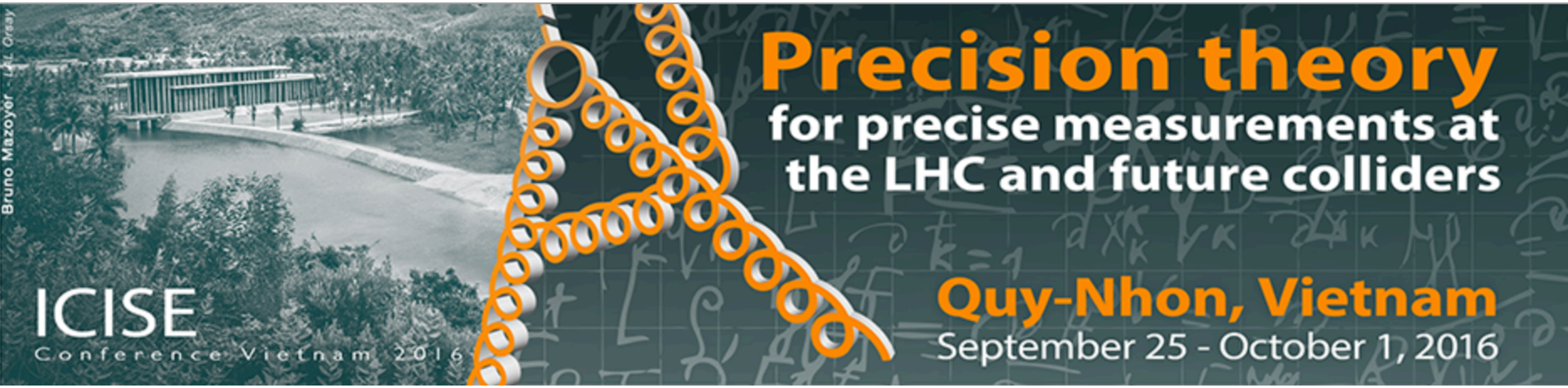


Constraints on PDFs from ATLAS

Francesco Giuli – University of Oxford

on the behalf of ATLAS Collaboration

26/09/2016

Oxford Physics

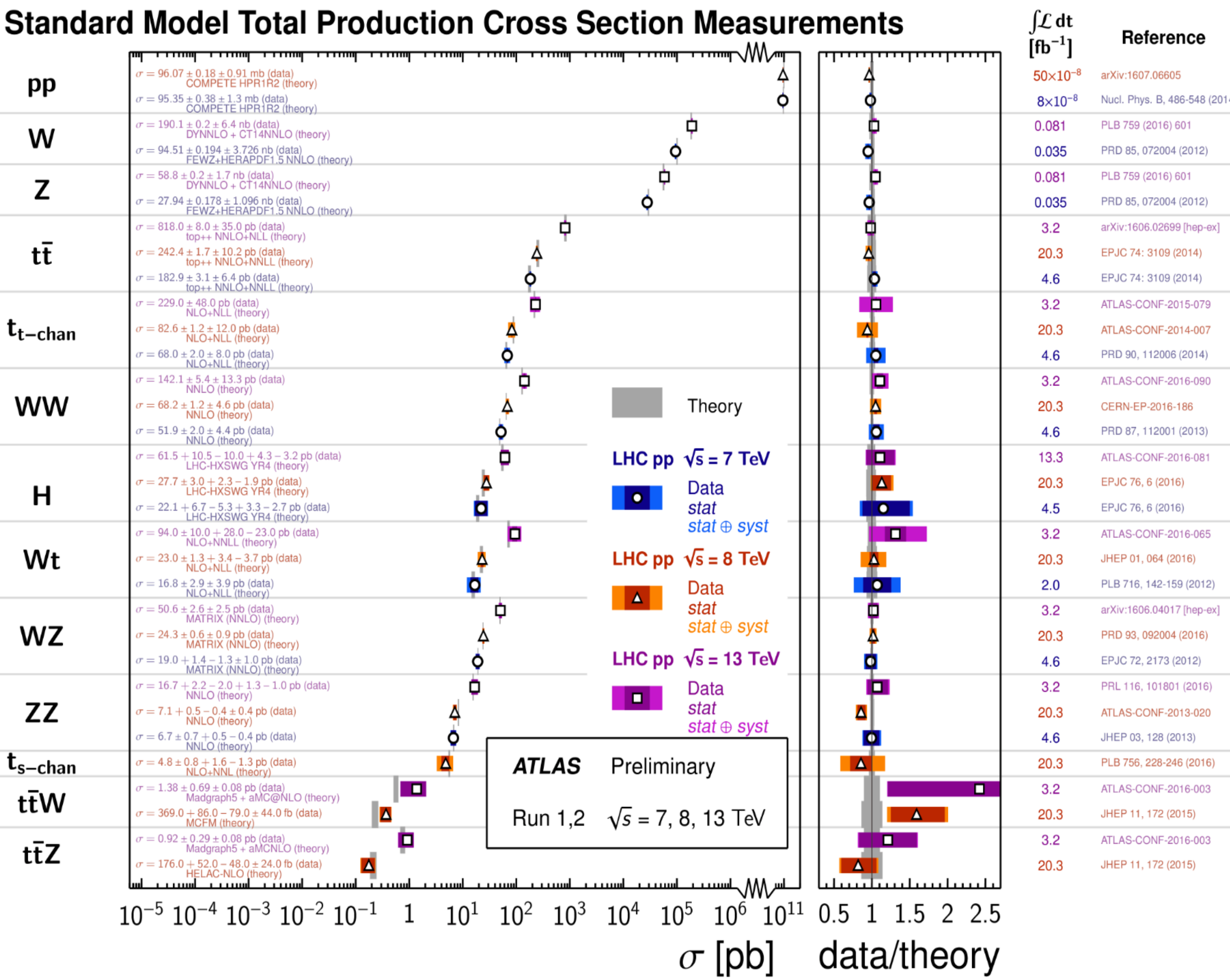
PDF4BSM
Parton Distributions in the Higgs Boson Era

erc
European Research Council
Established by the European Commission

ATLAS

The LHC SM measurements

- Hadron colliders can give us more insight into hard QCD, Parton Distribution Functions (PDFs), non-perturbative effects, and other SM parameters



Remarkable agreement with SM predictions! Much of theory error from PDFs

- **PDFs discrimination** (by confronting theory with data)
- **PDFs improvement** (by adding the LHC data)

Status: August 2016

The LHC measurements for PDFs

- Crucial for new cross section measurements and searches beyond the SM, as PDFs are often the dominant uncertainty and limiting factor
- Below, some measurements which can constraint PDFs:

Process	Sensitivity to PDFs
W asymmetry	Valence quarks
W and Z production (differential)	Quark flavour separation
W+c production, W and Z (differential)	Strange quark
Drell-Yan (DY): high invariant mass	Sea quarks, high-x, photon PDF
Drell-Yan (DY): low invariant mass	Low-x
W,Z + jets	Gluon medium-x
Inclusive jet and di-jet production	Gluon and $\alpha_s(M_Z)$
Direct photon	Gluon medium-, high-x
$t\bar{t}$, single top production	Gluon and $\alpha_s(M_Z)$

- Other interesting observables for posing PDFs constraints: Z p_T, Z polarisation, etc.

To extract precise PDFs, we need both precise data and precise calculations

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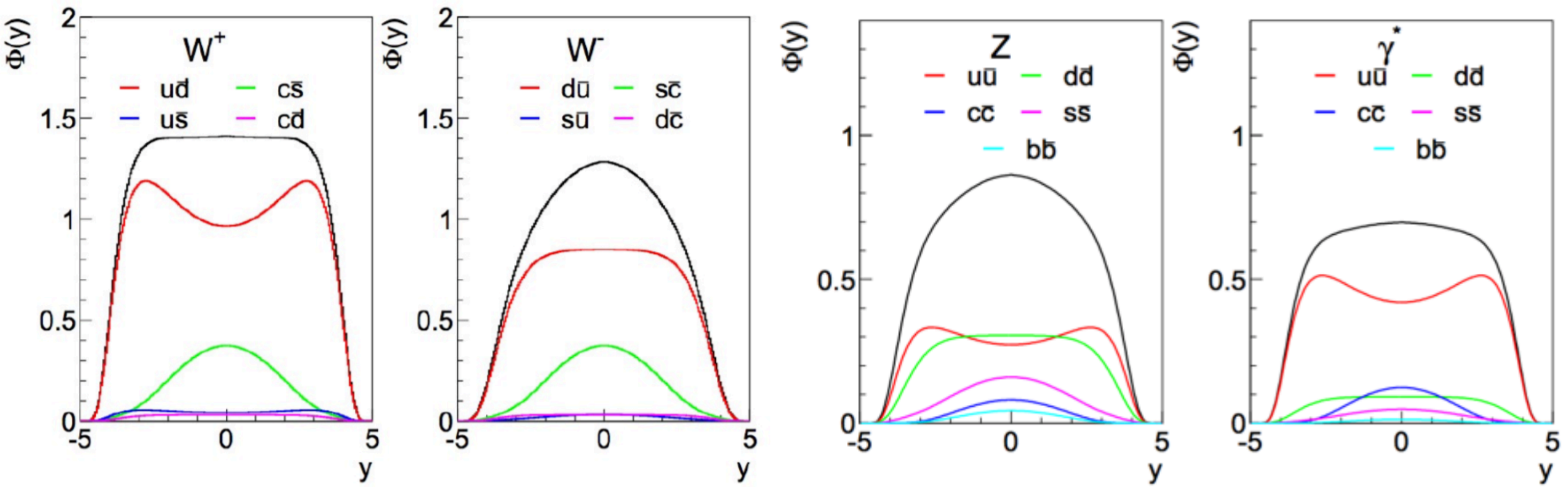
In **BOLD** the topics covered in this talk…

- Other interesting observables for posing PDFs constraints: Z p_T, Z polarisation, etc.

