W and Z boson precision measurements at ATLAS

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XVI Incontri di Fisica delle Alte Energie
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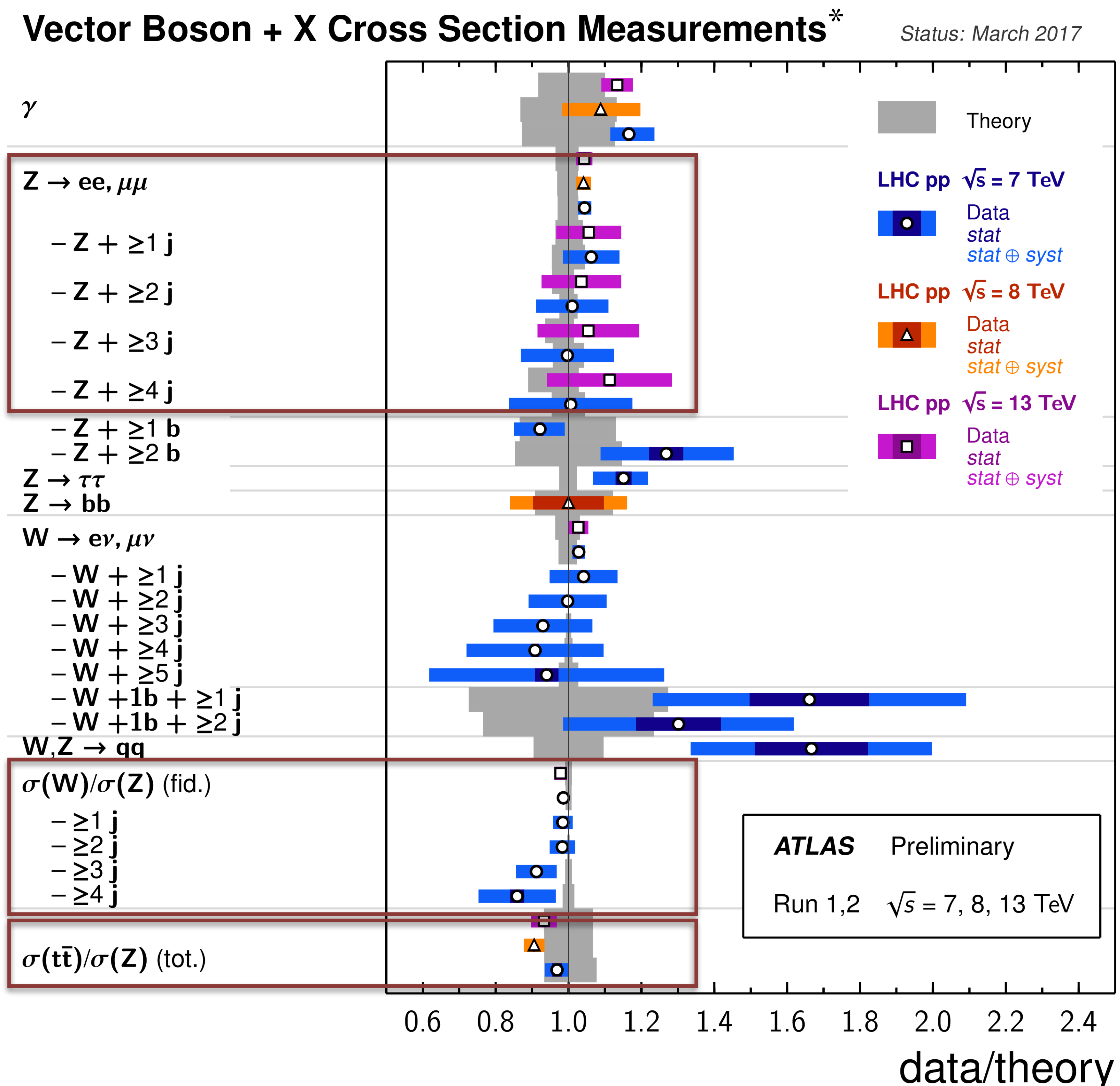
Outline

✤ **W and Z production @ 13 TeV**
- **Phys. Lett. B 759 (2016) 601**

✤ **tt/Z @ 7, 8 and 13 TeV**
- **JHEP 02 (2017) 117**

✤ **Z+jets @ 13 TeV**
- **arXiv:1702.05725**

✤ **W mass @ 7 TeV**
- **arXiv:1701.07240**



*https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SM/

W and Z vector are candles to test SM:

✧ **clear signature**, **large statistics** and small background

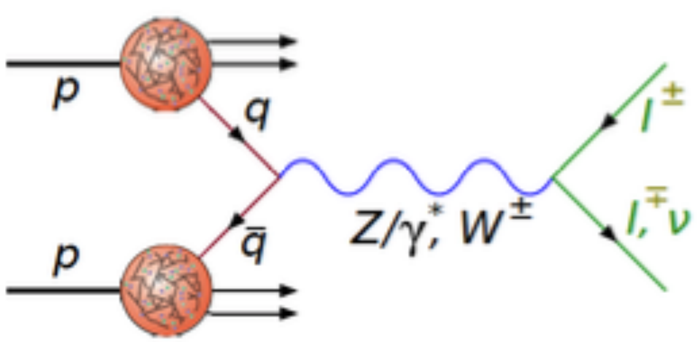
✧ benchmark for understanding QCD and EW processes

→ predictions available at NNLO accuracy in QCD + NLO EW corrections

✧ Sensitive to the dynamics of interacting partons → constraint on PDFs

✧ Powerful tool for → detector calibration and alignment

→ luminosity monitoring



✤ W+/W-, W/Z and tt/Z Ratios

◁ **cancellation of some uncertainties** (lumi+lepton-related+theoretical)

◁ Sensitivite to → $R_{W+/W-}$ to u,d-valence quarks at low Bjorken-x

→ $R_{W\pm/Z}$ to s-quark distribution

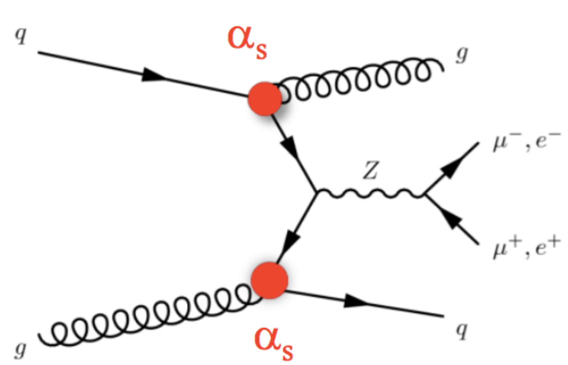
→ $R_{tt/Z}$ at a given $\sqrt{s}$ to gluon-to-quark PDF

✤ Z+jets

◁ dominated by strong interactions → pQCD studies

◁ **background for SM, Higgs and new Physics**

◁ very sensitive probe of different MC descriptions



W and Z cross sections 13 TeV, 81 pb^{-1}

Ratio of cross sections in different lepton final states

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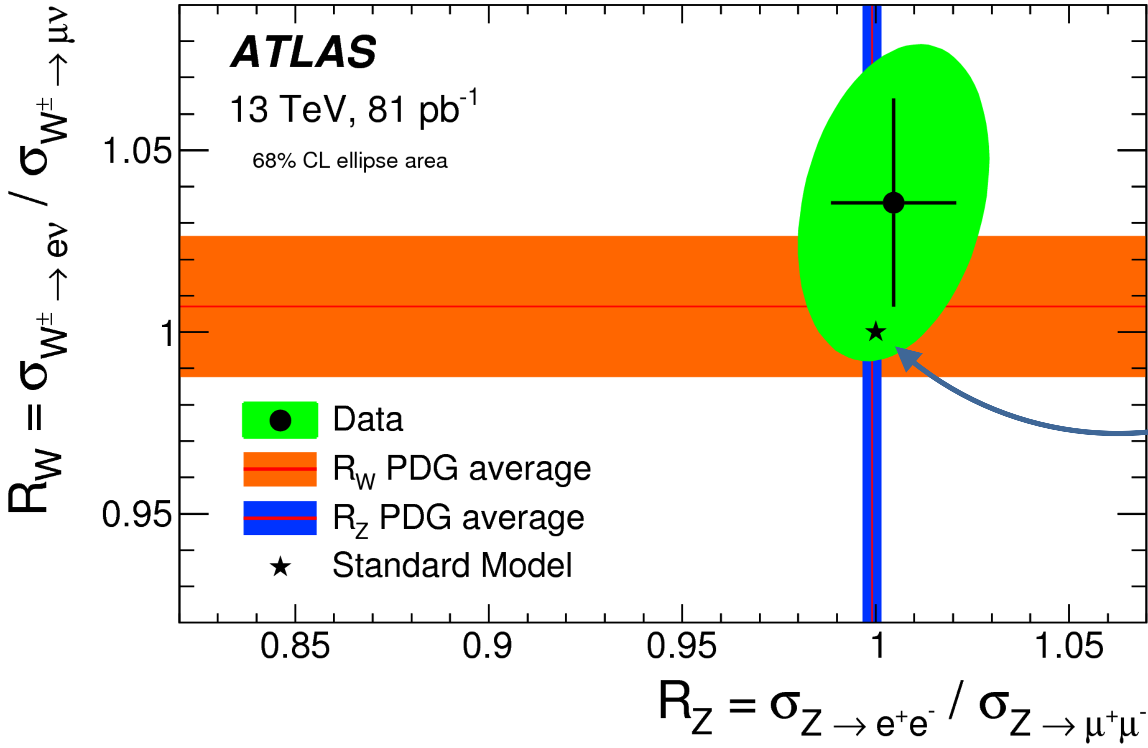
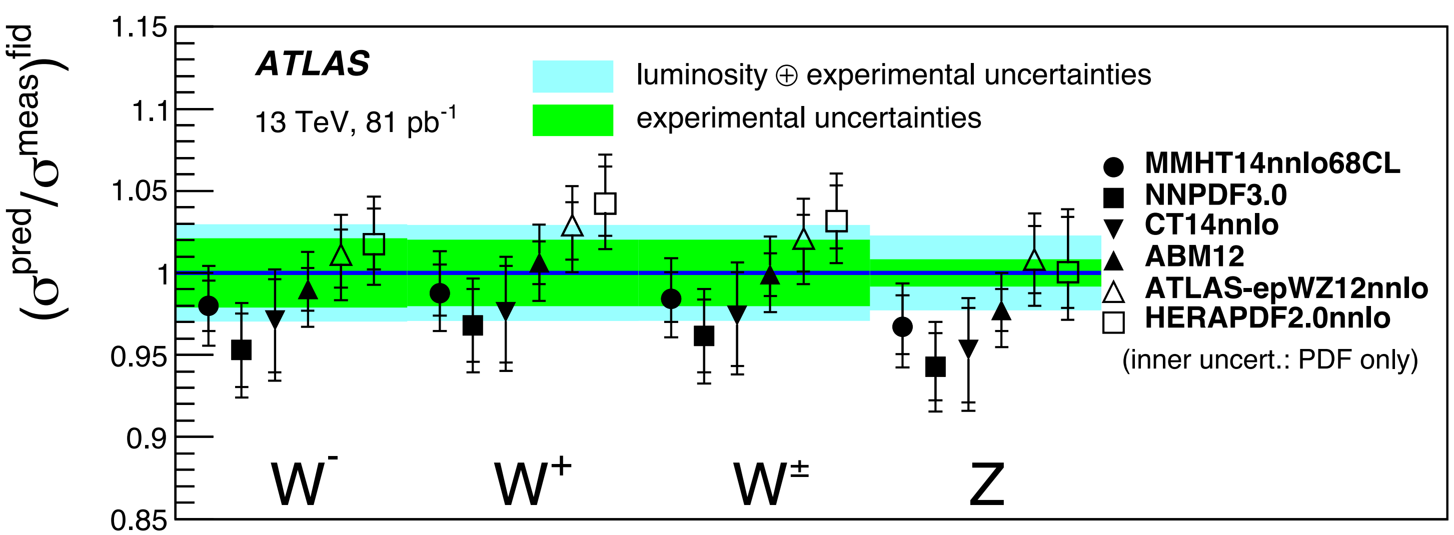


