Recent Progress in Nuclear Parton Distributions

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BNL

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Outline

- Why nuclear PDFs?
- Latest set of nPDFs
- Future experiments
- Exploiting current data
- Summary

Why nuclear PDFs?

Once upon a time, in a land not so far away…

… people decided to do e+A collisions for fun, because a nucleus **A** is just **Z** protons and **A-Z** neutrons, **right?**

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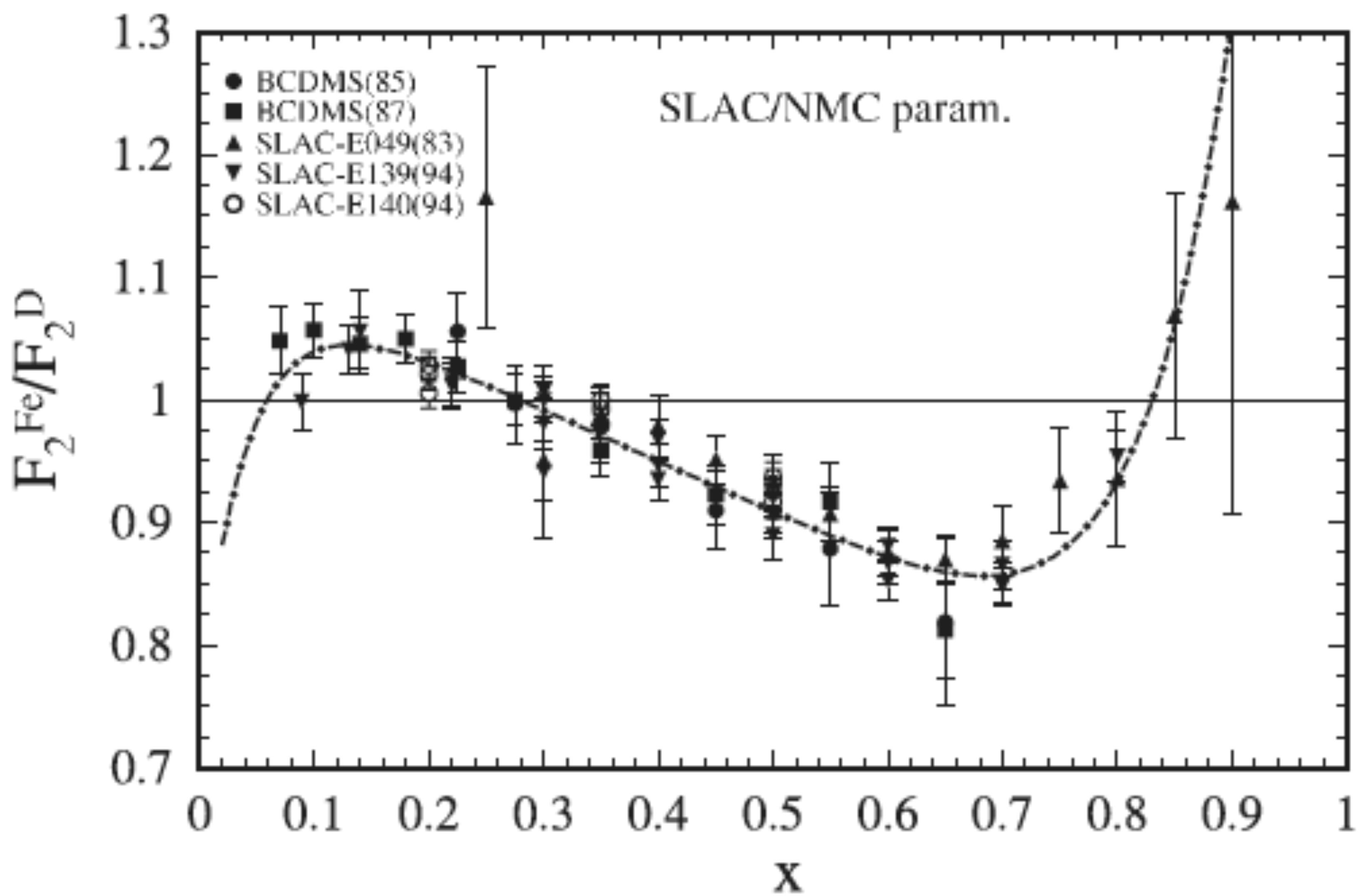


OK, they were SO wrong, so now:

what is affected by the nuclear environment?

a) the non-perturbative part?

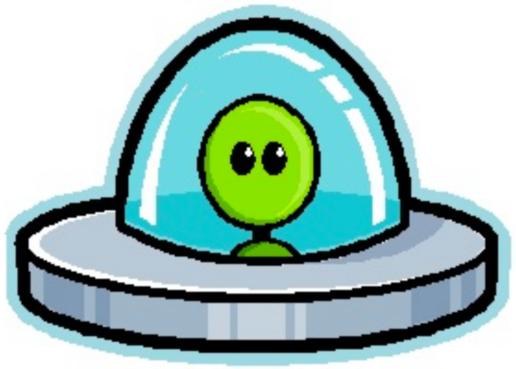
b) the perturbative part?

c) both?

b) and c) are unpopular answers

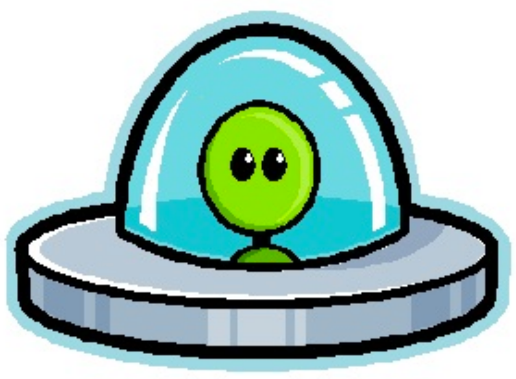
(but could be right!)

The simplest proposal:



✦ the partons know that they are not alone

The simplest proposal:



- ✦ the partons know that they are not alone
- ✦ introduce **nuclear** PDFs
- ✦ use the same evolution equations
- ✦ same perturbative expansion for the observables
- ✦ and try to perform a global fit to the world data*

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

***results usually shown as the ratio of the parton in nucleus to parton in proton PDF. Other depictions may be used**

- Why nPDFs if I do not care about e+A nor p+A?

    - neutrino initiated DIS (useful for proton PDFs)
    - e+d DIS (useful for proton PDFs)
    - non QGP effects in A+A
    - cosmic rays

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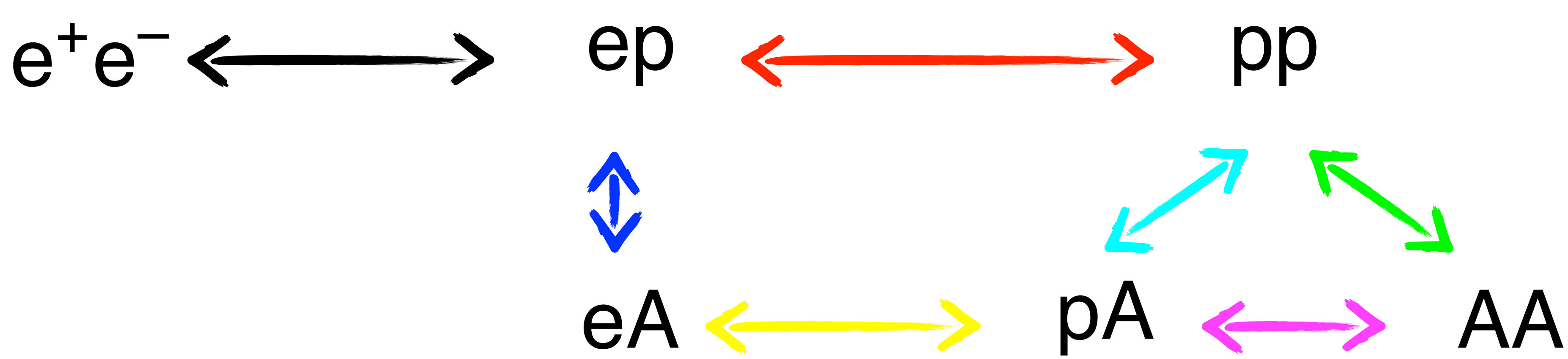
expectation:



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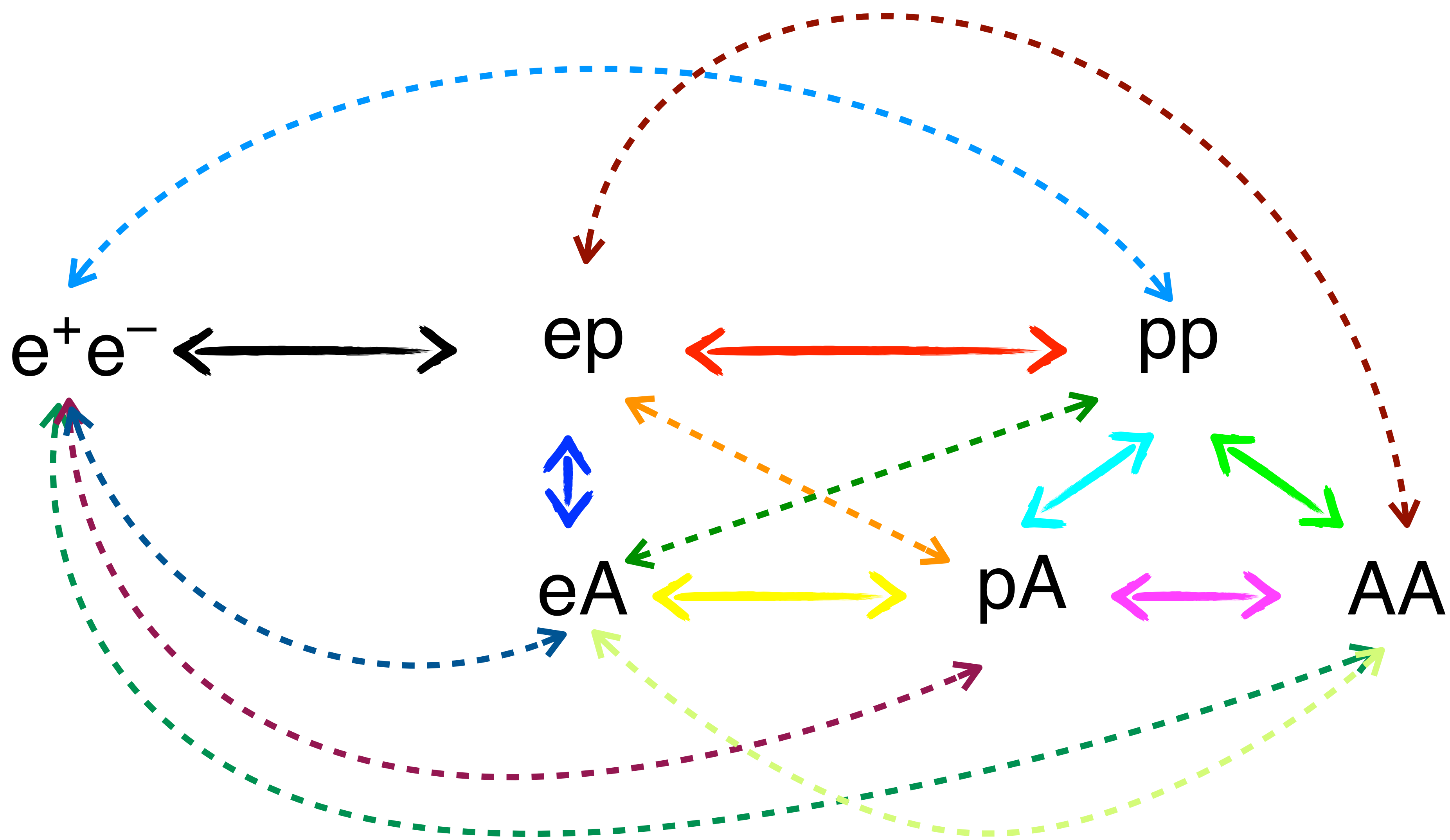
reality:



