NNPDF3.1

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on behalf of the NNPDF Collaboration

Why NNPDF3.1?

An **update of the NNPDF global analysis** was motivated by:

- ☑ The availability of a wealth of **high-precision PDF-sensitive measurements** from the Tevatron, ATLAS, CMS and LHCb, including processes such as the **Z p_T** and **differential distributions in top-quark production** that have never been used before in a PDF fit

- ☑ The striking **recent progress in NNLO QCD calculations**, which allows to include the majority of PDF-sensitive collider measurements into a **fully consistent NNLO global analysis**

- ☑ The recent realisation that **fitting the charm PDF** has several advantages in the global QCD fit (beyond comparison with non-perturbative models), in particular **stabilise the dependence with m_{charm}** and improve the **data/theory agreement** for some of the most precise collider observables.

Fitted vs Perturbative charm

- The **change of scheme** between a theory with *3 active quarks* and another with *4 active quarks* is determined by the **matching conditions:**

$$\alpha_s^{(4)}(m_h^2) = \alpha_s^{(3)}(m_h^2) + \mathcal{O}(\alpha_s^3)\,,$$
$$f_i^{(4)}(m_h^2) = \sum_j K_{ij}(m_h^2) \otimes f_j^{(3)}(m_h^2)$$

- Most global fits (including NNPDF3.0) **assume that $c^{(3)}(x)=0$,** in other words, the scale-independent (intrinsic) charm content of the proton vanishes

- Whether or not **$c^{(3)}(x)=0$ is a good assumption** can only be **determined from data**

- Releasing this assumption leads to the **modified matching conditions**

$$f_h^{(3)} = f_h^{(4)}(Q^2) - \alpha_s^{(4)}(Q^2)\left(K_{hh}^{(1)}(m_h^2) + P_{qq}^{(0)}L\right) \otimes f_h^{(4)}(Q^2) - \alpha_s^{(4)}(Q^2)LP_{qg}^{(0)} \otimes g^{(4)}(Q^2)$$

Scale-independent (intrinsic) charm

Scale-dependent charm PDF: to be determined from data at $Q_0>m_c$

Perturbative contribution from charm-anticharm radiation off gluons

NNPDF3.1 fits obtained **both** for a **fitted** and for a **perturbative charm PDF**

Ball, Bonvini, Rottoli, JHEP 17

Ball et al, PLB 17

New datasets in NNPDF3.1

Measurement	Data taking	Motivation
Combined HERA inclusive data	Run I+II	quark singlet and gluon
D0 legacy W asymmetries	Run II	quark flavor separation
ATLAS inclusive W, Z rap 7 TeV	2011	strangeness
ATLAS inclusive jets 7 TeV	2011	large-x gluon
ATLAS low-mass Drell-Yan 7 TeV	2010+2011	small-x quarks
ATLAS Z pT 7,8 TeV	2011+2012	medium-x gluon and quarks
ATLAS and CMS tt differential 8 TeV	2012	large-x gluon
CMS Z (pT,y) 2D xsecs 8 TeV	2012	medium-x gluon and quarks
CMS Drell-Yan low+high mass 8 TeV	2012	small-x and large-x quarks
CMS W asymmetry 8 TeV	2012	quark flavor separation
CMS 2.76 TeV jets	2012	medium and large-x gluon
LHCb W,Z rapidity dists 7 TeV	2011	large-x quarks
LHCb W,Z rapidity dists 8 TeV	2012	large-x quarks

Fit quality: χ^2

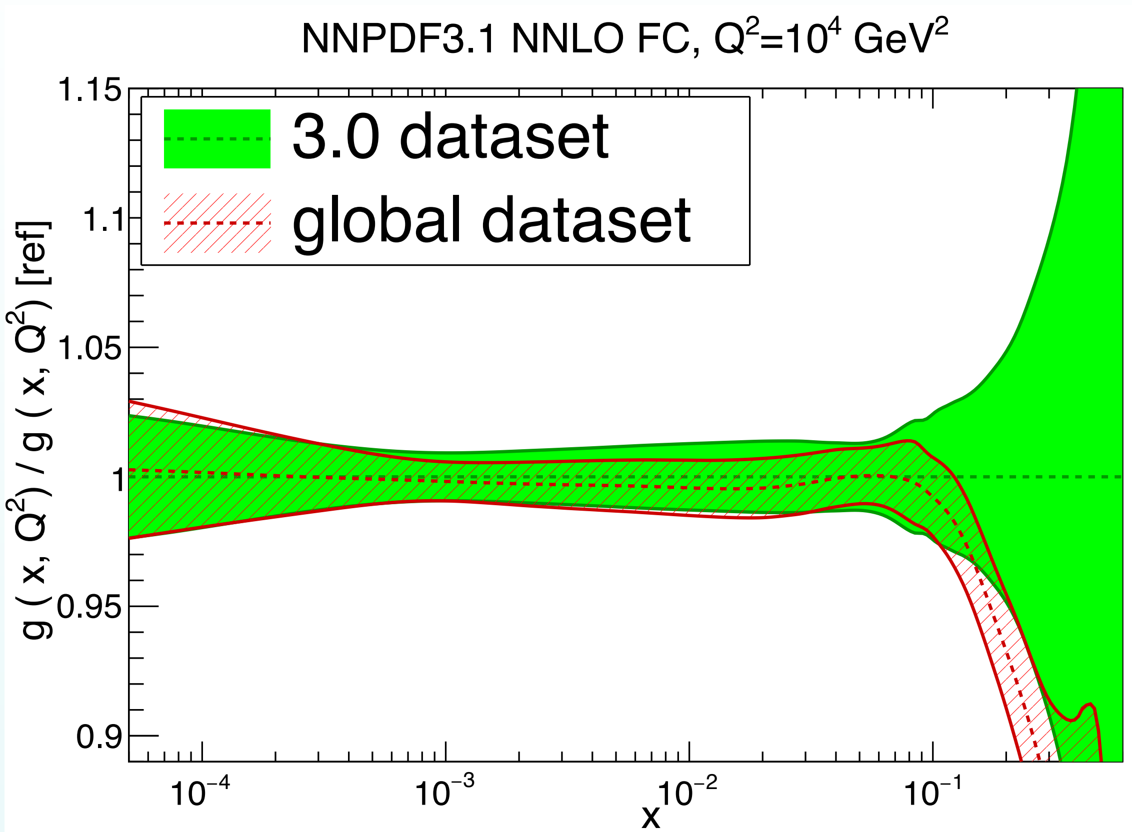
	NNLO FittedCharm	NNLO PertCharm	NLO FittedCharm	NLO PertCharm
HERA	1.16	1.21	1.14	1.15
ATLAS	1.09	1.17	1.37	1.45
CMS	1.06	1.09	1.20	1.21
LHCb	1.47	1.48	1.61	1.77
TOTAL	1.148	1.187	1.168	1.197

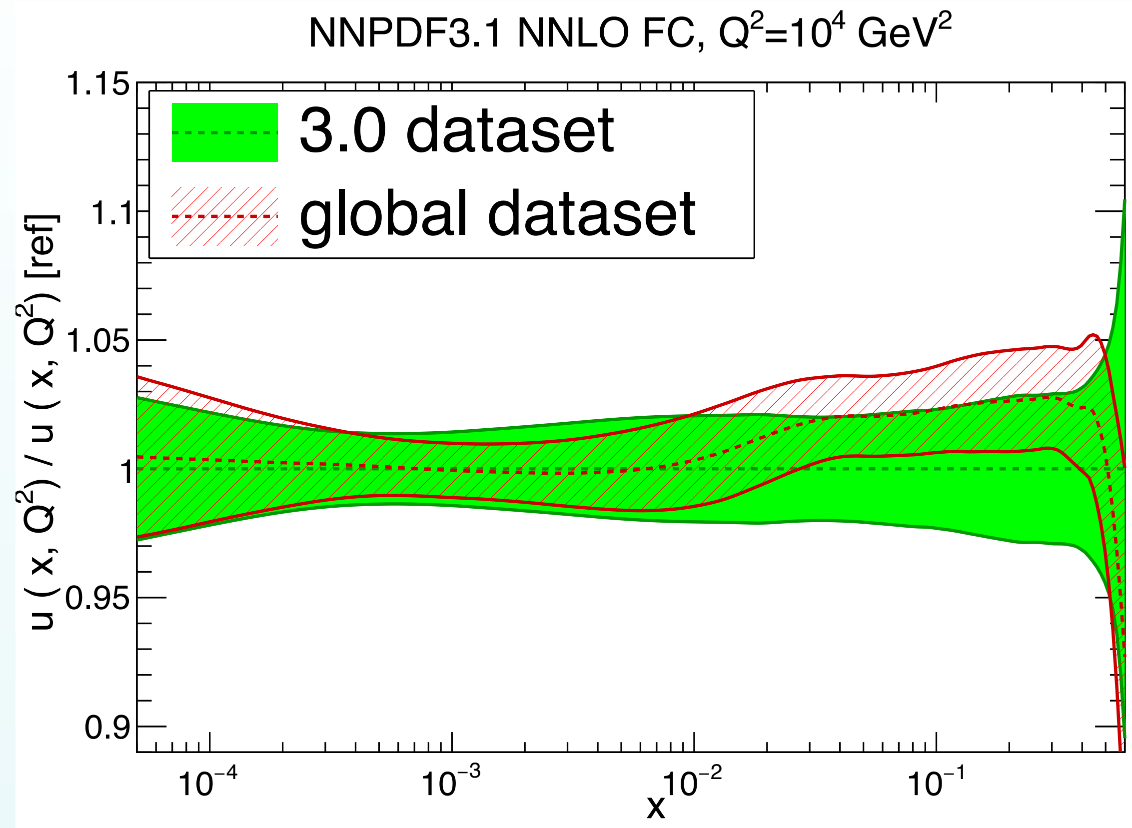
- For collider data, **NNLO theory** leads to a markedly better fit quality that than **NLO** (since the new data included has small experimental uncertainties, and NNLO corrections mandatory)

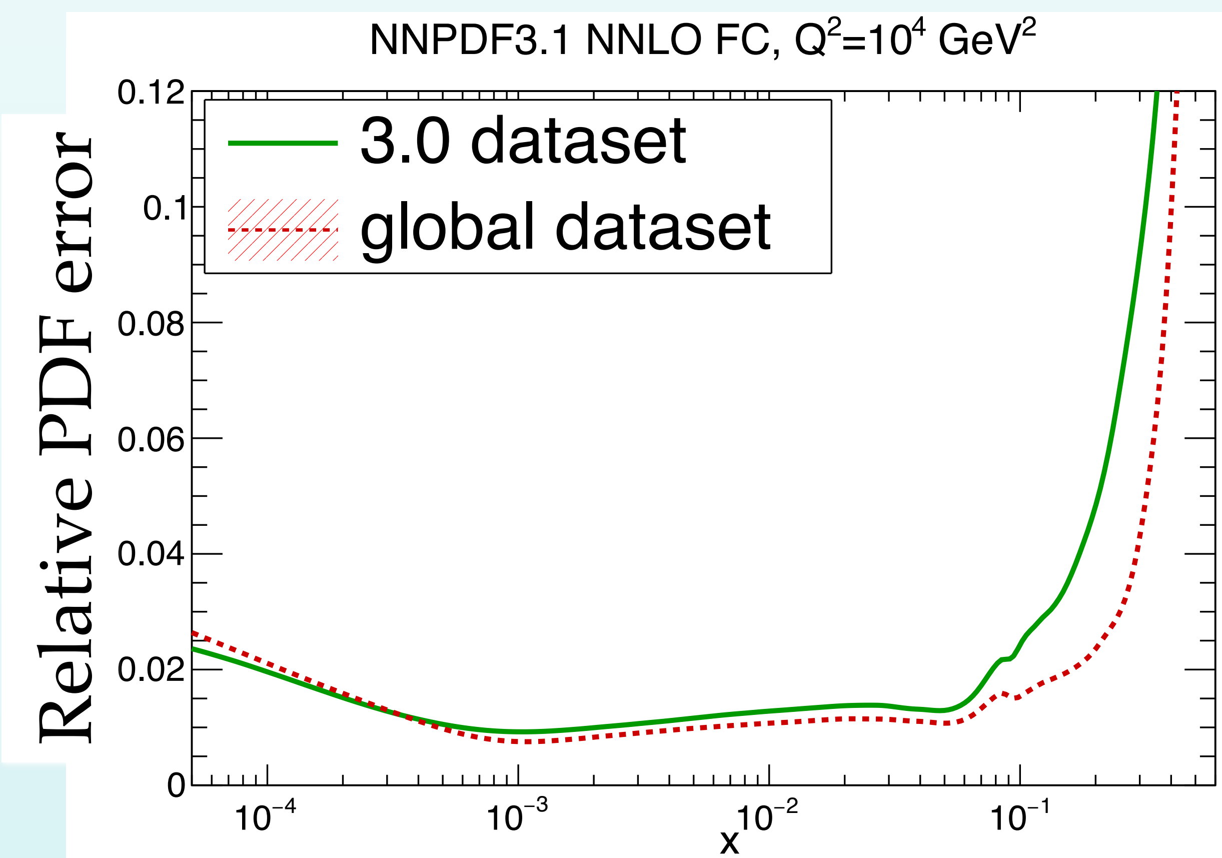
- The global PDF analysis where the charm PDF is fitted leads to a **slightly superior fit quality** than assuming a perturbatively generated charm PDF

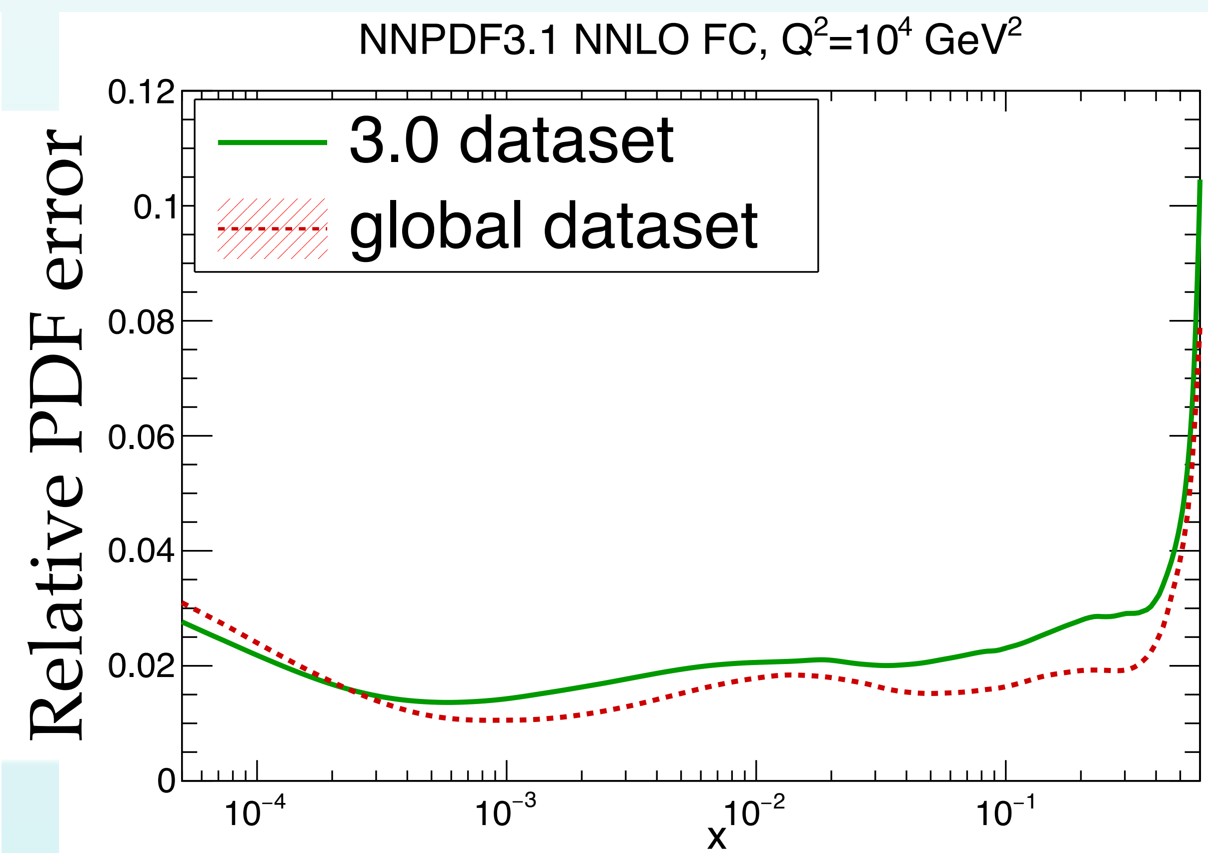
- In general **good description of all the new collider measurements** included in NNPDF3.1

