Measurement of the Inclusive W/Z Production Cross-Sections at CMS and W/Z as a Luminometer

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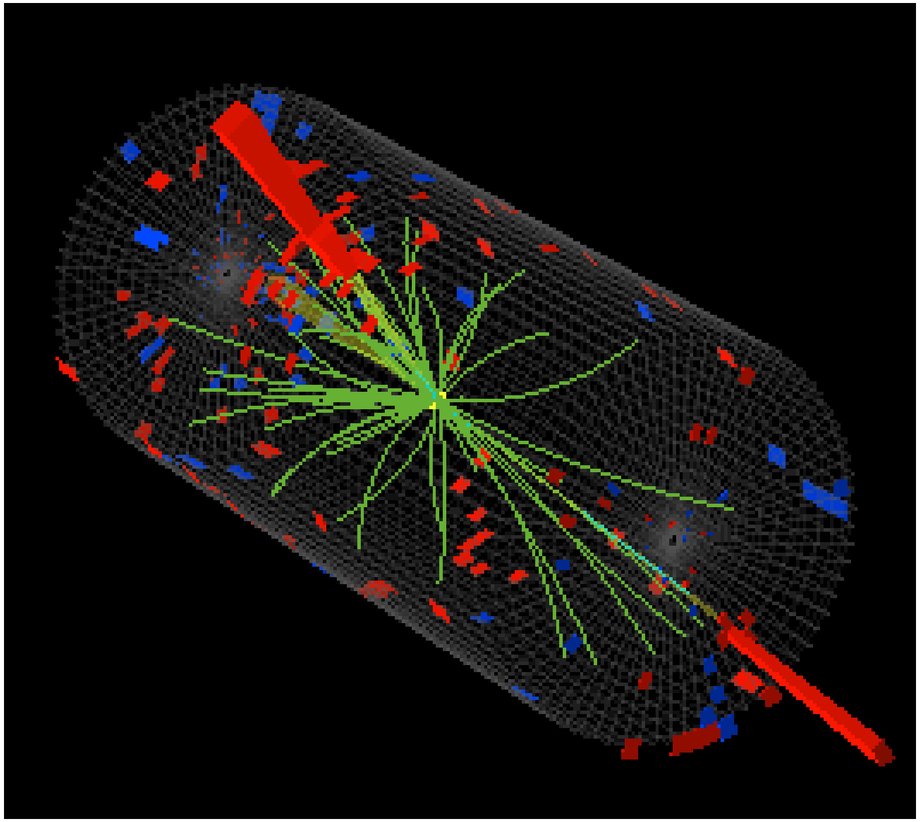
On Behalf of the CMS Collaboration

LHC Lumi Days
Jan 13, 2011



Motivations and Observable

Motivation

- W and Z production are the first EWK processes studied at the LHC
- First benchmark for high-P_T electron and muon reconstruction and identification
- Precision tests of perturbative QCD and proton PDFs
- **Estimator of the LHC luminosity**

First physics luminometer

Measurements

- Inclusive W/Z production cross sections
  - Measured separately for electrons and muons and combined
  - Directly compared with Standard Model NNLO predictions
  - Precision was limited by systematic uncertainty on the luminosity (11%)
- Ratio of W^+/W^- and W/Z production cross sections
  - Insensitive to luminosity and other sources of error (4% precision)

Data Sample

- $\int L dt = 2.88 \pm 0.32\ pb^{-1}$ of $\sqrt{S} = 7$ TeV pp collision data collected from Apr-Aug 2010
- 10 x larger data sample (47 pb-1) was delivered by LHC and is currently being analyzed

How many events were expected ?

$A_w \sim 55\%$, $A_z \sim 40\%$, $\varepsilon_{lepton} \sim 80\%$

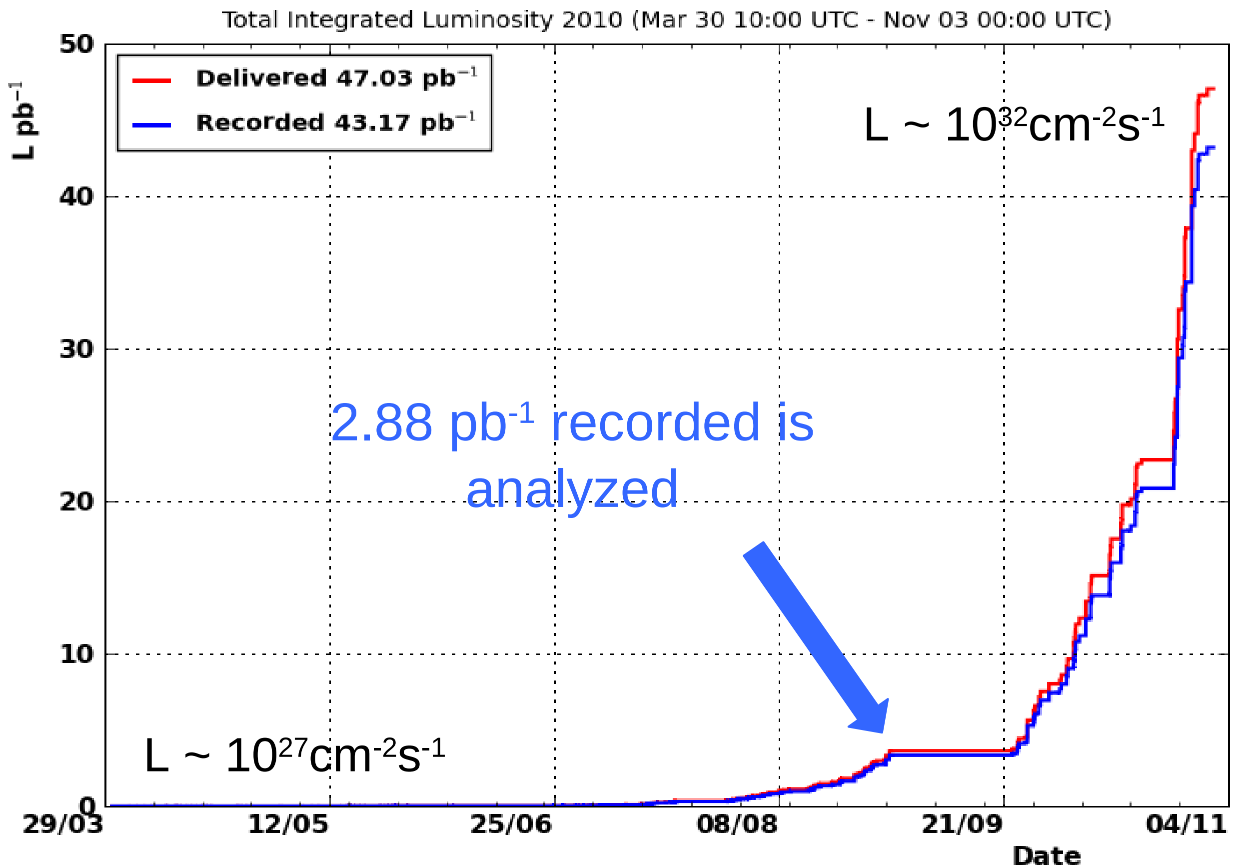
$N_w \sim 12000$ $\sigma_W \sim 10$ nb

$N_z \sim 700$ $\sigma_Z \sim 1$ nb

Target : $\sigma_{w,stat} \sim 1\%$

$\sigma_{z,stat} \sim 4\%$

Analysis approved for JHEP: http://arxiv.org/abs/1012.2466



Thanks to LHC for continuously increasing the luminosity!

