Impact of luminosity precision on ATLAS SM physics

focus on W, Z measurements

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on behalf of the ATLAS Collaboration

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LHC Lumi Days 2012

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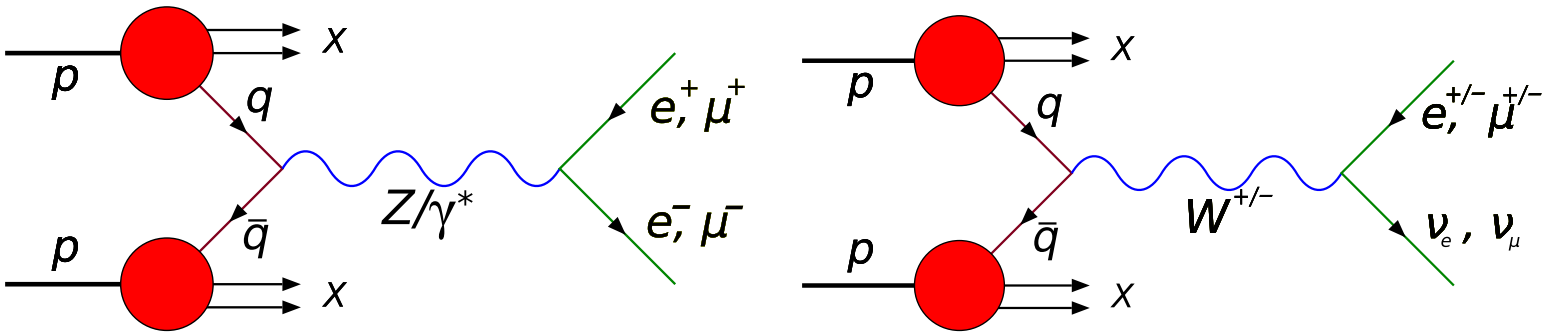
Precision of SM cross-section measurements

- Top-pair and W,Z+jets cross-sections are still at the level of $8, > 9\%$ precision
- Inclusive di-bosons measurements follows with $5 - 7\%$ uncertainties
- Inclusive single-bosons measurements are the most precise results, $1 - 2\%$

cross-section	n-lep	$\mathcal{L}$	Syst.	Syst. sources	Refs.
$\sigma_{t\bar{t}}$	2 lep	$35\,pb^{-1}$	$\sim 8\,\%$	b-tagging, MC	1108.3699
σ_{W+jets}	1 lep	$36\,pb^{-1}$	$\sim 9\,\%$ $N_{jets} \geq 1$	JES, lep-id	1201.1276
			$\sim 35\,\%$ $N_{jets} \geq 4$		
σ_{Z+jets}	2 lep	$36\,pb^{-1}$	$\sim 9\,\%$ $N_{jets} \geq 1$	JES, lep-id	1111.2690
			$\sim 23\,\%$ $N_{jets} \geq 4$		
σ_{WZ}	3 lep	$1.02\,fb^{-1}$	$\sim 7\,\%$	lep-id, $E_{\mathrm{T}}^{\mathrm{miss}}$	1111.5570
σ_{ZZ}	4 lep	$1.02\,fb^{-1}$	$\sim 4.6\,\%$	lep-id	1110.5016
σ_W	1 lep	$35\,pb^{-1}$	$\sim 1.2\,\%$ fid.	lep-id, $E_{\mathrm{T}}^{\mathrm{miss}}$, QCD	1109.5141
			$\sim 2.0\,\%$ tot.		
σ_Z	2 lep	$35\,pb^{-1}$	$\sim 1.0\,\%$ fid.	lep-id, isol, QCD	1109.5141
			$\sim 2.0\,\%$ tot.		

W and Z production at LHC

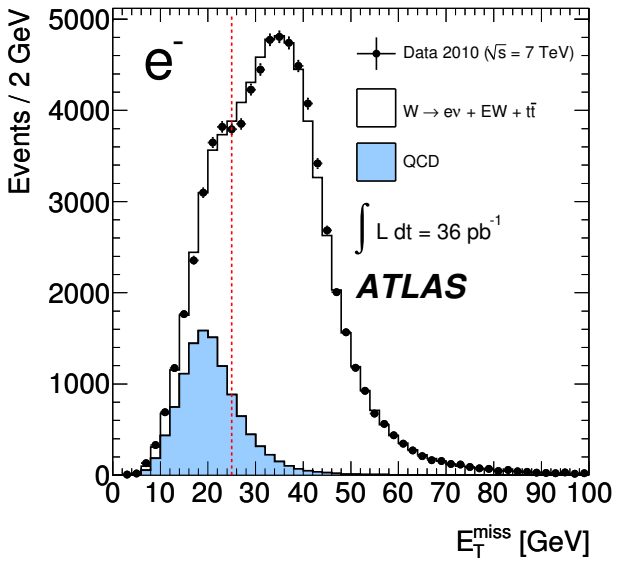
- Drell-Yan production of W and Z bosons calculable to high orders in pQCD
- An interesting testing ground of PDFs and their evolution to high Q^2 scale

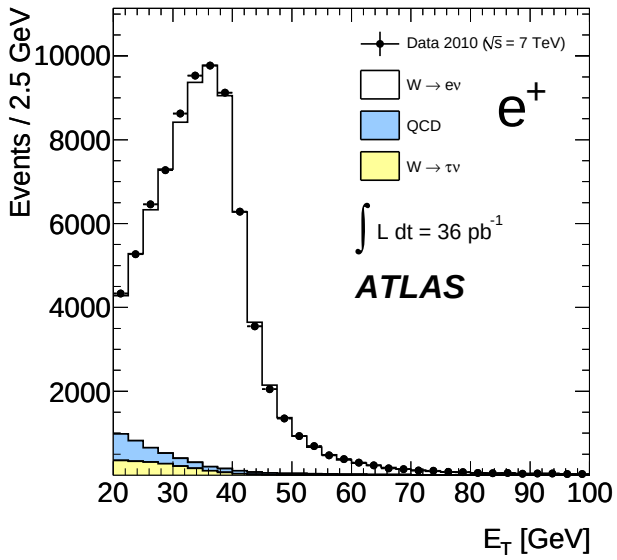


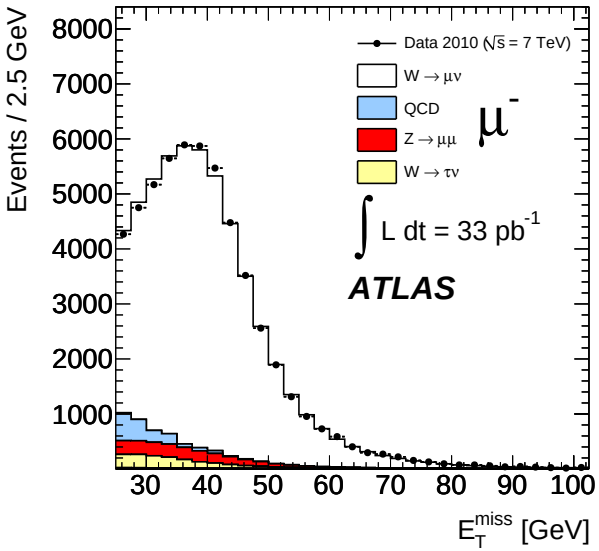
- Inclusive W and Z production with $Q^2 \sim M^2_{W/Z}$ and $10^{-3} < \bar{x} < 10^{-1}$
- Need most accurate theory predictions to match experimental precision, e.g. σ_{tot}, σ_{fid} calculated with `FEWZ`, `DYNNLO` NNLO tools
  - scale uncertainties at level of $0.6\,\%$ (using `MSTW08` PDFs)
  - agreement between codes of $0.5 - 1.0\,\%$ for total and fiducial cross-sections
  - missing pure weak effects impact at level of $0.5\,\%$
- Theoretical uncertainty on $\hat{\sigma}_{W,Z}$ at the level of $1 - 1.5\,\%$

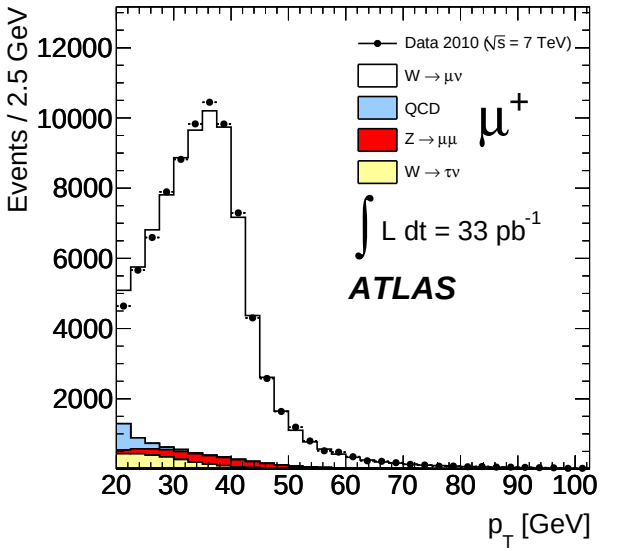
$W \to \ell\nu$ selection

- Single lepton triggers with high efficiency
- $p_{T,l} > 20\,GeV$
  $|\eta_e| < 2.47$, $|\eta_\mu| < 2.4$
  (elec. excl. calo crack)
  isolated leptons
  $E_{\mathrm{T}}^{\mathrm{miss}} > 25\,GeV$
  $m_T > 40\,GeV$
- QCD from data fitting $E_{\mathrm{T}}^{\mathrm{miss}}$ (e) and studying control regions in $iso - E_{\mathrm{T}}^{\mathrm{miss}}$ plane (μ)
- $131 - 140\,K$ candidates with $7 - 9\,\%$ background