Impact of new data









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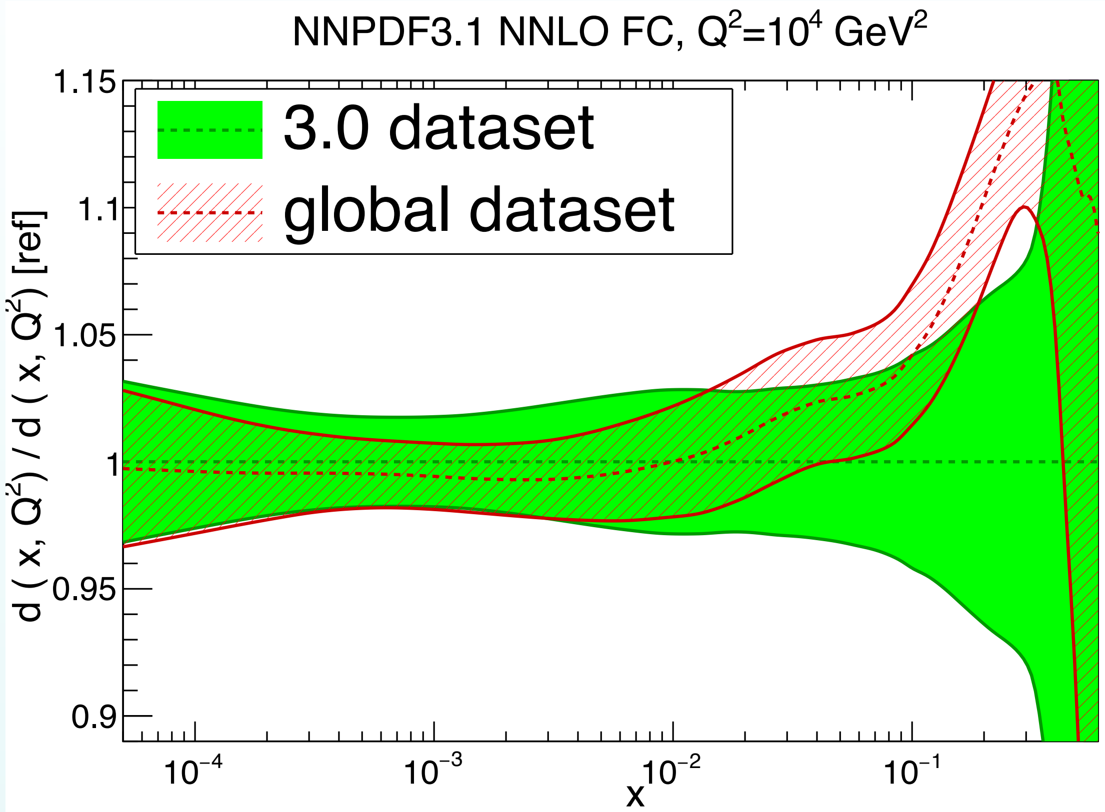

