



Recent developments in Nuclear PDFs

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Comunidad
de Madrid



Outline

- * Brief recap on parton distributions.
- * Why nPDFs? Why do we do this to ourselves?
WHY?!?!?
- * Latest sets and comparison.
- * Which one is the best?
- * Summary.

PDFs

- * In pQCD we can write “any” observable as

$$\mathcal{O} = \sum_{i=0}^{\infty} \alpha_s^i(\mu_r) O_i(\vec{\mu}, \vec{X})$$

$$O_i(\vec{\mu}, \vec{X}) = \sum_j C_{i,j}(\vec{\mu}, \vec{X}) \otimes \textcolor{red}{F}_j(\vec{\mu}, \vec{X})$$

PDFs

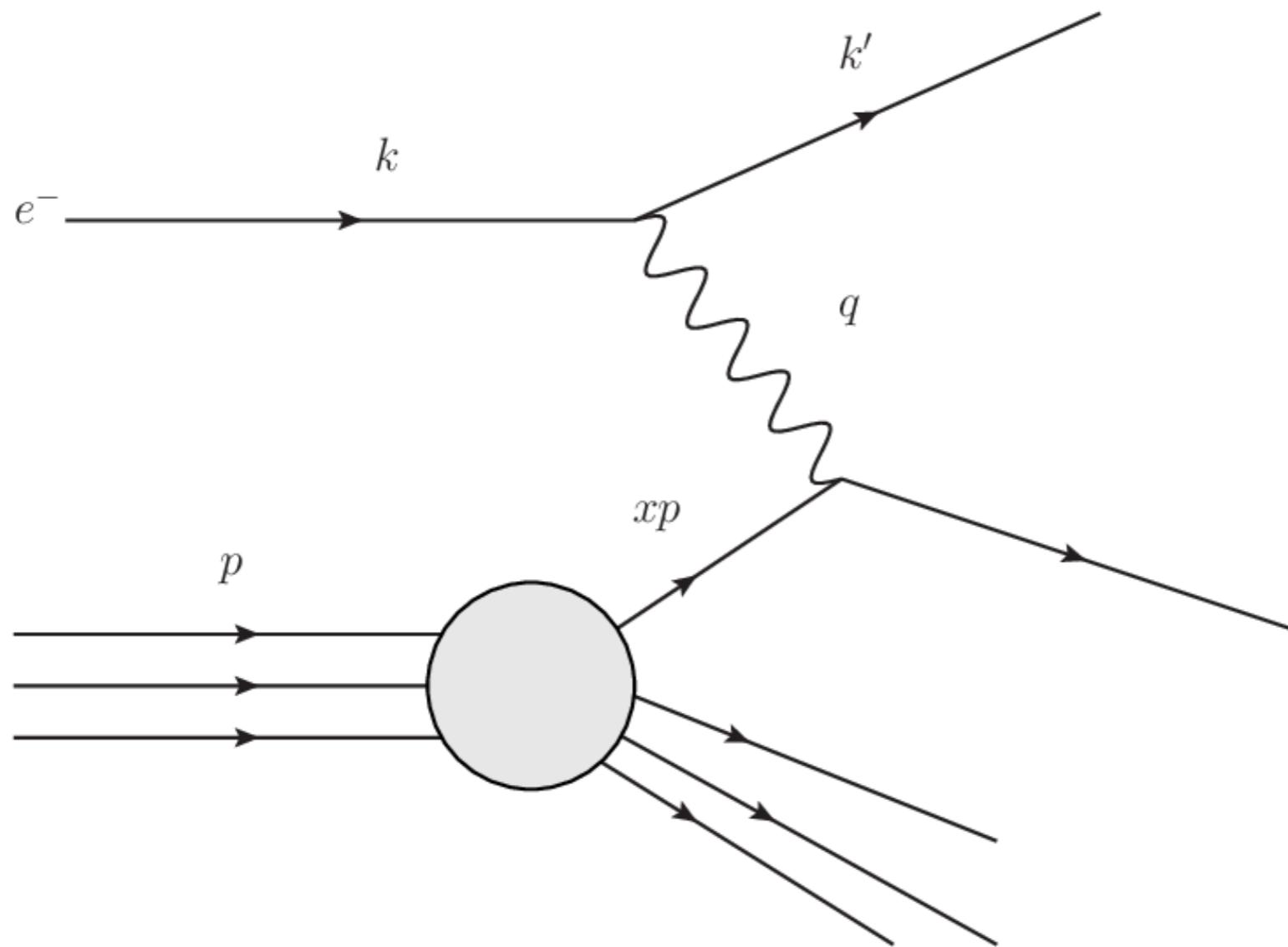
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- * $\textcolor{red}{F}_j(\vec{\mu}, \vec{X})$ are universal, non-perturbative and scale dependent ***parton distribution functions.***

The simplest process we can do is DIS: $l + p \rightarrow l' + X$.



$$Q^2 = -q^2$$

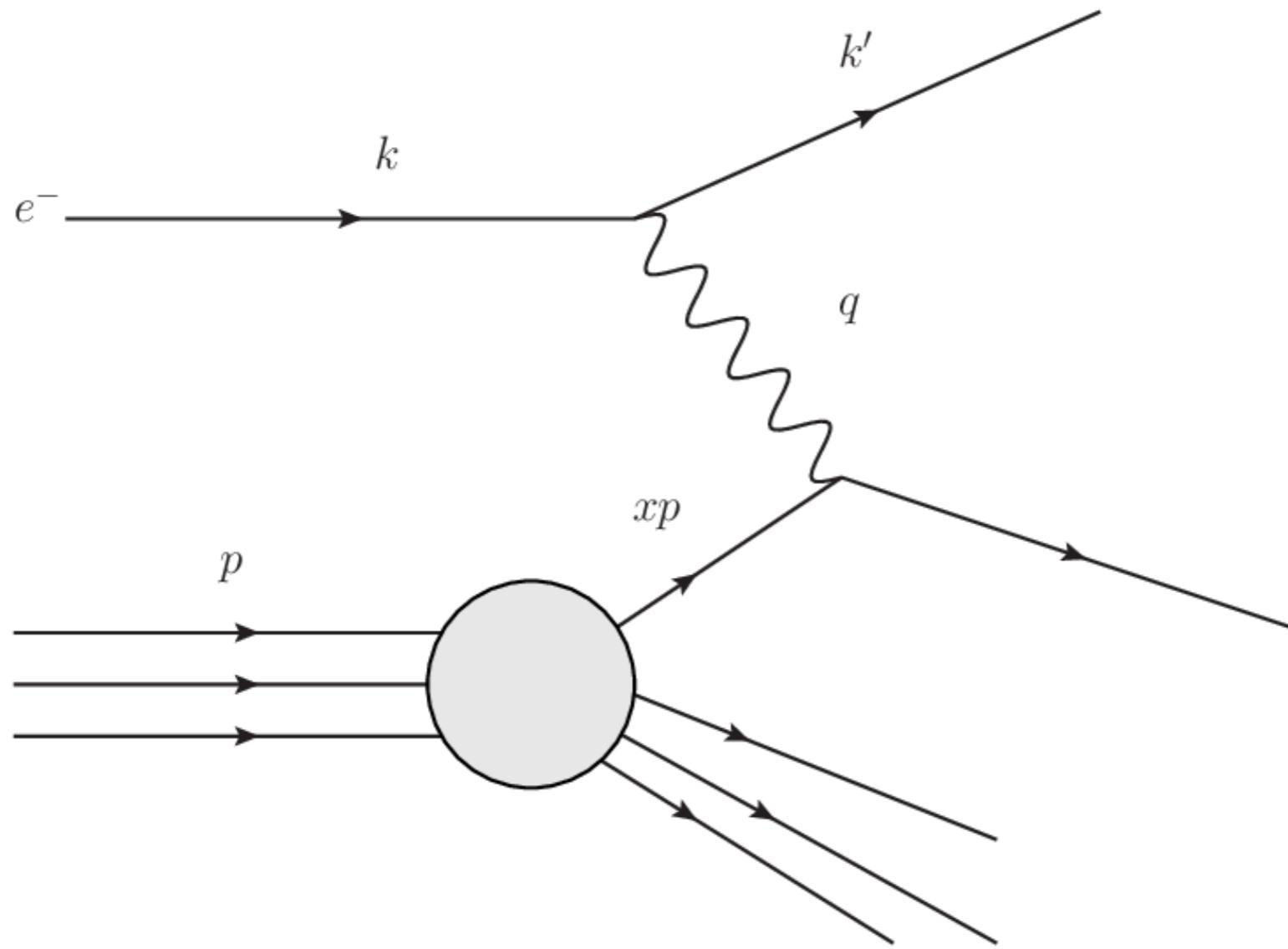
$$x = \frac{Q^2}{2p \cdot q}$$

$$W^2 = (p + q)^2$$

$$y = \frac{p \cdot q}{p \cdot l}$$

$$\frac{d^2\sigma^{NC}}{dxdQ^2} \propto F_2 - \frac{y^2}{1 + (1 - y)^2} F_L$$

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$$Q^2 = -q^2 \quad x = \frac{Q^2}{2p \cdot q}$$

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$$f_{proton}^S(x, Q^2) = \sum_{i=1}^{N_f} f_i(x, Q^2)$$

$$f_{proton}^{NS}(x, Q^2) = \sum_{i=1}^{N_f} e_i^2 f_i(x, Q^2)$$

$$g_{proton}(x, Q^2)$$

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- * NC-DIS is not enough to fully separate flavours. We complement it with CC-DIS, Drell-Yan, EW-boson production, jets, etc.
- * These are free proton collinear PDFs (a.k.a. PDFs). But we can do the same for other hadrons, the final state (FFs), TMDPDFs, TMDFFs, GPDs, etc.

Why nPDFs?

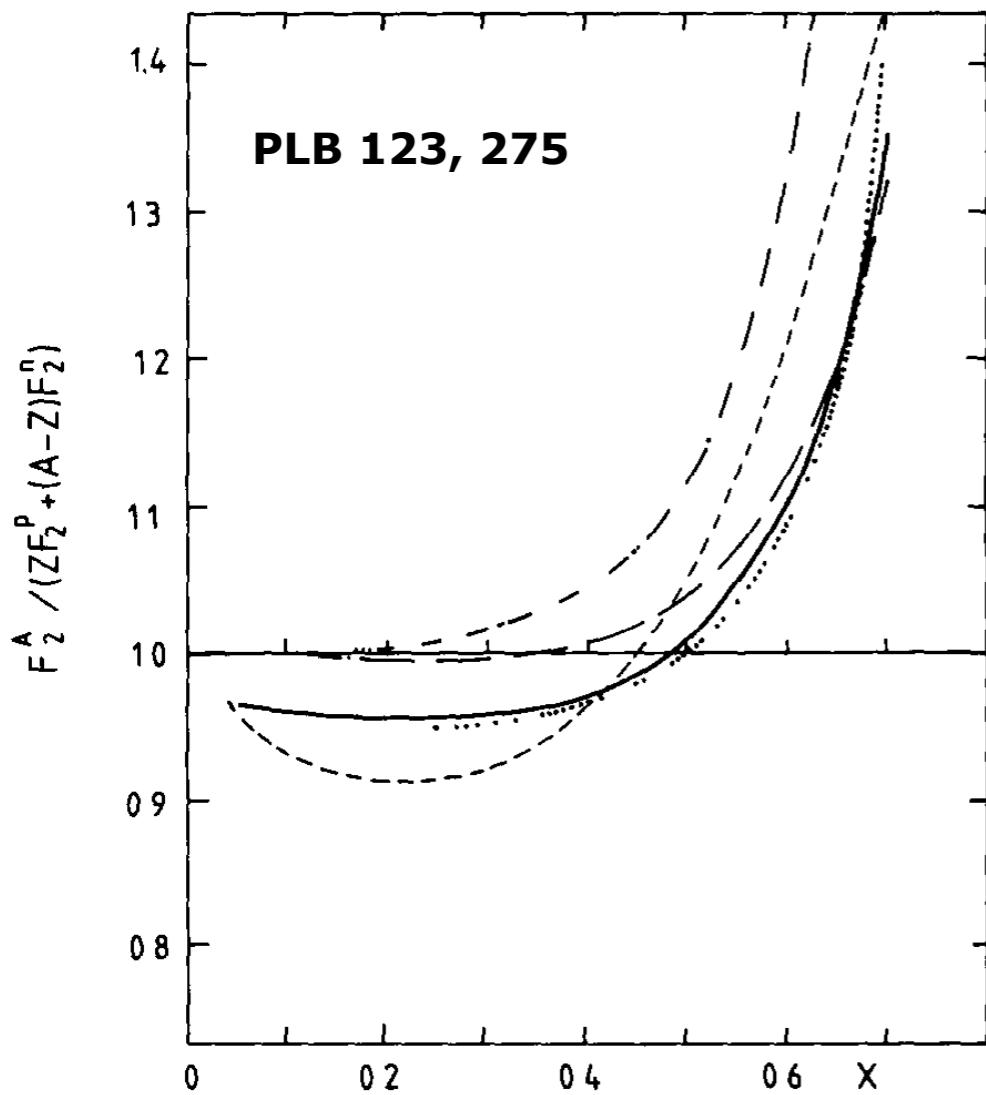
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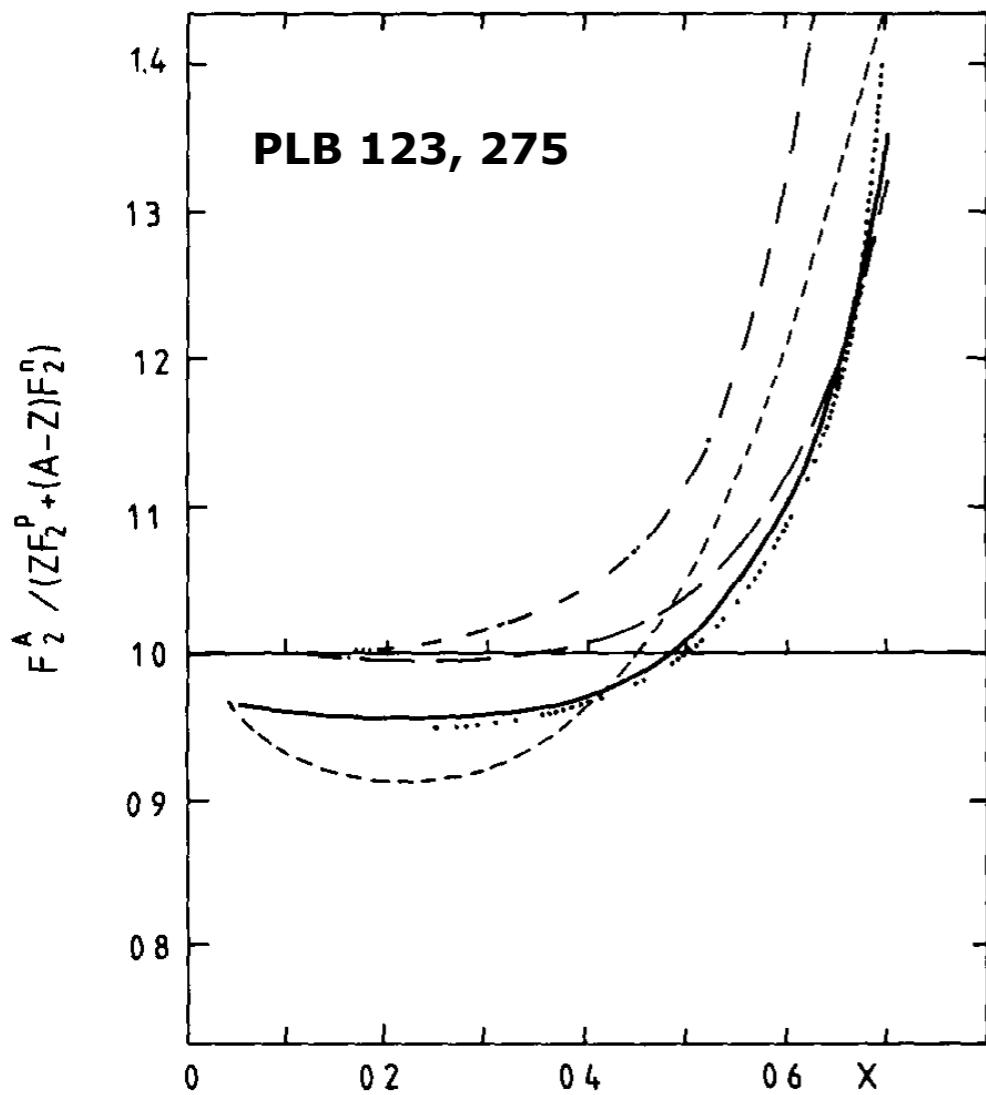
Expectation



