Ratio measurements at ATLAS: More sensitivity to constrain Parton Distributions

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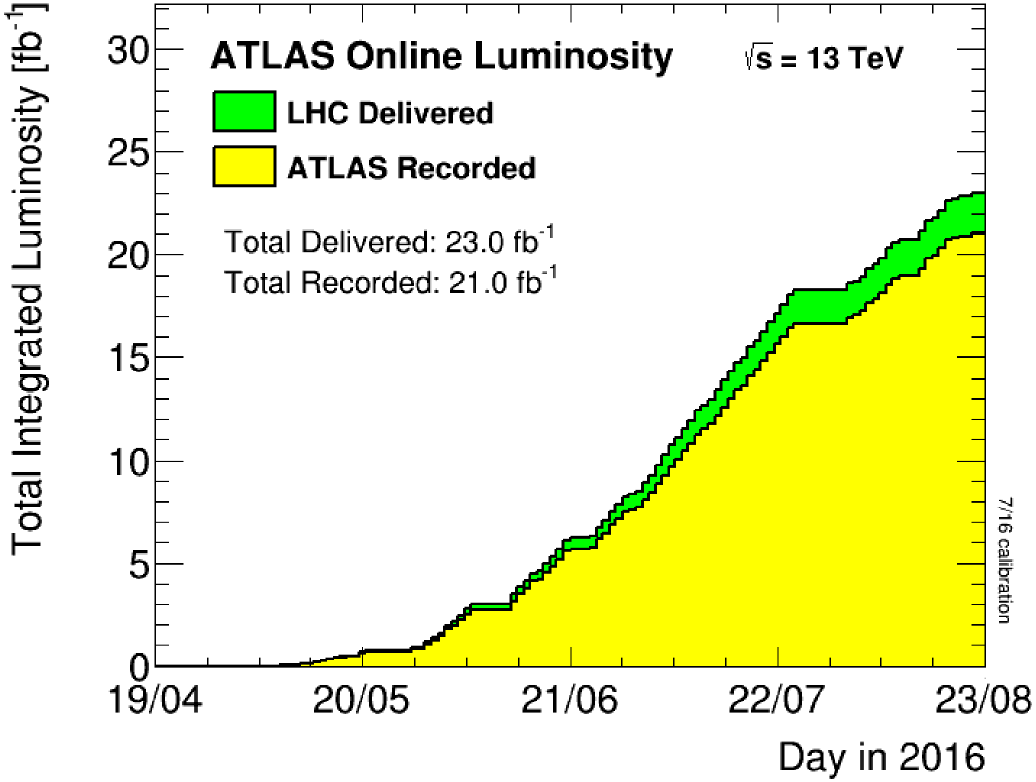
ATLAS EXPERIMENT

DESY

A wealth of data at the LHC

- >20 fb^{-1} and counting
- The largest data sample ever collected at a hadron collider



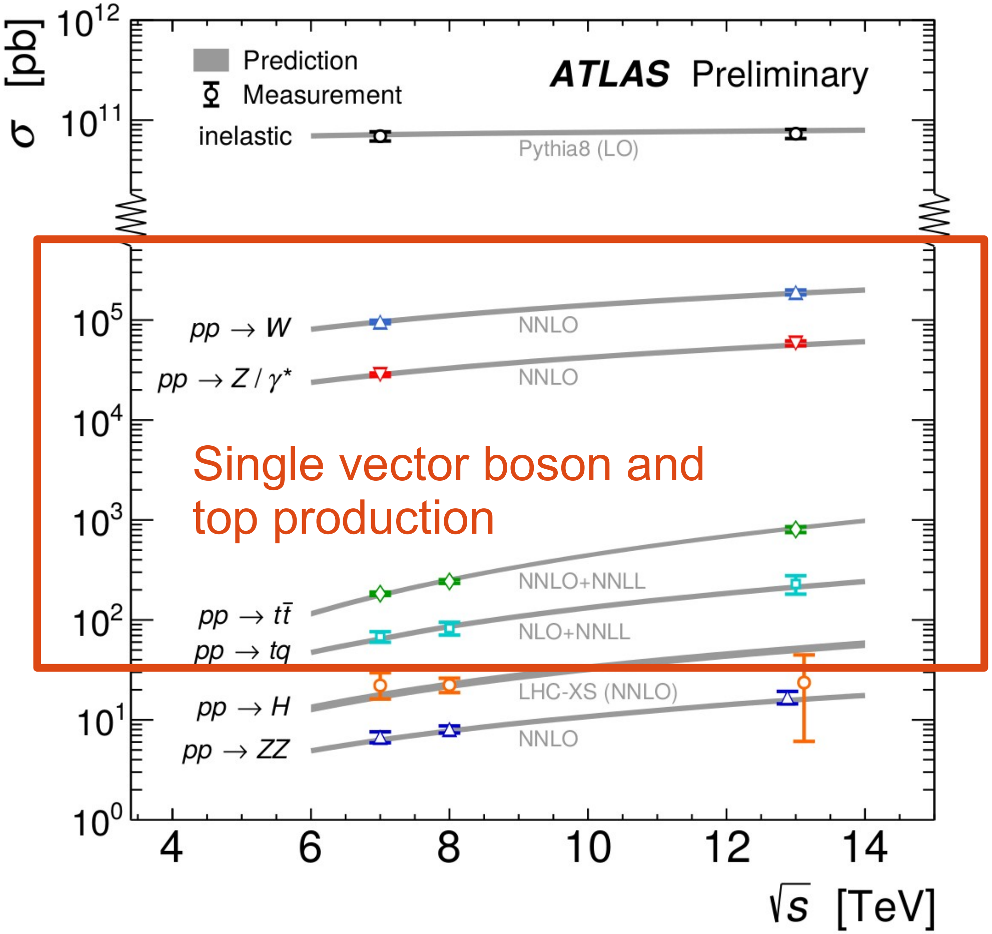
$\sqrt{s}$ = 2.76 TeV	5 pb^{-1}
$\sqrt{s}$ = 5 TeV	27 pb^{-1}
$\sqrt{s}$ = 7 TeV	4.7 fb^{-1}
$\sqrt{s}$ = 8 TeV	20.3 fb^{-1}
$\sqrt{s}$ = 13 TeV	>20 fb^{-1}

Luminosity uncertainty around 2%

Unique opportunity to understand the proton dynamics

Precise measurements and precise predictions

- Next-to-next-to leading order predictions allow for precise predictions
  - Scale and α_s uncertainties small compared to those of PDFs

