Towards PDF4LHC20 (or 21)

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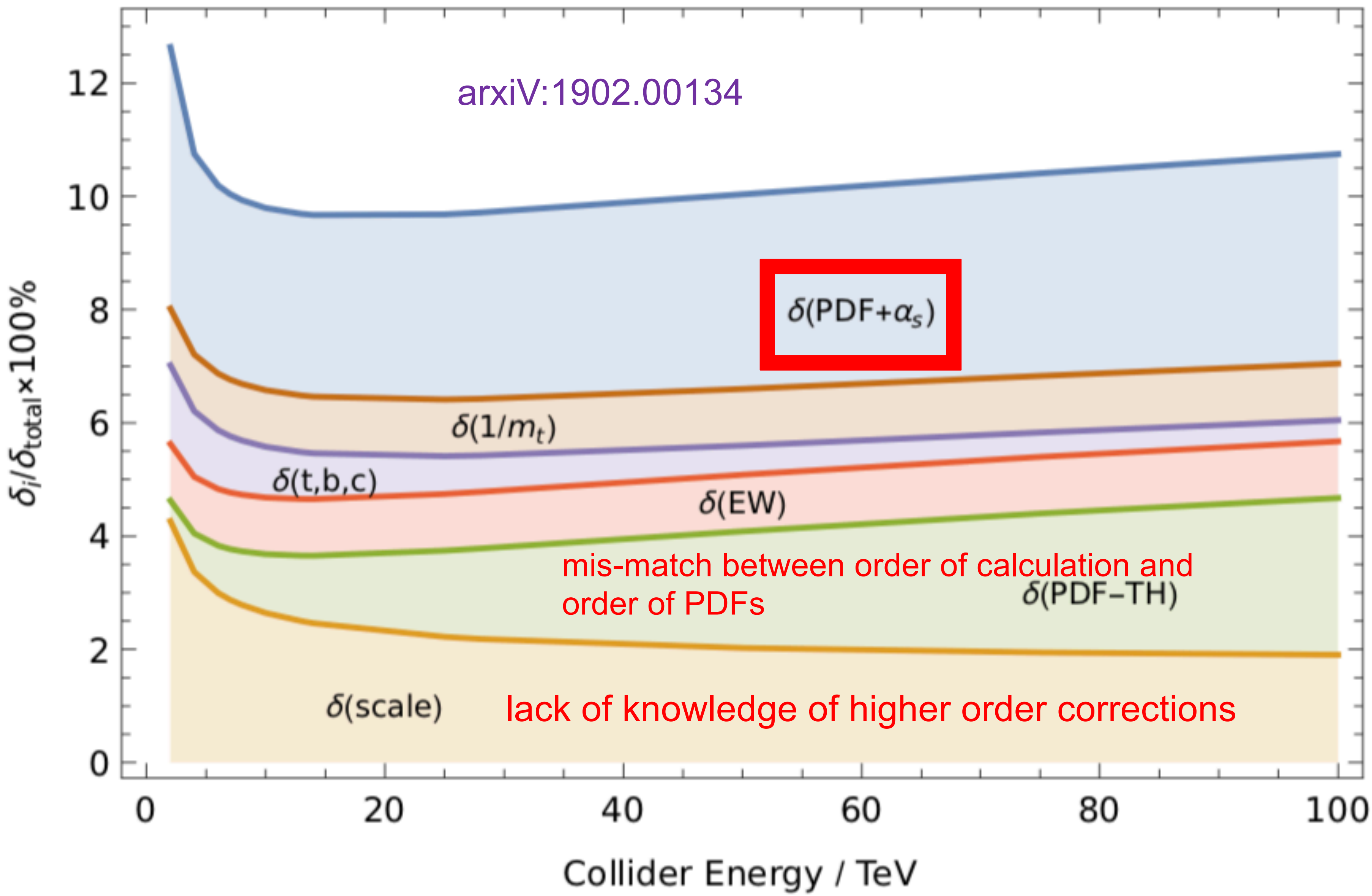
for the PDF4LHC benchmarking working group and the HXSWG PDF sub-group (J. Bendavid, J. Huston, R. Thorne, M. Ubiali)

Higgs Cross Section Working Group Nov. 9, 2020

Uncertainties for ggF



$\alpha_s(m_Z)$ uncertainties

importance of α_s uncertainties depends on order of calculation, so very important for Higgs through ggF at N3LO

- LO $\equiv \mathcal{O}(1)$,
- NLO QCD $\equiv \mathcal{O}(\alpha_s)$,
- NNLO QCD $\equiv \mathcal{O}(\alpha_s^2)$,
- NLO EW $\equiv \mathcal{O}(\alpha)$,
- NNNLO QCD $\equiv \mathcal{O}(\alpha_s^3)$,
- NNLO QCD+EW $\equiv \mathcal{O}(\alpha_s\alpha)$.

PDG2019 (JH, K. Rabbertz, G. Zanderighi)

$$\alpha_s(M_Z^2) = 0.1176 \pm 0.0011\,, \qquad \text{(without lattice)}$$

$$\alpha_s(M_Z^2) = 0.1182 \pm 0.0008\,, \qquad \text{(lattice)}$$

$$\alpha_s(M_Z^2) = 0.1179 \pm 0.0010\,.$$

Future improvements may come more from the lattice side than the experimental side.

