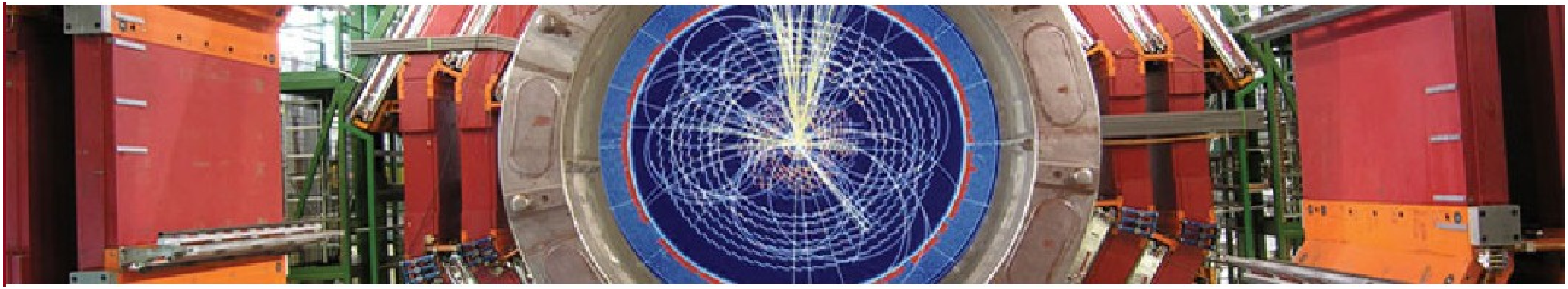
W/Z Physics at CMS



Kristian Hahn – MIT

High Energy Physics Seminar

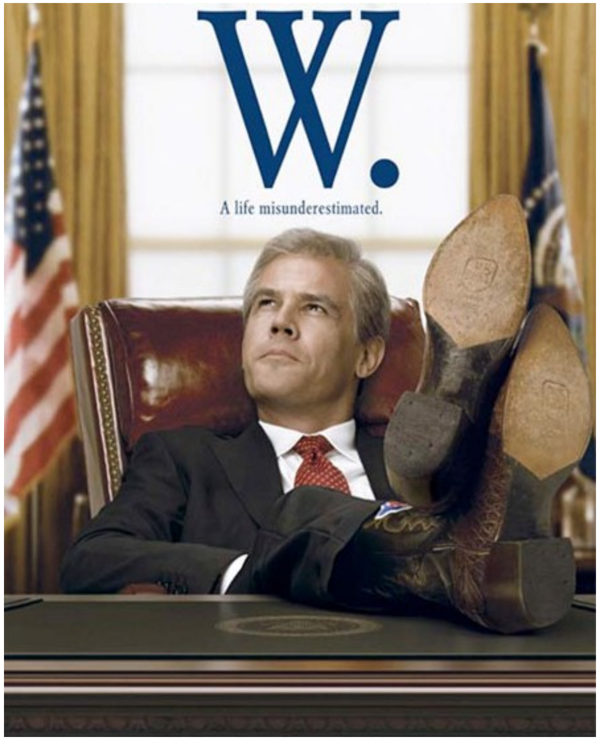
University of Virginia
Jan 19, 2011

- Focus of this talk : the first electron & muon-channel W/Z inclusive cross section and ratio measurements by CMS
- A simple expression for the cross sections …

$$\sigma(pp \rightarrow \{W,Z\}) \times BR(\{\ell\nu,\ell\ell\}) = \frac{N_{\{W,Z\}}}{\alpha\ \varepsilon \int L dt}$$

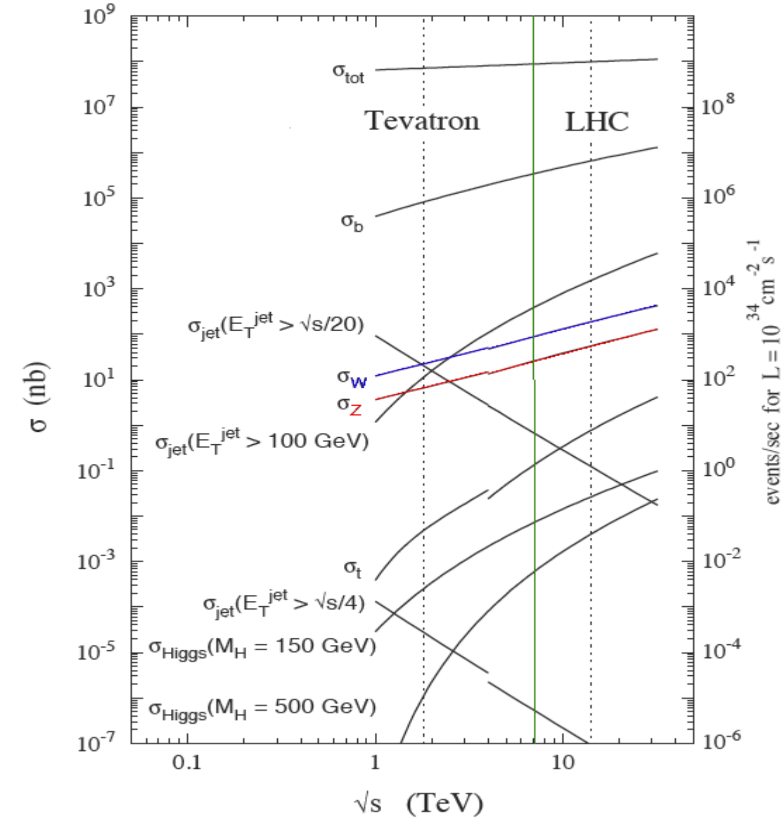
… but sophisticated treatments of the ingredients!

- Will address these in turn ...
  - Detector
  - Selection & Efficiency
  - W & Z Signal Extraction
  - Results



Why "rediscover" W and Z at the LHC?

- New perspectives on familiar physics ...
  - Cross sections ~4x larger than at Tevatron
    - σxBR(W → ℓν) ~ 10 nb per channel
    - σxBR(Z → ℓℓ) ~ 1 nb per channel
  - Larger sea-sea component, HERA-like low x
  - W production globally charge asymmetric
    - pp : 2x u-dbar collisions vs d-ubar due to valance quark content
    - Sea interactions dilute W+/W- from 2 → ~1.4



- CMS is a complex machine ...
  - Develop experience with the detector, high-pT leptons & MET using W/Z
  - Verify expected performance on "familiar roads" now, avoid problems later!

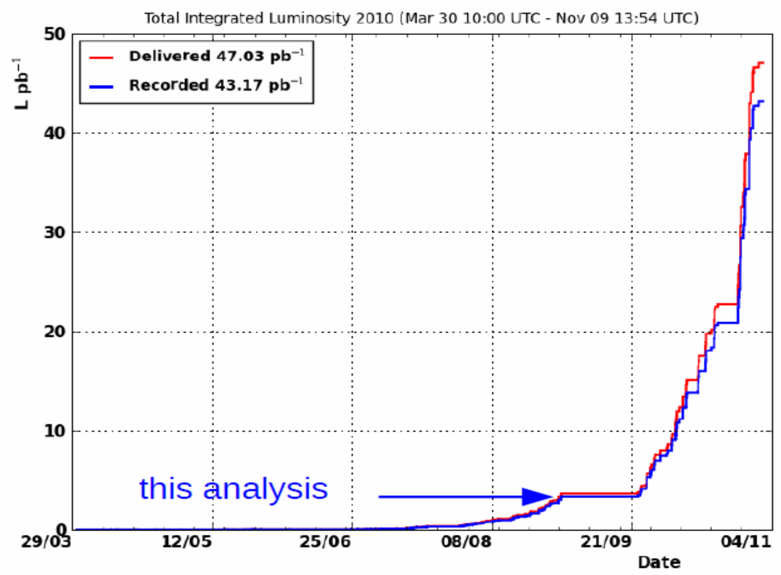
History & Data Samples

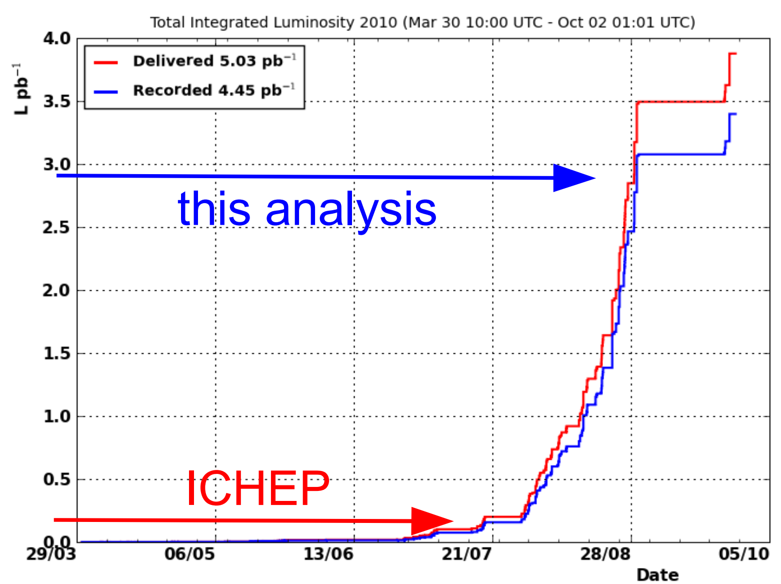
- March: first pp collisions @ 7 TeV
- June: 37 nb^{-1}, significant signals in all channels
- July 14: CMS approval for 78 nb^{-1} analysis. ~10% non-lumi precision
- July 20: Analysis updated to 198 nb^{-1} presented at ICHEP2010, July 22

  http://cdsweb.cern.ch/record/1279615
- Aug-Sept: 3 nb^{-1} collected, 10K W's, 1K Z's
- Oct-Nov: 3 nb^{-1} results complete, submitted to JHEP

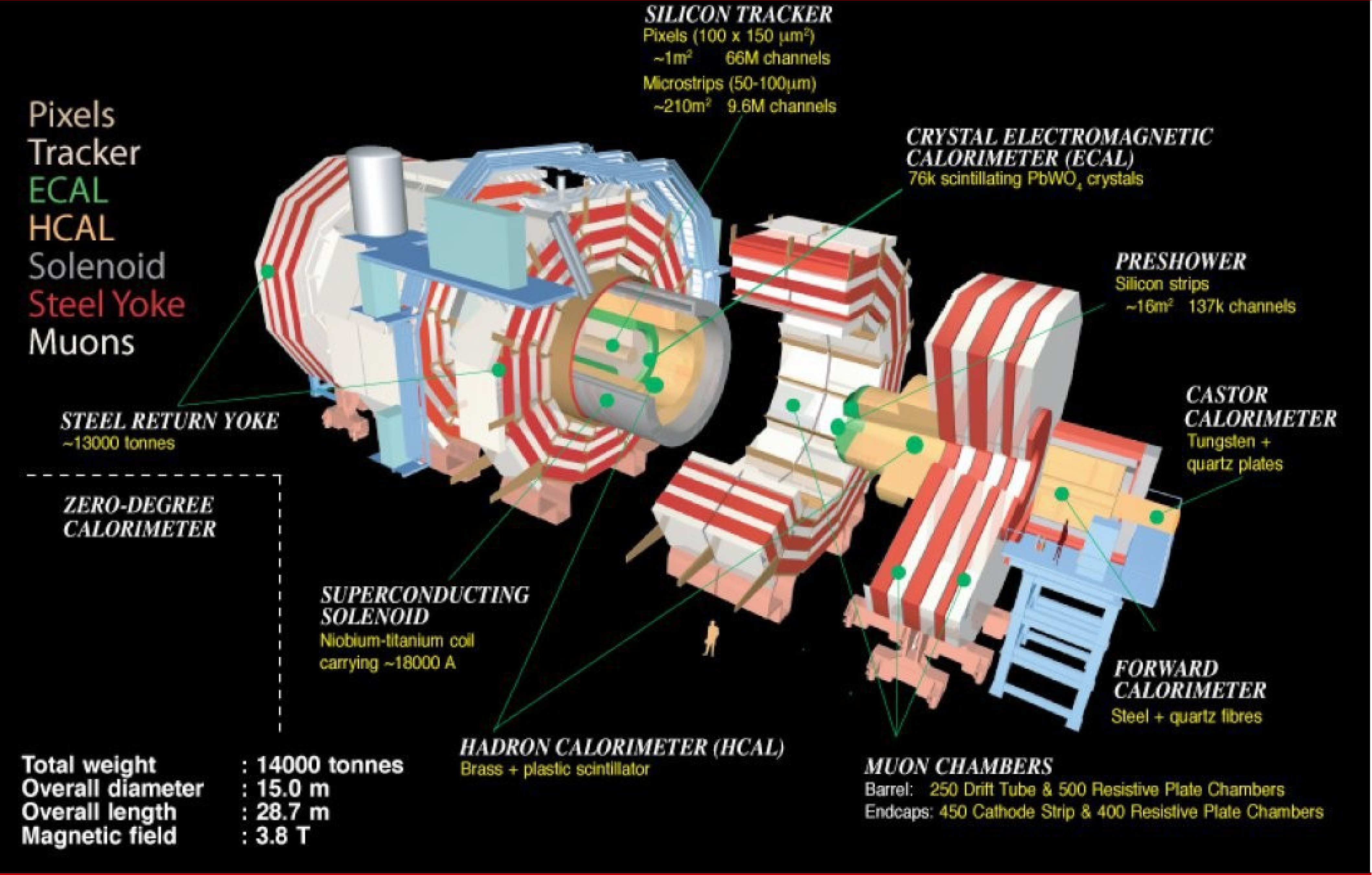
  arXiv:1012.2466v2
- Dec : accepted for publication
- Present : 35 pb^{-1} precision measurements in-progress

Integrated luminosity



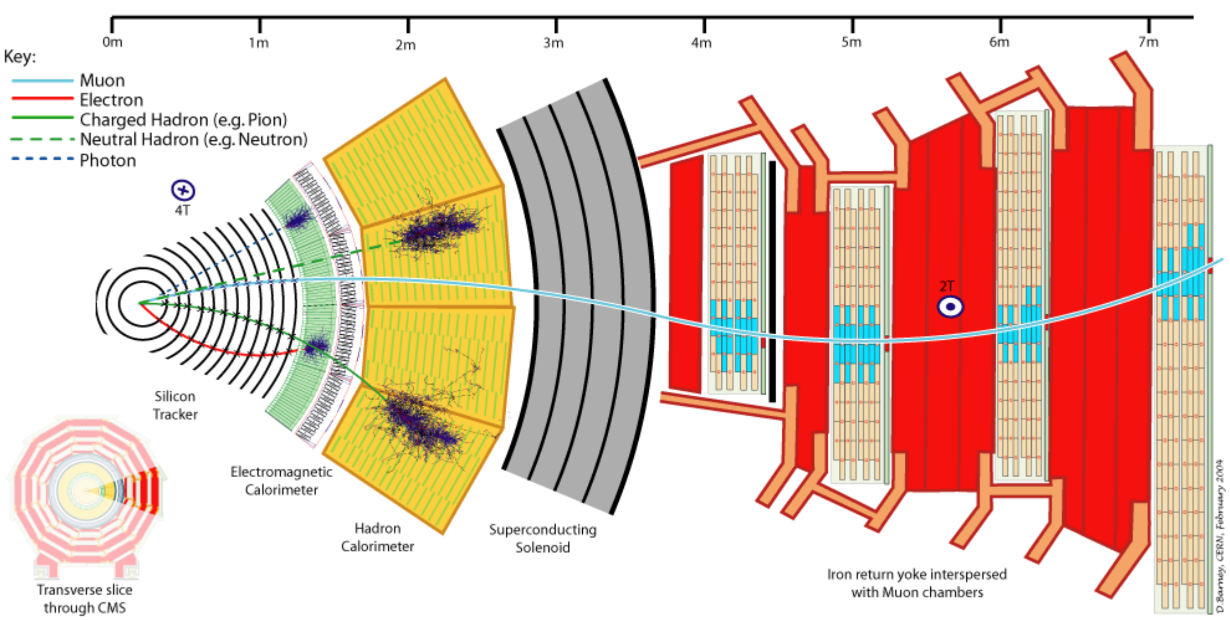


CMS Detector



CMS Detector (2)

- Subsystems central to the W/Z analysis :
  - Silicon Tracker – momentum measurements, direction, vertexing
    - ~10 M strip, 66 M pixel readout channels
  - Electromagnetic Calorimeter (ECAL) – electron (& photon) energy
    - 76 K PbTO4 crystals
  - Muon Chambers – muon identification
    - Drift Tubes, Cathode Strip, Resistive Plate
  - Trigger – Level-1 (L1) and High-Level (HLT)
    - Hardware and low latency processing farm



- Thorough commissioning → dividends to the analysis!
  - Not easy, many obstacles overcome ...
  - Ask about Tracker!

- Relative instantaneous luminosity from online HF occupancy
- Calibrated w/ absolute scale from Van der Meer scan for specific fills
  - Luminosity a function of beam separation (d), modeled as 2xGaussian

$$\mathcal{L} = \mathcal{L}_0 \left(\frac{h_j}{\sqrt{2\pi}\sigma_{1j}} \exp \frac{-d^2}{2\sigma_{1j}^2} + \frac{(1-h_j)}{\sqrt{2\pi}\sigma_{2j}} \exp \frac{-d^2}{2\sigma_{2j}^2} \right)$$

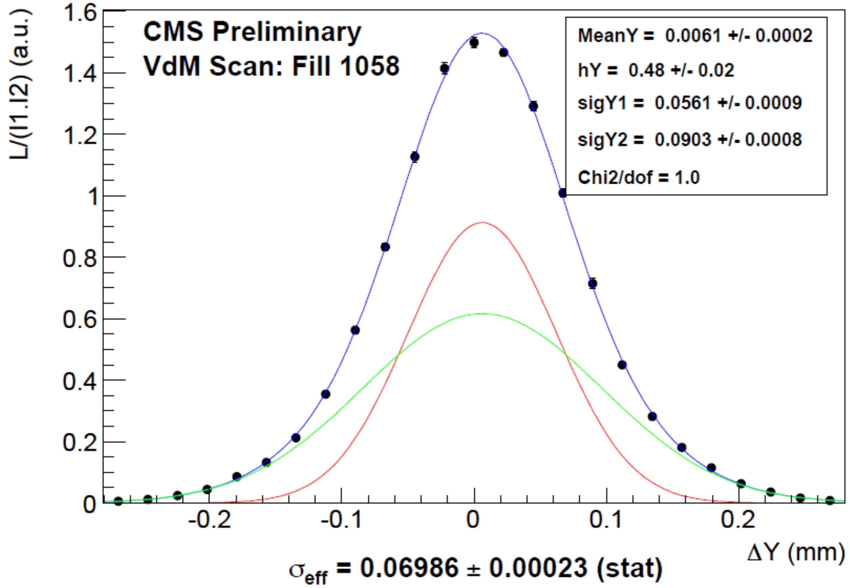
Bunch Intensities, from Beam Current Measurements

  - Peak lumi (L0) depends on effective beam width

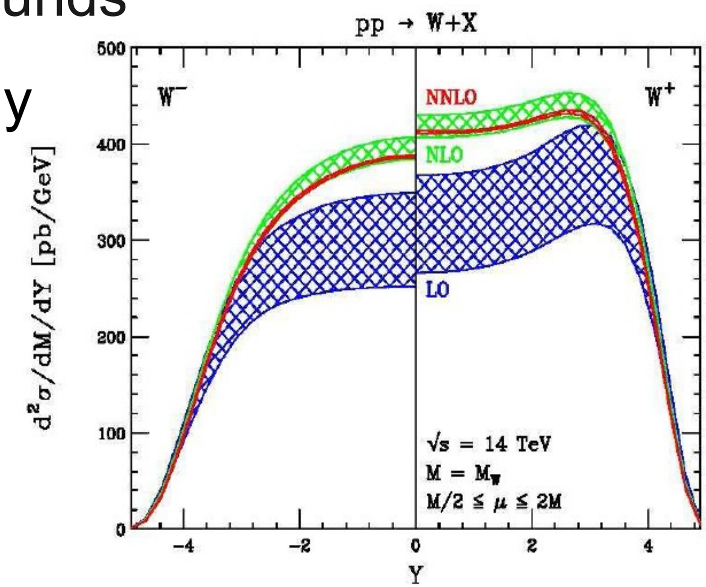
$$\sigma_{\text{eff}}(j) \equiv \left(\frac{\sigma_{1j}\sigma_{2j}}{h_j\sigma_{2j} + (1-h_j)\sigma_{1j}} \right) \qquad \mathcal{L}_0 \equiv \frac{N_1 N_2 \nu_{\text{orb}} N_b}{2\pi\sigma_{\text{eff}}(x)\sigma_{\text{eff}}(y)}$$

