Overview of nuclear PDFs

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5th International Conference on the Initial Stages in High-Energy Nuclear Collisions
(Initial Stages 2019)

June 24-28, Columbia University, NY, USA

Outline

- The big questions: what?, why? and how?
- Careful!
- Current sets of nPDFs
- Impact studies with data
- Work in progress & ideas
- Impact studies for future colliders
- Summary
- Publicity

What are the nuclear PDFs?

ONE* way of describing how the partons behave

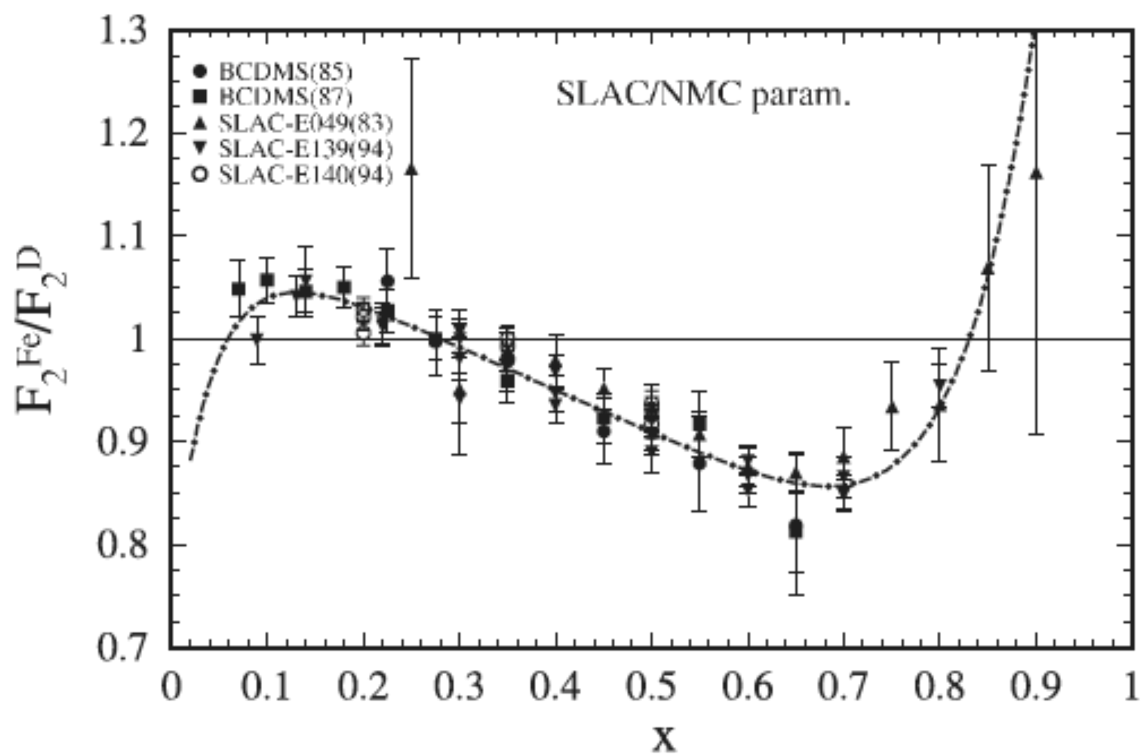
in a nucleon bounded in a nucleus

(in the collinear factorized approach)

*check I. Vitev's talk (Wednesday afternoon session) for a medium modified DGLAP approach

What are they for?

- describe data like these:



- initial state for HIC
- contribute to proton PDFs (flavour decomposition)

How do we get them? (I)

through global fits to data

1) Select the data

2) Write the (n)PDFs at some initial scale (Q_0) in terms of free parameters

$$f_i^{p/A}(x, Q_0^2, A) = F(x, Q_0^2, A)$$

- $f_i^p(x, Q_0^2) R_i(x, A)$
- $f_i^p(x, Q_0^2) \otimes R_i(x, A)$
- $f_i^{p/A}(x, Q_0^2, A)$
- **neural network**

3) Give values to the parameters

4) Determine the distributions at the experimental scales (Q) DGLAP

How do we get them? (II)

5) Use isospin symmetry to construct the nPDFs

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

6) Write the theoretical predictions using 5)

7) Construct a quantity that estimates the “goodness” of the description

8) Change the parameters until the fit is “good enough”

9) Use the best fit parameters and generate grids for public use

disclaimer:

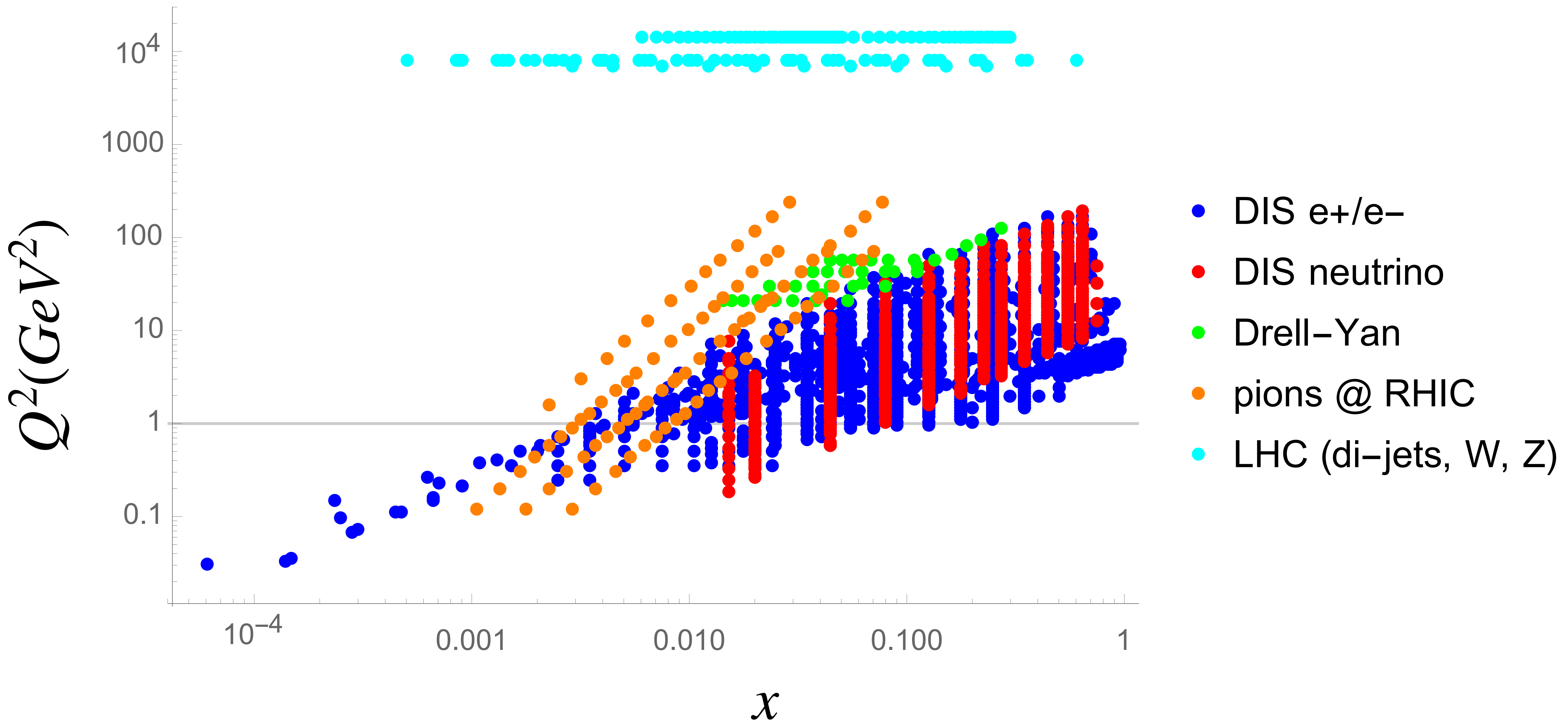
(almost) every step implies a choice

and each choice has an impact

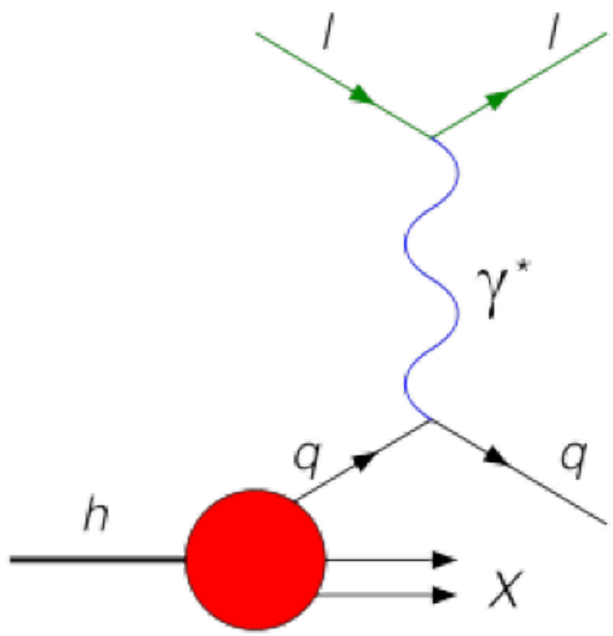
Careful!

