Measurements of Drell-Yan transverse momentum, lepton azimuthal decorrelation and angular distributions with the ATLAS detector

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Outline

- $P_{T,Z}$: Drell-Yan transverse momentum

  Z transverse momentum distribution (JHEP09 (2014) 145)
  ATLAS Pythia8 tunes to 7 TeV data (ATL-PHYS-PUB-2014-021)

- Φ^* : Angular decorrelation with Φ observable from decay leptons of Z/γ*

  Phi* distribution of Drell-Yan lepton pairs (Phys. Lett. B 720 (2013) 32-51)

- A_{FB} : Forward-backward asymmetry for the neutral current Drell-Yan process

  Forward-backward asymmetry in lepton pair production and Weinberg angle extraction (JHEP)

- $\sqrt{s}$ =13TeV: W/Z production cross section

  W, Z cross section measurements (LP 2015)

$P_{T,Z}$

- Low $P_{T,Z}$ range is governed by
  - initial state parton radiation
  - intrinsic transverse momentum of the initial state parton inside the proton

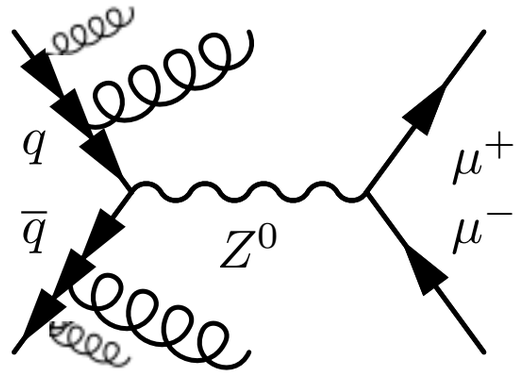
  is modelled by
  - resummation of soft-gluon emission
  - parton shower model

- High $P_{T,Z}$ range is governed by
  - quark-gluon scattering

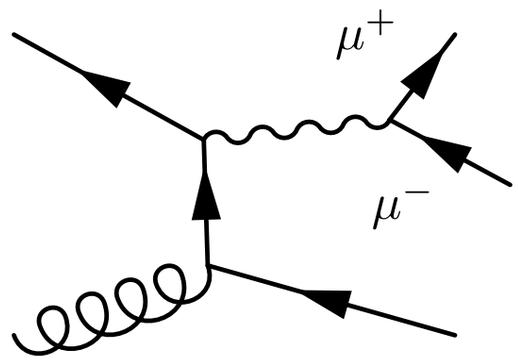
  is modelled by
  - perturbative QCD

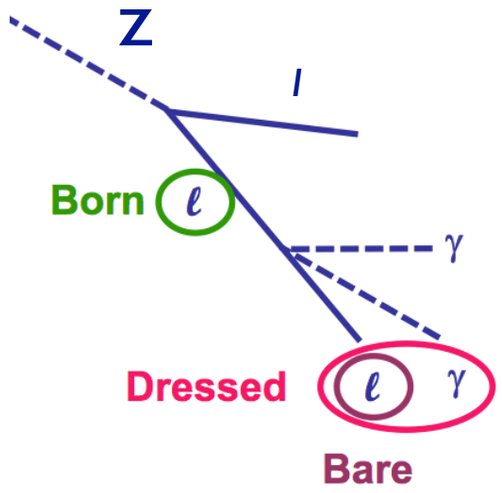
- Monte Carlo predicts three levels: Born, Dress, Bare

Parton Shower:

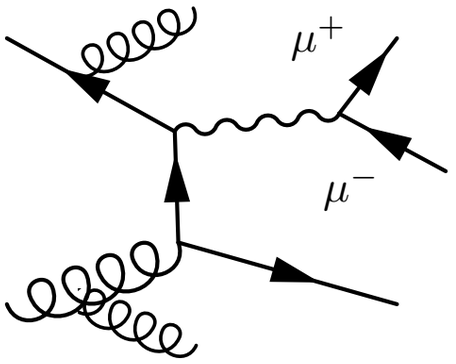


Next to Leading Order in α_s:



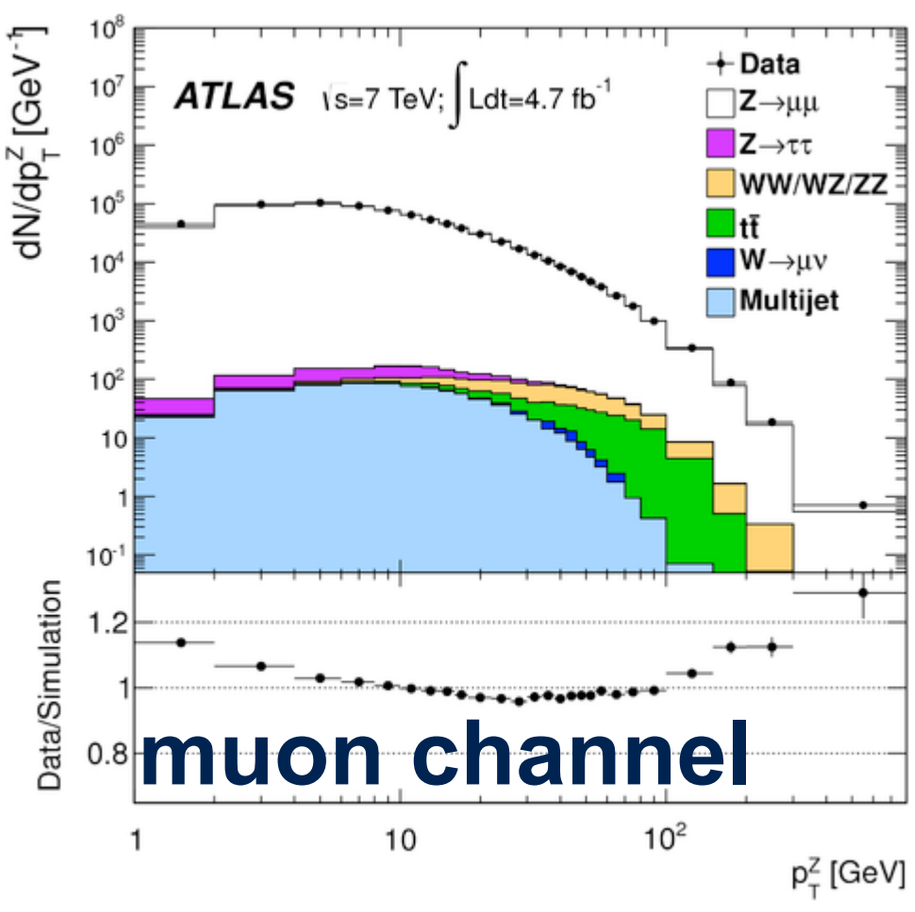


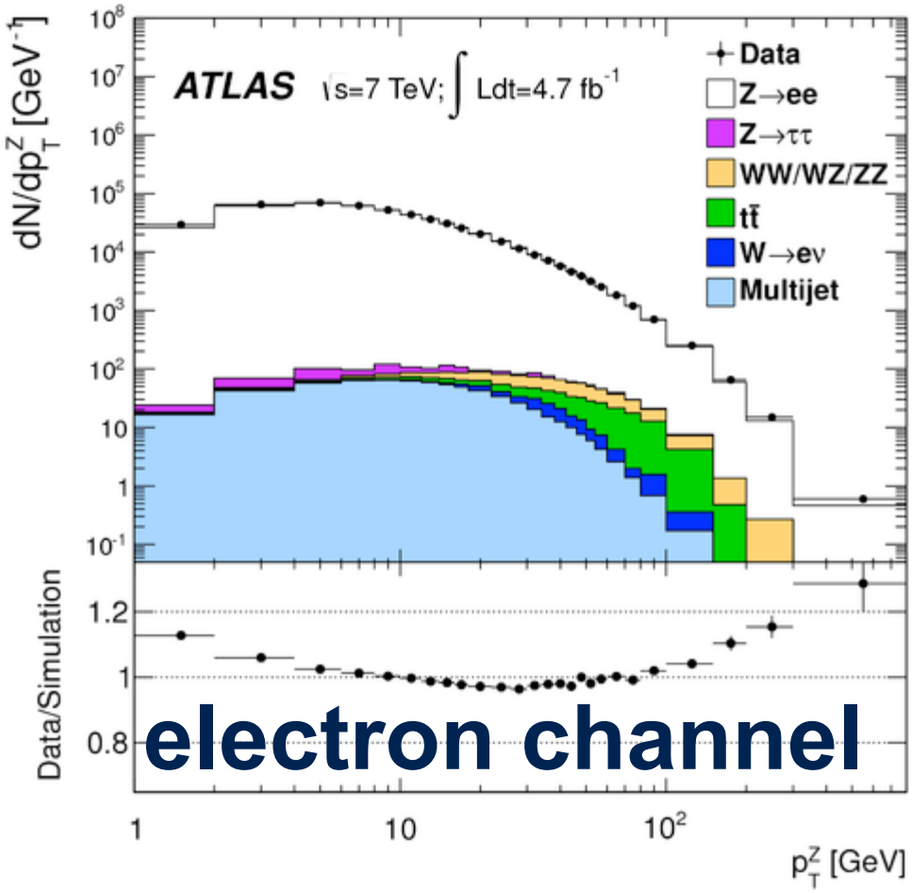
Combined Next Leading Order + Parton Shower :



$P_{T,Z}$ Distribution

- $P_{T,Z}$ Distribution for both electron and muon channel shown
- Event selection
  - Using single lepton triggers
  - Lepton P_T > 20GeV
  - Muons: isolated, |η|<2.4
  - Electrons: |η|<2.47 exclude transition range
- Multijet background is estimated by using data-driven methods, the other background are estimated by MC
- Only the statistical uncertainty shown in these two plots
- $P_{T,Z}$ distribution is measured in three different rapidity bins

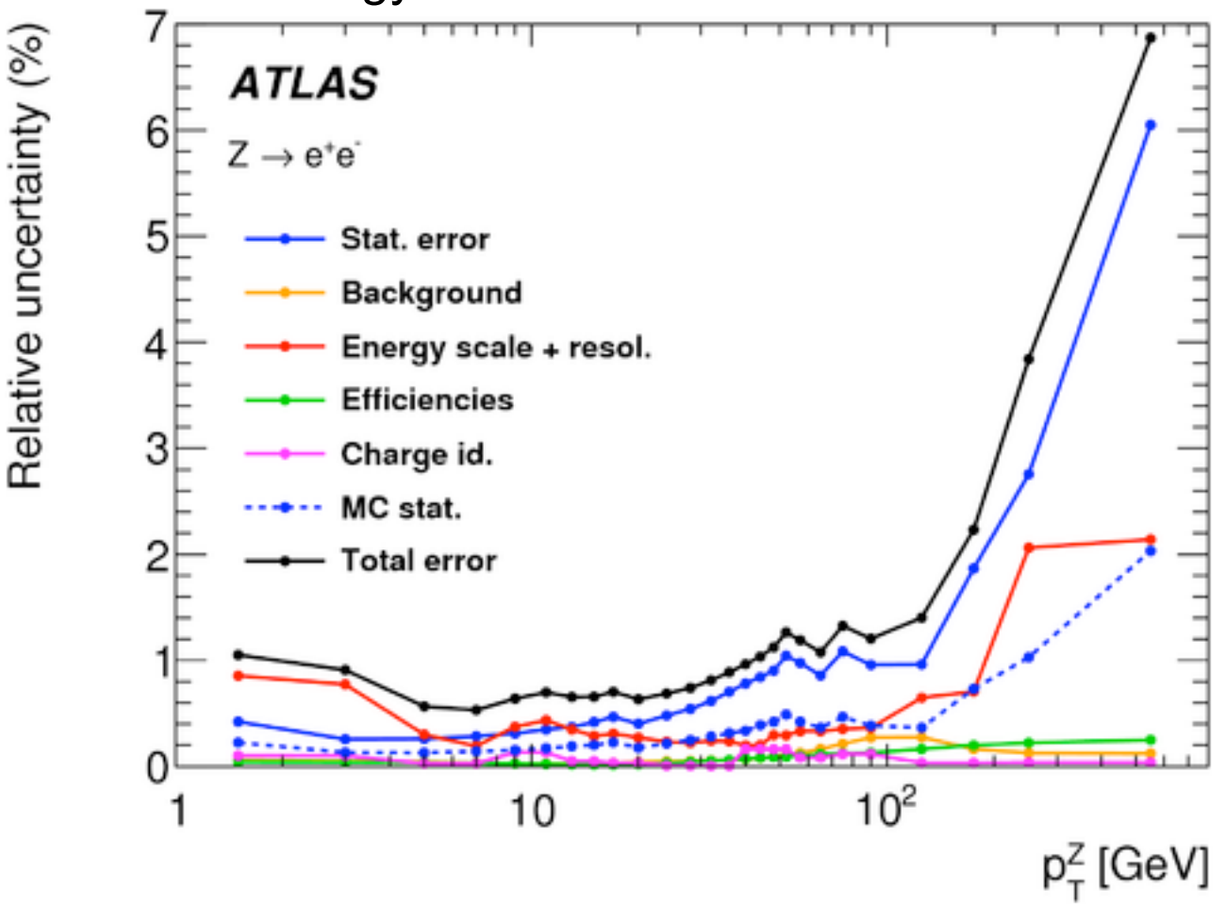




$P_{T,Z}$ Uncertainty

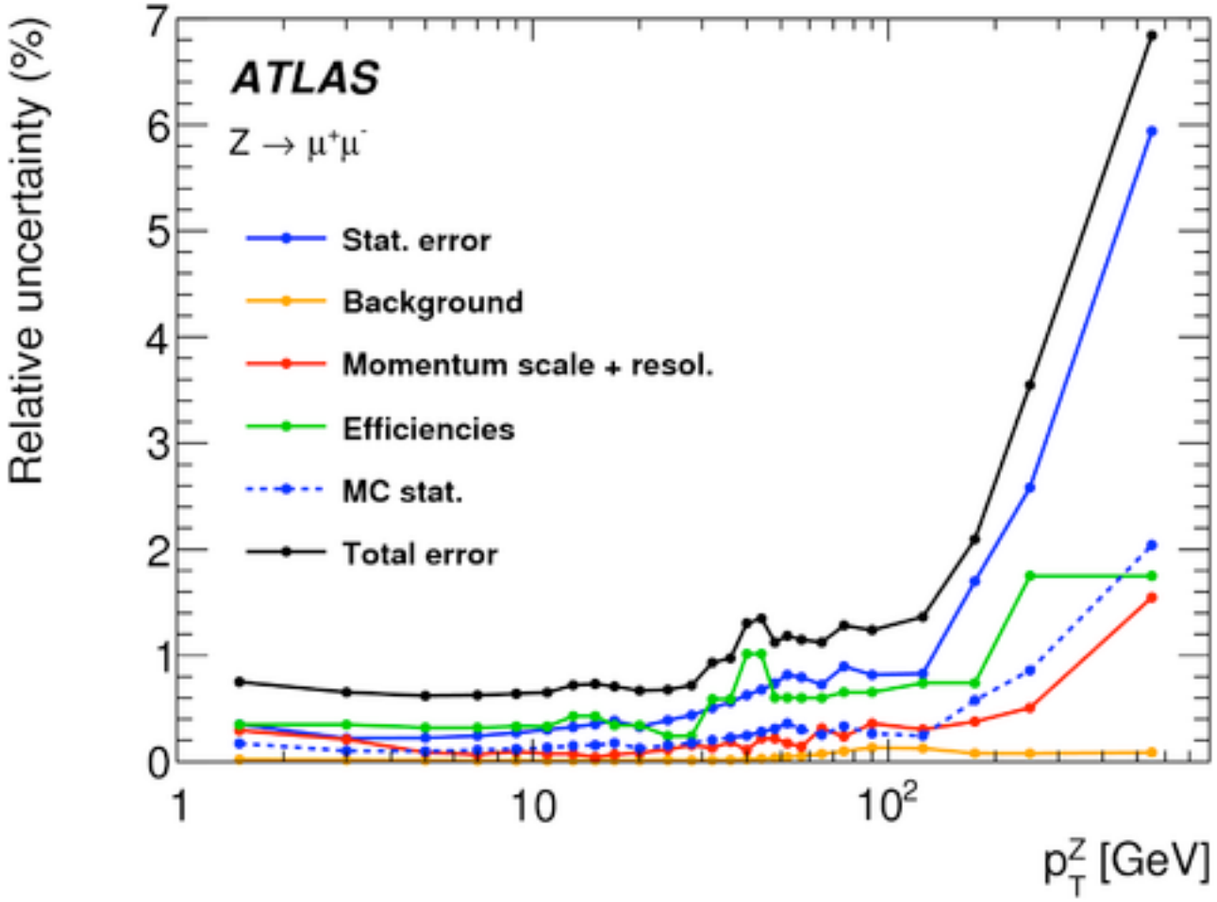
$P_{T,Z}$ Uncertainty in electron channel

