Inclusive $W^{\pm}$ and Z Measurements with the ATLAS Detector

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on behalf of the ATLAS Collaboration

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Overview

- W,Z inclusive measurement with 2010 data ($\mathcal{L} = 35\text{pb}^{-1}$)
  - arXiv:1109.5141, Phys. Rev. D 85, 072004 (2012)
  - Total and fiducial integrated cross sections
  - Differential cross sections
  - W charge asymmetry
- Application of this measurement to the determination of the strange quark density
  - arXiv:1203.4051, accepted by PRL
- Polarisation measurement of W at large transverse momentum
  - arXiv:1203.2165, sub. EPJC
- Proposal for common fiducial region for future measurement

Selection

- single lepton trigger
- $p_T^\ell > 20 GeV$
- μ channel: $|\eta^\mu| < 2.4$
- "central" e channel $|\eta^e| < 2.47$ (excluding calo. crack: $1.37 < |\eta^e| < 1.52$)

$W \to \ell\nu$

- single isolated lepton
- $E_T^{Miss} > 25 GeV$
- $m_T > 40 GeV$

$Z \to \ell\ell$

- 2 isolated leptons
- opposite charge
- $66 < m_{\ell\ell} < 116 GeV$

- For combination of e and μ channels extrapolate to common fiducial region: $|\eta_\ell| < 2.5$
- Complementary "Forward" $Z \to ee$ measurement:
  - One well identified electron in central region
  - One forward electron in range $2.5 \leq |\eta_e| \leq 4.9$

Cross Section Definitions

$$\sigma_{fid} = \frac{N - B}{C_{W/Z}\mathcal{L}} \qquad \sigma_{tot} = \frac{\sigma_{fid}}{A_{W/Z}}$$

- Fiducial cross section, σ_{fid}, is corrected for efficiencies
- Efficiency factor $C_{W/Z} = \frac{N_{MC,rec}}{N_{MC,gen,cut}}$
  - corrected for data/MC differences using "Tag and Probe" method
- $N_{MC,gen,cut}$ defined at three different levels of QED FSR corrections
  - Born: Leptons before QED FSR
  - Bare: Leptons after QED FSR
  - Dressed: Bare lepton re-summed with all FSR photons within $\Delta R < 0.1$
- QED FSR correction factors published on HepData hepdata.cedar.ac.uk/view/ins928289/d16
- Total cross section, σ_{tot}, is corrected for acceptance
- Acceptance, $A_{W/Z}$, derived from MC
- Theoretical uncertainties for $C_{W/Z}$ and $A_{W/Z}$ by comparing
  - MC@NLO
  - Powheg+Pythia and Powheg+Herwig
  - Reweighting to different PDF sets
  - PDF eigenvector propagation

Systematic Uncertainties on Fiducial Cross Section

Electron channel

- $W \to e\nu$: 1.8% - 2.0%
- $Z \to ee$: 2.7%

	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W+}$	$\delta\sigma_{W-}$	$\delta\sigma_Z$
Trigger	0.4	0.4	0.4	<0.1
Electron reconstruction	0.8	0.8	0.8	1.6
Electron identification	0.9	0.8	1.1	1.8
Electron isolation	0.3	0.3	0.3	—
Electron energy scale and resolution	0.5	0.5	0.5	0.2
Non-operational LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	0.0	0.1	0.1	0.6
QCD background	0.4	0.4	0.4	0.7
Electroweak+$t\bar{t}$ background	0.2	0.2	0.2	<0.1
$E_{\mathrm{T}}^{\mathrm{miss}}$scale and resolution	0.8	0.7	1.0	—
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.6	0.6	0.6	0.3
Total experimental uncertainty	1.8	1.8	2.0	2.7
$A_{W/Z}$ theoretical uncertainty	1.5	1.7	2.0	2.0
Total excluding luminosity	2.3	2.4	2.8	3.3
Luminosity		3.4		

Muon channel

- $W \to \mu\nu$: 1.6% - 1.7%
- $Z \to \mu\mu$: 0.9%

	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W+}$	$\delta\sigma_{W-}$	$\delta\sigma_Z$
Trigger	0.5	0.5	0.5	0.1
Muon reconstruction	0.3	0.3	0.3	0.6
Muon isolation	0.2	0.2	0.2	0.3
Muon p_{T} resolution	0.04	0.03	0.05	0.02
Muon p_{T} scale	0.4	0.6	0.6	0.2
QCD background	0.6	0.5	0.8	0.3
Electroweak+$t\bar{t}$ background	0.4	0.3	0.4	0.02
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution and scale	0.5	0.4	0.6	-
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.8	0.8	0.7	0.3
Total experimental uncertainty	1.6	1.7	1.7	0.9
$A_{W/Z}$ theoretical uncertainty	1.5	1.6	2.1	2.0
Total excluding luminosity	2.1	2.3	2.6	2.2
Luminosity		3.4		

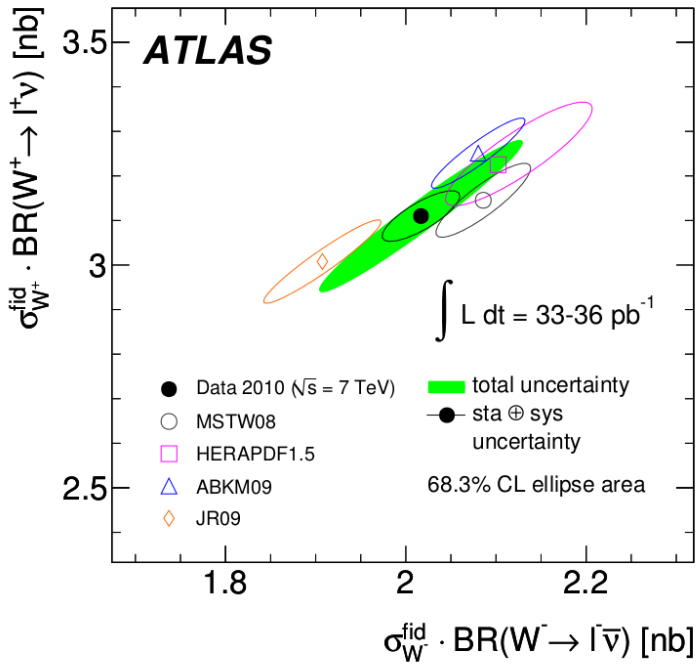
Combination and Treatment of Correlated Uncertainties