e+A and p(d)+A experiments ~1212 data points*

* average of newest nPDFs analyses



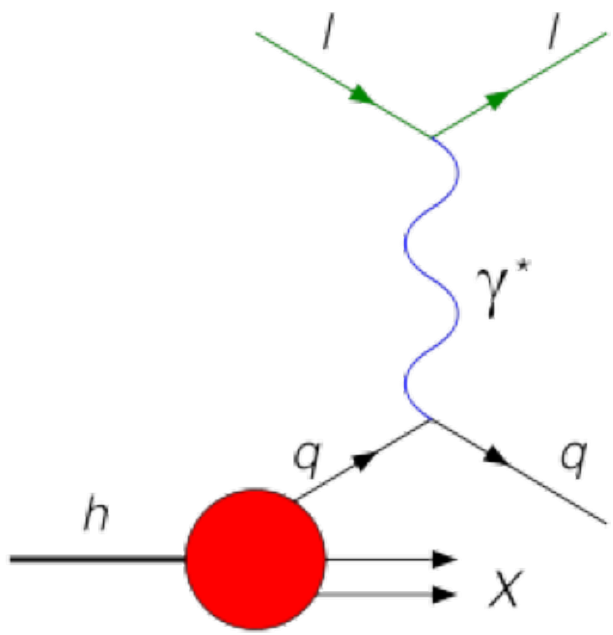
most data from DIS*



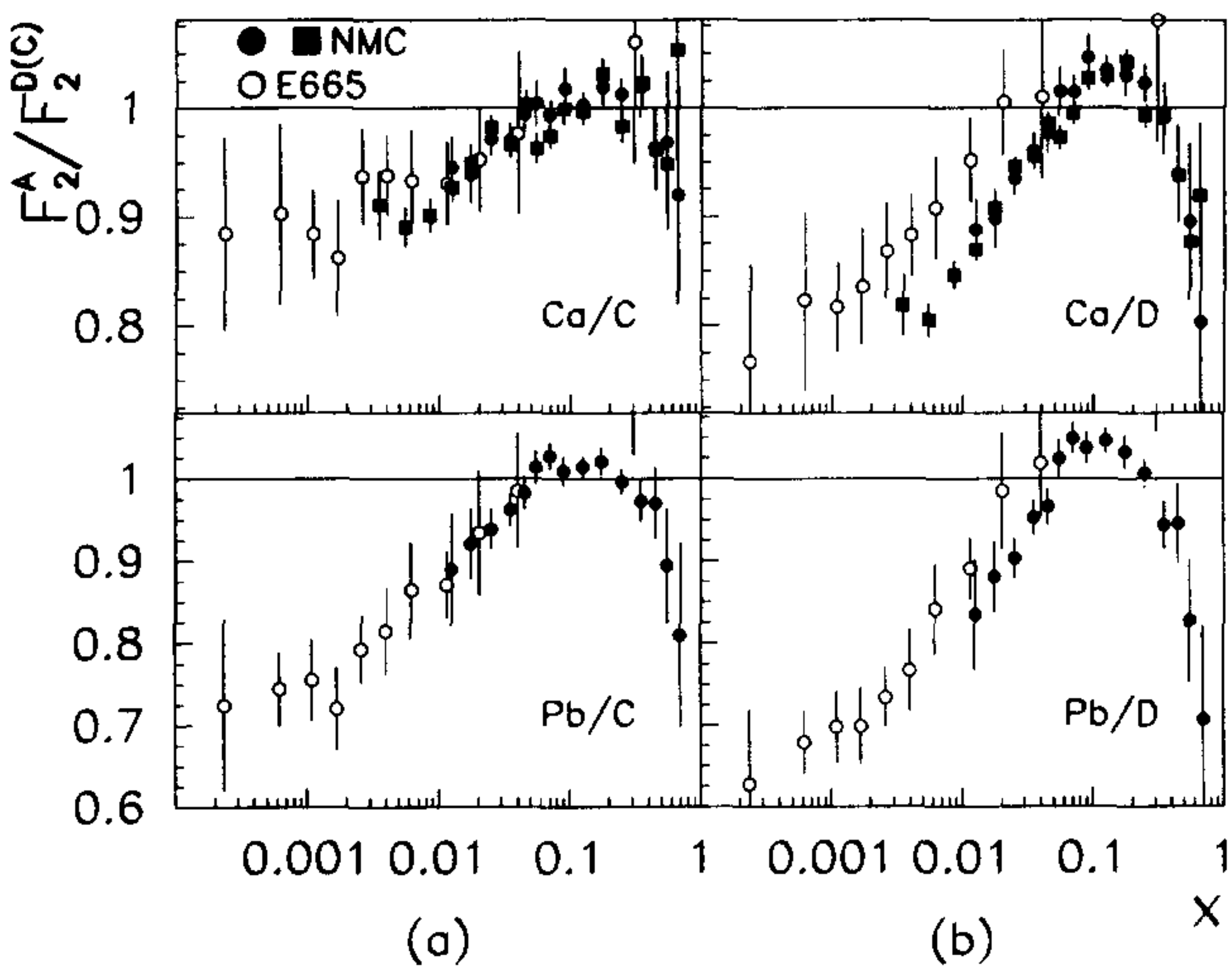
$$\sigma_{red} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

check C. Keppel's talk (Tuesday morning) for an overview of DIS most data from DIS

$$\frac{d\sigma^A}{d\sigma^{A'}} \approx \frac{F_2^A}{F_2^{A'}}$$



New Muon Collaboration, Nucl.Phys. B481 (1996) 3



$$\sigma_{red} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

*check C. Keppel's talk (Tuesday morning) for an overview of DIS

- data might be also sensitive to proton PDFs
- error treatment
- initial scale chosen for the evolution
- how to solve DGLAP
- treatment of heavy flavours (heavy flavour *scheme*)
- perturbative order
- strong coupling constant
- χ^2 definition and determination of uncertainties
- final state effects
- …

the interpretation of your result(s) will most likely be affected by at least one of these points*

* read the paper carefully and in case of doubt consult your favourite nPDF phenomenologist

Current sets of nPDFs

SET		DSSZ (PRD85, 074028)	nCTEQ15 (PRD93, 085037)	KA15 (PRD93, 014026)	EPPS16 (EPJ C77, 163)	nNNPDF1.0 (EPJ C79, 471)
data type	e-DIS	yes	yes	yes	yes	yes
	D-Y	yes	yes	yes	yes	no
	pions	yes	yes	no	yes	no
	v-DIS	yes	no	no	yes	no
	EW	no	no	no	yes	no
	jets	no	no	no	yes	no
# data points		1579	740	1479	1811	451
χ^2		1545	587	1696	1789	305.82
Q_0^2 (GeV^2)		1	1.69	2	1.69	1
Q^2_{min} (GeV^2)		1	4	1	1.69	3.5
W^2_{min} (GeV^2)		———	12.25	———	———	12.5
accuracy		NLO	NLO	NNLO	NLO	NLO & NNLO
proton PDF		MSTW2008	CTEQ6.1	JR09	CT14NLO	NNPDF3.1
deuteron		no	yes/no	?	no	no
flavour separation?		no	valence	no	yes	no

$$W^2 = M_N^2 + Q^2(1/x - 1)$$

leaves out high-x, low Q data

$$\Sigma = u + \bar{u} + d + \bar{d} + s + \bar{s}$$

$$T_3 = u + \bar{u} - (d + \bar{d})$$

$$T_8 = u + \bar{u} + d + \bar{d} - 2(s + \bar{s})$$

eigenstates of DGLAP

+ assuming isospin symmetry, we have, below the charm production threshold

$$F_2^{A,(LO)} = x\left[\frac{2}{9}\Sigma + \left(\frac{Z}{3A} - \frac{1}{6}\right)T_3 + \frac{1}{18}T_8\right]$$

$$\Sigma = u + \bar{u} + d + \bar{d} + s + \bar{s}$$
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eigenstates of DGLAP

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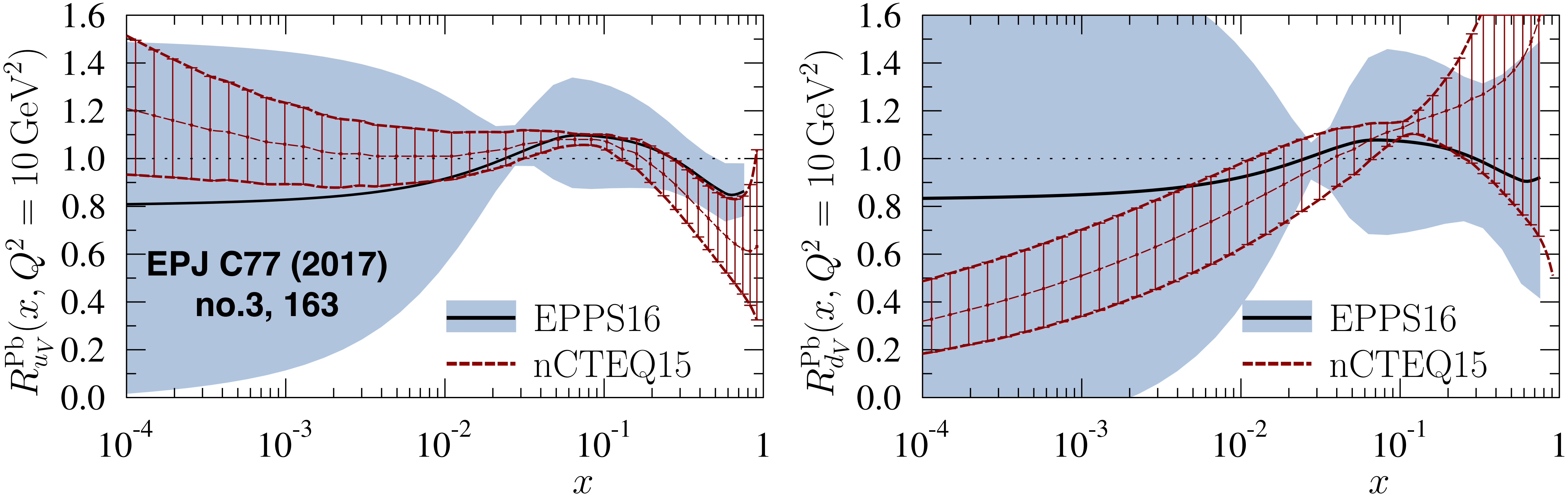
$$F_2^{A,(LO)} = x\left[\frac{2}{9}\Sigma + \left(\frac{Z}{3A} - \frac{1}{6}\right)T_3 + \frac{1}{18}T_8\right]$$

