Measurement of the W and Z boson production at ATLAS

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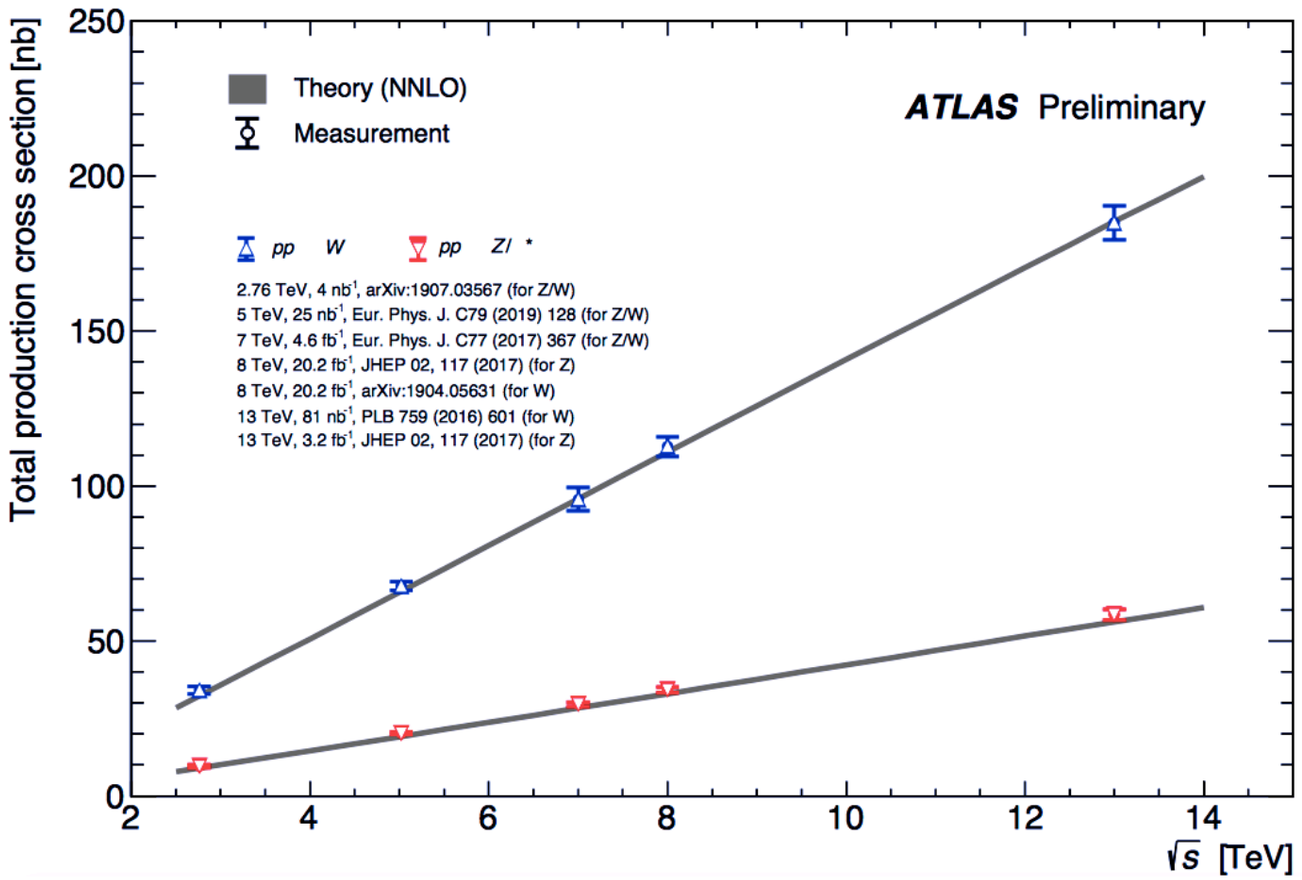
Introduction

W and Z production at proton-proton collisions

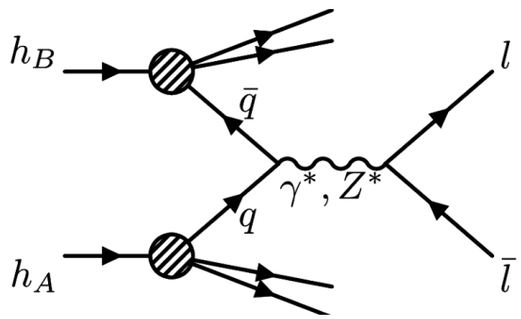
- W, Z total and differential cross sections, W+/W- asymmetry
- Very sensitive to QCD and Parton Distribution Functions (PDFs)
- In this talk, we focus on the:
  - 2.76 TeV W+, W- and Z cross sections
  - 5.02 TeV W+, W- and Z cross sections
  - 8 TeV W asymmetry results



