W and Z production measured using the ATLAS detector, and impact on parton densities of the proton

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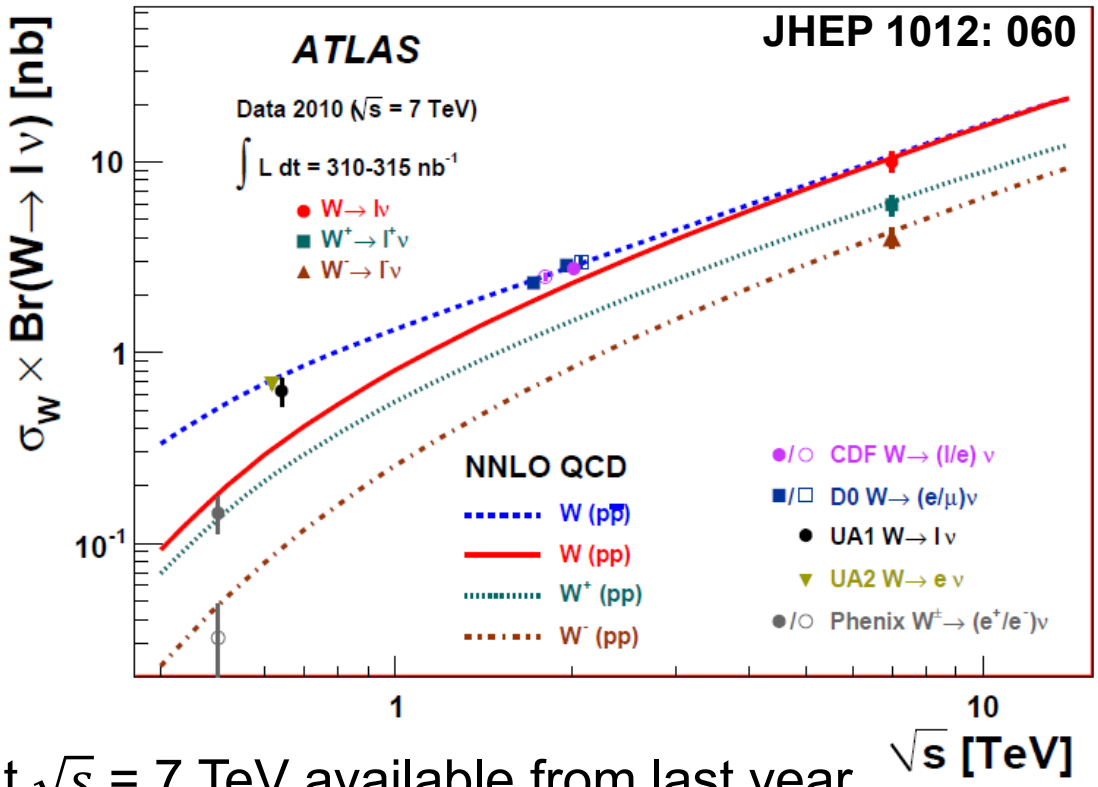
Introduction

- Where do we stand with the W/Z cross sections?
- **Last year:** Inclusive W/Z cross sections published using 0.3 pb^{-1}



Now:

- Up to 40 pb^{-1} of data at $\sqrt{s}$ = 7 TeV available from last year
- Electrons at pseudorapidities > 2.5 included
- Much reduced uncertainty on luminosity

➔Are we already sensitive to PDF differences?

Cross section determination

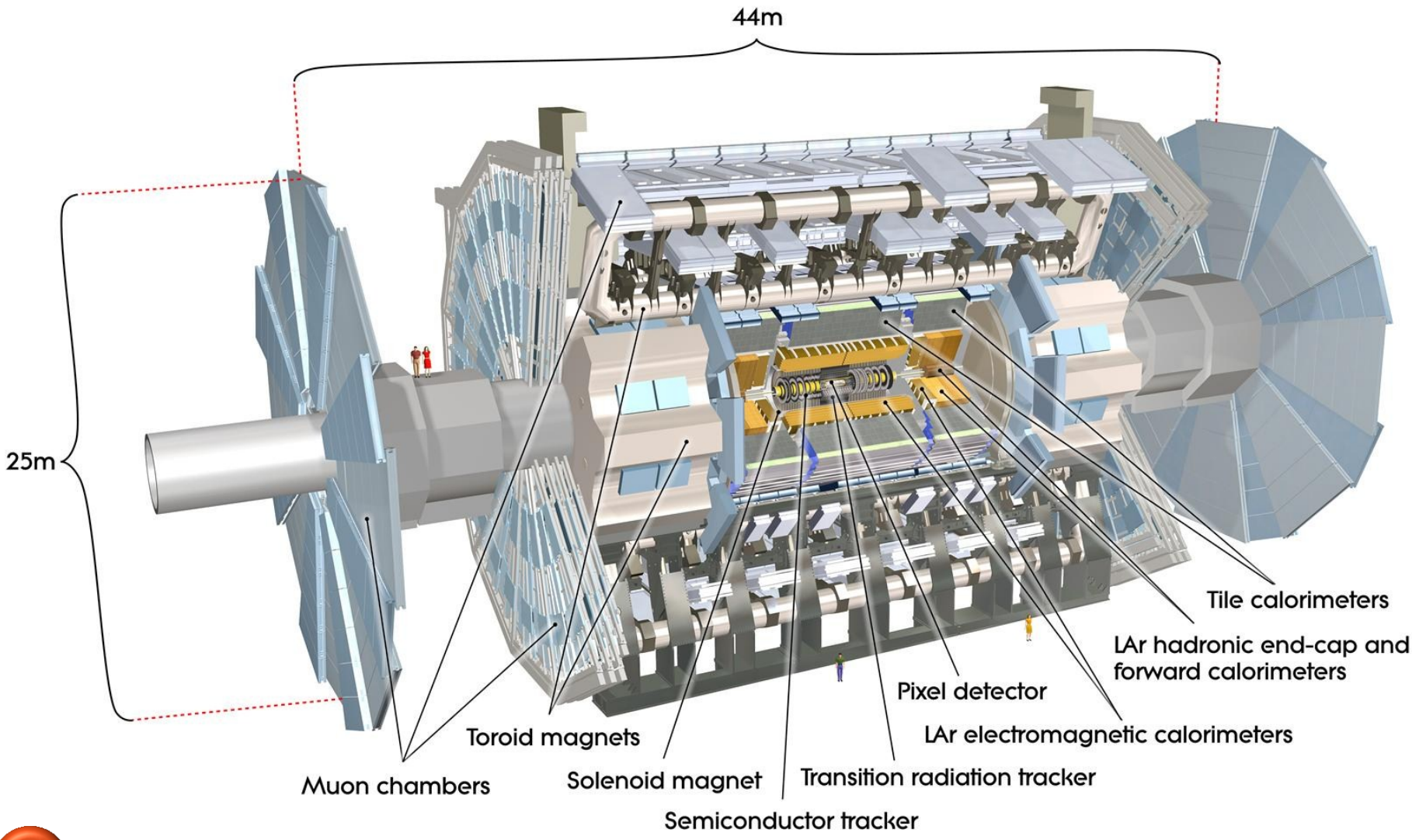
$$\sigma_{tot} = \sigma_{W/Z} \times BR(W/Z \to \ell\nu/\ell\ell) = \frac{N - B}{A_{W/Z} \cdot C_{W/Z} \cdot L_{int}}$$

- *N*: candidate events
- *B*: background events
- *L*: integrated luminosity
- $C_{W/Z}$: efficiency, calculated from fully simulated MC
- $A_{W/Z}$: acceptance, calculated from MC on generator level

$$C_{W/Z} = \frac{N_{\mathrm{MC,rec}}}{N_{\mathrm{MC,gen,cut}}}$$

$$A_{W/Z} = \frac{N_{\mathrm{MC,gen,cut}}}{N_{\mathrm{MC,gen,all}}}$$

ATLAS detector



Selection

Electron:

- Match shower in EM-Calorimeter and track in „inner detector“
- E_T >20 GeV
- $|\eta| < 2.47$, exclude $1.37 < |\eta| < 1.52$
- Identification criteria (e.g., shower shapes, track quality, transition radiation)

Muon:

- Match between track in „inner detector“ and track in muon spectrometer
- P_T >20 GeV
- $|\eta| < 2.4$
- Identification criteria (e.g., Track quality, isolation)

Corrections

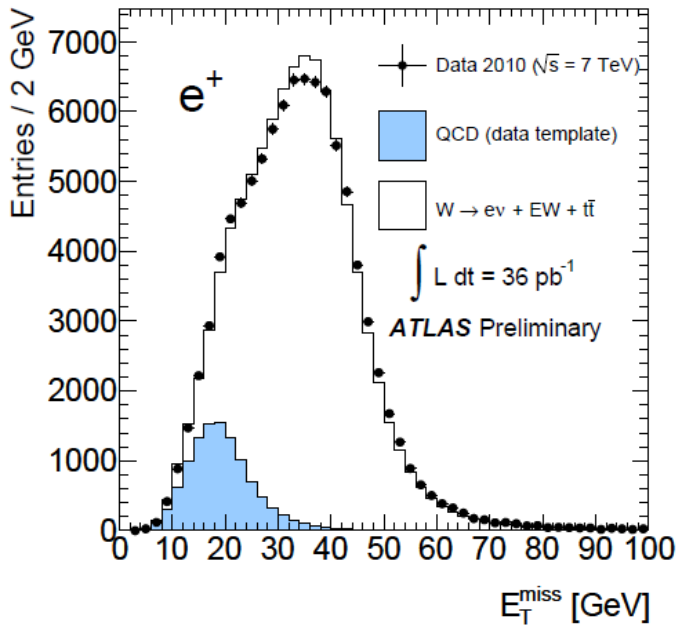
Good data-MC agreement
needed in order to calculate meaningful $C_{W/Z} = \frac{N_{\mathrm{MC,rec}}}{N_{\mathrm{MC,gen,cut}}}$

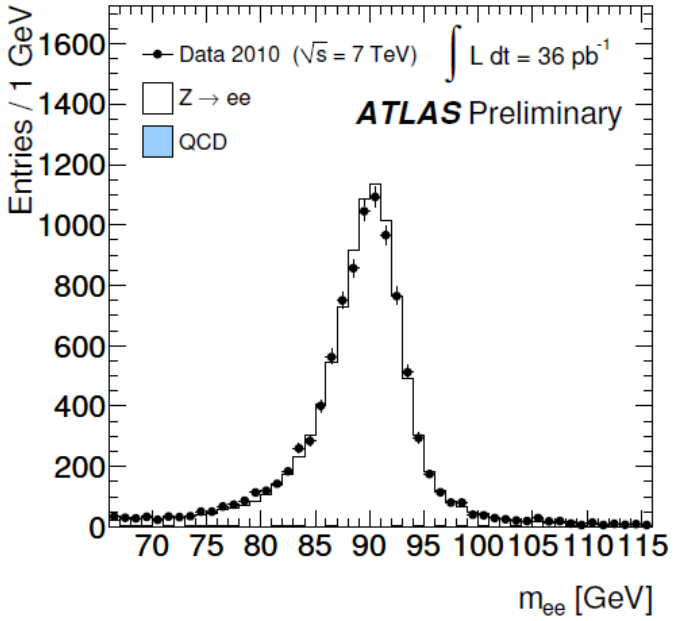
➔ Corrections:

- Efficiencies for identification, reconstruction, and trigger calculated from data and MC, differences are applied as scale factors to the MC
- energy scales (using e.g., Z or J/Psi peak position) applied to data
- MC smeared according to energy resolution from Z invariant mass distribution
- Map of hot or dead areas in calorimeter used in MC and data

Background

- Electroweak backgrounds and ttbar taken from MC
- QCD background data driven, many methods.....

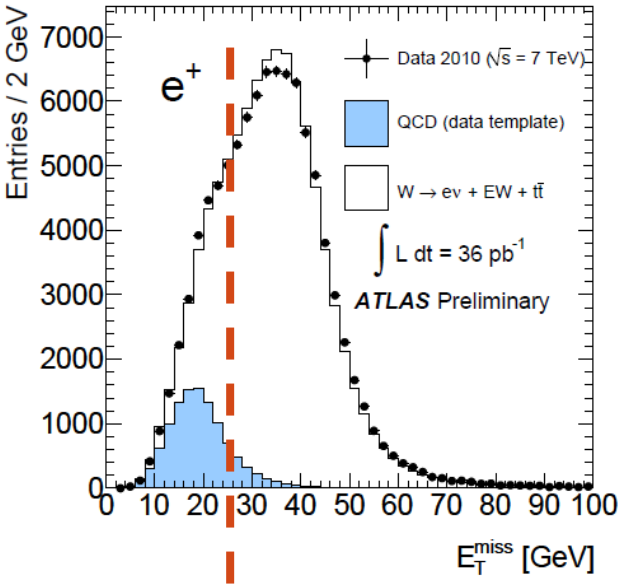


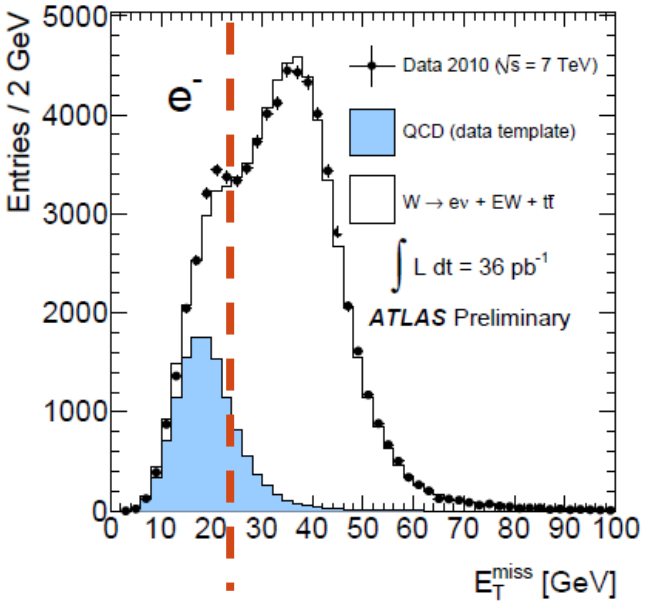


Fit distribution using QCD shape from data (non-isolated, inverted cuts) and shape of other BG and signal from MC

BG too small to fit (reliably).
➔ Fit to distribution derived by omitting some identification criteria. Scale resulting BG by rejection factor of omitted criteria..

