Measurement of W+bb and Search for MSSM Higgs Bosons

with the CMS Detector at the LHC

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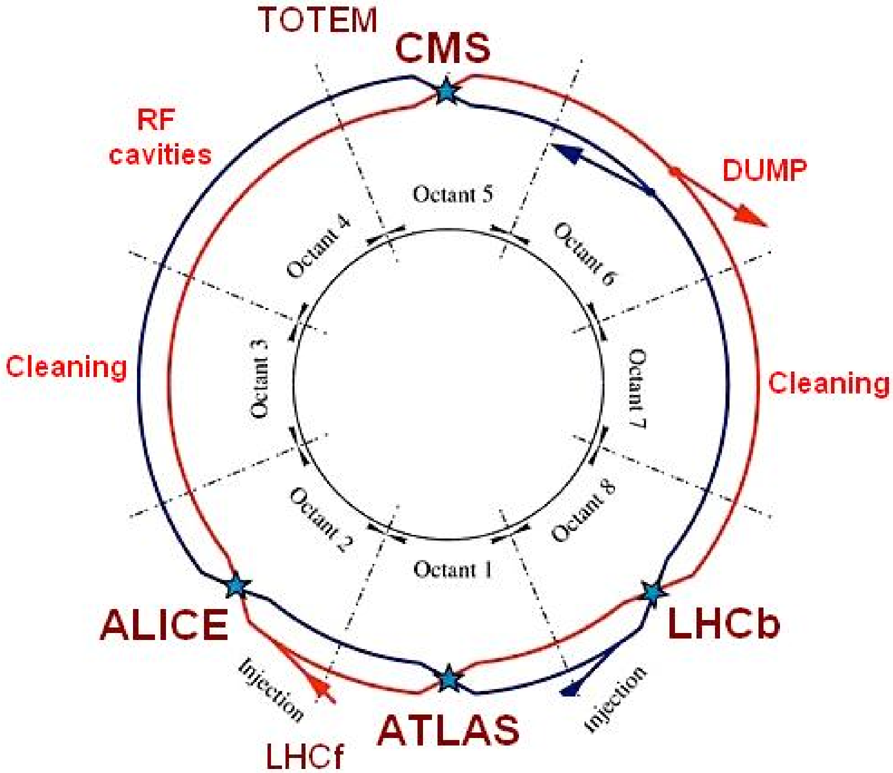
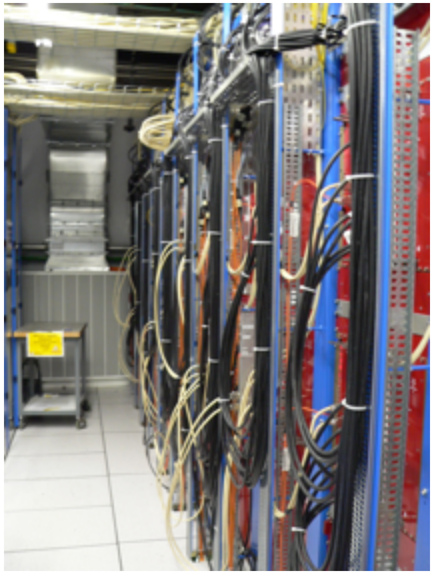
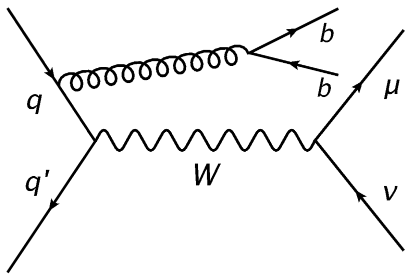
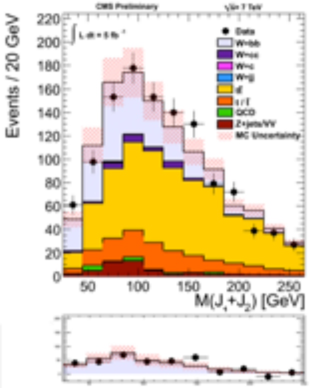
February 11th 2014

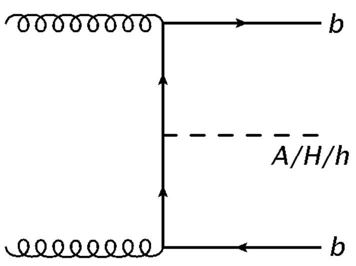
Overview

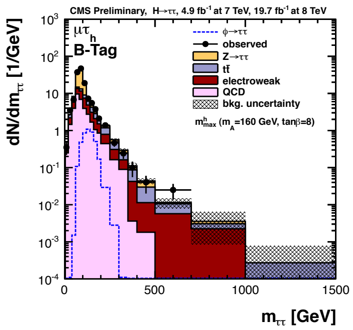

TOTEM
CMS
RF cavities
DUMP
Cleaning
Cleaning
Octant 1
Octant 2
Octant 3
Octant 4
Octant 5
Octant 6
Octant 7
Octant 8
ALICE
LHCb
ATLAS
LHCf
Injection
Injection




q
q'
b
b
W
μ
ν


Events / 20 GeV
M(J1+J2) [GeV]


b
b
A/H/h


CMS Preliminary, H→ττ, 4.9 fb⁻¹ at 7 TeV, 19.7 fb⁻¹ at 8 TeV
B-Tag
observed
electroweak
QCD
bkg. uncertainty
dN/dmττ [1/GeV]
mττ [GeV]

Standard Model of Particle Physics

Fermions split into 3 Generations of Quarks and Leptons

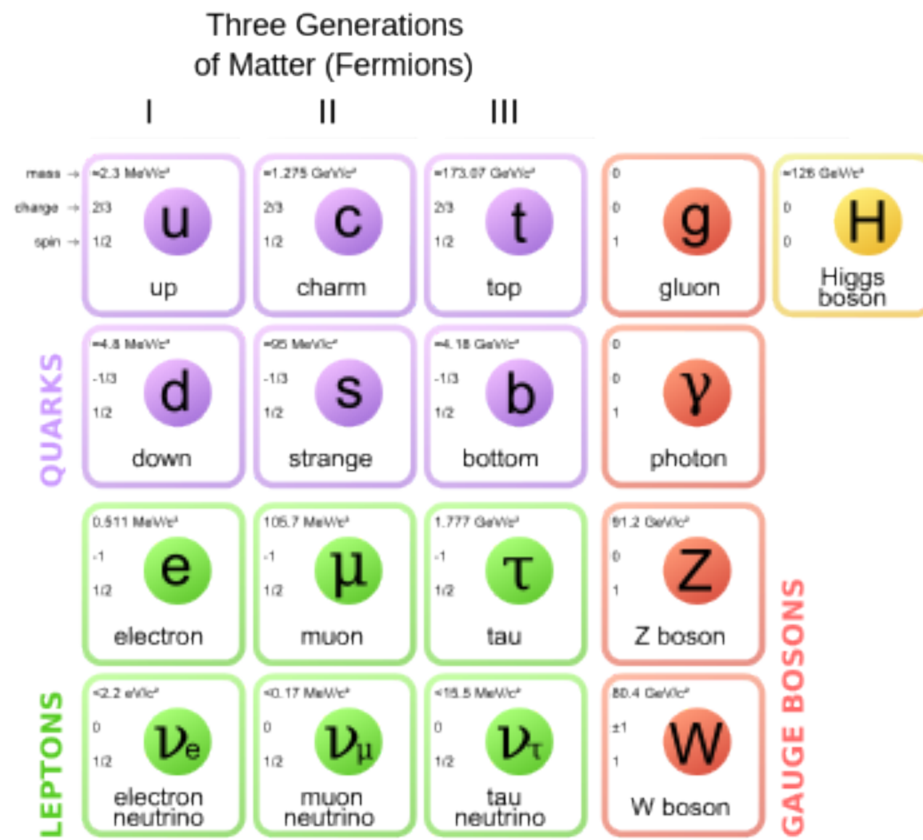
→Each fermion has an anti-particle partner with the same mass and opposite charge

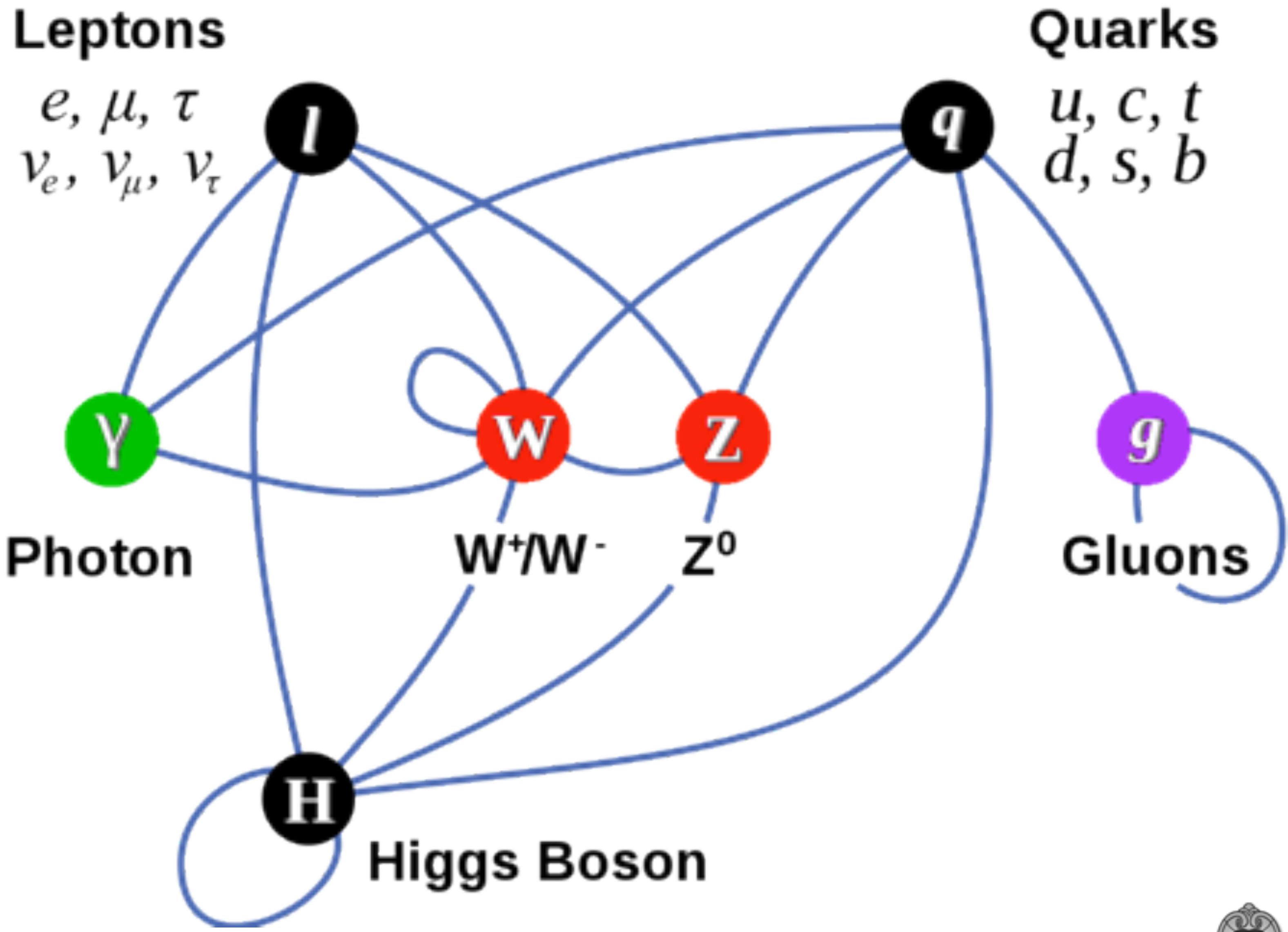
Fundamental Forces associated with the spin 1 mediator gauge bosons

→photons and gluons massless

→W/Z heavy -> gain mass by Spontaneous Symmetry Breaking

Scalar Higgs boson completes the SM

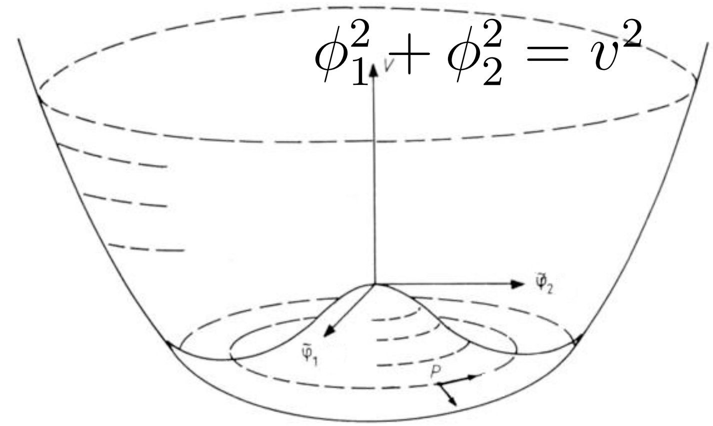



Leptons
e, μ, τ
νe, νμ, ντ
l
Quarks
u, c, t
d, s, b
q
γ
W
Z
g
Photon
W+/W-
Z0
Gluons
H
Higgs Boson

Spontaneous Symmetry Breaking

In $SU(2)_L xU(1)$ Symmetry
→Gauge Bosons massless

Electroweak Symmetry Breaking needed to give Gauge Bosons mass
→Two component complex scalar field (4 degrees of freedom)
→ 3 needed to give mass to W/Z
→ fourth appears as a physical particle: higgs boson



$$V = \frac{1}{2}\mu^2(\phi_1^2 + \phi_2^2) + \frac{1}{4}\lambda(\phi_1^2 + \phi_2^2)^2$$

Translating the potential to a new minimum , $\lambda > 0 \text{ and } \mu^2 < 0$

$$M_W = \frac{1}{2}vg \qquad m_h = \sqrt{2\lambda v^2}$$

$$\cos\theta_W = \frac{M_W}{M_Z}$$

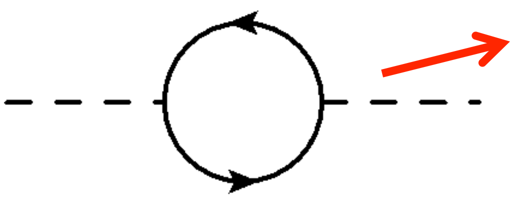
Fermions can acquire mass through interaction with the Higgs field (Yukawa coupling)
→Recent evidence for H→ττ !

Beyond the SM: Supersymmetry

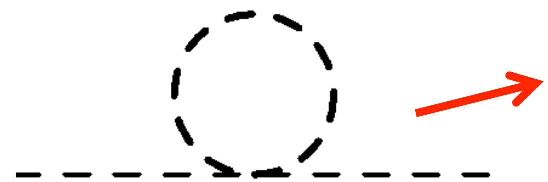
SM: A theory of almost everything!

What happens beyond the Electroweak Scale?

- m_H is sensitive to loop corrections
- Loop corrections to m_H become divergent (Λ_{UV}→infinity?)
- →Higgs is ~low mass! So excessive fine tuning is needed



$$-\frac{\lambda_f^2}{8\pi^2}\Lambda_{UV}^2$$



$$+\frac{\lambda_s}{16\pi^2}\Lambda_{UV}^2$$

Supersymmetry solves this problem:

Introduces a new symmetry between fermions and bosons

- Each SM fermion has a boson Super-partner
- Each SM boson has a fermion Super-partner

→Double the particle spectrum

→Divergences cancel by construction!

- Minimal Supersymmetric Extension to the Standard Model

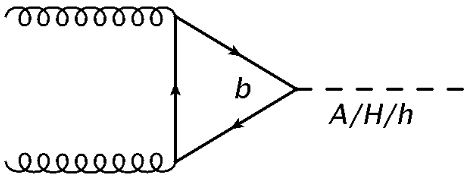
Higgs Sector of MSSM

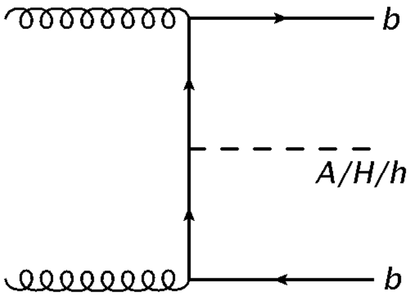
H, h, A, $H^{+/-}$

Production Mechanism @LHC

Gluon Fusion

b-associated Production





At Tree Level,

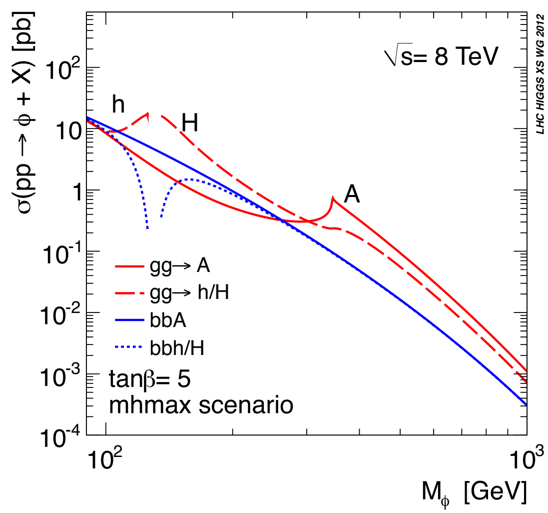
Independent Parameters:

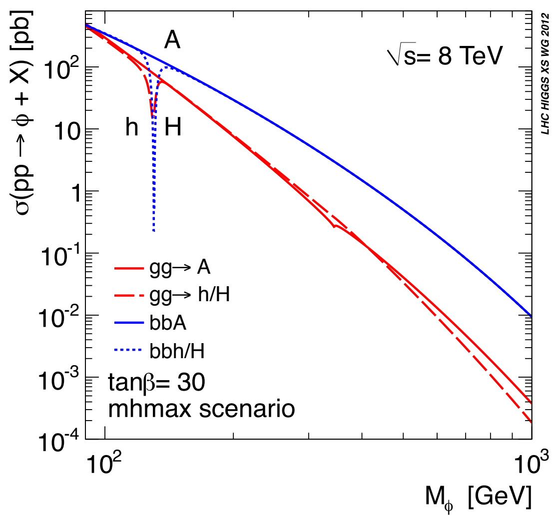
m_W, tan(β), m_A

$M_h < M_Z$

With Loop Corrections

$M_h < 133$ GeV





At large tan(β) A/H/h→ττ is enhanced

$$\tan(\beta) = \frac{v_2}{v_1}$$

Due to the large number of free parameters, a complete scan of MSSM parameter space is too involved **Using mhmax Scenario in this thesis**

→Fix parameters and scan in M_A, tan(β)

Higgs to $\tau\tau$

τ: Most massive Lepton → Presents opportunities to search for new physics

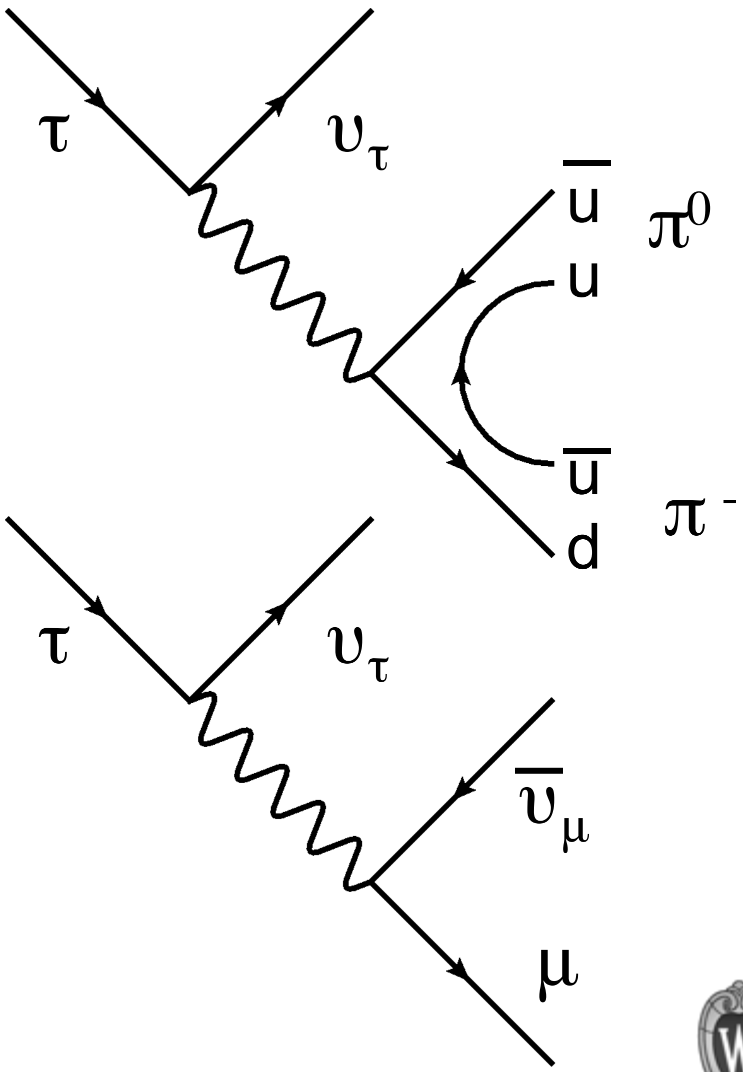
Lifetime: 2.9 x 10^{-13} s
Mass: 1.776 GeV

Decays via the Weak Interaction

- To muon/electron + 2 neutrinos (35%)
  - →Labeled τ_μ and τ_e
- To Hadrons+neutrino (65%)
  - →Labeled τ_h

Experimental solution:

Identify hadronic/leptonic τ indirectly



W+bb production

W Production @LHC

W Produced through annihilation of an up-type quark and anti-down type quark

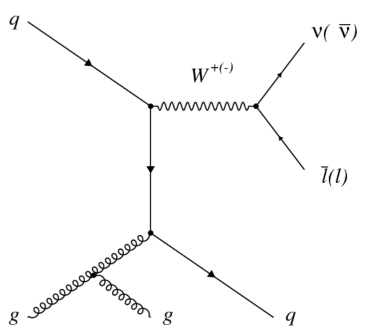
W coupling is favored within quark generations

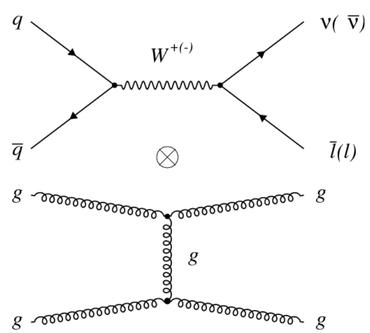
$b\bar{b}$ Production

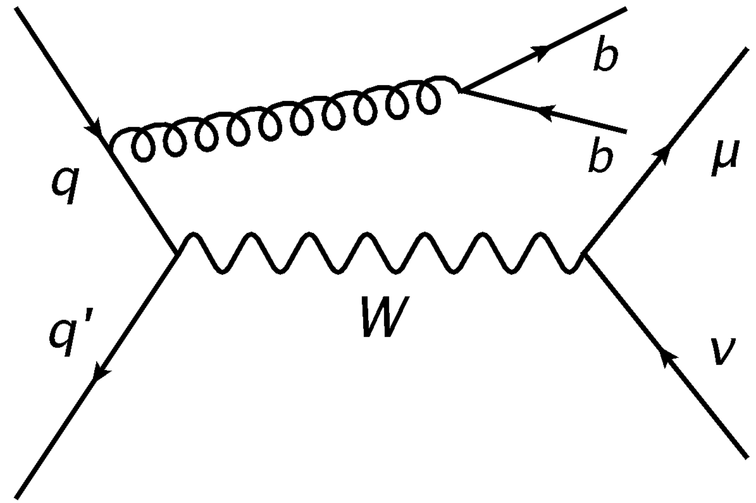
At leading order from gluon splitting

Double Parton Scattering

→Non-negligible Contribution







The CKM matrix parameterizes quark mixing across generations

q'=Vq

Constructed such that:
Cabbibo rotated states d',s',b' have no mixing across generations

Heavy Flavor Quarks/Hadronization

gluon→$q\bar{q}$

At ~10^{-15} m the strong interaction causes new quarks and anti-quarks to be produced

