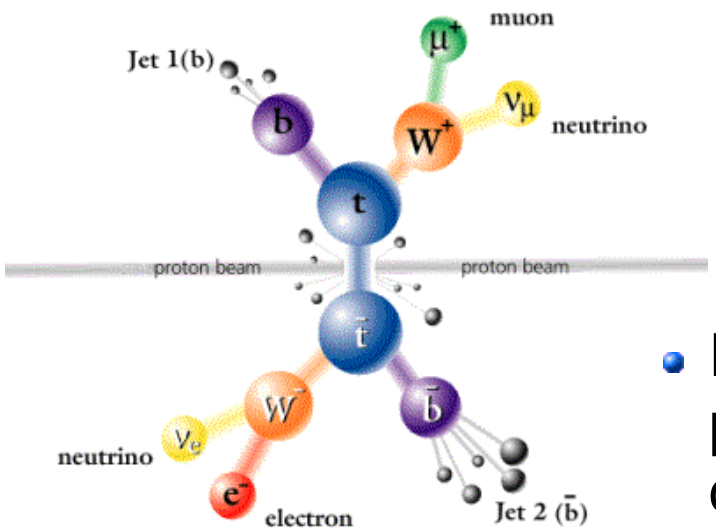
New results from ATLAS

Leptonic differential cross sections in $t\bar{t}$ production
and
Drell-Yan triple-differential cross sections

Stefano Camarda

PDF4LHC
March 28th 2018

New PDF results from ATLAS

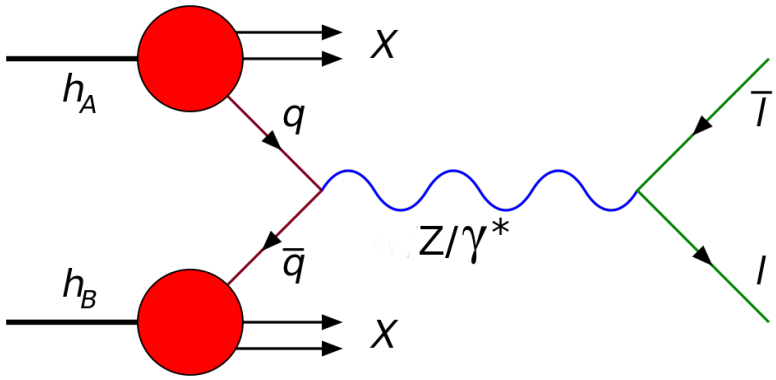


Eur. Phys. J. C 77 (2017) 804

- Leptonic differential cross sections in $t\bar{t}$ production at 8 TeV → QCD analysis and top quark pole mass determination

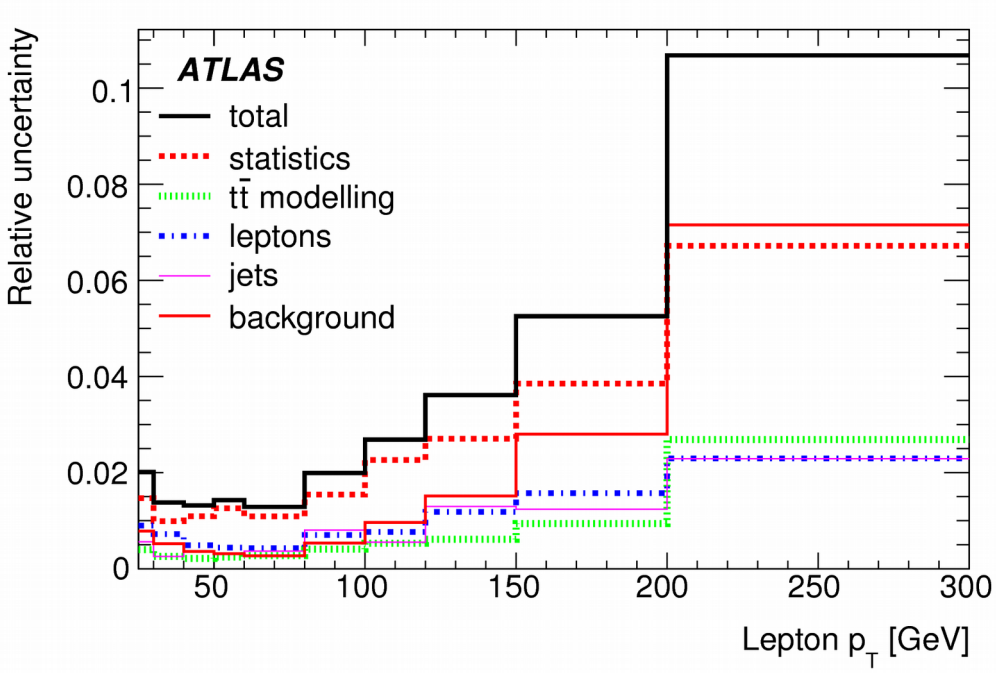
JHEP 12 (2017) 059

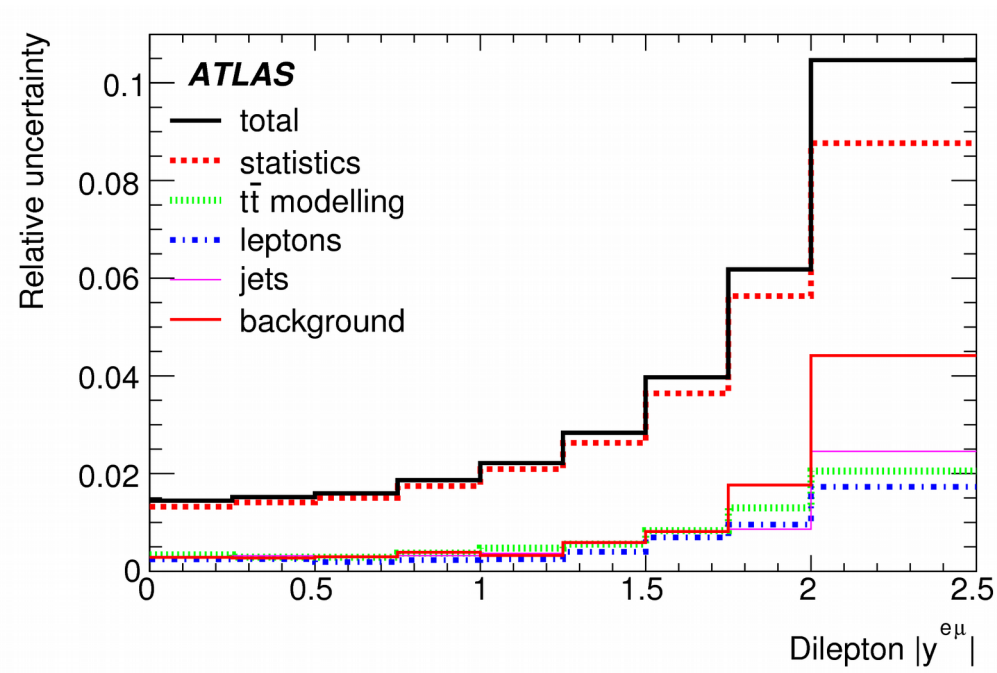
- Drell-Yan triple-differential cross sections at 8 TeV
- Questions to the PDF4LHC group from ATLAS



Top-antitop leptonic differential cross sections

- Measurement of $t\bar{t}$ leptonic differential cross sections in the $e\mu b\bar{b}\nu\bar{\nu}$ final states with L = 20.2 fb^{-1}, at sqrt(s) = 8 TeV
- Kinematic properties of leptons and dilepton system in $t\bar{t} \rightarrow e\mu b\bar{b}\nu\bar{\nu}$ are sensitive to m_{top}, and to the gluon PDF
- Clean experimental signature, little sensitivity to JES and QCD modelling
- Little dependence on non-perturbative QCD effects, such as colour reconnection and underlying event
- The dominant exp syst uncertainties are the Wt background ($t\bar{t}$/Wt interference), and the electron energy scale



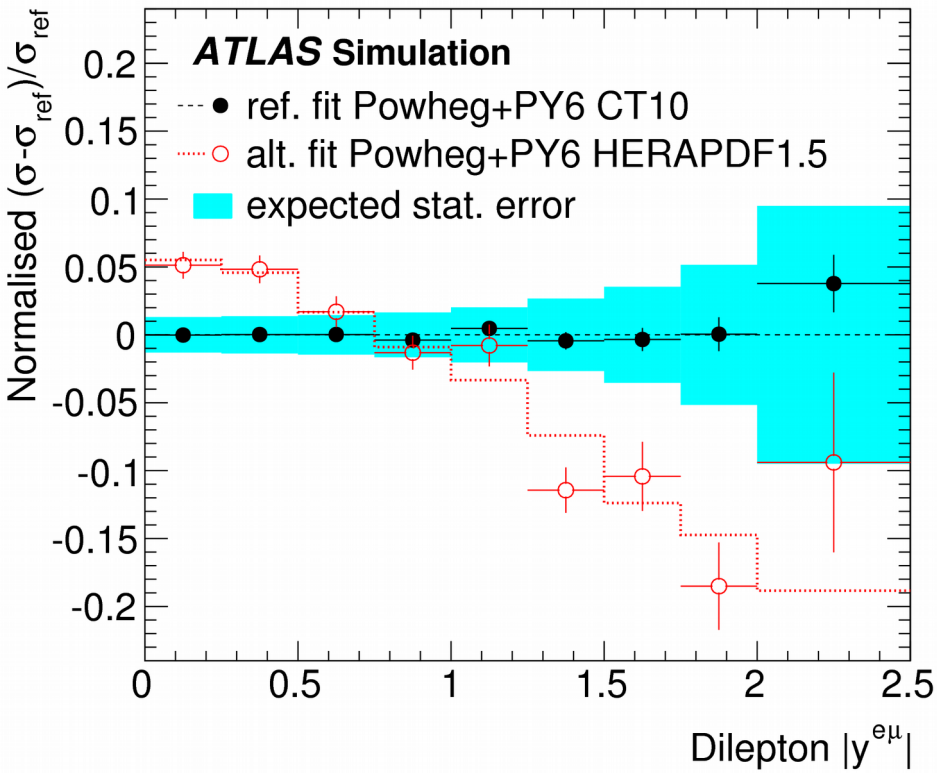


Measurement overview

- Same selection and methodology of the ATLAS $e\mu$+b-tagged jet total cross-section measurement: count 1 and 2 b-tags in bins of differential variables

$$
\begin{aligned}
N_1^i &= L\sigma_{t\bar{t}}^i\, G_{e\mu}^i 2\epsilon_b^i(1 - C_b^i\epsilon_b^i) + N_1^{i,\mathrm{bkg}} \\
N_2^i &= L\sigma_{t\bar{t}}^i\, G_{e\mu}^i C_b^i(\epsilon_b^i)^2 + N_2^{i,\mathrm{bkg}},
\end{aligned}
$$

- Solve tagging equations and measure ε_b and $\sigma^i_{t\bar{t}}$ simultaneously → yields a particle-level fiducial measurement for $p_T(\ell) > 25$ GeV and $|\eta(\ell)| < 2.5$, with no requirements on jets
- Measured 8 differential cross sections: $p_T(\ell)$, $\eta(\ell)$, $p_T(e\mu)$, $m(e\mu)$, $y(e\mu)$, $\Delta\phi(e\mu)$, $p_T(e)+p_T(\mu)$, $E(e)+E(\mu)$
- $W \to \tau \to e/\mu$ decays are included in the measurement definition (but τ decays are subtracted when comparing to NLO QCD predictions)



Tagging equations

Lepton reconstruction efficiency
(estimated from MC, corrected with data)

Integrated luminosity

$$C_b^i = \epsilon_{bb}^i / (\epsilon_b^i)^2$$

b-tagging correlation coefficient
(estimated from MC)

