W and Z boson cross section and W asymmetry at CMS

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on behalf of CMS collaboration

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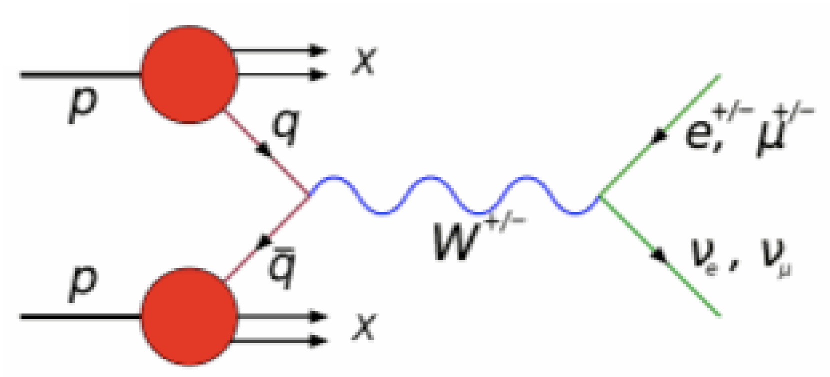
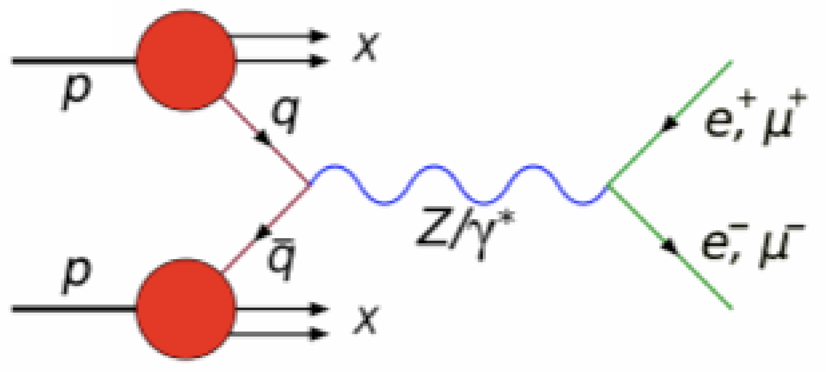
Contents

Physics Motivation

- W/Z decay at LHC





$$\sigma_{pp}(Q) = \sum_{i,j} \int dx_i \int dx_j \boxed{f_i(x_i) f_j(x_j)} \hat{\sigma}(Q/\mu, \alpha_s(\mu))$$

- Inclusive cross section is determined by Born-cross section($\hat{\sigma}$) and PDFs
  - It tests calculations based on higher-order perturbative QCD
  - ***It tests parton distribution functions (PDFs)***
- W/Z processes are well understood, unique signature, and have high rate
  - Good tool to calibrate the detector
  - Total cross section can be used as the luminosity candles at LHC
  - Pave the way for understanding complex final states for top or new physics

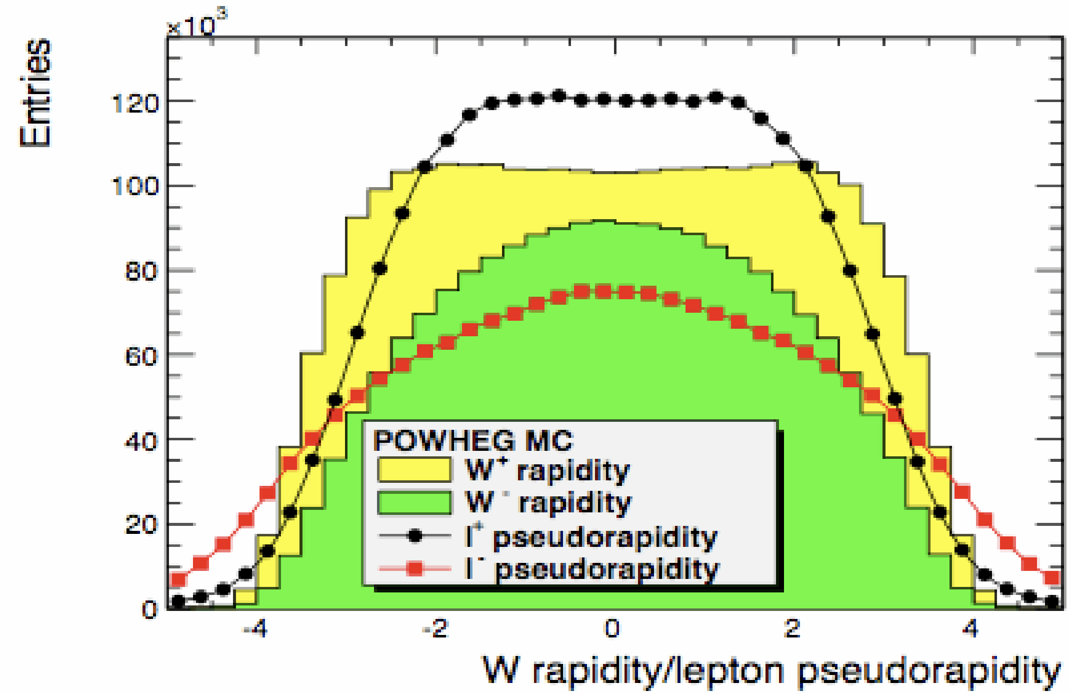
W^+ and W^- Asymmetry

- W^+ is more produced than W^- in pp collision because proton consists of uud
- W production is polarized due to ***parity violation at production***

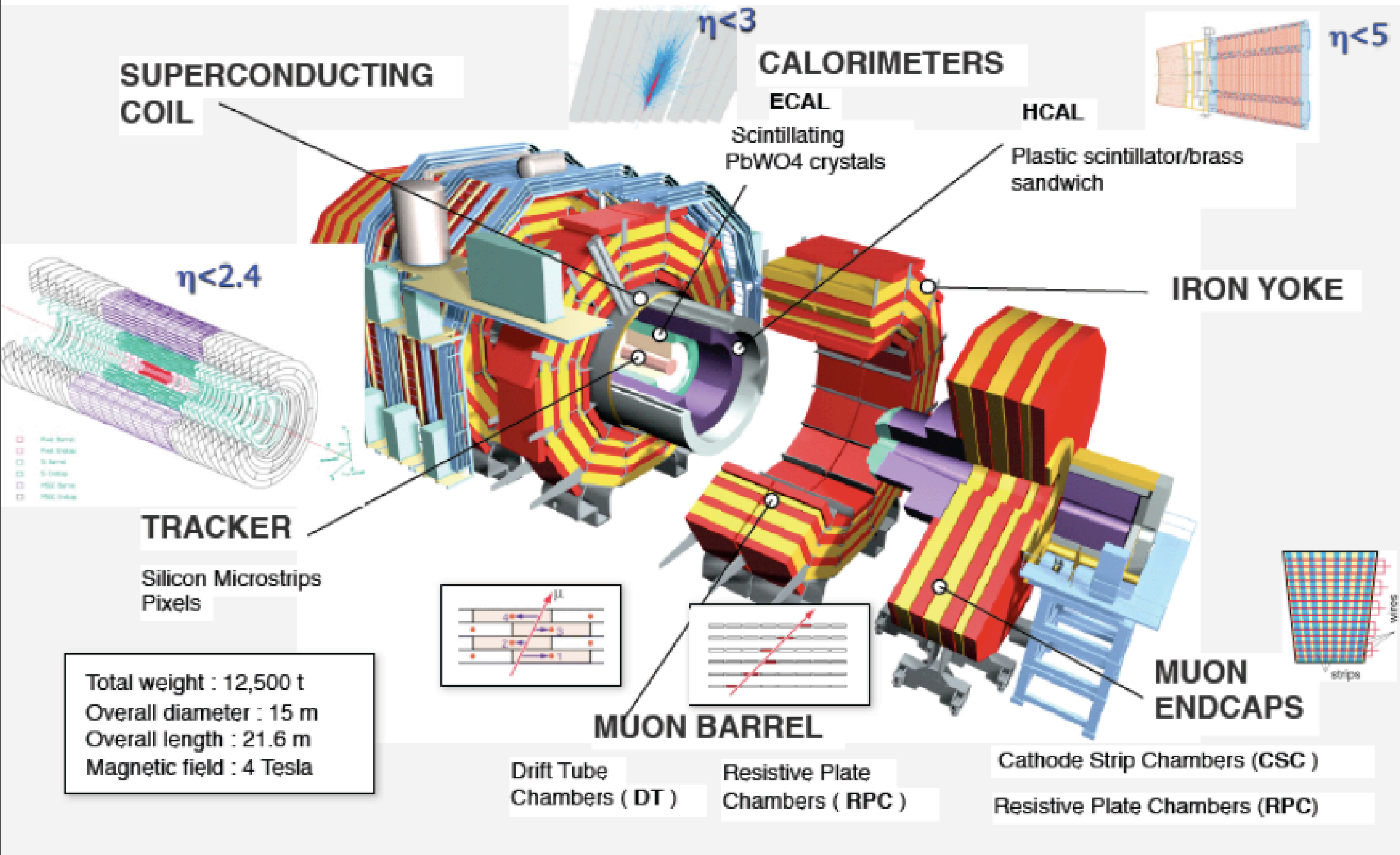
  → ***There is a strong asymmetry in the lepton decay***
- The lepton charge asymmetry of W