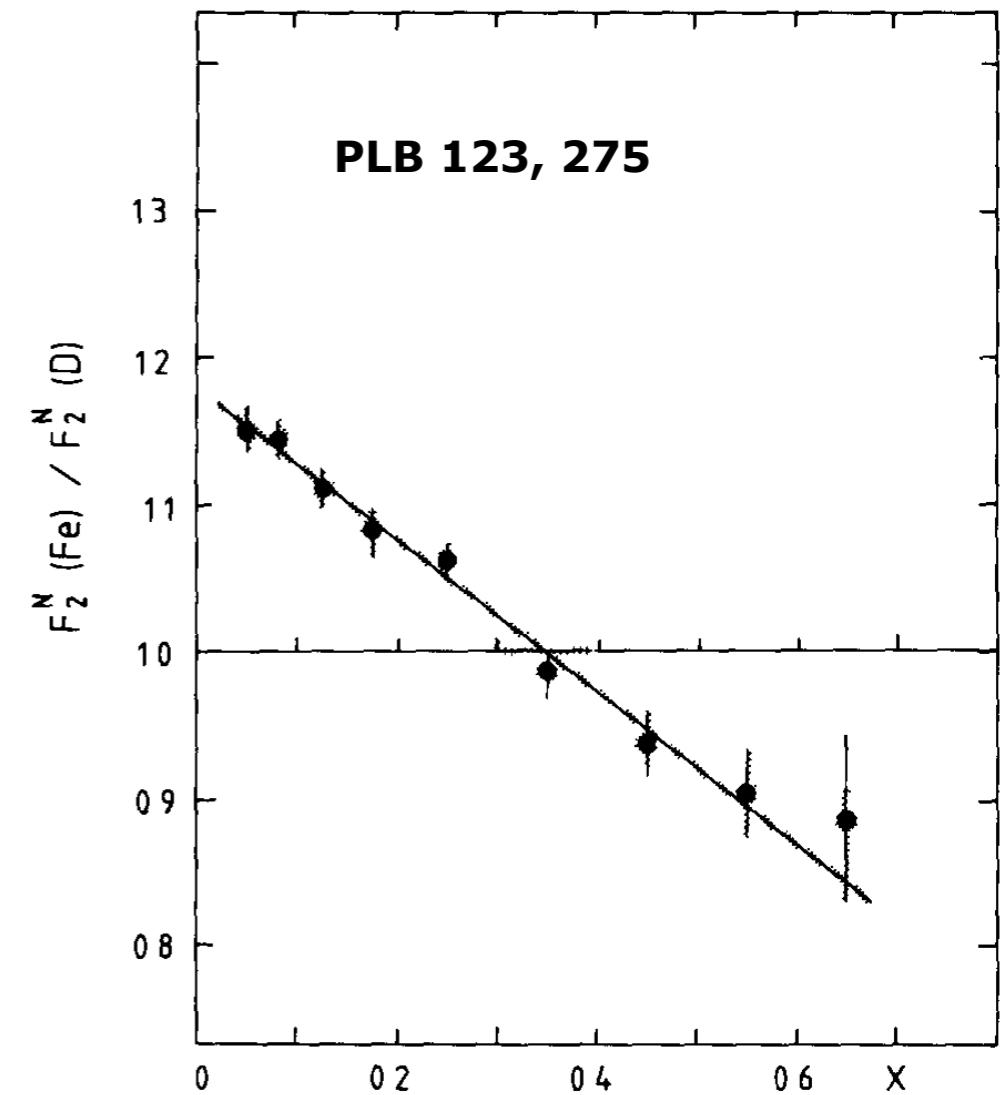
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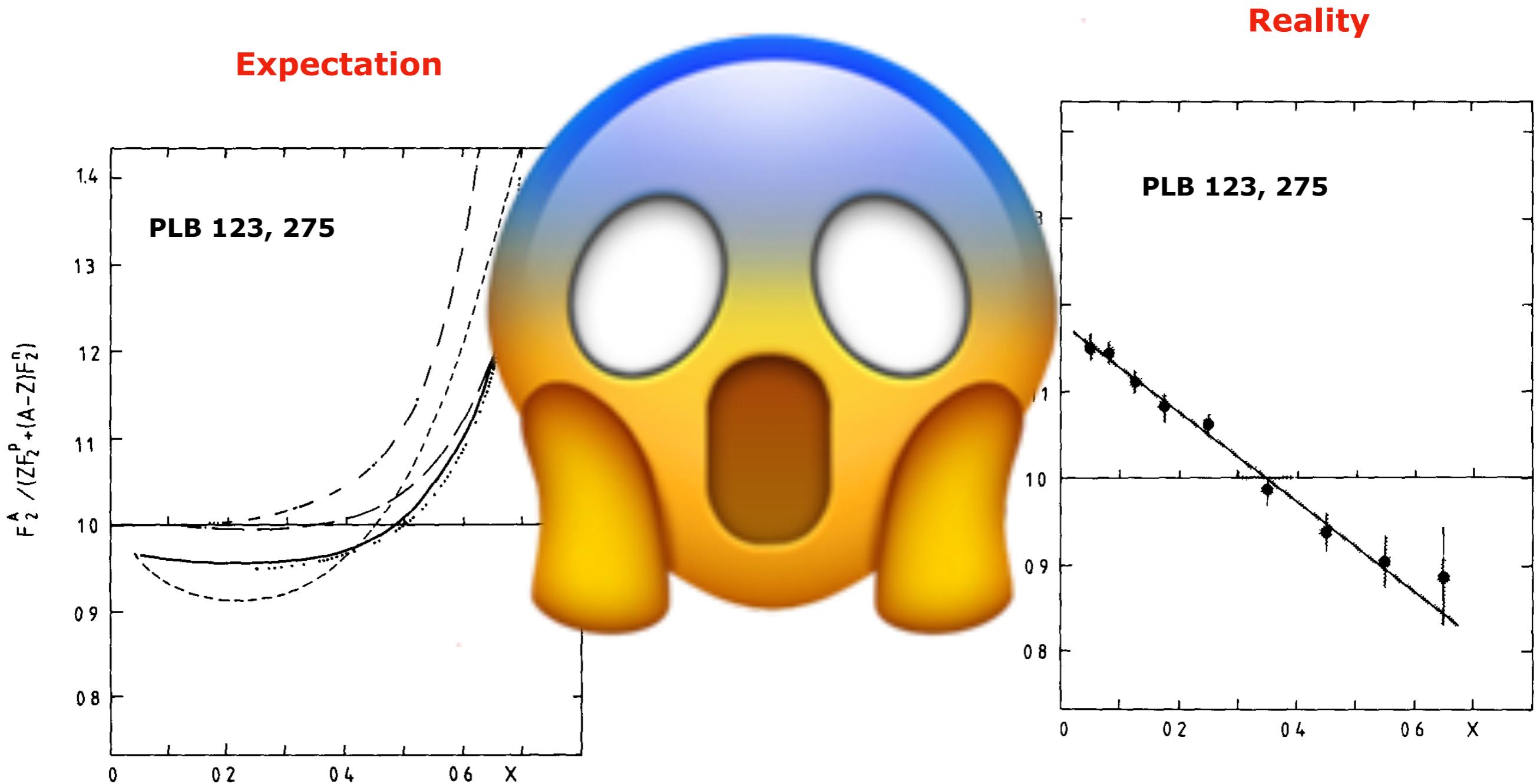


Reality

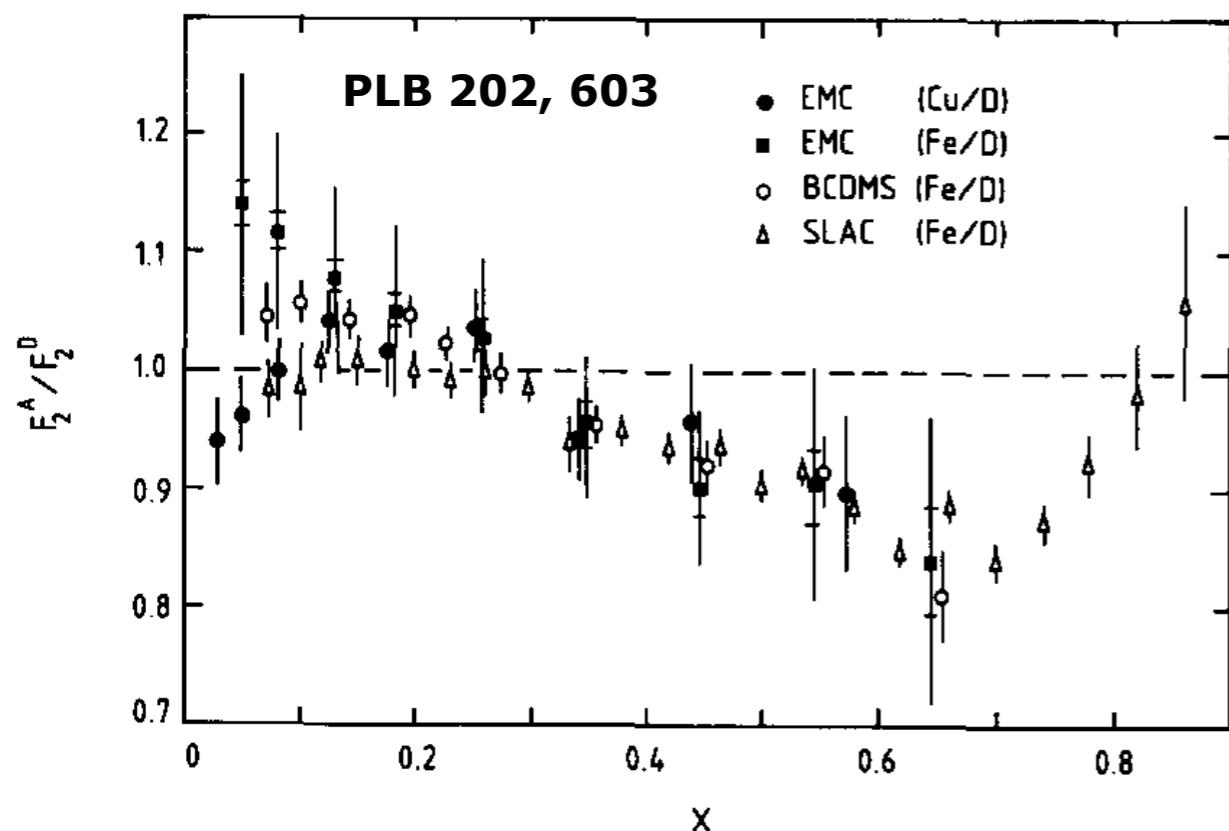


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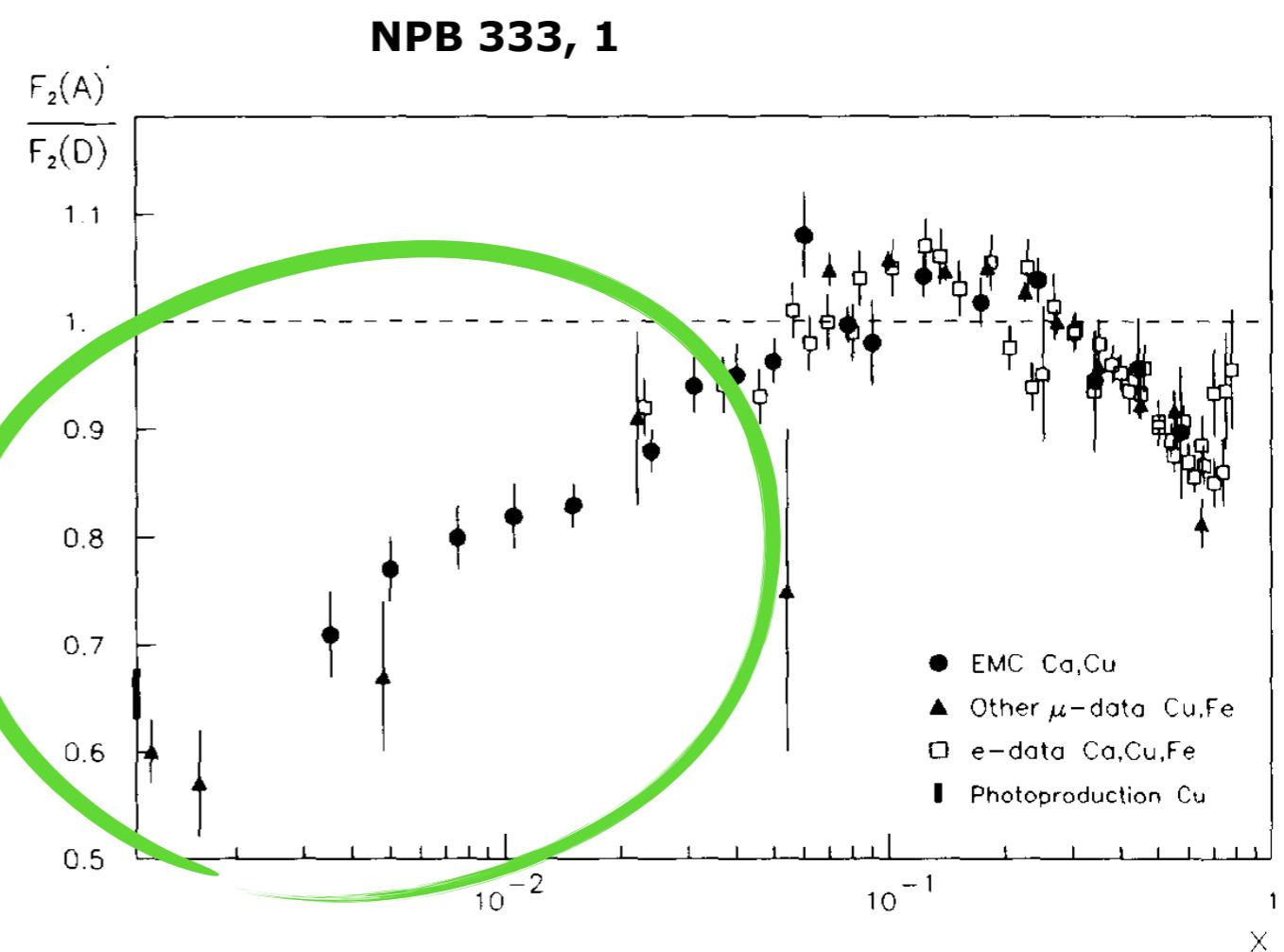
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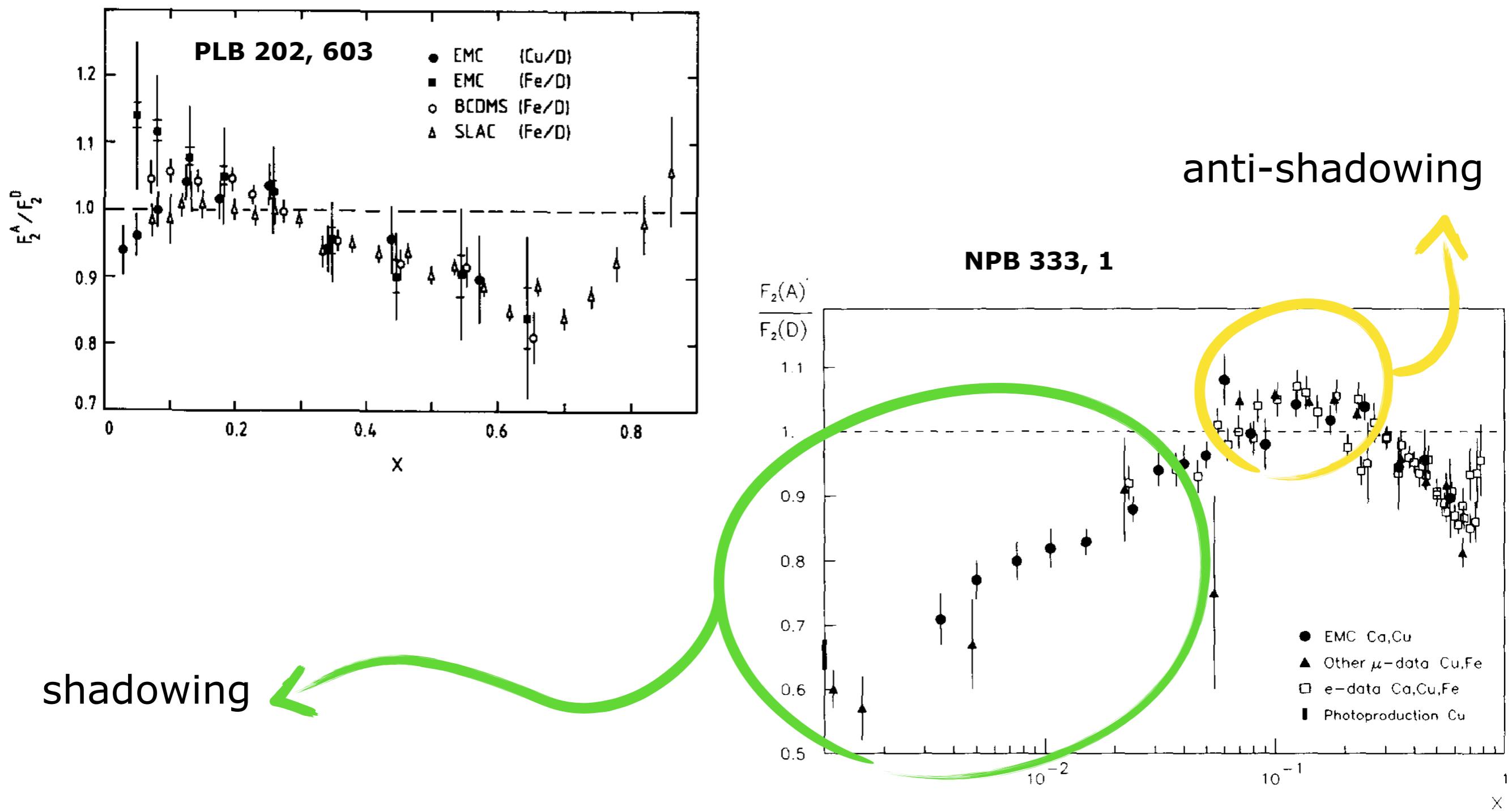
The more they measured, the more differences they found. The effects follow a very particular pattern:



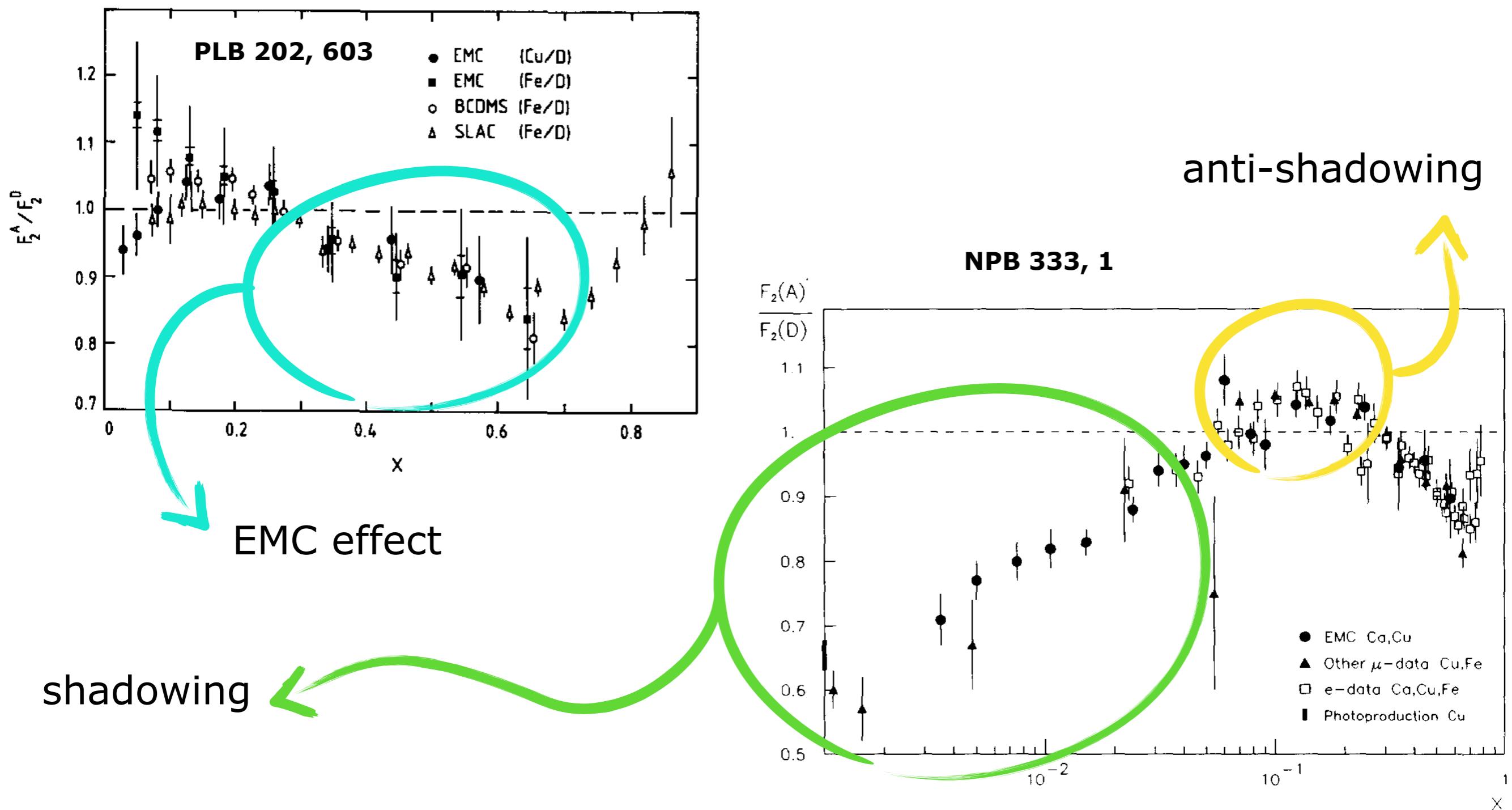
shadowing



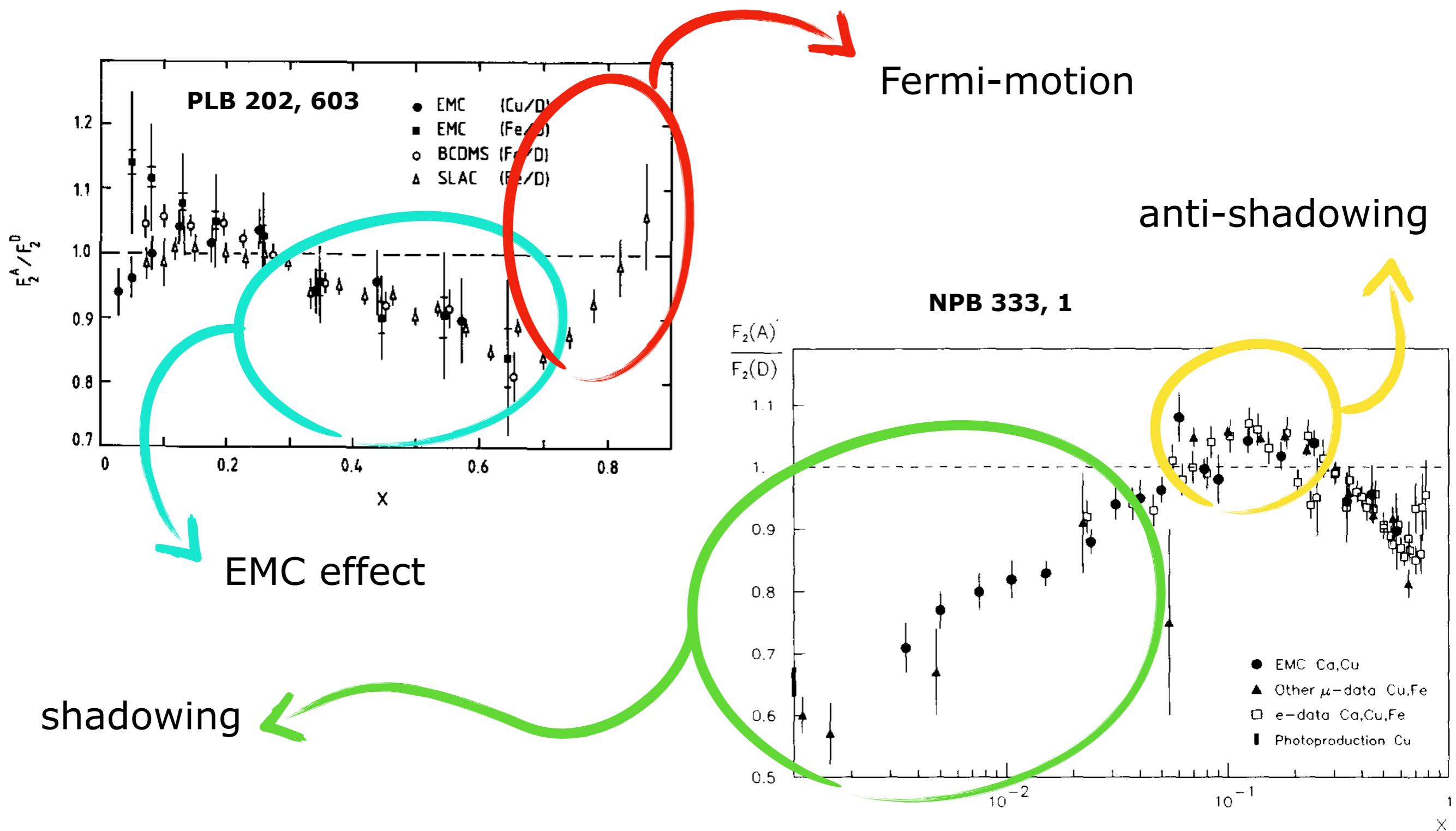
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- * But we can see if, just like PDFs, we can describe the data with just some parameters and "**without assumptions**".
- * We introduce de concept of **nuclear PDF**: like a PDF, but for a nucleus.
- * And we test this idea by **doing fits** to data. The procedure is the same as for proton PDFs.

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- * Because we are curious. We want to understand.

$$f_{i/A}(x, Q^2) = \frac{Z}{A} f_{i/p/A}(x, Q^2) + \frac{(A - Z)}{A} f_{i/n/A}(x, Q^2)$$

Sets

- *  and : **nCTEQ15**: PRD 93, 085037. **nCTEQ15WZ**: EPJC 80, 968.
nCTEQ15HiX: PRD 103, 114015. **nCTEQ15WZ+SIH**: PRD 104, 094005.
nCTEQ15HQ: PRD 105, 114043.

- *  and : **nDS**: PRD 69, 074028. **DSSZ**: PRD 85, 074028.

- * : **nTuJu19**: PRD 100, 096015. **nTuJu21**: PRD 105, 094031.

- * : **EKS**: EPJC 9, 61. **EPS09**: JHEP 0904, 065. **EPPS16**: EPJC 77, 163.
EPPS21: EPJC 82, 413.

- * : **HKM**: PRD 64, 034003. **HKN07**: PRC 76, 065207.

- *  and : **KA15**: PRD 93, 014026. **KSASG20**: PRD 104, 034010.

- * **NN**: **nNNPDF1.0**: EPJC 79, 471. **nNNPDF2.0**: JHEP 09, 183.
nNNPDF3.0: EPJC 82, 507.

Comparing sets

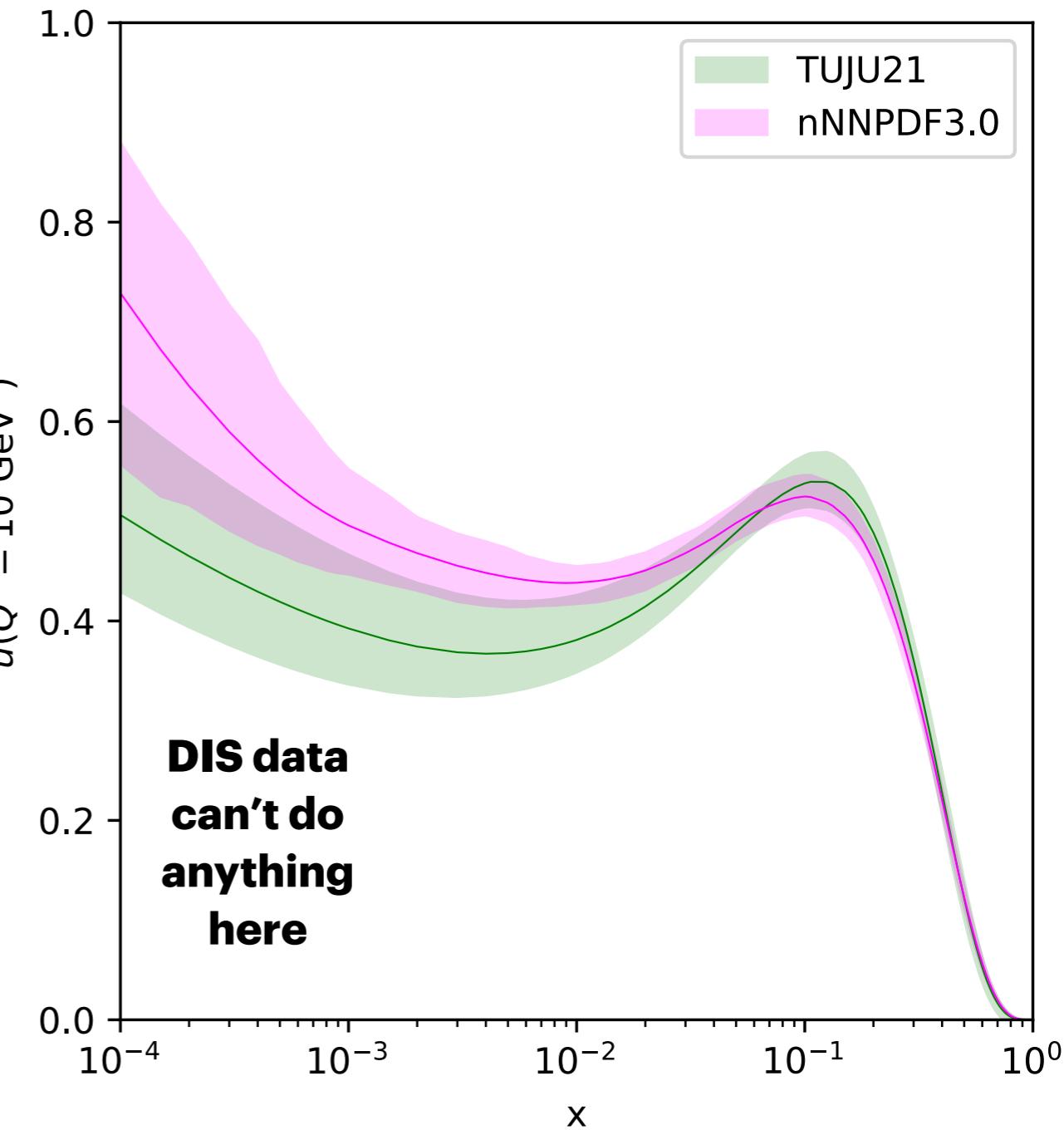
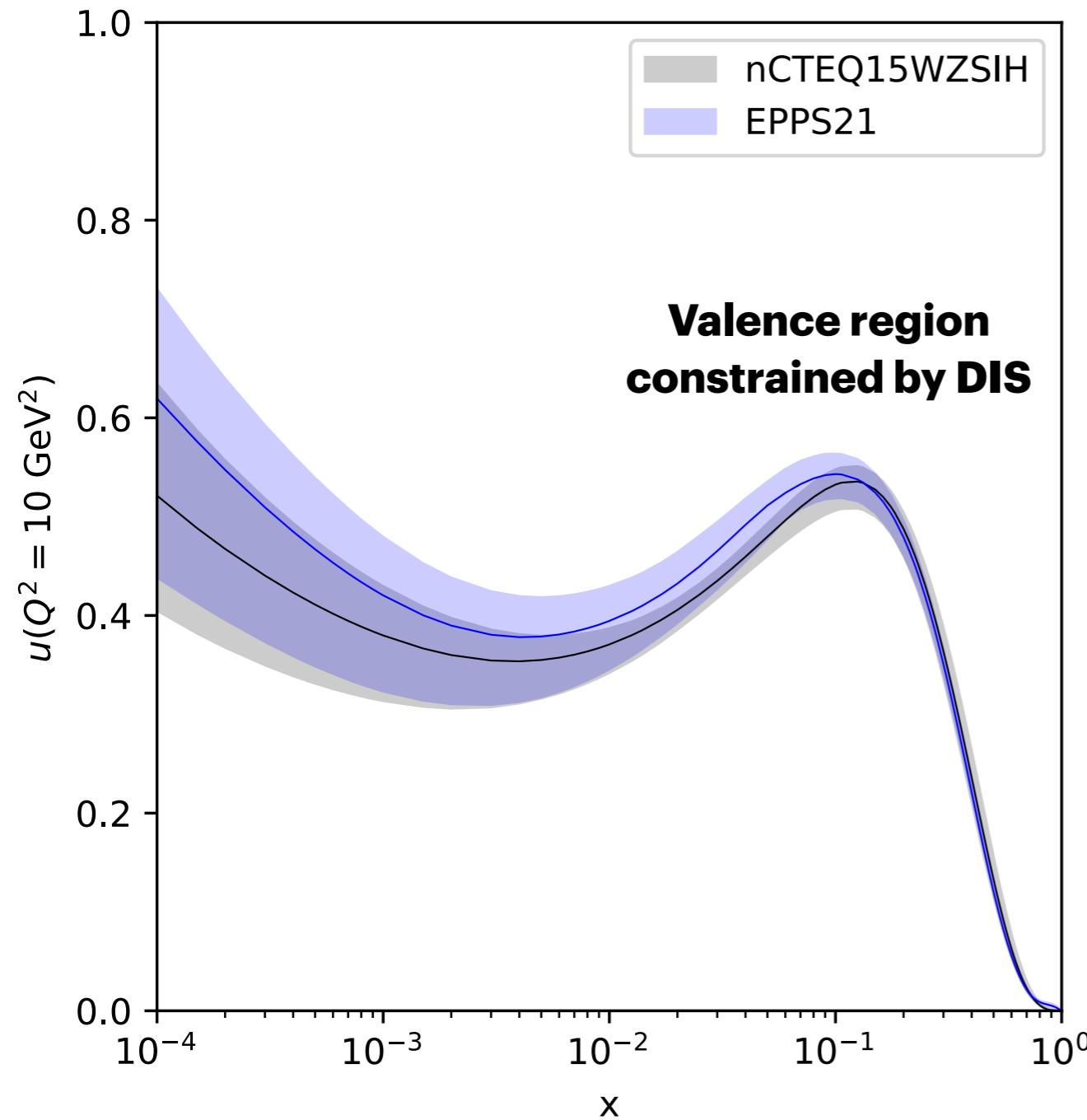
	KSASG20	TUJU21	EPPS21	nNNPDF3.0	nCTEQ15HQ
CC DIS	😊	😊	😊	😊	
DY: p+A	😊		😊	😊	😊
DY: π+A			😊		
SIH@RHIC			😊		😊
SIH@LHC					😊
di-jets@LHC			😊	😊	
W, Z @LHC		😊	😊	😊	😊
HQ@LHC			😊	😊	😊
direct γ@LHC				😊	
DIS cuts (GeV)	1.3, 0	1.87, 3.5	1.3, 1.8	1.87, 3.5	2.0, 3.5
proton PDF	CT18	own	CT18A	~NNPDF4.0	~CTEQ6M
# data points	4353	2410	2077	2188	1484