dominated by statistics and electron energy scale and resolution



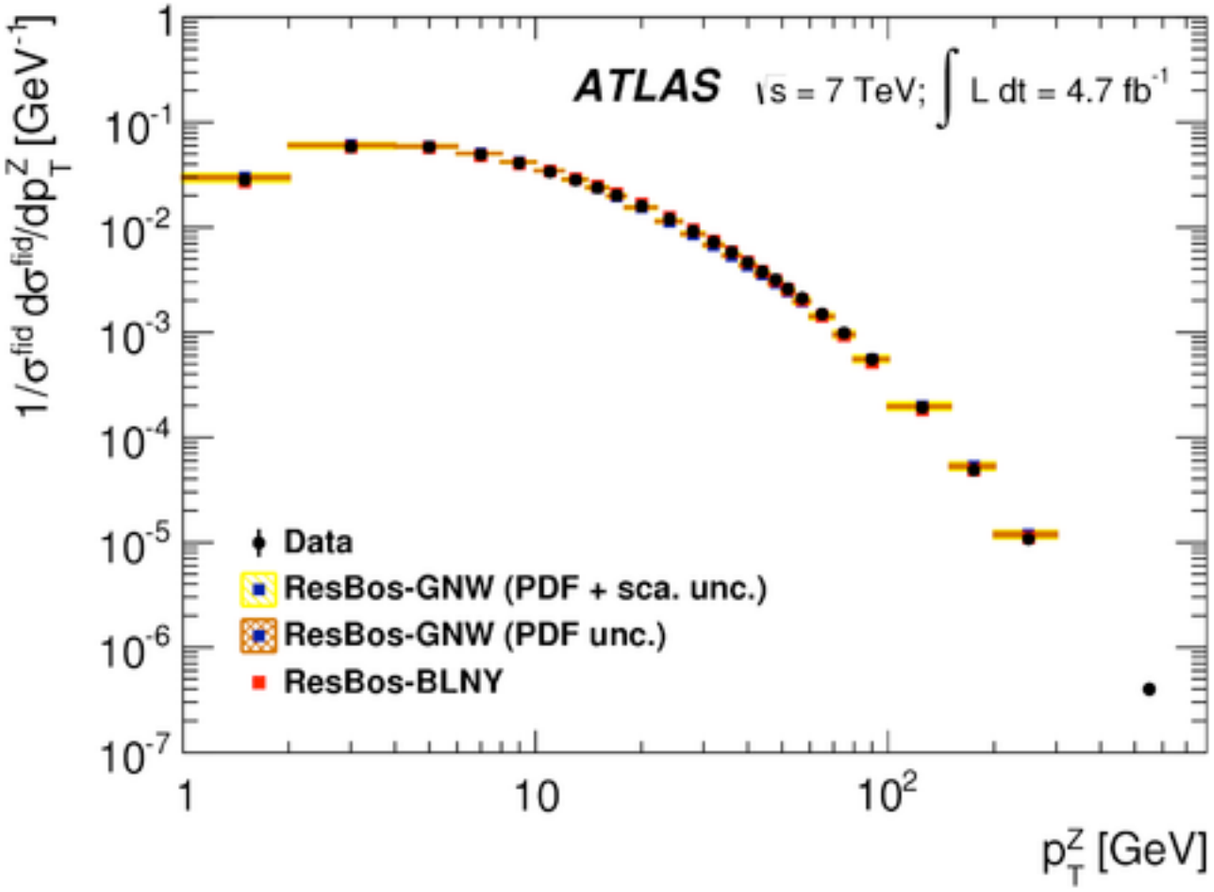
$P_{T,Z}$ Uncertainty in muon channel

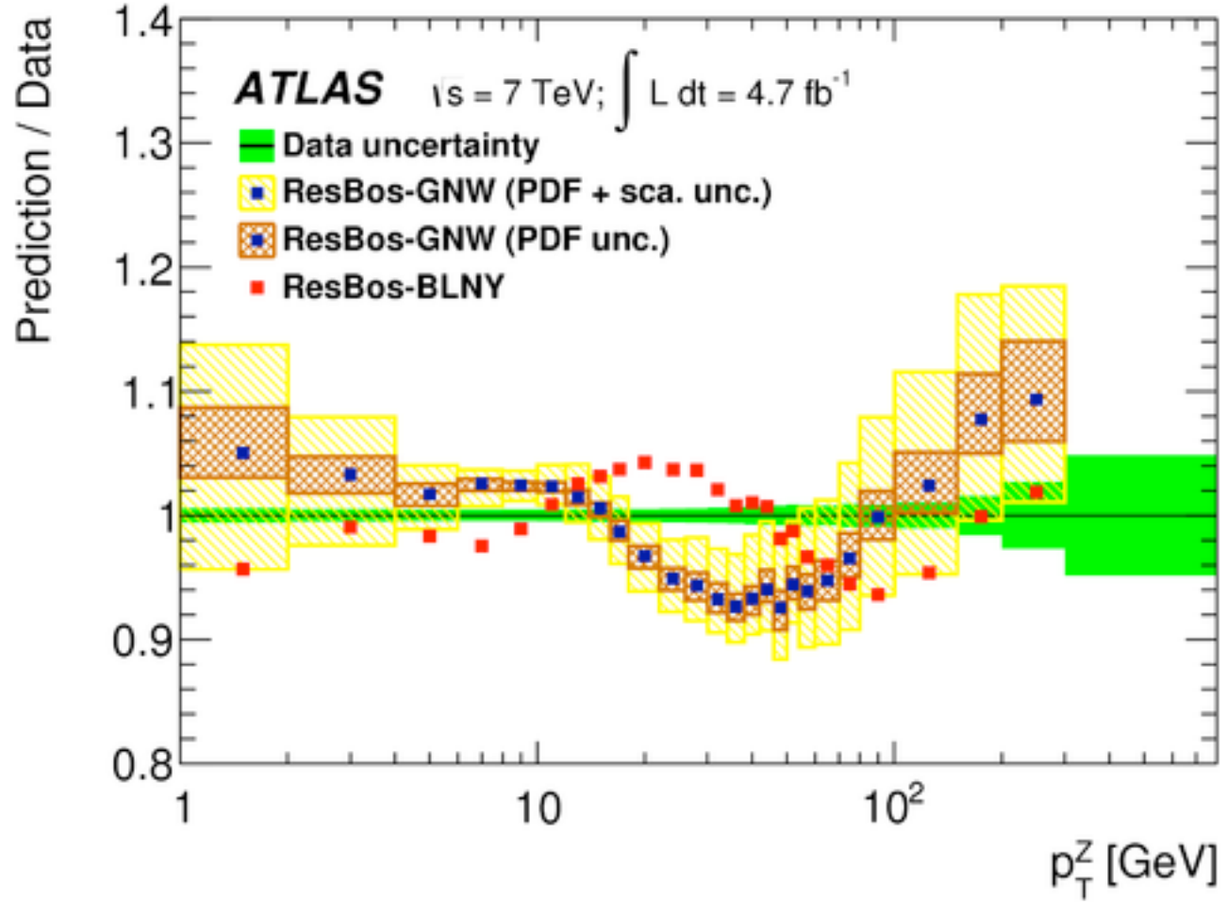
dominated by statistics and muon trigger efficiency



- Summary of uncertainty of $P_{T,Z}$ for both electron and muon channel, given as a percentage of the central bin
- Uncertainty is below 1% when $P_{T,Z}$ is less than 100GeV

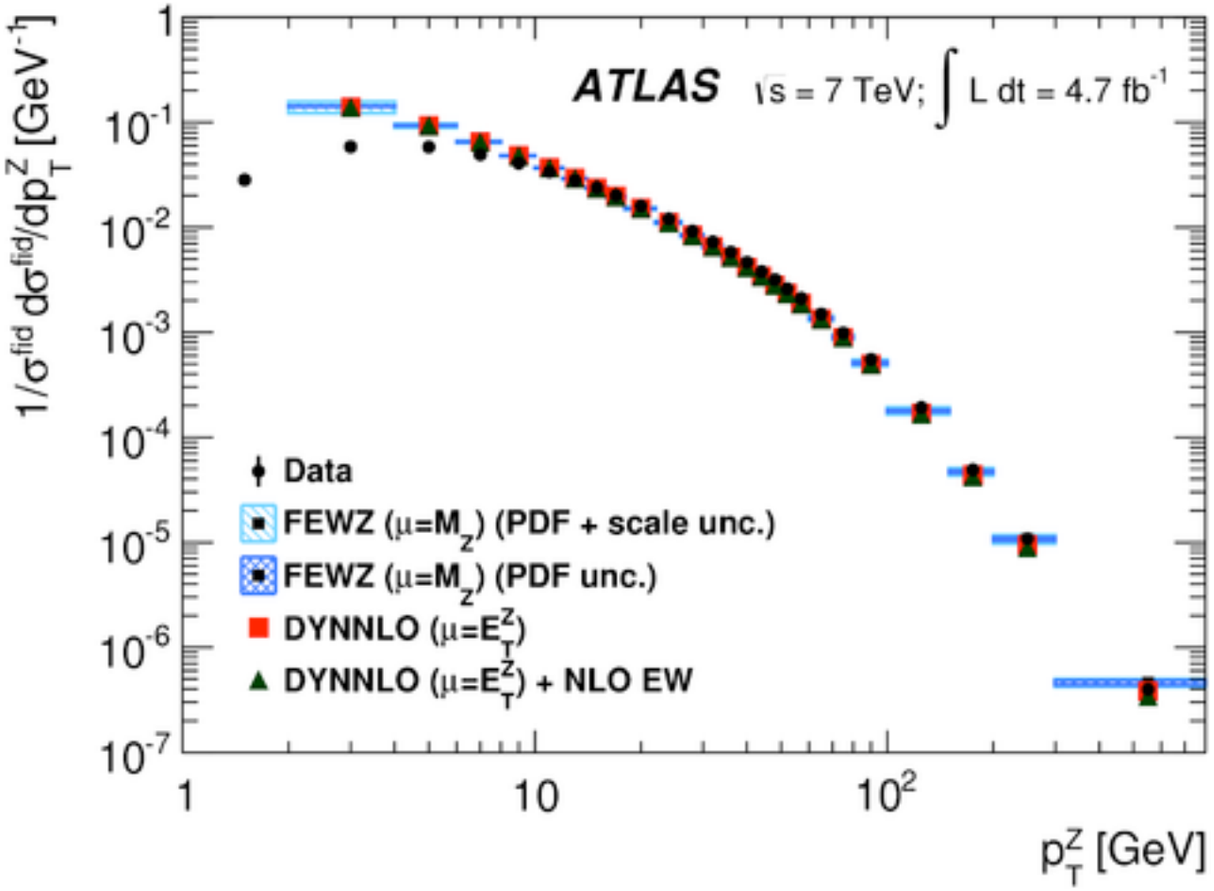
$P_{T,Z}$ compared with ResBos

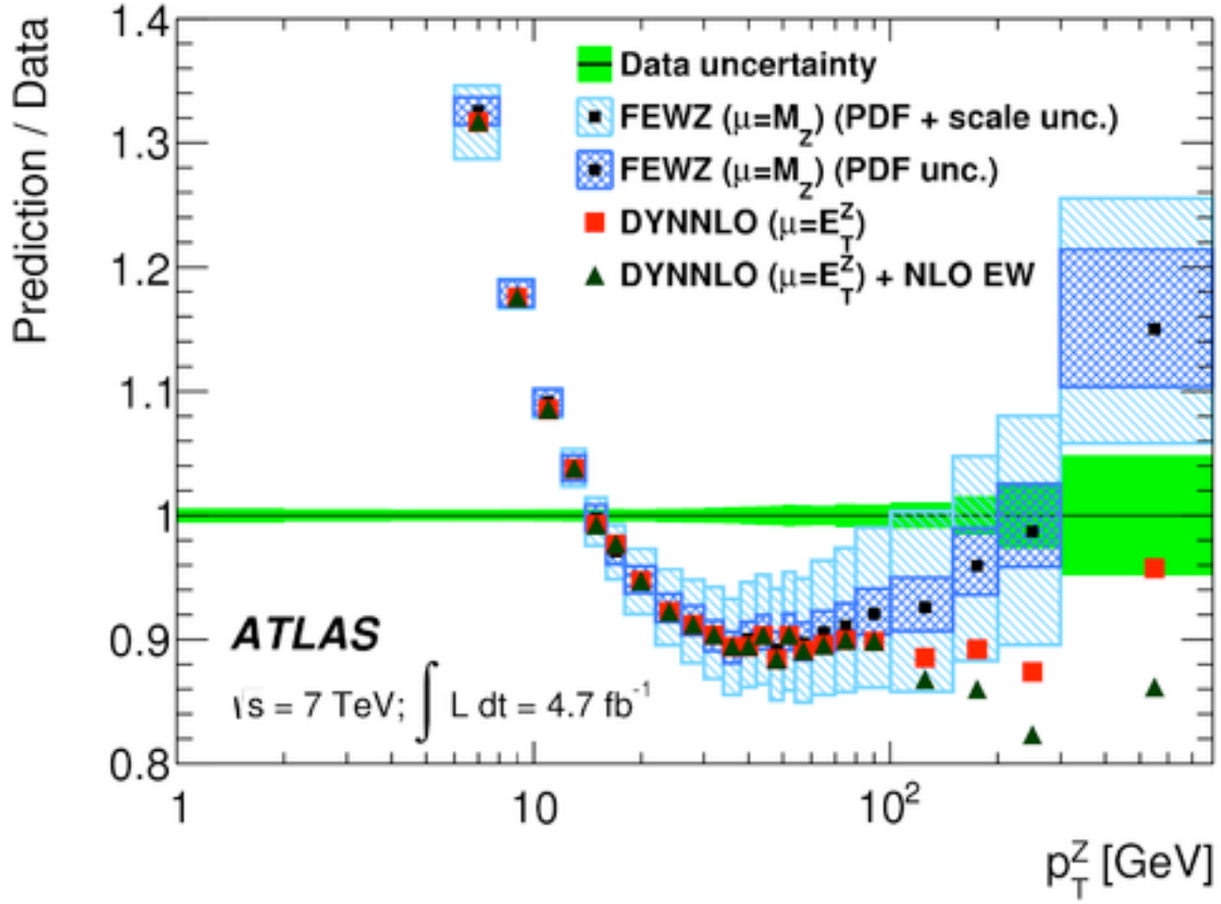




Combined cross section compare with prediction from ResBos : resummed multiple and collinear gluon emission, CT10 PDF

$P_{T,Z}$ compared with FEWZ

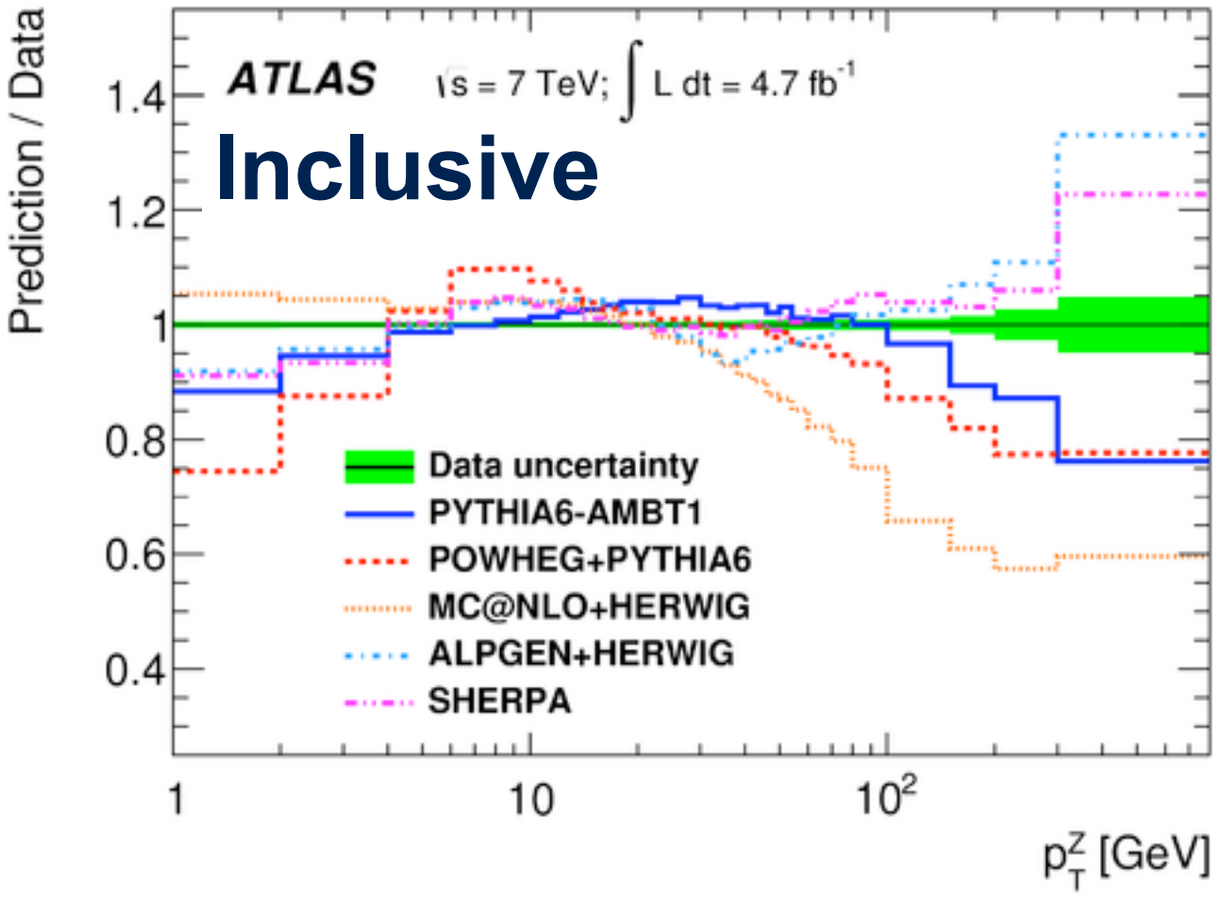




Combined cross section compare with prediction from FEWZ and DYNNLO : fixed-order calculation, CT10PDF