W/Z Cross Section Measurements

Signal W: Prompt, energetic, isolated lepton and significant MET
Background W: QCD multi-jets**,** γ+jets (electrons)**,** Drell-Yan, W → τν, Z → ττ, tt, diboson
Signal & background yields: by fitting MT (muons) or MET (electrons) distributions.

Signal Z: Two energetic, isolated leptons with M_{ll} around M_Z
Background Z: Negligible QCD bkg, EWK and top bkg known precisely @ NLO
Signal yields: Cut & count (electrons), Simultaneous fit for yield & efficiencies (muons)

$$\sigma \cdot Br = \frac{N_{candidates} - N_{background}}{Acceptance \cdot Efficiency \cdot L}$$

From MC (POWHEG)

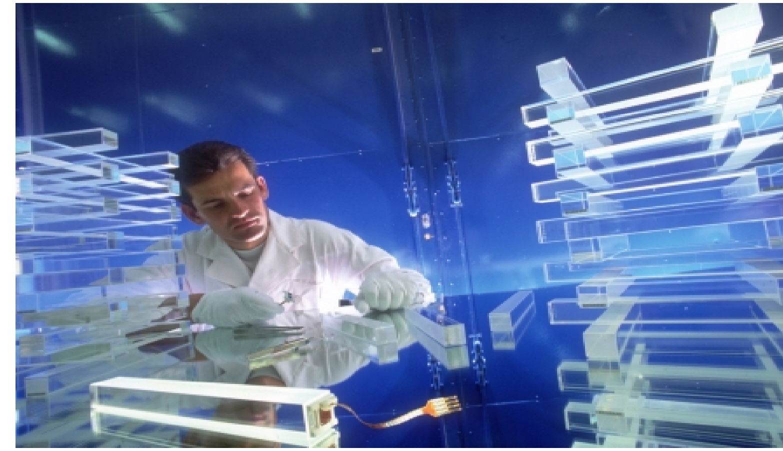
$$\epsilon_X = \epsilon_{MC\text{-}X} \times \rho_{eff\text{-}X},$$

$$\rho_{eff\text{-}X} = \frac{\epsilon_{TNP\text{-}X}(data)}{\epsilon_{TNP\text{-}X}(MC)}$$

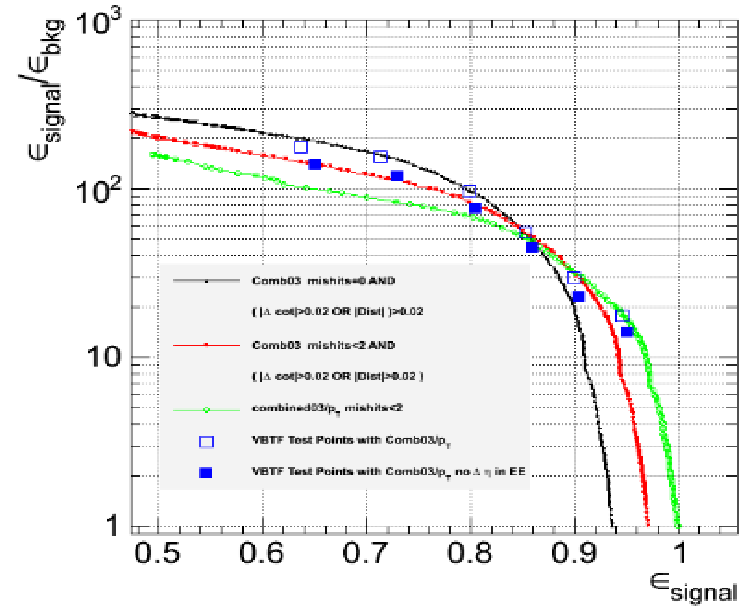
External input 11% uncert.

Offline Electron ID and Selection

- Kinematics:
  - E_T > 20 GeV and
    |η| < 1.4442 (barrel) OR 1.566< |η| < 2.5 (endcap)
  - High Level Trigger: Single e/γ E_T > 15 GeV, Level-1: E_T >5 GeV (≅ 99% efficient)



- Electron reconstruction & ID
  - Seeded from >5 GeV ECAL super-cluster
  - Specialized track reconstruction, incorporates bremsstrahlung
  - Cuts on ID variables:
    - track/cluster matching
    - shower shape, H/E
  - Conversion rejection:
    - require no missing hits in inner pixel layers
    - reject electrons having conversion partner track

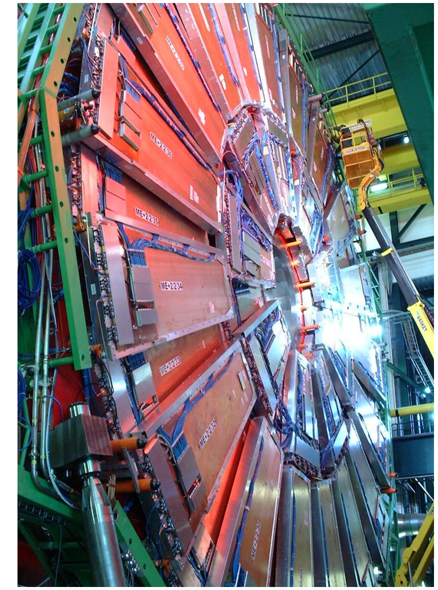


- Isolation variables:
- Both W & Z: separate, relative isolations in tracker, ECAL, and HCAL

$\varepsilon_{electron}$ ~ 83%

A_w ~ 57% A_z ~43.5%

Muon ID Selection



Kinematics

- p_T > 20 GeV, $|\eta|$ < 2.1
- Trigger: Single muon p_T>9 GeV

Quality Requirements

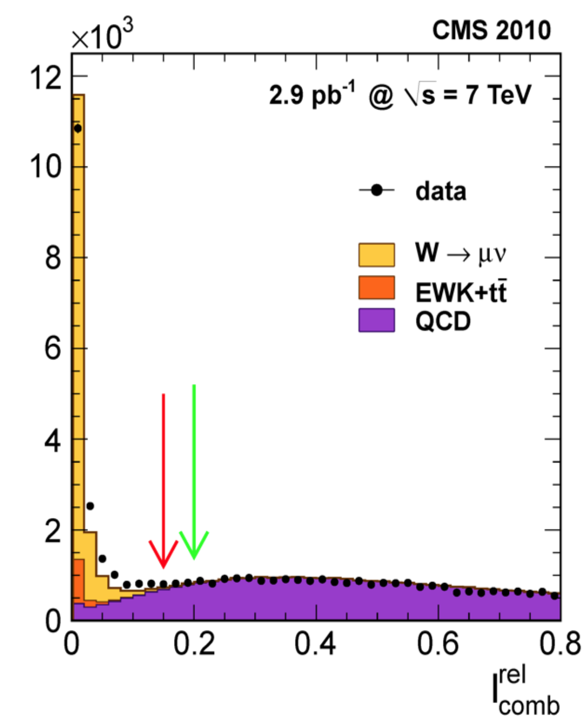
- ≥10 tracker hits, ≥1 pixel hits
- ≥1 good muon chamber hit
- Both inside-out & outside-in Reconstruction
- Track matching with ≥2 segments in the muon stations
- χ^2/ndf < 10 global fit
- Cosmic veto: impact parameter |dxy|<2 mm (w.r.t. the beam spot)

Isolation

- Combined relative isolation (R=0.3)

ε_{muon}~82%

A_w ~ 52% A_z ~40%



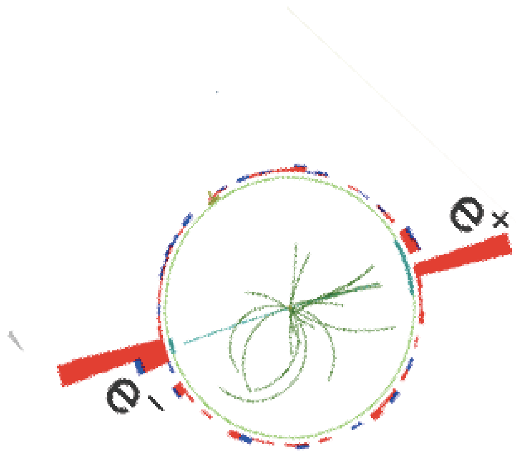
Efficiency Determination

Tag one leg of the Z and probe the other leg using invariant mass constraint

Tag Selection

Reconstructed electron with

- Super cluster within |η| acceptance
- $E_T > 20$ GeV
- Passing isolation and Id cuts
- Matched to the trigger electron candidate



Probe Selection

Super cluster or electron with

- $E_T > 20$ GeV, |η| in acceptance
- Fit the tag-probe invariant mass to get the signal yield.