Precise test of lepton universality

Agreement with NNLO SM predictions

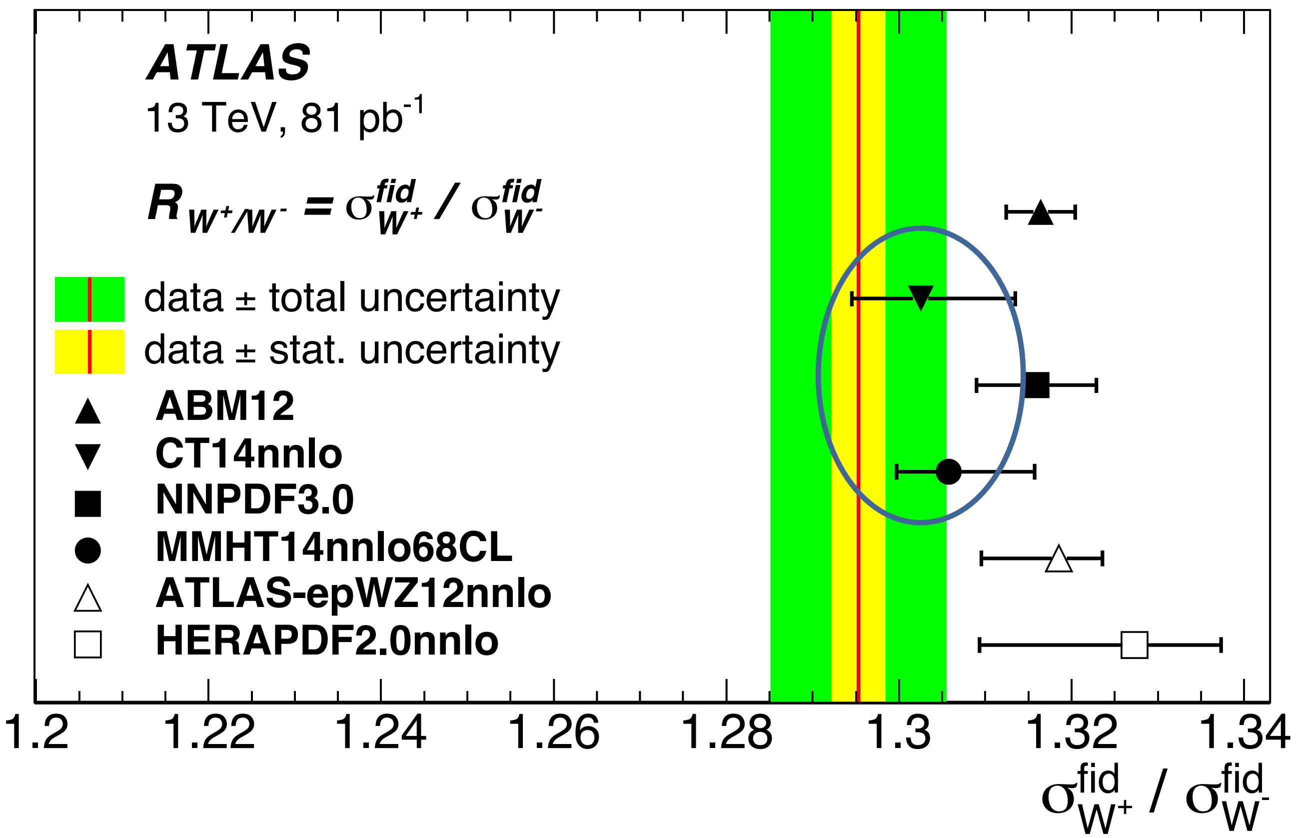
Simultaneous combination of W^+, W^- and Z fiducial cross sections



Z ~ 1% (± 2.1% lumi)
W ~ 2% (± 2.1% lumi)

Theoretical predictions uncertainty (dominated by PDFs): ~6% for $W^\pm$ and ~7% for Z.

Cross Sections can constrain proton PDFs



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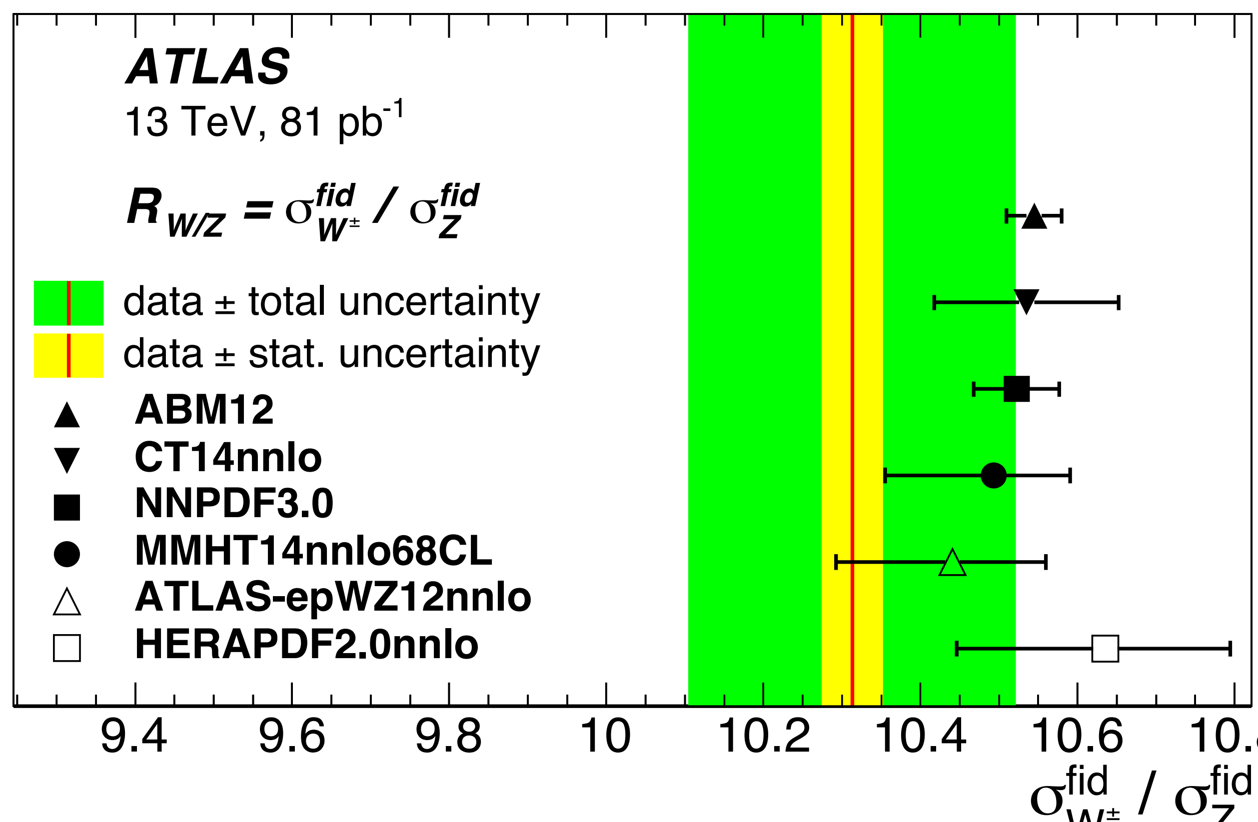
High precision measurement (~0.8%)
→ **discriminate among various PDFs**

W+/W- favours CT14nnlo and MMHT14nnlo PDFs

W±/Z compatible with all PDFs within uncertainties

ATLAS-epWZ12 is the most predictive calculation available and it contains fits on ATLAS data.



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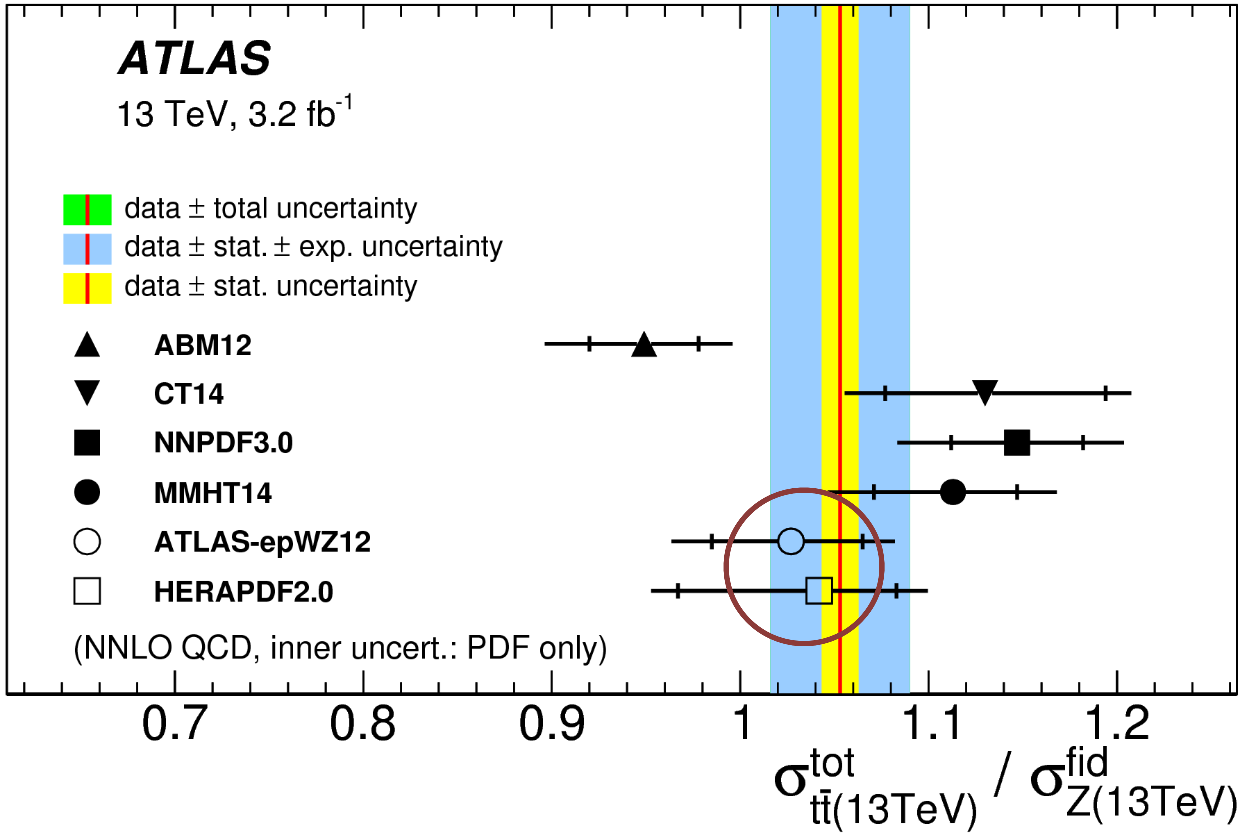
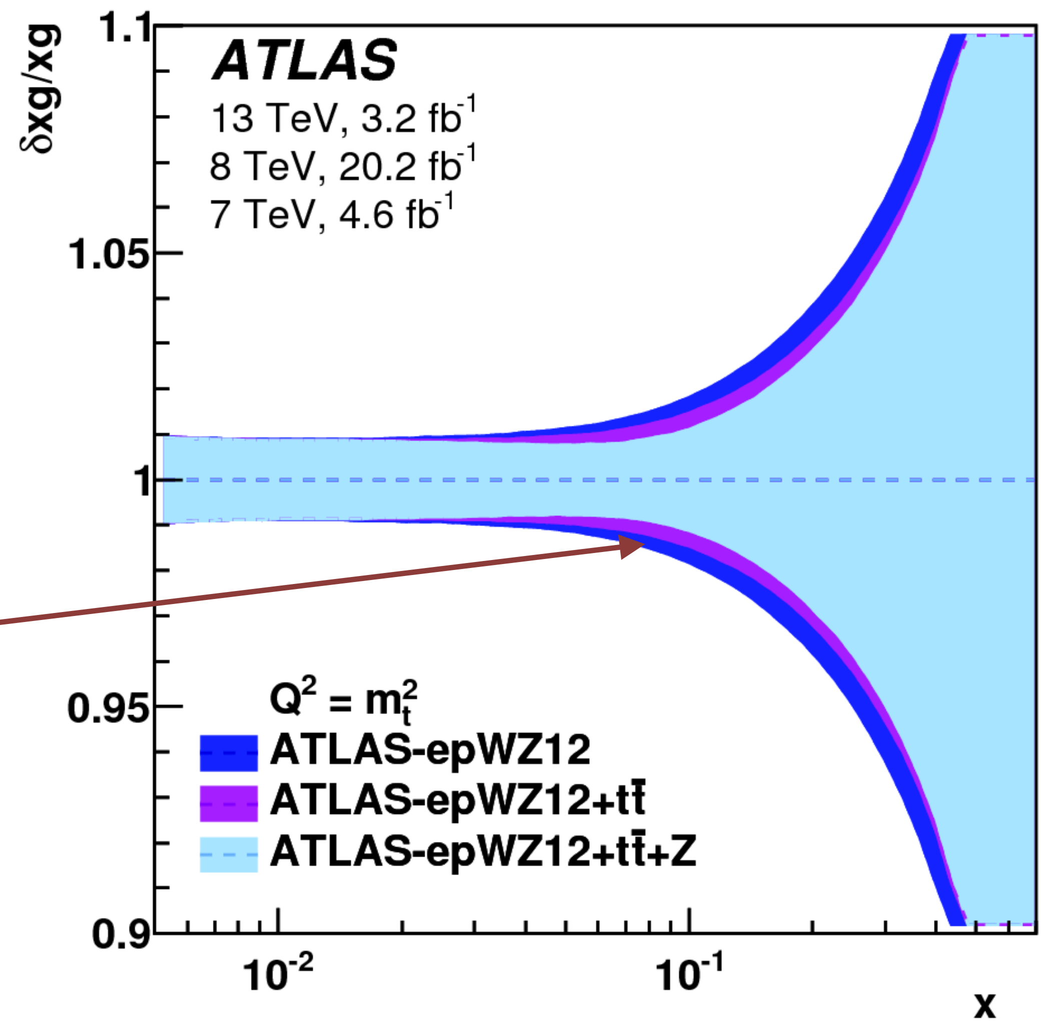
Single ratio $R_{tt/Z}$ at $\sqrt{s}$ = 13 TeV



