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Task C: BaBar Experiment at SLAC

Introduction

The study of weak and electromagnetic interactions has been the prime focus of research under this task starting with photo-production experiments at SLAC in the 70s, through the current Linear Collider (LC) R&D projects under the leadership of Prof. Richard Prepost and Prof. Sridhara Dasu. With the retirement of Prof. Prepost and the end of BaBar data taking, Task C is being ramped down in an orderly fashion. The emphasis of Prof. Dasu's research program is CMS. Senior Scientist Dr. Henry Band is transferring to the Daya Bay neutrino program. Both will continue to support the completion of BaBar analysis efforts through membership in committee and review panel tasks at a reduced level. The main focus of the task for the next two years will be to support the work of Assistant Scientist Dr. Kevin Flood to complete several key physics analyses using the full BaBar data set. BaBar management strongly supports the continued effort of Dr. Flood, who is the co-convenor of the "radiative penguin" analysis group, for the final BaBar analysis period of FY2011-12. Therefore, we are submitting this short two year proposal for FY2011-12.

Accomplishments

The BaBar collaboration has published over 400 papers in refereed journals on B meson physics since 2001. Our group's effort in BaBar has been split between detector design and support (H. Band has been IFR system manager since 2001), particle identification algorithm development (K. Flood, C. Vusalo, H. Band and earlier students implemented the best and most used BaBar muon identification algorithm and Dr. Flood served as co-convenor of the Particle ID group in 2007-8), and physics analyses in the area of B meson decays through "radiative penguin" processes (Dr. Flood has served as co-convenor of the Radiative Penguin group since 2008). The study of these rare processes enabled us to constrain indirectly the parameter space of new physics models. All four graduate students completed their thesis in this area. Three of them have moved on to post-doctoral appointments at LHC. The most recent graduate is Dr. Carl Vuosalo, who wrote his thesis on **Search for Rare decay of B meson to a kaon and two neutrinos**.

Dr. Flood has completed multiple analyses during the grant years of FY2008-10. In 2009, Dr. Flood worked with Prof. Jack Ritchie and Chris Schilling from Univ of Texas Austin, in completing "**Angular Distributions in the Decays $B \rightarrow K^* l^+ l^-$** ", **PRD 79:031102 (2009)**. This first model-independent angular analysis of the rare decay $B \rightarrow K^* l^+ l^-$ resulted in measurements in all di-lepton mass regions. Dr. Flood also worked with Prof. Gerald Eigen and Liang Sun from the Univ of Bergen in completing a related analysis, "**Direct CP, Lepton Flavor and Isospin Asymmetries in the Decays $B \rightarrow K^{(*)} l^+ l^-$** ", **PRL 102:091803 (2009)**. This analysis found an unexpectedly large and statistically significant isospin asymmetry in the low di-lepton mass region, which is ~ 4 sigma away from the SM prediction of a null asymmetry. Working with Carlos Chavez, Univ. of Liverpool and Bill Lockman, UC Santa Cruz, he completed "**Measurement of D0-D0Bar Mixing using the Ratio of Lifetimes for the Decays $D^0 \rightarrow K\pi$, $K\bar{K}^+$** ", **PRD 80:071103 (2009)**. This work complemented our earlier 2008 publication **PRD 78, 011105 (2008)** using tagged events with an analysis of the related untagged dataset. Combining

the results of the separate analyses provides the most significant evidence for charm mixing to date and rules out a null mixing rate by more than 4 sigma.

Future Plans

Graduate student Carl Vuosalo's thesis measurement, "**Search for the Rare Decays $B \rightarrow K\nu\nu$** " is currently in the form of a journal draft in collaboration-wide review and will be submitted to PRD. These results provide the most stringent limits to date on the rate of this rare electroweak penguin process.

Dr. Flood will work with Jennifer Watson and Steve Playfer of the University of Edinburgh in updating the **$B \rightarrow K^{(*)}l^+l^-$ angular analysis** using the full Babar Y(4S) dataset. CDF has recently presented results from a similar angular analysis, which can be combined with the most recent Belle results. However, the results of the previous BaBar analysis cannot be easily combined with the CDF and BELLE data. Work is currently on-going to re-optimize the Babar analysis to allow results from all three experiments to be combined to best effect. If as expected, Babar's results have precision similar to Belle's and the current experimental values of the lepton forward-backward asymmetry A_{FB} do not change, then the combined result of all three experiments would rule out at ~ 3 sigma the presence of a zero-crossing point in the distribution of A_{FB} , a precise SM theory prediction. Experimental determination of the value of this zero-crossing point is a prominent feature of the LHCb and proposed Super-B Factory(s) physics programs, both of which expect to integrate datasets up to a few orders of magnitude larger than the final Babar dataset.

Dr. Flood is also discussing with Belle physicist Ryosuke Itoh and others about the possibility of combining angular datasets a priori, rather than a posteriori, in order to obtain angular results in more bins of di-lepton mass than is possible from fitting either dataset separately. It should be possible to successfully perform combined angular fits in 5-6 di-lepton mass bins in the mass region below the J/Ψ , rather than in just three bins. If the current values of A_{FB} in this region are assumed and statistical uncertainties are similar to those of the current Belle analysis in any one mass bin, it would be possible to rule out any SM A_{FB} zero-crossing point with a significance substantially beyond the current ~ 3 sigma exclusion.

Dr. Flood will also work on a **semi-inclusive measurement of rates and asymmetries in $b \rightarrow sl^+l^-$ decays**. This builds on the results of the earlier $B \rightarrow K^{(*)}l^+l^-$ exclusive analysis by reconstructing a total of 28 separate $B \rightarrow X_s l^+l^-$ final states and performing a model-dependent extrapolation to the total inclusive rate. In addition to the total rates, results for the partial rate in several di-lepton mass bins, along with measurements of direct CP, lepton flavor and isospin asymmetries in the same bins will be reported. This analysis is expected in time for presentation at ICHEP 2010 later this year.

The semi-inclusive $b \rightarrow sl^+l^-$ dataset will additionally be used to **search for a possible low-mass CP-odd Higgs boson or axion candidate** which would appear as a resonance in the di-muon mass distribution recoiling against the strange X_s hadronic system. This analysis is complementary to similar searches using Y(1S,2S,3S) decays done at both Babar and Belle. Initial studies indicate there should be comparable sensitivity at the level of 10^{-7} for evidence of these non-SM particles in the mass range $2m_\mu$ to $(m(B)-m(X_s))$. Recent work on the phenomenology of inclusive $b \rightarrow sl+l^-$ decays (PRD 75, 034016 (2007)) has also demonstrated that an inclusive $b \rightarrow sl^+l^-$ angular analysis with signal yields roughly comparable to those expected in the final Babar dataset should have good sensitivity to possible non-SM effects. Such an inclusive angular analysis is an excellent candidate for a joint Babar-Belle analysis similar to

that proposed for its exclusive $B \rightarrow K^{(*)} l^+ l^-$ counterpart. Finally, it appears that it will be possible to leverage the efforts made to optimize the exclusive and inclusive $b \rightarrow s l^+ l^-$ analyses described above to perform a **fully inclusive $b \rightarrow s l^+ l^-$ analysis using a "Breco" technique** wherein the B meson recoiling against a signal B decay is reconstructed and used to provide the kinematic constraints usually associated with a fully reconstructed signal B.

In charm physics, Dr. Flood will work on an **update of the charm mixing lifetime ratio analysis** using a simultaneous fit of tagged and untagged D0 decays. This fitting technique, along with more sophisticated event selection, should yield increases in sensitivity substantially beyond the purely statistical gains following from the inclusion of Runs 6-7 data. This analysis should result in the observation of the first mixing signal from a single analysis beyond 5-sigma. In addition, we expect sensitivity to **CP violation in charm mixing** to improve by nearly a factor of two relative to an earlier analysis.

Dr. Flood will continue to lead as co-convenor of Babar's Radiative Electroweak Penguin Analysis Working Group. He will be a chapter editor and contributor to the B-Factory Legacy Book and final Babar detector NIM paper; a contributor to the Super-B Factory physics "white paper"; an author of a NIM paper providing a comprehensive discussion of charged particle identification algorithms and performance at Babar.

Senior scientist Dr. Band will be a chapter editor of the final Babar detector NIM paper and has been studying **Resistive Plate Chambers** recently extracted from the BaBar Forward Endcap. These chambers have accumulated a wide range of integrated charge in 6 years of data taking and exhibit several poorly understood aging related inefficiencies. The study of RPC chambers is important for extending the life of RPC chambers used in experiments like those at the LHC, Day Bay and future colliders. Dr. Band expects to publish the results of these studies next year.

Prof. Dasu, Dr. Band and Dr. Flood will continue to serve on physics analysis review committees and participate in publication review. Dr. Band also serves on the BaBar speaker's bureau, which allocates and monitors the quality of BaBar speaker presentations at conferences.

Publications and Talks

Over 400 papers were published by BaBar collaboration, of which 90 appeared since Jan 2008. The online listing of the papers can be obtained from spires catalog: <http://www.slac.stanford.edu/spires/find/hep/www?rawcmd=FINN+a+dasu+and+a+band+and+a+macfarlane+and+type+published+and+date+after+2007>

Vuosalo presented his work at APS, Pheno 2009 and Lake Louise Winter Institutes. Dr. Flood presented his work in three invited plenary talks, two at Moriond and one at Aspen.

Budget Discussion

We seek salary support for Assistant Scientist Dr. Kevin Flood for the period FY2011 and FY2012. We also request nominal travel support so that he may present results at conferences, and more importantly travel to Japan for collaboration with Belle authors.

**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**
 Institution Name University of Wisconsin - Madison
 Task/Title **Task C: BaBar**

Type of Position	Name	Activity #1	Activity #2	FTE Months on BaBar Research	# months funded by DOE-HEP University Program BaBar	Faculty Advisor
Faculty	Dasu, Sridhara	BaBar	CMS	0.10		
Post Doc	Flood, Kevin	BaBar		12	12	Dasu

Task D: String Theory and Theoretical Cosmology

A proposal submitted to the Department of Energy

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April 2010

1 Introduction and Overview

This document is a research proposal by the String Theory and Theoretical Cosmology Group (Task D) at the University of Wisconsin-Madison for the years 2010-2013. The principal investigators consist of faculty members Daniel Chung (cosmology), Akikazu Hashimoto (string theory), and Gary Shiu (string theory and cosmology). In addition to the primary research interests of string theory and cosmology, related theoretical physics interests of the researchers include astrophysics, condensed matter physics, particle physics, and mathematical physics. Other personnel of the group includes postdoctoral researchers and graduate students. The String/Cosmo task interacts actively with the other tasks of the High Energy Physics (HEP) program, through active collaboration, informal discussions and seminars.

The string theory program at UW-Madison was initiated in 2002-2003 with the recruitment of three faculty members Akikazu Hashimoto (2003), Albrecht Klemm (2003), and Gary Shiu (2002) through the Mathematics/Physics Cluster Initiative. Daniel Chung was also recruited in 2002 as a theoretical cosmologist.

String theory is a non-trivial paradigmatic extension of relativistic quantum mechanics which incorporates the physics of gravity and space-time from interesting new perspectives. It also provides a concrete framework for addressing puzzles in particle physics beyond the Standard Model that require a high energy completion. Theoretical cosmology, on the other hand, addresses questions such as what one might learn about high energy physics from the information accessible in the sky, and what one might learn from high energy physics about the history of the universe. The two synergistic disciplines constitute an integral part of the efforts to address long standing open issues in theoretical physics, such as uncovering the true quantum nature of space-time at ultra-short distances and its implications to the physics of early universe, particle physics, and related systems. Progress in these problems are driven by careful considerations of subtle issues from seminal perspectives, guided by collective experiences in theoretical physics. It is precisely to such enterprise that members of task D provide the necessary experience and expertise.

Until 2010, String Theory and Theoretical Cosmology were funded by the DOE under separate tasks, tasks D and J. In this proposal, we have combined the efforts of tasks D and J into a single task. There are two reasons for reorganizing the tasks in this way. One is that Albrecht Klemm who used to be part of task D has accepted a C4 position at Bonn University and has resigned his position at Wisconsin. The other is that task J, which funded Daniel Chung, was an OJI award which has completed its funding cycle in 2009. By combining the resources of tasks D and J, we are aiming to consistently support two postdoctoral researchers in the synergistic disciplines of string theory and theoretical cosmology. Another notable change in the personnel of task D is that Gary Shiu, who was

Name	Years	Notes
Calin Lazariou	2003-2004	→ Faculty appointment at University of Dublin, Ireland
Fernando Marchesano	2003-2005	→ Munich → CERN → Faculty appointment at IFT, Madrid
Ian Ellwood	2004-2007	→ University of Kentucky → UCSF
Minxin Huang	2004-2007	→ CERN → IPMU
Ghazal Geshnizjani	2004-2007	→ Perimeter Institute
Thomas Grimm	2005-2007	→ Bonn → Faculty appointment at Max Planck Institute, Munich
Heng-Yu Chen	2007-Present	Cambridge, UK → Appointed till 2011
Bjorn Garbrecht	2007-2009	→ Faculty appointment at RWTH Aachen University, Germany
Jinn-Ouk Gong	2007-2008	→ University of Leiden, Netherlands → CERN
Peter Ouyang	2007-Present	→ Purdue University
Thomas Van Riet	2008	Funded by Fulbright Fellowship → Uppsala University
Yoske Sumitomo	2009	Funded by Nishina Foundation Fellowship → Tata Institute
Diego Trancanelli	2010-	Santa Barbara → Arriving Fall 2010
Jiajun Xu	2010-	Cornell → Arriving Fall 2010

Table 1: Table of recent, current, and arriving postdoctoral researchers.

partially supported by his NSF CAREER Award until February 2009, is now fully funded by the DOE. Daniel Chung and Akikazu Hashimoto were promoted to Associate Professors with Tenure in 2009. Gary Shiu was promoted to Full Professor in 2010.

Support for the postdoctoral researchers constitutes the primary usage of the DOE grant by our task. We have been extremely successful in recruiting postdoctoral researchers of high caliber and their subsequent placements. The postdoctoral researchers have established an impressive record of projects completed *independently* or *in collaboration* with other members of the group. For the upcoming academic year, we have succeeded in recruiting Diego Trancanelli (Santa Barbara) and Jiajun Xu (Cornell) to continue in this tradition of attracting postdoctoral researchers of extremely high caliber. The list of past and current postdoctoral researchers and their subsequent trajectories are summarized in table 1.

Research resources were also applied towards the seminar program where visitors from other institutions were invited to speak on recent developments in the field. The seminars are attended by a broad range of local researchers including those of string theory, particle physics, cosmology, and mathematics. The visitor program has had significant impact on the research activities of the group. In some cases, interactions initiated during their visit has led to specific publications, and others have concretely influenced current and future research directions. Some of these researchers and their impact are described explicitly in the later sections. In addition to the seminar program, task D was involved in hosting the “Great Lakes Strings” conference in April of 2008 <http://uw.physics.wisc.edu/~strings/workshop08/> and

COSMO08 <http://www.physics.wisc.edu/cosmo08/> which were extremely successful. UW-Madison was selected to host the International String Phenomenology Conference in 2011.

The proposal is organized according to the main research areas represented by the principal investigators, which we broadly characterize as cosmology (Chung), formal aspects of string theory (Hashimoto), and string phenomenology/cosmology (Shiu). In the next three sections, these research directions of the PI's and their scientific merits will be described in detail. We will then provide a summary of the accomplishments and the future goals of the research work carried out by the postdoctoral researchers. Due to the severe page restrictions (30 pages for task D), we have elected not to include references to relevant literature in this proposal. Some links to supplemental documentations available on the internet are indicated at the relevant sections of this proposal.

2 Research of Daniel J. H. Chung

The research specialty of Chung is at the interface of high energy theory and cosmology, with the long term research goals of finding novel observables that connect these fields. Topically, his near-future research program can be described as three-pronged: the topics are (i) the electroweak phase transition, (ii) inflationary cosmology, and (iii) dark energy. As there is a significant overlap between Chung and Shiu regarding inflationary cosmology, synergistic collaboration is expected among Chung, Shiu, and the new group postdoc Xu, who will be arriving in fall 2010. In the following, Chung's research accomplishments of the past three years along with future directions will be presented. Due to space limitations imposed by the DOE, explicit references will be given only to PI's work in the form of archive numbers.

Electroweak Phase Transition

The most likely discovery at the LHC will be the origin of electroweak symmetry breaking. Hence, the LHC era provides a unique opportunity to uncover a new chapter in the history of our universe related to the time period of the electroweak phase transition. Recent past projects in this area have included work related to electroweak baryogenesis, aspects of leptogenesis during the electroweak phase transition, and gravity waves.

Recent Work on Electroweak Baryogenesis

Electroweak baryogenesis (EWBG) scenarios, in contrast with the popular thermal leptogenesis scenarios, represent one of the very few experimentally testable scenarios explaining the observed baryon asymmetry in the universe. Despite the long history of the topic, more than an order of magnitude uncertainty persists in the computation. Hence, a confrontation of the LHC results with EWBG will require significant improvements in the computational

technology. The EWBG process can be broken down into four broad ingredients: (i) bubble properties during the phase transition, (ii) CP asymmetry creation, (iii) CP asymmetry transport in the plasma, and (iv) baryon number production. During the past three years, Chung has put significant effort into improving the technology for computing CP asymmetry transport and model dependence of bubble properties.

- First Order Phase Transition in $\mu\nu$ SSM

An extension of the minimal supersymmetric standard model (MSSM) constructed by Munoz and Lopez-Fogliani called the $\mu\nu$ SSM does not allow a conventional thermal leptogenesis scenario because the model utilizes a low scale seesaw. Hence, Chung and his student Long in 1004.0942 investigated the possibility of electroweak baryogenesis. Specifically, they identified a parameter region for which the electroweak phase transition is sufficiently strongly first order to protect the baryon number in the broken phase. In addition to transitions that are similar to those in the next-to-minimal supersymmetric standard model (NMSSM), they found a novel class of phase transitions in which there is a rotation in the singlet vector space. The parametric tuning strategy and the role of approximate symmetries useful for identifying the relevant parametric region were clearly identified, in contrast with most papers on this topic.

- Lepton-Mediated Electroweak Baryogenesis

In traditional EWBG scenarios involving minimal extensions of the SM, the CP asymmetry diffusion out of the bubble is governed by the quark sector, particularly because large size of the top Yukawa coupling allows quarks to couple strongly to the CP violating interactions with the bubble. However, for systems with multiple Higgs doublets, the size of the τ Yukawa coupling need not be small. For example in the MSSM for $\tan\beta \gtrsim 20$, the τ Yukawa coupling (which is proportional to $\tan\beta$) can become important. In that regime, if $\{\tilde{t}, \tilde{b}\}$ have a particular set of masses, there is a cancellation of the contributions to the left handed CP asymmetry arising from the quarks, making the leptonic contribution dominant. Since the diffusion constants for the left and the right handed leptons are significantly different (because there are no $SU(3)_C$ interactions for the leptons), the diffusion equation solution for the leptonic scenario is qualitatively different than that of the standard scenario. This gives novel Higgs and slepton mass sensitivities to EWBG which are presented in the work 0905.4509.

- Importance of the Bottom Yukawa

In traditional EWBG scenarios involving minimal extensions of the SM, the bottom Yukawa coupling is neglected because it is presumed to be too small to be important. However, Chung and his collaborators in 0808.1144 have shown that in the MSSM (and MSSM extensions), the bottom Yukawa coupling is significant for $\tan\beta$ as small as 5 even though

the bottom Yukawa coupling is still much smaller than the top Yukawa coupling. The reason for this is that the transport process does not compare Yukawa interactions, but instead compares the diffusion time scales with equilibration times of currents associated with various approximate symmetries in the system. This in most of the relevant parametric region qualitatively changes the picture for electroweak baryogenesis in that the first two generations of quarks are no longer relevant for baryogenesis as their connection through the $SU(3)_C$ sphaleron is lost. In some cases, even the sign of baryon asymmetry is flipped with the CP violating phase fixed because of this effect. Hence, without this improvement in technology, wrong conclusions about the sign of baryon asymmetry would have been made in some situations.

- Numerical Investigation of CP Transport

In 0908.2187 done in collaboration with Garbrecht, Ramsey-Musolf, and Tulin, Chung presented a complete numerical treatment of the diffusion process for supersymmetric electroweak baryogenesis. One of the goals was to investigate how much the pair of superpartner chemical potentials can differ, and the resulting consequences on the baryon asymmetry. Close to the bubble wall, the equilibration generically fails at the order unity level. A catalog of all of the numerical inputs for MSSM-like baryogenesis computation was presented.

Near Future Work on Electroweak Baryogenesis

During the work on the $\mu\nu$ SMS, Chung and his student Long recognized the importance of the group theoretic structure underlying the parametric region ideal for a strongly first order phase transition. Preliminary investigations indicate that a broader, less model-dependent group theoretic prescription can be given for a scalar field sector beyond the SM that can lead to a strongly first order phase transition that is essential for electroweak baryogenesis. This will be useful for future analyses of models, including those based on the LHC data.

Recent Work on Leptogenesis and the Electroweak Phase Transition

In leptogenesis scenarios, baryon number is created when the lepton number is converted to baryon number through non-perturbative $SU(2)_L$ transitions. In previous literature involving MSSM embeddings, the formula $B = \frac{8}{23}(B - L)$ was used to convert $B - L$ to B . However, the precise coefficient in front of $B - L$ in this formula depends on the masses, particularly those of the sparticles because the partitioning of baryon and lepton number among different species depends on the energy cost while the $SU(2)_L$ transitions only couple to the left handed fermions. With the assumption of a strong first order electroweak phase transition, Chung with his collaborators in 0807.2283 have derived a formula to compute the conversion factor $B/(B - L)$ accounting for the mass effects. In some cases, the sign of the predicted baryon asymmetry actually flips compared to the formula given in previous literature due to this mass effect.

Near Future Work on Leptogenesis and the Electroweak Phase Transition

- Sparticle Mass Spectrum Effect on B-L to B Conversion for Weak Phase Transitions

Chung et al's previous work on incorporating sparticle mass effects in $B - L$ to B conversion focused on strong first order phase transitions since in that case the $B - L$ to B conversion takes place predominantly in the unbroken phase. However, electroweak phase transitions can generically be weaker than first order, requiring an analysis of the chemical potentials in the broken phase. The currently accepted analysis of this situation (without accounting for the sparticle mass effects of interest) are due to Khlebnikov, Laine, and Shaposhnikov, who use thermal effective potential to obtain a conversion formula. This work openly criticizes and contradicts the work of Harvey and Turner, who do not conserve hypercharge in the broken phase (the latter is intuitive but Khlebnikov et al's analysis contradicts this result). However, given that this is inherently a non-equilibrium problem with only the initial conditions coming from thermal equilibrium, a non-equilibrium approach such as the Schwinger-Keldysh formalism that Chung et al and others have employed for electroweak baryogenesis is more appropriate to understand how the boundary conditions and gauge symmetry breaking dynamics determine the final state which can be suitably described by a constrained thermal effective potential. In addition to obtaining a formula incorporating the mass effects (which can be large enough to flip the sign of the baryon asymmetry and is a trivial extension of the previous work if one blindly sides with either Harvey and Turner or Khlebnikov et al), one of the key clarifications that is hoped to be achieved is to construct suitably regularized gauge charges Q and their matrix elements such that $[H, Q] = 0$ can be maintained through the gauge symmetry breaking process.

- Low Scale Leptogenesis

In traditional thermal leptogenesis scenarios, the right handed neutrino mass has to be larger than about 10^8 GeV to achieve successful leptogenesis. This bound is mainly tied to the fact that the magnitude of CP violation apart from the phase is proportional to the Yukawa coupling squared $|Y|^2$, while the see-saw scale generating neutrino masses are fixed by $m_\nu \sim |Y|^2(246 \text{ GeV})^2/M_R \lesssim 10^{-1}\text{eV}$, where M_R is the right handed neutrino mass scale. However, there are other CP violating loops which are not proportional to $|Y|^2$ that can in principle be used. On the other hand, the well known theorem of Nanopoulos and Weinberg makes the usage of such CP violating loops nearly impossible unless equilibrium conditions are violated (this is unfortunately counter to several wrong statements in the literature, and some of these authors have been alerted to this fact through private communications). There have been recent developments in putting the leptogenesis equations into the non-equilibrium Schwinger-Keldysh formalism (for example by Garbrecht) which set the stage for investigating the usage of these novel CP violating sources. In collaboration with Garbrecht

and Ramsey-Musolf, Chung will investigate this possibility. Although a positive result does not seem particularly likely, any novel mechanisms for low scale leptogenesis are important as they may be equally testable at TeV scale colliders as electroweak baryogenesis.

Recent Past Work on Gravity Waves

Just as big bang nucleosynthesis allows a probe of the expansion rate when the temperature of the universe was around 1 MeV, the measurement of gravity waves from electroweak scale first order phase transitions may allow a probe of the expansion rate when the temperature of the universe was at the electroweak scale. A simple, robust transformation rule for the gravity wave spectrum under the scaling transformation of the Hubble expansion rate has been computed by Chung and his student Zhou in 1003.2462. Remarkably, this transformation is insensitive to the large computational uncertainty that exists in the overall normalization and the shape of the spectrum because of the finite frequency range relevant for LISA and BBO. This work also is related to the dark energy work that will be discussed below as one of the physically well-motivated contaminants (*i.e.*, that make the expansion rate during the electroweak phase transition deviate from that of radiation domination) is the kination phase of the dark energy degree of freedom.

Inflationary Cosmology

Advances in observations have led to constraints on three-point functions, advancing the inflationary action reconstruction program. In preparation for the Planck results which are scheduled to be released in 2014 and other large number of cosmological observational results expected in the near future, Chung's research in inflationary cosmology will focus on parameterizing and restricting the space of possible effective field theories describing inflation consistent with data in the near foreseeable future.

Recent Work on Inflationary Action Reconstruction

Given that primordial non-Gaussianities may be detected in future CMB experiments, it is important to find a formalism to reconstruct the class of inflationary actions of the form $S = \int d^4x \sqrt{g} \mathcal{L}(X, \Phi)$ consistent with such data where $X = (\partial\Phi)^2/2$ and Φ is the inflaton field. To this end, Chung, Geshnizjani, and Bean in 0801.0742 have developed two formalisms for the action reconstruction. In one approach, they have demonstrated that in an idealized case in which tree level N -point function are measured over a finite range of scales, they can analytically reconstruct the action. The analytic form of the action is surprisingly simple, and the degree of increased arbitrariness is as expected of a situation in which the X functional degree of freedom exists in the action. In another formalism, they use the Hamilton-Jacobi formalism to extend the inflationary flow parameter approach to describe the evolutionary trajectories of general actions.

Near Future Work on Inflationary Cosmology

- Large Local Non-Gaussianities from Superheavy Dark Matter

Superheavy dark matter in the hidden sector can be generically produced at the end of inflation through their gravitational couplings to the inflaton. This naturally generates a non-Gaussian spectrum, but only the two-point function contributing as an isocurvature perturbation is known. Chung and his student Yoo propose to compute the three and four-point functions and understand its possible relevance for the near future cosmological data. One of the key challenges to this computation is to understand the resulting UV sensitivity as well as phenomenological viability of this scenario.

- Fermionic Isocurvature Perturbations

One of the most anticipated results from Planck mission is the answer to the question whether or not the local non-Gaussianity hint from the WMAP data is real. Models that tend to produce large observable local non-Gaussianities (such as curvaton models) can also naturally produce significant isocurvature perturbations at the same time, since it is the non-adiabatic mixing of the isocurvature and curvature modes that lead to large observable non-Gaussianities. Traditionally, isocurvature perturbations have been thought of strictly as being composed of scalar fields. However, within the context of superheavy dark matter which can be fermions, it is simple to produce fermionic isocurvature perturbations. Chung and his students Yoo and Zhou propose to compute the N -point functions associated with fermionic isocurvature perturbations and understand their possible relevance for the near future cosmological data. Preliminary analysis indicates that phenomenologically viable models exist. Furthermore, one of the advantages of this class of models over the scalar field models is the presence of chiral symmetry, which can protect both the mass and the tadpoles associated with the dynamical degree of freedom.

Dark Energy*Recent Work on Connecting Dark Energy and Colliders*

One natural way to have the dark energy field degree of freedom be dominant during the freeze out of thermal dark matter but be insignificant by the time of BBN is to have the dark energy degree of freedom be a quintessence that is in a kinetic energy dominated phase and to have this energy dominate the total energy density in the universe (this is known as a kination dominated phase). As the quintessence energy density then dilutes as a^{-6} while radiation dilutes as a^{-4} , the quintessence energy can dominate during the dark matter freeze out ($T \sim 5$ GeV) and disappear by the time of BBN ($T \sim 10^{-3}$ GeV). Since dark matter freeze out abundance is proportional to the Hubble expansion rate H_F at the time of the freeze out, the effect of the quintessence scalar field kination domination is to increase H_F

during freeze out, which generically increases the relic abundance.

With collaborators Matchev, Kong, and Everett, Chung in 0706.2375 has explored to what extent the LHC and ILC can probe this scenario in the context of the constrained MSSM. In almost all the regions of parameter space in which this scenario can be effective, ILC measurements can constrain the dark energy contribution to be nonzero while the LHC data cannot provide substantive evidence for such contributions, simply because some of the key parameters can be better measured by the ILC as compared to the LHC. This conclusion assumes that there are no other dominant species of dark matter. Such assumptions can most likely be checked to within an order of magnitude if both direct detection and indirect detection obtain positive signals corroborating the WIMP candidate identified at colliders.

Previous studies of kination domination did not embed the quintessence dynamics within a consistent inflationary framework. Thus, in 0704.3285, Chung, together with Matchev and Everett, have embedded the kination domination scenario in a generic class of inflationary models. In this class of models, the inflaton and quintessence fields are both due to the same scalar degree of freedom; this is a natural setup in that the inflaton is characterized by its coherence and energy dominance, which are both also needed for kinetic energy dominated quintessence. The framework leads to cosmological predictions that can corroborate this scenario. In addition to the straightforward prediction that collider measurements will determine a thermal relic abundance in disagreement with the cosmological data, kination dominated scenarios predict almost model independently that no B-mode polarization arising from primordial tensor perturbations will be measured. This obviously has implications for ongoing and future CMB experiments. Other predictions include a modification of the gravity wave spectrum generated by the electroweak phase transition (see above), and a shift in the predicted baryon asymmetry. Furthermore, this scenario may provide a possible reconciliation between the thermal relic scenario and the enhanced annihilation rate required for the halo dark matter annihilation explanation of the observed positron excess near Earth.

Near Future Work on Dark Energy

In the context of the SM and its extensions containing a Higgs sector and any number of additional scalars, the total energy density includes a scalar field energy component $U(\vec{\phi}(T))$, where its vacuum expectation value (VEV) at finite temperature T is not equal to the VEV at $T = 0$: $\vec{\phi}(T) \neq \vec{\phi}(0)$. This energy, which is a form of dark energy since its stress energy contribution is with a -1 equation of state, can be estimated to be small within the context of a second order phase transition: expressed in fraction of the total energy density at any given epoch, it is typically $\mathcal{O}(1\%) \sim 1/g_*$, where g_* is the usual number of degrees of freedom present in the plasma during the electroweak phase transition. This is still an interesting result since it is a prediction of the SM regarding the fine tuned cosmological constant sector

and was to some extent already noted by Kolb and Wolfram. On the other hand, an ongoing investigation of Chung, Long, Tulin, and Wang indicates that if the scalar sector possesses the right properties, a number of phase transitions in the scalar sector can be of first order, and this effect can be easily enhanced to $\mathcal{O}(10\%)$, which may be experimentally relevant in the future. Hence, if the Higgs and extended scalar sector is measured sufficiently accurately at TeV scale colliders and if there is some way of probing the Hubble expansion rate at the phase transitions epochs of interest, there will be a calculable prediction coming from the scalar sector contribution to the dark energy as a function of temperature if one assumes that the cosmological constant is fine tuned (as the string landscape arguments suggest) without any adjustment mechanism operating below the phase transition temperatures.

Some of the probes will also be investigated. For example, since within the thermal relic hypothesis, the final freeze out abundance is $\Omega_M \propto H_F$, where H_F is the expansion rate at freeze out, the predicted shift $U(\vec{\phi}(T)) - U(\vec{\phi}(0))$ will lead to a shift in the predicted dark matter abundance which may be testable by cosmology. Furthermore, these shifts have implications for the gravity wave spectrum produced by the electroweak phase transition.

3 Research of Akikazu Hashimoto

The research of Akikazu Hashimoto is focused on formal aspects of quantum field theory and string theory. One of the goals of theoretical physics to formulate key ideas which may prove to be useful for addressing major unresolved issues. In this regard, string theory is a powerful formalism, challenging our mind to think just beyond the framework of the more traditional framework of quantum field theory.

In the following, we describe the accomplishments in the investigations by Hashimoto in the last three years, as well as promising directions to explore in the immediate future. The presentation will be organized in terms of broad research areas.

2+1d Chern-Simons theories and their holographic dual

Currently, Hashimoto's research program is focused primarily on the dynamics of Chern-Simons system coupled to matter and other degrees of freedom in 2+1 dimensions. This is a rich and active direction culminating in several projects and publications which we elaborate in greater detail below.

Field theory/gravity duality is a powerful conceptual tool for exploring physical features of a dynamical system in a broad range of parameters characterizing the system. Recently, a novel class of Chern-Simons matter theory in 2+1 dimensions with maximally extended supersymmetry $\mathcal{N} = 6, 8$ was discovered by Aharony, Bergman, Jafferis, and Maldacena,

building on earlier seminal work of Bagger, Lambert, and Gustavsson. This was a significant development, since theories with $\mathcal{N} = 8$ with superconformal symmetry is expected to describe the decoupled dynamics of M2-branes. The gauge/gravity duality predicts that the number of degrees of freedom on the stack of N M2 branes scales as $N^{3/2}$. Confirming this $N^{3/2}$ scaling on the field theory side amounts to a verification of Bekenstein-Hawking entropy in quantum gravity, at least in one context. Finding a Lagrangian description for the candidate theory is therefore an important step in addressing this important question, although confirming the $N^{3/2}$ scaling still remains a mystery due to the challenge of analyzing this theory at strong coupling.

Conformal field theories in 2+1 are important class of theories which may have applications in broader contexts, possibly including variety of condensed matter systems, as well as a theoretical laboratory for exploring issues related to the landscape of $3 + 1d$ string vacua with negative cosmological constant in a simple context. Another interesting aspect of field theories in 2+1 dimensions is the fact that by varying parameters such as the rank of the gauge group and the level of the Chern-Simons coupling, the theory can exhibit a rich phase structure.

These theories make concrete contact with string theory through an explicit brane construction involving Hanany-Witten like engineering of NS5-branes, $(1, k)$ 5-branes, and integer and fractional D3-branes. By considering this system in the zero slope decoupling limit, one obtains a dynamical system, decoupled from gravity, which flows in the IR to a 2+1 Chern-Simons matter theory with $\mathcal{N} = 6, 8$ supersymmetry. The fact that brane construction of these field theories are known explicitly allows one to also engineer the holographic duality explicitly.

Holographic RG flow from 2+1 YM-CS-Matter to $\mathcal{N} = 6, 8$ SCFT

One natural issue which arises in the context of holographic duals of these Chern-Simons-Matter theory is the holographic duals not just of the IR fixed point, but rather of the full RG flow from the zero-slope limit theory to the IR fixed point. The zero slope limit theory has various dynamical scales, which can potentially have important ramifications, which motivated Hashimoto's more recent work which will be reviewed in more detail below.

To study the full RG flow, one considers the T-dual of the NS5- $(1, k)$ 5-brane system giving rise to the ABJM theory in the far IR. In the T-dual frame, this system has a gravitational description in terms of 8 dimensional hyper-kahler geometry known as the Lee-Weinberg-Yi space, which is a generalization of the Taub-NUT geometry. The LWY geometry is also interesting in that it preserves $3/16$, a somewhat unusual fraction, of the total supersymmetries of the underlying string theory.

Adding integer D3 the brane construction maps to the addition of D2-branes, whose back

reaction can be written explicitly in terms of an ansatz involving the scalar greens function in this eight dimensional space. This is completely analogous to an earlier work by Hashimoto with Sergey Cherkis, where he considered the problem of finding the scalar Greens function in the geometry $R^4 \times TN$ in order to describe the holographic dual of 2+1 dimensional Yang-Mills theory with flavor matter in the fundamental representation of the gauge group.

Mathematically, the problem of finding the scalar greens function in LWY space, which have number of special properties such as hyper-Kahilarity, $sp(2)$ special holonomy, supersymmetry, etc, appears straight forward. Hashimoto considered this very problem with Wisconsin postdoc Peter Ouyang. This program, however, turns out to be extremely difficult technically. Hashimoto and Ouyang reported their conclusions, distilling a specific partial differential equation that encapsulates the physics of interest, and commented on the expected asymptotic behavior of the solution, in publication 0807.1500. The preliminary findings of this investigation were also reported at the workshop at McGill university, as well as in an impromptu seminar at Weizmann Institute in 2008.

Page/Maxwell/Brane charges and Cascading Field theories in 2+1d

The dynamical content of field theories arising from this class of models becomes richer upon inclusion of fractional D3-branes suspended between NS5 and $(1, k)$ 5-branes in the brane construction. One feature particular to the presense of these fractional branes is the possibility for the supersymmetry to be broken when the number of fractional branes exceeds the bound set by the s -rule.

To study the manifestation of preserving and breaking of supersymmetry depending on number of fractional branes from the dual gravity point of view, it is necessary to prescribe a precise rule for quantization of fluxes. Striclty speaking, this is a straight forward application of Dirac quantization. Nontheless, the precise implementation of this basic concept can be subtle when the effective action for the gravity theory includes a Chern-Simons term. This is the indeed the case for the type II supergravity theories arising as the low energy effective description of string theory. This key subtely, stemming from the realization that there exisit several different notions of charges whose distinction becomes apparent in the presence of Chern-Simons terms, was clarified in an important earlier work by Don Marolf. Marolf idenfitted three different notion of charges: Maxwell charge, Page charge, and brane charge, which respect some, but not all, of the properties usually attributed to charges, including guage invariances, conservation, locality, and integrality. Page charge, which is conserved, local, integer quantized, but not guage invariant, turns out to be the quantity which should be quantized in gravity duals of the construction involving fractional branes. The gauge ambiguity of these charges also admits a natural interpretation in terms of the existence of multiple dual (in the sense of Seiberg duality) field theroy description for the same theory.

In fact, this duality organizes itself into a structure of duality cascades, similar in many respects to the duality cascades in 3+1 dimensions discovered by Klebanov and Strassler. One important distinction between 2+1 and 3+1 is the fact that duality cascades terminate after certain iterations in 2+1 dimensions instead of continuing indefinitely in the ultraviolet as in $3+1d$. This is a natural consequence of super-renormalizability of gauge interaction in 2+1 dimensions. That the cascade is finite in 2+1 dimensions is connected to the finiteness of the Maxwell charge, a gauge invariant quantity characterizing the theory. The fact that the Maxwell charge is finite here helps in highlighting the physical significance of this parameter better than in the 3+1 dimensional counterpart where the value of this charge happens to be infinite.

The systematic analysis of the quantization of fluxes and the interpretation of various subtleties were carried out by Hashimoto in collaboration with Ofer Aharony from Weizmann Institute, Shinji Hirano from Niels Bohr Institute, and Wisconsin postdoc Peter Ouyang and was published in 0906.2390. One technical ingredient which is necessary in carrying out this program is the normalizable self-dual 4-form on L_{WY} space. Despite its apparent simplicity, this self-dual 4-form is not known in its closed form. The existence of such a 4-form was conjectured by Sen on the basis of S-duality and the existence of certain monopole bound states. Most of the analysis carried out in 0906.2390 relied only on the existence of the 4-form and its expected asymptotic behavior.

Since careful treatment of quantization of charges and fluxes require detailed consideration of integrality and normalization issues, we encountered a number of subtleties such as those arising from Freed-Witten anomalies and curvature corrections. The consistency of these anomalous shifts were tested using various baryonic probes.

This work was presented in several conferences, including the Great Lakes Strings Conference and the QTS Conference in 2009, as well as seminars at Chicago, Princeton, and Tokyo Institute of Technology.

s-rule and dynamical SUSY breaking

One of the most interesting issue one can investigate once the encoding of discrete field theory parameters are properly accounted for in the gravity dual is the exploration of the theory in the regime where *s*-rule is violated. The immediate issue which comes to mind is classification of phases of the low-energy effective field theory in this regime. The natural expectation is that supersymmetry is broken at some dynamically generated scale. It would be extremely interesting to capture such a dynamical phenomenon in the gravity dual description.

The gravity duals of YM-CS-Matter system studied extensively by Hashimoto and collaborators in 0807.1500 and 0906.2390 are perfect template for addressing these issues, except

for the fact that the closed analytic expressions for the warp factors and the self-dual 4-forms are currently inaccessible. This prevents explicit analysis of the detailed geometry for which features such as dynamical symmetry breaking are encoded. There are, however, closely related systems, based on eight dimensional manifolds with $spin(7)$ holonomy investigated originally by Cvetic and collaborators, for which the structures such as the warp factors and the self-dual 4-forms are accessible. The trade off is that the number of unbroken supersymmetry is smaller, and the field theory dual is harder to identify in detail. Nonetheless, the fact that the IR dynamics is under better control is an extremely useful advantage.

In a recent publication 1004.0903, in collaboration with Hirano and Ouyang, Hashimoto conducted a detailed analysis of the charges and fluxes in a model which is constructed by adding integer and fractional M2 branes to M-theory on $R^{1,2} \times \mathcal{M}_8$ where \mathcal{M}_8 is the eight dimensional $spin(7)$ manifold known as the A_8 . When the s -rule is not violated, this gravity solution can be interpreted as a $2 + 1d$ cascading field theory, flowing in the IR to the conformal fixed point of ABJ(M). In this setup, the gravity solution is known in closed analytic form. One can therefore explore the behavior of the background as one approaches the threshold of violating the s -rule and beyond.

Investigations in 1004.0903 revealed a simple criteria

$$Q = N - \frac{l(l-k)}{2k} > 0$$

for the preservation of supersymmetry. At $Q = 0$, there is a special, smooth gravity solution with some interesting properties. For $Q < 0$, the naive extrapolation gives rise to a singularity of a repulson type. One can interpret the appearance of this singularity as a result of unphysical extrapolation where some of the tensions of the sources have been extrapolated to take on a negative value. This in turn suggests that one should add non-BPS objects, such as an anti-brane, which is a physical object which sources positive tension and negative charge. This is a completely natural interpretation for how violating the s -rule gives rise to objects which break all supersymmetries. The scenario is strongly reminiscent of what was encountered in the earlier construction by Maldacena and Nastase.

The appearance of anti-brane also makes interesting contact to works on metastable vacua involving anti D3-branes in the Klebanov-Strassler background. It also illustrates the technical challenge that would be involved in extracting physical features such as the phases and the vacuum energy in the $Q < 0$ regime: one must identify a more general ansatz and the appropriate boundary condition. The main difference between the cases which arise from class of models we consider in $2 + 1d$ and the works based on Klebanov-Strassler models is the fact that in $2 + 1d$ in the $Q < 0$ region, we expect the true vacua, if it exists, not to be supersymmetric (as opposed to the KS models which has a supersymmetric true vacua in addition to the meta-stable non-supersymmetric vacua.) The consequences of this difference

is likely to reveal many interesting lessons concerning dynamical supersymmetry breaking in the context of AdS/CFT correspondence. Some of these findings were presented at a seminar at University of Illinois, Urbana-Champaign.

Fate of spontaneous SUSY breaking

Currently, Hashimoto is exploring the dynamical fate of $Q < 0$ theories. The immediate approach being pursued is to study the dynamics of brane probes in $Q = 0$ and related backgrounds. One expectation is that a mechanism somewhat similar to the enhancon mechanism is at work, although one expects the true physics to be far more messy in light of the fact that all of the supersymmetries are broken.

Another interesting approach is to treat anti D-brane in $Q = 0$ background as a probe. The presence of the anti-brane pushes the model into $Q < 0$ regime, and the strategy is to explore the analog of brane-flux transition encountered in the context of Klebanov-Strassler model in the earlier work of Kachru, Pearson, and Verlinde. Strictly speaking, the analysis of KPВ-like transition in the A_8 geometry is subtle due to the difference in the topology of the background. A useful first step is to study the related geometry, known as the B_8 geometry, where there is an S^4 BOLT which mimics the S^3 which appeared in the context of KPВ.

Some additional future directions

There are several unresolved issues that Hashimoto plans to explore in the immediate future: 1) It is remarkable that analytic expression for the warp factor and the self dual 4-forms on LWY geometry is not known. It would be interesting to study novel analytic techniques to find such an expression. 2) There is a related construction involving $TN \times TN$ which has $sp(1) \times sp(1)$ and $\mathcal{N} = 4$ SUSY whose field theory interpretation in 2+1 dimensions is not yet clear, but is related to some of the recent work by Gaiotto and Witten, which Hashimoto hopes to better understand. 3) The treatment of Page, Maxwell, and brane charges in 0906.2390 and 1004.0903 was based on IIA formulation. Their M-theory lift has some subtle issues which Hashimoto hopes to resolve in the near future. 4) It would be interesting to study the dynamical content of the $Q = 0$ theory in more detail. 5) Finally, there are numerous generalizations of special holonomy and related manifolds in eight dimensions to which similar considerations can be applied.

One concrete milestone that Hashimoto is aiming to reach is the construction of a supergravity solution which can be interpreted as a dual of field theory exhibiting mass gap and spontaneous breaking of supersymmetry. The hope is to find a regular gravity solution which makes both the mass gap in the IR and the restoration of SUSY in UV manifest. Hashimoto intends to explore various approaches to this very interesting construction.

In the remainder of this section, we will provide a brief overview of Hashimoto's accom-

plishments in other areas of research in the last three years.

Mass-spin relation for quark anti-quark bound states in non-commutative Yang-Mills theory

This is a slightly independent direction Hashimoto investigated with the graduate student Shajid Haque. It is well known that the computation of quark/anti-quark potential as was formulated by Maldacena do not generalize immediately to the gravity duals of non-commutative field theories. The fundamental reason behind this difficulty was not immediately clear. One way to probe this issue further is to study the relation between the energy and the angular momentum of quark/anti-quark bound state which indirectly captures the inter-quark potential. Haque and Hashimoto carried out this computation for the strongly coupled non-commutative Yang-Mills theory in the dual gravity description. Extensive numerical computation was carried out to show, contrary to earlier claims, that there is a notion of distances unaffected by the non-commutative deformation even though the structure of the bound state is affected dramatically. Another conclusion from this study is the fact that the holographic computation of the quark anti-quark potential using string probes are more natural to interpret as a function of momentum or angular momentum, instead of positions. These findings were published in 0903.4841.

Non-commutative geometry/Puff Field Theory

Hashimoto also worked with students Danny Dhokarh and Shajid Haque on aspects of non-commutative field theories which arise naturally from the Melvin twist construction. In publication 0704.1124, scattering amplitude of open string ending on D3-branes inside a Melvin universe was computed and was shown to give rise to an interaction vertex involving Kontsevich \ast -product for a *critical* string theory in the context where non-commutativity parameter is non-constant. In 0801.3812, Dhokarh, Haque, and Hashimoto constructed a different class of non-commutative geometry with non-constant non-commutativity parameter by twisting isometries which involved conformal transformations. Finally, in 0801.4354, Haque and Hashimoto applied their experience in their studies of brane dynamics in Melvin twists to construct a candidate Lagrangian description of Puff Field Theory, which Hashimoto studied earlier with Ori Ganor and several students in hep-th/0702030.

UV consistency of effective field theories with spontaneously broken Lorentz invariance

One of the main areas investigated by Hashimoto this past year is the subject of effective field theory with spontaneous breaking of Lorentz symmetry. This subject was a fruitful outcome of interaction with Wisconsin colleague Daniel Chung. In 2006, Chung and post-doctoral researchers Afshordi and Geshnizjani formulated a special class of k -essence type model for which the speed of sound is not only superluminal, but infinite. Their observation

was that in this special limit, infinite speed of sound conspired with decoupling so as to alleviate the causality issues. These models were shown to be consistent at the level of effective field theory, and to have the effect of modifying effects of gravitation at long distance. As such, it is an interesting potential framework to explore dark matter/dark energy issues. Chung and collaborators named their model “cuscuton field theory.”

Cuscuton action has a form closely resembling a Nambu-Goto action but with certain important differences. With former postdoc Ian Ellwood and Chung, Hashimoto embarked on the study of cuscuton models at the quantum level. The goal was to either show that this model is inconsistent at some basic level, or to show that this model can be reformulated more elegantly as a topological field theory. Although this attempt did not immediately bear fruit, this experience led Hashimoto to re-examine the diagnosis of effective field theories which exhibit peculiar features such as superluminality and spontaneous breaking of Lorentz invariance. Influenced by recent work of Adams et.al. on UV compatibility of effective field theory based on considerations of unitarity, analyticity, and locality, Hashimoto decided to study the status of a model of spontaneous Lorentz violation considered by Kraus and Tomboulis in 2002. This model can also be thought of as a simple case of “bumble bee” models studied extensively by Kostelecky and others. Through somewhat subtle sequence of manipulations, Hashimoto showed that the Kraus-Tomboulis model indeed suffers from obstruction to UV completion in an analytic, unitary, and local framework. This work was published in 0801.3266, and was presented at Berkeley, University of Texas, Austin, and Neve-Shalom, Israel.

4 Research of Gary Shiu

The research program of Shiu focuses on the fruitful interface between string theory, particle physics, and cosmology. The goal of this *string phenomenology* research program is to uncover new insights into high energy physics and cosmology while adhering to the rigor of ultraviolet consistency. His research program adopts a two-pronged approach: theoretical studies aimed at revealing the structure and properties of string vacua, and phenomenologically oriented studies aimed at exploring their experimental and cosmological consequences. Progress in this program is therefore vital to bridging the gap between string theory and experiment.

A major component of Shiu’s research program has been the construction and studies of particle physics models from string theory. Since gravity lies at the heart of the hierarchy problem, these top-down constructions can give us useful new perspectives on particle physics beyond the Standard Model. Guided by the hierarchy problem, his recent and ongoing work spans from the construction of realistic string models, to the derivation of their low energy

effective action, to the studies of LHC signatures of string scenarios, to developing techniques to analyze beyond the Standard Model physics. Over the next few years, he plans to further develop this research program to explore new frontiers of string model building (especially those with new distinctive features, see below) and their particle physics implications, given the exciting prospect that some of these ideas may be tested at the LHC.

Another major thrust of Shiu's research program is superstring cosmology. In the era of precision cosmology, the connection between fundamental physics and observations is stronger and more timely than ever. Inflation particularly underscores the significance of UV physics, as its successes and predictions are highly sensitive to its short distance completion. Thus it is essential to understand the general properties of the effective theories arising from string compactifications, and at the same time construct explicit examples that illustrate these properties in detail. Turning this around, the inflationary paradigm may offer an exciting opportunity of probing stringy physics through precision cosmology measurements, including current and upcoming CMB missions such as WMAP and PLANCK, and various large scale structure surveys. In light of these prospects, Shiu plans to further develop this research direction, i.e., to construct explicit string inflation models (especially those that appear unusual from a field theory viewpoint), to compare their predictions with data, and to solidify the idea of using cosmological measurements to test and constrain string theory.

This program is unique in that it addresses the above *inter-related* issues in one overarching framework. It has been a bridge between several research efforts at UW-Madison, resulting in concrete collaborations and publications with researchers in other areas (below). The results of completed work, some ongoing and proposed research projects are as follows:

String Compactifications: Model Building and 4D Effective Action

His recent work in this area focuses on D-brane models and warped flux compactifications. Flux compactifications are ubiquitous in string theory models of particle physics and cosmology. Besides stabilizing moduli, the background fluxes backreact on the compactification geometry, resulting in a warp factor that may explain the hierarchy of scales in nature. To draw precise quantitative predictions of these models, however, it is important to understand and derive the *warped effective action*. This turns out to be highly subtle at strong warping. Determining such warping contributions is particularly crucial for issues that are sensitive to small UV corrections, e.g., in the computation of soft SUSY breaking terms in gravity mediation and in the derivation of the inflaton potential. Together with his student B. Underwood, G. Torroba and M. Douglas (both then at Rutgers), Shiu undertook a detailed analysis of the dynamics of warped flux compactifications. They identified a gauge for the supergravity fluctuations, which makes the physical degrees of freedom manifest, in dimensionally reducing Type IIB string theory on a strongly warped background. They obtained

the low energy Lagrangian and found that the warped Kahler potential for the metric moduli differs from what was widely assumed in previous literature. Their results initiated a series of studies (by Shiu et al and by others) on deriving the warped effective action. With his student P. McGuirk, and F. Marchesano (CERN), Shiu computed the open string wavefunctions in warped compactifications. Besides their applications to determining the Yukawa couplings and hence the flavor structure of warped extra dimension models in string theory, the wavefunctions they found were used to extract the Kahler potential for open strings on D7-branes in warped backgrounds. With postdoc H. Chen and Y. Nakayama (Berkeley), he derived the combined Kahler potential including both D3-brane and closed string fluctuations. The results of this body of work are much needed for a precise determination of the effective action governing particle physics and inflation in warped string compactifications.

The work of Shiu with F. Marchesano and P. McGuirk represents the first step of a research program in constructing warped extra dimension models from string theory that he is actively pursuing. These warped models are interesting because other than providing a geometric way of generating the weak scale hierarchy, they can be understood, by way of the AdS/CFT correspondence, as holographic duals of technicolor-like (albeit supersymmetric) theories. Constructing these warped models from a UV complete theory allows us to go beyond a qualitative rephrasing of the strong coupling dynamics in terms of a gravity dual, and to make quantitative predictions. Explicit UV completions may also lead to new model building insights. Shiu et al are exploring warped chiral models where the Standard Model fields are embedded in various ways on the worldvolume of D7-branes (with gauge fluxes) and their intersections. Their setup thus provides a string theory realization of the *extended* Randall-Sundrum (RS) scenario in which the gauge and matter fields propagate in the “bulk”. Their preliminary studies also suggest novel F-theory models where additional hierarchical structure in the Yukawa couplings can be generated by warping. Other than realizing the Standard Model, these warped setups can also help understand the physics of strongly coupled hidden sectors, an important element in many SUSY breaking scenarios (see next subsection). Shiu is also interested in extending this program to non-supersymmetric warped backgrounds as they can serve as a starting point for constructing composite Higgs or technicolor-like models where strongly coupled dynamics leads to the breaking of electroweak symmetry. Some recent progress in constructing stable non-supersymmetric throats has been made by Kachru, Simic, and Trivedi though models with realistic particle physics features would require more sophisticated model building techniques that Shiu aims to explore.

Shiu plans to draw on his expertise on D-brane constructions to motivate new model building possibilities for F-theory (e.g., including warping as above). Furthermore, he is exploring the possibility of constructing realistic D-brane models from compactifications on generalized geometries and non-geometric backgrounds, partly because these unfamiliar

backgrounds have recently been shown by Shiu et al to be a useful ingredients in constructing classical de Sitter vacua in string theory (see below). In fact, duality arguments suggest that Calabi-Yau compactifications with background fluxes form only a small fraction of the type II string landscape. Non-geometric vacua in particular forces us to go beyond the supergravity approximation and may teach us interesting lessons about stringy physics. Furthermore, to understand better the effective action of $\mathcal{N} = 1$ string compactifications, he is investigating with H.Y. Chen and I. Garcia-Etxebarria (UPenn) certain instanton corrections in orientifold models that are inherent from their parent $\mathcal{N} = 2$ theories. With P. McGuirk and P. Ouyang, he is calculating higher derivative corrections to the D-brane action in warped backgrounds.

Moduli Stabilization, Supersymmetry Breaking and its Mediation

Shiu has been actively pursuing the issue of SUSY breaking and its mediation in string theory both because of the imminent impact on the LHC, and because SUSY occupies a central place in connecting several important areas in high energy physics, astrophysics (e.g. dark matter), and cosmology. SUSY breaking is also intimately tied to the some of the key questions in string theory such as moduli stabilization and vacuum selection. As illustrated in the completed and ongoing projects below, the issues of moduli stabilization and SUSY breaking are often highly coupled and so we describe these two topics together in this section.

While background fluxes and non-perturbative effects from wrapped branes (as in KKLT) can stabilize closed string moduli, a concrete realistic D-brane model where *all* moduli are stabilized is still lacking. Stabilizing open string moduli is phenomenological relevant as the masses attained by these moduli can be understood as soft terms on the D-brane worldvolume theory. With his student B. Underwood, O. DeWolfe (Colorado), L. McAllister (then at Princeton), Shiu investigated D3-brane moduli stabilization in local models of flux compactification. The explicitness of the local metrics enabled them to solve for the D3-brane vacua in the presence of a variety of moduli-stabilizing D7 (or Euclidean D3) branes. With postdoc H.-Y. Chen and L.-Y. Hung (Cambridge), he introduced multiple wrapped D-branes to local D-brane models to realize the tracetrack scenario and solved for the D3 vacua. The results of these works have direct applications to warped D-brane inflation (see below), as well as local constructions of particle physics models involving D3-branes. He is currently investigating the stabilization of D7 moduli in warped backgrounds, as such setups could lead to a non-trivial “open string discretuum”. Such analysis is also relevant for string inflation and for building warped extra dimension models from string theory (see previous subsection).

With student P. McGuirk and postdoc Y. Sumitomo (funded by Nishina Foundation), Shiu recently constructed the backreacted supergravity solution of $\overline{D3}$ -branes near the tip of the warped deformed conifold. This setup is interesting since: (i) $\overline{D3}$ is a key ingredient in many constructions of de Sitter vacua (e.g., KKLT), (ii) it provides a gravity dual of

metastable SUSY breaking and holography can give us a tool to compute soft SUSY breaking terms even when the messengers are strongly coupled (hence perturbative techniques are not applicable). In the holographic dual, the visible sector gauge symmetry is realized on the worldvolume of D7-branes in the warped background. The messengers are bi-fundamental quarks charged under the hidden and visible sectors but they do not participate in SUSY breaking, thus realizing semi-direct gauge mediation. Though an asymptotic solution far away from the $\overline{D3}$ brane have been obtained by DeWolfe et al, the surviving \mathbf{Z}_{2M} R-symmetry in UV region forbids the messenger quarks to contribute to the gaugino mass, as confirmed by an explicit computation in the recent work of Benini et al. Therefore, Shiu et al constructed solutions in the near tip region as the R-symmetry is broken to \mathbf{Z}_2 which allows for a non-vanishing gaugino mass. In a subsequent paper, they computed explicitly the gaugino mass using holography and found it differs *qualitatively* from that of standard gauge mediation scenarios where the messengers are weakly coupled. He is extending this holographic analysis to the sfermion sector in an ongoing work with F. Marchesano and P. McGuirk. Shiu also plans to further explore more broadly this holographic approach to other strong coupling extensions of the Standard Model, e.g., in realizing single sector SUSY breaking.

Non-perturbative instanton effects are often invoked in moduli stabilization, but the full moduli dependence of such effects are extremely difficult to determine explicitly. Thus it is of interests to develop new mechanisms to stabilize moduli and (motivated by the observational evidence of dark energy) to construct de Sitter vacua in string theory without introducing such effects. With students S. Haque, B. Underwood, and T. van Riet (Fulbright Fellow), Shiu examined and found the minimal ingredients for constructing de Sitter solutions in string theory using only classical ingredients (fluxes, orientifold planes, and curvature, etc). Their work substantiated and simplified an earlier proposal of E. Silverstein, and has elucidated how certain no-go theorems in the literature can be evaded. In a subsequent work with U. Danielsson (Uppsala), S. Haque and T. van Riet, Shiu demonstrated that classical de Sitter solutions can be constructed from compactifications of Type II string theory on generalized geometries, in particular, manifolds with $SU(3)$ structure. Shiu plans to investigate further this direction, especially to incorporate D-branes and particle physics features in such constructions as they represent a new distinctive class of de Sitter vacua in string theory. He also intends to explore other recent ideas of constructing de Sitter solutions, where the cosmological constant scale is hierarchically separated from the KK scale.

String Theory and LHC Phenomenology

Shiu has a long-standing interest in beyond the Standard Model phenomenology that are motivated from top-down string constructions. His previous works include studies of string resonances, extra dimensions, SUSY, additional gauge sectors, flavor and family symmetries, hidden sectors, extended Higgs sector, and exotic matter. His investigations in this area in

the past three years focuses on the LHC signatures of warped extra dimensions and novel SUSY breaking and mediation mechanisms (see above). Much work has been done in studying the LHC signatures of KK gravitons for the RS scenario. With student B. Underwood, D. Walker and K. Zurek (both then postdocs of the phenomenology task), Shiu compared and contrasted these results to that of warped string backgrounds. They found that small differences in the warped geometries can lead to drastic differences in the masses and couplings of the KK modes. Their work provided a proof of concept that collider data can help distinguish different string compactifications. Subsequently, with P. McGuirk and K. Zurek, he studied the effect of the infrared geometry on warped extra dimension phenomenology.

In anticipation of the LHC, his work for the next few years in this direction will first focus on models and scenarios that may lead to an early discovery, and then evolve his studies in response to data. Among the scenarios which can be tested at an early stage of the LHC operation is the possibility of a low string scale due to the existence of large or warped extra dimensions. While observing the effects of real or virtual KK modes emission will lend support to the brane world idea, the soft Regge behavior of string amplitudes is indicative that such scenario in fact descends from string theory. A systematic study of the relevant string amplitudes has recently been carried out by D. Lust, T.R. Taylor, and collaborators. It was found that certain amplitudes, to leading order in string coupling (but to all orders in α'), are universal, i.e., independent of the details of the compactification, such as the configuration of branes, the geometry of the extra dimensions, and whether supersymmetry is broken or not. In an ongoing collaboration with a student Z. Dong, M. Huang (IPMU) and his phenomenology colleague T. Han, Shiu is carrying out a detailed phenomenological study aimed at uncovering the discovery potential of string resonances at the LHC. They found that top quark pair production is a promising channel for detecting such resonances, due to their low Standard Model background and the aforementioned universality. The mass ratios of these resonances and the unusual angular distribution may distinguish them from other new physics. They are developing strategies for detecting these string resonances by combining techniques to reconstruct the $t\bar{t}$ center of mass frame from their semi-leptonic decay and some recent ideas in identifying highly boosted tops. As a spin-off of this study, Shiu is examining more generally the strategy for detecting resonances with approximately degenerate masses and exotic (higher) spins at the LHC as there may be interesting interference effects on resonances. Moreover, Shiu is interested in exploring some model-dependent amplitudes for concrete D-brane models, as they could be useful for precision tests that distinguish between different string compactifications. This body of work is also connected to the recent efforts in uncovering the symmetries and recursion relations of gauge/string theory amplitudes (at both weak and strong coupling), a subject that Shiu is actively investigating.

The minimal assumptions often made in the phenomenological studies of SUSY, such as

a “minimal choice” of the Kahler potential and the universality of UV boundary conditions, are not necessarily realized or motivated in top-down string constructions. Shiu plans to study the phenomenology of these “non-minimal” scenarios, applying results from his recent and ongoing work on the effective action of $\mathcal{N} = 1$ string compactifications.

String Cosmology

In addition to his work on building de Sitter vacua described above, Shiu’s recent research in string cosmology centers around string inflation: from its theoretical underpinnings to observational signatures. Inflation is currently the leading paradigm describing the early universe, but yet several important and data-driven questions about inflation *require* an understanding of its high energy completion. Most apparently, the conditions ensuring a sufficient e-fold of inflation are sensitive to dimension six, Planck suppressed corrections to the inflaton potential. This UV sensitivity is even stronger in models with observable tensors or large non-Gaussianities. Shiu’s recent and proposed work aims to address these UV aspects of inflation in string theory context, and conversely, to explore how observational data can serve as a discriminator of string theory models. This program is expected to generate synergistic collaborations with D. Chung and postdoc J. Xu who will join in fall 2010.

Since the dynamics of inflation and its observational signatures are sensitive to all kinds of corrections to the inflaton lagrangian, it is important to develop techniques in deriving the low energy effective action of string compactifications. His recent body of work on warped effective theory described above is a first step in this direction, as warping appears in many string inflation models. In particular, the Kahler potential obtained in his work with H.Y. Chen and Y. Nakayama describes the inflaton dynamics in strongly warped D-brane inflation. Shiu intends to further explore other issues in the effective action of string compactifications relevant for string inflation. For example, his proposed work with H.Y. Chen and I. Garcia-Etxebarria (UPenn) on instanton computations in $\mathcal{N} = 1$ string compactifications may shed light on the non-perturbative breaking of shift symmetry in axion monodromy inflation. His ongoing work with P. McGuirk and P. Ouyang on higher derivative corrections to D-brane action in warped backgrounds also has applications to string inflation in mind.

In regard to string inflation model building, Shiu with postdocs H.-Y. Chen and P. Ouyang analyzed the stability conditions on D7-branes in the warped deformed conifold. Understanding such D7-brane embeddings is important as instanton effects on the D7-branes are often invoked in stabilizing moduli and in generating an inflaton potential. They showed that holomorphicity is not sufficient to ensure that the D7-branes are energy-minimizing when supergravity fluxes which stabilize the exponential hierarchy of the throat are present. They demonstrated by explicit construction that these D7-branes can nevertheless be made stable with appropriate worldvolume flux. Their results enlarged the class of wrapped branes that

can be invoked in D-brane inflation. With postdocs H.Y. Chen and J.O. Gong, Shiu examined whether additional light fields associated with the angular directions of the conifold can generate significant power spectrum and non-Gaussianities at the end of brane inflation. They determined also the model building criteria for such effects to arise. With H.Y. Chen and L.Y. Hung, he presented a variant of brane inflation by incorporating multiple moduli-stabilizing D7-branes in a warped throat, and demonstrated that the bound on the gravitino mass in terms of the inflation scale discussed by Kallosh and Linde can be evaded.

String inflationary models often suggest new observational opportunities that may seem unusual from a conventional field theory viewpoint. His work on the primordial bispectrum of general single field inflation, motivated by the non-standard kinetic terms that often arise in string theory (e.g., DBI type), is an example. He continues this line of inquiry in several recent work. With M. Huang and B. Underwood, he investigated non-Gaussianities in multi-field DBI inflation, a model which can be realized with the motion of D3-branes in warped throats. With X. Chen, B. Hu, M. Huang, and Y. Wang, he computed the inflationary trispectrum for models with large non-Gaussianities. Besides observationally relevant, the non-Gaussian spectra obtained in this collection of works can provide a useful laboratory for testing various proposed holographic descriptions of de Sitter space, a subject that Shiu plans to revisit. The precise form of this holographic duality may help determine the non-Gaussian spectra for more complicated cases that have not yet been worked out.

Given the significance of observable primordial tensors in elucidating the underlying UV physics, Shiu is interested in exploring string inflation models with such feature. Recently, some interesting scenarios with observable tensor fluctuations have been proposed by E. Silverstein and collaborators, using ingredients such as the classical de Sitter solutions described above or the perturbative shift symmetry of the axion. Shiu plans to build on his expertise on these subjects to construct explicit models and study more quantitatively their signatures.

5 Independent research of postdoctoral researchers

Postdoctoral researchers constitute the core element of research resources of the string/cosmology group. These researchers are encouraged to work both as an independent researcher as well as in collaboration with the principal investigators. The following summarizes the research activities of postdoctoral researchers Heng-Yu Chen, Bjorn Garbrecht, Jinn-Ouk Gong and Peter Ouyang.

5.1 Heng-Yu Chen

Papers published since August 2007

- “Comments on the Boundary Scattering Phase,” H. Y. Chen and D. H. Correa, JHEP **0802**, 028 (2008) [arXiv:0712.1361 [hep-th]].
- “Systematics of multi-field effects at the end of warped brane inflation,” H. Y. Chen, J. O. Gong and G. Shiu, JHEP **0809**, 011 (2008) [arXiv:0807.1927 [hep-th]].
- “On Supersymmetric D7-branes in the Warped Deformed Conifold,” H. Y. Chen, P. Ouyang and G. Shiu, JHEP **1001**, 028 (2010) [arXiv:0807.2428 [hep-th]].
- “Towards a warped inflationary brane scanning,” H. Y. Chen and J. O. Gong, Phys. Rev. D **80**, 063507 (2009) [arXiv:0812.4649 [hep-th]].
- “Inflation on an Open Racetrack,” H. Y. Chen, L. Y. Hung and G. Shiu, JHEP **0903**, 083 (2009) [arXiv:0901.0267 [hep-th]].
- “On D3 Dynamics at Strong Warping,” H. Y. Chen, Y. Nakayama and G. Shiu, accepted by IJMPA, arXiv:0905.4463 [hep-th].
- “Towards a Holographic Model of Color-Flavor Locking Phase,” H. Y. Chen, K. Hashimoto and S. Matsuura, JHEP **1002**, 104 (2010) [arXiv:0909.1296 [hep-th]].
- “Wall-Crossing and Instantons in Compactified Gauge Theory,” H. Y. Chen, N. Dorey and K. Petunin, arXiv:1004.0703 [hep-th].

Invited talks

- “Updates on Warped Brane Inflation,” UIUC, January 2009.
- “Updates on Warped Brane Inflation,” Purdue University, March 2009.
- “On D3 Dynamics at Strong Warping,” QTS Meeting 6, University of Kentucky, July 2009.
- “Towards a Holographic Model of Color-Flavor Locking Phase,” Cornell University, December 2009.
- “Towards a Holographic Model of Color-Flavor Locking Phase,” State University of New York, Stony Brook, December 2009.
- “Wall-Crossing and Instantons in Compactified Gauge Theory,” Great Lake String Meeting 2010, University of Cincinnati, March 2010.

Description of recent research activities

Here is a brief summary of the work conducted by Chen in each of the papers in the

above list.

- In arXiv:0712.1361, done in collaboration with Diego Correa, they presented a simple solution to the crossing equation for an open string worldsheet reflection matrix, with boundaries preserving a $SU(1|2)^2$ residual symmetry. They also proposed an analogous crossing equation for the dressing factor where extra boundary degrees of freedom preserve a $SU(2|2)^2$ residual symmetry.
- In arXiv:0807.1927, done in collaboration with Jinn-Ouk Gong and Gary Shiu, they investigated in the context of warped brane inflation, the possibility of additional light scalar fields generating significant power spectrum and non-Gaussianities at the end of inflation affecting the CMB scale observations.
- In arXiv:0807.2428, done in collaboration with Peter Ouyang and Gary Shiu, they considered the supersymmetric conditions for D7-branes in warped deformed conifold, and constructed numerically the D7 worldvolume flux required for the supersymmetry condition to be satisfied for the simplest case.
- In arXiv:0812.4649, done in collaboration with Jinn-Ouk Gong, they presented a detailed systematics for comparing warped brane inflation with the observations, incorporating the effects of both moduli stabilization and ultraviolet bulk physics.
- In arXiv:0901.0267, done in collaboration with Ling-Yan Hung and Gary Shiu, they presented a variant of warped D-brane inflation by incorporating multiple sets of holomorphically-embedded D7-branes involved in moduli stabilization with extent into a warped throat.
- In arXiv:0905.4463, done in collaboration with Yu Nakayama and Gary Shiu, they studied the dynamics of a D3 brane in generic IIB warped compactifications, using the Hamiltonian formulation discussed in arXiv:0805.3700 [hep-th]. Taking into account of both closed and open string fluctuations, they derived the warped Kahler potential governing the motion of a probe D3 brane.
- In arXiv:0909.1296, done in collaboration with Koji Hashimoto and Shunji Matsuura, they demonstrated a holographic realization of color-flavor locking phase, using N=4 $SU(N_c)$ SYM coupled to N=2 Nf fundamental hypermultiplets, arising from D3-D7 branes as an example.
- In arXiv:1004.0703, done in collaboration with Nick Dorey and Krill Petunin, they calculated the leading weak-coupling instanton contribution to the moduli-space metric of N=2 supersymmetric Yang-Mills theory with gauge group $SU(2)$ compactified on $R^3 \times S^1$. The results are in precise agreement with the semiclassical expansion of the exact metric recently conjectured by Gaiotto, Moore and Neitzke based on considerations related to wall-crossing in the corresponding four-dimensional theory.

Current and planned research directions

As part of his current and future research, Chen plans to study the following:

- With Nick Dorey and other collaborators, Chen has initiated the semi-classical analysis of the recently discovered Wall-Crossing formulae in four dimensional supersymmetric gauge theories, and currently been trying to extend it to other non-trivial setups such as theories higher rank gauge groups, different matter contents, and explicit string theory embeddings. He is also investigating the connection between integrability and wall-crossing phenomena.
- Together with Jin-Ouk Gong, Kazuya Koyama and Gianmassimo Tasinato, Chen is constructing an explicit potential for the multi-field DBI inflation in warped deformed conifold throat, utilizing his earlier results in warped compactifications. The collaboration also plans to investigate the interesting phenomenology of such model, for example large non-Gaussianity and reheating .
- Finally, in collaboration with Shunji Matsuura, Chen would like to realize the holographic model of color-flavor locking phase in other string theory setups, where supersymmetry is broken or the fundamental degrees of freedom consist only of fermions.

5.2 Bjorn Garbrecht*Papers published 6/07-8/09*

- R. A. Battye, B. Garbrecht, A. Moss and H. Stoica, “Constraints on Brane Inflation and Cosmic Strings,” JCAP **0801**, 020 (2008) [arXiv:0710.1541 [astro-ph]].
- R. A. Battye, B. Garbrecht and A. Pilaftsis, “Textures and Semi-Local Strings in SUSY Hybrid Inflation,” JCAP **0809**, 020 (2008) [arXiv:0807.1729 [hep-ph]].
- D. J. H. Chung, B. Garbrecht and S. Tulin, “The Effect of the Sparticle Mass Spectrum on the Conversion of B-L to B,” JCAP **0903**, 008 (2009) [arXiv:0807.2283 [hep-ph]].
- D. J. H. Chung, B. Garbrecht, M. J. Ramsey-Musolf and S. Tulin, “Yukawa Interactions and Supersymmetric Electroweak Baryogenesis,” Phys. Rev. Lett. **102**, 061301 (2009) [arXiv:0808.1144 [hep-ph]].
- B. Garbrecht and T. Konstandin, “Separation of Equilibration Time-Scales in the Gradient Expansion,” Phys. Rev. D **79**, 085003 (2009) [arXiv:0810.4016 [hep-ph]].
- D. J. H. Chung, B. Garbrecht, M. J. Ramsey-Musolf and S. Tulin, “Lepton-mediated electroweak baryogenesis,” Phys. Rev. D **81**, 063506 (2010) [arXiv:0905.4509 [hep-ph]].
- D. J. H. Chung, B. Garbrecht, M. J. Ramsey-Musolf and S. Tulin, “Supergauge interactions and electroweak baryogenesis,” JHEP **0912**, 067 (2009) [arXiv:0908.2187 [hep-ph]].

Description of recent research activities done independently of the PI

- 0710.1541: By considering simple, but representative models of brane inflation from a single brane-antibrane pair in the slow roll regime, Garbrecht et al provide constraints on the parameters of the theory imposed by measurements of the CMB anisotropies by WMAP including a cosmic string component.
- 0807.1729: If the anomalously large cold spots observed in the CMB are a signal, they can be explained by textures. A realistic model of F-term hybrid inflation is constructed that leads to the formation of textures at the waterfall transition.
- 0810.4016: On and off-shell chemical potential equilibration processes in a semiclassical approach are analytically described.