$$A(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$

  - Constrains for PDFs :
    - The asymmetry ***constrains for the ratio of u and d quark***
    - Particularly on ***sea quark contributions*** at LHC



CMS Detector



Data Set

- Data : $\int L dt = 35.9 \pm 1.4\ \mathrm{pb}^{-1}$
  - Analysis is performed for the electron and muon channel for W/Z
  - High E_T electron trigger and single muon trigger (high p_T) are used
    - E_T and p_T threshold is changing in time

- MC :
  - MC simulation is used for the signal and background estimation
    - Signal MC for W and Z process :
      - Generated POWHEG interfaced with PYTHIA parton showering
    - Electroweak background :
      - Diboson/$Z\rightarrow\tau\tau$/W+jets processes are considered
      - Generated POWHEG interfaced with PYTHIA parton showering
    - QCD multi-jet and ttbar background : simulated with PYTHIA

Event Selection

- Lepton selection for the analysis
  - Kinematic selection : high pt lepton - E_T (e), p_T (μ) > 25 GeV, 20 GeV for Z($\mu\mu$)
  - Detector fiducial region : $|\eta_\mu|<2.1$, $|\eta_e|<1.44$ (EB) and $1.57<|\eta_e|<2.5$ (EE)
  - Isolated lepton is required
  - Drell-Yan contamination for W selection
    - Reject events with the second isolated lepton (loose selection)
  - Event selection for muon
    - The impact parameter, d_{xy} cut rejects most of the cosmic muons
      - The cosmic muon background rate : the order of 10^{-4} in the dxy < 2 mm
    - Good track quality selections
  - Event selection for electron
    - High E_T super-cluster matched to a high p_T track
    - Electron ID variables : shower shape, track cluster matching etc.
    - Conversion rejection variables

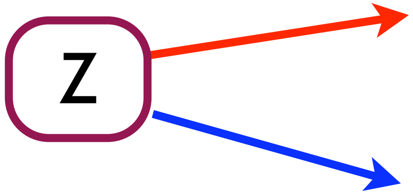
Acceptance

- The acceptance for W/Z process is calculated using signal MC sample
  - POWHEG with CT10 PDFs is used for the signal MC
  - PYTHIA parton showering is interfaced into POWHEG generator
  - Acceptance of W events
    - The event fraction with $E_T(e)$,$p_T(\mu)$ > 25 GeV in the detector fiducial region
  - Acceptance of Z events
    - The event fraction with $E_T(e)$,$p_T(\mu)$ > 25,20 GeV in the detector fiducial region
    - The acceptance is restricted by the Z mass range, $60 < M_{\ell\ell} < 120$ GeV
  - The total acceptance for W is ~ 50 % and for Z is ~ 40 % in e or μ channel

Process	$A_{W,Z}$	
	$\ell = \mathrm{e}$	$\ell = \mu$
$W^+ \to \ell^+\nu$	0.5017 ± 0.0004	0.4594 ± 0.0004
$W^- \to \ell^-\overline{\nu}$	0.4808 ± 0.0004	0.4471 ± 0.0004
$W \to \ell\nu$	0.4933 ± 0.0003	0.4543 ± 0.0003
$Z \to \ell^+\ell^-$	0.3876 ± 0.0005	0.3978 ± 0.0005

Efficiency

- The efficiency is determined for
  - The offline reconstruction of the lepton
  - The lepton selection with the identification (ID) and isolation criteria
  - The trigger efficiency (L1+HLT)
- The efficiencies are estimated using the tag and probe method in Z sample



***Tagged leg* : tight selection to clean up the sample**

***Probe leg* : used to determine the efficiency**

- The remaining background is subtracted using Z mass fitting

$$\boxed{\epsilon = \epsilon_{MC} \times \rho}$$

: where ρ is the efficiency scale factor of data to MC

Total Efficiency

Lepton channel	W process	Z process
Electron	0.735 ± 0.009	0.609 ± 0.011
Muon	0.848 ± 0.008	0.872 ± 0.002

Background Estimation for W

- Background estimation for W events
  - Main background is QCD multi-jet and Drell-Yan process
  - QCD background is estimated from the MET fit : ***data-driven method***
    - Background shape : obtained from QCD enriched sample
    - Signal shape : MC + $Z \rightarrow l^+ l^-$ data for hadron recoil tuning
  - The electroweak background is determined using the simulation
  - The background estimation from MET fit is confirmed with
    - M_T shape fitting and Iso vs. MET method (ABCD method)

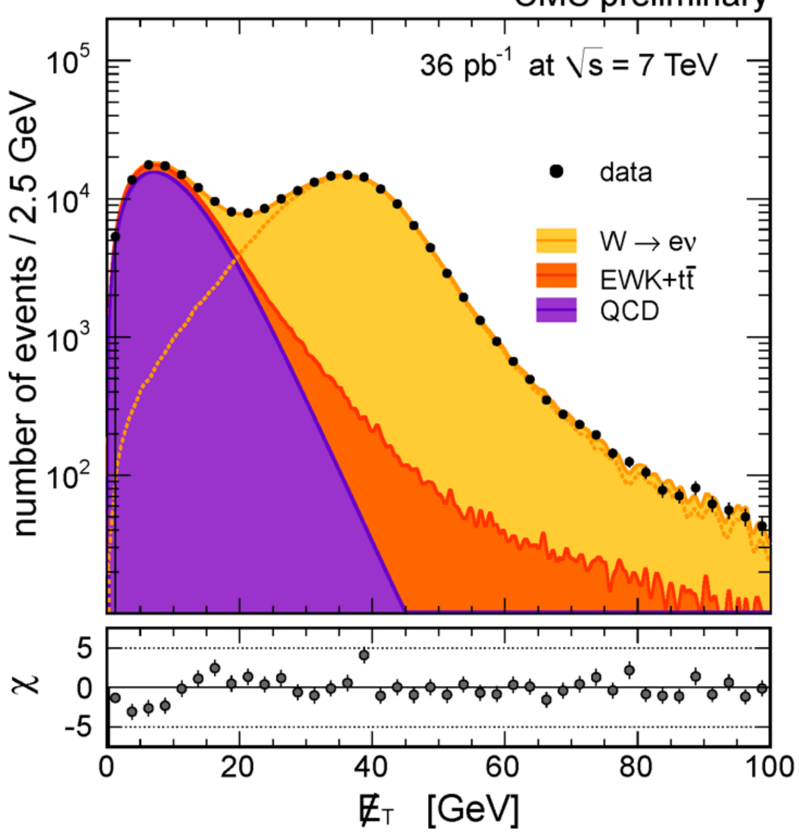
Background [%]	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$
Drell-Yan	7.6	4.6
$W \rightarrow \tau\nu$	3.0	3.0
WW/WZ/ZZ	0.1	0.1
ttbar	0.4	0.4
Cosmic	-	< 0.01
QCD	From fit	5.1