Good agreement with different PDFs

Measurements more precise than predictions

Gluon distributions



Impact of ATLAS data on the PDF uncertainties
quantified by PDF profiling using ATLAS-epWZ12

tt and Z data constraint:
Gluon at x ~ 0.1

Differential Z+jets cross section 13 TeV, 3.2 fb^{-1}

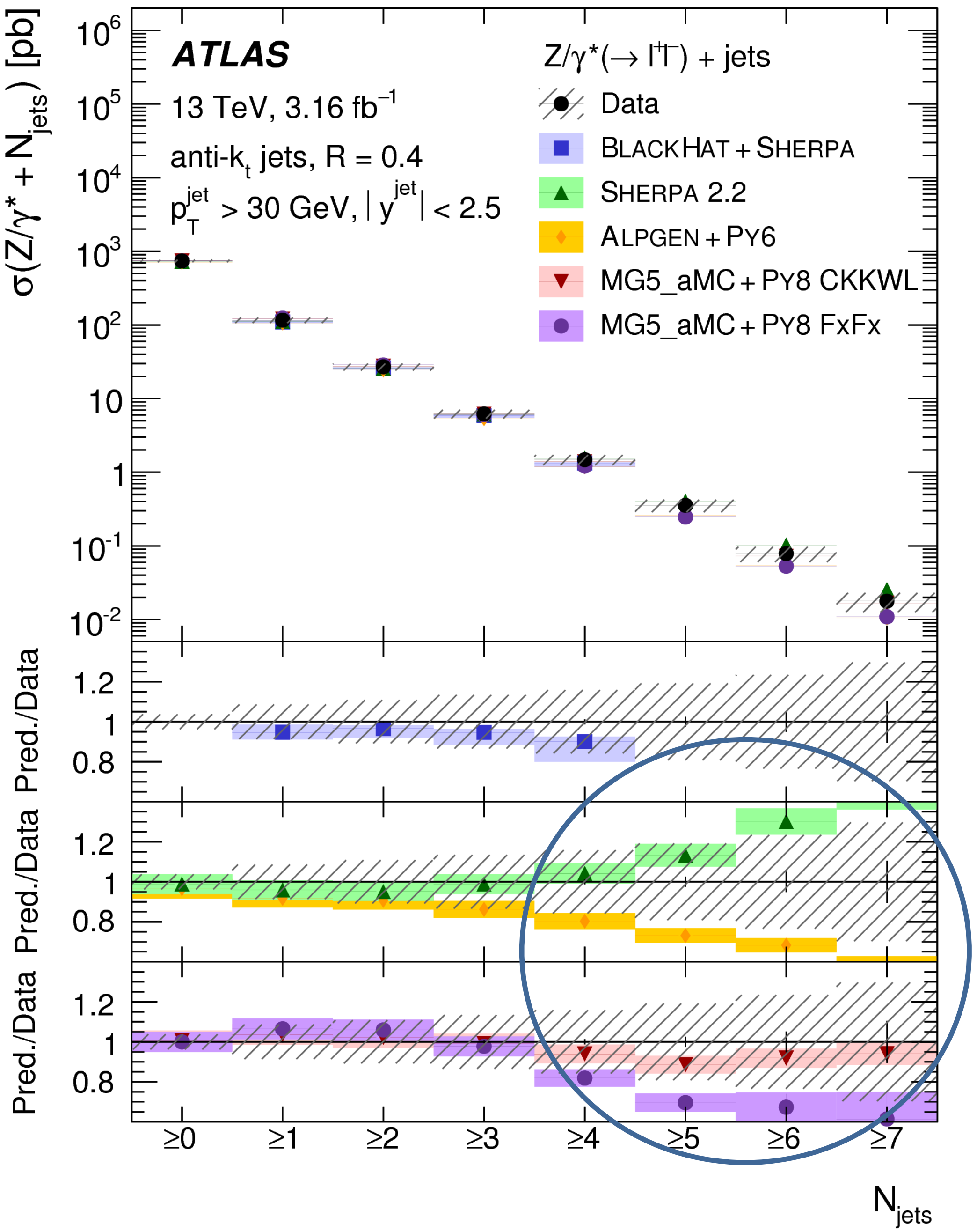
ATLAS EXPERIMENT

arXiv:1702.05725

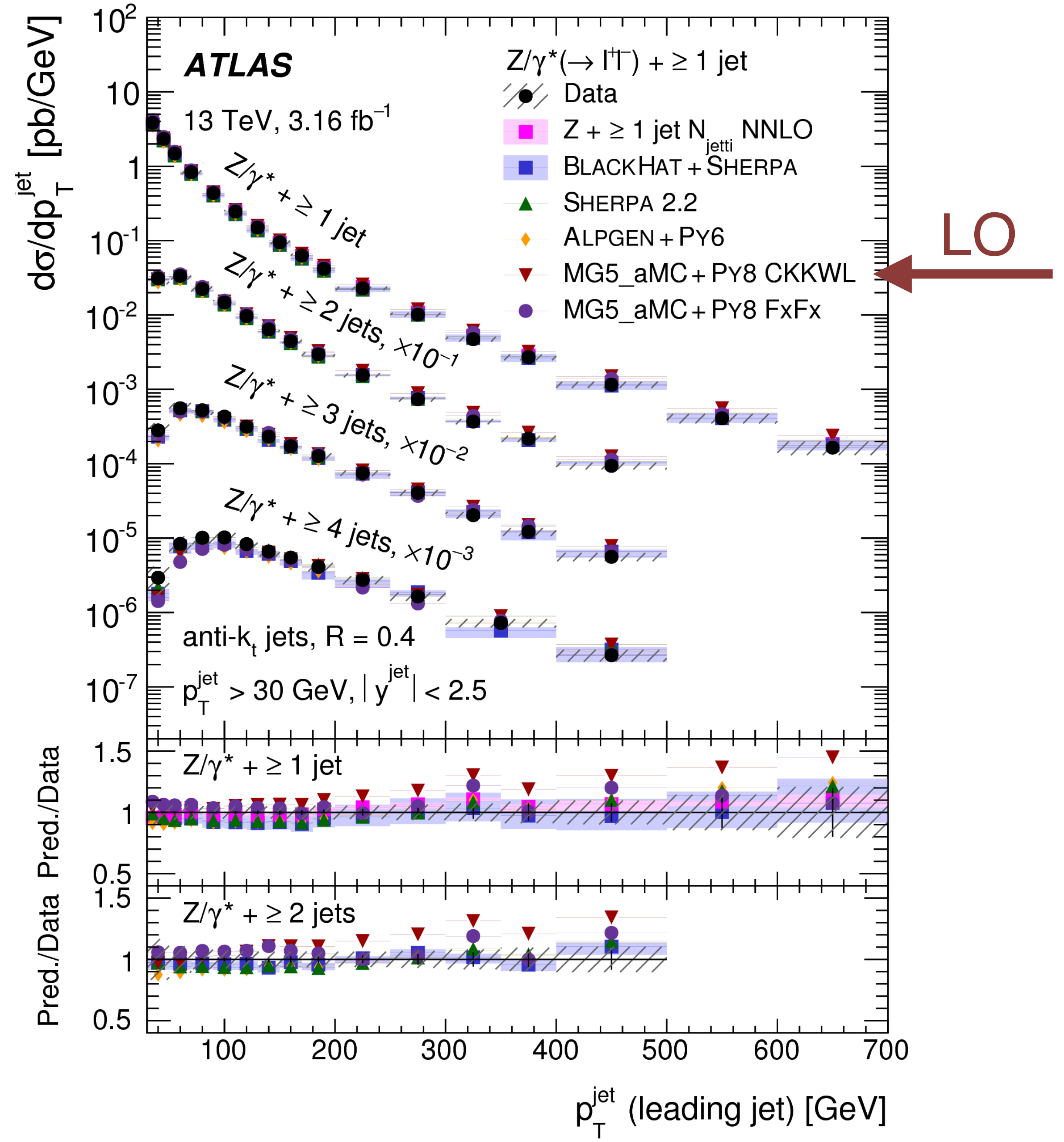
at particle level as a function of jet kinematic variables

→ comparison with NLO (BLACKHAT+SHERPA) and NNLO (Z+≥1jet Njetti) predictions

◁ **mismodelling for high N_{jets}**



◁ **LO prediction models a too hard jet spectrum (p_T^{jet}>200 GeV)**



W mass · Motivations 7 TeV, 4.6 fb^{-1}

arXiv:1701.07240

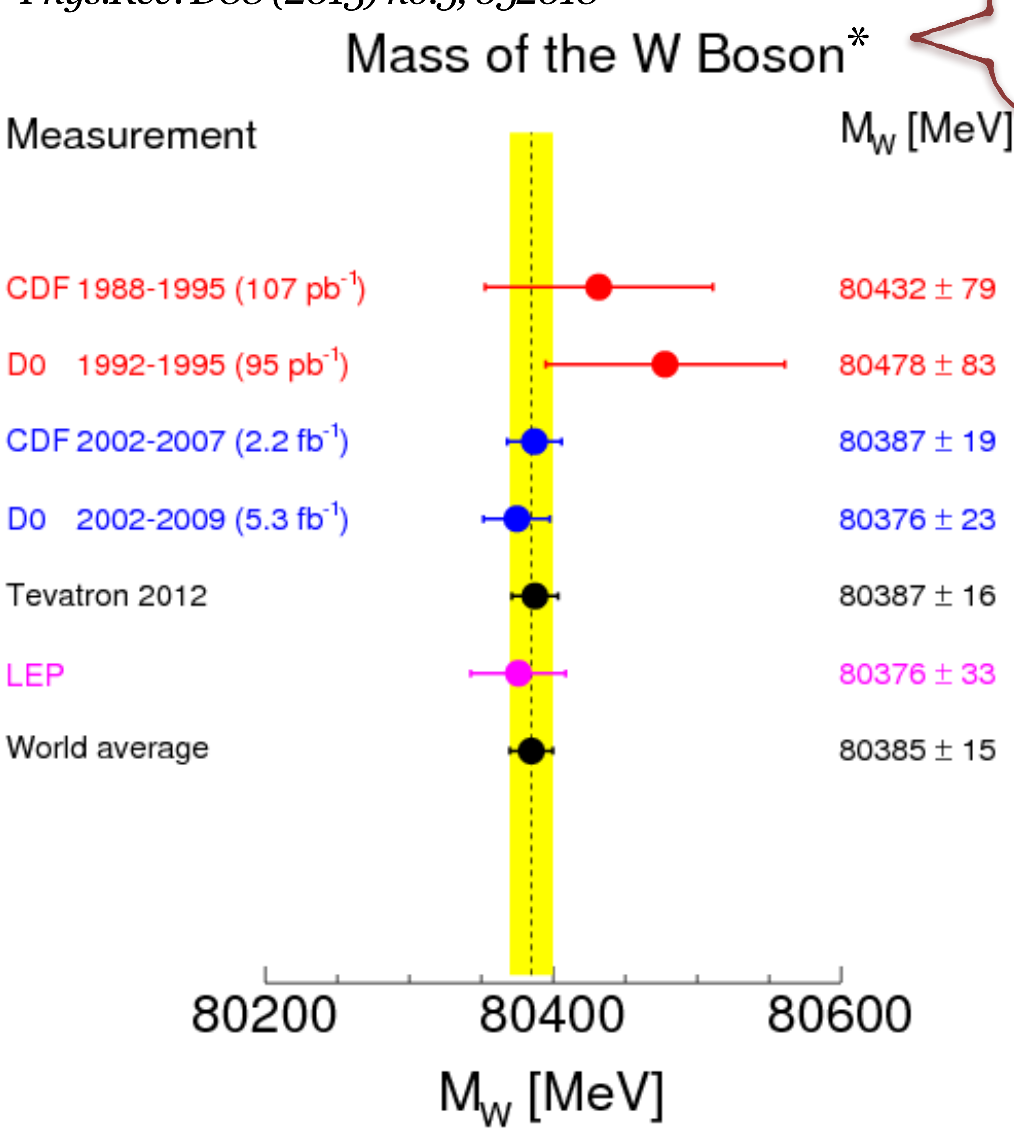
- W mass:

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$

in SM, Δr reflects NLO corrections and depends on m_t^2 and $\ln(m_H)$

- ◁ the relation between m_W, m_t and m_H provides consistency test of SM
- ◁ probe for BSM → Δr contains contributions from additional particles and interactions
- ◁ in the global fit contest, **constraints on new physics limited by W mass precision**