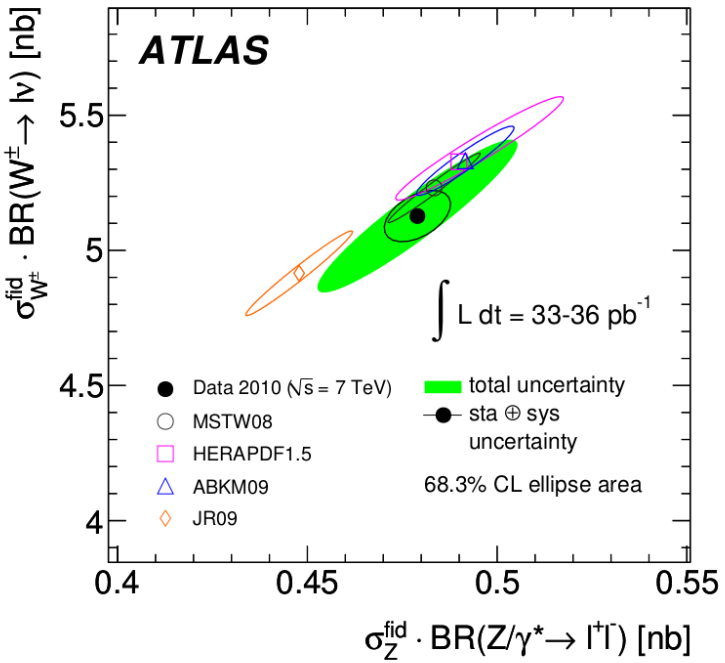
- Assuming lepton universality, can combine e and μ results with an averaging procedure
- Distinguish sources of uncertainty by their correlations
  - bin-to-bin
  - between e and μ channels
  - between W^+, W^- and Z measurements
- 30 sources of correlated uncertainty
- $\gamma^i_{j,k}$ quantifies influence of uncertainty i on measurement j in dataset k
- Useful input for PDF fits

$y_{min} - y_{max}$	0.0-0.4	0.4-0.8	0.8-1.2	1.2-1.6	1.6-2.0	2.0-2.4	2.4-2.8	2.8-3.6
$d\sigma/dy$ [pb]	129.27	129.44	125.81	118.23	113.37	105.26	92.18	53.38
δ_{sta}, %	1.46	1.47	1.50	1.61	1.84	2.57	3.24	4.21
δ_{unc}, %	0.59	0.50	0.47	0.45	0.63	1.37	3.81	4.37
δ_{cor}, %	1.07	1.08	0.93	0.97	1.26	2.19	3.77	8.06
δ_{tot}, %	1.90	1.89	1.83	1.94	2.32	3.65	6.26	10.09
γ_1, %	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
γ_2, %	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
γ_3, %	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
γ_4, %	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.18
γ_5, %	0.07	0.07	0.05	0.04	0.01	0.00	0.06	0.18
γ_6, %	-0.13	-0.10	-0.08	-0.05	-0.04	-0.07	-0.06	-0.03
γ_7, %	0.05	0.04	0.05	0.04	0.05	0.09	0.58	1.76
γ_8, %	-0.07	-0.09	-0.07	-0.09	-0.08	-0.19	-0.42	-1.16
γ_9, %	-0.03	-0.02	-0.05	0.01	0.05	0.18	0.61	1.28
γ_{10}, %	0.12	0.13	0.11	0.08	0.03	-0.05	-0.40	-0.93
γ_{11}, %	-0.10	-0.10	-0.10	-0.05	0.01	0.13	0.63	1.87
γ_{12}, %	0.06	0.06	0.06	0.15	0.33	0.76	2.26	4.97
γ_{13}, %	-0.28	-0.29	-0.17	-0.15	0.15	0.18	0.11	-0.39
γ_{14}, %	-0.02	0.01	-0.03	0.05	-0.01	0.23	1.16	3.19
γ_{15}, %	0.07	0.06	0.01	0.03	0.02	0.23	1.18	2.70
γ_{16}, %	-0.10	-0.08	-0.08	-0.03	-0.09	0.04	0.23	1.64
γ_{17}, %	-0.53	-0.55	-0.43	-0.37	-0.37	-0.58	-0.82	-1.95
γ_{18}, %	0.07	0.02	0.03	0.07	0.17	0.17	0.45	0.56
γ_{19}, %	-0.16	-0.16	-0.13	-0.06	-0.07	-0.06	0.03	0.37
γ_{20}, %	0.34	0.32	0.22	0.30	0.41	0.66	-0.03	-0.83
γ_{21}, %	-0.15	-0.17	-0.15	-0.09	0.04	0.13	0.04	-0.03
γ_{22}, %	-0.10	-0.15	0.00	-0.25	-0.45	-1.15	-0.28	1.39
γ_{23}, %	0.05	0.02	0.00	-0.23	-0.49	-0.85	-0.09	0.78
γ_{24}, %	0.22	0.23	0.23	0.16	0.00	0.15	0.49	0.28
γ_{25}, %	0.17	0.16	0.12	0.14	0.08	0.01	0.26	0.26
γ_{26}, %	0.18	0.25	0.28	0.18	0.24	0.69	0.03	-1.13
γ_{27}, %	0.00	-0.01	-0.04	-0.04	-0.06	-0.20	-0.19	-0.04
γ_{28}, %	0.50	0.47	0.45	0.52	0.66	0.62	0.70	0.26
γ_{29}, %	0.17	0.18	0.16	0.13	-0.06	-0.14	-1.68	-0.46
γ_{30}, %	-0.12	-0.11	-0.14	-0.12	-0.11	-0.20	-0.21	-0.21

Integrated Fiducial Cross Sections

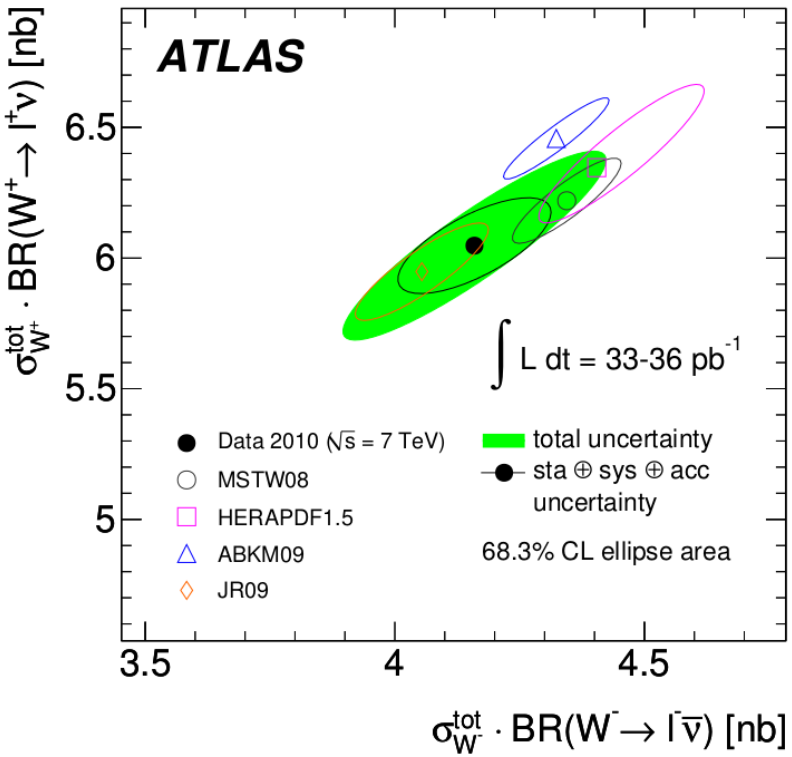
- Compare theory to measurement in fiducial region to disentangle theoretical and experimental effects
- Theoretical prediction at NNLO with different PDF sets
  - Compare FEWZ 2.1 (pre-release) to DYNNLO 1.1 (up to 1% differences for fiducial cross sections)
  - Remaining H.O. EW effects calculated separately (up to 0.5% effect)
  - In following plots use FEWZ without extra EW corrections
- Generally good agreement

