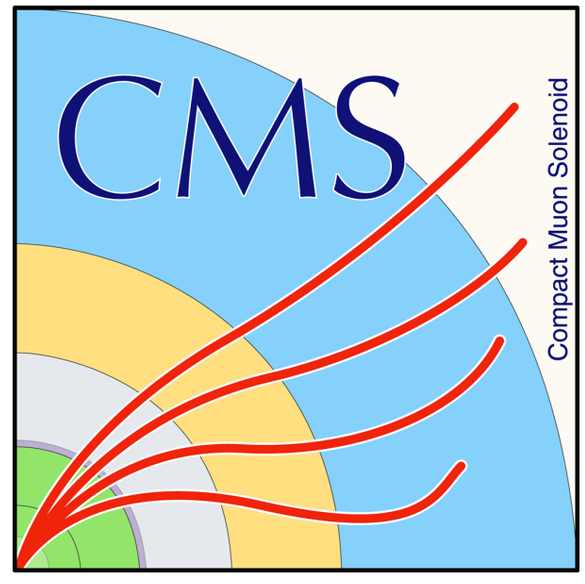


Experimental inputs to PDF fits

Higgs 2020

October 27th, 2020

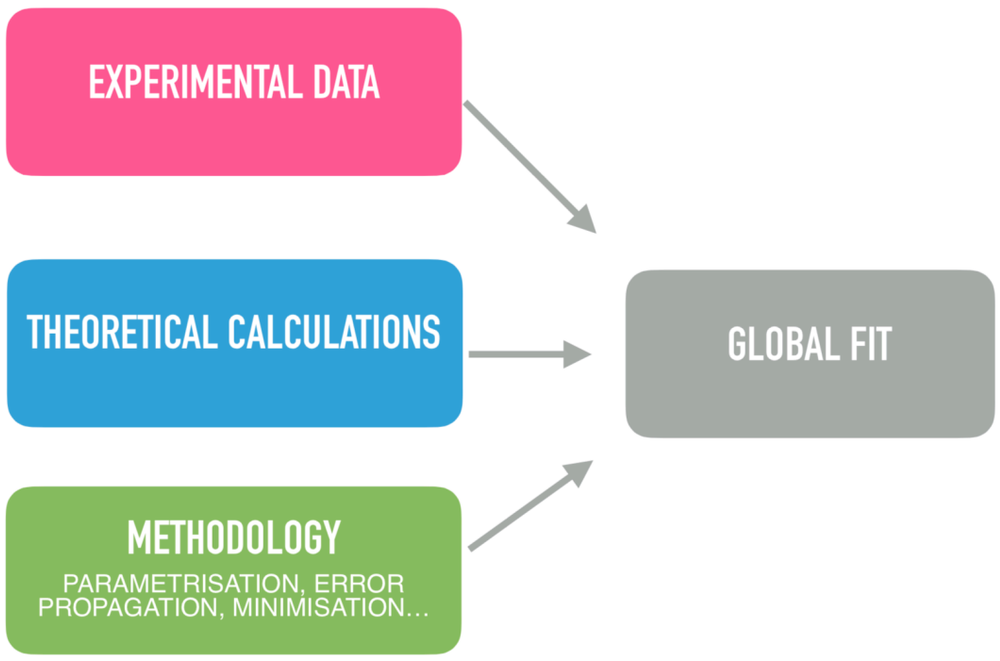
Simone Amoroso (DESY)
on behalf of the **ATLAS**
and **CMS** Collaborations

Introduction

- Knowledge of Parton Distribution Functions is a prerequisite for making predictions for hadron colliders
  - Precise knowledge of the PDFs and their uncertainties is crucial for a successful LHC physics program
- SM measurements can be used to improve our knowledge of PDFs
- As accurate theory predictions become available more and more SM processes can be incorporated in PDF fits

$$f_i(x, Q^2)$$

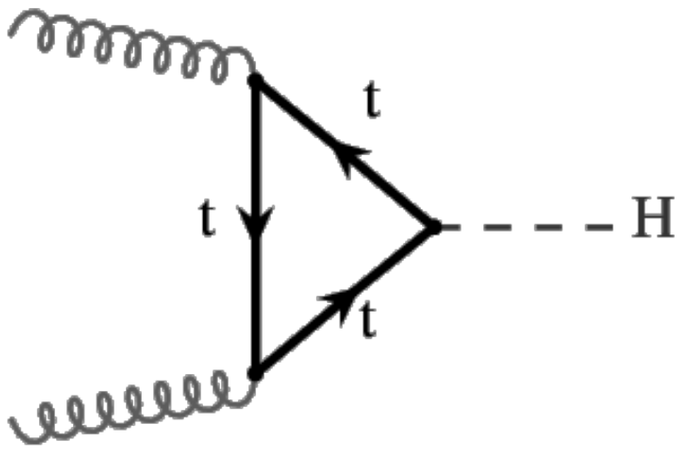
Determined by data — Predicted in pQCD



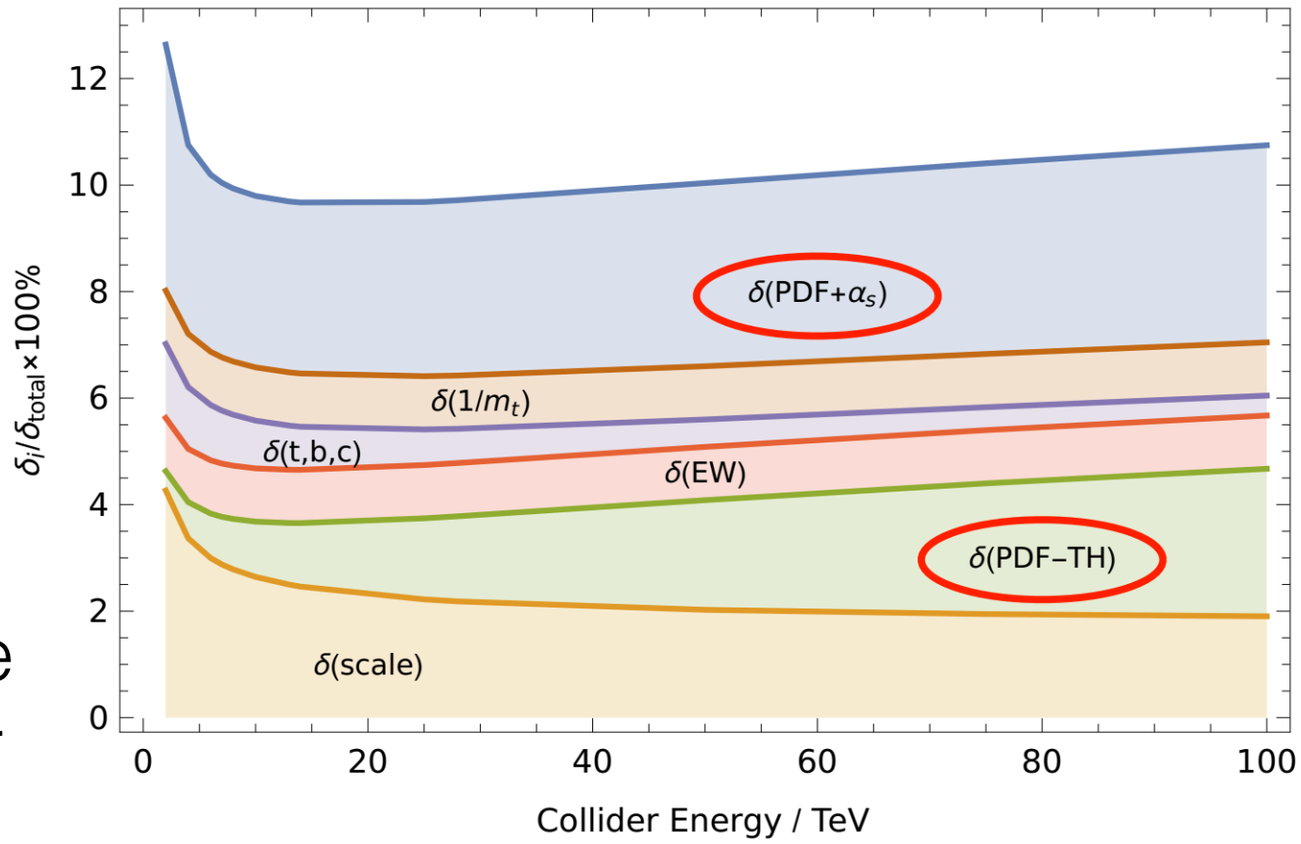
- Interplay between theory and experimental data, in a sort of “global consistency test” of the SM

Higgs physics

- Precise characterisation of the Higgs sector is one of the main goals of the LHC physics program



ggF Higgs cross-section



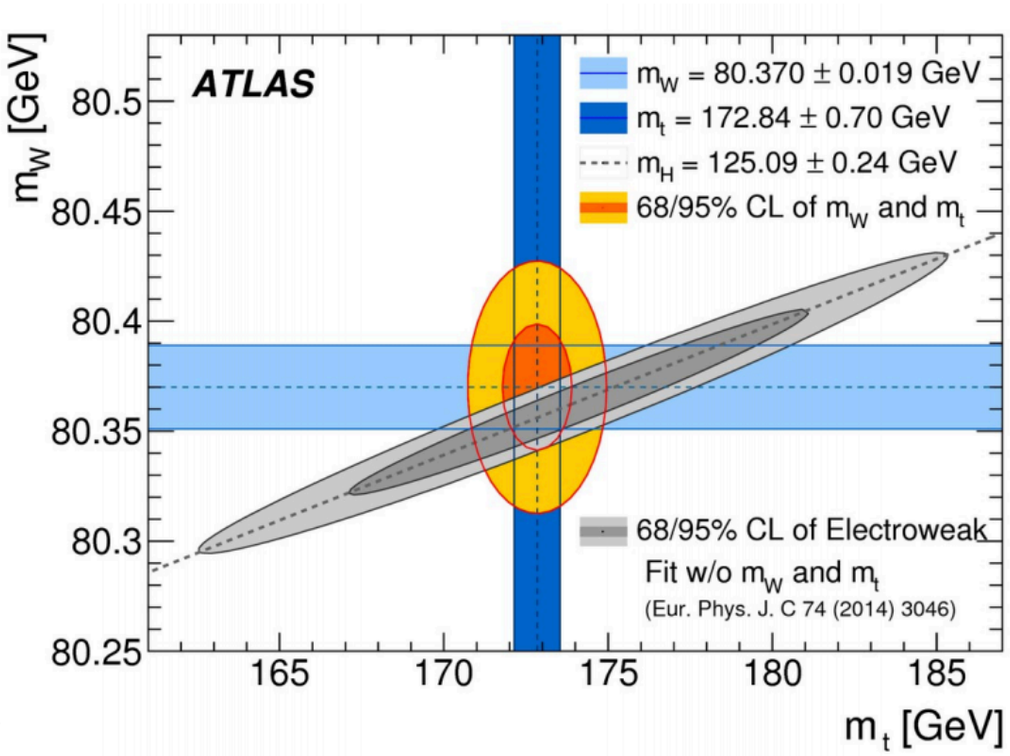
- And uncertainties due to the knowledge of PDFs are an important limiting factor in Higgs measurements

HL/HE-LHC YR, [1902.00134]

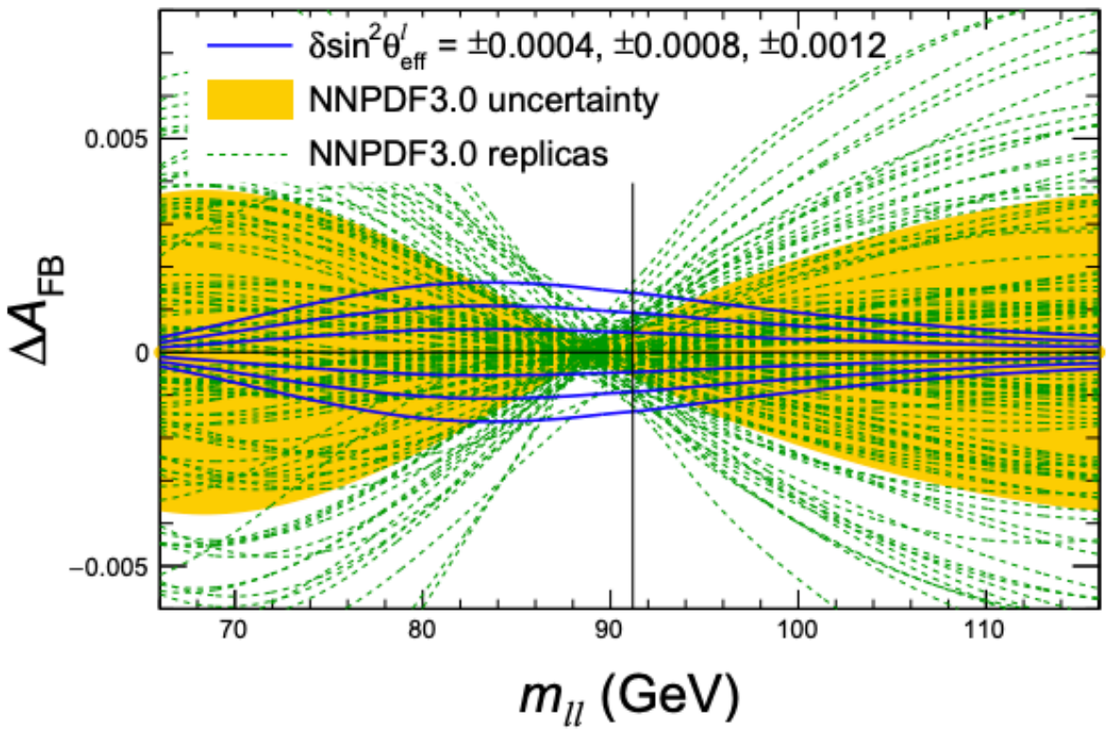
- Not just relevant for gluon-gluon fusion, but impacting also associated production, VBF, di-Higgs

EW precision measurements

- LHC now starting to be competitive with LEP/Tevatron



EPJC 78 (2018) 110

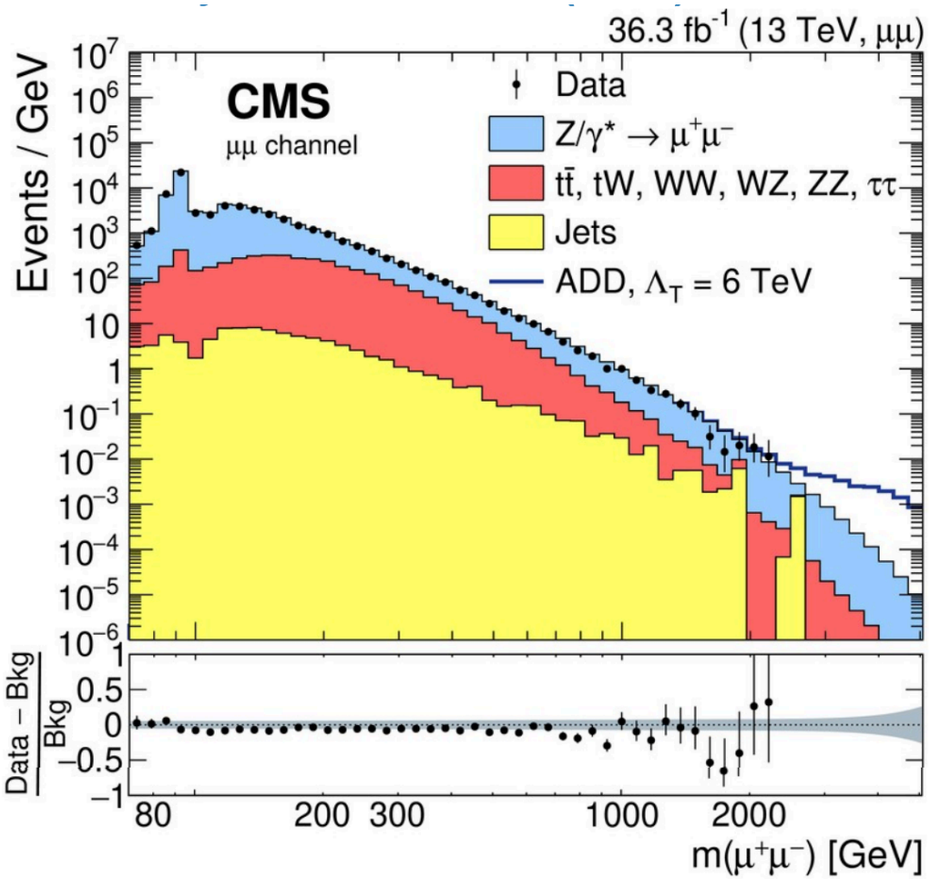


EPJC 78 (2018) 701

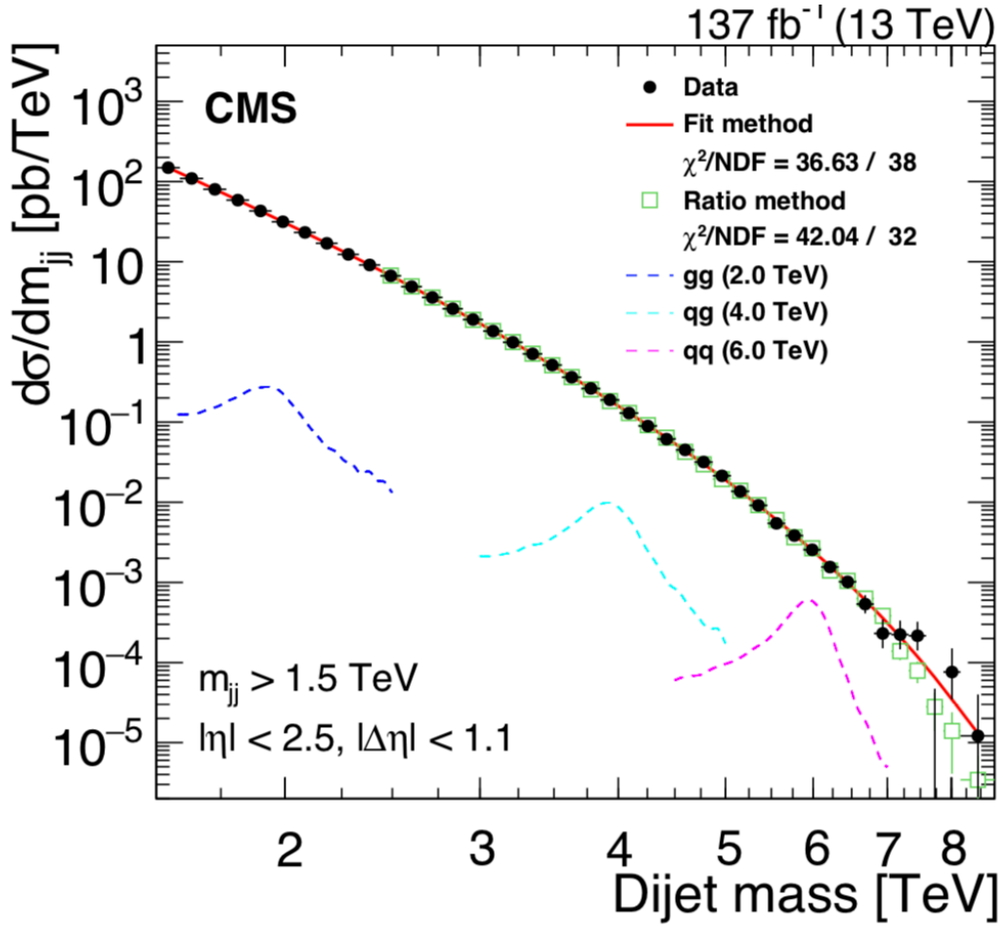
- Both measurements suffer from very large PDF uncertainties
  - $\sin^2\theta^{\text{eff}}_W$: Reduction of A_{FB} through "PDF dilution"
  - m_W: PDF induced W polarisation affects p_T^l (+ HF production)

BSM searches

- Searches for new particles and forces at high masses and high p_T are also limited by the knowledge of PDFs at high-x
- Not a lot of constraining data, large impact of parametrisation and other methodological choices
  - I.e.~20% PDF uncertainty for a 3 TeV Z' production

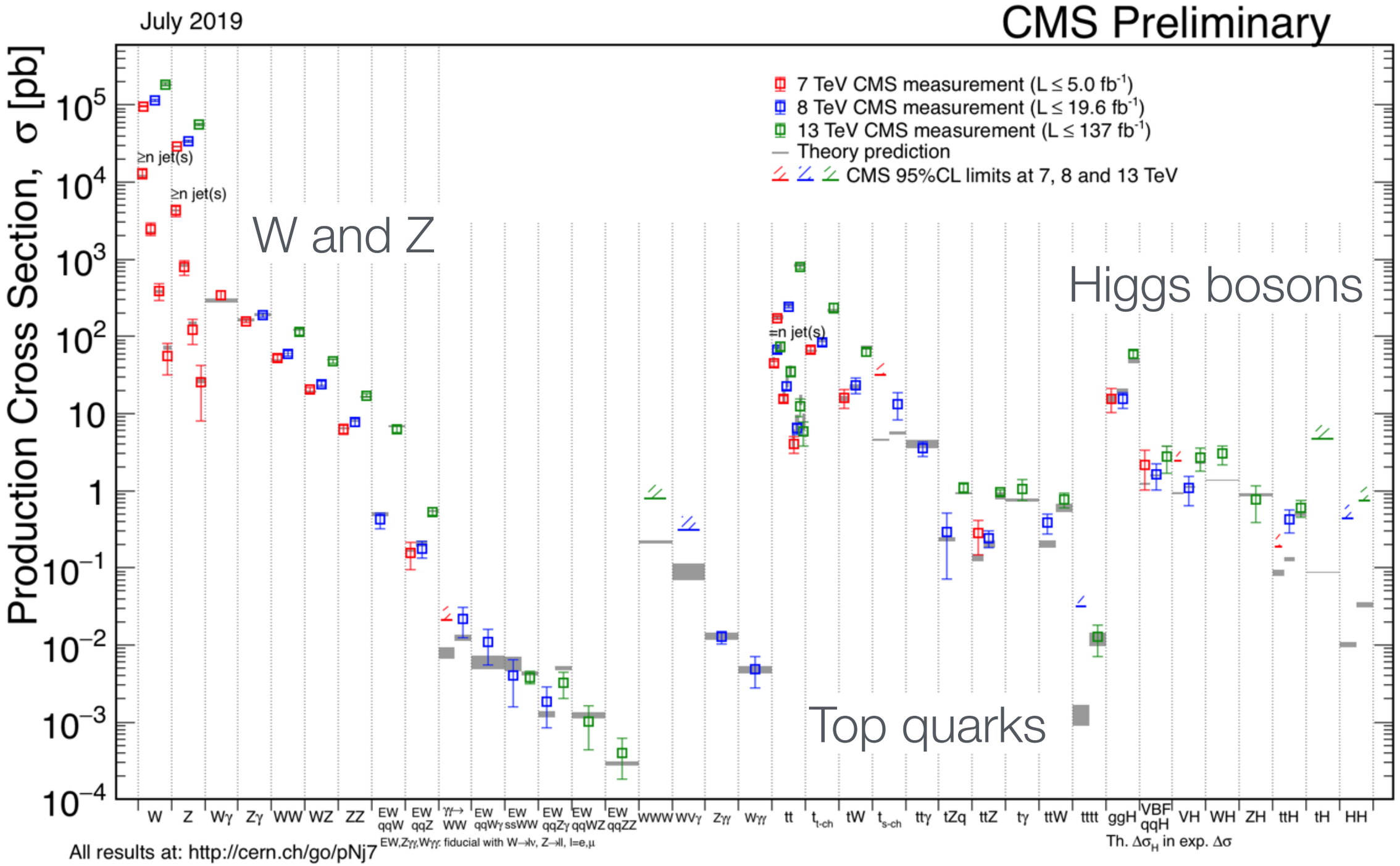


JHEP 04 (2019) 114



JHEP05 (2020) 033)