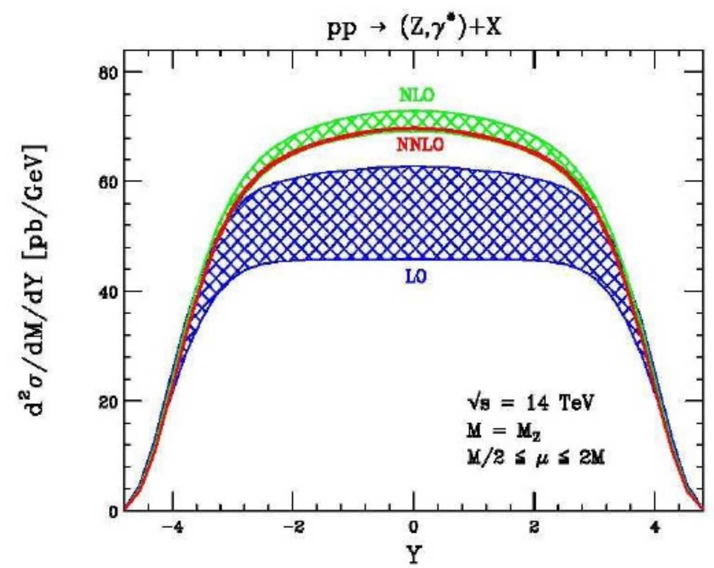
  - N1, N2, ν, & Nb given, scan d and fit L vs. d to determine h, σ & L0
- Uncertainty dominated by LHC beam currents (5% per beam, assumed correlated)

Error	Value (%)
Beam Background	0.1
Fit Systematics	1.0
Beam Shape	3.0
Scale Calibration	2.0
Zero Point Uncertainty	2.0
Beam Current Measurement	10.0
Total	11.0



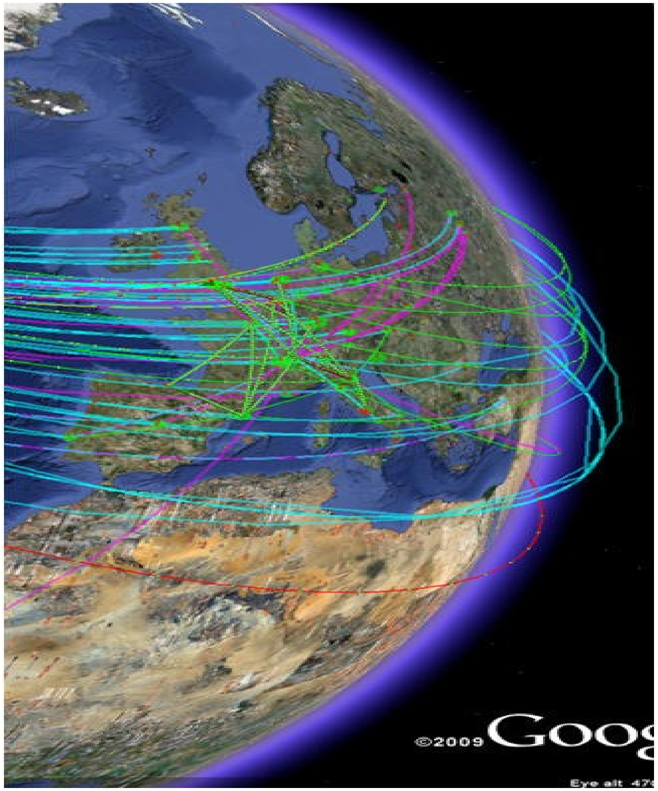
- Large-sample Monte Carlo (MC) for Electroweak processes
  - Acceptances for signal & non-QCD backgrounds
  - W, W-background missing transverse energy (MET) & Z mass shapes
  - Starting point for selection optimization
  - Initial efficiency estimates
    - Corrected with data-driven scale factors
- Baseline EWK MC generation
  - POWHEG NLO + CTEQ 6.6 (NLO)
  - PYTHIA showering
  - Tauola for W & Z tau-channel BGs
  - Full GEANT4 simulation
- Additional tools employed for systematics





CMS Computing

- Data handling/processing in CMS is necessarily *distributed*
  - MC generated at 51 international computing sites (T2's)
  - Data and MC reprocessed at 7 national computing centers (T1's), transferred to T2's/T3's for analysis
    - Prompt reconstruction direct from CERN generally not used in CMS analysis
    - Data for W/Z underwent multiple reprocessing passes with updated alignments and calibrations

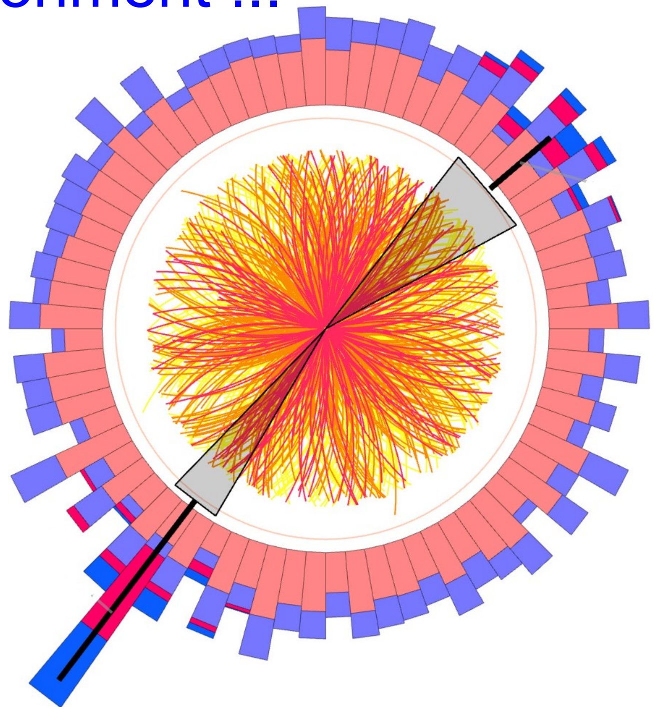


- DataOps a very active project in CMS!
  - And challenging : lots of data/MC to process, many places for problems to arise
  - Infrastructure, software, production tools and operators all must work seamlessly

- Example, 2010 statistics
  - 3.1 B MC events (2.2 PB) generated
  - 10 B data events (1.6 PB) reprocessed

Offline Reconstruction : Muons & Tracks

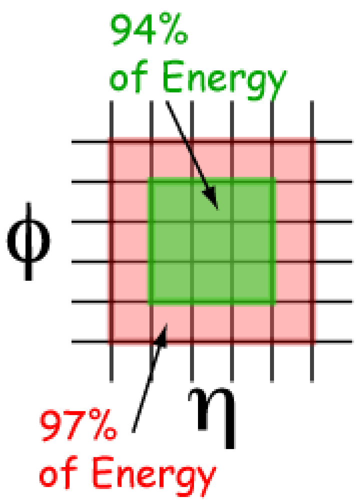
- Tracking a challenge in a dense detector environment ...
  - Lots of Tracker material → bremsstrahlung
  - Specialized tracking algorithm addressed this
    - Baseline : Gaussian model of energy loss
    - More accurately w/ a Gaussian mixture
    - "Gaussian Sum Filter" (GSF) used for eles



- Muon reconstruction
  - Two primary categories of muons in CMS
    - Track matched to muon detector segment ("tracker-only")
    - Hits from track and segment re-fit into a *global muon* track
  - Use candidates that have been reconstructed by *both* methods
    - But utilize kinematics from the tracker-only muons
    - Global tracking improves kinematics only at very high-pT
    - But requiring both methods reduces backgrounds

Offline Reconstruction : Electrons

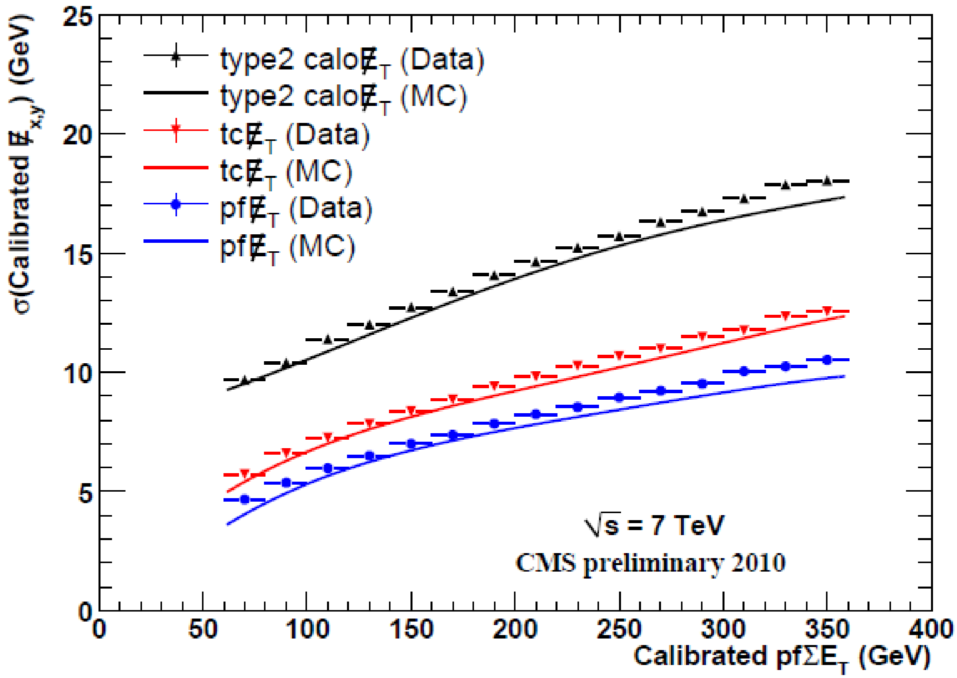
- Electron reconstruction
  - Candidates are a combination of GSF tracks and SuperClusters
    - electrons/photons deposit most energy in clusters, 5x5 crystals
    - Bremsstrahlung → multiple clusters spread in phi
    - Combine cluster into SuperCluster, recover incident energy
  - GSF tracking driven from an ECAL SuperCluster seed
    - ECAL Seed Et > 4 GeV
    - Add pixel hits from position of energy weighted cluster sum
      - Gives incident direction before radiation
    - We use energy from ECAL, direction from track



- Post-reconstruction corrections
  - Spike removal : Anomalous ECAL noise
    - Veto if Σ(adjacent energy)/energy < 5%
  - Additional Endcap alignment corrections

Offline Reconstruction : Missing Energy

- Three types of missing Energy (MET) reconstruction
  1) Purely calometric : negative vector sum of deposits in all towers
  2) Track-corrected : assume all tracks are pions. Corrections to energy deposits using track pT
  3) Particle-flow : MET calculated from full reconstruction of all stable particles in the event
- Significant improvements in resolution from corrected MET
  - TC & PF performance essentially equivalent for W → lν
  - PFMET part of a comprehensive reconstruction routine
    - Key benefits to jet and tau reconstruction
- We utilize PF MET in the W analyses



Lepton and Event Selection

Muon Selection : Online

- L1 muon trigger
  - Muon segment finding with DT & CSC, $\sigma(p_T)/p_T \sim 20\%$
  - RPC adds 1ns timing info, locates BX
  - Arbitration performed, highest pT segments passed to HLT
- HLT : first-pass muon reconstruction
  - Performs regional tracking using L1 inputs
  - Tracking algorithms simple, must balance precision and speed
  - Some information not available (PV)
- A single trigger path used for W/Z
  - L1 pT > 4 GeV
  - HLT pT > 9 GeV, no isolation

- Muon “Pre-triggering”
  - Trigger timing not exact in early 2010, sometimes trigger wrong event
  - Impacts 1% of barrel muons only, accounted for in efficiency

Muon Selection : Offline

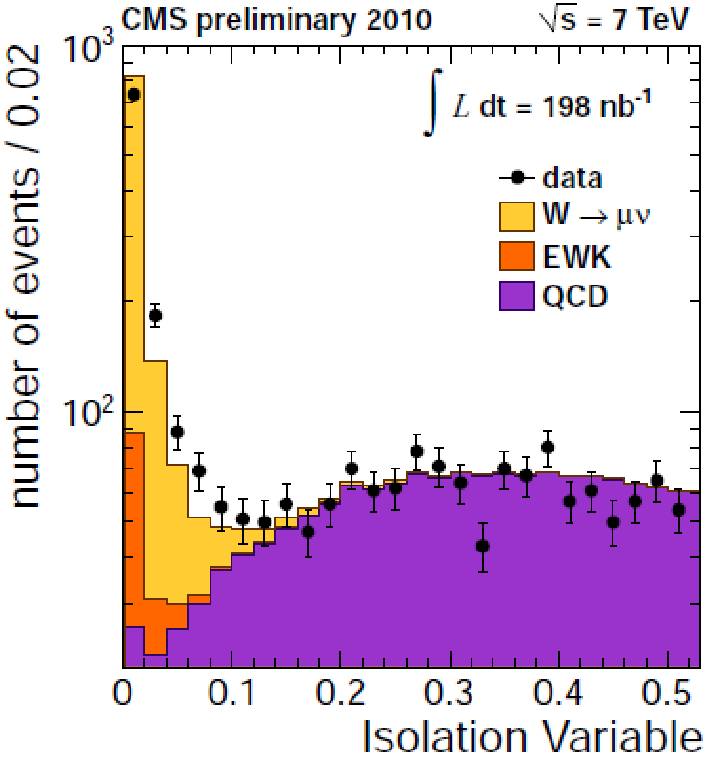
- Kinematic and event selection

$Z \rightarrow \mu\mu$

- 2 reconstructed μ's, p_T > 20 GeV
- | η | < 2.1, 2nd μ in | η | < 2.4
- 60 GeV < $M_{\mu\mu}$ < 120 GeV
- Opposite charge

$W \rightarrow \mu\nu$

- 1 reconstructed μ, p_T > 20 GeV
  - Veto if 2nd μ, p_T > 10 GeV
- | η | < 2.1



- Quality Requirements
  - ≥ 10 tracker hits, ≥ 1 pixel hits
  - ≥ 2 muon stations matched to track
  - Both Inside-out & outside-in reconstruction
  - χ^2/ndf < 10 from global fit
  - Cosmic veto, d_0 < 2 mm
- Combined Relative Isolation

$$I^{\rm rel}_{\rm comb} = \left\{ \sum (p_T(tracks) + E_T(em) + E_T(had)) \right\} / p_T(\mu) \quad < 0.15$$

Electron Selection : Online

- L1 Calorimeter triggers
  - Form pairs of Calo towers, send most energetic to HLT
  - Coarse isolation also calculated
- Electron and Photon HLT
  - Start with ECAL seeds from L1
    - Prompt calibration of ECAL scale, sigma(ET)/ET ~
  - If matching pixel hits then follow electron path, else γ
    - Electron reconstruction algorithms similar to offline
- *Run-dependent* trigger selection for W/Z
  - Needed to reduce rate as LHC intensity improved
    - Runs 132440-137028: HLT_Photon10_L1R
    - Runs 138564-140401: HLT_Photon15_Cleaned_L1R
    - Runs 141956-144114: HLT_Ele15_SW_CaloEleId L1R
  - Tried to avoid electron HLT for as long as possible …
    - Alignment concerns could complicate measurement of ε_{trg}

Cuts on Calorimeter quantities only

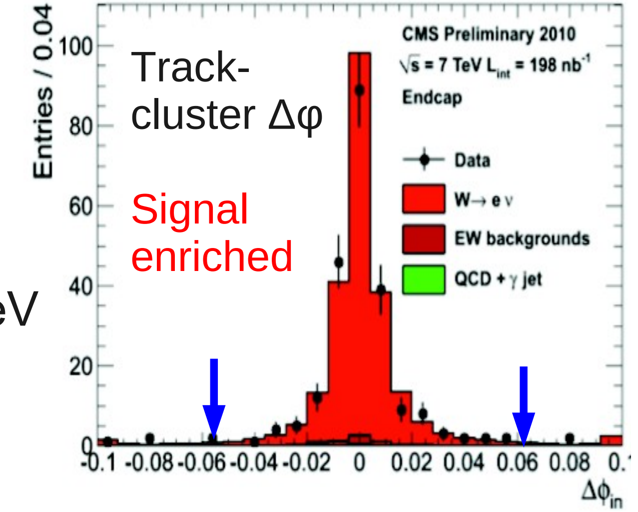
- Kinematic & event selection

$Z \to ee$

- 2 reco ele's, p_T > 20 GeV
- | η | < 2.1, 2^{nd} ele in | η | < 2.4
- No opposite charge requirement
- 60 GeV < M_{ee} < 120 GeV

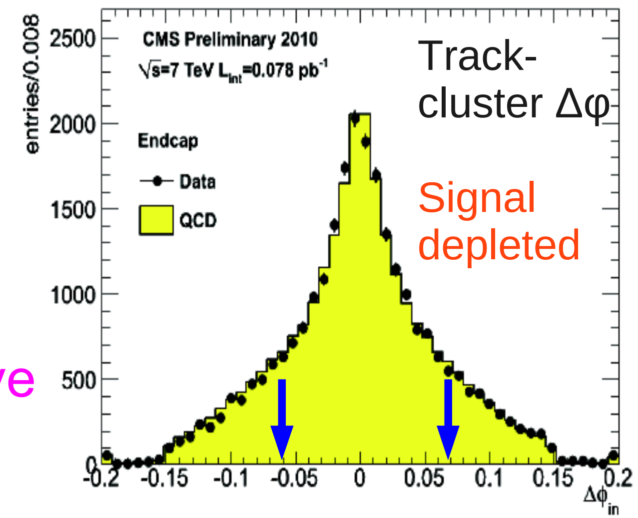
$W \to e\nu$

- 1 reco ele, p_T > 20 GeV
- Veto if 2^{nd} ele, p_T > 20 GeV passing WP95 (below)
- | η | < 2.1



- Identification : 2 sets of "working points" (WP), each split into Barrel and Endcap
  - Z originally WP95, later tightened to WP80

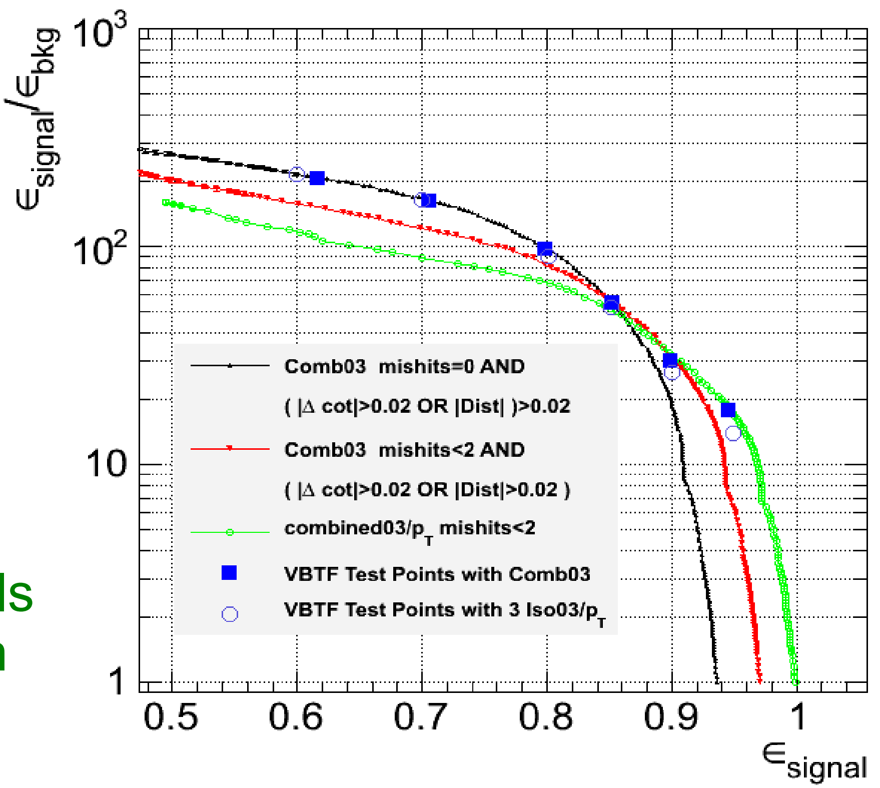
	WP95		WP80	
	Barrel	Endcap	Barrel	Endcap
I_{trk}/E_T	0.15	0.08	0.09	0.04
I_{ECAL}/E_T	2.0	0.06	0.07	0.05
I_{HCAL}/E_T	0.12	0.05	0.10	0.025
Missing hits ≤	1	1	0	0
Dcot	–	–	0.02	0.02
Dist	–	–	0.02	0.02
$\sigma_{i\eta i\eta}$	0.01	0.03	0.01	0.03
$\Delta\phi_{in}$	–	–	0.06	0.03
$\Delta\eta_{in}$	0.007	–	0.004	–
H/E	0.15	0.07	0.04	0.025



