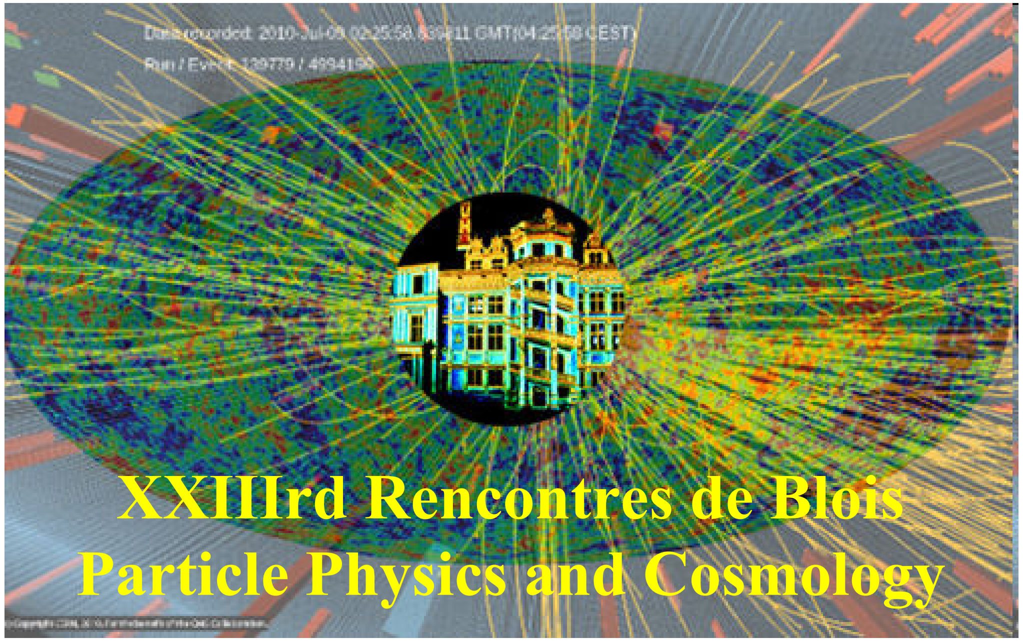
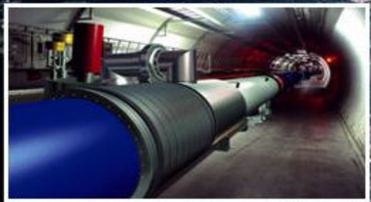
Inclusive W & Z cross sections and W-charge asymmetry measurements at LHC

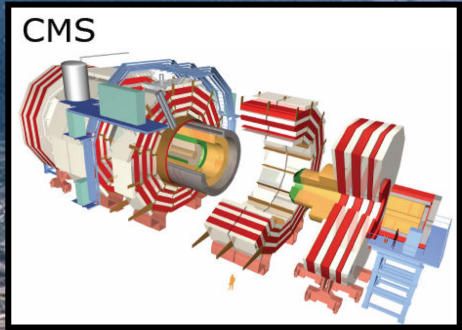


Georgios Daskalakis
N.C.S.R. "Demokritos"

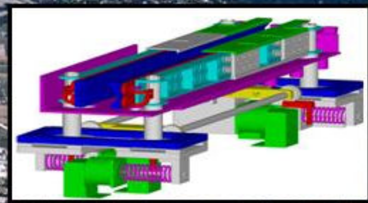
on behalf of
the ATLAS and CMS Collaborations

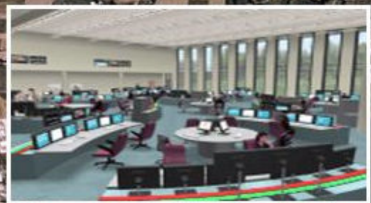
ATLAS + CMS detectors & the LHC

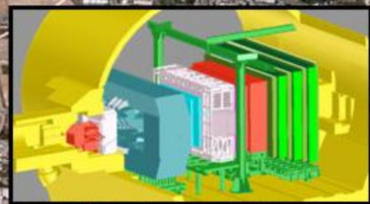




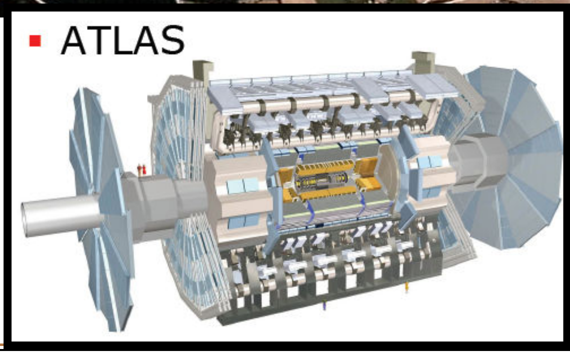
- **Tracker :** $|\eta| < 2.4$
  Pixel+Si strips
- **Calorimeter:** $|\eta| < 5.0$
  EM crystals + HAD brass/scint.
- **Muon Spect. :** $|\eta| < 2.4$
  Solenoid return yoke + precision tracking chambers



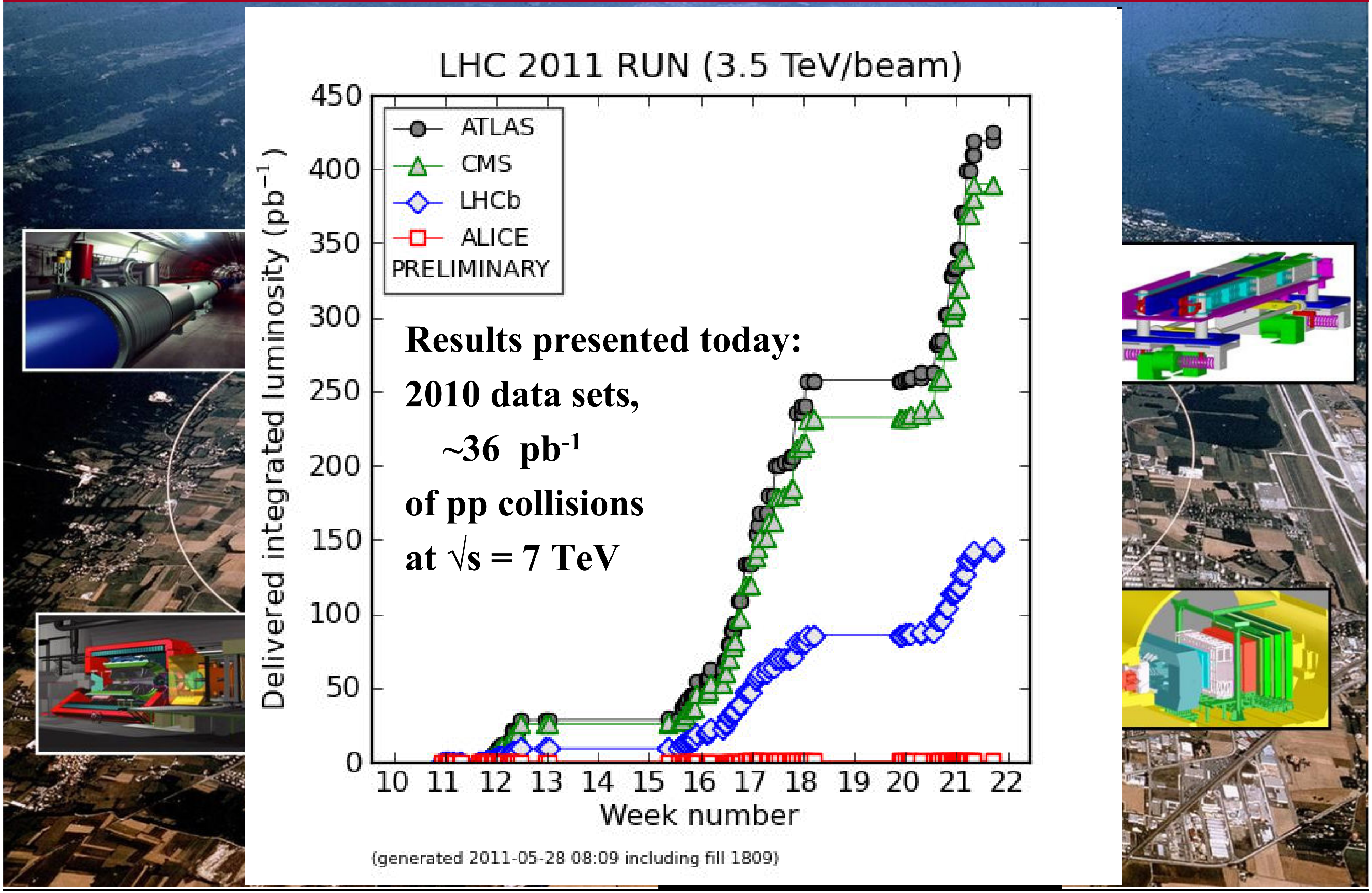




- **Tracker :** $|\eta| < 2.5$
  Pixel + Si strips + TRT
- **Calorimeter:** $|\eta| < 4.9$
  EM lead/LAr + HAD Fe/ scintillator or copper/LAr
- **Muon Spect. :** $|\eta| < 2.7$
  air-core toroid magnets + precision tracking chambers



ATLAS + CMS detectors & the LHC



Physics Motivation

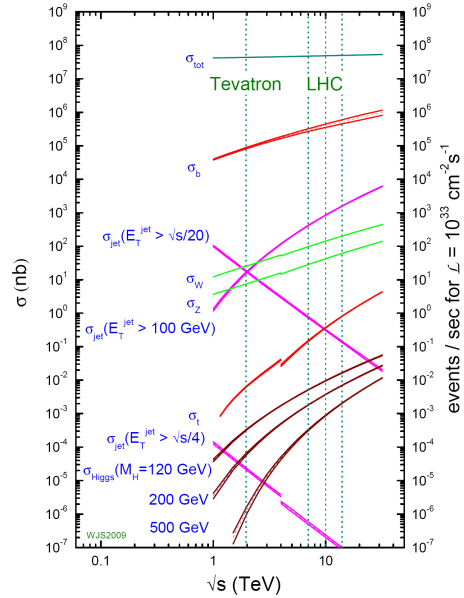
LHC hopefully will be proven to be a discovery machine but before that the measurement of the known “unknowns” in the new Energy frontier :

- is an excellent way to understand and commission “physics objects”
- will provide a good understanding of SM processes improving our knowledge on PDFs, pQCD, UE modeling …
- in most of the cases SM processes are backgrounds to searches for new Physics, so SM measurements are themselves by default “searches”.

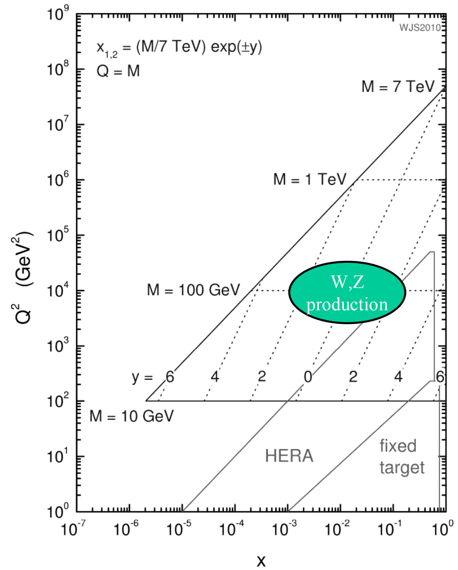
W & Z productions are theoretically well understood, have high rates and distinctive signatures.

The inclusive W & Z cross section measurements and their by-products form a test-bed for analysis techniques that aim for precision physics.

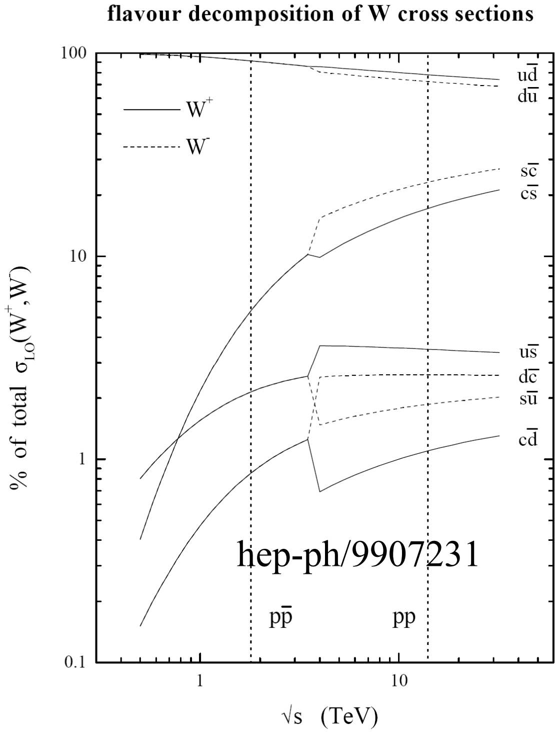
These measurements could be converted to luminosity estimations.

