Picture by Jorge Franganillo - link

The effects of new data on PDF constraints

Juan M. Cruz Martínez
CERN TH Department

QCD@LHC - Freiburg October 2024

About this talk

For more examples of which data constrains which PDFs you can see the following talks from previous iterations of QCD @ LHC:

Svenja Pflitsch, QCD@LHC 2019: link

Stefano Camarda, QCD@LHC 2020: link

Francesco Giuli, QCD@LHC2023: link

With projections from LHeC and HL-LHC

From Stefano's talk at QCD@LHC 2020

Process	Sensitivity
Drell-Yan	Flavour decomposition of the sea, u_v, d_v, g PDF
W+charm, W+jets	Strange PDF
V+jets	Medium-x gluon PDF
Jets	High-x gluon and quark PDF
Photon	Medium-x gluon PDF
Top pair	Medium- and high-x gluon PDF
Single top	High-x u/d ratio

- Precise data requires precise theory: NNLO QCD, NLO EW, non-pQCD, resummation

In this talk:

- Why PDFs, How PDFs? From what PDFs?
- Studies about existing data
- Studies about future (possible) data (FPF, EIC)

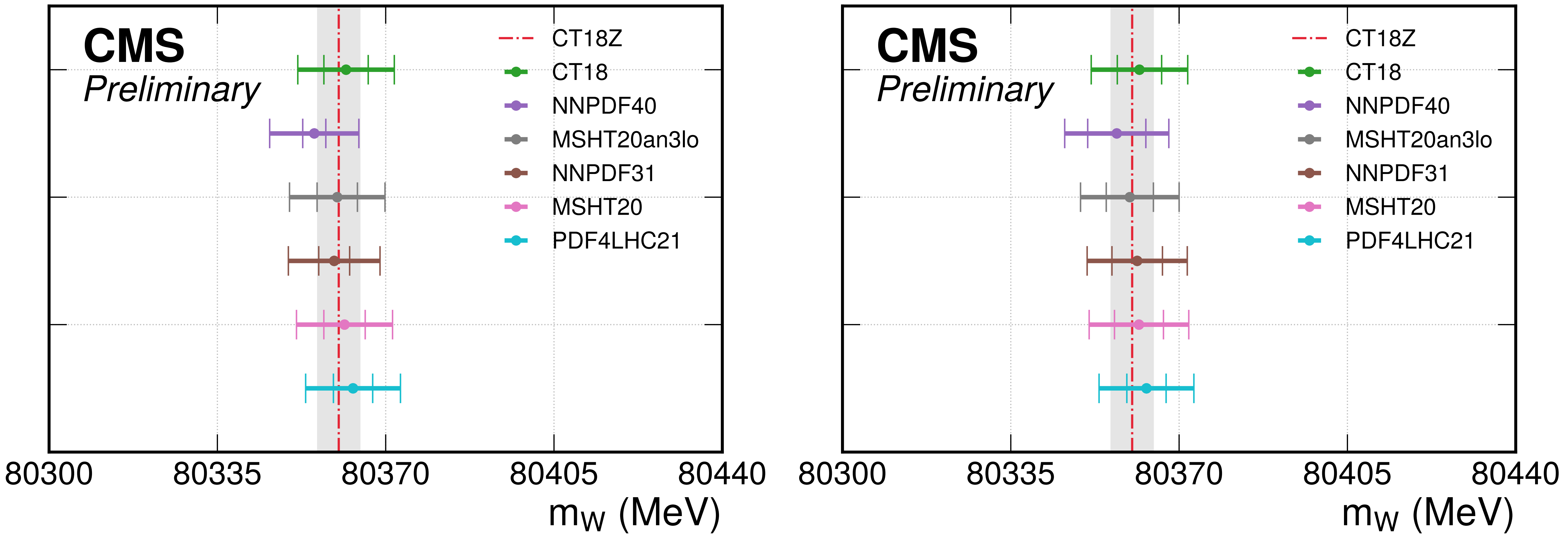
I will be talking only about collinear, unpolarized PDFs (apologies to the TMD enjoyers out there)

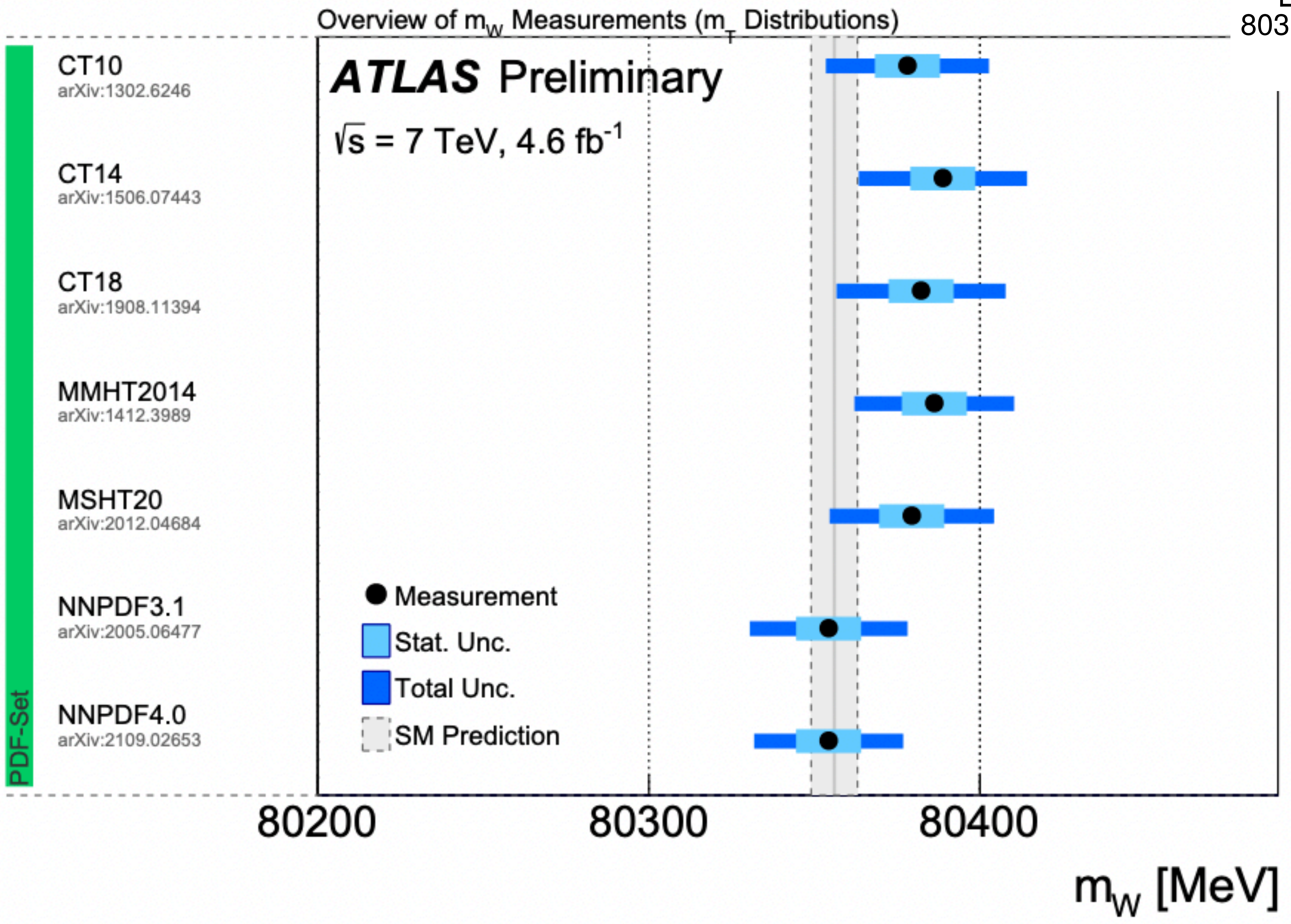
Why do we still care about PDFs?

As you saw in the two previous talks, they are still important!

A very relevant theoretical input with a non-negligible phenomenological impact and that depends on both theory and experiment.

CMS-PAS-SMP-23-002



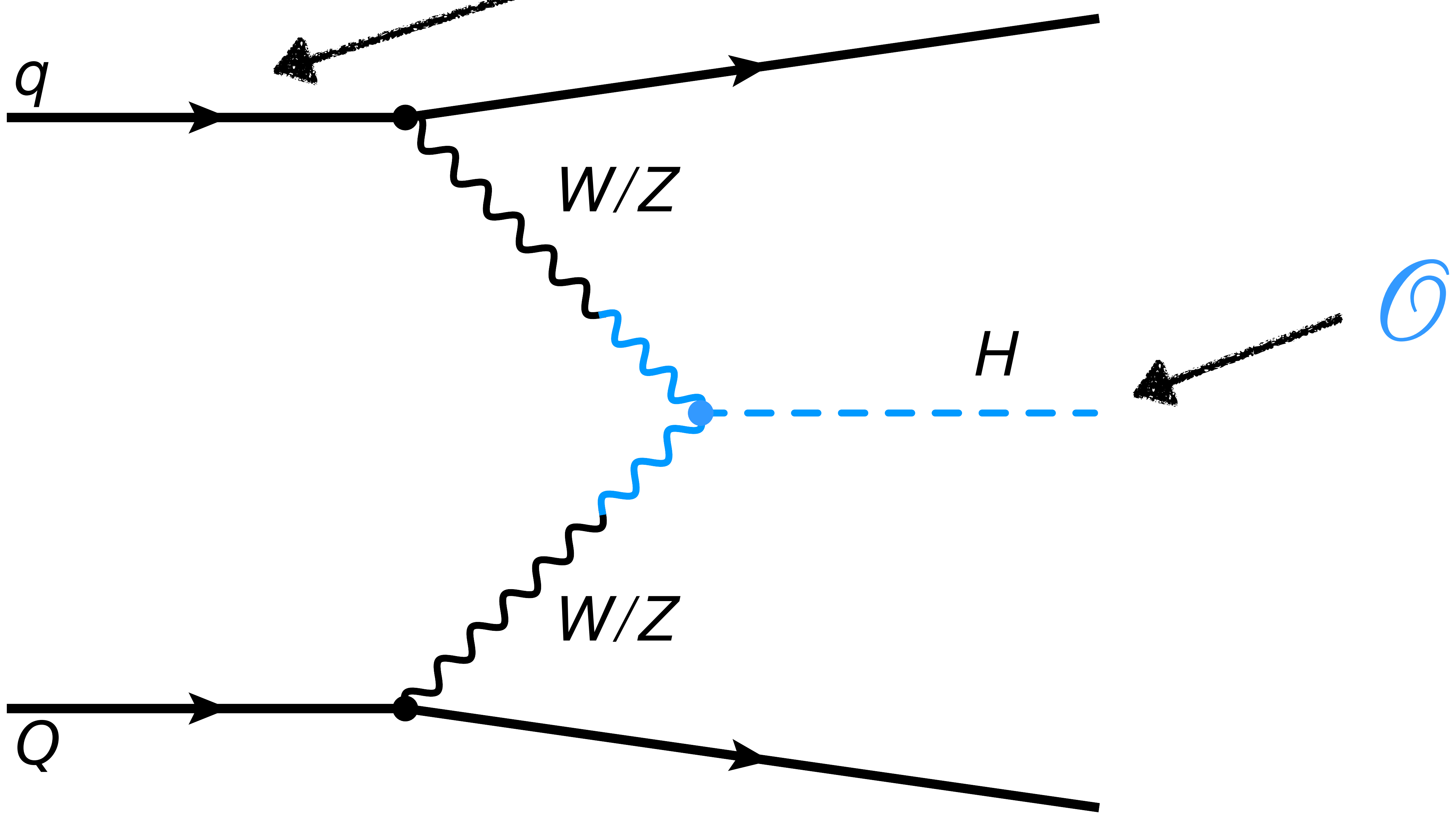


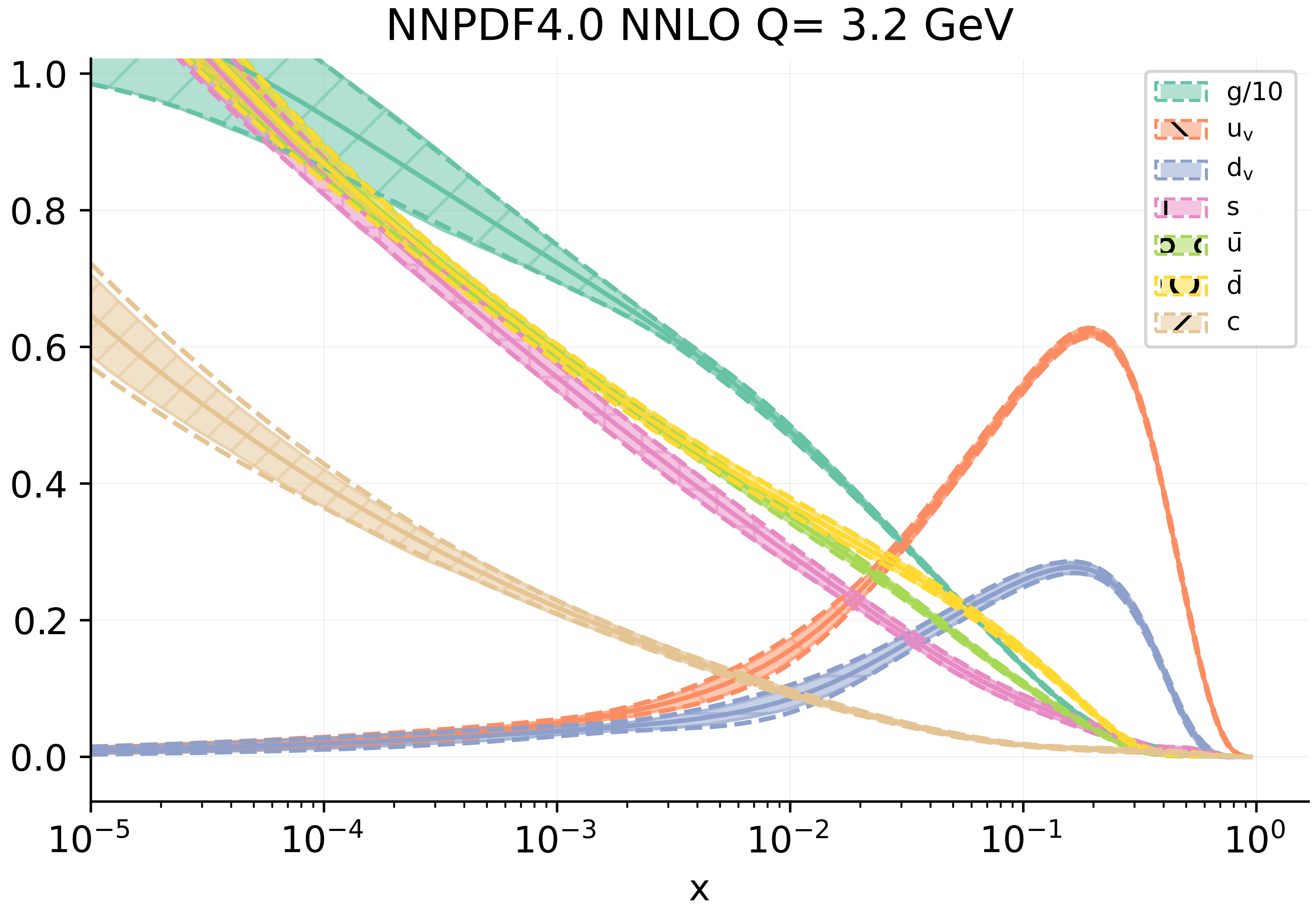
PDF set	Extracted m_W (MeV)	
	Original σ_{PDF}	Scaled σ_{PDF}
CT18Z	$80\,360.2 \pm 9.9$	
CT18	$80\,361.8 \pm 10.0$	
PDF4LHC21	$80\,363.2 \pm 9.9$	
MSHT20	$80\,361.4 \pm 10.0$	$80\,361.7 \pm 10.4$
MSHT20aN3LO	$80\,359.9 \pm 9.9$	$80\,359.8 \pm 10.3$
NNPDF3.1	$80\,359.3 \pm 9.5$	$80\,361.3 \pm 10.4$
NNPDF4.0	$80\,355.1 \pm 9.3$	$80\,357.0 \pm 10.8$

PDF determination ingredients

PDFs cannot be computed analytically from first principles… **or can they? More about that after the coffee break!**

$$\mathcal{O} = \sum_{ij} \int dx_1 dx_2 \; f_i(x_1, \mu_F) \; f_j(x_2, \mu_F) \; \hat{\sigma}_{ij}(x_1, x_2, \mu_R, \mu_F)$$

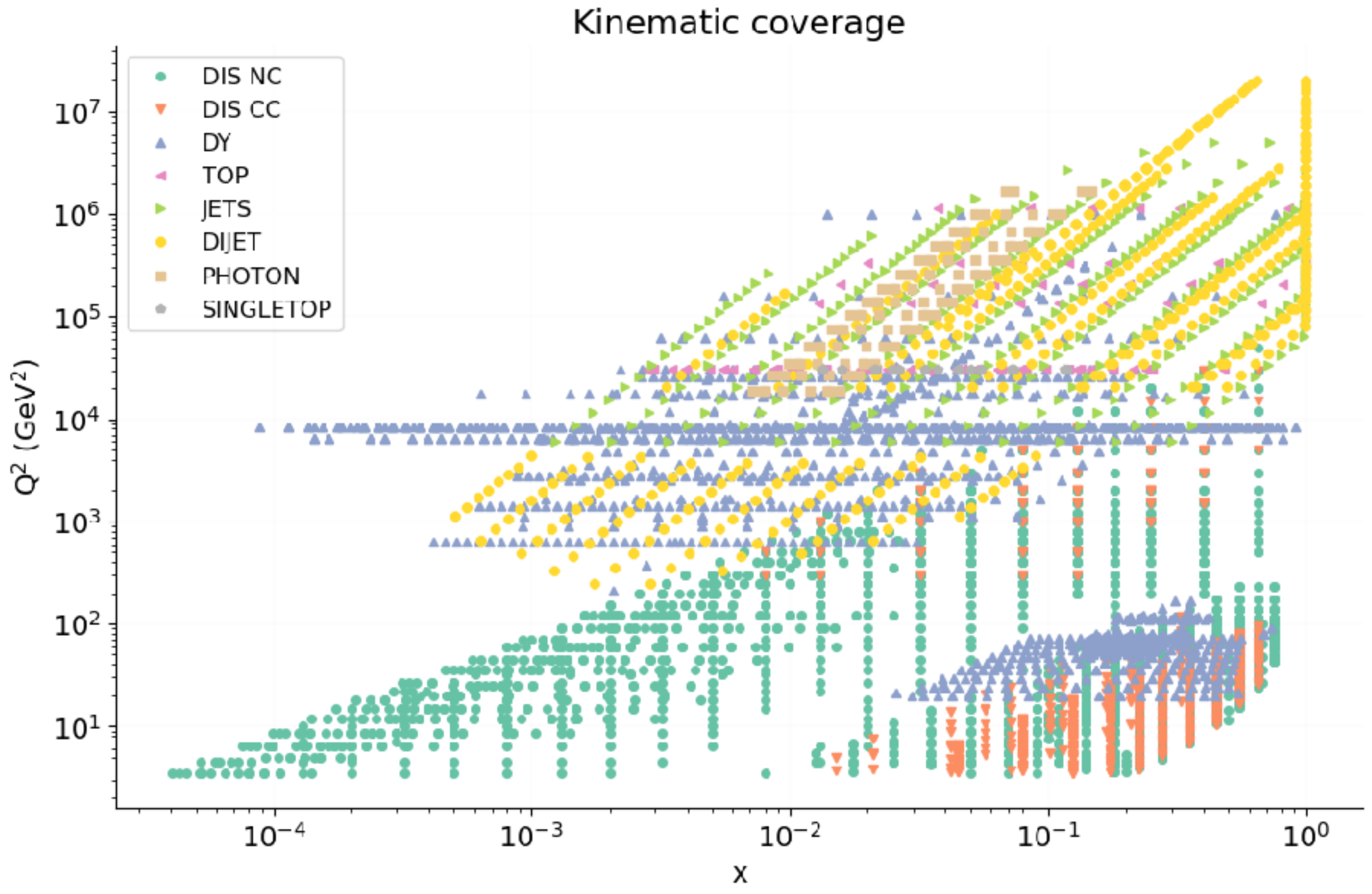


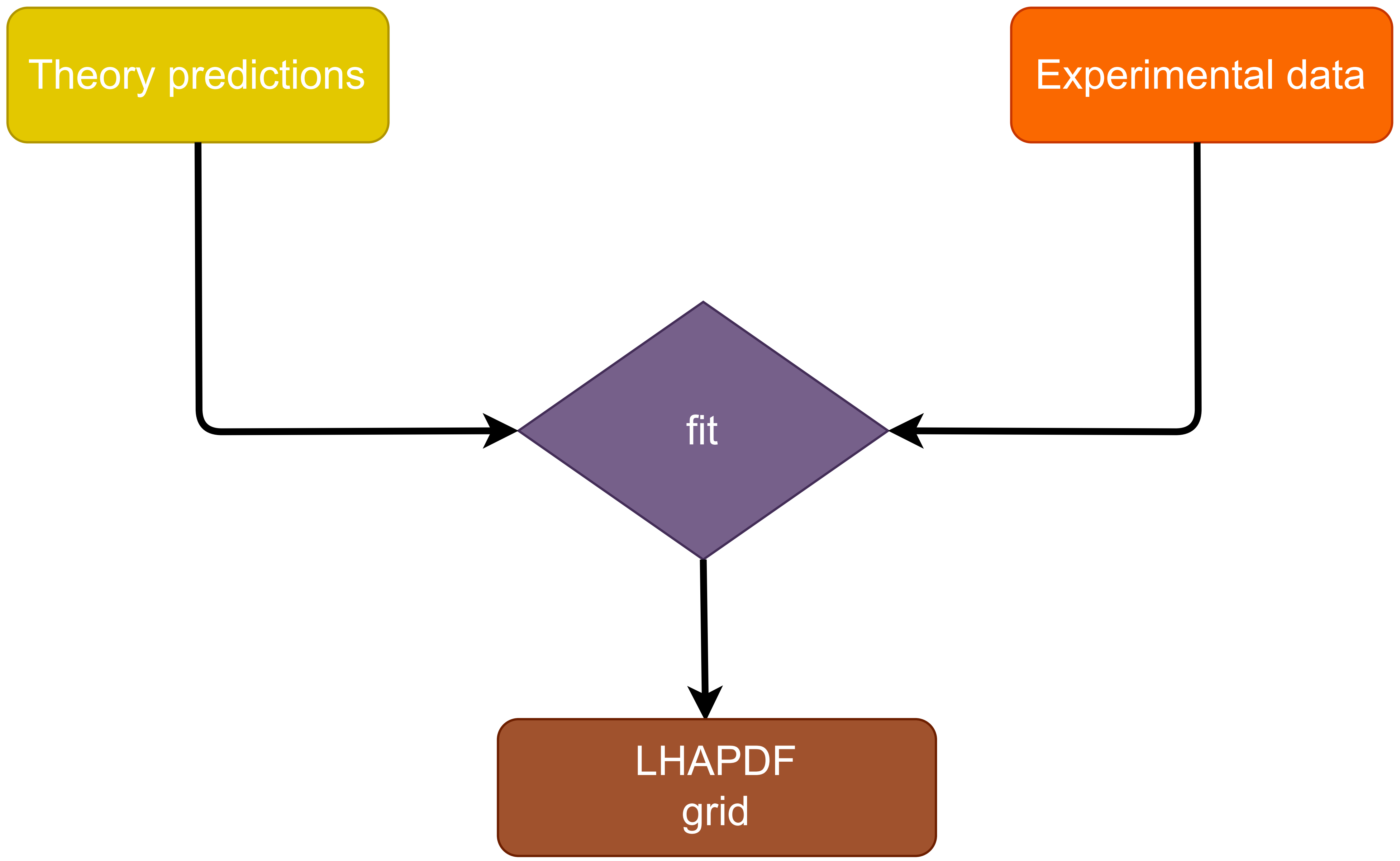


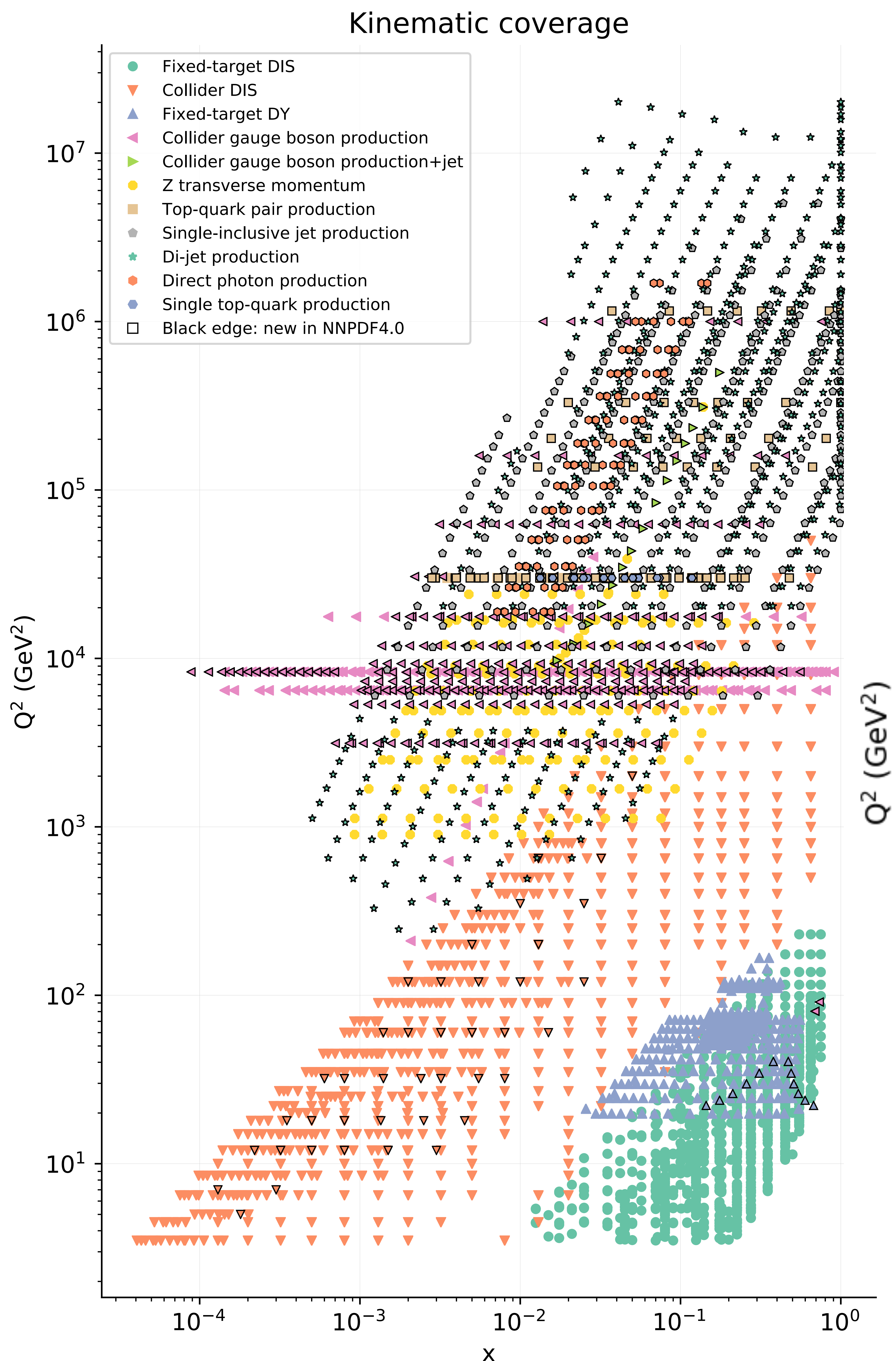
PDF determination ingredients

PDFs cannot be computed analytically from first principles… **or can they? More about that after the coffee break!**

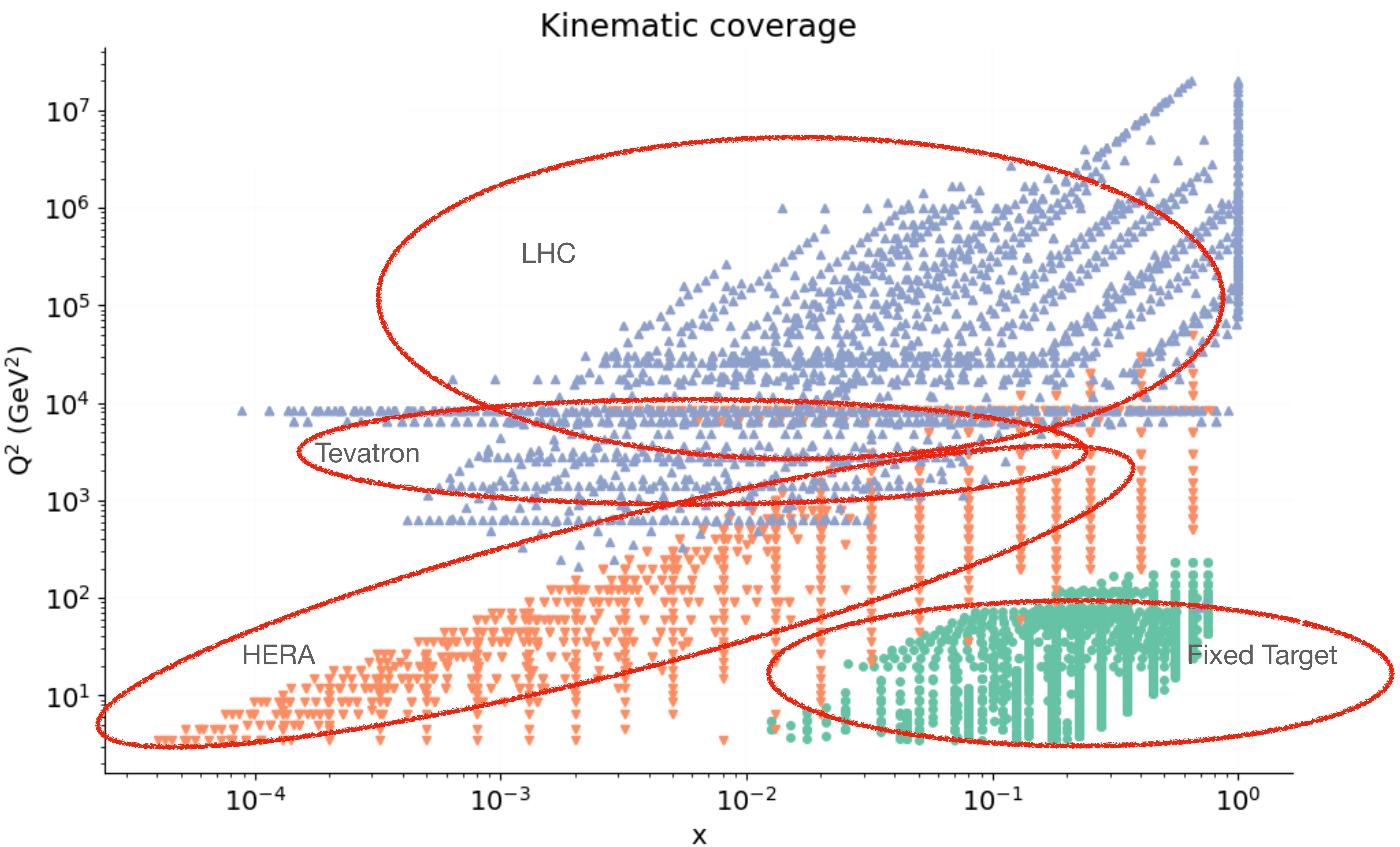
$$= \sum_{ij} \int dx_1 dx_2 \; f_i(x_1, \mu_F)\, f_j(x_2, \mu_F)\; \hat{\sigma}_{ij}(x_1, x_2, \mu_R, \mu_F)$$