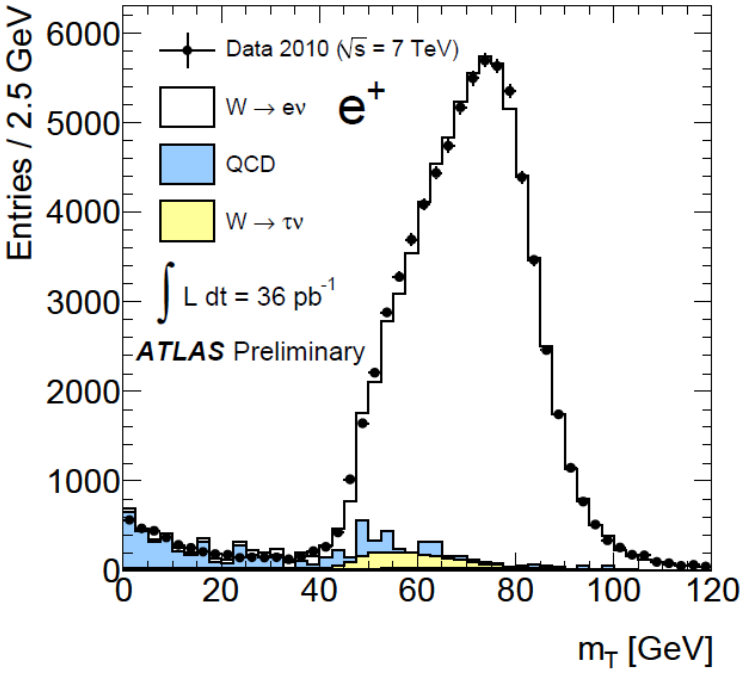
W→eυ distributions, further cuts





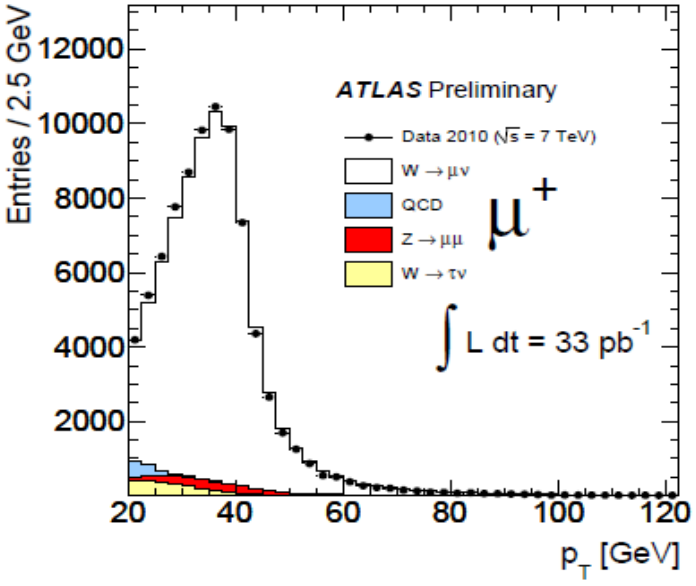
E_T^{miss} > 25 GeV

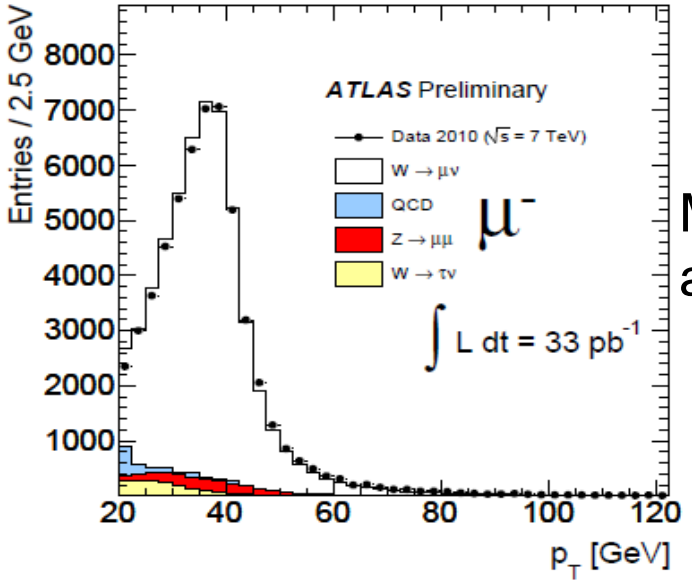
~120k events



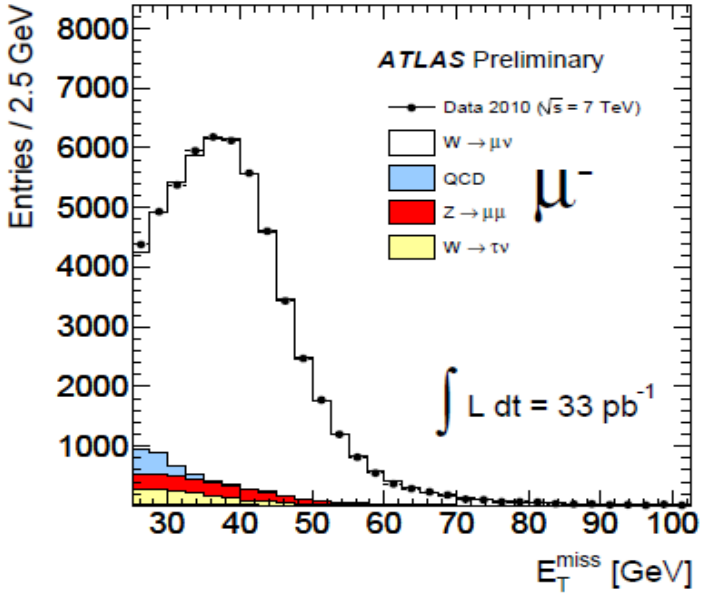
Also require m_T > 40 GeV

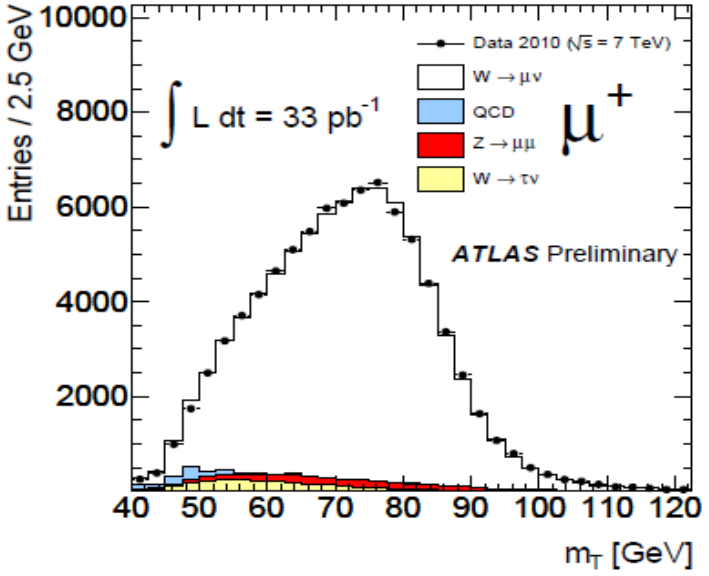
$W \rightarrow \mu \upsilon$





More W+ than W- as expected in pp





~140k events

Good description!

Acceptance

- Central value calculated using Pythia with MRST-LOmod PDF
- Acceptance around 45% (48%) for electron (muon) channels
- Systematic uncertainty, add in quadrature:
  - MC@NLO with CTEQ6.6 NLO PDF error set
  - Max deviation between central value and PYTHIA with CTEQ6.6 and HERAPDF1.0 NLO sets
  - Difference between PYTHIA and MC@NLO using same (CTEQ6.6) PDF
- Systematic uncertainties about 3% (4%) for W (Z)

Systematics details, electron channel

%	$\delta\sigma_W/\sigma_W$	$\delta\sigma_{W+}/\sigma_{W+}$	$\delta\sigma_{W-}/\sigma_{W-}$	Central $\delta\sigma_Z/\sigma_Z$
Trigger	0.5	0.5	0.5	<0.1
Electron Reconstruction	1.5	1.5	1.5	3.0
Electron Identification	1.1	1.2	1.1	1.6
Electron Energy scale	0.5	0.5	0.4	0.2
Electron Energy resolution	0.02	0.02	0.02	0.01
defective LAr channels	0.4	0.4	0.4	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
Background	0.4	0.5	0.5	0.3
$C_{W/Z}$ Theoretical uncertainty	0.3	0.3	0.3	0.5
Total experimental uncertainty	2.8	3.0	3.0	3.5
$A_{W/Z}$ Theoretical uncertainty	3.0	3.0	3.0	4.0
Total excluding Luminosity	4.1	4.2	4.2	5.3
Luminosity			3.4	

Cross section result (Z)

σ_{fid}: No extrapolation to full phase space, i.e., not corrected by $A_{W/Z}$

➔ Cross section in respective η range, $p_T > 20$ GeV, and $66 < m_{ee} < 116$ GeV

Electron channel	$\sigma^{fid}_{Z/\gamma^*} \cdot \mathrm{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^*	$0.433 \pm 0.004(\mathrm{sta}) \pm 0.016(\mathrm{sys}) \pm 0.015(\mathrm{lum})$
	$\sigma^{tot}_{Z/\gamma^*} \cdot \mathrm{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^*	$0.972 \pm 0.010(\mathrm{sta}) \pm 0.034(\mathrm{sys}) \pm 0.033(\mathrm{lum}) \pm 0.038(\mathrm{acc})$

Muon channel	$\sigma^{fid}_{Z/\gamma^*} \cdot \mathrm{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.456 \pm 0.004(\mathrm{sta}) \pm 0.005(\mathrm{sys}) \pm 0.015(\mathrm{lum})$
	$\sigma^{tot}_{Z/\gamma^*} \cdot \mathrm{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.941 \pm 0.008(\mathrm{sta}) \pm 0.011(\mathrm{sys}) \pm 0.032(\mathrm{lum}) \pm 0.037(\mathrm{acc})$