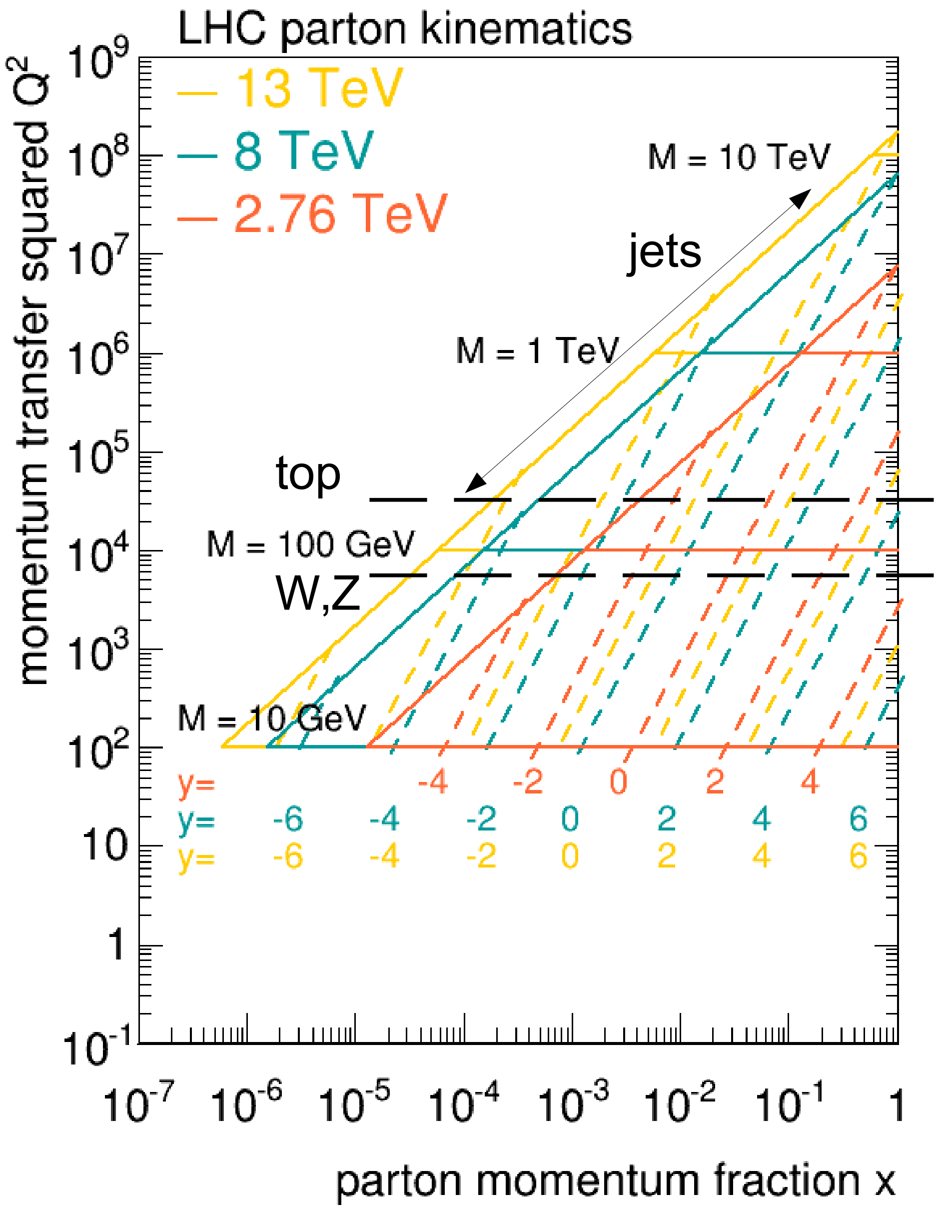


Single vector boson and top production

- **Cancellation of uncertainties in ratios:** Measurements can be more accurate due to cancellation of luminosity, energy scales, …
- Also some loss of information – **absolute cross sections provide additional information**
- **Ratios can be "easier" for outsiders:**
  Readily use data without keeping track of complicated correlation models (over years, over channels)

Phase space at the LHC

- **Kinematics are determined by centre-of-mass energy**
  - $x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$

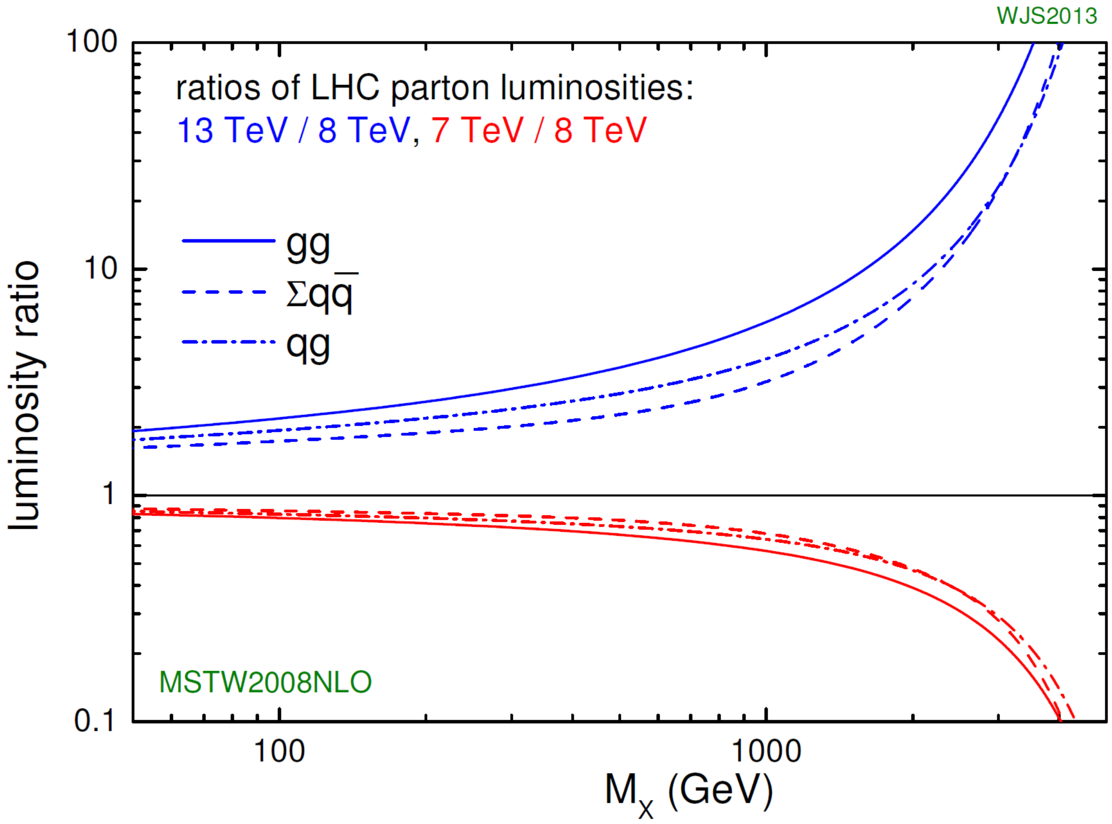


10.1007/JHEP08(2012)010
arXiv:1507.00556v1

Processes at different center-of-mass energies

- Kinematics are determined by centre-of-mass energy
  - $$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$

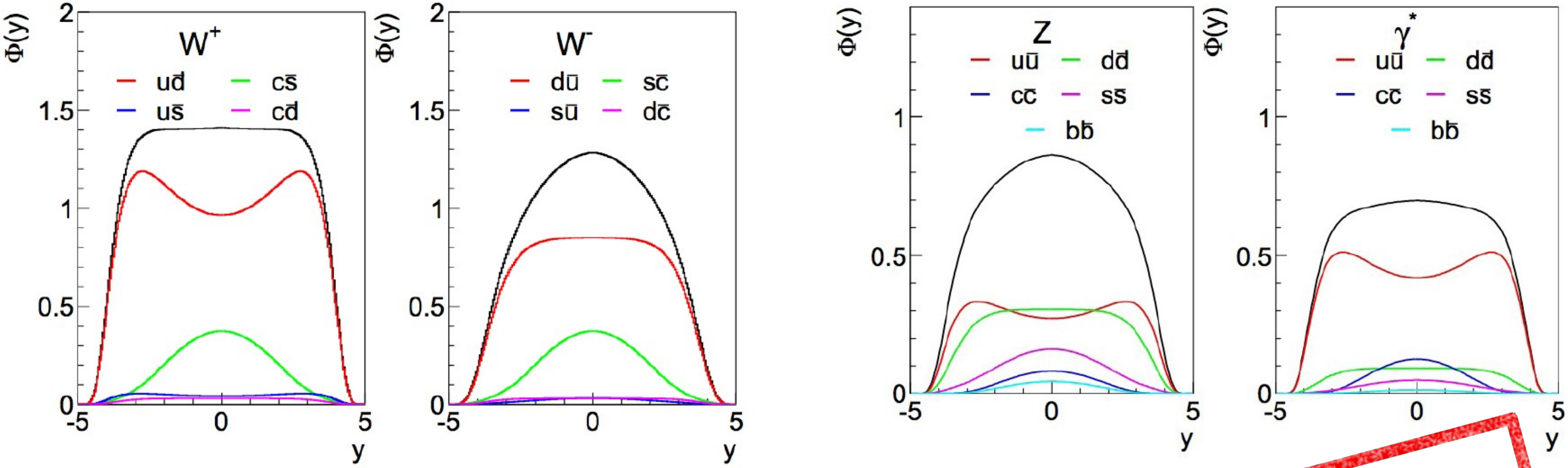
Jets
7 / 2.76 TeV
13 TeV (new!)



