
W/Z inclusive measurements in ATLAS

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On behalf of the Atlas collaboration

Standard Model @ LHC 2012 - 12/04/2012



W/Z physics at the LHC

LHC: a W/Z factory...

- ▶ Theoretically well understood bosons, produced at high rates
- ▶ Unique signature in the lepton decay

... in a QCD environment

- ▶ Cross sections factorise at scale μ on PDF:

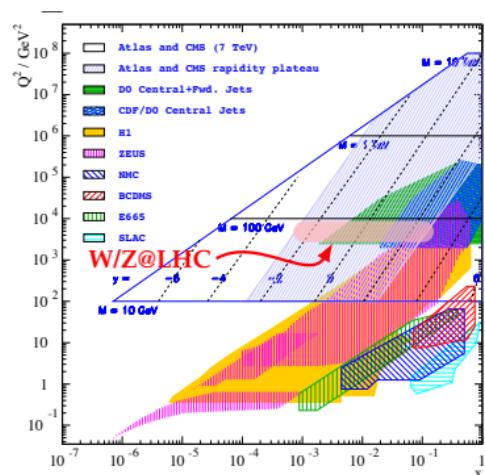
$$\sigma_{pp} = \sum_{(a,b)} \int dx_a dx_b f_a(x_a, \mu) f_b(x_b, \mu) \times \hat{\sigma}_{ab}(\hat{s})$$

- ▶ Explore phase space uncovered so far:

$$Q^2 = M_{W/Z}^2 \quad \text{and} \quad x_{1/2} = e^{\pm y} \frac{M_{W/Z}}{\sqrt{s}}$$

Motivations

- ▶ Test pQCD predictions up to NNLO
- ▶ Test phenomenological models: ME+PS, soft gluon resummations...
- ▶ Provide precision measurements: lepton universality, polarisation, m_W ...



Outline

Introduction

W/Z cross-section

In τ lepton

In light flavour leptons

Differential measurement in e/μ

Analysis of these cross-sections

Polarisation measurements

Conclusion

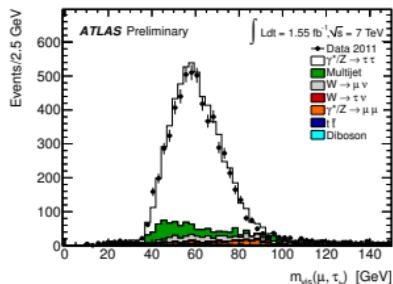
$W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$ cross sections

$W \rightarrow \tau\nu$ using 2010 data ($\sim 35 \text{ pb}^{-1}$)

$Z \rightarrow \tau\tau$ using $1.32 - 1.55 \text{ fb}^{-1}$ in three channels:

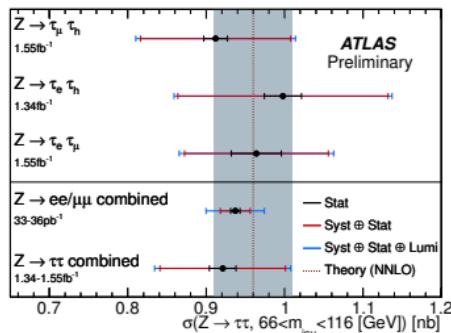
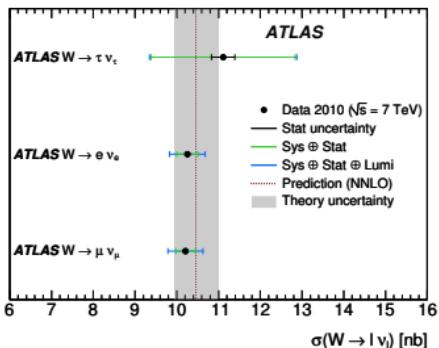
- ▶ $\mu + \text{hadrons} + 3\nu (\tau_\mu \tau_h)$
- ▶ $e + \text{hadrons} + 3\nu (\tau_e \tau_h)$
- ▶ $e + \mu + 4\nu (\tau_e \tau_\mu)$