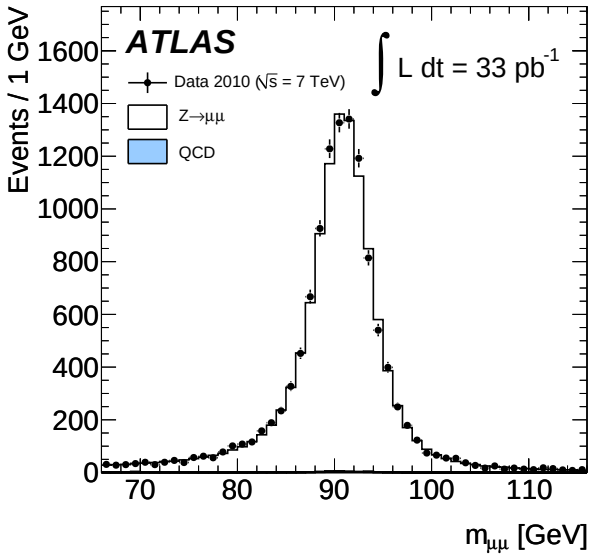


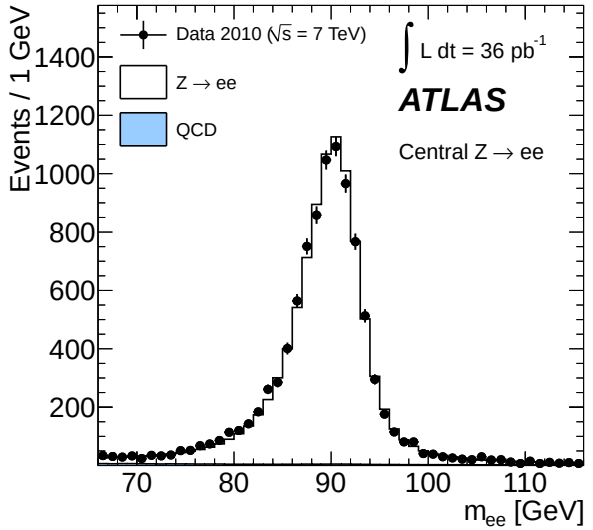


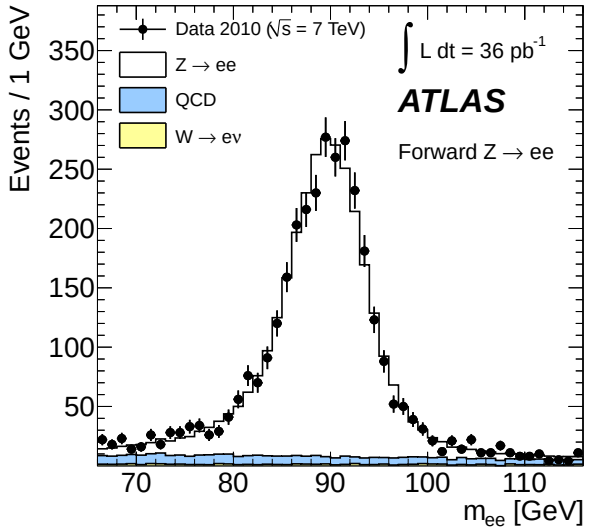


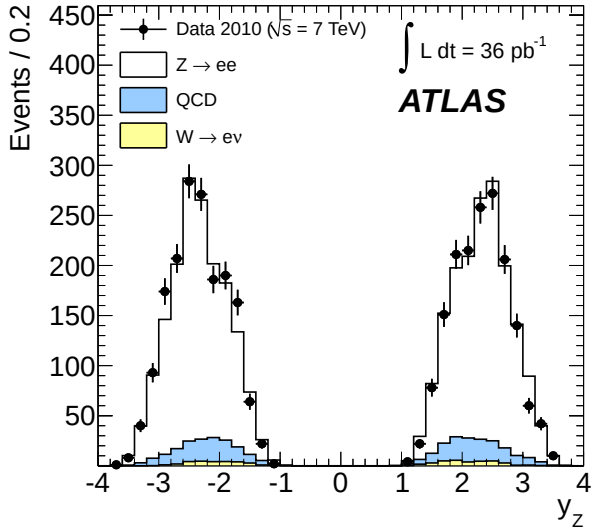
$Z \to \ell\ell$ selection

- Single lepton triggers with high efficiency
- $p_{T,l} > 20\,GeV$
  $|\eta_e| < 2.47$, $|\eta_\mu| < 2.4$
  (elec. excl. calo crack)
  isolated leptons
  opposite charge
  $66 < m_{\ell\ell} < 116\,GeV$
- QCD from data fitting $m_{\ell\ell}$ lineshape and studying control regions in $(iso, m_{\ell\ell})$
- $\sim 10 - 12\,K$ candidates with $1 - 2\,\%$ background









Electron and muon systematics uncertainties

- $\delta\sigma_{W\to e\nu}$ of $1.8-2.1\,\%$, dominated by electron reconstruction, identification and $E_{\mathrm{T}}^{\mathrm{miss}}$
- $\delta\sigma_{Z\to ee}$ of $2.7\,\%$, dominated by el. reconstruction and identification

Electron channels (%)	$W^{\pm}$	W^{+}	W^{-}	Z
Trigger	0.4	0.4	0.4	<0.1
Reconstruction	0.8	0.8	0.8	1.6
Identification	0.9	0.8	1.1	1.8
Isolation	0.3	0.3	0.3	—
Energy scale and resolution	0.5	0.5	0.5	0.2
Defective LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	<0.1	0.1	0.1	0.6
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.8	0.7	1.0	—
Pile-up	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
QCD Background	0.4	0.4	0.4	0.7
EWK+$t\bar{t}$ Background	0.2	0.2	0.2	<0.1
$C_{W/Z}$ Theor. uncertainty	0.6	0.6	0.6	0.3
Total Exp. uncertainty	**1.8**	**1.8**	**2.0**	**2.7**
$A_{W/Z}$ Theor. uncertainty	1.5	1.7	2.0	2.0
Total excluding Luminosity	2.3	2.4	2.8	3.3

- $\delta\sigma_{W\to\mu\nu}$ of $1.6-1.7\,\%$, dominated by muon efficiencies, QCD background and $E_{\mathrm{T}}^{\mathrm{miss}}$
- $\delta\sigma_{Z\to\mu\mu}$ of $0.9\,\%$, dominated by muon efficiencies

Muon channels (%)	$W^{\pm}$	W^{+}	W^{-}	Z
Trigger	0.5	0.5	0.5	0.1
Reconstruction	0.4	0.3	0.3	0.6
Isolation	0.2	0.1	0.2	0.3
p_{T} Resolution	0.04	0.03	0.05	0.02
p_{T} Scale	0.4	0.6	0.6	0.2
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.5	0.4	0.6	-
Pile-up	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
QCD Background	0.6	0.5	0.8	0.3
EWK+$t\bar{t}$ Background	0.4	0.3	0.4	0.02
$C_{W/Z}$ Theor. uncertainty	0.8	0.8	0.7	0.3
Total Exp. uncertainty	**1.6**	**1.7**	**1.7**	**0.9**
$A_{W/Z}$ Theor. uncertainty	1.5	1.6	2.1	2.0
Total excluding Luminosity	2.1	2.3	2.6	2.2

Acceptance theoretical uncertainties

- **Fiducial cross section** corrected for efficiency factor ($C_{W/Z}$), adjusted to data/MC differences

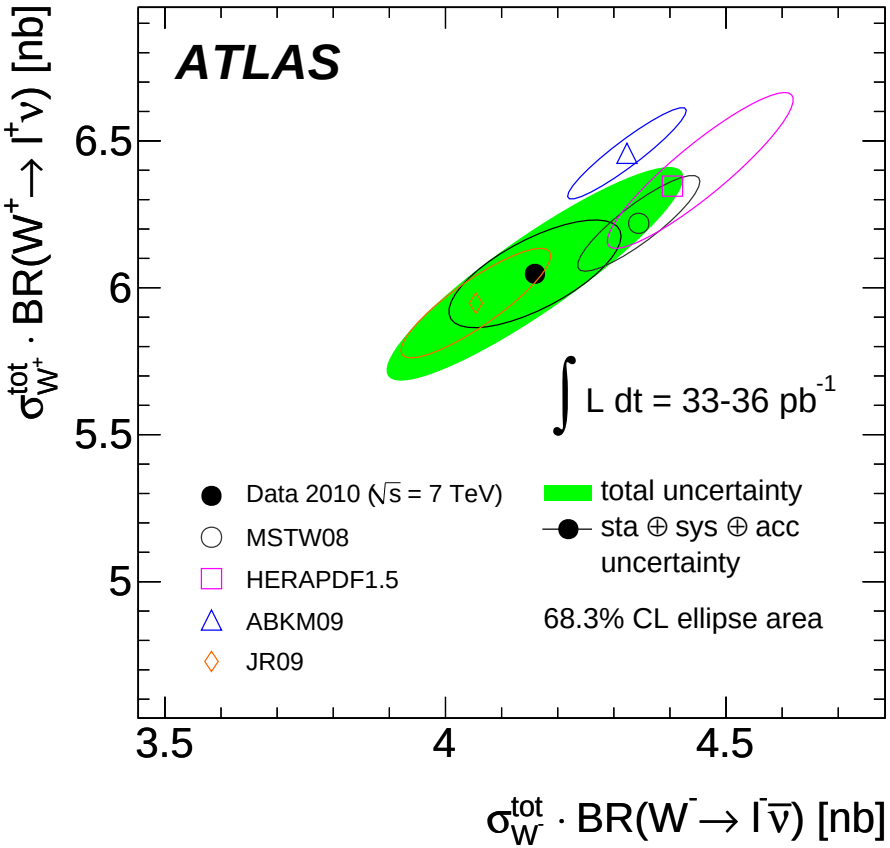
$$\sigma_{fid} = \frac{N - B}{C_{W/Z} \cdot L_{int}}, \quad \sigma_{tot} = \frac{\sigma_{fid}}{A_{W/Z}}$$

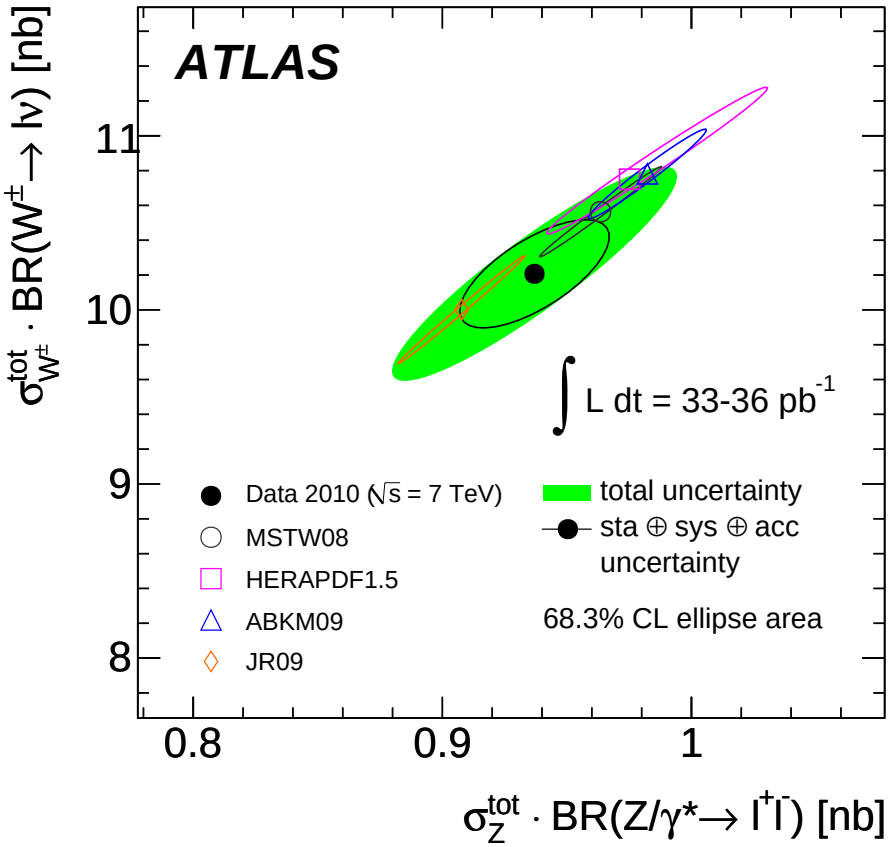
- **Total cross section** corrected for acceptance ($A_{W/Z} \sim 0.45 - 0.50$) based on MC@NLO and CTEQ 6.6 NLO PDF set
- Theoretical uncert. on $A_{W/Z}$ from error-set, PDF sets, MC@NLO-POWHEG and PYTHIA-HERWIG POWHEG comparisons ($\delta A_{W^\pm} \sim 1.5\,\%$, $\delta A_Z \sim 2.0\,\%$)