  - **Parton content different at different luminosities:**
- Ratios can reduce effort of tracking correlations for outsiders while preserving PDF sensitivity

Ratios of different processes

- **Composition of incoming flavours** different for W and Z production



  - Sensitive to u/d differences
  - Boost towards high y due to u valence contribution
  - Strange and charm important at central rapidity

W/Z ratio
W+/W- ratio
Z/ttbar ratio
(13 TeV)

- **Ratios can lead to cancellation of experimental systematics and enhance sensitivity to certain parton flavours**

Measurements of W and Z bosons

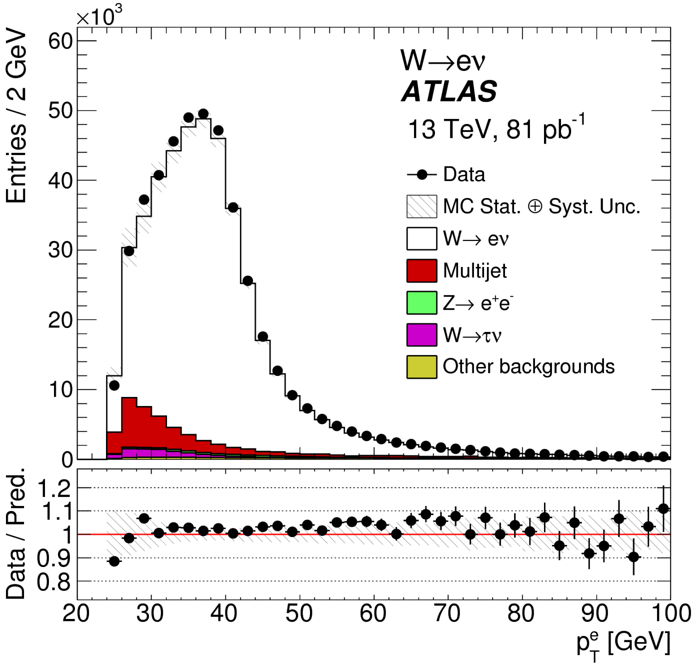
Phys. Lett. B 759 (2016) 601
arXiv:1603.09222

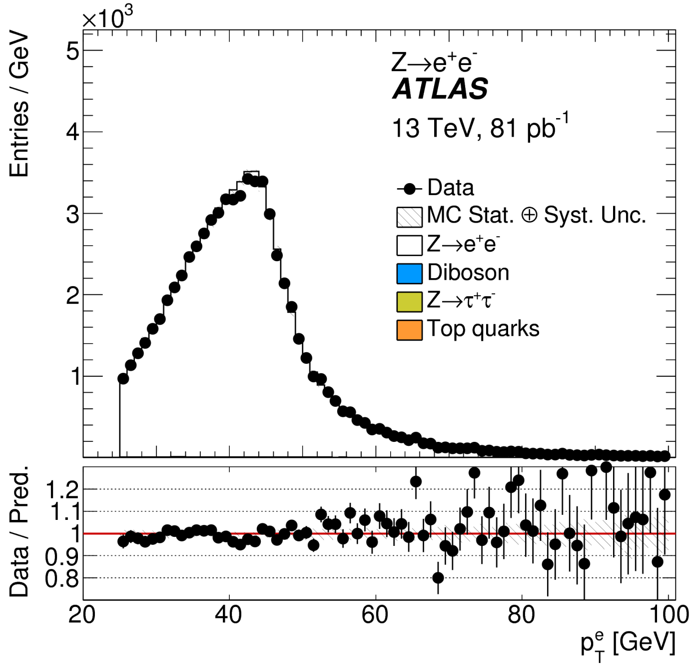
> First measurements at 13 TeV with 81 pb^{-1}

- Kinematic selections as for earlier measurements:

electron and muon channels: $p^T_{lepton} > 25$ GeV
pseudorapidity $|\eta| < 2.5$

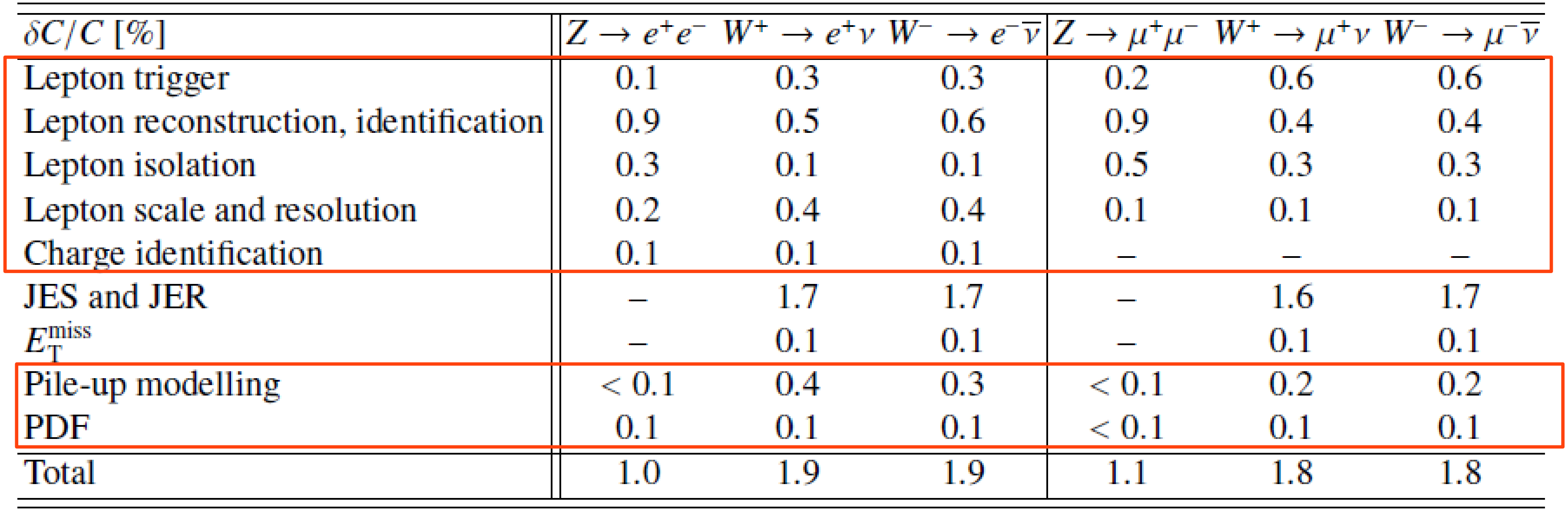
W boson: neutrino momentum > 25 GeV and $m_{T,W} > 50$ GeV
Z boson: $66 < m_{\ell\ell} < 116$ GeV





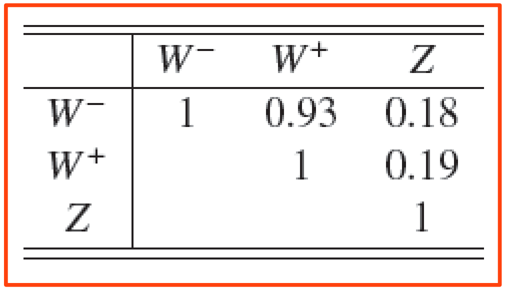
Measurements of W and Z bosons

> First measurements at 13 TeV with 81 pb^{-1}



$\delta C/C$ [%]	$Z \rightarrow e^+e^-$	$W^+ \rightarrow e^+\nu$	$W^- \rightarrow e^-\bar{\nu}$	$Z \rightarrow \mu^+\mu^-$	$W^+ \rightarrow \mu^+\nu$	$W^- \rightarrow \mu^-\bar{\nu}$
Lepton trigger	0.1	0.3	0.3	0.2	0.6	0.6
Lepton reconstruction, identification	0.9	0.5	0.6	0.9	0.4	0.4
Lepton isolation	0.3	0.1	0.1	0.5	0.3	0.3
Lepton scale and resolution	0.2	0.4	0.4	0.1	0.1	0.1
Charge identification	0.1	0.1	0.1	–	–	–
JES and JER	–	1.7	1.7	–	1.6	1.7
$E_{\mathrm{T}}^{\mathrm{miss}}$	–	0.1	0.1	–	0.1	0.1
Pile-up modelling	< 0.1	0.4	0.3	< 0.1	0.2	0.2
PDF	0.1	0.1	0.1	< 0.1	0.1	0.1
Total	1.0	1.9	1.9	1.1	1.8	1.8

- Z boson background uncertainty is negligible, 3.4 % (e) / 1.4 % (μ) for W boson
- Measurements correlated through leptons



	W^-	W^+	Z
W^-	1	0.93	0.18
W^+		1	0.19
Z			1

Predictions for single boson measurements

> Measurements are compared to total cross section obtained as

$$\sigma^{tot} = \frac{N_{sig}}{\mathscr{L} \times A \times C}$$

Signal events
Luminosity ~2.1% uncertainty
Acceptance correction ~1.8%
Detector correction ~1.9% (W) / 1.1 % (Z)