$\implies \sim 10\%$ systematic uncertainties



Validation of τ reconstruction performances critical for searches

Measurement in agreement with other leptonic decay channels



References

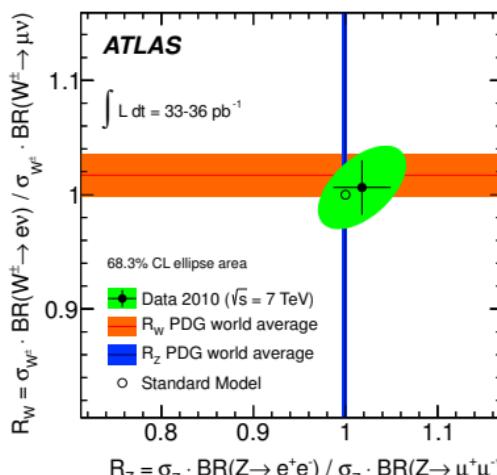
Phys. Lett. **B706** (276-294), ATLAS-CONF-2012-006

Lepton universality

$W \rightarrow \ell\nu$ and $Z^0 \rightarrow \ell^+\ell^-$ for $\ell = e, \mu$

- ▶ Inclusive measurements done with 2010 data ($\sim 35 \text{ pb}^{-1}$)
 \implies experimental accuracy of few %.
- ▶ Ratio of e and μ cross sections in common fiducial region
 $\implies R_W = 1.006 \pm 0.024$, to compare with world average 1.017 ± 0.019
 $\implies R_Z = 1.018 \pm 0.031$, when world average is 0.9991 ± 0.0024 (LEP)

Precise measurements guarantee lepton flavours combination



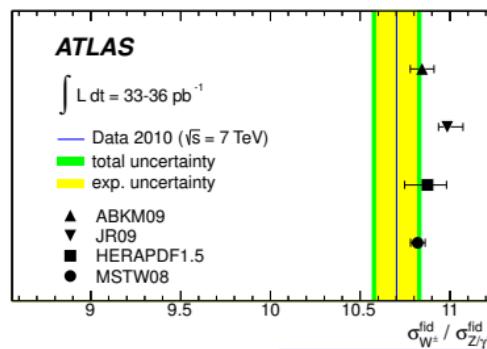
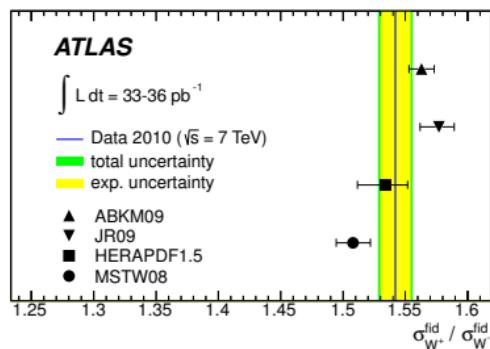
Reference

arXiv:1109.5141 sub. PRD

Flavour combined cross sections

Combination of lepton flavour

- ▶ Cross sections provided with correlations between channels ($Z^0 \rightarrow \ell^+ \ell^-$, $W^+ \rightarrow \ell^+ \nu$, $W^- \rightarrow \ell^- \bar{\nu}$)
- ▶ Ratios of fiducial cross sections avoid phase space extrapolation (larger theoretical uncertainty), and cancel luminosity terms
- ▶ Broad agreement with NNLO predictions, different PDF dependences
 $\Rightarrow \sigma_{W^+}^{\text{fid}} / \sigma_{W^-}^{\text{fid}}$ sensitive to up-down PDF differences
 $\Rightarrow \sigma_{W^\pm}^{\text{fid}} / \sigma_Z^{\text{fid}}$ rather PDF insensitive (provided sea is flavour symmetric)