- Separate relative isolations
- Conversion rejection : inner hit requirements & partner track
- Cuts on shower shape, track/cluster matching, and energy confinement

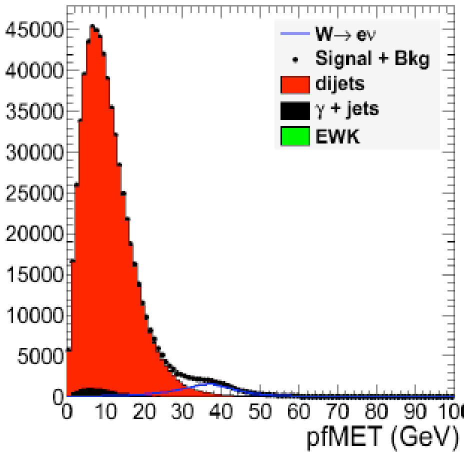
Electron Selection : Offline (2)

- WorkingPoint ID optimization
  - Initially with W & QCD simulation
    - – Iterative procedure, treats each variable individually, then together
  - Later, with data ...
    - – BG sample : MET < 15 GeV
    - – Signal : MET > 30 GeV
    - – Algorithm robust against small levels of signal/background contamination

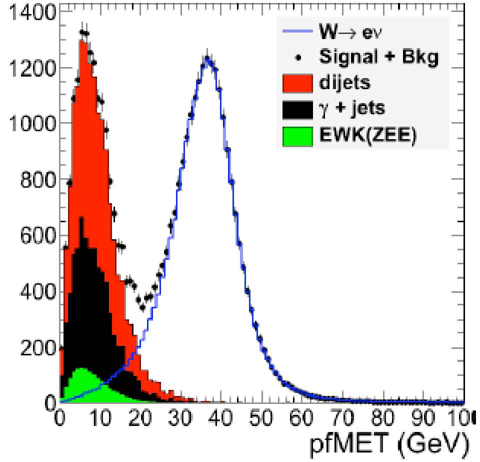


- More sophisticated ID techniques under study
  - Cuts categorized by E/P
  - Multivariate Methods
    - – Likelihood
    - – Neural Net
    - – K-Nearest Neighbor (kNN)

No ele ID



WP80



Signal Acceptance

$$\sigma x Br = \frac{N_{\{W,Z\}}}{\alpha\, \varepsilon \int L dt}$$

- What fraction of delivered signal events end up in our data sample?
  - 1st stage of event rejection (acceptance) from limited detector geometry
  - Subsequent stages from high-quality lepton requirements (efficiency)
- Signal acceptance (α) from kinematic selection applied to MC
  - Primarily theoretical, compartmentalizes assoc. uncertainties
- Dedicated studies explore effects not captured by baseline MC
  - Effects are small, taken as systematic uncertainty

EWK & FSR	HORACE
PDFs	CTEQ, MSTW, NNPDF
Higher-order corrections & ISR	ResBos for missing NNLO FEWZ for beyond NNLO
α_s scaling	ResBos

Signal Acceptance : Electrons

- α^{ECAL} : fraction of generated events with fiducial ECAL supercluster(s) passing kinematic selection
  - Separate into ECAL Barrel (EB : |η| < 1.44) and Endcap (EE: 1.57 < |η| < 2.5)
  - SuperCluster E_T > 20 GeV
  - Zee : 60 GeV < M_{ee} < 120 GeV

A^{ECAL}	W^+	W^-	$W^\pm$
EB	0.3618	0.3532	0.3571
EE	0.2277	0.1899	0.2070
EB+EE	0.5895	0.5431	0.5641

A^{ECAL}	$Z \to e^+e^-$
EB+EB	0.2257
EB+EE	0.1612
EE+EE	0.0476
all	0.4345

- Theory uncertainties are on order 1-2%
  - Take half of max. spread after re-weighting with various PDF sets
  - Other effects studied with dedicated programs

Quantity	Syst. (%)
W^+ acceptance (e)	0.9
W^- acceptance (e)	1.5
W acceptance (e)	0.8
Z acceptance (e)	1.1
W^+/W^- correction (e)	1.7
W/Z correction (e)	0.9

Source	$W^+ \to e\nu$	$W^- \to e\nu$	$Z \to ee$	W^+/W^- (e)	Z/W (e)
QCD-HO and ISR	-1.30%±0.09	-0.78%±0.10	±0.6%	0.56%±0.13	0.47%±0.17
QCD-α_s scaling	0.23%±0.22	0.37%±0.32	±1.1%	1.13%±0.63	0.57%±0.52
FSR	0.08%±0.17	0.07%±0.19	-0.11%±0.24	0.15%±0.27	-0.10%±0.30
EWK	0.07%±0.13	0.21%±0.19	-0.47%±0.22	0.00%±0.27	-0.70%±0.29
Total	1.33%	0.90%	1.34%	1.27%	1.03%

Signal Acceptance : Muons

- α^{μ} : fraction of generated events with generator-level muon(s) passing kinematic selection
  - Generator p_T > 20 GeV
  - Calculated after FSR
  - W : |η| < 2.1
  - Z : 60 GeV < $M_{\mu\mu}$ < 120 GeV, |η| < 2.1, 2.5
- Theory uncertainties are on order 1-2%
  - Take half of max. spread after re-weighting with various PDF sets
  - Other effects studied with dedicated programs

$W \to \mu\nu$	A
W^+	0.5413 ± 0.0060
W^-	0.5023 ± 0.0055
$W^\pm$	0.5253 ± 0.0058

A	$Z \to \mu^+\mu^-$
Z	0.3977 ± 0.0048

Quantity	Syst. (%)
W^+ acceptance (μ)	1.3
W^- acceptance (μ)	1.9
W acceptance (μ)	1.1
Z acceptance (μ)	1.2
W^+/W^- correction (μ)	2.1
W/Z correction (μ)	1.1

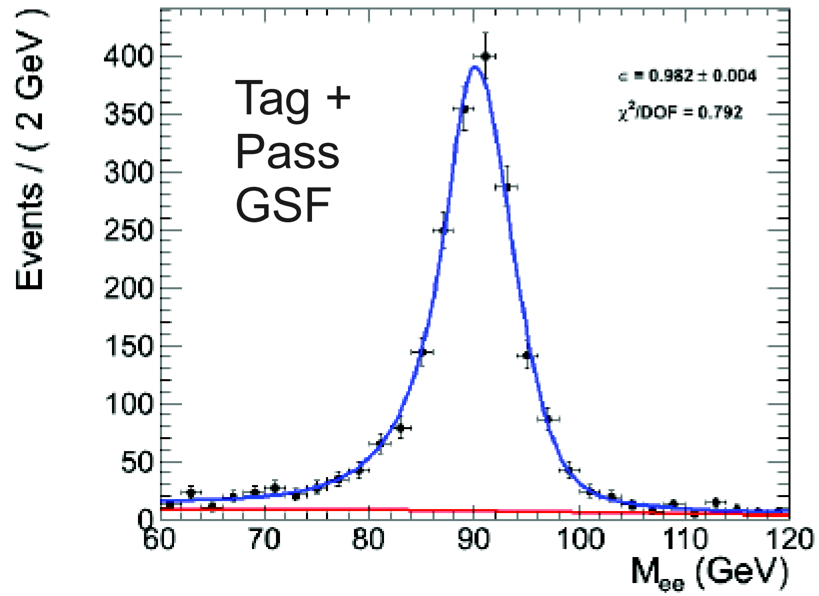
Source	$W^+ \to \mu\nu$	$W^- \to \mu\nu$	$Z \to \mu^+\mu^-$	W^+/W^- (μ)	Z/W (μ)
QCD-HO and ISR	-1.39%±0.09	-1.17%±0.14	±0.6%	0.22%±0.17	0.70%±0.18
QCD-α_s scaling	0.23%±0.22	0.37%±0.32	±1.1%	1.13%±0.63	0.57%±0.52
FSR	0.11%±0.12	0.01%±0.17	0.38%±0.24	-0.08%±0.19	0.15%±0.27
EWK	-0.02%±0.12	0.26%±0.17	-1.02%±0.24	0.28%±0.19	-0.98%±0.24
Total	1.42%	1.26%	1.58%	1.19%	1.35%

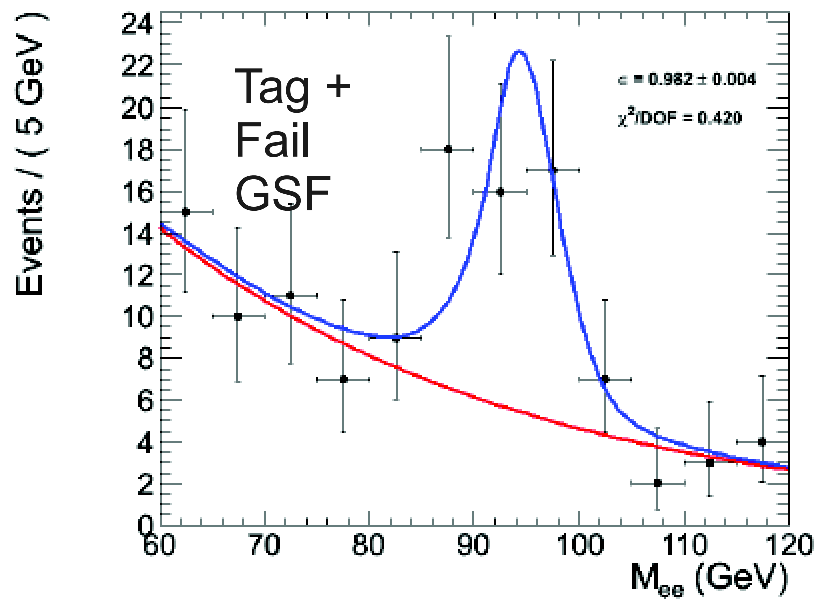
$$\sigma x Br = \frac{N_{\{W,Z\}}}{\alpha\, \varepsilon \int L dt}$$

- Trigger, identification & isolation requirements lead to additional event loss
  - Relevant efficiencies also determined with MC, ε^{MC}
  - BUT, do not expect simulation perfectly models data!
- Correct ε^{MC} with data-driven scale factors, $\rho_i = \varepsilon^{Data}_i / \varepsilon^{MC}_i$
  - Eg: total single-lepton efficiency : $\varepsilon^{MC}_{reco} \varepsilon^{MC}_{ID} \varepsilon^{MC}_{trig} \rho_{reco} \rho_{ID} \rho_{trig}$
- Determine ρ_i using Z-based "tag & probe" technique
  - Z selection : tight requirements on one leg (probe) + $60 < M_{\ell\ell} < 120$ GeV
  - Uncorrelated requirements on other leg (probe), apply selection
  - Could obtain efficiencies from counting after BG subtraction ...
  - Better, from simultaneous $M_{\ell\ell}$ fit to passing & failing samples
    - Exploits additional shape information
    - Benefits for assessing correlated uncertainties

Efficiencies : Electrons

- Tag & Probe
  - Tag always a WP80 electron
  - Signal shapes : MC or analytic
  - Background modeled as exp x polynomial
- ε_{reco} : SuperCluster → GSF track
  - Background most significant for this ε
  - Probe: Supercluster with loose H/E, shower-shape and Iso_{ECAL} cuts
  - Results cross-checked w/ MC BG template
- ε_{ID} : GSF track → ele passing WP cuts
  - Probe : Reco electron candidate
  - Check w/ MC BG template, SS/OS method
- ε_{ID} : ID'ed ele → trigger match
  - Probe : electron passing ID
  - No bg left at this stage, simple counting
  - Checked using ECAL activity trigger





Efficiencies : Electrons

Efficiency	Data	Simulation	Data/Simulation (ρ_{eff})
EB			
$\epsilon_{TNP\text{-}REC}$	(98.6 ± 0.5) %	98.50%	1.001 ± 0.005
$\epsilon_{TNP\text{-}WP80}$	(79.1 ± 1.8) %	85.50%	0.925 ± 0.021
$\epsilon_{TNP\text{-}WP95}$	(93.9 ± 1.5) %	96.4%	0.974 ± 0.016
$\epsilon_{TNP\text{-}TRG80}$	(98.9 ± 0.3) %	99.70%	0.992 ± 0.003
$\epsilon_{TNP\text{-}TRG95}$	(98.7 ± 0.2) %	99.4%	0.992 ± 0.002
$\epsilon_{TNP\text{-}WP80\text{-}ALL}$	(77.1 ± 1.8) %	83.9%	0.919 ± 0.022
$\epsilon_{TNP\text{-}WP95\text{-}ALL}$	(91.3 ± 1.5) %	94.4%	0.967 ± 0.016
EE			
$\epsilon_{TNP\text{-}REC}$	(96.2 ± 0.8) %	96.3%	0.999 ± 0.009
$\epsilon_{TNP\text{-}WP80}$	(69.2 ± 2.0) %	74.9%	0.924 ± 0.027
$\epsilon_{TNP\text{-}WP95}$	(90.3 ± 1.9) %	93.9%	0.962 ± 0.020
$\epsilon_{TNP\text{-}TRG80}$	(99.2 ± 0.5) %	98.80%	1.003 ± 0.005
$\epsilon_{TNP\text{-}TRG95}$	(99.16 ± 0.02) %	97.7%	1.015 ± 0.0003
$\epsilon_{TNP\text{-}WP80\text{-}ALL}$	(66.0 ± 2.0) %	71.3%	0.926 ± 0.028
$\epsilon_{TNP\text{-}WP95\text{-}ALL}$	(86.1 ± 1.9) %	88.3%	0.975 ± 0.022

- Trigger and Reco efficiency well modeled in MC
- ID efficiency less so
  - Some alignment discrepancies persist after post-hoc corrections

Single electron ε & ρ

ε & ρ as used in the analysis, acceptance weighted

	ρ_{eff}	ε_{MC}	ε_{MC} x ρ_{eff}
W+	0.917 ± 0.046	0.779 ± 0.005	0.714 ± 0.036
W-	0.927 ± 0.047	0.788 ± 0.006	0.730 ± 0.037
W	0.921 ± 0.036	0.782 ± 0.004	0.721 ± 0.028
Z	0.856 ± 0.050	0.656 ± 0.007	0.562 ± 0.033

Efficiency Systematics : Electrons

- Background Model
  - Consider power-law ($1/M^{\alpha}$) as alternative model to exponential
  - Fix α to value found from fit to dijet data and generate pseudo-experiments
  - Fit each trial with exponential, measure bias
- Energy Scale /Resolution
  - Scale corrections discussed on next slide
  - Apply corrections ± uncertainties to the MC, measure difference in yield
- Signal Shape
  - Extend Mee window to include more of the low mass tail, 50-120 GeV
  - Construct data-driven signal shapes by tightening selection on Tag+Fail
    - Fit with these templates, difference w.r.t nominal fit is the systematic

Source	% ε_{reco}	% $\varepsilon_{reco\text{-}WP95}$	% $\varepsilon_{reco\text{-}WP80}$	% $\varepsilon_{WP80\text{-}HLT}$	% $\varepsilon_{WP80\text{-}HLT}$
Background Model	0.06	0.25	0.24	0.01	< 0.00
Energy Scale	0.1	0.1	0.2	< 0.00	0.1
Signal Shape	1.2	1.0	2.0	-	-

- Technique somewhat more involved than for electrons ...
  - Multicategory simultaneous fit for all efficiencies and signal yield

$$
\begin{aligned}
N_{\mu\mu}^{2\mathrm{HLT}} &= N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}^2\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}^2,\\
N_{\mu\mu}^{1\mathrm{HLT}} &= 2N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}(1-\epsilon_{\mathrm{HLT}})\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}^2,\\
N_{\mu s} &= 2N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}\epsilon_{\mathrm{iso}}^2\epsilon_{trk}(1-\epsilon_{trk})\epsilon_{sa}^2,\\
N_{\mu t} &= 2N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}(1-\epsilon_{sa}),\\
N_{\mu\mu}^{\mathrm{non\ iso}} &= N_{Z\to\mu^+\mu^-}(1-(1-\epsilon_{\mathrm{HLT}})^2)(1-\epsilon_{\mathrm{iso}}^2)\epsilon_{trk}^2\epsilon_{sa}^2
\end{aligned}
$$

where ...