Latest set of nPDFs

within experimental uncertainties nPDF extraction is successful:

- HKM: Hirai, Kumano, Miyama, PRD64 (2001) 034003
- nDS: de Florian, Sassot, PRD69 (2004) 074028
- HKN: Hirai, Kumano, Nagai, PRC76 (2007) 065207
- EPS09: Eskola, Paukkunen, Salgado, JHEP 0904 (2009) 065
- DSSZ: de Florian, Sassot, Stratmann, PZ, PRD85 (2012) 074028
- nCTEQ15: Kovarik et al., PRD93 (2016) no.8, 085037
- KA15: Khanpour, Tehrani, PRD93 (2016) no.1, 014026
- **EPPS16: Eskola, Paakkinen, Paukkunen, Salgado, EPJ C77 (2017) no.3, 163**

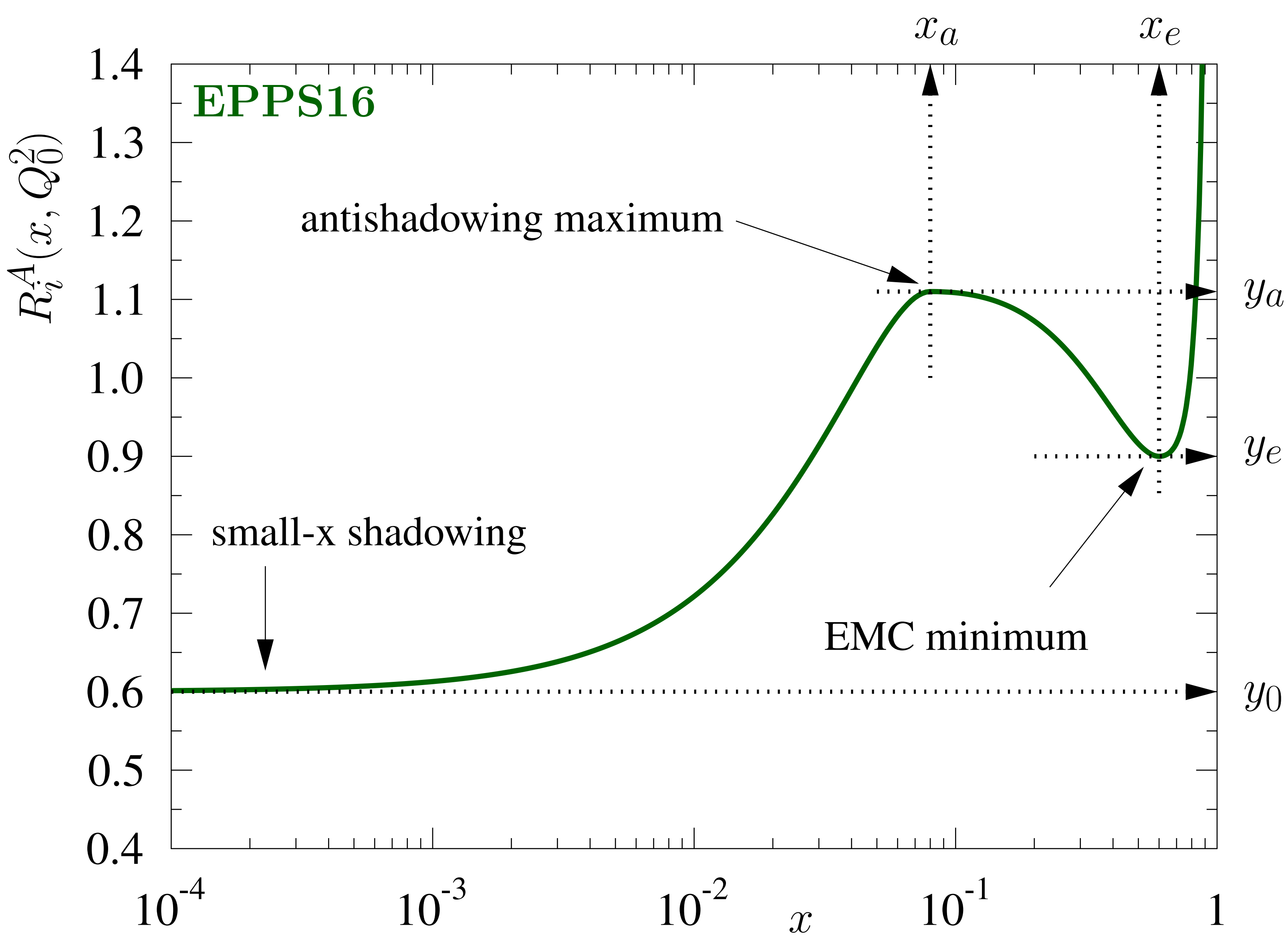
Latest set of nPDFs

$$f_{i/A}\left(x, Q_0^2\right) \equiv f_{i/p}\left(x, Q_0^2\right) R_i^A\left(x, Q_0^2\right)$$