SM Cross-sections

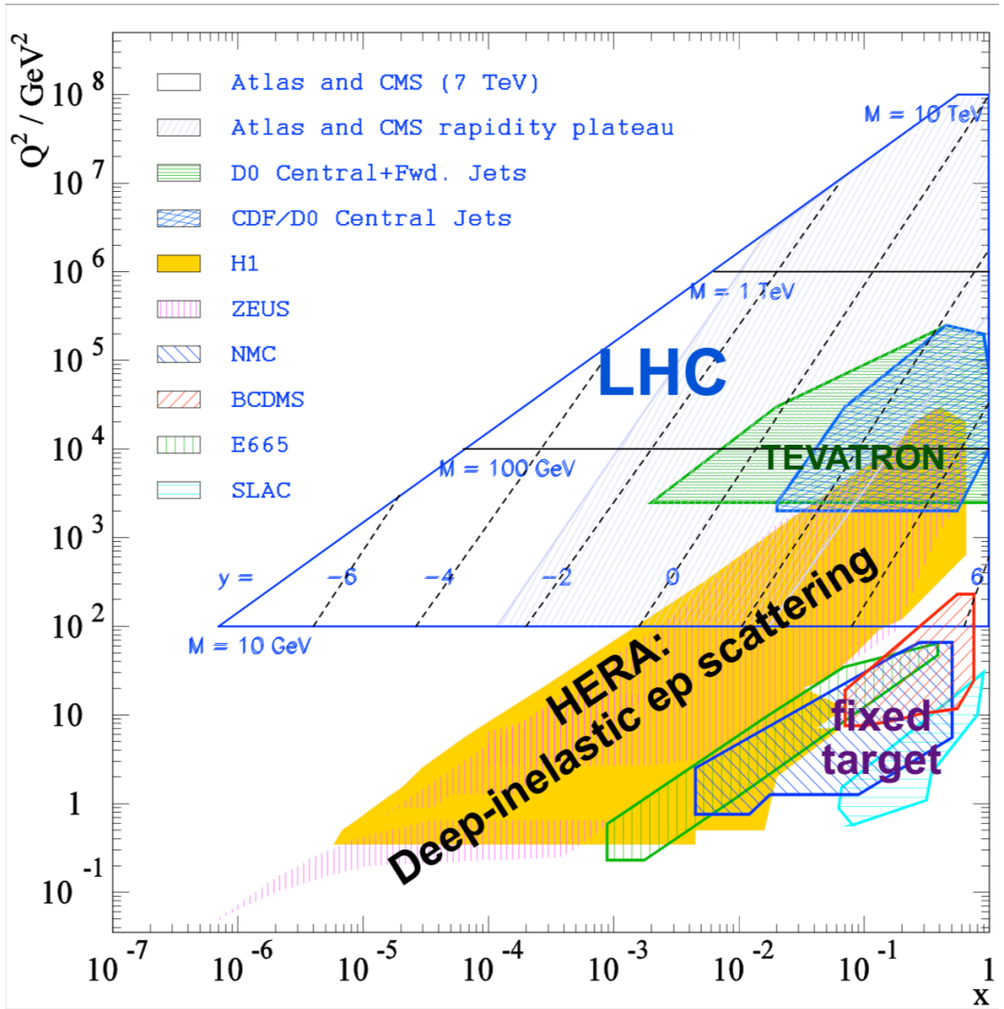


- Impressive number of measurements by the LHC Collaborations

And PDF constraints

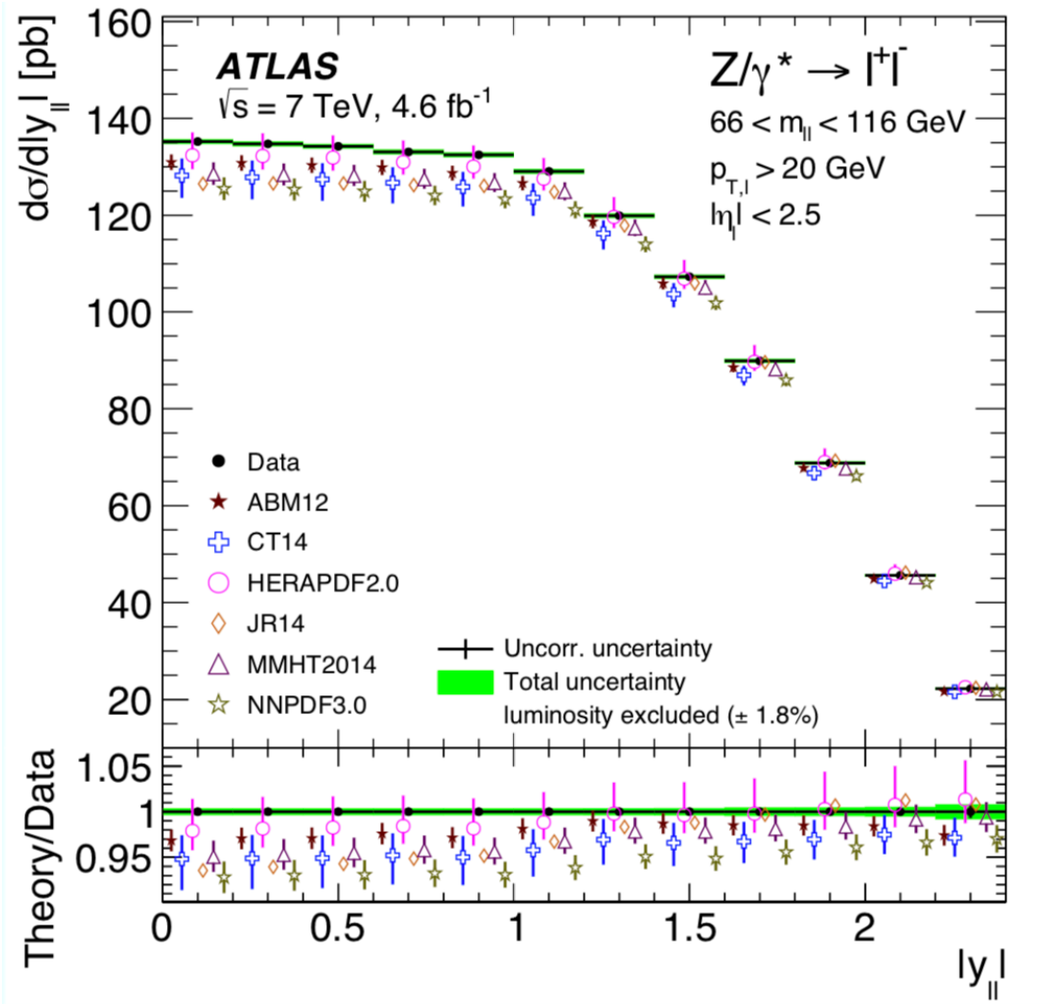
- While DIS data is still the backbone of global PDF fits, the LHC can now provide plenty of complementary information

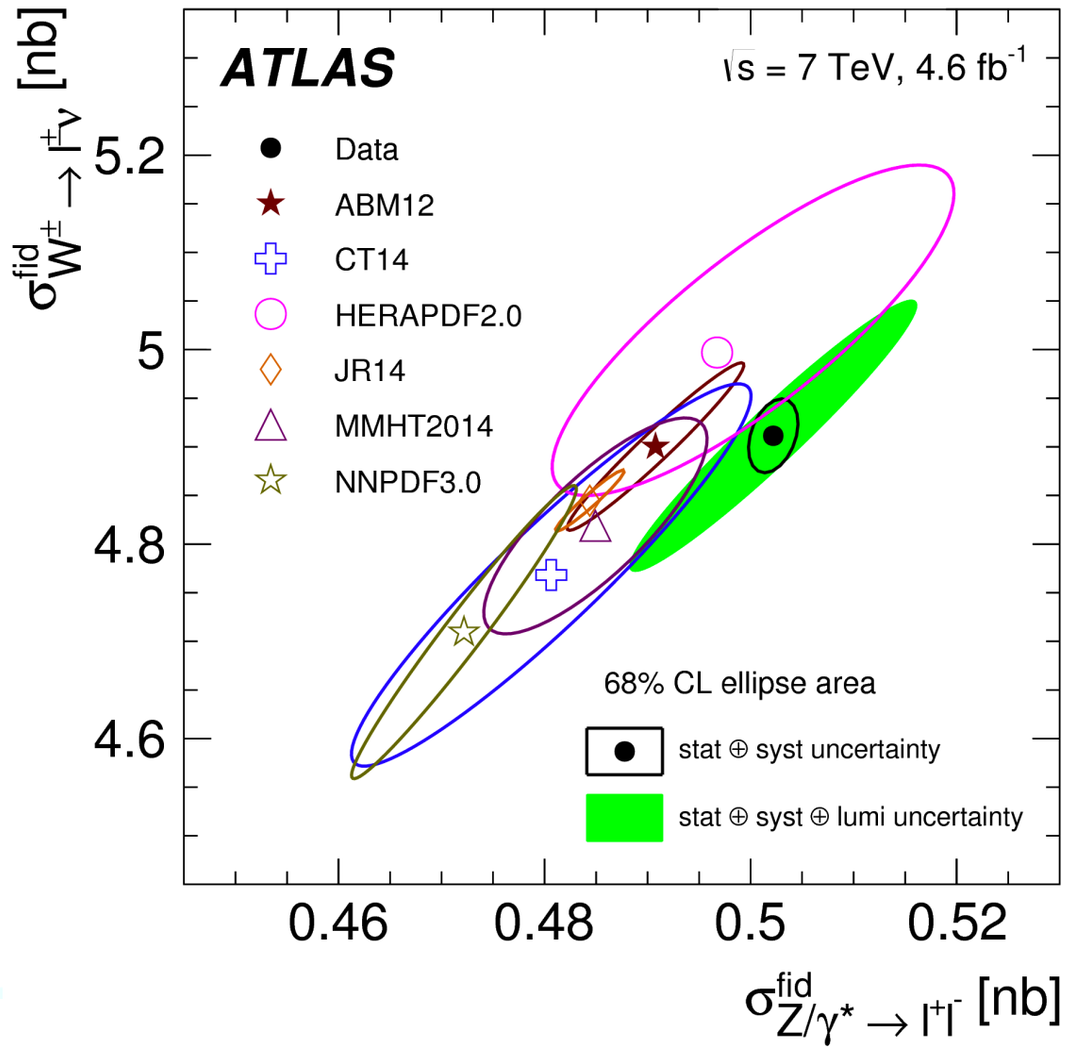
Process	PDF sensitivity
Drell-Yan	Flavour decomposition
W+charm	Strange-quark
V+jet	Medium-x gluon
Jets, dijets	High-x gluon and quark
photon+jet	Medium-x gluon
Top-pair	Medium and high-x gluon
single-top	u/d ratio at large-x



DY cross-sections 7 TeV

- W, Z cross-sections have significant impact on proton quark content
- Most precise measurement from ATLAS at 7 TeV
  - Experimental precision of 0.6, 0.5, and 0.32% for $W^{\pm}$,Z respectively

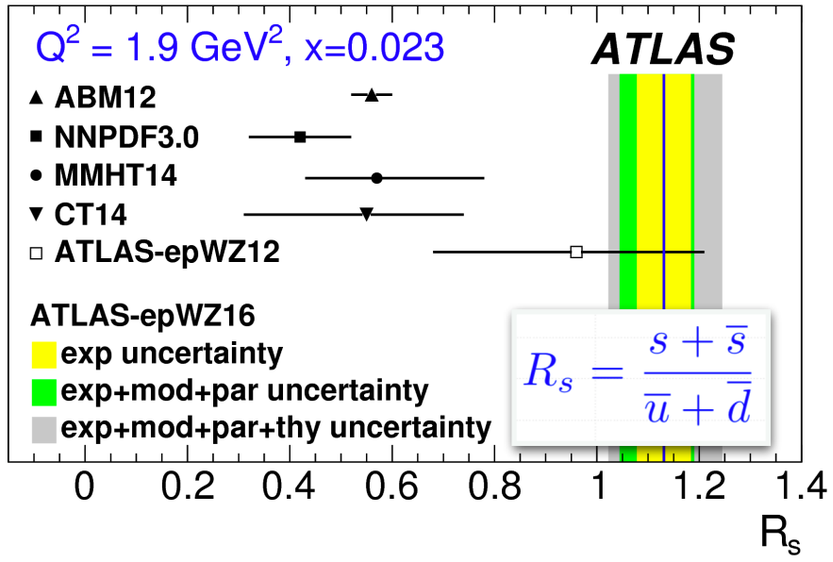


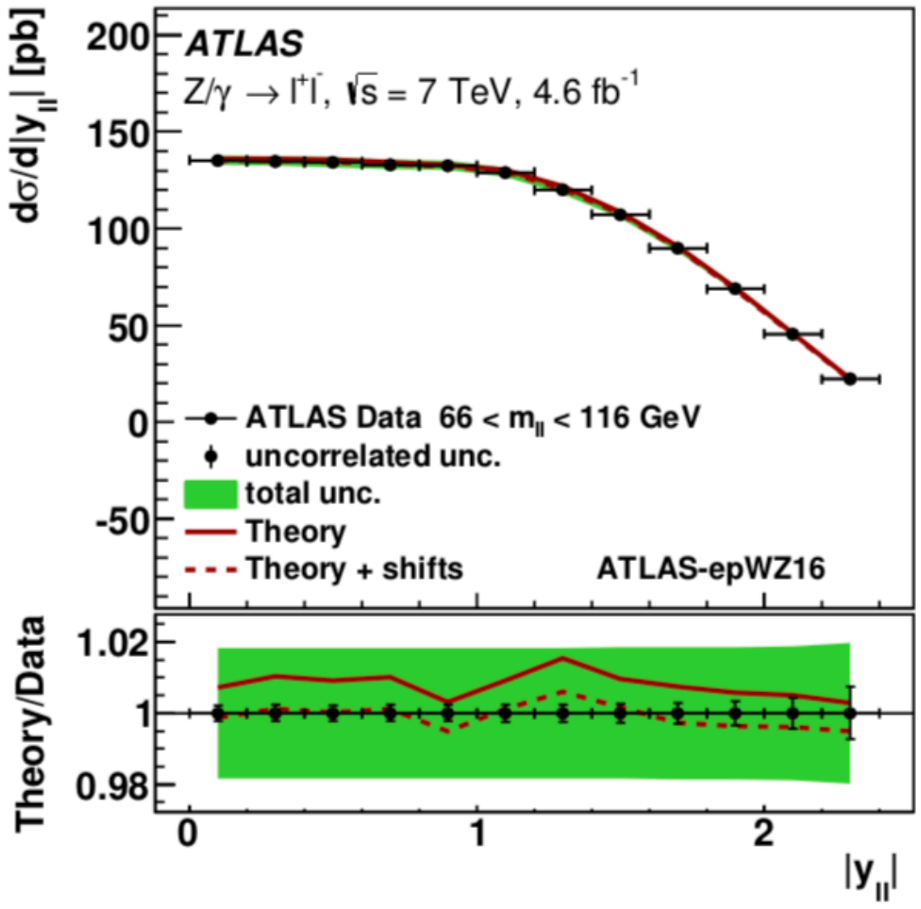


EPJC77 (2017) 367

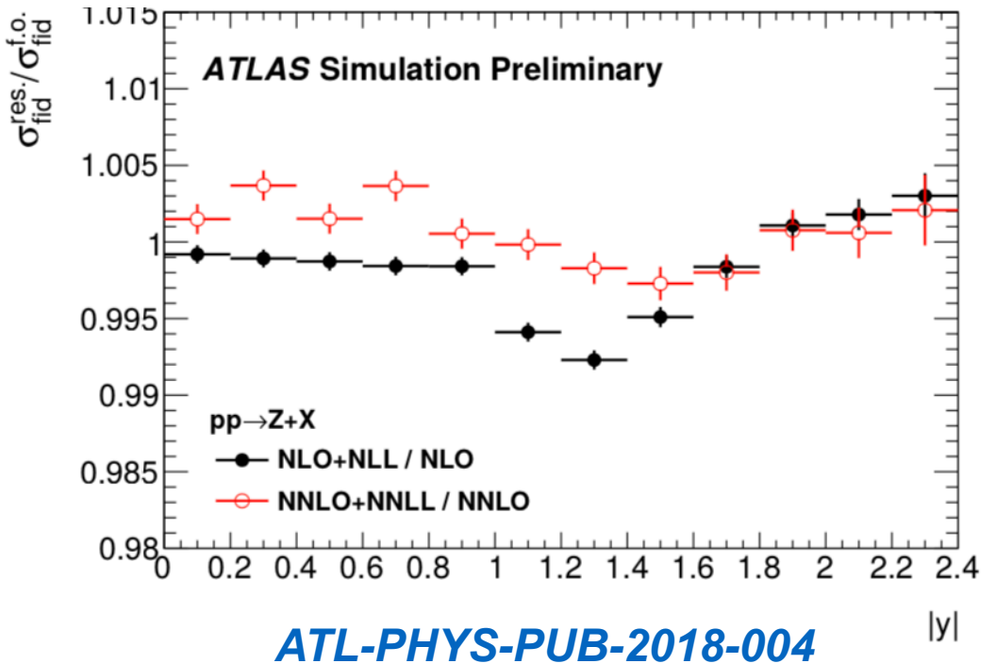
DY cross-sections 7 TeV

- Favours larger strangeness than in previous global fits
  - In tension with neutrino induced dimuon production ($\bar{\nu}s \rightarrow lc$)
  - At this level of precision theory systematics from NNLO subtraction and the effect power corrections from the lepton fiducial selections become important





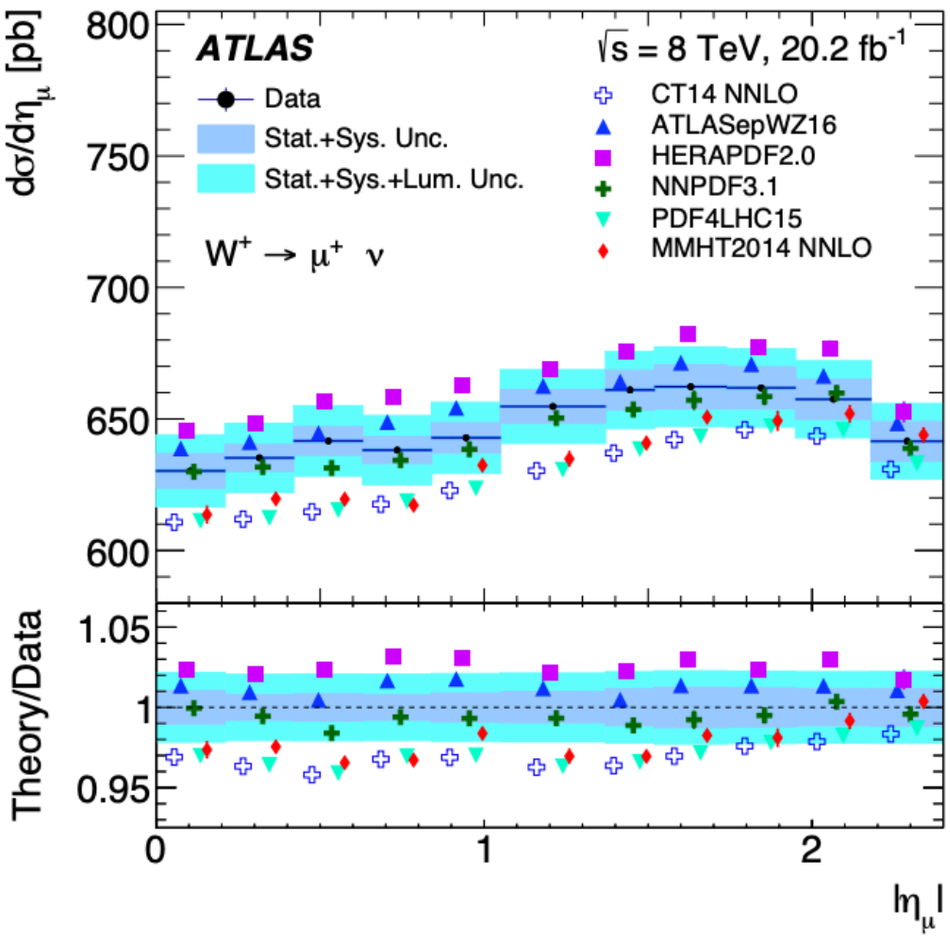
EPJC77 (2017) 367



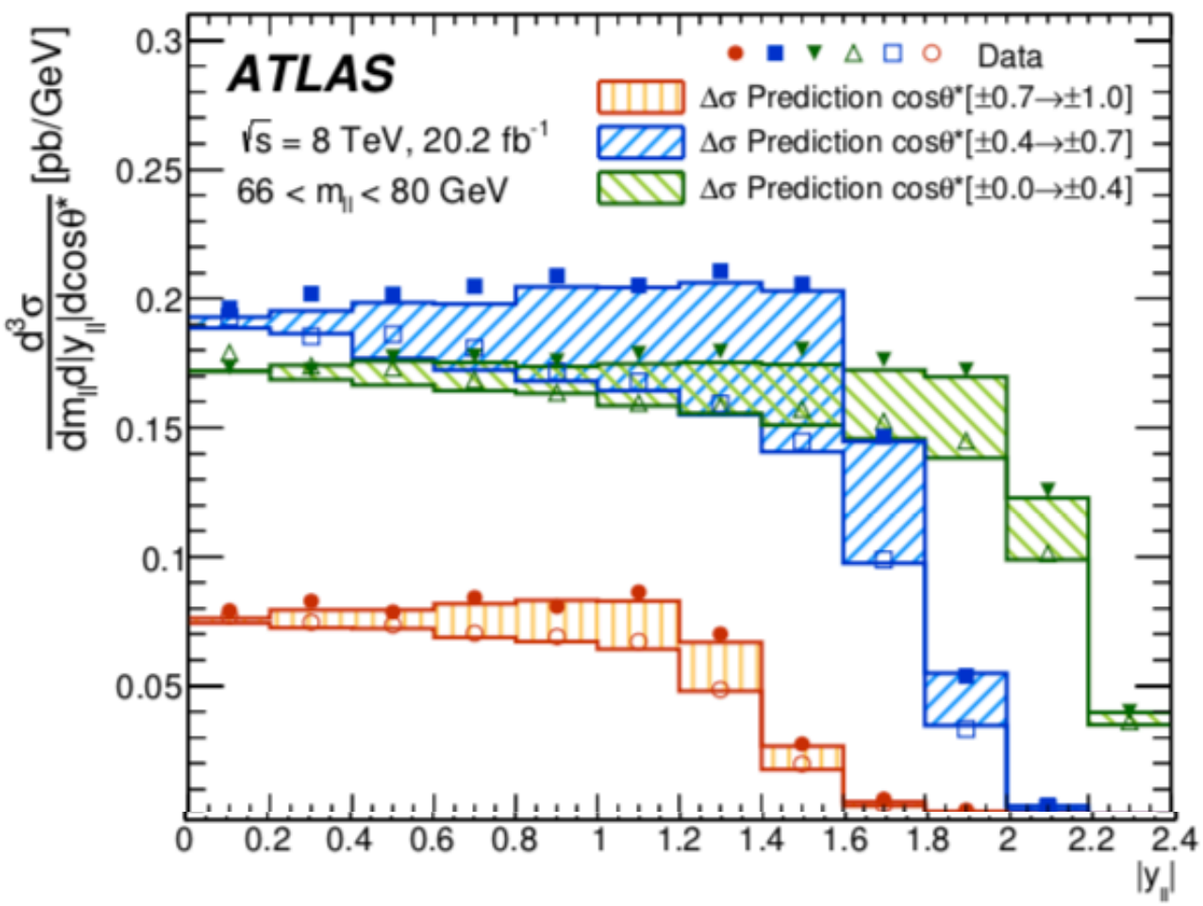
ATL-PHYS-PUB-2018-004

Multi-Differential DY at 8 TeV

- ATLAS 8 TeV W and Z cross-sections available
  - W cross-sections as a function of lepton rapidity
  - Z cross-sections triple-differential in mass, rapidity and $\cos\theta^*$