Total Z cross sections in electron and muon channels are consistent

Same is true for the W, W^+, and W^- cross sections

➔ Results can be combined

Combined Cross sections

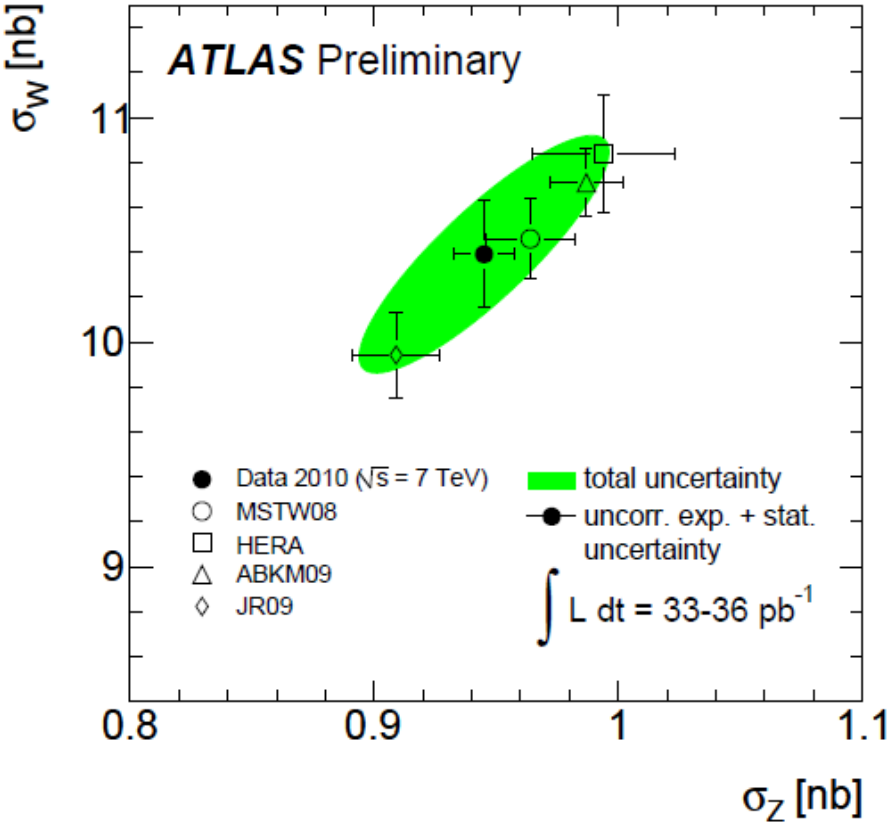
Uncertainties on luminosity, acceptance, and E_T^{miss} are assumed to be fully correlated, all others assumed uncorrelated

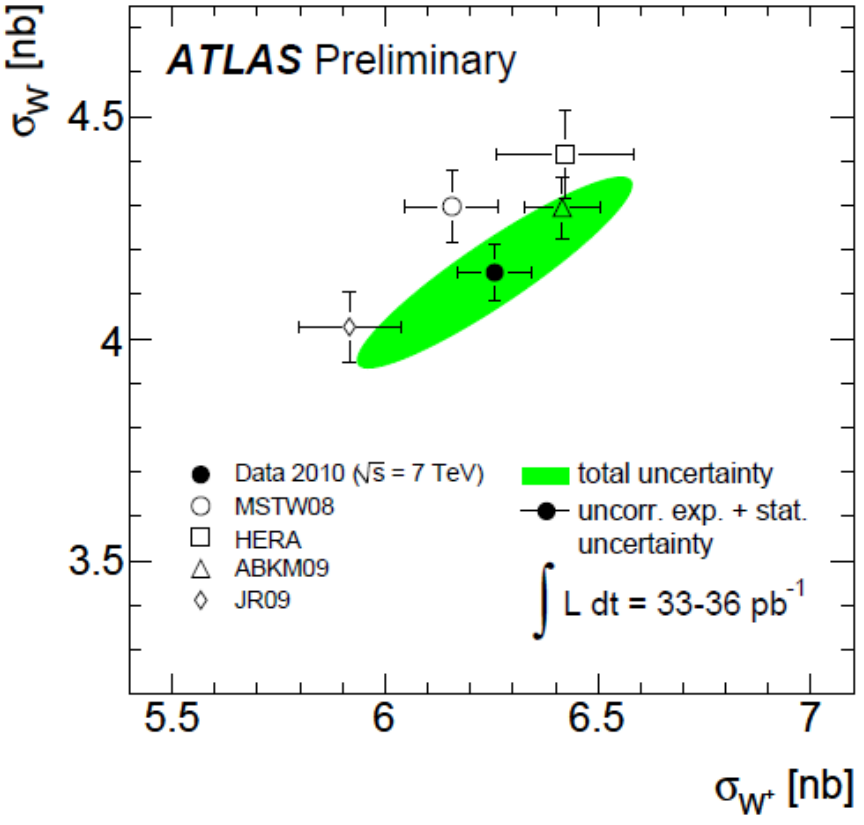
➔

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

Largest uncertainty on Z cross section already from theory (acceptance)!

Comparison with theory

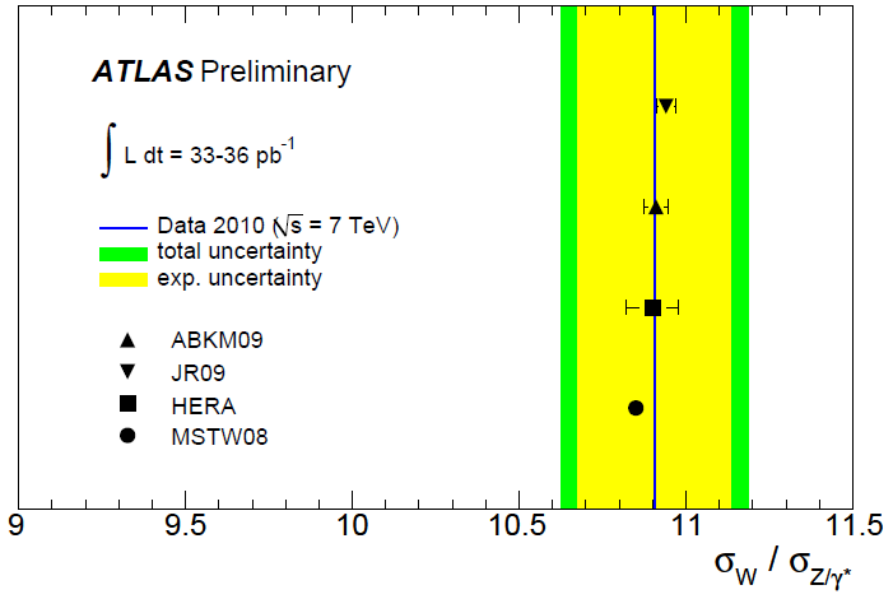




Good agreement with pQCD calculations at NNLO !