R_{u_v}, R_{d_v}

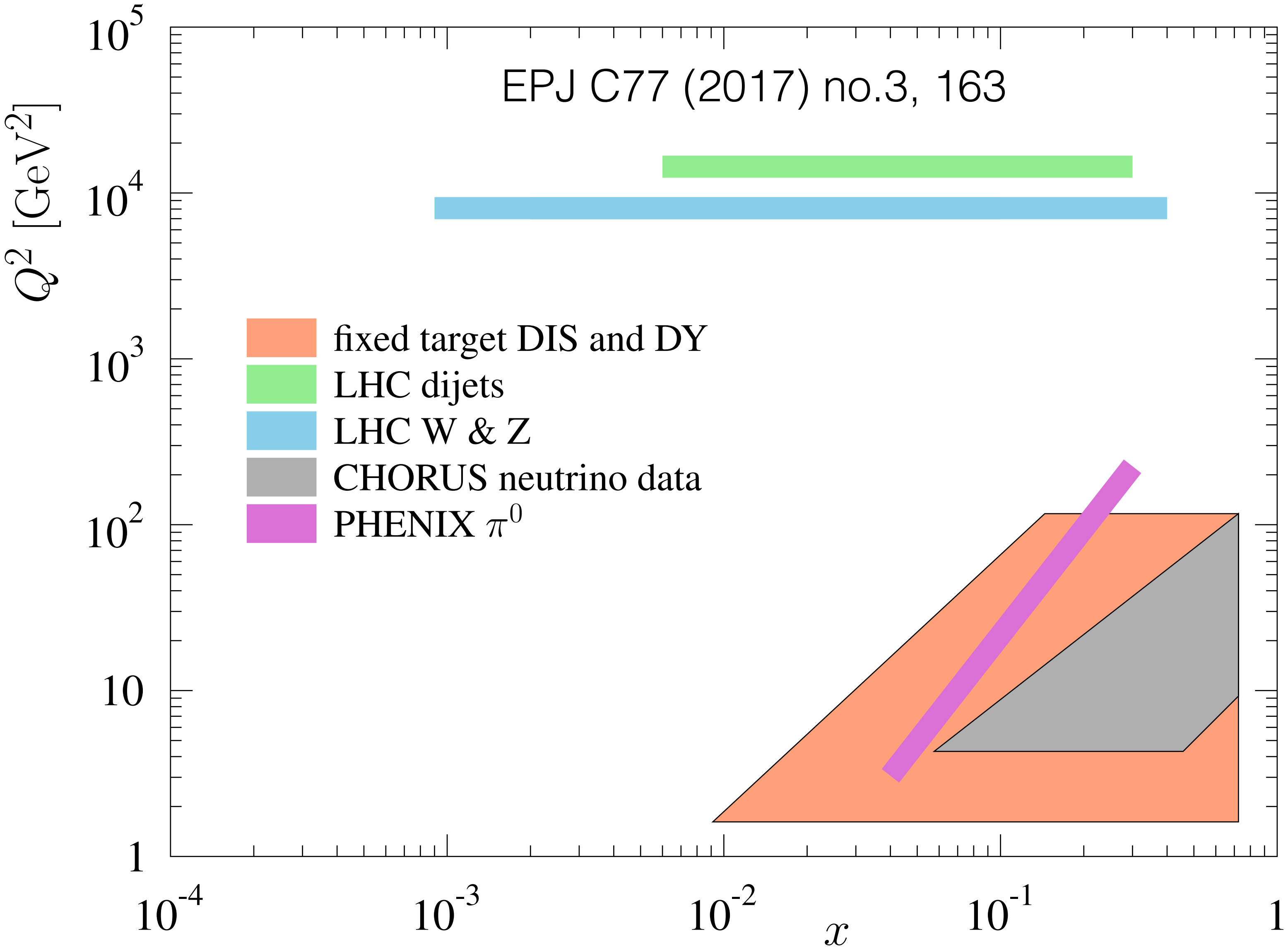
$R_{\bar{u}}$, $R_{\bar{d}}$, R_s

R_{gluon}



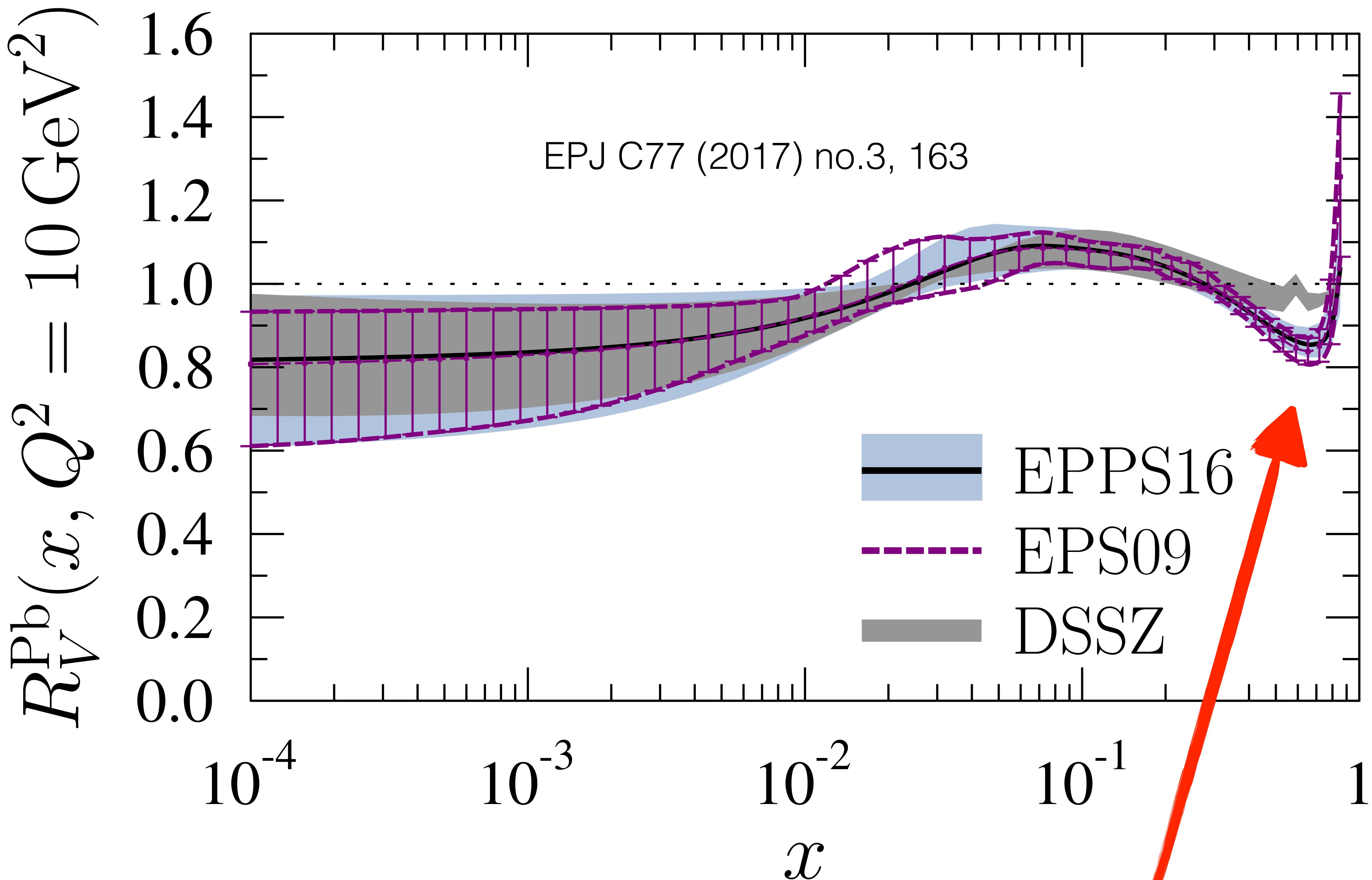
$$y_i(A) = y_i(A_{ref})\left(\frac{A}{A_{ref}}\right)^{\gamma_i[y_i(A_{ref})-1]}$$

e+A, ν+A and p(d)+A experiments
1811 data points



A	He	Li	Be	C	Al	Ca	Fe	Cu	Ag	Sn	W	Pt	Au	Pb
# points	37	168	35	232	35	66	78	19	7	159	58	7	41	869

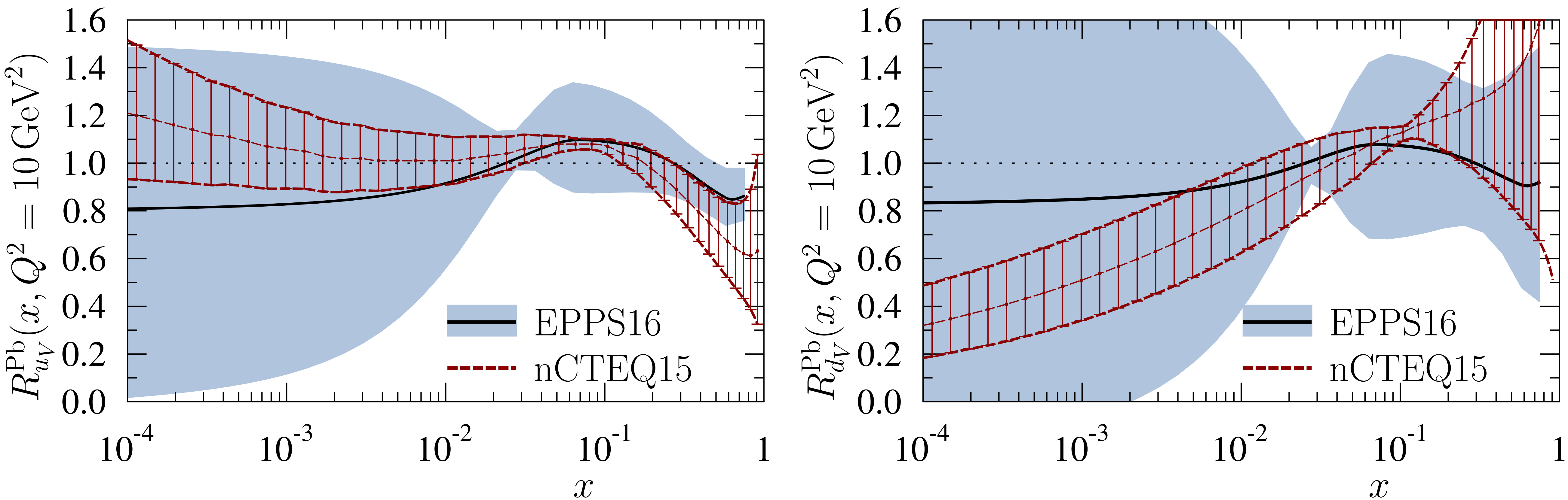
The valence



neutron excess/non-isoscalar corrections

The valence

EPJ C77 (2017) no.3, 163



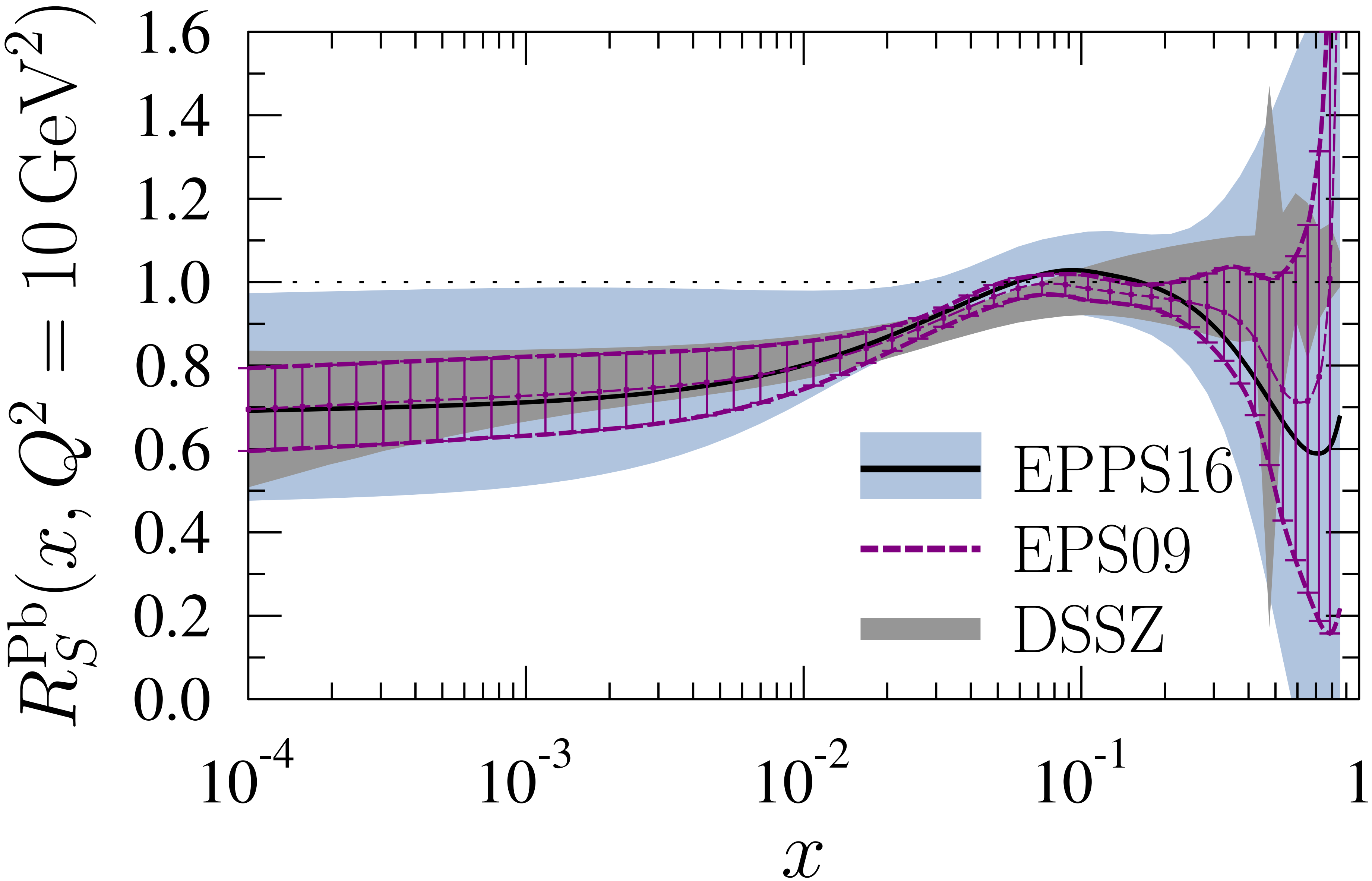
proton

nucleus

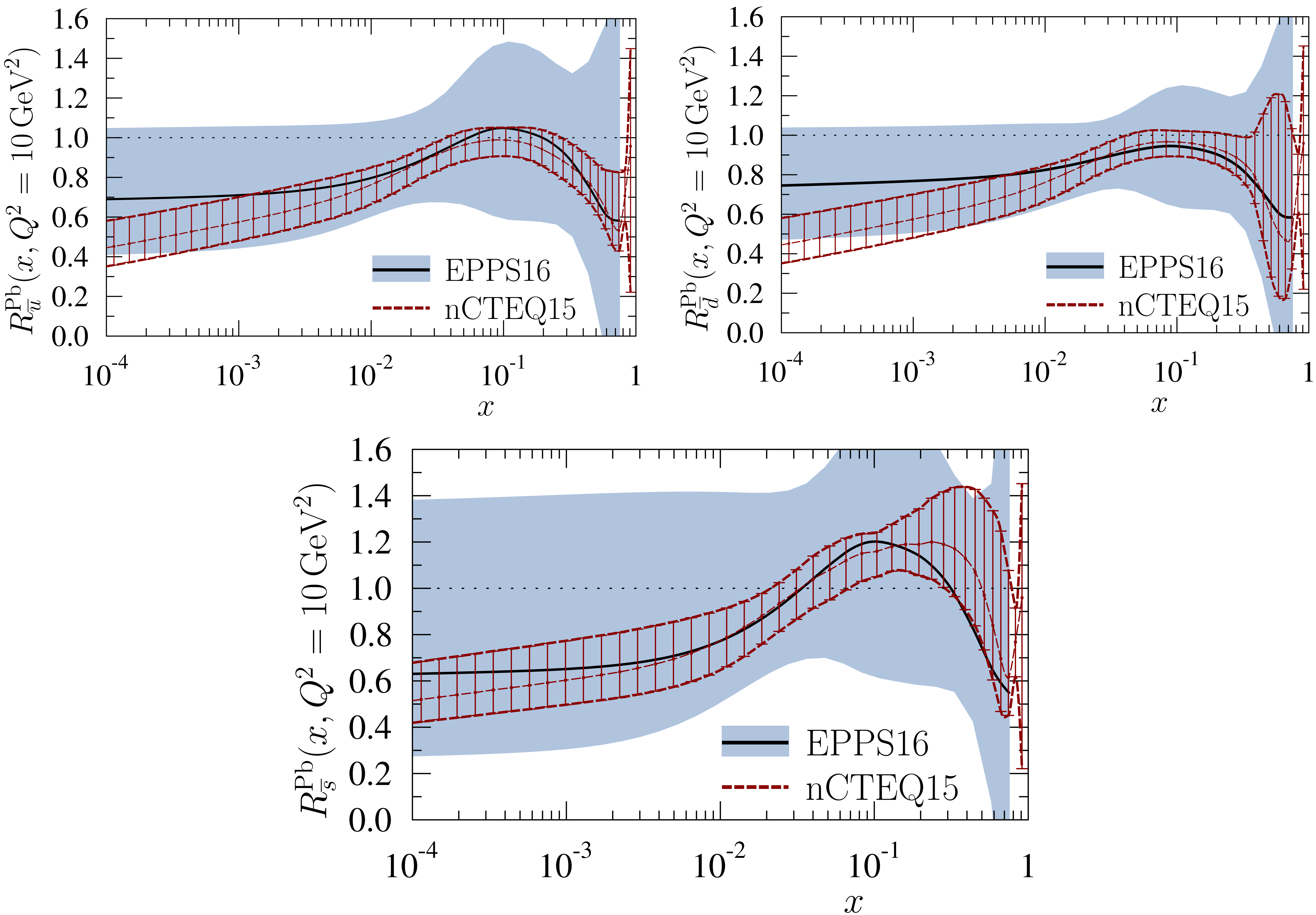
$$\frac{4}{9}u + \frac{1}{9}d \longrightarrow \left(\frac{A+3Z}{9A}\right)u + \left(\frac{4A-3Z}{9A}\right)d$$