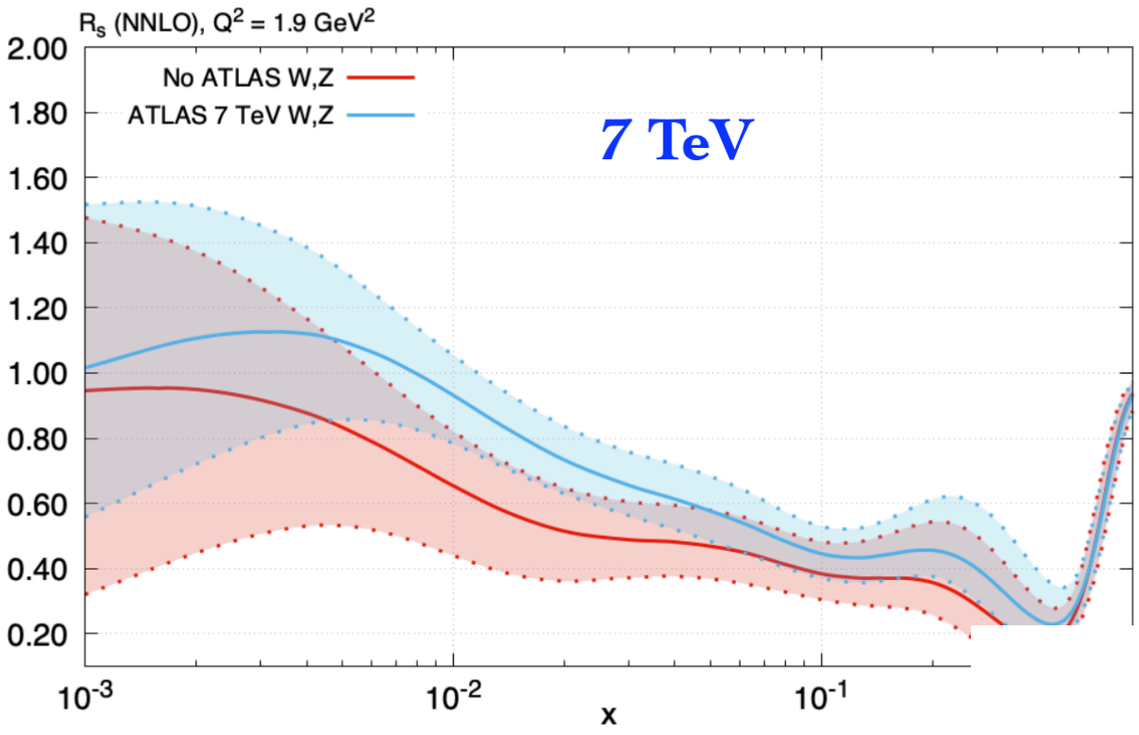
EPJC 79 (2019) 760

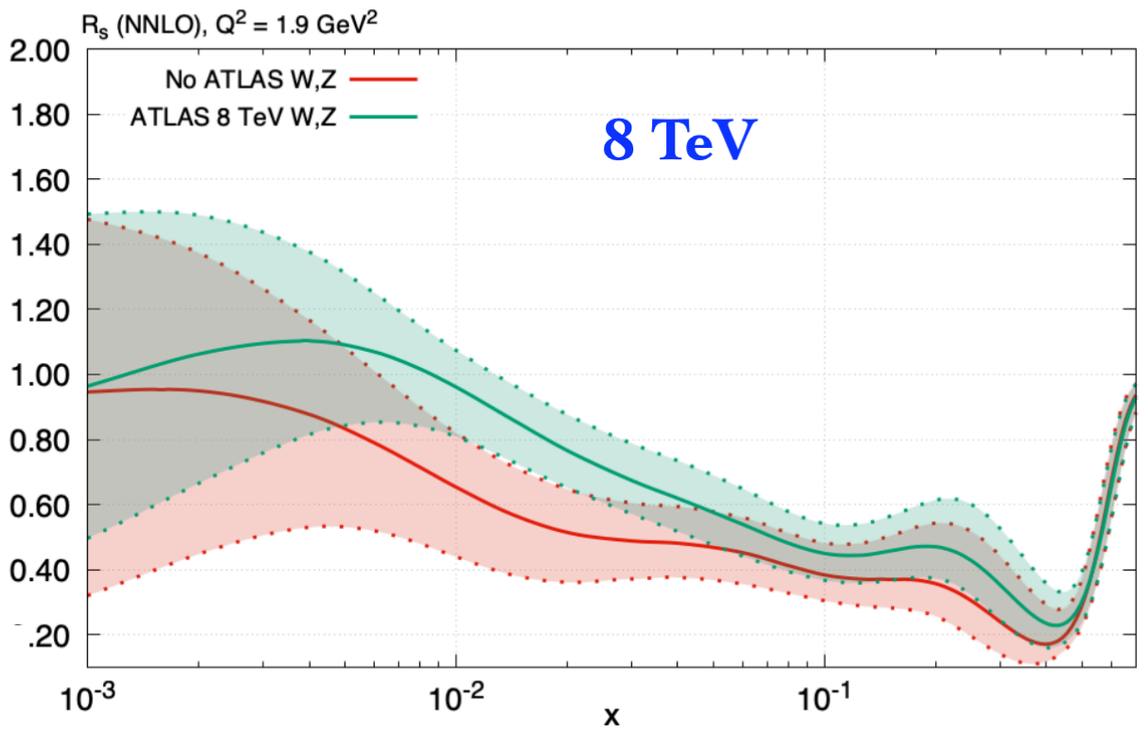


JHEP 12 (2017) 059

Multi-Differential DY at 8 TeV

- Measurements included in the upcoming MSHT2020 fit
  - Including ATLAS 7 TeV W,Z find a similar strangeness enhancement as the ATLAS QCD analysis
  - Similar impact on PDFs and strangeness enhancement at low-x preferred also by the ATLAS 8 TeV W,Z measurements

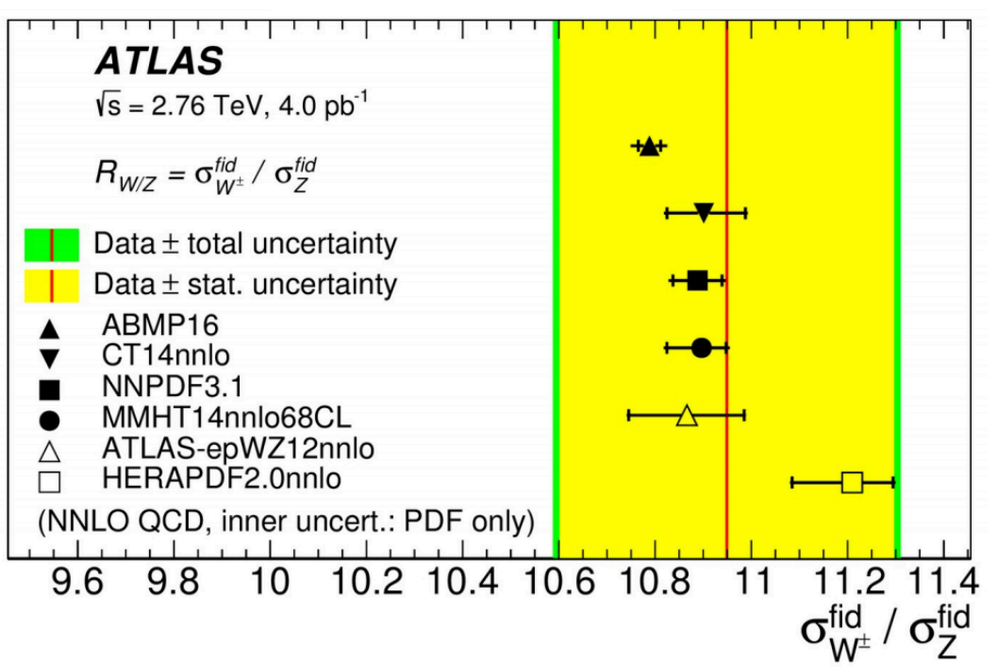




L. Harland-Lang, QCD@LHC20

W,Z at 2.76 and 5 TeV

- LHC datasets at lower energies can provide interesting cross-section measurements
  - Allows for powerful SM tests from cross-section ratios
  - Going to lower energies allows to probe higher x
  - Most PDFs underestimate the 5 TeV data at central y_Z



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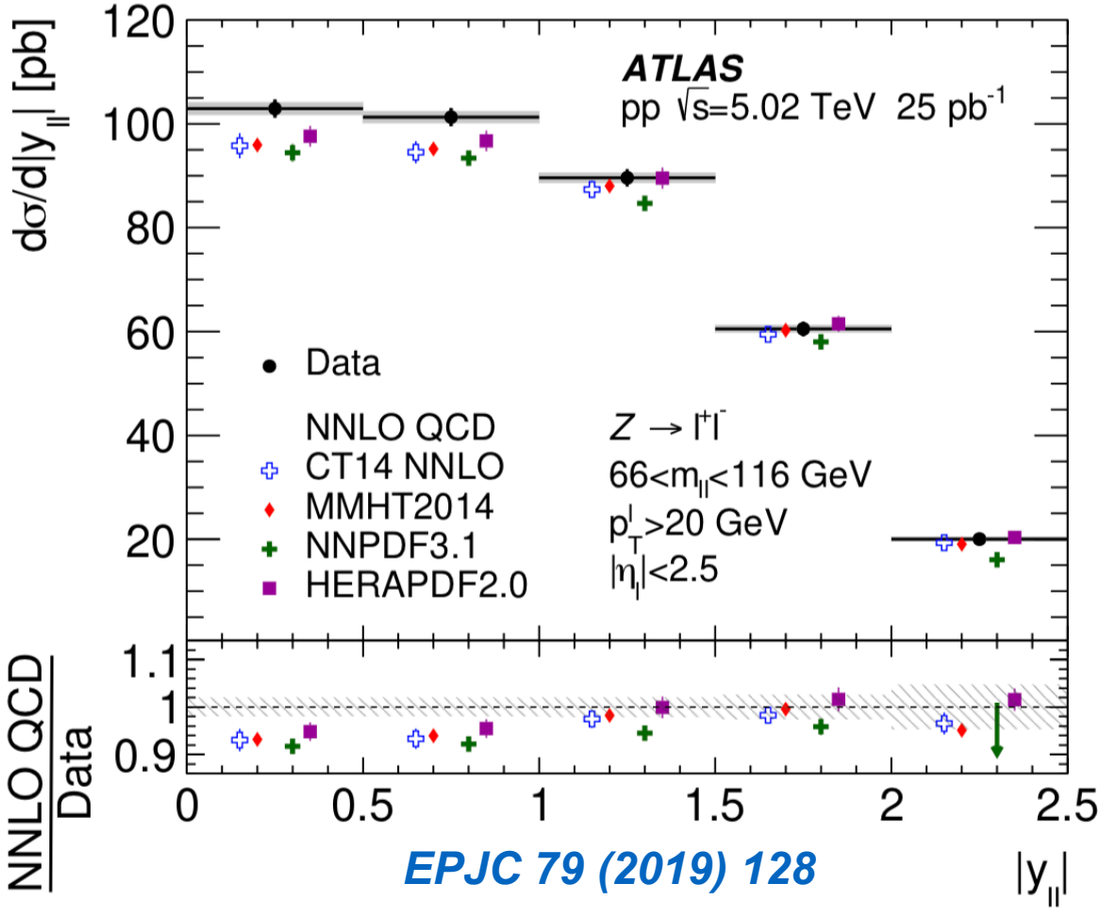
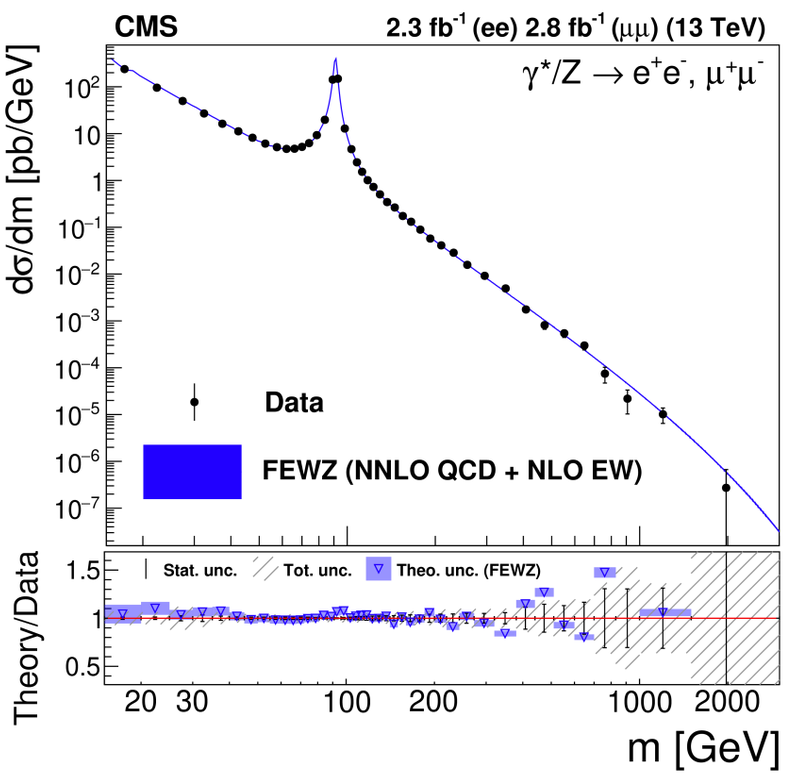


EPJC 79 (2019) 128

Z cross-sections at 13 TeV

- Two differential Z cross-section measurements at 13 TeV from CMS
  - As a function of m_{ll}, probing the photon PDF at high mass
  - As a function of p_{Tll}, y_{ll} and ϕ^*; probing the production dynamics
  - Data well described by NNLO QCD with NNPDF3.1



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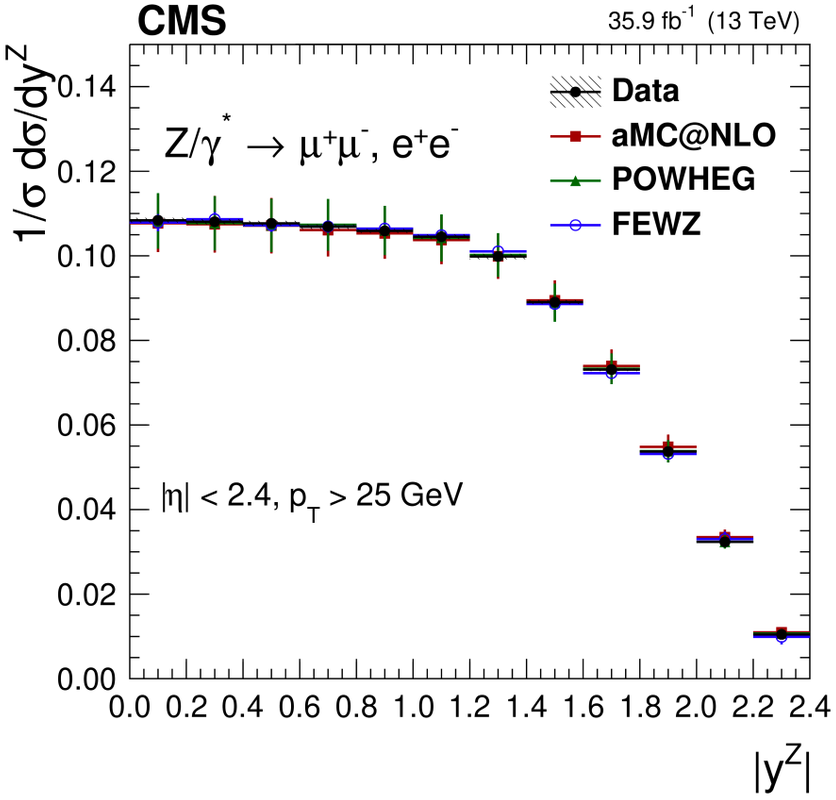
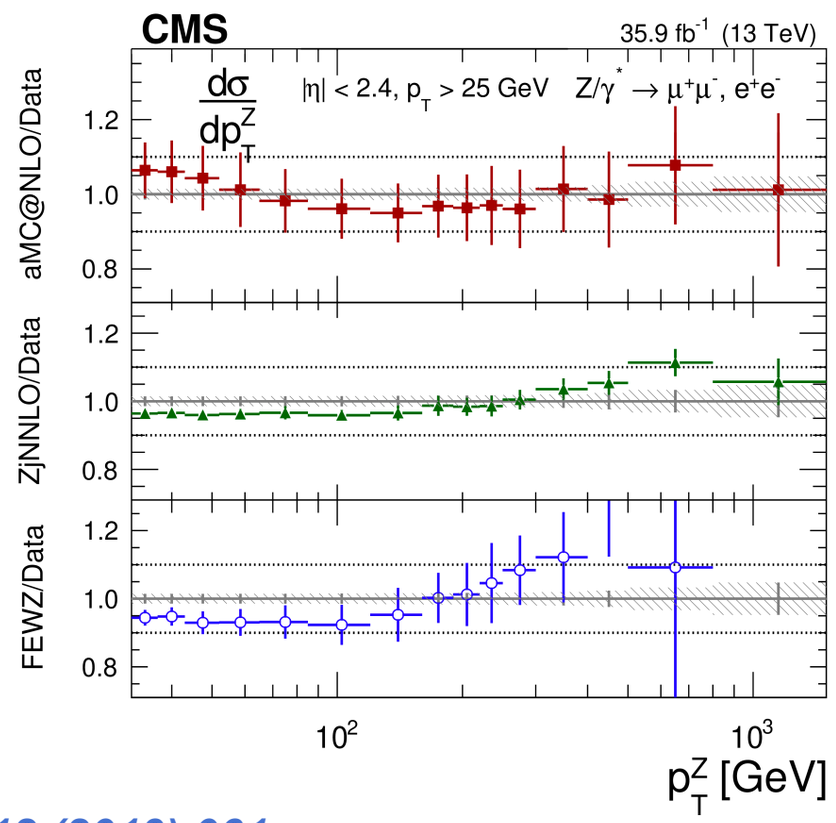
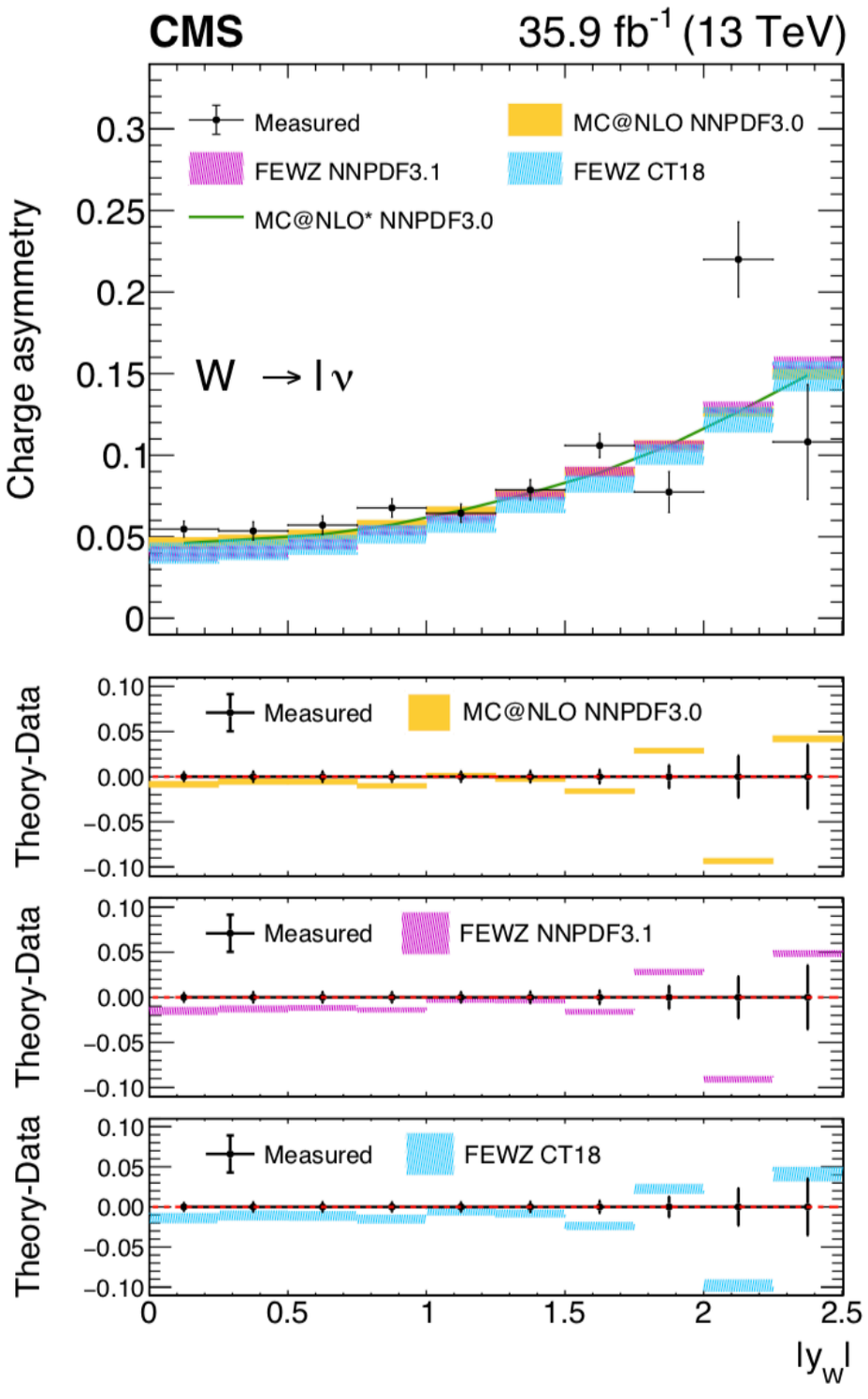