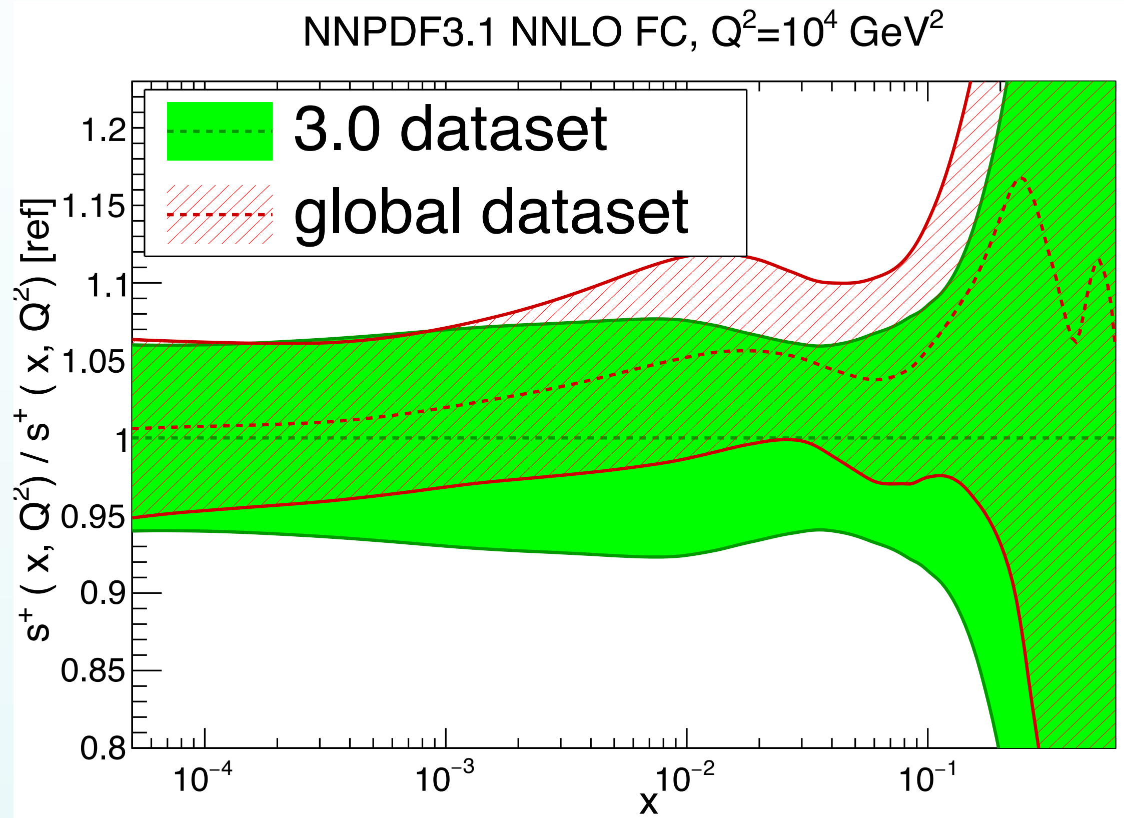

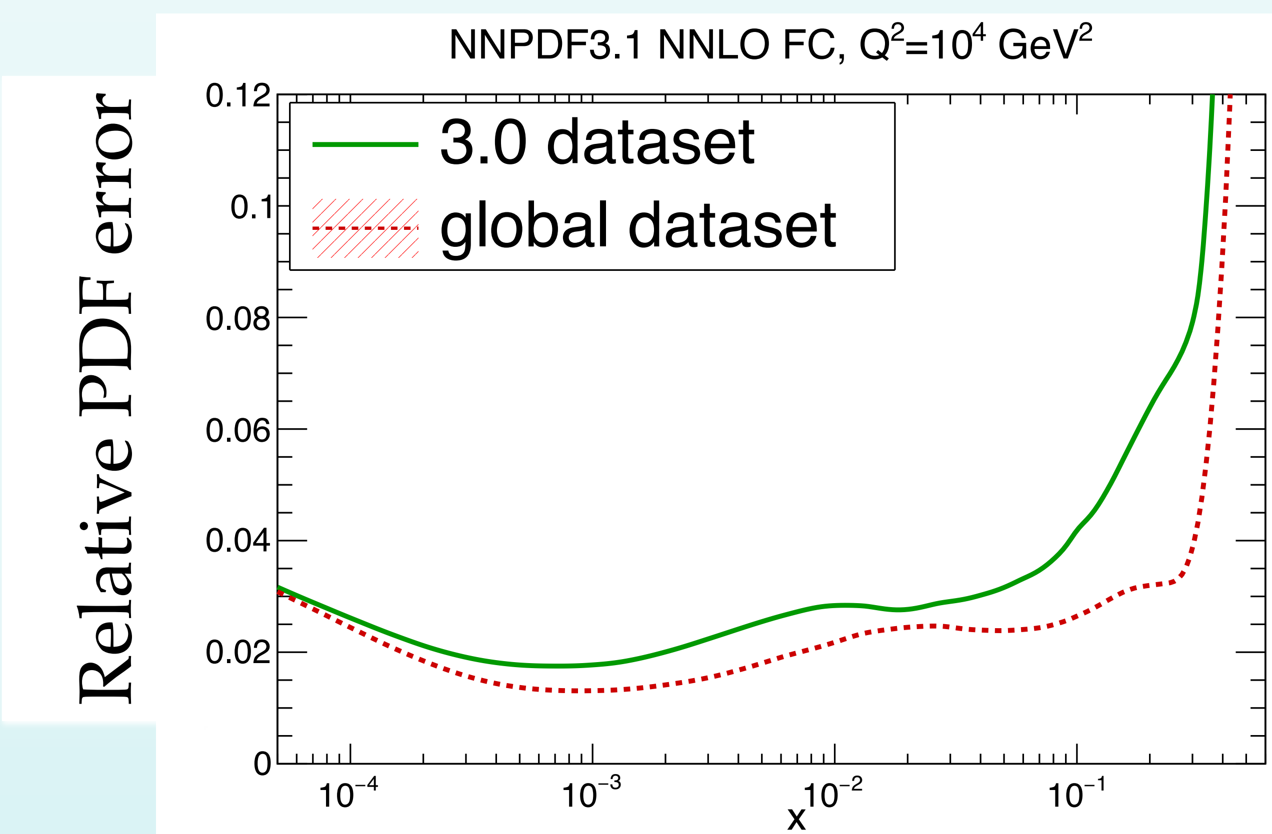

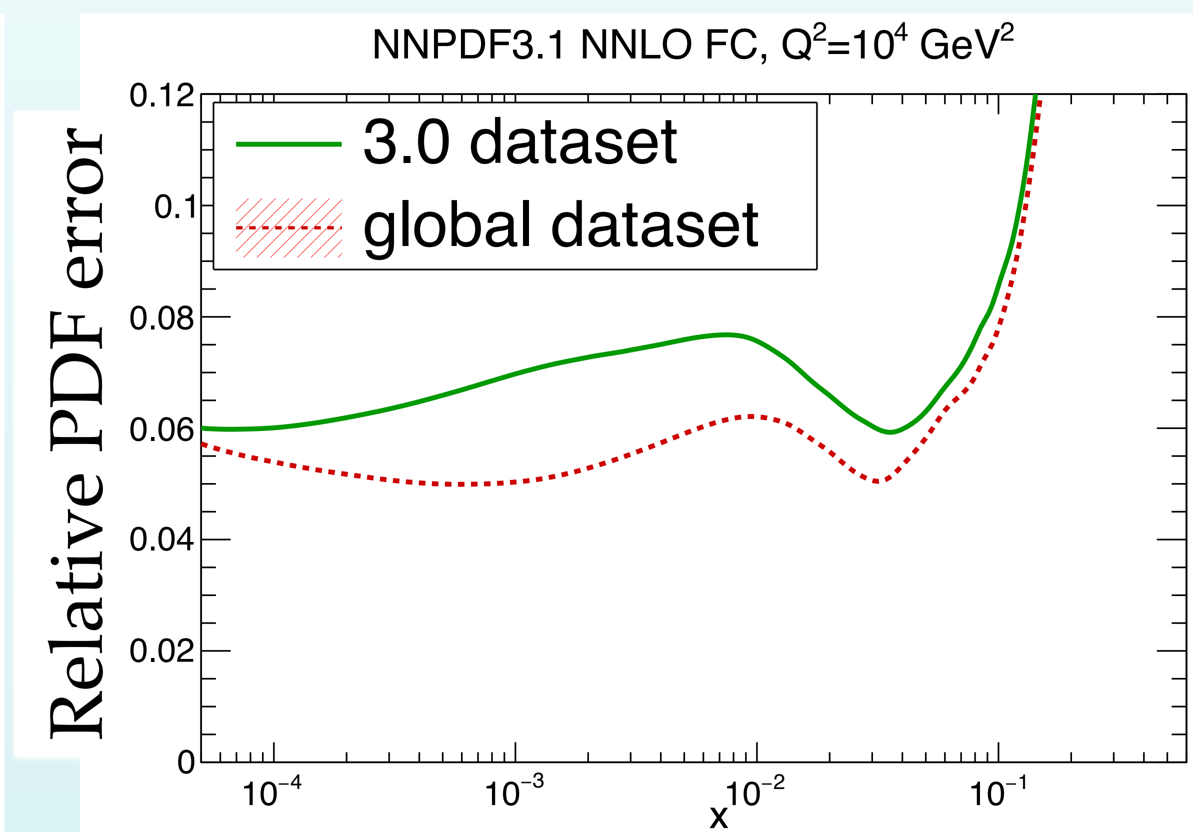

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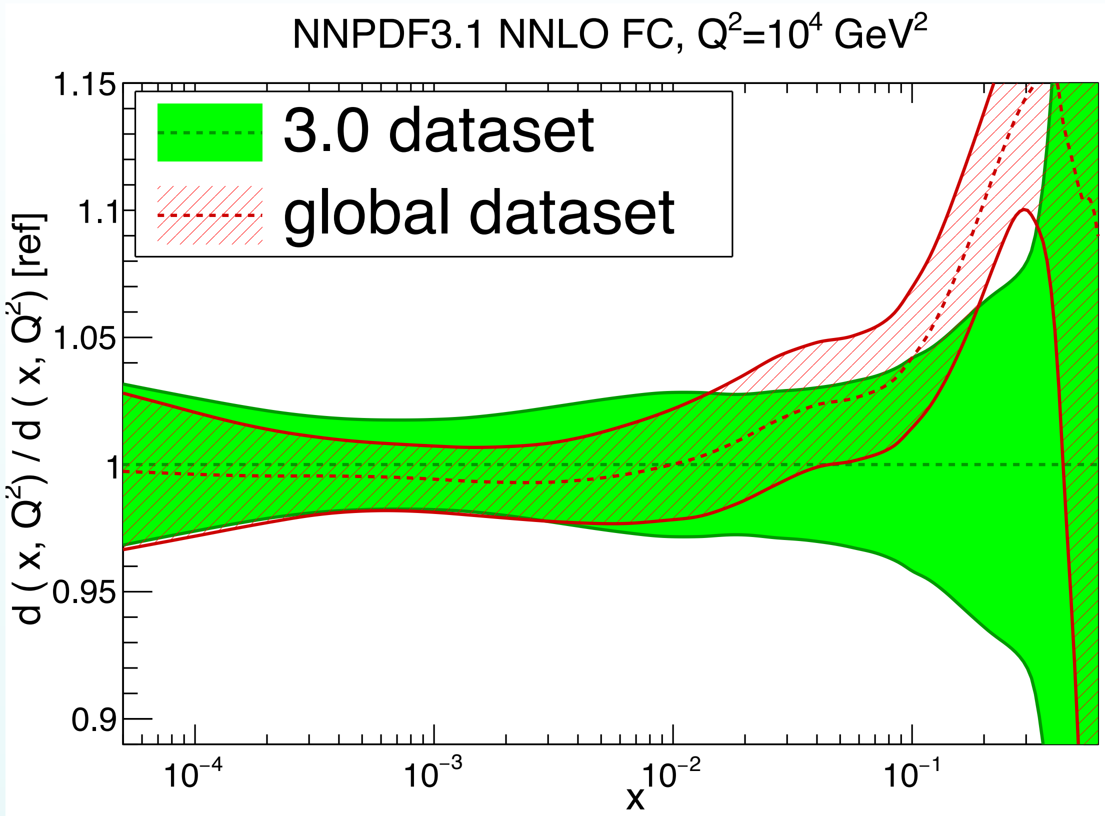
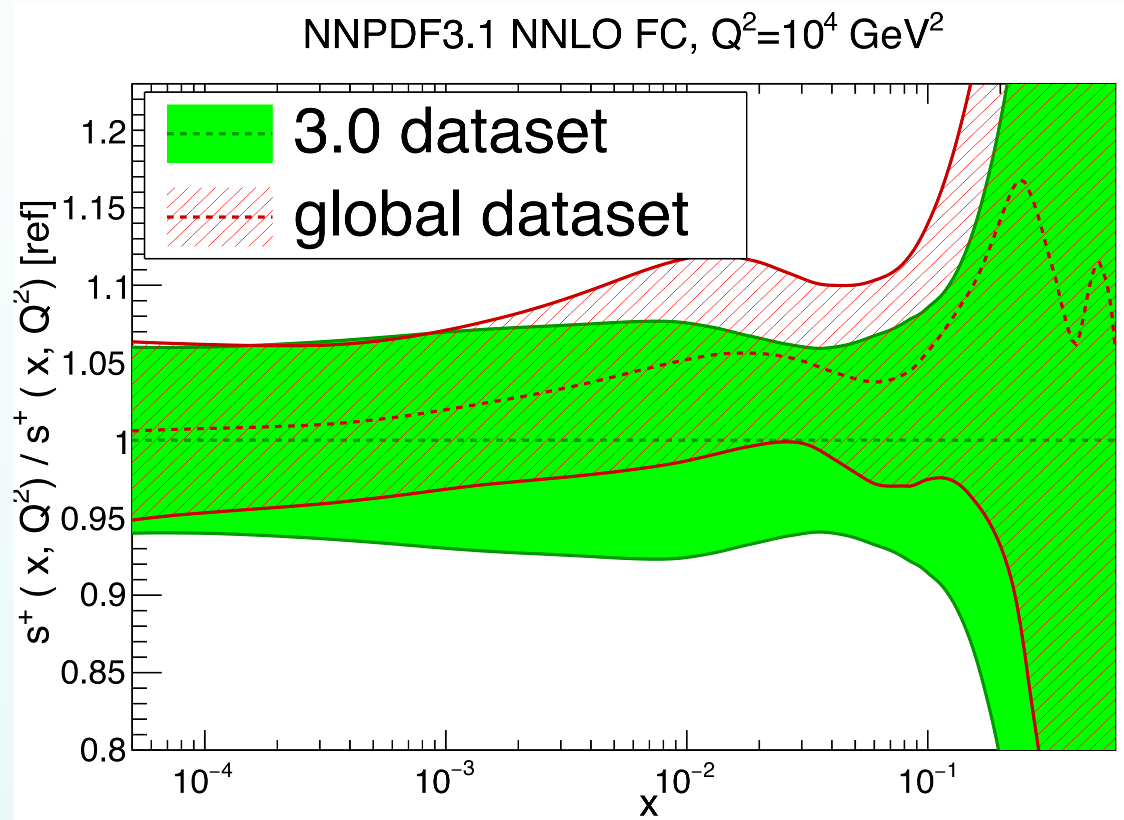
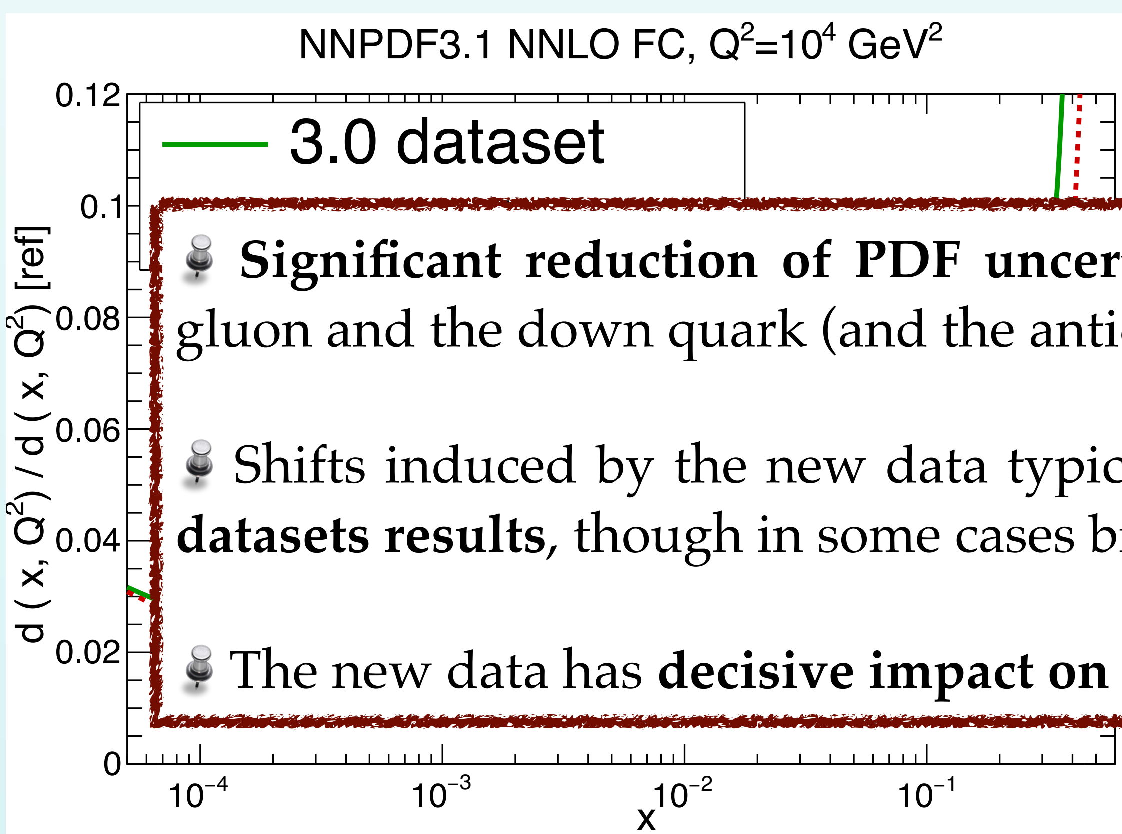
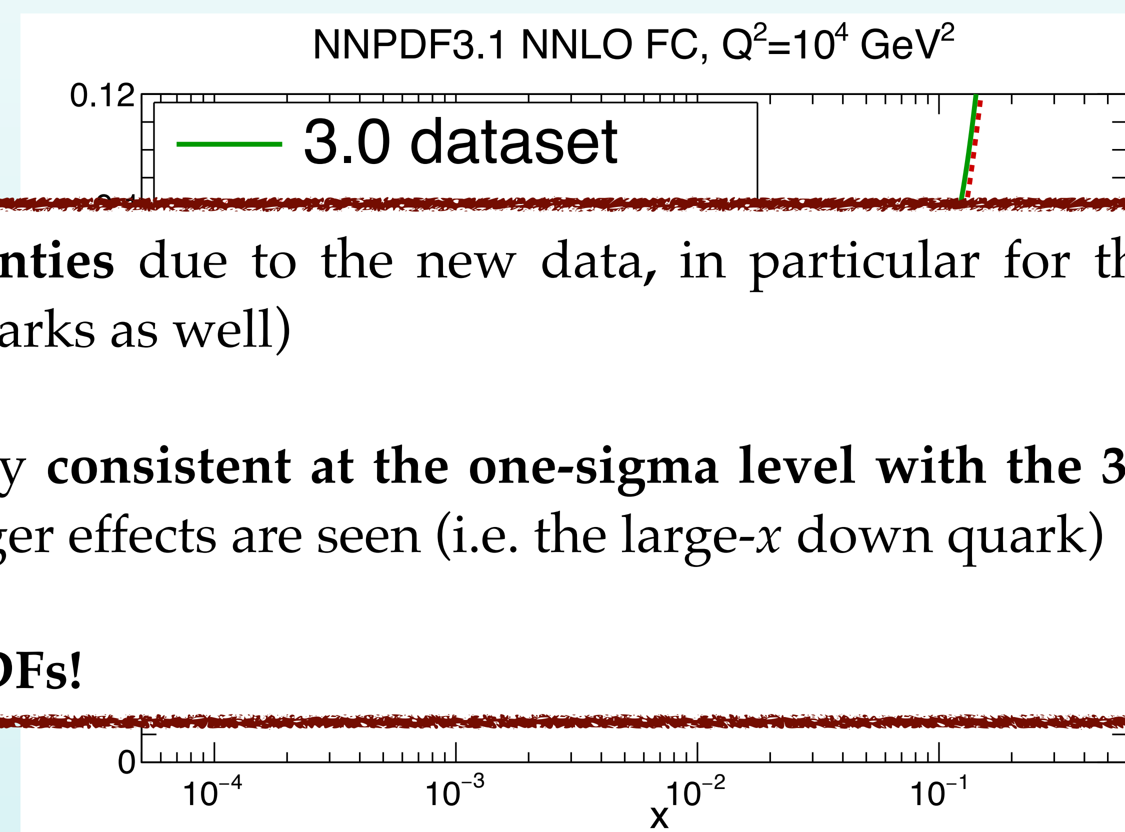






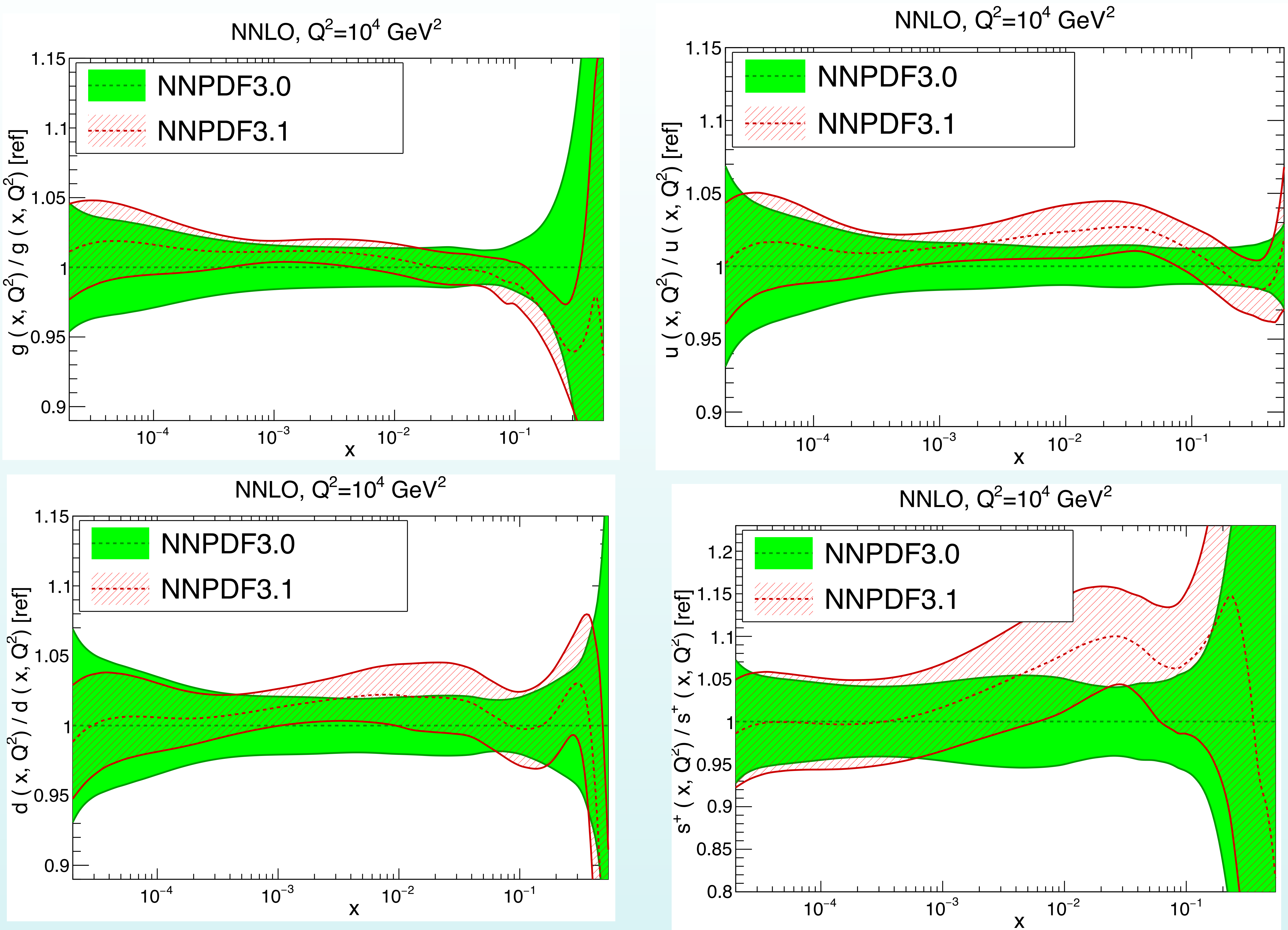


- **Significant reduction of PDF uncertainties** due to the new data, in particular for the gluon and the down quark (and the antiquarks as well)

- Shifts induced by the new data typically **consistent at the one-sigma level with the 3.0 datasets results**, though in some cases bigger effects are seen (i.e. the large-x down quark)

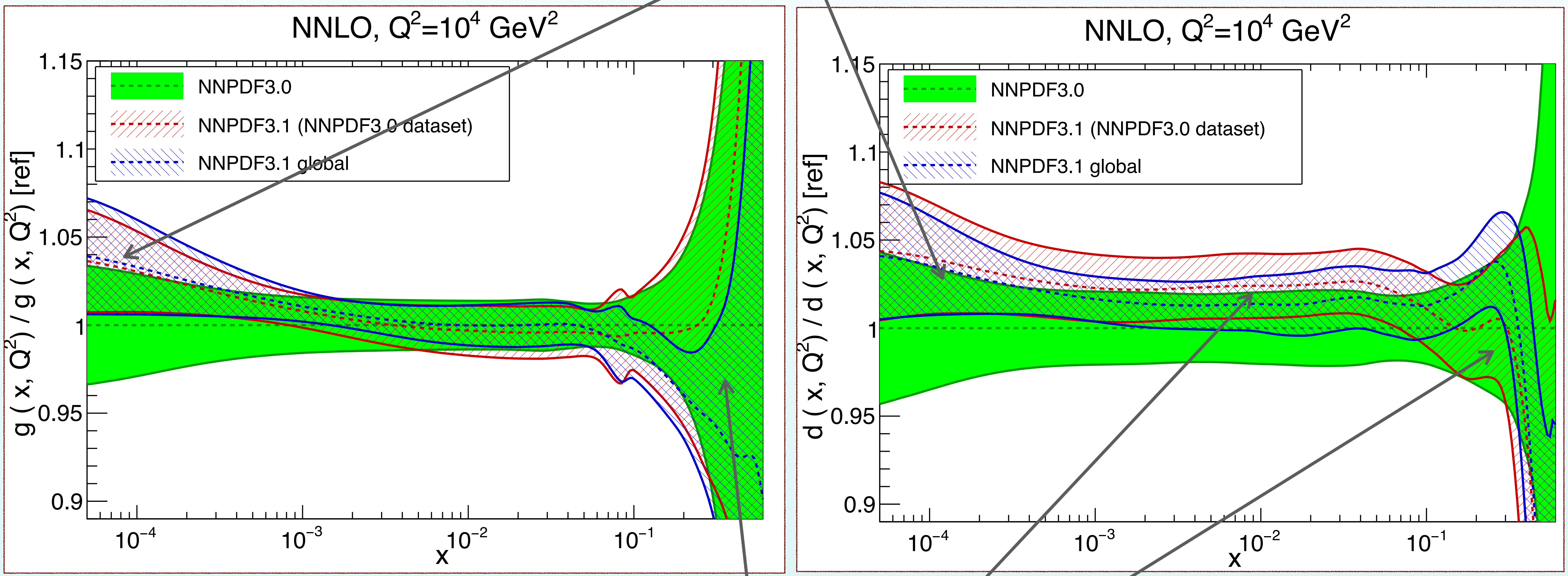
- The new data has **decisive impact on PDFs!**