Reference
 arXiv:1109.5141 sub. PRD

W/Z transverse momentum

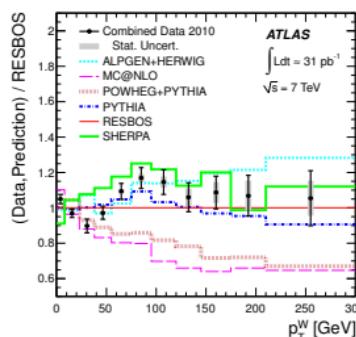
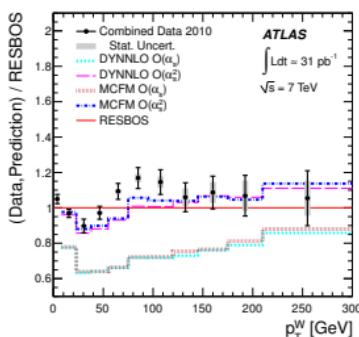
Test multiple models of QCD predictions

Low p_T soft/collinear partons.

- ⇒ Logarithmic resummations up to NNLL in RESBOS
- ⇒ PS (PYTHIA, HERWIG) iterative splitting and radiation of parton
- ⇒ ME+PS (MC@NLO, POWHEG), with ME $O(\alpha_s)$

High p_T hard partons.

- ⇒ FEWZ, DYNNNLO available to $O(\alpha_s^2)$
- ⇒ ME+PS (SHERPA, ALPGEN). High order ME but tree-level production hard parton



Overall p_T^W range

Agreement within 20 % of

- RESBOS
- ALPGEN
- PYTHIA
- SHERPA

References

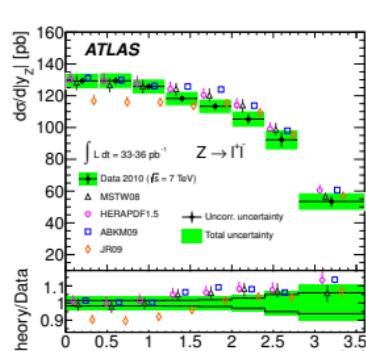
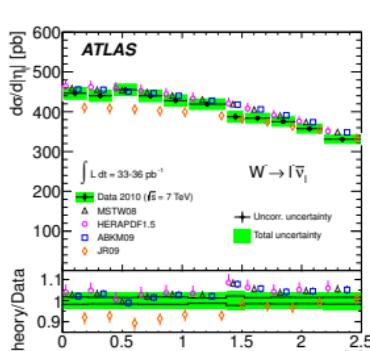
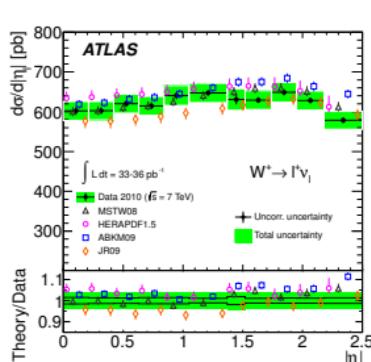
Phys. Rev. **D85** (012005), Phys. Lett. **B705** (415-434)

W/Z rapidity

- ▶ Boson rapidity linked to parton momentum fraction

$$x_{1/2} = e^{\pm y} \frac{M_{W/Z}}{\sqrt{s}}$$

- ▶ In the W boson case, lepton pseudo-rapidity η_ℓ is used.
- ▶ Comparison to NNLO models shows broad agreement
⇒ shows PDF sensitivity (even tension with few sets)



Reference
 arXiv:1109.5141 sub. PRD

Outline

Introduction

W/Z cross-section

Analysis of these cross-sections

W charge asymmetry
Strange quark density

Polarisation measurements

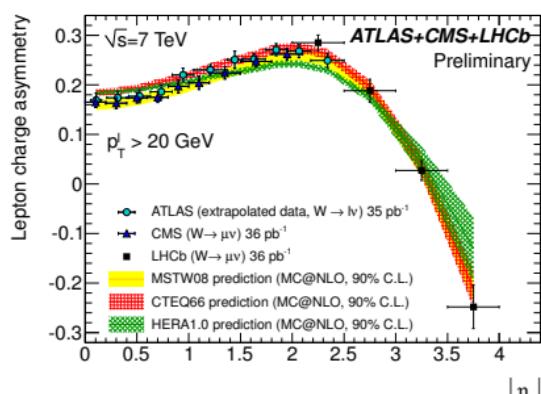
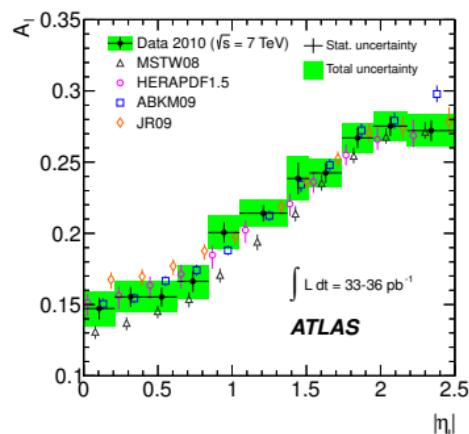
Conclusion