To extract precise PDFs, we need both precise data and precise calculations

Flavour decomposition of W,Z at the LHC

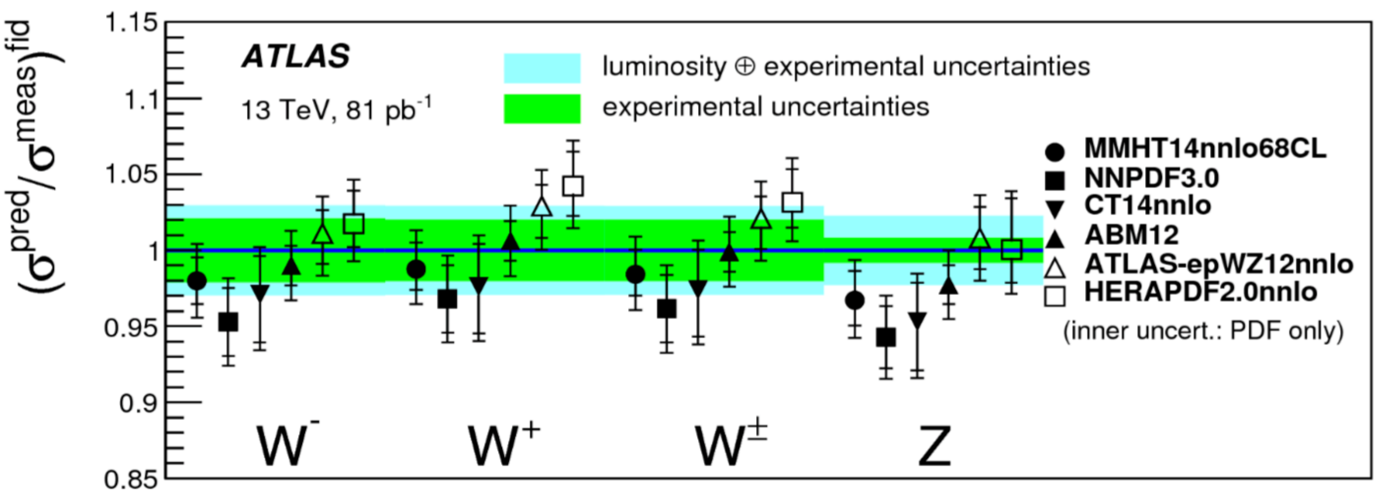
- W and Z bosons produced in abundance at LHC with clear experimental signatures
- Inclusive cross sections of W and Z well understood theoretically at NNLO
- Composition of incoming flavours different for W and Z production
- u and d quark dominate for W production; all flavours contibute for Z production



- Ratio measurements: W^+/W^- ratio, W/Z ratio, $t\bar{t}$ / Z ratio @13 TeV
- **Why are these ratio measurements so important?**
  Taking the ratio offer the chance to cancel out some systematics and to enhance sensitivity to some parton flavours

W,Z at 13 TeV

- Motivation for measuring W, Z inclusive cross sections with Run-2 LHC data:
  - Validate the Run-1 results
  - Access a different kinematic region in x which provides different PDFs sensitivity
  - Luminosity uncertainty: 2.1%; systematic uncertainties: 2% (W), 1% (Z)

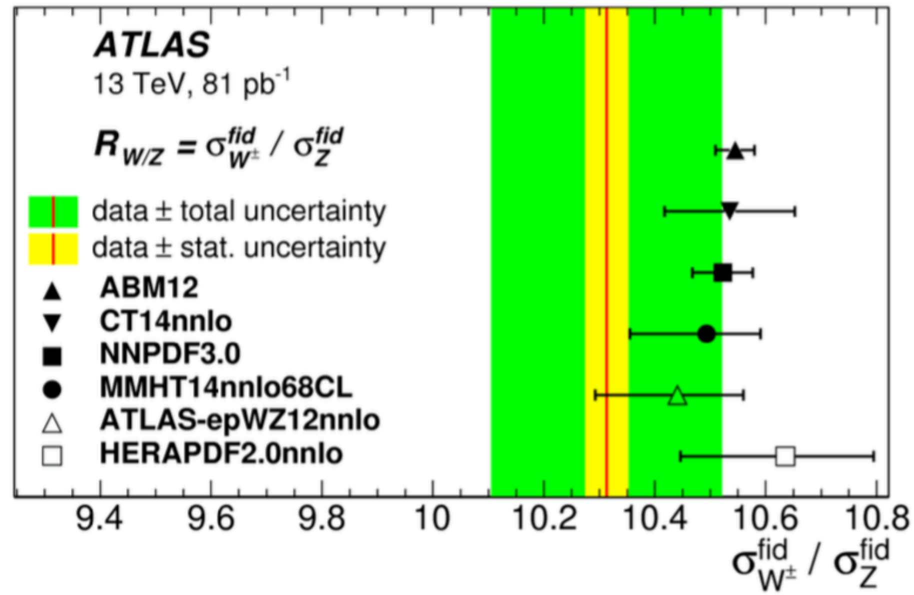


First results confirm the findings in Run1 and provide extra handle to better constraint PDFs

- **Most PDF sets describe the data well**
  - ABM12 has the best agreement with the data: no Tevatron data, but LHC W,Z and top
  - NNPDF3.0, MMHT14nnlo68CL and CT14nnlo generally a bit low: Tevatron as well as most LHC data (except top and W + c for CT14, except W + c for MMHT)
  - HERAPDF2.0nnlo a little bit high in W^+ (different u,d content from other PDFs): only HERA data

W and Z cross section ratio

- **W/Z ratio**
  - Sensitive to valence to strange ratio
  - W/Z ATLAS analysis (2010 data, 36 pb^{-1}): r_s = sbar/dbar = 1.00 ± 0.25 **(Phys Rev Lett 109(2012)012001)**
  - ATLAS W+c paper **(JHEP05(2014)068)** confirm the result: $r_s = 0.96+0.24/-0.31$
  - Consistent with previous results: preference for an enhanced r_s



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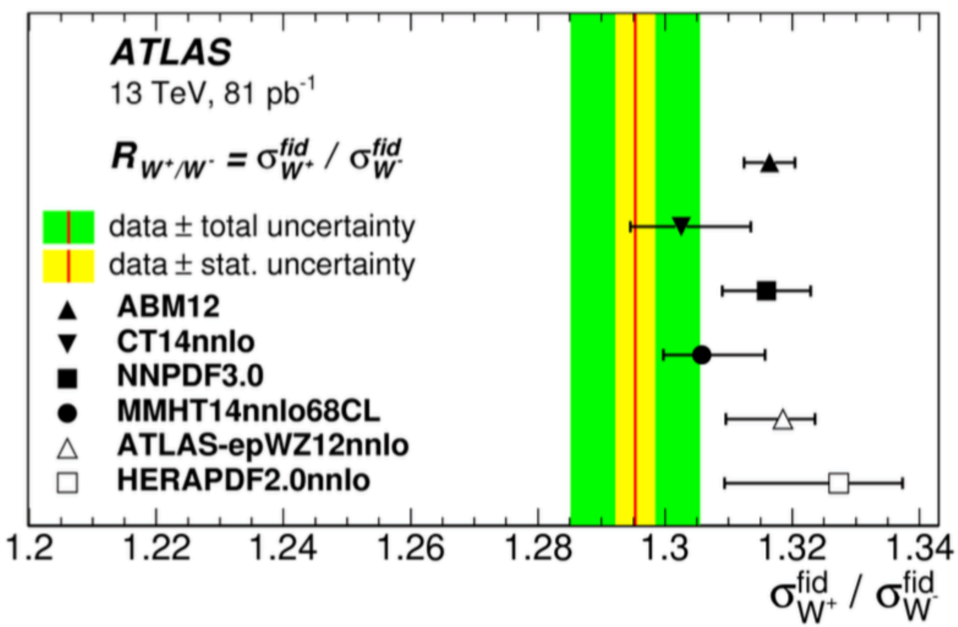