PDG world average

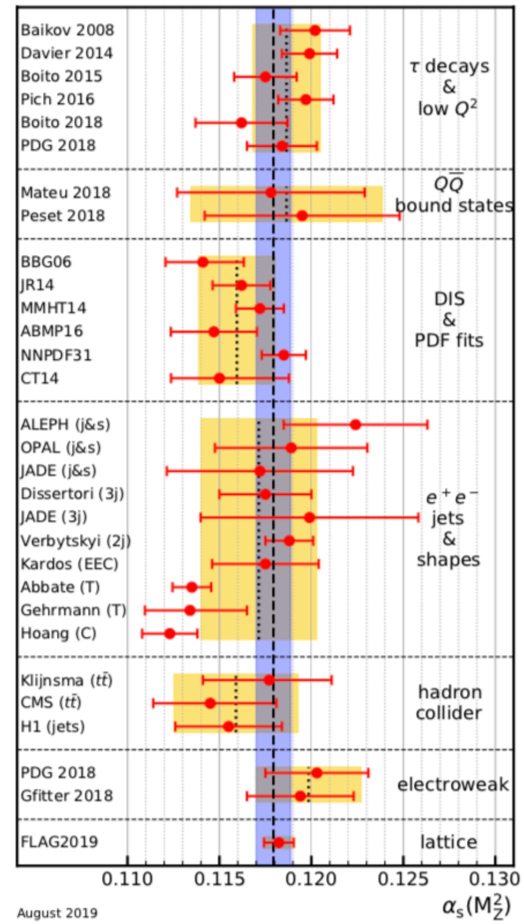
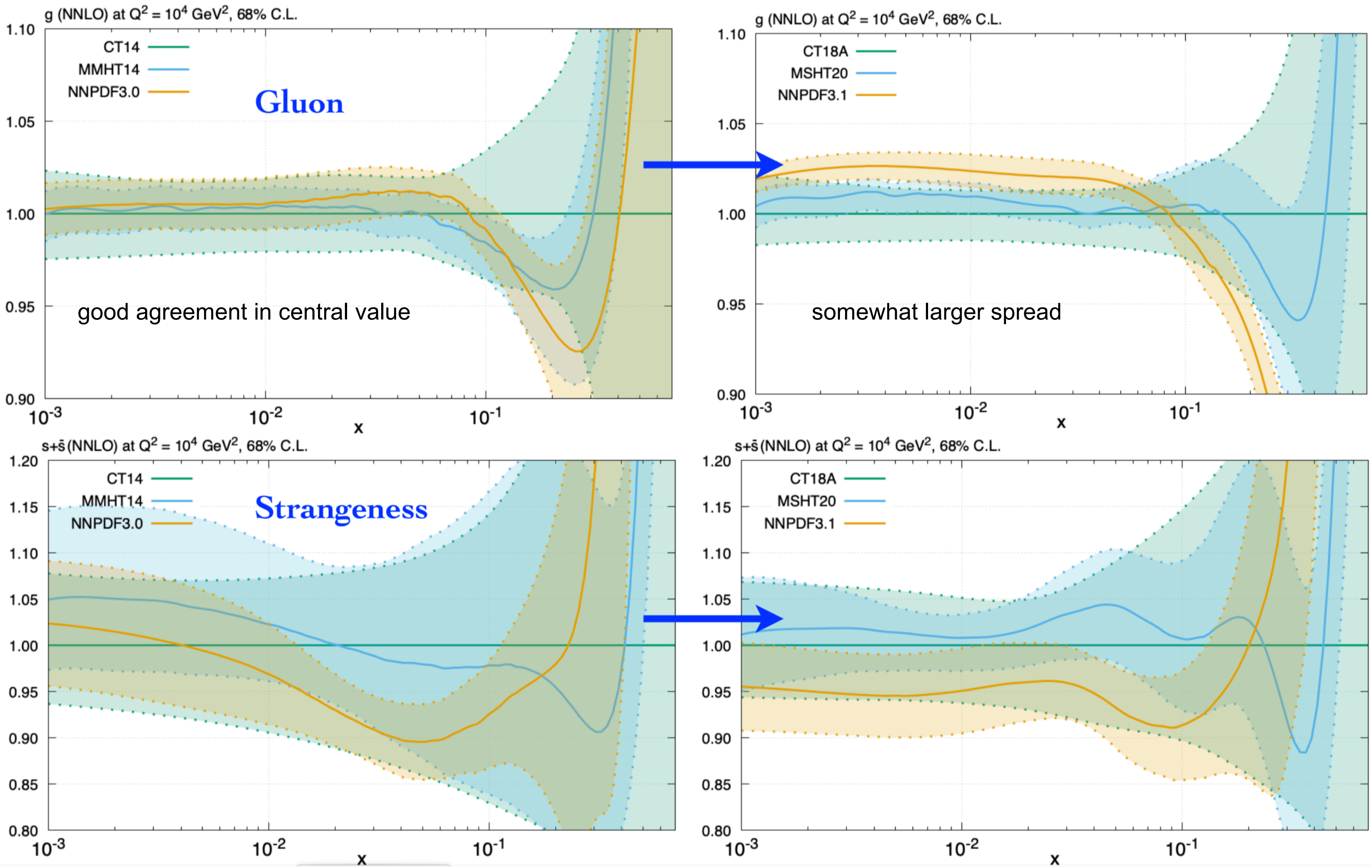


Figure 9.2: Summary of determinations of $\alpha_s(M_Z^2)$ from the seven sub-fields discussed in the text. The yellow (light shaded) bands and dotted lines indicate the pre-average values of each sub-field. The dashed line and blue (dark shaded) band represent the final world average value of $\alpha_s(M_Z^2)$.

New PDF developments

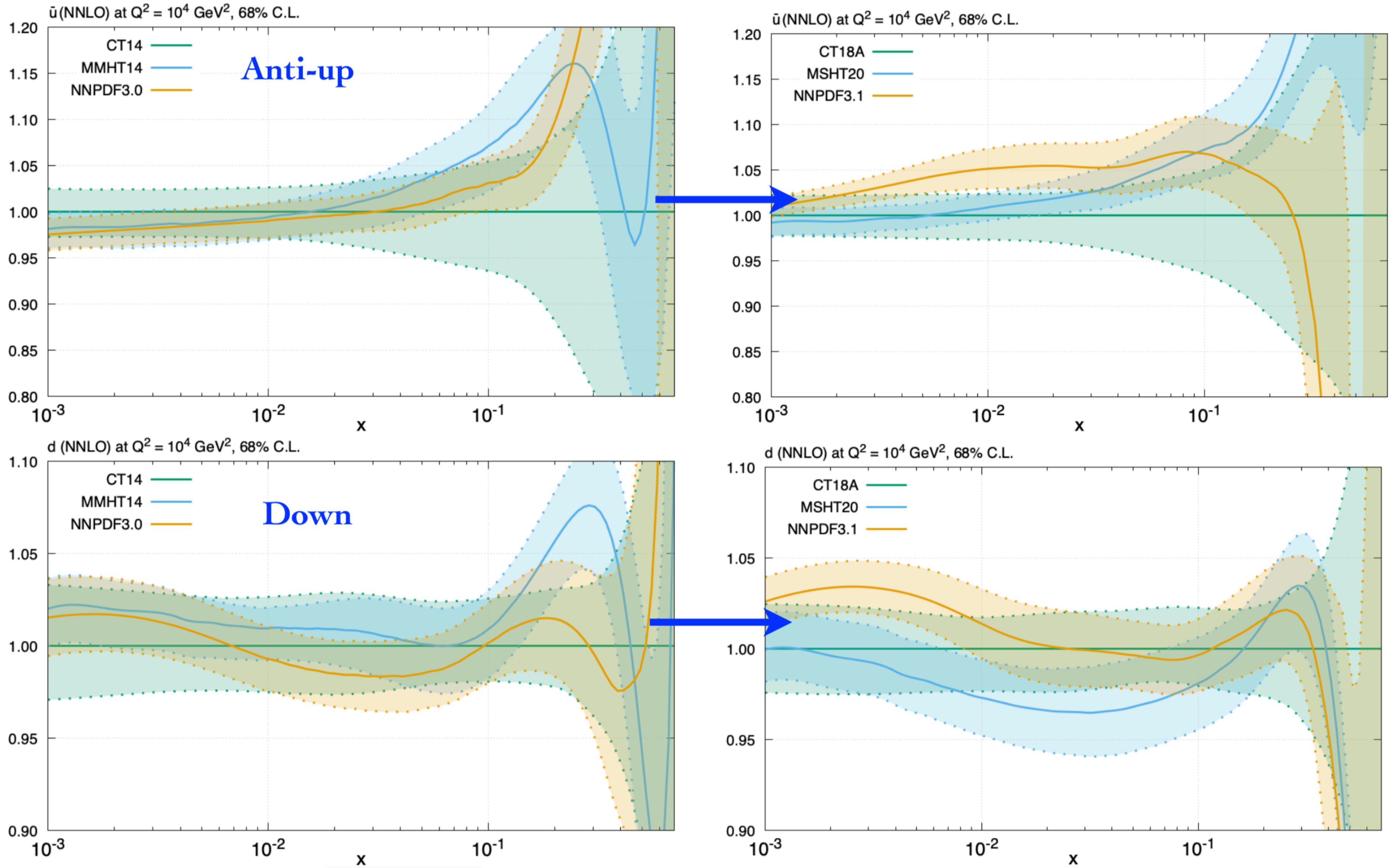
- There have been many developments in the world of PDFs since the last Higgs XSWG talk, but given the limited time the concentration on this talk will be on the PDF benchmarking of the new sets and the path towards combination
- The CT18 family of PDFs are available
  - CT18 (main PDF)
  - CT18A (including ATLAS precision W/Z data)
  - CT18X (special scale for DIS; mimicking small-x resummation)
  - CT18Z (including both ATLAS precision W/Z data and special scale for DIS)
- MSHT20 (new acronym; note in some plots will appear as MMHT20)
  - will be available in LHAPDF in the near future
- NNPDF3.1 available for some time
- All contain much more LHC data than their previous incarnations

