TASK T: CMS at the LHC

1 Overview

In order to search for 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 is leading physics analyses in searches for Higgs decays to taus and W and Z production with jets. 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.

UW has leading CMS roles. Prof. 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. He 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. UW Distinguished Scientist Dr. Richard Loveless is the US CMS EMU Deputy Operations Manager, CMS EMU Technical Coordinator, CMS EMU upgrade project manager 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, CMS Manager of the EMU Chamber factory for the upgrade and has served as the deputy convener of the EMU Detector Performance Group and the US CMS L3 EMU on-site operations manager. UW Associate Scientist Dr. Pamela Klabbers is the CMS Deputy Level-1 Trigger Technical Coordinator and Calorimeter Trigger Technical Coordinator. UW Associate Scientist Dr. Sascha Savin is the co-convener of the Tau Physics Object Group and was the co-convener of the CMS Trigger Performance Group. 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. Since January 2011 Wisconsin group members have been responsible for 7 published papers and 5 public physics analyses, and participated in 13 Analysis Review Committees. During this time we have given 22 talks and 8 posters at conferences and 700 internal CMS talks. Information on these is provided in the references.

2 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 CMS flagship analyses that Wisconsin group led are in modes with τ-leptons, especially the MSSM H search. The current physics efforts are primarily focused in the Trigger Studies Group (Trigger Coordinator: Prof. W. Smith), Electroweak Physics Group (Co-convener: Prof. S. Dasu, 2008-2009) and the Higgs Physics Group (Editor of H to ττ: Prof. Dasu, Editor of H to ZZ with τ-modes: Assoc. Scientist Savin). Associate Scientist A. Savin serves as the Tau Group co-convener and is responsible for all aspects of analyses using τ-leptons. Assistant Scientist M. Grothe, who is completing her tenure with our group, is leading the W+Jets analysis, to establish or refute the claims of the CDF collaboration. We are also leveraging our muon systems construction and commissioning experience in muon identification and tracking with A. Lanaro who served as the CSC detector performance group deputy convener. The group is also engaged in physics simulation studies to design upgrades for CMS (Upgrade Physics Coordinator: S. Dasu). In the following sections we indicate the analyses done by Wisconsin personnel

2.1 Trigger Studies

Prof. Smith leads 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). This was an unprecedented challenge as the instantaneous luminosity evolved from 10^{29} to 10^{33} cm^{-2} s^{-1} in one year of LHC operation, requiring more than a dozen new trigger menus from low P_T QCD in the early days to the very high P_T searches. Preserving the low thresholds on photons and leptons, important for EWK and Higgs triggers, became primary concern as we resumed operations in 2011.

Besides the leadership role, the UW group was responsible for 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 enabled both measurement of Z to ττ cross section and search for H to ττ signal. Swanson continues to improve tau trigger and ensure that it is monitored online and offline. Graduate Student Klukas, under the guidance of Assoc. Prof. Herndon, ensured that the muon HLT algorithms were validated and performed well. Graduate Student Anderson ensured that the single photon HLT triggers performed well. The UW group played a crucial role in both defining and validating triggers using all types of objects in CMS, which were important for both standard model measurements made in 2010 and continues to play that crucial role in the new physics searches in 2011. In particular, without our efforts the tau triggers which are enabling the best MSSM and SM higgs searches in tau modes would not have been possible. The focus of the group is now on muon and tau triggers.

2.2 Tau Reconstruction

Wisconsin group developed the Hadrons Plus Strips (HPS) tau reconstruction algorithm, as a result Assoc. Scientist Savin co-leads the Tau Physics Objects Group. Graduate student Bachtis's HPS algorithm relies on reconstructing the tau decay products using the tracker and

ECAL information in the particle flow method. The performance of this algorithm [1] is significantly better than the algorithms used in the CMS TDRs, and has become the de-facto standard within CMS having been used for the flagship search for H to ττ signal and measurement of Z to ττ cross section. The newly hired Postdoctoral Researcher Evan Friis developed another decay-mode reconstruction algorithm based on neural network technique (TaNC). He is currently merging the best aspects of HPS and TaNC into a common algorithm. The performance of these algorithms is shown in Figure 1. Graduate Student Swanson continues the validation work. The UW group is responsible for developing, refining and keeping up the performance of all aspects of tau objects.

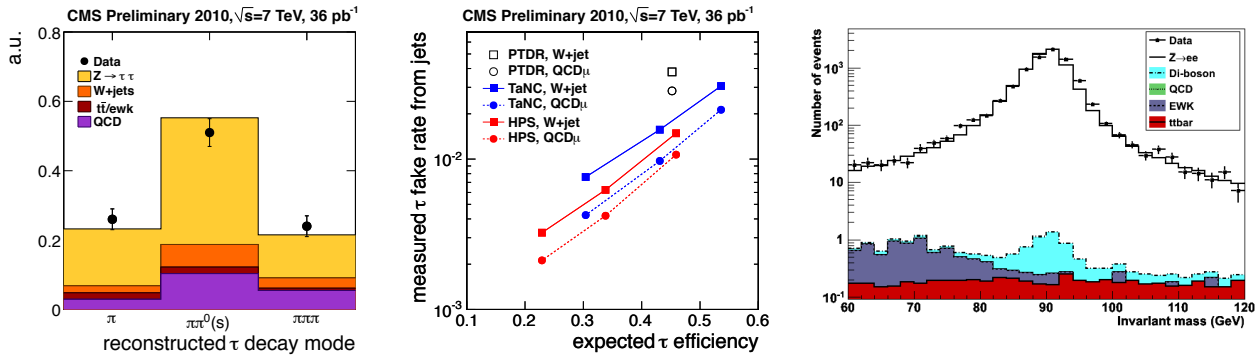

Figure 1: Reconstructed tau decay modes data versus MC (Bachtis) (left) and reconstruction performance determined using 2010 data (Swanson, Friis) (middle). Also shown is the electron-positron invariant mass after all selections from J. Leonard thesis (right)

2.3 Electroweak Physics

Measuring the electroweak processes is an important first step in the analysis of the data to be collected in 2010-2011. Prof. Dasu having led the Electroweak Physics Analysis Group has since focused on making Wisconsin group an important player in these analyses. Our contributions were crucial for CMS measurements of Z to ττ, W+jets, Z+jets, γ+jets, Zγ, ZW and ZZ cross sections, the latter being the smallest SM cross section measured to date by CMS. These measurements have already led us to new physics searches, especially in the searches for higgs as described in the next section.

2.3.1 Z decays to e^+e^-

Graduate student Leonard measured Drell-Yan γ*/Z cross-section with 36 pb^{-1} 2010 data using electron-positron mode independently providing a significant cross-check of CMS publication, of which a prime author is our new Res. Assoc. Cepeda. Leonard completed her thesis on this measurement, summarized in Figure 1, this July, measuring a cross section of 990 pb ± 11(stat) ± 17 (syst) ± 40 (lumi) ± 17 (theory), consistent with theoretical predictions. Earlier graduate students Leonard and Lazaridis, and Asst. Scientist Grothe contributed to the measurement CMS publication [2] by providing trigger efficiency and validating the data quality. This experience enabled Grothe and Lazaridis to move on to the study of jets produced in association with W and Z bosons.

2.3.2 Z decays to $\tau^+\tau^-$

Graduate students Bachtis and Swanson, Prof. Dasu and Assoc. Scientist Savin, measured the cross section for Z production using its decays to ττ [3]. The understanding of Z reconstruction in τ-modes is 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 ($\tau_\mu\tau_h$) and Swanson ($\tau_e\tau_h$) developed all aspects of the Z to ττ analysis and brought it to publication using 36 pb^{-1} data. The invariant mass spectra for Z to ττ signals along with background contributions, are shown in Figure 2. The innovative joint extraction of cross section and τ identification efficiency and comparison of measured cross sections to other experiments is also shown in Figure 2. Having established τ signals in CMS they have moved on to higgs boson searches for their thesis work.