The sea

EPJ C77 (2017) no.3, 163

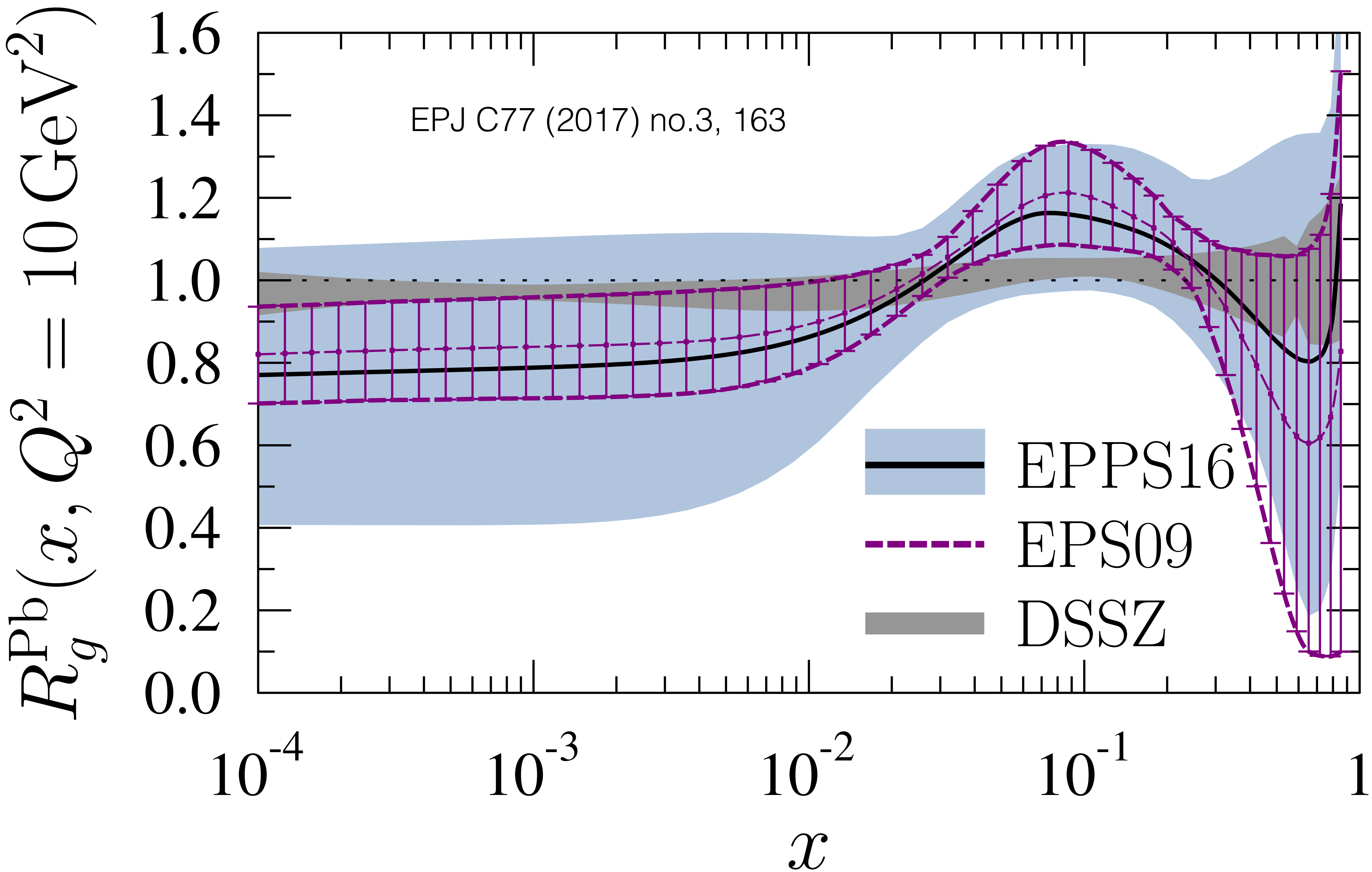


The sea

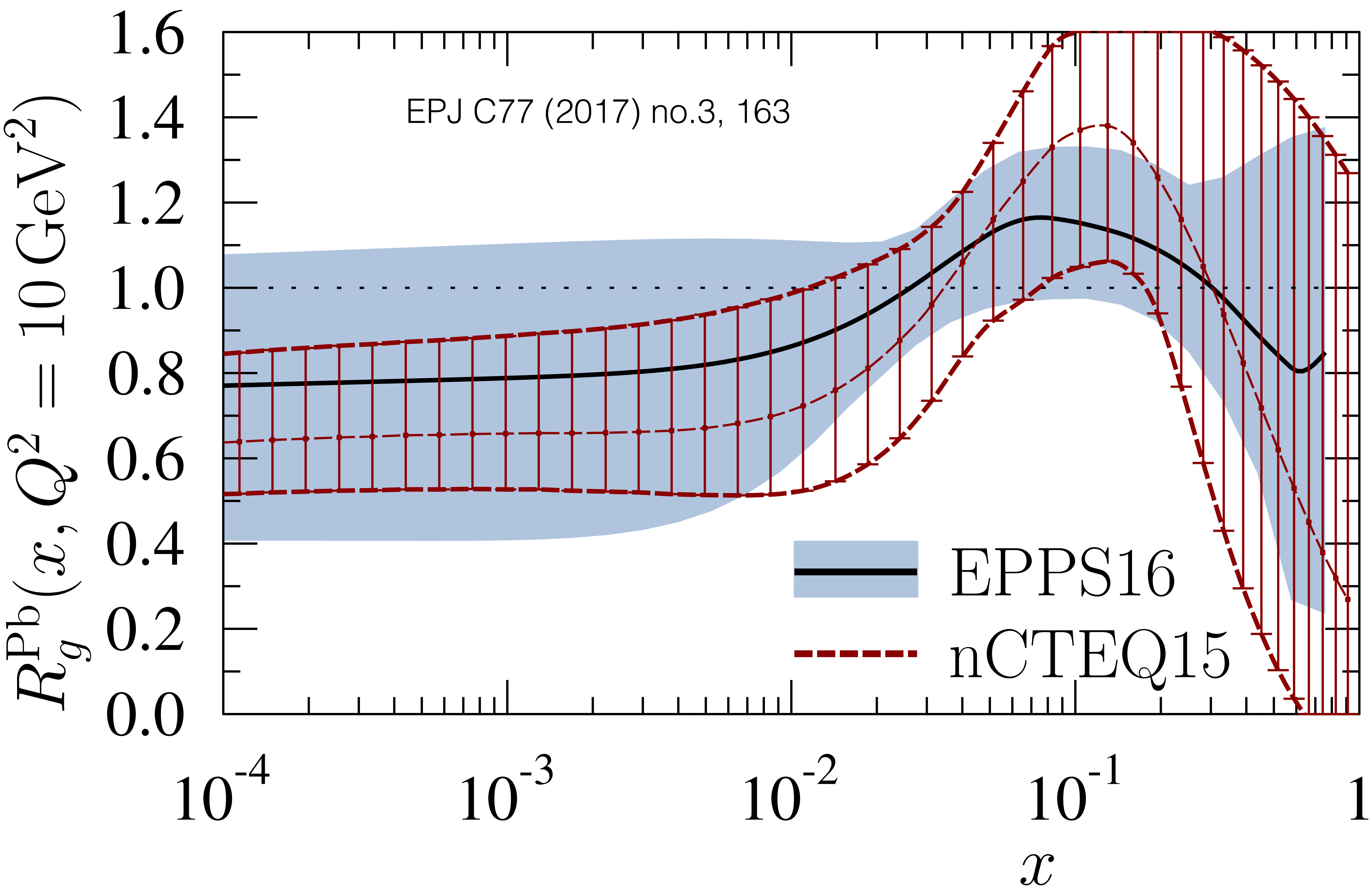


EPJ C77 (2017) no.3, 163

Latest set of nPDFs



the 😈 and 👻 gluon

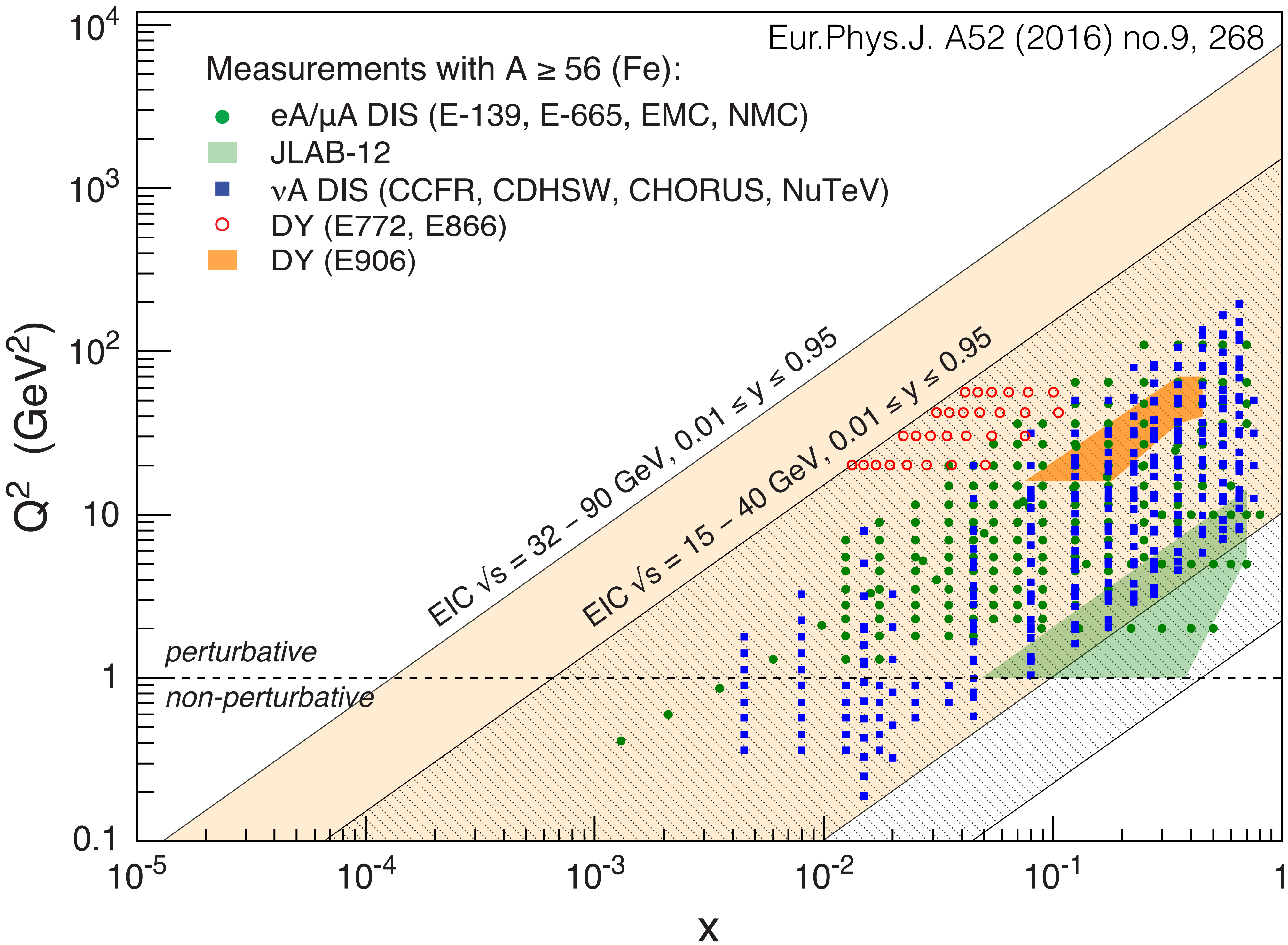


the 😈 and 👻 gluon

Future experiments

- “data” with **estimated** uncertainties