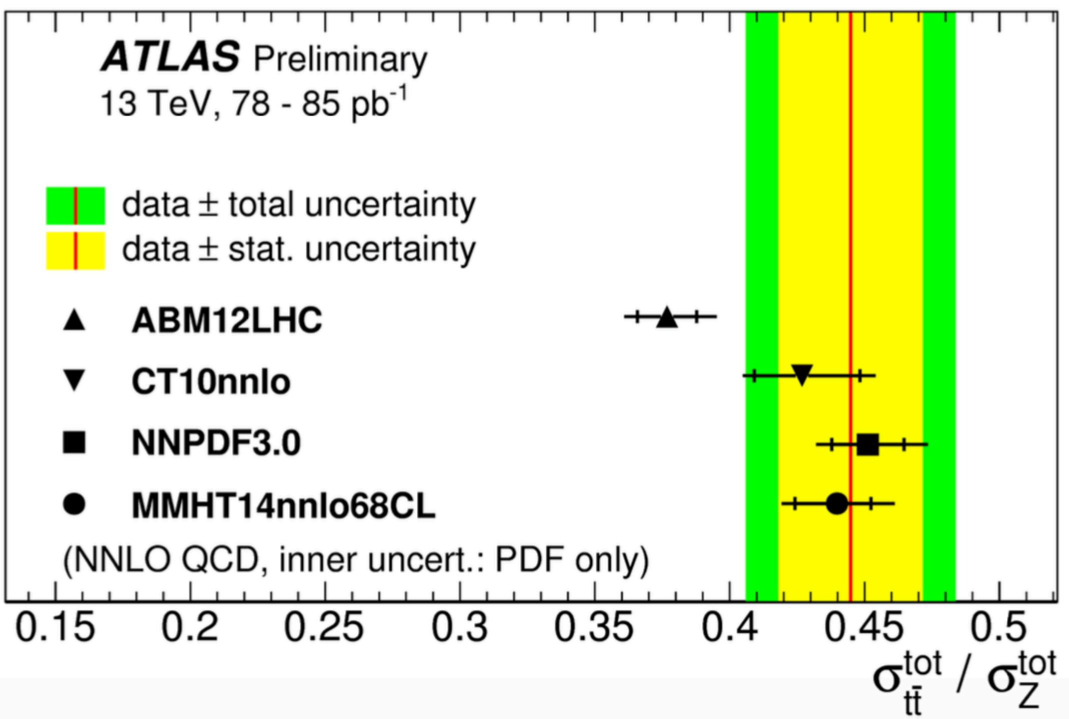
- **W^+/W^- ratio**
  - Sensitive to u_V and d_V at low-x
  - Smaller ratio than predicted by most PDFs

ttbar/Z ratio: to probe sea and gluon ratios

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

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

- $t\bar{t}$ cross section measured in the dilepton channel
- Ratio measurement still statistically dominated
- Sensitive for gluon and sea quark density between x = 0.01 and x = 0.1
- Most of the PDF sets describe data pretty well (ABM12LHC a bit low)

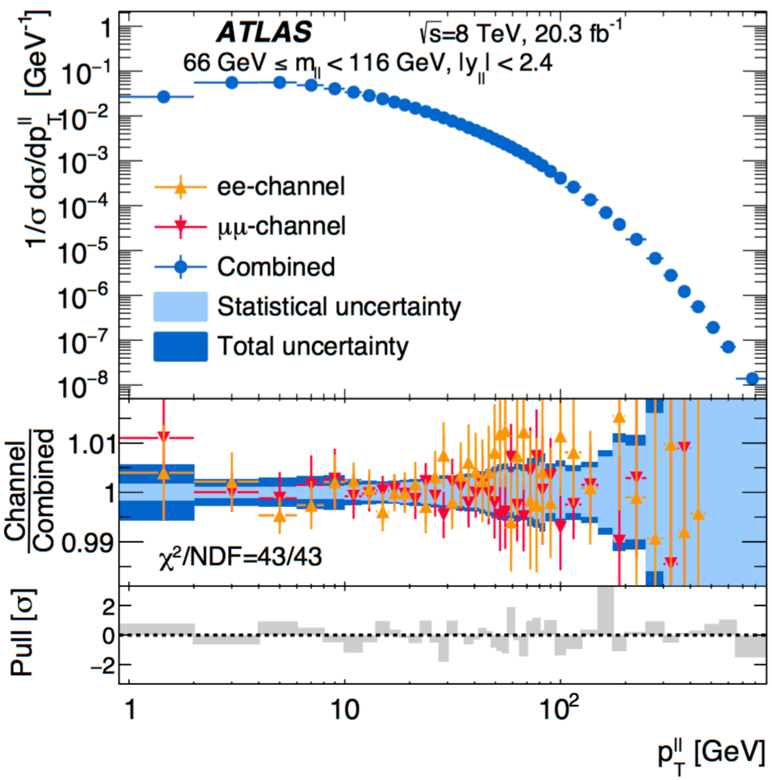


To be updated:
new σ_{tt}= 818 ±8 (stat) ±27 (syst) ±19 (lumi) ±12 (beam) pb

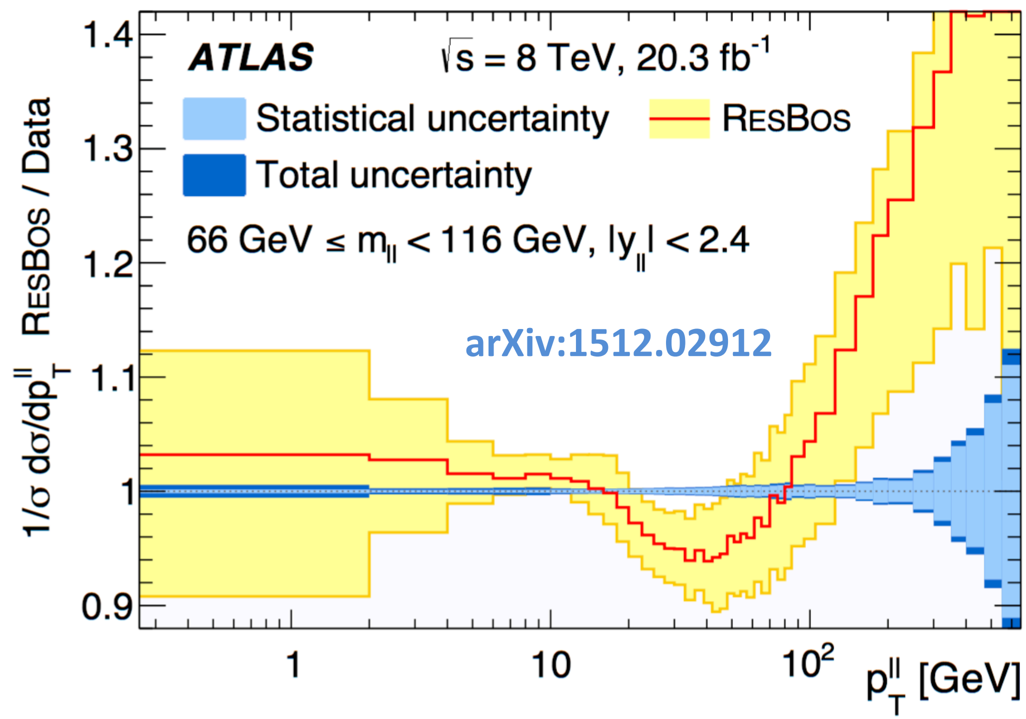
factor 6 reduction in statistical uncertainty

Z p_T measurement

- From the experimental point of view, very precise measurement, ideal for probing QCD
- **Low p_T region**: dominated by the emission of soft partons (resummation and shower models)
- **High p_T region**: dominated by the emission of hard partons (PDFs)