Comparison with NNPDF3.0



new data vs new methodology

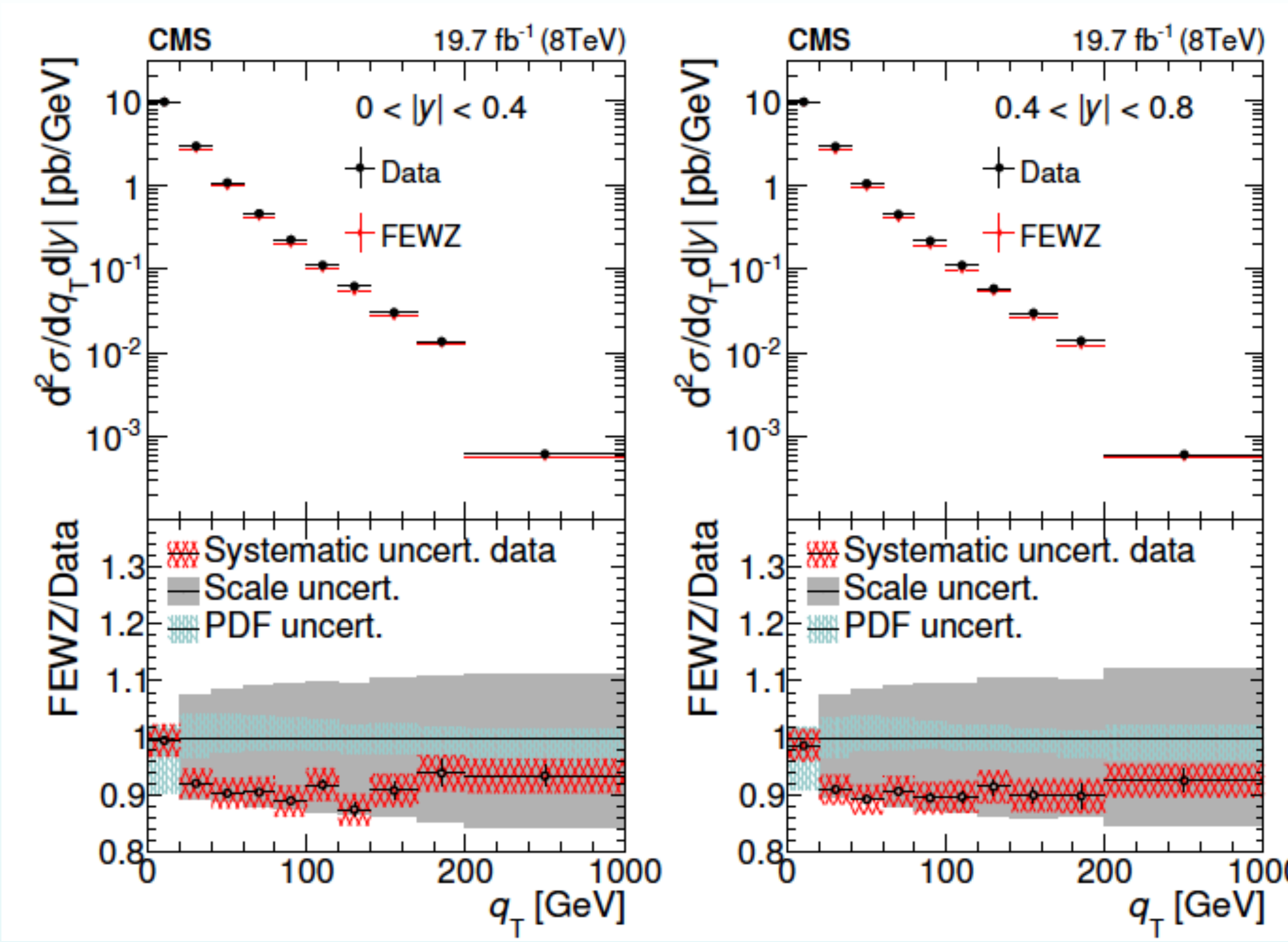
new methodology (mostly fitting charm)

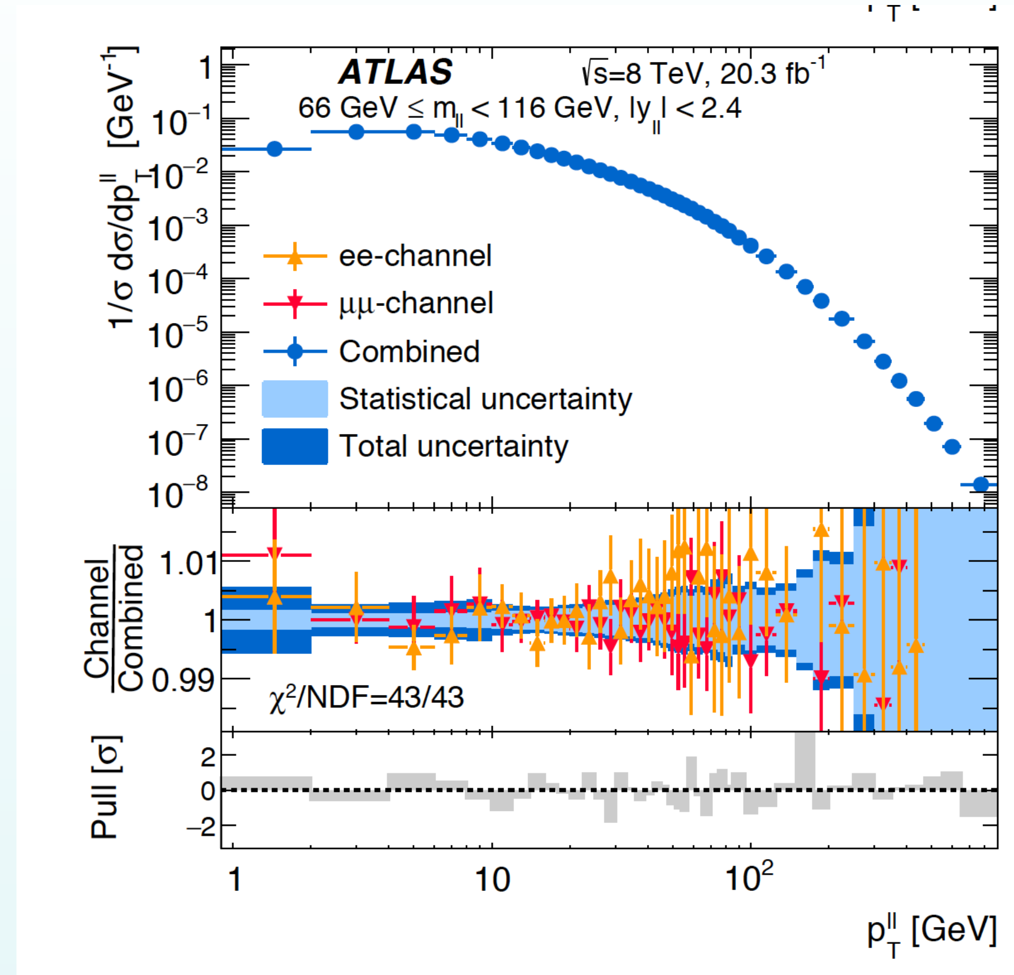


Impact of new data

Impact of Z pt data

See talk by M. Ubiali

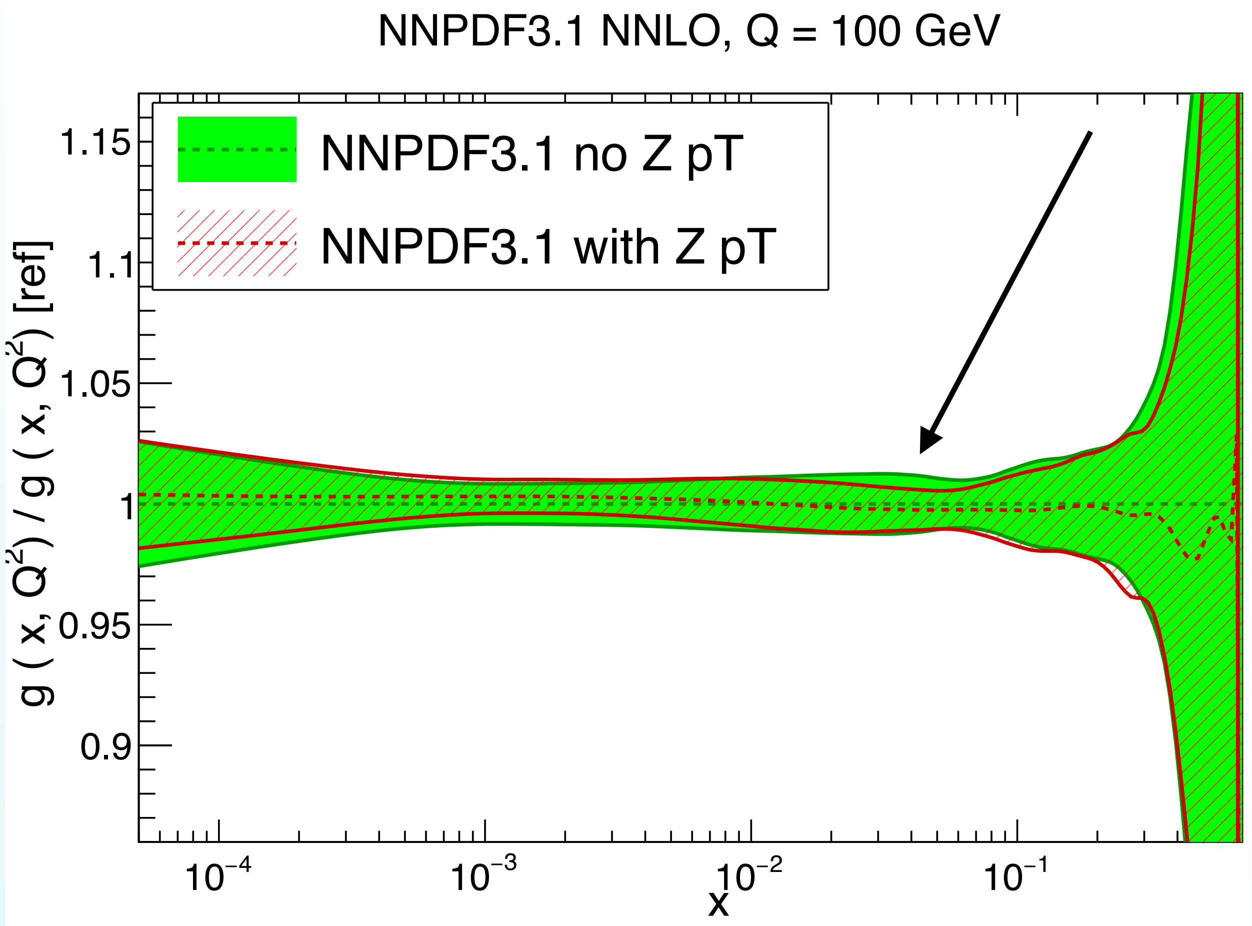


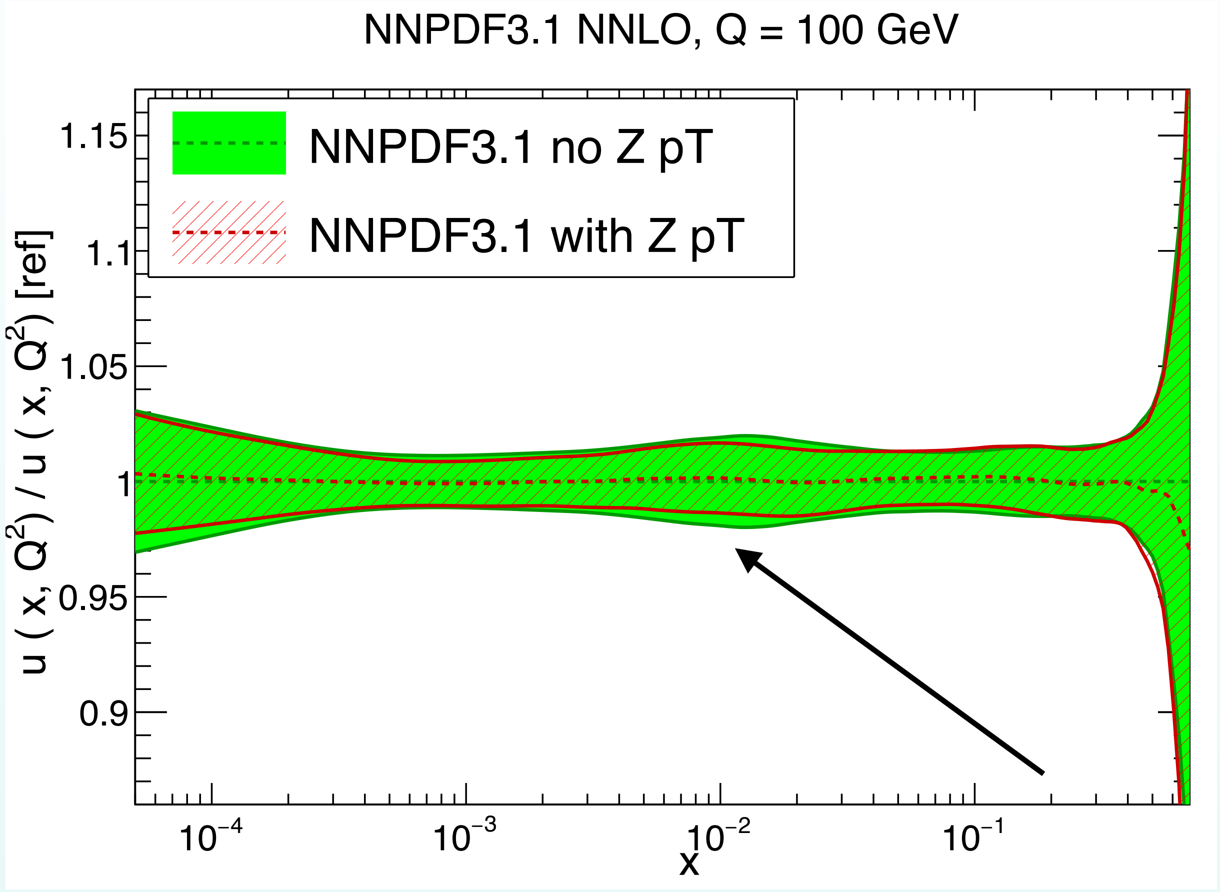


- **For the first time in a global fit, the transverse momentum of the Z boson has been included**
- **NNLO calculations for K-factors** very CPU time intensive
- All the Z p_T measurements from **ATLAS and CMS at 8 TeV** included in NNPDF3.1

	ATLAS 8 TeV (y,pT)	ATLAS 8 TeV (M,pT)	CMS 8 TeV (y,pT)
χ	**0.93**	**0.94**	**1.31**
χ	**1.17**	**1.78**	**3.62**

Impact of Z p_T data





- **Moderate error reduction in the intermediate-x** region, excellent consistency with the other experiments in the global fit.
- Given very high precision (sub-percent) of these experiments, this is quite a non-trivial achievement
- The ATLAS Z p_T 7 TeV data not included in NNPDF3.1. If included, **poor data/theory agreement, χ^2 = 3.5,** and shifts in gluon and quarks. ***Tension with 8 TeV data?***

