

Towards nNNPDF3.0: A global analysis of nuclear PDFs at NNLO and the impact of the EIC

Quarkonia as tools workshop

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Outline

Part 1 – Dijet production in nuclear PDF global analysis

- ◆ Extending the results of including (di)jet production in proton PDFs to nuclear PDFs.
- ◆ Investigating the CMS dijet p-p and p-Pb data at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$, extending:

“Phenomenology of NNLO jet production at the LHC and its impact on parton distributions”

— *Eur. Phys. J. C79(2019), no. 11 931* — arXiv:2005.11327

- ◆ Analysis of this data at NLO and NNLO with NNPDF3.1, and results of its fit in nNNPDF2.0.

Part 2 – Impact of the Electron-Ion collider on (n)PDFs

- ◆ Correlated fit of EIC pseudo-data on PDFs — NNPDF3.1 and nPDFs — nNNPDF2.0 in:

“Self-consistent determination of proton and nuclear PDFs at the Electron Ion Collider”

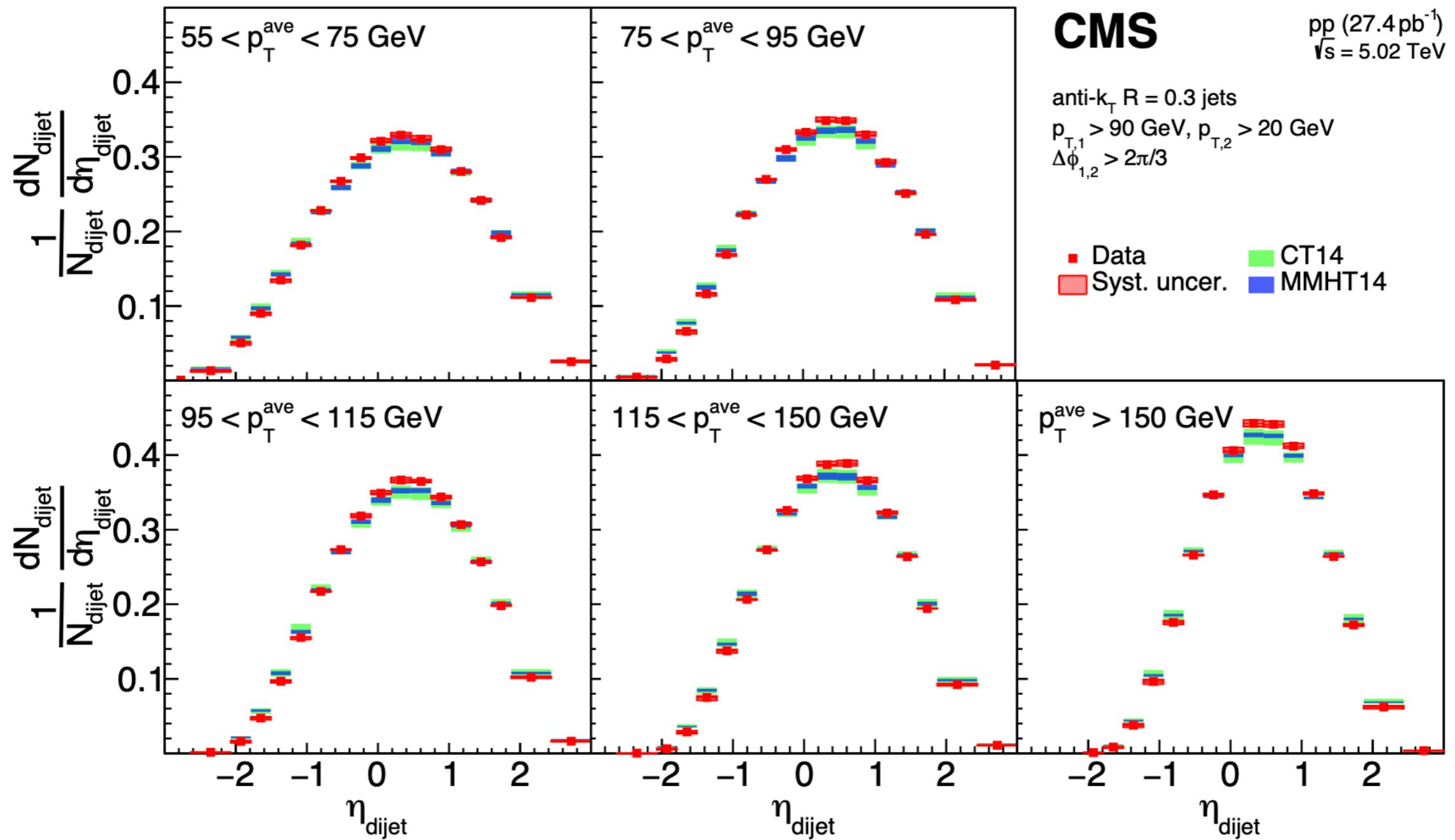
— arXiv:2102.00018

- ◆ Phenomenological implications on $\nu - A_{\text{earth}}$ cross section.

Part 1

Jet Production

p-p CMS 5 TeV



Fit quality

NNPDF3.1
+ 7 and 8 TeV Dijet (paper)
± CMS dijet 5 TeV

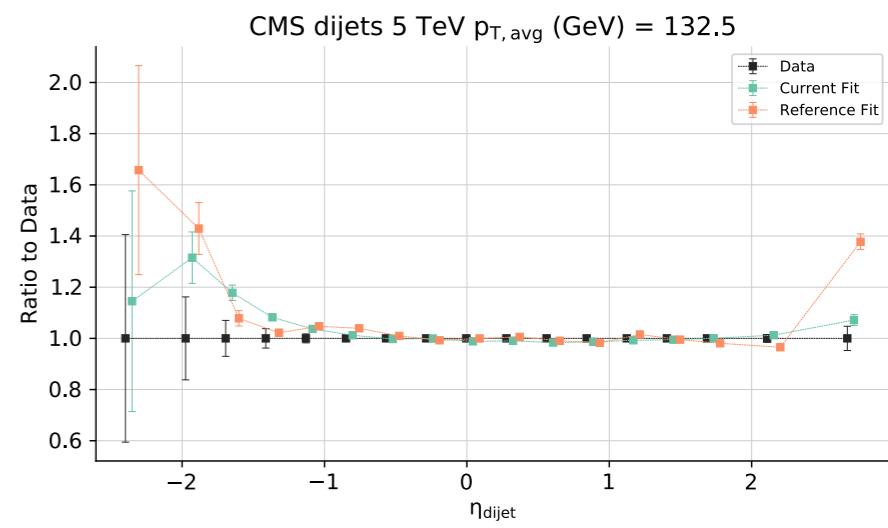
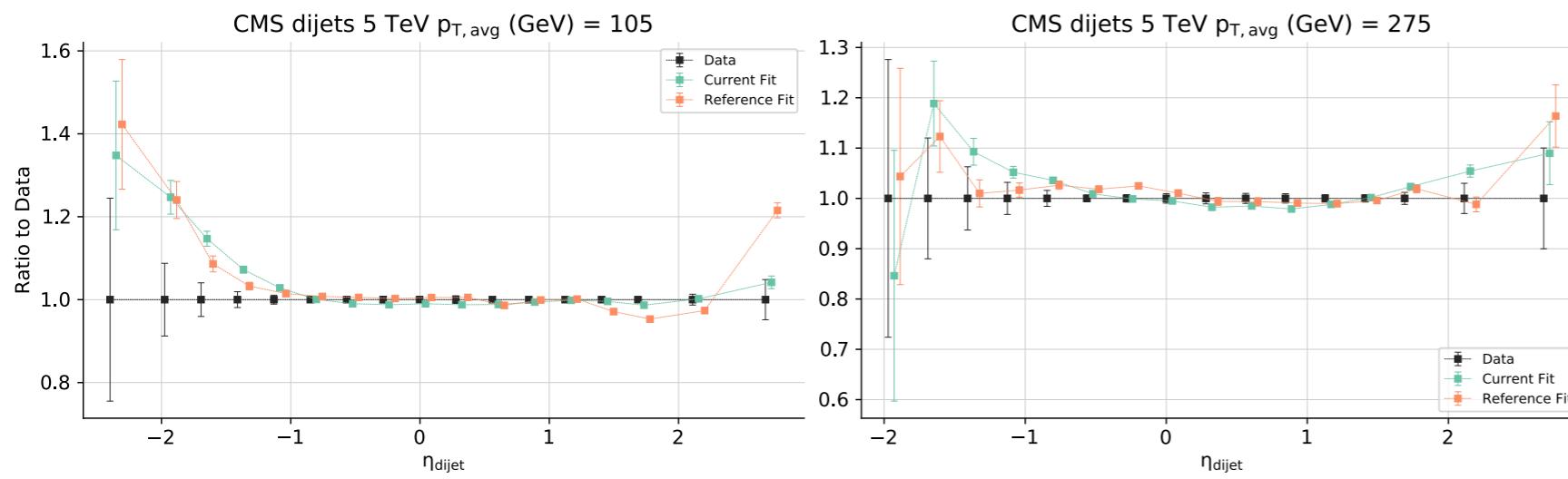
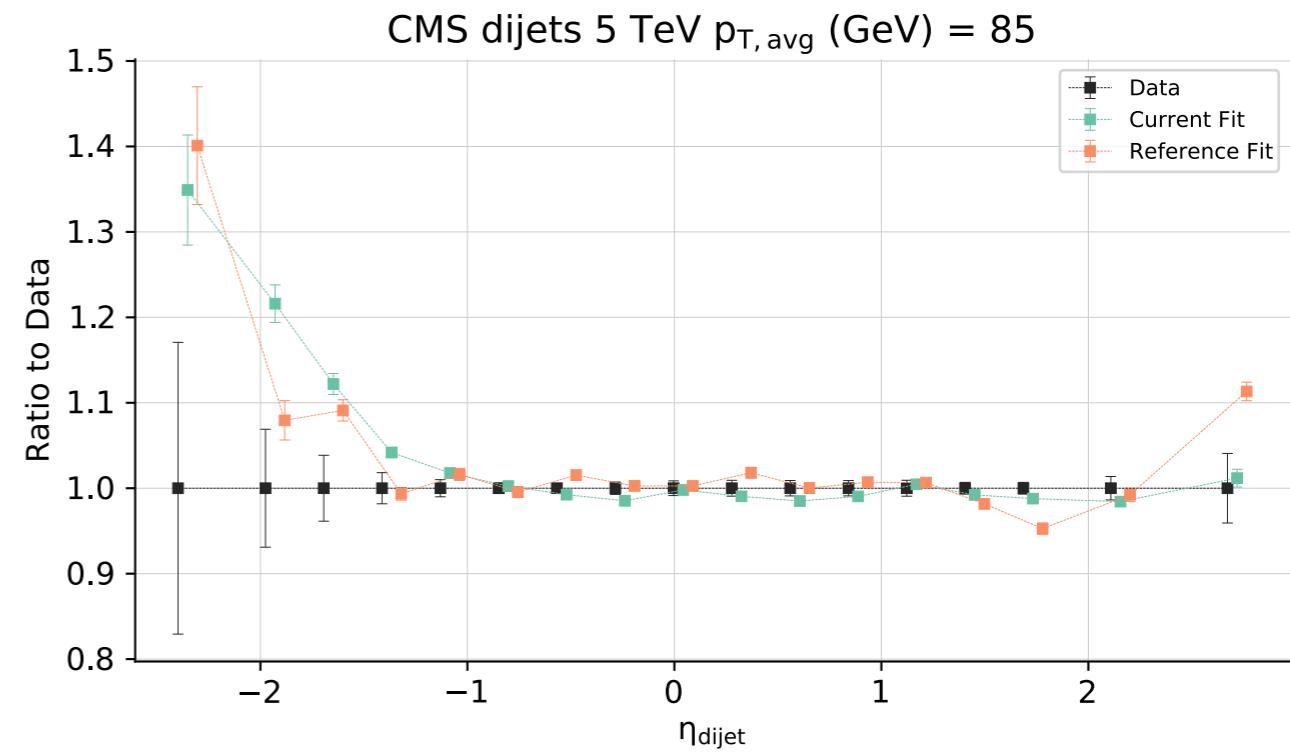
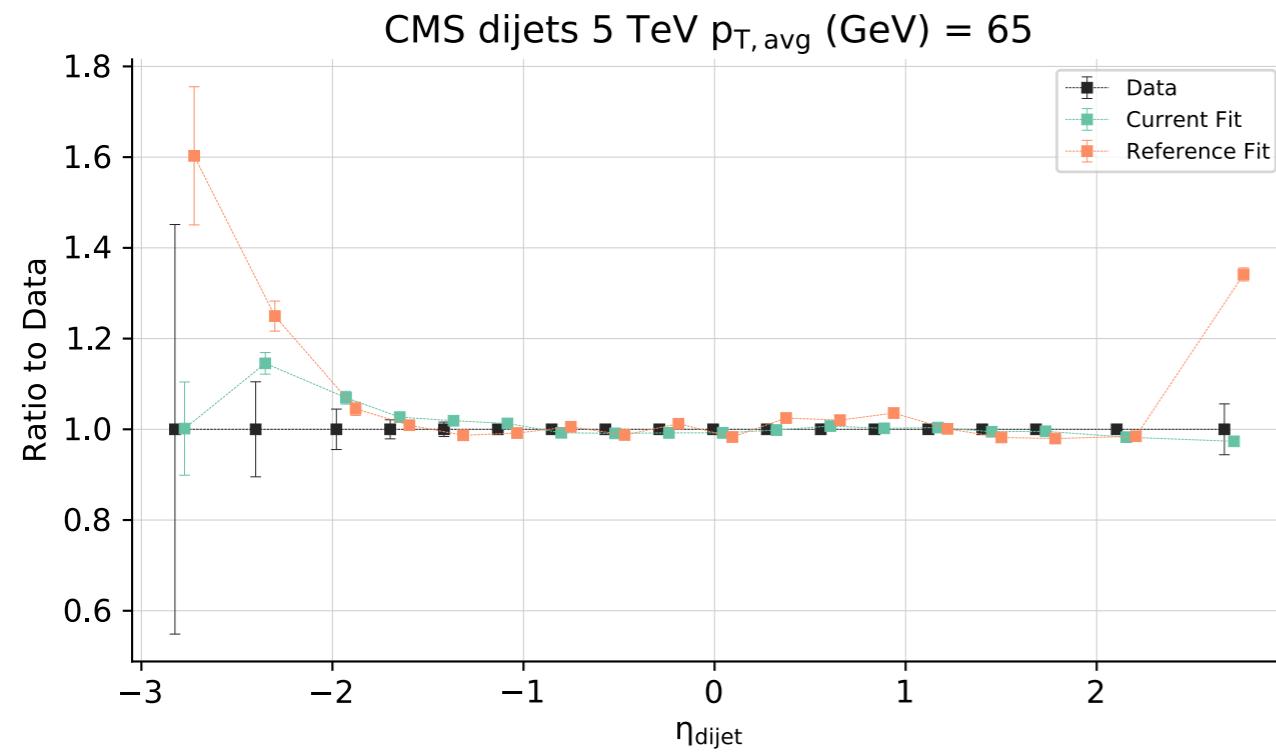
$$\chi^2/n_{\text{dat}}$$