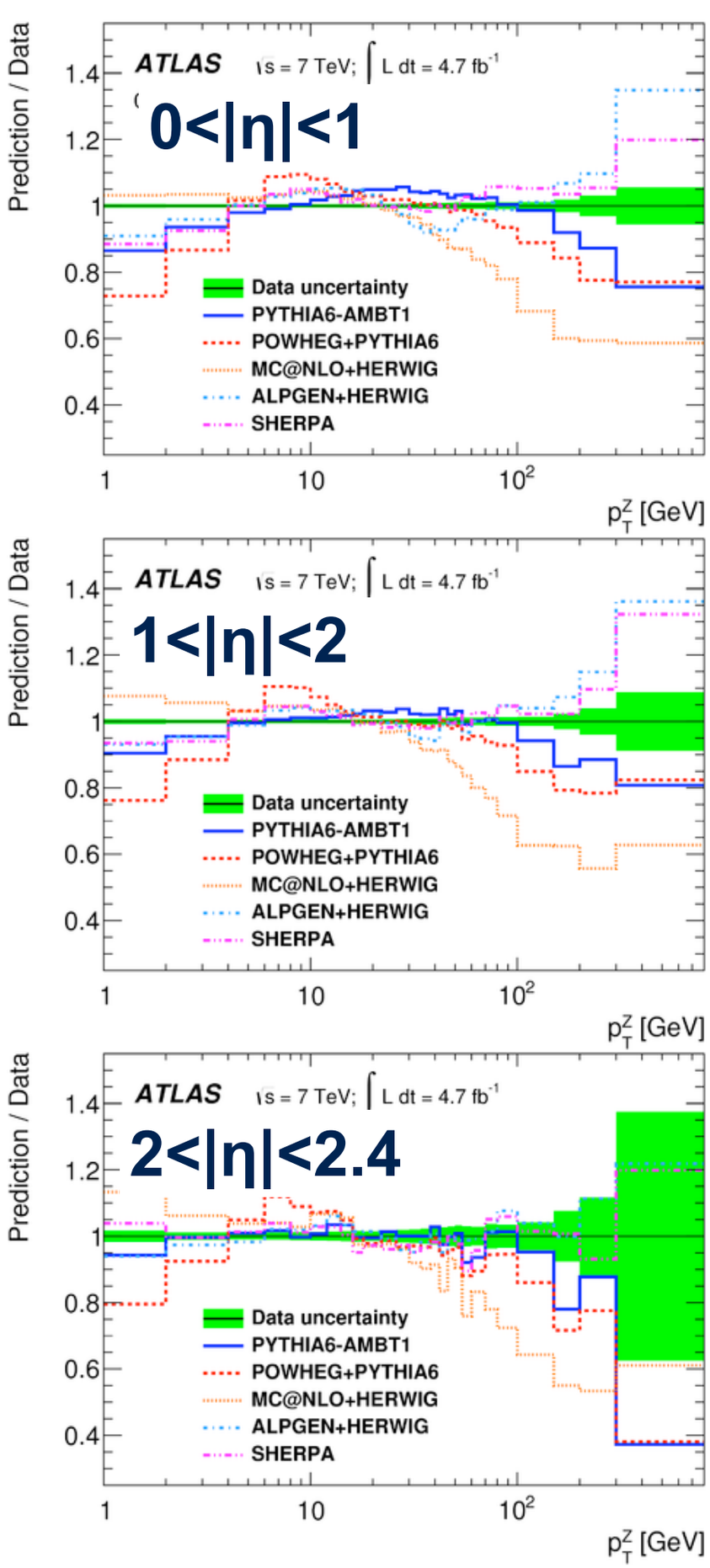
- Divergence at low $P_{T,Z}$ expected from lack of resummation. dynamic scale choice improves shape at high $P_{T,Z}$
- not yet sensitive to EW correction effects at high $P_{T,Z}$
- There is ~10% disagreement of MC to data in the region where fixed-order calculation are expected to work

$P_{T,Z}$ compared with different MC generators using parton shower approaches



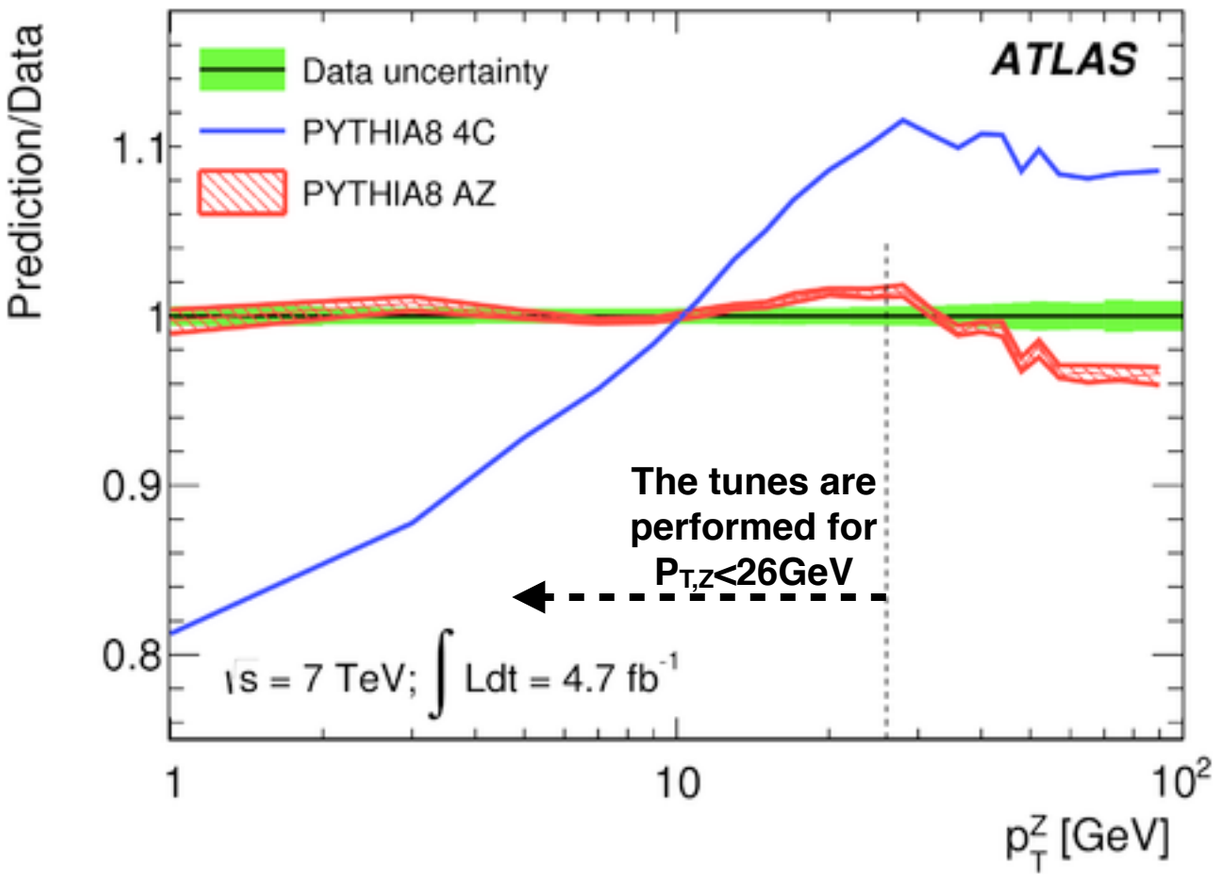
Ratio of the $P_{T,Z}$ distribution predicted by different MC generator at the born level.

- Inclusive and three different rapidity bin results are shown.
- Next step: Tune parton shower model parameters

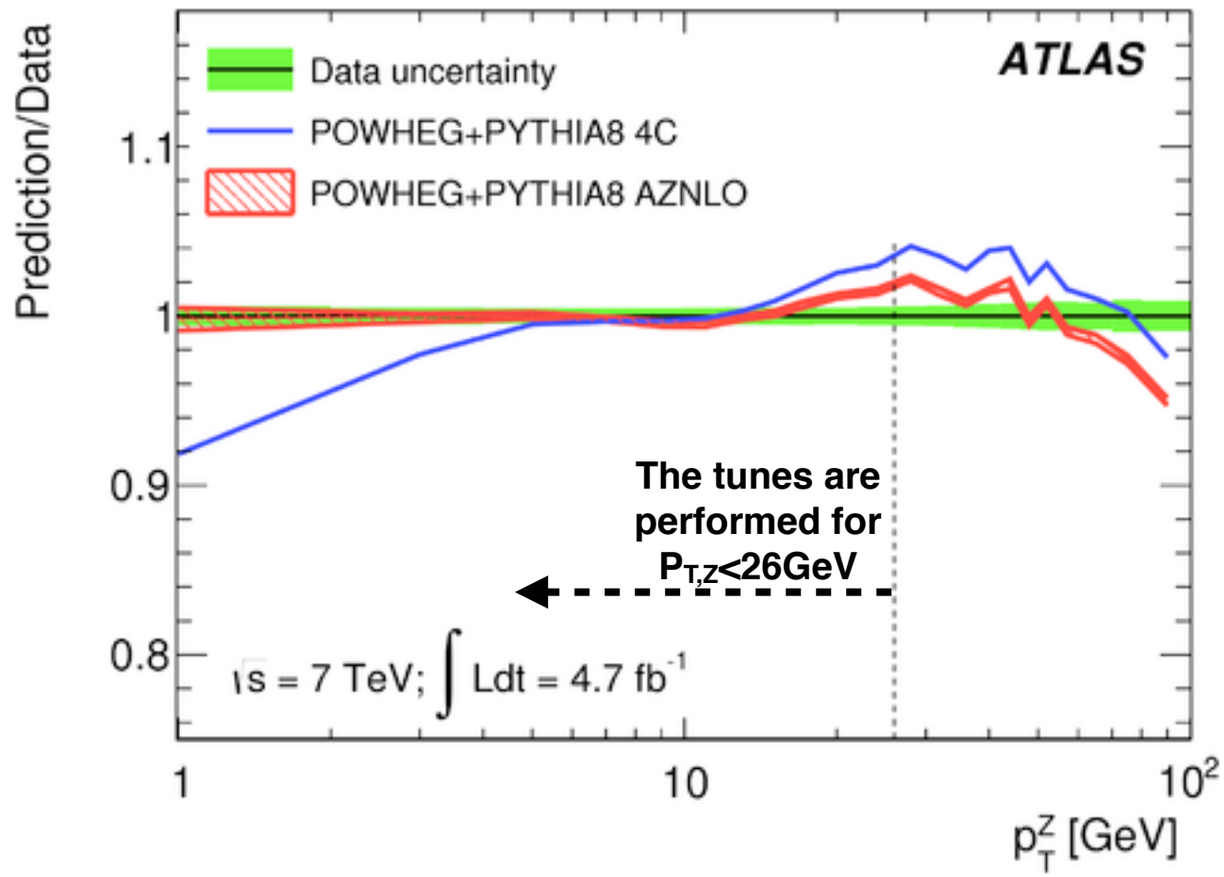


$P_{T,Z}$ compare with the prediction of tuned parton shower model parameters

Pythia8 tuning
ISR α_s order: LO



PowHeg+Pythia8 tuning
ISR α_s order: NLO



Comparison of Pythia8 and Powheg+Pythia8 predictions tuned using $P_{T,Z}$ measurement results at the dressed level (to minimise dependence on QED final state correction).

- Very good agreement observed after tuning!

Measurement of the Φ^* observable

Φ^* provides a measure of the azimuthal decorrelation between two objects.
Reconstruction from final-state lepton kinematics is affected by lepton energy and momentum measurement uncertainty. To minimise the impact, Φ^* is introduced as an alternative probe of $P_{T,Z}$

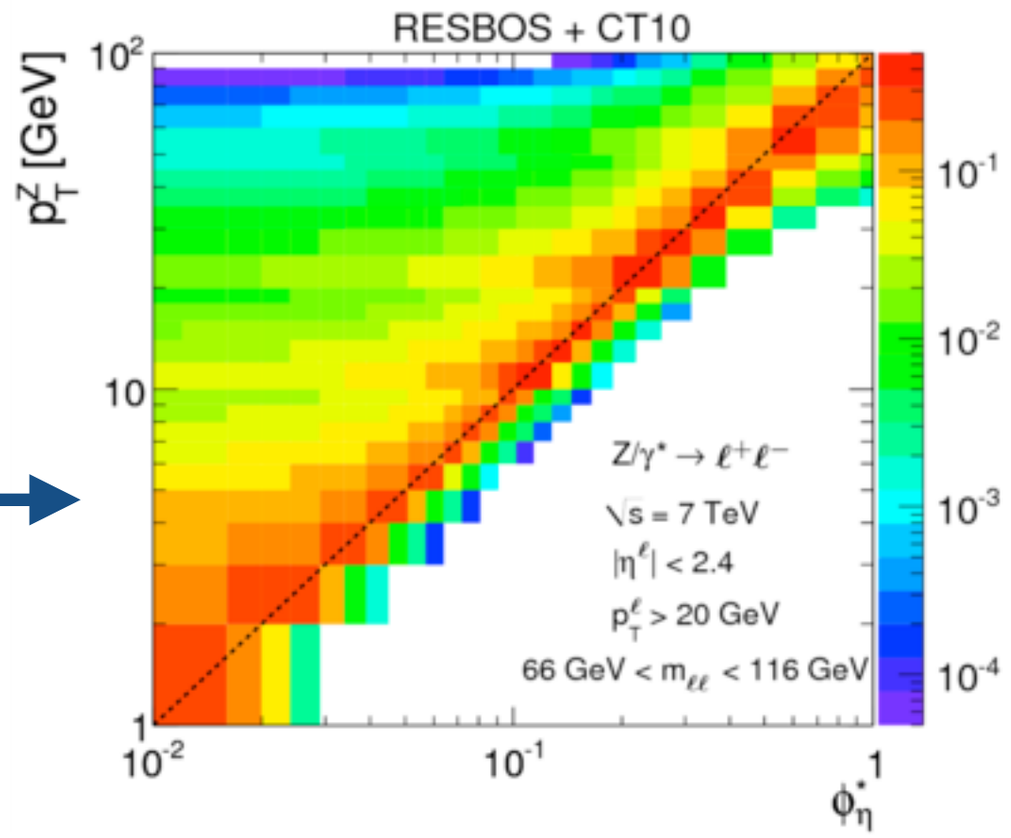
$$\phi_\eta^* = \tan\left(\frac{\phi_{\text{acop}}}{2}\right) \sin\theta_\eta^*$$

$$\phi_{\text{acop}} = \pi - (\phi^- - \phi^+)$$

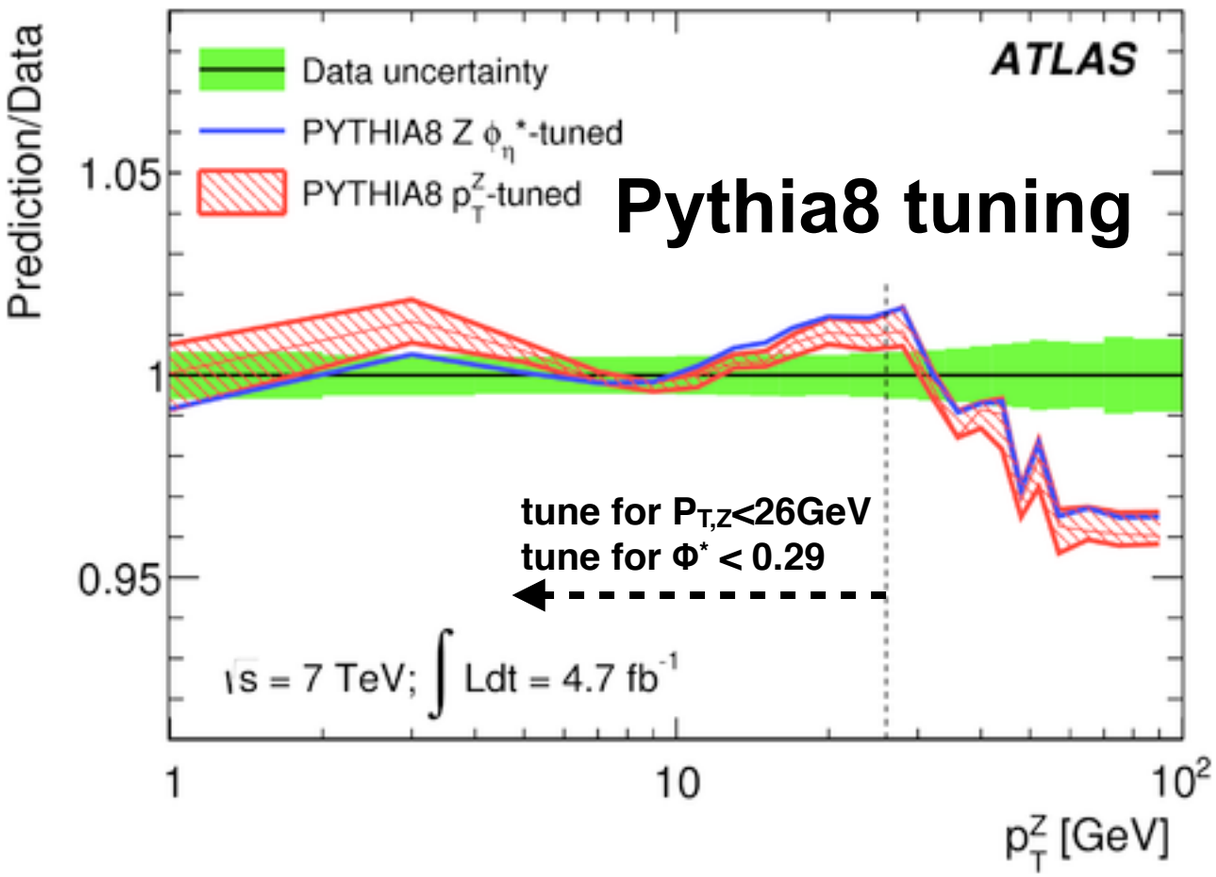
$$\cos\theta_\eta^* = \tanh\left(\frac{\eta^- - \eta^+}{2}\right)$$