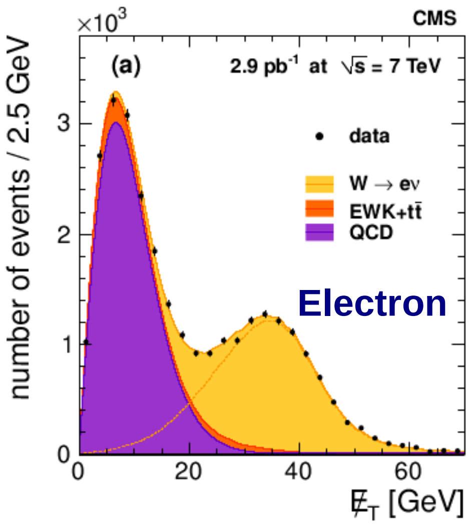
SuperCluster → electron → Id + isolation selection → HLT

$$\left(\varepsilon_{offline} \cdot \varepsilon_{online}\right) = \left(\varepsilon_{reco}\, \varepsilon_{reco}\right)\left(\varepsilon_{id}\, \varepsilon_{id}\right) \cdot \left(1 - \left(1 - \varepsilon_{trg}\right)\left(1 - \varepsilon_{trg}\right)\right)$$

W/Z Signal Extraction

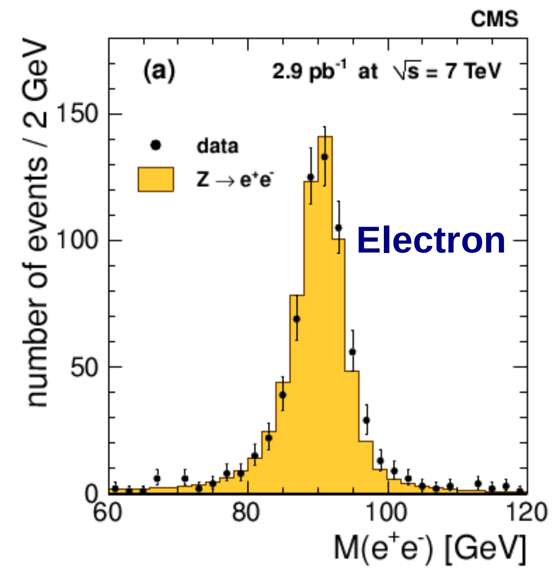
N = 11895 ± 115

Fit to MET



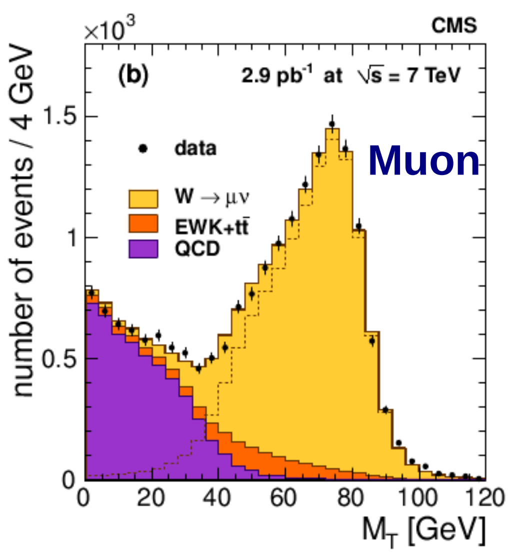
N = 677

Yield from counting



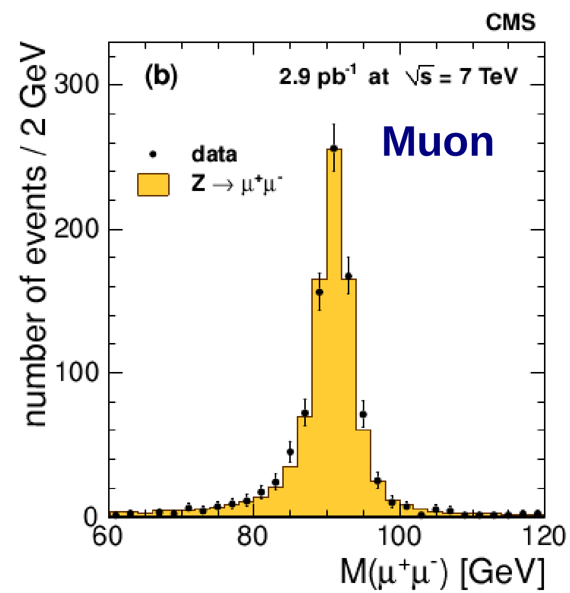
N = 12257 ± 111

Fit to M_T



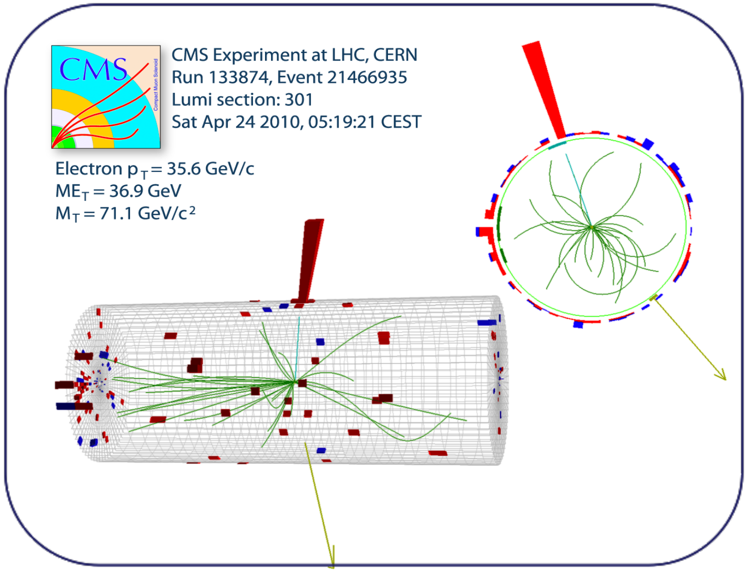
N/ε = 1050 ± 35

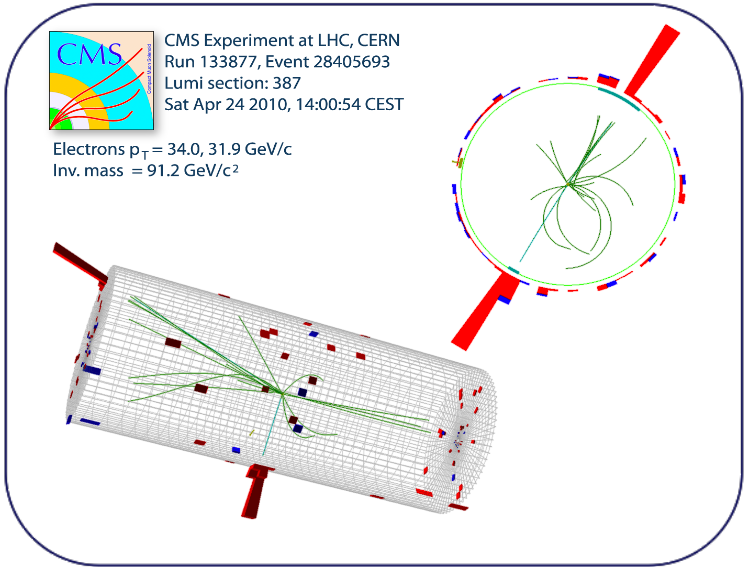
Yield/efficiency extracted via a simultaneous binned maximum likelihood fit



