

Review of nuclear PDFs

Pia Zurita

BNL

LHeC and FCC-eh Workshop

Sept. 11-13, 2017, CERN

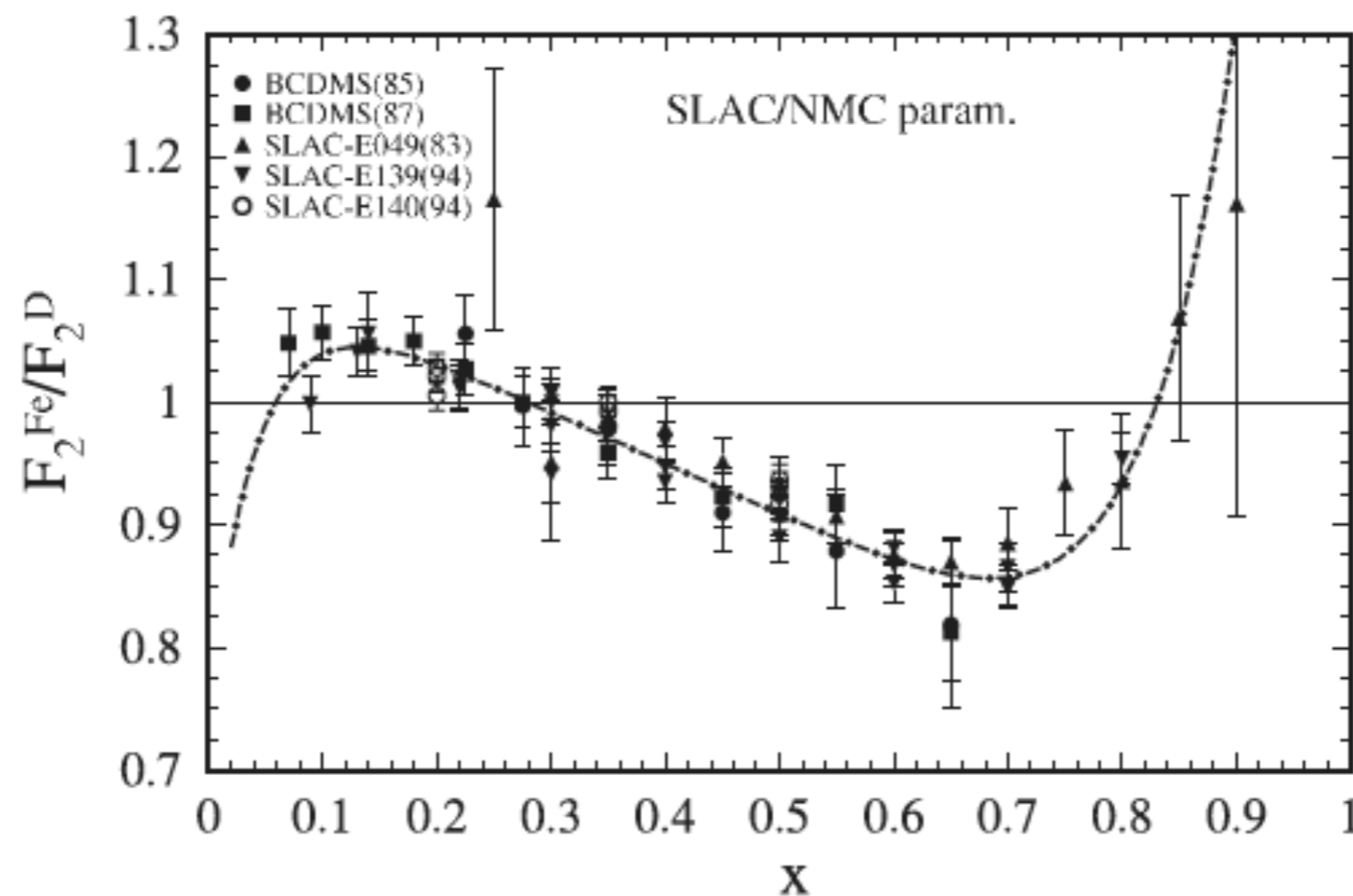
Outline

- ◆ *nPDFs: what are these?*
- ◆ *State of the art*
- ◆ *Possibilities at future colliders*
- ◆ *Summary*
- ◆ *Outlook*

- ◆ $f_i^A(x, \mu)$ describe the behavior of the parton in a *bound* proton
- ◆ non-perturbative, UNIVERSAL, obtained by global fits to the *world data*

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why? : because mother Nature wants it!



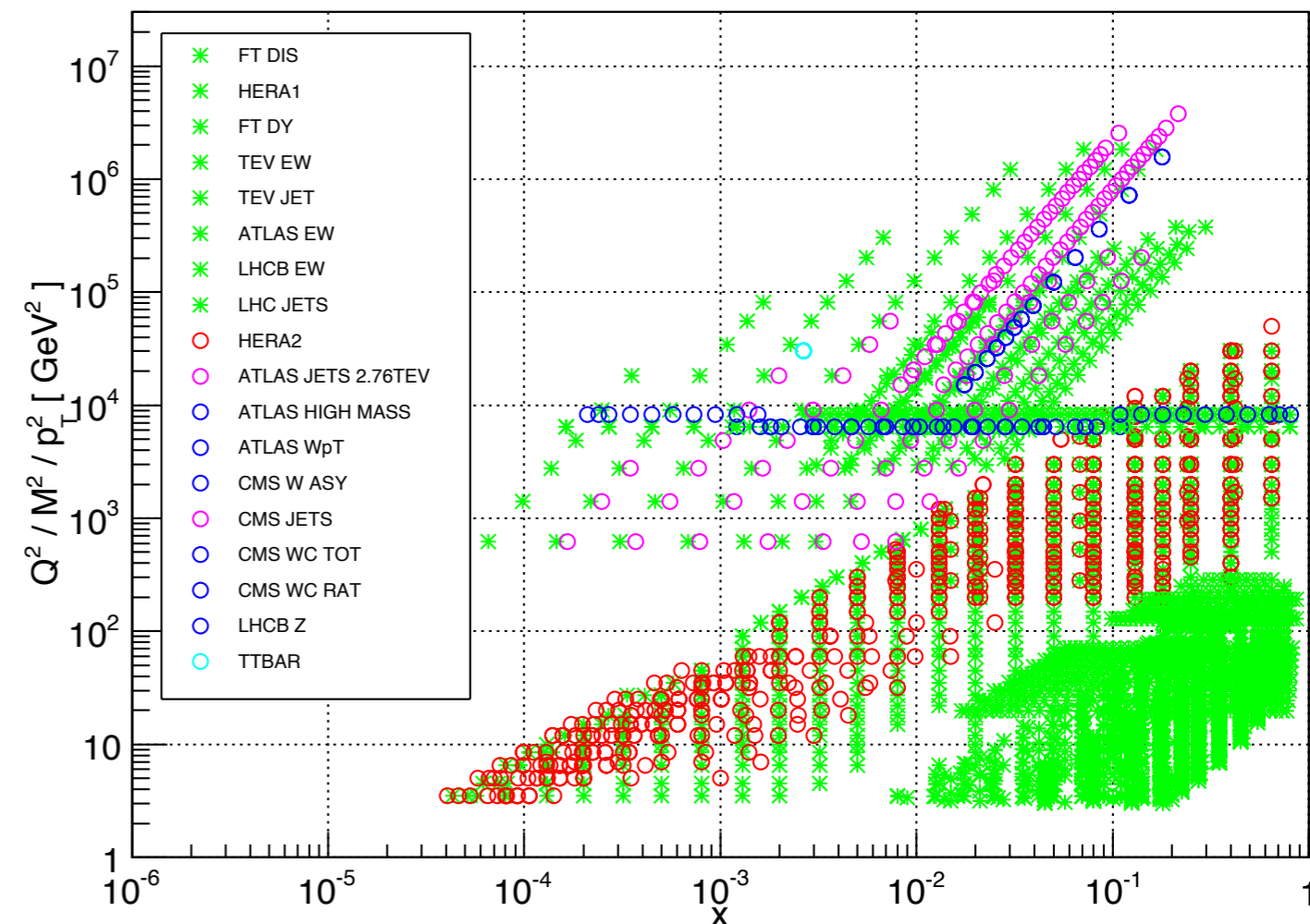
proton PDFs

- ◆ *mass scheme* (FF, ZM-VF, GM-VF)
- ◆ *heavy quarks* (struct. functions, masses, etc)
- ◆ α_s
- ◆ *flavor separation* (with deuteron/nuclei)
- ◆ *data selection*
- ◆ ...

~ 3500 data points

Ball et al. [NNPDF collaboration], JHEP 1504 (2015) 040

NNPDF3.0 NLO dataset

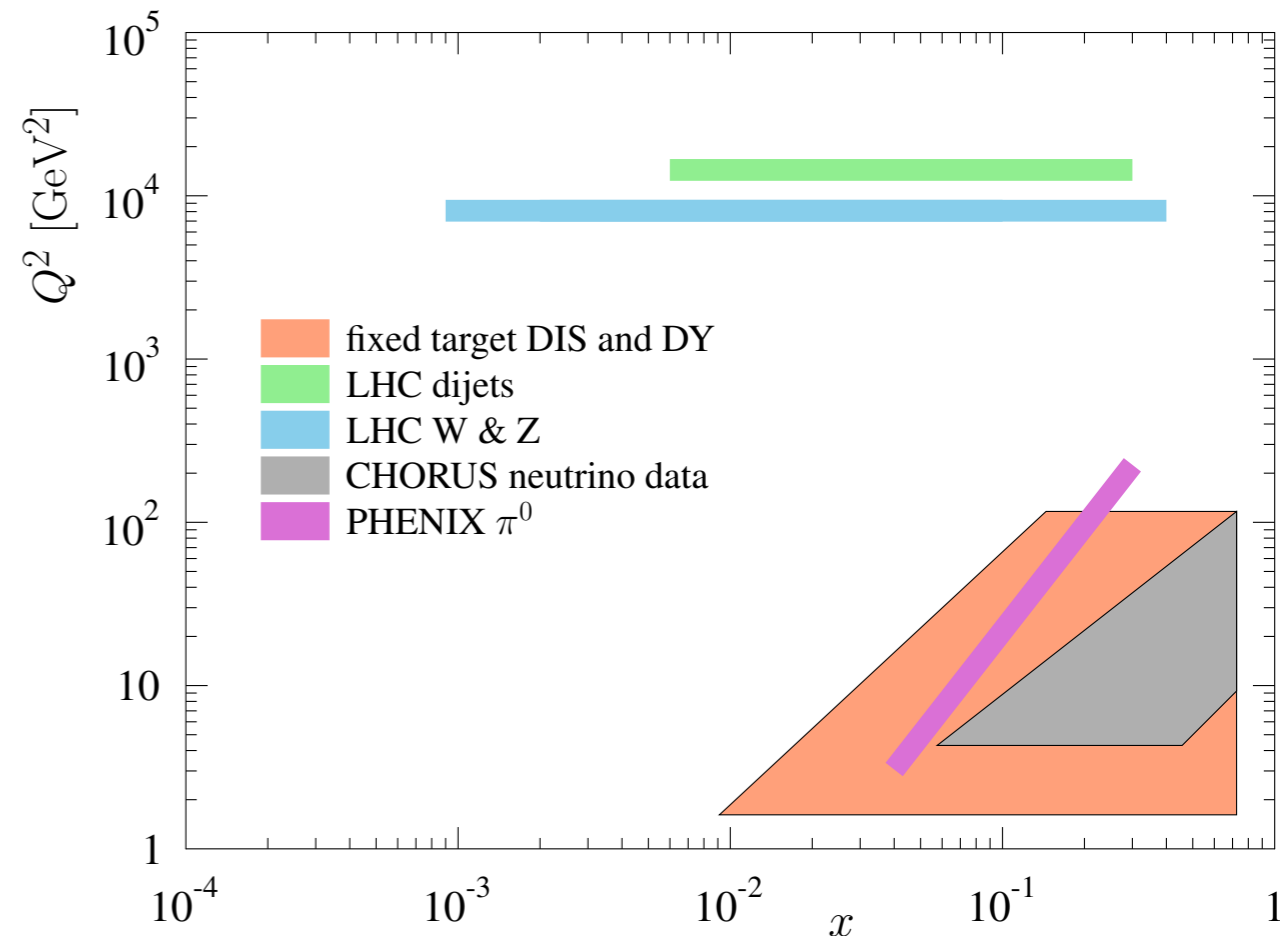


nuclear PDFs: all of that *plus*

- ◆ nuclear dependence
- ◆ limited amount of data per nucleus
- ◆ less precise
- ◆ nuclear effects in the final state?
- ◆ new phenomena?
- ◆ ...