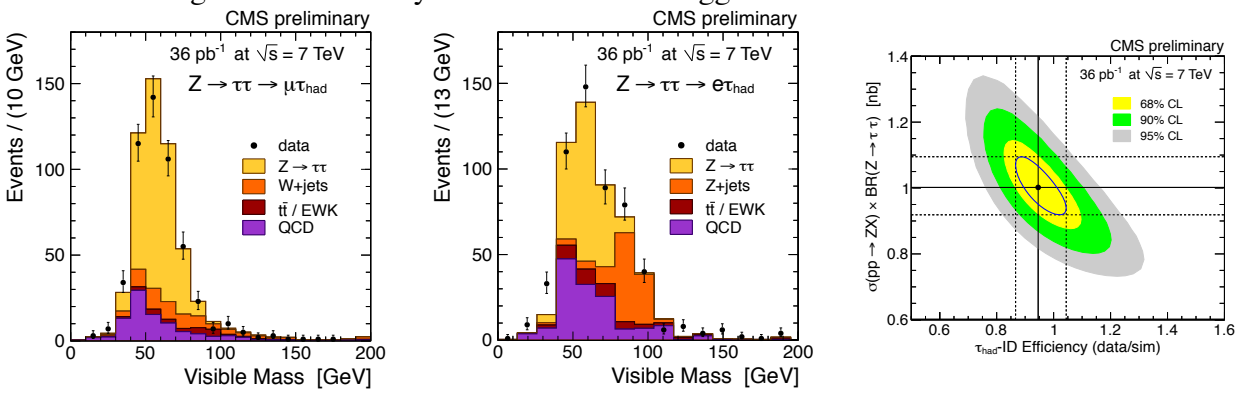

Figure 2: μ-τ (left, Bachtis) e-τ (middle, Swanson) and joint efficiency-cross section fit (right, Bachtis).

2.3.3 W + Jets Analysis

Graduate student Grogg, Asst. Scientist Grothe and Research Associate Efron, studied the production of W bosons, in decays to electrons, accompanied by jets. The study of QCD radiation in these events is of large interest as these events form substantial background for new physics searches. Grogg devised event selection cuts for W events with jets, developed several methods for estimating the QCD background using data driven techniques, performed fits to extract data, developed a method for unfolding jet multiplicity distributions, essentially all aspects of this analysis. The unfolded jet multiplicity spectrum is shown in Figure 3. This work is jointly published [4] with the Z+Jets analysis described next section, and was basis for Grogg's recently completed Ph.D. thesis.

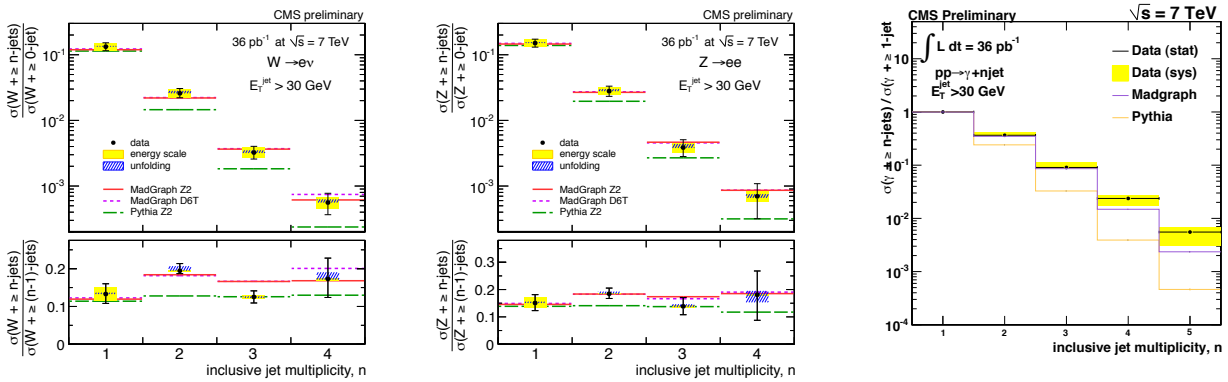

Figure 3: Ratio of cross sections for production of multiple jets in association with vector bosons to the lowest order process for W (left, Grogg), Z (middle, Lazaridis), γ (right, Anderson) versus jet multiplicity. Note that only γ + up to 3-jets processes are generated with Madgraph, unlike W/Z case.

2.3.4 Z + Jets Analysis

Graduate student Lazaridis studied the production of Z bosons, in electron-positron mode, accompanied by jets, with Asst. Scientist Grothe and Assoc. Scientist Klabbers. 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, signal extraction fits and framework for studying efficiencies. The unfolded jet multiplicity spectrum is shown in Figure 3. Graduate student Ross carried forward Lazaridis's measurements of electron trigger and reconstruction efficiencies using tag and probe technique.

Graduate students Grogg, Lazaridis, Ross and the scientists collaborated to make the Wisconsin one of the prime contributors to a formidable result that was shown at the Winter conferences and a publication [4] is in final stages of preparation. Lazaridis has completed his Ph.D. thesis based on this work.

Summary of vector bosons + jets measurements, including photon+jets discussed next, is shown in Figure 3. The experience with these analyses led to appointment of Asst. Scientist Grothe as the editor of a paper on the study of di-jet invariant mass in events produced in association with a W boson.

2.3.5 Direct Photon Analyses

Graduate student Anderson had studied isolated photon trigger and reconstruction details to measure their P_T spectrum using a fit to shower shape variables. The measured direct photon spectrum was one of the early CMS publications [5] and was in part possible due to Anderson's contribution. Under the supervision of Prof. Dasu he used isolated photon signal extraction experience to study jets produced in their association. He essentially carried out the equivalent of W/Z + jets analysis, signal extraction using shower shape fit, determining photon finding and reconstruction efficiency using Tag and Probe technique using Z events, unfolding technique adopted from W/Z+Jets analysis. Anderson's recently completed Ph.D. thesis is based on this measurement of γ+jets (shown in Figure 3), which will be converted in to a paper with new data.

2.3.6 Zγ production in SM and search for new physics

Graduate student Lindsey Gray, Assoc. Scientist Lanaro and Prof. Dasu studied Zγ production. Gray used 2010 data to extract Zγ signal in dimuon channel, and set limits on anomalous triple gauge boson couplings. He had developed Z selection and a ML fit to extract the aTGC, the results (shown in Figure 4) were published [6]. Gray's fit was used for setting aTGC limits using WW events as well. Gray and Lanaro continue to pursue this analysis, which is very much statistics limited at 36 pb^{-1}, using 2011 data.

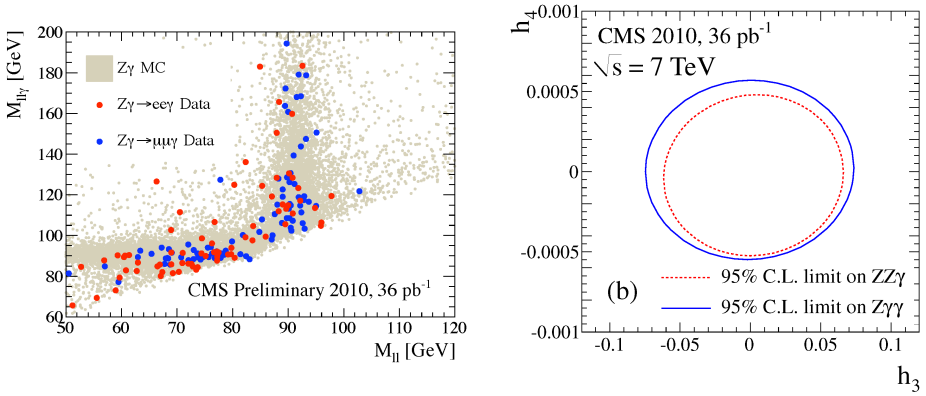

Figure 4: $M_{ll\gamma}$ vs M_{ll} scatter plot showing FSR Zγ signal peaking at $M_{ll} = M_Z$ (Gray, left). The limits on anomalous triple gauge boson couplings, which are zero in the SM, are shown (Gray, right).