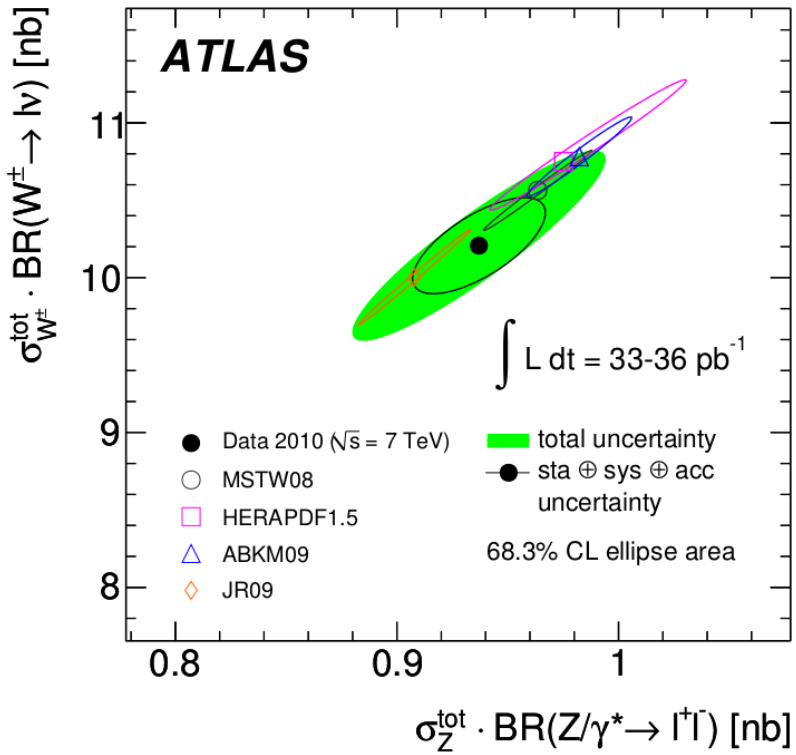




Integrated Total Cross Sections

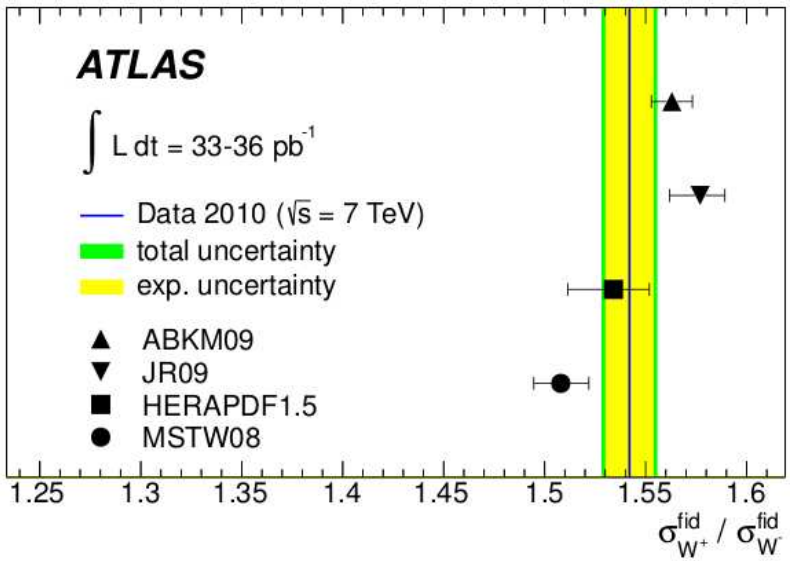
- $A_{W/Z} \sim 0.47 - 0.50$
- Introduces additional theoretical and model uncertainties
- As large or larger than experimental uncertainties
  - $\delta A_W \sim 1.5\%$
  - $\delta A_Z \sim 2\%$

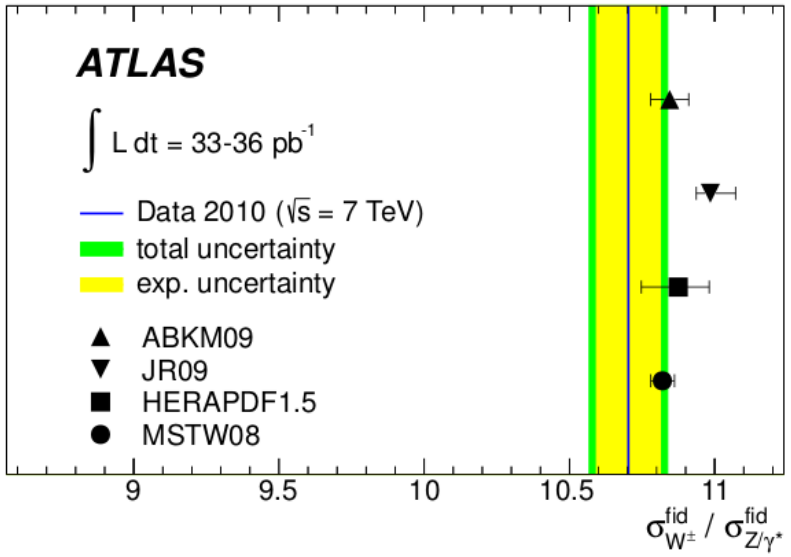




Cross Section Ratios

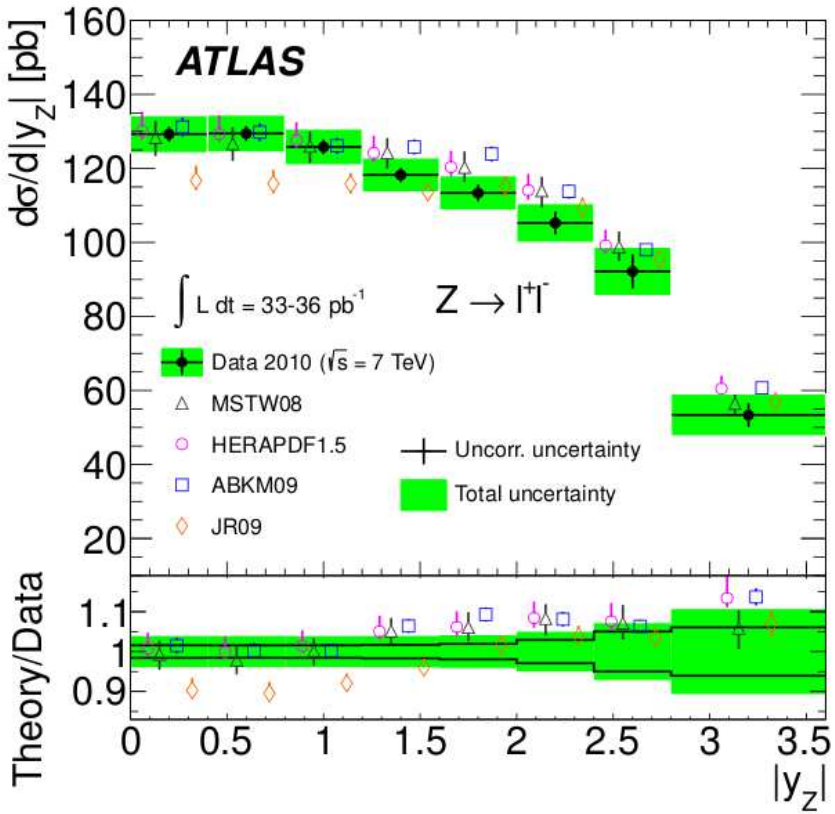
- Consider fiducial cross section ratios to cancel luminosity and other correlated uncertainties