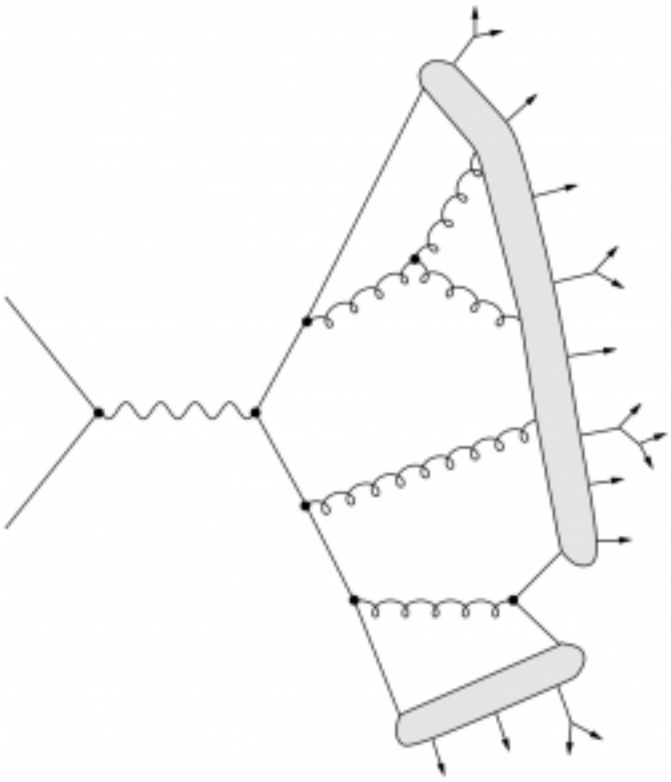
gluon→$b\bar{b}$

For a b-Hadron very little energy loss due to formation of light quarks

→Energy is carried by the b-Hadron

Mean lifetime of a b-hadron is 1.55×10^{-12} s

→Allows for the identification of Secondary Vertices! (used in W+bb analysis)



LHC
PA 4
PA 6
PZ 3.3
PM 3.2
PM 7.6
ALICE
BA 2 - SPS2
BA 4 - SPS4
BA 1 - SPS1
BA 5 - SPS5
SPS
ATLAS
LHC 1.8

LHC

Proton-Proton or Heavy-Ion Collider

27km in circumference, 100m underground

Center of Mass Energy 7 TeV 2011, 8TeV 2012

Four Major Detectors

- Two General Purpose, mainly proton physics
  - CMS, ATLAS
- Dedicated Heavy Ion
  - ALICE
- Forward Detector for b-Physics
  - LHCb

LHC Overview

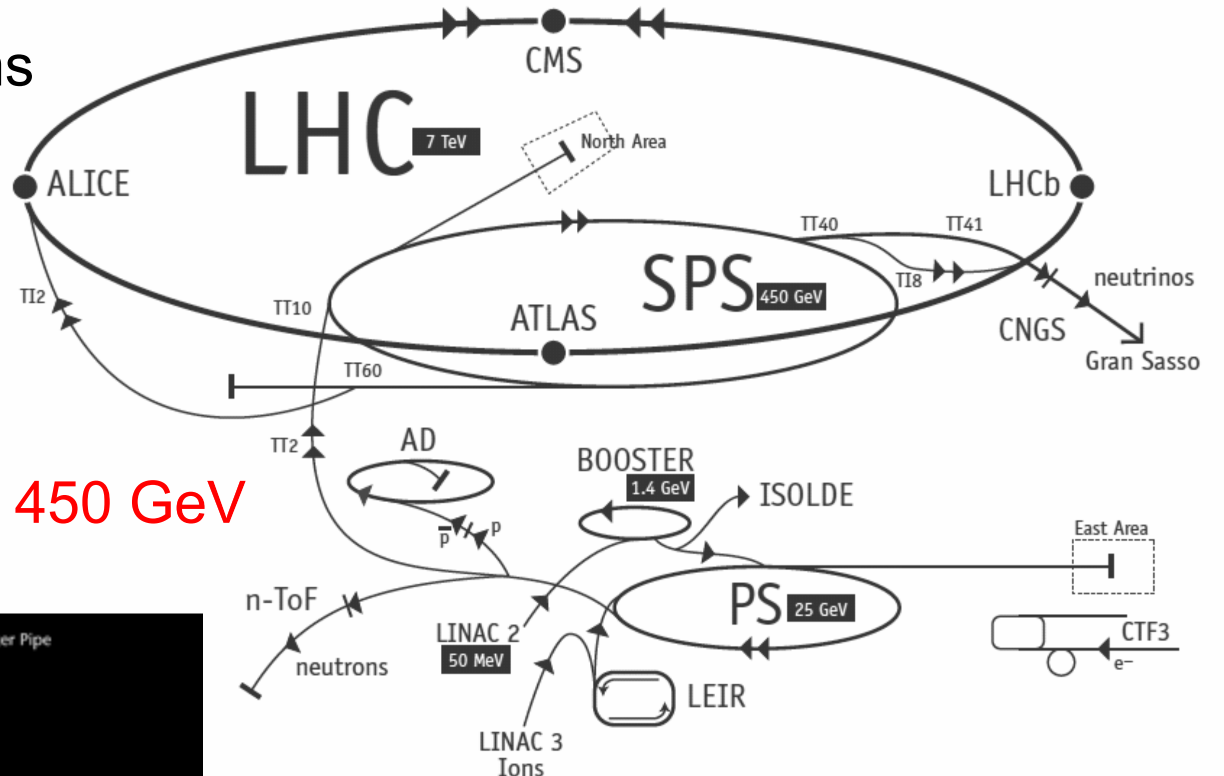
Start with Hydrogen Atoms

→first remove e^-

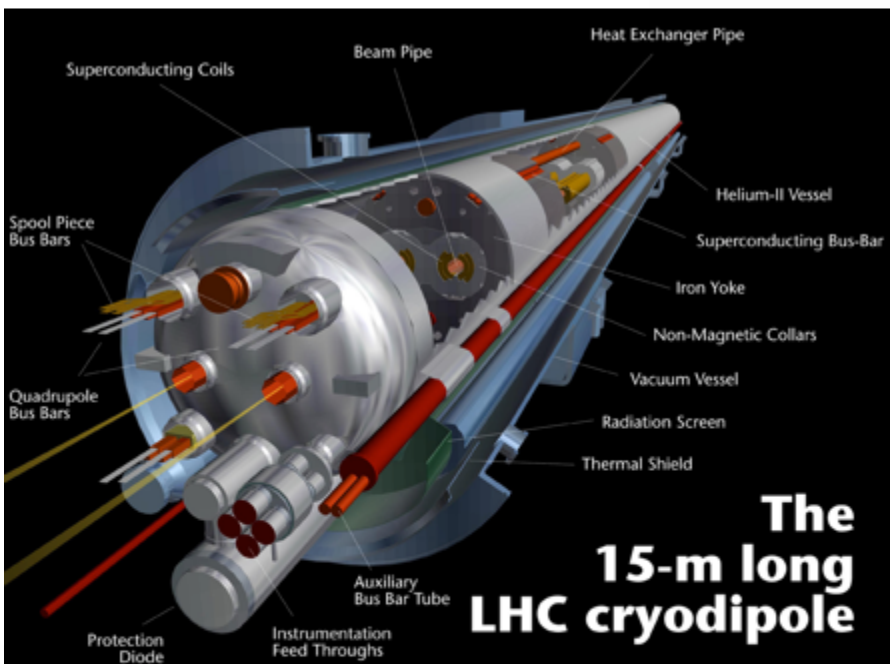
Accelerated in stages

→Using RF Cavities

→Forms bunches



Reach the LHC Ring with 450 GeV



Twin-Bore Design (NbTi)

→Super Conducting Magnets

Cooled to 2K, Magnetic Field up to 8T

→Requires tight control of current and heat dissipation

LHC: Operating Conditions

Number of Events for a Given Process

$$N = \sigma \int L dt$$

σ: Cross Section of Process

L: Instantaneous Luminosity of the collider **Units:** Particle Flux/time

Optimize Luminosity

→High Particle Density (per Bunch)

→Maximize the number of bunches per beam and Revolution Frequency

→Minimize Bunch Size

	Design	**2011**	**2012**	**2015**
Beam Energy	7 TeV	3.5 TeV	4 TeV	6.5 TeV
Bunches/ Beam	2835	1380	1380	~2800
Bunch Crossing	25 ns	50 ns	50 ns	25 ns
Protons/ bunch	1.15×10^{11}	1.5×10^{11}	1.5×10^{11}	
Peak Luminosity	$10^{34} cm^{-2}s^{-1}$	2×10^{33} $cm^{-2}s^{-1}$	7.7×10^{33} $cm^{-2}s^{-1}$	2×10^{34} $cm^{-2}s^{-1}$
Integrated Luminosity		$6.1\ fb^{-1}$	$23.3\ fb^{-1}$	

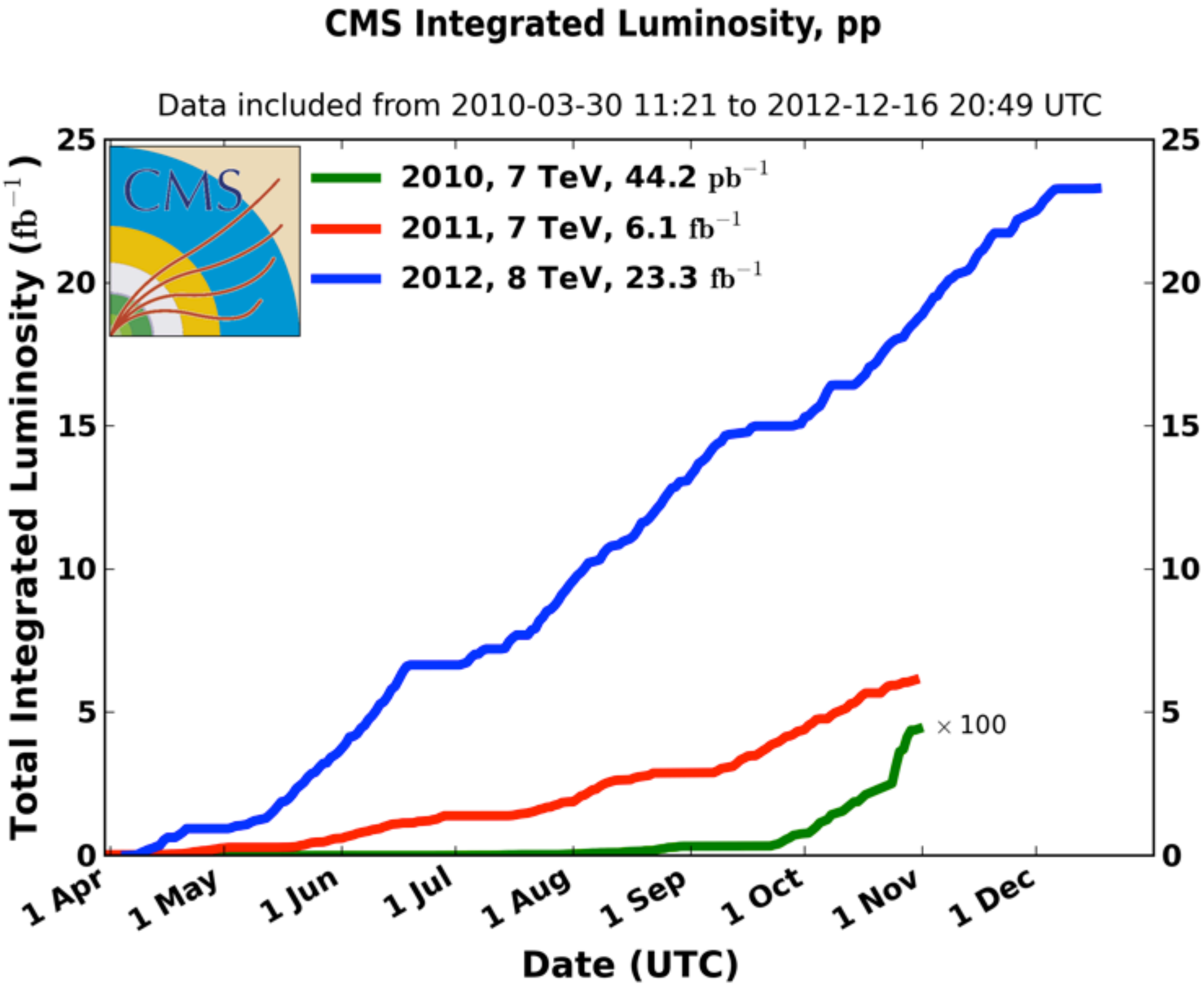
Mean Number of Interactions/Crossing

$$\mu = \frac{L\sigma_T}{R_B f_B}$$

Instantaneous Luminosity:

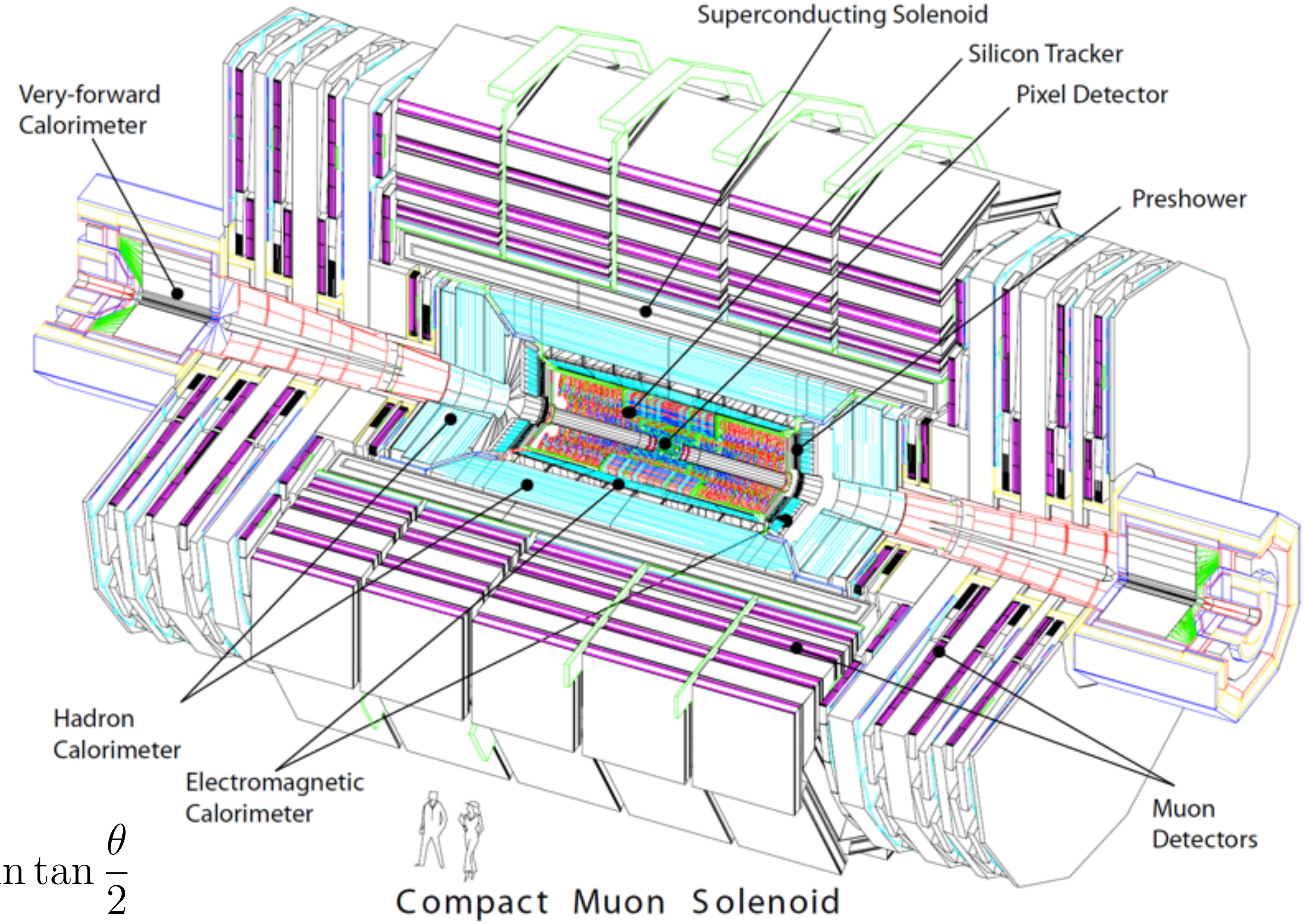
$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \epsilon_n \beta *} F$$

LHC Total Integrated Luminosity




CMS

CMS:Compact Muon Solenoid



$$\eta = -\ln \tan \frac{\theta}{2}$$

Solenoid

Solenoid Magnet provides bending power for momentum measurement

Sagitta of a particle trajectory,

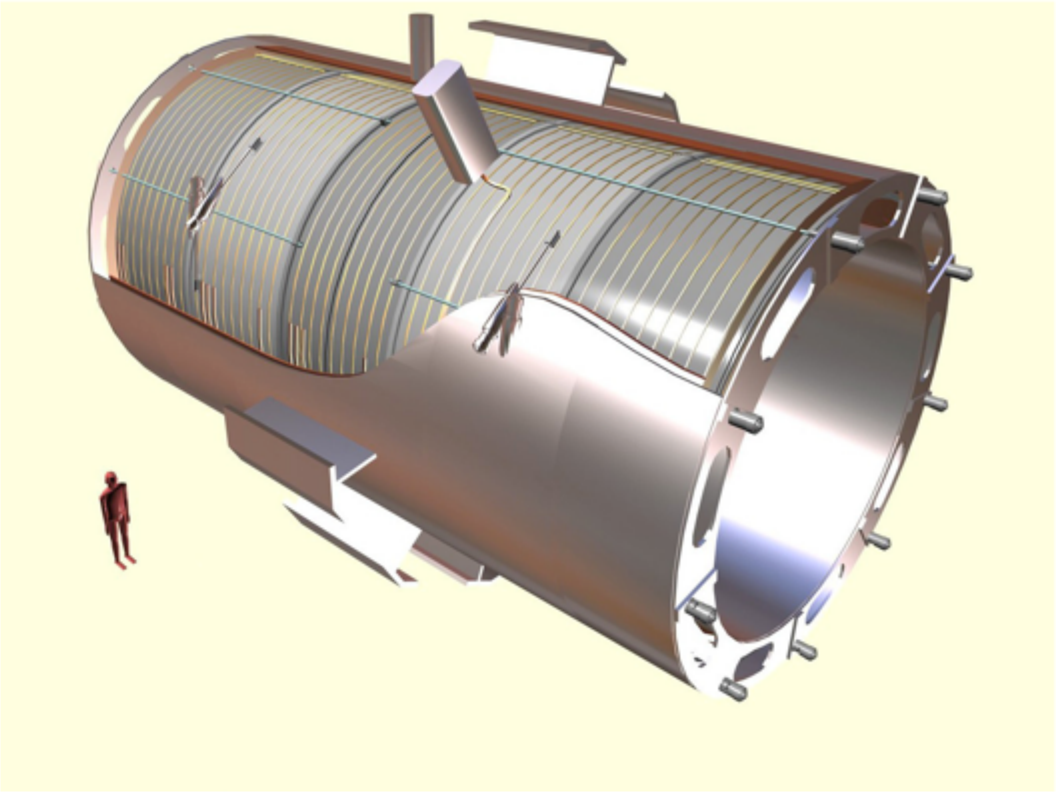
$$s = \frac{L^2}{8r} = \frac{qBL^2}{8p}$$

Momentum Resolution,

$$\frac{dp}{p} = \frac{p}{BL^2}$$

High Strength Magnetic Field to provide optimal resolution

- 3.8 Tesla
- 6.3 m in Diameter, 12.5 m Long



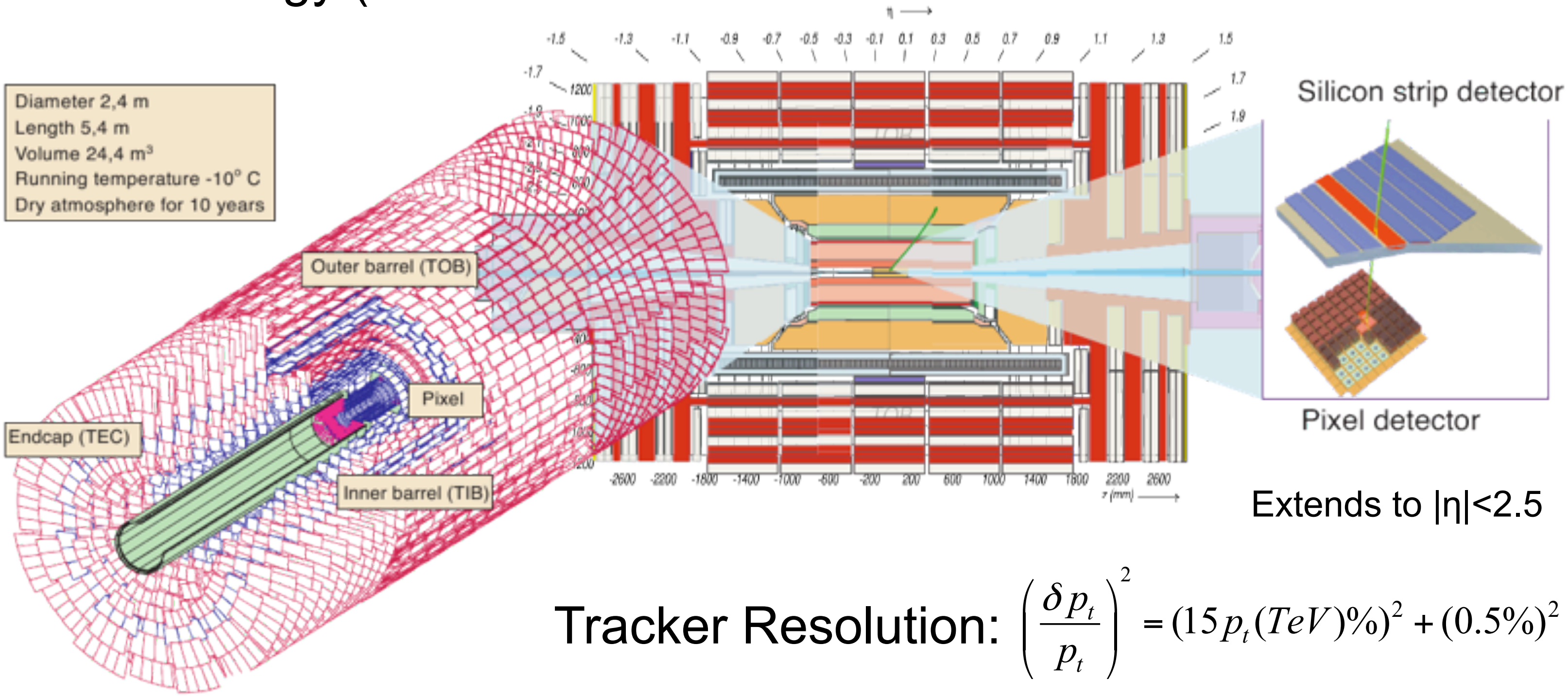
4 Layer Winding, Flux Returned by 10,000 ton Iron Yoke

$$B = \mu_0 n I$$

Tracker

Identifies Tracks, Measures Charge and Transverse Momentum

Silicon Technology (5.4m x 2.4m)



Extends to $|\eta|<2.5$

Tracker Resolution: $\left(\frac{\delta p_t}{p_t}\right)^2 = (15 p_t(TeV)\%)^2 + (0.5\%)^2$

Strong B-fields make the Tracker efficient for a wide range of p_T

Inner Pixel Detector

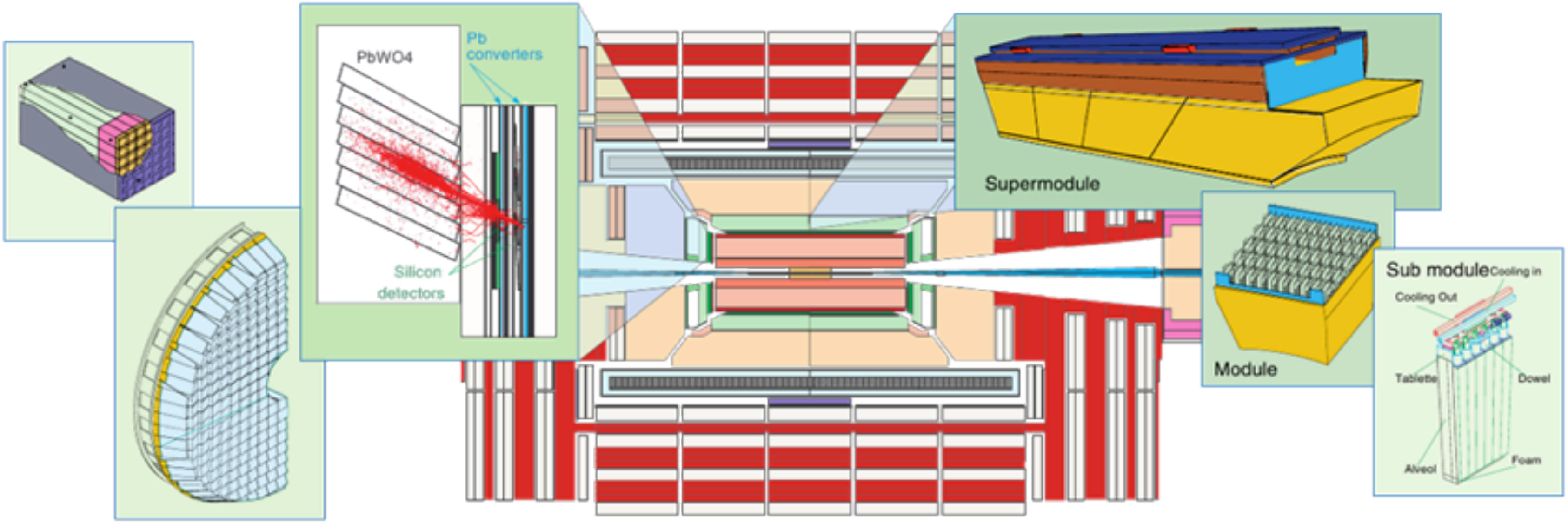
- Close to interaction point
- High Granularity
- →Reduce occupancy per cell