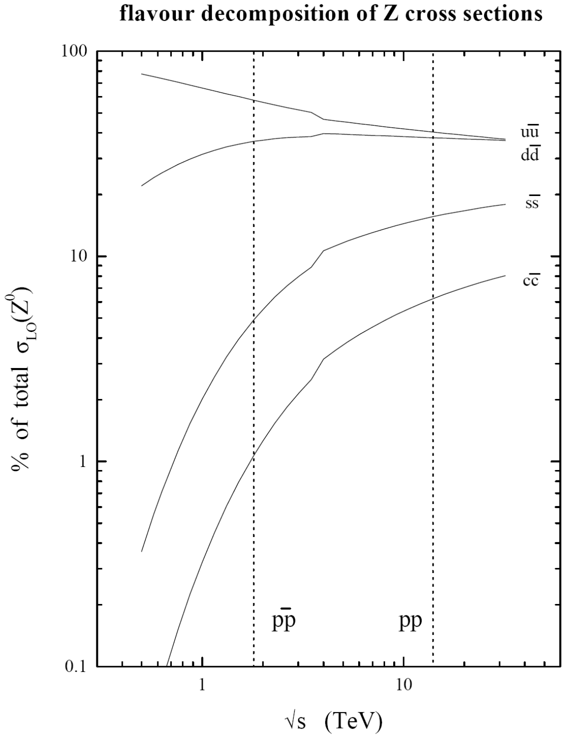


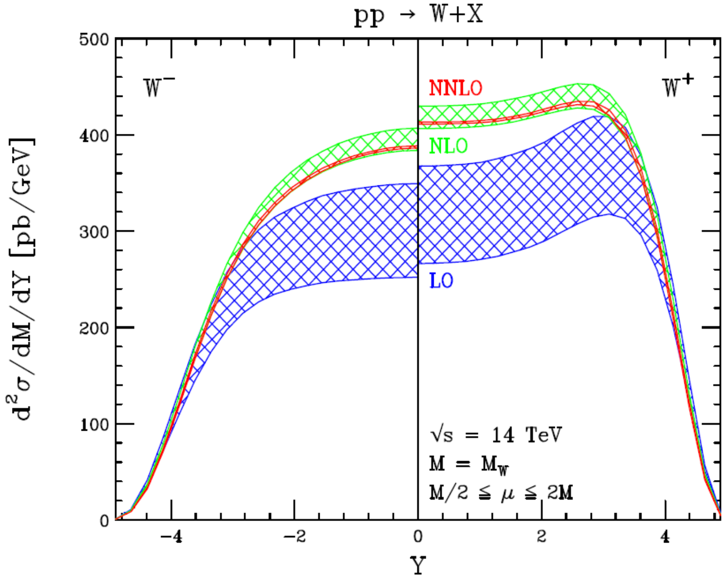
7 TeV LHC parton kinematics



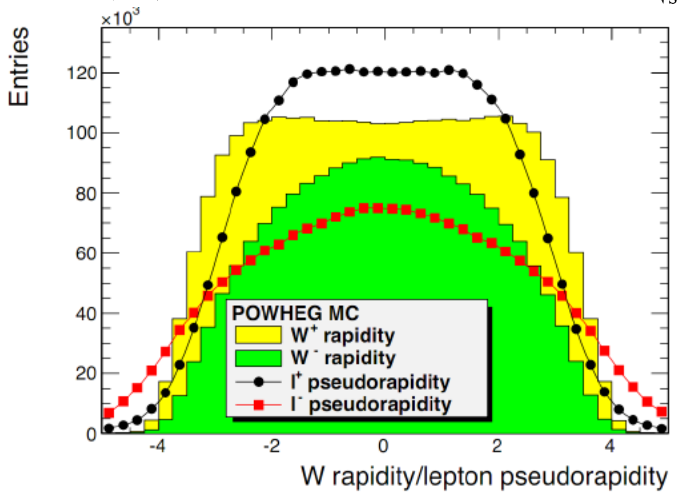
W & Z production

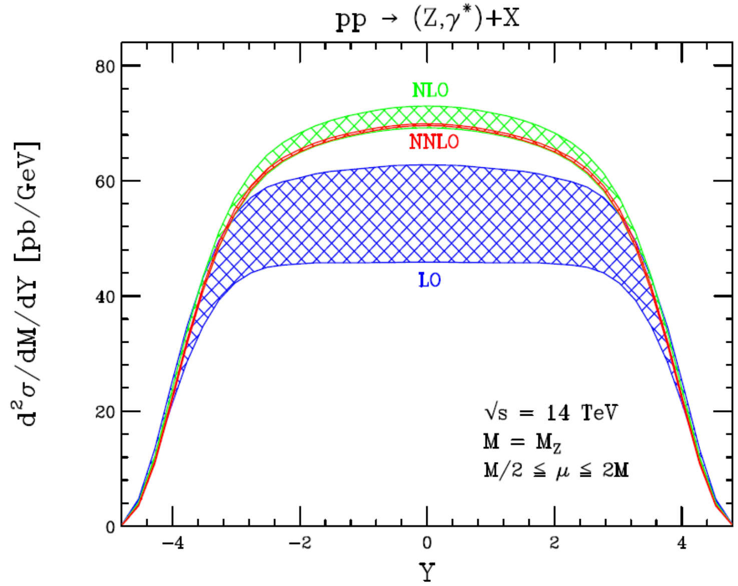






hep-ph/0312266





Inclusive Cross Sections & Charge Asymmetry

Signal yield extracted from
W: mainly MET, with data-driven methods for the QCD bkgd estimation
Z: di-lepton invariant mass

Integrated Luminosity:
(largest source of systematic uncertainty)
- 3.4% for ATLAS
- 4.0% for CMS

$$\sigma \times BR = \frac{N_{candidates} - N_{background}}{Acceptance \times Efficiency \times L}$$

Acceptance: Determined from simulation.
Source of theoretical uncertainties

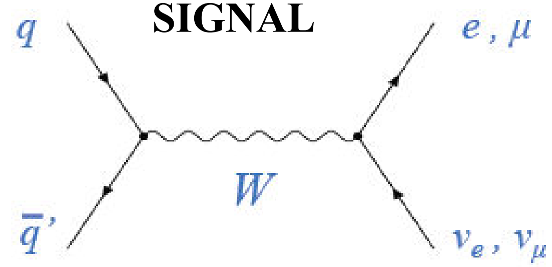
Efficiency: Selection efficiency for signal falling within the acceptance
- Obtained from simulation
- Corrected using efficiencies measured in data and MC with a T&P technique

$\varepsilon = \varepsilon_{MC} \times \rho_{eff}, \quad \rho_{eff} = \varepsilon_{T\&P}(data) / \varepsilon_{T\&P}(MC)$

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

Selection of W & Z Candidates

SIGNAL

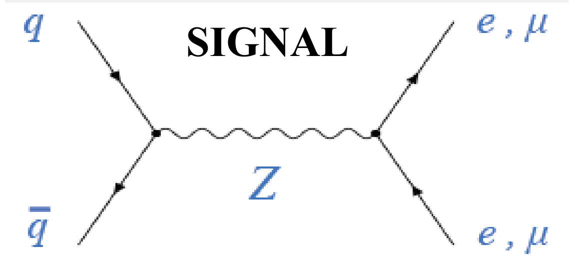


BACKGROUND

QCD multi-jets , γ+jets (electron)
$\gamma^*/Z \rightarrow e^+e^-, \mu^+\mu^-, \tau^+\tau^-$
$W \rightarrow \tau\nu$, tt, WW, WZ, ZZ

ATLAS	CMS
electrons	
$E_T > 20.0$, $E_T^{miss} > 25$, $M_T > 40$ GeV	$E_T > 25$ GeV
$\|\eta\|<2.47$, $1.37<\|\eta\|<1.52$ excl.	$\|\eta\|<2.50$, $1.44<\|\eta\|<1.57$ excl.
Tight ID	Tight ID
-	Isolation (Cal.+Tr.)
muons	
$P_T > 20.0$, $E_T^{miss} > 25$, $M_T > 40$ GeV	$P_T > 25$ GeV
$\|\eta\|<2.4$	$\|\eta\|<2.1$
$(\Sigma P_T^{tracks})/P_T < 0.2$	$(\Sigma P_T^{tracks} + \Sigma E_T^{CAL})/P_T < 0.1$
Other cuts	
vertex: at least 3 tracks	-
Z veto	Z veto

SIGNAL

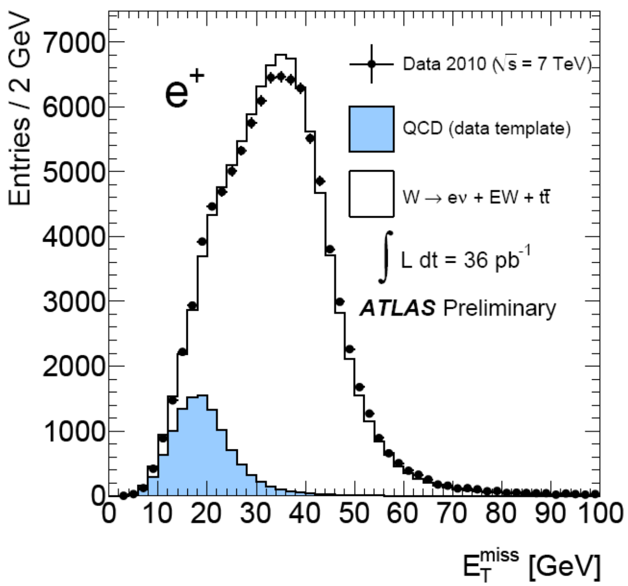


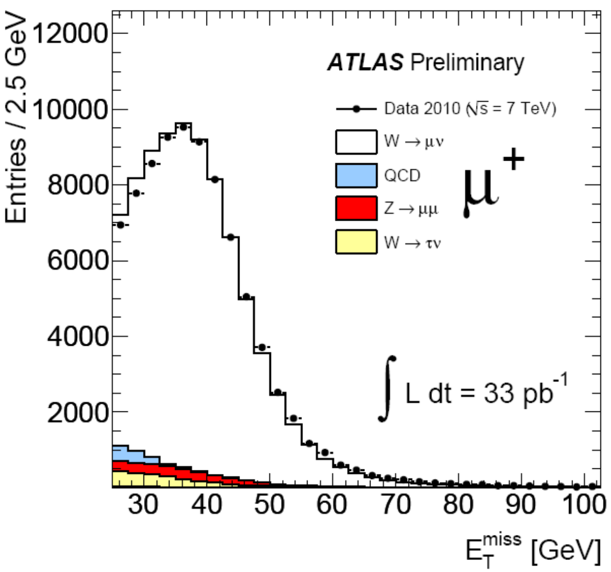
BACKGROUND

$\gamma^*/Z \rightarrow \tau^+\tau^-$, W+jets, tt,
WW, WZ, ZZ, QCD multi-jets

ATLAS	CMS
electrons	
E_T & $\|\eta\|$ as for Ws, Medium ID	as for Ws
OS charges	-
forward $e^\pm$: $2.5<\|\eta\|<4.9$	-
muons	
as for Ws, OS charges	$P_T > 20$ GeV , $\|\eta\|<2.1$, OS charges
-	$\Sigma P_T^{tracks} < 3$ GeV
di-leptons	
$66 < M_{ll} < 116$ GeV	$60 < M_{ll} < 120$ GeV

Selected W candidates



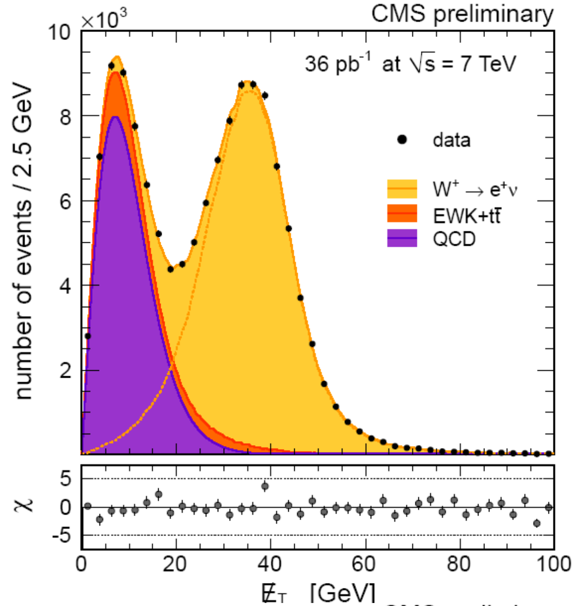


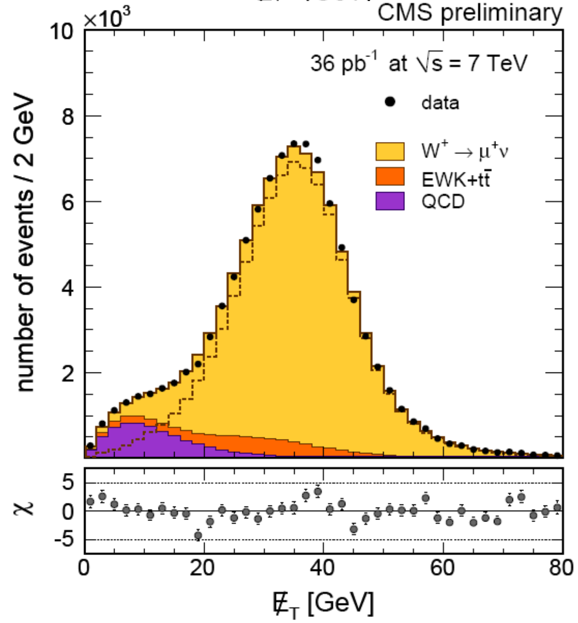
	ATLAS	CMS
Candidates		
$W \to e\nu$:	121 K	236 K
$W \to \mu\nu$:	139 K	166 K
Signal		
$W \to e\nu$:	113 K	136 K
$W \to \mu\nu$:	127 K	141 K
Acceptance × Efficiency (%)		
$W \to e\nu$:	29.6	36.3
$W \to \mu\nu$:	37.9	38.5

Signal shape:
MC + $Z \to ll$ data for Recoil tuning

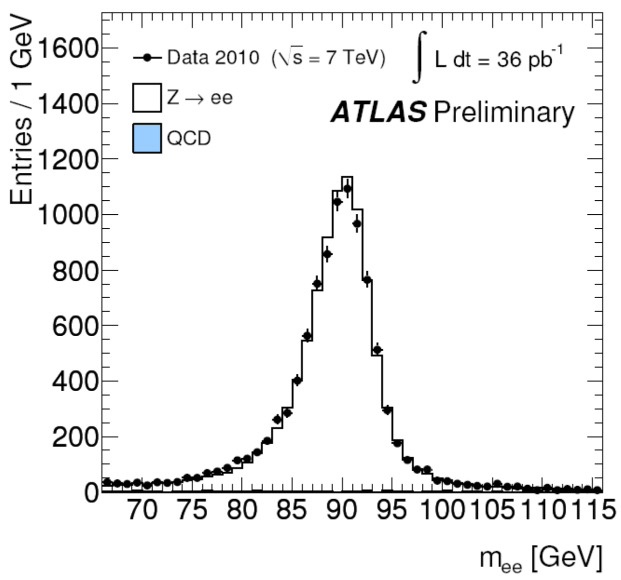
QCD bkgd shape:
from data with lepton ID criteria reversed

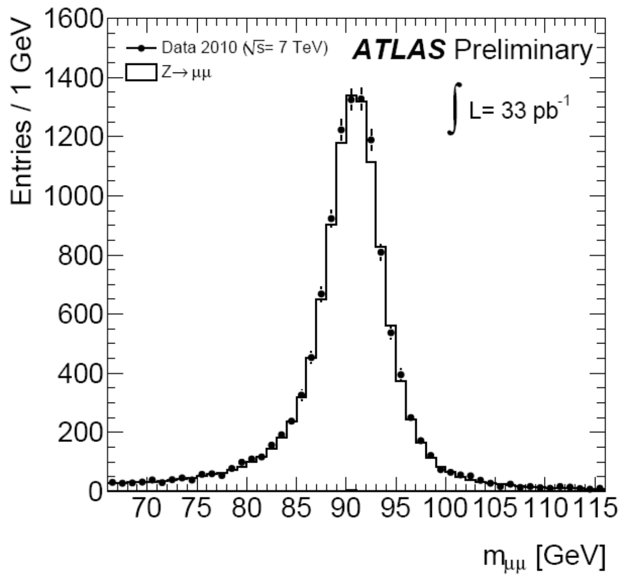
Signal extraction:
fits to missing transverse energy (MET) with templates or analytical functions, ABCD, matrix method





Selected Z candidates





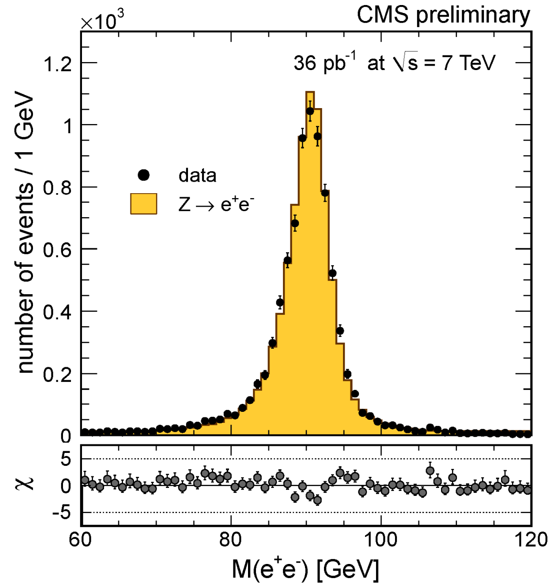
	ATLAS	CMS
Candidates		
Z→ee:	9.7 K	8.4 K
Z→μμ:	11.7 K	13.8 K
Signal		
Z→ee:	9.5 K	8.4 K
Z→μμ:	11.6 K	13.7 K
Acceptance × Efficiency (%)		
Z→ee:	27.0	23.6
Z→μμ:	37.9	39.4

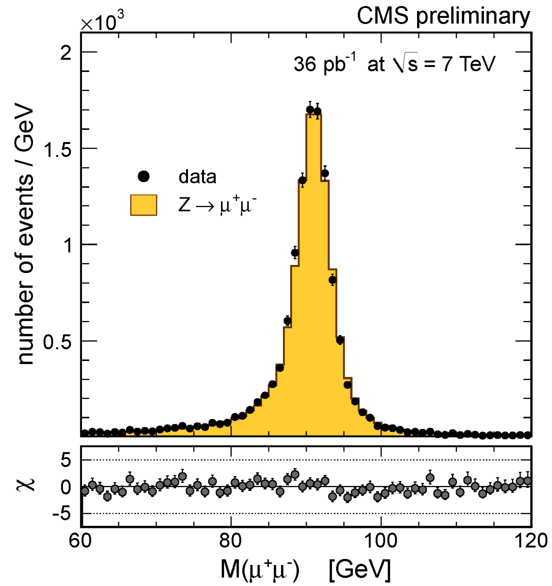
Backgrounds

Almost negligible.