~ 1400 data points

Eskola, Paakkinen, Paukkunen, Salgado,
Eur.Phys.J. C77 (2017) no.3, 163

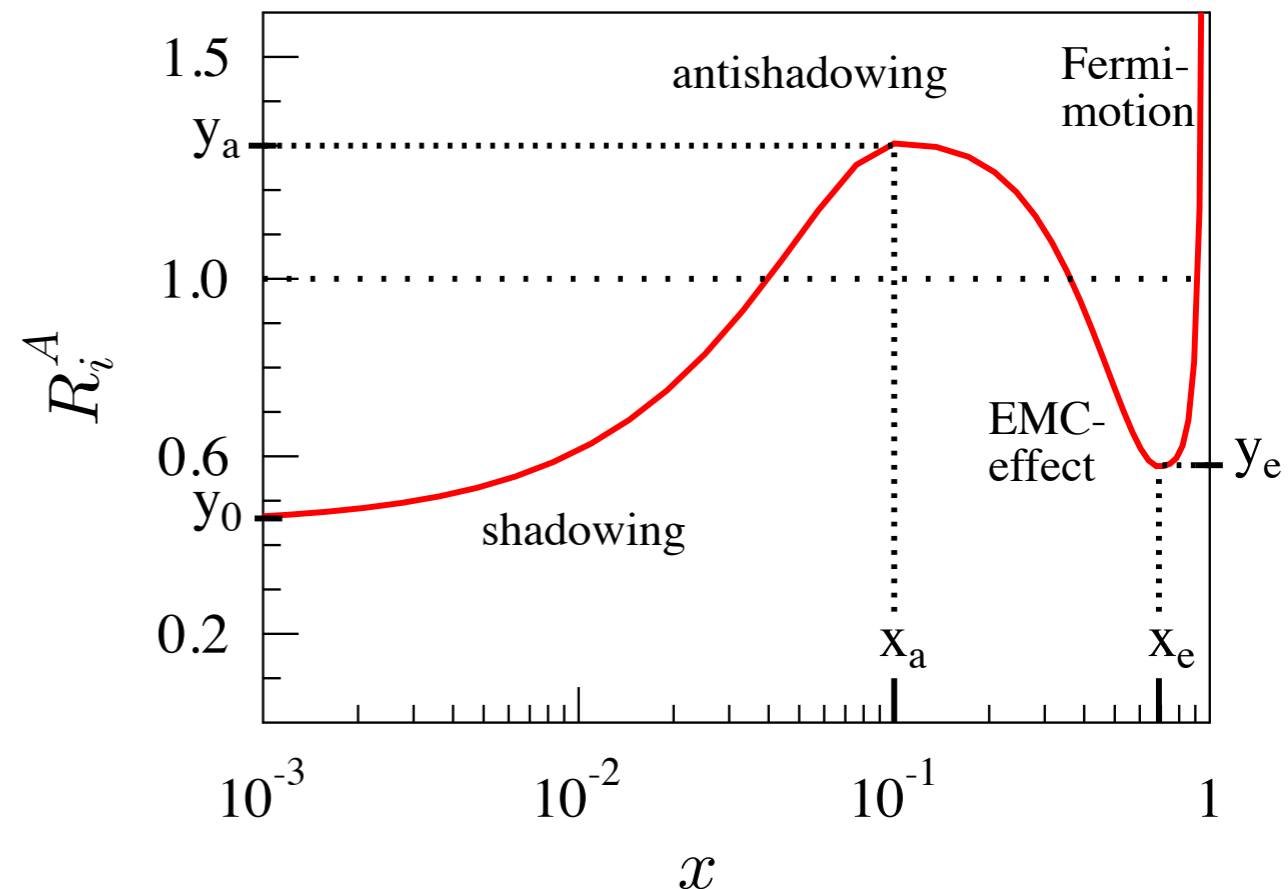


standard procedure for nPDFs:

- ◆ take as reference one set of proton PDFs and (*try to*) be consistent
- ◆ parameterize the nuclear/proton PDF ratio or the nPDFs directly

$$f_i^{p/A}(x, Q_0) = f_i^p(x, Q_0) R_i(x, A)$$

A-dependent parameters



LO

EKS: Eskola, Kolhinen, Salgado, *Eur.Phys.J.* C9 (1999)

HKM: Hirai, Kumano, Miyama, *Phys.Rev.* D64 (2001)

nDS: de Florian, Sassot, *Phys.Rev.* D69 (2004)

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HKN: Hirai, Kumano, Nagai, *Phys.Rev.* C76 (2007) \leadsto KEK nuclear physics textbook (2015)

EPS09: Eskola, Paukkunen, Salgado, *JHEP* 0904 (2009)

NLO

DSSZ: de Florian, Sassot, Stratmann, PZ, *Phys.Rev.* D85 (2012)

nCTEQ15: Kovarik et al., *Phys.Rev.* D93 (2016)

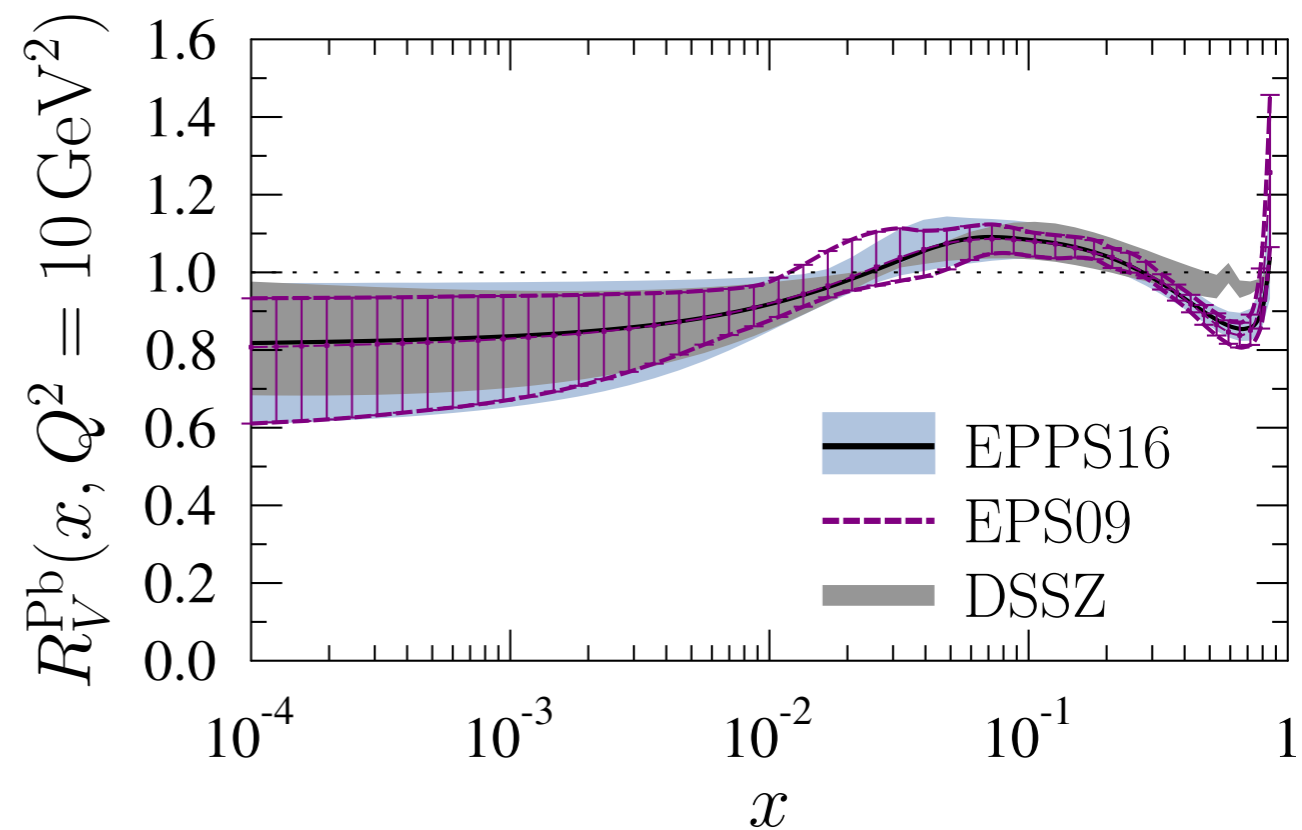
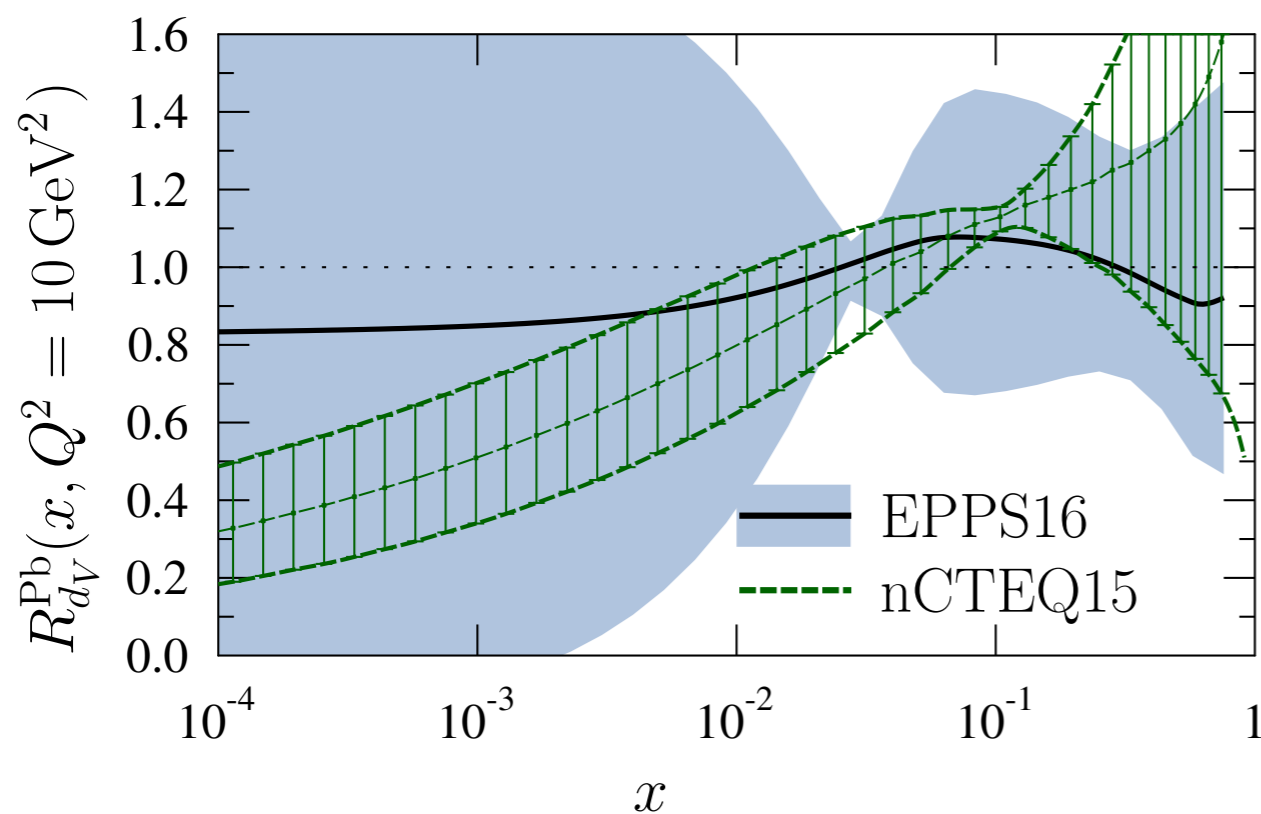
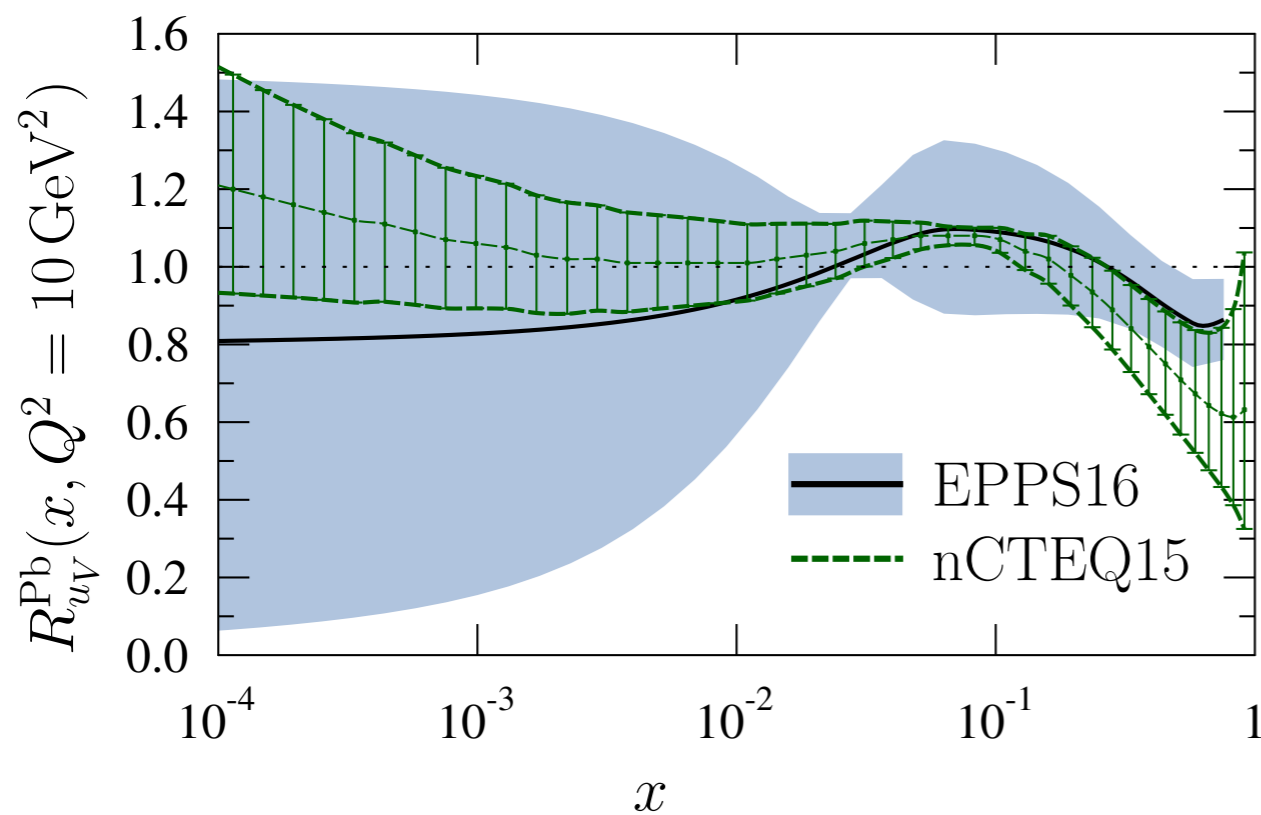
EPPS16: Eskola, Paakkinen, Paukkunen, Salgado, *Eur.Phys.J.* C77 (2017) no.3, 163