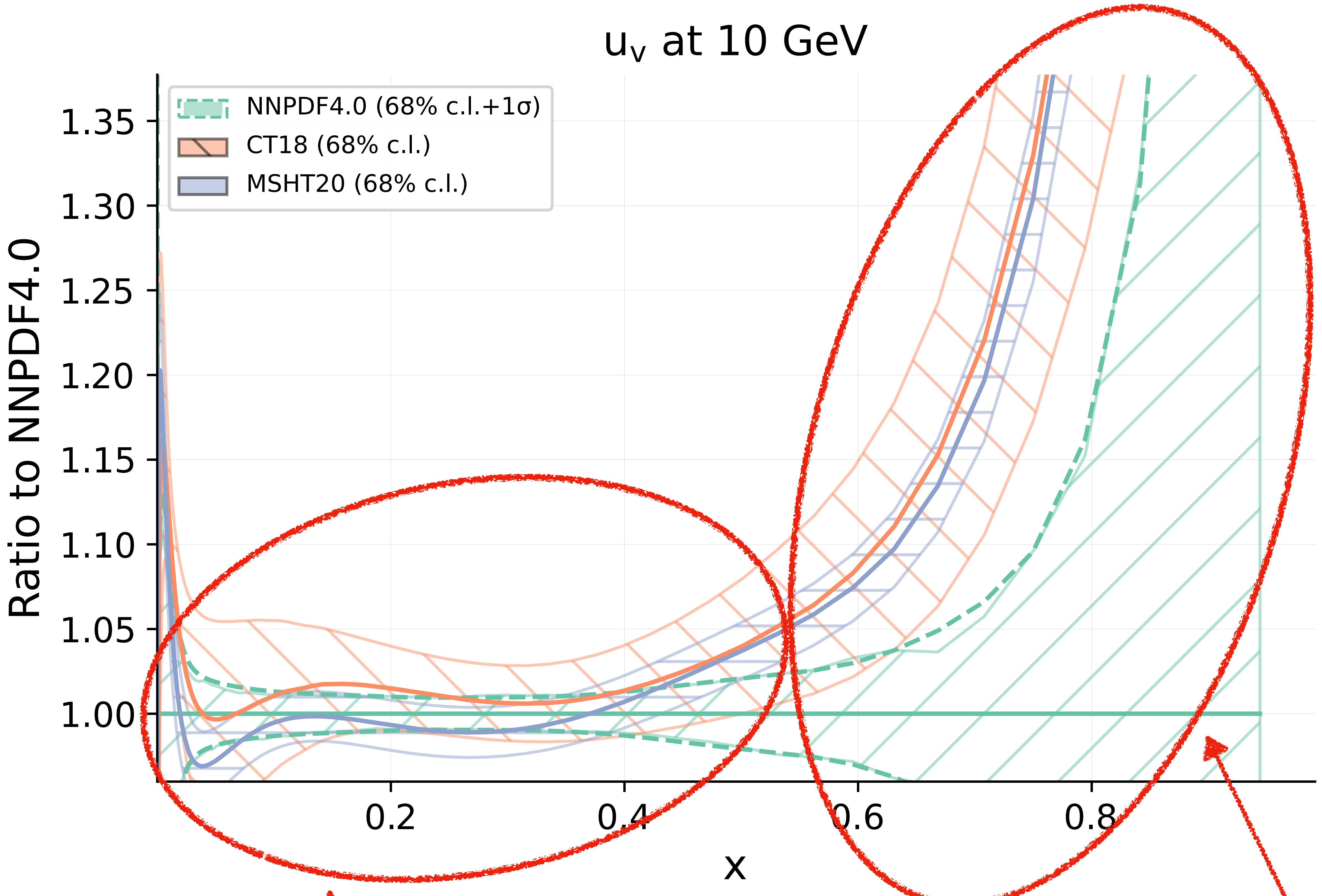
The PDF is defined by: theory, methodology, and **data**



Full list of datasets in this plot can be checked in Appendix B of the NNPDF4.0 paper: link

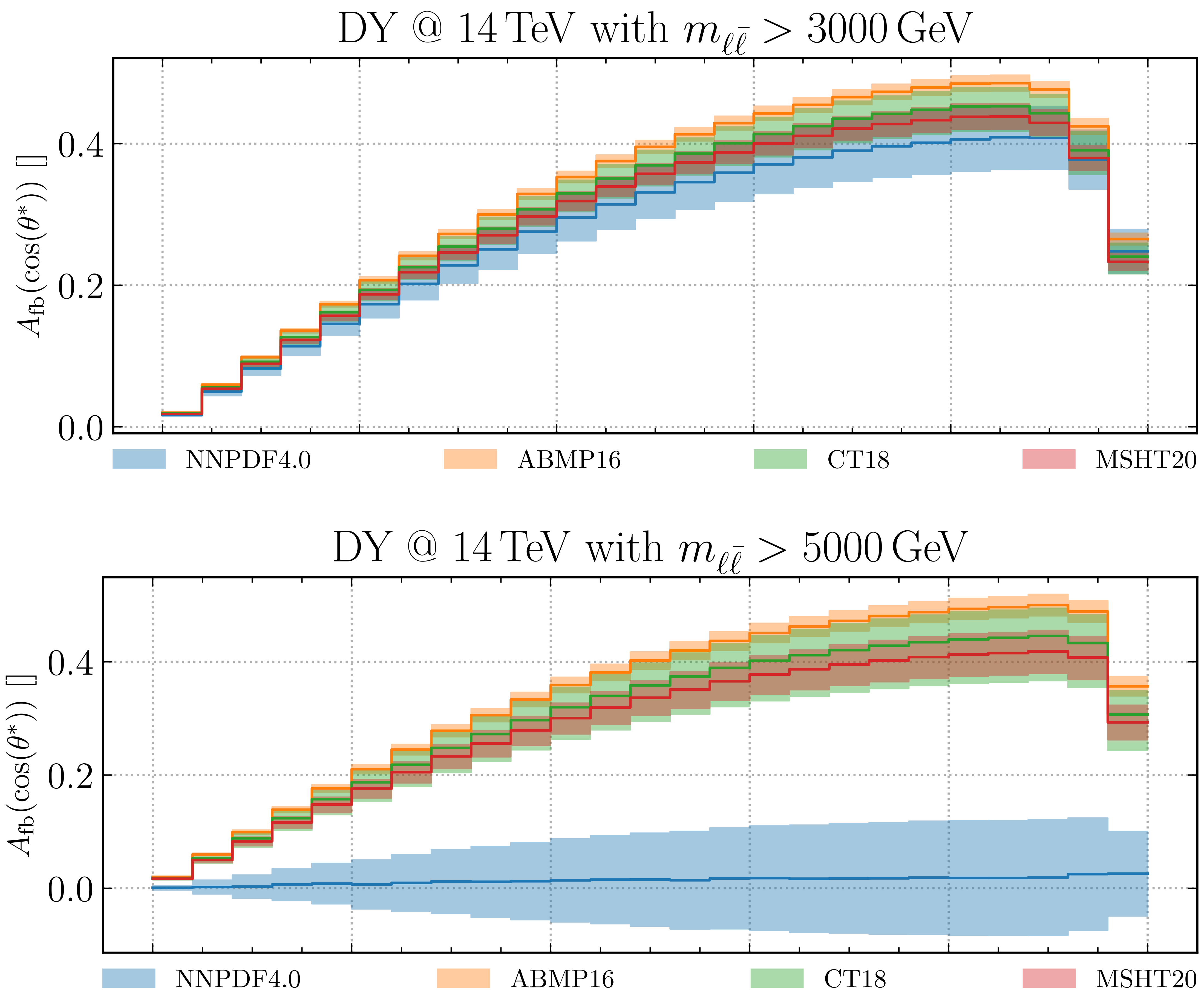
Precision follows the data

Not all regions are equally well determined, for PDFs as we go to higher values of x we leave the “data region”



Data region: reasonable agreement between different PDF sets even though they include different datasets.
aiming for both accuracy & precision

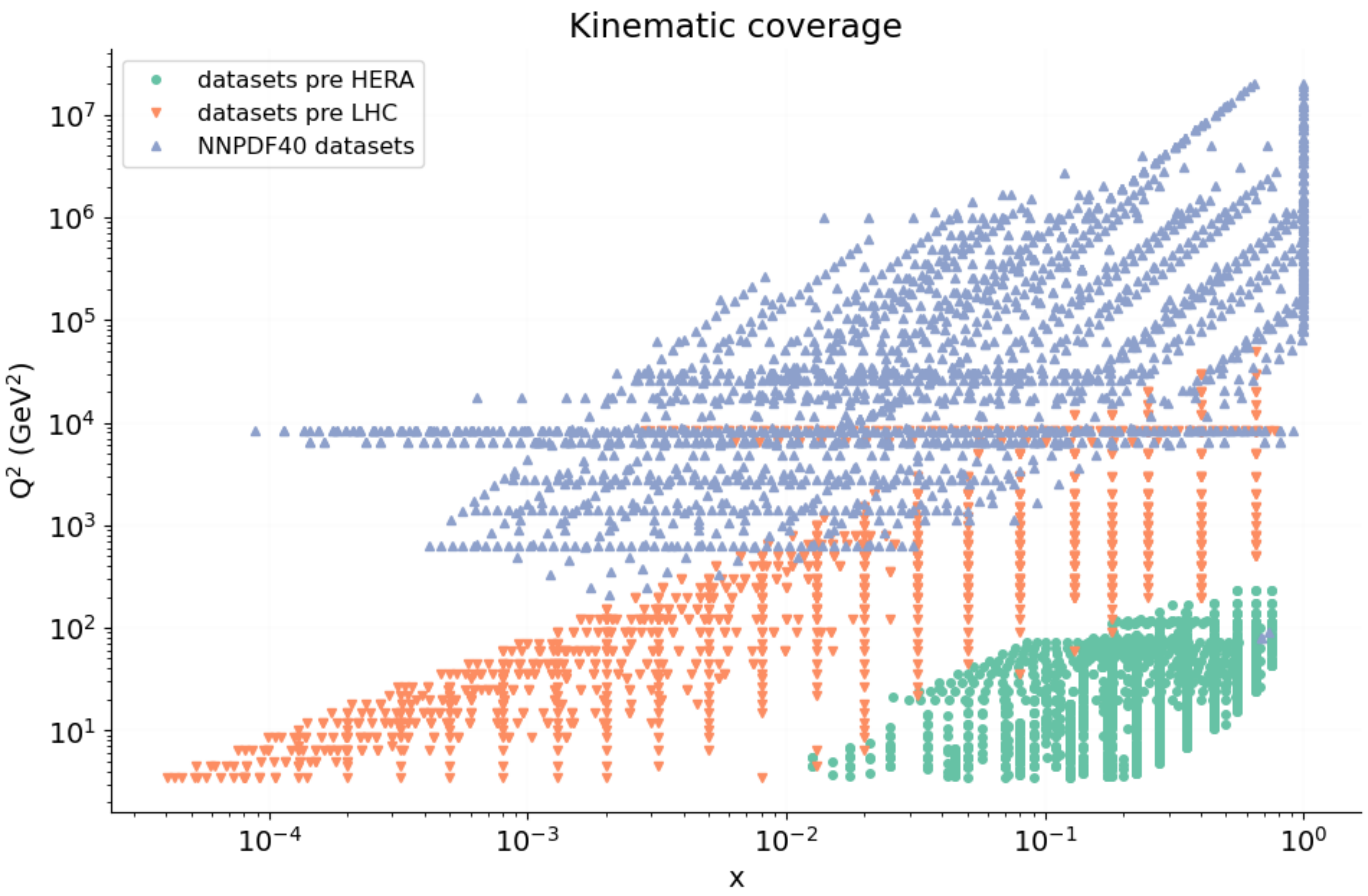
Extrapolation region
hic sunt dracones!



Parton distributions and new physics searches: the Drell–Yan forward–backward asymmetry as a case study [hep-ph] 2209.08115
R. Ball, A. Candido, S. Forte, F. Hekhorn, E. Nocera, J. Rojo, C. Schwan

Precision follows the data

We can play the same game by creating subsets of data, if the fitting methodology is sound, one would expect better accuracy and precision as more data is added.

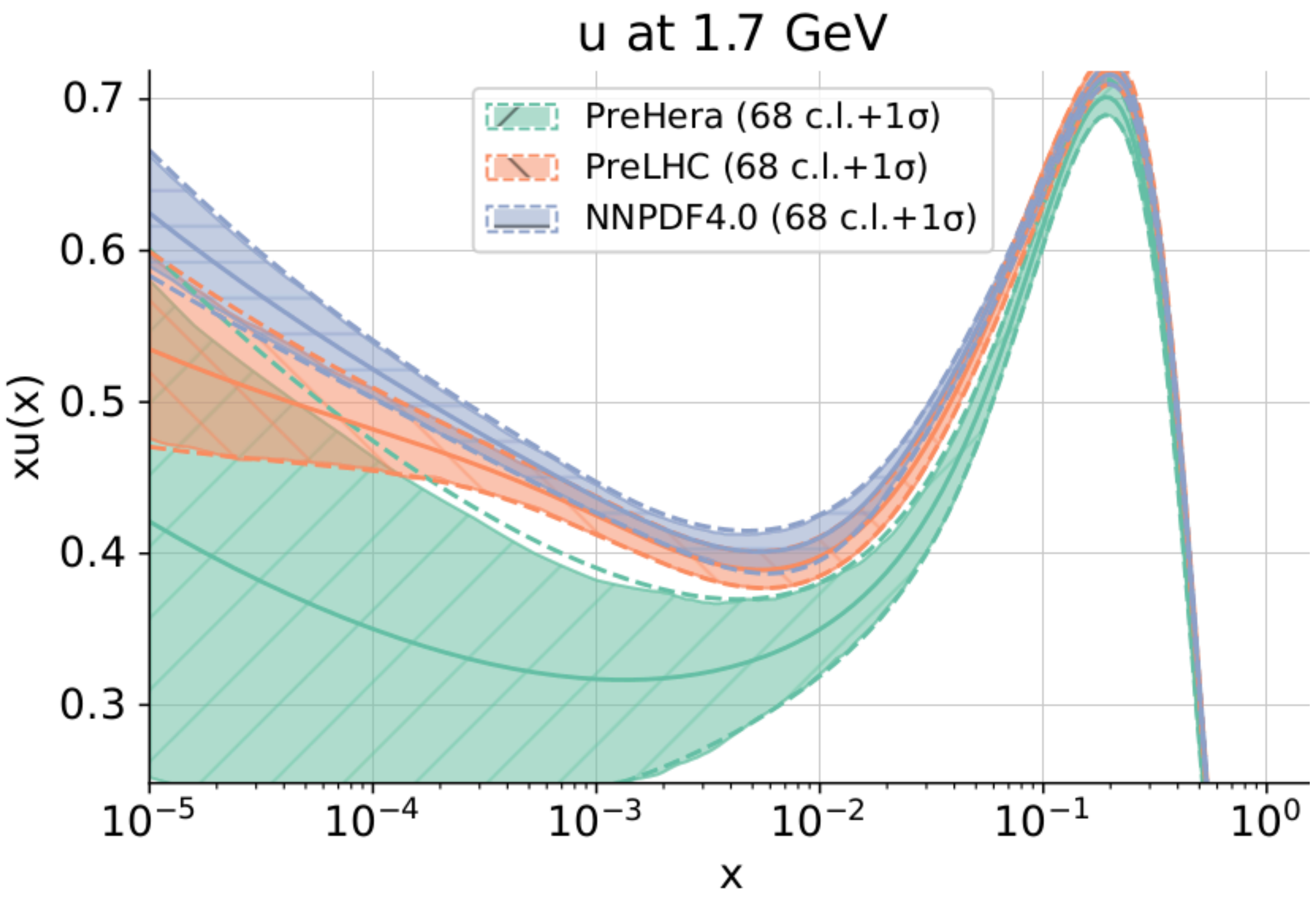


Using for this example the NNPDF dataset and open source fitting code

PDF errors included only in the **red** results

dataset \ fit	NNPDF4.0	pre-LHC	pre-HERA
pre-HERA			0.87
pre-LHC		1.18	**1.22**
NNPDF4.0	1.12	**1.30**	**1.38**

χ^2/N

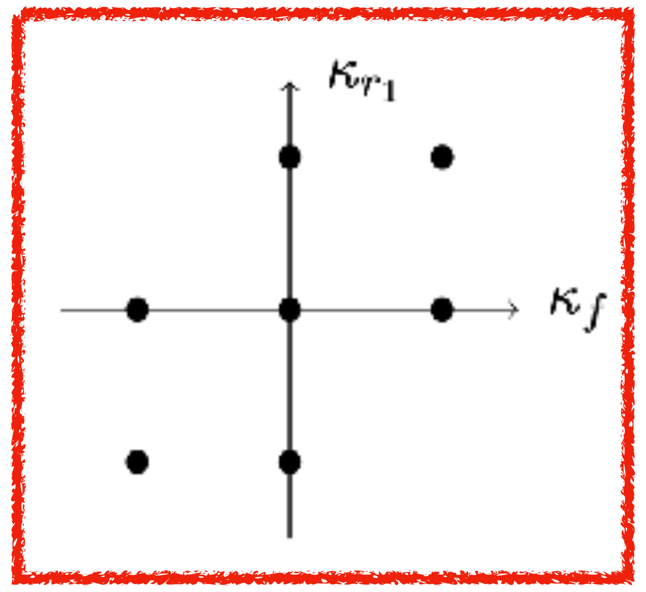


How well does a PDF accommodate new data?

Which should give us some clue on whether new data will have an effect

Parton distributions confront precision LHC Run II data: a quantitative assessment [hep-ph] In preparation
A. Chiefa, M. Constantini, JCM, E. Nocera, T. Rabemanajara, J. Rojo, T. Sharma, R. Stegeman, M. Ubiali

$$(\mathrm{cov_{mho}})_{ij} = \left[S_{ij}^{(7\mathrm{pt})}\right]^{1/2},$$



$$S_{ij}^{(7\mathrm{pt})} = \frac{1}{3}\left\{\Delta_i^{+0}\Delta_j^{+0} + \Delta_i^{-0}\Delta_j^{-0} + \Delta_i^{0+}\Delta_j^{0+} + \Delta_i^{0-}\Delta_j^{0-} + \Delta_i^{++}\Delta_j^{++} + \Delta_i^{--}\Delta_j^{--}\right\}$$

Monte Carlo PDF set

$$(\mathrm{cov_{pdf}})_{ij} = \frac{N_{\mathrm{rep}}}{N_{\mathrm{rep}}-1}\left(\left\langle T_i^{(k)}T_j^{(k)}\right\rangle - \left\langle T_i^{(k)}\right\rangle\left\langle T_j^{(k)}\right\rangle\right)$$

Hessian PDF set

$$(\mathrm{cov_{pdf}})_{ij} = \sum_{k=1}^{N_{\mathrm{eig}}}\left(\tilde{T}_i^{(k)} - T_i^{(0)}\right)\left(\tilde{T}_j^{(k)} - T_j^{(0)}\right)$$

$$\chi^2_{\mathrm{exp}} \leftrightarrow \mathrm{cov} = \mathrm{cov_{exp}}$$

$$\chi^2_{\mathrm{exp+mho}} \leftrightarrow \mathrm{cov} = \mathrm{cov_{exp}} + \boxed{\mathrm{cov_{mho}}}$$

$$\chi^2_{\mathrm{exp+mho+pdf}} \leftrightarrow \mathrm{cov} = \mathrm{cov_{exp}} + \mathrm{cov_{mho}} + \boxed{\mathrm{cov_{pdf}}}$$

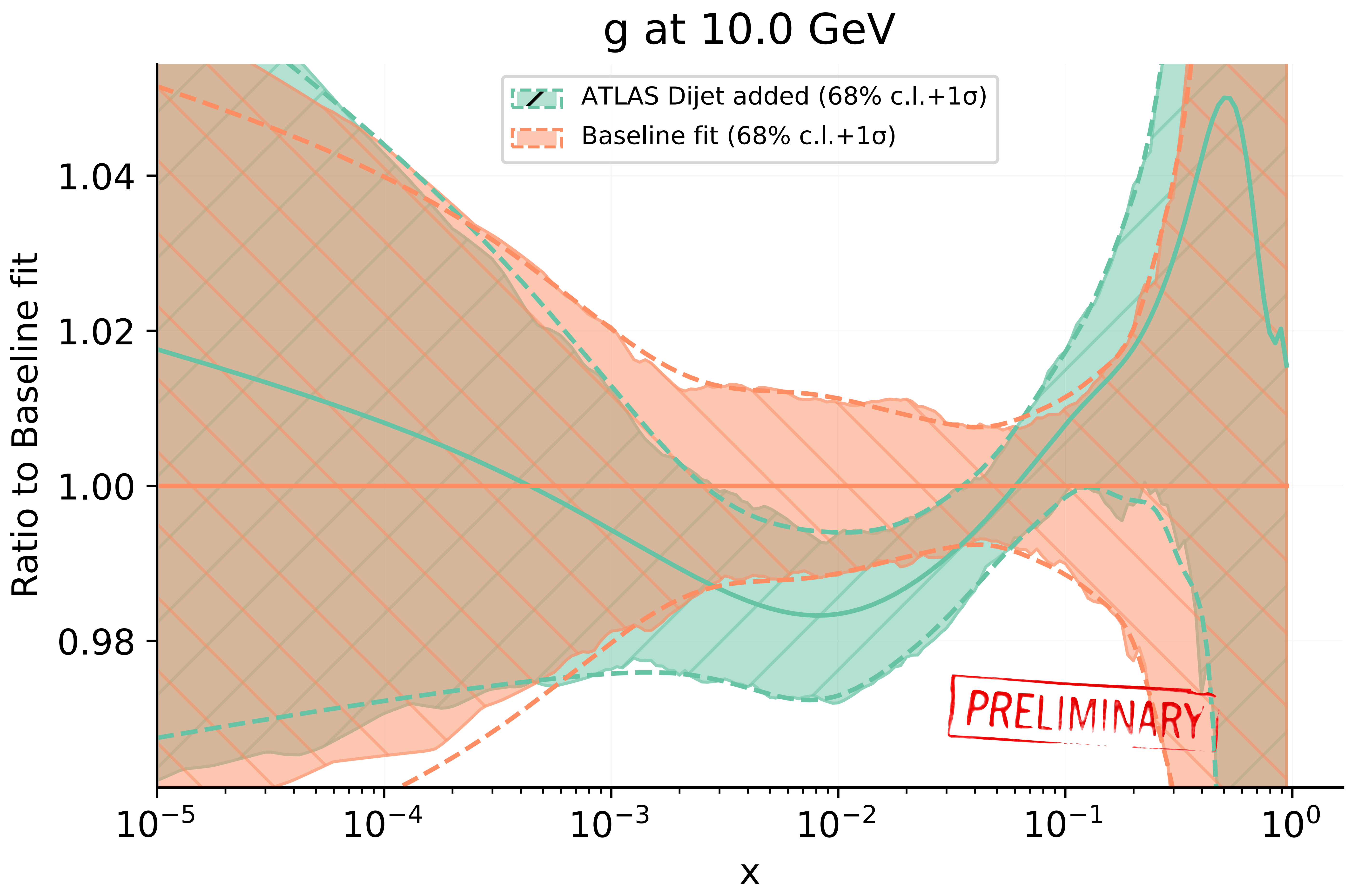
$$\chi^2_{\mathrm{exp+mho+pdf+as}} \leftrightarrow \mathrm{cov} = \mathrm{cov_{exp}} + \mathrm{cov_{mho}} + \mathrm{cov_{pdf}} + \boxed{\mathrm{cov_{as}}}$$

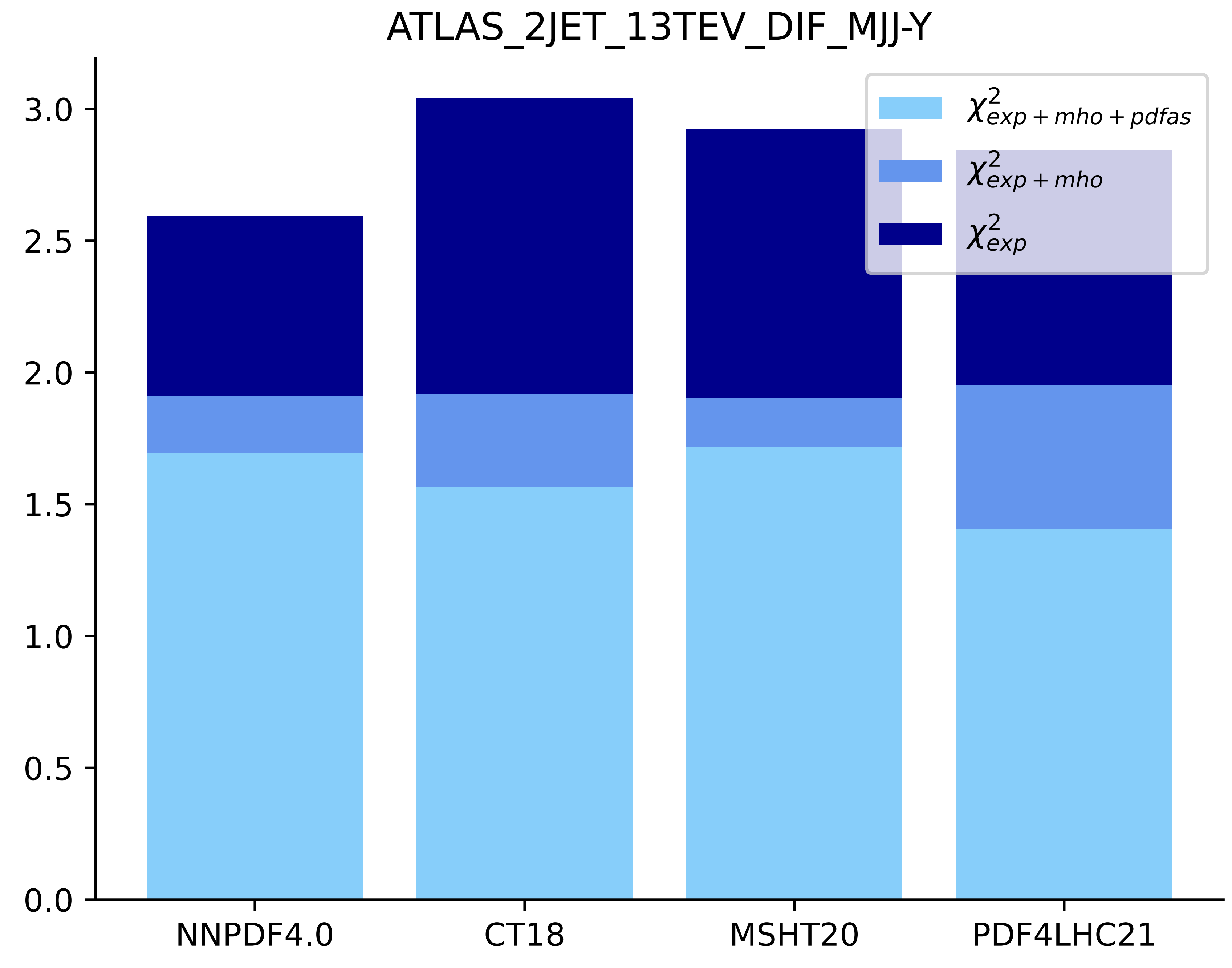
$$(\mathrm{cov_{as}})_{ij} = \frac{1}{2}\left\{\Delta^+_{i,\alpha_s}\Delta^+_{j,\alpha_s} + \Delta^-_{i,\alpha_s}\Delta^-_{j,\alpha_s}\right\}$$