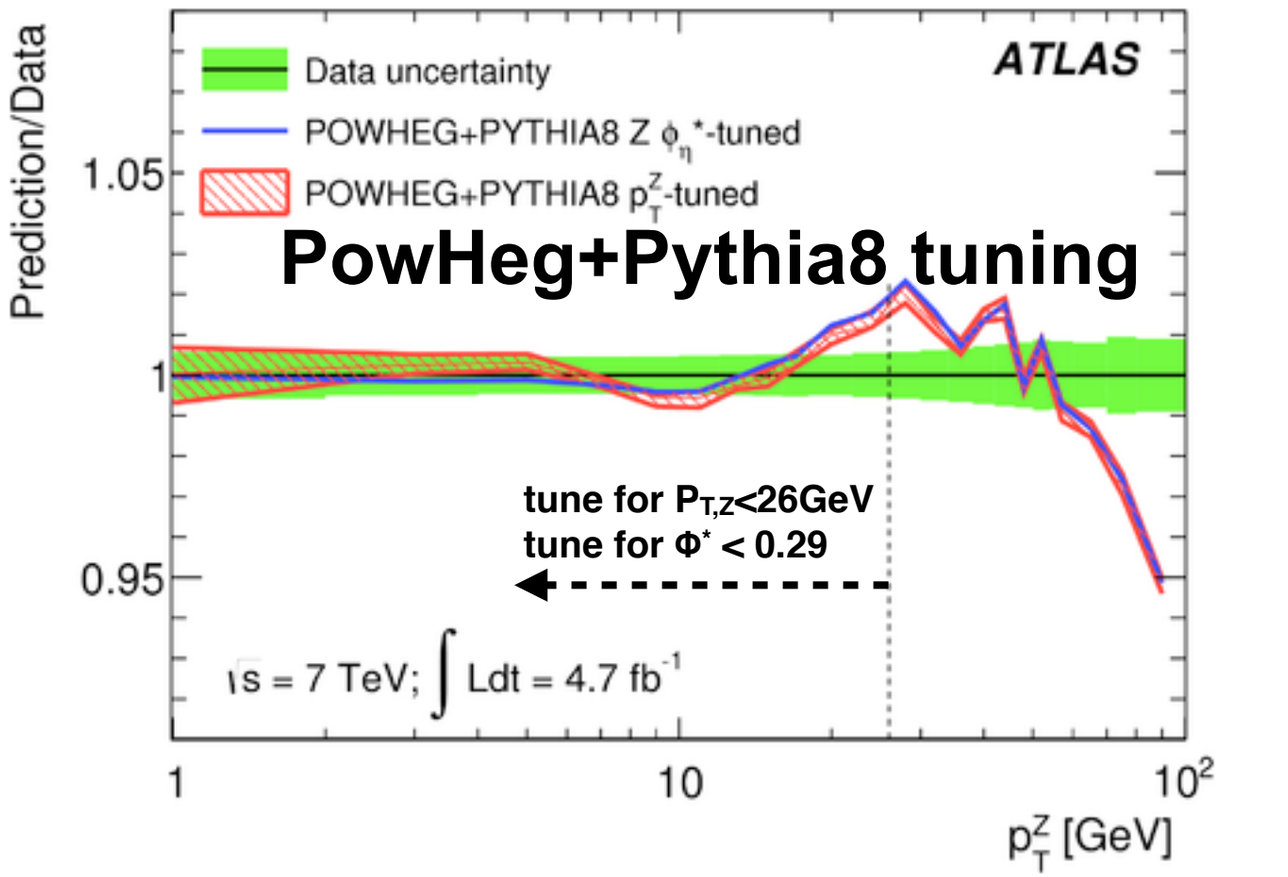
Correlation matrix between $P_{T,Z}$ Φ^* at born level

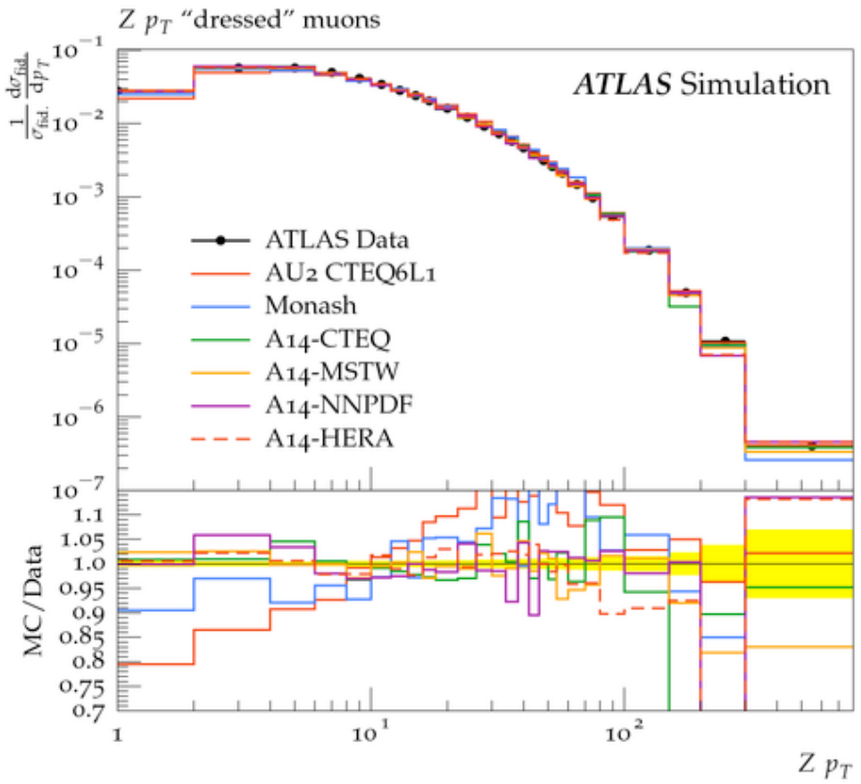
$$\sqrt{2} M_Z \phi_\eta^* \approx P_{T,Z}$$



Comparison with Φ^* and $P_{T,Z}$ tuned prediction







- Parton shower model parameters are tuned for Φ^* and $P_{T,Z}$
- Comparison of Pythia8 and Powheg +Pythia8 with Φ^* and $P_{T,Z}$ tuned measurement with the data at the dressed level.
- Summary of Pythia8 tunes shown.

Measurement of the forward backward asymmetry A_{FB} with ATLAS

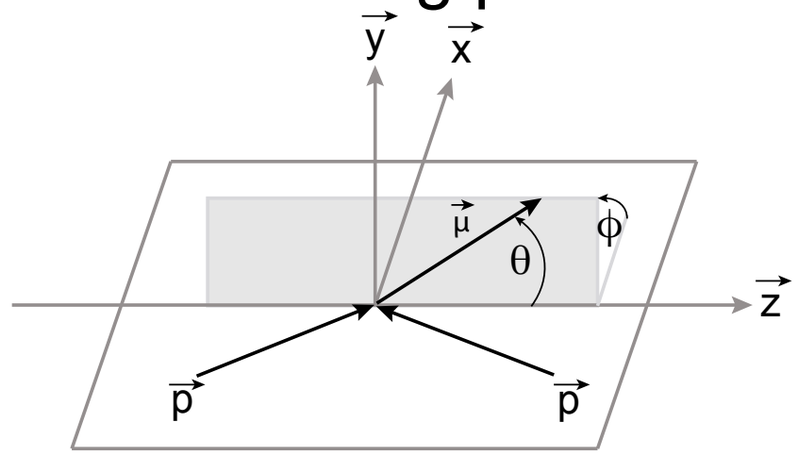
Define angles in Collins-Soper(CS) frame

z-axis defined as the one bi-sectiong the momenta of the incoming partons

$\cos\theta_{cs}$ is measured w.r.t. this axis

$$\cos\theta^*_{\rm cs} = \frac{p_z(l^+l^-)}{|p_z(l^+l^-)|}\frac{2(p_1^+p_2^- - p_1^-p_2^+)}{m(l^+l^-)\sqrt{m(l^+l^-)^2 + p_T(l^+l^-)^2}}$$

$$p_i^{\pm} = \frac{1}{\sqrt{2}}(E_i \pm p_{z,i})$$



Reduce the ambiguity in pp-collision ($P_{T,ll}$) to determine the direction of the incoming quark

Forward dilepton events : $\cos\theta^*_{cs} >= 0$

Backward dilepton events : $\cos\theta^*_{cs} < 0$

- $\cos\theta^*_{cs}$ is defined as the angle between the final state lepton and the initial state quark.

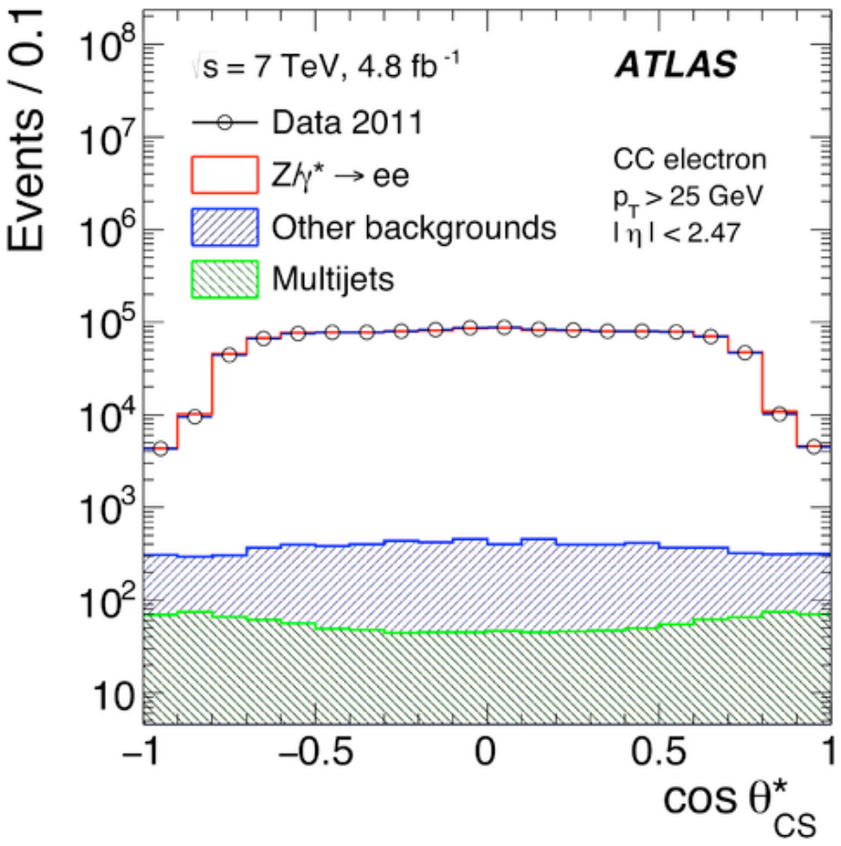
$$A_{\rm FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{N_{\cos\theta^*_{\rm cs}\geq 0} - N_{\cos\theta^*_{\rm cs}<0}}{N_{\cos\theta^*_{\rm cs}\geq 0} + N_{\cos\theta^*_{\rm cs}<0}}$$

Misidentified quark-direction results in dilution of A_{FB}

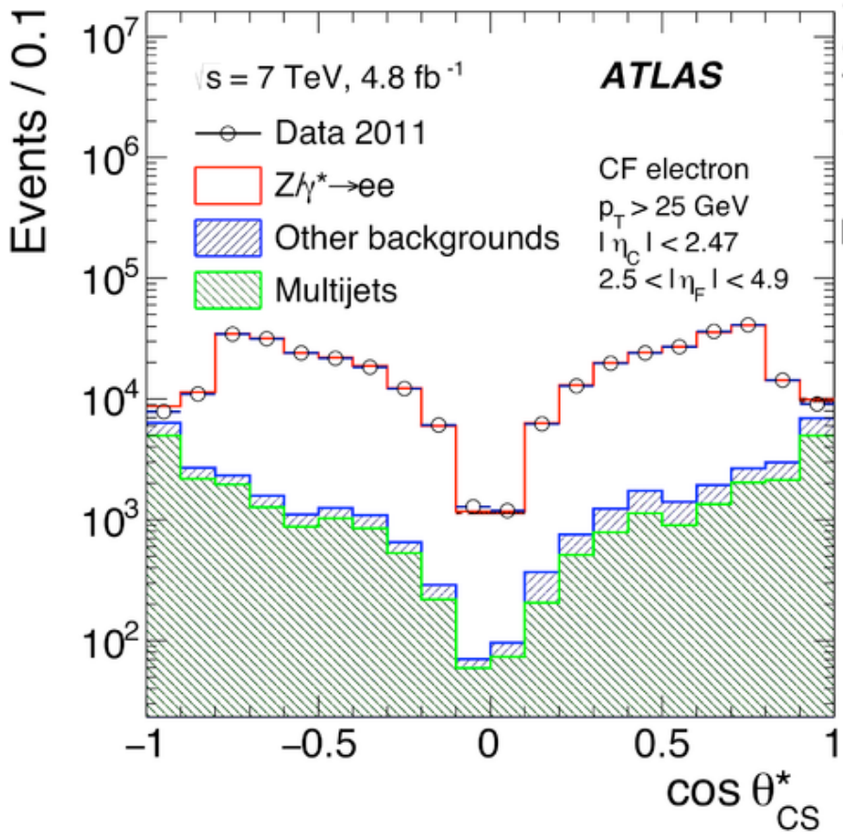
A_{FB} : $\cos\theta^*_{cs}$ distribution

Central : $|\eta| < 2.47$
Forward : $2.5 < |\eta| < 4.9$

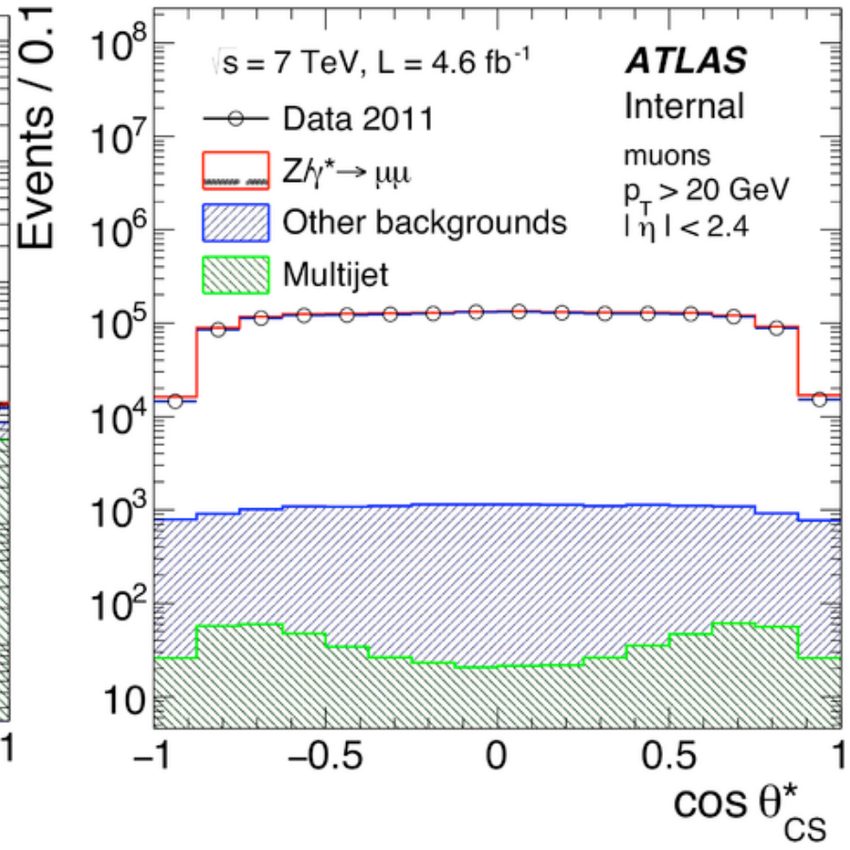
Central-Central Electron



Central-Forward Electron



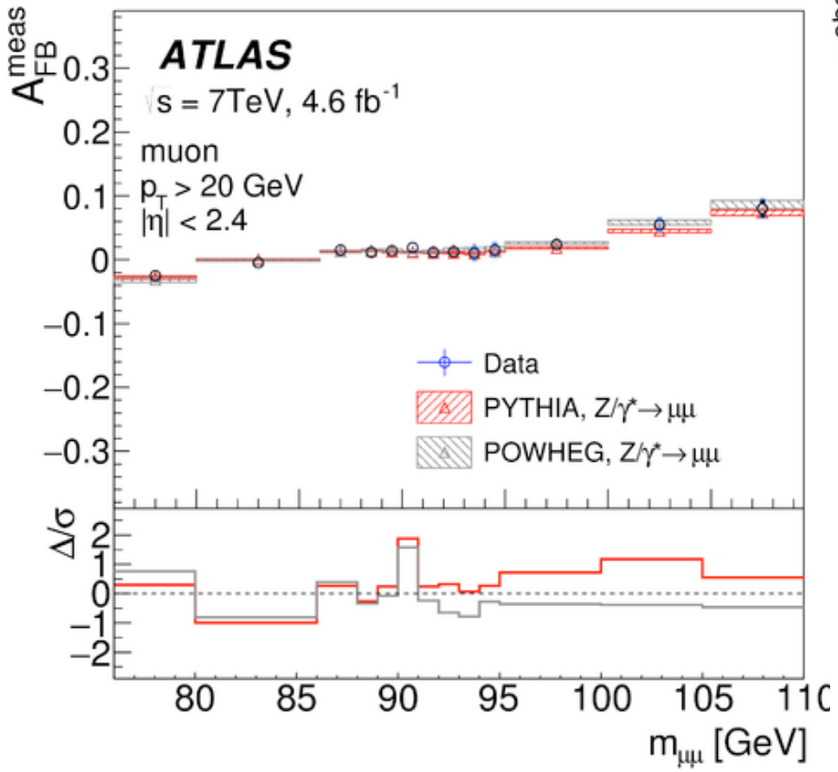
Muon



- Measure A_{FB} in two decay channels
- Also use forward electrons to extend and reach to high pseudorapidities (increase of separation between valence and sea quarks)