$$K_{\text{NNLO}}^{\text{QCD}} \equiv \frac{\sum_{ij} \tilde{\sigma}_{ij}^{\text{NNLO}} \otimes \mathcal{L}_{ij}^{\text{NNLO}}}{\sum_{ij} \tilde{\sigma}_{ij}^{\text{NLO}} \otimes \mathcal{L}_{ij}^{\text{NNLO}}},$$

Dataset	n_{dat}	w/o (NLO)	w/ (NLO)	w/o (NNLO)	w/ (NNLO)
DIS NC	2113	1.28	1.31	1.25	1.27
DIS CC	81	1.24	1.25	1.15	1.16
Drell-Yan	440	1.36	1.33	1.21	1.24
Z p_T	120	2.22	2.26	1.11	1.09
Top pair	25	1.67	1.11	1.27	1.27
Dijets (all)	351	3.27	2.43	4.21	3.00
ATLAS 7 TeV	90	1.03	1.01	1.98	1.91
CMS 7 TeV	54	1.58	2.03	1.75	1.92
CMS 8 TeV	122	3.87	3.61	1.48	1.55
CMS 5 TeV	85	[5.87]	2.51	[12.04]	6.91
Total		1.37	1.42	1.24	1.41

p-p CMS 5 TeV

NLO ($\chi^2_{tot}/N = 1.42$), ($\chi^2_{dataset}/N = 2.51$)
NNLO ($\chi^2_{tot}/N = 1.41$), ($\chi^2_{dataset}/N = 6.91$)



p-p CMS 5 TeV

Non-quadratic improved Hessian PDF reweighting and application to
CMS dijet measurements at 5.02 TeV

– arXiv:1903.09832

Kari J. Eskola^[1,2,a], Petja Paakkinen^[1,2,b], Hannu Paukkunen^[1,2,c]

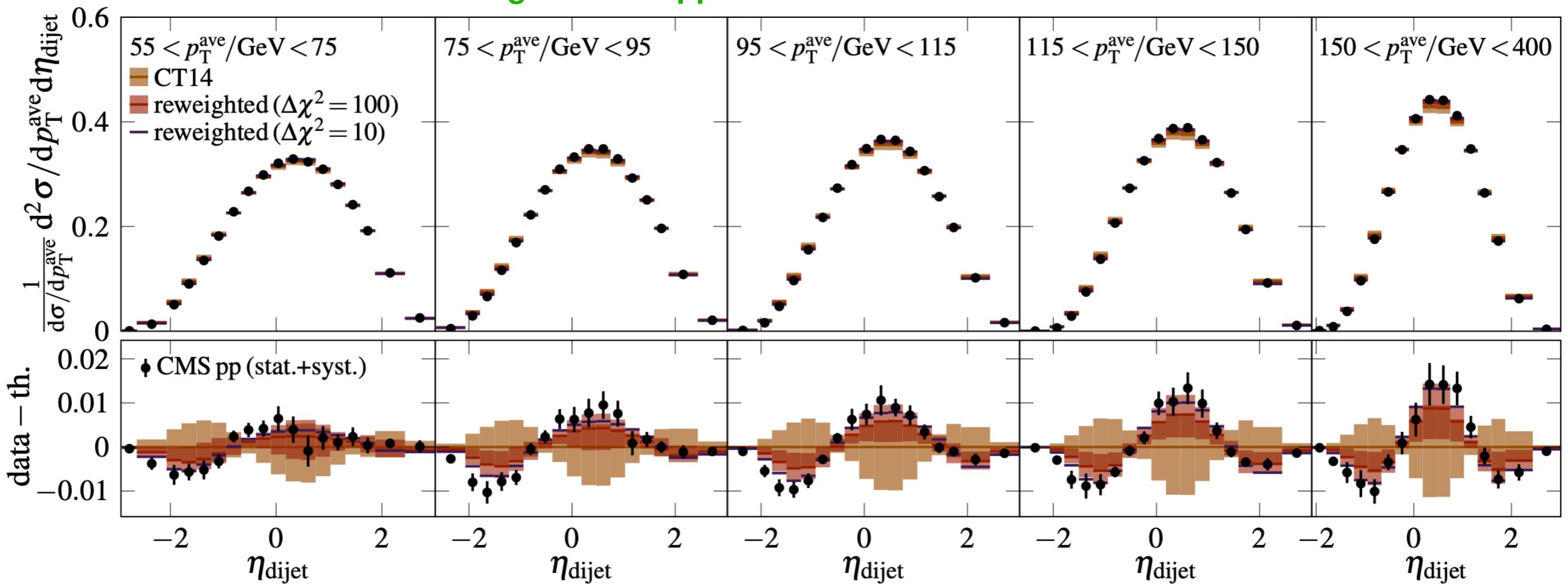
¹University of Jyvaskyla, Department of Physics, P.O. Box 35, FI-40014 University of Jyvaskyla, Finland