Outer Strip Detectors

- Further from interaction point
- Smaller particle flux

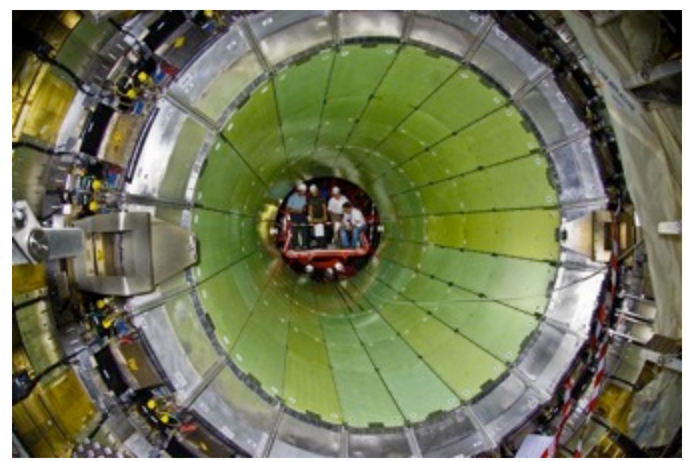
Electromagnetic Calorimeter

The ECAL measures the Energy of Electrons/Photons out to $|\eta|<3$



Lead Tungstate Crystals (~75,848)

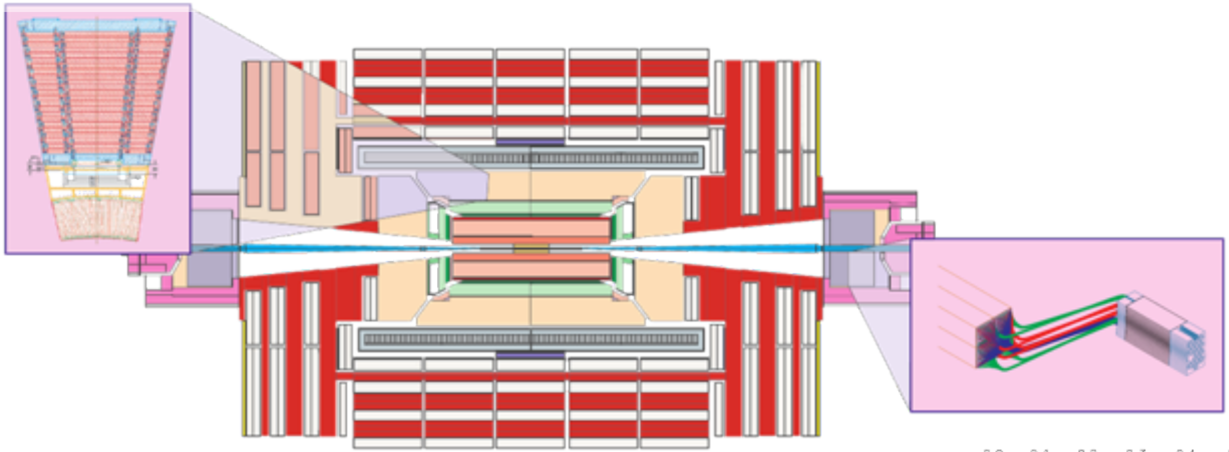
- High Density (8.2 g/cm^3)
- Short Radiation Length (8.9 mm)
  - Total Crystal Length 230 mm→25.8 X_0
- Small Moliere Radius (22 mm)
- 2 x 2 cm^2 crystal area
- 80% of light is emitted from $PbWO_4$ in 25 ns

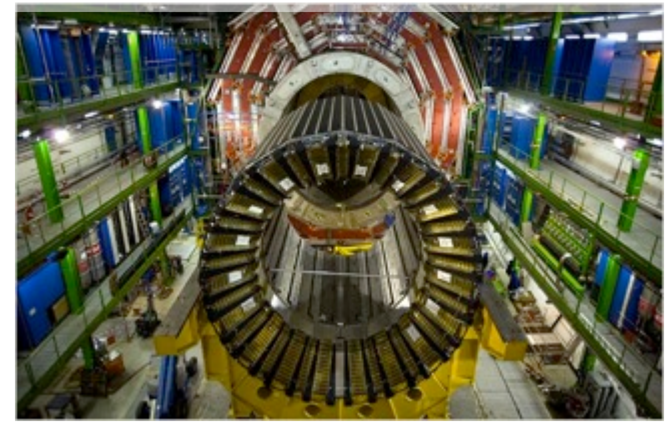


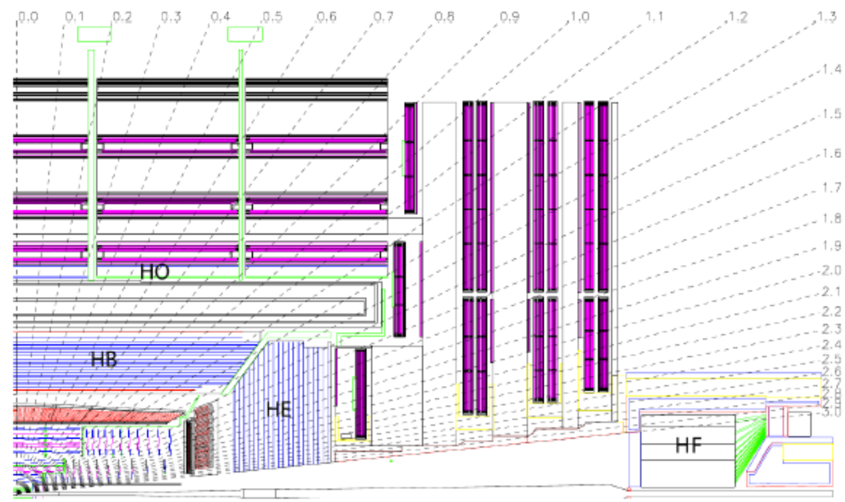
Resolution: $$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.83\%}{\sqrt{E}}\right)^2 + \left(\frac{0.124}{E}\right)^2 + (0.3\%)^2$$

Here, E is in GeV

Hadronic Calorimeter







Sampling calorimeter

Layers of Scintillators and Absorbers

→Covers 6-8 Interaction Lengths

Needed for measuring MET and Jets

Covers |η|<5

Barrel and Endcap Region

Brass and Scintillator

Barrel: $|\eta|<1.4$ Endcap: $1.4<|\eta|<3$

Resolution: $\left(\frac{\sigma}{\mathrm{E}}\right)^2 = \left(\frac{115\%}{\sqrt{E}}\right)^2 + (5.5\%)^2$

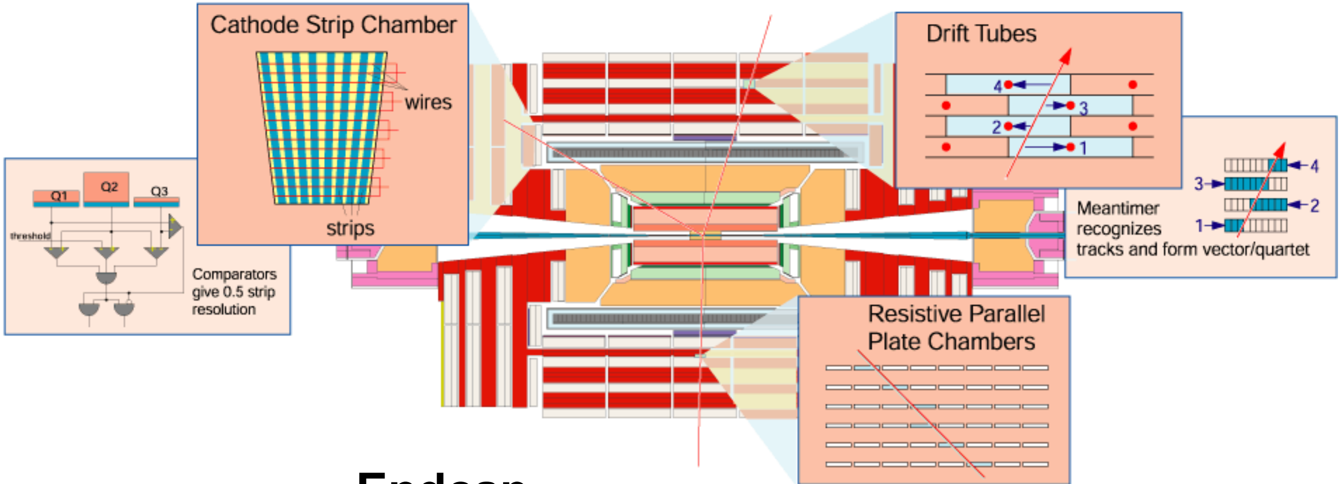
Forward Hadron Calorimeter

Steel and quartz fiber

$3<|\eta|<5$

Resolution: $\left(\frac{\sigma}{\mathrm{E}}\right)^2 = \left(\frac{280\%}{\sqrt{E}}\right)^2 + (11\%)^2$

Muon System



Barrel

Drift Tube Chambers

$|\eta|<1.3$

Resistive Plate Chambers

$|\eta|<1.3$

Endcap

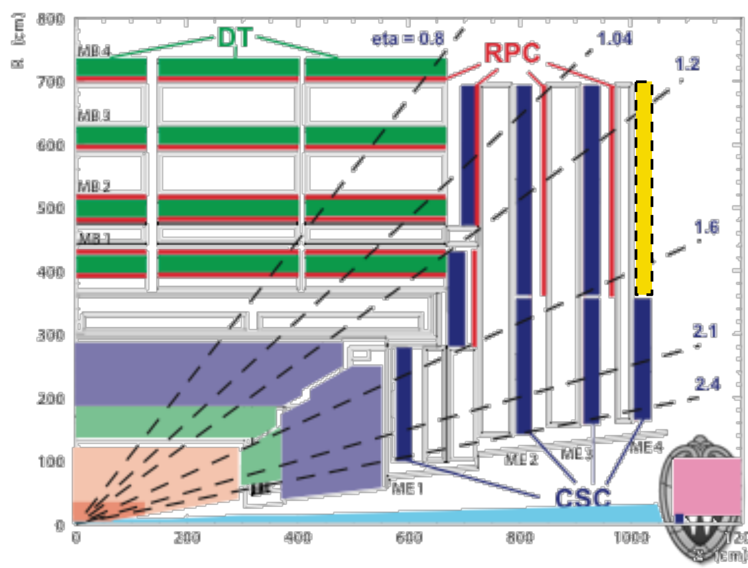
Cathode Strip Chambers

$0.9<|\eta|<2.4$

Resistive Plate Chambers

$|\eta|<1.6$

Resolution: 6-20% < 100 GeV
15-35% > 100 GeV



Designed for Efficient Muon Measurement:

Low P_T Muons: the p_T is assigned by the Tracker

High P_T Muons: the Tracker and Muon Chambers contribute to the p_T measurement

New Cathode Strip Chambers and RPC's (Yellow)

CMS Trigger System

Beams are designed to cross every 25 ns (50 ns)

20 pp interactions per crossing → Pile Up

.5 Billion particles per second grouped in 40 Million beam crossings per second with up to 1 MB data stored/event

→CMS trigger must reduce this to a recordable rate

2-Stage Trigger System:

1 GHz

Level 1 Trigger

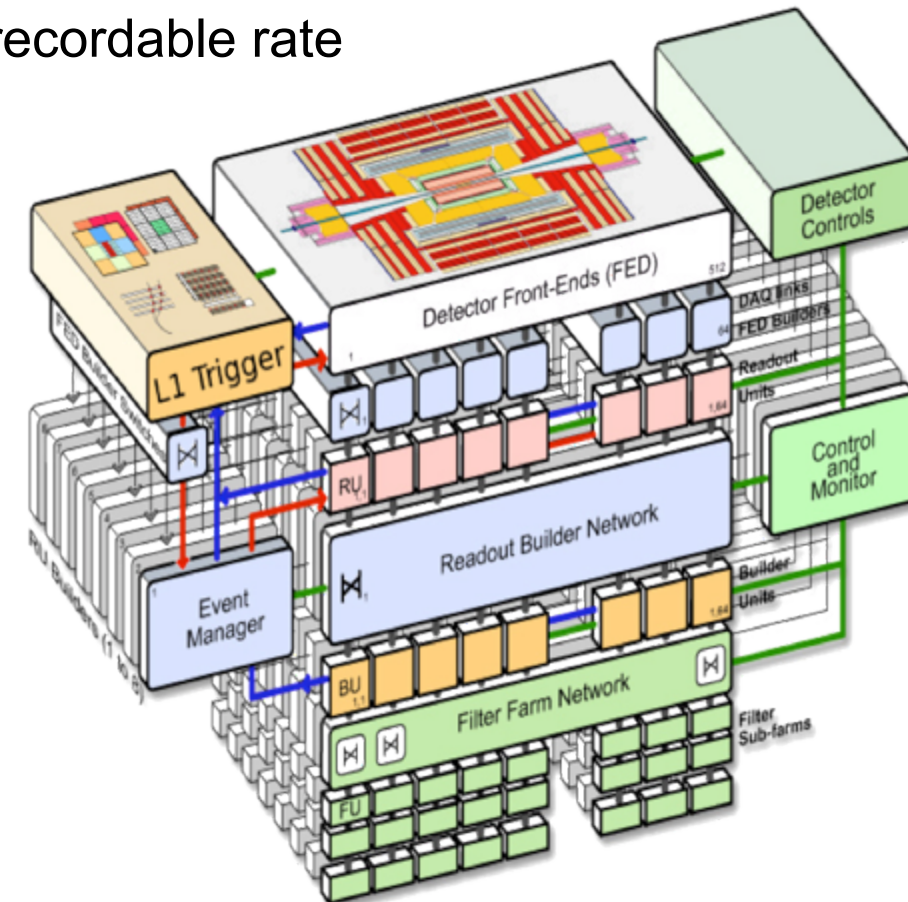
- High-speed Custom Hardware
- Specialized Algorithms

100 kHz

High Level Trigger

- Software running on Commercial Processor Farm
- Algorithms similar to offline Reco

300 Hz



Level 1 Trigger

Calorimeter Trigger

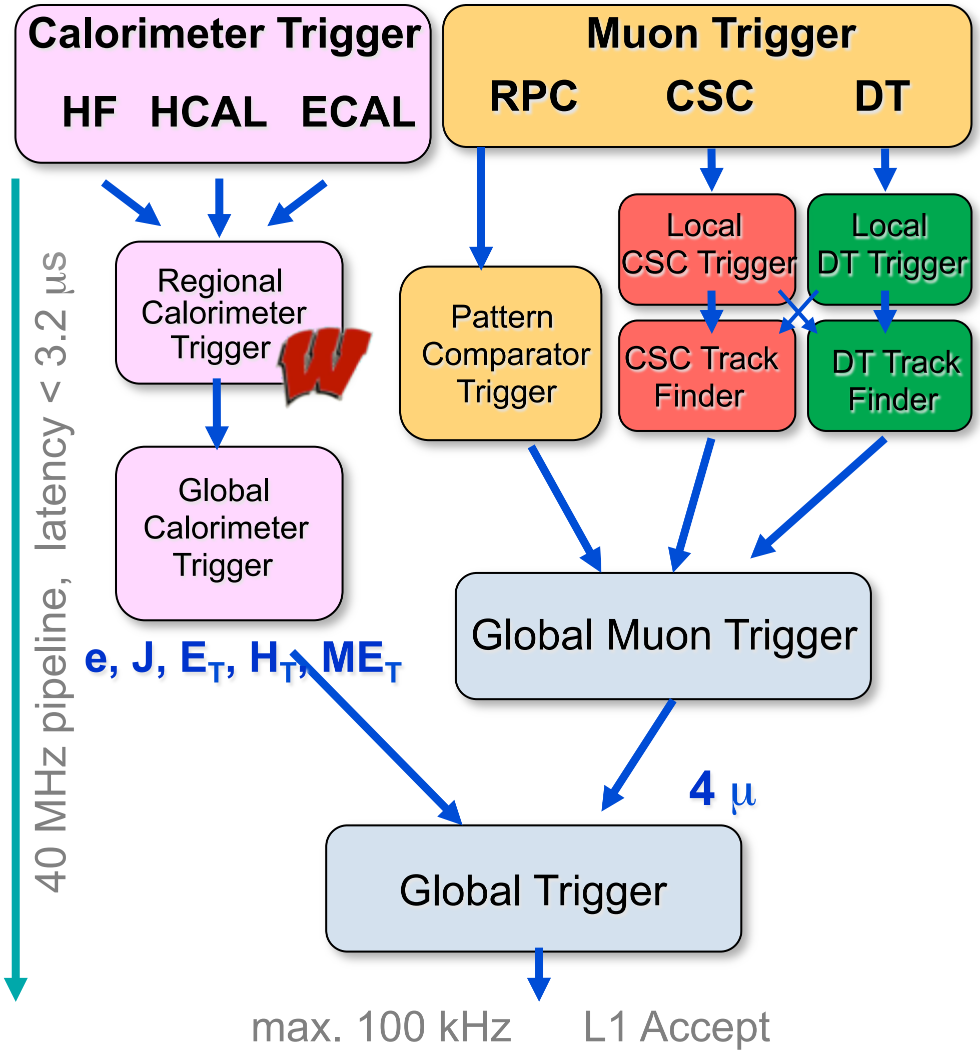
- Regional Calorimeter Trigger (RCT)
  - Finds e/γ energy deposits
  - And regional energy deposits
  - Calculate τ Veto Bit
  - Forwards RCT objects to GCT
- Global Calorimeter Trigger (GCT)
  - Sorts RCT Objects
  - Calculates Missing E_T
  - Performs Jet Clustering

Muon Trigger

- Regional Triggers
  - CSC, DT find tracks
- Global Muon Trigger
  - Sorts Muons

Global Trigger

- Makes Acceptance Decision
- Passes to HLT

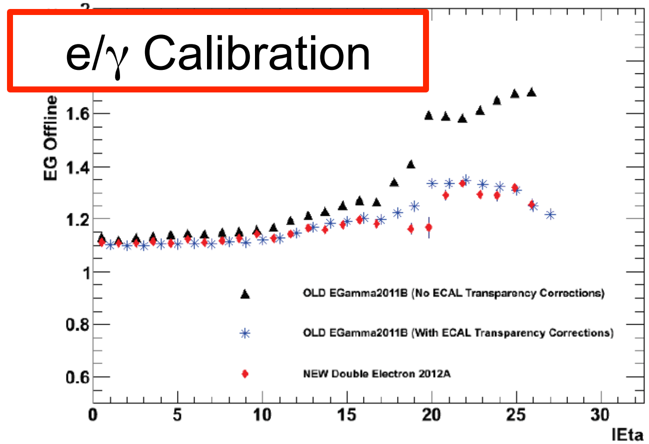


RCT: Overview of My Work

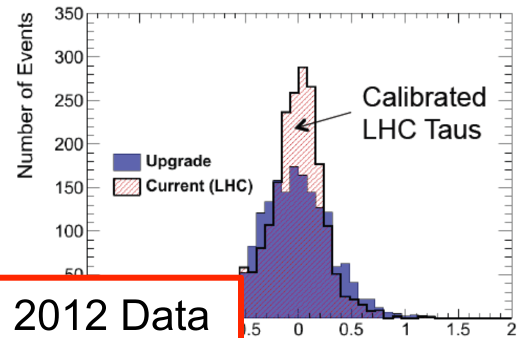
Calibration of RCT (electrons/photons)
→Used during the 2012 Run

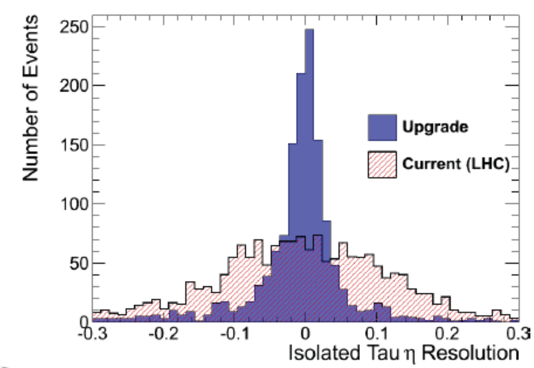
Monitoring and Debugging for 2011/2012 p-p and 2013 Heavy Ion Run
→Maintenance on RCT Receiver Cards

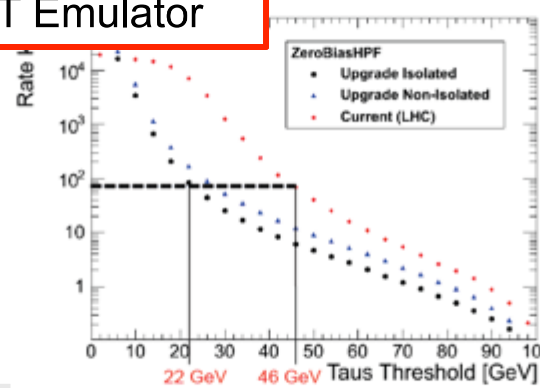
Level 1 Upgrade Development
(L1 Electrons, Photons, Taus, Jets)
→Estimate Rate and Efficiency of objects for future higher Luminosity Runs
→Design new algorithms!