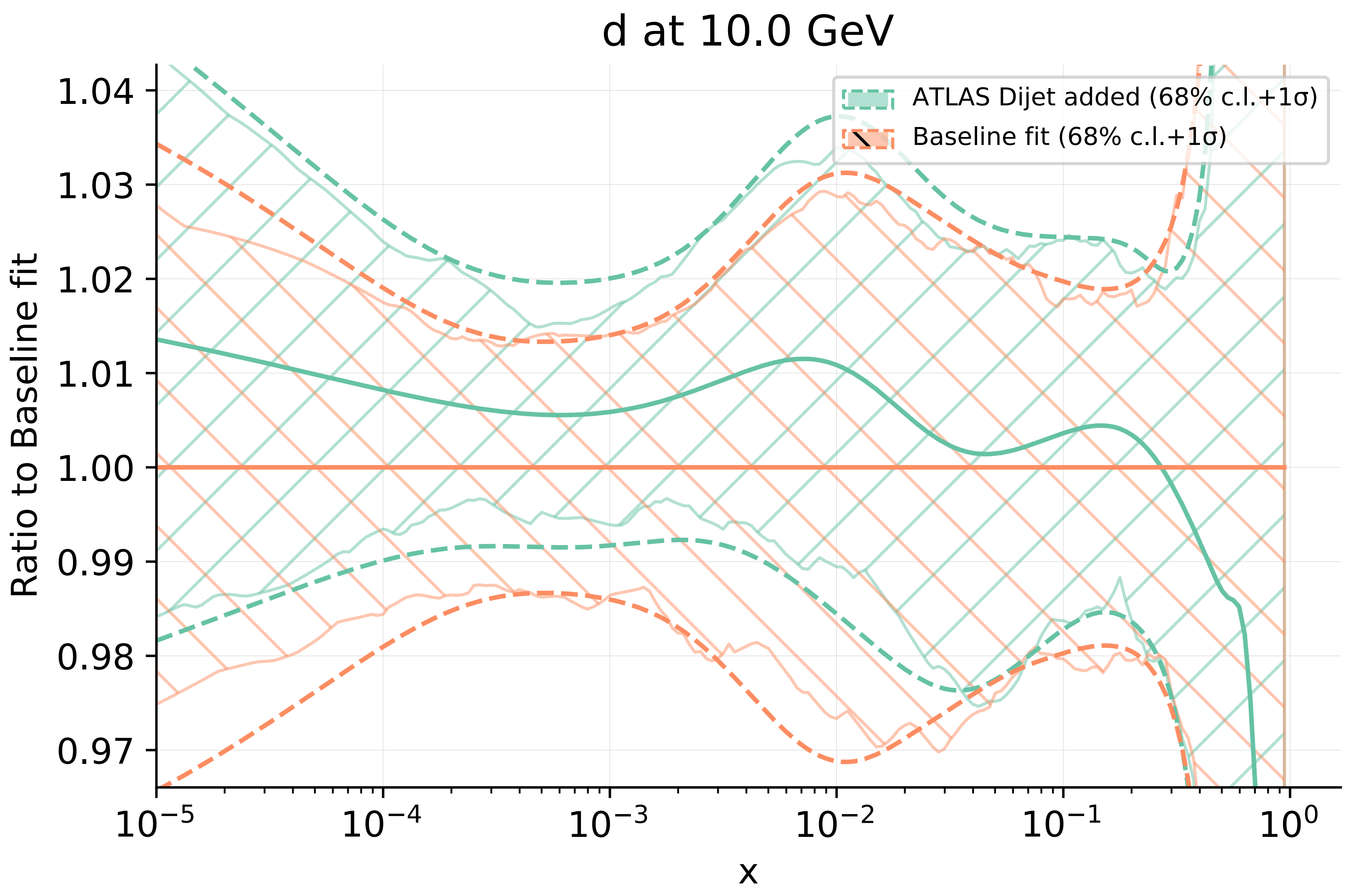
$$\Delta^+_{i,\alpha_s} = T_i(\alpha_s = 0.119) - T_i(\alpha_s = 0.118)$$
$$\Delta^-_{i,\alpha_s} = T_i(\alpha_s = 0.118) - T_i(\alpha_s = 0.117)$$

ATLAS dijet Data 13 TeV

From https://doi.org/10.17182/hepdata.79952 - 1711.02692 [hep-ex] about 140 points

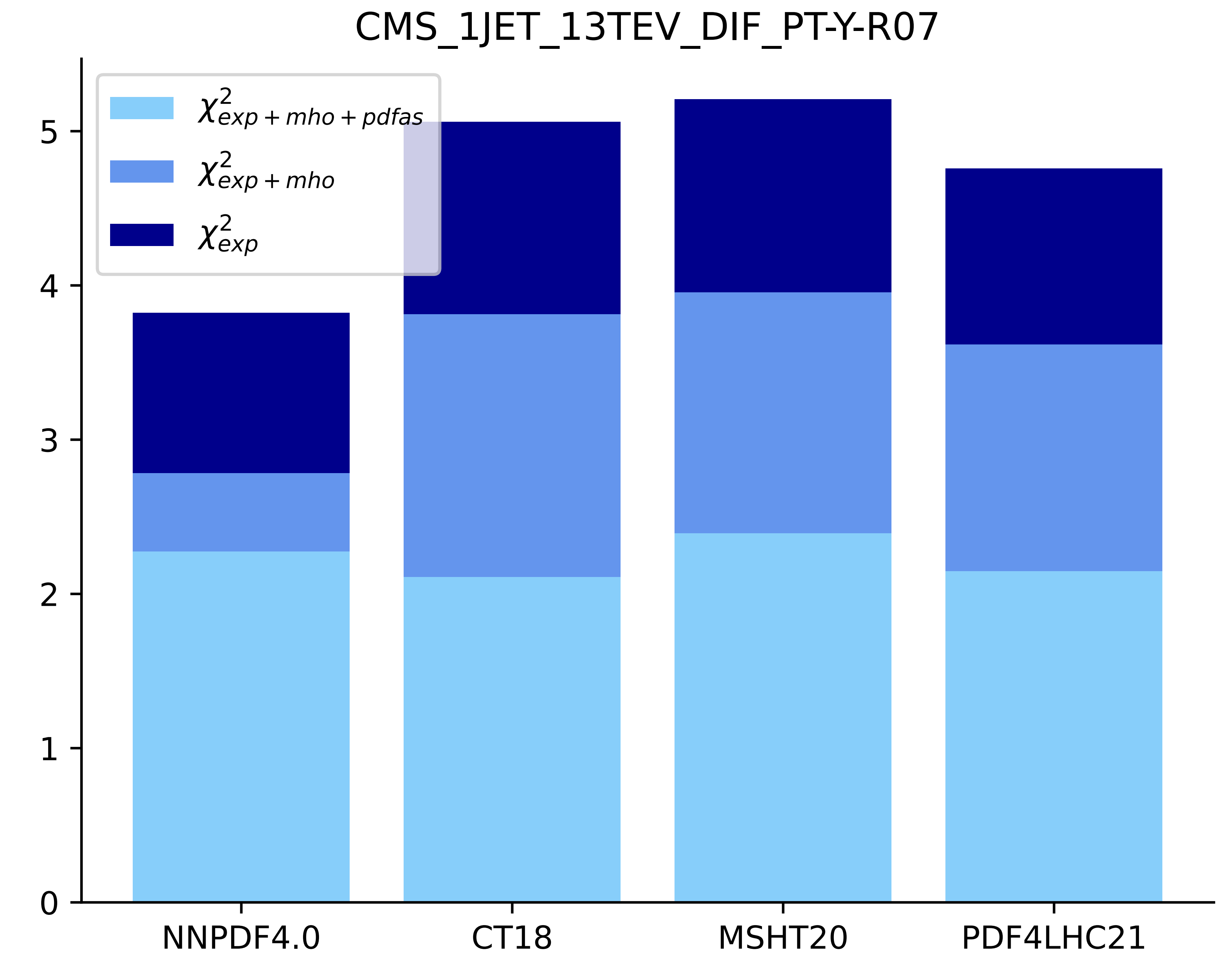


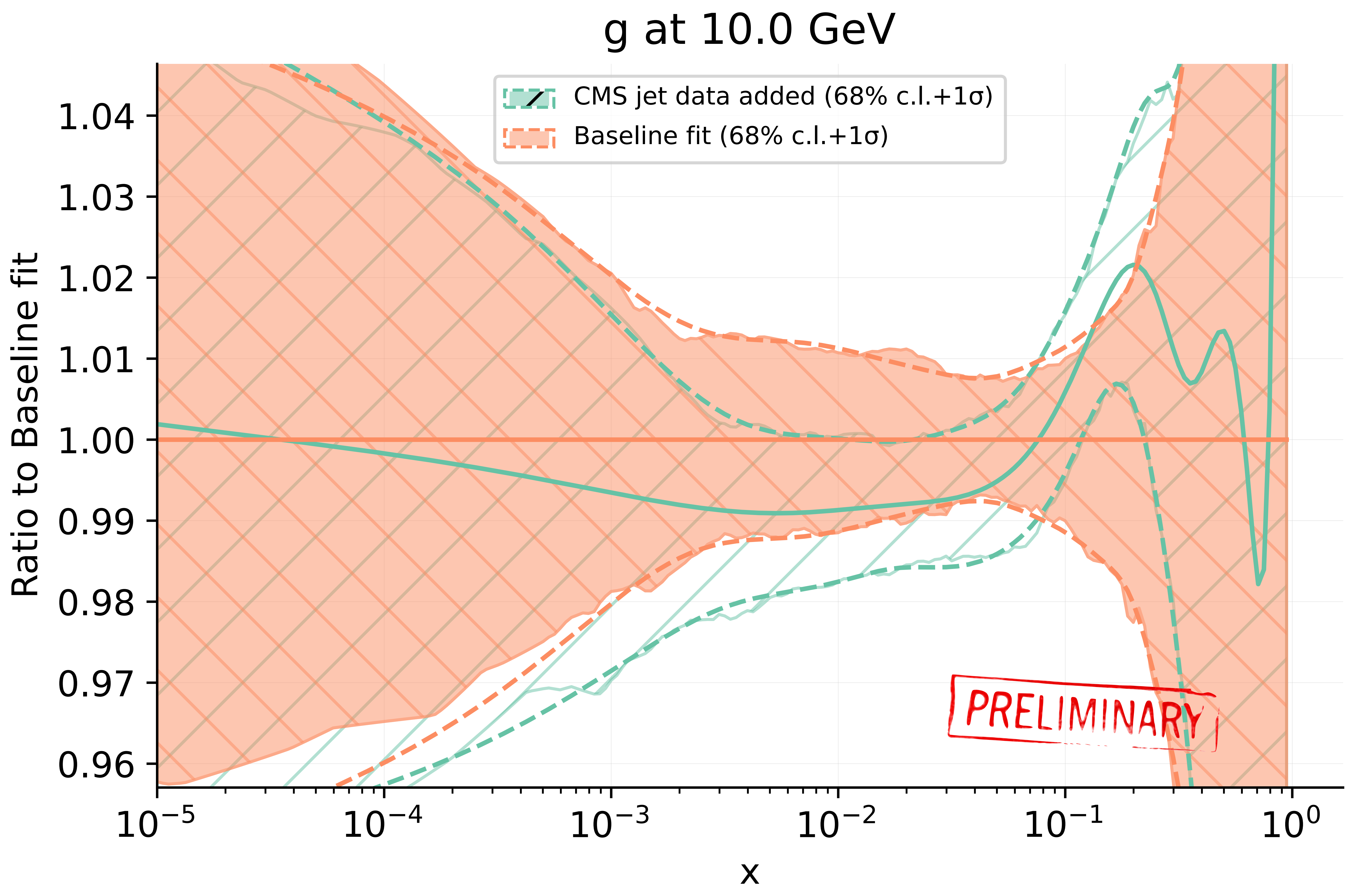


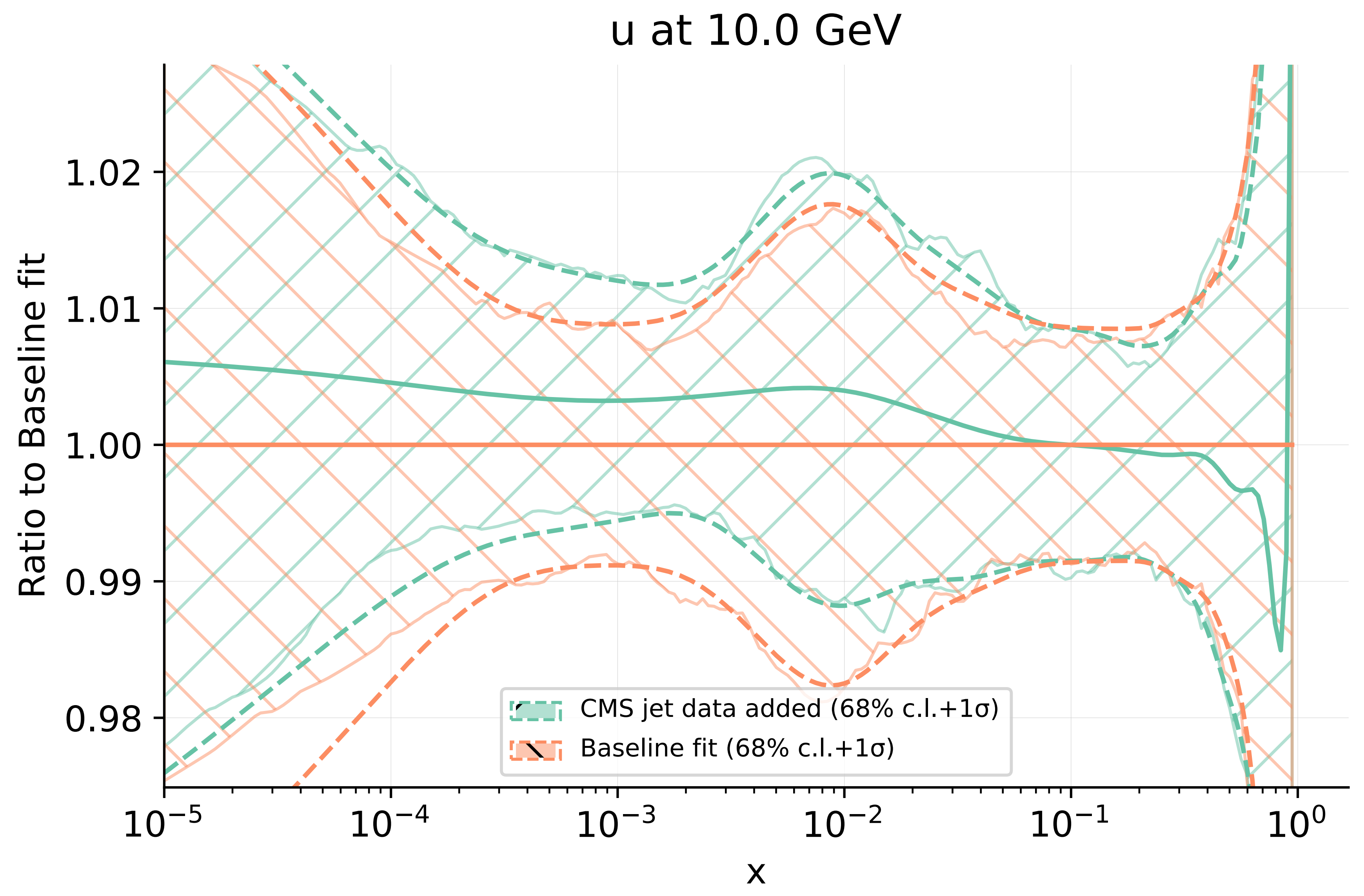


CMS inclusive jet Data 13 TeV

From https://doi.org/10.17182/hepdata.115022.v2 - 2111.10431 [hep-ex] about 80 points

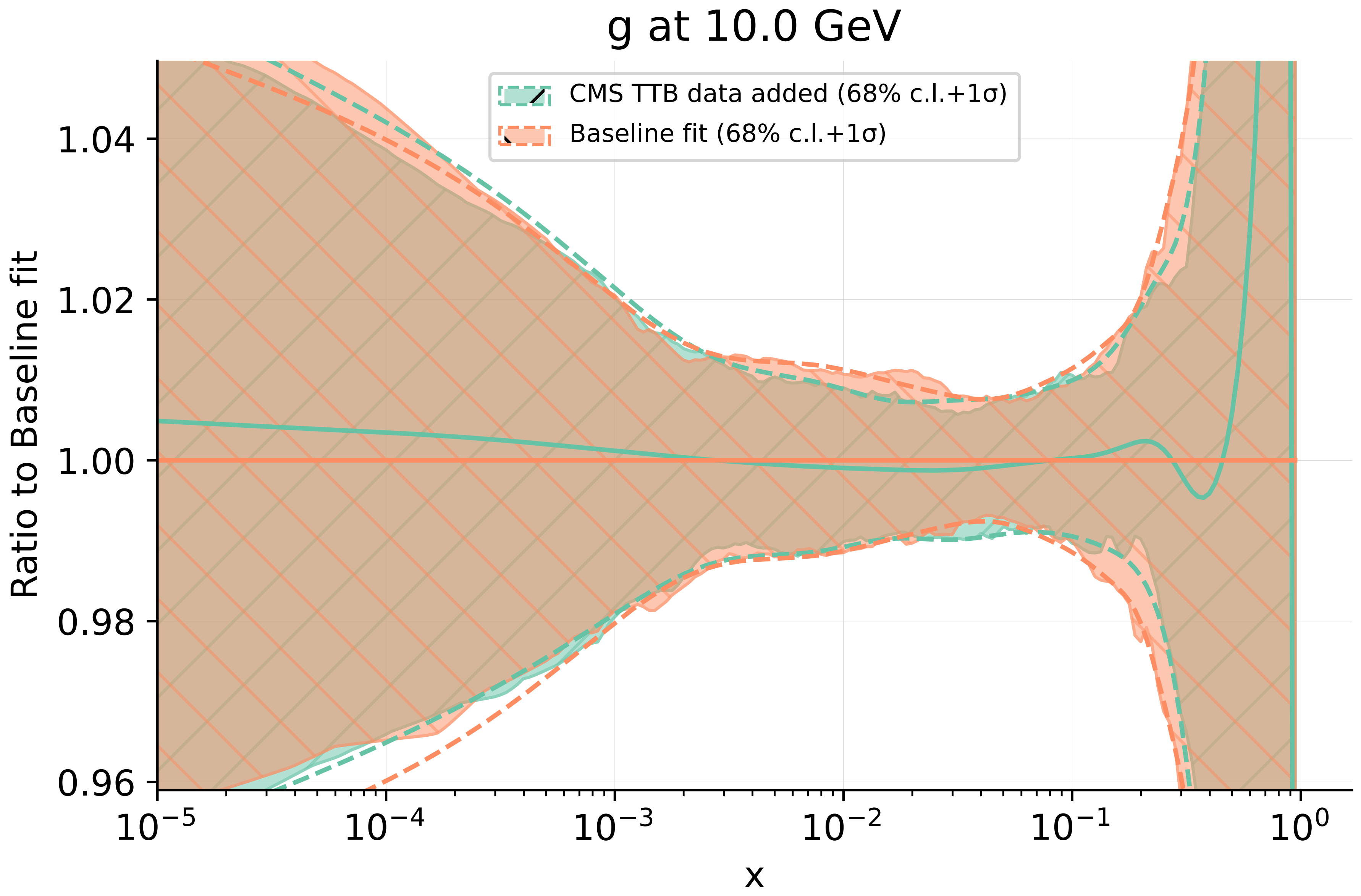


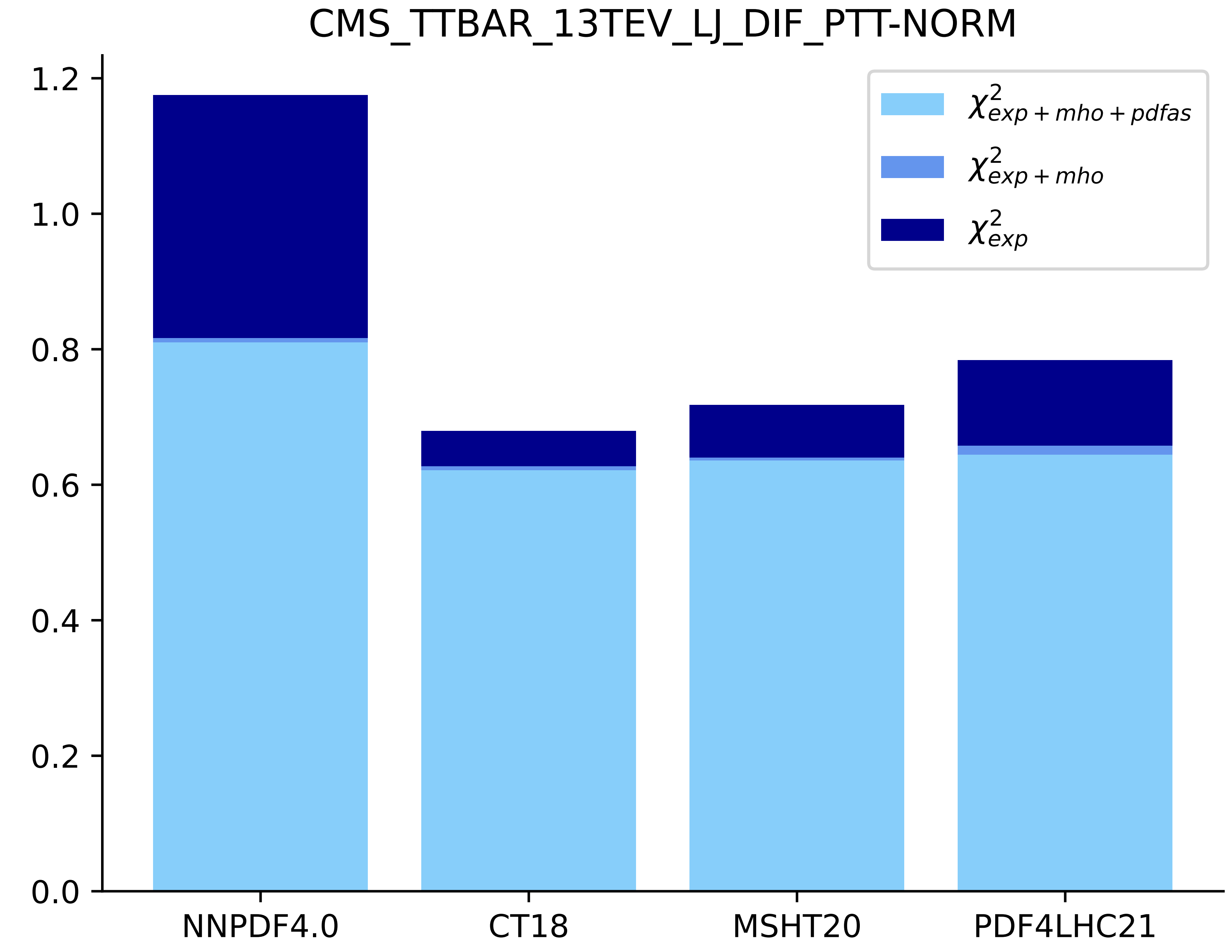


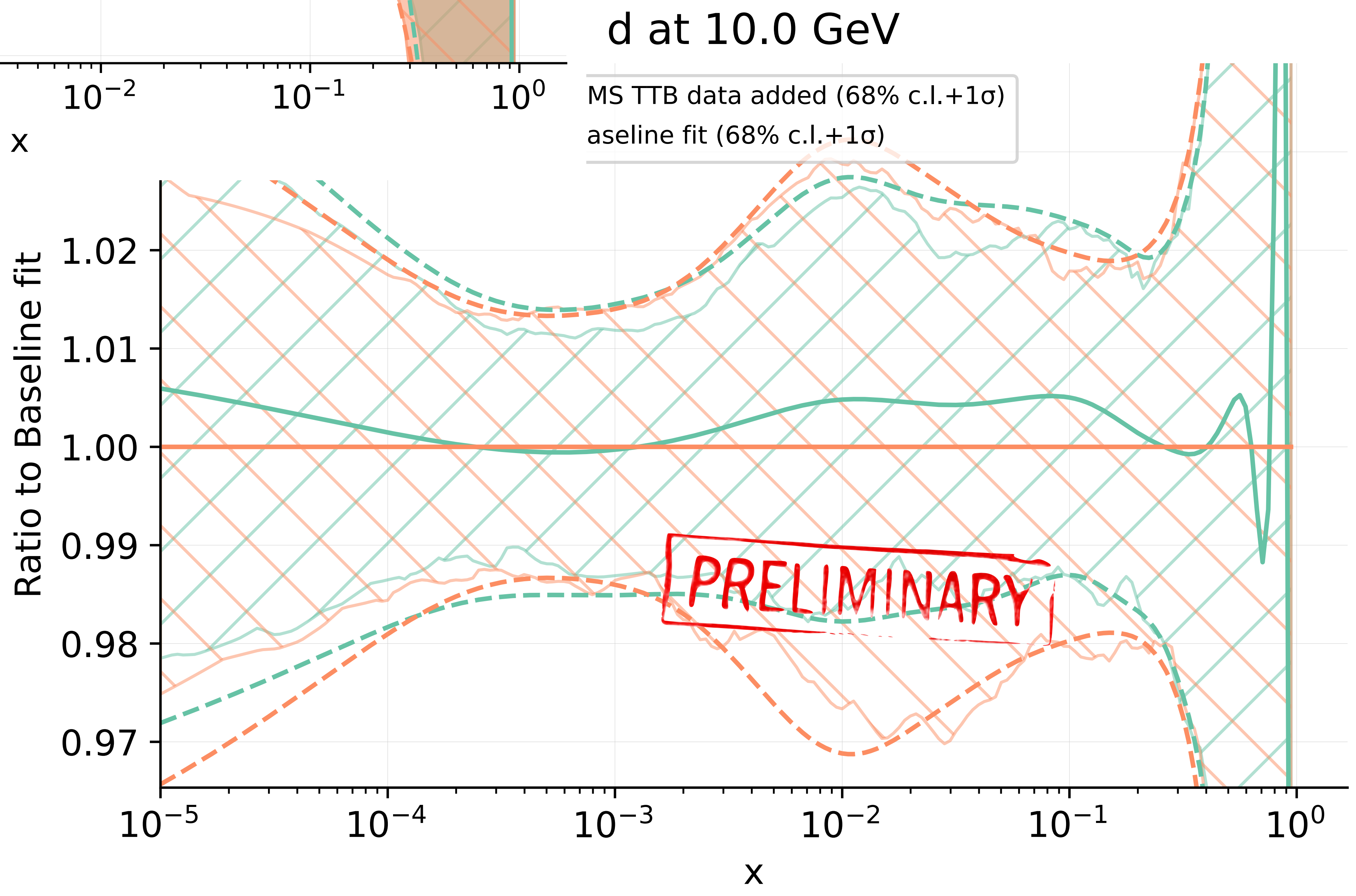


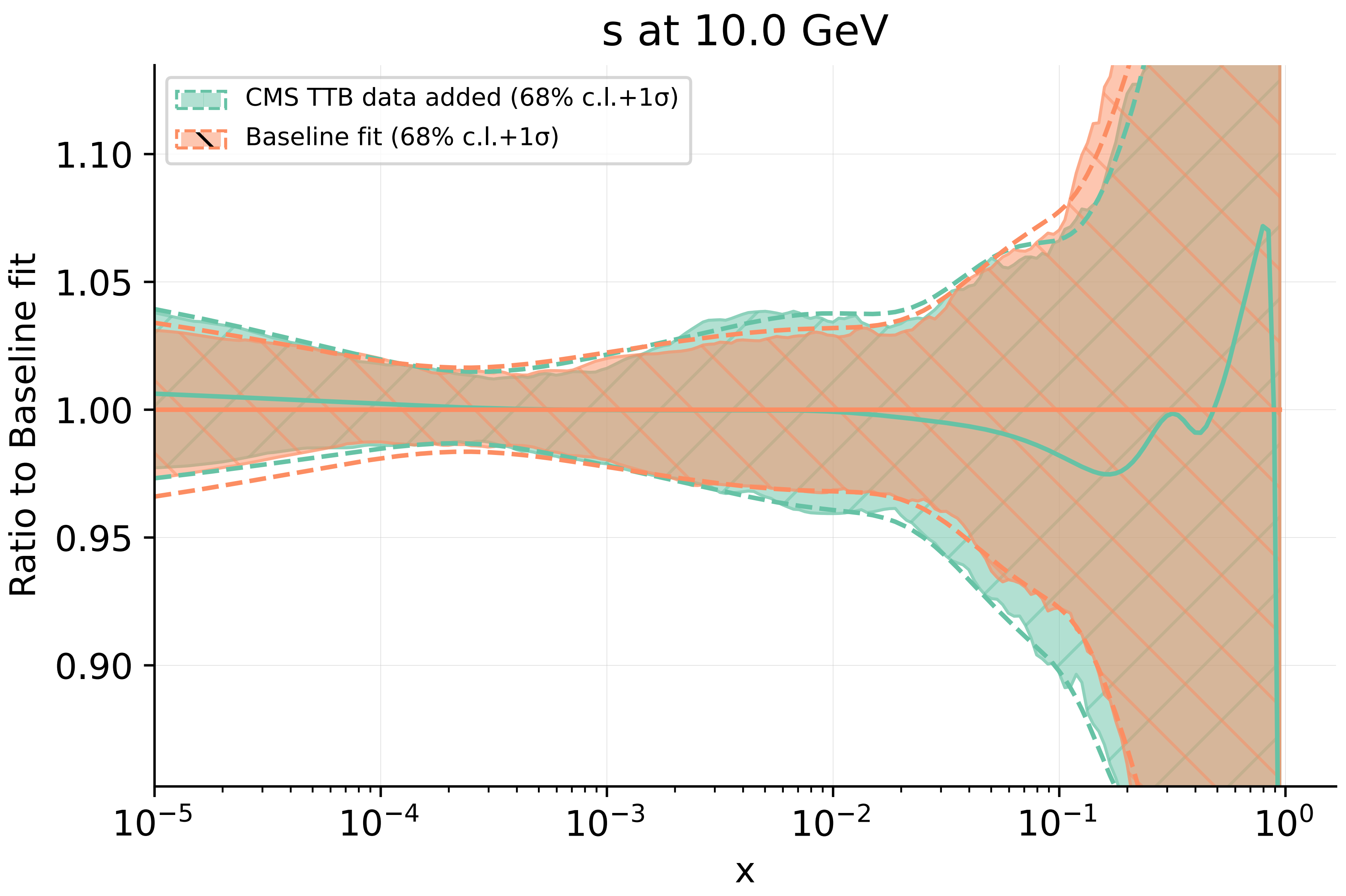
CMS TTB 13 TeV

From https://doi.org/10.17182/hepdata.102956 - 2108.02803 [hep-ex] about 15 points

