# Inclusive W&Z cross sections and the W charge asymmetry at LHC

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on behalf of the ATLAS and CMS Collaborations

SM@LHC, Durham, April 13th, 2011


UNIVERSITY OF LIVERPOOL

# The Challenge

- LHC is challenging the Standard Model in unchartered territory and many processes will be measured to high accuracy.

- LHC is a QCD machine (LEP was an electroweak machine).

- Successful experimental searches rely on accurate predictions for hard scattering processes, including HO QCD and EW radiative corrections, e.g.

  - Higgs and new physics phenomena (BSM)

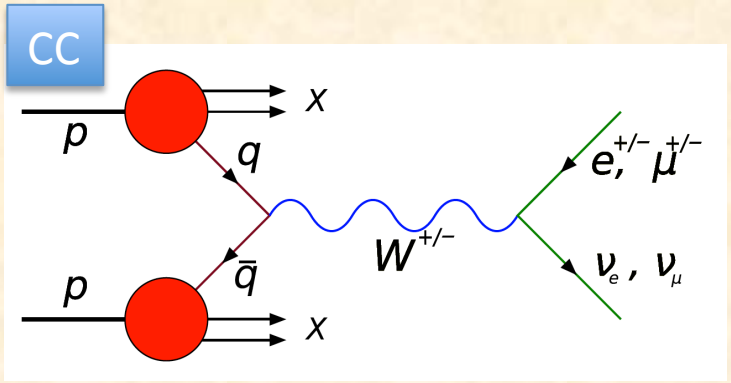
  - SM backgrounds

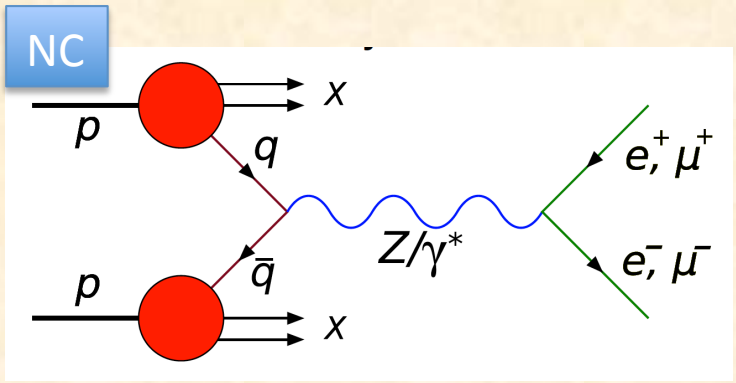
- Production of electroweak W and Z gauge bosons is theoretically very well understood, has unique signatures in the lepton decay channels and high rates.

  → Interesting first measurements at LHC published by ATLAS and CMS.

  → Ongoing efforts to understand single differential distributions e.g. in $p_T^Z$, $y_z$, lepton rapidity and transverse momentum.

# Production of W and Z




- Cross section factorises at scale $\mu$ based on parton distribution functions (*PDF*)

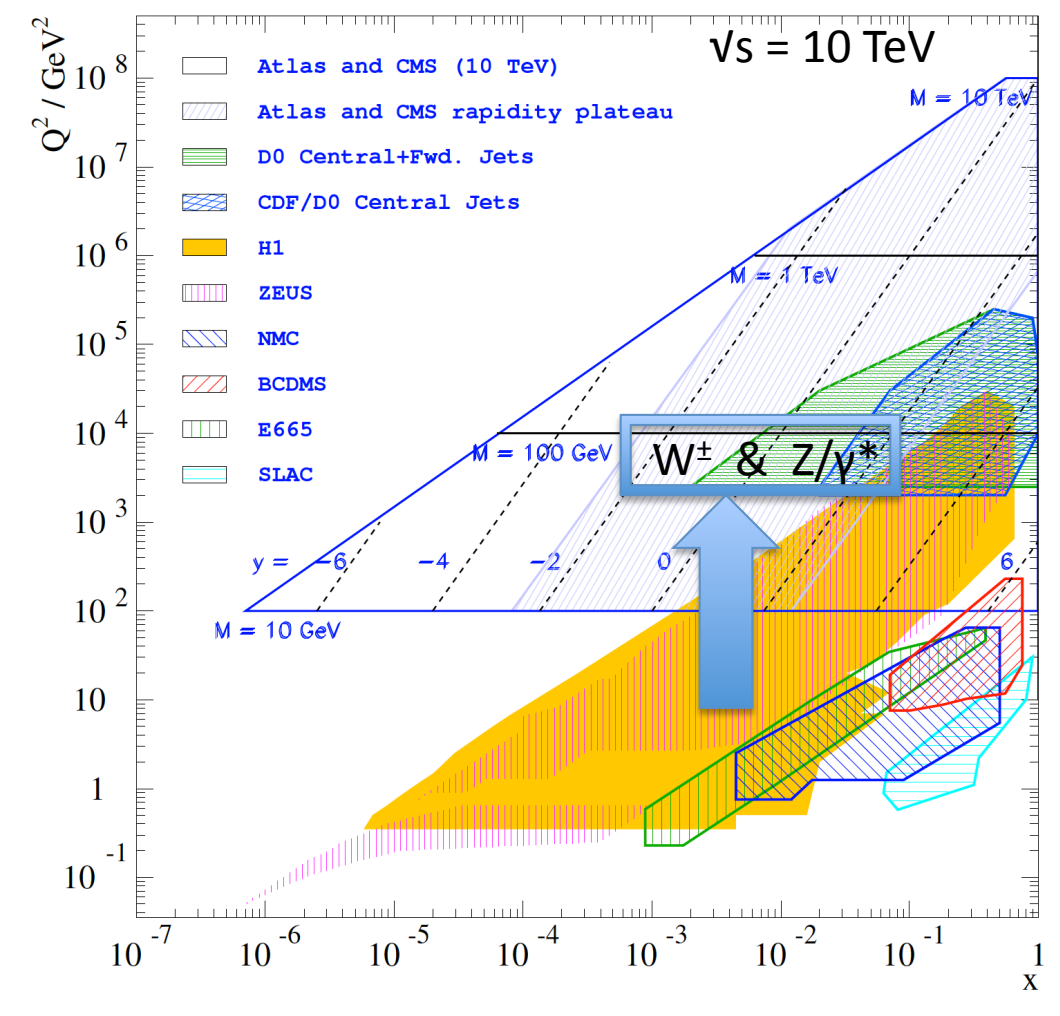
$$\sigma_{\mathrm{pp}}(Q) = \sum_{\mathrm{ij}} \hat{\sigma}_{\mathrm{ij}}(Q/\mu, \alpha_s(\mu)) \otimes PDF_{\mathrm{i}}(\mu) \otimes PDF_{\mathrm{j}}(\mu)$$

- Sensitive to parton luminosities: $PDF_i$ x $PDF_j$
- Theoretical uncertainties in $\sigma_{ij}$ (variation of scale $\mu$) controlled up to NNLO QCD → perturbative QCD essential and established part.
- Excellent tool to calibrate detector and to pave the way for understanding complex final states for top and new physics searches.

# LHC Parton Kinematics

- LHC measurements at high scales Q=M and testing parton kinematics at
  $x_{1,2} = (M/\sqrt{s}) \exp(\pm y)$
- HERA *PDF* measurements crucial for precision predictions at LHC
- Precision in QCD evolution of *PDF*s at NNLO for DIS

$$\frac{d}{d\ln Q^2} PDF(x,Q^2) = \left[P(\alpha_s(Q^2)) \otimes PDF(Q^2)\right](x)$$



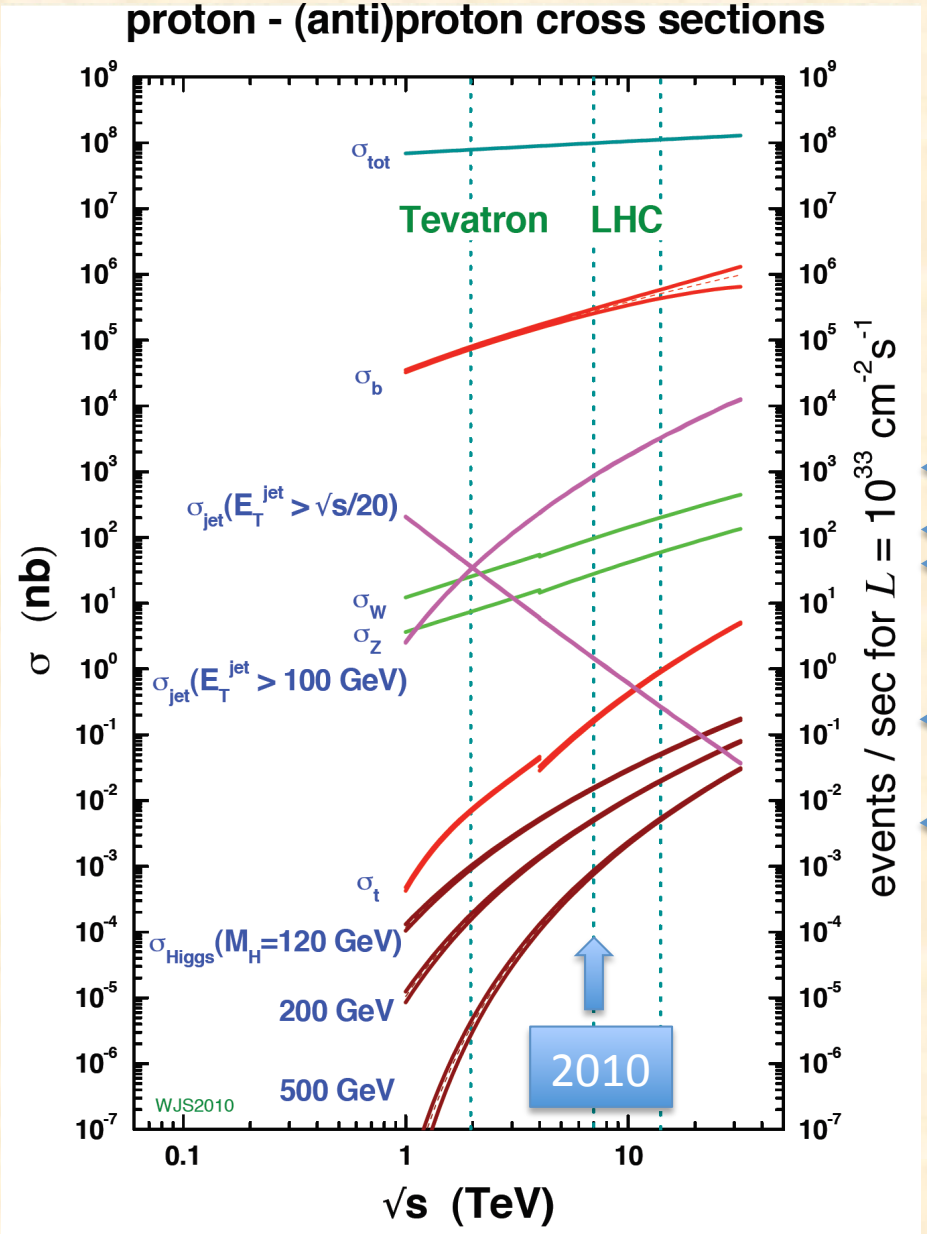

Note: In contrast to DIS, Drell Yan processes have also a dependence on $p_T$(Z,W).

# Standard Model Cross Sections

W and Z production at 7 TeV per lepton decay channel:

FEWZ@NNLO (MRST2008) predictions

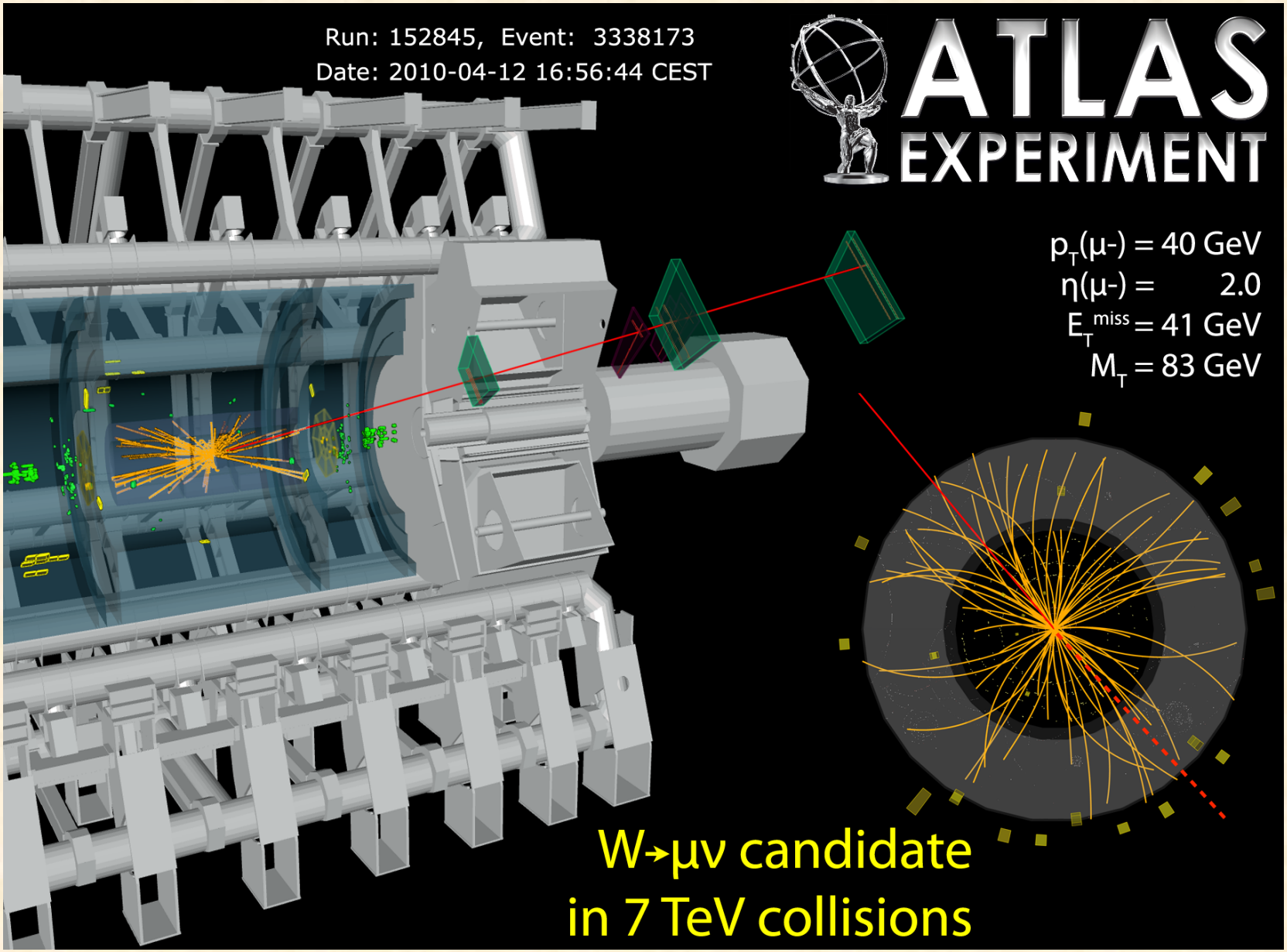
$\sigma(W^+) = 6.16$ nb
$\sigma(W^-) = 4.30$ nb
$\sigma(Z) = 0.99$ nb



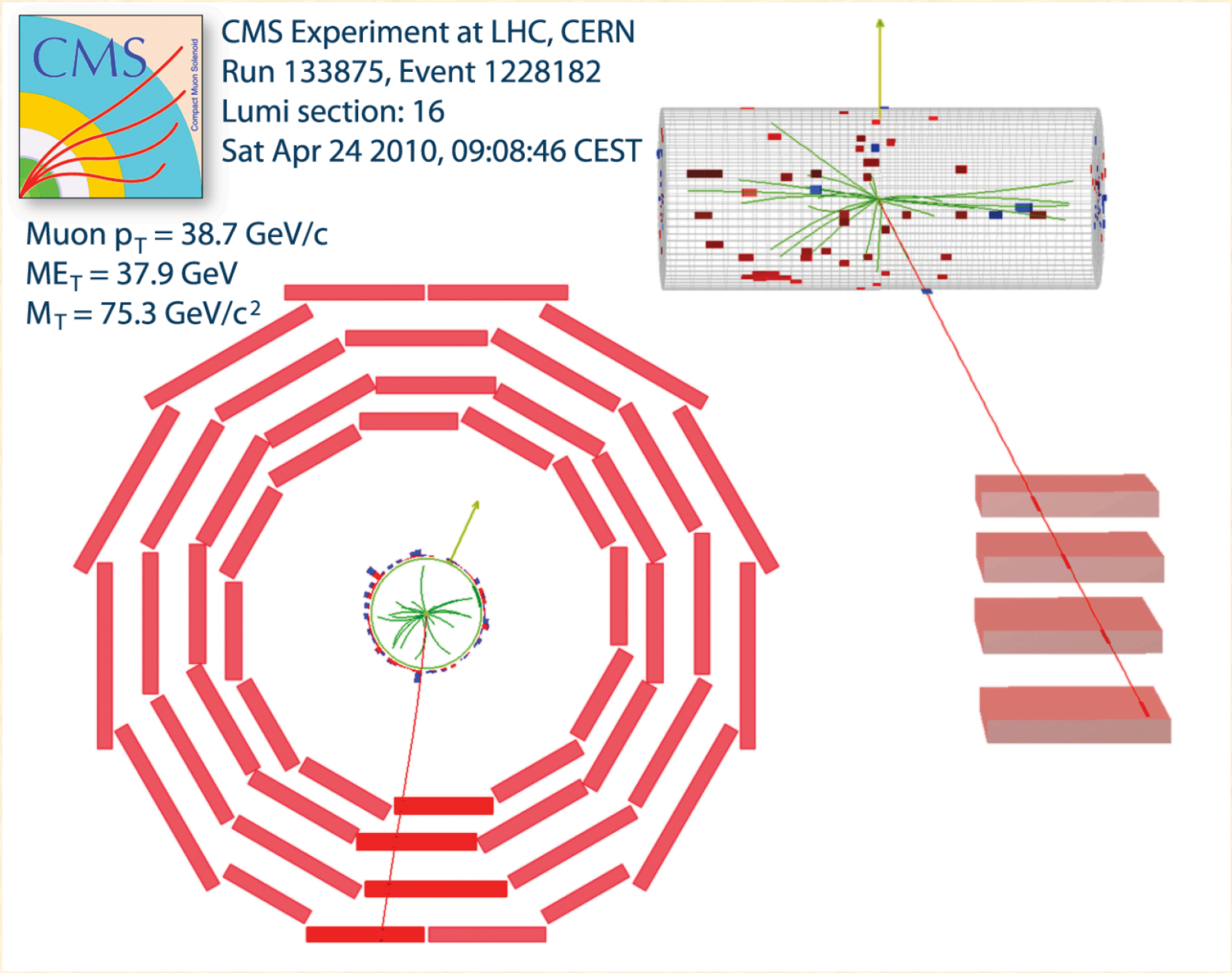

√s = 7 TeV

- high $p_T$ jets
- W
- Z
- top pairs
- Higgs (?)

