W/Z PRODUCTION AND PROPERTIES

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on behalf of the ATLAS collaboration

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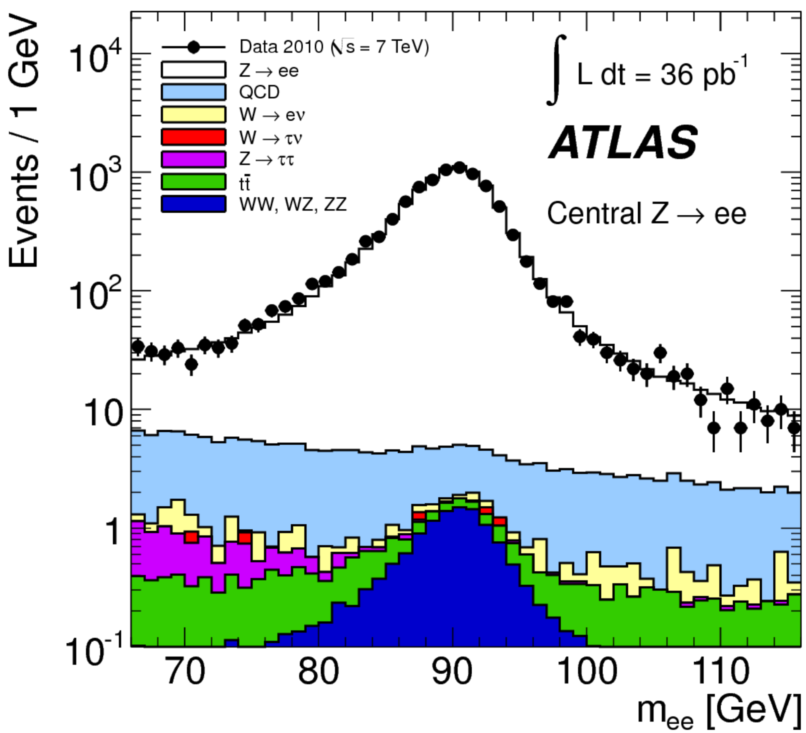
What this talk is about: W/Z physics

- **Why are W/Z measurements interesting?**
  - Clean signature: leptons and missing energy
  - Validation of our understanding of the detector
    - Critical before embarking on new physics searches
  - Precise tests of Standard Model / pQCD at 7 TeV
  - Constraints on Parton Distribution Functions (PDFs)
    - Emphasized in this talk
- I will cover results from the **2010 dataset (~35 pb^{-1})**:
  - ~270k W candidates
  - ~24k Z candidates
  - Measurements with the full 2011 dataset (~4.7 fb^{-1}) are in-progress, and will not be shown here.

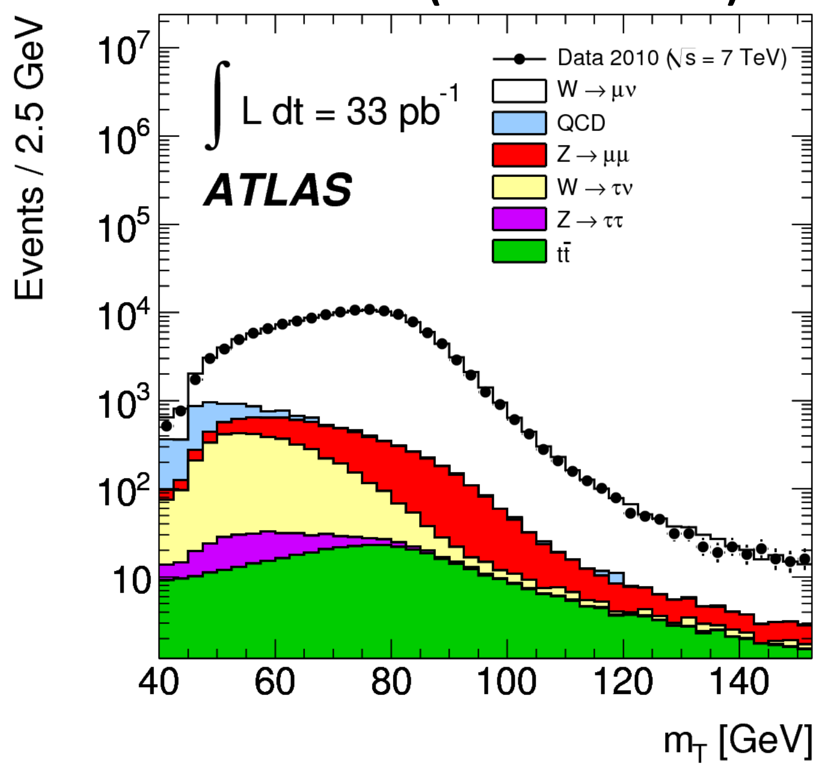
Monte-Carlo simulation

- Monte-Carlo generators interfaced with GEANT4 detector simulation
- Data-driven corrections are applied for pileup, reconstruction and identification efficiency, energy scale and resolution.
- EWK backgrounds are generally taken from MC; QCD is data-driven.
- Overall, simulation shows remarkable agreement with data:

Di-electron invariant mass



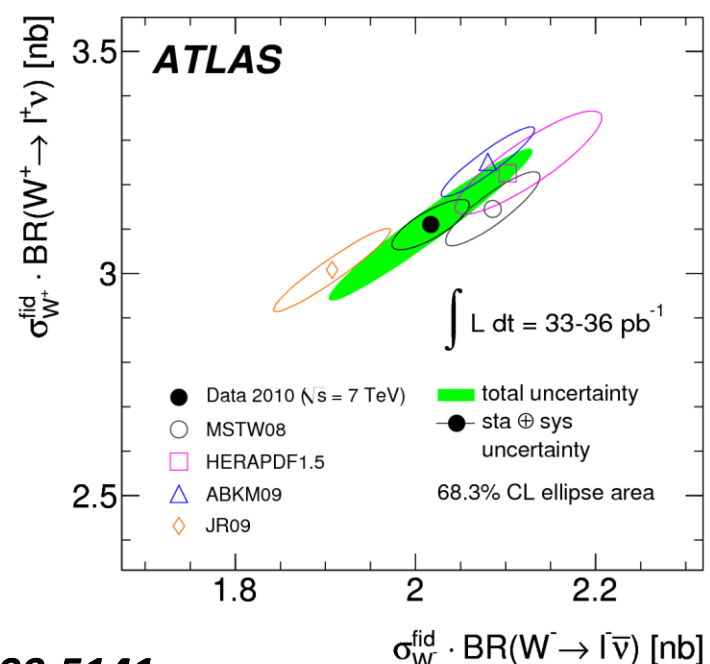
W transverse mass (muon channel)