²Helsinki Institute of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland

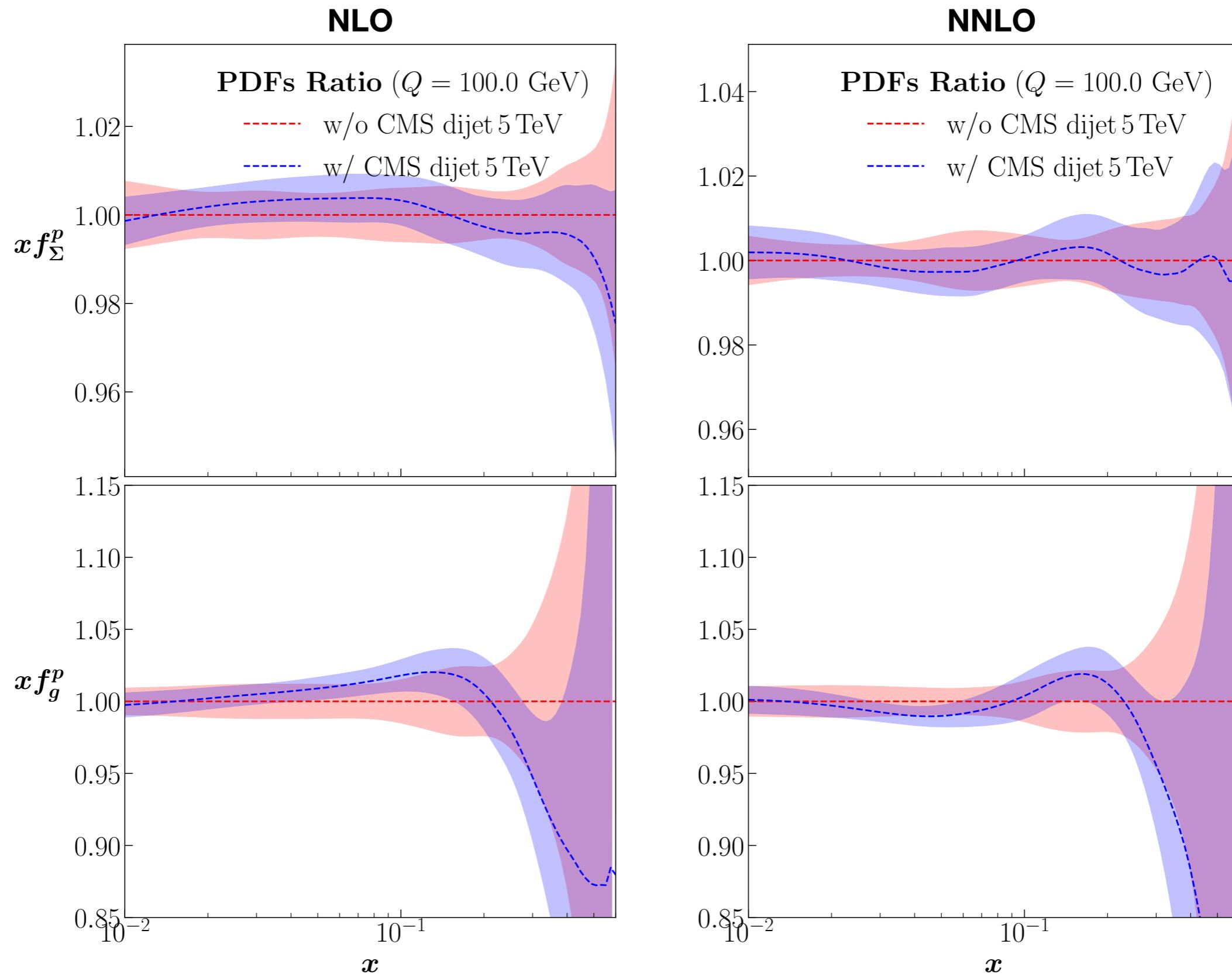
“The penalty term for the reweighted CT14 fit is rather high, with $P/\Delta\chi^2 = 1.17$, clearly indicating that we are reaching the limits of the applicability of the reweighting method.” $\rightarrow \chi^2/N = 2.0$

CT14nlo reweighted with pp

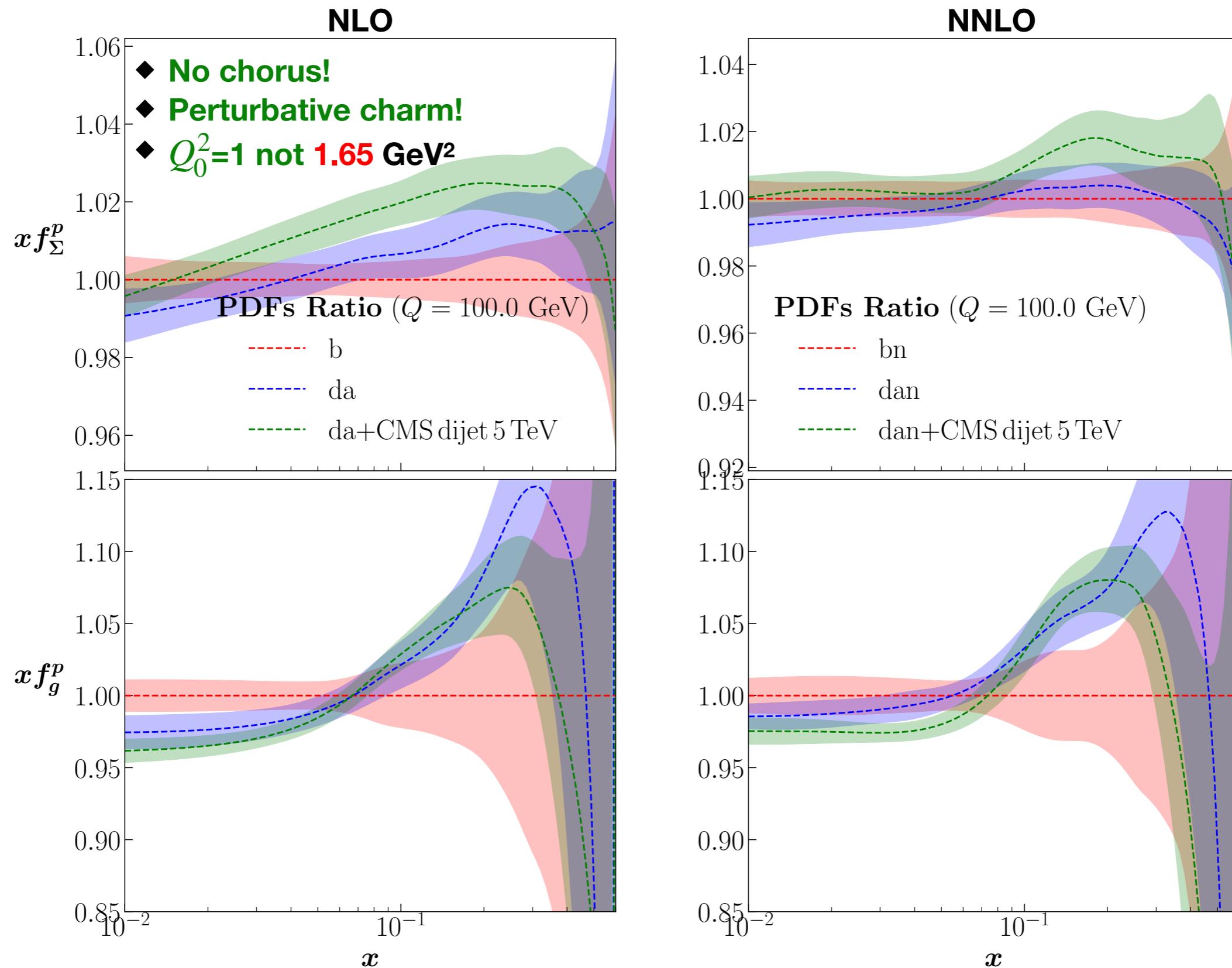
$$P = \sum_k (A_k(w_k^{\min})^2 + B_k(w_k^{\min})^3) \approx \chi_{\text{old}}^2(\mathbf{w}^{\min}) - \chi_0^2,$$



NNPDF3.1 + dijet + p-p CMS 5 TeV



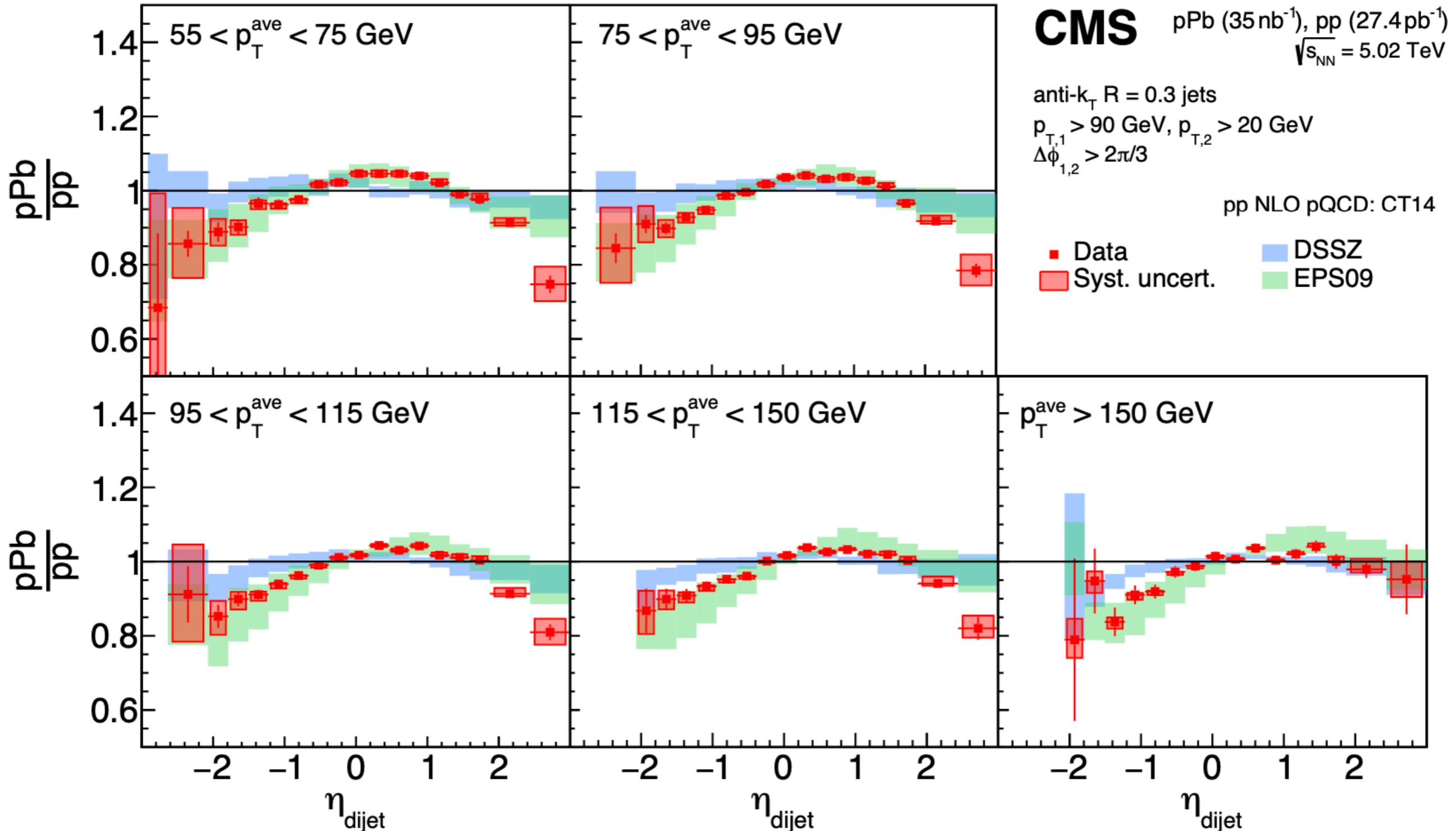
NNPDF3.1 + dijet + p-p CMS 5 TeV



Now using this as proton
baseline in nNNPDF2.0....