2.3.7 WZ production in SM and new physics

Graduate student Jeff Klukas and Prof. Herndon have just made the first measurement of the standard model WZ production cross section using 1 fb-1 data from 2011 [7]. The result was prepared for the Summer conferences, and is shown in Figure 5. The analysis will continue with the goal of searching for new physics, e.g., W' decay to WZ using full 2011 dataset and will comprise Mr. Kulkas's PhD thesis.

2.3.8 ZZ production in SM

Graduate students Swanson, Ross, Assoc. Scientist Savin and Prof. Dasu measured the ZZ production cross section, using 2011 data, using all three charged lepton flavors [7]. This is the smallest cross section measured to date by CMS. This 1-fb^{-1} result is shown in Figure 5, and has formed the basis for the Standard Model higgs search using all three charged lepton decays of the Zs described later.

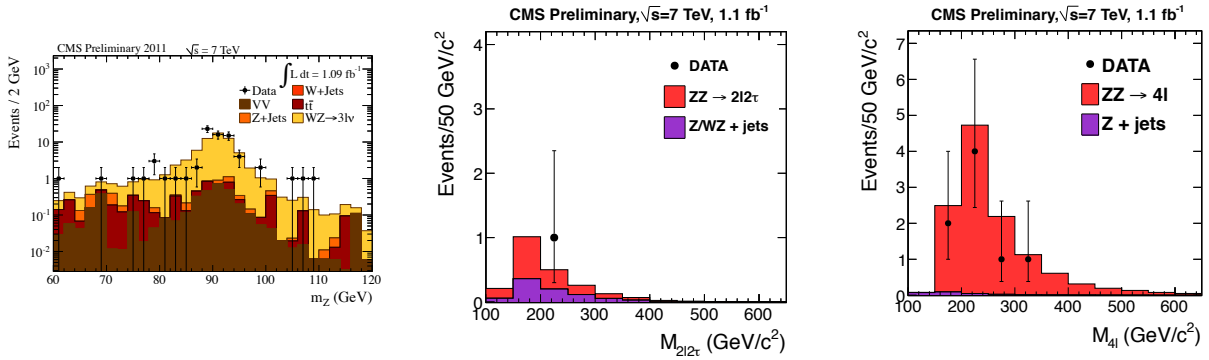

Figure 5: Z mass peak after W selection for WZ signal extraction (Klukas, left), $M_{2l2\tau}$ mass distribution (Swanson and Ross, middle), M_{4l} (Swanson and Ross, right).

2.3.9 Dijet Invariant Mass

Following the finding of CDF collaboration that there is a signal seen in the di-jet invariant mass spectrum, CMS has decided to investigate that phenomenon thoroughly and has appointed Assoc. Sci. Grothe as a co-convener of the group. Together with outgoing Res. Assoc. Efron she has begun the analysis in W to electron mode. Prof. Carlsmith and incoming Res. Assoc. Cepeda have joined this effort investigating W to muon mode. Initial results do not confirm the CDF signal, and are shown in Figure 6. This effort will find us naturally in the di-boson measurements with one of the bosons decaying in di-jet channel and evolve to higgs searches both low mass (b-jet pair) and high mass (ZZ to 2-l, 2-jet). Graduate student Ojalvo started investigating ZH production.

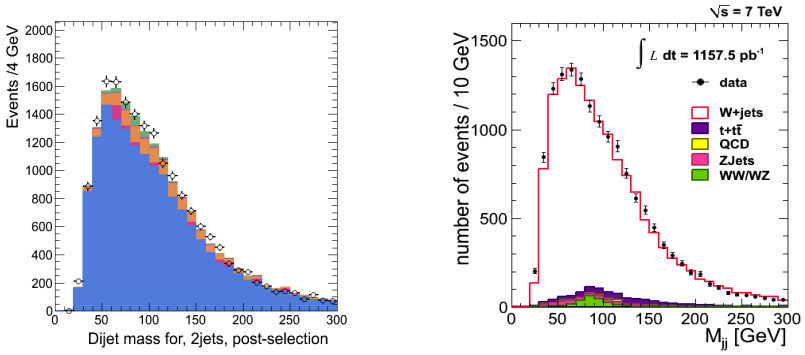

Figure 6: Dijet mass for W events selected using electrons (Efron, left) and muons (Cepeda, right).

2.4 Higgs Searches

2.4.1 Higgs Decays to tau pairs

Having performed the cross section measurement, the UW team, graduate students Bachtis, Swanson, Assoc. Sci. Savin and Prof. Dasu moved on to setting MSSM higgs limits, which turned out to be the best in field even with 2010 36 pb–1 data used, and were promptly published in Spring [8]. Graduate student Bachtis, who is the lead analyst for this analysis, along with the UW team now joined by Res. Assoc. Friis, moved on to 2011 analysis and has produced results for the EPS conference [9]. New results, including b-tagging to enhance MSSM sensitivity and forward jet tagging to enhance the SM higgs sensitivity, are shown in Figure 7. Prof. Dasu is the co-editor of these analyses. These results are again best results in the field, and are being further improved for the Lepton-Photon conference. In the coming months, in addition to the statistics being accumulated quickly, the UW team will further improve the analysis, with a goal to publish a discovery or a limit with the full 2011 data. This subject forms graduate student Bachtis' Ph.D. thesis.

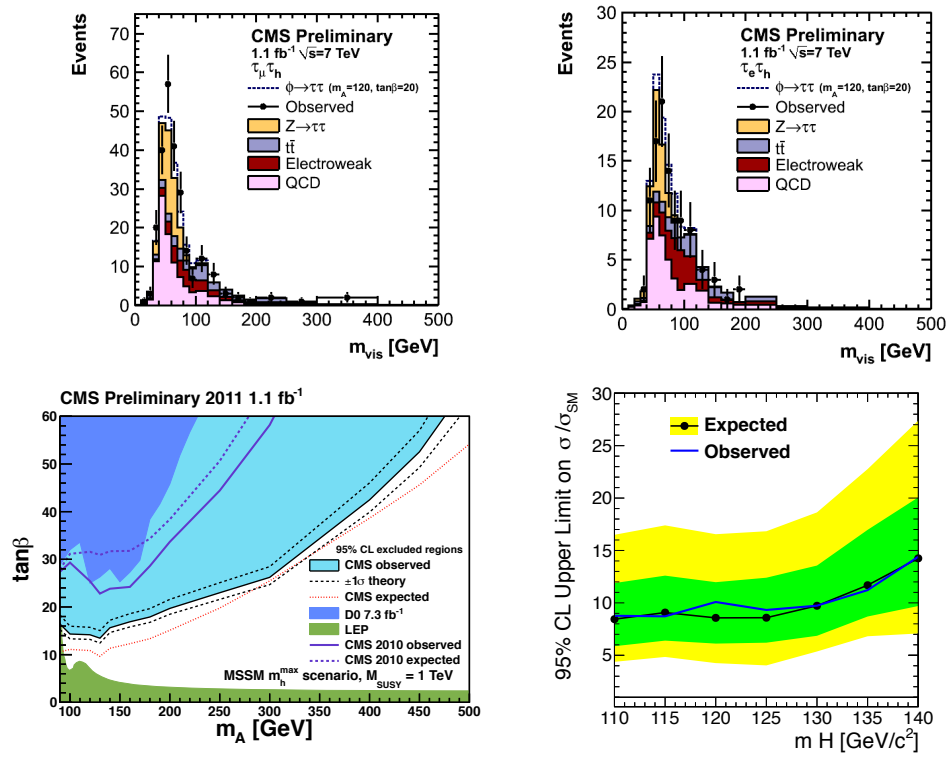

Figure 7: Visible di-tau mass spectra for mu-tau (top-left) and e-tau (top-right) after b-tag requirement, MSSM parameter space exclusion region (bottom-left) and SM higgs limit obtained using VBF (Bachtis).