Signal Extraction

Cut & count, Fits to M_{ll} for Signal yield and efficiencies.





Systematic Uncertainties

	W→eν (%)		W→μν (%)		Z→ee (%)		Z→μμ (%)	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
Experimental	2.8	1.5	2.4	1.1	3.5	1.8	1.1	0.7
Theoretical	3.0	0.9	3.0	1.1	4.0	1.7	4.0	2.0
Total (Exp. + Th.)	**4.1**	**1.7**	**3.9**	**1.6**	**5.3**	**2.5**	**4.1**	**2.1**
Luminosity	ATLAS : 3.4				CMS : 4.0			

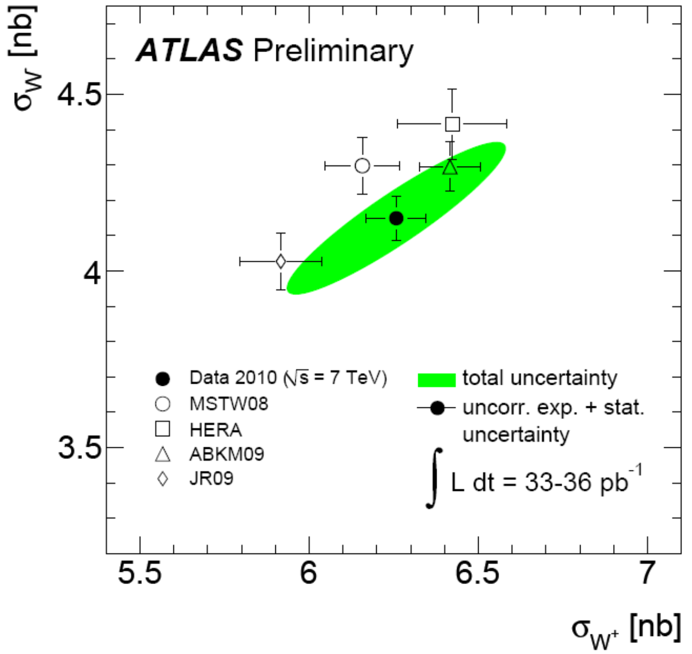
Experimental : Lepton reconstruction & ID , Trigger pre-firing, Momentum/Energy scale & resolution, MET scale and resolution, Background subtraction/modeling, Pileup

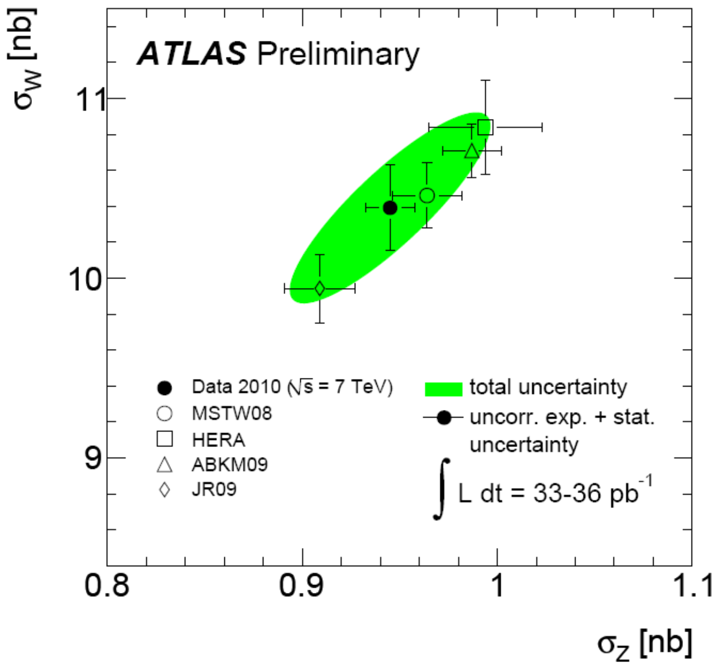
Theoretical : PDF & HO corrections uncertainties on acceptance & MC efficiencies
ATLAS: PYTHIA+MRST LO*, [MC@NLO 90% C.L. CTEQ6.6 ⊕ max. diff of PYTHIA with MRST LO*, CTEQ6.6, HERAPDF1.0 ⊕ diffs between PYTHIA-MC@NLO using CTEQ66]
CMS: POWHEG+CT10, PDF4LHC (68% CL) with [MSTW08, CT10, NNPDF2.0] , α_s errors, scale unc.

For W+/W- ratios & the Charge Asymmetry measurements, special attention on:
- Lepton charge mis-measurement (only for electrons CMS: 0.1-0.4%, ATLAS: 0.5-1.0%)
- Relative efficiencies between l+ and l-

Both measured from data using a clean sample of Z→ll events.

W & Z Cross Sections from ATLAS

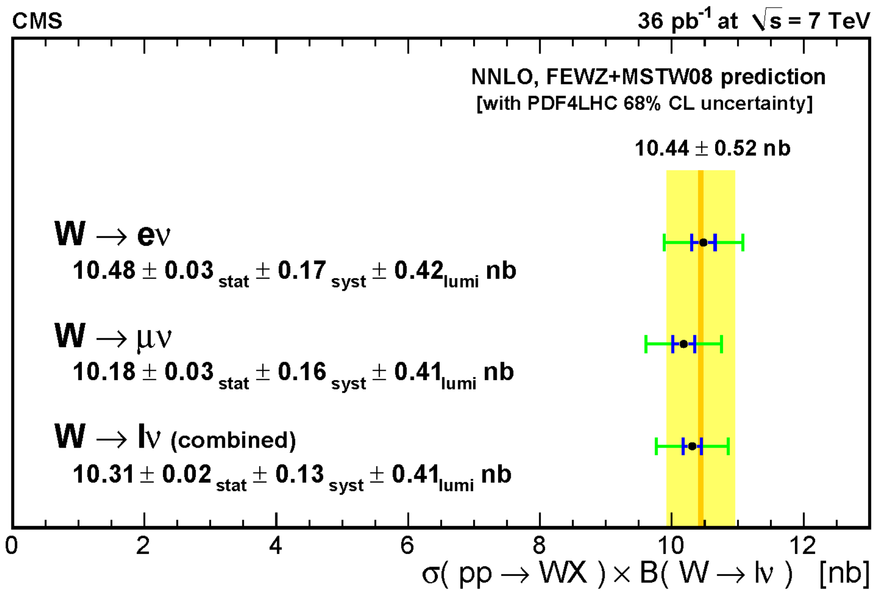


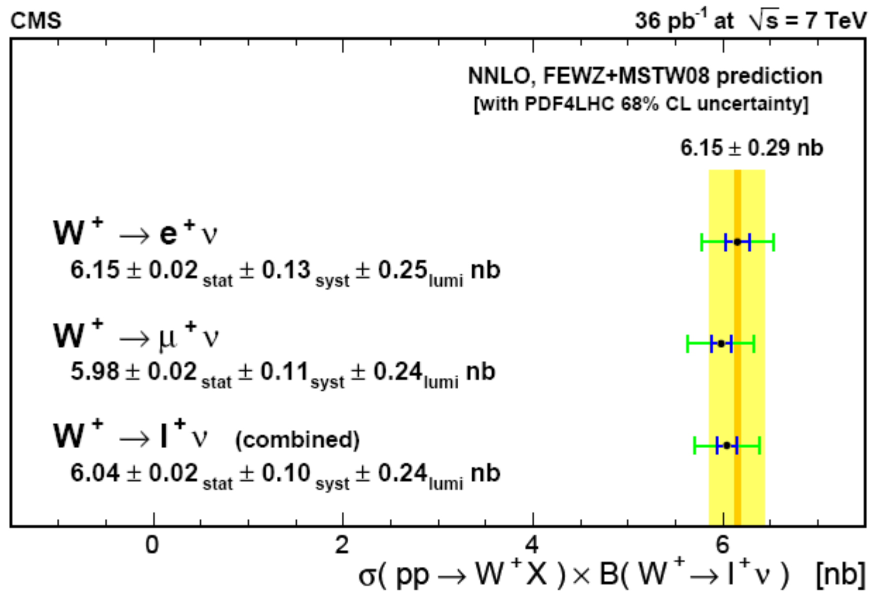


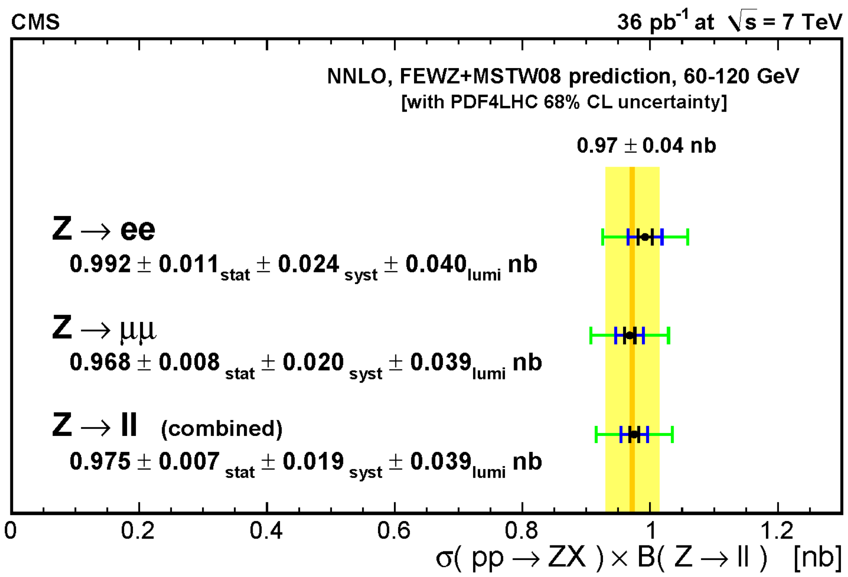
68% C.L theory errors without α_s contribution.
Correlations between A_{W+}/A_{W-} neglected for σ_{W+} versus σ_{W-}.

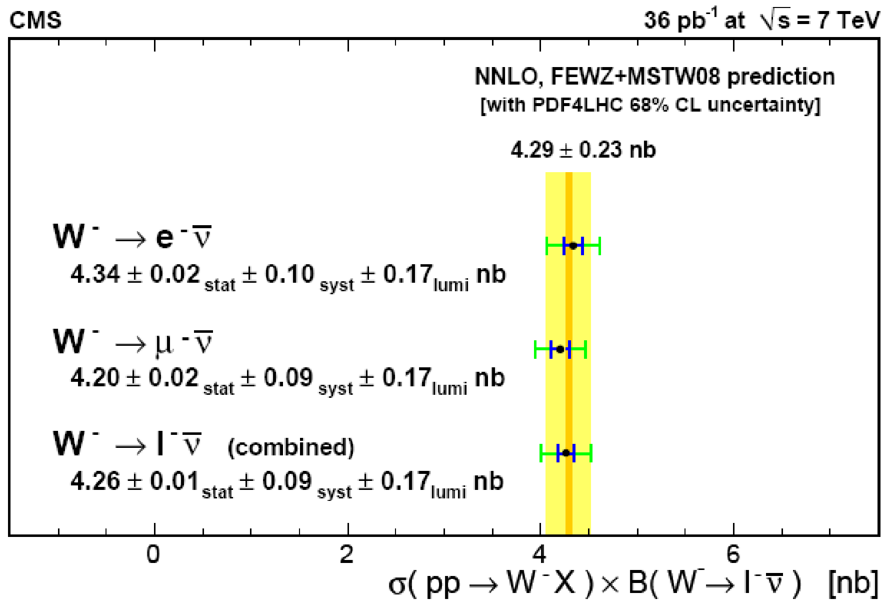
	$\sigma^{tot}_{W(\pm)} \cdot \mathrm{BR}(W \to \ell\nu)$ [nb]
W^+	$6.257 \pm 0.017(\mathrm{sta}) \pm 0.152(\mathrm{sys}) \pm 0.213(\mathrm{lum}) \pm 0.188(\mathrm{acc})$
W^-	$4.149 \pm 0.014(\mathrm{sta}) \pm 0.102(\mathrm{sys}) \pm 0.141(\mathrm{lum}) \pm 0.124(\mathrm{acc})$
W	$10.391 \pm 0.022(\mathrm{sta})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