NNLO

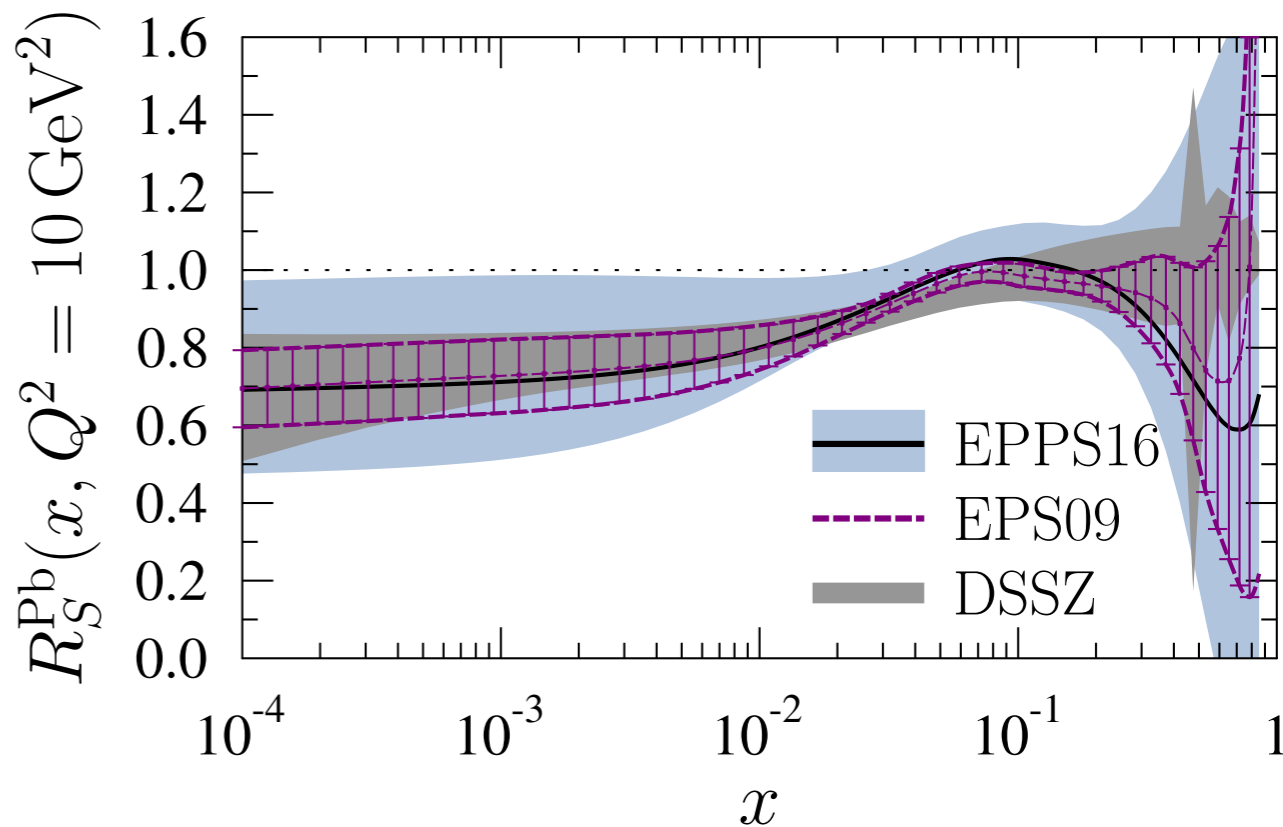
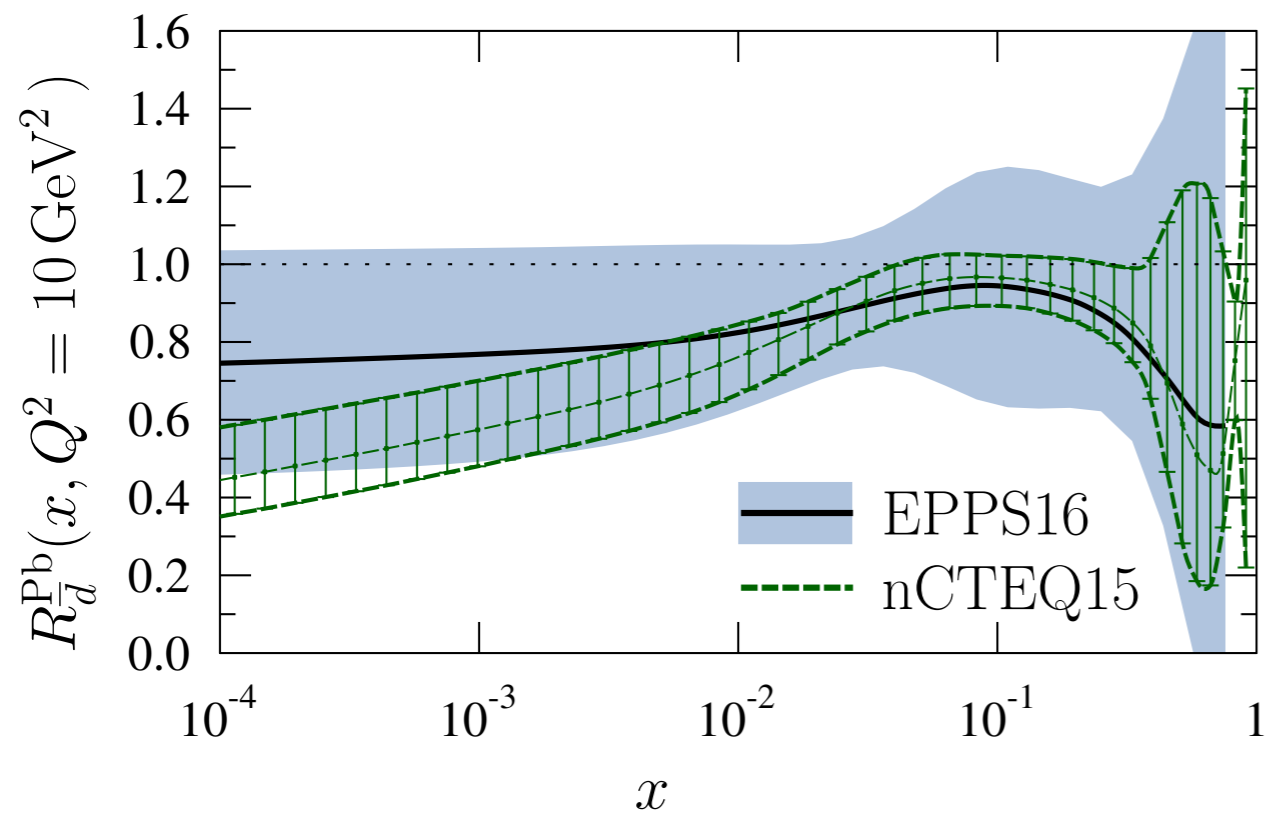
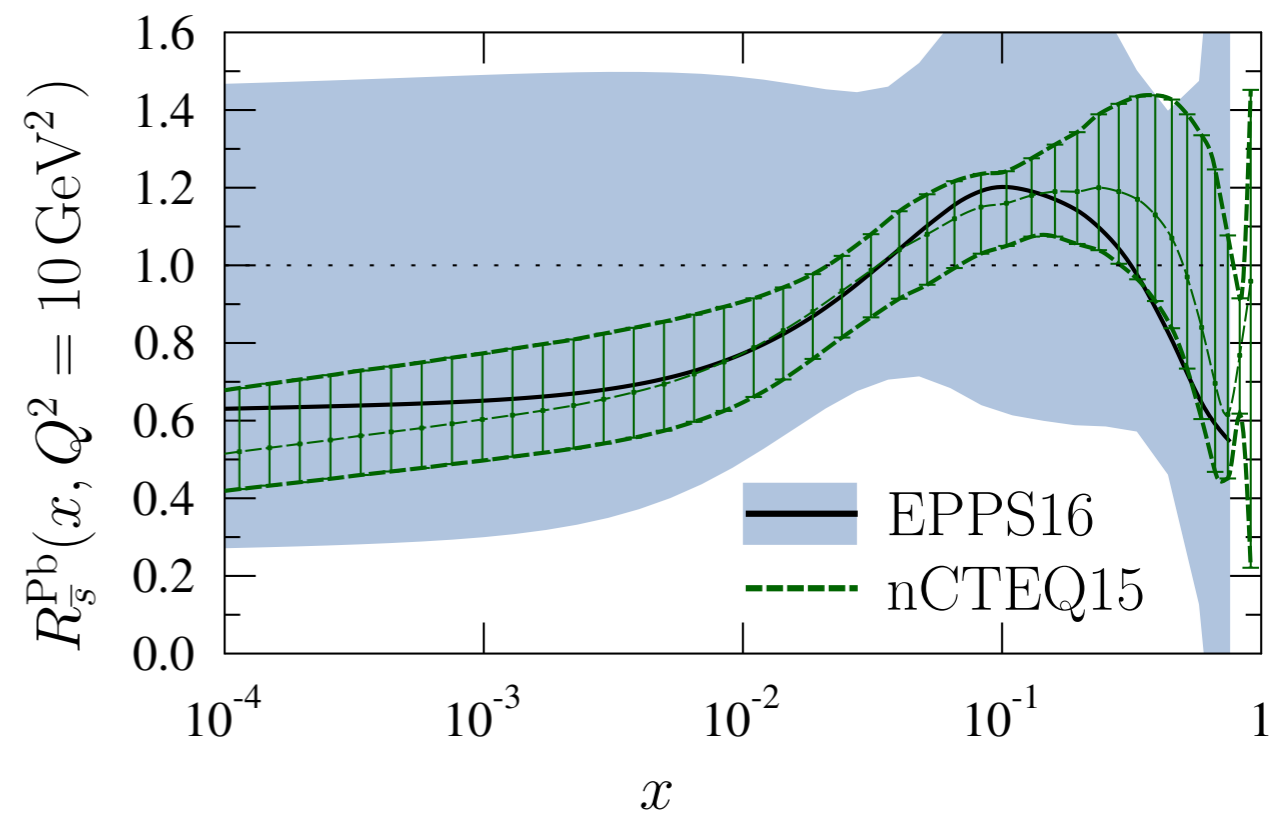
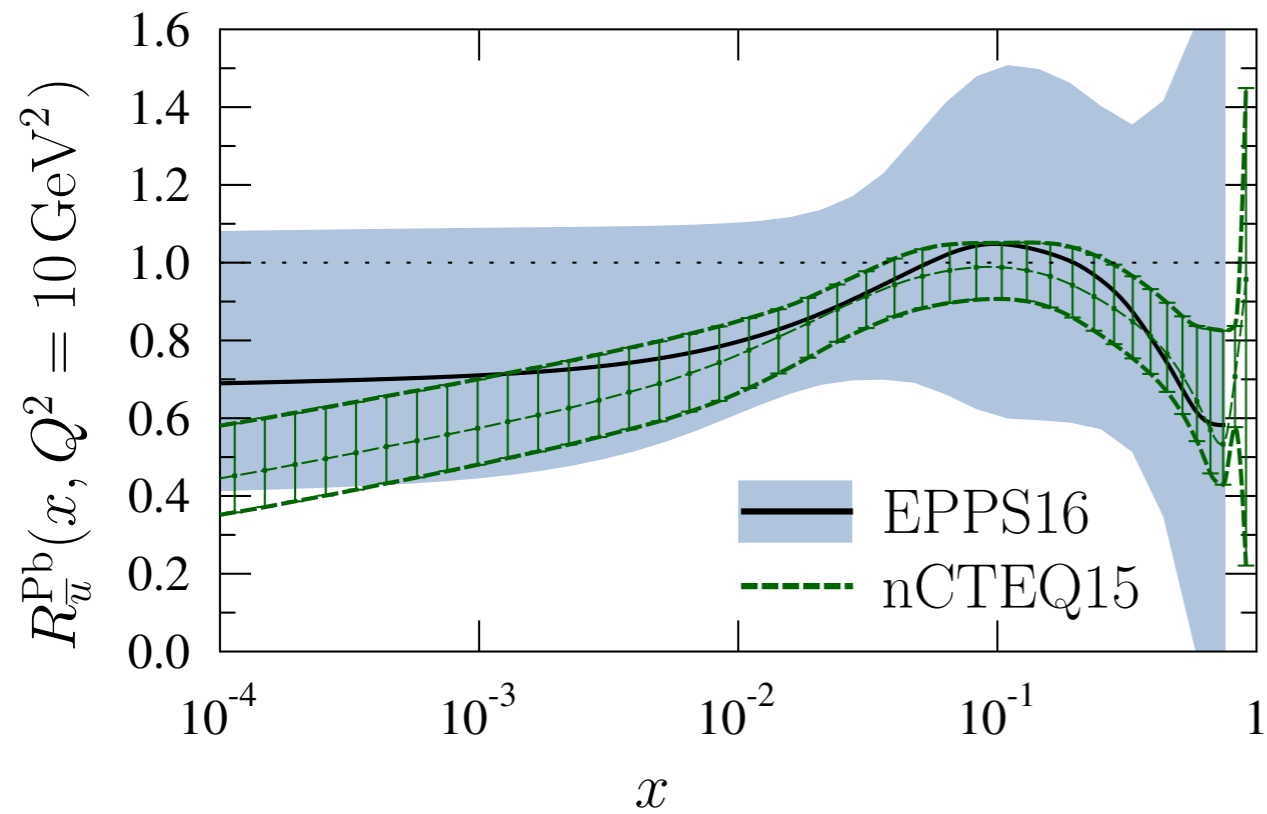
KA15: Khanpour, Tehrani, *Phys.Rev.* D93 (2016) no.1, 014026

SET		DSSZ	nCTEQ15	KA15	EPPS16
<i>d</i> <i>a</i> <i>t</i> <i>a</i> <i>t</i> <i>y</i> <i>p</i> <i>e</i>	<i>e</i> -DIS	✓	✓	✓	✓
	D-Y	✓	✓	✓	✓
	<i>pions</i>	✓	✓	x	✓
	<i>ν</i> -DIS	✓	x	x	✓
	EW	x	x	x	✓
	<i>jets</i>	x	x	x	✓
# <i>data points</i>		1579	740	1479	1811
<i>accuracy</i>		NLO	NLO	NNLO	NLO
<i>proton PDF</i>		MSTW2008	~ CTEQ6.1	JR09	CT14NLO
<i>flavour separation?</i>		<i>no</i>	<i>valence only</i>	<i>no</i>	<i>yes!</i>