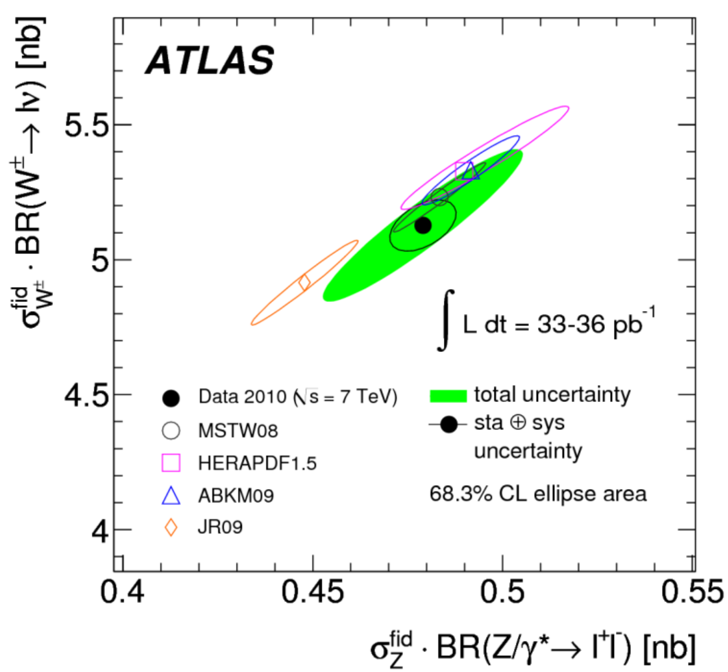


arXiv:1109.5141

W and Z inclusive cross-sections

- Electron and muon channels combined in common fiducial region
  - Lepton p_T > 20 GeV and $|\eta|$<2.5, Missing Energy > 25 GeV
  - W transverse mass > 40 GeV, Z mass = 66..116 GeV
- Data compared with NNLO calculation (FEWZ)
  - Consistent with the span of predictions from four NNLO PDFs
- Uncertainties: 1% systematic, negligible statistical, 3.4% luminosity
  - Extrapolation to full phase space (not shown) adds another 2%





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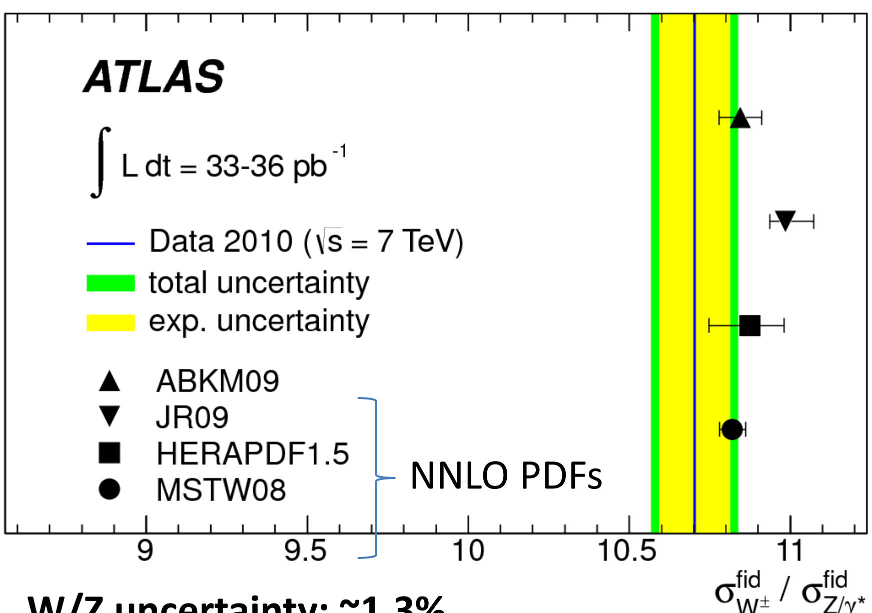
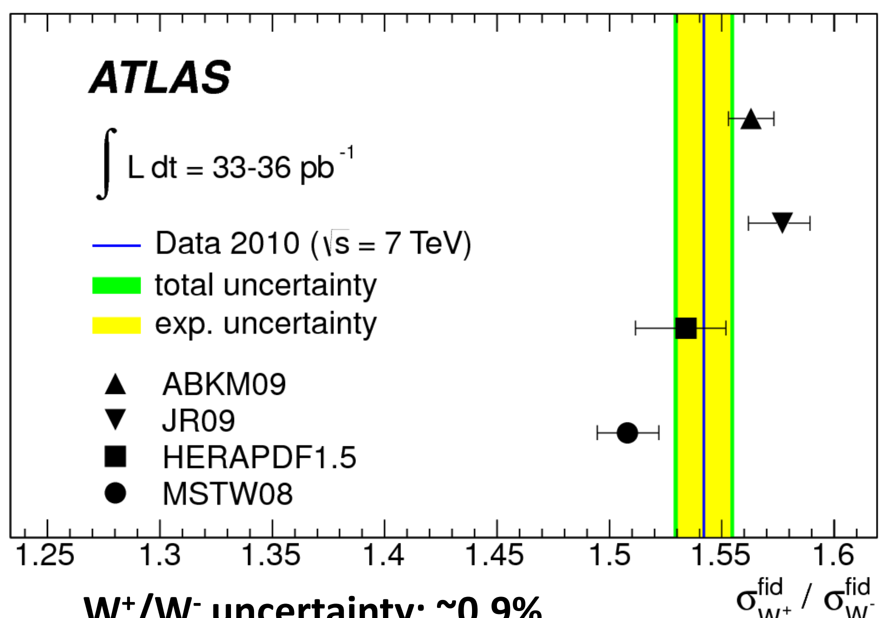
Cross-section ratios