1 b-tag and 2 b-tag events counted in data

$$N_1^i = L\sigma_{t\bar{t}}^i G_{e\mu}^i 2\epsilon_b^i (1 - C_b^i \epsilon_b^i) + N_1^{i,\mathrm{bkg}}$$

$$N_2^i = L\sigma_{t\bar{t}}^i G_{e\mu}^i C_b^i (\epsilon_b^i)^2 + N_2^{i,\mathrm{bkg}}$$

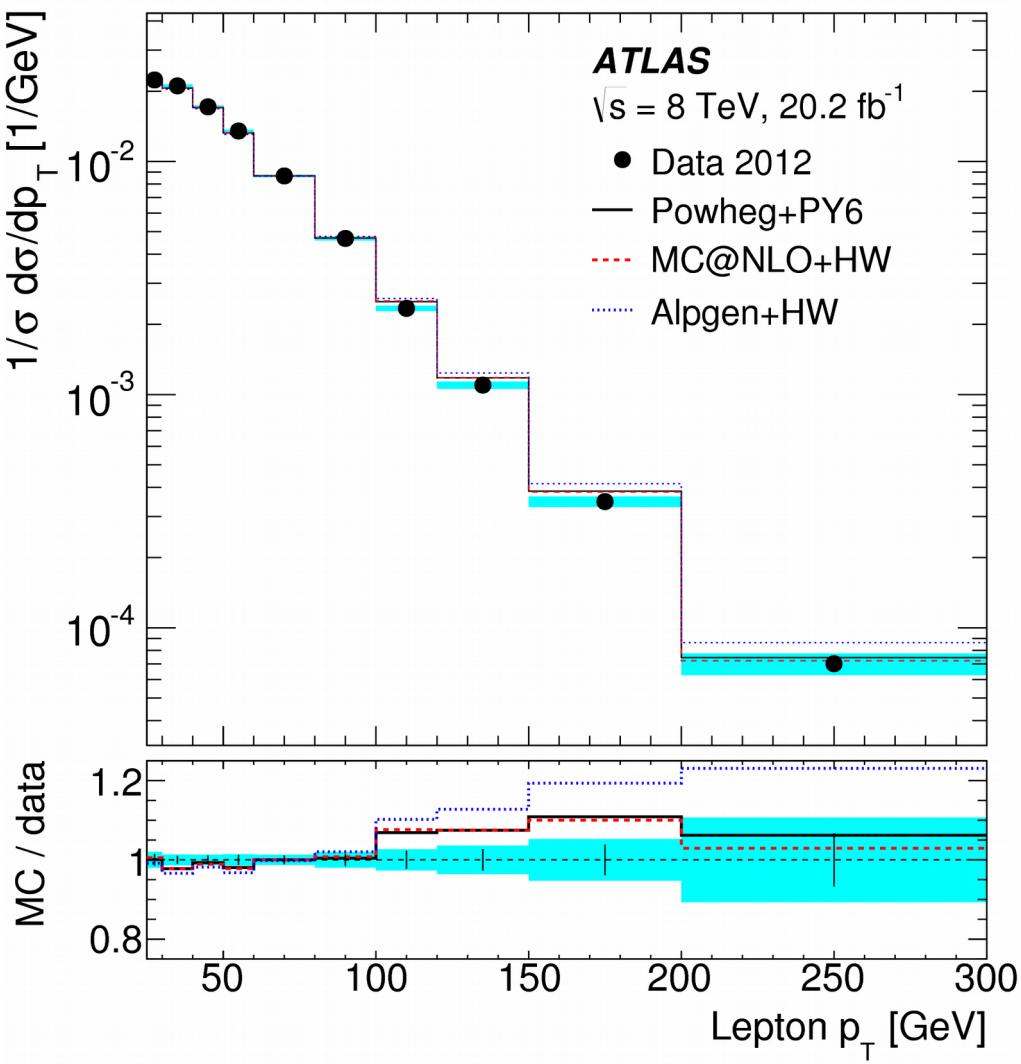
1 b-tag and 2 b-tag background estimated events

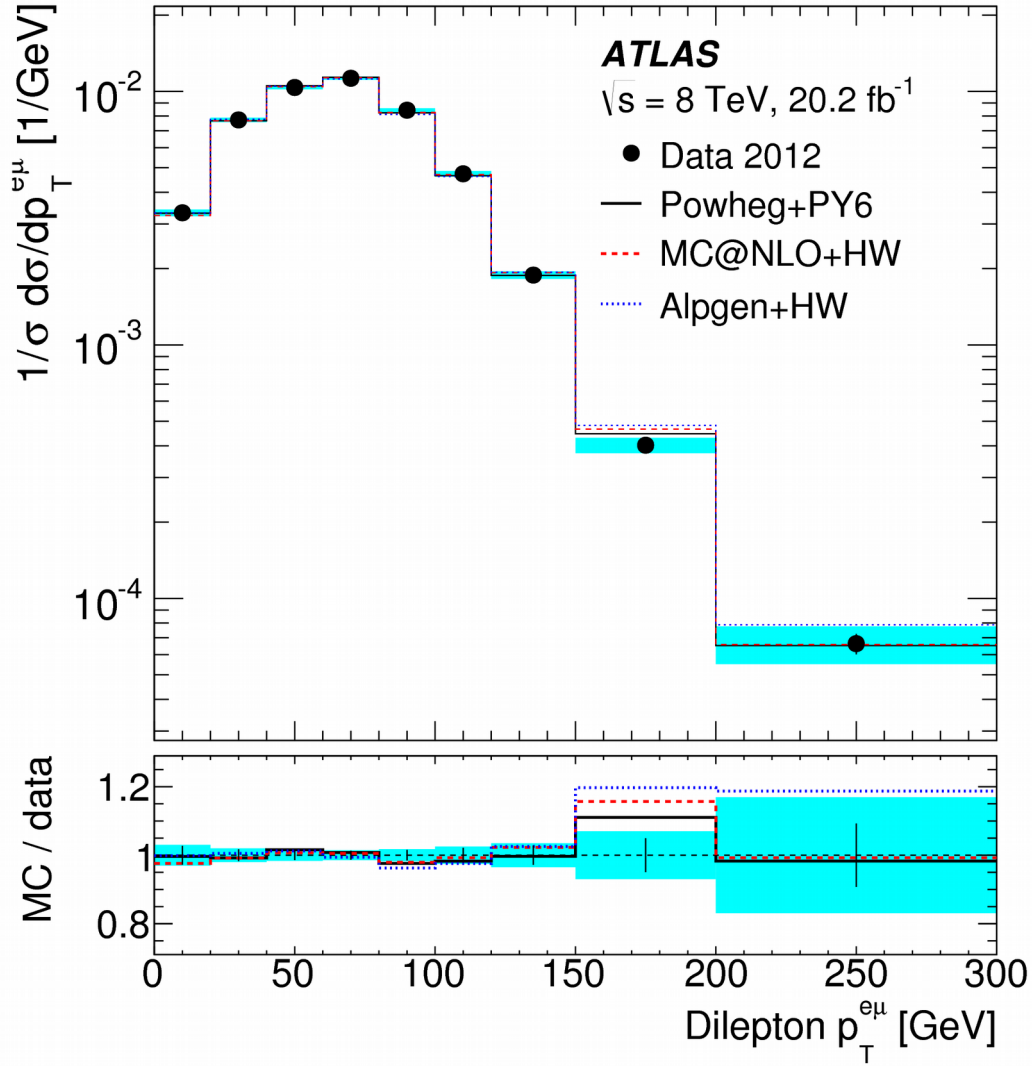
Measured cross section

Measured b-tagging efficiency * acceptance

- Procedure applied for each bin of the differential distributions
- b-jet acceptance is measured in data → yields a measurement definition with no requirements on jets

