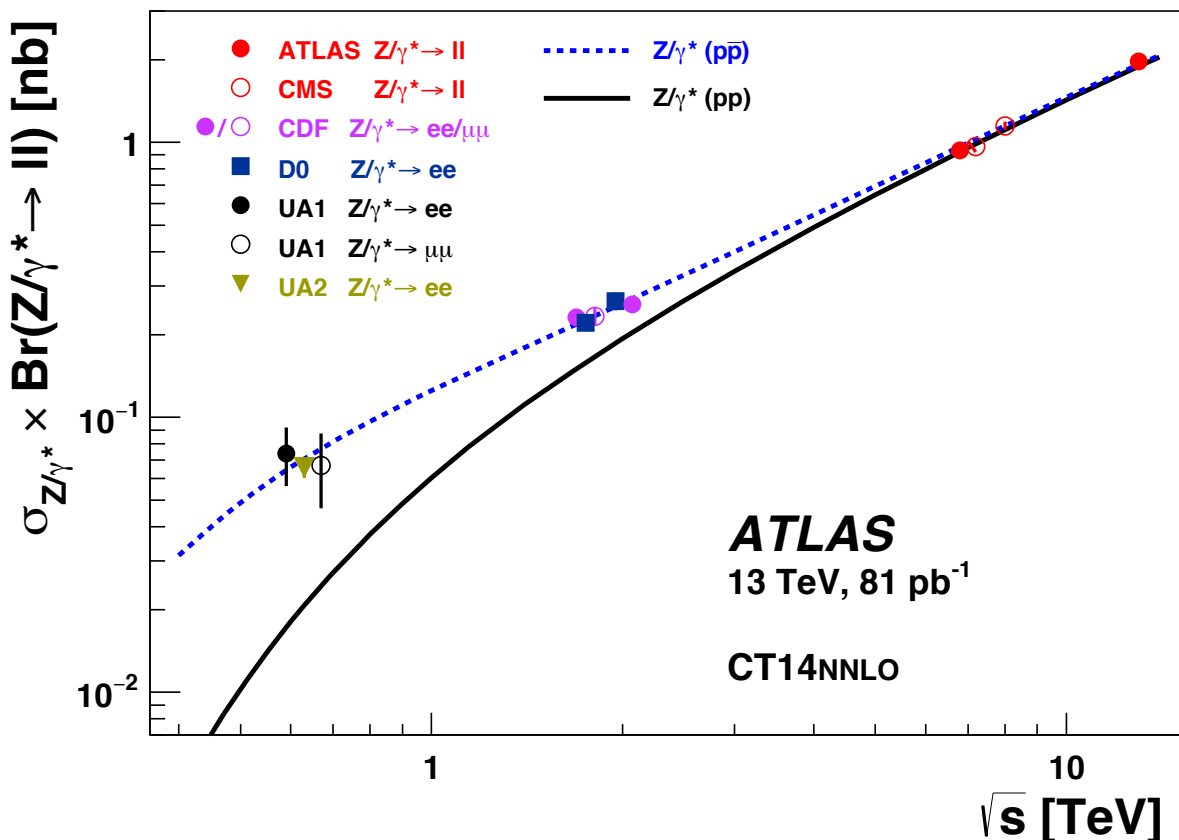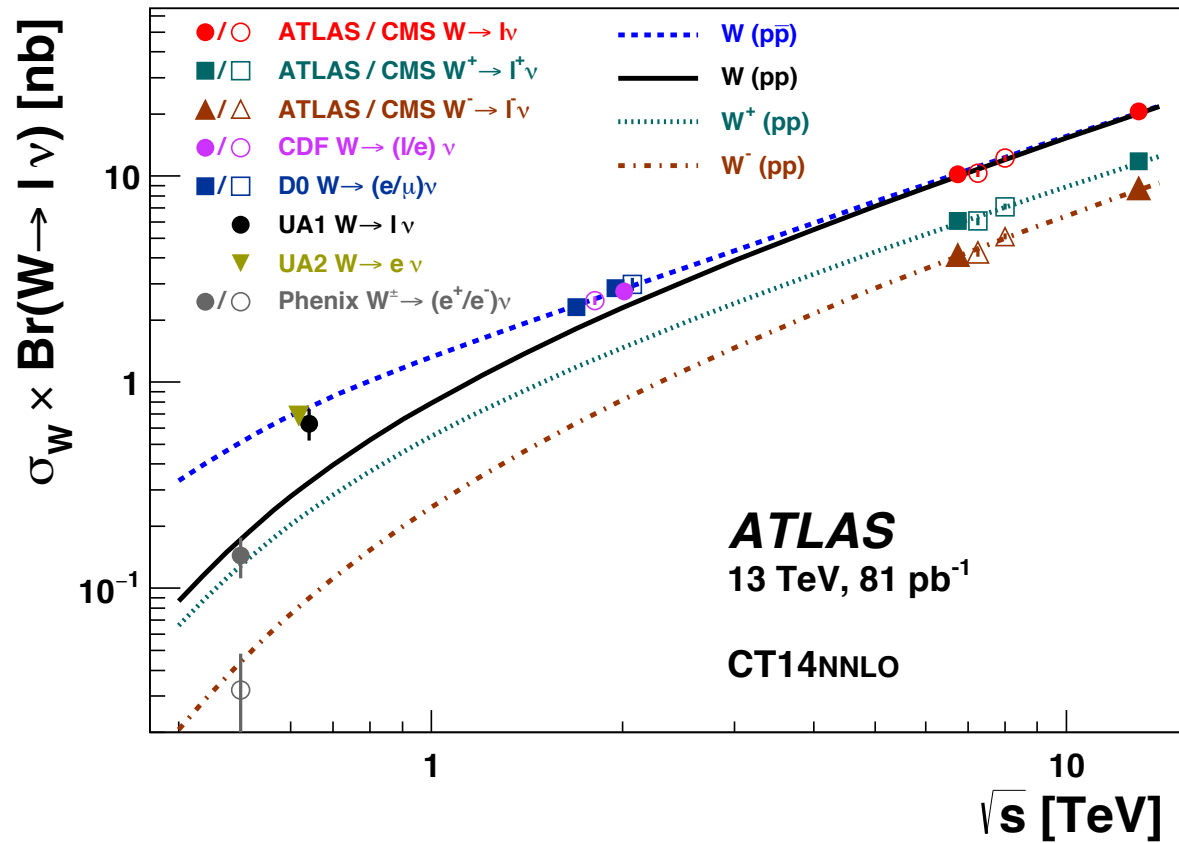# High precision measurement of the differential W and Z/γ*-boson cross sections

Ksenia Gasnikova
on behalf of the ATLAS collaboration

QCD@LHC 2017
Debrenec, Hungary

Precision measurements of W/Z bosons

Advantages:

- Clear experimental signature in leptonic channels
- Available NNLO pQCD predictions

Allows to:

- Probe higher order QCD predictions
- Access to fundamental parameters (m^T_W, $\cos\theta_W$)
- constrain PDF distributions

Today in the talk:

- Precision W and Z boson cross sections at 7 TeV (Eur. Phys. J. C 77 (2017) 367)
- Z-boson to top-quark ratios at 7, 8, and 13 TeV (JHEP 1702 (2017) 117)

Methodology

- Signal is generated using Powheg+Pythia

- EWK+top backgrounds are estimated using simulation

- Multijet background estimated using data-driven method

- Predictions at NNLO QCD + NLO EW level, using DYNNLO and FEWZ

Total and fiducial cross-section:

$$\sigma_{W/Z}^{fid} = \frac{N^{W/Z} - B^{W/Z}}{C_{W/Z}L_{int}}$$

$N^{W/Z}$ - candidate events in data

$B^{W/Z}$ - background events

$C_{W/Z}$ - efficiency correction factor

L_{int} - luminosity

$$\sigma_{W/Z}^{tot} = \frac{\sigma_{W/Z}^{fid}}{A_{W/Z}}$$
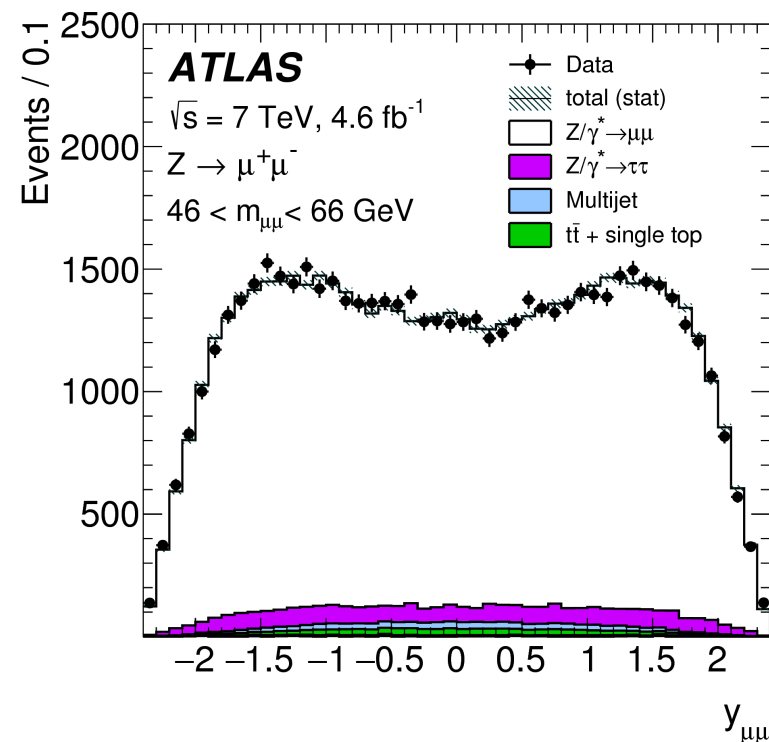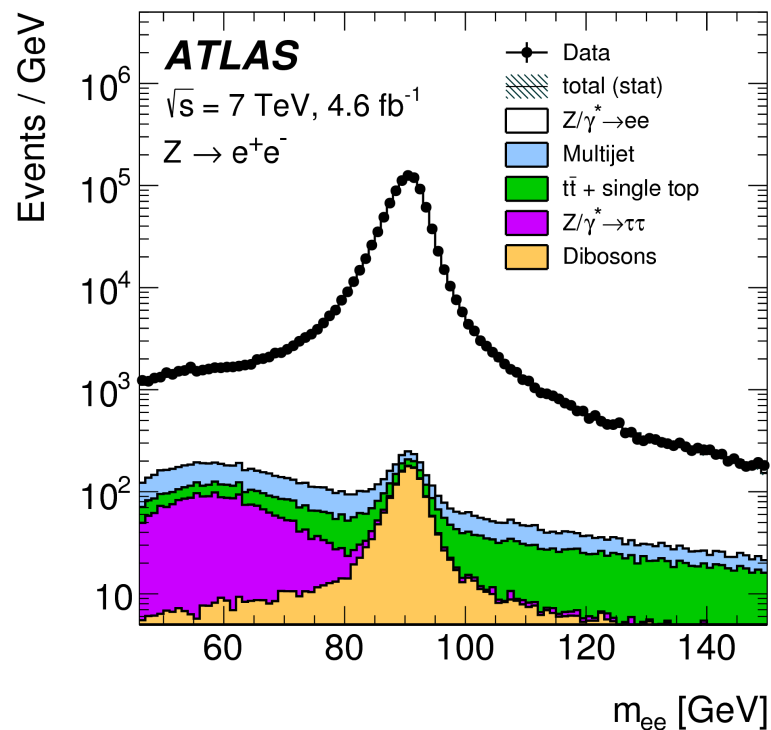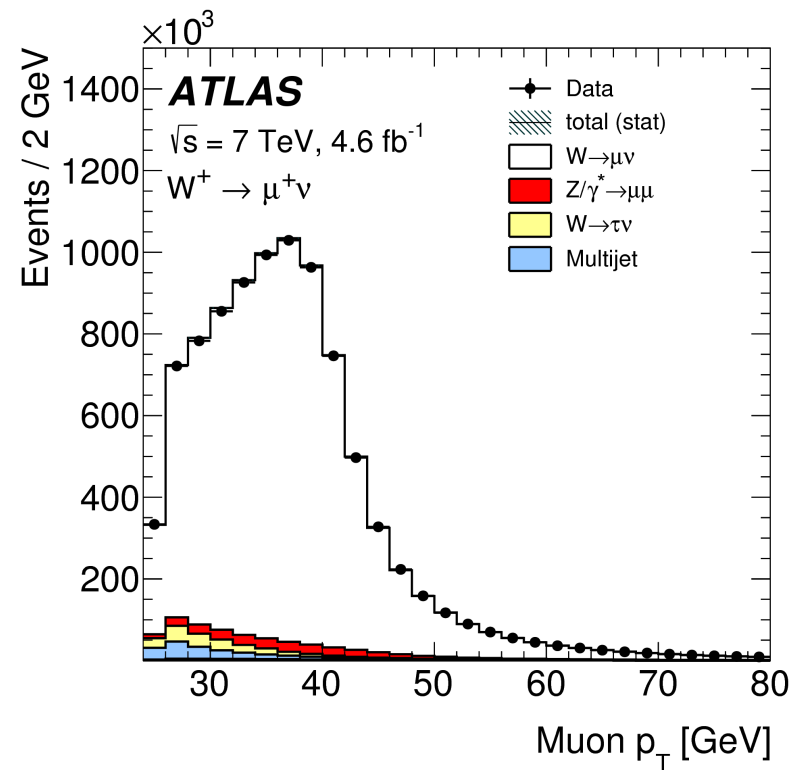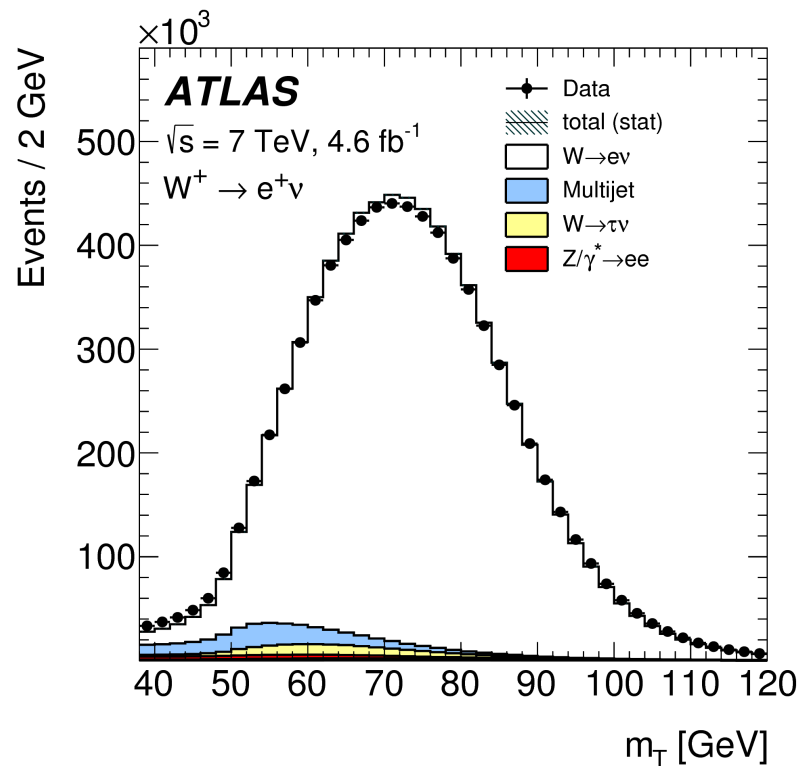
$A^{W/Z}$ - acceptance

Differential cross-section:

- W->lv: pseudorapidity bins ($|\eta_{ll}|$)

- Z->ll: rapidity bins ($|y_{ll}|$) in three mass regions m_{ll} = [44;66;116;150] GeV

3

4.6 fb^{-1} @ 7 TeV

Inclusive W$^+$, W$^-$ and Z/γ* production cross sections

W/Z-boson cross sections @ 7 TeV

Phase space definition

	W	Z	
		central	forward
p_T	> 25 GeV	> 20 GeV	
η	< 2.5	< 2.5	[2.5;4.9]
m_T /m_{ll}	> 40 GeV	[46;150] GeV	[66;150] GeV