# W→ μν Candidate



# W→ μν Candidate

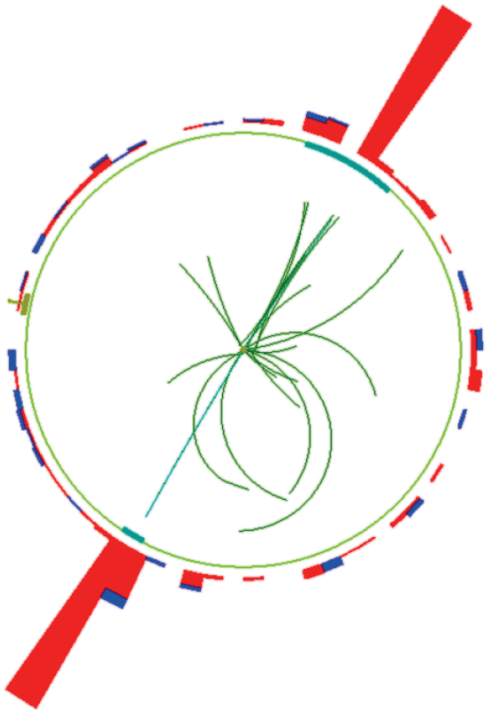


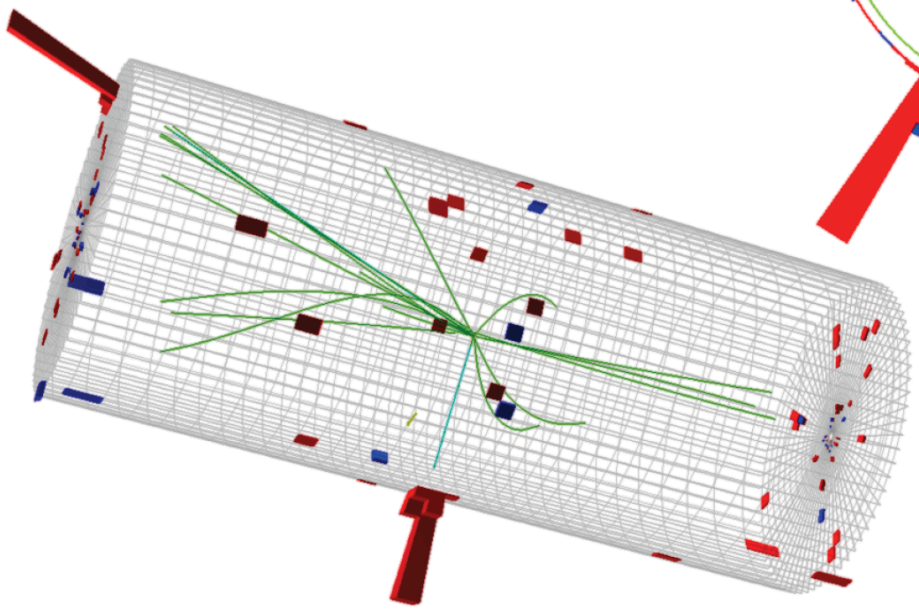
# Z→ ee Candidate

**Run number: 133877 Event number: 28405693 , Lumi Section : 387**

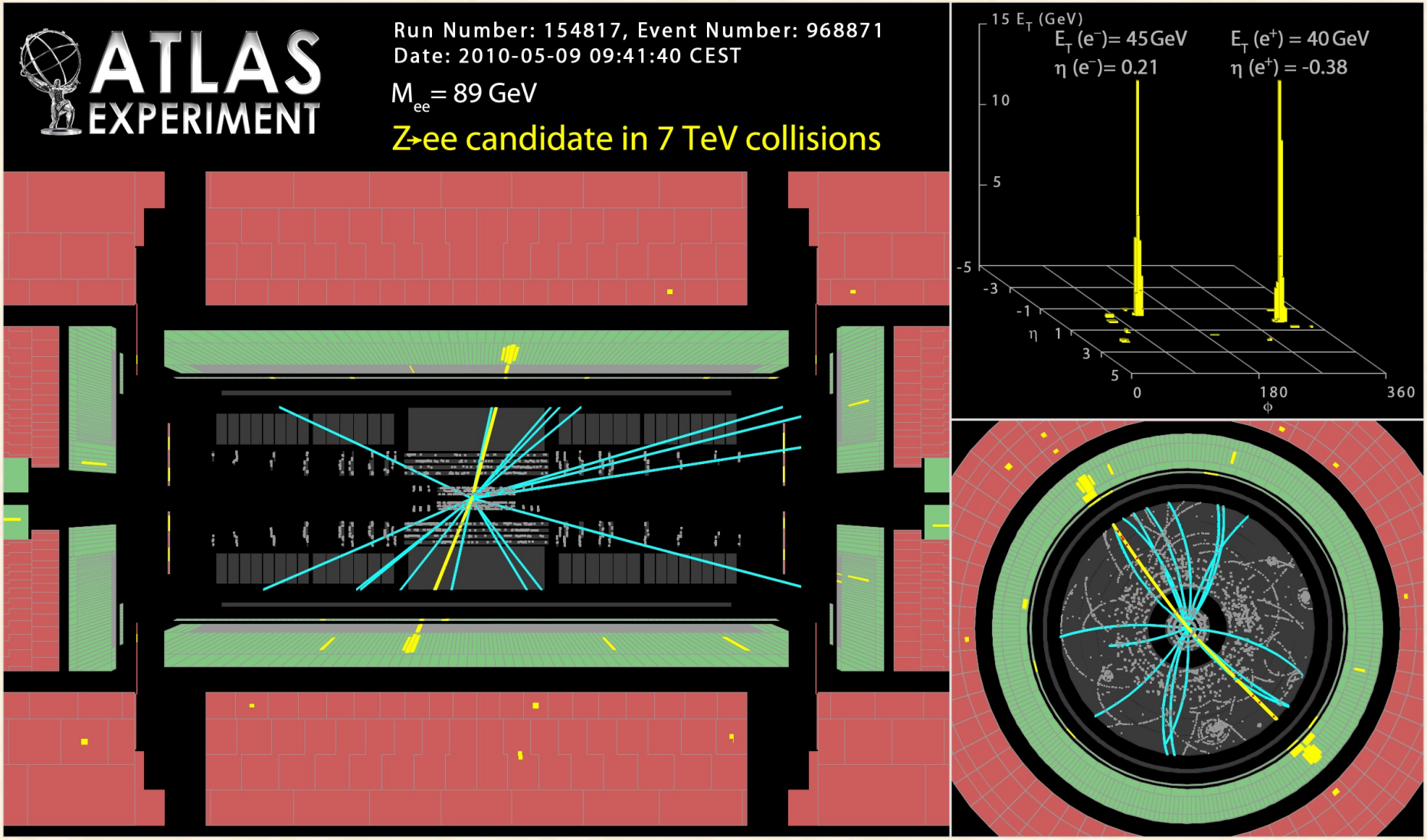
CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons $p_T = 34.0, 31.9$ GeV/c
Inv. mass $= 91.2$ GeV/$c^2$





# Z→ ee Candidate



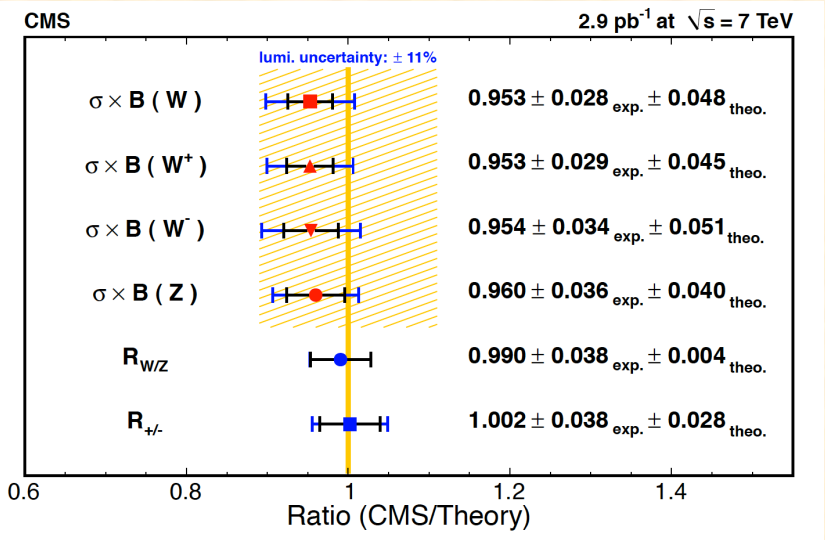
# First W and Z from LHC

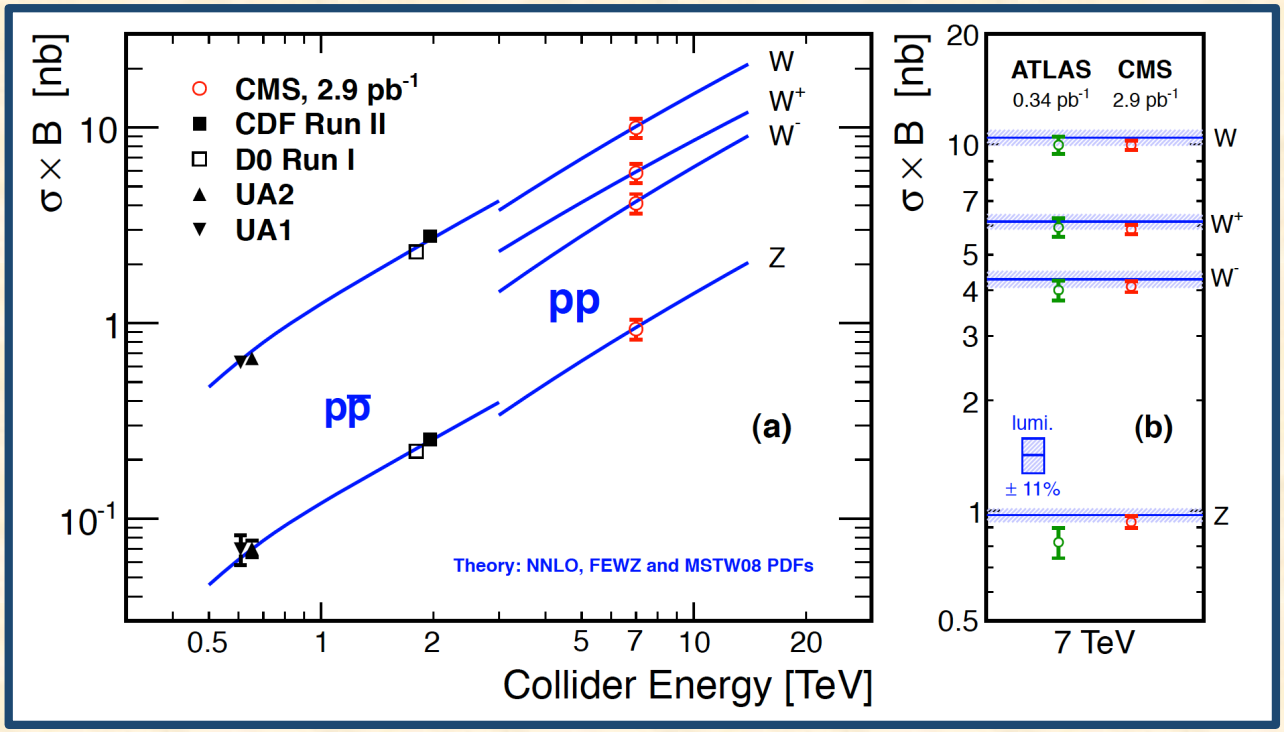
*ATLAS 0.32 pb$^{-1}$* JHEP**12**(2010)06
*CMS 2.9 pb$^{-1}$* JHEP**01**(2011)080

ATLAS and CMS uncertainty was **11% due to luminosity**!

W/o lumi, e.g. CMS exp. uncertainties were

- δσ(W) : 2.9%
- δσ(Z) : 3.9%
- δσ(W)/σ(Z): 3.8%



# *New* 2010 Luminosity scale and uncertainty

***ATLAS*** ATLAS-CONF-2011-011
***CMS*** CMS DPS -2011/002

- Series of Van der Meer (beam separation) scans

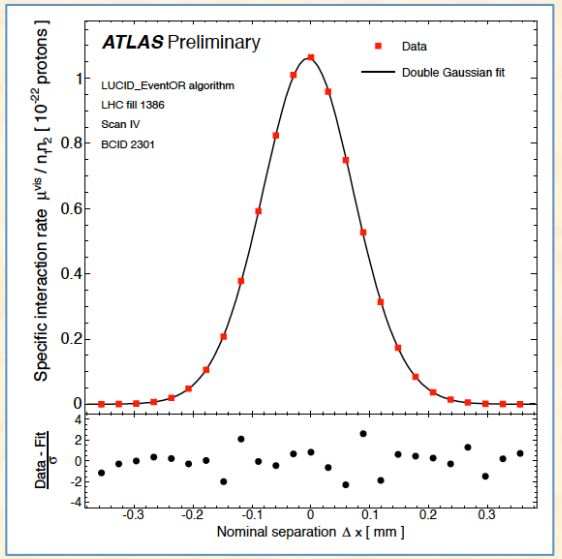
→ dedicated luminosity calibration runs for experiments in Oct 2010

- CMS : preliminary luminosity scale of 0.993 and uncertainty of 4%

- ATLAS : preliminary luminosity scale of 0.964, i.e. smaller than previous result and luminosity uncertainty improved to 3.4%

→ specific visible interaction rate (normalised to bunch charge product) is measured vs. nominal beam separation specified by the LHC control system

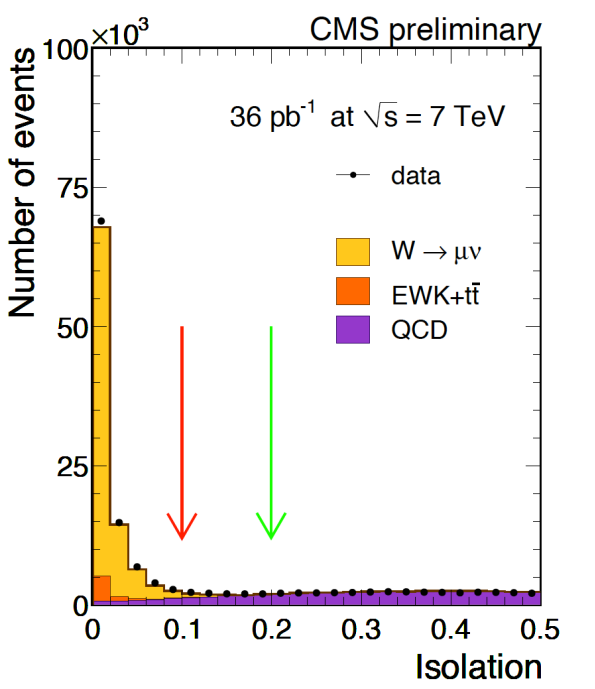
→ luminosity systematic dominated by knowledge of bunch charge product (3.1%)