5.3 Jinn-Ouk Gong*Papers published during 12/07-10/08*

- J. O. Gong and S. C. Park, “Minimal extra dimensional cosmology from hidden sector gauge theory,” arXiv:0801.0333 [hep-ph].
- J. O. Gong and M. Sasaki, “Curvature perturbation spectrum from false vacuum inflation,” JCAP **0901**, 001 (2009) [arXiv:0804.4488 [astro-ph]].
- H. Y. Chen, J. O. Gong and G. Shiu, “Systematics of multi-field effects at the end of warped brane inflation,” JHEP **0809**, 011 (2008) [arXiv:0807.1927 [hep-th]].
- R. K. Jain, P. Chingangbam, J. O. Gong, L. Sriramkumar and T. Souradeep, “Double inflation and the low CMB multipoles,” JCAP **0901**, 009 (2009) [arXiv:0809.3915 [astro-ph]].

Description of recent research activities done independently of the PI

- 0801.0333: An inflationary model is built with the assumption that one extra dimension is compactified on an S^1/\mathbb{Z}_2 with the extra dimension gauge field component playing the role of the inflaton.
- 0804.4488: In the inflationary cosmology it occurs frequently that the inflaton field is trapped in a local, transient minimum with non-zero vacuum energy. The difficulty regarding the curvature perturbation produced during such a stage is that classically the inflaton does not move such that the comoving hypersurfaces are not well defined at linear order in the scalar field perturbation. In this paper, assuming a mechanism of trapping which resembles a high temperature correction to the potential, the power spectrum of the curvature perturbation is computed by evaluating the quantum two-point correlation function directly. The spectrum is found to be steeply blue with the spectral index $n_R = 4$.

- 0809.3915: Double inflation allows a brief period of departure from inflation sandwiched between two stages of slow roll inflation. Such a background behavior leads to a step-like feature in the scalar power spectrum. If the scales are set such that the drop in the power spectrum occurs at a length scale that corresponds to the Hubble radius today, the lower power observed in the CMB quadrupole can be explained.

5.4 Peter Ouyang

Papers published since August 2007

- L. L. Everett, I. W. Kim, P. Ouyang and K. M. Zurek, “Deflected Mirage Mediation: A Framework for Generalized Supersymmetry Breaking,” *Phys. Rev. Lett.* **101**, 101803 (2008) [arXiv:0804.0592](#) [[hep-ph](#)].
- L. L. Everett, I. W. Kim, P. Ouyang and K. M. Zurek, “Moduli Stabilization and Supersymmetry Breaking in Deflected Mirage Mediation,” *JHEP* **0808**, 102 (2008) [arXiv:0806.2330](#) [[hep-ph](#)].
- H. Y. S. Chen, P. Ouyang and G. Shiu, “On Supersymmetric D7-branes in the Warped Deformed Conifold,” submitted to *JHEP* [arXiv:0807.2428](#) [[hep-th](#)].
- A. Hashimoto and P. Ouyang, “Supergravity dual of Chern-Simons Yang-Mills theory with $N=6,8$ superconformal IR fixed point,” *JHEP* **0810**, 057 (2008) [arXiv:0807.1500](#) [[hep-th](#)].
- O. Aharony, A. Hashimoto, S. Hirano and P. Ouyang, “D-brane Charges in Gravitational Duals of 2+1 Dimensional Gauge Theories and Duality Cascades,” [arXiv:0906.2390](#) [[hep-th](#)].
- A. Hashimoto, S. Hirano and P. Ouyang, “Branes and fluxes in special holonomy manifolds and cascading field theories,” [arXiv:1004.0903](#) [[hep-th](#)].

Invited talks

- “Supergravity Dual of Chern-Simons Yang-Mills theory with $N=6,8$ superconformal IR fixed point,” McGill Workshop on M2-branes, September 2008.
- “Flowing to Superconformal Chern-Simons in AdS/CFT,” University of Illinois at Urbana-Champaign, November 2008.
- “Fractional Branes in CS/YM/Matter Theories, Part II,” Great Lakes Strings Conference, University of Michigan, April 2009.
- “Charge Quantization in Gravity Duals of Three-Dimensional Gauge Theory,” McGill University, May 2009.

- “A Supersymmetric Cascade to Superconformal Chern Simons,” Quantum Theory and Symmetries, Lexington, KY, July 2009.
- “New Results in Gravity Duals of Cascading Field Theories,” Purdue University, November 2009.

Description of recent research activities

Since arriving in Wisconsin in 2007, Ouyang has worked on a variety of projects ranging from studies of gauge/gravity duality to concrete particle physics models based on the MSSM.

- A work with Chen and Shiu on D7-branes in the warped deformed conifold was completed (see Shiu’s section.)
- A pair of papers was written with Everett, Kim, and Zurek on their model for the mediation of supersymmetry breaking to the MSSM, which they called “Deflected Mirage Mediation.” This model combines aspects of certain well-known mediation mechanisms which may be embeddable in string theory (moduli mediation, gauge mediation, and anomaly mediation.) In particular, moduli mediation is a generic component of models constructed from flux compactifications, and anomaly mediation is generically present in all soft breaking scenarios, and if there are messenger fields charged under the Standard Model gauge group then gauge mediation can be present as well. The novelty of this idea is that the framework is sufficiently broad to contain a large variety of interesting specific models (there are five continuous free parameters) and as such gives an alternative to the dominant “minimal supergravity” framework for exploring the soft supersymmetry breaking terms of the MSSM.
- Ouyang has worked on a series of papers with Hashimoto, Hirano, and Aharony on gravity duals of 2+1 dimensional field theories with Chern-Simons interactions (see Hashimoto’s section.) He is interested in further extensions of this work in attempts to understand phases with dynamical supersymmetry breaking, as well as to investigate an obscure 2+1 dimensional field theory with 8 supercharges which is believed to flow to the ABJM superconformal theory, but whose Lagrangian description is currently unknown.
- In the future, Ouyang is interested in extending recent progress on the computation of scattering amplitudes for weakly coupled gauge theory and gravity in flat space to the case of anti-de Sitter space. In the flat space calculation, the amplitudes one computes are subject to certain kinematic constraints which are easy to derive in a spinor helicity formalism but which are not obvious by ordinary Feynman diagram methods. The question is whether these methods can be used to similarly constrain anti-de Sitter amplitudes and what these constraints would imply for correlation functions in the dual conformal field theory.
- Another current interest is in the study of Coleman-de Luccia tunneling processes in Kaluza-Klein theories where the dimension of spacetime can change dynamically.

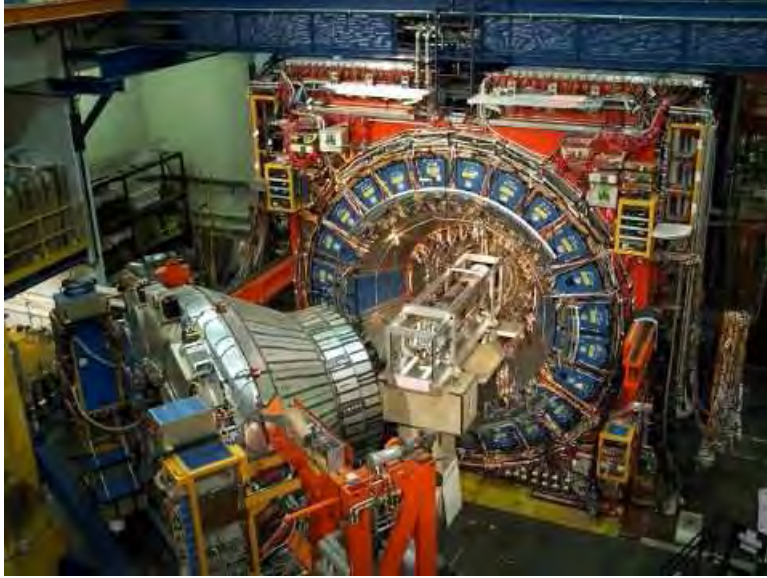
**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**

Institution Name University of Wisconsin - Madison

Task/Title **Task D: String Theory & Cosmology**

Type of Position	Name	Activity #1	FTE Months on String Th & Cosmo Research	# months funded by DOE-HEP University Program String Th/Cosmo	Faculty Advisor
Faculty	Chung, Daniel	Cosmology	2	2	
	Hashimoto, Aki	String Theory	2	2	
	Shiu, Gary	String Theory	2	2	
Post Doc	Trancanelli, Diego	String Theory	12	12	Hashimoto
Post Doc	Xu, Jiajun	String Theory	12	12	Shiu
Grad Student	Long, Andrew	Cosmology	3	3	Chung
Grad Student	Yoo, Hojin	Cosmology	3	3	Chung
Grad Student	Zhou, Peng	Cosmology	3	3	Chung
Grad Student	Haque, Shajid	String Theory	3	3	Hashimoto
Grad Student	Kiewe, Michael	String Theory	3	3	Shiu



Ultra High Energy Colliding Beam Physics

DOE Award DE-FG02-95ER40896 Task E

April 2010

Principal investigators: D. Carlsmith, M. Herndon, L. Pondrom

The activities of Task E are centered on the CDF II detector at the Fermilab Tevatron $\bar{p}p$ collider and synergistic with activities on the CMS detector at CERN. The Wisconsin group is responsible for the maintenance of the CDF intermediate angle muon system, and is active in data analysis in the Electroweak, QCD, B physics, and Higgs groups, and participates in a variety of CDF support activities. Our physics studies include the standard model Higgs boson, di-boson physics of W pairs and WZ , anomalous quark couplings through the measurement of high mass jet-jet angular distributions, multiparton interactions, and rare B meson decays such as $B_s \rightarrow \mu^+ \mu^-$. Especially interesting is the achievement of sensitivity to the production cross section for standard model Higgs boson production and the exclusion of masses from 163 to 166 GeV. These efforts will continue as the acquired luminosity increases.

1 Overview

Task E activities are centered on the CDF II detector at Fermilab. The Tevatron has delivered more than 8.5 fb^{-1} to CDF, with more than 7 fb^{-1} written to tape, since 2002. The CDF II detector runs smoothly with an overall efficiency of 85%. Run II data sets of approximately 6 fb^{-1} are available to physics groups. The CDF collaboration published over 50 papers in refereed journals in 2009 and is on track to publish a similar number of papers in 2010. The list of publications over the last year includes the first exclusion of the production of the Standard Model (SM) Higgs boson in the mass range 163 to 166 GeV. This landmark physics result provides the first direct information on SM Higgs boson since the final results from the LEP experiments 10 years ago and establishes the ability of the Tevatron program to discover or exclude this elusive particle. This analysis included major contributions from Wisconsin students, postdoctoral researchers, and professors. Operation of CDF through fiscal year 2011 is planned with a total integrated luminosity of approximately 10 fb^{-1} . The Wisconsin group plans to maintain present personnel strength through 2011 to accomplish this goal and to continue data analysis beyond the end of data taking.

The prime hardware responsibility of the Wisconsin CDF group is the Intermediate Muon system (IMU), which includes barrel muon drift chambers (BMU), barrel scintillators (BSU), and toroid scintillators (TSU). The design, construction, installation, and commissioning of this detector is described in the 2002 Task E. Through the efforts of our group, this system continues to operate smoothly.

The Wisconsin group is active in CDF service. Prof. Herndon served on task forces to study and improve the performance L00, the innermost silicon layer, and the high transverse momentum b tagger. Prof. Herndon is also chair of the publication committee on b flavored hadron lifetimes measured in exclusive decays. Previously Prof. Herndon had led the B and Higgs physics groups. In 2009 Prof. Carlsmith has served on the godparent committees for the doubly excited B meson observation and at present for the rare decay $W \rightarrow \pi\gamma$. Professor Pondrom concluded in 2009 a PYTHIA based quark substructure analysis making comparisons to NLO++ calculations. Dr. Pursley completed a one-year term as a CDF Operations Manager (Oct 08 through Sept 09). As Operations Manager, she was responsible for maintaining the quality of data-taking at CDF and reporting on data acquisition to the CDF Collaboration and Fermilab management. Dr. Pursley serves on the publication committee on a CDF measurement of hyperon (Λ , Σ , and Ω) production which will be submitted to Physical Review Letters shortly. Dr. Pursley also leads the $H \rightarrow WW$ high mass Higgs subgroup. Dr. Bellinger is responsible for maintenance of autoSVTMon and TrigMon online data quality monitoring codes and BMU reconstruction. simulation, and L3 trigger software. Dr. Bellinger recently led a team that prepared and released the update of the CDF software to be compatible with the latest Linux operating system release, an absolutely essential step for continued successful operation of CDF. Bellinger also supervises the CDF software Help service. Dr. Chung has overall responsibility for the maintenance of the IMU chambers and scintillators and is active in the global analysis of the asymmetry in decays of W and Z bosons to muons. He has served as ACE in preparation for more extensive

CDF operations responsibilities. Varsha Ramakrishnan carries the IMU pager and assists with IMU chamber maintenance. Under Carlsmith's supervision, she continues to pursue her thesis on multiparton interactions in $W^\pm + \text{dijet}$ events. Under Herndon's supervision, Jason Nett has completed an analysis of tri-lepton events in associated high mass Higgs production and will graduate this year. Wisconsin group members routinely undertake data acquisition shift responsibilities as Scientific Coordinator, Ace, and Consumer Operator. In 2009-10, completed or scheduled shift work includes Carlsmith, Herndon, Pondrom and Pursley as Sci-Co, Ramakrishnan, Nett and Chung as Ace (3 months), Bellinger, and Chung as Consumer Operator.

2 Intermediate Muon System

Designed by Prof. Carlsmith, the IMU system is comprised of 1728 drift tubes (BMU), 432 scintillation counters (BSU) surrounding steel absorber at both ends of CDF II. The detector system and data handling electronics is fully operational and stable. Excellent IMU system performance is maintained by monitoring, anticipating, and addressing problems such as high noise rates or high voltage instabilities, taking advantage of every opportunity for access to the detector, and by maintaining the supplies of spare parts. The maintenance is the responsibility of Dr. Chung.

In view of the possibility of extended Tevatron running, we note that we foresee no major impediment to maintenance of the IMU system. The four-cell chamber stacks have been quite robust. In fact no wire breakage or gas leak has appeared over the life of the experiment and 30 spare stacks are in hand. High voltage distribution boards and four-channel preamplifier circuit boards mounted on the detector occasionally (2-4 per year) fail and are replaced and refurbished and 20 HV and 40 preamp board spares are in hand. The four crates of Amplifier-Shaper-Discriminator circuits have operated without failure and five spare cards are in hand. As of this writing there are 7 dead channels in the BMU system, two of which are associated with 96-channel TDC board single channel problems considered not possible to fix.

Dr. Chung monitors IMU data triggered and unbiased data samples. Figures in the 2009 TASKE report illustrated monitoring of BSU and TSU trigger counter efficiency for aging with $Z \Rightarrow \mu^+\mu^-$ events triggered on a central muon. No evidence was found for aging.

3 WI Scientists, CDF Operations, and Computing

In addition to assisting with the supervision and support of Wisconsin graduate students, Wisconsin group scientists play a substantial role in the continuing successful operation of the CDF experiment. We call attention to their participation in the Operations Department. Dr. Pursley has served as Operations Manager at CDF in 2009 and Dr. Chung is expected to serve in 2010. The CDF Operations Department is charged with the efficient operation of the CDF detector and the acquisition of highest quality data. The Operations Department falls

under the Fermilab CDF Group but also reports to the spokespersons of the experiment. The CDF Ops Group Co-leaders negotiate with directorate, PMG, Accelerator Division head, and AD Run Coordinator to formulate global plans for CDF data collection activities and specific needs from lab and AD. At least one of the Co-leaders attends a Monday-Thursday 9am planning meeting in the AD. On Friday, the AD planning meeting is open to a larger audience and includes short summary reports from various accelerators and running experiments. CDF also reports at the All Experimenters' Meeting on Mondays at 4pm.

The three CDF Operations Managers are charged with implementing the overall run plan as set by the Operations Group Co-leaders. Each Operations Manager is on-duty for one week out of three and is basically on-call 24x7. The Operations Manager is responsible for day-to-day operations of the CDF experiment and is expected to be in-charge of implementing global plan and making operational decisions about that plan. Specific duties include:

- Formulating daily run plan and keeping shift crews informed of this plan (including posting plan on control room White Board). Plan should include what to do during stores, between stores, and during unplanned Tevatron downtime (i.e. after store aborts).
- Run the Monday-Friday 8am operations meeting.
- Keep Stores Summary and "This Week's Schedule" up to date.
- Keep track of access and work requests and initiate collision hall access negotiations.
- Run collision hall accesses (controlled or supervised) when Dee Hahn is not available.
- Report at weekly CDF meeting on Thursday.
- Report at All Experimenters' meeting 4 PM Monday in WH Curia II
- Identify those items costing CDF efficiency and/or data quality and enlist aid of Operations Group Associate Heads to correct those problems.
- Develop (or tweak) tools to help do Operations Manager job.
- Closely followed Tevatron operations and developed an understanding of the accelerator complex. Communicate with the MCR Crew Chief when necessary.

Figures 1 and 2 illustrate that both the Tevatron and CDF continue to operate with ever increasing luminosity and high efficiency.

Dr. Bellinger plays a major role in supporting the CDF computing infrastructure. CDF processes data on farms around the world, most of which are migrating to new operating systems. In 2009, Bellinger managed the Code Migration team, supervising a core group of seven scientists in the job of developing tools to support new operating systems (SL4 and SL5) and coordinating physics groups to validate the new packages and systems. In the process the group uncovered and found a work-around for a previously unknown compiler bug. Running

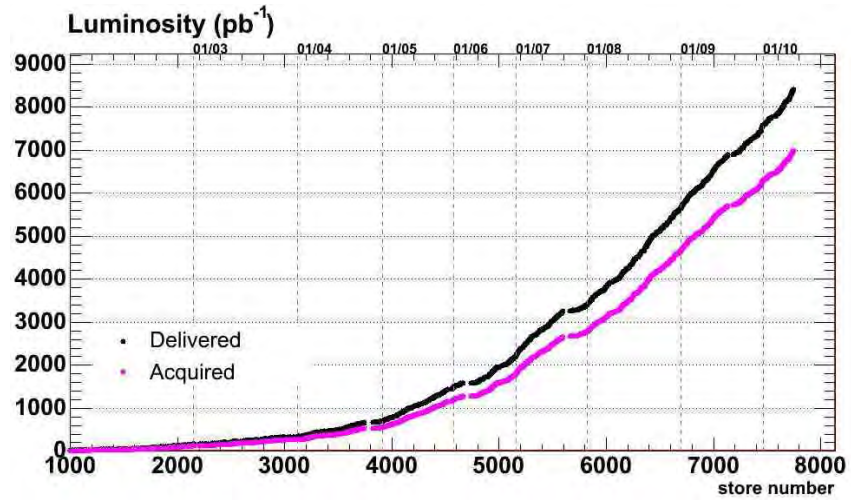


Figure 1: Luminosity delivered and acquired by CDF in Run II as a function of store number.

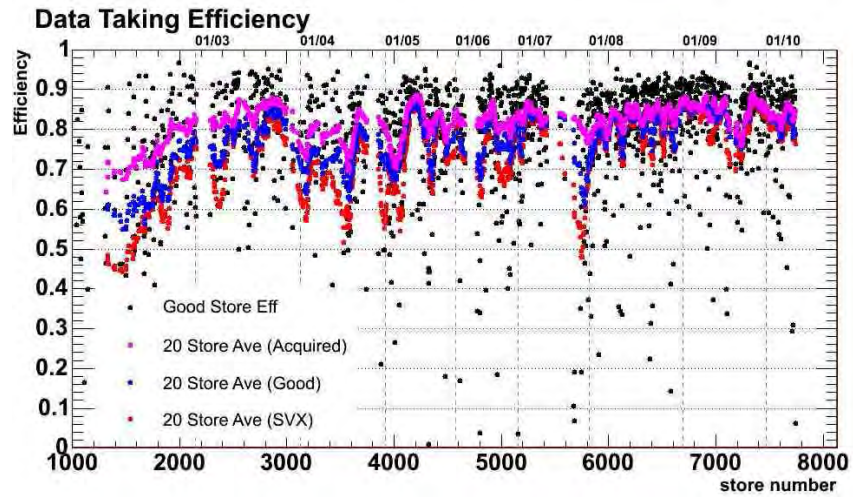


Figure 2: Efficiency of CDF data acquisition in Run II as a function of store number.

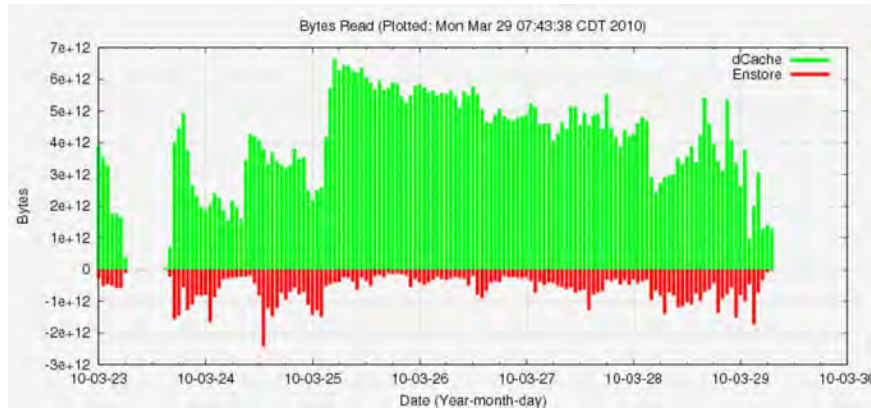


Figure 3: Bytes processed in the CDF data reduction computing farm as a function of time.

the CDF analyses is a large operation, as evidence by the data transfer rates shown in Figures 3. As many as 250 million events are processed per day. The CDF library consists of over 200,000 lines of code, written mostly by physicists, and requires maintenance as compilers become stricter and adjustments are made to keep up with operational conditions. Dr. Bellinger is responsible for supervising the CDF Software Help service, and is writing documentation for the CDF code. Locally, Bellinger is responsible for CDF software and computing support for the Wisconsin CDF group.

4 Improvements in Silicon Tracking

This year Prof. Herndon has participated in task forces to study and improve the performance of the L00 (innermost silicon layer) and the high transverse momentum b-tagger. These task forces primarily focused on understanding degraded efficiency of these systems and algorithms at high instantaneous luminosity. The work of understanding the underlying causes of the efficiency loss was performed by Prof. Herndon as the primary expert on silicon tracking at the CDF experiment. The degraded L00 performance was traced to problems with calibration of the system at high luminosity. The calibration problems are recoverable and the efficiency of the L00 system has been restored. During the L00 studies, ideas emerged to further improve the efficiency of the L00 and these ideas are being tested in the context of the $B_s \rightarrow \mu^+\mu^-$ analysis. Modifications to the clustering algorithm used to construct hits in the silicon detector for b-tagging were developed by Prof. Herndon that recover the majority of the efficiency loss and mitigate the luminosity dependence. These changes are being implemented for future data processing by CDF.

Prof. Herndon continues to be active in silicon detector software and is currently studying possible improvements to the primary vertex finding algorithm which exhibits substantial inefficiency at high instantaneous luminosity. This work is part of a continuing program of improvements to the silicon detector software of substantial benefit to the CDF collaboration.

5 QCD Physics

5.1 Quark Substructure

The PYTHIA based quark substructure search has been described in previous reports. The jet-jet angular distribution in the dijet center of mass as a function of dijet mass is sensitive to new physics. Quark substructure would be observed in a departure from the angular distribution predicted by QCD, a phenomenon which would become more pronounced as the dijet mass increases. The search for quark substructure with CDF Run II data has been the work of Prof. Pondrom. Systematic effects are a major contributor to the uncertainty in the PYTHIA analysis. No evidence for quark substructure was found, and a limit on the coupling parameter $\Lambda > 2.4$ TeV 95% confidence was obtained, dominated by systematic uncertainties. This version of the analysis was reported at a QCD conference in Dubna, Russia, in September, 2008. Subsequently a godparent committee has been formed to prepare the paper for publication by the collaboration in Phys Rev D.

A parallel effort is being pursued, which compares the CDF jet100 trigger data, corrected to the hadron level, to the predictions of a QCD NLO monte carlo program. Hadron level means that PYTHIA and the detector simulation program have been used to remove the effects of the CDF detector from the data, as far as possible, giving clusters of hadrons rather than calorimeter tower energies in the final state. The NLO monte carlo used is called NLOjet++, written by Zoltan Nagy (arXiv:hep-ph/0307268v2), and available from his CERN website. The jobs have been successfully run on the local UW Condor cluster.

The objective of the NLO calculation is to obtain QCD predictions which are less sensitive to the choice of hard scale than PYTHIA. The hard scale is one of the major sources of systematic uncertainty in the LO analysis. A comparison of the NLO angular distributions with $Q^2 = (E_T^{ave})^2$ to the hadron level corrected CDF dijet data shows that there is good agreement between the two. The comparison of the dijet data to the NLO calculation could be a separate publication.

5.2 Multiple Parton Interactions

Simultaneous hard scattering of two partons in a proton with two partons in an antiproton known as double parton scattering was observed by the CDF collaboration in Run I. Ramakrishnan and Profs. Carlsmith and Pondrom, along with undergraduate researcher Chih-Chien Wang advised by Carlsmith are extending the analysis with Run II data with the goal of potentially probing further parton-parton correlation within the proton.

A signature for double parton scattering is two back to back pairs of partons uncorrelated in azimuth. A collision of a single parton in the proton with a parton in the antiproton may also produce four final state partons (through for example initial and final state radiation) but these partons are correlated in azimuth. Multiple-parton scattering may distinguished from pairs of single parton collisions in multiple $p\bar{p}$ interactions within the same bunch crossing (at present luminosity a normal occurrence!) by requiring the partons originate from the same vertex within the interaction region.

The effort to extract a clean sample of multiparton interaction events in CDF data has focused on W^\pm plus two jet events in which the W bosons decay to electron and neutrino. The multiparton fraction is expected to be substantial for low energy jets and we focus on jet energies in the 5-10 GeV range. Considerable effort has gone into characterizing the events which have a well reconstructed vertex taking advantage of the CDF silicon tracking system in order to distinguish multiparton interactions from multiple proton interactions. The CDF track reconstruction folds together the results of several algorithms to maximize efficiency. We focus on events in which the electron track and one or more tracks within each jet have high quality vertex information from the silicon tracking system. To take advantage of the tracking resolution, we find we must extrapolate tracks to the instantaneous beamline determined for each run segment from a generic CDF data sample. (The instantaneous beamline is displaced from the nominal by millimeters and is slightly tipped relative the the detector axis.) The default jet reconstruction algorithms associate all tracks within a cone in rapidity and azimuth to jet energy observed in the calorimeters. For our analysis, we revisit the track list to distinguish tracks within a jet cone which arise from distinct vertices. The weighted average of the vertex location of high quality tracks from a single vertex associated with a jet is our best estimate of the jet vertex.

Figure 4 shows the distance along the instantaneous beam line between electron candidate and reconstructed vertex of the leading jet versus distance between electron candidate and reconstructed vertex of the second jet in W plus 2 jets data. We have achieved a vertex resolution in this data sample of about 130 microns (rms) to discriminate W +jet electroweak plus QCD single and multiparton events from multiple $p\bar{p}$ collisions within a single bunch crossing and are now well positioned to separate multiparton, QCD single parton, and multiple $p\bar{p}$ collision contributions to this extensive data sample.

6 B Physics: Search for the decays $B_{s,d} \rightarrow \mu^+ \mu^-$

Prof. Herndon was previously convener of the B physics group where he also participated in the observation of B_s mixing. He continues to participate in the searches for $B_s \rightarrow \mu^+ \mu^-$ and $B_d \rightarrow \mu^+ \mu^-$. The B_s decay, with an expected branching ratio in the standard model of 3.8×10^{-9} , is one of the most likely avenues for discovering new physics at the Tevatron, because this branching ratio could be considerably larger in SUSY models. Prof. Herndon has recently published a new search for the rare decays $B_s \rightarrow \mu^+ \mu^-$ and $B_d \rightarrow \mu^+ \mu^-$ [5] improving upon his previous publication by a factor of four. In 2009 Prof. Herndon and undergraduate student David Sperka updated this analysis to use 3.7 fb^{-1} . The improved analysis uses a likelihood discriminant for identifying muons, a neural net based selection technique for final candidate identification, and additional trigger acceptance. The result is a world's best limit of $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) < 4.3 \times 10^{-8}$ at 95% confidence level, which provides stringent constraints on mSUGRA and significantly reduces the allowed parameter space of R-parity violating and $S_0(10)$ SUSY models. The simultaneous search for the decay $B_d \rightarrow \mu^+ \mu^-$ has given the worlds best limit $\text{BR}(B_d^0 \rightarrow \mu^+ \mu^-) < 7.6 \times 10^{-9}$ at 95% confidence level. Mr. Sperka completed an undergraduate thesis on this topic and graduated in 2009

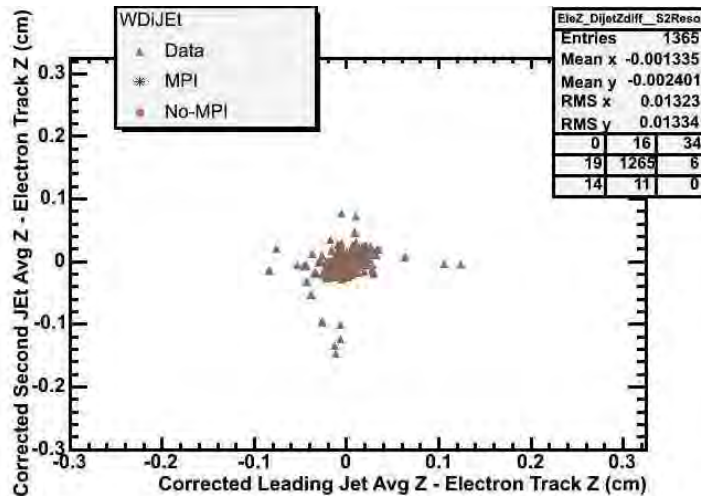


Figure 4: Distance along the instantaneous beam line between electron candidate and reconstructed best estimate vertex of the leading jet versus distance between electron candidate and best estimate vertex of the second jet in W plus 2 jets data. These variables are used to discriminate W +jet electroweak plus QCD single and multiparton events from multiple $p\bar{p}$ collisions within a single bunch crossing.

and has moved on to graduate school at Boston University. Prof. Herndon is collaborating with people from FermiLab and Cornell University to update this analysis with new data and improved use of L00 leveraging his work performed with the L00 task force.

7 Electroweak and Higgs Physics

7.1 Higgs Physics

Prof. Herndon co-convened the CDF Higgs discovery group from inception at the beginning of 2007 through the end of 2008. The group has over 100 active participants and pursues a broad range of Standard Model and exotic Higgs searches. Under Prof. Herndon's leadership the group quadrupled the data being analyzed and simultaneously further increased the sensitivity of the analyses by more than 50% by implementing improvements in search techniques bringing the standard model Higgs within reach. Prof. Herndon, postdoctoral researcher Dr. Jeniffer Pursley, and graduate student Jason Nett are active in the high mass Higgs searches and related Electroweak di-boson measurements where they have made substantial contributions to that research program.

The most sensitive searches at the Tevatron are in the $p\bar{p} \rightarrow H \rightarrow W^{(*)}W^{(*)} \rightarrow \ell^+\nu_\ell \ell^-\bar{\nu}_\ell$ channel. This analysis is being pursued by Prof. Herndon, Dr. Pursley and Mr. Nett extending previous work done by Dr. Carlsmith and his former students Liqun Zhang

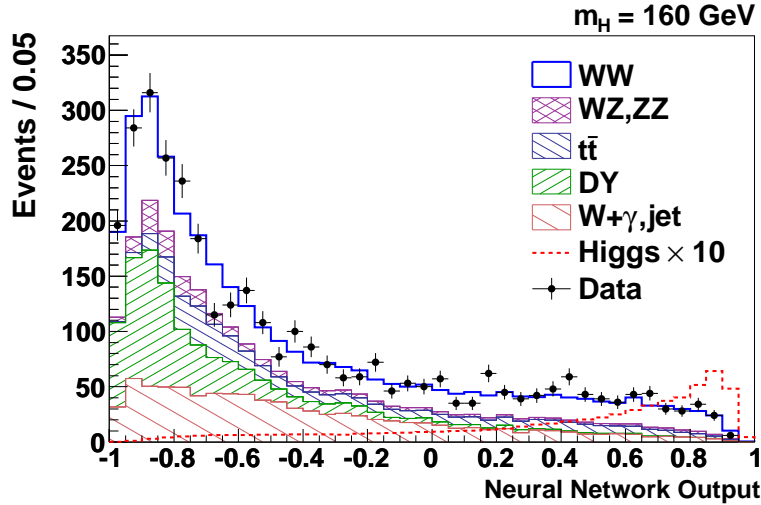


Figure 5: The combined distribution of NN scores for back-grounds and a $m_H = 160$ GeV Higgs boson compared to the observed data shown with statistical uncertainties. The Higgs boson distribution is normalized to ten times the SM expectation.

and Sunny Chuang focused on opposite sign dileptons with no jets. Dr. Pursley extended the acceptance for the $H \rightarrow W^{(*)}W^{(*)}$ analysis by including new analysis topologies. One such topology is events with two or more jets in the final state, in which the primary background is $t\bar{t}$ production and the dominant Higgs production processes are vector boson fusion and associated production, when a Higgs boson is produced in association with a W or Z boson. Another topology requires two like charge di-leptons in the final state, a channel with very little physics background and signal primarily from associated Higgs production. These new analysis topologies allow the CDF search to fully exploit all Higgs production processes including the associated production and vector boson fusion channels in addition to the gluon fusion process. The total increase in Higgs signal from new analysis topologies and production processes is approximately 50%. Figure 5 shows the distribution of a neural network based discriminant for the sum of backgrounds compared to the SM Higgs signal including the additional acceptance from new analysis channels and production modes.

Dr. Pursley has been a convener of the CDF Higgs to WW search group since March 2009. In the past year, many improvements to the sensitivity of the analysis have been made under Dr Pursley's leadership. These improvement include the implementation a likelihood function to improve electron identification and improved treatment of systematic uncertainties. The treatment of systematic uncertainties has been improved in collaboration with University of Wisconsin Higgs phenomenology expert Prof. Frank Petriello. Forward muons have been included in the Higgs analysis. In particular the addition of muons identified by the WI group's IMU system to $H \rightarrow W^{(*)}W^{(*)}$ analysis contributes approximately 10% of the total acceptance and substantially improves the purity of the muon sample over using minimum ionizing tracks as had been done previously. This work leverages previous work

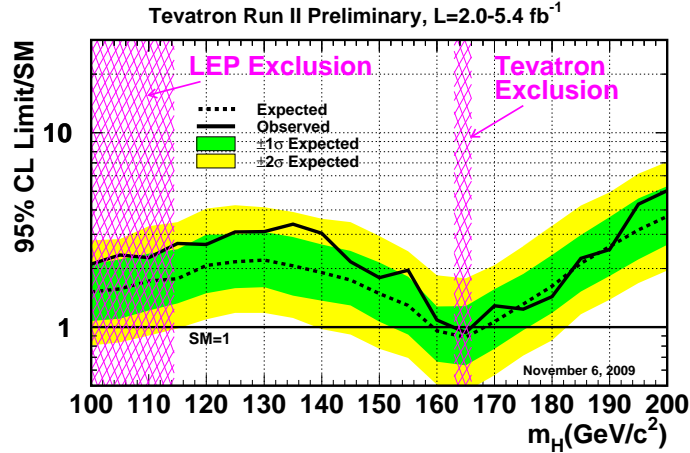


Figure 6: Limits on Higgs cross section shown as a ratio to the standard model cross section from the $p\bar{p} \rightarrow H \rightarrow W^{+(*)}W^{-(*)} \rightarrow \ell^+\nu_\ell \ell^-\bar{\nu}_\ell$ analysis including the two jet and same sign channels and combined with the D0 experiment.

by Mr. Nett on IMU based triggers.

With these improvements, the CDF analysis became sensitive to a Higgs production cross section of only 1.2 times the standard model cross section at 165 GeV, a substantial improvement over the previous CDF high mass Higgs analysis published last year [?]. The improved analysis was published in Physics Review Letters this year [?]. In combination with the D0 experiment, the new results have led an exclusion of the production of a standard Model Higgs boson between the masses of 163 and 166 GeV [3] (see figure 6. This research program has resulted in the arguably the most scientifically interesting results produced in High Energy physics this year. The Tevatron limits were featured on the cover of Physics Review Letters, highlighted as an Editors suggestion, and the subject of a special viewpoint article.

The high mass Higgs group has continued to develop improvements under Dr. Pursley's leadership including a search for dilepton pairs with very low invariant mass and a search for opposite-sign dileptons in which one lepton is a hadronically decaying tau lepton. The CDF Higgs to WW search group continues to take advantage of new data as soon as it becomes available, typically being the first physics analysis group to validate new data samples. The current analysis result uses the data corresponding to 5.3 fb^{-1} of integrated luminosity.

As his PhD thesis project Mr. Nett has performed a search for high mass Higgs boson production in the three lepton and missing energy final state under the guidance of Prof. Herndon and Dr. Pursley. This search is sensitive to associated production of a Higgs boson with a W or a Z boson with Higgs decay to a pair of W bosons. In the case of associated production with a W boson, all three vector bosons decay to leptons. In the

case of associated production with a Z boson, the Z boson decays to charged leptons and one of the two W bosons decays leptonically. This search achieves a sensitivity of 5.2 times the expected standard model production cross section at a mass of 165 GeV. This excellent sensitivity substantially contributes to the full CDF search and, with a new total sample corresponding to 5.3 fb^{-1} , the CDF analysis has achieved a sensitivity of 1.02 times the expected standard model production cross section. Mr. Nett is optimizing his analysis and we expect with an additional 0.5 fb^{-1} of data that CDF will achieve a single experiment exclusion of a range of SM Higgs boson masses. A publication of this result for Physical Review section D is already in preparation edited by Dr. Pursley.

Work to improve the sensitivity of the CDF Higgs high mass Higgs analysis continues. Efforts to improve Higgs boson acceptance include the implementation of likelihood functions for muon selection, the inclusion of additional triggers which allow leptons with lower transverse momentum than currently accepted, searching for $H \rightarrow W^{+(*)}W^{-(*)}$ in the lepton and jets topology, searching for lepton pairs from Higgs decay with very small opening angles, the inclusion of one hadronically decaying tau lepton in a search for the three lepton final state signature, and searching for $H \rightarrow ZZ(*)$ decays. The University of Wisconsin group is active in the final three improvements. The expectation of the Tevatron collaborations is that sensitivity to set either limits or, at certain masses, see evidence for production of a SM Higgs boson will be achieved across the entire range of allowed Higgs boson masses. The high mass Higgs search, where the University of Wisconsin will continue to concentrate its effort, will be the primary contributor at masses above 130 GeV.

7.2 WW and WZ Production Cross Section

Dr. Pursley completed a measurement of the W boson pair production cross section. The resulting WW measurement, made on 3.6 fb^{-1} of CDF data, is the best measurement of the WW pair production cross section in hadron collisions to date. The analysis uses a maximum likelihood fit to a matrix element-based discriminant to extract the number of WW events. The resulting measurement is in good agreement with the Standard Model prediction. In addition, this data sample was used to search for anomalous triple gauge boson couplings between $WW\gamma$ and WWZ ; the resulting limits are comparable to the current world-best limits. A paper on this research has been accepted for publication in the Physical Review Letters [4].

A measurement of the WZ production cross section is being undertaken by graduate student Jason Nett, assisted by Dr. Pursley and Prof. Herndon. The measurement is being made in the final state with three charged leptons and uses the same data sample as the associated production Higgs boson search. The primary background to the three lepton Higgs search is standard model direct WZ boson production and this sample allows a precise measurement of the WZ production. Using a data sample of 5.3 fb^{-1} Mr. Nett has measured the WZ production cross section to a precision of 20%. This is the worlds most accurate measurement and in combination with a further measurement of anomalous triple gauge boson couplings between $WZ\gamma$ and WZZ will lead to a separate publication, most likely in

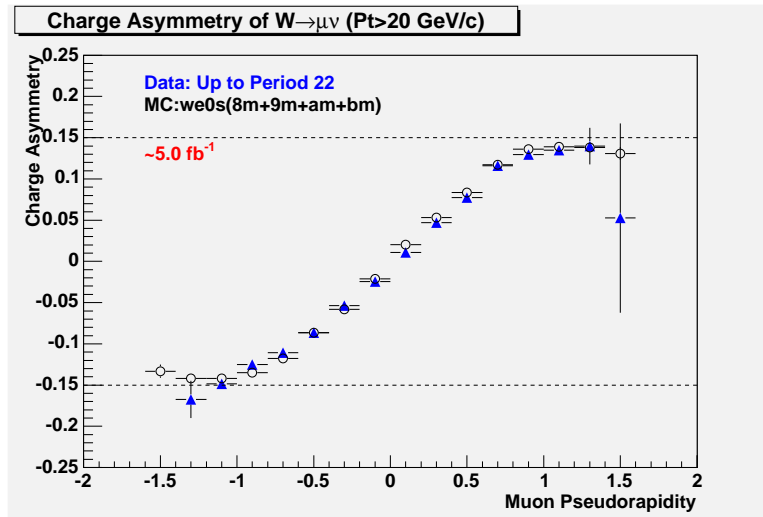


Figure 7: Forward-backward asymmetry in $W \Rightarrow \mu\nu$ as a function of muon rapidity in Run II. The data points are closed and the Monte Carlo open circles.

the Physical Review Letters.

The associated production Higgs search and the WZ production cross section measurement form the content of Mr. Nett's thesis and he will graduate this year.

7.3 W and Z

Dr. Chung continues to analyze high Pt muon data sets (both centrally and IMU triggered) and to compare W and Z samples with Monte Carlo. The data sets include central and BMU muons spanning an integral luminosity now of 5 fb^{-1} . Standard CDF high pt muon identification cuts (including fiducial and tight external stub to extrapolated central track cuts) are applied. Figures 7 and 8 show that the asymmetry in single muon and dimuon events compare well with expectation.

8 Future CDF operations

The Wisconsin CDF group will continue its responsibility for CDF hardware and service and will pursue exciting physics opportunities with a data sample of order 10 fb^{-1} . Several new analysis have been completed and are being prepared for publication. Others are ramping up with the integrated luminosity and improved understanding of the detector performance. The Tevatron collider program promises several years of exciting physics yet to come. At present, we anticipate supporting collider operation through 2011 with continued involvement through 2013.

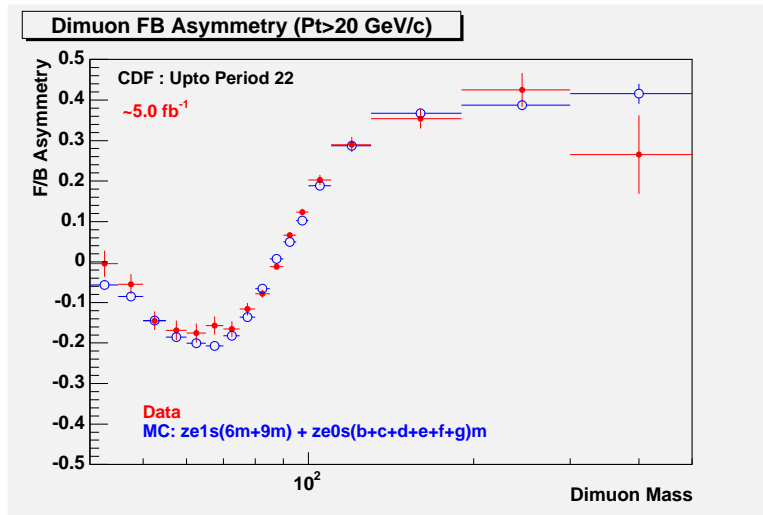


Figure 8: Forward-backward asymmetry in $Z \Rightarrow \mu\mu$ as a function of muon pair mass in Run II. The data points are closed and the Monte Carlo open circles.

Recently the possibility of simultaneous running of the Tevatron and the primary Fermilab neutrino experiments through 2014 has been proposed. Experts from the Fermilab beams division believe that it is possible to run both sets of experiments without a reduction in the Tevatron luminosity or the protons on target for neutrino physics. With current Tevatron performance this would double the current luminosity that has been provided to the collider experiments. This would open physics possibilities such as greater than three sigma evidence for a SM Higgs boson across a wide range of masses including masses just above the direct LEP Higgs mass limits.

The University of Wisconsin CDF group is interested in this exciting possibility. In addition, the UW groups expertise and experience is well suited to pursue the physics opportunities provided by extended Tevatron running. The UW group has extensive expertise in muon systems, related high transverse lepton identification software and physics analysis, silicon detector systems and software, related high transverse momentum b quark tagging algorithms, and Higgs physics in both leadership and analysis roles. These are the elements of the low mass Higgs search which is the most exciting physics opportunity of extended Tevatron running. The UW group would assume a leading role in these searches.

If Fermilab and the Department of Energy update the lab running plan to include extended Tevatron running through 2014 the UW group would revise its research plans to take advantage of this unique physics opportunity.

9 Talks:

- Pondrom, “Search for quark substructure in the angular distribution of dijets produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV”, XIX Baldin Conference on QCD, Dubna, Russia, September 30, 2008.
- Ye Li, ”Search for narrow Resonance Decaying to Muon Pairs in 2.3 fb^{-1} ”, APS, Louisville Kt, April 14, 2008.
- Nett, “High Mass Higgs Boson at CDF: Trilepton Signature,” American Physical Society Meeting, Washington, DC, February 2010.
- Pursley, “Searches for High Mass Standard Model Higgs Boson at CDF,” Fermilab Joint Theoretical-Experimental Physics Seminar, Batavia, Illinois, May 14, 2010.
- Pursley, “Searches for a Standard Model Higgs Boson at the Collider Detector at Fermilab,” University of Virginia Physics Department Colloquium, Charlottesville, Virginia, February 17, 2010.
- Pursley, “Status of the High Mass Higgs Search,” CDF Collaboration Meeting, 1-6 February 2010, Puerto Vallarta, Mexico.
- Pursley, “First Observation of Diboson Production in Hadronic Final State at Tevatron,” 2009 Meeting of the Division of Particles and Fields of the American Physical Society, 26-31 July 2009, Detroit, Michigan, USA. Proceedings available as arXiv:0910.1556 [hep-ex].
- Pursley, “Search for Standard Model Higgs Boson in $H \Rightarrow WW$ Channel at CDF,” 2009 Meeting of the Division of Particles and Fields of the American Physical Society, 26-31 July 2009, Detroit, Michigan, USA. Proceedings available as arXiv:0910.1540 [hep-ex].
- Pursley, “High Mass Standard Model Higgs Results from CDF”, The Johns Hopkins University High Energy Physics Seminar, Baltimore, Maryland, April 15, 2009.
- Pursley, “Searches for a High Mass Higgs Boson at the Tevatron”, Aspen Winter 2009 Conference on Particle Physics: Workshop on Physics in the LHC era, Aspen, Colorado, February 8-14, 2009.
- Pursley, “High Mass Standard Model Higgs Searches at CDF”, University of Wisconsin High Energy Physics Seminar, Madison, Wisconsin, September 22, 2008.
- Pursley, “Beauty and Charm Production Cross Section measurement at the Tevatron,” Rencontres de Moriond, QCD and Hadronic Interactions, La Thuile, Italy, Mar. 8, 2008.

- Herndon, “CDF Winter 2010 Results,” Fermilab Joint Theoretical-Experimental Physics Seminar, Batavia, Illinois, March, 2010.
- Herndon, “Searches for FCNC Decays $B_s(d)$ to $\mu\mu$,” University of Illinois, Champaign-Urbana, Illinois, March, 2009.
- Herndon, “An Inclusive Search for $H \rightarrow WW$ at CDF,” University of Maryland High Energy Physics Seminar, College Park, Maryland, October, 2009
Iowa State University High Energy Physics Seminar, Ames, Iowa, October, 2009
Fermi National Accelerator Laboratory Theory Seminar, FNAL, Illinois, August, 2009
- Herndon, “Standard Model Higgs Searches at CDF,” Higgs Days 2009, Santander, Spain, September, 2009
- Herndon, “Searches for the Standard Model Higgs Boson,” Plenary talk at the Collider Physics Conference, Argonne Laboratory, Illinois May 18-22, 2009.
- Herndon, “Searches for the Standard Model Higgs Boson,” Plenary talk at the Loopfest VIII Conference, Madison, Wisconsin, May 7-9, 2009.
- Herndon, “Searches for the Standard Model Higgs Boson,” Plenary talk at the Workshop on Higgs Boson Phenomenology, Zurich, Switzerland, Jan 7-9, 2009.
- Herndon, “Searches for the Higgs Boson” University of Massachusetts Amherst Physics Colloquium, Amherst, Massachusetts, December 10th, 2008.
- Herndon, “B Physics at the Tevatron,” Plenary talk at the 10-25 Years of $D\bar{0}$ France, Paris, France, October 13-14 29, 2008.
- Herndon, “Searches for the Higgs Boson,” Plenary talk at the 34th International Conference of High Energy Physics, Philadelphia, Pennsylvania, July 29-August 5, 2008.

References

- [1] ”Search for a Higgs Boson Decaying to Two W Bosons at CDF”, CDF Collaboration, T. Aaltonen *et al.*, Phys. Rev. Lett. **102** (2009) 021802.
- [2] ”Inclusive Search for Standard Model Higgs Boson Production in the WW Decay Channel using the CDF II Detector”, CDF Collaboration, T. Aaltonen *et al.*, Phys. Rev. Lett. **104** (2010) 061803.
- [3] ”Combination of Tevatron searches for the standard model Higgs boson in the $W+W$ -decay mode”, CDF and $D\bar{0}$ Collaboration, T. Aaltonen *et al.*, Phys. Rev. Lett. **104** (2010) 061802.

- [4] "Measurement of the W^+W^- Production Cross Section and Search for Anomalous $WW\gamma$ and WWZ Couplings in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV". CDF Collaboration, T. Aaltonen *et al.*, Accepted by Phys. Rev. Lett. (2010).
- [5] "Search for $B_s \rightarrow \mu^+\mu^-$ and $B_d \rightarrow \mu^+\mu^-$ Decays with 2 fb^{-1} of $p\bar{p}$ Collisions", CDF Collaboration, T. Aaltonen, *et al.*, Phys. Rev. Lett. **100** (2008) 101802.
- [6] "Measurement of b-jet Shapes in Inclusive jet Production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV", CDF Collaboration, T. Aaltonen, *et al.*, Phys. Rev. D **78**, (2008) 072005.
- [7] "Measurement of $\sigma(\Lambda_b)/\sigma(B^0) \times BR(\Lambda_b \Rightarrow \Lambda_c\pi^-)/BR(B^0 \rightarrow D^+\pi^-)$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV", CDF Collaboration, D. Acosta *et al.*, Phys. Rev. Lett. **98** (2007) 122002
- [8] "Search for a Neutral Higgs Boson Decaying to a W Boson Pair in p anti- p Collisions at $\sqrt{s} = 1.96$ TeV", CDF Collaboration, A. Abulencia *et al.*, Phys. Rev. Lett. **97** (2006) 081802

**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**
 Institution Name University of Wisconsin - Madison
 Task/Title **Task E: CDF**

Type of Position	Name	Activity #1	Activity #2	FTE Months on CDF Research	# months funded by DOE-HEP University Program CDF	Faculty Advisor
Faculty	Carlsmith, Duncan	CDF	CMS EMU	0.50	0	
	Herndon, Matthew	CDF	CMS EMU	0.75	0.75	
	Pondrom, Lee (retires 1/7/11)	CDF		1	0	
Assoc. Scientist	Bellinger, James	CDF	CMS EMU	3	3	Carlsmith
Assist. Scientist	Chung, Woo-Hyun	CDF		12	12	Carlsmith
Post Doc	Pursley, Jennifer	CDF		12	12	Herndon
Grad Student	Nett, Jason	CDF		12	12	Herndon
	Ramakrishnan, Varsha	CDF		12	12	Carlsmith
Computing	Rader, Stephen			1.22	1.22	
Computing	Radtke, Matthew			1.22	1.22	
Administration	Lefkow, Aimee			1.5	1.5	

Carlsmith funded on Task T: CMS.

Herndon also funded on Task T: CMS.

Bellinger also funded on Task T CMS and US CMS Project funds.

PROJECT DESCRIPTION

The phenomenology research program at the University of Wisconsin began in the mid-1960's as a collaboration of theoretical and experimental faculty. The Phenomenology Institute was created by the University in 1984 with support from the DOE, with Barger and Halzen as directors. In 2006 Han was appointed as Institute Director. With the addition of Petriello, an Associate Professor, and Everett, an Assistant Professor, the Institute has five faculty.

The mission of the Institute is to promote research at the interface of theory and experiment in particle physics, with emphasis on the interpretation of experimental data, the design of new experiments, and the construction and testing of theoretical models. The scope of our research is data-driven and encompasses collider physics, neutrino physics, particle astrophysics, particle cosmology, and low-energy physics. The Institute is internationally recognized for its leadership in this research. A hallmark of the Wisconsin Phenomenology effort is close interaction with experimental programs worldwide. The group has made many suggestions for probing models of particle interactions with existing and future experiments and has provided the field theory calculations which connect experimental results with the underlying theory description. These efforts have made the group a national leader in particle physics phenomenology. The training of postdocs and graduate students in phenomenology research is a high priority of our program and we have an excellent record in this regard. The next years promise to be one of the most exciting eras ever in particle physics phenomenology, and our group plans to take maximum advantage of the physics opportunities.

- With the turn-on of the Large Hadron Collider (LHC), collider physics phenomenology has become the central area of particle theory. The LHC is the first machine to reach the required energies to systematically investigate electroweak symmetry breaking, to probe supersymmetry and new models of electroweak symmetry breaking at the TeV mass scale where new particles or new exotic physics are predicted to be found. Researchers in our group are now preparing the theoretical tools to investigate these exciting possibilities and we expect to have a major impact on the physics of the LHC era.

With our expertise in collider physics phenomenology, both in the calculations of Standard Model (SM) backgrounds and the study of new physics models, we are in a very strong position to interpret data from the ATLAS and CMS experiments. Similarly, we are well prepared to interpret further Fermilab Tevatron data from the CDF and D0 collaborations.

- A revolution has occurred in neutrino physics over the past decade with the compelling experimental evidence that neutrinos have mass. Neutrino oscillation studies continue to hold great promise in unravelling the mysteries of flavor physics. We plan to continue our leadership in neutrino physics, in interpreting data from reactor, solar, and atmospheric experiments, and in contributing to the design of future long-baseline oscillation experiments. We will also continue to explore the ramifications for models of neutrino mass and the possible relation of low-energy neutrino physics with leptogenesis. Likewise, if neutrino mass generation results from new TeV scale physics, one may expect to observe the new leptonic states or even Majorana neutrinos at the LHC.

- CP violation is a vital part of understanding the matter-antimatter asymmetry in the universe. Recent B physics measurements by the BaBar and BELLE collaborations show CP-violation and rate anomalies in B decays, as well as $D^0 - \bar{D}^0$ mixing, that could indicate

the presence of new physics. Our high interest in explanations of these phenomena continues. We are exploring new sources of CP violation from theories beyond the SM and consider the possible observable signals at the LHC.

- Particle physics phenomenology is integral to major current issues in astrophysics, including the highest energy cosmic rays, gamma-ray bursts and high-energy neutrino interactions. Our group pioneered research in these areas, particularly with neutrino telescopes, and we plan to continue to pursue analyses of astrophysics data that are relevant to particle physics and to provide theoretical support for experimental programs.
- Observational cosmology has become a precision science. The nature of dark matter, dark energy, and inflation is very likely in the domain of particle theory. We will continue our research at the interface of particle physics and cosmology, especially in analyses of CMB and large-scale structure data that have direct bearing on neutrinos and scalar fields. In connection to collider physics, we are making progress in proposing strategies to measure the missing particle mass by kinematical means at the LHC.
- The International Linear Collider (ILC) is a project of great importance to the high-energy physics community. We have conducted many studies of linear collider physics (including Higgs, supersymmetry, and top quark studies), and we will continue to focus on issues of relevance for the ILC. Future facilities of importance are the Muon Collider and Neutrino Factories. We also focus our efforts on topics of relevance to these experimental programs.
- Model building is often the key to progress in theoretical particle physics connected to experiment. We plan to continue to explore Higgs boson, little Higgs, supersymmetry, extra dimensions, modified gravity, and string-motivated models that can be tested by data.

The research program of the Institute addresses the full range of theoretical particle physics relevant to present and future experiments. As such, the research problems addressed change as new data become available. We summarize here our research progress since January 2007, describe research in progress, and outline some projected goals.

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A. Research of Vernon Barger

Overview of Research Activities

Barger pursues a broad and vigorous research program in particle physics phenomenology that includes collider physics, neutrino physics, and cosmology. He co-authored the widely

used textbook *Collider Physics*. His recent investigations in collider physics are primarily directed to New Physics at the TeV scale that can be probed at the Large Hadron Collider. He currently supervises five graduate students: Yu Gao, Peisi Huang, Mathew McCaskey, Chiu-Tien Yu, and Brian Yencho. He and his former graduate student Shaughnessy, along with Langacker, introduced and studied models with extended Higgs, gauge, and neutralino sectors, and determined the experimental signatures by which the models can be tested. His PRL, with Langacker and postdoc Lee, on the six-lepton signal of a Z' resonance was featured by APS in “Physics—spotlighting exceptional research.” His PLB paper on triple-top production, with his graduate student Yencho and with Keung, attracted major attention on a particle physics blog. His model, with postdocs Fileviez Perez and Spinner, presented a fundamental new idea of a local B-L symmetry that is spontaneously broken at the TeV scale. His study, with Han and Walker, of s-channel resonances in top-quark pair production highlighted the promise of the LHC as a top-quark factory. With graduate student Yu and with Keung, he proposed an extended gauge theory model with a new top right-handed coupling that can explain the forward-backward asymmetry in top-quark pair production at the Tevatron. Barger, Baer, Lessa, and Tata have evaluated the supersymmetry discovery potential of LHC14 and they are now extending the study to LHC7.

Barger has a notable long-standing research program in neutrino physics. Barger, Pakvasa, Phillips, and Whisnant were the first to consider matter effects on long-baseline neutrino oscillations. Barger, Marfatia, and Whisnant later showed that an eight-fold parameter degeneracy arises in long-baseline neutrino studies and they demonstrated how these ambiguities could be resolved in future experiments with superbeams. Barger and collaborators made the first studies of the physics potential of Neutrino Factories and Muon Colliders. He has studied the impact on lepton-violating decays of neutrino Yukawa couplings in supersymmetric see-saw models, and has studied CPT and Lorentz violations with neutrinos and antineutrinos, the implications and tests of mass-varying neutrinos, and the cosmogenic neutrino flux at ultra-high energies. Barger has continuing research interests in the Fermilab neutrino and rare decay programs, the future deep underground experiments at DUSEL, and neutrino telescope observations. Barger is completing a research monograph entitled “Neutrino Physics” with Marfatia and Whisnant as coauthors.

Barger is actively engaged on research that connects particle physics and dark matter. With his student Gao and with Shaughnessy, Keung, and Marfatia, he studied three interpretations (dark matter annihilations, dark matter decays, pulsars) of the unexpected cosmic positron excess reported by the PAMELA satellite experiment in conjunction with the first data from the Fermi Gamma-Ray Space Telescope. They found that pulsars have the least tension with the data and that TeV dark matter with muon-pair or tau-pair final states is preferred over electron-positron pairs; they also predicted that a large bump in the high-energy gamma ray flux should be seen generically if the dark matter annihilation or decay is dominantly into the 3-body electron-positron-gamma final state. Barger and collaborators had previously studied the spin dependence of dark matter scattering in an assortment of new physics scenarios. With his student McCaskey, Langacker, Ramsey-Musolf, and Shaughnessy, Barger introduced a complex scalar extension of the Standard Model that can provide a dark matter candidate and a new scalar degree of freedom that mixes with the SM Higgs. This model can easily accommodate the possible DM signal from the CoGeNT experiment.

Barger intends to continue his pursuit of frontier research in collider physics, neutrino physics, rare decays, and dark matter, for which there is an emerging complementarity.

Papers published since January 2007

- V. Barger, W.-Y. Keung, C.-T. Yu, “Asymmetric Left-Right Model and the Top Pair Forward-Backward Asymmetry,” [arXiv:1002.1048 \[hep-ph\]](#)
- V. Barger, W.-Y. Keung, B. Yencho, “Triple-Top Signal of New Physics at the LHC,” *Phys. Lett. B* **687**, 70-74, 2010.
- V. Barger, M. McCaskey, G. Shaughnessy, “Single top and Higgs associated production at the LHC,” *Phys. Rev. D* **81**, 034020, 2010.
- V. Barger, P. Langacker, H.S. Lee, “Six-lepton Z-prime resonance at the LHC,” *Phys. Rev. Lett.* **103**, 251802, 2009.
- V. Barger, D. Marfatia, A. Mustafayev, A. Soleimani, “SUSY dark matter and lepton flavor violation,” *Phys. Rev. D* **80**, 076004, 2009.
- H. Baer, V. Barger, A. Lessa, X. Tata, “Supersymmetry discovery potential of the LHC at $s^{*(1/2)} = 10\text{-TeV}$ and 14-TeV without and with missing $E(T)$,” *JHEP* **0909**, 063, 2009.
- V. Barger, L. Everett, J. Jiang, P. Langacker, T. Liu, C. Wagner, “ $b \rightarrow s$ Transitions in Family-dependent $U(1)'$ Models,” *JHEP* **0912**, 048, 2009.
- V. Barger, Y. Gao, W.-Y. Keung, D. Marfatia, “Generic dark matter signature for gamma-ray telescopes,” *Phys. Rev. D* **80**, 063537, 2009.
- V. Barger, Y. Gao, W.-Y. Keung, D. Marfatia, G. Shaughnessy, “Dark matter and pulsar signals for Fermi LAT, PAMELA, ATIC, HESS and WMAP data,” *Phys. Lett. B* **678**, 283 (2009).
- V. Barger, L. Everett, J. Jiang, P. Langacker, T. Liu, C. Wagner, “Family non-universal $U(1)'$ gauge symmetries and $b \rightarrow s$ transitions,” *Phys. Rev. D* **80**, 055008 (2009).
- V. Barger, H. Logan, G. Shaughnessy, “Identifying Extended Higgs Models at the LHC,” *Phys. Rev. D* **79**, 115018 (2009).
- V. Barger, P. Fileviez Perez, S. Sogee Spinner, “Minimal gauged $U(1)_{(B-L)}$ model with spontaneous R-parity violation,” *Phys. Rev. Lett.* **102**, 181802 (2009).
- V. Barger, P. Langacker, M. McCaskey, M. Ramsey-Musolf, G. Shaughnessy, “Complex singlet extension of the Standard Model,” *Phys. Rev. D* **79**, 015018, 2009.
- S. Raby et al., “DUSEL Theory White Paper,” [arXiv:0810.4551 \[hep-ph\]](#)
- V. Barger, Y. Gao, Y. Mao, D. Marfatia, “Inflationary potential from 21 cm Tomography and Planck,” *Phys. Lett. B* **673**, 173, 2009.
- V. Barger, W. Keung, D. Marfatia, G. Shaughnessy, “PAMELA and dark matter,” *Phys. Lett. B* **672**, 141, 2009.
- H. Baer, V. Barger, G. Shaughnessy, “SUSY backgrounds to Standard Model calibration processes at the LHC,” *Phys. Rev. D* **78**, 095009, 2008.
- V. Barger, W. Keung, G. Shaughnessy, “Spin dependence of dark matter scattering,” *Phys. Rev. D* **78**, 056007, 2008.
- V. Barger, D. Marfatia, A. Mustafayev, “Neutrino sector impacts SUSY dark matter,”

Phys. Lett. B **665**, 242, 2008.

- V. Barger, Y. Gao, W. Keung, D. Marfatia, V. Senoguz, “Unparticle physics with broken scale invariance,” Phys. Lett. B **661**, 276, 2008, [arXiv:0801.3771 \[hep-ph\]](#)
- L. Anchordoqui, V. Barger, H. Goldberg, D. Marfatia, “Phase transition in the fine structure constant,” Phys. Lett. B **660**, 529, 2008.
- ISS Physics Working Group (A. Bandyopadhyay et al.), “Physics at a future Neutrino Factory and super-beam facility,” Rept. Prog. Phys. **72**, 106201, 2009.
- V. Barger, W. Keung, and G. Shaughnessy, “Monochromatic neutrino signals from dark matter annihilation,” Phys. Lett. B **664**, 190, 2008.
- V. Barger, W.-Y. Keung, G. Shaughnessy, A. Tregre, “High energy neutrinos from neutralino annihilations in the Sun,” Phys. Rev. **D76**, 095008, 2007.
- V. Barger, W.-Y. Keung, Y. Gao, “T-Anomaly Induced LHC Signals,” Phys. Lett. B **655**, 228-235, 2007.
- V. Barger, P. Langacker, M. McCaskey, M. Ramsey-Musolf, G. Shaughnessy, “LHC Phenomenology of an Extended Standard Model with a Real Scalar Singlet,” Phys. Rev. D **77**, 035005, 2008.
- V. Barger, D. Marfatia, K. Whisnant, “Challenging Lorentz noninvariant neutrino oscillations without neutrino masses,” Phys. Lett. B **653**, 267-277, 2007.
- V. Barger et al., “Report of the US long baseline neutrino experiment study,” [arXiv:0705.4396 \[hep-ph\]](#)
- H. Baer, V. Barger, G. Shaughnessy, H. Summy, L.-T. Wang, “Precision gluino mass at the LHC in SUSY models with decoupled scalars,” Phys. Rev. D **75**, 095010, 2007.
- V. Barger, P. Huber, D. Marfatia, W. Winter, “Which long-baseline neutrino experiments are preferable?”, Phys. Rev. D **76**, 053005 (2007).
- V. Barger, P. Langacker, I. Lewis, M. McCaskey, G. Shaughnessy, B. Yencho, “Recoil Detection of the Lightest Neutralino in MSSM Singlet Extensions,” Phys. Rev. D **75**, 115002, 2007.
- V. Barger, P. Langacker, G. Shaughnessy, “TeV physics and the Planck scale,” New J. Phys. **9**, 333, 2007.
- V. Barger, N. Deshpande, J. Jiang, P. Langacker, T. Li, “Implications of Canonical Gauge Coupling Unification in High-Scale Supersymmetry Breaking,” Nucl. Phys. B **793**, 307-325, 2008.

Professional service since January 2007

- Barger made site visits and associated major reviews of one National Laboratory and two University particle physics research programs. He served as the outside consultant on the selection committee for a distinguished university professorship in particle physics.
- He was co-organizer of the Neutrino Workshop at the Aspen Center for Physics (2007) . He co-authored the DUSEL Theory White Paper ([arXiv:0810.4551 \[hep-ph\]](#)) as the leader of the focus group on Long Baseline Neutrino Oscillations.
- He served a member of the Conference/Workshop Scientific Advisory Committees of the

following meetings: COSMO 07, 08; DUSEL Theory Workshop 08; Muon Collider Workshop 09, NNN 08, 09, NuFact 09; USTRON 07, 09, Pheno 07, 08, 08, 10; PPC 07 08, 09.

Description of recent research activities

- The forward-backward asymmetry measurement in top-pair production at the Tevatron is more than 2σ from the SM prediction. Barger, his graduate student Yu, and Keung, proposed an Asymmetric Left-Right Model which includes a W' boson with a right-handed coupling of d to t quarks, and a Z' boson with diagonal couplings to the u , t , and d quarks, with $M_{W'} \approx 175$ GeV and $M_{Z'} \approx 190$ GeV. The model accounts for the asymmetry and is consistent with the top-pair total cross-section and invariant mass distribution.
- Barger, his graduate student Yencho, and Keung presented leading-order cross sections for the production of three top quarks ($t\bar{t}t, t\bar{t}\bar{t}$) at the LHC. The total LO cross section for triple-top production in the SM is $\sigma \approx 2$ fb at $\sqrt{s} = 14$ TeV. Examples of two new physics models which have a significant enhancement to this channel are provided. With efficient identification and reconstruction of the top quarks, the triple-top signal could potentially provide evidence for new physics at the LHC.
- Barger, his student McCaskey, and Shaughnessy of Argonne/Northwestern studied the production of a SM Higgs boson in association with a single top quark and either a light jet or W -boson at the LHC with a center of mass energy of 14 TeV. Due to the destructive interference of the contributing SM diagrams, the value of the top Yukawa coupling and the sign of the WW_h coupling may be probed for Higgs masses above 150 GeV.
- New physics models admit the interesting possibility of a Z' weak boson and a Higgs boson that is heavy enough to decay into a pair of Z bosons. Barger, Langacker of IAS, and Lee of UC Riverside noted that Z' production and decay via $Z' \rightarrow ZH \rightarrow ZZZ$ has a distinctive LHC signal that is nearly background free and reconstructs the H and Z' masses and widths. The ZH decay mode exists even if the Z' is decoupled from leptons, which motivates an independent 6-lepton resonance search regardless of the dilepton search results.
- With Marfatia, Mustafayev, and Soleimani of Kansas U., Barger studied lepton flavor-violating (LFV) processes within a supersymmetric type-I seesaw framework with flavor-blind boundary conditions, properly accounting for the effect of the neutrino sector on the dark matter relic abundance. In viable regions of SUSY parameter space, LFV rates can differ from naive estimates by up to two orders of magnitude. Contrary to common belief, current LFV limits do not exclude neutrino Yukawa couplings larger than top Yukawa couplings.
- Barger, Baer and Lessa of Oklahoma U., and Tata of Hawaii U. examined the SUSY reach of the LHC at $\sqrt{s} = 10$ and 14 TeV within minimal supergravity, incorporating updated background calculations including a variety of $2 \rightarrow n$ SM processes. The results show that SUSY discovery is possible even before the detectors are understood well enough to utilize either E_T^{miss} or electrons in the signal. The early SUSY reach of the LHC at $\sqrt{s} = 10$ TeV is evaluated by examining multi-muon plus ≥ 4 jets and also dijet events with *no* missing E_T cuts. The LHC reach in no-lepton and multi-lepton plus jets channels *including* missing E_T cuts for $\sqrt{s} = 10$ and 14 TeV is also evaluated. For $\sqrt{s} = 10$ TeV, the reach extends to $m_{\tilde{g}} = 1.9, 2.3, 2.8$ and 2.9 TeV for $m_{\tilde{q}} \sim m_{\tilde{g}}$ and integrated luminosities of 10, 100, 1000 and 3000 fb^{-1} , respectively. For $\sqrt{s} = 14$ TeV, the reach is to $m_{\tilde{g}} = 2.4, 3.1, 3.7$ and 4.0 TeV.
- If the total angular momentum of the initial DM particle(s) vanishes and helicity suppres-

sion prevents annihilation/decay into light fermion pairs, the amplitude for the dominant 3-body final state $f^+f^-\gamma$ has a unique form dictated by gauge invariance. This holds for annihilation of DM Majorana fermions or self-conjugate scalars, and for decay of DM scalars. Within this scenario, Barger, his student Gao, Keung, and Marfatia analyzed Fermi LAT, PAMELA and HESS data, and predicted a hint in future Fermi gamma-ray data that portends a striking signal at atmospheric Cherenkov telescopes.

- With Gao, Keung, Marfatia, and Shaughnessy, Barger analyzed new diffuse gamma-ray data from the Fermi Gamma-ray Space Telescope with electron and positron flux measurements from PAMELA, Fermi and HESS within the context of three possible sources: dark matter annihilation or decay into charged leptons, and a continuum distribution of pulsars. All three scenarios represent the data well, with the pulsar description holding for a wide range of injection energy spectra. For cusped halo profiles, Fermi could observe a spectacular gamma-ray signal of DM annihilation from the galactic center while seeing no excess at mid-latitudes.
- With Logan of Carleton U. and Shaughnessy, Barger provided a complete catalog of extended Higgs sectors involving $SU(2)_L$ doublets and singlets, subject to natural flavor conservation. In each case the couplings of the light CP-even neutral Higgs boson are given in terms of model parameters. The work discussed the prospects for differentiation of extended Higgs models based on measurements at the LHC and ILC and identified the regions in which these experiments could detect deviations from the SM Higgs predictions.
- Barger and postdoctoral researchers Spinner and Fileviez Perez studied the phenomenology of the minimal gauged $U(1)_{B-L}$ supersymmetric model and showed that it provides an attractive theory for spontaneous R-parity violation. The $U(1)_{B-L}$ is broken by the vacuum expectation values of right-handed sneutrinos, providing a mechanism for generating neutrino masses and a realistic mass spectrum without extending the Higgs sector of the MSSM.
- Barger, Langacker, McCaskey, Ramsey-Musolf of the UW-Madison, and Shaughnessy analyzed a simple extension of the SM (the cxSM) that has a complex singlet in the Higgs sector. When the cxSM potential contains a global $U(1)$ symmetry that is both softly and spontaneously broken, the model has a viable dark matter candidate and a strong first order electroweak phase transition as needed for electroweak baryogenesis. The implications of the model for discovery of a Higgs boson at the LHC were studied.
- Three-dimensional neutral hydrogen mapping using the redshifted 21 cm line has recently emerged as a promising cosmological probe. Within slow-roll reconstruction, Barger, Gao, Mao, and Marfatia analyzed the reconstruction of the inflationary potential by combining data from 21 cm experiments and cosmic microwave background data from the Planck satellite. The 21 cm measurements were found to significantly improve constraints on the slow-roll parameters and the determination of the shape of the inflationary potential.
- Assuming that the positron excess in PAMELA satellite data is a consequence of annihilations of cold dark matter, Barger, Keung, Marfatia, and Shaughnessy considered from a model-independent perspective if the data show a preference for the spin of dark matter. They then performed a general analysis of annihilations into two-body final states to determine what weighted combination of channels best describes the data.
- With Baer and Shaughnessy, Barger showed that the presence of relatively low mass

supersymmetry (SUSY) particles may give rise to significant deviations from SM predictions of Z +jets and W +jets events for jet multiplicity ≥ 4 or ≥ 5 , respectively. Furthermore, the presence of low mass SUSY may cause non-standard deviations to appear in top quark invariant and transverse mass distributions. Thus, effects that might be construed as detector mal-performance could in fact be the presence of new physics. They advocated several methods to check when new physics might be present within SM calibration data.

- New experiments designed to discover a weakly interacting dark matter particle via spin dependent scattering can distinguish models of electroweak symmetry breaking. With Keung and Shaughnessy, Barger detailed representative predictions of mSUGRA, singlet extended SM and MSSM, a new Dirac neutrino, Littlest Higgs with T-parity (LHT) and Minimal Universal Extra Dimensions (mUED) models. Of these models, the nMSSM has the largest spin dependent (SD) cross section. The work also described a model independent treatment of the scattering of DM particles of different intrinsic spins.
- Barger, Marfatia, and Mustafayev studied the effect of neutrino Yukawa couplings on neutralino dark matter observables within the framework of a supersymmetric seesaw. Neutrino couplings are found to significantly affect the neutralino relic density in regions of parameter space where soft SUSY-breaking slepton masses and/or trilinear couplings are large. Depending on the size of the couplings, the neutralino relic density spans over an order of magnitude in the A-funnel, focus point and stop-coannihilation regions of mSUGRA. The dark matter detection rates can be modified by up to several orders of magnitude.
- If scale invariance is exact, unparticles are unlikely to be probed in colliders since there are stringent constraints from astrophysics and cosmology. However, if scale invariance is broken at a scale μ , with $1 \text{ GeV} < \mu < M_Z$, unparticles can be probed at and below the Z pole. Barger, Gao, Keung, Marfatia, and Nefer Senoguz showed that μ can naturally be in this range if only vector unparticles exist, and studied the implications for Higgs phenomenology. Constraints on unparticle parameters from $e^+e^- \rightarrow \mu^+\mu^-$ cross-section and forward-backward asymmetry data were obtained and compared with the constraints from mono-photon production and the Z hadronic width.
- Within the context of mass-varying neutrinos, Barger, with Marftia, Anchordoqui of UW-Milwaukee, and Goldberg of Northeastern U., constructed a cosmological model that has a phase transition in the electromagnetic fine structure constant α at a redshift of 0.5. The model accommodates hints of a time variable α in quasar spectra and the nonobservance of such an effect at very low redshifts. It is consistent with limits from the recombination and primordial nucleosynthesis eras and is free of instabilities.
- Dark matter annihilations in the Sun to neutrino-antineutrino pairs have striking signatures in neutrino detectors such as IceCube and KM3. Barger, Keung, and Shaughnessy made a model independent study of the signals after propagation of the neutrinos from the center of the Sun to the Earth. A large spin-dependent DM capture cross section in the Sun make the discovery prospects robust.
- Neutralino annihilations in the Sun to weak boson and top quark pairs lead to high-energy neutrinos that can be detected by the IceCube and KM3 experiments. Barger, Keung, Shaughnessy, and Barger's graduate student Tregre calculated the neutrino signals from real and virtual WW , ZZ , Zh , and $t\bar{t}$ production and decays, accounting for the spin-dependence

of the matrix elements and including neutrino propagation effects. For the standard estimate of neutralino captures, the muon signal rates in IceCube are identifiable over the atmospheric neutrino background for neutralino masses between M_Z and 400 GeV.