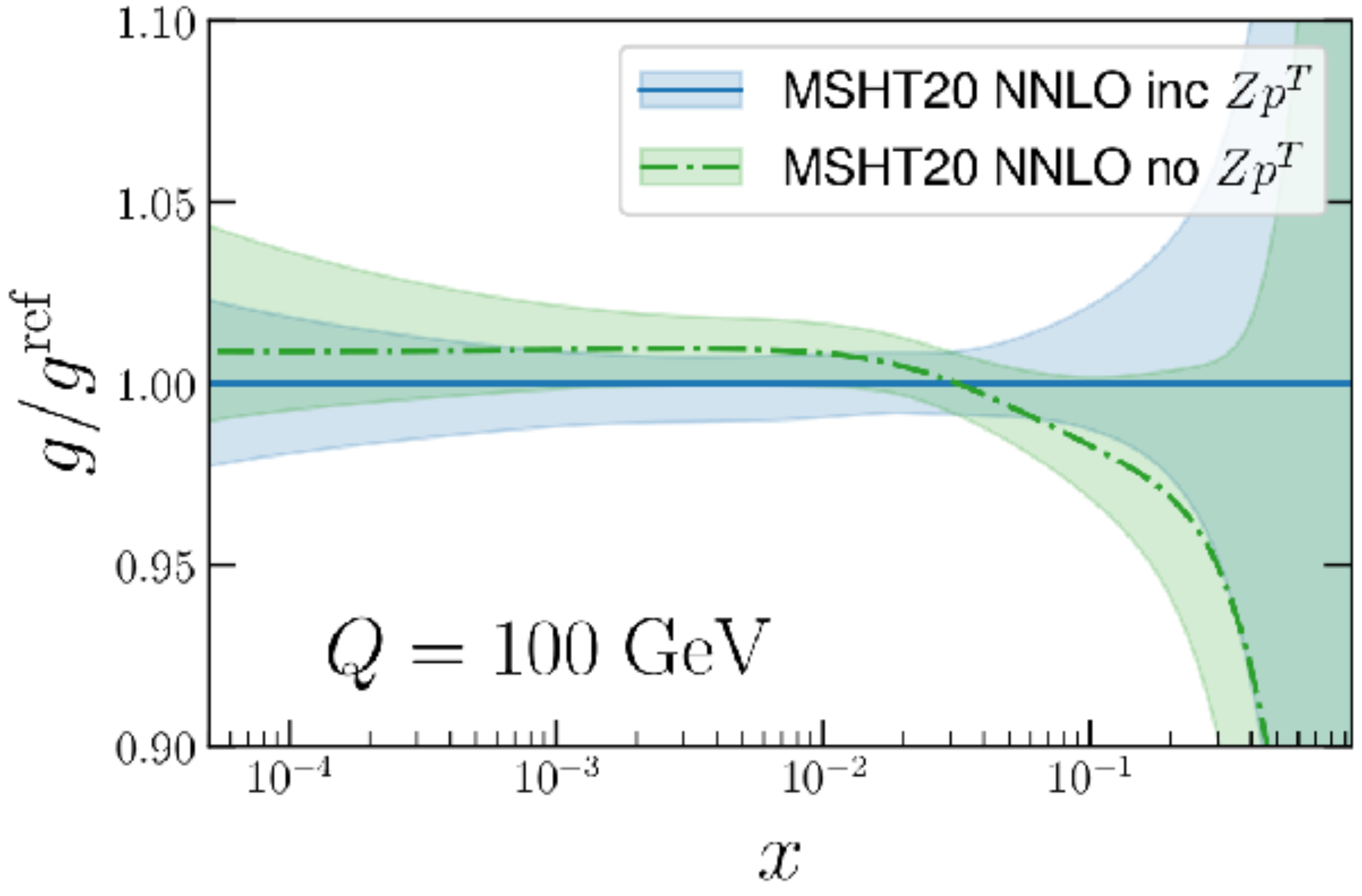




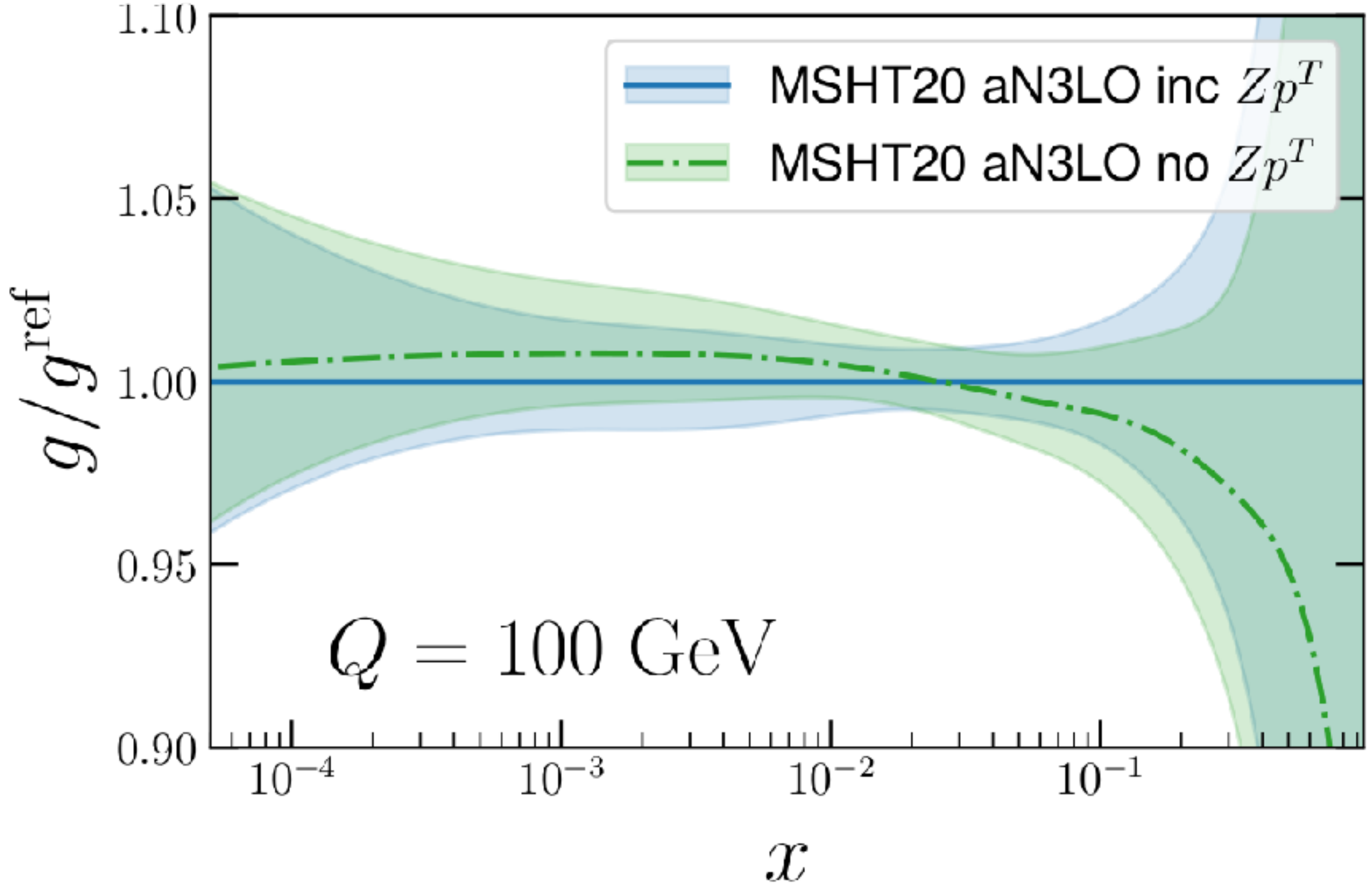


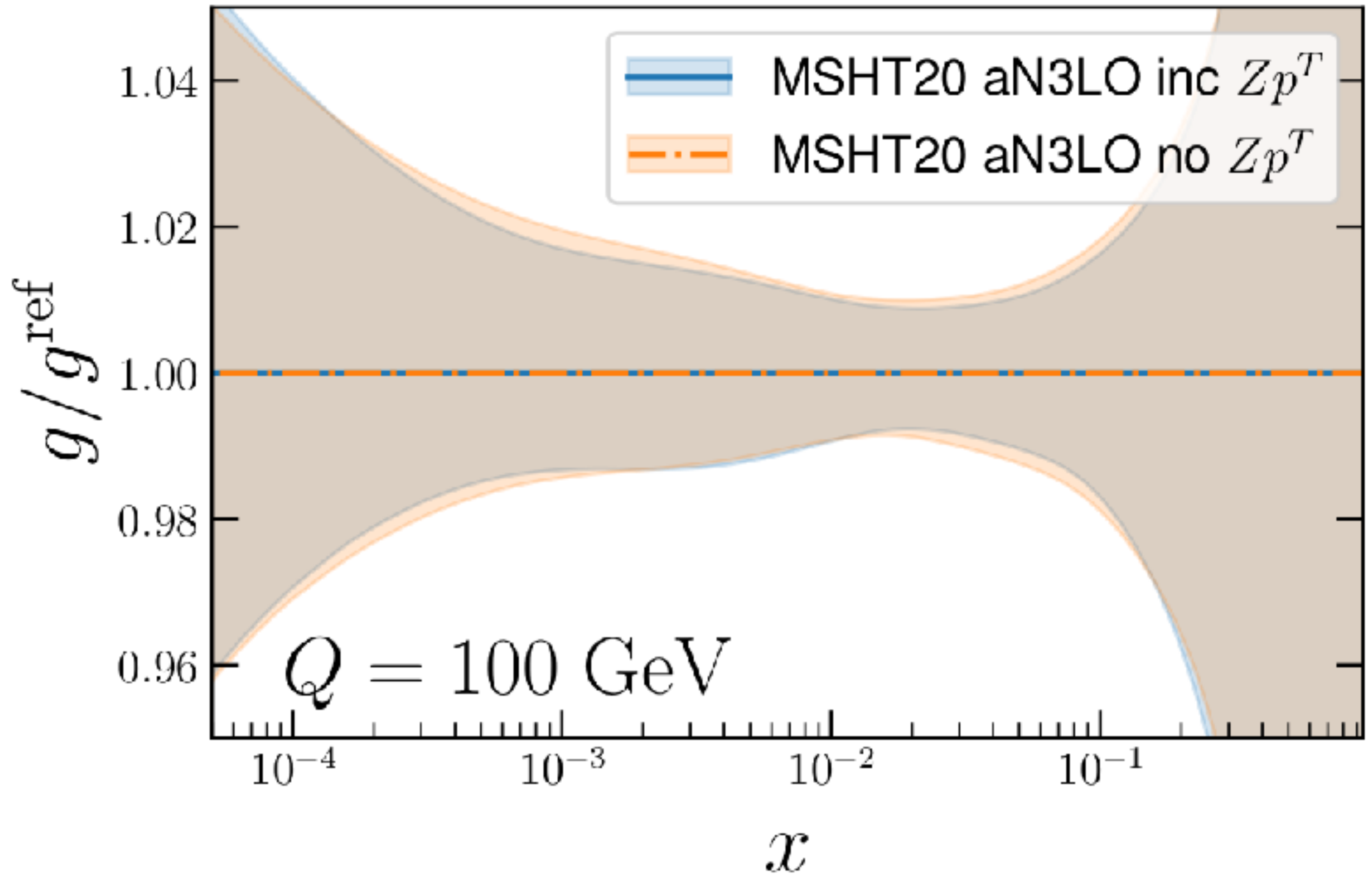


Impact of LHC Jet Data & Zp_t for aN3LO PDFs



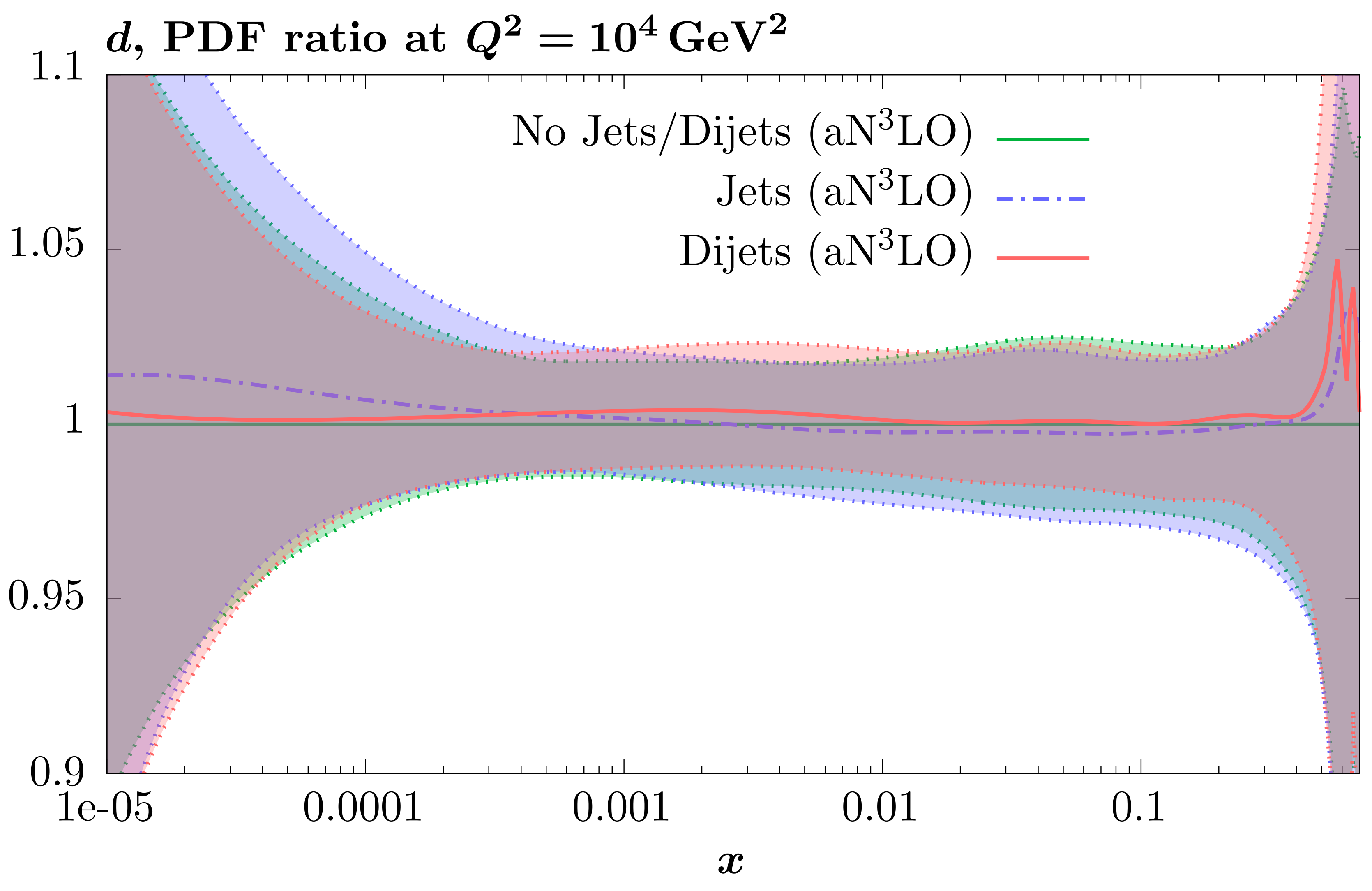
The Impact of LHC Jet and Z pT Data at up to Approximate N3LO Order in the MSHT Global PDF Fit [hep-ph] 2312.12505
T. Cridge, L.A. Harland-Lang, R. S. Thorne

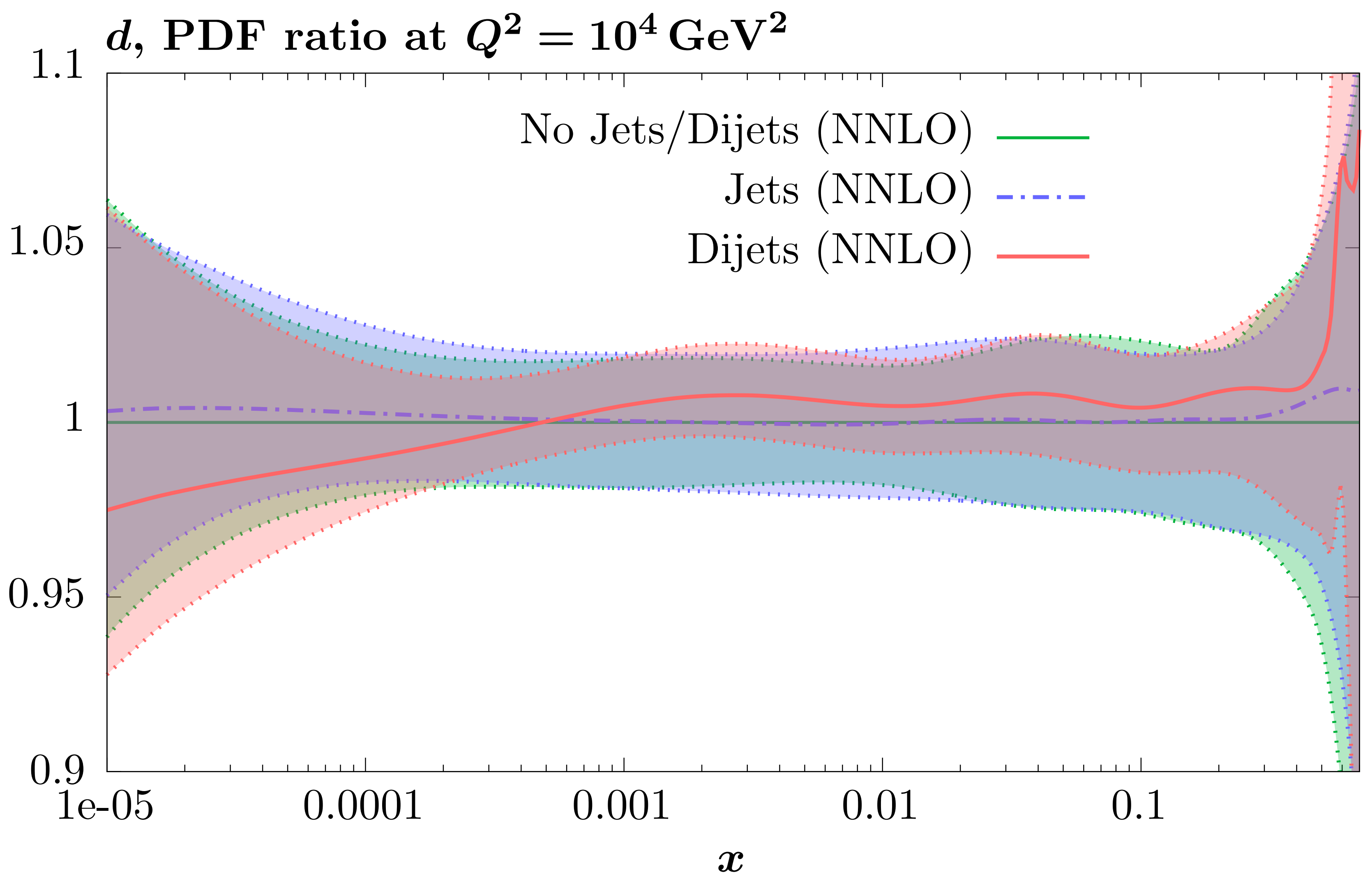


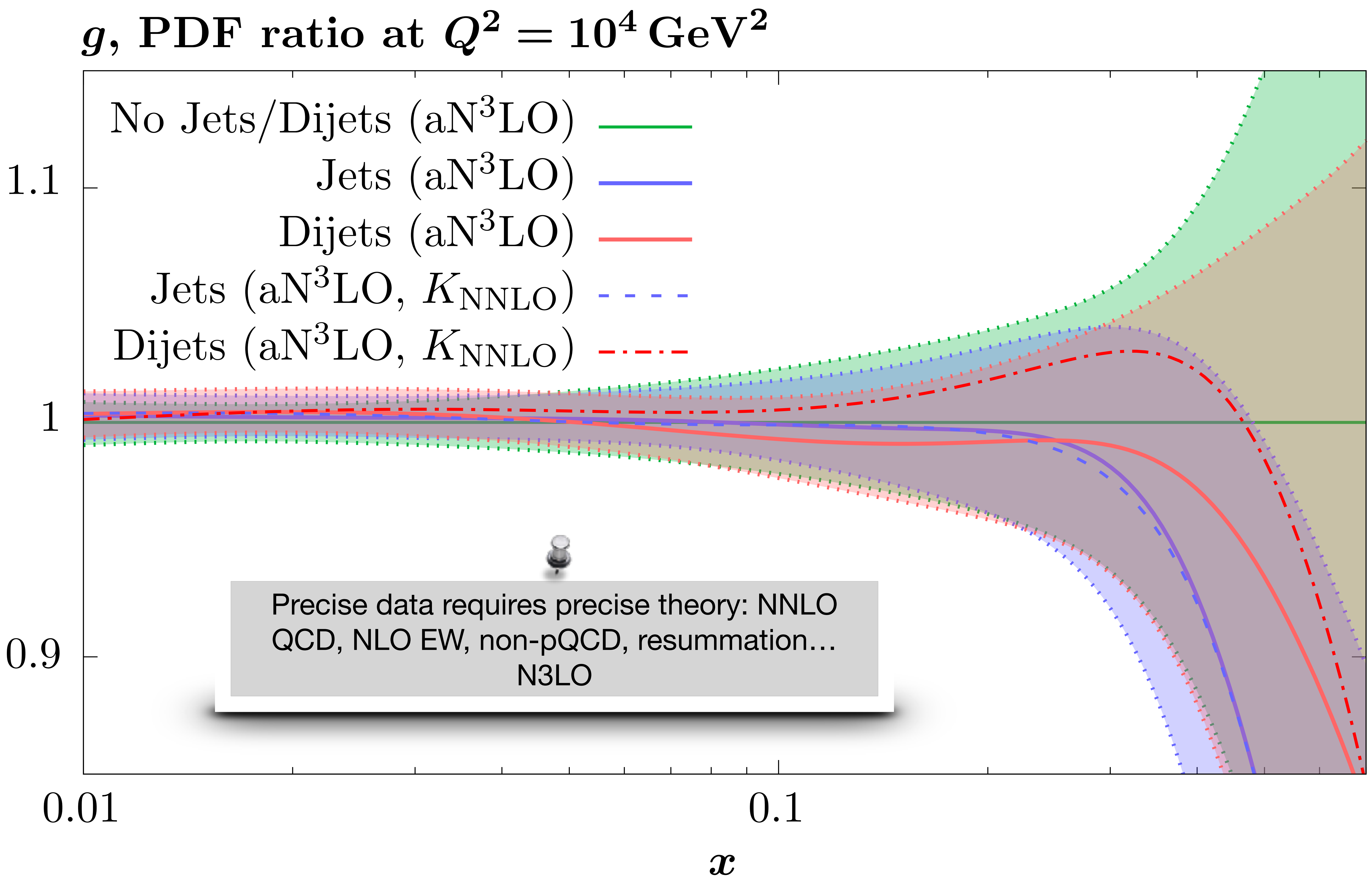


Impact of LHC Jet Data & Zp_t for aN3LO PDFs

The Impact of LHC Jet and Z pT Data at up to Approximate N3LO Order in the MSHT Global PDF Fit [hep-ph] 2312.12505
T. Cridge, L.A. Harland-Lang, R. S. Thorne



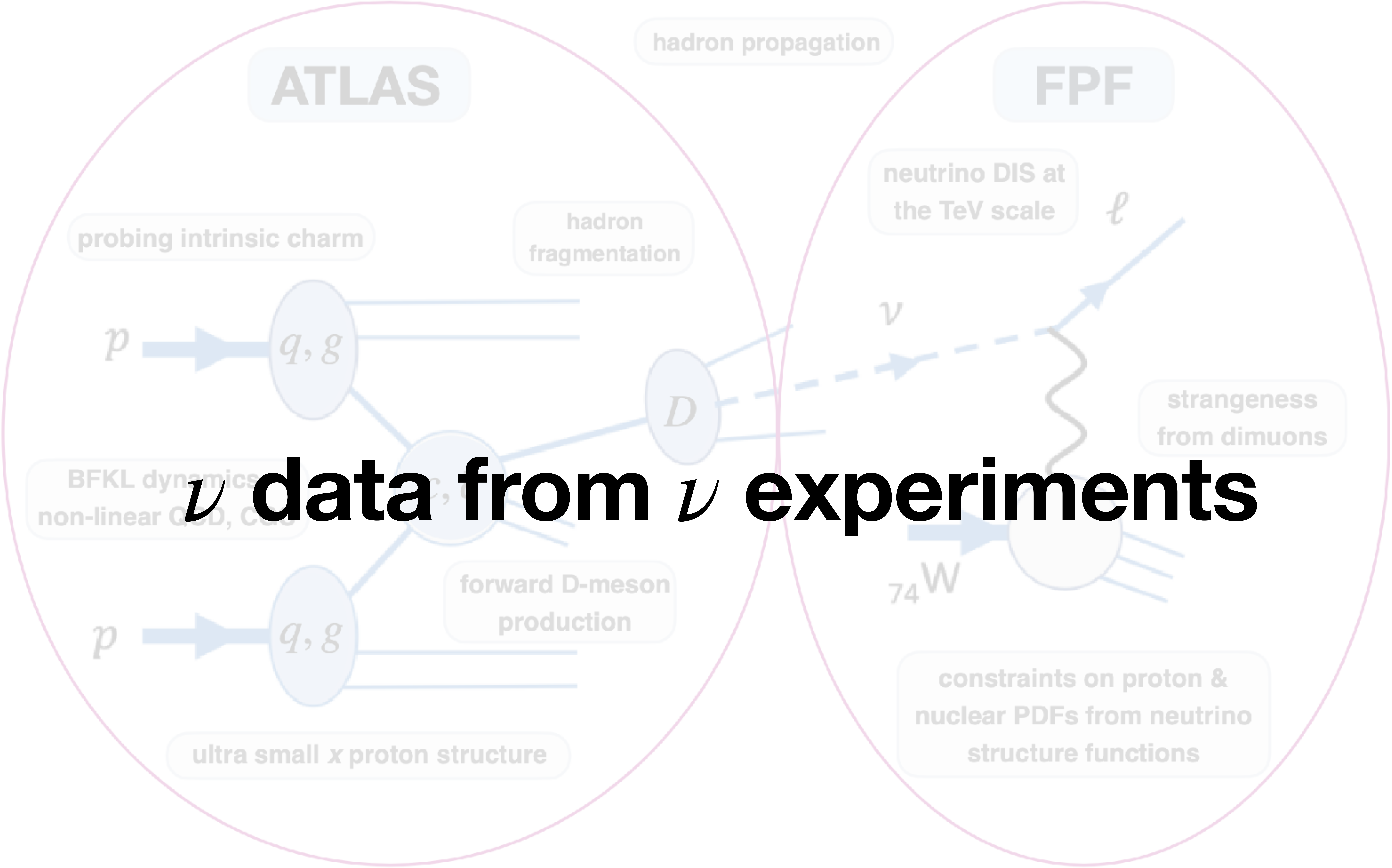




Precise data requires precise theory: NNLO QCD, NLO EW, non-pQCD, resummation… N3LO