** *Backgrounds are estimated for W^+, W^-, and W, respectively*

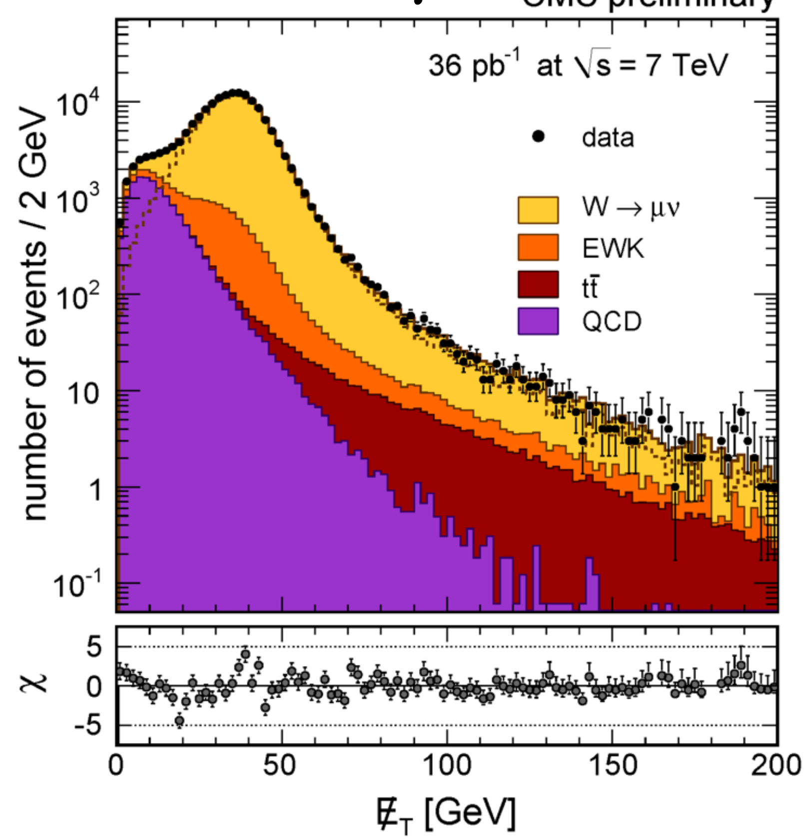
Signal Extraction for W

- Background and signal in MET distribution

$W \to e\nu$



$W \to \mu\nu$



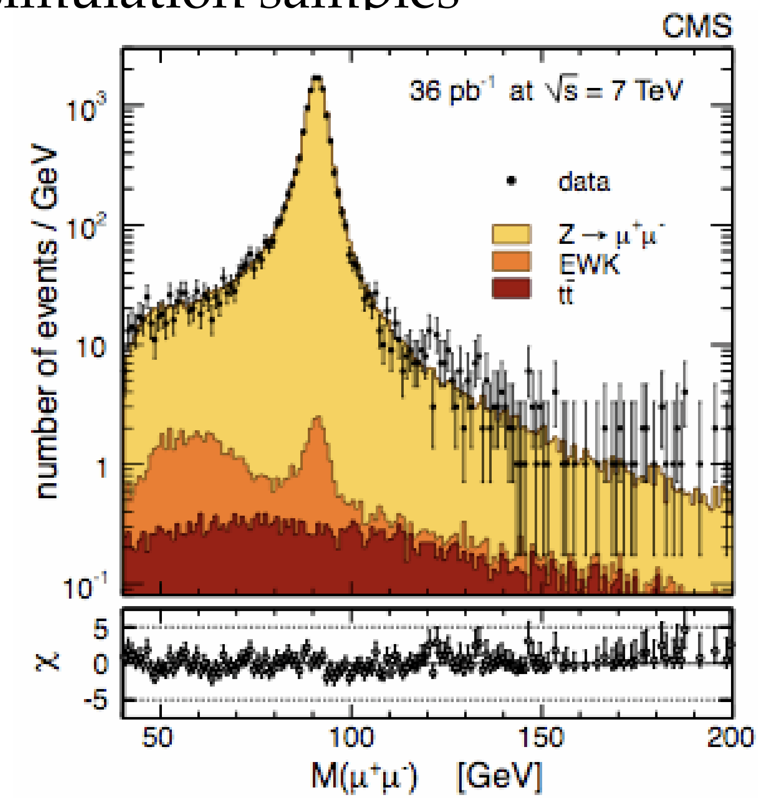
Signal Yield	Electron Channel	Muon Channel
W	136328 ± 386	140757 ± 383
W^+	81568 ± 297	84091 ± 291
W^-	54760 ± 246	56666 ± 240

Background Estimation for Z

- QCD background in Z sample
  - Isolation fitting method is used for the electron channel
  - The QCD simulation sample is used for muon channel : low background
  - Same/opposite charge method confirms the background estimation
- Electroweak background
  - Diboson/ttbar/$Z \rightarrow \tau\tau$/W+jets are considered
  - These backgrounds are estimated using the simulation samples

Processes	$Z \to e^+e^-$ sel.	$Z \to \mu^+\mu^-$ sel.
Diboson production	$(0.157 \pm 0.001)\%$	$(0.158 \pm 0.001)\%$
$t\bar{t}$	$(0.117 \pm 0.008)\%$	$(0.141 \pm 0.014)\%$
$Z \to \tau^+\tau^-$	$(0.080 \pm 0.006)\%$	$(0.124 \pm 0.005)\%$
W+jets	$(0.010 \pm 0.002)\%$	$(0.008 \pm 0.002)\%$
Total EWK plus $t\bar{t}$	$(0.365 \pm 0.010)\%$	$(0.430 \pm 0.015)\%$
QCD	$(0.06 \pm 0.14)\%$	$(0.013 \pm 0.001)\%$
Total background	$\boxed{(0.42 \pm 0.14)\%}$	$\boxed{(0.444 \pm 0.015)\%}$

Total background is ~ 0.4 % level



$Z \rightarrow e^+e^-$ yield = 8406 ± 92

$Z \rightarrow \mu^+\mu^-$ yield = 13728 ± 121

Systematic Uncertainty

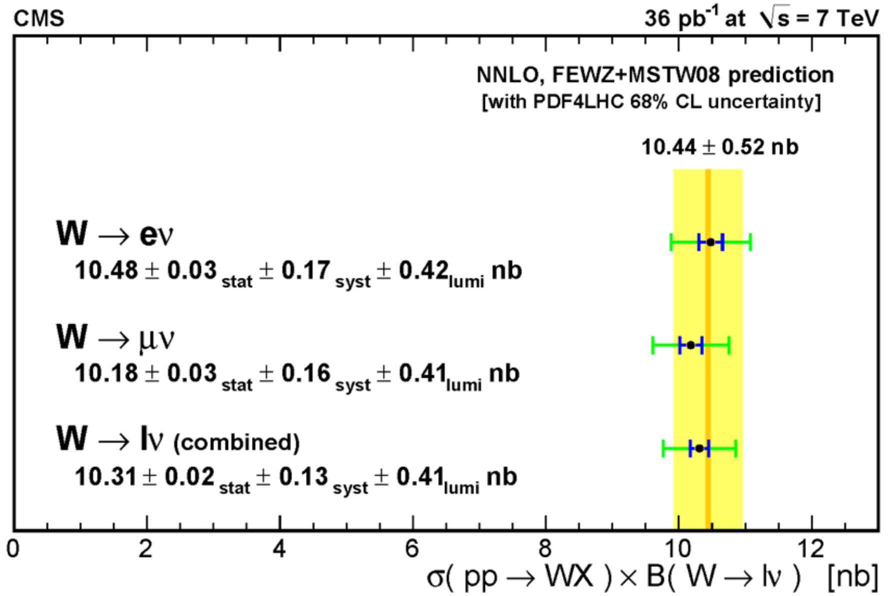
- The largest uncertainty source is the integrated luminosity : 4%
- The next most important source is the lepton efficiency
- Other systematic contributions are :