See talk by M. Ubiali

The large-x gluon from top-quark production

See talk by M. Ubiali
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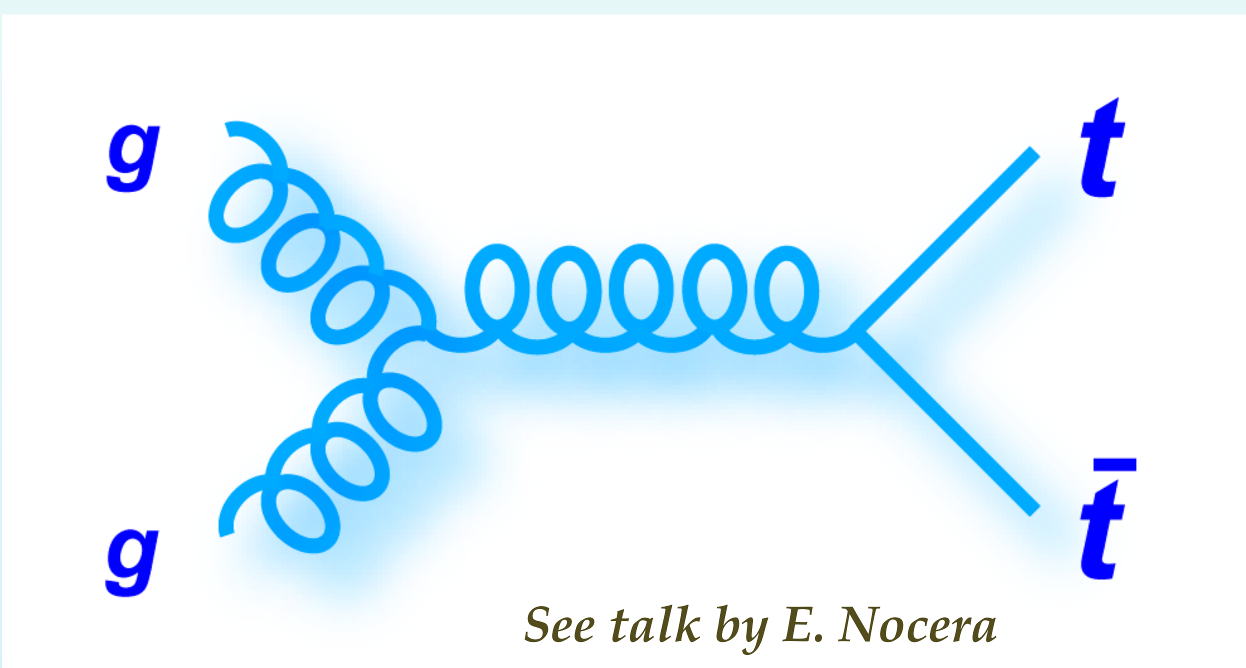
- Top-quark pair production driven by the **gluon-gluon luminosity**

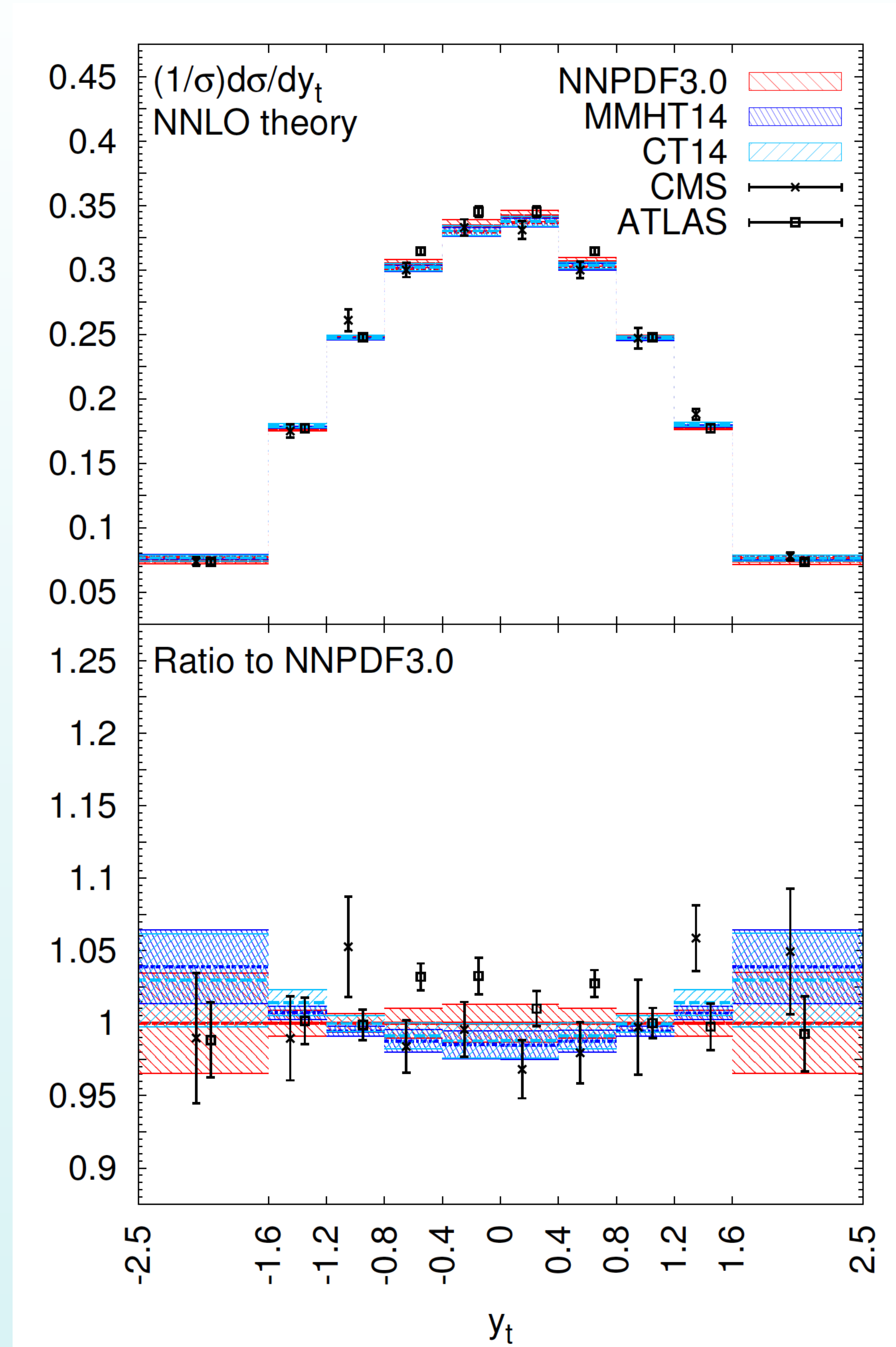
- **NNLO calculations for stable top quarks** available (with decays in the pipeline)

- Recent **precision data from ATLAS and CMS at 8 TeV** with full breakdown of statistical and systematic uncertainties

- For the first time, included ATLAS+CMS 8 TeV differential top measurements into the **global PDF fit**

Czakon, Hartland, Mitov, Nocera, Rojo 16





The large-x gluon from top-quark production

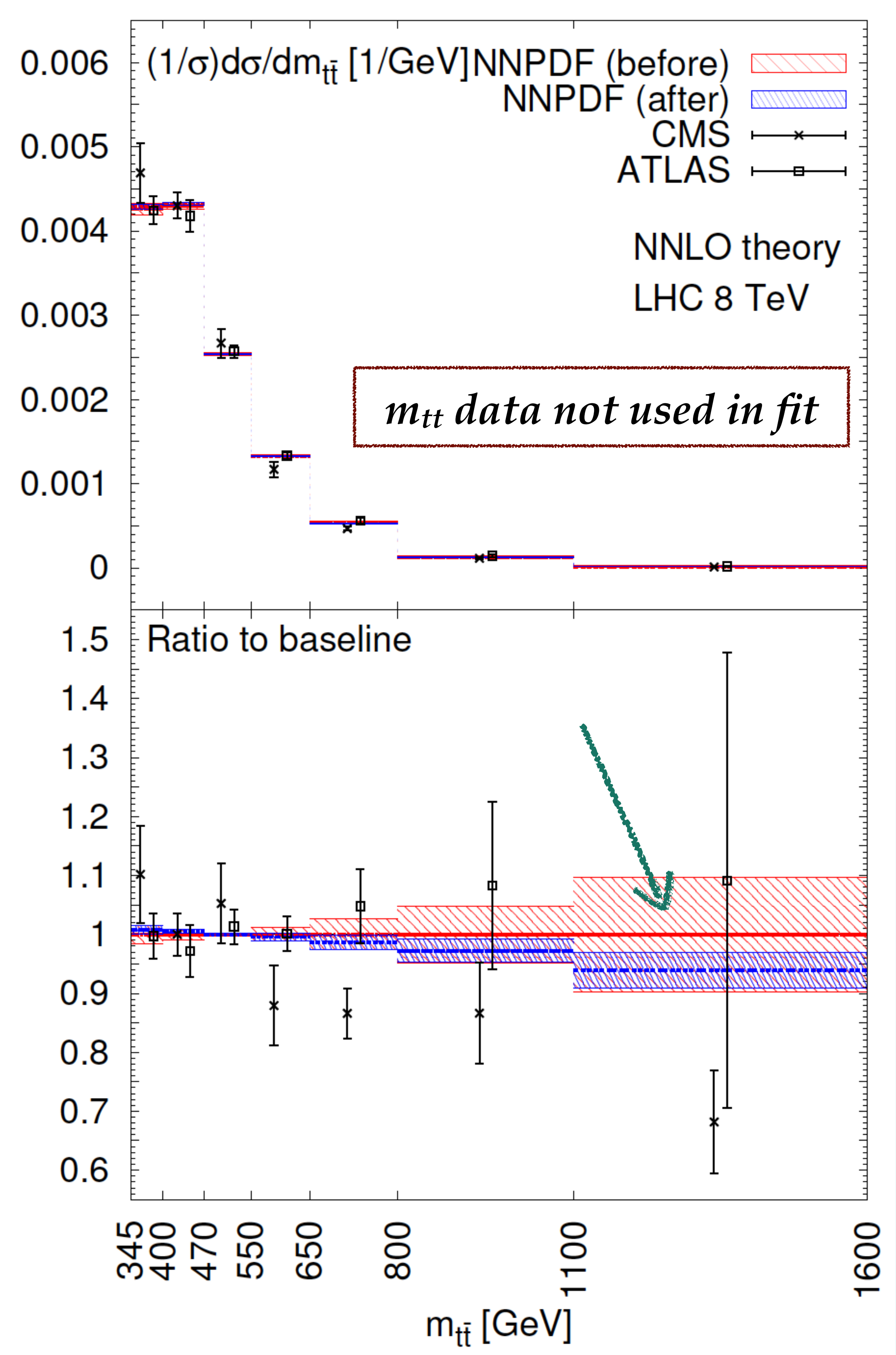
- PDF uncertainties reduced by more than a factor two for $\mathbf{m_{tt} \gtrsim 500}$ **GeV**

- Our choice of fitted distributions, $\mathbf{y_t}$ and $\mathbf{y_{tt}}$, reduces the **risk of *BSM contamination*** (kinematical suppression of resonances), which might show up instead in $\mathbf{m_{tt}}$ and $\mathbf{p^t_T}$, where PDF uncertainties are now much smaller

- Self-consistent program to **use top data to provide better theory predictions**

Improved sensitivity to BSM dynamics with top-quark final states

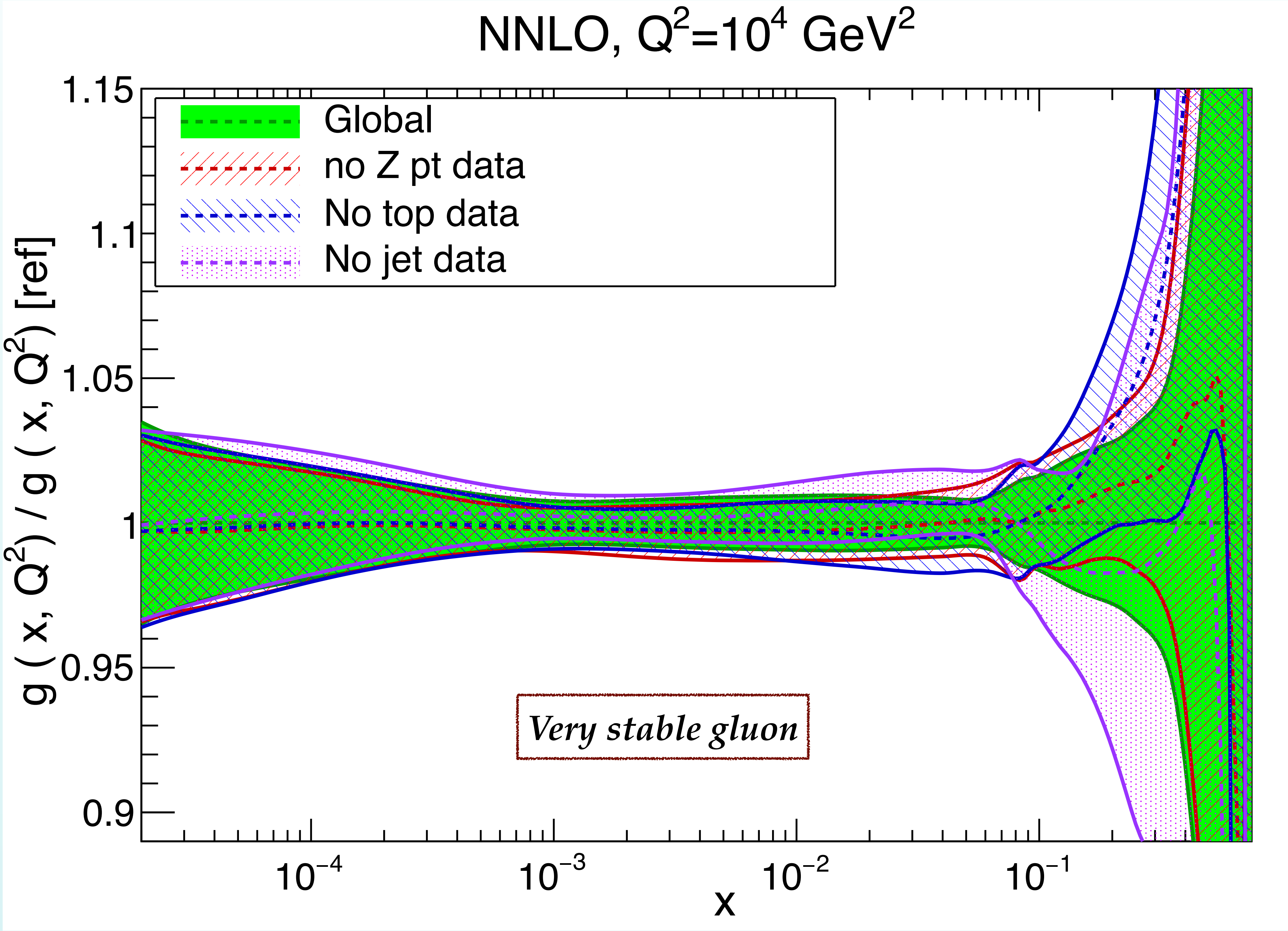
See talk by E. Nocera



Impact on the gluon

- In NNPDF3.1 we have three groups of processes that provide **direct information on the gluon**: inclusive jets, top pair differential, and the Z transverse momentum

- Are the constraints from each of these groups **consistent among them?** Yes!