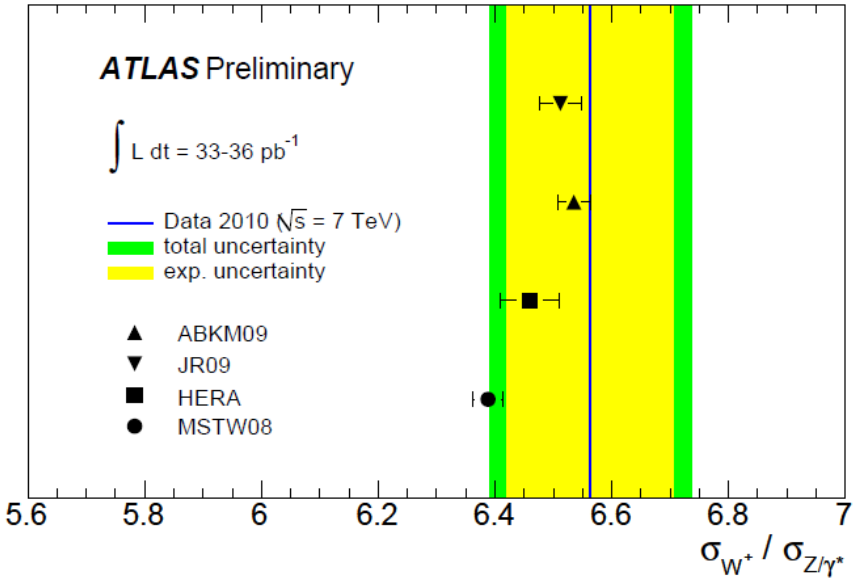
Cross section ratios

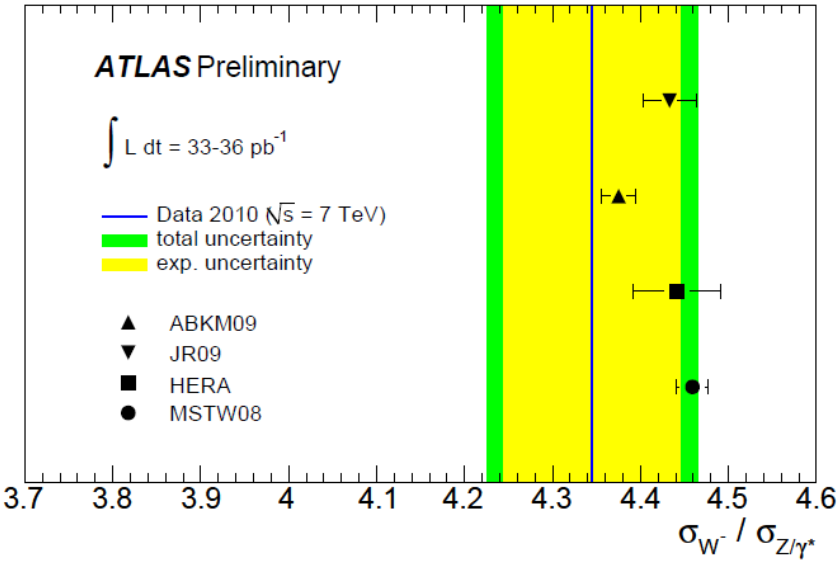
Calculate W/Z ratio ➔ Some systematic uncertainties cancel partially (e.g., reconstruction efficiency) or even entirely (e.g., Luminosity)



- Ratio measured with small total uncertainty (2.6%)
- Ratio seems not sensitive to PDF differences

W^+/Z and W^-/Z ratios





- In agreement with calculations
- Some sensitivity to PDF differences

  ➔ go differential…

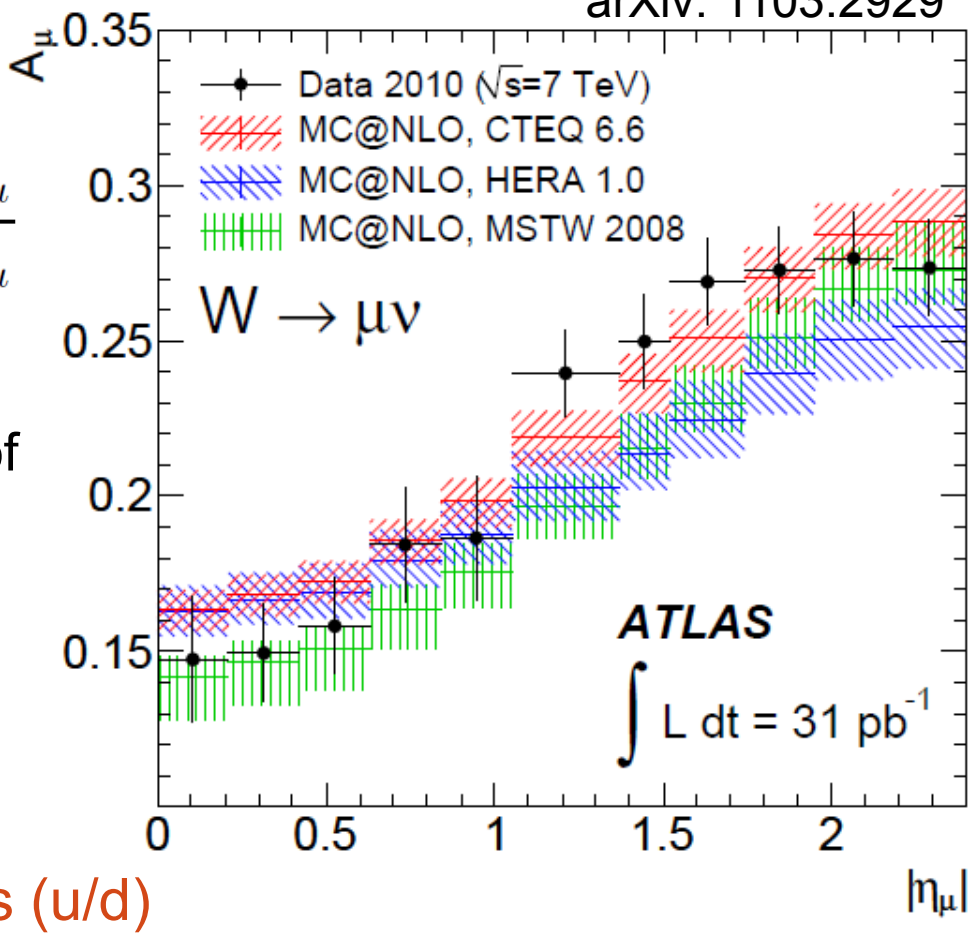
W charge asymmetry

$$A_\mu = \frac{d\sigma_{W\mu+}/d\eta_\mu - d\sigma_{W\mu-}/d\eta_\mu}{d\sigma_{W\mu+}/d\eta_\mu + d\sigma_{W\mu-}/d\eta_\mu}$$

Data: stat. and sys. uncertainties of similar size

MC: PDF error set uncertainties (90% CL)

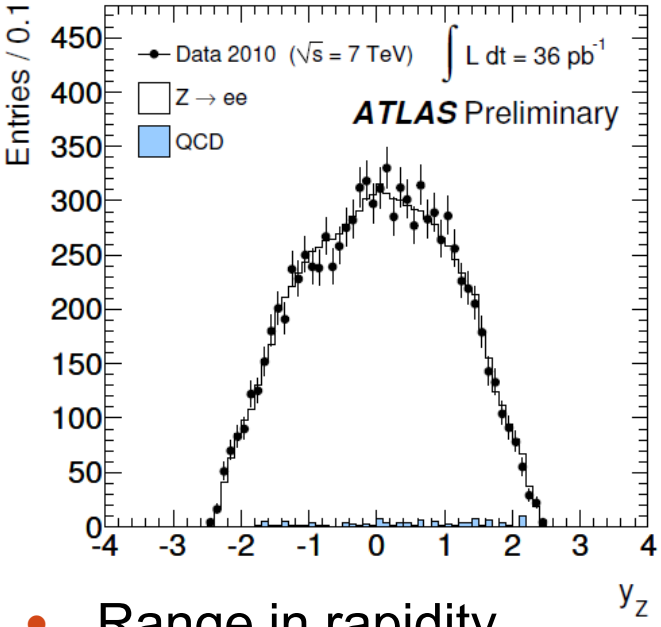
arXiv: 1103.2929



LHC: Valence quark distributions (u/d) at small x become accessible.