$N_{\mu\mu}^{2HLT}$: 2 tight μ's, both HLT matched

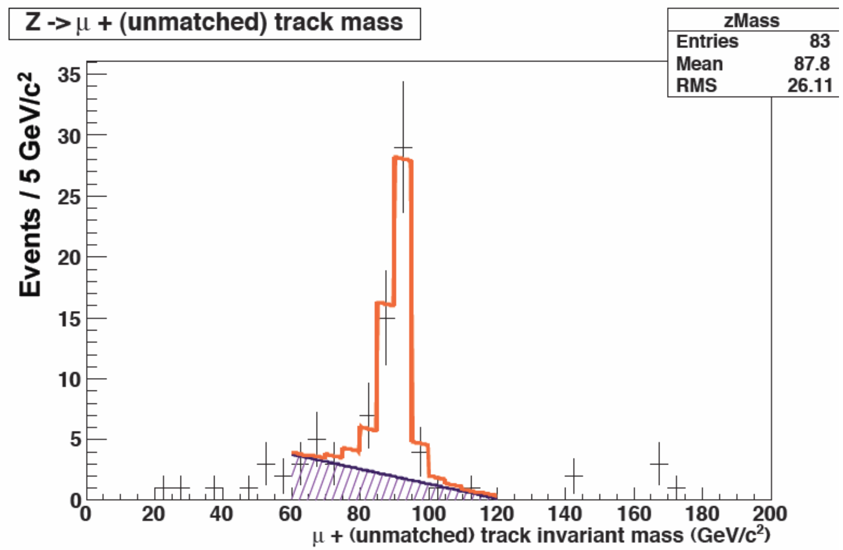
$N_{\mu\mu}^{1HLT}$: 2 tight μ's, one HLT matched

Nμs: tight μ + "stand alone" μ-segment

Nμt: tight μ + (generic) track

$N_{\mu\mu}^{non\ iso}$: Two tight μ's, one not isolated

  - Quality criteria subsumed into ε_{trk} and ε_{sa} in this formulation
  - Signal PDF : shape from 1 & 2 HLT categories, background free
  - Background PDF : Polynomial x exponential for Nμs, Nμs, $N_{\mu\mu}^{non\ iso}$



- Correctly accounts for correlations between $N_{Z\to\mu\mu}$ and ε's

Efficiencies : Muons

- Binned Maximum Log Likelihood fit for ε's and $N_{Z \to \mu\mu}$
  - Reformulate logL as (Poisson) Likelihood ratio
  - Distributed as χ2 for large N

$$\chi^2 = \frac{(N_{\mu\mu}^{2\mathrm{HLT}} - N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}^2\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}^2)^2}{N_{\mu\mu}^{2\mathrm{HLT}}} + \frac{(N_{\mu\mu}^{1\mathrm{HLT}} - 2N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}(1-\epsilon_{\mathrm{HLT}})\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}^2)^2}{N_{\mu\mu}^{1\mathrm{HLT}}} + \chi_{\mu s}^2 + \chi_{\mu t}^2 + \chi_{\mu\mu}^{\mathrm{non\ iso}\ 2}$$

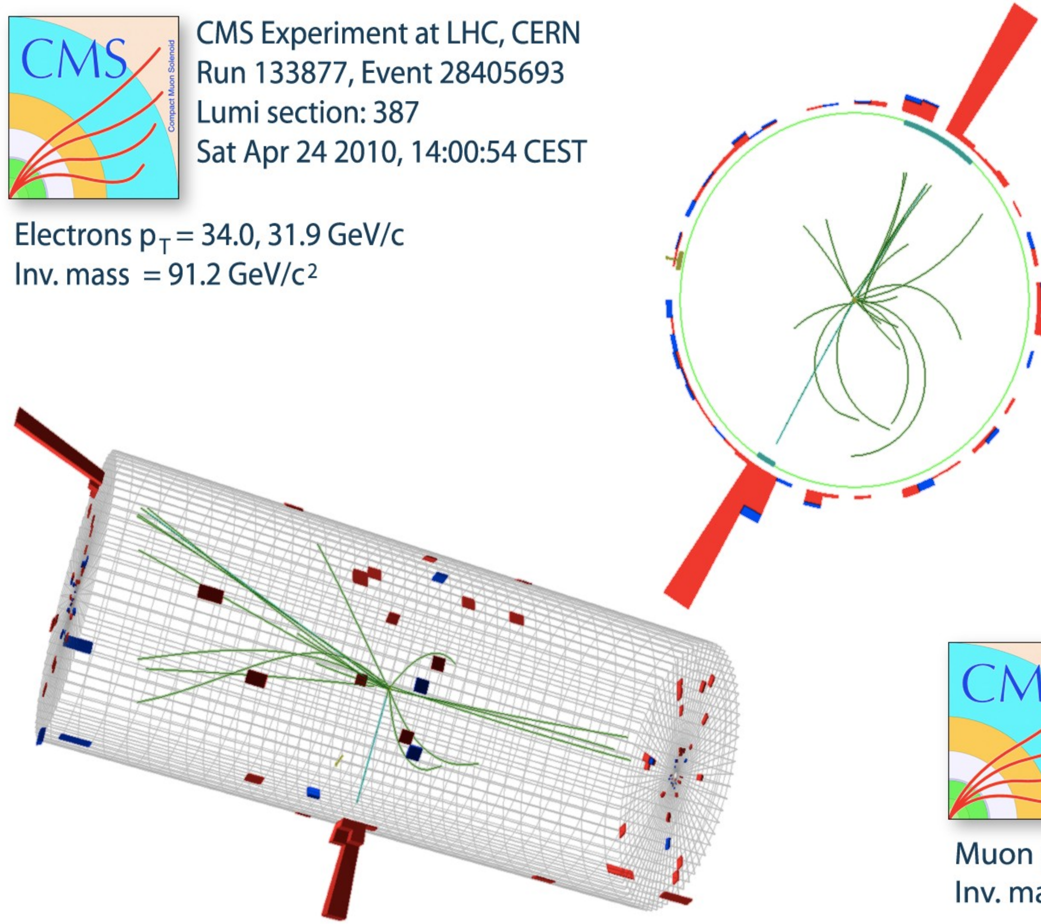
- Extract best-fit values by minimizing a global χ2

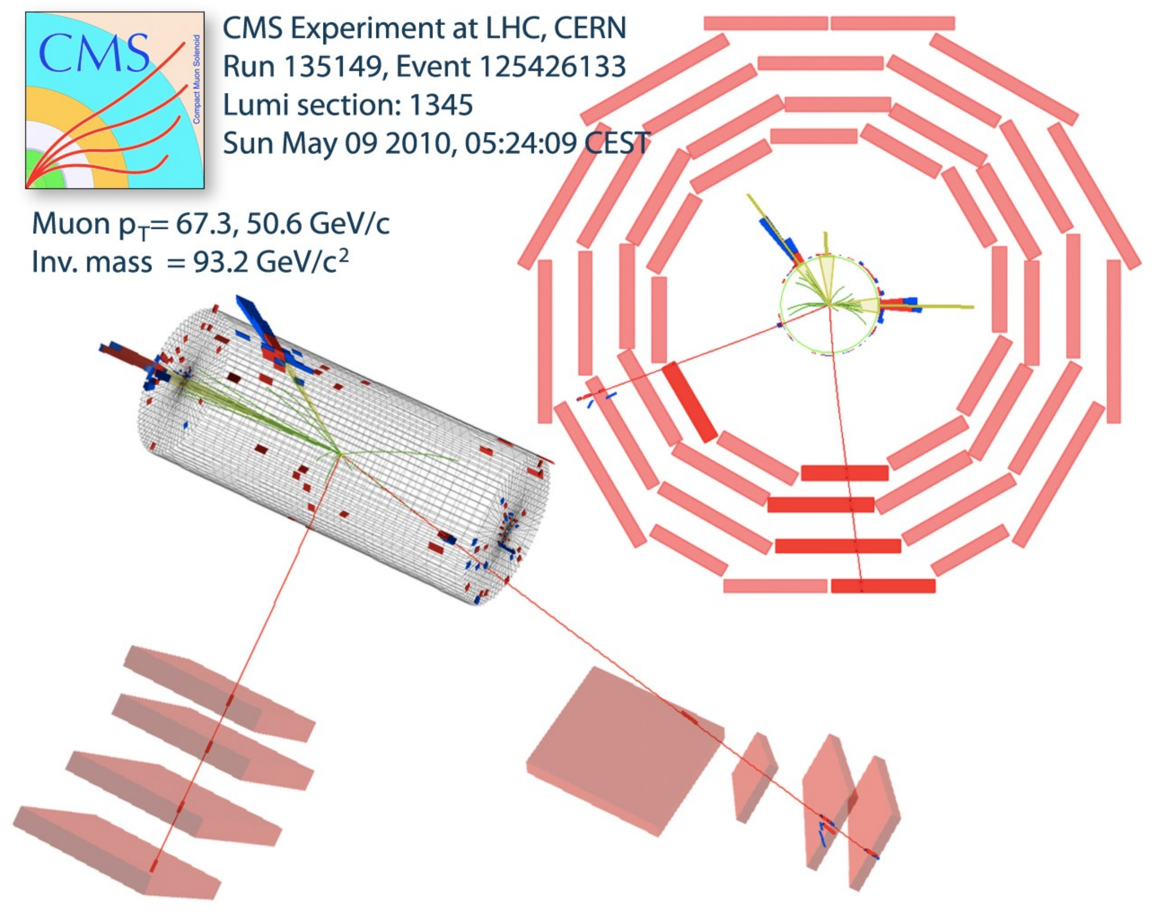
- Systematic Uncertainties
  - Background modeling contributes 1%
  - Zero background assumption for 1 & 2 HLT : 0.2%

Efficiency	Data	Simulation	Data/Simulation (ρ_{eff})
ϵ_{SA}	$(96.4 \pm 0.5)\,\%$	97.2%	0.992 ± 0.005
ϵ_{TRK}	$(99.1 \pm 0.4)\,\%$	99.3%	0.998 ± 0.003
ϵ_{SEL}	$(99.7 \pm 0.3)\,\%$	99.7%	1.000 ± 0.003
ϵ_{ISO}	$(98.5 \pm 0.4)\,\%$	99.1%	0.994 ± 0.004
ϵ_{TRG}	$(88.3 \pm 0.8)\,\%$	93.2%	0.947 ± 0.009
Net (W)	$(82.8 \pm 1.0)\,\%$	88.7%	0.933 ± 0.012

- Largest data/MC scale factor for trigger
  - Known L1 inefficiencies
  - Imperfect modeling of HLT seeding

Z & W Signal Extraction


CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST
Electrons p_T = 34.0, 31.9 GeV/c
Inv. mass = 91.2 GeV/c^2

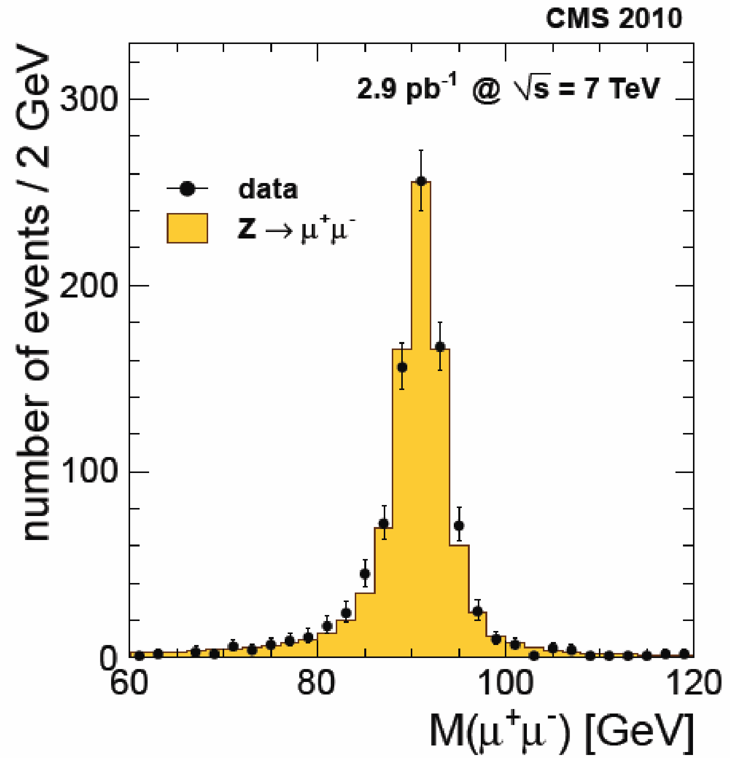

CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST
Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2

Z→μμ Signal Extraction: Results

- Yield from simultaneous fit, as discussed
- Event selection for the "golden" category
  - 2 opposite-Q muons passing ID
  - At least one passing trigger
  - 60 GeV < $M_{\mu\mu}$ < 120 GeV
- Yield in the "golden" category
  - Yield : 913
  - Expected Signal: 950

$$\sigma \times Br = \frac{N_{\{W,Z\}}}{\alpha\, \varepsilon \int L dt}$$

source	fraction	N_{est}
QCD multi-jet	negl.	0.048 ± 0.002
$W \to \mu\nu$	negl.	0.03 ± 0.03
$t\bar{t}$	$(0.12 \pm 0.01)\%$	1.19 ± 0.10
$Z \to \tau^+\tau^-$	$(0.05 \pm 0.01)\%$	0.52 ± 0.07
WZ	$(0.08 \pm 0.01)\%$	0.82 ± 0.09
WW	$(0.03 \pm 0.01)\%$	0.31 ± 0.05
ZZ	$(0.06 \pm 0.01)\%$	0.55 ± 0.12
total	$(0.37 \pm 0.02)\%$	3.48 ± 0.18



EWK backgrounds normalized to Z signal template

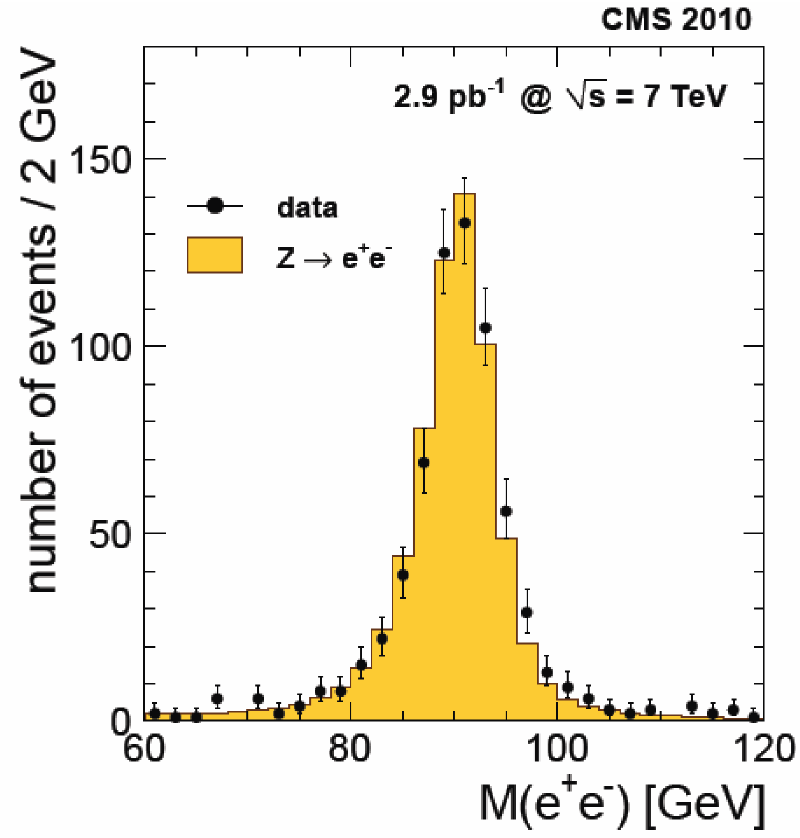
$Z \to ee$ Signal Extraction

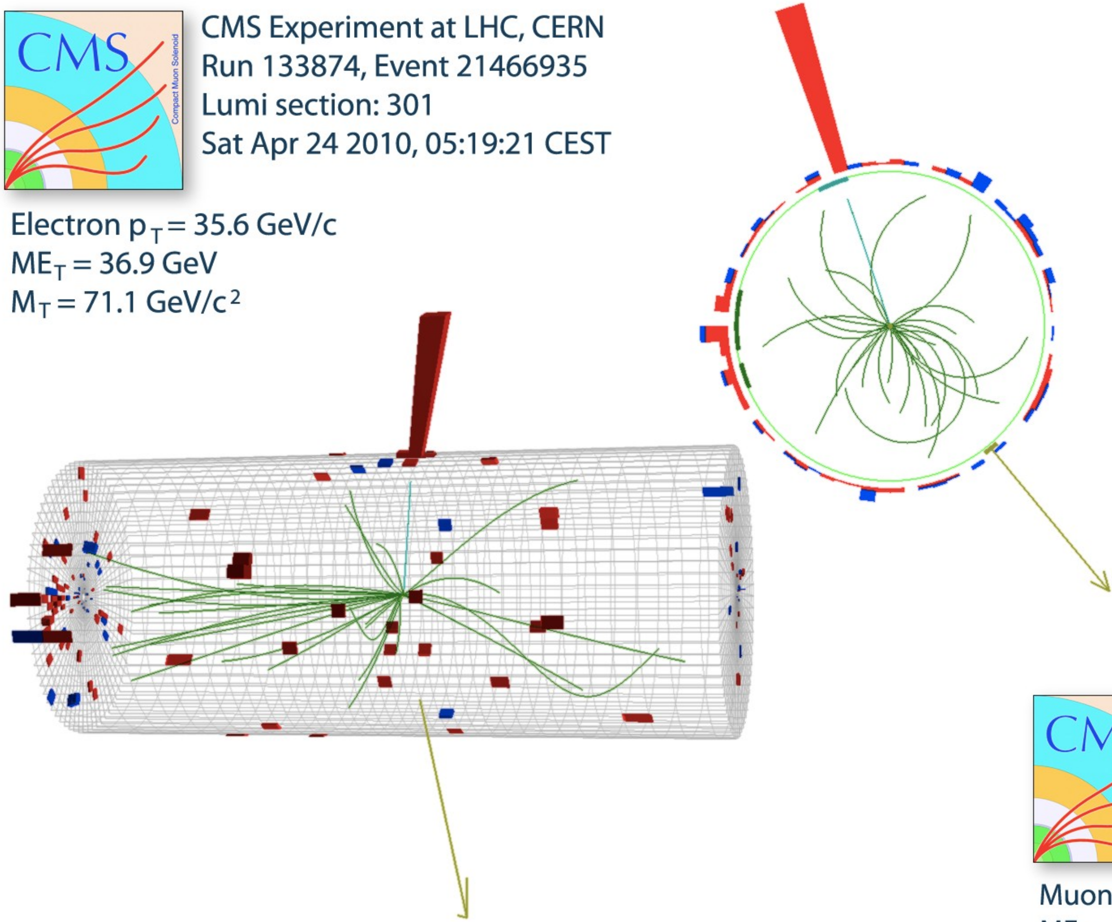
- Electroweak backgrounds estimated from MC
  - Normalized to signal via NLO cross sections, $N_{EWK} = 2.4$
- Several estimates for contributions from W+j, p+j, QCD multijets
  - "Fake Rate"
    - Find rates for jets in dijet samples to pass full selection
    - Apply to electron + jet events in signal sample
    - $N_{QCD} = 0.4 \pm 0.4$ (sys + stat)
  - Same-Sign/Opposite-Sign
    - Infer QCD background from same-sign events and charge misID
    - Charge misID measured from Z using tighter ID cuts
    - $N_{QCD} = 0.0 \pm 7.5$ (stat) ± 1.3 (sys)
  - Isolation template fit
    - Shapes from M_{ee} side and Z peak with tighter ID
    - $N_{QCD} = 2.1 \pm 4.6$ (stat) ± 0.1 (sys)
  - Use 0.4 ± 0.4 for the final estimate (expect 0.0 from MC)

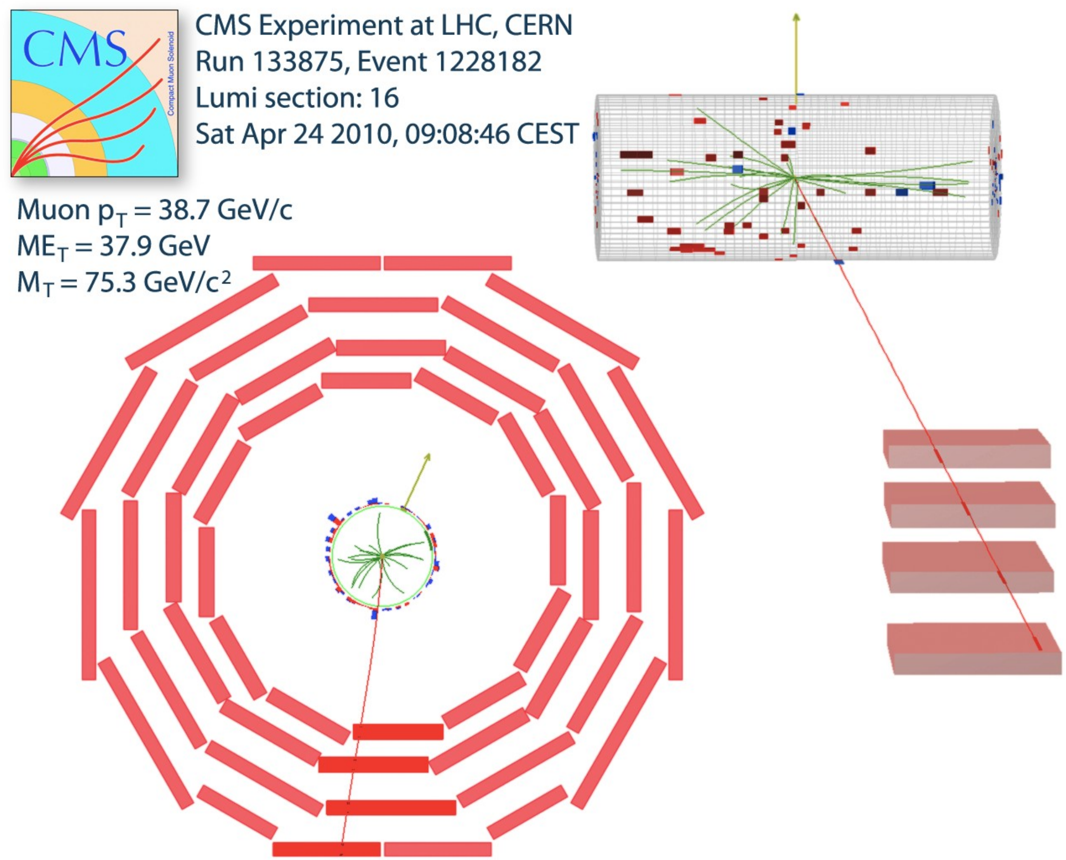
Z→ee Signal Extraction : Results

- Event selection
  - 2 WP80 e's
  - ≥ 1 passing trigger
  - 60 GeV < M_{ee} < 120 GeV
  - No opposite charge requirement
- Yields
  - Observed : 677
  - Signal : 674 ± 26

source	fraction	N_{est}
QCD multi-jet	0.06%	0.4 ± 0.4
$Z \to \tau^+\tau^-$ (MC)	0.11%	0.77
di-boson production (MC)	0.12%	0.76
$t\bar{t}$ (MC)	0.11%	0.83
EWK (MC)	0.35%	2.36
total	0.41%	2.8 ± 0.4




CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST
Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2

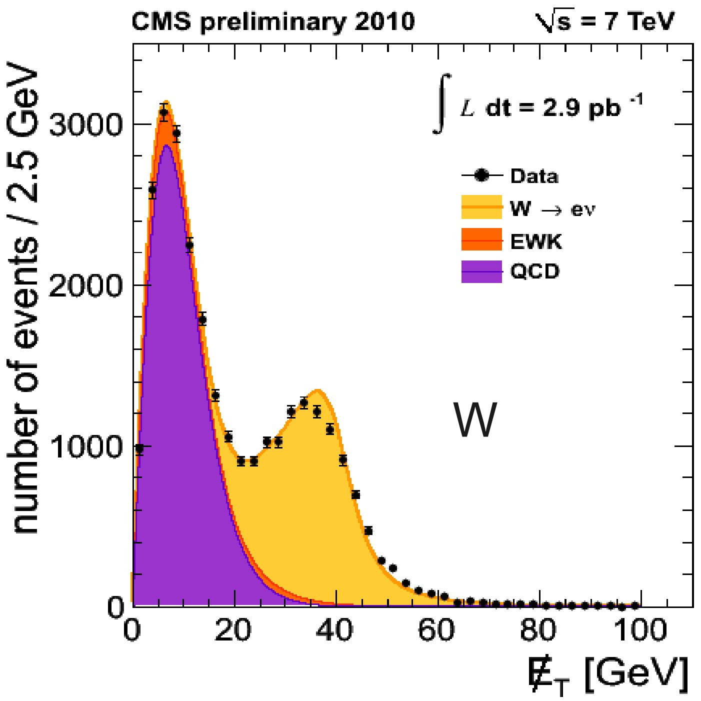

CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST
Muon $p_T = 38.7$ GeV/c
$ME_T = 37.9$ GeV
$M_T = 75.3$ GeV/c^2

$$\sigma x Br = \frac{N_{\{W,Z\}}}{\alpha\, \varepsilon \int L dt}$$

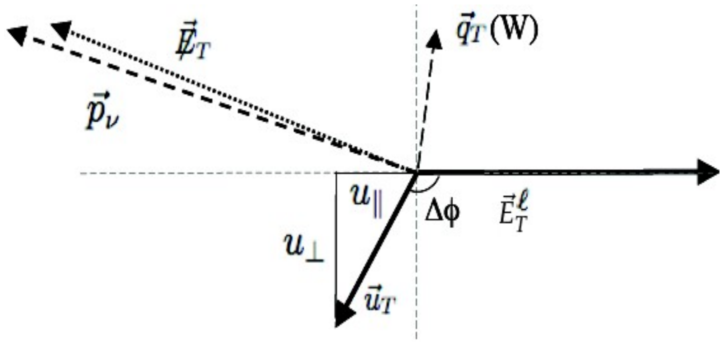
- MET a basis for signal extraction for both e & μ
  - Though some differences in approach ...
- Muons : extraction utilizes transverse mass (MT)

$$M_T = \sqrt{2 p_T(\mu) \not{E}_T (1 - \cos(\Delta\phi_{\mu,\not{E}_T}))}$$

  - Binned maximum likelihood template fit
    - Signal MT shapes from data-corrected MC
    - Background shape from cut inverted sample (w/ corrections)
  - Fit simultaneously for W+, W- and inclusive yields
- Electrons : employs MET distribution directly
  - Unbinned maximum likelihood “hybrid” fit
    - Signal MET shape from corrected MC
    - Background shape : Analytic function
  - Perform fit for inclusive yield and simultaneous fit for W+, W-



- Poor agreement for W → lν out of the box …
  - MC MET /MT shapes must be corrected for :
    - Lepton energy/momentum scale
    - Calorimeter response/resolution
    - Pileup and underlying event
- All addressed via the "recoil method"
  - Produces an improved, "best-fit" W → e/nu signal template



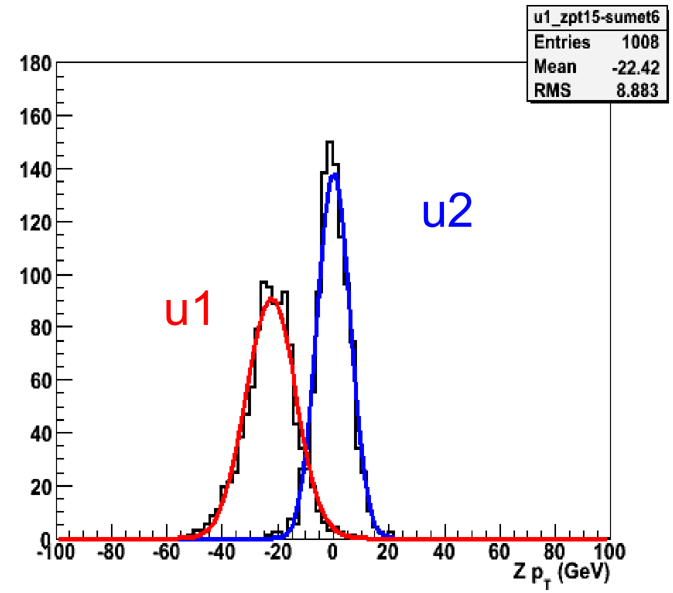
- Recoil vector (u) defined as MET after subtracting off the electron(s)

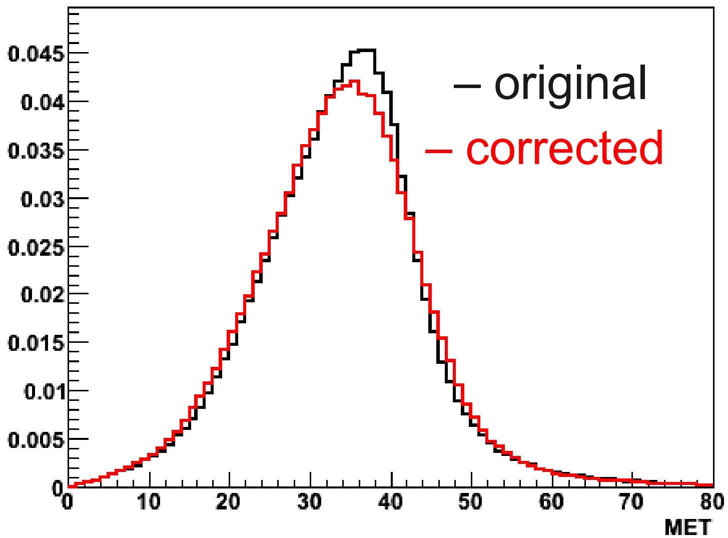
$$\vec{u} = \vec{\not{E}}_T - \vec{E}_T^{\ell}$$

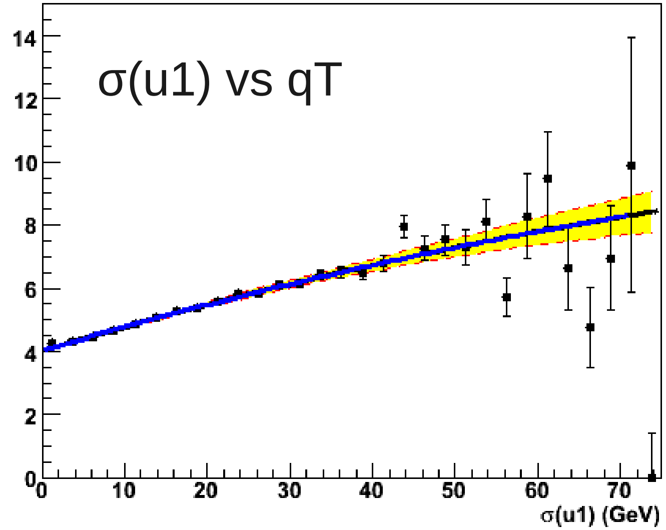
  - With PFMET, subtract using SC energy
  - Recoil components u1, u2 parallel/perpendicular to boson qT axis
  - Calculate u1,u2 for Z MC, Z data and W MC

W Shape Corrections : Recoil (2)

- Model components with Gaussians in qT
  - Fit response (mean) and resolution (width) in qT with 2nd order polynomials
  - Determine Z data/MC scale factors to correct W MC response/resolution
- Recalculate MET for each W MC event
  - Again, subtract off the electron electron
  - Sample u1/u2 distributions, parameters from scaled W MC curves
  - Add the lepton energy/momentum back to obtain corrected MET





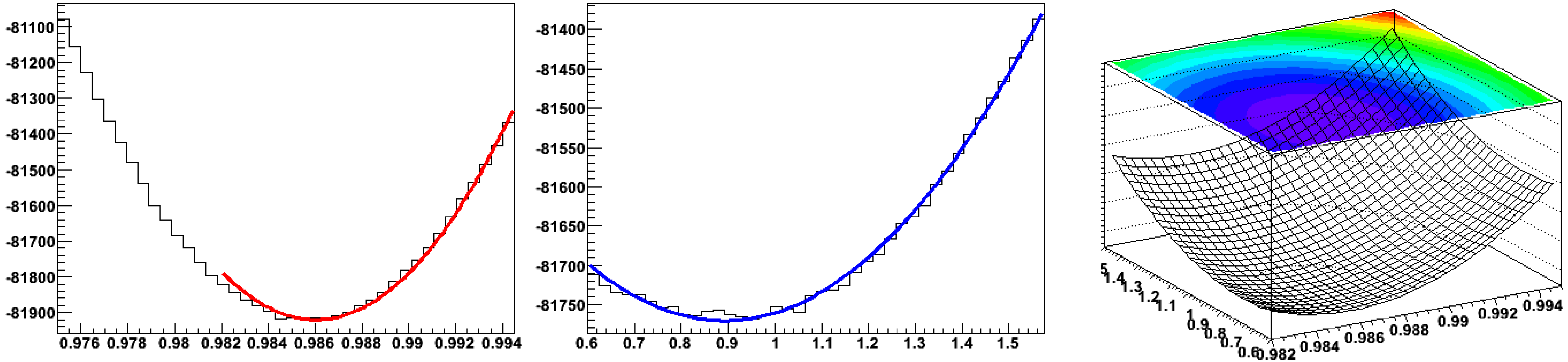


W Shape Corrections : Energy Scale

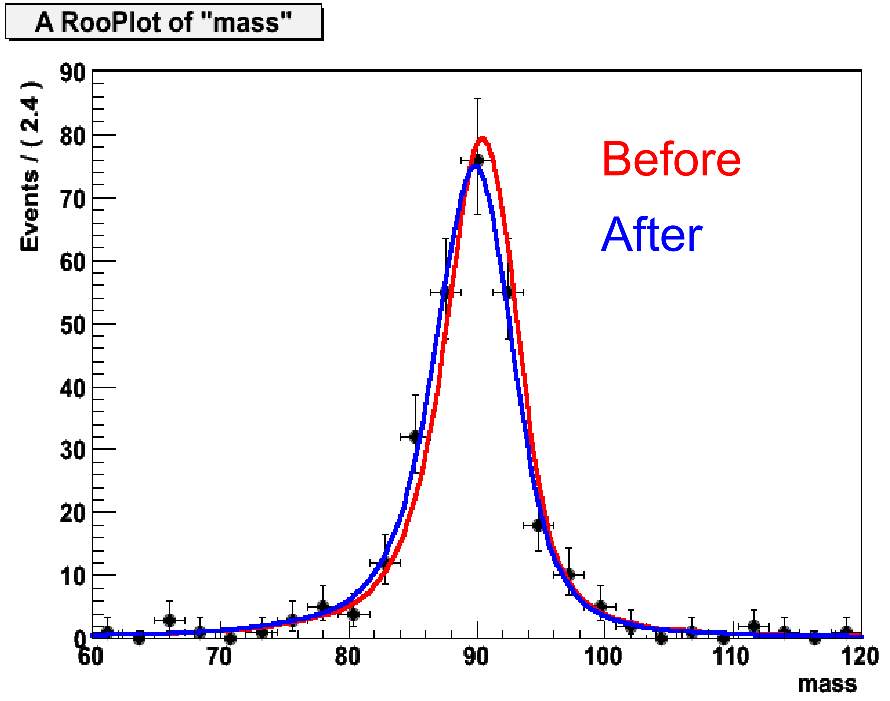
- Lepton energy/momentum also summed in the MET calculation
  - This must also be calibrated against data ...
- Electrons - energy scale & resolution correction factors from Z's
  - Scale and smear MC electron energy with Gaussian probability function

$$E_{new} = \mathrm{Gaus}(\alpha E_{old}, \beta)$$

  - Scan ranges of α and β, apply to reco MC
  - Calculate a new Mee in MC, fit to data, store -log(L) at each step
    - Results in a grid of -log(L) values vs α and β
  - Likelihood from fit approx. Gaussian in vicinity of maximum
    - Fit a 2D parabola to the minimum of -log(L)
    - This determines most probable scale factors
    - Stat. uncertainties from $[-\partial^2 \ell / \partial p_i^2]^{-1/2}$



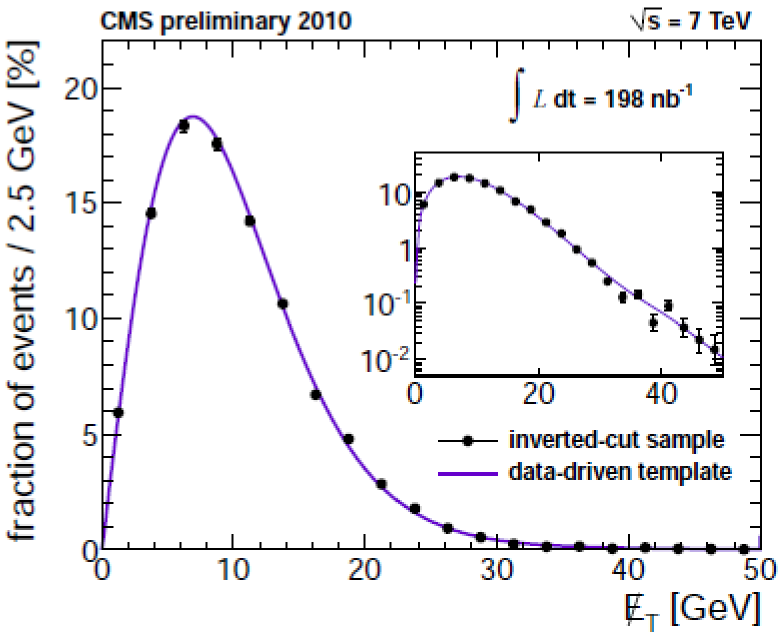
- Overall corrected MC shape: use scaled/smeared MC electrons when adding to corrected recoil
  - 1% shift in EB, 3% in EE
  - Smearing by 1-2 GeV
- Similar procedure for muons ...
  - Muon pT scale/resolution found to be adequate in MC
  - Use only for systematic bound : 0.4%



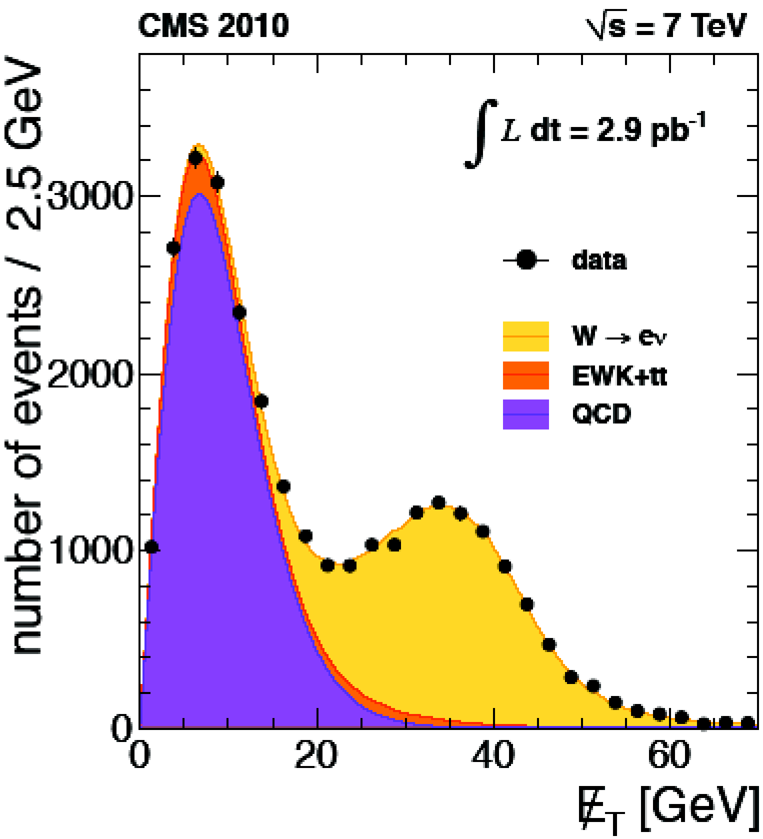
- Unbinned EML fit w/ static signal & parametrized background shape
  - Signal + EWK backgrounds : POWHEG
  - QCD background : Functional form from first principles …
    - Rayleigh distribution. : magnitude of vector w/ independent Gaussian components

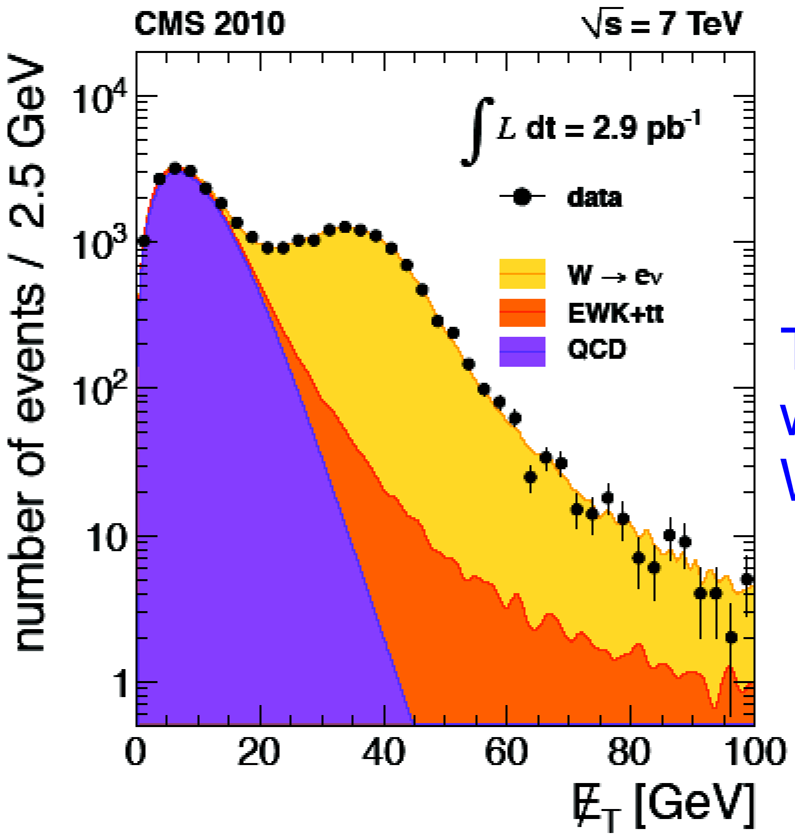
$$f(x) = Cx\exp\left(-\frac{x^2}{2(\sigma_0 + x\sigma_1)^2}\right)$$

    - Tail parameter σ_1 for ΣE_T dependence
    - And for real MET from b/c decays



- Validate background model with cut-inverted data samples
  - Iso_{Trk} & $\Delta\varphi$ least correlated w/ MET
  - Also used to assess modeling uncertainty