- \mathcal{T} -parity in the Little Higgs model could be violated by anomalies that allow the lightest \mathcal{T} -odd A_H to decay into ZZ and W^+W^- . Barger, Gao, and Keung analyzed these decays and the two-particle and the three-particle decay modes of other heavy quarks and bosons in this model which yield unique LHC signals with fully reconstructable events. The branching fractions of three-body decays are found to be at the level of a few percent in heavy quark decays while they can reach up to 10% for heavy bosons.
- Using the simplest extension of the SM scalar sector with one real singlet field, Barger, Langacker, McCaskey, Ramsey-Musolf, and Shaughnessy analyzed the implications of a singlet-extended scalar sector for Higgs phenomenology at the LHC. Two scenarios were considered: (i) the SM Higgs and singlet mix, and (ii) no mixing occurs and the singlet can be a dark matter particle. For models with a stable singlet, the conditions under which it can yield the observed relic density were determined, the cross sections for direct detection in recoil experiments were computed, and the corresponding signatures at the LHC were discussed.
- Barger, Whisnant, and Marfatia showed that the combined data from solar, long-baseline and reactor neutrino experiments can exclude the generalized bicycle model of Lorentz noninvariant direction-dependent and/or direction-independent oscillations of massless neutrinos.
- With Baer and Summy (then of Florida State U.), Shaughnessy, and Wang of Princeton U., Barger examined collider events expected to arise at the LHC in models with multi-TeV scalars, taking the focus point region of minimal supergravity region as a case study. The lengthy gluino cascade decays make mass reconstruction via kinematic edges difficult; however, since the hard component is nearly pure gluino pair production, the gluino mass can be extracted to 8% via total rate for missing transverse energy + ≥ 7 -jet + ≥ 2 b-jet events, assuming 100 fb^{-1} of integrated luminosity.
- Barger, then UW-Madison postdoctoral researcher Huber (now faculty at Virginia State U.), Marfatia, and Winter discussed the physics of superbeam upgrades, focusing on T2KK, NOvA*, and a wide band beam (WBB) experiment independent of the NuMI beam line. In order to compare the physics potential of the different experimental configurations, the concept of exposure is used to normalize the performance. Experiments with WBBs were found to be the best experimental concept, while NOvA* could be competitive with sufficient luminosity. If $\sin^2 2\theta_{13} > 0.01$, a WBB experiment can perform better than a neutrino factory.
- Barger and Langacker, together with students Lewis, McCaskey, Shaughnessy, and Yencho investigated the correlated predictions of singlet extended MSSM models for direct detection of the lightest neutralino with its cosmological relic density. The WMAP upper bound on the cold dark matter density was found to limit much of the parameter space to regions where the lightest neutralino can be discovered in recoil experiments. In general, most points in the parameter spaces of the singlet models considered are accessible to the WARP experiment.
- Barger, Langacker, and Shaughnessy discussed extensions of the MSSM with extended gauge symmetries, new vector-like supermultiplets with non-standard $SU(2) \times U(1)$ assignments, and extended Higgs sectors, focusing on the class of models involving an additional standard model singlet field. The latter provides a solution to the μ problem, and allows

significant modifications of the MSSM in the Higgs and neutralino sectors, with important consequences for collider physics, cold dark matter, and electroweak baryogenesis.

- Barger, Deshpande of Oregon U., Langacker, and Li of IAS and Texas A& M systematically construct two kinds of models with canonical gauge coupling unification and universal high-scale supersymmetry breaking. The first class of models have standard vector-like particles while in the second non-standard vector-like particles are also included. The gauge coupling unification scale is required to be between from 5×10^{15} GeV and the Planck scale, that the universal supersymmetry breaking scale is from 10 TeV to the unification scale, and that the masses of the vector-like particles are universal and in the range from 200 GeV to 1 TeV. In each case, the supersymmetry breaking scales, the gauge coupling unification scales, and the corresponding Higgs mass ranges are computed. When the vector-like particle masses are less than 1 TeV, these models can be tested at the LHC.

Current and planned research directions

- With Baer, Lessa, and Tata, Barger is examining the capability of the LHC to discover supersymmetry with energy $\sqrt{s} = 7$ TeV and integrated luminosity of order 1 fb^{-1} . Using a 6-dimensional grid of optimized cuts, including missing E_T , they find for $m_{\tilde{q}} \sim m_{\tilde{g}}$ an LHC reach of $m_{\tilde{g}} \sim 800, 950, 1100$ and 1200 GeV for $0.1, 0.3, 1$ and 2 fb^{-1} respectively. For $m_{\tilde{q}} \gg m_{\tilde{g}}$, the reach is instead near $m_{\tilde{g}} \sim 480, 540, 620$ and 700 GeV, for the same integrated luminosities. They also examine the LHC reach in the case of very low integrated luminosity where missing E_T may not be viable, focusing on the multi-muon, multi-lepton (including electrons) and dijet signals. The LHC reach is much lower in these cases but is still substantial: for 0.3 fb^{-1} , the dijet reach in terms of gluino mass is up to 600 GeV for very low m_0 , while the dilepton reach is to gluino masses of ~ 500 GeV.
- With Kumar of U. Hawaii, Marfatia, and Sessolo, Barger is studying the prospects for indirect detection of fermion WIMPless dark matter at neutrino telescopes IceCube and DeepCore, assuming that the dark matter is a relatively low-mass, hidden sector Majorana fermion that couples through Yukawa couplings to a connector particle and a visible sector particle. A five year 3σ discovery at IceCube is possible only in limited situations in the stau and sneutrino channels, but DeepCore is capable of discovery in all annihilation channels, without excessive tuning of the Yukawa couplings or connector mass.
- If a massive Majorana neutrino lie in an $SU(2)$ doublet, its weak decay will produce the particle and anti-particle versions of its charged lepton partner with equal rates. Pair production of such heavy neutrinos thus results in large like-sign lepton event signals. Barger, Keung, and Yencho are investigating the LHC signal resulting from a heavy neutrino pair that is produced via gluon fusion through a virtual s-channel Z or Higgs boson.
- In certain regions of the MSSM parameter space, the multi-lepton signal from the decay of a neutralino-chargino pair can be striking in comparison to the SM backgrounds. In well-motivated MSSM extensions such as the NMSSM and the nMSSM, the mixing of the additional scalar singlet field's fermionic partner, the singlino, with the other neutral fermionic fields composing the neutralinos can lead to very different predictions for the multi-lepton signals. Barger, Shaughnessy, and Yencho plan to make comparisons of the multi-lepton signals of the extended models with those of the MSSM.
- The CoGeNT experiment has presented evidence for the direct detection of a DM particle

of mass $7 - 12$ GeV. Barger, McCaskey, and Shaughnessy find that the inferred DM spin-independent cross-section is compatible with a complex scalar singlet extension of the SM and is consistent with a thermal cosmological DM density, the LEP2 constraints on the Higgs sector, and the PAMELA astrophysics \bar{p}/p flux ratio. They are analyzing the corresponding predictions for the masses, production, and decays of the two Higgs mass-eigenstates.

- A neutral Dark Matter particle can carry a small electric dipole or magnetic moment associated that may be detectable in direct search experiments. Barger, Keung, and Marfatia analyze the current experimental limits and the discovery potential for these moments, including complete expressions of their cross sections and the recoiling energy dependence.
- Barger, Gao, and Marfatia are performing a detailed simulation of dark matter annihilation in the Sun to neutrinos and their detection with IceCube/DeepCore, assuming a neutralino dark matter candidate within the minimal supergravity model. Spin correlations, solar medium absorption and full scattering effects during neutrino propagation are included. The low energy threshold of DeepCore greatly improves the capability of detecting the neutrino signal above the background from atmospheric neutrinos.

B. Research of Lisa Everett

Overview of Research Activities

Everett pursues a research program which aims to connect observable particle physics and fundamental theory. The goals are to understand and improve the extent to which collider, cosmological, and neutrino detection experiments can probe Planck and/or string scale physics. Her work focuses on two topics that can be integrated within the broad context of string phenomenology: neutrino flavor mixing and low energy supersymmetry.

Everett has studied models of neutrino masses and mixing within the context of quark-lepton unification, and is currently working with her graduate student Alex Stuart on models based on icosahedral symmetry as an underlying flavor symmetry group of the quarks and leptons. She has given several invited plenary talks on this work; Stuart has spoken about this work at the Pheno 2009 Symposium and at the 2009 DPF meeting. Everett also explores supersymmetry breaking model building as well as the phenomenology of string-motivated extensions of the minimal supersymmetric standard model (MSSM). Her graduate students working in this area are Yongyan Rao and Valerie Plaus. A highlight of Everett's current research is the development of a generalized framework for supersymmetry breaking known as "deflected mirage mediation." Deflected mirage mediation is a string-motivated scenario that includes comparable contributions from gravity mediation, gauge mediation, and anomaly mediation. The approach allows for the construction of simple, theoretically motivated models that can be used for LHC studies of TeV scale supersymmetry. Everett and postdoctoral researcher Kim have given numerous seminars and conference talks on this subject.

Further details of these projects and planned research directions will be described below.

Papers published since January 2007

- B. Altunkaynak, L. L. Everett, I. W. Kim, B. D. Nelson and Y. Rao, "Phenomenological Implications of Deflected Mirage Mediation: Comparison with Mirage Mediation,"

arXiv:1001.5261 [hep-ph].

- L. L. Everett, J. Jiang, P. G. Langacker and T. Liu, “Phenomenological Implications of Supersymmetric Family Non-universal $U(1)'$ Models,” arXiv:0911.5349 [hep-ph].
- L. L. Everett, P. Fileviez Perez and S. Spinner, “The Right Side of TeV Scale Spontaneous R-Parity Violation,” Phys. Rev. D **80**, 055007 (2009).
- V. Barger, L. L. Everett, J. Jiang, P. Langacker, T. Liu and C. E. M. Wagner, “ $b \rightarrow s$ Transitions in Family-dependent $U(1)'$ Models,” JHEP **0912**, 048 (2009).
- D. A. Demir, L. L. Everett, M. Frank, L. Selbuz and I. Turan, “Sneutrino Dark Matter: Symmetry Protection and Cosmic Ray Anomalies,” Phys. Rev. D **81**, 035019 (2010)
- V. Barger, L. Everett, J. Jiang, P. Langacker, T. Liu and C. Wagner, “Family Non-universal $U(1)'$ Gauge Symmetries and $b \rightarrow s$ Transitions,” Phys. Rev. D **80**, 055008 (2009).
- L. L. Everett and A. J. Stuart, “Icosahedral (A_5) Family Symmetry and the Golden Ratio Prediction for Solar Neutrino Mixing,” Phys. Rev. D **79**, 085005 (2009).
- L. L. Everett, I. W. Kim, P. Ouyang and K. M. Zurek, “Moduli Stabilization and Supersymmetry Breaking in Deflected Mirage Mediation,” JHEP **0808**, 102 (2008)
- L. L. Everett, I. W. Kim, P. Ouyang and K. M. Zurek, “Deflected Mirage Mediation: A Framework for Generalized Supersymmetry Breaking,” Phys. Rev. Lett. **101**, 101803 (2008).
- D. A. Demir, L. L. Everett and P. Langacker, “Dirac Neutrino Masses from Generalized Supersymmetry Breaking,” Phys. Rev. Lett. **100**, 091804 (2008).
- A. Bandyopadhyay *et al.* [ISS Physics Working Group], “Physics at a future Neutrino Factory and super-beam facility,” Rept. Prog. Phys. **72**, 106201 (2009).
- D. J. H. Chung, L. L. Everett, K. Kong and K. T. Matchev, “Connecting LHC, ILC, and Quintessence,” JHEP **0710**, 016 (2007).
- D. J. H. Chung, L. L. Everett and K. T. Matchev, “Inflationary Cosmology Connecting Dark Energy and Dark Matter,” Phys. Rev. D **76**, 103530 (2007).

Invited talks since January 2007

- “Flavor Symmetries: Models and Implications,” plenary talk, LAUNCH 2009, MPIK, Heidelberg, Germany, 18 November 2009.
- “Models of Neutrino Masses and Mixing: Understanding Lepton Flavor Mixing,” plenary talk, Neutrinos and Dark Matter 2009, U. Wisconsin, Madison, 3 September 2009.
- “Understanding Lepton Flavor Mixing,” The 2009 Meeting of the Division of Particles and Fields of the American Physical Society (DPF 2009), Wayne State U., 28 July 2009.
- “Deflected Mirage Mediation,” The 17th International Conference on Supersymmetry and the Unification of Fundamental Interactions (SUSY 09), Northeastern U., 6 June 2009.
- “LHC, ILC, and Quintessence,” plenary talk, New Prospects for Solving the Cosmological Constant Problem, Perimeter Institute, 26 May 2009.
- “LHC, ILC, and Quintessence,” plenary talk, The Third International Workshop on the Interconnection Between Particle Physics and Cosmology, U. Oklahoma, 21 May 2009.
- “Connecting LHC, ILC, and Quintessence,” International Linear Collider workshop (LCWS08 and ILC08), U. Illinois, Chicago, 18 November 2008.

- “Dirac Neutrino Masses from Generalized Supersymmetry Breaking,” The 16th International Conference on Supersymmetry and the Unification of Fundamental Interactions (SUSY 08), Seoul, Korea, June 2008.
- “Supersymmetry, Dark Matter, and Dark Energy,” The 15th International Conference on Supersymmetry and the Unification of Fundamental Interactions (SUSY 07), Karlsruhe, Germany, July 2007.
- “Supersymmetry, Dark Matter, and Dark Energy,” Brookhaven Forum 2007: New Horizons at Colliders, Upton, NY, May 2007.
- “Neutrino Oscillations and the SM Flavor Puzzle: Implications for Quark-Lepton Unification,” Neutrino Physics: Looking Forward, Aspen Summer 2007 Workshop, May 2007.
- “Supersymmetry, Dark Matter, and Dark Energy,” Celebration of the 70th Birthday of Gordon Kane, Michigan Center for Theoretical Physics, Ann Arbor, MI, January 2007.
- “Desperately Seeking Supersymmetry: How Might She Hide?” Colloquium at U. Arizona, Tucson, AZ, February 2009, and at U. Florida, Gainesville, FL, November 2008.
- 7 research seminars given at various universities and laboratories.

Professional service since January 2007

- Everett is co-organizing the annual meeting of the String Vacuum Project (SVP) at KITP in May 2010. She has been a member of the String Vacuum Project collaboration since 2008.
- Convener, Parallel Session on CP Violation, Flavor, Neutrinos, and Proton Decay, SUSY 2009, 3-9 June 2009; convener, Parallel Session on SUSY model building and Strings, SUSY 2008, 14-22 June, 2008.
- Principal Investigator, funded QuarkNet proposal (<http://quarknet.fnal.gov>). Leader of UW-Madison outreach program, together with lead teachers Eric Gettrust and Mike Lyman. Participating UW-Madison personnel include Professors Dasu (CMS), Heeger (Daya Bay), and Timbie (astrophysics), and scientists Maruyama (IceCube) and Wise (Daya Bay).
- Member, EPP Theory Panel, NSF, February 2007.

Description of recent research activities

- The phenomenology of TeV scale supersymmetry crucially depends on the soft supersymmetry breaking sector. In most models of supersymmetry breaking that have been studied, a single mediation mechanism is assumed to dominate. A complementary approach is to build models where more than one mediation mechanism plays an important role, as motivated from progress in moduli stabilization in string theory. A standard scenario of this type is mirage mediation, in which the gravity mediated terms are comparable to the anomaly mediated terms, resulting in a unification of the soft parameters at a “mirage” scale.

Together with postdoctoral researchers Kim, Ouyang, and Zurek, Everett recently proposed a scenario called deflected mirage mediation, which extends mirage mediation to include comparable contributions to supersymmetry breaking from gauge mediation. Gauge mediation introduces threshold effects that deflect the soft masses from their renormalization group trajectories, resulting in a deflected gaugino mass mirage unification scale. Everett, Kim, Ouyang, and Zurek have studied top-down model-building and the low energy spectra of such models. In work with Nelson of Northeastern U., Nelson’s student Altunkaynak,

postdoctoral researcher Kim, and Everett’s graduate student Rao, Everett has studied the differences between the collider phenomenology of deflected mirage mediation and mirage mediation scenarios. A wide variety of mass spectra and LHC signals are possible within deflected mirage mediation, including an intriguing scenario in which the gluino is the only light colored superpartner.

- Non-Abelian discrete symmetries have proven to be very fruitful candidates for family symmetries in the lepton sector. Everett and her student Stuart have an ongoing research program based on the possibility that the family symmetry group is the icosahedral symmetry group \mathcal{I} , which is isomorphic to \mathcal{A}_5 , the alternating group of five elements. Icosahedral symmetry is the only symmetry that arises within Plato’s five “perfect” solids (the tetrahedron, cube, octahedron, dodecahedron, and icosahedron) that had not yet been used as a family symmetry group, in part because it is not a crystallographic point group. An intriguing feature of the icosahedral symmetry group is that it provides a natural setting in which to explore the idea that the solar mixing angle is related at leading order to the golden ratio, $\phi = (1 + \sqrt{5})/2$, with $\theta_{12} = \tan^{-1}(1/\phi)$. Everett and Stuart have provided a toolbox for flavor model building using the rotational icosahedral symmetry group, and constructed a working model with the above “golden prediction” for the solar mixing angle.
- The intriguing question of the nature of the dark matter of the universe has recently been invigorated by the observation of potentially anomalous effects in cosmic rays, such as the positron excess seen at energies above 10 GeV by PAMELA. If such anomalies originate from dark matter annihilation or decays, supersymmetric models with sneutrino dark matter may provide an elegant framework in which to interpret these effects. With Demir of Izmir Tech. Institute, Frank of Concordia U., Selbuz of Izmir Tech. Institute and Ankara U., and Turan of Concordia U., Everett recently proposed an R-parity conserving sneutrino dark matter model that can accommodate the cosmic ray anomalies. In the model, the light Dirac neutrino masses result from higher-dimensional operators due to a TeV-scale Higgs-philic $U(1)'$ gauge symmetry, and the μ problem of the MSSM is naturally resolved.
- The standard seesaw mechanism and other scenarios for obtaining light neutrino masses rely on the supposition that the right-handed neutrinos are complete gauge singlets. With Demir of Izmir Tech. Institute and Langacker of IAS, Everett has shown that in (string-motivated) models in which the right-handed neutrinos are charged under additional low energy gauge symmetries, appropriately suppressed Dirac neutrino mass terms can arise from generalized supersymmetry breaking terms. In these scenarios, the usual neutrino superpotential Yukawa terms are forbidden by the extra gauge symmetries, but higher-dimensional Kähler potential terms involving the “wrong” Higgs (H_d^\dagger rather than H_u) are allowed. After supersymmetry breaking, these Kähler potential terms result in suppressed effective Dirac neutrino masses that are naturally in the allowed range.
- Extensions of the MSSM in which $U(1)_{B-L}$ is spontaneously broken at the TeV scale by the vacuum expectation values of right-handed sneutrinos are minimal R-parity violating models with predictive Z' phenomenology that can arise from grand unified theories. With postdoctoral researchers Fileviez Perez and Spinner, Everett studied a simple model of this type in which the Abelian sector of the theory consists of $B-L$ and right-handed isospin. The TeV scale phenomenology, issues of neutrino mass generation, and prospects of distinguishing this model from other $B-L$ models were analyzed.

- Extensions of the MSSM with additional $U(1)'$ gauge symmetries broken at the electroweak to TeV scale are well-motivated within many string and/or grand unified models. In work with Barger and Jiang of UW-Madison, Langacker of IAS, Liu of Chicago U., and Wagner of Argonne/Chicago U., Everett has explored the possibility that family non-universal $U(1)'$ gauge symmetries can account for the observed possible discrepancies in flavor-changing-neutral-current (FCNC) effects in the $b \rightarrow s$ transitions. The results of the model-independent analysis of the correlated constraints from $B_s \rightarrow B_s$ mixing and the time-dependent CP asymmetries of $B_d \rightarrow (\pi, \phi, \eta, \rho, \omega, f_o)K_S$ decays indicates that the currently observed discrepancies in some of these modes with respect to the SM predictions can be accommodated. Together with Jiang, Langacker, and Liu, Everett has also constructed an explicit family non-universal $U(1)'$ model motivated by E_6 embeddings, and showed that the B system anomalies can also be explained within this more restrictive model framework.
- Current cosmological data have revealed that the energy density of the universe today is dominated by dark energy, which may be associated with a light scalar field known as quintessence. While direct tests of the quintessence hypothesis are generically extremely difficult, indirect tests are possible because the thermal freezeout process for the dark matter can be strongly affected in quintessence scenarios in which a period of kination domination occurs before BBN. With Chung of the UW-Madison and Matchev of Florida U., Everett has explored this hypothesis first by constructing a viable inflationary model in which the inflaton and quintessence are the same scalar field. With Chung, Kong (then a postdoctoral researcher at Fermilab), and Matchev, Everett also studied collider probes of kination-dominated quintessence in the context of low energy supersymmetry. The work quantifies the advantage the ILC will have over the LHC in measuring dark energy properties within kination-dominated quintessence using a set of study points based on minimal supergravity.

Current and planned research directions

- Everett is currently studying a number of phenomenological and theoretical issues within the framework of deflected mirage mediation. A ongoing project with Altunkaynak, Nelson, Kim, and Rao is to analyze the pattern of the four lightest superpartners within deflected mirage mediation models, and compare the results with known results from the minimal supergravity/constrained MSSM framework. Other projects include a more comprehensive analysis of dark matter allowed regions of the deflected mirage mediation parameter space, and the determination of optimized benchmark points to be used for LHC studies. In work also with Zurek (now a faculty member at Michigan U.), Everett is also studying a generalization of the approach in which known models can be recovered by “dialing” the appropriate parameters. On the theoretical side, Everett has been working with postdoctoral researcher Kim and her graduate student Rao to analyze general issues of CP violation within this framework, as well as novel approaches to the μ problem of the MSSM.
- Icosahedral symmetry provides a rich setting in which to explore the flavor puzzle of the Standard Model. To this end, Everett and her graduate student Stuart are continuing their exploration of flavor model building based on this framework. Two projects currently underway are to study the issues of flavon sector vacuum alignment and naturalness within the lepton sector models, and to extend the investigation to the quark sector of the theory by providing a systematic analysis of the double-cover of the icosahedral symmetry group, \mathcal{I} . Other research goals include a systematic study of viable quark and lepton sector models

within icosahedral symmetry, including models that predict the much-studied tri-bimaximal lepton mixing pattern.

- In many top-down approaches, such as grand unified theories and string-derived extensions of the MSSM, additional Higgs doublet pairs are ubiquitous. Such additional pairs were used by Nelson and Randall to construct a scenario in which large values of $\tan\beta$, the ratio of the vacuum expectation values of the standard MSSM Higgs doublets, can arise naturally. Everett, in ongoing work with her student Plaus, as well as with Barger and his student McCaskey, is currently studying extensions of this idea that also address the μ problem through the breaking of an additional $U(1)'$ symmetry by SM gauge singlets. The preliminary results demonstrate that naive extensions of the Nelson-Randall approach are not viable due to accidental symmetries. The phenomenological bounds on more intricate scenarios due to collider, Z' , and Higgs-mediated flavor-changing neutral current bounds are underway.
- Orbifold grand unified theories provide an elegant mechanism for keeping the advantageous features of grand unified theories while allowing for split multiplets (doublet-triplet splitting) and modified Yukawa relations that are generically needed for realistic phenomenology. Together with Langacker, Everett is planning to study whether orbifold models based on E_6 can be constructed in which light Z' gauge bosons, viable Yukawa relations, and incomplete Higgs multiplets needed for viable gauge coupling unification are present.

C. Research of Francis Halzen

Overview of Research Activities

Halzen's particle physics related interests have focused on the particle physics aspects of the IceCube experiment and on its low energy extension, DeepCore that is now collecting data. A main focus has been the detection of weakly interacting massive particles (WIMPs), especially neutralinos anticipated in supersymmetric extensions of the Standard Model.

Papers published since January 2007

- R. Abbasi *et al.* [The IceCube collaboration], "Limits on a muon flux from Kaluza-Klein dark matter annihilations in the Sun from the IceCube 22-string detector," *Phys. Rev. D* **81**, 057101 (2010) [arXiv:0910.4480](#) [[astro-ph.CO](#)].
- L. Anchordoqui and F. Halzen, "Lessons in Particle Physics," [arXiv:0906.1271](#) [[physics.ed-ph](#)].
- F. Halzen and D. Hooper, "The Indirect Search for Dark Matter with IceCube," *New J. Phys.* **11**, 105019 (2009) [arXiv:0910.4513](#) [[astro-ph.HE](#)].
- R. Abbasi *et al.* [ICECUBE Collaboration], "Limits on a muon flux from neutralino annihilations in the Sun with the IceCube 22-string detector," *Phys. Rev. Lett.* **102**, 201302 (2009) [arXiv:0902.2460](#) [[astro-ph.CO](#)].

Invited talks and lectures since January 2007

- COSMO 09: International Workshop on Particle Physics and the Universe, CERN, Geneva, Switzerland, 2009.
- Nijmegen 09: International Summer School on Particle and Nuclear Astrophysics, Nijmegen, Netherlands, 2009.

- Summer School on Nuclear and Particle Astrophysics, U. Washington, Seattle, 2009.
- XXIèmes Recontres de Blois, Windows on the Universe, Blois, France, 2009.
- Nuclear Physics talk, APS Meeting, San Diego, California, 2009.
- American Association of Physics Teachers, Boston U., 2009.
- American Association of Physics Teachers, Harrisburg, Pennsylvania, 2009.
- National Science Teacher Association, New Orleans, Louisiana, 2009.
- XIII International Workshop on Neutrino Telescopes, Venice, Italy, 2009.
- Discrete 08, Valencia University, Valencia, Spain, 2008.
- PANIC 08, Student Day Lecturer on Particle Astrophysics, Eilat, Israel, 2008.
- Neutrino Frontiers, University of Minneapolis, Minneapolis, Minnesota, 2008.
- 50 Years of MPI for Physics in Munich, Munich, Germany, 2008.
- Neutrino Oscillations in Venice, Venice, Italy, 2008.

Professional service since January 2007

- Chair, Advisory Committee of the Telescope Array, 2010.
- Advisory Committee of KIT, Karlsruhe, Germany, 2008 and 2010.
- Advisory Committee of the Max Planck Institute for Nuclear Physics, Heidelberg, Germany, 2009.
- CCAPP Advisory Board, The Ohio State University, 2009.
- Comité d’Evaluation du APC, Paris, France, 2008.
- Sudbury Neutrino Detector Advisory Committee, 2007.
- Chair, Comité d’Evaluation du CPPM à Marseille, France, 2007.
- Chair, Canada Foundation for Innovation (CFI) review of Cryopit at SNOLab, Ottawa, Ontario, Canada, 2007.
- KVI Groningen Advisory Committee, 2007.
- Max Planck Institute Scientific Council, Munich, 2007.

Current and planned research directions

- **Constraining the GZK neutrino flux.** Together with M. Ahlers and M. C. Gonzalez-Garcia, Halzen is comparing HiRes and recent Auger data to model spectra of protons propagated from extragalactic sources, taking into account GZK interactions on intervening radiation fields and allowing for cosmological evolution of the sources. Besides interactions on the cosmic microwave background, interactions on the cosmic infrared background are also considered in order to match the precision of the data. They also track the electromagnetic cascade initiated by neutral pions and electrons produced in the photoproduction of cosmic rays on background photons. The condition that their flux not exceed the recent high quality data for the diffuse photon flux from the Fermi satellite at GeV energies is imposed. The goal is to establish constraints on the neutrino flux resulting from the GZK interactions that will be searched for by a new generation of radio detectors such as ANITA, ARA, and others.
- **Neutrino Physics with DeepCore.** Besides its potential to detect dark matter, Ice-

Cube’s opportunities for particle physics range from the search for neutrino physics beyond the Standard Model to the effect of quantum gravity on their propagation. The Deep Core upgrade of IceCube will significantly extend IceCube’s scientific potential as an atmospheric neutrino detector. It will accumulate atmospheric neutrino data covering the oscillation dip near 20 GeV with unprecedented statistics of 200,000 events per year. Its instrumented volume exceeds 12 Mton at 20 GeV and reaches 25 Mton at higher energies. It has been shown that the event statistics is sufficient to observe the appearance of tau-neutrinos in the atmospheric beam and to determine the mass hierarchy to at least 90% confidence level assuming the current best-fit values of the oscillation parameters, and for values of θ_{13} close to the present bound. Early data from DeepCore confirm the statistics anticipated. The collaboration proposes to do a detailed phenomenological analysis of DeepCores physics potential, including realistic systematics.

D. Research of Tao Han

The research program of Han focuses on LHC phenomenology and new physics searches. It includes a broad scope of topics:

- exploring the mechanisms for electroweak symmetry breaking,
- determining the missing particle mass (a dark matter candidate) at the LHC environment,
- strategies of searching for new gauge bosons and fermions,
- top-quark properties as windows to new physics,
- testing the symmetry-violation of CP, lepton number, baryon number etc. at colliders,
- QCD effects on new physics searches,
- assessing the physics potential for future colliders such as the ILC and Muon Collider.

His program involves collaborations with world-wide top physicists (both theorists and experimentalists), postdoctoral researchers in Madison and elsewhere (including serving as a co-PI with postdoctoral researcher Christensen for one of the prestigious LHC Theory Initiative fellowships), and training of graduate students (currently six at UW). Since January 2007, Han has co-authored 28 journal papers, two chapters for LHC review books, two CMS physics analysis notes, and edited a book of the TASI proceedings. The outputs of Han’s research have made deep impacts in collider physics and in the community. During this period, he has given 16 invited talks in conferences, 13 seminars and 13 colloquia in research institutions, and has delivered 8 lecture series on collider physics in summer schools.

Han remains an active member for community service. He has served as an organizer for international conferences, a convener for numerous workshops, the TASI-08 scientific director, and a “National Advisory Board” member for Kavli Institute of Theoretical Physics - China. He is on the editorial board for Phys. Rev. D and Chinese Physics C. He serves as a reviewer and on review panels for funding agents in the US and abroad.

Selected Recent Projects

- **Higgs and EWSB.** With Krohn, Wang, and Zhu of Princeton, Han studied new physics signals in longitudinal gauge boson scattering at the LHC. they introduce a novel technique designed to look for signatures at the TeV scale. This functions by measuring the polariza-

tion of the vector bosons to determine the *relative* longitudinal to transverse production. In studying this ratio one can directly probe the high energy E^2 -growth of longitudinal vector boson scattering amplitudes characteristic of models with non-Standard Model (SM) interactions. They showed that this technique is stable against the large uncertainties that can result from variations in the factorization scale when taking into account the QCD showering and jets, improving upon previous studies that measure cross section alone.

Building on our strength in understanding the gauge boson fusion mechanism for SM Higgs production, Han and Mellado of the UW-Madison assessed the opportunity for deeply inelastic electron-proton scattering at the LHC. They demonstrated that the use of forward jet tagging plus central jet vetoing as a means to secure the observation and to significantly improve the purity of the Higgs boson signal in the $H \rightarrow b\bar{b}$ decay mode. This leads to the possible determination of the Hbb Yukawa coupling in a model-independent way, beyond the LHC capabilities.

- **Particle dark matter and the LHC.** It seems most likely that the dark matter (DM) relic preferred from the numerous cosmological observations may be of the particle physics origin. If this is the case, then LHC will have the potential to produce the DM particle and even probe its properties. It has been realized that even with the establishment of the missing energy events at the LHC, it will be extremely difficult to determine the mass and properties of the missing particles, due largely to the underconstrained kinematics.

With postdoctoral researcher Kim and visiting professor Song, Han examined a different kind of kinematics, an “antler decay”, $D \rightarrow A_1 A_2 \rightarrow (a_1 X_1) (a_2 X_2)$, where a_1 and a_2 are observable SM particles and X_1 and X_2 are missing particles, presumably the DM candidates. They observed kinematic cusp structures in certain invariant mass distributions. Knowing a parent mass (M_D), the cusped peak is sensitive to the mass of an intermediate decaying particle (A), and its end-point is sensitive to the mass of the final state particle (X), that may be escaping from the detection. The shape of the cusp distribution depends on the spins of particles involved. These features may help determine the masses and spins of the missing particles at the LHC.

- **Quarks above the top.** Recent theoretical developments with warped extra dimensions have opened new possibilities for existence of vector-like quarks. These new vector-like quarks can mix sizably with light Standard Model quarks without violating low energy constraints. With Atre, Carena, and Santiago, they performed a model-independent analysis to determine the Tevatron reach in the search for new quarks. They found that the Tevatron has great potential to observe such quarks via their electroweak single production due to their mixing with valence quarks. With 4 (8) fb^{-1} integrated luminosity, one may reach a 5σ statistical significance for a heavy quark of mass 580 (630) GeV if the heavy quark-Standard Model quark mixing parameter is order one.

- **New gauge bosons at the LHC.** New gauge bosons exist in many theoretical extensions beyond the SM, and are likely to be striking signals at the LHC. However, the properties of the electroweak gauge bosons vary drastically with different model incarnations. We have explored a variety of challenging scenarios, proposed searching strategies for the new gauge bosons, and quantified their reach at the LHC. In three separate publications involving different collaborations, Han found that the charged gauge bosons in a realistic Randall-

Sundrum model (W_{KK}^\pm) may be convincingly observed at the LHC up to 2 – 3 TeV; the KK gauge bosons in Higgsless models may be studied well at the LHC including its suppressed coupling to t , b quarks; and for the “coset” gauge bosons (a residual gauge bosons from a larger gauge group, often as a SU(2) doublet), it would be rather challenging to establish a strong signal beyond a 2 TeV mass.

- **Majorana neutrino mass and the LHC.** The inclusion of right-handed neutrinos (N , a sterile neutrino) can generate both Dirac and Majorana type of neutrino masses, leading to the so-called Type I seesaw mechanism. However, the couplings (via mass mixing) to the SM particles are very small, of the order of $V^2 \sim m_\nu/M_N$. This would be nearly impossible to test at collider experiments even if the scale of M_N happens to be at TeV. On the other hand, the Type I scheme with three generations of right-handed neutrinos (N_i) provides an attractive option of gauging the $B - L$ accidental symmetry in the standard model. The mediation via the gauge boson Z_{B-L} results in large production rates for the heavy neutrinos at the LHC. The masses of the heavy neutrinos can thus be related to the scale of $B - L$ breaking. The flavor combinations of the charged leptons from the decay of N_i are related to the light neutrino mass and mixing parameters and thus may reveal the neutrino mass pattern. With postdoctoral researcher Fileviez Perez and visiting graduate student Li, Han studied these issues and obtained optimistic results to test this mechanism at the LHC.

Following his early proposal of searching for lepton-number violation signals at the LHC, Han and experimental colleagues at the Fermilab LPC (Wei-Min Wu et al.) carried out a detailed study including the CMS detector simulations (CMS Note 2008/054). Upon the request of the CMS Exotic Physics Group, they updated the study for the 10 TeV LHC with lower luminosity and the results appeared as a reviewed CMS note (CMS PAS Exo-09-003).

- **QCD corrections to new physics scenarios.** Hadron colliders are QCD machines: the strong interaction of the colored partons leads to overwhelmingly dominant event rate in hadronic collisions. Thus any new particles, as long as they have QCD interactions, will be strongly produced with favorable rates. For rather heavy particles, the valence quarks are still the major contributors for their production. A simple argument indicates that quark-quark scattering could give the bosonic color states $\mathbf{6} \oplus \mathbf{\bar{3}}$, rather exotic color representations beyond the SM particle spectrum. Such states include scalar quarks of color triplets in supersymmetric theories (SUSY) with R-parity violation, and scalar diquarks of color sextet. With graduate student Lewis and postdoctoral researcher McElmurry, Han carried out the calculations for their production at hadron colliders including the NLO QCD corrections. They found that the QCD corrections can be as large as 30% at the LHC, and 20% at the Tevatron. They also presented their transverse momentum spectrum by including the leading-log soft gluon resummation to all orders in the strong coupling.

- **Genuine CP-odd variables at the LHC.** New sources of CP violation are needed in order to explain the observed matter-antimatter asymmetry of the Universe. The expectation is high for the LHC to uncover new physics, including testing the CP properties. However, it is quite challenging to construct genuine CP-odd observables at the LHC, due to the facts that (a). the initial state of the LHC as a pp collider is not a CP eigenstate; (b). the initial states $q(p_1)\bar{q}(p_2)$ and $g(p_1)g(p_2)$ can form a CP eigenstate only in their center-of-mass frame which is in general different from the lab frame; (c). the symmetric beams of pp at the LHC make it impossible to identify the direction of a quark versus an anti-quark on an event-by-

event basis. Extending on the literature and tailored in particular for the LHC environment, Y.C. Li and Han proposed a few genuine CP-odd variables to have overcome the difficulties above, which could be applicable to many scenarios beyond the SM.

Current and Planned Research Directions

Han has been taking the lead in a few important directions on LHC phenomenology and new physics searches, and will continue on the prolific research program as outlined in the overview. A few ongoing projects are listed for illustration.

- **More on Higgs boson physics.** The direct search bound on a SM Higgs boson mass from LEP is about 114 GeV, which yields some tension with the EW precision fit ~ 67 GeV. A lot of effort has been made to consider the scenarios of non-SM Higgs bosons to reconcile the situation. Han is exploring the possibility that new gauge bosons might modify the Higgs interactions, which can be tested at the LHC in the near future.

- **The top quark as a window to new physics.** The prompt decay of the top quark sets it apart from the other SM quarks, and enables one to trace its fundamental properties such as spin, etc. This information may help probe new physics associated with the top quark.

With Lewis and visiting professor Si, Han is considering a signal $W' \rightarrow t\bar{b}$, where W' can be a generic new gauge boson in many extended theories beyond the SM. The point is to show that the angular distribution of the top-quark decay products carries information on the W' chirality. This information is not available for light quarks nor leptons. In fact, for a pure left-handed or a pure right-handed coupling, one would result in the same (parity violating) polar angular distribution at the W' peak, just like the case of a SM W^\pm . They are making use of the correlation with the top-quark polarizations and the techniques are applicable for any heavy particles that yields a top quark in its decay.

There has been a renewed interest to consider the low-scale string scenarios at the LHC. With graduate student Dong, former postdoctoral researcher Huang, and Shiu of the UW-Madison, Han has proposed to search for the TeV scale stringy states from their decay to $t\bar{t}$ final state. Preliminary results indicate that one may be able to observe a string resonance up to a scale about 4 TeV, and likely to observe more than one states. Their mass ratio and distinctive angular distributions due to higher spins would distinguish the string scenario from other models.

- **Particle dark matter at the LHC.** Based on the previous discovery of the “antler decay” topology, we have observed several other related kinematical structures such as on-shell chain decays, that can all help determine the missing particle mass. Han, Kim, and Song are writing two lengthy papers to layout the full scheme and reveal the kinematical and mathematical reasons behind the distinctive structures. We are also performing detailed simulations for specific processes and check the feasibility in a realistic LHC environment.

- **SUSY theory and phenomenology at the LHC.** Seiberg and collaborators recently analyzed some generic SUSY breaking models with gauge mediation. They obtained some general prediction with sum rules for the soft SUSY masses, possibly testable at collider experiments. There is an assumption, commonly made in the literature, that the messengers do not participate in any Yukawa-type interactions with the SM fields, although they respect all known symmetries. These new interactions, analogue to R-parity violating operators, may mediate low energy processes that are tightly constrained by flavor physics, including proton

decay, With visiting professor Tata, Han has set out a task to address this question: within the current experimental bounds, what operators are allowed and what the consequences are with respect to the sum rules obtained by Seiberg et al.

It is conceivable and even well-motivated in certain SUSY models that the chargino NLSP is nearly degenerate with the lightest neutralino LSP. Consequently, the decay products from the charginos may be too soft to be observable and thus the NLSP's even appear to be missing energy. This is particularly motivated by the consideration of SUSY dark matter relic density. It is thus important to address the possibility to identify those events at the LHC. Han is studying these issues in collaboration with Guidice of CERN, Han's former student K. Wang, and L.-T. Wang of Princeton. All three leading production mechanisms for the signal are considered: gluino production and decay to gauginos, the Drell-Yan type of gaugino pair production in association with a hard QCD jet, and weak boson fusion to gaugino pairs. They have obtained encouraging results for the signal observation. Searching for additional isolated soft leptons with $p_T \sim 3 - 10$ GeV in the data sample may help enrich the signal in an unambiguous way for this unique theoretical scenario.

- **QCD effects on new physics at the LHC.** At hadron colliders, it is important to understand QCD effects in order to predict Standard Model processes precisely and to search for physics beyond the SM. Han is continuing his efforts in calculating QCD corrections on new physics processes, including higher order effects and all order resummation.
- **CP-violation at the LHC.** Han recently proposed some genuine CP-odd variables for the LHC experiments. There are many important processes that are of the potential to lead us to the discovery of the new CP-violation. Examples include the couplings $t\bar{t}H$, VVH in an extended Higgs sector, gaugino signals with complex soft mass parameters, and τ -EDM, or top-quark chromo-EDM etc. He is in the process of systematically examining those processes by taking the advantage of these previously proposed CP-odd observables at the LHC.

Papers Published in Refereed Journals Since January 2007 (28 papers)

- Y.-Q. Chen, T. Han, and Z.-G. Si, "QCD corrections to single slepton production at hadron colliders," JHEP **0705**, 068 (2007).
- T. Han, B. Mukhopadhyaya, Z. Si, and K. Wang, "Pair production of doubly-charged scalars: Neutrino mass constraints and signals at the LHC," Phys. Rev. D. **76**, 075013 (2007).
- K. Agashe, H. Davoudiasl, S. Gopalakrishna, T. Han, Gui-Yu Huang, G. Perez, Z.-G. Si, A. Soni, "LHC Signals for Warped Electroweak Neutral Gauge Bosons," Phys. Rev. D. **76**, 115015 (2007).
- V. Barger, T. Han, and D.G.E. Walker, "Top Quark Pairs at High Invariant Mass – A Model-Independent Discriminator of New Physics at the LHC," Phys. Rev. Lett. **100**, 031801 (2008).
- T. Han, Z.-G. Si, K. M. Zurek, and M. J. Strassler, "Phenomenology of hidden valleys at hadron colliders," JHEP **0807**, 008 (2008).
- M. Carena, T. Han, G.-Y. Huang, C.E.M. Wagner, "Higgs Signal for $h \rightarrow aa$ at Hadron Colliders," JHEP **0804**, 092 (2008).
- S. Bar-Shalom, G. Eilam, T. Han, and A. Soni, "Charged Higgs Boson Effects in the

Production and Decay of a Heavy Majorana Neutrino at the CERN LHC,” *Phys. Rev. D.* **77**, 115019 (2008).

- P. Fileviez Perez, T. Han, G.-Y. Huang, T. Li, and K. Wang, “Testing a Neutrino Mass Generation Mechanism at the LHC,” *Phys. Rev. D.* **78**, 071301 (2008).
- P. Fileviez Perez, T. Han, G.-Y. Huang, T. Li, and K. Wang, “Neutrino Masses and the CERN LHC: Testing Type II Seesaw,” *Phys. Rev. D.* **78**, 015018 (2008).
- T. Han, “The “Top Priority” at the LHC,” *Int. J. Mod. Phys.* **A23** 4107, (2008).
- M. Raidal et al., “Flavour physics of leptons and dipole moments,” *Eur. Phys. J.* **C57**, 13 (2008).
- A. Arhrib, B. Bajc, D. Ghosh, T. Han, G. Huang, I. Puljak, G. Senjanovic, “Collider Signatures for Heavy Lepton Triplet in Type I+III Seesaw,” [arXiv:0904.2390 \[hep-ph\]](#).
- T. Han, R. Mahbubani, D.G.E. Walker, and L.-T. Wang, “Top Quark Pair plus Large Missing Energy at the LHC,” *JHEP* 0905:117, 2009.
- A. Atre, M. Carena, T. Han, J. Santiago, “Heavy Quarks Above the Top at the Tevatron,” *Phys. Rev. D.* **79**, 054018 (2009).
- P. Fileviez Perez, T. Han, T. Li, M.J. Ramsey-Musolf “Leptoquarks and Neutrino Masses at the LHC,” *Nucl. Phys. B.* **819**, 139 (2009).
- A. Atre, T. Han, S. Pascoli, and B. Zhang, “The Search for Heavy Majorana Neutrinos,” *JHEP* 0905:030, 2009.
- K. Agashe, S. Gopalakrishna, T. Han, G.-Y. Huang, and A. Soni, “LHC Signals for Warped Electroweak Charged Gauge Bosons,” [arXiv:0810.1497 \[hep-ph\]](#).
- A. Arhrib, B. Bajc, D. Ghosh, T. Han, G. Huang, I. Puljak, and G. Senjanovic, “Collider Signatures for Heavy Lepton Triplet in Type I+III Seesaw,” [arXiv:0904.2390 \[hep-ph\]](#).
- T. Han, I.-W. Kim, and J. Song, “Kinematic Cusps: Determining the Missing Particle Mass at the LHC,” [arXiv:0906.5009 \[hep-ph\]](#).
- P. Fileviez Perez, T. Han, T. Li, “Testability of Type I Seesaw at the CERN LHC: Revealing the Existence of the B-L Symmetry,” *Phys. Rev. D* **80**: 073015, 2009.
- T. Han, H. Liu, M. Luo, K. Wang, and W. Wu, “Like-sign Di-lepton Signals in Higgsless Models at the LHC,” *Phys. Rev. D* **80** :095010,2009.
- T. Han and B. Mellado, “Higgs Boson Searches and the $H b \bar{b}$ Coupling at the LHC,” [arXiv:0909.2460 \[hep-ph\]](#).
- T. Han, I. Lewis, and T. McElmurry, “QCD Corrections to Scalar Diquark Production at Hadron Colliders,” *JHEP* 1001:123,2010.
- K. Agashe, A. Azatov, Y. Li, Z. Si, and L. Zhu, “LHC Signals for Coset Electroweak Gauge Bosons in Warped/Composite PGB Higgs Models,” [arXiv:0911.0059 \[hep-ph\]](#).
- T. Han and Y. Li, “Genuine CP-odd Observables at the LHC,” *Phys. Lett. B* 683:278, 2010.
- T. Han, D. Krohn, L.-T. Wang, and W. Zhu, “New Physics Signals in Longitudinal Gauge Boson Scattering at the LHC,” *JHEP* 1003:082,2010.
- T. Han, I. Lewis, and M. Sher, “Mu-Tau Production at Hadron Colliders,” *JHEP*

1003:090,2010.

- A. De Roeck et al., “From the LHC to Future Colliders,” *Eur.Phys.J.C*66:525-583,2010.

Other Publications Since January 2007 (8 publications)

- ILC Collaboration (James Brau, (Ed.) et al.), “ILC Reference Design Report: ILC Global Design Effort and World Wide Study,” FERMILAB-APC, Aug 2007. 147pp. [arXiv:0712.1950](#) [[physics.acc-ph](#)].
- ILC Collaboration (Ties Behnke, (Ed.) et al.), “ILC Reference Design Report Volume 4 - Detectors,” FERMILAB-APC, Dec 2007. [arXiv:0712.2356](#) [[physics.ins-det](#)].
- LC (Gerald Aarons et al.), “International Linear Collider Reference Design Report Volume 2: PHYSICS AT THE ILC,” Sep 2007, [arXiv:0709.1893](#) [[hep-ph](#)].
- T. Han, “The “Top Priority” at the LHC,” Apr 2008. 25pp. Contributed chapter to *Perspectives on the LHC*, edited by G. Kane and A. Pierce.
- W. Clarida, T. Yetkin, S. Mrenna, R. Vidal, W. Wu, T. Han, H. Pi, E. Yazgan, “Searching for 100 and 200 GeV Majorana Neutrinos at the LHC Using Like Sign Dilepton Final State,” CMS Note 2008/054.
- *The Dawn of the LHC Era: TASI 2008*, Proceedings of the 2008 Theoretical Advanced Study Institute in Elementary Particle Physics. Editor: Tao Han, World Scientific Publishing Co., 2010.
- *The Hunt for New Physics at the Large Hadron Collider* (P. Nath et al.), Jan 2010. 234pp, Summary document Pre-SUSY 2009: Beyond the Standard Model Physics and LHC Signatures (BSM-LHC), Boston, Massachusetts, 2-4 Jun 2009, [arXiv:1001.2693](#) [[hep-ph](#)].
- “Searching for Majorana Neutrinos in the Like-sign Di-lepton Final State at the 10 TeV LHC,” CMS Collaboration Physics Analysis Notes, CMS PAS Exo-09-003 (2009).

Invited Conference Talks Since January 2007 (16 talks)

- “ILC in the LHC Era,” plenary talk, *ACFA and ILC GDE Joint Conference*, Feb.4, 2007, IHEP, Beijing, China.
- “The International Linear Collider: Challenge and Opportunity for China,” plenary talk, *Fragrant Hill Conference*, Dec. 5, 2006, Beijing, China.
- “The “Top Priority” at the LHC,” plenary talk, *Princeton Joint LHC Workshop*, March 20, 2007, Princeton University.
- “Resonant Signals,” plenary summary talk, *The Early Phase of the LHC for the ILC*, April 14, 2007, Fermilab.
- “High Energy Physics: the Next Two Decades,” plenary talk, *International Conference on Frontier Physics*, May 26, 2007, KITP-C, Beijing, China.
- “The Search for Lepton-number Violation,” plenary talk, *Neutrino masses and the TeV scale physics*, Triumph, Canada, Oct. 20, 2007.
- “The Search for Lepton-number Violation,” plenary talk, *Wei-Hai Forum*, Wei-Hai, China, July 8, 2008.
- “Kickoff for the Exotic Physics Working Group,” plenary talk, *LHC2FC: LHC to Future Colliders*, CERN, Feb. 9, 2009.

Task G. University of Wisconsin-Madison Phenomenology Institute Project Description, cont.

- “Gauge Boson self-interactions,” plenary talk, *LHC2FC: LHC to Future Colliders*, CERN, Feb. 13, 2009.
- “Lepton-number Violation at the LHC,” plenary talk, *Yukawa Symposium*, YITP, Kyoto U., Japan, March 10, 2009.
- “Non-SUSY Beyond the Standard Model Physics,” plenary talk, *Particle Physics and Cosmology 09*, U. of Oklahoma, Norman, May 20, 2009.
- “The “Top Priority” at the LHC,” plenary talk, *Beyond the Standard Model at the LHC-2009*, Northeastern University, Boston, June 2, 2009.
- “Missing Energy at the LHC: Dark Matter Connection,” plenary talk, *Innovative Team Meeting*, Shandong University, Wei-Hai, China, July 23, 2009.
- “Physics Working Group Summary,” plenary talk, *Workshop on Physics, Detector and Accelerator at Muon Colliders*, Fermilab, Nov. 12, 2009.
- “Genuine CP-Odd Observables and the Test of ZZH Coupling,” *Workshop on International Linear Collider*, Beijing, China, March 29, 2010.
- “Vision from The Top,” theory summary talk, *International Workshop: Top 2010*, Bruges, Belgium, June 4, 2010.
- Lectures on “*Collider Physics and New Physics Searches*,” Four-hour series at the *Summer School on Particle Physics in the LHC Era*, The Abdus Salam International Center for Theoretical Physics, Trieste, Italy, June 2009.
- Lectures on “*Collider Physics*,” Five-hour series at the *BUSSTEPP*, The University of Liverpool, UK, Aug. 2009.
- Lectures on “*Tools for LHC Physics*,” Tsinghua University, Beijing, China, Aug. 2010.
- Lectures on “*Collider Physics*,” Five-hour series at the *BUSSTEPP*, The University of Swansea, UK, Aug.-Sept. 2010.
- 13 seminars at and 13 colloquia; 8 lectures in international summer schools since 2007; 22 conferences attended.

Professional Service Since January 2007

- Overseas Chinese Physics Association (OCPA) Coordinator (HEP Division), since 2006.
- Advisory Board for Kavli Institute of Theoretical Physics-China (KITPC), since 2007.
- Review panelist for the Science and Technology Facilities Council (STFC), UK, on the IPPP ten years grant renewal, 2008.
- Review panelist for DOE Early Career Research Program (2009).
- Editorial board member of *Physical Review D*.
- Overseas editorial board member of *Chinese Physics C*.
- Organizing committee chair for Pheno Symposia, UW-Madison, since 1998.
- Co-convenor for the Working Group IV, Beyond the Standard Model, The LHC Early Phase for the ILC workshop, Fermilab, April 12-14, 2007.
- Co-organizer for the workshop, CTEQ-2007, May 30-June 7, 2007, Madison.
- Co-organizer for the KITP workshop, “Physics at the LHC,” Feb.20 - June 6, 2008,

University of California, Santa Barbara.

- Scientific Director for TASI 08 (Theoretical Advanced Study Institute), University of Colorado, Boulder, CO., June 2-28, 2008.
- Co-organizer for the KITP-C workshop, Physics beyond the Standard Model, June – Nov., 2008, KITP-C/ITP, Beijing, China.
- Co-convenor for the Working Group IV, “Other New Signatures Beyond the Standard Model,” The LHC to Future Colliders workshop, CERN, Feb. 9-27, 2009.
- Co-convenor for the High-Energy Physics Division, Oversea Chinese Physics Association Meeting IV, Lanzhou, China, Aug. 3–7, 2009.
- Co-convenor for the Working Group, “Missing Energy,” 2009 Linear Collider Workshop of the Americas, Albuquerque, New Mexico, Sept. 29–Oct. 3, 2009.
- Co-Convener for Physics working group, Workshop on Physics, Detector and Accelerator at Muon Colliders, Fermilab, Nov. 10-12, 2009.
- Co-Convener for Higgs and Electroweak symmetry breaking working group, International Linear Collider Workshop 2010, Beijing, China (March, 2010).
- International Advisory Board for TOP2010: Conference on top quark physics, Brugge, Belgium, May 31- June 4, 2010.
- Co-organizer for Summer School and International Conference on LHC Physics, Tsinghua University, Beijing, China, to be held in Aug. 2010.

E. Research of Frank Petriello

Overview of Research Activities

Petriello pursues a research program in precision QCD and collider phenomenology. The primary goal of his research is to identify and obtain precision predictions for important experimental observables and their backgrounds. He has developed novel methods for performing ultra-precise calculations in perturbative QCD, and has applied them to obtain theoretical predictions needed for experimental analyses. A recent important result of this effort is an updated prediction for Higgs boson production at the Tevatron. Petriello derived the three-loop mixed QCD-electroweak corrections to Higgs production in gluon fusion, and improved the theoretical treatment of parton distribution functions and bottom-quark effects used by the Tevatron collaborations. This calculation led to a re-evaluation and improvement of the Tevatron exclusion limit on the Standard Model Higgs boson. This work benefited greatly from discussions with Matt Herndon of the UW-Madison CDF Task. A second goal is the development of novel strategies to search for and study new physics at the LHC and in other experiments. Recent results include a new analysis technique to infer details of high-scale physics from observations of new gauge bosons at the LHC, and a possible explanation of the annual modulation signal seen by the DAMA experiment. Petriello has found that projects studying new phenomena at colliders are useful for beginning graduate students. They provide an introduction to many different aspects of high energy physics without overwhelming technical complications. The specific ideas and future topics that he plans to study are discussed in detail in this proposal.

Petriello, his graduate students and associated postdoctoral researchers maintain a highly visible research program. During this budget period, Petriello presented over 25 invited conference talks, lectures and colloquia on his work throughout the world, and gave 20 invited research seminars. A complete list of his invited talks is given below. Graduate student Seth Quackenbush (now at Argonne) gave talks at the 2008 Brookhaven Forum and at the 2009 TRIUMF LHC Theory Workshop on work done with Petriello. Graduate student Ryan Gavin gave talks at the 2008 Pheno Symposium and at the 2009 TRIUMF LHC Theory Workshop, and will present new work done with Petriello at the 2010 Brookhaven Forum. Postdoctoral researcher Tom McElmurry (now at Brookhaven) gave an invited plenary talk at the 2008 LoopFest conference on work done with Petriello, and also spoke at the 2008 Brookhaven Forum and the 2008 International Linear Collider Workshop in Chicago. Postdoctoral researcher Kathryn Zurek (now an assistant professor at Michigan) gave numerous talks on joint work studying the DAMA signal. Current postdoctoral researcher Sonny Mantry (supported by a Sloan fellowship) has given several recent talks on his joint work with Petriello studying low- p_T resummation in soft-collinear effective theory (SCET), and will present this research at the 2010 SCET workshop in Germany. Petriello is an extremely active member of the high energy community, and is currently organizing workshops on QCD at CERN, the KITP in Santa Barbara, and at Aspen. He was recently appointed the gluon-fusion theory convener of a joint ATLAS-CMS-theory working group on Higgs cross sections at the LHC. He was the host and organizer of the 2007 and 2009 CTEQ summer schools held in Madison. A complete list of his professional activities is given below.

Papers published since January 2007

- R. Boughezal and F. Petriello, “Color-octet scalar effects on Higgs boson production in gluon fusion,” [arXiv:1003.2046](#).
- S. Mantry and F. Petriello, “Factorization and Resummation of Higgs Boson Differential Distributions in Soft-Collinear Effective Theory,” [arXiv:0911.4135](#), accepted for publication in Phys. Rev. D.
- Y. Li, F. Petriello and S. Quackenbush, “Reconstructing a Z' Lagrangian using the LHC and low-energy data,” Phys. Rev. D **80**, 055018 (2009).
- W.-Y. Keung and F. Petriello, “Electroweak and finite quark-mass effects on the Higgs boson transverse momentum distribution,” Phys. Rev. D **80**, 013007 (2009).
- C. Anastasiou, R. Boughezal and F. Petriello, “Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion,” JHEP **0904**, 003 (2009).
- D. Hooper, F. Petriello, K. M. Zurek and M. Kamionkowski, “The New DAMA Dark-Matter Window and Energetic-Neutrino Searches,” Phys. Rev. D **79**, 015010 (2009).
- Y. Gershtein, F. Petriello, S. Quackenbush and K. M. Zurek, “Discovering hidden sectors with mono-photon Z' searches,” Phys. Rev. D **78**, 095002 (2008).
- P. Fileviez Perez, R. Gavin, T. McElmurry and F. Petriello, “Grand Unification and Light Color-Octet Scalars at the LHC,” Phys. Rev. D **78**, 115017 (2008).
- F. Petriello and K. M. Zurek, “DAMA and WIMP dark matter,” JHEP **0809**, 047 (2008).
- A. Lazopoulos, T. McElmurry, K. Melnikov and F. Petriello, “Next-to-leading order QCD corrections to $t\bar{t}Z$ production at the LHC,” Phys. Lett. B **666**, 62 (2008).
- F. Petriello, S. Quackenbush and K. M. Zurek, “The Invisible Z' at the CERN LHC,” Phys. Rev. D **77**, 115020 (2008).

- F. Petriello and S. Quackenbush, “Measuring Z' couplings at the CERN LHC,” Phys. Rev. D **77**, 115004 (2008).
- A. Lazopoulos, K. Melnikov and F. Petriello, “NLO QCD corrections to the production of $t\bar{t}Z$ in gluon fusion,” Phys. Rev. D **77**, 034021 (2008).
- A. Lazopoulos, K. Melnikov and F. Petriello, “QCD corrections to tri-boson production,” Phys. Rev. D **76**, 014001 (2007).

Invited talks and lectures since January 2007

- Three lectures on “*Perturbative QCD*,” Paul Scherrer Institute Summer School on Particle Physics: Gearing up for LHC Physics, 1 - 7 Aug 2010 (to be given).
- One lecture on “*Perturbative QCD*,” 2009 SLAC Summer Institute: Revolutions on the Horizon, 7 Aug 2009.
- Six lectures on “*Higgs Physics*,” IV Torino School in Physics at Colliders, Torino, Italy, 29 Jun - 3 Jul 2009.
- Two lectures on “*Higgs and Electroweak Gauge Bosons*,” 2009 CTEQ Summer School, Madison, WI, 24-25 Jun 2009.
- “Higgs production beyond the Standard Model,” plenary talk, LoopFest IX, Stony Brook, NY 21 - 23 Jun 2010 (to be given).
- “Higgs boson production at the LHC,” plenary talk, 10th DESY Workshop On Elementary Particle Theory: Loops And Legs In Quantum Field Theory 2010, Wörlitz, Germany, 28 Apr 2010.
- “Higgs production via gluon fusion,” plenary talk, Exploring the Origin of Mass: A New Dawn, Durham, England, 21 Apr 2010.
- “Searching for the Higgs in gluon fusion,” plenary talk, Emerging Problems in Particle Physics Phenomenology, Initiative for Theoretical Sciences, City University of New York, 9 Apr 2010.
- “Recent results in perturbative QCD,” invited talk, APS April Meeting 2010, Washington, DC, 14 Feb 2010.
- “Determining Z' couplings using LHC data and low energy measurements,” plenary talk, Perimeter Institute ATLAS-LHC day, Waterloo, Canada, 30 Oct 2009.
- “Higher-order corrections and BSM physics,” plenary talk, LHC Theory Initiative Fellows Meeting, Fermilab, 29 Oct 2009.
- “ Z' bosons from low to high energies,” invited talk, CIPANP 2009: Tenth Conference on the Intersections of Particle and Nuclear Physics, San Diego, California 29 May 2009.
- “Recent progress on QCD and electroweak corrections to Higgs production,” plenary talk, Collider Physics 2009: Joint Argonne & IIT Theory Institute, Argonne National Laboratory, 20 May 2009.
- “Precision Higgs physics,” plenary talk, Workshop on Physics at the LHC: the 1st Year, TRIUMF, Canada, 27 Apr 2009.
- “Getting ready for the LHC: a QCD status report” plenary talk, Brookhaven Forum 2008, Terra Incognita: From LHC to Cosmology, Brookhaven National Laboratory, 7 Nov 2008.
- “ Z' bosons from $Q^2 = 0$ to the LHC,” plenary talk, Collider Physics Symposium: Preparing for the LHC, Institute for Nuclear Theory, Seattle, 30 Sep 2008.
- “QCD at the LHC,” plenary talk, Quark Confinement and the Hadron Spectrum, Mainz, Germany, 2 Sep 2008.

Task G. University of Wisconsin-Madison Phenomenology Institute Project Description, cont.

- “QCD effects in Higgs physics at the Tevatron and the LHC,” plenary talk, CDF collaboration meeting, Fermilab, 18 Jun 2008.
- “ Z' bosons and light hidden sectors at the LHC,” plenary talk, Anticipating Physics at the LHC, KITP, Santa Barbara, 5 Jun 2008.
- “Electroweak gauge bosons through NNLO in QCD,” plenary talk, LoopFest VI: Radiative Corrections for the LHC and ILC, 17 Apr 2007.
- “Advances in perturbative QCD for LHC physics,” invited talk, APS April Meeting 2007, Jacksonville, FL, 14 Apr 2007.
- “Recent progress in QCD theory,” plenary talk, 2007 Winter Conference On Particle Physics, Aspen, CO, 11 Jan 2007.
- Colloquia and laboratory division seminars on “The Hunt for the Higgs Boson” given at Florida State University, Northwestern University, SUNY Buffalo, and Argonne National Laboratory; “QCD predictions for LHC processes” given as a Research Progress Meeting talk at LBNL.
- 20 research seminars given at various universities and laboratories.

Professional service since January 2007

- Joint ATLAS-CMS-Theory working group on Higgs cross sections, theory convener for gluon-fusion mode, Feb. 2010-present.
- Organizer, The Harmony of Scattering Amplitudes, KITP Santa Barbara, 4 Apr-8 Jul 2011 (to be held).
- Organizer, Perturbative higher-order effects at work at the LHC, CERN theory institute, 21 Jun-9 Jul 2010 (to be held).
- Organizer, Forefront QCD and LHC Discoveries, Aspen summer workshop, 23 May-20 Jun 2010 (to be held).
- Convener, Jet and Photon Energy Measurements working group, *2009 Linear Collider Workshop of the Americas*, Albuquerque, NM, 29 Sep-3 Oct 2009.
- Organizer of the 2009 CTEQ Summer School on QCD Analysis and Phenomenology, Madison, WI, 24 Jun-2 Jul 2009.
- Organizer, LoopFest VIII: Radiative corrections for the LHC and the ILC, Madison, WI, 7-9 May 2009.
- Organizer, Workshop on Higgs Boson Phenomenology, ETH and University of Zurich, Switzerland, 7-9 Jan 2009.
- Convener, Jet and Photon Energy Measurements working group, *2007 American Linear Collider Physics Workshop*, Fermilab, 22-26 Oct 2007.
- Organizer of the 2007 CTEQ Summer School on QCD Analysis and Phenomenology, Madison, WI, 30 May-7 Jun 2007.

Notable Appointments

- Visiting scientist, Argonne National Laboratory, 7 Jan-23 May 2010.

Description of recent research activities

- The Higgs boson is the last undiscovered particle of the Standard Model. The search for the Higgs is a primary goal of the LHC physics program, and is also a top priority at the Tevatron. The Tevatron experiments are becoming sensitive to Higgs signals in the $H \rightarrow WW$ channel for masses near the threshold $M_H \approx 2M_W$. The Tevatron collaborations currently report a

95% confidence-level exclusion of a Standard Model Higgs boson with a mass in the range $162 \text{ GeV} \leq M_H \leq 166 \text{ GeV}$. Understanding the theoretical prediction is crucial to both the search for and exclusion of the Standard Model Higgs boson. Backgrounds to the Higgs signal are severe in many channels, particularly when a mass peak cannot be reconstructed such as in $H \rightarrow WW \rightarrow l\nu l\nu$. Knowledge of the signal shape and normalization is needed to optimize experimental searches. The work of Petriello has been crucial in establishing the current Tevatron exclusion limit. In a recent paper he computed the QCD corrections to enhanced light-quark terms in the Higgs production cross section using an effective-theory approach. Before this calculation, the K -factor for these terms was unknown; values between 1 and 3.5 were assumed in the literature. The work of Petriello demonstrated that the higher value of 3.5 is correct, leading to an increased cross section prediction at the Tevatron.

Petriello also provided an updated prediction for the Higgs boson production cross section in gluon fusion for use in setting Tevatron exclusion limits. Several aspects of the numbers used by CDF and D0 prior to this work required updating, including the parton distribution functions, the bottom-quark contributions, and the electroweak effects. The results of this study included significant shifts in both the central value and estimated error of the theoretical prediction, both of which are absolutely crucial for understanding the implications of the Tevatron analysis. These changes were implemented by both CDF and D0.

- Petriello extended the previous work to include a detailed study of the various contributions to the Higgs transverse momentum spectrum. Production of a high- p_T Higgs together with one or more hard jets is important at the Tevatron, and will be used at the LHC to reduce backgrounds in Higgs searches with photon and tau final states. He identified a previously missed set of electroweak corrections that leads to destructive interference effects at large transverse momentum. The combination of electroweak and finite quark-mass effects can shift the usual approximation used for the Higgs production cross section by -30% at the LHC, and is especially important if large momenta are selected by experimental cuts.
- Petriello and postdoctoral researcher McElmurry developed a novel numerical approach to calculating multi-leg one-loop integrals, which are required for next-to-leading order (NLO) QCD computations. It entails performing a contour deformation of the Feynman parameter representation of loop integrals to avoid internal thresholds and sector decomposing the resulting expressions to extract soft and collinear singularities. They tested this method on the calculation of the NLO QCD corrections to $pp \rightarrow ZZZ$. An understanding of this process is needed to study gauge boson self-interactions at the LHC.
- Petriello and postdoctoral researcher McElmurry completed a calculation of the NLO QCD corrections to $t\bar{t}Z$ production at the LHC. The theoretical error on this process coming from higher order QCD corrections is the limiting factor in measuring $t\bar{t}Z$ electroweak couplings, which cannot be accessed at the Tevatron. This mode contains the full spectrum of difficulties present in the most complex $2 \rightarrow 3$ processes. The phenomenological results of this work include the reduction of the theoretical error from $\pm 30\%$ to $\pm 10\%$. This leads to almost a factor of two improvement in the achievable precision in $t\bar{t}Z$ coupling measurements.
- New Z' gauge bosons appear in E_6 theories, left-right symmetric models, Little Higgs theories, and in almost all other extensions of the Standard Model. Z' gauge bosons with masses of 2 TeV or less are relatively straightforward to discover in initial LHC running. How-

ever, determining their properties to uncover the underlying theory from which they arise is more difficult. Petriello and graduate student Quackenbush performed an analysis of Z' properties at the LHC using a fully differential next-to-leading order QCD calculation with spin correlations, interference effects, and experimental acceptances included. This study examined the distinguishability of different models and the feasibility of extracting general coupling information with statistical, residual scale, and current parton distribution function error estimates included. It also extended previous model-independent parametrizations of Z' couplings to include parity-violating coupling combinations, and introduced a convenient technique for simulating new gauge bosons on-peak using the concept of basis models. This new approach allows four combinations of generation-independent quark and lepton couplings to be measured at the LHC.

- Together with graduate students Li and Quackenbush, Petriello extended the previous analysis to incorporate off-peak data and information from precision low-energy measurements. Inclusion of these additional search channels lifts several degeneracies that remain when only on-peak data is considered. In particular, a degeneracy between Z' couplings to quarks and leptons present after measurements in the Drell-Yan channel at the LHC can be broken by a new Moller-scattering experiment proposed at Jefferson Laboratory. This study also identified an alternative to the standard fit of the resonance peak for extracting the Z' width. A simultaneous fit of on- and off-peak data to the possible Z' parameters gives an extraction of the width with errors comparable to the standard procedure and which is less dependent on experimental resolutions.
- Z' bosons often appear as messengers which connect the Standard Model to hidden sectors, such as in models of supersymmetry breaking and in Hidden Valley models, and can decay to light particles in this hidden sector. Measurement of the invisible Z' width can shed light on the hidden sector spectrum. Petriello, postdoctoral researcher Zurek and graduate student Quackenbush demonstrated that invisible decays of the Z' can be detected at the LHC using the channel $pp \rightarrow ZZ' \rightarrow l^+l^- \cancel{E}_T$. The structure of this cross section admits a simple parametrization using two effective charges, associated with emission of the Z boson from either initial state quarks or final state neutrinos. This allows invisible Z' decays to be studied in a model-independent fashion. Assuming that the only invisible decays of the Z' are to Standard Model neutrinos, these charges are predicted by the Drell-Yan study described above. Any deviation would indicate Z' couplings to light hidden sector states. Hidden sector decays making up 20-30% of the total invisible width can be observed at the LHC. Petriello, postdoctoral researcher Zurek, graduate student Quackenbush and Yuri Gerhstein, a member of D0 and CMS, extended this analysis to include mono-photon searches for invisible Z' bosons.
- Petriello and postdoctoral researcher Zurek studied whether spin-independent or dependent scattering of weakly-interacting massive particles (WIMPs) with nuclei can account for the annual modulation signal reported by the DAMA collaboration. They found that there is a region of WIMP parameter space which can simultaneously accommodate DAMA and the null results of other experiments. This region corresponds to an ordinary, elastically-scattering WIMP with a standard Maxwell-Boltzmann distribution, a mass $3 \text{ GeV} \leq m_{\text{DM}} \leq 8 \text{ GeV}$, and a spin-independent cross section with nucleons $3 \times 10^{-41} \text{ cm}^2 \leq \sigma_{\text{p}}^{\text{SI}} \leq 5 \times 10^{-39} \text{ cm}^2$. This new region of parameter space depends crucially on the effect of

channeling on the energy threshold for WIMP detection in the DAMA experiment; without the inclusion of this effect, the DAMA allowed region is essentially closed by null experiments. Future experiments with low energy thresholds for detecting nuclear recoils will be able to probe the DAMA region of parameter space. Recent results from the CoGeNT experiment indicate a potential signal consistent with this region.

- Petriello and Zurek extended the previous analysis to consider constraints arising from dark matter annihilation in the Sun. This process predicts a neutrino flux that was searched for and not found by the Super-K collaboration. The resulting constraints impose severe restrictions on the properties of any dark matter candidate which explains DAMA.
- An interesting scenario of physics beyond the Standard Model (SM) is the possibility of a scalar sector containing more than the single Higgs doublet of the SM. Scalars transforming as $(\mathbf{8}, \mathbf{2})_{1/2}$ under the SM gauge group automatically have fermionic couplings proportional to the SM Yukawa structure, and do not lead to dangerous flavor-changing neutral currents. Color-octet scalars also potentially provide a window to high scale physics. Grand unified theories based on $SU(5)$ contain these states. Measuring the properties of this scalar may test one of the fundamental predictions of grand unified theories, that of bottom-tau Yukawa unification. Petriello, postdoctoral researchers McElmurry and Fileviez Perez, and graduate student Gavin showed the production of the associated production of color-octet scalars with top quarks could be observed above background at the LHC and could be used to determine the high-scale theory from which they arose.

Current and planned research directions

- Fixed-order calculations provide precise predictions for fairly inclusive quantities. For measurements in which several widely separated scales are constrained, large logarithms formed from the ratios of these scales can overwhelm the suppression from α_s at each order in perturbation theory. Such terms must be resummed to all orders in α_s to derive an accurate prediction for these observables. Petriello and postdoctoral researcher Mantry studied the resummation of low- p_T logarithms in the context of soft-collinear effective theory, using Higgs production as an example. They derived a factorization theorem for the Higgs boson p_T and rapidity distributions at hadron colliders. In addition to the factorization of the various scales involved, the perturbative physics at the p_T -scale was further factorized into two collinear impact-parameter Beam Functions (iBFs) and an inverse Soft Function (iSF). These newly defined functions are of a universal nature for the study of differential distributions at hadron colliders. Large logarithms of the relevant scales in the problem can be summed using the renormalization group equations of the effective theories directly in momentum space. This avoids the need to introduce a prescription for non-perturbative QCD at moderate transverse momenta, an issue that affects the standard approach to low- p_T resummation. Power corrections to the factorization theorem are suppressed by p_T/m_h and Λ_{QCD}/p_T and can be systematically derived.

Mantry and Petriello plan to extend this analysis. They are currently studying both the gluon and quark iBFs more thoroughly, and are including the mixing between them. This will allow for the study of Higgs and electroweak gauge-boson p_T -distributions to next-to-leading logarithmic (NLL) accuracy. They will then extend the calculation of the iBFs and iSFs to higher orders, which will permit an NNLL+next-to-leading order (NLO) study of

transverse momentum distributions at colliders with a clear separation between perturbative and non-perturbative effects.

- The fully differential W and Z production cross sections are needed to provide a percent-level partonic luminosity monitor at the LHC. Petriello has previously calculated the next-to-next-to-leading order (NNLO) QCD corrections to the fully differential cross section, and released the numerical program FEWZ for use in experimental simulations. Together with graduate students Gavin and Li, he is implementing several improvements to this code. The new version will allow for arbitrary differential histograms to be obtained with a single run of the program, and will automatically calculate the PDF errors on all observables. The integration routines will be improved and optimized for running on computer clusters. The new FEWZ, together with new phenomenological predictions for NNLO Z production at the LHC, will first be presented by Gavin at the 2010 Brookhaven Forum.