Motivation (1): PDFs

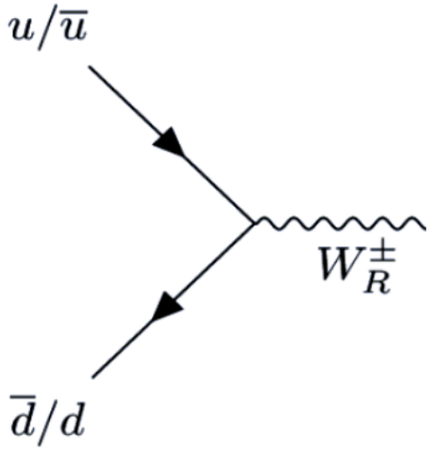
PDFs in electroweak measurement

- PDF itself is important, leading systematics in electroweak measurement
- For W and Z rapidity (Y):
  - Y dominted by difference in quark energies
  - large |Y| region constrains large and small x region PDF



$$x = \frac{M}{\sqrt{s}} \times e^{\pm Y}$$

- For W+ and W- charge asymmetry
  - sensitive to valence u/d quarks and sea ubar/dbar quarks



Bonus: W and Z together can specifically constrain s quark PDFs

Motivation (2): QCD calculation

Cross section due to QCD

- Higher order QCD significantly changes W and Z cross section from LO
- LHC experimental sensitivity matches (N)NLO predictions

Differential cross section in low transverse momentum region dominated by non-perturbative QCD

However the total cross section can be well described by fixed order calculation

In addition:

- an important reference for weak-boson productions in heavy-ion collisions

LHC provide p+Pb and Pb+Pb collisions at the same energy points

W and Z measurement at 5.02 TeV

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Overview

- 5.02 TeV, 2015 data, 25.0 pb^{-1}
- Low pile-up contribution data set (average pp interaction ber bunch = 1.5)

- Integrated cross sections of W+, W- and Z production
  - electron and muon final states, results include branching ratio
- Differential cross sections of Z as a function of boson rapidity (Y_Z)
- Differential cross sections of W+ and W- as a function of lepton pseudo-rapidity in the final state
- W+/W- charge Asymmetry as a function of lepton pseudo-rapidity

- Measurements corresponds to phase space:
  - W: lepton $p_T > 25$ GeV, lepton $|\eta| < 2.5$, $m_T > 40$ GeV
  - Z: lepton $p_T > 20$ GeV, lepton $|\eta| < 2.5$, $66 < M_Z < 116$ GeV

Data and selections

Online trigger

- Single electron with pT > 15 GeV
- Single muon with pT > 14 GeV

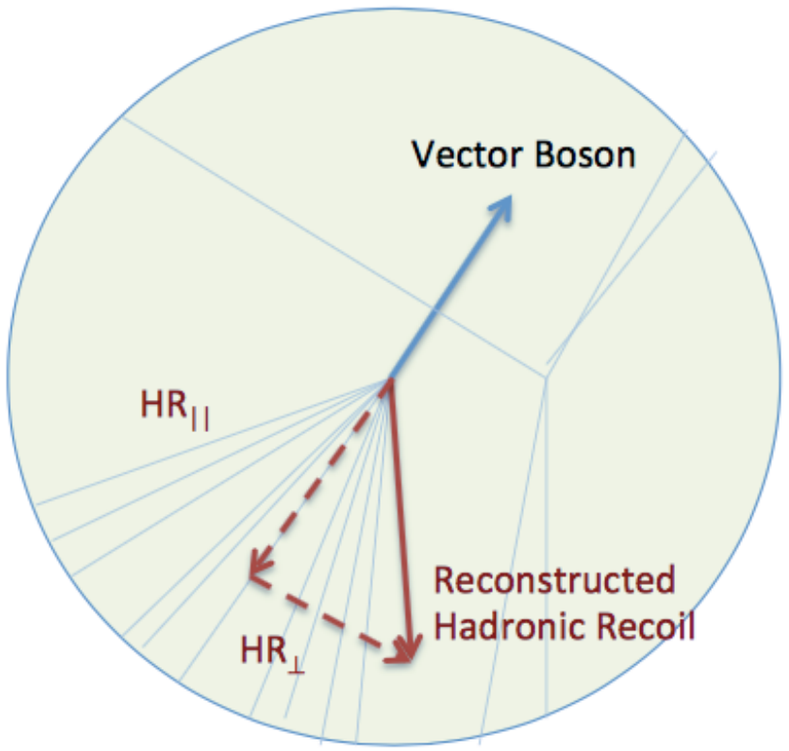
Offline requirement

- Particles further required to be in good quality, and originating from primary vertex
- Acceptance cuts applied to match the phase space defined before
- For W candidates: transverse mass and missing ET

$$\vec{E}_{\mathrm{T}}^{\,\mathrm{miss}} = -\left(\vec{u}_{\mathrm{T}} + \vec{p}_{\mathrm{T}}^{\,\ell}\right)$$