Selected candidates:

- W->ev: ~13M
- W->μv: ~16M
- Z->ee: 1M (CC), 320k (CF)
- Z->μμ: 1.6M

Background contamination:

- W->lv:~7-9%
- Z->ll: ~1-3%

W/Z bosons @ 7 TeV
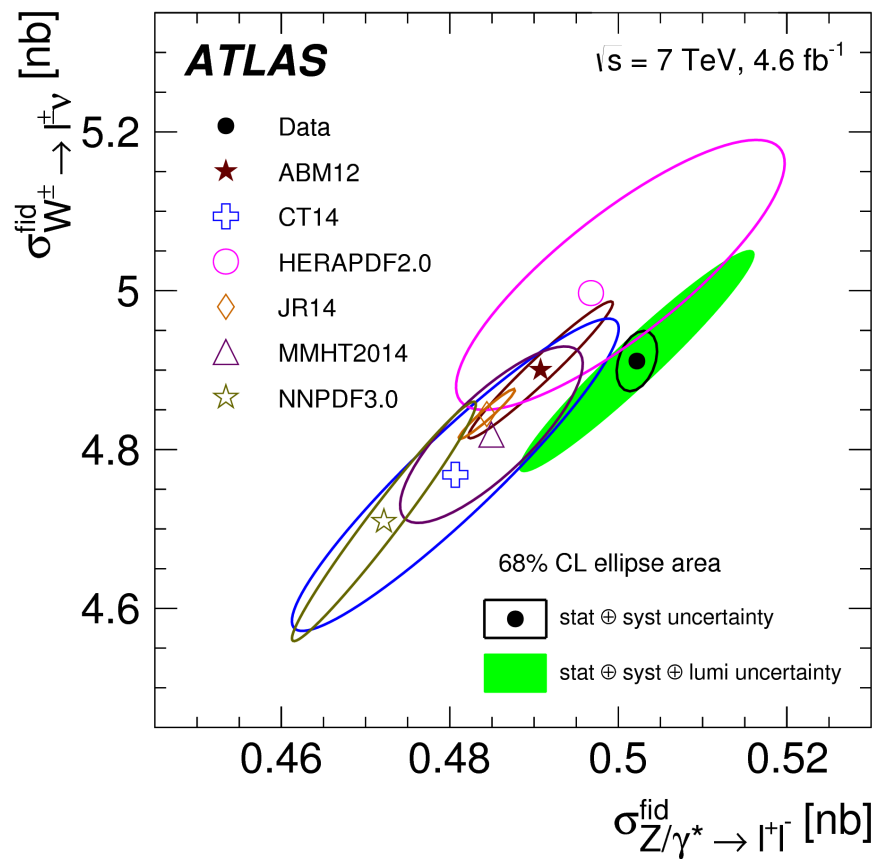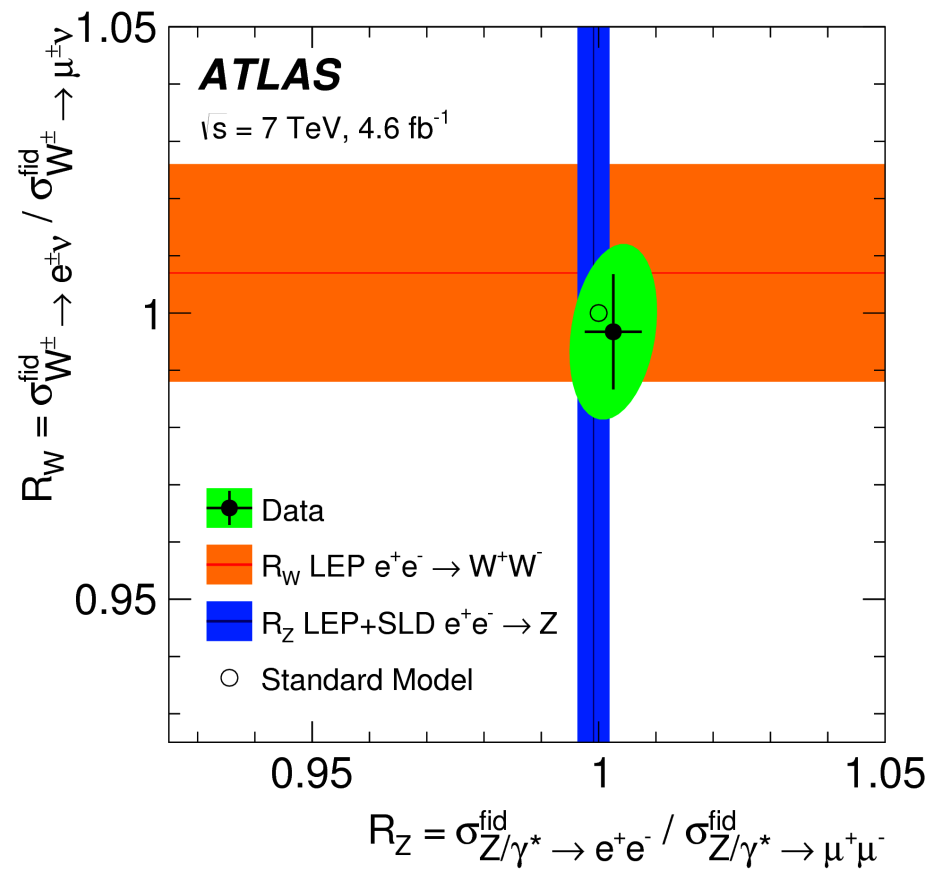
Dominating systematics:

- Luminosity uncertainty (1.8%)
- Lepton reconstruction efficiencies (0.3% for Z, 0.2% for W)
- W signal modelling (< 0.64%)
- Background estimation (0.14% for Z, 0.72% for W)

Cross-sections are measured separately in muon and electron channel and combined

- ▸ Good agreement for electron to muon ratios with SM
- ▸ Rw is more precise then the combination of LEP results

	$\sigma_{W \to \ell\nu}^{\text{tot}}$ [pb]
$W^+ \to \ell^+\nu$	$6350 \pm 2\,(\text{stat}) \pm 30\,(\text{syst}) \pm 110\,(\text{lumi}) \pm 100\,(\text{acc})$
$W^- \to \ell^-\bar{\nu}$	$4376 \pm 2\,(\text{stat}) \pm 25\,(\text{syst}) \pm 79\,(\text{lumi}) \pm 90\,(\text{acc})$
$W \to \ell\nu$	$10720 \pm 3\,(\text{stat}) \pm 60\,(\text{syst}) \pm 190\,(\text{lumi}) \pm 130\,(\text{acc})$
	$\sigma_{Z/\gamma^* \to \ell\ell}^{\text{tot}}$ [pb]
$Z/\gamma^* \to \ell\ell$	$990 \pm 1\,(\text{stat}) \pm 3\,(\text{syst}) \pm 18\,(\text{lumi}) \pm 15\,(\text{acc})$