This calculation must also be combined with the $\mathcal{O}(\alpha)$ electroweak corrections. Petriello and graduate students Gavin and Li are working to merge NNLO QCD and NLO electroweak corrections to W and Z production.

- The Tevatron exclusion limit on Higgs production severely constrains forms of new physics which increase the predicted Higgs cross section. Petriello has initiated a study of the implications the Tevatron limit has for various forms of new physics. He began by studying the effects of color-octet scalars in the $(\mathbf{8}, \mathbf{1})_0$ representation on gluon-fusion induced Higgs production. He derived the NNLO Wilson coefficient which describes the effect of both the scalar and the top-quark on the Higgs-gluon effective interaction, and explained an interesting technical aspect associated with the quartic-scalar potential. The inclusion of the NNLO corrections is absolutely necessary to reduce the theory errors sufficiently to distinguish the scalar-induced cross section from the Standard Model result. A renormalization-group analysis was performed to map out the theoretically allowed region of parameter space, and phenomenological results for both the Tevatron and the LHC were presented.

The Tevatron collaborations have very recently released an exclusion limit on the $gg \rightarrow h \rightarrow WW$ production mode. This allows bounds on new particles which shift this mode to be easily obtained. Petriello is currently deriving the Tevatron bounds on the parameter space of color-octet scalars and other new colored states. Preliminary results indicate that the constraints are competitive with direct search limits, albeit slightly more model-dependent. Together with postdoctoral researcher Trenkel, he is extending the calculation of the NNLO Wilson coefficient to models with a more complicated scalar potential, and is also developing a two-step matching procedure which simplifies the calculation when the mass of the new state is sufficiently heavier than the top-quark mass.

- Together with postdoctoral researcher Trenkel and graduate student Gavin, Petriello is studying the effect of Standard-Model extensions on the standard-candle $pp \rightarrow Z \rightarrow l^+l^-$ at the LHC. Several proposed new states shift the gg partonic channel at the LHC, and may lead to significant deviations from Standard-Model predictions.

F. Research of Postdoctoral Scholars

Our current postdoctoral scholars supported on Task G are Ian-Woo Kim and Sogee Spinner, who are both working on collider physics and physics beyond the Standard Model, and Maike Trenkel, who is working on collider physics and QCD. In addition to their joint work with the faculty, they are actively pursuing independent research projects, as summarized below.

Research of Dr. Ian-Woo Kim

- K. Choi, I. W. Kim and C. Shin, “Warped Gauge Threshold Corrections,” Invited review to Focus Issues in New Journal of Physics, [arXiv:1001.1473 \[hep-th\]](#).
- W. S. Cho, J.-H. Huh, I. W. Kim, J. E. Kim and B. Kyae, “Constraining WIMP magnetic moment from CDMS II,” *Phys. Lett. B* **687**, 6-10 (2010), [arXiv:1001.0579 \[hep-ph\]](#).
- I. W. Kim, “Algebraic Singularity Method for Mass Measurement with Missing Energy,” *Phys. Rev. Lett.* **104**, 081601 (2010), [arXiv:0910.1149 \[hep-ph\]](#).

Kim’s current research focuses on finding general systematic methods of determining masses and spins at the LHC and exploring the phenomenology of theoretically preferred models. For mass and spin determination, Kim’s main focus is to apply the algebraic singularity method he developed for missing mass measurements to the minimal missing energy topology at the LHC. With Cheng of UC Davis, Wang of Princeton, and Z. Han of Harvard, Kim is studying spin determination in SUSY-like cascade decays using event reconstruction. In future work, he plans to apply the techniques he has developed to the question of distinguishing between new physics models at the LHC, either using spin measurement techniques or by determining model parameters such as gaugino mass ratios and gluino-to-squark mass ratios.

Research of Dr. Sogee Spinner

- P. Fileviez Perez, S. Spinner, “TeV Scale Spontaneous R-Parity Violation”, *AIP Conf. Proc.* 1200:529-532, 2010 [arXiv:0909.1841 \[hep-ph\]](#).
- P. Fileviez Perez, H. Iminniyaz, G. Rodrigo, S. Spinner, “Gauge Mediated SUSY Breaking via Seesaw,” submitted to *Phys. Rev. D.*, [arXiv:0911.1360 \[hep-ph\]](#).

In collaboration with Barger, Fileviez Perez, and G. Shaughnessy, Spinner is studying the phenomenology of his minimal gauged $U(1)_{B-L}$ model. The Z' can decay into sneutrinos which then have lepton flavor violating decays which could lead to spectacular signals such $e\mu e\mu$ or $e\tau e\tau$. With Fileviez Perez, Spinner is surveying SUSY breaking scenarios which may provide a negative mass squared for the right-handed sneutrino, and thus would be consistent with the R-parity violation mechanism described above.

Research of Dr. Maike Kristina Trenkel

- J. Germer, W. Hollik, E. Mirabella, and M. K. Trenkel, “Hadronic production of squark-squark pairs: The electroweak contributions,” [arXiv:1004.2621 \[hep-ph\]](#).

With J. Germer, W. Hollik, and E. Mirabella, Trenkel has been considering squark–anti-squark, stop–anti-stop, gluino–squark, gluino–gluino and squark–squark production processes and calculated the tree-level and next-to-leading order cross section contributions of electroweak origin. It is planned to round off this work by addressing the NLO EW corrections to sbottom–anti-sbottom production and to provide a comparative study of the various processes and their electroweak contributions.

IMPACT OF RESEARCH AND SERVICE

- **Training of Phenomenology Researchers.** Institute Faculty have trained 102 PhDs and 70 Postdocs in phenomenology since 1967. 50% of the graduate students and 74% of the postdocs now hold academic or laboratory positions in physics, with 44% of the graduate students and 65% of the postdocs in particle physics positions.

Our recent postdocs and students have been very successful. In fall 2008, our postdoc Patrick Huber became a faculty member at Virginia State University. Our postdoc Kathryn Zurek became a Schramm Fellow at Fermilab in fall 2008, and joined the faculty at the University of Michigan in fall 2009. Our postdoc Devin Walker was selected as a Presidential Fellow at UC-Berkeley in 2007. Our postdoc Thomas McElmurry went on to a postdoctoral position at Brookhaven in fall 2009. Our current postdoc Ian-Woo Kim will begin a postdoctoral position at the U. of Michigan in fall 2010. Petriello's student Seth Quackenbush became a postdoc at Argonne in fall 2009. Barger's student Gabe Shaughnessy became a postdoc at Argonne/Northwestern in fall 2008, and his students Yu Gao and Mat McCaskey begin postdocs at the U. of Oregon and the U. of Kansas in fall 2010, respectively. Han's students Kai Wang and Guiyu Huang began postdocs at IPMU and UC Davis in fall 2008, respectively.

The Institute has an impressive record in the training of women physicists, with all seven of our former women postdocs now in tenured or tenure-track faculty positions.

A remark in a letter sent to us from Keith Ellis, former Fermilab Theory Group Head, underscores the very important role that the Institute has in the training of phenomenology researchers: "I wanted to write to you to express the importance which we at Fermilab attach to the existence of a high quality phenomenology group in Madison. As well as the feeling of solidarity which comes from having kindred spirits close by, there is also the matter of the training of students with an interest in particle physics which relates to experiment. As you know, one can count on the fingers of one hand the U.S. universities that train students who we can hire as post-docs."

- **Research Collaborations.** Our research is characterized by an extensive network of collaborations with physicists at other universities, institutes, and laboratories. We regularly host visiting theorists on sabbaticals. Our recent long-term visitor roster includes Howard Baer, Oscar Eboli, Kaoru Hagiwara, Gordon Kane, C.-S. Kim, Wai-Yee Keung, Paul Langacker, Danny Marfatia, Kirill Melnikov, Biswarup Mukhopadhyaya, Zong-Guo Si, Marc Sher, Jeonghyeon Song, Xerxes Tata, Lian-Tao Wang, and Bin Zhang. We also maintain a continuous flow of short-term visitors for seminars and collaborative work. Han has a grant from China to conduct collaborative research on collider physics, and holds a Lecturing professorship in TsingHua University, Beijing. He has advised the ITP, KITP-C and the Chinese government on future research in particle physics.

- **Relationship to Experimental Groups.** Our research provides ongoing support to experimental groups, in consultation about new theoretical ideas and providing computer program packages for data analyses. We have provided theoretical support to the ATLAS, CMS, CDF, D0, H1, ZEUS, NLC, Neutrino Factory, IceCube, and Muon Collider collaborations. Recent examples of our assistance concerned the Little Higgs model, next-to-leading order corrections to Higgs production in WW fusion and for tH^\pm at the LHC, and next-to-

next-to-leading order calculations for Higgs and electroweak gauge boson production at the Tevatron and the LHC. Han has been closely involved with the LHC Physics Center (LPC) at Fermilab, and has had CMS internal publications. Barger has written theory summaries of major experimental working group reports on neutrino factories, muon colliders, and superbeams. Petriello maintains several QCD simulation tools used by experimentalists to understand theoretical predictions and uncertainties for both Tevatron and LHC analyses. He was recently appointed the gluon-fusion theory convener of a joint ATLAS-CMS-theory working group on Higgs cross sections at the LHC.

- **Support of CTEQ Summer Schools.** Han and Petriello hosted and co-organized the 2007 and 2009 CTEQ summer schools on QCD analysis and phenomenology at UW-Madison. Roughly 80 graduate students (theorists and experimentalists) high energy from around the world attended each of these schools. Many students came from geographic areas, especially in South America, traditionally underrepresented in physics. Several leading researchers in the fields of QCD and collider physics presented lectures at these schools, including George Sterman, the 2003 Sakurai prize winner, and Chris Hill, the head of the Fermilab theoretical physics division. Student response was overwhelmingly positive. More information on the school can be found at <http://www.cteq.org/>.

- **Institute-Sponsored Symposia.** Over the last 20 years we have sponsored 29 symposia and workshops. The annual Pheno symposia (<http://www.pheno.info/symposia/>) provide an important venue for talks by young physicists and for interactions with senior theorists and experimentalists. The number of participants has increased from 135 in 2003 to 261 in 2009, of which many are junior researchers. The symposia have the largest student participation of US HEP meetings, including popular schools like TASI and SLAC summer schools.

- **Conference Organizing.** Petriello hosted and co-organized the conference “LoopFest VIII: Radiative corrections for the LHC and ILC” at the UW-Madison from 7-9 May 2009. LoopFest is a major international conference series that brings together leading researchers in the fields of QCD, precision quantum field theory and collider physics from around the world to discuss the theoretical challenges posed by the unprecedented experimental precisions of the LHC and a future linear collider. It is the premier conference focusing on precision quantum field theory in the United States. More information on LoopFest can be obtained from the web site <http://www.hep.wisc.edu/Loopfest/>.

- **Invited Talks.** Institute faculty have given over 130 invited conference talks, seminars and colloquia over the past three years, while the current group postdocs have given 33 conference talks and seminars during their time at the UW-Madison.

- **Indicators of Research Quality.** Over the past 3 years, Institute faculty have authored 133 research publications. One measure of the impact of our research is the high number of citations of our publications. According to the SPIRES database, V. Barger ranked no. 11 of top-cited theory authors in 2004 over the preceding 5 years. His papers have received about 23,100 citations, with 8 published papers with more than 250 citations and 48 with more than 100 citations. Everett’s works have 1960 citations, with 6 papers over 100 citations. Halzen’s works have received over 11,200 citations, with 20 papers over 100 citations. Han’s papers have over 11,800 citations, with 16 papers over 100 citations and two over 500 citations. Petriello’s papers have received over 1990 citations, with 5 papers over 100 citations.

FACILITIES AND RESOURCES STATEMENT

Computing Facilities

The Institute has state-of-the-art computing facilities based on a cluster of 25 networked Linux workstations and 4 Apple Mac workstations provided by UW-Madison funding. Each faculty member, postdoc, graduate student and visitor has an individual workstation. In addition, Institute computers are networked with the UW-Madison CONDOR Linux cluster of 700 CPUs and the Grid Laboratories of Wisconsin has 700 Linux CPUs. We have made extensive use of the CONDOR cluster in our Monte Carlo simulations relevant to LHC physics and cosmology.

Research Areas of Current Postdocs and Graduate Students

Postdoctoral Scholars

Neil Christensen	Collider physics
Ian-Woo Kim	Collider physics, Beyond the Standard Model
Sonny Mantry	QCD, Effective field theory
Sogee Spinner	Collider physics, Beyond the Standard Model
Maike Trenkel	QCD, Collider physics

Graduate Students

Zhe Dong	Collider physics
Yu Gao	Dark energy, Beyond the Standard Model
Camilo Garcia	Collider physics
Ryan Gavin	QCD, Collider physics
Peisi Huang	Collider physics
Ian Lewis	Collider physics
Zhen Liu	Collider physics
Mathew McCaskey	Collider physics, Beyond the Standard Model
Aongus O'Murchadha	Astroparticle physics
Valerie Plaus	Beyond the Standard Model
Yongyan Rao	Beyond the Standard Model
Jared Schmittehenner	Collider physics
Alex Stuart	Beyond the Standard Model
Zhihui Wang*	Collider physics
Brian Yencho	Collider physics, Dark matter
Ye Li	QCD, Collider physics
Chiu-Tien Yu	Collider physics

* exchange student

CURRENT & PENDING SUPPORT STATEMENT

The University has made major ongoing financial contributions in support of the Institute program. These contributions include support in the following categories:

- Named professorship and distinguished faculty grants: Institute faculty hold several named professorships and faculty awards. Barger is a University Vilas professor, while Halzen is a Hilldale professor. Han is a Romnes faculty fellow and he won a Vilas Associate award.
- Faculty salaries for research and research leaves of absence.
- Start-up funds for new faculty.
- Capital funds for computers.
- Funding for visitors.

Petriello received an Alfred P. Sloan Foundation Research Fellowship, and was selected as an Outstanding Junior Investigator by the DOE in 2007.

Institute faculty have also received support from Fermilab, Argonne, and CERN for research leaves. Petriello received salary support during the spring 2010 semester from Argonne.

**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**
 Institution Name University of Wisconsin - Madison
 Task/Title **Task G: Phenomenology**

Type of Position	Name	Activity #1	FTE Months on Phenome nology Research	# months funded by DOE-HEP University Program Phenome nology	Faculty Advisor
Faculty	Barger, Vernon	Phenomenology	2	2	
Faculty	Everett, Lisa	Phenomenology	2	2	
Faculty	Han, Tao	Phenomenology	2	2	
Faculty	Petriello, Frank	Phenomenology	2	2	
Post Doc	Spinner, Sogee	Phenomenology	12	12	Barger
Post Doc	Christensen, Neil	Phenomenology	12	0	Han
Assist. Scientist	Fileviez Perez, Pavel	Phenomenology	12	12	Han
Post Doc	Mantry, Sonny	Phenomenology	3	0	Petriello
Post Doc	Trenkel-Lenz, Maike	Phenomenology	12	12	Petriello
Grad Student	Huang, Peisi	Phenomenology	3	3	Barger
Grad Student	McCaskey, Mathew	Phenomenology	3	3	Barger
Grad Student	Yencho, Brian	Phenomenology	7.5	7.5	Barger
Grad Student	Yu, Chiu-Tien	Phenomenology	12	0	Barger
Grad Student	Plaus, Valerie	Phenomenology	7.5	7.5	Everett
Grad Student	Rao, Yongyan	Phenomenology	7.5	7.5	Everett
Grad Student	Stuart, Alex	Phenomenology	7.5	7.5	Everett
Grad Student	Dong, Zhe	Phenomenology	7.5	7.5	Han
Grad Student	Garcia, Camilo	Phenomenology	3	3	Han
Grad Student	Lewis, Ian	Phenomenology	7.5	7.5	Han
Grad Student	Liu, Zhen	Phenomenology	3	0	Han
Grad Student	Schmitthenner, Jared	Phenomenology	3	3	Han
Grad Student	Gavin, Ryan	Phenomenology	7.5	7.5	Petriello
Grad Student	Li, Ye	Phenomenology	7.5	7.5	Petriello
Secretary	Dolan, Linda	Phenomenology	12	0	Barger
Administration	Lefkow, Aimee		1.36	1.36	

Neil Christensen is supported on an LHC Theory Fellowship funded through Johns Hopkins (NSF).

Sonny Mantry is supported by Petreillo's Sloan Fellowship and DOE Nuclear.

Chiu-Tien Yu received an NSF GSRP Fellowship.

Zhen Liu is supported by Univeristy funds for summer FY11.

Linda Dolan is supported by the College.

- TASK H -
STUDY OF ELECTROWEAK INTERACTIONS AT CERN (ATLAS AT LHC)

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SECTION 1: INTRODUCTION AND HIGHLIGHTS

PI Sau Lan Wu started this task (Task H) in 1977 when she joined Wisconsin as an assistant professor. In 1974, she was a postdoc at M.I.T. and she was one of the authors of the experiment which led to the discovery of the J/ψ particles at Brookhaven, providing first evidence of the charmed quark and a Nobel Prize for its team leader in 1976. After our very successful physics program in the TASSO experiment at PETRA, DESY (1977-1989), the ALEPH experiment at LEP, CERN (1980-2001), and the BaBar experiment (1995-2007), our present activities focus on the ATLAS experiment (1993-present). We were the first American Group to join ATLAS. The work at TASSO has led to Sau Lan Wu's sharing of the 1995 High Energy and Particle Physics Prize of the European Physical Society "for the first evidence for three-jet events in e^+e^- collisions at PETRA," which gives the first direct observation of the gluon. A year later in 1996, Wu was elected Fellow of the American Academy of Arts and Sciences.

1.1 THE ATLAS EXPERIMENT. In the fall of 2000, the first possible evidence of a Higgs boson signal at $115 \text{ GeV}/c^2$ in ALEPH, which drew so much public attention, is largely the work of our Wisconsin group. The final state observed was four jets and the ALEPH published significance was 3σ . One of the exciting prospects for the LHC (Large Hadron Collider) at CERN is to confirm or reject this observation. The Higgs boson is the particle which is responsible for the mass of all matter and is the centerpiece of the Standard Model, a model which has enjoyed tremendous success. For over twenty years since working in the ALEPH collaboration, Sau Lan Wu has chosen the search for the Higgs boson to be the primary challenge for her and members of the Wisconsin group. The Higgs boson is one of the most compelling reasons for constructing the LHC at CERN. In September 1993, our group joined the ATLAS collaboration at LHC. ATLAS consists of more than 150 universities and laboratories in 35 countries and we were the first American group to join the collaboration. Our contribution to ATLAS focuses on:

1. We are fully responsible for the design and production of the Read-out Driver (ROD) system for pixel and silicon strip detectors. We started this effort in 1994.
2. We play a leading role in the design, development, implementation and commissioning of the ATLAS High Level Trigger. Again, we started this effort in 1994.
3. We have been making a vigorous effort to contribute to the ATLAS computing operations.
4. We are making important contributions to detector performance studies and software development in ATLAS.
5. For a number of years, our group has played a leading role in the ATLAS Higgs studies. Our main goal is to continue our leadership in the observation of the Higgs at the LHC. From 2007 to present we have expanded our physics horizon to SUSY, Exotic particle searches and Standard Model processes.

1.2 PHYSICS FOCUS: Our physics preparation and studies focus on the following topics:

1. Higgs bosons covering all important decay channels: $H \rightarrow WW$, $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$, $H \rightarrow \tau\tau$
2. Inclusive SUSY searches with leptons, missing transverse energy and jets. This signature has enormous discovery potential in 2010-2011 with integrated luminosity as low as 20 pb^{-1} .

3. Exotic particles – Z' , W' , diphoton resonance (graviton), TeV-Scale Gravity induced effects (Black Holes and String Balls) and di-jet resonances.
4. Early data with Standard Model processes: signatures and cross-sections for W , Z , Z/W plus jets; jet transverse momentum spectrum.

1.3 STRATEGY: STRIVING TO MAKE IMPORTANT CONTRIBUTIONS TO THE SUCCESS OF ATLAS

1. Deliver successfully to ATLAS all the Read-Out Driver electronic components and its hardware and software functionality.
2. Successfully fulfill our commitment to the ATLAS High Lever Trigger at LHC turn-on and substantiate our efforts in its maintenance and operation.
3. Position ourselves to make important contributions to ATLAS for early discovery. We have at least one member of our group who has expertise and makes contributions to:
 - a. Electron identification (e/π rejection) and energy calibration – Assist. Scientist Flores
 - b. Photon identification (γ /jet rejection) and energy calibration – Y. Fang & H. Wang
 - c. Calorimeter-based Muon identification – Assistant Scientist Flores
 - d. Tau lepton reconstruction and identification – Assistant Scientist Vickey
 - e. High pt jet energy calibration – Grad. Student Ji
 - f. Missing transverse energy performance – Prof. Mellado and Postdoc Zhu
 - g. B-tagging – Grad. Student Asfandiyarov
 - h. Trigger – Zobernig and Postdoc Sarangi
 - i. Tier 3 computing – N. Xu, Prof. S.L.Wu and Grad students Carrillo and Asfandiyarov
 - j. Statistics tools – Postdoc Quayle
 - k. Monte Carlo event Generation – N. Xu, Grad students Carrillo and Asfandiyarov

1.4 CONTRIBUTION TO US ATLAS COMPUTING OPERATIONS AND PROTOTYPE FOR TIER-3. To prepare for the LHC physics data-taking era, our group needs to meet a series of fundamental computing challenges. In the past few years, we have been successfully collaborating with Professor Miron Livny of the Wisconsin Computer Science Department, Michael Ernst of Tier-1 at BNL, the PROOF (Parallel ROOT Facility) team at CERN, the ATLAS DDM (Distributed Data Management) team and our colleagues of the Wisconsin CMS Tier-2. The collaboration covers the area of data management, file transfer, session scheduling and system structure design. Our experience and our developed software position us as a powerful Tier-3 facility on the Wisconsin campus, fully operational at present to meet the incoming LHC data challenges.

1.5 ASPIRATION: The driving force behind this group is a compelling desire to produce physics results and it will be a great pleasure for us to participate in and to contribute to ATLAS early discovery of new particles and new phenomena. We believe that because the funding agents have supported this monumental LHC project, it is the duty of LHC physicists to produce ground-breaking and exciting physics results. Our group joined the ATLAS collaboration in 1993; after 17 years of preparation, our years of hard work will finally bear fruit.

1.7 EDUCATION: Education is one of our primary missions. Forty-eight graduate students have obtained their Ph.D. degrees from this task, including 10 theses from TASSO, 22 from ALEPH, 10 from BaBar, and six from ATLAS. Twenty-eight of our former postdocs and graduate students obtained professorships, most of which are at U.S. institutions, and so far 19 of them have been granted tenure. Ten of our former postdocs and graduate students received

permanent staff positions in national and international High Energy Physics laboratories. In addition, a number of our graduates have entered the workforce of well-known industries, serving the function of technology transfer.

1.8 INTEGRATION WITH MEMBERS OF VARIOUS PHYSICS WORKING GROUPS FROM OTHER ATLAS INSTITUTIONS. Although most of our Monte Carlo-based physics studies so far are largely from members of the Wisconsin group, we are fully integrated with members of various physics working groups from other ATLAS institutions and especially in the analysis of the incoming data.

SECTION 2: CONTRIBUTION TO ATLAS SILICON READOUT DRIVER

(Engineer Joseph, Prof S.L.Wu, Assist. Scientist Vickey, Grad. Students Chen, Pedraza and Stradling)

2.1. INTRODUCTION: The two major ATLAS detector subsystems closest to the interaction point are the Pixel Detector and the Semi-Conductor Tracker (SCT), with over 80 million and 6.2 million channels, respectively. They provide tracking information in the pseudo-rapidity region $|\eta| < 2.5$, and are used to tag secondary vertices from B -hadron decays. The silicon Read-out Driver (ROD) is a large VME board, which interfaces the Pixel Detector and SCT front-end electronics to the Level-2 Trigger, the data acquisition, and the run control systems.

Our involvement started in 1994, initiated and organized by Sau Lan Wu. In the early development stage of the ROD, the design proposed and advocated by our former postdoc Fasching was unanimously supported by the corresponding twelve-member review panel. Since then, we assumed major responsibility for the design, production, installation and commissioning of the Read-out Driver for these detectors, and long-term maintenance of the hardware and firmware on the ROD. There has been the misunderstanding that the Wisconsin Silicon ROD project is done by LBNL engineers; instead what has happened is that we have contracted them to help us. In fact, throughout the years, a number of our scientists, postdocs and graduate students have worked very hard, each for a number of years, on this project, for example, Assistant Scientist Vickey, Postdocs Ferguson and Fasching, Graduate Students Charles and Stradling.

2.2 THE PRODUCTION ROD: Each Pixel ROD collects data at 40 MHz from up to ~ 1.5 million individual pixels (or ~ 750 thousand pixels at 80 MHz or ~ 375 thousand pixels at 160 MHz) and each SCT ROD handles up to 74 thousand strips. There is a total of 260 RODs in the experiment (approximately 100 for the silicon strip detector and 160 for the pixel detector, including spares for each system). *Our group was responsible for delivering 100% of the Pixel and SCT ROD boards to the ATLAS Experiment*, a task that was successfully accomplished.

- a. SCT RODs.** Before 2007, our group provided prototype and production RODs to support SCT module testing, detector construction, reception testing at CERN and cosmic-ray commissioning runs. Since then, the Wisconsin group has delivered the *full complement of 100 production SCT RODs, all of which have been installed inside of the ATLAS counting room*, where they have performed extremely well.
- b. Pixel RODs.** Before 2007, our group sent RODs to various institutes to assist in the construction of Pixel barrel staves and in the assembly of the three Pixel Barrels at CERN, in addition to being used for the Pixel Endcap cosmic-ray commissioning run. Since then, we have sent the *full complement of Pixel RODs* to CERN where they have been installed into the ATLAS counting room and have performed extremely well.

2.3. WORK ON THE ROD SCT SOFTWARE AND PIXEL FIRMWARE FUNCTIONALITY:

Recent work by the Wisconsin Group on the production RODs focused on increasing the speed of the board during time-critical operations, adding new functionality necessary for calibrations and physics data-taking in addition to enhancing those features that were already available and making them more robust.

- a.* The use of data compression algorithms, to reduce the time required to transfer calibration data from the Slave DSPs to the Host, has been explored with the SCT and proven feasible.
- b.* To cope with the large numbers of SCT modules online in data-taking, module recovery and re-configuration tools have been developed and implemented. They allow the ROD to detect noisy or error-prone channels, mask them out and issue a soft reset for the corresponding module, which is brought back into the run at the beginning of the following luminosity block.

2.4 COSMIC-RAY COMMISSIONING RUNS WITH THE SCT AND PIXEL DETECTORS:

During 2007-2009, numerous cosmic-ray data-taking runs, unprecedented in their scale, proved to be crucial in debugging the data-path, exercising the DAQ chain, and serving as a detector shake-down while providing data for detector efficiency and alignment studies.

- a. The SCT Detector cosmic-ray data-taking runs.* The *production SCT RODs* and the *Wisconsin Group DSP software and FPGA firmware* played an indispensable role during the cosmic-ray data-taking runs involving the entire SCT detector.
- b. The Pixel Detector Endcap cosmic-ray data-taking runs.* The Cosmic data runs involved full Pixel Detector, *160 production Pixel RODs* and the *Wisconsin Group FPGA firmware*, have successfully recorded over a hundred million cosmic-ray events.

2.4. THE INSTALLATION PHASE AND ATLAS DATA-TAKING PHASE: During the detector installation phase, which began in 2006 and continued through most of 2007, our group played an active role in the routing of fiber-optics into the ROD racks, and performing acceptance tests in the ATLAS counting room and collision hall. Once our ROD's were integrated with the rest of ATLAS, several significant milestones were achieved: the entire SCT and Pixel detectors were used for the acquisition of cosmic-ray data and calibration. During the collision data-taking periods in 2009 and 2010, the entire SCT ROD and Pixel ROD were used for the acquisition of collision data, successfully recording more than 20 million events at the time of this writing. Members of our group contribute operation shifts of the SCT detector.

2.5 PUBLICATIONS: *From 2007 our group has published a total of 8 journal publications in collaboration with other ATLAS institutions.*

The list of the talks is given in (<http://wisconsin.cern.ch/a/ROD.html>)

SECTION 3: CONTRIBUTION TO THE ATLAS HIGH LEVEL TRIGGER (HLT)
(Engineers Dos Anjos, Wiedenmann and Zobernig, Prof. S.L. Wu, Assistant Scientist Flores)

In 1994, Sau Lan Wu initiated the Wisconsin efforts in this project and since then she has been managing and organizing its contribution. In ATLAS interesting physics processes are selected with a three-level trigger architecture. The fast hardware-based Level-1 trigger uses coarse-grained calorimeter and muon spectrometer information to achieve an output rate of about 75 kHz. Level-2 and Event Filter, the High Level Triggers (HLT), are implemented with software components and use data with full detector granularity for further rate reductions. The Level-2 trigger examines only detector data in Level-1-guided "Regions-of-Interest", while the Event

Filter uses full event data to reduce the 2 kHz Level-2 output rate by an additional factor of 10 before the events are transferred to permanent mass storage.

Since 1994, the early phase of the trigger project, Wisconsin has made important contributions to the definition of the overall High Level Trigger selection strategy, its hardware and software architecture and its final implementation, commissioning and operation. We have taken responsibility for key software components and continue to make important contributions to the implementation, testing and operation of the ATLAS High Level Trigger.

3.1 CONTRIBUTIONS TO THE HIGH LEVEL TRIGGER CORE SOFTWARE

Within the ATLAS TDAQ M&O Support, Wisconsin is responsible for the maintenance and the operational support of the:

- a. ATLAS Event Format Library.* This library represents the ATLAS raw data format and is of crucial importance for the detector readout.
- b. HLT Application Control Framework.* The Data Flow Application Control Framework provides the run control interface for the HLT applications.
- c. HLT Event Selection Framework.* The HLT framework constitutes the basic HLT selection code environment in online and provides common algorithm interfaces to the Level-2, the Event Filter, and the offline environments.
- d. HLT Integration Tools.* Wisconsin provides the emulators for testing HLT applications, for reprocessing data with trigger information in the “Calibration and Analysis Facility” and the tools for generating the ATLAS data taking configurations.

The work described above is reflected in the *specific milestones Wisconsin achieved in the period from 2007 to 2009. They are defined in the MoU for the years 2007 to 2010.*

Major software enhancements to the above components included e.g. a complete Python scripting interface to the Event Format Library with testing and debugging tools for raw data files. The HLT Event Selection Framework was integrated with the ATLAS trigger configuration database, with the muon calibration infrastructure and with the ATLAS event routing and streaming setup. The possibility to switch on and off trigger selection chains and to change their pre-scales in the HLT framework without reconfiguring the system provided a major improvement for online operations. In addition special framework services were created which serve directly from the ATLAS online information system conditions data to the HLT selection algorithms.

3.2 TRIGGER COMMISSIONING AND LHC DATA TAKING

All components provided by Wisconsin have been successfully used for detector specific readout and commissioning periods and for ATLAS data taking. For commissioning the TDAQ/HLT software and hardware members of the Wisconsin group actively participated in “TDAQ Technical Run Weeks” and “TDAQ 24 Hour Test Periods” with shifts and organizational support. The Level-2 HLT farm processors were entirely commissioned under Wisconsin’s supervision with our testing tools. From the very beginning of data taking with cosmics and LHC beams our HLT framework components were configured in the readout and proved their versatility. Our HLT emulator applications are used routinely to test new selection algorithms and to optimize the online HLT selection menus. The same applications are furthermore used to monitor specific detector components and to reprocess events with trigger information.

3.4 LEADERSHIP AND CONTRIBUTIONS TO ATLAS TRIGGER WORKING GROUPS

Members of our group play key roles in the coordination of the trigger project and lead trigger-wide working groups. These working groups consist of specialists and their leaders are appointed by the trigger management or the trigger institutes board.

- a. Dos Anjos has been appointed as co-leader of the event format working group and coordinates the Dataflow Evolution project.*
- b. Wiedenmann is a member of the Trigger Coordination Group and is the coordinator of the High Level Trigger Applications working group.*
- c. Zobernig is a member of the Trigger Coordination Group and is the coordinator of the Level-2 working group.*
- d. Zobernig was from 2005 to 2009 member of the ATLAS TDAQ Speakers Committee and chaired the committee from 2007 to 2009.*

3.6 PUBLICATIONS, ATLAS DOCUMENTS, TALKS (SEPTEMBER 2007 - MARCH 2010):

- a. Presentation at conferences and workshops, 7 in total (<http://wisconsin.cern.ch/a/HLT.html>)*
- b. Publications in Journals, 3 in total (<http://wisconsin.cern.ch/a/HLT.html>)*
- c. Presentations in ATLAS working groups, 44 in total (<http://wisconsin.cern.ch/a/HLT.html>)*

SECTION 4: CONTRIBUTION TO US ATLAS COMPUTING OPERATIONS AND PROTOTYPE FOR ATLAS TIER-3

4.1 CONTRIBUTION TO THE PROPOSAL “US ATLAS TIER 3 TASK FORCE”

Prof. Mellado participated in the writing of the proposal “US ATLAS Tier 3 Task Force”

4.2 CONTRIBUTION TO US ATLAS COMPUTING OPERATIONS

(Soft. Engineer Neng Xu, Grad. Student Carrillo, and Prof. S.L. Wu)

In the past few years, we have been successfully collaborating with Professor Miron Livny (Condor team) of the Wisconsin Computer Science Department, Michael Ernst of ATLAS Tier-1 at BNL, the PROOF (Parallel ROOT Facility) team at CERN, the ATLAS DDM (Distributed Data Management) team and our colleagues of the Wisconsin CMS Tier-2. Our experience and our developed software will be valuable to other US ATLAS Tier-3 facilities. Our contribution can be seen from the following topics.

- 1. Data management.** We work in close collaboration with the PROOF team at CERN and the ATLAS DDM team on a new local data management system. To manage the data more efficiently, our group developed tools for file cataloguing, space management and disaster recovery. These tools allowed us to build a multi-layer and multi-site storage system.
- 2. File Transfer System (FTS).** The data transfer channel between BNL (Tier-1) and our storage element in Wisconsin was built through our collaboration with BNL and the CERN DDM team. The average transfer speed was increased from 2 MB/s to 400 MB/s due to our development and testing of the BestMan/Xrootd system.
- 3. Integration of the US ATLAS PANDA system with our Wisconsin computing pool.** We have collaborated closely with the Wisconsin Condor team on the development of the “Condor glide-in” technology and a multi-layer Condor system, which have been integrated into the US ATLAS PANDA production system. We have also successfully contributed to the US ATLAS PANDA Monte Carlo production.

SECTION 5: CONTRIBUTION TO DETECTOR PERFORMANCE STUDIES AND SOFTWARE DEVELOPMENT IN ATLAS

Our vigorous effort in the physics program of ATLAS requires that we also make significant contributions to detector performance studies. Our group has acquired expert-level knowledge of and is making strong contributions to the most relevant aspects of the ATLAS detector performance in collaboration with other institutions. Our group is also contributing to define data-driven approaches to the calibration of the detector.

5.1 MISSING TRANSVERSE MOMENTUM RECONSTRUCTION– THE OBJECT-BASED METHOD (Profs. S.L.Wu, Pan and Mellado, Assist. Scientist Flores and Grad. Student X. Chen)

Our group has accumulated expertise in several areas of the ATLAS detector subsystems performance, and has made contributions to the reconstruction of the corresponding physics objects. As a result, we are in a good position to contribute to the reconstruction of the overall missing transverse momentum. The object-based algorithm is integrated into the ATLAS missing transverse momentum software package.

- Chen, Mellado, Pan, SL Wu, “Calculation of MET Significance at ATLAS”, ATL-COM-PHYS-2008-089

5.2 SUPPRESSION OF FAKE MISSING TRANSVERSE ENERGY FROM COSMIC RAYS (Profs. S.L. Wu, Pan and Mellado, Postdocs Zhu, Peng)

Large energy depositions arising from muons produced by cosmic rays are a significant potential source of fake missing transverse energy. We study the characteristics of fake jets in cosmic-ray muon data recorded in 2008 and 2009. A log-likelihood ratio tool based on jet variables is developed to distinguish the fake jets from real jets.

- Zhu, Mellado, Peng, S.L. Wu, Assamagan (BNL), Valls (Valencia), “Suppression of Fake Missing Transverse Energy from Cosmic Ray Muons in the ATLAS Calorimeter,” ATL-COM-PHYS-2010-054 and ATL-PHYS-INT-2010-028

5.3 HADRONIC AND IN-SITU HIGH PT JET ENERGY CALIBRATION: (Postdoc Poveda and Grad. Student Ji)

The correct calibration of the very high p_T jet is a key element in the Standard Model jet physics results. Our group is involved in the data-driven calibration and resolution of high- p_T jets with the multijet balance method. In this method, high- p_T jets are calibrated by comparison with recoil formed by several lower- p_T jets which are already calibrated with the γ -jet method.

5.4 ELECTRON CALIBRATION: (Assist. Scientist Flores)

In 2007-2008, our group has developed one of the multiple calibration techniques which has been adopted by the ATLAS collaboration as a baseline for electron calibration for various clusterization schemes. Working together with Sheffield and BNL, we provided the electron calibration constants used in the ATLAS reconstruction software in 2008.

5.5 PHOTON CALIBRATION AND IDENTIFICATION: (Postdoc Fang)

A calibration technique, similar to the one proposed for electrons, has been developed for photons by our group. Extreme care has been taken to calibrate converted photons. As a result, we obtain the best Higgs mass resolution in $H \rightarrow \gamma\gamma$ in ATLAS. Our group has developed a new and more powerful technique to suppress fake photons. We also actively check the calibration and identification techniques using 2009 collision data. The calibration constants produced by our group are used in the $\text{Pi}0$ analysis and 13 official photon identification performance plots included in the first ATLAS performance paper.

- *Abreu, H. et al. "Electron and Photon Reconstruction and Identification Results from ATLAS at 900 GeV," ATL-COM-PHYS-2010-172 (2010).*

5.6 PHOTON PURITY: (Postdoc Fang)

We have proposed a subtraction method to estimate photon purity. The result has been included in a photon purity ATLAS note (in preparation) and will be on the official methods to be used with early data.

5.7 CALORIMETER-BASED MUON IDENTIFICATION: (Assist. Scientist Flores)

Our group has pioneered a calorimeter-based muon identification technique in ATLAS based on the combination of longitudinal and transverse profile information of energy depositions in all the calorimeter systems (both electromagnetic and hadronic). This is crucial for recovering muons in regions where the muon chambers have a reduced efficiency; as a result, tails in the missing E_T reconstruction are reduced by almost an order of magnitude. In collaboration with NIKHEF, Netherlands, we added this Analysis Object Data collection to the ATLAS software.

5.8 TAU RECONSTRUCTION AND PERFORMANCE: (Assist. Scientist Vickey).

In the context of the MSSM, Higgs bosons could be quite massive (≈ 500 GeV). The identification of hadronic taus produced from such massive particles must be specially tuned. In collaboration with other institutions we were the first in ATLAS to develop identification criteria for these high p_T hadronic taus.

- *P. Beachtle et al., "Reconstruction and Identification of Hadronic Decays," ATL-PHYS-PUB- 2009-017; ATL-COM-PHYS-2009-113 (2009).*

5.9 MONTE CARLO PRODUCTION: (Programmer Xu, Grad. student Asfandiyarov)

Our group contributes to the production of fully simulated Monte Carlo events used by ATLAS for physics feasibility studies. We have produced tens of millions of Monte Carlo events which were added to the central production pool to increase statistics.

SECTION 6: CONTRIBUTION TO ATLAS HIGGS PHYSICS WORKING GROUP

From 2007 to April 2010, we gave **255** talks in Higgs working groups.

The list and content of the talks are given in (<http://wisconsin.cern.ch/physics/t.html>).

Since our earliest involvement with the ATLAS experiment, the search for the Higgs boson has been at the center of our research efforts. Our work in this area has always emphasized the development of new strategies to extract the Higgs boson signal and estimate the relevant backgrounds using background-enriched regions of phase space. This emphasis still features prominently in our current work, and now, in the data-taking era, it is complemented by an effort to adapt the Higgs boson searches to the conditions expected in the early data. Our work in the area of Higgs boson searches spans a wide variety of Higgs boson final states:

6.1. STUDIES OF HIGGS WITH $H \rightarrow WW$ ASSOCIATED WITH 0, 1 OR 2 HIGH P_T JETS (Profs. S.L.Wu and Mellado, Postdocs Fang, Quayle, Grad. Students Asfandiyarov and Carrillo).

Postdoc Quayle was co-editor of the contribution to CERN-OPEN-2008-020 (the CSC book) on $H \rightarrow WW$ channel. Prof. Mellado is currently the convener of the ATLAS $H \rightarrow WW$ subgroup.

- 1. STUDIES AT 14 TeV.** Higgs to WW is the most promising channel for Standard Model Higgs boson searches in the early data. Our group has a long history of leadership in this channel, developing detailed strategies to measure the various backgrounds using control

samples and fits. Our work on cut-based and fit-based analyses of the $H+0$ jets and $H+2$ jets (where $H\rightarrow WW\rightarrow l\nu l\nu$ and $H\rightarrow WW\rightarrow lvqq$) channels featured prominently in the Higgs boson physics section of the *CSC book* (“Expected performance of the ATLAS experiment: detector, trigger and physics”), CERN-OPEN-2008-020 (<http://cdsweb.cern.ch/record/1125884>).

- *The ATLAS Collaboration*, “Higgs Boson Searches in Gluon Fusion and Vector Boson Fusion using the $H\rightarrow WW$ Decay Mode,” in *ATL-PHYS-PUB-2009-056* (<http://cdsweb.cern.ch/record/1174270>).
- *Mellado, Quayle, Vickey, and S.L. Wu*, “Multivariate and Fit-based Approaches to $H+0j$, $H\rightarrow WW\rightarrow l\nu l\nu$,” *ATL-PHYS-INT-2009-083*
- *Goldschmidt, Mellado, Padhi, Quayle, and S. L. Wu*, “Background Determination in the $H+2j$, $H\rightarrow lvqq$ Analysis,” *ATL-PHYS-INT-2009-061*
- *Mellado, Quayle, and S.L.Wu*, “Fit-based Search for $H+2j$, $H\rightarrow WW\rightarrow e\nu\mu\nu$,” *ATL-PHYS-INT-2009-062*

2. STUDIES AT 7 AND 10 TeV. Our group has led the effort to adapt the $H\rightarrow WW\rightarrow l\nu l\nu$ analysis to the conditions expected in the early data. Very recently the Wisconsin group has produced a set of five notes which describe dedicated searches in the $H+0j$, $H+1j$, and $H+2j$ channels, including results at 10TeV (in accordance to the previous LHC plan) and 7TeV (as expected for the 2010/2011 run). Four of the following five notes have been refereed and approved as ATLAS INT notes by the collaboration:

- *Asfandiyarov, Carrillo, Fang, Ma, Quayle, S.L.Wu*, “Prospects for $H+0j$, $H\rightarrow WW\rightarrow l\nu l\nu$ in 10 TeV Collisions,” *ATL-COM-PHYS-2010-010*, *ATL-PHYS-INT-2010-032* [includes 7 TeV results]
- *Asfandiyarov, Carrillo, Fang, Ma, Quayle, S.L.Wu*, “Prospects for $H+1j$, $H\rightarrow WW\rightarrow l\nu l\nu$ in 10 TeV Collisions,” *ATL-COM-PHYS-2010-039*, *ATL-PHYS-INT-2010-045* [includes 7 TeV results]
- *Asfandiyarov, Carrillo, Fang, Ma, Quayle, S.L.Wu*, “Prospects for $H+2j$, $H\rightarrow WW\rightarrow l\nu l\nu$ in 10 TeV Collisions,” *ATL-COM-PHYS-2009-654*, *ATL-PHYS-INT-2010-010* [includes 7 TeV results]
- *Asfandiyarov, Carrillo, Fang, Ma, Quayle, S.L.Wu*, “Estimation of Backgrounds for $H\rightarrow WW$ with Data-Driven methods,” *ATL-COM-PHYS-2009-607*
- *Asfandiyarov, Carrillo, Fang, Ma, Quayle, S.L.Wu*, “Combined Sensitivity to $H\rightarrow WW\rightarrow l\nu l\nu$ in 7 TeV Collisions at ATLAS,” *ATL-COM-PHYS-2010-154*, *ATL-PHYS-INT-2010-047*.

We contributed significantly to an assessment of the sensitivity to the $H\rightarrow WW$ modes in the early data, as well as to a comprehensive note, authored by 38 ATLAS members, on the sensitivity to $H\rightarrow WW\rightarrow l\nu l\nu$ with 200 pb^{-1} of 10TeV collisions:

- *Armbruster et al.*, “Higgs Boson Searches using the $H\rightarrow WW\rightarrow l\nu l\nu$ Decay Mode with the ATLAS Detector,” *ATL-COM-PHYS-2009-620* and *ATL-PHYS-INT-2010-035*.
- *Asfandiyarov et. al.*, “Estimates of the Standard Model Higgs Discovery Potential in the Channel $H\rightarrow WW$ as a Function of the Center of Mass Energy,” *ATL-COM-PHYS-2009-062*

6.2. STUDIES OF HIGGS WITH $H\rightarrow\gamma\gamma$ ASSOCIATED WITH 0, 1 OR 2 HIGH P_T JETS

(*Profs. S.L.Wu, Pan and Mellado, Postdoc Fang, Grad. student Wang*)

Mellado was co-editor of the $H\rightarrow\gamma\gamma$ section in CERN-OPEN-2008-020

(<http://cdsweb.cern.ch/record/1125884>)

This is one of the most promising channels for Higgs boson with masses below 140 GeV. After demonstrating a significant increase in the sensitivity to this channel by exploiting information about jets produced in association with the Higgs boson, the Wisconsin group has spearheaded the effort to incorporate these ideas together with several discriminating variables into a fit based approach to the Higgs search. Our group was the first to present an estimate of the sensitivity of

this channel in 10 TeV collisions to the Higgs working group, and we are currently preparing a note on the sensitivity of this channel in 7 TeV collisions.

- Fang, Mellado, Pan, and S.L.Wu, “Search of the Standard Model Higgs boson with $H \rightarrow \gamma\gamma$,” *ATL-PHYS-INT-2009-081*
- Fang, Wang, and S.L.Wu, “Prospects for $H \rightarrow \gamma\gamma$ in 7 TeV Collisions,” in preparation

6.3. STUDIES OF HIGGS WITH $H \rightarrow ZZ \rightarrow 4l$

(Prof. S.L.Wu, Assistant Scientist Flores, Postdoc Quayle, Grad. student Carrillo)

Although its event rate is small for low luminosity, this channel's clean signature leads to a strong sensitivity for Higgs boson masses near 150 GeV and above 190 GeV. We were the first group in ATLAS to replace the sliding-cuts strategy in this channel by a global fit-based approach, which improves and better describes the discovery potential of this channel.

- Flores, Quayle, and S.L. Wu, “Search for $H \rightarrow ZZ \rightarrow 4l$ using a global fit procedure,” *ATL-PHYS-INT-2009-043*

We were the first group in ATLAS to estimate the sensitivity of this channel in 10TeV collisions.

6.4. STUDIES OF HIGGS WITH $H \rightarrow \tau\tau$

(Profs. S.L.Wu and Mellado, Assist. Scientist Vickey, Postdoc Quayle, Grad. Student Chen)

This decay mode complements the $H \rightarrow \gamma\gamma$ channel in the low-mass region in the Standard Model, but may receive large enhancements in models with more than one Higgs doublet. During the last three years, we have provided a tool to extract the $Z \rightarrow \tau\tau$ background in this and other final states, as well as making significant improvements to the reconstruction of the missing P_T (and hence the Higgs boson mass reconstruction). We have also led the development of a fit-based analysis of this channel.

- Mellado, Vickey, S.L.Wu, “Searching for New Physics Using High-Pt Tau Pair in ATLAS,” *ATL-PHYS-INT-2008-038*
- Vickey, Chen, Mellado, Quayle, and S.L.Wu, “A Data-driven Control Sample for $Z \rightarrow \tau\tau + \text{jets}$ Backgrounds to Higgs Searches,” *ATL-COM-PHYS-2008-144*
- Chen, Mellado, Vickey, and S.L.Wu, “Search of a SM Higgs in the VBF $H \rightarrow \tau\tau$ channel at ATLAS,” *ATL-PHYS-INT-2009-030*

Recently, we have also presented to the Higgs working group an evaluation of the sensitivity to the MSSM Higgs boson using the early data.

- Ruiz-Martinez, Mellado, Castillio, Valls, S.L.Wu, “b-Tag-Independent Search for the Neutral MSSM Higgs Boson Search in the Dimuon Decay Channel,” *ATL-PHYS-INT-2009-086*
- Mellado, Quayle, S. L. Wu, “Feasibility of the searches for a Higgs Boson using $H \rightarrow WW \rightarrow l+l-$ missing P_T and high P_T jets at the Fermilab Tevatron”, *Phys.Rev. D 76, 093007 (2007)*
(<http://cdsweb.cern.ch/record/1052147>).

6.5. HIGGS CROSS SECTIONS AS FUNCTION OF THE CENTER OF MASS ENERGY

(Prof. Mellado, Assist. Scientist Vickey, Grad. Student Carrillo)

In 2007 and 2008, our group played a crucial role in the study of the Higgs boson production cross-section using the state of art tools available from the theory community. After a number of iterations with a large number of ATLAS collaborators, a final note was written summarizing the results for several Higgs boson production mechanisms in the Standard Model and the MSSM Higgs, including estimates of the uncertainties and higher-order corrections.

- Asfandiyarov, et. al, “Production Cross Section of the Higgs Boson and Other Standard Model Processes in pp Collisions at Different Center-of-Mass Energies”, *ATL-COM-PHYS-2009-051*

- Andari, et. al, "Higgs Production Cross Sections and Decay Branching Ratios," ATL-COM-PHYS-2010-046

6.6. CONTRIBUTION TO THE PRODUCTION OF AN ISOLATED HIGGS PARTICLE (Prof. S.L.Wu and collaborator from Harvard and Katholieke Universiteit Leuven)

Gluon fusion, which is responsible for the major contribution to Higgs production at LHC, has so far been studied on the basis of the gluon distribution function. Since this distribution function has been determined using mostly the electron-proton data, there is some question how accurate it is. It is therefore of interest to calculate the Higgs boson production cross section without using the gluon distribution function. The class of events considered is

$$p + p \rightarrow A + H + B ,$$

where A represents a group of particles that mostly go down one beam pipe, B a similar one going down the other beam pipe, and H the produced Higgs particle whose velocity is moderate in the center-of-mass system so that its decay products are well detected. In other words, an isolated Higgs particle is produced. The contribution from Sau Lan Wu is in the area of experimental feasibility.

- R. Gastmans, Sau Lan Wu, and Tai Tsun Wu, "Production of isolated Higgs particle at the Large Hadron Collider", *Physics Letters B* 683, 354 (2010) (<http://wisconsin.cern.ch/b/IsoHiggs.pdf>)

SECTION 7: CONTRIBUTION TO ATLAS SUPERSYMMETRY WORKING GROUP

From 2007 to April 2010, we gave **85** talks in SUSY working groups.

The list and content of the talks are given in <http://wisconsin.cern.ch/physics/t.html> .
(*Profs. S.L.Wu and Pan, Postdocs Chen, Poveda, Sarangi, and Grad. Student A. Castaneda*)

Supersymmetry, often called SUSY, is the symmetry between fermions (matter) and bosons (forces) and predicts the existence of a superpartner particle (sparticle) for every known particle. Results from recent experiments have suggested that most of our universe is made of "dark matter". The discovery of sparticles will shed light on the nature of this dark matter, connecting observations performed at earth-based accelerators with those performed by astrophysicists and cosmologists. The LHC is going to operate in a energy regime which hasn't been explored by any accelerator experiment so far, thus providing a unique opportunity to discover these particles. Our group is making a strong contribution in the ATLAS SUSY working group by studying the most important signatures (leptons, missing transverse momentum and jets) that can lead to early discoveries. During 2008, our group was heavily involved in the elaboration of the SUSY chapters in the *CSC book*, (<http://cdsweb.cern.ch/record/1125884> , CERN-OPEN-2008-020), which considered a center-of-mass energy of 14TeV and integrated luminosity of 1 fb⁻¹. However, we are currently focused on studies that will lead to discovery in data as early as possible, *i.e.* a few tens of pb⁻¹ of integrated luminosity collected by the ATLAS detector in 2010 at a center-of-mass energy of 7 TeV.

7.1 INCLUSIVE SUSY STUDIES - ONE LEPTON + MISSING TRANSVERSE MOMENTUM (ETMISS).

This final state is expected to be the most sensitive to discover Supersymmetry in early ATLAS data. Our group has developed a number of variables to discriminate and strongly suppress the events from Standard Model processes. We also developed methods to optimize the event selection criteria in order to enhance the SUSY signal events compared to the Standard Model background events.

7.2 INCLUSIVE SUSY STUDIES – TWO LEPTONS + ETMISS.

Even though the one lepton+etmiss signature is considered the most sensitive, the two-lepton+etmiss channel also has a high potential to discover SUSY in the early data. Despite a lower signal cross-section, the Standard Model background event rate is much reduced compared to that of the one-lepton channel. This property provides a clean environment to discover Supersymmetry beyond the Standard Model. Our group leads a search for SUSY with two leptons with the same charge in the final state. The study includes a unique approach to understand and separate Standard Model background events from the SUSY signal events. This analysis is aimed for an early data scenario; *i.e.* a few tens of pb^{-1} of integrated luminosity. The analysis is documented in the following refereed ATLAS INT notes:

- Sarangi, Chen, A. Castaneda, Pan, Poveda and S.L. Wu, “Searching for Supersymmetry with two same-sign leptons, multi-jets plus missing transverse energy in ATLAS at $\sqrt{s} = 10 \text{ TeV}$ ”, *ATL-PHYS-INT-2009-065*.
- Also this note has been approved by the ATLAS collaboration to be publicly available as *ATLAS-PHYS-PUB-2009-085*.

7.3 INCLUSIVE SUSY STUDIES – THREE LEPTONS + ETMISS.

This channel is worth looking forward to despite very low cross-section for the signal but there is almost negligible contribution from the Standard Model processes. We would be able to observe a clean signal if SUSY exists and produces a trilepton final state. We have proposed several variables and selection criteria in order to observe such excess in the real data in collaboration with other institutions.

7.4 FIT-BASED ANALYSIS FOR ONE-LEPTON + ETMISS CHANNEL.

Due to the theoretical and experimental uncertainties, the rates of the various background events to Supersymmetry signals are not precisely known. For this reason, we have developed a fit-based analysis method that can extract the background and signal rates directly from the data in the one-lepton signature channel by fitting several physics distributions. The results show that the fit-based approach has higher discovery and exclusion potential than the cut and count approach. The analysis procedure is documented and under review as an ATLAS INT note:

- Chen, A. Castaneda, Pan, Poveda, Sarangi and S.L. Wu, “Initial sensitivity of ATLAS inclusive SUSY search at $\sqrt{s} = 10 \text{ TeV}$ in the one-lepton final state by fitting and number counting”, *ATL-COM-PHYS-2010-050*.

7.5 SUSY PARAMETER SCANS:

The properties of sparticles depend upon a wide range of parameters in the most general formulation of Supersymmetry theory. It is difficult to cover such a large parameter space with the current simulation techniques. Therefore, we have used a model called minimal SuperGRAvity (mSUGRA) that reduces the number of free parameters to only five. We have simulated a huge amount of data that cover several configurations of these parameters in order to determine the SUSY discovery potential with different signatures mentioned above. Discovery potential of ATLAS can be evaluated by the mass range of sparticles such as squarks, gluinos, charginos. For a lower range of sparticle masses the discovery could be possible within 100 pb^{-1} of integrated luminosity at a center-of-mass energy of 7 TeV. The output of these studies was summarized in the following ATLAS INT note:

- Poveda, A. Castaneda, Chen, Pan, Sarangi and S.L. Wu: “Discovery Potential and Exclusion Limits for R-Parity Conserving SUSY Signals at $\sqrt{s} = 10 \text{ TeV}$ in ATLAS”, *ATL-PHYS-INT-2009-114*.

SECTION 8: CONTRIBUTION TO ATLAS EXOTICS PHYSICS WORKING GROUP

From 2007 to April 2010, we gave **96** talks in Exotics working groups.

The list and content of the talks are given in <http://wisconsin.cern.ch/physics/t.html>.

Even with the reduced center of mass energy planned for the initial LHC run, there is a strong physics potential for searches of several extensions of the Standard Model. Our group has been strongly involved in the preparation of searches for new gauge bosons (W' , Z') and for the exciting possibilities of *gravitons*, *black hole* and *string ball* production. With the exception of black holes, all these searches are expected to go beyond Tevatron limits with a few tens of pb^{-1} of 7 TeV data.

Luis Flores is the co-convener of the ATLAS Lepton+X Exotics subgroup, which is in charge of Exotic physics searches involving leptons or photons (among other searches, it covers W' , Z' , gravitons, excited leptons, leptoquarks and left-right symmetry models) and is the largest subgroup of the ATLAS Exotic physics group.

8.1 SEARCH FOR A W' WITH $W' \rightarrow l\nu$, ($l=e,\mu$).

(Prof. S.L.Wu, Assist. Scientist Flores, Grad. Student Pedraza)

Theories based on extensions of the gauge group of the Standard Model predict the existence of new heavy gauge bosons such as a Z' and a W' . Our group is leading the effort of ATLAS to assess the discovery potential of the W' search, based on our expertise in missing transverse energy and in lepton reconstruction. Our group was the first in ATLAS to develop a global fit procedure to extract the signal based on the transverse mass shape. Our group has also been strongly involved in the evaluation of the impact that a lower center-of-mass energy will have on this search; among other activities, we provided input to the 2009 and 2010 Chamonix workshops, for the discussion on the initial LHC center-of-mass and luminosity plans.

- Flores, Pedraza, S.L.Wu, “ W' to lepton-neutrino prospects as a function of LHC center-of-mass energy with ATLAS”, ATL-COM-PHYS-2009-087, ATL-PHYS-INT-2009-038.

8.2 SEARCH FOR A Z' WITH $Z' \rightarrow ll$ ($l=e,\mu$)

(Prof. S.L.Wu, Assist. Scientist Flores, Grad. Student E. Castaneda)

The Wisconsin Group is strongly involved in the search of di-lepton resonances. We have studied lepton reconstruction at high transverse momenta for both electrons and muons, methods to extract the width of Z' signals from different models, fit-based procedures to determine the significance of a potential signal or limits. As in the case of the W' search, our group also provided input about the potential of the Z' search to the 2009 and 2010 Chamonix workshops.

- E. Castaneda, Flores, S.L.Wu, “ Z' to ll prospects as a function of LHC center-of-mass energy with ATLAS”, ATL-COM-PHYS-2009-038, ATL-PHYS-INT-2009-036.

8.3 SEARCH FOR A Z' WITH $Z' \rightarrow \tau\tau$ (Profs. S.L.Wu and Mellado, Assist. Scientist Vickey)

Models with extended weak or hypercharge gauge groups give rise to Z' bosons that couple preferably to the third generation of fermions. The strong $Z' \rightarrow \tau\tau$ coupling in these models, and relatively low backgrounds, can be exploited for the di-lepton and lepton-hadron final states. The Wisconsin Group has led the early exploration of these channels.

- Mellado, Vickey, S.L.Wu, et al., “Searching for New Physics Using High-Pt Tau Pairs in ATLAS”, ATL-PHYS-INT-2008-038.

8.4 SEARCH FOR GRAVITONS DECAYING INTO PHOTON PAIRS ($G \rightarrow \gamma\gamma$)

(Profs. S.L.Wu and Pan, Postdoc Fang and Grad. Student Wang)

Models in which only gravity propagates through extra spatial dimensions predict the existence of gravitons, which can decay into pairs of photons. Model-independent searches for these particles can produce new limits with luminosities as low as a few tens of pb^{-1} . Harnessing our expertise in the search for a low mass Higgs in the diphoton channel, our group is strongly involved in the study of this search, contributing specifically to the areas of photon calibration and resolution, photon/jet separation, signal extraction and limit setting.

8.5 DIJET RESONANCES (Prof. S.L.Wu, Postdocs Poveda and Grad. Student Ji)

Our efforts on high p_T calibration and spectrum unfolding within the Standard Model group are also applied to the Exotics searches. These studies include the search for dijet resonances (new massive particles decaying to jets, such as excited quarks or axiguons) or anomalies in the dijet p_T spectrum due to gravity-mediated effects in large extra dimensions theory.

8.6 TOPOLOGICAL SEARCH

(Prof. S.L.Wu and Pan, Postdocs Peng and Sarangi and Grad. Student Wang)

The LHC is opening a vast new region for the creation and search for new particles. To maximize the probability of discovery, we have implemented a model-independent search that relies only on the *event topology* (for example, e^+e^+ , e^-e^- , $\mu^+\mu^+\mu^+$). This is done by identifying which event topologies are expected to be background free, and are sensitive to discovery.

- Pan, Peng, Flores, Sarangi, Wang, S. L. Wu “Searching for Hints of New Physics using a Topological Method in ATLAS at $\sqrt{s}=10$ TeV” ATL-COM-PHYS-2009-600

8.7 SEARCH FOR TeV-SCALE GRAVITY INDUCED EFFECTS (e.g. Microscopic Black Holes and String Balls) (Prof. S.L.Wu, Postdoc Peng and Grad. Students A. Castaneda and Ji)

Some of the models that predict the existence of extra spatial dimensions allow the creation of microscopic *black holes*, as well as objects called *string-balls*, as a result of the pp collisions at LHC energies. Our group has studied the potential of these searches, and has been one of the first to propose data-driven background estimation techniques for this search.

SECTION 9: CONTRIBUTION TO STANDARD MODEL PHYSICS WORKING GROUP

From January 2010 to April 2010, we gave **25** talks in Standard Model working groups.

The list and content of the talks are given in <http://wisconsin.cern.ch/physics/t.html> .

One of the first crucial challenges that ATLAS will face in the early data is to demonstrate a good understanding of Standard Model processes and a clear understanding of the detector performance. In the past, our group has made major efforts in preparation of the Higgs analysis and SUSY analysis. Due to the change of the LHC schedule as well as the energy being reduced to 7 TeV for 2010 and 2011, we have recently redirected partially our effort on early data in the Standard Model Working Group and we have become active in a broad variety of studies of Standard Model processes:

9.1 CONTRIBUTIONS TO STANDARD MODEL JET SUBGROUP

(Prof. S.L.Wu, Postdoc Poveda)

Several distributions, such as inclusive jet transverse momentum or di-jet invariant mass, are of great interest to QCD; any unexpected bump or shoulder is a possible indication of physics beyond the Standard Model, and needs to be investigated. The correct calibration of the very high p_T jets is a key element in the Standard Model jet physics results. Our group is involved in the data-driven calibration and resolution of high- p_T jets with the multijet balance method. In this

method, high- p_T jets are calibrated by comparison with a recoil formed by several lower p_T jets which are already calibrated with the γ -jet method. Furthermore, our group also works on the unfolding methods for the inclusive jet p_T spectrum. This study is meant to obtain a distribution which can be directly compared to the results by other experiments or to theory predictions once the detector effects are deconvoluted from the data measured at ATLAS. This work has been documented:

- *Poveda, Li and S.L. Wu: "Inclusive Jet Transverse Momentum Unfolding in ATLAS", ATL-COM-PHYS-2009-640*

9.2 MEASUREMENTS OF W/Z PRODUCTION CROSS-SECTIONS IN THE W/Z SIGNATURE SUBGROUP

(Profs. S.L. Wu, Pan and Mellado, Postdoc Zhu, Grad. Student Carrillo)

The precisely measured cross-sections and properties of the W/Z bosons provide strong constraints on electroweak parameters and the detector performance. Our contributions include: developing the W/Z Benchmark package ZToTwoElectrons, investigating data-driven methods to estimate the backgrounds, understanding the performance of the missing transverse energy and optimizing the lepton identification. Work has also been started to estimate the uncertainty on the W acceptance due to missing transverse energy systematics.

9.3 MEASUREMENT OF Z PLUS JETS CROSS SECTION IN THE W/Z PLUS JETS SUBGROUP

(Profs. S.L. Wu, Pan and Mellado, Postdoc Sarangi)

Production of Z boson associated with n-jets is a very interesting measurements which will help to fix and constraint uncertainties in theoretical models for light and heavy flavor production in association with neutral currents. On the other hand Z plus jets is an important background to searches for SUSY, exotic particles and the Higgs boson. Our contribution lies on extracting the signal from the background by devising control regions using data-driven methods; our work is included in the most recent note produced by the W/Z+jets subgroup:

- *Prospects for W/Z+jets early data measurements with the ATLAS detector at the LHC: An analysis walkthrough, ATL-COM-PHYS-2010-150*

9.4 MASS SPECTRA AND PRODUCTION CROSS SECTIONS OF PI0 AND ETA WITH 900 GEV DATA FROM 2009

(Postdocs Fang and Quayle)

This result is submitted to a winter conference of 2010. The purpose of this study is to understand the performance of the ATLAS electromagnetic shower detector. Our contribution is the longitudinal weight photon calibration and fitting algorithm to extract the signal. We also developed a pi0 identification algorithm by using track veto.

9.5 NORMALIZATION OF THE WEAK BOSON PAIR PRODUCTION AT THE LARGE HADRON COLLIDER

(Profs. S.L. Wu and Mellado, Postdoc Fang, Grad. Student E. Castaneda and two collaborators from other institutions)

The production of two weak bosons at the LHC is one of the most important sources of SM backgrounds for final states with multiple leptons. Our contribution consisted of the calculation of the ratios of inclusive cross-sections for production of two weak bosons and Drell-Yan, and their corresponding theoretical errors. The result is published in Phys. Rev. D.

- *"Normalizing Weak Boson Pair Production at the Large Hadron Collider", E. Castaneda-Miranda; Fang; Mellado; Wu, Sau Lan et al. Phys. Rev. D80:054023,2009*
(<http://prd.aps.org/abstract/PRD/v80/i5/e054023>)

SECTION 10: CONTRIBUTION TO ATLAS COMPUTING SYSTEM COMMISSIONING (CSC) BOOK (CERN-OPEN-2008-20, <http://cdsweb.cern.ch/record/1125884>)

In anticipation of data taking, the ATLAS Collaboration has mounted a major effort to prepare over 50 CSC notes (CSC stands for *Computing Systems Commissioning*). These notes were collected into a book which presents a snapshot of the current "state of the art" of physics analysis. The analysis done to prepare these notes has exercised the computing system of ATLAS to mimic the usage patterns expected during data-taking. This exercise provided valuable experience with the process of producing physics results from the ATLAS collaboration. The public reference is "*Expected performance of the ATLAS experiment-Detector, Trigger and Physics*", (<http://cdsweb.cern.ch/record/1125884> , CERN-OPEN-2008-020).

Members of our group either led or were heavily engaged in the following 25 CSC notes; our names are listed as contributors in the corresponding internal document of each of CSC note.

1. Calibration and Performance of the Electromagnetic Calorimeter
2. Reconstruction and Identification of Electrons
3. Reconstruction and Identification of Photons
4. Reconstruction of Photon Conversions
5. Reconstruction of Low-Mass Electron Pairs
6. Muons in the Calorimeters: Energy Loss Corrections and Muon Tagging
7. Reconstruction and Identification of Hadronic Tau Decays
8. Jet Energy Scale: In-situ Calibration Strategies
9. Measurement of Missing Transverse Energy in ATLAS
10. A Study of Minimum Bias Events
11. Prospects for the Discovery of the Standard Model Higgs Boson Using the $H \rightarrow \gamma \gamma$ Decay
12. Search for the Standard Model $H \rightarrow ZZ^* \rightarrow 4\text{leptons}$
13. Search for the Higgs boson via Vector Boson Fusion production process in the di-tau channels
14. Higgs Boson Searches in Gluon Fusion and Vector Boson Fusion using the $H \rightarrow WW$ Decay Mode
15. Discovery Potential of $h/A/H \rightarrow \tau^+ \tau^- \rightarrow l^+ l^- 4\nu$
16. Charged Higgs Boson Searches
17. Statistical Combination of Several Important Standard Model Higgs Boson Search Channels
18. Data-Driven Determinations of W, Z and Top Backgrounds to Supersymmetry
19. Estimation of QCD Backgrounds to Searches for Supersymmetry
20. Prospects for Supersymmetry Discovery Based on Inclusive Searches
21. Multi-Lepton Supersymmetry Searches
22. Dilepton resonances at high mass
23. Lepton plus Missing Transverse Energy Signals at High Mass
24. Trigger for Early Running
25. Physics performance studies and strategy of the Electron and Photon Trigger Selection

SECTION 11: ATLAS INTERNAL NOTES by WISCONSIN GROUP MEMBERS (2007-2010)

From 2007 to April 2010, we produced 41 ATLAS notes.

The list is given in <http://wisconsin.cern.ch/a/ATLAS-NOTES.html>

SECTION 12: TALKS GIVEN IN ATLAS WORKING GROUPS (Jan 2007 – April 2010)

From January 2007 to April 2010, we gave **749** talks in ATLAS working groups.

The list is given in <http://wisconsin.cern.ch/physics/t.html>

Importance is placed in giving many talks in the ATLAS working groups. We have given an unusually large number of talks in various ATLAS Working Group meetings. This reflects our intensive activities in the different physics areas.

ATLAS Working Groups	# talks	ATLAS Working Groups	# talks
Higgs	255	Egamma	37
SUSY	85	Jet Etmiss, TileCal	53
Exotics	96	Computing Operations	31
Standard Model	25	High Level Trigger	69
Statistics Forum	24	Physics Validation & Analysis tools	24
Tau and b-tagging	13	Others	37
TOTAL TALKS IN ATLAS WORKING GROUPS (Jan.2007-April 2010) :			749

SECTION 13: TALKS GIVEN IN CONFERENCES AND WORKSHOPS (January 2007 – April 2010)

From January 2007 to April 2010, we gave **74** talks in conferences and workshops.

The list is given in <http://wisconsin.cern.ch/a/ATLAS-CONF-TALKS.html>

SECTION 14: CONFERENCES AND WORKSHOPS PROCEEDINGS AND PUBLICATIONS (January 2007 – April 2010)

From January 2007 to April 2010, we produced **29** proceedings and publications.

The list is given in <http://wisconsin.cern.ch/a/ATLAS-PUB.html>

SECTION 15: WISCONSIN LEADERSHIP ROLES AND RESPONSIBILITY IN ATLAS Memberships, Convenorships and Responsibility Roles (2007-April 2010)

Name	Appointment	Period
Andre Dos Anjos	Co-leader of the event format group	2007-present
R. Asfandiyarov	In charge of the Higgs→WW validation	2009-present
German Carrillo	In charge of Higgs→ZZ→4leptons validation	2009-present
Yaquan Fang	Referee for ATLAS note ATL-COM-PHYS-2010-107 (H→γγ)	2010
Yaquan Fang	Coordinator of a conference note on H→WW backgrounds	2010
Luis Flores	Coordinator of the first ATLAS W' publication	2010
Luis Flores	Co-convenor for Exotic subgroup on leptonic channels	2008-present
Luis Flores	Co-editor of the W' CSC note	2007-2008
Luis Flores	Convener for Monte Carlo production in H→ZZ→4 leptons	2007-2009
Luis Flores	Referee for ATLAS note ATL-COM-PHYS-2009-449 (J/Psi)	2009
Bruce Mellado	Convener of the Higgs→WW analysis group	2009-present
Bruce Mellado	Member of US ATLAS Resource Allocation Committee	2005-2009

Bruce Mellado	Co-convenor US ATLAS Standard Model and Higgs forum	2006-2008
Bruce Mellado	Co-convenor of Higgs $\rightarrow\gamma\gamma$ CSC note	2006-2008
Bruce Mellado	Co-convenor of W/Z+jets CSC note	2006-2008
Sanjay Padhi	Member of Grid Tools and Services Coordination	2007-2008
Sanjay Padhi	Member of ATLAS LCG-EGEE Task Force	2007-2008
Sanjay Padhi	Leader of CRONUS-ATLAS Production System	2006-2007
Sanjay Padhi	Member of ATLAS Computing Operations	2006-2007
William Quayle	On editorial board for a series of 5 Etmiss/Jet conference notes	2010
William Quayle	On editorial board for the ATLAS detector performance journal publication	2010
William Quayle	Representative of the Higgs Group for ATLAS statistics forum	2007-present
William Quayle	Co-convenor of the Higgs \rightarrow WW CSC note	2006-2008
Tapas Sarangi	Coordinator of background estimation in W/Z plus jets group for the first publication on 7 TeV data	2010
Tapas Sarangi	Referee for ATLAS note ATL-COM-PHYS-2009-529	2009
Haichen Wang	In charge of the Higgs $\rightarrow\gamma\gamma$ validation	2009-present
W. Wiedenmann	Coordinator of Level 2 and HLT applications group	2007-present
W. Wiedenmann	Member of DAQ/High Level Trigger Coordination Group	2006-present
Sau Lan Wu	Member of Top Cross-section Review Committee	2010
Sau Lan Wu	Member of Advisory Board: Western ATLAS Tier 2	2006-present
Haimo Zobernig	Member of DAQ/ High Level Trigger Coordination Group	2006-present
Haimo Zobernig	Co-coordinator of March 2007 TDAQ "Technical Run"	2007
Haimo Zobernig	Head of ATLAS TDAQ Speakers Committee	2007-2009
Haimo Zobernig	Co-coordinator of Level 2 and HLT applications group	2007-present

SECTION 16: THESES ON THE RESEARCH WITH THE ATLAS EXPERIMENT

Our task has granted six Ph.D. degrees on research with the ATLAS experiment.

ATLAS THESES (2005-2009)

1. **K. Cranmer** (Goldhaber Fellow at BNL; Presidential Early Career Award for Scientists and Engineers 2007, now Assistant Professor at New York University) *Advisor: Prof. S. L. Wu.*
Searching for New Physics: Contributions to LEP and the LHC, 2005
2. **K. Loureiro** (Postdoc at Ohio State University) *Advisor: Prof. S. L. Wu.*
Measuring the Photon Energy Scale Through Test Beam Data, 2006
3. **A. Stradling** (Postdoc at University of Texas-Arlington) *Advisor: Prof. Mellado.*
An Examination of Backgrounds to Early-Run Minimum-Bias Events in ATLAS at the LHC, 2008
4. **Y. Fang** (Postdoc at University of Wisconsin-Madison) *Advisor: Prof. Mellado.*
Search for SM Higgs Decaying to Two Photons via ATLAS Detector, 2008
5. **W. Quayle** (Postdoc at University of Wisconsin-Madison) *Advisor: Prof. S. L. Wu.*
Searches in the $H\rightarrow WW$ Decay Mode Using the ATLAS Detector, 2008
6. **X. Chen** (Postdoc at University of Wisconsin-Madison) *Advisor: Prof. Mellado.*
Reconstruction of the missing transverse energy and search for a SM Higgs boson via VBF in the di-tau decay with ATLAS", 2009

SECTION 17: ACHIEVEMENTS OF FORMER GRADUATE STUDENTS & POSTDOCS
- Education is one of our primary missions

The success of this program stems from the fact that our group is able to attract high quality young physicists. Since we are not in a position to offer a sufficient number of permanent positions to our researchers, in contrast to national laboratories, our ability to attract postdocs and graduate students depends on our track record of achievements of our former postdocs and graduate students. In fact, our former members have an impressive list of accomplishments based on the experience gained throughout their training in our physics program.