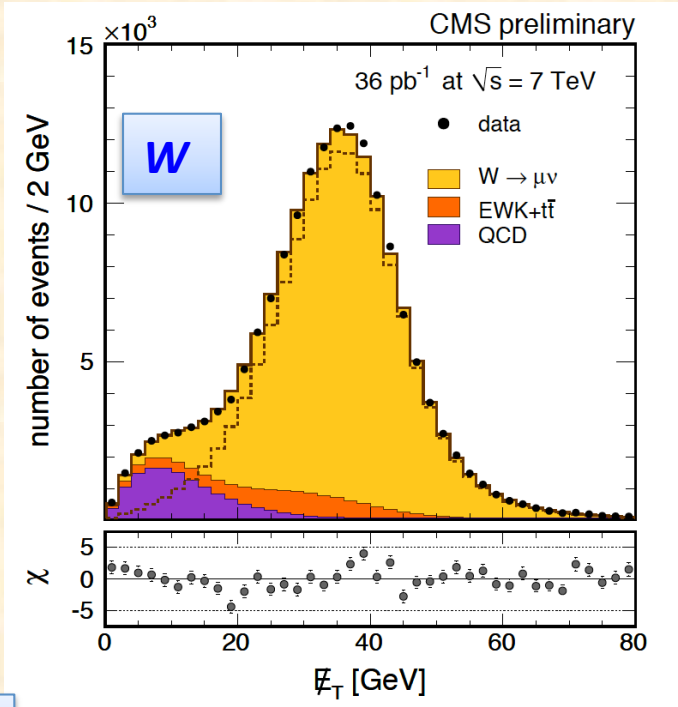


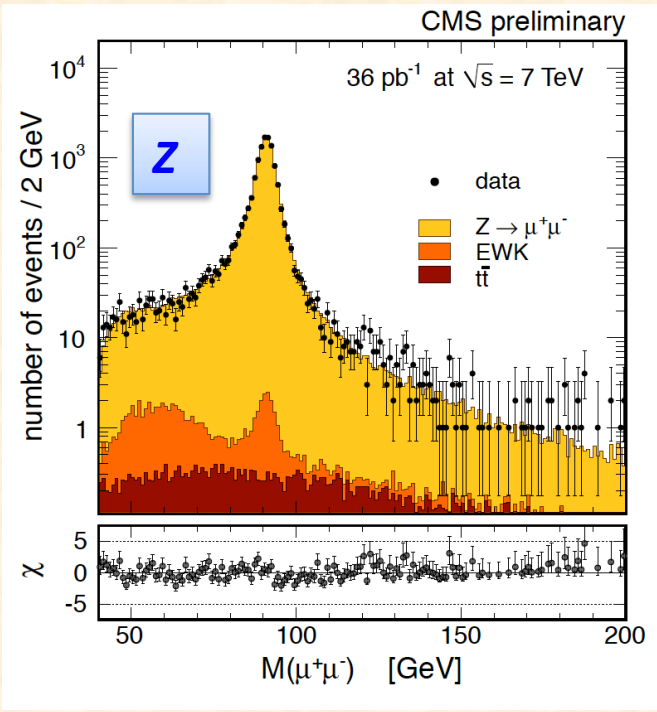
# CMS W and Z Muons

***13.7k Z→μμ candidates***
***141k W→μν candidates***

- W selection: $p_T^{\mu} > 25$ GeV, $|\eta^{\mu}|<2.1$ & combined isolation criteria, no $E_{T,miss}$ *or* $m_T$ cuts but fit to $E_{T,miss}$ distribution (calibrated with particle flow algorithm).
- Z selection: $60<M_{ll}<120$ GeV, $p_T^{\mu} > 20$ GeV, $|\eta^{\mu}|<2.1$ & pure track based isolation



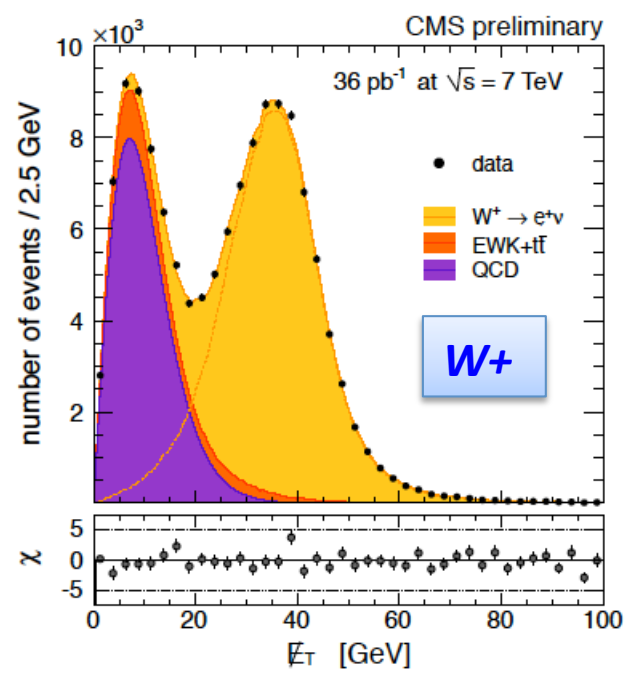

*Isolation for selected muons*
$p_T^{\mu} > 25$ GeV, $|\eta^{\mu}|<2.1$

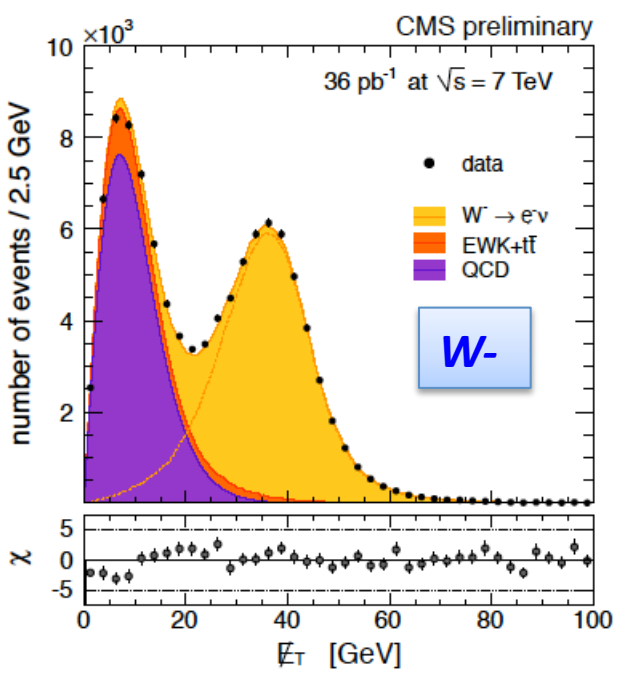
CMS-PAS-EWK-10-005

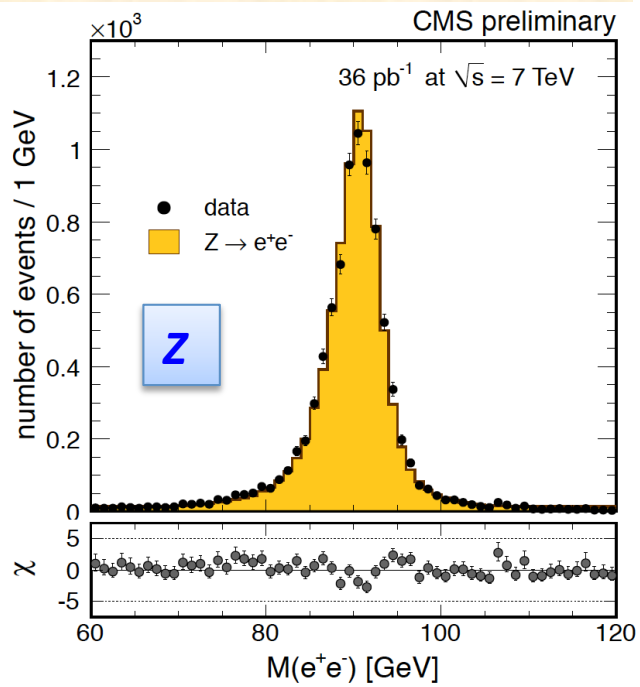
# CMS W and Z Electrons

***8.4k Z→ee candidates***
***136k W→eν candidates***

- Electrons: $E_T^e$>25 GeV, $|\eta^e|$<1.44, 1.57<$|\eta^e|$<2.5 & isolation criteria
- Z selection: 60<$M_{ll}$<120 GeV
- W selection: no $E_{T,miss}$ *or* $m_T$ cuts but fit to $E_{T,miss}$ distribution.



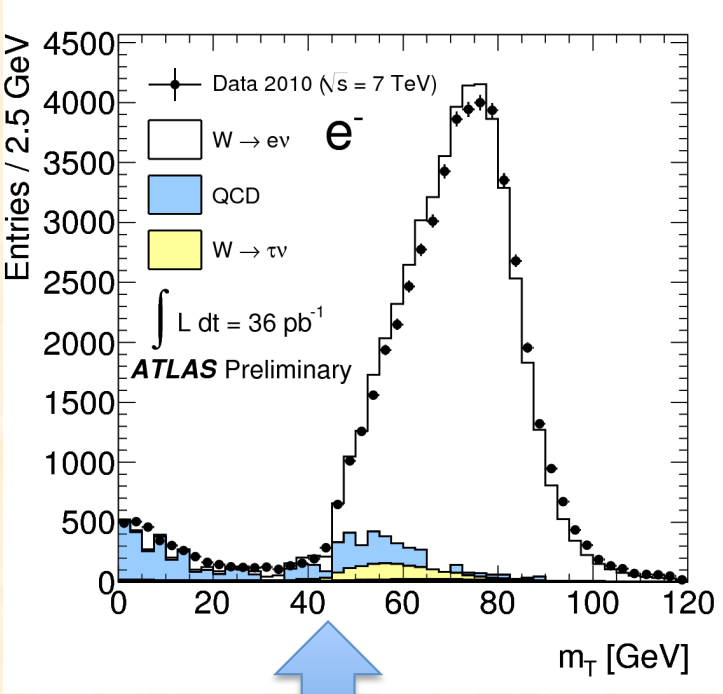




CMS-PAS-EWK-10-005

# ATLAS W Selection

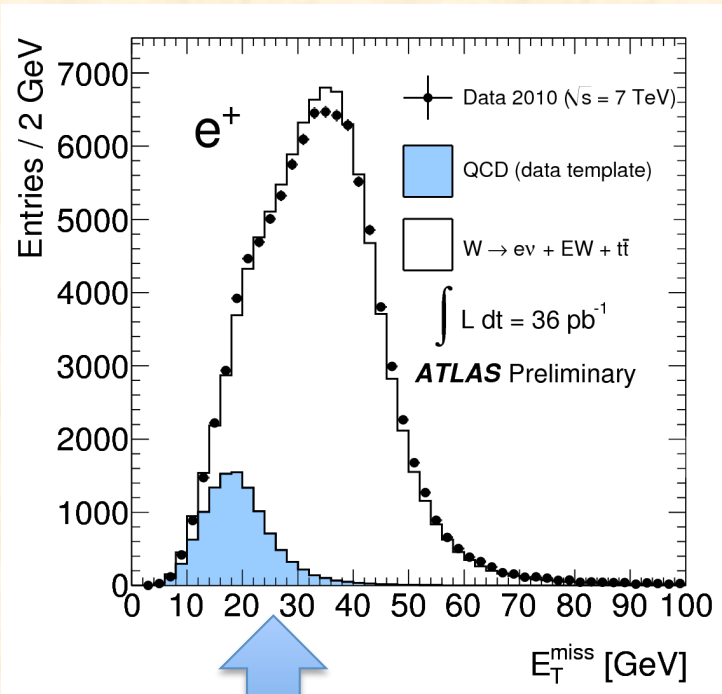
***121k W→eν candidates***
***140k W→μν candidates***

- $m_T$>40 GeV and $E_{T,miss}$ >25 GeV, vertex with at least 3 tracks
- muons : $|\eta^{\mu}|$<2.4 and $p_T$>20 GeV, track isolation cut of $\Delta R$=0.2
- electrons : *"Tight"* identification within
  $|\eta^{e}|$<1.37 and 1.52<$|\eta^{e}|$<2.47 and $E_T$>20 GeV




$m_T$>40 GeV

$$m_{\mathrm{T}} = \sqrt{2\, p_{\mathrm{T}}^{\ell}\, E_{\mathrm{T}}^{\mathrm{miss}}\, (1-\cos\Delta\phi)}$$




$E_{T,miss}$>25 GeV

$E_{T,miss}$ calibrated for different particle response

ATLAS-CONF-2011-041

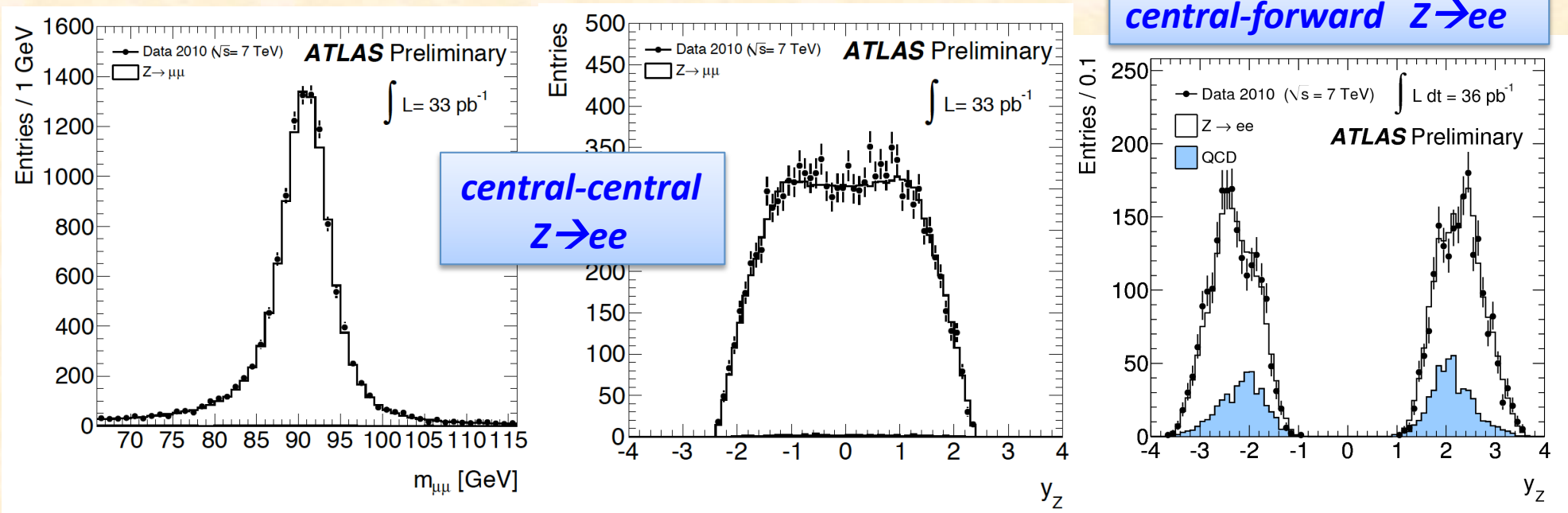
# ATLAS Z Selection $66<M_{ll}<116$ GeV

- 2 oppositely charged leptons identified as for W selection
- *"Medium"* electron identification
- Very low backgrounds (<2.5%)

***11.7k Z→μμ candidates***
***9.7k Z→ee candidates***

***4.0k c-f Z→ee candidates***

- ***New:*** select central, $|\eta^e|<2.47$, and *forward,* $2.5<|\eta^e|<4.9$, electrons
- Larger backgrounds of about 28%






ATLAS-CONF-2011-041

# CMS Cross Section Measurement

$$\sigma \times \mathcal{B} = N/(A \times \varepsilon \times \mathcal{L})$$

- Fiducial cross sections for described kinematic and geometrical cuts corrected for detector effects w/o further QED FSR corrections.
- Determine the efficiency corrections in data and simulation in the same way using the ratio $\rho = \varepsilon/\varepsilon_{\mathrm{sim}}$
- Calculations done effectively via a factor $F = A \times \varepsilon_{\mathrm{sim}}$

  purely from simulation (fraction of events selected in simulation *after QED FSR*) and efficiencies ε taken from data

  ➔ $A \times \varepsilon = F \times \rho = A \times \varepsilon_{sim} \times \rho$

- Correction factor $\rho$ derived from data and the related systematic uncertainties are only experimental ones.
- The values for *F* are derived from Monte Carlo (Powheg interfaced to Pythia and Photos) and uncertainties on *F* are derived from the uncertainties of *A* (theory models).