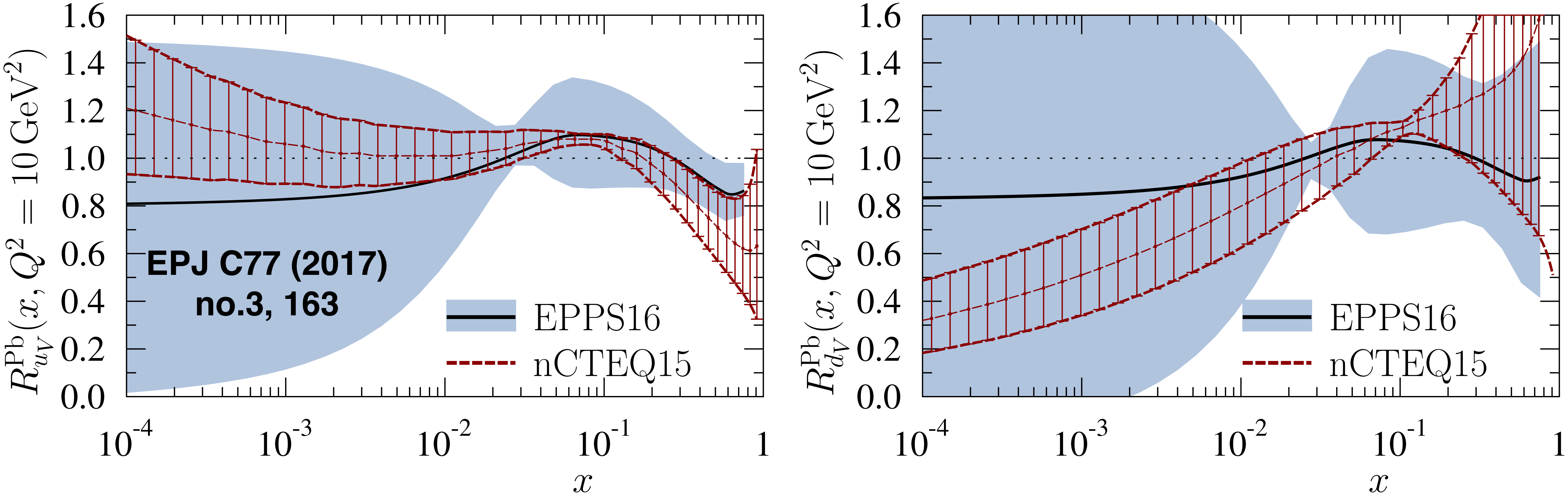
- in nNNPDF1.0 the second term is neglected
- gluon and the combination $\Sigma + \frac{1}{4}T_8$ are fitted
- Assumptions are needed for compliance with LHAPDF format ($u = d, \bar{u} = \bar{d} = s = \bar{s}$)*

* not a limitation of the method, but of applying the method to such a reduced data set

Current sets of nPDFs



$$\frac{d^2\sigma^{(LO)}}{dx\,dQ^2} \propto \frac{4}{9}(u + \bar{u}) + \frac{1}{9}(d + \bar{d} + s + \bar{s})$$



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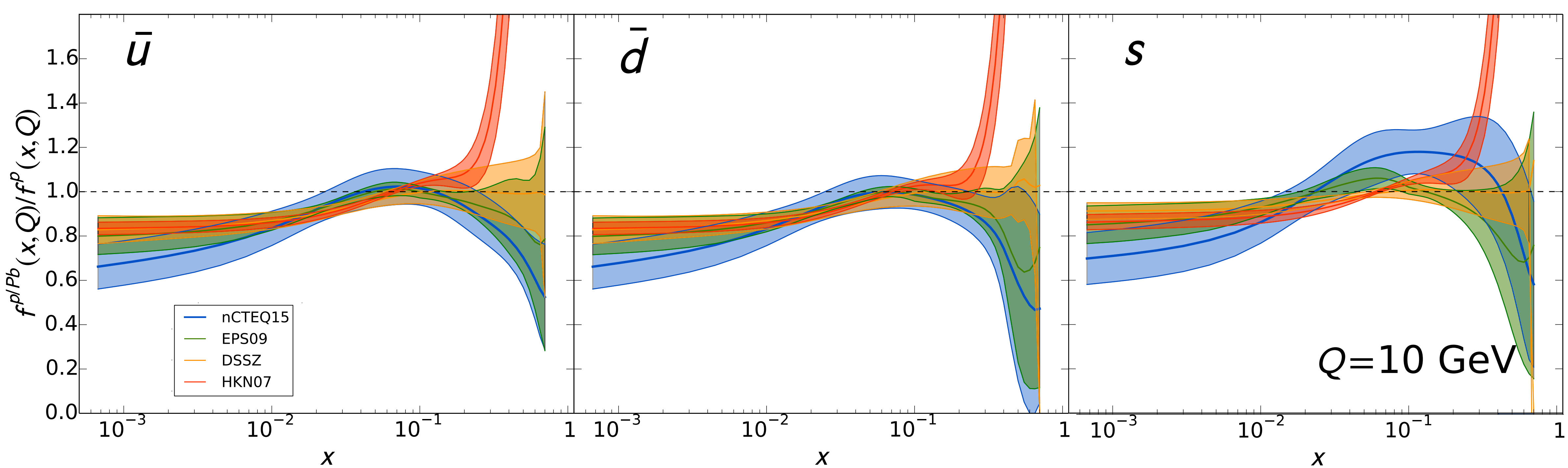
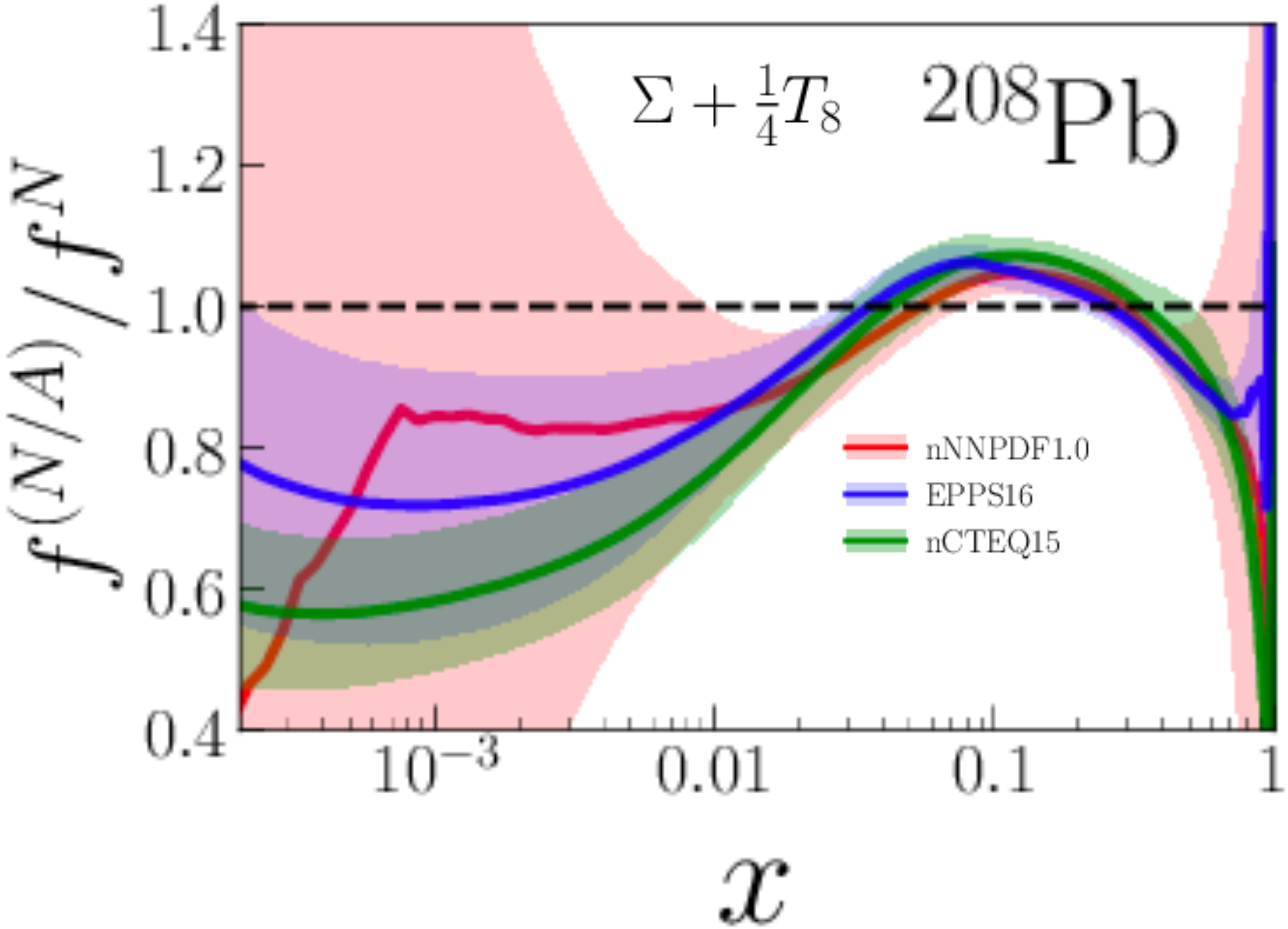