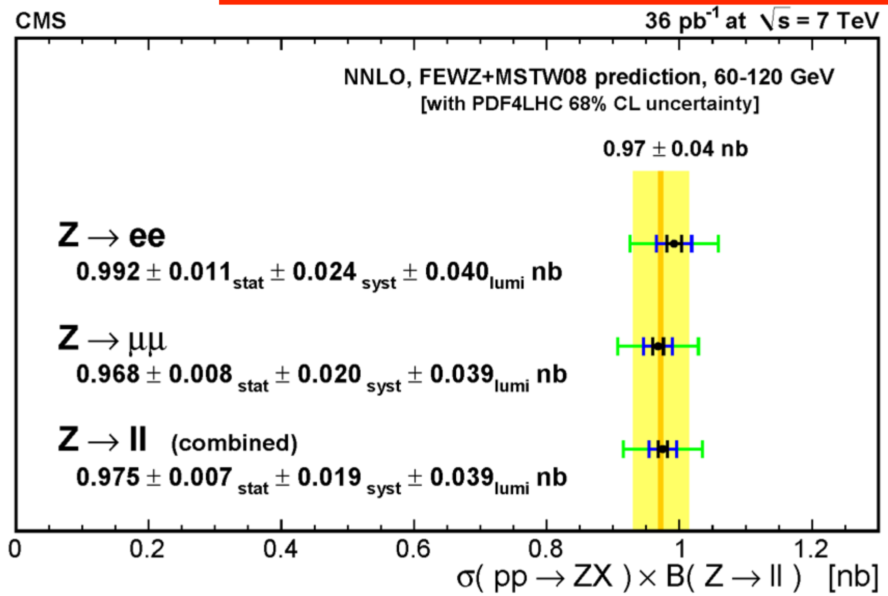
Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	1.4	0.9	1.8	n/a
Trigger prefiring	n/a	0.5	n/a	0.5
Energy/momentum scale & resolution	0.5	0.22	0.12	0.35
$\not{E}_T$ scale & resolution	0.3	0.2	n/a	n/a
Background subtraction / modeling	0.35	0.4	0.14	0.28
Trigger changes throughout 2010	n/a	n/a	n/a	0.1
Total experimental	1.6	1.1	1.8	0.7
PDF uncertainty for acceptance	0.6	0.8	0.9	1.1
Other theoretical uncertainties	0.7	0.8	1.4	1.6
Total theoretical	0.9	1.1	1.6	1.9
Total (excluding luminosity)	1.8	1.6	2.4	2.0

Experimental uncertainty is comparable to theoretical uncertainty !!

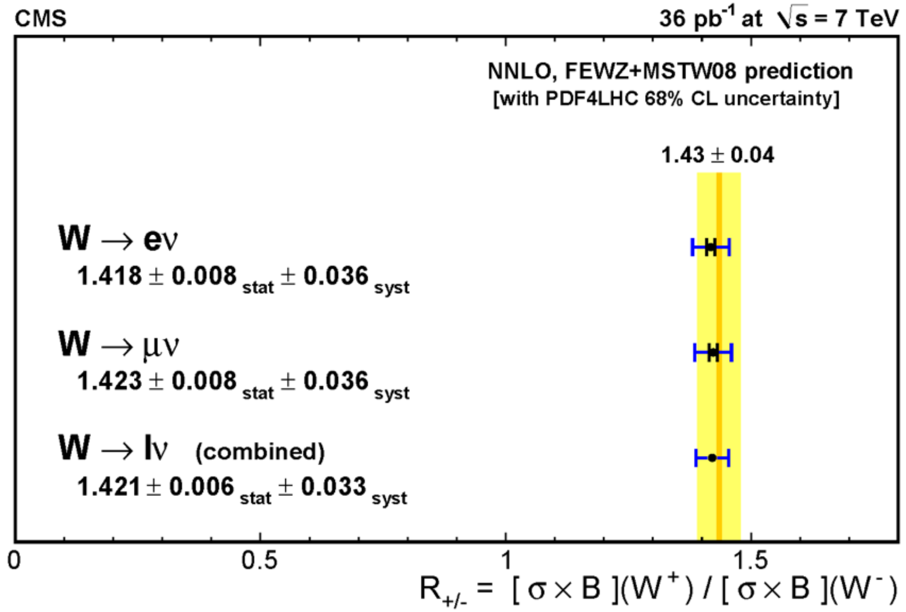
W / Z Cross Section Results

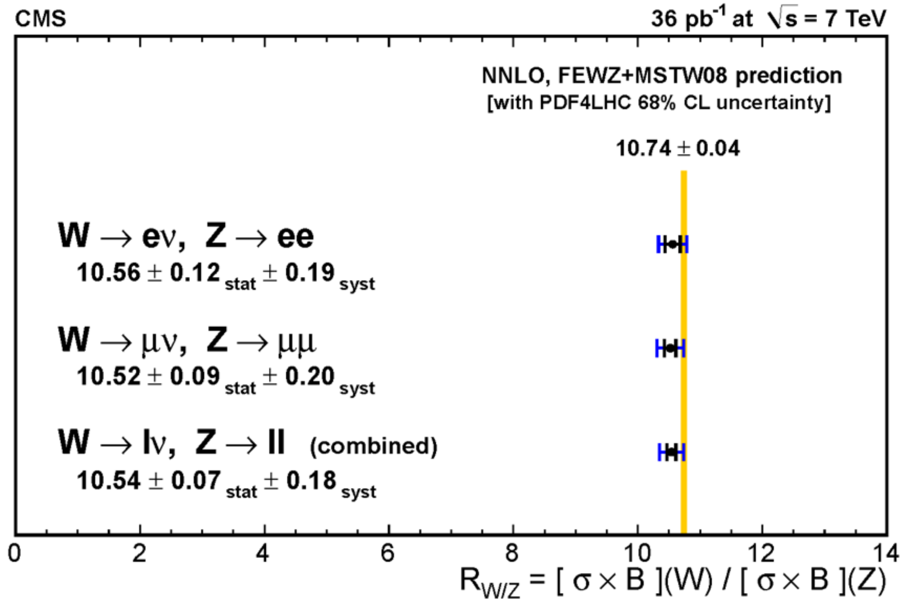
- W / Z production cross section measurements: $\sigma \times \mathcal{B} = N/(A \times \varepsilon \times \mathcal{L})$