- impact estimations are tied to the initial parameterizations
- for $x < 0.001$ the theoretical curves are **extrapolations**
- mostly focused on the gluon

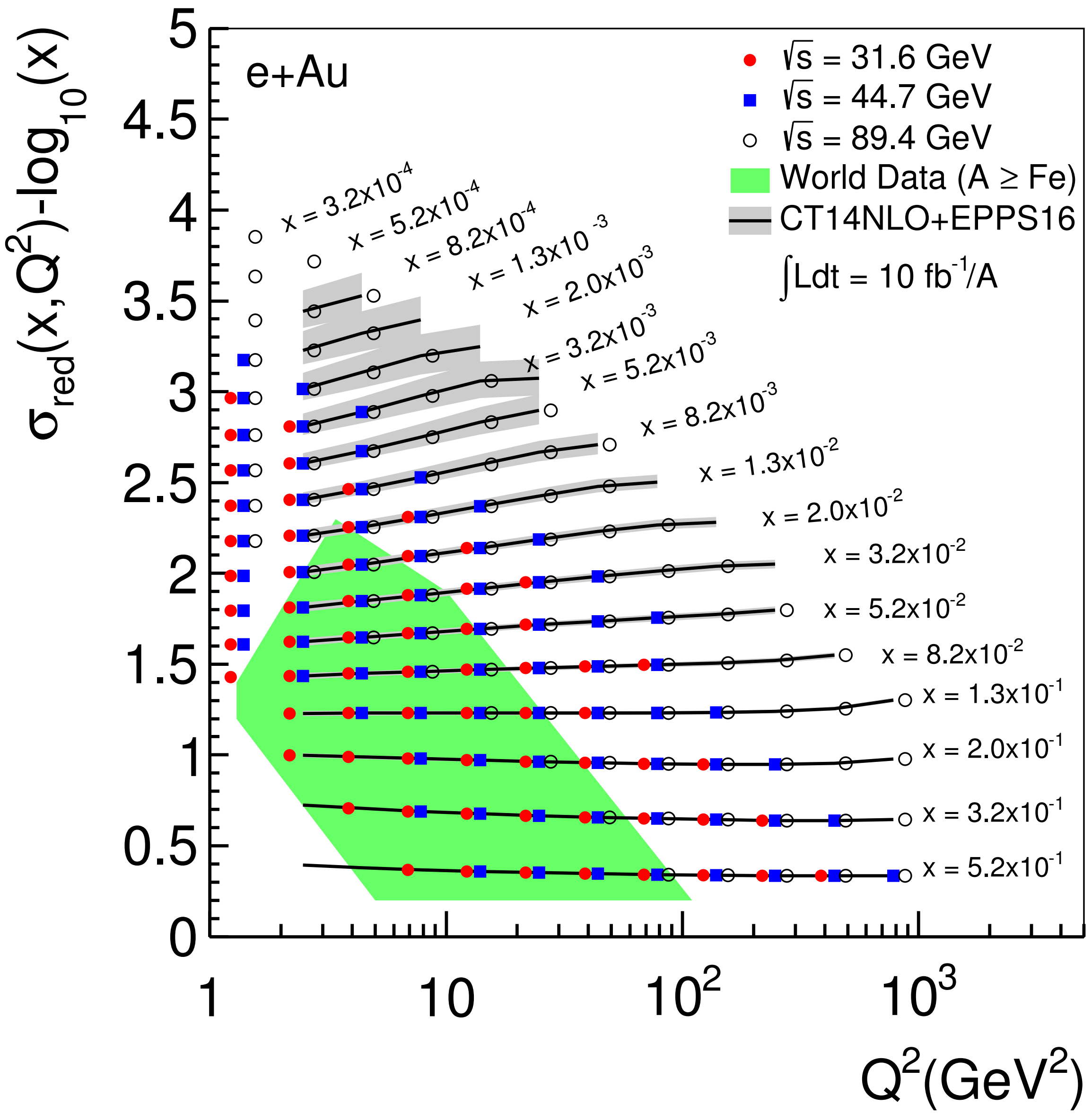
Electron-Ion collider

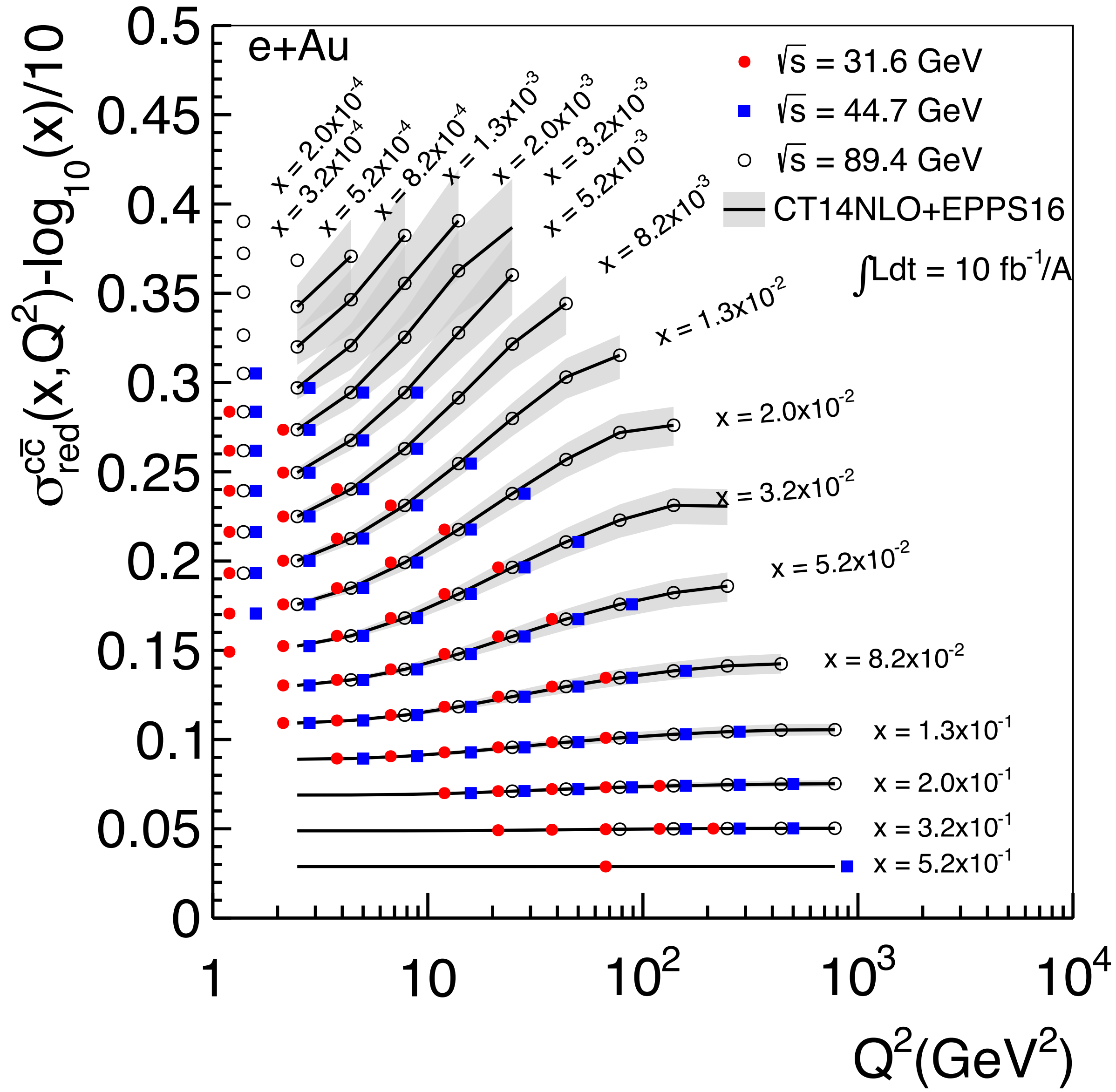


there is much more about EIC than nPDFs (duh!)