PRD93 (2016) no.8, 085037

EPJ C79, 471

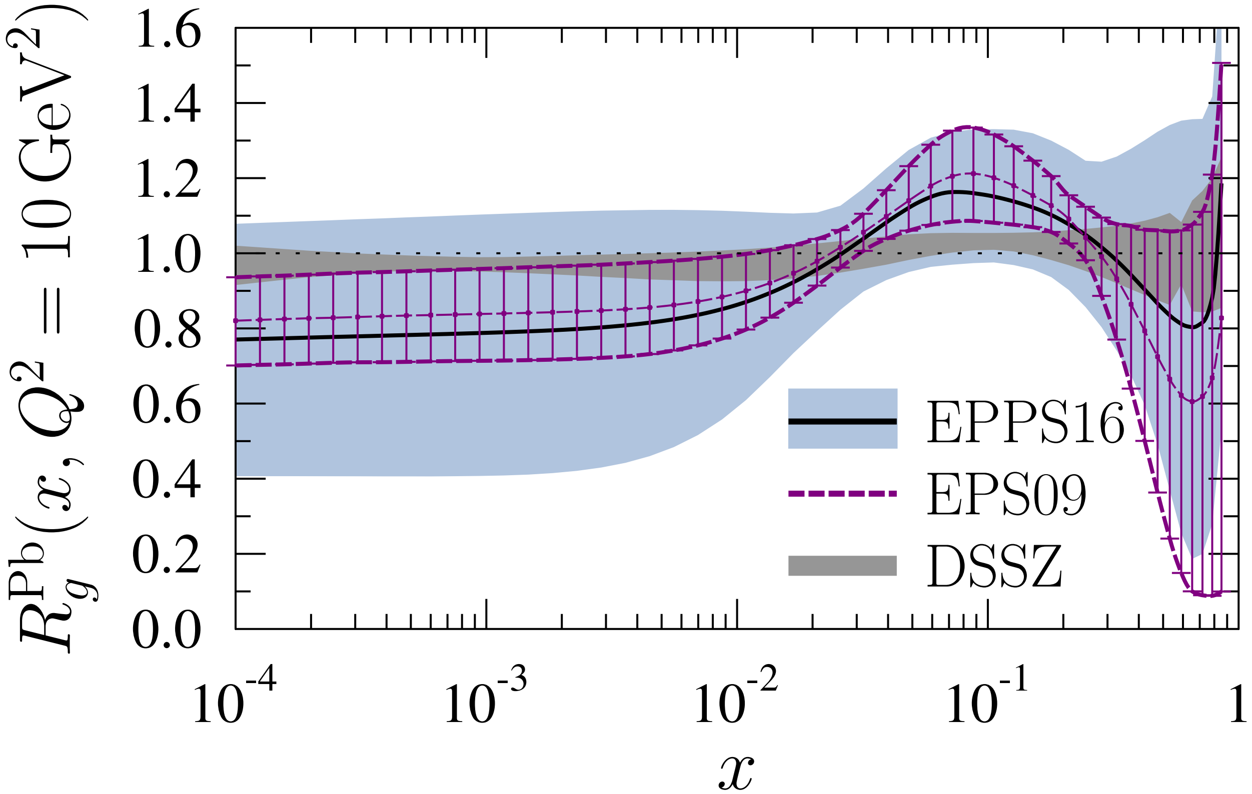


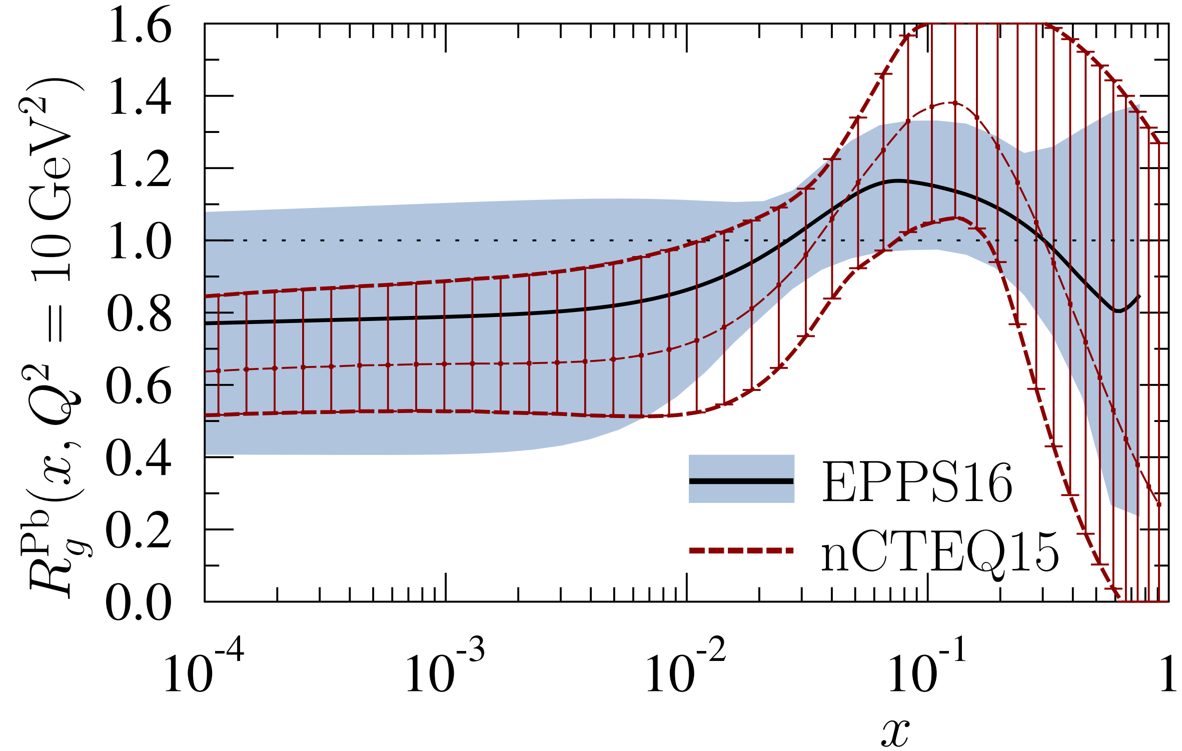
$$\Sigma = u + \bar{u} + d + \bar{d} + s + \bar{s}$$