W/Z Event Displays

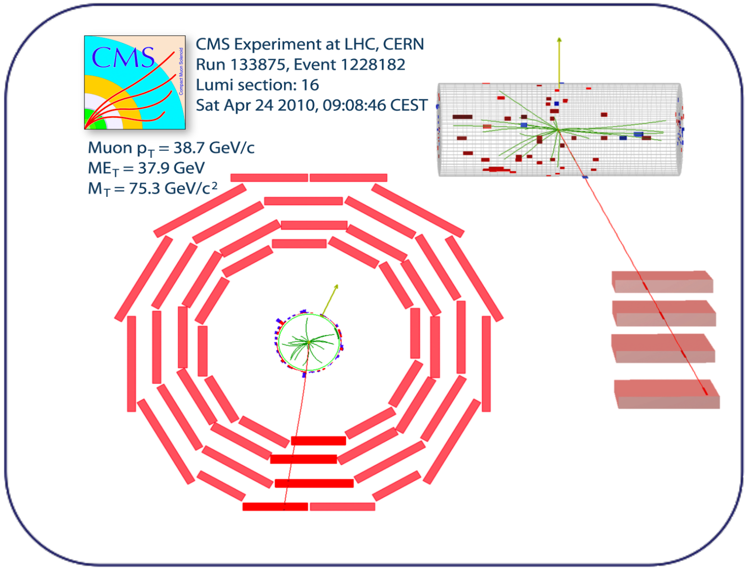
W→eυ

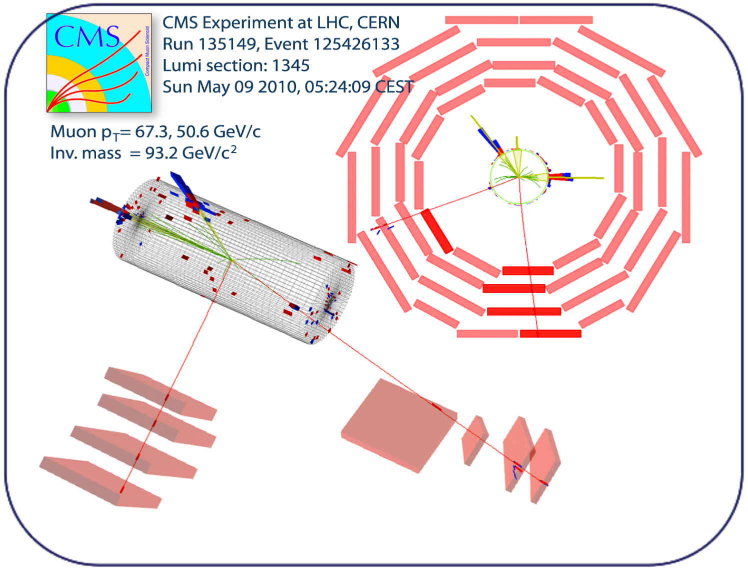




Z→ee

W→μυ





Z→μμ

Systematic Uncertainties: Electron Channels

Source	2.88 pb^{-1} (%) – published		36 pb^{-1} (%) – projected*	
	$W \to e\nu_e$	$Z \to ee$	$W \to e\nu_e$	$Z \to ee$
Reco & ID	3.9	5.9	***2.5***	***3.8***
P_T Scale and Resolution	2.0	0.6	2.0	0.6
MET Scale and Resolution	1.8	0	1.8	0
Background Subtraction/Modeling	1.3	0.1	***0.4***	0
PDF Uncertainty on Acceptance	0.8	1.1	0.8	1.1
Other Theoretical Uncertainties	1.3	1.3	1.3	1.3
Total Systematic	5.1	6.2	***4.0***	***4.2***
Statistical	0.6	3.8	***0.2***	***1.1***
Total	5.1	7.3	***4.0***	***4.3***

** All projections are those of the speaker/No projections are endorsed by CMS*

Systematic Uncertainties: Muon Channels

Source	$2.88\ pb^{-1}$ (%) – published		$36\ pb^{-1}$ (%) – projected *	
	$W \to \mu\nu_\mu$	$Z \to \mu\mu$	$W \to \mu\nu_\mu$	$Z \to \mu\mu$
Reco & ID	1.5	0.5	***1.0***	***0.3***
P_T Scale and Resolution	0.3	0.2	0.3	0.2
MET Scale and Resolution	0.4	0	0.4	0
Background Subtraction/Modeling	2.0	1.0	***0.6***	***0.3***
PDF Uncertainty on Acceptance	1.1	1.2	1.1	1.2
Other Theoretical Uncertainties	1.4	1.6	1.4	1.6
Total Systematic	3.1	2.3	***2.2***	2.1
Statistical	0.7	3.1	***0.2***	***0.9***
Total	3.4	3.9	***2.2***	***2.3***