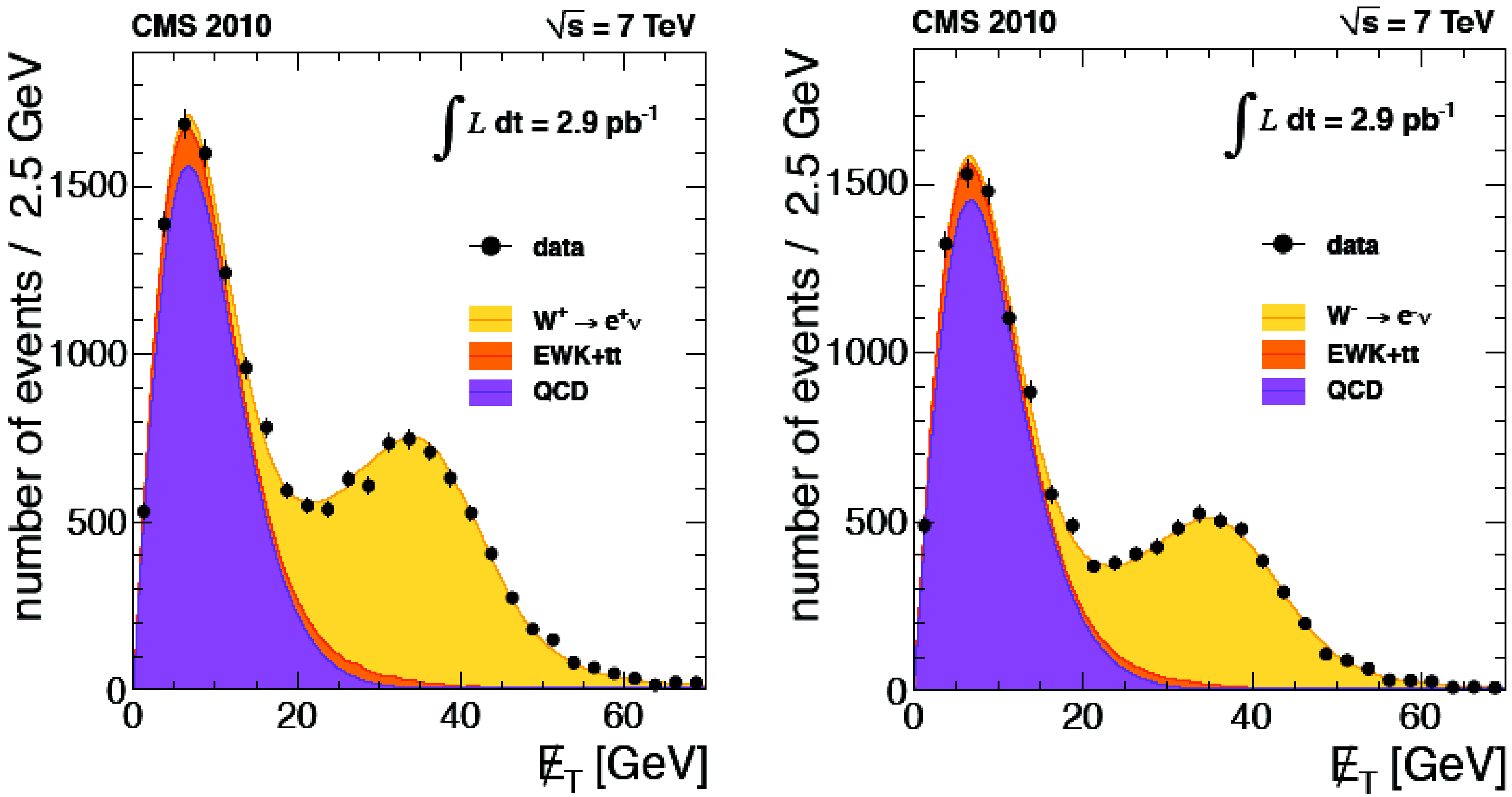


This fit performed with an inclusive W template

- Selected Events : 28601
- Extracted Yield : 11895 ± 115
- KS Probability : 0.49

source	N_{bkg}/N_W	how estimated
QCD multi-jet + γ-jet	~ 1.3	from UML fit
$Z \rightarrow e^+e^- + Z \rightarrow \tau^+\tau^-$	8.3%	MC
$W \rightarrow \tau\nu$	4.5%	MC
di-boson production	0.13%	MC
$t\bar{t}$	0.4%	MC
EWK	13.3%	MC

W→eν Extraction : Results (2)

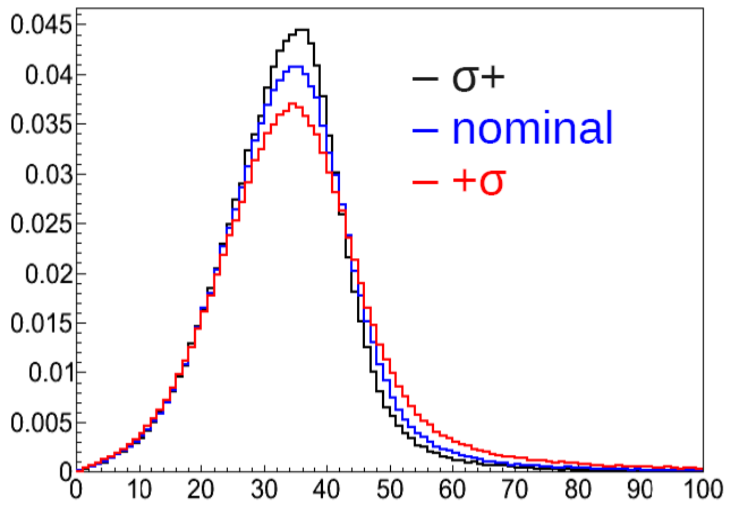


This (simultaneous) fit performed with W+ & W - templates

- e+ events obs. : 15859
- 7193 ± 89
- KS Prob. : 0.39

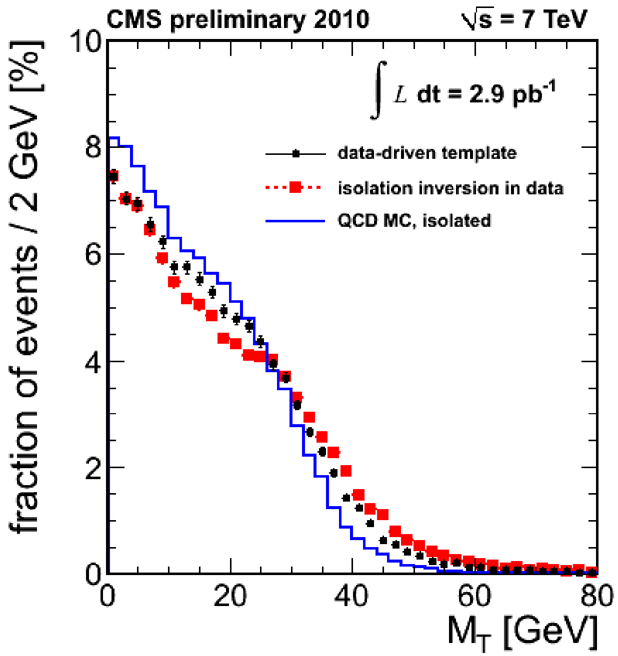
- e- events obs. : 12742
- 4728 ± 73
- KS Prob. : 0.53

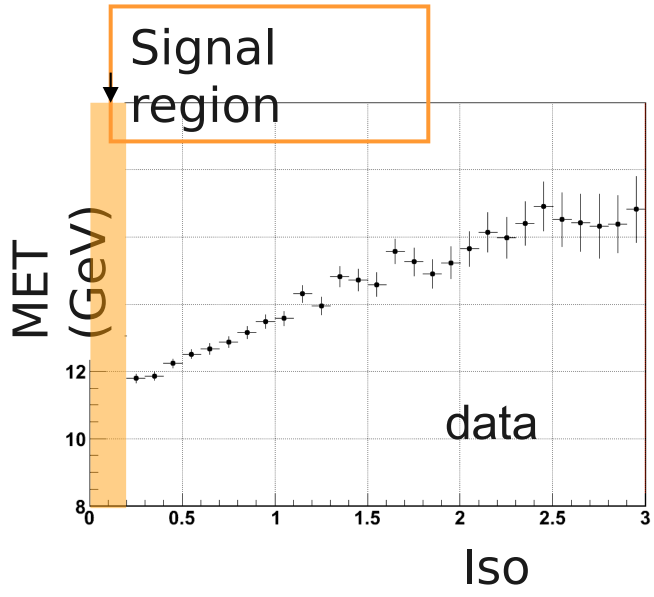
- Signal shape : propagate recoil model & energy scale uncertainties to MET & MT
  - This gives fluctuated shapes w.r.t that determined from best-fit parameters
  - Perform pseudo-experiments, generate with fluctuated shapes, fit with nominal
  - σ(recoil) : 1.8%, σ(scale) : 2.0%



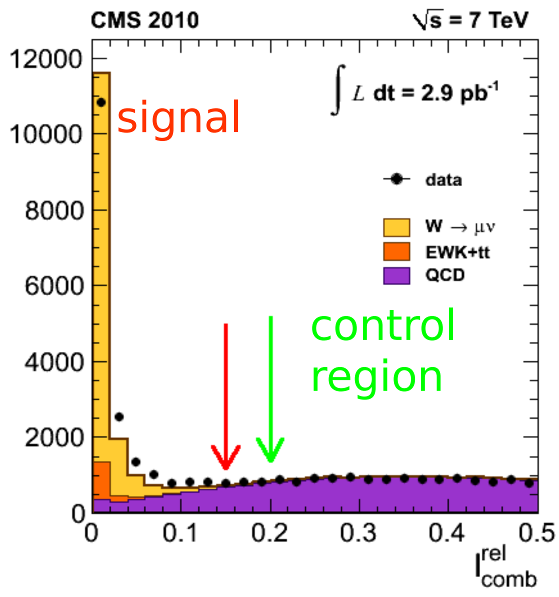
- Background model
  - Add an additional power to the model tail, $\sigma_2 x^2$
  - Constrain parameter to largest value found among anti-selected data, anti-selected MC, selected MC
  - Use this shape for generation of pseudo-experiements, fit w/ nominal
  - σ(background) : 1.3%

- Expect MC to describe QCD only qualitatively
- Better description from sample with isolation requirement inverted
  - Signal contamination negligible here
- But MT and Isolation are correlated …
  - Hadronic activity decreases isolation, increases SumET, influences MET

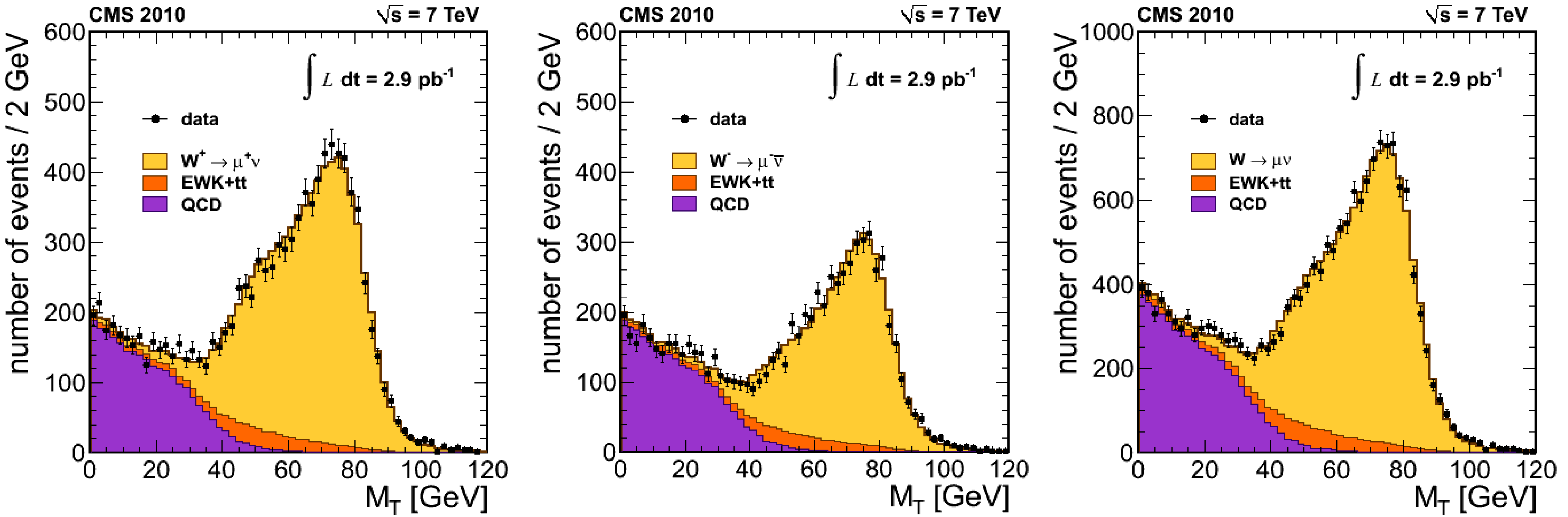




- Determine needed MET correction from behavior in iso-inverted sample
  - MET → MET/(1+axIso), a ~ 0.2
  - Largest spread among 3 predictions as systematic



W→μν Extraction : Results

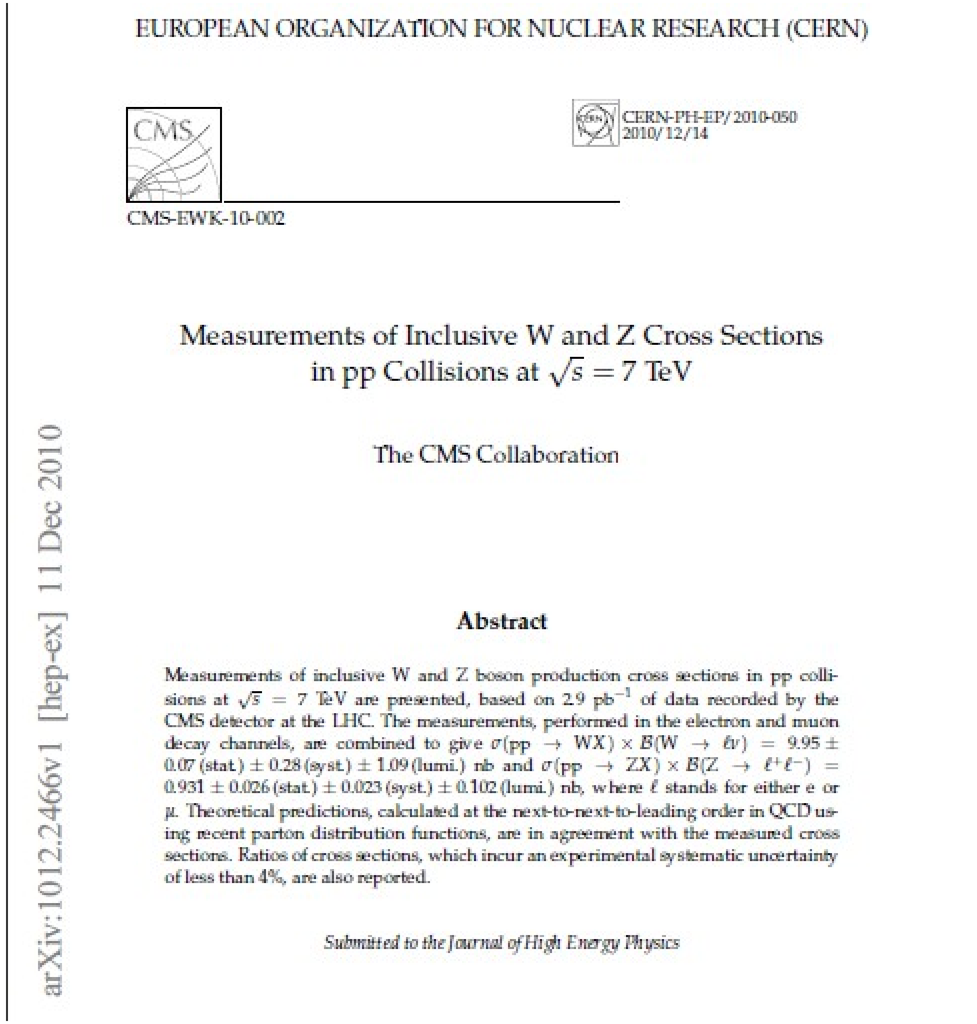


- μ^+ events obs. : 10682
- W Yield : 7445 ± 87

- μ^- events obs. : 7889
- W Yield : 4812 ± 68

- μ events Obs. : 18571
- W Yield : 12257 ± 111

- W+ & W- yields extracted from a simultaneous fit
  - Total W yield and ratio follow as a result


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2010-050
2010/12/14

CMS-EWK-10-002

Measurements of Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration

Abstract

Measurements of inclusive W and Z boson production cross sections in pp collisions at $\sqrt{s} = 7$ TeV are presented, based on 2.9 pb^{-1} of data recorded by the CMS detector at the LHC. The measurements, performed in the electron and muon decay channels, are combined to give $\sigma(\mathrm{pp} \to \mathrm{W}X) \times \mathcal{B}(\mathrm{W} \to \ell\nu) = 9.95 \pm 0.07\,(\mathrm{stat.}) \pm 0.28\,(\mathrm{syst.}) \pm 1.09\,(\mathrm{lumi.})$ nb and $\sigma(\mathrm{pp} \to \mathrm{Z}X) \times \mathcal{B}(\mathrm{Z} \to \ell^+\ell^-) = 0.931 \pm 0.026\,(\mathrm{stat.}) \pm 0.023\,(\mathrm{syst.}) \pm 0.102\,(\mathrm{lumi.})$ nb, where ℓ stands for either e or μ. Theoretical predictions, calculated at the next-to-next-to-leading order in QCD using recent parton distribution functions, are in agreement with the measured cross sections. Ratios of cross sections, which incur an experimental systematic uncertainty of less than 4%, are also reported.

Submitted to the Journal of High Energy Physics

Cross Section Results

Channel		$\sigma \times \mathcal{B}$ (nb)	NNLO (nb)
W	$e\nu$	10.04 ± 0.10 (stat.) ± 0.52 (syst.) ± 1.10 (lumi.)	10.44 ± 0.52
	$\mu\nu$	9.92 ± 0.09 (stat.) ± 0.31 (syst.) ± 1.09 (lumi.)	
	$\ell\nu$	9.95 ± 0.07 (stat.) ± 0.28 (syst.) ± 1.09 (lumi.)	
W^+	$e^+\nu$	5.93 ± 0.07 (stat.) ± 0.36 (syst.) ± 0.65 (lumi.)	6.15 ± 0.29
	$\mu^+\nu$	5.84 ± 0.07 (stat.) ± 0.18 (syst.) ± 0.64 (lumi.)	
	$\ell^+\nu$	5.86 ± 0.06 (stat.) ± 0.17 (syst.) ± 0.64 (lumi.)	
W^-	$e^-\bar{\nu}$	4.14 ± 0.06 (stat.) ± 0.25 (syst.) ± 0.45 (lumi.)	4.29 ± 0.23
	$\mu^-\bar{\nu}$	4.08 ± 0.06 (stat.) ± 0.15 (syst.) ± 0.45 (lumi.)	
	$\ell^-\bar{\nu}$	4.09 ± 0.05 (stat.) ± 0.14 (syst.) ± 0.45 (lumi.)	
Z	e^+e^-	0.960 ± 0.037 (stat.) ± 0.059 (syst.) ± 0.106 (lumi.)	0.972 ± 0.042
	$\mu^+\mu^-$	0.924 ± 0.031 (stat.) ± 0.022 (syst.) ± 0.102 (lumi.)	
	$\ell^+\ell^-$	0.931 ± 0.026 (stat.) ± 0.023 (syst.) ± 0.102 (lumi.)	