> Theoretical predictions are computed using DYNNLO 1.5 and FEWZ 3.1

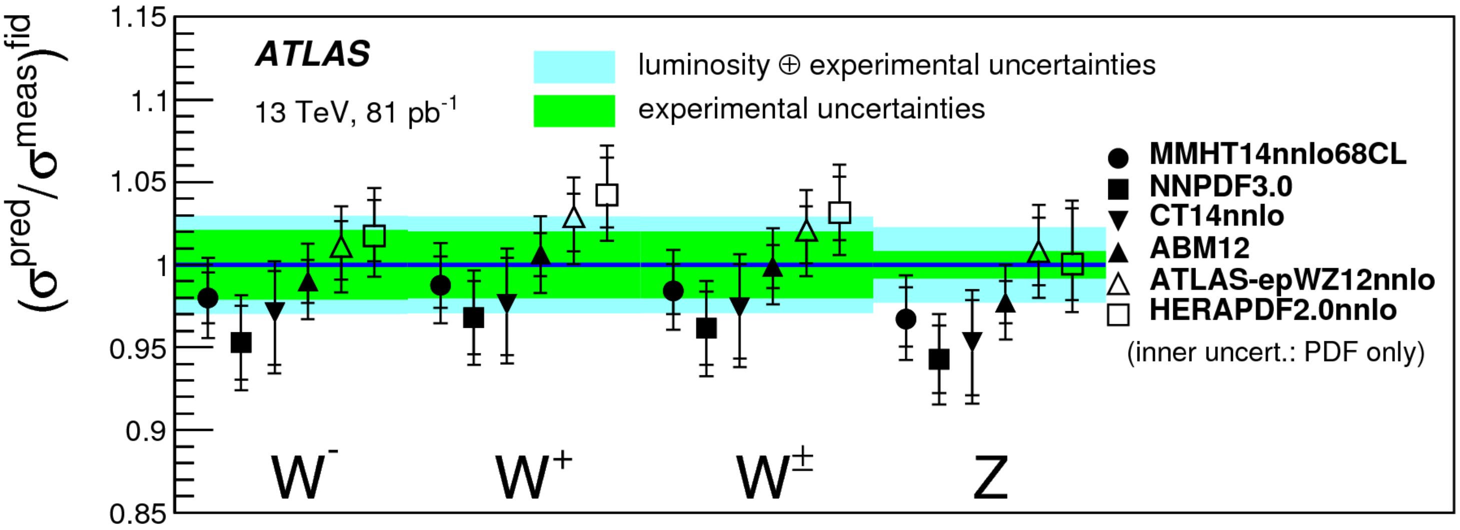
- Electroweak corrections calculated using FEWZ (Z) and SANC (W)
- Leptons on BORN-level (before emission of photons)
  → thus NLO EW corrections comprise of: virtual QED and weak corrections, initial-state radiation (ISR) and ISR-FSR interference

> Systematic uncertainties on the theory predictions dominated by PDFs

- Scale uncertainties (variation by factor 2 and constraint $\mu_R/\mu_F \leq 2$) **~1.1%**
- α_s varied by ± 0.001
- Beam energy known to only 1% *(→ now 0.066%)* **in total ~1.2%**

PDF uncertainties twice as large: ~2.4%

Absolute cross sections



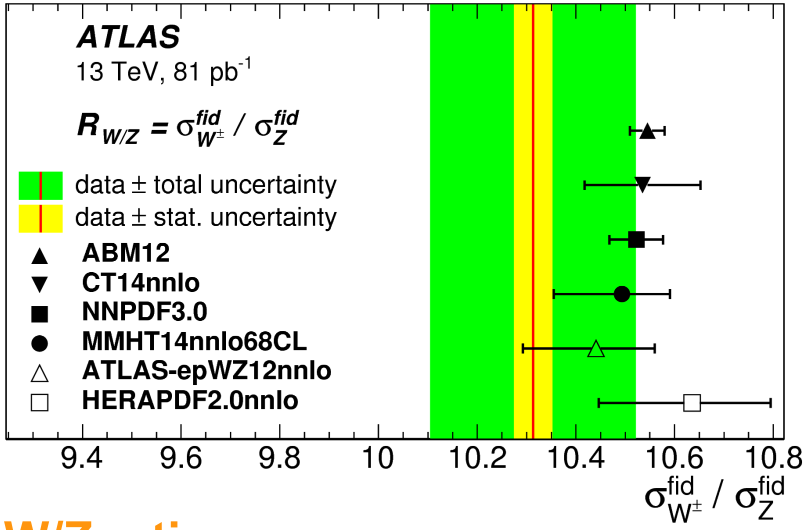
- **Despite small data set experimental comparable to theoretical uncertainties**
  - 1/250 of total 2015+2016 set

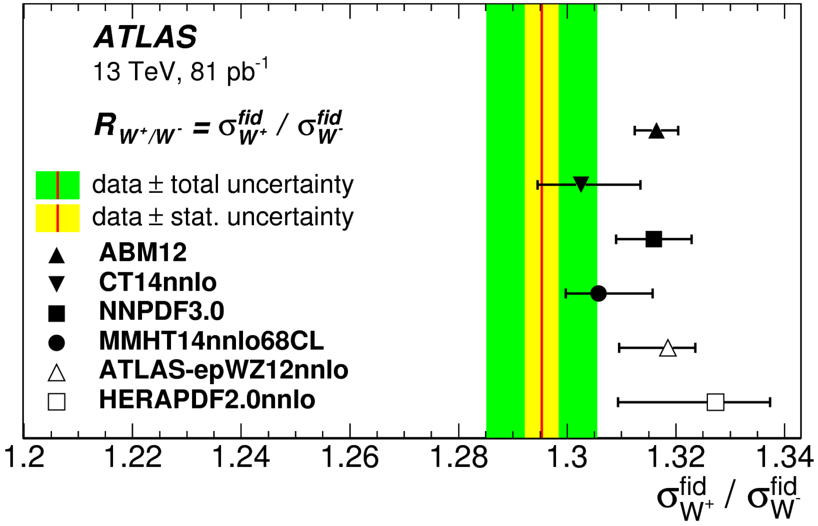
- **Most PDF sets describe the data well**
  - ABM12 has the best agreement with the data
    includes no Tevatron data, but LHC WZ and top
  - NNPDF3.0, MMHT14nnlo68CL and CT14nnlo generally a bit low
    include Tevatron as well as most LHC data (except top and W+c for CT14, except W+c for MMHT)
  - HERAPDF2.0nnlo and ATLAS-epWZ12nnlo generally a bit high
    only HERA data (+LHC WZ data for ATLAS-epWZ12)

Cross section ratio

> Ratios yield valuable additional information

- Direct comparison allows more direct test of predictions





> W/Z ratio

- Sensitive to valence to strange ratio (Phys.Rev.Lett. 109 (2012) 012001)
- Consistent with prior results: preference for an enhanced strange content

> W+/W- ratio

- Sensitive to u/d valence content of the proton
- Smaller ratio than predicted by most PDFs

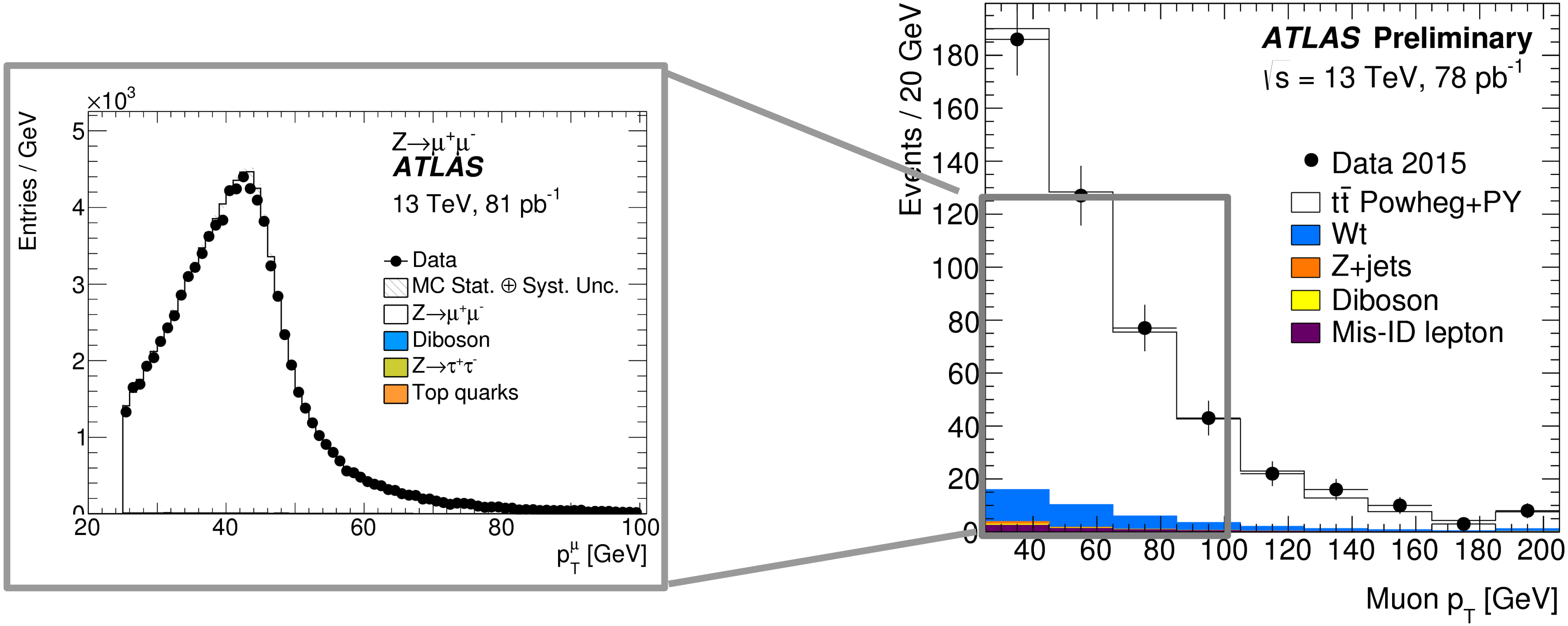
Z/ttbar ratio: Probing sea and gluon ratios