visit http://www.eicug.org/ for more info

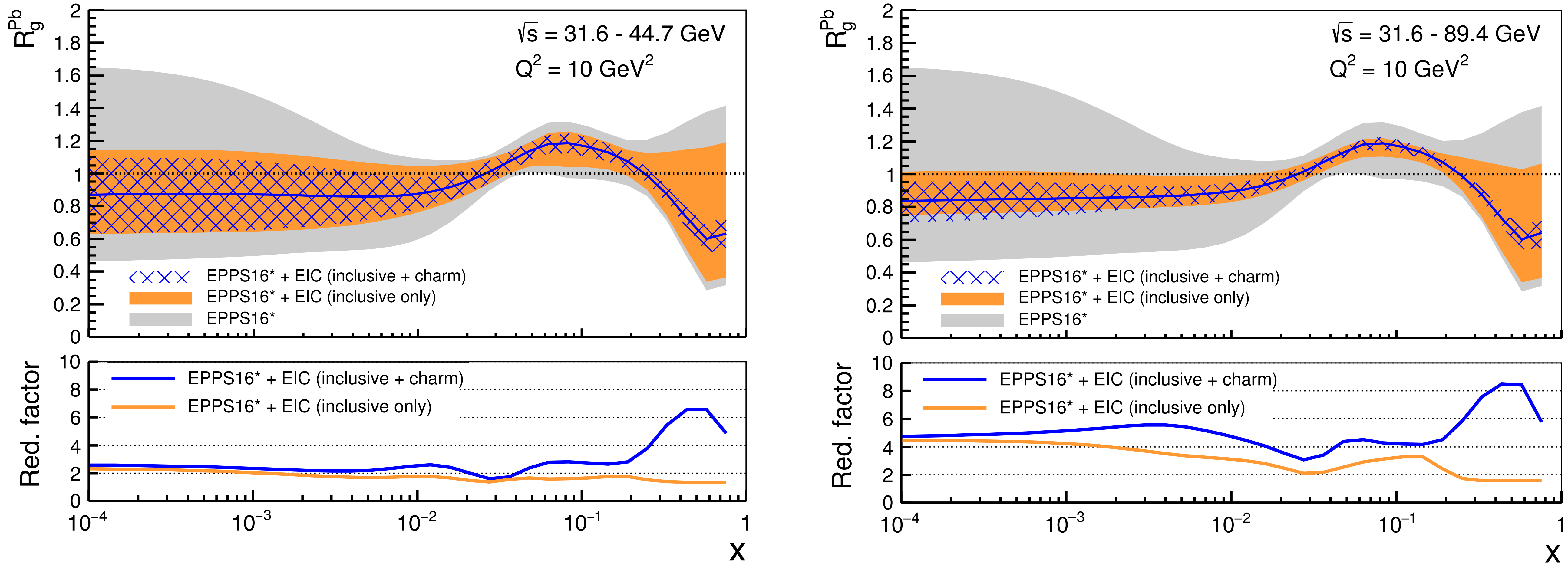
Inclusive and charm reduced cross-section





Aschenauer, Fazio, Lamont, Paukkunen, PZ, PRD96 (2017) no.11, 114005

impact on **EPPS16*** nPDFs



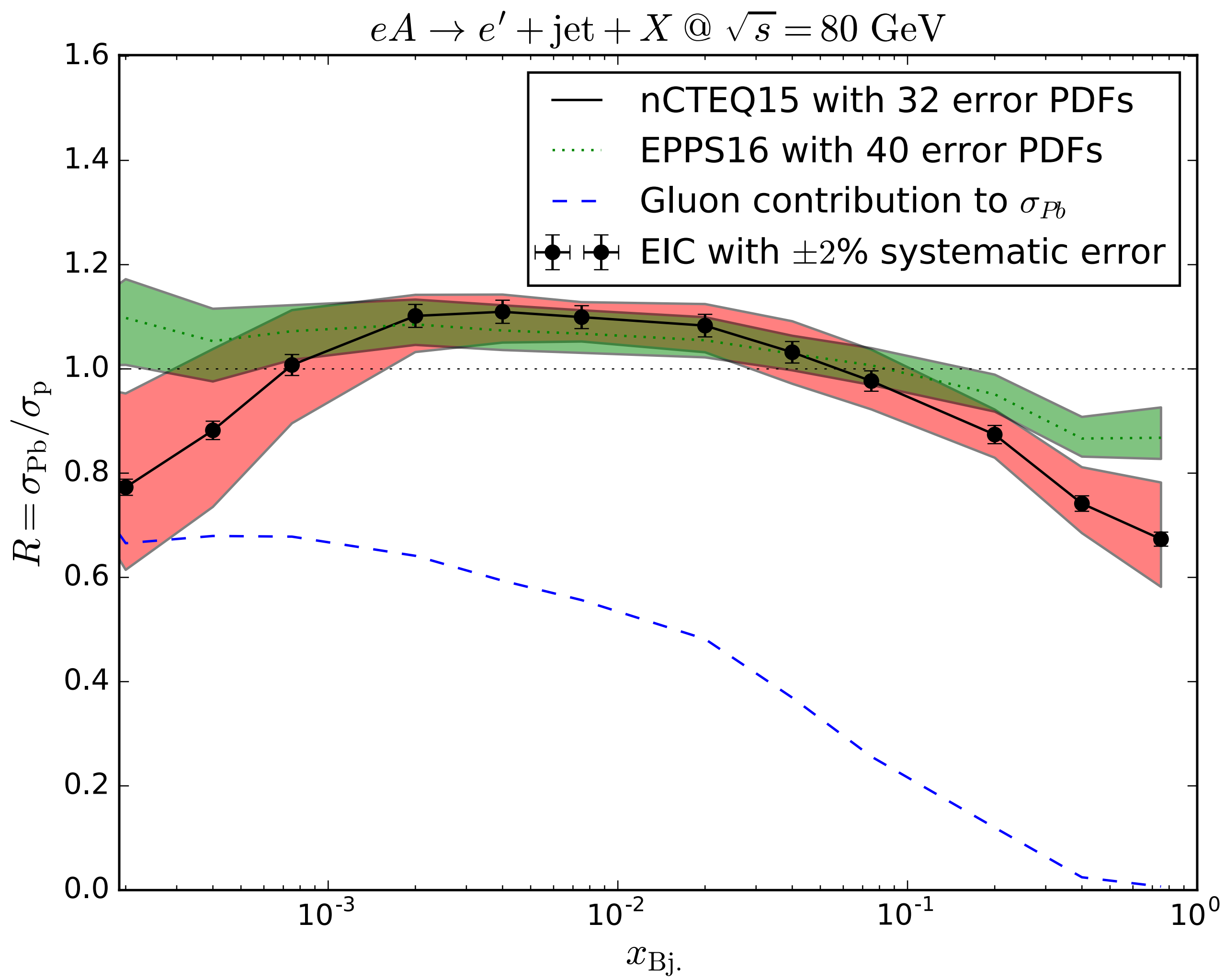
PRD96 (2017) no.11, 114005

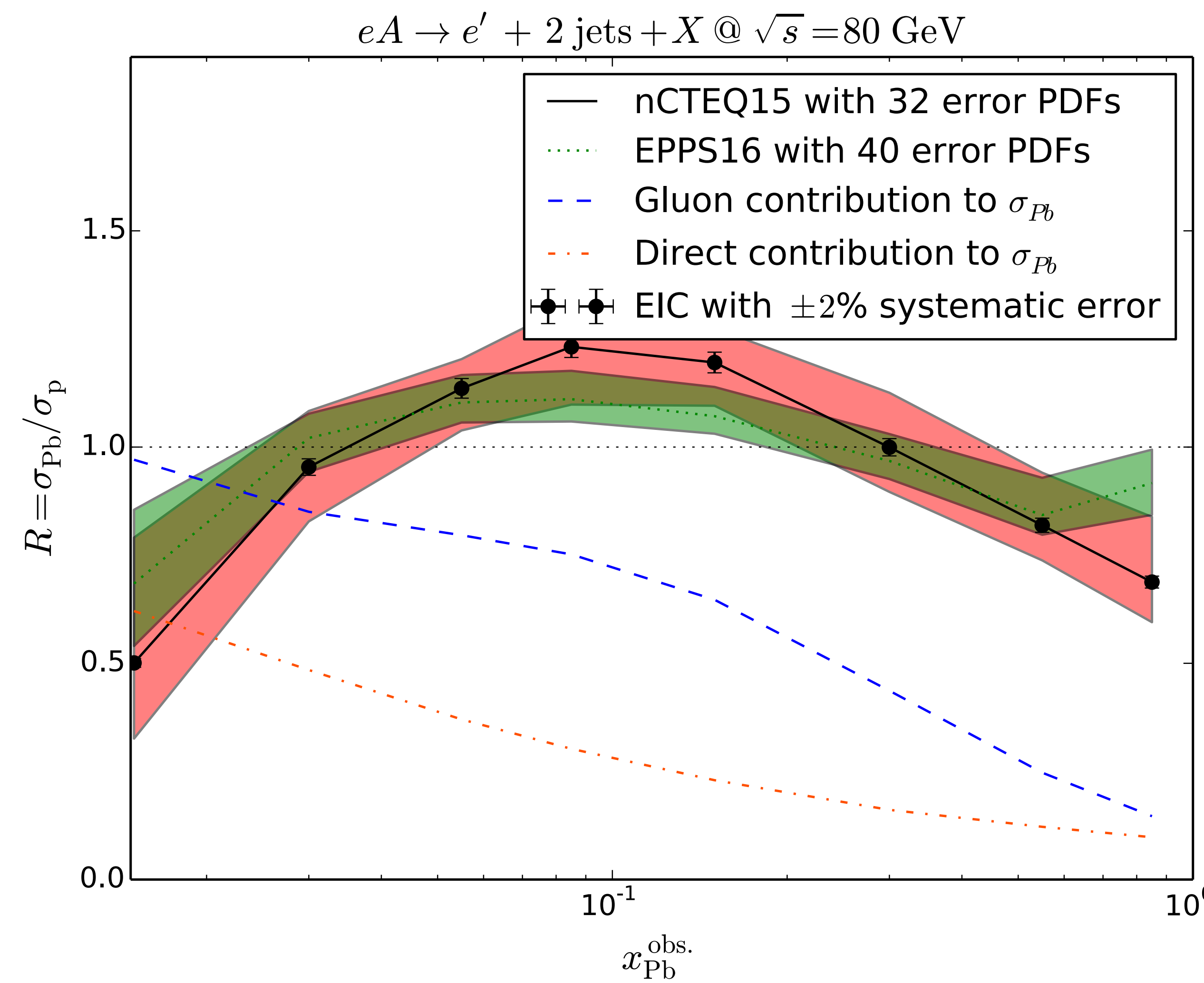
See also C. Weiss talk at “Santa Fe Jets and Heavy Flavor Workshop, 30-Jan-18”

https://indico.fnal.gov/event/15328/session/4/contribution/15/material/slides/0.pdf