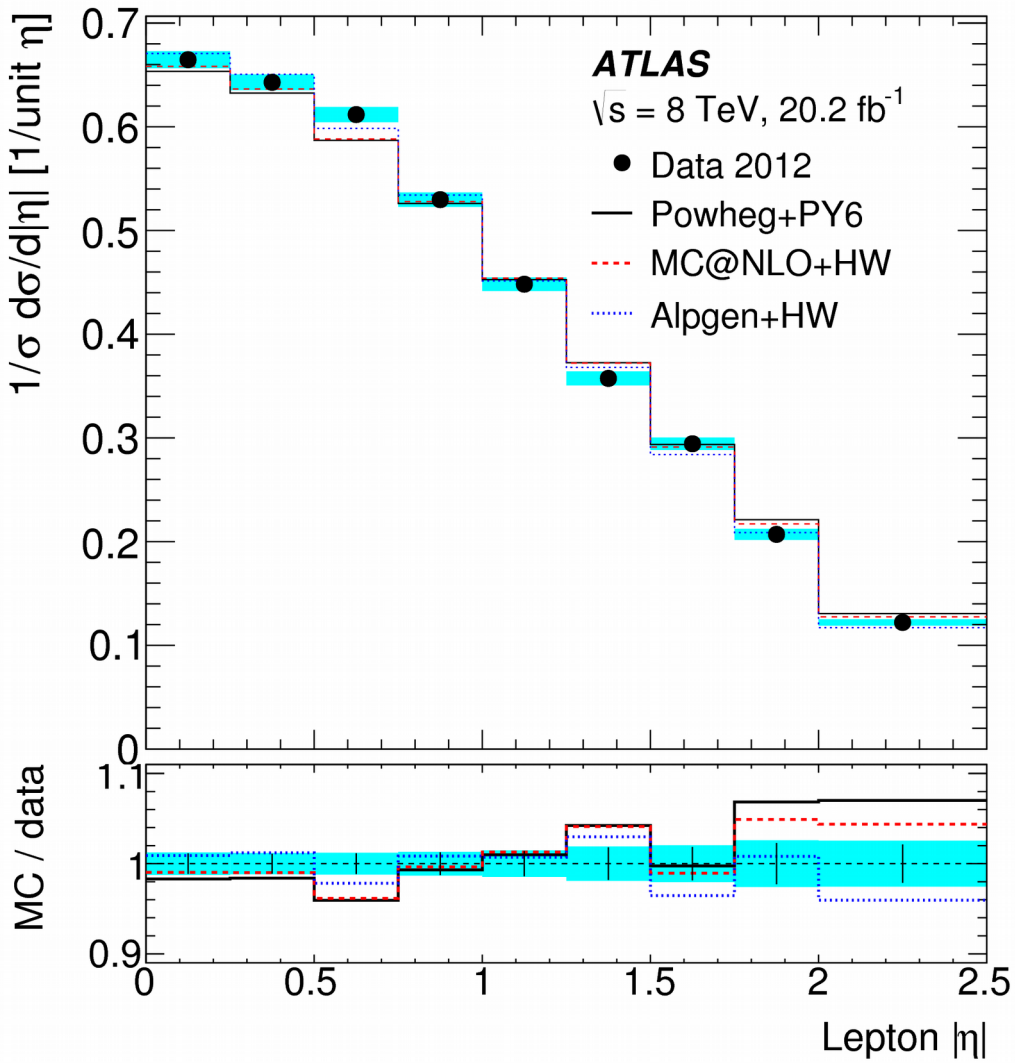
Measured cross sections

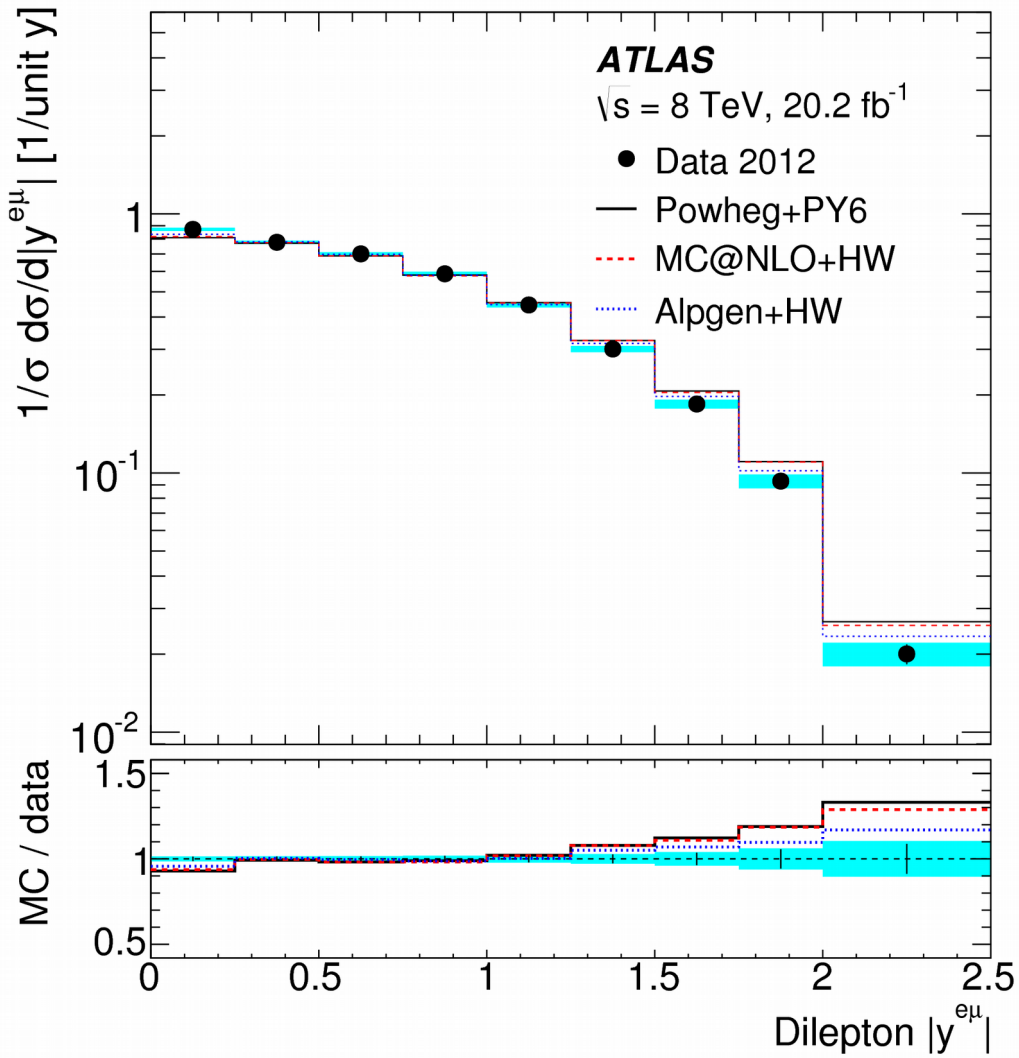




- Measured absolute and normalised differential cross sections
- Total uncertainties for the normalised cross sections at the level of 1-2% at low p_T, and 10-20% at high p_T

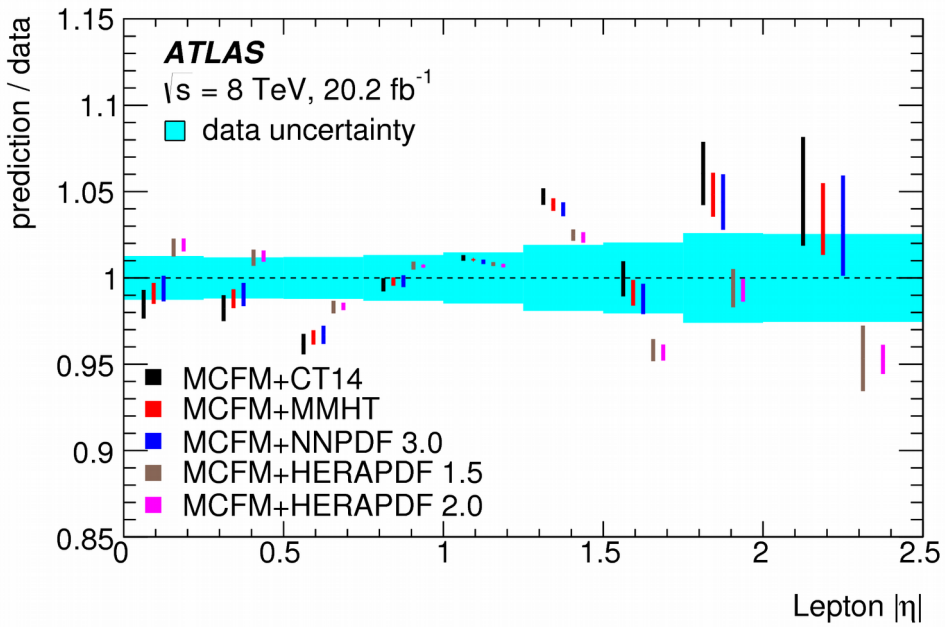
Measured cross sections

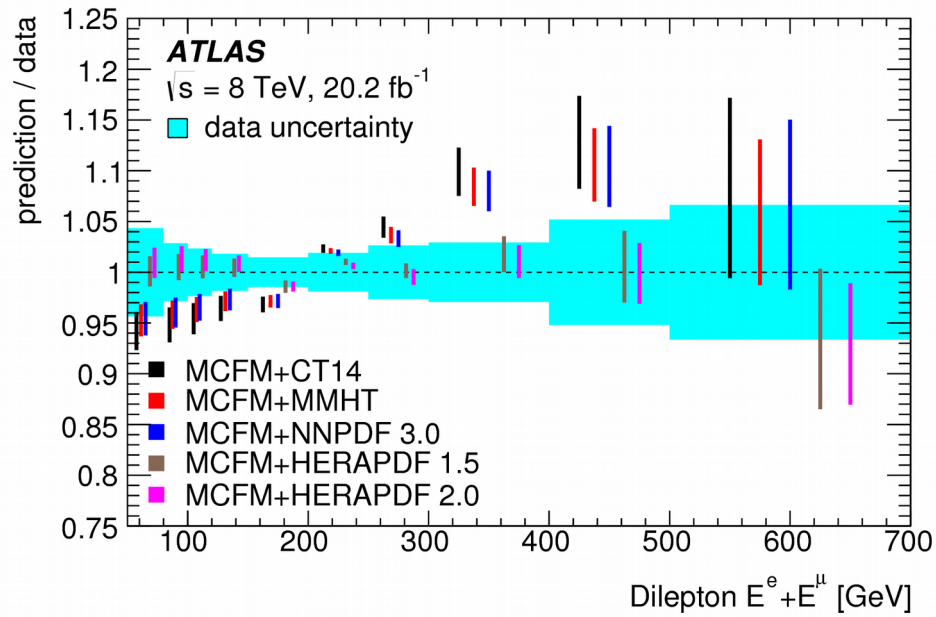


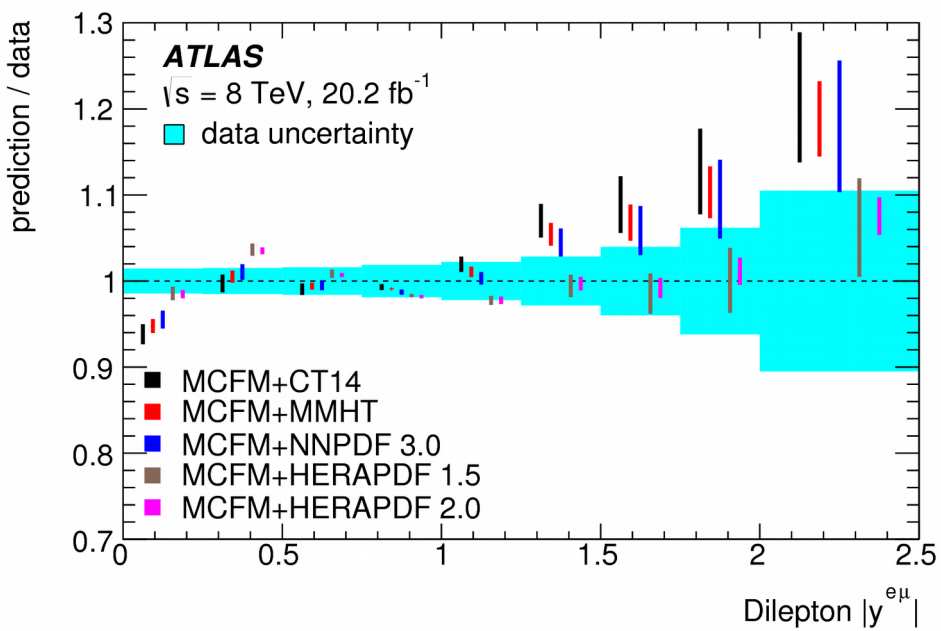


- Measured absolute and normalised differential cross sections
- Total uncertainties for the normalised pseudorapidity cross sections at the level of 1-2%, and 10% for dilepton rapidity at large y

PDF sensitivity

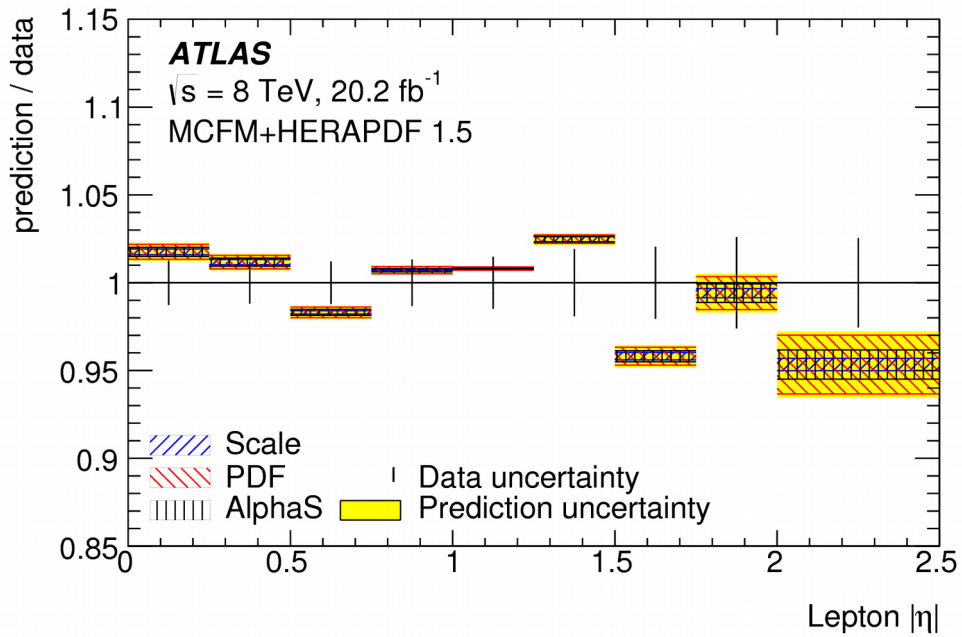






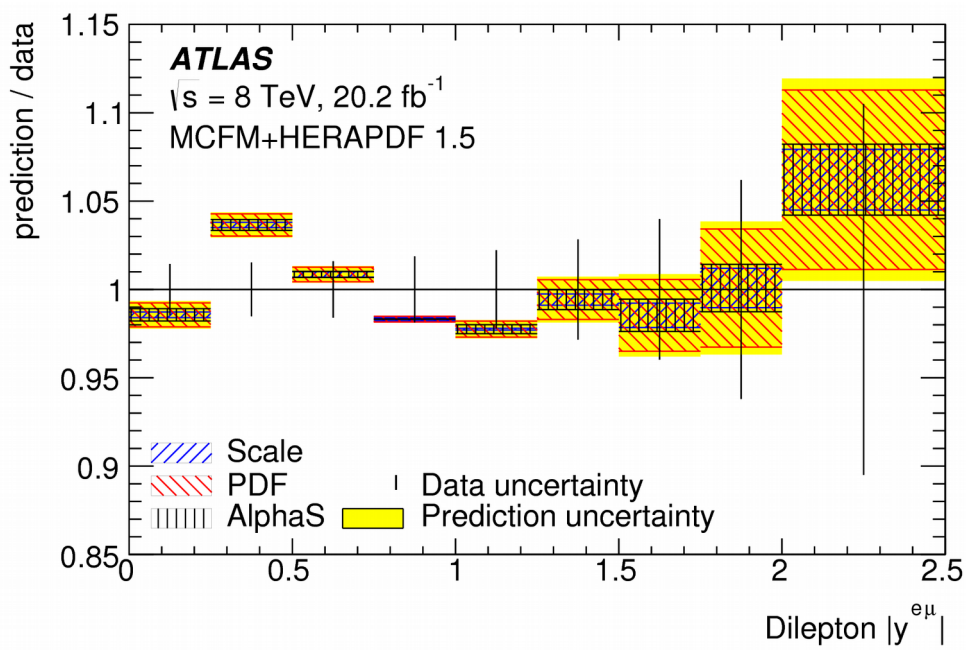
- Lepton η, dilepton y, and E^e+E^μ distributions show sensitivity to PDFs
- Mild preference for HERAPDF predictions