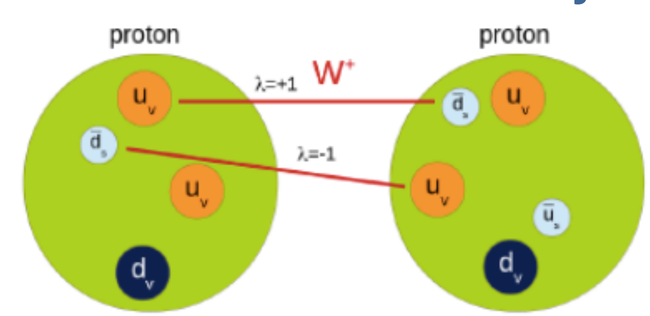
*Phys.Rev. D88 (2013) no.5, 052018



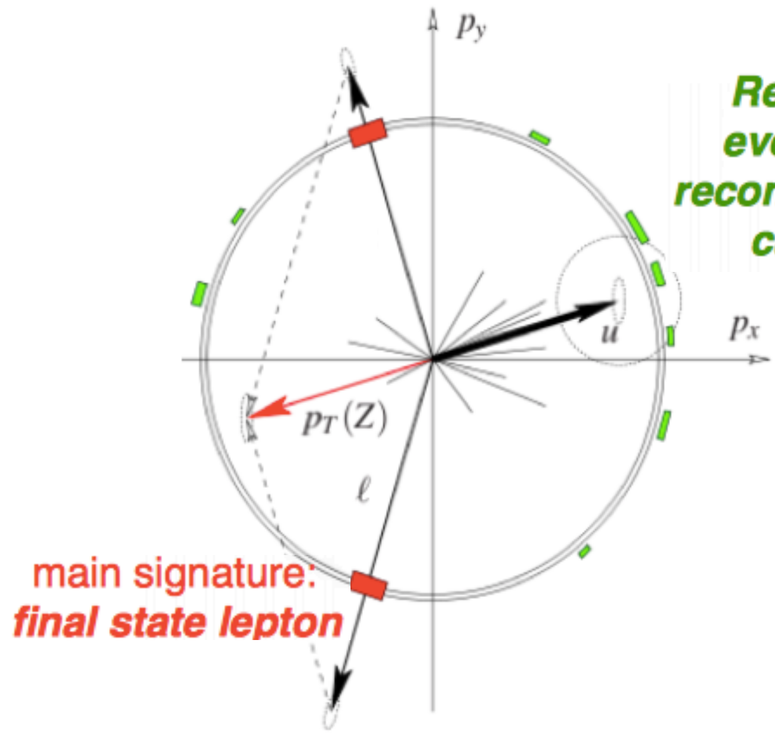
LEP+Tevatron: M_W unc. ~15 MeV
Best individual measurement from CDF: M_W unc. ~19 MeV

First measurement of W mass in pp collisions @LHC by ATLAS

- **Challenging environment @LHC:**
  - ◁ second generation of quark PDFs play a larger role (25% W production)
    → additional uncertainty on PDFs



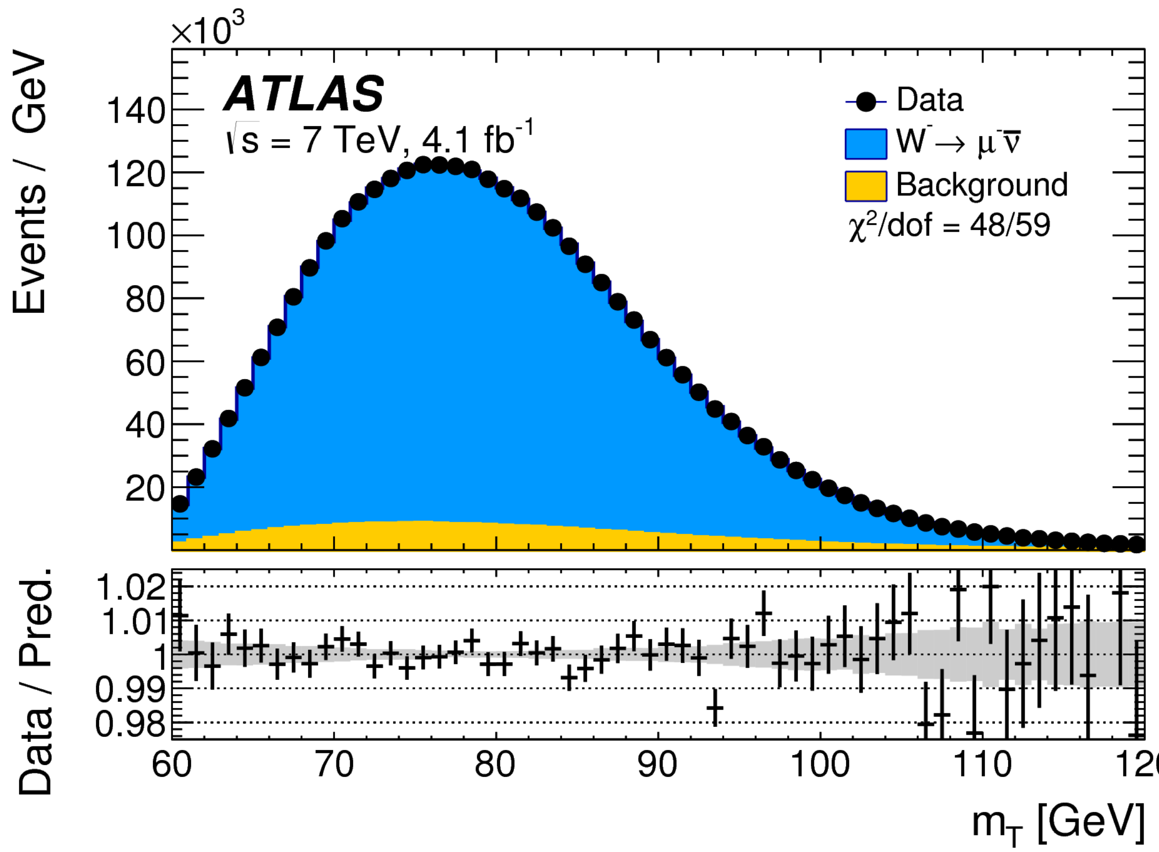
arXiv:1701.07240



$$\vec{u}_T = \sum_i \vec{E}_{T,i}$$

- <u>Important components:</u> charged lepton and recoil to reconstruct p_T^{ν}
- **<u>m_Z measurements in Z-boson samples</u>**
  - ◁ provide experimental (lepton and recoil calibrations) and theoretical constraints from comparison with LEP.
  - ◁ additional systematics for Z → W extrapolation

- **<u>m_W from fits on p_T^l and m_T^W for different values of m_W</u>**
  - ◁ χ^2 minimisation gives the best fit template
  - ◁ **predictions** for m_W **reweighing m_W** according to the Breit-Wigner
    → m_W blinded in [-100,100] MeV
  - ◁ **measurement in 28 categories**



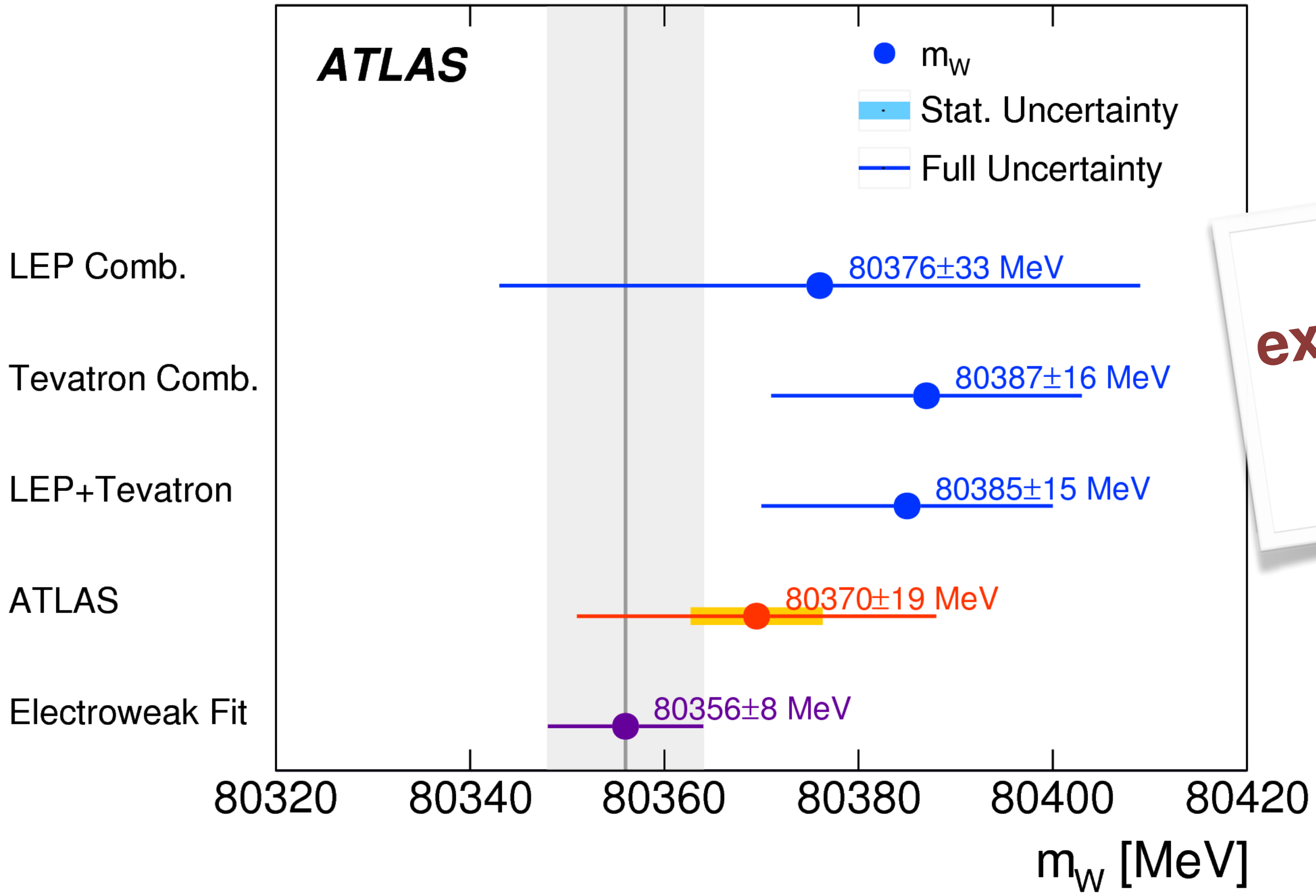
W mass · Results

arXiv:1701.07240

$$m_W = 80370 \pm 7(\text{stat.}) \pm 11(\text{syst.}) \pm 14(\text{mod.})\ \text{MeV} = 80370 \pm 19\ \text{MeV}$$

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bkg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.
m_T, p_T^l, $W^{\pm}$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5

The uncertainty is dominated by theoretical modelling



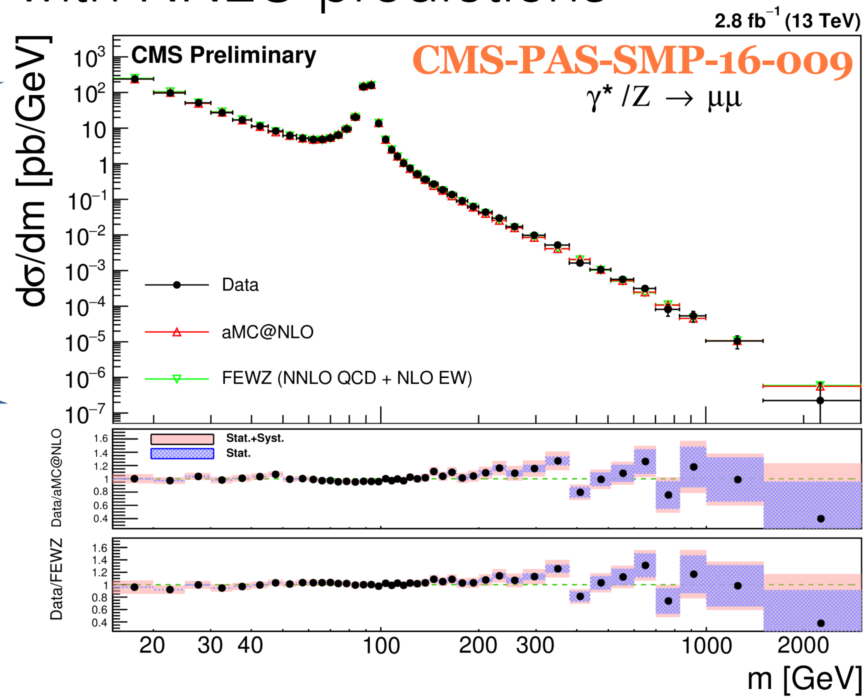
Result consistent with SM expectation, compatible with the world average and competitive with CDF measurements

CMS Results

Differential Drell-Yan cross section

Comparison with NNLO predictions

9 orders of magnitude

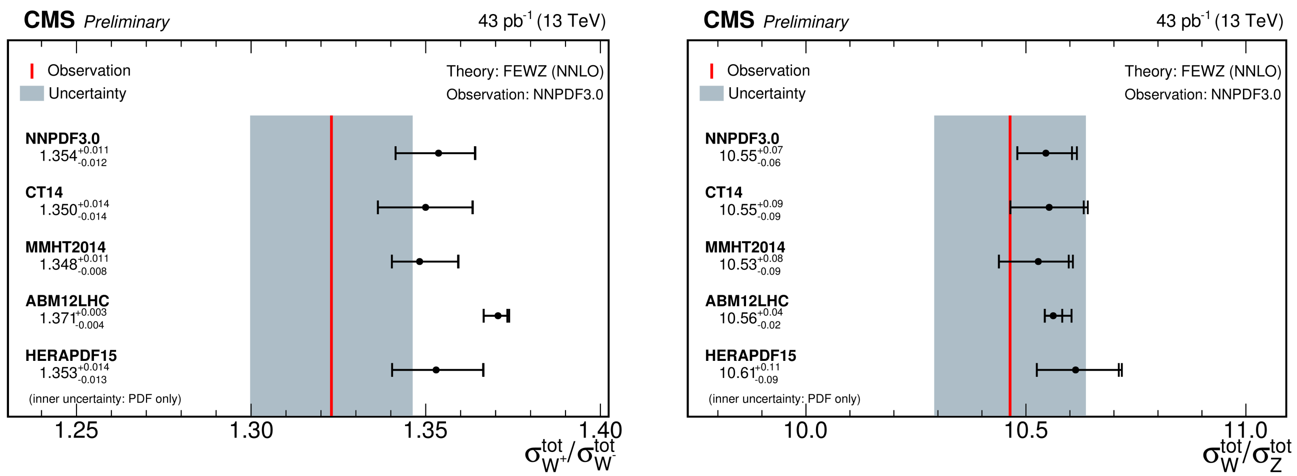


W and Z cross section ratios

Agreement with NNLO predictions.