	A	$\delta A^{\mathrm{pdf}}_{\mathrm{err}}$	$\delta A^{\mathrm{pdf}}_{\mathrm{sets}}$	δA_{hs}	δA_{ps}	δA_{tot}
Electron channels						
W^+	0.478	1.0	0.7	0.9	0.8	1.7
W^-	0.452	1.5	1.1	0.2	0.8	2.0
$W^\pm$	0.467	1.0	0.5	0.6	0.8	1.5
Z	0.447	1.7	0.6	0.2	0.7	2.0
Muon channels						
W^+	0.495	1.0	0.8	0.6	0.8	1.6
W^-	0.470	1.5	1.1	0.3	0.8	2.1
$W^\pm$	0.485	1.0	0.5	0.4	0.8	1.5
Z	0.487	1.8	0.6	0.2	0.7	2.0

Theory comparisons - total cross sections

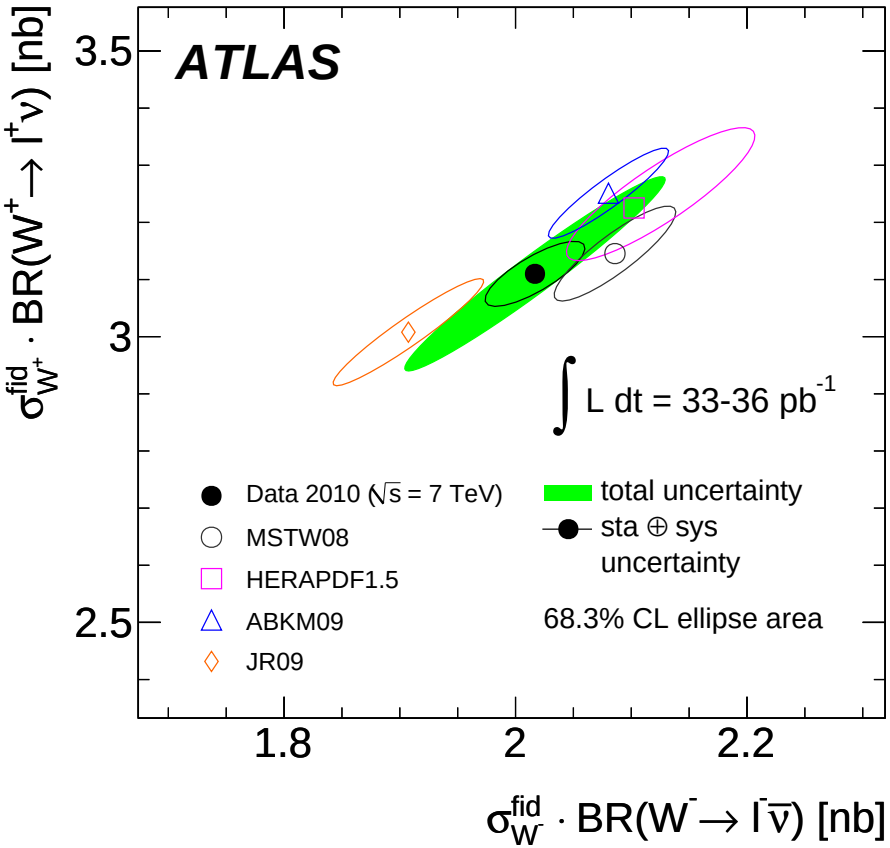
- Overall remarkable agreement with NNLO PDF predictions
- A few differences between different PDFs (w/ only 68 % CL PDF errors)
- Comparing total cross sections, the acceptance uncertainty accounts for effect of different PDFs on the unmeasured phase space ...

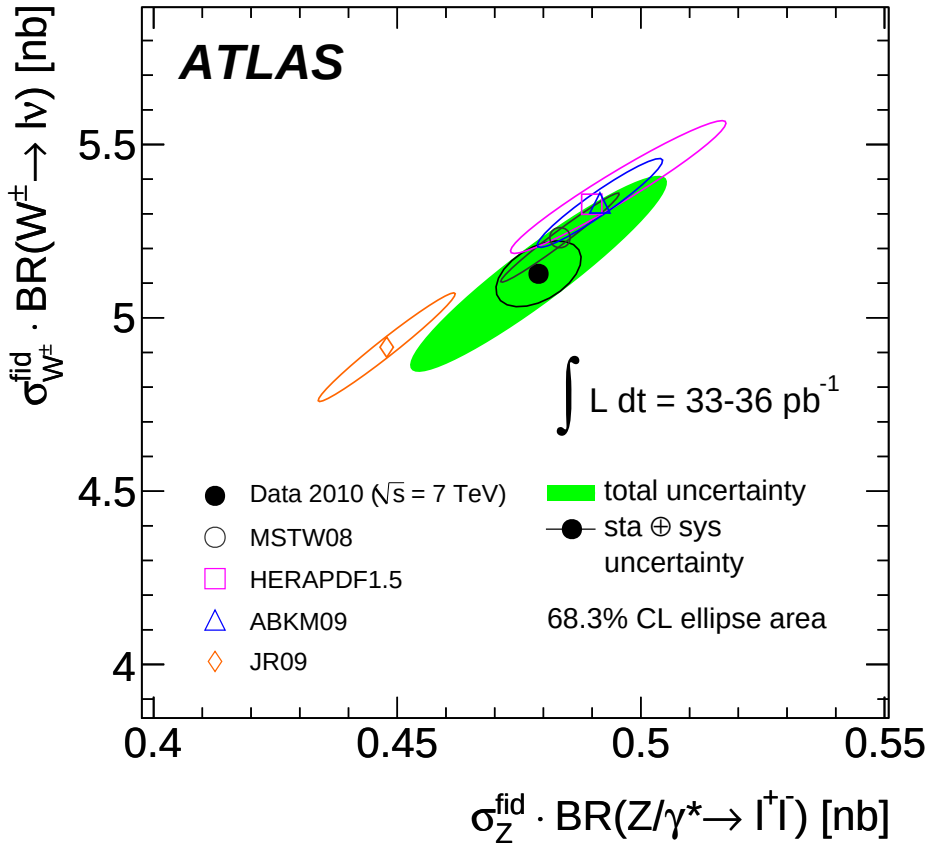




Theory comparisons - **fiducial** cross sections

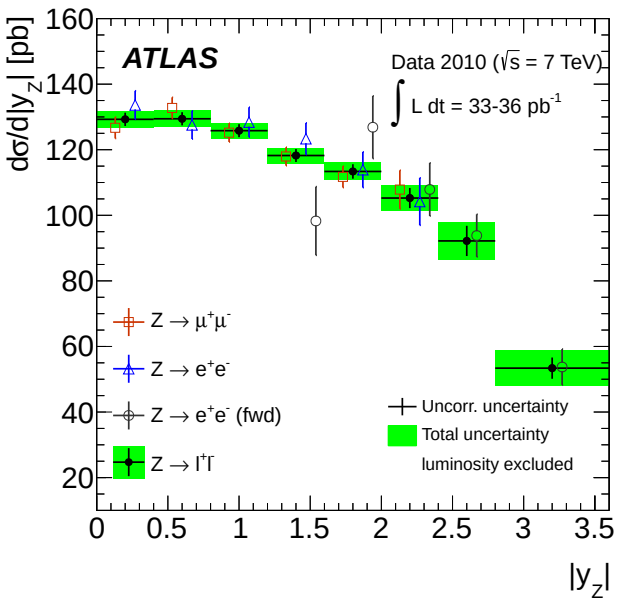
- . . . comparing in the fiducial region disentangles theor. and exp. effects
- This enables more interesting comparisons among different PDF sets
- Improving luminosity uncertainty means shrinking green ellipse to internal one, resulting in very precise constraints on PDFs predictions

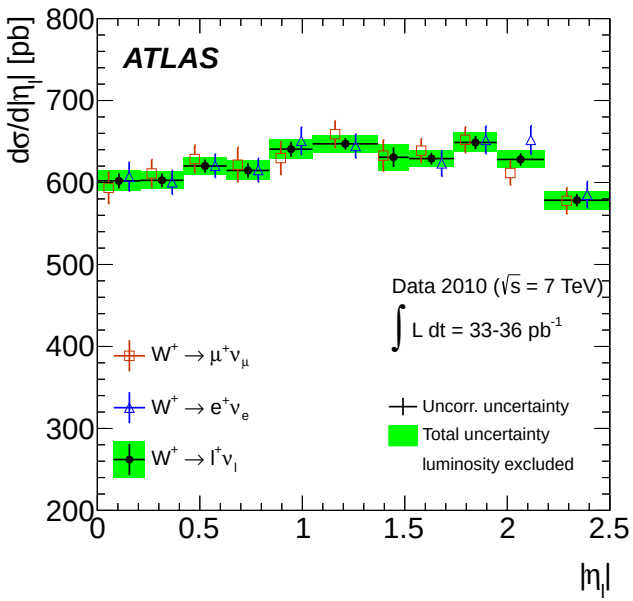


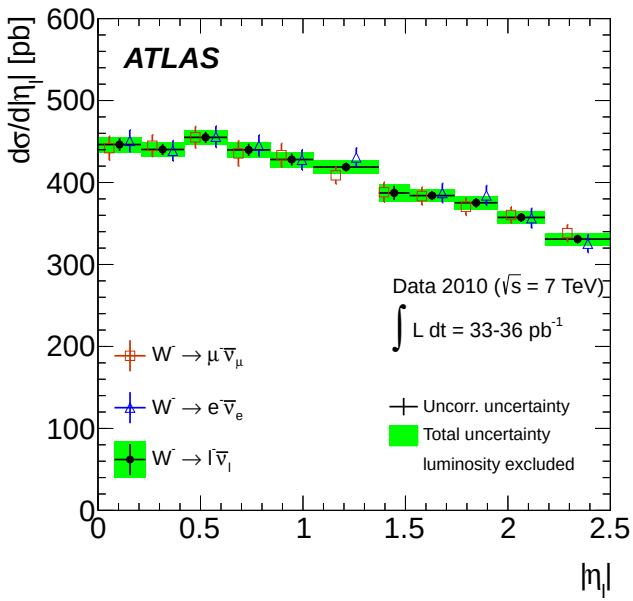


W and Z (pseudo)-rapidity differential cross sections

- Differential $\sigma_{W^\pm}$ and σ_Z measured vs. lepton η and boson rapidity
- Electron and muon measurements combined together with full covariance (meas., bins, channels) matrix available ($\chi^2/N_{DF} = 33.9/29$)
- Z rapidity coverage up to $|y| = 3.5$ including the forward $Z \to ee$ measurement
- Accuracy of $\sim 2\,\%$ in central y_Z and W meas, of $6\,(10)\,\%$ at $y_Z = 2.6\,(3.2)$