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

uT: hadronic recoil of vector sum of calorimeter energy clusters excluding lepton. It respresents the pT of W boson



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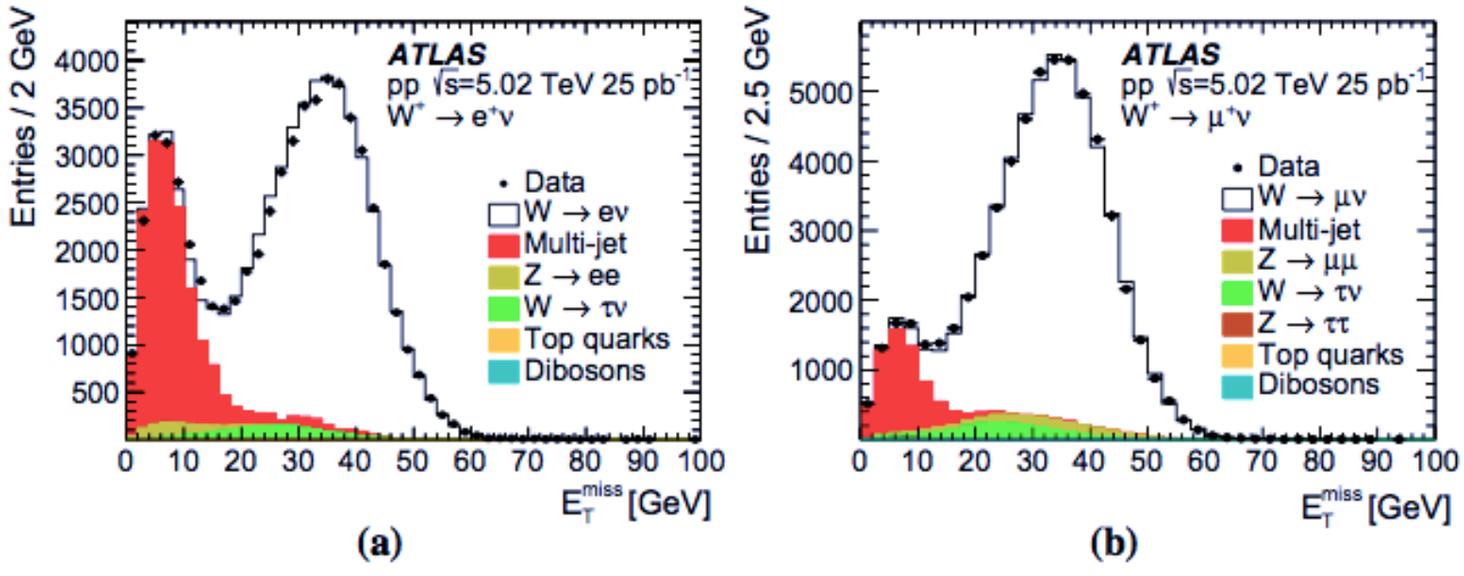
Detector effects and backgrounds

Detector performance

- Trigger and offline selection efficiencies for muon and electrons measured using tag-and-probe method
- Lepton energy or momentum calibrated using Z-ll events
- Recoil calibrated using Z boson candidates

Background determination

- Physics bkg: genuine electron and muon (W/Z, diboson, top contribution …)
  - estimated from simulated Monte Carlo samples
- Multi-jet bkg: jets fake electron or muon
  - estimated from data by template fitting on missing E_T