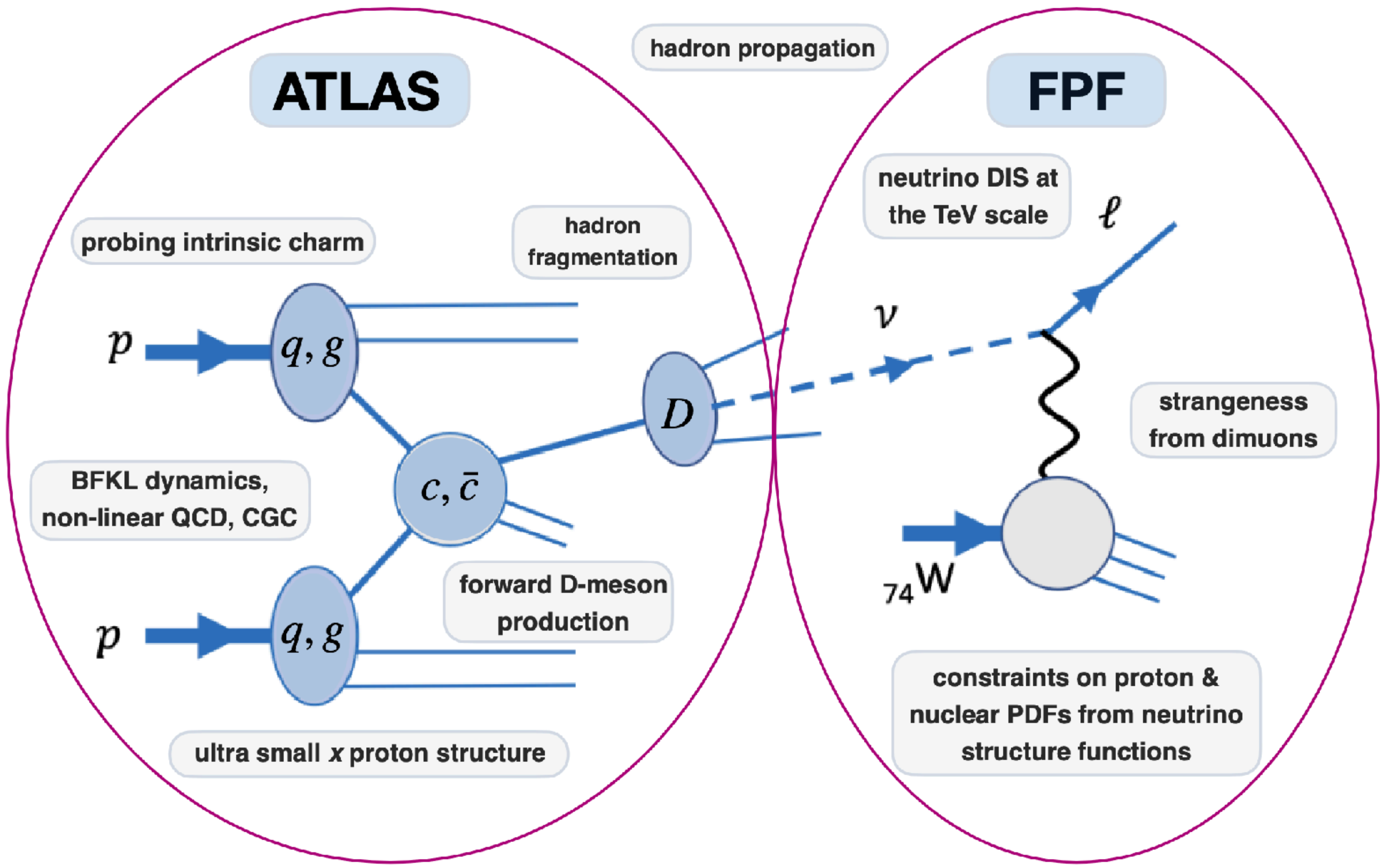
New data from new experiments

ν data from ν experiments



The effect of ν data: Neutrino DIS in the far-forward regions

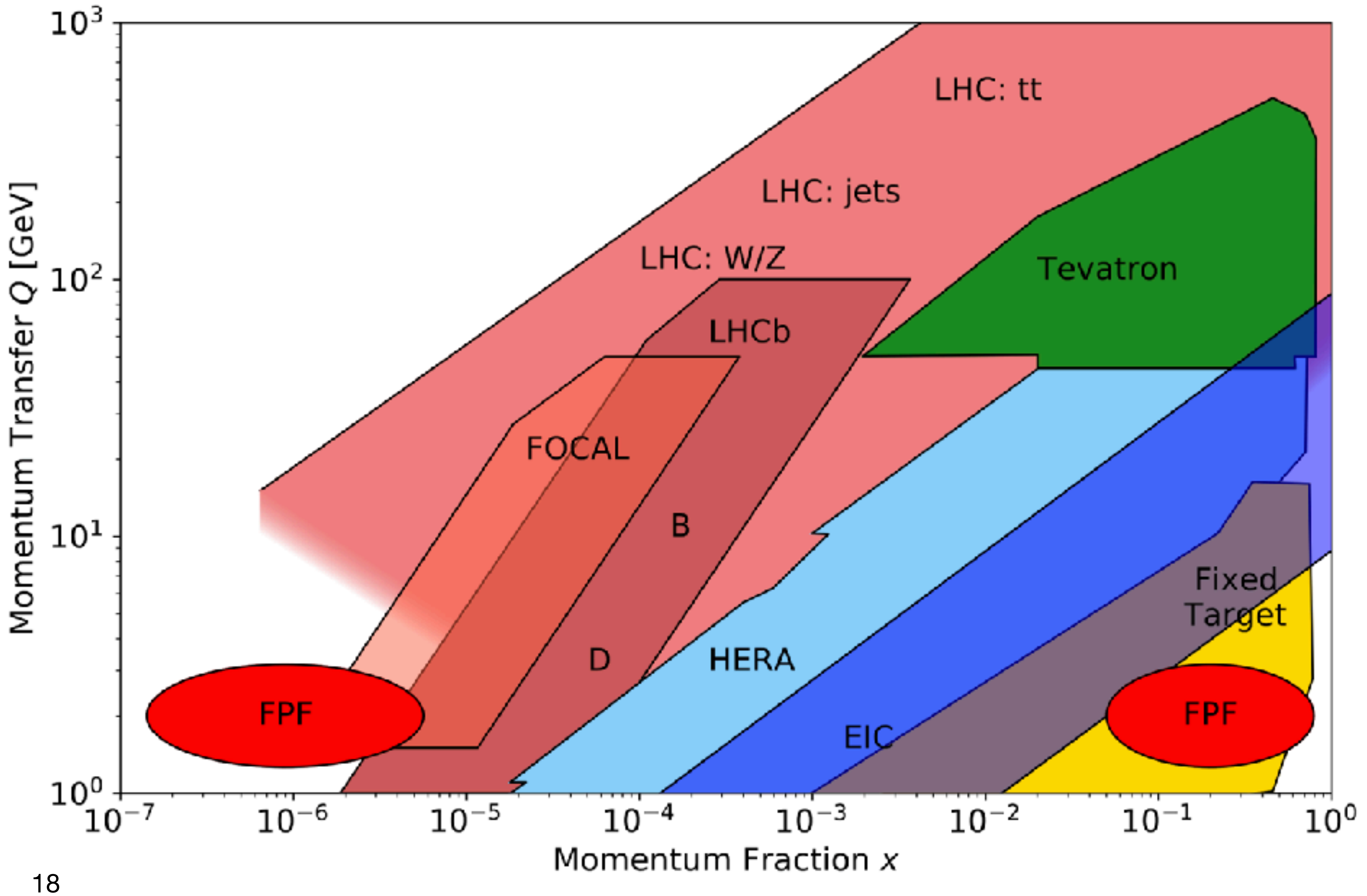
Following slides from T. Rabemananjara talk at Low-x 2023 [link]



Hadron Substructure & QCD

- Explore **kinematic regions unavailable** to current and planned experiments
- Constrain PDFs via both NC and CC DIS neutrino scattering
- Improve determination of **D-meson Fragmentation**

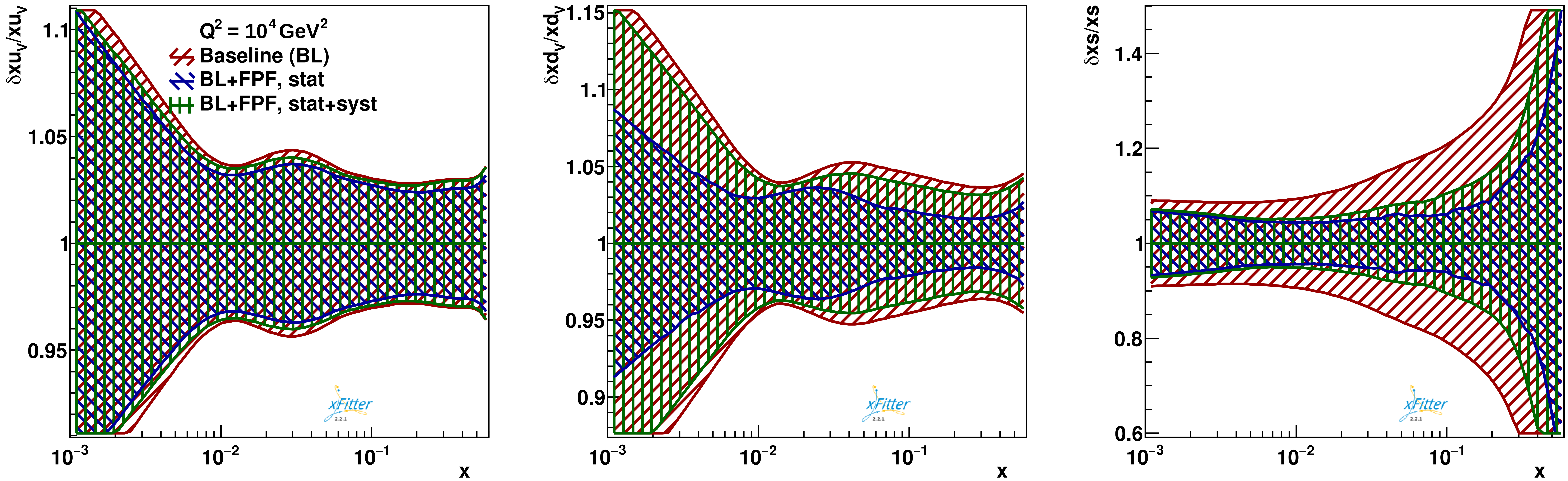
Let's focus on the effect that measurements of the DIS neutrino structure functions might have on PDFs, with results using methodologies from both xFitter and NNPDF.



The LHC as a Neutrino-Ion Collider [hep-ph] 2309.09581
JCM, M. Fieg, T. Giani, P. Krack, T. Mäkelä, T. Rabemananjara, J. Rojo

Impacts on Proton PDFs

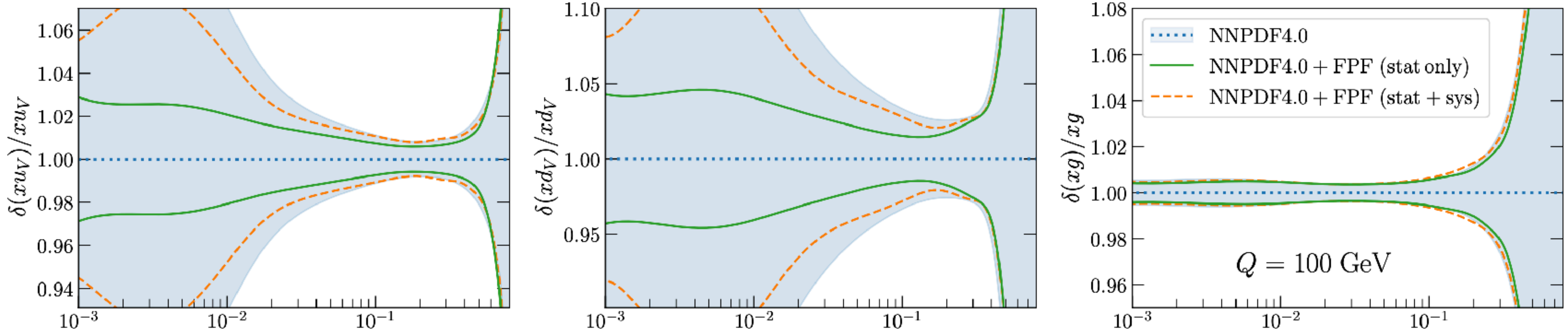
Using the profiling method applied to Hessian PDFs using the xFitter framework.

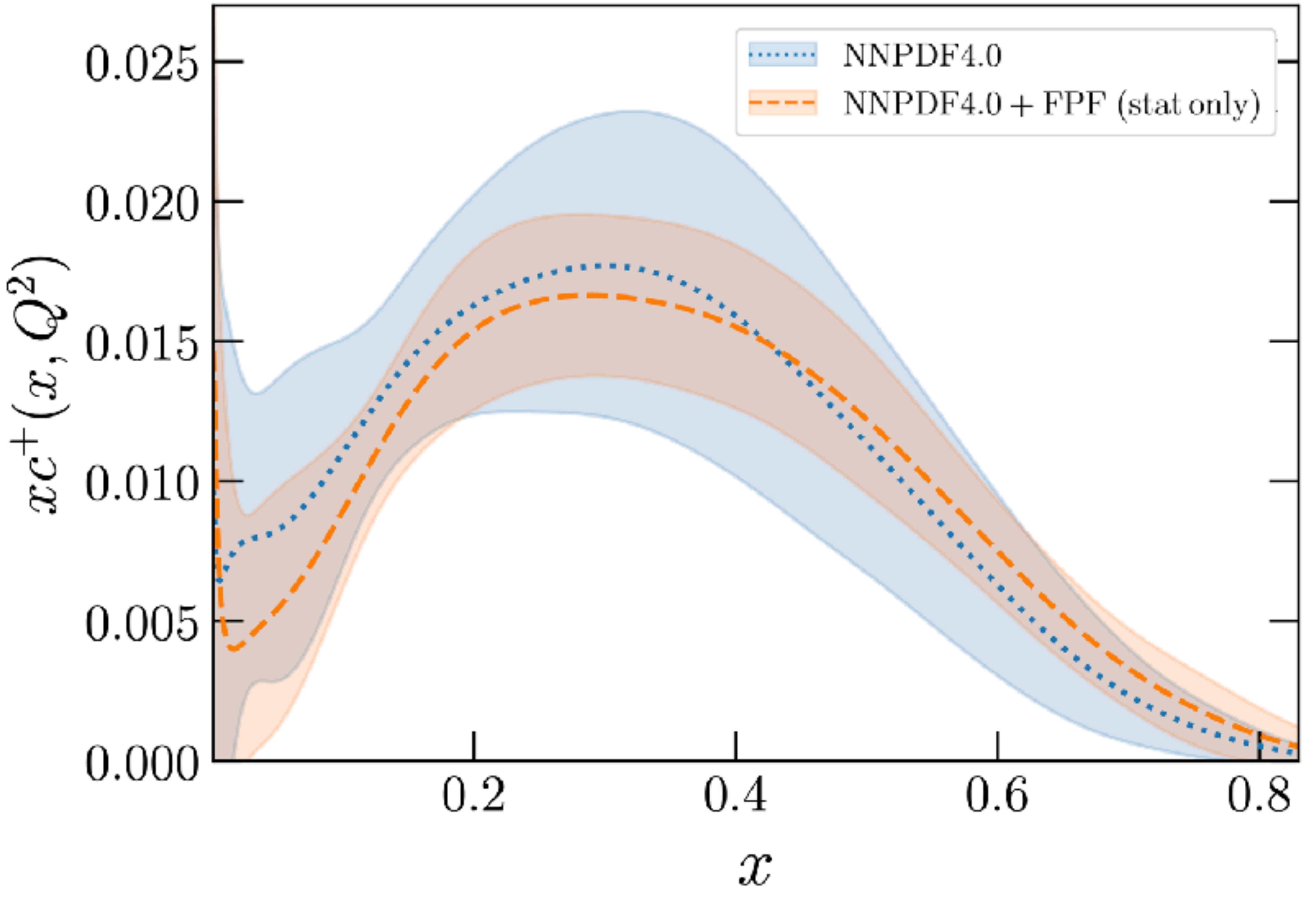


- Strong impacts on the up & down valence quarks and strangeness
- For a rather conservative estimate of the Systematic, Systematic Uncertainties present some limitations
- PDF determination improve with LHC neutrino enhance HL-LHC measurements (W mass, etc.)

The LHC as a Neutrino-Ion Collider [hep-ph] 2309.09581
JCM, M. Fieg, T. Giani, P. Krack, T. Mäkelä, T. Rabemananjara, J. Rojo

Impacts on Proton PDFs

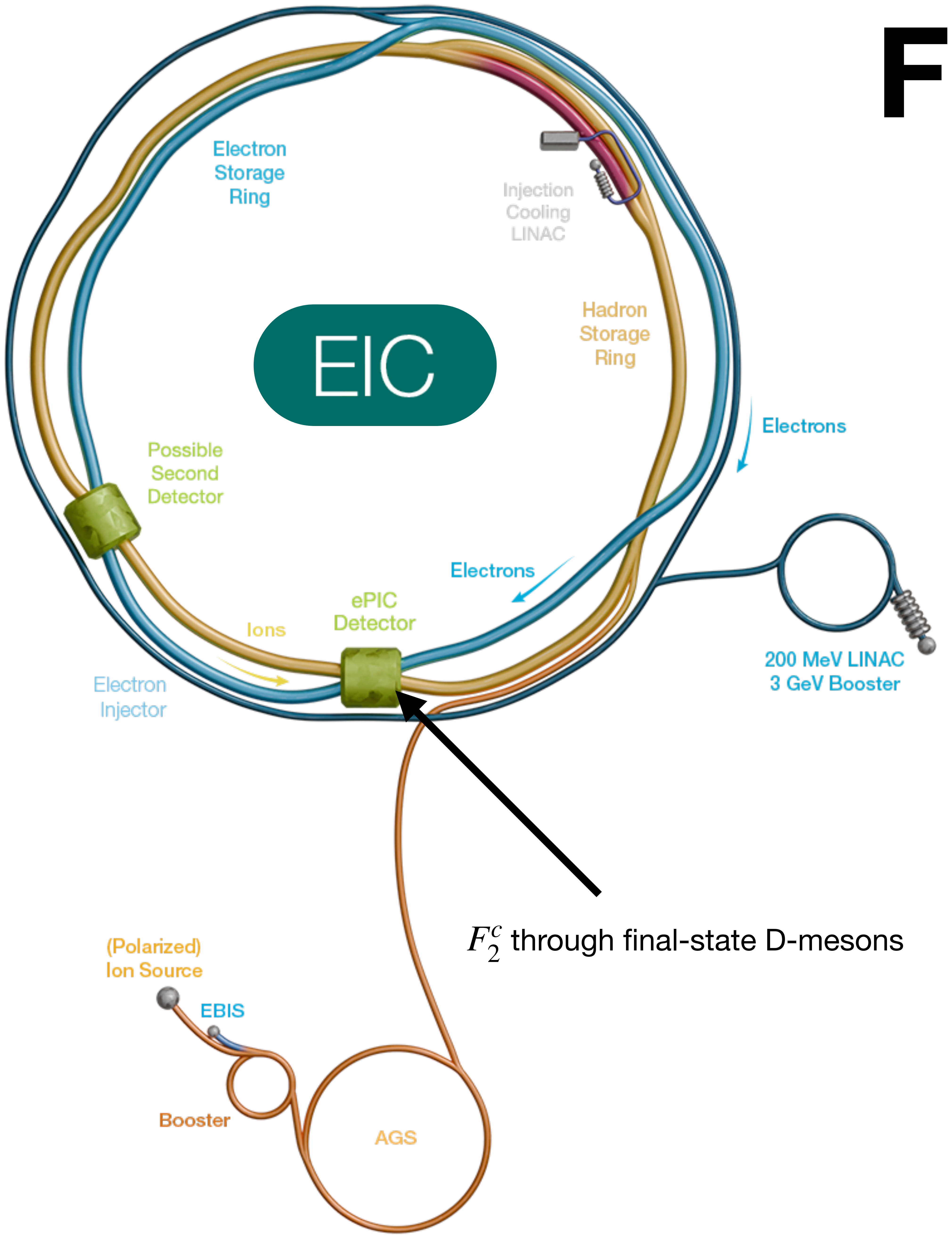




- Negligible impact on the gluon distribution (even when only accounting for statistical errors)
- Provides more information on large-x charm PDF!! An intrinsically interesting result ;)

The LHC as a Neutrino-Ion Collider [hep-ph] 2309.09581
JCM, M. Fieg, T. Giani, P. Krack, T. Mäkelä, T. Rabemananjara, J. Rojo

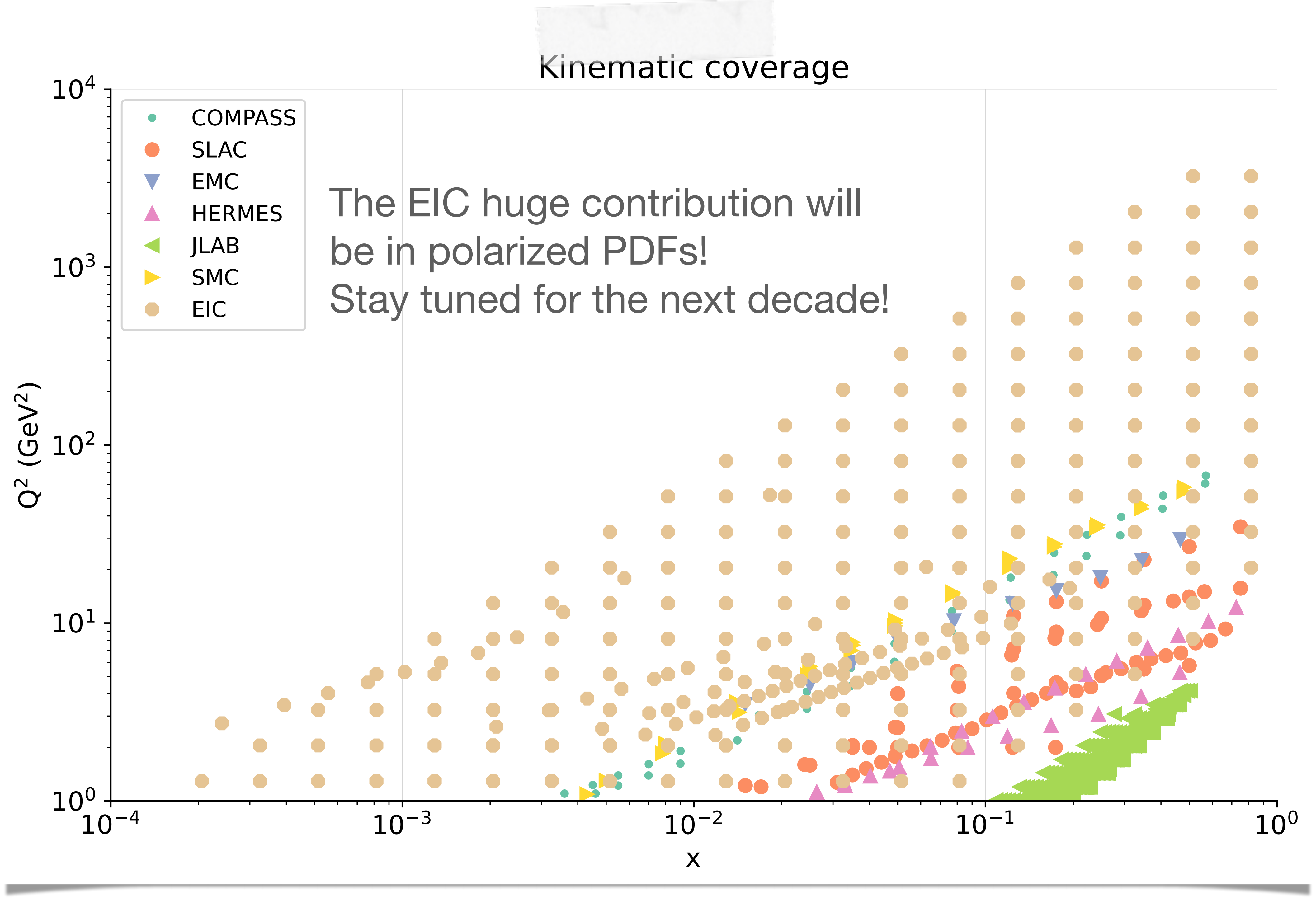
From EIC:



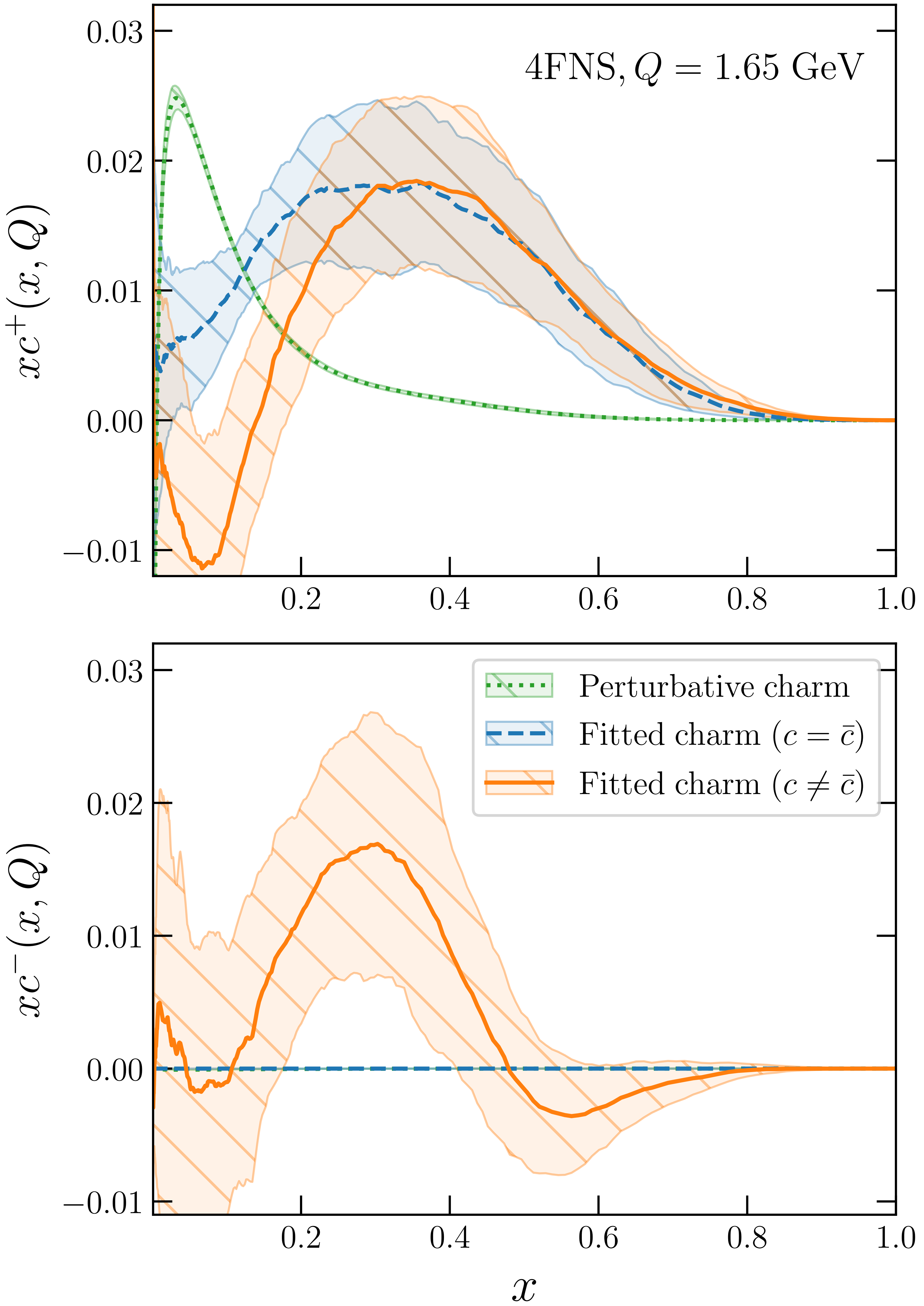
F_2^c through final-state D-mesons

Experimental probes for a charm-anticharm asymmetry!

- Flavour-tagged structure functions
- Global impact

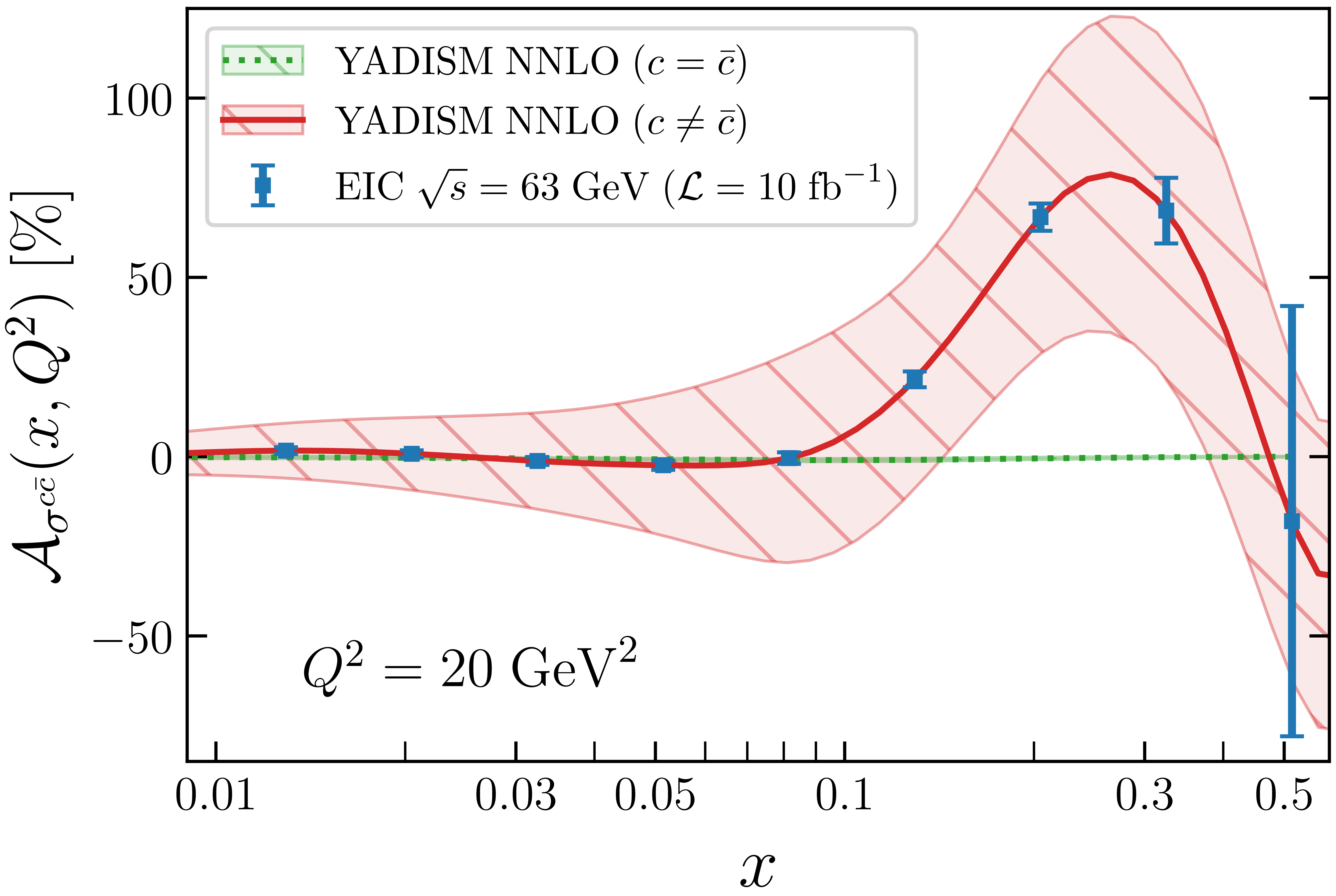


Intrinsic* charm asymmetry in the EIC



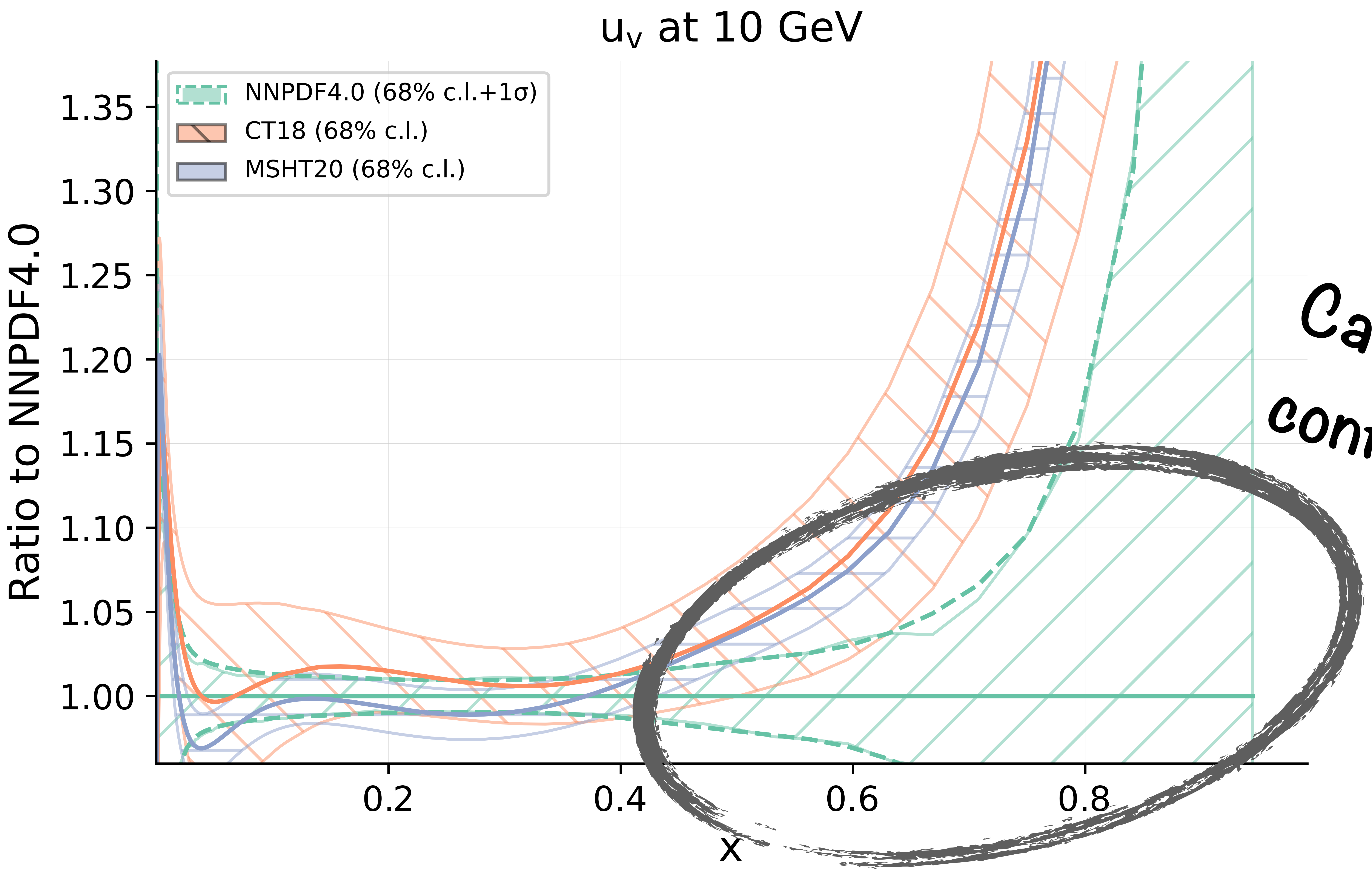
through favour-tagged structure functions