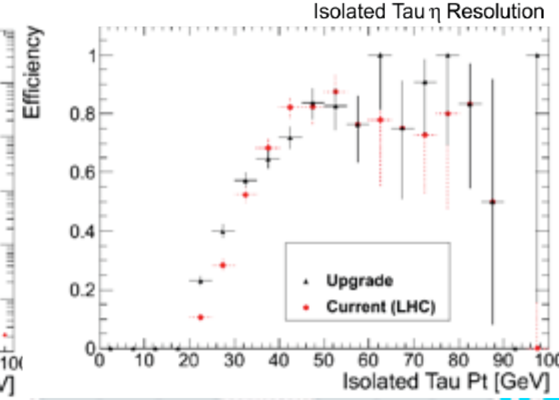


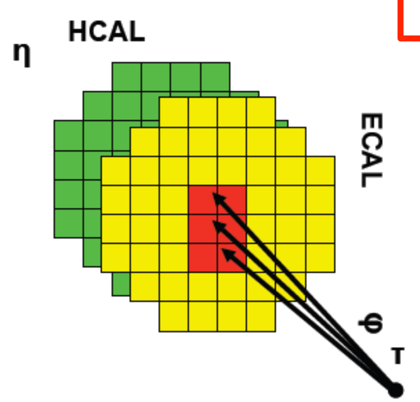
Comparing 2012 Data and RCT Emulator











High Level Trigger

Processes events selected by Level 1

Algorithms Similar to Offline Reconstruction

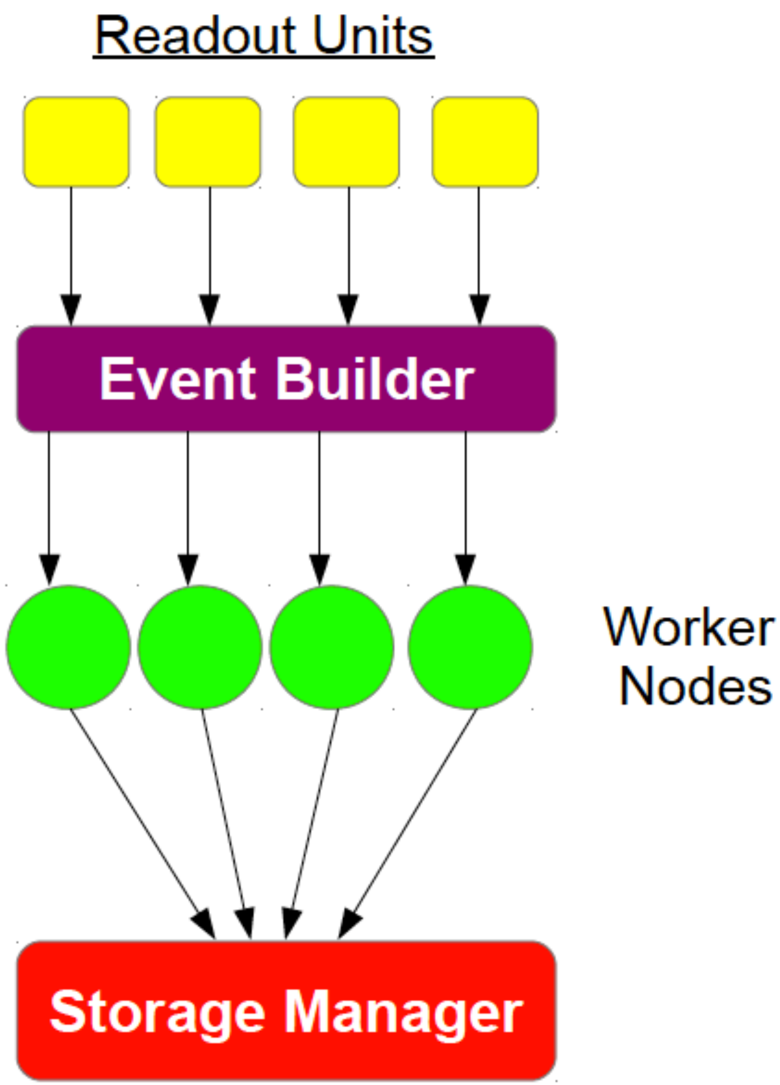
- Written in C++ run on commercial processor farm

Optimized for Speed

- Simple Algorithms run first
- After passing Simple Selections, Complex Algorithms are run

Tag Events for Analysis

Event Rate Reduces to ~100Hz



Particle Reconstruction
and
Simulation

Electron ID

Requires a track matched to an ECAL deposit

Electromagnetic deposit formed as a Super Cluster in ECAL

SC→ Cluster of Clusters, Grows in φ

→Accounts for electron-material interactions

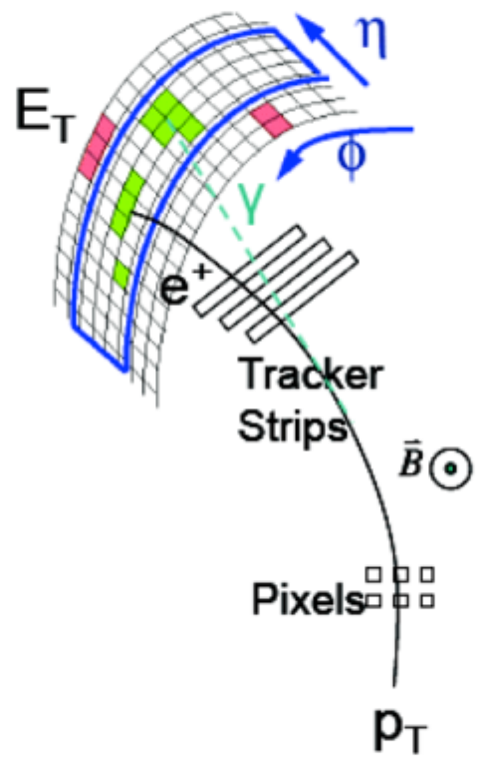
SCs must have low hadronic activity

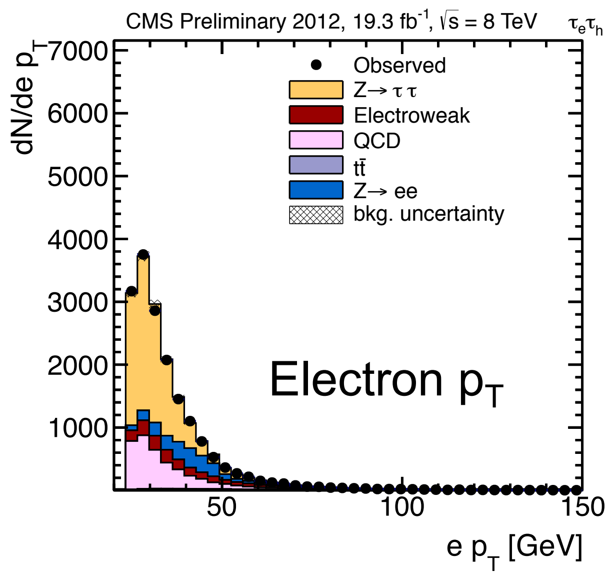
HCAL Energy/ECAL Energy<0.05

→MVA used to improve Identification

Uses 'training events' for which the output is known to determine a mapping function for that describes a classification or a regression

Also reject Converted Photons





Muon ID

Three types of muon Reconstruction

Standalone Muon

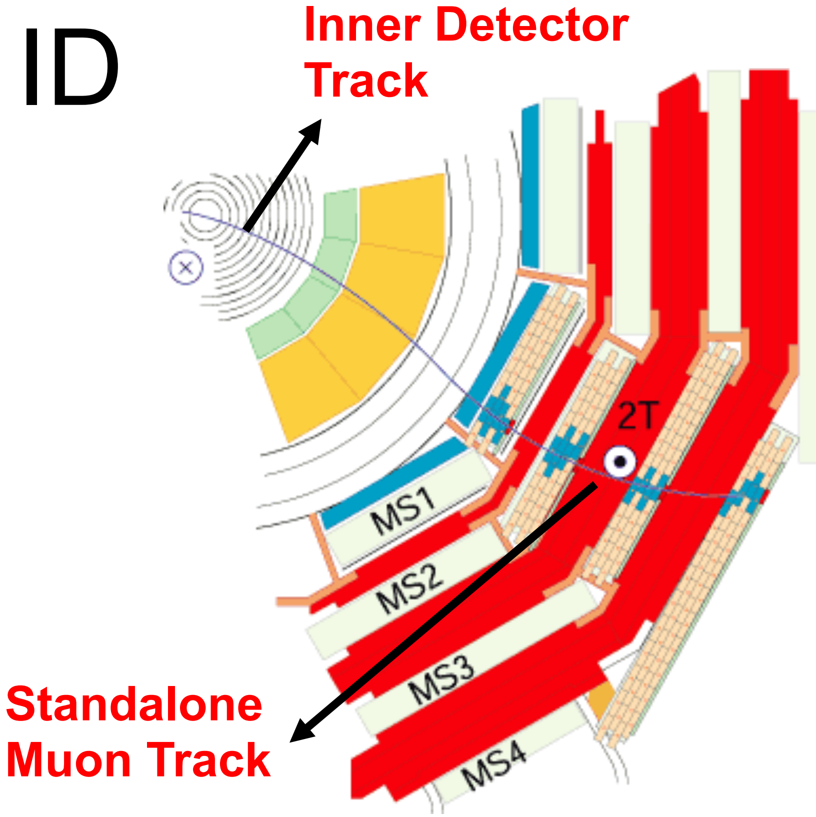
Track Reconstructed in Muon System

Tracker Muon

Constructed in Tracker with at least one hit in muon system

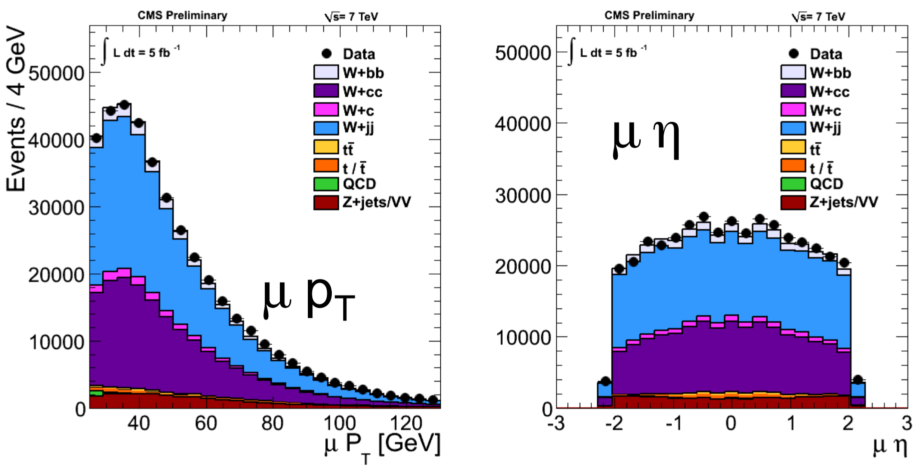
Global Muon

Tracker Muon Matched to tracks in Muon System

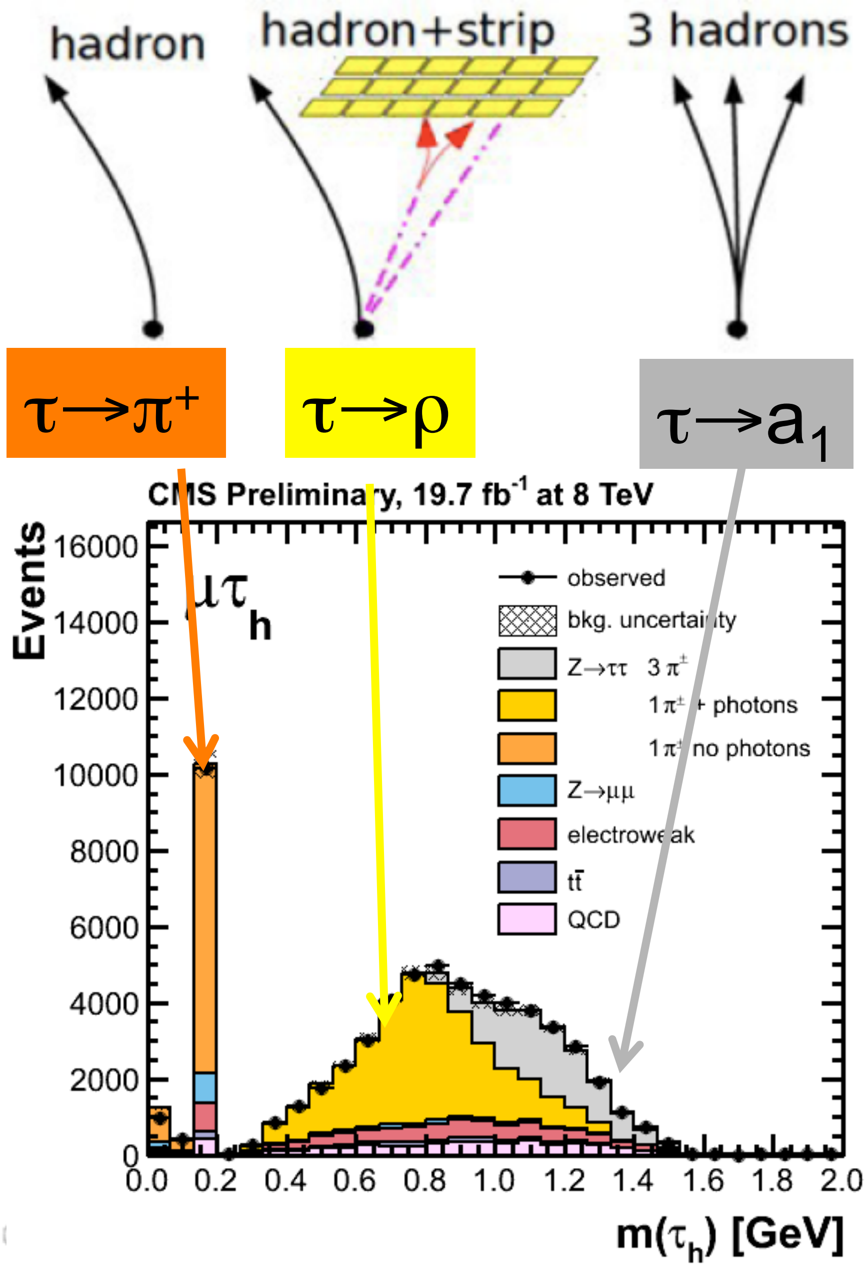


Muon Requirements for Analysis:

Global Muon, Good fit to extrapolated muon trajectory, Minimum number of "Hits" in muon chambers



Hadronic Tau Reconstruction



Tau reconstruction: hadron+strip

Particle-flow based algorithm to reconstruct different hadronic tau decay modes

τ_h identification: efficiency ~ 60%

fake rate ~ 1%

The τ_h mass distribution is used to control the tau energy-scale within 3%

Isolation

Leptons from QCD processes are inside jets

Electron/muon Isolation

Uses Particle Candidates in a cone of 0.4

Relative Isolation:

$$\frac{\Sigma Particles_{cone<0.4}}{P_T Lepton}$$

Including Pile-Up Corrections

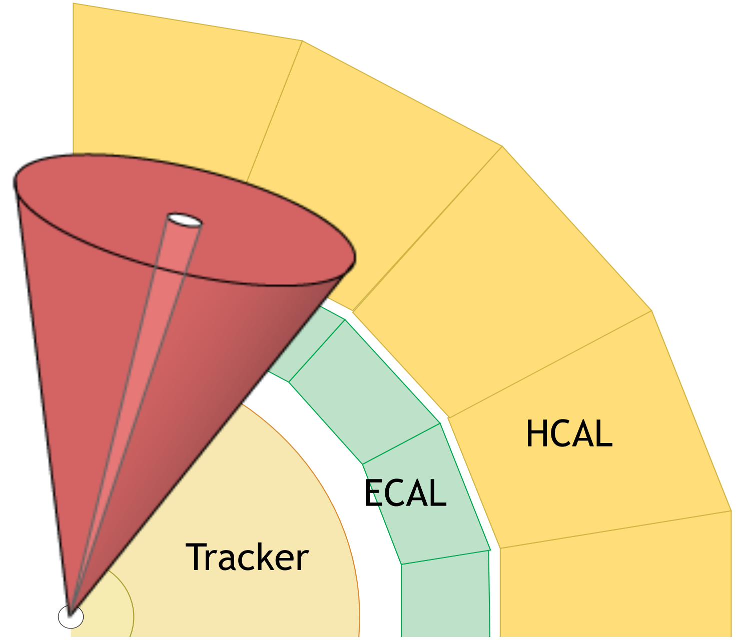
→Neutral/Charged Particle Total Energy≈0.5

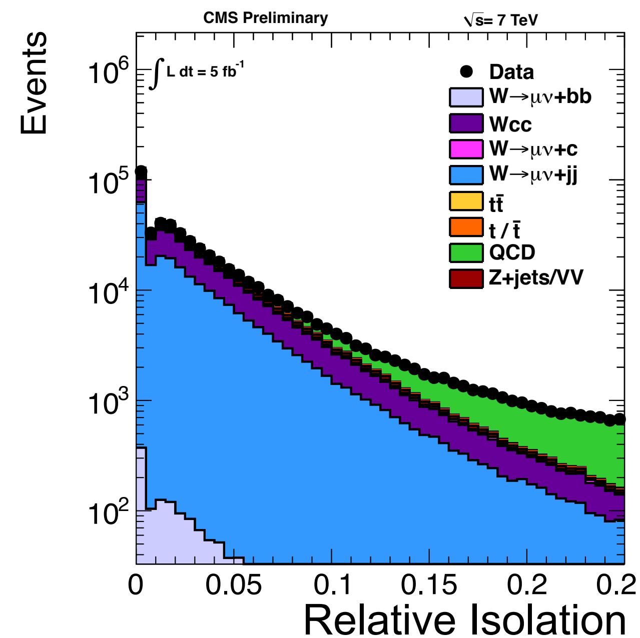
→Subtract Estimate of Neutral Energy deposit in Jet Cone using Charged Energy

$$I_{\text{rel}} = \frac{\sum \text{p}_\text{T}(\text{charged}) + \max\left(\sum E_T(\text{neutral}) + \sum E_T(\text{photon}) - \Delta\beta, 0\right)}{\text{p}_\text{T}(\mu \text{ or } e)}$$

Tau Isolation →Absolute Isolation

$$I_{\tau_{had}} = \sum P_T^{charged}(\Delta z < 2 \text{ mm}) + \max\left(P_T^{\gamma} - \Delta\beta, 0\right)$$





Jet ID and MET

Jet clustering

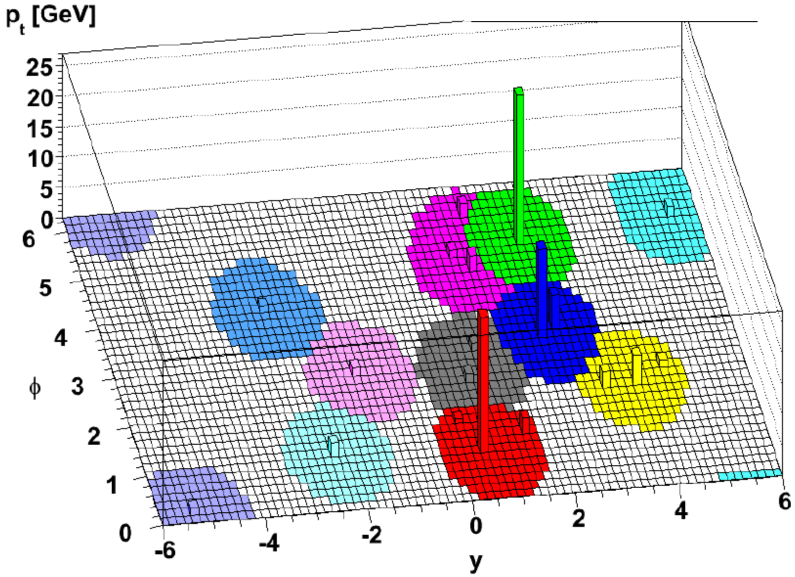
Performed using particle candidates

Energy Corrections Applied

L1 FastJet –Remove energy from PU

L2 Relative –Equalize Jet Response in the Detector

L3 Absolute –Equalize jet response with different P_T

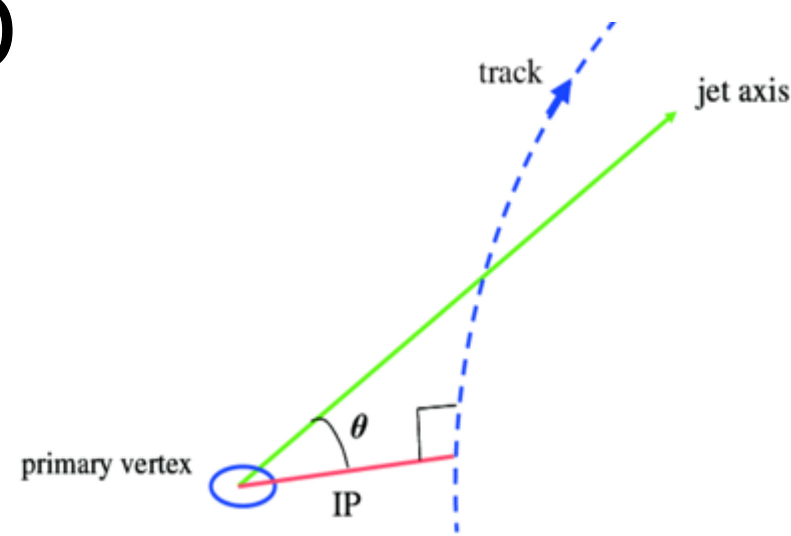


Residual Corrections Applied to data to account for further differences with simulation

Met is summed using, $E_{\mathrm{T}}^{\mathrm{miss}} = -\sum_{i} p_T$

and corrected for recoil mismodelling using Z→μμ events

b-Jet ID

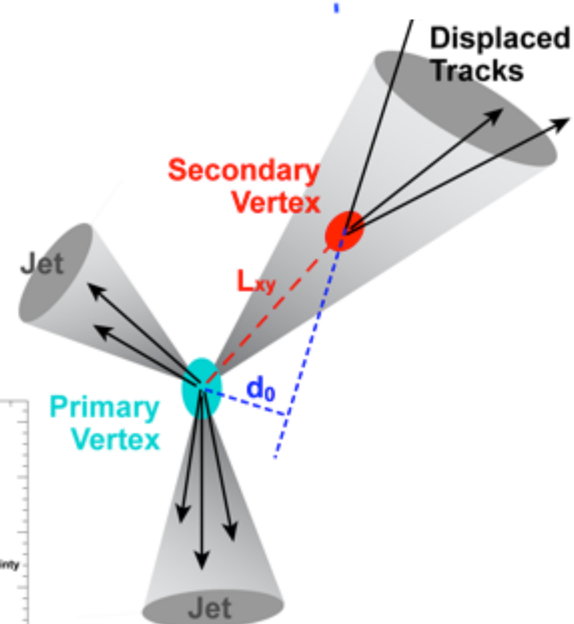


b-hadrons have a long life time + high mass

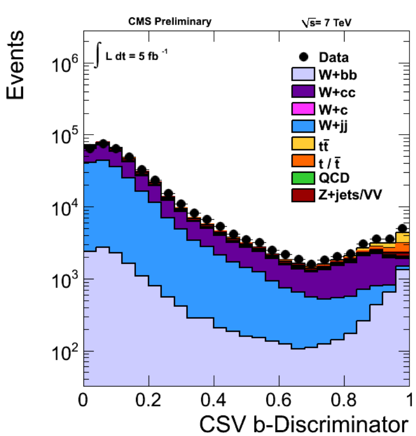
→Can be identified via secondary vertices, displaced tracks and soft leptons

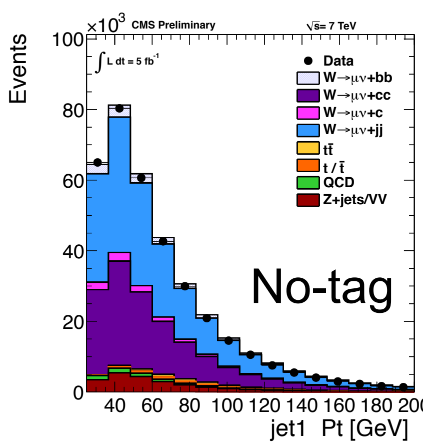
Jet Variables are combined in a Multivariate Likelihood to produce a single discriminator

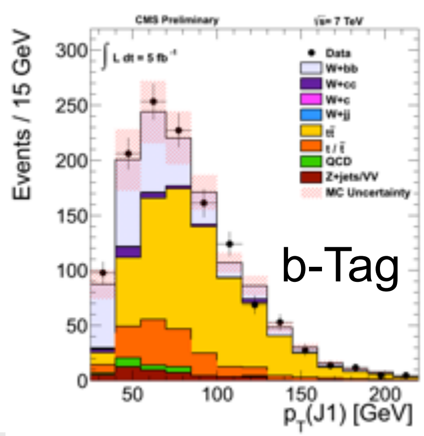
Secondary Vertices are found in Jets by fitting tracks associated to the Jet



Efficiency of 50% with reduction of light jets by a factor of ~100





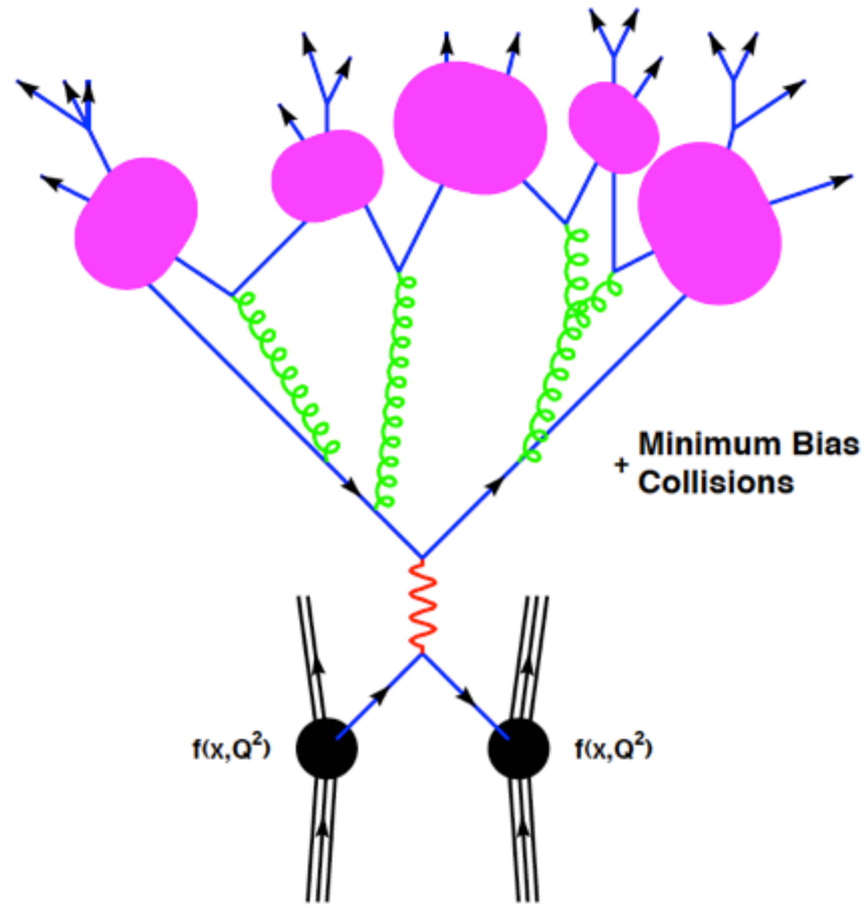


Simulation

Precise Simulation

Essential for experiment design + validation

Performed using Monte Carlo Method



Simulation Steps

Physics Event Generator

Simulation of Passage of Particles through matter

Hardware Emulation

Detector Simulation performed using GEANT

→Final Output identical to Data

Monte Carlo Generators

MCFM

Gives NLO predictions for wide range of Events, Uses Final State Parton Jets, Not Adequate for DPS Simulation

MADGRAPH

Matrix Element Calculator for SM processes at any collider, Includes MPI simulation