Different types of PASTA

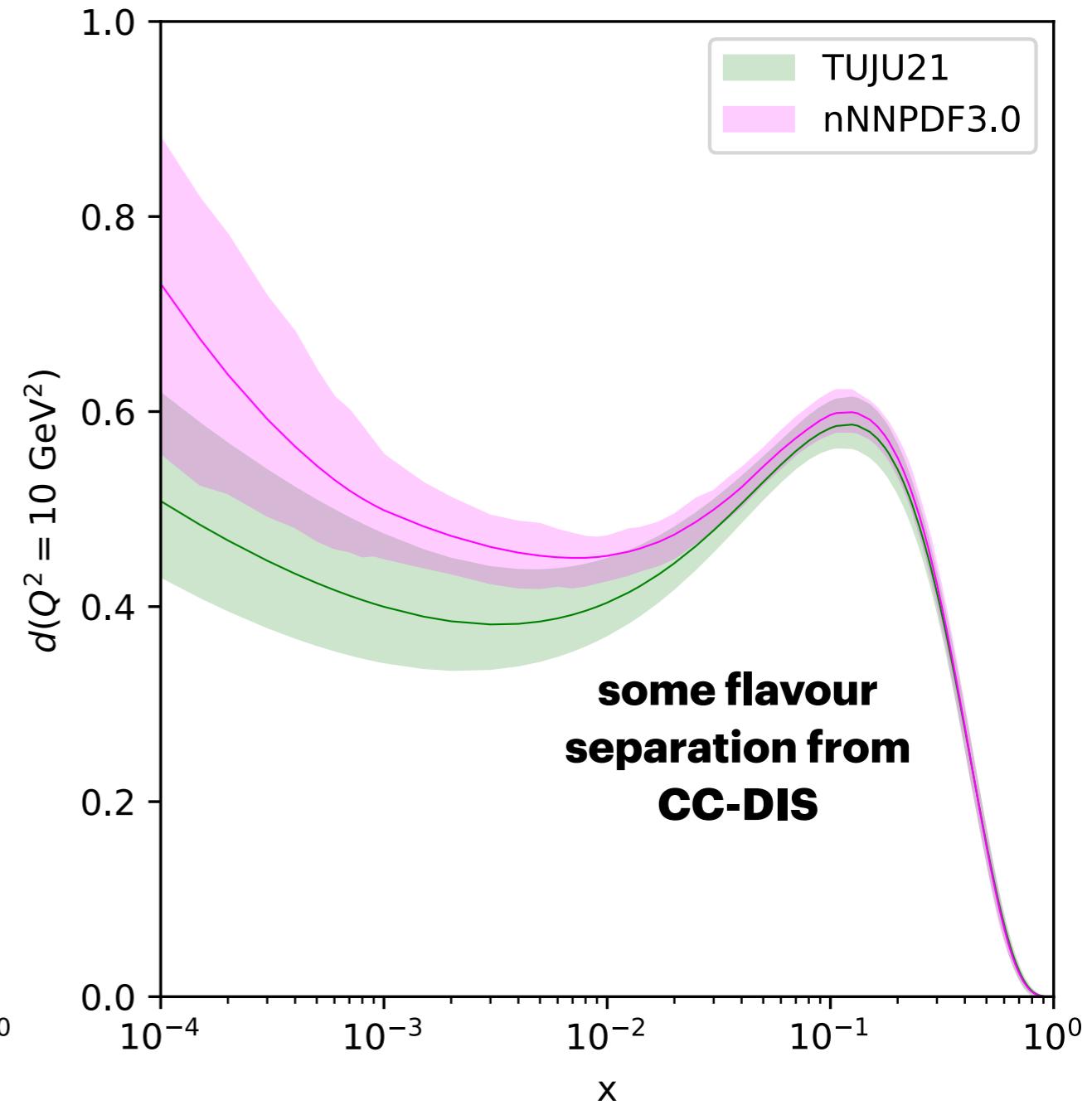
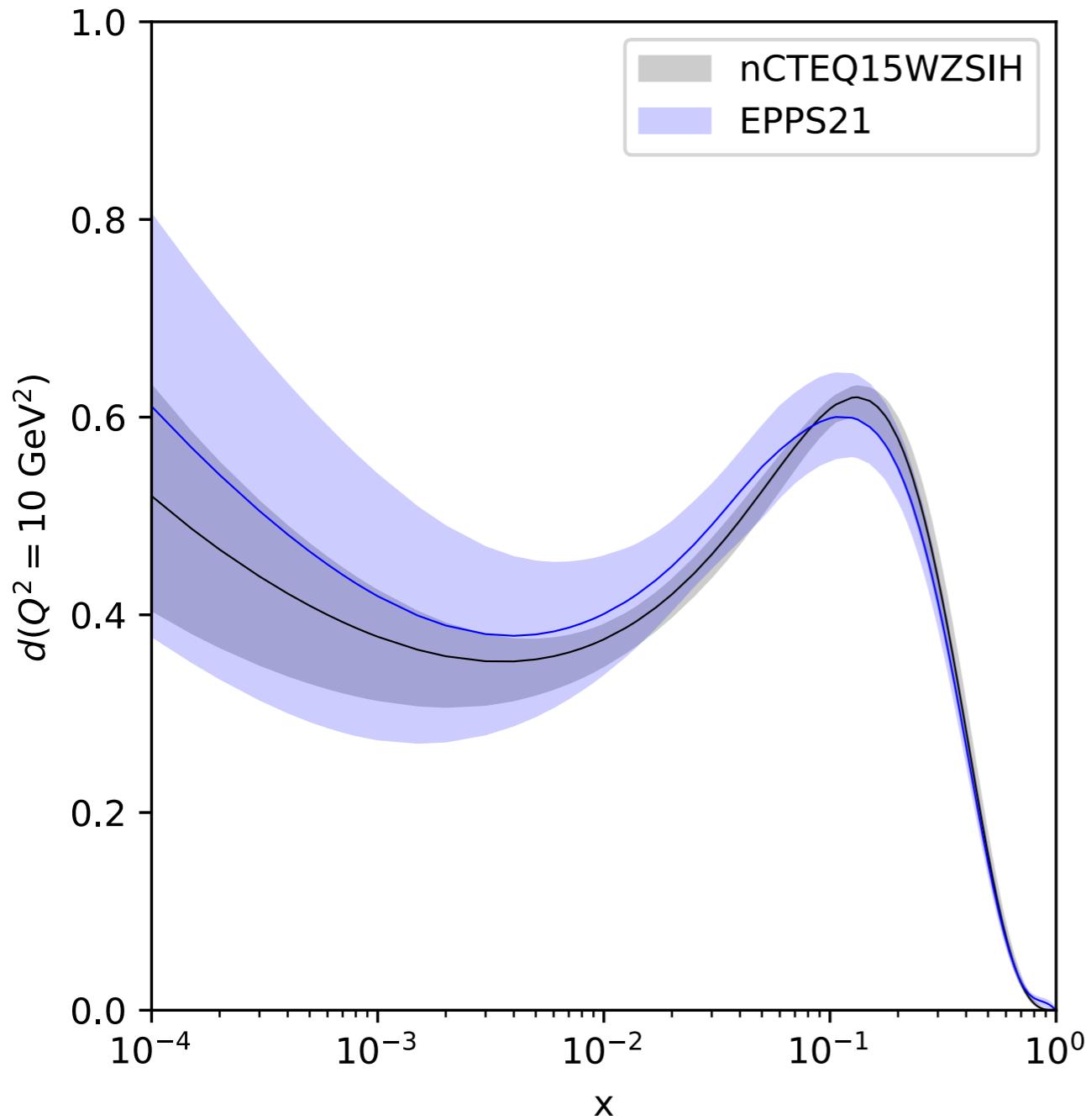
Comparing sets



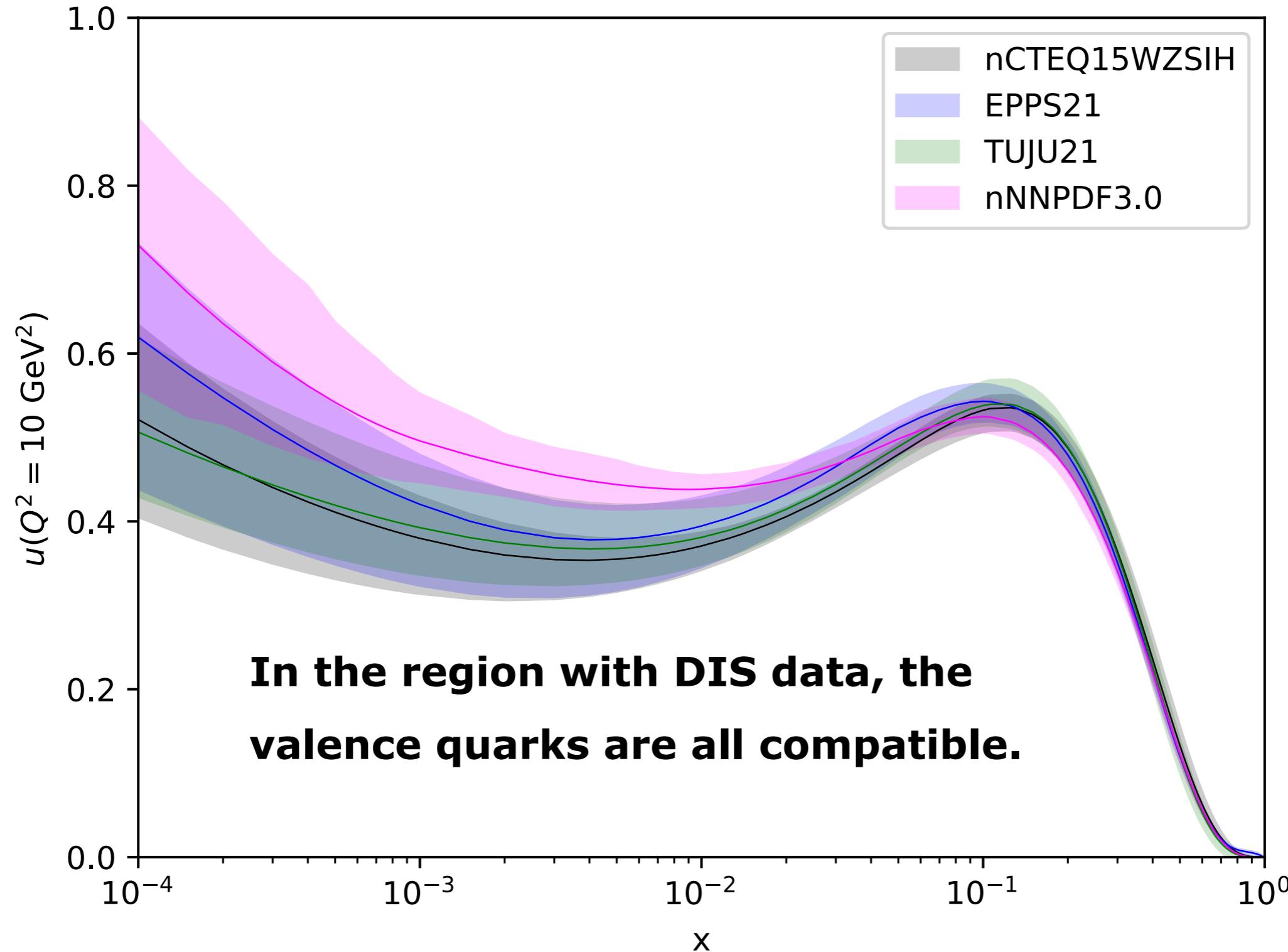
up



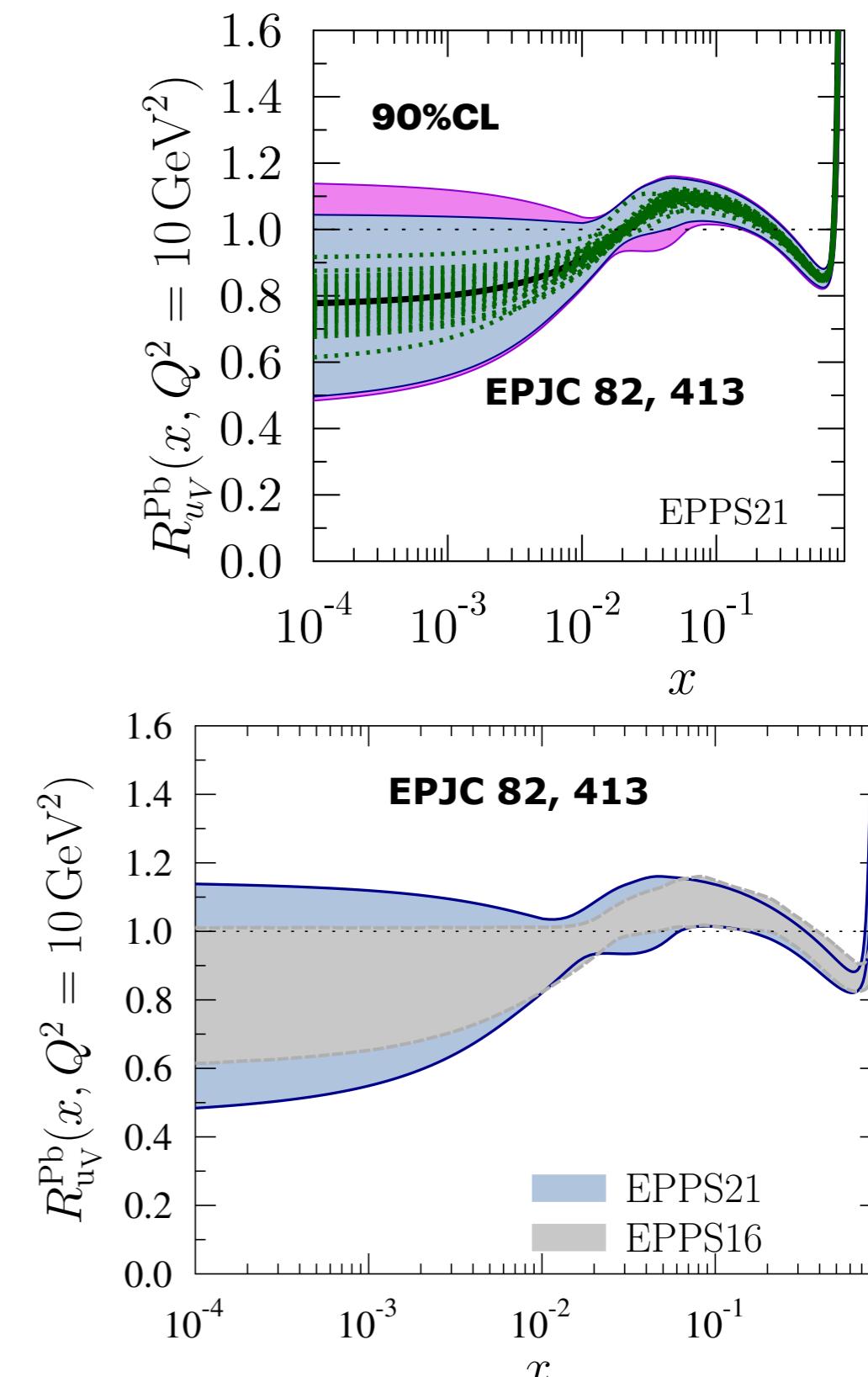
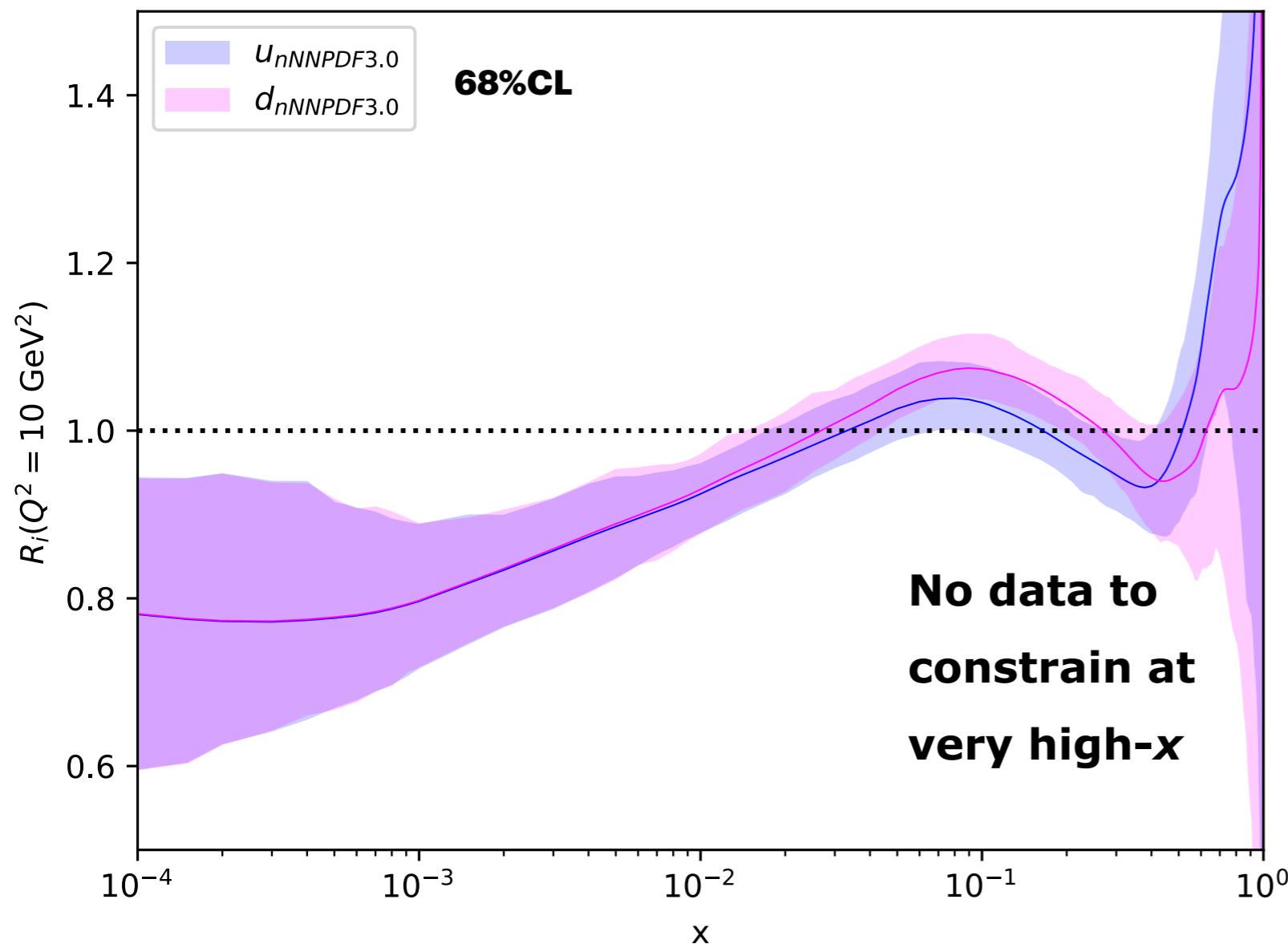
down