Intrinsic charm quark valence distribution of the proton [hep-ph] 2311.00743
R. Ball, A. Candido, JCM, S. Forte, T. Giani, F. Hekhorn, G. Magni, E. Nocera, J. Rojo, R. Stegeman



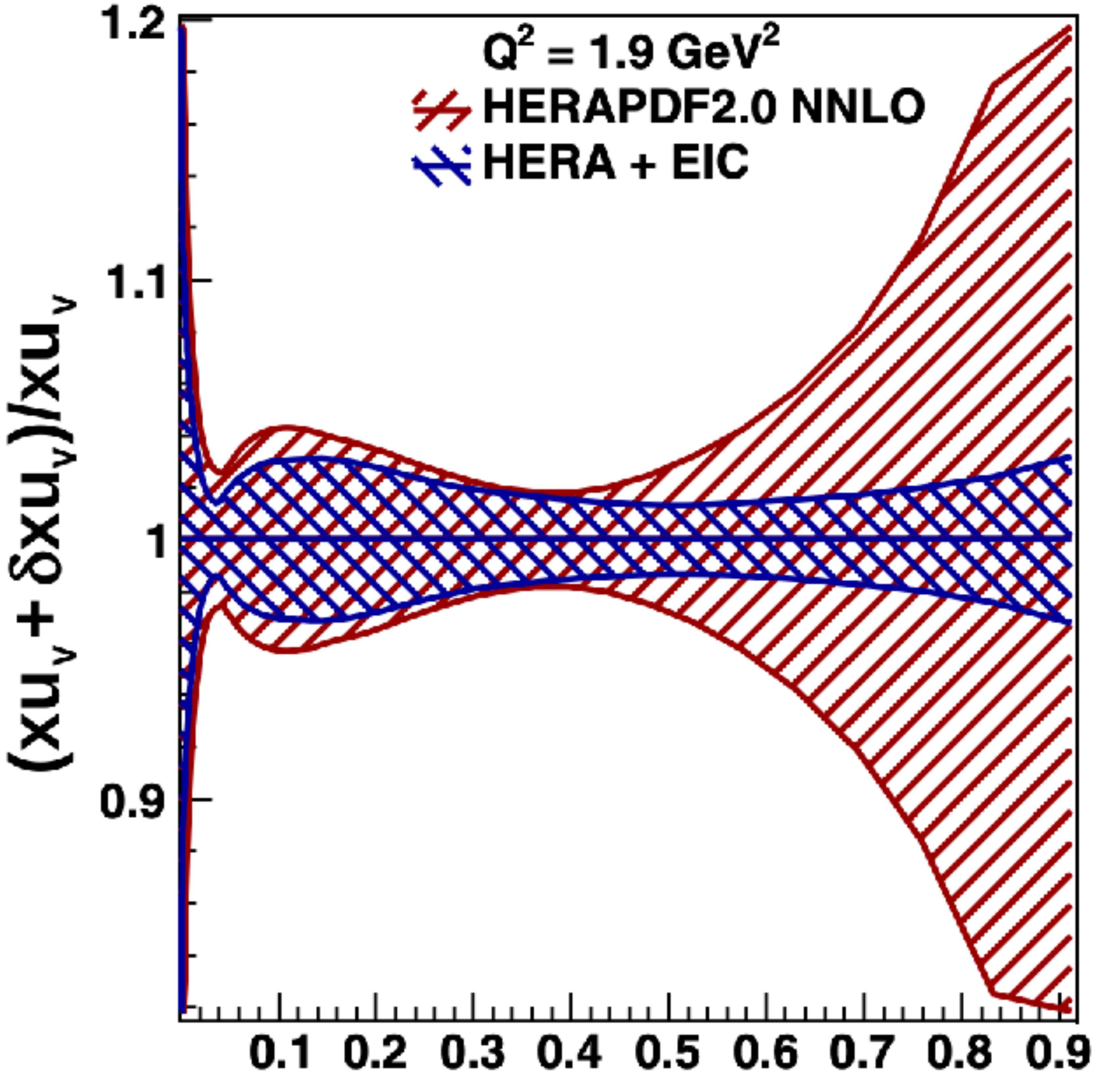
*i.e., whatever is left after the removal of the contribution coming from DGLAP

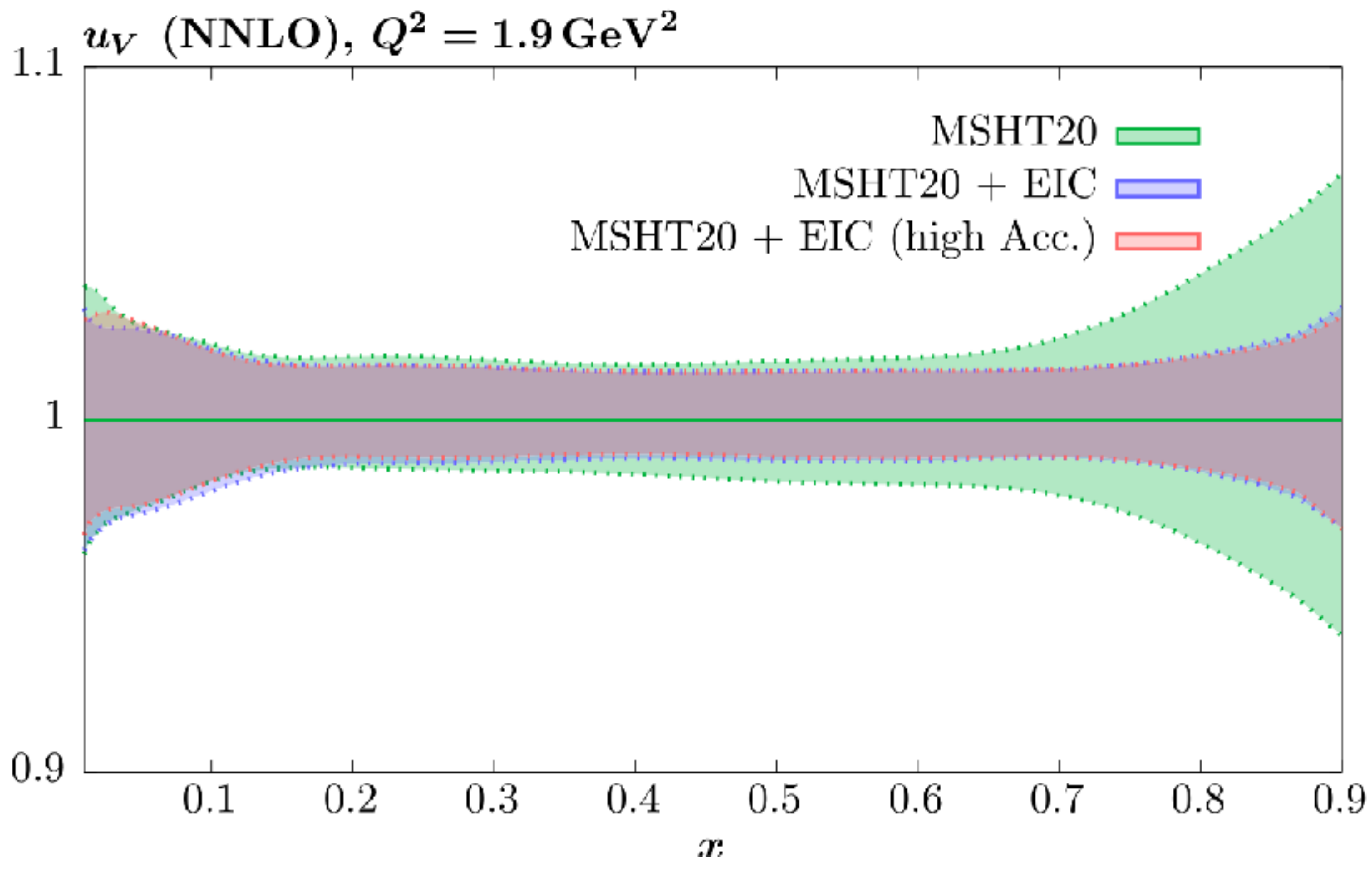
And what about the large x region?

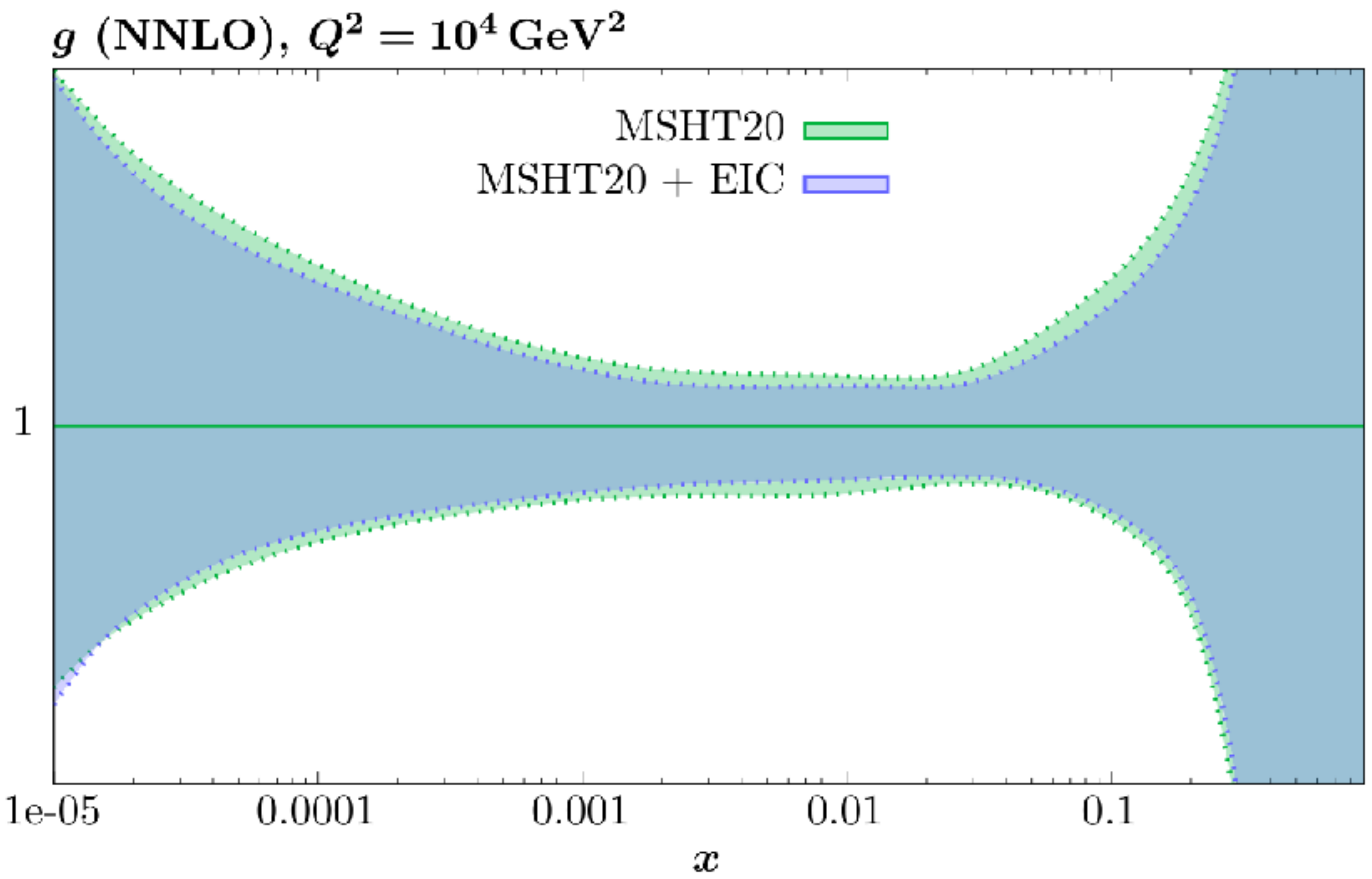


Can we get it under control?

Impact of EIC in global fits







Impact of inclusive electron ion collider data on collinear parton distributions
[hep-ph] 2309.11269
N. Armesto, T. Cridge, F. Giuli, L. Harland-Lang, P. Newman, B. Schmookler, R. Thorne, K. Wichmann

Conclusions

- ☑ The time between Run III and HL-LHC will be amazing and exciting in the PDF world.
- ☑ A lot to learn still from the LHC data that we already have.
- ☑ New experiments open new horizons, new regions
  - Far-forward detectors: coverage of very large and very small x
  - Electron-Iion Collider: BSM-safe data that can constrain a BSM-rich region!

Thanks!

Backup

Data set	NNPDF3.1	NNPDF4.0	ABMP16	CT18	MSHT20
CMS W asym. 7 TeV ($\mathcal{L} = 36$ pb^{-1})	✗	✗	✗	✗	✓
CMS Z 7 TeV ($\mathcal{L} = 36$ pb^{-1})	✗	✗	✗	✗	✓
CMS W electron asymmetry 7 TeV	✓	✓	✗	✓	✓
CMS W muon asymmetry 7 TeV	✓	✓	✓	✓	✗
CMS Drell-Yan 2D 7 TeV	✓	✓	✗	(✓)	✓
CMS Drell-Yan 2D 8 TeV	(✓)	✗	✗	✗	✗
CMS W rapidity 8 TeV	✓	✓	✓	✓	✓
CMS W, Z p_T 8 TeV ($\mathcal{L} = 18.4$ fb^{-1})	✗	✗	✗	(✓)	✗
CMS Z p_T 8 TeV	✓	✓	✗	(✓)	✗
CMS $W + c$ 7 TeV	✓	✓	✗	(✓)	✓
CMS $W + c$ 13 TeV	✗	✓	✗	✗	(✓)
CMS single-inclusive jets 2.76 TeV	✓	✗	✗	✗	✓
CMS single-inclusive jets 7 TeV	✓	(✓)	✗	✓	✓
CMS dijets 7 TeV	✗	✓	✗	✗	✗
CMS single-inclusive jets 8 TeV	✗	✓	✗	✓	✓
CMS 3D dijets 8 TeV	✗	(✓)	✗	✗	✗
CMS $\sigma_{tt}^{\rm tot}$ 5 TeV	✗	✓	✗	✗	✗
CMS $\sigma_{tt}^{\rm tot}$ 7, 8 TeV	✓	✓	✗	✗	✗
CMS $\sigma_{tt}^{\rm tot}$ 8 TeV	✗	✗	✗	✗	✓
CMS $\sigma_{tt}^{\rm tot}$ 5, 7, 8, 13 TeV	✗	✗	✓	✗	✗
CMS $\sigma_{tt}^{\rm tot}$ 13 TeV	✓	✓	✓	✗	✗
CMS $t\bar{t}$ lepton+jets 8 TeV	✓	✓	✗	✗	✓
CMS $t\bar{t}$ 2D dilepton 8 TeV	✗	✓	✗	✓	✓
CMS $t\bar{t}$ lepton+jet 13 TeV	✗	✓	✗	✗	✗
CMS $t\bar{t}$ dilepton 13 TeV	✗	✓	✗	✗	✗
CMS single top $\sigma_t + \sigma_{\bar{t}}$ 7 TeV	✗	✓	✓	✗	✗
CMS single top R_t 8, 13 TeV	✗	✓	✓	✗	✗
CMS single top 13 TeV	✗	✗	✗	✗	(✓)

Data set	NNPDF3.1	NNPDF4.0	ABMP16	CT18	MSHT20
ATLAS W, Z 7 TeV ($\mathcal{L} = 35$ pb^{-1})	✓	✓	✓	✓	✓
ATLAS W, Z 7 TeV ($\mathcal{L} = 4.6$ fb^{-1})	✓	✓	✗	(✓)	✓
ATLAS low-mass DY 7 TeV	✓	✓	✗	(✓)	✗
ATLAS high-mass DY 7 TeV	✓	✓	✗	(✓)	✓
ATLAS W 8 TeV	✗	(✓)	✗	✗	✓
ATLAS DY 2D 8 TeV	✗	✓	✗	✗	✓
ATLAS high-mass DY 2D 8 TeV	✗	✓	✗	(✓)	✓
ATLAS $\sigma_{W,Z}$ 13 TeV	✗	✓	✓	✗	✗
ATLAS W+jet 8 TeV	✗	✓	✗	✗	✓
ATLAS Z p_T 7 TeV	(✓)	✗	✗	(✓)	✗
ATLAS Z p_T 8 TeV	✓	✓	✗	✓	✓
ATLAS $W + c$ 7 TeV	✗	✓	✗	(✓)	✗
ATLAS $\sigma_{tt}^{\rm tot}$ 7, 8 TeV	✓	✓	✓	✗	✗
ATLAS $\sigma_{tt}^{\rm tot}$ 7, 8 TeV	✗	✗	✓	✗	✗
ATLAS $\sigma_{tt}^{\rm tot}$ 13 TeV ($\mathcal{L} = 3.2$ fb^{-1})	✓	✗	✓	✗	✗
ATLAS $\sigma_{tt}^{\rm tot}$ 13 TeV ($\mathcal{L} = 139$ fb^{-1})	✗	✓	✗	✗	✗
ATLAS $\sigma_{tt}^{\rm tot}$ and Z ratios	✗	✗	✗	✗	(✓)
ATLAS $t\bar{t}$ lepton+jets 8 TeV	✓	✓	✗	✓	✓
ATLAS $t\bar{t}$ dilepton 8 TeV	✗	✓	✗	✗	✓
ATLAS single-inclusive jets 7 TeV, R=0.6	✓	(✓)	✗	✓	✓
ATLAS single-inclusive jets 8 TeV, R=0.6	✗	✓	✗	✗	✗
ATLAS dijets 7 TeV, R=0.6	✗	✓	✗	✗	✗
ATLAS direct photon production 8 TeV	✗	(✓)	✗	✗	✗
ATLAS direct photon production 13 TeV	✗	✓	✗	✗	✗
ATLAS single top R_t 7, 8, 13 TeV	✗	✓	✓	✗	✗
ATLAS single top diff. 7 TeV	✗	✓	✗	✗	✗
ATLAS single top diff. 8 TeV	✗	✓	✗	✗	✗

Data set	NNPDF3.1	NNPDF4.0	ABMP16	CT18	MSHT20
CDF Z rapidity	✓	✓	✗	✓	✓
CDF $W \to \ell\nu$ asymmetry (1.8 TeV)	✗	✗	✗	✓	✗
CDF $W \to e\nu$ asymmetry ($\mathcal{L} = 170$ pb^{-1})	✗	✗	✗	✓	✗
CDF $W \to e\nu$ asymmetry ($\mathcal{L} = 1$ fb^{-1})	✗	✗	✗	✗	✓
CDF k_t inclusive jets	✓	✗	✗	✗	✓
CDF cone-based inclusive jets	✗	✗	✗	✓	✗
D0 Z rapidity	✓	✓	✗	✓	✓
D0 $W \to e\nu$ asymmetry ($\mathcal{L} = 0.75$ fb^{-1})	✗	✗	✗	✗	✓
D0 $W \to e\nu$ (prod.) asymmetry ($\mathcal{L} = 9.7$ fb^{-1})	✗	✗	(✓)	✗	✓
D0 $W \to e\nu$ (prod. and decay) asymmetry ($\mathcal{L} = 9.7$ fb^{-1})	✓	(✓)	✓	✓	✗
D0 $W \to \mu\nu$ asymmetry ($\mathcal{L} = 0.3$ fb^{-1})	✗	✗	✗	✓	✗
D0 $W \to \mu\nu$ asymmetry ($\mathcal{L} = 7.3$ fb^{-1})	✓	✓	✓	✗	✓
D0 cone-based inclusive jets	✗	✗	✗	✓	✓
CDF and D0 top-pair production	✗	✗	(✓)	✗	✓
CDF and D0 single-top production	✗	✗	✓	✗	✗

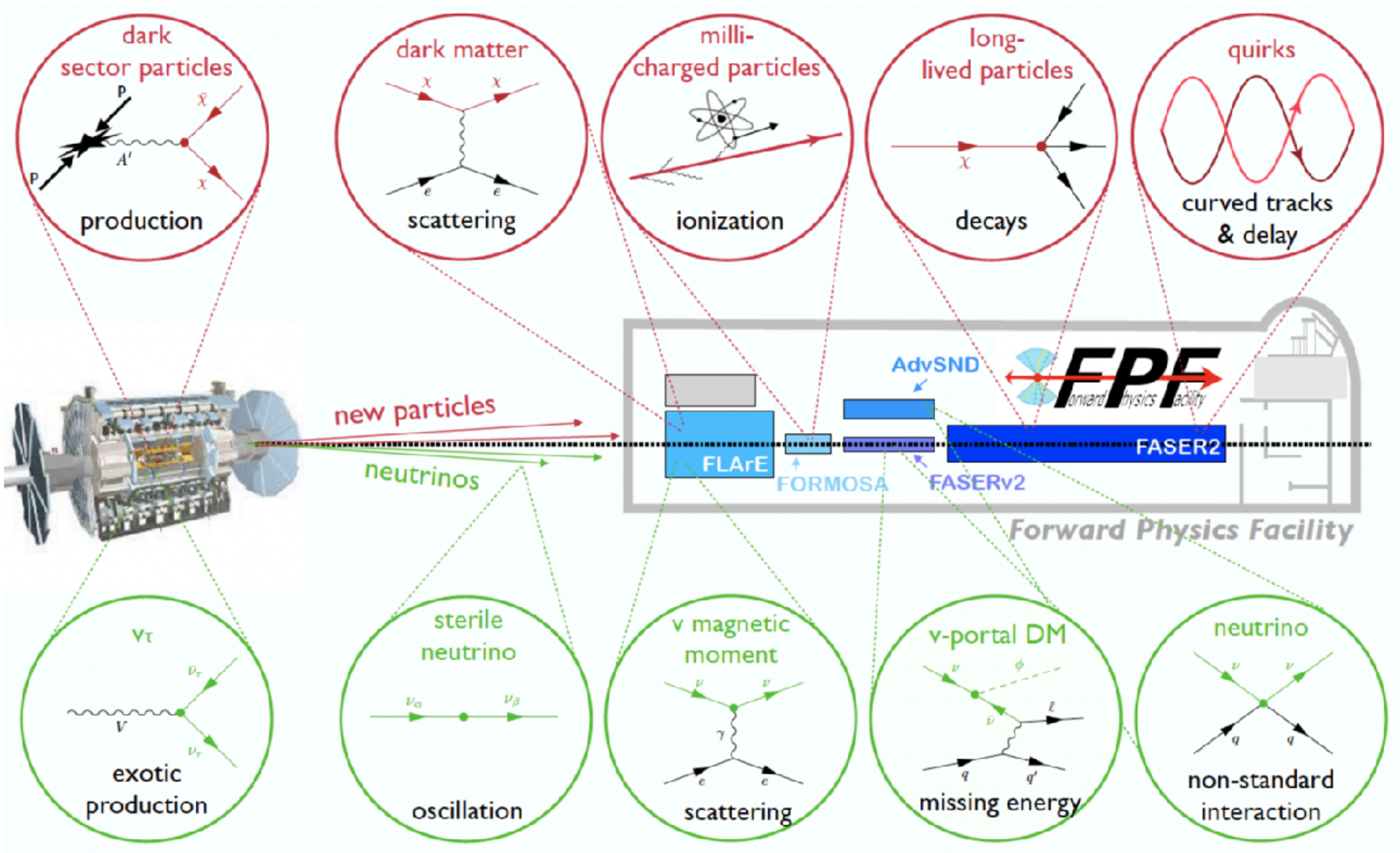
Data set	NNPDF3.1	NNPDF4.0	ABMP16	CT18	MSHT20
DY E866 $\sigma^d_{\rm DY}/\sigma^p_{\rm DY}$ (NuSea)	✓	✓	✓	✓	✓
DY E866 $\sigma^p_{\rm DY}$	✓	✓	✗	✓	✓
DY E605 $\sigma^p_{\rm DY}$	✓	✓	✓	✓	✗
DY E906 $\sigma^d_{\rm DY}/\sigma^p_{\rm DY}$ (SeaQuest)	✗	✓	✗	✗	✗

LHCb Z 7 TeV ($\mathcal{L} = 940$ pb^{-1})	✓	✓	✗	✗	✓
LHCb $Z \to ee$ 8 TeV ($\mathcal{L} = 2$ fb^{-1})	✓	✓	✓	✓	✓
LHCb W 7 TeV ($\mathcal{L} = 37$ pb^{-1})	✗	✗	✗	✗	✓
LHCb $W, Z \to \mu$ 7 TeV	✓	✓	✓	✓	✓
LHCb $W, Z \to \mu$ 8 TeV	✓	✓	✓	✓	✓
LHCb $W \to e$ 8 TeV	✗	(✓)	✗	✗	✗
LHCb $Z \to \mu\mu, ee$ 13 TeV	✗	✓	✗	✗	✗

Data set	NNPDF3.1	NNPDF4.0	ABMP16	CT18	MSHT20
NMC F_2^d/F_2^p	✓	✓	✗	✗	✓
NMC $\sigma^{{\rm NC},p}$	✓	✓	✗	✓	✓
SLAC F_2^p, F_2^d	✓	✓	✓	✗	✓
BCDMS F_2^p	✓	✓	✓	✓	✓
BCDMS F_2^d	✓	✓	✗	✓	✓
BCDMS, NMC, SLAC F	✗	✗	✗	✗	✓
CHORUS $\sigma^{\nu}_{CC}, \sigma^{\bar\nu}_{CC}$	✓	✓	✗	✗	✓
CHORUS	✗	✗	✓	✗	✗
NuTeV F_2, F_3	✗	✗	✗	✗	✓
NuTeV/CCFR $\sigma^{\nu}_{CC}, \sigma^{\bar\nu}_{CC}$	✓	✓	✓	✓	✓
EMC F_2^c	(✓)	(✓)	✗	✗	✗
NOMAD	✗	(✓)	✓	✗	✗
CCFR xF_3^p	✗	✗	✗	✓	✗
CCFR F_2^p	✗	✗	✗	✓	✗
CDSHW F_2^p, xF_3^p	✗	✗	✗	✓	✗
E665 F_2^p, F_2^d	✗	✗	✗	✗	✓
HERA NC, CC	✗	✗	✗	✗	✓
HERA I+II $\sigma^p_{\rm NC,CC}$	✓	✓	✓	✓	✗
HERA I+II $\sigma^{\rm red}_{c\bar c}$	✗	✓	✗	(✓)	✓
HERA I+II $\sigma^{\rm red}_{b\bar b}$	✗	✓	✗	(✓)	✗
HERA I+II $\sigma^{\rm red}_{c\bar c}$	✓	✗	✓	✓	✗
H1 $F_2^{c\bar c}$	✗	✗	✗	✓	✗
H1 $F_2^{b\bar b}$	✓	✗	✓	✗	✗
ZEUS $\sigma^{\rm red}_{b\bar b}$	✓	✗	✓	✗	✗
H1 $F_{\rm L}$	✗	✗	✗	✓	✓
H1 and ZEUS $F_{\rm L}$	✗	✗	✗	✗	✓
ZEUS 820 (HQ) (1j)	✗	(✓)	✗	✗	✗
ZEUS 920 (HQ) (1j)	✗	(✓)	✗	✗	✗
H1 (LQ) (1j-2j)	✗	(✓)	✗	✗	✗
H1 (HQ) (1j-2j)	✗	(✓)	✗	✗	✗
ZEUS 920 (HQ) (2j)	✗	(✓)	✗	✗	✗

FPF summary

Rich and Vast Beyond the Standard Model (BSM) scenarios can be studied at the FPF.