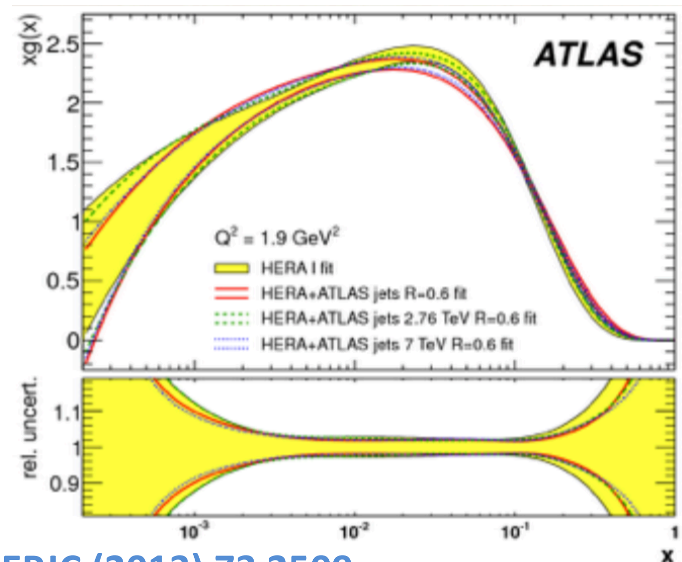
ATLAS measurements use both ee,μμ channels (compatible accuracy). The combined result is accurate to better than 0.5% for p_T < 100 GeV range



Ongoing efforts in extracting PDFs using resummed calculations

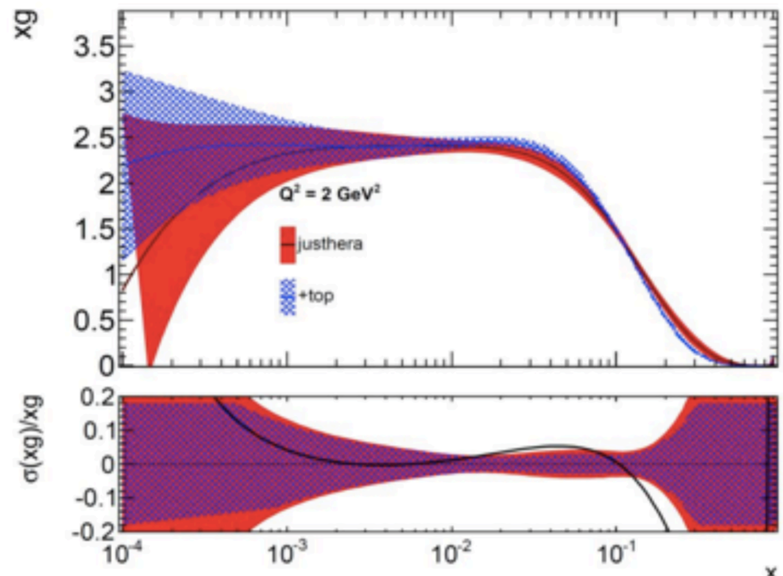
Measurements for high x gluon

- Jet and top pair production data can put important constrain on gluon PDF at high x:
  - **jet**: correlation between α_s and gluon
  - **top-quark**: $t\bar{t}$ production at the LHC probes high-x gluon ($x \approx 0.1$): g(x), α_s and the top-quark mass
- The impact of the LHC 7 TeV inclusive jet data (ATLAS official) and top quark production (A. Cooper-Sarkar) on proton PDFs was investigated; these were NLO analyses
- In both the analyses, data included in a combine fit with the HERA-I inclusive DIS cross sections



EPJC (2013) 73 2509

Adding inclusive jet data:
harder high-x gluon



A. Cooper-Sarkar, PDF4LHC, March 2016

Adding top p_T, $t\bar{t}$ mass, $t\bar{t}$ y:
softer high-x gluon

Measurements for high x gluon

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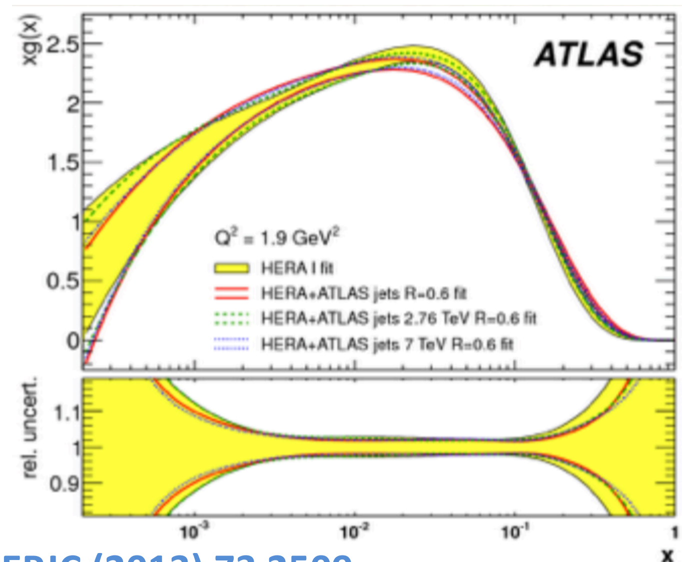

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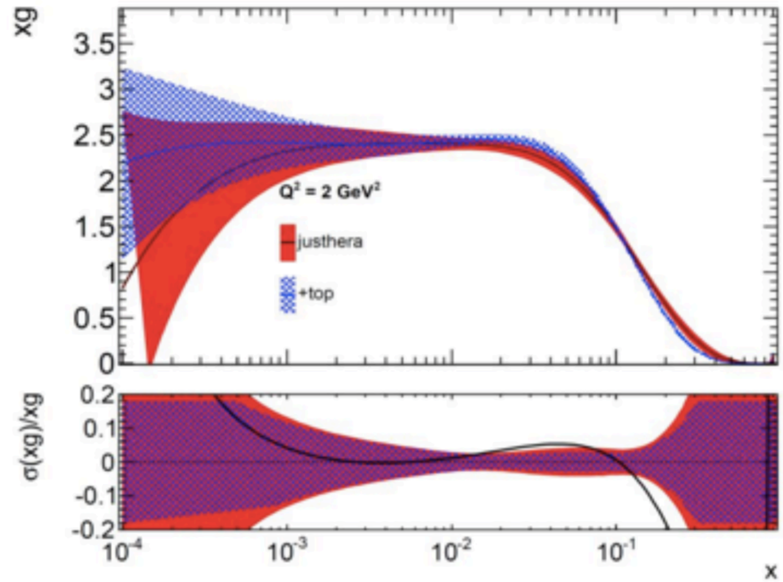
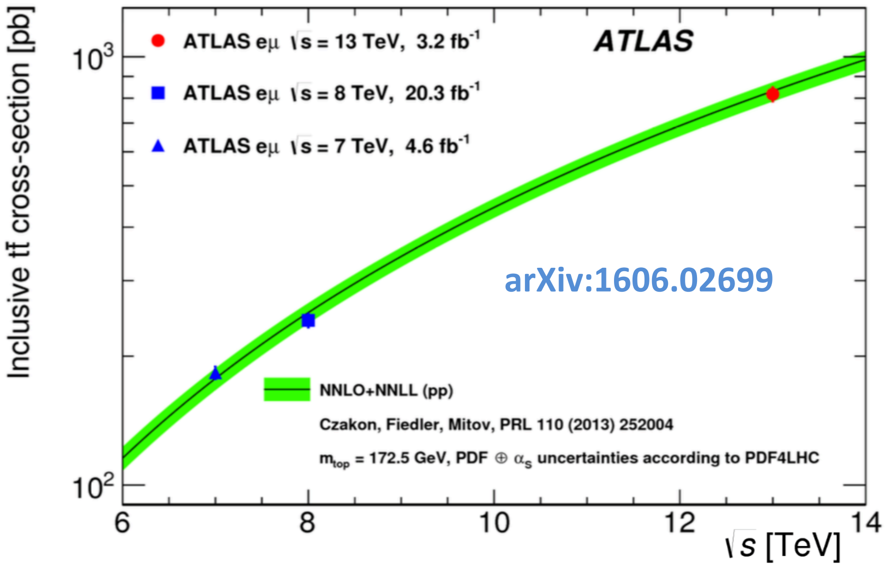