2.4.2 Higgs Decays to Z pairs in lepton modes

Graduate students Swanson and Ross, Assoc. Sci. Savin, Profs. Dasu and Smith, have developed an analysis to look for Z pairs, which decay to any of the three charged lepton pairs. Having measured the SM Z pair production cross section, they have set limits on the SM higgs boson production in its decays to Z pairs [10]. The results with full 2011 data set, shown in Figure 8, are being reviewed by the collaboration for inclusion in combined SM higgs search for

Lepton-Photon conference. Scientist Savin is the editor of this analysis for CMS and the subject forms the Ph.D. theses of graduate students Swanson and Ross.

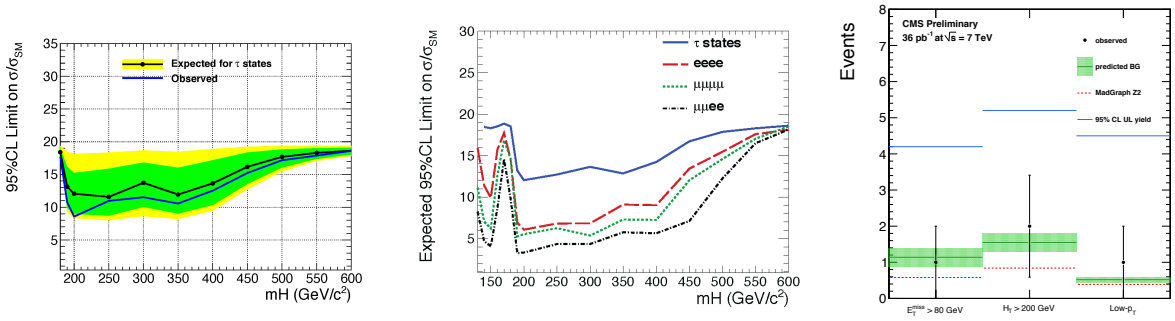

Figure 8: Expected and observed limits for Higgs to ZZ to two leptons and two taus (Swanson, Ross, left) and comparison to those from the light leptons (middle) as a function of SM higgs mass. Also shown is the prediction for same sign light lepton pairs compared to CMS data with upper limits (Weinberg, right).

2.5 Search for SUSY in like-sign leptons mode

Graduate student Weinberg and Assoc. Scientist Savin, measured the top production cross section using dilepton mode, and cross checked with CMS published result. They moved on to use like-sign dileptons to search for SUSY particles. The yields for like-sign light-lepton pairs are in agreement with SM background prediction with control samples, using 2010 data, and are shown in Figure 8. These results are in agreement with published CMS results. Weinberg's contribution to the published SUSY paper [11] was in the study of trigger efficiency, which is important because of the low p_T di-leptons used in that analysis. These results are the basis of his thesis, which he defended in August.

2.6 Other Physics Activity

2.6.1 WW aTGC Limits

Graduate student Gray, who developed a triple gauge boson limits setting tool, used it to set limits using WW channel [12]. This contribution resulted in his authorship of the CMS analysis notes on the subject, and the results are published using 2010 data set. It is expected that he will maintain this tool for not only his Zγ analysis but also for the other diboson modes.

2.6.2 Charmonium and Bottomonium Physics

Graduate student Gray, Assoc. Sci. Lanaro and Senior Sci. Loveless have been involved in the study of low invariant mass di-muon pairs, their interest stemming from their responsibility for the endcap muon sub-detectors. CMS ability to trigger on and measure low momentum muon pairs has enabled a wealth of physics in this subject [13], some of which is already published. Graduate student Gray has developed a fit to extract J/Ψ polarization, which he will also use for Vγ analyses in near future, will form a part of his Ph.D. thesis.

2.6.3 Physics Analyses Service

Prof. Dasu, Senior Sci. Loveless and graduate student Bachtis, have been invited to join the CMS physics analysis review committees, which are involved in scrutinizing both the analysis methodology for accuracy and produce publishable papers. Dasu and Loveless chaired

five analysis review committees, which produced the papers in exotica [14] and EWK physics [15]. Other faculty and scientists are joining analysis review committees.

2.7 Upgrade Trigger & Physics Simulations

Graduate students Ojalvo, Belknap, and Ross, Asst. Scientist Grothe, and Profs. Dasu and Smith, worked on trigger and physics simulations to define the scope of the calorimeter trigger and pixel system upgrade. The primary goal of the upgrade is to implement more sophisticated calorimeter trigger algorithms, e.g., with robust clustering and lepton isolation algorithms and improving the position resolution of all objects identified by the calorimeter trigger.

The simulation results, for the case of 25 pile-up (PU) events, showing improved performance for electron/photon and tau trigger were included in the CMS Upgrade Technical Proposal. The estimated efficiencies, comparing current and upgraded trigger, for various physics channels, were also documented. Graduate students Ojalvo and Belknap are updating these simulation results for the case of 50 PU events expected level of 2×10^{34} cm^{-2} s^{-1} instantaneous luminosity. They have also begun using the real data (trigger primitives are recorded in the CMS raw data) from the LHC to compare the performance of existing trigger system results to the emulated results from the upgraded trigger. These studies will be used to fine-tune the upgrade algorithms as the hardware is being defined and will form the basis of the trigger upgrade design report.

Prof. Dasu as the upgrade physics coordinator was responsible for developing a physics-case for the upgrades, especially the pixel upgrade project. Because development of a full physics case requires a large dedicated effort and all the younger students and postdocs are busy with 2010 data analysis, the work had to be performed with minimal resources. Prof. Dasu developed an ultra fast simulation program with four-vector smearing and parameterizations of b-tag performance, worked with colleagues from Nebraska and Iran to study associated low-mass higgs production with Z. Although the cross section for this channel is low, the presences of leptonically decaying vector boson reduces the background so that higgs decays to b-jet pairs can be measured. Such a measurement is needed for measuring Yukawa coupling of the higgs to b-quarks, which is one of the goals of the LHC program with high luminosity. Other physics channels are being explored to solidify the upgrade possibilities.

3 CMS Trigger Activity

3.1 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 μs, 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.

As the CMS Trigger Coordinator, Prof. Smith has overall responsibility for the online L1 and Higher Level Triggers. 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 Klabbers is the Deputy Trigger Coordinator and Calorimeter Trigger

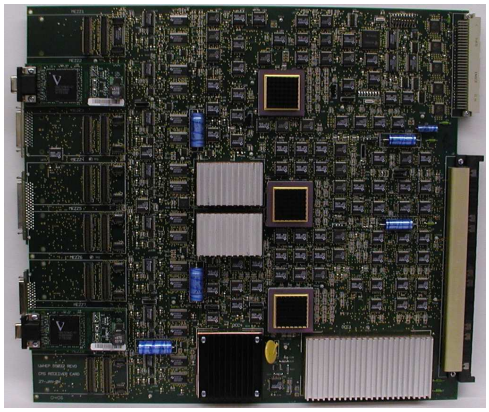

Figure 9. One of 154 RCT Receiver Cards with 2 mezzanine cards.