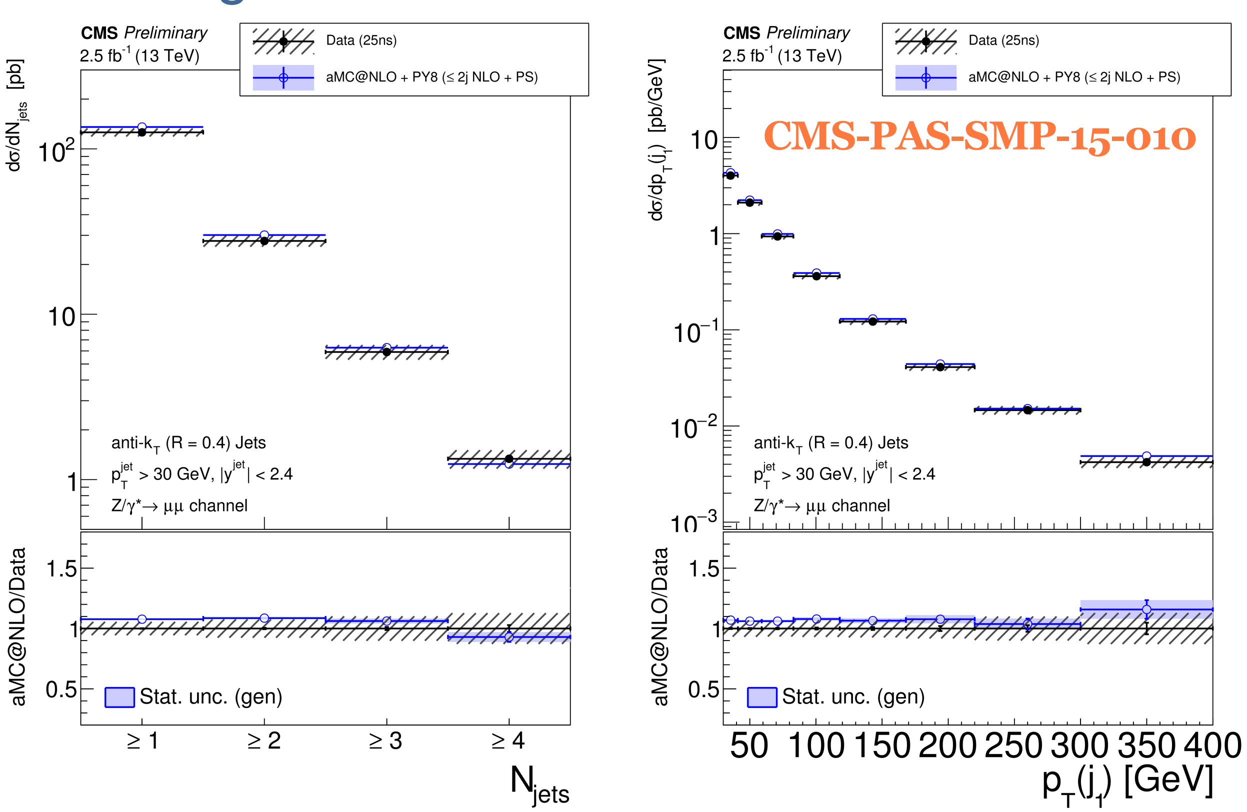
Experimental precision comparable with theoretical uncertainties.

CMS-PAS-SMP-15-004



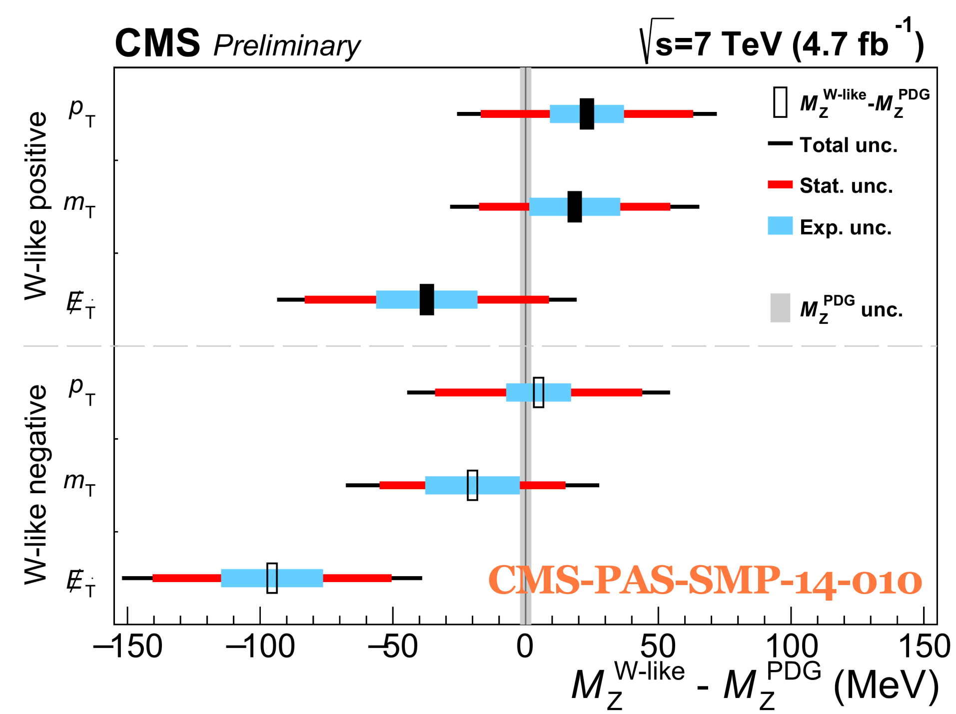
Z+jets differential cross sections

Good agreement with NNLO simulations.



Z mass measurement in "W-like"

m_Z extracted through the W-like method and compatible with the world-average value.



Conclusions

- W and Z cross sections at the % level in agreement with NNLO calculations

- W^+/W^-, W/Z and tt/Z ratios benefit from the cancellation of several experimental and theoretical uncertainties
  - comparable with NNLO predictions
  - W^+/W^- precision ~0.8% → discriminate among PDFs

- Z+jets differential cross sections at particle level for **high jet multiplicity**
  - agreement with calculations at NNLO and NLO
  - some deviations for LO calculations at p_T^{jet}>200 GeV
  - Z+bb@13 TeV measurement on going

- **First W mass measurements @7 TeV with ATLAS**
  - consistent with SM predictions and the current world average value
  - uncertainty dominated by theoretical modelling (PDFs and QCD)
    - → future **benefit in PDF uncertainty including most recent W/Z measurements**

$$m_W = (80370 \pm 19)\ \mathrm{MeV}$$

- General agreement between **ATLAS and CMS**
  - The W mass measurement in CMS is ongoing → ***Poster di Elisabetta MANCA***
  - Interesting W-like measurement of the Z mass, in agreement with world average.

Thanks for your attention!

Extra Slides

W and Z cross sections 13 TeV, 81 pb^{-1}

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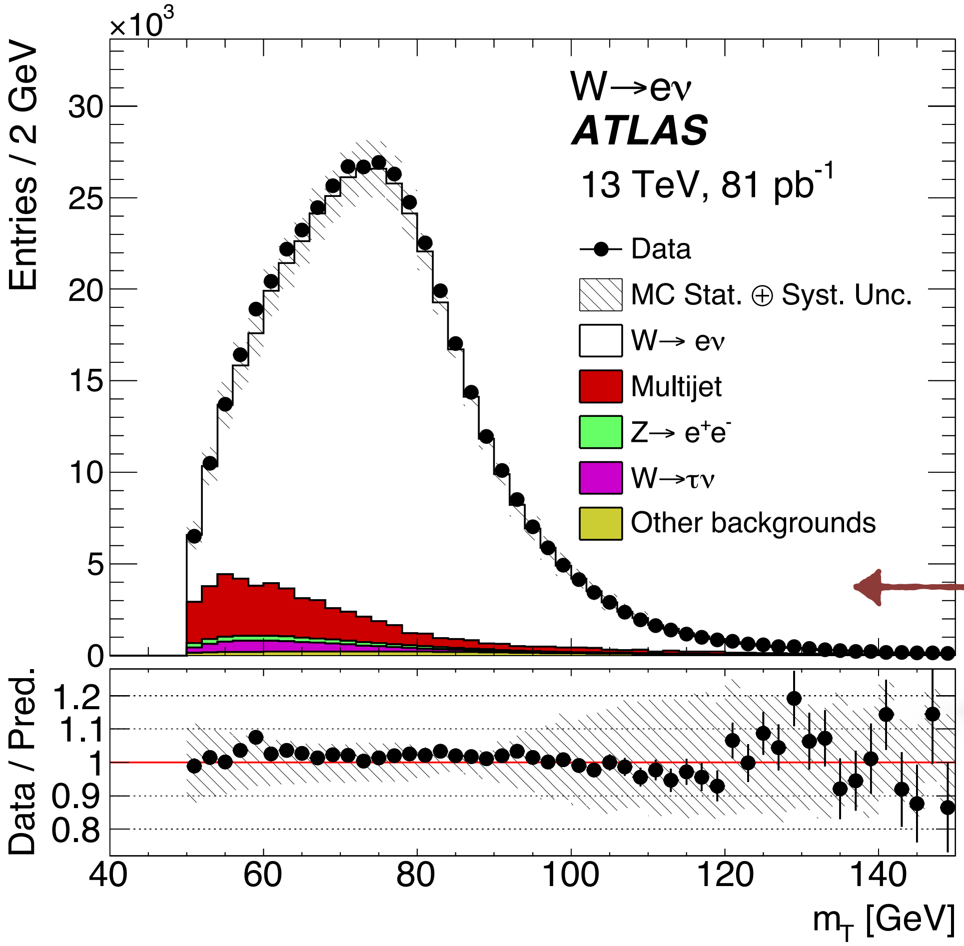
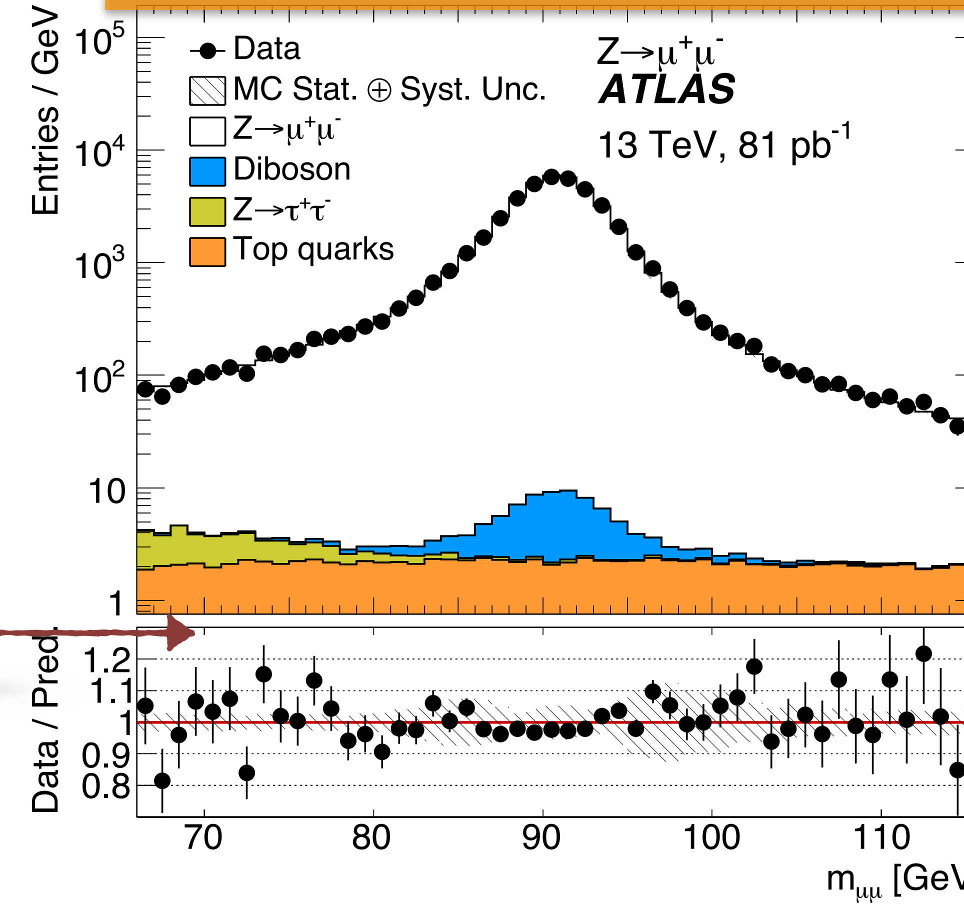