W charge asymmetry

Definition

$$A(\eta_\ell) = \frac{d\sigma_{W+}(\eta_\ell) - d\sigma_{W-}(\eta_\ell)}{d\sigma_{W+}(\eta_\ell) + d\sigma_{W-}(\eta_\ell)}$$

- ▶ Sensitive to valence quark ($u\bar{d} \rightarrow W^+$ / $d\bar{u} \rightarrow W^-$)
- ▶ Usable to constrain u_v / d_v at low x



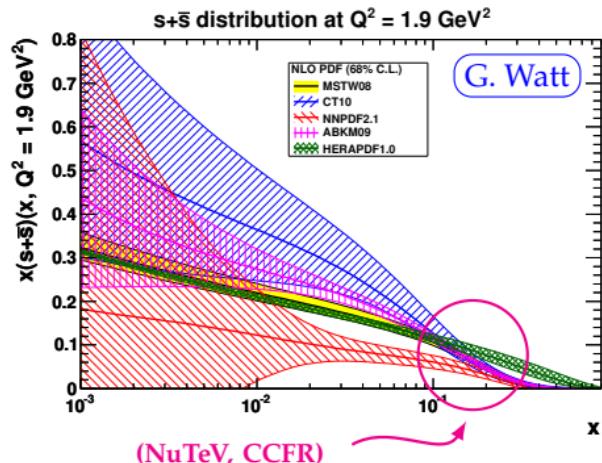
Combined results

- ▶ More constrained in central region (CMS+ATLAS)
- ▶ Extended up to $\eta \sim 3.7$ (LHCb)

References

ATLAS-CONF-2011-129, arXiv:1109.5141 sub. PRD

Strange density: state of the art



Little is known about strange density

- Flavour $SU(3)$ suggests equal proportion in sea (u, d and s)
- $r_s = \frac{1}{2} \frac{(s(x) + \bar{s}(x))}{\bar{d}(x)}$
- s suppression assumed in many PDFs because of s mass ($r_s \sim 0.5$)

Motivations

- Higher relevance than at Tevatron
 \Rightarrow central $W^+ c\bar{s}$ 30%(pp) / 10%($p\bar{p}$)
- Better accuracy needed for precision measurement as m_W (c and b already measured by HERA with 5% and 20% accuracy)
- Might be constrained by Z rapidity and W +charm

Measurement principle

Perform NNLO fits on

- ▶ HERA $e p$ DIS data (sensitive to linear combination of $q + \bar{q}$)
 \Rightarrow cover $10^{-4} \lesssim x \lesssim 0.6$ for $1 \lesssim Q^2 \lesssim 10^4 \text{ GeV}^2$
- ▶ ATLAS W^+ , W^- and Z^0 data (sensitive to bilinear combination of $q + \bar{q}$)
 \Rightarrow cover $0.001 \lesssim x \lesssim 0.1$ for $Q^2 = M_{W/Z}^2 \text{ GeV}^2$

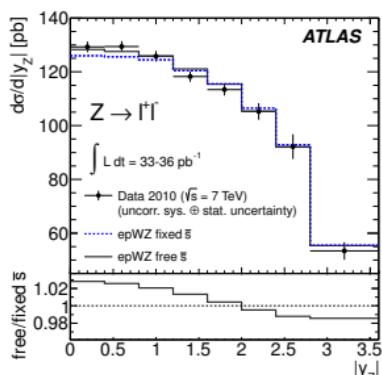
Results extrapolated to low Q^2 with pQCD (chosen scale $Q_0^2 = 1.9 \text{ GeV}^2$)