W & Z Cross Sections from CMS

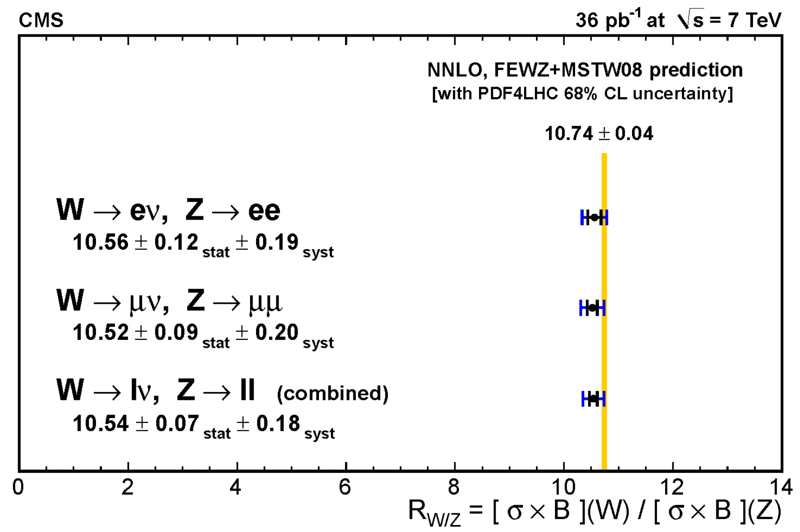


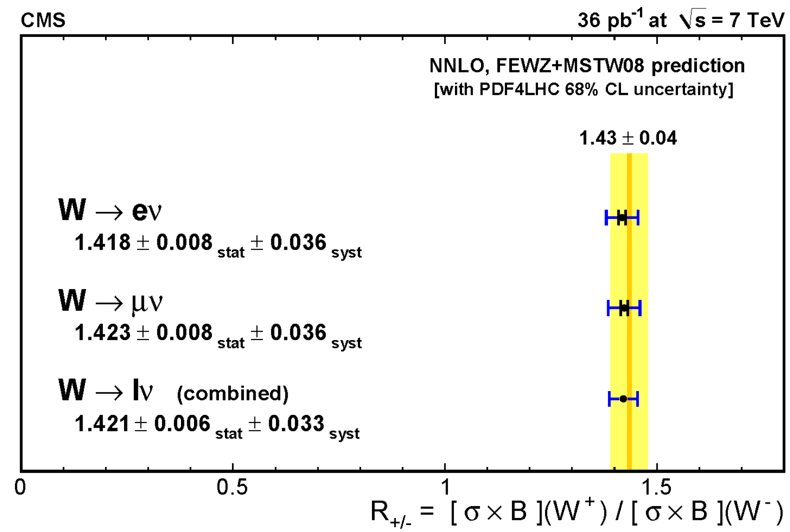






Inclusive Cross Section Ratios from CMS



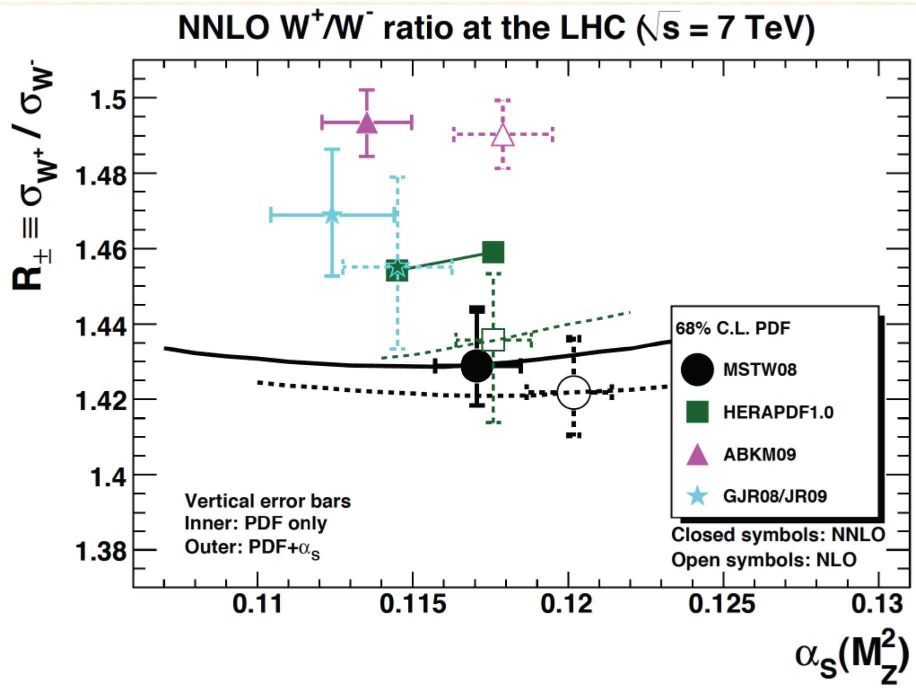


CMS

W/Z and W+/W- ratios agrees well with the NNLO FEWZ+MSTW08NNLO prediction

W^+/W^- ratio shows small dependence on NNLO vs NLO and the α_s value.

Important differences between different predictions at both NNLO and NLO PDFs.

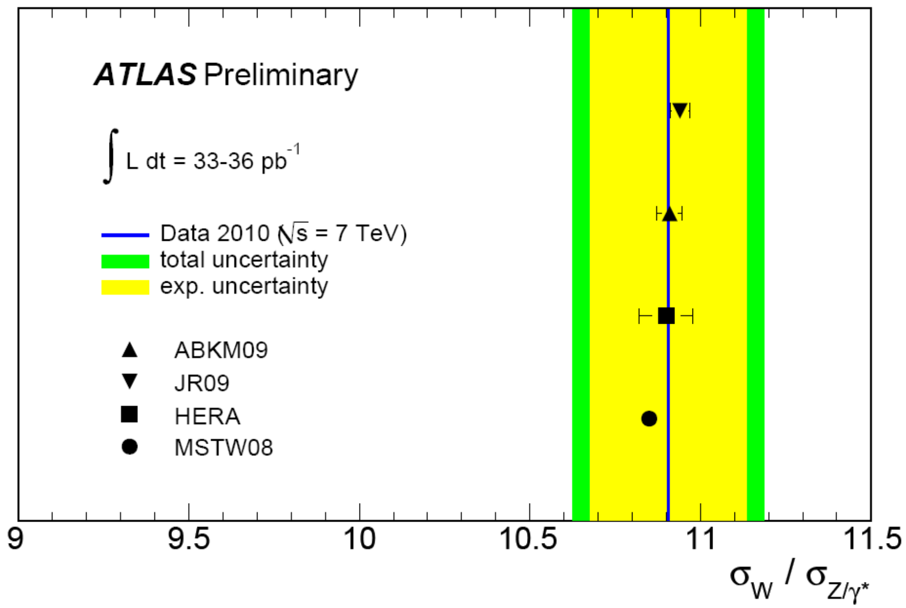


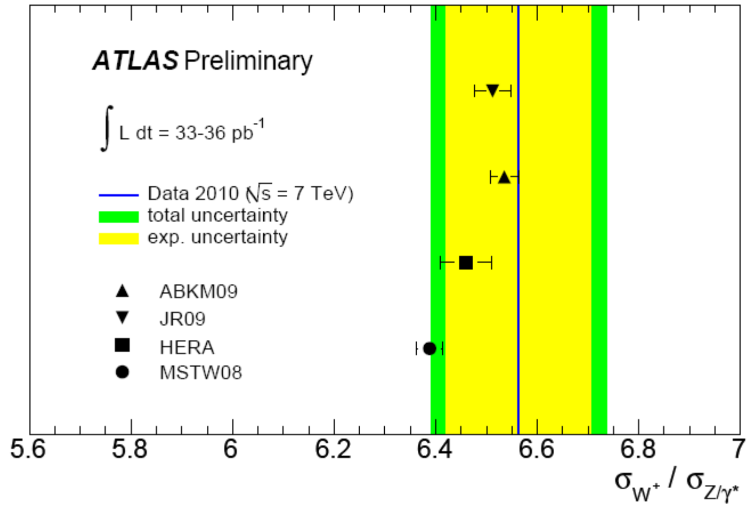
Courtesy of Graeme Watt

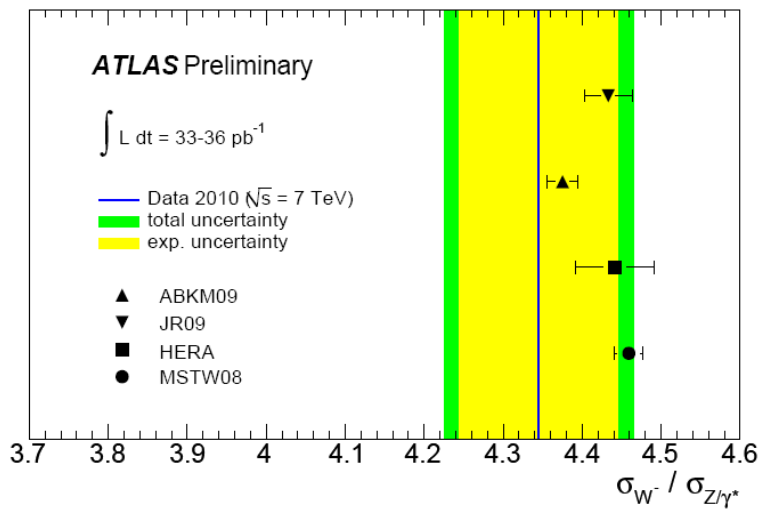
Inclusive Cross Section Ratios from ATLAS

ATLAS

Ratios W^+/Z and W^-/Z seems to be **sensitive** to the PDF choice. Evidence of anti-correlation.





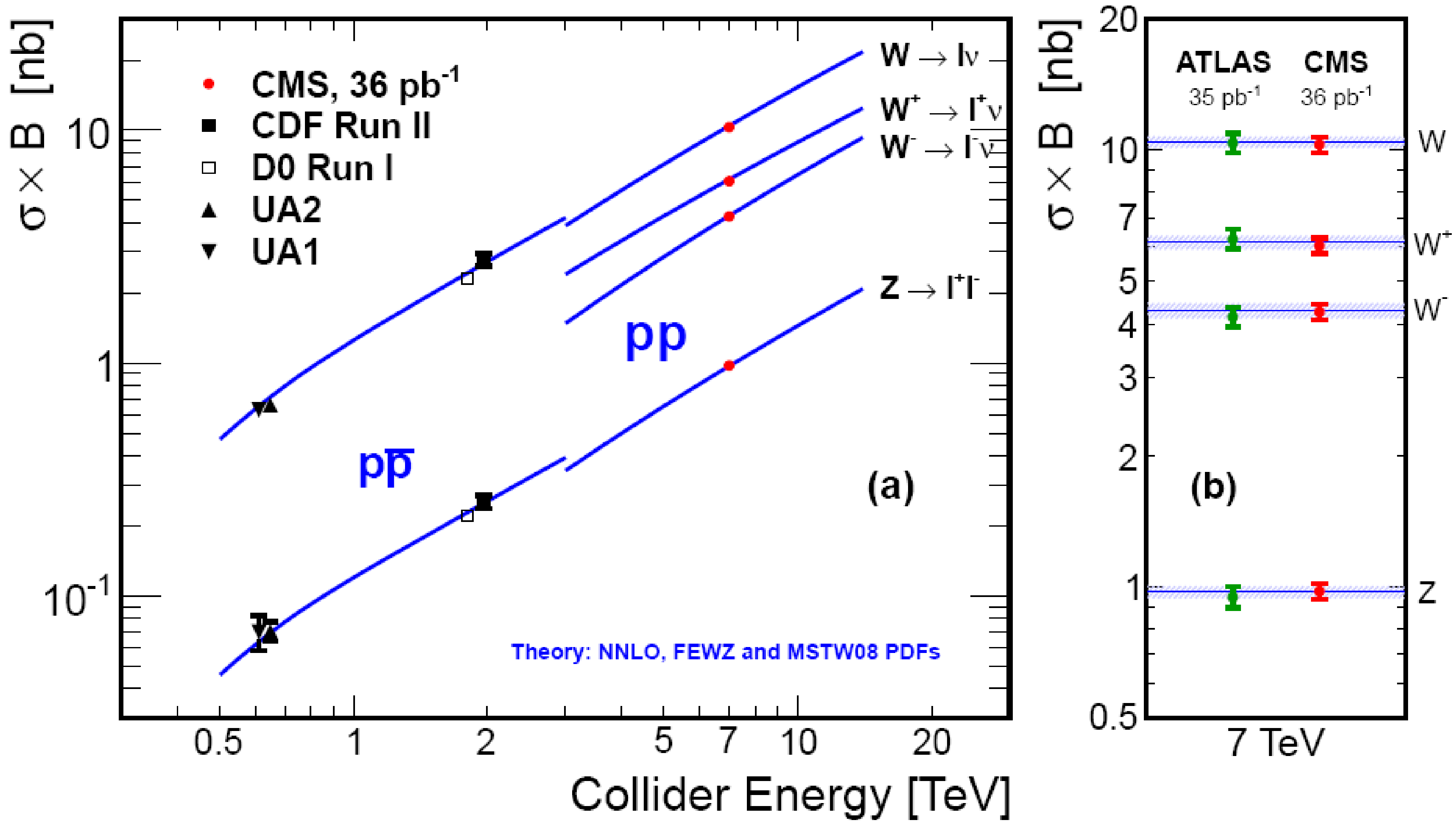


Good agreement with NNLO predictions.

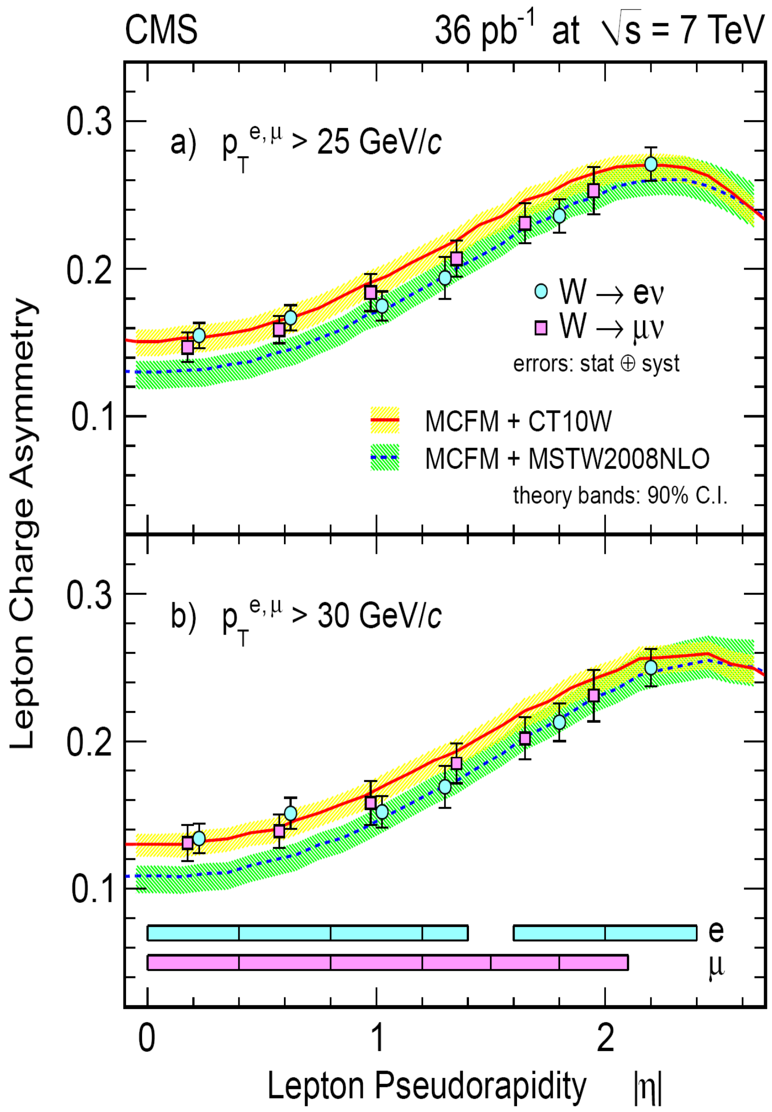
The Ratio of W/Z inclusive cross sections seems to be **insensitive** to the choice of PDFs.