Fiducial Phase Space

$p_T^l > 25$ GeV
$p_T^\nu > 25$ GeV
$|\eta^l| < 2.5$

$m_T^W > 50$ GeV
66 GeV $< m_{ll} <$ 116 GeV



Cross Section strategy:

signal events

$$\sigma^{fid}_{W/Z} \cdot BR(\%) = \frac{N^{obs}_{W/Z} - B_{W/Z}}{C_{W/Z}\, L}$$

Identification, Reconstruction and Trigger Efficiency

Luminosity

Backgrounds:

→ Top-quark and EW from MC (8% for W, 0.7% for Z)

→ QCD multijet: data driven (W → eν: 9%, W → μν: 4%)

From fiducial volume to full phase space: $\sigma^{tot}_{W/Z} = \sigma^{fid}_{W/Z} \,/\, A_{W/Z}$

Acceptance (from MCs)

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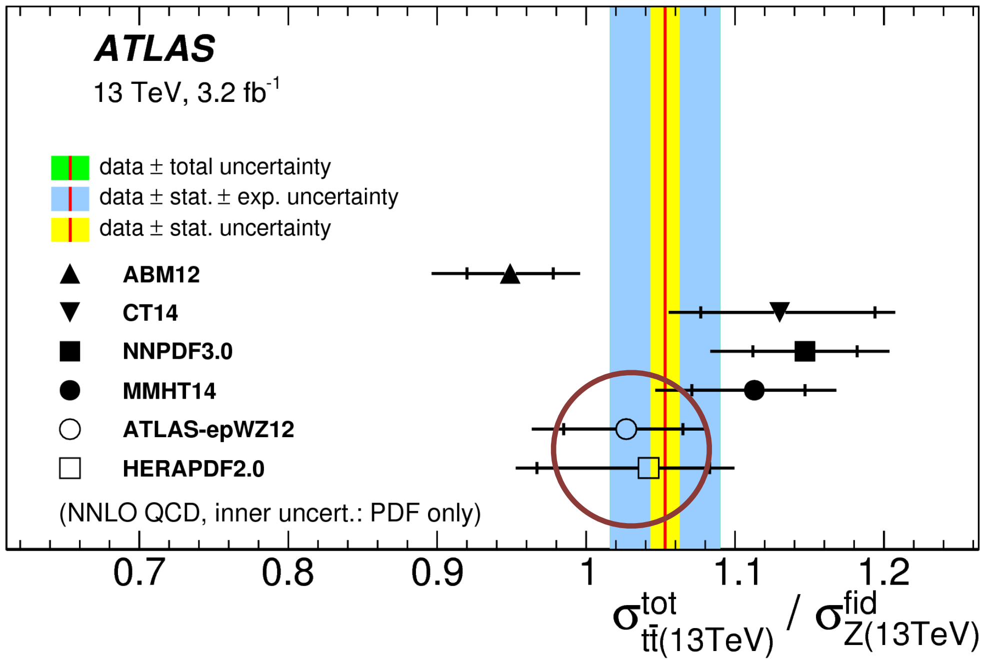
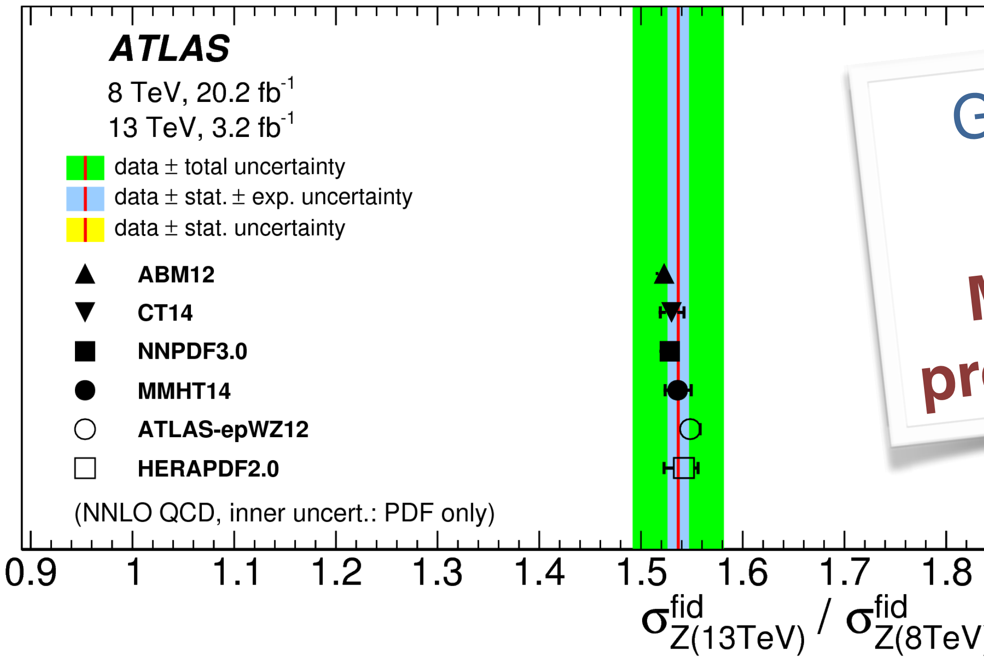
Dependence of σ on √s

Single ratio $R_{tt/Z}$ at √s = 13 TeV



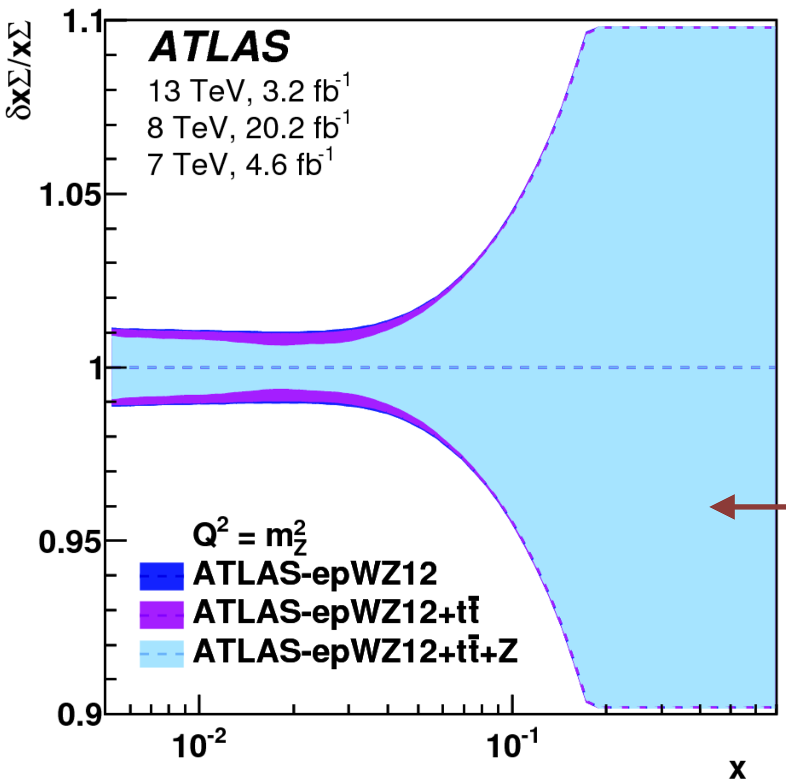
Single ratio $R_{Z(13\ TeV)/Z(8\ TeV)}$



Good agreement with different PDFs

Measurements more precise than predictions

Light quark sea distributions



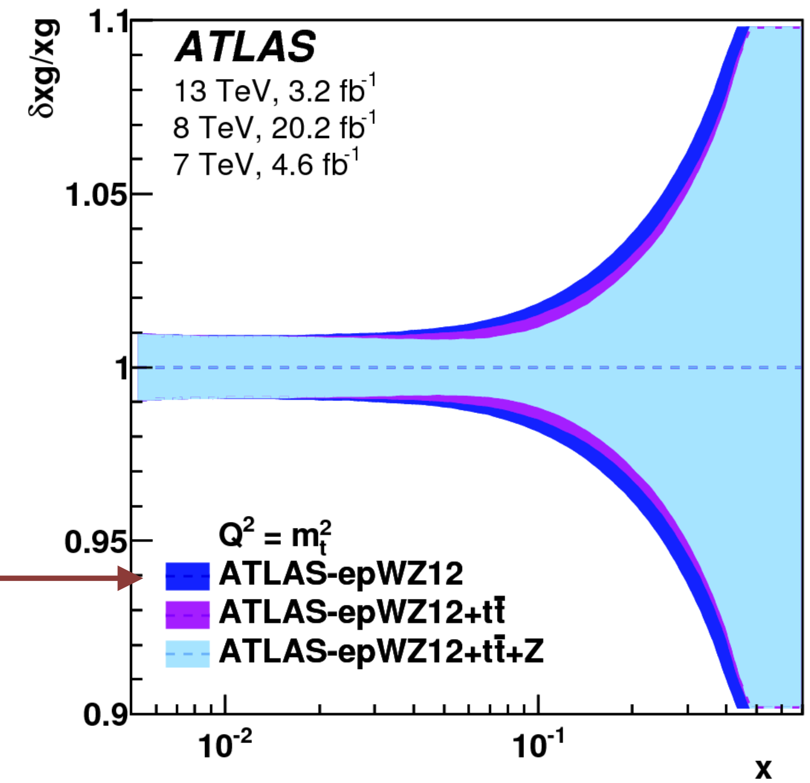
Impact of ATLAS data on the PDF uncertainties quantified by PDF profiling using ATLAS-epWZ12

tt and Z data constraint:

Light quark sea at x < 0.02

Gluon at x ~ 0.1

Gluon distributions



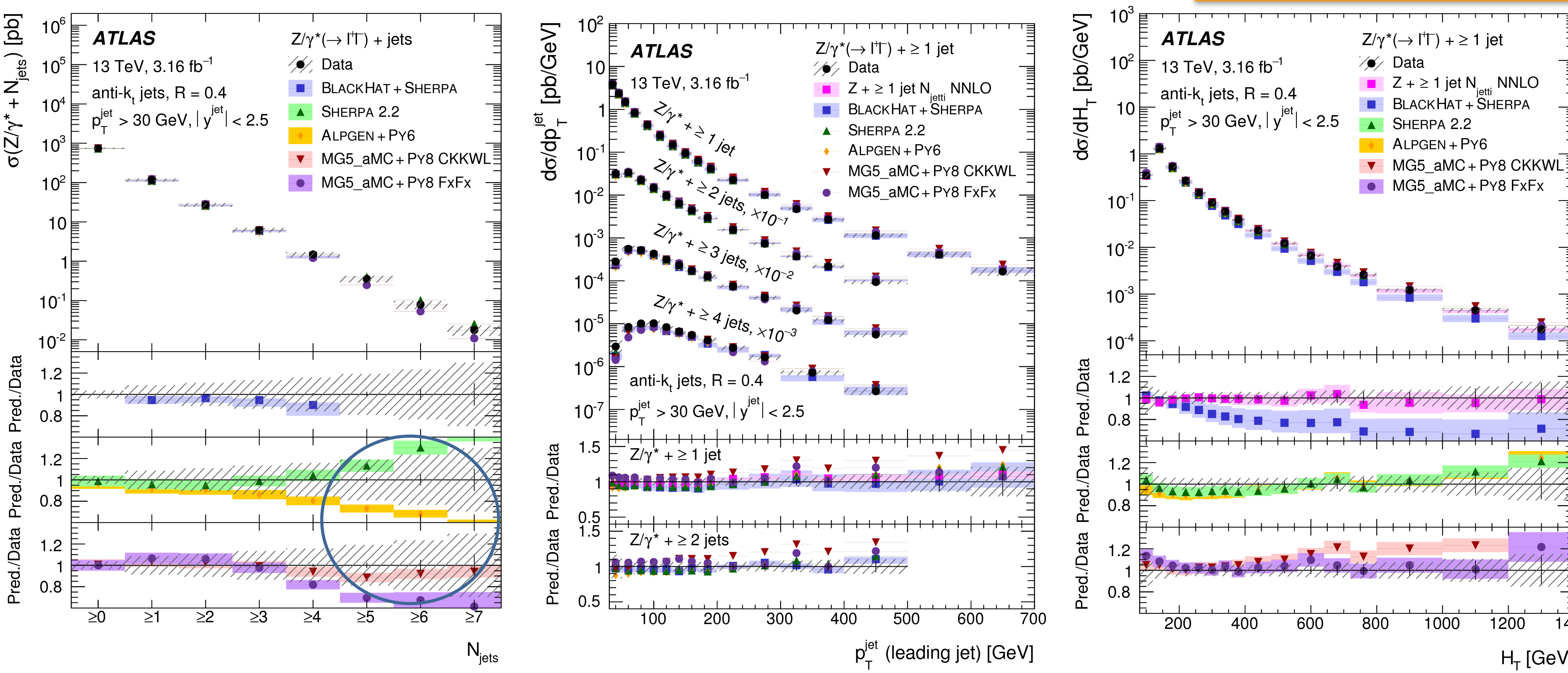
Z+jets cross section   13 TeV, 3.2 fb^{-1}