PDF Changes



Plot from presentation by Lucian Harland-Lang at Higgs 2020

PDF Changes



Plot from presentation by Lucian Harland-Lang at Higgs 2020

In 2014-15, we carried out a year-long exercise to (1) perform a benchmarking exercise for all PDFs, and (2) to present recommendations for LHC Run II (PDF4LHC15 PDFs)

The PDF4LHC report on PDFs and LHC data: Results from Run I and preparation for Run II

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OUTP-15-11P, LCTS/2015-14, GLAS-PPE/2015-01, DESY 15-088, JL CERN-PH-TH-2015-150

PDF4LHC recommendations for LHC Run II

Jon Butterworth[1], Stefano Carrazza[2,4], Amanda Cooper-Sarkar[3], Albert De Roeck[4,5], Joël Feltesse[6], Stefano Forte[2], Jun Gao[7], Sasha Glazov[8], Joey Huston[9], Zahari Kassabov[2,10], Ronan McNulty[11], Andreas Morsch[4], Pavel Nadolsky[12], Voica Radescu[13], Juan Rojo[14] and Robert Thorne[1].

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Abstract:

We provide an updated recommendation for the usage of sets of parton distribution functions (PDFs) and the assessment of PDF and PDF+α_s uncertainties suitable for applications at the LHC Run II. We review developments since the previous PDF4LHC recommendation, and discuss and compare the new generation of PDFs, which include substantial information from experimental data from the Run I of the LHC. We then propose a new prescription for the combination of a suitable subset of the available PDF sets, which is presented in terms of a single combined PDF set. We finally discuss tools which allow for the delivery of this combined set in terms of optimized sets of Hessian eigenvectors or Monte Carlo replicas, and their usage, and provide some examples of their application to LHC phenomenology.

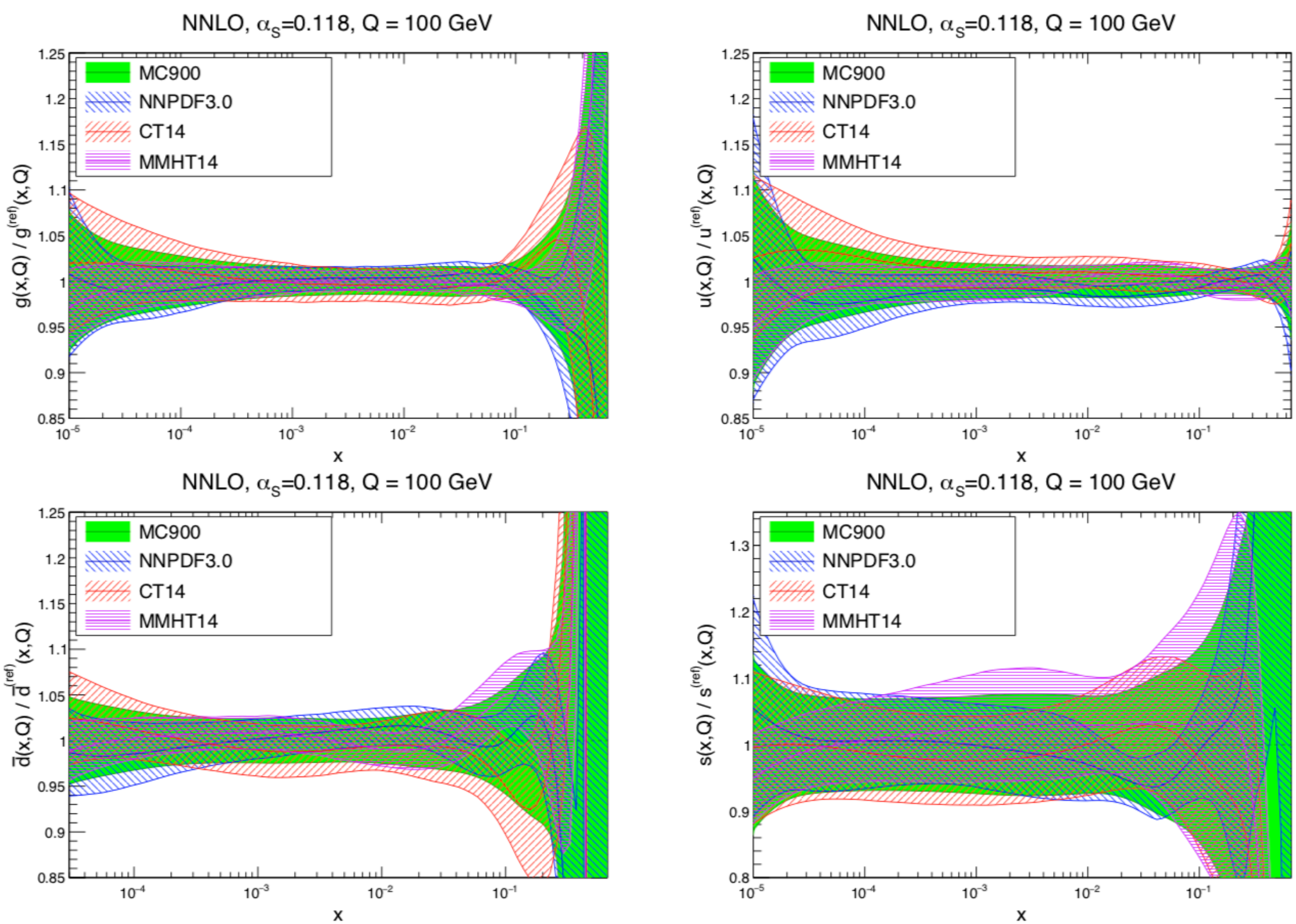
This paper is dedicated to the memory of Guido Altarelli (1941-2015), whose seminal work made possible the quantitative study of parton distribution functions.