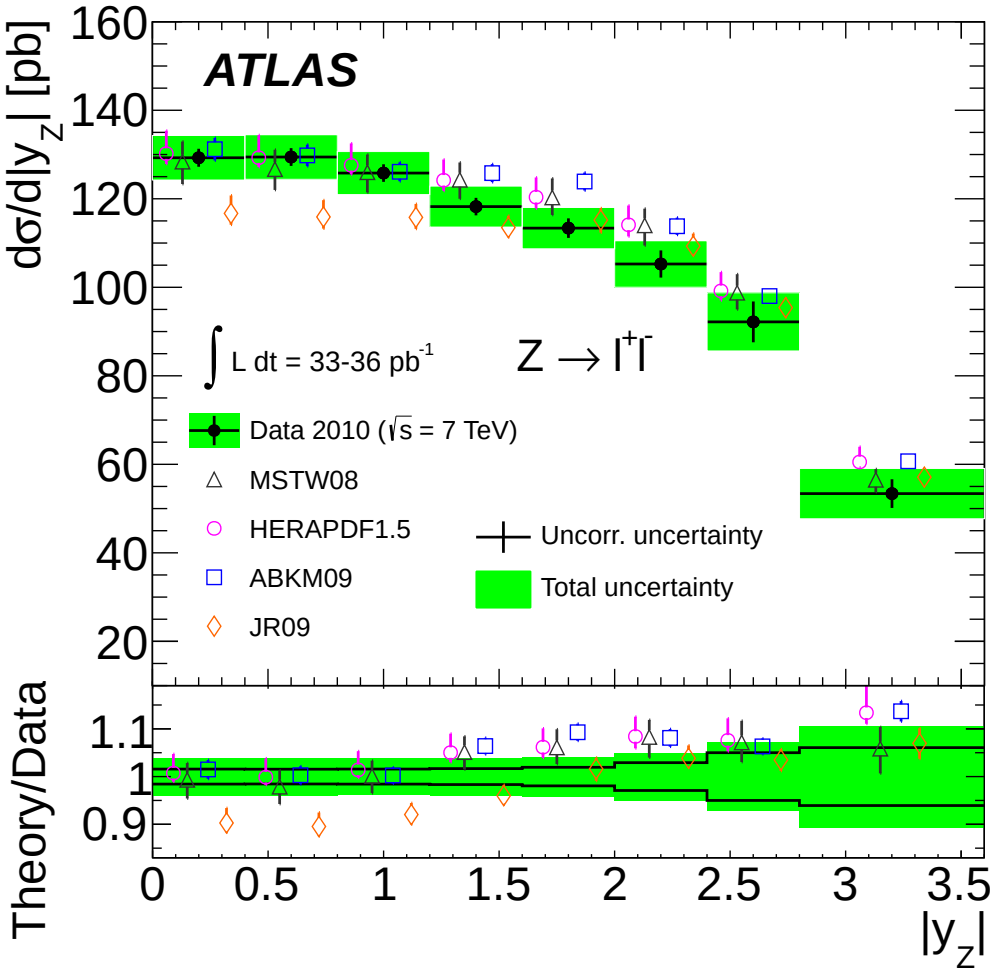






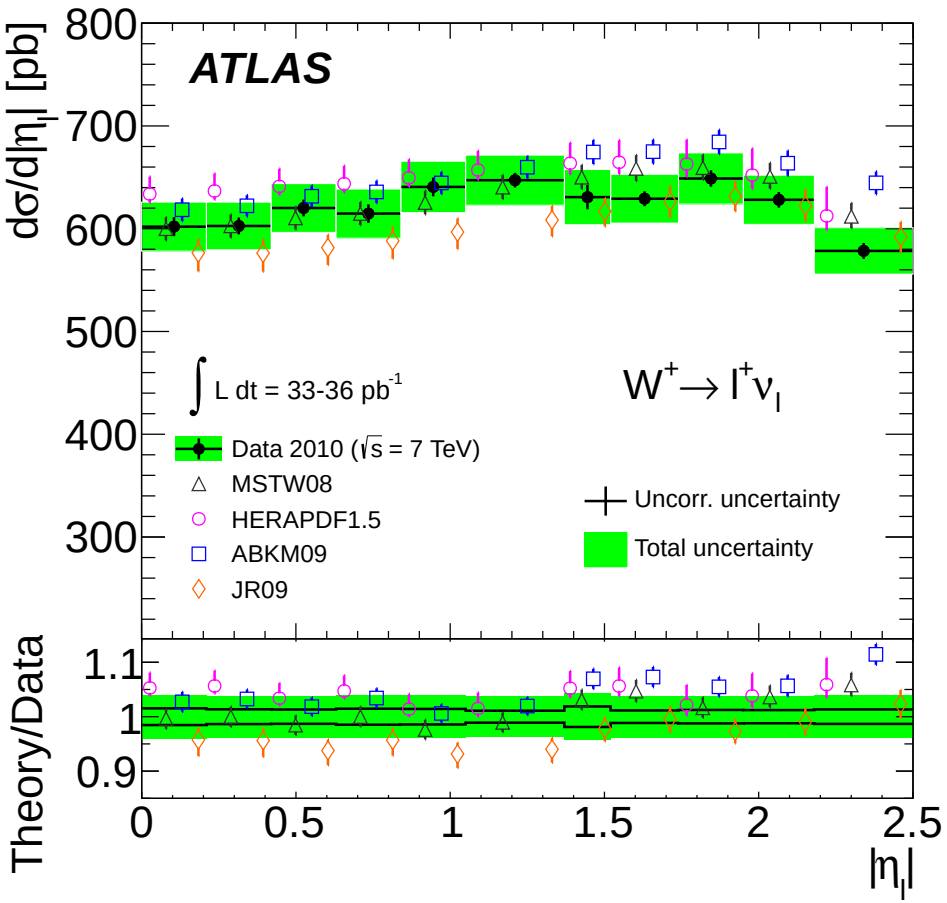
Combined e-mu $d\sigma_Z/dy_Z$ vs PDF predictions to NNLO

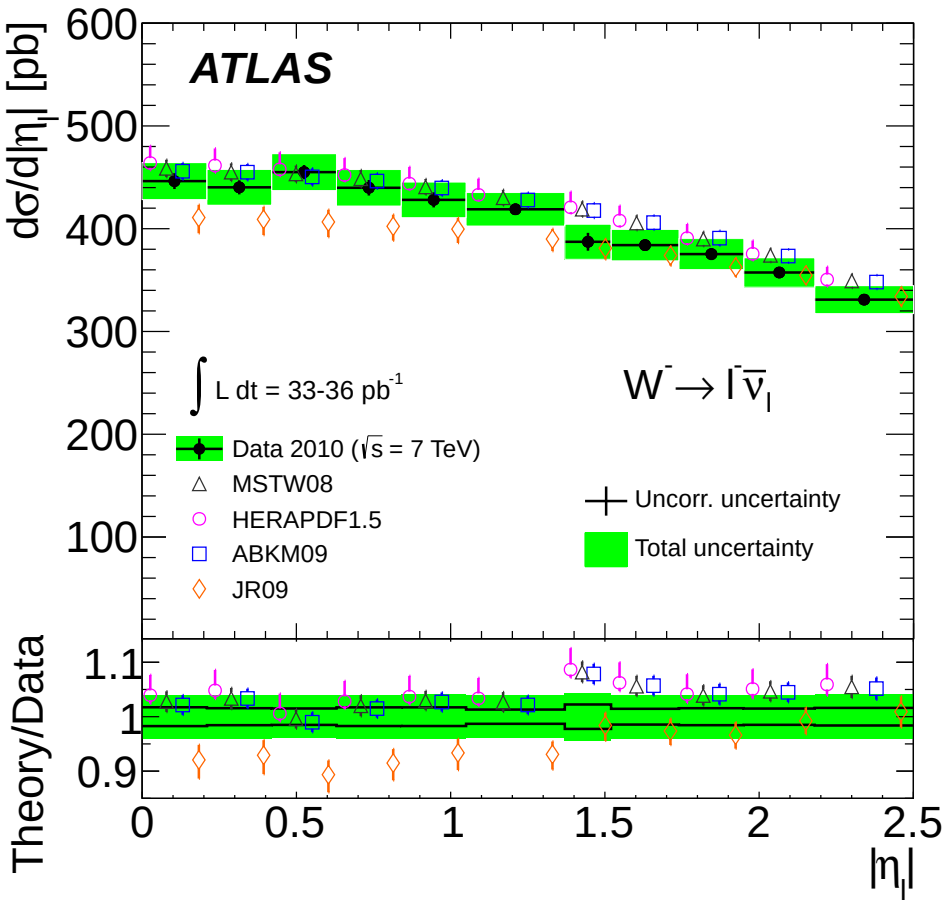
- Measurements can impact on PDF central values and uncertainties
- Bin-by-bin uncorrelated exp. uncertainty in $0.5 - 4.4\,\%$ range, correlated uncer. in $0.9 - 8.1\,\%$ range, plus additional $3.4\,\%$ luminosity uncertainty