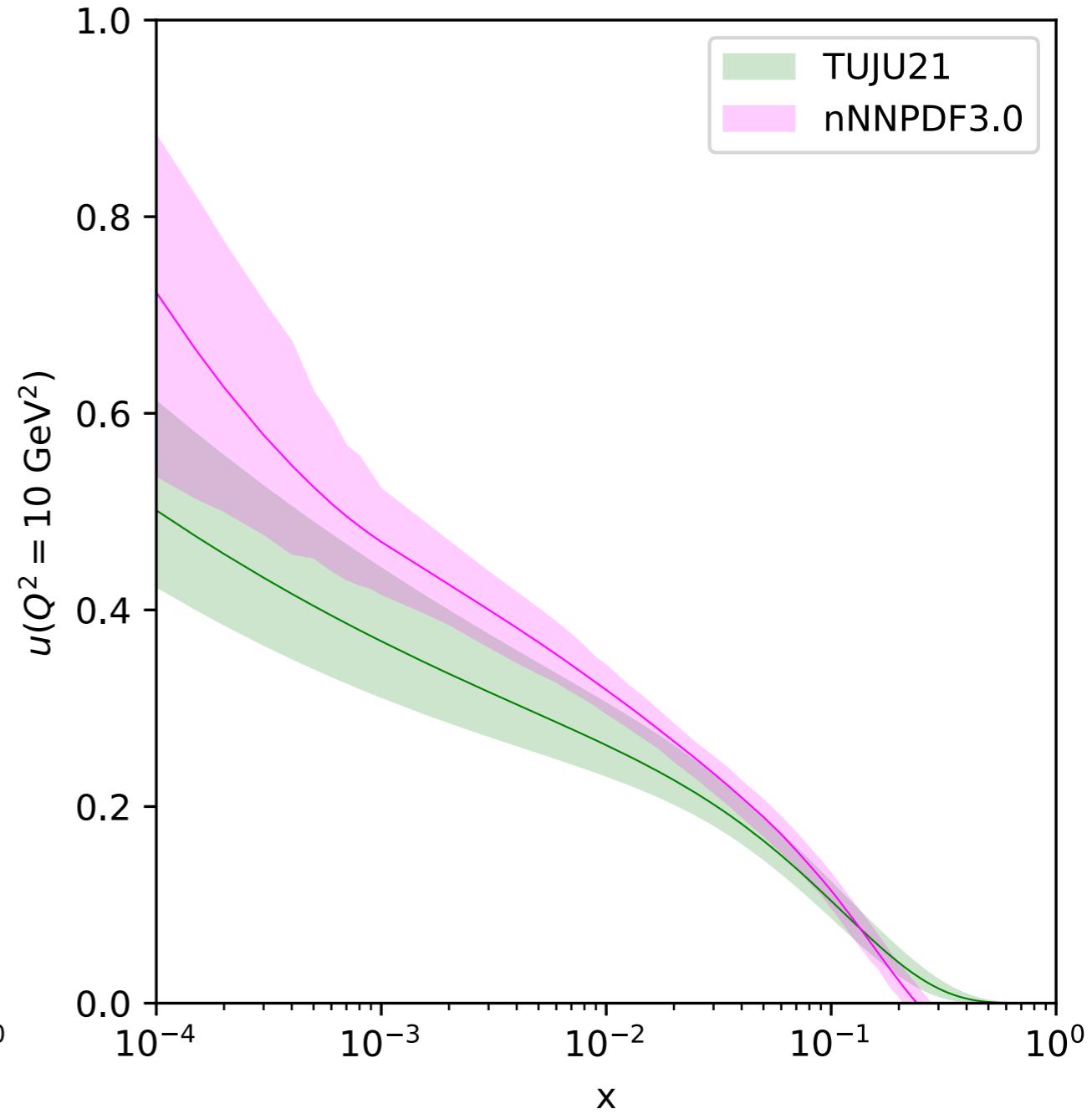
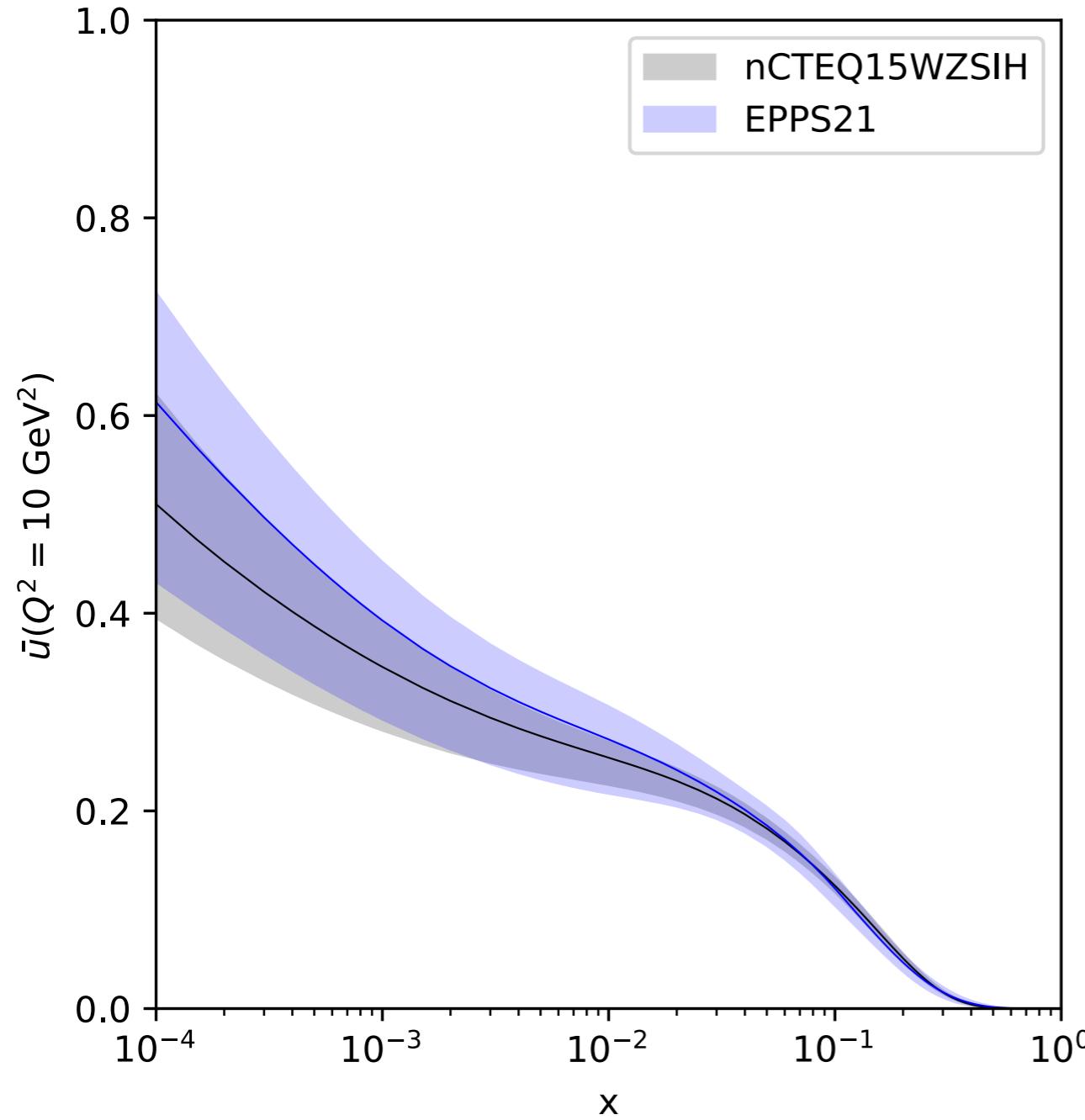
up and down



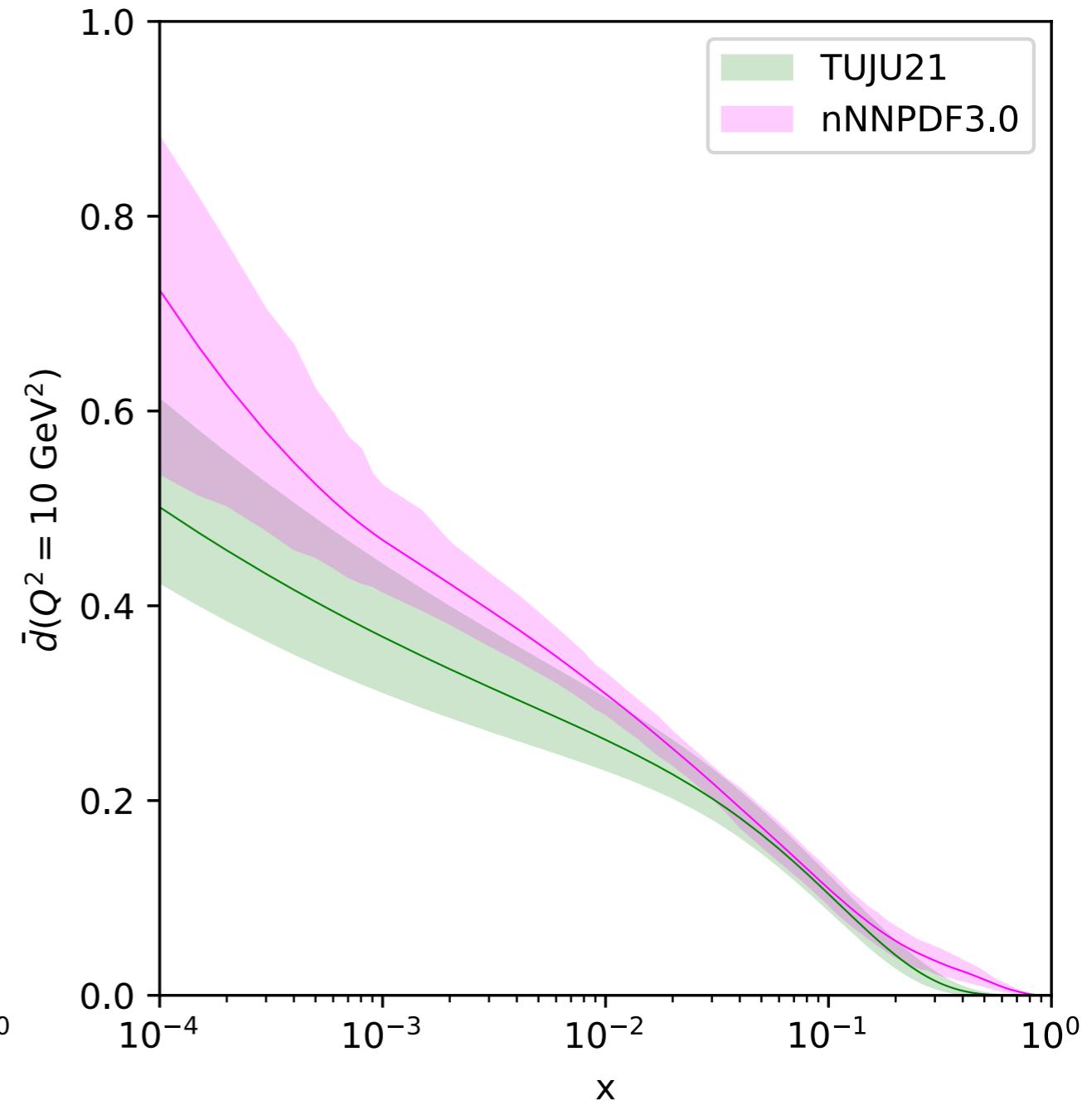
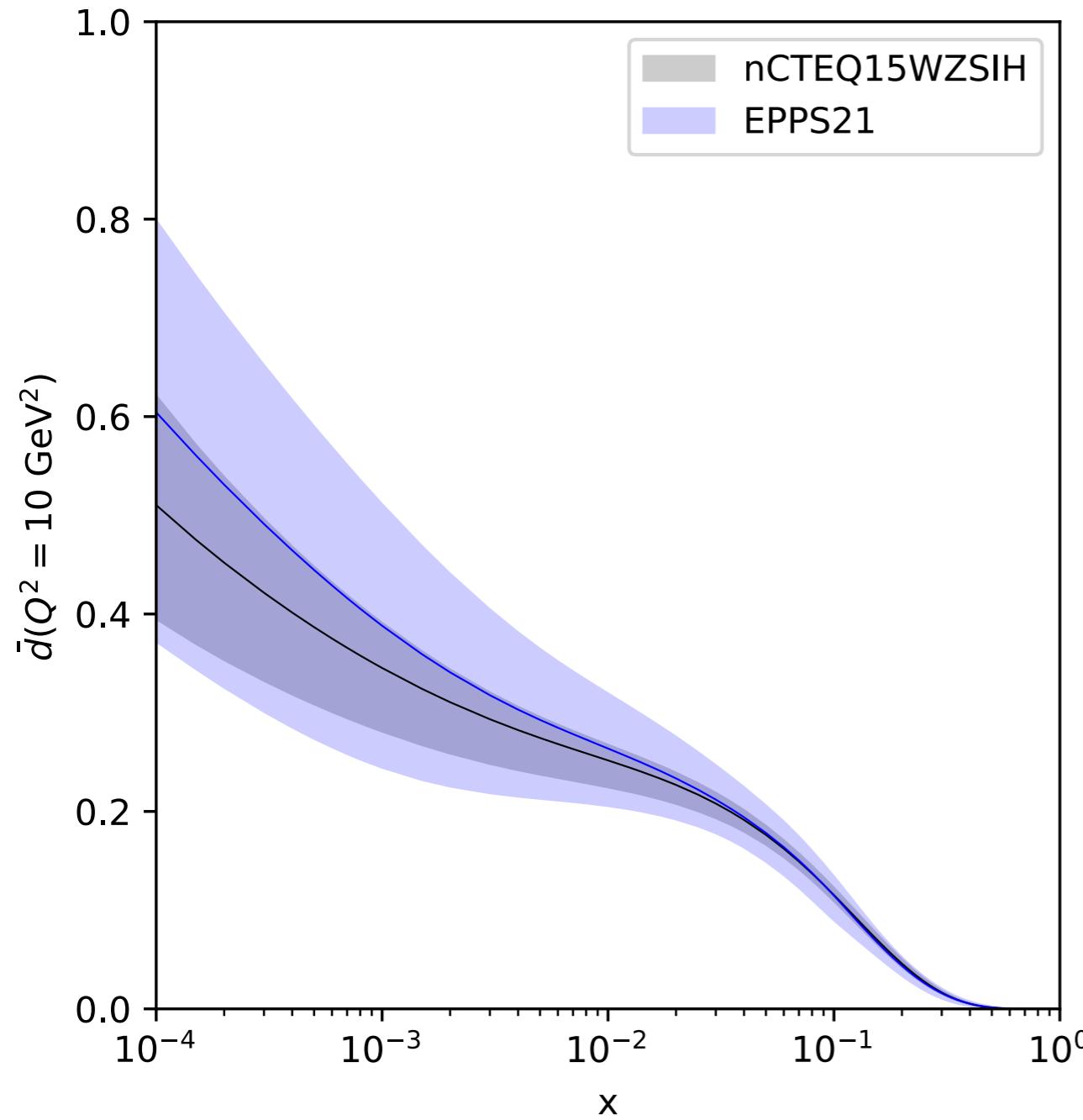
ratios: *up* and *down*



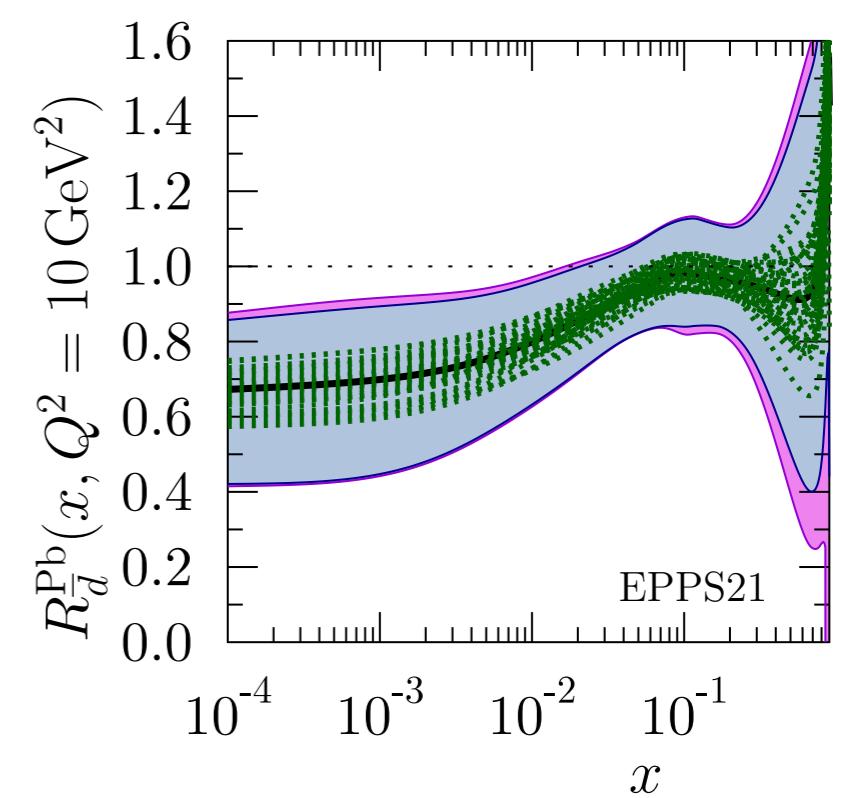
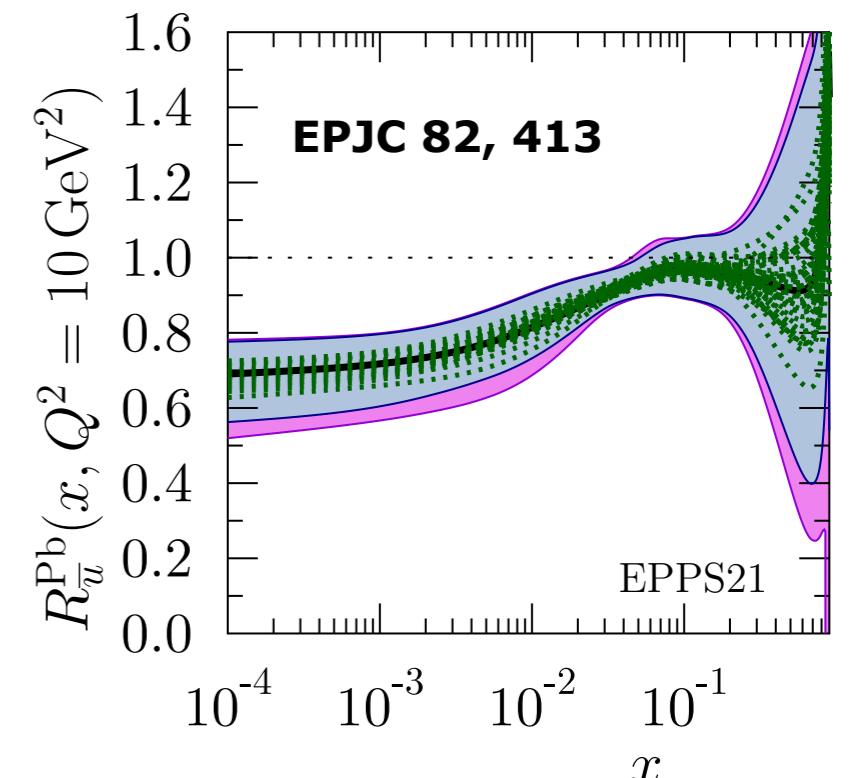
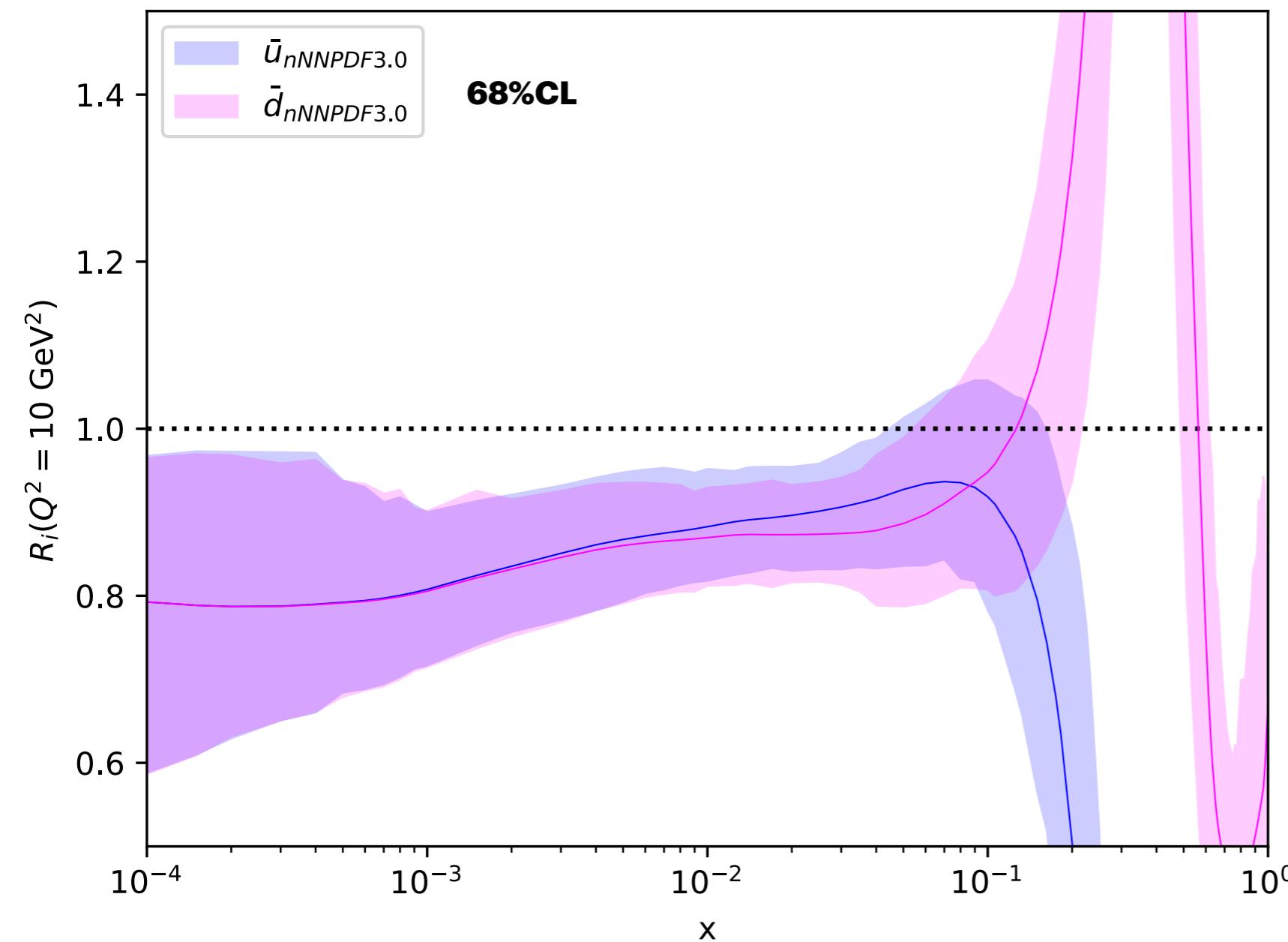
anti-up