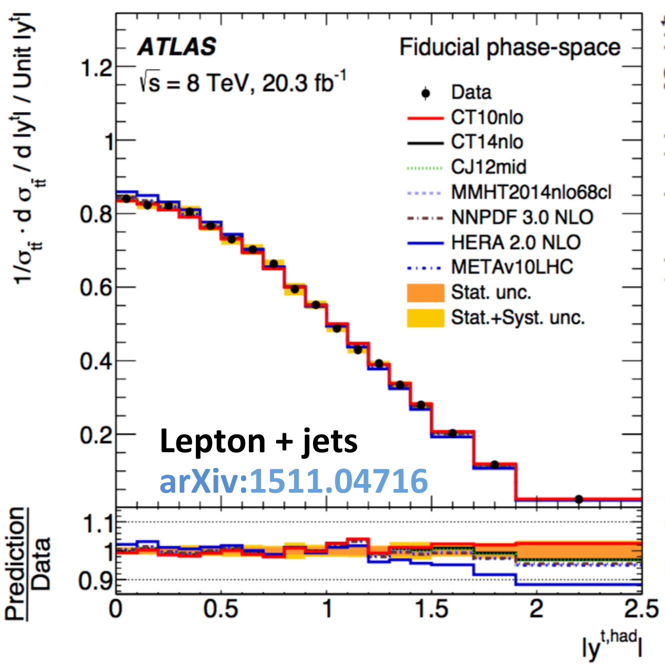
A. Cooper-Sarkar, PDF4LHC, March 2016

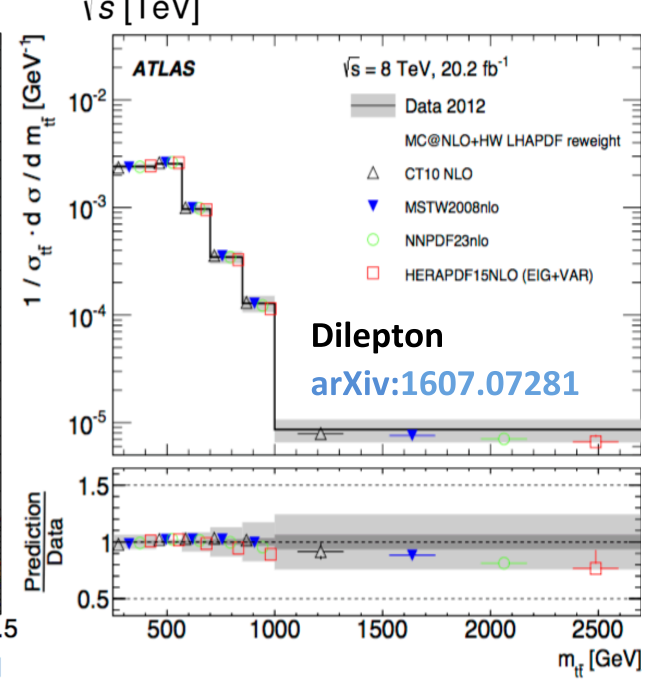
Need for better theory (NNLO + HO EW effects); maybe resummation for top p_T?

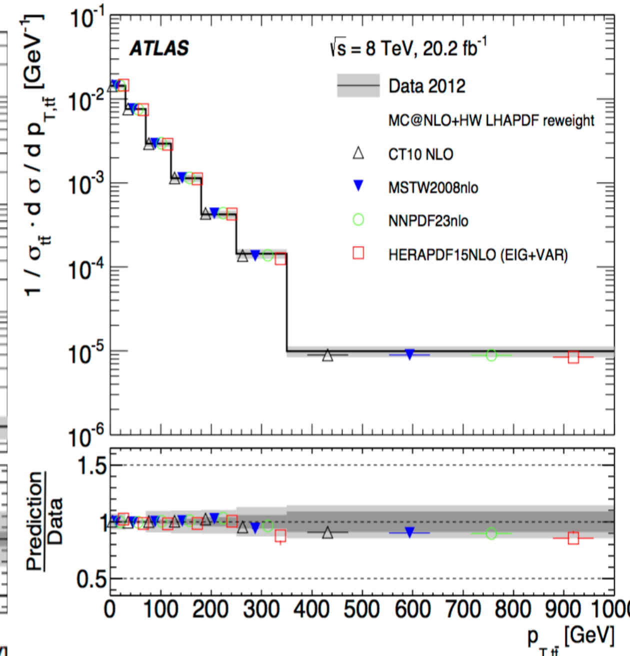
Top measurements @ 7,8,13 TeV



- Production mainly in gluon-gluon channel → sensitivity to gluon PDF ($x > 0.1$)
- Tails at large m_{tt} or high p_T sensitive to quark PDFs
- Results consistent with prediction based on NNLO + NNLL or POWHEG & PYTHIA
- New measurements @ 8,13 TeV available soon





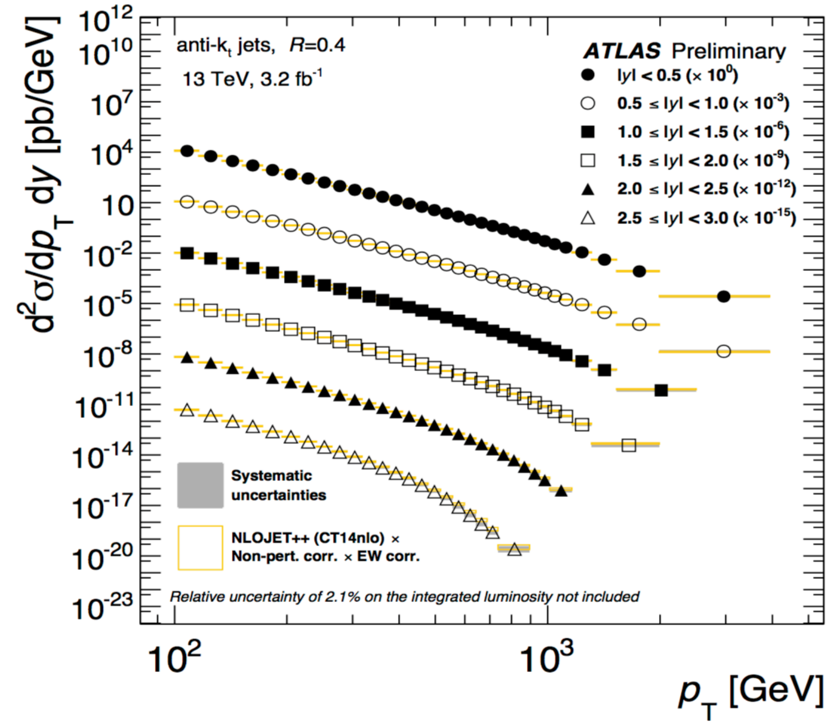


Inclusive jet production at Run II

ATLAS-CONF-2016-092

- Jet measurements of 2015 bring a new kinematic reach (reaching up to p_T = 4 TeV), interesting to observe if it will help to further constrain PDFs

- Exploiting ratio measurements to better control the dominant Jet Energy Scale (JES) uncertainty, as done for 2010 data (arXiv: 1304.4739), would enhance its impact