JHEP**01**(2011)080

# CMS Cross Section Systematics [%]

| Source | $W \to e\nu$ | $W \to \mu\nu$ | $Z \to e^+e^-$ | $Z \to \mu^+\mu^-$ |
|---|---|---|---|---|
| Lepton reconstruction & identification | 1.3 | 0.9 | 1.8 | n/a |
| Trigger pre-firing | n/a | 0.5 | n/a | 0.5 |
| Momentum scale & resolution | 0.5 | 0.22 | 0.12 | 0.35 |
| $\not{E}_T$ scale & resolution | 0.3 | 0.2 | n/a | n/a |
| Background subtraction / modeling | 0.35 | 0.4 | 0.14 | 0.28 |
| Total experimental | 1.5 | 1.1 | 1.8 | 0.7 |
| PDF uncertainty for acceptance | 0.6 | 0.7 | 0.9 | 1.2 |
| Other theoretical uncertainties | 0.7 | 0.8 | 1.4 | 1.6 |
| Total theoretical | 0.9 | 1.1 | 1.7 | 2.0 |
| Total | 1.7 | 1.6 | 2.5 | 2.1 |

- Experimental uncertainty for fiducial cross sections is dominated by lepton reconstruction efficiency. It is smallest with 0.7% for the Z→μμ and at most 1.8% for the Z→ ee channel.
- To be added: Luminosity uncertainty of 4%.
- PDF uncertainty from 68% C.L. envelope of CT10, NNPDF2.0 and MSTW08 PDF sets .

CMS-PAS-EWK-10-005

# ATLAS Cross Section Measurement

$$\sigma^{\text{tot}}_{W(Z)} \cdot BR(W(Z) \to \ell\nu\ (\ell\ell)) = \frac{N^{\text{sig}}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)} \cdot L_{W(Z)}}$$

$$A_{W/Z} = \frac{N_{\text{MC,gen,cut}}}{N_{\text{MC,gen,all}}} \qquad C_{W/Z} = \frac{N_{\text{MC,rec}}}{N_{\text{MC,gen,cut}}}$$

- Fiducial cross section for described kinematic and geometrical cuts are corrected for detector and QED FSR effects.
- Corrections for reconstruction, trigger, lepton identification and QED FSR effects are performed with a single factor $C_{W(Z)}$ taken from Pythia Monte Carlo interfaced with Photos ($N_{MC,gen}$ *before QED FSR*).

- Total cross section is obtained calculating the geometrical acceptance $A_{W(Z)}$ using Pythia and dedicated MC@NLO samples using CTEQ6.6 and HERAPDF1.0 PDFs.

  → PDF model, CTEQ6.6 90% C.L. eigenvector sets and Monte Carlo generator model systematics in the range of 1.5-4%.



JHEP**12**(2010)06

# ATLAS Electron Systematics [%]

- Efficiencies are high and usually well modelled by simulation.

| | $\delta\sigma_W/\sigma_W$ | $\delta\sigma_{W+}/\sigma_{W+}$ | $\delta\sigma_{W-}/\sigma_{W-}$ | Central $\delta\sigma_Z/\sigma_Z$ | Forward $\delta\sigma_Z/\sigma_Z$ |
|---|---|---|---|---|---|
| Trigger | 0.5 | 0.5 | 0.5 | <0.1 | 0.5 |
| Electron Reconstruction | 1.5 | 1.5 | 1.5 | 3.0 | 1.5 |
| Electron Identification | 1.1 | 1.2 | 1.1 | 1.6 | 8.2 |
| Electron Energy scale | 0.5 | 0.5 | 0.4 | 0.2 | 1.4 |
| Electron Energy resolution | 0.02 | 0.02 | 0.02 | 0.01 | <0.1 |
| defective LAr channels | 0.4 | 0.4 | 0.4 | 0.8 | 0.8 |
| Charge misidentification | — | 1.1 | 1.1 | 0.2 | — |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution | 2.0 | 2.0 | 2.0 | — | — |
| pile-up | 0.1 | 0.1 | 0.1 | 0.1 | 1.7 |
| Background | 0.4 | 0.5 | 0.5 | 0.3 | 3.2 |
| $C_{W/Z}$ Theoretical uncertainty | 0.3 | 0.3 | 0.3 | 0.5 | 0.9 |
| Total experimental uncertainty | 2.8 | 3.0 | 3.0 | 3.5 | 8.6 |
| $A_{W/Z}$ Theoretical uncertainty | 3.0 | 3.0 | 3.0 | 4.0 | 3.9 |
| Total excluding Luminosity | 4.1 | 4.2 | 4.2 | 5.3 | 9.4 |
| Luminosity | 3.4 | | | | |

ATLAS-CONF-2011-041

# ATLAS Muon Systematics [%]

| | $\delta\sigma_W/\sigma_W$ | $\delta\sigma_{W+}/\sigma_{W+}$ | $\delta\sigma_{W-}/\sigma_{W-}$ | $\delta\sigma_Z/\sigma_Z$ |
|---|---|---|---|---|
| Trigger | 0.7 | 0.8 | 0.9 | 0.1 |
| Muon Reconstruction | 0.5 | 0.6 | 0.6 | 0.8 |
| Muon Isolation | 0.3 | 0.3 | 0.3 | 0.6 |
| Muon $p_T$ Resolution | 0.02 | 0.03 | 0.02 | 0.01 |
| Muon $p_T$ Scale | 0.4 | 1.1 | 0.8 | 0.2 |
| QCD Background | 0.8 | 0.7 | 1.1 | 0.1 |
| Electroweak Background | 0.4 | 0.4 | 0.5 | 0.02 |
| $E_T^{miss}$ Cleaning | 0.07 | 0.07 | 0.07 | - |
| $E_T^{miss}$ Resolution and Scale | 2.0 | 2.0 | 2.0 | - |
| $C_{W/Z}$ Theoretical uncertainty | 0.3 | 0.3 | 0.3 | 0.3 |
| Total experimental uncertainty | 2.4 | 2.7 | 2.7 | 1.1 |
| $A_{W/Z}$ Theoretical uncertainty | 3.0 | 3.0 | 3.0 | 4.0 |
| Total excluding Luminosity | 3.9 | 4.0 | 4.0 | 4.1 |
| Luminosity | 3.4 | | | |

ATLAS-CONF-2011-041

- Experimental uncertainty with 1.1% smallest for Z→μμ.

# Fiducial Cross Sections (1)

ATLAS-CONF-2011-041
CMS-PAS-EWK-10-005

## ATLAS electron channels, QED FSR corrected

$|\eta^e|<1.37$ and $1.52<|\eta^e|<2.47$
$E_T>20$ GeV

$E_{T,miss}>25$ GeV
$m_T > 40$ GeV

| | $\sigma^{\text{fid}}_{W^{(\pm)}} \cdot \text{BR}(W \to e\nu)$ [nb] |
|---|---|
| $W^+$ | $2.950 \pm 0.011(\text{sta}) \pm 0.090(\text{sys}) \pm 0.100(\text{lum})$ |
| $W^-$ | $1.927 \pm 0.009(\text{sta}) \pm 0.059(\text{sys}) \pm 0.063(\text{lum})$ |
| $W$ | $4.877 \pm 0.015(\text{sta}) \pm 0.138(\text{sys}) \pm 0.166(\text{lum})$ |
| | $\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV |
| $Z/\gamma^*$ Central | $0.433 \pm 0.004(\text{sta}) \pm 0.016(\text{sys}) \pm 0.015(\text{lum})$ |
| $Z/\gamma^*$ Forward | $0.179 \pm 0.004(\text{sta}) \pm 0.017(\text{sys}) \pm 0.006(\text{lum})$ |

## CMS, QED FSR not further corrected

*Z: $60<M_{ll}<120$ GeV, $p_T^{\mu}>20$ GeV*

| Channel | $\sigma \times \mathcal{B}$ in acceptance $A$ (nb) | $A$ | |
|---|---|---|---|
| $W \to e\nu$ | $5.449 \pm 0.015\,(\text{stat.}) \pm 0.086\,(\text{syst.}) \pm 0.218\,(\text{lumi.})$ | $0.520 \pm 0.003$ | $p_T > 25\,\text{GeV}$ |
| $W^+ \to e^+\nu$ | $3.257 \pm 0.012\,(\text{stat.}) \pm 0.061\,(\text{syst.}) \pm 0.130\,(\text{lumi.})$ | $0.530 \pm 0.004$ | $\lvert\eta\rvert < 2.5$ |
| $W^- \to e^-\bar{\nu}$ | $2.193 \pm 0.010\,(\text{stat.}) \pm 0.039\,(\text{syst.}) \pm 0.088\,(\text{lumi.})$ | $0.506 \pm 0.007$ | |
| $Z \to e^+e^-$ | $0.420 \pm 0.005\,(\text{stat.}) \pm 0.010\,(\text{syst.}) \pm 0.017\,(\text{lumi.})$ | $0.423 \pm 0.004$ | |
| $W \to \mu\nu$ | $4.723 \pm 0.012\,(\text{stat.}) \pm 0.066\,(\text{syst.}) \pm 0.189\,(\text{lumi.})$ | $0.464 \pm 0.003$ | $p_T > 25\,\text{GeV}$ |
| $W^+ \to \mu^+\nu$ | $2.815 \pm 0.009\,(\text{stat.}) \pm 0.042\,(\text{syst.}) \pm 0.113\,(\text{lumi.})$ | $0.471 \pm 0.005$ | $\lvert\eta\rvert < 2.1$ |
| $W^- \to \mu^-\bar{\nu}$ | $1.920 \pm 0.008\,(\text{stat.}) \pm 0.027\,(\text{syst.}) \pm 0.077\,(\text{lumi.})$ | $0.457 \pm 0.008$ | |
| $Z \to \mu^+\mu^-$ | $0.385 \pm 0.003\,(\text{stat.}) \pm 0.007\,(\text{syst.}) \pm 0.015\,(\text{lumi.})$ | $0.398 \pm 0.005$ | |

ATLAS-CONF-2011-041
CMS-PAS-EWK-10-005

# Fiducial Cross Sections (2)

***ATLAS muon channels, QED FSR corrected***

| | $\sigma^{\text{fid}}_{W^{(\pm)}} \cdot \text{BR}(W \to \mu\nu)$ [nb] |
|---|---|
| $W^+$ | $3.008 \pm 0.011(\text{sta}) \pm 0.080(\text{sys}) \pm 0.109(\text{lum})$ |
| $W^-$ | $1.950 \pm 0.009(\text{sta}) \pm 0.053(\text{sys}) \pm 0.072(\text{lum})$ |
| $W$ | $4.959 \pm 0.015(\text{sta}) \pm 0.120(\text{sys}) \pm 0.181(\text{lum})$ |

| | $\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV |
|---|---|
| $Z/\gamma^*$ | $0.456 \pm 0.004(\text{sta}) \pm 0.005(\text{sys}) \pm 0.015(\text{lum})$ |

$|\eta^{\mu}|<2.4$
$p_T>20$ GeV

$E_{T,miss}>25$ GeV
$m_T > 40$ GeV

***CMS, QED FSR not further corrected***

*Z: $60<M_{ll}<120$ GeV, $p_T^{\mu}>20$ GeV*

| Channel | $\sigma \times \mathcal{B}$ in acceptance $A$ (nb) | $A$ | |
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| $W \to e\nu$ | $5.449 \pm 0.015\,(\text{stat.}) \pm 0.086\,(\text{syst.}) \pm 0.218\,(\text{lumi.})$ | $0.520 \pm 0.003$ | $p_T > 25\,\text{GeV}$ |
| $W^+ \to e^+\nu$ | $3.257 \pm 0.012\,(\text{stat.}) \pm 0.061\,(\text{syst.}) \pm 0.130\,(\text{lumi.})$ | $0.530 \pm 0.004$ | $\lvert\eta\rvert < 2.5$ |
| $W^- \to e^-\bar{\nu}$ | $2.193 \pm 0.010\,(\text{stat.}) \pm 0.039\,(\text{syst.}) \pm 0.088\,(\text{lumi.})$ | $0.506 \pm 0.007$ | |
| $Z \to e^+e^-$ | $0.420 \pm 0.005\,(\text{stat.}) \pm 0.010\,(\text{syst.}) \pm 0.017\,(\text{lumi.})$ | $0.423 \pm 0.004$ | |
| $W \to \mu\nu$ | $4.723 \pm 0.012\,(\text{stat.}) \pm 0.066\,(\text{syst.}) \pm 0.189\,(\text{lumi.})$ | $0.464 \pm 0.003$ | $p_T > 25\,\text{GeV}$ |
| $W^+ \to \mu^+\nu$ | $2.815 \pm 0.009\,(\text{stat.}) \pm 0.042\,(\text{syst.}) \pm 0.113\,(\text{lumi.})$ | $0.471 \pm 0.005$ | $\lvert\eta\rvert < 2.1$ |
| $W^- \to \mu^-\bar{\nu}$ | $1.920 \pm 0.008\,(\text{stat.}) \pm 0.027\,(\text{syst.}) \pm 0.077\,(\text{lumi.})$ | $0.457 \pm 0.008$ | |
| $Z \to \mu^+\mu^-$ | $0.385 \pm 0.003\,(\text{stat.}) \pm 0.007\,(\text{syst.}) \pm 0.015\,(\text{lumi.})$ | $0.398 \pm 0.005$ | |

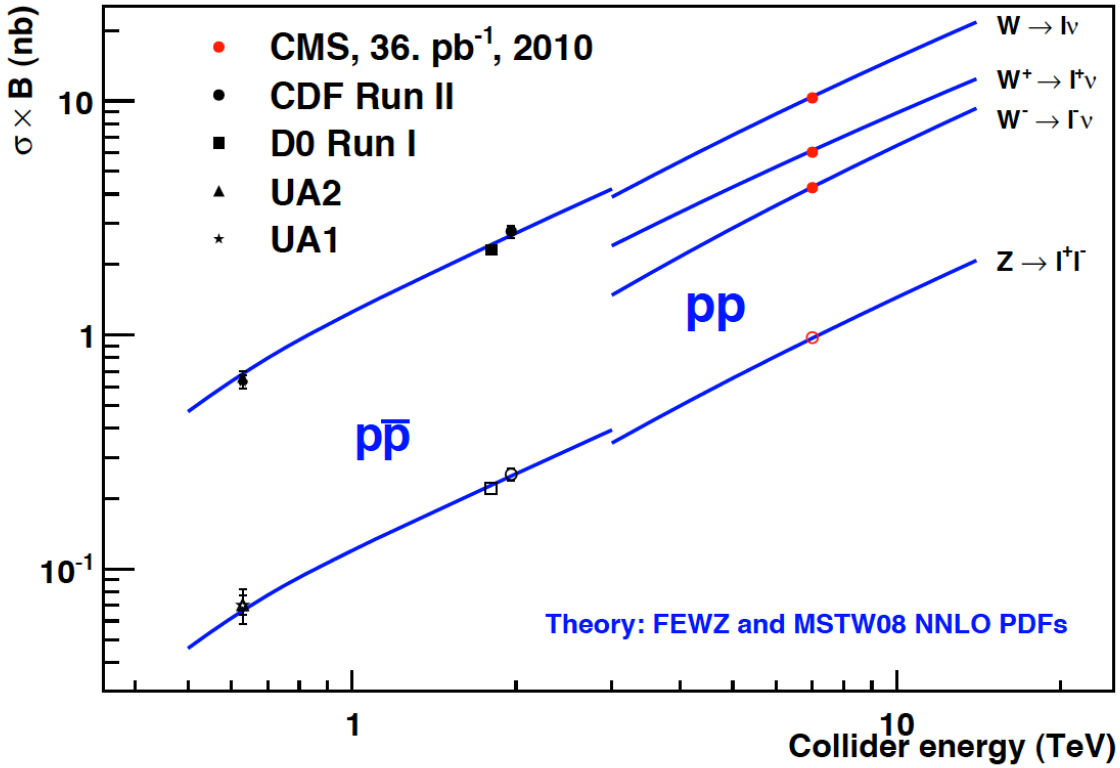
# W and Z Cross Total Sections

**ATLAS**

| | $\sigma^{\text{tot}}_{W^{(\pm)}} \cdot \text{BR}(W \to \ell\nu)$ [nb] |
|---|---|
| $W^+$ | $6.257 \pm 0.017(\text{sta}) \pm 0.152(\text{sys}) \pm 0.213(\text{lum}) \pm 0.188(\text{acc})$ |
| $W^-$ | $4.149 \pm 0.014(\text{sta}) \pm 0.102(\text{sys}) \pm 0.141(\text{lum}) \pm 0.124(\text{acc})$ |
| $W$ | $10.391 \pm 0.022(\text{sta}) \pm 0.238(\text{sys}) \pm 0.353(\text{lum}) \pm 0.312(\text{acc})$ |
| | $\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \ell\ell)$ [nb], $66 < m_{ee} < 116$ GeV |
| $Z/\gamma^*$ | $0.945 \pm 0.006(\text{sta}) \pm 0.011(\text{sys}) \pm 0.032(\text{lum}) \pm 0.038(\text{acc})$ |