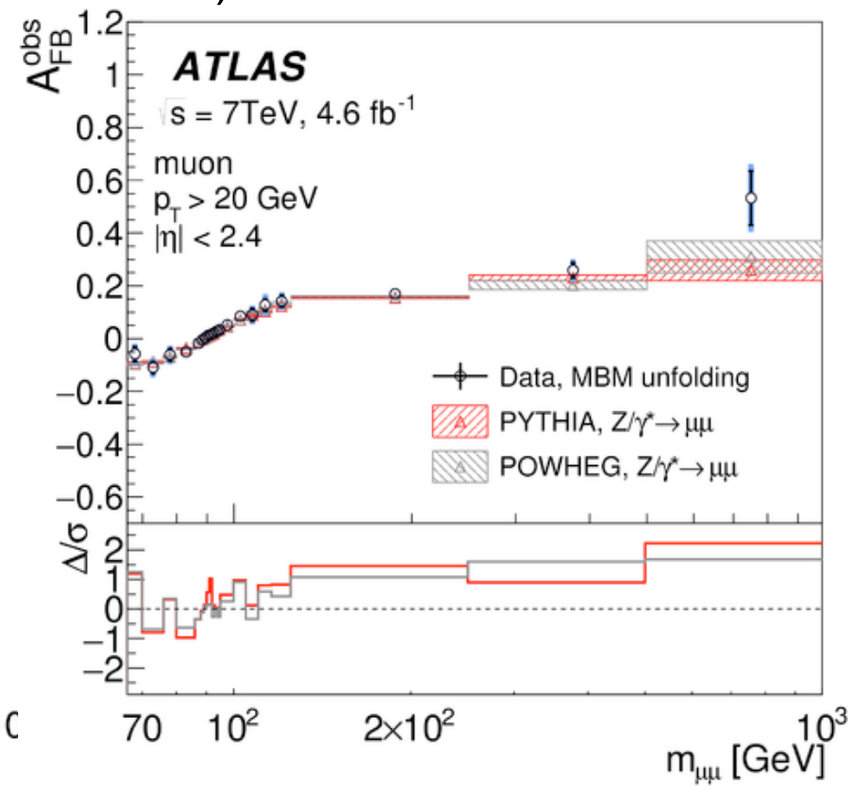
A_{FB} : $m_{\mu\mu}$ measurement

Raw Asymmetry



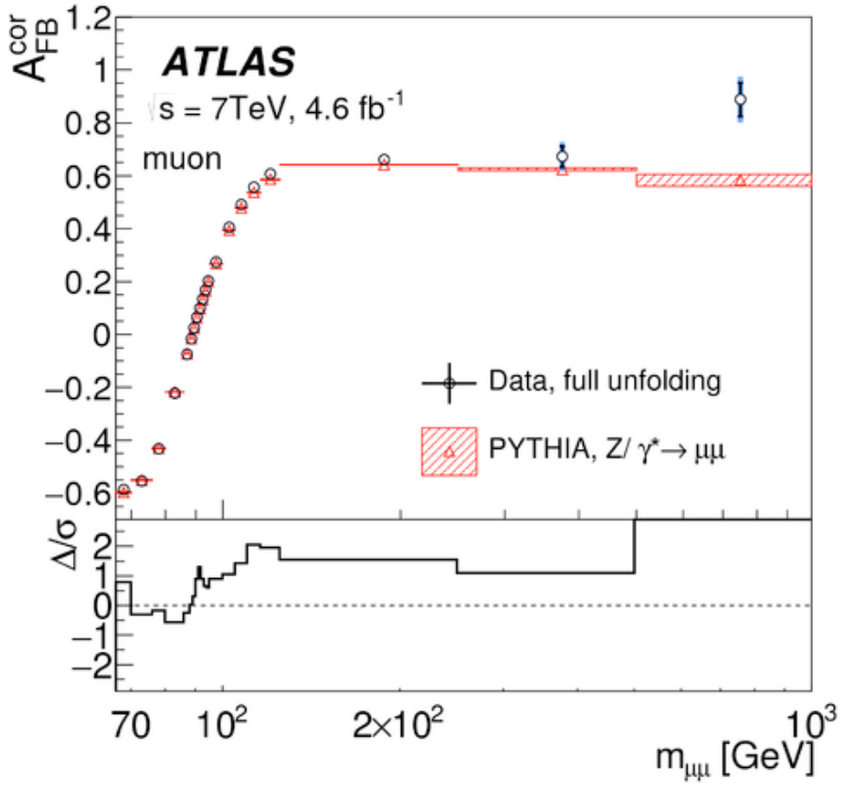
Unfolded to Born Level

(raw asymmetry corrected for detector effects and QED FSR)



Fully unfolded to Born Level

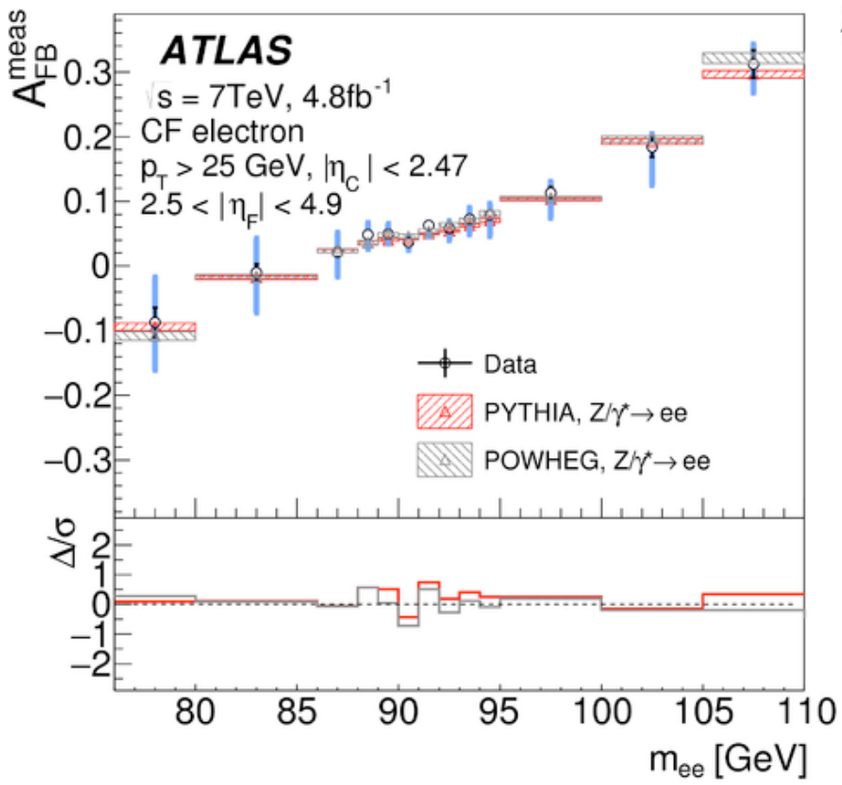
(further corrected for dilution effects)



- Similar results obtained using central electrons
- Significant dilution effects due to the ambiguity in the quark direction (sign of $\cos\theta^*_{cs}$)

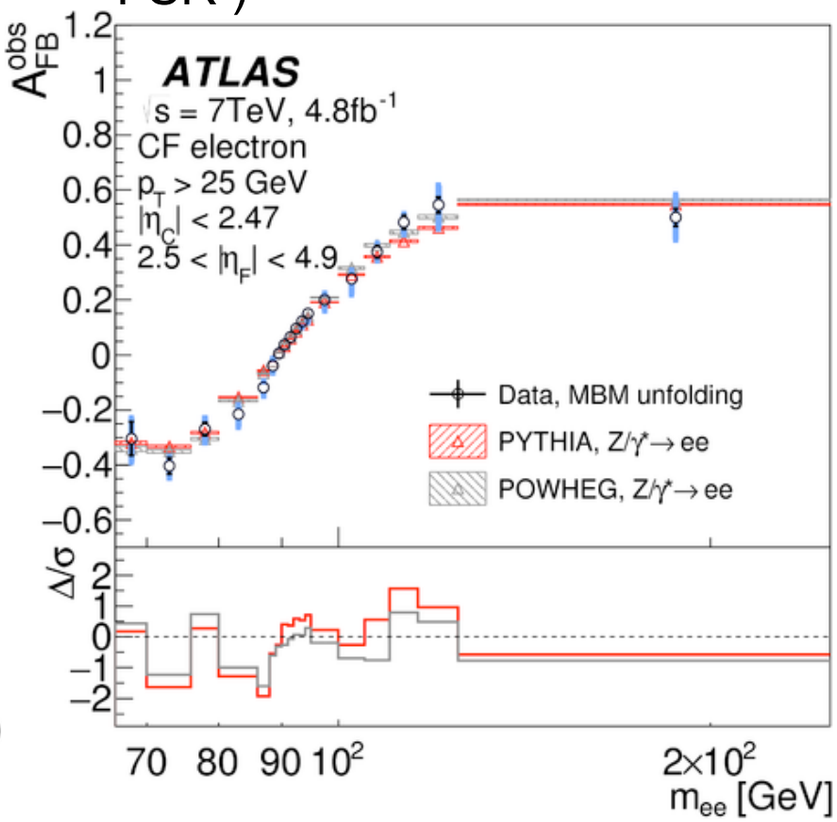
A_{FB} : m_{ee} measurement

Raw Asymmetry



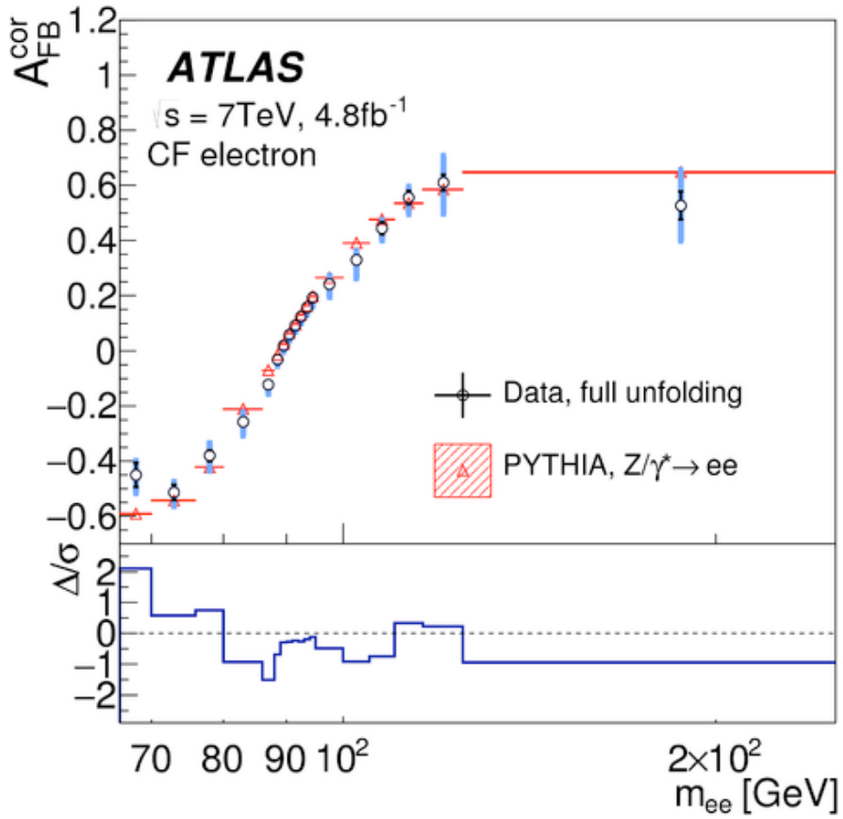
Unfolded to Born Level

(raw asymmetry corrected for detector effects and QED FSR)



Fully unfolded to Born Level

(further corrected for dilution effects)



- Results for central-forward electrons show much reduced dilution effects.

Determination of Weak mixing angle $\sin^2\theta_w^{eff}$

Leptonic effective weak mixing angle measurement

- based on raw A_{FB} spectra

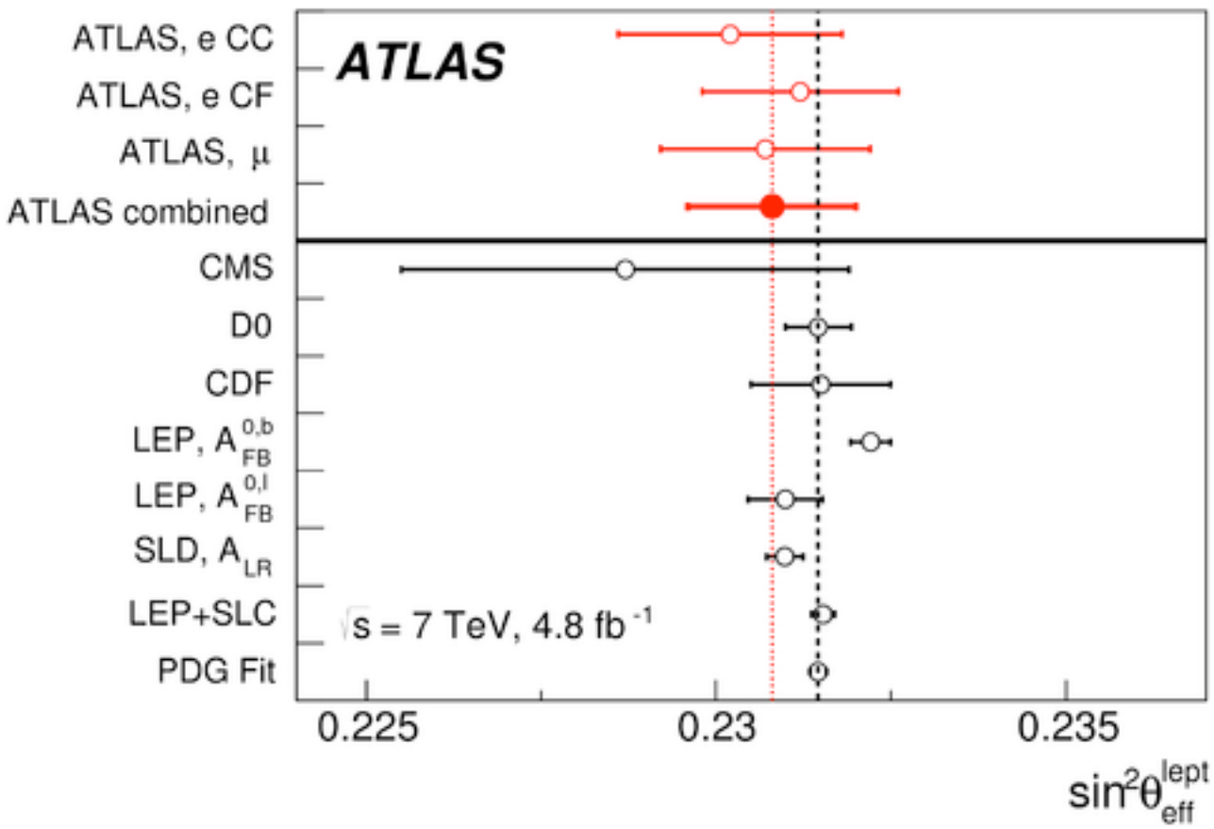
	$\sin^2\theta_{\text{eff}}^{\text{lept}}$
CC electron	$0.2302 \pm 0.0009(\text{stat.}) \pm 0.0008(\text{syst.}) \pm 0.0010(\text{PDF}) = 0.2302 \pm 0.0016$
CF electron	$0.2312 \pm 0.0007(\text{stat.}) \pm 0.0008(\text{syst.}) \pm 0.0010(\text{PDF}) = 0.2312 \pm 0.0014$
Muon	$0.2307 \pm 0.0009(\text{stat.}) \pm 0.0008(\text{syst.}) \pm 0.0009(\text{PDF}) = 0.2307 \pm 0.0015$
El. combined	$0.2308 \pm 0.0006(\text{stat.}) \pm 0.0007(\text{syst.}) \pm 0.0010(\text{PDF}) = 0.2308 \pm 0.0013$
Combined	$0.2308 \pm 0.0005(\text{stat.}) \pm 0.0006(\text{syst.}) \pm 0.0009(\text{PDF}) = 0.2308 \pm 0.0012$