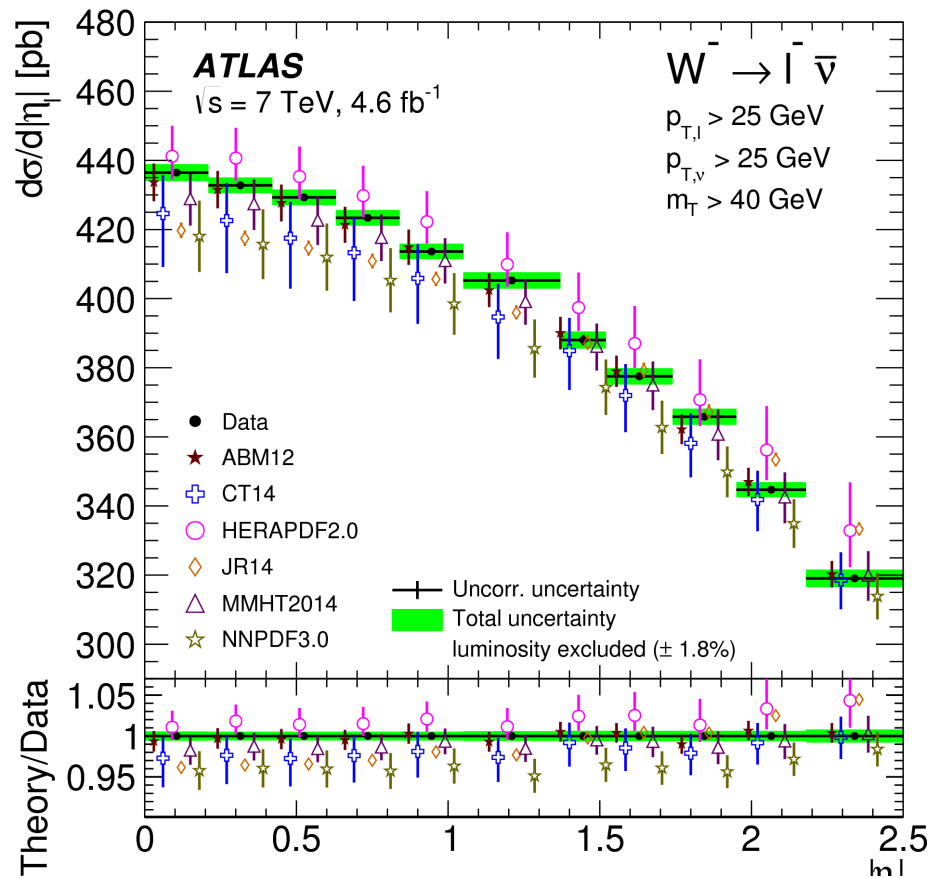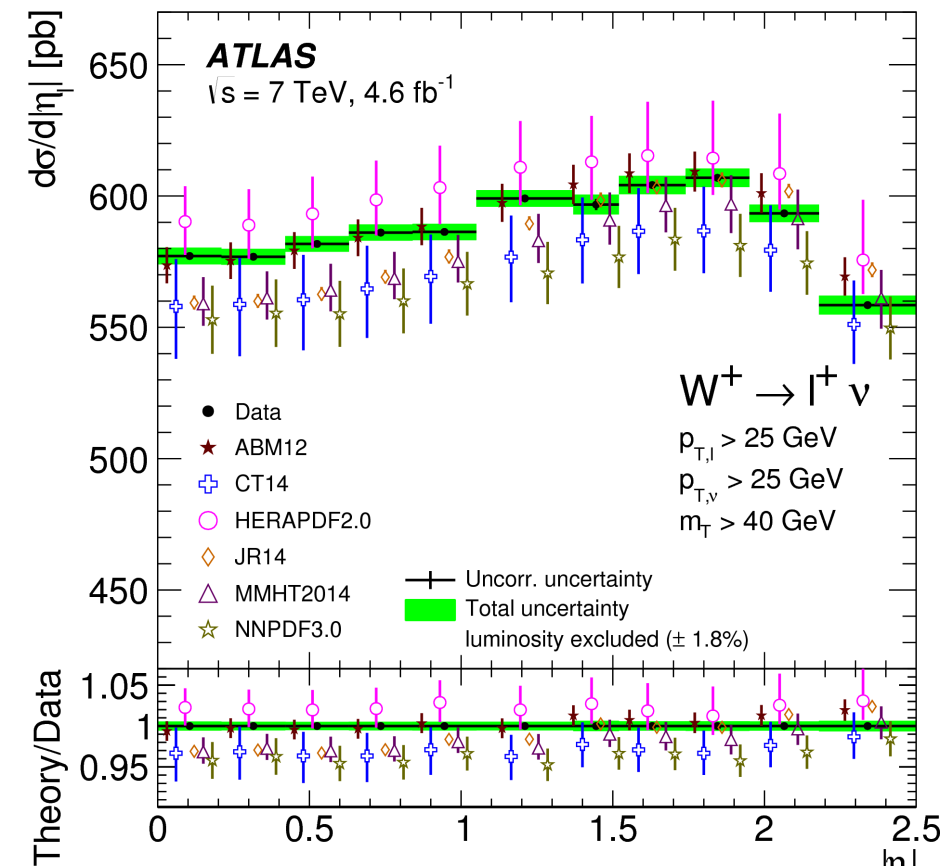**Most precise integrated vector boson measurements**
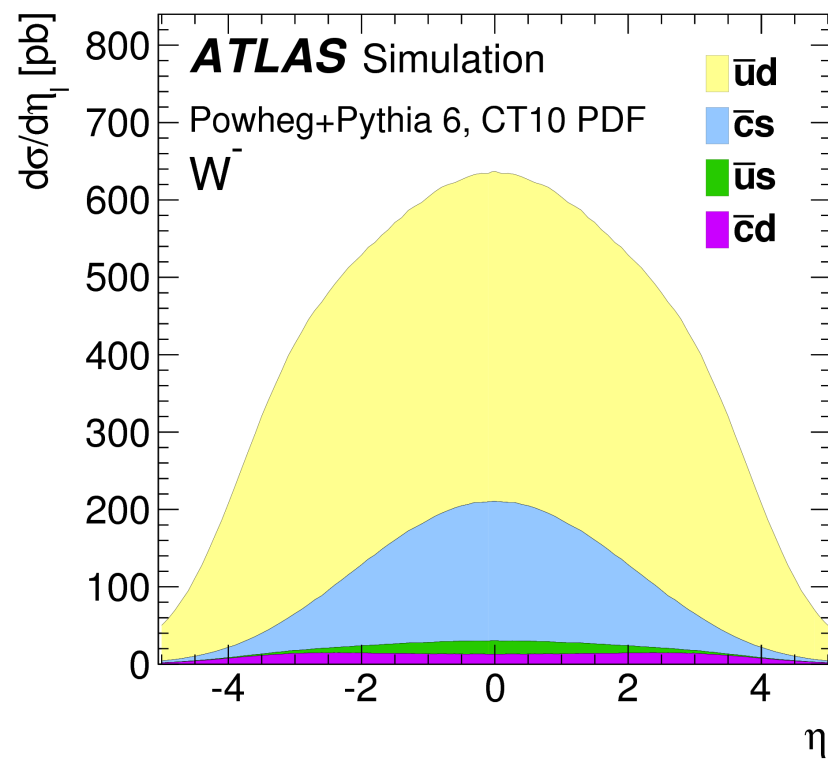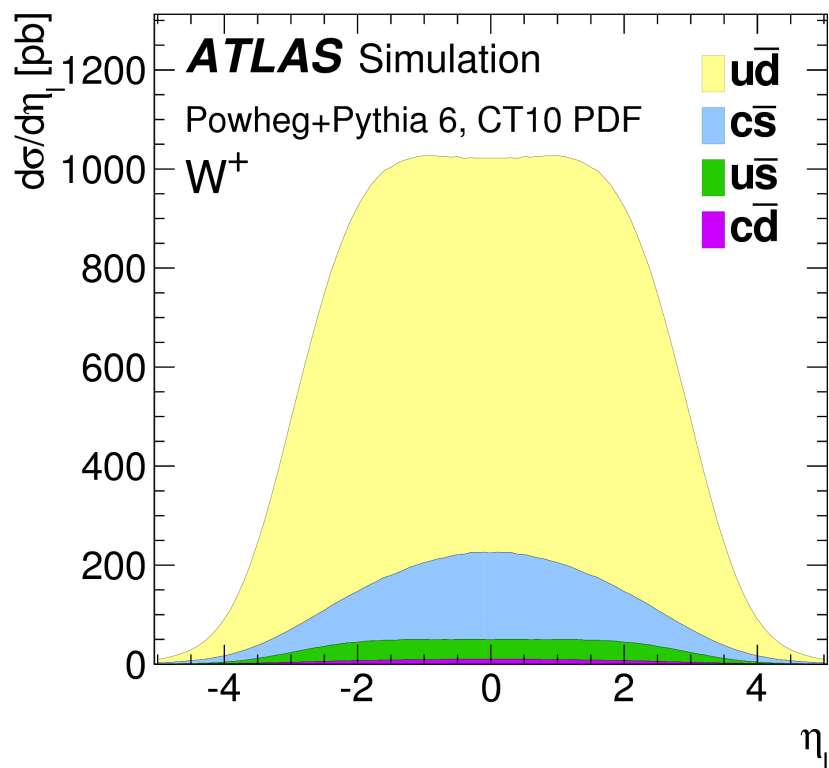
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Cross section ratios @ 7 TeV
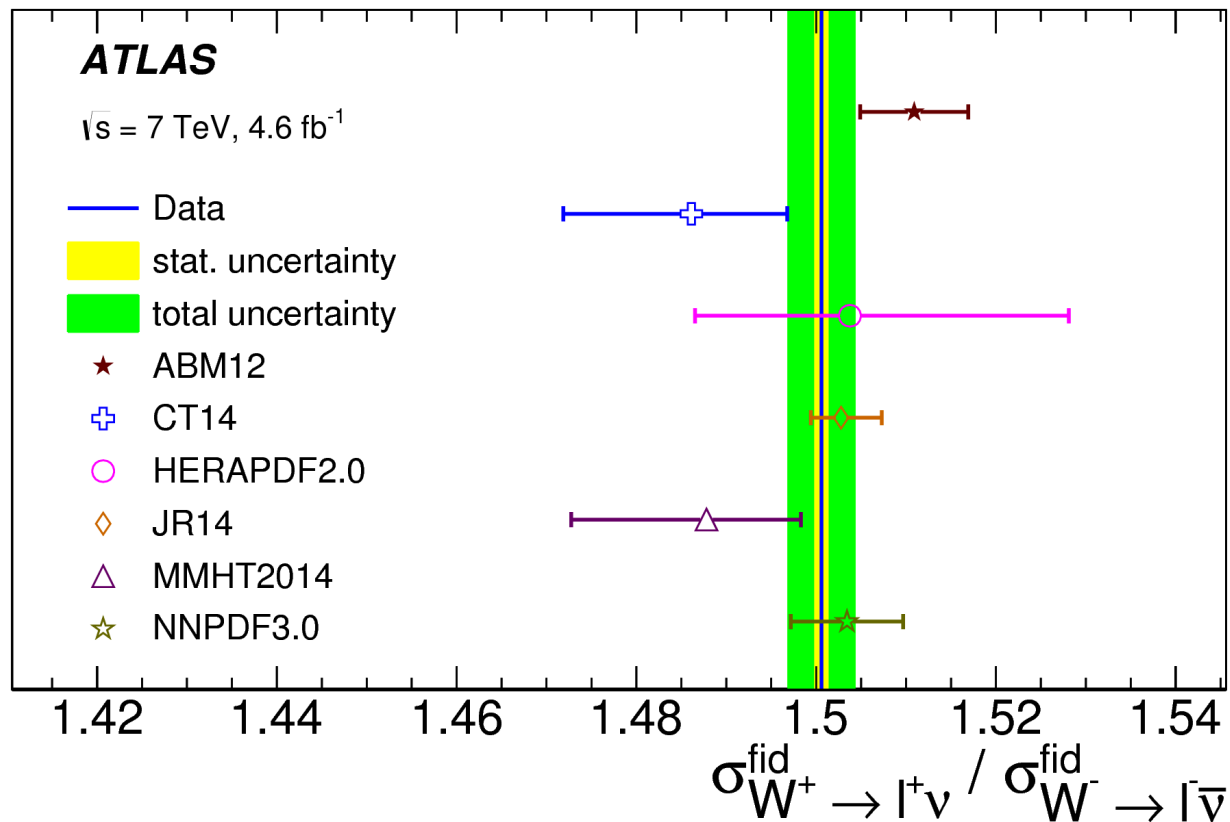
- Cancellation of the luminosity uncertainty
- More precise, than theory predictions
- Predictions for W/Z ratio are significantly higher, than data
  - ‣ Comparable with W/Z@13 TeV (Phys.Lett. B759)
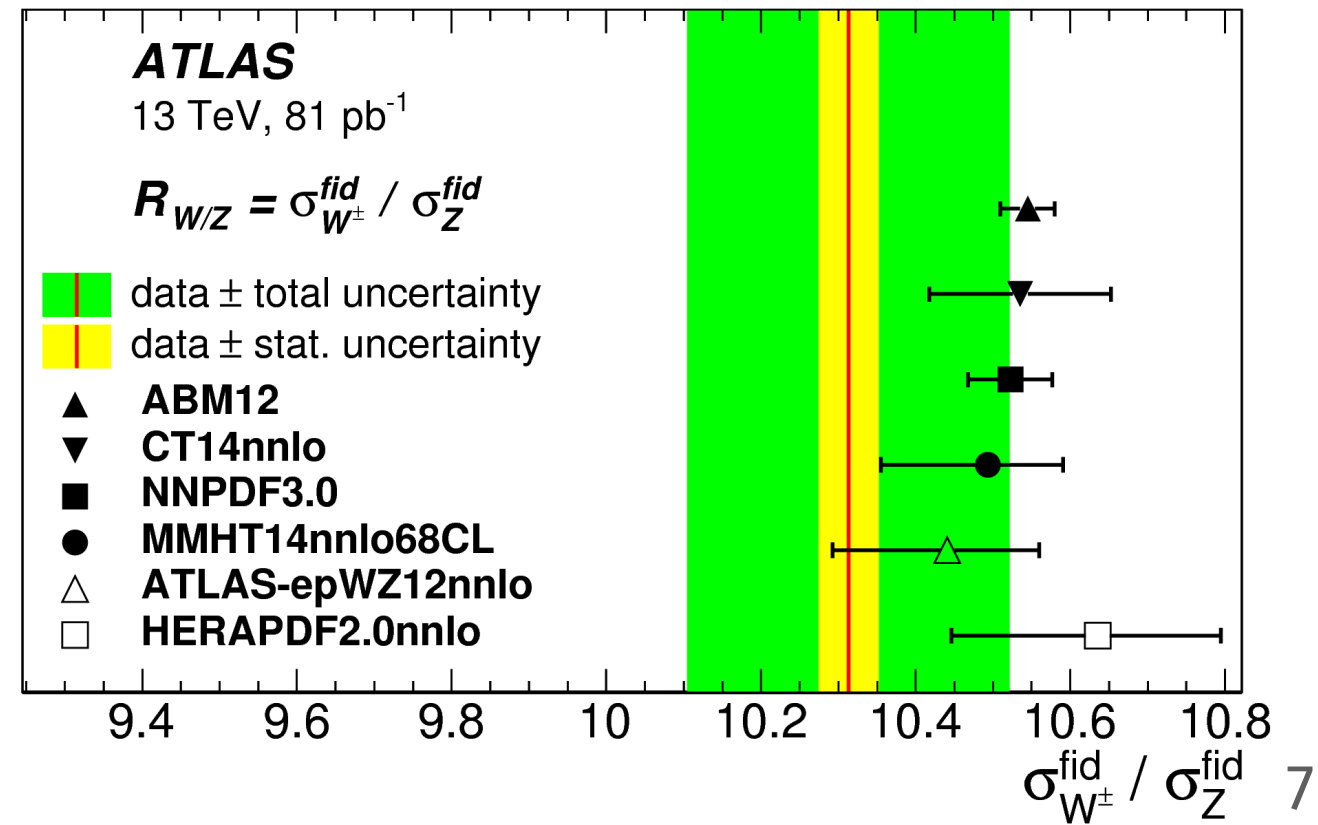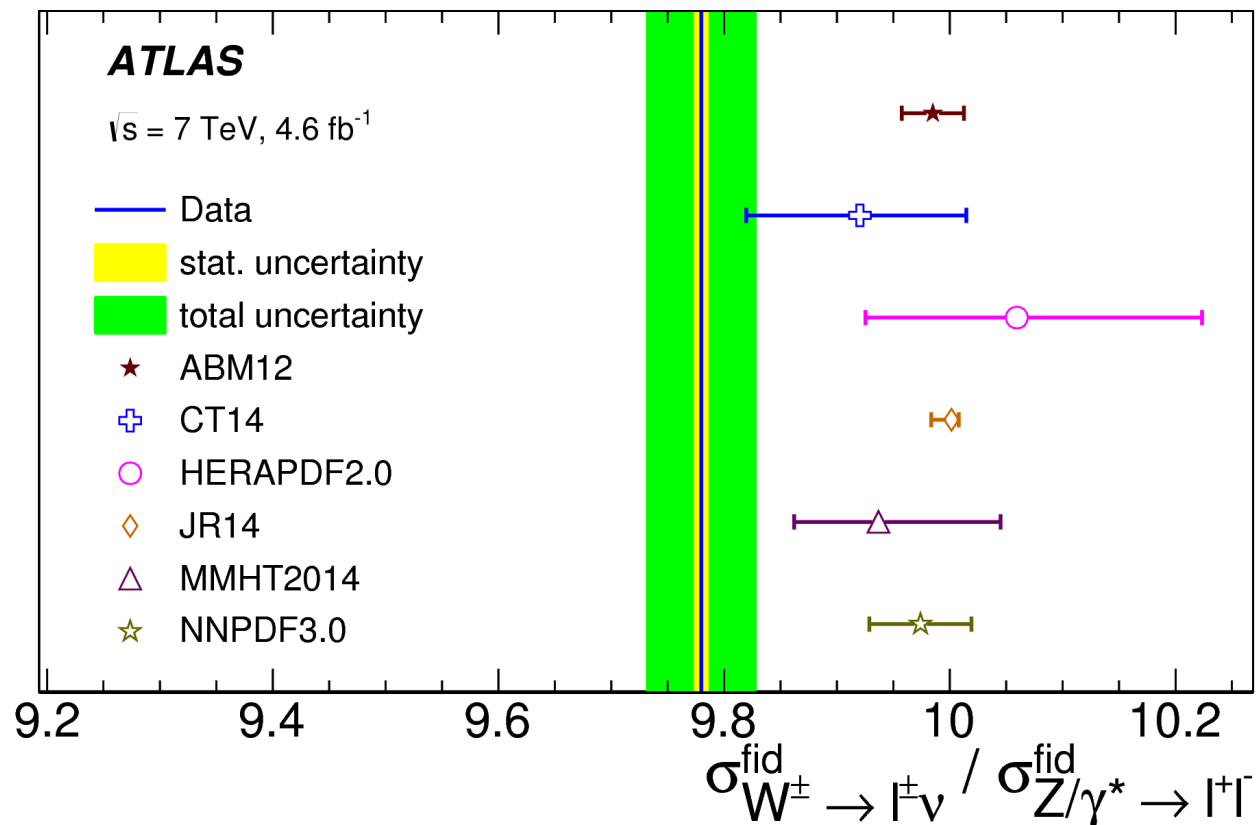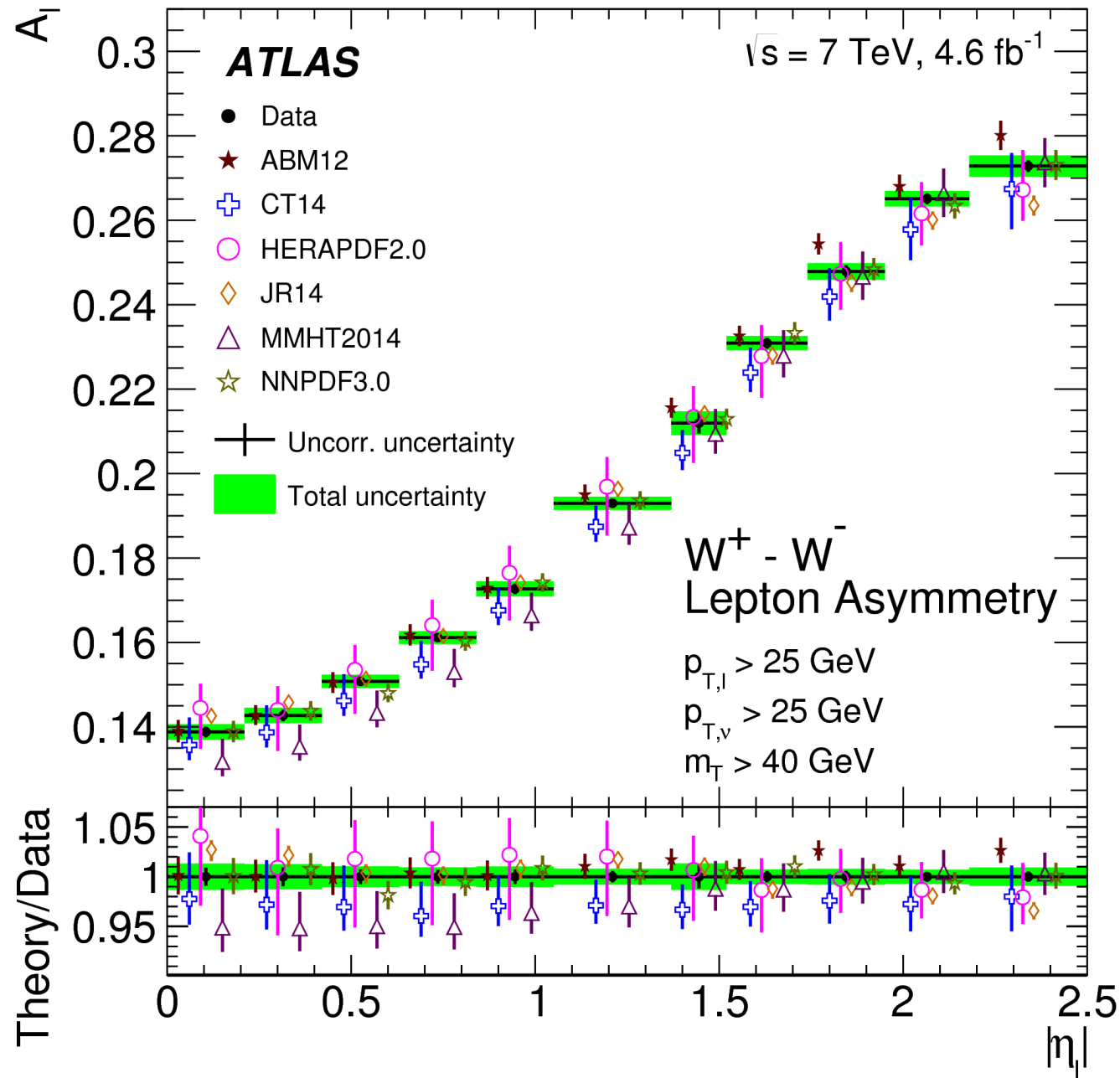
Differential W cross sections @ 7 TeV

- Sensitive to strange quark density
- All (except for HERAPDF) predictions are lower than data

Potential indication of the enhanced strangeness with respect to d-sea

Differential W cross sections @ 7 TeV

- Despite disagreement for individual cross-sections there is a good agreement for charge assymetry:
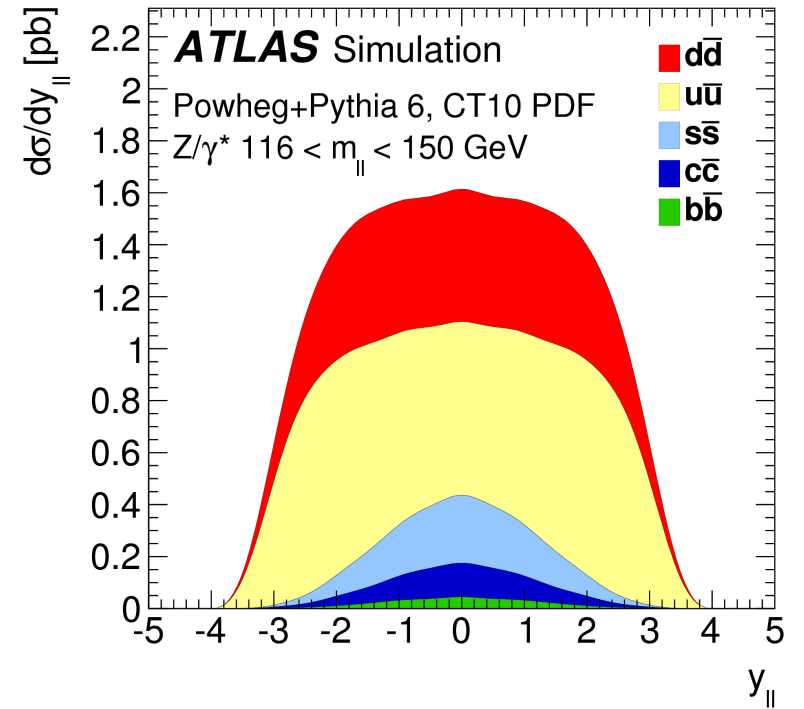
$$A_\ell = \frac{d\sigma_{W^+}/d|\eta_\ell| - d\sigma_{W^-}/d|\eta_\ell|}{d\sigma_{W^+}/d|\eta_\ell| + d\sigma_{W^-}/d|\eta_\ell|}$$