2 fits procedure

	Fixed \bar{s}/\bar{d}	Free \bar{s}/\bar{d}
χ^2/NDF	All data 546.1/567	538.4/565
ATLAS data	45.0/30	33.9/30

\Rightarrow Free \bar{s}/\bar{d} fit determines value of r_s

$$r_s = 1.00 \pm 0.20_{\text{exp}} \pm 0.07_{\text{mod}}^{+0.10}_{-0.15} \pm 0.06_{\text{par}}^{+0.06} \pm 0.08_{\text{th}}$$



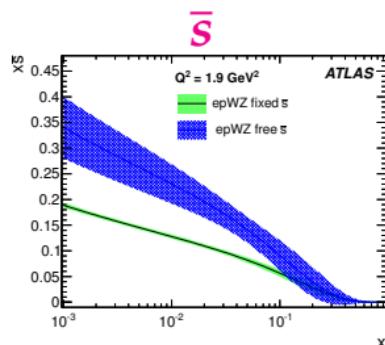
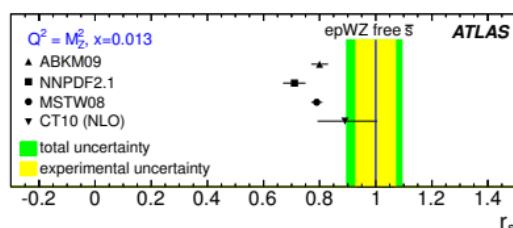
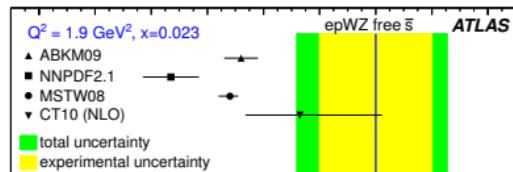
Reference

arXiv:1203.4051 sub. PRL

Results and interpretations

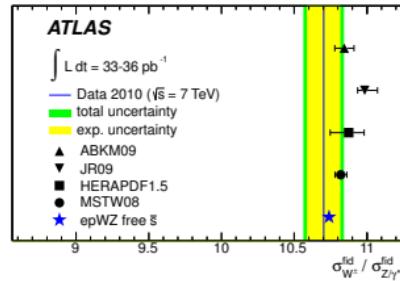
Results in two kinematical zones

- ▶ $(Q^2, x) = (1.9, 0.023)$ and $(M_{W/Z}^2, 0.013)$
- ▶ Uncertainties are smaller at $Q^2 = M_{W/Z}^2$
 gluon splitting into $q\bar{q}$ flavour independant
 \implies Same tension with predictions



Effect of \bar{s} increasing

- ▶ \bar{u}, \bar{d} decrease by 10%
- ▶ total sea is enhanced by 8%
- ▶ better agreement found in ratio $\sigma_{W^\pm}^{\text{fid}} / \sigma_Z^{\text{fid}}$



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W boson polarisation

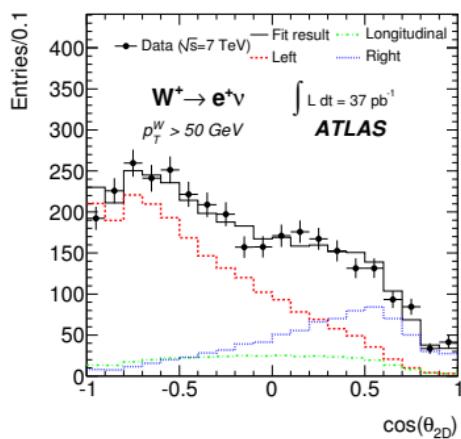
τ polarisation from $W \rightarrow \tau\nu$