Source	W^+ (e)	W^- (e)	W^+/W^- (e)	W/Z (e)
Lepton reconstruction & identification	5.1	5.1	5.2	3.0
Momentum scale & resolution	2.2	1.8	0.4	2.0
$\not{E}_T$ scale & resolution	1.6	1.9	0.4	1.8
Background subtraction / modeling	1.1	1.5	0.7	1.3
PDF uncertainty for acceptance	0.9	1.5	1.7	0.9
Other theoretical uncertainties	1.3	0.9	1.3	1.0
Total	6.1	6.2	5.7	4.4

Source	W^+ (μ)	W^- (μ)	W^+/W^- (μ)	W/Z (μ)
Lepton reconstruction & identification	1.5	1.5	2.8	0.9
Momentum scale & resolution	0.3	0.3	0.3	0.1
$\not{E}_T$ scale & resolution	0.4	0.4	0	0.4
Background subtraction / modeling	1.7	2.3	0.7	2.2
PDF uncertainty for acceptance	1.3	1.9	2.1	1.1
Other theoretical uncertainties	1.4	1.3	1.2	1.4
Total	3.0	3.6	3.8	3.0

Cross Sections

Channel		$\sigma \times \mathcal{B}$ (nb)	NNLO (nb)
W	$e\nu$	10.04 ± 0.10 (stat.) ± 0.52 (syst.) ± 1.10 (lumi.)	10.44 ± 0.52
	$\mu\nu$	9.92 ± 0.09 (stat.) ± 0.31 (syst.) ± 1.09 (lumi.)	
	$\ell\nu$	9.95 ± 0.07 (stat.) ± 0.28 (syst.) ± 1.09 (lumi.)	
W^+	$e^+\nu$	5.93 ± 0.07 (stat.) ± 0.36 (syst.) ± 0.65 (lumi.)	6.15 ± 0.29
	$\mu^+\nu$	5.84 ± 0.07 (stat.) ± 0.18 (syst.) ± 0.64 (lumi.)	
	$\ell^+\nu$	5.86 ± 0.06 (stat.) ± 0.17 (syst.) ± 0.64 (lumi.)	
W^-	$e^-\bar{\nu}$	4.14 ± 0.06 (stat.) ± 0.25 (syst.) ± 0.45 (lumi.)	4.29 ± 0.23
	$\mu^-\bar{\nu}$	4.08 ± 0.06 (stat.) ± 0.15 (syst.) ± 0.45 (lumi.)	
	$\ell^-\bar{\nu}$	4.09 ± 0.05 (stat.) ± 0.14 (syst.) ± 0.45 (lumi.)	
Z	e^+e^-	0.960 ± 0.037 (stat.) ± 0.059 (syst.) ± 0.106 (lumi.)	0.972 ± 0.042
	$\mu^+\mu^-$	0.924 ± 0.031 (stat.) ± 0.022 (syst.) ± 0.102 (lumi.)	
	$\ell^+\ell^-$	0.931 ± 0.026 (stat.) ± 0.023 (syst.) ± 0.102 (lumi.)	

- Good agreement across channels
- Combine e & μ by maximizing a joint likelihood
  - Including statistical and correlated systematic errors

- Additionally quote cross-sections restricted to acceptance region
  - Transfer theoretical uncertainties from measurements → predictions

Channel	$\sigma \times \mathcal{B}$ in acceptance A (nb)	A	
$W \to e\nu_e$	6.04 ± 0.06 (stat.) ± 0.31 (syst.) ± 0.66 (lumi.)	0.601 ± 0.005	$p_T > 20$ GeV, $\lvert\eta\rvert < 2.5$
$W^+ \to e^+\nu_e$	3.69 ± 0.05 (stat.) ± 0.22 (syst.) ± 0.41 (lumi.)	0.622 ± 0.006	
$W^- \to e^-\bar{\nu}_e$	2.36 ± 0.04 (stat.) ± 0.14 (syst.) ± 0.26 (lumi.)	0.571 ± 0.009	
$Z \to e^+e^-$	0.460 ± 0.018 (stat.) ± 0.028 (syst.) ± 0.051 (lumi.)	0.479 ± 0.005	
$W \to \mu\nu_\mu$	5.21 ± 0.05 (stat.) ± 0.15 (syst.) ± 0.57 (lumi.)	0.525 ± 0.006	$p_T > 20$ GeV, $\lvert\eta\rvert < 2.1$
$W^+ \to \mu^+\nu_\mu$	3.16 ± 0.04 (stat.) ± 0.10 (syst.) ± 0.35 (lumi.)	0.541 ± 0.006	
$W^- \to \mu^-\bar{\nu}_\mu$	2.05 ± 0.03 (stat.) ± 0.06 (syst.) ± 0.22 (lumi.)	0.502 ± 0.006	
$Z \to \mu^+\mu^-$	0.368 ± 0.012 (stat.) ± 0.007 (syst.) ± 0.040 (lumi.)	0.398 ± 0.005	

- POWHEG acceptance after QED, basic cuts

Cross Section Ratios

Quantity		Ratio	NNLO
$R_{W/Z}$	e	$10.47 \pm 0.42\,(\text{stat.}) \pm 0.47\,(\text{syst.})$	10.74 ± 0.04
	μ	$10.74 \pm 0.37\,(\text{stat.}) \pm 0.33\,(\text{syst.})$	
	ℓ	$10.64 \pm 0.28\,(\text{stat.}) \pm 0.29\,(\text{syst.})$	
$R_{+/-}$	e	$1.434 \pm 0.028\,(\text{stat.}) \pm 0.082\,(\text{syst.})$	1.435 ± 0.044
	μ	$1.433 \pm 0.026\,(\text{stat.}) \pm 0.054\,(\text{syst.})$	
	ℓ	$1.433 \pm 0.020\,(\text{stat.}) \pm 0.050\,(\text{syst.})$	

- Luminosity drops out in the ratio
- good agreement w/ NNLO

- Relative to theory ...
  - Systematic shift in cross sections observed, not in ratio
  - Presumably luminosity bias
    - Well covered by present uncertainties

Quantity		Ratio (CMS/Theory)	Lumi. Uncertainty
$\sigma \times \mathcal{B}$	W	$0.953 \pm 0.028\,(\text{exp.}) \pm 0.048\,(\text{theo.})$	± 0.11
	W^+	$0.953 \pm 0.029\,(\text{exp.}) \pm 0.045\,(\text{theo.})$	
	W^-	$0.954 \pm 0.034\,(\text{exp.}) \pm 0.051\,(\text{theo.})$	
	Z	$0.960 \pm 0.036\,(\text{exp.}) \pm 0.040\,(\text{theo.})$	
$R_{W/Z}$		$0.990 \pm 0.038\,(\text{exp.}) \pm 0.004\,(\text{theo.})$	nil
$R_{+/-}$		$1.002 \pm 0.038\,(\text{exp.}) \pm 0.028\,(\text{theo.})$	

Systematic Uncertainties

Source	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$	$Z \rightarrow e^+e^-$	$Z \rightarrow \mu^+\mu^-$
Lepton reconstruction & identification	3.9	1.4	5.9	n/a
Pre-triggering	n/a	0.5	n/a	0.5
Momentum scale & resolution	2.0	0.3	0.6	0.2
$\not\!\!E_T$ scale & resolution	1.8	0.4	n/a	n/a
Background subtraction / modeling	1.3	2.0	0.1	1.0
PDF uncertainty for acceptance	0.8	1.1	1.1	1.2
Other theoretical uncertainties	1.3	1.4	1.3	1.6
Total	5.1	3.1	6.2	2.3
Statistical (%)	1.0	0.9	3.9	3.4

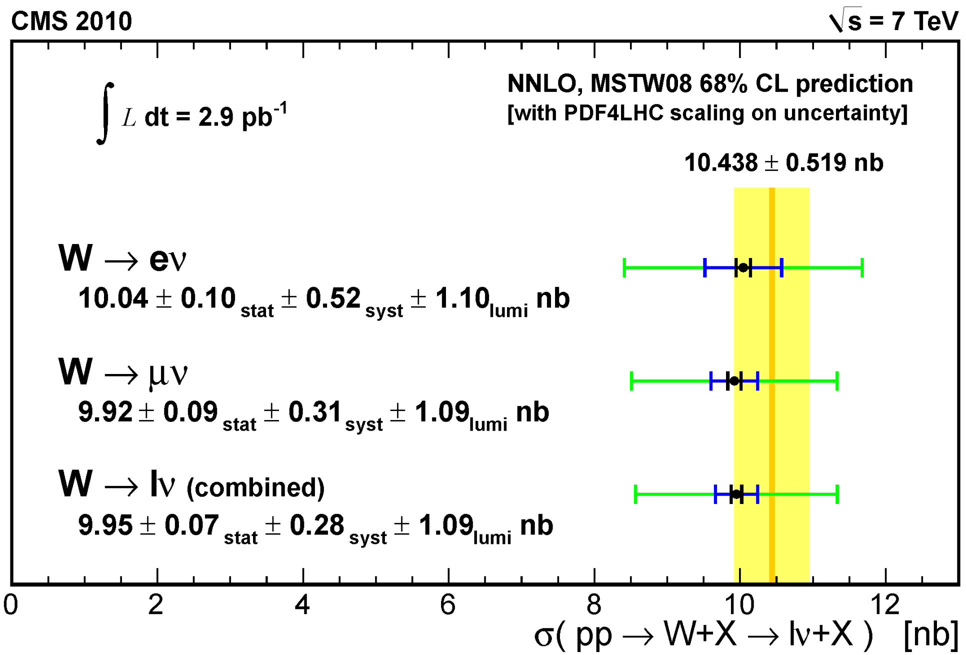
- W cross-section limited by signal/background modeling and lepton efficiency measurements
- Z cross-section limited by statistics and systematics from lepton efficiency

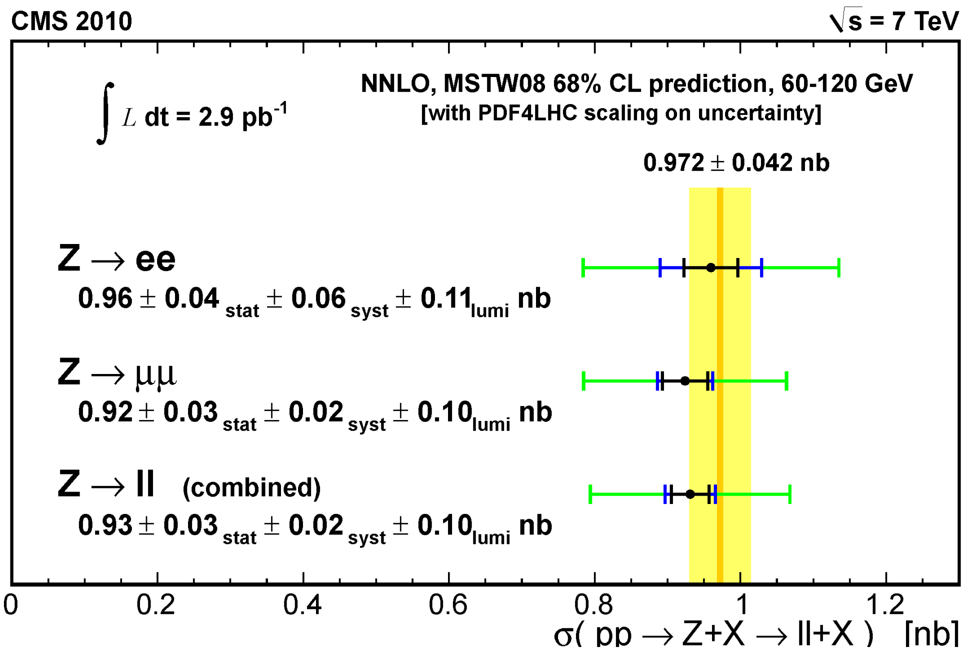
Systematics Uncertainties (2)

Source	W^+ (e)	W^- (e)	W^+/W^- (e)	W/Z (e)
Lepton reconstruction & identification	5.1	5.1	5.2	3.0
Momentum scale & resolution	2.2	1.8	0.4	2.0
$\not\!\!E_T$ scale & resolution	1.6	1.9	0.4	1.8
Background subtraction / modeling	1.1	1.5	0.7	1.3
PDF uncertainty for acceptance	0.9	1.5	1.7	0.9
Other theoretical uncertainties	1.3	0.9	1.3	1.0
Total	6.1	6.2	5.7	4.4

Source	W^+ (μ)	W^- (μ)	W^+/W^- (μ)	W/Z (μ)
Lepton reconstruction & identification	1.5	1.5	2.8	0.9
Momentum scale & resolution	0.3	0.3	0.3	0.1
$\not\!\!E_T$ scale & resolution	0.4	0.4	0	0.4
Background subtraction / modeling	1.7	2.3	0.7	2.2
PDF uncertainty for acceptance	1.3	1.9	2.1	1.1
Other theoretical uncertainties	1.4	1.3	1.2	1.4
Total	3.0	3.6	3.8	3.0

- W+ W- ratio limited by ratio of lepton efficiencies
  - Determined from statistically limited sample of Z
- W/Z ratio limited by BG model and lepton efficiencies