It's important to measure individual cross-sections, not only charge assymetry

Differential Z cross sections @ 7 TeV

Predictions are below data in central region ($y_{ll} < 1.0$):

▸ Potential indication of the enhanced strangeness with respect to d-sea
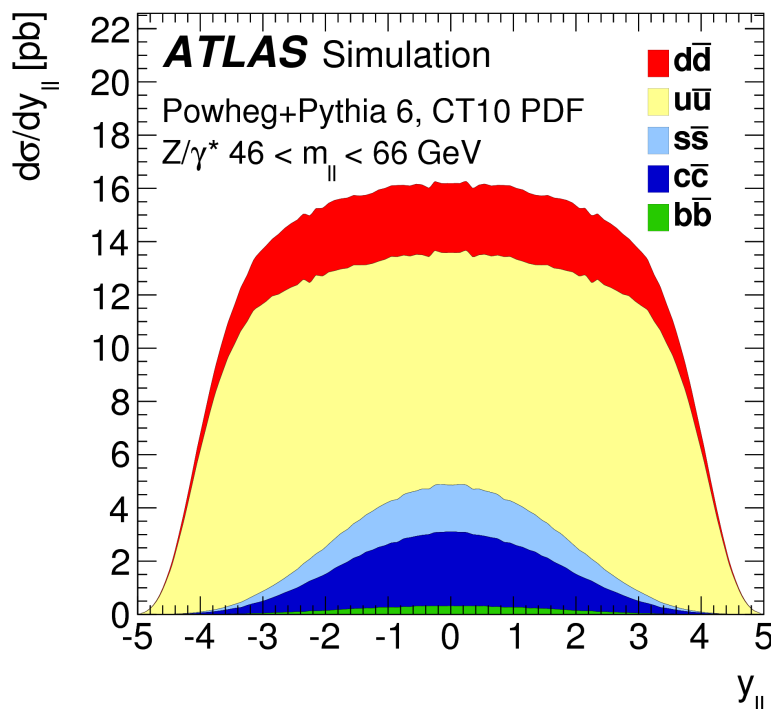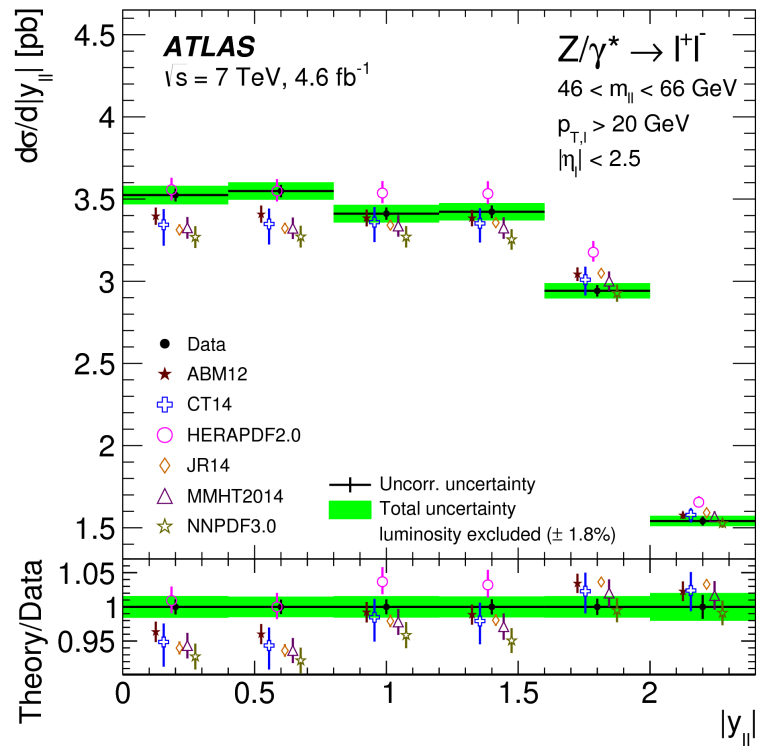
QCD analysis

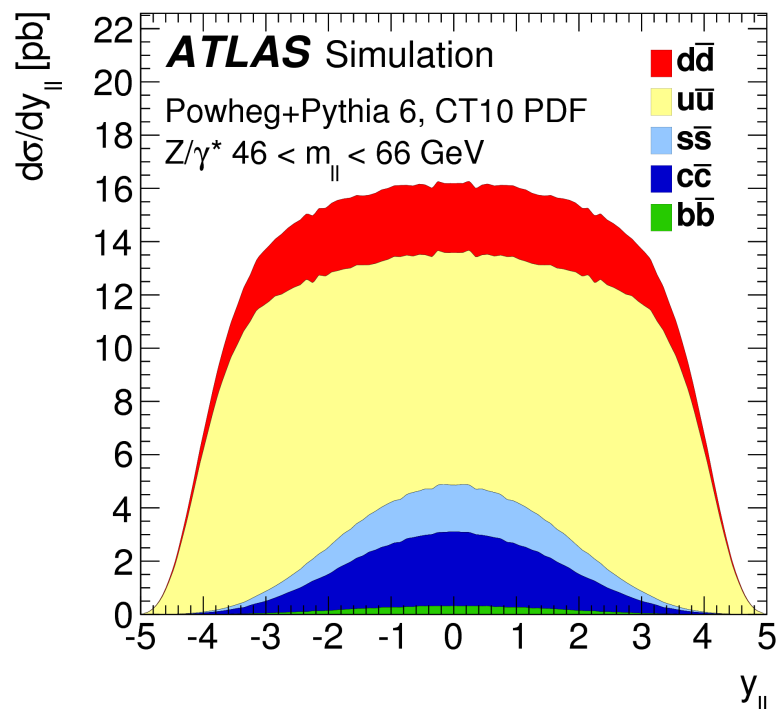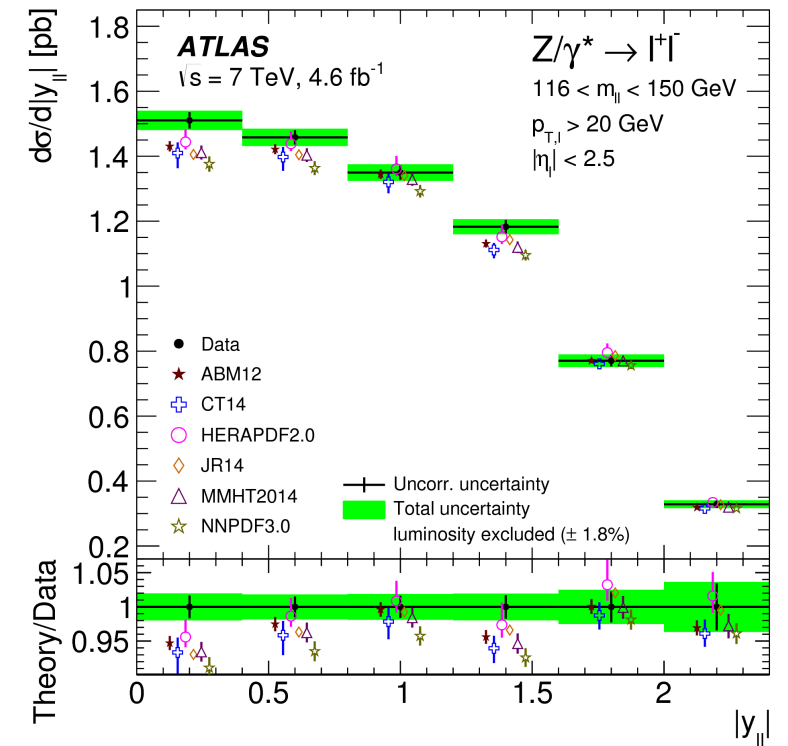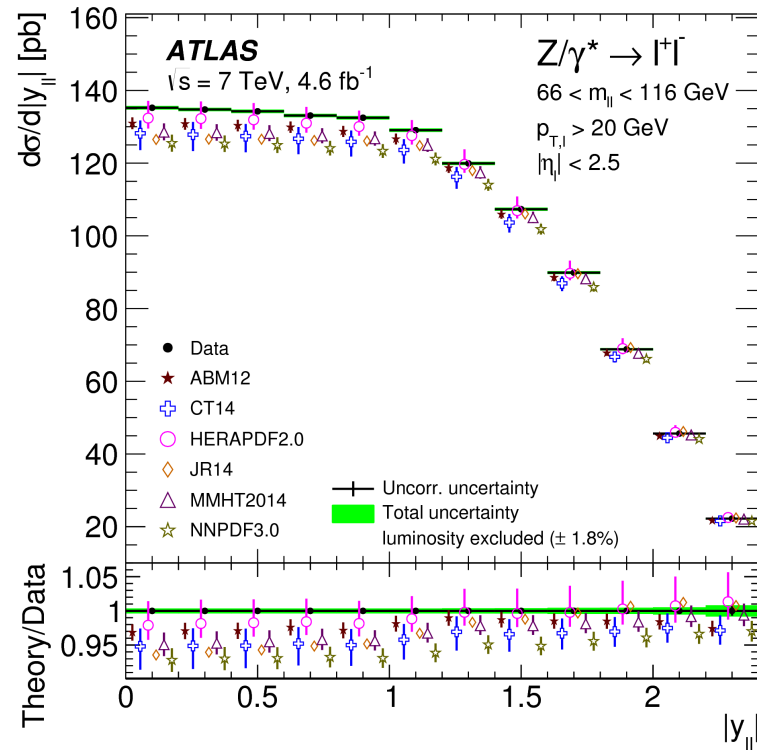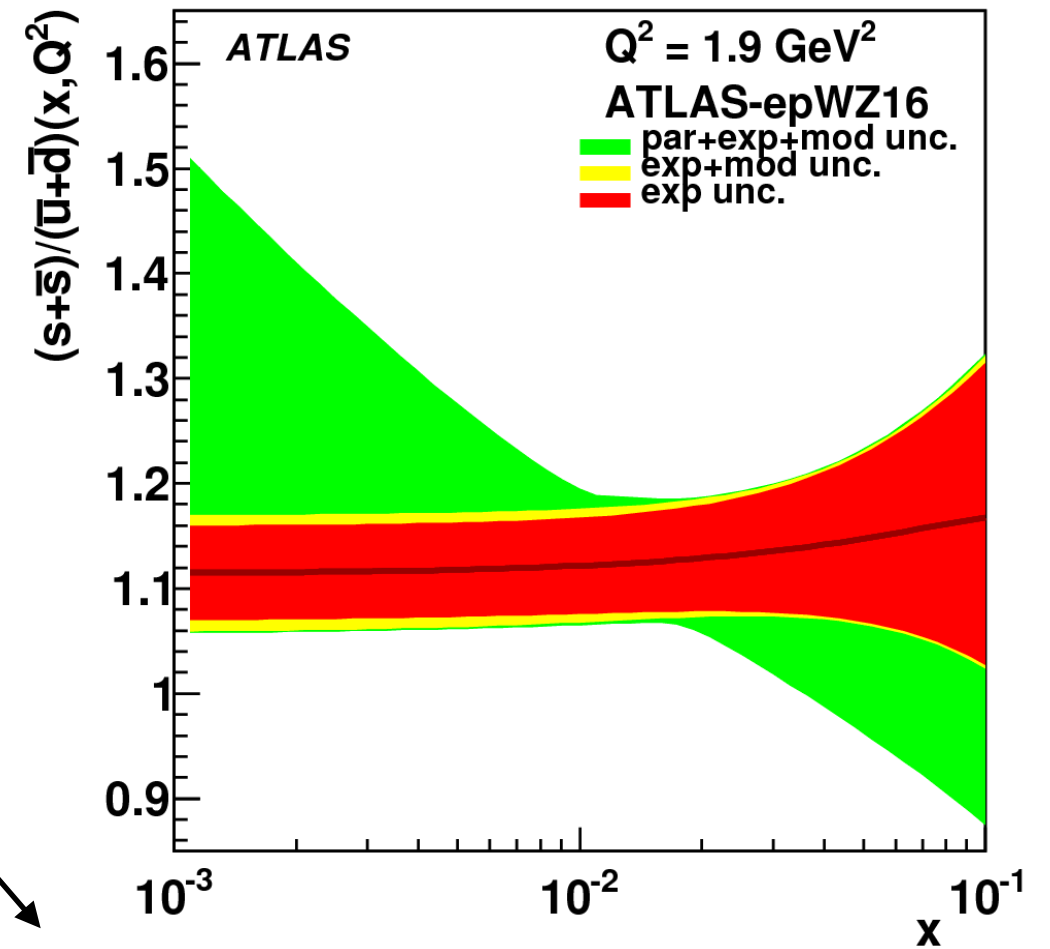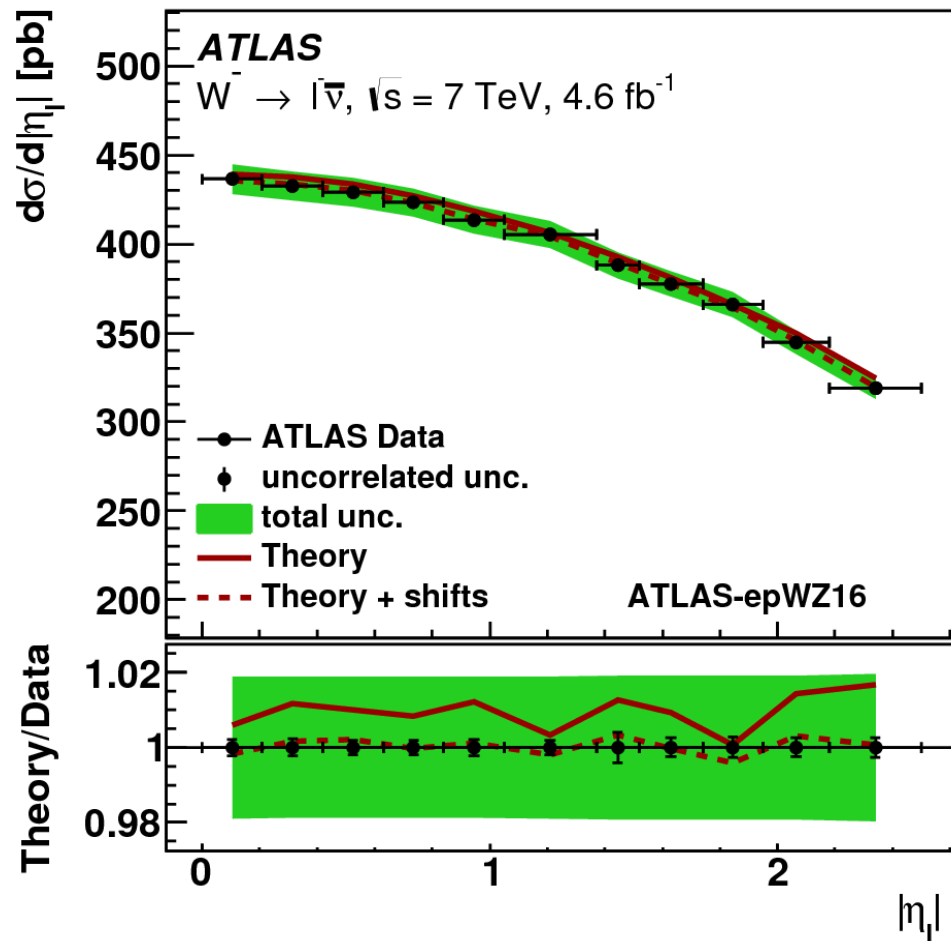Performed using DIS HERA I+II and ATLAS DY data -> new **ATLAS-epWZ16** PDF set