Experimental Acceptance & Performance for faser

Detector	Rapidity	Target	Charge ID	Acceptance	Performance
FASERν	$\eta_\nu \geq 8.5$	Tungsten (1.1 tonnes)	muons	$E_\ell, E_h \gtrsim 100$ GeV $\tan\theta_\ell \lesssim 0.025$ reco E_h & charm ID	$\delta E_\ell \sim 30\%$ $\delta\theta_\ell \sim 0.06$ mrad $\delta E_h \sim 30\%$
SND@LHC	$7.2 \leq \eta_\nu \leq 8.4$	Tungsten (0.83 tonnes)	n/a	$E_\ell, E_h \gtrsim 20$ GeV $\theta_\mu \lesssim 0.15, \theta_e \lesssim 0.5$	n/a
FASERν2	$\eta_\nu \geq 8.5$	Tungsten (20 tonnes)	muons	$E_\ell, E_h \gtrsim 100$ GeV $\tan\theta_\ell \lesssim 0.05$ reco E_h & charm ID	$\delta E_\ell \sim 30\%$ $\delta\theta_\ell \sim 0.06$ mrad $\delta E_h \sim 30\%$
AdvSND-far	$7.2 \leq \eta_\nu \leq 8.4$	Tungsten (5 tonnes)	muons	$E_\ell, E_h \gtrsim 20$ GeV $\theta_\mu \lesssim 0.15, \theta_e \lesssim 0.5$ reco E_h	n/a
FLArE (*)	$\eta_\nu \geq 7.5$	LAr (10, 100 tonnes)	muons	$E_\ell, E_h \gtrsim 2$ GeV, $E_e \lesssim 2$ TeV $\theta_\mu \lesssim 0.025$, $\theta_e \lesssim 0.5$ reco E_h	$\delta E_e \sim 5\%$, $\delta E_\mu \sim 30\%$ $\delta\theta_\ell \sim 15$ mrad $\delta E_h \sim 30\%$

LHC Run III
$\mathscr{L} = 150\ \text{fb}^{-1}$

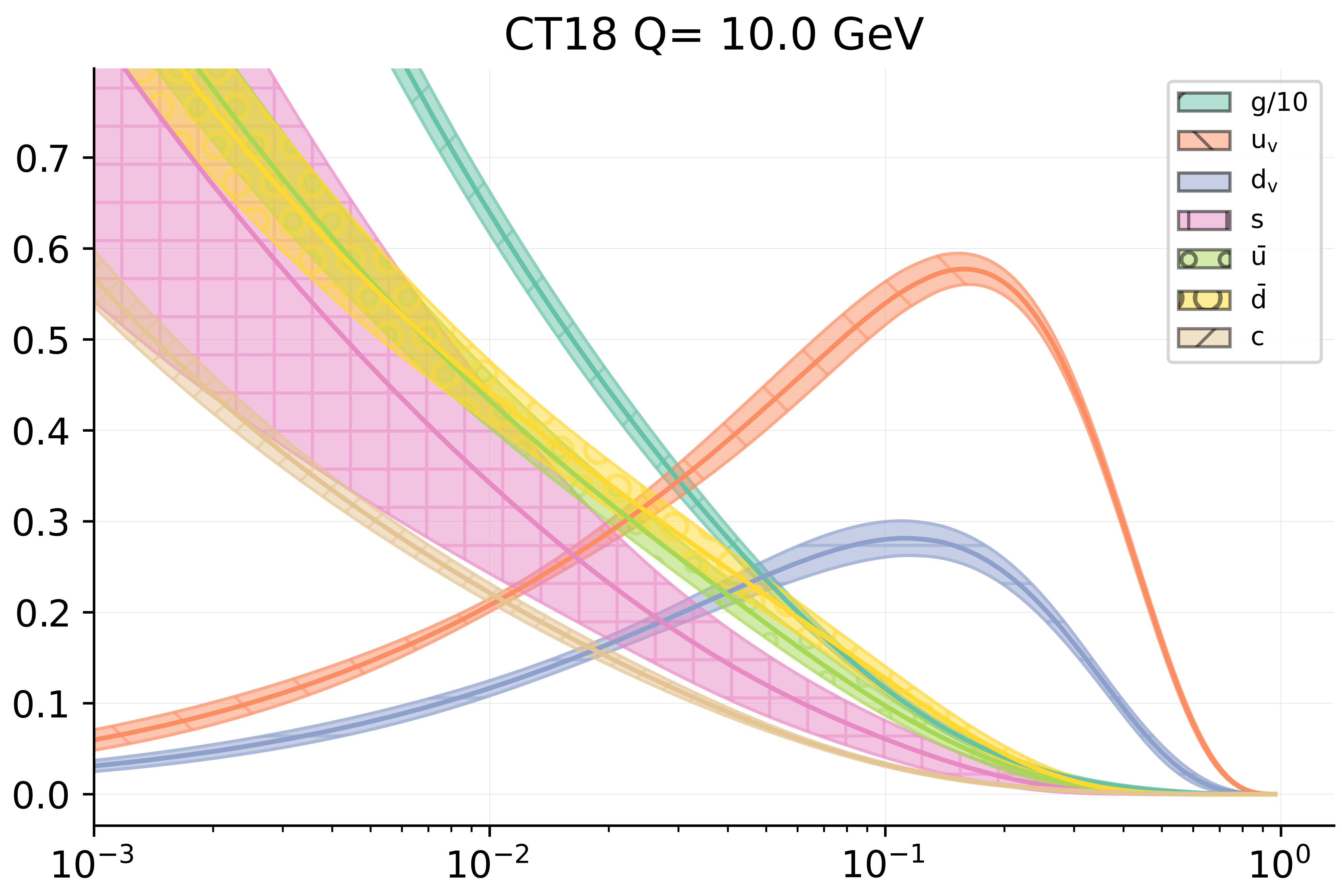
Current estimate of the experimental acceptance and performance; may subject to change in final realisation.

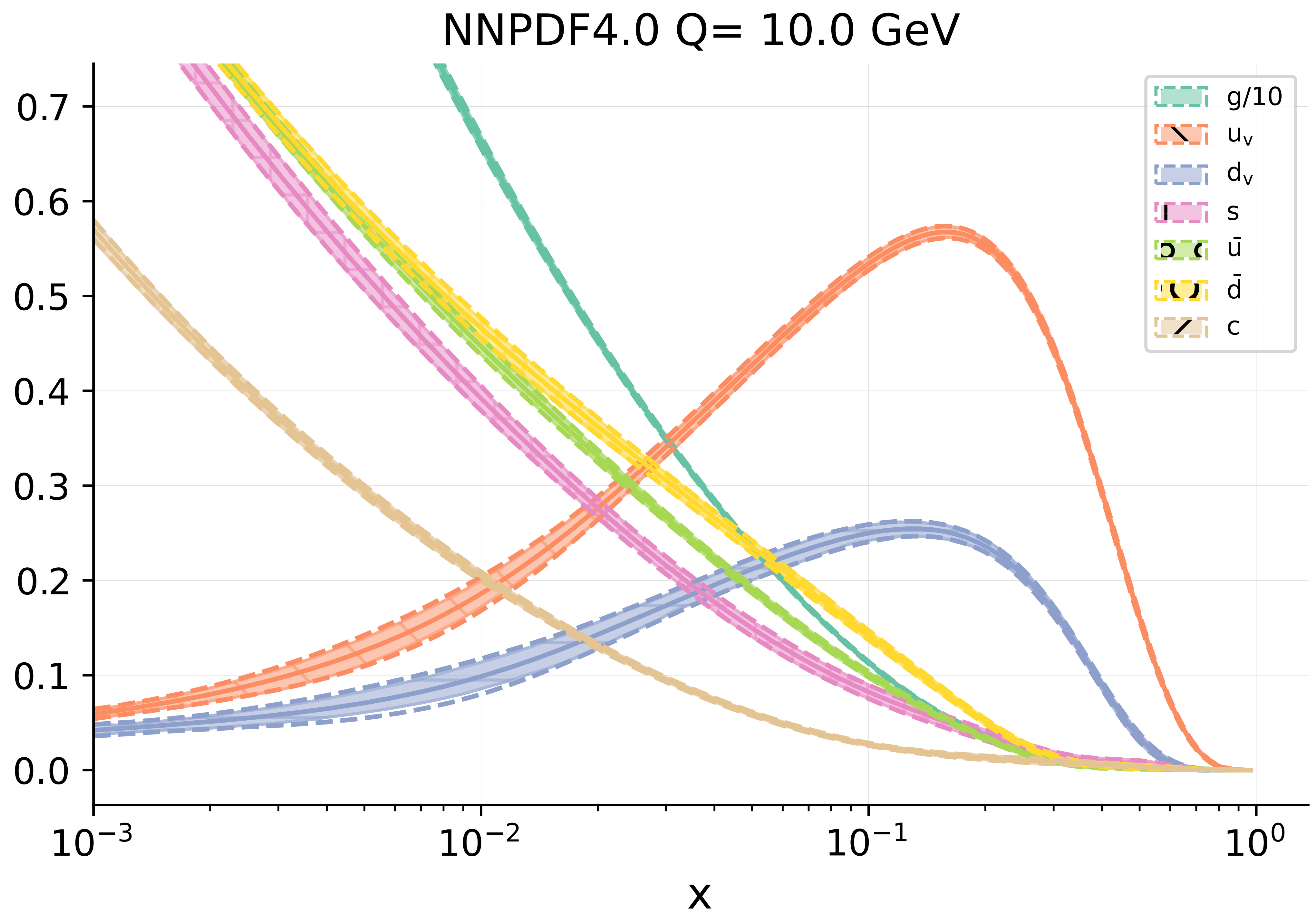
LHC Run III
$\mathscr{L} = 3\ \text{ab}^{-1}$

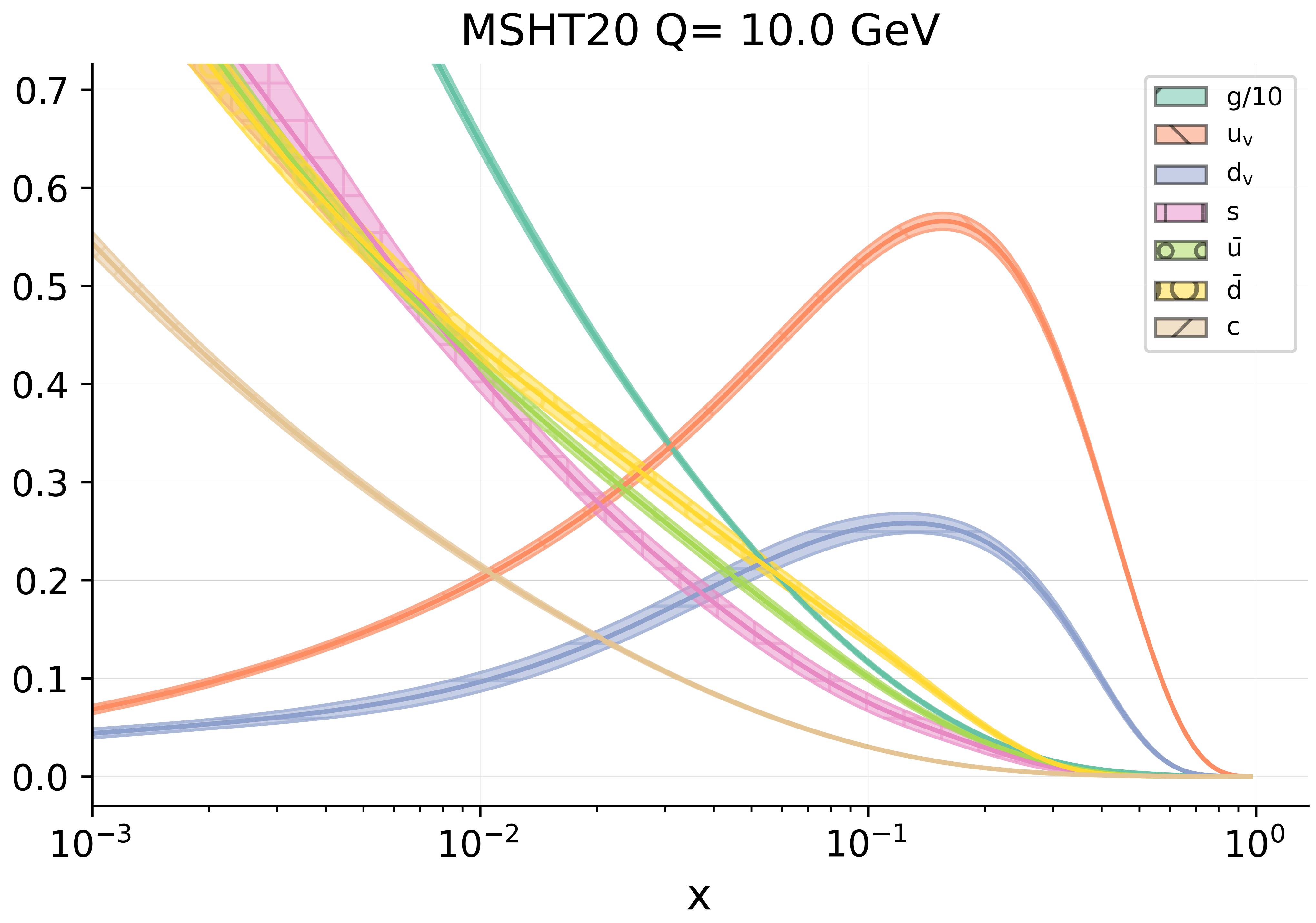
Global NNLO PDFs

Some differences between the global NNLO PDF groups included in PDF4LHC21

- **CT18** [hep-ph] 1912.10053
  -> perturbative charm, hessian, tolerance
- **MSHT20** [hep-ph] 2012.04684
  -> perturbative charm, hessian, dynamic tolerance
- **NNPDF4.0** [hep-ph] 2109.02653
  -> fitted (intrinsic) charm, monte carlo







PDF4LHC21 combination - hep-ph/2203.05506

NNPDF4.0 not included in the PDF4LHC21 combination as it came out when PDF4LHC21 was already at a very advanced stage.

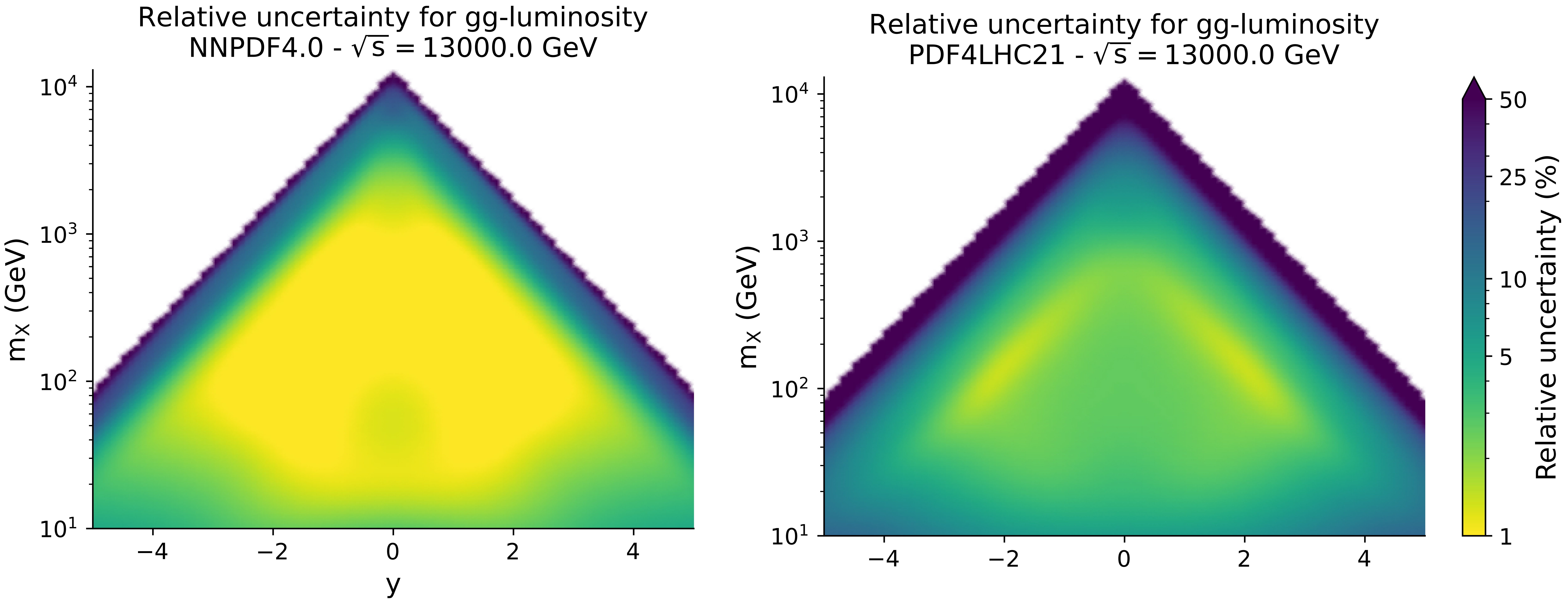
A comparison of NNPDF4.0 and PDF4LHC21 was done in Appendix B of hep-ph/2203.05506

- NNPDF31' (changes to m_c and dataset)
- CT18' (changes to m_c)
- MSHT20

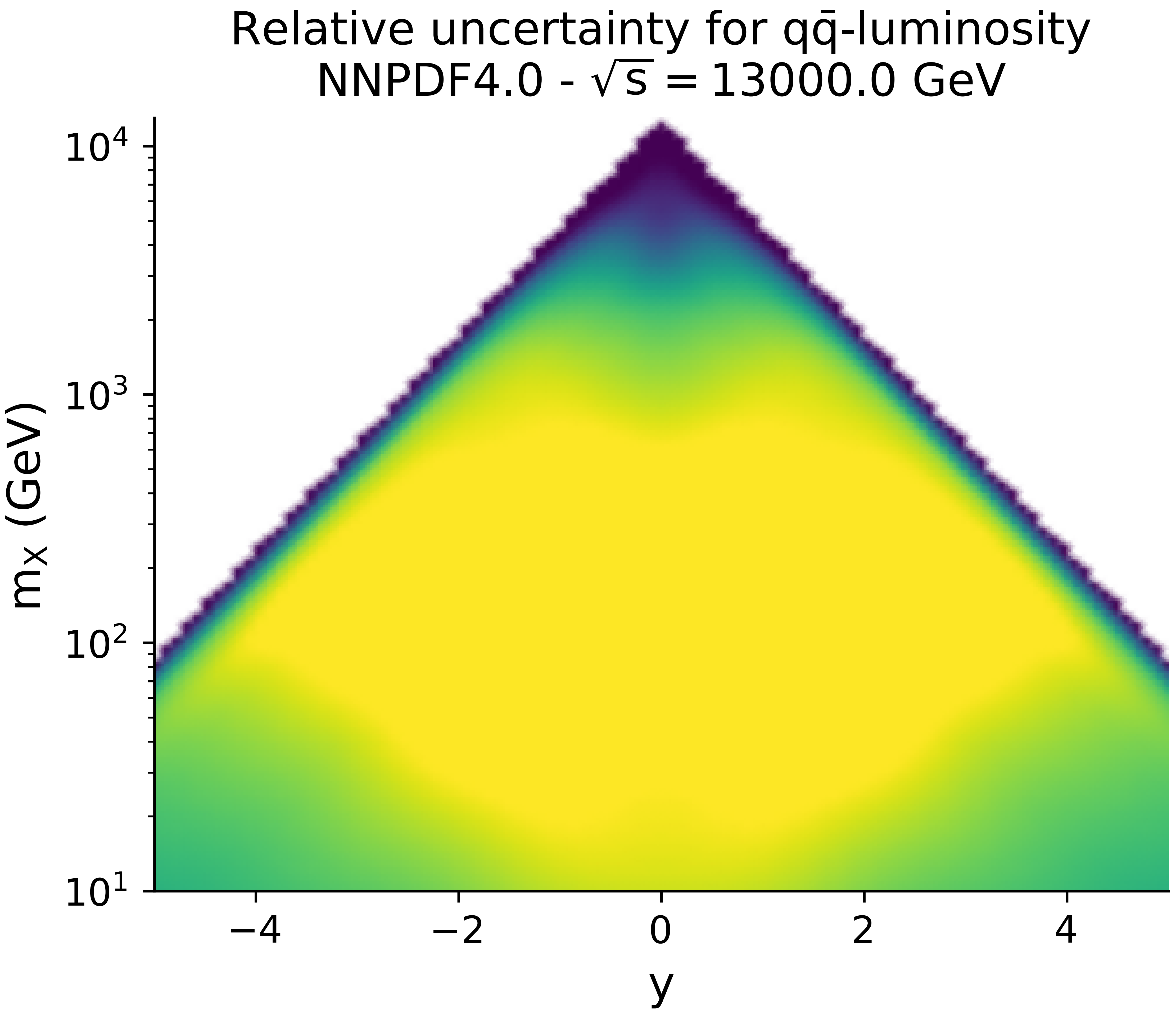
Smaller uncertainties (~1% in some regions) for NNPDF4.0 when comparing, i.e., to PDF4LHC21

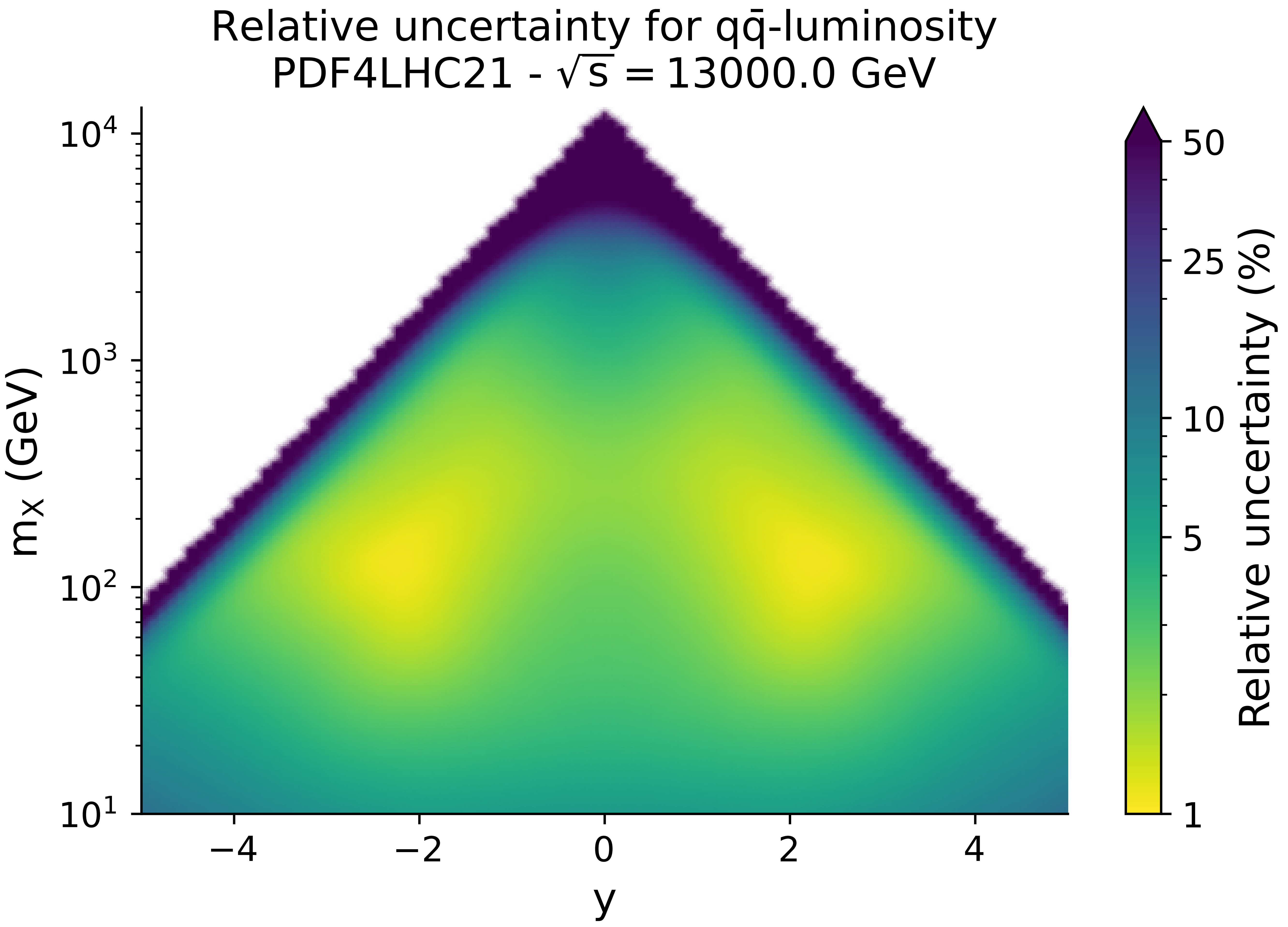
Uncertainty comparison - gq

Uncertainty comparison - gg



Uncertainty comparison - qqbar

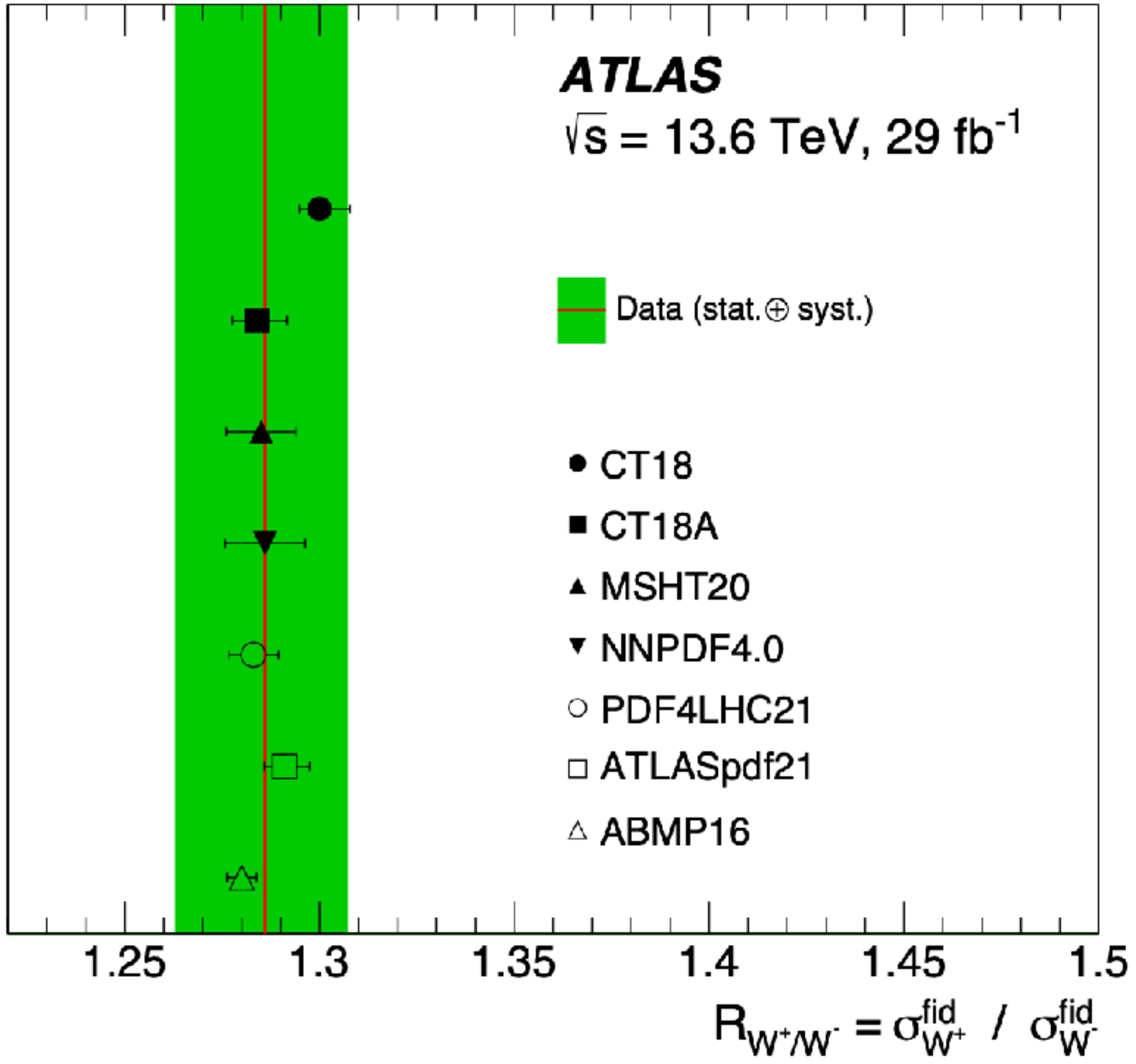


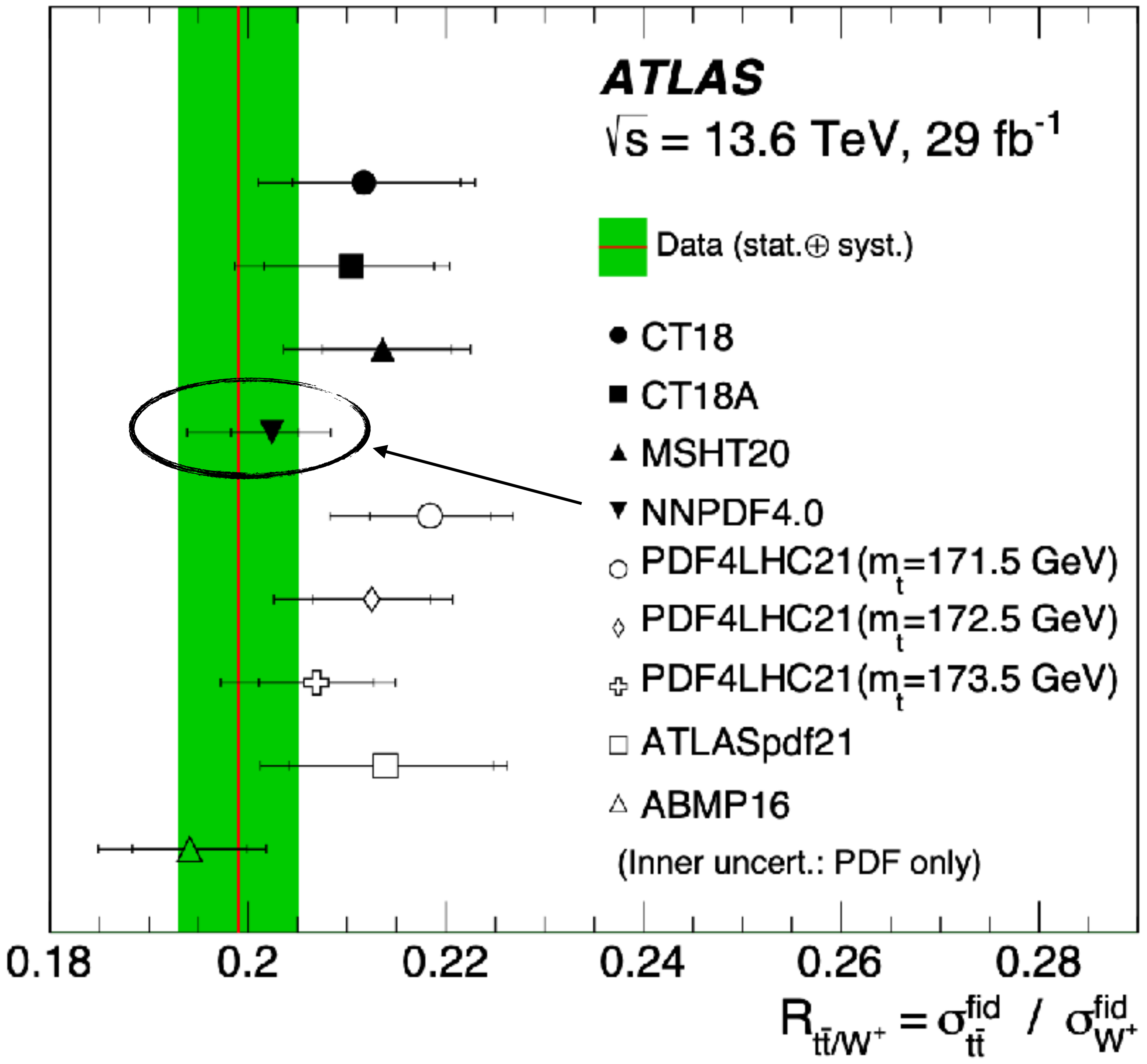


Phenomenological impact of the choice of PDF?