ATLAS-CONF-2015-033
ATLAS-CONF-2015-049

- **Ratio defined as**

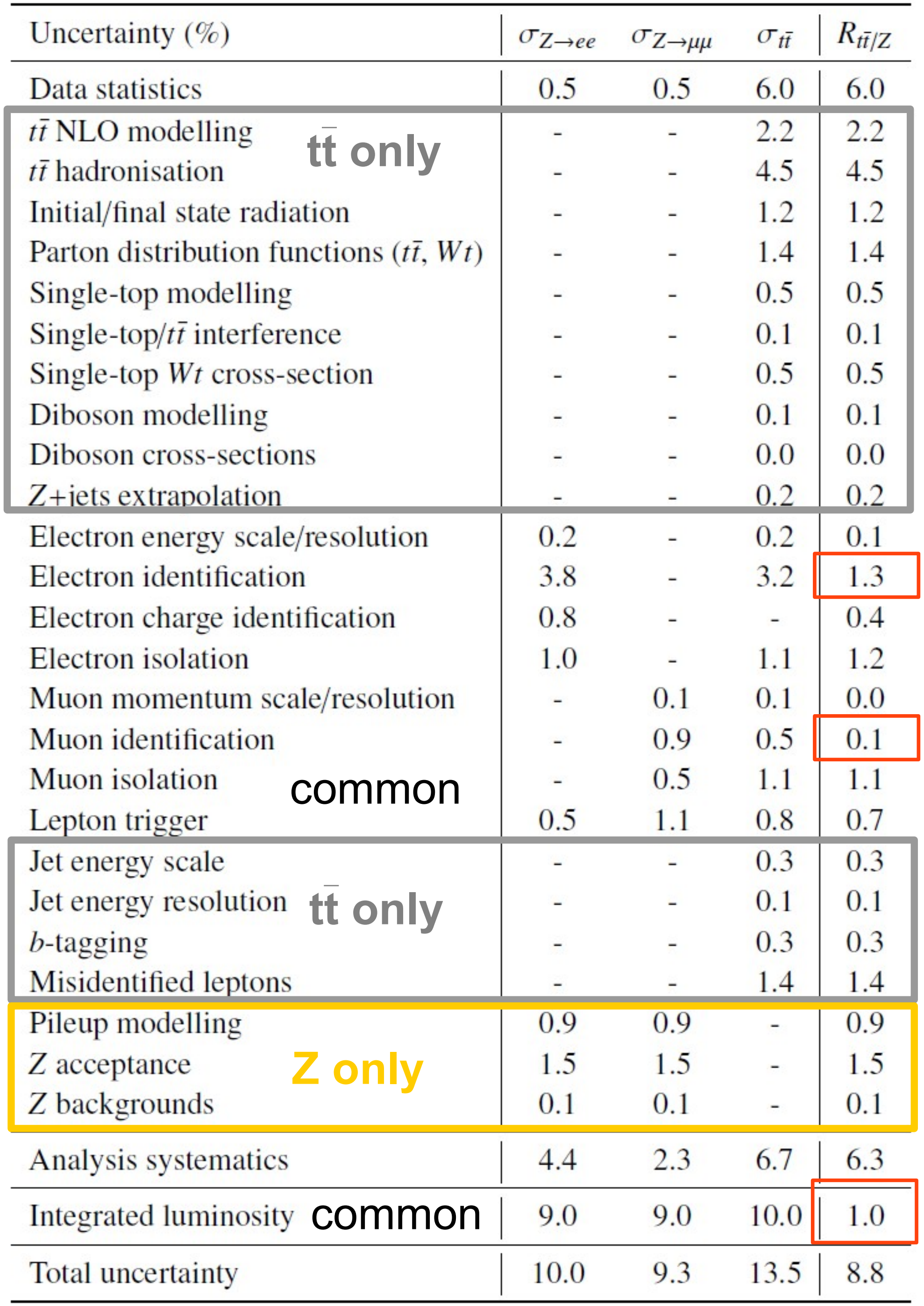
$$R_{t\bar{t}/Z} = \frac{\sigma_{t\bar{t}}}{0.5\left(\sigma_{Z\to ee} + \sigma_{Z\to\mu\mu}\right)}$$

- **$t\bar{t}$ Selection using eμ events with one or two b-tagged jets above 25 GeV**
  - Cross section extracted in combined fit using one and two b-tag regions
- **Z selection as detailed before**
  - Different lepton kinematics hinders complete uncertainty cancellation



Uncertainties

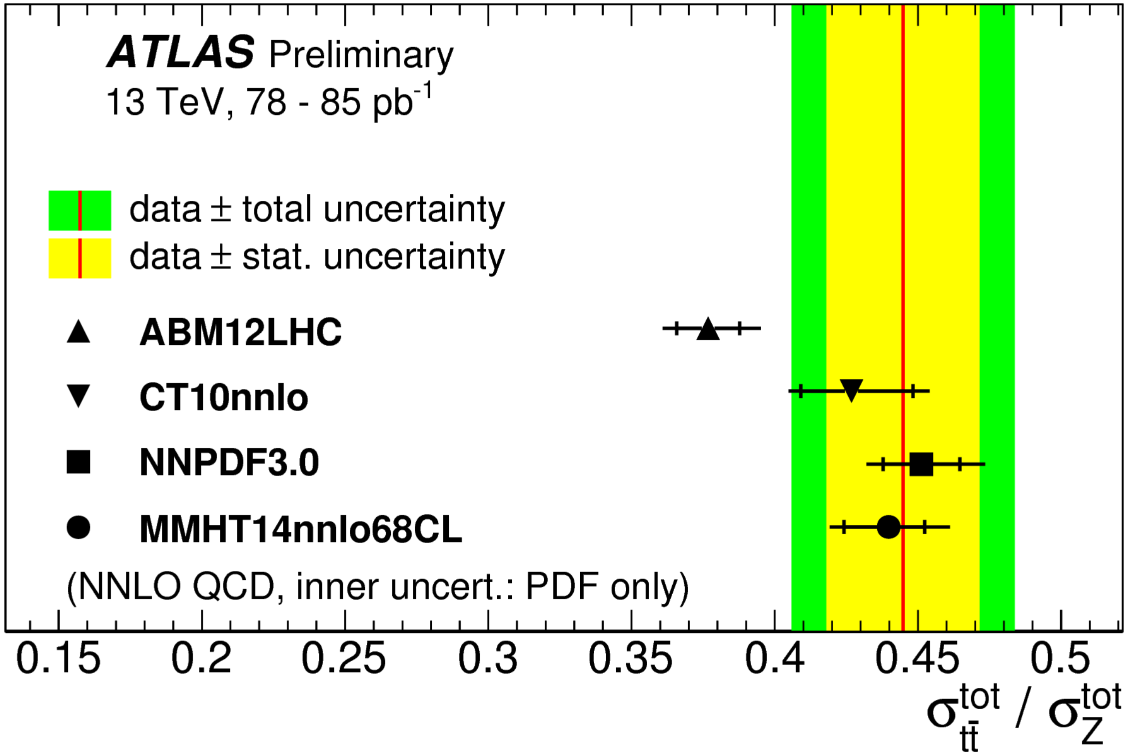
- **Jet and single top-related uncertainties**
  - $t\bar{t}$ only
- **Few uncertainties**
  - Z only
- **Significant cancellation of common uncertainties**
  - Lepton identification
  - Luminosity
- **PDF uncertainties entering detector corrections**
  - Taken to be uncorrelated based on study with eigenvectors using CT10 PDF set