** All projections are those of the speaker/No projections are endorsed by CMS*

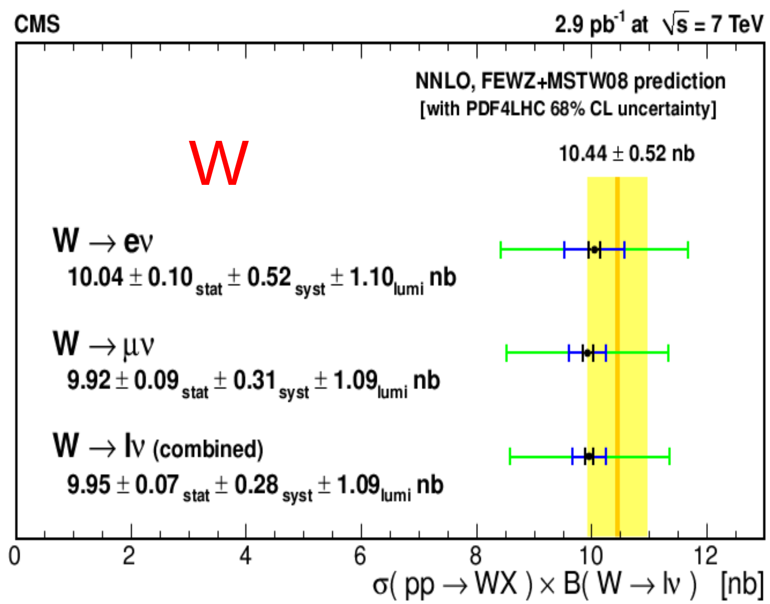
Cross Section Results

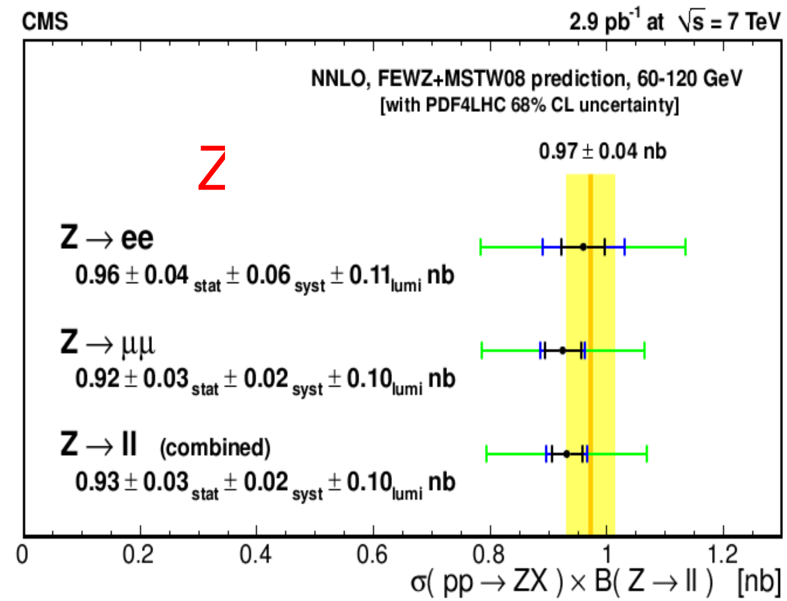
Channel		$\sigma \times \mathcal{B}$ (nb)	NNLO (nb)
W	$e\nu$	10.04 ± 0.10 (stat.) ± 0.52 (syst.) ± 1.10 (lumi.)	10.44 ± 0.52
	$\mu\nu$	9.92 ± 0.09 (stat.) ± 0.31 (syst.) ± 1.09 (lumi.)	
	$\ell\nu$	9.95 ± 0.07 (stat.) ± 0.28 (syst.) ± 1.09 (lumi.)	
W^+	$e^+\nu$	5.93 ± 0.07 (stat.) ± 0.36 (syst.) ± 0.65 (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.)	

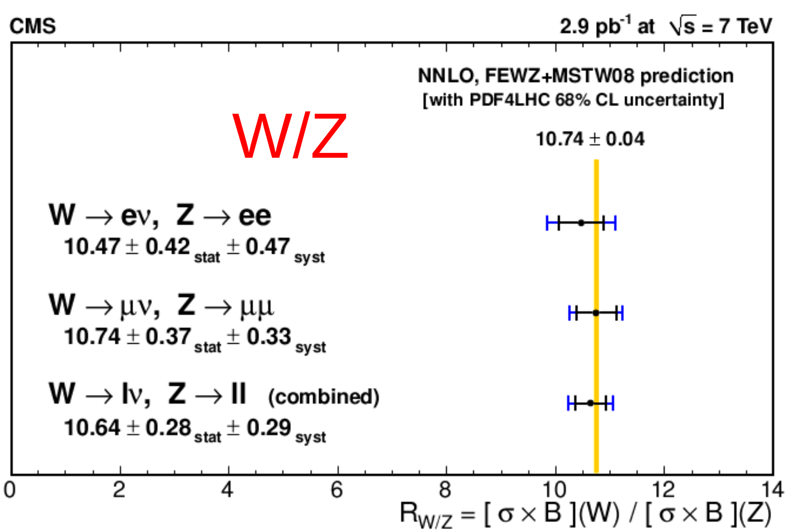
W/Z production cross section measurements and theoretical calculations are consistent with each other

Can EWK bosons be used to measure the absolute luminosity ?

Cross Section Results







Uncertainty in theory prediction
Statistical uncertainty
Systematic uncertainty
Luminosity uncertainty

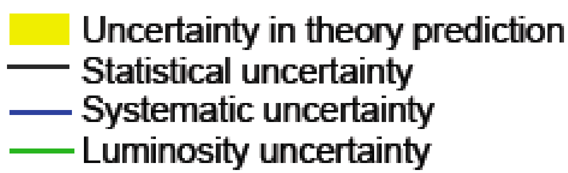
W cross section $\sigma_{systematic}$~2.9%

Z cross section $\sigma_{systematic}$~3.9%

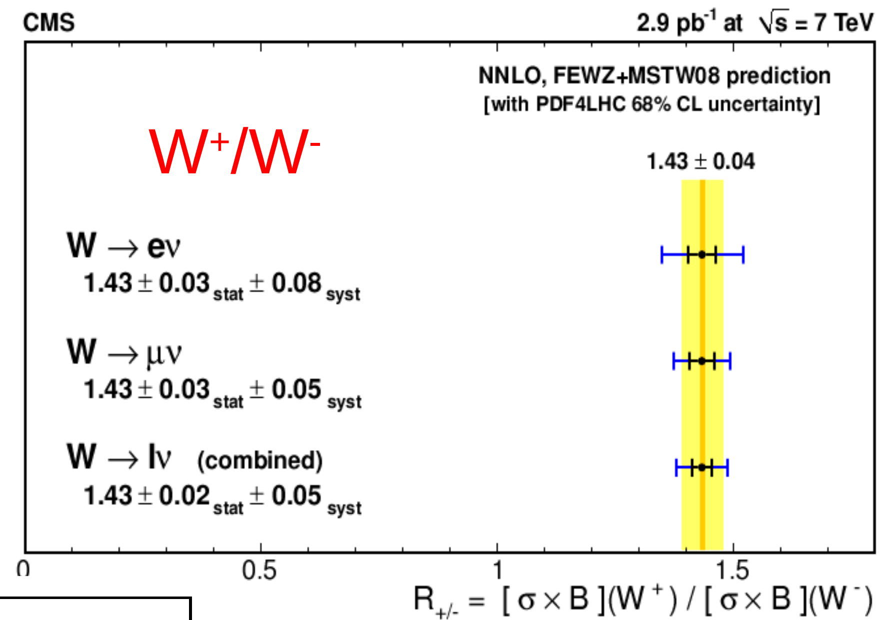
W/Z cross section $\sigma_{systematic}$~3.8%

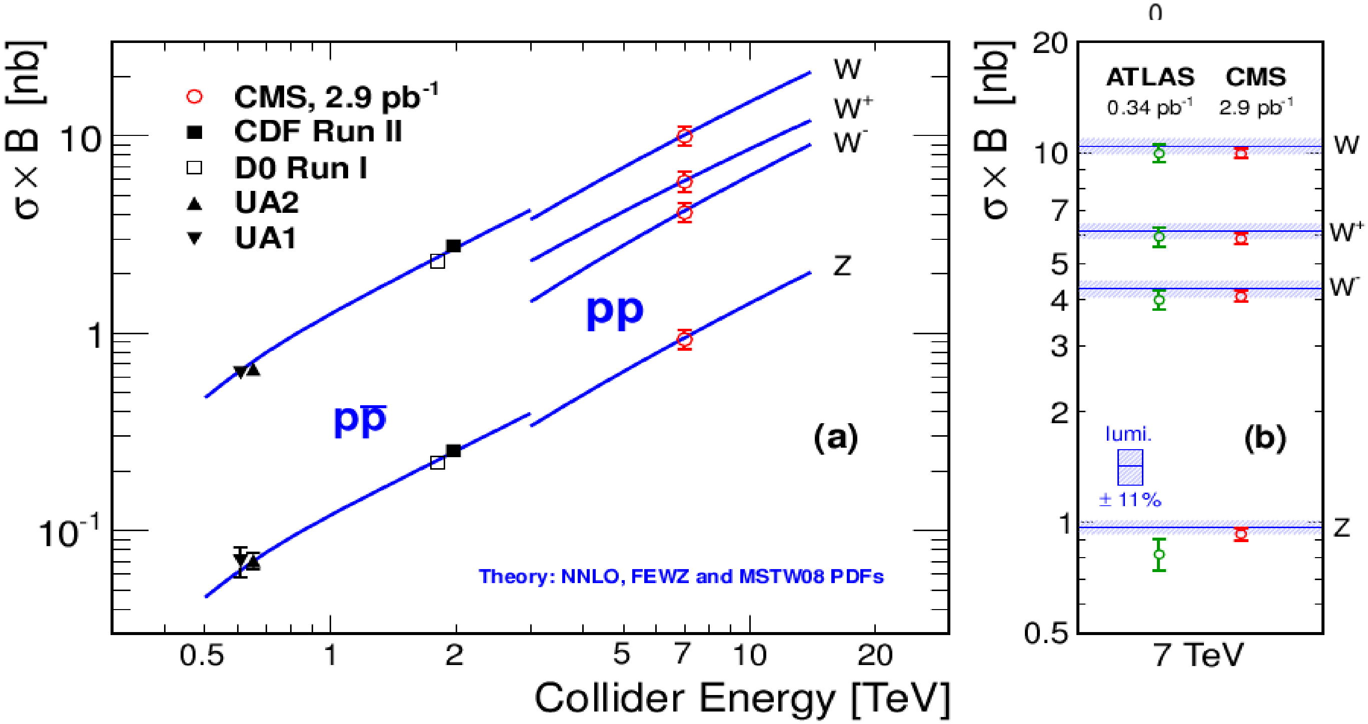
Internally consistent and agrees with theory calculations