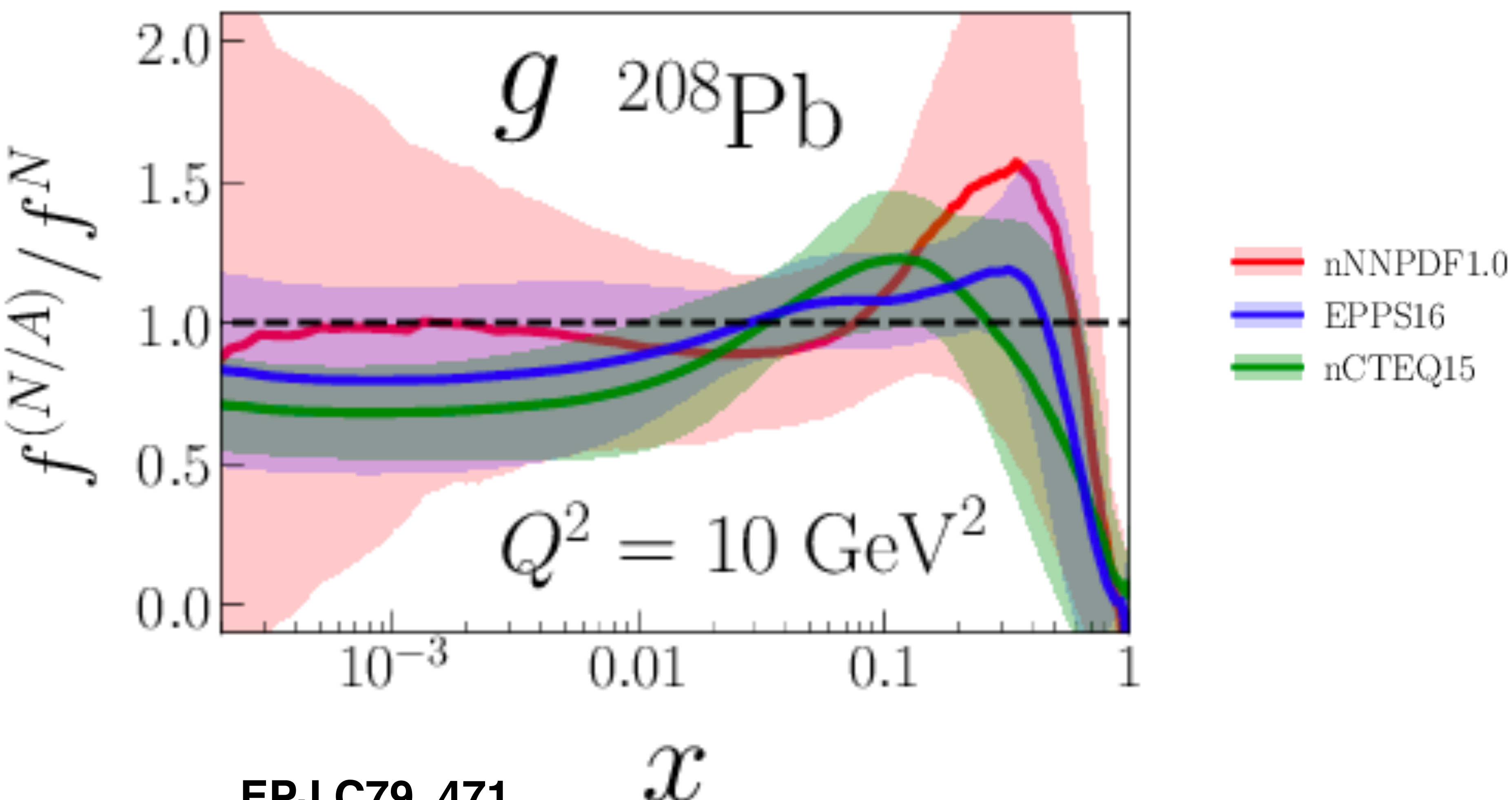
$$T_8 = u + \bar{u} + d + \bar{d} - 2(s + \bar{s})$$

Current sets of nPDFs

EPJ C77 (2017) no.3, 163







EPJ C79, 471

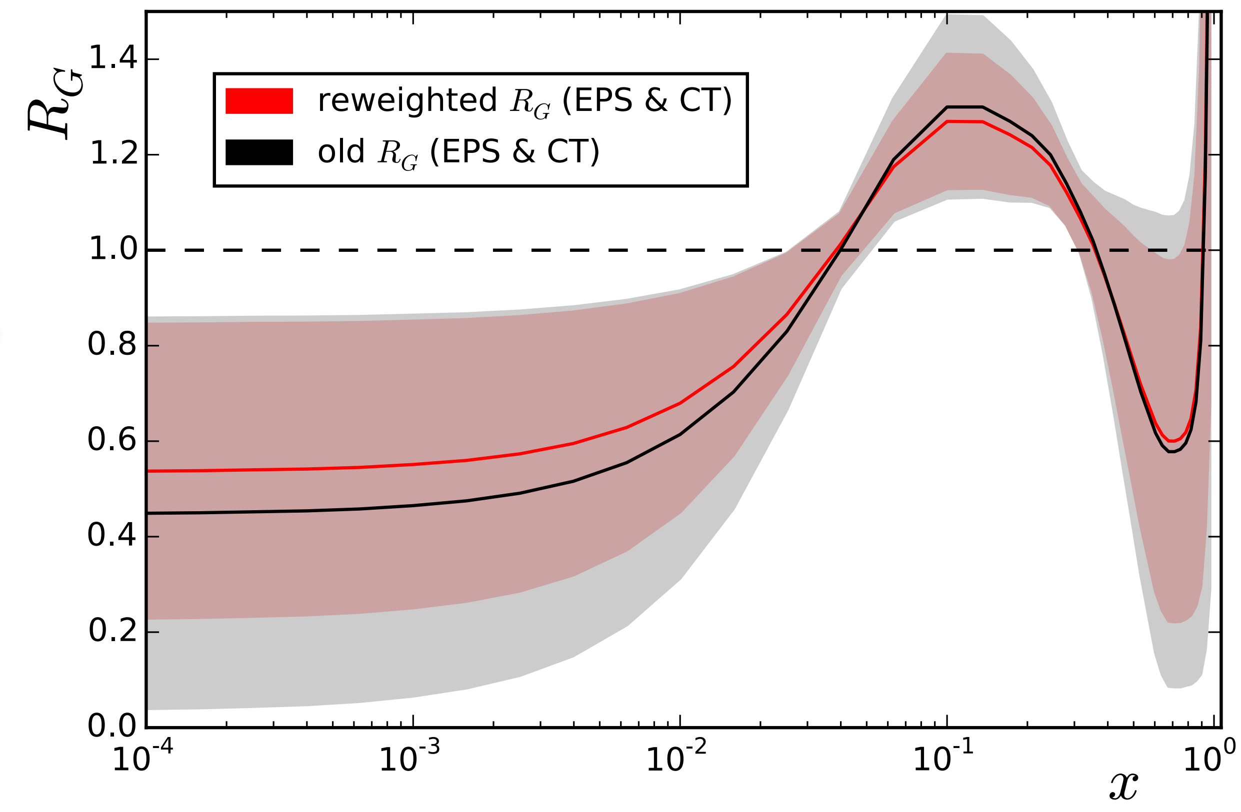
Impact studies with data

- use a purely statistical method to see the impact of new data, while avoiding to do a new fit
- different re-weighting methods, equivalent as long as some care is taken

Paukkunen and P.Z., JHEP 1412 (2014) 100

W+, W-, Z, jets, dijets, charged hadrons

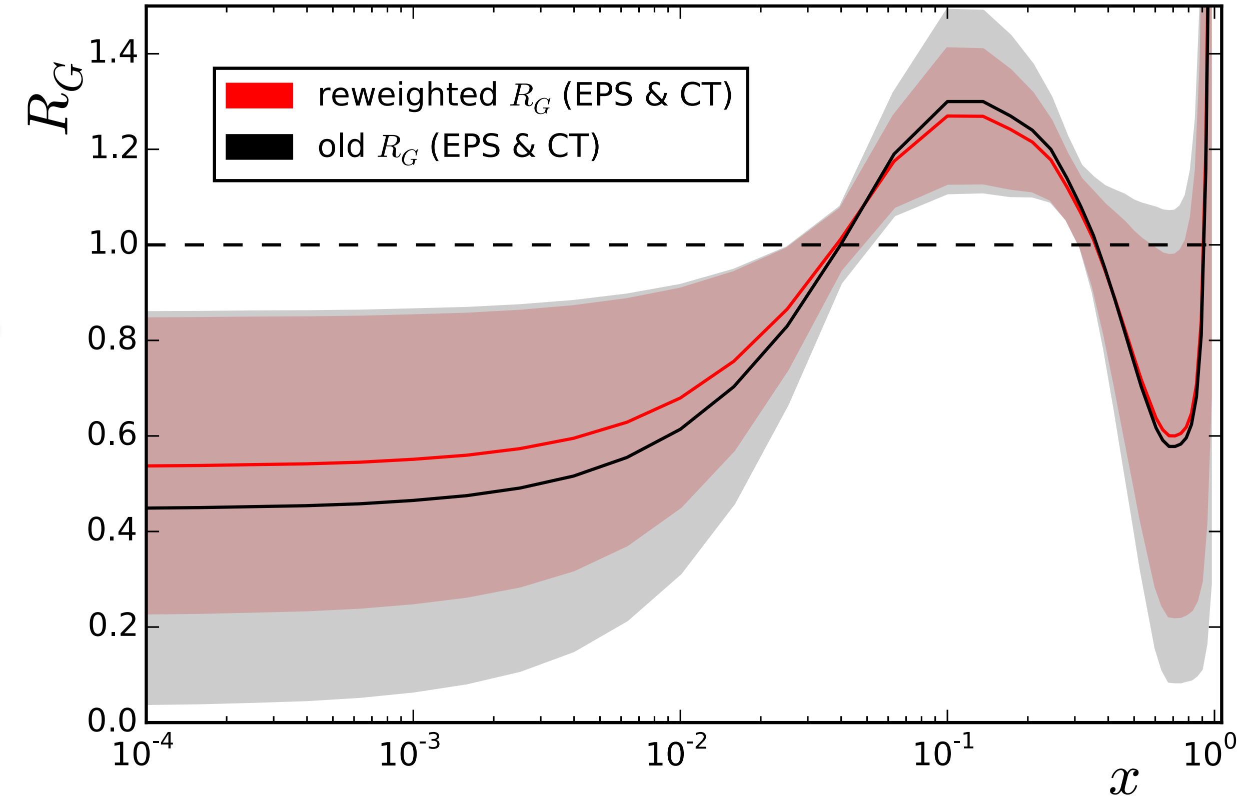
Armesto, Paukkunen, Penín, Salgado, P.Z., EPJ C76 (2016) no.4, 218