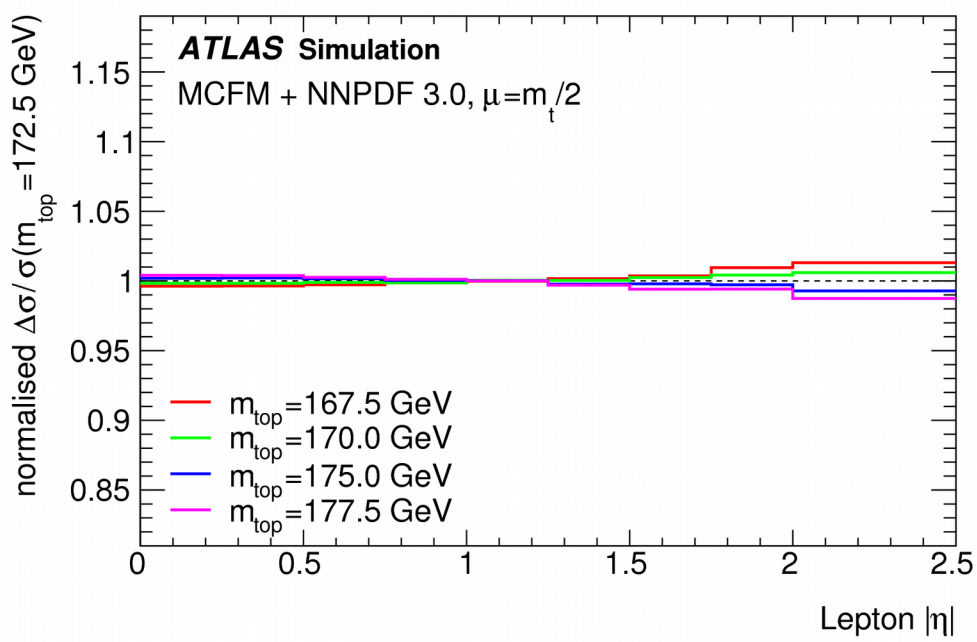
PDF sensitivity



- Normalised rapidity distributions have small sensitivity to QCD scale variations
- They also have small sensitivity to m_t

→ Good observables for PDF fits





PDF analysis

- The three most sensitive distributions (lepton η, dilepton y, E^e+E^μ) are included in a PDF fit at NLO together with HERA I+II data
- MCFM APPLgrid predictions at NLO in production and decay J.Phys. G 42 (2015) no.1, 015005
- Extra flexibility of the gluon parametrisation at high x

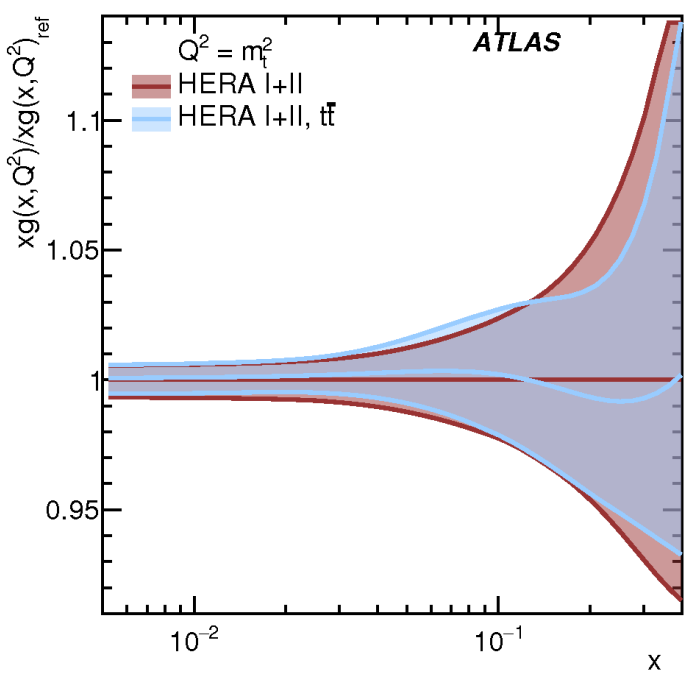
$$xg(x) = Ax^B(1-x)^C(1+Ex^2)\,e^{Fx}$$

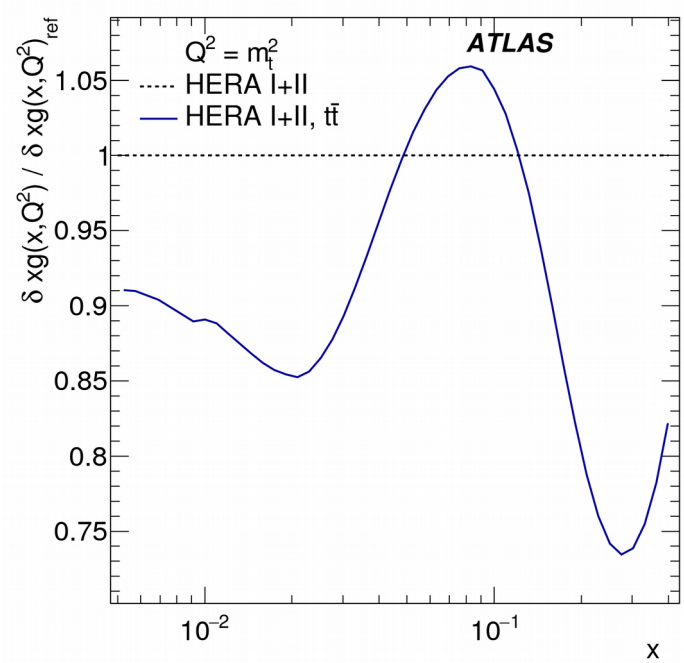
Datasets fitted	HERA I+II	HERA I+II + $t\bar{t}$
Partial χ^2 / N_{point}		
- HERA I+II	1219 / 1056	1219 / 1056
- $t\bar{t}$ ($\lvert\eta^\ell\rvert$, $\lvert y^{e\mu}\rvert$, E^e+E^μ)	-	27 / 25
Total χ^2 / N_{dof}	1219 / 1042	1247 / 1067

- Good partial χ^2/dof of the $t\bar{t}$ data
- χ^2/dof of the HERA data not degraded in the combined fit

- Similar central gluon PDF in the two fits

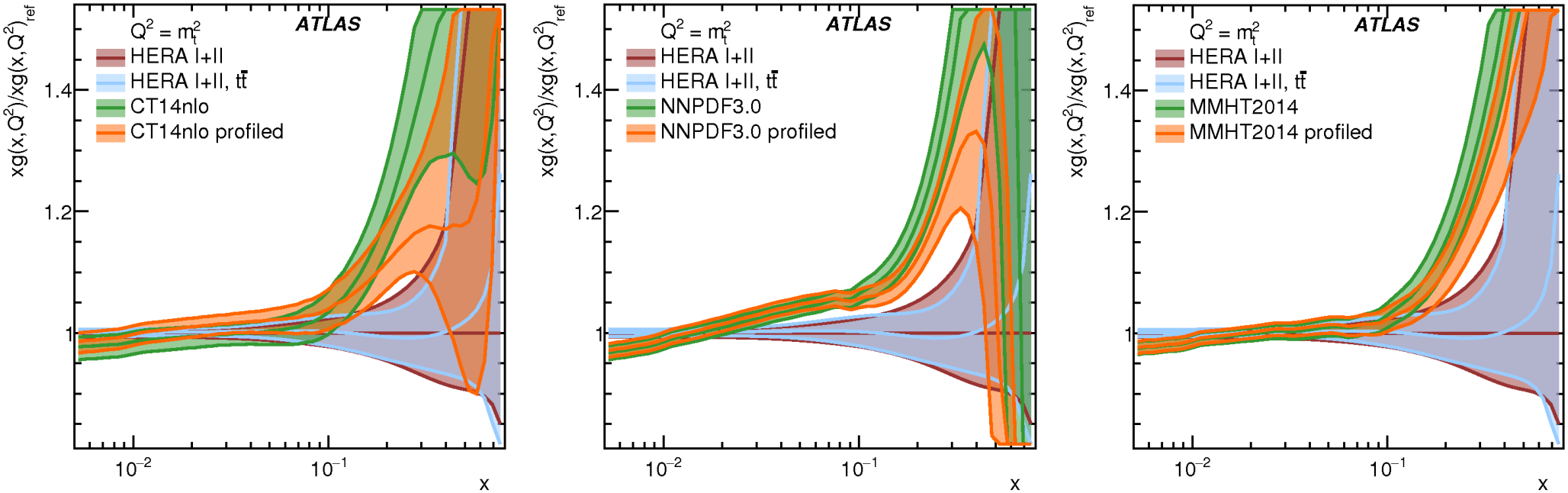
  → no tension between the two data sets
- Reduction of the gluon PDF uncertainty at medium and high x





PDF profiling

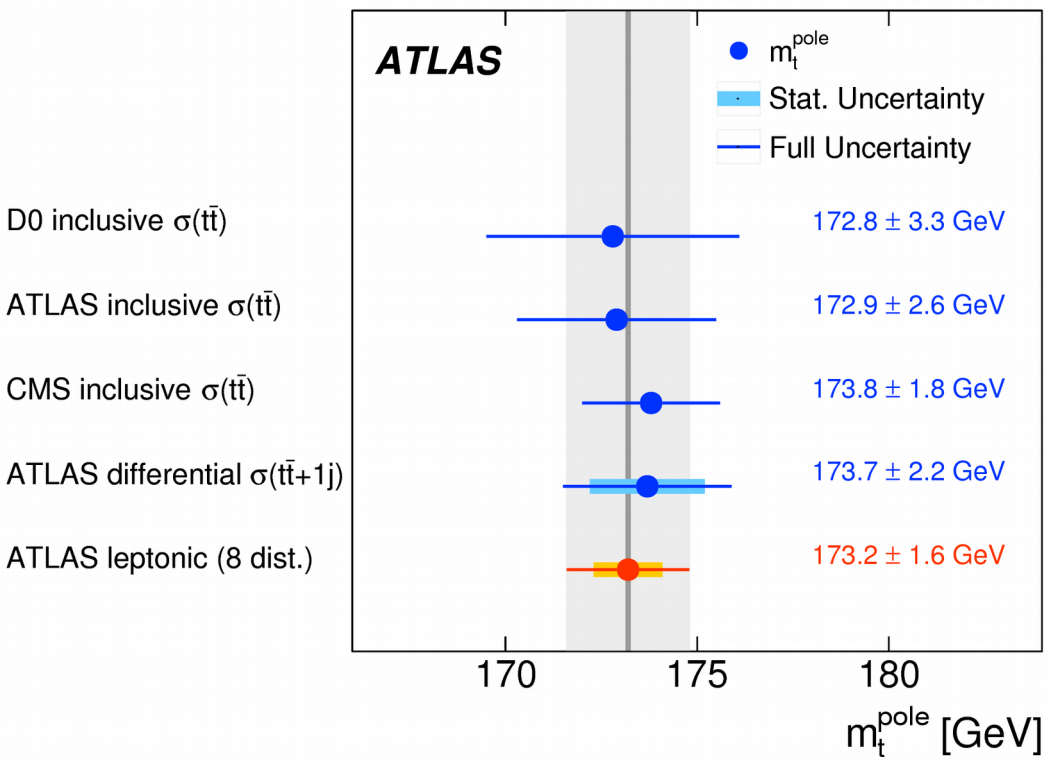
- The PDF4LHC PDF sets are profiled to the same distributions used in the PDF fit
- The high-x gluon PDF is pulled towards a softer HERA-like gluon PDF by approximately one standard deviation