ATLAS-CONF-2011-041

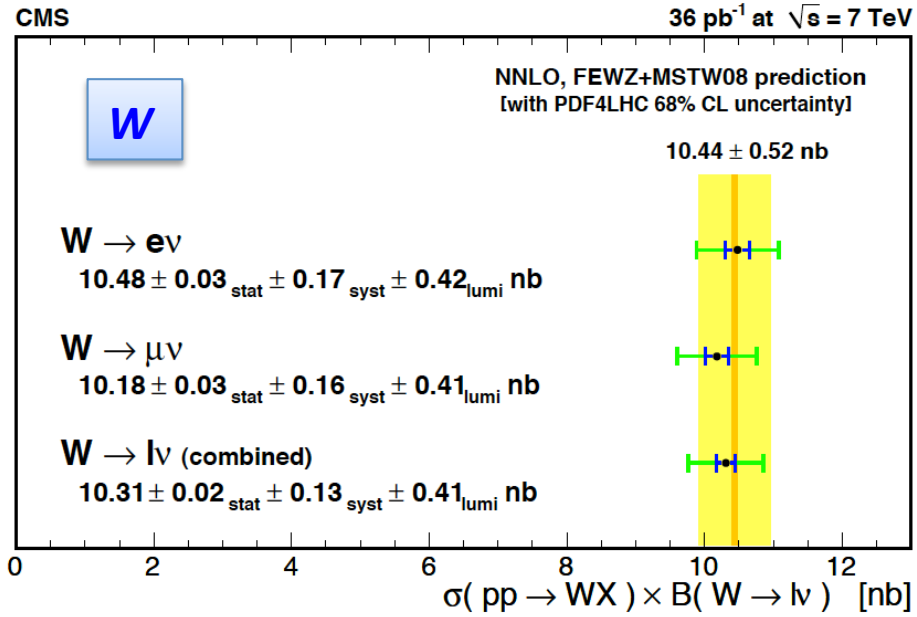
**CMS**

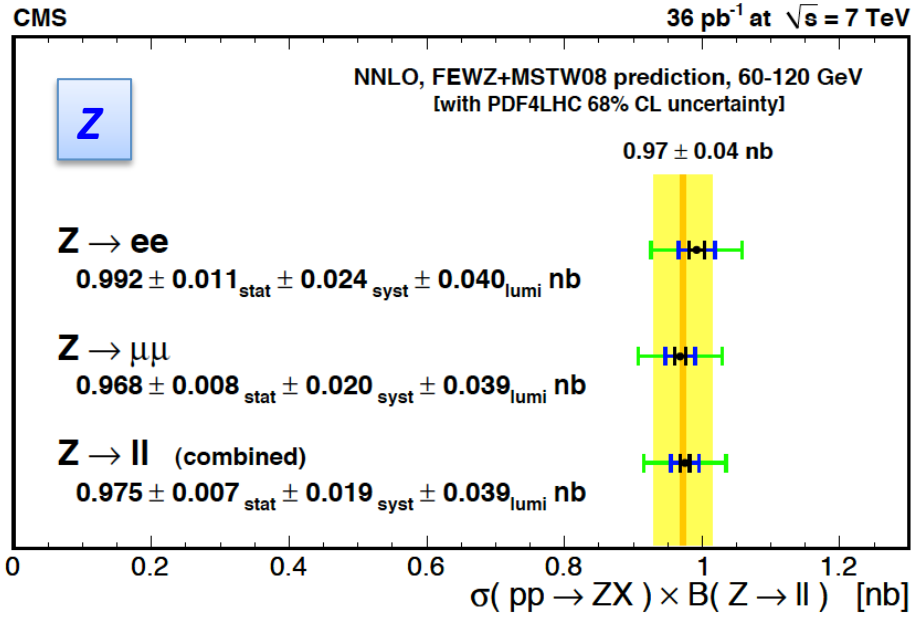



CMS-PAS-EWK-10-005

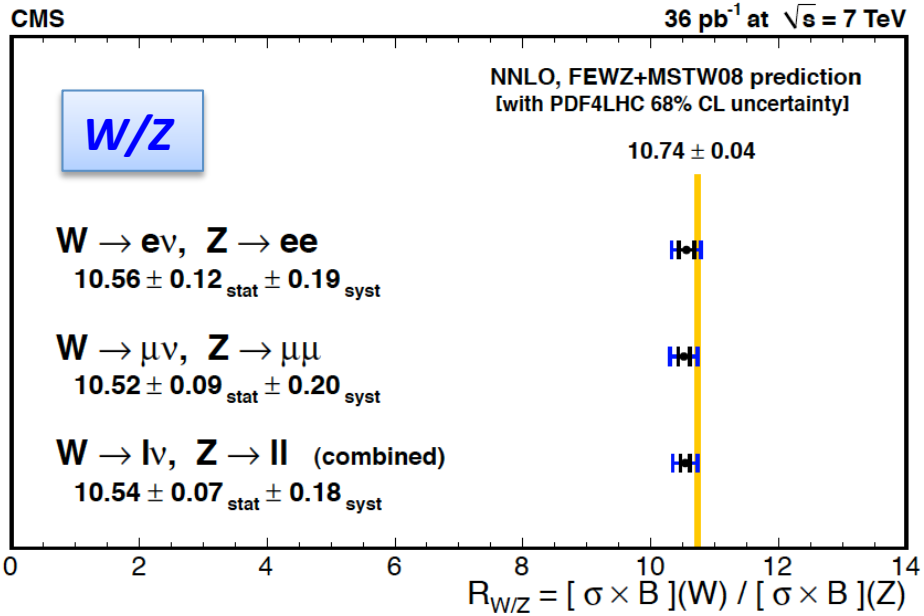
CMS

# W & Z Cross Sections and their Ratios



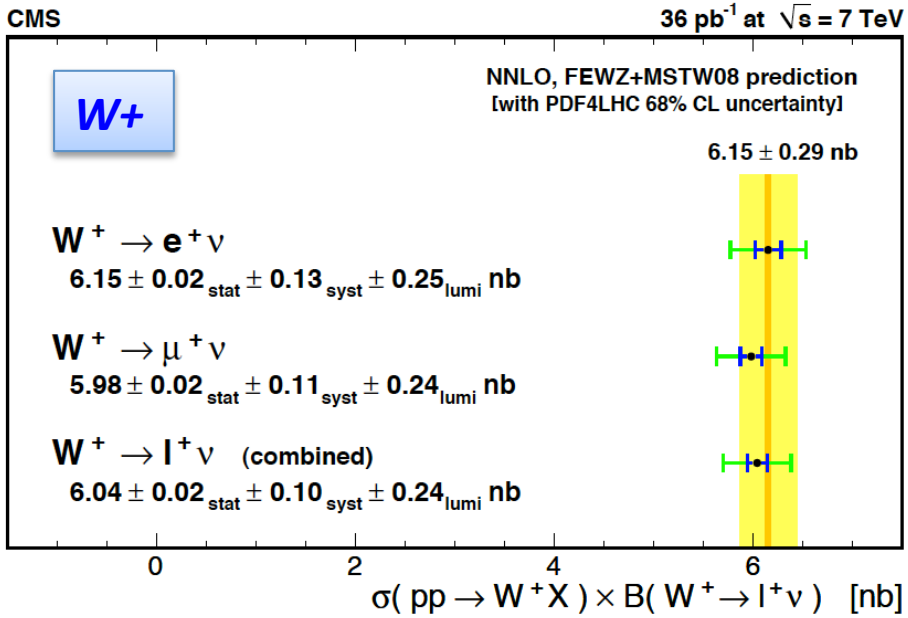

$$\frac{N_W}{N_Z}\frac{\varepsilon_Z}{\varepsilon_W}\frac{A_Z}{A_W}$$

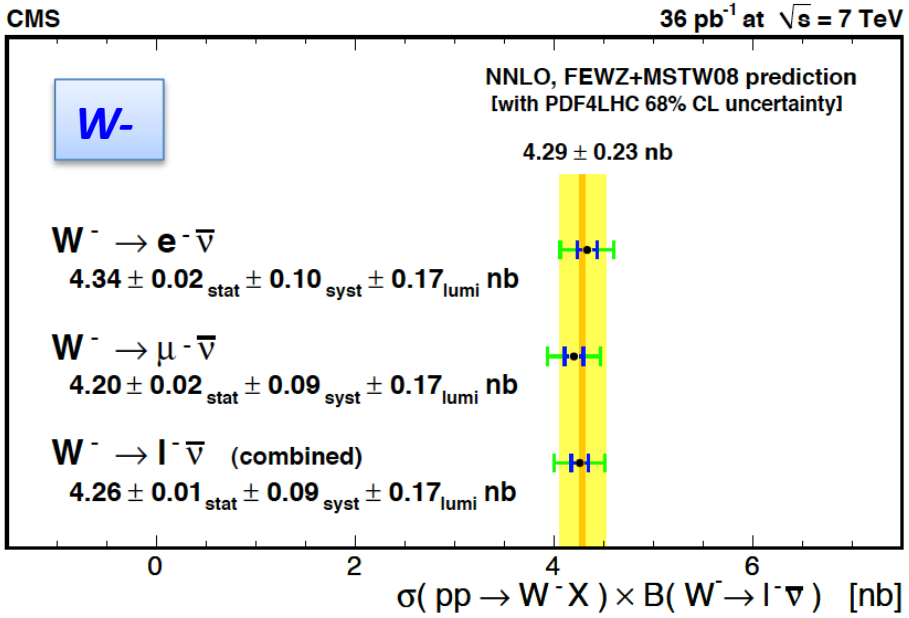



CMS-PAS-EWK-10-005

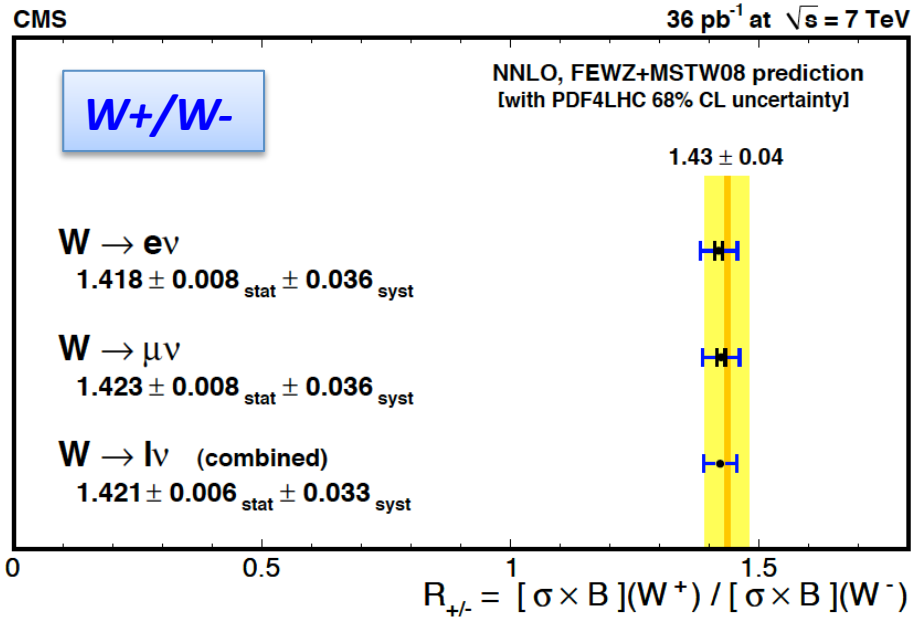
# $W^+$ & $W^-$ Cross Sections and their Ratio

CMS




$$\frac{N_{W+}}{N_{W-}}\frac{\varepsilon_{W-}}{\varepsilon_{W+}}\frac{A_{W-}}{A_{W+}}$$



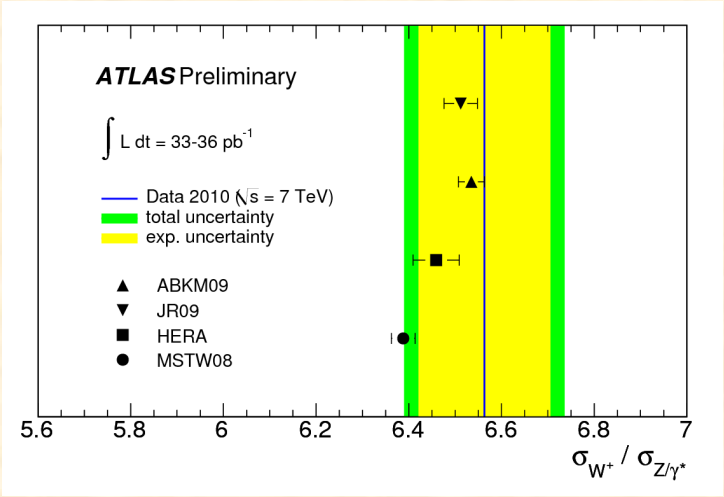

CMS-PAS-EWK-10-005

ATLAS

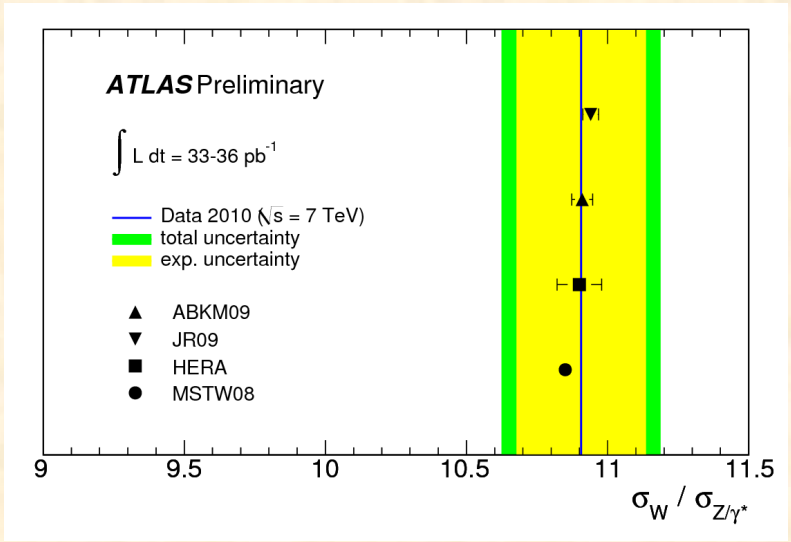
# W and Z and their Ratios

$$R = \frac{N_W^{\text{sig}}}{N_Z^{\text{sig}}} \cdot \frac{A_Z}{A_W} \cdot \frac{C_Z}{C_W}$$