2403.12902

Measurement of vector boson production cross section and their ratios at $\sqrt{s} = 13.6$ with the ATLAS detector





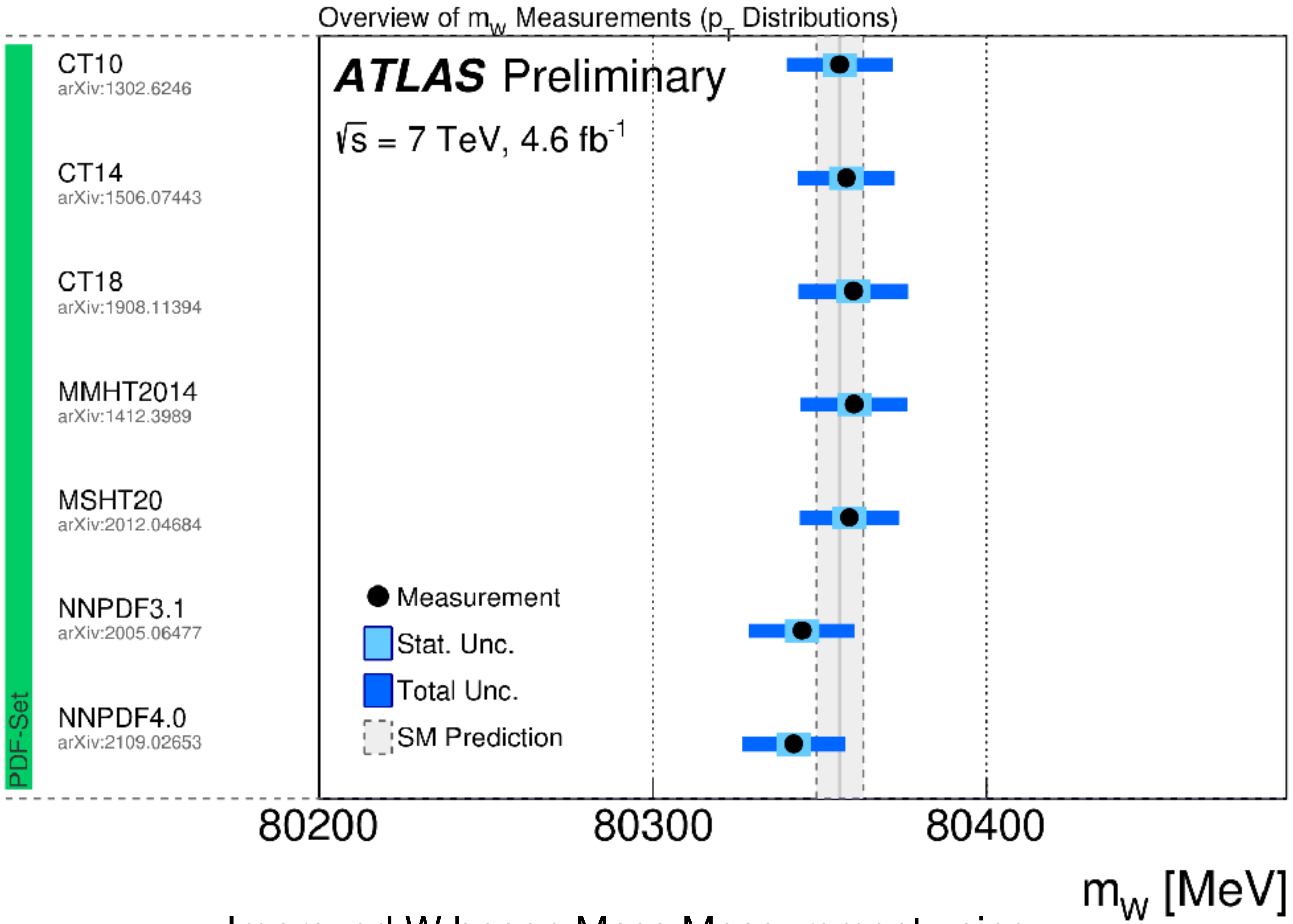
A precise determination of the strong-coupling from the recoil of Z bosons with the ATLAS experiment at $\sqrt{s} = 8$ TeV

arXiv:2309.12986

PDF set	$\alpha_s(m_Z)$	PDF uncertainty
MSHT20 [37]	0.11839	0.00040
NNPDF4.0 [84]	0.11779	0.00024
CT18A [29]	0.11982	0.00050
HERAPDF2.0 [65]	0.11890	0.00027

$$\Delta_{\mathrm{PDF}}\left(\mathrm{MSHT20\ only}\right) = 0.34\,\%$$

$$\Delta_{\mathrm{PDF}}\left(\mathrm{NNPDF4.0} - \mathrm{CT18A}\right) = 1.6\,\%$$



Improved W boson Mass Measurement using $\sqrt{s} = 7$ TeV pp Collisions with the ATLAS Detector

ATLAS-CONF-2023-004

The importance of data

The biggest change didn't come from the perturbative order or the methodology, but rather from the dataset selection!

e.g., CT18 is closer to MSHT20 than to CT18Z!

Table from the recent CMS' m_W extraction

PDF set	Extracted m_W (MeV)	
	Original σ_{PDF}	Scaled σ
CT18Z	$80\,360.2 \pm 9.9$	
CT18	$80\,361.8 \pm 10.0$	
PDF4LHC21	$80\,363.2 \pm 9.9$	
MSHT20	$80\,361.4 \pm 10.0$	$80\,361.7 \pm$
MSHT20aN3LO	$80\,359.9 \pm 9.9$	$80\,359.8 \pm$
NNPDF3.1	$80\,359.3 \pm 9.5$	$80\,361.3 \pm$
NNPDF4.0	$80\,355.1 \pm 9.3$	$80\,357.0 \pm$

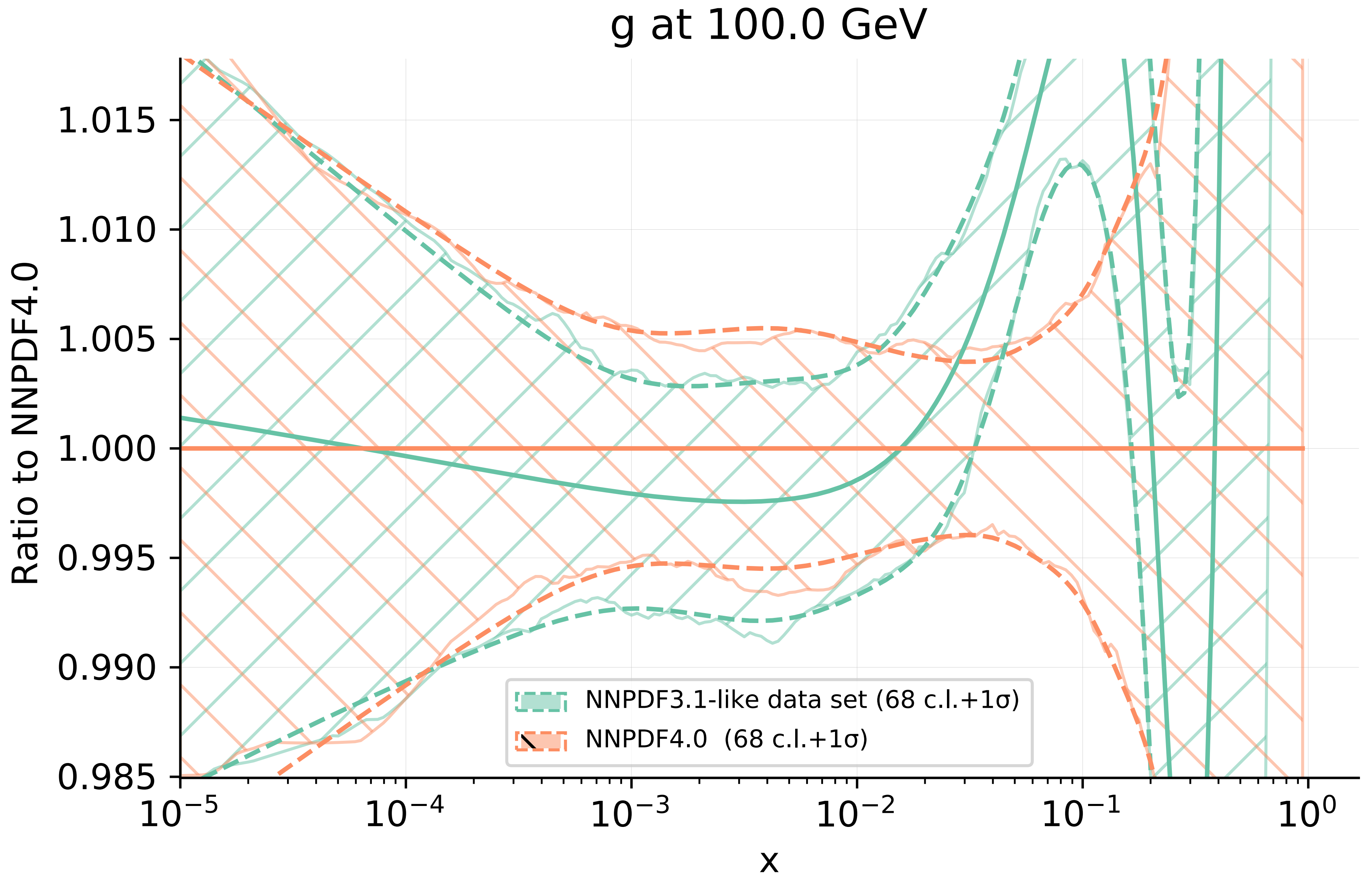
similar datasets

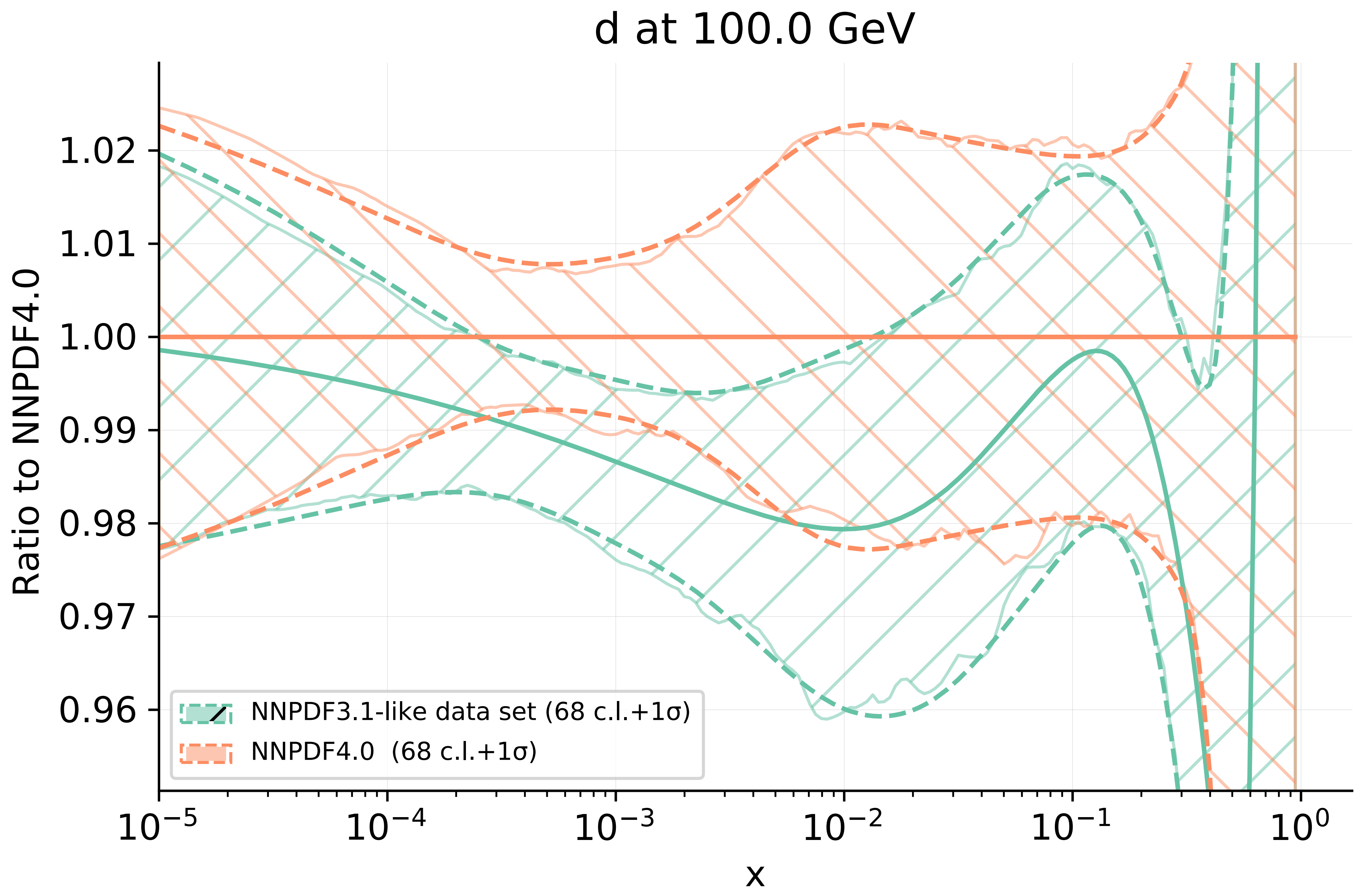
So let's start by looking at the differences between 3.1 and 4.0 and build from there

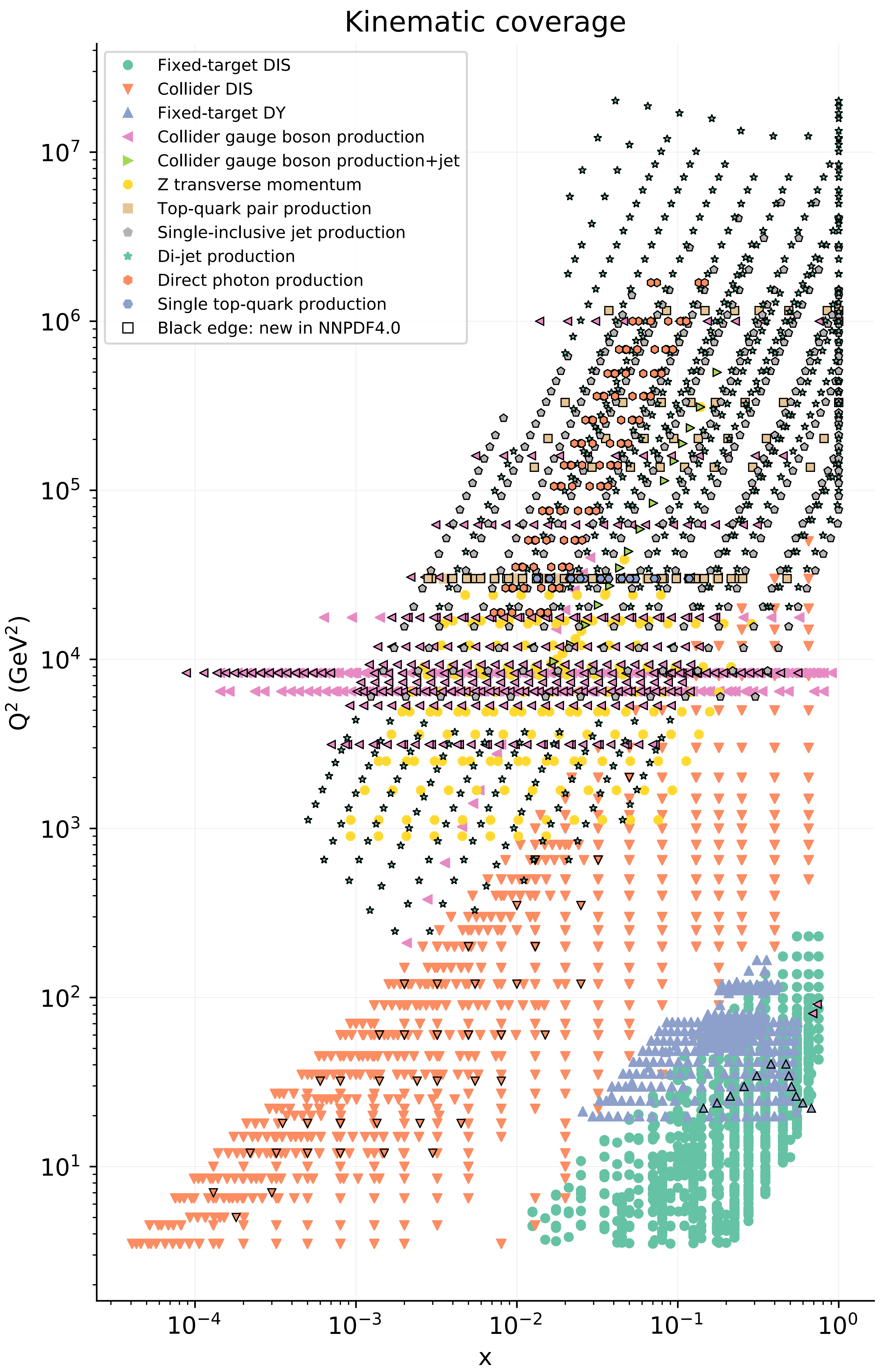
Disclaimer: the following analyses use the NNPDF methodology and open source code at https://github.com/NNPDF/nnpdf

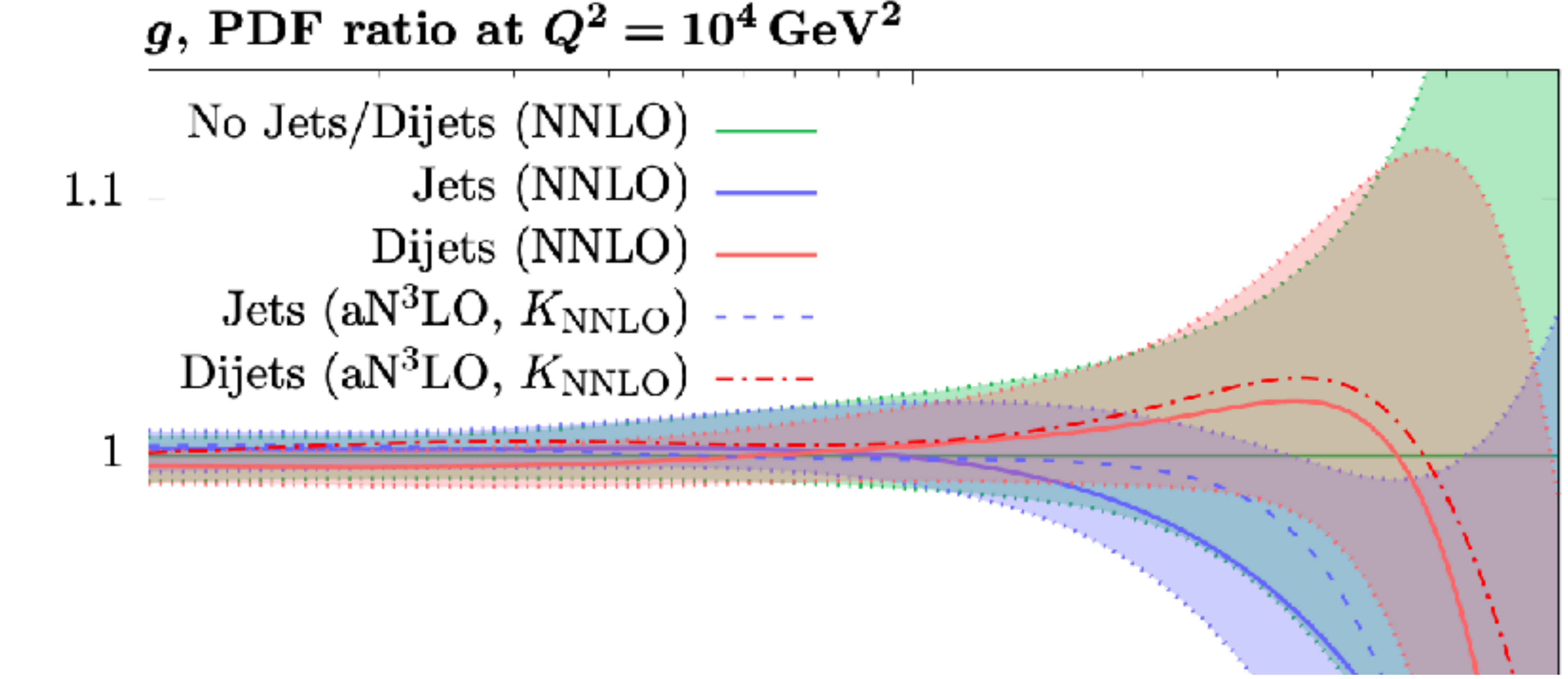
Therefore there is the implied assumption that the constraints introduced by new datasets in PDF extractions will be similar across variations of the methodology and theory settings.

The importance of data



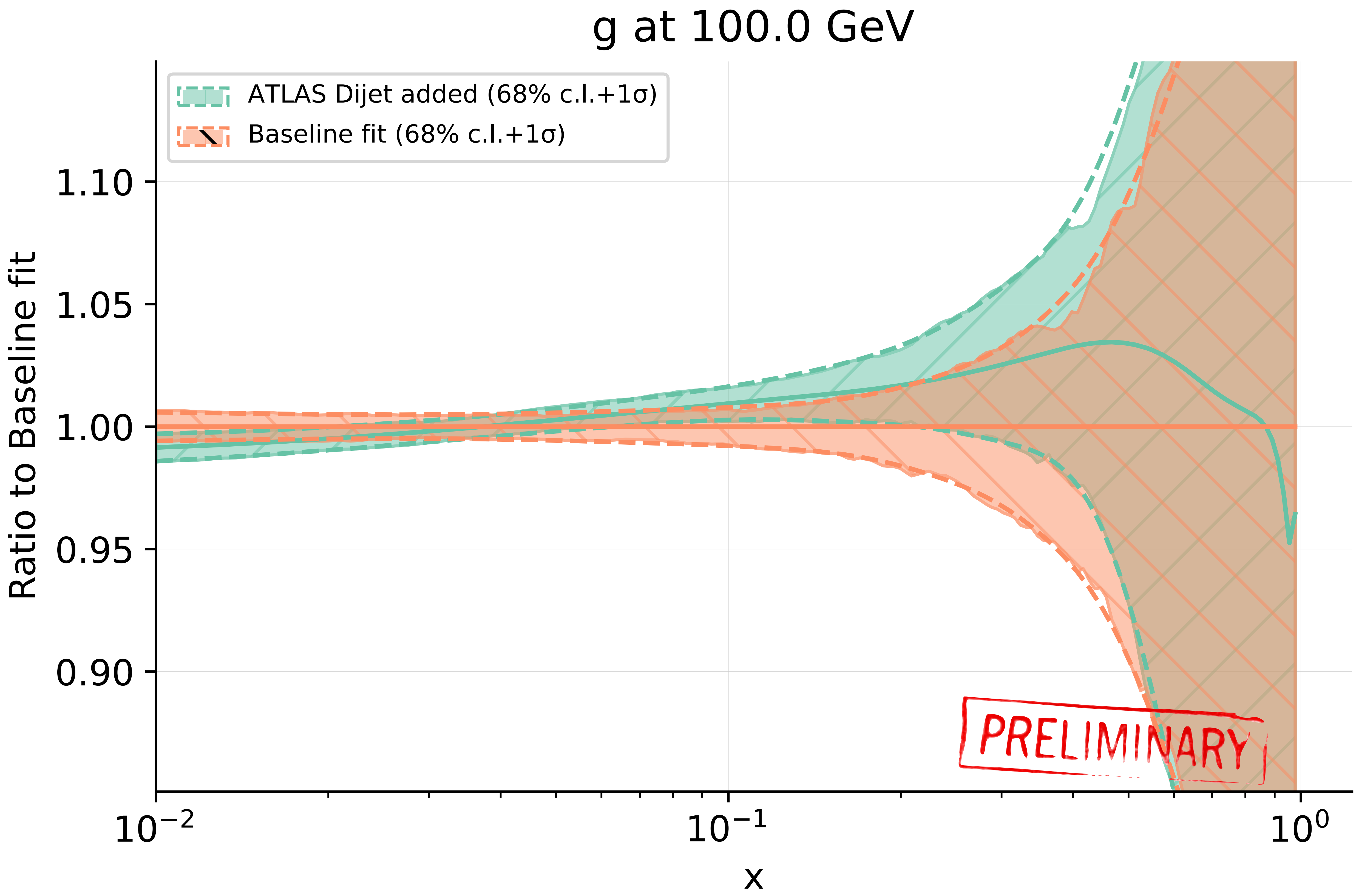


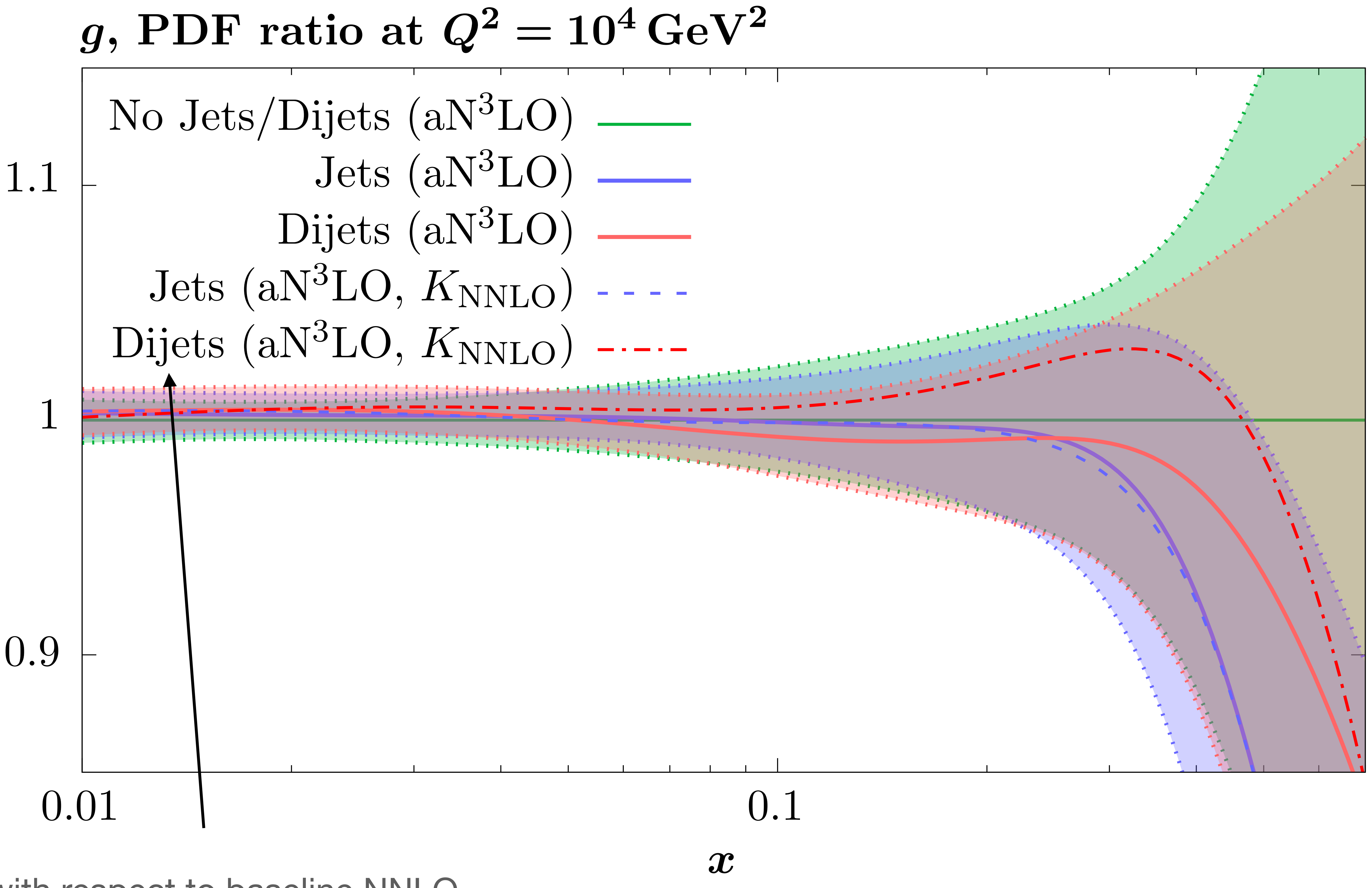




Adding dijet data to different PDFs

The shift of the central value is given by the approximation to the N3LO k-factor





This line is comparable(ish) in that they both add dijet data with respect to baseline NNLO
the datasets themselves, theory settings or methodologies are completely different. However baseline on the left does include jet and dijet data already at 7 and 8 TeV