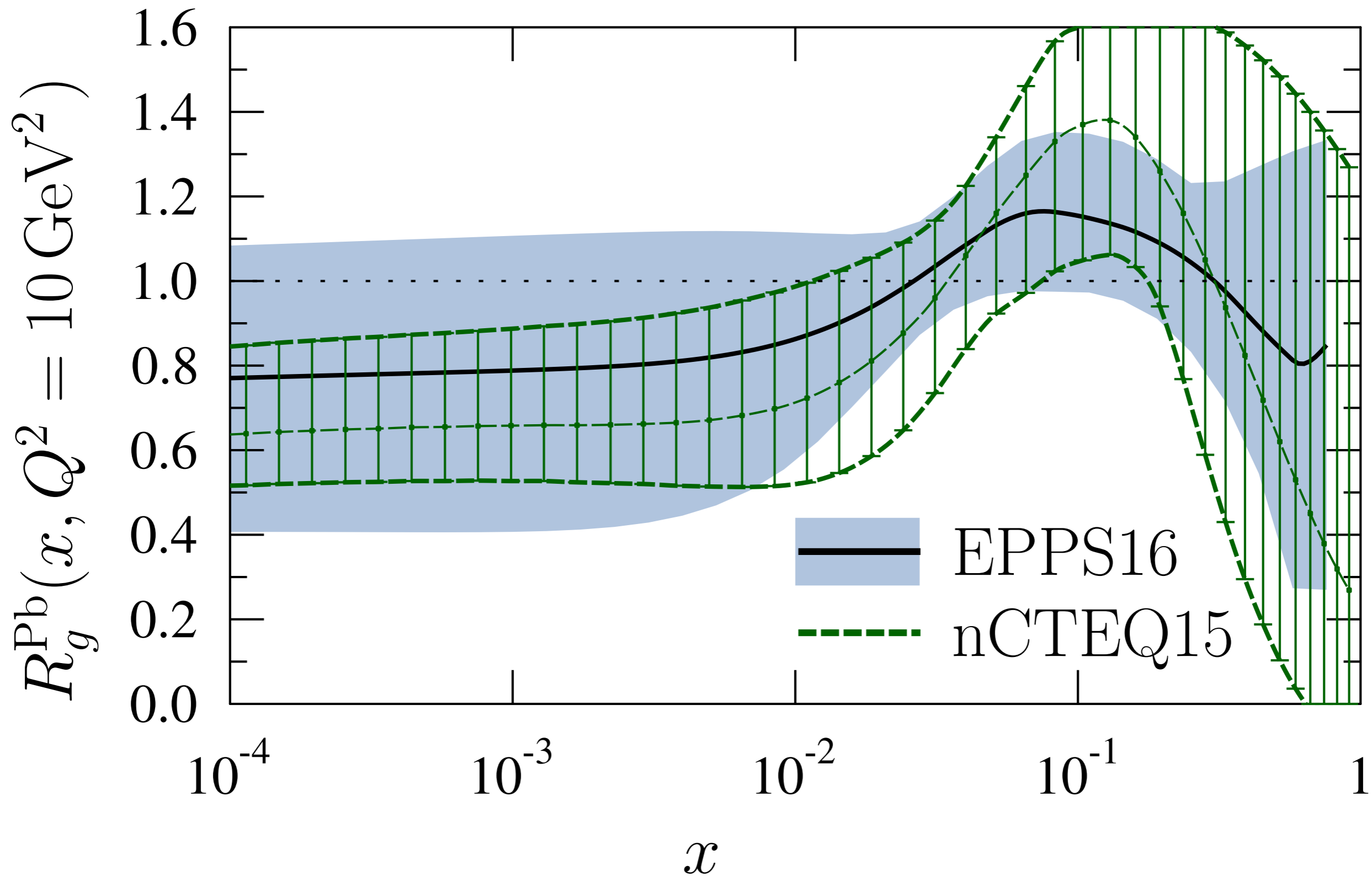
R_{valence}



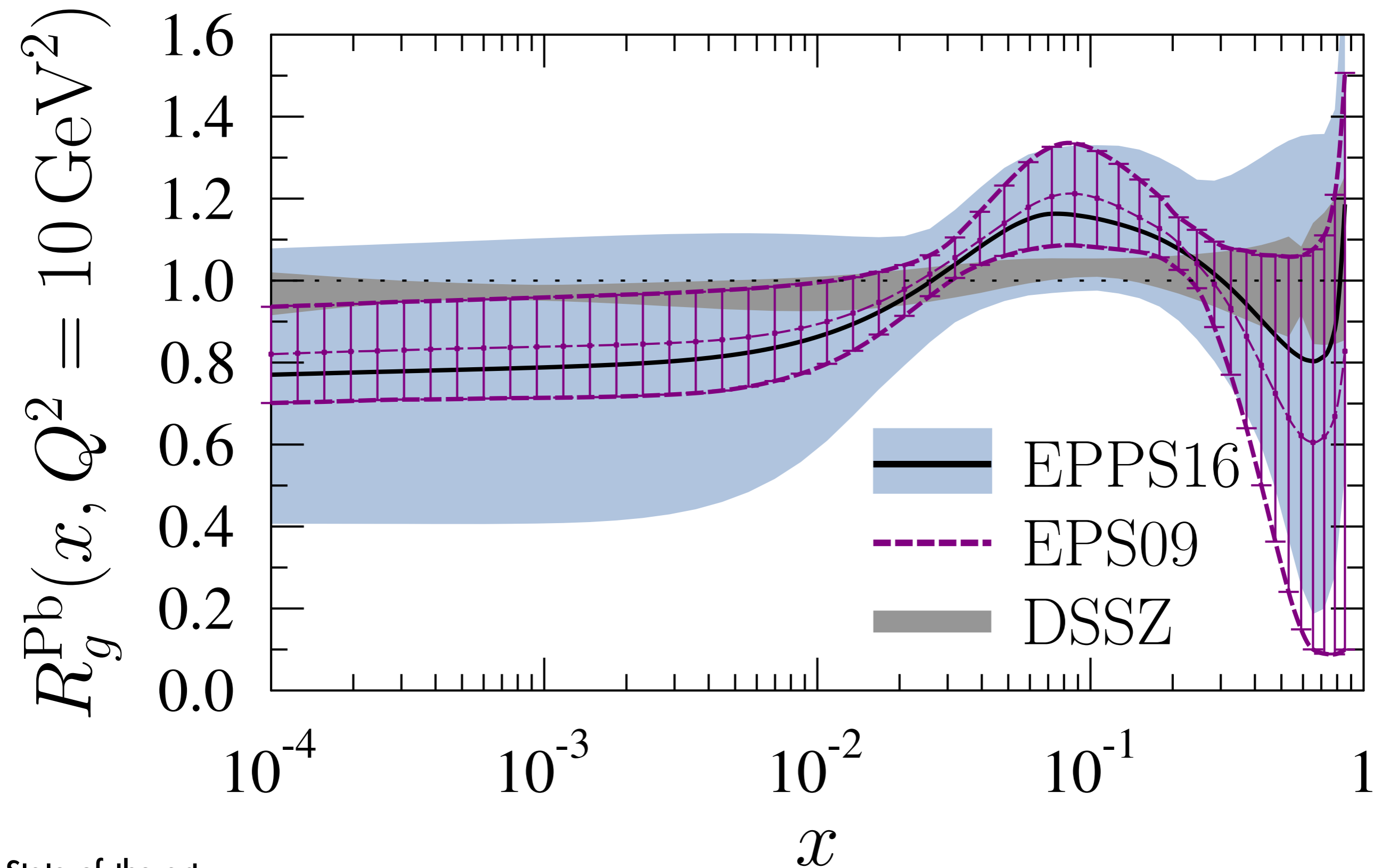
R_{sea}



$R_{g\text{luon}}$



R_{gluon}

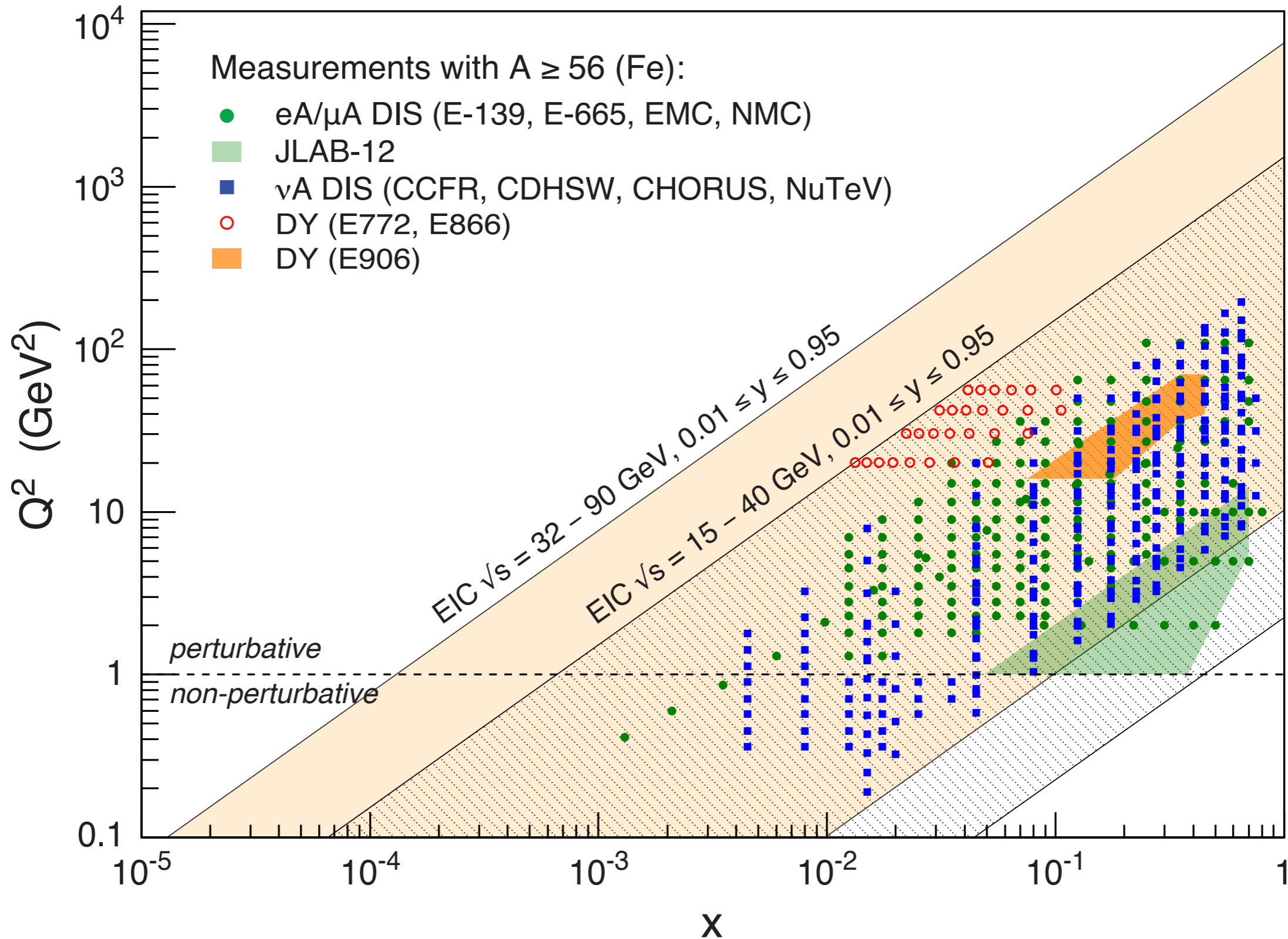


*can we improve this at
future colliders?*

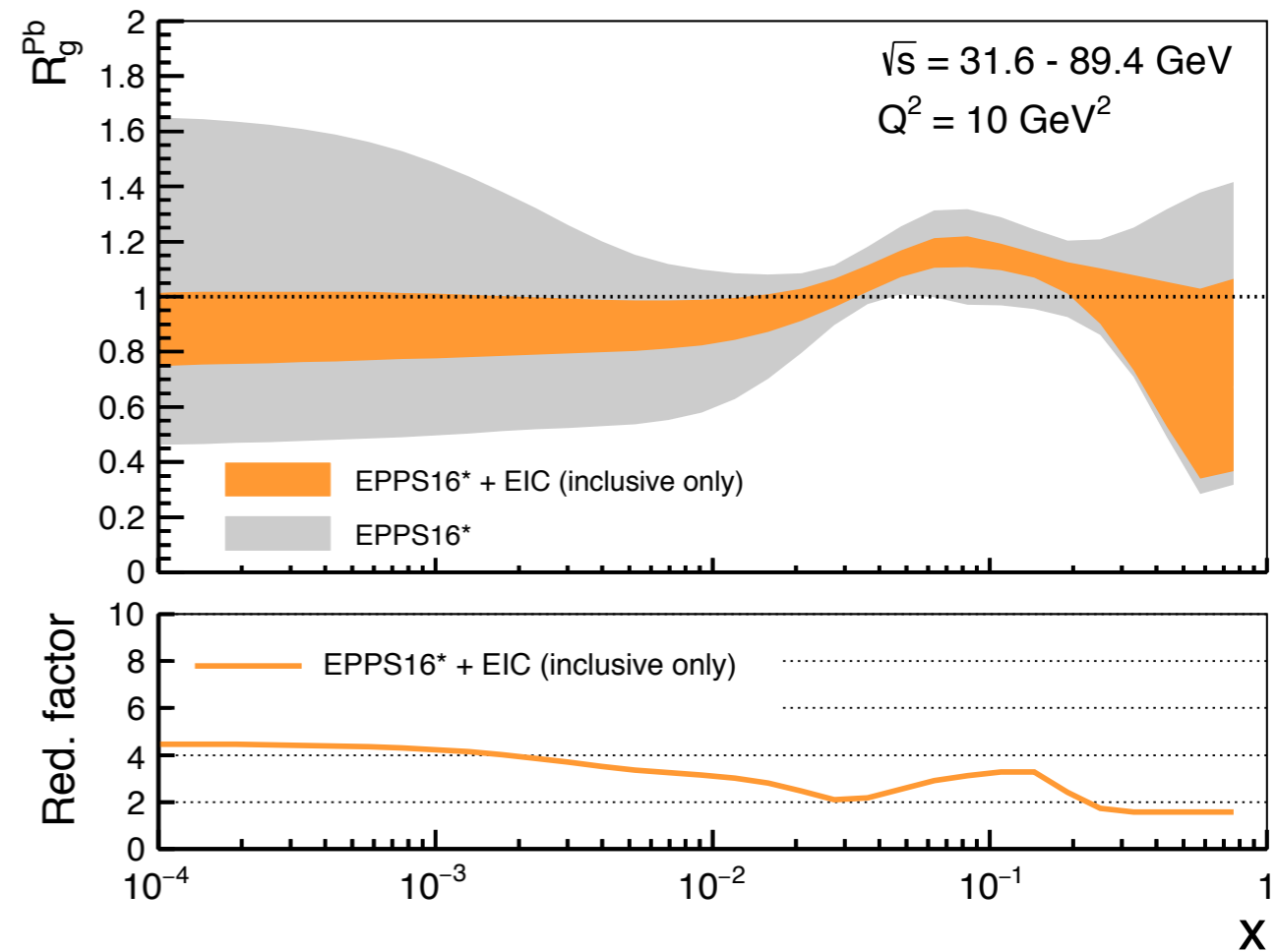
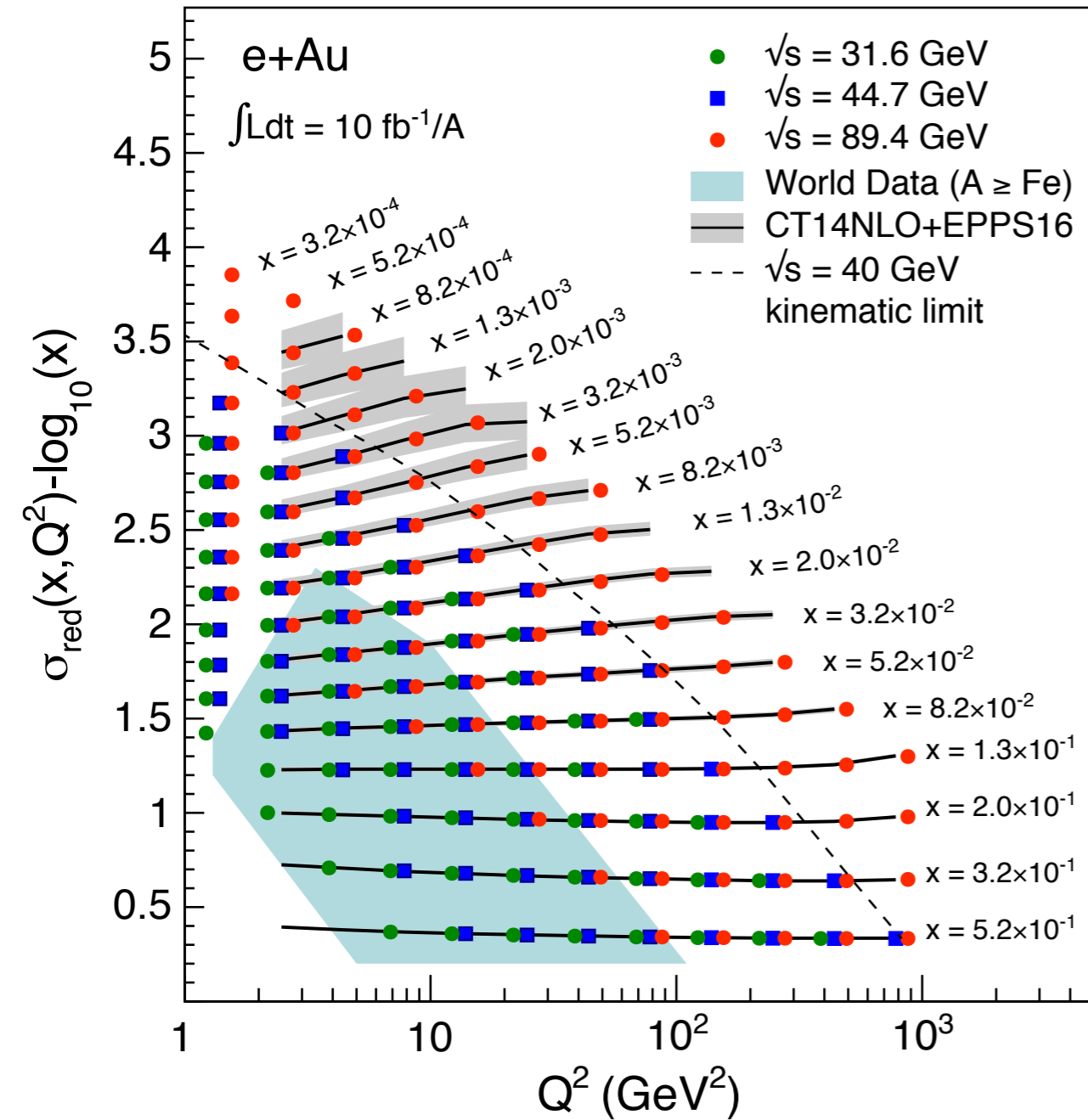
a few remarks:

- ◆ *“data” used, with assumed experimental uncertainties*
 - ◆ *impact estimations are tied to the initial parameterizations*
- & below $x \sim 10^{-2/-3}$ the theoretical curves are*
- EXTRAPOLATIONS:** *there is ALWAYS a bias*
- ◆ *mostly focused on the nightmare (a.k.a. gluon)*

EIC

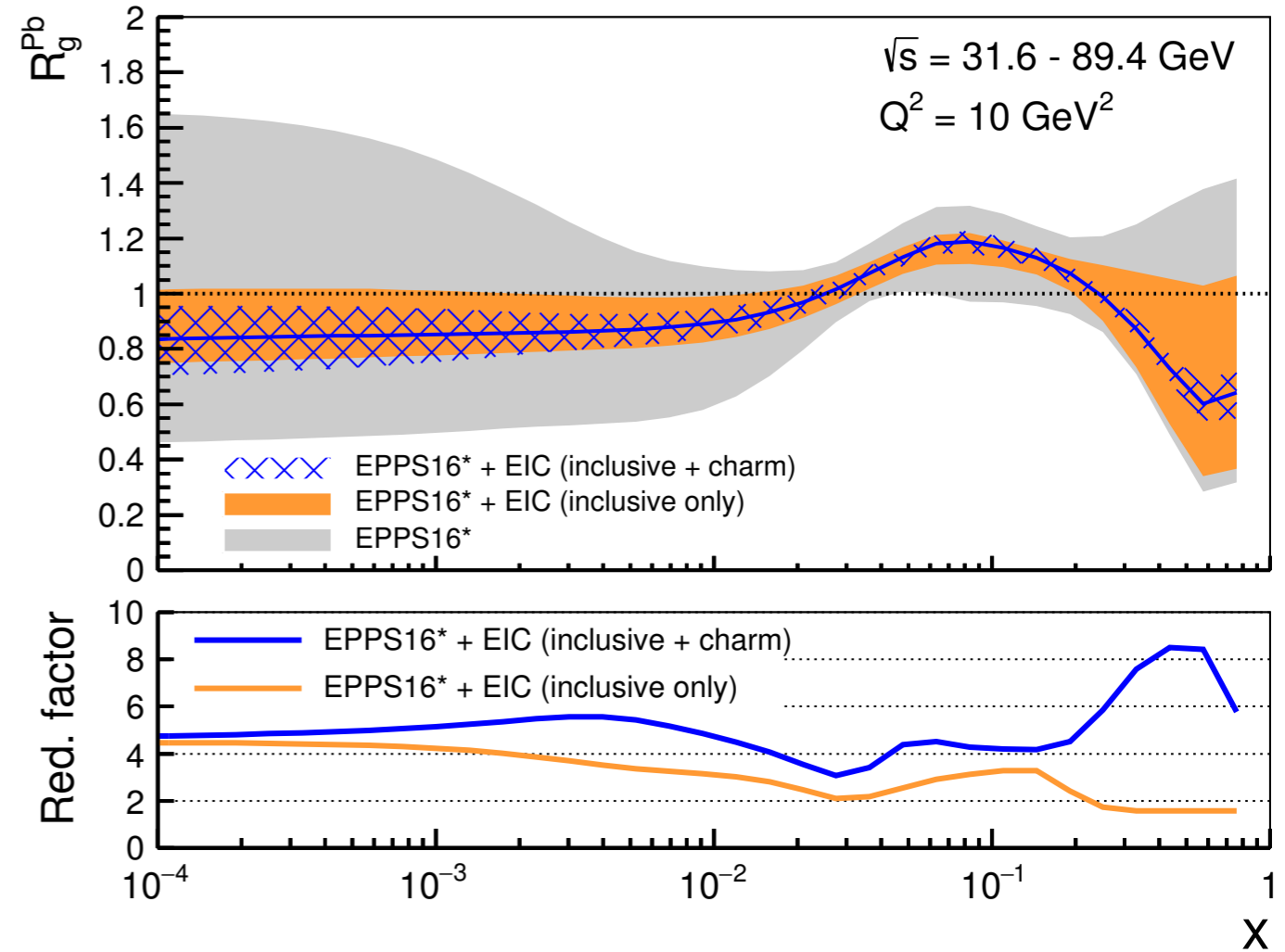
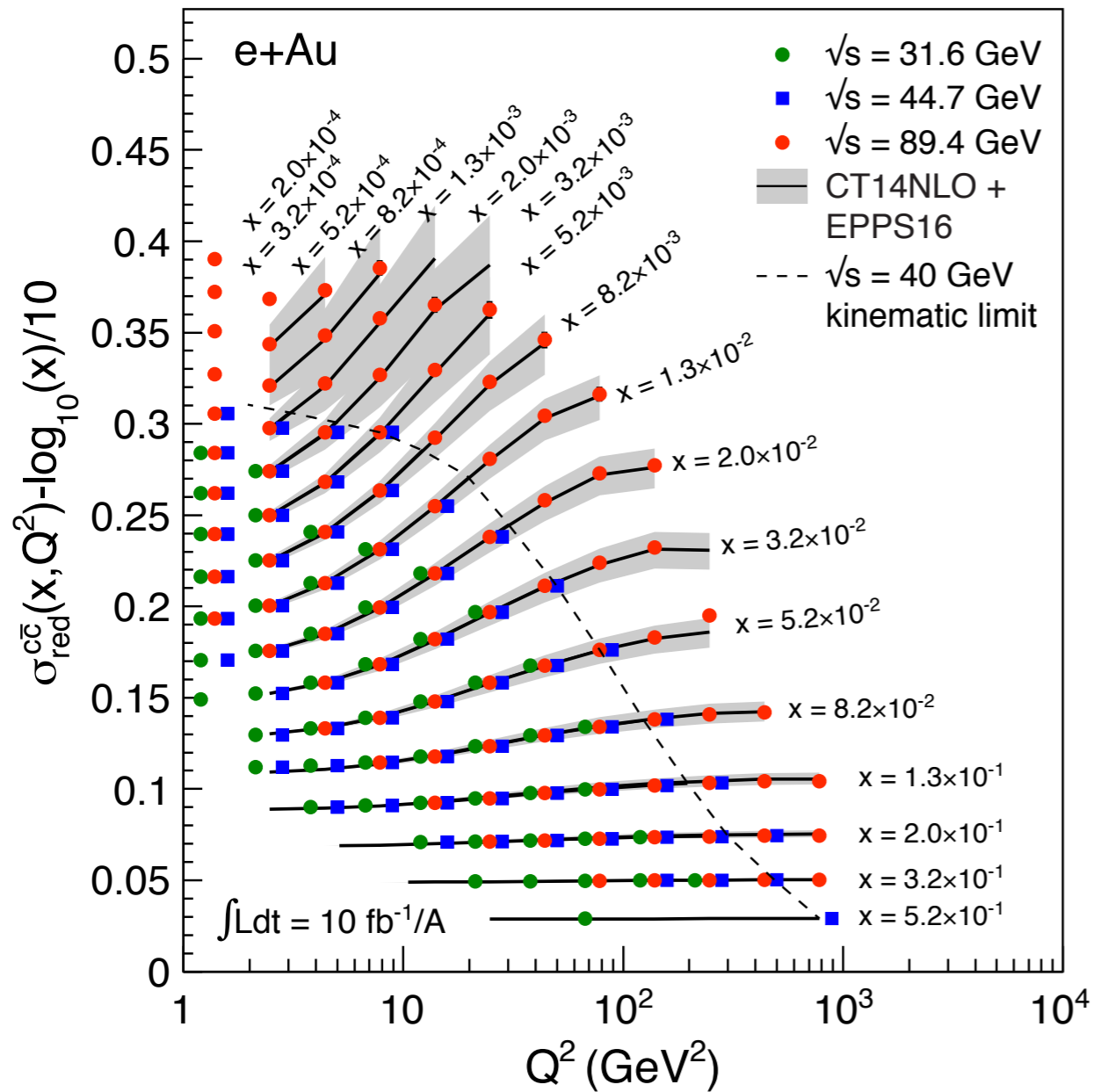