Uncertainty (%)	$\sigma_{Z\to ee}$	$\sigma_{Z\to\mu\mu}$	$\sigma_{t\bar{t}}$	$R_{t\bar{t}/Z}$
Data statistics	0.5	0.5	6.0	6.0
$t\bar{t}$ NLO modelling	-	-	2.2	2.2
$t\bar{t}$ hadronisation	-	-	4.5	4.5
Initial/final state radiation	-	-	1.2	1.2
Parton distribution functions ($t\bar{t}$, Wt)	-	-	1.4	1.4
Single-top modelling	-	-	0.5	0.5
Single-top/$t\bar{t}$ interference	-	-	0.1	0.1
Single-top Wt cross-section	-	-	0.5	0.5
Diboson modelling	-	-	0.1	0.1
Diboson cross-sections	-	-	0.0	0.0
Z+jets extrapolation	-	-	0.2	0.2
Electron energy scale/resolution	0.2	-	0.2	0.1
Electron identification	3.8	-	3.2	1.3
Electron charge identification	0.8	-	-	0.4
Electron isolation	1.0	-	1.1	1.2
Muon momentum scale/resolution	-	0.1	0.1	0.0
Muon identification	-	0.9	0.5	0.1
Muon isolation	-	0.5	1.1	1.1
Lepton trigger	0.5	1.1	0.8	0.7
Jet energy scale	-	-	0.3	0.3
Jet energy resolution	-	-	0.1	0.1
b-tagging	-	-	0.3	0.3
Misidentified leptons	-	-	1.4	1.4
Pileup modelling	0.9	0.9	-	0.9
Z acceptance	1.5	1.5	-	1.5
Z backgrounds	0.1	0.1	-	0.1
Analysis systematics	4.4	2.3	6.7	6.3
Integrated luminosity	9.0	9.0	10.0	1.0
Total uncertainty	10.0	9.3	13.5	8.8

Results

- **Ratio measurement still statistics dominated: room for improvement (x100)**
- **Sensitive for gluon and sea quark density at 0.1 < x < 0.01**
- **Most PDFs well described** – ABM12LHC a bit low
- **To be updated: new $\sigma_{t\bar{t}}$:** 818 ±8 (stat) ±27 (syst) ±19 (lumi) ±12 (beam) pb
  → factor 6 reduction in statistical uncertainty



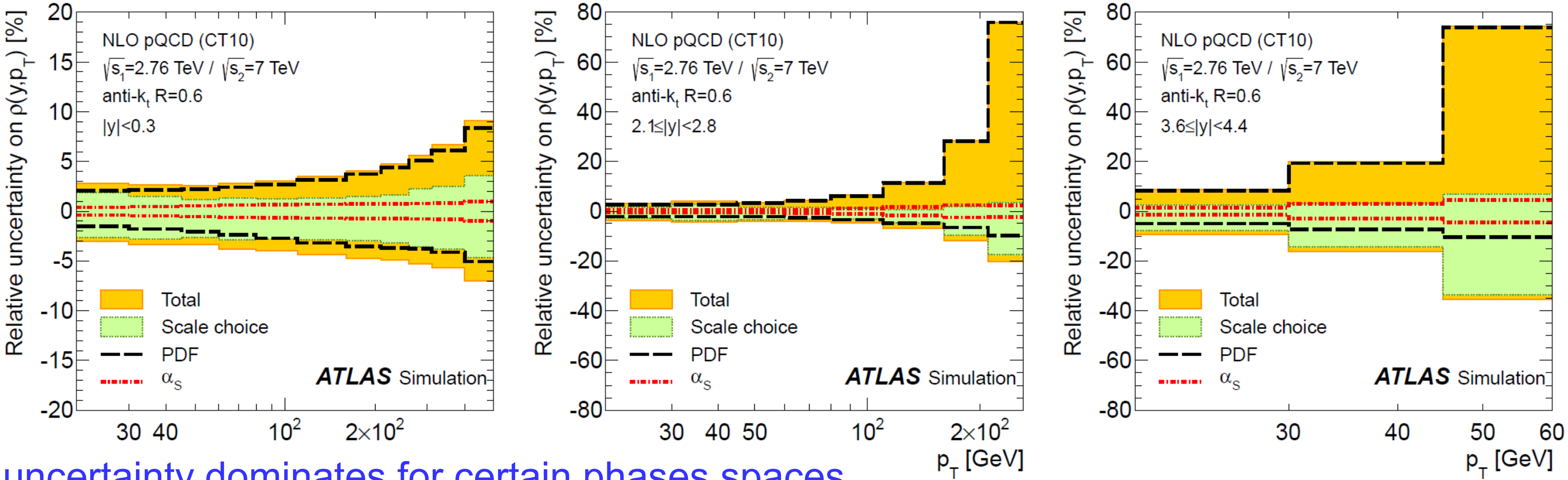
Measurements of inclusive jet cross sections

- **Systematic uncertainties correlated between centre-of-mass energies**
  - Ratio measurements reported already by UA1, UA2, CDF and D0

- **For ATLAS: reported between 7 and 2.76 TeV** (EPJC (2013) 73 2509)

  - Unfolded double differential cross sections as function of p_T^{jet} and rapidity (also as function of $x_T = 2\ p_T / \sqrt{s}$ and for anti-kT R=0.4)

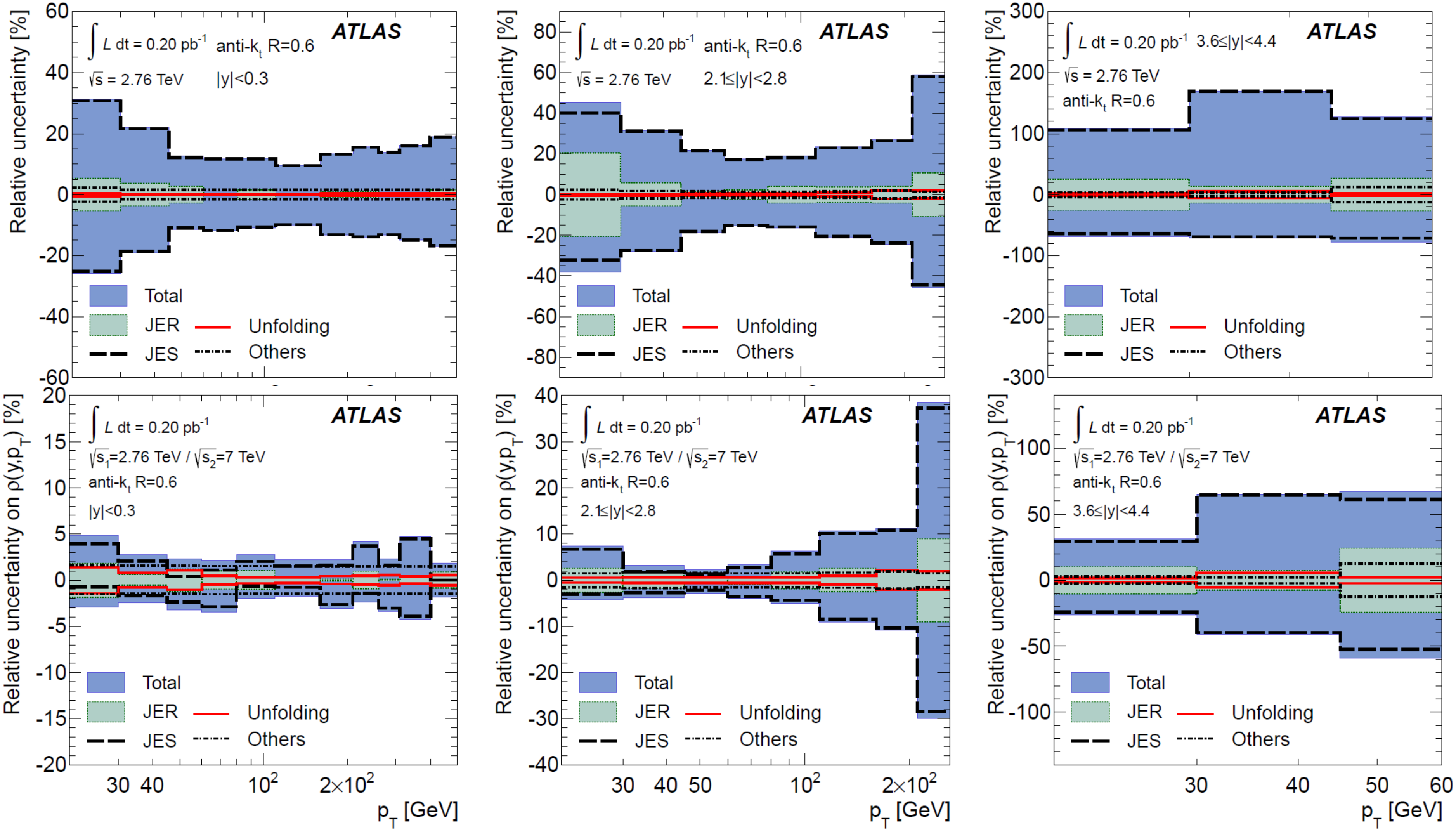
- **Prediction: NLO pQCD using NLOJET++ 4.1.2 + APPLgrid + NP corrections**
  - Scale set to p_T^{max} (variation by factor 2 and constraint $\mu_R/\mu_F \leq 2$)
  - α_s variations carried out based on CTEQ group PDFs and recommendations
  - PDF uncertainty at 68% according to each PDF group recommendation