- Many systematics (including luminosity) cancel in the **ratios of $W^{\pm}/Z$ (left figure) and W^{+}/W^{-} (right figure) cross-sections**.
- Good agreement with NNLO (FEWZ) predictions
  - Demonstrates success of pQCD and DGLAP evolution of largely HERA-constrained PDFs into LHC kinematic regime
- Sensitivity to different PDF sets, especially in the W^{+} to W^{-} ratio.
  - This is further exploited in differential measurements



W/Z uncertainty: ~1.3%

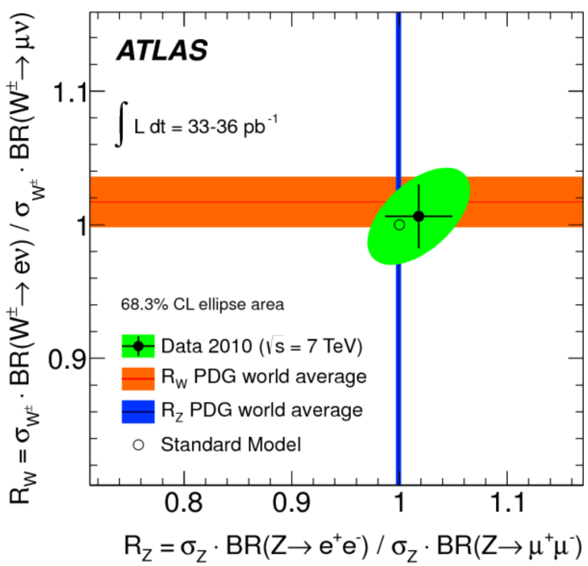


W^{+}/W^{-} uncertainty: ~0.9%

arXiv:1109.5141

Lepton universality

- Ratio of electron and muon branching ratios in the fiducial region
- Many uncertainties are correlated and cancel
- e-μ universality is confirmed in both W and Z ratios:
  - **R_W= 1.006±0.024** (PDG=**1.0017±0.019**)
    - Competitive with PDG, previously dominated by LEP
  - **R_Z = 1.018±0.031** (PDG=**0.9991±0.0024**)
    - Strongly constrained by LEP, rather than hadron colliders
- Taking R_Z from PDG as a constraint, we obtain a stronger result:
  - **R_W= 0.999±0.020** (assuming world-average R_Z)



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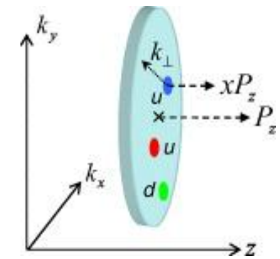
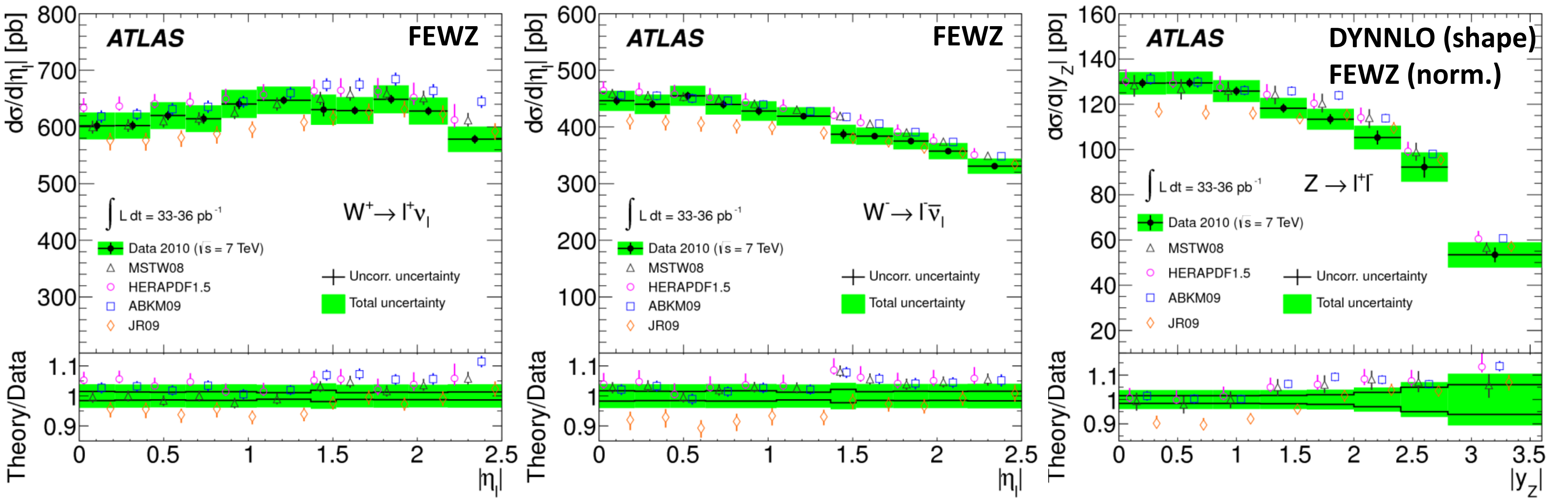
Differential cross-sections



- Vector boson rapidity (y) is sensitive to PDFs:
  - $x \in \left[e^{-y}\frac{M_{W,Z}}{\sqrt{s}}..e^{+y}\frac{M_{W,Z}}{\sqrt{s}}\right]$, where x is the parton momentum fraction:
- For W's, it's easier to work with lepton pseudorapidity (η_l)
  - No need to guess the right solution for neutrino p_Z component



Overall, there is good agreement with NNLO predictions, although there is tension with some PDF choices:

- JR09 predicts lower Z cross-section at central rapidities
- ABKM09 overshoots W cross-section at larger $|\eta_l|$