Combined e-mu $d\sigma_{W^{\pm}}/d\eta_l$ vs PDF predictions to NNLO

- Measurements can impact on PDF central values and uncertainties
- Bin-by-bin uncorrelated exp. uncertainty in $0.8-1.4\,\%$ range, correlated uncer. in $1.2-1.7\,\%$ range, plus additional $3.4\,\%$ luminosity uncertainty





Prospects for 2011 measurements sensitivity

- Using 2010 W, Z measurements bins
- Assuming improved experimental uncertainties (factor $2-3$)

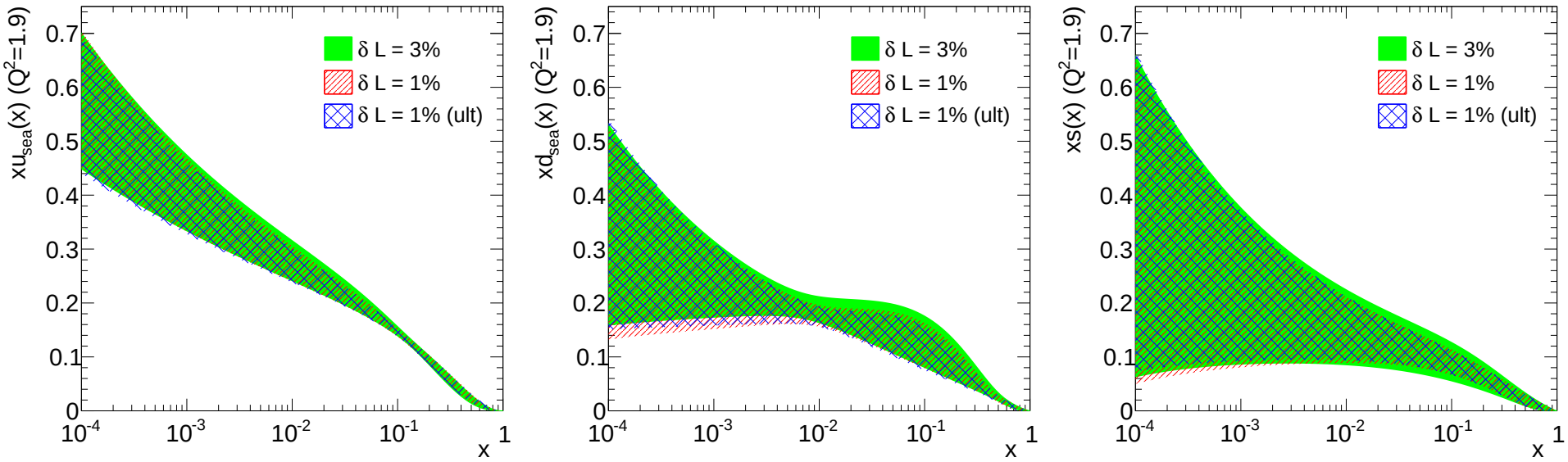
channel	bin uncorr.	bin corr.	W corr.
Z central	0.25%	0.3%	0.3%
Z forward	2%	2%	
W	0.25%	1%	0.3%

- Assuming *ultimate* Z measurement

channel	bin uncorr.	bin corr.	W corr.
Z central	0.25%	0.1%	0.1%
Z forward	1%	1%	

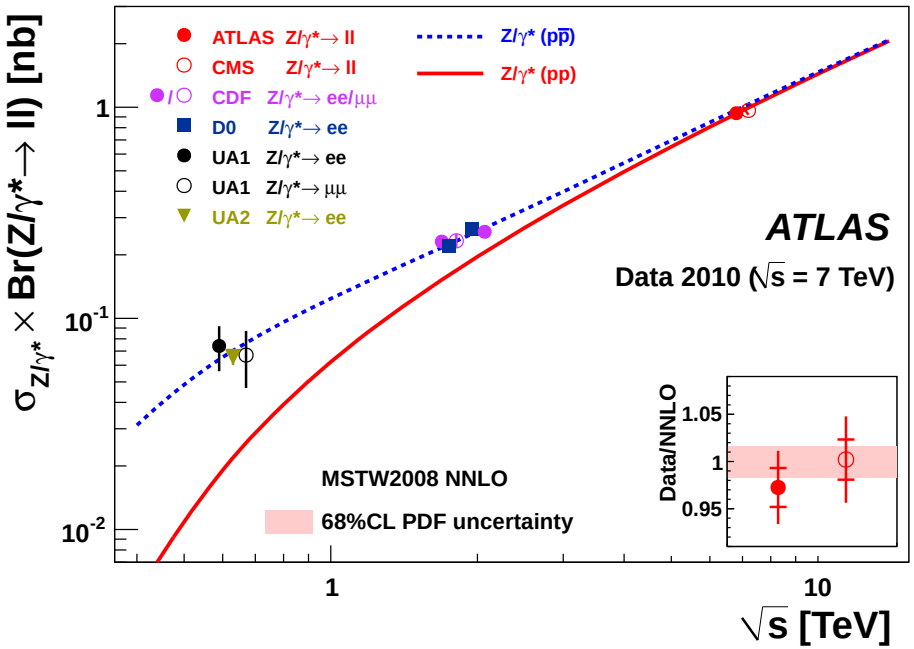
- Combined PDF fit using HERA plus W,Z differential "data" from toy-MC with different uncertainty-scenarios (and no flavour constraints on low x sea)
  - $d\mathcal{L} = 3\,\%$ and improved W, Z measurements
  - $d\mathcal{L} = 1\,\%$ and improved W, Z measurements
  - $d\mathcal{L} = 1\,\%$ and *ultimate* W, Z measurements

Prospects for 2011 measurements sensitivity /2



- Uncertainty reduction in most sensitive region: $x \sim 10^{-2}$ for u_{sea}, d_{sea} and s
- Uncertainties explodes at $x \sim 10^{-4}$ because there is no measurement which would provide flavour separation
- Looking at uncertainty reduction relative to "$d\mathcal{L} = 3\,\%$ and improved W, Z measurements" scenario:
  - $d\mathcal{L} = 1\,\%$ and improved W, Z measurements $\Rightarrow$ $13.8\,\%$, $19.7\,\%$ and $12.9\,\%$
  - $d\mathcal{L} = 1\,\%$ and *ultimate* W, Z measurements $\Rightarrow$ $17.2\,\%$, $23.9\,\%$ and $15.8\,\%$
- Gain most when luminosity uncertainty matches the experimental one

Ratio of cross-sections at $\sqrt{s} = 7$ to $8\,\mathrm{TeV}$



- Measure ratios of cross-sections at $\sqrt{s} = 7$ to $8\,\mathrm{TeV}$ c.m.e.
- It could be an interesting exercise with great cancellation of uncertainties
  - Need to carefully study correlations, on both experimental, theoretical and luminosity sides
- E.g. possibility to compare W at $7\,\mathrm{TeV}$ and Z at $8\,\mathrm{TeV}$ at ~same x value

Concluding remarks

- W and Z inclusive cross section in electron and muon channels measured in 2010 dataset with $\sim 1\%$ experimental precision and $1.5-2\%$ theoretical uncertainty for extrapolation to full-phase space
- Absolute rapidity differential cross sections are measured in electron and muon channels and combined with accuracy of $\sim 2\,\%$ for bulk of measurement bins (central y_Z and all W) and of $6-10\,\%$ for forward Z region
- Partonic W, Z cross-sections known at NNLO with $1-1.5\%$ precision, with calculation available in experimental fiducial volumes
- A luminosity uncertainty also at $1-2\%$ level would make these measurements even more interesting, increasing their constraining power (e.g. PDF determinations)

Back-up slides

- Top Cross-Secton Luminosity and PDF potental

2011 Dilepton Cross-Section Uncertainties

- Dilepton-channel analysis with 0.7 fb-1
  - https://cdsweb.cern.ch/record/1426582/files/topxs-2l.pdf
  - Final uncertainty ~2.9% (stat) + 7.3% (syst) + 4.3% (lumi)

- Future measurements:
  - Most large uncertainties being reduced through other measurements
  - Luminosity will become largest uncertainty if not reduced

Uncertainties $\Delta\sigma/\sigma[\%]$	ee	$\mu\mu$	$e\mu$	eTL	μTL	Combined
Data statistics	$\pm$8.1	$\pm$6.1	$\pm$3.9	$\pm$14.1	$\pm$14.2	$\pm$2.9
Luminosity	+4.4/-3.8	+4.4/-3.9	$\pm$4.2	+5.1/-4.2	+5.4/-4.4	$\pm$4.3
MC statistics	$\pm$1.6	$\pm$1.2	$\pm$0.8	$\pm$5.5	$\pm$4.6	+0.7/-0.6
Lepton uncertainties	+6.2/-5.4	+2.9/-1.3	$\pm$3.1	$\pm$4.1	+1.8/-1.6	+2.6/-2.2
Track-leptons	—	—	—	$\pm$4.4	$\pm$1.9	+0.3/-0.2
Jet/$E_{\mathrm{T}}^{\mathrm{miss}}$ uncertainties	+5.7/-5.7	+6.4/-3.5	+4.7/-3.2	+14.8/-6.4	$\pm$13.1	+4.4/-3.4
b-tagging uncertainties	+1.2/-1.0	$\pm$0.7	—	—	—	+0.4/-0.0
Z/γ^*+ jets evaluation	$\pm$0.4	+0.5/-0.0	—	$\pm$6.2	+2.4/-2.7	+0.3/-0.2
Fake lepton evaluation	$\pm$3.3	1.5/-1.3	$\pm$3.0	$\pm$13.7	$\pm$15.1	$\pm$1.7
Generator	+12/-11	+4.5/-4.3	+4.8/-4.5	+14/-11	+14/-13	+5.1/-4.9
All syst.(except lumi.)	+16.4/-14.4	+8.8/-6.4	+8.2/-6.8	+27.9/-20.7	+26.5/-23.7	+8.0/-6.5
Stat. + syst.	+18.9/-16.9	+11.6/-9.5	+10.1/-8.8	+31.8/-25.2	+30.7/-27.8	+9.6/-8.2