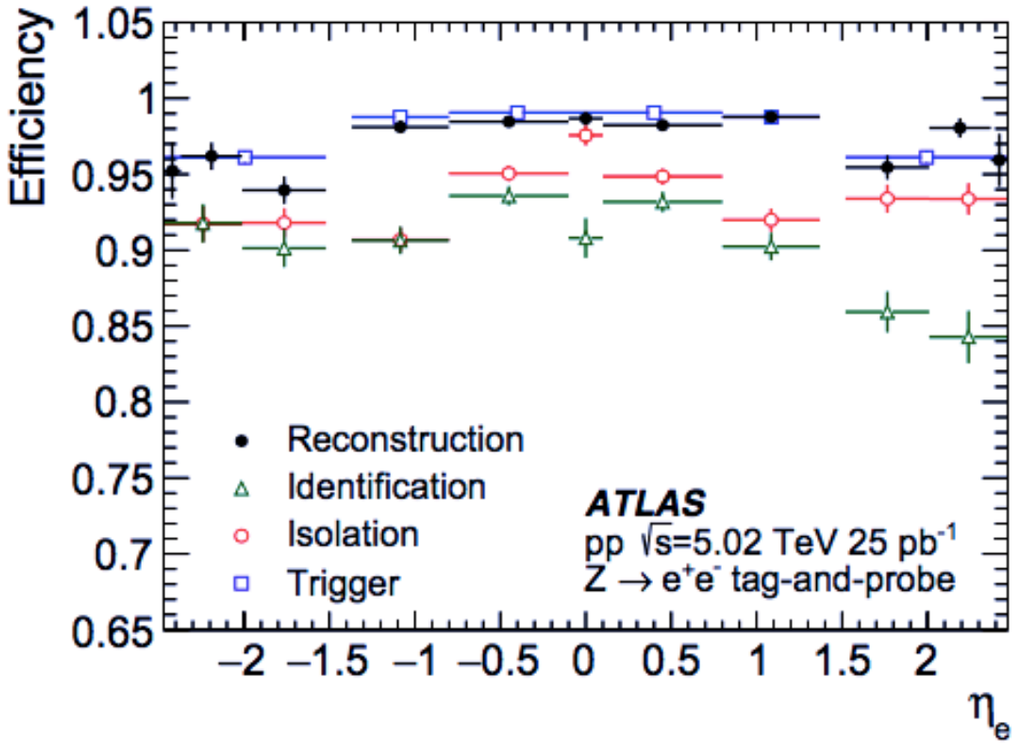


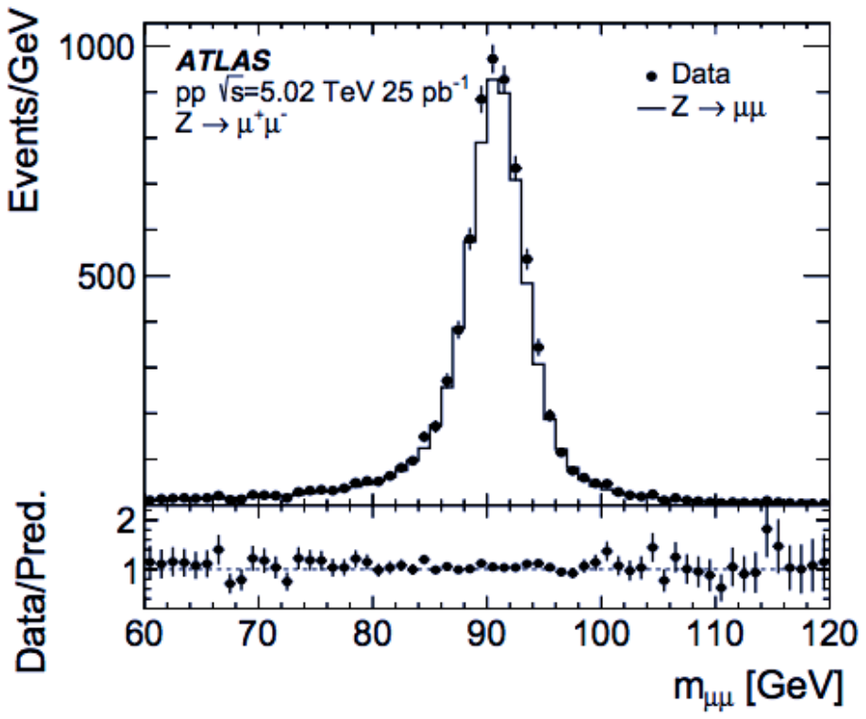
Some control plots and bkg estimations

Table 1 Background contributions as a percentage of the total for the W^+, W^- and Z candidate samples in the electron (muon) channels