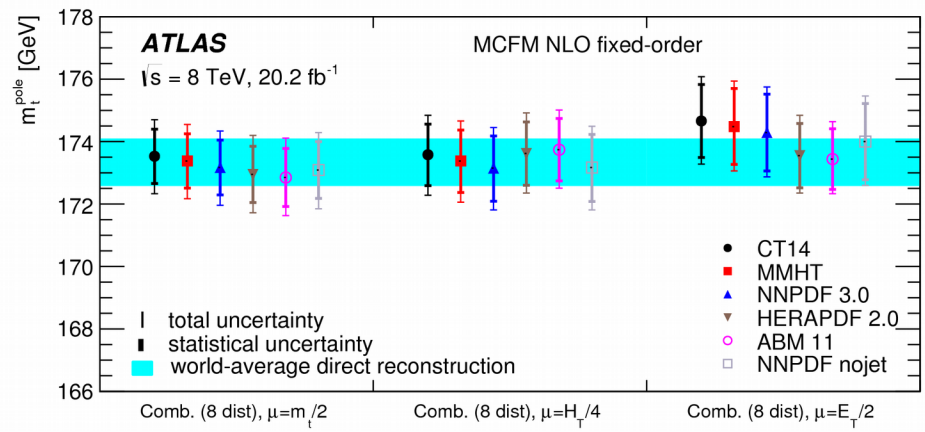


Determination of m_t^{pole}

- Top-quark pole-mass determined from a combined fit to all measured distributions using NLO QCD
- Current m_t^{pole} determination with the smallest uncertainty
- Uncertainty dominated by QCD scale variations (1.1 GeV)

$$m_t^{\rm pole} = 173.2 \pm 0.9({\rm stat}) \pm 0.8({\rm exp.syst}) \pm 1.2({\rm theory})\ {\rm GeV}$$





- Small PDF uncertainty (0.4 GeV), and dominated by the difference between PDF sets
- Single PDF sets give ~0.1 GeV

Comparison to m_t^{pole} from total cross section

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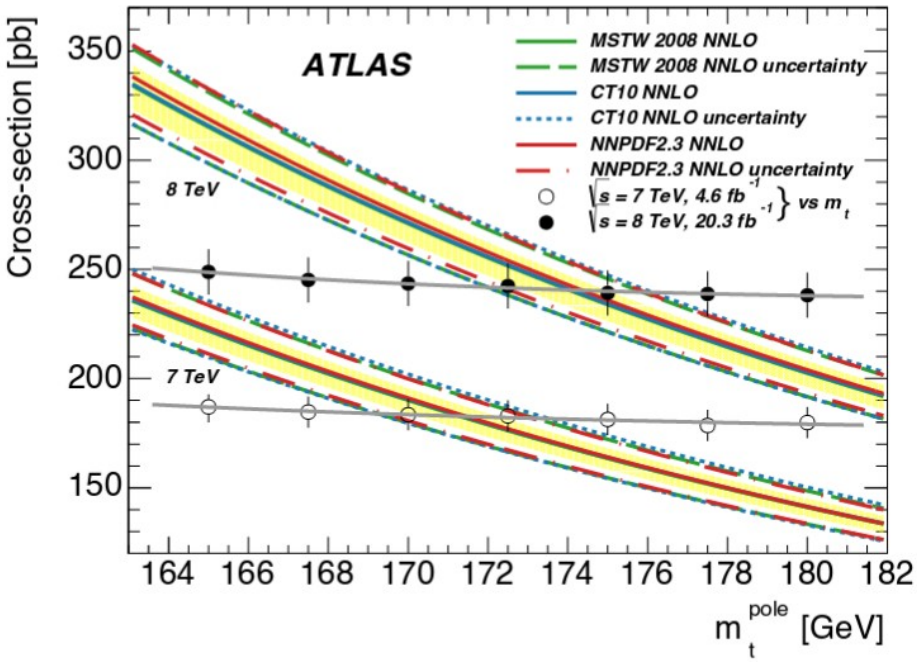
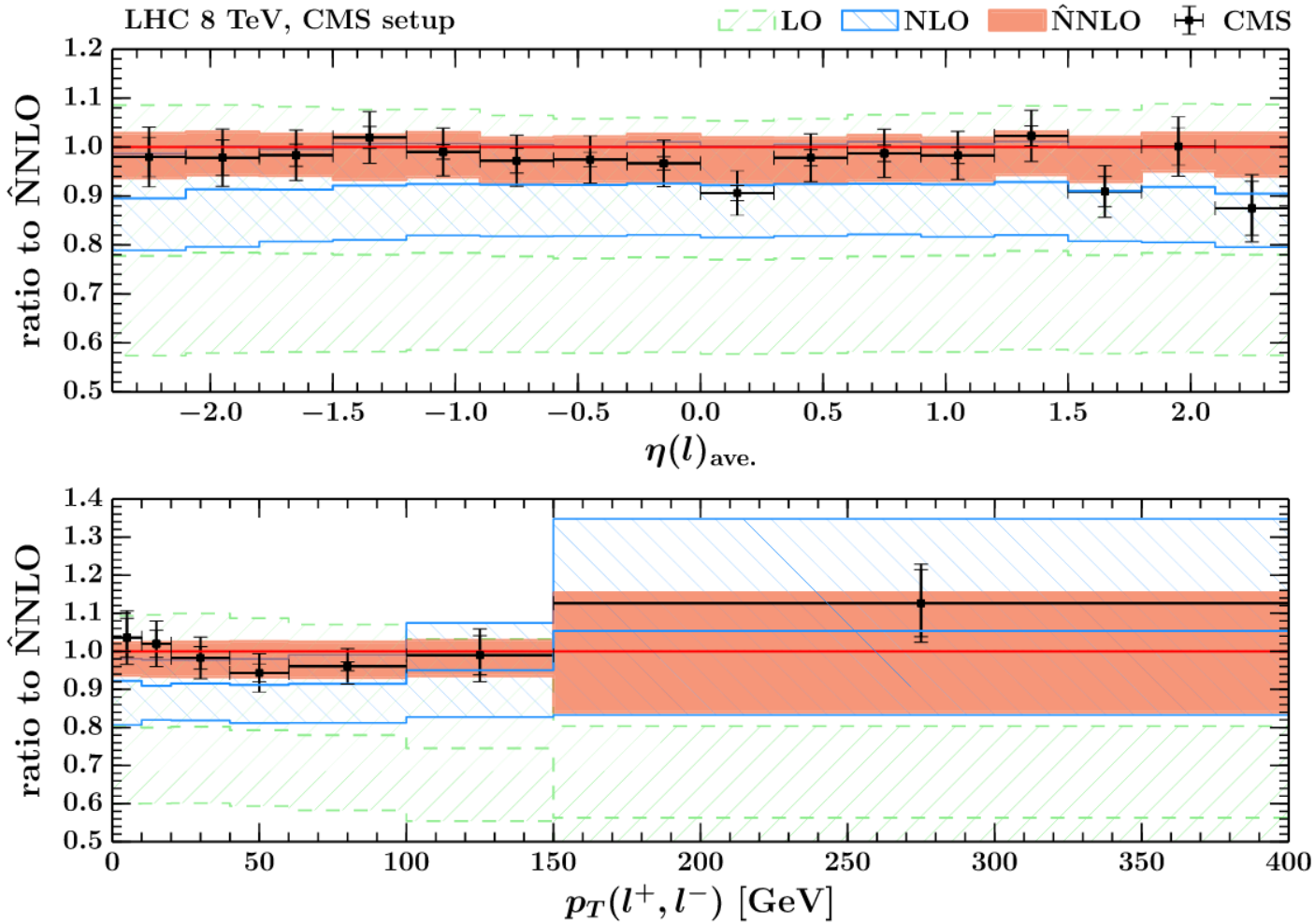


Uncertainty [GeV]	Total cross section	Leptonic cross sections
Statistical	0.3	0.9
Exp. syst.	0.9	0.8
Luminosity	1.2	<0.1
PDFs + α_s	1.7	0.4
QCD scales	+0.9 -1.3	1.1
Total	2.6	1.6

- m_t from total cross section dominated by PDF uncertainties, difficult to reduce
- PDF uncertainties are much smaller for m_t from leptonic cross sections, thanks to the inclusion in the fit of distributions (e.g. rapidities) sensitive to PDFs and not to m_t. The α_s uncertainty is negligible
- Leptonic cross sections are significanty less affected by the m_t-α_s-gluon PDF correlation
- QCD scale variations are similar, but large room for improvement for leptonic cross sections (current analysis is NLO)

Prospects – NNLO predictions

PRD 96 (2017) 5, 051501

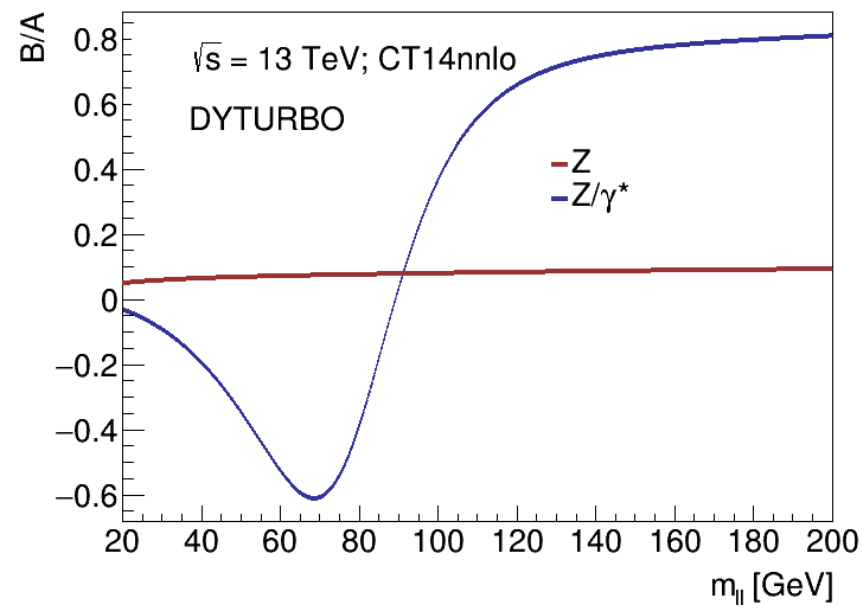


- NNLO predictions in top prodution (approx NNLO) and decay (exact NNLO) now available
- Expect roughly a factor of 2 reduction in scale variations
- Allow including this data in a NNLO PDF fit