Shows sensitivity to PDFs; best agreement with CTEQ6.6

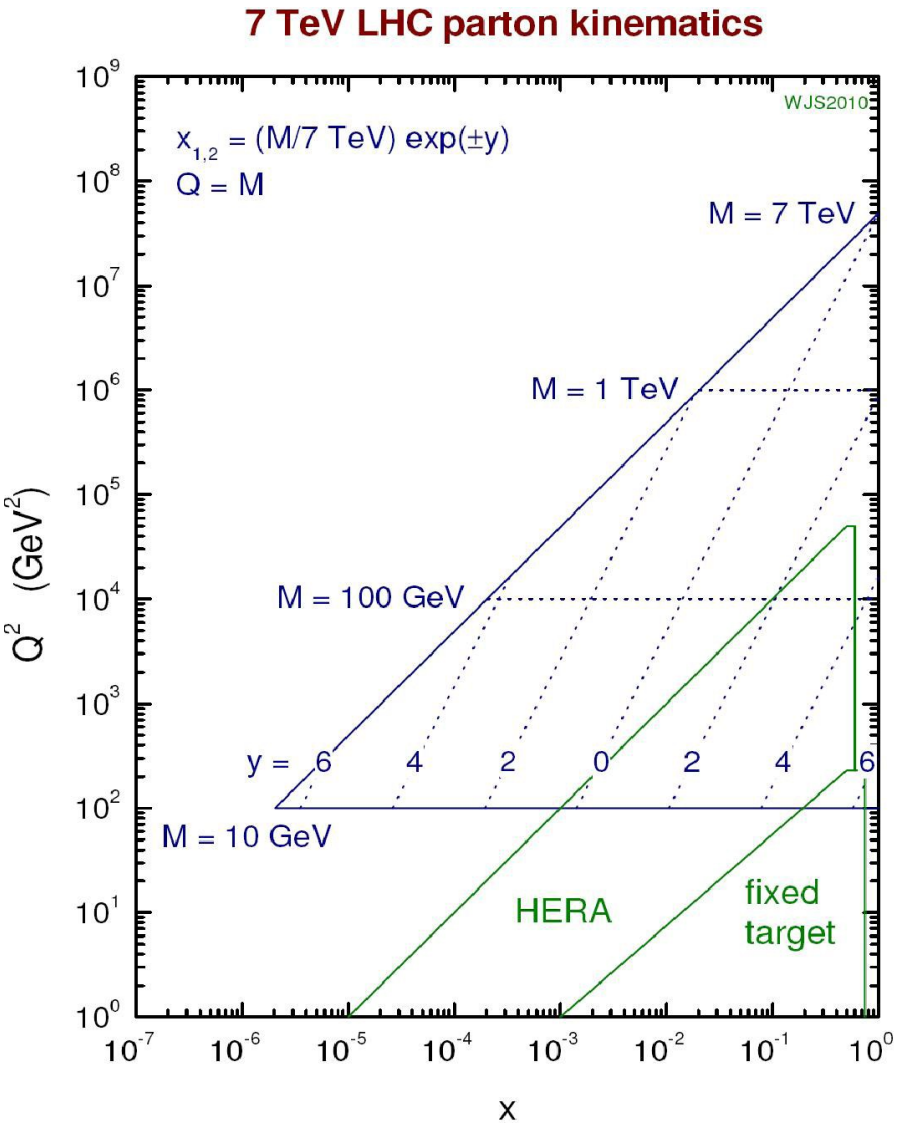
Z rapidity and x-range



- Range in rapidity

  (|Y| < 2.4) determines range in x
- Sensitivity to smaller and larger x when measuring Z cross section at „forward“ rapidities

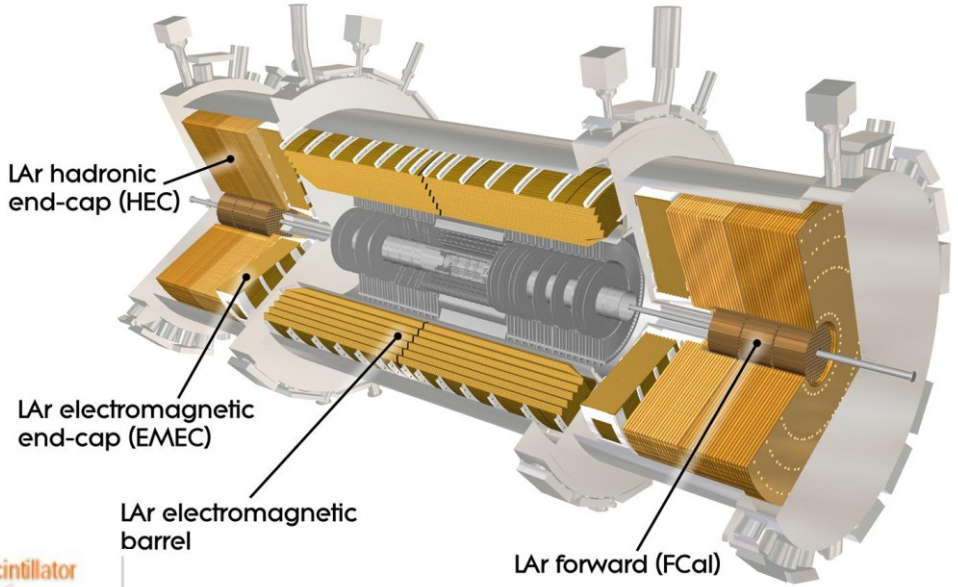
  ➔ Needs detection of electrons beyond |η| = 2.47

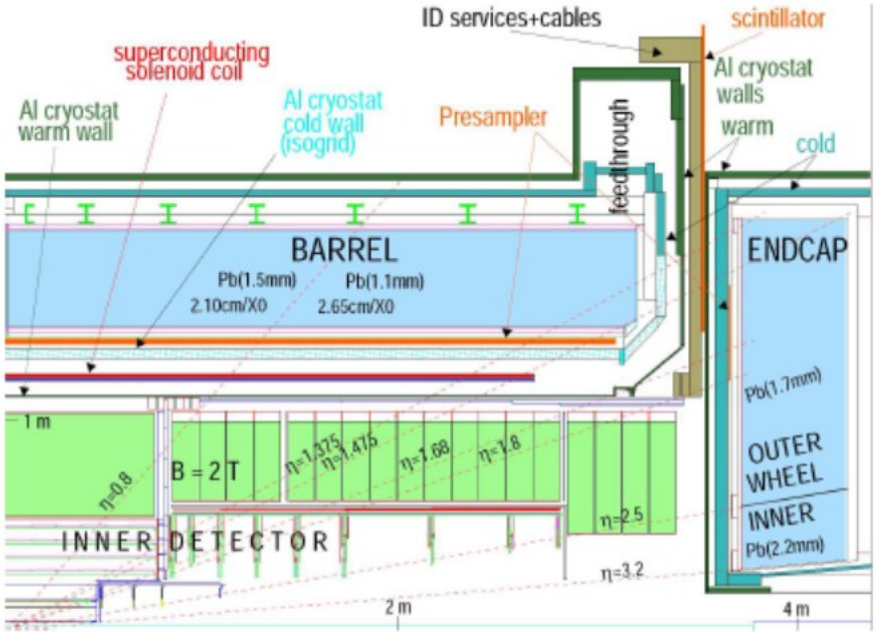


Electron detection

Electrons beyond $\eta = 2.47$:

- EM-Calorimeter Inner wheel:
  $2.5 < |\eta| < 3.2$
- Forward Calorimeter:
  $3.2 < |\eta| < 4.9$
- No tracking available….