2

Systematic Uncertainties on Dilepton-Channel Cross-Section

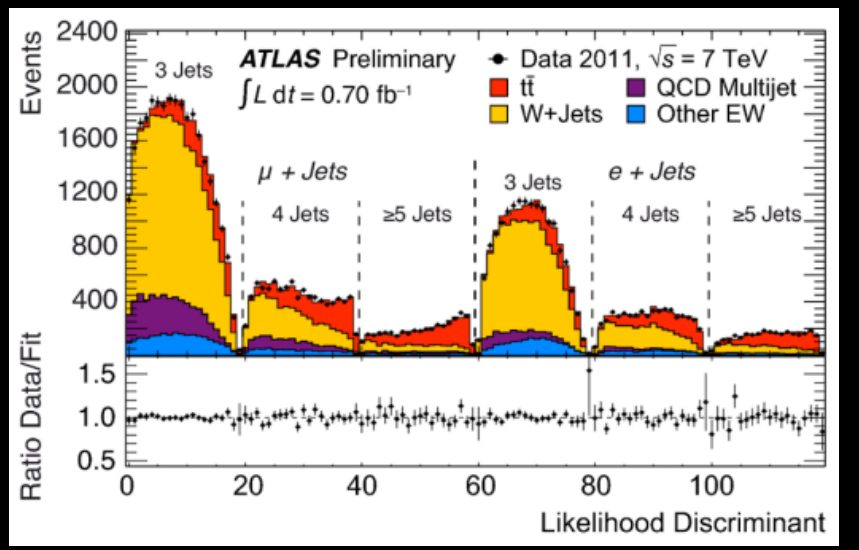
Untagged Lepton plus Jet Cross-Section

- Preliminary (0.7 fb-1): Fit kinematic information in many jet bins and profile
  - Final uncertainty ~2.2% (stat) + 5.0% (syst) + 3.7% (lumi)

- Future measurements:
  - Most large uncertainties being reduced through other measurements
  - Systematics expected to reduce with more data available for profiling
  - Luminosity uncertainty already largest, will become limiting if not reduced

Uncertainty	up (pb)	down (pb)	up (%)	down (%)
Statistical	3.9	−3.9	2.2	−2.2
Detector simulation				
Jets	3.2	−4.3	1.8	−2.4
Muon	4.1	−4.1	2.3	−2.3
Electron	2.7	−3.0	1.5	−1.7
$E_{\mathrm{T}}^{\mathrm{miss}}$	2.0	−1.6	1.1	−0.9
Signal model				
Generator*)	5.4	−5.4	3.0	−3.0
Hadronization*)	0.9	−0.9	0.5	−0.5
ISR/FSR	3.0	−2.3	1.7	−1.3
PDF*)	1.8	−1.8	1.0	−1.0
Background model				
QCD shape*)	0.7	−0.7	0.4	−0.4
W shape*)	0.9	−0.9	0.5	−0.5
Monte Carlo statistics*)	3.2	−3.2	1.8	−1.8
Systematic	9.0	−9.0	5.0	−5.0
Stat. & Syst.	9.8	−9.8	5.4	−5.4
Luminosity	6.6	−6.6	3.7	−3.7
Total	11.8	−11.8	6.6	−6.6

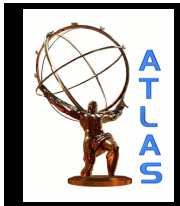
Lepton+Jet Uncertainties



Lepton+jet Fits

Comments on the Luminosity

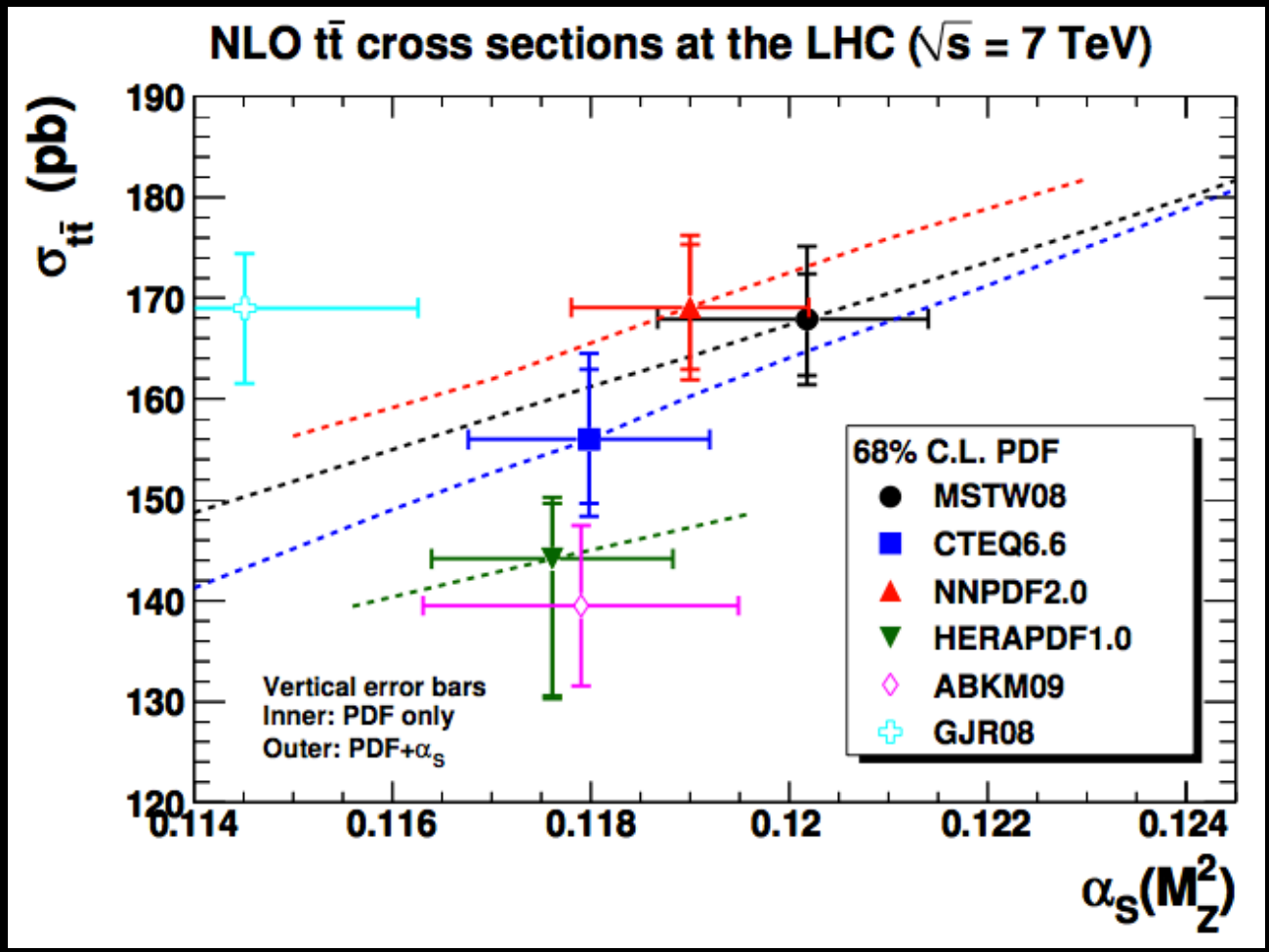
- Luminosity one of the largest uncertainties for the approved dilepton paper
  - It is also the largest uncertainty on preliminary lepton+jet results
  - Other significant uncertainties will be reduced
    - Through dedicated measurements
    - Or use of in-situ profiling techniques
  - Improved lumi uncertainties would improve top cross-section precision
- However other tricks might allow us to bypass the lumi uncertainty
  - For example, measure ratio of ttbar to Z cross-sections instead of raw ttbar cross-section



Comments on PDFs

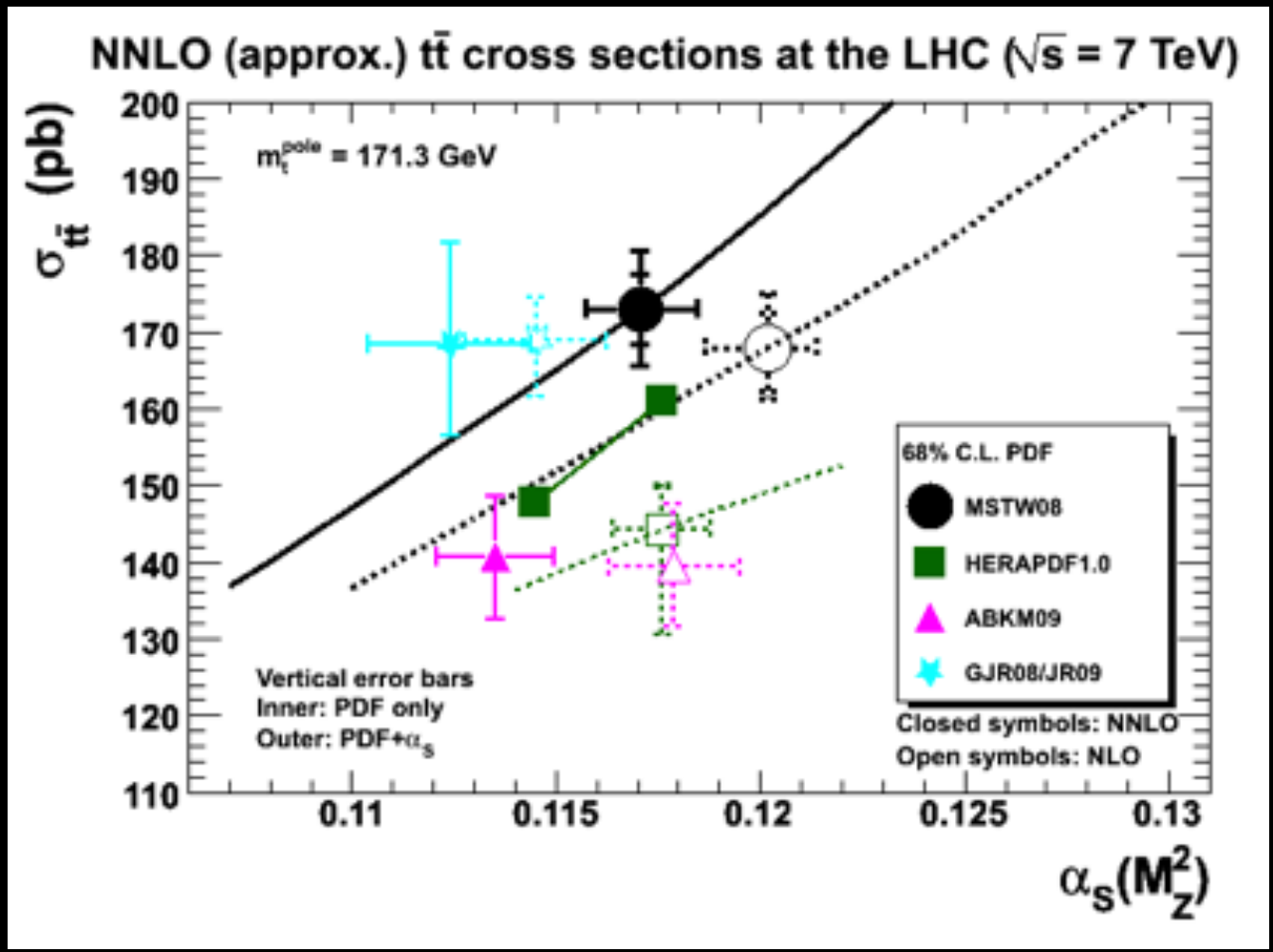
PDFs and α_S Significant for top Cross-section