Jets and di-jets

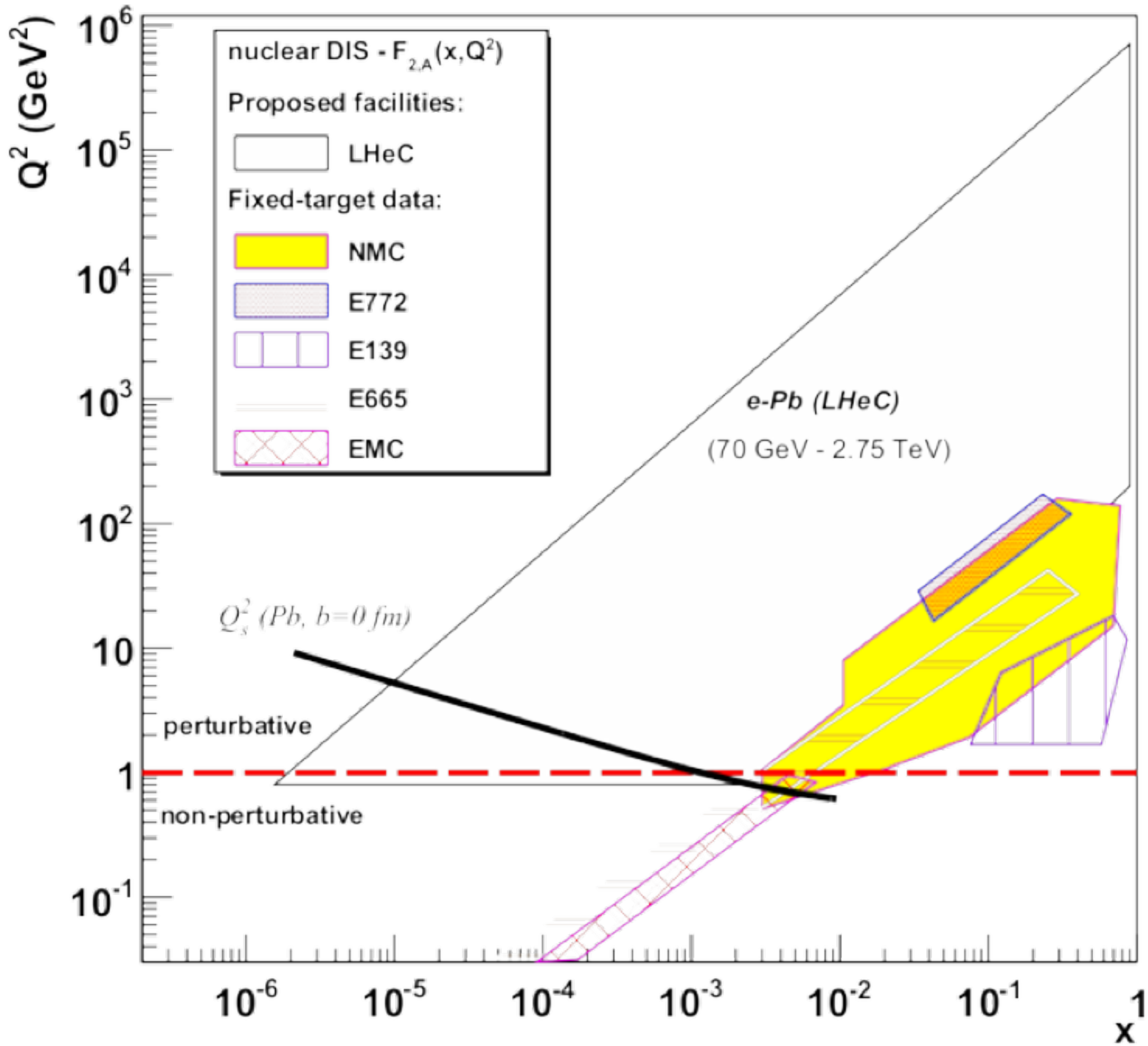
Klasen and Kovarik, arXiv:1803.10985 [hep-ph].





Klasen, Kovarik, Potthoff, PRD95 (2017) no.9, 094013

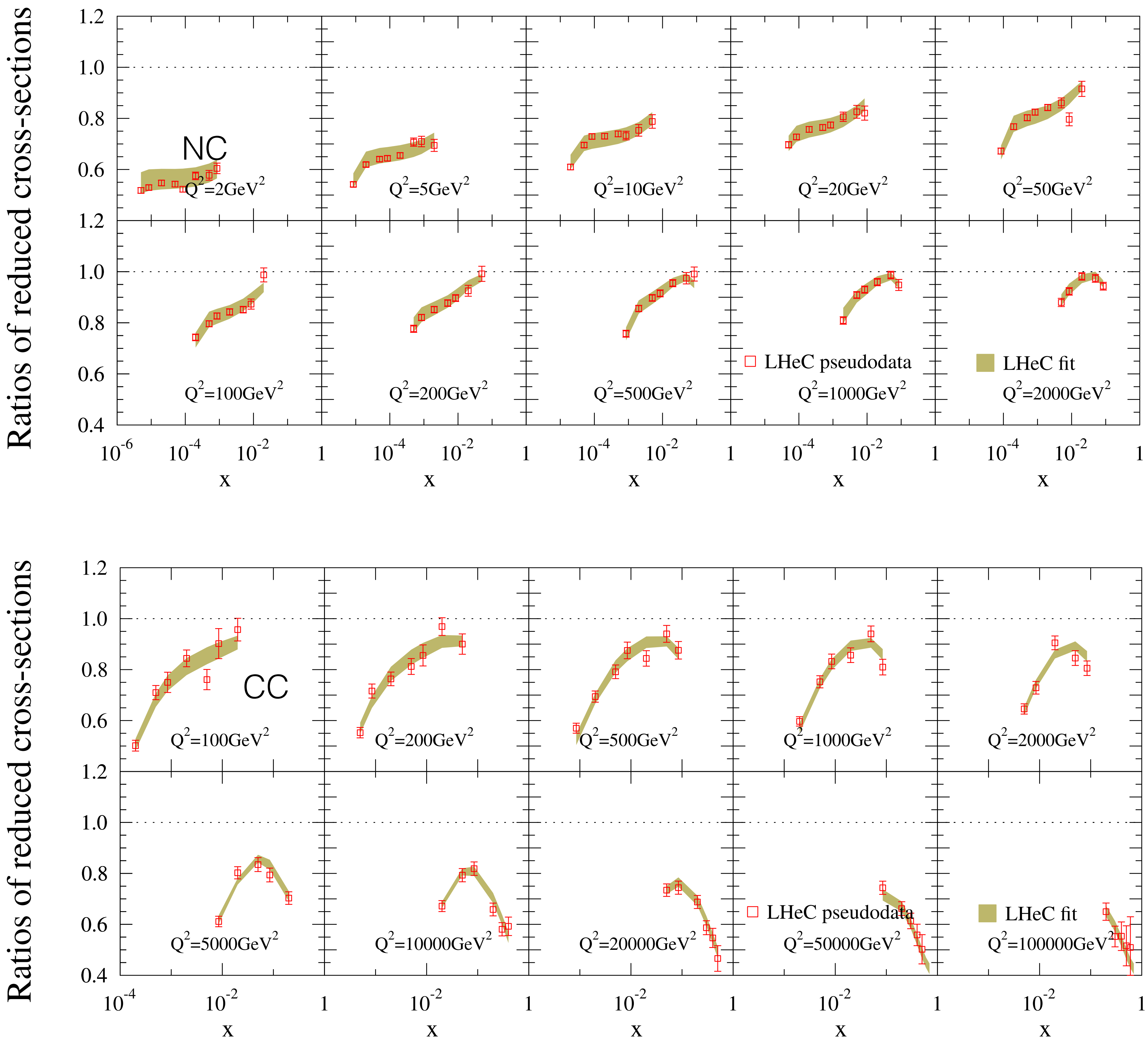
LHeC


nuclear DIS - $F_{2,A}(x,Q^2)$
Proposed facilities:
LHeC
Fixed-target data:
NMC
E772
E139
E665
EMC
e-Pb (LHeC)
(70 GeV - 2.75 TeV)
Q_s^2 (Pb, b=0 fm)
perturbative
non-perturbative
Q^2 (GeV^2)
x
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10^{-1}
10
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}

LHeC

- "data" from EPS09
- NC & CC

from H. Paukkunen's talk in POETIC8



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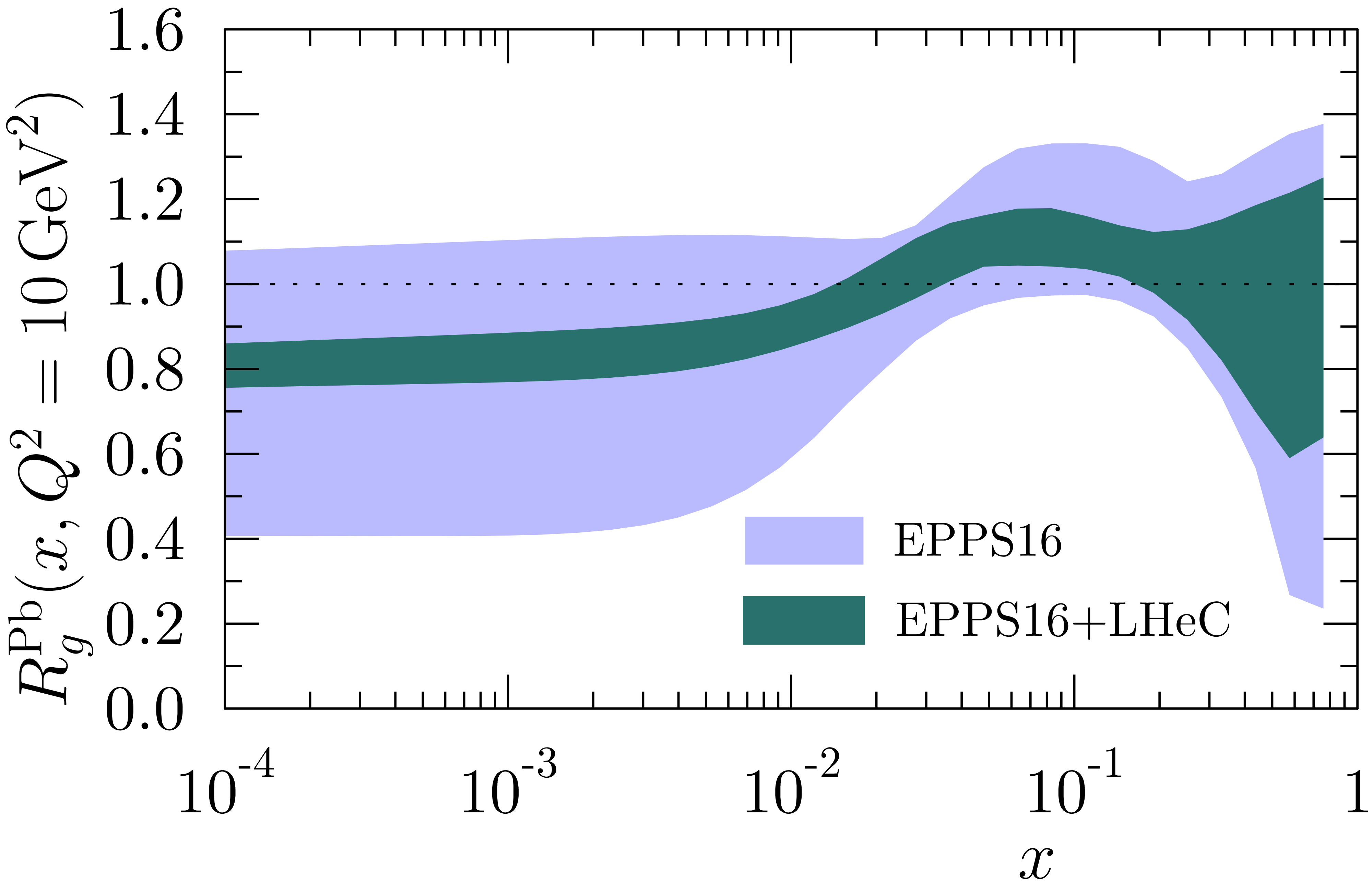


AFTER

- Proposed fixed target experiment at LHC
  - **study the large-x parton content in nucleons/ nuclei**
  - study the dynamics and spin of gluons inside (un)polarised nucleons/nuclei
  - Study heavy-ion collisions between RHIC and SPS energies towards large rapidities

For more information see Ingo Schienbein's talk:

https://indico.ectstar.eu/event/9/contributions/191/attachments/119/141/trento_160418.pdf

Exploiting current data

- Archeology: DY in π+A
  - Badier, et al., Phys. Lett. B104 (**1981**) 335, P. Bordalo, et al., Phys. Lett. B193 (**1987**) 368, J. G. Heinrich, et al., Phys. Rev. Lett. 63 (**1989**) 356–359.
  - Paakkinen, Eskola, Paukkunen, Phys.Lett. B768 (**2017**) 7-11