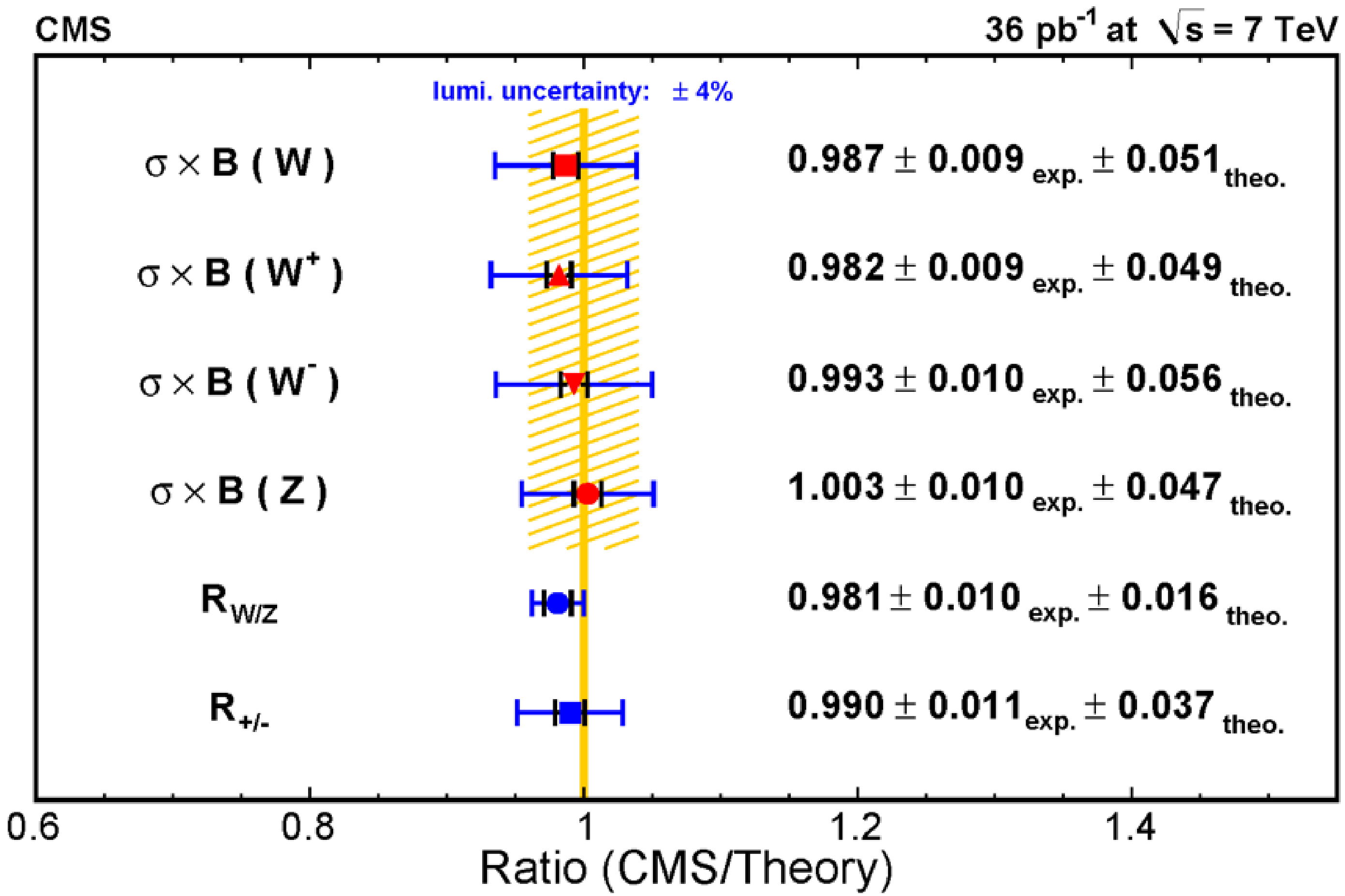


- The ratio of W^+ to W^- and W to Z





- The measurements compared to theory prediction (NNLO)



The measurements are consistent with NNLO theory prediction within the uncertainty !

Lepton Charge Asymmetry of W production

- Lepton charge asymmetry of W production

$$\boxed{A(\eta) = \frac{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) - d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \rightarrow \ell^+\nu) + d\sigma/d\eta(W^- \rightarrow \ell^-\bar{\nu})}}$$

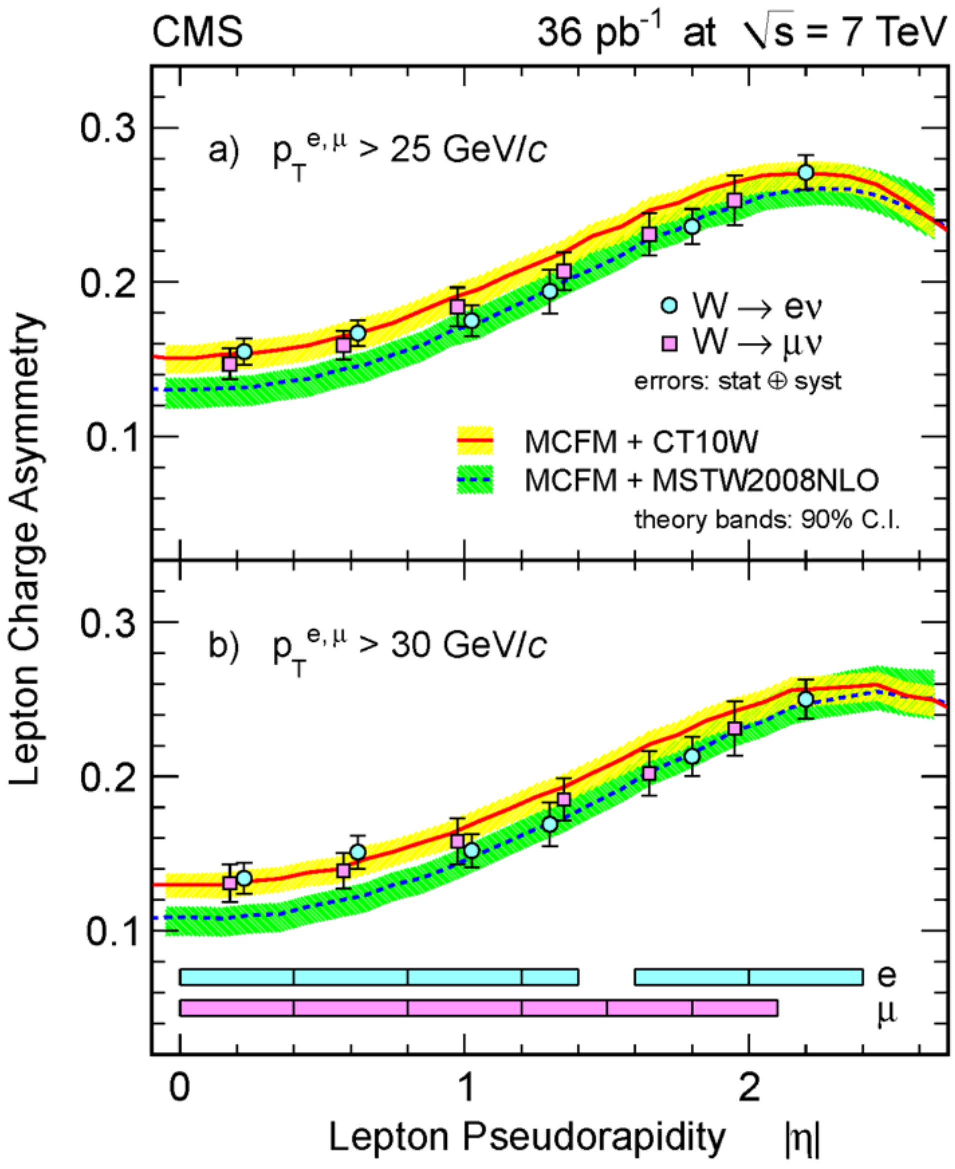
  - A(η) is measured in two p_T bins, p_T>25 and p_T>30 GeV

  - It is important to understand η dependence for efficiencies and background
    - The efficiencies are estimated as a function of p_T and η
    - QCD background in η : shape fitting method used (data-driven)
      - Electron channel : MET fit in 6 η bins up to |η|<2.4
      - Muon channel : modified isolation variable fit in 6 η bins up to |η|<2.1
    - Electroweak background is estimated using the simulation samples

All other methods are same as used for the inclusive cross section measurement !!

A(η) of W production Result

- Lepton charge asymmetry of W production in p_T>25 / p_T>30 GeV



- Charge asymmetry agrees between electron and muon channel
- *The precision is < 1.1 % (stat.) and < 1.5 % (total) for all bins*
- *Data prefers CT10 PDFs in low η, but follows MSTW2008NLO in high η*

⇒ New input to PDF global fits

Summary

- We measure W and Z production cross section using 36 pb^{-1} data
  - $\sigma \times B$ ($W \rightarrow l\nu$) = 10.31 ± 0.02(stat.) ± 0.09(syst.) ± 0.10(th.) ± 0.41(lumi.) nb
  - $\sigma \times B$ ($Z \rightarrow ll$) = 0.975 ± 0.007(stat.) ± 0.007(syst.) ± 0.018(th.) ± 0.039(lumi.) nb
  - The production σ and its ratio (W/Z, W^+/W^-) agrees with theory prediction
    - Theory prediction is calculated in NNLO QCD
    - The experimental uncertainty is below 5%
  - The lepton charge asymmetry is measured and compared with various PDFs
    - The measured asymmetry agrees with the theory predictions
      - Low η region prefers CT10 PDFs and high η region prefers MSTW2008NLO
      - New input into the global PDF fit
- ***CMS already stored more than 1fb^{-1} data***
  - ***More precise result will come soon !!!***

public note / publication info (reference) :