Systematics uncertainties:

- Dominant uncertainty due to PDFs is correlated between the three measurements

Uncertainty source	CC electrons $[10^{-4}]$	CF electrons $[10^{-4}]$	Muons $[10^{-4}]$	Combined $[10^{-4}]$
PDF	10	10	9	9
MC statistics	5	2	5	2
Electron energy scale	4	6	–	3
Electron energy resolution	4	5	–	2
Muon energy scale	–	–	5	2
Higher-order corrections	3	1	3	2
Other sources	1	1	2	2

Weak mixing angle $\sin^2\theta_w^{eff}$



ATLAS measurement for A_{FB} mass range $70 < m_{ll} < 250$GeV

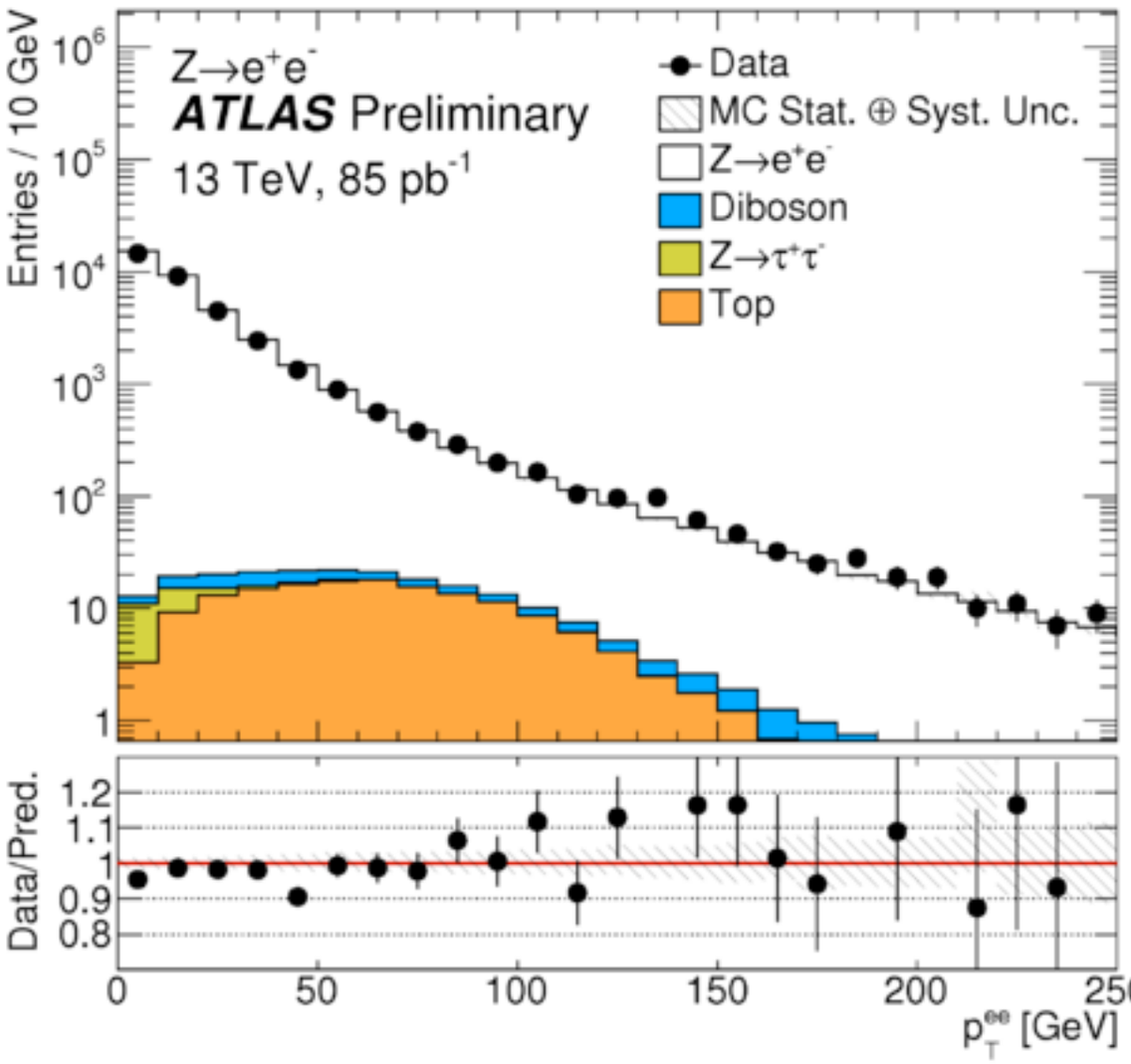
$\sin^2\theta_w^{eff} = 0.2308 \pm 0.0005(stat.) \pm 0.0006(syst.) \pm 0.0009(PDF)$

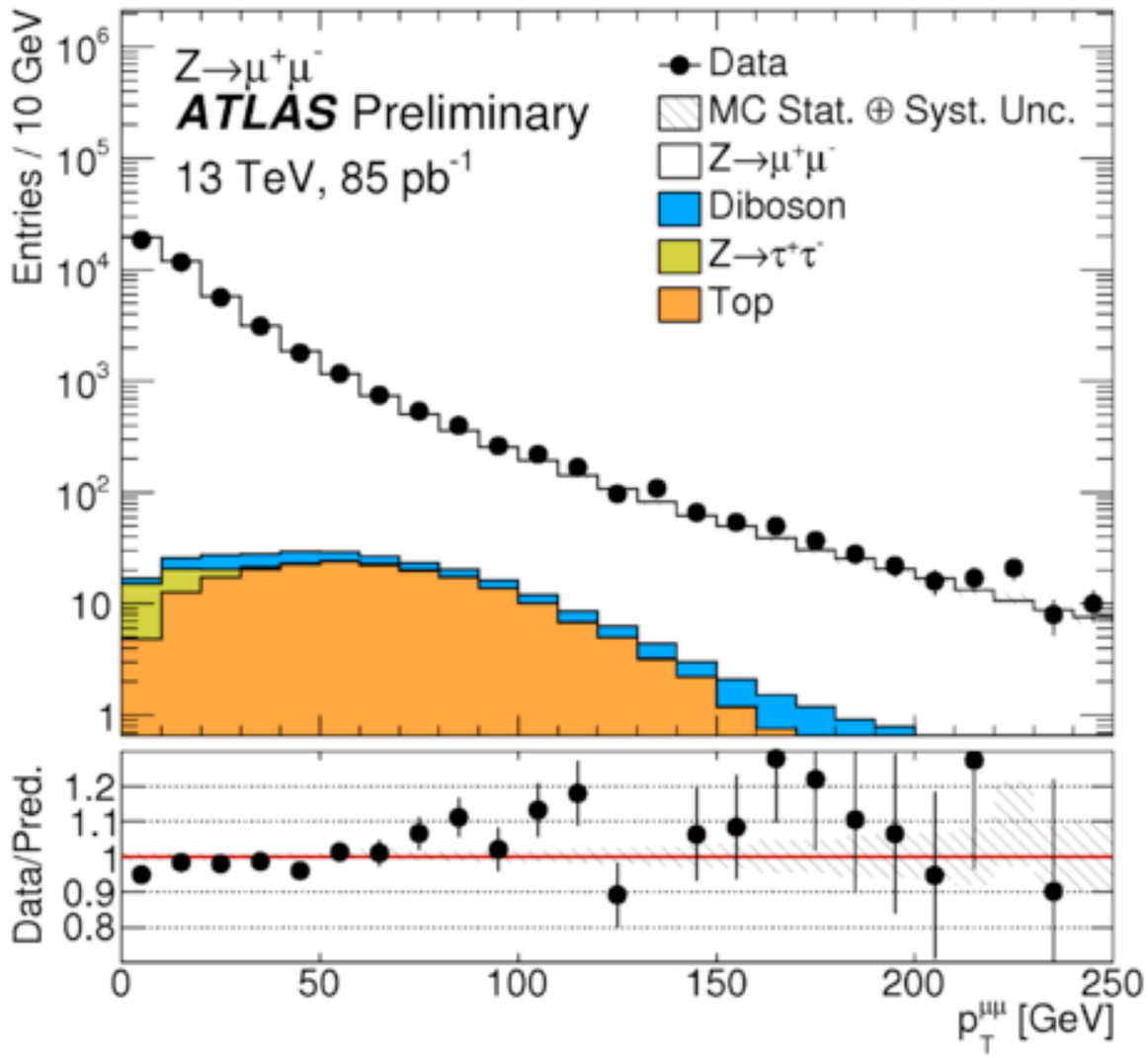
$= 0.2308 \pm 0.0012(tot.)$

- Agreement with PDG gobal fit (0.6σ)

  $\sin^2\theta_w^{eff} = 0.2308 \pm 0.00012$

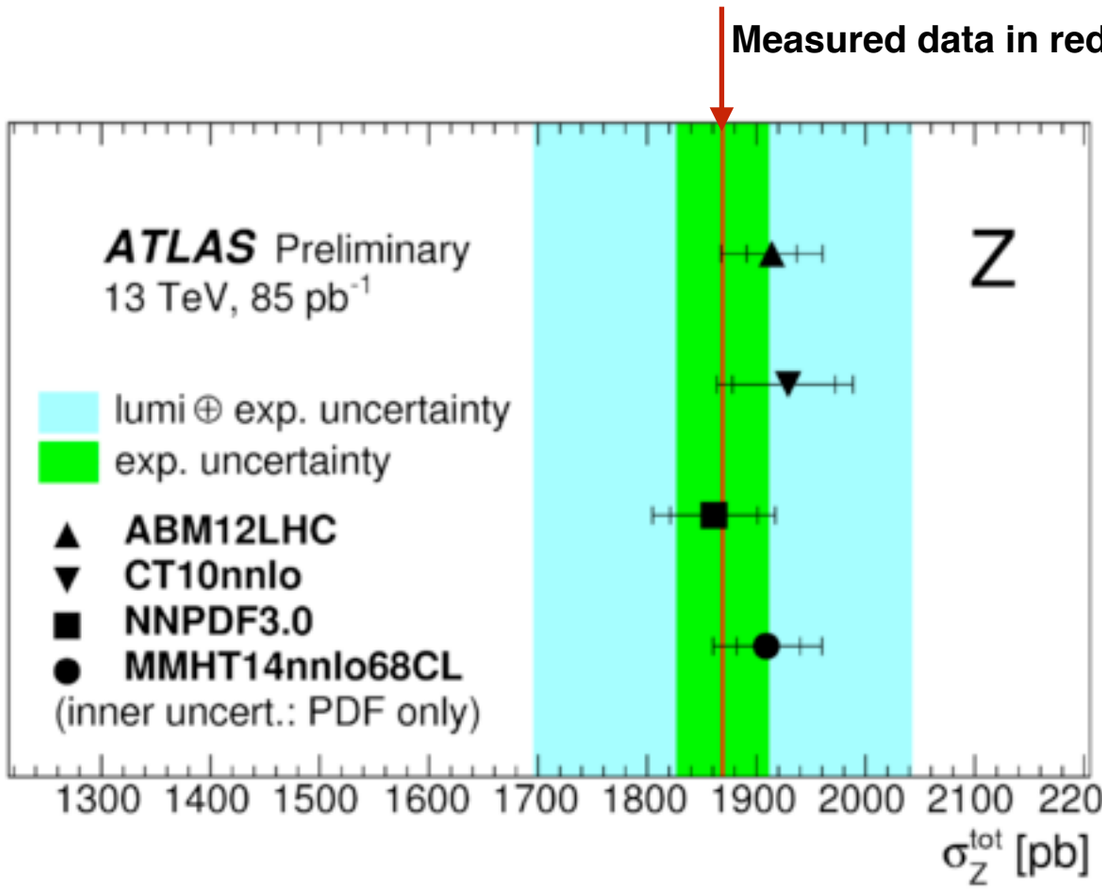
$P_{T,Z}$ Distribution at 13 TeV

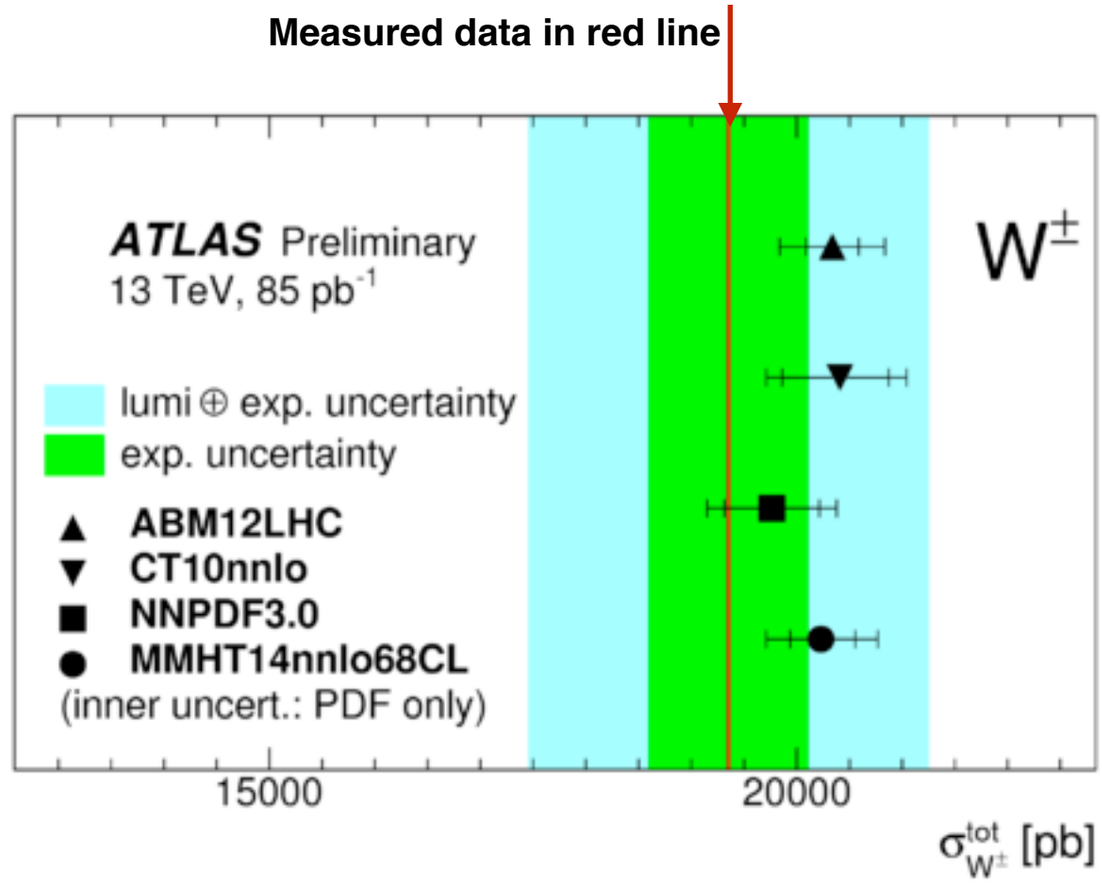




- First measurements of Z to ll and W to lv production crosss section corresponding to luminosity of 85pb^{-1}
- Measurements of vector boson cross sections with new data can be used to constrain PDF uncertainties.