Technical Coordinator. U. Wisconsin built, operates and has institutional responsibility for the Regional Calorimeter Trigger (RCT) and its upgrade for higher luminosity LHC running.

3.2 Regional Calorimeter Trigger

The CMS level-1 electron/photon, τ-lepton, jet, and missing transverse energy trigger decisions are based on the RCT, which receives input from the CMS hadron calorimeter (HCAL) and 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.

3.3 RCT Progress and Plans

The UW RCT effort is led by CERN-resident Scientists Pamela Klabbers and Alexander Savin and Madison-resident UW Engineer Tom Gorski and technician Robert Fobes and CERN-resident UW Postdocs Evan Friis and Maria Cepeda. 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 9), 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. UW students Michail Bachtis, Ian Ross, and Joshua Swanson currently work on RCT operations. During 2011-2012, graduate students Isobel Ojalvo and Austin Belknap will be taking over the RCT duties of the UW students who have already worked 2 years on the RCT (Bachtis, Ross, and Swanson) as they finish their theses. Our goals for the RCT for the next few years are to continue ensuring 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.

3.4 L1 Trigger Software

The development of the RCT monitor, control, and emulation software is a UW responsibility. Scientists Klabbers and Savin, and Prof. S. Dasu, have all developed software with the students and postdocs for testing and configuring the trigger hardware. This software is integrated with the CMS online and offline environments. The ever-changing beam and detector conditions, operational experience, physics data and priorities and the evolving CMS software environment demand continuous effort to update the software.

UW Scientist Klabbers developed the RCT online crate testing software. UW Postdoc Friis and student Ross will continue the development of the 18-crate system test that loads patterns into the logic and sends them at speed in a sequence of tests that fully validate the RCT hardware. This procedure is executed frequently and is currently being integrated into the TS framework to provide greater sophistication and automation. Under the supervision of Postdoc Friis, graduate student Ojalvo will be taking over this task from Mr. Ross during 2012.

The L1 RCT emulator is a critical piece of the CMS software that duplicates the exact bit-by-bit function of the hardware. Necessary for diagnostics and for simulation of the trigger system, it requires constant validation detector data with changing configurations. Mr. Swanson with the assistance of Mr. Bachtis is maintaining the emulator and checking its performance with physics data. Postdoc Cepeda is using the emulator with data to update the RCT calibration and improve the calorimeter trigger performance. Student Belknap will take over the emulator support in 2012 as Mr. Swanson writes his thesis and Mr. Bachtis graduates.

The RCT Trigger Supervisor (TS) is the interface between the CMS Run Control Trigger Interface, called the Central TS and the RCT. It configures (calibrations, thresholds, masked channels, etc.), starts and stops RCT operation with the rest of the trigger systems, and processes hardware status and alarms. It has been fully tested and I. Ross now maintains and upgrades the software as needed under the supervision of P. Klabbers and E. Friis. UW student Ojalvo will be taking over the Trigger Supervisor support in 2012 as Mr. Ross writes his thesis.

The RCT online, offline, and stand-alone Data Quality Monitoring (DQM) has been written and tested by UW Scientist A. Savin and is maintained by Mr. Swanson. The first of these three tasks reads and analyzes the data as it is being taken, makes histograms, tests these against specific criteria and alerts the shift crew when there is a problem. The latter two analyze the offline data using detailed 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 10 shows how the RCT DQM can be used to diagnose problems in the calorimeters by identifying inefficient calorimeter trigger towers. UW student Belknap will be taking over the DQM support next year.

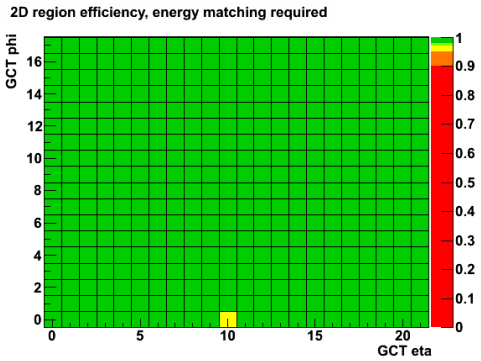

Figure 10. RCT DQM η-ϕ map with one inefficient calorimeter trigger tower.

The set-up and parameters of all the programmable aspects of the RCT, including the memory lookup tables and the list of channels masked 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 Database. 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 Friis writes and maintains these databases both online and offline.

Mr. Ross maintains RCT Detector Controls System (DCS) for the RCT monitoring hardware developed by UW engineer T. Gorski. 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. UW Graduate student Isobel Ojalvo will be taking over the DCS support next year as Mr. Ross finishes.

3.5 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 one UW RCT expert is on call 24 hours a day. We keep a quantity of spares to provide quick solutions to problems. UW scientist P. Klabbers is able to handle most repairs on the defective modules at CERN and after repair and retesting they are returned to service as spares. Postdocs and 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 Prevessin 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. Klabbers is responsible for setting up and maintaining this facility and it enables us to provide local testing, maintenance and repair of the RCT, resulting in dependable operation. Postdocs Friis and Cepeda and the students assist her with this.

3.6 Upgrade Trigger Program

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 chapters for the US CMS "CD0" SLHC document and the CMS Upgrade Technical Proposal. Prof. Dasu is responsible for the physics chapters.

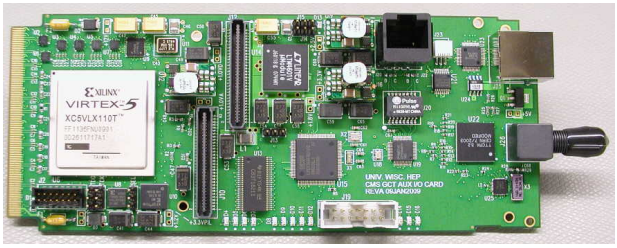

Figure 11. Prototype UW SLHC Calorimeter Trigger Card (Aux Card).

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 μTCA standard crate. 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 11 has been fully tested. 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 and has validated inter-FPGA data exchange. This system provides 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. We are now designing and plan to construct and test the first full-function prototype upgrade calorimeter trigger 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 the new optical 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 new optical system will be installed during the 2013-14 shutdown so that testing with real physics data can take place during the 2015-16 run.

4 CMS Endcap Muon Activity

4.1 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 disks (built by Kawasaki Heavy Industries in Japan under UW supervision) were bolted together to insure predictability, uniformity and quality assurance of the connections. 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. Now Dr. Loveless is the Project Manager for the construction of the remaining 72 ME4/2 chambers.

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 Muon Upgrade Manager for leading the CSC ME4/2 detector construction facility at CERN. He has been deputy convener of the CSC Detector Performance Group (DPG) until early in 2011 when the involvement in the setting up and organization of the CSC production factory became more demanding.

As CMS Field Technical Coordinator, Dr. Lanaro is responsible for the maintenance and operation of the CSC Muon system infrastructures in the experimental underground hall, and for the planning and execution of the technical interventions on the detector and services planned during the scheduled LHC technical stops. He also serves on the CMS prompt intervention expert team and permanently available (on call) at any request for any major emergency intervention. He is the CSC Safety coordinator (GLIMOS) and member of the CMS Technical Implementation Group, lead by the CMS Technical Coordinator, in charge of investigating and planning innovative solutions aimed at improving the reliability and technical performance of the CMS experimental complex. From July 2009 to March 2011 Dr. Lanaro was the DPG (Detector Performance Group) deputy coordinator.