PDF uncertainty dominates for certain phases spaces

Systematic uncertainties

- **Reduction of uncertainty by a factor of 2-4 compared to 2.76 TeV cross section**



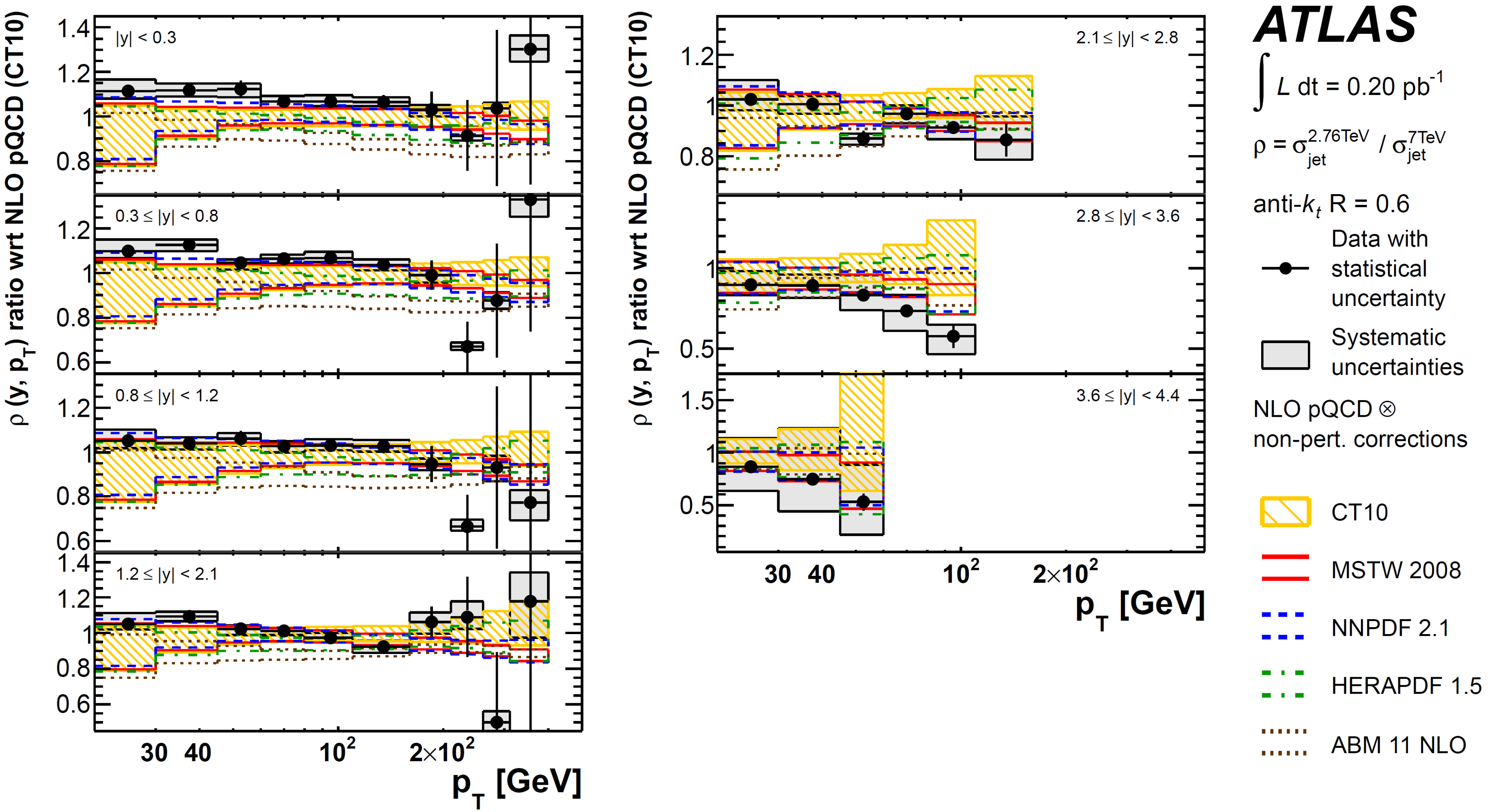
(d) $\rho(y, p_{\mathrm{T}}), |y| < 0.3$

(e) $\rho(y, p_{\mathrm{T}}), 2.1 \leq |y| < 2.8$

(f) $\rho(y, p_{\mathrm{T}}), 3.6 \leq |y| < 4.4$

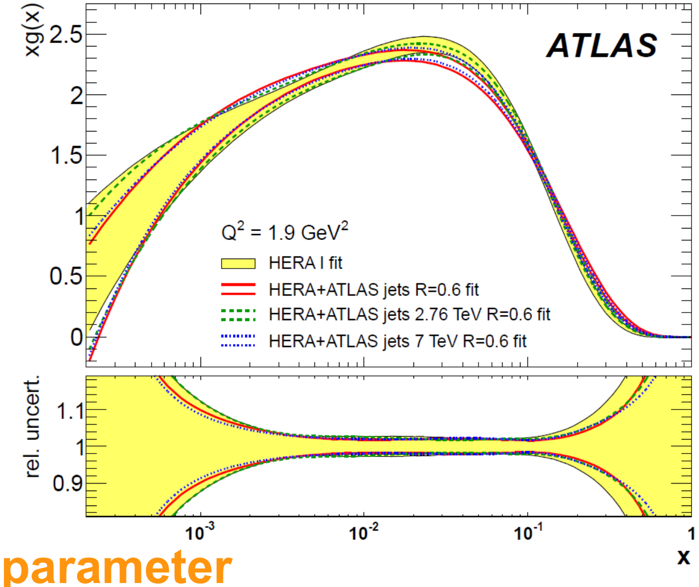
Comparison of predictions to the ratio

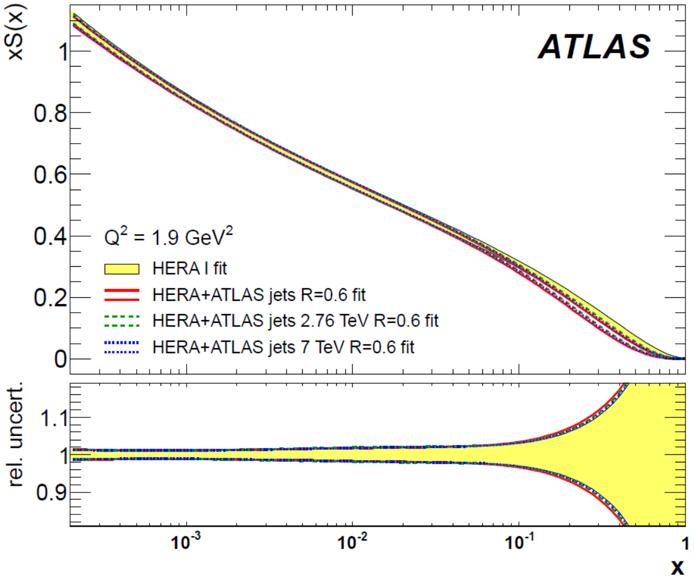
- Agreement with most PDF sets
- But there is more one can do...



PDF fits using ATLAS Jet data

- **No stringent constraints from HERA data on the gluon above x>0.01**
- **HERAFitter Analysis:** slightly harder gluon at high-x (softer at low-x)
  little change to sea quarks





- **13 free parameter**

$$xu_v(x) = A_{u_v}x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2),$$
$$xd_v(x) = A_{d_v}x^{B_{d_v}}(1-x)^{C_{d_v}},$$
$$x\bar{U}(x) = A_{\bar{U}}x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}},$$
$$x\bar{D}(x) = A_{\bar{D}}x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}},$$
$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}$$

m_c = 1.4 GeV
m_b = 4.75 GeV
$\alpha_s(M_Z)$=0.1176
Q^2_{min} > 3.5 GeV²
f_s = 0.31 (strangeness)
P_t^{min} (ATLAS)>45 GeV
C'_g = 25