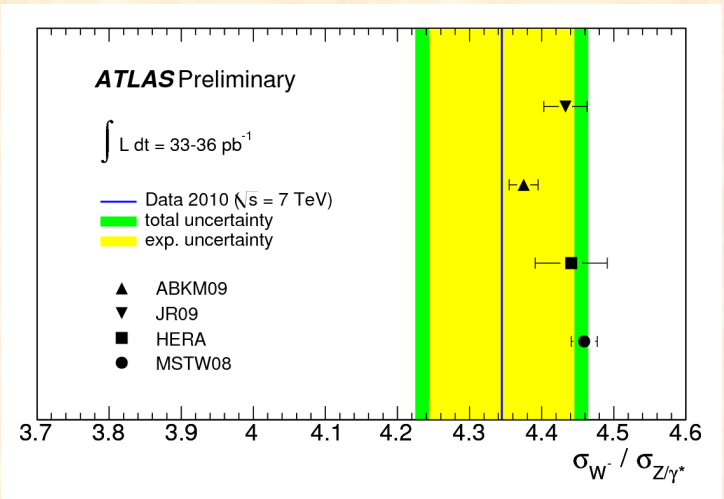
W+/Z




W/Z




W-/Z



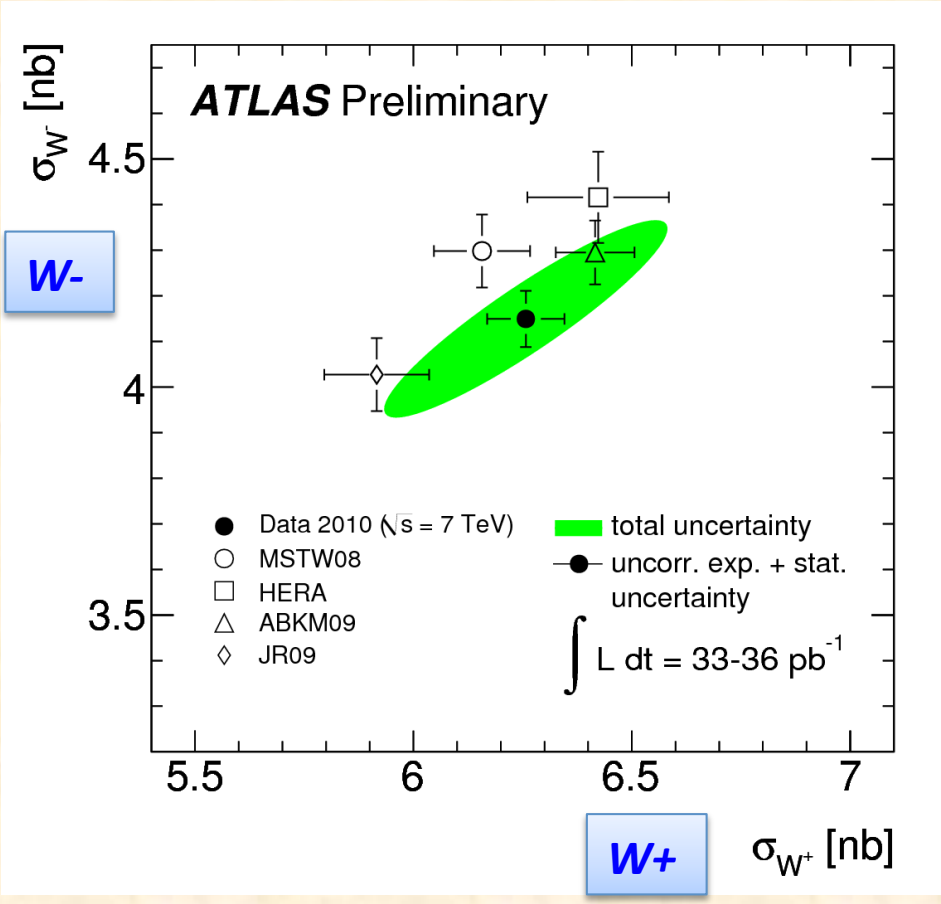

ATLAS-CONF-2011-041

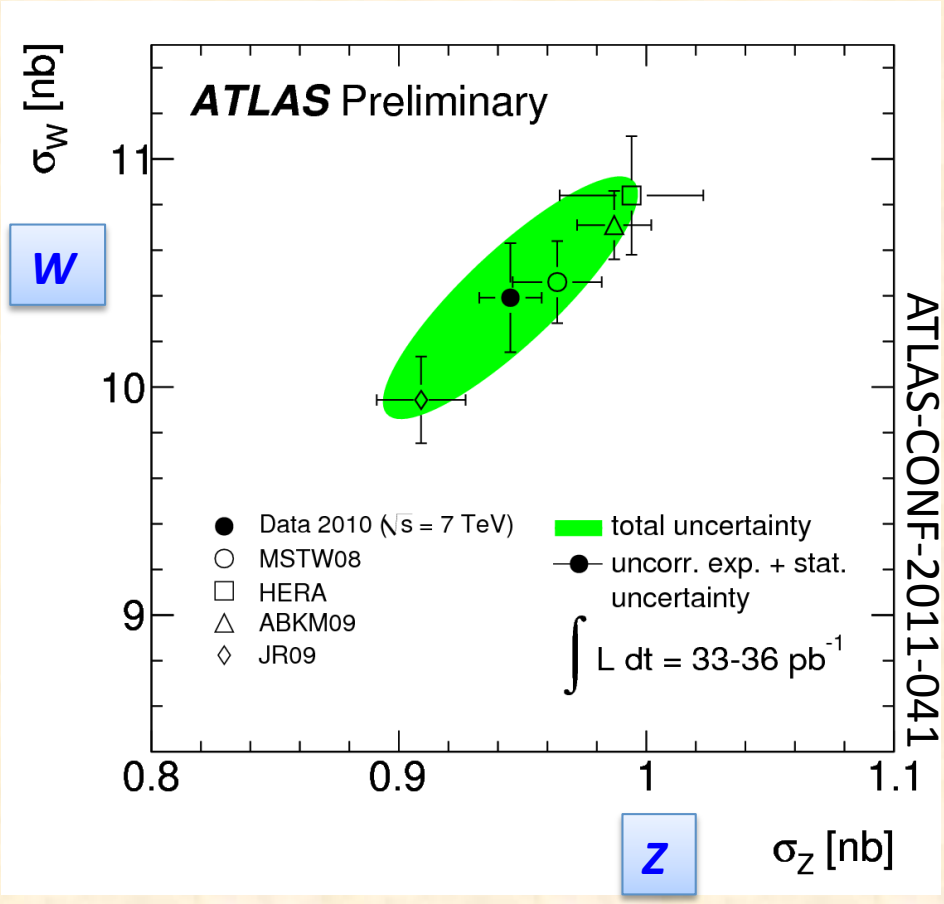
Good agreement with NNLO predictions for W and Z boson production cross sections and their ratios within quoted uncertainties.
Differences in NNLO predictions apparent.

ATLAS

# W & Z Cross Section Correlations

- Total cross section results.




Preliminary error ellipses caveats:

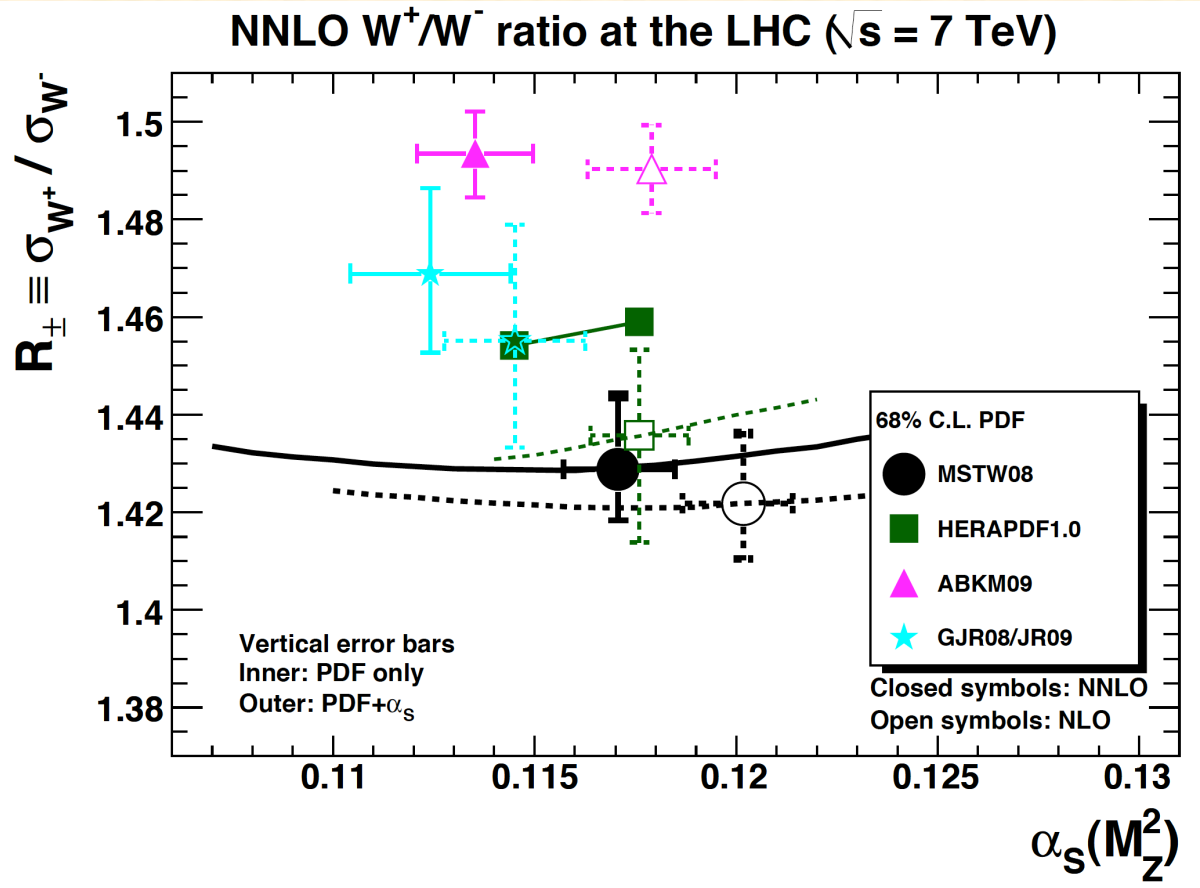
-68% C.L. theory errors – without $\alpha_s$ contribution

-correlation between $A_{W+}/A_{W-}$ neglected for $\sigma_{W-}$ versus $\sigma_{W+}$

-

# PDF Sensitivity of $\sigma_{W+}/\sigma_{W-}$

- Cross section ratio $\sigma_{W+}/\sigma_{W-}$ has only mild dependencies on NNLO vs NLO and the choice of $\alpha_s$.
- But apparent difference between the predictions of different NNLO (and NLO) PDF sets.

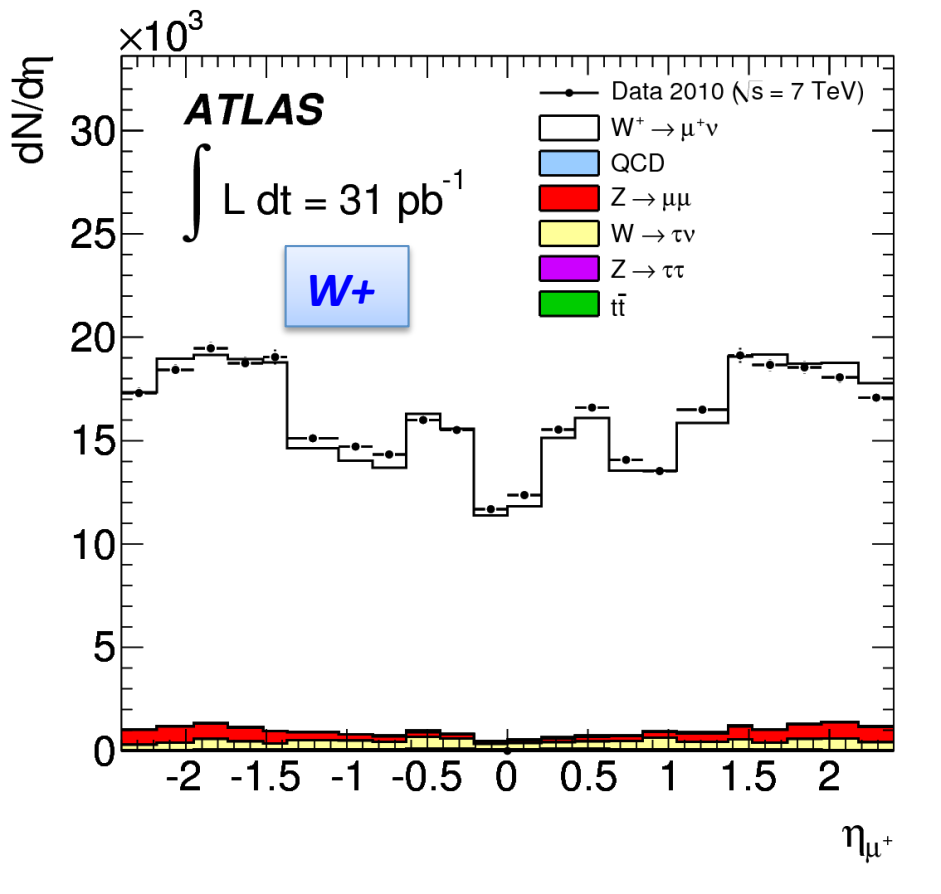


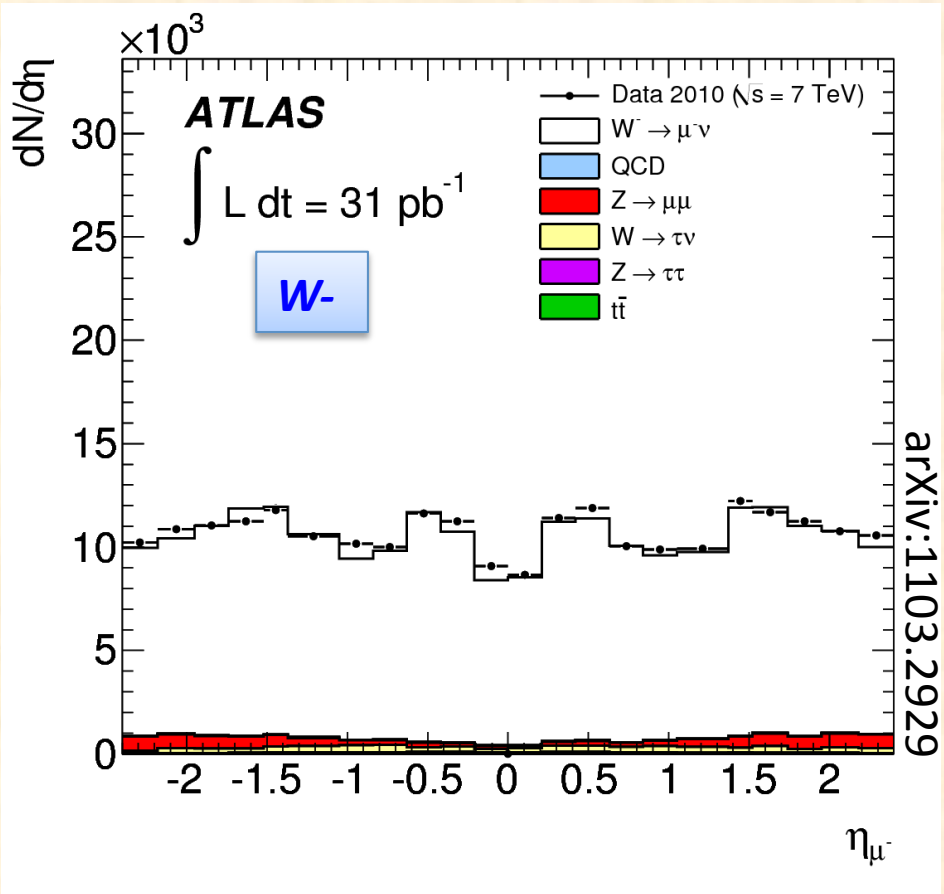

Plot courtesy of Graeme Watt.

ATLAS

# W Charge Asymmetry

- Results for fiducial cuts : $p_T^{\mu}$>20 GeV, $E_{T,miss}$>25 GeV, $m_T$>40 GeV
- Luminosity uncertainty cancels.
- Main experimental uncertainties are related to charge dependencies of efficiency corrections and/or are statistical dominated.