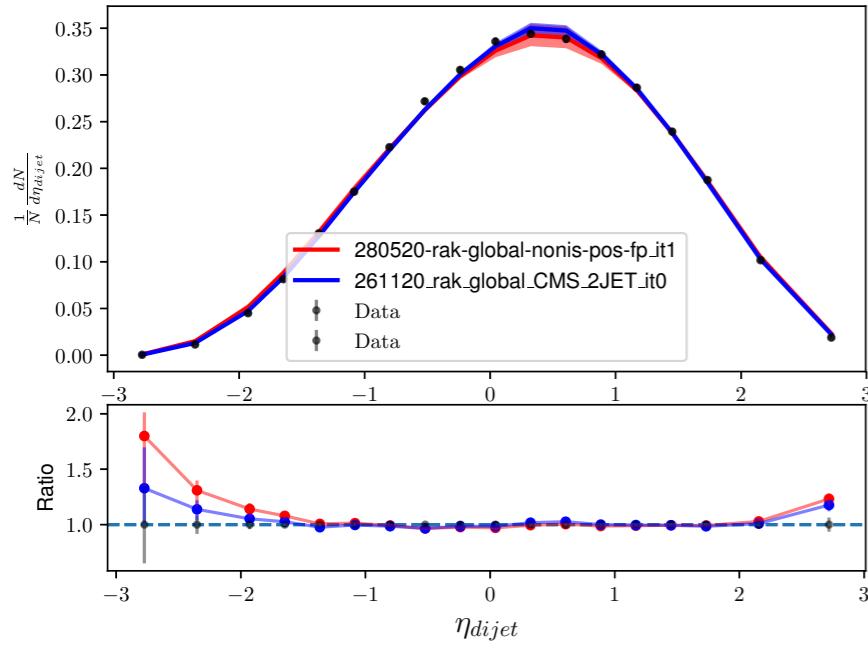
p-Pb CMS 5 TeV

Both spectra (See slide 3) and $R_{\text{pPb}}^{\text{norm.}} = \frac{\frac{1}{d\sigma^{\text{pPb}}/dp_T^{\text{ave}}} d^2\sigma^{\text{pPb}}/dp_T^{\text{ave}} d\eta_{\text{dijet}}}{\frac{1}{d\sigma^{\text{pp}}/dp_T^{\text{ave}}} d^2\sigma^{\text{pp}}/dp_T^{\text{ave}} d\eta_{\text{dijet}}}.$

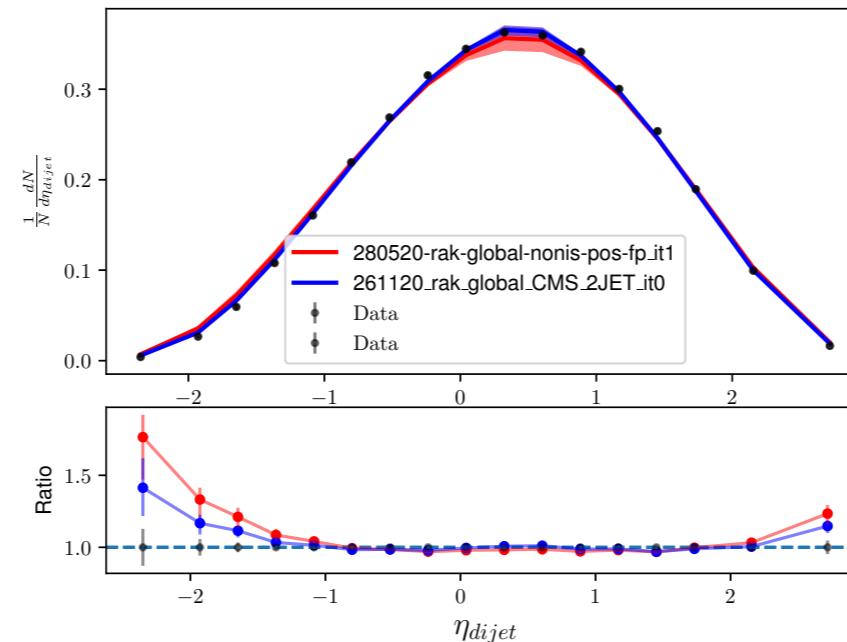


p-Pb CMS 5 TeV

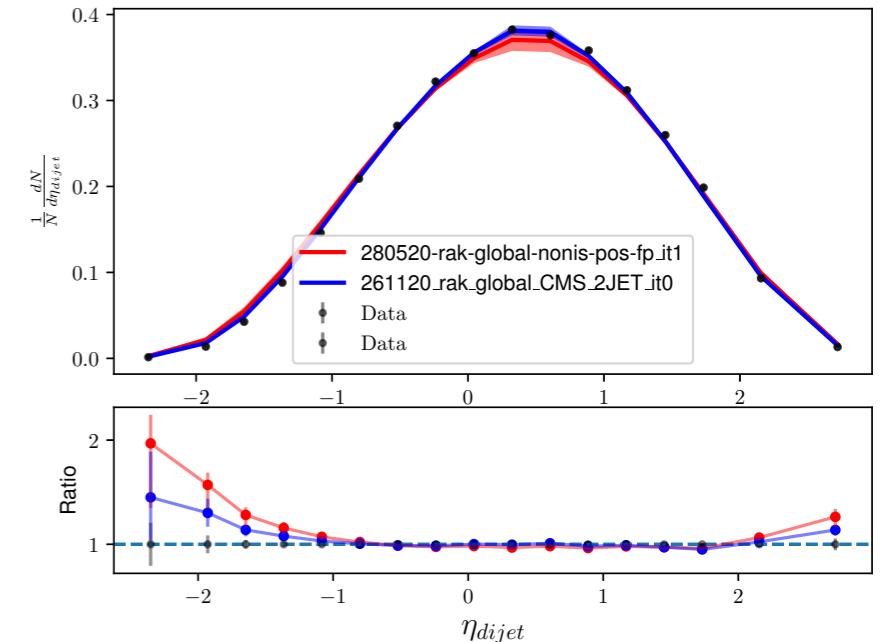
CMS^{5TeV} $\sigma^{p\text{Pb}(A=208)\rightarrow\text{dijet+X}}(55 < p_{\text{T}}^{\text{avg}} < 75)$



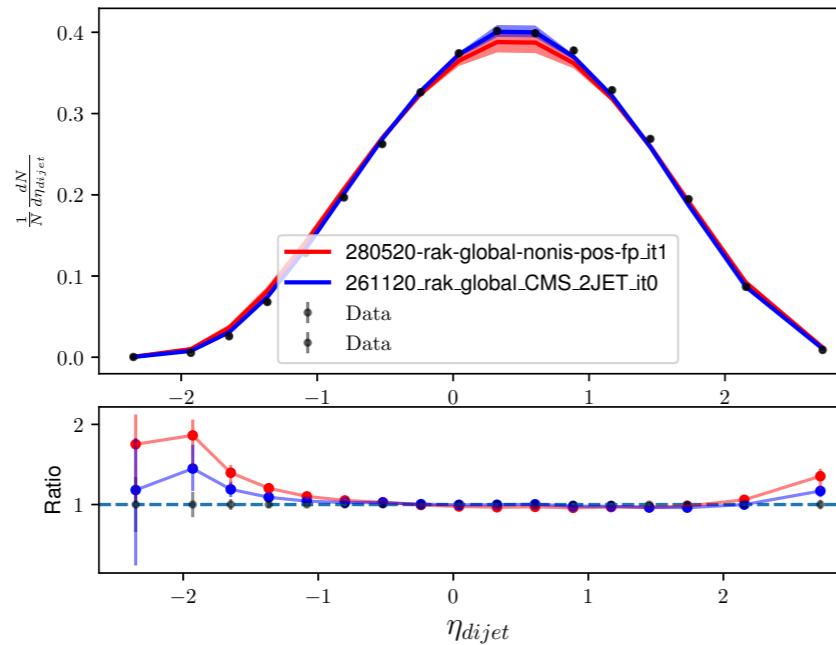
CMS^{5TeV} $\sigma^{p\text{Pb}(A=208)\rightarrow\text{dijet+X}}(75 < p_{\text{T}}^{\text{avg}} < 95)$



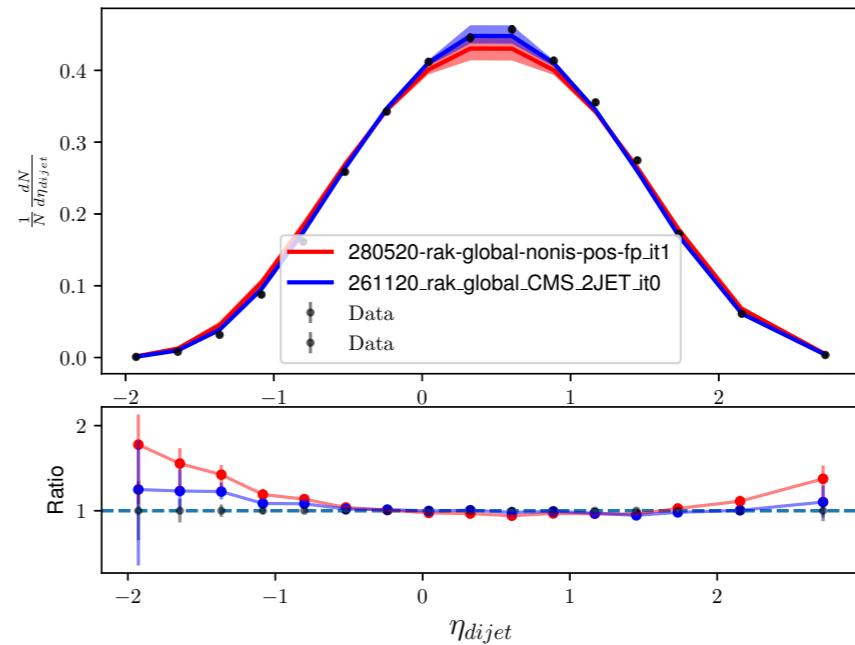
CMS^{5TeV} $\sigma^{p\text{Pb}(A=208)\rightarrow\text{dijet+X}}(95 < p_{\text{T}}^{\text{avg}} < 115)$