13TeV W/Z production cross section

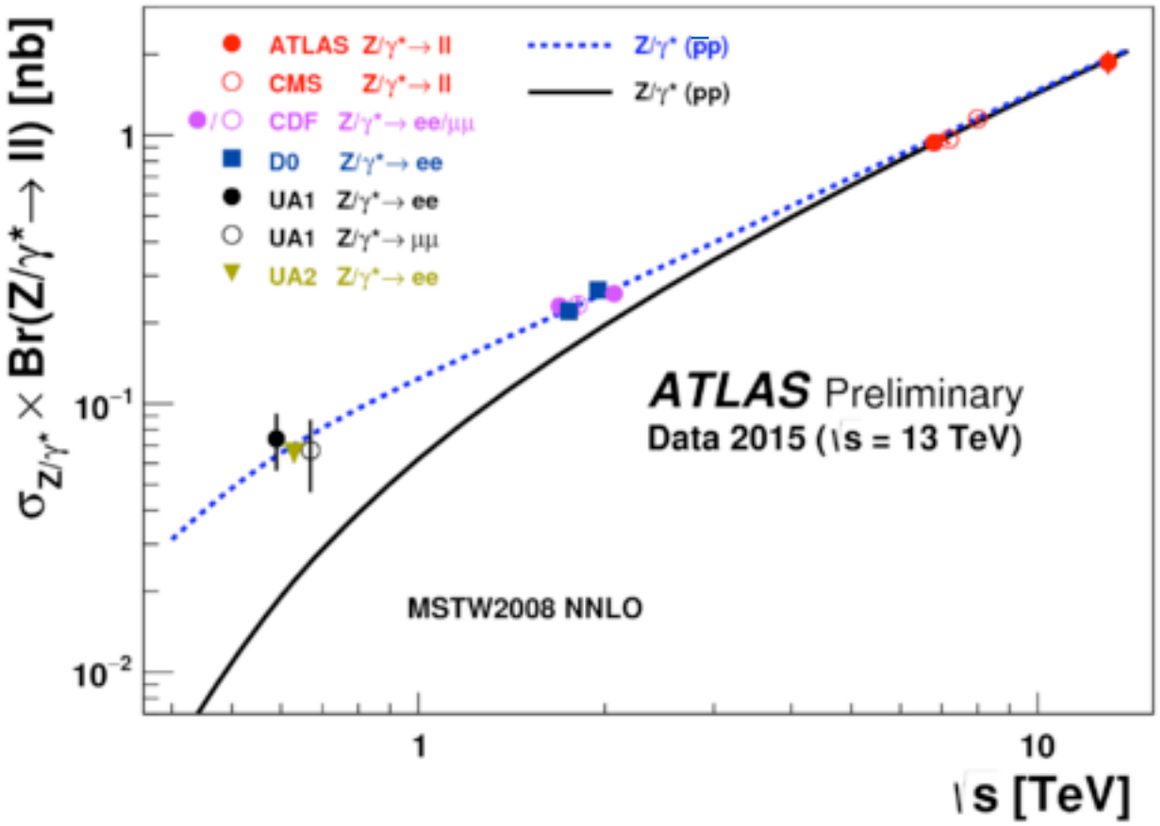


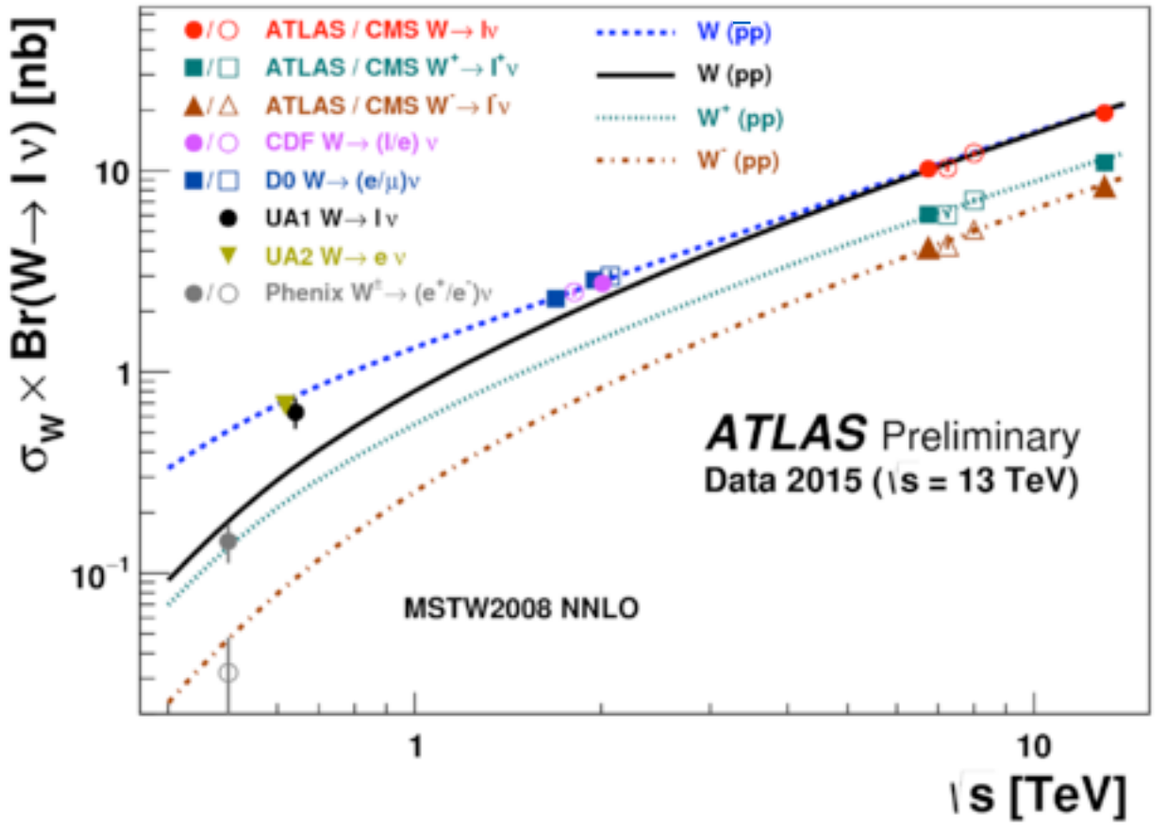


- Measured data compared with different theoretical prediction of FEWZ with different PDF sets.

PDF	σ^{tot}_{W+} [pb]	σ^{tot}_{W-} [pb]	$\sigma^{tot}_{W\pm}$ [pb]	σ^{tot}_{Z} [pb]
CT10NNLO	11770^{+270}_{-310}	8640^{+210}_{-240}	20400^{+500}_{-500}	1930^{+40}_{-50}
NNPDF3.0	11360 ± 260	8410 ± 200	19800 ± 500	1860 ± 40
MMHT14NNLO	11610^{+200}_{-170}	8620^{+140}_{-130}	20230^{+330}_{-290}	1909^{+31}_{-27}
ABM12LHC	11760 ± 150	8580 ± 100	20340 ± 250	1914 ± 23

13TeV W/Z production cross section





- Combined electron muon results compared with the previous measurement
- The prediction are shown for both proton-proton and proton and anti-proton colliders
- Cross section increase following the expectations

Summary

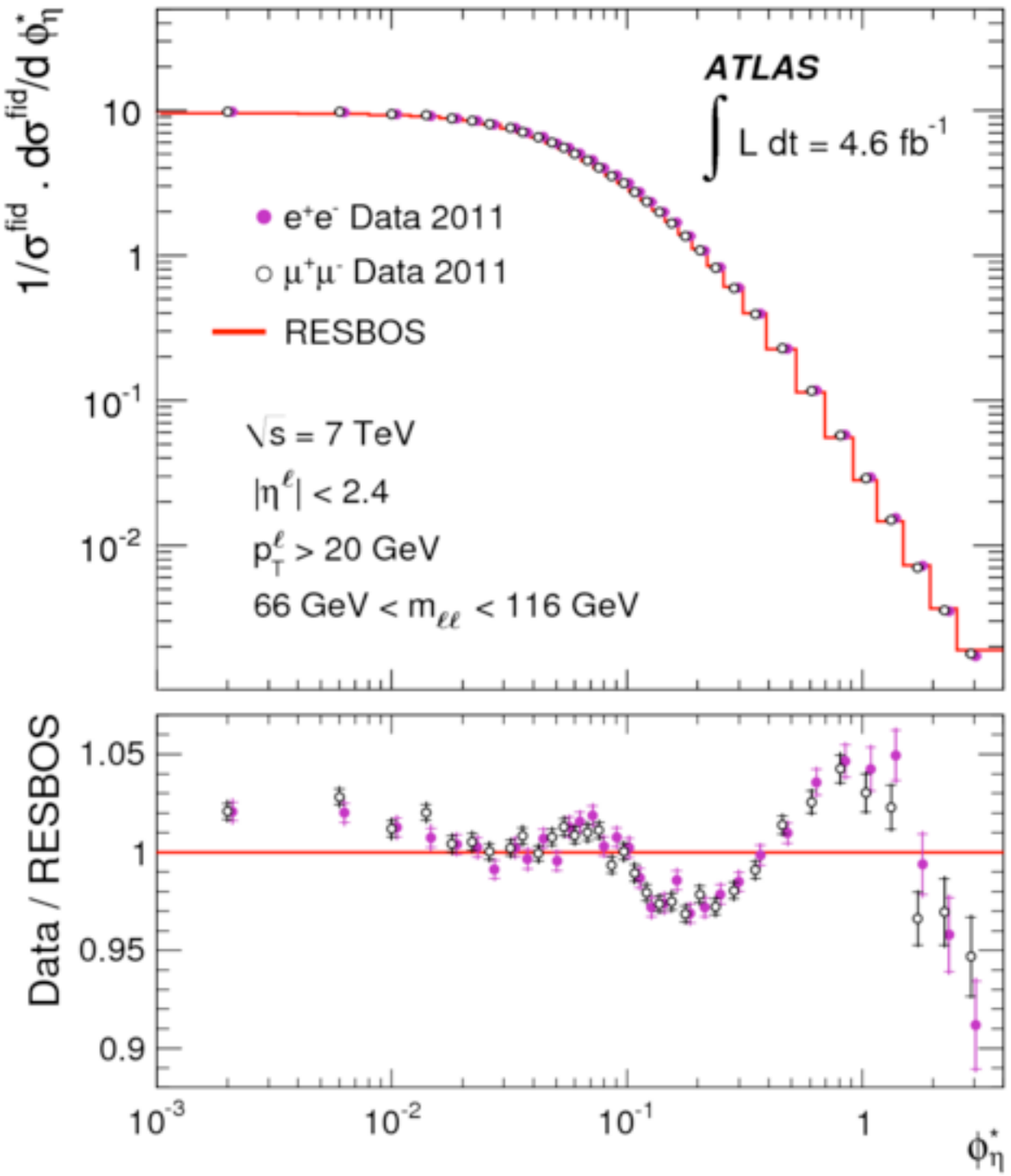
- $P_{T,Z}$ and Φ^* measurements provide wealth of information on partonic structure

- Results allow to test performance of calculation and provide a handle to tune parton shower parameters and models

- First combined electron and muon channel results for the leptonic weak mixing angle from hadron collider based on A_{FB} measurement

- First W, Z production cross section at 13 TeV show agreement with NNLO QCD predictions

Backup Φ^* Distribution



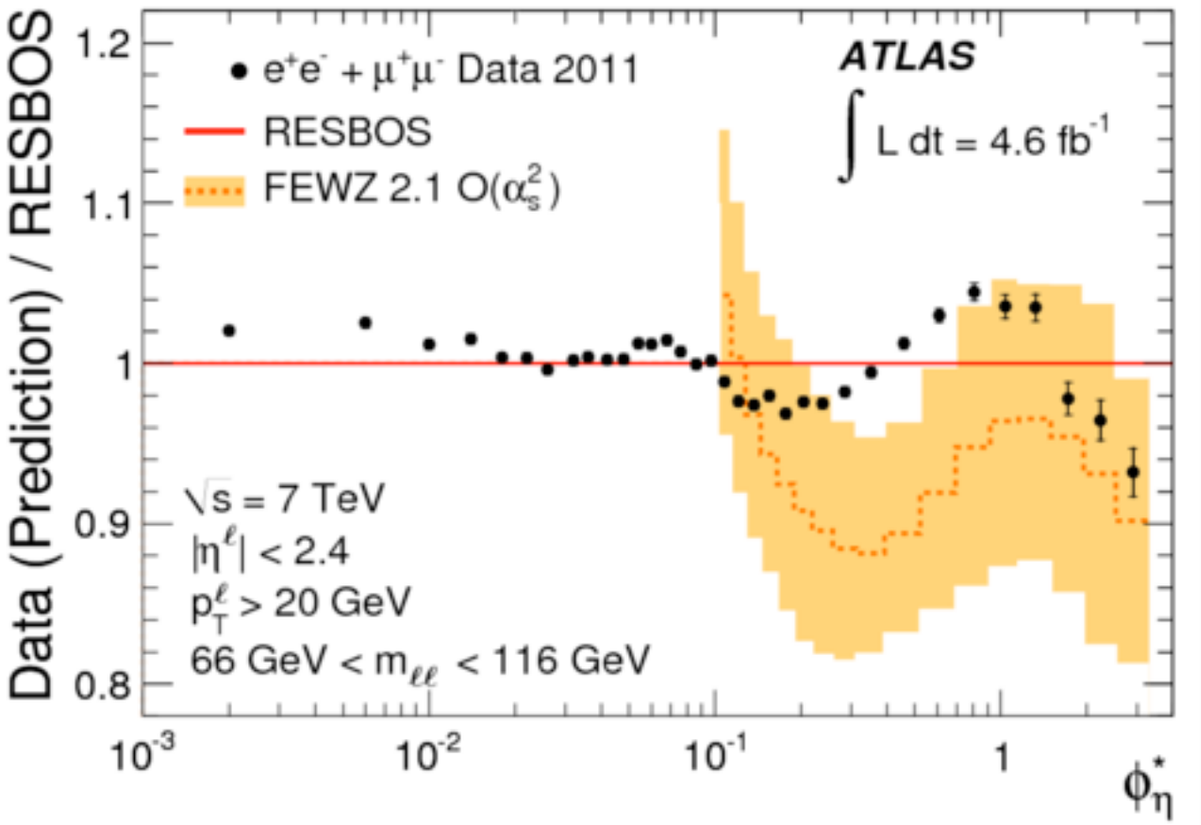
- The measured normalised differential cross section as function of Φ^*

- The measured results are compared to ResBos predictions.

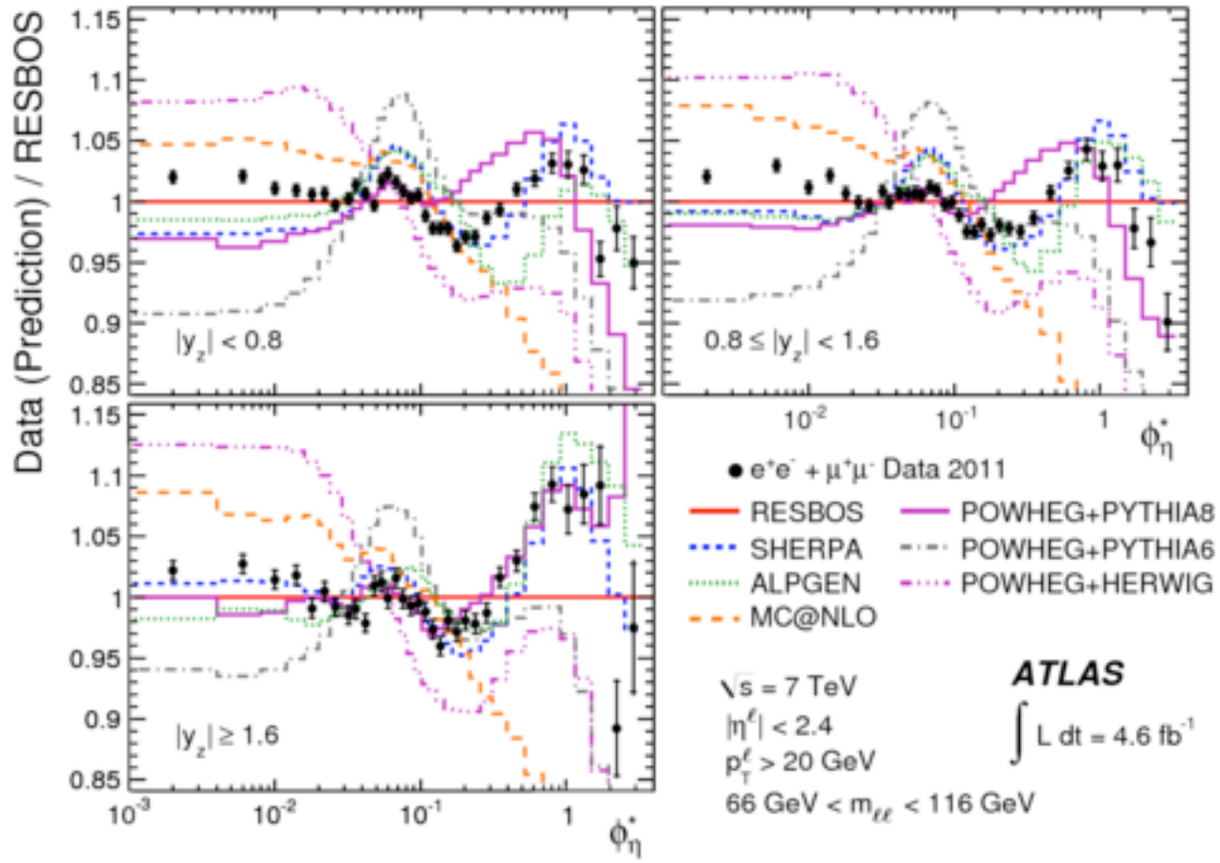
- The inner and outer error bars on data points represent the statistical and total uncertainty, respectively.