- Plot shows PDF uncertainties for theoretical top cross-section prediction at NLO
  - Plot from http://projects.hepforge.org/mstwpdf/pdf4lhc/
  - Uncertainties are significant, but at NLO accuracy, PDF uncertainties on top cross-section from theory are less than scale uncertainties



Fundamental PDF & α_S Uncertainties

- At NNLO accuracy, PDF + α_S uncertainties dominate
  - About half of uncertainty comes from α_S



Summary of Theory Uncertainties

- Including scale, PDFs, and alpha_s, theory uncertainty ~10-11%
  - Experimental errors already much better than this

[Beneke, Falgari, Klein, Schwinn 11]

m_t [GeV]	NLO	NNLO_{app}	NNLL_2
165	$203.9\,^{+25.5+17.8}_{-27.4-16.7}$	$207.6\,^{+15.0+6.1+19.3}_{-14.3-6.1-18.6}$	$209.5\,^{+7.3+6.1+19.6}_{-7.5-6.1-18.8}$
166	$197.7\,^{+24.7+17.3}_{-26.5-16.2}$	$201.2\,^{+14.5+5.9+18.8}_{-13.9-5.9-18.0}$	$203.1\,^{+7.1+5.9+19.0}_{-7.3-5.9-18.2}$
167	$191.6\,^{+23.9+16.8}_{-25.7-15.7}$	$195.1\,^{+14.0+5.7+18.2}_{-13.4-5.7-17.5}$	$196.9\,^{+6.9+5.7+18.5}_{-7.1-5.7-17.7}$
168	$185.8\,^{+23.1+16.3}_{-24.9-15.3}$	$189.2\,^{+13.5+5.5+17.7}_{-13.0-5.5-17.0}$	$190.9\,^{+6.7+5.5+17.9}_{-6.9-5.5-17.2}$
169	$180.2\,^{+22.4+15.8}_{-24.2-14.9}$	$183.5\,^{+13.1+5.4+17.2}_{-12.6-5.4-16.5}$	$185.2\,^{+6.5+5.4+17.4}_{-6.7-5.4-16.7}$
170	$174.7\,^{+21.7+15.3}_{-23.4-14.4}$	$177.9\,^{+12.7+5.2+16.7}_{-12.2-5.2-16.0}$	$179.6\,^{+6.3+5.2+16.9}_{-6.5-5.2-16.2}$
171	$169.5\,^{+21.0+14.9}_{-22.7-14.0}$	$172.6\,^{+12.3+5.0+16.2}_{-11.8-5.0-15.6}$	$174.2\,^{+6.1+5.0+16.5}_{-6.3-5.0-15.8}$
172	$164.4\,^{+20.3+14.5}_{-22.0-13.6}$	$167.5\,^{+11.9+4.9+15.8}_{-11.4-4.9-15.1}$	$169.0\,^{+6.0+4.9+16.0}_{-6.1-4.9-15.3}$
173	$159.6\,^{+19.7+14.0}_{-21.4-13.3}$	$162.5\,^{+11.5+4.7+15.4}_{-11.0-4.7-14.7}$	$164.0\,^{+5.8+4.7+15.6}_{-6.0-4.7-14.9}$

scale

uncalculated NNLO

pdf + α_s

compatible at 0.2% with Hathor if qg is set to zero in NNLO

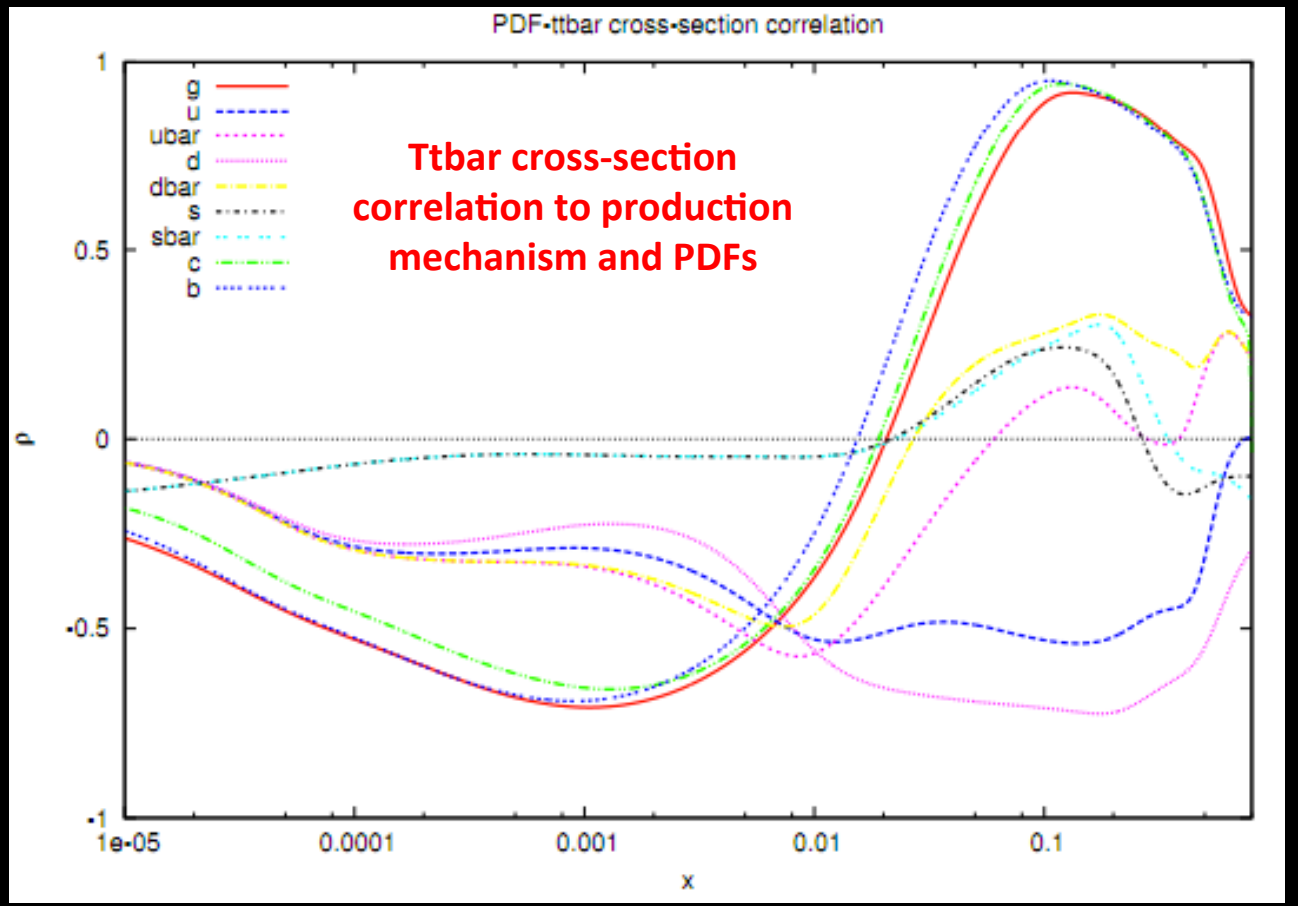
+1%

PDF Constraints?

- Looks like top cross-section uncertainty ~5% may be possible
  - Constraints on a ~9% PDF +α_S uncertainty possible

From A. Guffanti:

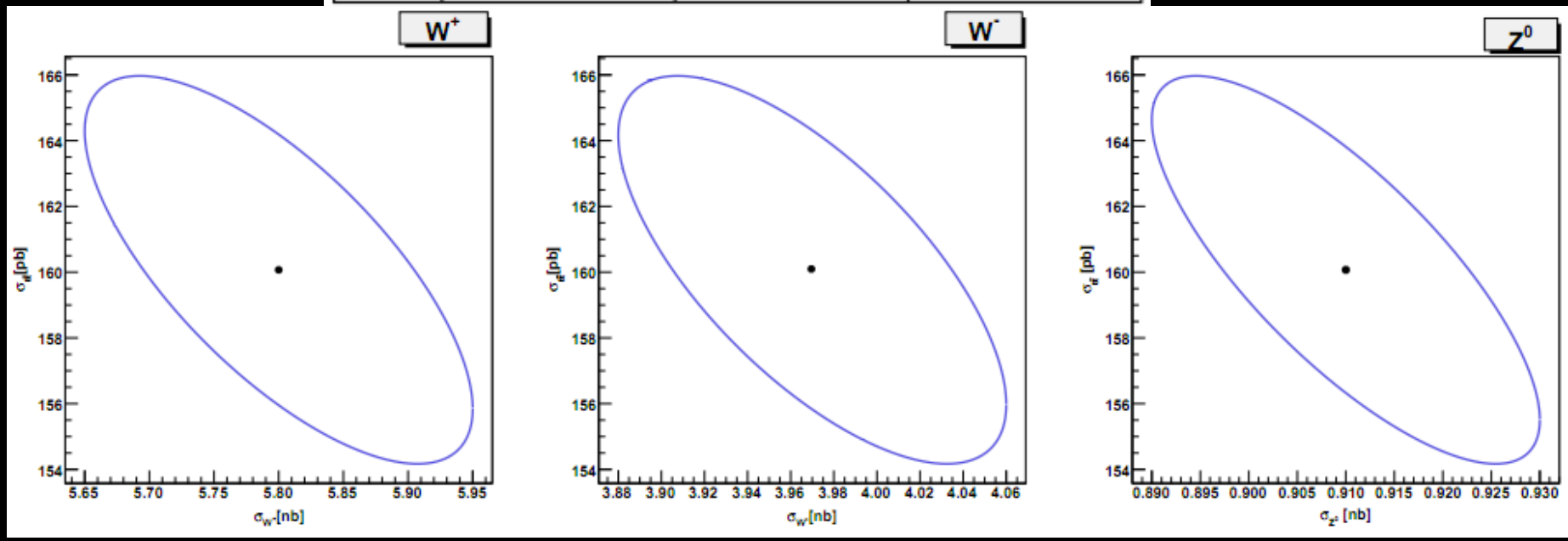
- http://agenda.irmp.ucl.ac.be/getFile.py/access?contribId=10&sessionId=1&resId=0&materialId=slides&confId=538



Ttbar Correlations

- Top cross-section and W/Z cross-sections correlated to PDFs in opposite ways
  - Possible to constrain PDFs with simultaneous measurements? Will require *very* high precision.