EIC: inclusive σ_{red}

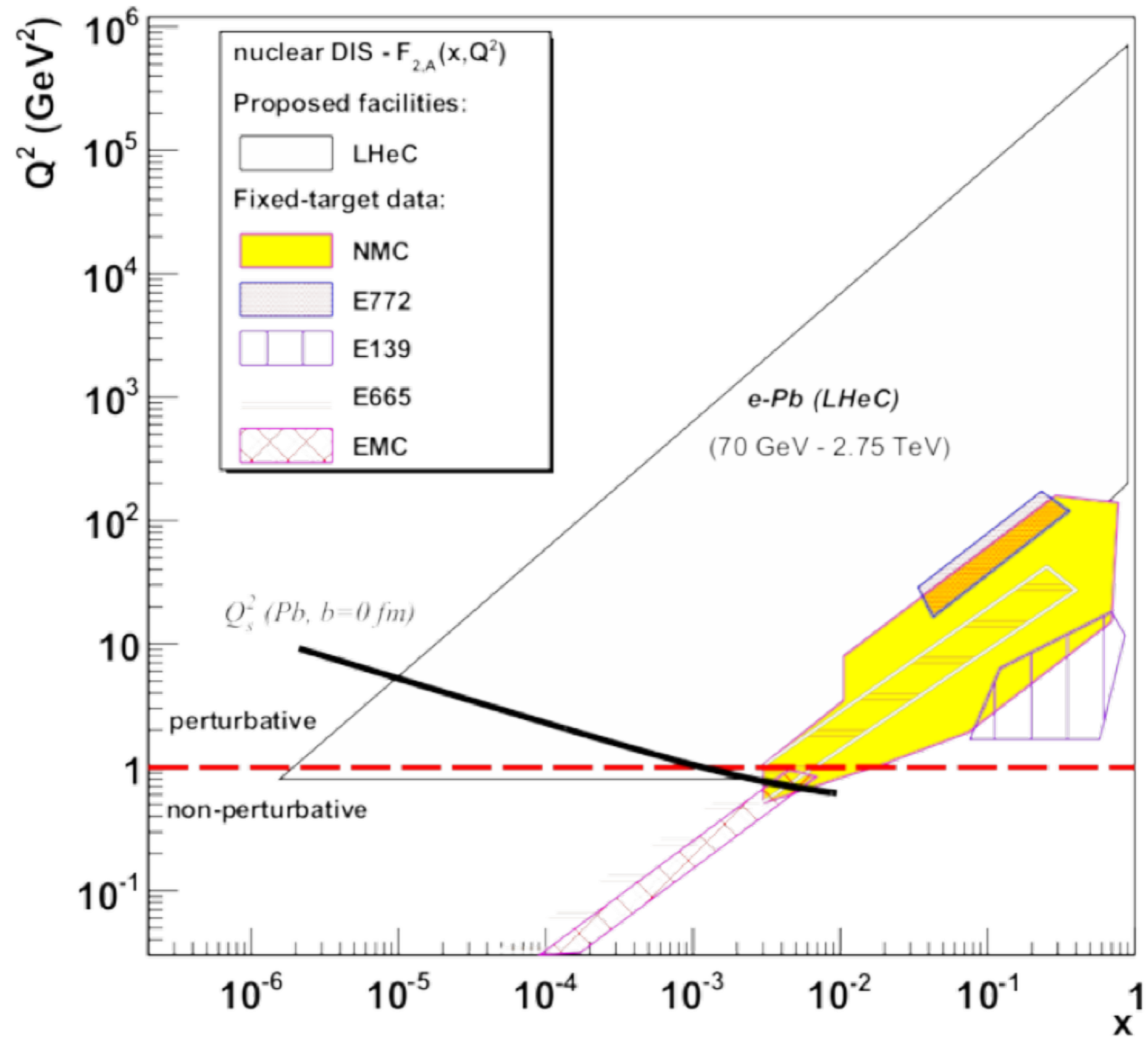


EPPS16*: EPPS16, but less stiff at low x

EIC: $\sigma_{red}^{c\bar{c}}$



LHeC



LHeC

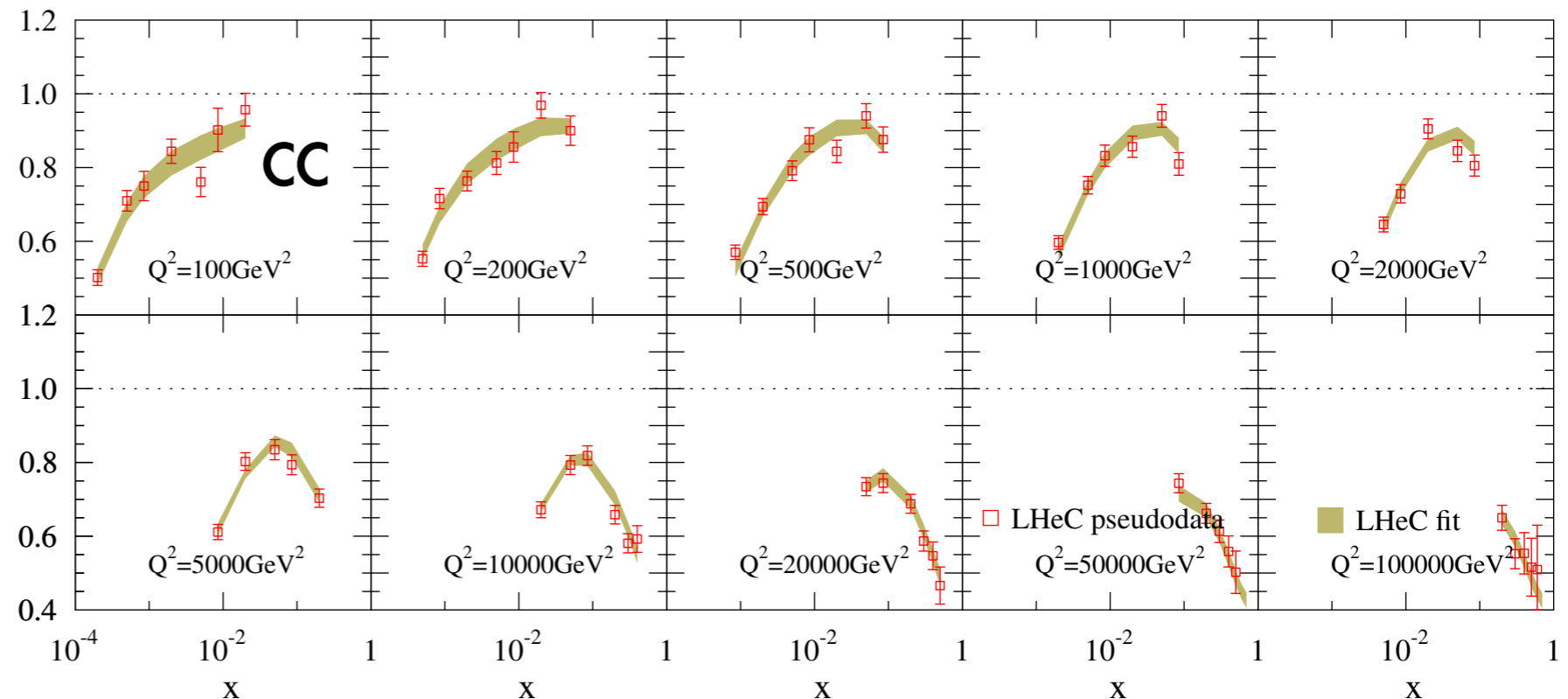
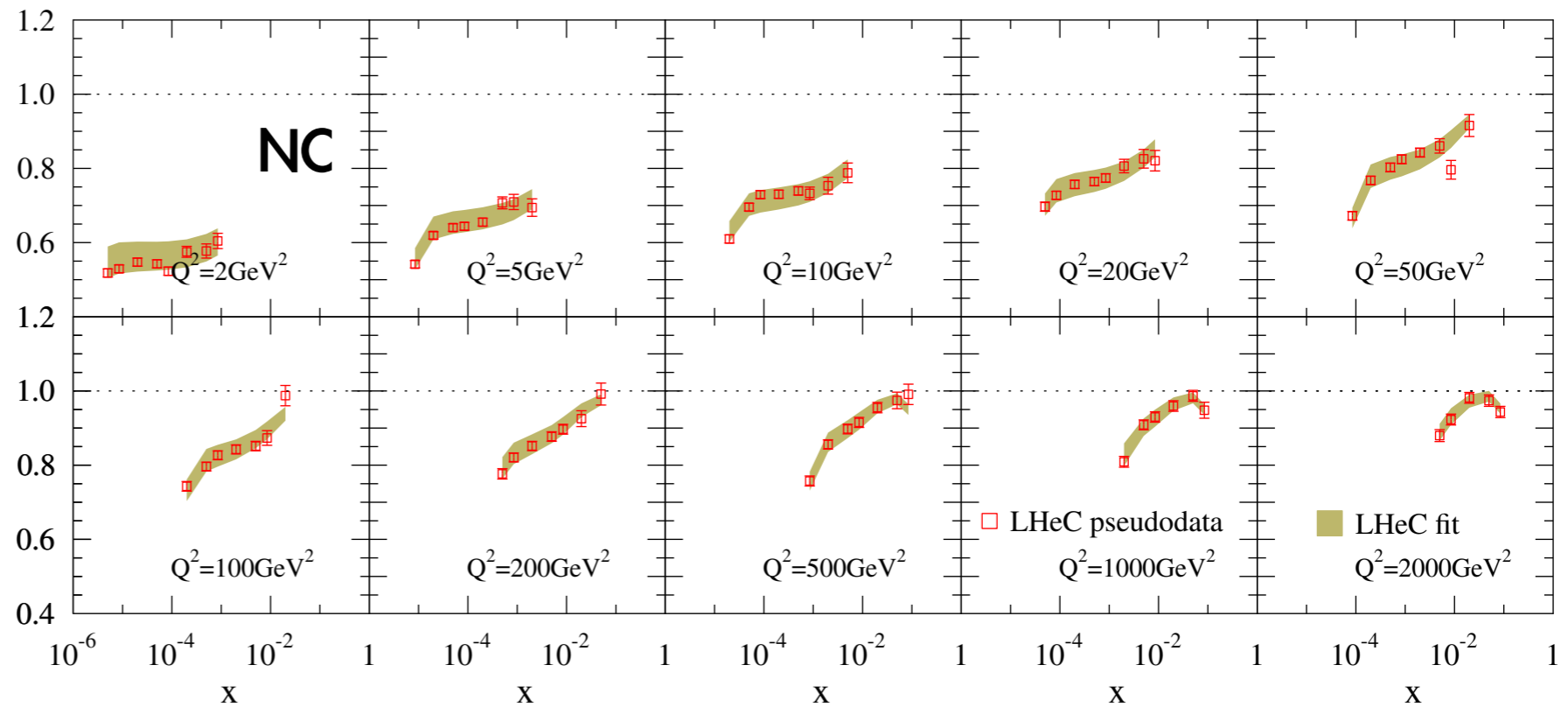
$$\frac{4}{9}u_v + \frac{1}{9}d_v$$

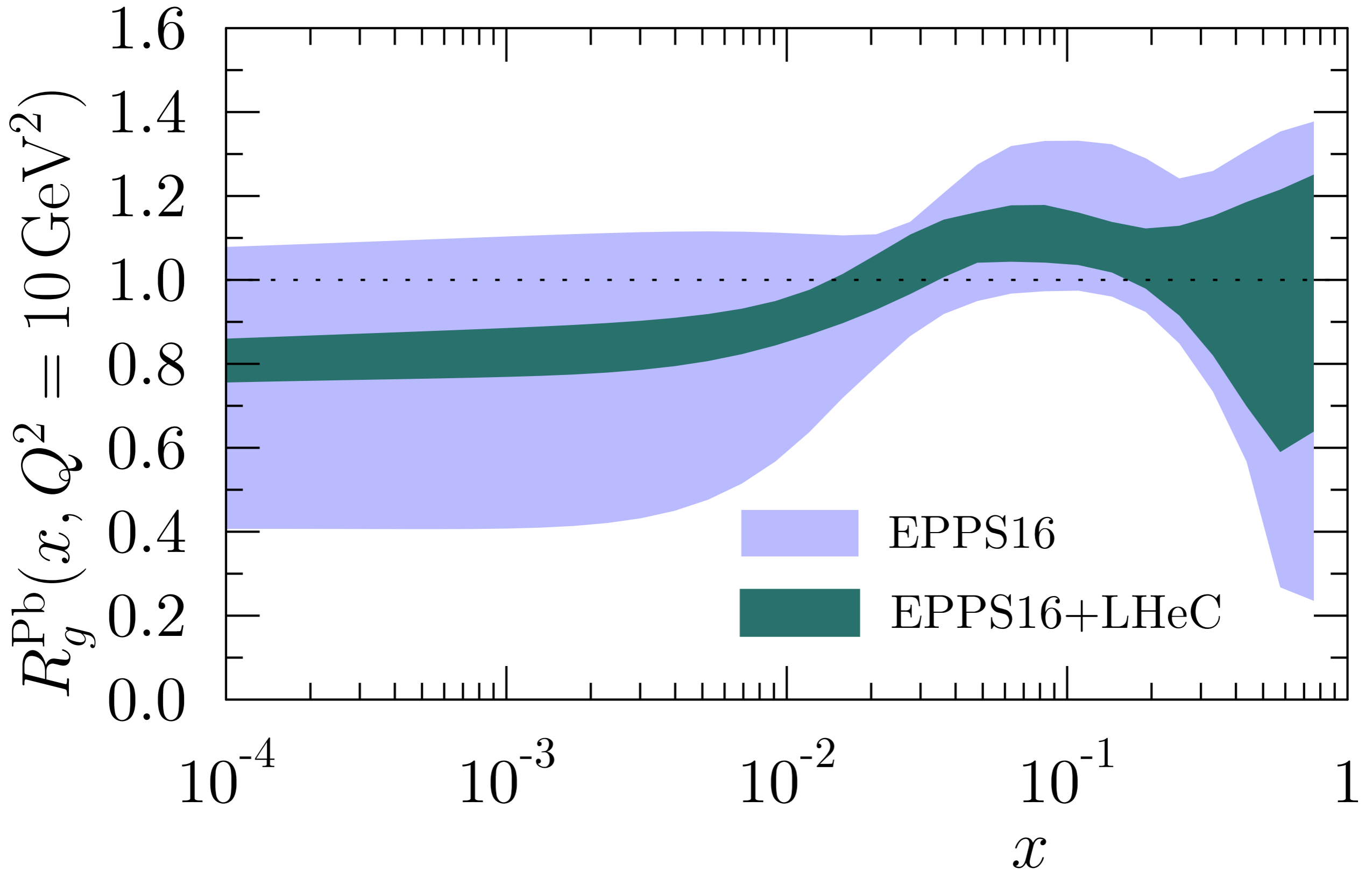
- "data" from EPS09

- joint analysis NC and CC

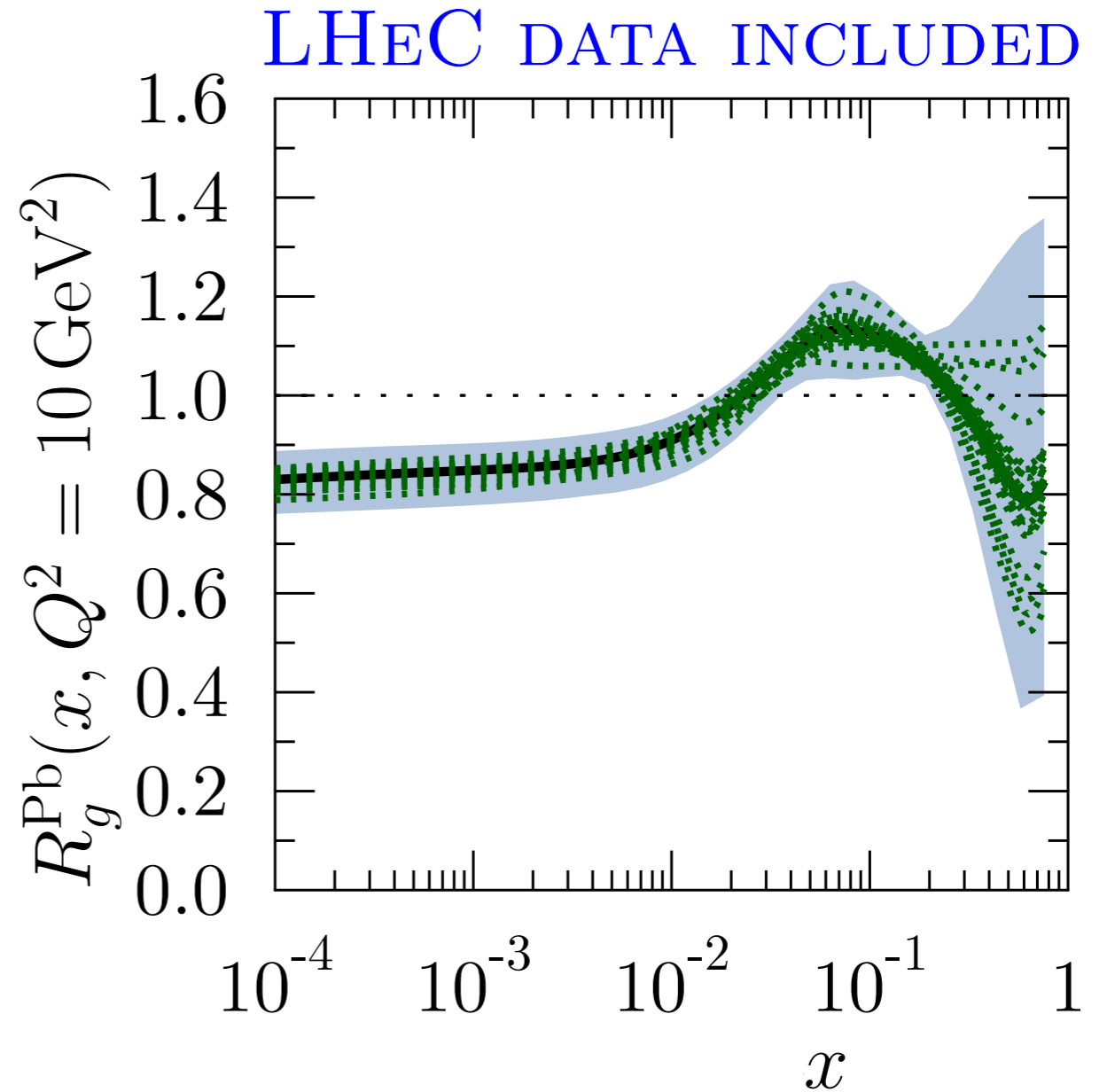
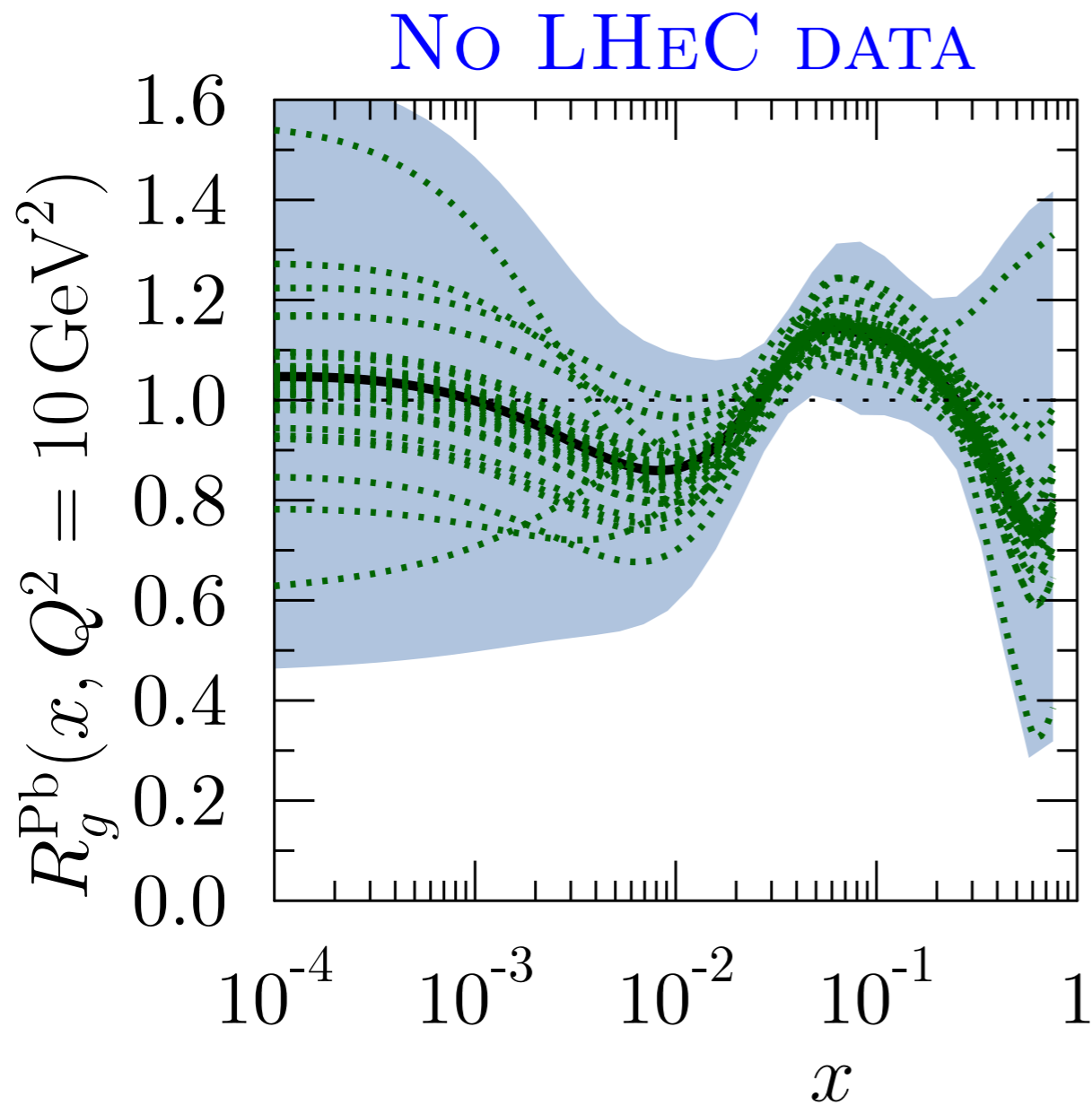
$$u_v + d_v$$