125 citations

1054 citations

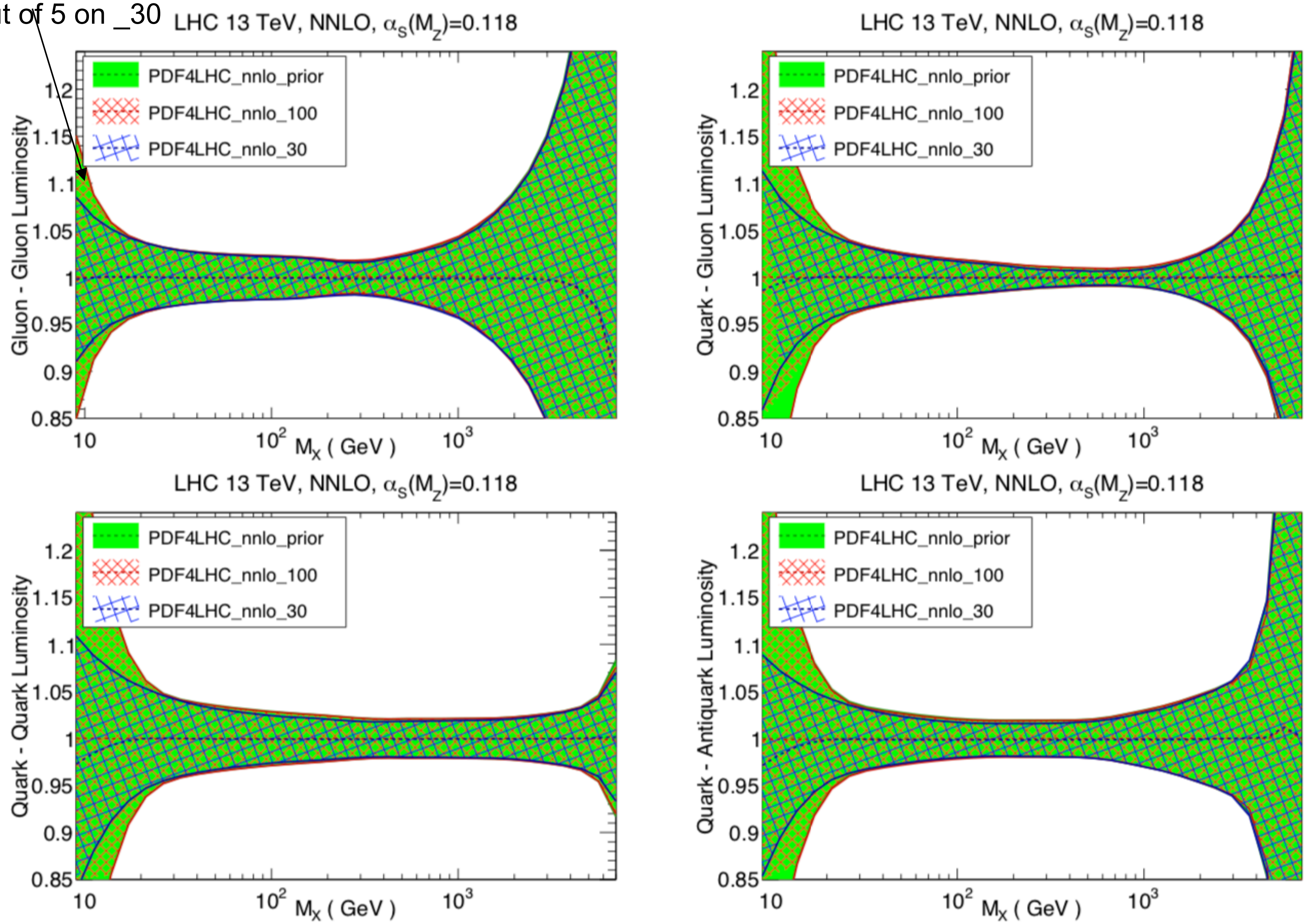
PDF4LHC15 exercise

- 300 Monte Carlo replicas generated from error sets of each of the 3 global PDF sets; information can be summarized in far fewer error PDFs