17.1. PH.D. DEGREES GRANTED IN THIS TASK

Forty-eight graduate students have obtained Ph.D. degrees from this task, including 10 theses from TASSO, 22 from ALEPH, 10 from BaBar, and 6 from ATLAS. Twenty-seven out of the forty-eight graduates have remained in the field of high energy physics. We list here below their postdoc positions after they obtained their PhD. Of the above, 43 PhD degrees were granted by Professor Wu, 2 by Associate Professor Pan and 3 by Assistant Professor Mellado.

	<u>Postdoc Position</u>		<u>Postdoc Position</u>
1) James Freeman (1981)	Fermilab	25) Peter Elmer (1998)	Princeton
2) Timothy Barklow (1983)	SLAC, Stanford	26) S. Armstrong (1998)	CERN Fellow
3) Eric Wicklund (1984)	Caltech	27) W. Orejudos (1998)	Berkeley
4) H. Venkataramania(1985)	Yale	28) Xidong Wu (1999)	SBC Communications
5) David Strom (1986)	Chicago	29) Owen Hayes (1999)	Booz Allen Hamilton
6) Michael Cherney (1987)	Berkeley	30) T. Greening (1999)	CERN Fellow
7) Allen Caldwell (1987)	Columbia	31) D. Ferguson (2001)	Wisconsin
8) Steven Ritz (1988)	Columbia	32) Jason Nielsen (2001)	Berkeley
9) David Muller (1989)	SLAC, Stanford	33) Eric Charles (2002)	Berkeley
10) M. Takashima(1989)	CERN Fellow	34) P. McNamara (2002)	Rutgers
11) Douglas Cowen (1990)	Caltech	35) Steve Sekula (2004)	MIT
12) John Hilgart (1991)	CERN Fellow	36) Ran Liu (2004)	Berkeley Business School
13) Joe Boudreau (1991)	CERN Fellow	37) Jinwei Wu (2005)	Harvard
14) Jim Wear (1991)	U.C. Santa Cruz	38) Kyle Cranmer (2005)	BNL
15) Yibin Pan (1991)	Wisconsin	39) Zhitang Yu (2005)	Clearshape Technologies
16) David Cinabro (1991)	Harvard	40) M. Datta (2005)	Fermilab
17) Jolean Pater (1992)	CERN Fellow	41) Baosen Cheng(2005)	Avestar-IP
18) Fred Webber (1993)	CERN Fellow	42) Attila Mihalyi(2005)	Princeton Consultants
19) Michael Walsh (1995)	Rutgers	43) K. Loureiro (2006)	Ohio State
20) Leo Bellantoni (1995)	Fermilab Lederman & Wilson Fellows	44) Paul Kutter (2006)	Citizen's Insurance
21) Zhong Feng (1995)	John Hopkins	45) Alden Stradling (2008)	U of Texas-Arlington
22) Yongsheng Gao (1995)	Harvard	46) Yaquan Fang (2008)	Wisconsin
23) Jane Nachtman (1997)	UCLA, Wilson Fellow	47) William Quayle (2008)	Wisconsin
24) Jim Grahl (1998)	Iowa	48) Xin Chen (2009)	Wisconsin

17.2. FACULTY POSITIONS OF FORMER GRADUATE STUDENTS AND POSTDOCS

Twenty-eight former Postdocs and Graduate Students are (or have been) faculty members mainly in major U.S. universities and 10 are permanent staff members at major High Energy laboratories (14 full prof., 5 associate prof. with tenure, 7 assistant prof. and 2 former assistant prof.).

FACULTY POSITIONS OF FORMER POSTDOCS

(1) Robert Johnson: Full Professor (U.C. Santa Cruz) and Associate Director of Santa Cruz Institute for Particle Physics
(2) Vivek Sharma: Full Professor (U.C. San Diego)
(3) Joe Izen: Full Professor (UT Dallas)
(4) John Harton: Full Professor (Colorado State University)
(5) Yuanning Gao: Full Professor and Director of Center for HEP (TsingHua Univ., Beijing)
(6) Shan Jin: Full Professor and Deputy Director of Exp. Physics (Institute of HEP, Beijing)
(7) Hongbo Hu: Full Professor and Deputy Director of Astroparticle Physics Laboratory (Institute of HEP, Beijing)
(8) Haibo Li: Full Professor (Institute of HEP, Beijing)
(9) Gerald Rudolph: Associate Professor with tenure (Universität Innsbruck)
(10) John Conway: Full Professor (University of California, Davis)
(11) Michael Schmitt: Associate Professor with tenure (Northwestern University)
(12) Stathes Paganis: Lecturer with tenure (Sheffield University, UK)
(13) Tom Meyer: Former Assistant Professor (Texas A&M)
(14) Bruce Mellado: Assistant Professor (University of Wisconsin)
(15) Trevor Vickey: Senior Lecturer (University of the Witwatersrand, Johannesburg)

FACULTY POSITIONS OF FORMER GRADUATE STUDENTS

(16) Allen Caldwell: Deputy Managing Director of Max-Planck-Institute, Munich (2002-present); Former Full Professor (Columbia University)
(17) David Strom: Full Professor (University of Oregon)
(18) Michael Cherney: Full Professor (Creighton University)
(19) David Cinabro: Full Professor (Wayne State University)
(20) Joe Boudreau: Associate Professor with tenure (University of Pittsburgh)
(21) Douglas Cowen: Associate Professor with tenure (Penn State University)
(22) Yibin Pan: Associate Professor with tenure (University of Wisconsin)
(23) Steven Ritz: Former Assistant and Associate Professor (Columbia University), former Astrophysicist at NASA/Goddard Space Flight Center, and now Full Professor (U.C. Santa Cruz) and Associate Director of Santa Cruz Institute for Particle Physics
(24) Yongsheng Gao: Assistant Professor (California State University, Fresno)
(25) Jason Nielsen: Assistant Professor (University of California, Santa Cruz)
(26) Jane Nachtman: Assistant Professor (University of Iowa)
(27) Kyle Cranmer: Assistant Professor (New York University); BNL Goldhaber Fellow (2006); Presidential Early Career Award for Scientists and Engineers (2007).
(28) Stephen Sekula: Assistant Professor (Southern Methodist University)

17.3. PERMANENT STAFF POSITIONS IN NATIONAL HIGH ENERGY LABS

Ten of our former postdocs and graduate students received permanent staff positions in national and international high energy laboratories.

Former Graduate Students

1. Steven Ritz	Former Astrophysicist, NASA/Goddard Space Flight Center
2. Jim Freeman	Scientist II, FNAL
3. Tim Barklow	Staff Physicist, SLAC
4. David Muller	Former Staff Physicist at SLAC, now Program Officer, DOE
5. Eric Wicklund	Staff Physicist, FNAL
6. Leo Bellantoni	Scientist I, FNAL (former Wilson and Lederman Fellows at FNAL)

Former Postdocs

7. Saul Gonzalez	Program Officer, DOE
8. Pierre Lecomte	Staff Physicist, ETH (Switzerland)
9. Tom C. Meyer	Staff Physicist, CERN
10. John Walsh	Senior Researcher, INFN

SECTION 18: FUTURE PLANS OF PROFESSOR SAU LAN WU FOR FY11-FY13

Associate Professor Pan and Assistant Professor Mellado have decided to form a new ATLAS group and request a new, separate budget. With this development, and with the continuing support of the University of Wisconsin, Sau Lan Wu and her present team plan to carry out the program we have prepared for the last five years into the data-taking era, with the same strength of graduate students and research associates.

Our group joined the ATLAS collaboration in 1993; after 17 years of preparation, our hard work will finally bear fruit. The work described in sections 1 to 17 will continue with vigor into the data-taking period with the goal of major discoveries at the energy frontier opened up by LHC.

18.1 MANPOWER. Sau Lan Wu will work closely with our present team of graduate students and research associates:

DOE BASED PROGRAM SUPPORTED PERSONNEL (FY11 REQUEST)

1. Assistant Scientist Luis Flores
2. One Research Associate – William Quayle.
3. Six Graduate Students – Yang Heng, Haoshuang Ji, Luca Sabbatini, Haichen Wang, Suli Yang, Fangzhou Zhang.
4. One third FTE Computing Software Engineer – Neng Xu

UNIVERSITY SUPPORTED PERSONNEL

Since LHC is a high-profile research project, the University would like to assure Sau Lan Wu's success in this endeavor by supporting her research. The University Support was initiated by former Chancellor Donna Shalala, who was motivated in part by the fact that Sau Lan Wu is one of the few female leaders in the male-dominated field of Experimental High Energy Physics. This continuing commitment of support from the University is made with the understanding of a similar continuing commitment of support for Sau Lan Wu from DOE.

1. Research Associates – Yaquan Fang, Ximo Poveda and Tapas Sarangi
2. Graduate Students – Ruslan Asfandiyarov and German Carrillo.
3. Graduate Students with a joint program with Mexican Universities – Alfredo Castaneda (University of San Luis Potosi) and Elizabeth Castaneda (CINVESTAV, IPN).
4. Two thirds FTE Computing Software Engineer – Neng Xu
5. Sau Lan Wu's academic salary (9 months) each year is supported by her Vilas Professorship award. This allows her to be full-time on research at CERN.

For more details on the University support, please refer to the Budget Narrative of Prof. Wu.

18.2 SHIFTS AND OPERATION TASK PLANNER (OTP) TASKS. 30% of our manpower is required by ATLAS to be devoted to shifts and OTP (Operation Task Planner) tasks. We plan to continue to fulfill these service tasks in the areas: Silicon Strip Tracker, Trigger, Computing, Muon, electron/gamma, data quality monitoring and Monte Carlo production.

18.3 FUTURE PLANS FOR THE SILICON READ OUT DRIVER (ROD). As ATLAS enters the physics data-taking era, our current efforts on the Silicon ROD will continue with the goal of delivering the full functionality of this system to the ATLAS detector. We will continue to repair and maintain the RODs until the end of the experiment. We will continue maintenance of the DSP and FPGA firmware for the SCT (Semi-Conductor Tracker) and FPGA firmware for the Pixel detector that provides the data path and control functions of the ROD.

Assistant Scientist Flores and Professor Wu will continue to coordinate with Engineer John Joseph, working with Graduate Students Sabbatini and Yang.

18.4 FUTURE PLANS FOR THE ATLAS HIGH LEVEL TRIGGER (HLT). As ATLAS enters the physics data-taking era, our current efforts and responsibilities (see 3.1) on the HLT will continue with the goal of delivering the full functionality of this critically important contribution to ATLAS. Our work will concentrate on the following areas:

1. We expect to continue our effort on functional enhancements, monitoring, fault tolerance, robustness and performance optimization of the High Level Trigger event selection software.
2. With the increasing use of multi- and many-core high performance processors in the HLT farms, we will continue to optimize key framework components for these hardware platforms.
3. We will continue our studies of new dataflow software architectures for detector upgrades.
4. Due to the rare nature of the most interesting processes, our group will continue to take an active role in understanding the online and offline trigger performance and their effect on physics analysis, benefitting from the extensive physics analysis experience of our group.

Assistant Scientist Flores and Professor Wu will continue to coordinate with Engineers Zobernig and Wiedenmann, working with Postdocs Quayle and Sarangi and Graduate Students A. Castaneda, Heng, Ji and Wang.

Graduate students and postdocs will also continue to contribute in the following trigger tasks:

1. **Offline trigger monitoring** (grad student A. Castaneda)
2. **e/γ trigger selection validation** (grad student Wang)
3. **b-physics trigger selection monitoring** (grad student Ji)
4. **J/ψ trigger selection monitoring** (grad student Ji)
5. **Development for the trigger validation framework** (postdoc Quayle)
6. **HLT Calorimeter Software** (postdoc Sarangi)

18.5. FUTURE PLANS FOR THE CONTRIBUTION TO ATLAS TIER-3 DEVELOPMENT.

We will vigorously build up our ATLAS Tier-3 computing facility largely from University funding. We will supplement the ATLAS Monte Carlo production, contribute significantly to the ATLAS Tier-3 development and strengthen our Tier-3 for physics analysis.

- a. **Collaboration with the PROOF team (Parallel ROOT Facility) at CERN.** PROOF provides a transparent, scalable and efficient method to do data analysis on a distributed storage system.
- b. **Virtual dynamic Tier-3 structure.** Our group plans to design a system structure which allows users to dynamically run a data analysis pool in a large existing batch system, alleviating the heavy I/O network load problem.
- c. **Contribution in ATLAS Tier-3 working groups.**

Again, this effort is organized by Software Engineer Xu, Assistant Scientist Flores and Professor Wu, working together with Grad Students Carrillo and Asfandiyarov.

18.6. FUTURE PLANS FOR PHYSICS ANALYSES AND PUBLICATIONS WITH DATA.

For a number of years, we have focused on the preparation and studies of physics at LHC, especially that of Higgs, SUSY, and Exotic searches. With the expectation of collecting 1 fb^{-1} of data at 7 TeV in 2010 and 2011, we are now in an excellent position for physics discoveries. Moreover, in FY12, LHC is planning to upgrade from 7 TeV to the design energy of 14 TeV, and the expectation is that in FY13 and FY14 we will be able to analyze the first 14 TeV data.

For each process listed below, we shall either lead or contribute significantly, expecting publications in 2010 and/or 2011. Although the list is long, there is a great deal of commonality and interplay between the analyses of these processes, and thus they can be studied together efficiently. Also, after this data

taking period of 2010-2011, we will be in a good position to adapt our previous work, carried out for several years under the assumption of 14 TeV, to the conditions expected in 2013-14.

1. **H \rightarrow WW** (*Sau Lan Wu, postdoc Quayle, Grad. Students Asfandiyarov and Sabbatini*). This is the most sensitive Higgs channel. We are involved with all 3 topologies, $H\rightarrow WW+0jet$, $H\rightarrow WW+1 jet$, and $H\rightarrow WW+2 jets$, as well as with the techniques needed for the proper statistical combination of these results. *According to our estimation, with the expected 2010/2011 data ($1fb^{-1}$ at 7TeV) ATLAS could exclude, using only $H\rightarrow WW\rightarrow l\nu l\nu$, Higgs masses between 144 and 183GeV (current exclusion from Tevatron: 162 to 166GeV).*
3. **H \rightarrow ZZ \rightarrow 4 leptons** (*Sau Lan Wu, Assistant Scientist Flores and Grad. Student Carillo*). With $1fb^{-1}$ of 7TeV data, it is possible to establish upper limits on the Higgs cross section in a mass range that has been inaccessible so far. We are working towards this exclusion, and developing new data-driven methods to estimate the expected background for this search, both for the early run and for higher luminosities. *We estimate that $1fb^{-1}$ of 7TeV data (end of 2011) will allow the exclusion of ~ 2 or more times the SM $H\rightarrow ZZ\rightarrow 4l$ cross section for masses around 200GeV.*
4. **H \rightarrow $\gamma\gamma$** (*Sau Lan Wu, Postdoc Fang and Grad. Students Wang and Zhang*). This is the most sensitive channel for low mass Higgs (115-140GeV). Our group has worked on this channel since 2005, and will continue this effort vigorously. *Our preliminary projection is that with $1fb^{-1}$ of 7 TeV collision data, the limit on the $H\rightarrow\gamma\gamma$ cross section with a mass around 120 GeV is expected to be about 4 or 5 times its Standard Model cross-section, exceeding the current limits of 13.1(22.5) set by CDF(D0).*
5. **SUSY** (*Sau Lan Wu, Postdocs Poveda and Sarangi, Grad. Students A. Castaneda and Heng*). For a range of sparticle masses, discovery could be possible even with integrated luminosities as low as a few hundreds of pb^{-1} . Accordingly, our group will continue to pursue vigorously the analysis techniques that we have developed for these searches.
 1. Inclusive studies: 1, 2 or 3 leptons plus missing energy. We will devote a significant effort to the analysis of, and the first publication on, these search channels, which will yield a discovery or new limits with luminosities as low as a few tens of pb^{-1} in 2010.
 2. Fit-based analysis for one-lepton plus missing energy. Having shown that this analysis strategy has a higher discovery and exclusion potential than the cut-and-count approach, we will adapt the technique to the current run at 7TeV with $200pb^{-1}$ to $1fb^{-1}$ in 2011.
 3. SUSY parameter scans. We will continue to work in the scan of the mSUGRA parameter space to make the most out of the reduced center-of-mass energy of the current run. There will be publishable results both in 2010 and 2011. *According to our estimations, with the above analysis strategies we will be able to discover SUSY if it exists up to squark/gluino masses of 0.8 TeV at the end of the 2011 run or set limits in the mSUGRA parameter space up to squark/gluino masses of 1 TeV, which is well beyond the current limits obtained at the Tevatron.*
6. **Exotics $W'\rightarrow e\nu$ and $\mu\nu$; $Z'\rightarrow ee$ and $\mu\mu$** (*Sau Lan Wu, Assistant Scientist Flores, Grad. Students E. Castaneda and Yang*). New heavy gauge bosons may provide the first evidence of physics beyond the Standard Model at the LHC. We will continue our leading role in these searches through further development of fit-based methods and through the study of instrumental uncertainties relevant to the early data-taking period.

We estimate that as low as 10pb^{-1} (50pb^{-1}) of 7TeV data could establish discovery or set exclusion limits beyond the current Tevatron limit of 1TeV (1 TeV) for a W' (Z'). With 1fb^{-1} of data, in 2011 we could extend the limit up to about 2TeV (1.5TeV).

Luis Flores is the coordinator of the first ATLAS paper on the W' search.

7. **Exotics Black Hole and String Ball searches (Sau Lan Wu, Postdoc Sarangi, Grad. Student Ji).** At 7TeV, the production cross section of Black Holes is small; however, the same analysis strategy can also be used for the search of a different type of objects called *string balls*, which cross section remains large enough for discovery even with $O(10)\text{pb}^{-1}$. We will continue to develop our analysis strategy and data-driven background estimation techniques for both searches.
At the end of 2010 (approx. 50pb^{-1}) we will be able to have a 3 sigma observation of String Balls up to a mass of 3TeV; at the end of 2011, with 1fb^{-1} it may be possible to observe microscopic black holes. Publications are expected both in 2010 and 2011.
8. **Search for gravitons decaying into photon pairs (Sau Lan Wu, Postdoc Fang, Grad. Students Wang and Zhang).** Model-independent searches for these particles can produce new limits with luminosities as low as a few tens of pb^{-1} . Building upon our expertise in the search for Higgs into diphotons, our group will maintain its strong involvement in this search.
9. **Exotic dijet resonances (Sau Lan Wu, Postdoc Poveda and Grad. Student Ji).** New massive particles decaying to jets, or anomalies in the dijet p_T spectrum due to gravity-mediated effects, could lead to a discovery of physics beyond the Standard Model with integrated luminosities of the order of a few pb^{-1} . We are involved strongly in the study of high p_T jet calibration and spectrum unfolding, and will search for dijet resonances with the 7TeV data.
10. **Topological searches (Sau Lan Wu, Assistant Scientist Flores, Postdocs Poveda and Sarangi and Grad. Student Ji).** We have developed an automatic, model-independent, search for deviations from the Standard Model expectations for a large number of the event topologies that can be reconstructed by ATLAS (where "topology" refers to a specific combination of reconstructed physics objects; for example, three leptons of the same charge and flavor). We will pursue this line of work to identify topologies for which the Standard Model predicts very low backgrounds with the 7 TeV data. It will provide us with an early indication of potential new physics signals.
11. **Standard Model Studies (Sau Lan Wu, Postdocs Poveda and Sarangi and Grad. Students Asfandiyarov and Carrillo).** The study of Standard Model processes at the new energy frontier is important on its own, and it will be especially relevant to evaluate potential signs of new physics early on. We will continue our involvement in Standard Model W/Z signature group to reach the best possible understanding of jet calibration, jet momentum unfolding and W/Z production cross sections and transverse momentum distributions.

18.7 FUTURE PLAN ON STATISTICAL TOOLS AND TECHNIQUES (Sau Lan Wu, Assistant Scientist Flores, Postdocs Fang, Quayle, Grad. Student Wang)

We have led the development of fit-based searches for Exotics, SUSY, and Higgs, including all the main Higgs channels ($H \rightarrow \gamma\gamma$, $H \rightarrow \tau\tau$, $H \rightarrow ZZ \rightarrow 4l$, and $H \rightarrow WW$) as well as their combination. We will further develop our fit-based searches at 7 TeV, using both Frequentist and Bayesian approaches, and refine the techniques to combine the searches, whenever applicable.

Postdoc Quayle is the Representative of the Higgs Group in the ATLAS Statistics Forum.

18.8 DETECTOR PERFORMANCE. We will continue our active involvement in the study and improvement of the techniques used in ATLAS for the reconstruction of physics objects

1. Missing transverse momentum (Assist. Scientist Flores, Postdoc Poveda and Grad. Student Heng)
2. Hadronic and in-situ high P_T jet energy calibration (Grad Student Ji)
3. Electron calibration, efficiency and fake rate studies (Assistant Scientist Flores, Postdoc Poveda and Grad. Student Zhang)
4. Photon calibration, identification and purity (Postdoc Fang, Grad. Students Wang and Zhang)
5. Calorimeter-based muon identification: (Assistant Scientist Flores)
6. Muon efficiency and fake rate studies (Postdoc Poveda and Grad. Student E. Castaneda)
7. Monte Carlo production (Programmer Xu and Grad. student Asfandiyarov)

18.9 FUTURE THESES. *Theses expected to be completed during the period 2010-2013 using ATLAS data (thesis advisor Sau Lan Wu):*

1. H. Wang, "Search for Higgs bosons and Gravitons decaying into diphotons with 7TeV data"
2. H. Ji, "Search for TeV-Scale Gravity effects (String Balls, Microscopic Black Holes) with 7TeV data"
3. E. Castaneda, "Search for a dilepton resonance with 7TeV data"
4. A. Castaneda, "Search for Supersymmetric particles with 7TeV data"
5. R. Asfandiyarov, "Search for Higgs bosons in $H \rightarrow WW$ to dileptons with 7TeV data"
6. G. Carrillo, "Search for Higgs bosons in $H \rightarrow ZZ \rightarrow 4$ leptons with 7TeV data"
7. L. Sabbatini, "Search for Higgs bosons in $H \rightarrow WW$ to lepton and hadrons with 7TeV data"
8. S. Yang, "Search for W' and Z' resonances with 7TeV data"

Education is one of our primary missions. Forty-three graduate students have obtained Ph.D. degrees from Prof. S.L. Wu, including 10 from TASSO, 22 from ALEPH, 8 from BaBar, and 3 from ATLAS. Twenty-seven of her former postdocs and graduate students are (or have been) faculty members in major Universities and ten are permanent staff at major HEP laboratories.

18.10 UPGRADE PLANS -- High Level Trigger (HLT) for high luminosity running. To explore possible enhancements to the existing dataflow software and in the framework of LHC upgrade preparations, we have started to examine different architectural possibilities to adapt the HLT selection process for future LHC running conditions, especially at high luminosity. We have initiated a series of working meetings to discuss such questions and we have presented a high level design proposal in an ATLAS upgrade workshop. The proposal includes a more uniform treatment of the Level-2 and Event Filter selection. On the basis of existing dataflow and HLT software components, we have already started a prototype development to study critical system parameters of the new architecture. We will continue to coordinate the activity and to evaluate the functionality and performance of the new architecture on various dataflow test beds. *Prof. Sau Lan Wu will coordinate this effort with Software Engineers Zobernig and Wiedenmann, working also with Postdocs Quayle and Sarangi.*

18.11 TALKS IN ATLAS WORKING GROUPS

Importance is placed in giving many talks in various ATLAS working groups. From 2007 to April 2010 the Wisconsin group in ATLAS has given 749 talks <http://wisconsin.cern.ch/physics/t.html>. Maintaining the intensity and quality of our contribution to ATLAS performance and physics groups will remain our goal. For example, in December 2009, ATLAS collected 1.3 million events at 900 GeV and 52K events at 2.36 TeV and, from January to February 2010, our group made intensive efforts to analyze these first data to understand the detector performance. In these

two months our postdocs and graduate students gave 13 presentations on the first data in various ATLAS Physics Working Groups (<http://wisconsin.cern.ch/c/TALKS-2009DATA.html>).

DOE-HEP University Program Grant Information Personnel Distribution Table

Fiscal Year **2011**
Institution Name University of Wisconsin - Madison
Task/Title **Task H: ATLAS I (Professor Sau Lan Wu)**

Type of Position	Name	Activity #1	FTE Months on ATLAS I Research	#months funded by DOE-HEP University Program ATLAS I	Faculty Advisor
Faculty	Wu, Sau Lan	ATLAS	12	2	
Assist. Scientist	Flores Castillo, Luis	ATLAS	12	12	
Postdoc	Quayle, William	ATLAS	12	12	
Grad Student	Heng, Yang	ATLAS	12	12	Wu
Grad Student	Ji, Haoshuang	ATLAS	12	12	Wu
Grad Student	Sabbatini, Luca	ATLAS	12	12	Wu
Grad Student	Wang, Haichen	ATLAS	12	12	Wu
Grad Student	Yang, Suli	ATLAS	12	12	Wu
Grad Student	Zhang, Fangzhou	ATLAS	12	12	Wu
Postdoc	Fang, Yaquan	ATLAS	12	0	
Postdoc	Poveda-Torres, Ximo	ATLAS	12	0	
Postdoc	Sarangi, Tapas	ATLAS	12	0	
Grad. Student	Asfandiyarov, Ruslan	ATLAS	12	0	Wu
Grad. Student	Carrillo, German	ATLAS	12	0	Wu
Grad. Student	Castaneda, Alfredo	ATLAS	12	0	Wu
Grad. Student	Castaneda, Elizabeth	ATLAS	12	0	Wu
Software Engineer	Xu, Neng	ATLAS	12	4	
Software Engineer	Wiedenmann, Werner	ATLAS	12	0	
Software Engineer	Zobernig, Haimo	ATLAS	12	0	
Engineer	Joseph, John	ATLAS	2.4	0	
Administration	Lefkow, Aimee		3.63	3.63	

Post Docs Fang, Poveda Torres, & Sarangi supported by University funds.

Grads Asfandiyarov and Carrillo supported by Univeristy funds.

Grads Castaneda & Castaneda supported by Univeristy funds & Mexico.

Software engineer Xu supported by Univeristy funds for 9 months.

Software engineers Wiedenmann & Zobernig supported by ATLAS M&O funds.

Engineer Joseph support by ATLAS M&O funds.

**SECTION 19: FUTURE PLAN OF ASSOCIATE PROFESSOR YIBIN PAN
AND ASSISTANT PROFESSOR BRUCE MELLADO FOR FY11-FY13**

Participation in the Tile Hadronic Calorimeter. *Prof. Pan, Mellado, one postdoc, two graduate students.* Our group has recently joined the Tile Calorimeter (TileCal) community in ATLAS with the full support of the project leader, Ana Henriques. We plan to contribute to areas that are close to our expertise in electronics and where manpower is required. The accomplishment of these tasks involves questions in the interface between physics and engineering. For this purpose we are collaborating with the Electrical and Computing Engineering (ECE) department of UW Madison. Jointly with faculty and an assistant Dean from ECE we are developing a program for the training of graduate and undergraduate engineering students. Progress in this area will be periodically reported to conferences and published in dedicated peer reviewed journals.

Maintenance and development of the Read Out Driver. We plan to participate in the maintenance and operations, specifically in the area of the Read Out Driver (ROD) and the interface to the Data Acquisition system (DAQ). Our expertise in the design, development and maintenance of the RODs of the Silicon Strip and Pixel detectors has helped us in quickly becoming efficient in the maintenance of the TileCal RODs. At present all the data, or samplings recorded by the front-end electronics in each event, is passed through the DAQ and recorded off-line. This will no longer be possible when high luminosity scenarios will be reached due to limitations on data bandwidth. As a result, only the reconstructed energy and time computed on-line by the RODs will be recorded and the actual data will be lost. This imposes stringent quality requirements on the reconstruction of energy and time online. The latter needs to be understood thoroughly together with several aspects of the data handling, processing, transmission, monitoring and error recovery. Of particular importance are questions related to data corruption and recovery in the challenging environment of on-line transfer of large data volumes. Work on the interface to the DAQ system involves developing functionality, not available at present with which to provide robustness against transmission and other errors.

Maintenance and development of Trigger and DAQ software. The TDAQ software used in the operation of the ATLAS experiment is common for each sub-detector. The Tile online software is built on top of the Trigger and DAQ (TDAQ) software as a set of specific tools and plugins to operate the Tile Calorimeter. TileRODGui is the expert tool to monitor and debug the Tile RODs and DSPs. It has direct communication with the back-end electronics independently of the run control state, so it is the ultimate tool for experts. We plan to contribute to the integration of the low level monitoring of the DSP (RITMO) into the TileRODGui. This includes updating this tool with other functionalities that are currently available like the automatic removal and recovery of a read-out channel and additional ones that have not been fully developed like the configuration on the fly of the conditional dumping of raw data (samples). The set of conditions required per DSP are stored in the ATLAS conditions database (COOL), and a shifter tool is needed to change these during an LHC fill. We also plan to develop this and other operation tools like to further improve the operations of the TileCal and make it more labor effective.

R&D upgrade program of the Off-Detector Electronics. With the LHC luminosity upgrade it is expected that high radiation levels will produce corruption of data transmitted by the front-end electronics to the RODs. In order to solve this problem a new additional module has been developed. In a first phase a functional prototype of the PreROD module (also known as Optical Multiplexer Board or OMB) has been produced. This module is aimed to select which of the two

fibers coming from each of the front-end channel is error free. We plan to participate in the debugging and refining of this prototype. This involves participating in the design and implementation of a test bed for the running of test. With this experience the final design of the PreROD module will be achieved.

Reconstruction of the Missing Transverse Momentum. *Prof. Pan, Mellado, Two Postdocs.* The Missing Transverse Momentum (MET) is arguably one of the most complex experimental signatures. Our group has contributed heavily over the years to the development of the MET reconstruction currently used in ATLAS. These studies were based on MC, test beams and cosmic ray data. Now that the data-taking period has started we are heavily involved in the definition of the quality criteria with the aim of serving the needs of a large span of physics analyses.

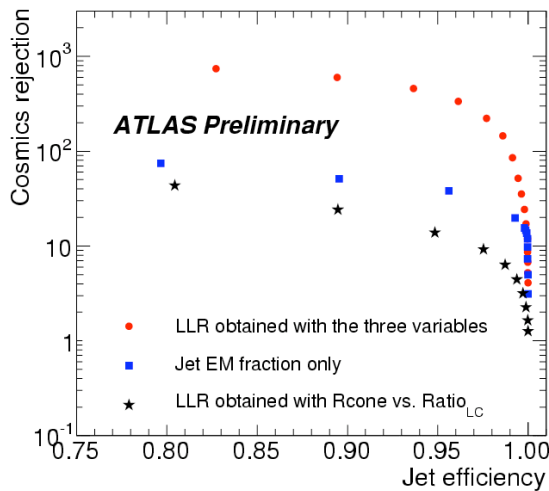


Figure 1. Rejection of fake MET due to energetic cosmic rays vs. jet efficiency (see text). The plot is from Ref. [1]

fake MET, such as cosmic halo is the use of timing. Calorimeter timing, and particularly that reconstructed by the TileCal, is currently not used for the suppression of fake MET. We plan to understand the resolution and tails in the reconstruction of this quantity. It is also planned to integrate this quantity in the definition of goodness of MET in ATLAS.

Development and maintenance of the MET significance. The quantity of MET significance has been successfully used by the Tevatron experiments. It quantifies the likelihood that the observed MET is due to resolution effects of various objects in the final state and not due to genuine MET. Based on MC studies our group has generalized this quantity for any kind of resolution function and arbitrary significances. We plan to develop and validate tools that incorporate the MET significance.

Measurements of Standard Model processes in preparation for Higgs Boson searches. *Prof. Pan, Mellado, One Postdoc and one graduate student.* The first two years of data taking at 7 TeV will provide an excellent opportunity to make measurements that are

Definition and development of Quality Flags.

Use of calorimeter timing. Various are the sources of fake MET. The presence of coherent noise in the TileCal is one of them. We plan to characterize and simulate this complex phenomenon. Another source of fake MET are energetic calorimeter depositions from cosmic rays. Our group has developed a tool to identify calorimeter showers that is integrated with the official ATLAS reconstruction software [1]. This tool is based on a Likelihood Ratio (LLR) constructed with various calorimetric quantities and has the ability to remove efficiently energetic calorimeter depositions while providing high efficiency for jets (see Fig. 1). This tool needs to be validated with collision data and propagated to the analysis communities. Another important quantity for the identification of this and other sources of

¹ Y.Zhu et al, ATL-PHYS-INT-2010-028

directly relevant for setting the first limits on the production of the Higgs boson and to eventually discover it.

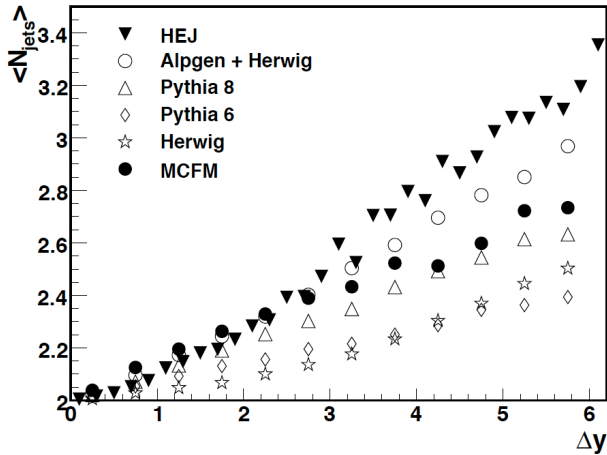


Figure II. Average jet multiplicity vs. the rapidity separation between the two leading jets in $W+\text{jets}$ events. Compared are different predictions for the LHC (Courtesy of J.Andersen, CERN)

QCD studies with high transverse momentum dijets and $W+\text{jets}$. Some searches for Higgs bosons rely heavily on the suppression of QCD backgrounds with the use of a veto on high P_T jets. This aspect of QCD is not very well understood due to the emergence of logarithmic corrections. Studies with the first data will prove essential to develop accurate modeling the jet veto. Due to the large phase space and rapidity coverage of the ATLAS calorimeters we are in a good position to explore the jet multiplicity in the presence of widely separated jets. This measurement can be performed with high P_T dijets and $W+\text{jets}$ with the data expected to be taken within the next two years. The first measurements will be done with high P_T dijets (the requirement of large P_T in dijet events suppresses the contribution from diffraction). Due to the

large cross-section the first data is expected to have enough statistics to understand QCD radiation in events with rapidity difference of 8 or more, not measured before. As seen in Fig. II (shown for $W+\text{jets}$) predictions by different tools vary strongly even for moderate dijet rapidity gaps. Another important measurement is the jet veto survival probability and the exclusive production of jets Z and W events. As demonstrated in [2] this measurement can be used to predict the jet veto survival probability for WW events, the main background in Higgs searches with the $H \rightarrow WW \rightarrow ll$ decay.

Measurements of double W and Z boson production. Following the measurement of the single W/Z production the observation of the double weak boson will become a major milestone for the first Higgs boson searches. As shown in [2] the production of double weak bosons is intimately related to the production of single weak bosons. Of particular relevance is the determination of contributions from gluon fusion via a quark loop not present in the single production. A measurement of the double weak boson production will settle this important issue. The ability to predict the jet veto survival probability for WW production will also be checked.

First limits on the Higgs boson Production. Prof. Pan, Mellado and one postdoc and one student. Following the evidence of double Weak boson production we plan to participate in the first limits on the Standard Model Higgs production.

Limits using the $H \rightarrow WW \rightarrow ll\nu\nu$ decay. This channel provides the most sensitivity with the first data. A 95% CL limit can be set in the mass range of 140-180 GeV of the SM Higgs if it does

² J.Campbell, N.Kauer, B.Mellado et al, Phys.Rev.D80:054023,2009

not exist. We plan to contribute with data-driven techniques to extract the double weak boson and top backgrounds, in addition to the identification and suppression of fake MET.

Limits using the $H \rightarrow ZZ \rightarrow 4l$ decay. This channel provides sensitivity for SM Higgs around 150 GeV and for masses greater than twice the Z mass with the first data if it does not exist. Other scenarios beyond the SM can be explored with the first data, as well. We plan to contribute with the extraction of the ZZ background.

Searches for Supersymmetry with large P_T jets and MET. *Prof. Pan, Mellado, one postdoc, and one graduate student.* The large phase-space and gluon luminosity at high energies opens a window of opportunity to explore the SUSY parameter space beyond the sensitivity of the Tevatron with the first data. Our group has invested significant time and talents and made major contributions to ATLAS's SUSY search efforts. We've developed effective SUSY search methods covering all important inclusive channels from zero to three leptons. Due to the large backgrounds with real and fake MET from the SM the reconstruction of MET is crucial, this is especially true for the SUSY searches in the first year or two when we don't have enough data to understand backgrounds with required precision. We plan to use our expertise in the TileCal, the reconstruction of MET and the identification of fake MET in order to contribute to the first searches. MC studies have indicated that the use of MET significance proposed here would greatly enhance the suppression against events with fake MET.

General searches for new physics *Prof. Pan, Mellado, one postdoc and one graduate student.* One of the most exciting prospects of the physics program of ATLAS is the search for the unknown. We have devised a methodology for a model independent way to search for deviations from the Standard Model. This comprises the development of multi-dimensional matrixes of in the phase-space defined by the kinematics, multiplicity, and very importantly, the physical characteristics (e.g. flavors and charges of leptons) of high P_T physics objects (leptons, γ s, τ s, jets, MET). Since it is very difficult, if ever possible, to develop data driven methods for all points in the phase space matrix, one practical strategy is to identify those phase space points at which the SM backgrounds are expected to be very small so the tolerance on the uncertainty of the background level can be relatively large. Various test statistics can be used in order to quantify the potential deviation from the SM. One of the most perspective ones in searches for unknown new physics the concept of rarity. The methodology of search for new physics proposed here is strongly tied to the ability to extract backgrounds by means of iterative procedures. Therefore, the reliance on detailed MC simulations is avoided.

**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**
 Institution Name University of Wisconsin - Madison
 Task/Title **Task H: ATLAS II (Pan & Mellado)**

Type of Position	Name	Activity #1	FTE Months on ATLAS II Research	# months funded by DOE-HEP University Program ATLAS II	Faculty Advisor
Faculty	Mellado, Bruce	ATLAS	2	2	
Faculty	Pan, Yibin	ATLAS	2	2	
Post Doc	Zhu, Yinchun	ATLAS	12	12	Mellado
Post Doc	Lapoire, Cecile	ATLAS	12	12	Pan
Grad Student	Kruse, Amanda	ATLAS	12	12	Mellado
Grad Student	Geng, Dalong	ATLAS	12	12	Mellado
Grad Student	New	ATLAS	12	12	Pan

Introduction

The experimental neutrino group at the University of Wisconsin-Madison (UW) led by Associate Professor Karsten Heeger has been a leader in the design, hardware, and simulation of the antineutrino detectors for the Daya Bay experiment. Daya Bay is a next-generation reactor experiment to measure the yet unknown neutrino mixing angle θ_{13} . Heeger's group has primary responsibility in the US project for the design, construction, and installation of the eight antineutrino detectors used in the experiment. The detectors measure with high precision the flux and energy of electron antineutrinos through the inverse beta-decay reaction and are designed to cancel the source systematics of the reactor flux between detectors placed near and far from the power plant. Following an intense period of design and construction from 2008-2010, the Wisconsin group is now preparing itself for the commissioning of the experiment and the start of data taking and analysis.

The Wisconsin Daya Bay group consists of Associate Professor Karsten Heeger, Senior Scientist Henry Band, Researcher Thomas Wise, postdoctoral researcher Wei Wang, and graduate students Michael McFarlane, Bryce Littlejohn, and Christine Lewis. In addition, Professor Baha Balantekin, Chair of the Physics Department and theoretical nuclear physicist, is a collaborator on the Daya Bay project. He is involved in the analysis topics of the group ranging from neutrino cross-sections to nuclear fuel or supernova topics. Some ten engineers and technical staff from the UW Physical Sciences Laboratory (PSL) in Madison currently support the project work of the Wisconsin group on Daya Bay. Their work is supervised and coordinated by the senior members of Heeger's group.

As US Level-2 manager for the Daya Bay Antineutrino Detector (AD) system Professor Heeger has overall responsibility for the design, construction, and commissioning of the eight antineutrino detectors for the experiment. Heeger oversees and provides scientific guidance for the design effort, supervises the fabrication and construction of detector components and their final assembly and commissioning on-site. In the daily management of the antineutrino detector effort Heeger is assisted by a senior engineer from the University of Wisconsin Physical Sciences Laboratory. As US L2 manager for the antineutrino detectors Professor Heeger has responsibility for about one third of the total US project cost (\$35M). The work of the Daya Bay group at Wisconsin is supported by this DOE HEP Task L and Daya Bay project funds.

Senior research scientist Henry Band joined the Daya Bay project in 2008 and brings extensive experience in subsystem management, testing, and commissioning from Babar and other experiments to the group. Henry has essentially completed his work on Babar and is now fully involved in Daya Bay. He is the Level-3 manager for detector assembly and installation of the antineutrino detectors and helps coordinate the technical effort at UW. He is also leading the development of techniques for leak checking the complex antineutrino detector assembly with the three detector zones. With his experience Henry will provide scientific guidance during the commissioning of the experiment and the start of data taking.

Thomas Wise is the Level-3 manager for the liquid handling system of the experiment. This includes the filling of the unique 3-zone antineutrino detectors and the measurement of their target mass to $< 0.1\%$. The number of target protons directly scales the observed antineutrino rate and is one of the critical parameters for the physics analysis of the experiment. It is the responsibility of the Wisconsin group to provide this parameter with sufficient accuracy. Researcher Thomas Wise and the PSL technical staff working on this task are supported by project funds. Tom is also the US coordinator for underground work related to the antineutrino detectors.

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Senior postdoctoral researcher, Wei Wang, is leading the simulation effort of the Daya Bay antineutrino detectors and the performance characterization of the detectors. He has been closely involved in the software development for Daya Bay and is an expert on Daya Bay analysis tools. Together with graduate students Bryce Littlejohn, Michael McFarlane, and Christine Lewis he is using detector simulations to evaluate the performance of the antineutrino detectors and study the impact of detector systematics on the “identicalness” of detectors and the scientific reach of the experiment. He is also leading the testing and integration of the liquid instrumentation in the Daya Bay antineutrino detectors that is needed to measure the number of target protons during data taking.

In Search of θ_{13} : A Gateway to New Physics

Reactor neutrino experiments have played a key role in the history of neutrino physics, from the first direct observation of the antineutrino by Reines and Cowan in 1956 to the searches for neutrino oscillation at Palo Verde, Chooz, and KamLAND. Experiments at reactors discovered the neutrino, made the first observation of reactor ν_e disappearance, and recently measured spectral distortion as a unique signature of neutrino oscillation. Non-accelerator neutrino experiments have provided unambiguous evidence for the flavor transformation and mixing of massive neutrinos. The size of this effect is parameterized by the neutrino mixing angles. Super-Kamiokande, SNO, and KamLAND have determined two of the three mixing angles in the U_{MNSP} neutrino mixing matrix :

$$U_{MNSP} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{atmospheric/accelerator } \nu} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_D} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_D} & 0 & c_{13} \end{pmatrix}}_{\text{reactor/accelerator } \nu} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{solar/reactor } \nu}$$

where $c_{ij}(s_{ij})$ is cosine (sine) of the mixing angle between neutrino generations i and j . θ_{12} and θ_{23} were found to be large and maximal, respectively. The third mixing angle, θ_{13} , is yet unknown. The best upper limit comes from the Chooz reactor antineutrino disappearance experiment. The observation of neutrino oscillation has far reaching implications. To date, it is the only evidence of physics beyond the standard model in particle physics. The pattern of the neutrino mixing parameters revealed so far is strikingly different from that of quark mixing. This already places significant constraints and guidance on the construction of models involving new physics. As one of the six neutrino parameters measurable in neutrino oscillations, θ_{13} , is a fundamental parameter of the new Standard Model.

The discovery of sub-dominant effects in $\bar{\nu}_e \rightarrow \bar{\nu}_{\mu,\tau}$ oscillation and the precise measurement of θ_{13} will have a profound impact on the future program in neutrino physics. The magnitude and value of the mixing angle θ_{13} and the phase δ_{CP} determine whether CP violation in the leptonic sector is significant. The observation of leptonic CP violation in neutrino oscillation experiments is only possible if θ_{13} is non-zero. The matter effect, which can be used to determine the mass hierarchy, also depends on the size of θ_{13} . If $\sin^2 2\theta_{13} > 0.01$, accelerator-based, long-baseline experiments using conventional technology with appropriate beam and detector upgrades can be used to search for CP violation. If θ_{13} is smaller, new experimental techniques and accelerators such as neutrino factories will be required to carry out a future program in

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precision neutrino oscillation physics. The size of θ_{13} will define the direction of future of neutrino oscillation research for the next decade and beyond. While CP violation in the quark sector is now well established, it remains an intriguing possibility in the neutrino sector. Should leptonic CP violation prove sizable, it could offer an attractive explanation for the observed matter-antimatter asymmetry in the Universe through a mechanism called leptogenesis.

A measurement of θ_{13} is a first step in answering some of the central questions in neutrino oscillation physics:

- Why are the neutrino mixing angles θ_{12} , θ_{23} , θ_{13} large, maximal, and small respectively?
- Are the symmetries CP, T, or CPT violated in the lepton sector?
- Can the mixing of massive neutrinos and CP violation explain the baryon asymmetry in the Universe?
- Is there a connection between the lepton and baryon sector?

A Precision Measurement of $\sin^2 2\theta_{13}$ at Daya Bay

The Daya Bay experiment located near Hong Kong, China, is a next-generation reactor experiment to measure the yet unknown neutrino mixing angle θ_{13} with a sensitivity of $\sin^2 2\theta_{13} < 0.01$ at 90% C.L. Daya Bay will use eight liquid scintillator detectors placed at three distances between 0.3-2 km from the Daya Bay and Ling Ao nuclear reactors to measure the rate and energy spectrum of electron antineutrinos through the inverse beta-decay reaction as a function of distance from the reactor source. A change in the observed electron antineutrino interaction rate as a function of distance due to the decrease in survival probability,

$$P_{ee} \simeq 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{atm}^2 L}{4E}\right) - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{sol}^2 L}{4E}\right)$$

would be an indication of sub-dominant $\bar{\nu}_e \rightarrow \bar{\nu}_{\mu,\tau}$ oscillation and allow the determination of $\sin^2 2\theta_{13}$. A relative measurement between detectors placed near and far from the reactors largely eliminates the reactor flux uncertainty and most of the detector-related systematics that limit absolute antineutrino flux measurements in other reactor experiments.

Eight Antineutrino Detectors (AD) form the core of the Daya Bay experiment. They will be distributed around the site as shown in Figure 1 with two detectors each at the Daya Bay and Ling Ao near sites and four antineutrino detector modules at the far site. This will facilitate the systematic cross-check with at least two detectors at each site. The antineutrino detectors use a 3-zone design with 20-ton target mass of Gd-doped liquid scintillator surrounded by 20 tons of undoped liquid scintillator to detect gammas leaking out of the central target volume. A mineral oil buffer region provides shielding of the center detector volumes from the radioactivity of the PMTs and the detector walls. A model of the Daya Bay antineutrino detectors as developed by the Wisconsin engineering team is shown in Figure 1.

Key to making a relative measurement between near and far detectors is the control of detector-related systematic uncertainties. Table 1 shows the breakdown of the detector-related relative systematic as estimated in the Daya Bay Physics Proposal. Understanding the relative target mass and composition and uncertainties in the energy cut efficiency are the largest contributions to the relative detector error budget. The energy cut at 6 MeV is used to identify the 8-MeV n-capture signal on Gd and separate it from the n-capture on H. Free protons in the detector make up the target for the antineutrinos. The event rate in the detector is proportional to the total mass of free protons. For the near and far detectors to be considered “identical” we require the relative number of target protons to be known to $< 0.28\%$ (baseline) or $< 0.1\%$ (goal)

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and the relative antineutrino detection efficiency to $< 0.25\%$ (baseline) and $< 0.15\%$ (goal). Through the combination of load cells and flowmeters we have demonstrated in the past three years an accuracy of < 0.05 in the measurement of the number of target protons.

Daya Bay is the largest and most sensitive reactor experiment under construction. Civil construction of the underground tunnel and experimental halls is well underway and the tunnel head is now within 50m of the experiment's far hall. Occupancy of the first experimental hall is expected for late 2010. The assembly of the first detector pair at Daya Bay is also reaching completion. After production of the liquid scintillator underground we expect filling of the first pair of detectors in late 2010 or early 2011. Data taking in the Daya Bay near hall is scheduled to start in Spring 2011.

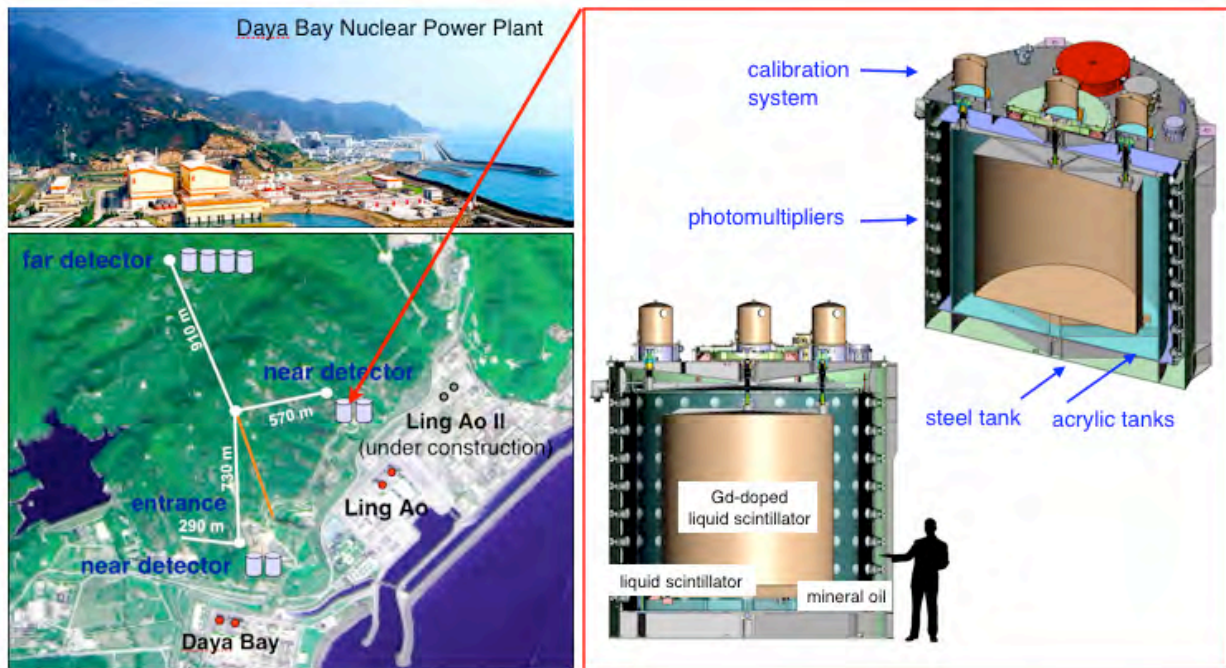


Figure 1: Left: Photograph and layout of the Daya Bay and Ling Ao power plants. The bottom panel shows the layout of the underground tunnels and the location of the antineutrino detectors. Right: Cross-sectional views of the antineutrino detector model developed by the UW group.

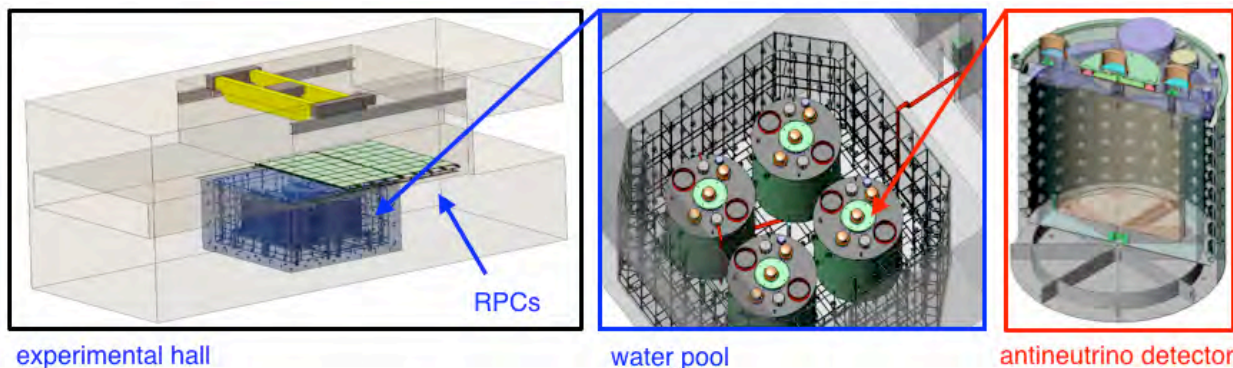


Figure 2: Left: Experimental hall at the Daya Bay far site with water pool, RPCs, crane, and antineutrino detectors. Middle: Water pool with four antineutrino detectors. Right: Single antineutrino detector.

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Source of uncertainty		Chooz (<i>absolute</i>)	Daya Bay (<i>relative</i>)		
			Baseline	Goal	Goal w/Swapping
# protons	H/C ratio	0.8	0.2	0.1	0
	Mass	-	0.2	0.02	0.006
Detector Efficiency	Energy cuts	0.8	0.2	0.1	0.1
	Position cuts	0.32	0.0	0.0	0.0
	Time cuts	0.4	0.1	0.03	0.03
	H/Gd ratio	1.0	0.1	0.1	0.0
	n multiplicity	0.5	0.05	0.05	0.05
	Trigger	0	0.01	0.01	0.01
	Live time	0	< 0.01	< 0.01	< 0.01
Total detector-related uncertainty		1.7%	0.38%	0.18%	0.12%

Table 1: Left: Detector-related systematic uncertainties of the Chooz experiment (absolute) compared to projections for Daya Bay (relative). Baseline systematics for Daya Bay have been demonstrated. The systematic error due to the target mass will be mitigated through load cell measurements and has been shown to be < 0.05%.

Daya Bay Program at the University of Wisconsin-Madison

The Wisconsin neutrino group has responsibility for a major part of the Daya Bay antineutrino detectors. The UW tasks that are supported by the Daya Bay project include:

1. Design of the acrylic target vessel system and fabrication of the 4m acrylic vessels. Shipment and delivery of the acrylic vessels to China and installation on-site.
2. Development of a liquid handling system for the filling of the antineutrino detectors and the precise measurement of the detectors' target protons to < 0.1%.
3. Development of instrumentation for the monitoring and safe operation of the antineutrino detectors.
4. Design and integration of the Daya Bay antineutrino detectors with particular emphasis on the detector interfaces for the acrylic vessels, overflow tanks, and detector instrumentation.
5. Technical oversight and management of the antineutrino detector assembly and detector installation effort at Daya Bay.

To complement these technical activities we propose a physics research program aimed at addressing critical issues related to the characterization and evaluation of the antineutrino detectors. In addition, we plan to participate in the first data-taking and analysis. With our detailed technical knowledge of the Daya Bay antineutrino detectors and their assembly, the Wisconsin Daya Bay group is in a unique position to make key contributions to the evaluation of detector systematics. The proposed research program will capitalize on the technical understanding we have developed of the antineutrino detectors for the past three years. Going forward we will apply this knowledge to better understand the detector response and intrinsic characteristics in the antineutrino data. Our research goals and approximate timeline are outlined below:

6. Measuring the detector target mass to <0.1%. This involves the development and characterization of liquid sensors, load cells, and flowmeter instrumentation used in the

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liquid handling system. The observed antineutrino event rate directly scales with the effective number of target protons inside the inner detector volume and is a critical input to the oscillation analysis. (2010-2011).

7. Modeling and simulation of the “as-built” antineutrino detectors. Evaluation of the as-built detector performance through simulation and calibration data and quantifying the “identicalness” of near-far detector pairs. Specifically, we will identify and study residual systematic effects due to imperfections in the detectors. This will include characterization of the optical and material properties of the as-built acrylic vessels, simulation of signal events and backgrounds, and development of detector performance parameters. (2010-2011)
8. Commissioning studies at the Daya Bay near site: With approximately 1000 events/detector/day the statistics of the detectors in the Daya Bay near hall will allow a high-precision measurement of the reactor antineutrino spectrum at the Daya Bay near site. Comparing the event rate and spectra recorded in both detectors we can perform a study of relative antineutrino detector systematics at the level of $<0.5\%$ and make a precise measurement of reactor spectra. This measurement will provide a general proof of principle of the near/far concept of the reactor θ_{13} experiments. Studies of the temporal variation of the fuel composition as well as background studies will also be possible. (2011)
9. Defining the physics potential of the Daya Bay near site: Using the general simulation package GLOBES as well the Daya Bay analysis framework we study the physics potential of detector operation at the Daya Bay near site. Specifically, we will attempt to better understand the sensitivity of the Daya Bay near hall to oscillation physics and potential systematic effects and backgrounds. (2012-2012)
10. Data taking with the full detector configuration: Commissioning and physics studies with all eight antineutrino detectors will begin in mid 2012. A first high-sensitivity search for θ_{13} with a sensitivity of $\sin^2 2\theta_{13}$ of $\sim 0.1-0.2$ can be performed after 6-12 months of data taking. Among other things we will study how important the reactor flux knowledge is to the oscillation result. (2012-2013)

The Wisconsin Daya Bay group currently involves three graduate students. Their thesis work reflects the above mentioned physics goals of our group. Tentative thesis titles are listed below along with their expected graduation dates:

1. *“A High-Precision Measurement of the Reactor Electron Antineutrino Flux and Spectrum At Daya Bay”*, Bryce Littlejohn, graduation expected in 2011
2. *“Search for the Neutrino Mixing Angle θ_{13} at the Daya Bay Near Site and Systematic Effects in the Antineutrino Spectrum and Rate”*, Mike McFarlane, graduation expected in 2011/2012
3. *“First Results from the Daya Bay Experiment: A Search for the Mixing Angle θ_{13} ”*, Christine Lewis, graduation expected in 2012/2013

With the completion of the first detector assembly on-site senior scientist Henry Band will increase his involvement in the Daya Bay analysis effort both locally at UW as well as in the collaboration to provide guidance and coordination of the physics effort.

Accomplishments in 2008-2010

Design of the Daya Bay antineutrino detectors:

Over the past three years the Wisconsin group has coordinated the design and R&D studies for the Daya Bay antineutrino detectors. This involved supervising engineering work, managing subsystem communication and interaction, and providing scientific guidance. The results of this design work are shown in Figures 1 and 2. In the last two years elements and parts for the Daya Bay antineutrino detector system have been fabricated in the US, China, and Taiwan, and were brought to the Daya Bay site for assembly.

Assembly of the first pair of antineutrino detectors:

The Daya Bay project has made a transition from design and planning to detector construction and assembly at Daya Bay. With the start of the detector assembly much of the focus of our work has shifted to Daya Bay. With scientist Henry Band, researcher Tom Wise, and senior PSL engineers, Wisconsin is currently providing the senior US oversight for the detector assembly on-site. Starting from an empty assembly hall the Wisconsin group provided much of the infrastructure and coordination needed to setup the detector assembly at Daya Bay. The stainless tanks, acrylic vessels, PMTs, and many other parts are now on-site for the assembly of the first detector pair. Band and Heeger oversee and manage the technical effort through weekly meetings between scientists and engineers in the US and China. The results of this work are shown in Figure 3 with images of the assembly of the first detector.

A special item in the Daya Bay antineutrino detectors is the nested acrylic target vessels. They are the core of the antineutrino detectors. They hold the liquid scintillators, define the target region, and must provide excellent optical properties for the detection of the antineutrino interaction. We have completed fabrication of the first two production vessels at Reynolds Polymer Technology in Colorado and successfully shipped them from Colorado to Daya Bay. The vessels are now used in the detector assembly at Daya Bay. The oversight for the vessel fabrication and integration on-site is provided by UW scientists Heeger, Band, and Wise. Graduate student Bryce Littlejohn has performed extensive optical studies on the vessels and evaluated their impact on the antineutrino detector performance.

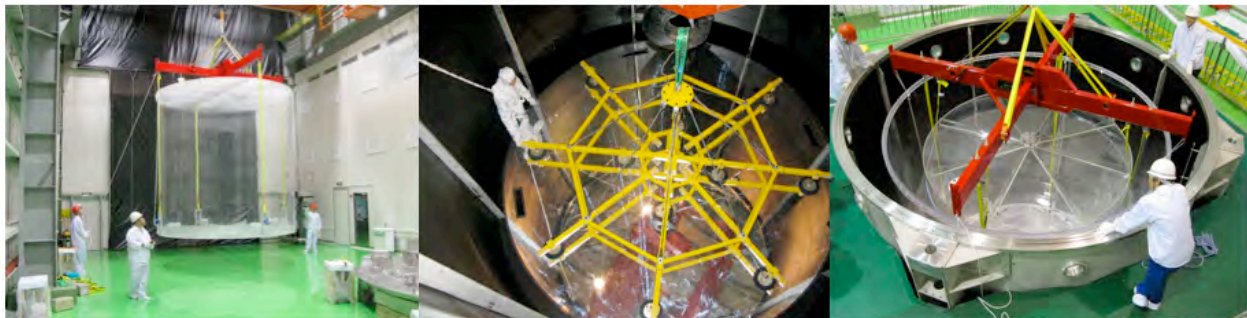


Figure 3: Lifting of the acrylic target vessel in the cleanroom at Daya Bay (left). Installation and inspection of the bottom acrylic reflector in the first antineutrino detector (middle). Installation and positioning of the 3m acrylic vessel inside the 4m acrylic vessel during the assembly of the first antineutrino detector.

Detector filling with liquids and target mass measurement:

The 3-zone detector design with thin-walled, nested acrylic vessel requires the

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simultaneous filling of the target vessels. At the time of the filling we also need to measure the target mass to precision of $< 0.1\%$. The filling process poses risks to the integrity of the vessels, PMTs, and other detector elements. The measurement of the target mass has been the largest systematic uncertainty in the experiment. In the past two years researcher Tom Wise together with engineers from PSL completed the detailed design of the filling and target mass measurement system. Long-lead items such as the teflon-lined ISO weighing tank were procured. See Figure 2. Many components and critical instrumentation including load cells and liquid level sensors have been tested in our lab at Wisconsin and were found to exceed the design requirements of the experiment in terms of accuracy and long-term stability. Load cells and Coriolis mass flowmeters provide the primary measurement of the target mass while capacitance and ultrasonic liquid level sensors are used to monitor the liquid vessels during data taking. With a demonstrated accuracy of 0.05% the load cells far exceeds our baseline requirement of 0.3% for the measurement of the target mass and will improve the ultimate sensitivity of the experiment. See Figure 5. A photograph and engineering model of the detector filling system are shown in Figure 4. The systematic uncertainty in the relative number of protons is controlled by precise measurements of the relative total target mass and volumes as well as filling the modules from a common batch of scintillator liquid so that the H/C ratio is the same to high precision.

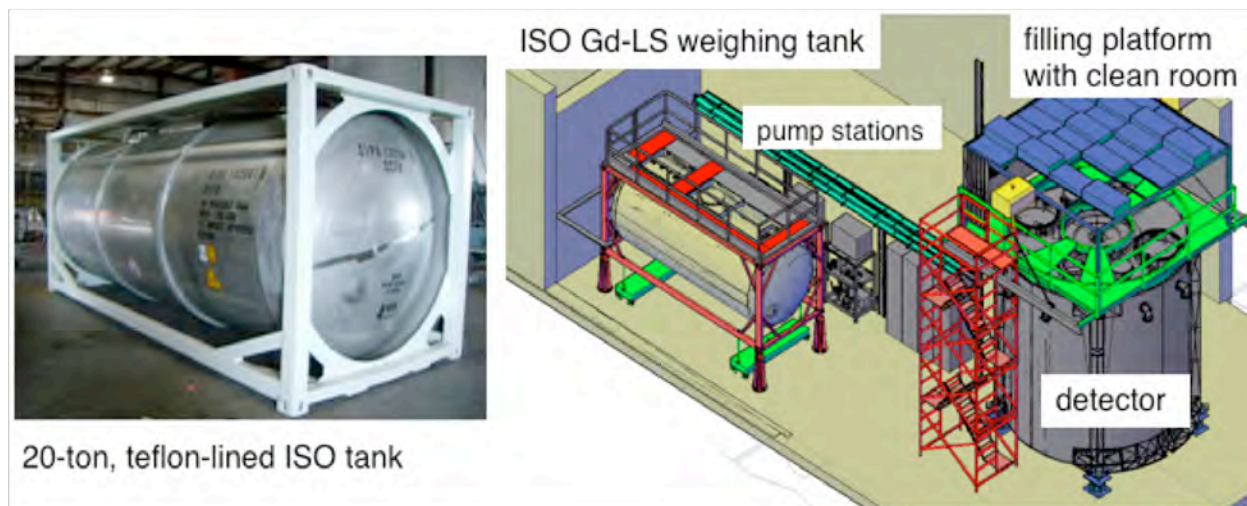


Figure 4: Photograph of the teflon-lined ISO tank for the target mass measurement (left) and engineering model of the liquid filling and target mass measurement system (right). The system will be assembled and tested at Wisconsin in summer 2010 and then commissioned at Daya Bay in late 2010 and early 2011.

Detector simulations and physics studies:

Over the past two years the simulation and physics studies at Wisconsin have focused on understanding the performance of the final detector design and evaluating the impact of non-identical detectors on the physics reach of the experiment. Postdoctoral researcher Wei Wang is leading the collaboration's effort to evaluate performance metrics of the antineutrino detectors with simulations based on the detailed engineering detector model that he implemented in the Geant4 simulation framework. Wei has organized a Daya Bay analysis workshop in Madison summer 2010 to coordinate the simulation effort and help people get involved in the Daya Bay analysis framework. Graduate student Bryce Littlejohn has used Geant4 simulations to study the impact of variations in the acrylic light transmission and reflection on the optical model and efficiencies of the detector. Using the GLOBES analysis framework graduate students Michael

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McFarlane and Christine Lewis have performed a study of the sensitivity and discovery reach of the Daya Bay experiment for various running times and detector systematics. See Figure 5. The discovery reach of Daya Bay to non-zero θ_{13} shortly after turn-on is of particular interest for the planning of future long-baseline experiments. With only one year of running time and a conservative relative detector systematics of $\sigma_d = 0.38\%$ we find the 3- σ discovery reach to be $\sin^2 2\theta_{13} = 0.02$. For a running time of 5 years and $\sigma_d = 0.12\%$ the Daya Bay experiment can provide a 3-sigma discovery of $\sin^2 2\theta_{13} = 0.01$ or a 5- σ discovery at $\sin^2 2\theta_{13} = 0.02$ for all currently allowed values of Δm^2_{23} . A systematic program of detector simulations and physics studies is underway to provide detailed understanding of the final detector design in anticipation of first data taking in spring 2011.

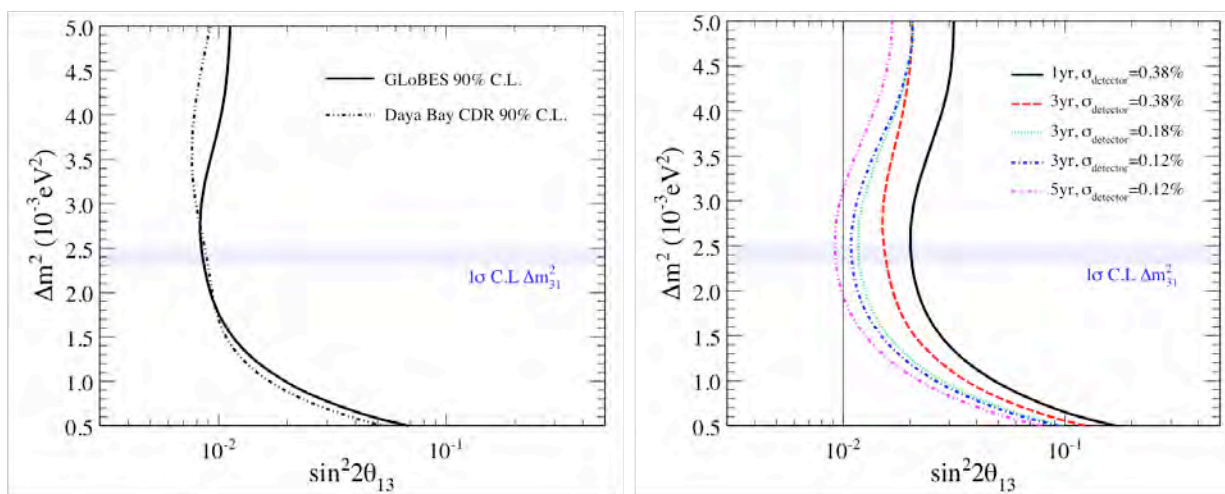


Figure 5: Left: Comparison between the sensitivities of Daya Bay to $\sin^2 2\theta_{13}$ as predicted in our GLOBES calculation and the Daya Bay design report. We find good agreement in the allowed region of Δm^2_{23} . The remaining difference is partially due to the difference in the modeling of the number of detectors and reactors cores and the χ^2 minimization. Right: The 3- σ discovery reach of the Daya Bay experiment for different running times and detector systematics. The detector systematics σ_d of 0.38% and 0.18% correspond respectively to the baseline and goal values of the Daya Bay experiment.

Daya Bay in 2011: Turn-on and Commissioning of the First Detector Pair

In the coming year the Daya Bay experiment will complete the installation of the first two antineutrino detectors in the experimental hall at the Daya Bay near site and start data taking. This includes the filling of the detectors and the target mass measurement. The operation of the first two detectors side-by-side in the same underground experimental hall will be a major milestone for the Daya Bay project. It will allow the direct comparison of the reactor antineutrino spectra measured with two detectors in the same experimental hall and provides a direct measure of the residual, relative detector systematics. With about 900 signal antineutrino events per detector per day, three months of data are sufficient to perform a systematic comparison of the two detectors to $<0.4\%$. Data from the first pair of detectors will allow us to study detector systematics, backgrounds, and to make the highest-precision measurement to date of reactor antineutrino spectra. During this period scientists in the Wisconsin Daya Bay group will transition from the current design, assembly, and simulation work to data analysis. I expect that all scientists of the Wisconsin group will participate in this first round of analysis. For this

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analysis Wisconsin will provide at a minimum a detailed and thorough analysis of the number of target protons in the detector and the impact of possible variations from the acrylic vessels.

Daya Bay in 2012: Physics Studies with the Daya Bay Near Sites

With support of the engineering team and technical personnel from the Physical Sciences Laboratory, the detector assembly at Daya Bay will continue through 2012. At the same time Wisconsin scientists will focus on physics studies with the Daya Bay near site. Based on his experience Henry Band will help guide the detector commissioning effort. Postdoctoral researcher Wei Wang will perform detailed comparisons of the simulated detector performance with first data and optimize the Monte Carlo simulations based on data. The assembly of detectors #3-8 in parallel with the turn-on of the first two detectors provides a unique opportunity for training students and postdocs in both hardware work and data analysis. This will provide the experiment with the required in-depth understanding of the detector performance to reach the ambitious sub-percent precision.

Daya Bay in 2013: Precision Measurement of θ_{13} with the Full Detector Configuration

Following the installation of the remaining antineutrino detectors in 2012 data taking with the full experiment will begin in late 2012. At that time we have already analyzed data from detectors at the Daya Bay near site and all analysis software and tools have been exercised. Given the statistical power of the Daya Bay experiment and the implications of a non-zero θ_{13} I anticipate the need for a quick first θ_{13} result from Daya Bay in 2013. During this time the Wisconsin group will fully focus on the Daya Bay analysis to make a contribution to the first results from Daya Bay. With the graduate student theses outlined above, the postdoc effort in detector simulation, and our experience from previous experiments I expect us to be in an excellent position to lead one of the first oscillation analyses in Daya Bay.

Beyond Day Bay

The measurement of θ_{13} is a gateway to understanding the physics behind many fundamental questions in neutrino physics: Why are the neutrino mixing angles θ_{12} , θ_{23} , θ_{13} large, maximal, and small respectively? Are the symmetries CP, T, or CPT violated in the lepton sector? Can the mixing of massive neutrinos and CP violation explain the baryon asymmetry in the Universe? And is there a connection between the lepton and baryon sector?

A long-baseline experiment such as the LBNE project at FNAL and Homestake is an ideal project to follow Daya Bay. It will make a precision measurement of a suite of oscillation parameters if θ_{13} is found to be non-zero and $\sin^2 2\theta_{13} > 0.01$. Professor Heeger is the institutional representative from Wisconsin to the LBNE collaboration and keeps up with the developments of this project. While participation in a long-baseline neutrino experiment such as LBNE would be a natural extension of Wisconsin's current work in precision neutrino oscillation physics most of the UW neutrino group is currently tied up with Daya Bay. The completion of the Daya Bay antineutrino detectors and first physics analysis with Daya Bay are the short-term priority. As the LBNE project evolves over the coming years senior scientist Band and others may want to contribute to some of the open R&D questions for the LBNE detectors as time and expertise permit.

Task L: A Precision Measurement of $\sin^2 2\theta_{13}$ at Daya Bay

Relevant Publications in 2008-2010

1. *Design and Simulation of the Daya Bay Antineutrino Detectors*, X. Guo et al. (Daya Bay Collaboration), In preparation (2010).
2. *Study of the Sensitivity of the Daya Bay Reactor Neutrino Experiment to $\sin^2 2\theta_{13}$ Using GLOBES*, K.M. Heeger, C. Lewis, M. McFarlane, W. Wang, P. Huber, In preparation (2010).
3. *Solar fusion cross sections II: the pp chain and CNO cycles*, E. G. Adelberger et al., arXiv:1004.2318, Submitted to Rev.Mod.Phys. (2010)
4. *Study of the Production of Radioactive Isotopes through Cosmic Muon Spallation in KamLAND*
S. Abe et al. (KamLAND Collaboration), Phys. Rev. C 81, 025807 (2010)
5. *UV Degradation of the Optical Properties of Acrylic for Neutrino and Dark Matter Experiments*
B. Littlejohn, K.M. Heeger, T. Wise, E. Gettrust, and M. Lyman, JINST 4:T09001 (2009)
6. *The KamLAND Full-Volume Calibration System*
B.E. Berger et al. (KamLAND Collaboration), JINST 4:P04017 (2009)
7. *Measurement of the Cosmic Ray and Neutrino-Induced Muon Flux at the Sudbury Neutrino Observatory*
B. Aharmim, et al. (SNO Collaboration), Phys.Rev.D80:012001 (2009)
8. *Independent Measurement of the Total Active ^8B Solar Neutrino Flux Using an Array of ^3He Proportional Counters at the Sudbury Neutrino Observatory*,
B. Aharmim, et al. (SNO Collaboration), Phys. Rev. Lett. 101, 111301 (2008).
9. *Precision Measurements of Neutrino Oscillation Parameters with KamLAND*
S. Abe et al. (KamLAND Collaboration), Phys. Rev. Lett. 100, 221803 (2008).
10. *Neutrino Oscillation Physics with KamLAND: Reactor Antineutrinos and Beyond*,
K.M. Heeger, book edited by J. Thomas and T. Vahle, World Scientific, 71-89 (2008).