- ▸ reduced uncertainties
- ▸ R_s confirms that the strangeness is unsuppressed at low x and low W *
- ▸ more sensitivity to light-quark composition at low x *
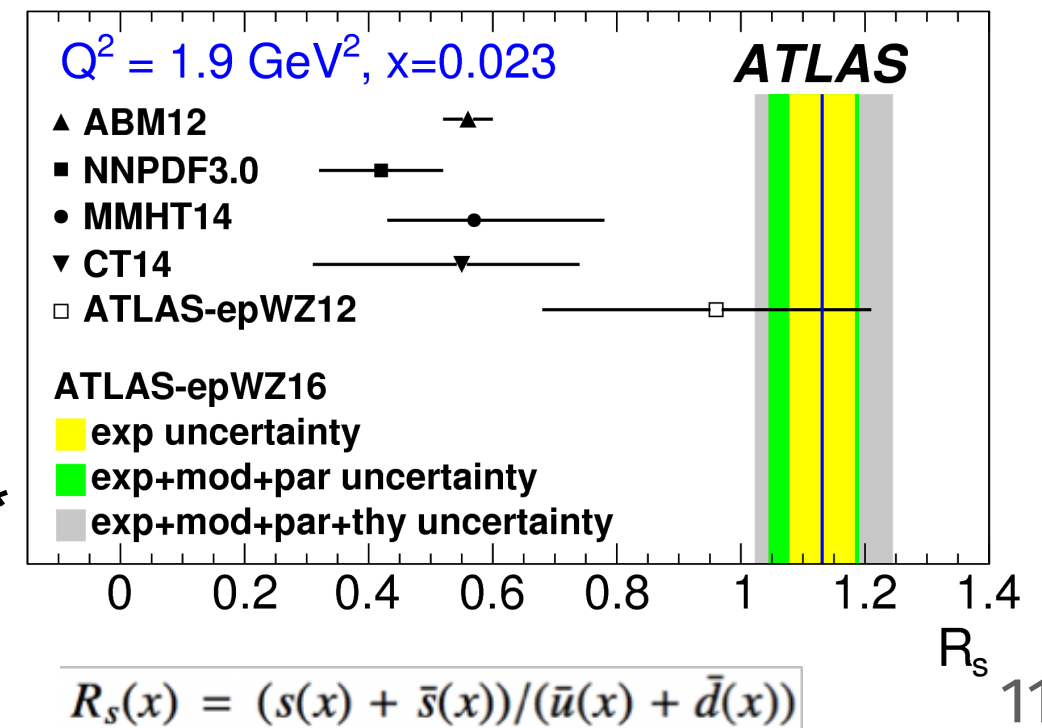
- There is a criticism of this <u>interpretation</u>...

$$R_s(x) = (s(x) + \bar{s}(x))/(\bar{u}(x) + \bar{d}(x))$$

Interpretation of results @ 7 TeV

before profiling · after profiling
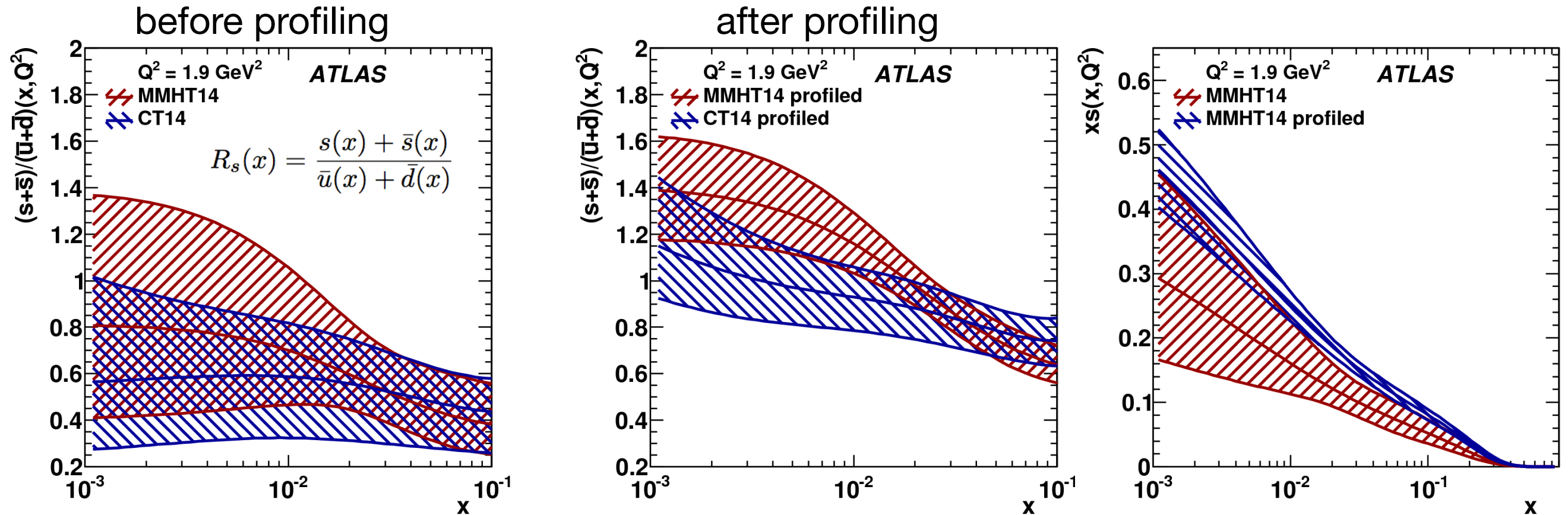
Profiling results:

For R_s:

- Significantly reduced uncertainties
- Central values are increased towards unity

For strange quark:

- s-quark distribution is increased
- uncertainties reduced
  - reduction of light sea at low x

Profiling of other PDF sets shows the same increased s-quark distribution at low x

3.2, 20.3, 4.6 fb^{-1} @ 13, 8, 7 TeV

Top quark pair to Z-boson ratios@ 7, 8, 13 TeV

JHEP 1702 (2017) 117

Top quark pair to Z-boson ratios@ 7, 8, 13 TeV

Motivation

- Sensitive to quark to gluon ratio
- Cancellation in experimental uncertainties (mainly luminosity and lepton-related systematic)
- Double ratios serve as precision tests of SM predictions

Measured ratios:

- Single ttbar $t\bar{t}$ to Z ratio:

$$R_{t\bar{t}/Z} = \frac{\sigma_{t\bar{t}}}{0.5(\sigma_{Z \to ee} + \sigma_{Z \to \mu\mu})}$$

- Ratios at different center-of-mass energy for a giv
- Double ratio for different center-of-mass energies (j))

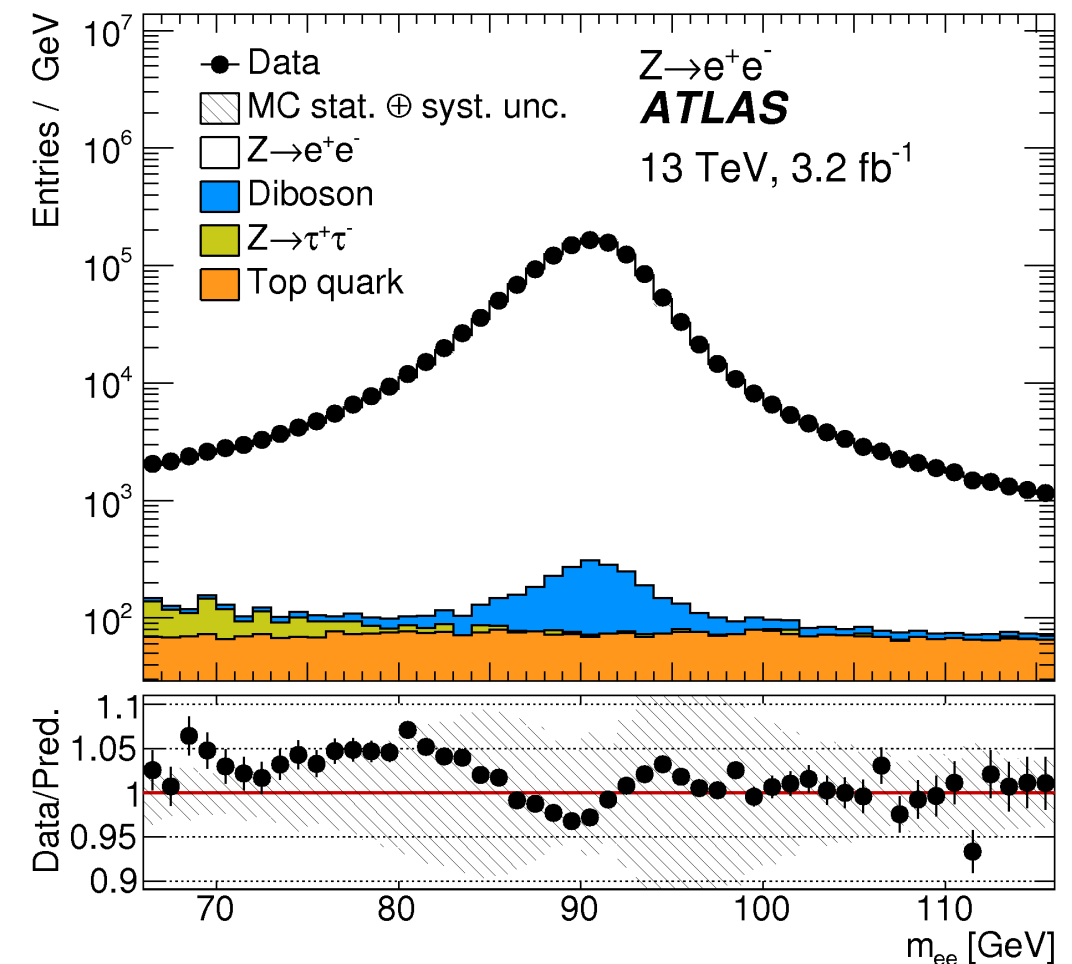# Top quark pair to Z-boson ratios@ 7, 8, 13 TeV

Used cross sections:

- Z-boson cross sections at 7, 8 TeV (Eur. Phys. J. C 77 (2017) 367, Eur. Phys. J. C 76(5), 1-61 (2016))
- Top quark pair cross sections at 7, 8, 13 TeV (Eur. Phys. J. C74 (2014) 3109; Eur. Phys. J. C76 (2016) 642, Phys. Lett. B761 (2016) 136)
- new measurement: Z at 13 TeV

Phase space definition for Z

	Z
p_T	> 25 GeV
η	< 2.4
m_{ll}	[66;116] GeV

$\sqrt{s}$ [TeV]	Value $\pm$ stat $\pm$ syst $\pm$ beam $\pm$ lumi [pb]			
	σ_Z^{fid}			
13	$777\pm\ 1\ (0.1\%)$	$\pm 3\ (0.4\%)$	$\pm 5\ (0.7\%)$	$\pm 16\ (2.1\%)$
8	$506\pm< 1\ (< 0.1\%)$	$\pm 3\ (0.6\%)$	$\pm 3\ (0.6\%)$	$\pm 10\ (1.9\%)$
7	$451\pm\ <1\ (0.1\%)$	$\pm 1\ (0.3\%)$	$\pm 3\ (0.6\%)$	$\pm 8\ (1.8\%)$
	$\sigma_{t\bar{t}}^{\text{tot}}$			
13	$818\pm\ 8\ (0.9\%)$	$\pm 27\ (3.3\%)$	$\pm 12\ (1.5\%)$	$\pm 19\ (2.3\%)$
8	$243\pm\ 2\ (0.7\%)$	$\pm 5\ (2.3\%)$	$\pm 4\ (1.7\%)$	$\pm 5\ (2.1\%)$
7	$183\pm\ 3\ (1.7\%)$	$\pm 4\ (2.3\%)$	$\pm 3\ (1.8\%)$	$\pm 4\ (2.0\%)$

All data is dominated by the systematic uncertainty

Top quark pair to Z-boson ratios@ 7, 8, 13 TeV

Correlation model

Source / $\sqrt{s}$ [TeV]	$\delta\,\sigma_Z^{\text{fid}}$			$\delta\,\sigma_{t\bar{t}}^{\text{tot}}$		
	13	8	7	13	8	7
Luminosity	A	B	C	A	B	C
Beam energy	A	A	A	A	A	A
Muon (lepton) trigger	A	A*	A	A	B	B
Muon reconstruction/ID	A	B	C	A	D	D
Muon isolation	A	A	A	B	C	D
Muon momentum scale	A	A	A	A	A	A
Electron trigger	A	A	A	A	—	—
Electron reconstruction/ID	A	B	C	A	D	D
Electron isolation	A	A	—	B	C	D
Electron energy scale	A	A	A	A	A	A
Jet energy scale	—	—	—	A	B	B
b-tagging	—	—	—	A	B	B
Background	A	A	A	B	B	B
Signal modelling (incl. PDF)	A	A	A	B*	B	B

Uncertainties

Systematic [%] / $\sqrt{s}$ [TeV]	$\delta\,\sigma_Z^{\text{fid}}$			$\delta\,\sigma_{t\bar{t}}^{\text{tot}}$		
	13	8	7	13	8	7
Luminosity	2.1	1.9	1.8	2.3	2.1	2.0
Beam energy	0.7	0.6	0.6	1.5	1.7	1.8
Muon (lepton) trigger	0.1	0.6	0.1	0.1	0.2	0.2
Muon reconstruction/ID	0.7	0.5	0.3	0.4	0.4	0.3
Muon isolation	0.4	0.0	0.2	0.3	0.2	0.4
Muon momentum scale	0.1	0.0	0.0	0.0	0.0	0.1
Electron trigger	0.0	0.2	0.0	0.1	—	—
Electron reconstruction/ID	0.4	0.8	0.3	0.3	0.4	0.1
Electron isolation	0.1	0.0	—	0.4	0.3	0.6
Electron energy scale	0.3	0.1	0.1	0.2	0.5	0.2
Jet energy scale	—	—	—	0.4	0.7	0.4
b-tagging	—	—	—	0.5	0.4	0.5
Background	0.1	0.2	0.1	1.1	1.0	1.0
Signal modelling (incl. PDF)	0.1	0.1	0.3	3.0	1.7	1.8

- Same row and letter: correlated
  - ‣ Starred letter: mostly correlated
- Different row: uncorrelated

Dominating systematics:

- Luminosity uncertainty
- Beam energy
- Signal modeling (ttbar)