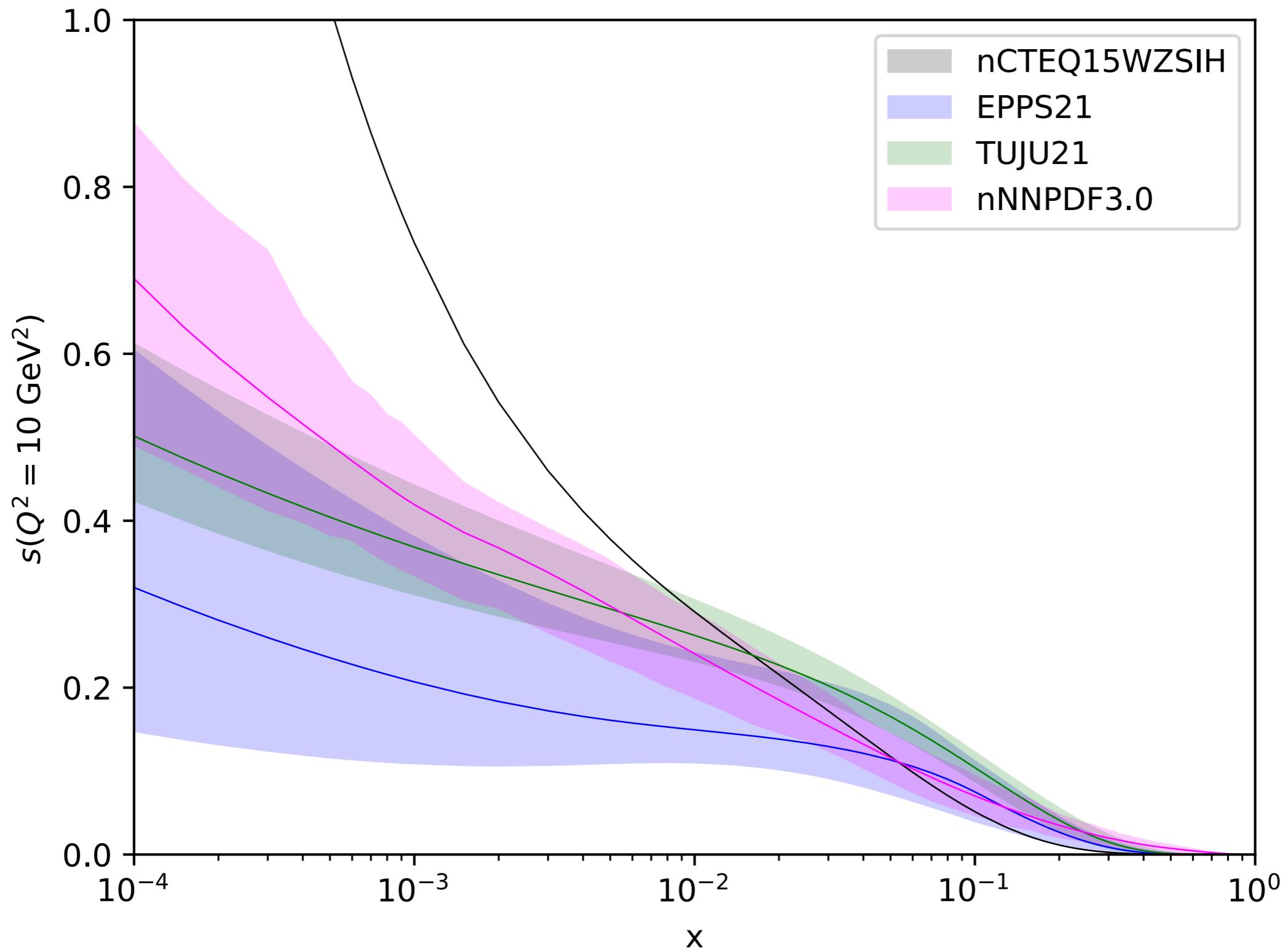
anti-down



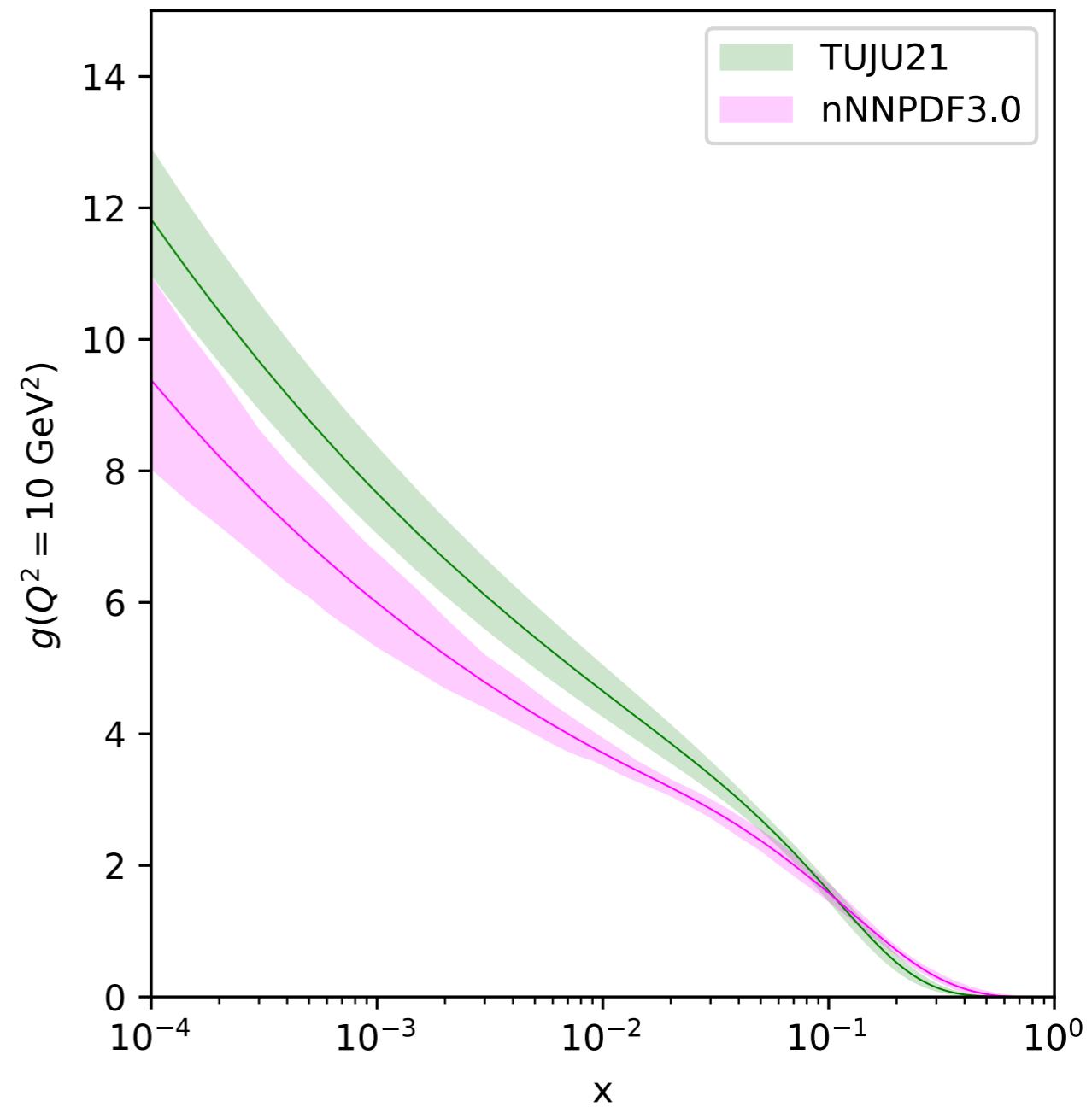
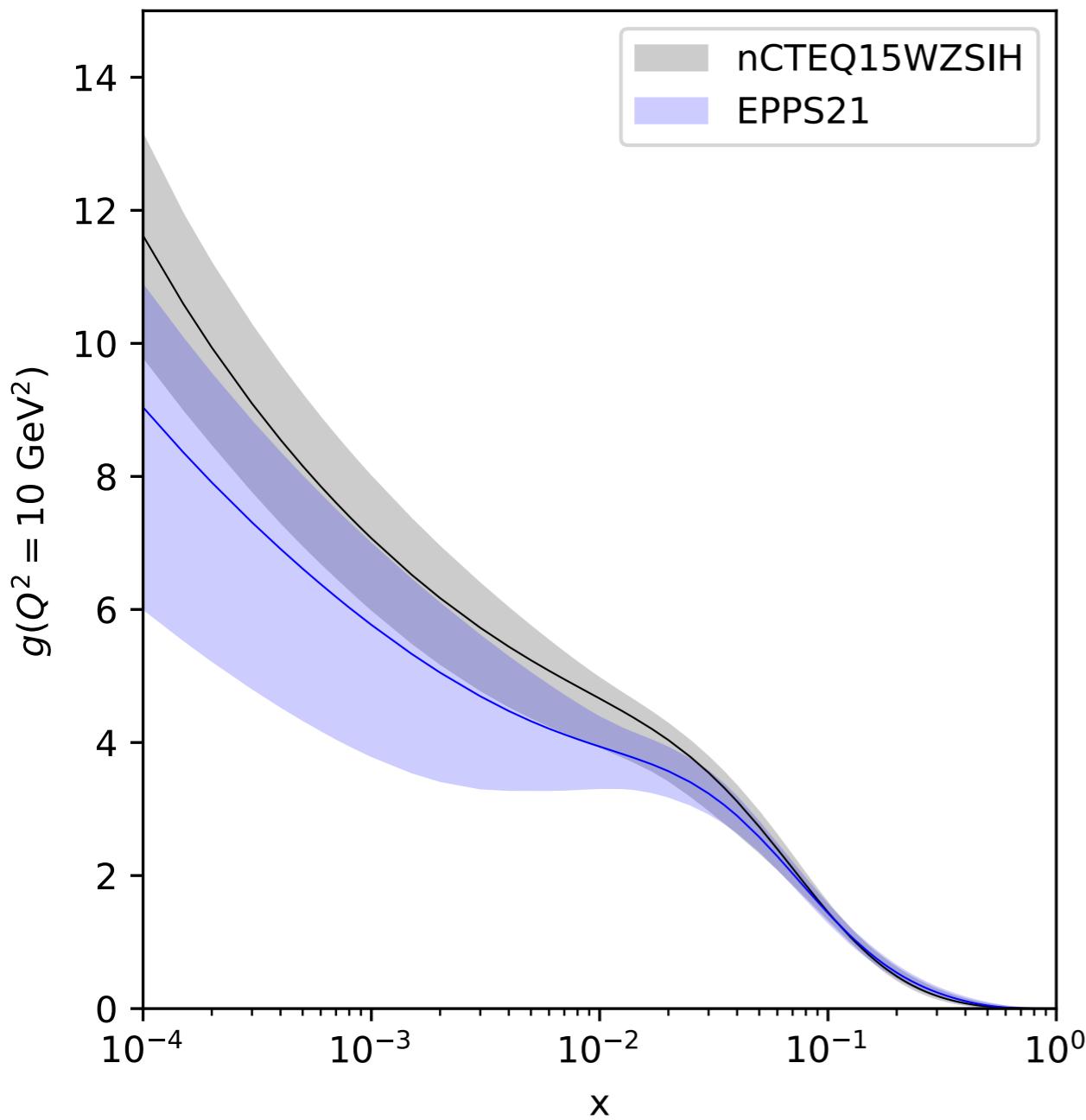
ratios: anti-up and anti-down