Conclusion

W boson polarisation

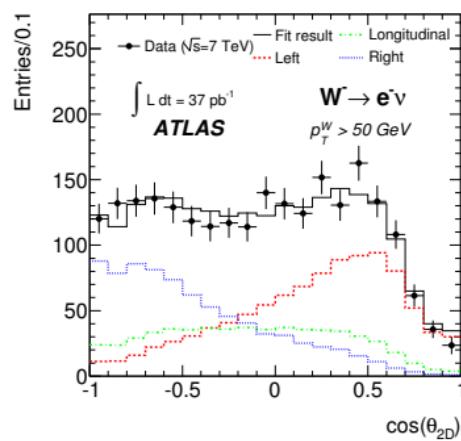
Motivations

- ▶ W in three states: f_L, f_0 and f_R :
 ⇒ LO: predominantly left-handed
 ⇒ NLO: all states possible.
- ▶ Compare to LO and NLO predictions
- ▶ Good understanding needed for precision measurement



Principle

- ▶ No p_ν^ν ⇒ use reduction of $\cos\theta^*$
 $\cos\theta_{2D} = (\vec{p}_T^{\ell^*} \cdot \vec{p}_T^W) / (|\vec{p}_T^{\ell^*}| |\vec{p}_T^W|)$
- ▶ $35 < p_T^W < 50$ and $p_T^W > 50$ GeV
- ▶ Template fits give access to f_0 and $f_L - f_R$



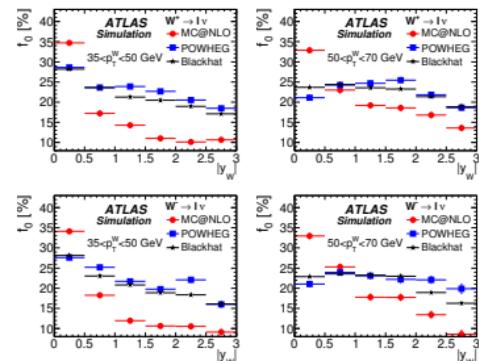
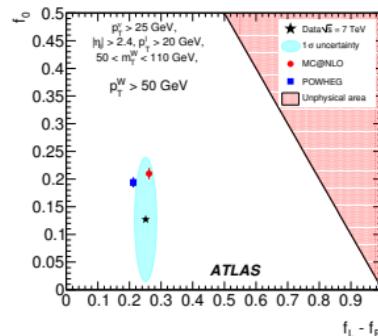
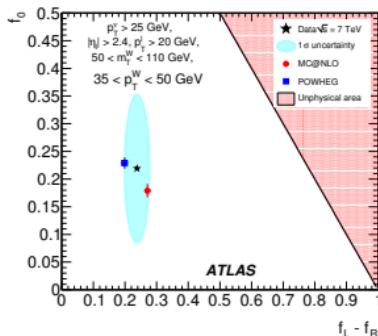
Reference

arXiv:1203.2165 sub. EPJC

W boson polarisation

Measurement and results

- ▶ Measurement done with 2 Monte-Carlo generators: MC@NLO, POWHEG
⇒ get uncertainty for unfolding procedure
- ▶ High sensitivity to energy scale (lepton, E_T)
- ▶ Scale uncertainty on $f_L - f_R$ drastically reduced when averaged over charge
- ▶ Agreement with predictions within uncertainties ($f_L - f_R \sim 25\%$)



Future

- ▶ Would like to have access to the 9 polarisation matrix elements in MC

Reference
 arXiv:1203.2165 sub. EPJC

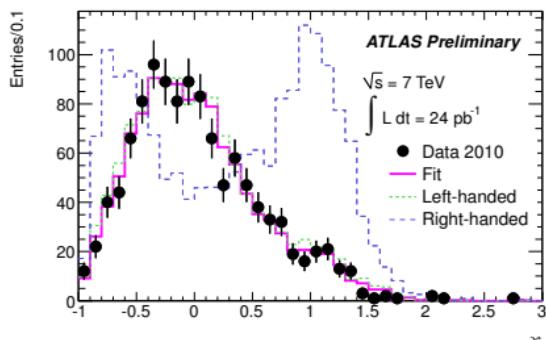
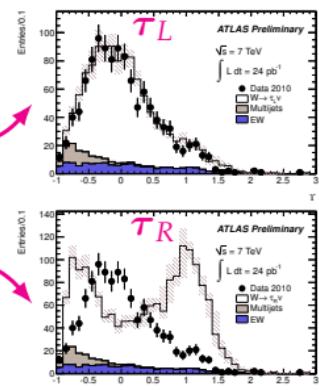
τ polarisation from $W \rightarrow \tau\nu$ decay