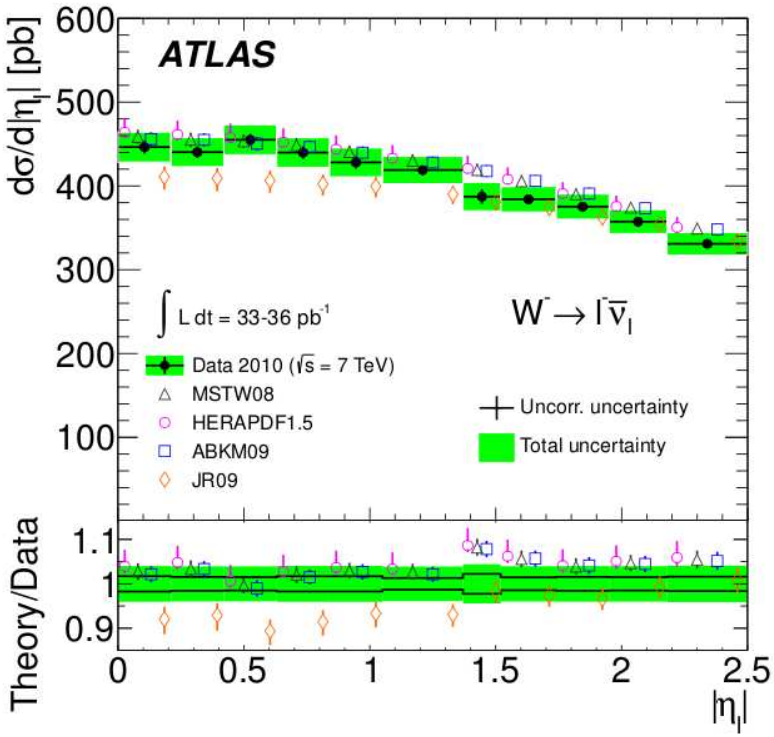
Z differential cross section

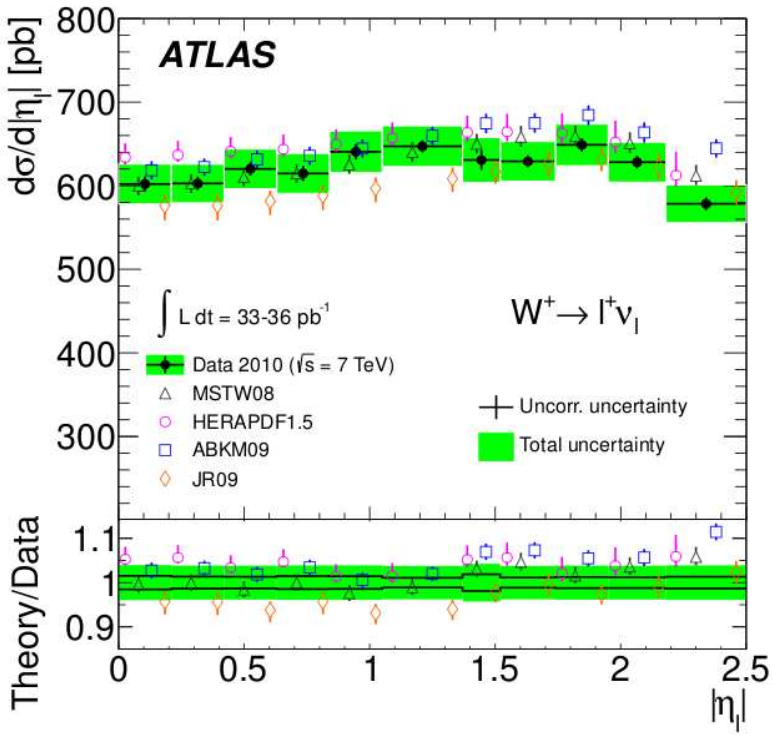
- $\frac{d\sigma}{dy_Z}$ with fiducial cuts (except η)
- Measurement extrapolated to all η
- Combination of "central" and "forward" measurements
- Theoretical predictions at NNLO from FEWZ with different PDF sets
- Generally good agreement with some tension between PDF sets



$W^{\pm}$ Differential Cross Sections

- $\frac{d\sigma}{d\eta_\ell}$ in common fiducial region
- Normalisation of prediction from FEWZ
- Shape of prediction from DYNNLO due to higher statistical precision
- Generally good agreement with some tension between PDF sets



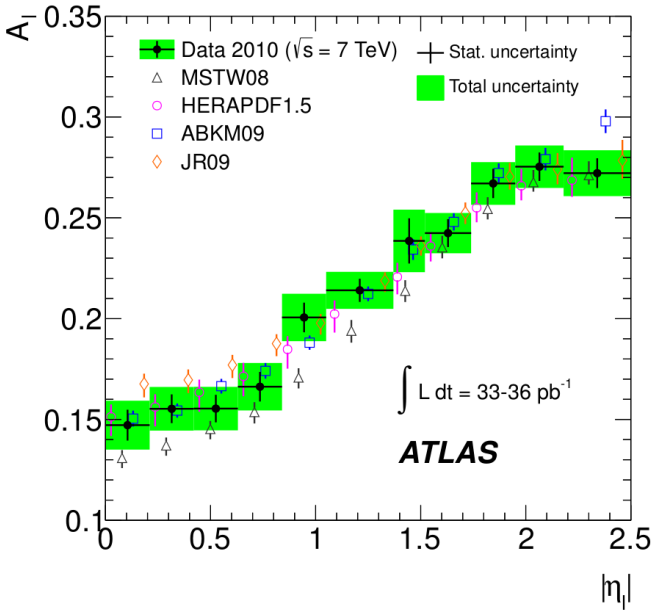


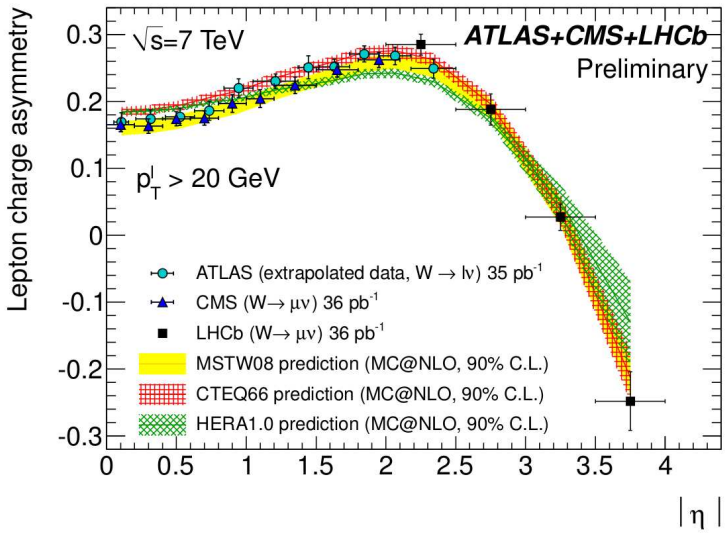
W Differential Charge Asymmetry

$$A(\eta_\ell) = \frac{\sigma^+(\eta_\ell) - \sigma^-(\eta_\ell)}{\sigma^+(\eta_\ell) + \sigma^-(\eta_\ell)}$$