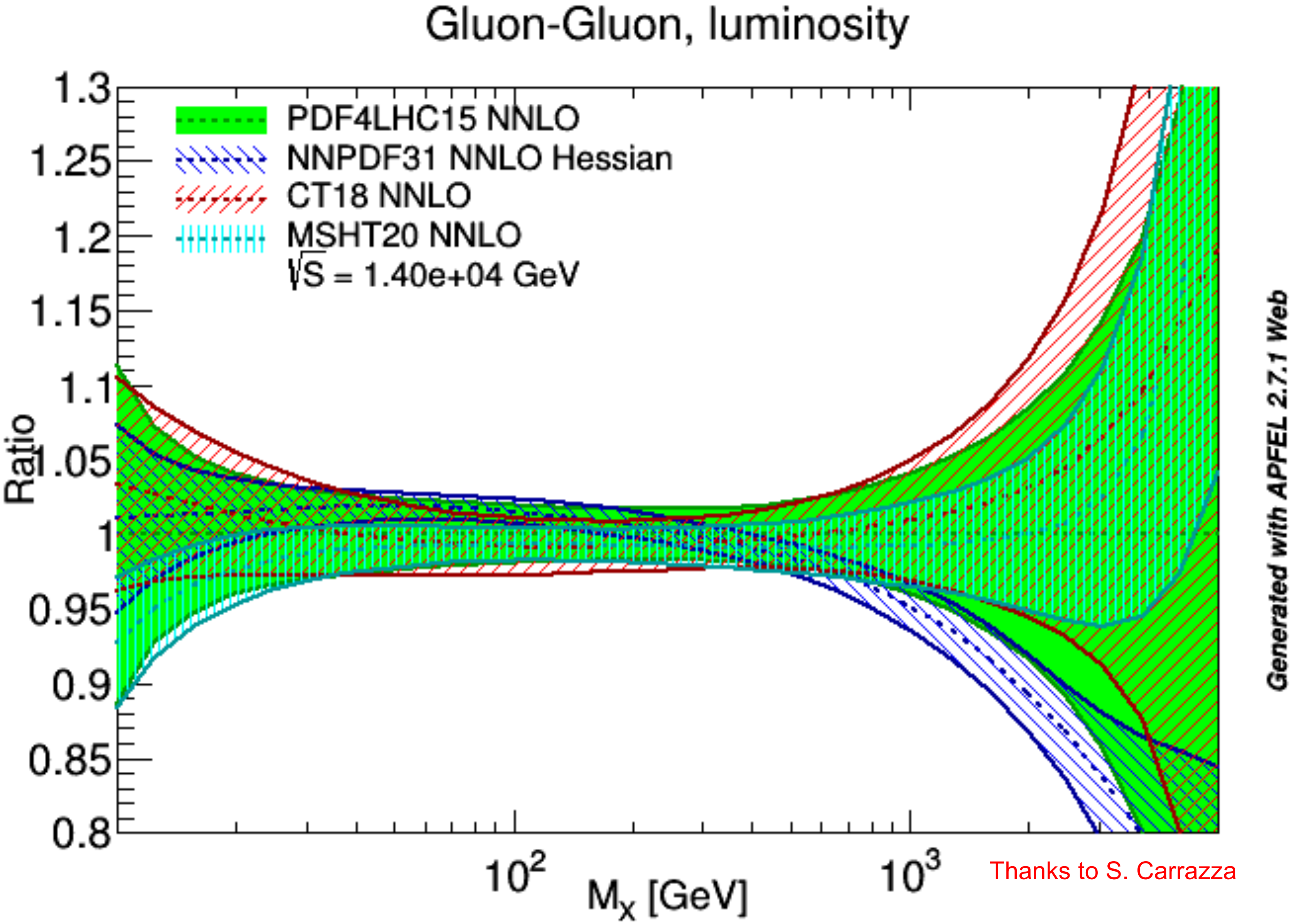


3 forms of distribution in 2015

differences at very small
mass due to imposition of rapidity
cut of 5 on _30



Comparison of new PDFs to PDF4LHC15



Thanks to S. Carrazza

A great deal of LHC information has now been included in global PDF fits: it's been 5 years, so time for benchmarking

- Why is benchmarking necessary?
- Most of the relevant data is in common
  - but different cuts on the data in some cases, which can lead to varying amounts of tension
- Each group uses a different (but perfectly valid) GM-VFNS
  - and NNPDF uses a fitted charm approach versus perturbative charm used by CT/MSHT
- Each group uses a different approach for determining PDF uncertainties
  - MSHT/CT: variants of Hessian
  - NNPDF: Monte Carlo replicas
  - one-to-one comparison can be tricky

LHC data in MSHT: Robert Thorne EWWG Meeting Oct. 2020

	no. points	NNLO χ^2
D0 W asymmetry	14	12.0
$\sigma_{t\bar{t}}$ Tevatron +CMS+ATLAS $7, 8\mathrm{TeV}$	17	14.5
LHCb 7+8 TeV $W + Z$	67	99.4
LHCb 8 TeV e	17	26.2
CMS 8 TeV W	22	12.7
ATLAS 7 TeV jets $R = 0.6$	140	221.6
CMS 7 TeV $W + c$	10	8.6
ATLAS 7 TeV W, Z	61	116.6
CMS 7 TeV jets $R = 0.7$	158	175.8
ATLAS 8 TeV Zp_T	104	188.5
CMS 8 TeV jets	174	261.3
ATLAS 8 TeV $t\bar{t} \to l + \mathrm{j}$ single-diff	25	25.6
ATLAS 8 TeV $t\bar{t} \to l^+l^-$ single-diff	5	3.5
ATLAS 8 TeV high-mass Drell-Yan	48	56.7
ATLAS 8 TeV $W^{+,-} + \mathrm{jet}$	32	18.1
CMS 8 TeV $(d\sigma_{t\bar{t}}/dp_{T,t}dy_t)/\sigma_{t\bar{t}}$	15	22.5
ATLAS 8 TeV W^+, W^-	22	57.4
CMS 2.76 TeV jets	81	102.9
CMS 8 TeV $t\bar{t}$ y_t distribution	9	13.2
ATLAS 8 TeV double differential Z	59	85.6
total	4363	5122

PDF benchmarking

- We're in the process of carrying out benchmark studies with the goal of an ultimate combination of modern PDFs similar to what was done for PDF4LHC15 using the then-current PDF sets CT14, MMHT2014, NNPDF3.0
- We are starting from a **reduced data set,** simple enough that each group should get similar results for central values and uncertainties, but complete enough that the results make sense
- Useful, for example, to normalize the uncertainty definition which is different for the three groups
- We are also starting with common theoretical settings, again to allow for easier comparison of the results of each group
- PDF groups CT, MSHT, NNPDF and ATLAS participating
- All PDF groups invited to participate in benchmarking