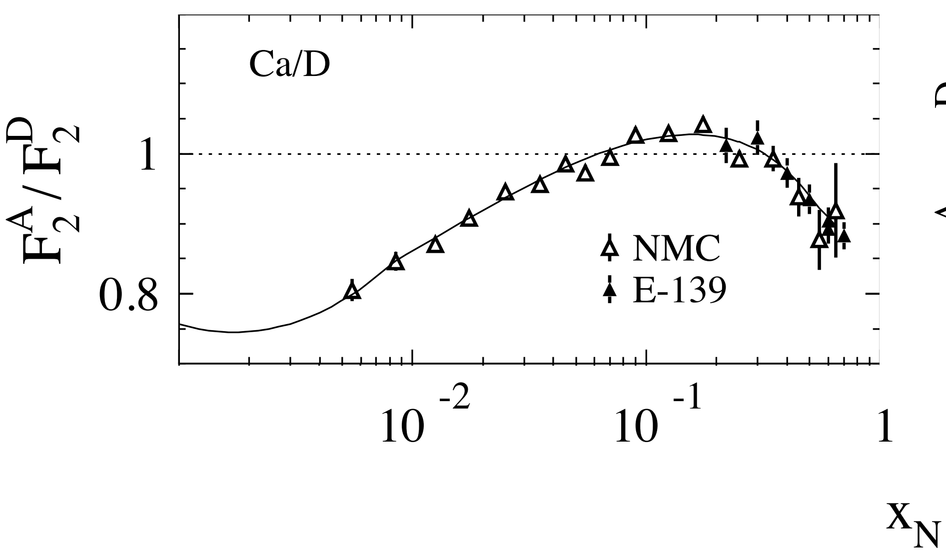
- Centrality dependent data:
  - Helenius, Eskola, Honkanen, Salgado, JHEP 1207 (2012) 073.
  - Paukkunen, Phys.Lett. B745 (2015) 73-78, Helenius, Paukkunen, Eskola, Eur.Phys.J. C77 (2017) no.3, 148.

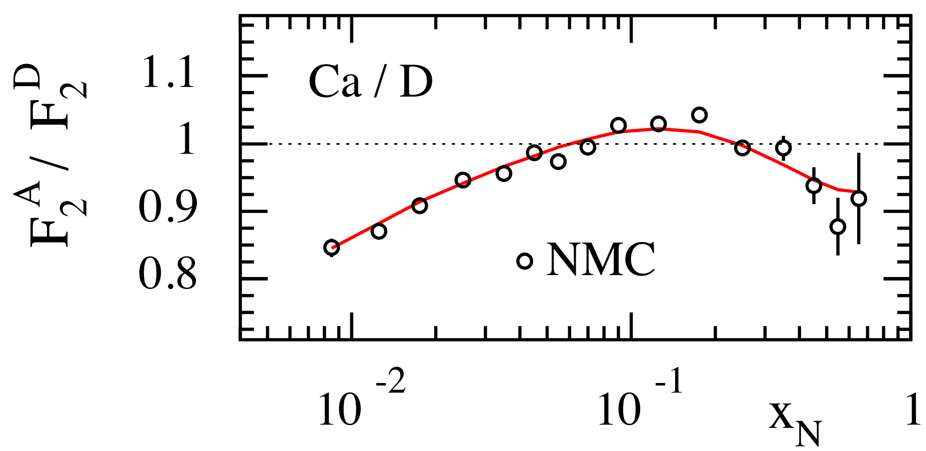
- Particle production:
  - Helenius, Eskola, Paukkunen, Nucl.Phys. A932 (2014) 415-420
  - https://indico.cern.ch/event/663878/contributions/2926133/attachments/1618981/2574636/Paukkunen_POETIC8.pdf
  - Kusina, Lansberg, Schienbein, Shao, arXiv:1712.07024 [hep-ph]

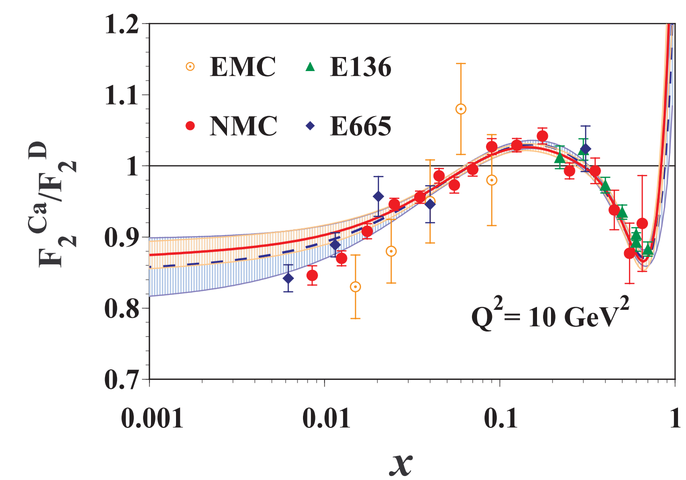
Summary

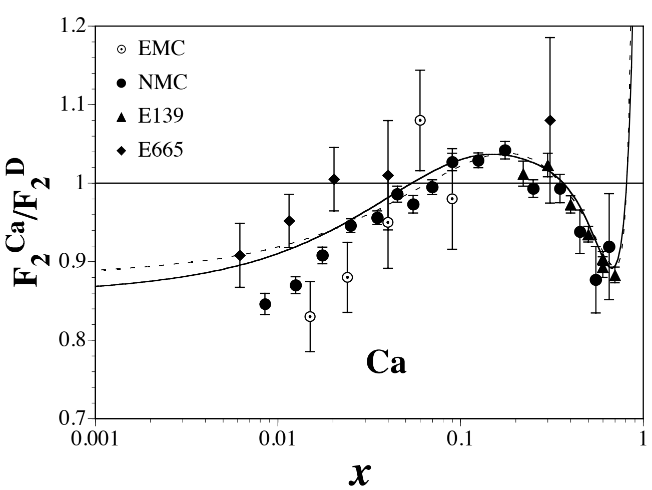
- several nPDFs sets available, comparing them is tricky

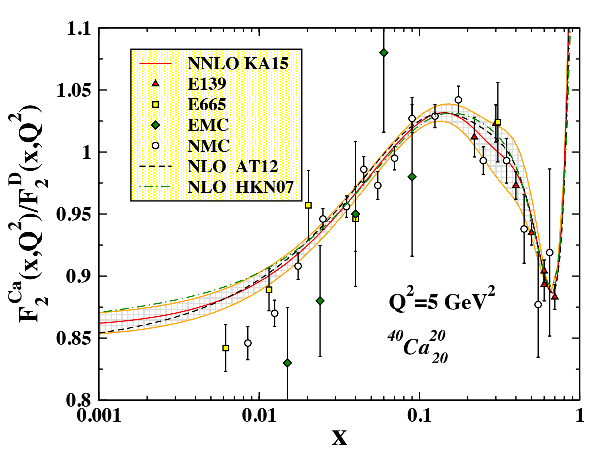
all give **NICE** descriptions of the data

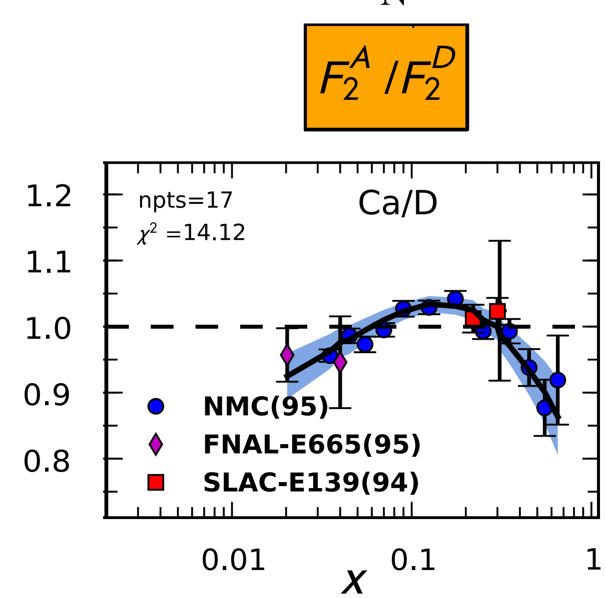


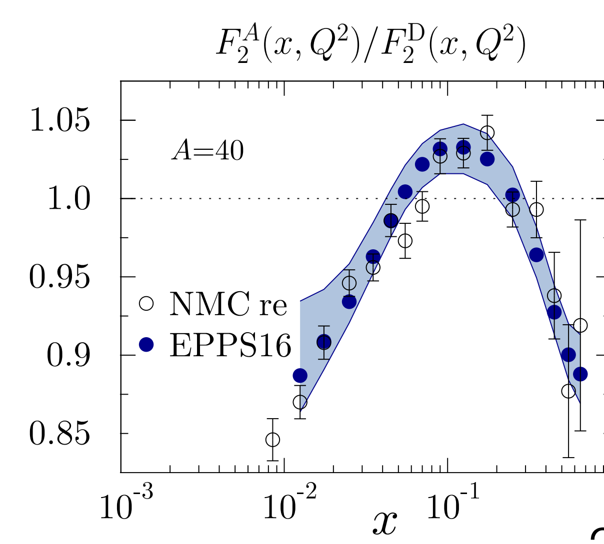












- far from the precision of proton PDFs due to the available data
- future colliders have a huge potential to help us improve:

- for DIS at an EIC:

  - low energy: kinematical range moderately extended, high precision data
  - high energy: kinematical range extended, more chances of finding new phenomena
  - for charm: win-win situation!
  - also F_L will help determine the gluon

- for jets and di-jets at an EIC:

  - relevant decrease of the gluon uncertainty
  - higher energy c.o.m. relevant

- also great possibilities for LHeC

- While we wait for new results to include:
  - look for other measurements/observables (be creative!)
  - improve FFs so we can use available data
  - apply more refined techniques in nPDFs extractions
  - joint PDFs + nPDFs + FFs + nFFs analysis?
  - …

- Coming soon… ish:
  - LHC Run II
  - RHIC isobar run
  - JLAB 12

Latest set of nPDFs

Comparing nuclear PDFs

SET		HKM	nDS	HKN	EPS09	DSSZ	nCTEQ15	KA15	EPPS16
data type	e-DIS	yes	yes	yes	yes	yes	yes	yes	yes
	D-Y	no	yes	yes	yes	yes	yes	yes	yes
	pions	no	no	no	yes	yes	yes	no	yes
	ν-DIS	no	no	no	no	yes	no	no	yes
	EW	no	no	no	no	no	no	no	yes
	jets	no	no	no	no	no	no	no	yes
# data points		309	420	1241	929	1579	740	1479	1811
χ^2/N		1.828	0.714	1.197	0.787	0.978	0.793	1.147	0.988
Q_0^2(GeV^2)		1	0.4	1	1.69	1	1.69	2	1.69
accuracy		LO	NLO	NLO	NLO	NLO	NLO	NNLO	NLO
proton PDF		MRST2001	GRV	MRST98	CTEQ6.1M	MSTW2008	CTEQ6.1	JR09	CT14NLO
deuteron		no/yes	no	yes	no	no	yes/no	?	no
flavour separation?		valence	no	no	no	no	valence	no	yes