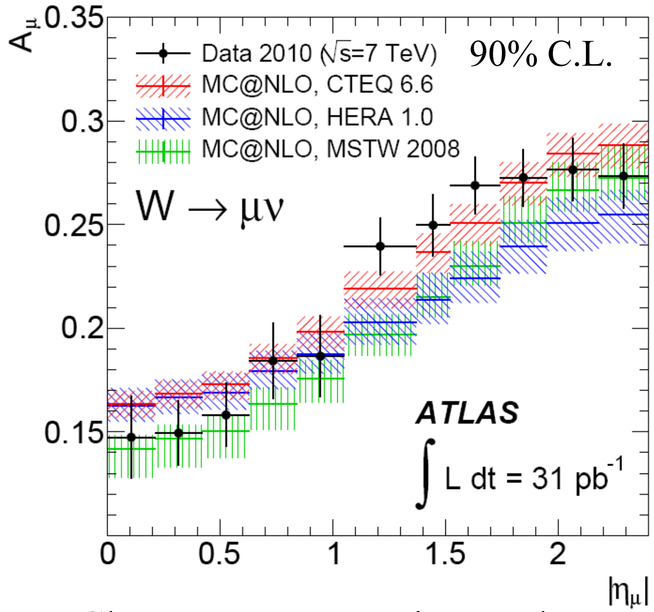
<u>NNLO PDFs tested:</u>
ABKM09, JR09, HERA, MSTW08

Inclusive Cross Sections vs Collider Energy



W Charge Asymmetry





P_T >20 GeV
E_T^{miss} > 25 GeV
M_T > 40 GeV

ATLAS :
CTEQ PDF preferred

χ^2/n.d.f
9.2 / 11 , CTEQ6.6
27.3 / 11 , MSTW08
35.8 / 11 , HERA1.0

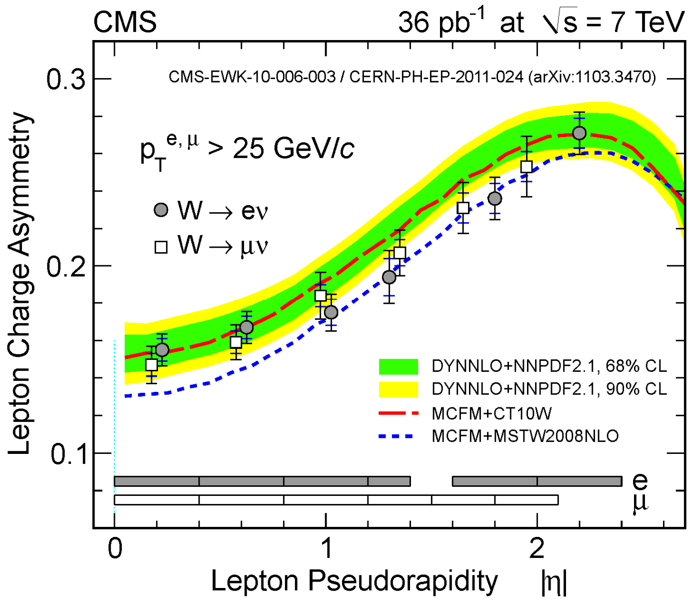
- Charge asymmetry in e and μ agree with each other.
- CMS & ATLAS asymmetries are corrected for QED FSR. The two experiments select different phase space. No extrapolation to the full phase space attempted.
- Stat. & Syst. uncertainties at the same level.

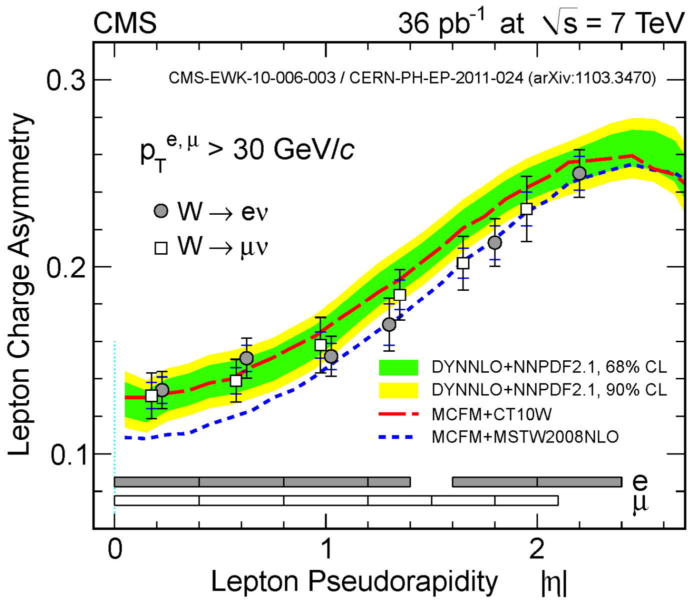
- ATLAS syst. unc. (trigger & reco efficiencies)

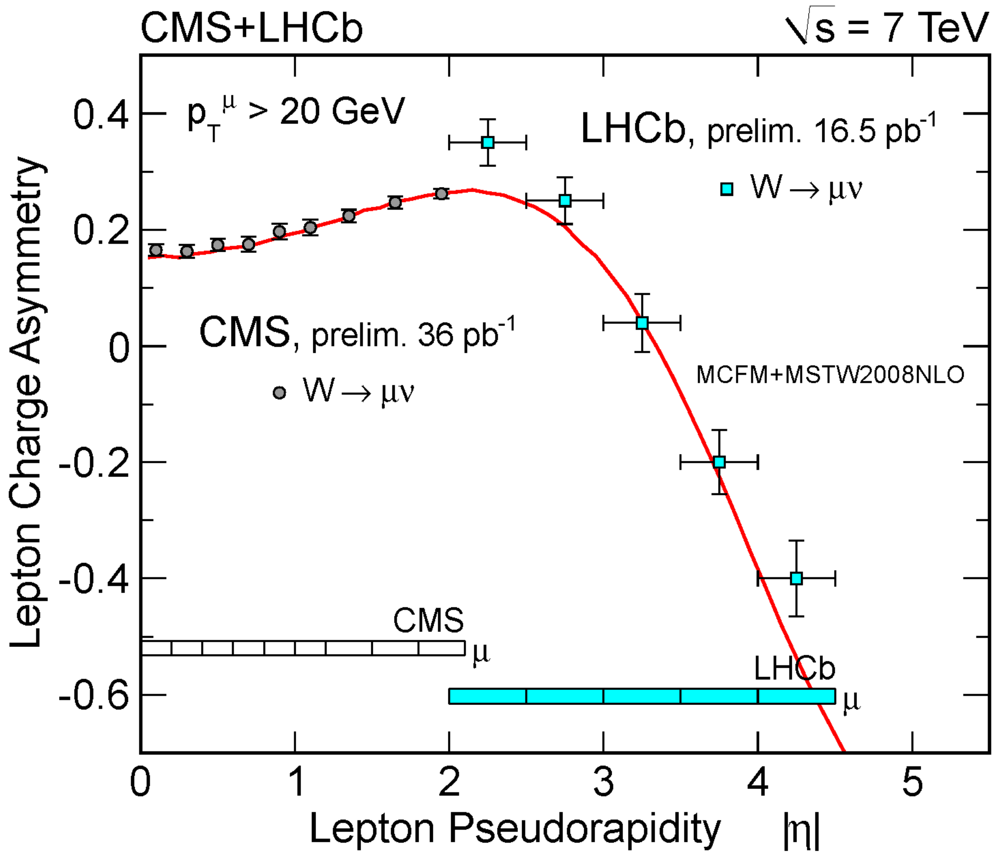
- CMS syst. Unc.(eff. ratio, energy scale)

- Predictions from different PDF models don't agree each other within the PDF uncertainties.
- Precision of the measurement good enough to provide new inputs to the PDF global fits.

DYNNLO+NNPDF21 & CMS+LHCb with muons

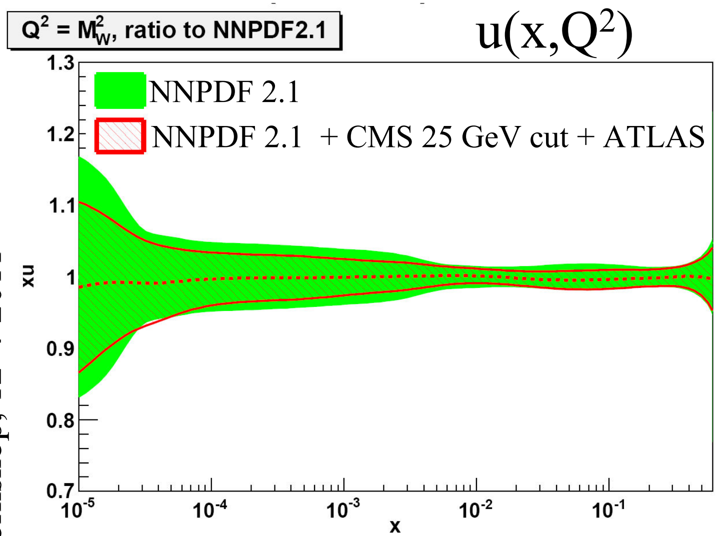


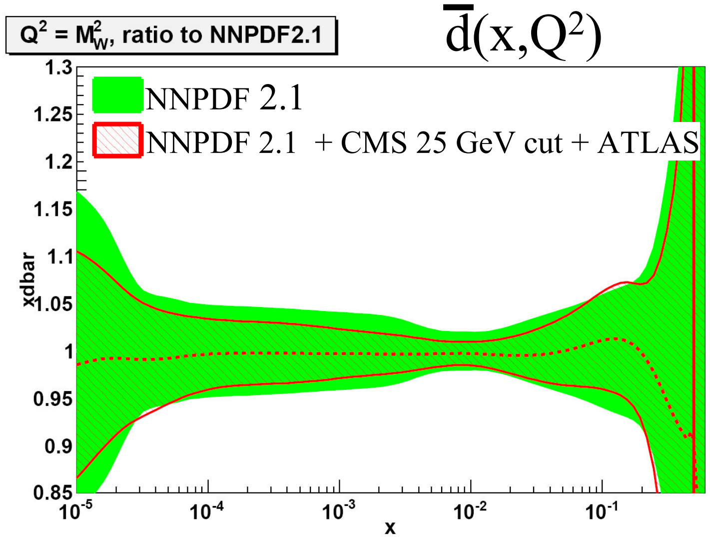




W Charge Asymmetry and New PDF Constraints

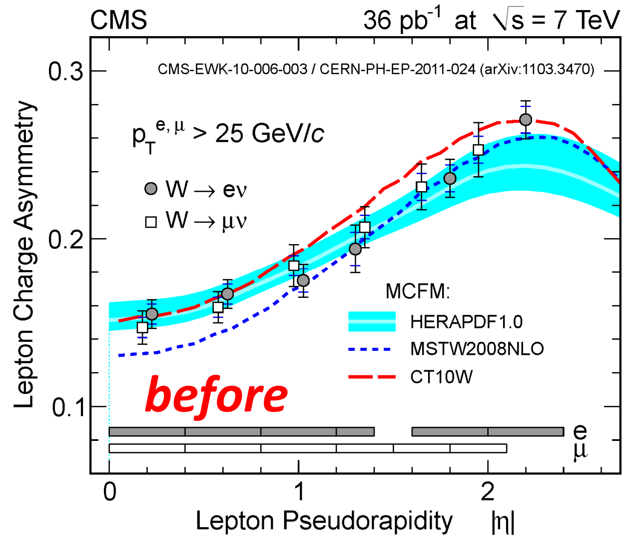
Reduction of PDF uncertainties (~ 30-40 %) for medium and small-x light (anti) quarks



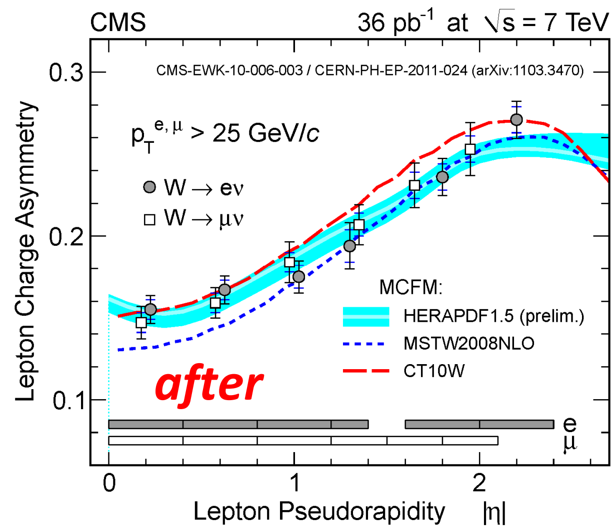


J. Rojo, DIS 2011 workshop, 12-4-2011

(HERAPDF) already incorporated the CMS measurement:



Many more details from Maria Ubiali



Conclusions

- Both ATLAS & CMS performed impressively well during 2010. Physics “objects” are in a very good shape, giving the opportunity to perform high precision measurements.

- Inclusive W & Z cross sections and ratios, from both ATLAS and CMS, are in agreement with the NNLO predictions. Both experiments quote also restricted acceptances which have minimal dependence on theoretical uncertainties.

- ATLAS+CMS data, through the W lepton asymmetry, constrain already small-x sea quark PDFs.