JHEP 12 (2019) 061

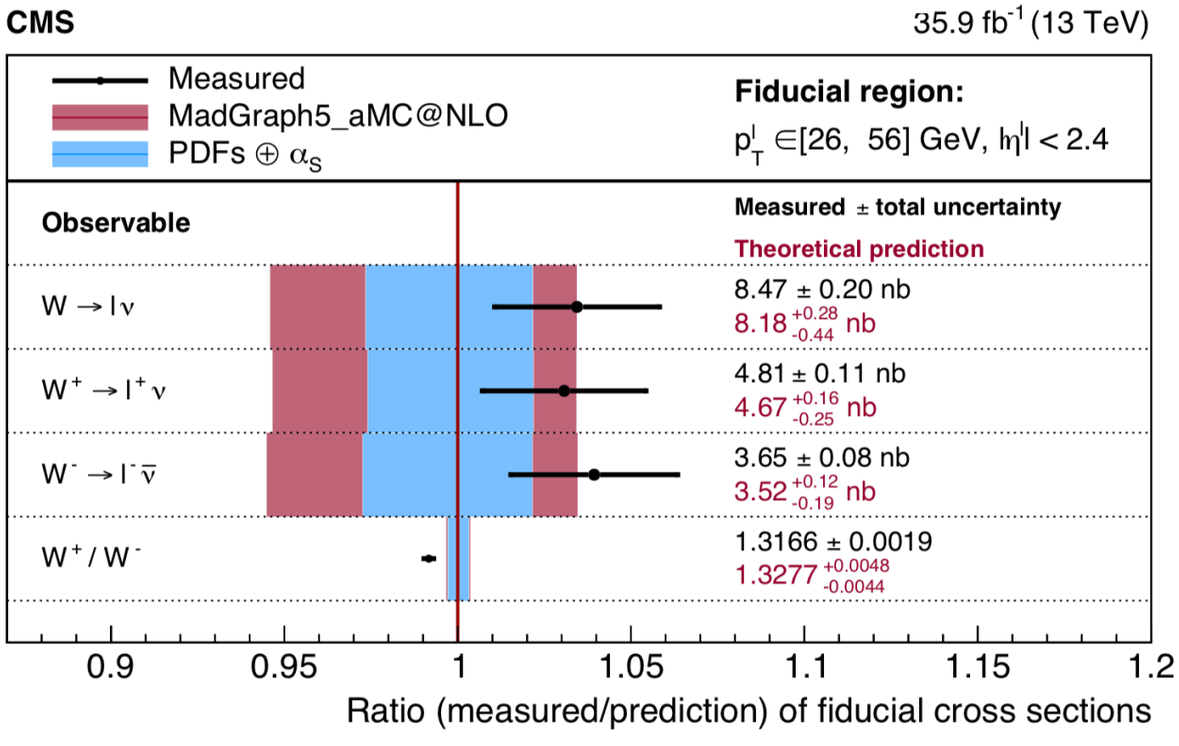
W polarisation at 13 TeV

- Novel CMS measurement of differential cross-sections and charge asymmetry for the two W helicity states



- Cross-sections measured as a function of p_T^l and η^l
- Integrated W cross-sections and charge asymmetry sensitive to valence quark PDFs

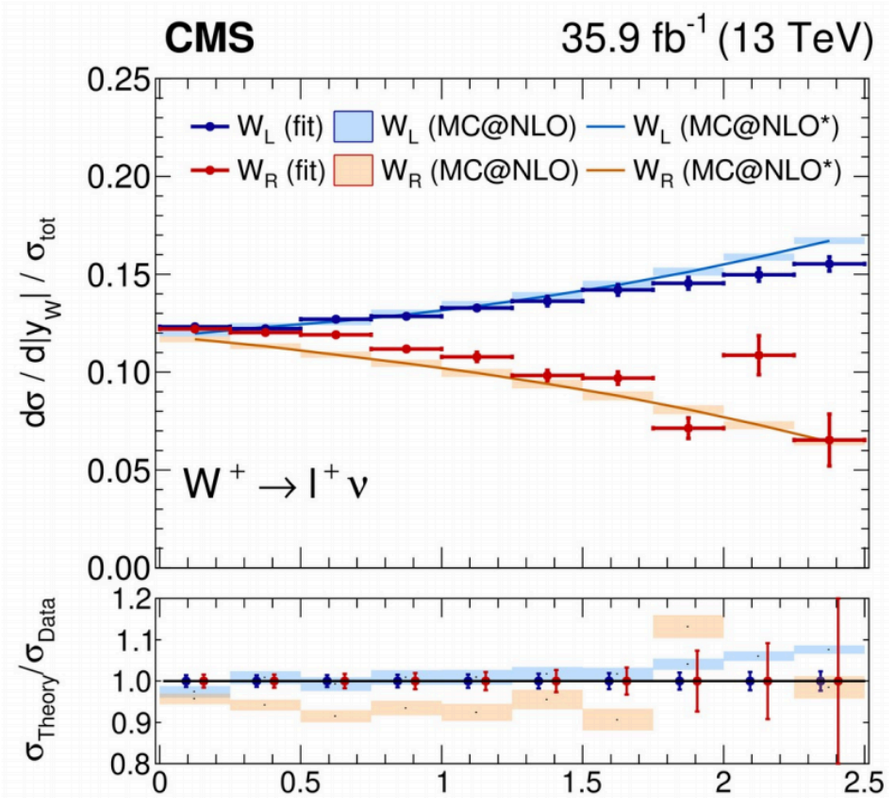
$$A_W \sim \frac{u_V(x_0) - d_V(x_0)}{u(x_0) + d(x_0)}$$

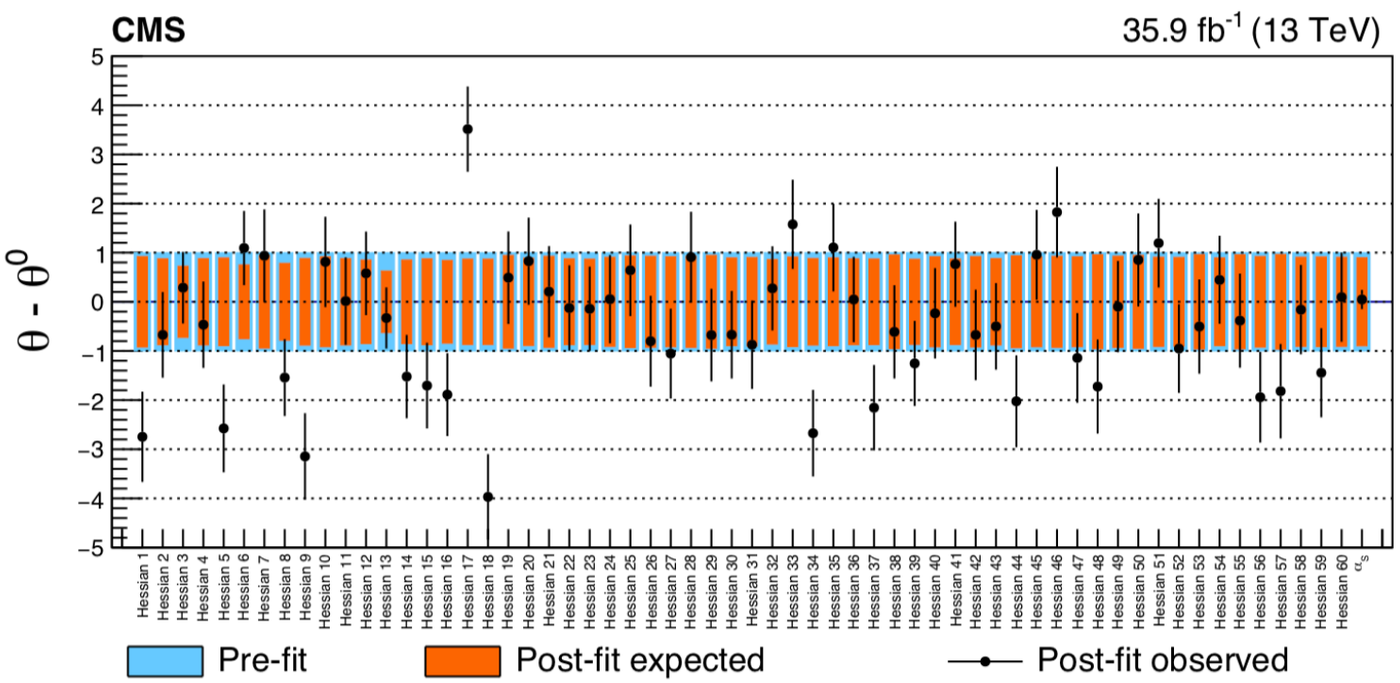


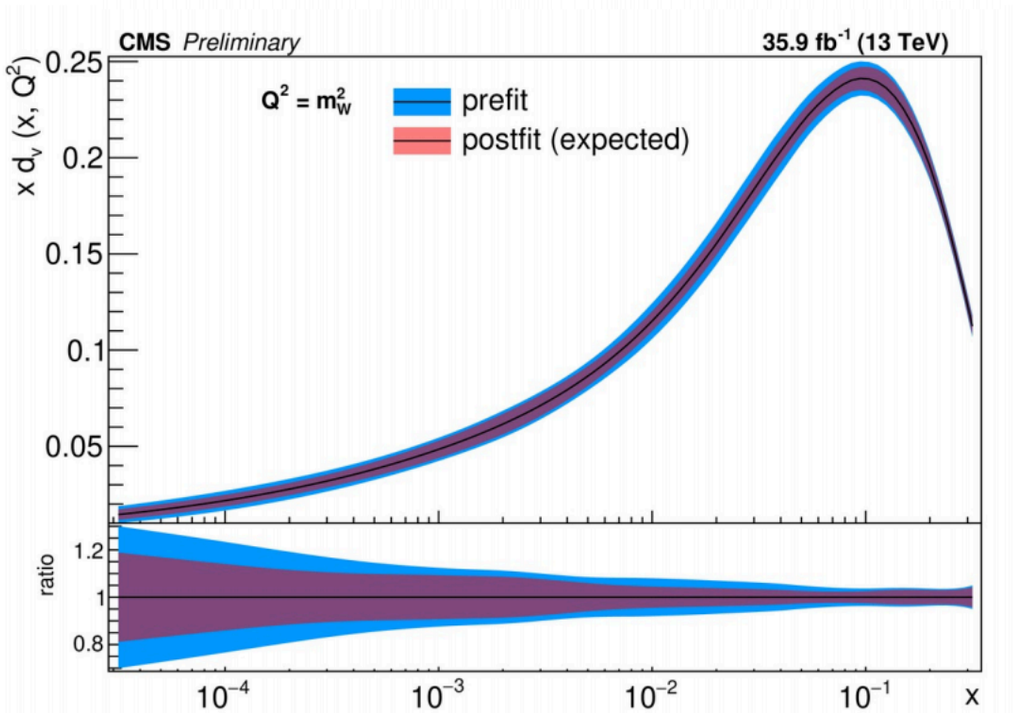
2008.04174, accepted by PRD

W polarisation at 13 TeV

- Impact on PDF evaluated using Hessian profiling of the NNPDF31 set
  - Using NLO+PS predictions from madgraph_aMC@NLO
- Strong sensitivity to the PDF eigenvectors, and large uncertainty reduction for valence-quark PDFs



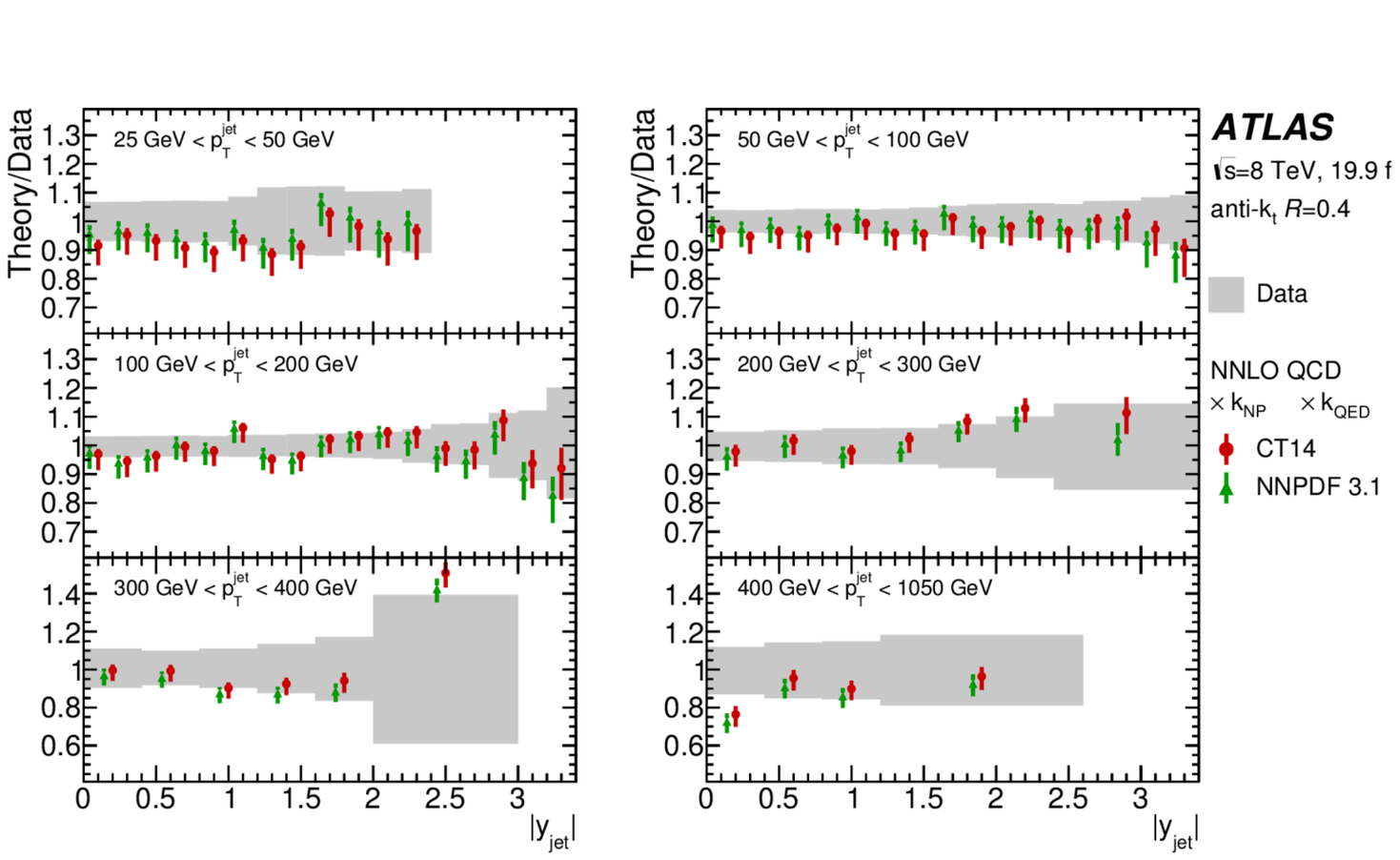


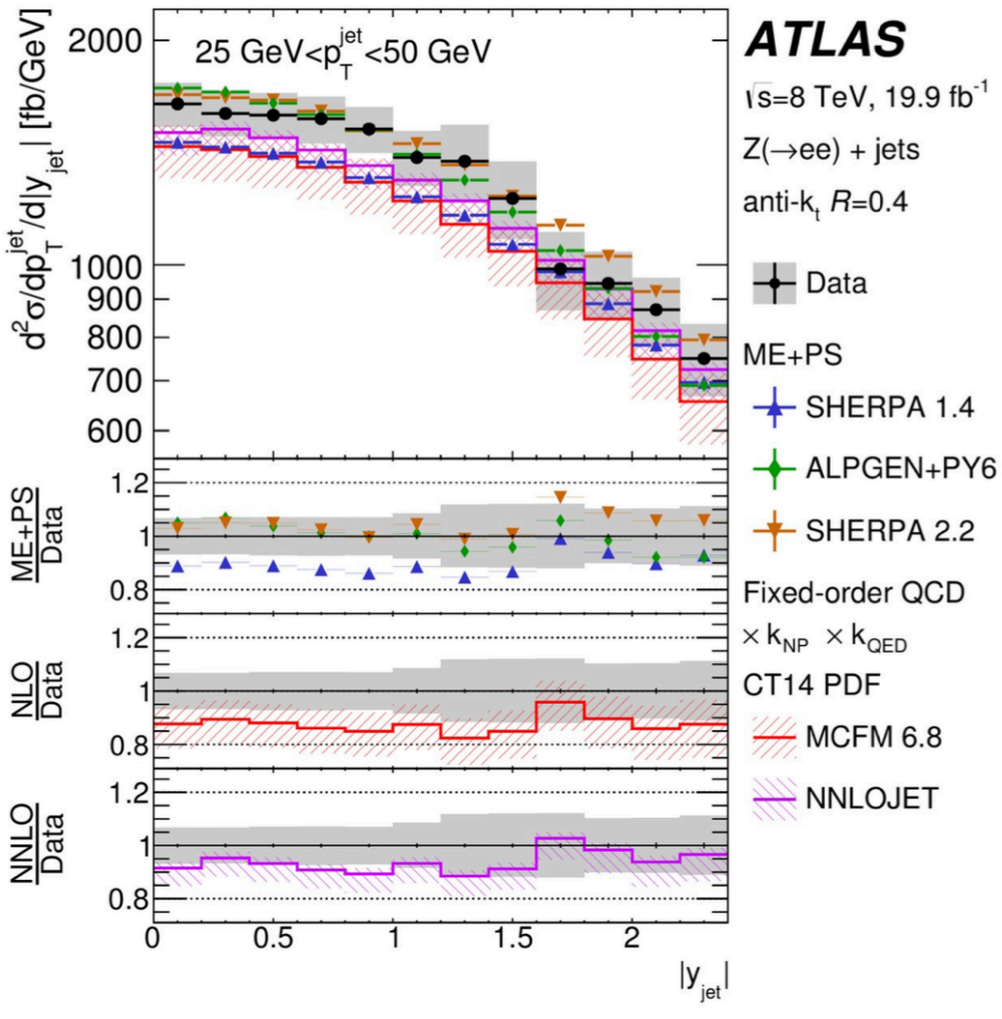


2008.04174, accepted by PRD

V+JETS

- NNLO QCD predictions for V+1jet production have now been computed
  - Available with antenna (NNLOJET) and Njettiness subtraction
  - Allow consistent inclusion of existing V+jet measurements in PDF fits
- Sensitive to the valence quark PDFs and the strange PDF at medium-x

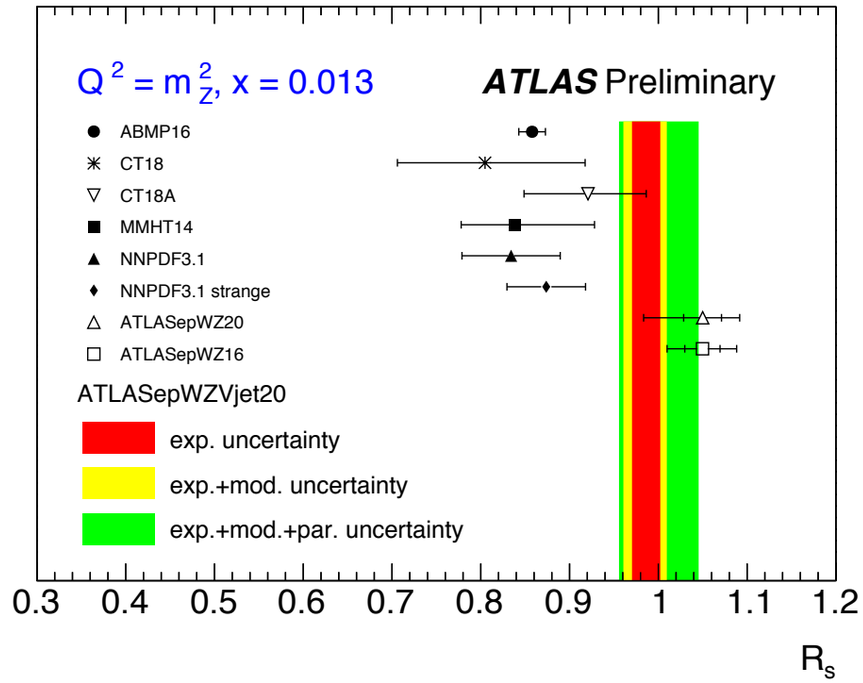


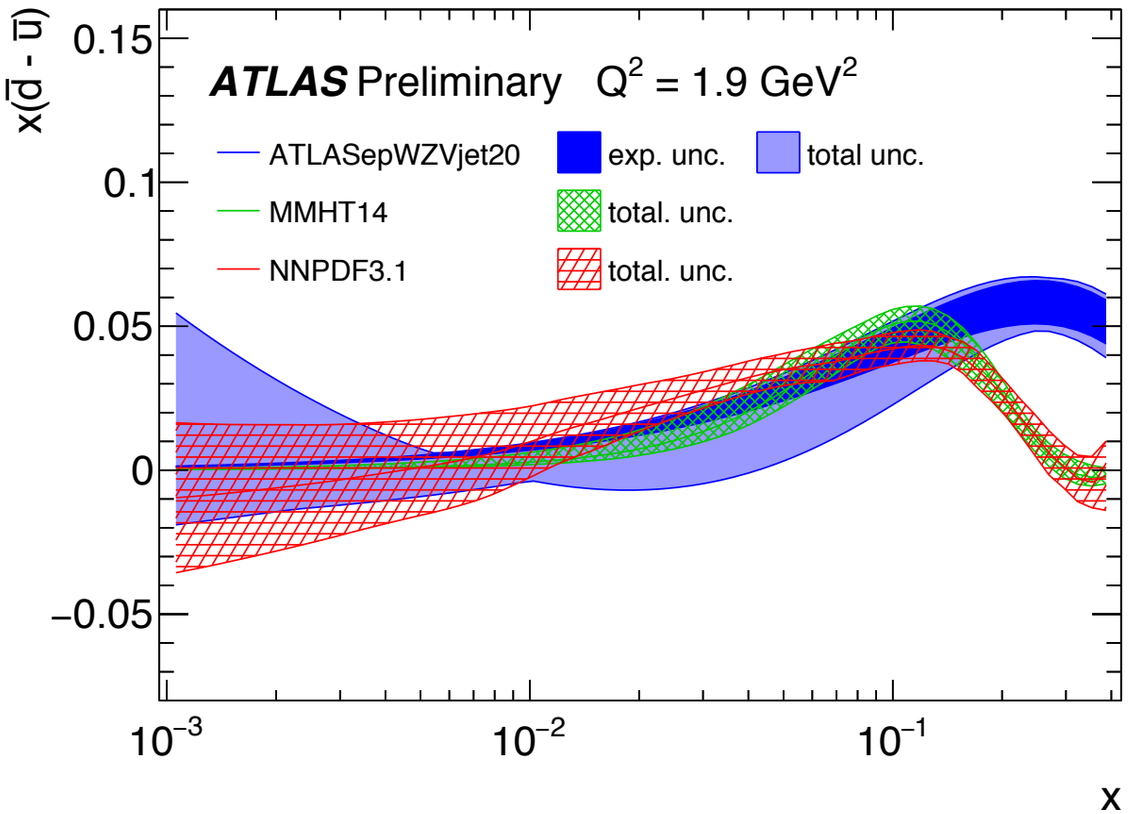


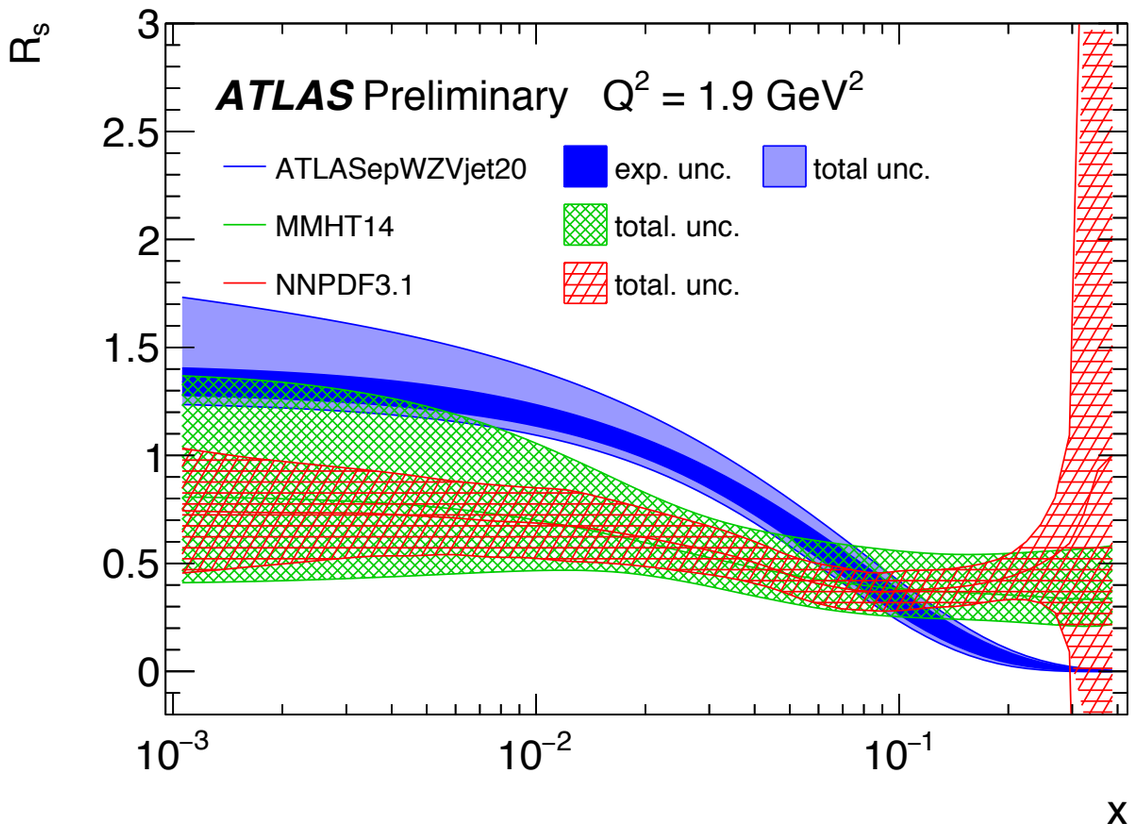
EPJC 79 (2019) 847

V+JETS

- New ATLAS NNLO QCD analysis of 8 TeV W,Z+1jet measurements
  - Consistent with inclusive W,Z and an unsuppressed strange at small-x
  - Dbar-ubar distribution in better agreement with global fits in the region covered by data (x<0.1)