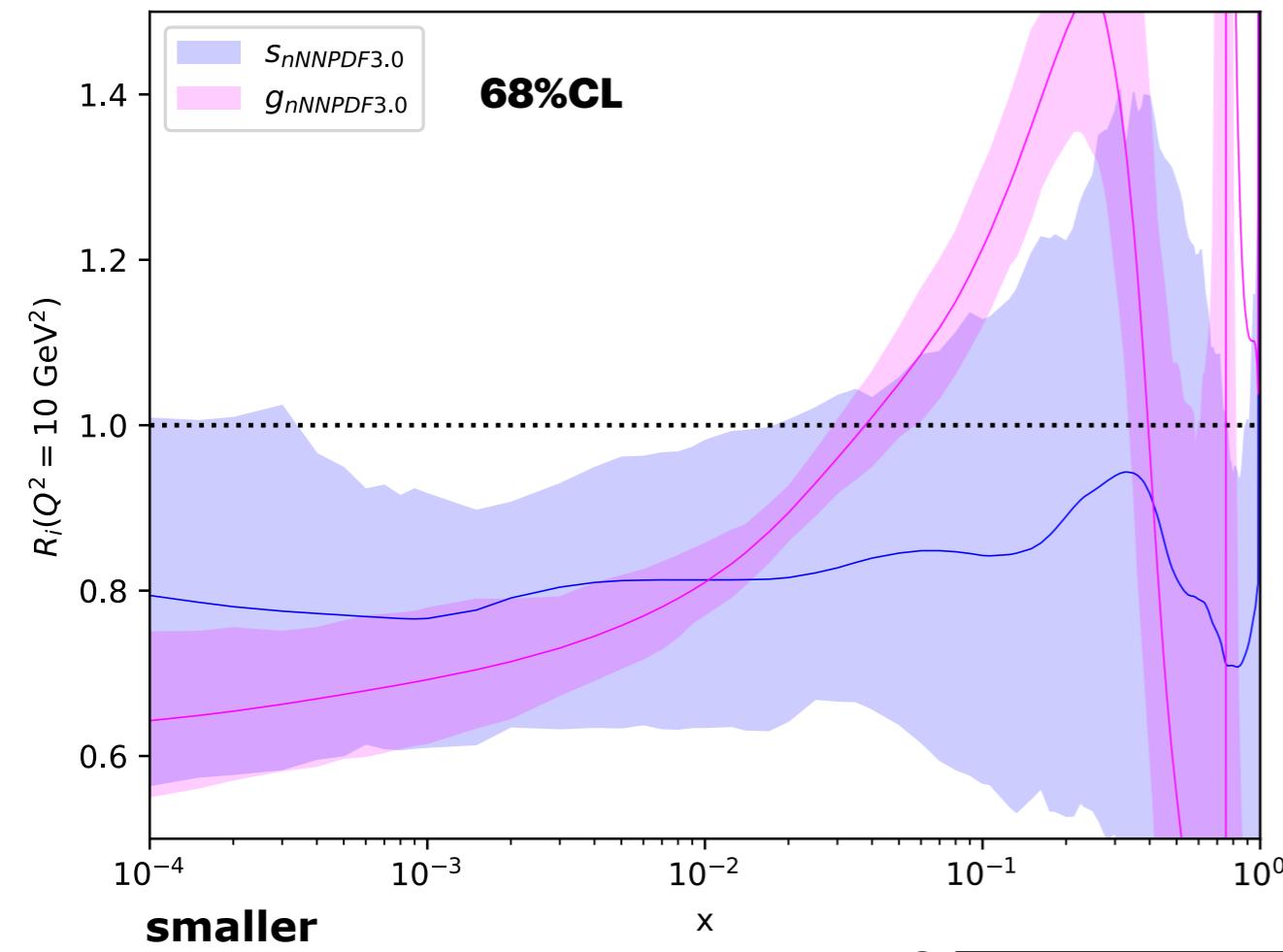
strange



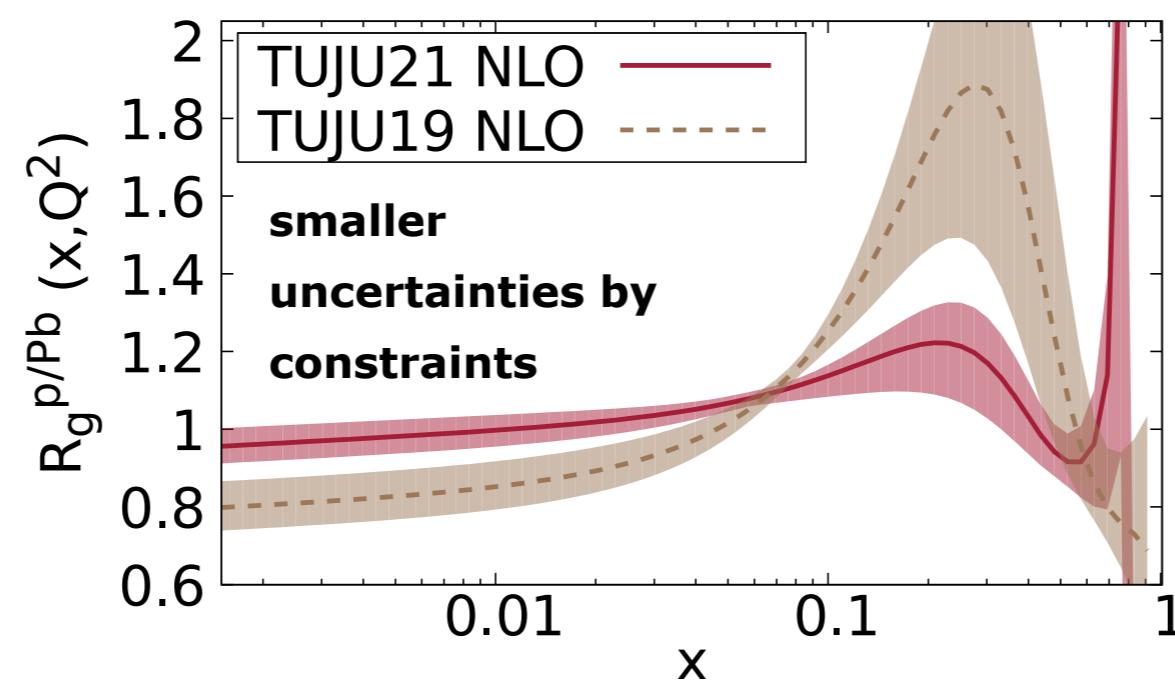
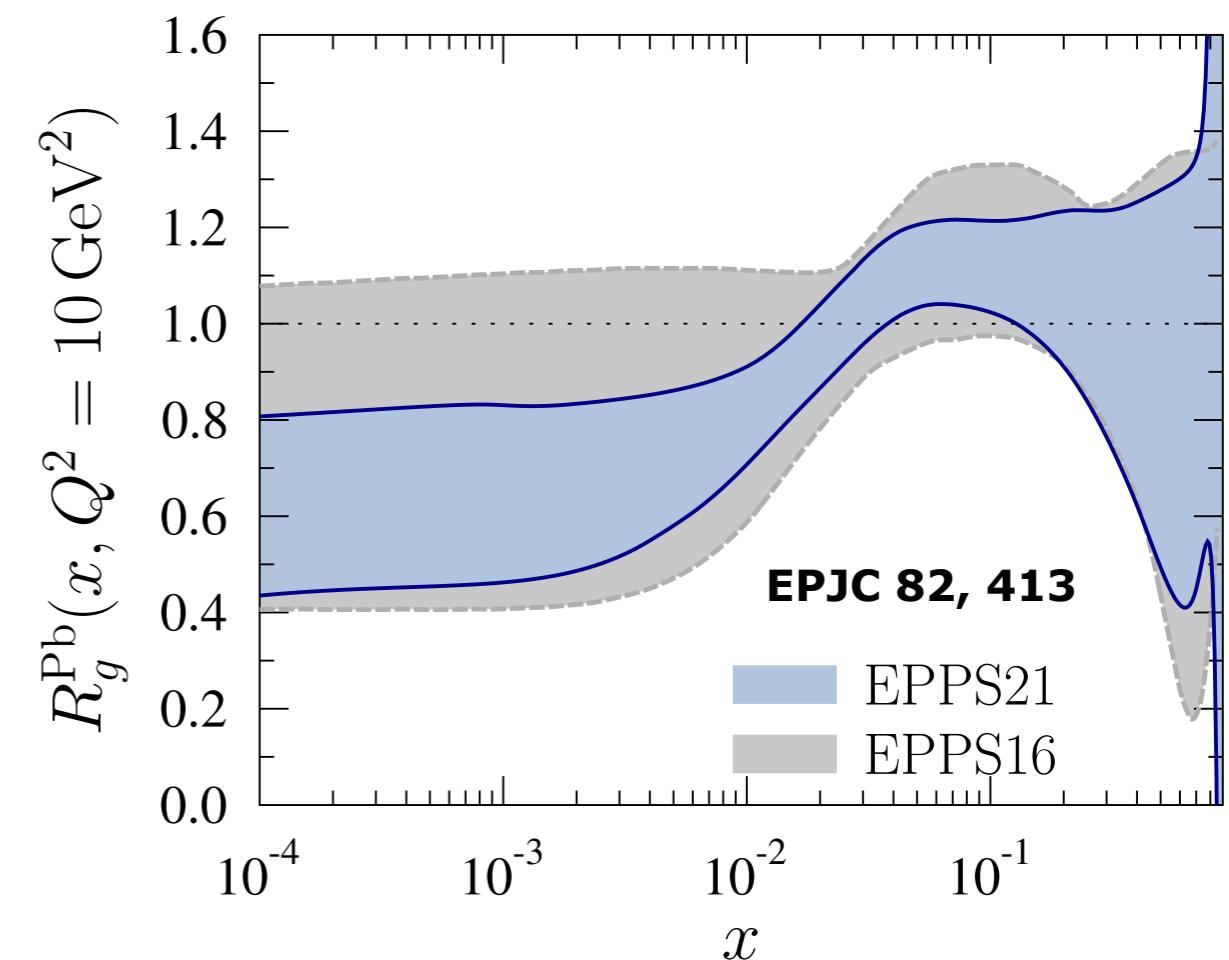
gluon



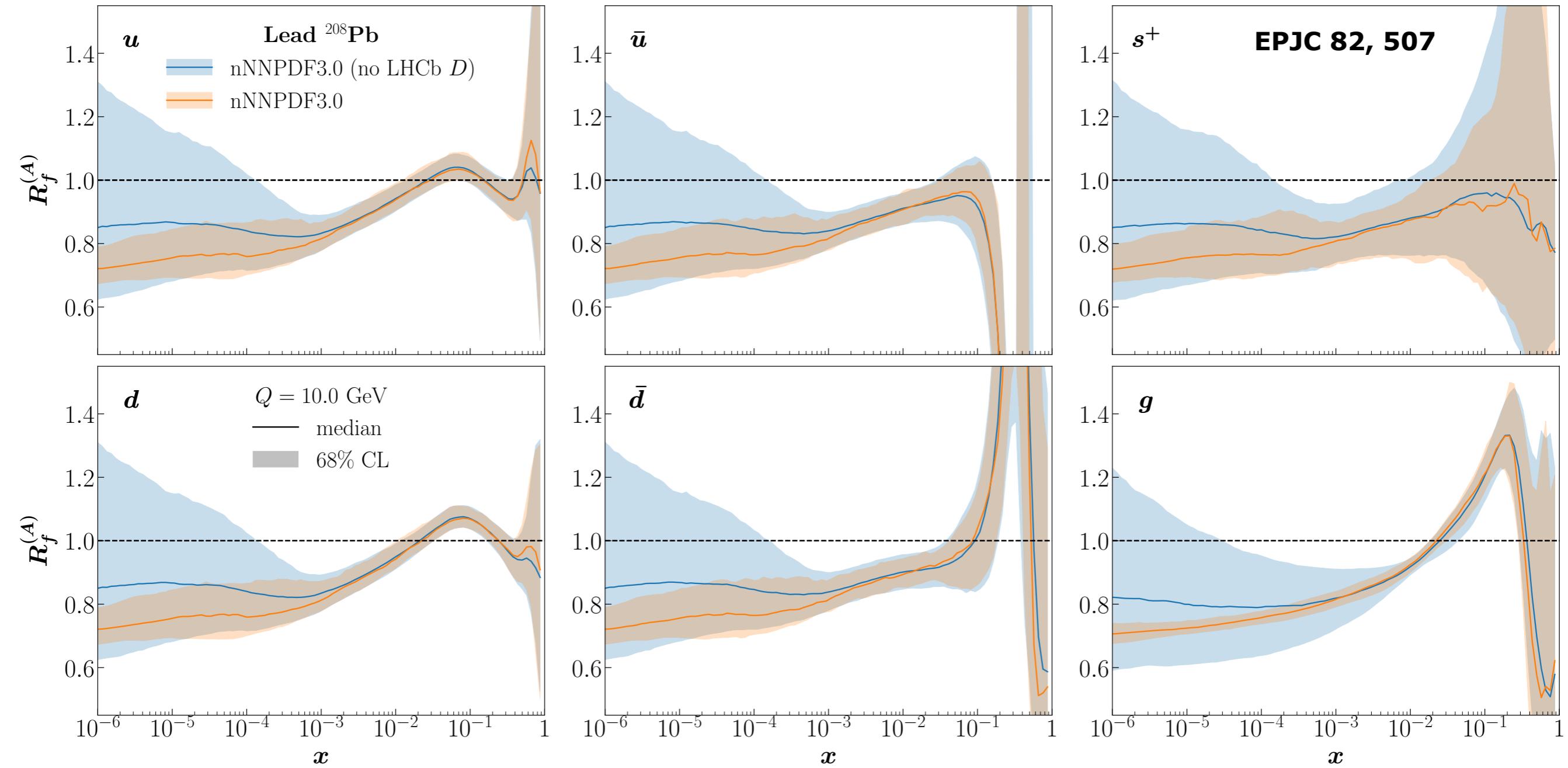
ratio: strange and gluon



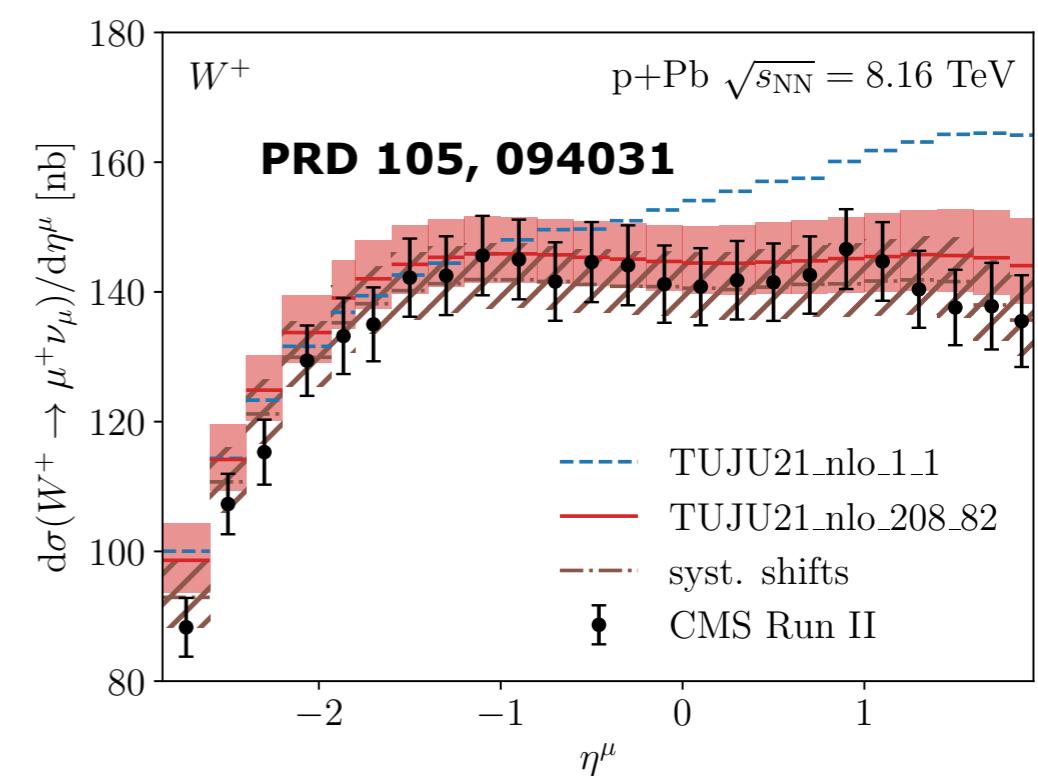
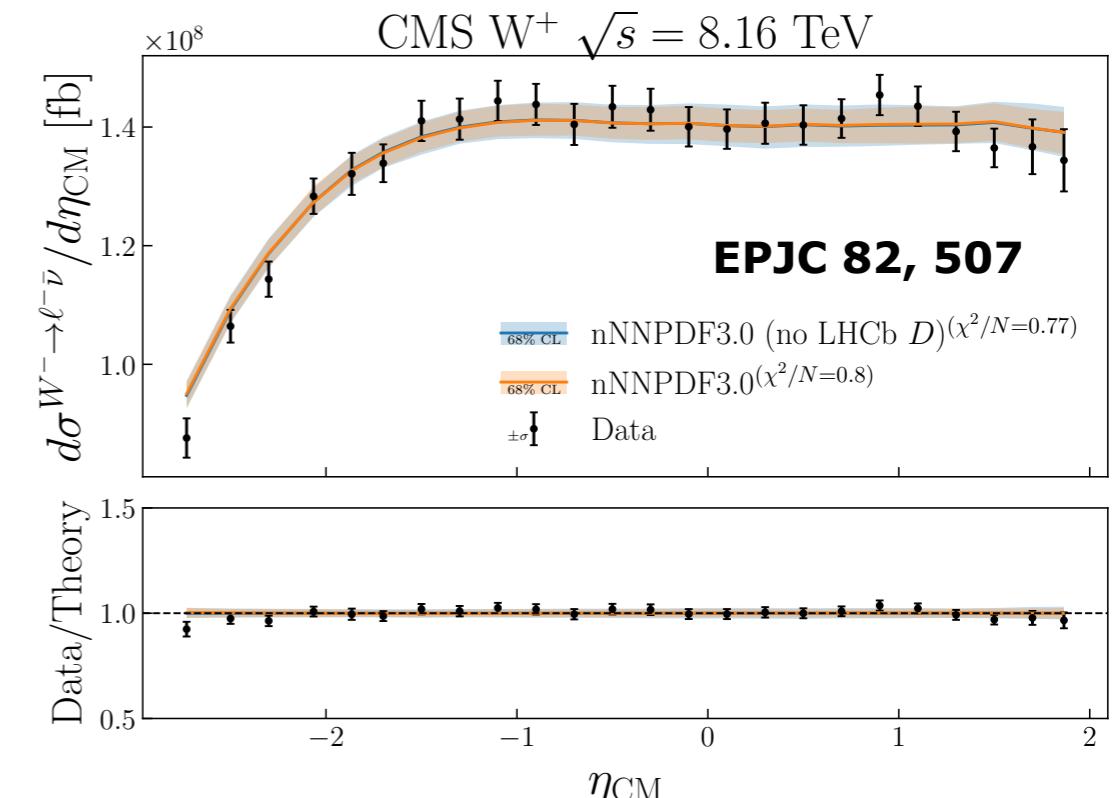
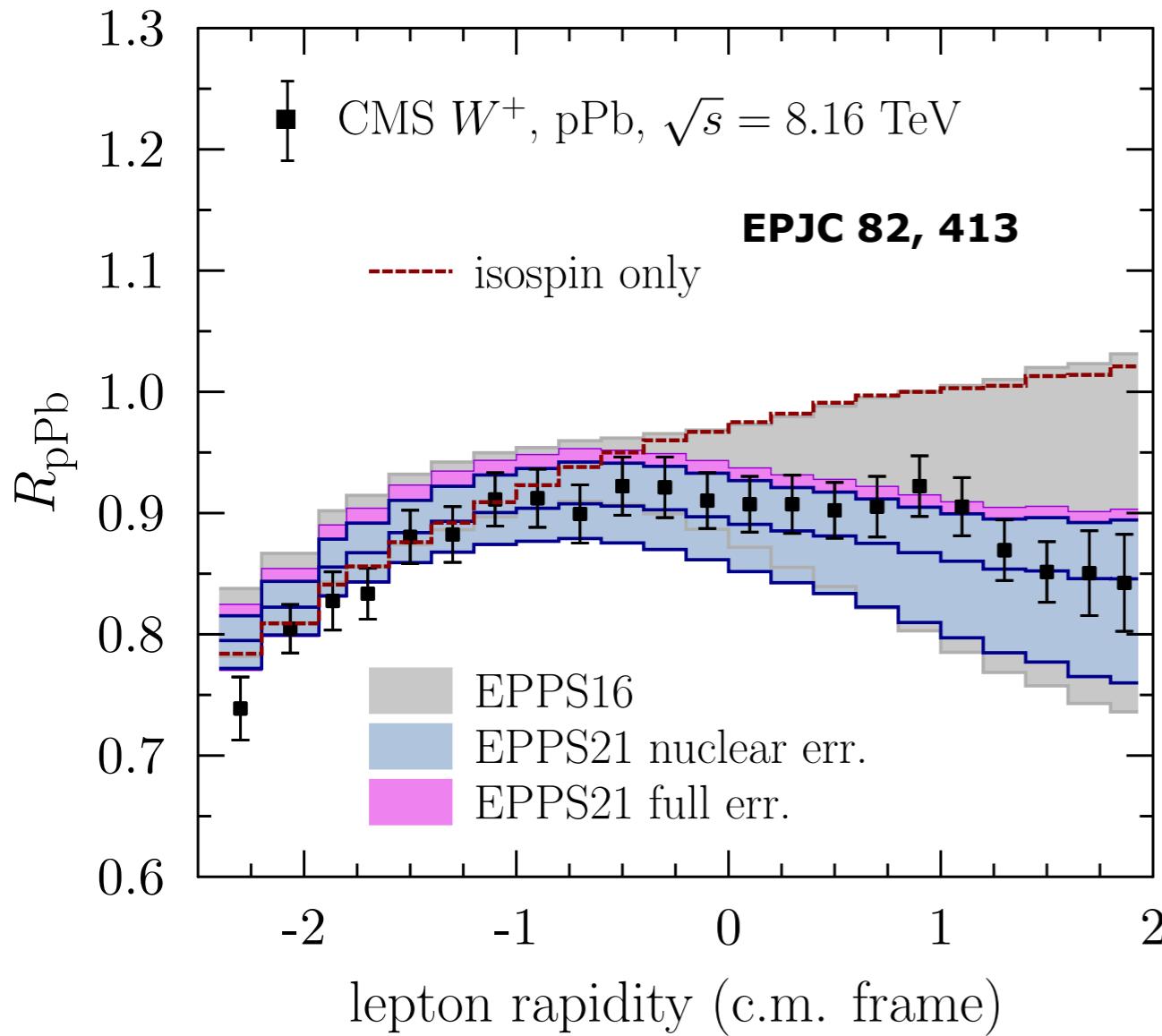
**smaller
uncertainties
from D-mesons**