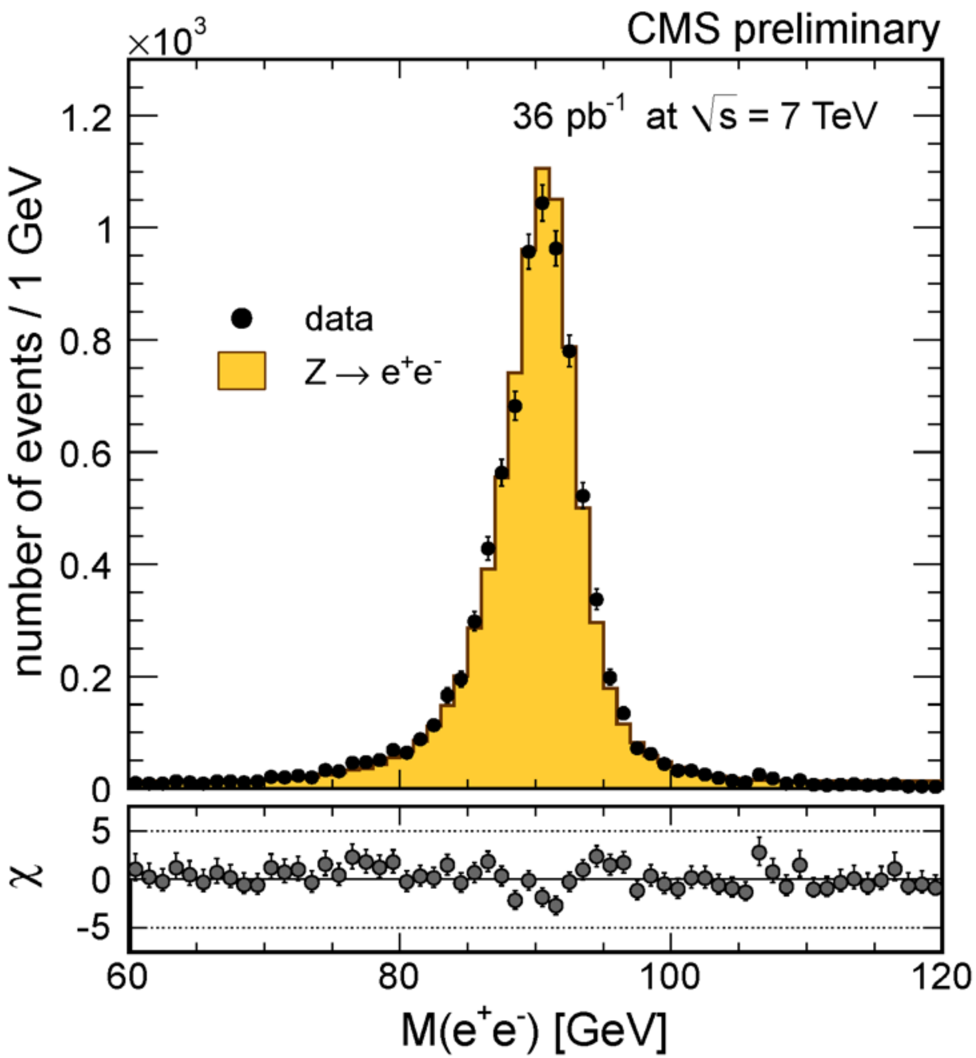
Inclusive W/Z cross section : CMS PAS EWK-10-005

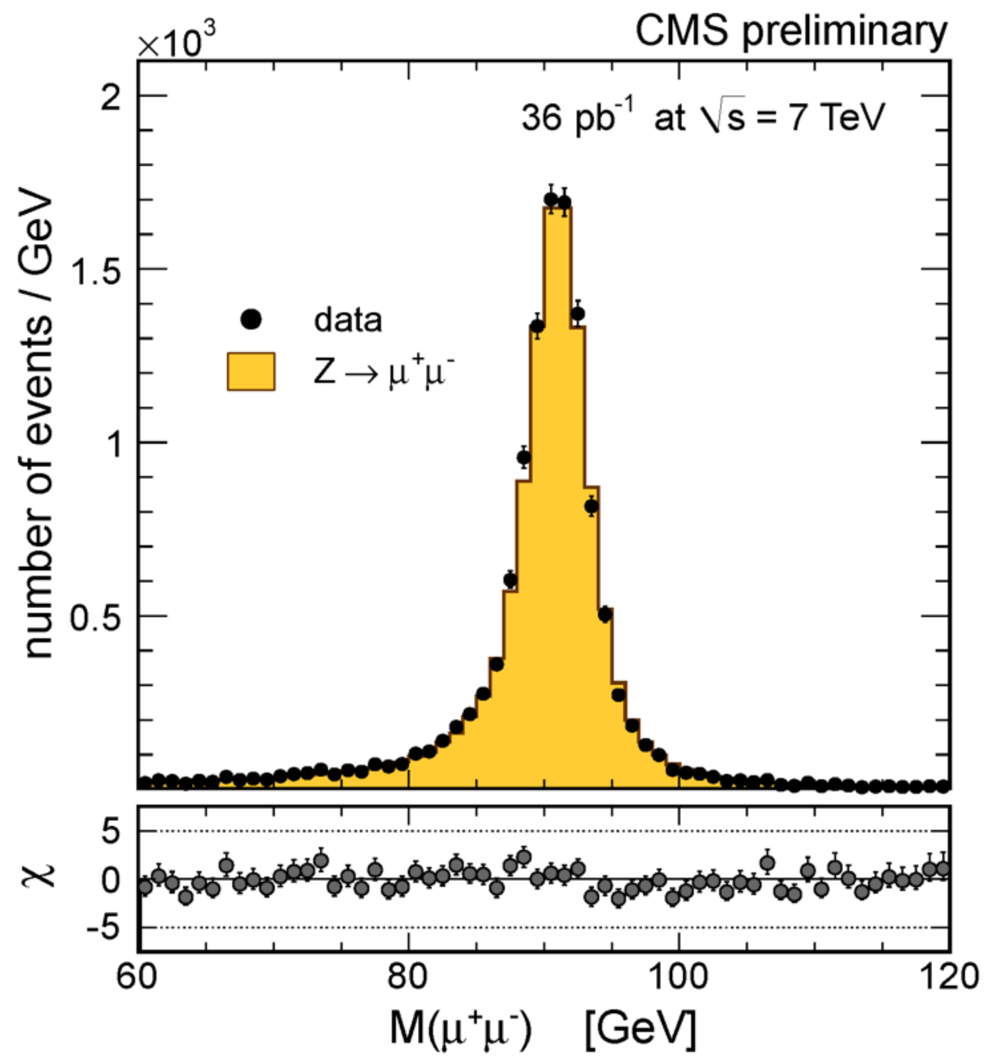
Lepton charge asymmetry of W production : JHEP 2001, 050 (2011)

Back-up Pages

Z Mass Spectrum

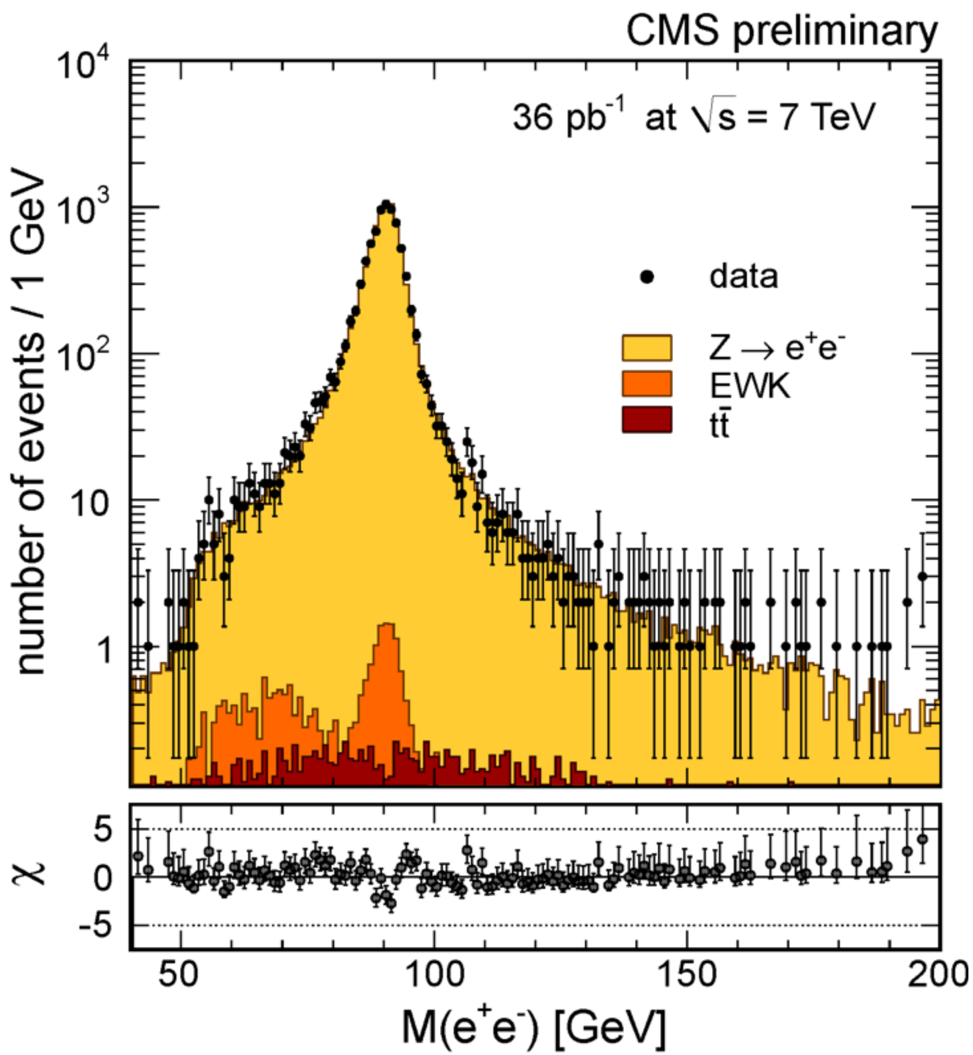
- Z mass distribution in the electron and muon channel