# W Asymmetry Systematics

CMS arXiv:1103.3470
ATLAS arXiv:1103.2929

**CMS**

$p_T^{\ell} > 25\ \mathrm{GeV}/c$

| $\lvert\eta\rvert$ bin | Electron Channel | | | | | | Muon Channel | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [0.0, 0.4] | [0.4, 0.8] | [0.8, 1.2] | [1.2, 1.4] | [1.6, 2.0] | [2.0, 2.4] | [0.0, 0.4] | [0.4, 0.8] | [0.8, 1.2] | [1.2, 1.5] | [1.5, 1.8] | [1.8, 2.1] |
| Charge Misident. | 0.02 | 0.03 | 0.03 | 0.08 | 0.09 | 0.10 | 0 | 0 | 0 | 0 | 0 | 0 |
| Eff. Ratio | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.59 | 0.39 | 0.92 | 0.72 | 0.81 | 1.17 |
| $e/\mu$ Scale | 0.11 | 0.09 | 0.19 | 0.47 | 0.40 | 0.45 | 0.50 | 0.48 | 0.50 | 0.48 | 0.50 | 0.42 |
| Sig. & Bkg. Estim. | 0.16 | 0.19 | 0.26 | 0.33 | 0.25 | 0.25 | 0.23 | 0.29 | 0.34 | 0.40 | 0.53 | 0.58 |
| Total | 0.73 | 0.73 | 0.77 | 0.90 | 0.85 | 0.87 | 0.80 | 0.68 | 1.10 | 0.95 | 1.08 | 1.37 |

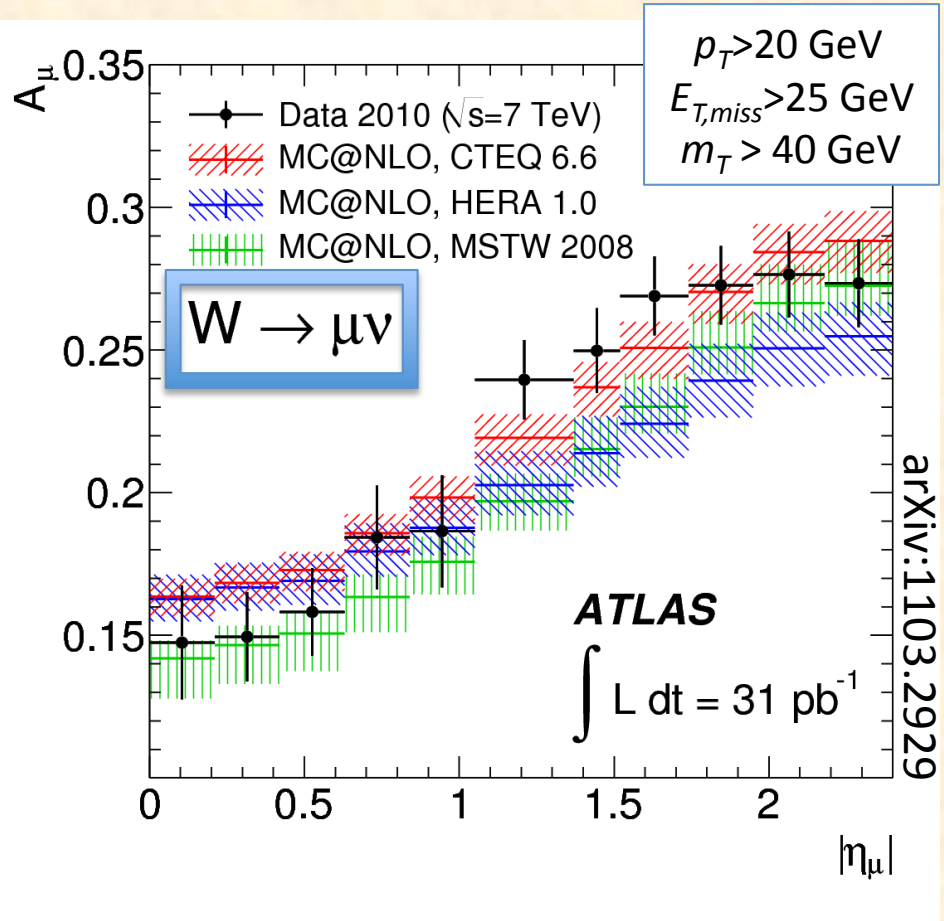
**ATLAS muon channel**

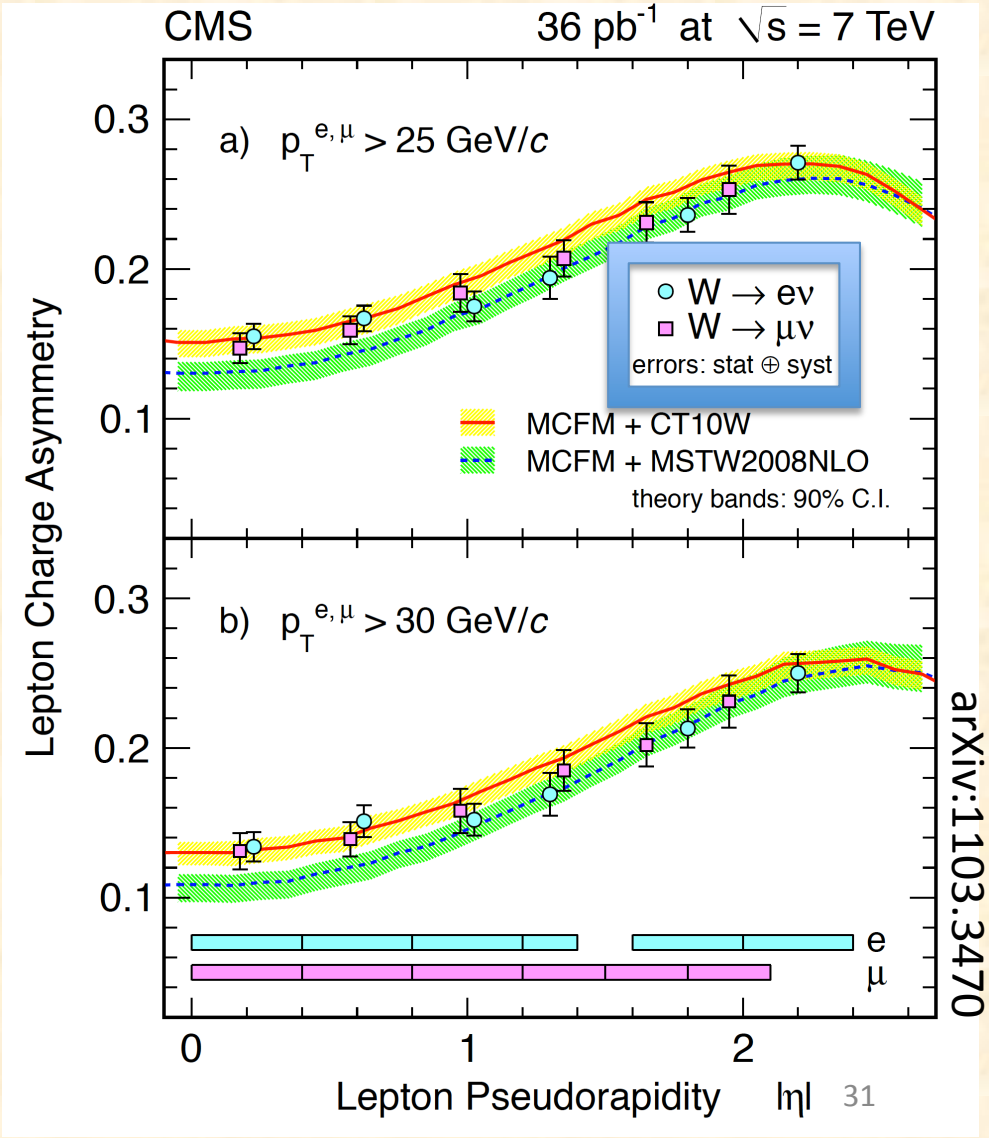
$p_T$>20 GeV
$E_{T,miss}$>25 GeV
$m_T$ > 40 GeV

| | Data | MSTW 2008 | CTEQ 6.6 | HERA 1.0 |
|---|---|---|---|---|
| $0.00 < \lvert\eta_\mu\rvert < 0.21$ | $0.147 \pm 0.011 \pm 0.017$ | $0.142^{+0.006}_{-0.014}$ | $0.164^{+0.006}_{-0.007}$ | $0.163 \pm 0.007$ |
| $0.21 < \lvert\eta_\mu\rvert < 0.42$ | $0.150 \pm 0.010 \pm 0.012$ | $0.147^{+0.007}_{-0.014}$ | $0.168^{+0.006}_{-0.007}$ | $0.167 \pm 0.007$ |
| $0.42 < \lvert\eta_\mu\rvert < 0.63$ | $0.158 \pm 0.010 \pm 0.012$ | $0.151^{+0.007}_{-0.013}$ | $0.173^{+0.006}_{-0.007}$ | $0.169 \pm 0.007$ |
| $0.63 < \lvert\eta_\mu\rvert < 0.84$ | $0.184 \pm 0.010 \pm 0.015$ | $0.163^{+0.008}_{-0.012}$ | $0.186^{+0.007}_{-0.008}$ | $0.179^{+0.008}_{-0.007}$ |
| $0.84 < \lvert\eta_\mu\rvert < 1.05$ | $0.186 \pm 0.011 \pm 0.017$ | $0.176^{+0.009}_{-0.012}$ | $0.198^{+0.007}_{-0.008}$ | $0.188 \pm 0.008$ |
| $1.05 < \lvert\eta_\mu\rvert < 1.37$ | $0.240 \pm 0.008 \pm 0.011$ | $0.197 \pm 0.010$ | $0.219^{+0.008}_{-0.010}$ | $0.203^{+0.009}_{-0.008}$ |
| $1.37 < \lvert\eta_\mu\rvert < 1.52$ | $0.250 \pm 0.011 \pm 0.010$ | $0.215^{+0.011}_{-0.010}$ | $0.237^{+0.009}_{-0.010}$ | $0.214 \pm 0.009$ |
| $1.52 < \lvert\eta_\mu\rvert < 1.74$ | $0.269 \pm 0.009 \pm 0.010$ | $0.230^{+0.012}_{-0.010}$ | $0.251^{+0.009}_{-0.011}$ | $0.224 \pm 0.009$ |
| $1.74 < \lvert\eta_\mu\rvert < 1.95$ | $0.273 \pm 0.009 \pm 0.010$ | $0.251^{+0.013}_{-0.009}$ | $0.270^{+0.010}_{-0.011}$ | $0.239^{+0.010}_{-0.009}$ |
| $1.95 < \lvert\eta_\mu\rvert < 2.18$ | $0.276 \pm 0.009 \pm 0.012$ | $0.266^{+0.014}_{-0.010}$ | $0.284^{+0.010}_{-0.011}$ | $0.251^{+0.009}_{-0.010}$ |
| $2.18 < \lvert\eta_\mu\rvert < 2.40$ | $0.273 \pm 0.010 \pm 0.012$ | $0.272^{+0.015}_{-0.011}$ | $0.288^{+0.009}_{-0.010}$ | $0.255^{+0.009}_{-0.010}$ |

# W Charge Asymmetry

$$A_\ell = \frac{\sigma^{\text{fid}}_{W^+} - \sigma^{\text{fid}}_{W^-}}{\sigma^{\text{fid}}_{W^+} + \sigma^{\text{fid}}_{W^-}}$$




Both, CMS and Atlas asymmetries, are corrected for QED FSR.

# Rapidity Shape $y_{ll}$ $60<M_{ll}<120$ GeV

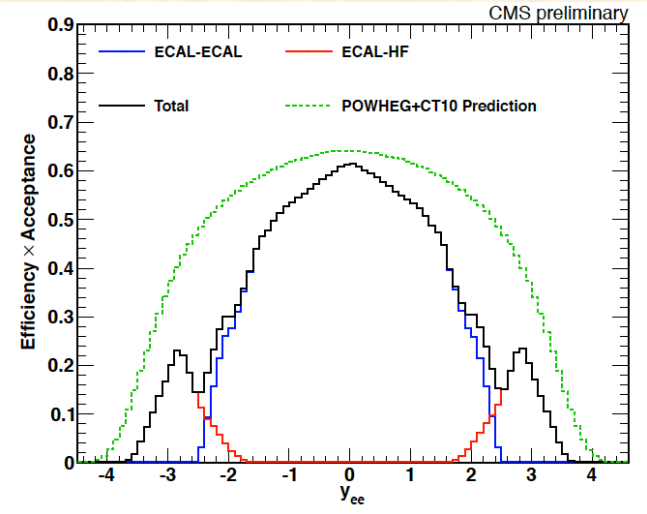
- corrected for detector and QED FSR effects
- $p_{T,l} > 20$ GeV
- muons $|\eta|<2.1$
- electrons

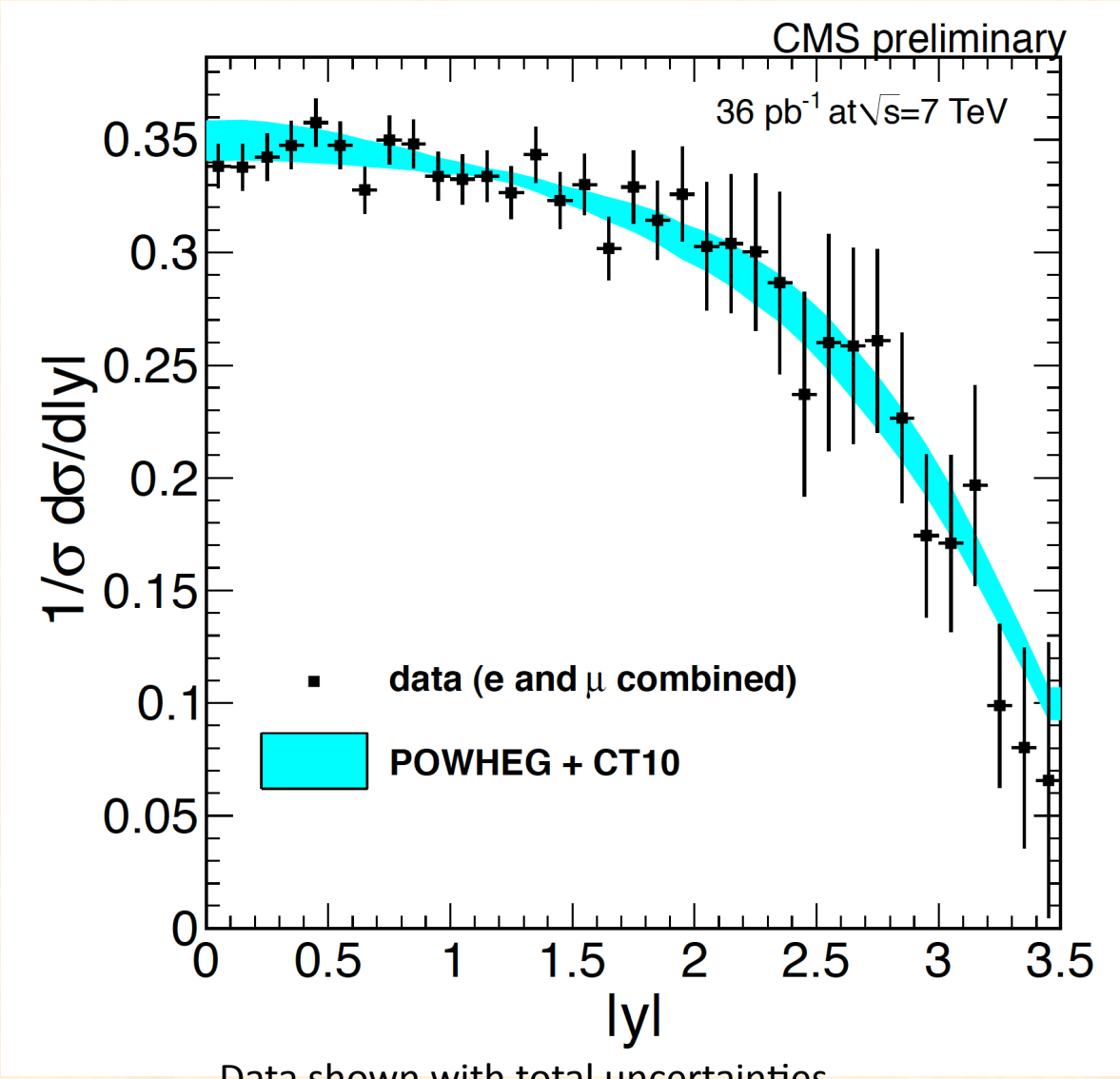
$|\eta|<1.444$

$1.566<|\eta|<3.0$

$3.1<|\eta|<4.6$

→ $y_{ee}$ up to 3.5 (as ATLAS)




CMS-PAS-EWK-10-010

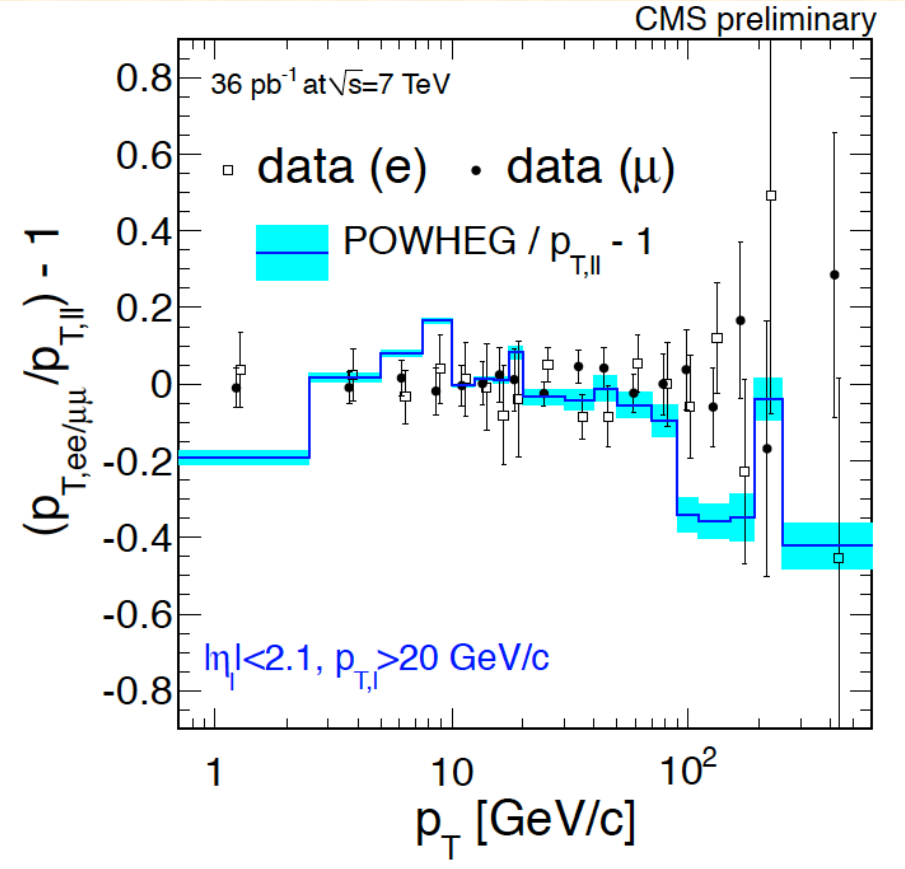
Data shown with total uncertainties.
Blue band : 1σ errors from CT10 eigenvectors