Background	$W^+ \to e^+\nu$ ($W^+ \to \mu^+\nu$) [%]	$W^- \to e^-\nu$ ($W^- \to \mu^-\nu$) [%]	$Z \to e^+e^-$ ($Z \to \mu^+\mu^-$) [%]
$Z \to \ell^+\ell^-, \ell = e, \mu$	0.1 (2.8)	0.2 (3.8)	–
$W^\pm \to \ell^\pm\nu, \ell = e, \mu$	–	–	<0.01 (<0.01)
$W^\pm \to \tau^\pm\nu$	1.8 (1.8)	1.8 (1.8)	<0.01 (<0.01)
$Z \to \tau^+\tau^-$	0.1 (0.1)	0.1 (0.1)	0.07 (0.07)
Multi-jet	0.9 (0.1)	1.4 (0.2)	<0.01 (<0.01)
Top quark	0.1–0.2 (0.1–0.2)	0.1–0.2 (0.1–0.2)	0.06 (0.08)
Diboson	0.1 (0.1)	0.1 (0.1)	0.14 (0.08)

Generally, a few % bkg in W candidates, and <1% bkg in Z candidates





Unfolding

Unfold to the fiducial phase space

- **Observed candidate number, background subtraction, corrected for efficiencies and acceptance**

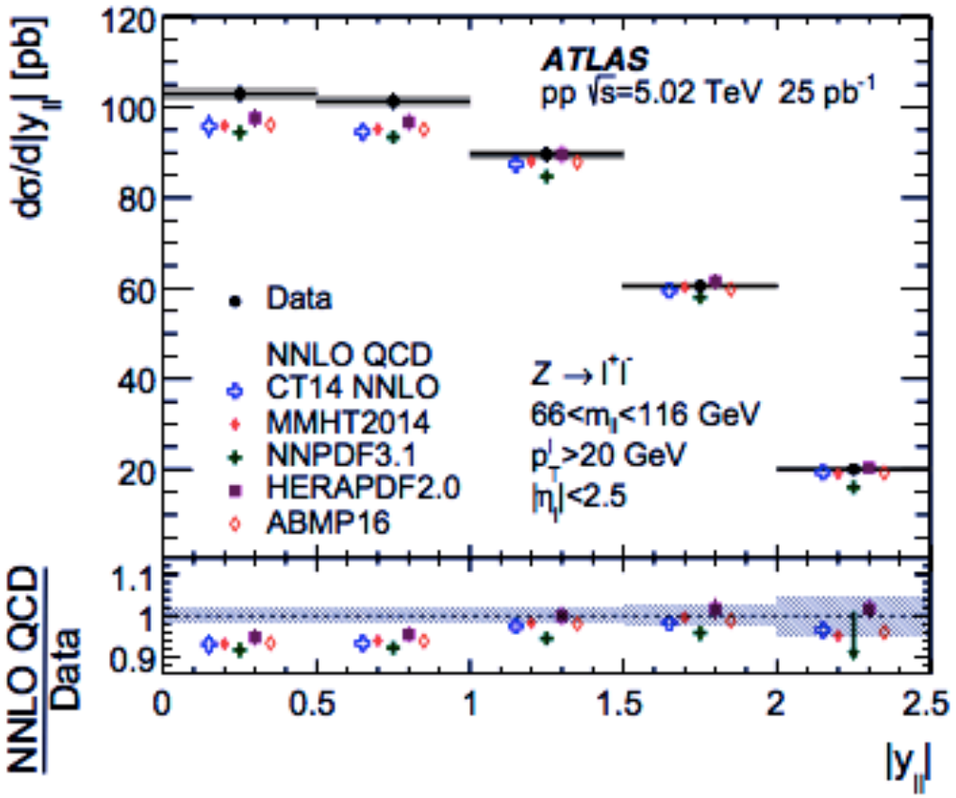
$$\sigma^{\text{fid}}_{W^{\pm}\to\ell^{\pm}\nu[Z\to\ell^{+}\ell^{-}]} = \frac{N_{W[Z]} - B_{W[Z]}}{C_{W[Z]} \cdot L_{\text{int}}} \qquad C_{W[Z]} = \frac{N^{\text{MC,sel}}_{W[Z]}}{N^{\text{MC,fid}}_{W[Z]}}$$