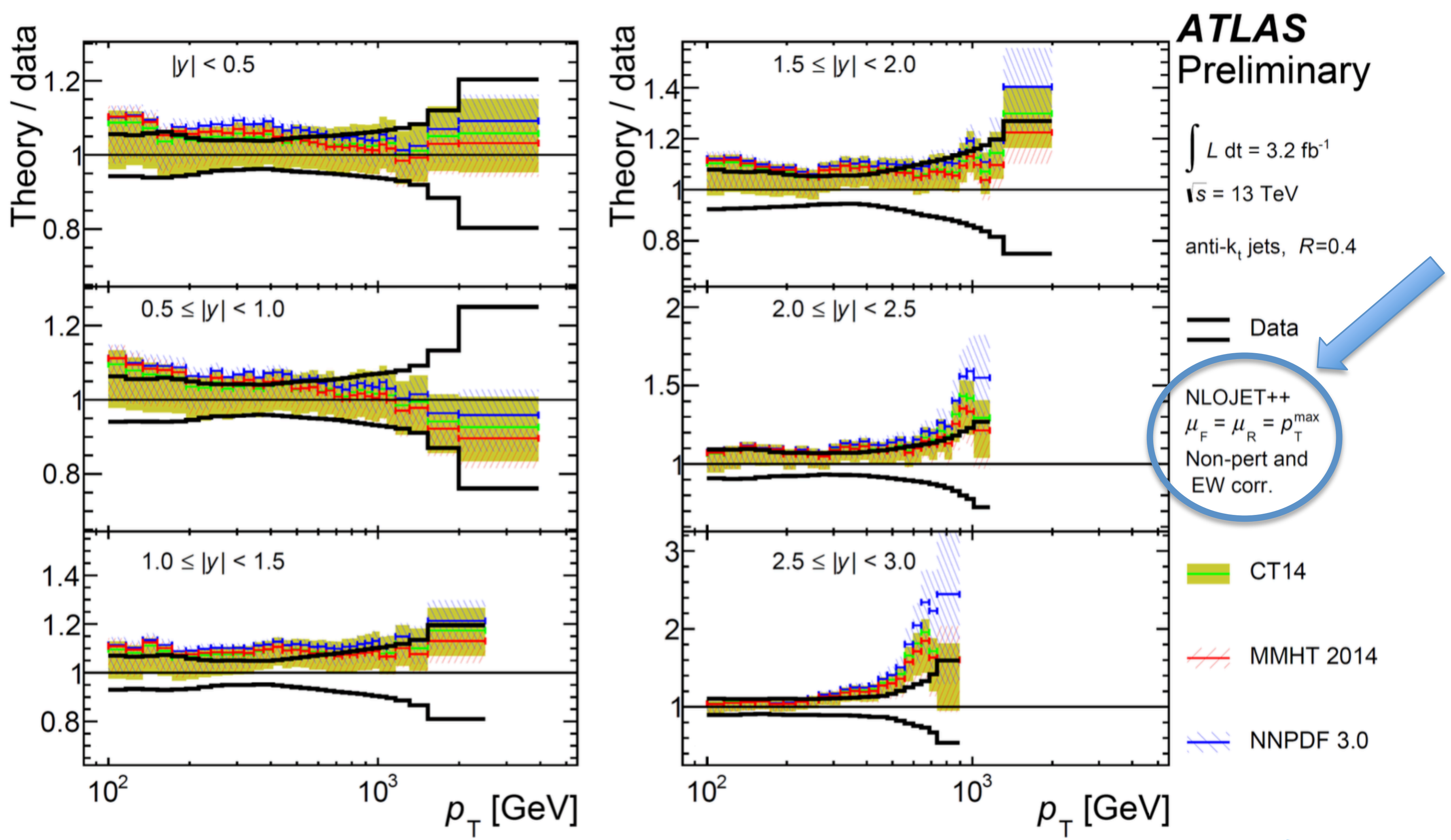


New results at 13 TeV: good agreement with SM
NNLO calculations for jets: more leverarm to the test of SM

- In the following slides, **double-differential inclusive jet cross section with 2015 data**
  - Integrated luminosity of 3.2 fb^{-1}
  - Following the procedure already outlined for 2.76 and 7 TeV analysis
  - PDF sensitivity at high p_T and in the forward region

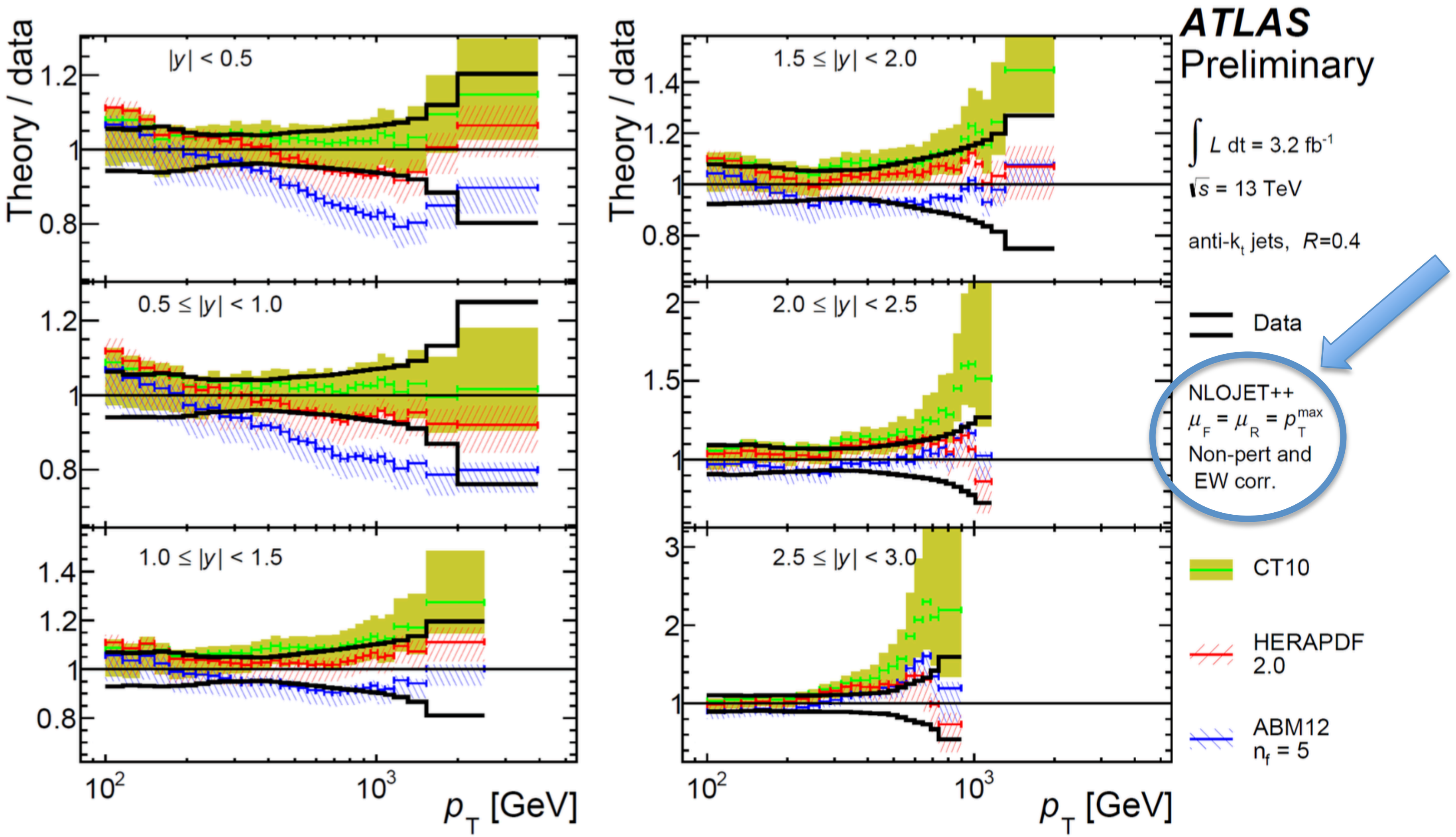
Double differential inclusive jet cross section

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



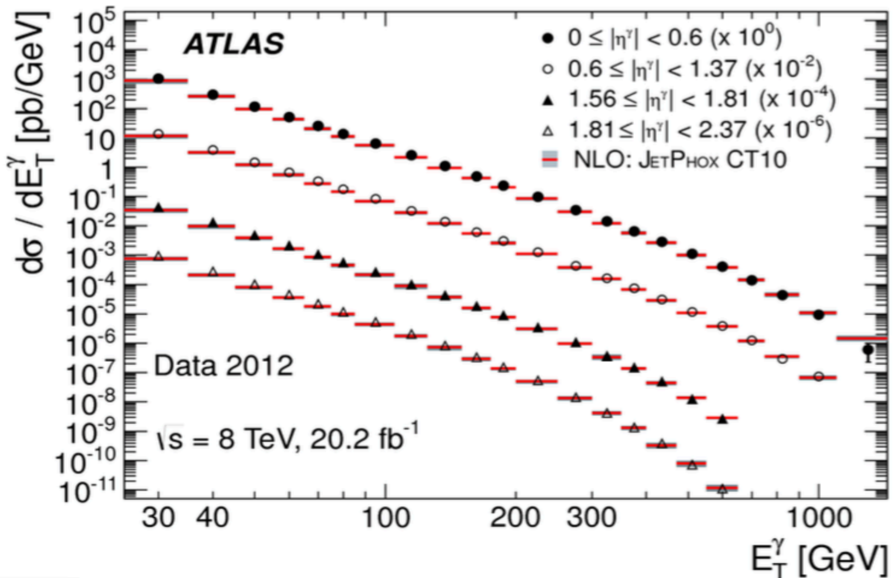
Double differential inclusive jet cross section