Invited Talks of Wisconsin Group in 2008-2010

1. *Status and Prospects of Neutrino Oscillation Experiments*, K.M. Heeger, International Conference of Nuclear Physics, INPC2010, Vancouver, BC, Canada, July 4-9, 2010
2. *Probing Neutrino Mixing with Non-Accelerator Experiments*, K.M. Heeger, APS April/AAPT Meeting 2010, Washington, DC, USA, February 13-17, 2010

Task L: A Precision Measurement of $\sin^2 2\theta_{13}$ at Daya Bay

3. *Reactor Neutrino Experiments: Recent Results and Future Prospects*, K.M. Heeger, CTP International Conference on Neutrino Physics in the LHC Era, Luxor, Egypt, November 15-19, 2009
4. *Understanding Neutrino Mass and Mixing with Low-Energy Experiments*, K.M. Heeger, Inaugural Fall Meeting of the APS Prairie Section Iowa City, Iowa, November 12-14, 2009
5. *The Daya Bay Reactor Neutrino Experiment*, W. Wang, NuFact09, Chicago, IL, July 20-25, 2009
6. *Reactor Neutrino Experiments*, K.M. Heeger, 2009 International Neutrino Summer School, Fermilab, Batavia, IL, USA, July 6-17, 2009, <http://projects.fnal.gov/nuss/>
7. *A High-Precision Measurement of θ_{13} with the Daya Bay Reactor Neutrino Experiment*, K.M. Heeger, TAUP 2009, International Conference on Topics in Astroparticle and Underground Physics, Laboratori Nazionali del Gran Sasso, Italy, July 1-5, 2009
8. *Understanding Neutrino Mass and Mixing with Low-Energy Experiments*, K.M. Heeger, 4th International Symposium on Symmetries in Subatomic Physics, Taipei, Taiwan, June 2-5, 2009
9. *The Daya Bay Experiment*, B. Littlejohn, colloquium at Marquette University on April 16, 2009
10. *Antineutrino Detectors for a High-Precision Measurement of the Neutrino Mixing Angle θ_{13} at Daya Bay*, TIPP09, Technology and Instrumentation in Particle Physics Tsukuba, Japan, March 12-17, 2009
11. *Precision Measurements of Neutrino Oscillation Parameters with Reactor Neutrinos*, K.M. Heeger, Les Rencontres de Physique de la Vallée d'Aoste, La Thuile, Aosta Valley, Italy, March 1-7, 2009
12. *Probing New Physics in Neutrino Experiments*, K.M. Heeger, colloquium at Columbia University, New York, NY, USA, February 16, 2009
13. *Neutrino Masses and Oscillations: Status and Prospects*, K.M. Heeger, colloquium at Technical University Munich (TUM), Munich, Germany, February 2, 2009
14. *Probing New Physics in Neutrino Experiments*, K.M. Heeger, colloquium at Illinois Institute of Technology, Chicago, IL, USA, December 4, 2008

Contributed Conference Talks of Wisconsin Group in 2008-2010

1. *Antineutrino Detectors for a High-Precision Measurement of the Neutrino Mixing Angle θ_{13} at Daya Bay*, K.M. Heeger, Neutrino 2010, Athens, Greece, June 14-19, 2010

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2. *Status and Sensitivity of the Daya Bay Reactor θ_{13} Experiment*, K.M. Heeger, Third Joint Meeting of the Nuclear Physics Divisions of the American Physical Society and The Physical Society of Japan, Hawaii, HI, USA, October 13-17, 2009

3. *Design, Simulation, and Performance of the Daya Bay Antineutrino Detectors*. K.M. Heeger, APS April Meeting, Denver, CO, USA, May 2-5, 2009

4. *Precision Measurement of Target Mass in the Antineutrino Detectors of the Daya Bay Reactor θ_{13} Experiment*, P. Mende, APS DNP Meeting, Oakland, CA, October 24-26, 2008

5. *Design and Simulation of the Daya Bay Antineutrino Detectors*, W. Wang, APS DNP Meeting, Oakland, CA, October 24-26, 2008

**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**
 Institution Name University of Wisconsin - Madison
 Task/Title **Task L: Daya Bay**

Type of Position	Name	Activity #1	Activity #2	FTE Months on Daya Bay Research	# months funded by DOE-HEP University Program Daya Bay	Faculty Advisor
Faculty	Heeger, Karsten	Daya Bay	CUORE	1	1	
Faculty	Balantekin, Baha	Daya Bay	Nuc Theory	0.5	0	
Sr. Scientist	Band, Henry	Daya Bay		12	12	
Post Doc	Wang, Wei	Daya Bay		12	12	Heeger
Grad Student	McFarlane, Michael	Daya Bay		12	12	Heeger
	Littlejohn, Bryce	Daya Bay		12	12	Heeger
	Lewis, Christine	Daya Bay		12	0	Heeger
Researcher	Wise, Tom	Daya Bay		12	0	Heeger
Computing	Rader, Stephen			1.225	1.225	
Computing	Radtke, Matthew			1.225	1.225	

Karsten Heeger 1 month funded by DOE Nuclear
 Baha Balantekin cost share of his 9 month effort toward Daya Bay.
 Tom Wise funded by Daya Bay Project funds.
 Christine Lewis funded by Daya Bay Project funds.

TASK T: CMS at the LHC

1 Overview

The LHC will operate at up to 7 times the energy and 100 times the luminosity of the Fermilab Tevatron and will search for the mechanism of particle mass generation, supersymmetry, which introduces a partner for each known particle, stabilizes the Higgs mass and provides a candidate for the dark matter making up most of the universe, extra dimensions and other exciting new physics possibilities. The LHC started taking physics data at the end of March and is expected to continue running through 2011 with up to 1 fb^{-1} at 7 TeV center of mass energy. After a year shutdown, we expect running close to 14 TeV with luminosity climbing to $50 \text{ fb}^{-1}/\text{year}$ during 2013 and 2014. There are several physics channels with the potential for discovery at the LHC. New physics producing resonances could include a new Z' , e.g. any new heavy gauge boson or from models with compact extra dimensions. Spectacular multi-jet, multi-lepton and missing energy signatures would also be produced by SUSY, with production of ~ 100 events per day at luminosities of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ for squark and gluino masses of $\sim 1 \text{ TeV}$. Almost all of the allowed Higgs mass range will be explored by CMS with 10 fb^{-1} , and with 30 fb^{-1} is covered to more than 7σ over the whole range.

In order to search for these new physics phenomena at the TeV scale, the UW group of Profs. Duncan Carlsmith, Sridhara Dasu, Matt Herndon, Wesley Smith and Distinguished Scientist Dr. Richard Loveless, has leadership roles in the Compact Muon Solenoid (CMS) collaboration at the LHC. The UW group built, commissioned, operates, maintains major parts of CMS: the trigger system, including the calorimeter level-1 (L1) trigger and higher level triggers (HLT), the endcap muon system (EMU), including its infrastructure and alignment, software for simulation and event processing and a leading Tier-2 US CMS computing facility, including supervision of worldwide MC production. The construction and commissioning of the trigger, muon and Tier-2 systems carries with it the obligation to maintain, monitor and do physics analysis with them. This commitment and the need to leverage the group's detector and physics knowledge to meet the CMS physics goals, requires a significant level of base program effort.

UW has leading CMS management, design, construction, operations and physics roles. Prof. Wesley Smith has served as the CMS Trigger Coordinator since 2007 with responsibility for the CMS event selection from detector to disk through the L1 and HLT. Prof. Smith was also the CMS Trigger Project Manager from 1994 until the operations phase began in 2007, with responsibility for construction, installation and commissioning of the overall CMS L1 trigger. Prof. Smith also serves on the CMS Executive and Management Boards, Electronics Systems Steering Committee and on the CMS Upgrade Management Board as Chair of the CMS Upgrade Peer Review Board, which reviews all CMS upgrade R&D proposals and programs. For US CMS, Prof. Smith served as the Trigger L2 Construction Project Manager and now serves as the Trigger L2 Operations Project Manager and is on the Project Management Group, Institutional Advisory Board, and Technical Advisory Board. Prof. Sridhara Dasu serves as the US-CMS Level-3 Manager for the Calorimeter Trigger, the CMS Manager for the Regional Calorimeter Trigger (RCT) and the Manager of the CMS Tier-2 Computing Center at Wisconsin. Prof. Dasu is the Upgrade Physics Coordinator following his service as the co-convener of the CMS Electroweak Physics Group and before that as the Online Selection Physics Group co-convener. He is also a member of the CMS Upgrade Management Board. He also serves on the Executive Committee of the US LHC Users Organization. Prof. Duncan Carlsmith is the US CMS L3

Manager of EMU alignment and served on the US CMS Election Committee. In support of their activities, UW granted full-year sabbaticals to Prof. Dasu in 2007-8, Smith in 2008-9 and for Fall 2009, and Carlsmith for Fall 2008. UW Distinguished Scientist Dr. Richard Loveless is the US CMS EMU Deputy Operations Manager, CMS EMU Technical Coordinator and serves on the US CMS Election Committee. Dr. Loveless also served as the CMS EMU Project Manager and both US CMS EMU Level-2 Common Projects and EMU Construction Project Manager. UW Associate Scientist Dr. Armando Lanaro is the US CMS Level-3 Manager in charge of Endcap Muon System Integration, the deputy convener of the EMU Detector Performance Group and the US CMS L3 EMU on-site operations manager. UW Associate Scientist Dr. Pamela Klabbbers is the CMS Calorimeter Trigger Technical Coordinator. UW Associate Scientist Dr. Sascha Savin is the co-convener of the CMS Trigger Performance Group. UW Assistant Scientist Dr. Monika Grothe is in charge of the electroweak physics group data validation, a member of the CMS Conference Committee and was the CMS Forward Physics Convener. UW Associate Researcher Dr. A. Mohapatra is the CMS Distributed monte carlo Production Co-coordinator and is in charge of US CMS Tier-2 production.

2 CMS Trigger Activity

2.1 Trigger Overview and Responsibilities

For the nominal LHC design luminosity of 10^{34} , 17 events on average occur at each beam crossing with a frequency of 25 ns. This input rate of 10^9 interactions every second is reduced by a factor of 10^7 to 150 Hz, the maximum rate that can be archived by the on-line computer farm. CMS reduces this rate in two steps. At Level-1 (L1) all data is stored for 3.2 μ s, after which no more than 100 kHz of the stored events are forwarded to the High Level Triggers. The L1 system uses custom electronics to identify, find the position and sort in importance physics objects such as electrons, muons, jets, and taus as well as the sum of missing energy. The High Level Trigger (HLT) system relies upon networked commercial processors and runs algorithms eventually approaching offline reconstruction.

As the CMS Trigger Coordinator, Prof. Smith has overall responsibility for the online L1 and HLT CMS trigger. Prof. S. Dasu serves as the US-CMS Level-3 Manager for the Calorimeter Trigger. Prof. Dasu was responsible for the design and simulation of the L1 calorimeter triggers in the Technical Proposal and Trigger Technical Design Report. UW Scientist Dr. Pamela Klabbbers is the Calorimeter Trigger Technical Coordinator. UW Scientist Dr. Alexander Savin is the co-convener of the CMS Trigger Performance Group. U. Wisconsin has institutional responsibility for the Regional Calorimeter Trigger (RCT).

2.2 Regional Calorimeter Trigger

The CMS level-1 electron/photon, τ -lepton, jet, and missing transverse energy trigger decisions are based on the level-1 Regional Calorimeter Trigger (RCT). UW designed, built and operates the RCT. The RCT receives input from the brass and scintillator CMS hadron calorimeter (HCAL) and PbWO₄ crystal electromagnetic calorimeter (ECAL), that extend to $|\eta|=3$. An additional hadron calorimeter in the very forward region (HF) extends coverage to $|\eta|=5$. The RCT uses a deadtimeless pipelined architecture that processes 2 Terabits/sec of HCAL, ECAL and HF data from 40 MHz of crossings and forwards the found electron/photon, jet and tau candidates to the Global Calorimeter Trigger (GCT) for refining, sorting and transmission to the level-1 Global Trigger.

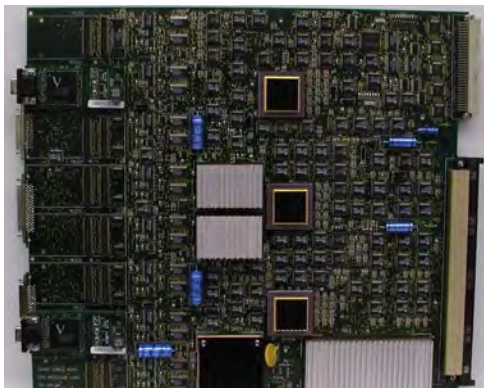


Figure 1. One of 154 RCT Receiver Cards with 2 mezzanine cards.

2.3 RCT Progress and Plans

The UW RCT effort is led by CERN-resident Scientists Pamela Klabbbers, Alexander Savin and Monika Grothe and Madison-resident UW Engineer Tom Gorski, along with technician Robert Fobes and CERN-resident UW Postdoc Jonathan Efron. UW maintains the full 22 (18 + spare/test) 9U-crate 1800-card system based on 5 distinct custom (UW-designed) high-speed ASICs and including 28 high-speed 160 MHz backplanes, 154 Receiver Cards (shown in Figure 1), 154 Electron ID Cards, 25 Jet Summary Cards, 25 Clock Cards, 25 Crates with power supplies and a 1400 card 4 Gbit/s copper serial data link mezzanine card

system with associated testing cards. This system was installed and commissioned at CERN by the personnel mentioned above and CERN-resident UW graduate students Michail Bachtis, Kira Grogg, Christos Lazaridis, Jessica Leonard, and Marc Weinberg. During 2011-2012, graduate students Isobel Ojalvo, Will Parker, Ian Ross and Joshua Swanson will be taking over the RCT duties of the UW students who have already worked 2-3 years on the RCT (Leonard, Grogg, Lazaridis and Weinberg) as they finish their theses. Figure 2 shows one of 18 fully operating RCT crates in the underground counting room (USC55) at CERN. Our goals for the RCT for the next few years are to maintain reliable RCT operations with beam as well as operating and maintaining a testing facility in the CMS Electronics Integration Center for repair and software development.

2.4 L1 Trigger Software

The development of the RCT monitor, control and emulation software is a UW responsibility. Scientists P. Klabbbers, M. Grothe, A. Savin, Postdoc J. Efron and Prof. S. Dasu, have all developed software with the students for testing and configuring the trigger hardware. This software has been integrated with the CMS online environment by J. Efron and the offline environment by A. Savin. The onset of beam operations and physics data are providing valuable experience leading to extensive optimization of this software. Our scientific personnel and students have improved these software libraries and integrated them with the Trigger Supervisor and Run Control software. The ever-changing beam and detector conditions along with the evolving CMS software environment require continuous effort to keep the RCT operating.



Figure 2. Installed RCT Crate.

UW Scientist P. Klabbbers developed the RCT online crate testing software. UW Postdoc J. Efron and student K. Grogg have written and are operating a full 18-crate system test that loads detailed patterns into the logic, shifting them through at speed in a sequence of tests that fully validate the RCT hardware. This procedure is executed before most LHC fills. This test is currently being expanded to include inserting patterns in the ECAL and HCAL Front-Ends to test the performance of the full Calorimeter Trigger chain. Under the supervision of Postdoc Efron, graduate student Ojalvo will be taking over this task from Ms. Grogg during 2011.

The L1 regional calorimeter trigger emulator is a critical piece of the CMSSW software that duplicated bit by bit the exact function of the hardware. It is needed for online and offline diagnostics, and for simulation of the trigger system, and has been developed, tested and compared against detector data by graduate student J. Leonard under the supervision of Prof. S. Dasu. Graduate Student M. Bachtis is now maintaining the emulator and checking its performance with data collected in CMS cosmic-ray and colliding-beam operations. Postdoc J. Efron is also using the emulator to develop the RCT calibration to improve the overall calorimeter trigger performance. UW Graduate student Ian Ross will be taking over the emulator support in the latter part of this year as Mr. Bachtis begins to write his thesis.

The RCT Trigger Supervisor cell is the interface between the CMS Run Control Trigger Interface, called the Central Trigger Supervisor, and the RCT. It configures (calibrations, thresholds, masked channels, etc.), starts and stops RCT operation with the rest of the trigger systems, and processes status information and alarms. It was written and tested by UW scientist M. Grothe. UW graduate student C. Lazaridis now maintains and upgrades the software as

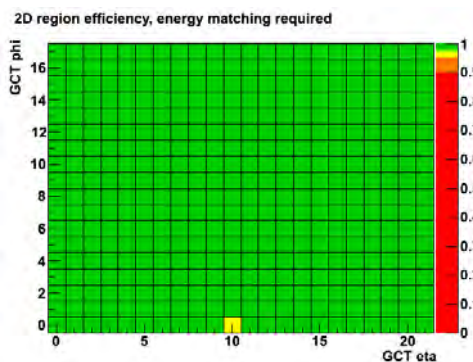


Figure 3. RCT DQM η - ϕ map with one inefficient calorimeter trigger tower.

needed under the supervision of P. Klabbers and M. Grothe. Mr. Lazaridis has also been working on the development of alarm infrastructure for all trigger systems in the Trigger Supervisor as part of our general trigger responsibilities. UW Graduate student Joshua Swanson will be taking over the Trigger Supervisor support in the latter part of this year as Mr. Lazaridis begins to write his thesis.

The RCT online, offline, and stand-alone Data Quality Monitoring (DQM) has been written and tested by UW Scientist A. Savin and graduate student M. Weinberg. The first of these three tasks reads and analyzes the data, as it is being taken online, makes histograms, tests these

against specific criteria and issues errors and alarms for immediate actions to be taken when required. The second and third analyze the data written to disk offline using detailed high statistics histograms and checks to determine if the RCT function meets the criteria to declare the run usable for physics purposes. An example online-DQM histogram in Figure 3 shows how the RCT DQM can be used to diagnose problems in the calorimeters by identifying inefficient calorimeter trigger towers. Dr. Savin has overall responsibility for Trigger Monitoring as co-convener of the CMS Trigger Performance Group. UW Graduate student Will Parker will be taking over the DQM support next year as Mr. Weinberg writes his thesis.

The set-up and parameters of all the programmable aspects of the RCT, including the memory lookup tables and the list of channels shut off due to noise or other malfunctions are derived from the online Configuration Database. The actual sets of configurations loaded, the online status, including errors and alarms, and all other information about the state of the RCT are recorded in the conditions databases. Both of these have analogous offline databases that are interfaced to the RCT emulator so that it can duplicate the function of the hardware in the simulation. UW Postdoc J. Efron writes and maintains these databases both online and offline. These databases are critical for analyzing the trigger efficiency for physics analysis as they include such information as the trigger algorithm settings, calibration and shut-off channels.

Dr. Jonathan Efron also is responsible for the RCT calibration. This involves analyzing the energies of triggered objects at threshold and then matching these thresholds to the offline

reconstructed energies so that accurate threshold setting can be placed for online triggers that reflect the correct offline energies.

Dr. Monika Grothe has provided the RCT Detector Controls System (DCS) for the RCT monitoring hardware developed by UW engineer T. Gorski. Graduate student K. Grogg assisted her and is now responsible for maintenance under the supervision of Dr. Grothe. Each of the 10 RCT racks is equipped with a Rack Monitoring Card (RMC). The components of the RCT DCS are a UW-produced software package based on the CERN-adopted slow control software framework (PVSS), installed on a Windows PC in the underground electronics cavern working with the 10 RMCs with custom firmware developed and maintained by T. Gorski. Under the supervision of Dr. Grothe, UW Graduate student Isobel Ojalvo will be taking over the DCS support next year as Ms. Grogg writes her thesis.

2.5 L1 Trigger Maintenance and Operations

Our group must sustain a major effort to monitor, operate, and evaluate the performance of the RCT. We perform tests daily to ensure it is working correctly and properly calibrated. We maintain and update lists of bad channels (either dead or mis-calibrated) as part of the data quality documentation. We also diagnose and repair RCT electronics modules, cables, power supplies and system components. Since the RCT is a critical item for CMS, during running two UW RCT experts are on call 24 hours a day. We keep a quantity of spares to provide quick solutions to problems. UW scientist P. Klabbbers is able to handle most repairs on the defective modules at CERN and after repair and retesting they are returned to service as spares. Postdoc Efron and the students assist with these repairs. Over time a number of difficult-to-repair cards and other problems accumulate that require the services of UW-based expert engineer, T. Gorski at CERN.

A key facility is our RCT testing lab in the CMS Electronics Integration Center (EIC) in Building 904 on the CERN Preveessin site. This environment duplicates in detail that found in USC55 and allows realistic and complete testing of all the RCT cards independent of data-taking operations. Scientist P. Klabbbers is responsible for setting up and maintaining this facility and it enables us to provide local reliable testing, maintenance and repair of the RCT, which pays off in dependable operation. Postdoc J. Efron and the students assist her with this.

A major feature of the RCT is its programmability and flexibility. Changing beam conditions or physics priorities lead to requests for trigger modifications, causing us to design a modified trigger, study it with data and monte carlo simulation and evaluate its effects on physics signals and background rejection. The need to modify the trigger, particularly in the early running, causes this to be continuously worked on by our scientists, postdoc and students.

The never-ceasing demands of 24x7 operation, being on call and taking CMS shifts, changing physics priorities, operational conditions, and rising luminosity require a significant staff, particularly if these individuals are to have the time to do the physics analysis described below. A key part of the team is students. It is very important to provide the excellent training of working on the RCT in order to prepare the next generation of trigger experts. We believe that a minimum team of six students resident at CERN is appropriate. Our plan has two students starting out and learning the system in their first year, two experienced students who lead shifts with the scientists and train the younger students, and two senior students working mostly on their theses, but available for occasional assistance and consultation in their third year. Since students do not flow through academia at such a steady pace, we anticipate having an additional

student working in the group occasionally. Exceptionally at the moment, the delay of almost two years in the LHC schedule presents an unusual situation where a number of students have completed the usual year we ask to work on the hardware and are now preparing to do their theses with the first data. We expect to graduate them once a sample of analyzable data is accumulated. Meanwhile, they will help with operating the trigger during the long duration of the first data run and training of the new students, while they work on their analyses.

2.6 Higher Level Triggers

Prof. W. Smith was appointed as the (first) CMS Trigger Coordinator in 2007 and was subsequently renewed for at least another two years through 2011, with responsibility to oversee the deployment, configuration and monitoring of the entire CMS trigger system from level-1 through the data storage. Earlier from 2005 until 2008, when Prof. S. Dasu was the online selection physics group co-convener, he had the responsibility of developing trigger menus and their optimization for not only the level-1 triggers but also those running in software at higher levels.

Prof. Smith leads the Trigger Coordination, which includes the Trigger Studies Group (TSG) of about 100 CMS physicists that is responsible to ensure that the CMS trigger is optimized for any given time/luminosity, including integration of algorithms and code provided by detector physics groups and physics object groups into the trigger code, creation of trigger tables via representatives from each detector and physics group, and the monitoring of physics performance of the combined online selection (L1 + HLT). The Trigger Studies Group develops sets of triggers that are designed for different luminosity, beam and running conditions. These triggers are required to have well-defined methods for determining efficiency, purity, and performance evaluation/monitoring and to produce the data sets needed for physics, trigger studies, detector calibration, alignment and monitoring.

UW Associate Scientist Sascha Savin is co-convener of the TSG Trigger Performance Group of about 30 CMS physicists who evaluate the physics performance of the individual trigger algorithms (physics efficiency of signal events, background rejection, monitoring) with Data and monte carlo. They perform online trigger Data Quality Management (DQM) while the experiment is running to check that the trigger is working properly. They do offline trigger DQM to evaluate the trigger performance with higher statistics and to certify each run as usable for physics. They are also responsible for validating the online and offline software releases for proper trigger function.

There are many major challenges facing the implementation, evaluation and monitoring of the proper trigger algorithms, including determining their efficiency, purity and acceptance, the samples needed for these determinations, and the execution time for the algorithms and associated data unpacking. UW Students Mike Anderson, Mike Bachtis, Jeff Klukas and Joshua Swanson are working with Profs. Dasu, Herndon and Smith and Dr. Savin on the tau, muon, photon and electron HLT studies. Mike Anderson is working with Prof. Dasu on validating and improving photon trigger algorithms. Mike Bachtis is working with Dr. Savin on validating and improving tau trigger algorithms involving muons and has achieved substantial gains in trigger efficiency and background rejection. Mr. Bachtis is the official trigger contact for the Tau Physics Object Group. Mr. Bachtis' tau algorithm is also connected with his work on trigger upgrades. Joshua Swanson is working with Dr. Savin on tau algorithms and will take over Mr. Bachtis' tau HLT work as he starts writing his thesis. Jeff Klukas is working with Prof. Herndon on validation and improvement of the muon trigger algorithms, taking advantage of Prof

Herndon's extensive experience with muon physics in CDF. Mr. Klukas is one of two official trigger contacts for the Muon HLT performance.

2.7 Upgrade Trigger Program

The present CMS trigger will work well up to $1 \times 10^{34} \text{ s}^{-1} \text{ cm}^{-2}$ but will need significant modifications to operate above the LHC design luminosity (SLHC). Due to the increased occupancy of each crossing at the SLHC, the Level-1 trigger systems would experience degraded performance of their trigger algorithms. While the upgrade to the CMS trigger system will provide good trigger performance at SLHC luminosities, it also provides enhanced capabilities and improved performance at luminosities below LHC design luminosity. Thus the trigger upgrade provides the opportunity to increase the physics yield of the CMS detector before the SLHC begins. The availability of new technological advances in Field Programmable Gate Arrays (FPGAs) and telecommunications industry high-speed links and fast flexible backplanes not available when the CMS trigger was designed provide us with an opportunity to make these significant improvements in the next 5 years.

We have an active R&D program for the CMS trigger upgrade. Prof. Smith is Chair of the CMS Upgrade Peer Review Board, which reviews all CMS upgrade R&D proposals, and serves on the CMS Upgrade Management Board. As the US CMS Trigger Level-2 manager, he is responsible for the US CMS trigger upgrade. Prof. Dasu is the US CMS Calorimeter Trigger Level-3 manager. Prof. Dasu is also the CMS Upgrade Physics Coordinator and as such supervises studies of the physics performance of the upgrade trigger designs. Prof. Smith was responsible for the trigger chapter for the US CMS "CD0" SLHC document and is also editing the update of this document. Prof. Dasu is responsible for the physics chapter and the calorimeter trigger sub-section.

The UW group is responsible for the upgrade of the Regional Calorimeter Trigger. Prof. Dasu performed simulations of the upgrade trigger algorithms with UW Scientist Kevin Flood and graduate students Mike Bachtis and Ian Ross. When Dr. Flood moved back to Babar analysis, Dr. Monika Grothe took over supervision of the simulation. With Mr. Bachtis starting on his thesis and Mr. Ross beginning RCT duties at CERN, UW graduate students Isobel Ojalvo and Will Parker will be continuing the upgrade calorimeter trigger algorithm and simulation studies. We propose to develop physics triggers needed at the SLHC, the algorithms needed to provide these triggers against the substantially increased backgrounds and pile-up, and the types of electronics solutions that can support these more sophisticated algorithms. We are also studying the improvements these triggers can provide at LHC luminosities.

The Phase 1 upgrade RCT algorithms start with a particle-level cluster finder that makes 2x2 tower cluster sums along with identification of $e\gamma$ -like or τ -like flags. The upgrade RCT reduces the jet and missing energy trigger rates by clustering jets in multiples of 2 x 2 trigger towers: 6 x 6, 8 x 8, 10 x 10, with a sliding window making one or two tower steps, and use of higher resolution scales with more precise geometry for missing energy. The algorithms are based on the existing input calorimeter trigger-tower granularity of $0.087 \eta \times 0.087 \phi$ and calculate output object location at half-tower position precision with improved clustering and filtering. Initial simulation results indicate a factor of two reduction in rate for somewhat improved efficiency.

The calorimeter trigger upgrade will use modern FPGA and data communication technologies such that the algorithms can be reprogrammed as necessary. Our plan involves

building the complete calorimeter trigger system based on high speed optical interconnects and large FPGAs for data reception and processing. The system will use a new standard crate to replace the present VME system. The candidate choice is the μ TCA standard. We envision the new system to comprise 6-8 crates with up to 10 cards each. Under the supervision of Profs. Dasu and Smith and Dr. Klabbers, UW Engineer Tom Gorski and technician/CAD expert Bob Fobes are working on the hardware design, assembly and testing. The first UW prototype trigger card (Aux Card) shown in Figure 4 is under test. The card consists of a Virtex-5 FPGA, a controller, a Complex Programmable Logic Device (CPLD), and several peripherals to interface the test-bed platform to the CMS Trigger, Clocking, Data Acquisition and Controls systems. The trigger algorithm firmware is being tested in a 2x2 test bed composed of 4 Wisconsin Aux Cards with Xilinx Virtex-5's mounted on a 3 x 4x4 switch fabric with two 4x additional interconnects per FPGA apiece to test inter-FPGA data exchange. This will test the system synchronization and link data alignment and provide a development platform for multi-FPGA algorithm design. The firmware is being written in collaboration with UW engineering Professors Michael Schulte and Kati Compton and their students. These tests will be followed by the construction and test of the first prototype upgrade calorimeter trigger card.



Figure 4. Prototype UW SLHC Calorimeter Trigger Card (Aux Card).

The UW group is collaborating with the Lisbon group, who developed the calorimeter readout trigger link mezzanine transmitter cards (Serial Link Boards – SLB) matched to the UW-built calorimeter trigger receiver mezzanine cards, to develop a new optical transmission system which will connect the present RCT to either a new optical or the present copper cable connections and provide an additional output to connect to the upgrade RCT so that both systems may be operated in parallel with physics data during a transition period. The first prototype cards of the new system are planned for installation during the 2012 shutdown so that the testing with real physics data can take place during the 2013-14 run.

3 CMS Endcap Muon Activity

3.1 Endcap Muon Disk and Chamber Activity

UW Distinguished Scientist Dr. R. Loveless has been the US CMS Common Projects Manager and the Endcap Muon Construction Project Manager, and is now the CMS EMU L2 Deputy Project Manager. Under his leadership, the UW group designed, completed and installed the massive CMS endcap iron structure. The huge magnetic forces ($> 8g$) presented a considerable design challenge. The disks (built by Kawasaki Heavy Industries in Japan under UW supervision) were bolted together to insure predictability, uniformity and quality assurance of the connections. This innovative construction technique not only decreased the overall cost, but also provided better control of disk tolerances. Following UW designs and under UW management, a large shipyard in Shanghai, China built the supports for the endcap iron structure. Other components of the endcap infrastructure were constructed by collaborating countries (Great Britain, Serbia) based on UW designs and under the supervision of the UW group. The entire 4000-ton system was finished, delivered and assembled on schedule and under budget.

UW Associate Scientist Dr. Armando Lanaro is the CMS Field Technical Coordinator for the Cathode Strip Chamber (CSC) forward muon system, the US CMS L3 EMU on-site operations manager and the deputy convener of the CSC Detector Performance Group (DPG). During the CMS construction and assembly phase he was the US CMS Level-3 Manager in charge of Endcap Muon System Integration and the CSC Safety coordinator (GLIMOS). Dr. Lanaro is also in charge of the CMS Gas Infrastructure Task Force, which addresses and resolves all problems related to the CMS detector gas systems. Under the leadership of Drs. Loveless and Lanaro, the installation of the 473-CSC forward muon system was successfully completed in 2008.

As part of the CSC project integration with the rest of CMS Drs. Loveless and Lanaro have led the design and implementation of the detector services in the endcaps. A complex 3D model of all the piping (gas, cooling, N₂ inertion system, safety monitoring) and detector cabling was developed and the execution of the production drawings was supervised. Under the responsibility of Drs. Loveless and Lanaro the installation of all services and cables in the CMS endcaps was successfully completed before the lowering of the CMS disks and wheels into the underground collision hall. The UW team was responsible for preparing the endcap disks for the lowering. Figure 5 shows the YE+2 disk being lowered.



Figure 5. Disk YE+2 starting lowering into the 100 m shaft to the collision hall.

After the lowering and the complete reassembling of the CMS elements in the underground hall, Dr. Lanaro has been actively involved with the CSC detector commissioning effort and subsequent detector operation. He has been appointed to be a permanent member of the CMS Technical Coordination team that is responsible for the CMS detector opening and closing operations. CMS needs a team of expert people to open CMS at any occurrence of machine downtime periods to perform any required repair and maintenance intervention to the detector components.

As a result of his successful work on CMS integration, UW PSL engineer, Farshid Feyzi, was requested to develop and build a

series of supports for the beam pipe. These beam supports are an essential part of the opening and closing sequences of the CMS detector. This allows CMS to open and close the detector without breaking the seal on the beam pipe.

Since July '09 Dr. Lanaro has been the DPG (Detector Performance Group) deputy coordinator. This position involves considerable responsibility for converting the recorded data into physics results and implies a deep knowledge of all detector features. Some of the major tasks facing the CSC DPG during the coming years are: (1) optimize the detector response performances - occupancy, resolution and efficiency - and their monte carlo simulation; (2) contribute, together with the Physics Object Group (POG), to the study and improvement of the muon identification, reconstruction and triggering; (3) optimize the alignment of the various disks and detector elements (chambers) to achieve a muon momentum measurement with optimal resolution, (4) update and develop the offline software and unpacking algorithms to track

the new CMS software releases and (5) supply data monitoring tools and perform data-quality validation. UW graduate student Lindsey Gray is working with Dr. Lanaro on items (4) and (5). On item (4) Mr. Gray has been developing algorithms to validate the unpacking from CSC raw to digitized data and back. On item (5) Mr. Gray is member of the CSC data validation team and the CSC contact person within the CMS Prompt Feedback Group whose role is to collect immediate feedback from the different subsystem performance and contribute to detailed studies of subsystem response cross-correlations. Dr. Lanaro is also planning to work on item (3), which requires the consolidation of results from the hardware alignment (a major UW task described in section 3.4) with the alignment using muon tracks from cosmic rays and from halo muons.

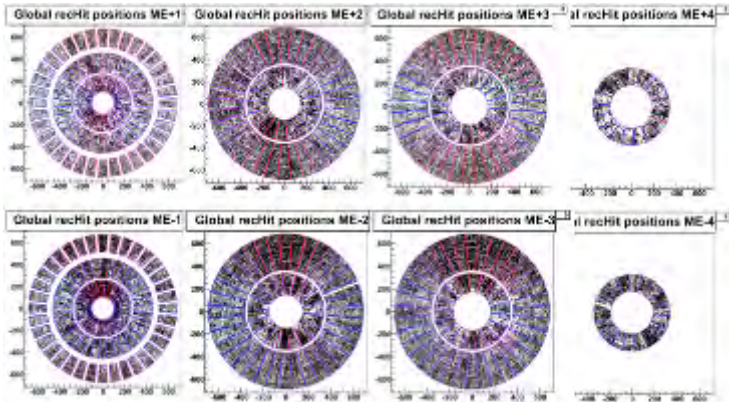


Figure 6: Display showing reconstructed $r\phi$ track hits from all CSC stations operating during Cosmic Ray data-taking.

typically $160\ \mu\text{m}$ and the efficiencies for cathode strips and anode wires hits were $\sim 100\%$. These figures match the designed performances. Figure 6 shows a 2D display of the hits recorded by all CSC chambers operating during cosmic ray data taking. The few visible radial white strips in ME2-4 indicate non-functioning detector areas ($<3\%$).

In October '09, CMS suffered a major water leak caused by the cracking of an over-tightened plumbing fitting. As a result of this incident (and other indications of a weak fitting component), CMS used the January LHC shutdown period to re-open the CMS endcap disks and undertake a major replacement campaign of all the cooling fittings (396) that were vulnerable to over-tightening. The major constraint was that the intervention (CMS opening, repair, CMS closing) had to be completed in a very tight time window of ~ 6 weeks. Drs. Loveless and Lanaro, working with Wisconsin engineers, CERN technical teams and external contractors, developed a very aggressive plan and successfully replaced (see Figure 7) all the vulnerable fittings and re-commissioned the entire cooling system during the designated two-week window from 8-22 January 2010. This demonstrates the vital importance to CMS of maintaining the Wisconsin EMU team to future successful running.

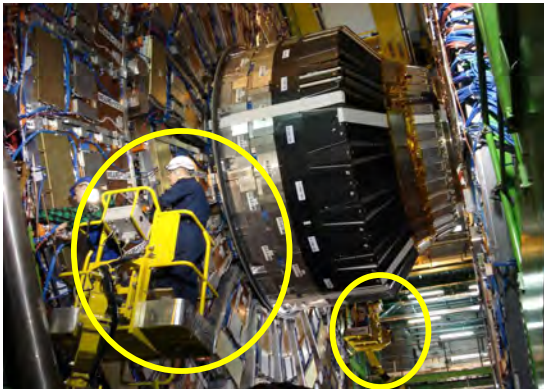


Figure 7: Two teams at work during the cooling fitting replacement, Jan 2010.

During a two week LHC running period in Dec '09 CMS recorded data at 0.9 and 2.36 TeV. The CSC Endcap Muon system performed extremely

well (efficiency for trigger and readout > 98%) despite the low rate of collision muons, and even observed a J/Ψ candidate event from its di-muon decay. With the increase in luminosity expected during the 2010/2011 run, new high-level trigger scenarios are foreseen which exploit the full detector capability and optimize the data collection. Any proposed new muon trigger algorithm needs to be carefully evaluated by the Detector Performance Group. Dr. Lanaro is particularly active in improving the cross-coordination among the different muon subsystems communities and the links with the trigger and physics analysis groups. The CSC Endcap Muon System is fully operational and ready for recording large data samples from the first LHC extended run.

3.2 Future Endcap Muon Disk and Chamber Activities

Wisconsin is responsible for all EMU mechanical maintenance, such as the successful bushing replacement described above. In the confined space of the collision hall, it is extremely difficult to dismount any CSC chamber and only the action of Wisconsin experts, like Drs. Loveless and Lanaro, can reduce considerably the occurrence of any possible collateral damage. We anticipate the Wisconsin team will be invaluable for completing the maintenance we know will be necessary and to undertake any repair or upgrade of the existing system. Every action during scheduled accesses will need to be planned with proper engineering and a complete knowledge of how the system was installed. Diagnosing problems will also require considerable knowledge of the installed system.

UW is also responsible for various EMU operations projects. During the 2008 commissioning of the CSC chambers we used a large amount of very expensive CF_4 gas. For 2009 we lowered the percentage of CF_4 from 10% to 5% to contain the costs since there was no beam activity planned. Beginning in late 2009 we began a project to develop an efficient method of recovering the spent CF_4 and recycling it. Dr. Loveless is supervising the CERN Gas Group who are designing and building this recovery system. A prototype has been built and we are now optimizing the design. We anticipate that recycling will become operational by summer 2010.

3.3 Muon Endcap Upgrade

For the SLHC phase 1 upgrade the Endcap Muon group plans to restore the 4th plane of CSCs (ME4/2) on the YE3 disk at intermediate η , which covers the region where endcap tracks overlap with the barrel drift tubes. This project is essential to provide more robust and efficient pattern recognition on high momentum muons and enhance the level 1 trigger capabilities at high luminosity. The ME4/2 upslope is part of the official CMS plans for the full luminosity detector. The present plan is to produce all chamber and electronics components in the US, and assemble the chambers at CERN, which has allocated a large fraction of Building 904 for this assembly area. Dr. Lanaro is designated as the Manager of the ME4/2 chamber production factory in Building 904 and will be moving the factory tooling from Fermilab to CERN during 2010. This project is expected to get funding in FY 2011 and we anticipate a three-year production of the 75 ME4/2 chambers.

At the same time there is a plan to install RPC chambers on YE3 where they will share a very tight volume with the ME4/2 chambers. As a result, the integration of that area will be complex. Dr. Loveless leads a team that will supervise the integration of this YE3 area. The UW team is an important part of this upgrade program as their expertise on EMU infrastructure is needed to plan, design, integrate and implement the whole muon upgrade project.

As the LHC begins operation, we need to develop maintenance plans that permit people to work near irradiated areas of CMS. Hence we need to design and build shielding that can be inserted during maintenance periods to protect workers. This involves moving large weights of shielding into very tight areas inside the vacuum tank and around the beam pipe without any crane coverage. Dr. Loveless leads a team of CERN and Wisconsin engineers to design and implement the necessary shielding and supports.

3.4 Endcap Muon Alignment

Prof. D. Carlsmith and Dr. J. Bellinger are active in the commissioning of the endcap hardware alignment system for CMS. The CMS Muon alignment system is a network of straight-line monitors (SLMs), proximity sensors, carbon fiber structures, and cameras that provide the position of tracking detector elements within CMS to a precision of a fraction of a mm. The endcap component of the system tracks the positions of the CMS cathode strip chambers used for muon detection and reconstruction. Each SLM is composed of optical devices (DCOPS) which monitor the positions of cross hair laser beams passing from the ends in both directions. Changes in the relative alignment of CMS subsystems are derived by an analysis program COCOA. The DCOPS sensors were engineered at Fermilab and constructed under contract with Fermilab at the UW Physical Sciences Laboratory in 2006.

As Task Manager for this US responsibility, Prof. Carlsmith coordinates efforts of scientists and engineers at Fermilab, Florida Tech, UCLA, CERN and UW and Texas A&M. The US endcap alignment group works closely with European groups (Instituto de Física de Cantabria and ATOMKI in Hungary) responsible for the link and barrel alignment systems. Dr. Bellinger is author of the software for data acquisition and fitting for the DCOPS system and online hardware monitoring and is active in the COCOA reconstruction and validation.

The DCOPS sensors, lasers, and the data acquisition have been installed and operated automatically and reliably since 2008. The software is integrated with the CERN DCS control system, delivers data every 16 minutes to an ORACLE database and is controlled through a CERN PVSS umbrella. The fitting procedure has been refined to identify reflected light contamination in CCD profiles and asymmetry in the line shape. The radial SLMs were commissioned in 2008. A major accomplishment in 2009 was commissioning the transfer line SLMs spanning the CMS barrel. This entailed using the new picomotor system to adjust the laser angles by about 3 mrad in order to thread the SLMs when operating at a solenoidal magnetic field of 3.8 T.

COCOA performs a grand minimization incorporating DCOPS calibration data, the ideal positions of lasers and chambers and mounts, and the results of fits to DCOPS laser profiles to deduce the position of the CSCs instrumented with alignment sensors. Dr. Bellinger is responsible for the detailed modeling of the SLMs on station ME+1 and ME-1 and for the transfer lines. He completed the models in 2009 and is validating the models and COCOA fitting procedures through comparison to photogrammetry measurements and internal consistency checks. Figure 8 shows the results of a fit to the DCOPS data for two lasers within one of six transfer SLMs. The figure shows that both lasers thread the SLM and agree with each other with a point rms deviation of 124 microns. The redundant lasers provide measurements of the positions of all DCOPS. Demonstration that this was possible in radial and transfer line SLMs was a significant milestone.

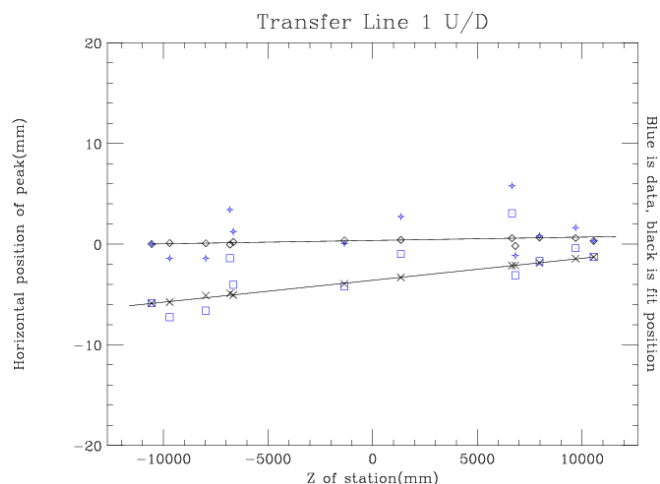


Figure 8: Azimuthal position in mm of DCOPS along a transfer SLM measured with lasers from each end. The centroids of the laser profiles before (squares and plus signs) and after (diamonds and crosses) deriving the DCOPS offsets agree with each other. The rms deviation is 124 micron.

At present, all DCOPS and lasers are operational but some hardware issues are unresolved. Several DCOPS require occasional remote power cycling. Several of the picomotor drivers have failed and several fail to operate in the magnetic fringe field despite the additional of shielding. Additionally, a few percent of alignment events continue to suffer partial data loss resulting from ethernet bus contention. These issues will not prevent successful operation during the coming run and will be addressed when possible.

A major goal of this program is to integrate and validate the results of separate COCOA models of the Barrel, the Link (Barrel MAB and ME1 connection), the Transfer Lines, and the radial SLMs in order to provide the CSC chamber center

coordinate deliverables. Dr. Bellinger will play a major role in this integration. Validation will be done with halo and collision muons using detailed comparisons with tools that have been under development by the Texas A&M group. The DCS system sends endcap alignment system hardware failure error flags to the central DCS system. However, data quality monitoring performed from Wisconsin remotely has not been automated and remains an important task, which will evolve with our experience with the system. We will also complete the implementation of the COCOA reconstruction of the endcap alignment system and exercise the global reconstruction. Muon data collected in 2010-11 will be used to check the results of the global reconstruction.

Prof. Carlsmith and Dr. Bellinger will continue to travel roughly quarterly to CERN for periods of several weeks to coordinate hardware alignment maintenance and development. Both Carlsmith and Bellinger are also actively participating in CSC shift duties. The alignment task will require considerable and continuous work to maintain and operate and compare results with data. We propose to hire a graduate student to work with Carlsmith and Bellinger on this activity.

In FY12 we propose to hire a new postdoctoral researcher coinciding with the elimination of a core scientist position supporting Intermediate Muon System M&O on Task E - CDF at the scheduled end of the Tevatron run. This postdoc will contribute to muon alignment, muon upgrade installation and muon system commissioning. In addition, this position is intended to leverage the experience gained in muon commissioning and from the group's physics activities on the CDF experiment in the areas of Higgs and related Electroweak physics.

3.3 Muon Higher Level Trigger

Prof. Herndon and his graduate student Jeff Klukas are active in the Muon High Level Trigger (HLT) group. This work leverages Prof. Herndon's expertise in muon triggers and physics from the CDF experiment where he participated in low and high p_T muon physics including the $H \rightarrow WW$ analysis, designed muon triggers, and performed detector performance monitoring using offline muon samples.

Working under the guidance of Prof. Herndon Mr. Klukas has written the CMS online muon trigger monitoring DQM software. This software monitors both muon L1 and HLT trigger performance in real time. The primary product is differential efficiencies for each muon detector subsystem and trigger. Mr. Klukas and Prof. Herndon are also involved in the offline muon trigger monitoring, where they have recently taken responsibility for the software. In addition, Mr. Klukas is leading design of a new monitoring software package amalgamating the various muon trigger performance programs written by the muon HLT group into a powerful program that is run on new data offline to produce expert level monitoring of trigger performance. This new program provides rapid response by the muon HLT group to any trigger problems that occur and facilitates detailed expert monitoring of the trigger performance. These programs have been tested on collision data and are used extensively to help identify problems with the trigger code when run on new data. These programs are also used test HLT performance when developing new muon trigger software and building new releases of CMS software. Finally, these programs provide validation of trigger performance for monte carlo samples.

In addition, Prof. Herndon and Mr. Klukas are also involved in trigger software development. Their primary work has been on the development of more effective isolation algorithms for medium transverse momentum tracks in order to allow unrescaled muon triggers at low momentum. These triggers will be useful at higher luminosities and development will continue based on collision data collected during the 2010 run.

4 Computing

The UW group operates one of the largest university-based computing facilities for HEP in the country under the supervision of Prof. S. Dasu. The Director of Computing, S. Rader, and the System Manager M. Radtke provide core services for all the tasks of this DOE grant and are supported by DOE and the University at 50%-level each. Core computing services provided include unix login, productivity & scientific data analysis software, personal file storage space (on AFS), mail, web, desktop support, backup facility, etc. The NSF supported Assoc. Researcher Dr. A. Mohapatra, Software Engineer D. Bradley, and System Manager W. Maier operate the CMS Tier-2 facility at Wisconsin (Figure 9) which is a ~1000-core computing cluster providing >2500 kSI2K units and 900-TB high-availability distributed storage service. The Tier-2 is based on the Condor distributed high-throughput computing technologies developed by



Figure 9: UW Tier-2 computing facility.

UW CS department, Grid services and dCache-based storage services. Our Tier-2 computing center is part of the Data Intensive Science University Network (DISUN), a grid-based facility comprising computing, network, middle-ware and personnel resources from four CMS universities. This facility is unique in its collaboration with a strong computer science team and seamless integration with the campus-wide grid - the Grid Laboratory of Wisconsin (GLOW) plus UW Center for High Throughput Computing (CHTC) facilities providing >4000 kSI2K, and the nation-wide Open Science Grid (OSG). We are also providing core middle ware for the CMS and other grid users through NSF ITR projects such as Rapid-response Adaptive Computing Environment (RACE). Idle tier-2 resources are available to the full UW HEP group.

4.1 CMS Tier-2

Our Tier-2 facility serves as the primary computational resource for the CMS Trigger Studies, Electroweak and Forward Physics groups besides producing monte carlo events. In addition to UW CMS team, over 50 CMS-wide users routinely use our systems either through direct login (RACE) or via the OSG, or the World-wide LHC Computing Grid (WLCG). Recent achievements made possible by these resources include the optimization of trigger menus for various startup luminosities, papers on W and Z production with and without accompanying jets, di-boson production and exclusive di-lepton cross-section measurements. Many of these analyses were run as part of the CMS “October exercise” in 2009. On demand production of specific types of physics events is crucial for timely input in configuring and operating our trigger systems. The ability of our group to independently study specific physics channels using our local grid resources is unique. We have already used data produced on our UW campus grid to obtain physics results in a timely fashion that influenced CMS decisions.

Dr. A. Mohapatra serves as the distributed monte carlo production co-coordinator for CMS and is also responsible for the integration and operation of the US CMS monte carlo simulation production using the Open Science Grid (OSG). The UW GLOW/Tier-2 facility has delivered about 25 million hours of CPU since October 2005: 60% - CMS simulation production, 15% - CMS local analysis, 10% by CMS grid analysis, and 5% by non-CMS grid users. Non-CMS UW HEP users, primarily members of the phenomenology group, used the remaining 10% of resources, i.e., ~3 million hours. Over 329 million (2.4 billion) events have already been produced using Wisconsin (OSG) in the past year as shown in Table 1. Wisconsin (Assoc. Researcher Mohapatra) has not only managed the production of these events but also has been one of the largest contributors of resources, which are efficiently managed by System Manager Maier.

Table 1: Simulation production statistics. Full simulation takes ~10m/event versus fast simulation which takes ~10s/event. Wisconsin has about 10% of OSG resources.

Since January 2009 to March 2010	Number of Events Produced (Millions)
Wisconsin	329
Open Science Grid (including UW)	2380
Worldwide (OSG + EGEE + ...)	4664

UW Tier-2 physics analysis activities are some of the most successful in CMS because of innovative solutions for job management developed using NSF-RACE funds (Systems Programmer Bradley). Graduate students Anderson and Gray (NSF supported), and Bachtis and Swanson (DOE supported), who were based in Madison in 2009-10, ensure that the facility is exercised for physics analysis with new releases of software and data downloads and remains productive. The electroweak and trigger groups successfully utilized our systems and rely on our abilities to deliver again in the coming years. We plan that students based in Madison (Ojalvo, Parker and Reilly) continue to exercise our Tier-2 computing systems, and work with our NSF supported computing team to ensure that UW physics/computing operations run smoothly.

4.2 Core HEP Computing

In order to save costs, all core UW HEP computing services are centrally shared and managed by Rader and Radtke, who are 50% paid by the Physics Dept. in exchange for supporting Dept. computing. Their services enable us to maximally leverage the high-throughput data analysis facilities on our campus and beyond: CMS Tier-2, Grid Laboratory Of Wisconsin

(GLOW), Center for High-Throughput Computing (CHTC) and the Open Science Grid (OSG). The personnel costs are put in this task rather than pro-rata across HEP tasks. The equipment costs are put in “virtual Task” P (see appendix). Excluding the Tier-2 bulk-computing infrastructure, we operate about 50 desktop computers; a 20-TB AFS distributed storage service, login, mail, backup and web servers. These facilities serve about 100 local users working on all DOE supported tasks, and about 50 remote (including non-UW) CMS collaborators. Besides providing the computing support for users, Rader and Radke provide valuable consultation to the CMS Tier-2 personnel in managing the existing bulk-computing infrastructure, and in the planning and development of CMS Tier-2 data storage and analysis facilities.

5 Physics Analysis Activity

Wisconsin group’s primary physics interest is in the study of electroweak symmetry breaking mechanism and searches for new physics phenomena. The current physics efforts are primarily focused in the Trigger Studies Group (Trigger Coordinator: Prof. W. Smith) and Electroweak Physics Group (Co-convenor: Prof. S. Dasu, 2008-2009), to firmly re-establish the standard model at LHC energy scale and provide absolute luminosity for cross section normalization [1-11]. Assistant Scientist M. Grothe has served as the Forward Physics convenor (2006-2008), establishing a robust program for forward physics [12-15], including the potential for central exclusive Higgs production, before transitioning to work on electroweak physics. We are also leveraging our muon systems construction and commissioning experience in muon identification and tracking with A. Lanaro becoming the CSC detector performance group deputy convenor. Combined with the CDF analysis expertise of Professors Carlsmith and Herndon in lepton physics and tracking, we are now providing a solid base of knowledge to pursue physics analysis. Prof. Herndon’s recent tenure as CDF Higgs group convenor is especially important for our CMS efforts. The group is also engaged in physics simulation studies to design upgrades for CMS (Upgrade Physics Coordinator: S. Dasu).

5.1 Trigger Studies

The extraction of the final physics results from the CMS requires a thorough understanding of how the signal and the background events pass all the way from the level-1 trigger, through the higher level triggers and the event reconstruction programs, to the analysis. The Trigger Studies Group (TSG), under the supervision of Professor Smith, is currently determining the configuration of L1 and HLT trigger systems. In FY08 as a leader of the Online Selection group Prof. Dasu was instrumental in the completion of L1 emulator and an initial set of HLT algorithms, and evaluation of those for 2009 operations when the luminosity is expected to reach $10^{32} - 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. Prof. Smith is now guiding the TSG, which has about 100 people including US students and postdoctoral researchers from Brown, CERN, UI-Chicago, INFN Minnesota, Rice, Texas A&M, UCSB and Wisconsin, in defining the trigger configurations for data taking. Improvements are being made to the startup L1 configurations and HLT algorithms as the data taking evolves with increasing LHC luminosity. For instance, UW graduate student Jessica Leonard and Assoc. Scientist Dr. Klabbers have helped tune the L1 calorimeter trigger configuration to lower electron/photon trigger thresholds and isolation criteria. Postdoc Dr. Efron is putting together a procedure, which can be real data driven, for calibrating the L1 calorimeter trigger objects. Prof. Dasu, with the help of a Texas A&M postdoc, improved the tau trigger isolation algorithm to reduce QCD backgrounds by a factor of two while keeping the signal efficiency constant. UW graduate student Bachtis developed a more sophisticated calorimeter cluster isolation to improve the HLT tau algorithm significantly. This is connected with his work

on trigger upgrades. Prof. Herndon and his graduate student Klukas have developed improved isolation algorithms for medium transverse momentum muons, which are important for single and multiple boson physics. Graduate student Anderson is working on improving photon trigger algorithms. Scientist Savin leads the Trigger Performance Group within the TSG organization. Anderson, Bachtis and Klukas are responsible for validation of photon, tau and muon triggers respectively under Savin’s supervision. The collaboration relies on their work in the commissioning of these triggers in the coming months. The UW group plays a crucial role in both defining and validating triggers using all types of objects in CMS, which are important for both standard model measurements and new physics searches.

5.1.1 Photon Trigger

Graduate Student Anderson is responsible for photon trigger validation both online and offline [16]. He has participated with the electron/photon group in developing validation software and is monitoring both MC and real data samples. The expected photon trigger efficiency for loose high level trigger using only the calorimeter information (left) and with isolation using tracker (right) are shown in Figure 10.

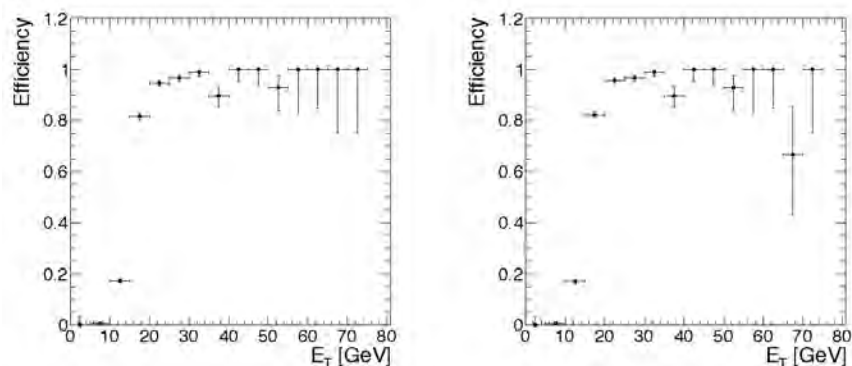
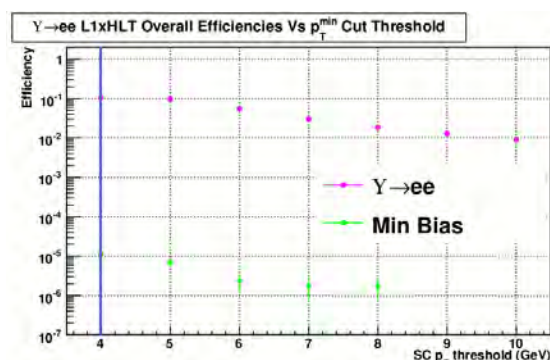


Figure 10. Photon trigger efficiency versus generated photon transverse energy for calorimeter only (left) and using track isolation (right).

5.1.2 Electron Trigger

Graduate Student Leonard worked on improving the electron trigger lowering its threshold and increasing efficiency for low P_T electrons, especially those from upsiion decays [17]. Combined L1 and HLT efficiency of the optimized low E_T dielectron trigger for upsiion and minimum bias event is shown in Figure 11.



trigger for upsiion and minimum bias events.

5.1.3 Muon Trigger

Prof. Herndon and his graduate student Jeff Klukas are active in the monitoring and evaluation of muon HLT trigger performance. This work includes both online and offline monitoring, provides rapid analysis of muon system performance in new data, and also provides the first measurements of efficiencies needed for physics analysis. Figure 12 shows the muon trigger efficiencies for all of the muon trigger paths included in the trigger table used for first

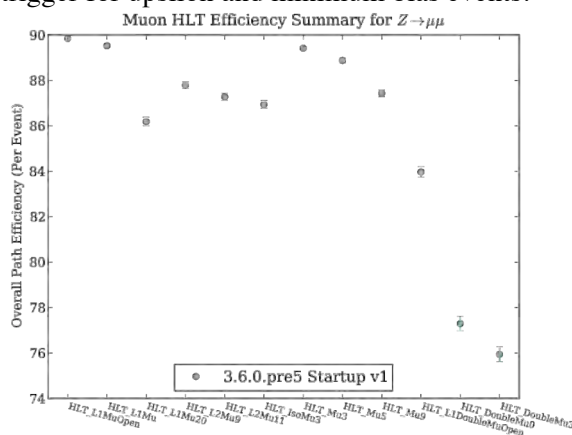


Figure 12. Efficiencies for the muon triggers evaluated using simulated Z decays to muons.

data taking at 7 TeV center of mass energy. Simulated Z decays to dimuons are used to validate the trigger performance. Studies involving first collision data are in progress though currently the samples of high quality muons from the collision data are too small to accurately quantify trigger performance.

5.1.4 Tau Trigger

Graduate Student Bachtis worked on improving the tau trigger both at L1 and HLT under the supervision of Assoc. Scientist Savin and Prof. Dasu. The improved tau trigger, built using particle flow ideas [18], is now being commissioned with initial data. Bachtis has also prepared a tau trigger validation package that is being used online and offline as the real data is being accumulated. The MC expected performance of the L1 and HLT triggers is shown in Figure 13. The QCD background is under control, i.e., below 5 kHz at L1 and few Hz at HLT for reasonable thresholds (< 30 GeV) for the expected luminosities of 2010-11. The collection of about 1 fb^{-1} data with this trigger will be especially valuable to establish the Z to $\tau\tau$ signature before the LHC luminosities increase to design levels. Graduate student Swanson is inheriting the responsibility of maintaining and validating the τ -trigger.

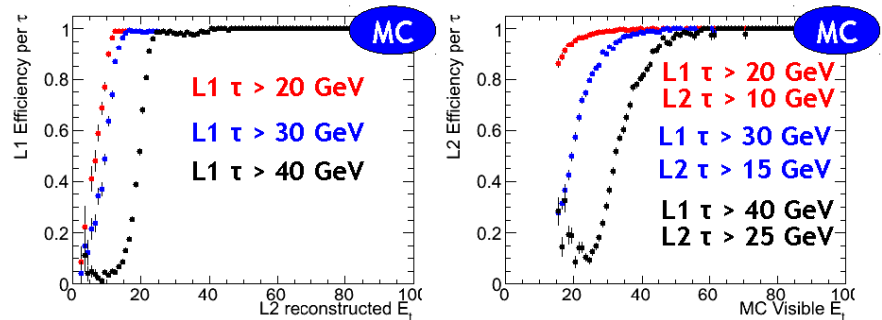


Figure 13: L1 and L2 trigger efficiencies are shown versus L2 reconstructed and offline (visible) energies of the tau candidates showing a reasonably sharp turn-on.

5.2 Electroweak Physics

Observing electroweak processes is an important first step in the analysis of the data to be collected in 2010-2011. Studies of electroweak bosons will form a solid basis for all new physics searches. Prof. Dasu just completed his two-year term as the co-convenor of the CMS electroweak physics subgroup. Under his leadership over 150 physicists worked to establish event selection criteria, and background determination to extract electroweak signals. Planned measurements include Drell-Yan (DY) cross sections and asymmetries, W/Z inclusive cross sections, charge and forward-backward asymmetries, W/Z + jets cross sections, boson P_T and angular distributions, W/Z + heavy flavor jets cross sections and multi-boson production ($W\gamma$, $Z\gamma$, WW, WZ, ZZ). These initial measurements will allow us to understand and/or constrain the parton distribution functions and QCD radiation effects on backgrounds for many beyond the standard model processes. They will also allow extraction of triple and quadruple-boson couplings. The UW group has completed eleven analyses [1-11] producing physics summary documents, and is ready to analyze the new data as it arrives.

Electroweak analyses require several datasets that are based on isolated high momentum leptons. We have defined a procedure to collect events efficiently in primary datasets made online using lepton triggers. Streams of events triggered with loose lepton requirements are skimmed for events with isolated high transverse momentum leptons. Those skimmed datasets are placed at Tier-2 centers, including UW Tier-2, where we expect to promptly analyze the data. Monte carlo signal and background events are selected using the same lepton trigger and

identification criteria applied to data events. Assistant Scientist Monika Grothe, supported by graduate students J. Leonard, K. Grogg and C. Lazaridis, have taken on the responsibility for validating the data quality. The validation procedure involves promptly making a standard set of histograms and comparing them to templates validated earlier. Feedback is provided to the Physics Validation Team. The responsibility also includes placement of data at Tier-2 centers for analysis.

5.3 Wisconsin Physics Analyses

All Wisconsin students have chosen a physics channel that can be studied with initial expectations of luminosity ($\sim 1 \text{ pb}^{-1}$ to $\sim 1 \text{ fb}^{-1}$), and have begun studying it in simulation. Our scientists are paired up with the students, working closely with them on the data analysis and providing local supervision. The majority of the analyses are in the electroweak physics area.

5.3.1 Direct Photon Analysis

Graduate student Anderson has developed a multi-variate technique to better identify isolated photons and discriminate them from jets that on occasion fluctuate to have very large neutral content. The effectiveness of his improved photon identification is documented in two analysis notes prepared in anticipation of real data [19, 20]. Figure 14 compares simulated background subtracted photon spectrum extracted from a fit to the MC expectation. Anderson has also compared the photon + jet production processes in Pythia, AlpGen and MadGraph MC programs. He is prepared to extract the photon+jet cross section with 100 pb^{-1} data that we expect to collect this year. Relaxing the isolation requirement for higher p_T photons, he will also be looking for any new physics signatures, for example that realized in gravity mediated SUSY breaking scenario, in photon(s)+jets channel. The photon spectrum analysis is feasible even with few pb^{-1} . Anderson is playing an important part in the team setup to present initial studies of the photon spectrum for this summer's conferences.

5.3.2 Drell-Yan Di-electron Analysis

Graduate student Leonard is studying the di-electron invariant mass spectrum, with Asst. Scientist Grothe. She is concentrating on prompt analysis and data quality monitoring for Drell-Yan γ^*/Z cross-section measurement with few pb^{-1} expected this summer. She will be measuring the DY cross-section and also deriving information for tuning the underlying event parameters for QCD monte carlos. Figure 15 shows the expected di-electron mass spectrum, with underlying backgrounds, from 10 pb^{-1} data. Any deviations at the very highest M_{ll} range provide a chance for the observation of new Z' particles, even with $100\text{-}200 \text{ pb}^{-1}$ data expected this year. Her analysis is documented in reference [21].

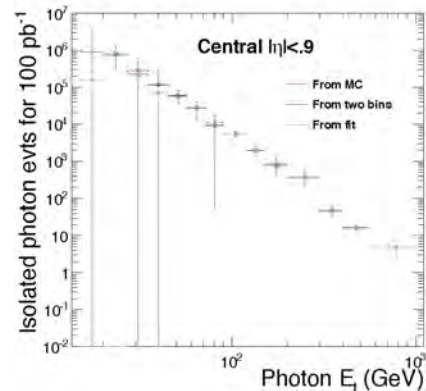


Figure 14. MC expected direct photon spectrum compared to that extracted from MC data after subtracting QCD background using two different methods.

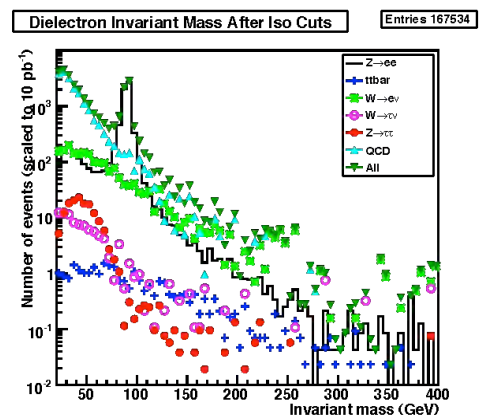


Figure 15. Electron-positron invariant mass spectrum showing the Z peak.

5.3.3 W + Jets Analysis

Graduate student Grogg is studying the production of W bosons accompanied by jets, with Research Associate Efron. The study of QCD radiation in these events is also of large interest as these events form substantial background for new physics searches. The ratio of W and Z events is well predicted in theory and will help discriminate amongst various new physics models. Although W events are produced at a higher rate than the Z events, the indirect reconstruction of the neutrino presents problems. Therefore, Grogg is playing a role in the commissioning of the missing transverse energy (MET) using particle flow (PF) technique. She is studying PF MET produced in association with electrons for the initial inclusive W analysis with $\sim 1 \text{ pb}^{-1}$ for the summer conferences, while waiting for higher luminosity for the study of jet production in association with W bosons.

Grogg devised event selection cuts for W events with jets and has shown good signal yields and documented her work in a CMS Analysis Note [22]. Figure 16 shows the W transverse mass spectrum after applying her tuning of electron identification and isolation cuts. She has developed several methods for estimating the QCD background using data driven techniques. Grogg is also investigating options for further reduction of backgrounds, e.g., using various isolation cuts and heavy flavor and invariant mass vetoes to suppress top production.

5.3.4 Z + Jets Analysis

Graduate student Lazaridis is studying the production of Z bosons accompanied by jets, with Assoc. Scientist Klabbbers. Study of QCD radiation in these events is of large interest as such events form substantial background for new physics searches. Additionally, leptonic decay modes of the Z can be identified well, and removed from the event, to experimentally determine the missing E_T spectrum in multi-jet events. Quantifying this background is an important precursor for any SUSY searches. Lazaridis developed event selection strategies and has shown that even with 100 pb^{-1} data one can reach multi-jet topologies well beyond the Tevatron reach, and has documented it as a CMS Analysis Note [22]. Figure 17 shows a clean Z mass peak with low background.

5.3.5 Z decays to $\tau\tau$

Graduate students Bachtis and Swanson are studying the reconstruction of Z decays to $\tau\tau$, with Prof. Dasu and Assoc. Scientist Savin. The understanding of Z reconstruction in τ -modes is

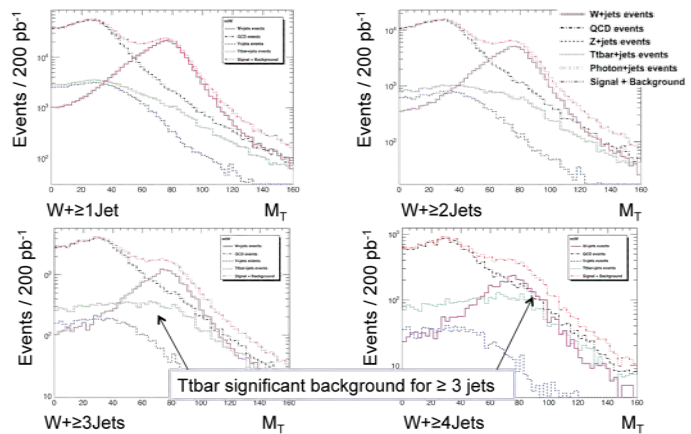


Figure 17. W transverse mass spectrum showing a clear W peak, for 1-4 jet events, but with substantial QCD fake lepton and top backgrounds.

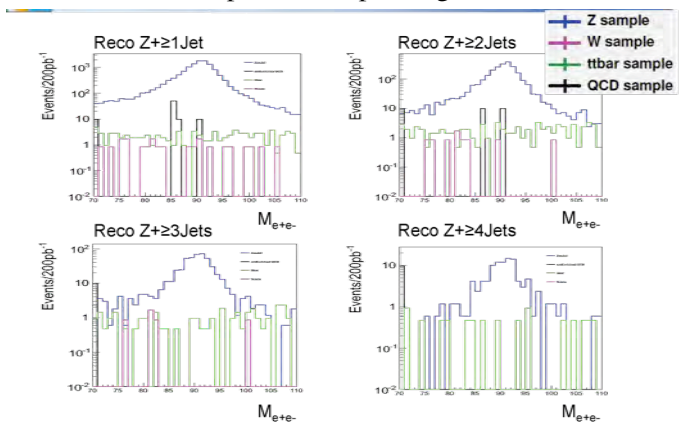


Figure 16. Dielectron invariant mass spectrum for 1-4 jet events showing a clear Z mass peak in all cases. The background is negligible.

necessary before CMS can claim discoveries of a SM Higgs boson in τ -modes, which are important because of their enhanced Yukawa couplings, or MSSM heavy Higgs bosons, which have enhanced decay rates to τ -modes. Bachtis has studied a MC sample of Z events, where one of the τ leptons decayed to a muon [23]. He has simulated backgrounds from both EWK and QCD processes and demonstrated that the Z peak can be reconstructed in the visible mass distribution, with even 40 pb^{-1} data, as shown in Figure 18. Graduate student Swanson has developed an analysis of Z to $\tau\tau$ production with one of the τ leptons decaying to an electron. He focused on the measurement using the expected 1 fb^{-1} 2010-11 data. The invariant mass spectrum of the reconstructed electron and τ in Figure 19 shows a clear Z to $\tau\tau$ signal along with backgrounds, and mis-reconstructed Z to electron-positron events peaking at higher mass.

5.3.6 Multiboson production and muon detector studies

The goal of multi-boson ($W\gamma$, $Z\gamma$, WW , WZ , ZZ) analyses is to measure triple and quadruple boson couplings, to discover or set limits on anomalous couplings of the vector bosons, and to search for new resonances and even Higgs production. Graduate students Gray and Klukas, Research Associate Efron, Scientists Lanaro and Loveless and faculty Herndon, Carlsmith, and Dasu are working on this. Carlsmith’s and Herndon’s CDF experience with these analyses is especially valuable. For multi-muon final states from diboson decays, the extended coverage of muon system, provided by the endcap CSC system Carlsmith helped build, install and commission, is crucial.

5.3.7 $Z\gamma$ production in SM and search for new physics

Graduate student Lindsey Gray is working with Assoc. Scientist Lanaro and Prof. Dasu and on the studies of $Z\gamma$ production. He has also worked on the generator of $Z\gamma$ events with SUNY Buffalo

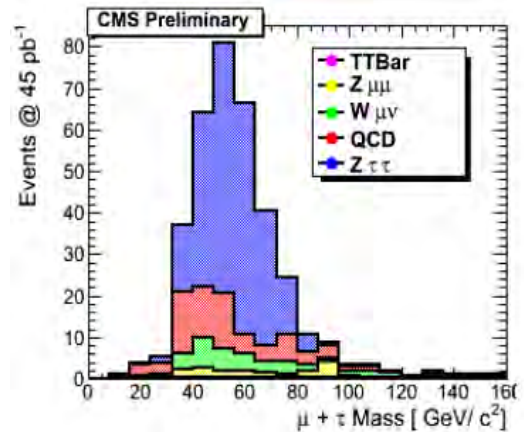


Figure 18. Visible mass peak for Z decays to $\tau\tau$, where one of the τ decayed into a muon and the other hadronically.

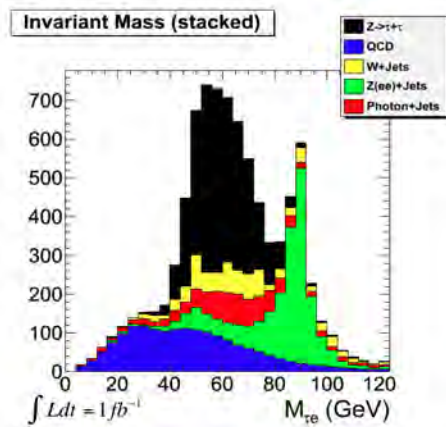


Figure 20. Visible mass peak for Z decays to $\tau\tau$, where one of the τ decayed into an electron and the other hadronically.

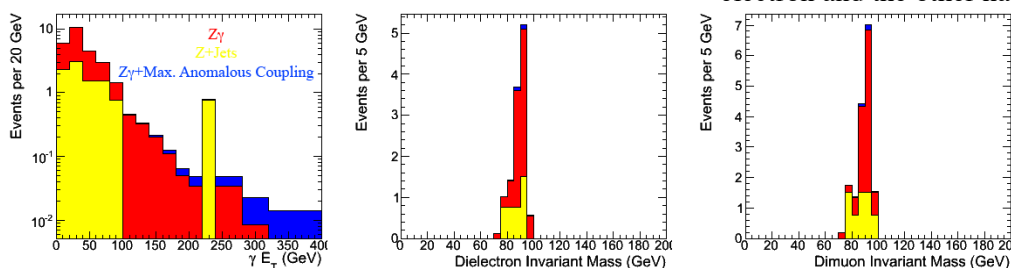


Figure 19: Photon E_T spectrum produced in association with a Z boson (left). Z mass peak for events produced in association with a high E_T photon in electron (middle) and muon (right) channels.

phenomenologist Prof. Baur. Results with Anderson’s improved multivariate photon ID permit a measurement of the $Z\gamma$ production cross section in the dielectron and dimuon Z-decay channels with the first 200 pb^{-1} of data [24] as shown in Figure 19. Anomalous coupling can be probed by requiring the photon $E_T > 200 \text{ GeV}$. Postdoc Efron is studying $W\gamma$ and $Z\gamma$ final states and is working with students and scientists from India, to study these modes in electron channels.

5.3.8 WZ production in SM and new physics

Prof. Herndon and graduate student Jeff Klukas are authors of an analysis document describing the measurement of the standard model WZ production cross section and of an analysis document describing a search for new physics in the WZ sample. This physics analysis work is based on the experience of Prof. Herndon on the CDF experiment where he performed measurements of the WW and WZ cross sections with his students and postdoc and is a participant in the search for the SM Higgs boson in the $H \rightarrow WW$ channel. This work will comprise Mr. Klukas’s PhD thesis.