Impact studies with data: EW bosons and jets*

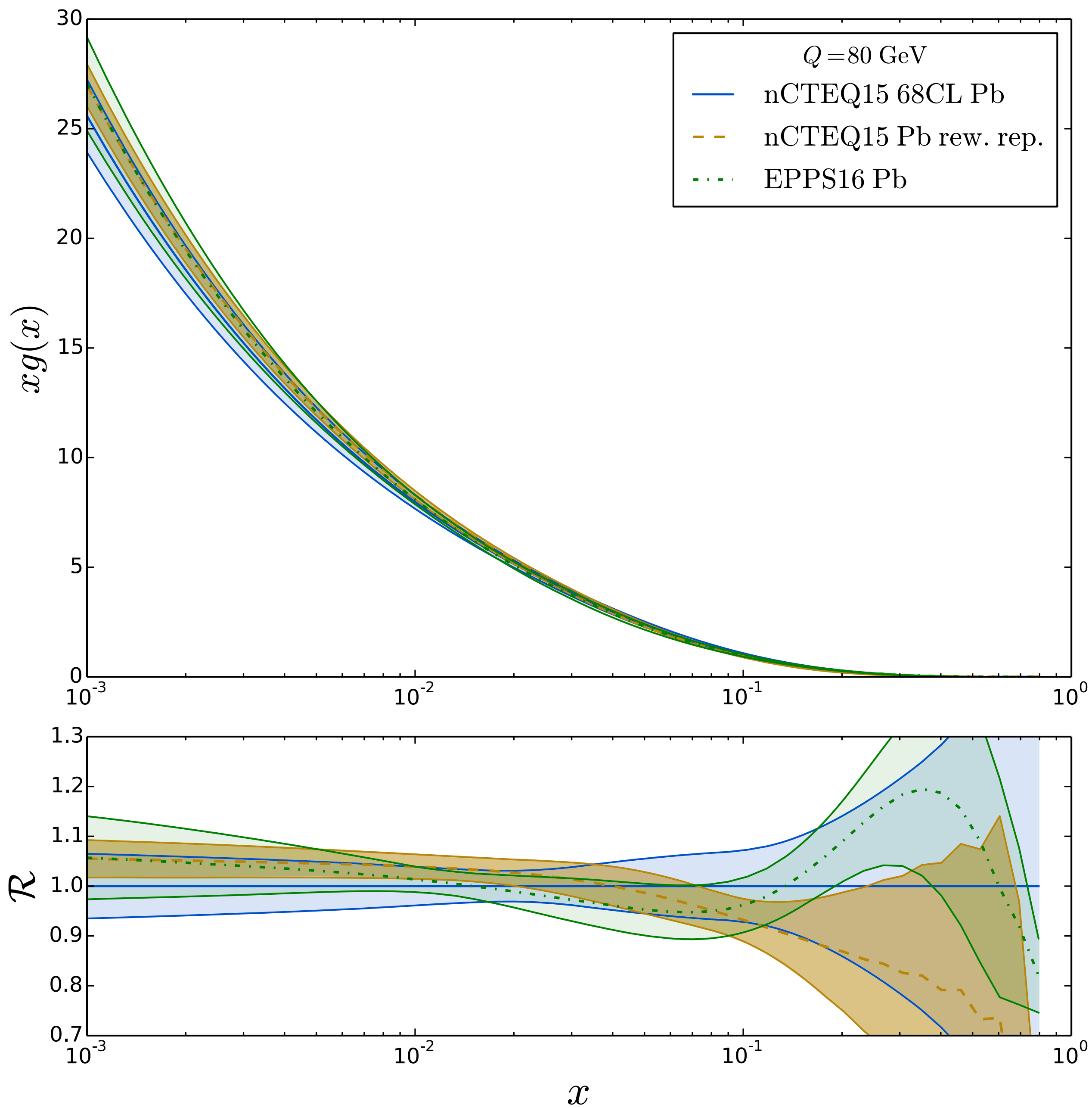
W+, W-, Z, jets, dijets, charged hadrons

Armesto, Paukkunen, Penín, Salgado, P.Z., EPJ C76 (2016) no.4, 218



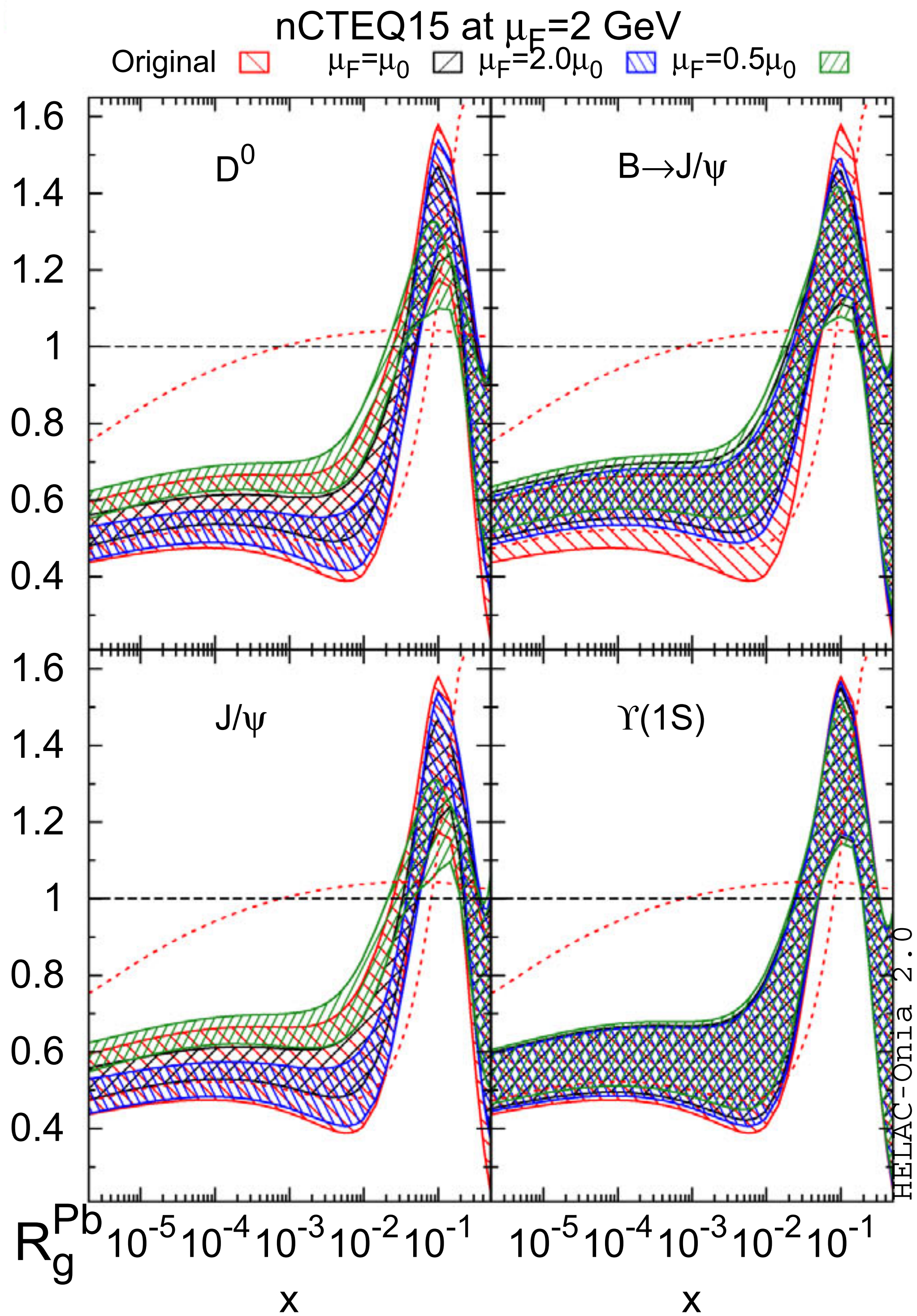
W+, W-, Z

Kusina, Lyonnet, Clark, Godat, Jezo, Kovarik, Olness, Schienbein, Yu, EPJ C77 (2017) no.7, 488