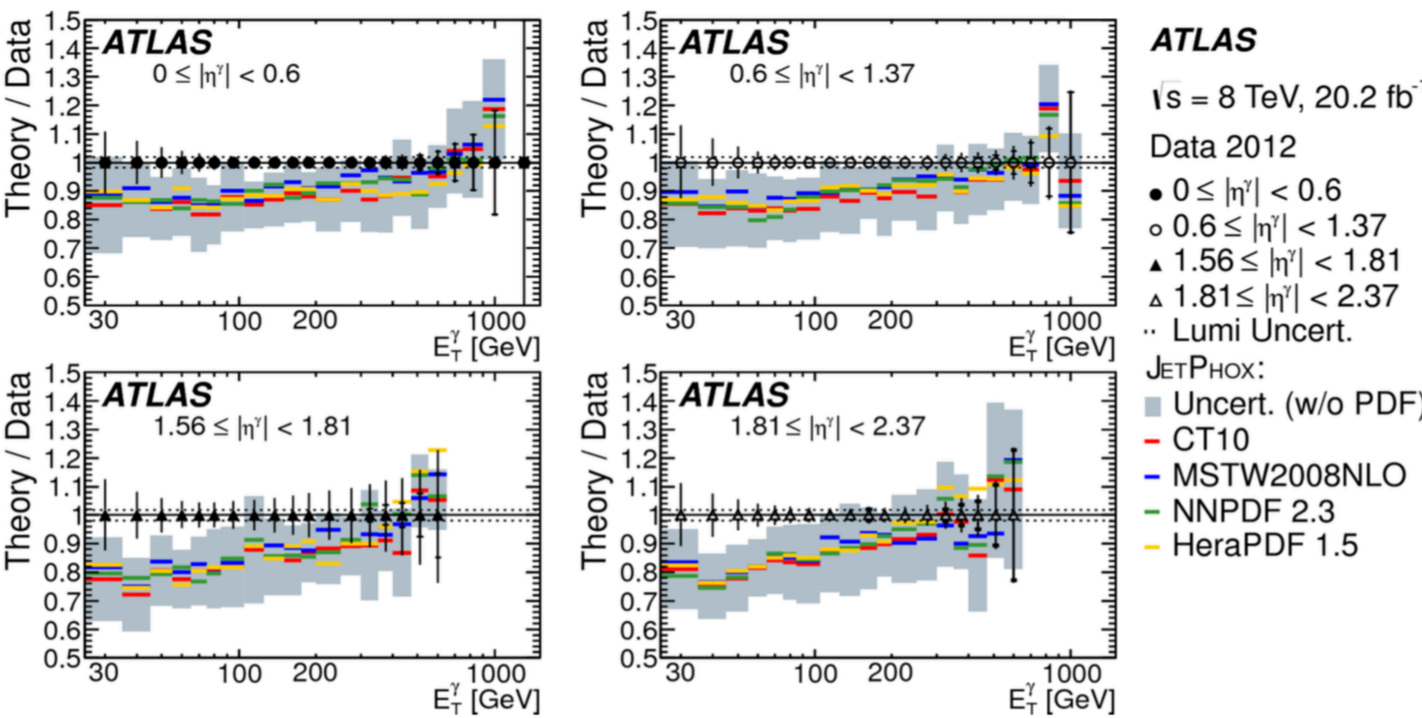
- **CT10 prediction larger than data, while ABM12 is lower; HERAPDF2.0 is ok**
  (but quantitative analysis needed due to large correlations between bins)



Isolated photons @ 8 TeV

- Dominant production: q g → q γ
- Constraint on gluon at medium x e.g. x ~ 0.1
- Range: 25 GeV < E_T < 1500 GeV
- Dominant systematic uncertainties:
  - Energy scale
  - Background correlations
- JetPhox: low in normalisation (~20% lower than data)
- NLO predictions: large scale uncertainties

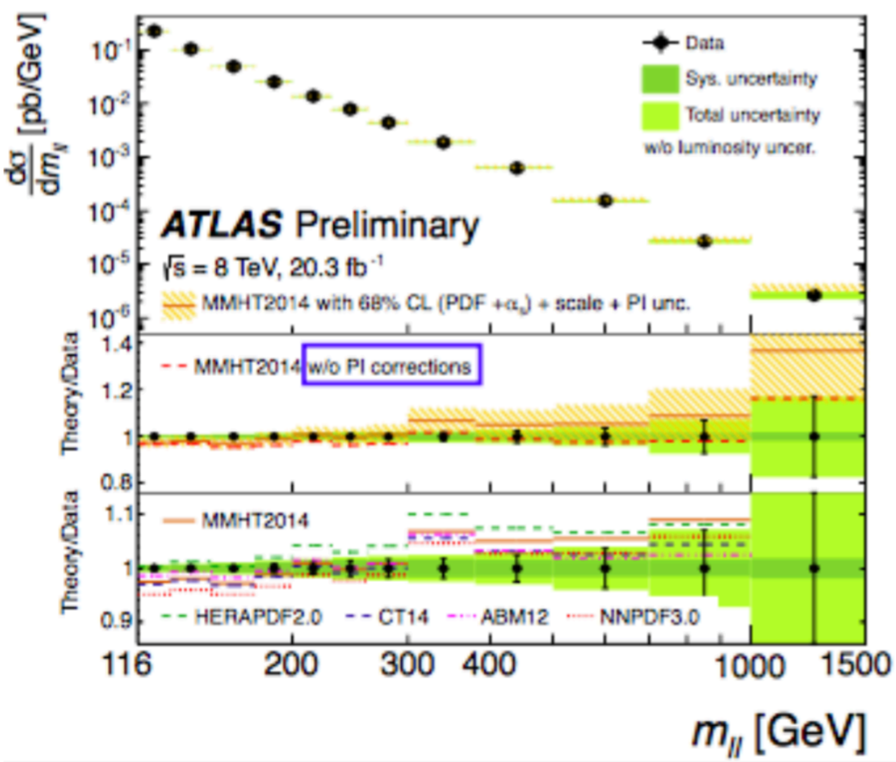




arXiv:1605.03495

High mass Drell Yan @8 TeV: comparison to theory

- ATLAS high mass Drell Yan at 8 TeV (published now) **arXiv:1606.01736**
- The measured cross sections are compared to theoretical predictions using a selection of recent PDF sets
- Theory = NNLO pQCD $\otimes$ NLO EW + LO photon-induced (PI); pQCD uses MMHT14 NNLO PDF
- PI uses NNPDF23qed for photon PDF ± 68% of replicas; α_s = 0.118 ± 0.001
- Scale error: envelope of μ_F and μ_R varied by factors of 2



- Theory uncertainties are larger than data uncertainties → potential for PDF constraints
- Theory generally in agreement with data
- Comparison with other NNLO PDF sets (HERAPDF2.0, CT14, ABM12, NNPDF30)
- Photon induced contribution reaches 15% at large m_{ll}
- Where PI contribution is large, theory uncertainty dominated by the PI piece
- Else PDF uncertainty dominates theory precision