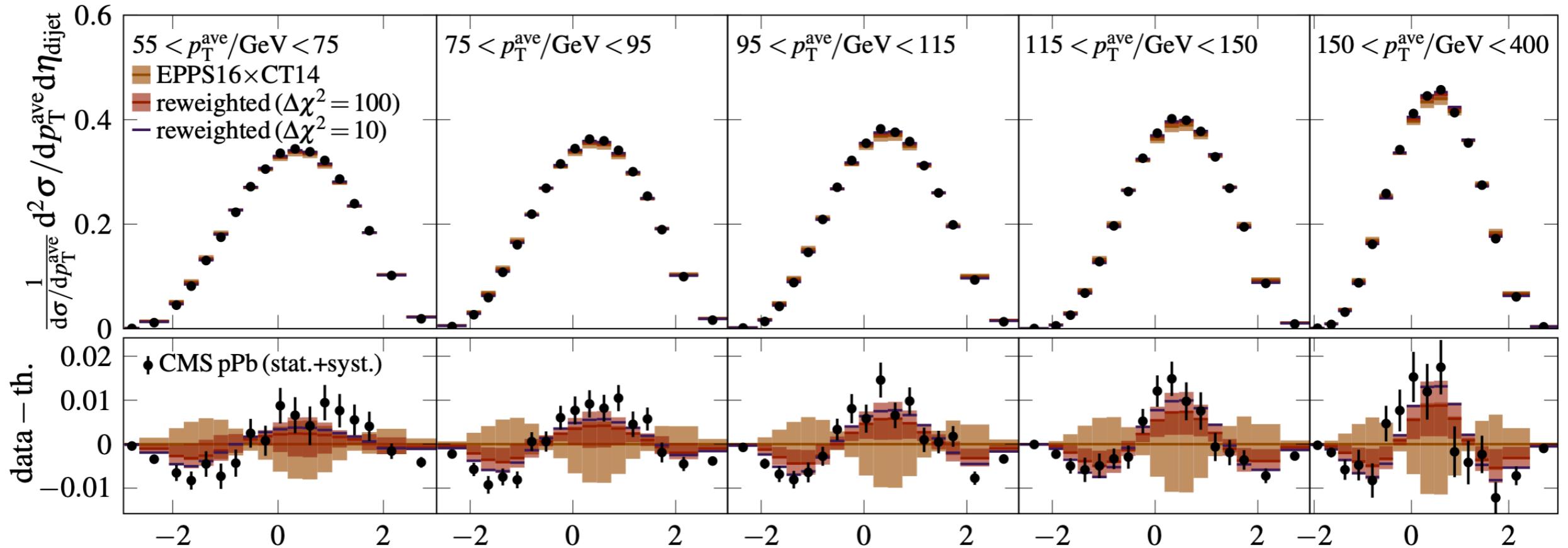
CMS^{5TeV} $\sigma^{p\text{Pb}(A=208)\rightarrow\text{dijet+X}}(115 < p_{\text{T}}^{\text{avg}} < 150)$



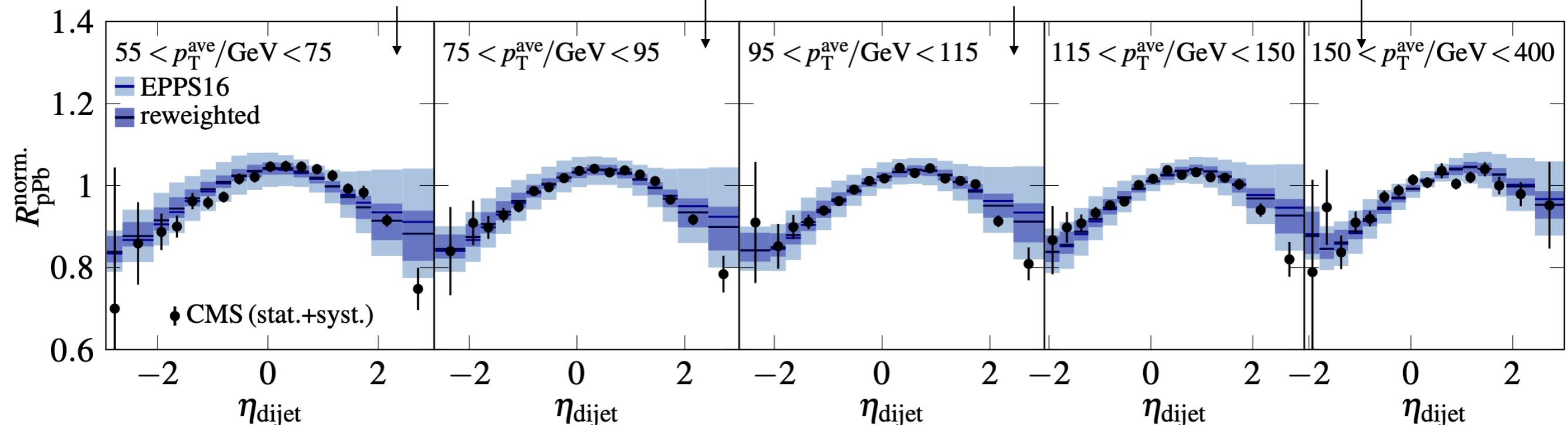
CMS^{5TeV} $\sigma^{p\text{Pb}(A=208)\rightarrow\text{dijet+X}}(150 < p_{\text{T}}^{\text{avg}})$



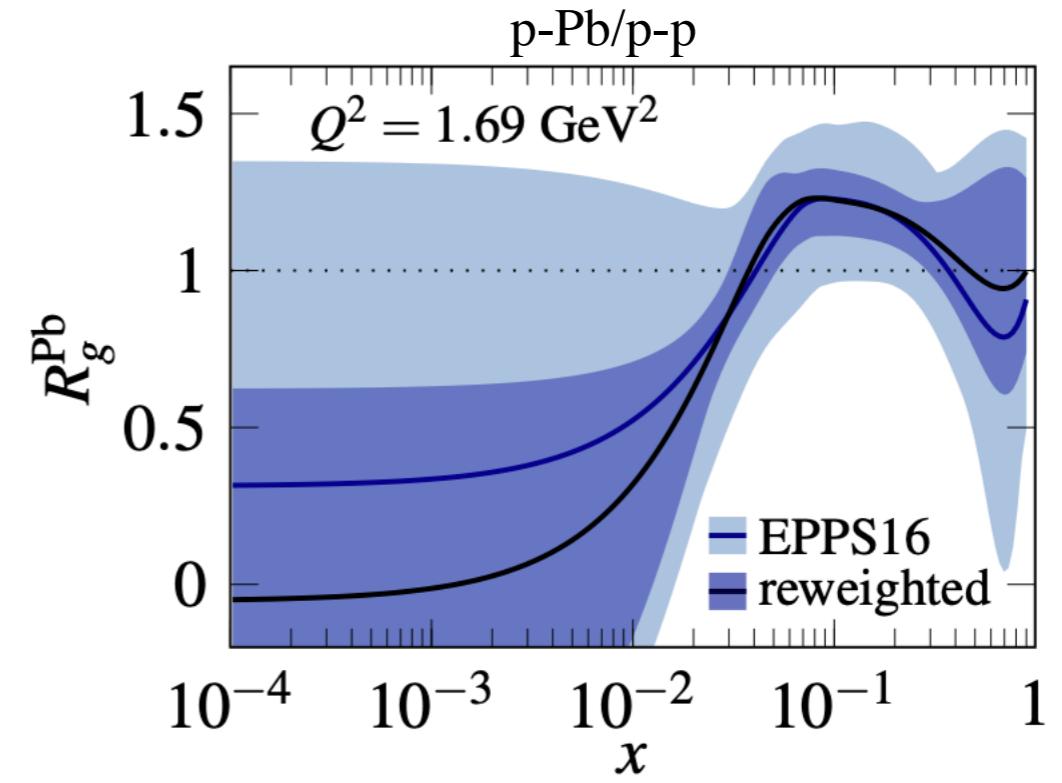
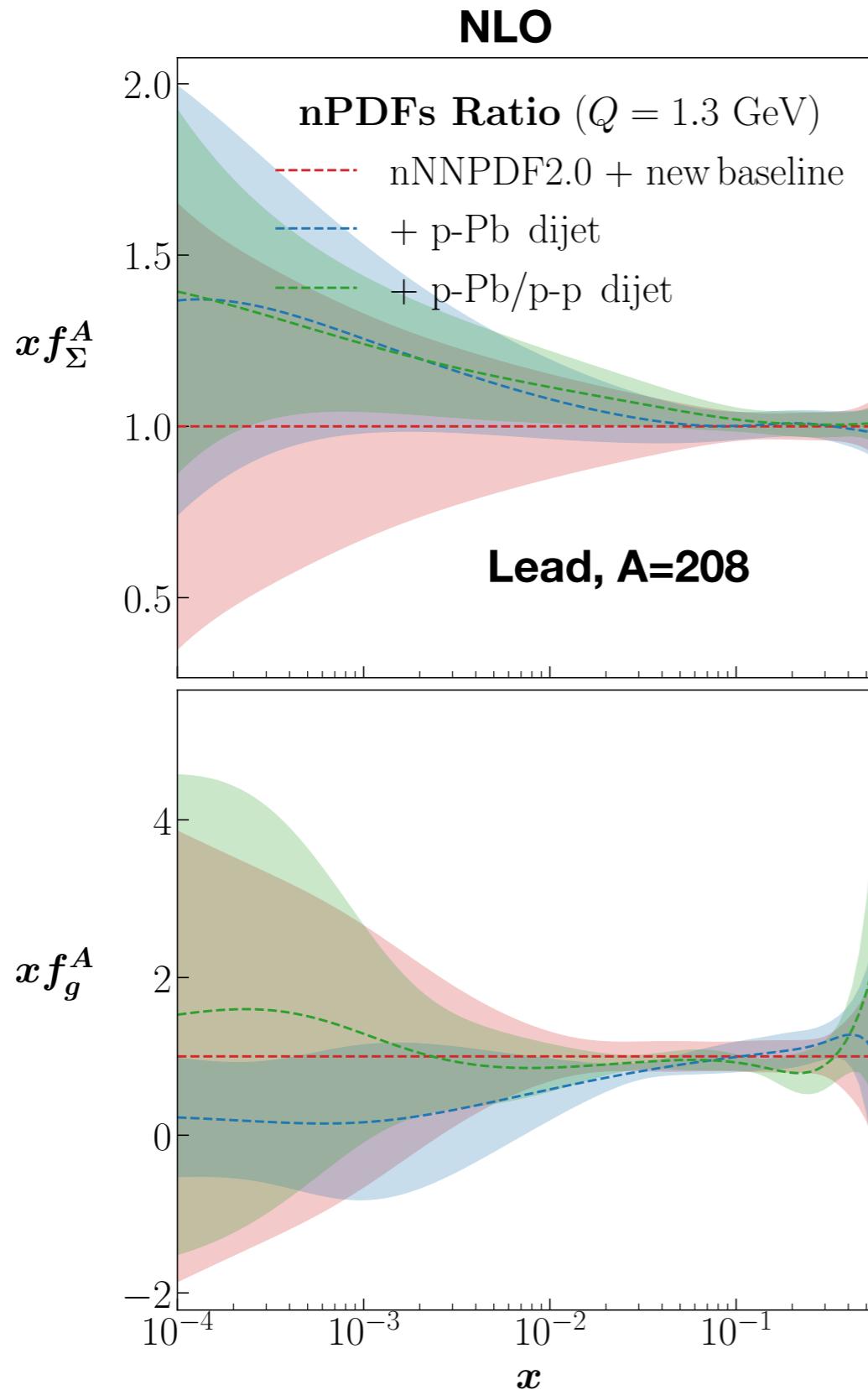
EPPS16