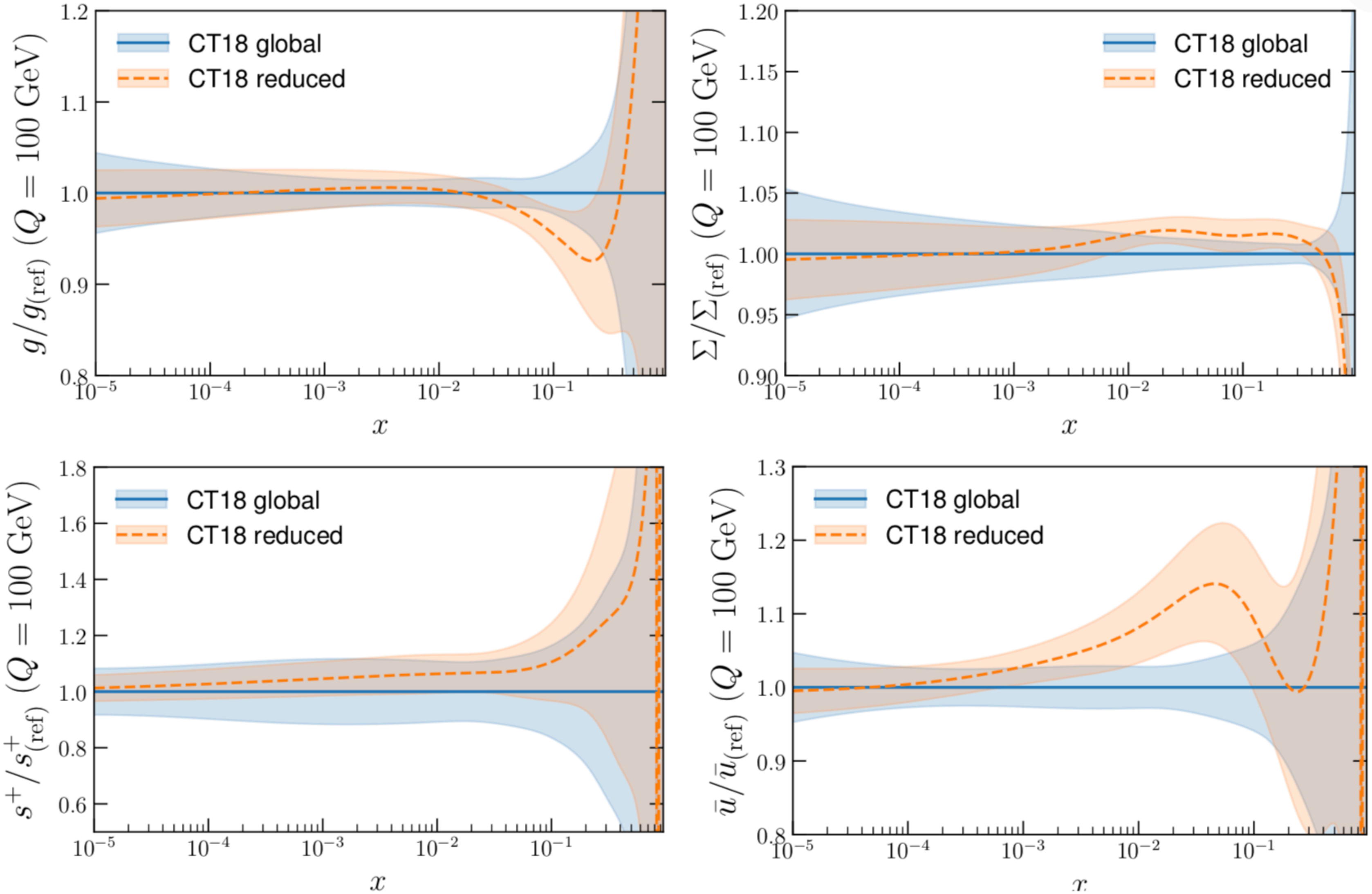
- Each group uses their own GM-VFNS
  - intrinsic part of each group's approach
- But otherwise, common theoretical settings for tests with reduced set
  - positive-definite PDFs
  - common value of $\alpha_s(m_Z)$ and uncertainty (we do this anyway)
  - no deuteron or nuclear corrections
  - use common value for heavy quark masses
  - use perturbative charm rather than fitted charm

Reduced data set

- NMC deuteron to proton ratio in DIS
- NuTeV dimuon cross sections
- HERA I+II inclusive DIS cross sections
- E866 fixed target Drell-Yan pd/pp data
- D0 Z rapidity distribution
- ATLAS W,Z 7 TeV rapidity distributions (Z peak data only and not forward rapidities)
- CMS 7 TeV W asymmetry
- CMS 8 TeV inclusive jet data
- LHCb 7,8 TeV W,Z rapidity distributions
- BCDMS proton and deuteron DIS data

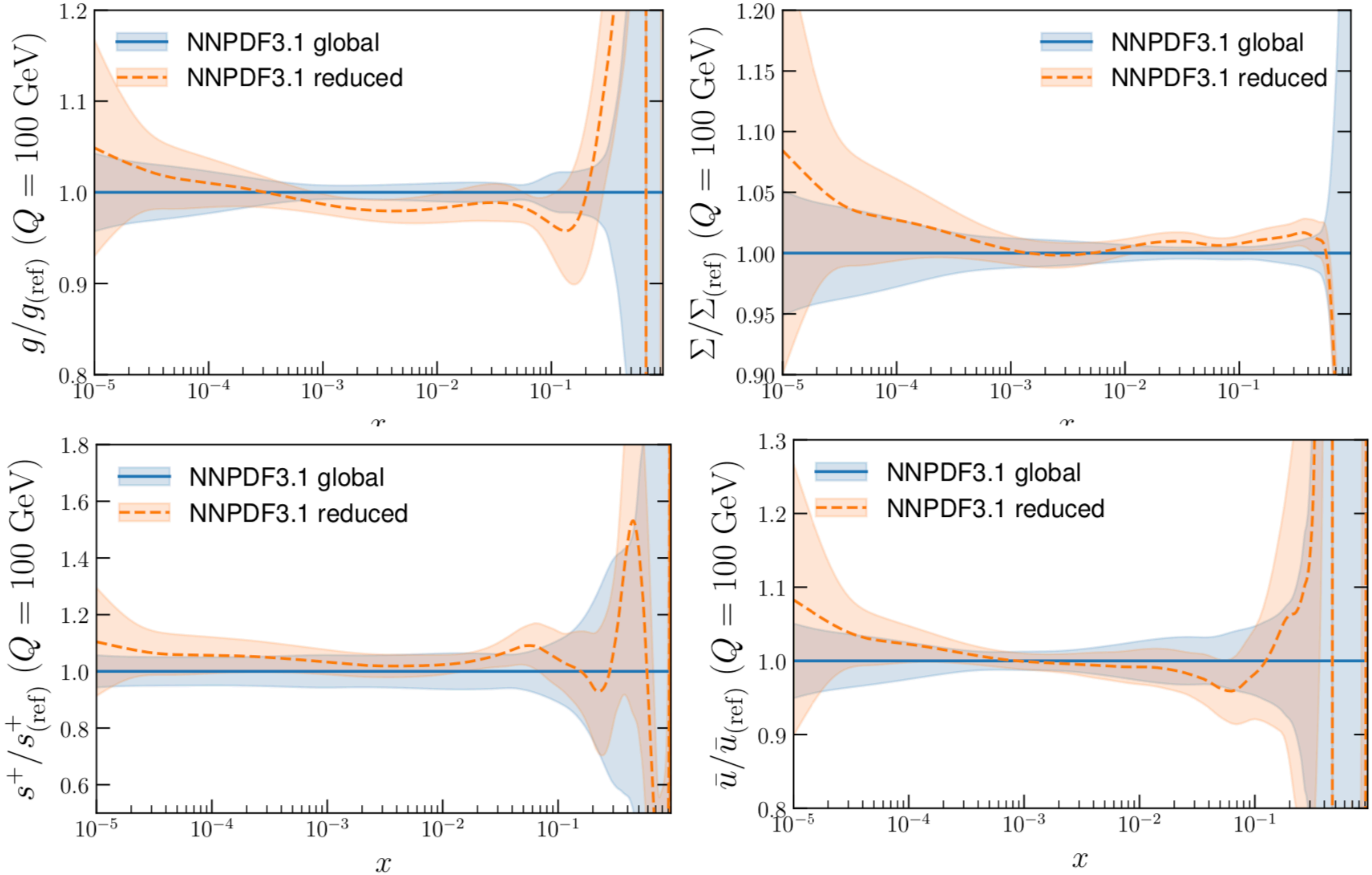
- We started by having each group compare theory predictions to this reduced data set using PDF4LHC15 PDFs (as a sanity check)
- Good agreement was observed