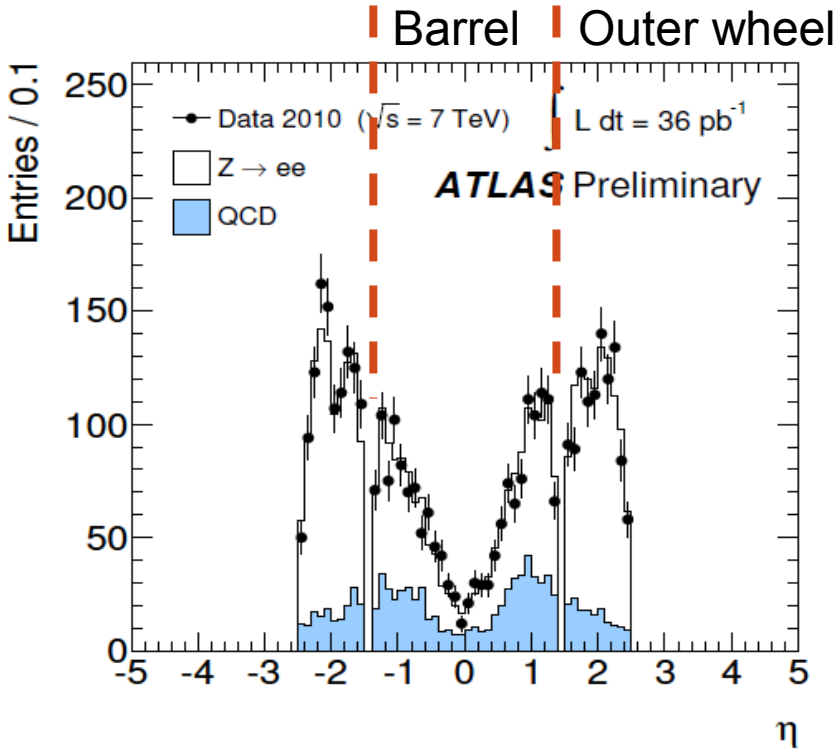


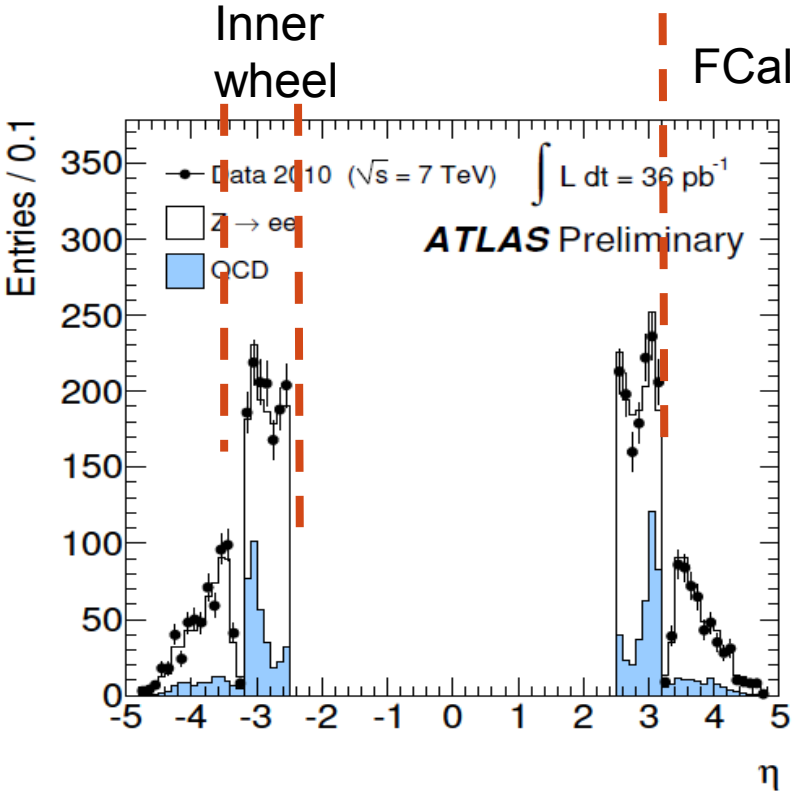


➔ Use configuration with one electron in the „forward“ ($|\eta| > 2.5$) and one in the central ($|\eta| < 2.47$) region

electron pseudorapidities

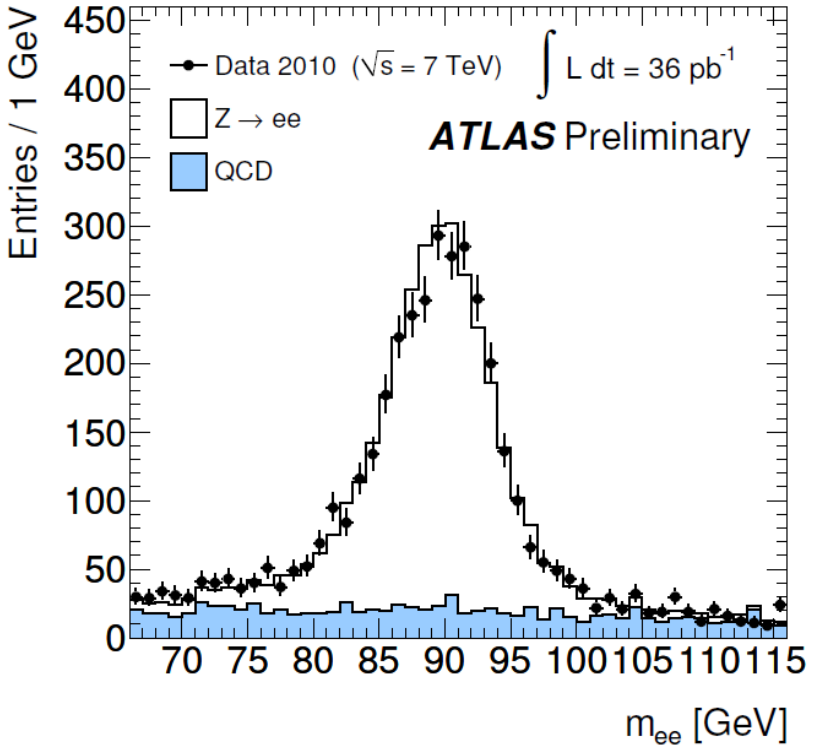
Electron pseudorapidities for all Z candidates with one central and one forward electron.





Good agreement with MC ➔ Identification efficiency under control in forward (i.e., w/o tracking) region

Background and systematics



Fit distribution directly to get QCD background ➔ up to about 25%.

	Central $\delta\sigma_Z/\sigma_Z$	Forward $\delta\sigma_Z/\sigma_Z$
Trigger	<0.1	0.5
Electron Reconstruction	3.0	1.5
Electron Identification	1.6	8.2
Electron Energy scale	0.2	1.4
Electron Energy resolution	0.01	<0.1
defective LAr channels	0.8	0.8
Charge misidentification	0.2	—
E_T^{miss} scale and resolution	—	—
pile-up	0.1	1.7
Background	0.3	3.2
$C_{W/Z}$ Theoretical uncertainty	0.5	0.9
Total experimental uncertainty	3.5	8.6
$A_{W/Z}$ Theoretical uncertainty	4.0	3.9
Total excluding Luminosity	5.3	9.4
Luminosity	3.4	

Large increase in systematics due to uncertainty in electron identification. Room for improvement with more data….

Results

	N	B	$C_{W/Z}$	$A_{W/Z}$
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

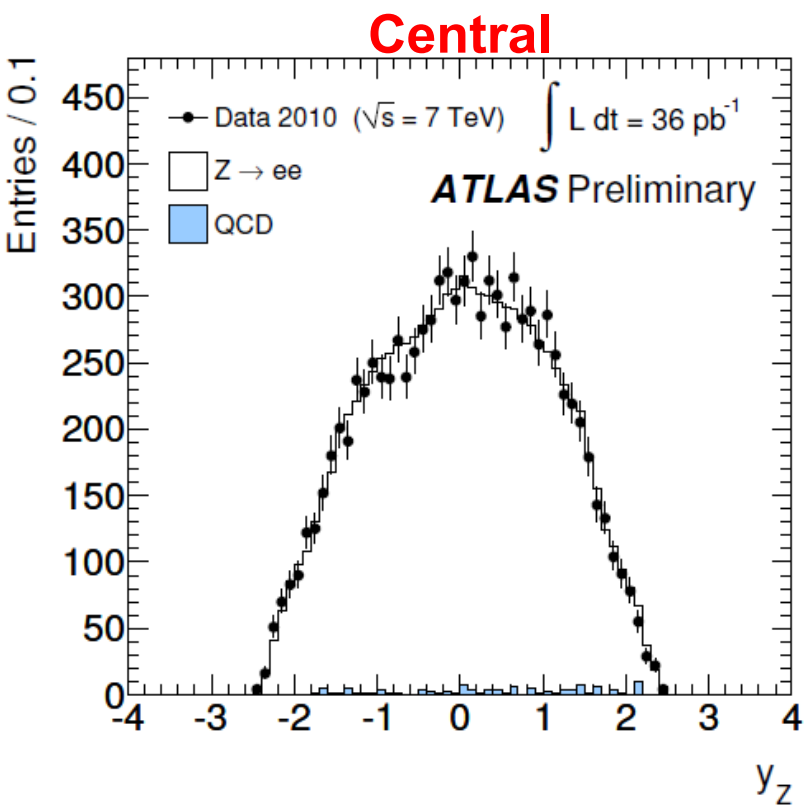
Measured phase space increases from 45% to 65%