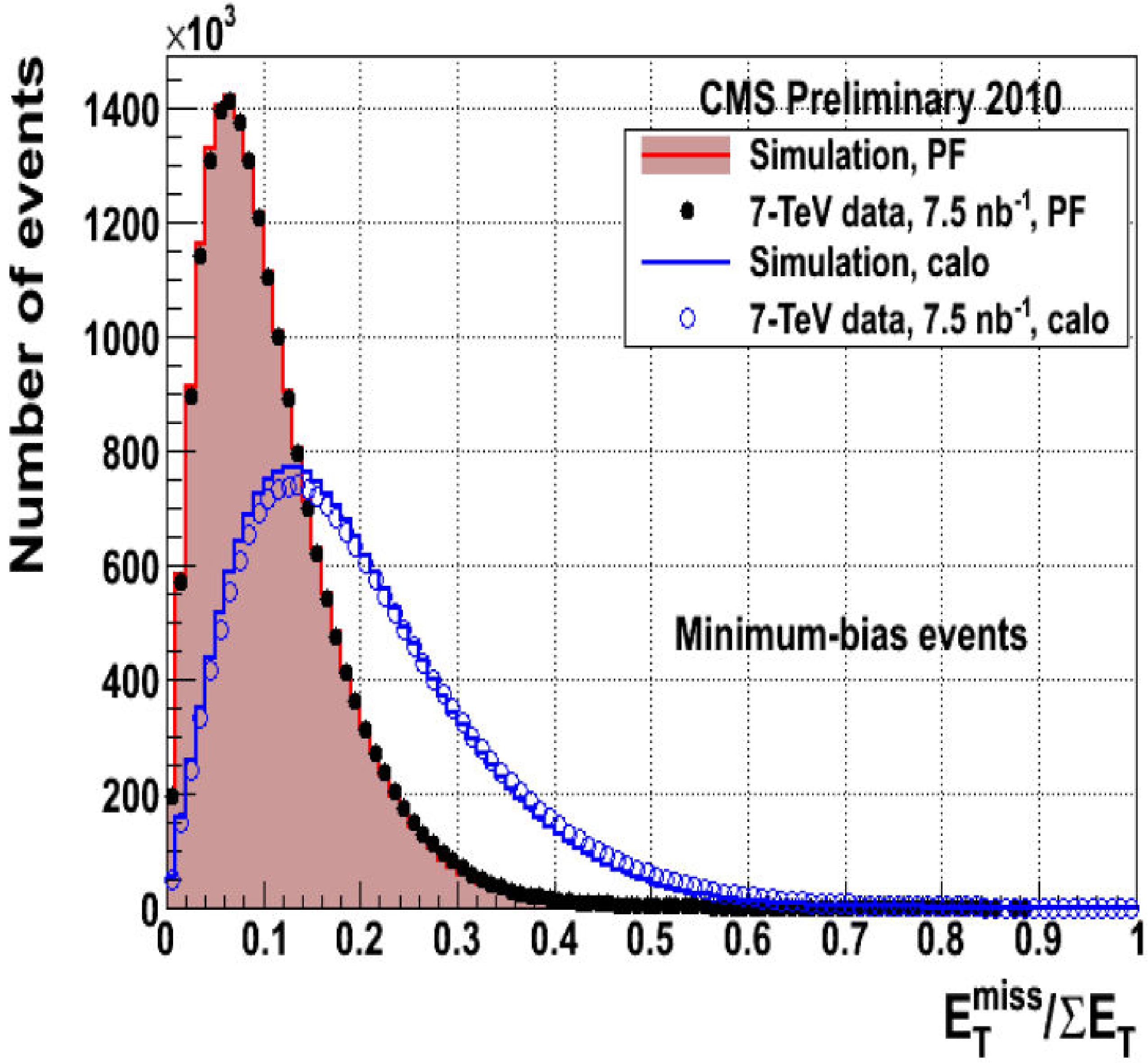
- LHC is collecting data. Already a $\times 10$ increase w.r.t. 2010 data sets.
Higher precision measurements and further constraints of PDFs will be soon available.

ATLAS:
Inclusive cross sections ATLAS-CONF-2011-041
Charge Asymmetry arXiv: 1103.2929

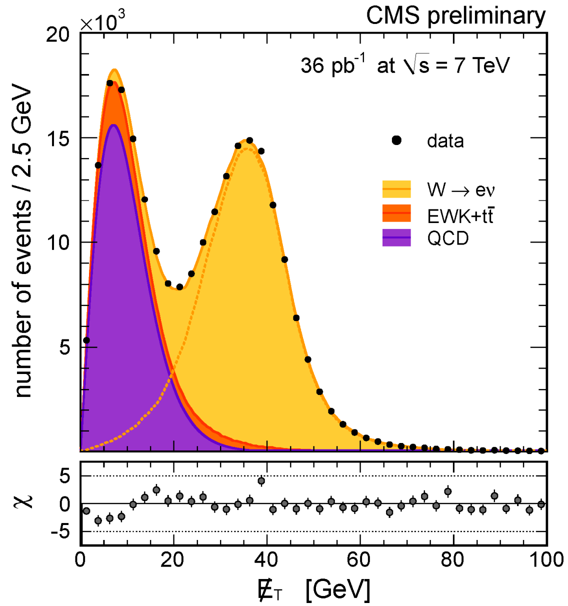
CMS:
Inclusive cross sections CMS PAS EWK-10-005
Charge Asymmetry JHEP04(2011)050

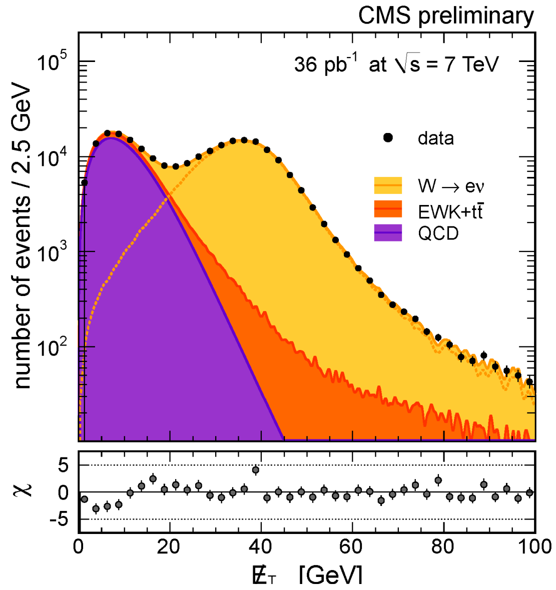
BACKUP

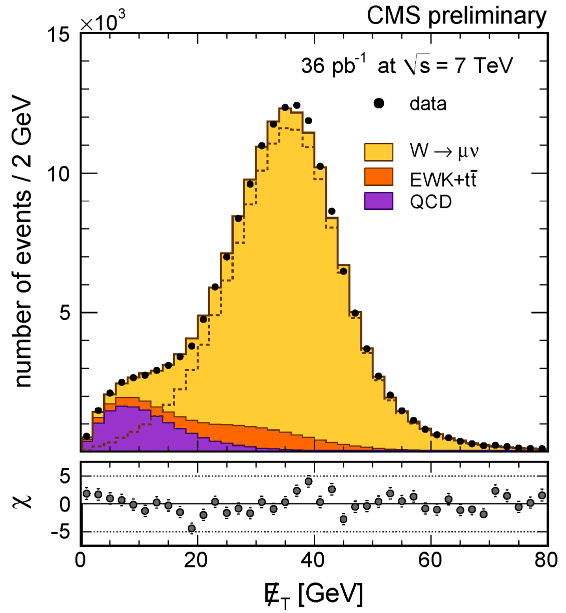
CMS – Particle Flow

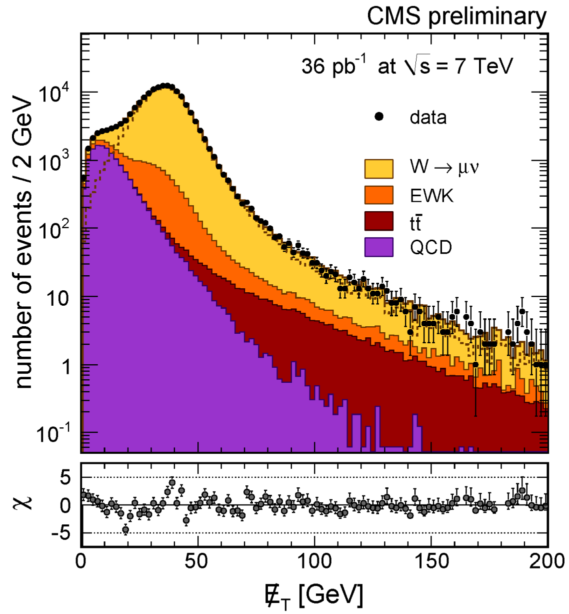


CMS - W missing E_T distributions

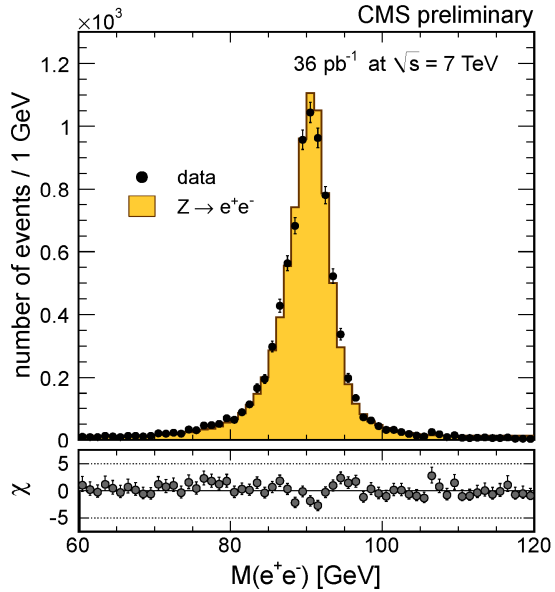


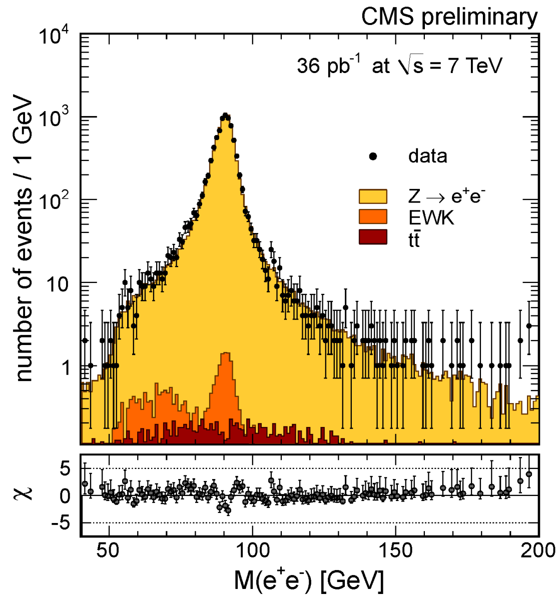


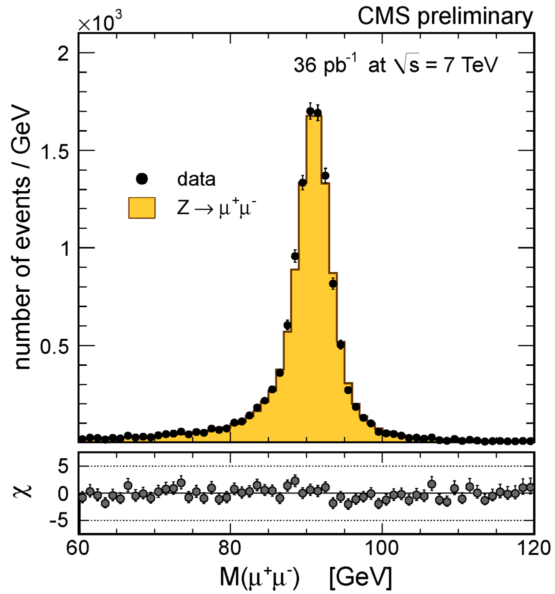


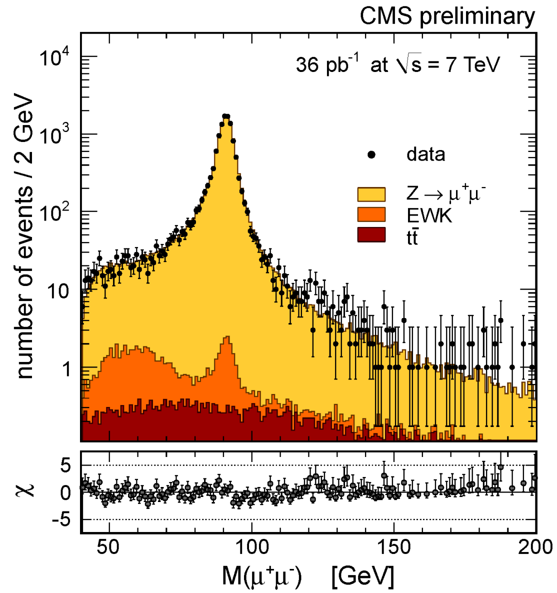


CMS γ^*/Z inv. masses

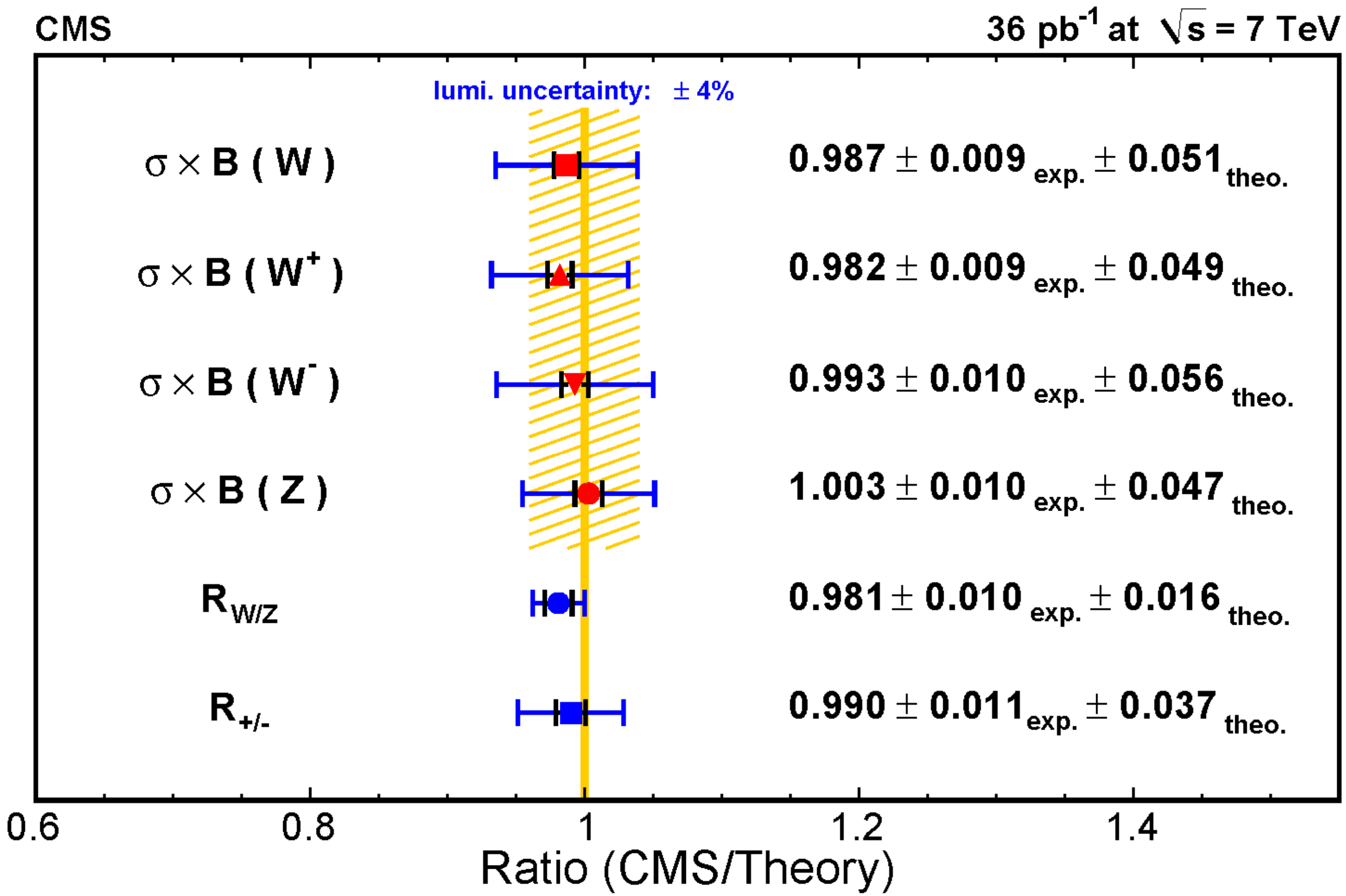








CMS – Ratio (Measurement/Theory)