Differential measurements in several jet distributions compared to various simulations

- ◁ very sensitive probe of different MC approaches, tuning
- ◁ Good agreement with calculation at NNLO (Z+≥1jet Njetti) or NLO (BLACKHAT+SHERPA, MG5_aMC+PY8 FxFx), while LO ME MG5_aMC+PY8 CKKWL models a too hard jet spectrum
- ◁ **Some deviations for large jet pt (>200 GeV)**
- ◁ HT is the sum of inclusive pT of final state objects

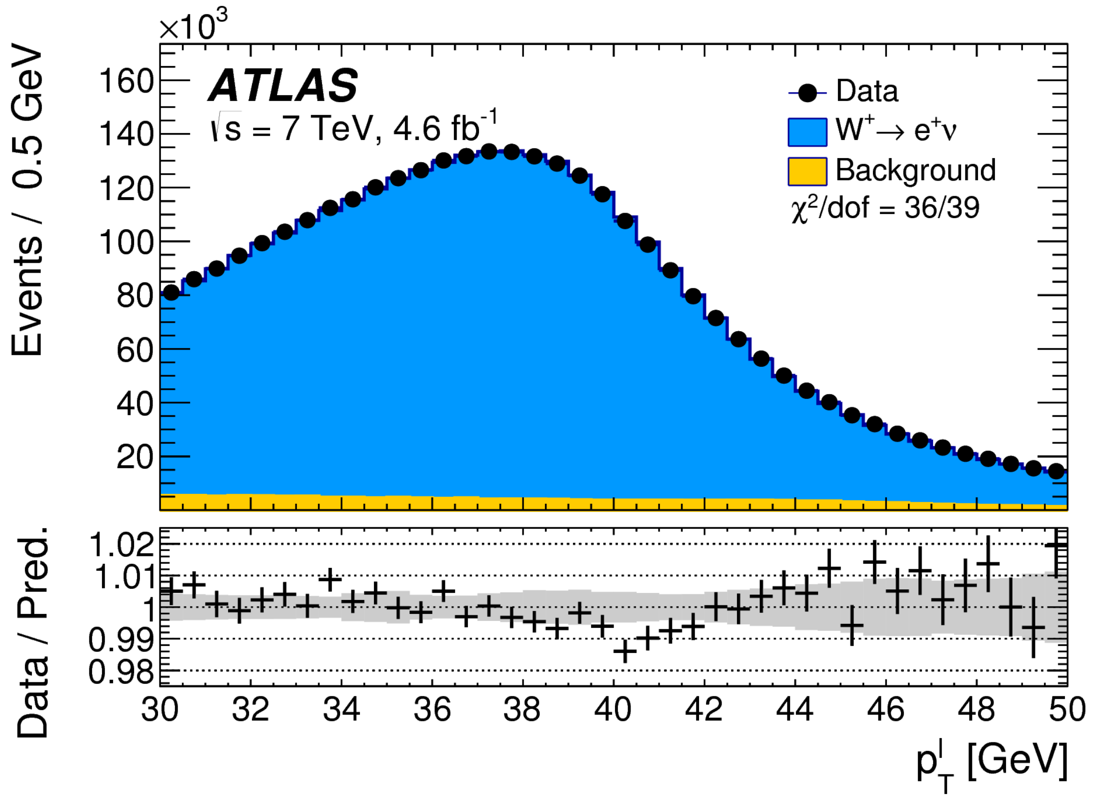
  BLACKHAT (fixed order NLO ME) underestimates the cross section measurements due to the missing contributions from event with higher parton multiplicity.

arXiv:1702.05725

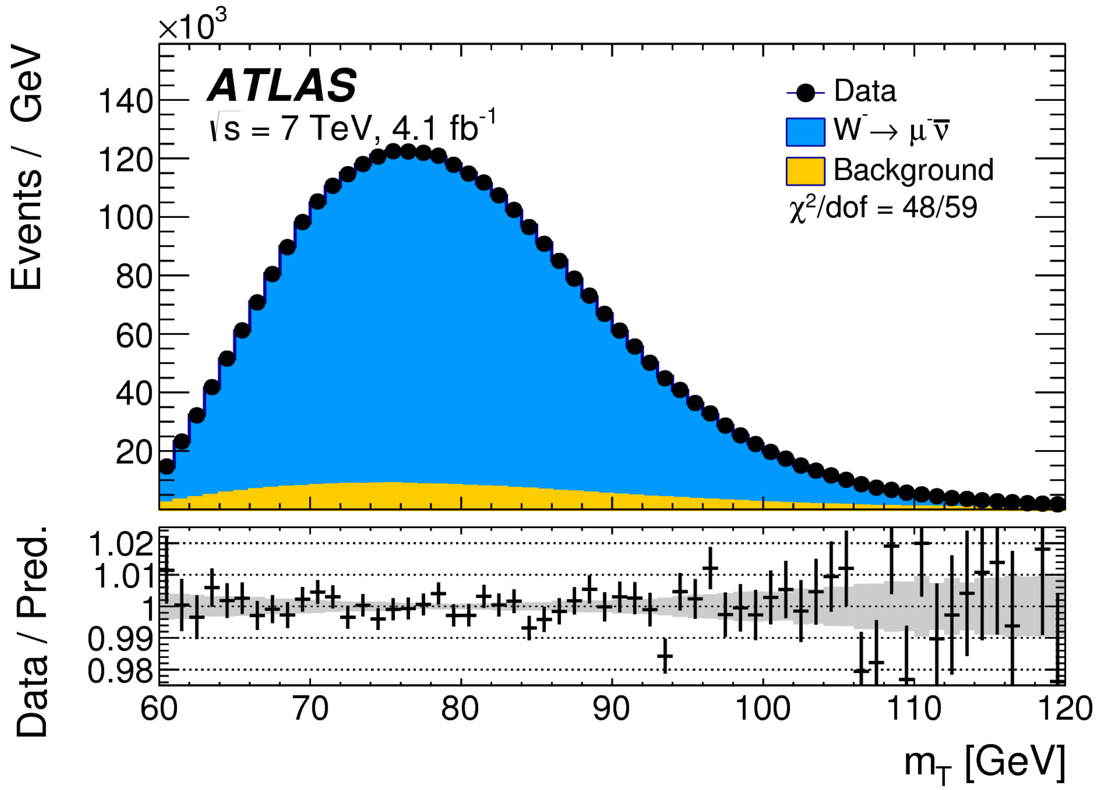


arXiv:1701.07240

✤ **Template fit approach:** compute the p_T^l and m_T distributions for different assumed values of m_W → χ^2 minimisation gives the best fit template



p_T^l has a Jacobian edge at $m_W/2$



m_T has a Jacobian edge at m_W

arXiv:1701.07240

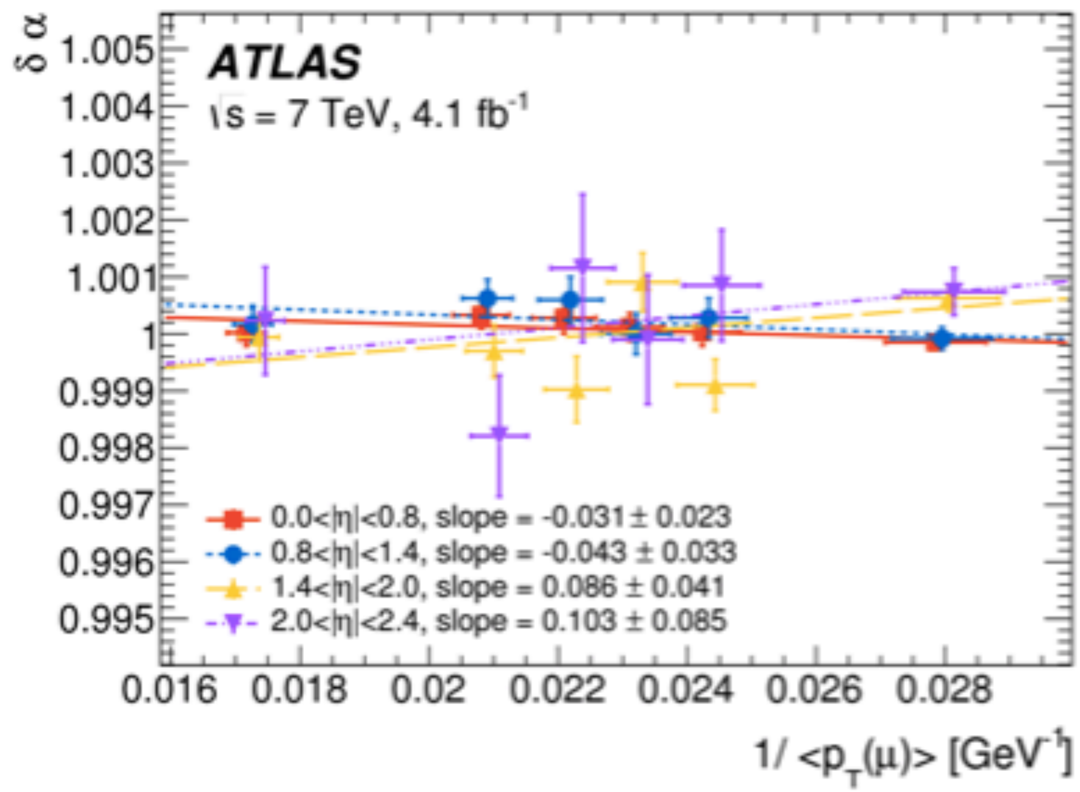
- Calibration of ID muons using Z

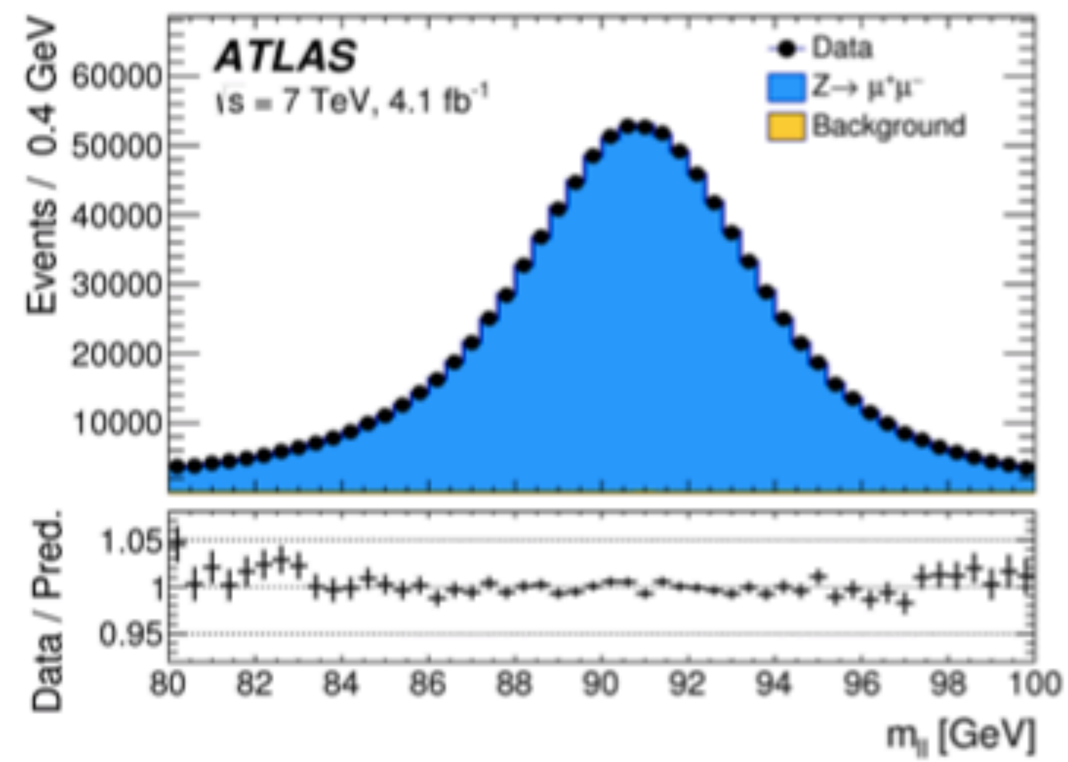
$$k^c = (\boxed{A} - 1)k + \boxed{qM} + \boxed{\frac{k}{1 + k\,\epsilon \sin\theta}}$$