- **Efficiencies and acceptance corrections from signal MC samples**

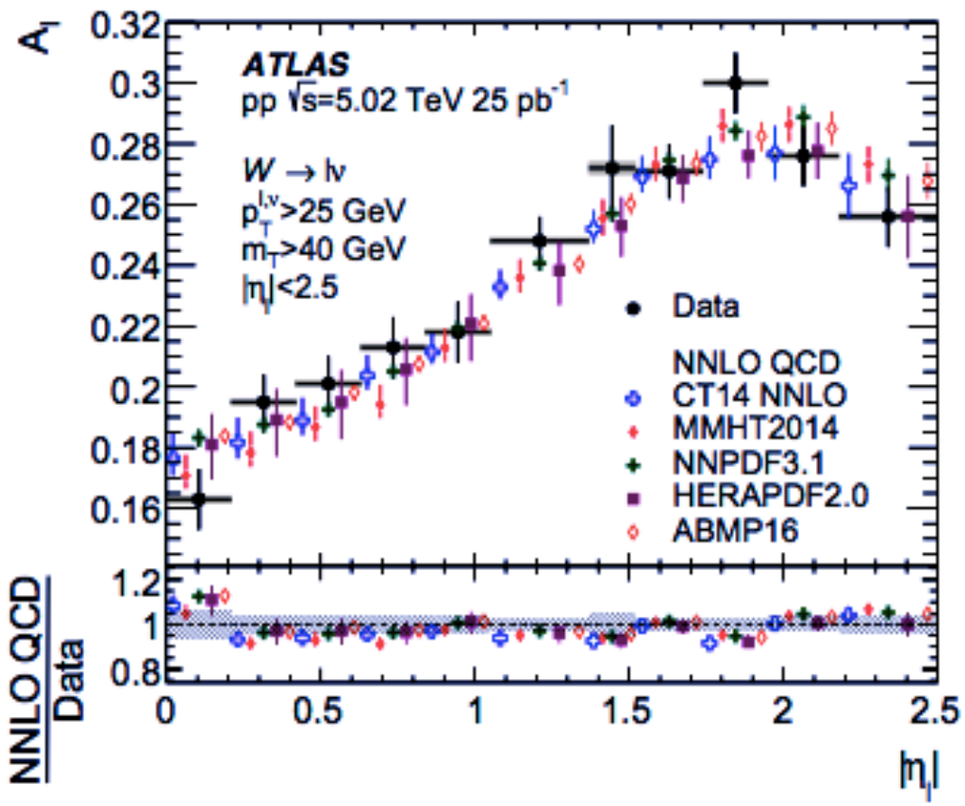
Channel	C_W $(W^+ \to \ell^+\nu)$	C_W $(W^- \to \ell^-\nu)$	C_Z
Integrated cross-section measurements			
Electron channel	0.657 ± 0.006	0.667 ± 0.005	0.522 ± 0.007
Muon channel	0.723 ± 0.011	0.720 ± 0.010	0.780 ± 0.007
Differential cross-section measurements			
Electron channel	0.55–0.80		0.52–0.62
Muon channel	0.55–0.85		0.60–0.82

Results

$$\begin{aligned} \sigma_{W+} &= 2266 \pm 9(\text{stat}) \pm 29(\text{syst}) \pm 43(\text{lumi}) pb \\ \sigma_{W-} &= 1401 \pm 7(\text{stat}) \pm 18(\text{syst}) \pm 27\text{lumi} pb \\ \sigma_{Z} &= 374.5 \pm 3.4(\text{stat}) \pm 3.6(\text{syst}) \pm 7.0(\text{lumi}) pb \end{aligned}$$



Z boson rapidity (dilepton rapidity) spectrum



W charge asymmetry as a function in lepton pseudo-rapidity

W charge asymmetry at 8 TeV

Overview

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arXiv:1904.05631[hep-ex]

- **8 TeV, 2015 data, 20.2 fb^{-1}**
- **In muon channel, results include branching ratio**
- **Higher pile-up contribution data set (average pp interactions per bunch = 20.7)**

- **W+ and W- cross sections, and asymmetry as a function of muon pseudo-rapidity**
- **Measurement corresponds to a phase space of:**
  - **lepton $p_T > 25$ GeV, lepton $|\eta| < 2.4$, $m_T > 40$ GeV**

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

Measurements details

Event selection

- Online trigger: single muon pT>36 or pT>24 GeV
- Offline requirement: pT>25 GeV, particle quality required