τ polarisation $P_\tau = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L)$ can be measured at LHC

Expected P_τ	$W \rightarrow \tau_h \nu$	$Z \rightarrow \tau\tau$	$H \rightarrow \tau\tau$	$H^- \rightarrow \tau\nu$
-1	~ 0.15	0	+1	

First τ polarisation measurement at LHC

- ▶ Use charged asymmetry variable in one prong decay
 $\Upsilon = (E_T^{\pi^-} - E_T^{\pi^0}) / |\vec{p}_T^{\pi^-} + \vec{p}_T^{\pi^0}|$
- ▶ Produce left- and right-handed templates
- ▶ Fit 24 pb^{-1} with these templates
 $\Rightarrow P_\tau = -1.06 \pm 0.04_{\text{stat}}^{+0.05}_{-0.07 \text{syst}}$
- ▶ Results in agreement with SM predictions



Reference
ATLAS-CONF-2012-009

Conclusion

W/Z cross section

- ▶ Inclusive measurement done with every lepton channel
- ▶ Differential measurement as function of p_T , η or y
⇒ very accurate measurement in e/μ (R_W comparable to world average)
- ▶ Can already be used to constrain PDFs models
 - ⇒ W charge asymmetry for u/d
 - ⇒ strange quark density (underestimated in most PDF sets)

Particles properties

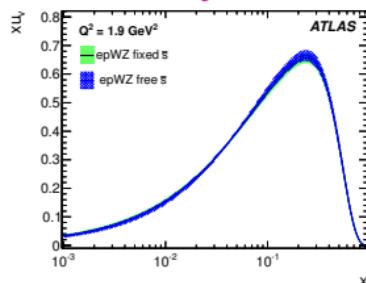
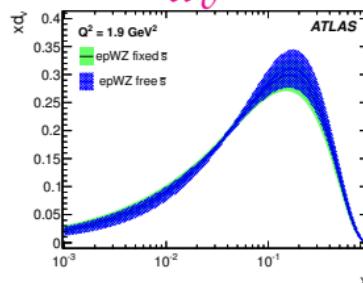
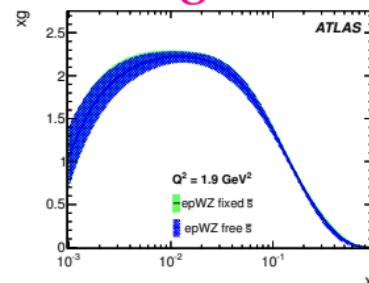
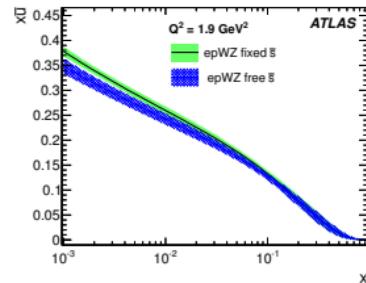
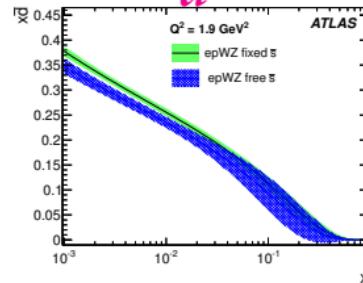
- ▶ τ polarisation from $W \rightarrow \tau\nu$ decay
- ▶ W boson polarisation

To be pursued

- ▶ Exploit much larger dataset available to explore more differential distributions
- ▶ Increase the menu of measurements

Back-up

Effect of r_s on PDFs

 u_v  d_v  g  \bar{u}  \bar{d}  $2(\bar{u} + \bar{d} + \bar{s})$ 