magnetic field

mis-alignement

material

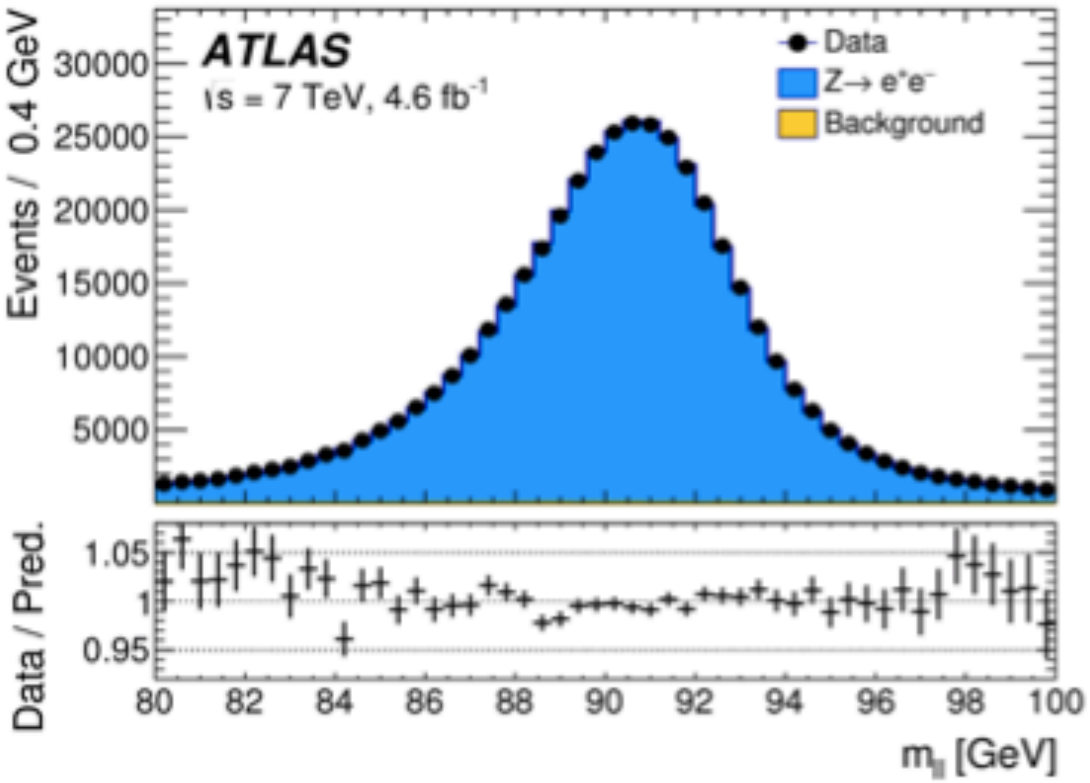




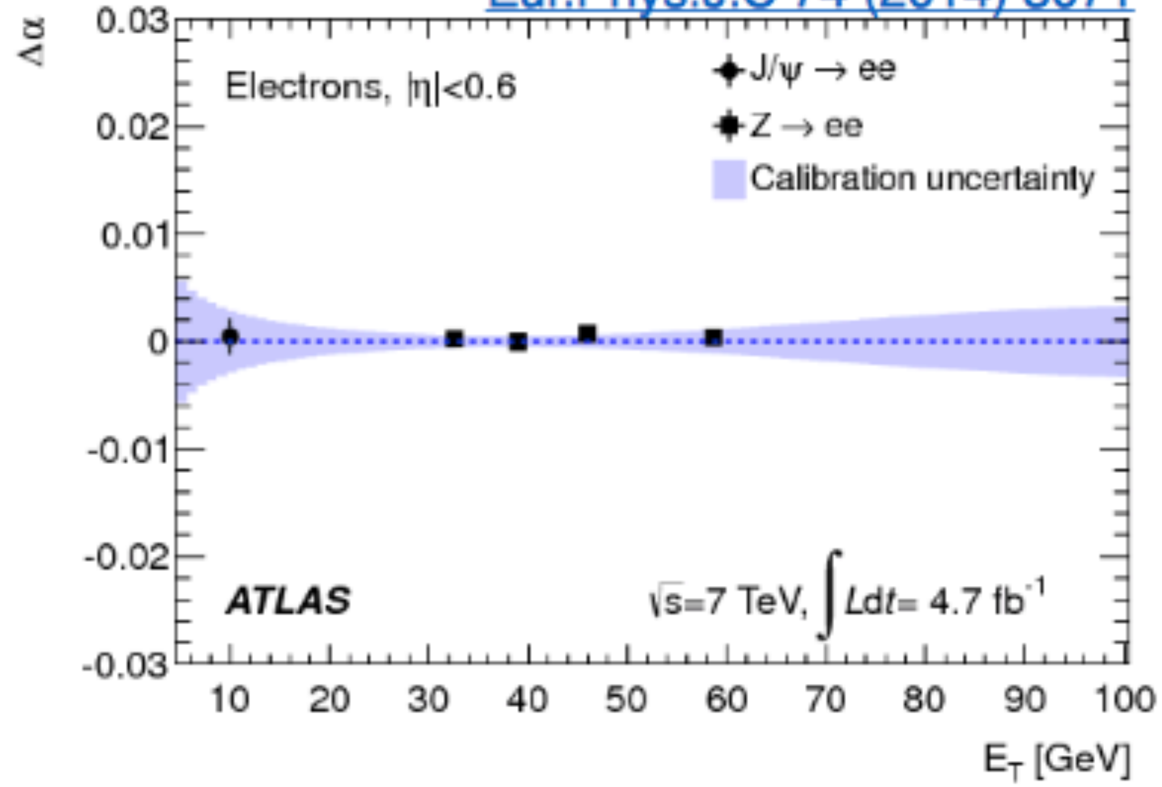
$\|\eta_\ell\|$ range	[0.0, 0.8]		[0.8, 1.4]		[1.4, 2.0]		[2.0, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]										
Momentum scale	8.9	9.3	14.2	15.6	27.4	29.2	111.0	115.4	8.4	8.8
Momentum resolution	1.8	2.0	1.9	1.7	1.5	2.2	3.4	3.8	1.0	1.2
Sagitta bias	0.7	0.8	1.7	1.7	3.1	3.1	4.5	4.3	0.6	0.6
Reconstruction and isolation efficiencies	4.0	3.6	5.1	3.7	4.7	3.5	6.4	5.5	2.7	2.2
Trigger efficiency	5.6	5.0	7.1	5.0	11.8	9.1	12.1	9.9	4.1	3.2
Total	11.4	11.4	16.9	17.0	30.4	31.0	112.0	116.1	9.8	9.7

arXiv:1701.07240

- Exclude bin 1.2<|eta|<1.82 as the amount of passive material and its uncertainty are largest



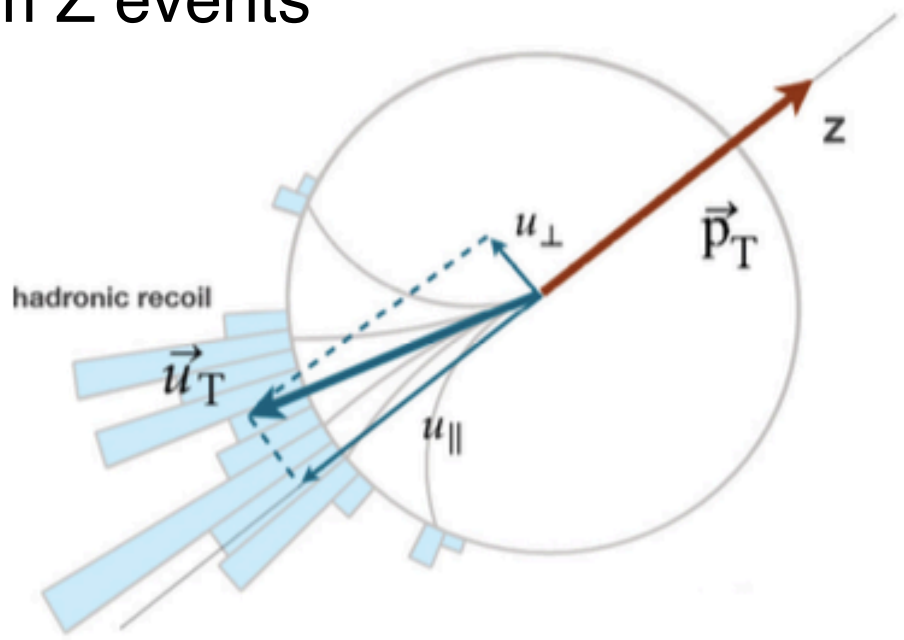
Eur.Phys.J.C 74 (2014) 3071

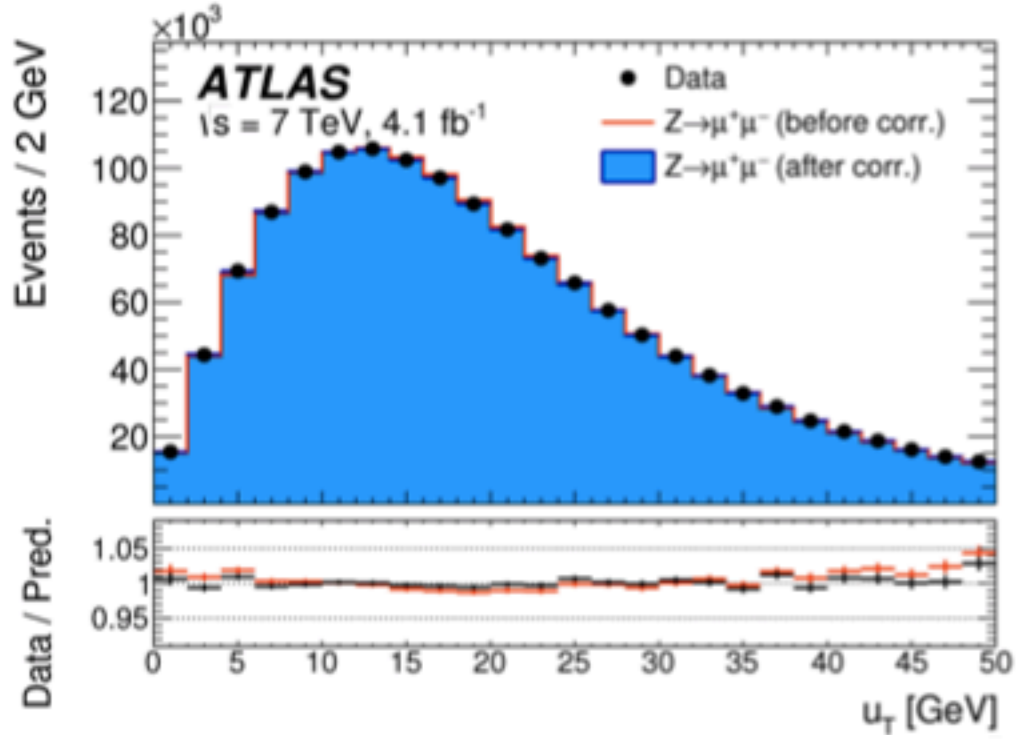


$\lvert\eta_\ell\rvert$ range	[0.0, 0.6]		[0.6, 1.2]		[1.82, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]								
Energy scale	10.4	10.3	10.8	10.1	16.1	17.1	8.1	8.0
Energy resolution	5.0	6.0	7.3	6.7	10.4	15.5	3.5	5.5
Energy linearity	2.2	4.2	5.8	8.9	8.6	10.6	3.4	5.5
Energy tails	2.3	3.3	2.3	3.3	2.3	3.3	2.3	3.3
Reconstruction efficiency	10.5	8.8	9.9	7.8	14.5	11.0	7.2	6.0
Identification efficiency	10.4	7.7	11.7	8.8	16.7	12.1	7.3	5.6
Trigger and isolation efficiencies	0.2	0.5	0.3	0.5	2.0	2.2	0.8	0.9
Charge mismeasurement	0.2	0.2	0.2	0.2	1.5	1.5	0.1	0.1
Total	19.0	17.5	21.1	19.4	30.7	30.5	$\boxed{14.2}$	$\boxed{14.3}$

arXiv:1701.07240

- Vector sum of the moment of all clusters measured in the calorimeters
- Calibrate the scale (resolution) of the recoil using ull (u⊥) from Z events





ATLAS

W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]						
$\langle\mu\rangle$ scale factor	0.2	1.0	0.2	1.0	0.2	1.0
$\Sigma \bar{E}_T$ correction	0.9	12.2	1.1	10.2	1.0	11.2
Residual corrections (statistics)	2.0	2.7	2.0	2.7	2.0	2.7
Residual corrections (interpolation)	1.4	3.1	1.4	3.1	1.4	3.1
Residual corrections ($Z \to W$ extrapolation)	0.2	5.8	0.2	4.3	0.2	5.1
Total	2.6	14.2	2.7	11.8	2.6	13.0

12