"We obtain an improvement in the goodness of fit from $\chi^2/N_{\text{data}} = 1.7$ to 1.4 with a penalty $P/\Delta\chi^2 = 0.14$ "



nNNPDF2.0 + p-Pb CMS 5 TeV



Conclusion

- ◆ Systematic uncertainties and missing correlations are crucial to describe well this dataset.
- ◆ pp data and inability to well describe it seems the main bottleneck
- ◆ **NNLO k-factors need investigation.**

Dataset	w/o (NLO)	w/ (NLO)	w/o (NNLO)	w/ (NNLO)
CMS 5 TeV (pp)	[5.87]	2.51	[12.04]	6.91
CMS 5 TeV (pPb)	[11.07]	3.53 [9.86]	—	—
CMS 5 TeV (pPb/pp)	[6.47]	3.85 [6.16]	—	—

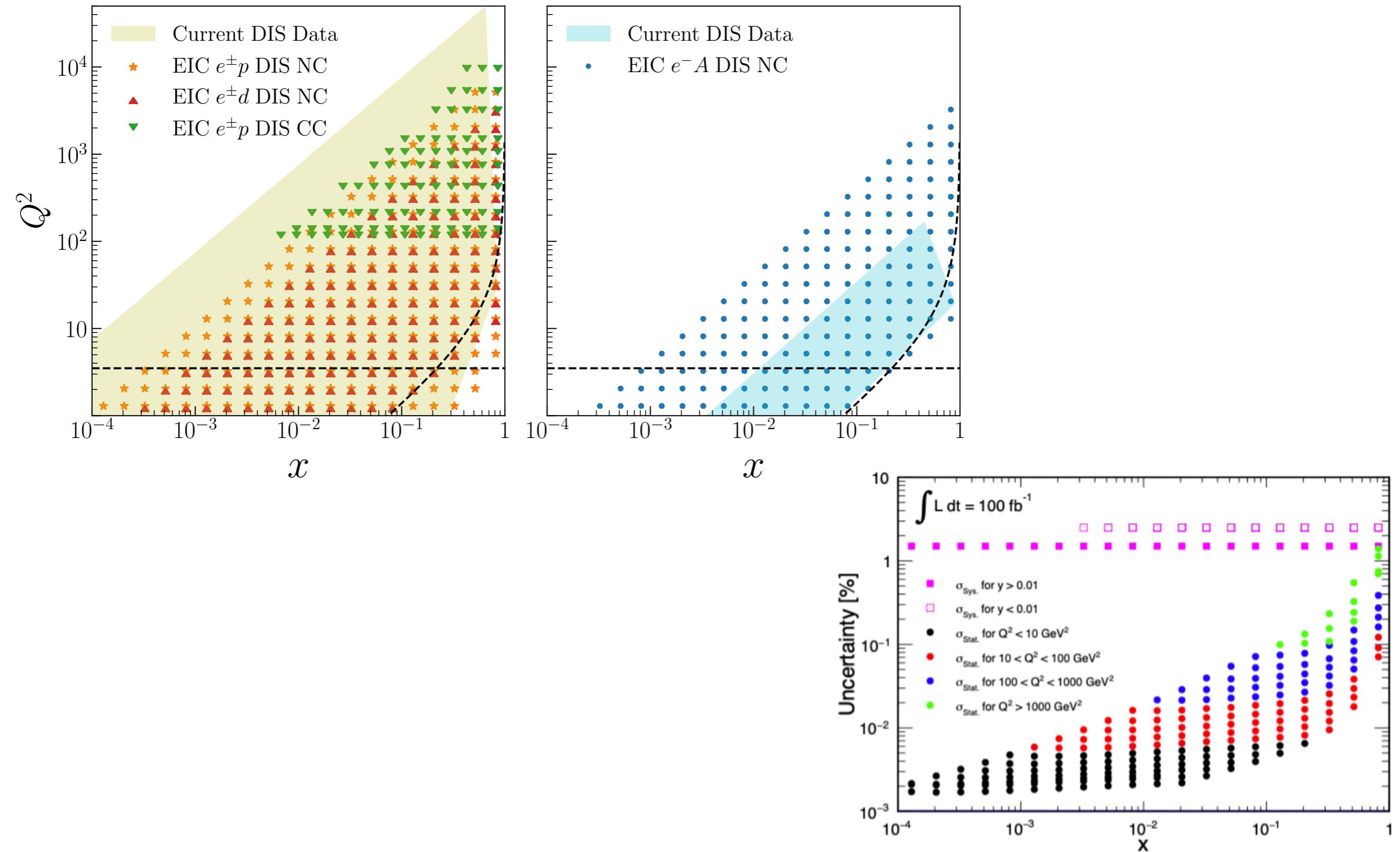
EPPS16 –

“After reweighting, a much more reasonable χ^2/N (1.4) value for the dijet data was found, but this came with a price of a rather high penalty term, i.e. the new central set had diverted quite far from the original minimum. The reason for this apparent discrepancy χ^2/N (2.0) between CT14 and the dijet data remains elusive.”