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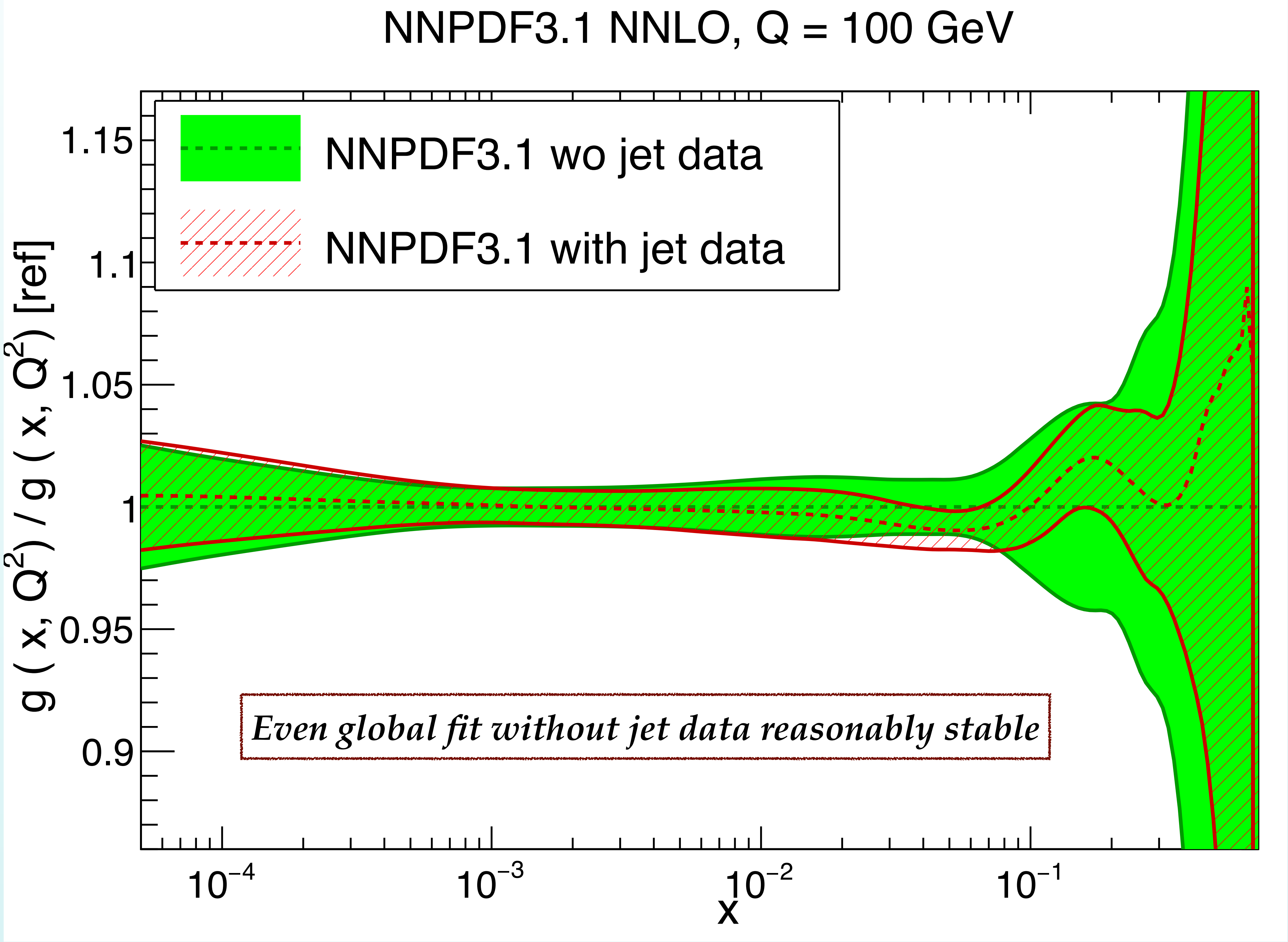
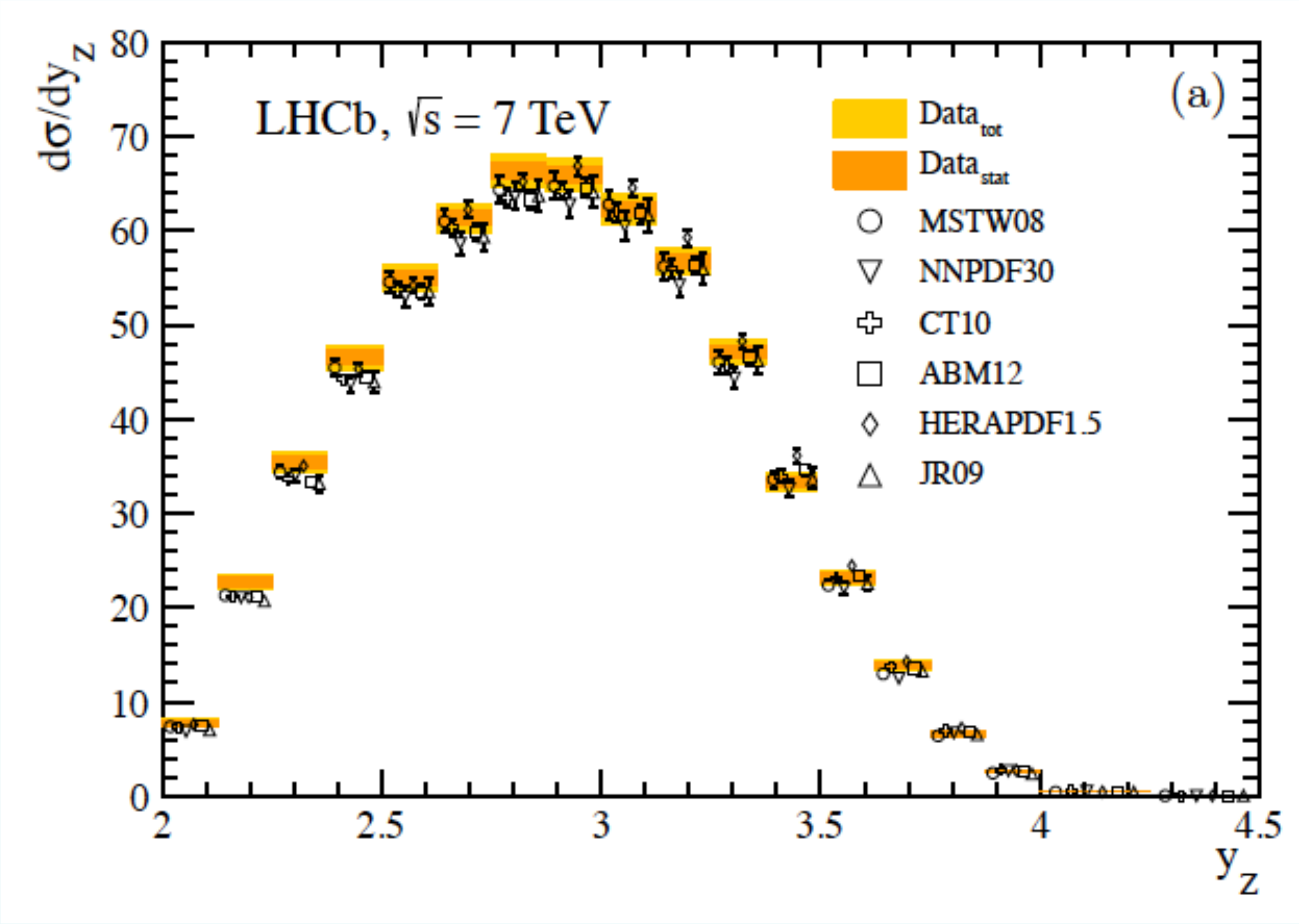
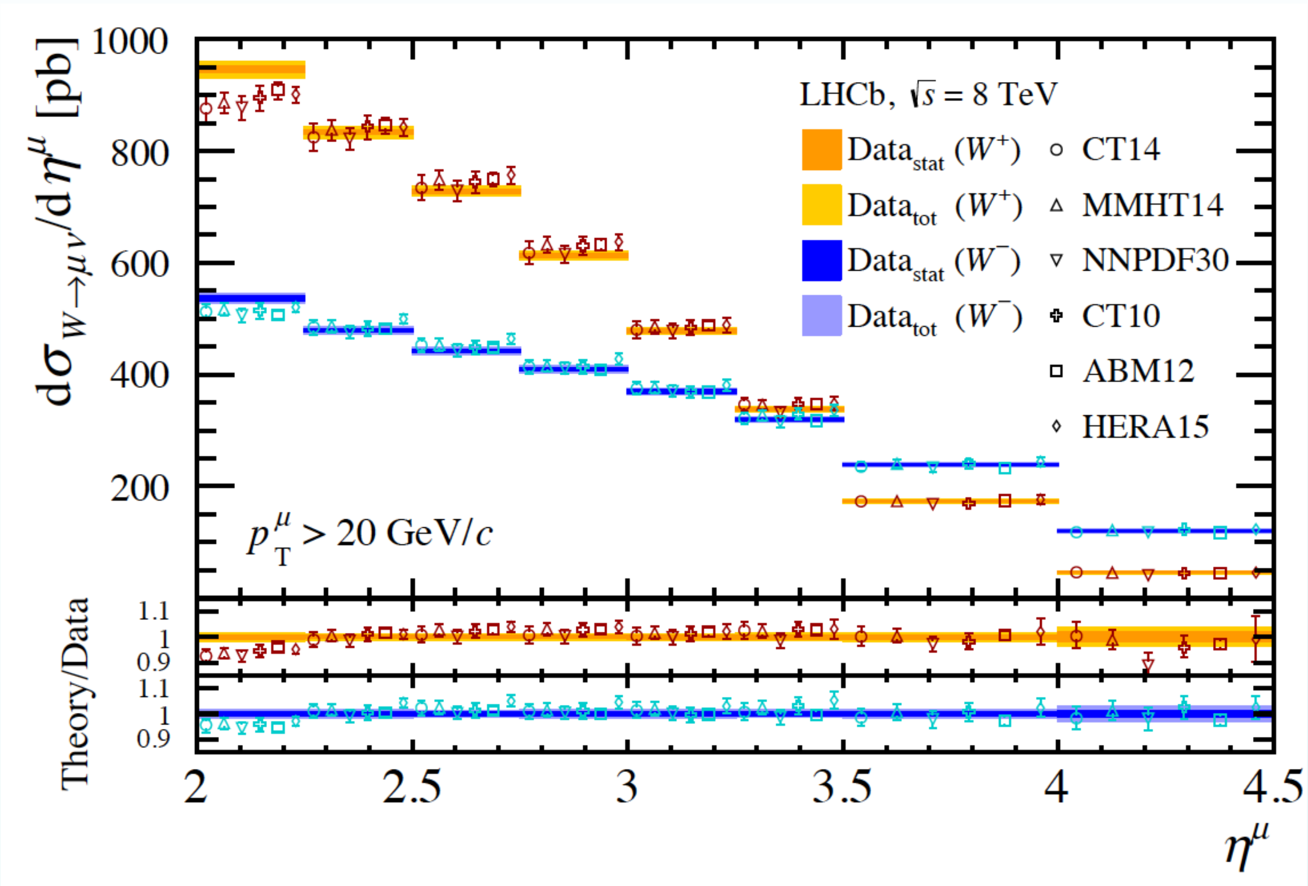