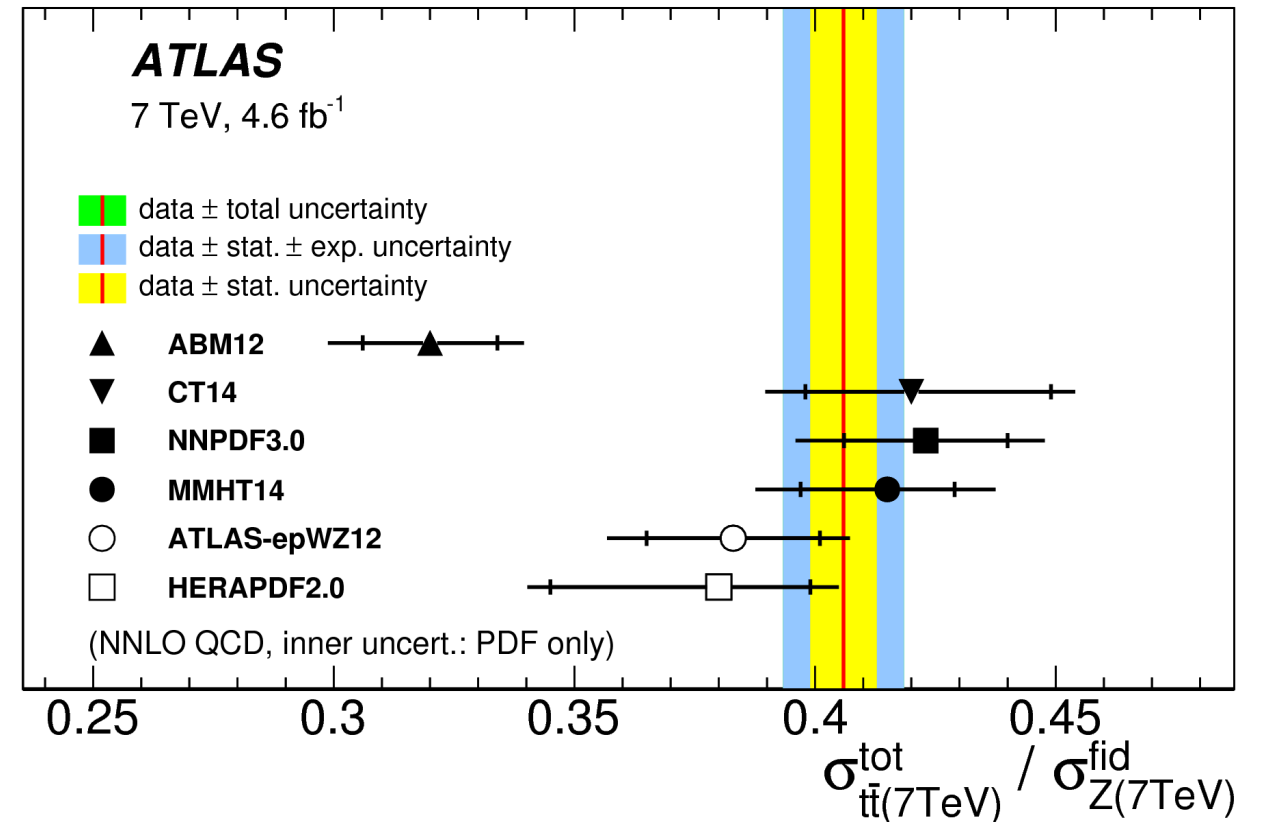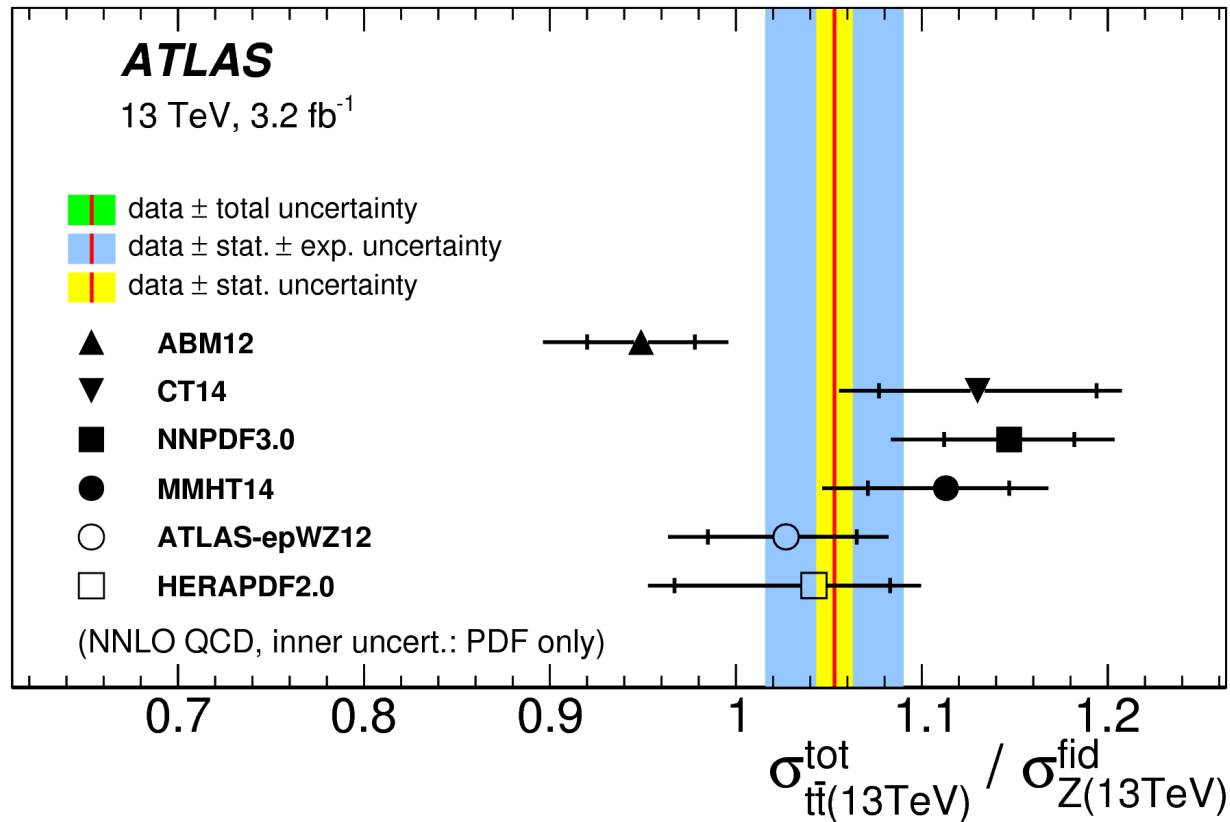# Theoretical predictions @ 7, 8, 13 TeV

	σ_Z^{fid}			$\sigma_{t\bar{t}}^{\text{tot}}$		
$\sqrt{s}$ [TeV]	13	8	7	13	8	7
Central value [pb]	744	486	432	842	259	182
Uncertainties [%]						
PDF	+2.7 −3.4	+2.5 −3.1	+2.5 −3.0	+2.6 −2.7	+3.9 −3.4	+4.4 −3.7
α_S	+0.9 −1.1	+1.0 −0.8	+1.0 −0.7	+1.9 −1.8	+2.1 −2.1	+2.2 −2.1
Scale	+0.5 −0.8	+0.5 −0.5	+0.7 −0.3	+2.4 −3.6	+2.6 −3.5	+2.6 −3.5
Intrinsic Z	+0.7 −0.7	+0.7 −0.7	+0.7 −0.7	N/A	N/A	N/A
m_t	N/A	N/A	N/A	+2.8 −2.7	+3.0 −2.9	+3.1 −3.0
Total	+3.0 −3.7	+2.8 −3.3	+2.9 −3.2	+5 −6	+6 −6	+6 −6

ttbar cross section predictions:

- NNLO+NNLL QCD with Top++v2.0
- Only total cross sections available

- Correlation of measured cross-sections is opposite sign to theoretical predictions
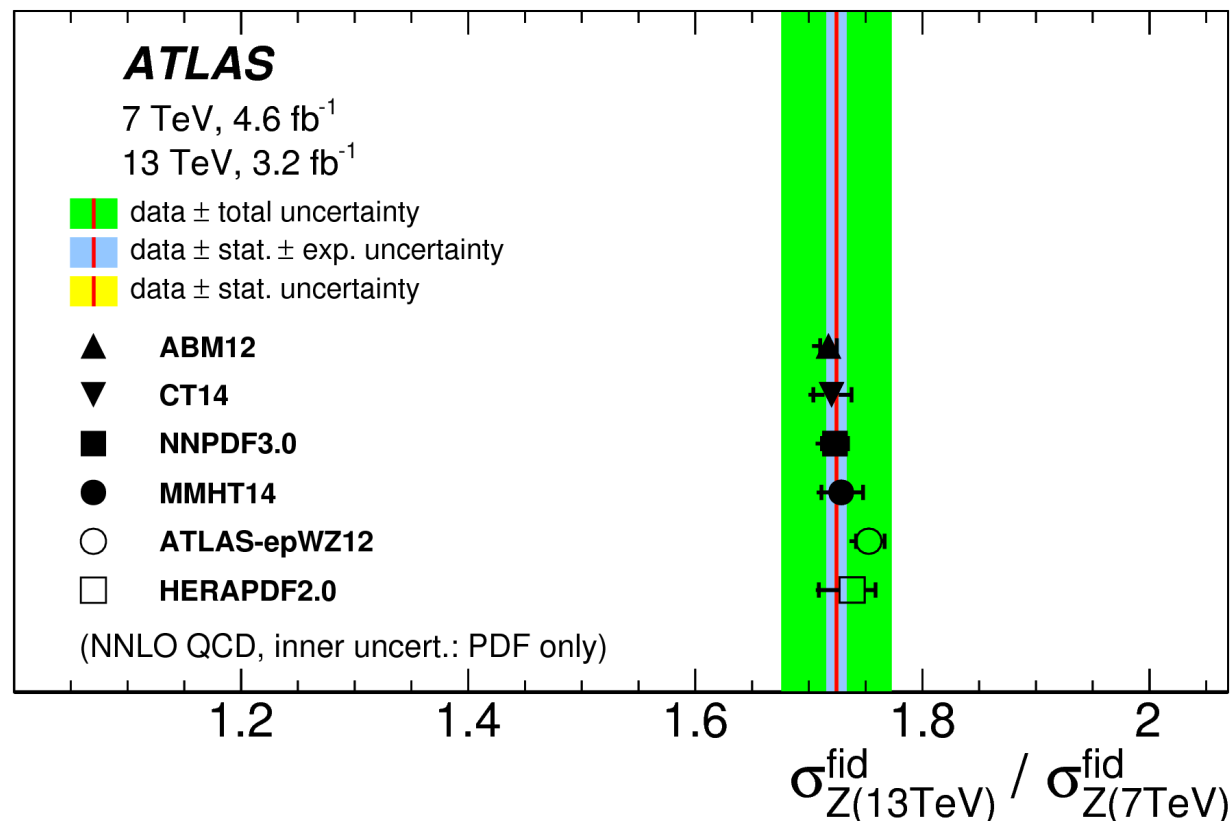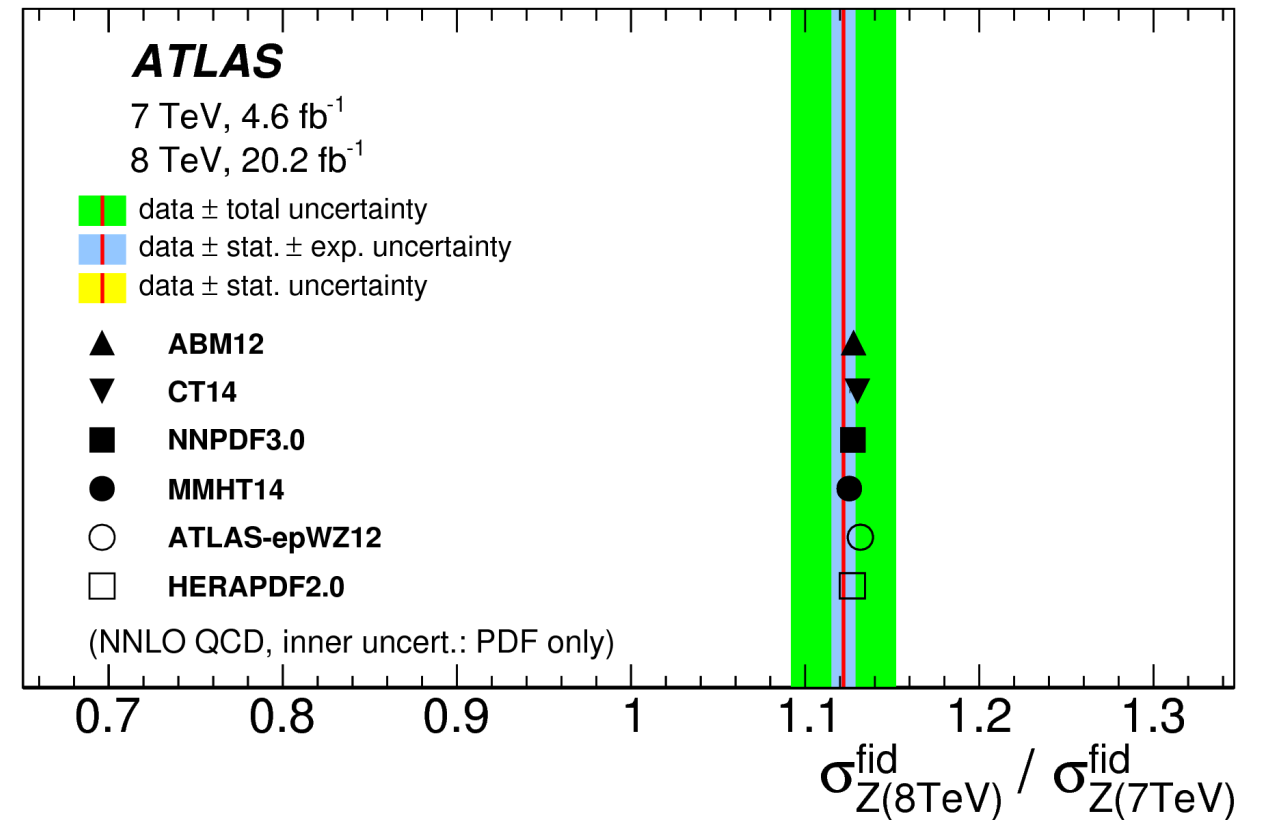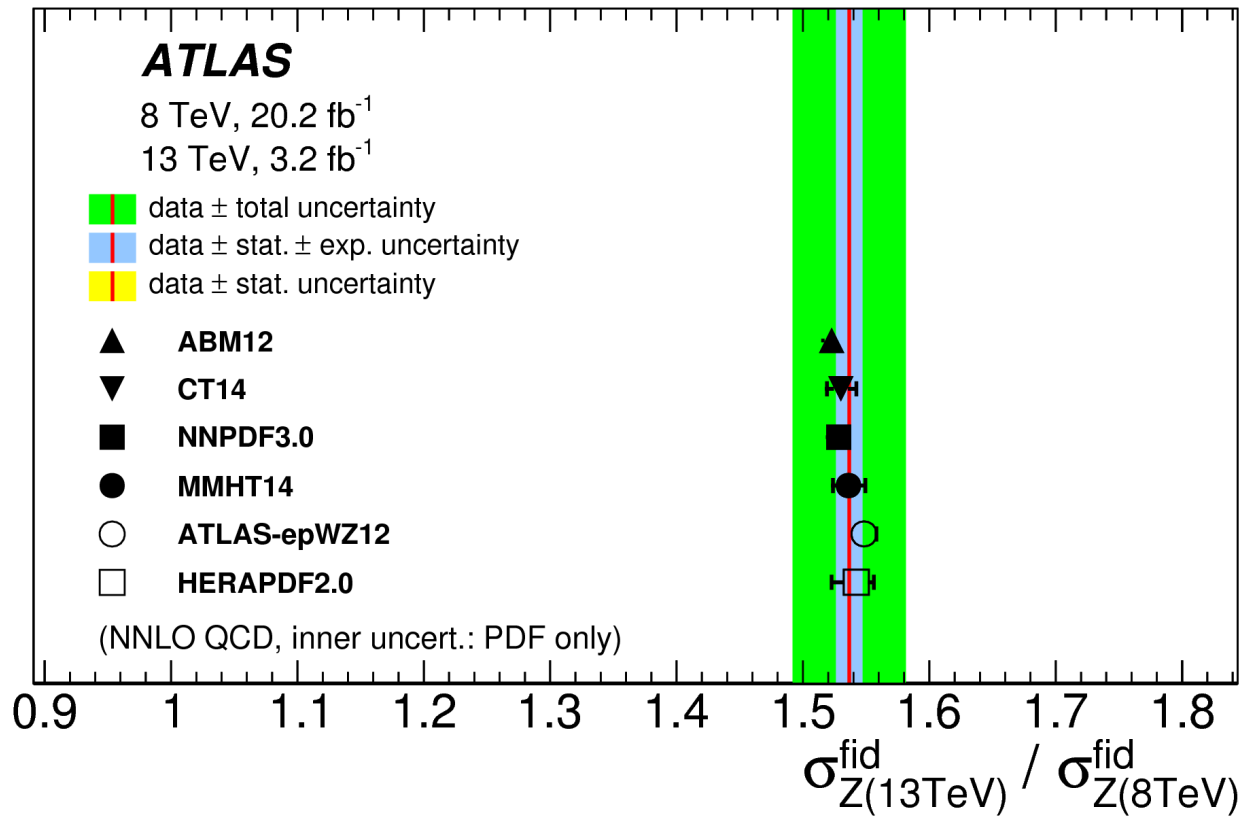 - ▸ Predictions enhance sensitivity to constrain PDF
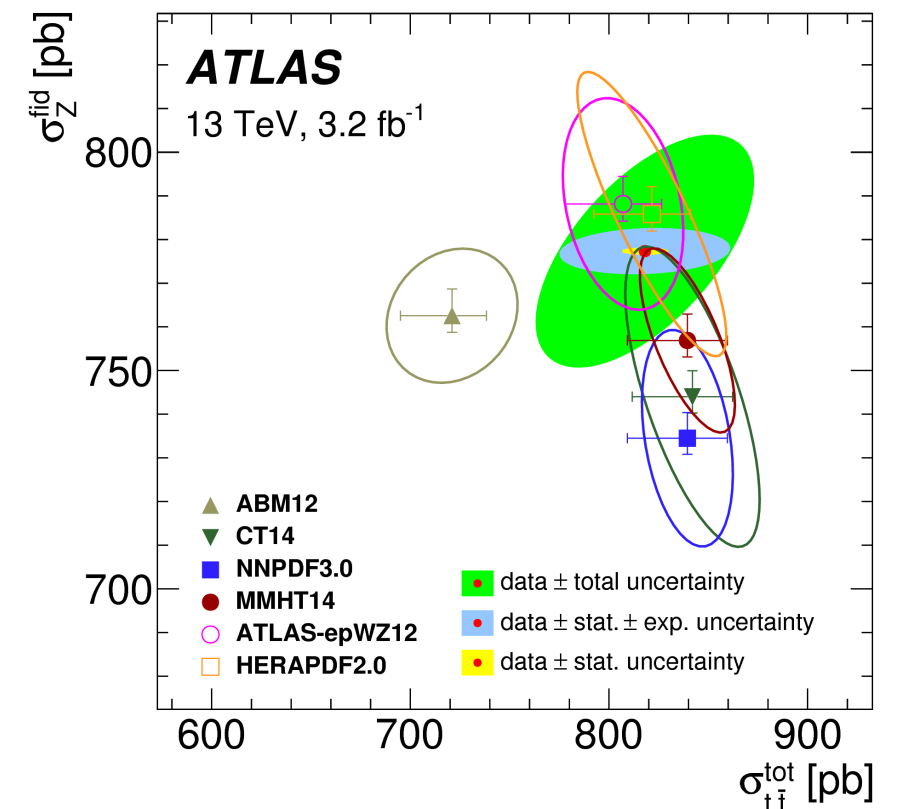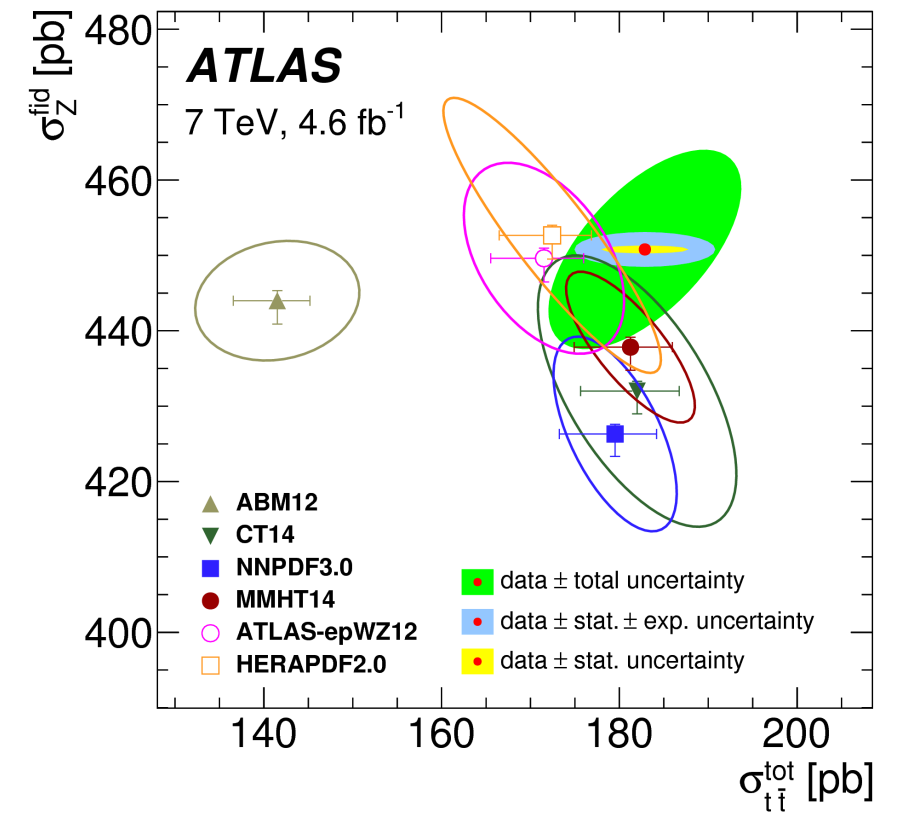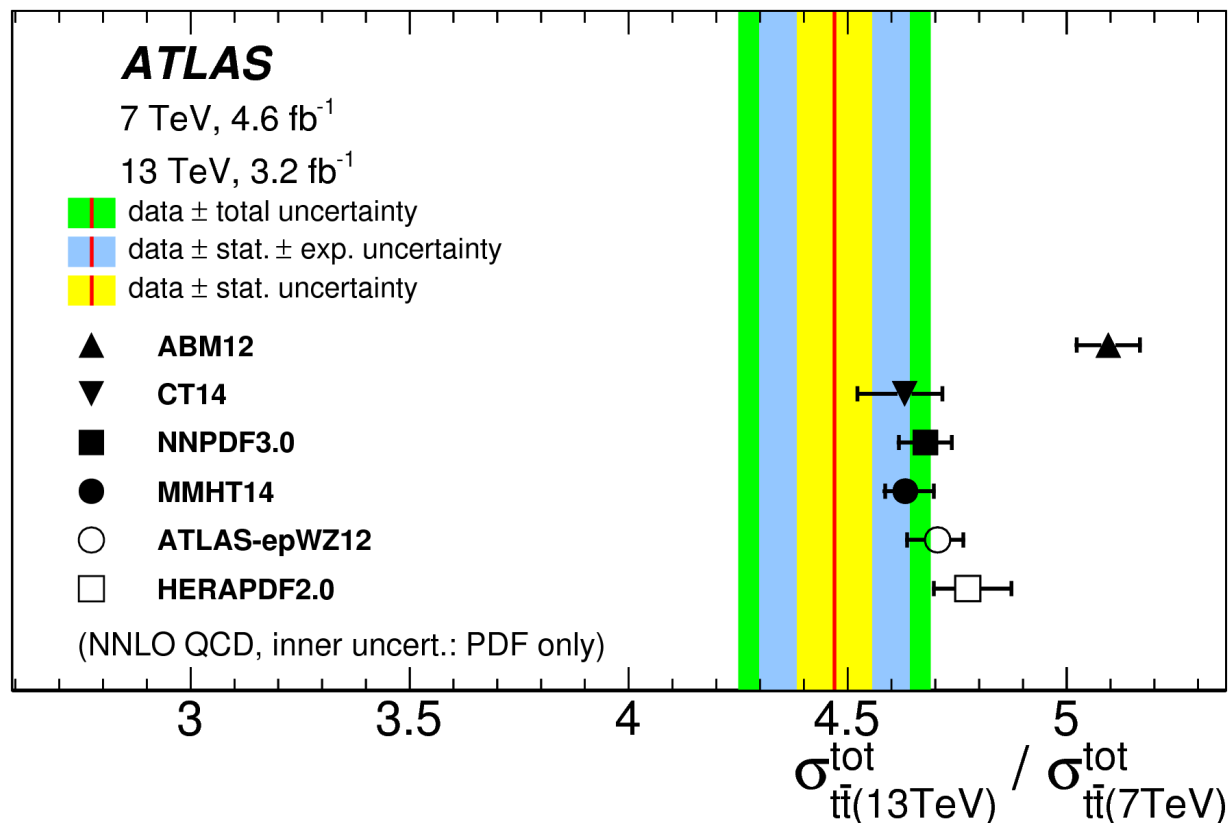
Cross section ratios for fixed energies