Z forward-backward asymmetry and $\sin^2\theta_W$

- The weak-mixing angle can be measured from the forward-backward asymmetry in Z-boson Drell-Yan production
- The Drell-Yan production cross section is a function of the scattering angle θ

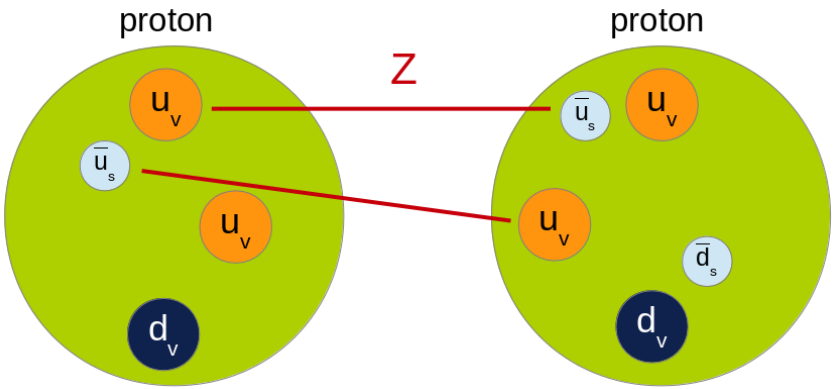
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4\hat{s}}\left[A(1+\cos^2\theta) + B\cos\theta\right]$$

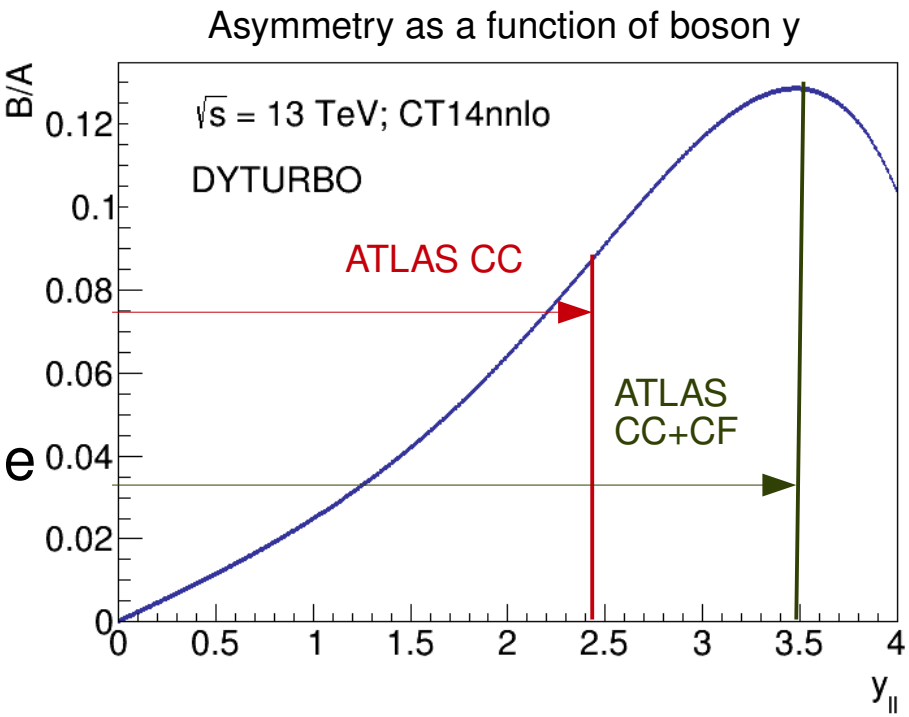


- The linear term in $\cos(\theta)$, due to the Z/γ^* and V-A interferences, gives rise to a non-vanishing forward-backward asymmetry
- The FB asymmetry at hadron colliders is determined by the $q/\bar{q}$ asymmetry in the initial state → sensitivity to PDFs
- The V-A interference contribution varies slowly with $m_{\ell\ell}$, and depends on the weak-mixing angle θ_W
- The Z/γ^* interference contribution changes sign at m_Z, and depends on well-known EW parameters → the $m_{\ell\ell}$ dependence of AFB can be used to constrain PDFs

Z forward-backward asymmetry and $\sin^2\theta_W$

- The orientation of the incoming quark is unknown





- In pp collisions, it is more likely to be in the same orientation as the Z boson, due to the u/$\bar{u}$ and d/$\bar{d}$ valence asymmetry
- Use θ^* scattering angle defined in the Collins-Soper frame, with z-axis orientation defined by the Z rapidity
- At the LHC the colliding proton beams are FB symmetric → the asymmetry vanishes at $y_{\ell\ell} = 0$, and increases with $y_{\ell\ell}$, due to the larger difference in q and $\bar{q}$ contributions
- What we actually observe in the detector is a Forward-Central asymmetry, which is converted to a FB asymmetry by the choice of the z-axis

Drell-Yan triple differential cross sections

- Measurements of $\sin^2\theta_W$ at the LHC are affected by large PDF uncertainty

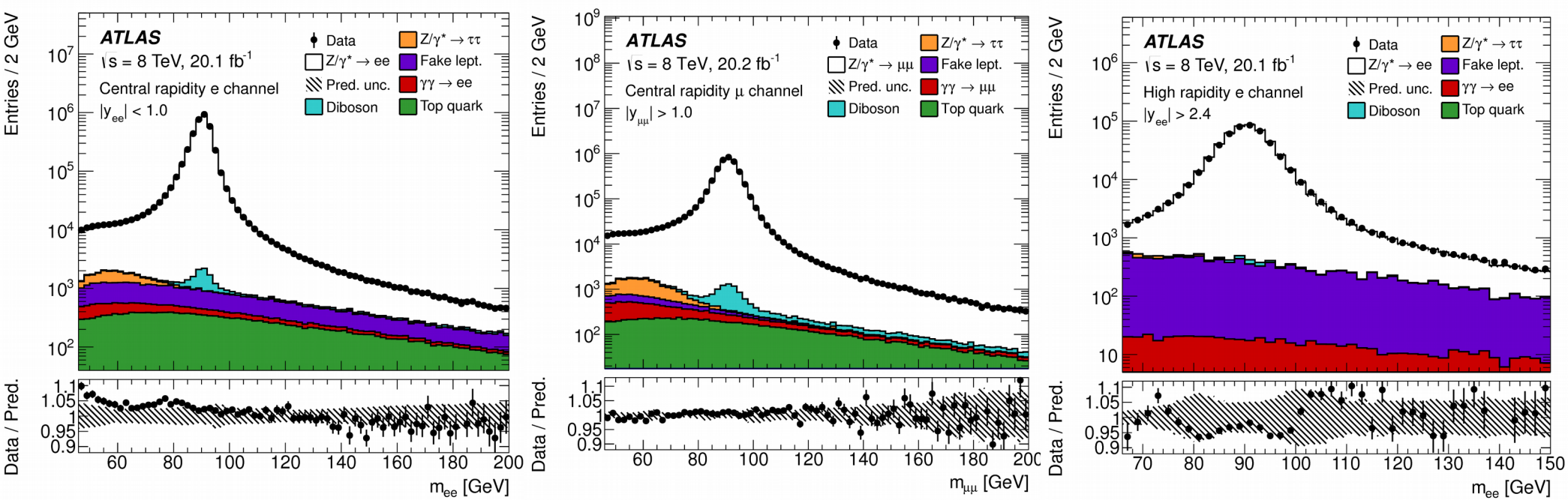
	$\sin^2(\theta_W^{eff})$ [10^{-4}]
ATLAS 7 TeV 4.8 fb^{-1}	2308 ± 4 (stat) ± 9 (syst)
CMS 8 TeV 20 fb^{-1}	2310.1 ± 3.6 (stat) ± 1.8 (syst) ± 1.6 (theory) ± 3.0 (pdf)
LHCb 7/8 TeV 1/2 fb^{-1}	2314.2 ± 7.3 (stat) ± 5.2 (syst) ± 5.6 (theory)
LEP+SLD	2315.3 ± 1.6

- Design unfolded measurement to be sensitive to both PDFs and $\sin^2\theta_W$
- The Z/γ^* differential cross section is a convolution of PDFs and partonic cross sections, difference in quark-Z/γ^* couplings allows for PDF decomposition
- Terms proportional to Z and γ^* contribute differently at different $m_{\ell\ell}$ and $y_{\ell\ell}$
- Z/γ^* interference term generates a forward-backward ($\cos\theta$) asymmetry which changes sign at m_Z
- The asymmetry vanishes at $y_{\ell\ell} = 0$, and increases with $y_{\ell\ell}$, due to the larger difference in q and $\bar{q}$ contributions

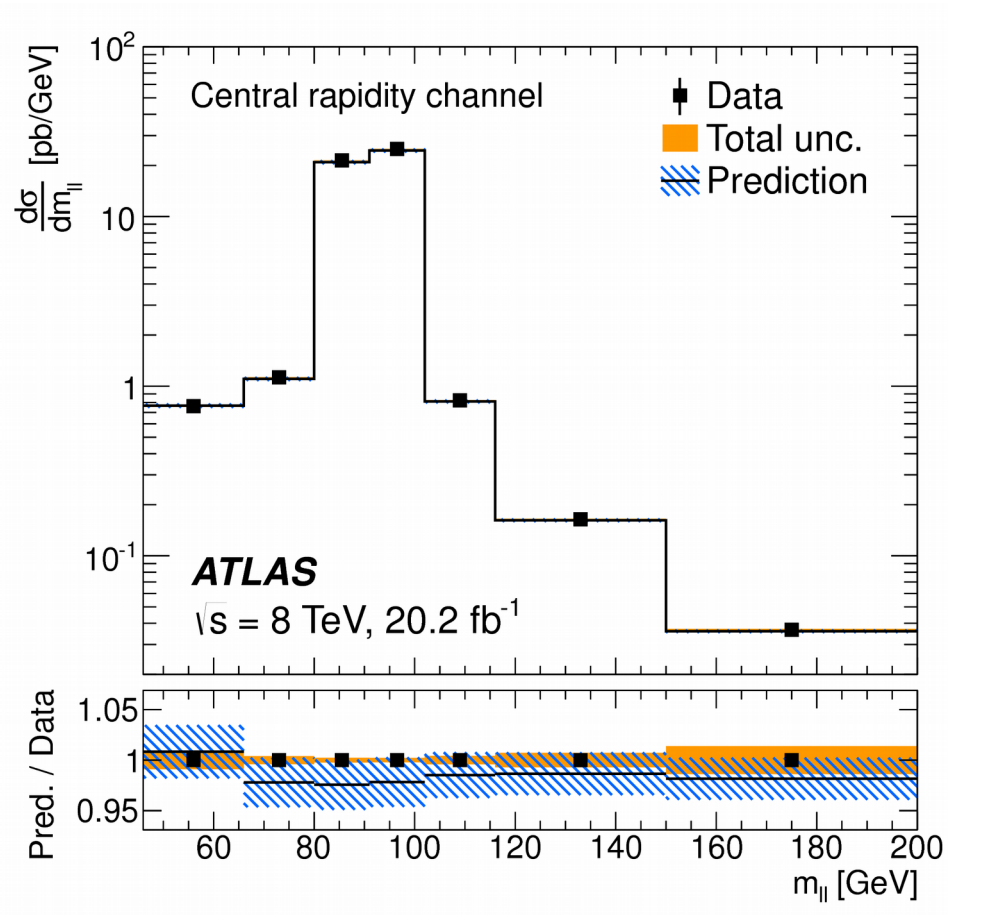
  → Measure triple-differential cross section as a function of $m_{\ell\ell}$, $y_{\ell\ell}$, $\cos\theta^*$