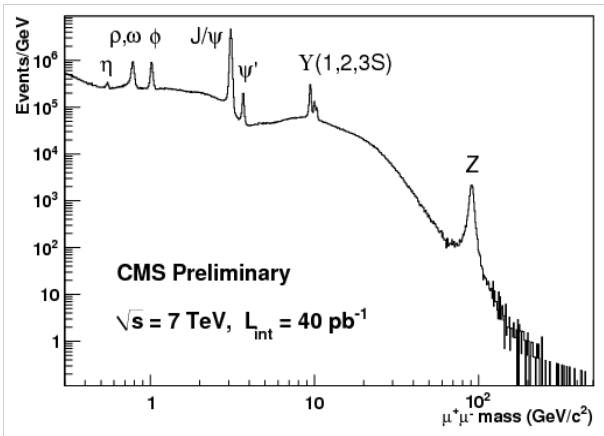

Figure 5: Dimuon mass spectrum recorded by CMS with the data collected in 2010.

Dr. Lanaro has valuably contributed to the study of the performance of the CSC system and the RPC and DT subsystems. He has supervised the work of UW graduate student Lindsey

Gray within the context of the CSC DPG. One of the main tasks of Dr. Lanaro and Mr. Gray has been to provide immediate feedback on the performance of the CSC system to the CMS operation and run coordination. During the entire 2010 run period the CSC system has operated stably with efficiency (total fraction of live detector channels) constantly above 98.5%. Fig. 5 shows the reconstructed dimuon mass spectrum using 2010 data.

Prof. Carlsmith is involved in CSC detector performance activities through participation in weekly CSC operations and DPG meetings and through shift work. During the commissioning phase of CMS, Prof. Carlsmith served operations shifts at Point 5, twice in 2010. In 2011, Prof. Carlsmith served one of the first post-technical-stop shifts as CSC data quality monitor and is contributing to CSC DQM and track based alignment.

4.2 Future Endcap Muon Disk and Chamber Activities

Wisconsin is responsible for all EMU mechanical maintenance, such as the successful bushing replacement in January 2010. In the confined space of the collision hall, it is extremely difficult to dismount any CSC chamber and requires experts, like Drs. Loveless and Lanaro to reduce risk of any possible collateral damage. The UW 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 2008 the CSC chambers we used a large amount of very expensive CF_4 gas. Dr. Loveless supervised the CERN Gas Group in successfully developing an efficient method of recovering the spent CF_4 and recycling it. The system is now completely installed and the commissioning is underway.

4.3 Muon Endcap Upgrade

During the 2013-14 shutdown the Endcap Muon group plans to restore the 4^{th} 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. Dr. Loveless is the Project Manager for this effort, and Dr. Lanaro is the Manager of the chamber assembly factory at CERN. CERN has allocated a 1000 m^2 lab space for the assembly of the ME4/2 chambers. Most parts for the chambers will be purchased by the University of Wisconsin and shipped to the assembly factory. Tooling from the previous assembly at Fermilab was shipped to CERN and the factory is now nearly operational.

Dr. Lanaro is leading an international team of about 15 people (physicists, engineers, students, and technical personnel) to complete the project in 3 years. In early June this year construction of the first chamber prototype has successfully started. Chamber mass production is expected to begin early this fall at a rate of 3-4 chambers per month. The facility will incorporate an area for integrating the on-chamber electronics and performing the final validation tests. Fig. 7 shows the CSC factory during the setting up phase and the team of people currently involved.

The ME4/2 upgrade project offers an excellent learning experience for a graduate student and Professor Carlsmith will supervise future student involvement in this upgrade project as well as in CSC operations and DPG activities.

Figure 7: The ME4/2 CSC factory at the CERN 904 building and the factory personnel.

4.4 Endcap Muon Alignment

Prof. D. Carlsmith and UW Scientist Dr. J. Bellinger have been active in the commissioning, operation, and data analysis of the endcap hardware alignment system for CMS, and participants in CSC operation and detector performance evaluation. 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. 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 coordinated efforts of scientists and engineers at Fermilab, Florida Tech, UCLA, CERN and UW and Texas A&M. Prof. Carlsmith and Dr. Bellinger along with Fermilab collaborators installed and commissioned the DCOPS system. Dr. Bellinger is author of the software for data acquisition and fitting for the DCOPS system and online hardware monitoring, created and validated the alignment related geometry data base by comparing photogrammetry data with design drawings, and has been active in the COCOA reconstruction and validation.

At present, all DCOPS and lasers are operational with only minor hardware issues. Such issues have not prevented successful continuous operation and data collection. In 2011, Dr. Bellinger created procedures and scripts to automate Endcap Alignment operations and he expects to complete documentation of these scripts. Additionally, simple fit methods have been used to study the transfer lines and validate the COCOA model. In particular, these fits spanning CMS showed that an apparent tracker-to-barrel twist was not a physical twist in the barrel.

In 2011, Task T support for Dr. Bellinger (25% in 2010) ended as a consequence of overall Task T budget constraints.

5 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, provides core services for all the tasks of this DOE grant and is 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. In order to save costs, all core UW HEP computing services are centrally shared and managed under the direction of Rader.

The NSF supported Assoc. Researcher Dr. A. Mohapatra, co-leader of CMS MC production, Software Engineer D. Bradley, and System Manager W. Maier operate the CMS Tier-2 facility at Wisconsin which is a 2800-core computing cluster providing 23400 HS06 units and 2.1-PB high-availability distributed storage service. The Tier-2 is based on the Condor distributed high-throughput computing technologies developed by UW CS department, Grid services and Hadoop-based storage services. UW Tier-2 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 additional thousand cores, and the nation-wide US 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.

Our Tier-2 facility serves as the primary computational resource for the CMS Trigger Studies, Tau, Electroweak and Forward Physics groups besides producing monte carlo events. Local users are involved heavily in the EWK measurements and Higgs searches. In addition to UW CMS team, over 50 CMS-wide users routinely use our systems either through direct login, which takes advantage of opportunistic resources and high throughput analysis prioritization (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 Higgs decays to τ-leptons, 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 to complete analyses in time for Winter and Summer conferences in 2010 and 2011. On demand high priority access to resources for analysis while keeping the CPUs active with MC generation in “backfill” mode is crucial for timely completion of analyses. UW Tier-2 achievements are compared to other sites in Table 1, indicating a high degree of our productivity.

Table 1: UW Tier-2 achievements compared to US OSG and all CMS.

Activity	**Wisconsin T2**	**US OSG T2s <Ave>**	**All CMS T2s (54)**
MC Events Produced	483 M	2.56 B <365 M>	7.05 B <130 M>
Analysis Jobs Done	2.56 M	10.0 M <1.43 M>	N/A
Storage Served	364 TB	2.08 PB <297 TB>	N/A

We request continued support for Director of Computing Rader, at 50% level, because his service, experience and advice are essential for the full UW HEP group.