PYTHIA

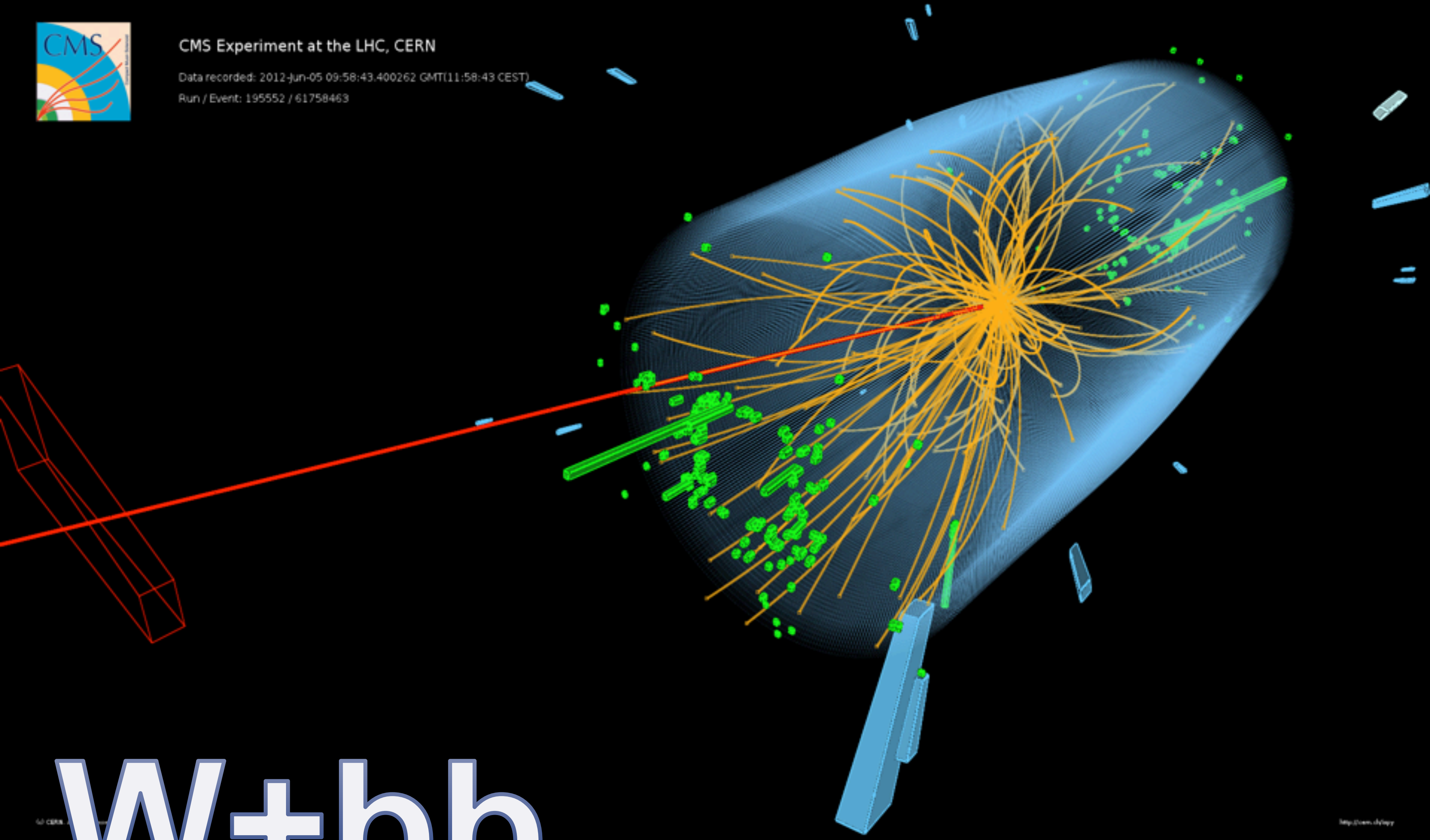
Good simulation of hadronization, uses Lund String Model

POWHEG

Alternate method for hadronization modeling→ Generates hardest radiation and uses a shower generator for subsequent softer radiation

Tauloa

Used to simulation tau-leptons including polarizations

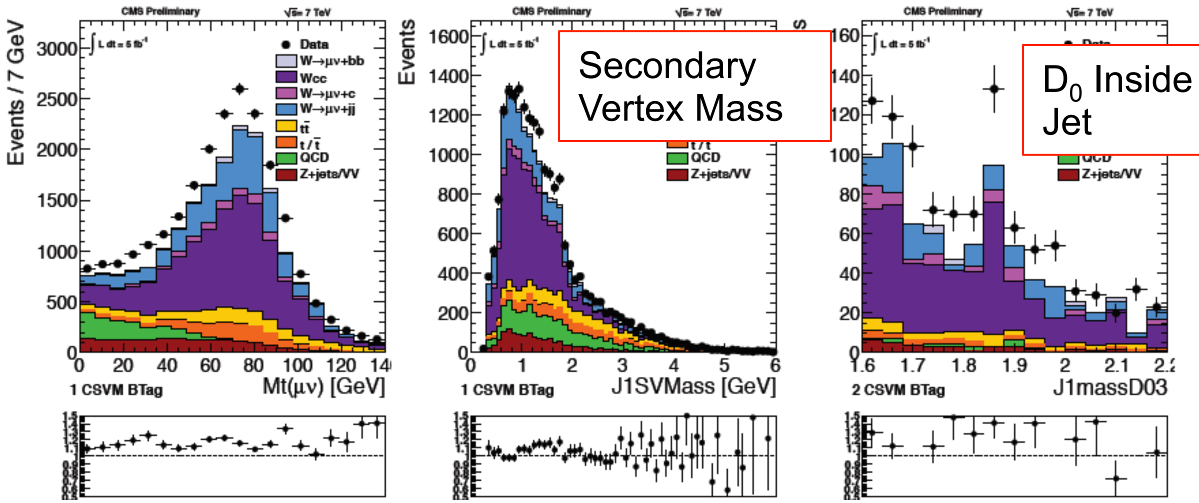

CMS Experiment at the LHC, CERN
Data recorded: 2012-Jun-05 09:58:43.400262 GMT(11:58:43 CEST)
Run / Event: 195552 / 61758463

W+bb

W+bb Cross Section Measurement

Goal:

Measure W→munu + 2 b-Jet cross section at 7TeV



W+1b: Poor Agreement

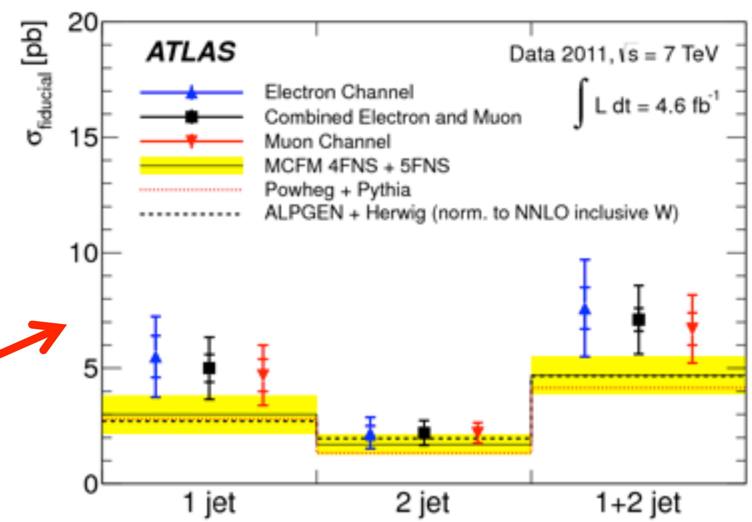
Motivations:

Background to W+h→bb, h→ττ + b

+many other physics searches

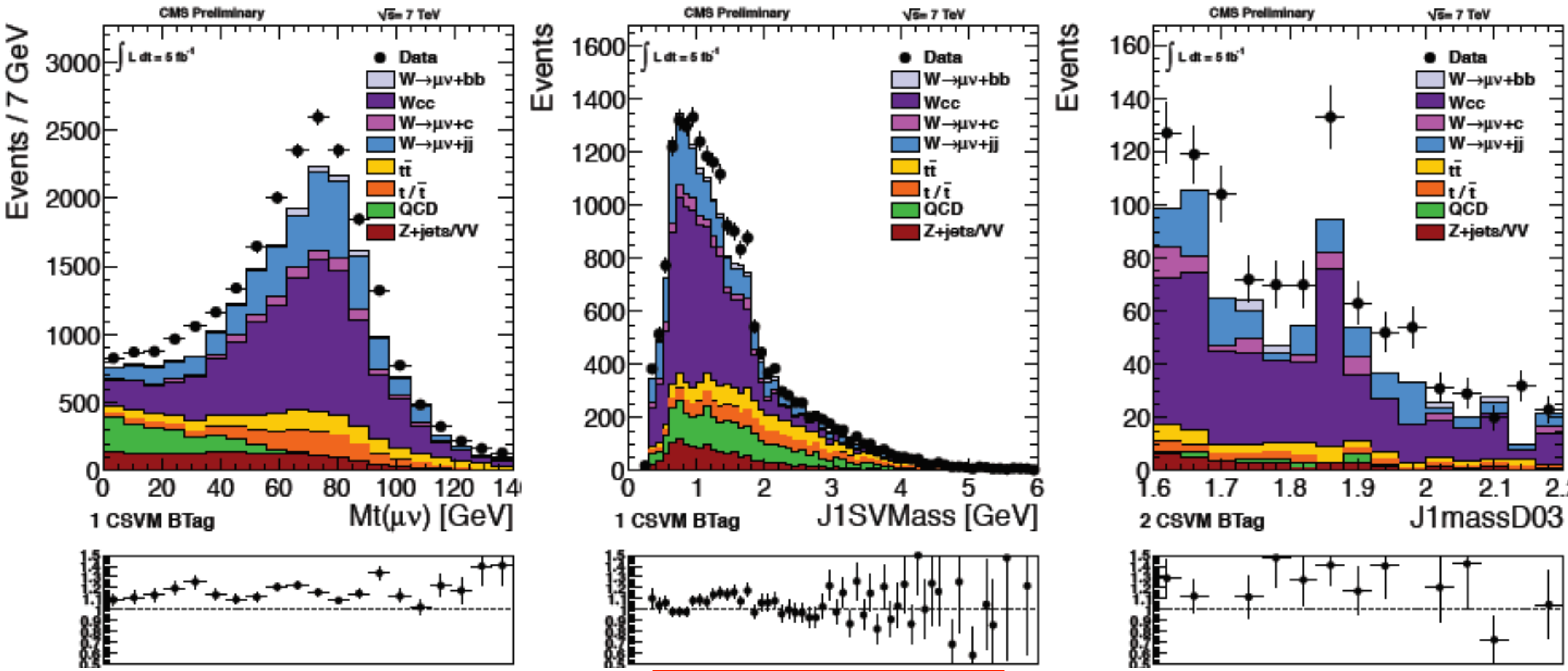
Previous Studies:

Independent studies have shown tensions in W+1b vs. W+2b



ATLAS study performed in completely separate phase-space

W+bb: W+1b



Secondary Vertex Mass

D_0 Inside Jet

W+bb: Selection of Muon + Jets

Muon Selection:

- Muon + Tau Trigger
- Muon P_T>25 GeV
- Muon |Eta|<2.1
- Isolation Required

Jet Selection:

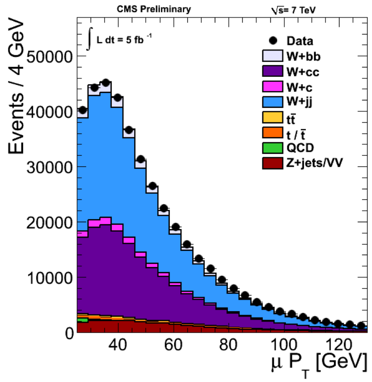
- 2 Jets P_T>25 GeV
- Eta<2.4

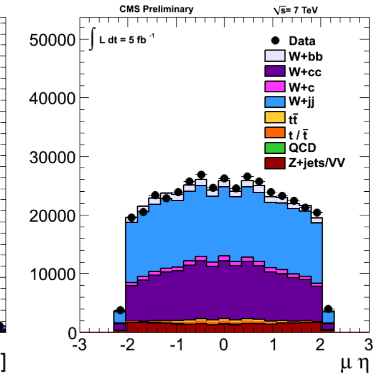
M_T>45 GeV

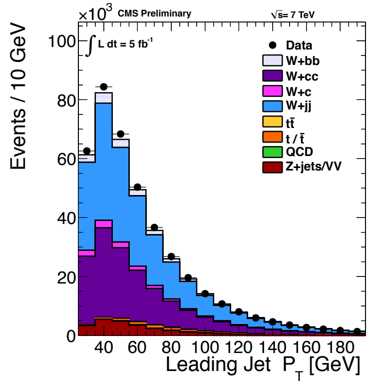
- ~eliminates QCD
- M_T<45 GeV used as a control region

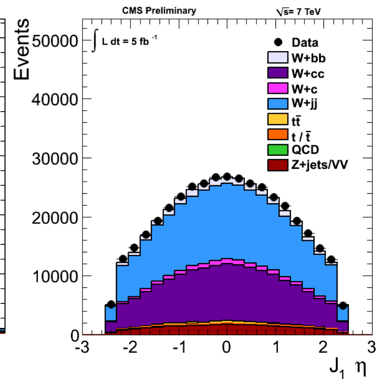
Veto Events with Extra Leptons, Jets

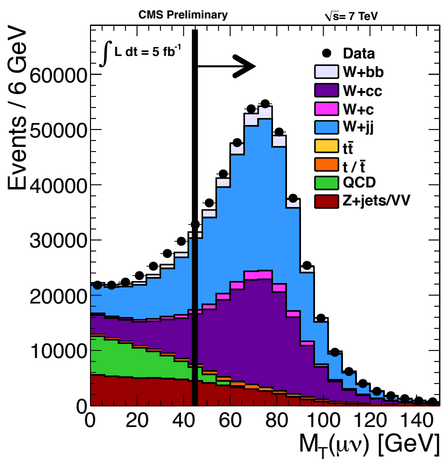
$$M_{\mathrm{T}} = \sqrt{2 \mathrm{p_T}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi\right)}$$











b-Jet Selection

Start with two jets that **exhibit qualities of b-Jets**

→**Minimum number of Tracks,**

Secondary Vertex

Makes use of Multivariate Analysis

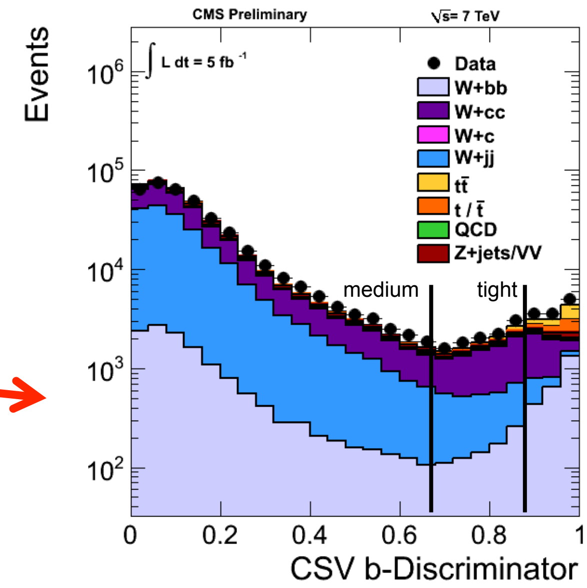
→Uses ‘training events’ for which the output is known to determine a mapping function for that describes a classification or a regression

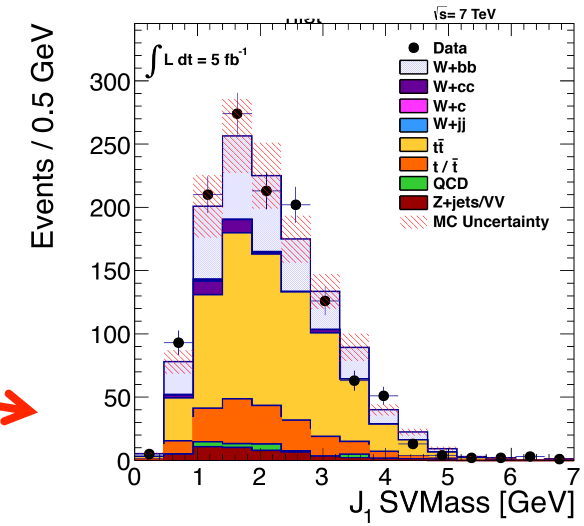
CSV Multi-Variate Algorithm

→Uses Jet Variables to create a discriminator separating b-Jets from light

→Requiring a Secondary Vertex

Data/MC corrections applied →Measured in QCD and top events





Backgrounds to W+bb

tt

Largest Irreducible background

→Single Muon + 2 b-Jets + W

W→jj used for simultaneous fit

Single Top

Second Largest Background

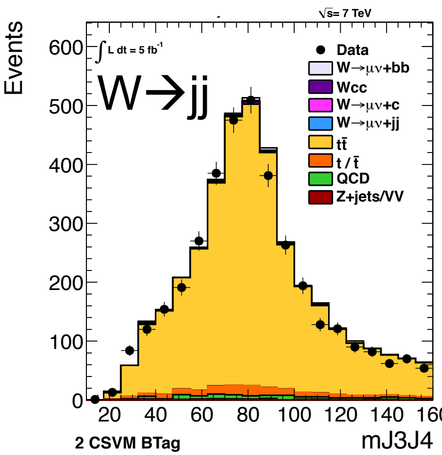
→1 b-Jet + 1 Forward Jet

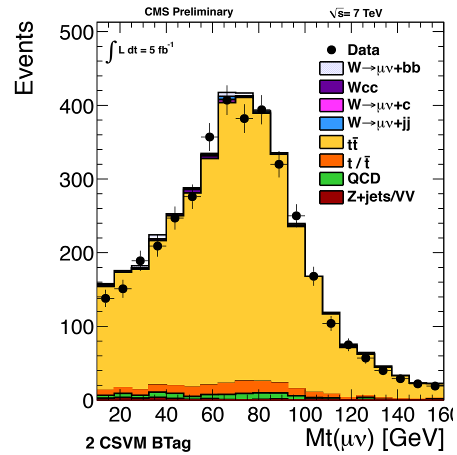
Z+Jets

Very Small Contribution

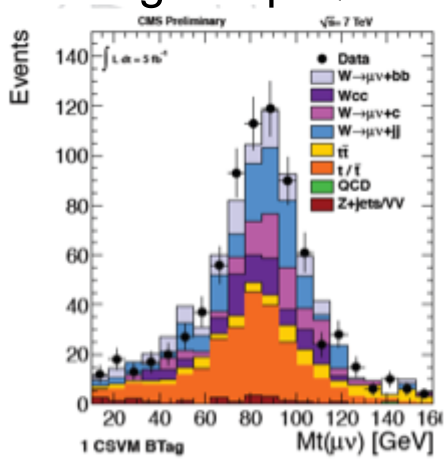
Control Region To Test Analysis Strategy

di-Top Quark

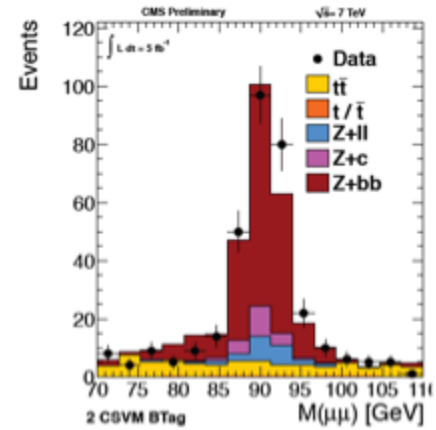




Single Top Quark



Z+bb



Yields/Systematic Uncertainties

Process	Wbb	W+l	W+c	W + $c\bar{c}$	Z+jets	$t\bar{t}$	Single-t	VV	QCD	Total MC	Total Data
W+2jets	39333.1	378197.2	23502.8	284441.3	94169.7	74082.9	15880.3	10195.0	42276.7	962079.0	928445.0
$M_T > 45$ GeV	30381.9	291990.5	18282.5	221570.1	35144.1	54095.4	11909.0	7780.7	8393.9	672138.2	642674.0
JetVeto $\eta < 2.4$	21605.7	237049.8	14498.1	175253.2	26490.8	9027.4	6599.4	5744.0	6520.0	498028.4	478315.0
JetVeto $\eta < 4.5$	17152.9	196618.2	11853.4	142711.5	21440.5	5390.2	4356.3	4727.3	5298	405888.5	408705.0
Lepton Veto	17125.9	196213.9	11836.3	142517.5	18994.8	4707.9	4155.8	4446.5	5284.3	401973.7	402742.0
2 CSV Tight Tags	356.5	47.3	1.7	56.3	34.5	620.6	168.0	19.9	36.3	1249.3	1387.0
>=1 SV in each jet	332.3	1.5 ±0.2	1.3 ±0.3	21.0 ±4.3	30.9 ±2.9	595.5 ±32.8	160.3 ±7.8	18.9 ±0.8	33.1 ±2.7	1194 ±78.0	1230.0 ±35.0

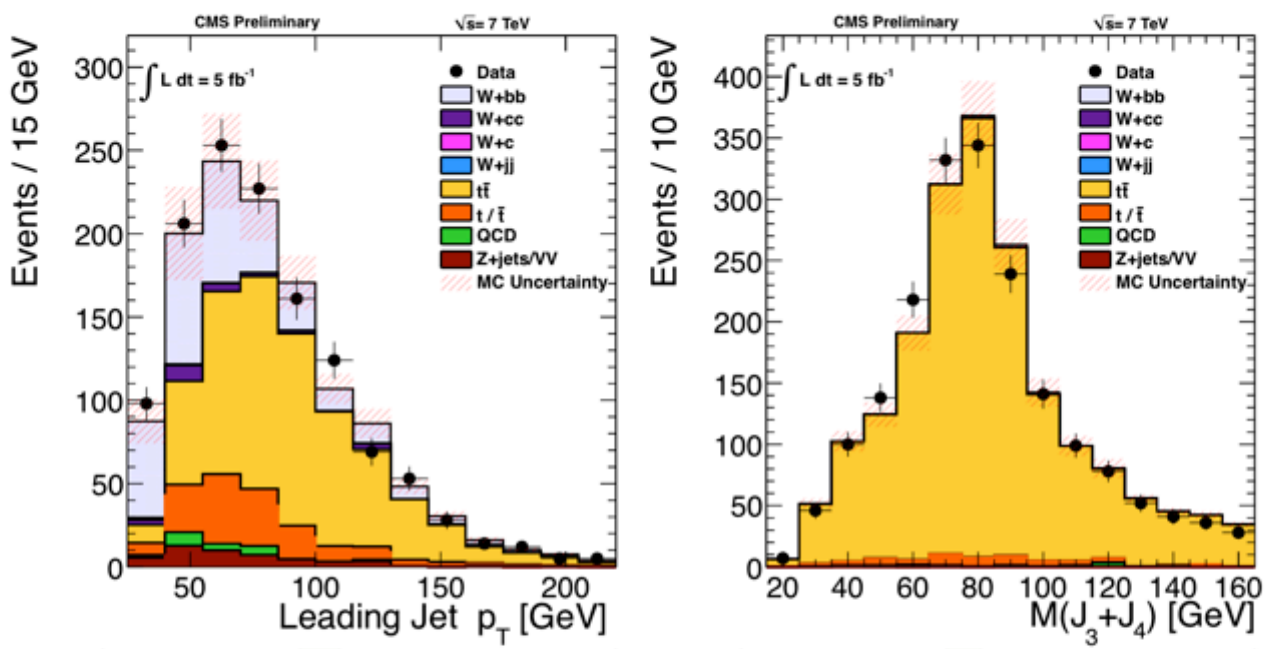
Included in Final fit for Signal Extraction

Nuisance	Uncertainty
b-Tag Efficiency	6%
b-Tag Efficiency Top Samples	3%
b-Tag Efficiency Charm Sample	15%
b-Tag Fake Rate	12%
Luminosity	2.2%
Jet Energy Scale	1 σ from Jet Database
Jet Energy Clustering	10%
Muon Energy Scale	1%

Signal Yield Extraction

Combined fit between Signal Region and largest background

Variable	Signal Region	$t\bar{t}$ Region
# Jets $p_T > 25$ GeV $\eta < 2.4$	2	> 3
# Jets $p_T > 25$ GeV $2.4 < \eta < 4.5$	0	-
CSVT	2	2
Mass($Z_{\mu\mu} > 60$ GeV)	0	0
# Isolated Electrons	0	-
Secondary Vertex	1 per Jet	-



Cross Section Measurement

W+bb Cross Section

Branching Fraction

Signal Events Post-fit to data

$$\sigma(\mathrm{pp} \to \mathrm{W} + \mathrm{b\bar{b}}) \times \mathcal{B}(\mathrm{W} \to \mu\nu) = \frac{N_S}{\int \mathrm{Ldt}\ \epsilon_{\mathrm{sel}}}$$

Integrated Luminosity

Acceptance x Efficiency of Selection

Hadronization correction (from bHadrons→ final state partonJets) for comparison with MCFM $C_{b \to B}$= **0.92 +-0.02**