Backgrounds

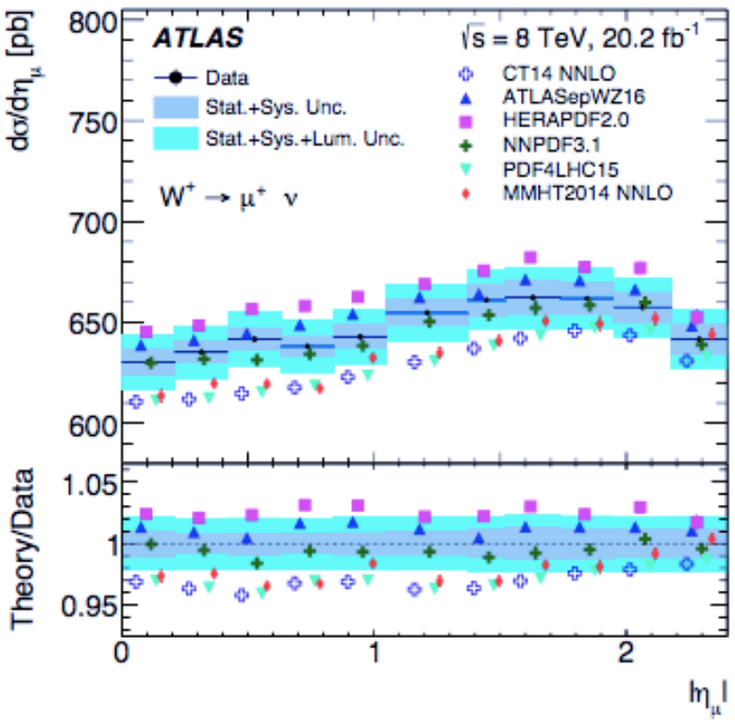
- Physics bkg from MC simulation samples
- Multijet bkg from data driven method

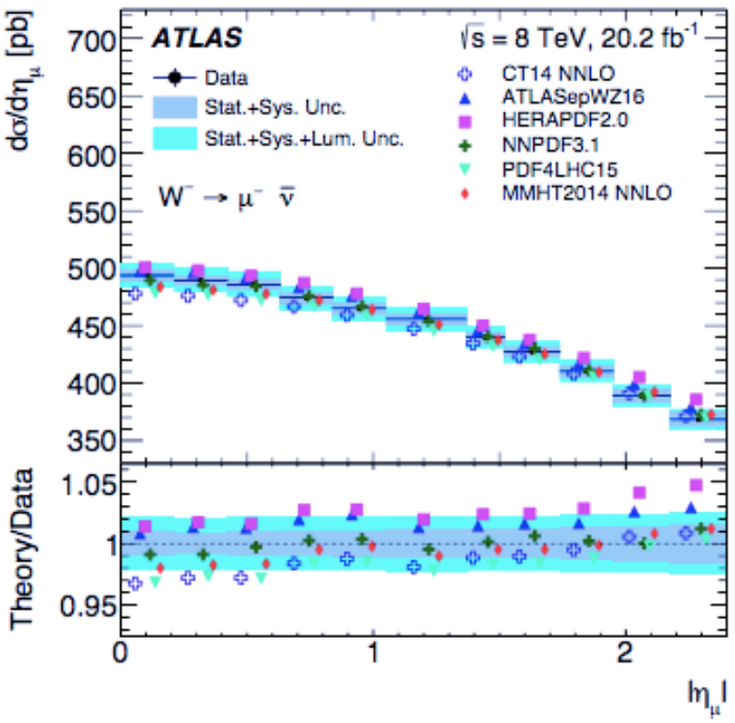
	$W^+ \to \mu^+\nu$	$W^- \to \mu^-\bar{\nu}$
	Number of events	
Data	50 390 184	34 877 365
	Percentage of data	
Multijet	2.4 ± 0.3	3.1 ± 0.3
$W \to \tau\nu$	1.9 ± 0.1	2.0 ± 0.1
$Z \to \mu\mu$	3.1 ± 0.2	4.0 ± 0.2
Others	0.62 ± 0.02	0.82 ± 0.03