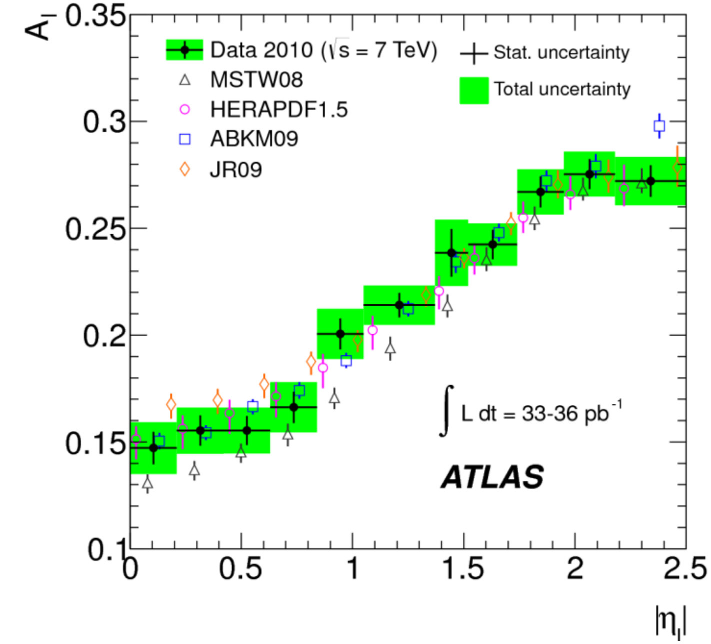
arXiv:1109.5141

W charge asymmetry

$$A_\ell(\eta_\ell) = \frac{d\sigma_{W^+}/d\eta_\ell - d\sigma_{W^-}/d\eta_\ell}{d\sigma_{W^+}/d\eta_\ell + d\sigma_{W^-}/d\eta_\ell}$$

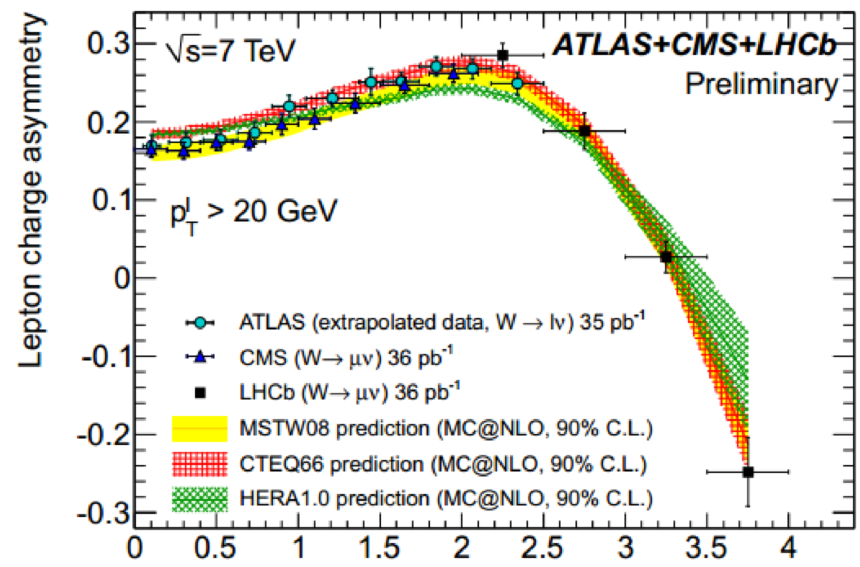
Motivation:

- Another way to cast differential cross-section results
- Convenient probe of PDF structure
  - Sensitive to x ≈ 0.001 – 0.1, where PDFs are not strongly constrained by DIS (HERA).
  - Many systematics cancel



Measurement:

- Largely statistically limited
- ABKM09 and HERAPDF give the best agreement.
- ATLAS+CMS+LHCb combination →
- First useful PDF constraint from LHC (→NNPDF2.2)

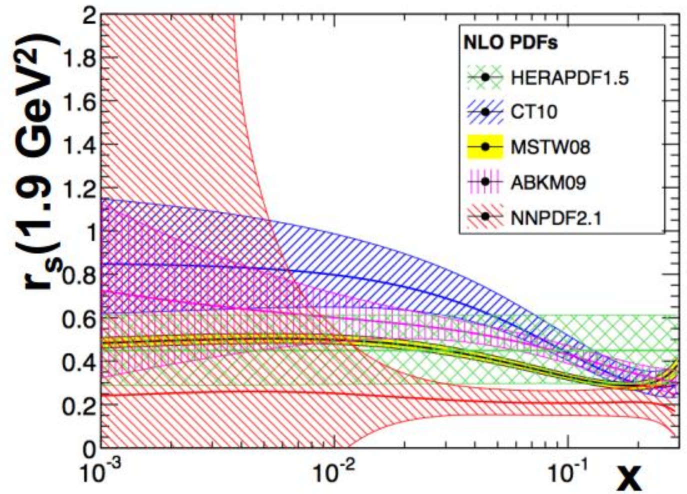


arXiv:1109.5141; ATLAS-CONF-2011-129

Strange quark density

- Flavor SU(3) symmetry → equal proportions of light sea quarks (u,d,s)
  - However, strange is much heavier and may be suppressed
- Experimental constraints on s(x) are highly uncertain:
  - DIS experiments at HERA are not very sensitive to s(x)
  - Results from neutrino scattering are subject to nuclear corrections
- Large variability in PDF predictions for strange-dbar ratio (r_s):

➢ $r_s(x, Q^2) = \frac{1}{2}\frac{[s(x)+\bar{s}(x)]}{\bar{d}(x)}$



We perform a new NNLO fit (in HERAFitter framework) to assess sensitivity of ATLAS data. The fit is simultaneously performed on:

- Combined HERA-1 DIS data, 1992-2000
- ATLAS W^+,W^-,Z data (differential cross-section data in bins of η_l and y_Z)

Outcome of the fit: a new "epWZ" PDF set.