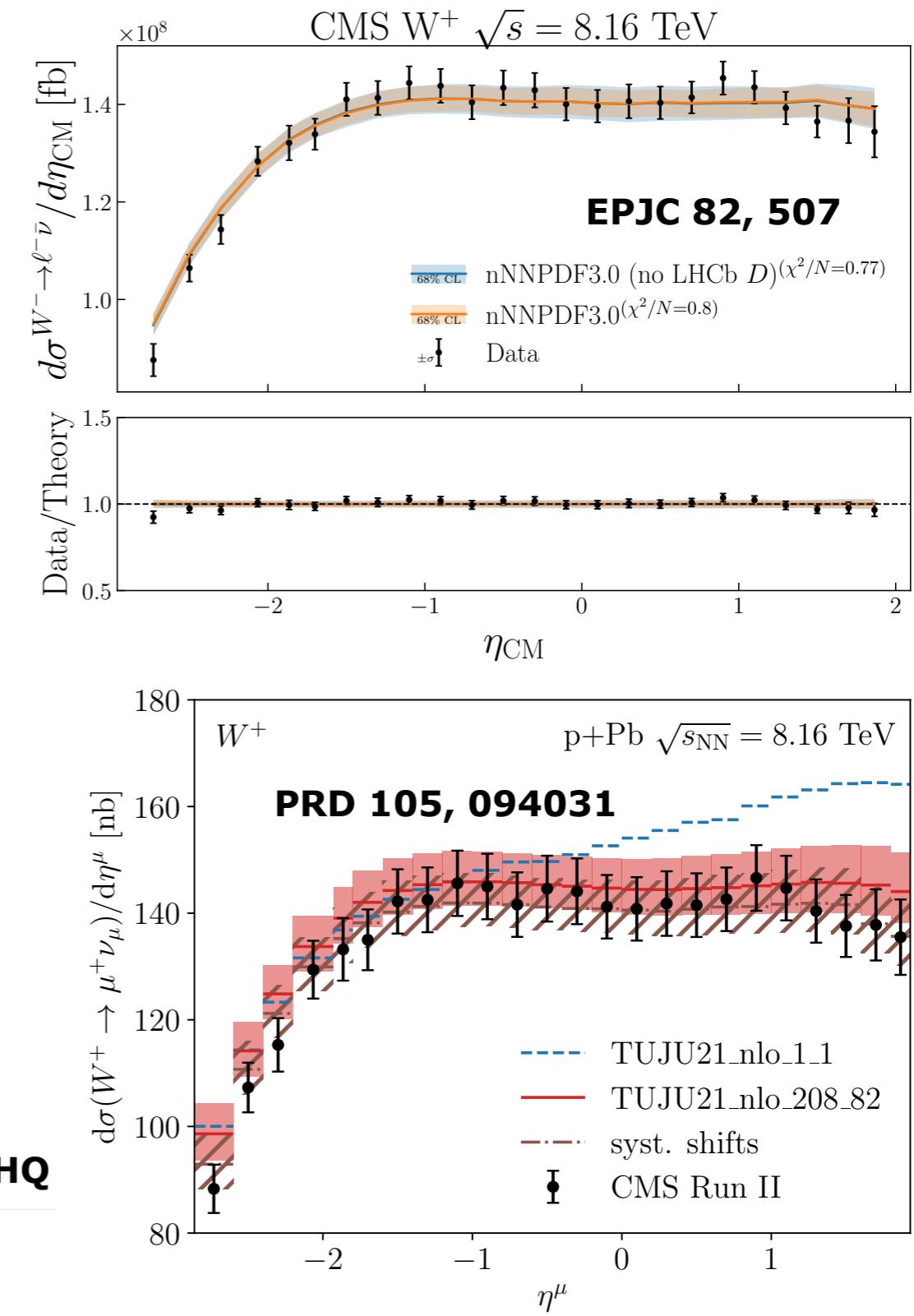
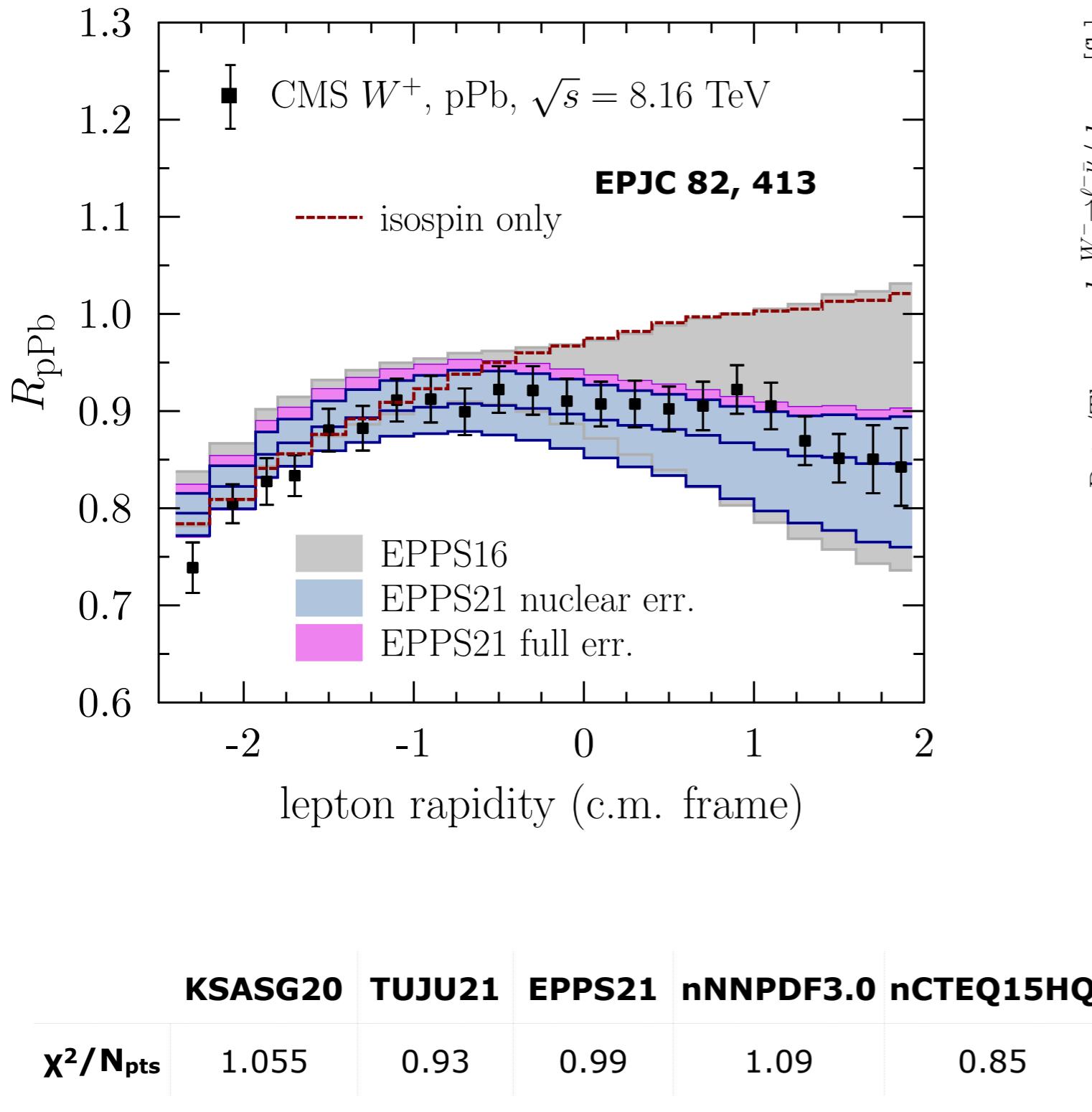
remember: everything is connected



Which one is the best?



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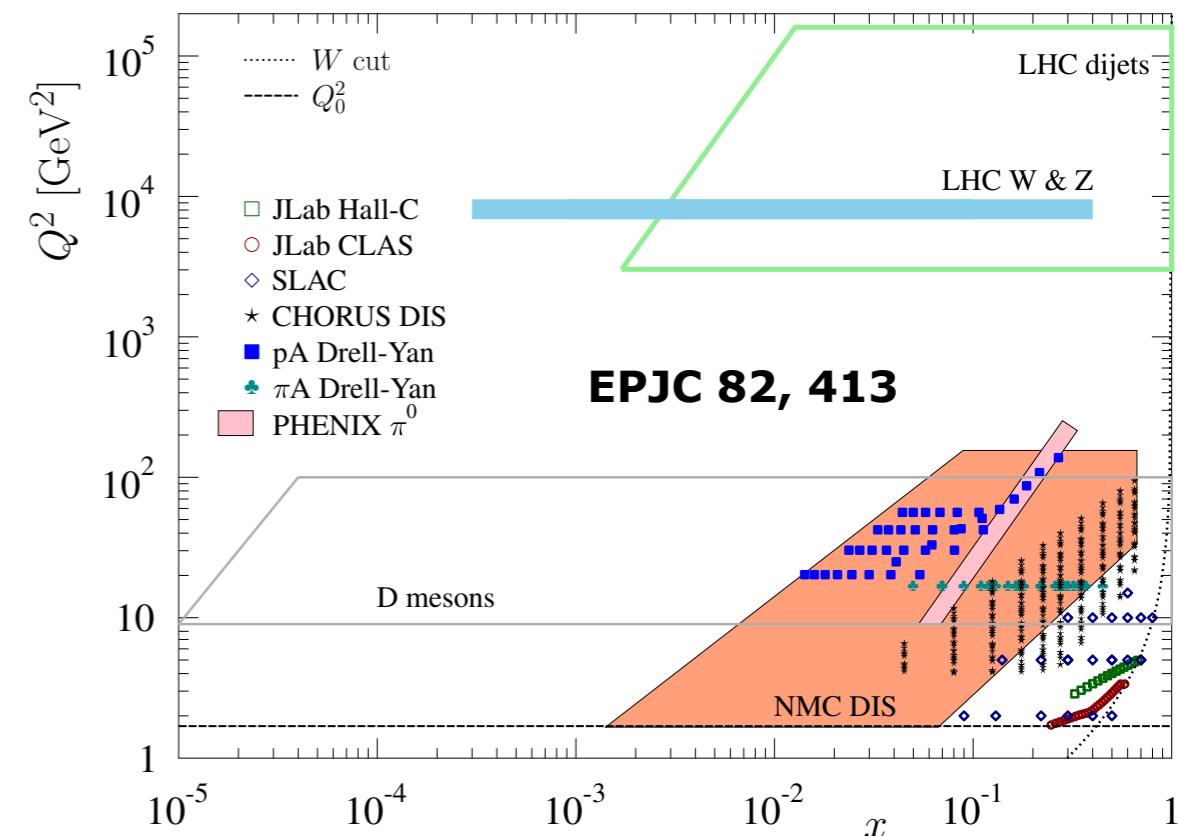


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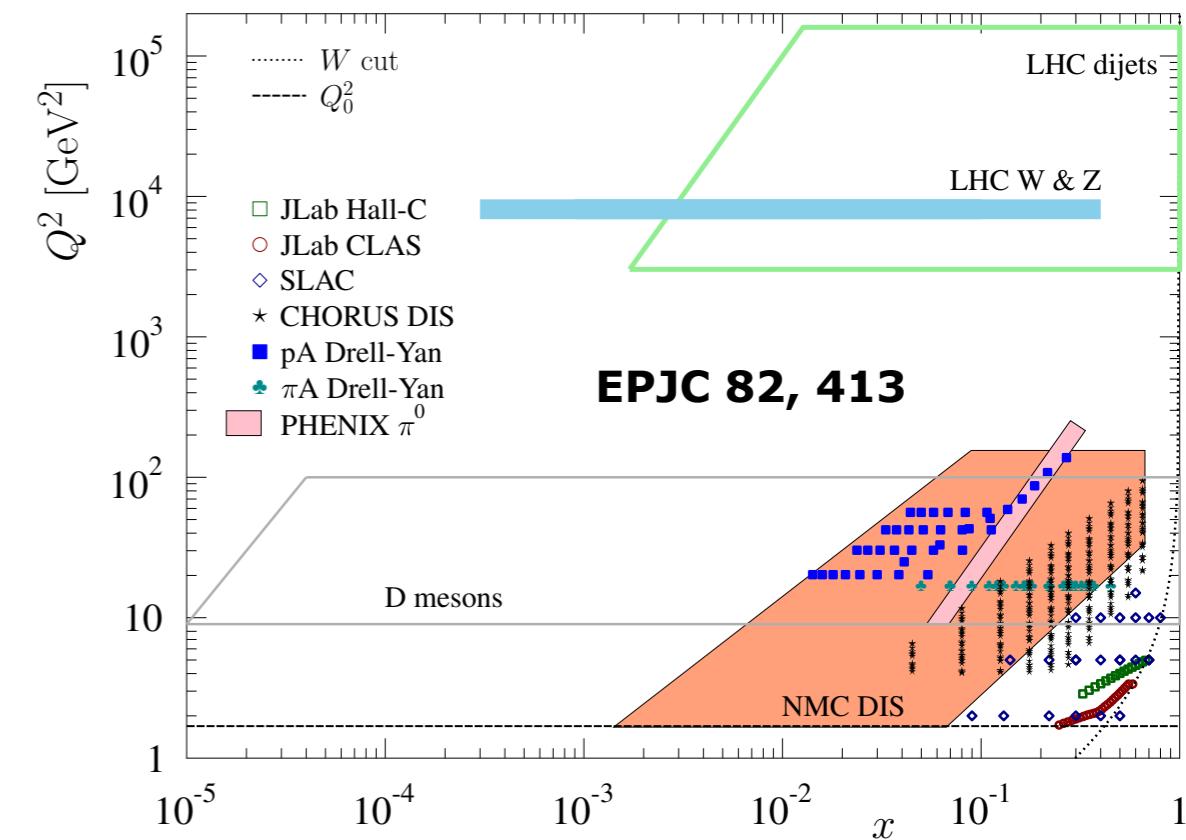
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- * The up and down distributions have not changed much in the high- x region. In the low- x region they remain largely unconstrained.

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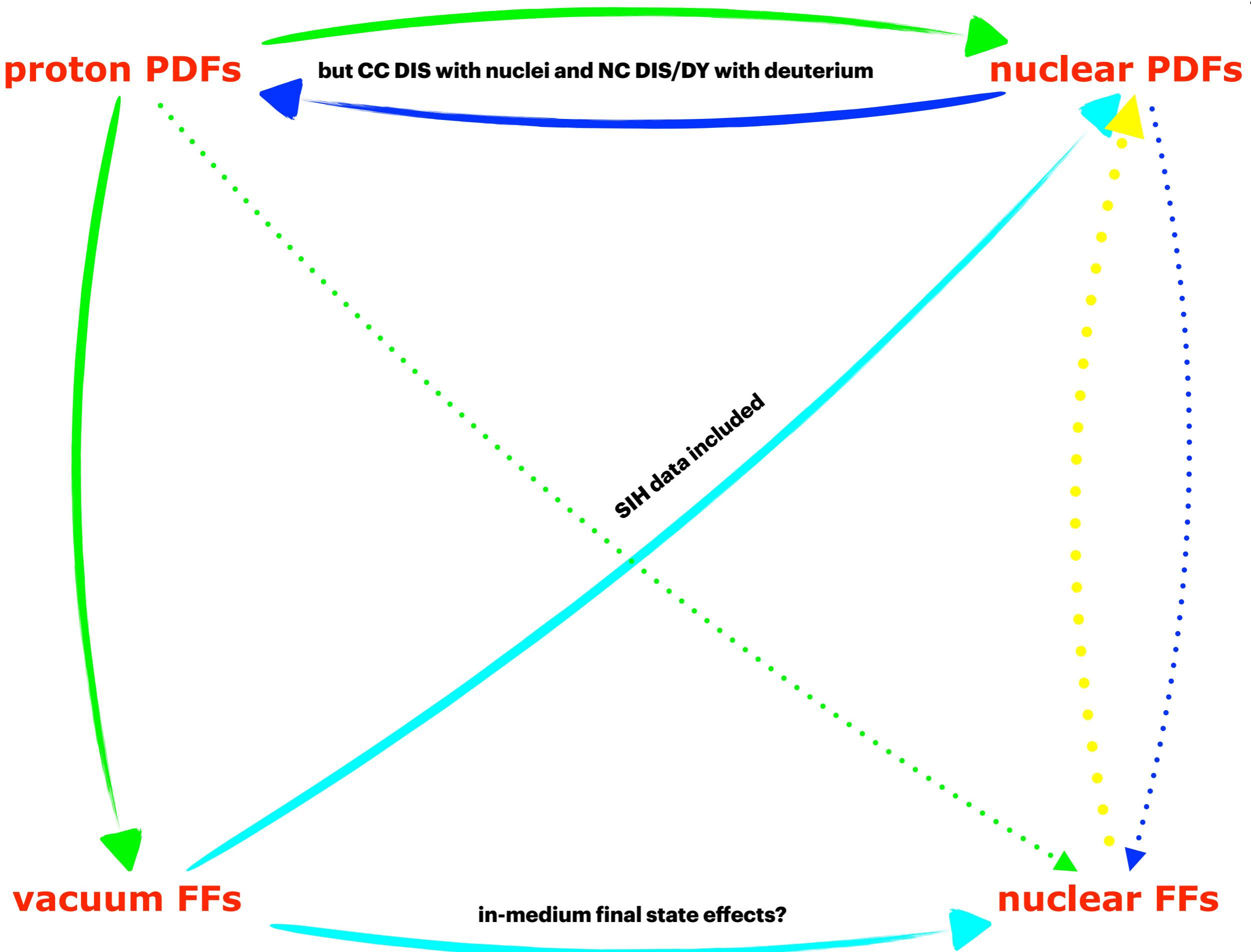
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- * Even more, shadowing and anti-shadowing of the gluon are now determined by data.
- * The use of some data rely on assumptions/other densities for the modelling, and those should be further explored.



proton PDFs

but CC DIS with nuclei and NC DIS/DY with deuterium

nuclear PDFs

double counting
effects is just too
easy!!!!

vacuum FFs

in-medium final state effects?

nuclear FFs

Soon we will have more very precise data from the EIC (LHeC? FCC-eh?) and we will be able to explore the complex observables better.

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A non-terrifying hat.

My drawing didn't represent a hat. It represented a boa digesting an elephant.



Not a hat.

Thus I draw the interior of the boa, so that grown-ups could understand. They always need explanations.