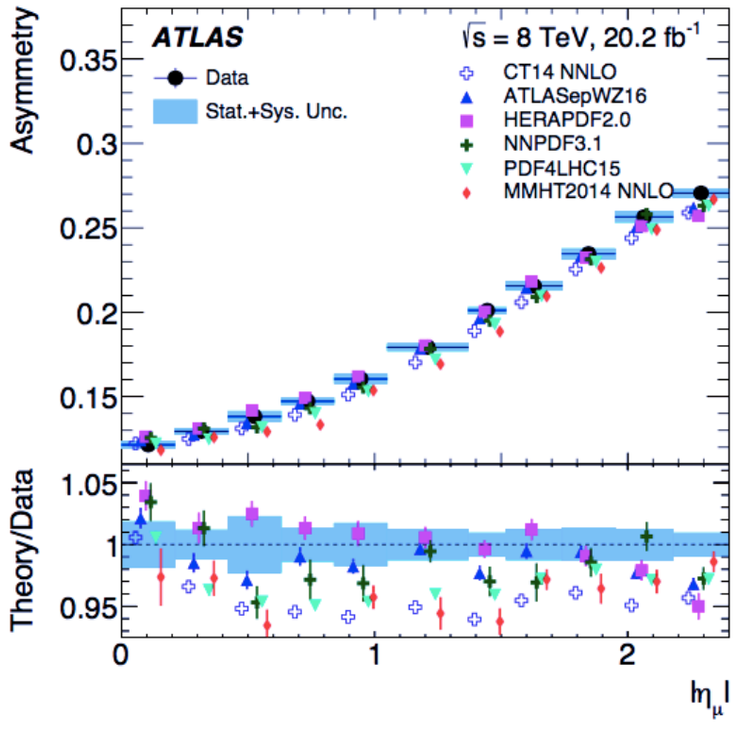
Results

Data	
$\sigma\,(W^+ \to \mu^+\nu)$ [pb]	3110 ± 0.5 (stat.) ± 29 (syst.) ± 59 (lumi.)
$\sigma\,(W^- \to \mu^-\bar{\nu})$ [pb]	2137 ± 0.4 (stat.) ± 22 (syst.) ± 41 (lumi.)
Sum [pb]	5247 ± 0.6 (stat.) ± 50 (syst.) ± 100 (lumi.)
Ratio	1.4558 ± 0.0004 (stat.) ± 0.0040 (syst.)
DYNNLO (CT14 NNLO PDF set)	
$\sigma\,(W^+ \to \mu^+\nu)$ [pb]	3015 ± 92 (PDF) ± 15 (scale)
$\sigma\,(W^- \to \mu^-\bar{\nu})$ [pb]	2105 ± 53 (PDF) ± 10 (scale)
Sum [pb]	5120 ± 140 (PDF) ± 23 (scale)
Ratio	1.4320 ± 0.0100 (PDF) ± 0.0007 (scale)

W charge asymmetry as a function in muon pseudo-rapidity, compared to different PDFs







W and Z @ 2.76 TeV

Overview

Submitted to Eur. Phys. J. C
arXiv:1907.03567[hep-ex]

- **2.76 TeV, 2013 data, 4 pb^{-1}**
- **Both electron and muon channels**
- **Measurement corresponds to a phase space of:**
  - **lepton p_T > 20 GeV, lepton $|\eta|$ < 2.4**
  - **m_T > 40 GeV, missing E_T > 25 GeV (for W candidates)**
  - **66 < M < 116 GeV (for Z candidates)**

	Value ± stat. ± syst. ± lumi. (± extr.)	Value ± stat. ± syst. ± lumi. (± extr.)
	$W^+ \to e\nu$	$W^+ \to \mu\nu$
$\sigma^{fid}_{W^+}$ [pb]	1416 ± 24 ± 36 ± 44	1438 ± 23 ± 19 ± 45
$\sigma^{tot}_{W^+}$ [pb]	2284 ± 38 ± 58 ± 71 (±30)	2319 ± 36 ± 30 ± 72 (±30)
	$W^- \to e\nu$	$W^- \to \mu\nu$
$\sigma^{fid}_{W^-}$ [pb]	789 ± 18 ± 20 ± 25	799 ± 17 ± 11 ± 25
$\sigma^{tot}_{W^-}$ [pb]	1385 ± 31 ± 36 ± 43 (±21)	1402 ± 30 ± 19 ± 44 (±21)
	$Z \to ee$	$Z \to \mu\mu$
σ^{fid}_{Z} [pb]	197.6 ± 9.6 ± 9.5 ± 6.1	205.6 ± 8.1 ± 2.6 ± 6.4
σ^{tot}_{Z} [pb]	313.6 ± 15.2 ± 15.0 ± 9.7 (±5.3)	326.3 ± 12.9 ± 4.1 ± 10.1 (±5.5)

$$R_{W/Z} = 10.95 \pm 0.35\,(\text{stat.}) \pm 0.10\,(\text{syst.});$$
$$R_{W^+/W^-} = 1.797 \pm 0.034\,(\text{stat.}) \pm 0.009\,(\text{syst.}).$$

Summary

W and Z measurements at 5.02 TeV pp collision

- Integrated and differential cross section observed
- W charge asymmetry measured
- In good agreement with NNLO QCD calculations

W charge asymmetry measurement at 8 TeV pp collision

- Differential cross section and asymmetry as a function of muon pseudo-rapidity
- Compared to different calculations and PDFs

W and Z measurements at 2.76 TeV pp collision

- Integrated and differential cross section observed
- Ratios between W+, W- and Z cross sections observed