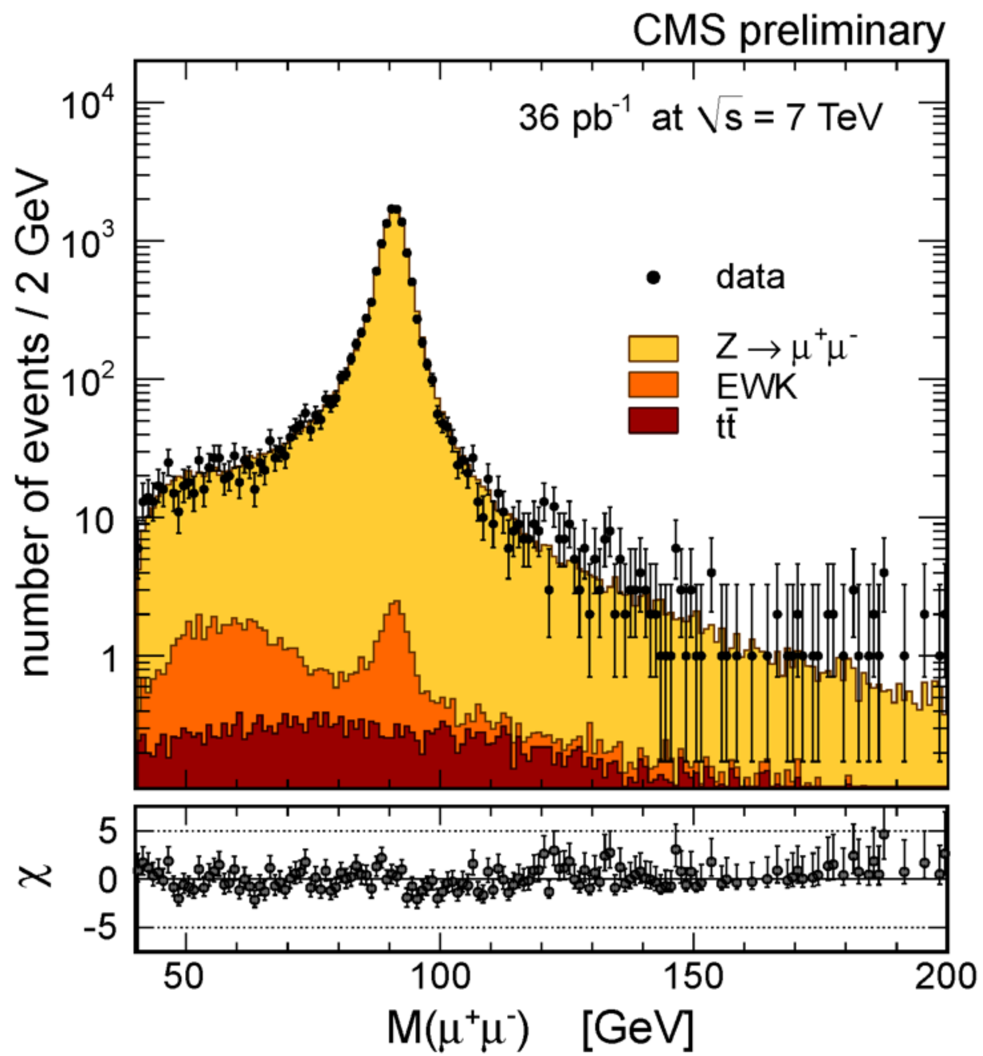




Z Mass with Backgrounds

- Z mass distribution in the electron and muon channel





Systematics of W Asymmetry

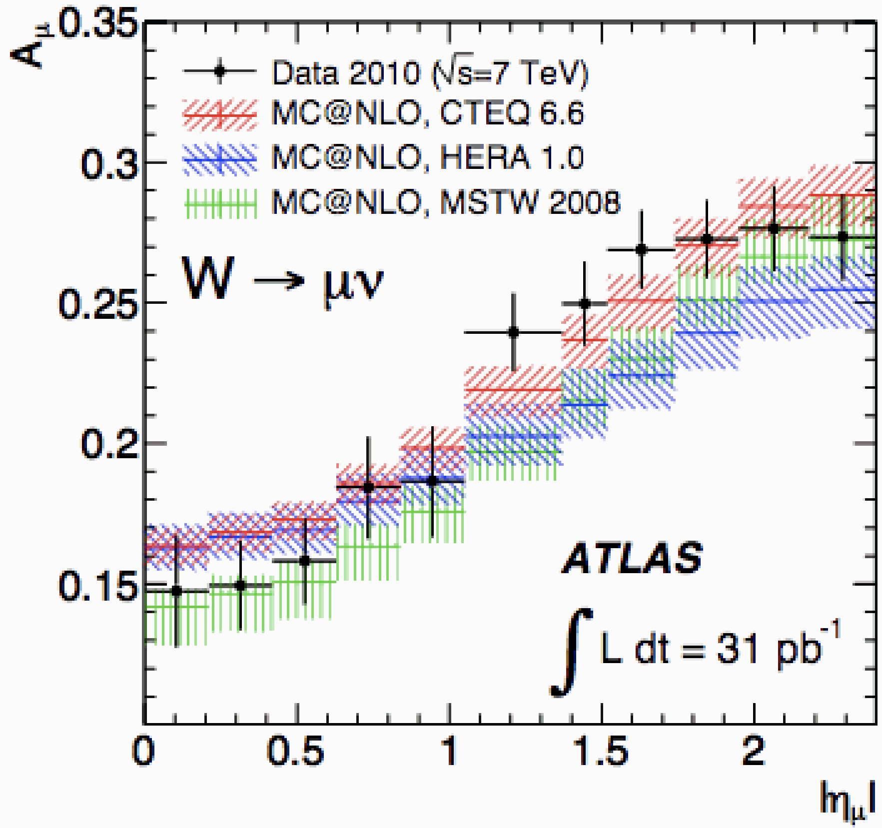
- Systematic uncertainty of the lepton charge asymmetry

$p_T^\ell > 25\,\text{GeV}/c$	Electron Channel						Muon Channel					
$\lvert\eta\rvert$ bin	[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/μ 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

$p_T^\ell > 30\,\text{GeV}/c$	Electron Channel						Muon Channel					
$\lvert\eta\rvert$ bin	[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	0.02	0.03	0.07	0.08	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	0.93	0.72	0.82	1.18
e/μ Scale	0.07	0.17	0.26	0.46	0.53	0.55	0.80	0.78	0.83	0.81	0.73	0.77
Sig. & Bkg. Estim.	0.16	0.19	0.26	0.33	0.25	0.25	0.20	0.20	0.27	0.35	0.51	0.56
Total	0.72	0.75	0.79	0.91	0.92	0.93	1.01	0.90	1.27	1.14	1.21	1.52