Following previous discussion at LHC EWK working group extrapolated ATLAS charge asymmetry result to common fiducial region to aid comparisons with CMS and LHCb

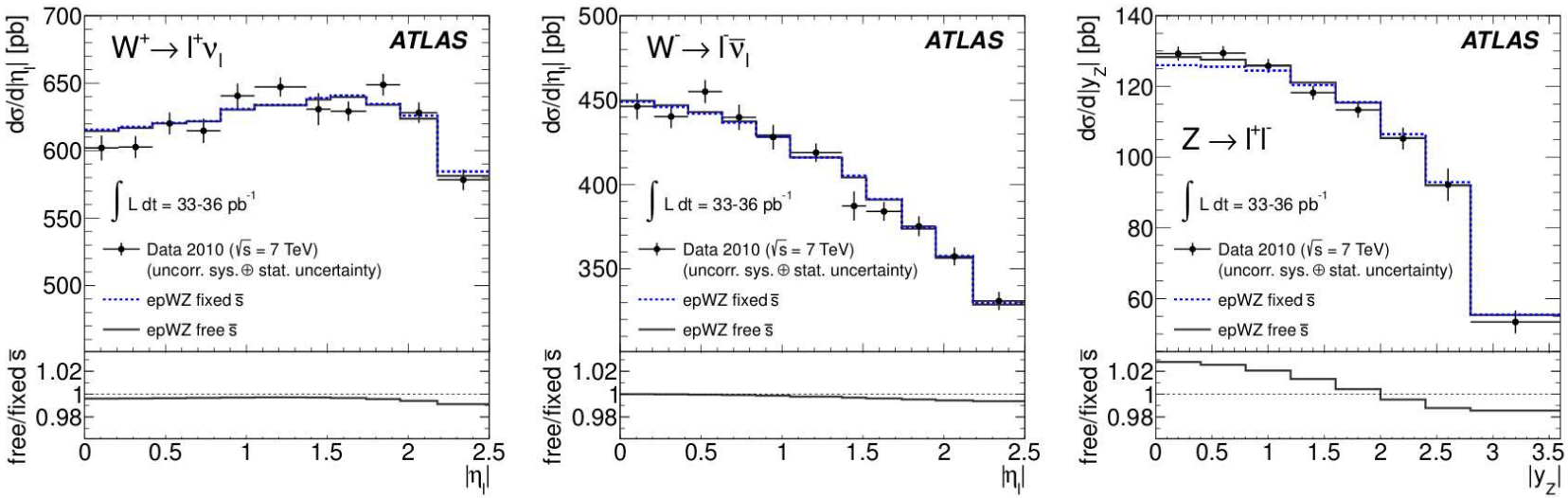
- only $p_\ell > 20$ GeV





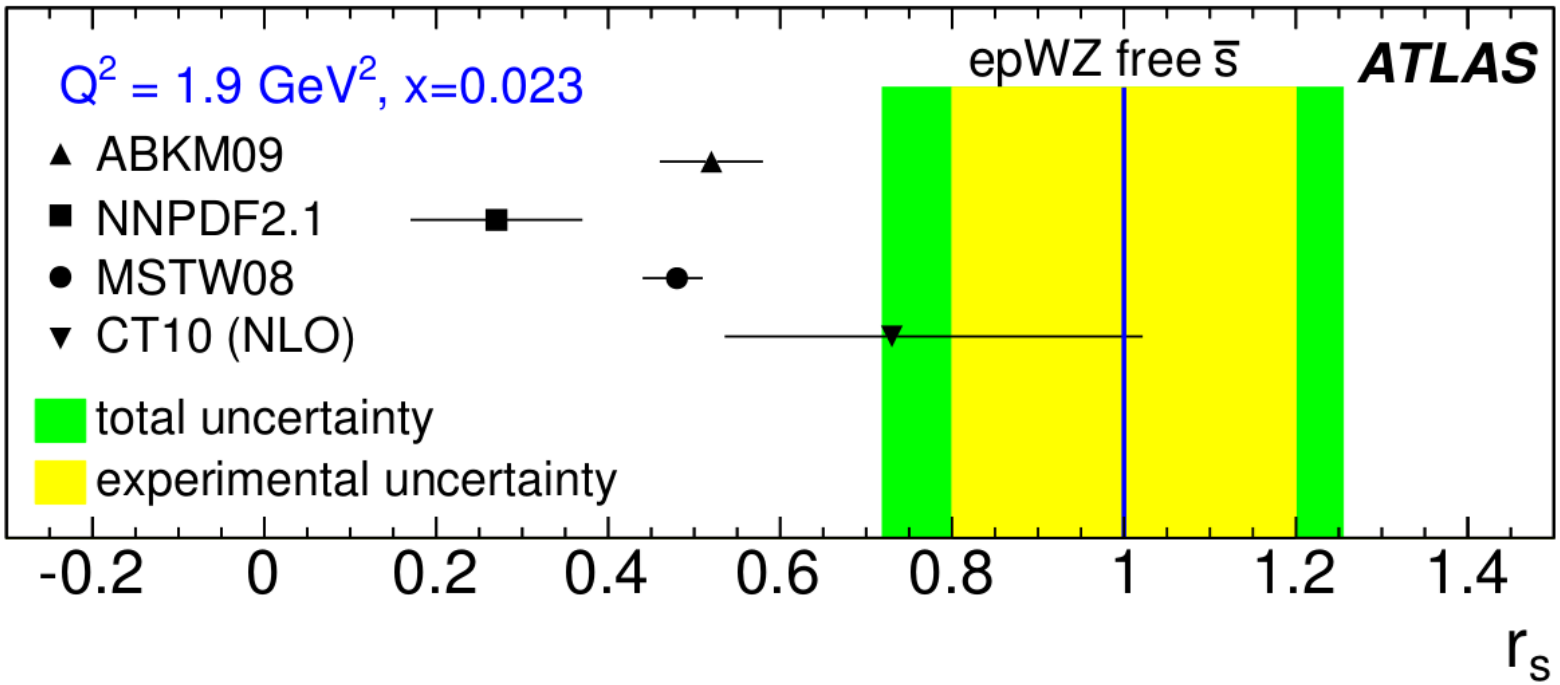
Application of Measurement: Determination of Strange Quark Density