Cross section ratios for Z cross sections


- Uncertainty is dominated by luminosity
- Less precise than theory predictions
- Predictions are in agreement with data within the uncertainty

Cross section ratios for top cross sections
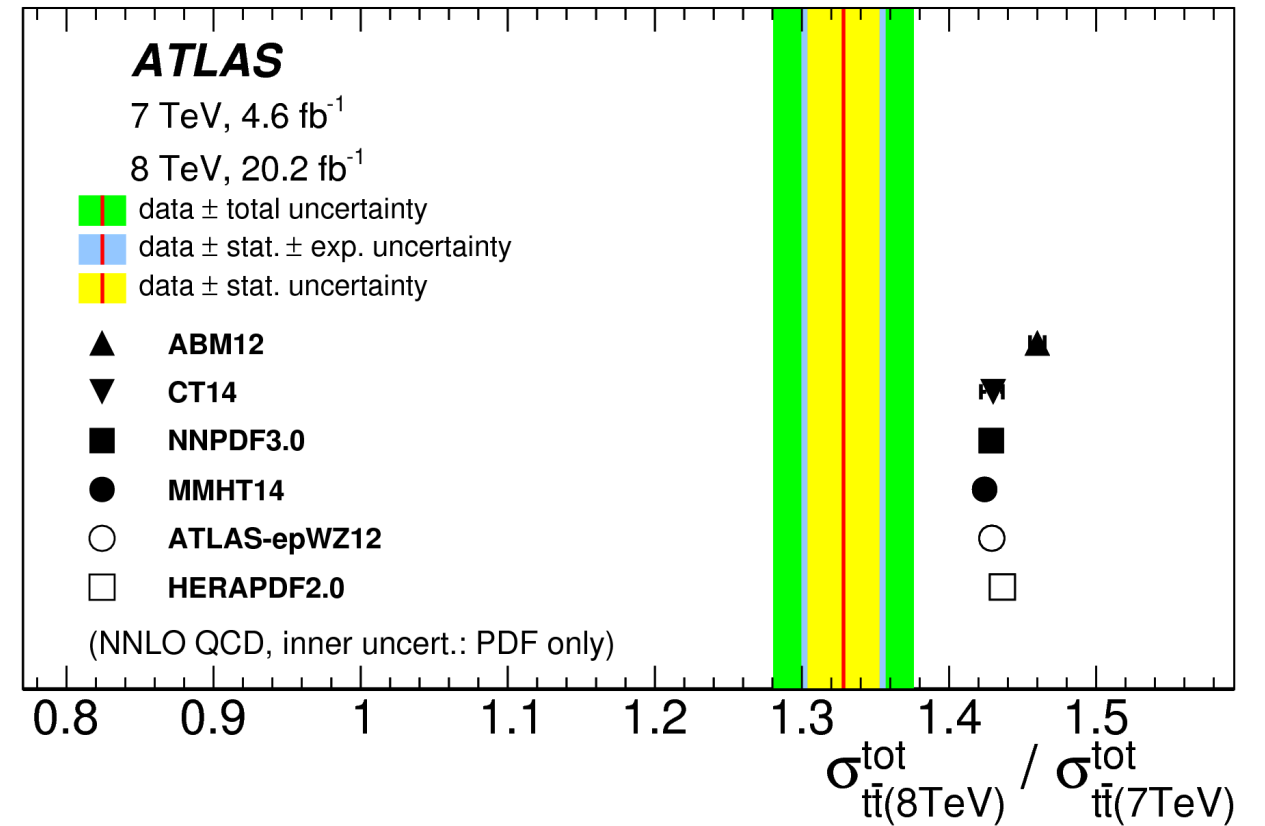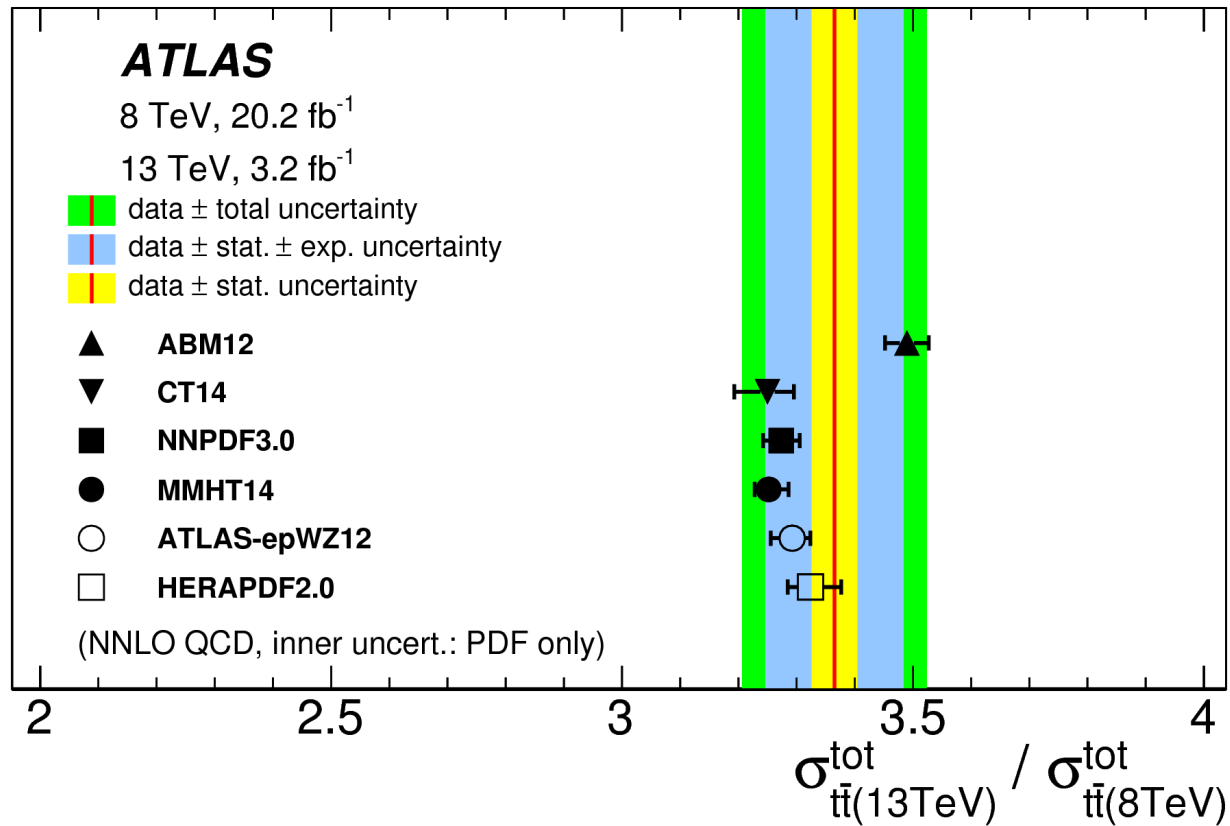
- Less precise than theory predictions
- Predictions are in agreement with data within the uncertainty for 13 TeV/8 TeV
- Predictions are off for ratios with 7 TeV data