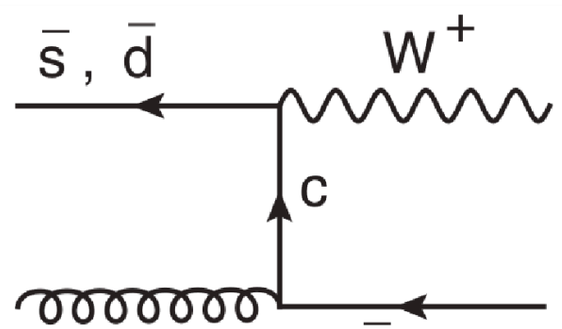


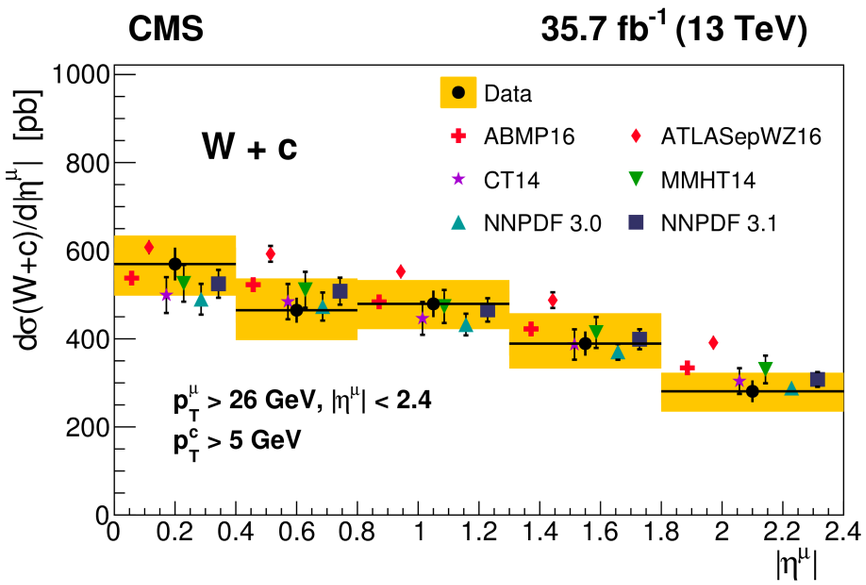


ATL-CONF-2020-057

W + CHARM

- W+charm quark events mostly produced by gs->W+c
- Direct sensitivity to the strange PDF
- Can exploit charge correlations to separate W+c from W+g(->ccbar)
- Recent CMS 13 TeV measurement, when interpreted in a PDF analysis prefers a lower strangeness than ATLAS W,Z data
  - So far predictions exists only at NLO, would be important to have NNLO





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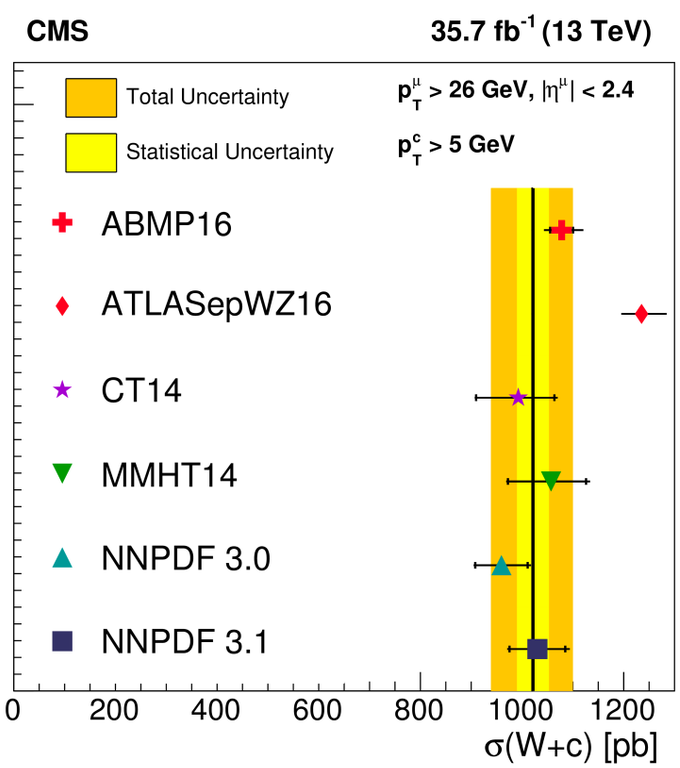
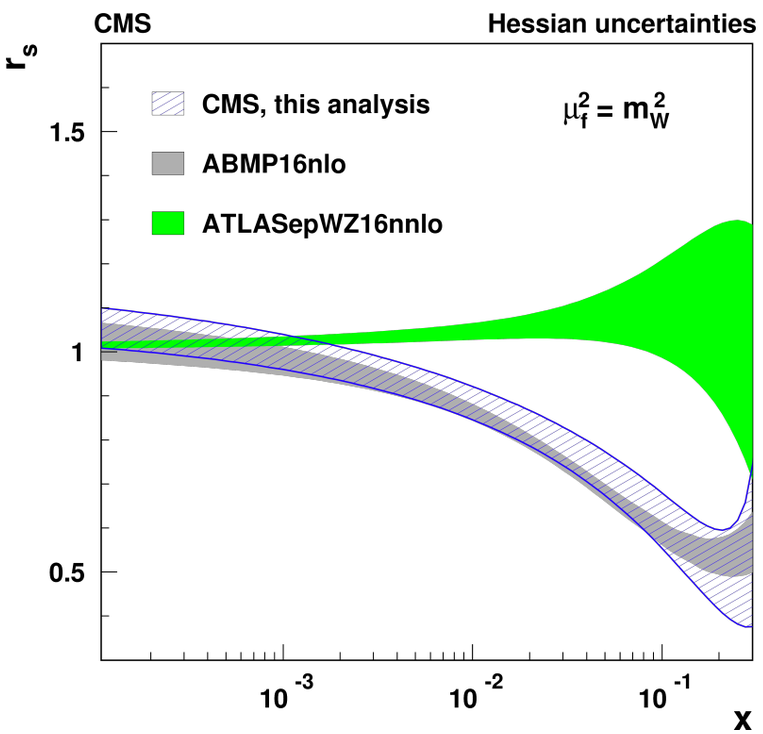
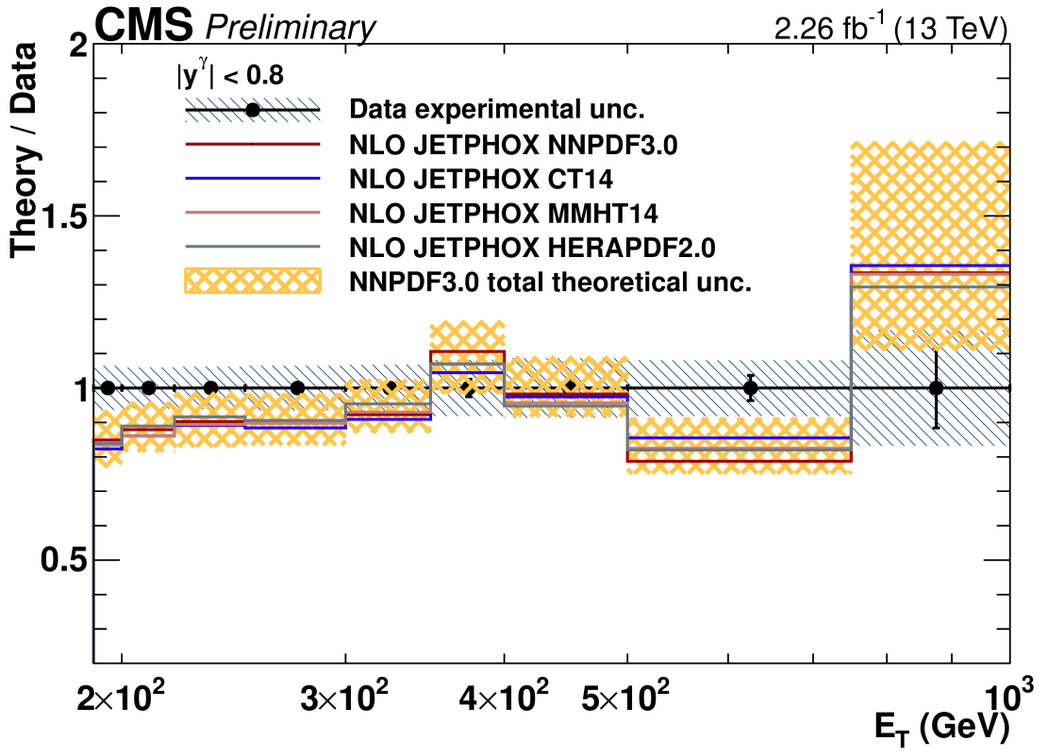




Prompt-photon production

- Prompt-photon production sensitive to the gluon PDF at medium-x
  - Relevant to constrain uncertainties for ggH production
- Large reduction in MHOU when going to NNLO theory
- But uncertainties from fragmentation component at low-/medium-E_T



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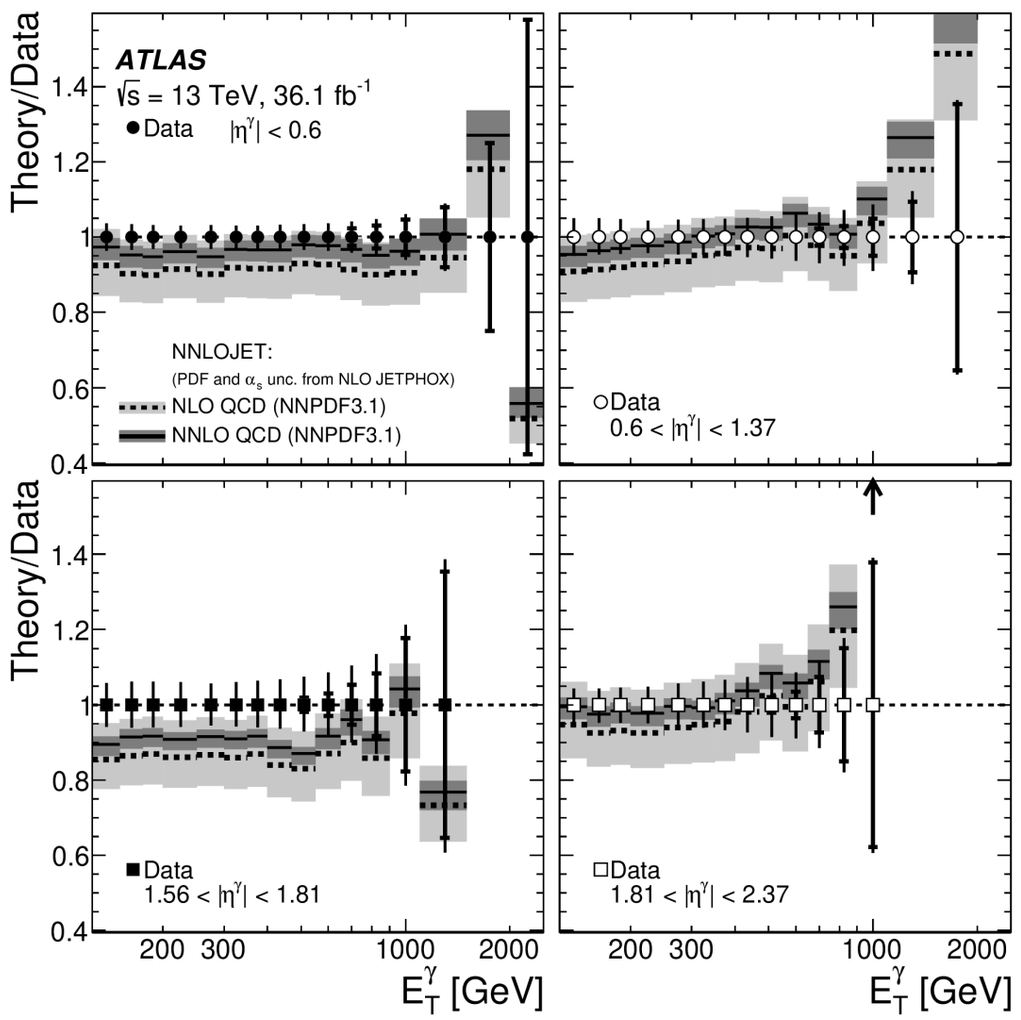
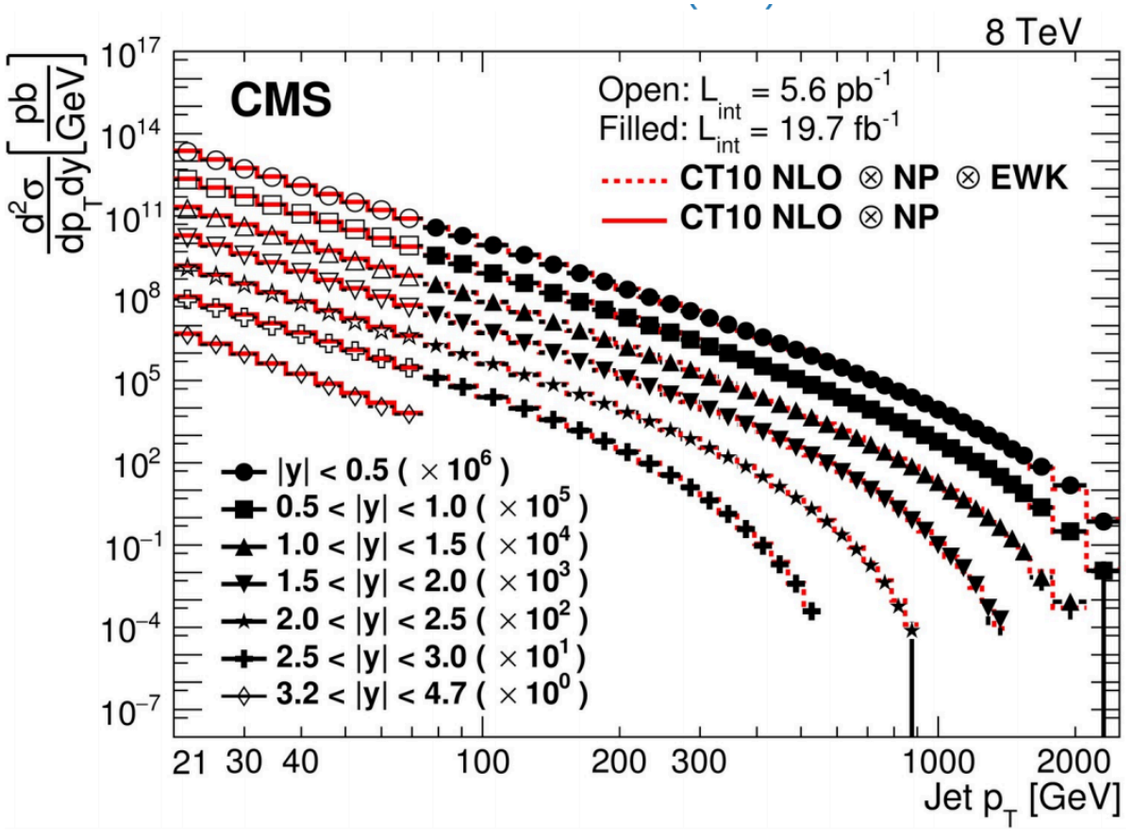
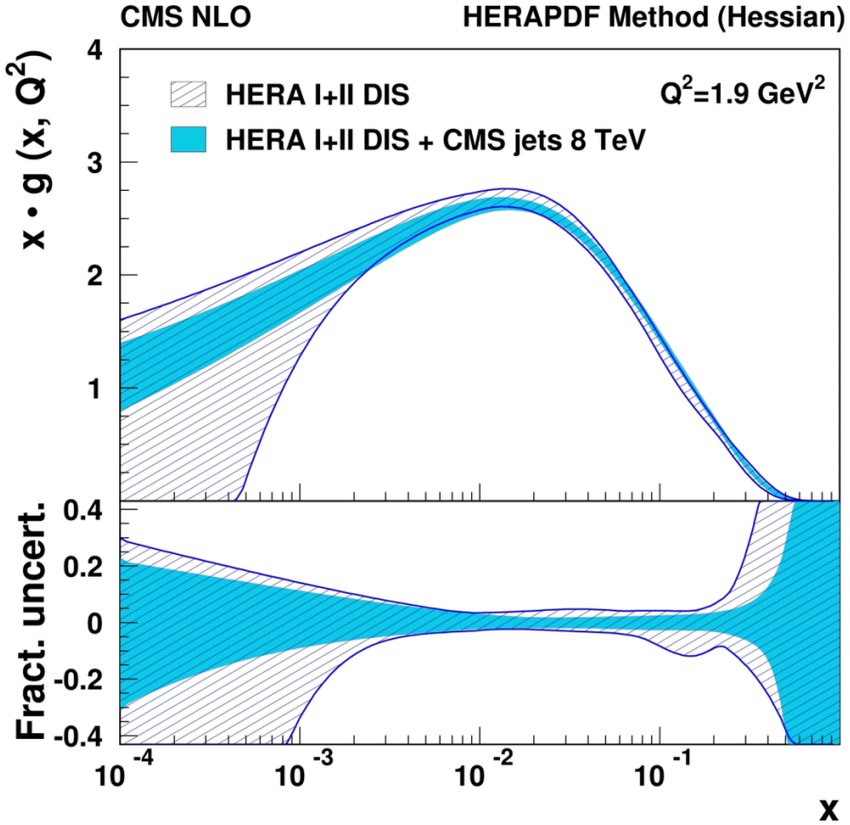


JHEP 10 (2019) 203

Inclusive jets

- Jets and dijets data very sensitive to the gluon PDF at large-x
  - Simultaneous sensitivity to the strong coupling
  - Theory now available to NNLO QCD, yet still important differences from choice of nominal scale
  - And some issues in obtaining a good fit of the ATLAS jet data (unclear if an experimental or theoretical issue)