References for Task T

Since January, 2011 Wisconsin group members have been responsible for the 7 published papers and 5 public physics analyses listed below. We have also participated on 13 Analysis Review Committees for CMS results, also listed below. We have given 22 conference talks, 8 conference posters and 700 internal CMS talks. Information on the talks is provided on these is provided on:

http://www.hep.wisc.edu/wsmith/cms/doe11/

1. *Public Physics Analysis Summary*: Tau Identification in CMS, CMS PAS TAU-11-001, 2001
   Internal Note: M. Bachtis, E. Friis, A. Savin, J. Swanson, et al., Performance of tau reconstruction algorithms with 2010 data in CMS, CMS AN-2011/045
2. *Public Paper*: Measurements of Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s}$ = 7 TeV, *J. High Energy Phys.* 01 (2011) 080
   Internal Note: M. Cepeda, M. Grothe, C. Lazaridis, et al., Updated Measurements of the Inclusive W and Z Cross Sections at 7 TeV, CMS AN 2010/264
3. *Public Paper*: Measurement of the Inclusive Z Cross Section via Decays to Tau Pairs in pp Collisions at $\sqrt{s}$ = 7 TeV, CMS EWK-10-013, 2010 (Submitted to JHEP)
   Internal Note: M.Bachtis, S.Dasu, A.Savin. J.Swanson, Measurement of $\sigma(pp \rightarrow Z)B(Z \rightarrow \tau\tau)$ using $\mu\tau$ and $e\tau$ final states with CMS detector at $\sqrt{s}$ =7 TeV, CMS AN-2010/387
4. *Public Physics Analysis Summary*: Rates of Jets Produced in Association with W and Z Bosons in pp collisions at $\sqrt{s}$ = 7 TeV, CMS PAS EWK-10-012fxbe. To be submitted to JHEP.
   Internal Note: K. Grogg, C. Lazaridis, J. Efron, P. Klabbers, M. Grothe, S. Dasu, et al., Measurement of the Associated Production of Vector Bosons and Jets in proton-proton collisions at $\sqrt{s}$ = 7 TeV, CMS AN-2010/413
5. *Public Paper*: Measurement of isolated photon production cross section in pp collisions at $\sqrt{s}$ = 7 TeV, *Phys. Rev. Lett.* 106 (2011) 082001
   Internal Note: M. Anderson et al., Measurement of isolated photon production cross section in pp collisions at $\sqrt{s}$ = 7 TeV, CMS AN-2010/268
6. *Public Paper*: Measurement of Wγ and Zγ production in pp collisions at $\sqrt{s}$ = 7 TeV, *Physics Letters B* 701 (2011) 535–555
   Internal Note: L. Gray, A. Lanaro, S.Dasu et al., Measurement of inclusive Wgamma and Zgamma cross sections and limits on anomalous trilinear gauge boson couplings at 7 TeV, CMS AN-2010/279
7. *Public Physics Analysis Summary*: Measurement of WW and observation of WZ and ZZ in leptonic modes, CMS PAS EWK-11-010
   Internal Note: J. Swanson, I. Ross, M. Bachtis, A. Savin, S.Dasu and W.H. Smith, Study of H to ZZ and ZZ Production in the 2l 2tau final state using CMS at 7TeV, CMS AN-2011/134
   Internal Note: J. Klukas, et al., Measurement of the WZ cross section at the CMS Experiment, CMS AN-2011/259
8. *Public Paper (2010):* Search for Neutral Higgs Boson Production and Decay to Tau Pairs, Phys. Rev. Lett., 106 (2011) 231801
   Internal Note: M. Bachtis, J. Swanson, S. Dasu, A. Savin, et al., Search for neutral Higgs boson decaying into tau pairs with 35 pb^{-1} at $\sqrt{s}$ = 7 TeV using HPS tau identification algorithm, CMS AN-2010/430

9. *Public Physics Analysis Summary (2011):* Search for Higgs Bosons Decaying to Tau Pairs in pp Collisions at $\sqrt{s}$ = 7 TeV, CMS PAS HIG-11-009
   Internal Note: M. Bachtis, J. Swanson, E. Friis, S. Dasu, A. Savin, et al., Search for Higgs Bosons Decaying to Tau Pairs in pp Collisions at $\sqrt{s}$ = 7 TeV, CMS AN-2011/153
10. *Public Physics Analysis Summary*: (*in approval process*.)
    Internal Note: J. Swanson, I. Ross, M. Bachtis, A. Savin, S. Dasu, W. H. Smith et al, Search for H->ZZ->2l2tau, CMS AN-2011/293
11. *Public Paper*: Search for new physics with same-sign isolated dilepton events with jets and missing transverse energy at the LHC, J. High Energy Phys., 06 (2011), 77
    Internal Note: M. Weinberg, A. Savin, et al., Inclusive Search for Supersymmetry in Same-Sign Dilepton Final State at $\sqrt{s}$ = 7 TeV with the full 2010 dataset, CMS AN-2010/300
12. *Public Physics Analysis Summary*: (*in approval process*.)
    Internal Note: L. Gray, et al., Spin alignment of prompt and non-prompt J/ψ mesons in pp collisions at $\sqrt{s}$ = 7~TeV, CMS AN-2011/91
    Internal Note: L. Gray, et al., A Fitting Routine for Extracting the Spin Alignment of J/ψ Mesons, CMS AN-2011/92

Papers and Physics Analysis Summaries from Analysis Review Committees served by Wisconsin Personnel

1. Observation of Zbb, CMS PAS EWK-10-015, R. Loveless (Chair)
2. Search for Microscopic Black Hole Signatures at the Large Hadron Collider, *Phys. Lett. B* 697 (2011) 434-453, R. Loveless
3. Search for Heavy Stable Charged Particles, EXO-11-021, R. Loveless
4. Updated Search for Black Holes in pp collisions at $\sqrt{s}$ = 7 TeV, EXO-11-071, R. Loveless
5. Search for Pair Production of First-Generation Scalar Leptoquarks in pp Collisions at $\sqrt{s}$ = 7 TeV, *Phys. Rev. Lett.* 106 (2011) 201802, S. Dasu (Chair)
6. Search for Pair Production of Second-Generation Scalar Leptoquarks in pp Collisions at $\sqrt{s}$ = 7 TeV, *Phys. Rev. Lett.* 106 (2011) 201803 , S. Dasu (Chair)
7. Search for First Generation Scalar Leptoquarks in the evjj Channel in pp Collisions at $\sqrt{s}$ = 7 TeV, EXO-10-006, S. Dasu (Chair)
8. Search for heavy neutrino and right-handed W of the left-right symmetric model, EXO-11-002, S. Dasu (Chair)
9. Measurement of the energy flow at large pseudorapidity at the LHC at $\sqrt{s}$ = 900, 2360 and 7000 GeV , FWD-10-002, M. Grothe (Chair)
10. Inclusive forward jet production cross sections in proton-proton collisions at $\sqrt{s}$ = 7 TeV, FWD-10-003, M. Grothe (Chair)
11. Forward energy flow in the CMS detector, FWD-10-011, M. Grothe (Chair)
12. First measurement of the top production cross section in the dilepton channel with tau leptons in the final state in pp collisions at $\sqrt{s}$ = 7 TeV, TOP-11-006, M. Bachtis
13. Search for the charged Higgs boson with $H^+ \rightarrow \tau^+ \nu$ decay in top quark decays, HIG-11-008, M. Bachtis

Task T Budget Commentary

1 Salaries and Wages

1.1 Faculty Support

We request 2 months summer salary support for Prof. Wesley Smith, Sridhara Dasu and Duncan Carlsmith. We request 1.5 months of salary support for Prof. Herndon who continues his move his effort from Task E – CDF to Task T – CMS. While Profs. Smith, Dasu, Carlsmith and Herndon work on physics analysis, Prof. Smith works on the Trigger activity, Prof. Dasu splits effort between Trigger and Computing, Prof. Carlsmith works on the Muon activity and Prof. Herndon works on the Muon activity and the Muon Higher Level Trigger.

1.2 Changes with respect to FY11

In response to DOE guidance and funding, two of our scientists, Drs. Bellinger and Grothe are no longer supported by Task T. Dr. Bellinger now works on the Ice Cube project and Dr. Grothe has left Wisconsin. One of our postdocs, Dr. Efron also completed his four years in August, 2011 and has also left Wisconsin. To continue our research program, in July 2011 we hired two postdocs, Dr. Maria Cepeda and Dr. Evan Friis. Dr. Cepeda graduated from CIEMAT, Spain with her thesis the published CMS W cross section. Dr. Friis graduated from U.C. Davis with his thesis on the published CMS search for Higgs bosons decaying to taus. We also graduated 5 students, Mike Anderson, Kira Grogg, Christos Lazaridis, Jessica Leonard and Marc Weinberg during July and August 2011 with theses based on the 2010 CMS data.