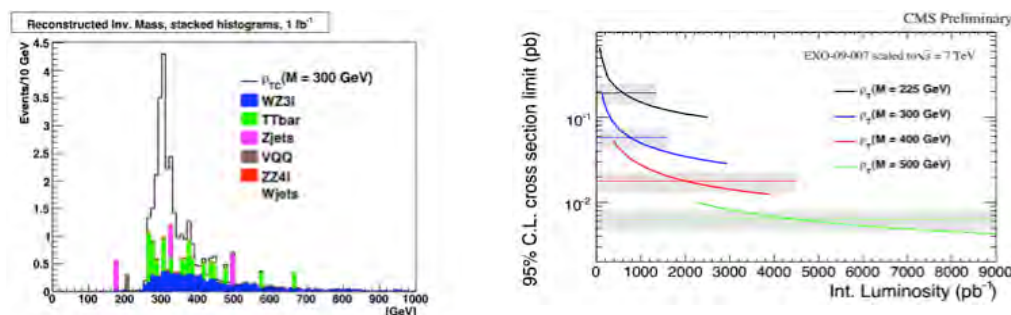


Figure 21: Reconstructed mass of WZ resonance shown above SM backgrounds (left). Simulated 95% CL limits on technirho production cross section for various values of technirho mass. With datasets on order 1 fb^{-1} limits on technirho production can be set up to masses of 300 GeV.

Mr. Klukas has primarily focused on the role of high transverse momentum muons in physics involving W and Z bosons. He has designed optimal reconstruction criteria for these muons and methods for data driven background estimation for the WZ analysis. These methods were first developed for a search for decays to WZ of heavy particles such as a W' or technirho. As shown in Figure 21 with modest datasets on order 1 fb^{-1} the CMS experiment will have the ability to set exclusion limits or see the evidence of these types of new physics models. Analysis notes [25] on this subject have been approved by the CMS collaboration and are publically available as preliminary CMS results. Prof. Herndon and Jeff Klukas are also involved in the SM WZ decay analysis. The technicolor analysis work is currently being adapted for the SM WZ cross-section measurement where it is directly applicable.

5.3.9 ZZ production in SM

Guided by Prof. Dasu, graduate student Ian Ross is building an analysis program to reconstruct double Z boson production at the LHC. He has begun to look at four lepton final states in $eeee$, $ee\mu\mu$ and $\mu\mu\mu\mu$ modes. These signatures are simulated to have very little background as shown in Figure 22. Unfortunately, the signals are not statistically very significant with the expected 1 fb^{-1} data to be collected in 2010-11. Therefore, Ross will include modes where one of the bosons decays hadronically, and determine ways of reducing the potential Z+jets background.

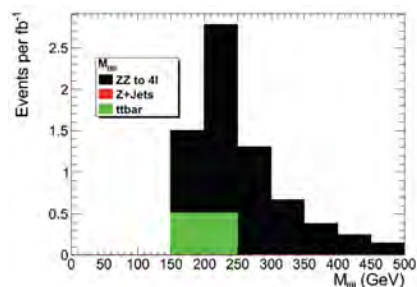


Figure 22: Invariant mass of four leptons (oppositely charged electron or muon pairs) along with dominant backgrounds after all cuts.

5.3.10 Search for SUSY in like-sign leptons mode

Guided by Assoc. Scientist Savin, graduate student Weinberg has begun a search for SUSY particles, in which like-sign isolated leptons are created in cascading decays accompanied by large missing transverse energy and jet production. His study shows a long tail of the missing E_T spectrum in Figure 23. Because the QCD background with fake dileptons is small and its missing E_T falls off rapidly, SUSY discovery in this mode is feasible with 100 pb^{-1} data as also shown in Figure 23 [26]. Weinberg is currently optimizing his MC analysis, *e.g.* lepton isolation [27], and analyzing the data with colleagues from Imperial College.

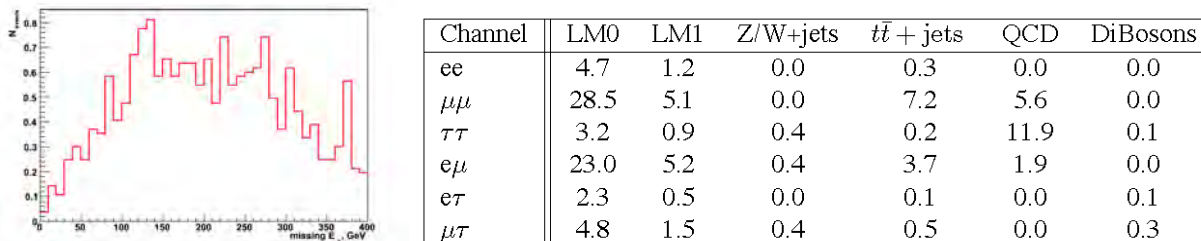


Figure 23: Left: number of events passing same-sign dilepton event selection cuts, including the missing E_T are shown indicating discovery feasibility with 100 fb^{-1} of data. Right: the missing E_T spectrum produced by SUSY decays (LM1), in events with two like-sign leptons of $P_T > 10, 6 \text{ GeV}$.

5.3.11 Further initiatives in Electroweak Physics

We propose to hire a new postdoc in FY12 to work on muon system and related muon physics such as Higgs and Electroweak physics. This postdoc will work closely with the students involved in Electroweak physics in the single and diboson channels and also in Higgs physics. This position is intended to simultaneously leverage the Wisconsin CMS group's expertise from the construction, alignment and commissioning of the muon system and the CDF group's experience in Higgs and related diboson physics to pursue these important physics priorities.

5.4 Upgrade Trigger & Physics Simulations

Along with the Madison-based graduate students, Asst. Scientist Grothe and Profs. Dasu and Smith are working on trigger and physics simulations to define the scope of the calorimeter trigger upgrade. The primary goal of the upgrade is to implement more sophisticated calorimeter trigger algorithms, especially for the τ -trigger, as well as robust clustering and lepton isolation algorithms and also to improve the position resolution of the objects identified by the calorimeter trigger. The improved τ -trigger and isolation for leptons will be especially useful to increase the CMS physics reach while the LHC increases luminosity. Having improved L1 triggers during the lower luminosity LHC operation will provide unique opportunities, *e.g.*, study of the Higgs boson decays to τ -pairs and b-jet pairs.

Graduate student Bachtis has simulated new electron, τ and jet trigger algorithms, tested to be implementable in the latest Xilinx FPGAs. Graduate student Ian Ross and Asst. Scientist Grothe have used this simulation to calculate background trigger rates and signal efficiencies at various levels of luminosity (including event pile-up). Figure 25 shows the electron/photon trigger performance. The asymptotic efficiency is tuned to be flat and high as a function of the electron/photon E_T by optimizing the isolation cuts, which are improved in the upgraded trigger system. The corresponding QCD background rates are plotted versus the threshold for various

values of pileup (40-200 events per bunch crossing). It is seen that the new isolation algorithm will remain effective even when there are 80 interactions in a bunch.

Figure 24 shows the isolated tau trigger efficiency turn on as a function of visible E_T of the generator level τ 's in Z decays for various settings of pileup (40 – 200 events per bunch crossing). The QCD background rate corresponding to these settings is also shown (right). The thresholds that are sustainable for single τ - trigger are 70-80

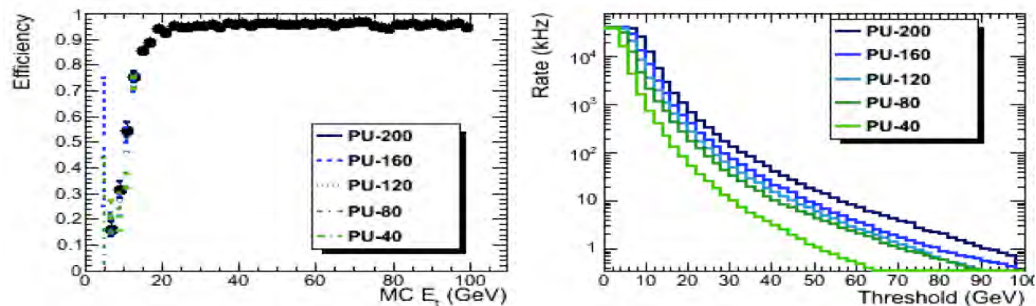


Figure 25. Isolated electron/photon trigger efficiency turn-on (left) and expected background rate (right) shown for pileup of 40 – 200 events per bunch crossing.

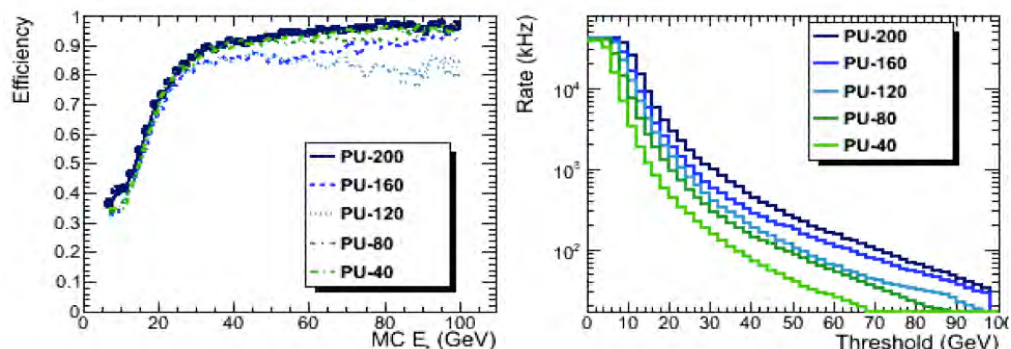


Figure 24. Isolated tau trigger efficiency turn-on (left) and expected background rate (right) for pileup of 40 – 200 events per bunch crossing.

GeV at up to twice the design luminosity satisfying the requirement of having a trigger for MSSM charged Higgs decays to $\tau\nu$. The di- τ trigger thresholds can be sustained at the level needed for MSSM heavy neutral Higgs bosons even at very high luminosities. For low luminosities these triggers can be lowered sufficiently to study SM Higgs (produced in vector-boson fusion process) in its decays in di- τ mode, which will be a significant extension of CMS physics capability. With the current trigger we are restricted to the di- τ modes where one of the τ s decays to an electron or muon. The hadronic modes have the advantage of having larger visible energy deposited in the detector.

Scientist Grothe and junior graduate student Ross will continue these simulations, and also include offline analysis to study the feasibility of these new modes, with summer students Ojalvo, Parker and Reilly, who will be based in Madison. We propose to devote the efforts of younger students to the upgrade physics studies as the more senior students will be devoting their efforts to analyzing the data that will be accumulated in 2010-11. We expect that the younger students will hone their analysis skills, using these simulation studies, without being overwhelmed by the intensity of working on the latest data acquired by CMS. This has worked very well with Bachtis, who moved to CERN last year and Ross, who is moving to CERN this year. Moreover, summer students in Madison can interact with the trigger hardware R&D team.

5.5 Prompt Physics Analysis

CMS began collecting data in November 2009. CMS published a first paper on particle

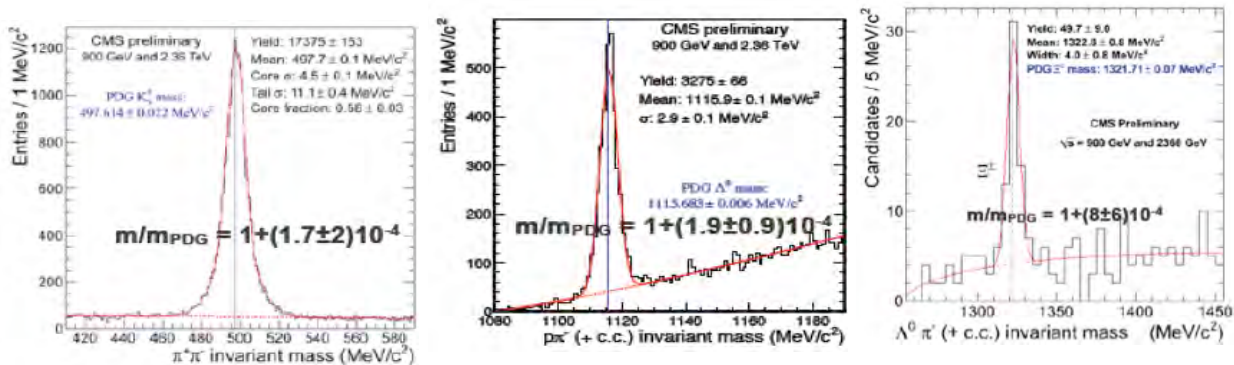


Figure 26: Observation of $K \rightarrow \pi\pi$, $\Lambda \rightarrow p\pi$, $\chi \rightarrow \Lambda\pi$ in CMS 2009 data.

charge multiplicities and p_T distributions based on 2009 data in early 2010. Invariant mass plots of many resonances are an indication that momentum and energy calibrations as well as particle ID are already well under control (Figure 26). We are now looking forward to a long data run at 7 TeV beginning in March 2010. On the way to 1 fb^{-1} data by 2011, CMS has already accumulated over $150 \mu\text{b}^{-1}$ data enabling a preliminary look at event and object reconstruction characteristics.

Organized efforts are underway at CERN to analyze the incoming data promptly with the target of presentations and early papers on rediscovery of SM processes at the LHC. We anticipate collecting and analyzing a few pb^{-1} of luminosity in time for the ICHEP conference in July. Our activity is primarily in the electroweak physics area. Asst. Scientist Grothe and Graduate Students Leonard, Grogg, Bachtis and Lazaridis have taken on important commissioning roles in the Vector Boson Task Force (VBTF), and have already made several presentations at VBTF meetings. For instance they have shown that the electron identification and isolation variables in the data ($\sim 100 \mu\text{b}^{-1}$) are in reasonably close agreement with the MC prediction as shown in Figure 27.

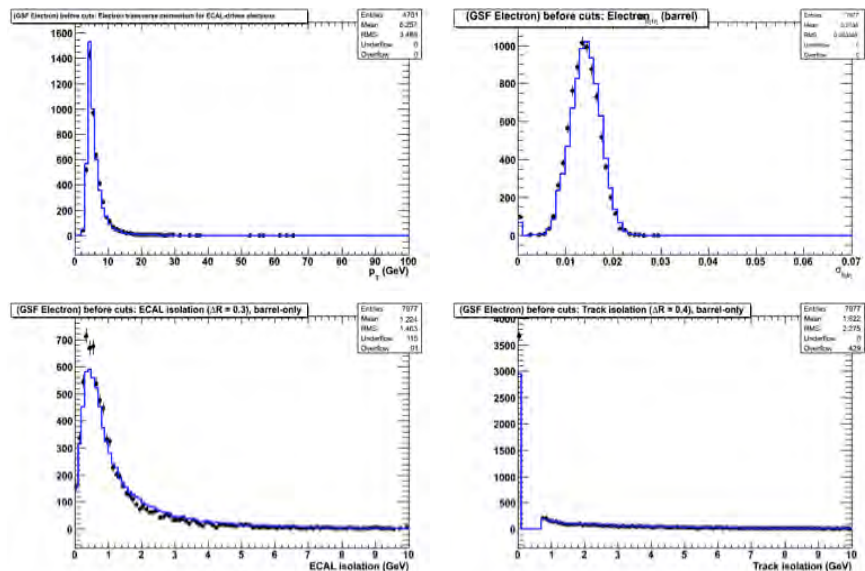


Figure 27: Properties of electron candidates in 7-TeV data compared to MC prediction: Electron p_T , transverse shower spread, isolation in ECAL and tracker.

Graduate student Bachtis has looked at the μ , τ and MET reconstruction with the particle flow group in the same $\sim 100 \mu\text{b}^{-1}$ real data. Figure 28 shows his comparisons of the latest data to

MC prediction for the muon kinematic variables. He also looked at some of the quantities used for their identification and isolation, which show reasonable agreement.

Graduate student Anderson is participating in the prompt analysis of photon events. He looked at photon and jet variables for the latest data and compared them to MC prediction. His results again show good agreement (Figure 29). The photon data from his sample will be used to correct the jet energy scale as soon as sufficient data is available.

Many of these distributions are still made with some of the tighter selection and isolation cuts not applied. In the coming weeks we expect that these students will report the first observation of vector boson, and high p_T direct photon events. After playing a useful role in preparing the first publications for this summer, they will move on to complete their planned analyses with $O(100) \text{ pb}^{-1}$ data expected in 2010. The less senior students will focus on the data taking, and will pursue their analyses with the aim of completing their work with the full 2010-2011 data sample. We even hope to discover new physics in the larger 1 fb^{-1} sample.

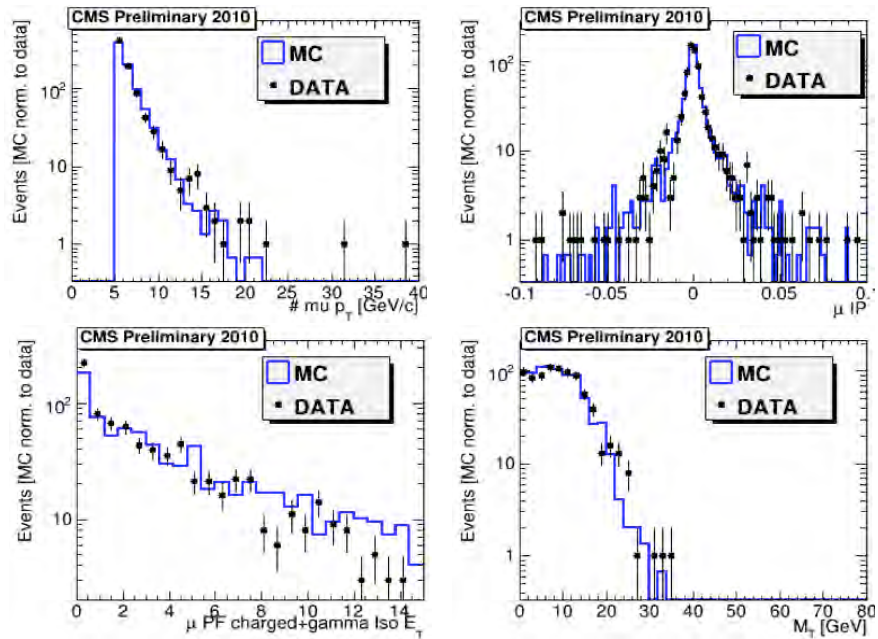


Figure 28: Data versus MC comparison for muon variables, P_T , impact parameter, isolation using PF candidates, and reconstructed transverse mass.

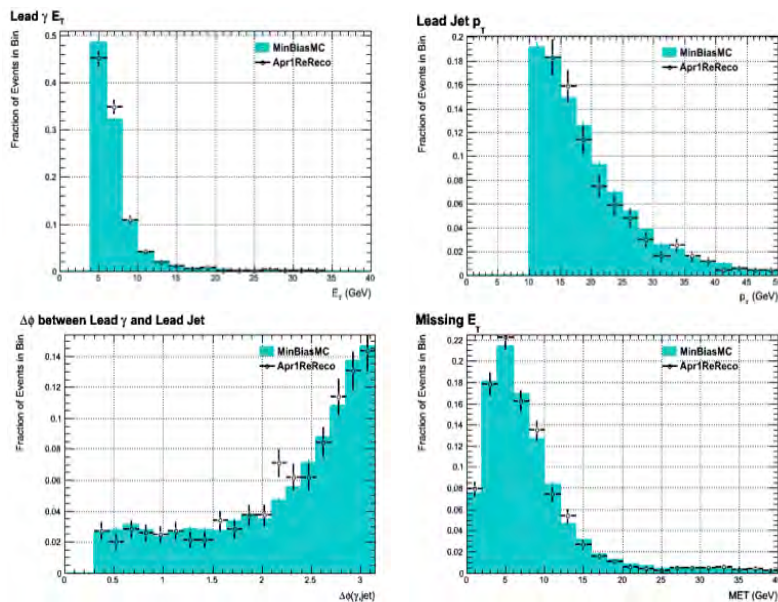


Figure 29: Leading photon and jet P_T spectra are shown along with the angle between them. The missing E_T expected from these events is peaked at low values as expected

6 Papers & Talks

6.1 Papers in refereed journals since January 2008

1. Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV, CMS Collaboration, J. High Energy Phys. 02 (2010) 041.
2. The CMS experiment at the CERN LHC, CMS Collaboration, JINST 3: S08004, 2008.
3. Measurement of the CMS Magnetic Field. V.I. Klyukhin et al., IEEE Trans. Appl. Supercond. 18: 395-398, 2008.
4. Measuring the Magnetic Field Inside the CMS Steel Yoke Elements, V.I. Klyukhin et al., to be published in IEEE Trans. Nucl. Sci.
5. Transverse momentum and pseudo-rapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 GeV, CMS collaboration, JHEP 1002:041, 2010
6. Commissioning of the CMS Experiment and the Cosmic Run at Four Tesla, CMS collaboration, JINST 5:T03001, 2010, arXiv:0911.4845v1 [physics.ins-det]
7. Performance of the CMS Level-1 Trigger during Commissioning with Cosmic Rays, CMS collaboration, JINST 5:T03002, 2010, arXiv:0911.5422v1 [physics.ins-det]
8. Performance of the CMS Drift-Tube Chamber Local Trigger with Cosmic Rays, CMS collaboration, JINST 5:T03003, 2010, arXiv:0911.4893v2 [physics.ins-det]
9. Fine Synchronization of the CMS Muon Drift-Tube Local Trigger using Cosmic Rays, CMS collaboration, JINST 5:T03004, 2010, arXiv:0911.4904v1 [physics.ins-det]
10. Commissioning of the CMS High-Level Trigger with Cosmic Rays, CMS collaboration, JINST 5:T03005, 2010, arXiv:0911.4889v1 [physics.ins-det]
11. CMS Data Processing Workflows During an Extended Cosmic Ray Run, CMS collaboration, JINST 5:T03006, 2010, arXiv:0911.4842v1 [physics.ins-det]
12. Commissioning and Performance of the CMS Pixel Tracker with Cosmic Rays, CMS collaboration, JINST 5:T03007, 2010, arXiv:0911.5434v1 [physics.ins-det]
13. Commissioning and Performance of the CMS Silicon Strip Tracker with Cosmic Ray Muons, CMS collaboration, JINST 5:T03008, 2010, arXiv:0911.4996v1 [physics.ins-det]
14. Alignment of the CMS Silicon Tracker During Commissioning with Cosmic Ray Particles, CMS collaboration, JINST 5:T03009, 2010, arXiv:0910.2505v2 [physics.ins-det]
15. Performance and Operation of the CMS Electromagnetic Calorimeter, CMS collaboration, JINST 5:T03010, 2010, arXiv:0910.3423v3 [physics.ins-det]
16. Time Reconstruction and Performance of the CMS Electromagnetic Calorimeter, CMS collaboration, JINST 5:T03011, 2010, arXiv:0911.4044v2 [physics.ins-det]
17. Performance of the CMS Hadron Calorimeter with Cosmic Ray Muons and LHC Beam Data, CMS collaboration, JINST 5:T03012, 2010, arXiv:0911.4991v3 [physics.ins-det]
18. Performance of CMS Hadron Calorimeter Timing and Synchronization using Test Beam, Cosmic Ray and LHC Beam Data, CMS collaboration, JINST 5:T03013, 2010, arXiv:0911.4877v1 [physics.ins-det]
19. Identification and Filtering of Uncharacteristic Noise in the CMS Hadron Calorimeter, CMS collaboration, JINST 5:T03014, 2010, arXiv:0911.4881v1 [physics.ins-det]
20. Performance of the CMS Drift Tube Chambers with Cosmic Rays, CMS collaboration, JINST 5:T03015, 2010, arXiv:0911.4855v1 [physics.ins-det]
21. Calibration of the CMS Drift Tube Chambers and Measurement of the Drift Velocity with Cosmic Rays, CMS collaboration, JINST 5:T03016, 2010, arXiv:0911.4895v1 [physics.ins-det]

22. Performance study of Barrel CMS Resistive Plate Chambers with Cosmic Rays, CMS collaboration, JINST 5:T03017, 2010, arXiv:0911.4045v1 [physics.ins-det]
23. Performance of the CMS Cathode Strip Chambers with Cosmic Rays, CMS collaboration, JINST 5:T03018, 2010, arXiv:0911.4992v1 [physics.ins-det]
24. Aligning the CMS Muon Chambers with the Muon Alignment System during an Extended Cosmic Ray Run, CMS collaboration, JINST 5:T03019, 2010, arXiv:0911.4770v1 [physics.ins-det]
25. Alignment of the CMS Muon System with Cosmic-Ray and Beam-Halo Muons, CMS collaboration, JINST 5:T03020, 2010, arXiv:0911.4022v1 [physics.ins-det]
26. Precise Mapping of the Magnetic Field in the CMS Barrel Yoke using Cosmic Rays, CMS collaboration, JINST 5:T03021, 2010, arXiv:0910.5530v2 [physics.ins-det]
27. Performance of CMS Muon Reconstruction in Cosmic-Ray Events, CMS collaboration, JINST 5:T03022, 2010, arXiv:0911.4994v1 [physics.ins-det]
28. Measurement of the muon stopping power of Lead Tungstate, CMS collaboration, JINST 5:P03007, 2010, arXiv:0911.5397v1 [physics.ins-det]
29. The CMS experiment at the CERN LHC, CMS collaboration, JINST 0803:S08004,2008, JINST 3:S08004,2008.
30. Measurement of the CMS Magnetic Field. V.I. Klyukhin *et al.*, IEEE Trans. Appl. Supercond. 18: 395-398, 2008.
31. Measuring the Magnetic Field Inside the CMS Steel Yoke Elements, V.I. Klyukhin *et al.*, to be published in IEEE Trans. Nucl. Sci.

6.2 Conference Talks since January 2008

1. W. Smith, Invited Plenary Talk, CMS Detector Global Status, *XXth Hadron Collider Physics Symposium*, Evian, France, November 2009, Published in Proc. of Science (HCP2009) 003.
2. S. Dasu, Invited Plenary Talk, *LHC Status and Its Physics Potential*, DAE-BRNS Symposium on High Energy Physics, Varanasi, India, December 2008.
3. W. Smith, Invited Plenary Talk, LHC start-up and Early Data, *16th International Workshop on Deep Inelastic Scattering (DIS '08)*, London, England, April 2008.
4. M. Grothe, Invited Plenary Talk, CMS forward detectors and their physics potential, *Workshop on high-energy photon collisions at the LHC*, CERN, April 2008
5. W. Smith, Invited Plenary Talk, The SLHC Program and Detector Upgrades, *Aspen Winter Conference on Particle Physics*, Aspen, Colorado, January 2008
6. M. Grothe, Invited Plenary Talk, *Forward physics with CMS*, Proceed. of 4th Conference on physics at LHC, Split, Croatia, Sept./Oct 2008
7. M. Grothe, Invited Plenary Talk, *Forward detectors around the CMS interaction point and their physics potential*, Proceed. of Workshop on high-energy photon interactions at the LHC, CERN, April 2008, Nucl.Phys.Proc.Suppl.179-180:173-180,2008
8. M. Grothe, Invited Plenary Talk, *Forward physics with CMS*, Proceedings of "HERA and the LHC: A Workshop on the Implications of HERA for LHC Physics", arXiv:0903.3861 [hep-ph]

6.3 Conference Proceedings since January 2008

1. CMS Detector Global Status, W. H. Smith, *XXth Hadron Collider Physics Symposium*, Evian, France, November 2009, Published in Proc. of Science (HCP2009) 003.

2. LHC start-up and Early Data, W. H. Smith, *16th International Workshop on Deep Inelastic Scattering (DIS '08)*, London, England, April 2008, Published in London 2008, Deep inelastic scattering, e-Print: arXiv:0808.3131 [hep-ex].
3. Operation and Monitoring of the CMS Regional Calorimeter Trigger Hardware, P. Klabbbers et al, Topical Workshop on Electronics for Particle Physics, Naxos, Greece, September 2008
4. Performance of the CMS Regional Calorimeter Trigger, P. Klabbbers et al, Topical Workshop on Electronics for Particle Physics, Paris, France, September 2009
5. Forward physics with CMS, M. Grothe, Proceedings of 4th Conference on physics at LHC, Split, Croatia, Sept./Oct 2008
6. Forward detectors around the CMS interaction point and their physics potential, M. Grothe, Proceedings of Workshop on high-energy photon interactions at the LHC, CERN, April 2008, Nucl.Phys.Proc.Suppl.179-180:173-180,2008
7. Forward physics with CMS, M. Grothe et al, Proceedings of "HERA and the LHC: A Workshop on the Implications of HERA for LHC Physics", DESY-PROC-2009-02, arXiv:0903.3861 [hep-ph]
8. CMS Monte Carlo production in the WLCG Computing Grid, A. Mohapatra, C. Lazaridis et al. 2008. 10pp., Published in J.Phys.Conf.Ser.119:052019, 2008.
9. CMS Monte Carlo production operations in a distributed computing environment, A. Mohapatra, C. Lazaridis et al. FERMILAB-CONF-08-312-CD, 2008. 2pp., 18th Hadron Collider Physics Symposium 2007 (HCP 2007) 20-26 May 2007, La Biodola, Isola d'Elba, Italy, Published in Nucl.Phys.Proc.Suppl.177-178:324-325, 2008
10. Measurement of the CMS Magnetic Field, R. Loveless *et al.*, Proceedings of the 20th Inter. Conf. on Magnet Technology, MT-20, Philadelphia, PA, USA, August 2007, IEEE Transactions on Applied Superconductivity, June 2008.
11. Measuring the Magnetic field Inside the CMS Steel Yoke Elements. R. Loveless *et al.*, Proceedings of the IEEE Nuclear Science Symposium, Dresden, Germany, October, 2008, IEEE Transactions on Nuclear Science, June 2009.

6.4 References for Section 5

(CMS Physics Analysis Summaries prepared under the supervision of S. Dasu, who was the electroweak physics group co-convener in 2008-2009 and M. Grothe, who was the forward physics group convener in 2006-2008. These CMS PAS documents are available online at: <https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResults>)

1. Study of the ratio of W+jets to Z+jets in proton-proton collisions at $\sqrt{s} = 10$ TeV with the CMS detector at the CERN LHC, CMS PAS EWK-09-006
2. Study of the $Z \rightarrow ee$ differential cross section as a function of Z rapidity at $\sqrt{s} = 10$ TeV, CMS PAS EWK-09-005
3. Towards a Measurement of the Inclusive $W \rightarrow ev$ and $\gamma^*/Z \rightarrow ee$ Cross Sections in pp Collisions at $\sqrt{s} = 10$ TeV, CMS PAS EWK-09-004
4. Muon Differential Cross Section and Charge Asymmetry in Inclusive pp to $W(\mu\nu) + X$ Production at $\sqrt{s} = 10$ TeV, CMS PAS EWK-09-003
5. Prospects for first measurement of the WW production cross-section in pp collisions at 10 TeV center of mass energy with the CMS detector, CMS PAS EWK-09-002
6. Towards a measurement of W and Z cross sections into muons in pp collisions at $\sqrt{s} = 10$ TeV, CMS PAS EWK-09-001

7. Study of Z production in association with jets in proton-proton collisions at $\sqrt{s} = 10$ TeV with the CMS detector at the CERN LHC, CMS PAS EWK-08-006
8. Towards a Measurement of the Inclusive $W \rightarrow e\nu$ and $\gamma^*/Z \rightarrow ee$ Cross Sections in pp Collisions at $\sqrt{s} = 14$ TeV, CMS PAS EWK-08-005
9. Study of the process pp to WZ to $l(+/-)$ neutrino $l(+)$ $l(-)$ ($l = \text{electron, muon}$), CMS PAS EWK-08-003
10. Measurement of the Muon Charge Asymmetry in the $pp \rightarrow W \rightarrow \mu\nu$ process at $\sqrt{s} = 14$ TeV, CMS PAS EWK-08-002
11. Measurement of the $Zbb, Z \rightarrow ll$ cross section with 100 pb^{-1} of early CMS data at the LHC, CMS PAS EWK-08-001
12. Observation of Single-Diffractive Production of Di-jets at the LHC, CMS PAS FWD-08-002
13. Low-x QCD studies with jets in the Hadron Forward calorimeter in p-p collisions at $\sqrt{s} = 14$ TeV, CMS PAS FWD-08-001
14. Study of single-diffractive production of W bosons at the LHC, CMS PAS DIF-07-002
15. Exclusive Dilepton Production, CMS PAS DIF-07-001

CMS Analysis and Internal Notes since January 2008

16. Electron and Photon High-Level Trigger in CMS, M. Anderson et al, CMS AN-2010/066.
17. Low P_T Double Electron Trigger Proposal for CMS, J. Leonard, M. Grothe, P. Klabbers, A. Savin, S. Dasu, W. H. Smith, et al., CMS IN-2010/007.
18. Tau Trigger and Particle Flow, M. Bachtis, A. Savin et al., CMS AN-2010/031.
19. Prospects for Measuring The Isolated Photon Cross Section at CMS, M. Anderson et al., CMS AN-2010/026.
20. Review of clustering algorithms and energy corrections in ECAL, M. Anderson et al, CMS IN-2010/008.
21. Study of dielectron spectrum, J. Leonard & M. Grothe, CMS AN-2010/021.
22. A Study of W/Z+jets Events Using Electron Modes, K. Grogg, C. Lazaridis, J. Efron, P. Klabbers, S. Dasu, W.H.Smith et al, CMS AN-2009/170 and AN-2008/093.
23. Prospects for measurement of $\sigma(pp \rightarrow Z).B(Z \rightarrow \tau\tau)$ with CMS in pp Collisions at $\sqrt{s}=7\text{TeV}$, M. Bachtis, A. Savin and S. Dasu, CMS AN-2010/082.
24. $Z\gamma$ analysis, L. Gray, S. Dasu, et al, CMS AN-2009/169.
25. Search for Technicolor with the CMS Experiment, J. Klukas, M. Herndon et al, CMS AN-2009/099 and CMS PAS EXO-09-007.
26. Search for Supersymmetry in Same-Sign Dilepton Final States with CMS Detector at LHC, M. Weinberg, A. Savin et al, CMS AN-2009/168.
27. Study of Isolation Properties of SUSY Low- p_T Leptons, M. Weinberg, A. Savin et al, CMS AN-2009/167

Talks given at CMS collaboration meetings since January 2008

The group has given over six hundred talks at CMS collaboration meetings since January 2008. The details of the talks given are available at:

<http://www.hep.wisc.edu/cms/cms-collaboration-talks.html>.

**DOE-HEP University Program Grant Information
Personnel Distribution Table**

Fiscal Year **2011**
 Institution Name University of Wisconsin - Madison
 Task/Title **Task T: CMS**

Type of Position	Name	Activity #1	Activity #2	FTE Months on CMS Research	# months funded by DOE-HEP University Program CMS	Faculty Advisor
Faculty	Carlsmith, Duncan	CMS EMU CMS	CDF	1.50	2	
Faculty	Dasu, Sridhara	TR/S&C	BaBar	1.90	2	
Faculty	Herndon, Matthew	CMS EMU	CDF	1.25	1.25	
Faculty	Smith, Wesley	CMS TR		2	2	
Distinguished Scientist	Loveless, Richard	CMS EMU		12	12	
Assoc. Scientist	Bellinger, James	CMS EMU		6	6	Carlsmith
Assoc. Scientist	Lanaro, Armando	CMS EMU		12	12	Loveless
Assoc. Scientist	Klabbers, Pam	CMS TR		12	12	Smith
Assoc. Scientist	Savin, Sascha	CMS TR		12	12	Smith
Assist. Scientist	Grothe, Monika	CMS TR		12	12	Smith
Post Doc	Efron, Jonathan	CMS TR		12	12	Smith
Grad Student	Gray, Lindsay	CMS EMU		12	12	Dasu
Grad Student	Klukas, Jeff	CMS EMU		12	12	Herndon
Grad Student	New Grad Student	CMS EMU		3	3	Herndon
Grad Student	Bachtis, Michail	CMS TR		12	12	Dasu
Grad Student	Ross, Ian	CMS TR		12	12	Dasu
Grad Student	Leonard, Jessica	CMS TR		12	12	Smith
Grad Student	Grogg, Kira	CMS TR		12	12	Smith
Grad Student	Weinberg, Marc	CMS TR		12	12	Smith
Grad Student	Lazaridis, Christos	CMS TR		12	12	Smith
Grad Student	Swanson, Josh	CMS TR		12	12	Smith
Grad Student	Parker, Will	CMS S&C		5	5	Smith
Grad Student	Reilly, Bethany	CMS S&C		5	5	Dasu
Grad Student	Ojalvo, Isobel	CMS S&C		5	5	Smith
Grad Student	Belknap, D. Austin	CMS S&C		3	3	Smith
Engineer	Bradley, Dan	CMS S&C		12	0	Dasu
Engineer	Mohapatra, Ajit	CMS S&C		12	0	Dasu
Engineer	Maier, Will	CMS S&C		12	0	Dasu
Engineer	Gorski, Tom	CMS TR		12	0	Smith
Technician	Fobes, Robert	CMS TR		12	0	Smith
Computing	Rader, Stephen			3.555	3.555	
Computing	Radtke, Matthew			3.555	3.555	
Administration	Lefkow, Aimee			1.57	1.57	

Bellinger also funded 3 months on US CMS Project funds (UCLA/NSF)
 Gorski funded by US CMS Project funds (UCLA/NSF)
 Bradley funded by DISUN Computing funds (UCLA/NSF)
 Mohapatra funded by US CMS Project funds (UCLA/NSF)
 Maier funded by US CMS Project funds (UCLA/NSF)
 Fobes funded by US CMS Project funds (UCLA/NSF)

Biographical Sketch – **Henry R. Band**

Professional Preparation

Massachusetts Institute of Technology	Physics	B.Sc.	1973
Duke University	Physics	M.A.	1975
Duke University	Physics	Ph.D.	1980
Northeastern University	High Energy Physics	Post Doc	1980-1984

Appointments

Senior Scientist	University of Wisconsin-Madison	2001-Present
Associate Scientist	University of Wisconsin-Madison	1992-2001
Assistant Scientist	University of Wisconsin-Madison	1986-1992
Senior Research Associate	Northeastern University	1984-1986

Synergistic Activities

- BaBar Speakers Bureau, 2009-Present, Deputy Chair 2004-5.
- SLAC Users Organization Executive Committee 2009-Present
- BaBar IFR System manager, 2001-Present
- SiD Design Concept Advisory Board 2005 – present
- NSS Program Reviewer IEEE2006,7,8
- SLAC Operating Safety Committee 2005-6
- Deputy BaBar IFR System manager, 1998-2000
- Spokesperson for T-419 SLAC Test Beam Experiment 1997-8

Collaborators & Other Affiliations

(i) Collaborators

Since there are many collaborators in each group, I have listed web pages.

The Daya Bay Collaboration	http://dayawane.ihep.ac.cn/collaboration.php
The BaBar Collaboration	http://www.slac.stanford.edu/cgi-wrap/colli
Silicon Detector Design Study	http://www-sid.slac.stanford.edu/SiD_org_chart_02.pdf
Particle Data Group	http://pdg.lbl.gov/2009/html/authors_2009.html

Selected Publications in Refereed Journals and Books (out of >503):

(most cited, Detector R&D, most recent)

1. Resistive Plate Chambers, Review of Particle Physics, Particle Data Group, Phys.Lett.B667:1, 2008. Particle Data Group, J.Phys.G33:1-1232, 2006.
2. The BaBar Detector, by the BaBar Collaboration, Nucl.Instrum.Meth.A479:1-116,2002.
3. Observation of a narrow meson decaying to $D^{+}(s) \pi^0$ at a mass of $2.32 \text{ GeV}/c^2$. BABAR Collaboration, Phys. Rev. Lett. 90, 242001 (2003).
4. Determination of the Neutron Spin Structure Function. E142 Collaboration, Phys. Rev. Lett. 71:959-962, (1993).

Biographical Sketch – **Henry R. Band**

5. Observation of a broad structure in the $\pi^+ \pi^- J/\psi$ mass spectrum around 4.26-
GeV/c². BABAR Collaboration, Phys. Rev. Lett. 95:142001, 2005.
6. Measurement of the CP violating asymmetry amplitude $\sin 2\beta$. BABAR
Collaboration, Phys. Rev. Lett. 89:201802, 2002.
7. Observation of CP violation in the B₀ meson system. BABAR Collaboration,
Phys. Rev. Lett. 87:091801, 2001.
8. Measurements of the proton and deuteron spin structure functions $g(1)$ and $g(2)$. By
E143 Collaboration, Phys.Rev.D58:112003,1998.
9. Precision determination of the neutron spin structure functions $g_1(n)$. By E154
Collaboration, Phys.Rev.Lett.79:26-30,1997.
10. Precision measurement of the proton spin structure functions $g_1(p)$. By E154
Collaboration, Phys.Rev.Lett.74:346-350,1995.
11. Lifetime of Particles Containing B Quarks, MAC Collaboration, Phys. Rev. Lett.
51:1022, (1983).
12. Precise measurement of the left-right cross-section asymmetry in Z boson production
by $e^+ e^-$ collisions. SLD Collaboration, Phys. Rev. Lett. 73:25-29 (1994).
13. Evidence for D₀ anti D₀ Mixing. BaBar Collaboration,
Phys.Rev.Lett.98:211802,2007.
14. Search for lepton flavor violation in the decay $\tau^+ \rightarrow e^+ \gamma$. BaBar
Collaboration, Phys.Rev.Lett. 96:041801,2006.
15. Study of HF Production in BaBar Resistive Plate Chambers, by H.R. Band et al.
Nucl.Instrum.Meth.A594:33-38,2008.
16. Performance and Aging Studies of BaBar Resistive Plate Chambers, by H.R. Band et
al, BABAR/IFR Collaboration, Nucl. Phys. Proc. Suppl. 158:139-142, 2006.
17. Performance of second generation resistive plate chambers , by F. Anulli et al.
BABAR/IFR Collaboration, Nucl. Instr. Meth. A 552(2005)276-291.
18. Gas system upgrade for the BABAR IFR detector at SLAC, by S. Foulkes et al, Nucl.
Instr. Meth. A 538(2004)801-809.
19. BaBar Forward Endcap Upgrade, by F. Anulli et al. BABAR/IFR Collaboration, Nucl.
Instr. Meth. A 539(2005)155-291.
20. A Moller polarimeter for high-energy electron beams, By H. R. Band et al. Nucl.
Instr. Meth. A 400(1997)24-33.
21. Hadronic charm decays from B factories, by H.R. Band for the BaBar and Belle
Collaborations, Nucl.Phys.Proc.Suppl.170:232-236, 2007.
22. Search for Charged Lepton Flavor Violation in Narrow Upsilon Decays by BABAR
Collaboration, Phys.Rev.Lett.104:151802, 2010.
23. Precise measurement of the $e^+ e^- \rightarrow \pi^+ \pi^- (\gamma)$ cross section with the Initial
State Radiation method at BABAR. By BABAR Collaboration,
Phys.Rev.Lett.103:231801,2009.
24. A Search for Invisible Decays of the Upsilon(1S). By BABAR Collaboration,
Phys.Rev.Lett.103:251801,2009.
25. Searches for Lepton Flavor Violation in the Decays $\tau^+ \rightarrow e^+ \gamma$ and $\tau^+ \rightarrow \mu^+ \gamma$. By BABAR Collaboration, Phys.Rev.Lett.104:021802,2010.
26. Search for a low-mass Higgs boson in $Y(3S) \rightarrow \gamma A_0$, $A_0 \rightarrow \tau^+ \tau^-$ at
BABAR. By BABAR Collaboration, Phys.Rev.Lett.103:181801, 2009.

Biographical Sketch – **Vernon Barger**

Professional Preparation

Pennsylvania State University	Engineering Science	B.S.
Pennsylvania State University	Theoretical Physics	Ph.D.
University of Wisconsin-Madison	Theoretical Physics	Post Doc

Appointments

Vilas Research Professor	University of Wisconsin-Madison	1991-
Hilldale Professor	University of Wisconsin-Madison	1987-
Director, Institute for Elementary Particle Physics Research	University of Wisconsin-Madison	1984-
John Hasbrouck Van Vleck Professor	University of Wisconsin-Madison	1983-
Professor	University of Wisconsin-Madison	1968
Associate Professor	University of Wisconsin-Madison	1967
Assistant Professor	University of Wisconsin-Madison	1965

Honors and Awards

Hilldale Award of the University of Wisconsin-Madison
Frontier Fellow, Fermi National Accelerator Laboratory
Fellow, American Physical Society
Fellow, John Simon Guggenheim Memorial Foundation
Senior Visiting Fellow, British Science-Engineering Research Council
Executive Committee of the Division of Particles and Fields of the American Physical Society
Alumni Fellow, Pennsylvania State University

Synergistic Activities (Since Jan. 2007)

- Site visits and associated major reviews of one National Laboratory and two University particle physics research programs. Served as the outside consultant on the selection committee for a distinguished university professorship in particle physics.
- Member of the Conference/Workshop Scientific Advisory Committees of the following meetings: COSMO 08; Muon Collider Workshop 09; NNN 08, 09; NuFact 09; USTRON 09; Pheno 08-10; PPC 08, 09.
- Co-authored the DUSEL Theory White Paper as the leader of the focus group on Long Baseline Neutrino Oscillations.

Non-UW Collaborators (Since Jan. 2007)

L. Anchordoqui, H. Baer, C.-W. Chiang, H. Goldberg, W.Y. Keung, J. Kumar, P. Langacker, H.S. Lee, A. Lessa, T. Liu, H.E. Logan, D. Marfatia, Y. Mao, A. Mustafayev, V.N. Senoguz, E. Sessolo, G. Shaughnessy, A. Soleimani, H. Summy, X. Tata, C.E.M. Wagner, L.T. Wang, K. Whisnant, W. Winter

Biographical Sketch – Vernon Barger

Thesis Advisor

I have been thesis advisor to 25 graduate students who have received a Ph.D degree. 10 of these became faculty. I am currently thesis advisor to the following 5 students.

(*=expected):

Name	Degree	Year	Current Post	Current Institution
Yu Gao	*Ph.D.	*2010	Research Asst.	U. Wisconsin
Pesei Huang			Research Asst.	U. Wisconsin
Matthew McCaskey	*Ph.D.	*2010	Research Asst.	U. Wisconsin
Chiu-Tien Yu			NSF Fellow	U. Wisconsin
Brian Yencho			Research Asst.	U. Wisconsin

Postdoctoral Advisor

I have been a joint postdoctoral sponsor for ~ 70 physicists. 43 of these became faculty. See the Grant Proposal for those since Jan. 2007.

Publications in Refereed Journals since Jan. 2007: See Grant Proposal.

Selected Top-cited Publications:

1. Breaking Eight-fold Degeneracies in Neutrino CP Violation, Mixing, and Mass Hierarchy (V. Barger, D. Marfatia and K. Whisnant), Phys. Rev. **D65**:073023 (2002).
2. Bimaximal Mixing of Three Neutrinos (V. Barger, S. Pakvasa, T.J. Weiler and K. Whisnant), Phys. Lett. **B437**:107 (1998).
3. The Supersymmetric Particle Spectrum (V. Barger, M.S. Berger and P. Ohmann), Phys. Rev. **D49**:4908 (1994).
4. Supersymmetric Grand Unified Theories: Two-loop Evolution of Gauge and Yukawa Couplings (V. Barger, M.S. Berger and P. Ohman), Phys. Rev. **D47**:1093 (1993).
5. Implications of $b \rightarrow s$ Gamma Decay Measurements in Testing the MSSM Higgs Sector (V. Barger, M.S. Berger and R.J.N. Phillips), Phys. Rev. **Lett.** **70**, 1368 (1993).
6. New Constraints on the Charged Higgs Sector in Two Higgs Doublet Models (V. Barger, J.L. Hewett and R.J.N. Phillips), Phys. Rev. **D41**:3421 (1990).
7. Some New Aspects of Supersymmetry R-Parity-Violating Interactions (V. Barger, G.F. Giudice and T. Han), Phys. Rev. **D40**:2987 (1989).
8. Phenomenological Mass Limits on Extra Z of E_6 Superstrings (V. Barger, N.G. Deshpande and K. Whisnant), Phys. Rev. Lett. **56**, 30 (1986).
9. Matter Effects on Three-Neutrino Oscillations (V. Barger, K. Whisnant, S. Pakvasa and R.J.N. Phillips), Phys. Rev. **D22**:2718 (1980).
10. Quark-Parton Model Relations in Deep Inelastic Lepton Scattering (V. Barger and R.J.N. Phillips), Nucl. Phys. **B73**, 269 (1974).

Biographical Sketch – **Duncan L. Carlsmith**

Professional Preparation

Yale University	Physics/Math	B.S./B.S.	1979
University of Chicago	Physics	M.S./Ph.D.	1984

Appointments

			1984-Present
Professor	University of Wisconsin-Madison		1999-Present
Associate Professor	University of Wisconsin-Madison		1993-1999
Associate Professor	University of Wisconsin-Madison		1987-1993
Project Associate	University of Wisconsin-Madison		1984-1987

Research Activities

Compact Muon Solenoid (CMS) Collaboration, CERN, 1994-present.

A general purpose detector for the Large Hadron Collider (LHC).

Endcap system design, cathode strip chamber R&D. Production Planning.

Laser alignment system and Tracking Alignment Task Management, USCMS Election Committee 2008-10, EMU operations

Collider Detector Facility (CDF), Fermilab, 1984-present.

Physics in Proton-antiproton Collisions at CM energy=1.8 TeV,

CDF Forward Muon Spectrometer System construction and operation, Muon Group Convener, Muon Upgrade Group Leader, Shift Captain/Scientific Coordinator, Executive Board.

Intermediate Muon System design, fabrication, installation, commissioning and M&O.

Superconducting Super Collider Subsystem R & D, 1986-1991.

1986 Snowmass Muon Group Co-leader, WI SSC Workshop Group Leader, SSC Generic Muon Subsystem Design Activities, Drift Chamber Development, High Pressure Gas Calorimetry Development, Muon Detector and Facilities Design, Engineering and Integration, Fermilab Experiment T816: SSC Muon Subsystem Beam Tests.

Solenoidal Detector Collaboration (SDC), SSCL, 1991-1993.

Proton-proton collisions at CM energy 40 TeV.

Muon Chamber Selection Committee, Muon Technical Board, Air Core Toroid Task Force, Intermediate Muon System Task Leader, RPC Committee (1993), Muon Trigger Review Committee (1993), Institutional Board.

Fermilab Experiment E617, 1980-1984.

Measurements of neutral kaon CP violation parameters and of the strange-quark magnetic moment.

Community

American Physical Society Member (1984-present),

IEEE member (1987-present), PHENIX Muon System Review Panel(1993)

<http://www.physics.wisc.edu/people/faculty/dcarlsmith/>

Biographical Sketch – Duncan L. Carlsmith

Selected publication in 2010 (see:

<http://usparc.ihep.su/spires/find/hep/wwwcite?rawcmd=FOUND+AUTHOR+CARLSMITH&FORMAT=www&SEQUENCE=ds%28d%29>)

Measurement of W-Boson Polarization in Top-quark Decay in ppbar Collisions at $\sqrt{s} = 1.96$ TeV. By The CDF Collaboration ([T. Aaltonen et al.](#)). FERMILAB-PUB-10-041-E, Mar 2010. Submitted to *Phys.Rev.Lett.*
e-Print: [arXiv:1003.0224](#) [hep-ex]

Measurement of the Top Quark Mass and ppbar \rightarrow ttbar Cross Section in the All-Hadronic Mode with the CDFII Detector. By The CDF Collaboration ([T. Aaltonen et al.](#)). FERMILAB-PUB-10-023-E, Feb 2010. (Received Mar 1, 2010). Published in *Phys.Rev.D81:052011,2010*.
e-Print: [arXiv:1002.0365](#) [hep-ex]

Combination of Tevatron searches for the standard model Higgs boson in the W+W- decay mode. By CDF and D0 Collaborations ([T. Aaltonen et al.](#)). FERMILAB-PUB-10-017-E, Jan 2010. 11pp. Published in *Phys.Rev.Lett.104:061802,2010*.
e-Print: [arXiv:1001.4162](#) [hep-ex]

Inclusive Search for Standard Model Higgs Boson Production in the WW Decay Channel using the CDF II Detector. By The CDF Collaboration ([T. Aaltonen et al.](#)). FERMILAB-PUB-10-016-E, Jan 2010. (Received Feb 12, 2010). Published in *Phys.Rev.Lett.104:061803,2010*.
e-Print: [arXiv:1001.4468](#) [hep-ex]

Measurement of the WW+WZ Production Cross Section Using the Lepton+Jets Final State at CDF II. By CDF Collaboration ([T. Aaltonen et al.](#)). FERMILAB-PUB-09-593-E, Nov 2009. (Received Mar 12, 2010). Published in *Phys.Rev.Lett.104:101801,2010*.
e-Print: [arXiv:0911.4449](#) [hep-ex]

Biographical Sketch – Daniel J. H. Chung

Professional Preparation

The University of Chicago	Physics	Ph.D. 1998
Massachusetts Institute of Technology	Physics	B.S. 1993
Massachusetts Institute of Technology	Elec. Eng.	B.S. 1993

Appointments

University of Wisconsin, Madison	Associate Professor	2009-present
University of Wisconsin, Madison	Assistant Professor	2003-2009
CERN, Switzerland	Postdoctoral Fellow	2001-2003
University of Michigan, Ann Arbor	Postdoctoral Fellow	2000-2001

Awards and Honors

Outstanding Junior Investigator Award	2005
---------------------------------------	------

Synergistic Activities

- White paper contributions: 0902.4759 (non-Gaussianity), 0811.3919 (CMBPol)
- KIAS Scholar, Korea Institute for Advanced Study, 2008-2010.
- Co-organizer for Strings 2000 (Ann Arbor, MI), PASI 2006 (Puerto Vallarta), COSMO 08 (Madison, WI), Workshop on DM, LHC and Cosmology 2009 (Seoul, Korea).
- Pedagogical lectures on cosmology at schools in Mexico, Korea, and Peru.

Non-proceeding Publications Since January 2007

1. “Electroweak Phase Transition in the $\mu\nu$ SSM,” (w/ A. Long) arXiv:1004.0942 [hep-ph].
2. “Gravity Waves as a Probe of Hubble Expansion Rate During An Electroweak Scale Phase Transition,” (w/ P. Zhou) arXiv:1003.2462 [astro-ph.CO].
3. “Supergauge interactions and electroweak baryogenesis,” (w/ B. Garbrecht, M. J. Ramsey-Musolf and S. Tulin), JHEP **0912**, 067 (2009) [arXiv:0908.2187 [hep-ph]].
4. “Lepton-mediated electroweak baryogenesis,” (w/ B. Garbrecht, M. J. Ramsey-Musolf and S. Tulin), Phys. Rev. D **81**, 063506 (2010) [arXiv:0905.4509 [hep-ph]].
5. “Yukawa Interactions and Supersymmetric Electroweak Baryogenesis,” (w/ B. Garbrecht, M. J. Ramsey-Musolf, and S. Tulin), Phys. Rev. Lett. **102**, 061301 (2009) [arXiv:0808.1144 [hep-ph]].

6. “The Effect of the Sparticle Mass Spectrum on the Conversion of B-L to B,” (w/ B. Garbrecht and S. Tulin), JCAP **0903**, 008 (2009) [arXiv:0807.2283 [hep-ph]].
7. “Reconstructing a general inflationary action” (w/ R. Bean and G. Geshnizjani), Phys. Rev. D **78**, 023517 (2008) [arXiv:0801.0742 [astro-ph]].
8. “Connecting LHC, ILC, and Quintessence” (w/ L. L. Everett, K. Kong and K. T. Matchev), JHEP **0710**, 016 (2007) [arXiv:0706.2375 [hep-ph]].
9. “Inflationary Cosmology Connecting Dark Energy and Dark Matter” (w/ L. Everett and K. Matchev), Phys. Rev. D **76**, 103530 (2007) [arXiv:0704.3285 [hep-ph]].
10. “Cuscuton Cosmology: Dark Energy meets Modified Gravity” (w/ N. Afshordi, Michael Doran, and G. Geshnizjani), Phys. Rev. D **75**, 123509 (2007) [arXiv:astro-ph/0702002].

Talks Since 2007 14 conference talks, 4 seminars. 1 summer school.

Collaborators & Other Affiliations

(i) Collaborators (during last 3 years):

Niayesh Afshordi (Perimeter), Rachel Bean (Cornell), Bjorn Garbrecht (Aachen), Ghazal Geshnizjani (Perimeter), Kyoungchul Kong (SLAC), Andrew Long (Madison), Konstantin Matchev (Florida), Michael Ramsey-Musolf (Madison), Sean Tulin (TRIUMPH), Peng Zhou (Madison)

(ii) Graduate Advisors:

Ph.D.: Edward Kolb and Michael Turner (Univ. of Chicago)

Education and Supervision

Postdoctoral Supervision:

Bjorn Garbrecht, Fall 2007–2009 → Faculty at Aachen, Germany

Jinn-Ouk Gong, 12/2007-10/2008 → Leiden, Netherlands → CERN

Ghazal Geshnizjani, Fall 2004–2007 → Perimeter

Graduate Student Supervision:

Antonio Enea Romano (PhD 2006, currently a postdoc at University of Kyoto, Japan)

Andrew Long (2007 – Present)

Peng Zhou (2008 – Present)

Hojin Yoo (2008 – Present)

Biographical Sketch – Sridhara Rao Dasu

Professional Preparation:

Nizam College, Osmania University	B. Sc. (Math, Physics, Chemistry) 1981
University of Hyderabad	M. Sc. (Physics) 1983
University of Rochester	M.A. (Physics) 1985, Ph. D. (Physics) 1988

Appointments:

University of Wisconsin	Associate Professor, 2006 – Present
University of Wisconsin	Assistant Professor, 2000 – 2006
University of Wisconsin	Associate Scientist, 2000
University of Wisconsin	Lecturer, Fall 1995
University of Wisconsin	Assistant Scientist, 1992-1999
Stanford Linear Accelerator Center	Research Associate, 1988 – 1992

Professional Responsibilities

1. Co-leader, Electroweak Physics Group, CMS Project
2. Co-leader, CMS Calorimeter Trigger Upgrade Project
3. Level-3 Manager, CMS Calorimeter Trigger Project
4. Manager, UW CMS Tier-2 Computing Center
5. Chair of Technical Board, Grid Laboratory of Wisconsin (GLOW)
6. Member, CMS Institutional Advisory Board
7. Member and past Secretary, US LHC Users Organization

Selected Publications:

1. CMS Collaboration, “*Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV*”, J. HEP 02 (2010) 041
2. CMS Collaboration, “*The CMS experiment at the CERN LHC*,” JINST 0803, S08004 (2008)
3. CMS HLT Group, “*The CMS high level trigger*”, Euro. Phys. J. C46, 605 (2006)
4. S. Dasu, “*Higgs physics at LHC*”, Pramana – J. of Physics, Vol 62, No 2, p177, 2004.
5. S. Dasu [CMS Collaboration], “*CMS Trigger And Event Selection*”, Eur. Phys. J. C4S1, 09 (2002).
6. BaBar Collaboration, “*Direct CP, Lepton Flavor and Isospin Asymmetries in the Decays $B \rightarrow K^* l^+ l^-$* ”, Phys. Rev. Lett. **102**, 091803 (2009).
7. BaBar Collaboration, “*Angular Distributions in the Decays $B \rightarrow K^* l^+ l^-$* ”, Phys. Rev. **D79**, 031102 (2009).
8. BaBar Collaboration, “*Search for Radiative Penguin Decays $B^+ \rightarrow \rho^+ \gamma$, $B^0 \rightarrow \rho^0 \gamma$, and $B^0 \rightarrow \omega^0 \gamma$* ”, Phys. Rev. Letters **94**, 011801 (2005).
9. BaBar collaboration, “*Measurement of branching fractions, and CP and isospin asymmetries, for $B^0 \rightarrow K^* \gamma$* ”, Phys. Rev. **D70**, 112006 (2004).

Collaborators:

Since there are several hundred members in the CMS and BaBar collaborations, a web reference is provided, in lieu of a complete list.

1. CMS Collaboration, <http://cmsdoc.cern.ch/people/PEOPLE1>
2. BaBar Collaboration, <http://www.slac.stanford.edu/babar-internal/colli?letter=showall>
3. Condor, Prof. Miron Livny, Dept. of Computer Science, U. Wisconsin

Research Program:

The primary focus of S. Dasu’s research program is to study the physics of the fundamental

Biographical Sketch – Sridhara Rao Dasu

particles and their interactions. As a member of the BaBar experiment at SLAC, he is studying physics of B meson decays, with the aim of understanding asymmetries in matter-antimatter behavior and place constraints on new physics phenomena. As a member of the CMS experiment at CERN, he is responsible for several aspects of its trigger and computing systems design, implementation, integration and commissioning. He is preparing to extract exciting signatures of new physics phenomena, which are very likely to manifest at the TeV scale probed by the CMS experiment from 2009.

Synergistic Activities:

S. Dasu's experimental program requires large scale computing and sophisticated electronics systems. The research and development needed for putting together these systems is an inter-disciplinary effort with computer and electrical engineering experts for exploitation of new ideas in those fields. Therefore, he collaborates with both ECE and CS departments on UW Campus. He lead the establishment of the Grid Laboratory of Wisconsin (GLOW), and is collaborating with the Open Science Grid (OSG).

Graduate and Postdoctoral Advisors:

1. Prof. Arie Bodek, U. of Rochester
2. Prof. D. W. G. S. Leith, SLAC
3. Prof. W. H. Smith, U. of Wisconsin
4. Prof. R. Prepost, U. of Wisconsin

Current Researchers and Professionals:

Dr. Monika Grothe, Asst. Scientist, CMS
Dr. Pamela Klabbers, Assoc. Scientist, CMS
Dr. Ajit Mohapatra, Researcher, CMS
Dr. Jonathan Efron, Res. Assoc., CMS
Dr. Kevin Flood, Asst. Scientist, BaBar
Mr. Dan Bradley, Software Engineer, CMS
Mr. Will Maier, System Administrator, CMS
Mr. Steve Rader, System Administrator, HEP
Mr. Matt Radtke, System Administrator, HEP

Physics Students:

Ms. Bethany Reilly, Sep 2009 – Now
Mr. Ian Ross, May 2009 – Now
Mr. Mike Bachtis, Aug 2007 – Now
Mr. Lyndsey Gray, Jul 2007 – Now
Mr. Mike Anderson, May 2005 – Now
Mr. Carl Vuosalo, Jan 2010 (Ph.D)
Ms. Kendra Rand, May 2005 (MS)
Ms. Meghan O'Connel, May 2005, (MS)
Dr. Ping Tan, Jun 2004 (Ph.D)
Ms. Ada Rubin, May 2004, (MS)

Engineering Students:

Mr. Vishal Mehta, 2005-2007
Mr. Vivek Puttabudhi, 2004-2005
Mr. Radhakrishna Gowrishankara, 2002-2004
Mr. Rajesh Rajamani, 2001-2002

BIOGRAPHICAL SKETCH

LISA LORRAINE EVERETT

Professional Preparation

Bryn Mawr College
University of Pennsylvania

A.B./M.A., *summa cum laude*, 1992
Ph.D., Physics, 1998

Appointments

1998–2001 Postdoctoral Research Scholar, University of Michigan
2001–2003 Postdoctoral Research Scholar, CERN
2003–2006 Postdoctoral Research Scholar, University of Florida
2006– Assistant Professor of Physics, University of Wisconsin

Publications

1. “Phenomenological Implications of Deflected Mirage Mediation: Comparison with Mirage Mediation,” (B. Altunkaynak, L. L. Everett, I. W. Kim, B. D. Nelson, and Y. Rao), arXiv:1001.5261 [hep-ph].
2. “Phenomenological Implications of Supersymmetric Family Non-universal $U(1)'$ Models” (L. L. Everett, J. Jiang, P. Langacker, and T. Liu), arXiv:0911.5349 [hep-ph].
3. “The Right Side of TeV Scale Spontaneous R-Parity Violation” (L. L. Everett, P. F. Perez and S. Spinner), Phys. Rev. D **80**, 055007 (2009) [arXiv:0906.4095 [hep-ph]].
4. “ $b \rightarrow s$ Transitions in Family-dependent $U(1)'$ Models,” (V. Barger, L. L. Everett, J. Jiang, P. Langacker, T. Liu and C. Wagner), JHEP 0912:048 (2009) [arXiv:0906.3745 [hep-ph]].
5. “Sneutrino Dark Matter: Symmetry Protection and Cosmic Ray Anomalies” (D. A. Demir, L. L. Everett, M. Frank, L. Selbuz and I. Turan), Phys. Rev. D **81**, 035019 (2010) [arXiv:0906.3540 [hep-ph]].
6. “Family Non-universal $U(1)'$ Gauge Symmetries and $b \rightarrow s$ Transitions” (V. Barger, L. L. Everett, J. Jiang, P. Langacker, T. Liu, and C. Wagner), Phys. Rev. D **80**:055008 (2009), [arXiv:0902.4507 [hep-ph]].
7. “Icosahedral (A_5) Family Symmetry and the Golden Ratio Prediction for Solar Neutrino Mixing” (L. L. Everett and A. J. Stuart), Phys. Rev. D **79**, 085005 (2009), [arXiv: 0812.1057 [hep-ph]].
8. “Moduli Stabilization and Supersymmetry Breaking in Deflected Mirage Mediation” (L. L. Everett, I. W. Kim, P. Ouyang, and K. Zurek), JHEP 0808:102 (2008) [arXiv:0806.2330 [hep-ph]].

9. “Deflected Mirage Mediation: A Framework for Generalized Supersymmetry Breaking” (L. L. Everett, I. W. Kim, P. Ouyang, and K. Zurek), Phys. Rev. Lett. **101**, 101803 (2008) [arXiv:0804.0592 [hep-ph]].
10. “Dirac Neutrino Masses from Generalized Supersymmetry Breaking” (D. Demir, L. L. Everett, and P. Langacker), Phys. Rev. Lett. **100**, 091804 (2008) [arXiv:0712.1341 [hep-ph]].
11. “Connecting, LHC, ILC, and Quintessence” (D. J. Chung, L. L. Everett, K. C. Kong, and K. Matchev), JHEP 0710:016, 2007 [arXiv:0706.2375].
12. “Inflationary Cosmology Connecting Dark Energy and Dark Matter” (D. J. Chung, L. L. Everett, and K. Matchev), Phys. Rev. D **76** 103530 (2007) [arXiv:0704.3285 [hep-ph]].

Synergistic Activities/Service

1. Everett is co-organizing the annual meeting of the String Vacuum Project (SVP) at KITP in May 2010. She has been a member of the String Vacuum Project collaboration since 2008.
2. Convener, Parallel Session on CP Violation, Flavor, Neutrinos, and Proton Decay, SUSY 2009, 3-9 June 2009; convener, Parallel Session on SUSY model building and Strings, SUSY 2008, 14-22 June, 2008.
3. Principal Investigator, funded QuarkNet proposal (<http://quarknet.fnal.gov>).
4. Member, EPP Theory Panel, NSF, February 2007.

Collaborators (since 2007)

B. Altunkaynak (Northeastern U.), V. Barger (U. Wisconsin), D. J. Chung (U. Wisconsin), D. Demir (Izmir Inst. Tech.), M. Frank (Concordia U.), P. Fileviez Perez (U. Wisconsin), J. Jiang (U. Wisconsin), I.-W. Kim (U. Wisconsin), K. C. Kong (FNAL), P. Langacker (IAS), T. Liu (U. Chicago), K. Matchev (U. Florida), P. Ouyang (U. Wisconsin), B. Nelson (Northeastern U.), L. Selbuz (Izmir Inst. Tech.) S. Spinner (U. Wisconsin), A. Stuart (U. Wisconsin), I. Turan (Concordia U.), C. Wagner (Argonne/U. Chicago), Y. Rao (U. Wisconsin), K. Zurek (U. Michigan).

Fellowships and Awards

1. L’Oreal For Women in Science U.S. Postdoctoral Fellowship Award, 2005.
2. National Science Foundation Graduate Fellowship, 1992.

Graduate and Postdoctoral Advisors

M. Cvetič (U. Pennsylvania), Paul Langacker (IAS), G. L. Kane (U. Michigan), P. Ramond, K. Matchev (U. Florida).

Graduate and Postdoctoral Advisees

Major Advisor: A. Stuart, V. Plaus, Y. Rao.

Member of Thesis committee: A. Atre, Y. Gao, R. Gavin, S. Haque, C. Lazaridis, M. McCaskey, J. Schmittehenner, G. Shaughnessy, A. Tregre, K. Wang, B. Yencho.

Postdoctoral scholars supervised: I.-W. Kim.

Biographical Sketch – **Tao Han**

Professional Preparation

Nankai University	Theoretical Physics	M.S.	1983
University of Wisconsin, Madison	Physics	Ph.D.	1990
Fermi National Accelerator Lab	Theoretical Physics	Post Doc	1990-93

Appointments

Co-Director, Phenomenology Inst.	University of Wisconsin-Madison	2006-Present
Professor	University of Wisconsin-Madison	2001-Present
Associate Professor	University of Wisconsin-Madison	1997-2001
Associate Professor II	University of California-Davis	1997
Assistant Professor	University of California-Davis	1993-1997

Awards.

National Superconducting Super-Collider Fellowship	1991-92
H.I. Romnes Faculty Fellowship, UW-Madison	2001-06
Hilldale Undergraduate/Faculty Research Award, UW-Madison	2001
Outstanding Researcher Award, Natural Science Foundation of China	2002-05
Election to Fellowship, American Physical Society	2003
Fermilab Frontier Fellowship	2004
Chang-Jiang Professorship, Ministry of Education, P. R. China	2004-07

Synergistic Activities

- Editorial Board: Physical Review D, 2008-2010; Chinese Physics C, 2005-present
- National Advisory Board, KITP–China, 2006–2011
- Series of lectures on LHC phenomenology: TASI04; China Center for Advanced Science and Technology (CCAST) 2004; Univ. of Bonn, Germany, 2005; CERN LHC Olympics 2006; Asian School of Particle, String, Cosmology, Japan 2006; National School of LHC Physics, Israel 2006; BUSSTEPP, Liverpool U, 2009 and Swansea U, 2010
- Co-organizer/Co-convenor, Beyond the Standard Model Workshop of the LHC Early Phase for the ILC, Fermilab, 2008; Muon Collider workshop, FNAL 2009; ILC workshop, U. of New Mexico, 2009; Beijing, March 2010.
- Chair, Organizing Committee, Phenomenology Symposia, UW-Madison, 2002—present

Collaborators & Other Affiliations

(i) *Recent collaborators*

V.~Barger, P.~Fileviez Perez, B.~Mellado, M.~Ramsey Musolf (UW-Madison), J.~Song (Konkuk Univ.), Lian-Tao Wang (Princeton), K. Agashe (Maryland), Z-G. Si (Shandong U.), G.~Senjanovic (ICTP, Trieste), S.~Pascoli (Durham Univ.), Bin Zhang (Tsinghua Univ.), A.~Soni (Brookhaven), Devin Walker (LBNL), S.~Bar-Shalom (Technion), G.~Eilam (Technion), M.~Carena (Fermilab), C.E.M. Wagner (Argonne National Lab & Univ. of Chicago), K.M. Zurek (Michigan), M. Strassler (Rutgers Univ.), H.~Davoudiasl (Brookhaven), G.~Perez (Weizmann.), G.~ Giudice (CERN)

(ii) *Supervision of graduate students:* Recent Ph.D. graduate students (*=expected):

Name	Degree	Year	Current Post	Current Institution
Zhen Liu	Ph.D.	*2014	Research Asst.	U. Wisconsin

Biographical Sketch – **Tao Han**

Zhe Dong	Ph.D.	*2013	Research Asst.	U. Wisconsin
Camilo Garcia	Ph.D.	*2012	Research Asst.	U. Wisconsin
Jared Schmitthener	Ph.D.	*2012	Research Asst.	U. Wisconsin
Ian Lewis	Ph.D.	*2011	Research Asst.	U. Wisconsin
Tong Li	Ph.D.	2008	Post Doc	Peking U.
Kai Wang	Ph.D.	2008	Post Doc	U. Tokyo, IPMU
Gui-Yui Huang	Ph.D.	2008	Post Doc	UC-Davis
Anupama Atre	Ph.D.	2007	Post Doc	Fermilab
Piyabut Burikham	Ph.D.	2005	Assoc. Prof.	Chulalongkorn U., Bangkok
Bob McElrath	Ph.D.	2003	Post Doc	Heidelberg U.

(iii) *Supervision of postdoctoral fellows:* Recent postdoctoral fellows:

Name	Position	Years	Current Post	Current Institution
Neil Christensen	Postdoc	2008-	LHC TI Fellow	University of Wisconsin
Ian-Woo Kim	Postdoc	2007-10	Postdoc	University of Wisconsin
Sogee Spinner	Postdoc	2008-	Postdoc	University of Wisconsin
Tom McElmurry	Postdoc	2006-09	Postdoc	Brookhaven National Lab
Kathryn Zurek	Postdoc	2006-08	Asst. Professor	University of Michigan
Hooman Davoudiasl	Postdoc	2004-06	Assoc. Physicist	Brookhaven National Lab
Cheng-Wei Chiang	Postdoc	2003-04	Assoc. Professor	National Central Univ, Taiwan
Heather Logan	Postdoc	2002-05	Asst. Professor	University of Toronto
Liantao Wang	Postdoc	2002-04	Asst. Professor	Princeton University
Tilman Plehn	Post Doc	1998-02	Professor	University of Heidelberg

Selected publications in Refereed Journals:

1. Some New Aspects of Supersymmetry R-Parity-Violating Interactions (V. Barger, G. Giudice and T. Han), *Phys. Rev.* **D40** (1989) 2987.
2. Strong W+W+ Scattering Signals at pp Supercollider (V. Barger, K. Cheung, T. Han, and R.J.N. Phillips), *Phys. Rev.* **D42** (1990) 3052.
3. Extending the Higgs Boson Reach at the Upgraded Fermilab Tevaron (T. Han and R.J. Zhang), *Phys. Rev. Lett.* **82**, 25 (1999).
4. On Kaluza-Klein States from Large Extra Dimension (T. Han, J. Lykken and R.J. Zhang), *Phys. Rev.* **D59**, 105006 (1999).
5. Signatures for Majorana Neutrinos at Hadron Colliders (T. Han and B. Zhang), *Phys. Rev. Lett.* **97**, 171804 (2006).
6. Neutrino Masses and the CERN LHC: Testing Type II Seesaw (P. Fileviez Perez, T. Han, G.-Y. Huang, T. Li, and K. Wang), *Phys. Rev.* **D78**, 015018 (2008).
7. The “Top Priority” at the LHC (T. Han), *Int. J. Mod. Phys.* **A23**, 4107 (2008).
8. The Search for Heavy Majorana Neutrinos (A. Atre, T. Han, S. Pascoli, and B. Zhang), *JHEP* 0905:030 (2009).
9. Genuine CP violating observables at the LHC (T. Han and T.-C. Li), *Phys. Lett.* B683, 278 (2010).
10. Kinematic Cusps: Determining the Missing Particle Mass at the LHC (T. Han, I.-W. Kim, J. Song), e-Print: arXiv:0906.5009 [hep-ph].