Cross Section Results



Close to challenging global PDF expectations





Consistency with Theoretical expectations

Feasibility of W/Z as Luminometers

W/Z Bosons as Standard Candles for Luminosity

$$\sigma^{\exp}(z)\cdot BR(z\to\ell\ell)=\frac{N^{obs}}{\varepsilon A_z}\frac{1}{\int L\,dt}$$

$$\int L\,dt=\frac{N^{obs}}{\varepsilon}\frac{1}{A_z\sigma^{theory}(z)\cdot BR(z\to\ell\ell)}$$

Can EWK bosons be used to measure the absolute luminosity ?

What is the systematic uncertainty on the L measurement using W/Z ?
Is data stable in different periods ?
What is the expected rate of the W/Z ?

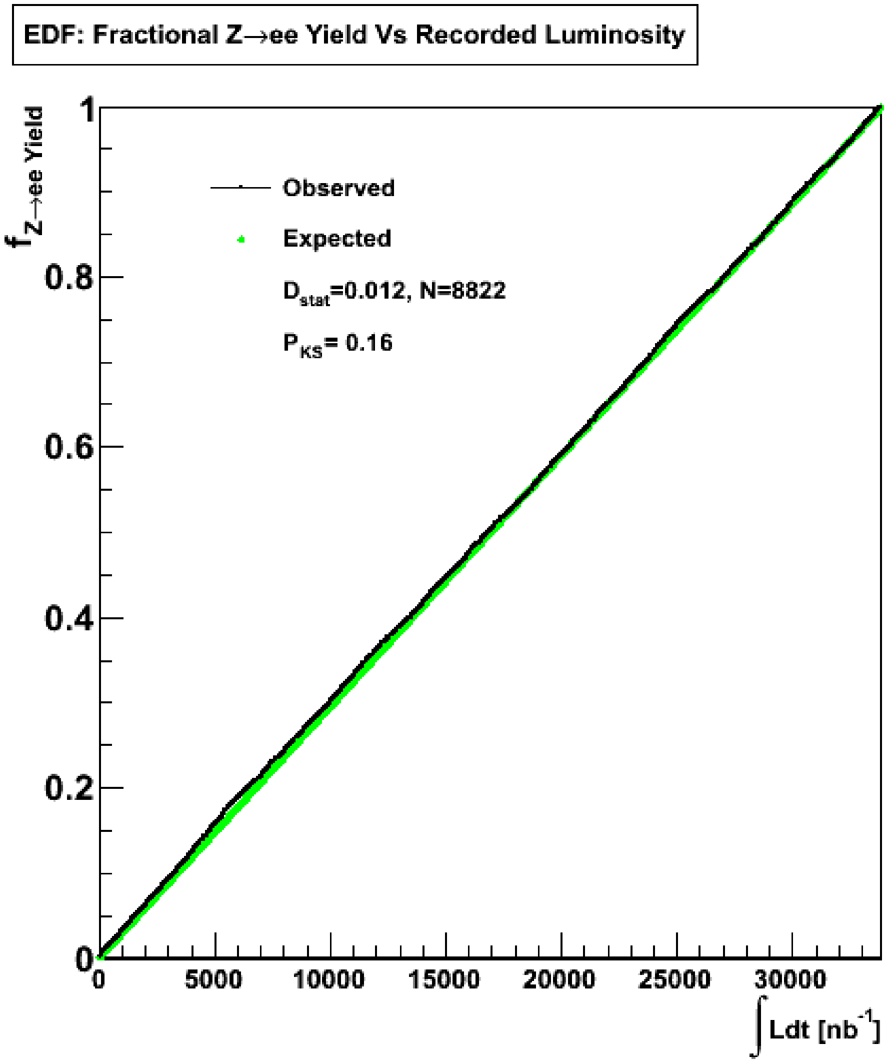
VdM Scan Based CMS Lumi Measurement Vs $Z \rightarrow \ell\ell$ Based Lumi Measurement

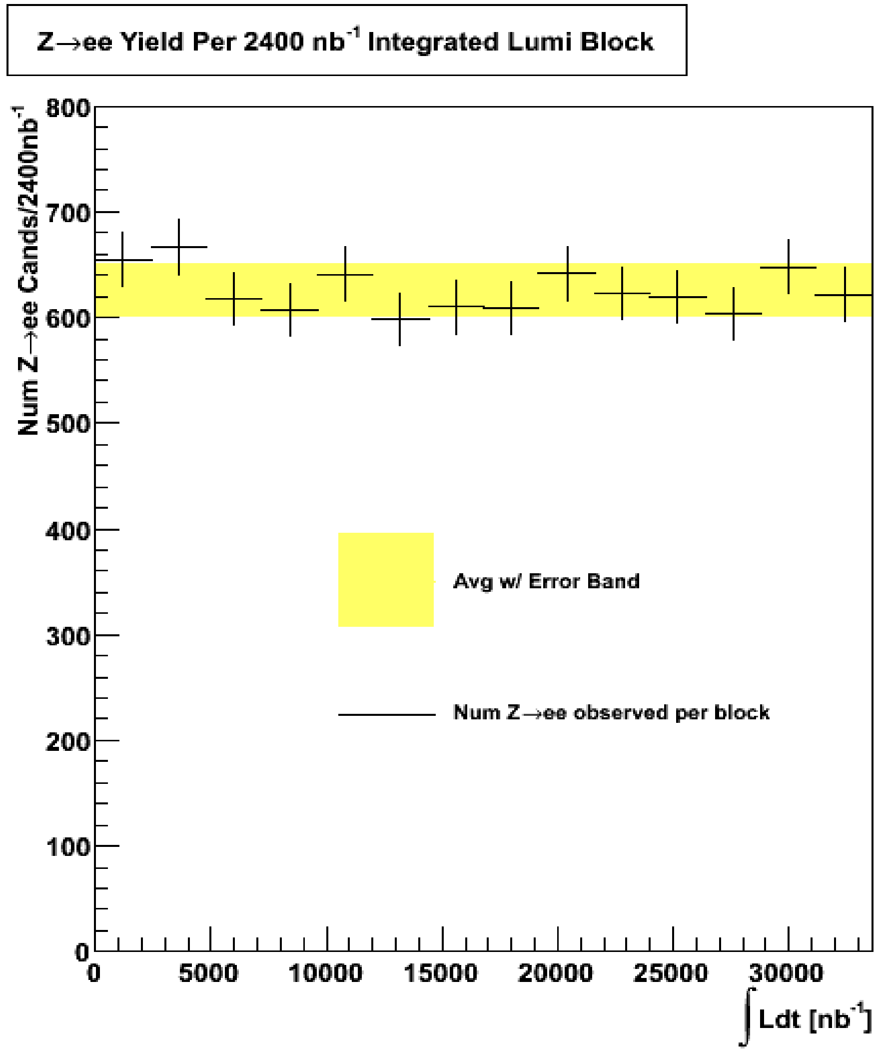
Time	Systematics Summary			
	VdM Scan		$Z \rightarrow \ell\ell$	
	Source	Value (%)	Source	Value (%)
Current	$4 \oplus 10$(Beam Current)	11	$4 \oplus 4$(σ NNLO)*	6
Future	$4 \oplus 4$(Beam Current)	**5-6**	$2 \oplus 4$(σ NNLO)	**4-5**