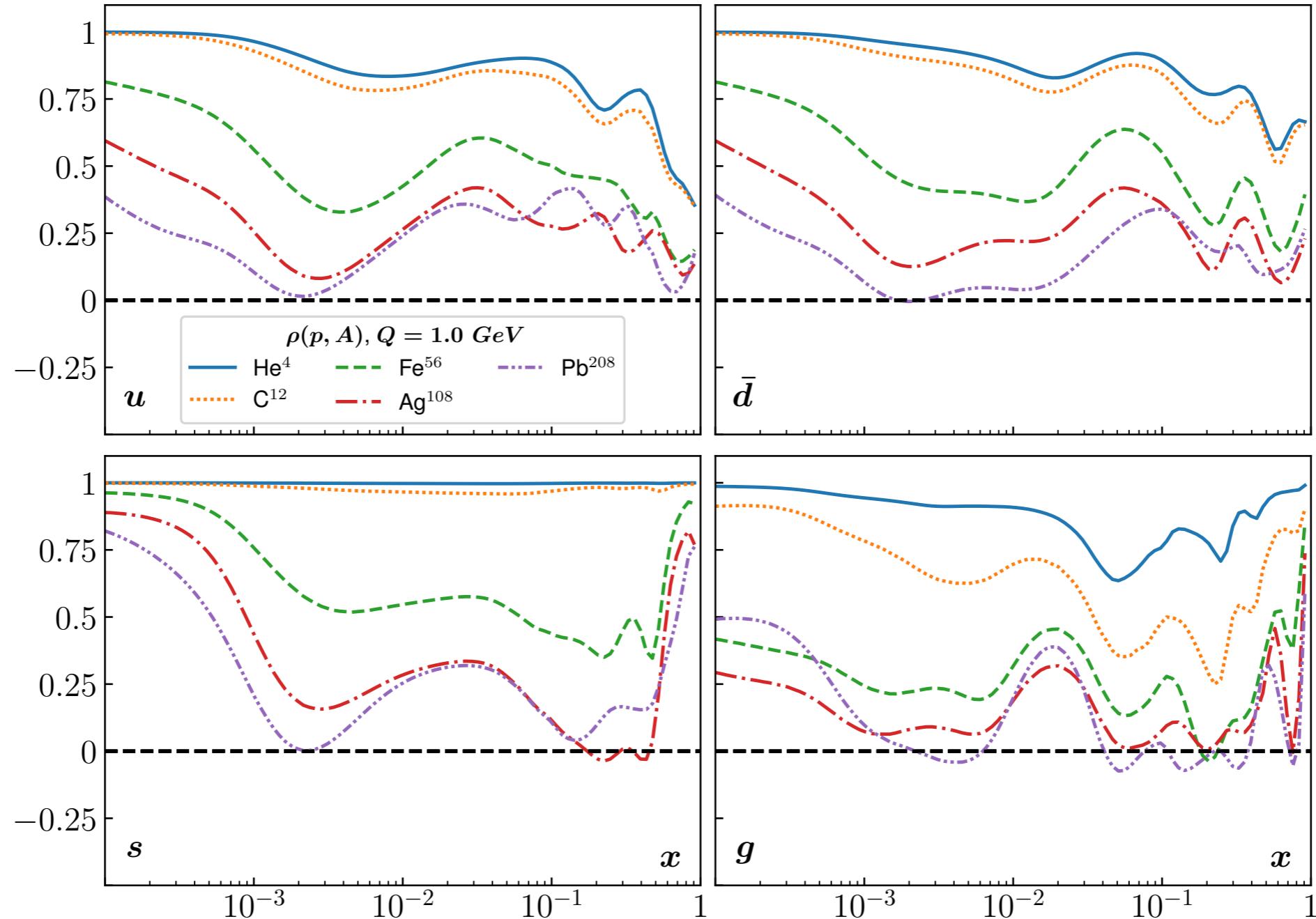
Part 2

EIC Impact

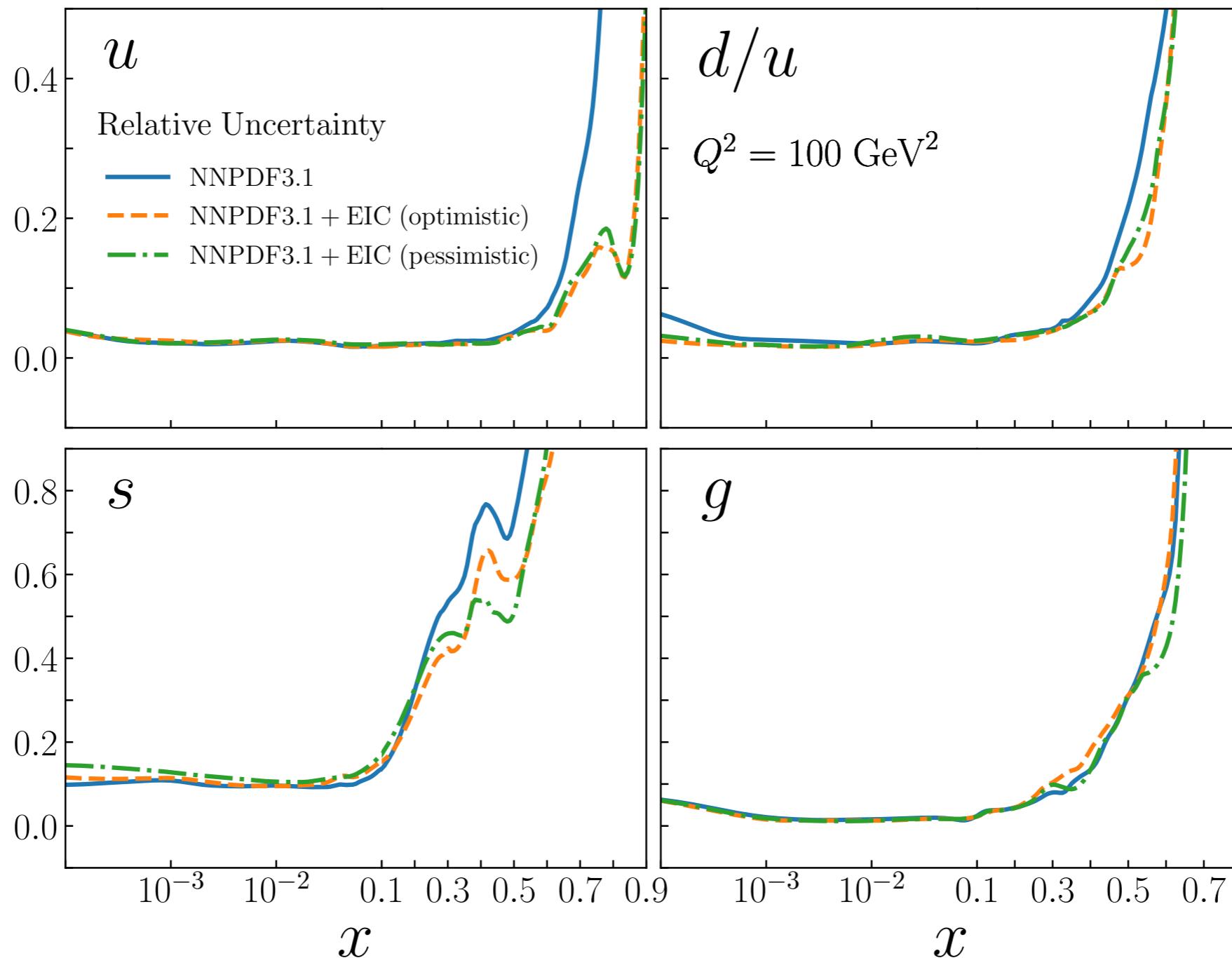
EIC unpolarised projections



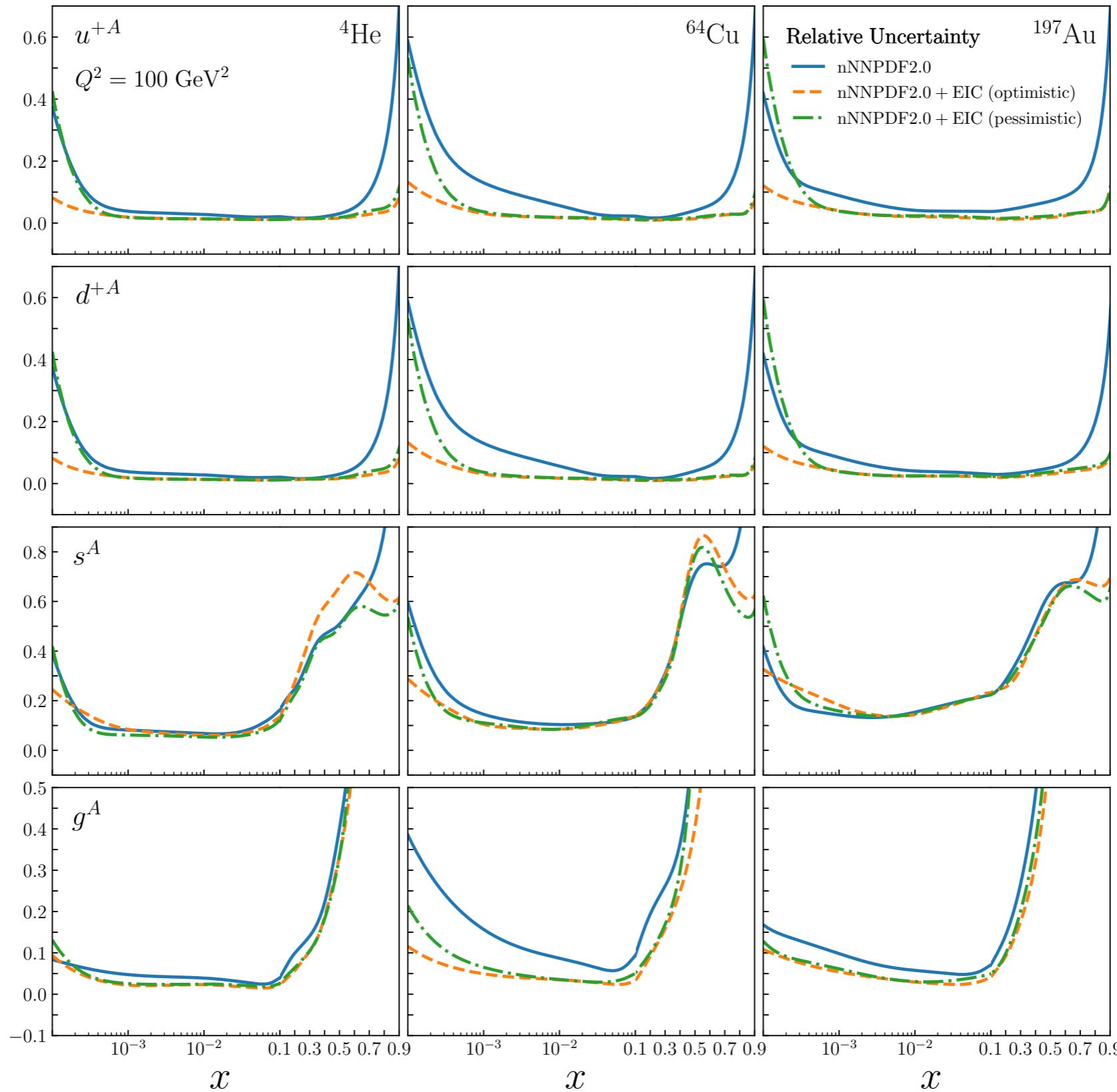
Emphasis on PDF/nPDF correlation



EIC impact on PDFs



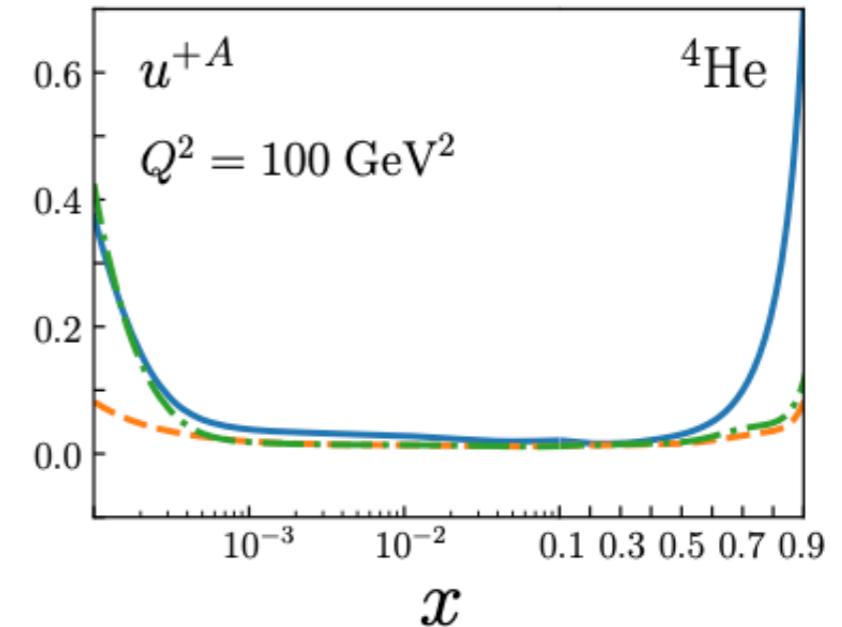
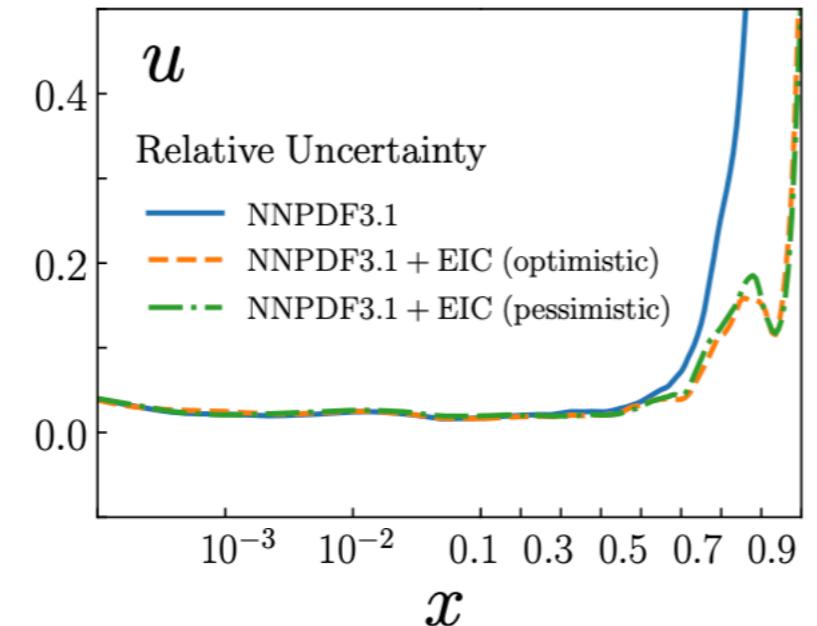
EIC impact on nPDFs



Conclusion

Recap

- ◆ EIC could reduce the uncertainty of the light quark PDFs of the proton at large x , and, more significantly, the quark and gluon PDF uncertainties for nuclei in a wide range of atomic mass A values both at small and large x .
- ◆ In general the size of this reduction turns out to be similar for both the optimistic and pessimistic scenarios. We therefore conclude that it may be sufficient to control experimental uncertainties to the level of precision forecast in the latter scenario.
- ◆ The reduction of PDF uncertainties is localized in the small- x region, where little or no data are currently available and in the large- x region, where nuclear PDF benefit from the increased precision of the baseline proton PDFs.