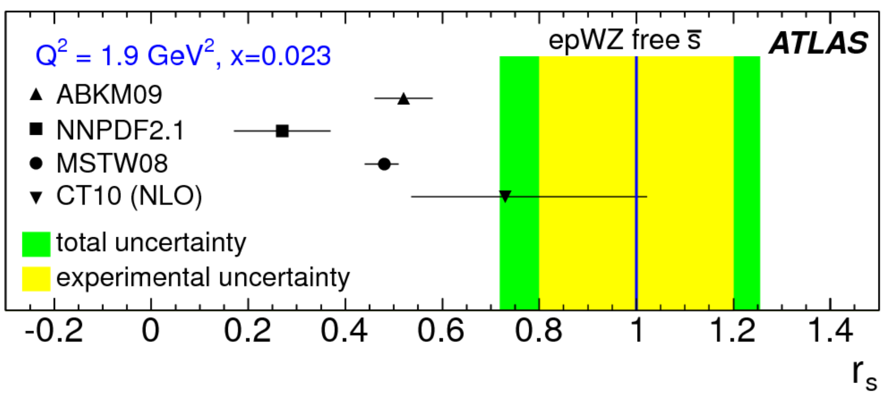
arXiv:1203.4051

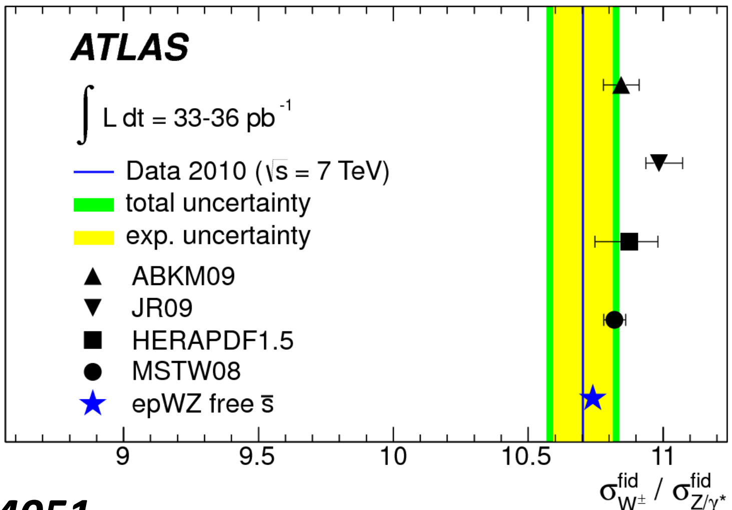
Strange quark density: results

- The new combined epWZ PDF corresponds to:

$$r_s = 1.00 \pm 0.20_{\rm exp} \pm 0.07_{\rm mod}{}^{+0.10}_{-0.15}{}_{\rm par}{}^{+0.06}_{-0.07}{}_{\alpha_S} \pm 0.08_{\rm th}$$ (at Q^2=1.9 GeV^2 and x=0.023)

- Uncertainty on r_S is dominated by the uncertainties on W and Z differential cross-sections
- Most of the sensitivity comes from Z rapidity distribution
- Existing NNLO and NLO PDFs show tension with epWZ result
  - They tend to cluster around r_S=0.5 (at the initial evolution scale)
- Using combined epWZ PDF to re-derive the ratio of W to Z cross-sections (right figure) results in nearly-perfect agreement with data.





arXiv:1203.4051

Conclusions

- W and Z measurements provide stringent tests for electroweak theory predictions and give us confidence that we understand the detector
- In this talk, I presented a selection of ATLAS results:
  - Total and differential W and Z cross-sections
  - Ratios of W^+/W^- and W/Z cross-sections
  - Tests of lepton universality
  - W charge asymmetry and first PDF constraints from LHC
  - Novel sensitivity to strange quark density
- Much larger 2011 (and 2012!) datasets will explore more differential distributions, substantially expand kinematic reach of the measurements, and reduce statistical and some of the systematic uncertainties.

BACKUP SLIDES

Inclusive cross-section values

Common fiducial region

$\sigma_W^{fid} \cdot$ **BR**$(W \to \ell\nu)$ **[nb]** $\lvert\eta_\ell\rvert < 2.5$, $p_{T,\ell} > 20$ GeV, $p_{T,\nu} > 25$ GeV and $m_T > 40$ GeV					
		sta	sys	lum	acc
W^+	3.110	± 0.008	± 0.036	± 0.106	± 0.004
W^-	2.017	± 0.007	± 0.028	± 0.069	± 0.002
$W^\pm$	5.127	± 0.011	± 0.061	± 0.174	± 0.005
$\sigma_{Z/\gamma^*}^{fid} \cdot$ **BR**$(Z/\gamma^* \to \ell\ell)$ **[nb]** $\lvert\eta_\ell\rvert < 2.5$, $p_{T,\ell} > 20$ GeV and $66 < m_{\ell\ell} < 116$ GeV					
		sta	sys	lum	acc
Z/γ^*	0.479	± 0.003	± 0.005	± 0.016	± 0.001

Extrapolation to total phase space

$\sigma_W^{tot} \cdot$ **BR**$(W \to \ell\nu)$ **[nb]**					
		sta	sys	lum	acc
W^+	6.048	± 0.016	± 0.072	± 0.206	± 0.096
W^-	4.160	± 0.014	± 0.057	± 0.141	± 0.083
$W^\pm$	10.207	± 0.021	± 0.121	± 0.347	± 0.164
$\sigma_{Z/\gamma^*}^{tot} \cdot$ **BR**$(Z/\gamma^* \to \ell\ell)$ **[nb]** $66 < m_{\ell\ell} < 116$ GeV					
		sta	sys	lum	acc
Z/γ^*	0.937	± 0.006	± 0.009	± 0.032	± 0.016

Inclusive cross-section systematics

Electron channel:

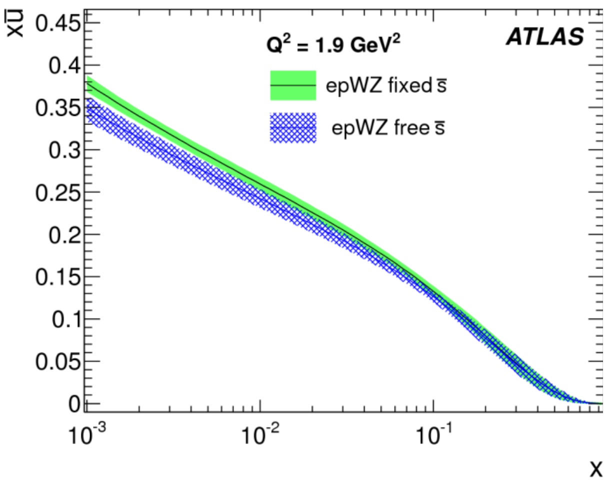
	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W+}$	$\delta\sigma_{W-}$	$\delta\sigma_Z$
Trigger	0.4	0.4	0.4	<0.1
Electron reconstruction	0.8	0.8	0.8	1.6
Electron identification	0.9	0.8	1.1	1.8
Electron isolation	0.3	0.3	0.3	—
Electron energy scale and resolution	0.5	0.5	0.5	0.2
Non-operational LAr channels	0.4	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_T^{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			

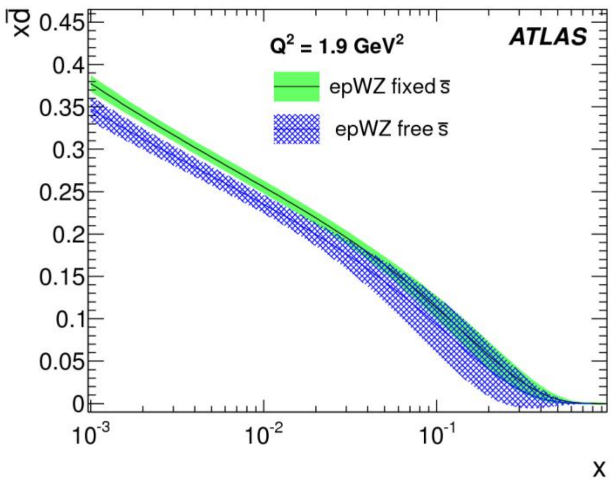
Muon channel:

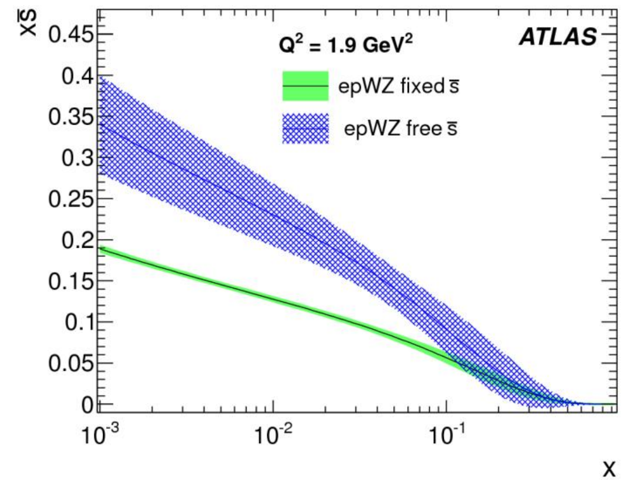
	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W+}$	$\delta\sigma_{W-}$	$\delta\sigma_Z$
Trigger	0.5	0.5	0.5	0.1
Muon reconstruction	0.3	0.3	0.3	0.6
Muon isolation	0.2	0.2	0.2	0.3
Muon p_T resolution	0.04	0.03	0.05	0.02
Muon p_T scale	0.4	0.6	0.6	0.2
QCD background	0.6	0.5	0.8	0.3
Electroweak+$t\bar{t}$ background	0.4	0.3	0.4	0.02
E_T^{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			

Strange quark density: fitted PDF curves

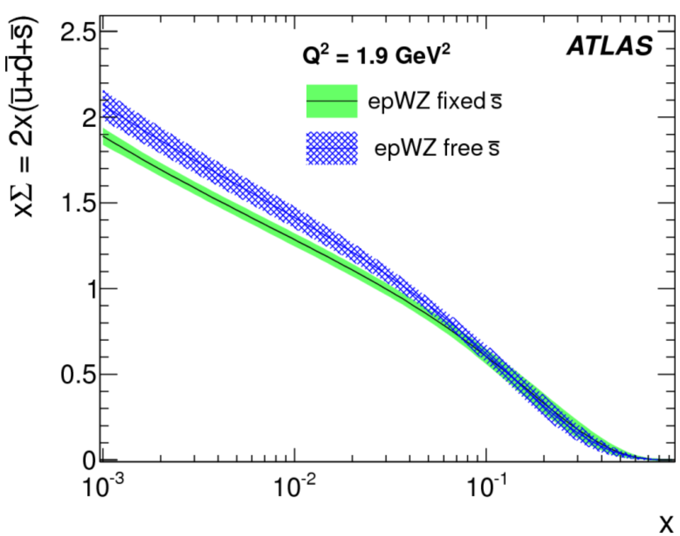
Modification of light sea densities if strange-to-dbar ratio is allowed to float:





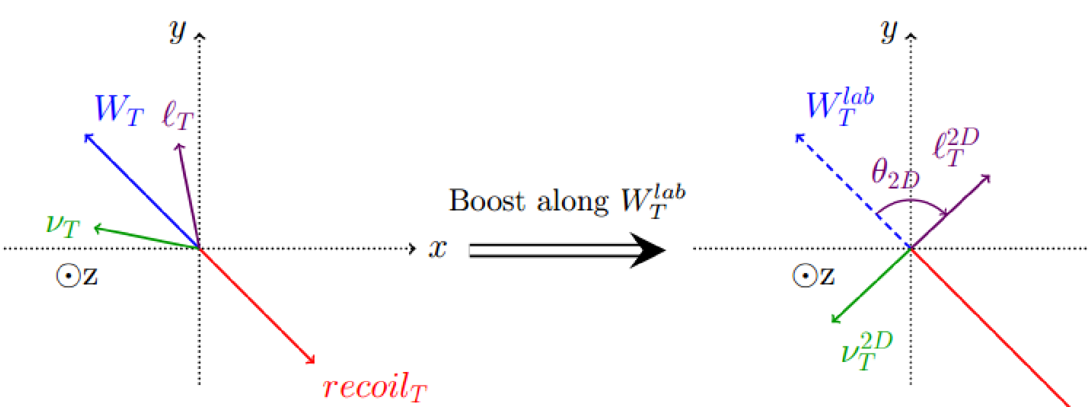


Change in the total light sea: enhancement by ~8%)