Double ratios
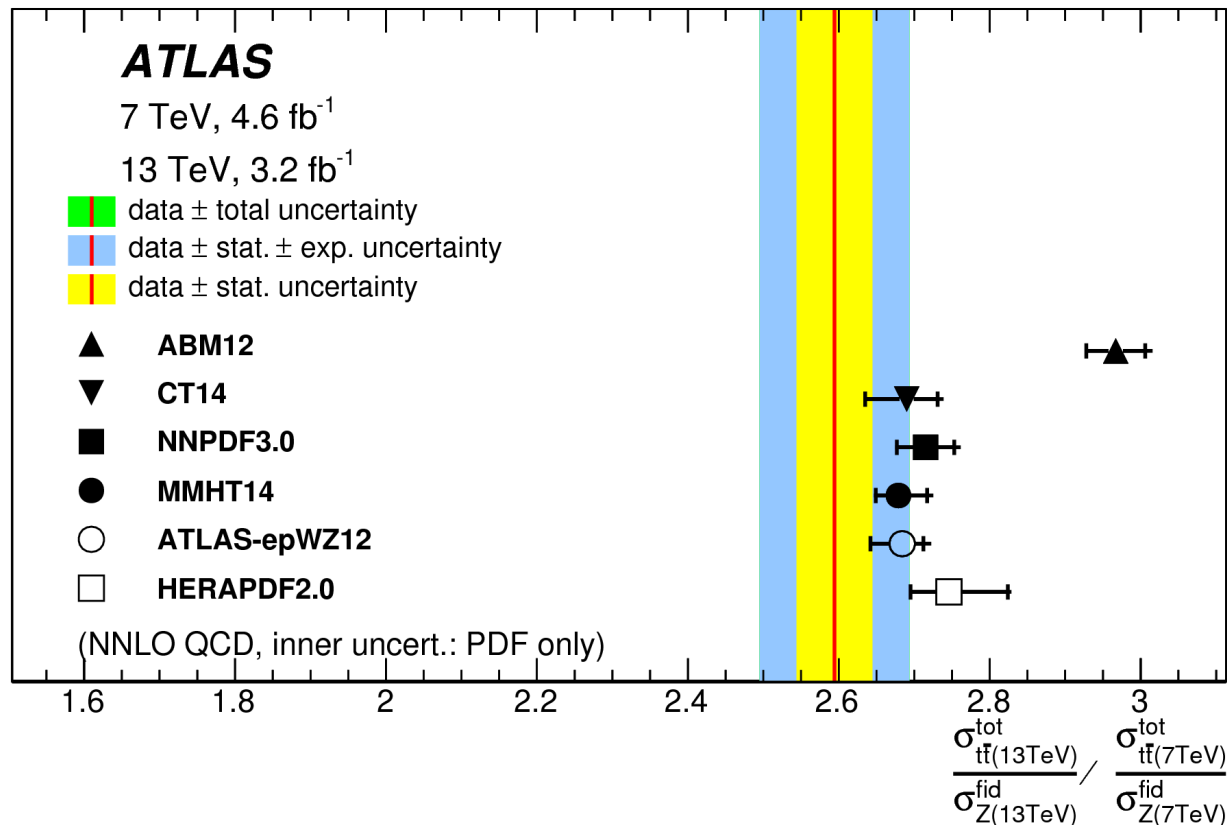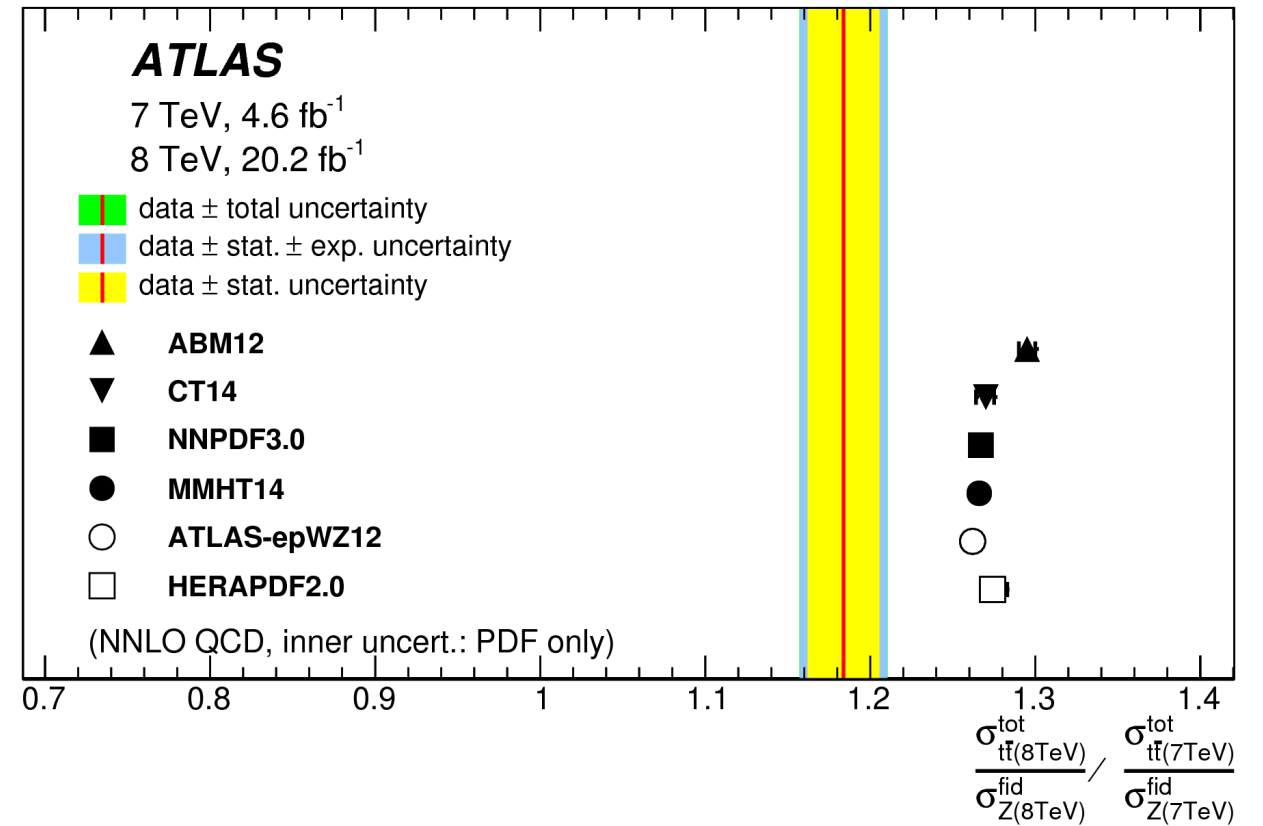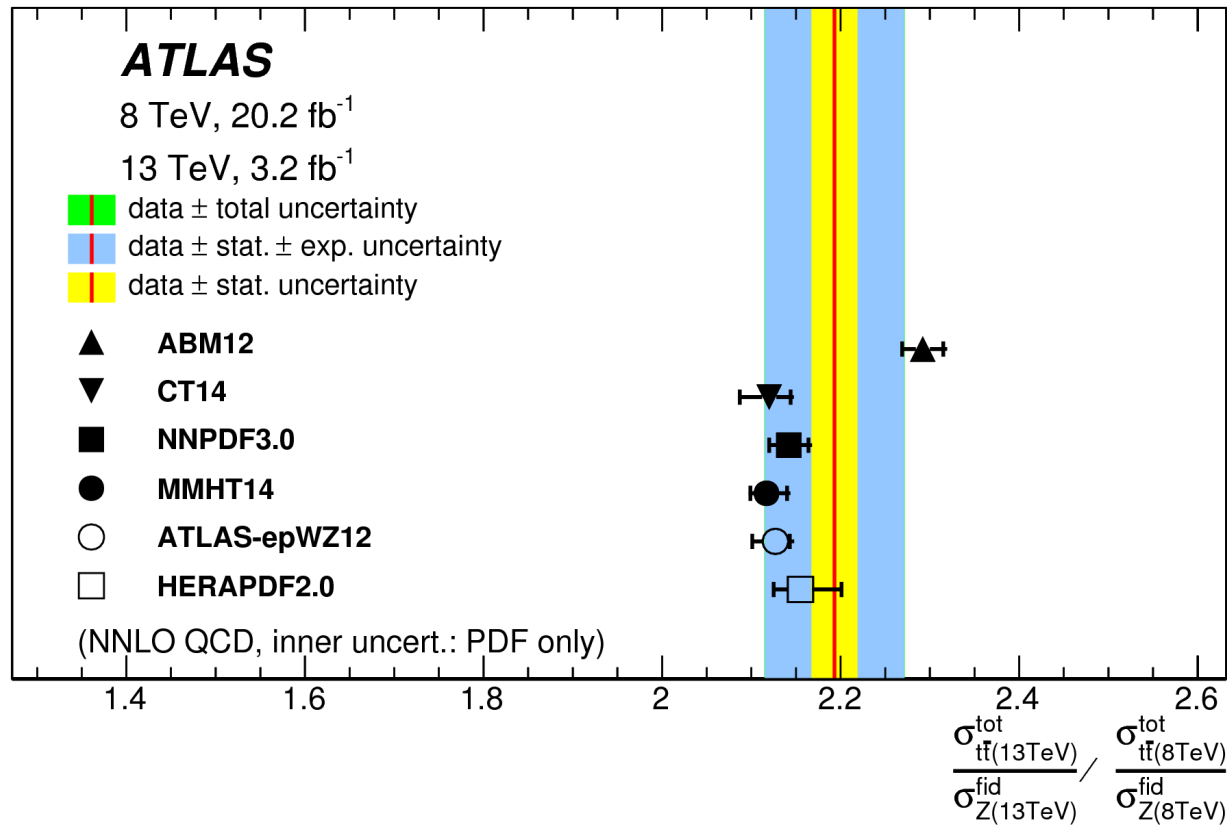
- Luminosity almost cancels

- 13/8 TeV, 13/7 TeV almost all predictions within experimental uncertainty

- 8/7 TeV predictions are 3 standard deviations off:

  ▸ not described in PDFs

Top quark pair to Z-boson ratios@ 7, 8, 13 TeV
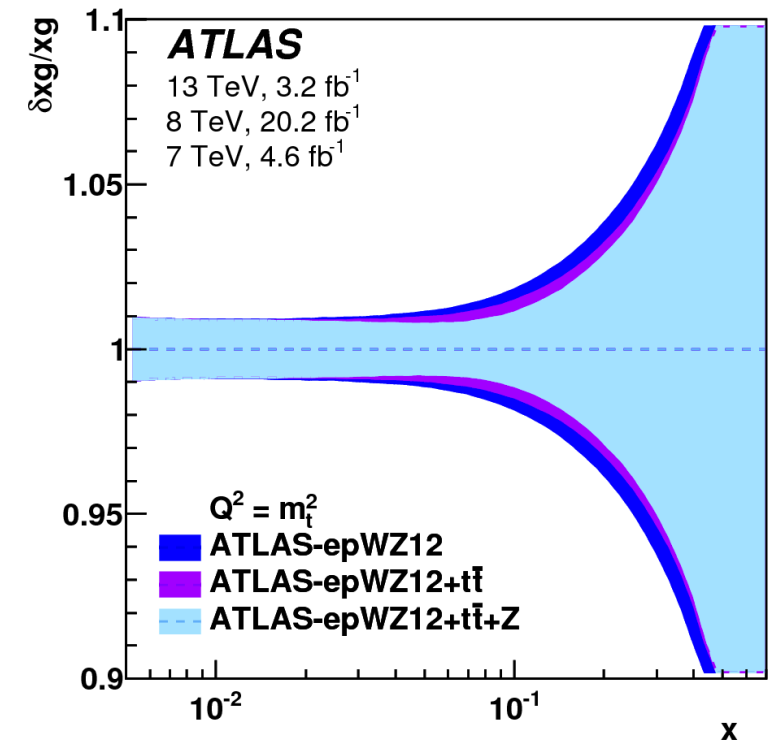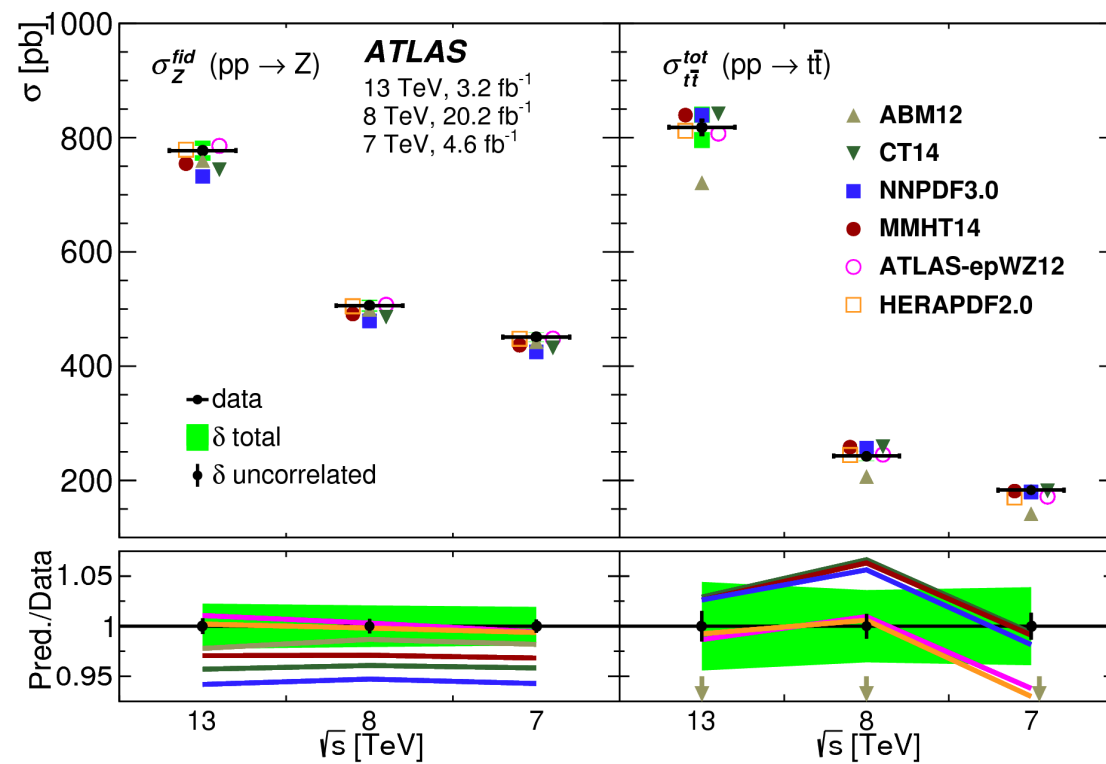
- Six cross sections have been used to profile ATLAS-epWZ12 PDF set
- Gluon distribution is constrained at x~0.1
- Light sea quarks distributions are additionally constrained
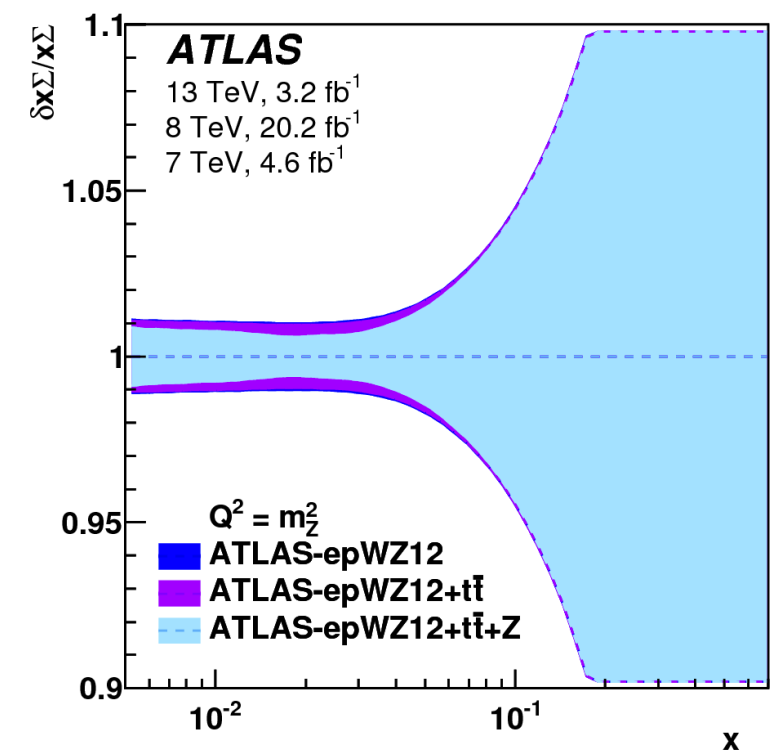
Summary

Summary

W/Z precision measurement at 7 TeV:

- Sub percent level of uncertainty
- More precise, than predictions
- Impact on s-quark distributions
- New ATLAS-epWZ16 PDF set
- Confirmed unsupressed strangeness

Top quark pair to Z-boson ratios at 7, 8, 13 TeV

- Benefit from uncertainty cancellation
- Some ratios are more precise, than predictions
- Impact on gluon and light sea distributions