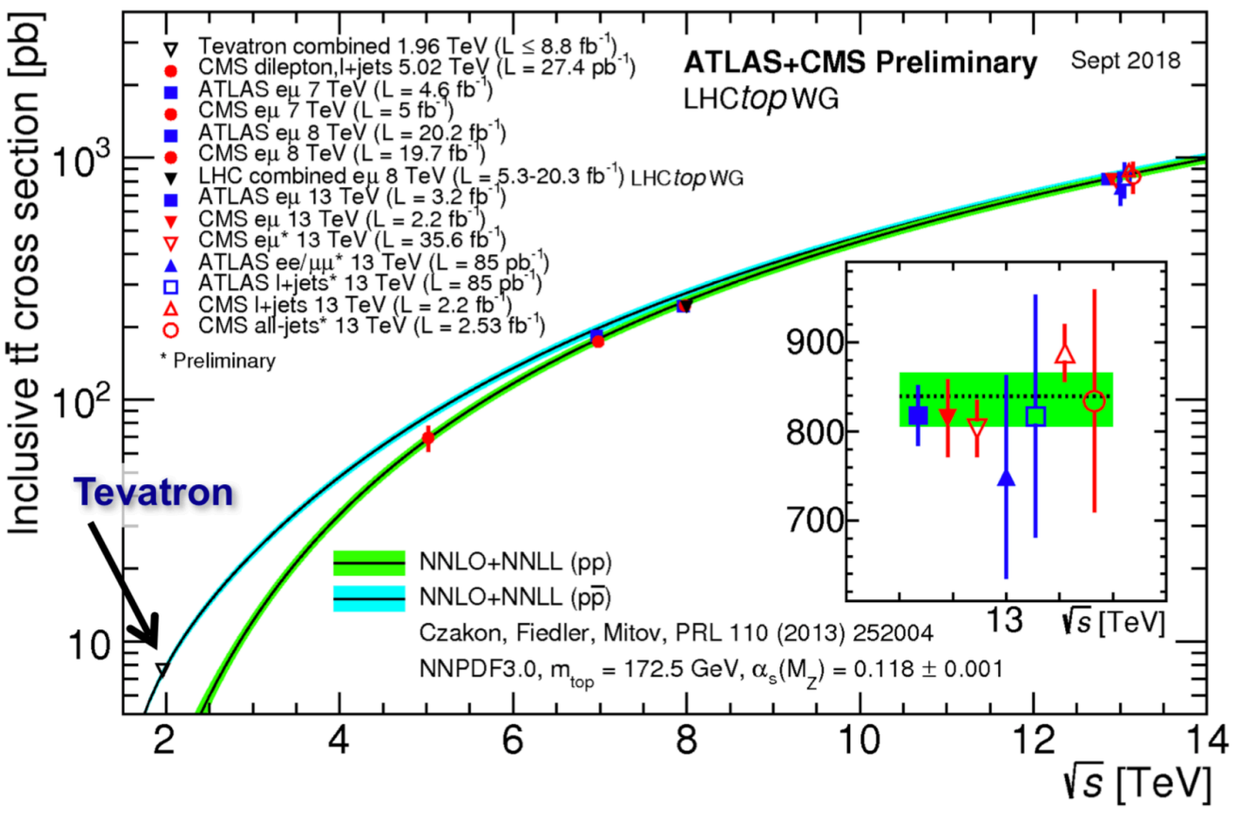


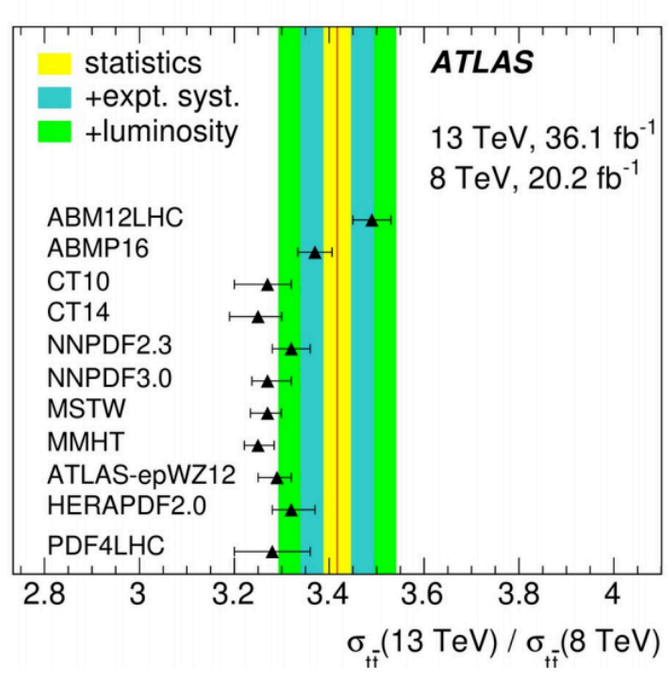


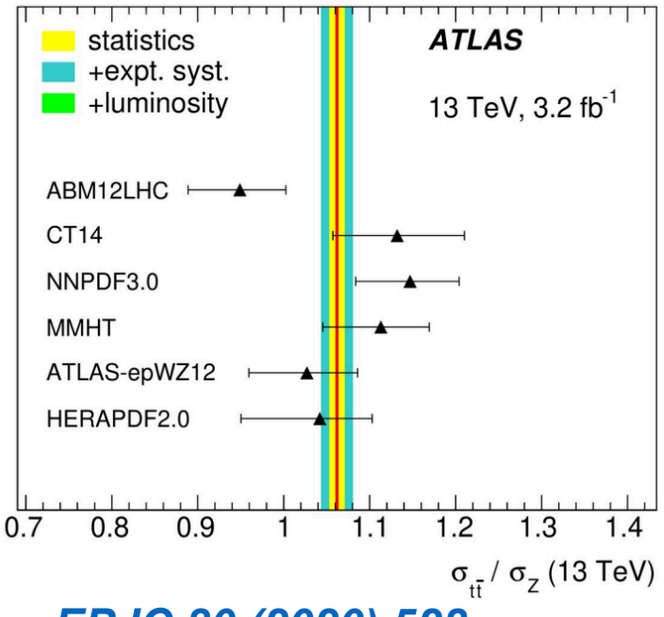
JHEP 03 (2017) 156

TTBAR CROSS-SECTIONS AT 13 TEV

- Top-pair production cross-section now measured to ~2%
- Sensitive to the gluon PDF (and the strong coupling)





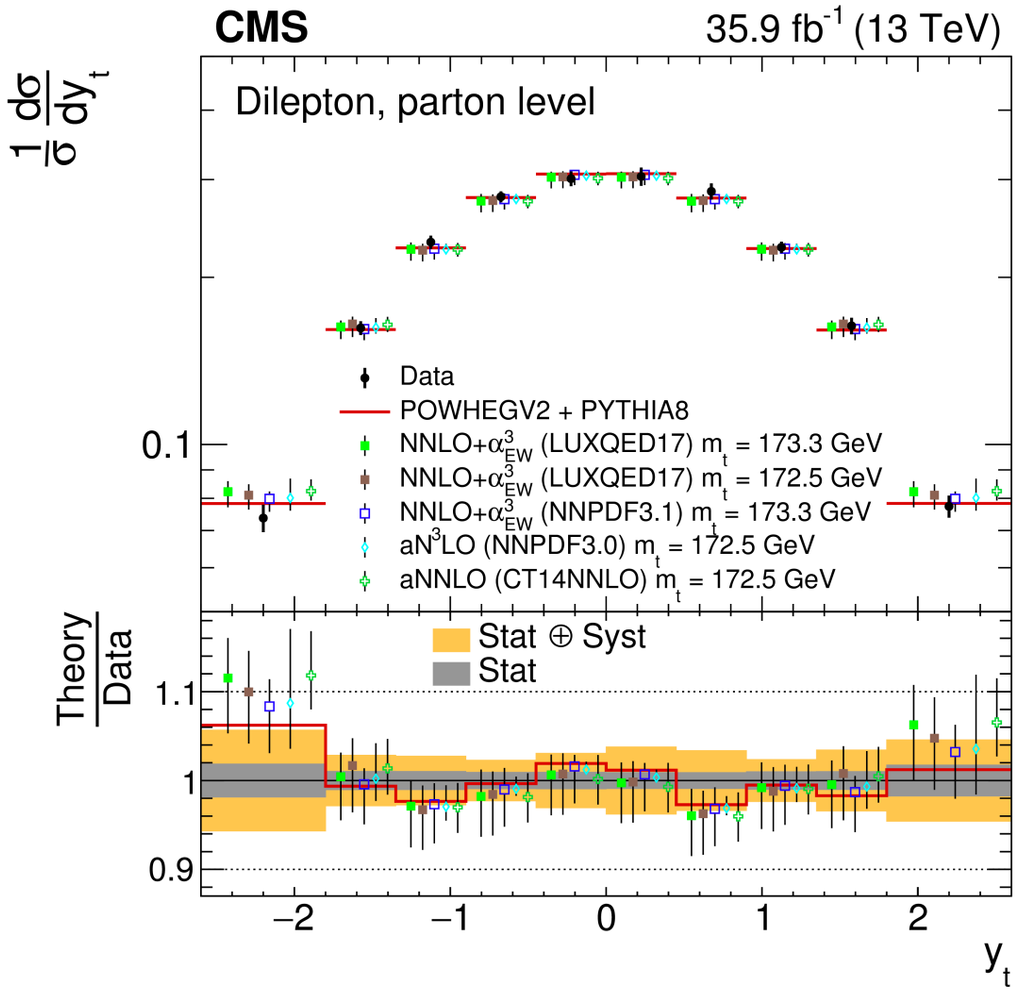


- Cross section ratios at different energies, and ttbar/Z ratios can further enhance PDFconstraints
- Determined to better than 4% precision

EPJC 80 (2020) 528

Differential ttbar cross-sections

- Differential cross-section measurements enhance the PDF sensitivity and extend it to even higher x
  - NNLO QCD differential predictions now available allowing for a consistent inclusion in NNLO PDF fits
  - But beware of uncertainties from particle-parton level



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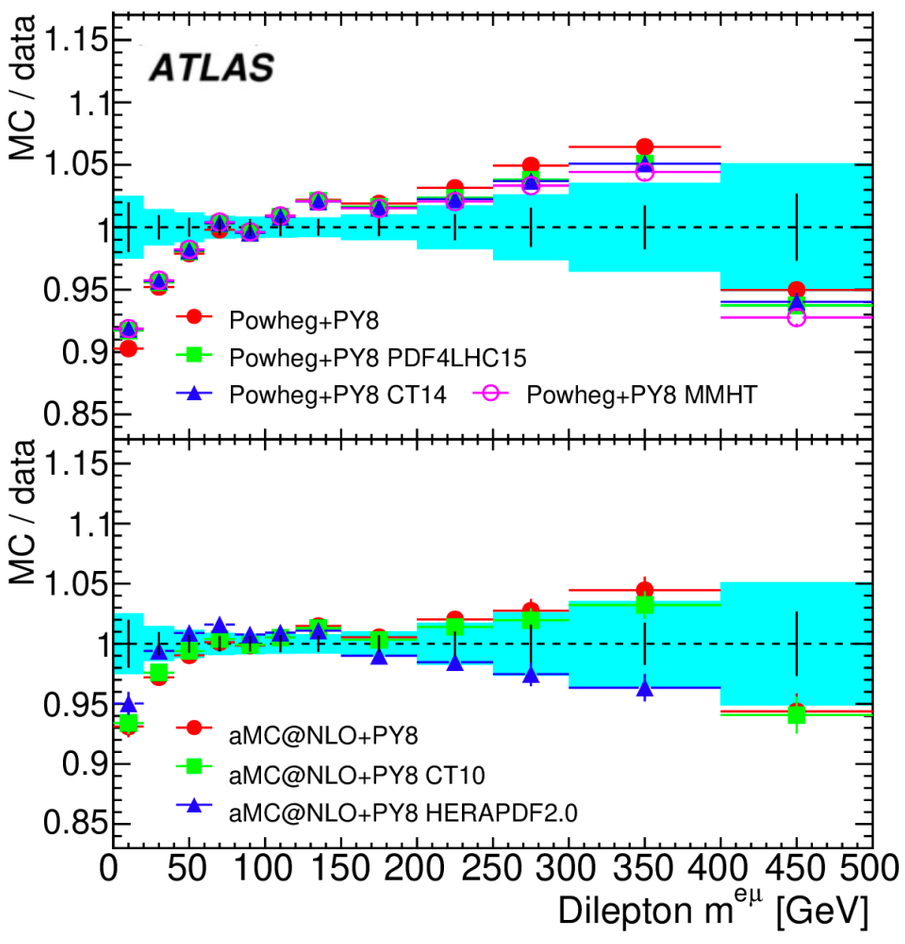
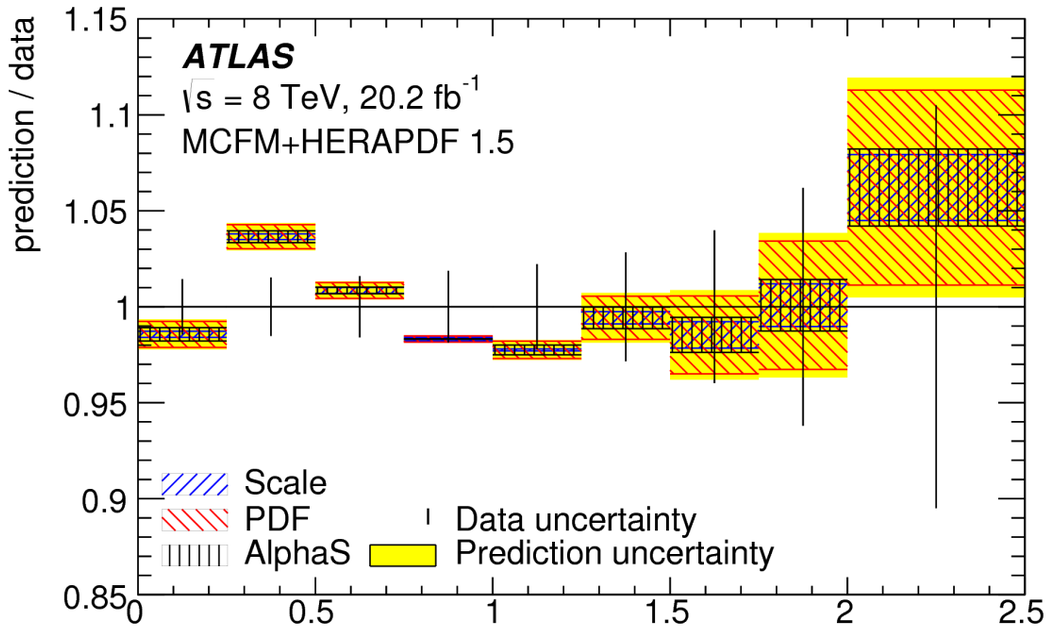


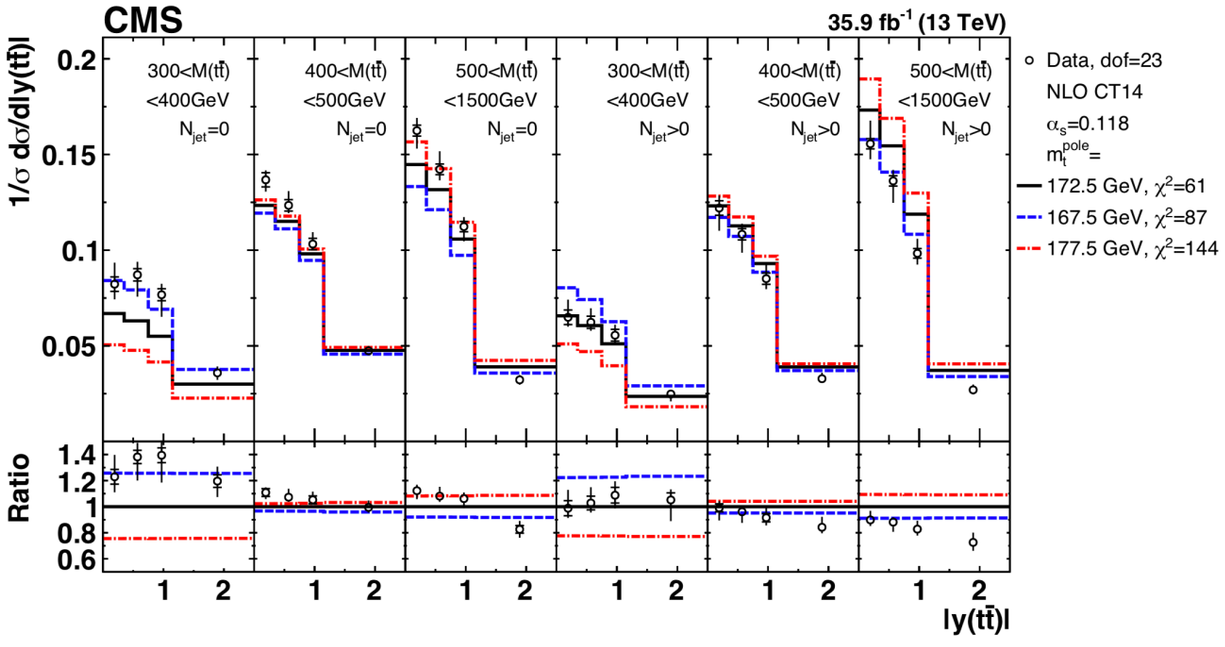
EPJC 80 (2020) 528

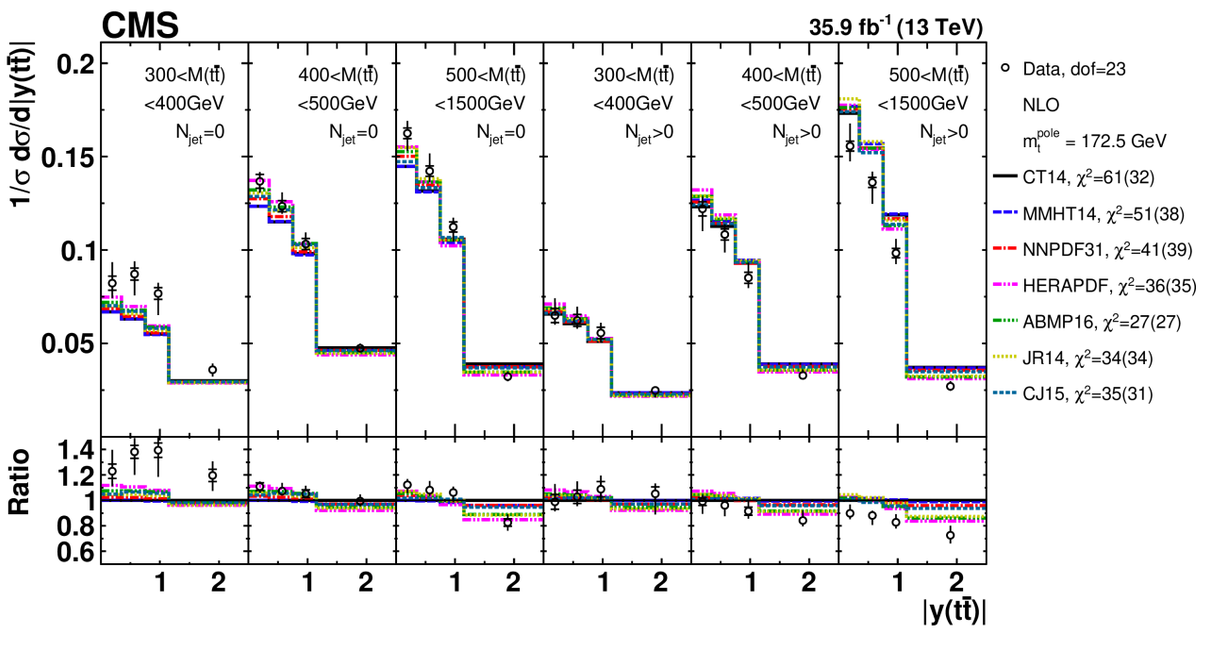
Differential ttbar cross-sections

- Two measurements have been used by LHC Collaborations in simultaneous fits of the PDFs and m_t
  - 8 TeV ATLAS measurement of differential cross-sections in dileptonic events
  - 13 TeV CMS measurement of triple-differential ttbar cross-sections in the dilepton channel as a function of (m_{tt},y_{tt},nj_{ets})



EPJC 77 (2017) 804





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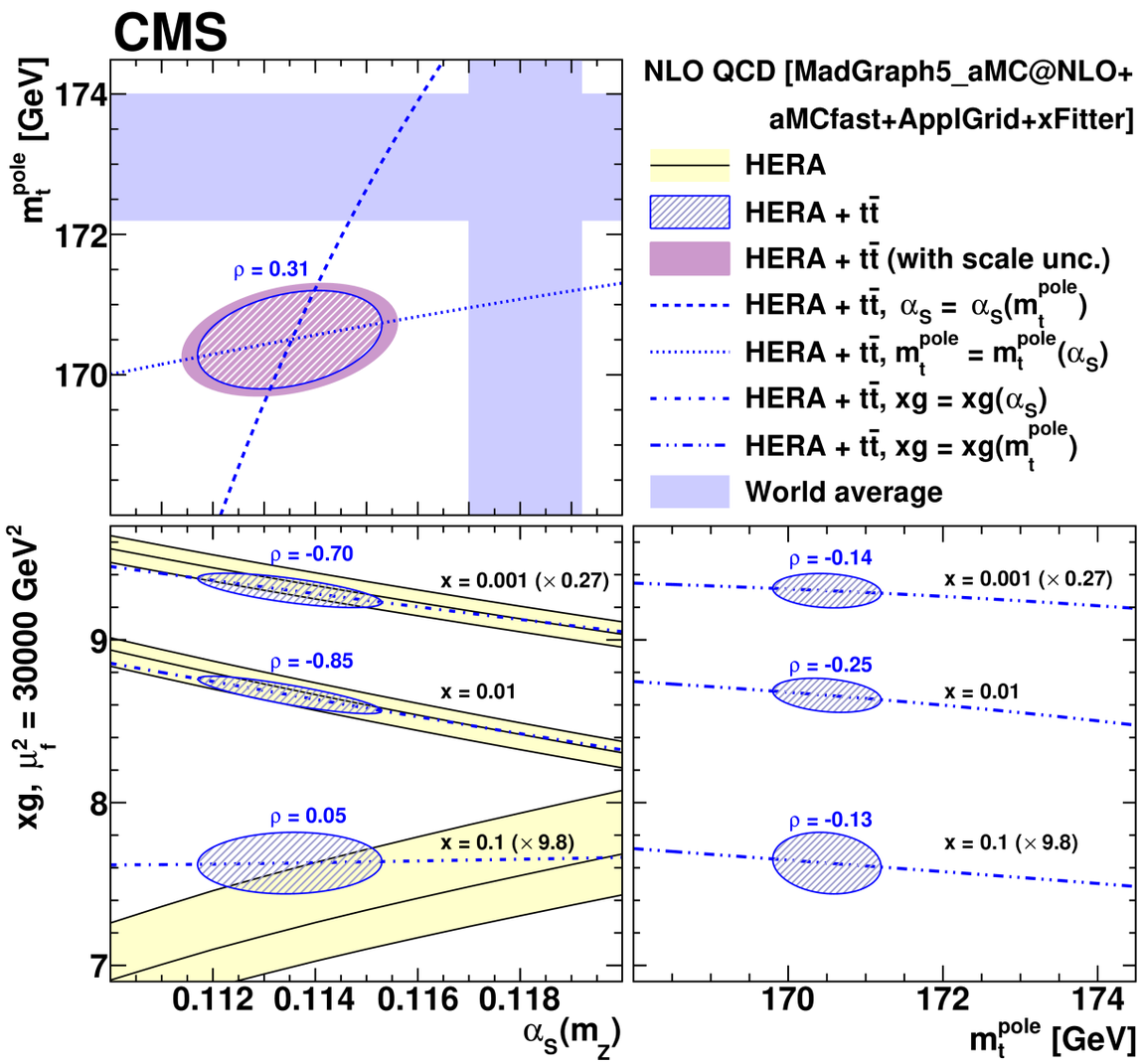
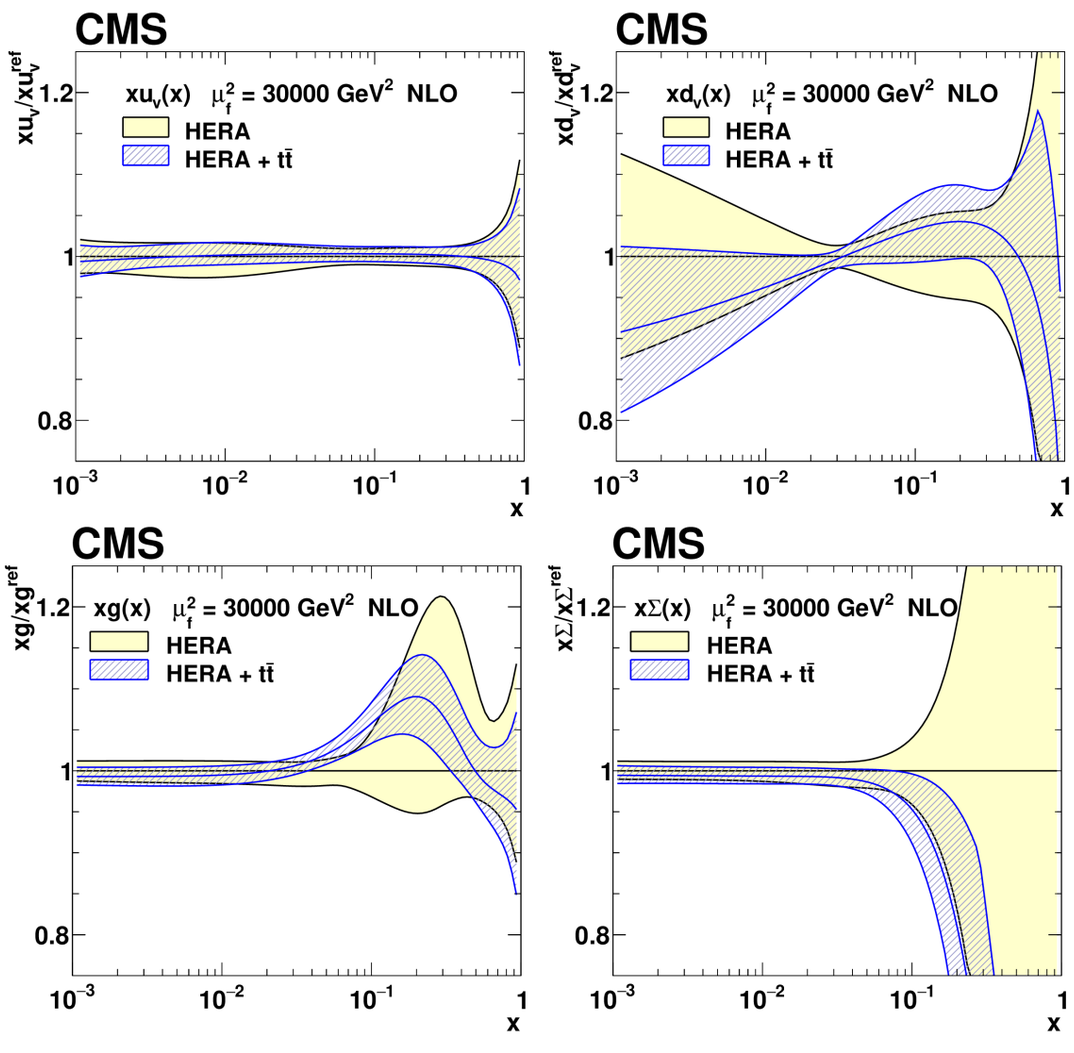
Dilepton $|y^{e\mu}|$