Ratios of reduced cross-sections





if the tight low- x shape is released (like EPPS16*)

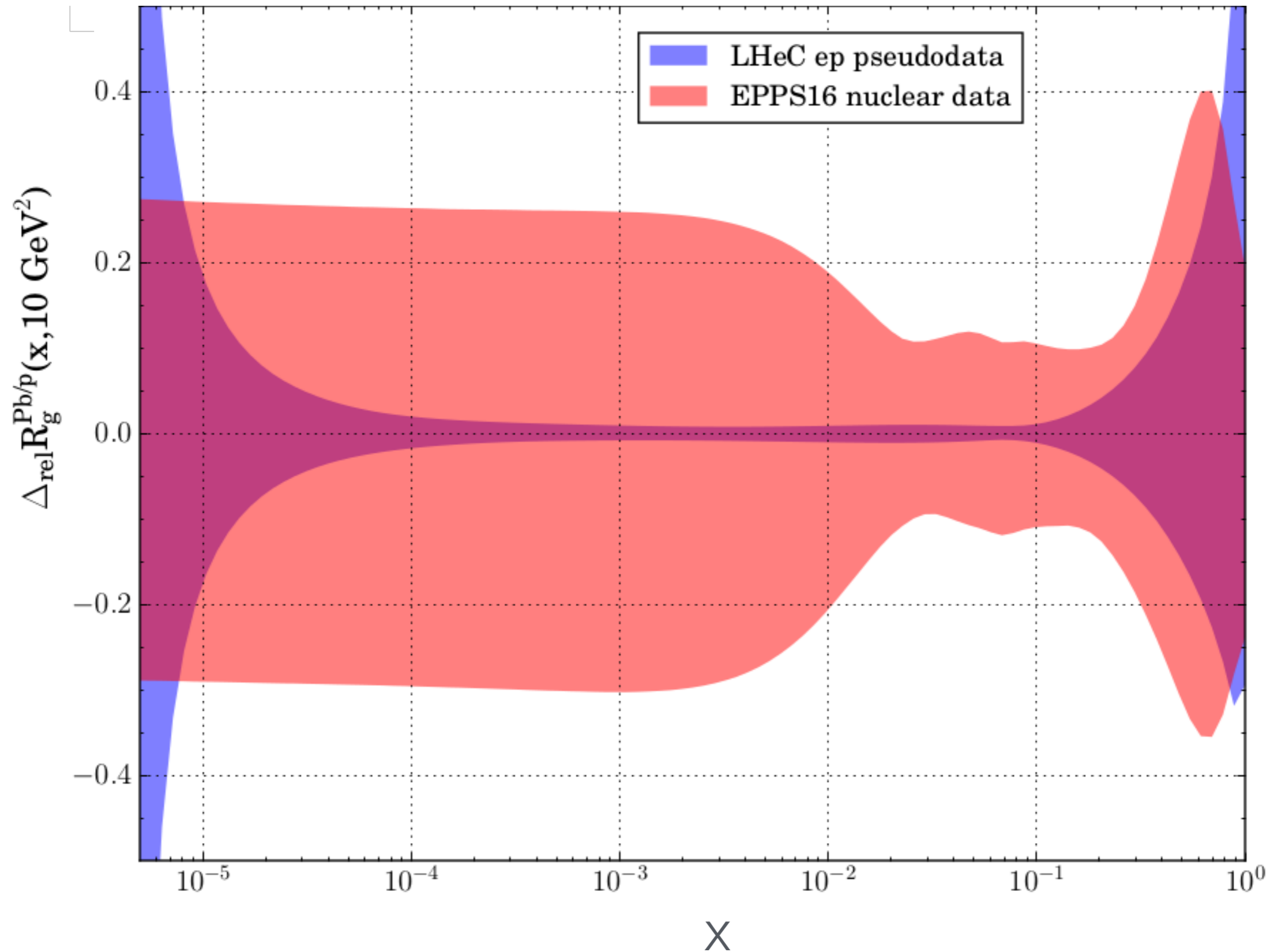


Fit one nucleus directly

- ◆ I first heard this proposal from Juan Rojo, but for Pb at LHC
- ◆ there is a scarce amount of data on Pb from DIS
- ◆ struggle with parameterization

for LHeC:

P. Agostini Infante and N. Armesto, Master Thesis,
Department of Particle Physics, USC

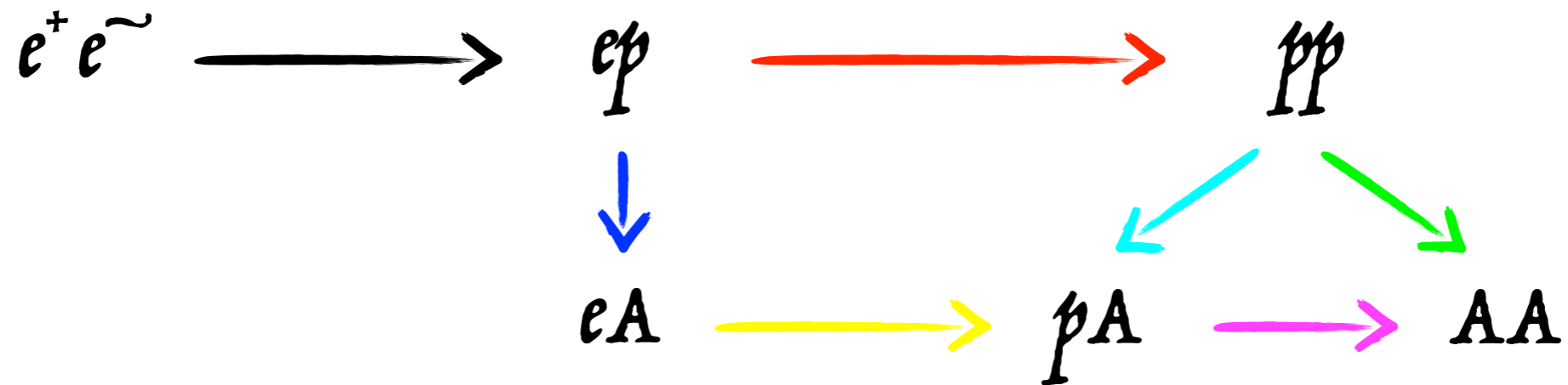


Summary

- ◆ There are several nPDFs sets available in the market, in constant improvement, but they contain all the “issues” of proton PDFs plus more
- ◆ RHIC and LHC are not the best machines to constrain partons in the nuclear medium (*in the present conditions*)

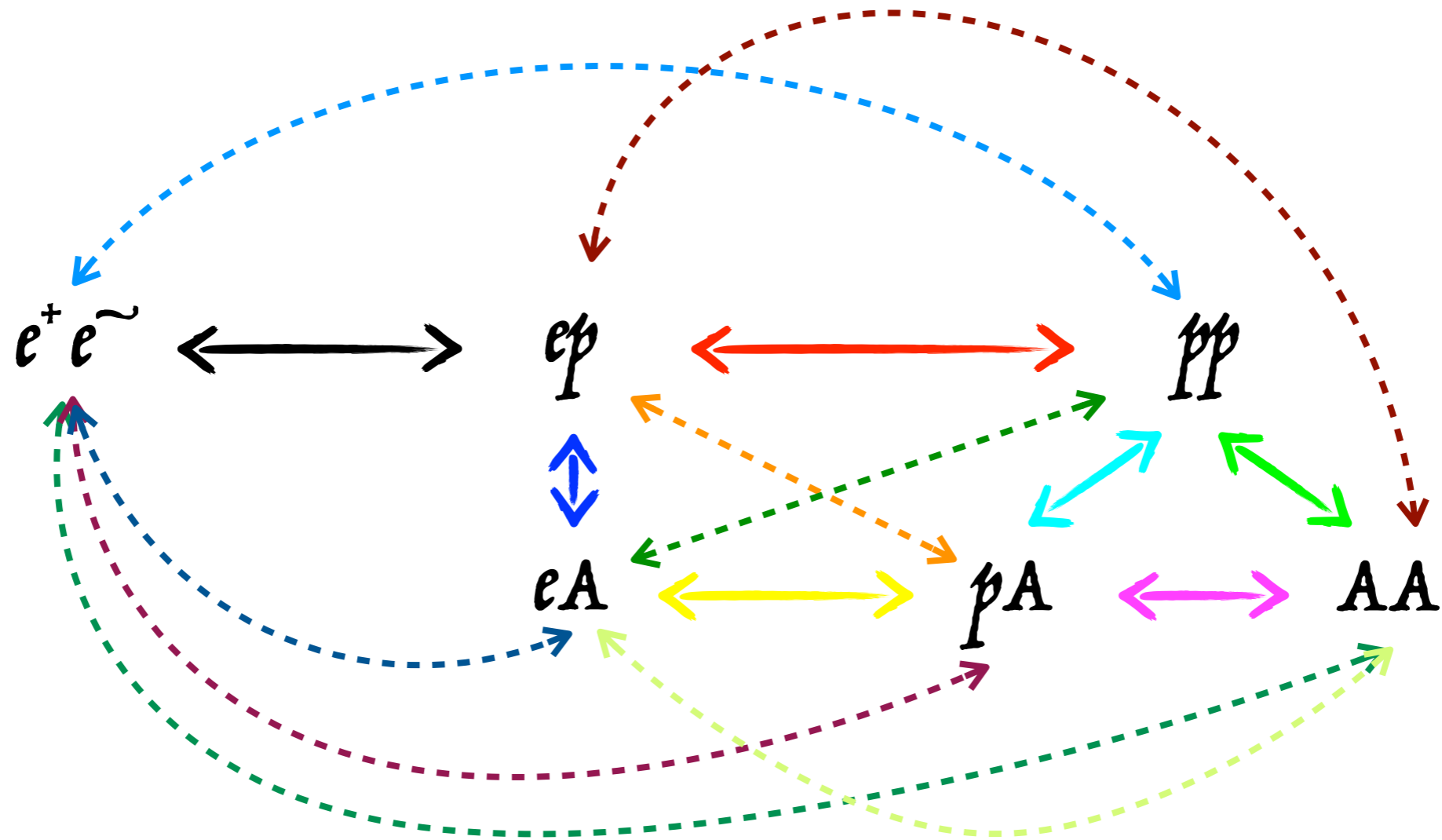
- ◆ we really need to understand proton/nuclear PDFs and FFs/nFFs

expectation:



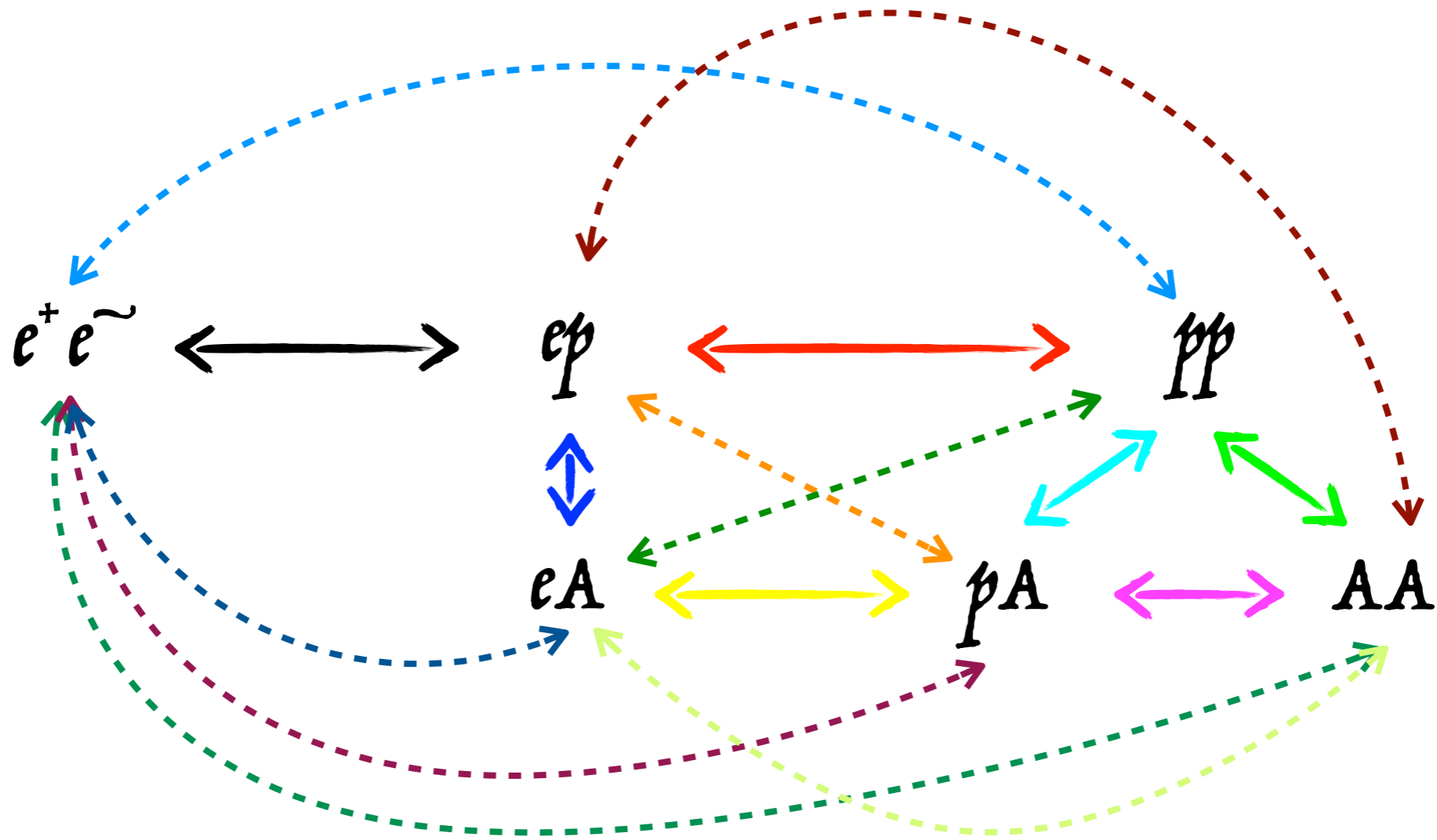
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reality:



- ◆ we really need to understand proton/nuclear PDFs and FFs/nFFs

reality:



- ◆ future colliders, for the nuclear case, are a **MUST**

Outlook:

keeping up with the

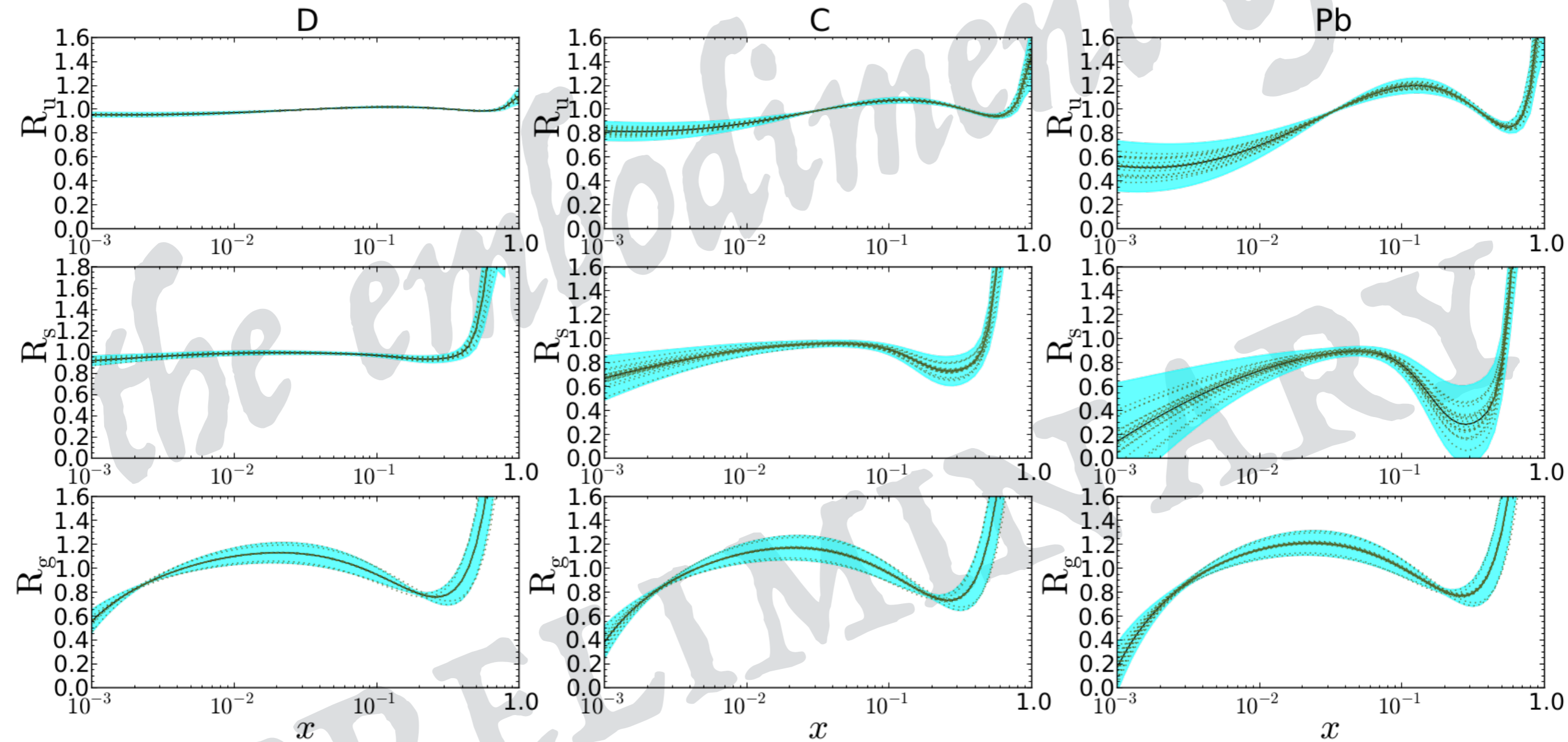
protons

- ◆ *use current colliders... but we need DATA (and convince experimentalists to publish uncertainty correlations)*
- ◆ *improve FEs so we can use available (not only LHC) data*
- ◆ *apply proton PDFs analysis techniques and improvements in nPDFs extractions*
- ◆ *go for a proton + nuclear PDFs analysis*

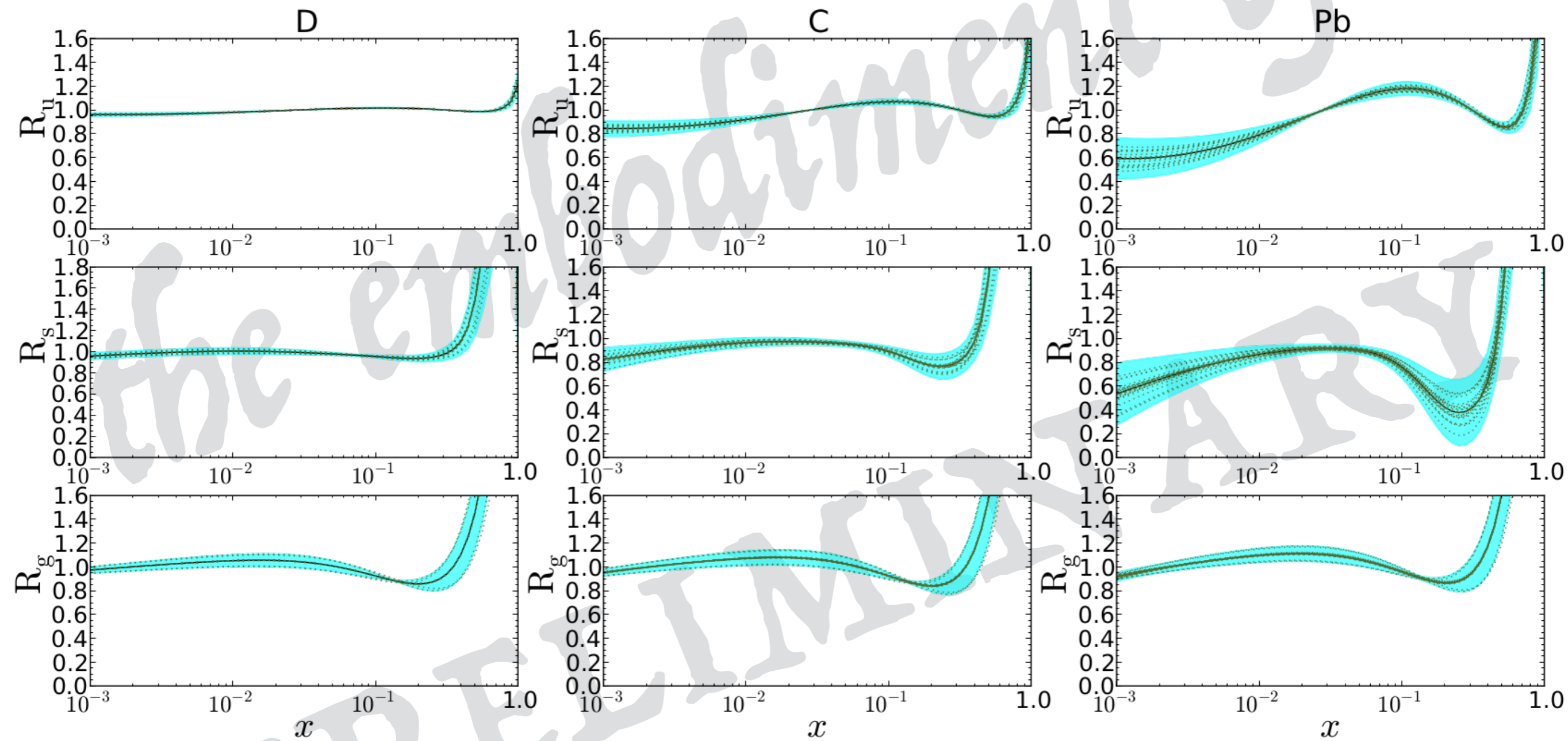
SET		DSS \mathcal{Z}	nCTEQ15	KA15	EPPS16	A \mathcal{Z} (VERY preliminar)
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	D-Y	✓	✓	✓	✓	not yet
	<i>pions</i>	✓	✓	x	✓	?
	ν -DIS	✓	x	x	✓	✓
	EW	x	x	x	✓	?
	jets	x	x	x	✓	?
# data points		1579	740	1479	1811	3115 (2-5 k)
accuracy		NLO	NLO	NNLO	NLO	NNLO
proton PDF		MSTW2008	~ CTEQ6.1	JR09	CT14NLO	MMHT2014
flavour separation?		no	valence only	no	yes!	not yet

A \mathcal{Z} : Carlota Andrés and P. \mathcal{Z} , (work in progress)

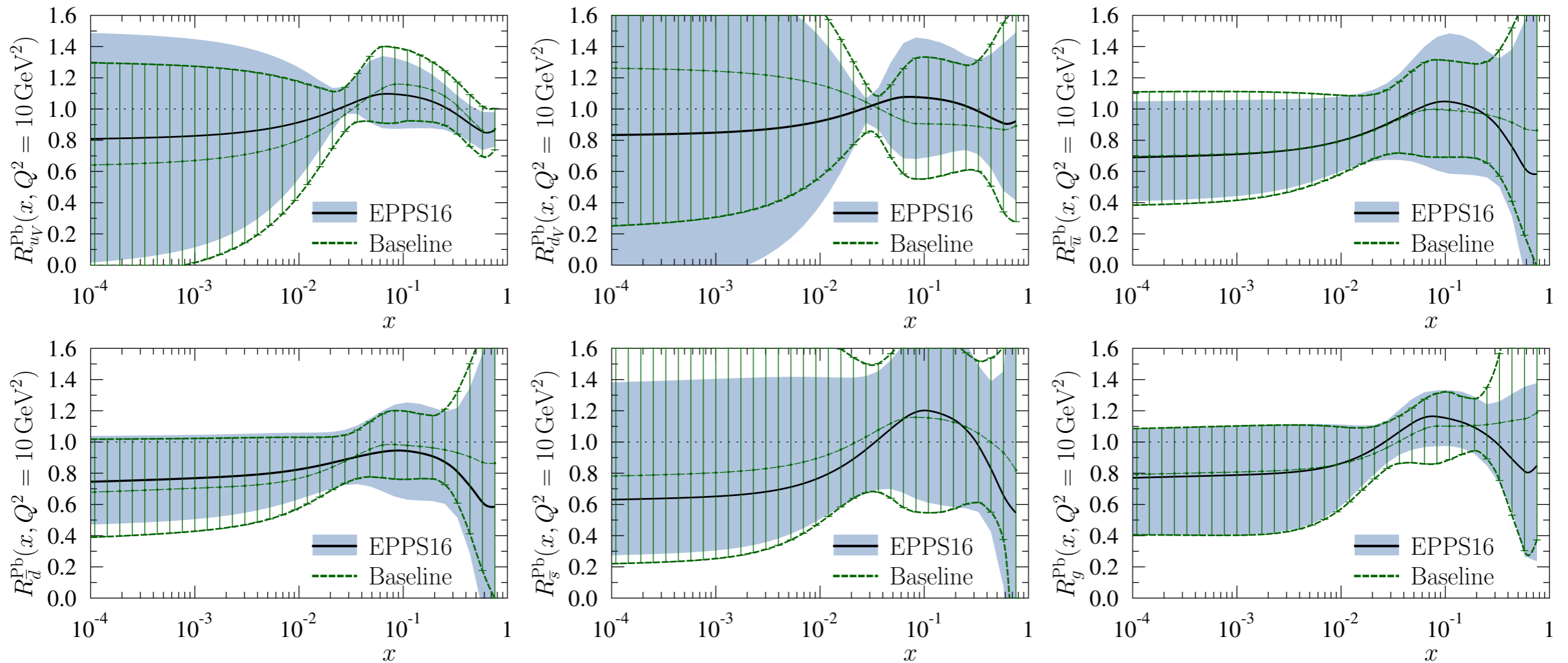
$$Q^2 = 2 \text{ GeV}^2$$



$$Q^2 = 10 \text{ GeV}^2$$



The impact of the LHC data



- ◆ few points (30 out of 1811, $\sim 1.7\%$)
- ◆ not very precise (correlations not included in general)
- ◆ ratios taken, information lost
- ◆ very high Q^2 (2 o.o.m. away from DIS and DY data)
- ◆ DGLAP evolution washing away effects