Reduced to full data set comparison for PDFs



Plot from Juan Rojo's presentation at the October 2020 PDF4LHC meeting

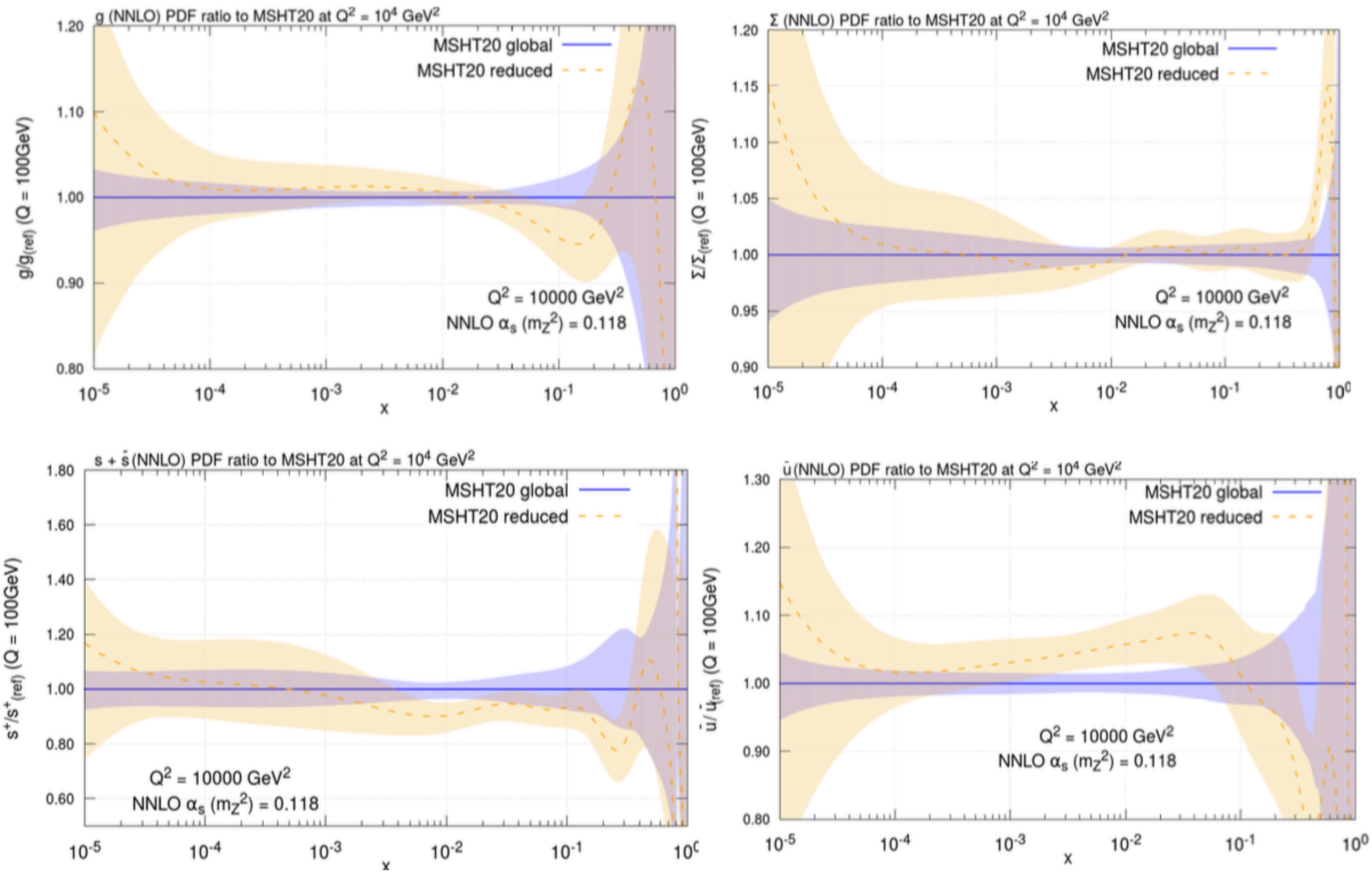
Reduced to full data set comparison



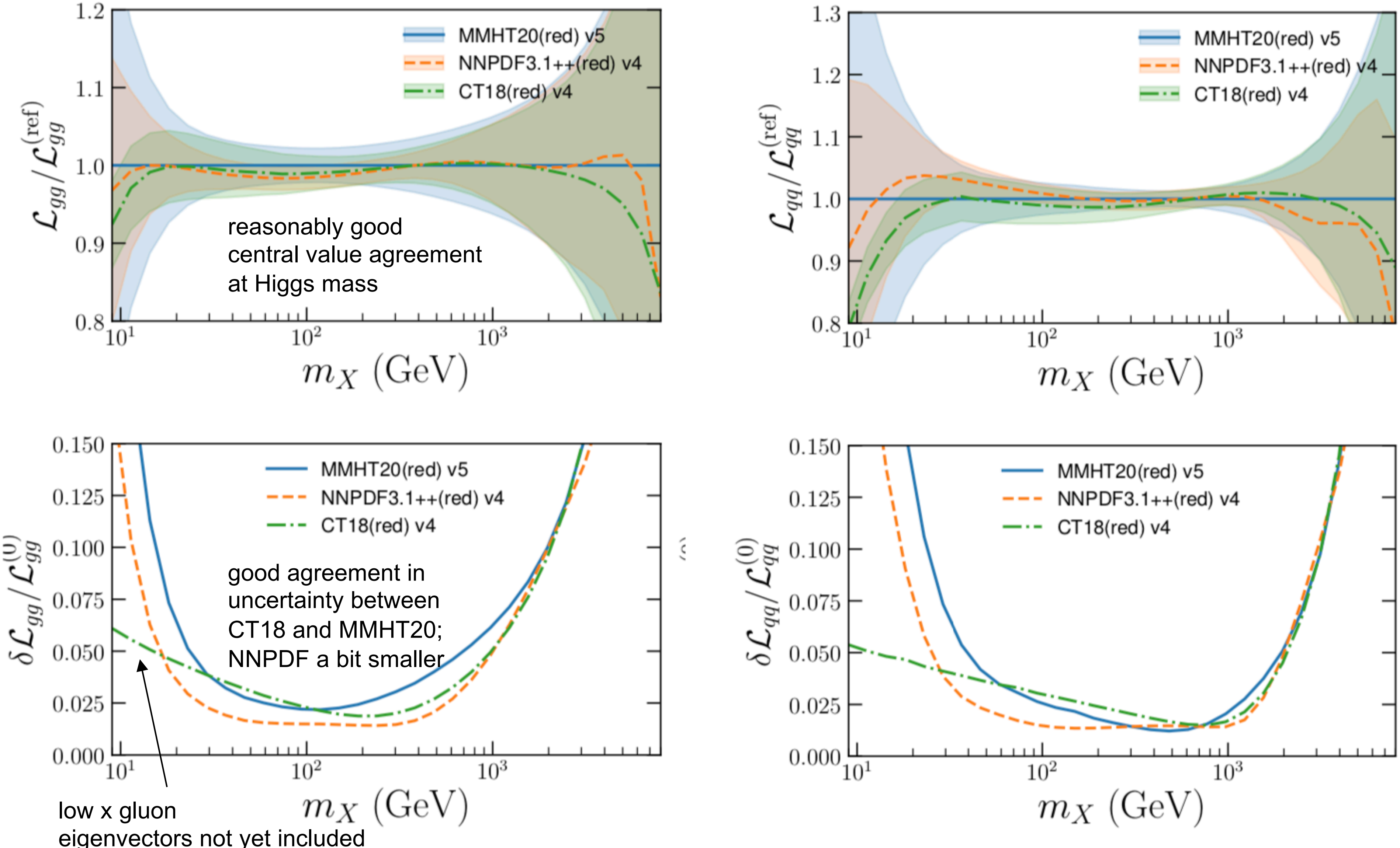
Plot from Juan Rojo's presentation at the October 2020 PDF4LHC meeting