Differential ttbar cross-sections

- CMS data used in a simultaneous extraction of m_t, α_S and PDFs at NLO
  - Top data helps reducing correlations between the three quantities
  - Large impact on the gluon and strange PDFs

$$\alpha_S(m_Z) = 0.1135^{+0.0021}_{-0.0017} \quad m_t^{\text{pole}} = 170.5 \pm 0.8\,\text{GeV}$$

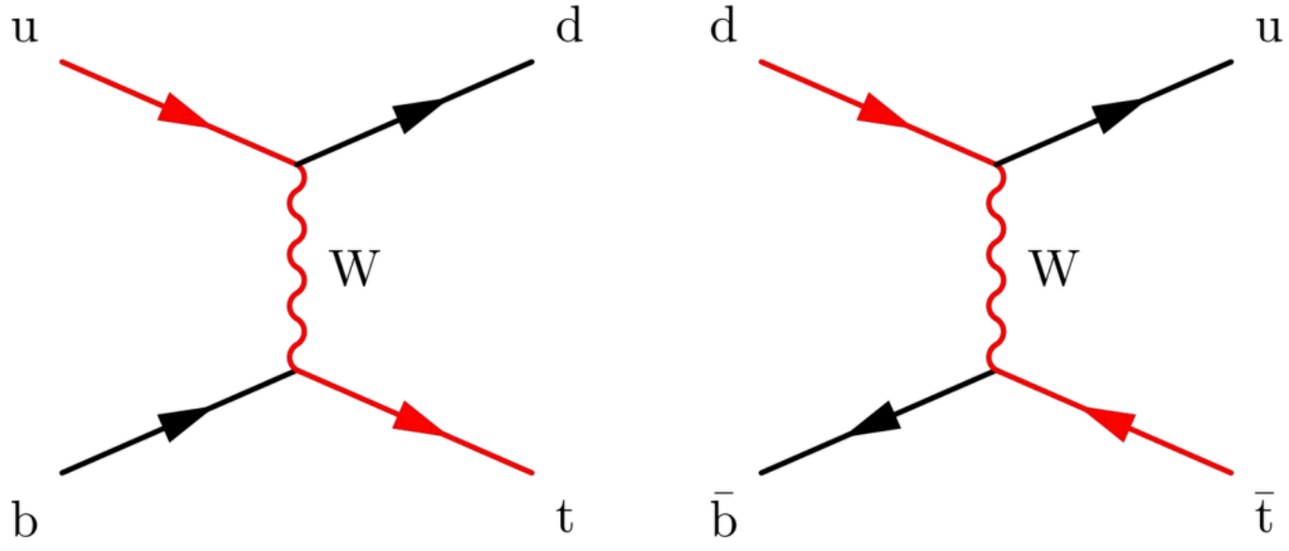




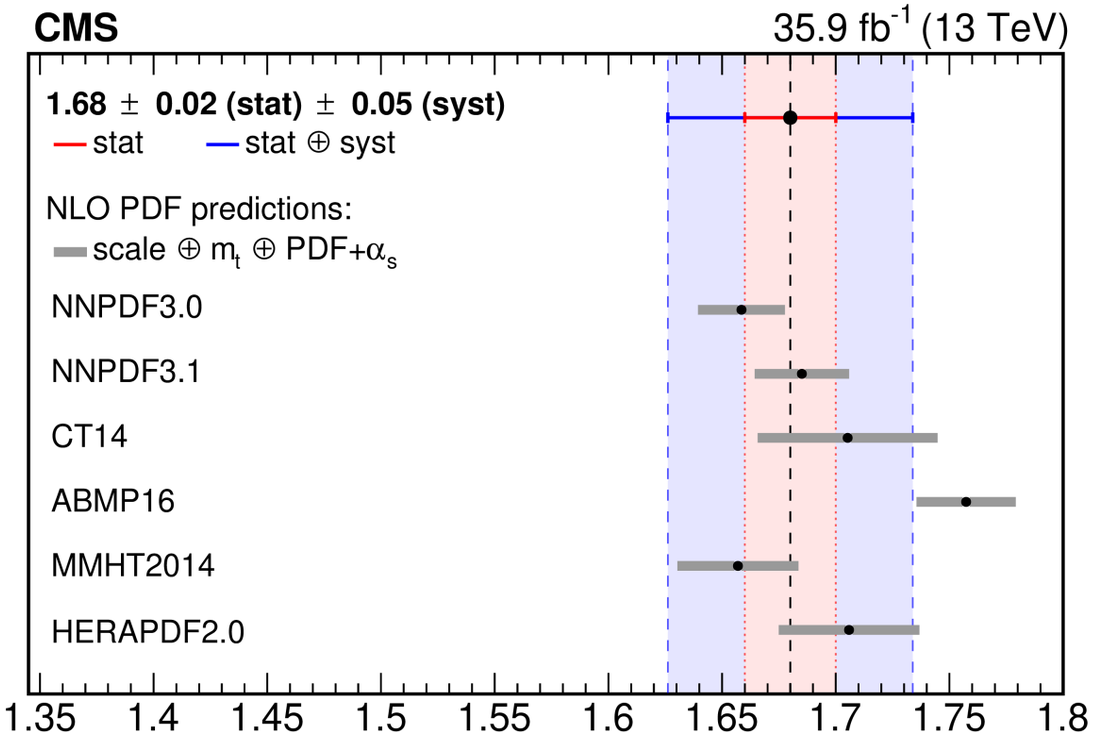
EPJC 80 (2020) 658

T-CHANNEL SINGLE-TOP

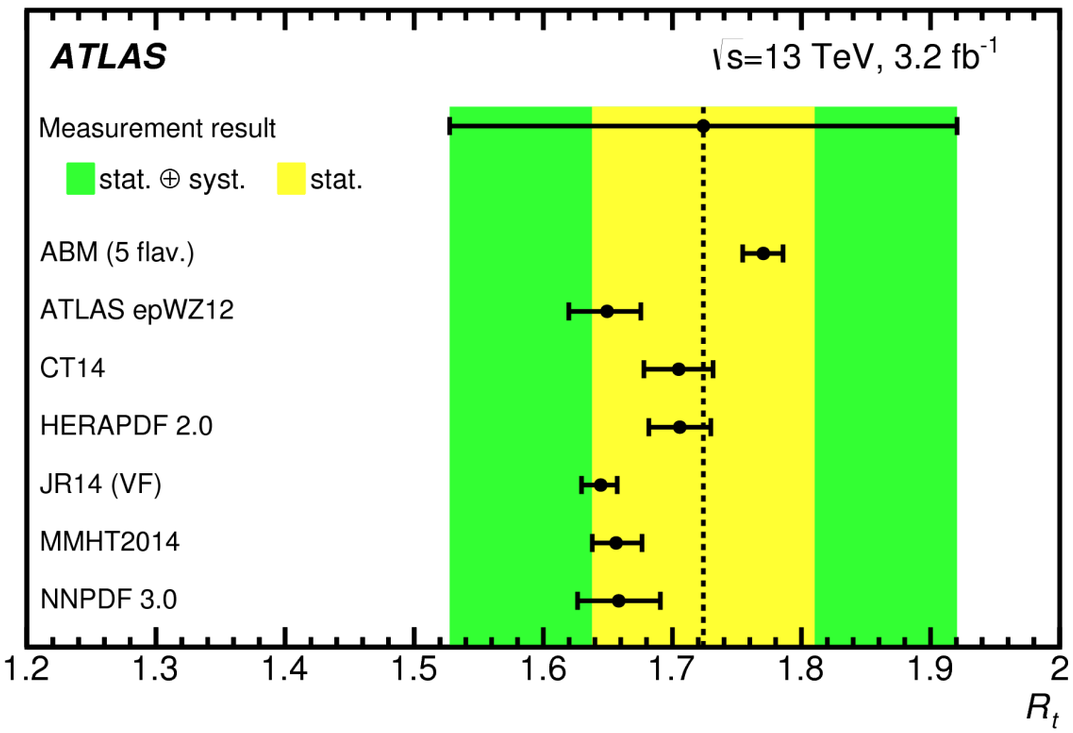
- t-channel single-top sensitive to the u/d ratio at high-x
- The cross-section ratio
  $R_t = \sigma(tq)/\sigma(\bar{t}q)$
  cancels out common systematic uncertainties



- Good description by modern PDF fits (but for ABMP16)



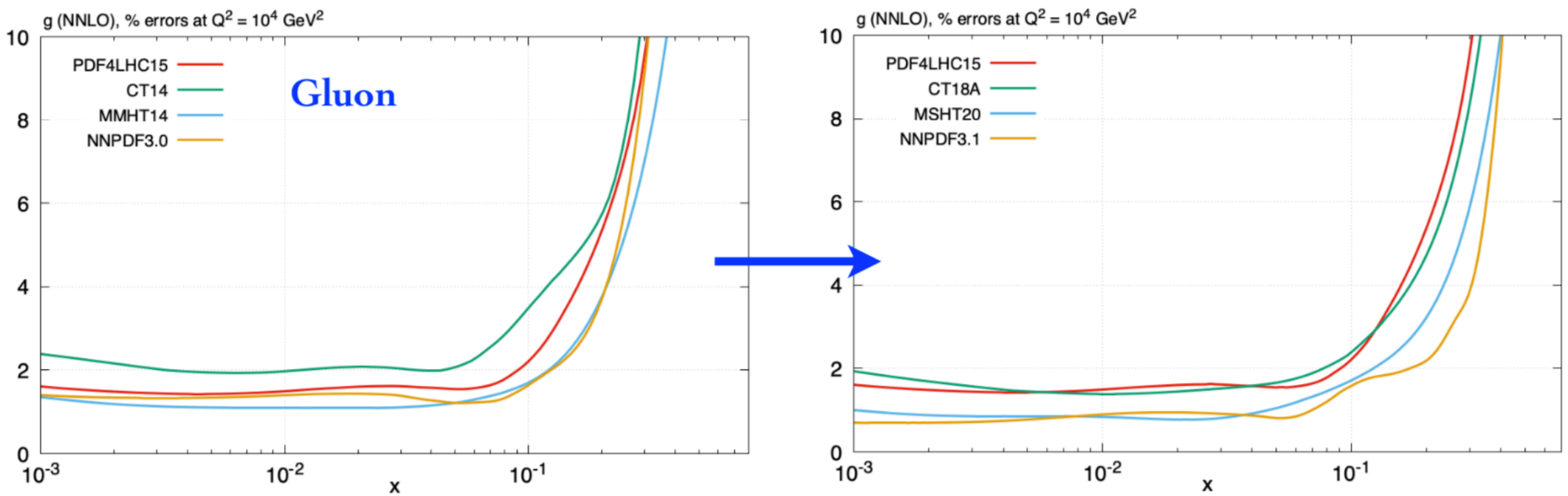
[PLB 800 (2019) 135042]



[JHEP04(2017)086]

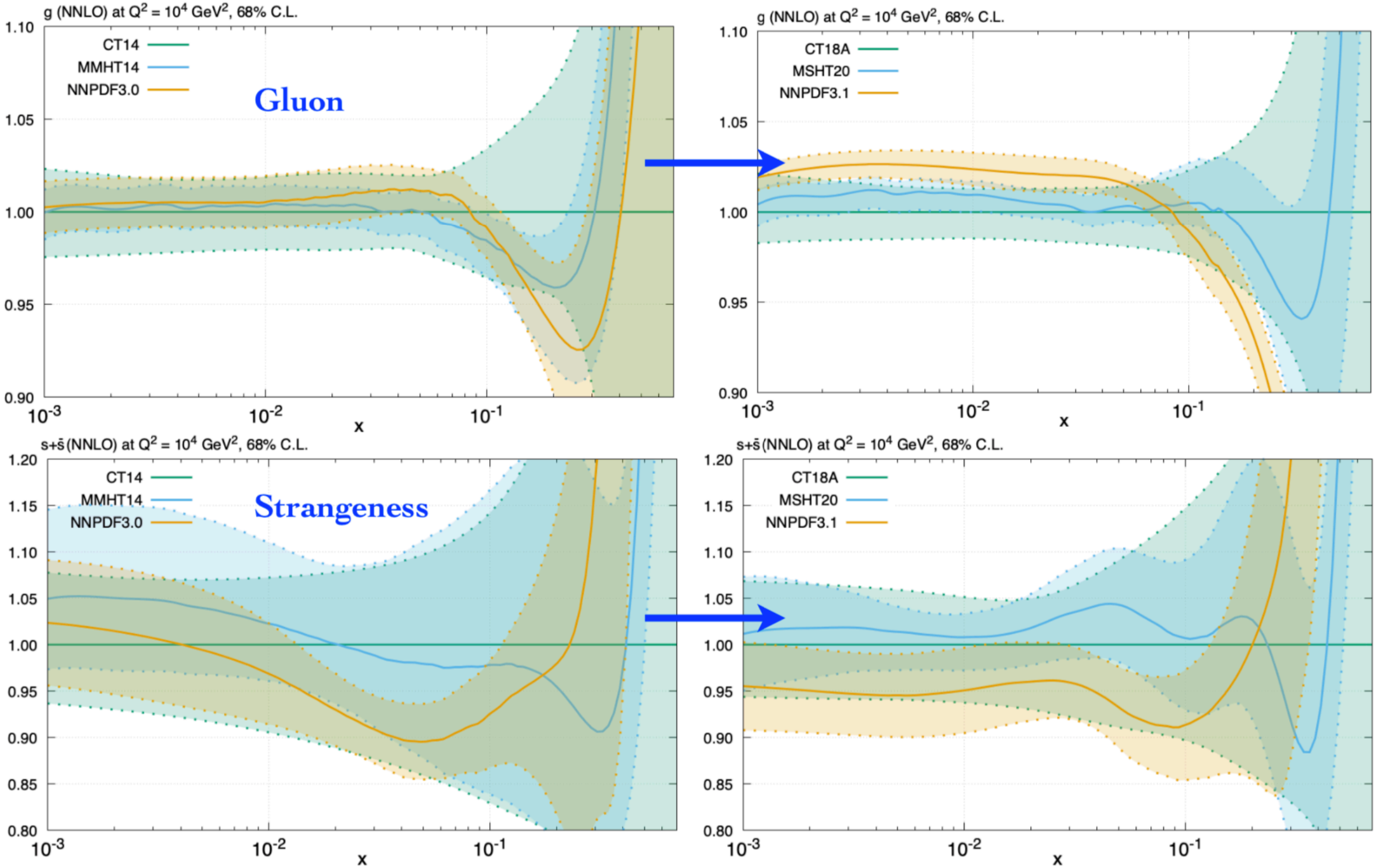
Status of Global fits

- Post Run-1 fits (almost) available from the three major groups: CT18, MSHT20, NNPDF3.1
  - Increase relevance of LHC data (and more processes included)
  - Theory predictions at higher accuracy (NNLO QCD+NLO EW)
  - Improvements in fit methodology and uncertainties
- Visible reduction in uncertainties as more data is added
- Does not always goes together with increase consistency among fit