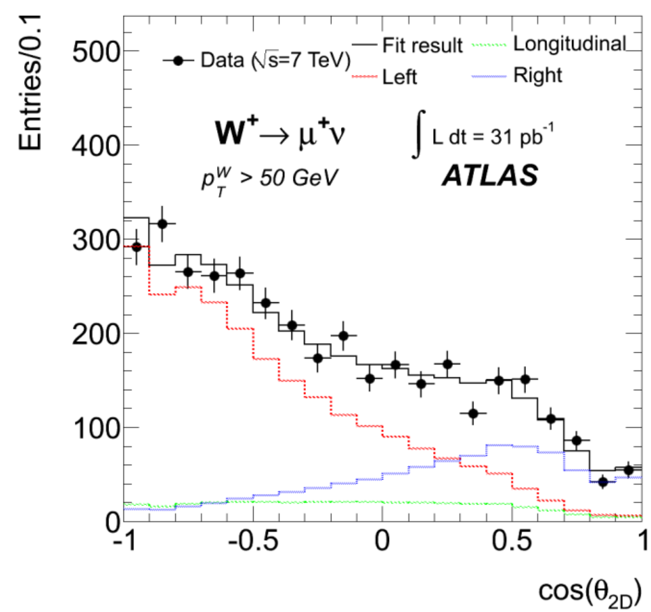


W polarization

- W boson has 3 helicity states, with fractions f_L, f_R, f_0 (longitudinal)
- Helicity predictions are more challenging (and interesting) for high-p_T W's that involve gluons: $ug \to W^+ d$, $u\bar{d} \to W^+ g$ and $g\bar{d} \to W^+ \bar{u}$
- Each helicity state has characteristic angular decay kinematics
- Perform template fit to a variable sensitive to angular kinematics:
  - $\cos(\theta_{3D})$ – angle between W direction (lab frame) and lepton (W rest frame)
- Experimentally, it's easier to work with a transverse angle $\cos(\theta_{2D})$
  - Doesn't suffer from neutrino p_Z ambiguity
  - End result unfolded back to "full helicity"