CMS Inclusive Cross Sections 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

CMS – Fiducial Cross Sections

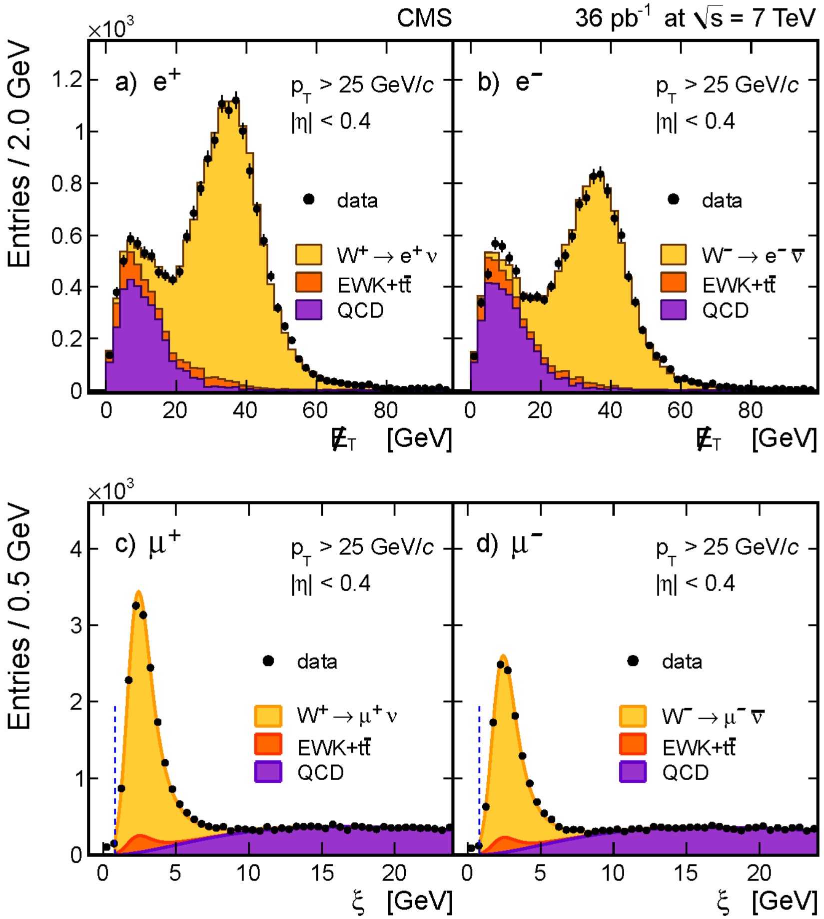
Channel	$\sigma \times \mathcal{B}$ in acceptance A (nb)	A	
$W \to e\nu$	5.449 ± 0.015 (stat.) ± 0.086 (syst.) ± 0.218 (lumi.)	0.520 ± 0.003	$p_T > 25$ GeV, $\|\eta\| < 2.5$
$W^+ \to e^+\nu$	3.257 ± 0.012 (stat.) ± 0.061 (syst.) ± 0.130 (lumi.)	0.530 ± 0.004	
$W^- \to e^-\overline{\nu}$	2.193 ± 0.010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

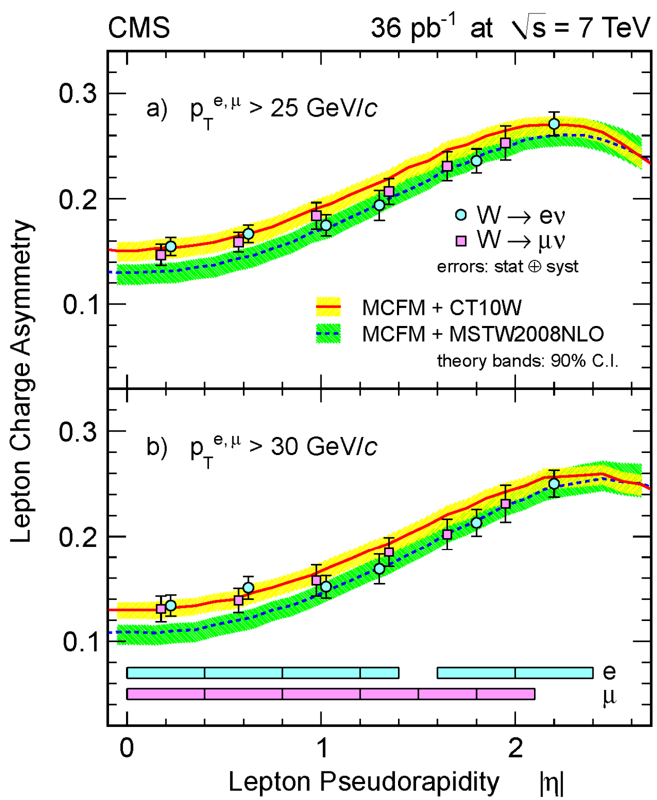
Ratios of CMS/Theory

Table 3: Summary of ratios of CMS measurements to the theoretical values.

Quantity	Ratio (CMS/Theory)	Lumi. uncert. (4%)
$\sigma \times BF(W^{\pm})$	0.987 ± 0.009 (ex) ± 0.051 (th) [± 0.051(tot)]	0.039
$\sigma \times BF(W^{+})$	0.982 ± 0.009 (ex) ± 0.049 (th) [± 0.050(tot)]	0.039
$\sigma \times BF(W^{-})$	0.993 ± 0.010 (ex) ± 0.056 (th) [± 0.057(tot)]	0.040
$\sigma \times BF(Z)$	1.003 ± 0.010 (ex) ± 0.047 (th) [± 0.048(tot)]	0.040
$\sigma \times BF(W) / \sigma \times BF(Z)$	0.981 ± 0.010 (ex) ± 0.016 (th) [± 0.019(tot)]	–
$\sigma \times BF(W^{+}) / \sigma \times BF(W^{-})$	0.990 ± 0.011 (ex) ± 0.037 (th) [± 0.039(tot)]	–

CMS Charge Asymmetry





CMS Charge Asymmetry

$p_T^\ell > 25$ GeV/c												
	Electron Channel						Muon Channel					
$\|\eta\|$ 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
$p_T^\ell > 30$ GeV/c												
	Electron Channel						Muon Channel					
$\|\eta\|$ 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

Table 1. Summary of the systematic uncertainties. All values are in percent.

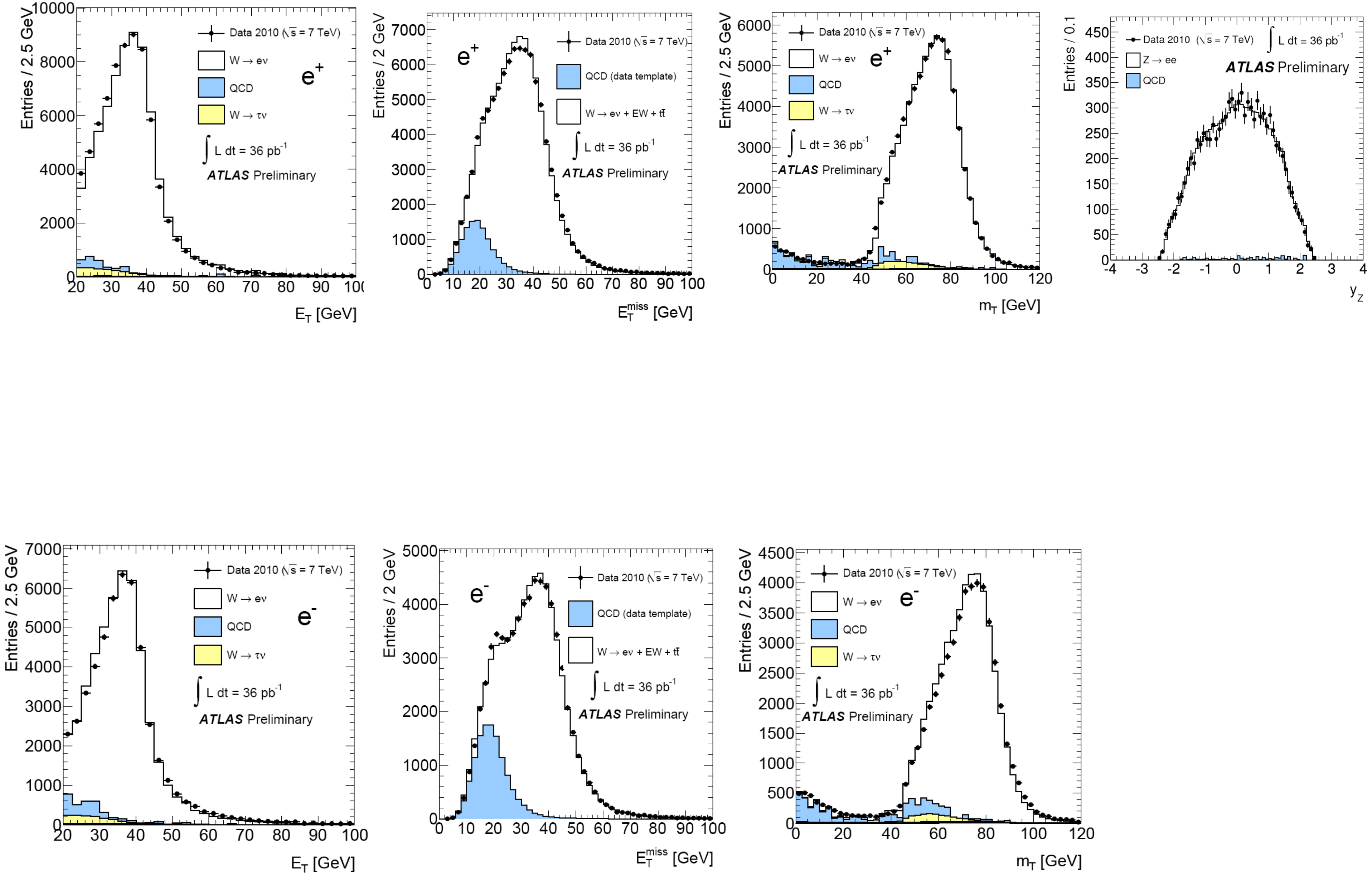
CMS Charge Asymmetry

	$p_T^\ell > 25\,\mathrm{GeV}/c$				$p_T^\ell > 30\,\mathrm{GeV}/c$			
$\|\eta^e\|$	$\mathcal{A}(e)$ ($\pm$stat $\pm$ sys)	$\mathcal{A}^R$	$\mathcal{A}^M$	$\Delta(+/-)$	$\mathcal{A}(e)$ ($\pm$stat $\pm$ sys)	$\mathcal{A}^R$	$\mathcal{A}^M$	$\Delta(+/-)$
[0.0, 0.4]	$15.5 \pm 0.6 \pm 0.7$	15.7	15.3	$+0.8/-1.0$	$13.4 \pm 0.7 \pm 0.7$	13.4	13.1	$+0.7/-0.9$
[0.4, 0.8]	$16.7 \pm 0.6 \pm 0.7$	16.9	16.7	$+0.9/-1.0$	$15.1 \pm 0.7 \pm 0.8$	14.6	14.5	$+0.8/-0.8$
[0.8, 1.2]	$17.5 \pm 0.7 \pm 0.8$	19.3	19.2	$+0.8/-1.1$	$15.2 \pm 0.7 \pm 0.8$	16.9	16.8	$+0.8/-1.0$
[1.2, 1.4]	$19.4 \pm 1.0 \pm 0.9$	21.6	21.7	$+0.8/-1.1$	$16.9 \pm 1.1 \pm 0.9$	19.1	18.9	$+0.8/-1.0$
[1.6, 2.0]	$23.6 \pm 0.8 \pm 0.9$	25.6	25.4	$+0.8/-1.1$	$21.3 \pm 0.9 \pm 0.9$	23.4	23.7	$+0.8/-1.1$
[2.0, 2.4]	$27.1 \pm 0.8 \pm 0.9$	27.1	26.9	$+0.8/-1.1$	$25.0 \pm 0.9 \pm 0.9$	25.7	25.4	$+0.8/-1.1$
$\|\eta^\mu\|$	$\mathcal{A}(\mu)$($\pm$stat $\pm$ sys)	$\mathcal{A}^R$	$\mathcal{A}^M$	$\Delta(+/-)$	$\mathcal{A}(\mu)$($\pm$stat $\pm$ sys)	$\mathcal{A}^R$	$\mathcal{A}^M$	$\Delta(+/-)$
[0.0, 0.4]	$14.7 \pm 0.6 \pm 0.8$	15.7	15.3	$+0.8/-1.0$	$13.1 \pm 0.7 \pm 1.0$	13.4	13.1	$+0.7/-0.9$
[0.4, 0.8]	$15.9 \pm 0.6 \pm 0.7$	16.9	16.7	$+0.9/-1.0$	$13.9 \pm 0.7 \pm 0.9$	14.6	14.5	$+0.8/-0.8$
[0.8, 1.2]	$18.4 \pm 0.6 \pm 1.1$	19.3	19.2	$+0.8/-1.1$	$15.8 \pm 0.7 \pm 1.3$	16.9	16.8	$+0.8/-1.0$
[1.2, 1.5]	$20.7 \pm 0.7 \pm 1.0$	22.0	22.0	$+0.8/-1.1$	$18.5 \pm 0.8 \pm 1.1$	19.6	19.4	$+0.8/-1.0$
[1.5, 1.8]	$23.1 \pm 0.8 \pm 1.1$	24.6	24.5	$+0.8/-1.1$	$20.2 \pm 0.8 \pm 1.2$	22.2	21.9	$+0.8/-1.1$
[1.8, 2.1]	$25.3 \pm 0.8 \pm 1.4$	26.5	26.3	$+0.8/-1.0$	$23.1 \pm 0.9 \pm 1.5$	24.5	24.1	$+0.8/-1.1$

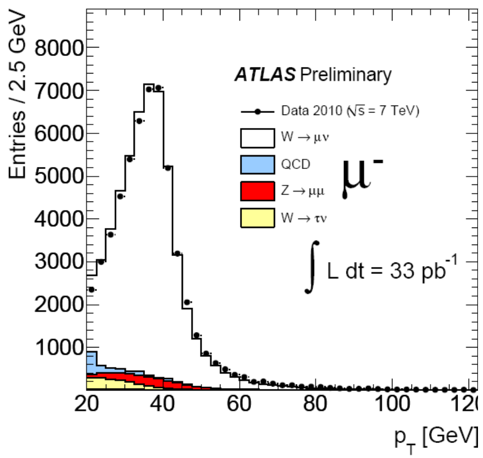
Table 2. Summary of charge asymmetry ($\mathcal{A}$) results. The first uncertainty is statistical and the second is systematic. The theoretical predictions are obtained using RESBOS ($\mathcal{A}^R$) and MCFM ($\mathcal{A}^M$) interfaced with CT10W PDF model. The PDF uncertainties ($\Delta(+/-)$) are estimated using the PDF reweighting technique. The charge asymmetries and PDF errors are given in percent. For each pseudorapidity bin the theoretical prediction is calculated using the averaged differential cross sections for positively and negatively charged leptons respectively. The statistical uncertainty on the theoretical prediction is about 0.1%.