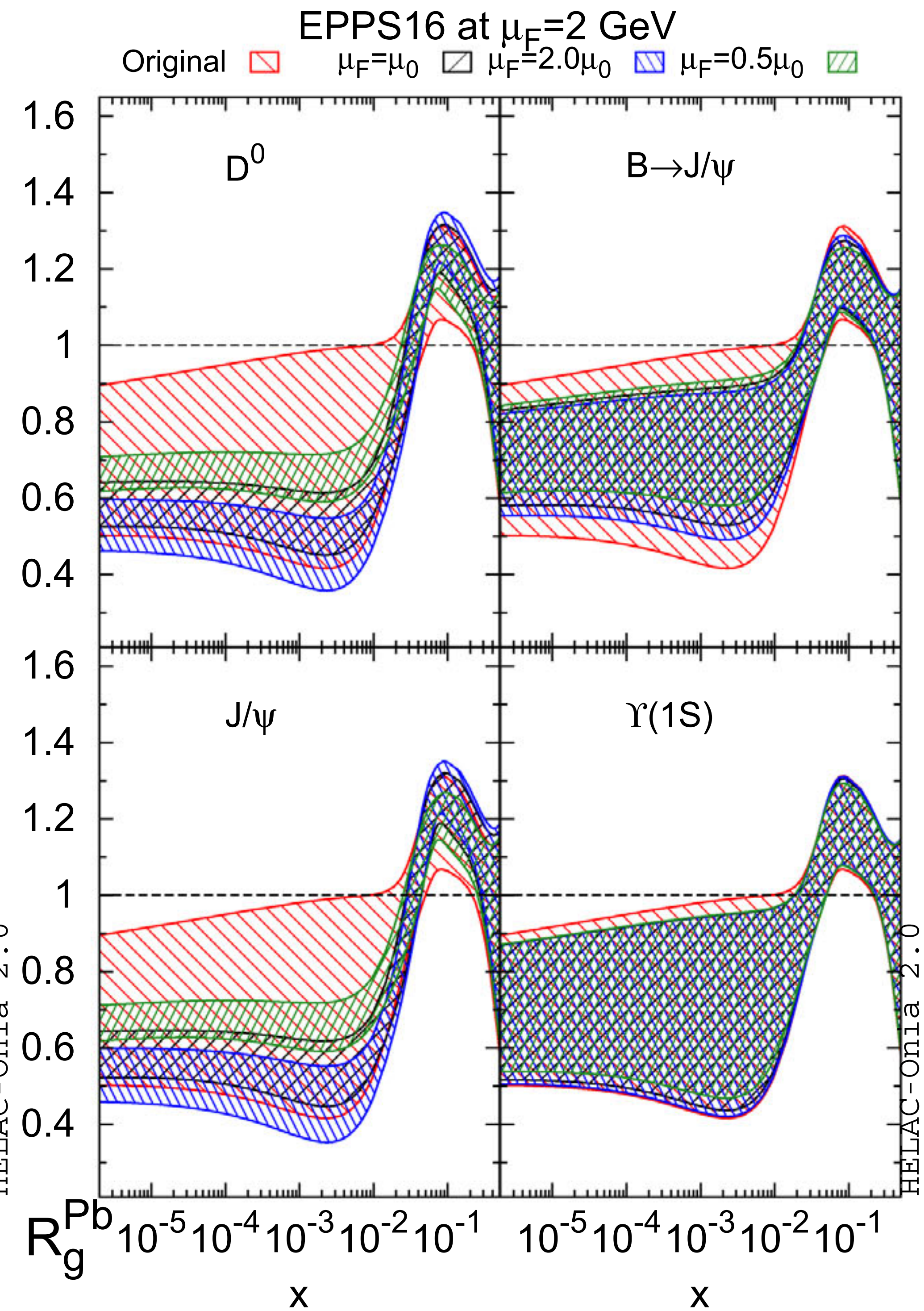


*check talks by E. Chapon and A. Bylinkin (Tuesday afternoon), and C. Andrés (Thursday afternoon) for more info

Impact studies with data: heavy mesons



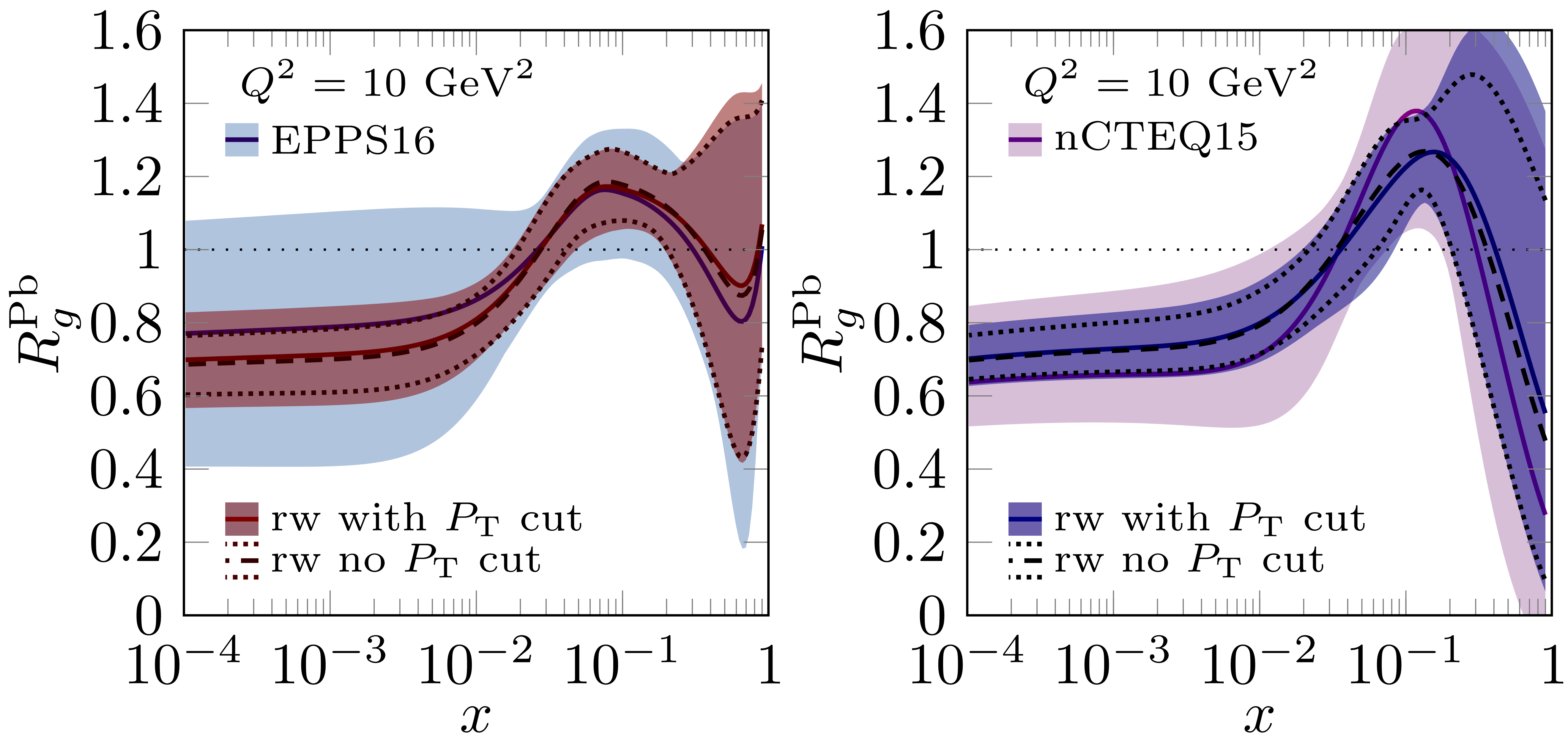
(e) nCTEQ15 nPDF



(f) EPPS16 nPDF

Kusina, Lansberg, Schienbein and Shao, PRL 121 (2018) no.5, 052004

based on the data-given method of **Lansberg and Shao, EPJ C77, 1 (2017)**



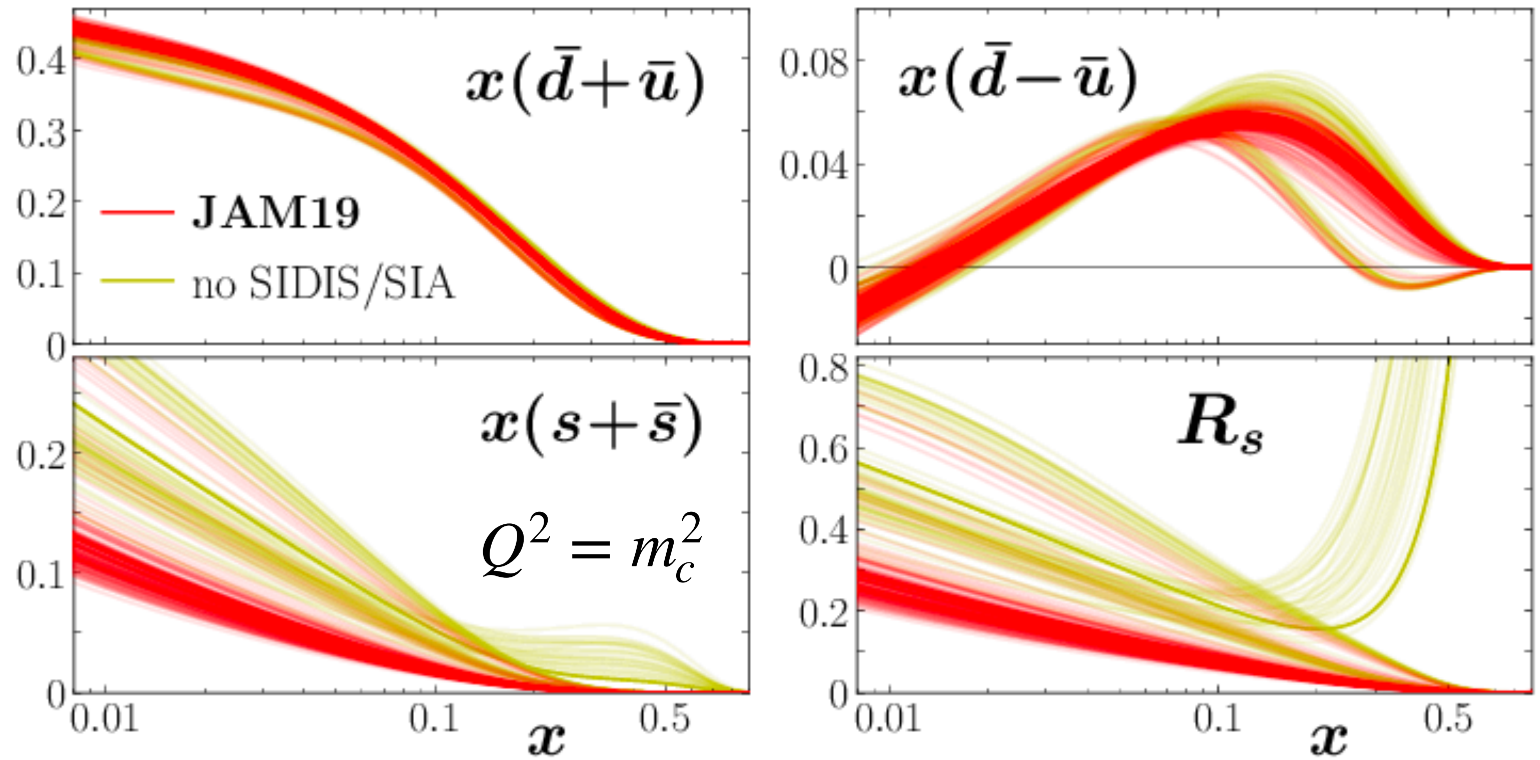
Eskola, Helenius, Paakkinen and Paukkunen, arXiv:1906.02512 [hep-ph]