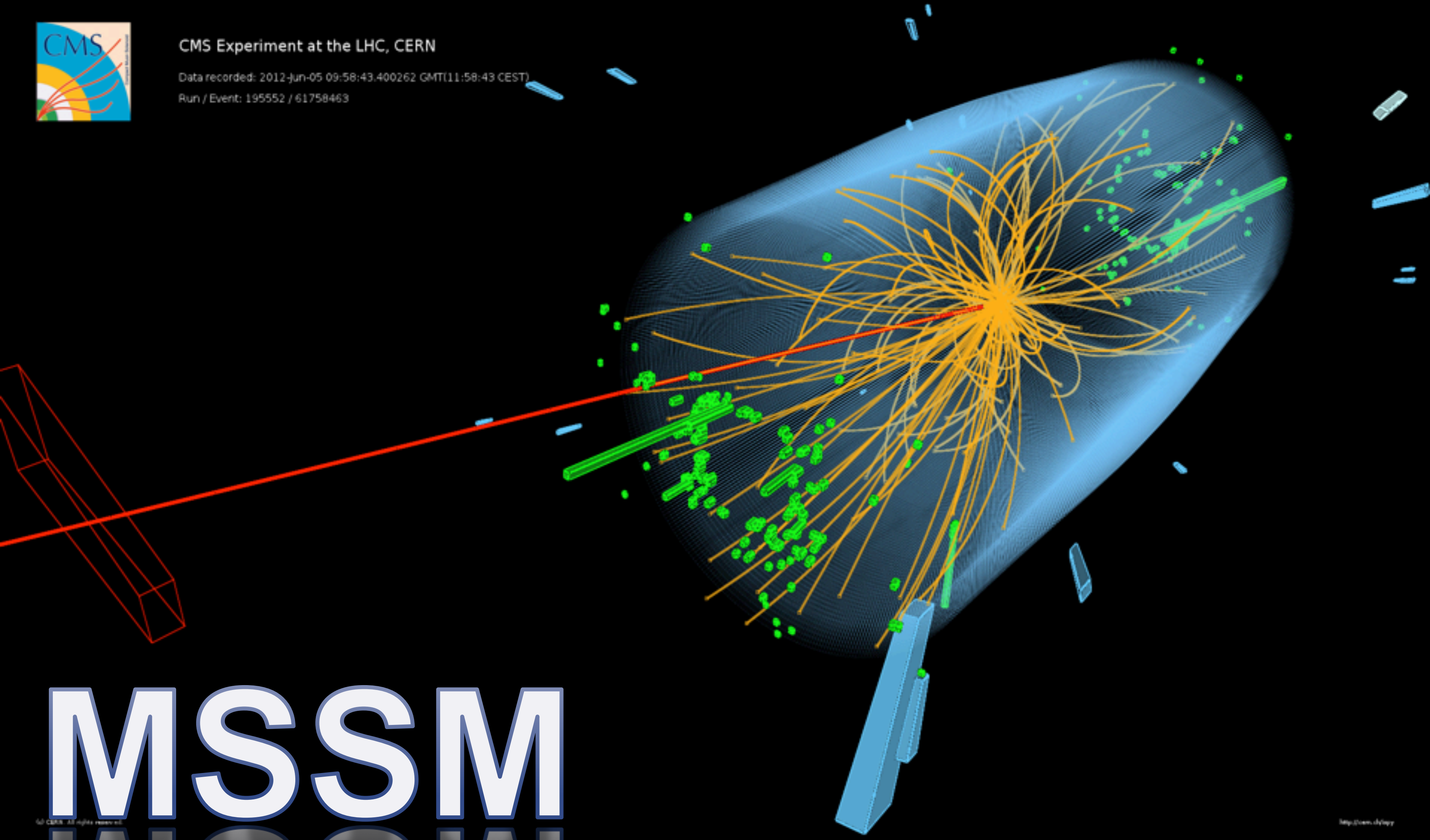
DPS contribution:

$$\sigma_{\mathrm{DPS}} = (\sigma_{\mathrm{W}} \times \sigma_{\mathrm{b\bar{b}}})/\sigma_{\mathrm{eff}} = 0.08 \pm 0.05 pb.$$

Final Cross Section Measurement:

$\sigma = \sigma_{MCFM}$ x $C_{b \to B} + \sigma_{DPS}$

$$0.55 \pm 0.03(\mathtt{MCFM}) \pm 0.01(\mathrm{had}) \pm 0.05(\mathrm{DPS}) pb$$



MSSM

$\phi \to \tau\tau$

Search for MSSM higgs bosons

Search with 4.9 fb^{-1} of data at 7TeV and 19.3 fb^{-1} at 8 TeV

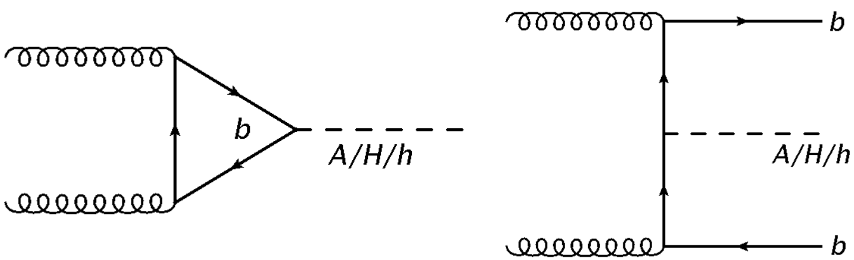
Final States: Semi-leptonic Tau + Hadronic Tau, $\tau_e\tau_h$ $\tau_\mu\tau_h$

Analyzed in the mhmax Scenario

→Vary m_A and tan(β)

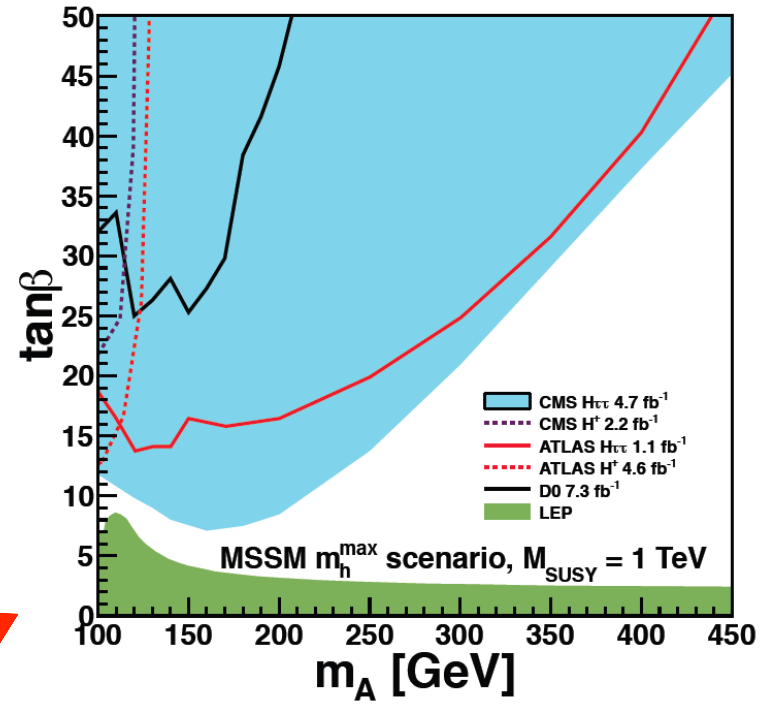
Improve Sensitivity by selecting final states

No b-tag | b-tag



→Again, using CSV Algorithm

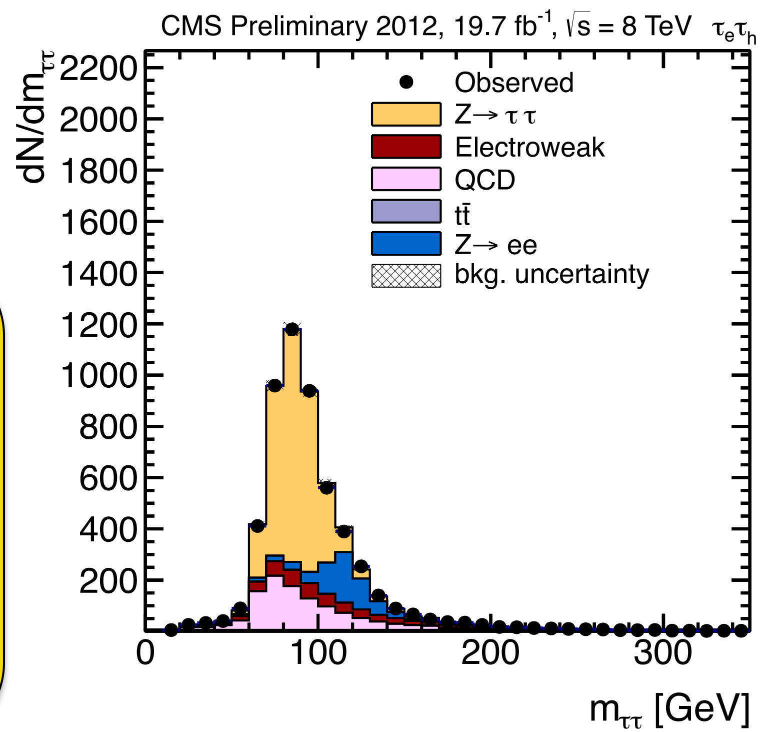
Summary of Previous Results



→Note X-Axis Scale

Background Estimation

All normalizations are data-driven



Z→ττ:
embedded samples
No MET/JES scale uncertainties
Shape estimation and correction for selection efficiencies

W+jets:
- Normalization from high m_T control region
- Shape from MC

ttbar:
- Normalization from b-tag control region
- Shape from MC

Z→ee/μμ
- Normalization scale factor from tag-and-probe in data
- Shape from MC

QCD:
- Normalization from ratio of same-sign(SS) to opposite-sign (OS) data events
- Shape from SS data events

W+Jets/QCD Backgrounds

W+Jets

Normalization taken from high M_T sideband (M_T>70 GeV),

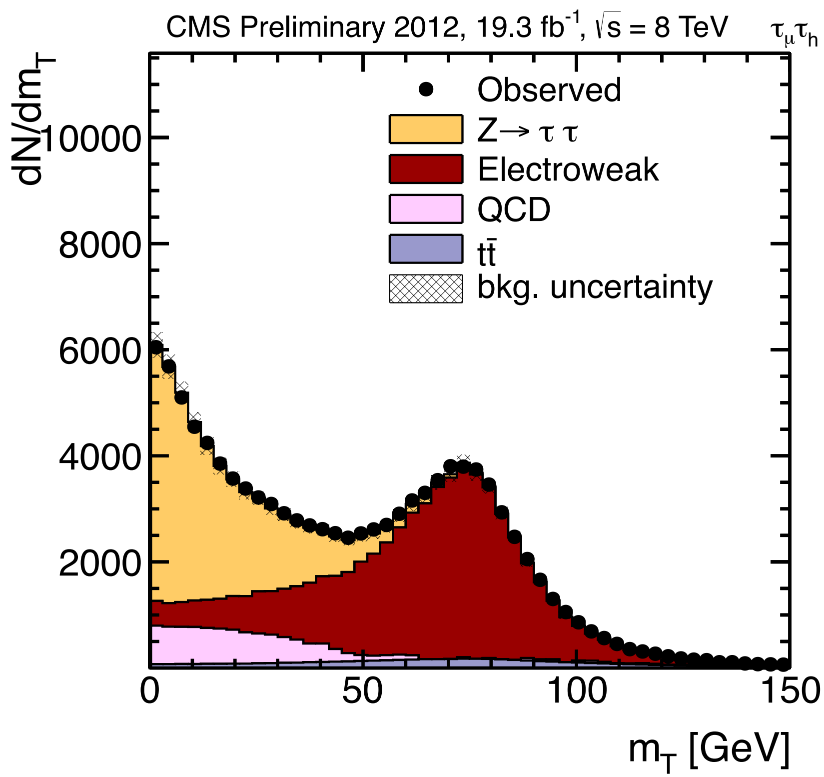
Extrapolation from high M_T to low M_T from Monte Carlo Shape

QCD

Data Driven shape and Normalization

Shape from Same Sign region

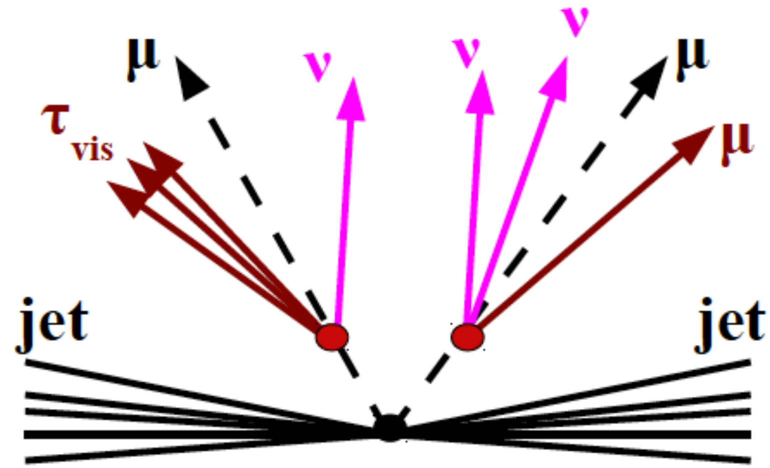
Measure SS/OS ratio in Anti-Isolated Region



Z→ττ embedding

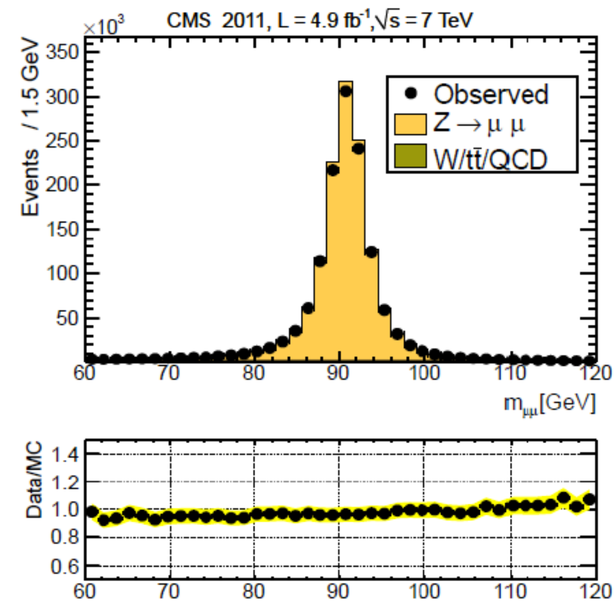
Take Z→μμ events from data

- Reconstruct Event
- Remove muon objects
- Replace with simulated taus



MET, Jets, b-tagging from data!

→Significant reduction in uncertainty for this background



Normalization taken from Z→μμ

Selection

$\tau_\mu \tau_h$ Selection:

Muon + Tau Trigger

Muon P_T>20 (18) GeV for 2012(2011)

Muon |Eta|<2.1, Isolated

Tau P_T>20 GeV, eta<2.3, Isolated

$\tau_e \tau_h$ Selection:

Electron + Tau Trigger

Muon P_T>24 (20) GeV for 2012(2011)

Muon |Eta|<2.1, Isolated

Tau P_T>20 GeV, eta<2.3, Isolated

Jet Selection:

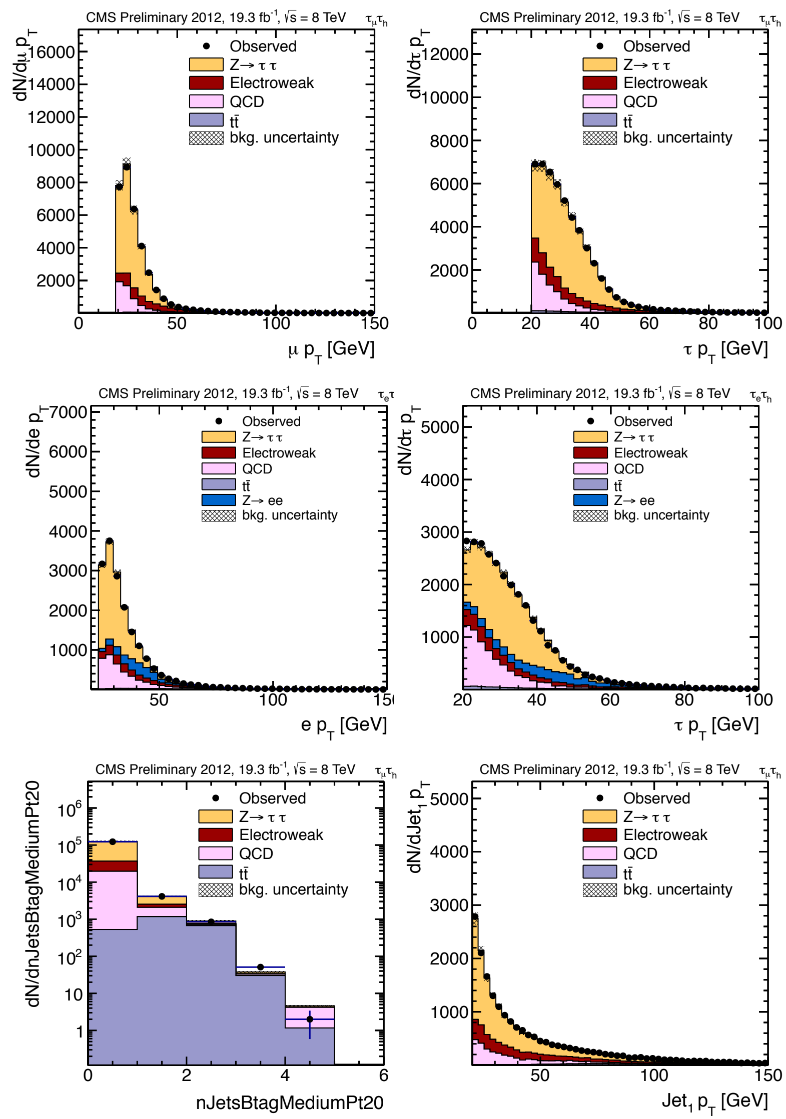
1 Jet P_T>25 GeV

Eta<2.4

M_T<30 GeV

Reduces W+Jets

Veto Events with Extra Leptons

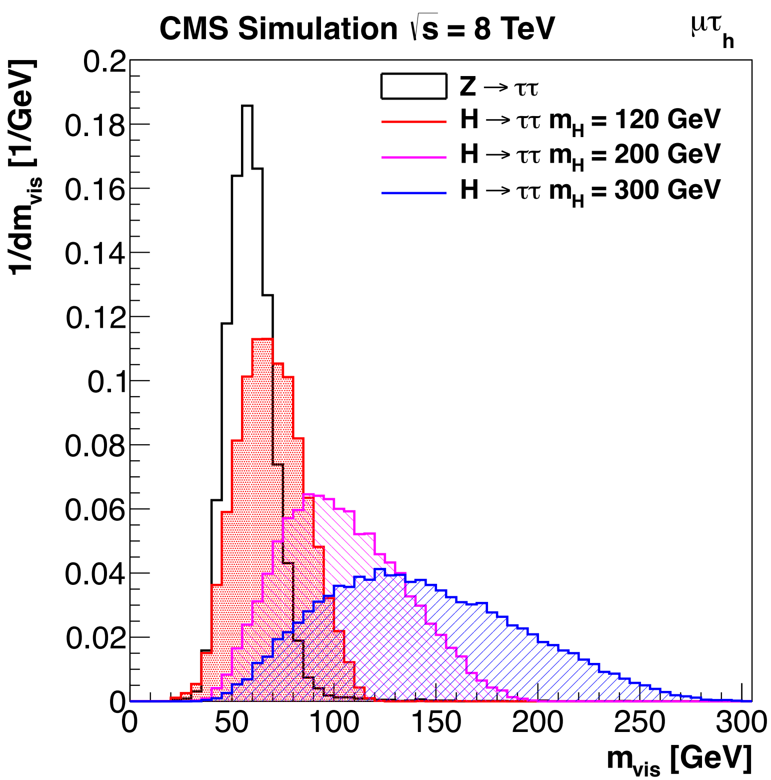


di-τ Mass Reconstruction

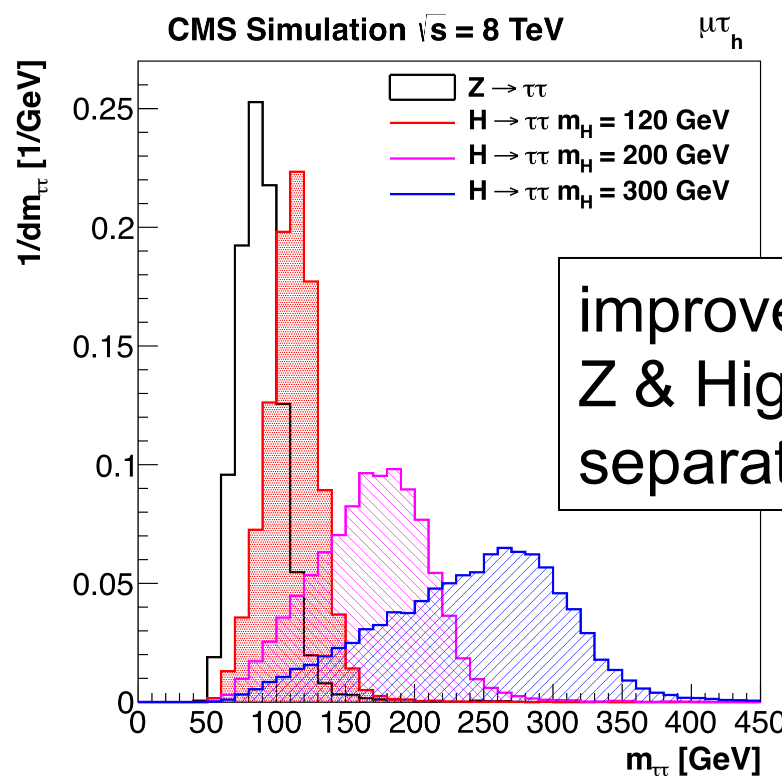
Di-tau mass estimation uses visible decay products & missing E_T in a maximum likelihood fit