1.3 CMS Trigger

For the CMS Trigger activity, we request 12 months support for Associate Scientist Pamela Klabbers to work on the installation, testing, commissioning and operation of the Regional Calorimeter Trigger (RCT) and the CMS L1 Trigger system. Dr. Klabbers is resident at CERN and is the L1 Deputy Trigger Technical Coordinator and the Calorimeter Trigger Technical Coordinator. She has ultimate responsibility for maintenance and operation of the calorimeter trigger. She is working with students on Z+jets production. She is also working on the upgrade trigger design.

We request 12 months support for Associate Scientist Dr. Sascha Savin, who is the co-convener of the CMS Tau Physics Object Group (POG) and responsible for the online and offline RCT Data Quality Management, including the online monitoring and error detection and the offline diagnostics and certification of runs for physics. He is working on Higgs decays to $\tau\tau$ and searches for SUSY particles with like-sign isolated leptons.

We request 12 months support each year for Postdoc Dr. Maria Cepeda, who is resident at CERN and works with Dr. Klabbers on the maintenance and operation of RCT and its software, including simulation. She is responsible for the RCT controls system and the calorimeter trigger run control system that interfaces the RCT to the experiment run control. She is working on new physics signals in W and Z plus jets. She is also working on simulation of the upgrade trigger designs

We request 12 months support each year for Postdoc Dr. Evan Friis, who is resident at CERN and in charge of the RCT hardware test program and the online and offline configuration and conditions databases for the RCT. He is working on searches for Higgs decays to taus.

For the CMS trigger activity, we are requesting support of 4 full-time graduate students resident at CERN to support the RCT and trigger activities, and 10 months support of Bachtis, who will graduate in August 2012. Our planned support of the RCT involves 6 resident students. We were unable to fund bringing on additional students while we had 5 existing students who were waiting for data in order to graduate and who have now graduated. We depend on a steady stream of students to enable us to provide the required 24x7 support of the trigger, while performing physics analysis. Summer assistantships allow us to evaluate students for entry into our thesis program and begin training and are particularly important this year to build back our group.

In response to the funding situation of the DOE University program we omit requesting support for Senior Engineer T. Gorski and Technician R. Fobes in the expectation that they will be funded totally on the US CMS project. Mr. Gorski's knowledge of and expertise in the trigger system is essential to its successful commissioning and long-term operation. He is also leading the engineering effort on our upgrade trigger program. Mr. Fobes has a significant amount of technical work required at UW for CMS in the next few years, including repair of printed circuit boards with surface mount devices, general repair of electronic components, cabling, inventory of parts and maintaining supply cabinets, parts ordering and maintenance and repair of test setups. While it may be possible to get CMS project support on US CMS Maintenance and Operations funding, the need for T. Gorski and R. Fobes will remain through the CMS Maintenance and Operations phase into the SLHC upgrade.

1.4 CMS Muon

For the CMS Muon Activity we are requesting 12 months support for UW Distinguished Scientist Dr. R. Loveless, who is the US CMS EMU Deputy Operations Manager, CMS EMU Technical Coordinator, CMS EMU upgrade project manager and serves on the US CMS Election Committee. He is based in Madison, spending 50% of his time at CERN. Over the next years as the EMU system is operated, maintained, produces physics and is upgraded his leadership will be essential.

For the CMS Muon activity, we are requesting 12 months support for Associate Scientist Armando Lanaro. Dr. Lanaro is based at CERN and is the US CMS Level-3 Manager in charge of Endcap Muon System Integration, CMS Manager of the EMU Chamber factory for the upgrade and has served as the deputy convener of the EMU Detector Performance Group and the US CMS L3 EMU on-site operations manager. He is directly responsible for the maintenance and operations of the Endcap Muon CSC chamber system and its infrastructure as well as running the CSC Chamber factory for the upgrade. He is working on studies of $V\gamma$ final states, measurement of $Z\gamma$ anomalous Triple Gauge Coupling and J/ψ polarization .

For the CMS muon activity, we are requesting support of one full-time graduate students and 7 months of another. Graduate student Jeff Klukas is working on muon track reconstruction and the muon HLT with Prof. Herndon. Graduate student Lindsey Gray is working on EMU detector performance with scientist Lanaro. Gray will graduate in May 2012 and Klukas in 2013, and will be replaced by additional students. We request support of a summer assistantship to allow us to evaluate a student to replace Gray.

1.5 CMS Computing

For the CMS Computing Activity and for the upkeep of UW HEP base program-wide general computing facilities, we are requesting 50% support each year of S. Rader. The

complexity and performance of our computing facilities can only be maintained by senior experienced systems engineering professionals. We are fortunate to have one with Mr. Rader. In order to reduce our funding for this task we made arrangements with the Physics Department to cover 50% of S. Rader's salary. We underline the importance of continued support of Mr. Rader, because this allows us to leverage important software engineering and computing resources provided by the NSF supported CMS Tier-2 and other research projects on the UW campus, to further our physics reach.

We are also funded through the NSF for support of CMS Tier-2 software engineers Dan Bradley, Ajit Mohapatra, and Will Maier to operate our CMS Tier2-C (DISUN) computing center. While we do not bear the cost on the base program for these individuals, physicists on the base program expend effort in supervision and collaboration with them to make sure that the proper service is provided to the US CMS program.

2 Travel

We monitor the travel budget very seriously. In order to meet his responsibilities as CMS Trigger Coordinator, CMS Management Board member, US CMS Trigger Level 2 Project Manager, CMS Upgrade R&D Board chair and other responsibilities in CMS and the SLHC upgrade, W. Smith must be present at the experiment and must attend numerous meetings at CERN each year. As US CMS EMU Deputy Operations Manager, CMS EMU Technical Coordinator and CMS EMU upgrade project manager R. Loveless must make a number of overseas trips each year as part of his duties. As the CMS Manager for the Regional Calorimeter Trigger, and the Upgrade Physics Coordinator S. Dasu also has required travel. We also request support for D. Carlsmith to spend the summer at CERN working on EMU support and upgrades. The other researchers on Task T must attend meetings at which the activities of the Trigger, Muon, Alignment, and Computing Systems are coordinated. We have major responsibilities for operating and maintaining the Trigger and Muon (including alignment) systems at CERN, as well as substantial computing activity in support of data analysis and simulation. This requires substantial travel to support and coordinate these activities. Moreover, most members of the group have either Trigger or EMU shift duties at CERN.

Significant travel support is necessary in order for a University group to sustain its leadership responsibilities. Despite our effort to contain travel costs, the decline of the US Dollar and inflation of lodging and airfare costs have caused increasing strain. Although we make extensive use of videoconferencing, there remain an irreducible number of critical meetings at CERN where our presence is required. We must also maintain and operate Trigger and Muon systems with personnel at CERN. While we receive support from the US CMS Project Office for some of the specific travel associated with our official Maintenance and Operations tasks, these costs are not fully covered. We are absolutely dependent on additional DOE CMS University travel help funds and yearly supplemental DOE University program support to close the gap in the level of travel funding.

3 Other Direct Costs

The computing supplies include software, software licenses and computing consumables. Supplies include general consumables, office supplies and freight charges for shipping supplies to CERN. The CERN Wisconsin account pays for similar supplies for use at CERN plus safety equipment, tools, meters and other supplies to sustain our trigger and muon activities at CERN.