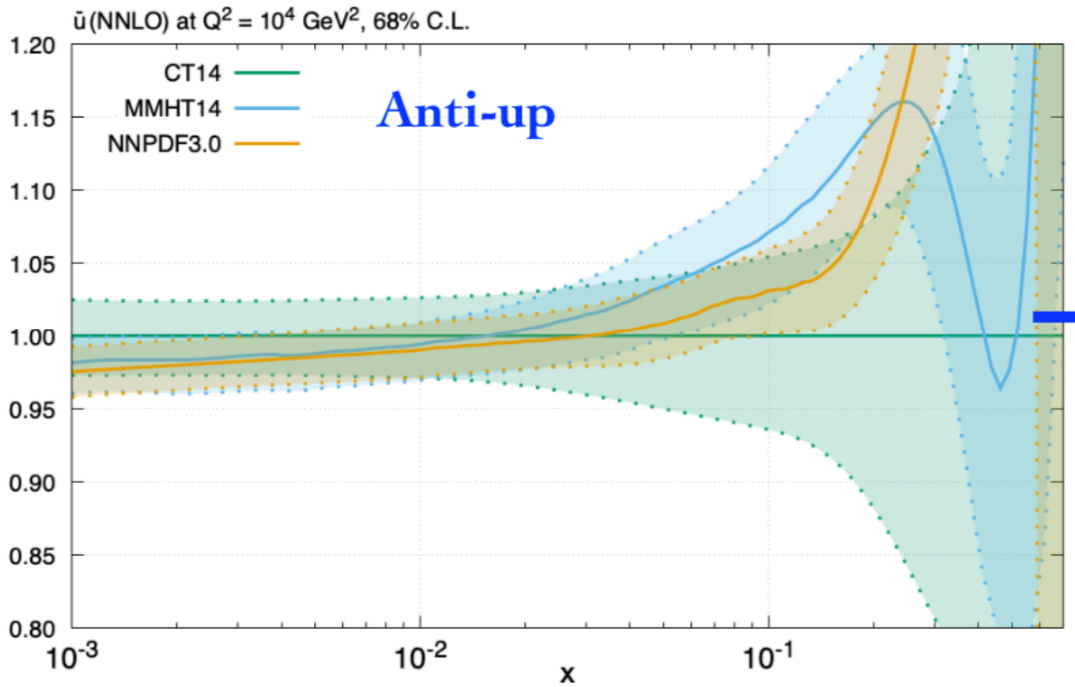
L. Harland-Lang, QCD@LHC20

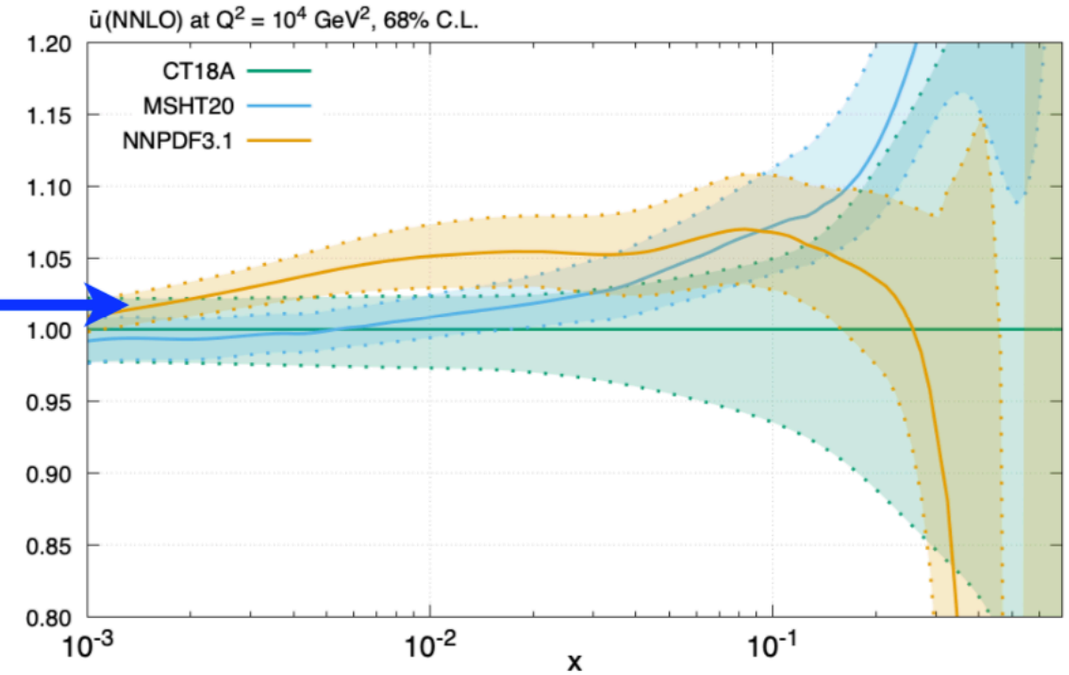
Status of global fits

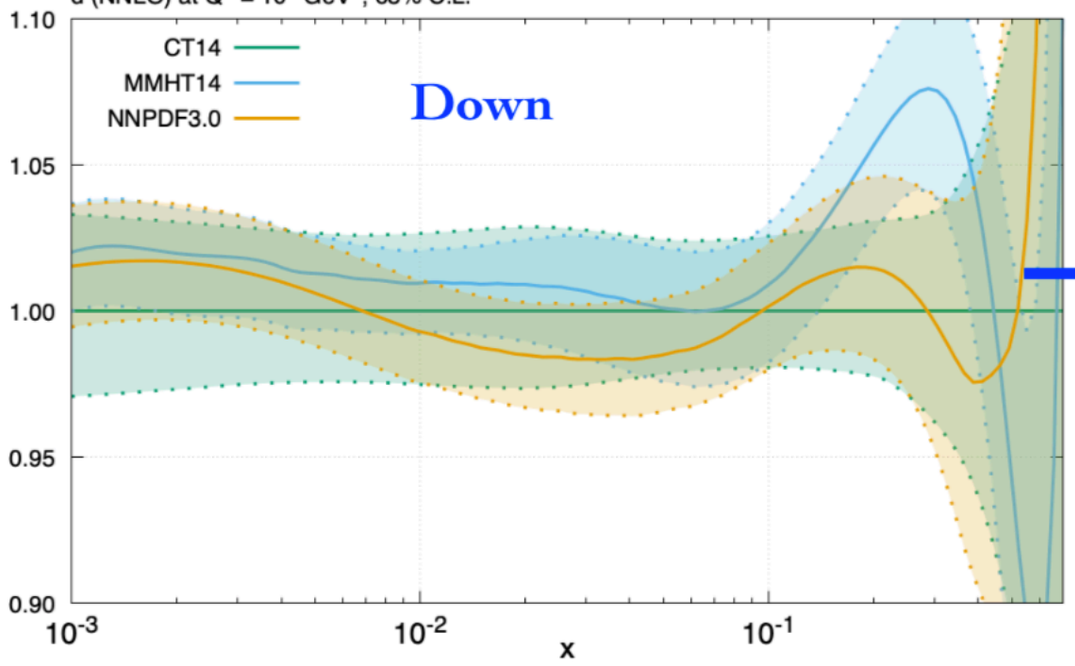


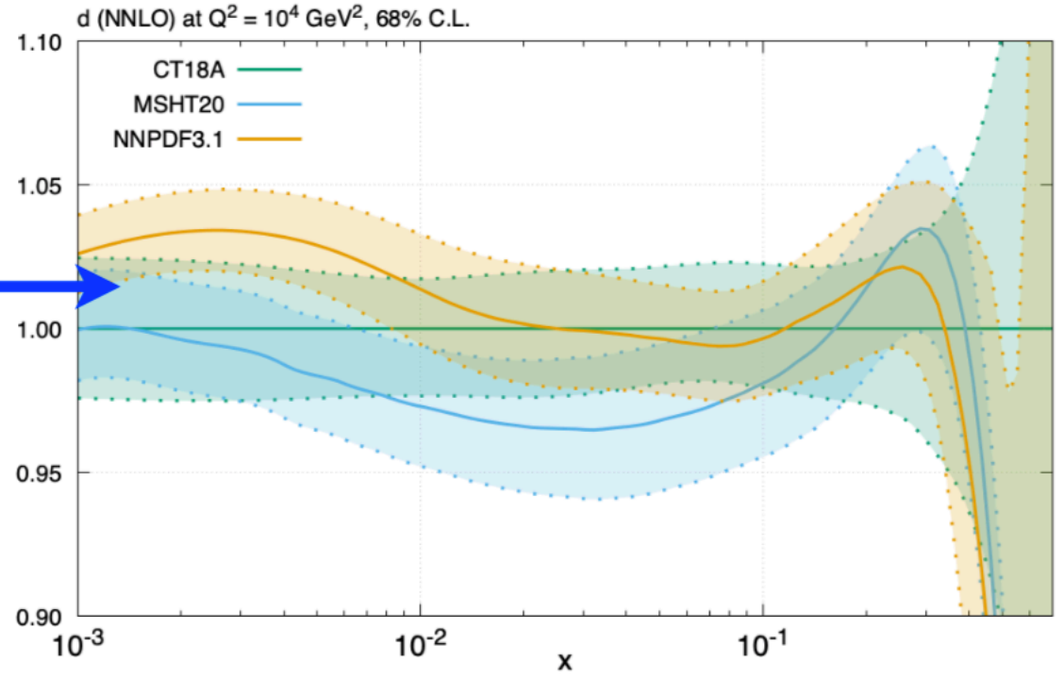
L. Harland-Lang, QCD@LHC20

Status of global fits





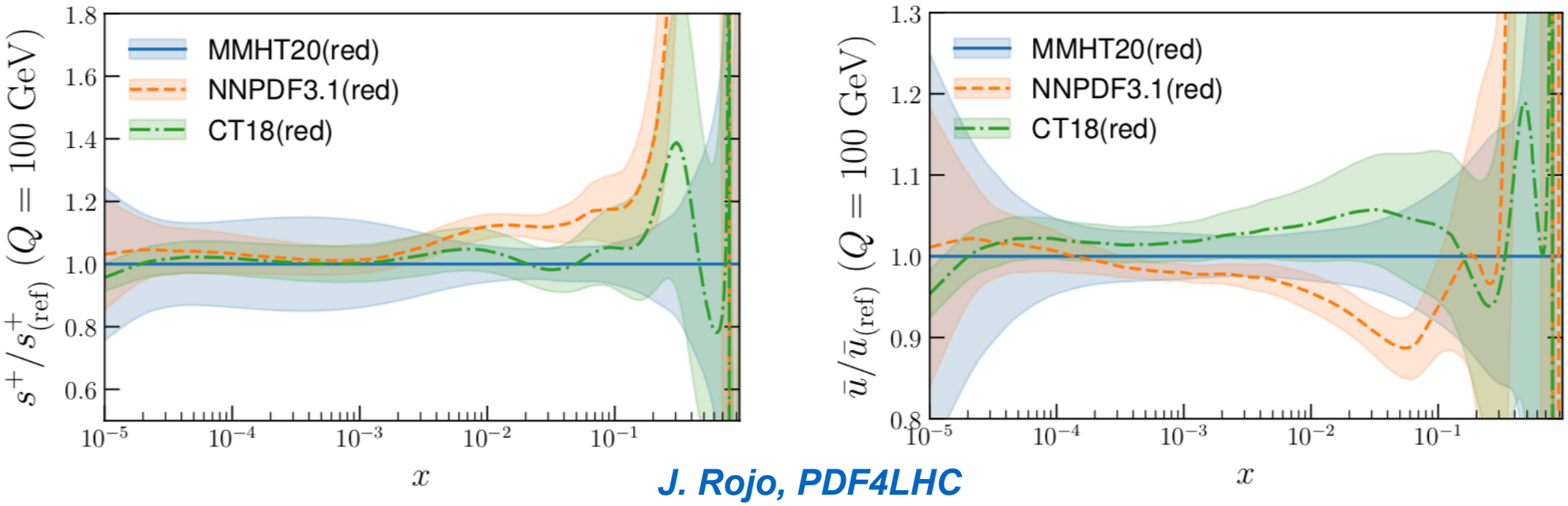




L. Harland-Lang, QCD@LHC20

Benchmarking and correlations

- Crucial to understand how significant are differences between different PDF sets and predictions which use them
- New PDF4LHC benchmarking exercise started
  - Evaluate consistency of PDF group on a common subset of data
  - Using same theory predictions and systematics treatment
  - Differences found for strange and quark flavour separation

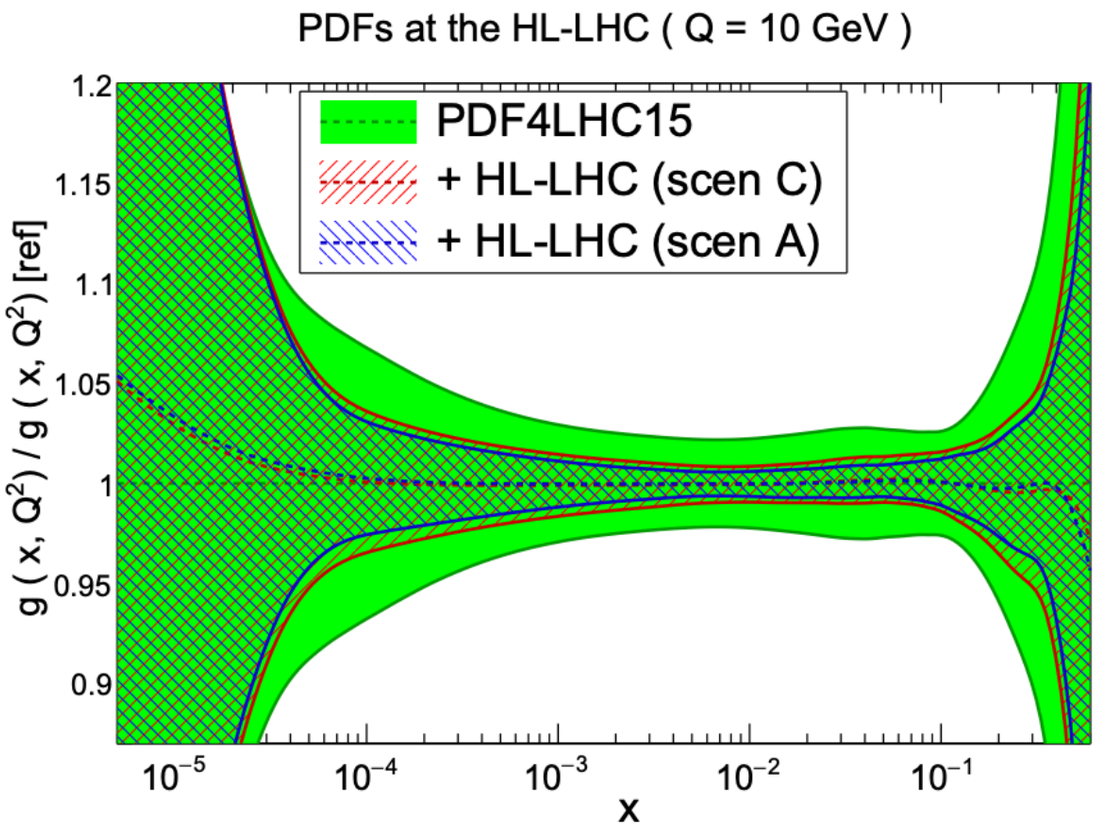


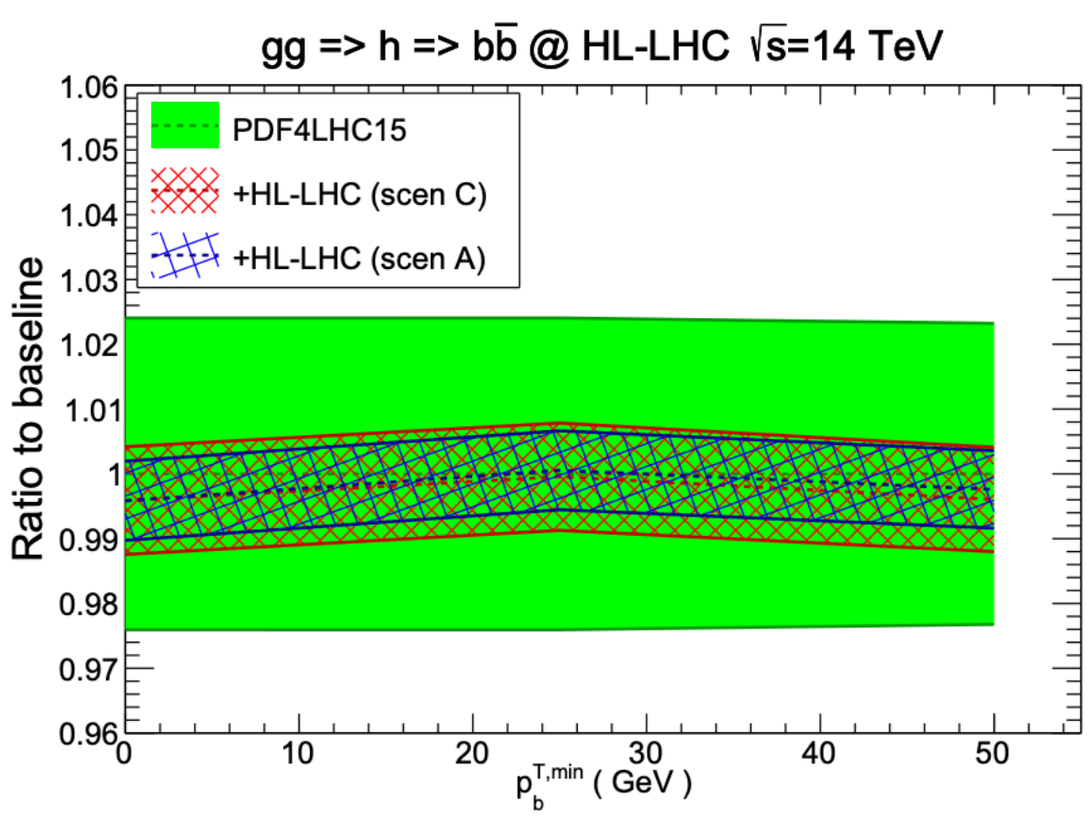
J. Rojo, PDF4LHC

- Also LHCEWWG effort to evaluate correlations between different PDFs through fits to pseudo-data

HL-LHC PROSPECTS

- Thanks to upcoming higher precision measurements expect reduction in PDF uncertainties by factors 2-4 at HL-LHC
- Significant improvements in the uncertainties for medium- and high-x gluons and for the strange PDF
- Uncertainties on ggH production below the percent level





HL/HE-LHC YR

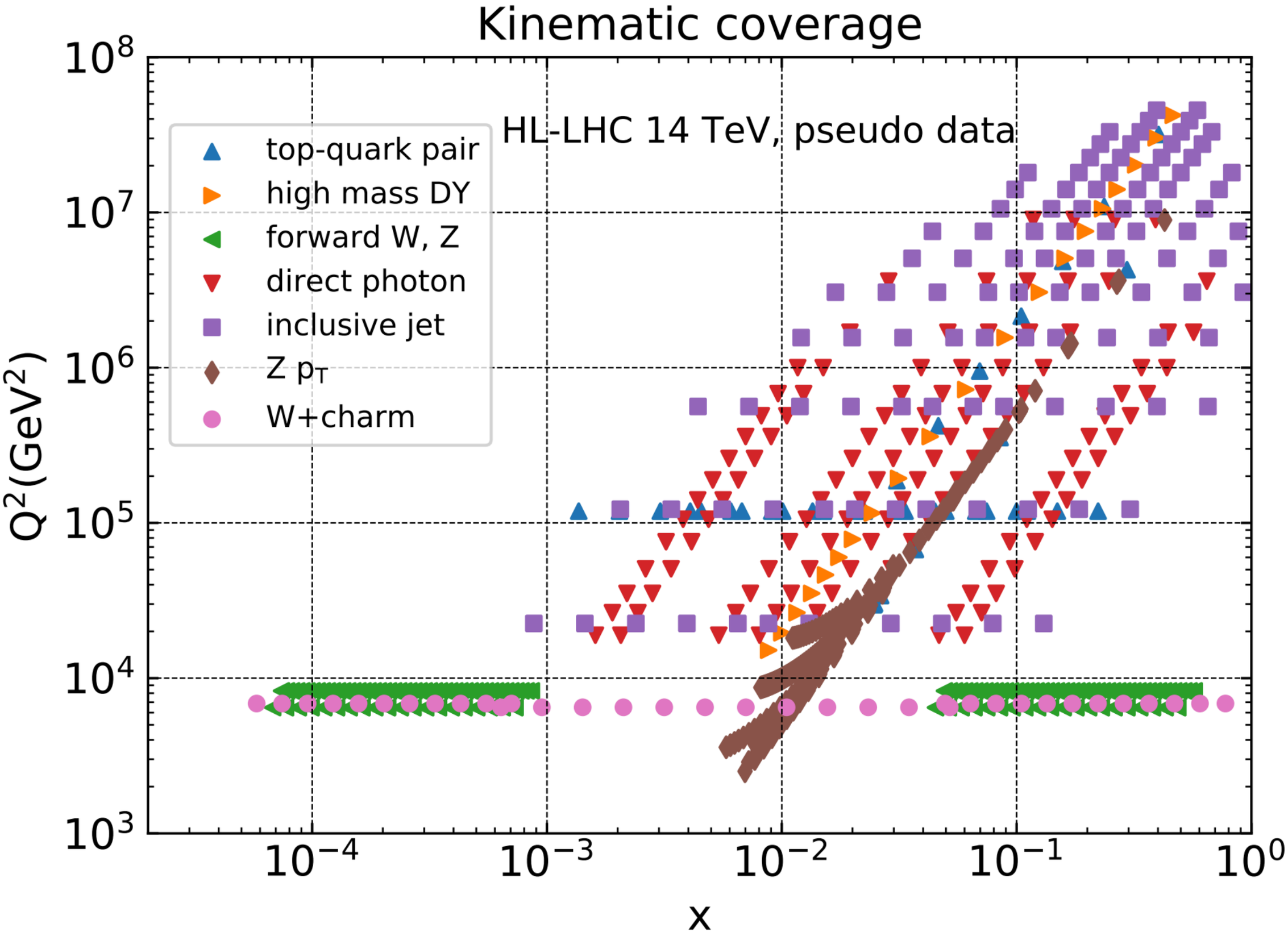
Summary

- Inclusion of LHC measurements crucial for the progress in the PDFs understanding of the last few years
  - Complementary to DIS data, precise enough to constrain the valence, strange and gluon PDFs

- As measurement became more precise they start challenging the accuracy of our theory predictions
  - NNLO QCD not always enough: N^{3}LO QCD, NLO EW, soft-gluon resummation effects can be important

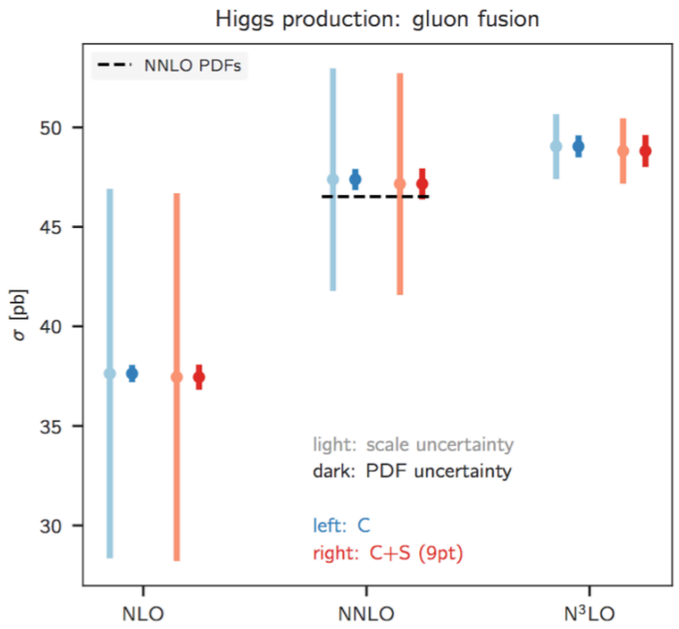
- Bright prospects for further reduction of uncertainties by including even more precise Run2 measurements
  - Ensuring this will go together with a reduction in the spread between different fits is essential to reduce theory systematics for the HL-LHC physics program

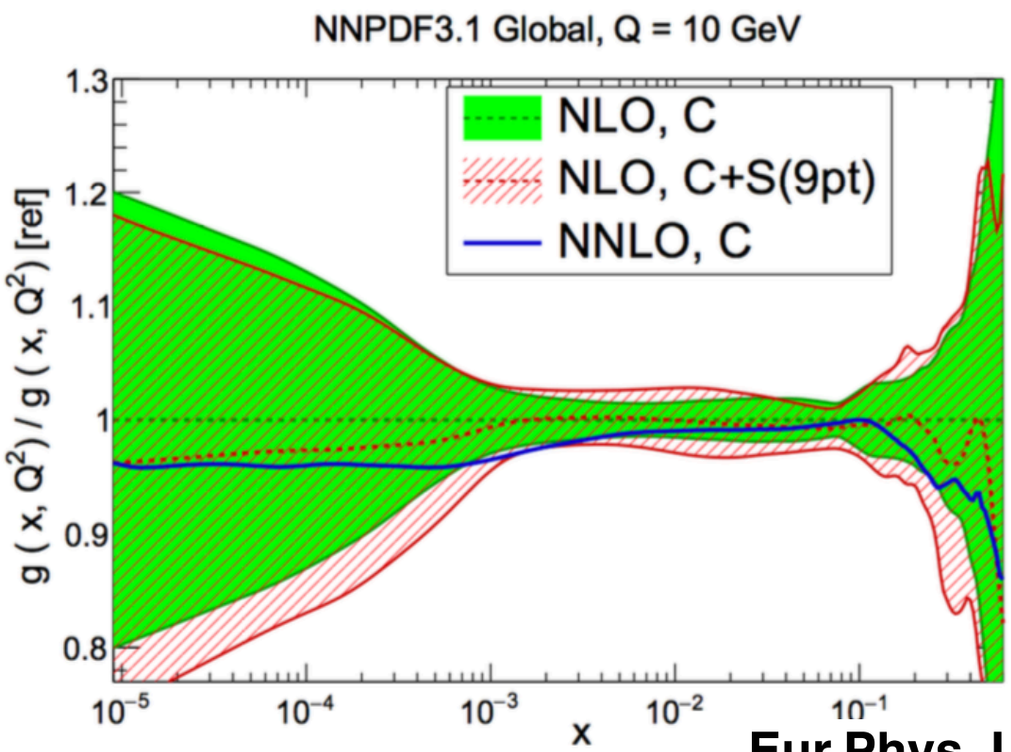
Backup

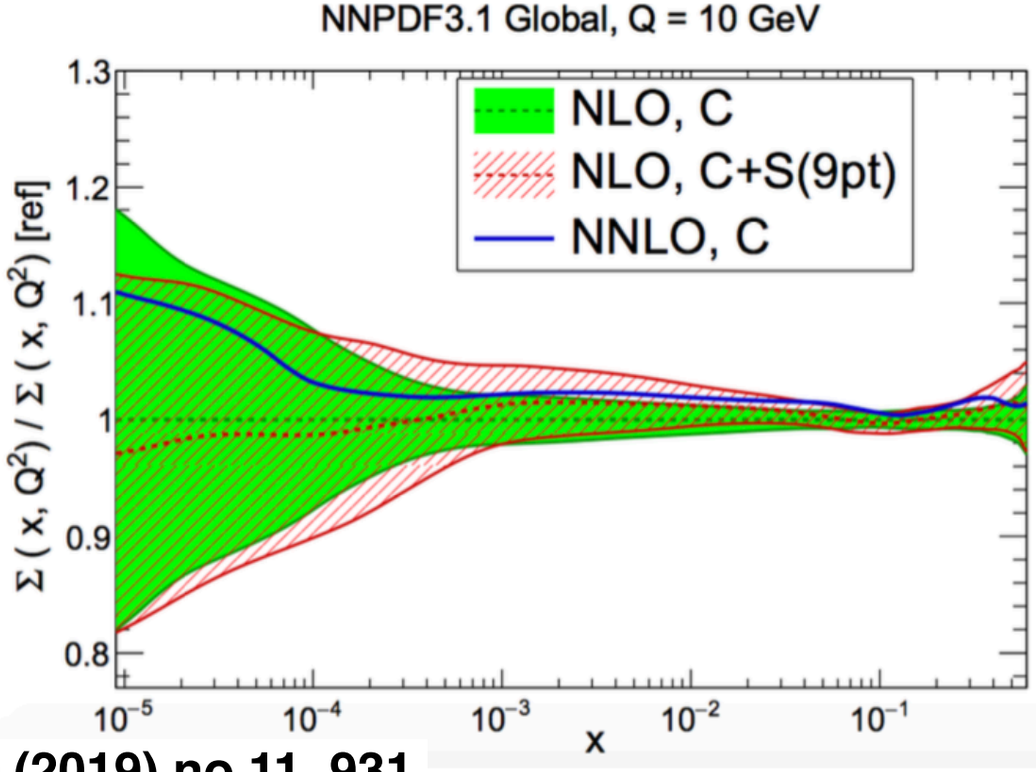

Kinematic coverage
HL-LHC 14 TeV, pseudo data
top-quark pair
high mass DY
forward W, Z
direct photon
inclusive jet
Z p_T
W+charm
Q^2(GeV^2)
10^8
10^7
10^6
10^5
10^4
10^3
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
x

PDFs with MHOU

- Construct a theory covariance matrix from scale variations
- Scales assumed correlated across all phase-space, renormalisation scale uncorrelated process by process
- Including MHOUs in the fit improves the fit quality for several datasets, relaxes tensions among them
- Are needed not to double count MHOU in the PDFs and in the cross-section predictions







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Fit to V+jets data