The mass resolution is ~ 10-20% depending on channel/category

Visible mass

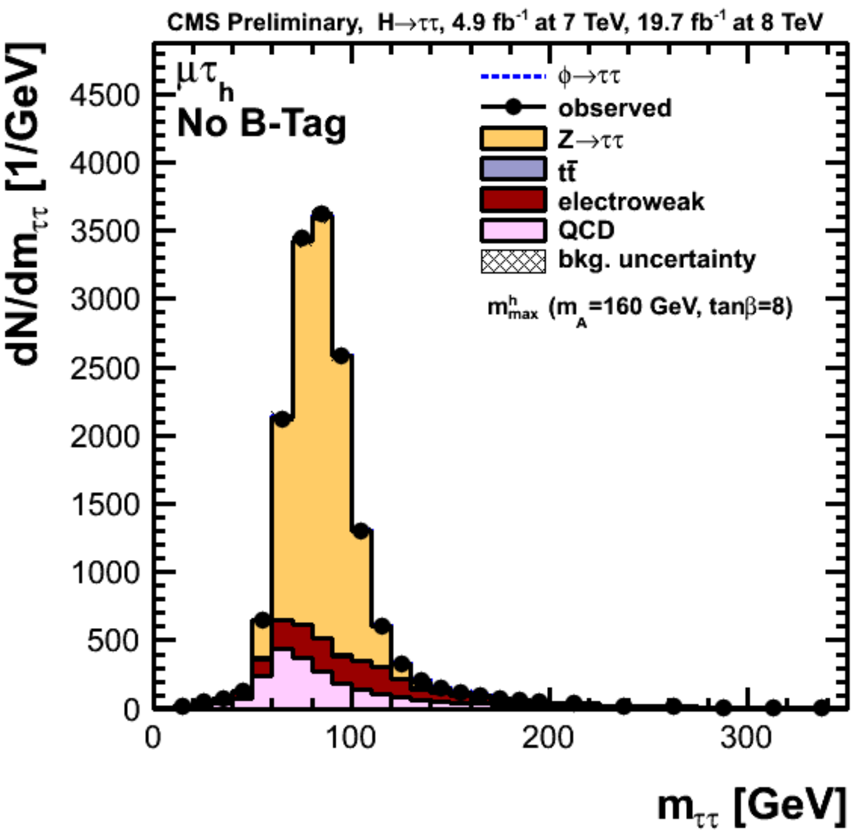


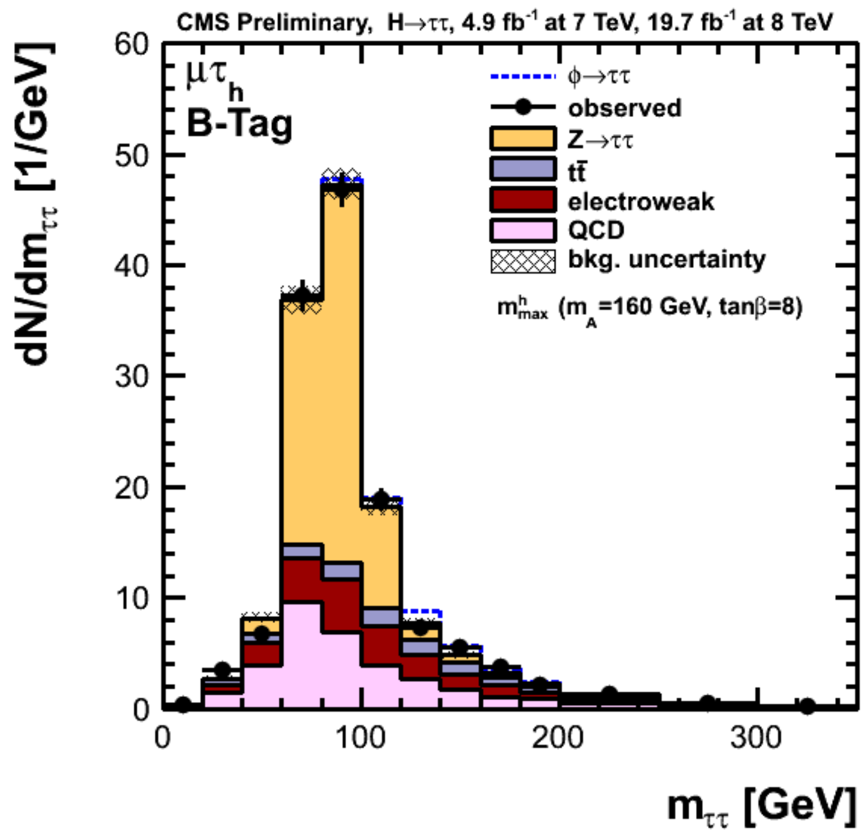
SV fit Reconstructed mass



improved Z & Higgs separation

Categories





No b-Tag

0 b-Tagged Jets in the Event

Gluon Fusion Production

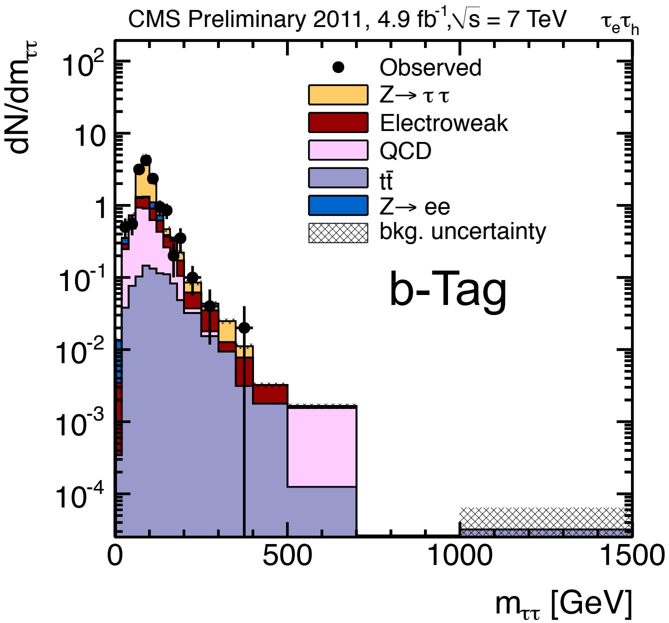
b-Tag

At Least 1 b-Tagged Jets in the Event

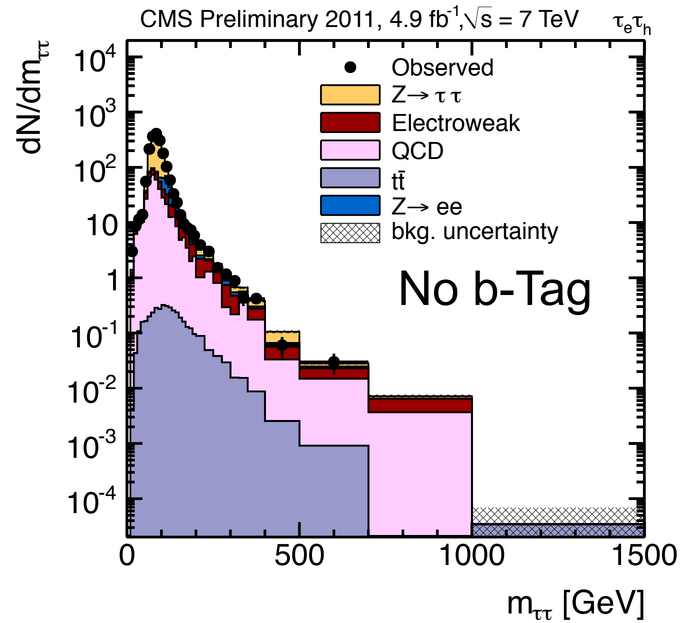
No other Jets with P_T>30 GeV

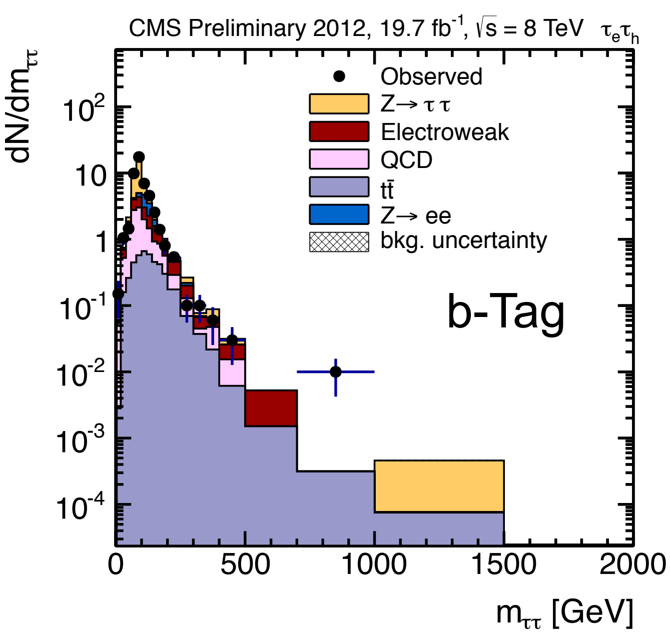
b-Associated Production

$\tau_e + \tau_h$

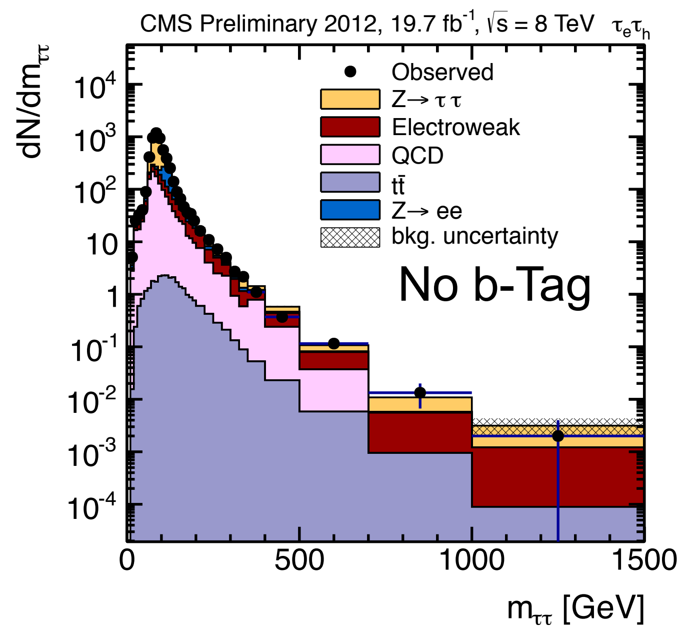


7 TeV

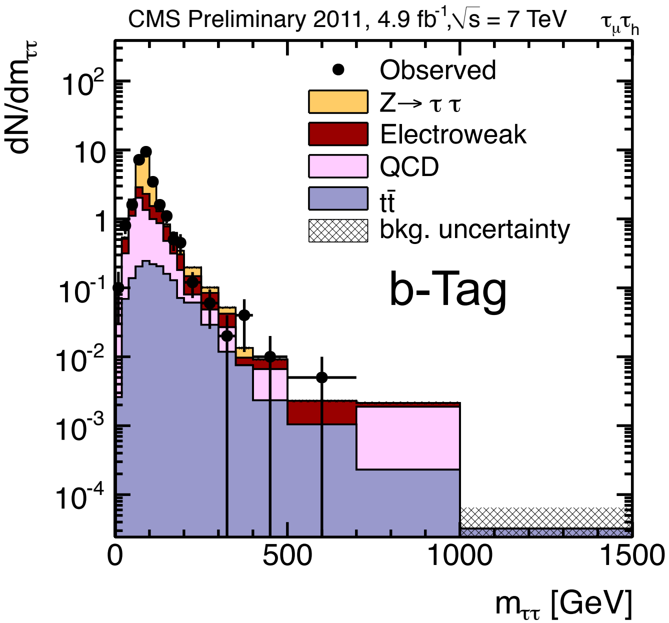


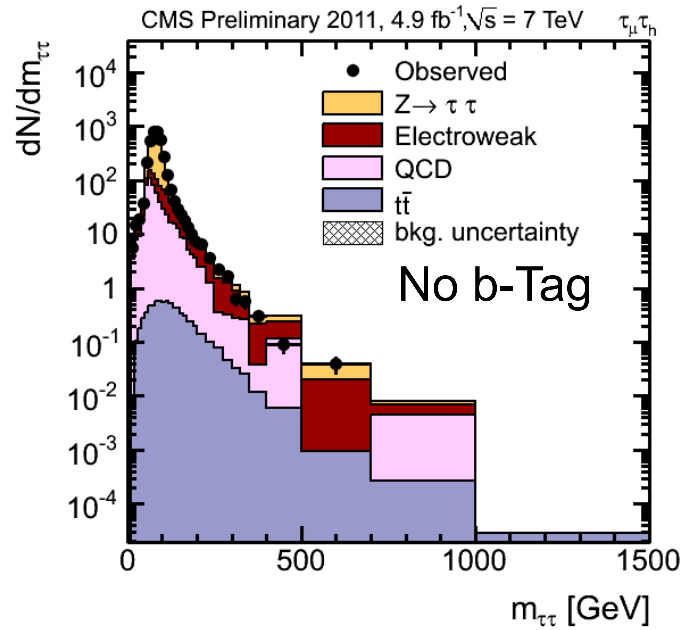


8 TeV

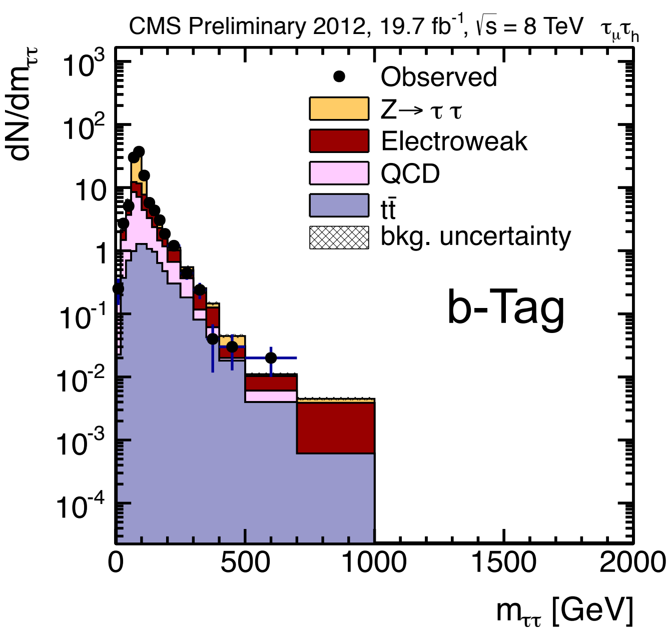


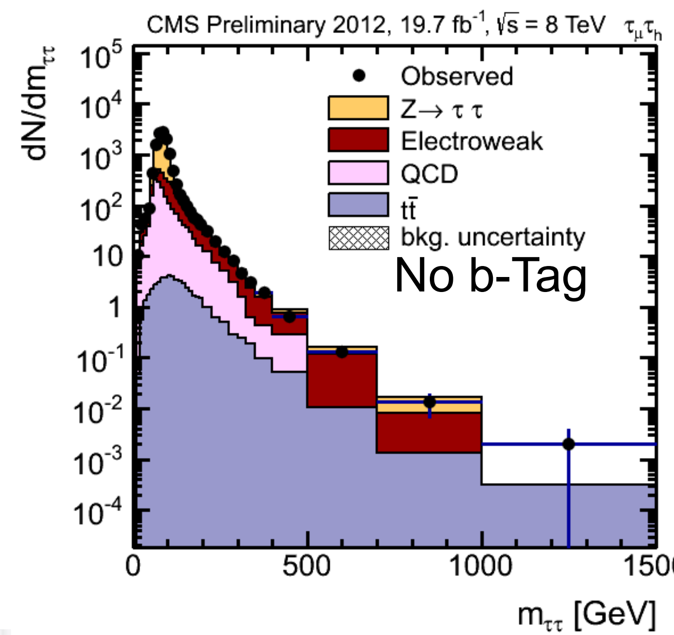
$\tau_\mu + \tau_h$





7 TeV



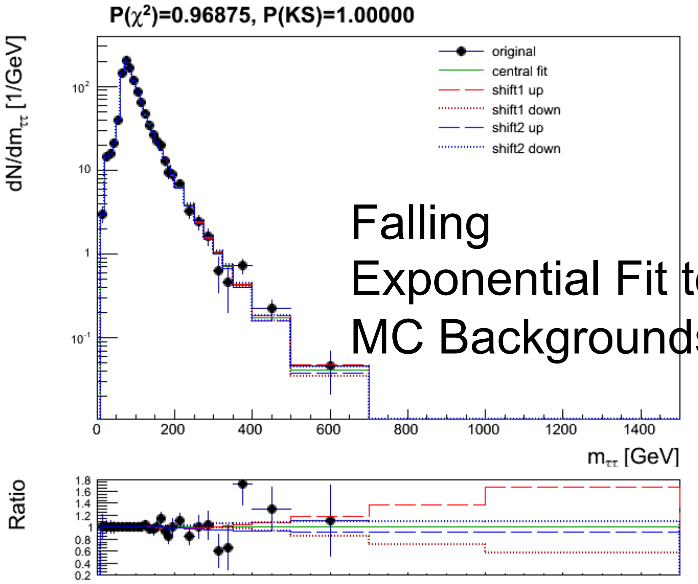


8 TeV

Final Fit

Most Relevant Nuisance Parameters:
Tau Energy Scale +/- 3%
b-tagging efficiency and fake rate

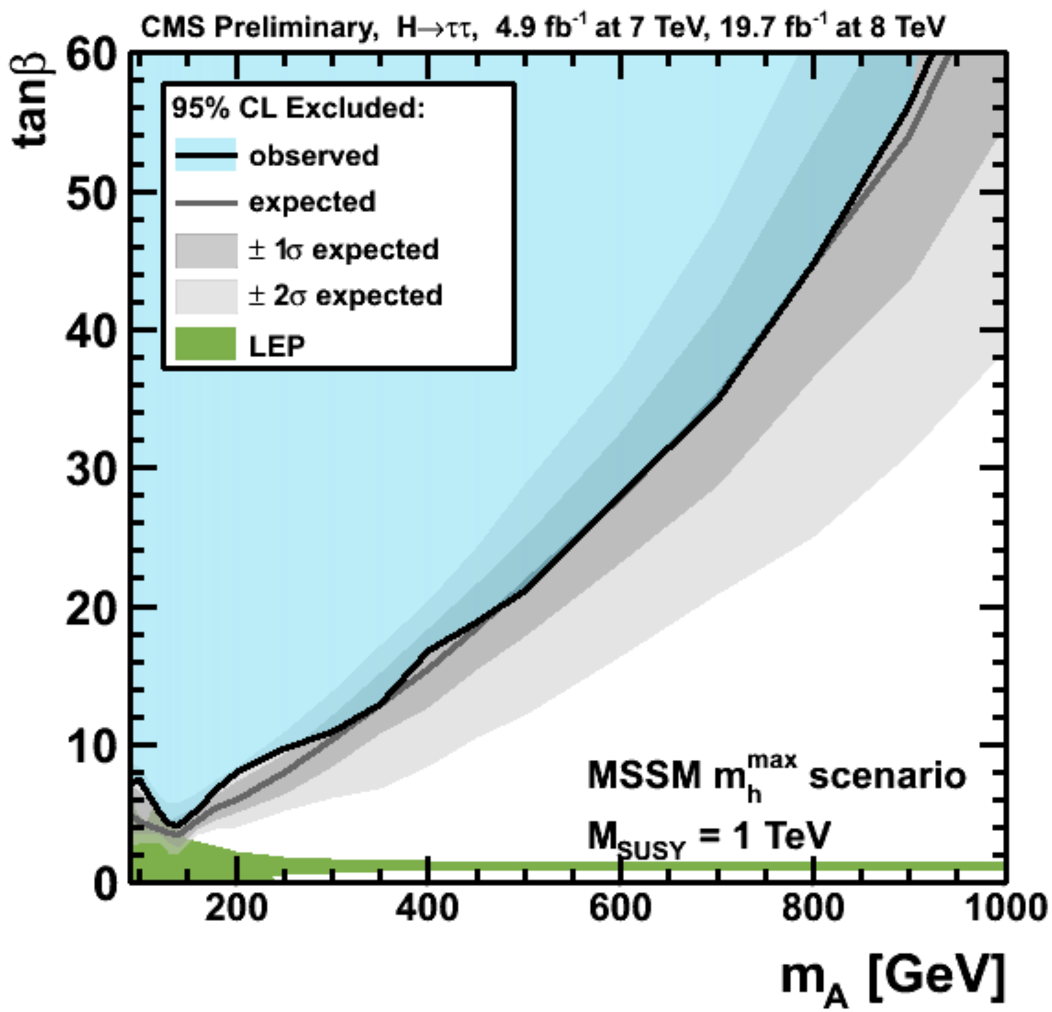
Highest Yield Backgrounds fit to a falling exponential distribution to preserve integrity in low MC yield regions



Falling Exponential Fit to MC Backgrounds

Final Limit on 95% Upper CLs are set
Using modified Frequentist Approach

Results: Mhmax



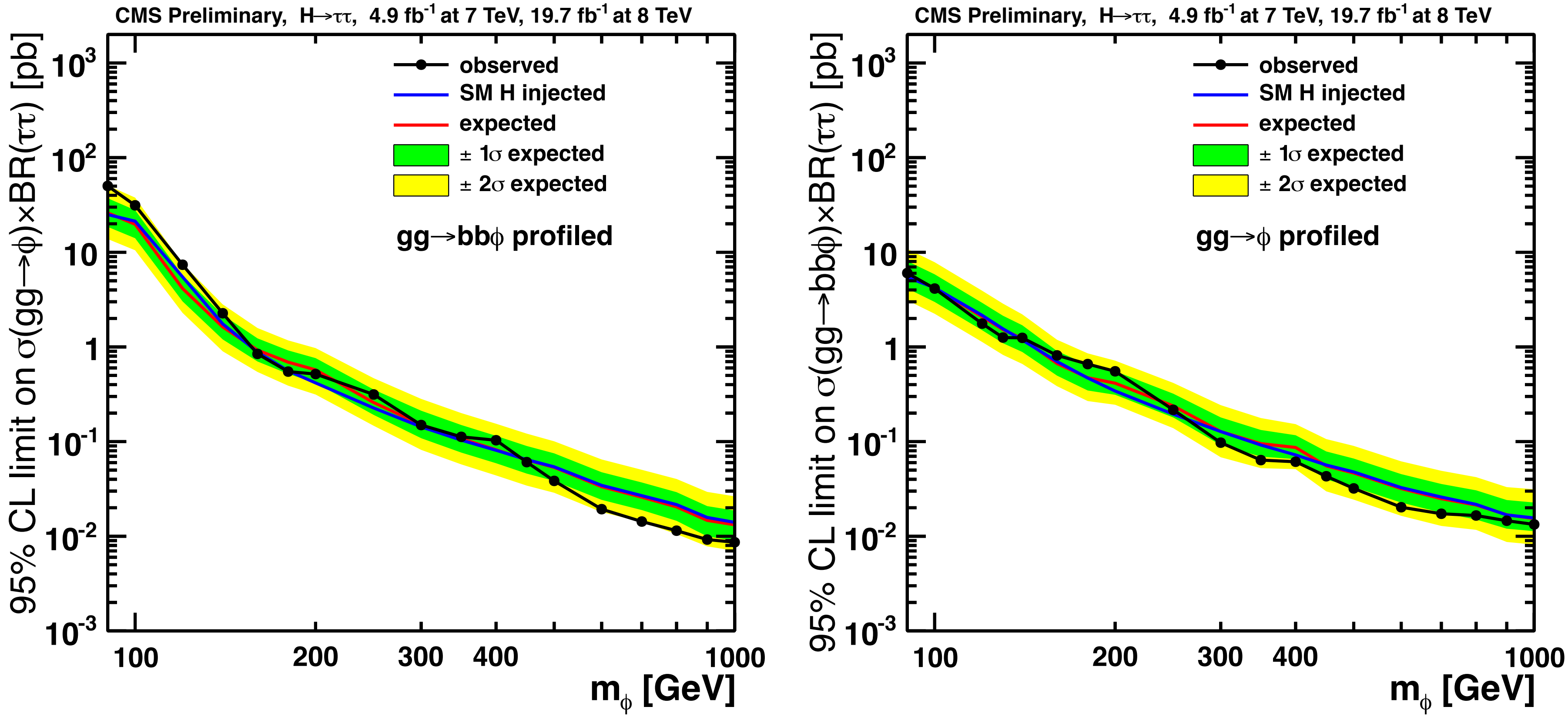
Excluding tan(β)>7 at low M_A

Insignificant Excess at M_A=200 GeV

Closing the wedge at high M_A, Low tan(β)

No Significant Excess is Observed in the search for MSSM higgs bosons

Results: Model Independent



Limits on σ(gg→ϕ)xBR(ϕ→ττ) and σ(gg→bbϕ)xBR(ϕ→ττ)

No Significant Excess is Observed in the search for MSSM higgs bosons

Conclusions

A cross section of W+bb was measured in the full 7TeV dataset

This measurement was performed in a unique phase-space with a simultaneous fit between a Signal Region and ttbar Background Region

Measurement Consistent with the Standard Model

→**Only measurement of its type at the LHC**

A search for MSSM higgs bosons in the $\tau\tau$ final state were presented

No significant deviation from background only hypothesis was observed

→Most Stringent Limits on the MSSM model in regions of tan(β)-M_A plane

More data in 2015+ will continue the search for physics beyond the standard model

Back Up

2015 LHC Parameter Scenarios

Scenario	# bunches	I_p ($\times 10^{11}$)	Emittance (μm)	$\mathcal{L}$ (Hz/cm^2)	Pile-up	L (fb^{-1})
25 ns	2760	1.15	3.5	9.2×10^{33}	21	24
25 ns low emit	2320	1.15	1.9	1.6×10^{34}	43	42
50 ns	1380	1.6	2.3	0.9–1.7 $\times 10^{34}$	40–76	45
50 ns low emit	1260	1.6	1.6	2.2×10^{34}	108	–

b-Jet selection

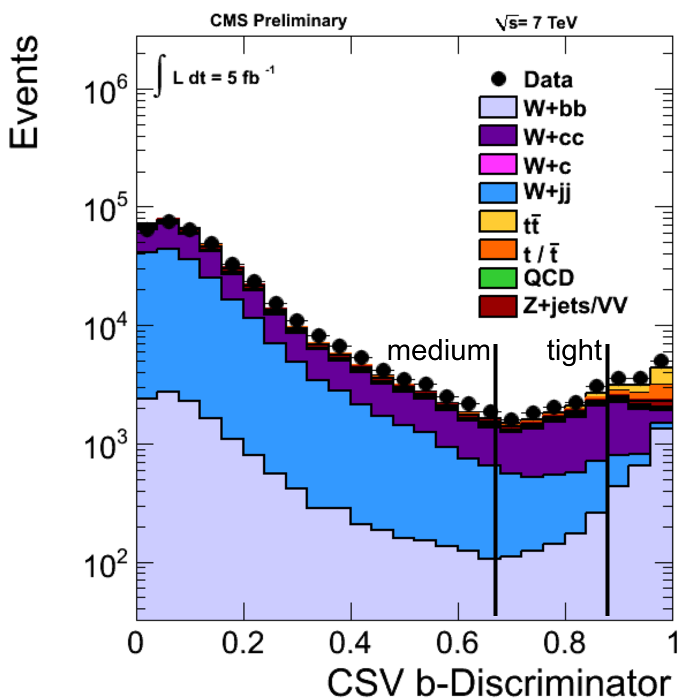
Start with two jets that **exhibit qualities of b-Jets** (CSV Medium working point)

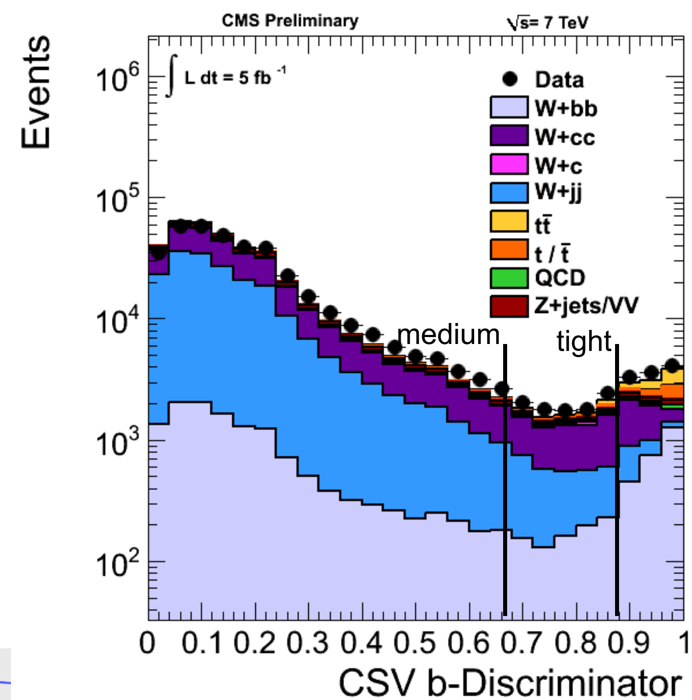
CSV Algorithm is

The CSV b-tagging algorithm combines the following variables into a single discriminating variable using a Likelihood ratio technique: **secondary vertex mass**, **multiplicity of charged particles associated to the secondary vertex**, the **flight significance associated to the secondary vertex**, **the energy of charged particles associated to the SV divided by the energy of all charged particles associated to the jet, the rapidities of charged particle tracks associated to the secondary vertex**, and the t**rack impact parameter significance exceeding the charm threshold**.