Appendix

Dijet Paper

Experiment	Measurement	\sqrt{s} [TeV]	\mathcal{L} [fb^{-1}]	R	Distribution	n_{dat}
ATLAS	Inclusive jets	7	4.5	0.6	$d^2\sigma/dp_T d y $	140
CMS	Inclusive jets	7	4.5	0.7	$d^2\sigma/dp_T d y $	133
ATLAS	Inclusive jets	8	20.2	0.6	$d^2\sigma/dp_T d y $	171
CMS	Inclusive jets	8	19.7	0.7	$d^2\sigma/dp_T d y $	185
ATLAS	Dijets	7	4.5	0.6	$d^2\sigma/dm_{jj} d y^* $	90
CMS	Dijets	7	4.5	0.7	$d^2\sigma/dm_{jj} d y_{\max} $	54
CMS	Dijets	8	19.7	0.7	$d^3\sigma/dp_{T,\text{avg}} dy_b dy^*$	122

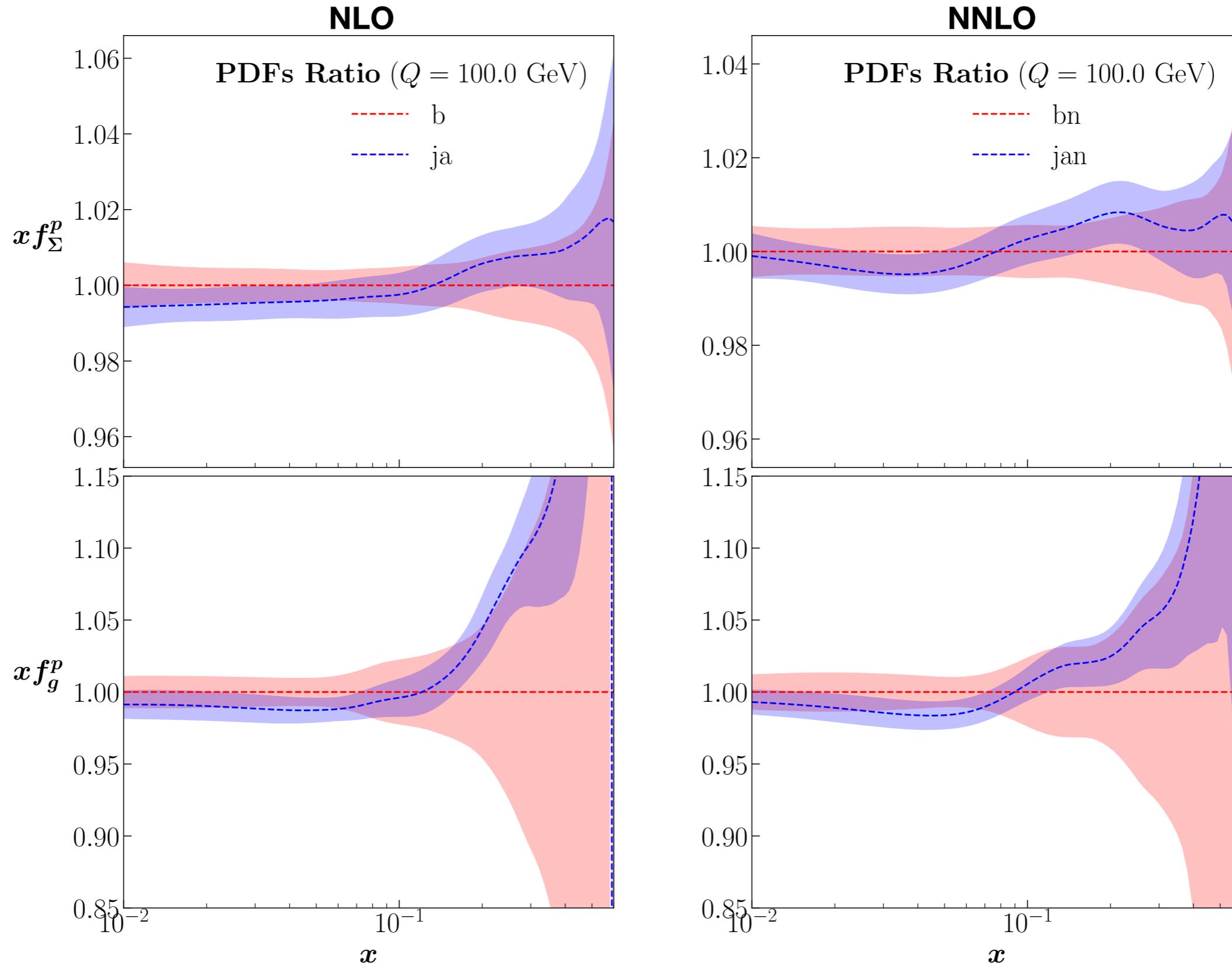
	NLO _{QCD}	NNLO _{QCD}	+ EW corrections considered in the paper
baseline (NNPDF3.1 w/o jets)	b	bn	
ATLAS & CMS jets 7-8 TeV	ja	jan	
ATLAS & CMS dijets 7-8 TeV	da	dan	

Absence of correlation

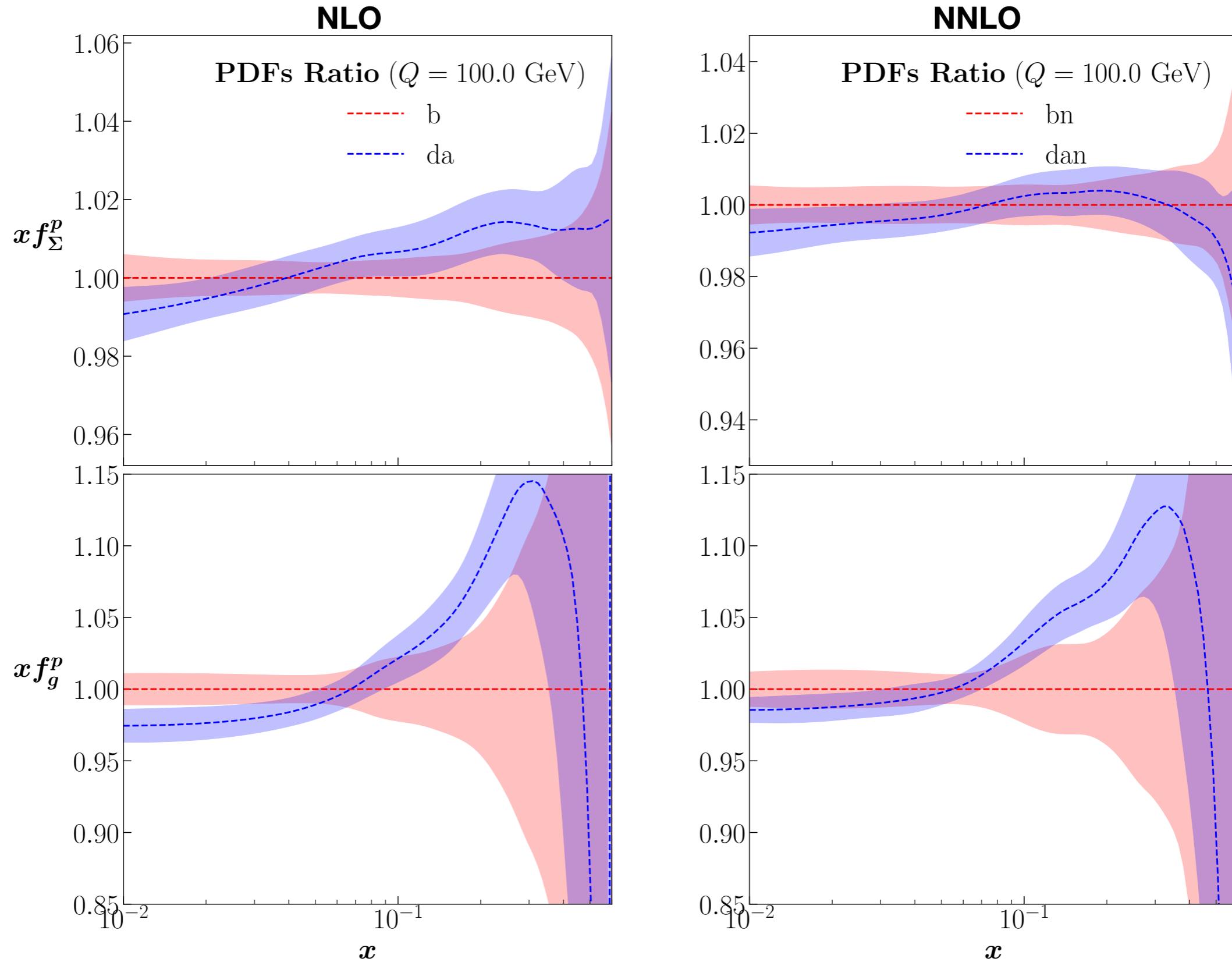
Fit quality

Dataset	n_{dat}	NLO			NNLO			
		b	ja	da	n_{dat}^*	bn	jan	dan
DIS NC	2113	1.19	1.20	1.23	2103	1.18	1.19	1.19
DIS CC	989	1.04	1.07	1.10	989	1.08	1.09	1.08
Drell-Yan	567	1.35	1.35	1.35	580	1.37	1.33	1.31
$Z p_T$	120	1.97	2.04	2.16	120	1.03	1.06	1.11
Top pair	25	1.12	2.27	1.53	25	1.07	1.55	1.39
ATLAS $\sigma_{t\bar{t}}$	3	2.02	1.58	1.06	3	0.90	0.79	0.68
ATLAS $t\bar{t}$ rap	10	1.12	3.45	2.16	10	1.21	2.53	2.08
CMS $\sigma_{t\bar{t}}$	3	0.53	0.30	0.05	3	0.22	0.16	0.64
CMS $t\bar{t}$ rap	9	1.01	1.83	1.49	9	1.24	1.18	1.12
Jets (all)	629	[1.52]	1.21	[1.56]	629	[2.63]	1.78	[2.04]
ATLAS 7 TeV	140	[0.92]	0.74	[0.86]	140	[1.64]	1.36	[1.48]
ATLAS 8 TeV	171	[2.60]	2.14	[2.31]	171	[5.01]	3.23	[3.36]
CMS 7 TeV	133	[0.60]	0.66	[0.76]	133	[1.06]	0.93	[0.99]
CMS 8 TeV	185	[1.64]	1.12	[1.97]	185	[2.29]	1.35	[2.00]
Dijets (all)	266	[4.17]	[3.99]	2.67	266	[3.52]	[2.40]	1.81
ATLAS 7 TeV	90	[1.49]	[1.50]	1.04	90	[2.47]	[2.28]	1.96
CMS 7 TeV	54	[2.08]	[1.78]	1.65	54	[2.41]	[2.06]	1.75
CMS 8 TeV	122	[7.07]	[6.80]	4.33	122	[4.79]	[2.65]	1.72
Total		1.20	1.21	1.33		1.18	1.27	1.22

Single Jet



Dijet



nNNPDF2.0 + p-Pb CMS 5 TeV