- Very little is known about strange quark distribution in proton
- 2 types of NNLO QCD fit of HERA DIS and ATLAS W/Z cross section data
  - s quark distribution suppressed and fully coupled to d, $\bar{s}/\bar{d} = 0.5$
  - s quark distribution parameterised with 2 free parameters
- Fit with free $\bar{s}$ results in better partial χ^2/N_{DF} for ATLAS data (33.9/30 vs 44.5/30)
- Enhanced strange fraction in free fit improves prediction of y_Z distribution



Strange Quark Density Fit Result

- $r_s = 0.5(s + \bar{s})/\bar{d}$
- Free $\bar{s}$ fit results in r_s consistent with unity
- Considerable tension with most PDF sets
- See A. Cooper-Sarkar's talk on Wednesday for more detail
- arXiv:1203.4051, accepted by PRL



Measurement of the W Polarisation

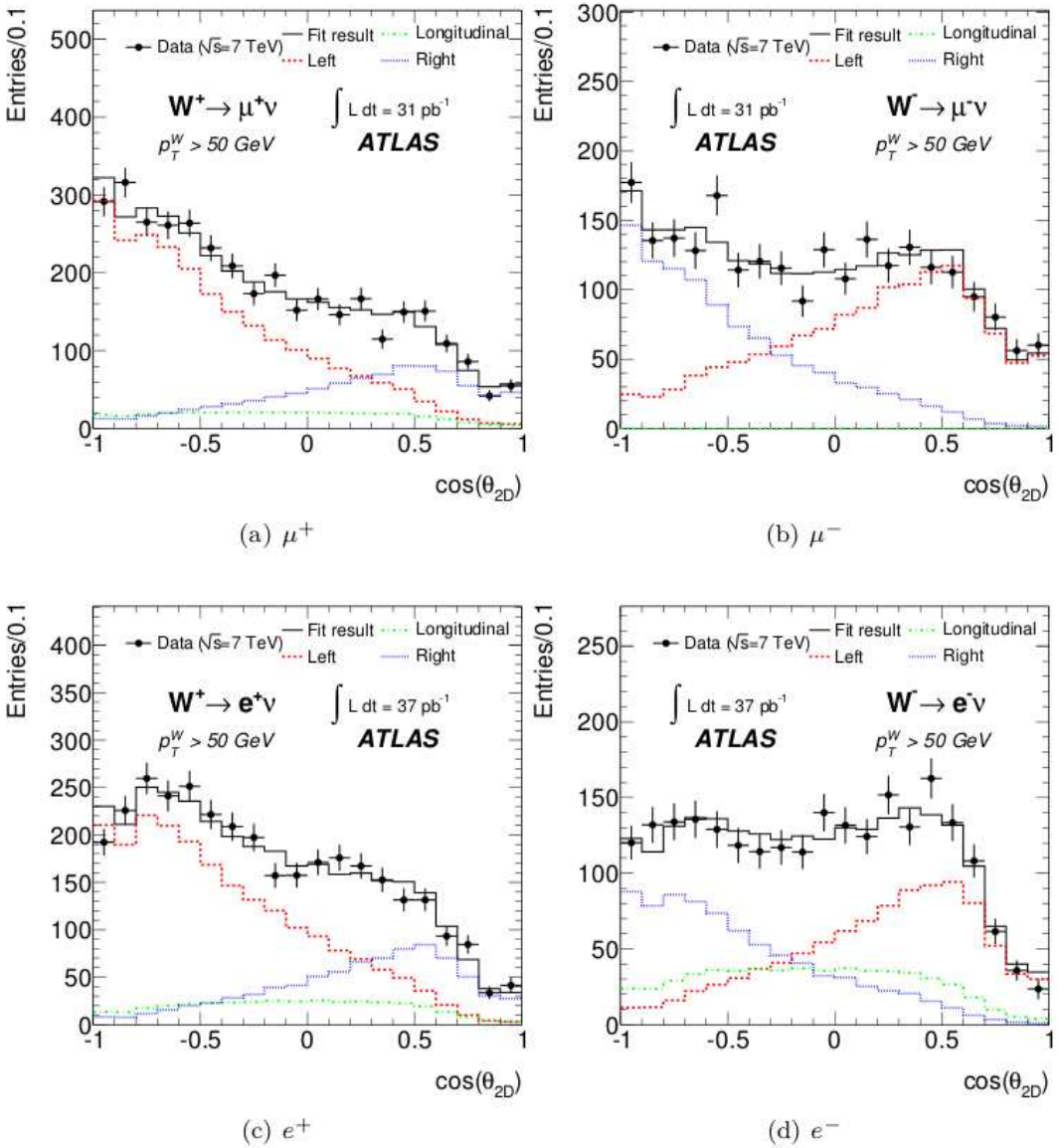
- W helicity fractions: f_0, f_L and f_R
  - Low p_T^W: Mixture of LH and RH states (mostly LH for large y_W)
  - High p_T^W: All states possible

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_{3D}} = \frac{3}{8}f_L(1 \mp \cos\theta_{3D})^2 + \frac{3}{8}f_R(1 \pm \cos\theta_{3D})^2 + \frac{3}{4}f_0\sin^2\theta_{3D}$$

- Helicity angle θ_{3D}:
  - Angle between direction of W in lab frame and direction of decay lepton in W rest frame
  - Not possible to reconstruct unambiguously
- Use transverse helicity angle: $\cos\theta_{2D} = \frac{\vec{p}_T^{\ell *} \cdot \vec{p}_T^W}{|\vec{p}_T^{\ell *}||\vec{p}_T^W|}$
- Fit $\cos\theta_{2D}$ distribution to MC templates corresponding to LH, RH and longitudinal states
- $f_L + f_R + f_0 = 1 \rightarrow$ report results for f_0 and $f_L - f_R$

Template Fits

- Use MC@NLO and Powheg
- Reweight events to purely LH, RH or longitudinal $cos\theta_{3D}$ distributions at generator level
- Apply selection
  - Standard W selection
  - $50 < m_T < 110 GeV$
  - Two p_T^W bins: $35 < p_T^W < 50 GeV$ and $p_T^W > 50 GeV$
- Background subtraction in data
- Fit $\cos\theta_{2D}$ distribution to templates