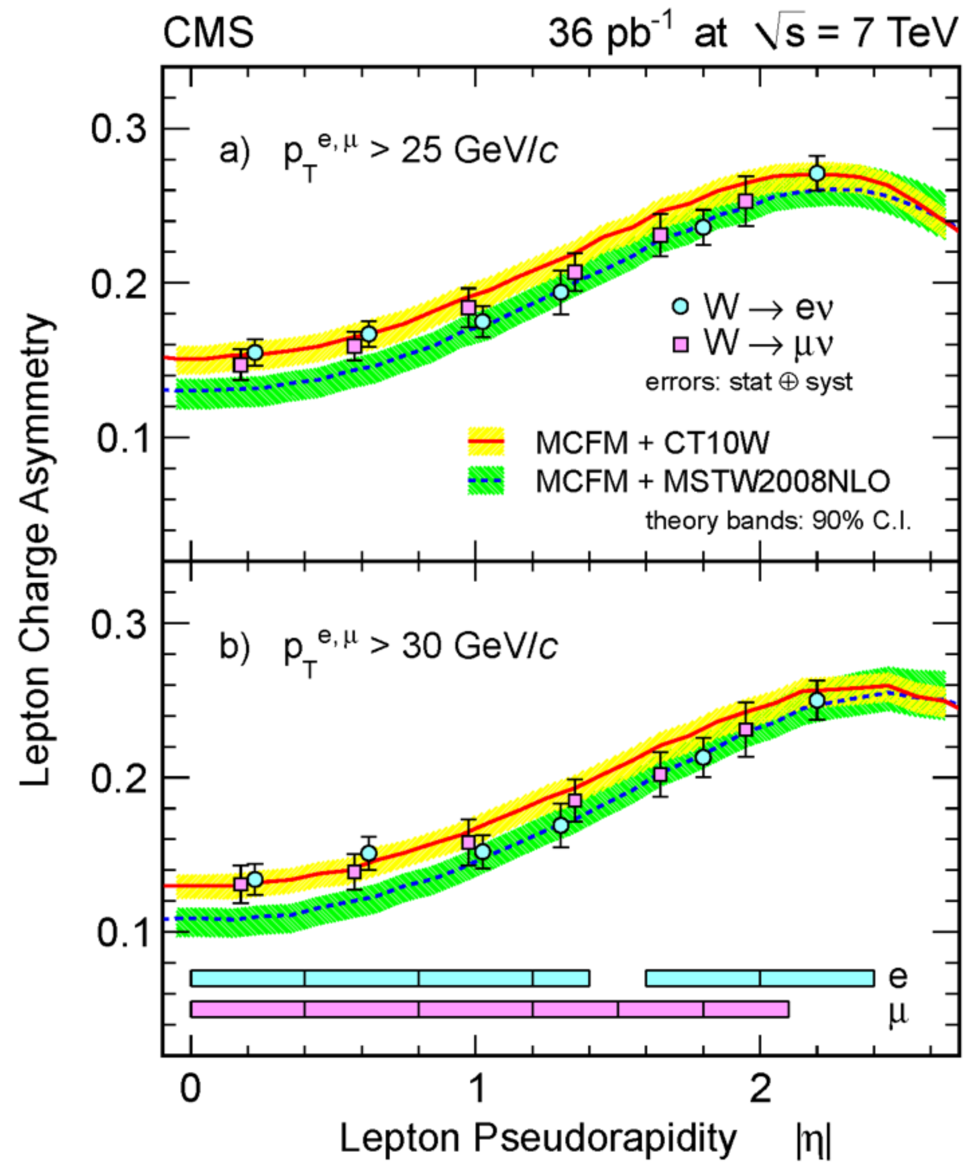
Lepton Charge Asymmetry

- Muon charge asymmetry at ATLAS vs. CMS



Phys.Lett.B 701, 31 (2011)

Figure 4: The muon charge asymmetry from W-boson decays in bins of absolute pseudorapidity. The kinematic requirements applied are $p_T^\mu > 20$ GeV, $p_T^\nu > 25$ GeV and $m_T > 40$ GeV. The data points (shown with error bars including the statistical and systematic uncertainties) are compared to MC@NLO predictions with different PDF sets. The PDF uncertainty bands are described in the text and include experimental uncertainties as well as model and parametrization uncertainties.



W / Z Cross Section at Atlas

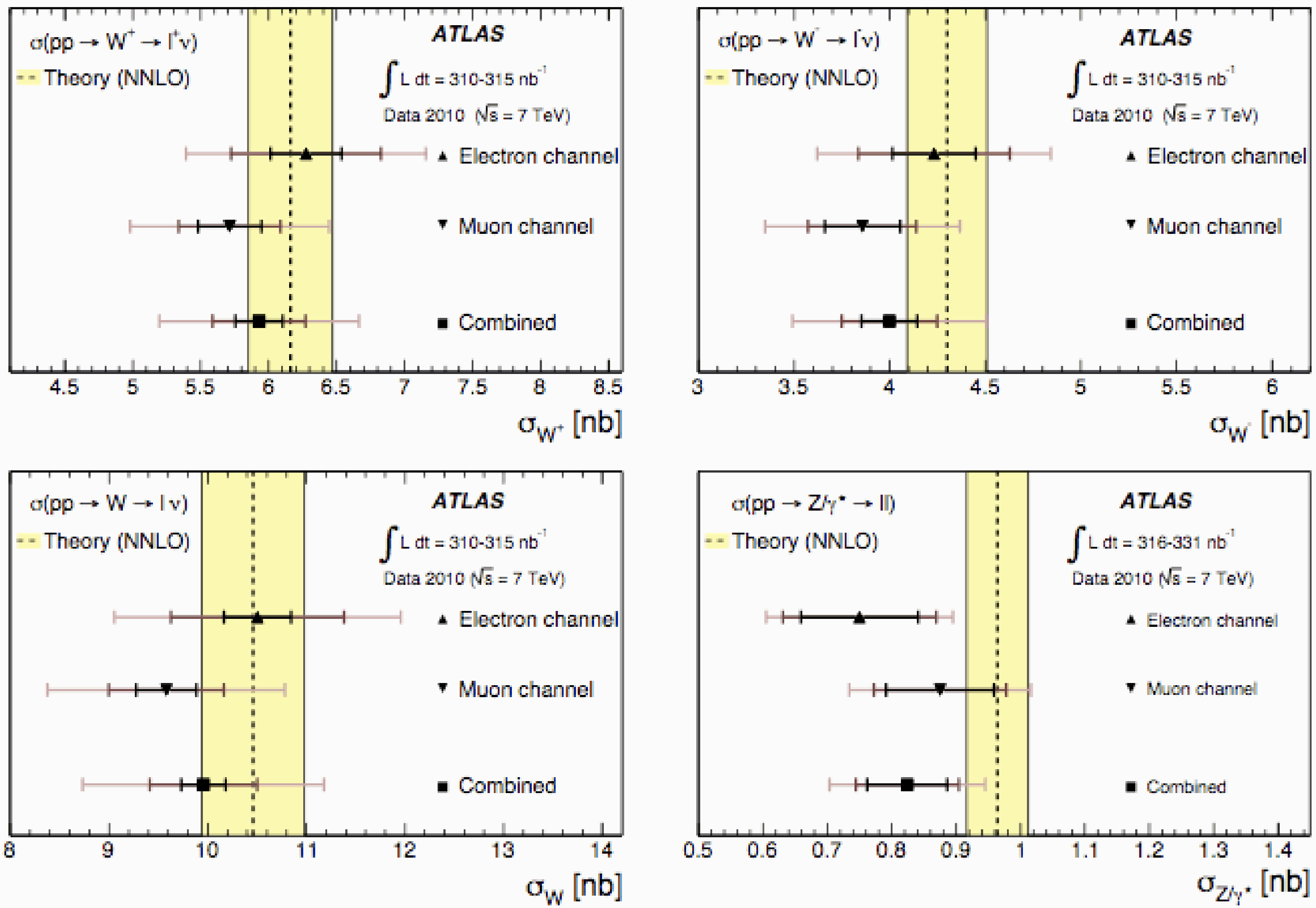


Fig. 11: *The measured values of $\sigma_W \cdot$ BR $(W \to \ell\nu)$ for W^+, W^- and for their sum and of $\sigma_{Z/\gamma^*} \cdot$ BR $(Z/\gamma^* \to \ell\ell)$ compared to the theoretical predictions based on NNLO QCD calculations (see text). Results are shown for the electron and muon final states as well as for their combination. The error bars represent successively the statistical, the statistical plus systematic and the total uncertainties (statistical, systematic and luminosity). All uncertainties are added in quadrature.*