First results of inclusive jet cross sections at 13 TeV

ATLAS-CONF-2016-092

> Double-differential inclusive jet cross section with 2015 data

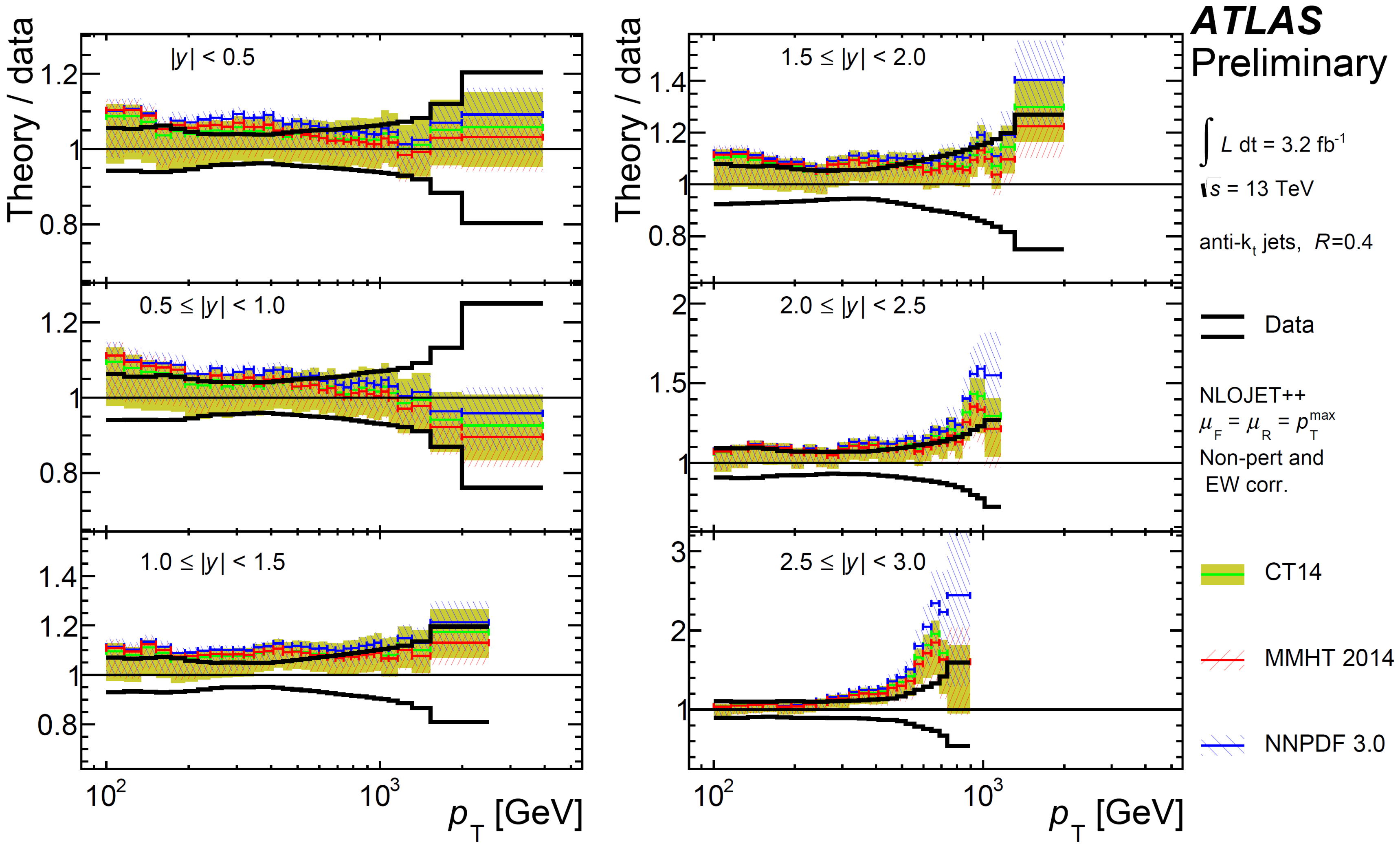
- Integrated luminosity of 3.2 fb^{-1}
- As function of p_T and absolute rapidity

$$|y| < 0.5, \quad 0.5 \leq |y| < 1.0, \quad 1.0 \leq |y| < 1.5$$
$$1.5 \leq |y| < 2.0, \quad 2.0 \leq |y| < 2.5, \quad 2.5 \leq |y| < 3.0$$

- Anti-k_T jets with R=0.4, using all jets with $p_T > 100$ GeV and within $|y| < 3.0$
- Following the procedure already outlined for 2.76 and 7 TeV analysis
- **Reaching up to ~4 TeV → extending significantly reach of earlier analysis**

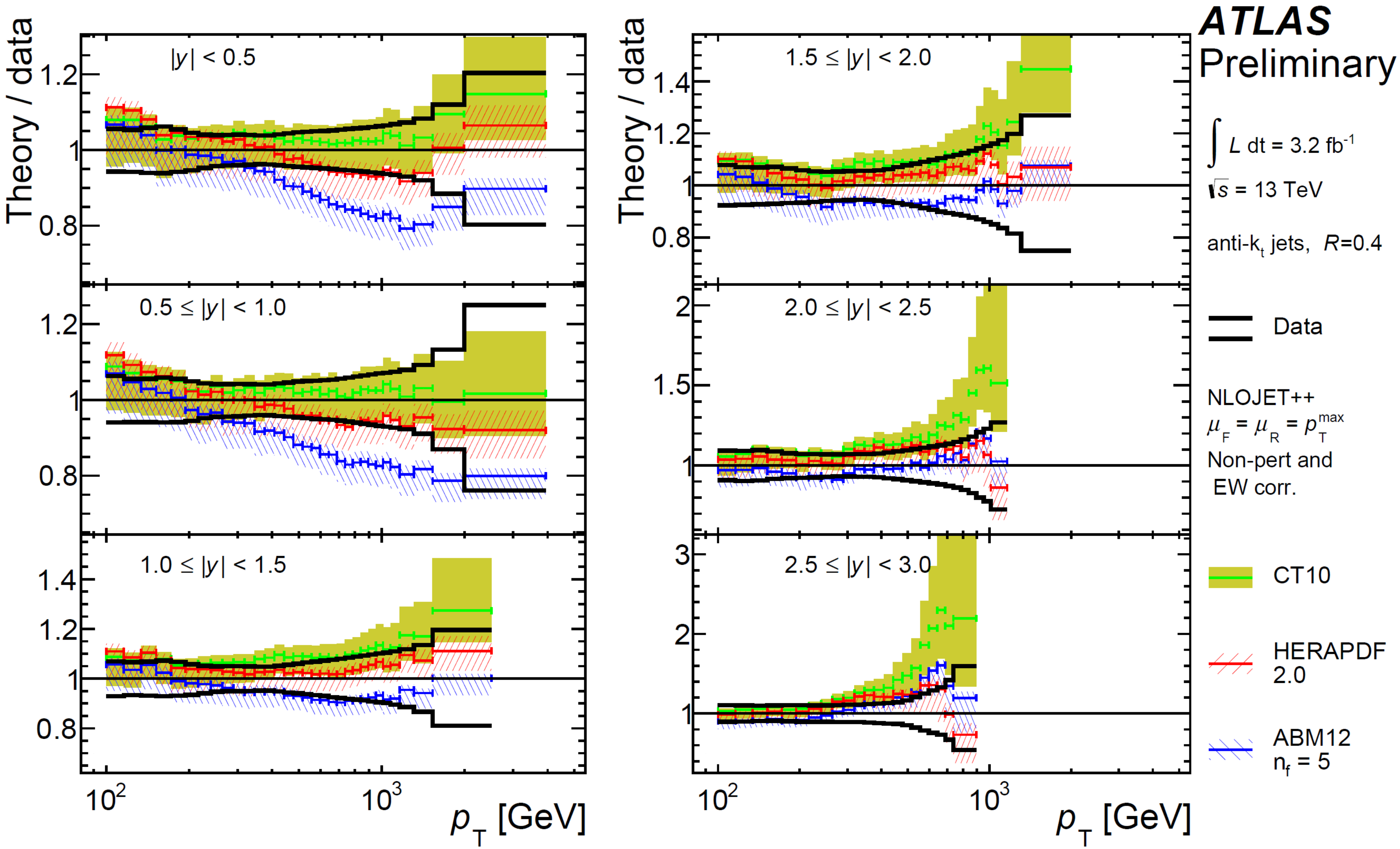
Preliminary results

- **Data are generally lower than the theory for CT14, MMHT2014, NNPDF3.0** (general feature seen comparing anti-kT R=0.4 to R=0.6 for Run 1 already)



Preliminary results

- **CT10 prediction larger than data, while HERAPDF2.0 and ABM12 are lower** (but quantitative analysis needed due to large correlations between bins)



Conclusions

> Ratios can deliver stringent constraints on PDFs

- Ratios of different processes and at different centre-of-mass energies
- Cancellation of important theoretical and experimental uncertainties
- Ratios can reduce effort to track complicated correlations,
  allow combination of various channels with different PDF sensitivities

> A huge amount of LHC data is being analysed

- W/Z and W+/W- ratios at 13 TeV support previous hints for enhanced strange
- Z/$t\bar{t}$ ratio will gain more power with larger statistics (100x more data available)
- Jet data at 2.76 and 7 TeV centre-of-mass energy with small uncertainties
- Preliminary 13 TeV inclusive jet cross section mesurement

>More is to come!

Backup slides.