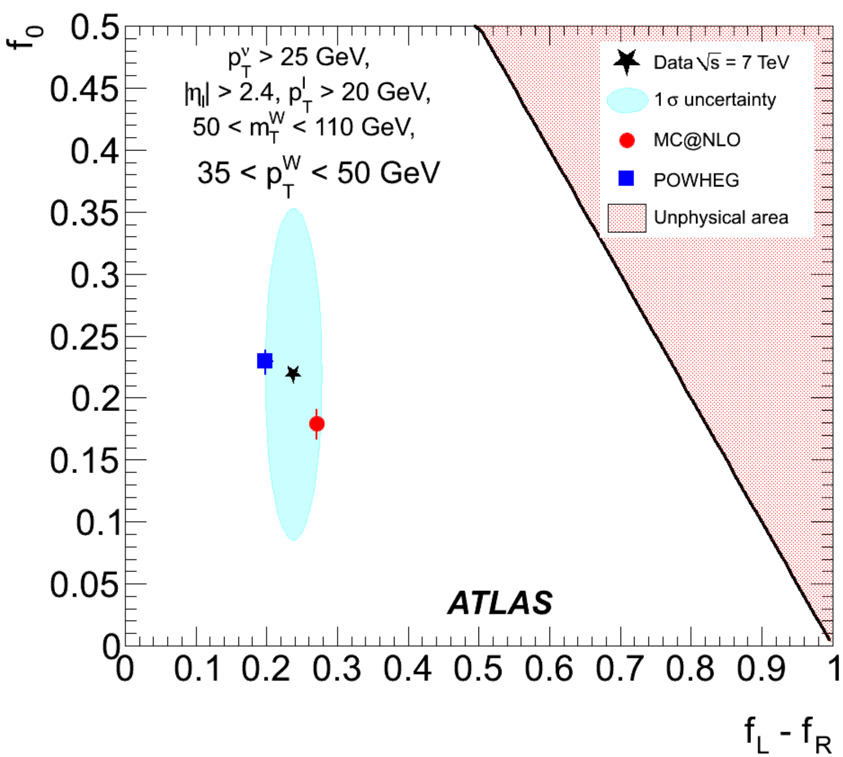
J-B. Blanchard

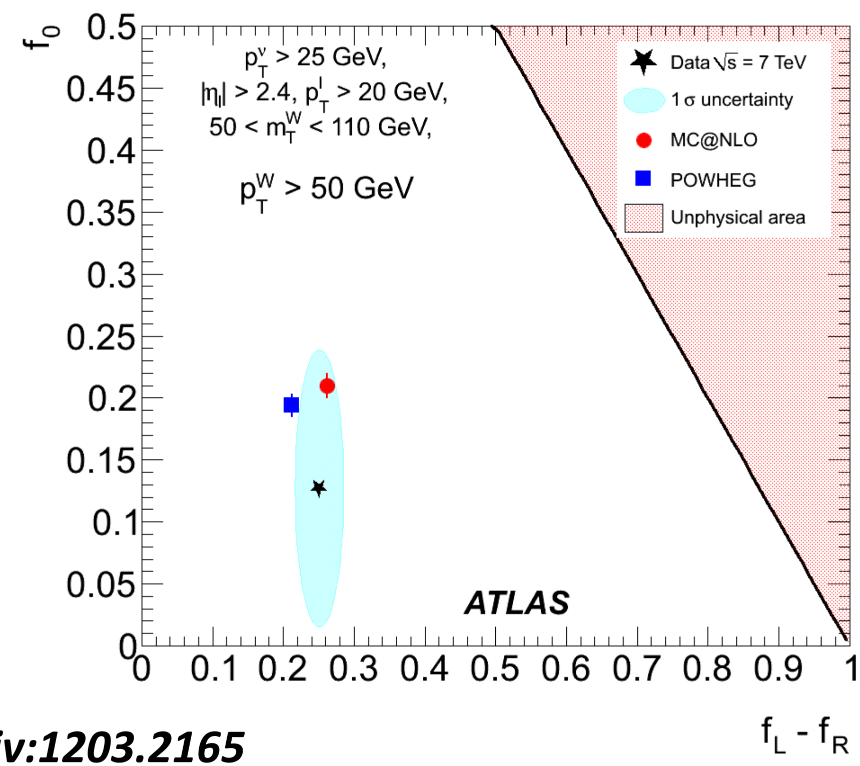


arXiv:1203.2165

W polarization - results

- Measurements performed separately in two p_T^W bins
- Results are averaged over lepton flavors and charges.
- Main systematics: recoil energy scale (i.e. jets); lepton energy scale
- Good agreement with theoretical predictions:
  - Low p_T^W bin: compatible with both MC@NLO and POWHEG
  - High p_T^W bin: data favors somewhat lower values of f_0





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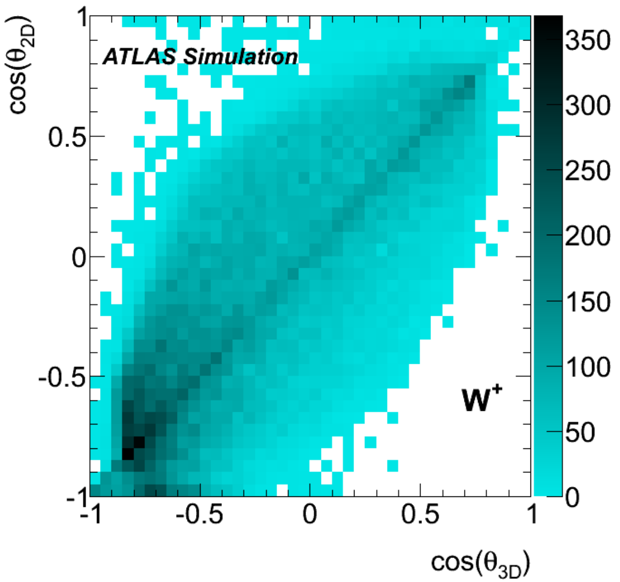
W polarization

Results numerically. First uncertainty is statistical, second is systematic

	$f_L - f_R$		f_0	
	$35 < p_T^W < 50$ GeV	$p_T^W > 50$ GeV	$35 < p_T^W < 50$ GeV	$p_T^W > 50$ GeV
Data	$23.8 \pm 2.0 \pm 3.4$	$25.1 \pm 1.7 \pm 3.0$	$21.9 \pm 3.3 \pm 13.4$	$12.7 \pm 3.0 \pm 10.8$
MC@NLO	27.1 ± 0.7	26.2 ± 0.5	17.9 ± 1.2	21.0 ± 1.0
POWHEG	19.9 ± 1.0	21.2 ± 0.8	22.9 ± 1.0	19.4 ± 0.8

$\cos(\theta_{3D})$ vs $\cos(\theta_{2D})$ in MC:



Systematics uncertainties:

		$35 < p_T^W < 50$ GeV				$p_T^W > 50$ GeV			
		μ^+	μ^-	e^+	e^-	μ^+	μ^-	e^+	e^-
EW background	δf_0	0.5	0.6	0.3	0.4	0.6	0.6	0.3	0.5
	$\delta(f_L - f_R)$	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.2
jet background	δf_0	1.5	1.5	1.5	1.5	2.3	1.3	2	2
	$\delta(f_L - f_R)$	0.3	0.7	1.5	1.5	1.2	1.3	1.5	1.5
p_T^ℓ scale	δf_0	$\mp$ 4.5	$\mp$ 5.0	$\mp$ 4.5	$\mp$ 4.5	$\mp$ 3.5	$\mp$ 3.5	$\mp$ 3.5	$\mp$ 4.5
	$\delta(f_L - f_R)$	$\mp$ 2.5	$\pm$ 2.0	$\mp$ 2.5	$\pm$ 2.0	$\mp$ 1.5	$\pm$ 1.5	$\mp$ 2.0	$\pm$ 1.5
	$\delta(f_L - f_R)_{mean}$	1.1		0.4		0.1		0.4	
Recoil scale	δf_0	$\pm$ 12.5	$\pm$ 16.8	$\pm$ 12.5	$\pm$ 13.3	$\pm$ 8.1	$\pm$ 10.2	$\pm$ 9.4	$\pm$ 11.1
	$\delta(f_L - f_R)$	$\pm$ 9.9	$\mp$ 10.4	$\pm$ 10.9	$\mp$ 9.5	$\pm$ 7.7	$\mp$ 7.7	$\pm$ 8.2	$\mp$ 8.2
	$\delta(f_L - f_R)_{mean}$	3.0		2.9		1.2		0.7	
PDF set	δf_0	2.0	2.0	0.4	0.8	2.0	2.0	0.2	0.8
	$\delta(f_L - f_R)$	1.5	1.5	0.5	1.5	1.5	1.5	0.4	1.1
Charge mis-ID	δf_0	–	–	0.2	0.4	–	–	0.2	0.2
	$\delta(f_L - f_R)$			0.3	0.4			0.2	0.3
p_T^ℓ resolution	δf_0	0.1	0.1	0.5	0.5	0.1	0.2	0.2	1.2
	$\delta(f_L - f_R)$	0.1	0.1	0.3	0.3	0.1	0.2	0.2	0.2
p_T^W reweighting	δf_0	2.5	1.1	0.6	0.9	1.9	1.6	0.5	1.2
	$\delta(f_L - f_R)$	$\mp$ 4.9	$\pm$ 5.2	$\mp$ 4.2	$\pm$ 4.0	$\mp$ 2.7	$\pm$ 2.9	$\mp$ 2.6	$\pm$ 2.3
	$\delta(f_L - f_R)_{mean}$	0.2		0.1		0.1		0.2	