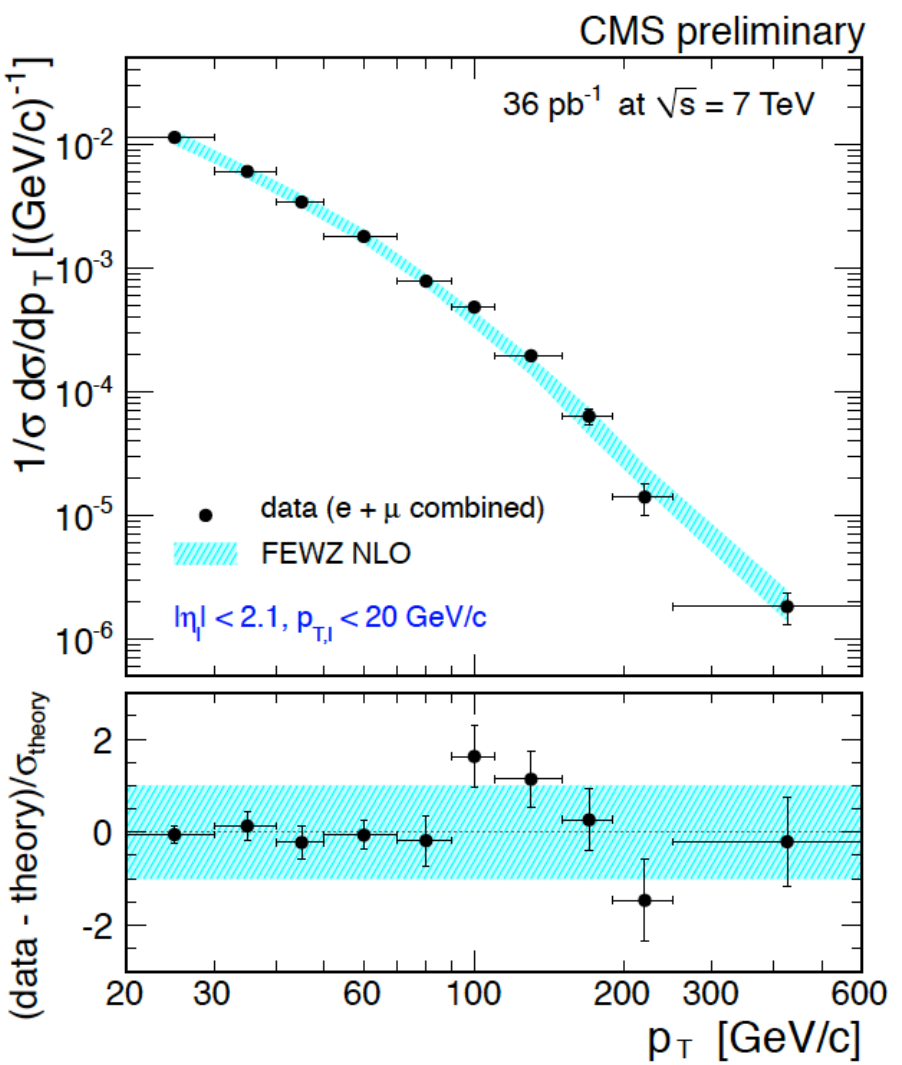
CMS

# Shape of $p_{T,ll}$ $60<M_{ll}<120$ GeV

- total uncertainties of 4.5% at lowest and about 30% at highest $p_{T,ll}$
- fair agreement to Powheg+Pythia within 20-40%
- good agreement to inclusive

FEWZ NLO using CT10 (prediction normalised to $20<p_{T,ll}<600$ GeV)




CMS-PAS-EWK-10-010

Blue band : Scale variation error from FEWZ authors.

# Summary

- ATLAS and CMS performed excellently in their first physics year and could achieve a luminosity uncertainty of 3.4% (Atlas) and 4% (CMS), respectively.

- Both experiments measured fiducial and total $W^+$, $W^-$ and Z production cross sections and their ratios to about 5% total experimental precision using the central detectors. The fiducial cross sections have almost no theoretical uncertainty.

- Both CMS and ATLAS are extending the Z→ee kinematic coverage up to $y_Z$ of 3.5. ATLAS showed central-forward cross sections with a total experimental precision of 10%, and CMS showed first $y_Z$ and $p_T^Z$ shape measurements.

- Good agreement of both CMS and ATLAS total cross section results with each other and with NNLO QCD predictions which have a spread about as large as the current measurement uncertainties.

# Outlook

- *Ongoing* efforts: Publication of full 2010 data results including differential cross sections and $p_T^Z$ and $y_Z$ shapes.

  Reminder : All presented results, except the W asymmetry, are preliminary.

- LHC restarted with 3.5 TeV and we expect a 100 times higher luminosity than in 2010 which will lead to higher precision W&Z measurements and further constraints on PDFs.

- A new level of W, Z precision measurements require improved and fast tools for HO QCD and EW models and theory predictions for the inclusive and differential measurements in the fiducial phase space.

# BackUp

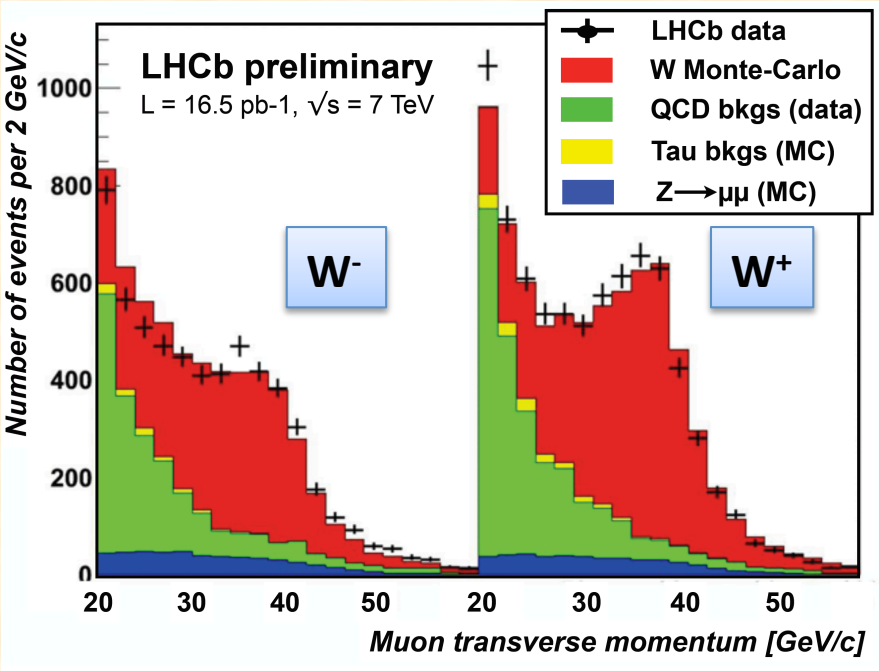
# Lhcb W Charge Asymmetry

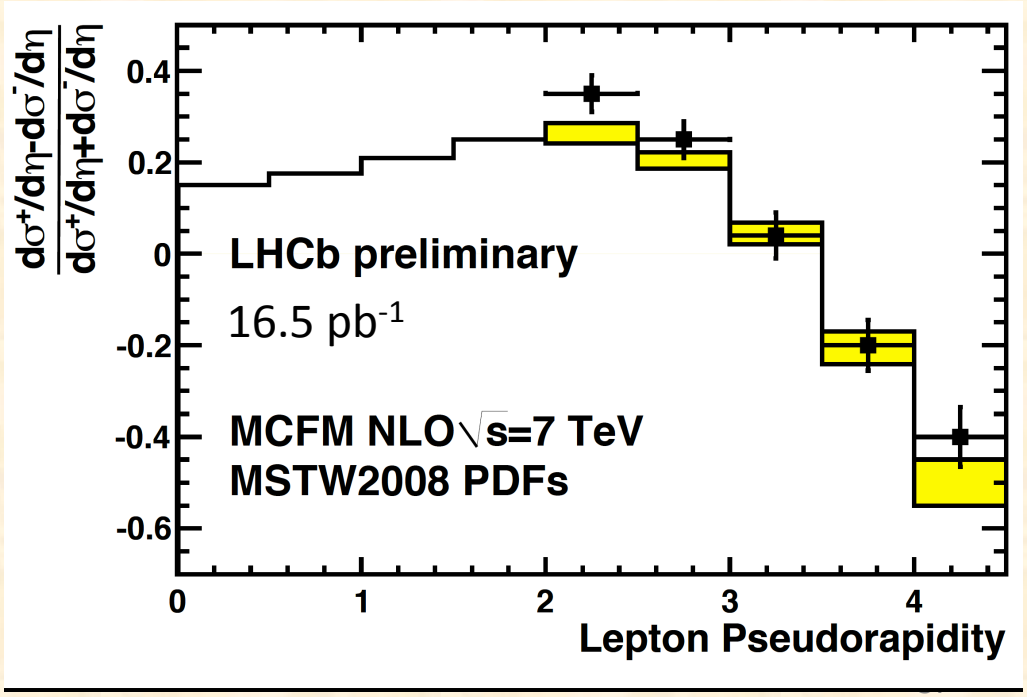
## $2<|\eta^{\mu}|<4.5$

CONF note in preparation

See e.g. talk by R. McNulty IOP Half Day, 12.1.2011, Liverpool;
Private Comm. T. Shears.

- acceptance 17% (16%) for $W^+$ ($W^-$)
- require $p_T^{\mu} > 20$ GeV and 'little' activity in the 'rest of the event'
- mass of 'rest event' < 20 GeV and $p_T$ of 'rest event' <10 GeV
- charged transverse momentum in cone of $\Delta R$ around muon < 2 GeV
- QCD background around 30%
- QED FSR not simulated



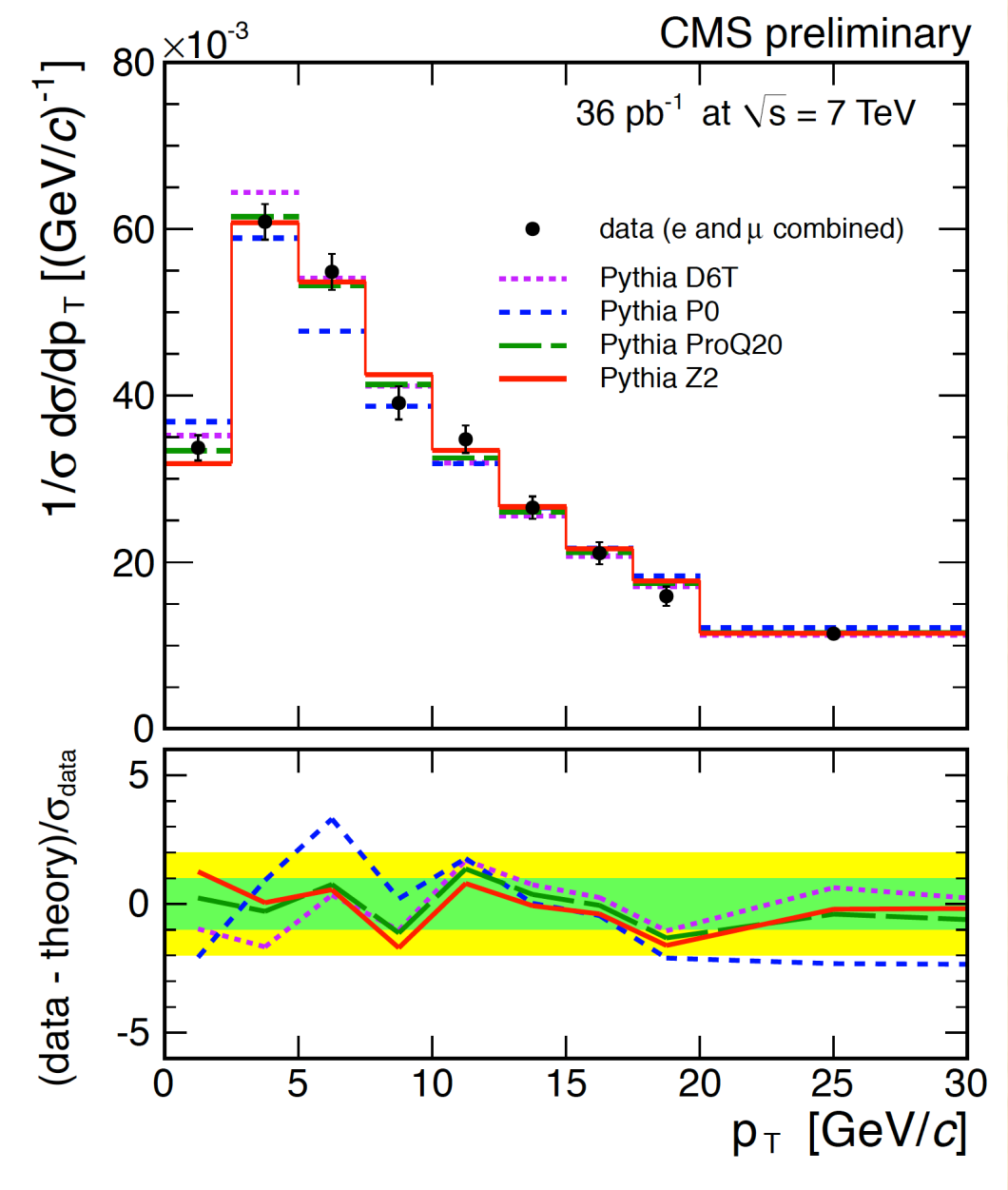
# ATLAS W Asymmetry Systematics

| | Trigger | Reconstruction | $p_T$ Scale and Resolution | QCD Normalisation | Electro-weak and $t\bar{t}$ Normalisation | Theoretical Modelling |
|---|---|---|---|---|---|---|
| $0.00 < \lvert\eta_\mu\rvert < 0.21$ | 0.011 | 0.010 | 0.003 | 0.003 | $< 0.001$ | 0.007 |
| $0.21 < \lvert\eta_\mu\rvert < 0.42$ | 0.010 | 0.004 | 0.003 | 0.003 | $< 0.001$ | 0.005 |
| $0.42 < \lvert\eta_\mu\rvert < 0.63$ | 0.009 | 0.004 | 0.003 | 0.003 | $< 0.001$ | 0.006 |
| $0.63 < \lvert\eta_\mu\rvert < 0.84$ | 0.012 | 0.004 | 0.003 | 0.002 | 0.001 | 0.007 |
| $0.84 < \lvert\eta_\mu\rvert < 1.05$ | 0.013 | 0.006 | 0.003 | 0.003 | 0.001 | 0.008 |
| $1.05 < \lvert\eta_\mu\rvert < 1.37$ | 0.006 | 0.007 | 0.002 | 0.002 | 0.001 | 0.006 |
| $1.37 < \lvert\eta_\mu\rvert < 1.52$ | 0.006 | 0.005 | 0.002 | 0.003 | 0.002 | 0.005 |
| $1.52 < \lvert\eta_\mu\rvert < 1.74$ | 0.005 | 0.004 | 0.002 | 0.003 | 0.002 | 0.007 |
| $1.74 < \lvert\eta_\mu\rvert < 1.95$ | 0.006 | 0.003 | 0.002 | 0.002 | 0.001 | 0.006 |
| $1.95 < \lvert\eta_\mu\rvert < 2.18$ | 0.006 | 0.004 | 0.002 | 0.003 | 0.002 | 0.009 |
| $2.18 < \lvert\eta_\mu\rvert < 2.40$ | 0.007 | 0.005 | 0.002 | 0.003 | 0.002 | 0.007 |

# CMS W Asymmetry Comparisons

https://twiki.cern.ch/twiki/bin/view/CMSPublic/LeptonChargeAsymmetryEWK10006

# CMS Comparisons to Pythia for $p_T(ll)$




CMS-PAS-EWK-10-010