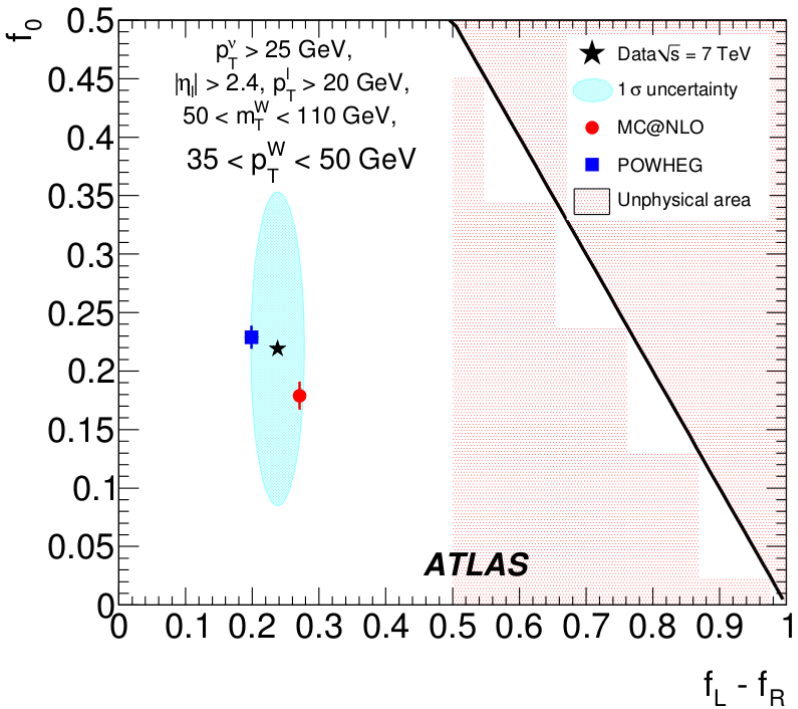


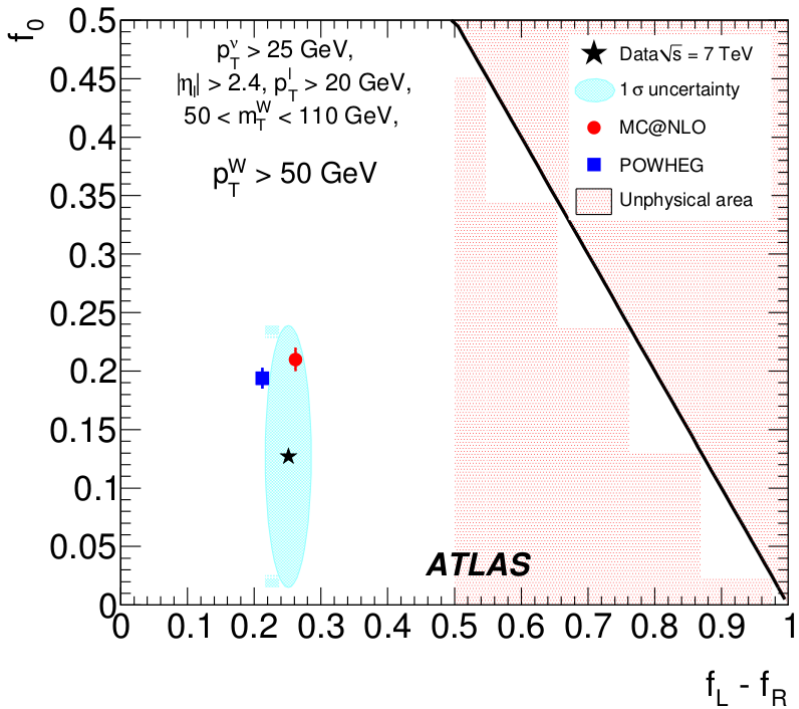
(a) μ^+ (b) μ^-

(c) e^+ (d) e^-

W Polarisation Results

- Correct fit results
  - Resolution effects
  - Effects of using $\cos\theta_{2D}$ rather than $\cos\theta_{3D}$
- Largest uncertainties:
  - Powheg vs MC@NLO templates
  - Recoil energy scale uncertainty reduced for $f_L - f_R$ by averaging over lepton charges
- Results in agreement with prediction within uncertainties





Changes to the Fiducial Selection

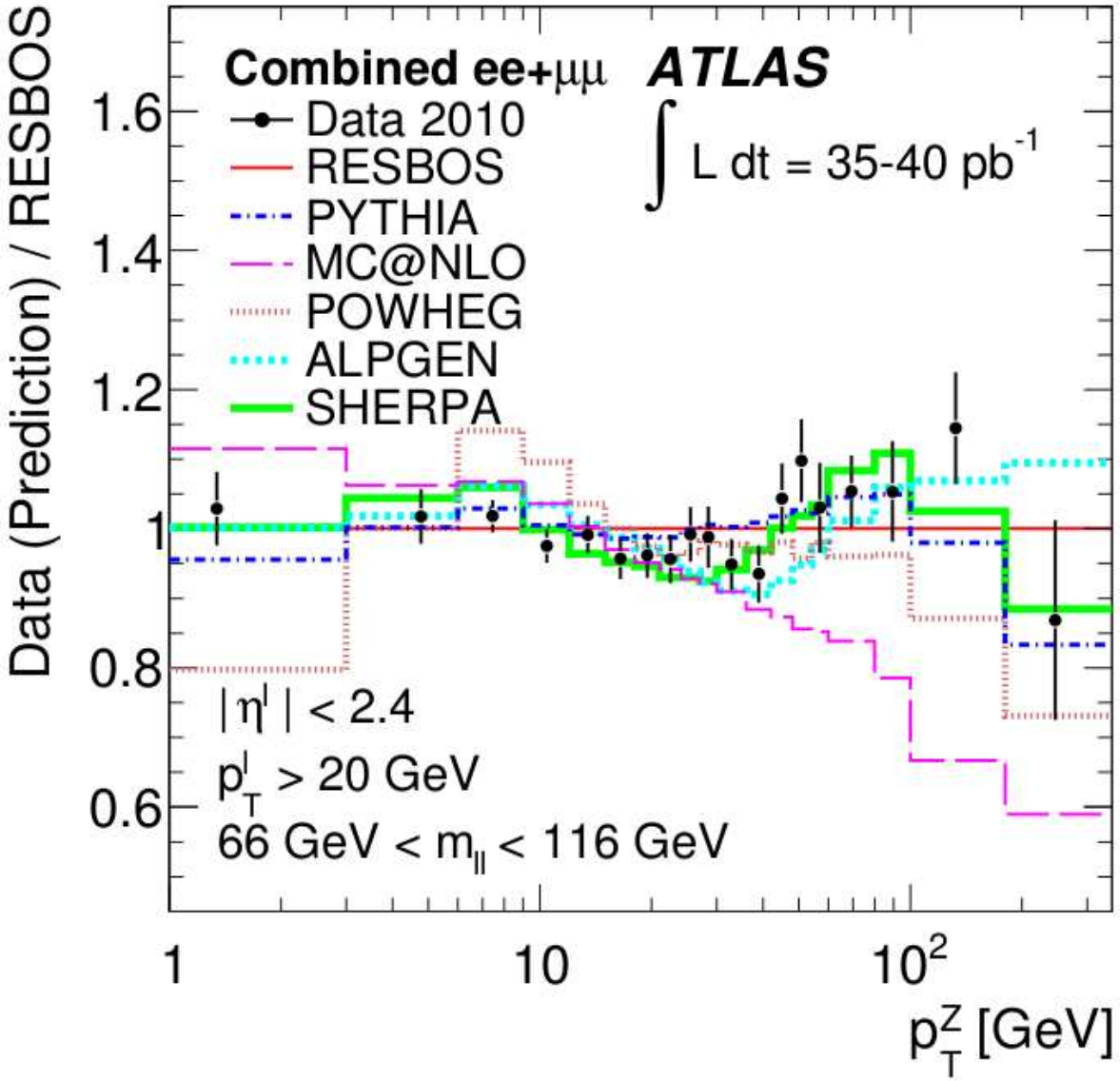
- Small changes to fiducial volume definition
- W and "forward" Z measurement
  - Higher single lepton trigger threshold
  - For 2011 data: p_T^ℓ cut in range 20-25 GeV
  - For 2012 data: p_T^ℓ cut in range 25-27 GeV
- Central Z measurement will use dilepton triggers with lower threshold $\rightarrow$ can stay with $p_T^\ell > 20$ GeV
- Other fiducial cuts can remain unchanged
  - $E_T^{Miss} > 25$ GeV
  - $m_T > 40$ GeV
  - $66 < m_{\ell\ell} < 116$ GeV