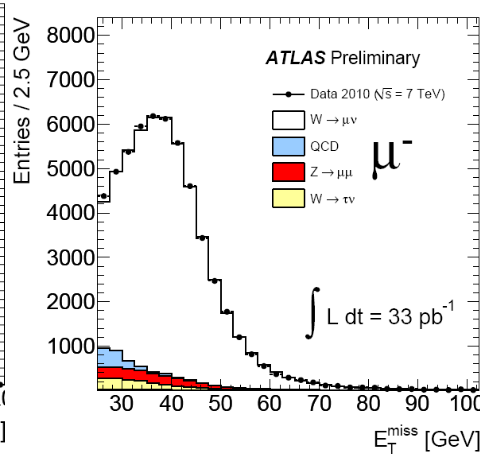
ATLAS material

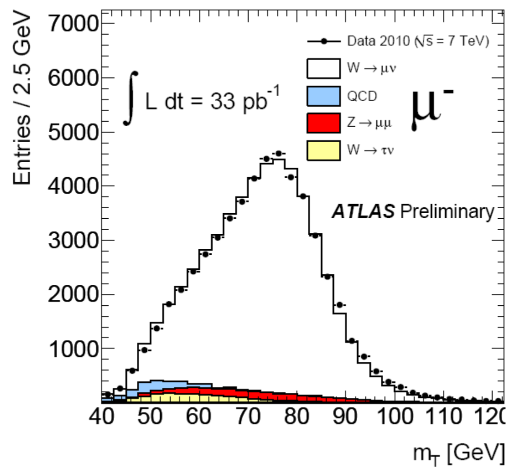
ATLAS kinematic distributions (e)

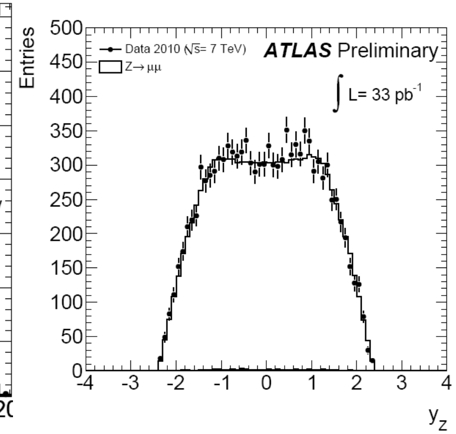


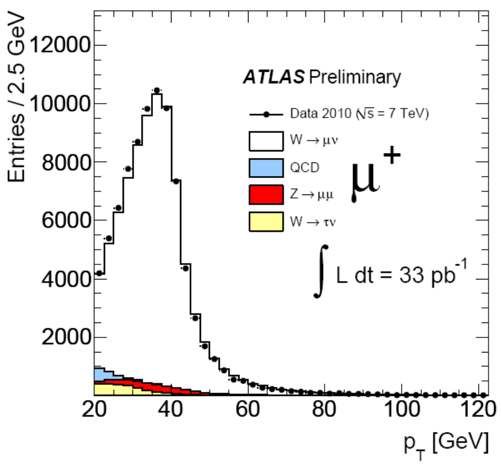
ATLAS kinematic distributions (μ)

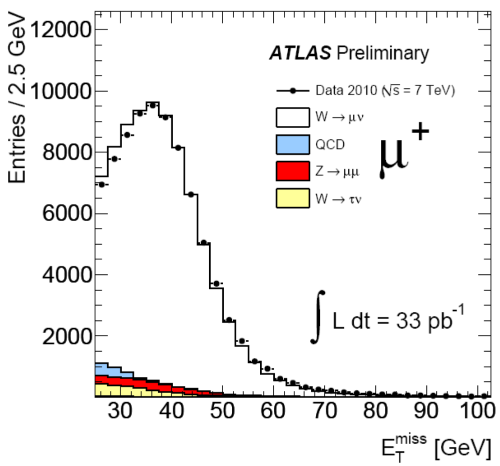


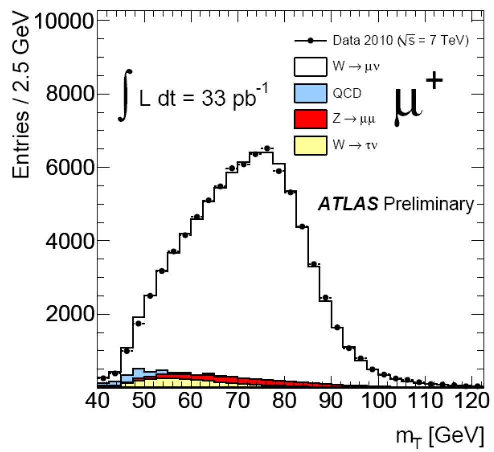












ATLAS Cross Sections & Systematics (electrons)

	N	B	$C_{W/Z}$	$A_{W/Z}$
W^+	72207	4170 ± 345	0.637 ± 0.019	0.466 ± 0.014
W^-	49103	3925 ± 264	0.647 ± 0.019	0.457 ± 0.014
$W^+ + W^-$	121310	8095 ± 532	0.641 ± 0.018	0.462 ± 0.014
Central Z	9721	217 ± 31	0.606 ± 0.021	0.445 ± 0.018
Forward Z	4000	1099 ± 128	0.448 ± 0.039	0.198 ± 0.008

	$\sigma^{\text{fid}}_{W(\pm)} \cdot \text{BR}(W \to e\nu)$ [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	$4.877 \pm 0.015(\text{sta}) \pm 0.138(\text{sys}) \pm 0.166(\text{lum})$
	$\sigma^{\text{tot}}_{W(\pm)} \cdot \text{BR}(W \to e\nu)$ [nb]
W^+	$6.333 \pm 0.025(\text{sta}) \pm 0.193(\text{sys}) \pm 0.215(\text{lum}) \pm 0.190(\text{acc})$
W^-	$4.217 \pm 0.021(\text{sta}) \pm 0.129(\text{sys}) \pm 0.138(\text{lum}) \pm 0.127(\text{acc})$
W	$10.551 \pm 0.032(\text{sta}) \pm 0.300(\text{sys}) \pm 0.359(\text{lum}) \pm 0.316(\text{acc})$
	$\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^* Central	$0.433 \pm 0.004(\text{sta}) \pm 0.016(\text{sys}) \pm 0.015(\text{lum})$
Z/γ^* Forward	$0.179 \pm 0.004(\text{sta}) \pm 0.017(\text{sys}) \pm 0.006(\text{lum})$
	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^* Central	$0.972 \pm 0.010(\text{sta}) \pm 0.034(\text{sys}) \pm 0.033(\text{lum}) \pm 0.038(\text{acc})$
Z/γ^* Forward	$0.903 \pm 0.022(\text{sta}) \pm 0.087(\text{sys}) \pm 0.031(\text{lum}) \pm 0.035(\text{acc})$

	$\delta\sigma_W/\sigma_W$	$\delta\sigma_{W+}/\sigma_{W+}$	$\delta\sigma_{W-}/\sigma_{W-}$	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_T^{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				

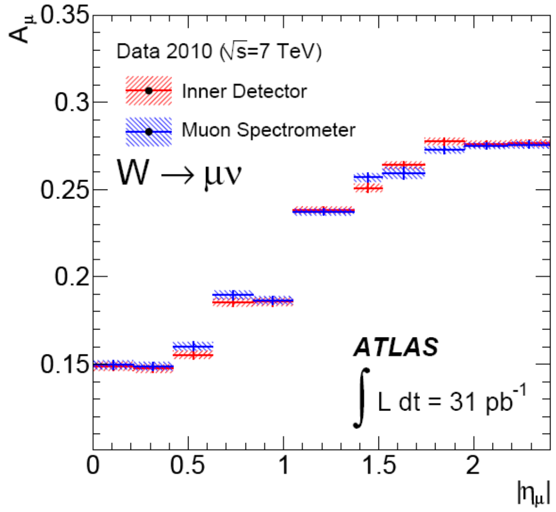
ATLAS Cross Sections & Systematics (muons)

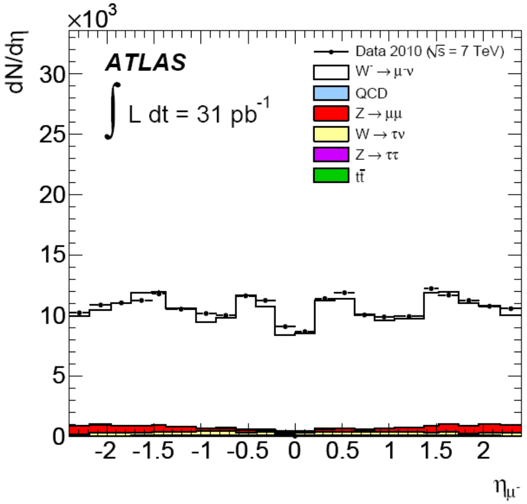
	N	B	$C_{W/Z}$	$A_{W/Z}$
W^+	84103	6214 ± 784	0.794 ± 0.020	0.484 ± 0.015
W^-	55163	5569 ± 812	0.780 ± 0.019	0.474 ± 0.014
$W^+ + W^-$	139266	11783 ± 1580	0.790 ± 0.018	0.480 ± 0.014
Z	11669	66 ± 21	0.779 ± 0.009	0.486 ± 0.019

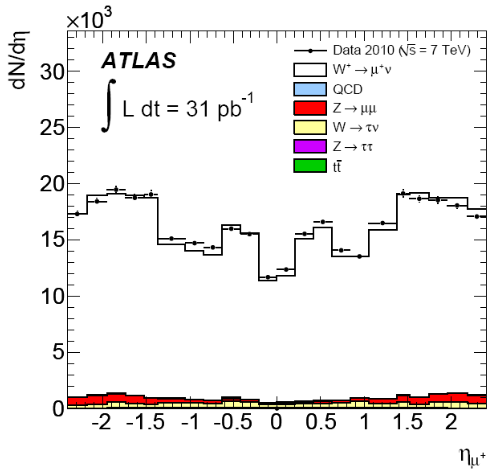
	$\sigma^{\text{fid}}_{W(\pm)} \cdot \text{BR}(W \to \mu\nu)$ [nb]
W^+	$3.008 \pm 0.011(\text{sta}) \pm 0.080(\text{sys}) \pm 0.109(\text{lum})$
W^-	$1.950 \pm 0.009(\text{sta}) \pm 0.053(\text{sys}) \pm 0.072(\text{lum})$
W	$4.959 \pm 0.015(\text{sta}) \pm 0.120(\text{sys}) \pm 0.181(\text{lum})$
	$\sigma^{\text{tot}}_{W(\pm)} \cdot \text{BR}(W \to \mu\nu)$ [nb]
W^+	$6.215 \pm 0.023(\text{sta}) \pm 0.165(\text{sys}) \pm 0.225(\text{lum}) \pm 0.187(\text{acc})$
W^-	$4.107 \pm 0.020(\text{sta}) \pm 0.112(\text{sys}) \pm 0.152(\text{lum}) \pm 0.123(\text{acc})$
W	$10.322 \pm 0.030(\text{sta}) \pm 0.249(\text{sys}) \pm 0.377(\text{lum}) \pm 0.310(\text{acc})$
	$\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.456 \pm 0.004(\text{sta}) \pm 0.005(\text{sys}) \pm 0.015(\text{lum})$
	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.941 \pm 0.008(\text{sta}) \pm 0.011(\text{sys}) \pm 0.032(\text{lum}) \pm 0.037(\text{acc})$

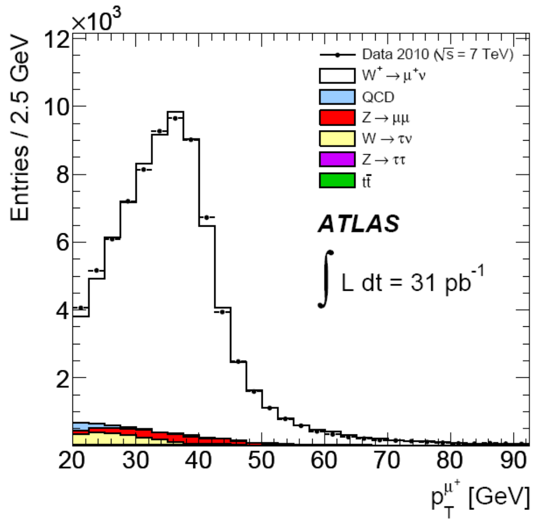
	$\delta\sigma_W/\sigma_W$	$\delta\sigma_{W+}/\sigma_{W+}$	$\delta\sigma_{W-}/\sigma_{W-}$	$\delta\sigma_Z/\sigma_Z$
Trigger	0.7	0.8	0.9	0.1
Muon Reconstruction	0.5	0.6	0.6	0.8
Muon Isolation	0.3	0.3	0.3	0.6
Muon p_T Resolution	0.02	0.03	0.02	0.01
Muon p_T Scale	0.4	1.1	0.8	0.2
QCD Background	0.8	0.7	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			

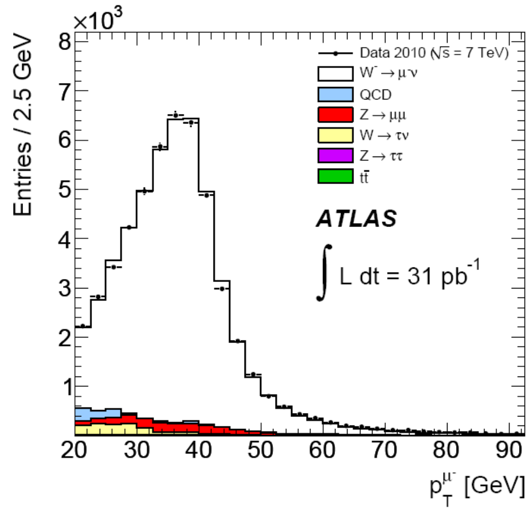
ATLAS Charge Asymmetry

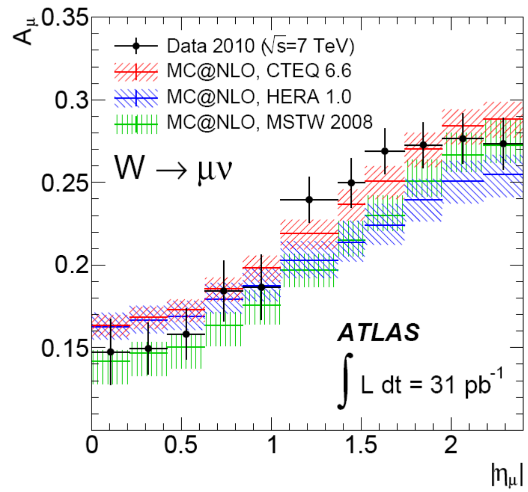












ATLAS Charge Asymmetry Systematics (muons)

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

Table 2: Absolute systematic uncertainties on the W charge asymmetry from different sources as a function of absolute muon pseudorapidity that are described in the text.

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