If a jet does not have an SV then CSV algorithm computes “pseudo Vertex” and “No-Vertex” values

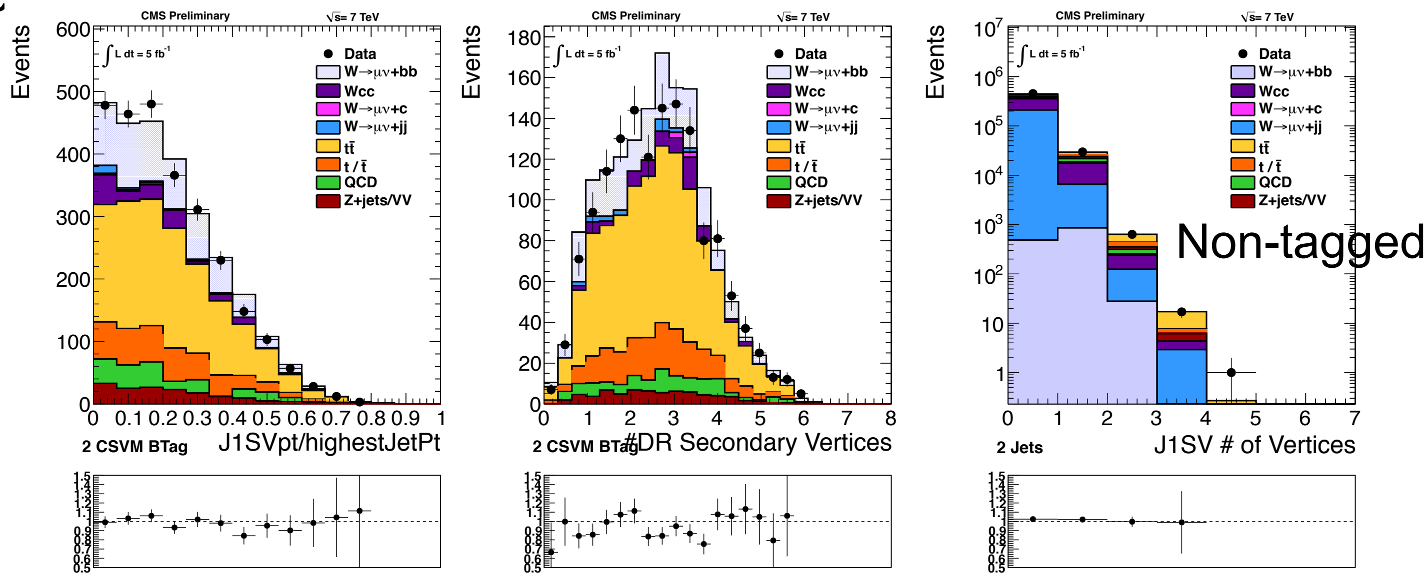
- **In this Analysis the Final Selection Requires a Vertex!**



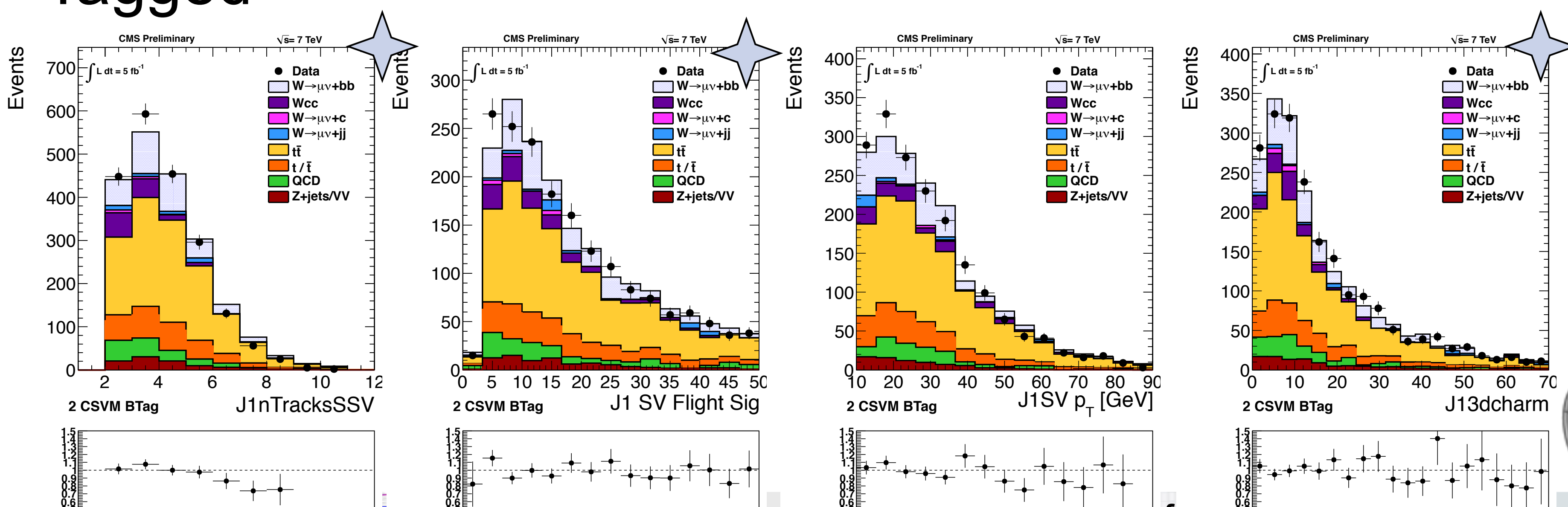


Jet Variables

Starred Variables are used in CSVM Likelihood b-Discriminator



Tagged



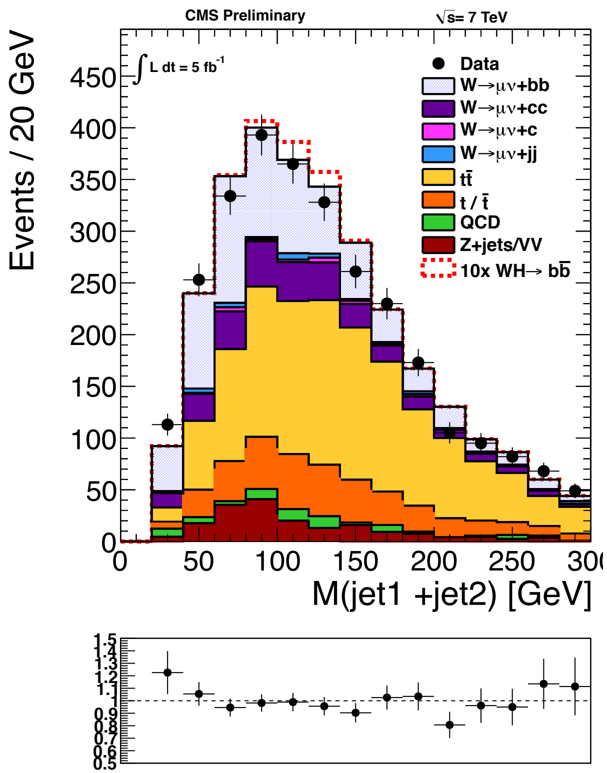
☆ Higgs→b$\bar{b}$

Two tight tags: Expected 2.15 WH→bb Events

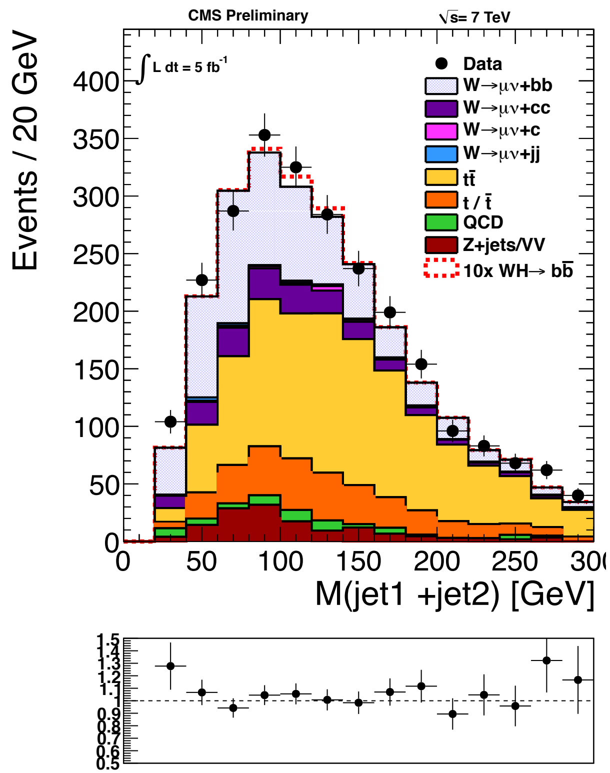
Two Medium tags: Expected 3.20 WH→bb Events

Two Loose tags: Expected 4.14 WH→bb Events

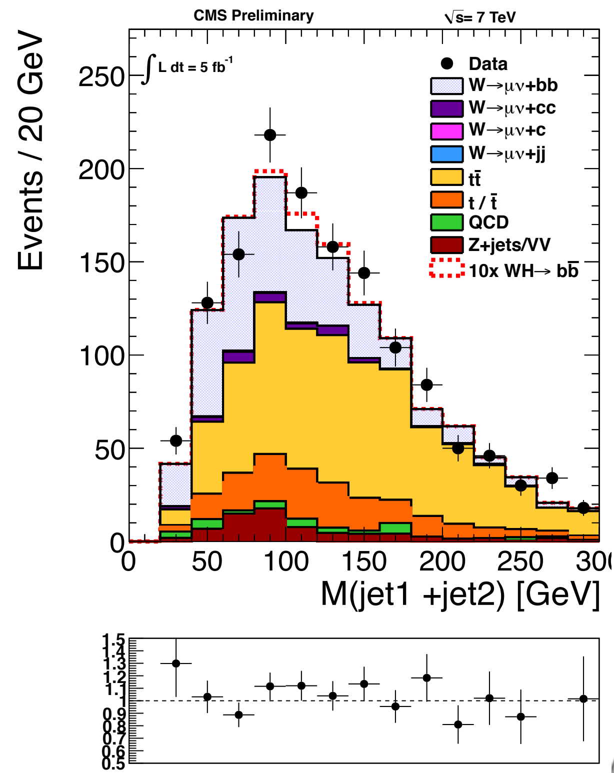
(from Monte Carlo)



Two Loose Tags



Two Med Tags



Two Tight Tags

E_t^{miss}

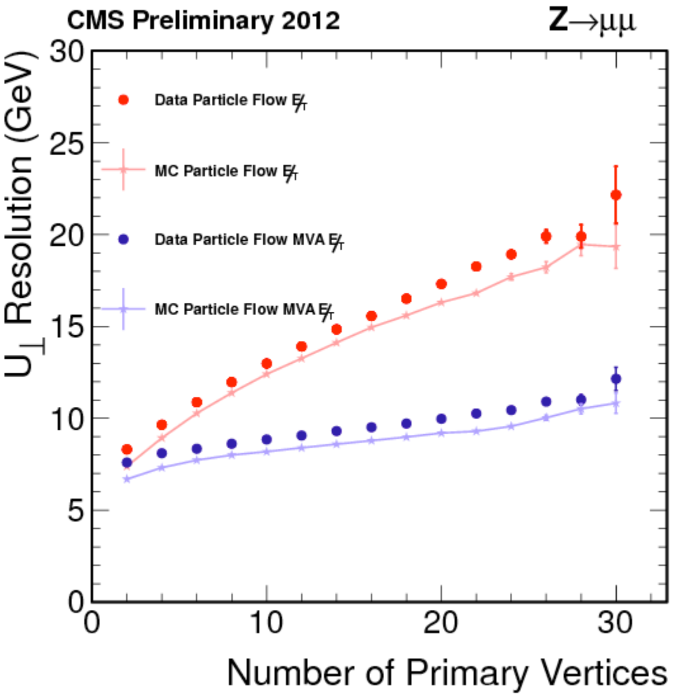
For Wbb analysis MET variable is created by:

$$E_{\mathrm{T}}^{\mathrm{miss}} = -\sum_i p_T$$

MC is corrected for recoil using:

$$E_{\mathrm{T}}^{\mathrm{miss}} + q_T + u_T = 0$$

Where, q_T is the sum of non- Boson decay products
u_T is the recoil which is corrected using $Z \rightarrow \mu\mu$ events

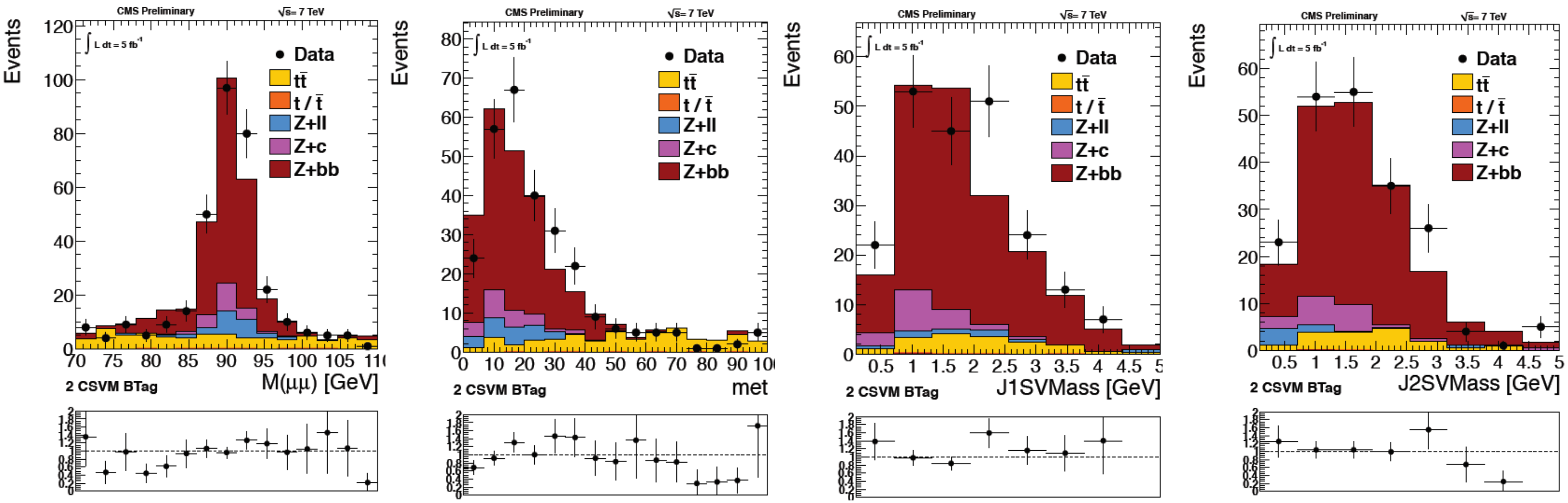


MVA E_T^{miss}: Uses MVA Regression to correct recoil for pile up

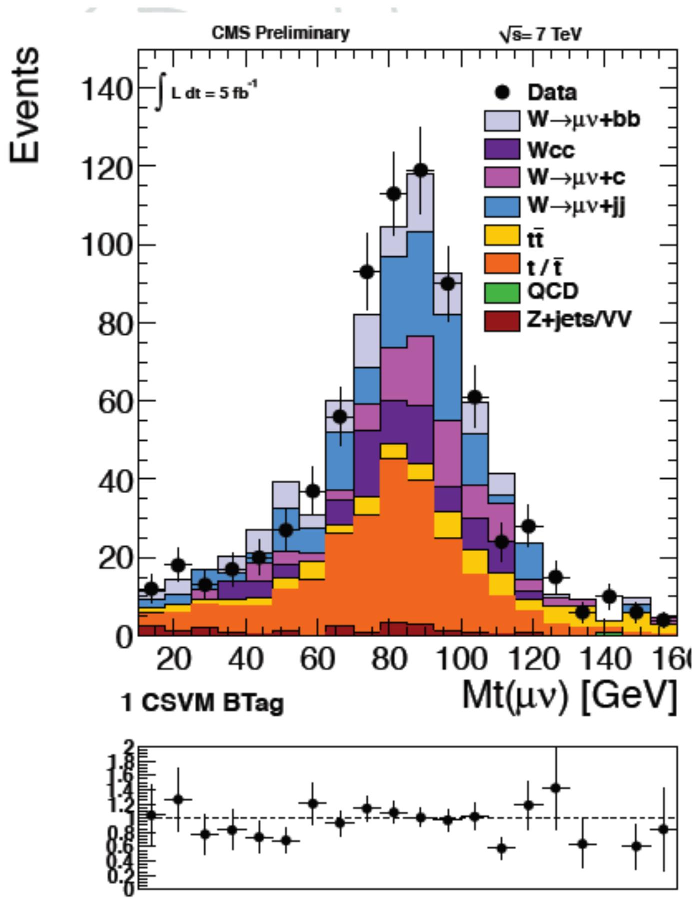
Z+Jets Estimate/Test of Analysis Strategy

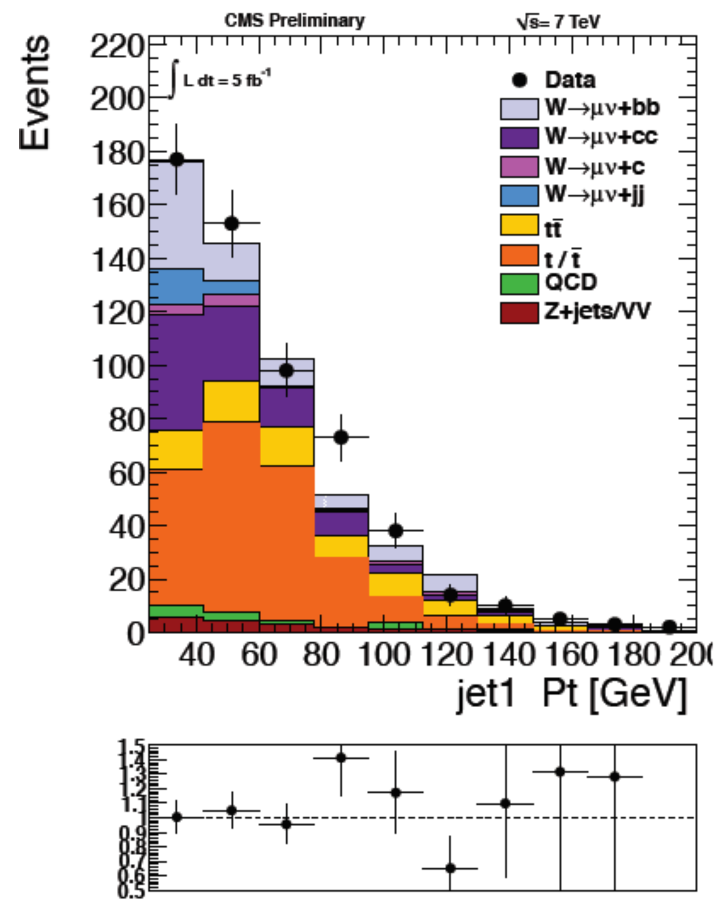
Requirements

- Two identified isolated muons
- Each muon must have combined relative isolation < 0.15
- Selected muons must have an invariant mass between 85 and 95GeV
- Each event must have atleast two jets with $p_T > 25\,\mathrm{GeV}$ and $|\eta| < 2.4$
- Events must have a total $E_T^{\mathrm{miss}} < 40$
- Both jets are required to have a CSV b-tag at the medium working point.



Single Top Estimation





1 b-tagged jet |eta|<2.4,1 non-tagged jet |eta|>2.8, 1 Isolated Muon

mhmax Scenario

If the new boson discovered is interpreted as the lightest in the MSSM model then regions of tan(β) excluded

$$M_{SUSY} = 1\text{TeV}, \mu = -200\text{GeV},$$

$$m_{\tilde{g}} = 0.8 M_{SUSY}, M_A \leq 1000\text{GeV},$$

$$X_t = 2M_{SUSY}, A_b = A_t$$

$$m_h^2 = \frac{1}{2}\left(m_A^2 + M_Z^2 - \left[(m_A^2 + M_Z^2)^2 - 4M_Z^2 m_A^2 \cos^2(2\beta)\right]^{\frac{1}{2}}\right)$$

$$m_{H\pm}^2 = m_A^2 + M_W^2$$

$$m_H^2 = \frac{1}{2}\left(m_A^2 + M_Z^2 + \left[(m_A^2 + M_Z^2)^2 - 4M_Z^2 m_A^2 \cos^2(2\beta)\right]^{\frac{1}{2}}\right)$$

ττ Systematic Uncertainties

Uncertainty	Affected processes	Change in acceptance
Tau energy scale	signal & sim. backgrounds	1–29%
Tau ID (& trigger)	signal & sim. backgrounds	6–19%
e misidentified as τ_h	$Z \to ee$	20–74%
μ misidentified as τ_h	$Z \to \mu\mu$	30%
Jet misidentified as τ_h	$Z + \text{jets}$	20–80%
Electron ID & trigger	signal & sim. backgrounds	2–6%
Muon ID & trigger	signal & sim. backgrounds	2–4%
Electron energy scale	signal & sim. backgrounds	up to 13%
Jet energy scale	signal & sim. backgrounds	up to 20%
E_T^{miss} scale	signal & sim. backgrounds	1–12%
$\varepsilon_{b\text{-tag}}$ b jets	signal & sim. backgrounds	up to 8%
$\varepsilon_{b\text{-tag}}$ light-flavoured jets	signal & sim. backgrounds	1–3%
Norm. Z production	Z	3%
$Z \to \tau\tau$ category	$Z \to \tau\tau$	2–14%
Norm. $W + \text{jets}$	$W + \text{jets}$	10–100%
Norm. $t\bar{t}$	$t\bar{t}$	8–35%
Norm. diboson	diboson	6–45%
Norm. QCD multijet	QCD multijet	6–70%
Shape QCD multijet	QCD multijet	shape only
Norm. reducible background	Reducible bkg.	15–30%
Shape reducible background	Reducible bkg.	shape only
Luminosity 7 TeV (8 TeV)	signal & sim. backgrounds	2.2% (2.6%)
PDF (qq)	signal & sim. backgrounds	4–5%
PDF (gg)	signal & sim. backgrounds	10%
Norm. ZZ/WZ	ZZ/WZ	4–8%
Norm. $t\bar{t} + Z$	$t\bar{t} + Z$	50%
Scale variation	signal	3–41%
Underlying event & parton shower	signal	2–10%
Limited number of events	all	shape only

mhmax Scenario

Due to the large number of free parameters a complete scan of MSSM parameter space is too involved

→Fix parameters and scan in M_A, tan(β)

$$M_{SUSY} = 1\mathrm{TeV}, \mu = -200\mathrm{GeV},$$

$$m_{\tilde{g}} = 0.8 M_{SUSY}, M_A \leq 1000\mathrm{GeV},$$

$$M_1 = \frac{5\sin^2\theta_w}{3\cos^2\theta_w} M_2$$

$$X_t = 2M_{SUSY}, A_b = A_t$$

Higgs masses:

$$m_{H^\pm}^2 = m_A^2 + M_W^2$$

$$m_H^2 = \frac{1}{2}\left(m_A^2 + M_Z^2 + \left[(m_A^2 + M_Z^2)^2 - 4M_Z^2 m_A^2 \cos^2(2\beta)\right]^{\frac{1}{2}}\right)$$

$$m_h^2 = \frac{1}{2}\left(m_A^2 + M_Z^2 - \left[(m_A^2 + M_Z^2)^2 - 4M_Z^2 m_A^2 \cos^2(2\beta)\right]^{\frac{1}{2}}\right)$$