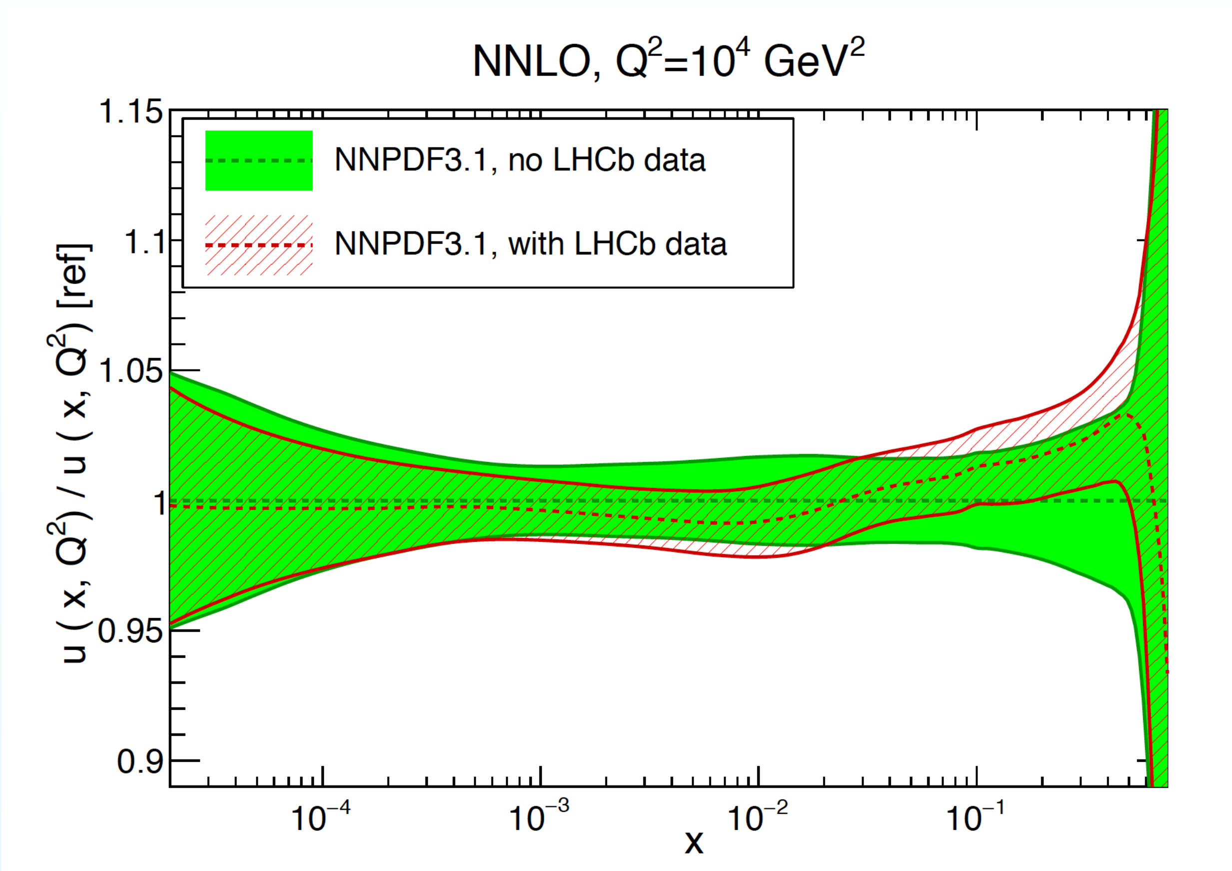
Forward W,Z production at LHCb

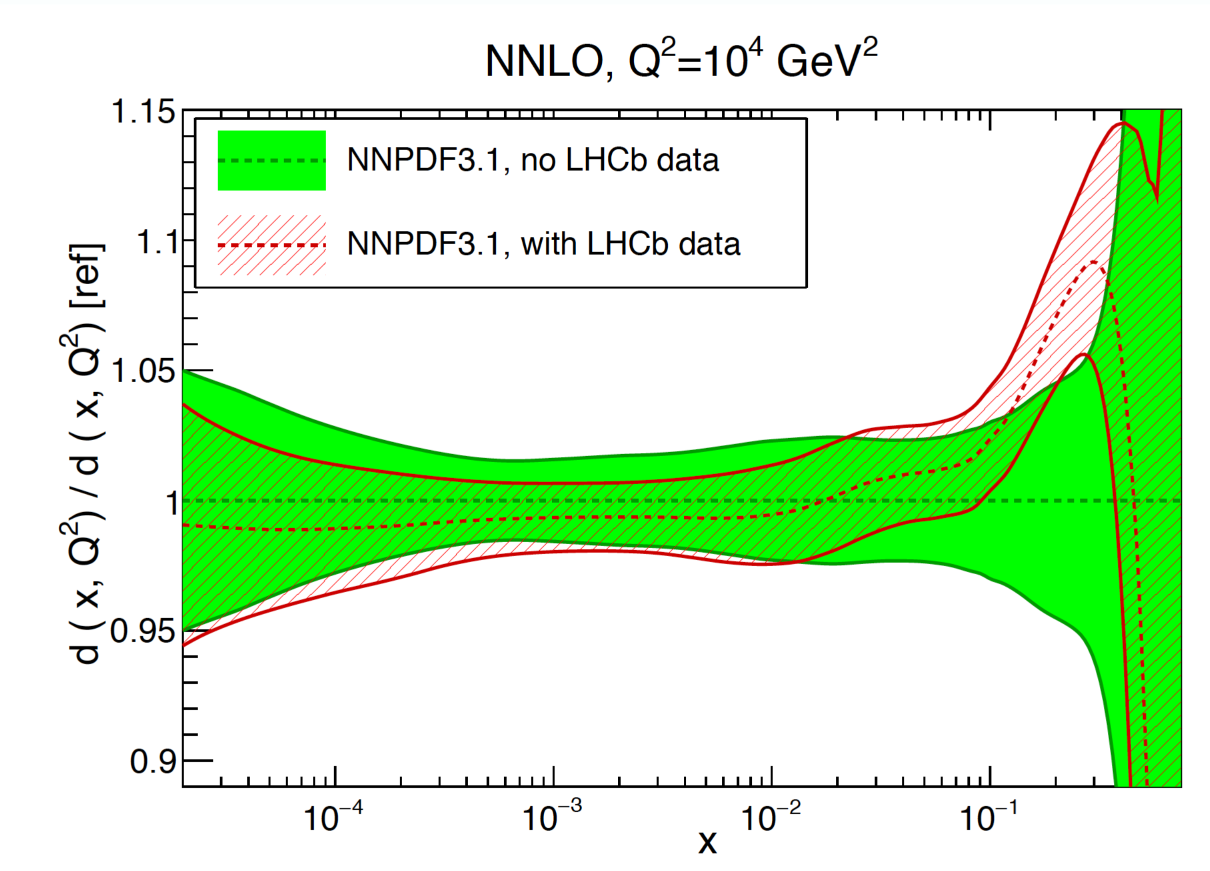




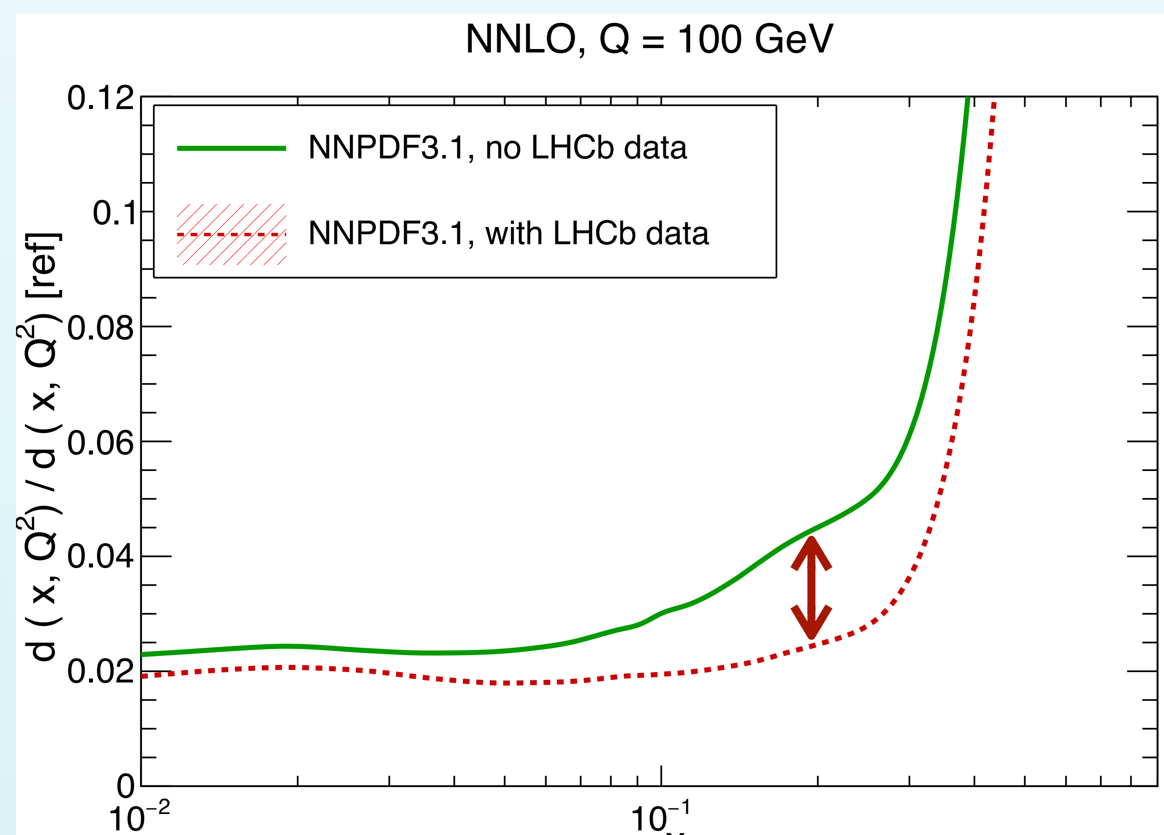
- NNPDF3.1 includes the **complete 7 TeV and 8 TeV W,Z measurements** in the muon channel, as well as **most of the electron channel measurements**
- Crucial to account for the **cross-correlations** between the W and Z data
- Expect improved **quark-flavor separation** for **large-x quarks,** thanks to LHCb **forward kinematics**
- **Complementary information** to that from W, Z production from ATLAS and CMS

Forward W,Z production at LHCb



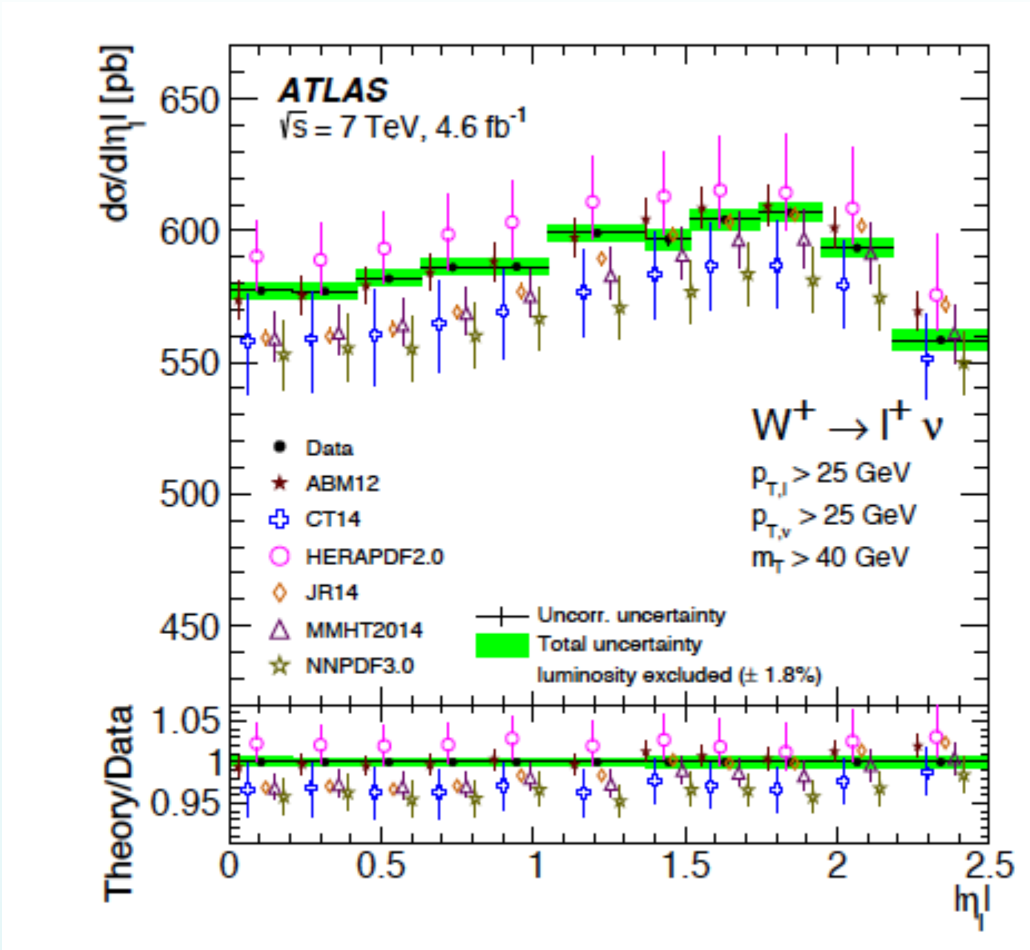


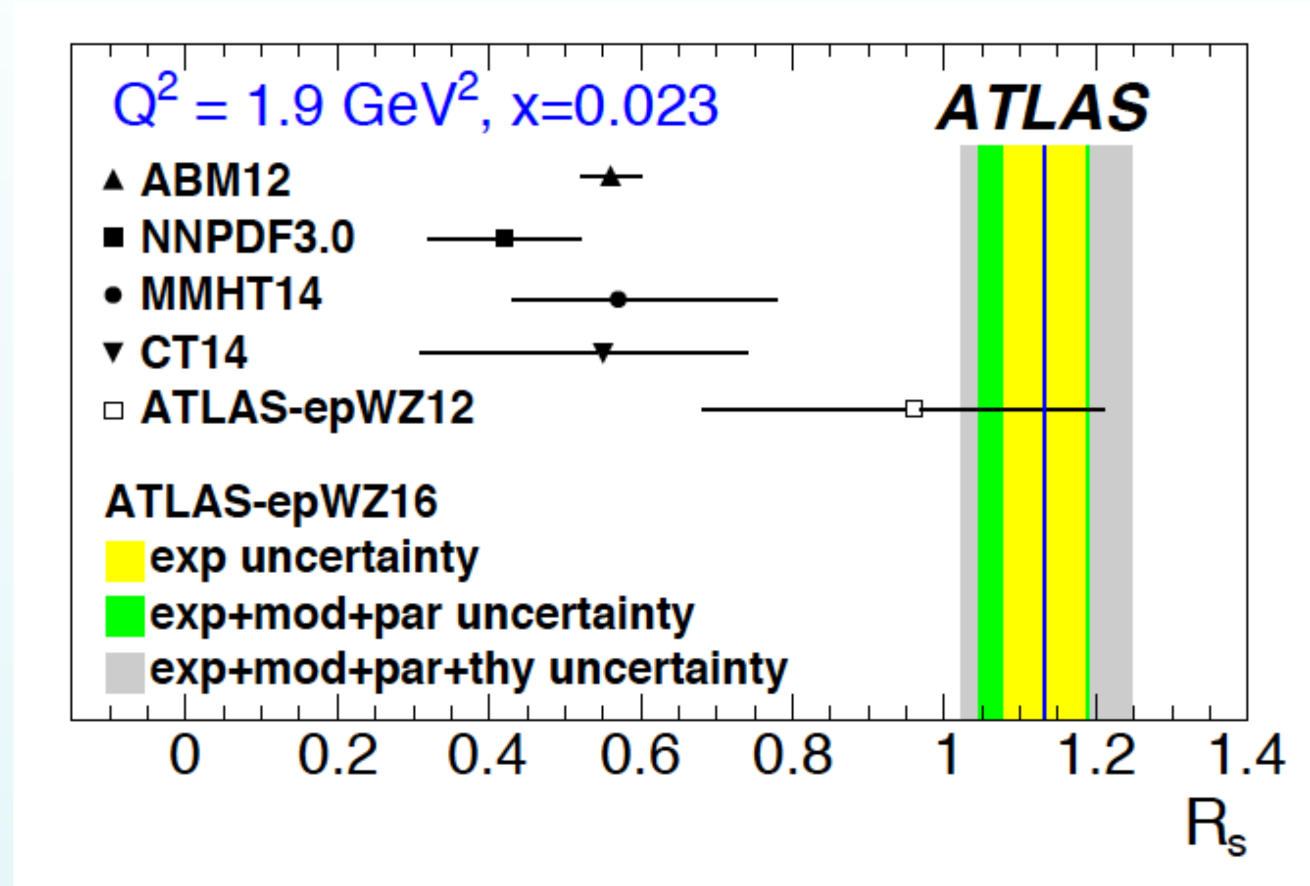
- The reduction of PDF uncertainties from the LHCb data is more marked for the **large-x quarks**
- Note **shift on central values**, in addition to reducing PDF errors
- For the down quark, PDF errors decrease by almost a **factor 2** for *x=0.2*



The strangeness content of the proton

$$R_s(x, Q^2) = \frac{s(x, Q^2) + \bar{s}(x, Q^2)}{\bar{u}(x, Q^2) + \bar{d}(x, Q^2)}$$





- **xFitter analysis** of the ATLAS W,Z 2011 inclusive data prefers a **symmetric strange sea** with small uncertainty, at odds with all other PDF fits

- Actually the ATLAS data suggest that there are **more strange than up and down sea quarks in the proton**, which is **very difficult to understand** from non-perturbative QCD arguments

- Can one accommodate the ATLAS W,Z 2011 data in the **global fit**? What happens to strangeness?

The strangeness content of the proton

PDF set	$R_s(x = 0.023, Q = 1.65\ \text{GeV})$	$R_s(x = 0.013, Q = M_Z)$
NNPDF3.0	0.47±0.09	0.79±0.04
NNPDF3.1	0.62±0.12	0.83±0.05
NNPDF3.1 collider-only	0.86±0.17	0.94±0.07
NNPDF3.1 HERA + ATLAS W, Z	0.96±0.20	0.98±0.09
ATLAS W, Z 2011 `xFitter` (Ref. [93])	$1.13^{+0.11}_{-0.11}$	-
ATLAS W, Z 2010 `HERAfitter` (Ref. [120])	$1.00^{+0.25}_{-0.28}$ (*)	$1.00^{+0.09}_{-0.10}$ (*)

- **Confirmed the strange symmetric fit** preferred by the ATLAS W,Z 2011 measurements, though we find PDF uncertainties larger by a factor 2

- The **global fit** accommodates both the neutrino data and the ATLAS W,Z 2011 ($\boldsymbol{\chi^2_{\text{nutev}}=1.1}$, $\boldsymbol{\chi^2_{\text{AWZ11}}=2.1}$) finding a compromise value for **R_S=0.62+-0.12**

- **Mild tension** in the global fit (1.5-sigma level at most) when simultaneously included neutrino data, CMS W+charm and ATLAS W,Z 2010+2011

The strangeness content of the proton

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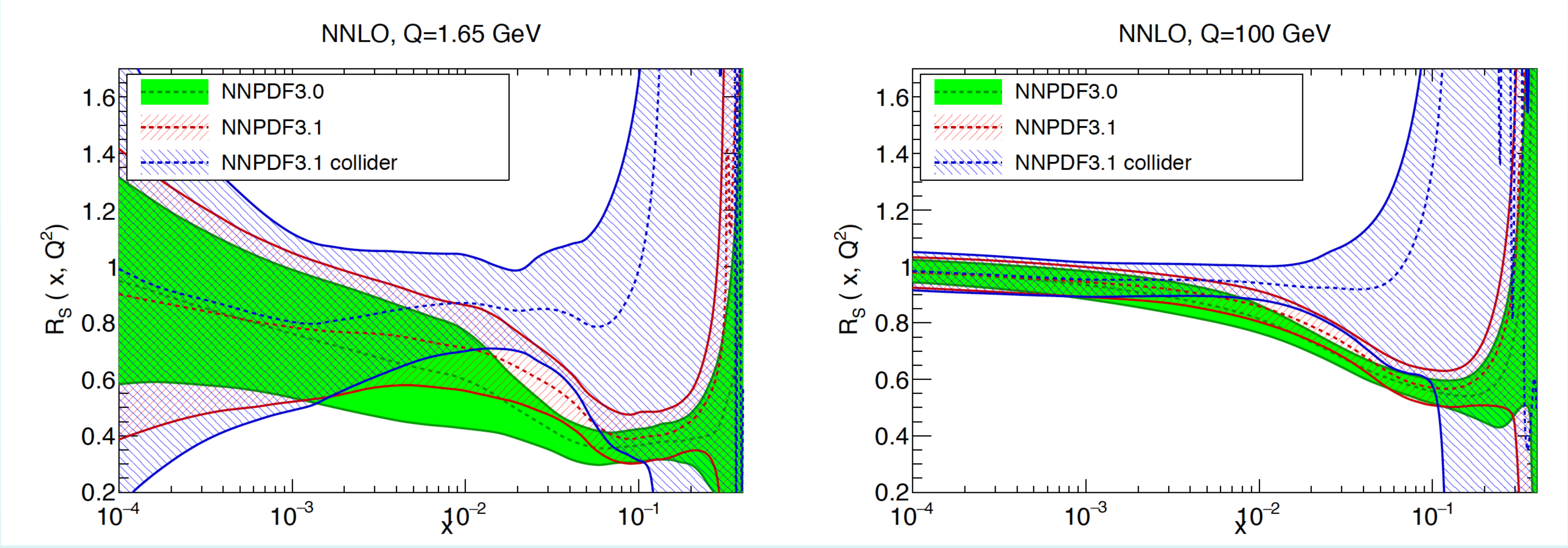