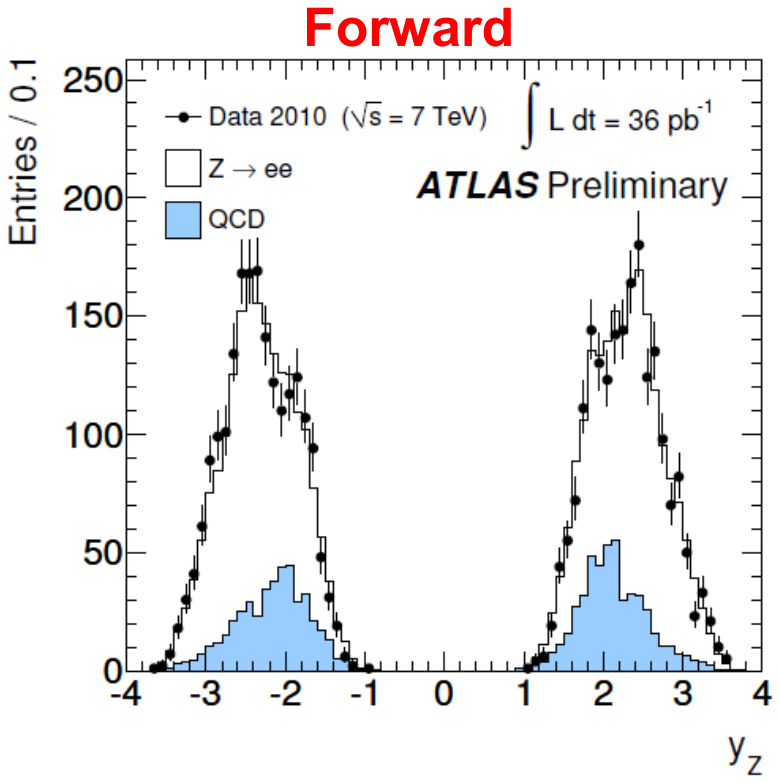
➔ Reduced PDF uncertainties when extrapolating

	$\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [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	$0.903 \pm 0.022(\text{sta}) \pm 0.087(\text{sys}) \pm 0.031(\text{lum}) \pm 0.035(\text{acc})$

Good agreement between cross sections.

Accessible rapidity range





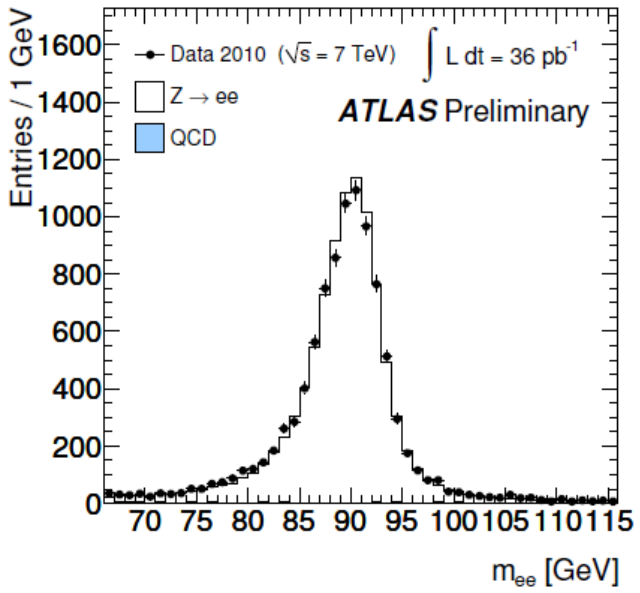
- Accessible range in rapidity extended from 2.4 to 3.6
- Differential measurement in rapidity in progress….

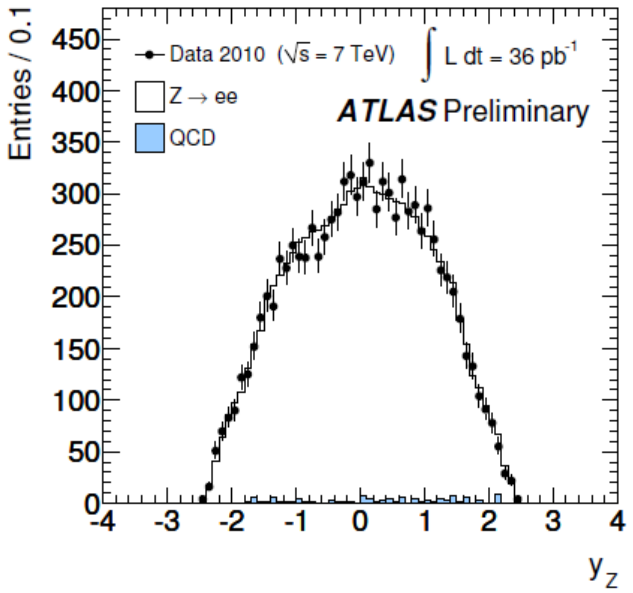
Summary

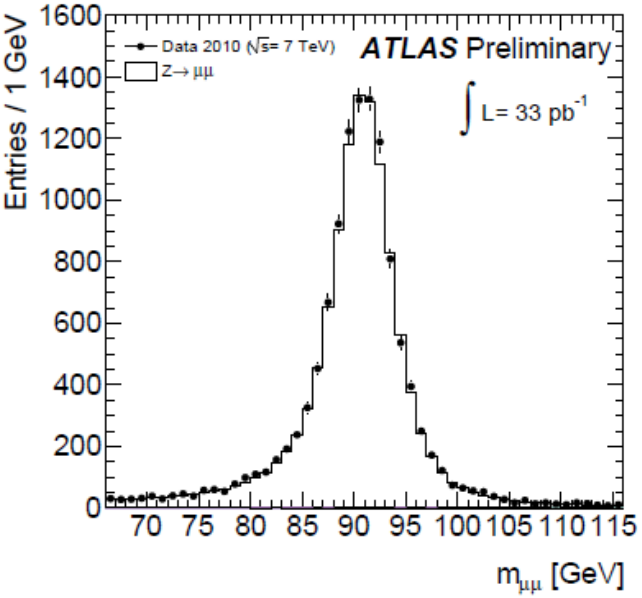
- ATLAS W/Z production at $\sqrt{s}$ = 7 TeV on 2010 data ~35pb^{-1} (ATL-CONF-2011-041)
- Inclusive W and Z cross sections in electron and muon channel calculated ➔ consistent
- Combined cross sections and ratios already rather precise
- Good agreement with NNLO calculations
- W charge asymmetry differential in η shows already some sensitivity to PDFs
- Z differential measurement up to a rapidity of 3.6 in progress…..can access extended range in x

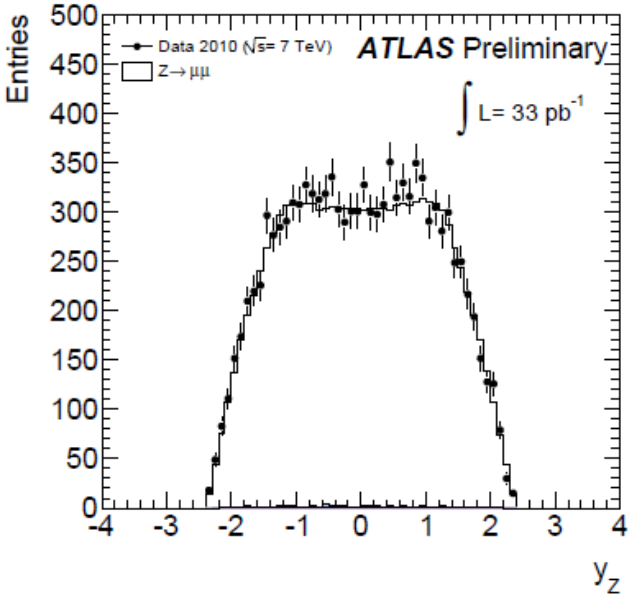
Backup

Z invariant mass and rapidity









Good description!

Results and systematics

Electron channels

	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
Z	9721	217 ± 31	0.606 ± 0.021	0.445 ± 0.018

Muon channels

	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

Cross section results W

σ_{fid} : No extrapolation to full phase space, i.e., not corrected by A_W/Z

➔ Cross section in respective η range, pt > 20 GeV, Etmiss > 25 GeV, mT > 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	$4.877 \pm 0.015(\text{sta}) \pm 0.138(\text{sys}) \pm 0.166(\text{lum})$
	$\sigma^{\text{tot}}_{W^{(\pm)}} \cdot \text{BR}(W \to e\nu)$ [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	$10.551 \pm 0.032(\text{sta}) \pm 0.300(\text{sys}) \pm 0.359(\text{lum}) \pm 0.316(\text{acc})$

	$\sigma^{\text{fid}}_{W^{(\pm)}} \cdot \text{BR}(W \to \mu\nu)$ [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	$10.322 \pm 0.030(\text{sta}) \pm 0.249(\text{sys}) \pm 0.377(\text{lum}) \pm 0.310(\text{acc})$