Reduced to full data set comparison

larger difference in uncertainty between reduced and full data sets



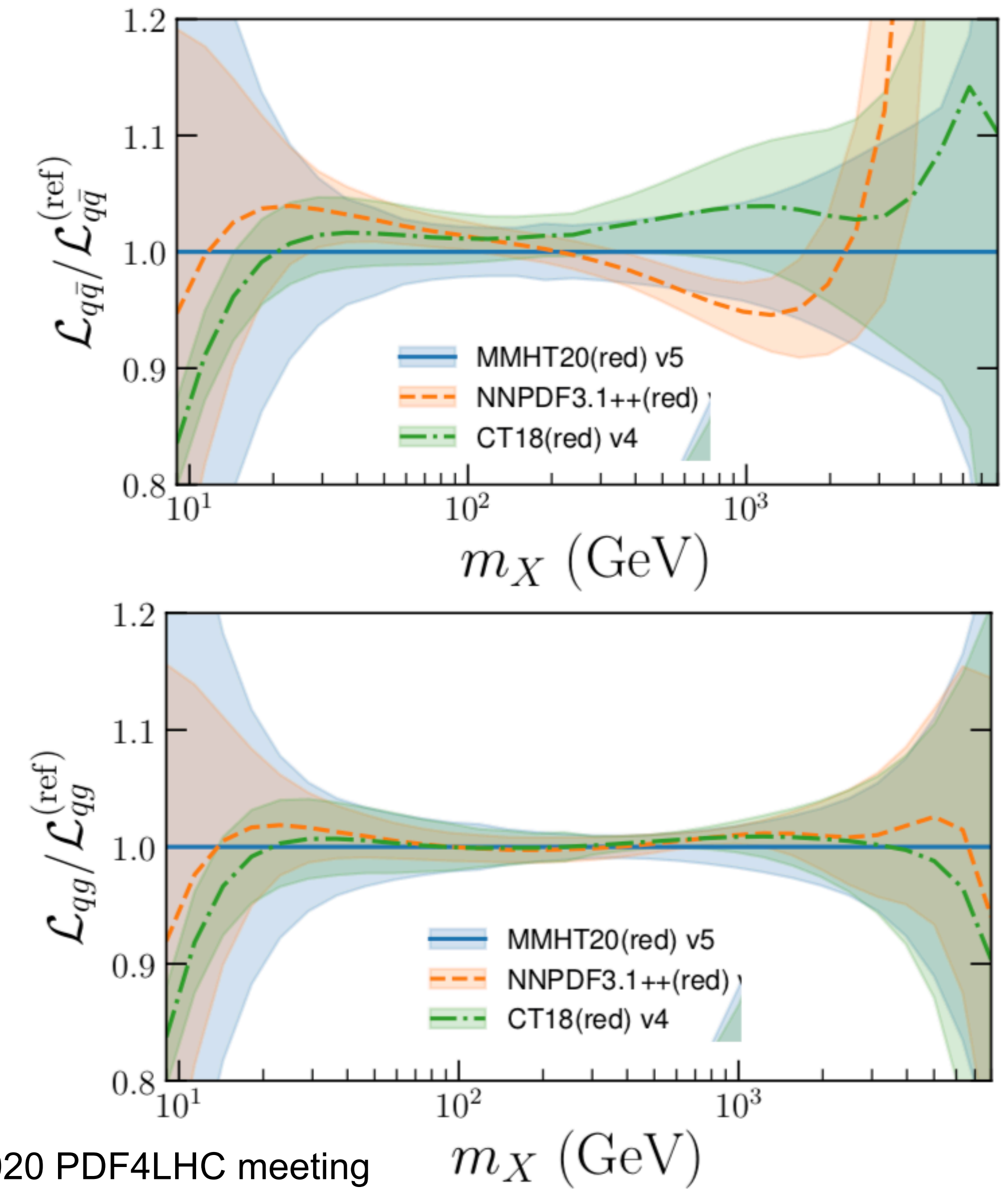
Comparison of reduced PDF luminosities (14 TeV)



Plot from Juan Rojo's presentation at the October 2020 PDF4LHC meeting

Comparison of reduced PDF luminosities (14 TeV)

- In general, reasonably good agreement for the PDFs produced using the reduced data set.
- Some divergence, for example, for the qqbar PDF luminosity at high mass



Plot from Juan Rojo's presentation at the October 2020 PDF4LHC meeting

Summary/to-do

- We're ready to move from the reduced data set to the full data sets that the groups used to produce their latest PDF sets, and with the PDF groups using their standard theoretical formalisms (but with common heavy quark masses)
- From the fits to this data, we will follow a procedure similar to that carried out in 2015
  - some number of Monte Carlo replicas (300 in 2015) generated from each PDF set and then combined
    - will examine the impact of variations, such as the use or not of fitted charm (may have an influence on the gluon uncertainty), the presence or not of the ATLAS 7 TeV W and Z data (an impact on strangeness), and with/without small-x resummation for the gluon distribution (impact on gluon at smaller x that is relevant for ggF, especially at higher center-of-mass energies)
  - the 900 replica set being condensed to a smaller representative Hessian error PDF set (personal opinion: <100 should be sufficient)
  - with both benchmarking and recommendation papers being prepared, and the resultant PDFs made available on LHAPDF
- Timescale for the PDFs, on the order of a few months

To forgo future controversy

- You are encouraged to use the resultant set for Monte Carlo generation


You know, it's very strange
I have been in the Remove Trump business so long, now that it's over, I don't know what to do with the rest of my life
Have you ever considered PDF benchmarking?