Backup Φ^* Comparison

ResBos and FEWZ



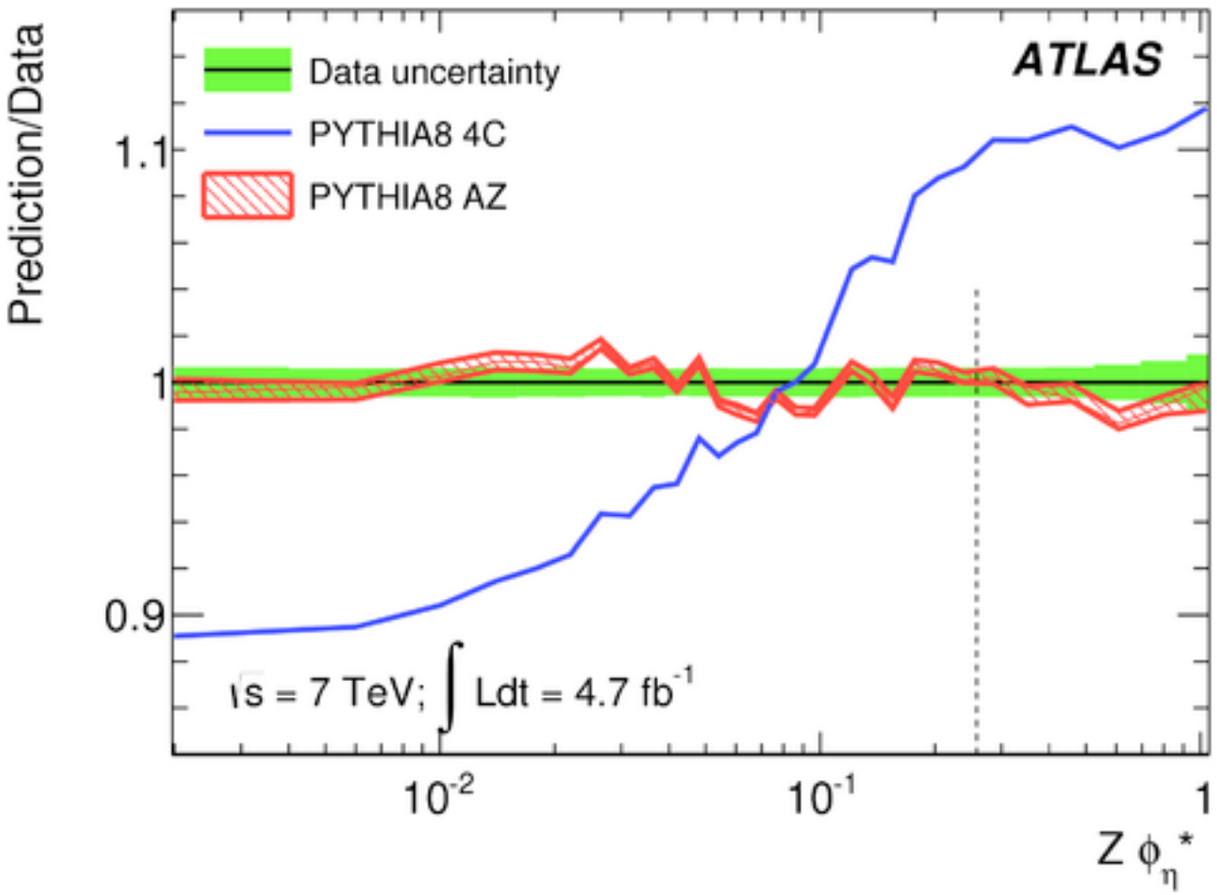
MC Generators



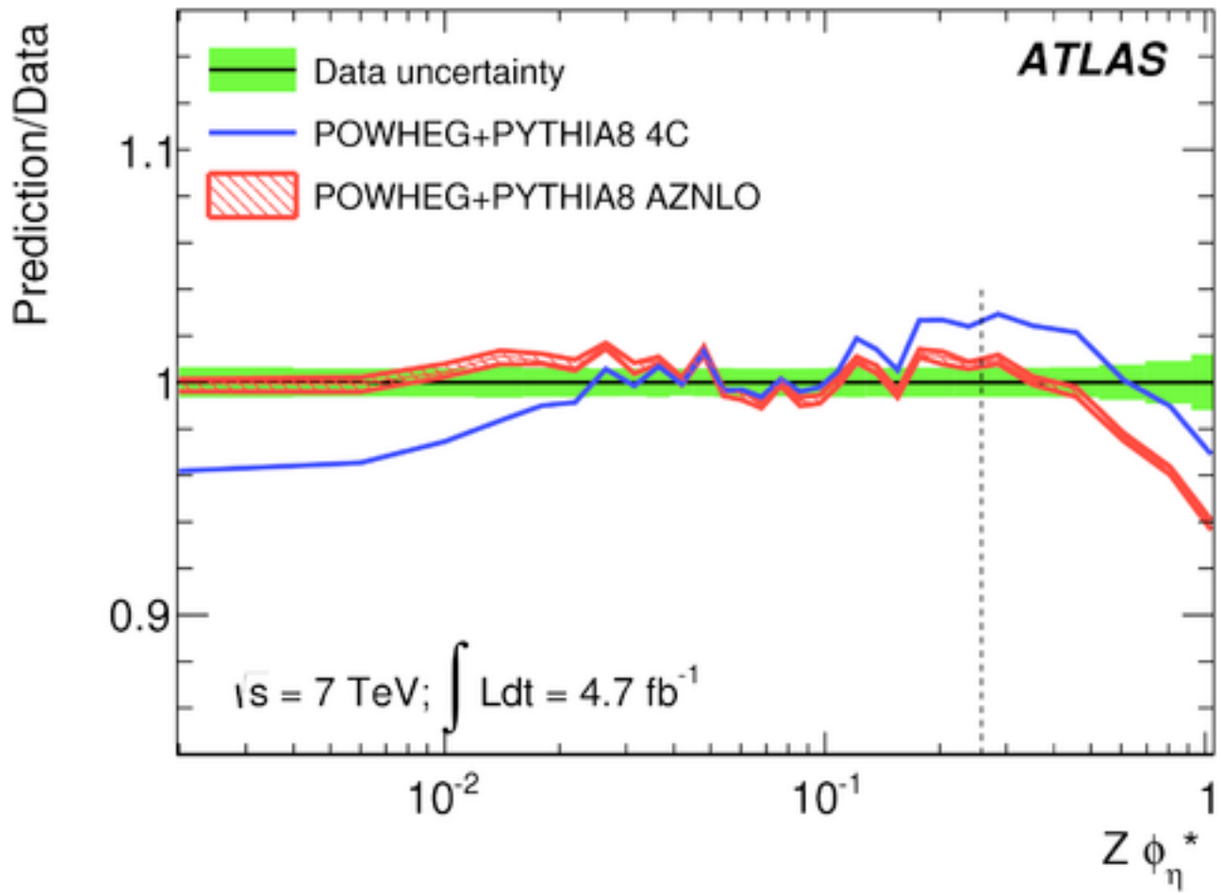
- Combined ee+μμ cross section compared to ResBos.
- Comparison to MC generators and to various parton showe models.
- FEWZ 2.1 prediction is only shown for Φ^* is larger than 0.1

Backup Φ^* compare with tuned prediction

Pythia8 tuning
ISR αs order: LO

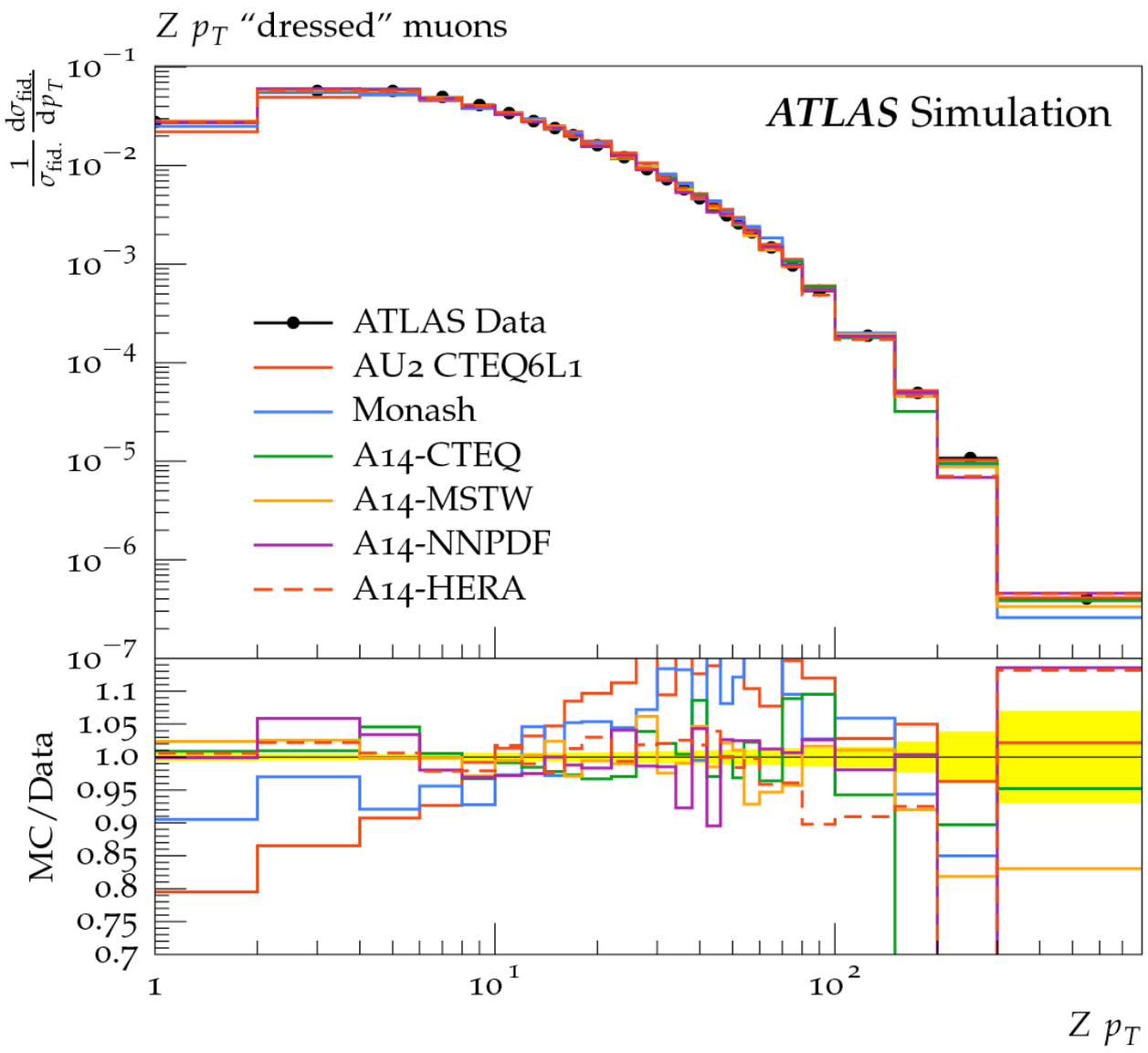


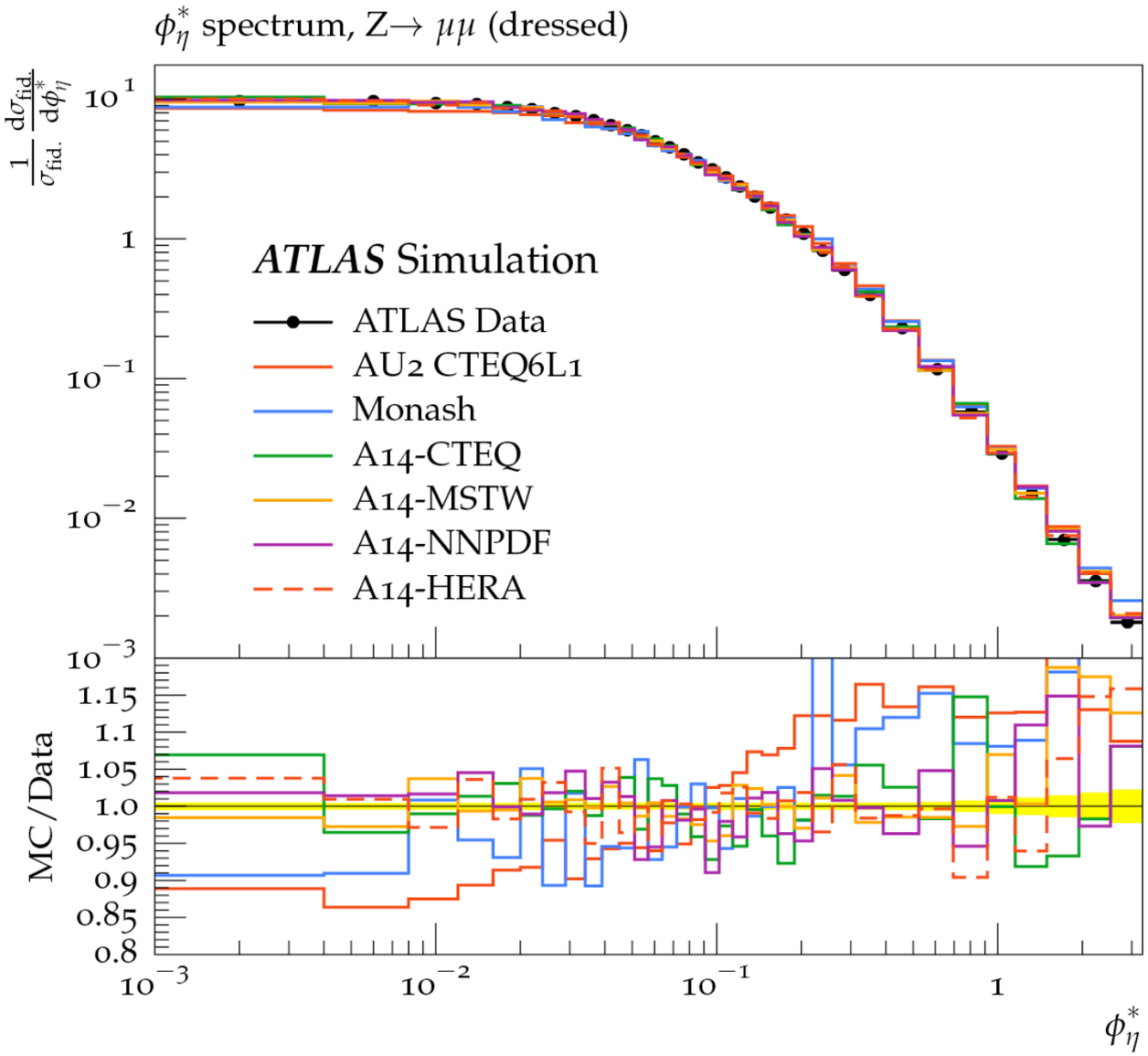
PowHeg+Pythia8 tuning
ISR αs order: NLO



Comparison of Pythia8 and Powheg+Pythia8 tuned predictions base on Φ^* measurement with the data for the dressed kinematics.

Backup


Z p_T "dressed" muons
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
MC/Data
Z p_T


ϕ^*_η spectrum, Z→ $\mu\mu$ (dressed)
ATLAS Simulation
ATLAS Data
AU2 CTEQ6L1
Monash
A14-CTEQ
A14-MSTW
A14-NNPDF
A14-HERA
MC/Data
ϕ^*_η

Backup

CC electrons			
Uncertainty	66–70 GeV	70–250 GeV	250–1000 GeV
Unfolding	$\sim 1\times10^{-2}$	$(2\text{–}5)\times10^{-3}$	$\sim 4\times10^{-4}$
Energy scale/resolution	$\sim 7\times10^{-3}$	$(0.5\text{–}2)\times10^{-3}$	$\sim 2\times10^{-2}$
MC statistics	$\sim 5\times10^{-3}$	$(0.1\text{–}1)\times10^{-3}$	$(3\text{–}20)\times10^{-3}$
PDF	$\sim 2\times10^{-3}$	$(1\text{–}8)\times10^{-4}$	$(0.7\text{–}3)\times10^{-3}$
Other	$\sim 1\times10^{-3}$	$(0.1\text{–}2)\times10^{-3}$	$(5\text{–}9)\times10^{-3}$
CF electrons			
Uncertainty	66–70 GeV	70–250 GeV	250–1000 GeV
Unfolding	$\sim 2\times10^{-2}$	$(0.5\text{–}2)\times10^{-2}$	–
Energy scale/resolution	$\sim 1\times10^{-2}$	$(0.5\text{–}7)\times10^{-2}$	–
MC statistics	$\sim 1\times10^{-2}$	$(1\text{–}7)\times10^{-3}$	–
Background	$\sim 3\times10^{-2}$	$(0.5\text{–}1)\times10^{-2}$	–
PDF	$\sim 4\times10^{-3}$	$(2\text{–}6)\times10^{-4}$	–
Other	$\sim 1\times10^{-3}$	$(1\text{–}5)\times10^{-4}$	–
Muons			
Uncertainty	66–70 GeV	70–250 GeV	250–1000 GeV
Unfolding	$\sim 1\times10^{-2}$	$(1\text{–}4)\times10^{-3}$	$\sim 5\times10^{-4}$
Energy scale/resolution	$\sim 8\times10^{-3}$	$(3\text{–}6)\times10^{-3}$	$\sim 5\times10^{-3}$
MC statistics	$\sim 5\times10^{-3}$	$(0.1\text{–}1)\times10^{-3}$	$(2\text{–}30)\times10^{-3}$
PDF	$\sim 2\times10^{-3}$	$(1\text{–}8)\times10^{-4}$	$(0.3\text{–}3)\times10^{-3}$
Other	$\sim 1\times10^{-3}$	$(0.5\text{–}1)\times10^{-3}$	$(3\text{–}10)\times10^{-3}$