Full CV is available on: <http://www.pheno.wisc.edu/~than/vita.pdf>

Biographical Sketch – Akikazu Hashimoto

Professional Preparation

Princeton University	(Advisor: Igor Klebanov)	Physics	Ph.D. 1997
Massachusetts Institute of Technology		Physics	B.S. 1993
Massachusetts Institute of Technology		Mathematics	B.S. 1993

Appointments

University of Wisconsin, Madison	Associate Professor	2009-present
University of Wisconsin, Madison	Assistant Professor	2003-2009
Institute for Advanced Study, Princeton	Long Term Member	2001-2003
Institute for Advanced Study, Princeton	Member	2000-2001
Kavli Institute for Theoretical Physics, Santa Barbara	Research Associate	1997-2000

Awards and Honors

Publication “Monopoles and Dyons in Non-commutative Geometry,” A. Hashimoto and K. Hashimoto, *JHEP* **11** (1999) 005, hep-th/9909202, has been awarded the 2006 Soryushi Medal Shorei Prize by the Soryushiron Group (Japan Elementary Particle Theory Group)

Publications Since January 2007

1. A. Hashimoto, S. Hirano, and P. Ouyang. “Branes and fluxes in special holonomy manifolds and cascading field theories,” arXiv:1004.0903
2. O. Aharony, A. Hashimoto, S. Hirano, and P. Ouyang. “D-brane Charges in Gravitational Duals of 2+1 Dimensional Gauge Theories and Duality Cascades.” *JHEP* **01** (2010) 072 arXiv:0906.2390
3. S. S. Haque and A. Hashimoto, “Positronium-like states in strongly coupled $\mathcal{N} = 4$ supersymmetric Yang-Mills theory,” *Nucl. Phys.* **B829** (2010) 555-572. arXiv:0903.4841
4. A. Hashimoto, P. Ouyang, “Supergravity dual of Chern-Simons Yang-Mills theory with $\mathcal{N} = 6, 8$ superconformal IR fixed point,” *JHEP* **10** (2008) 057 arXiv:0807.1500
5. S. S. Haque and A. Hashimoto, “Microscopic Formulation of Puff Field Theory,” *JHEP* **05** (2008) 040, arXiv:0801.4354.
6. D. Dhokarh, S. S. Haque and A. Hashimoto, “Melvin Twists of global $AdS_5 \times S_5$ and their Non-Commutative Field Theory Dual,” *JHEP* **08** (2008) 084, arXiv:0801.3812.

7. A. Hashimoto, "A Note on Spontaneously Broken Lorentz Invariance," *JHEP* **08** (2008) 040, [arXiv:0801.3266](#).
8. "Non-commutativity and Open Strings Dynamics in Melvin Universes," Danny Dhokrah, Akikazu Hashimoto, and Sheikh Shajidul Haque, *JHEP* **08** (2007) 027, [arXiv:0704.1124](#)
9. "Aspects of Puff Field Theory," Ori J. Ganor, Akikazu Hashimoto, Sharon Jue, Bom Soo Kim, and Anthony Ndirango, *JHEP* **08** (2007) 035, [hep-th/0702030](#).

Invited Talks and Seminars

1. "Branes and fluxes in special holonomy manifolds and cascading field theories" University of Illinois Urbana-Champaign, November 2009
2. "Charges and anomalies in supergravity duals of $\mathcal{N} = 3, 4$ field theories in 2+1 dimensions." QTS06 Symposium, Kentucky, July 2009
3. "Fractional branes in 2+1 Super-Yang-Mills and Super-Yang-Mills-Chern-Simons Theories." Princeton University, April 2009; Great Lakes Strings Conference, Michigan, April 2009; Tokyo Institute of Technology, March 2009
4. "Supergravity duals: overview and prospects," McGill Workshop "3D SCFTs and Their Gravity Duals," September 2008
5. "Supergravity dual of $\mathcal{N} = 3$ SYM-CS theory," Weizmann Institute, Israel, June 2008
6. "Effectiveness of Effective Field Theories with Spontaneous Lorentz Violation" Neve Shalom, Israel, June 2008; University of California, Berkeley, April 2008
7. "Cosmology to topological field theory" University of Texas, September 2007
8. "Microscopic Formulation of Puff Field Theory," Kentucky, February 2007

Other Professional Activities

- Supervision of postdoctoral researchers and graduate students
- "Great Lakes String Conference" April 2008, Madison, WI.
- Referee for journals and funding agencies
- University of Wisconsin Faculty Senate
- Undergraduate Physics Society Advisor

Karsten M. Heeger - Biographical Sketch

Department of Physics, University of Wisconsin,
1150 University Ave, Madison, WI 53706, USA

Full CV is available at: <http://neutrino.physics.wisc.edu/heeger.php>

Professional Preparation:

2002 Ph.D. Physics, University of Washington, Seattle, WA
1999 M.A. Oxford University, England
1996 M.Sc. Physics, University of Washington, Seattle, WA
1995 B.A. (hons) Oxford University, England

Appointments & Affiliations:

2009 – Present Associate Professor (with tenure), University of Wisconsin
2008 – Present Senior Scientist, Institute for Physics and Mathematics of the Universe (IPMU), Tokyo, Japan
2006 – 2009 Assistant Professor, University of Wisconsin
2005 – 2006 Physicist Scientist, Lawrence Berkeley National Laboratory
2002 – 2005 Chamberlain Fellow, Lawrence Berkeley National Laboratory

Recent Honors and Awards:

2009 – 2011 Alfred P. Sloan Research Fellow
2008 Outstanding Junior Investigator Award, DOE Office of High Energy Physics, “*Precision Studies of the Reactor Antineutrino Spectrum and the Search for θ_{13} at Daya Bay*”
2008 Outstanding Junior Investigator Award, DOE Office of Nuclear Physics, “*Investigation of Neutrino Properties with Bolometric Detectors*”
2004 Michelson Postdoctoral Prize Lectureship, Case Western Reserve University
2003 APS Dissertation Award in Nuclear Physics
2002 – 2005 Chamberlain Fellowship, Lawrence Berkeley National Laboratory

Synergistic Activities:

- Daya Bay US Antineutrino Detector L2 Manager (2006-)
- Daya Bay Elected Executive Board Member (2007-)
- CUORE Calibration Subsystem Manager (2007-)
- CUORE Data and Analysis Vetting Committee (2009-)
- National Nuclear Physics Summer School Steering Committee (2008-2010)
- APS Committee on International Scientific Affairs; leading development of new APS US-China program (2009-2011)
- APS Forum on Graduate Student Affairs (FGSA) Chair (2003)

Collaborators:

Web pages with lists of my current collaborators are given below:

2004 – Daya Bay Reactor θ_{13} Experiment
<http://dayawane.ihep.ac.cn/collaboration.php>
2005 – CUORE (Cryogenic Underground Observatory for Rare Events)
<http://crio.mib.infn.it/wigmi/media/cuore/meetings/last-meeting/lists/CUORE.pdf>
2002 – 2009 KamLAND (Kamioka Liquid Scintillator Antineutrino Detector)
1996 – 2002 SNO (Sudbury Neutrino Observatory)

Karsten M. Heeger - Biographical Sketch

Thesis Advisor: I am currently advisor to 5 students. (*=expected):

Name	Degree	Year	Current Position	Project	Current Institution
Christine Lewis	Ph.D.*	2012*	Research Asst.	Daya Bay	U. Wisconsin
Adam Dally	Ph.D.*	2012*	Research Asst.	CUORE	U. Wisconsin
Michael McFarlane	Ph.D.*	2011*	Research Asst.	Daya Bay	U. Wisconsin
Larissa Ejzak	Ph.D.*	2011*	Research Asst.	CUORE	U. Wisconsin
Bryce Littlejohn	Ph.D.*	2011*	Research Asst.	Daya Bay	U. Wisconsin
Daniel Passmore	M.Sc	2007	Software developer		Industry

Postgraduate-Scholar Sponsor:

Name	Position	Years	Current Position	Project	Current Institution
Daniel Lenz	Postdoc	2010-	Research Asst.	CUORE	U. Wisconsin
Wei Wang	Postdoc	2007-	Research Asst.	Daya Bay	U. Wisconsin
Samuele Sangiorgio	Postdoc	2007-10	Scientist	CUORE	Livermore Natl. Lab.

Selected Publications in Refereed Journals and Books from 2008-2010:

1. *Solar fusion cross sections II: the pp chain and CNO cycles*, E. G. Adelberger et al., arXiv:/1004.2318, Submitted to Rev.Mod.Phys. (2010)
2. *Study of the Production of Radioactive Isotopes through Cosmic Muon Spallation in KamLAND*, S. Abe et al. (KamLAND Collaboration), Phys. Rev. C 81, 025807 (2010)
3. *The low-temperature energy calibration system for the CUORE bolometer array*, S. Sangiorgio, L.M. Ejzak, K.M. Heeger, R.H. Maruyama, A. Nucciotti, M. Olcese, T.S. Wise, A.L. Woodcraft, LTD13, arXiv:0908.0167 (2009)
4. *UV Degradation of the Optical Properties of Acrylic for Neutrino and Dark Matter Experiments*, B. Littlejohn, K.M. Heeger, T. Wise, E. Gettrust, and M. Lyman, JINST 4:T09001 (2009)
5. *The KamLAND Full-Volume Calibration System*, B.E. Berger et al. (KamLAND Collaboration), JINST 4:P04017 (2009)
6. *Measurement of the Cosmic Ray and Neutrino-Induced Muon Flux at the Sudbury Neutrino Observatory*, B. Aharmim, et al. (SNO Collaboration), Phys.Rev.D80:012001 (2009)
7. *Independent Measurement of the Total Active ^8B Solar Neutrino Flux Using an Array of ^3He Proportional Counters at the Sudbury Neutrino Observatory*, B. Aharmim, et al. (SNO Collaboration), Phys. Rev. Lett. 101, 111301 (2008).
8. *Precision Measurements of Neutrino Oscillation Parameters with KamLAND* S. Abe et al. (KamLAND Collaboration), Phys. Rev. Lett. 100, 221803 (2008).
9. *Neutrino Oscillation Physics with KamLAND: Reactor Antineutrinos and Beyond*, K.M Heeger, review book on neutrino oscillations by World Scientific, edited by J. Thomas and T. Vahle. World Scientific 2008

Biographical Sketch - **Matthew F. Herndon**

Professional Preparation

Johns Hopkins University	Physics	Research Scientist	1998-2005
University of Maryland	Physics	Ph.D.	1998
University of Texas	Physics	B.S	1994

Appointments

University of Wisconsin-Madison	Associate Professor	2009-present
University of Wisconsin-Madison	Assistant Professor	2005-2009

Selected Publications

- The CDF and D0 Collaborations, T. Aaltonen, et al., “Combination of Tevatron searches for the standard model Higgs boson in the W^+W^- decay mode,” *Phys. Rev. Lett.* **104**, 061802 (2010), arXiv:hep-ex/1001.4162.
- The CDF Collaboration, T. Aaltonen, et al., “Inclusive Search for Standard Model Higgs Boson Production in the WW Decay Channel using the CDF II Detector,” *Phys. Rev. Lett.* **104**, 061803 (2010), arXiv:hep-ex/1001.4468.
- The CDF Collaboration, T. Aaltonen, et al., “Measurement of the W^+W^- Production Cross Section and Search for Anomalous $WW\gamma$ and WWZ Couplings in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV,” Submitted to *Phys. Rev. Lett.* (2009), arXiv:hep-ex/0912.4500.
- The CDF Collaboration, T. Aaltonen, et al., “Search for a Higgs Boson Decaying to Two W Bosons at CDF,” *Phys. Rev. Lett.* **102**, 021802 (2009), arXiv:hep-ex/0809.3930.
- The CDF Collaboration, T. Aaltonen, et al., “Search for Bs to mumu and Bd to mumu Decays with 2fb-1 of ppbar Collisions,” *Phys. Rev. Lett.* **100**, 101802 (2008), arXiv:hep-ex/0712.1708.
- The CDF Collaboration, D. Abulencia et al., “Observation of $B_s - \bar{B}_s$ Oscillations,” *Phys. Rev. Lett.* **97**, 242003 (2006), arXiv:hep-ex/0609040.
- The CDF Collaboration, D. Abulencia et al., “Measurement of the $B_s - \bar{B}_s$ Oscillation Frequency,” *Phys. Rev. Lett.* **97**, 062003 (2006), arXiv:hep-ex/0606027.
- The CDF Collaboration, D. Acosta et al., “Search for $B_s^0 \rightarrow \mu^+\mu^-$ and $B_d^0 \rightarrow \mu^+\mu^-$ Decays in $p\bar{p}$ Collisions with CDF II,” *Phys. Rev. Lett.* **95**, 221805 (2005), arXiv:hep-ex/0508036.
- The CDF Collaboration, D. Acosta et al., “Search for $B_s^0 \rightarrow \mu^+\mu^-$ and $B_d^0 \rightarrow \mu^+\mu^-$ Decays in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV,” *Phys. Rev. Lett.* **93**, 032001 (2004), arXiv:hep-ex/0403032.
- C. Hays, Y. Huang, A.V. Kotwal, H.K. Gerberich, S. Menzemer, K. Rinnert, C. Lecci, M. Herndon, and F. D. Snider, “Inside-out Tracking at CDF,” *Nucl. Instrum. Meth. A* **538**, 249 (2005).

Synergistic-Activities

- CDF Higgs physics group leader: 2007-2008.
- CDF B physics group leader: 2005-2006.

- Leader CDF Dilepton and J/ψ physics subgroup: 2004-2005.
- Leader CDF Tracking group: 2002-2004.
- Leader CDF Silicon Studies group: 2001-2002
- Participant in Quark Net Program at Johns Hopkins University. Directed high school teachers in tracking based research at CDF.
- Organizer “Higgs Physics” session at the American Physical Society Department of Particles and Fields Meeting, Detroit, MI, 2009
- Organizer “ B_s Physics” session at the American Physical Society April Meeting, Jacksonville, FL, 2007
- Organizer “B Physics” session at the Hadron Collider Physics Meeting, Elba, Italy, 2007.
- Organizer “Heavy Flavor Physics and Search for New Particles” session at the Particles and Nuclei International Conference, 2005, Santa Fe, NM.

Collaborators & Other Affiliations

- Collaborators
Collider Detector and Fermilab(CDF) Collaboration
Compact Muon Solenoid(CMS) Collaboration
- Graduate & Postdoctoral Advisers
Professor Bruce Barnett: Johns Hopkins University
Professor Hassan Jawahery: University of Maryland
- Thesis & Postgraduate Advisees
Jason Nett: Graduate Student: University of Wisconsin,
Jeff Klukas: Graduate Student: University of Wisconsin,
Michael Glatzmaier: Summer Graduate Student: University of Wisconsin
David Sperka: Undergraduate Student: University of Wisconsin (graduated with thesis 2009)

Biographical Sketch - Richard J. Loveless

Professional Preparation

Rensselaer Polytechnic Institute	Physics	B. Sc.	1963
SUNY at Stony Brook	Physics	M.A., Ph.D.	1965, 1969

Appointments

Distinguished Scientist	University of Wisconsin	2007 – present
Senior Scientist	University of Wisconsin	1985 – 2007
Associate Scientist	University of Wisconsin	1979 – 1985
Assistant Scientist	University of Wisconsin	1978 – 1979
Project Associate	University of Wisconsin	1972 – 1978
Research Associate	SUNY at Stony Brook	1969 – 1972

Publications (19 > 137)

- 1) Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV. CMS Collaboration, JHEP02.2010:41-58,2010.
- 2) Measurement of the CMS Magnetic Field. V.I. Klyukhin, A. Ball, F. Bergsma, D. Campi, B. Cure, A. Gaddi, H. Gerwig, A. Herve, J. Korienek, F. Linde, C. Lindenmeyer, R. Loveless, M. Mulders, T. Nebel, R.P. Smith, D. Stickland, G. Teafoe, L. Veillet, J.K. Zimmerman, IEEE Trans.Appl.Supercond.18:395-398,2008.
- 3) Large CMS cathode strip chambers: Design and performance. D. Acosta *et al.*, Nucl.Instrum.Meth.A453:182-187,2000.
- 4) Large cathode strip chambers for the CMS endcap muon system. D. Acosta *et al.*, Nucl.Instrum.Meth.A419:469-474,1998.
- 5) The Muon Project – Technical Design Report. CMS Collaboration, CERN note CERN/LHCC 97-32, December 1997.
- 6) CMS, the magnet project: Technical design report. By CMS Collaboration (G. Acquistapace *et al.*). CERN-LHCC-97-10, May 1997.
- 7) Measurement of the proton structure function F2 from the 1993 HERA data. By ZEUS Collaboration (M. Derrick *et al.*), Z.Phys.C65:379-398,1995.
- 8) Observation of hard scattering in photoproduction events with a large rapidity gap at HERA, ZEUS Collaboration (M. Derrick *et al.*), Phys.Lett.B346:399-414,1995.
- 9) Measurement of total and partial photon proton cross-sections at 180-GeV center-of-mass energy. By ZEUS Collaboration (M. Derrick *et al.*), Z.Phys.C63:391-408,1994.
- 10) ZEUS hardware control system. R. Loveless *et al.*, Comput. Phys. Commun.57:313-315,1989.
- 11) A Search For Nucleon Decay With Multiple Muon Decays. By HPW Collaboration (T.J. Phillips *et al.*), Phys.Lett.B224:348-352,1989.
- 12) Neutrino Production By 400-Gev/C Protons In A Beam-Dump Experiment. M.E. Duffy *et al.*, Phys.Rev.D38:2032,1988.
- 13) The HALEAKALA Gamma-ray Observatory. L.K. Resvanis *et al.* Nucl. Instrum.Meth.A269:297-304,1988.
- 14) New Experimental Limits on muon-neutrino ---> electron-neutrino Oscillations. C. Angelini

Biographical Sketch - Richard J. Loveless

et al., Phys.Lett.B179:307,1986.

- 15) Observation Of Shortlived Particles Produced In High-Energy Neutrino Interactions. H.C. Ballagh *et al.*, Phys.Lett.B89:423,1980.
- 16) A Neutrino Induced Four Lepton Event. R.J. Loveless *et al.*, Phys. Lett. B78:505,1978.
- 17) K⁰ Phenomena Associated with Neutrino Induced m- e+ EVENTS. P. Bosetti *et al.*, Phys.Rev.Lett.38:1248-1251,1977.
- 18) Direct E+ E- Pair Production by 300-GeV/c Protons in Neon. R.J. Loveless, A.R. Erwin, E.H. Harvey, J. Mapp, M. Thompson, Phys.Rev.D16:546,1977.
- 19) Observation of m- e+ K⁰(S) Events produced by a Neutrino Beam. J. von Krogh *et al.*, Phys.Rev.Lett.36:710,1976.

Research Activities

1. CMS Endcap Muon Project Manager, 2007-2009
2. US-CMS Common Project Level 2 manager, 1995 – 2005
2. US-CMS Common Project Level 2 deputy manager, 2010 – present
2. US-CMS Endcap Muon Level 2 Construction manager, 2001 – 2007
3. CMS Endcap Muon Technical Coordinator, 1995 – present
4. SDC Muon system
5. ZEUS Calorimeter system (DESY)
6. Haleakala Gamma Ray telescope
7. BEBC Neutrino Oscillation exp. (CERN)
8. HPW Proton Decay experiment
9. Beam Dump Neutrino exp. (Fermilab)
10. Bubble Chamber exps. (15-ft, 30-in, 80-in)
11. Lambda Beta Decay (PPA)

Collaborators & Other Affiliations

- (i) Collaborators
 - CMS Collaboration
 - SDC Collaboration
 - ZEUS Collaboration

Honors & Awards

SPS Physics Honorary

Judith Craig Award for Outstanding Service

Biographical Sketch – **Bruce Mellado**

Professional Preparation

Moscow State University	Physics	B.Sc/M.Sc.	1995
Columbia University	Physics	Ph.D.	2001
University of Wisconsin-Madison	High Energy Physics	Post Doc	2002-2004
University of Wisconsin-Madison	High Energy Physics	Ass. Scientist	2004-2006

Appointments

Assistant Professor	University of Wisconsin-Madison	2006-present
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Honors

Fellowship of Spanish-Russian Ministries of Education	1989-1995
Awarded B.Sc. and M.Sc. with Honors	1995
Marie Curie Fellowship with Univ. of Oxford	2001
CERN Fellowship	2001
UW System President's Summit on Excellence in Teaching and Learning	2010
EMC2 Visiting Fellow, LAL, France	2010

Synergistic Activities

- Convener of the ATLAS Higgs→WW,inv group (2008-present)
- Co-Convener of ATLAS Higgs→ $\gamma\gamma$ Group (2006-2008)
- Co-Convener of ATLAS W/Z+jets Group (2006-2008)
- Co-Convener of US ATLAS Standard Model and Higgs Physics group (2006-2007)
- Member of the ATLAS SM cross-section Task Force (2010-present)
- Member of the Higgs cross-section Task Force (2009-2010)
- Member of the US ATLAS Tier3 Task Force (2008-2009)
- Member of US ATLAS Computing Resource Allocation Committee (2005-2010)
- Elected Member of the CTEQ collaboration (2007-present)
- Member of the Executive Committee of the UW Latino Faculty Staff Association (2007-)
- Convener of Higgs group of Kruger 2010, South Africa, December 2010.
- Chair of Tevatron session of PHENO2009, May 11th 2009.
- Chair of LHC session of DAE-BRNS-HEP08 Symposium, December 2008.
- Chair of the top-physics session of PHENO2008, May 2008
- Co-convener of Working Group Collider and Flavor Physics of WHEPP X, January, Chennai, India, January 2nd-13th 2008.
- Co-organizer of the North American Standard Model and Higgs Jamboree, Argonne National Laboratory, January 2007.
- Co-organizer of North American Standard Model and Higgs Workshop, Argonne National Laboratory, April 2006.
- Co-Convener of Tevatron-LHC Connection Session at WIN03, Lake Geneva, 2003

Collaborators & Other Affiliations

(i) Collaborators

ZEUS Collaboration	http://www-zeus.desy.de/
ATLAS Collaboration	http://atlas.web.cern.ch/Atlas/ORGANISATION/Directory/alphabetic.html
CTEQ Collaboration	http://www.phys.psu.edu/~cteq/

Biographical Sketch – Bruce Mellado

(ii) *Thesis Advisor* (*=expected, #=co-advisor)

Name	Degree	Year	Current Post	Current Institution
Dalong Geng	*Ph.D.	*2015	Research Asst.	U. Wisconsin (ATLAS)
Amanda Kruse	*Ph.D.	*2014	Research Asst.	U. Wisconsin (ATLAS)
Eva Valladolid [#]	*Ph.D.	*2012	Research Asst.	IFIC/Valencia (ATLAS)
Yesenia Hernandez [#]	*Ph.D.	*2012	Research Asst.	IFIC/Valencia (ATLAS)
Carlos Solans [#]	*Ph.D.	*2010	Research Asst.	IFIC/Valencia (ATLAS)
Joaquin Poveda [#]	Ph.D.	2009	Post Doc	U. Wisconsin (ATLAS)
Arantxa Ruiz [#]	Ph.D.	2009	Post Doc	Iowa State U. (ATLAS)
Xin Chen	Ph.D.	2008	Post Doc	U. Wisconsin (ATLAS)
Yaquan Fang	Ph.D.	2008	Post Doc	U. Wisconsin (ATLAS)
Alden Stradling	Ph.D.	2008	Post Doc	U. Texas-A (ATLAS)

Full CV is available on: <http://www.physics.wisc.edu/people/faculty/bmellado/bmellado-cv.pdf>

Top 10 Publications as a principal author

1. ZEUS results on the measurement and phenomenology of F(2) at low x and low Q**2. By ZEUS Collaboration, *European Physical Journal C* **7**: 609-630 (1999) **TOPCITE = 100+ with 239 cites**
2. Exclusive photoproduction of J / psi mesons at HERA. By ZEUS Collaboration, *European Physical Journal C* **24**: 345-360 (2002) **TOPCITE = 100+ with 119 cites**
3. Prospects for Pentaquark Searches in e+e- Annihilations and Gamma Gamma Collisions, S. Armstrong, B. Mellado and S.L. Wu, *J.Phys.G* **30**:1801 (2004)
4. Prospects for the Search of a Standard Model Higgs Boson in ATLAS Using Vector Boson Fusion, S. Asai et al., *Eur. Phys. J., C* **32** (2004) 19-54 **TOPCITE = 100+ with 132 cites**
5. Prospects for the Observation of a Higgs Boson with $H \rightarrow \tau^+\tau^- \rightarrow l^+l^- p_T$ associated with one high- P_T jet at the LHC, B. Mellado, W. Quayle, S.L.Wu, *Physics Letters B* **611**, 60 (2005)
6. Measurement of the Decays $B^0 \rightarrow \bar{D}^0 p\bar{p}$, $B^0 \rightarrow \bar{D}^{*0} p\bar{p}$, $B^0 \rightarrow D^- p\bar{p}\pi^+$, and $B^0 \rightarrow D^{*-} p\bar{p}\pi^+$ By BABAR Collaboration (B. Aubert et al.) *PRD-RC* **74**: 051101 (2006)
7. Feasibility of Searches for a Higgs Boson using $H \rightarrow W^+ W^- \rightarrow l^+l^- p(T)$ and High P(T) Jets at the Tevatron B. Mellado, W.Quayle and S.L.Wu, *Phys.Rev.D***76**:093007 (2007)
8. The ATLAS Experiment at the CERN Large Hadron Collider, ATLAS Collaboration, *JINST* **3**:S08003 (2008) **TOPCITE = 100+ with 168 cites**
9. Prospects of Searches for the Higgs Boson at the LHC (**review article**) B. Mellado. “Physics at the Large Hadron Collider”, Platinum Jubilee of the Indian National Science Academy (INSA)”, Springer-Verlag, page 75 (2009)
10. Normalizing weak boson pair production at the Large Hadron Collider, J.M.Campbell, E. Castaneda-Miranda, Y. Fang, N. Kauer, B. Mellado and S.L.Wu, *Phys. Rev. D***80**, 054023 (2009)

Complete list of publications can be found on the following website:

<http://www.physics.wisc.edu/people/faculty/bmellado/bmellado-pubs.pdf>

Biographical Sketch – Yibin Pan

Professional Preparation

Peking University, China	Physics	B.Sc	1985
University of Wisconsin-Madison	Physics	Ph.D.	1991
University of Wisconsin-Madison	High Energy Physics	Post Doc	1992-1996
University of Wisconsin-Madison	High Energy Physics	Ass. Scientist	1996-1998

Appointments

Assistant Professor	University of Wisconsin-Madison	1999-2004
Associate Professor	University of Wisconsin-Madison	2004-present

Collaborators:

1988-2000: ALEPH Collaboration

1998-2007: BABAR Collaboration

2001-present: ATLAS Collaboration

Synergistic Activities

- Co-Convener of BaBar Hadronic 3-Body Group (2003-2004)

Publications and Talks

- 303 ALEPH Physics Refereed Publications
- 431 BaBar Referenced Publications
- 6 Published Conference Proceedings
- 1 Technical Publication

PhD Thesis Advisor and co-advisor

- Steve Sekula, “A Search for $B^+ \rightarrow \tau^+ \nu_\tau$ Recoiling Against $B^- \rightarrow D^0 l^- \nu_l X$ ”, 2004
- Mousumi Datta, “A Search for the Rare Leptonic B Decay $B^+ \rightarrow \tau^+ \nu_\tau$ ”, 2005
- Ran Liu, “Measurement of CP Asymmetries and Branching Fractions in Neutral B Meson Decays to Charged Rhos and Pions”, 2004
- Jinwei Wu, “Study of Branching Fractions and CP-Violating Asymmetries in B Meson Decays to Rho and Pion Final States with the BaBar Detector”, 2005
- Zhitang Yu, “Dalitz Plot Analysis of $B^0 \rightarrow K^+ \pi^- \pi^0$ Decays”, 2005
- Baoshen Cheng, “Study of Branching Ratio and Polarization Fraction in $B^0 \rightarrow K^{*+} \rho^-$ ”, 2005
- Attila Mihayi, “Measurement of the CKM angle alpha at the BaBar detector using B meson decays to rho final states”, 2005
- Paul Kutter, “Measurement of CP violation in $B^0 \rightarrow \phi K^0$, and of CP violation in and branching fraction of $B^0 \rightarrow f^0(980) K_s$ ”, 2006

Top 10 Publications as a principal author

1: SEARCH FOR THE NEUTRAL HIGGS BOSON FROM Z0 DECAY

By ALEPH Collaboration, D. Decamp et al.,

CERN-EP/89-157, December 1st 1989, *Physics Letters B* 236 (1990) 233.

Biographical Sketch – Yibin Pan

2: SEARCH FOR THE NEUTRAL HIGGS BOSON FROM Z DECAy IN THE HIGGS MASS RANGE BETWEEN 11 AND 24 GeV

By ALEPH Collaboration, D. Decamp et al.,
CERN-EP/90-16, January 31st 1990, *Physics Letters B* 241 (1990) 141.

3: MEASUREMENT OF $B - \bar{B}$ MIXING AT THE Z USING A JET-CHARGE METHOD

By ALEPH Collaboration, D. Decamp et al.,
CERN-PPE/92-48, March 26th, 1992, *Physics Letters B* 284 (1992) 177.

4: SEARCH FOR THE STANDARD MODEL HIGGS BOSON

By ALEPH Collaboration, D. Buskulic et al.,
CERN-PPE/93-110, July 5th, 1993, *Physics Letters B* 313 (1993) 299.

5: SEARCH FOR THE STANDARD MODEL HIGGS BOSON IN e^+e^- COLLISIONS AT $\sqrt{s} = 161, 170$ and 172 GeV

By ALEPH Collaboration, R. Barate et al.,
CERN-PPE/97-70, June 17, 1997, *Physics Letters B* 412 (1997) 155.

6: OBSERVATION OF AN EXCESS IN THE SEARCH FOR THE STANDARD MODEL HIGGS BOSON AT ALEPH

By ALEPH Collaboration, R. Barate et al.,
CERN-EP/2000-138, November 13, 2000, *Physics Letters B* 495 (2000) 1.

7: MEASUREMENT OF CP-VIOLATING ASYMMETRIES IN B^0 DECAYS TO CP EIGENSTATES

By BaBar Collaboration, B. Aubert et al.,
SLAC-PUB-8777, February 12, 2001, *Physical Review Letters* 86 (2001) 2515.

8: OBSERVATION OF CP VIOLATION IN THE B^0 MESON

By BABAR Collaboration, B. Aubert et al.,
SLAC-PUB-8904, July 2001, *Physical Review Letters* 87 (2001) 091801.

9: SEARCH FOR THE RARE LEPTONIC DECAY $B^- \rightarrow \tau^- \bar{\nu}_\tau$

By BaBar Collaboration, B. Aubert et al.,
SLAC-PUB-10568, July 21, 2004, *Physical Review Letters* 95, 041804 (2005)

10: MEASUREMENT OF CP-VIOLATING ASYMMETRIES IN $B^0 \rightarrow (\rho\pi)^0$ USING A TIME-DEPENDENT DALITZ PLOT ANALYSIS

By BaBar Collaboration, B. Aubert et al.,
SLAC-PUB-07003, March 3, 2007 *Physical Review D* 76, 012004 (2007)

Complete list of publications can be found on the following website:

<http://www.physics.wisc.edu/people/faculty/pan/pan-pubs.pdf>

Biographical Sketch – Frank J. Petriello

Professional Preparation

Johns Hopkins University	Physics	Post Doc	2003-2005
Stanford University	Physics	Ph.D.	2003
University of Florida	Physics/Math	BS/BA	1999

Appointments

Associate Professor	University of Wisconsin, Madison	2009-present
Visiting Scientist	Argonne National Laboratory	Spring 2010
Visiting Scientist	Fermilab	Spring 2006
Assistant Professor	University of Wisconsin, Madison	2005-2009

Selected Professional Activities and Honors

- Joint ATLAS-CMS-Theory working group on Higgs cross sections, theory convener for gluon-fusion mode (Feb. 2010-present)
- Organizer, *Perturbative higher-order effects at work at the LHC*, CERN theory institute (June-July 2010)
- Organizer, *Forefront QCD and LHC discoveries*, Aspen workshop (May-June 2010)
- Host and organizer, *LoopFest VIII*, Madison, WI (May 2009)
- Sloan fellow, 2006-2009

Selected Recent Publications

1. *Color-octet scalar effects on Higgs boson production in gluon fusion*, R. Boughezal and F. Petriello, *arXiv:1003:2046*.
2. *Factorization and resummation of Higgs boson differential distributions in soft-collinear effective theory*, S. Mantry and F. Petriello, *arXiv:0911:4135*, accepted for publication in *Phys. Rev. D*.
3. *Reconstructing a Z' Lagrangian using the LHC and low-energy data*, Y. Li, F. Petriello and S. Quackenbush, *Phys. Rev. D* **80**:055018 (2009).
4. *Electroweak and finite quark-mass effect on the Higgs boson transverse momentum distribution*, W.-Y. Keung and F. Petriello, *Phys. Rev. D* **80**:013007 (2009).
5. *Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion*, C. Anastasiou, R. Boughezal and F. Petriello, *JHEP*:**0904**:003 (2009).
6. *Discovering hidden sectors with monophoton Z' searches*, Y. Gershtein, F. Petriello, S. Quackenbush and K. Zurek, *Phys. Rev. D* **78**:095002 (2008).
7. *Grand unification and light color-octet scalars at the LHC*, P. Fileviez Perez, R. Gavin, T. McElmurry and F. Petriello, *Phys. Rev. D* **78**:115017 (2008).
8. *DAMA and WIMP dark matter*, F. Petriello and K. Zurek, *JHEP*:**0809**:047 (2008).
9. *Next-to-leading order QCD corrections to ttZ production at the LHC*, A. Lazopoulos, T. McElmurry, K. Melnikov and F. Petriello, *Phys. Lett. B***666**:62 (2008).

Biographical Sketch – Frank J. Petriello

10. *Measuring Z' couplings at the LHC*, F. Petriello and S. Quackenbush, *Phys. Rev. D* 77:115004 (2008).

Synergistic Activities

- Host and Organizer, 2007 and 2009 CTEQ summer schools on QCD analysis and phenomenology, Madison, WI.
- Co-organizer for QuarkNet at UW-Madison, summer 2008.
- Lecturer at numerous summer schools for graduate students in high energy physics.

Collaborators & Other Affiliations

(i) Collaborators (outside UW)

Charalampos Anastasiou	ETH, Zurich
Radja Boughezal	University of Zurich
Yuri Gershtein	Rutgers University
Dan Hooper	Fermilab
Marc Kamionkowski	Caltech
Wai-Yee Keung	University of Illinois, Chicago
Achilleas Lazopoulos	ETH, Zurich
Kirill Melnikov	University of Hawaii. Manoa

(ii) Graduate & Postdoctoral Advisors

Professor Jonathan Bagger	Johns Hopkins University
Professor JoAnne Hewett	Stanford University

(iii) Thesis Advisor

Name	Degree	Year	Current Institution
Seth Quackenbush	Ph.D.	2009	Postdoc, Argonne
Ryan Gavin	Ph.D.	2011 (expected)	UW-Madison
Ye Li	Ph.D.	2012 (expected)	UW-Madison

(iv) Postgraduate-Scholar Sponsor

Name	Degree	Ph.D. Year & Institution	Current Institution
Maike Trenkel	Ph.D.	2009, Max Planck Institute for Physics, Munich	UW-Madison
Sonny Mantry	Ph.D.	2005, MIT	UW-Madison
Thomas McElmurry	Ph.D.	2006, University of Illinois, Urbana-Champaign	Postdoc, Brookhaven
Kathryn Zurek	Ph.D.	2006, University of Washington-Seattle	Faculty, University of Michigan

VITA SHEET – Lee Pondrom

NAME: Lee Girard Pondrom

ADDRESS: 210 Princeton Ave.
Madison, Wisconsin 53726

TELEPHONE: 608-238-7548
608-262-2284 (Physics Dept., University of Wisconsin)

BIRTHPLACE AND DATE: Dallas, Texas
December 26, 1933

EDUCATION: B.S. Southern Methodist University 1953
M.S. University of Chicago 1956
Ph.D. University of Chicago 1958

EXPERIENCE:

- 1st Lt. U.S.A.F. 1958-60
- Instructor, Physics Department, Columbia University New York 1960-63
- Associate Professor, Physics Department University of Wisconsin - Madison 1963-69
- Professor, Physics Department University of Wisconsin - Madison 1969-present
- Robert W. Wood Professor 1992-present
- Chairman, Physics Department University of Wisconsin - Madison 1997-2000

HONORS:

- John S. Guggenheim Memorial Fellow 1971-72
- Fellow, Japan Society for the Promotion of Science, 1981
- Distinguished Alumni Award, Southern Methodist University, 1983
- W.K.H. Panofsky Prize, American Physical Society, 1994
- President, Wisconsin Alpha, Phi Beta Kappa, 1996-97

MEMBERSHIPS: Fellow of American Physical Society

SPECIALTY AREA: Experimental studies in elementary physics using electronic techniques; general instrumentation problems in elementary particle physics

VITA SHEET – Lee Pondrom

Selected Publications 2010

1. Inclusive Search for Standard Model Higgs Boson in the WW decay Channel, T. Aaltonen et al, CDF Collaboration, Phys Rev Lett 104, 061803 (2010).
2. Observation of Single Top Quark Production and Measurement of $|V_{tb}|$. T. Aaltonen et al, CDF Collaboration, arXiv:1004.1181 (2010) submitted to Phys Rev D.
3. Measurement of W boson Polarization in top quark decay. T. Aaltonen et al CDF Collaboration, arXiv: 1003.0224 (2010) submitted to Phys Rev Lett.
4. Studying the Underlying Event in Drell Yan and High Transverse Momentum Jet Production, T. Aaltonen et al CDF Collaboration, arXiv:1003.3146 (2010) submitted to Phys Rev D.
5. Measurement of WW and WZ Production Cross sections. T. Aaltonen et al, CDF Collaboration, Phys Rev Lett 104, 101801 (2010).

Selected Publications 2007-2008

1. Analysis of the Quantum Numbers of the X(3872), A. Abulencia et al, Phys Rev Lett 98,132002 (2007).
2. **Observation of WZ Production**
A. Abulencia et al., The CDF Collaboration, Phys. Rev. Lett. 98, 161801 (2007).
3. **Measurement of the Inclusive Jet Cross Section using the k_T Algorithm in p anti-p Collisions at $s^{1/2} = 1.96$ TeV with the CDF II Detector**
A. Abulencia et al., The CDF Collaboration, Phys. Rev. D75, 092006 (2007).
4. **First Measurement of the W Boson Mass in Run II of the Tevatron**
T. Aaltonen et al., The CDF Collaboration, Phys. Rev. Lett. 99, 151801 (2007).
5. **Measurements of Inclusive W and Z Cross Sections in p anti-p Collisions at $s^{1/2} = 1.96$ TeV**
A. Abulencia et al., The CDF Collaboration, J. Phys. G: Nucl. Part. Phys. (2007) 2457-2544.
6. **Precise Measurement of the Top Quark Mass in the Lepton+Jets Topology at CDF II**
A. Abulencia et al., The CDF Collaboration, Phys. Rev. Lett. 99, 182002 (2007).
7. **Model-Independent Global Search for New High-p(t) Physics at CDF**
T. Aaltonen et al., The CDF Collaboration, FERMILAB-PUB-07-667-E. Submitted to Phys. Rev. Lett. December 18, 2007.
8. **Measurement of W-Boson Helicity Fractions in Top-Quark Decays using $\cos\theta^*$**
T. Aaltonen et al., The CDF Collaboration, Fermilab-Pub-08-511-E. Submitted to Phys. Lett. B November 7, 2008.
9. **Measurement of b-jet Shapes in Inclusive Jet Production in p anti-p Collisions at $s^{1/2} = 1.96$ TeV**
T. Aaltonen et al., The CDF Collaboration, Phys. Rev. D78, 072005 (2008).
10. **Measurement of the Inclusive Jet Cross Section at the Fermilab Tevatron p anti-p Collider Using a Cone-Based Jet Algorithm**
T. Aaltonen et al., The CDF Collaboration, Phys. Rev. D78, 052006 (2008).

Biographical Sketch: Gary Shiu

Professional Preparation

Cornell University	Physics	Ph.D., 1998; M.S., 1996
Chinese University of Hong Kong	Physics	B.S. (First Class Honors), 1993

Appointments

University of Wisconsin, Madison	Associate Professor	2006-present
University of Wisconsin, Madison	Assistant Professor	2002-2006
University of Pennsylvania	Senior Research Associate	2000-2002
Institute for Theoretical Physics, Stony Brook	Research Associate	1998-2000

Selected Honors and Awards

Fellow, Hong Kong Institute for Advanced Study	2009
John Simon Guggenheim Memorial Foundation Fellow	2008
Vilas Associate, University of Wisconsin	2008
Kavli Frontiers Fellow, National Academy of Sciences	2006
Cottrell Scholar Award	2005
NSF CAREER Award	2004
Research Innovation Award	2003

Recent Synergistic Activities

- Co-organizer: String Vacuum Project Meeting, KITP Santa Barbara, May 2010; Cosmo 2008 International Conference, UW-Madison; Great Lake Strings Conference 2008, UW-Madison.
- International Advisory Committee, String Phenomenology Conference (2004, 2007, 2010).
- Delivered numerous public lectures, and lectures series on *String Phenomenology and Cosmology* at international schools worldwide; see <http://uw.physics.wisc.edu/~strings/shiu/CVfull.pdf>.
- Mentor, Undergraduate Research Scholars Program, UW-Madison.
- Designed two new graduate courses at UW-Madison: String Theory (2003) and Supersymmetry (2008); the latter aimed at preparing theory & experimental students for the LHC.

Publications (since 2007)

1. P. McGuirk, G. Shiu and Y. Sumitomo, “Holographic gauge mediation via strongly coupled messengers,” *Phys. Rev. D* **81**, 026005 (2010) [arXiv:0911.0019 [hep-th]].
2. P. McGuirk, G. Shiu and Y. Sumitomo, “Non-supersymmetric infrared perturbations to the warped deformed conifold,” arXiv:0910.4581 [hep-th].
3. U. H. Danielsson, S. S. Haque, G. Shiu and T. Van Riet, “Towards Classical de Sitter Solutions in String Theory,” *JHEP* **0909**, 114 (2009) [arXiv:0907.2041 [hep-th]].
4. H. Y. Chen, Y. Nakayama and G. Shiu, “On D3-brane Dynamics at Strong Warping,” to appear in *Int. J. Mod. Phys. A.*, arXiv:0905.4463 [hep-th].
5. X. Chen, B. Hu, M. x. Huang, G. Shiu and Y. Wang, “Large Primordial Trispectra in General Single Field Inflation,” *JCAP* **0908**, 008 (2009) [arXiv:0905.3494 [astro-ph.CO]].

6. H. Y. Chen, L. Y. Hung, G. Shiu, “Inflation on an Open Racetrack,” JHEP **0903**, 083 (2009).
7. F. Marchesano, P. McGuirk and G. Shiu, “Open String Wavefunctions in Warped Compactifications,” JHEP **0904**, 095 (2009) [arXiv:0812.2247 [hep-th]].
8. S. S. Haque, G. Shiu, B. Underwood and T. Van Riet, “Minimal simple de Sitter solutions,” Phys. Rev. D **79**, 086005 (2009) [arXiv:0810.5328 [hep-th]].
9. H. Y. Chen, P. Ouyang and G. Shiu, “On Supersymmetric D7-branes in the Warped Deformed Conifold,” JHEP **1001**, 028 (2010) [arXiv:0807.2428 [hep-th]].
10. H. Y. Chen, J. O. Gong and G. Shiu, “Systematics of multi-field effects at the end of warped brane inflation,” JHEP **0809**, 011 (2008) [arXiv:0807.1927 [hep-th]].
11. G. Shiu, G. Torroba, B. Underwood and M. R. Douglas, “Dynamics of Warped Flux Compactifications,” JHEP **0806**, 024 (2008) [arXiv:0803.3068 [hep-th]].
12. P. McGuirk, G. Shiu and K. M. Zurek, “Phenomenology of Infrared Smooth Warped Extra Dimensions,” JHEP **0803**, 012 (2008) [arXiv:0712.2264 [hep-ph]].
13. M. x. Huang, G. Shiu and B. Underwood, “Multifield DBI Inflation and Non-Gaussianities,” Phys. Rev. D **77**, 023511 (2008) [arXiv:0709.3299 [hep-th]].
14. S. Sarangi, G. Shiu and B. Shlaer, “Rapid Tunneling and Percolation in the Landscape,” Int. J. Mod. Phys. A **24**, 741 (2009) [arXiv:0708.4375 [hep-th]].
15. G. Shiu, B. Underwood, K. M. Zurek and D. G. E. Walker, “Probing the Geometry of Warped String Compactifications at the LHC,” Phys. Rev. Lett. **100**, 031601 (2008).
16. O. DeWolfe, L. McAllister, G. Shiu and B. Underwood, “D3-brane Vacua in Stabilized Compactifications,” JHEP **0709**, 121 (2007) [arXiv:hep-th/0703088].

Talks (since 2007): 5 Public Lectures, 7 International School Lecture Series, 18 Conference Talks, 3 Colloquia, 19 Seminars. Complete list at <http://uw.physics.wisc.edu/~strings/shiu/CVfull.pdf>.

Graduate and Postdoctoral Advisors:

PhD: Henry Tye (Cornell Univ.)

Post-doctoral: Peter van Nieuwenhuizen (Stony Brook), Mirjam Cvetič (Univ. of Penn).

Post-doctoral Supervision

Lian-Tao Wang, 2002 – 2004 → Harvard postdoc → Assistant Prof., Princeton

Fernando Marchesano, 2003 – 2005 → Munich postdoc → CERN postdoc → IFT Madrid faculty

Minxin Huang, 2004 – 2007 → CERN Postdoc → IPMU Researcher

Thomas Grimm, 2005 – 2007 → Bonn postdoc → Max Planck Institute, Munich faculty (Fall 2010)

Kathryn Zurek, 2006 – 2008 → Schramm Fellow, FNAL → Assistant Prof., U. Michigan

Jinn-Ouk Gong, 2007 – 2008 → Leiden Postdoc → CERN postdoc (Fall 2010)

Peter Ouyang, 2007 – present → Purdue postdoc (Fall 2010)

Heng-Yu Chen, 2007 – present

Thomas Van Riet (Fulbright Fellow), January – May, 2008 → Uppsala U. postdoc

Yoske Sumitomo (Nishina Foundation Fellow), March – November, 2009 → Tata Institute postdoc

Student Supervision

John Maiden, PhD 2006, Finance Industry

Bret Underwood, PhD 2008, Postdoc at McGill Univ. (awarded IPP & Lorne Trottier Fellowships)

Steve Kecskemeti, 2004 – 2006, 1 joint publication, currently PhD in medical physics

Paul McGuirk, PhD 2011 (expected)

Michael Kiewe, PhD 2014 (expected)

Biographical Sketch – Wesley H. Smith

Professional Preparation

Harvard University	Physics	A.B/A.M.	1976
University of California-Berkeley	Physics	Ph.D.	1981
Columbia University	High Energy Physics	Post Doc	1981-1982

Appointments

Bjorn Wiik Professor of Physics	University of Wisconsin-Madison	2006-Present
Professor	University of Wisconsin-Madison	1992-2006
Associate Professor	University of Wisconsin-Madison	1988-1992
Associate Professor	Columbia University	1987-1988
Assistant Professor	Columbia University	1982-1987

Awards.

National Science Foundation Presidential Young Investigator Award	1984
Exxon Education Foundation Award	1984
Department of Energy Outstanding Junior Investigator Award	1987
Vilas Associate, University of Wisconsin	1995
Election to Fellowship, American Physical Society	1996
WARF Kellet Mid-Career Faculty Researcher Award, U. Wisconsin	1999
Named Professorship, U. Wisconsin	2006

Synergistic Activities

- Spokesman, Fermilab E-770: CCFR Neutrino Experiment, 1986 – 1998.
- Trigger Technical Coordinator/Convener. ZEUS Experiment, DESY, 1988-2007.
- Department of Energy High Energy Physics Advisory Panel, 1995-8
- Chair, U.S. Zeus Executive Committee, DESY, 1995-1997, 2003-6
- Trigger Project Manager/Trigger Coordinator, CMS Experiment, CERN, 1994 - present.
- Vice-Chair, DOE and NSF HEP Subpanel on the University Research Program, 2006-7

Collaborators & Other Affiliations

(i) Collaborators

Since there are over 300 collaborators in each group I have listed the web pages.

The ZEUS Collaboration http://www-zeus.desy.de/zeus_members/

The CMS Collaboration <http://cms.web.cern.ch/cms/Collaboration/index.html>

(ii) Thesis Advisor

I have been a thesis advisor to 20 graduate students who have earned a Ph.D. 3 have earned a Ph.D. in the last 3 years. I am currently advisor to 5 students. (*=expected):

Name	Degree	Year	Current Post	Current Institution
Joshua Swanson	*Ph.D.	*2013	Research Asst.	U. Wisconsin (CMS)
Christos Lazaridis	*Ph.D.	*2012	Research Asst.	U. Wisconsin (CMS)
Kira Grogg	*Ph.D.	*2012	Research Asst.	U. Wisconsin (CMS)
Mike Weinberg	*Ph.D.	*2012	Research Asst.	U. Wisconsin (CMS)
Jessica Leonard	*Ph.D.	*2011	Research Asst.	U. Wisconsin (CMS)
Homer Wolfe	Ph.D.	2008	Post Doc	Ohio State U. (CDF/CMS)
Erik Brownson	Ph.D.	2008	Post Doc	Vanderbilt U. (CMS)
Tom Danielson	Ph.D.	2008	Post Doc	U.C. Santa Barbara (CMS)

Biographical Sketch – Wesley H. Smith

(iii) *Postgraduate-Scholar Sponsor*

I have been postdoctoral sponsor for 10 people. Below are those within the last three years.

Name	Position	Years	Current Post	Current Institution
Jonathan Efron	Postdoc	2007-pres.	Postdoc/CMS	University of Wisconsin
Armando Lanaro	Scientist	2003-pres.	Scientist/CMS	University of Wisconsin
Monika Grothe	Scientist	2003-pres.	Scientist/CMS	University of Wisconsin
Pamela Chumney	Scientist	2000-pres.	Scientist/CMS	University of Wisconsin
Alexandre Savin	Scientist	2000-pres.	Scientist/CMS	University of Wisconsin

Full CV is available on: <http://www.hep.wisc.edu/wsmith/vita.pdf>

Selected Publications in Refereed Journals and Books (out of a total of 280) -- from 2008-10:

1. Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV, CMS Collaboration, J. High Energy Phys. 02 (2010) 041
2. Performance of the CMS Level-1 Trigger during Commissioning with Cosmic Rays, CMS collaboration, JINST 5:T03002, 2010, arXiv:0911.5422v1 [physics.ins-det]
3. Multi-lepton production at high transverse momentum at HERA, S. Chekanov *et al.*, Phys. Lett. **B680** 13, 2009.
4. Measurement of High- Q^2 Neutral Current Deep Inelastic e^- Scattering Cross Sections with a Longitudinally Polarised Electron Beam at HERA, S. Chekanov *et al.*, Eur. Phys. J. **C62** 625, 2009.
5. Measurement of Charged Current Deep Inelastic Scattering Cross Sections with a Longitudinally Polarised Electron Beam at HERA, S. Chekanov *et al.*, Eur. Phys. J. **C61** 223, 2009.
6. A Measurement of the Q^2 , W and t Dependences of Deeply Virtual Compton Scattering at HERA, S. Chekanov *et al.*, J. High Energy Phys., **0905** 108, 2009.
7. Deep Inelastic Scattering with Leading Protons or Large Rapidity Gaps at HERA, S. Chekanov *et al.*, Nucl. Phys. **B816** 1, 2009.
8. Leading Proton Production in Deep Inelastic Scattering at HERA S. Chekanov *et al.*, J. High Energy Phys., **0906** 074, 2009.
9. Multi-jet cross-sections in charged current e^+p scattering at HERA, S. Chekanov *et al.*, Phys. Rev. **D78**:032004, 2008.
10. Energy dependence of the charged multiplicity in deep inelastic scattering at HERA, S. Chekanov *et al.*, J. High Energy Phys. **0806** 061, 2008.
11. Beauty photoproduction using decays into electrons at HERA, S. Chekanov *et al.*, Phys. Rev. **D78** 072001, 2008.
12. The CMS experiment at the CERN LHC, the CMS Collaboration, J. Instrumentation **3**: S08004, 2008.

CURRICULUM VITAE – Sau Lan Wu

(1) Professional Preparation:

Vassar College	B.A.	1963	(<i>Summa cum Laude and Phi Beta Kappa</i>)
Harvard University	M.A.	1964	
Harvard University	Ph.D.	1970	
MIT		Postdoc	1970-1972
MIT		Research Physicist	1972-1977

Graduate Advisor	Professor Karl Strauch	Harvard University
Postdoctoral Advisor	Professor Samuel C.C. Ting	MIT

(2) Scholarships and Fellowships:

1964-1965	Leopold Schepp Foundation Fellowship
1963-1964	Harvard Fellowship
1960-1963	Vassar Scholarship

(3) Appointments:

1998-present	Vilas Professor (highest ranking professorship), University of Wisconsin-Madison
1991 -1998	Hilldale Professorship, University of Wisconsin, Madison
1990-present	Enrico Fermi Distinguished Professor, University of Wisconsin-Madison
1983-present	Professor, Physics Dept., University of Wisconsin-Madison
1980-1983	Associate Professor, Physics Dept., University of Wisconsin-Madison
1977-1980	Assistant Professor, Physics Dept., University of Wisconsin-Madison

(4) Awards:

- **1999 – present:** Honored to be included in the Archive on “Contributions of Women to 20th Century Physics.” Unveiled at the APS Centennial Meeting in Atlanta, March 1999. (www.physics.ucla.edu/~cwp)
- **1998 – present :** Vilas Professorship, University of Wisconsin, Madison (Vilas Professorships are the highest ranking professorships at the University of Wisconsin)
- **1996 :** Elected to be a fellow of the American Academy of Arts and Sciences
- **1995 :** Recipient of the 1995 High Energy and Particle Physics Prize of the European Physical Society “for the first evidence for three-jet events in e+e- collisions at PETRA,” which gives the first direct observation of the gluon (With P. Söding, B. Wiik, & G. Wolf)
- **1995 :** 1995 Executive Committee Special Prize of the European Physical Society “for establishing the existence of the gluon in independent and simultaneous ways.”
- **1992 :** Fellow of the American Physical Society
- **1991 -1998 :** Hilldale Professorship, University of Wisconsin, Madison
- **1990 – present :** Enrico Fermi Distinguished Professor of Physics, University of Wisconsin
- **1981 :** Romnes Faculty Award, University of Wisconsin, Madison. (Award given to outstanding faculty member soon after tenure)
- **1980 :** Outstanding Junior Investigator Award by the U.S. Dept. of Energy

(5) Committees:

- **2006 – present :** Advisory board for the Western ATLAS Tier 2 Center
- **2001–2004:** SLAC Scientific Policy Committee to advise Stanford University President
- **1997 – 2001:** General Councillor, The American Physical Society
- **1993 – 1996 :** High Energy Physics Advisory Panel, U.S Department of Energy
- **1993 :** DOE Annual Review Committee on SLAC programs
- **1992 :** DOE Review Committee on SLAC programs for SLC and SLD

- **1989 – 1993** : Advisory Committee of CERN Users; appointed by the CERN Director-General, representing the non-member state users at CERN
- **1987 – 1990** : Advisory Committee on Outstanding Junior Investigator Award, DOE
- **1983 – 1985** : Experimental High Energy Physics Advisory Committee, SLAC

(6) Synergistic Activities:

- MIT Postdoc with the experiment that led to the discovery of the J particle (charmed quark) at Brookhaven National Laboratory (Nobel Prize for S.C.C Ting and B. Richter in 1975)
- Leading figure for the Gluon discovery at DESY (co-recipient of the 1995 High Energy and Particle Physics Prize of the European Physical Society “for the first evidence for three-jet events in e+e- collisions at PETRA,” which gives the first direct observation of the gluon)
- Participation in and contribution to the discovery of CP Violation in B decays and to the measurements of the CKM angles β and α at the BaBar experiment
- Group leader of the Wisconsin/ATLAS group at CERN, supervising 18 graduate students, research associates, engineers and scientists. The focus of the group has been on the preparation and studies of physics at LHC, especially HIGGS, SUSY, and Exotic searches. Since LHC started to produce data, this focus is now on discoveries in these areas.
- 43 Wisconsin graduate students obtained Ph.D. degrees under my supervision. 27 of my former students and postdocs obtained faculty positions and 10 obtained permanent staff positions in national and international high energy laboratories.

Below is a list of **name (postdoc position)** of the 43 PhD degree recipients.

J. Freeman (FNAL), T. Barklow (SLAC), E. Wicklund (Caltech), H. Venkataramania (Yale), D. Strom (Chicago), M. Cherney (Berkeley), A. Caldwell (Columbia), S. Ritz (Columbia), D. Muller (SLAC), M. Takashima (CERN), D. Cowen (Caltech), J. Hilgart (CERN), J. Boudreau (CERN), J. Wear (U.C. Santa Cruz), Y. Pan (Wisconsin), D. Cinabro (Harvard), J. Pater (CERN), F. Webber (CERN), M. Walsh (Rutgers), L. Bellantoni (FNAL), Z. Feng (John Hopkins), Y. Gao (Harvard), J. Nachtman (UCLA), J. Grahl (Iowa), P. Elmer (Princeton), S. Armstrong (CERN), W. Orejudos (Berkeley), X. Wu (SBC Communications), O. Hayes (Booz Allen Hamilton), T. Greening (CERN), D. Ferguson (Wisconsin), J. Nielsen (Berkeley), E. Charles (Berkeley), P. McNamara (Rutgers), R. Liu (Berkeley Business School), J. Wu (Harvard), K. Cranmer (BNL), Z. Yu (Clearshape Technologies), B. Cheng (Avestar-IP), A. Mihalyi (Princeton Consultants), K. Loureiro (Ohio State), P. Kutter (Citizen’s Insurance), W. Quayle (Wisconsin).

(8) Collaborators & Other Affiliations:

TASSO Collaboration (1977-1985), **ALEPH** Collaboration (1982-2001),
BABAR Collaboration (1995-2008), **ATLAS** Collaboration (1993-present).

(9) Publications & Talks:

Publications 26 review articles,
 835 total publications in refereed journals
 (91 from TASSO, 303 from ALEPH, 427 from BaBar, 14 from DESY/BNL/ISR)
 73 ATLAS internal and refereed public notes

Talks 49 invited talks in conferences
 116 colloquia and seminars

(10) Additional information: (<http://wisconsin.cern.ch/d/Wu.html>)

Current and Pending Support

VERNON BARGER

4/29/10

Current:

Project: Institute for Elementary Particle Physics Research: Task G (Everett, Halzen, Han, Petriello, Co-Is)
Source: DOE - HEP
Total Award: \$ 9,188,094 Period: 11/01/96-10/31/10
Location: UW-Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: University Houses Professorship
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 56,000 Period: 07/01/83-06/30/10
Location: UW-Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: Vilas Professor of Physics (awarded annually)
Source: William F Vilas Trust Estate
Total Award: \$ 48,000 Period: 07/01/09-06/30/10
Location: UW-Madison
Commitment to Project: Cal: 0.00 Acad: 0.50 Sumr: 0.00

Project: Elementary Particle Physics Institute
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 500,000 Period: 07/01/86-11/14/13
Location: UW-Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

This proposal

Current and Pending Support

DUNCAN CARLSMITH

4/29/10

Current:

Project: High Energy Physics Research: Task T: CMS @ LHC (Co-I with Smith, Dasu, Herndon)

Source: DOE

Total Award: \$ 15,023,628

Period: 11/01/96-10/31/10

Location: UW Madison, CERN

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: High Energy Physics Research: Task E: CDF (Co-I with Pondrom, Herndon)

Source: DOE

Total Award: \$ 8,470,891

Period: 11/01/96-10/31/10

Location: UW Madison, Fermilab

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

This proposal

Current and Pending Support

DANIEL CHUNG

4/29/10

Current:

Project: High Energy Physics Research: Task J: Cosmology

Source: DOE

Total Award: \$ 415,000

Period: 11/01/04-10/31/10

Location: UW Madison

Commitment to Project:

Cal: 0.00

Acad: 0.00

Sumr: 2.00

Pending

This proposal

Current and Pending Support

SRIDHARA DASU

4/29/10

Current:

Project: Data Intensive Science University Network
Source: UCLA (NSF) 1000 G GB083
Total Award: \$ 2,303,000 Period: 06/01/05-05/31/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.90 Sumr: 0.00

Project: High Energy Physics Research: Task C: BaBar & ILC
Source: DOE
Total Award: \$ 5,824,087 Period: 11/01/96-10/31/10
Location: UW Madison, SLAC
Commitment to Project: Cal: 0.00 Acad: 0.90 Sumr: 0.00

Project: High Energy Physics Research: Task T: CMS @ LHC
Source: DOE
Total Award: \$ 15,023,628 Period: 11/01/96-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: US CMS M&O: Trigger, Computing, Muon, Common Ops
Source: UCLA (NSF) 1000 G HE150
Total Award: \$ 1,711,593 Period: 01/01/07-12/31/11
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.20 Sumr: 0.00

Project: Collaborative Research: Design and Integration of Complex Digital Systems for High Energy Physics (PI: M. Schulte)
Source: NSF ENGR 0824040
Total Award: \$ 183,828 Period: 09/01/08-08/31/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.25 Sumr: 0.00

Project: MRI: Acquisition of the Second Phase of the Grid Laboratory of Wisconsin (GLOW-II) (PI: M. Livny)
Source: NSF CNS-0722936
Total Award: \$ 500,000 Period: 09/01/09-08/31/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.25 Sumr: 0.00

Project: Student Support
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 33,725 Period: 07/01/09-06/30/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Current and Pending Support

SRIDHARA DASU

4/29/10

Pending

Project: US CMS M&O: Trigger, Computing, Muon, Common Ops
Source: UCLA (NSF) 1000 G HE150
Total Award: \$ 777,640 Period: 01/01/07-12/31/11
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.20 Sumr: 0.00

Project: ARRA: Research Infrastructure for Particle Physics
Source: DOE
Total Award: \$ 286,100 Period: 11/01/09-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

& This proposal

Current and Pending Support

LISA L. EVERETT

4/29/10

Current:

Project: Institute for Elementary Particle Physics Research: Task G (Barger, Halzen, Han, Petriello, Co-Is)

Source: DOE - HEP

Total Award: \$ 1,050,000

Period: 11/01/06-10/31/10

Location: UW-Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: QuarkNet – Teacher Training

Source: University of Notre Dame

Total Award: \$ 9,240

Period: 09/15/07-08/31/10

Location: UW-Madison

Commitment to Project: Cal: 0.00 Acad: 0.50 Sumr: 0.00

Project: Student Support

Source: Wisconsin Alumni Research Foundation

Total Award: \$ 33,735

Period: 07/01/09-06/30/10

Location: UW-Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

This proposal

Current and Pending Support

TAO HAN

4/29/10

Current:

Project: Institute for Elementary Particle Physics Research: Task G (Barger, Everett, Halzen, Petriello, Co-Is)

Source: DOE - HEP

Total Award: \$ 9,188,094

Period: 11/01/96-10/31/10

Location: UW-Madison

Commitment to Project: Cal: 0.00 Acad: 0.00

Sumr: 2.00

Project: LHC Theory Post Doc: Neil Christensen

Source: Johns Hopkins (NSF)

Total Award: \$ 150,000

Period: 09/01/09-08/31/11

Location: UW-Madison

Commitment to Project: Cal: 0.00 Acad: 0.09

Sumr: 0.00

Pending

This proposal

Current and Pending Support

AKI HASHIMOTO

4/29/10

Current:

Project: High Energy Physics Research: Task D: String Theory (Co-I Shiu & Chung (FY11))
Source: DOE
Total Award: \$ 1,261,571 Period: 11/01/06-10/31/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Pending

This proposal

Current and Pending Support

KARSTEN HEEGER

4/29/10

Current:

Project: High Energy Physics Research: Task L: Daya Bay
Source: DOE, DE-FG02-95ER40896
Total Award: \$ 765,000 Period: 11/01/06-10/31/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 1.00

Project: Daya Bay R&D
Source: LBNL, 6810325
Total Award: \$ 1,074,243 Period: 11/01/06-09/30/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Project: Daya Bay Mechanical Systems
Source: LBNL, 6844593
Total Award: \$ 2,195,893 Period: 06/06/08-09/30/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Project: Daya Bay Acrylic Vessel
Source: LBNL, 6844884
Total Award: \$ 3,299,609 Period: 06/06/08-02/28/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Project: Investigation of Neutrino Properties with Bolometric Detectors
Source: DOE Nuclear, DE-FG02-08ER41551
Total Award: \$ 357,000 Period: 07/01/08-06/30/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 1.00

Project: CUORE R&D
Source: LBNL, 6833046
Total Award: \$ 194,500 Period: 11/01/07-09/30/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: Dusel R&D: Development of Bolometric Detectors for Neutrinoless Double Beta
Decay and Neutrino Mass Experiments
Source: NSF, PHY-0704995
Total Award: \$ 225,000 Period: 08/01/07-07/31/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Current and Pending Support

KARSTEN HEEGER

4/29/10

Project: Sloan Fellowship
Source: Sloan Foundation, BR-5029
Total Award: \$ 50,000 Period: 09/16/09-09/15/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Project: Student Support
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 37,979 Period: 07/01/08-06/30/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

Project: CUORE R&D
Source: LBNL, 6833046
Total Award: \$ 775,000 Period: 11/01/07-09/30/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: ARRA: Research Infrastructure for Particle Physics
Source: DOE
Total Award: \$ 286,100 Period: 11/01/09-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

& This proposal

Current and Pending Support
MATTHEW F. HERNDON
4/29/10

Current:

Project: High Energy Physics Research: Task T: CMS @ LHC (Co-I with Smith, Dasu, Carlsmith)
Source: DOE
Total Award: \$ 5,721,000 Period: 11/01/06-10/31/09
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: High Energy Physics Research: Task E: CDF (Co-I with Pondrom, Carlsmith)
Source: DOE
Total Award: \$ 2,419,000 Period: 11/01/06-10/31/09
Location: UW Madison, Fermilab
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: Post Doc support
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 33,735 Period: 07/01/09-06/30/10
Location: UW Madison, Fermilab
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

This proposal

Current and Pending Support

BRUCE MELLADO

4/29/10

Current:

Project: High Energy Physics Research: Task H: ATLAS @ LHC (PI: S-L. Wu, Co-PI:
Y. Pan)
Source: DOE
Total Award: \$ 3,896,144 Period: 11/01/06-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Pending

Project: ATLAS Research
Source: IN2P3, Centre National de la Recherche Scientifique
Total Award: \$ 12,536 Period: 05/01/10-08/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 1.00

This proposal

Current and Pending Support

YIBIN PAN

4/29/10

Current:

Project: High Energy Physics Research: Task H: ATLAS @ LHC (PI: S-L. Wu, Co-PI:
Y. Pan, B. Mellado)
Source: DOE
Total Award: \$ 13,292,734 Period: 11/01/01-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Pending

This proposal

Current and Pending Support
FRANCIS "FRANK" J. PETRIELLO

4/29/10

Current

Project: High Energy Physics Research: Task G: Institute for Elementary Particle Physics Research (Co-I with Barger, Han, Everett)

Source: DOE

Total Award: \$ 2,705,571

Period: 11/01/06-10/31/10

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: High Energy Physics Research: Task Q: OJI
(95K annually incorporated into Task G starting FY10 when tenure granted)

Source: DOE

Total Award: \$ 285,000

Period: 11/01/06-10/31/09

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.50 Sumr: 0.00

Project: Sloan Foundation Fellowship

Source: Sloan Foundation

Total Award: \$ 45,000

Period: 09/01/07-09/15/10

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Project: Student Support

Source: Wisconsin Alumni Research Foundation

Total Award: \$ 33,735

Period: 07/01/09-06/30/10

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: Spring Teaching Buyout

Source: Argonne National Lab

Total Award: \$ 69,481

Period: 01/08/10-05/23/10

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 4.50 Sumr: 0.00

Pending

This proposal

Current and Pending Support

LEE PONDROM

4/29/10

Current:

Project: High Energy Physics Research: Task E: CDF (Co-I with Pondrom, Herndon)

Source: DOE

Total Award: \$ 8,470,891

Period: 11/01/96-10/31/10

Location: UW Madison, Fermilab

Commitment to Project:

Cal: 0.00

Acad: 0.00

Sumr: 2.00

Pending

This proposal

Current and Pending Support

GARY SHIU

4/28/10

Current

Project: High Energy Physics Research: Task D: String Theory (Co-I with Hashimoto & in FY11 Chung)

Source: DOE DE-FG02-95ER40896

Total Award: \$ 280,000

Period: 11/01/08-10/31/09

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: Connecting String Theory to Experiment

Source: Research Corporation Cottrell Scholar CS1271

Total Award: \$ 100,000

Period: 05/15/05-12/31/11

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Project: Vilas Associate

Source: Vilas Trust Estate

Total Award: \$ 36,244

Period: 07/01/09-06/30/10

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: Post Doc Support

Source: Wisconsin Alumni Research Foundation

Total Award: \$ 27,830

Period: 01/01/10-06/30/11

Location: UW Madison

Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

This proposal

Current and Pending Support

WESLEY H. SMITH

4/29/10

Current:

Project: Data Intensive Science University Network
Source: UCLA (NSF)
Total Award: \$ 2,303,000 Period: 06/01/05-05/31/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.50 Sumr: 0.00

Project: High Energy Physics Research: Task T: CMS @ LHC
Source: DOE
Total Award: \$ 16,451,628 Period: 11/01/96-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: US CMS M&O: Trigger, Computing, Muon, Common Ops
Source: UCLA (NSF)
Total Award: \$ 1,711,593 Period: 01/01/07-12/31/11
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.20 Sumr: 0.00

Project: US CMS Trigger, EMU, & Common Projects Construction
Source: FNAL (DOE)
Total Award: \$ 15,384,441 Period: 10/01/97-09/30/10
Location: UW Madison, CERN, Fermilab
Commitment to Project: Cal: 0.00 Acad: 0.50 Sumr: 0.00

Project: Collaborative Research: Design and Integration of Complex Digital Systems for High Energy Physics (PI: M. Schulte)
Source: NSF
Total Award: \$ 183,828 Period: 09/01/08-08/31/11
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.25 Sumr: 0.00

Project: MRI: Acquisition of the Second Phase of the Grid Laboratory of Wisconsin (GLOW-II) (PI: M. Livny)
Source: NSF CNS-0722936
Total Award: \$ 500,000 Period: 09/01/09-08/31/10
Location: UW Madison
Commitment to Project: Cal: 0.00 Acad: 0.25 Sumr: 0.00

Project: Bjorn Wiik Professor of Physics
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 75,000 Period: 07/01/06-06/30/11
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

Current and Pending Support

WESLEY H. SMITH

4/29/10

Pending

Project: US CMS M&O: Trigger, Computing, Muon, Common Ops
Source: UCLA (NSF) 1000 G HE150
Total Award: \$ 777,640 Period: 01/01/07-12/31/11
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.20 Sumr: 0.00

Project: ARRA: Research Infrastructure for Particle Physics
Source: DOE
Total Award: \$ 286,100 Period: 11/01/09-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

& This proposal

Current and Pending Support
SAULAN WU
4/29/10

Current:

Project: High Energy Physics Research: Task H
Source: DOE - HEP
Total Award: \$ 21,283,931.31 Period: 11/01/96-10/31/10
Location: UW-Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 2.00

Project: US ATLAS M&O
Source: Brookhaven National Lab (DOE)
Total Award: \$ 2,460,724 Period: 06/29/05-09/30/10
Location: CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: Vilas Professor of Physics (awarded annually)
Source: William F Vilas Trust Estate
Total Award: \$ 48,000 Period: 07/01/09-06/30/10
Location: CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: ATLAS Higgs Research
Source: University of Wisconsin Foundation
Total Award: \$ 318,150 Period: 07/01/05-06/30/11
Location: CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Project: ATLAS Higgs Research
Source: Wisconsin Alumni Research Foundation
Total Award: \$ 315,700 Period: 07/01/09-06/30/10
Location: CERN
Commitment to Project: Cal: 0.00 Acad: 0.00 Sumr: 0.00

Pending

Project: ARRA: Research Infrastructure for Particle Physics
Source: DOE
Total Award: \$ 286,100 Period: 11/01/09-10/31/10
Location: UW Madison, CERN
Commitment to Project: Cal: 0.00 Acad: 0.09 Sumr: 0.00

& This proposal

TASK P: Core Computing Services

Overview: Core computing services, *e.g.* Unix login for access to high-throughput computing, AFS based storage, mail, backup and network services, needed by all HEP DOE Grant recipients are provided centrally. We have maximally leveraged the high-throughput data analysis facilities on our campus and beyond: the Wisconsin CMS Tier-2, Grid Laboratory Of Wisconsin (GLOW), the Wisconsin Center for High-Throughput Computing (CHTC) and the Open Science Grid (OSG), by providing the core computing services to exploit these facilities to all experimental and theoretical HEP DOE Grant users in a centrally managed operation. Here we are requesting support for the central services needed to support all HEP tasks. The equipment costs from the individual tasks were extracted into a single effort as part of a plan to realize an economy of scale to provide the best overall cost-effective computing solution. These central services now support 114 users covering all the tasks at UW, as well as providing some support for about 150 guest users from other Universities and labs. This plan was successful and received DOE HEP funding averaging \$35K/year from FY00-06, but was zeroed out in FY07-10. Only one quarter of the computing requests made through UW ARRA proposal were funded. The \$32K ARRA funds paid for five storage and three login server machines. The remnants of that request and items needed for continued maintenance of our computing services are included here apportioned appropriately over the three years.

Computer Hardware Breakdown: We request \$20.75K to modernize our backup and archive service. These resources are necessary because increased disk utilization will exceed our current capacity in the next year. We have included the tape supplies and associated software license in this category. We request \$4.8K to purchase a UPS system for our core storage servers purchased from ARRA funds. The core servers supporting AFS and other central services need to be shutdown in an organized fashion to avoid extensive outages accompanying unscheduled power loss. We request \$4.8K to replace 3 heavily used old desktop systems that do not have adequate CPU nor memory to run modern analysis programs. We also request \$4K in funding for software license to manage ever-increasing spam volume. The budget breakdown for FY 2011 is in Table 1. The out-year budgets are \$35K each for FY 2012 and FY2013 as shown in Tables 2 and 3. In the out years we will be primarily purchasing servers to expand login services, tape supplies and replacing the oldest equipment nearing its nominal lifetime of 4-5 years.

Table 1: FY2011 Computing Budget

<u>Qty</u>	<u>Description of Computing Element</u>	<u>Price Each</u>	<u>Ext. Price</u>	<u>Total</u>
1	RAID subsystem for backup cache	3,600	3,600	
1	16 slot SDLT600 tape autoloader	5,400	5,400	
1	New autoloader software license	6,500	6,500	
70	SDLT600 tapes	75	5,250	
Subtotal: Backup services				20,750
2	2U 2.2KVA UPSs	2,400	2,400	
Subtotal: Storage services				4,800

Qty	Description of Computing Element	Price Each	Ext. Price	Total
3	Desktop computers	1,500	4,500	
			Subtotal: Desktop services	4,500
1	Spam protection software license	4,000	4,000	
			Subtotal: Mail services	4,000
			TOTAL Computing Services	34,050

Table 2: FY 2012 Budget

Qty	Description of Computing Element	Price Each	Ext. Price	Total
1	Backup software license renewal	1,200	1,200	
70	SDLT600 tapes	75	5,250	
			Subtotal: Backup services	6,450
4	Dual 8-core server systems	4,200	16,800	
1	2U 2.2KVA UPS	2,400	2,400	
			Subtotal: Storage & login services	19,200
4	Desktop computers	1,500	6,000	
			Subtotal: Desktop services	6,000
1	Spam protection software license	4,000	4,000	
			Subtotal: Mail services	4,000
			TOTAL Computing Services	35,650

Table 3: FY2013 Budget

Qty	Description of Computing Element	Price Each	Ext. Price	Total
1	Backup software license renewal	1,200	1,200	
70	SDLT600 tapes	75	5,250	
			Subtotal: Backup services	6,450
4	Dual 8-core server systems	4,200	16,800	
1	2U 2.2KVA UPS	2,400	2,400	
			Subtotal: Storage & login services	19,200
4	Desktop computers	1,500	6,000	
			Subtotal: Desktop services	6,000
1	Spam protection software license	4,000	4,000	
			Subtotal: Mail services	4,000
			TOTAL Computing Services	35,650