Drell-Yan triple differential cross sections

- Triple differential measurement in $m_{\ell\ell}$, $y_{\ell\ell}$, $\cos\theta^*$
- Measurement using central $|\eta^\ell| < 2.4$, $p^\ell_T > 20$ GeV electrons and muons, in seven $46 < m_{\ell\ell} < 200$ GeV, twelve $y_{\ell\ell} < 2.4$ and six $\cos\theta^*$ bins (2×504 bins)
- Measurement using one central (with $p_T > 25$ GeV) and one forward electron $|\eta^\ell| > 2.5$, $p^\ell_T > 20$ GeV in five $66 < m_{\ell\ell} < 150$, five $1.2 < y_{\ell\ell} < 3.6$ and six $\cos\theta^*$ bins (150 bins)
- Drell-Yan signal MC uses Powheg with CT10, $m_{\ell\ell}$-dependent NNLO/NLO k-factor and p_T-dependent angular coefficients corrections at NNLO

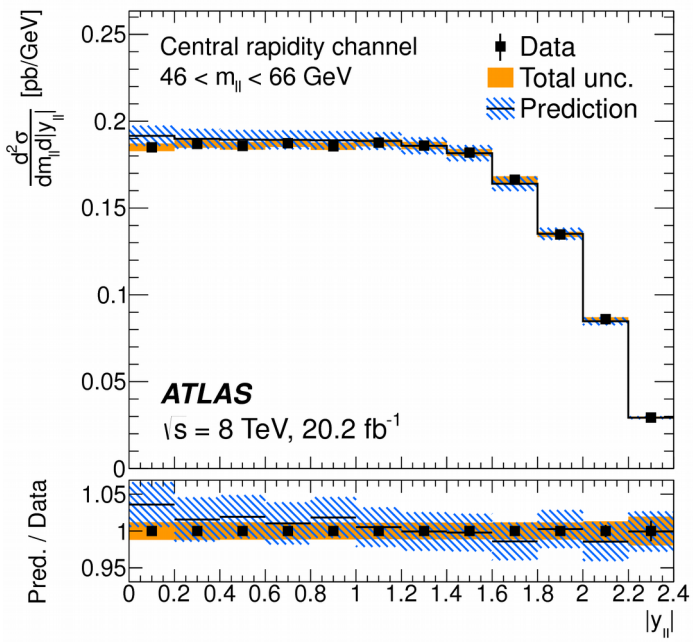


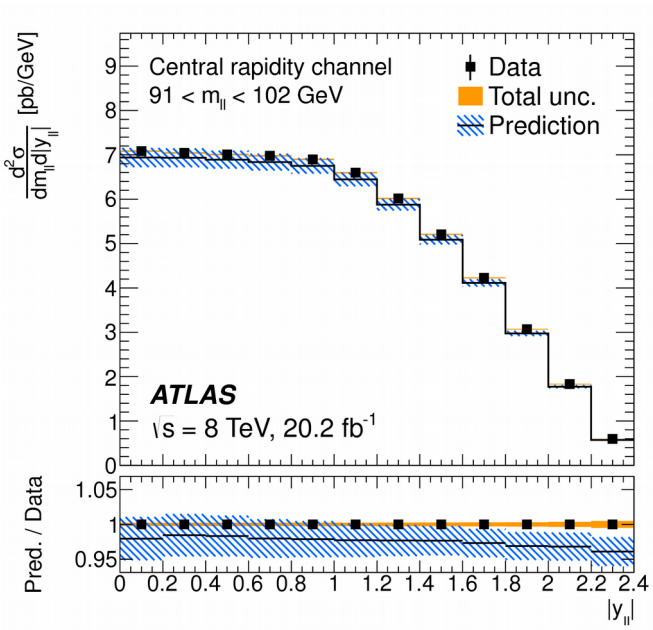
Single differential $d\sigma/dm_{\ell\ell}$ cross section

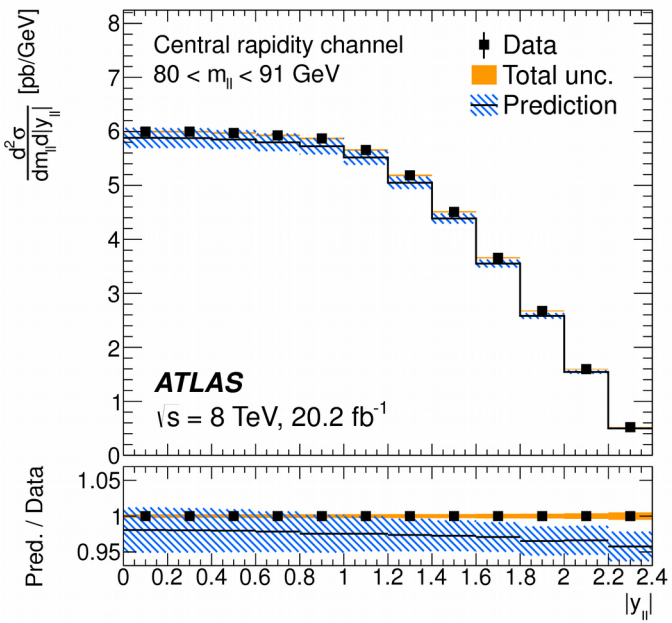


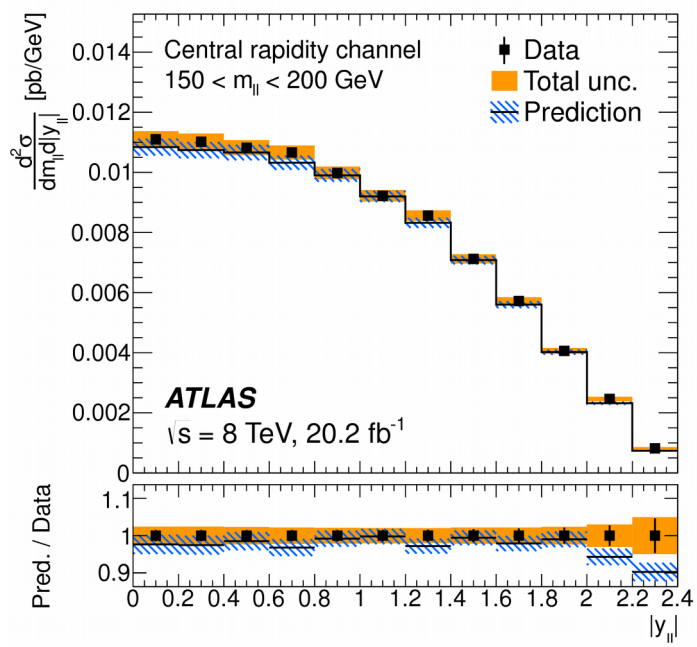
- Unfolded 3D cross sections measured in electron and muon CC channels can be integrated to 1D and 2D distributions and compared to each other. For $d\sigma/dm_{\ell\ell}$, combination χ^2/dof=12.8/7
- Comparison with the Powheg-based prediction shows good agreement overall

Double differential $d^2\sigma/dm_{\ell\ell}dy_{\ell\ell}$ cross section





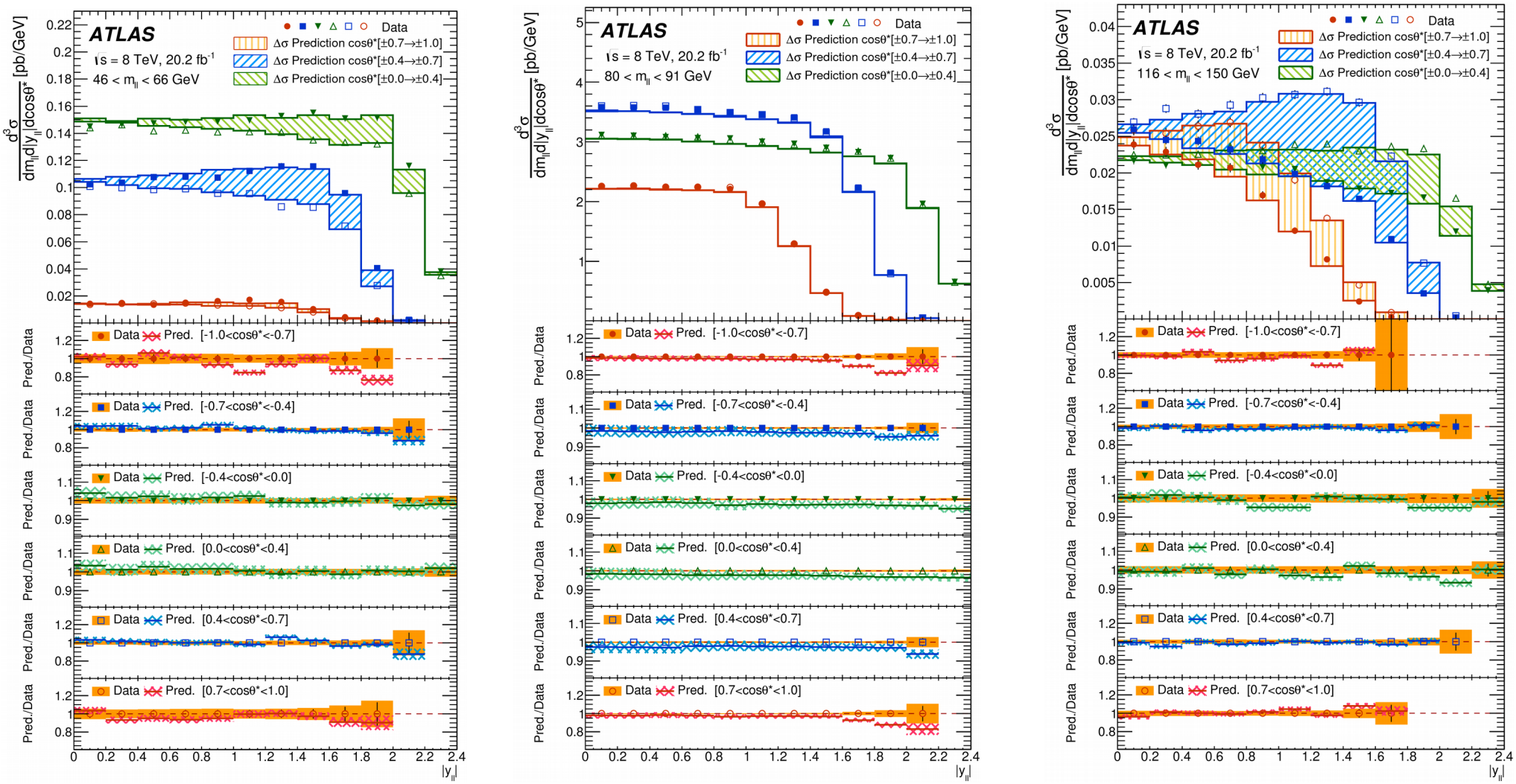




- Similarly, cross sections can be integrated to two-dimensions: $m_{\ell\ell}$ and $y_{\ell\ell}$
- Electron and muon channels agree well with χ^2/dof=103.4/84
- The comparison with Powheg-based predictions are good overall
- These cross sections are sensitive to PDFs, but not to $\sin^2\theta_W$