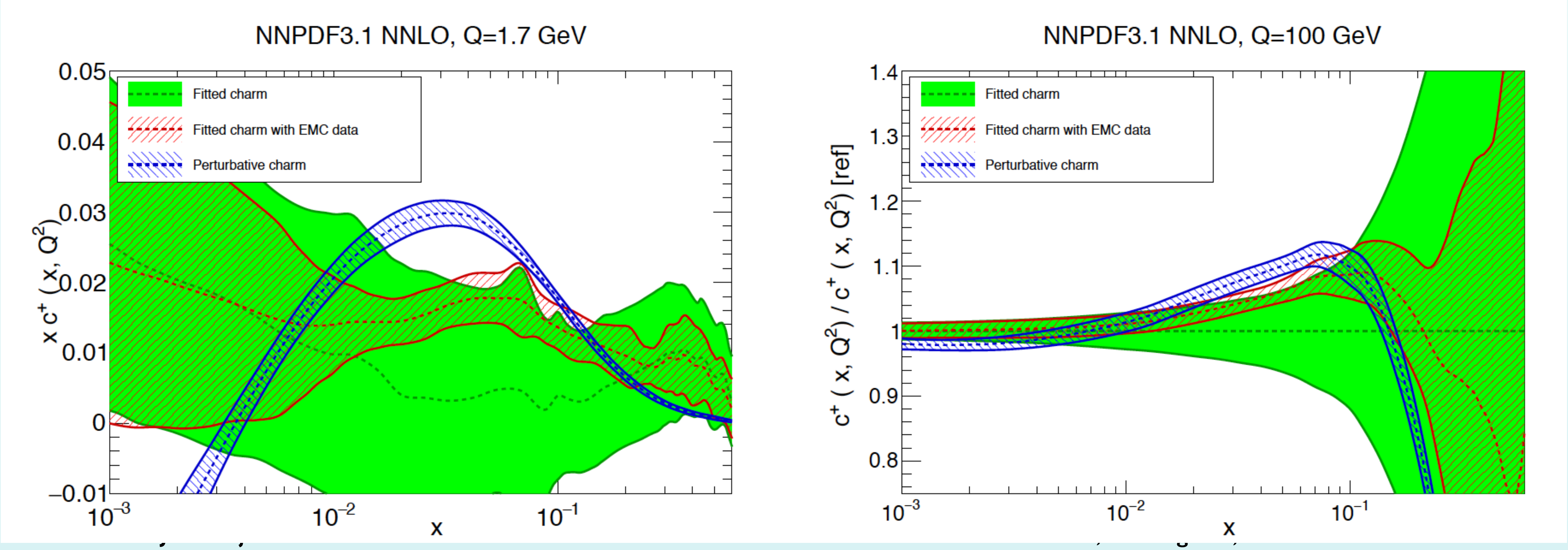
Charm content of proton revisited

- The new LHC experiments provide additional constraints on **non-perturbative charm**

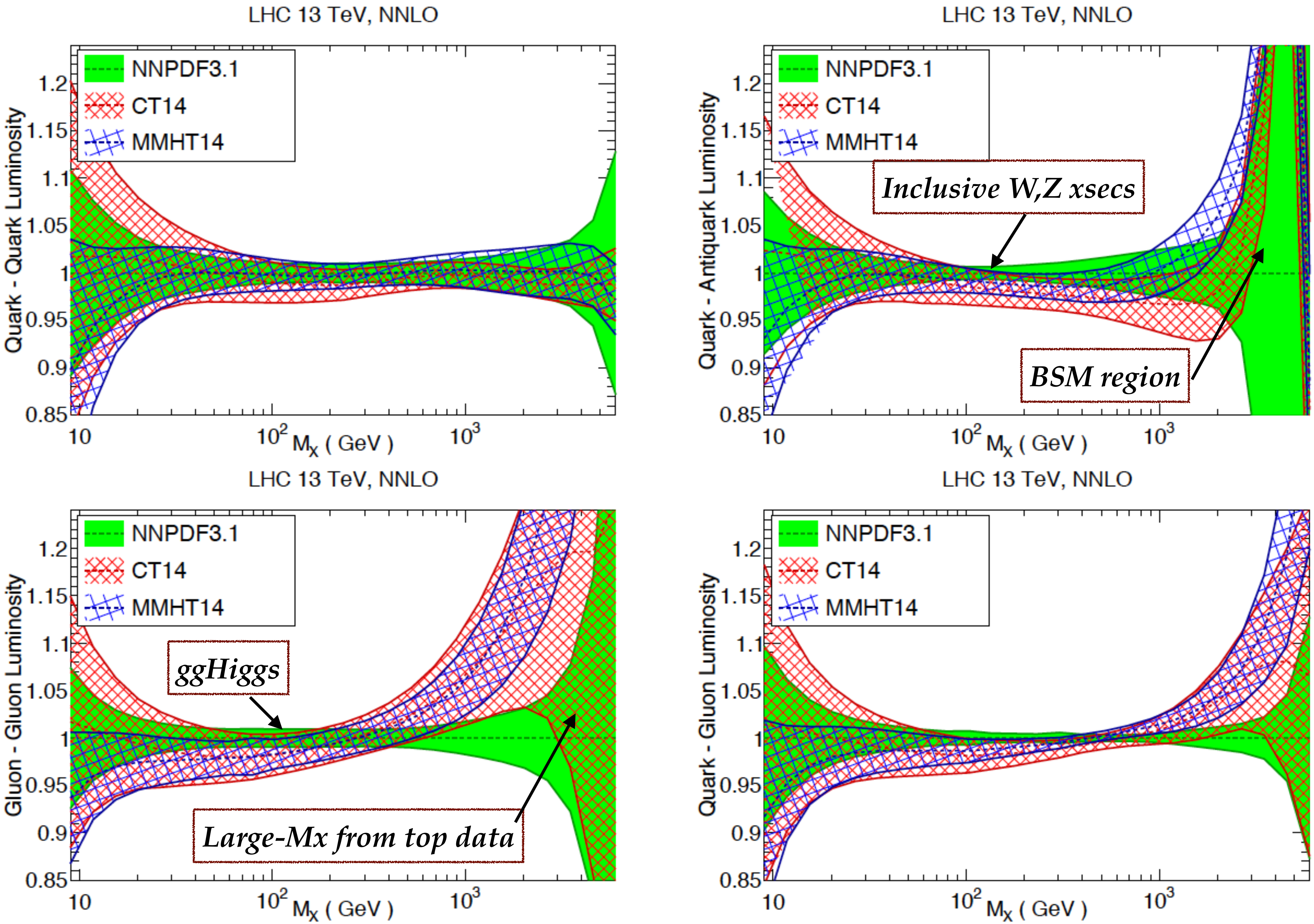
- Including the EMC charm data, we find **evidence for non-perturbative charm at the 1.5 sigma level.** Even without EMC data**, non-perturbative charm bounded < 1.0 % at the 90% CL**

$$[C(Q^2)] \equiv \int_0^1 dx\ \left(xc(x,Q^2) + x\bar{c}(x,Q^2)\right)$$

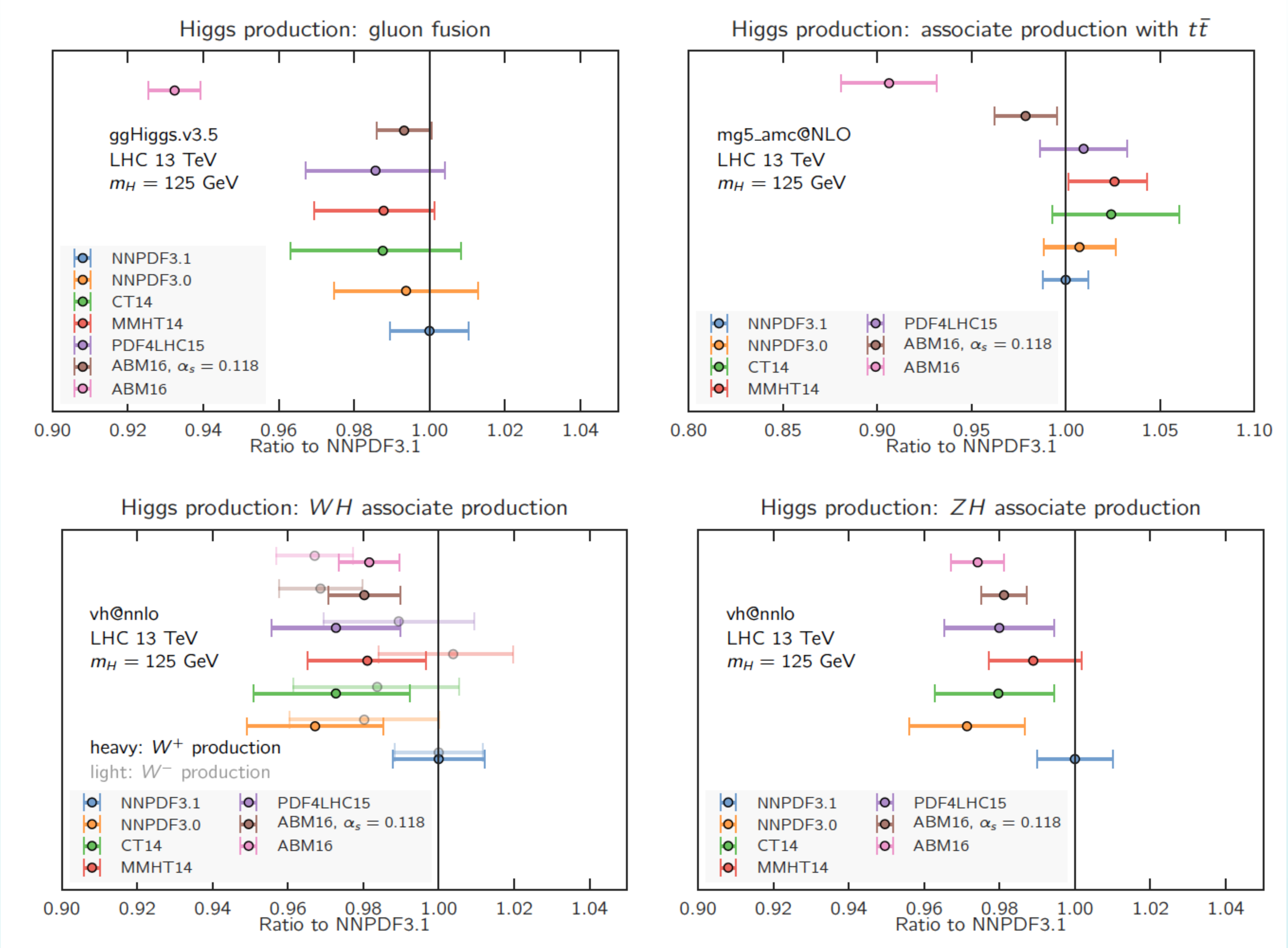
PDF set	$C(Q = 1.65\ \text{GeV})$	$C(Q = 100\ \text{GeV})$
Perturbative charm	$(0.360 \pm 0.007)\%$	$(3.77 \pm 0.02)\%$
Fitted charm	$(0.45 \pm 0.40)\%$	$(3.8 \pm 0.2)\%$
Fitted charm with EMC data	$(0.52 \pm 0.14)\%$	$(3.86 \pm 0.08)\%$



PDF luminosities



Higgs production cross-sections



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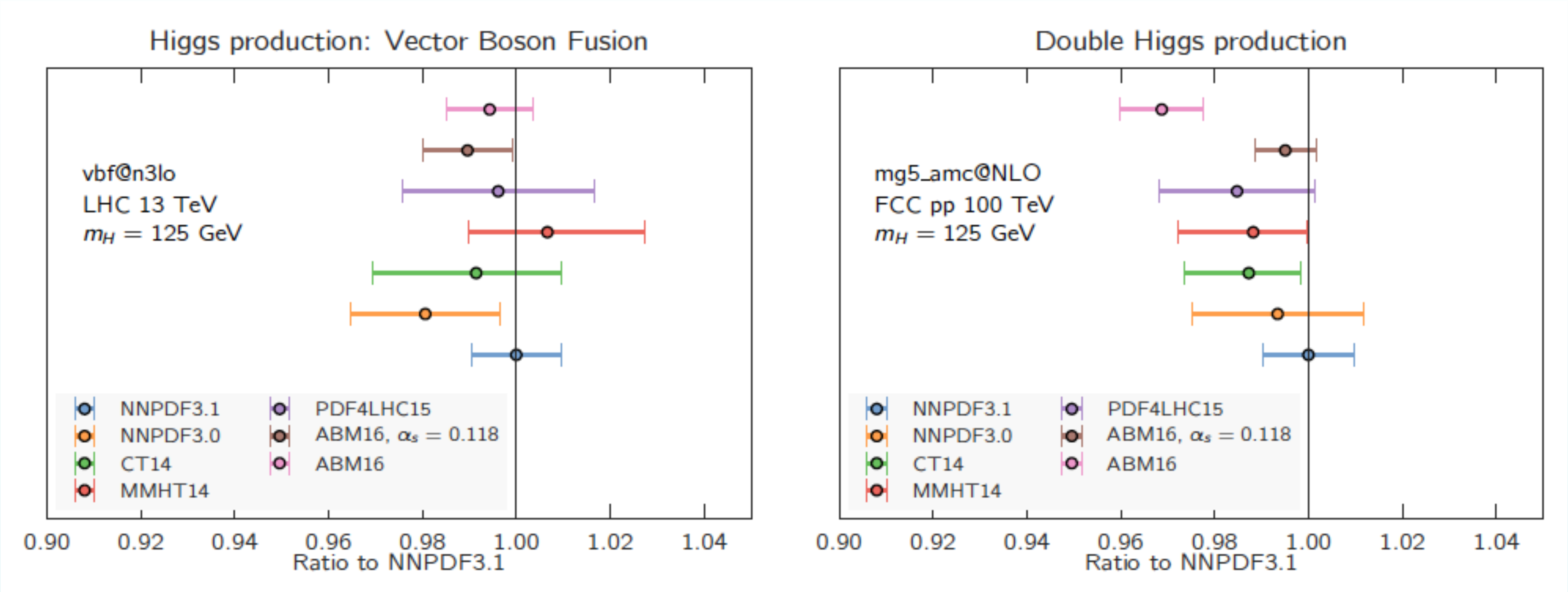

- For **gluon-initiated processes**, good agreement between 3.1 and 3.0 with reduced PDF uncertainties in the latter case

- For **quark-initiated processes**, the new collider data pulls towards higher cross-sections

- The new **ABMP16 set** is in reasonable agreement with the other sets provided the PDG value of the strong coupling is used

NNPDF3.1: summary and outlook

- **Several new datasets included**, from the HERA and Tevatron legacy data to precision LHC electroweak production measurements, the 8 TeV Z p_T data, and top quark production differential distributions

- Good **stability with respect to NNPDF3.0,** with main differences being a **reduction of the large-*x* PDF uncertainties** and an **improved quark flavour separation**

- **Improved stability of the gluon** from the combination of **top, Z $p_{T,}$ and jet data**

- **Increase in strangeness** from inclusion of the ATLAS W,Z 2011 data

- **Improved fit quality once the charm PDF is fitted**, rather than perturbatively generated. Non-negligible differences at the PDF level. NNPDF3.1 fits for the **two options** will be released.

- **NNPDF3.1 to be sent to LHAPDF later this week**

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Thanks for your attention!