	σ_{W^+}	σ_{W^-}	σ_{Z^0}
ρ	-0.716	-0.694	-0.773

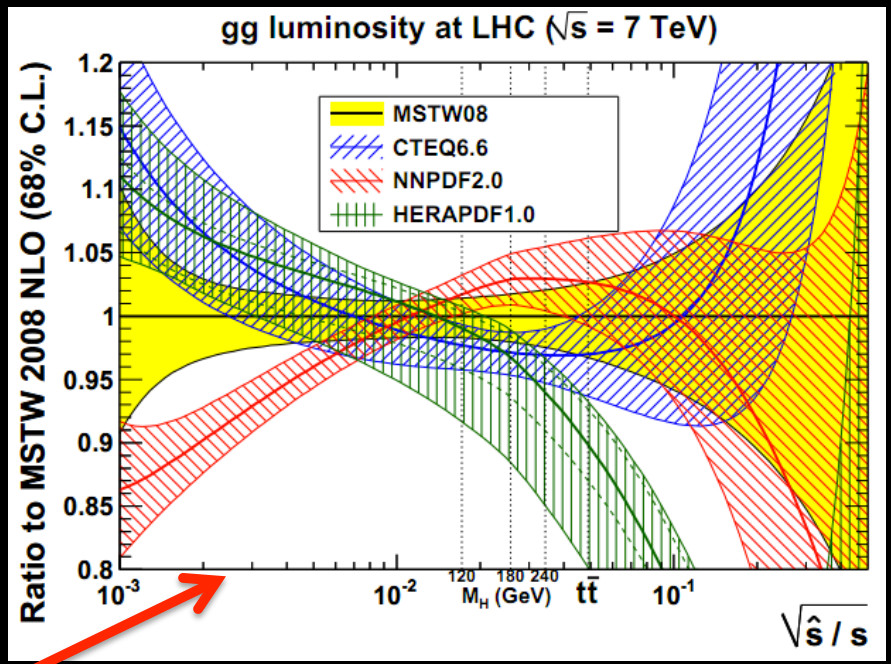


PDF-Induced Correlation of ttbar Cross-section to W and Z Cross-sections

PDF Constraints?

From Graeme Watt:
http://indico.cern.ch/getFile.py/access?contribId=0&resId=0&materialId=slides&confId=87871

- Properties measurements could also help us to pin down gluon PDFs
  - Differential top cross-section (in momenta)
  - Production mechanism (qqbar vs gg).
  - Again, very high accuracy needed to see these differences

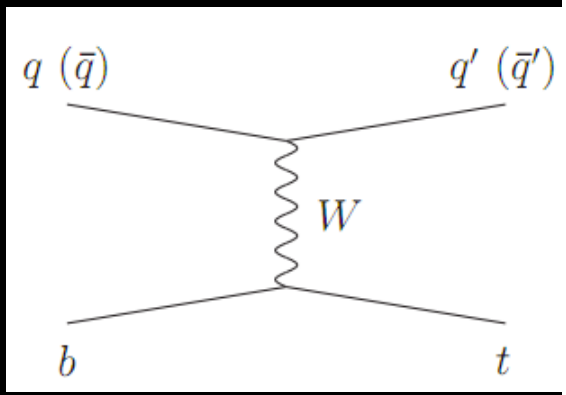


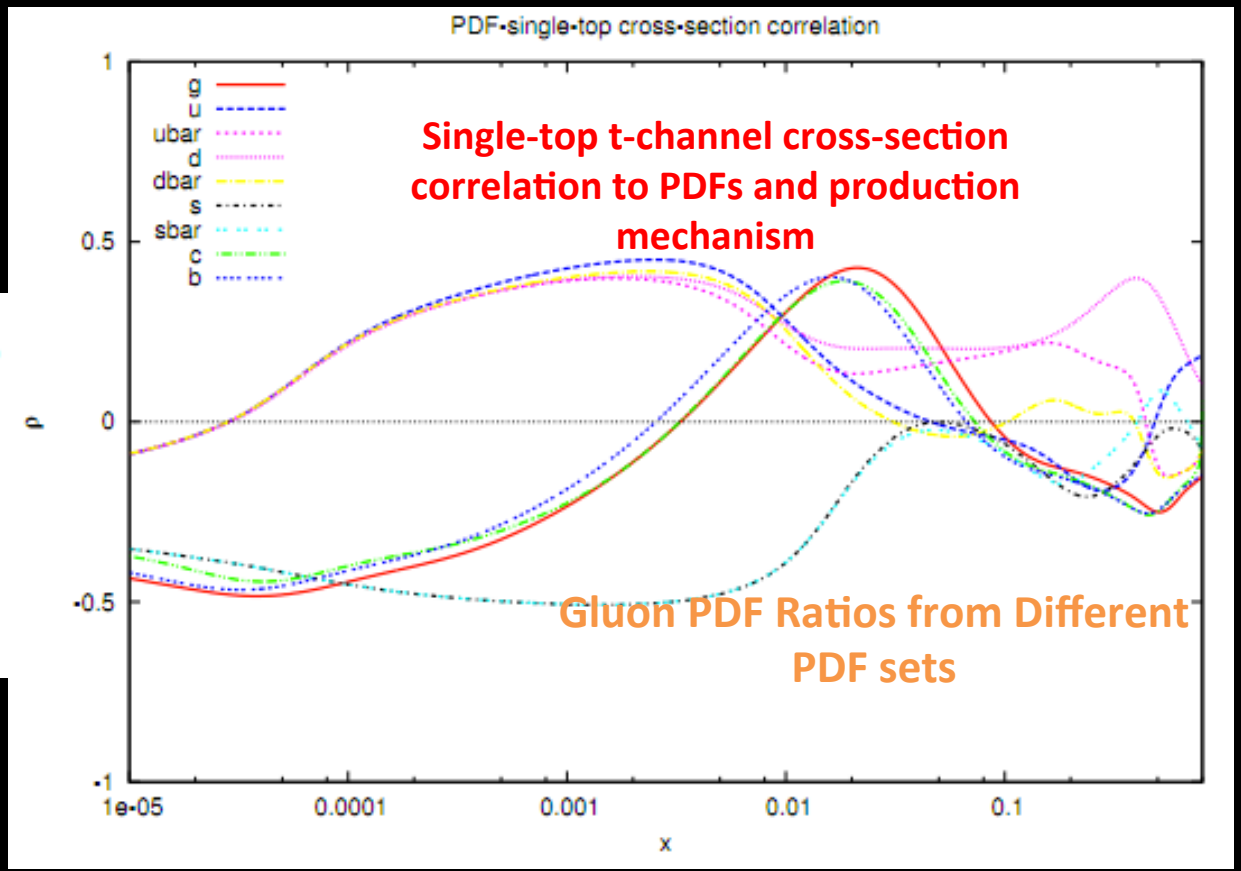
Gluon PDF Ratios from Different PDF sets

Single-Top Constraints

- T-channel of single-top production also sensitive to PDFs
  - ~2% uncertainty from *b*-quark PDF

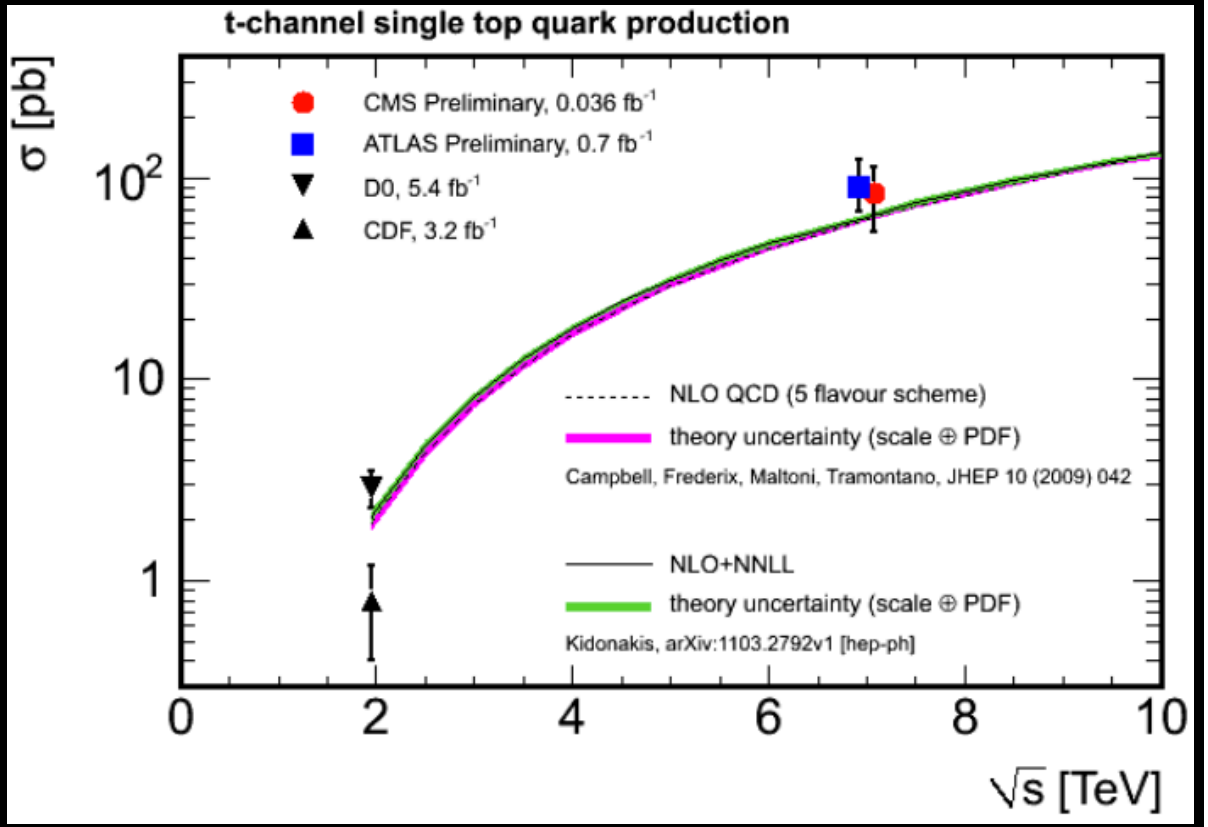
- T-channel of single-top:





T-Channel Measurements

- Atlas single-top uncertainties ~30-45% with 700 pb-1
  - Driven by jet energy, *b*-tagging, modeling systs
  - Direct PDF sensitivity seems out of reach



T-Channel Single Top Cross-Sections