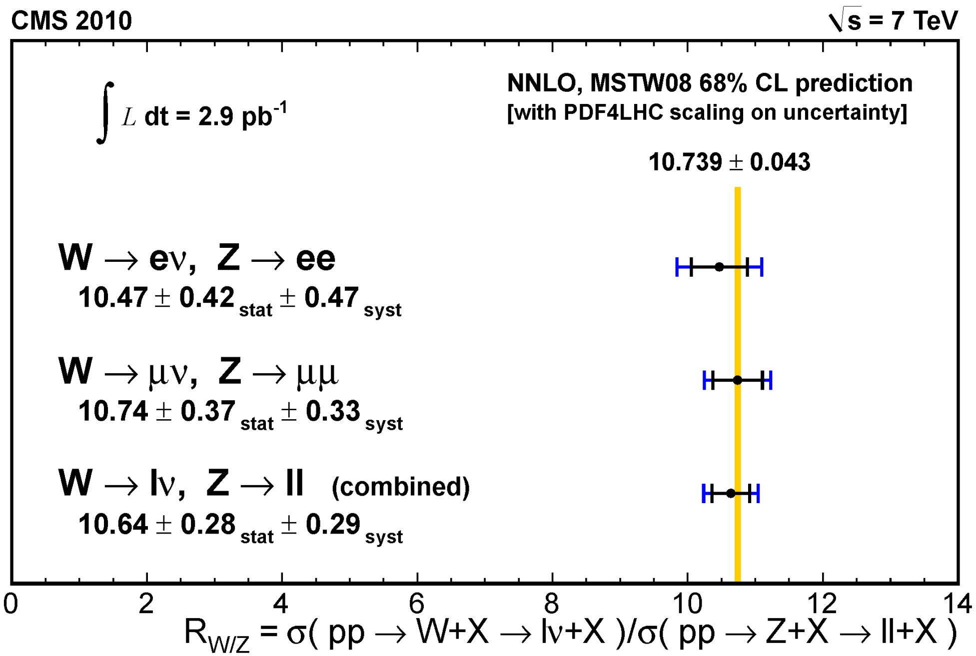
W cross section non-lumi error 2.9%

Z cross section non-lumi error 3.9%

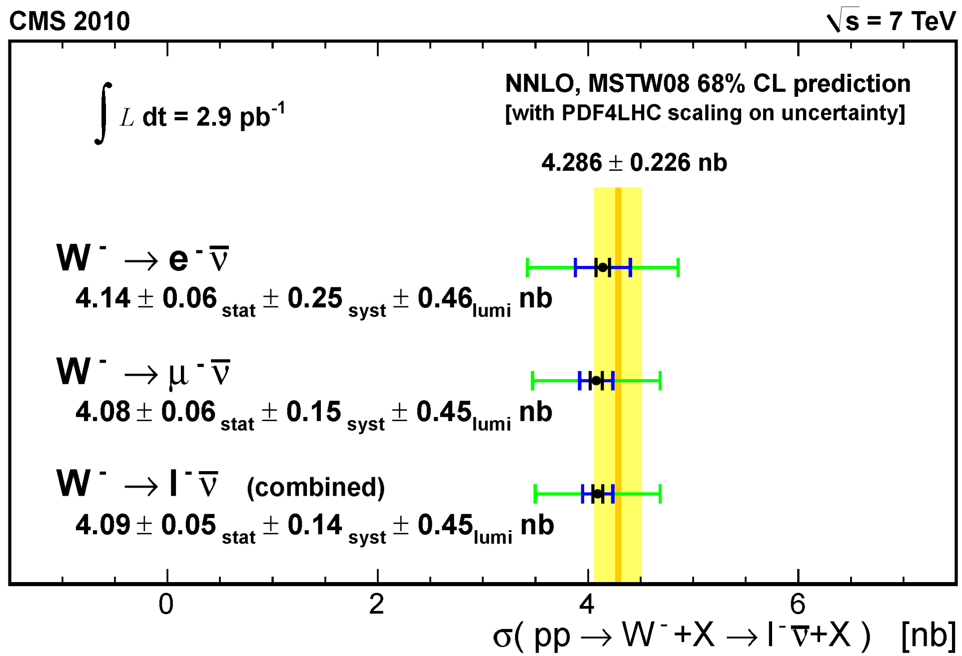
W/Z ratio total error 3.8%

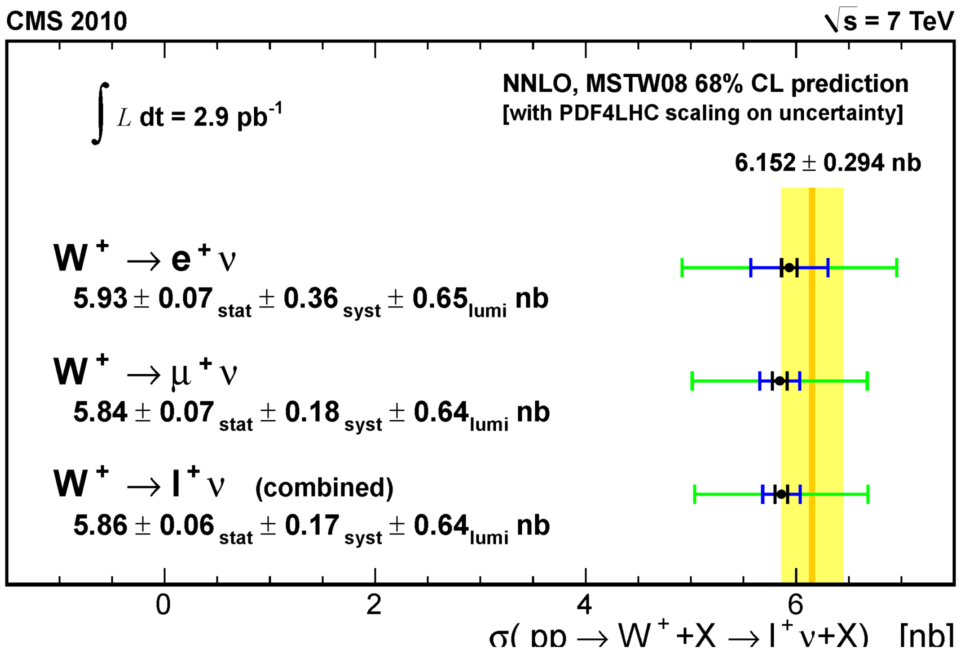
Internally consistent across channels

Everywhere close to systematics limited

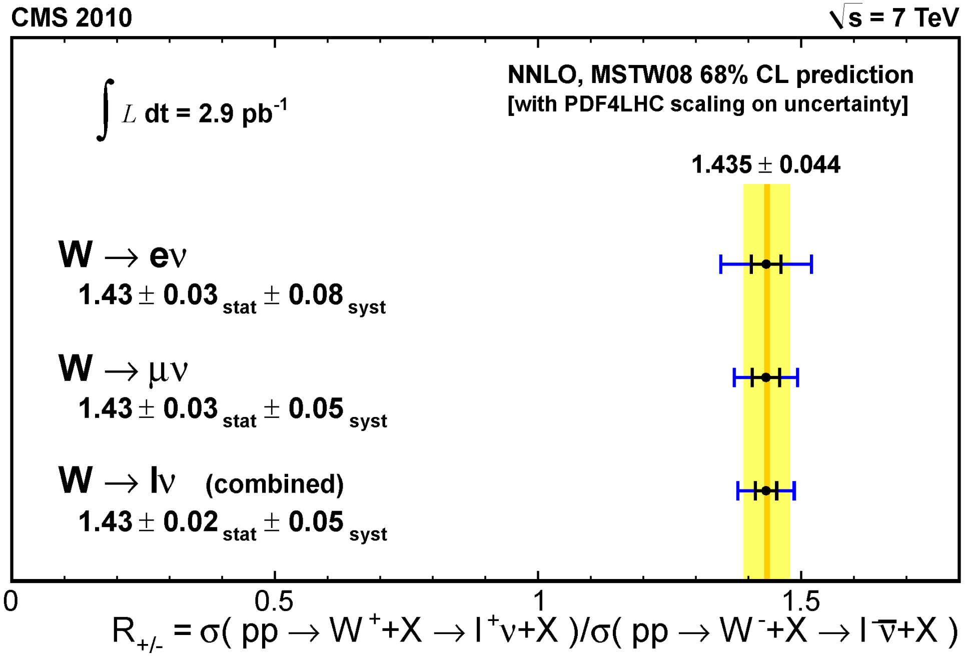


Graphical W+ & W-

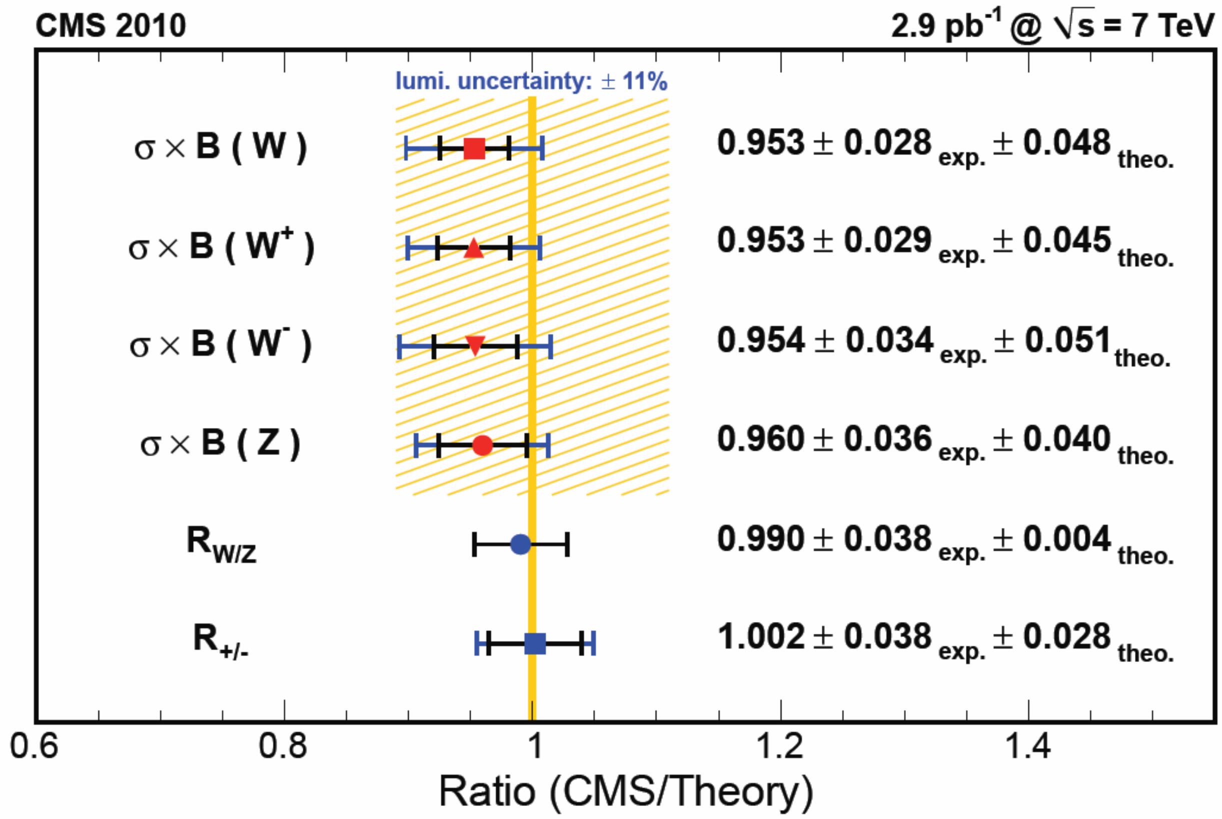


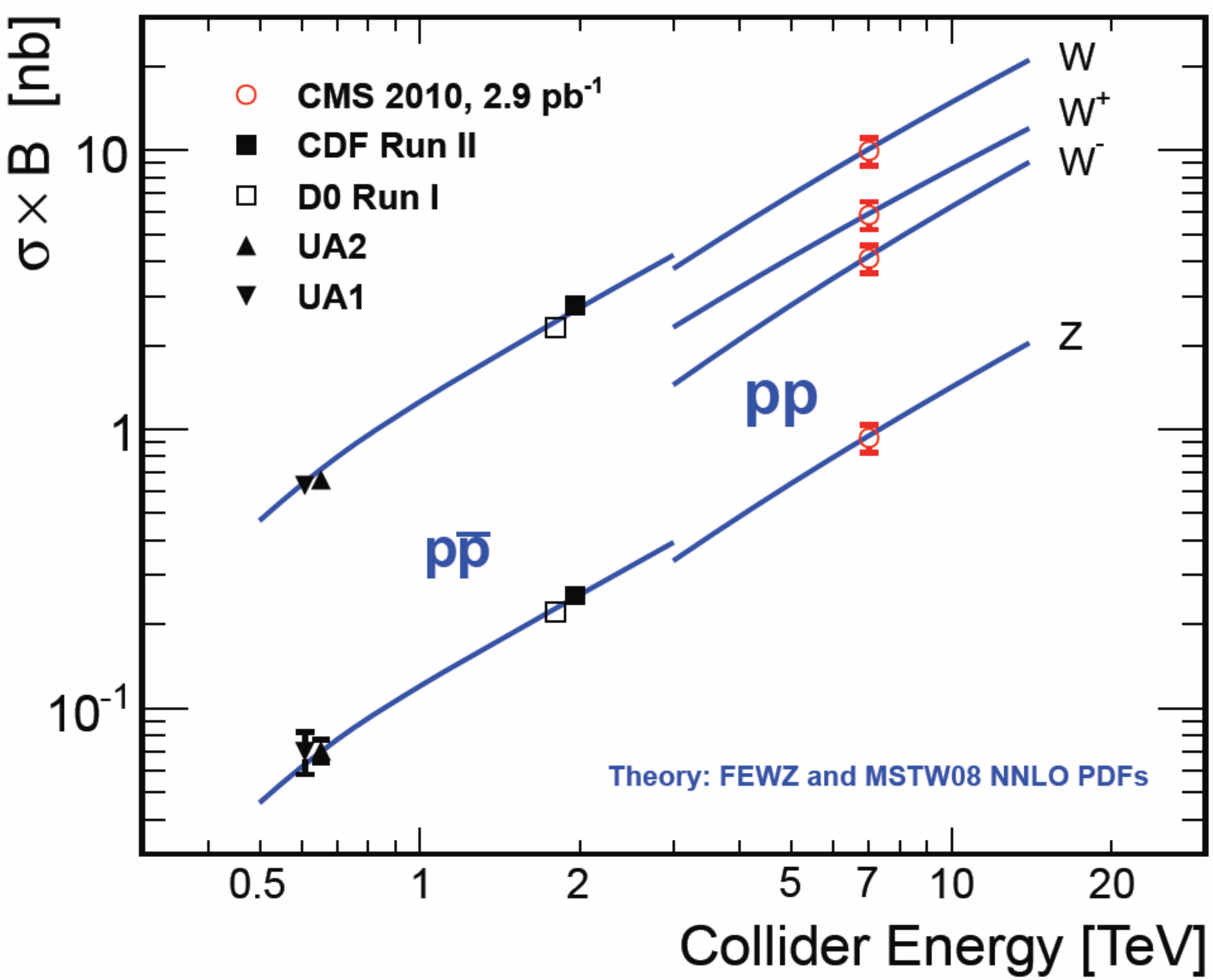


- W+ and W- consistent with PDF expectations
- Close to challenging global PDF precision!
- Limited primarily by +/- efficiency ratio (Z statistics)

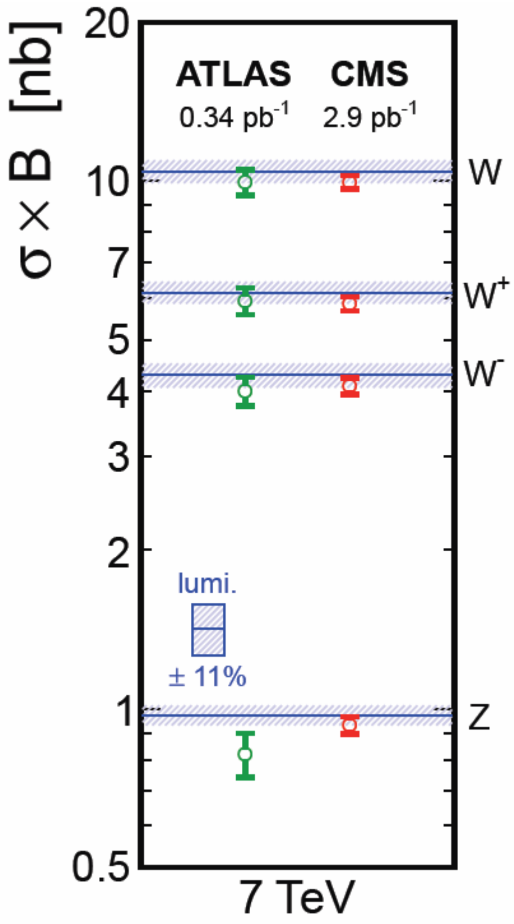


Results vs Theory

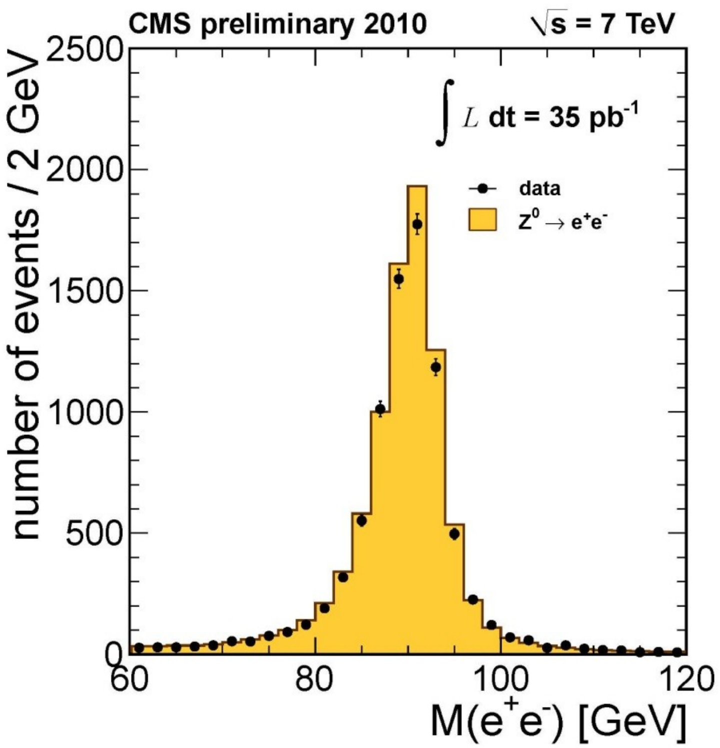




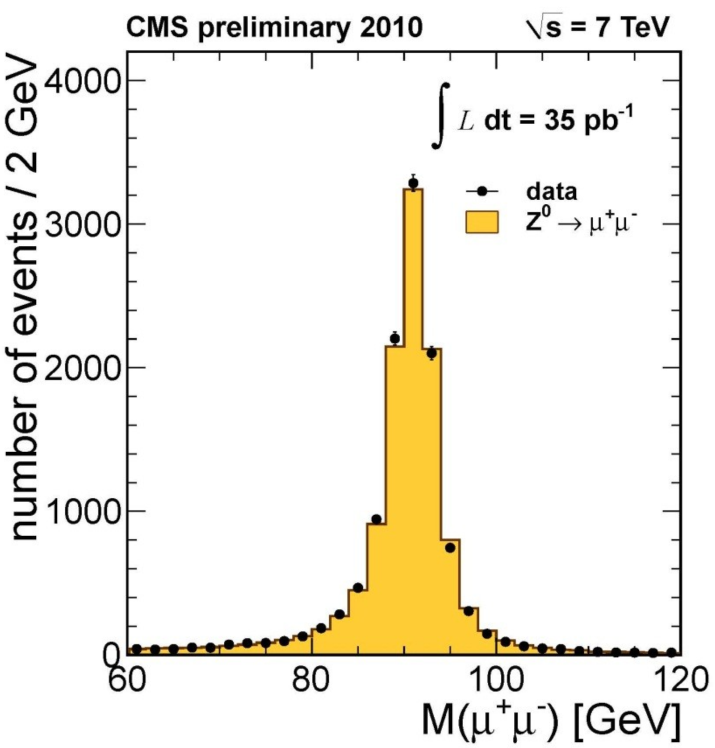
CMS 2010, 2.9 pb-1
CDF Run II
D0 Run I
UA2
UA1
W
W+
W-
Z
pp
pp̄
Theory: FEWZ and MSTW08 NNLO PDFs
σ × B [nb]
Collider Energy [TeV]
0.5
1
2
5
7
10
20
10
1
10-1



ATLAS
0.34 pb-1
CMS
2.9 pb-1
W
W+
W-
Z
lumi.
± 11%
σ × B [nb]
7 TeV
20
10
7
5
4
3
2
1
0.5

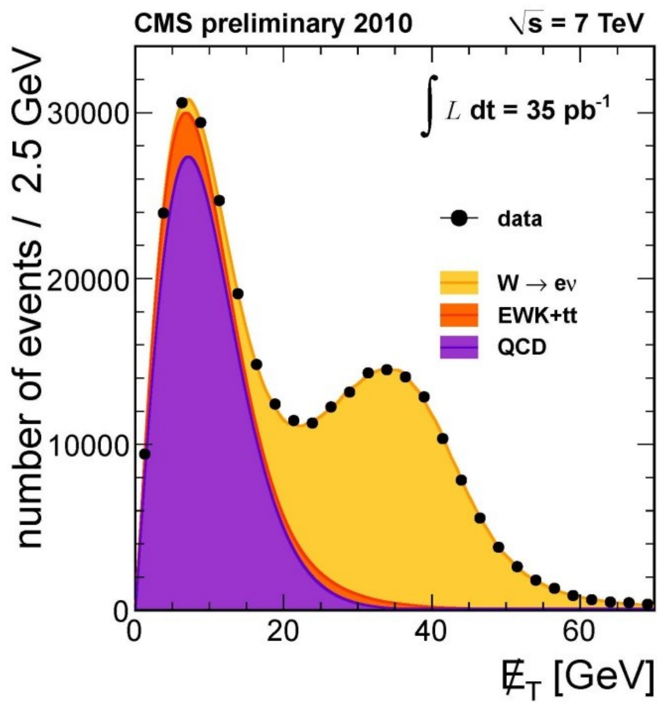


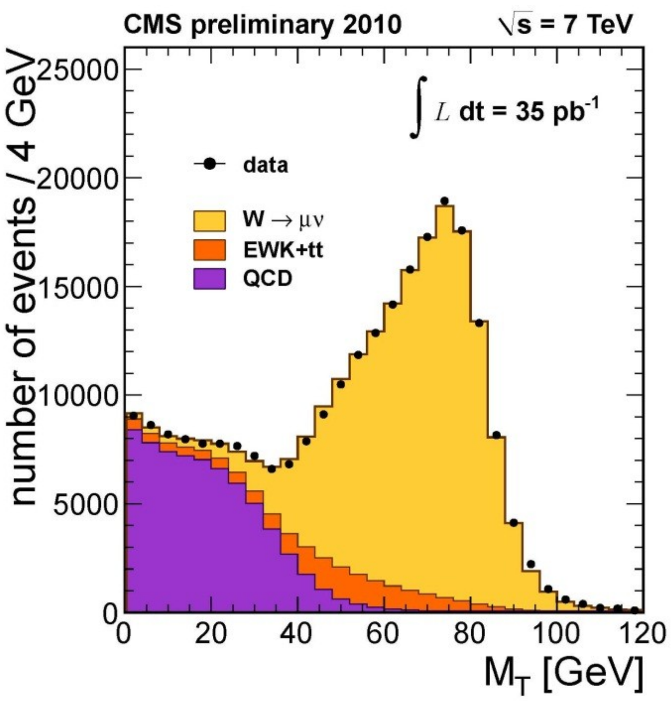
Z candidates: 8253



Z candidates: 11697

- Observed candidates agree with expectations (within old systematics)
- Dimuon candidates exhibit excellent first pass scale and resolution
- Dielectron candidates require ECAL crystal transparency correction
  - In progress EB,EE-averaged rescaling shown here





First pass fit: 161k Ws	First pass fit : 144k Ws
W+ yield : 98156	W+ yield : 87884
W- yield : 62714	W- yield : 56912

- Observed candidates agree with expectations (within old systematics)
- Updated recoil corrections to W signal, electron energy scale
  - Method continues to give an excellent description of data

The Road Ahead

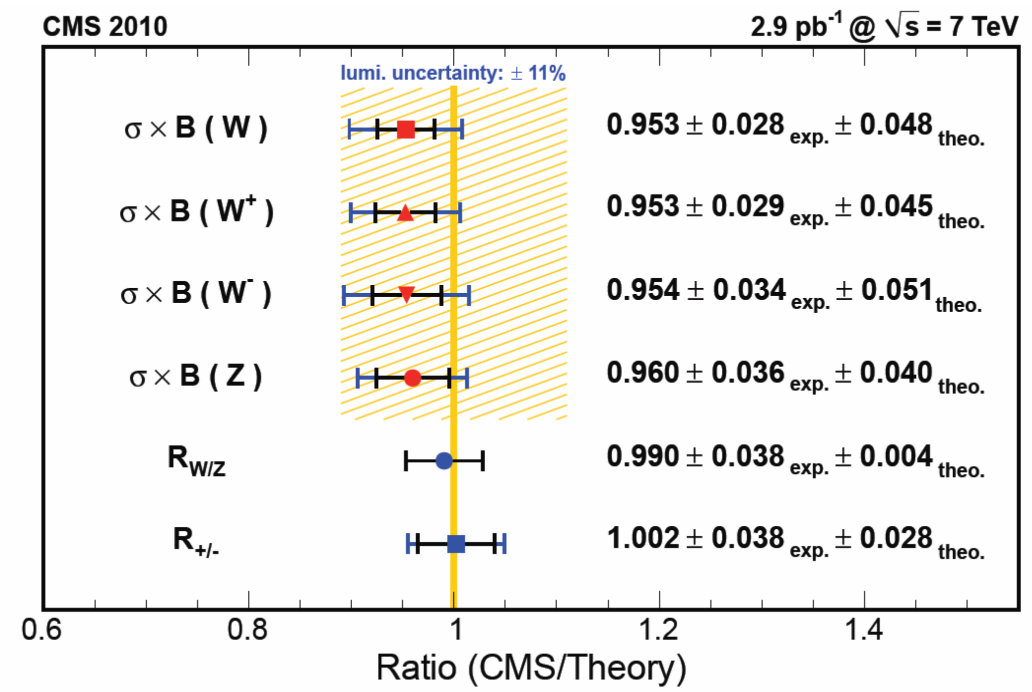
- Target experimental precision of 2% (non-lumi)
  - Then theory error from acceptance dominates
  - 2% is a x2 improvement in uncertainties
- Key systematics to reduce
  - Lepton efficiency
    - Signal and background shapes for passing and failing samples
    - Some improvement expected from better statistics
  - Background modeling for $W \rightarrow l\nu$
- Other improvements will be required …
  - Efficiencies and corrections in finer binning
  - Simultaneous fit for efficiencies extended to electrons

Conclusions

- Just eight months into its first 7 TeV collision run, CMS has achieved 4% precision tests of electroweak physics.

- Electrons, muons, and missing energy are well-calibrated detector objects ready for precision analysis.

- Extraordinary performance by detector operations, computing, detector simulation, and physics objects groups made this possible.



- W and Z production rates are already superior estimators of integrated luminosity and real time detector performance.