$\Longrightarrow$ VdM Scans can be used to constrain the proton PDFs

** arXiv:1006.3766v4 – Adam, Halyo, Yost*

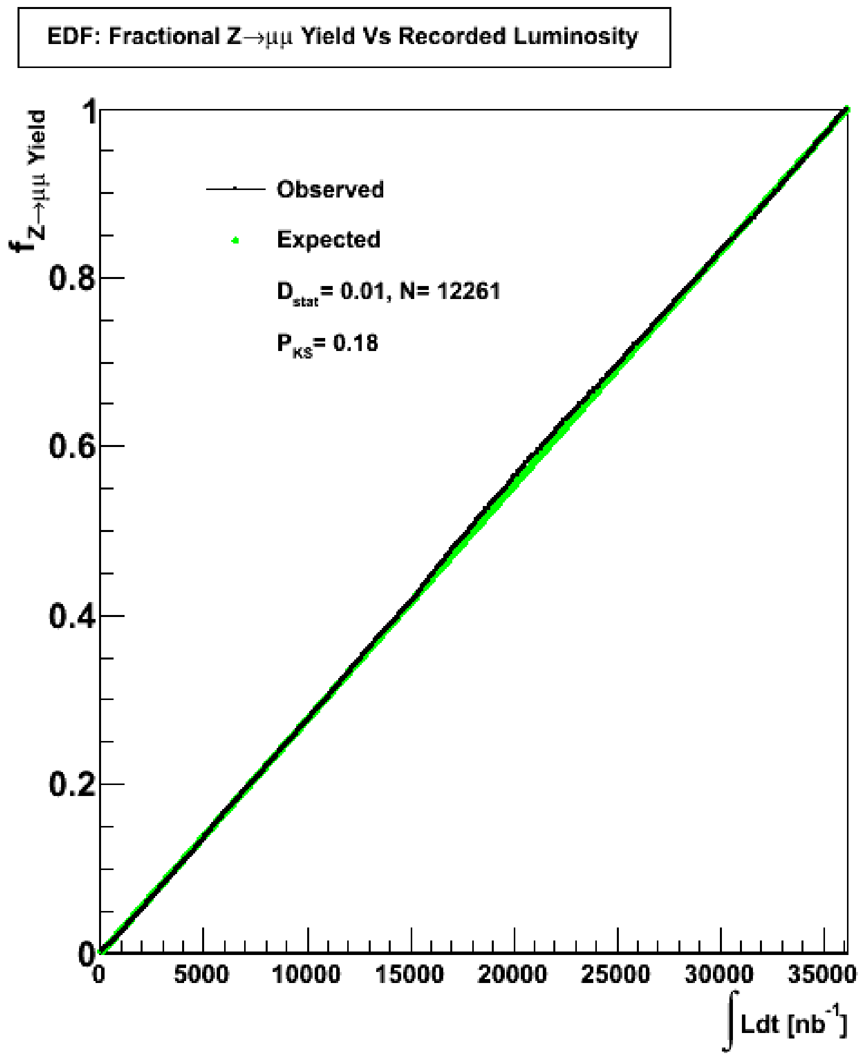
W/Z for Luminosity – Sample Z→ee Plots

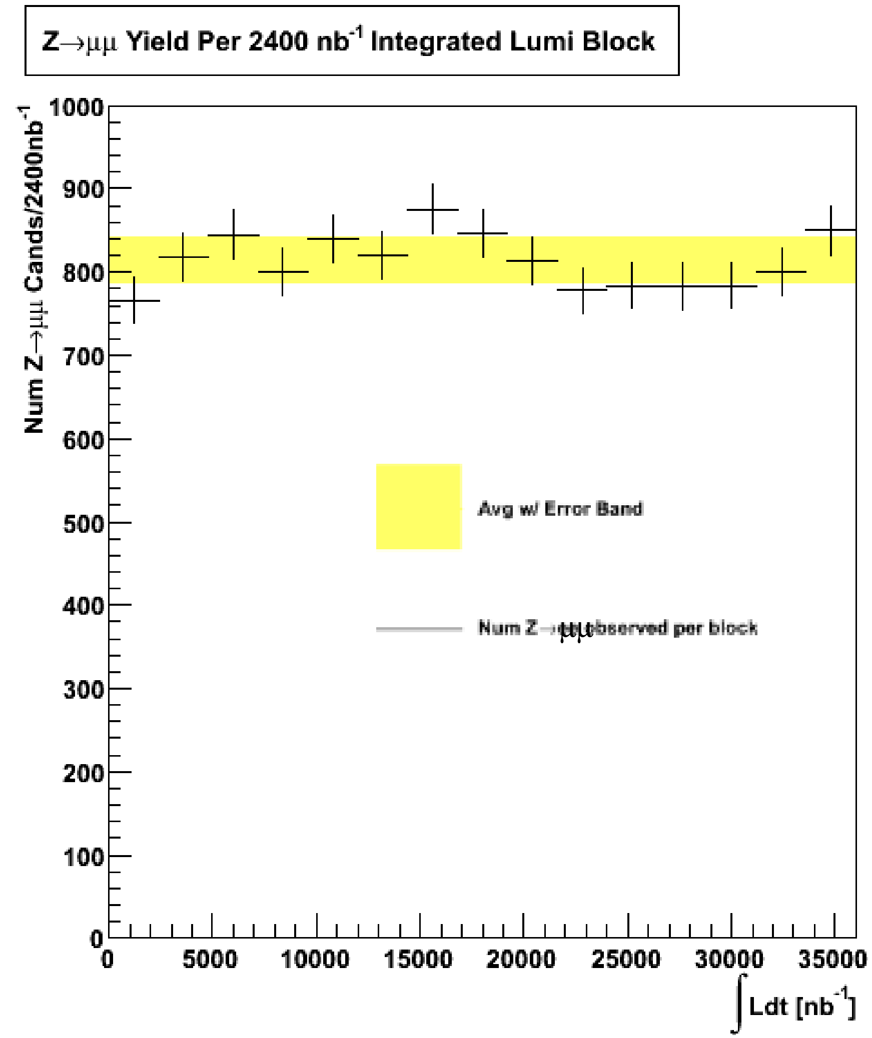




We observe that the Z→ee event yield is stable Vs. HF based luminosity

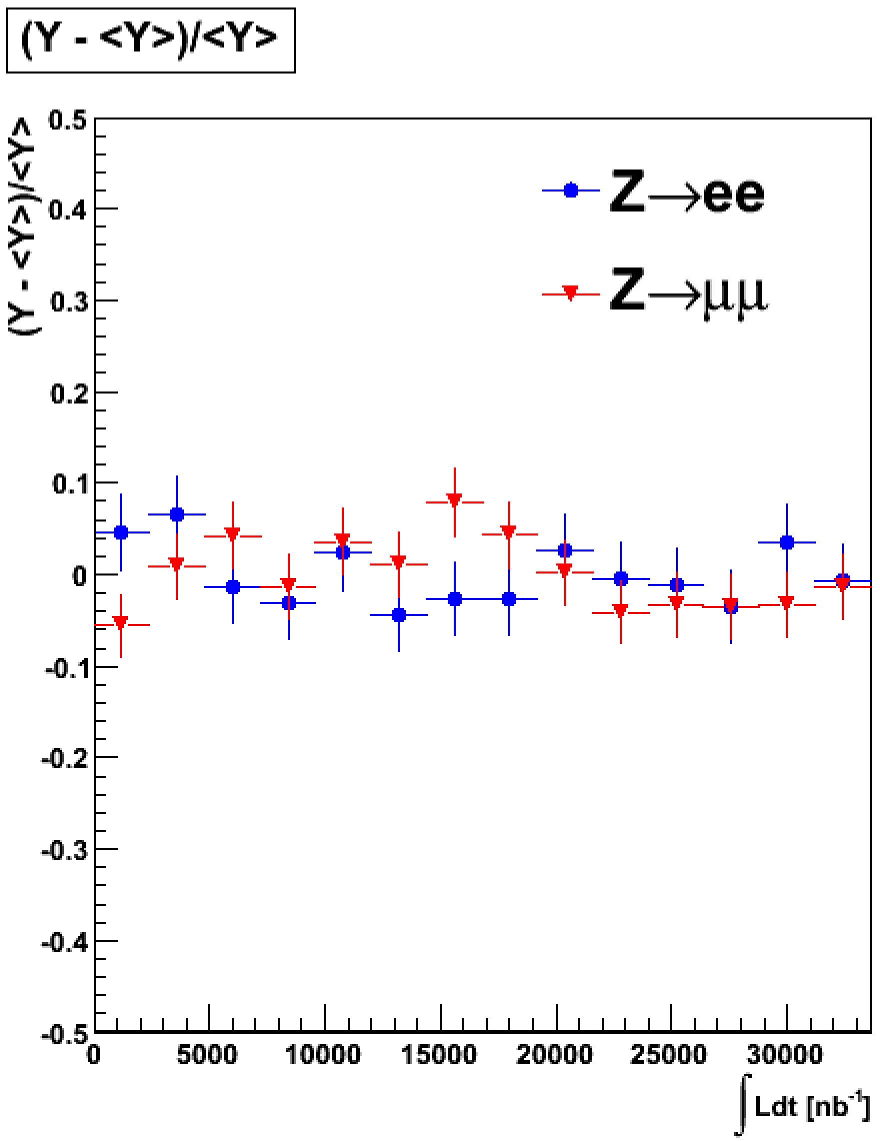
W/Z for Luminosity – Sample Z→μμ Plots

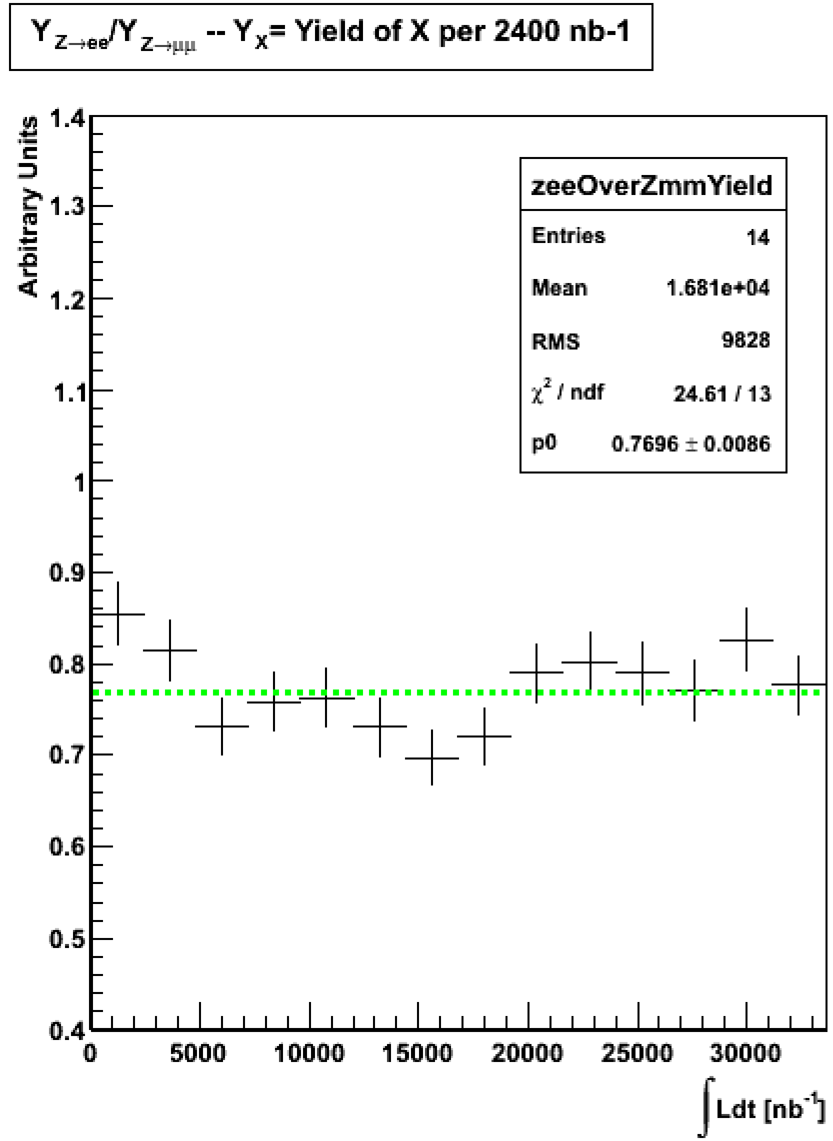




We observe that the Z→μμ event yield is stable Vs. HF based luminosity

Stability of the data





Z Rates for Different Run Conditions at 3.5 TeV Beam Energy Per Lepton Channel

#BX	Lumi ($cm^{-2}s^{-1}$)	Z Rate Hz (per channel)		Rate/day (per channel)		$\int_{1\ day} Ldt$ (pb^{-1})
		Prod	Reco	Prod	Reco	
43	3.8×10^{29}	4×10^{-4}	1×10^{-4}	30	10	3×10^{-2}
156	5.6×10^{31}	0.06	0.02	5×10^{3}	2×10^{3}	5
930	7×10^{32}	0.7	0.2	6×10^{4}	2×10^{4}	60
2808	2.8×10^{33}	3	1	3×10^{5}	1×10^{5}	200
2808	1×10^{34}	10	3	9×10^{5}	2×10^{5}	900

Collisions with 4TeV beam energies have 17% larger cross sections.

All numbers ~10 times higher for W bosons

Summary

- CMS has achieved ~ 4% precision tests of electroweak physics.
  - Electrons, muons, and missing energy are well-calibrated detector objects ready for precision analysis
  - Uncertainty on the W+/W− cross-section ratio is becoming comparable to the theoretical uncertainty
- W/Z could be used already to calibrate the relative luminosity
  - ~2 hours at 7×10^{32} $cm^{-2}s^{-1}$ we can achieve similar systematic uncertainty as the VdM scan by combining electron, muon channels
- Extraordinary performance by detector operations, computing, detector simulation, and physics objects groups
- Last but not least many thanks to LHC for making it possible