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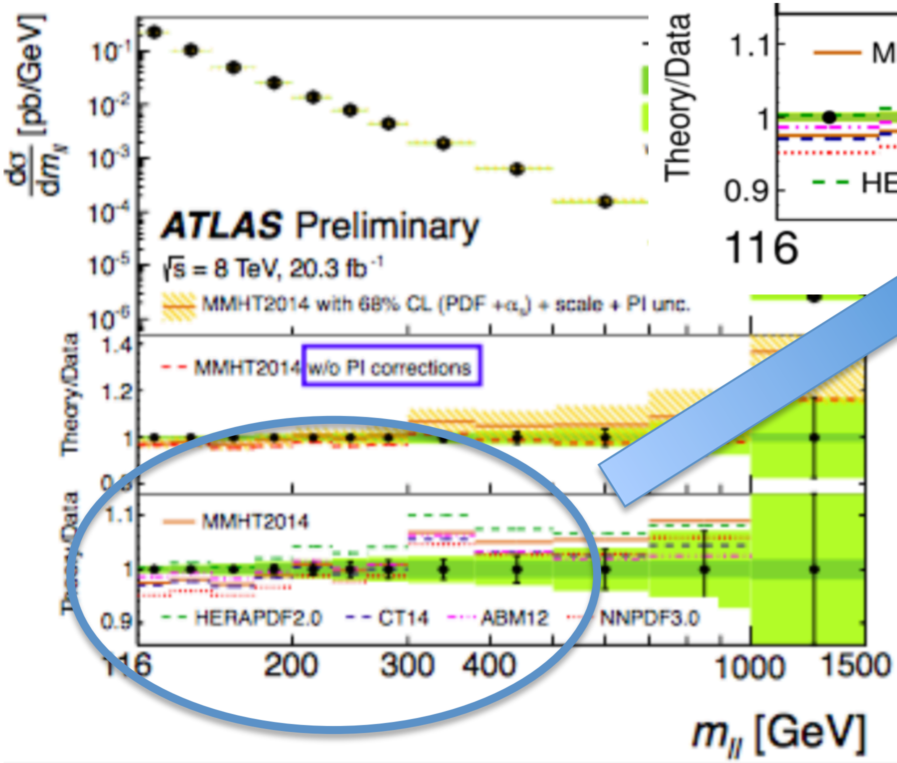
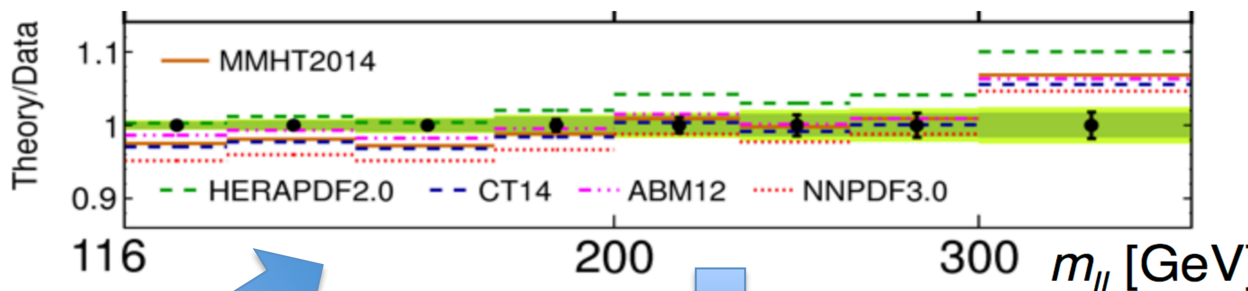
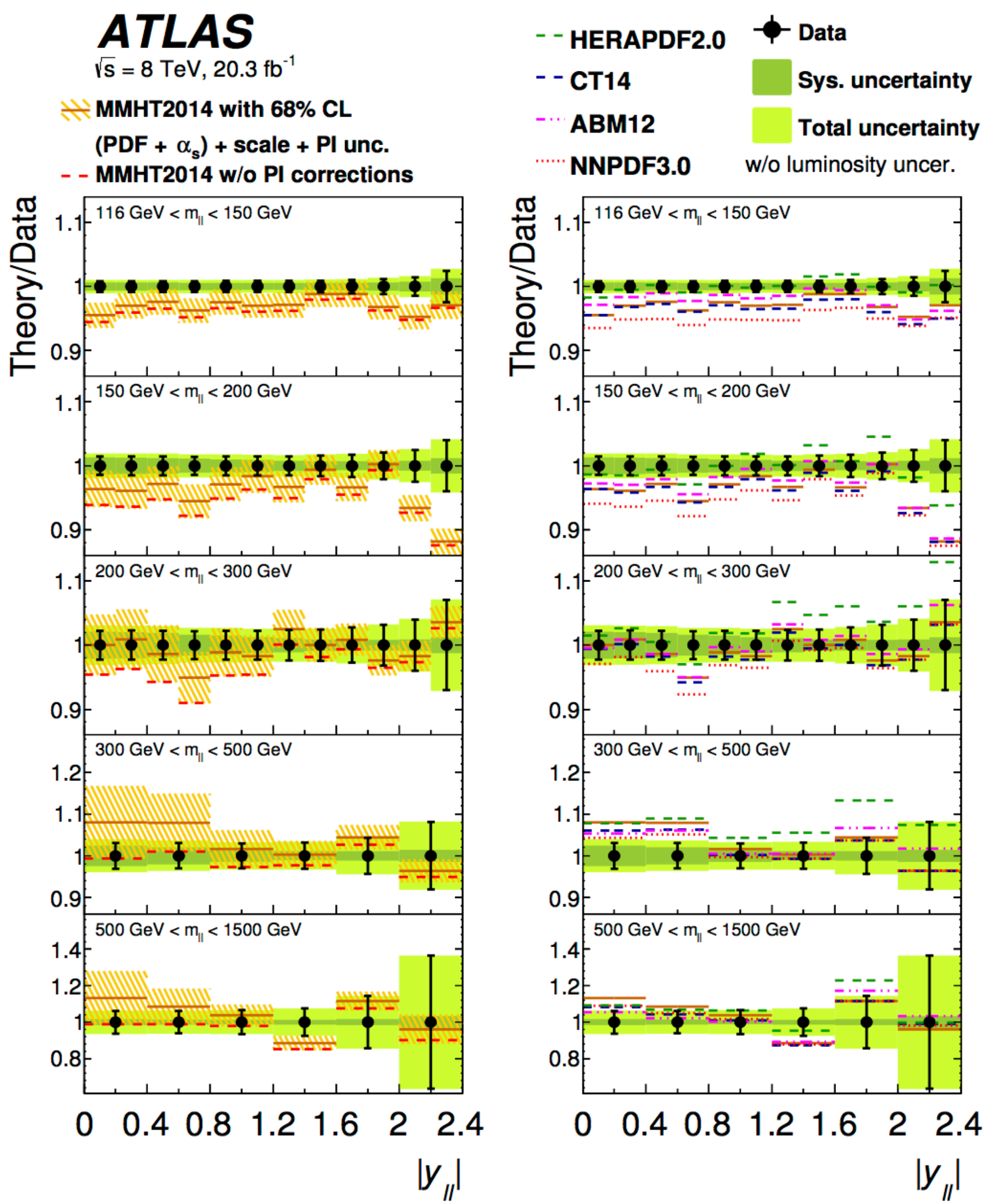




At low m_{ll} observe large spread of predictions from different PDFs compared to experimental accuracy → **large potential to constrain PDFs!**

High mass Drell Yan @8 TeV: comparison to theory



$$\frac{d^2\sigma}{dm_{ll}d|y_{ll}|}$$ **data/theory ratio**

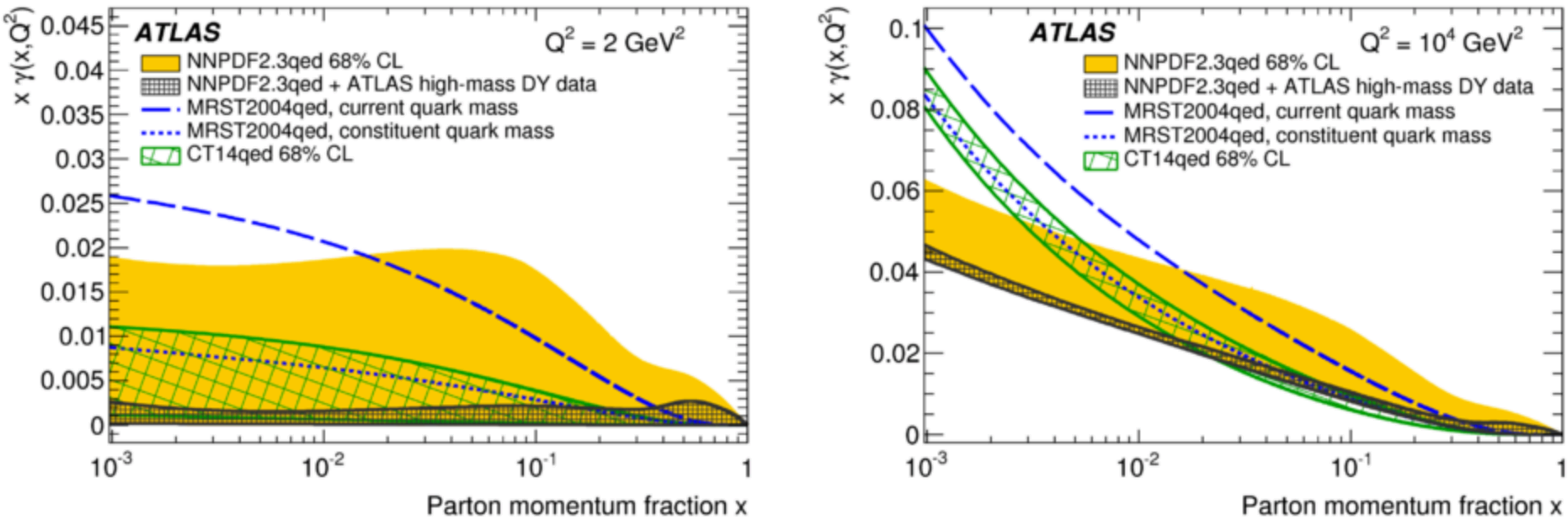
- Photon-induced (PI) contribution increases with m and decreasing $|y_{ll}|$
- PDF uncertainties calculated for each PDF scaled to 68% CL
- Compatibility of data to predictions with other PDFs test with χ^2 function

	$m_{\ell\ell}$	$\lvert y_{\ell\ell}\rvert$	$\lvert\Delta\eta_{\ell\ell}\rvert$
MMHT2014	18.2/12	59.3/48	62.8/47
CT14	16.0/12	51.0/48	61.3/47
NNPDF3.0	20.0/12	57.6/48	62.1/47
HERAPDF2.0	15.1/12	55.5/48	60.8/47
ABM12	14.1/12	57.9/48	53.5/47

Data in agreement with predictions

(χ^2 probability at worst ~6%)

Photon PDF



- Assess impact of new data on photon PDF → use Bayesian reweighting of NNPDF replicas
- Each replica receives a weight according to χ^2 function
- Poorly fitting replicas receive a small weight; replicas fitting the data well receive a large weight
- New PDF central value is estimated from mean of weighted replicas
- New PDF uncertainty determined from 68% CL
- **Original NNPDF uncertainty dramatically reduced in reweighting**

Conclusion

- In this talk, I’ve reported a summary of the latest ATLAS measurements regarding PDFs
- W,Z @13 TeV
- Ratio cross section measurements
- Top measurements
- Double differential inclusive jet cross section
- Isolated photons @8 TeV
- High mass Drell-Yan @8TeV
- Looking for new data coming and new interesting analyses