Summary

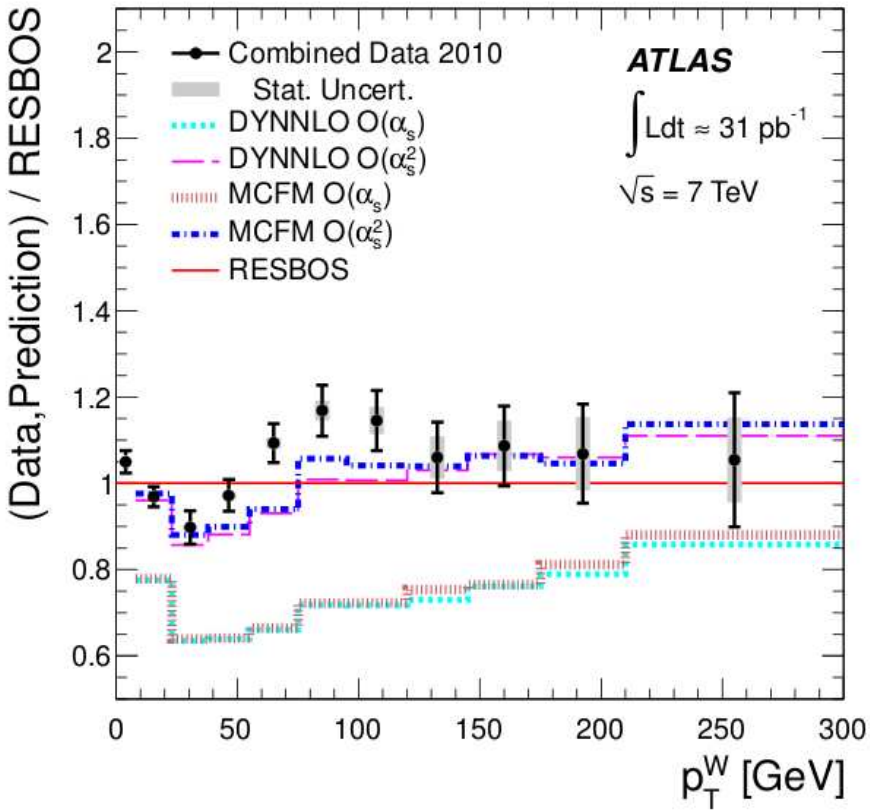
- W and Z cross section measurements
  - Total and fiducial integrated cross sections
  - Differential cross sections
  - Full correlation information between measurements
  - Experimental precision of 1% - 2.7%
  - Generally good agreement with NNLO prediction
- Determination of the strange quark distribution
  - Fit of HERA DIS and ATLAS W/Z data
  - Result consistent with $r_s = 1.0$
- W polarisation measurement at high p_T^W
  - Template fit $\cos\theta_{2D}$ distribution
  - Measurement of $f_L - f_R$ and f_0
  - Results in agreement within uncertainties with Powheg and MC@NLO
- Change in fiducial cuts in 2011/2012 measurements
  - Slight increase of lepton p_T
  - Other cuts can remain the same

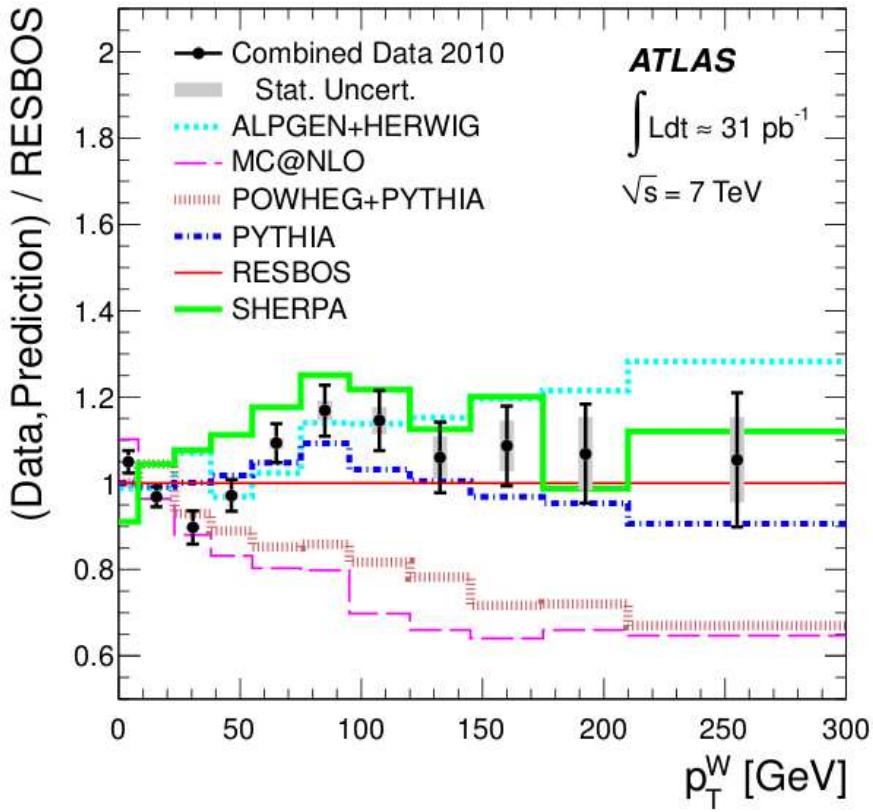
Backup

p_T^Z


Combined ee+μμ
ATLAS
Data 2010
RESBOS
PYTHIA
MC@NLO
POWHEG
ALPGEN
SHERPA
∫ L dt = 35-40 pb-1
|η^l| < 2.4
p_T^l > 20 GeV
66 GeV < m_ll < 116 GeV
Data (Prediction) / RESBOS
1.6
1.4
1.2
1
0.8
0.6
1
10
10^2
p_T^Z [GeV]

p_T^W


Combined Data 2010
Stat. Uncert.
DYNNLO O(α_s)
DYNNLO O(α_s^2)
MCFM O(α_s)
MCFM O(α_s^2)
RESBOS
ATLAS
∫Ldt ≈ 31 pb^-1
√s = 7 TeV
(Data,Prediction) / RESBOS
p_T^W [GeV]


Combined Data 2010
Stat. Uncert.
ALPGEN+HERWIG
MC@NLO
POWHEG+PYTHIA
PYTHIA
RESBOS
SHERPA
ATLAS
∫Ldt ≈ 31 pb^-1
√s = 7 TeV
(Data,Prediction) / RESBOS
p_T^W [GeV]