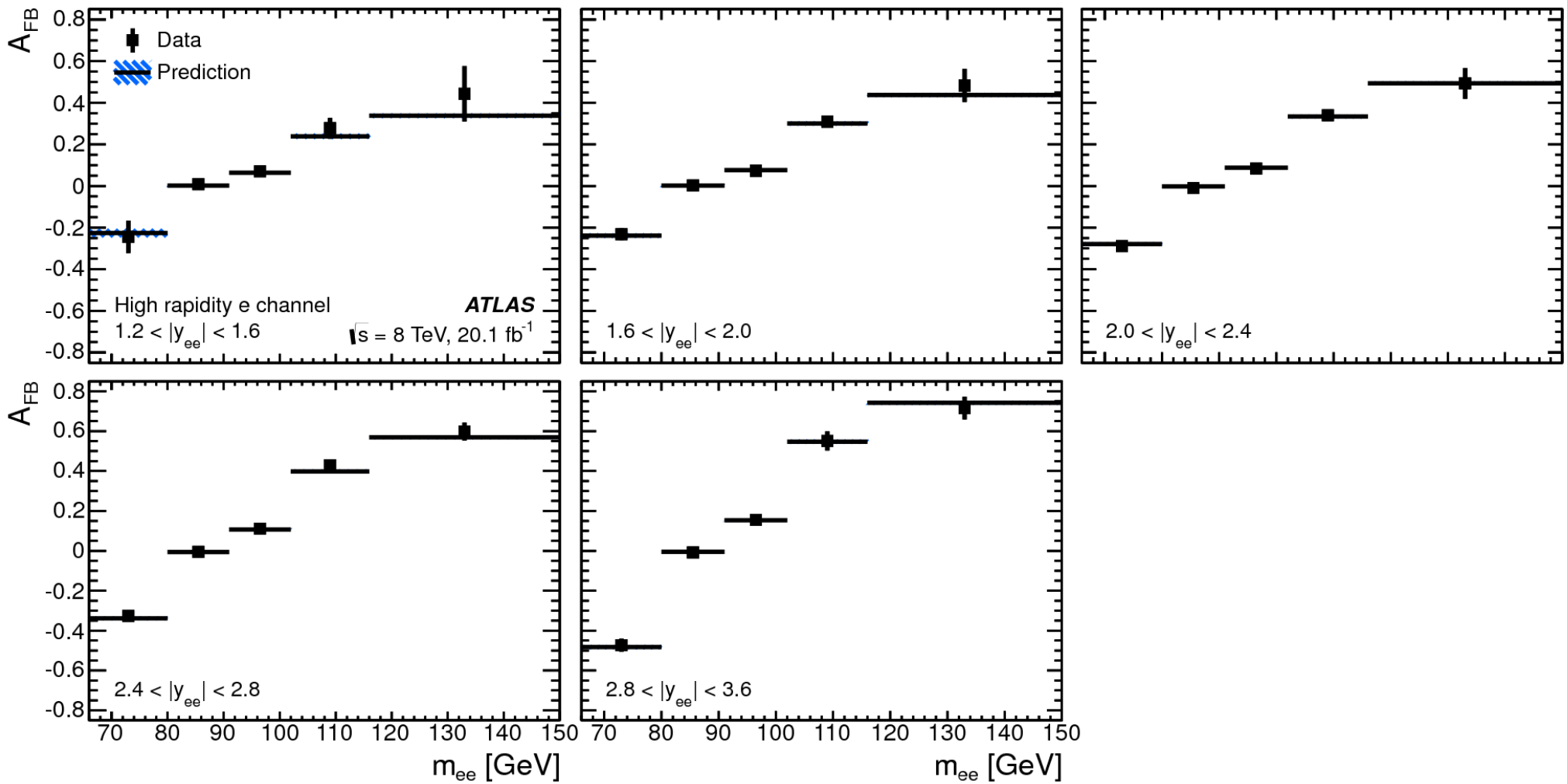
  → good for inclusion in PDF fits

Triple-differential cross sections



- Negative FB-asymmetry below the Z-peak, vanishing at the peak, flips sign above Z-peak and increases towards larger $m_{\ell\ell}$
- Combination of electron and muon channels yield good χ^2/dof=489.4/451
- The data accuracy is better than 0.5% in the Z-peak region for $|y_{\ell\ell}|<1.4$

Forward-backward asymmetry



- Similarly to 1D and 2D integrations, the 3D cross section is trasformed to fiducial FBA accounting for all correlations of uncertainties
- FB-asymmetry in the CF configuration is measured up to $y_{\ell\ell}$ = 3.6, which is the most sensitive region for $\sin^2\theta_W$ and PDFs

Summary and conclusions

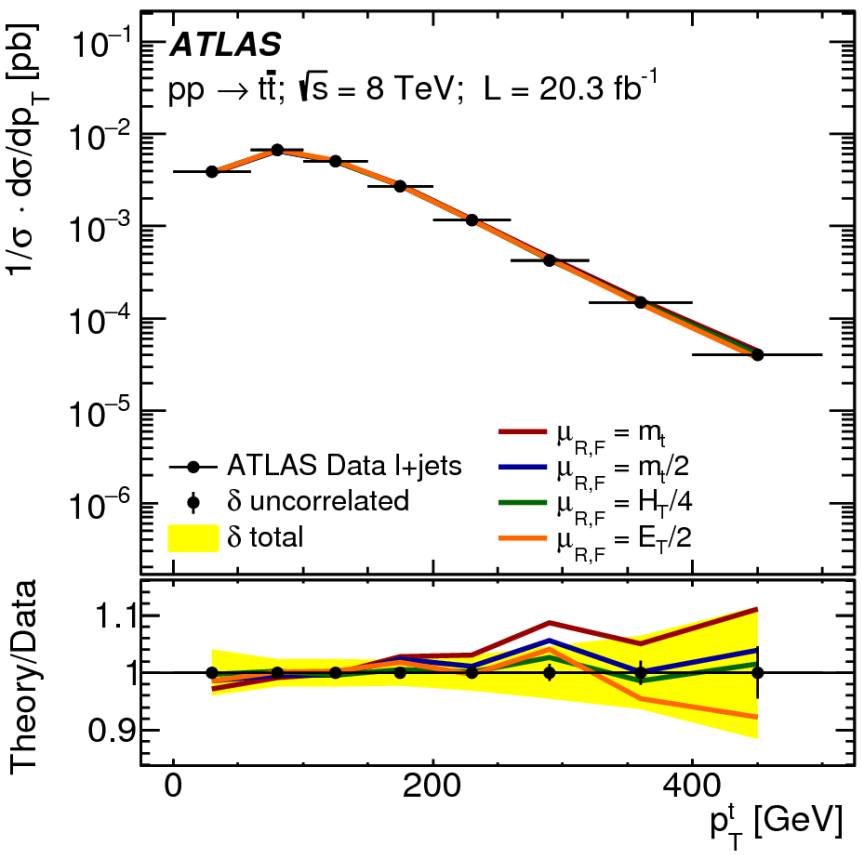
- Leptonic differential cross sections in $t\bar{t}$ production mesured at 8 TeV are sensitive to the gluon PDF and their inclusion in PDF fits at NLO show a preference for a softer gluon PDF
- The determination of the top quark pole mass from the $t\bar{t}$ leptonic cross sections has a smaller PDF uncertainty than the corresponding extraction from the total cross section
- Triple-differential $m_{\ell\ell}$, $y_{\ell\ell}$, and $\cos\theta^*$ Drell-Yan cross sections measured at 8 TeV are sensitive to the weak-mixing angle and to the PDFs

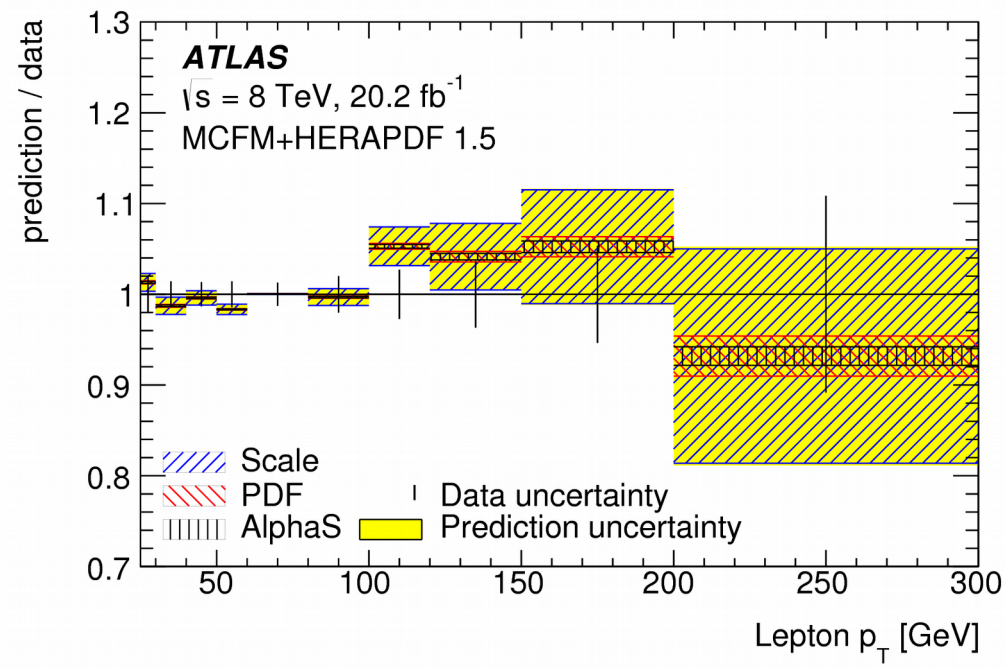
ATLAS Questions to the PDF4LHC group

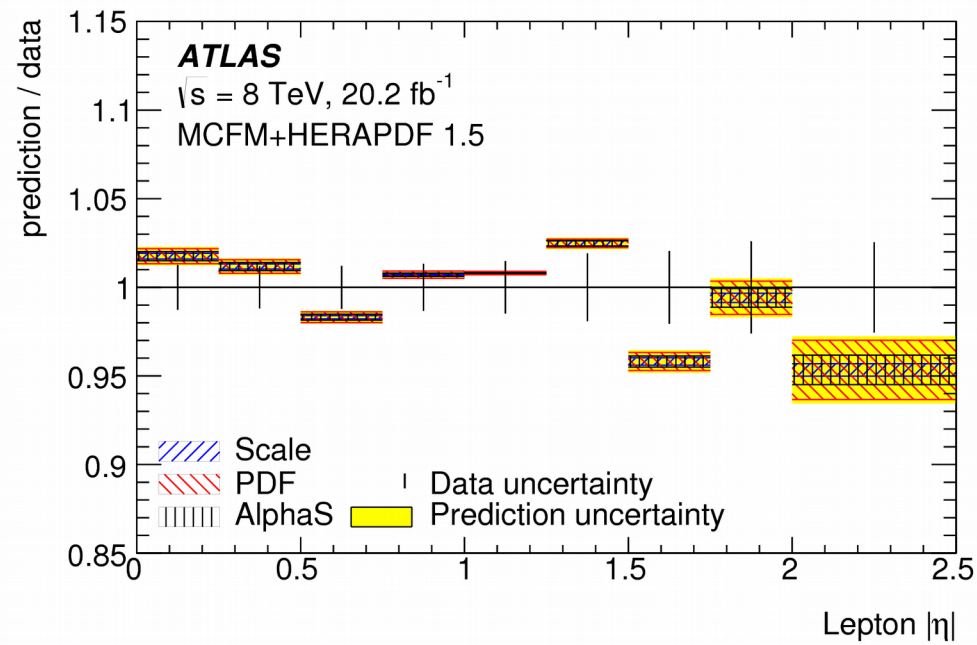
- We know of a recent update to NNPDF, but do we expect timely updates by the other PDF collaborations that we could also take into consideration for our next big round of MC production?
- Is there going to be an updated PDF4LHC combined set, too, and what would it be good for us to use it?
  - Will it cover the relevant regions of phase space for MCs (low Q2, low x)?
- Have the low-x resummed (N)NLO PDFs seen any uptake in MC authors/tune usage, or do you expect it?
- Which is the recommended set to use if we also want photon initial states (with LUXqed precision)?
  - Is this going to have any impact on non-photon IS?

BACKUP

Scale variations – Choice of functional form







- The choice of QCD scales is important for a good description of the top pT distribution
- Relevant for the lepton p_T, but marginal for the lepton η