Work in progress and ideas

- study the impact of semi-inclusive data on the initial state densities

Sato, Andrés, Ethier, Melnitchouk [JAM Collaboration], arXiv:1905.03788 [hep-ph]

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$



- **TuJu19** nuclear fit in FONLL-C scheme using xFitter

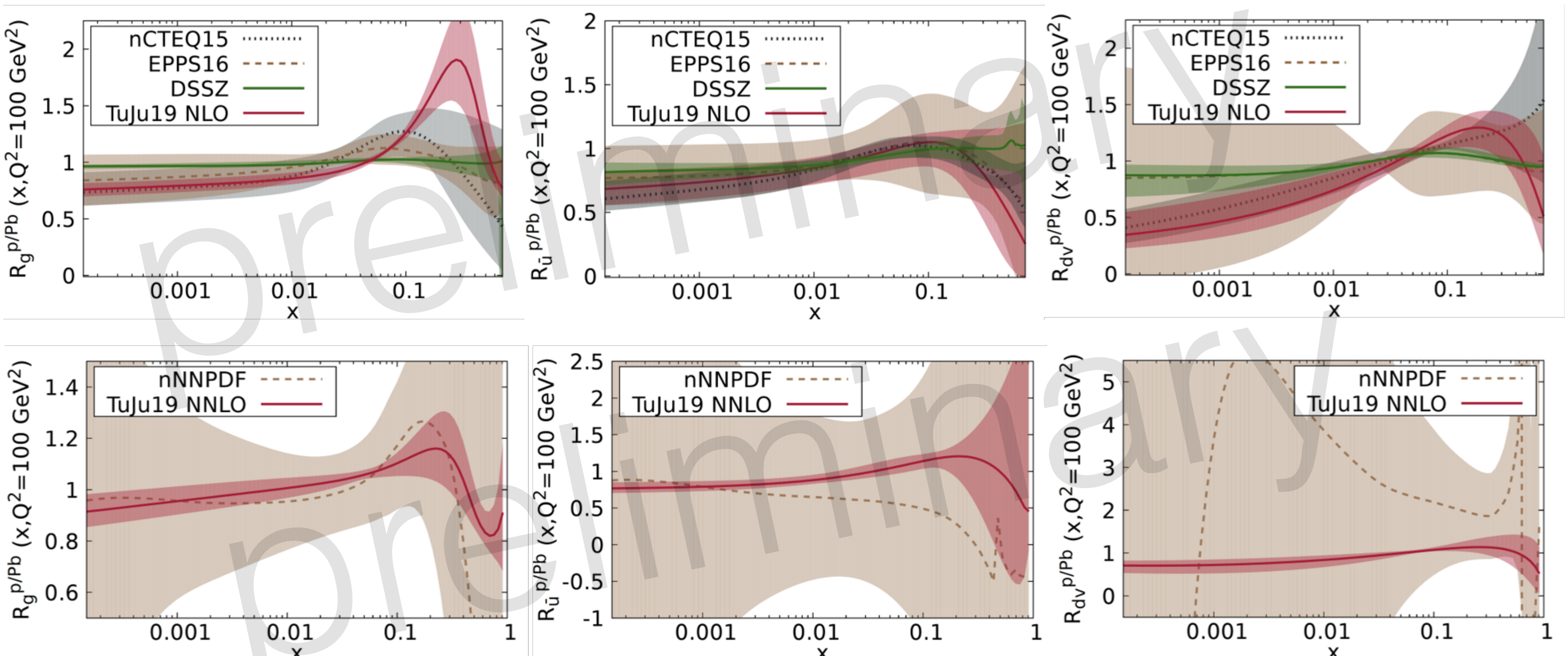
M. Walt *et al.*, in preparation

TuJu19

DIS NC and DIS CC data (CDHSW and CHORUS)

$\bar{u} = \bar{d} = \bar{s}$ $\Delta\chi^2 = 40$

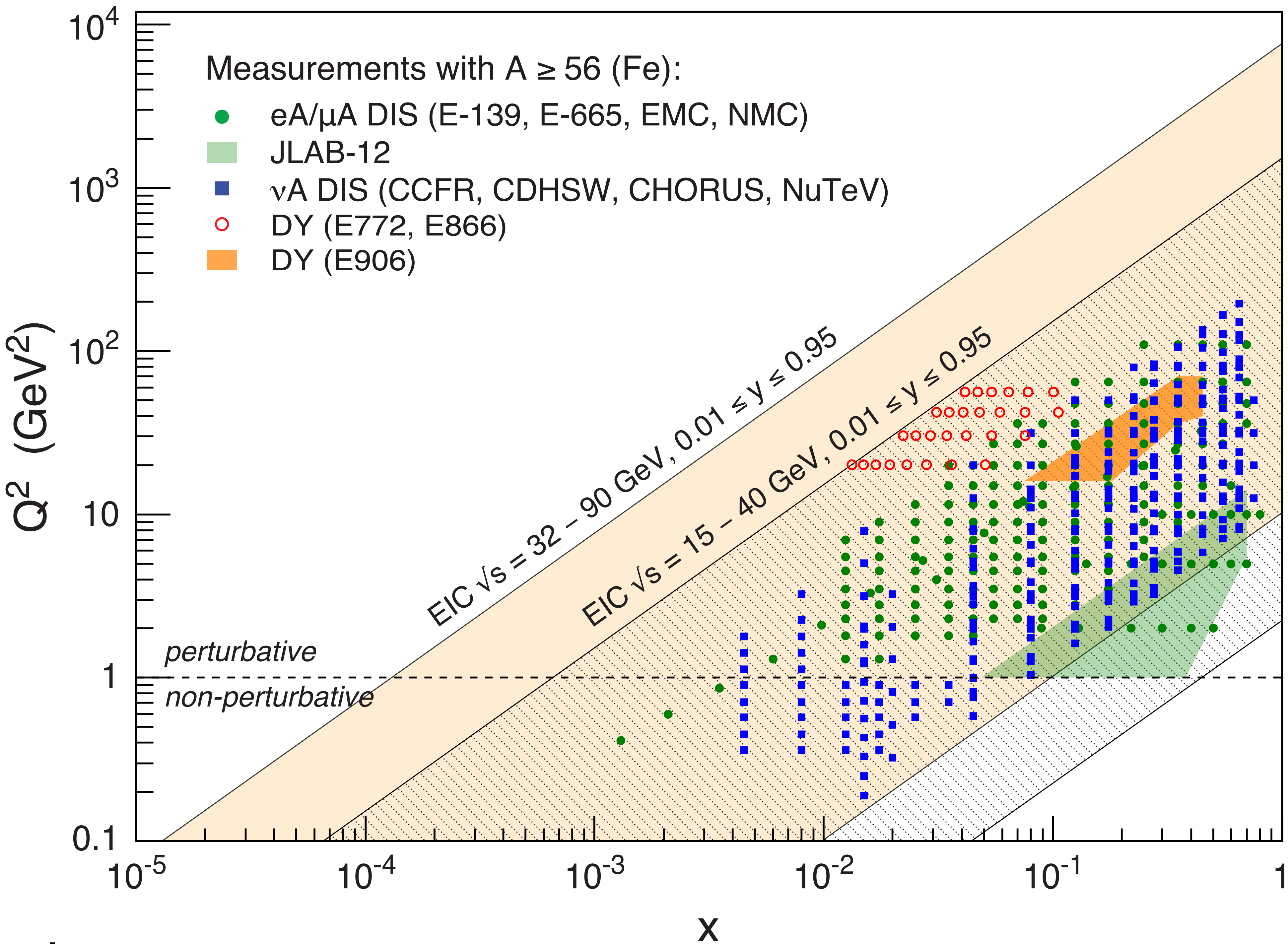
own proton pdf set as baseline (based on DIS NC and DIS CC proton data)



Impact studies for EIC/LHeC

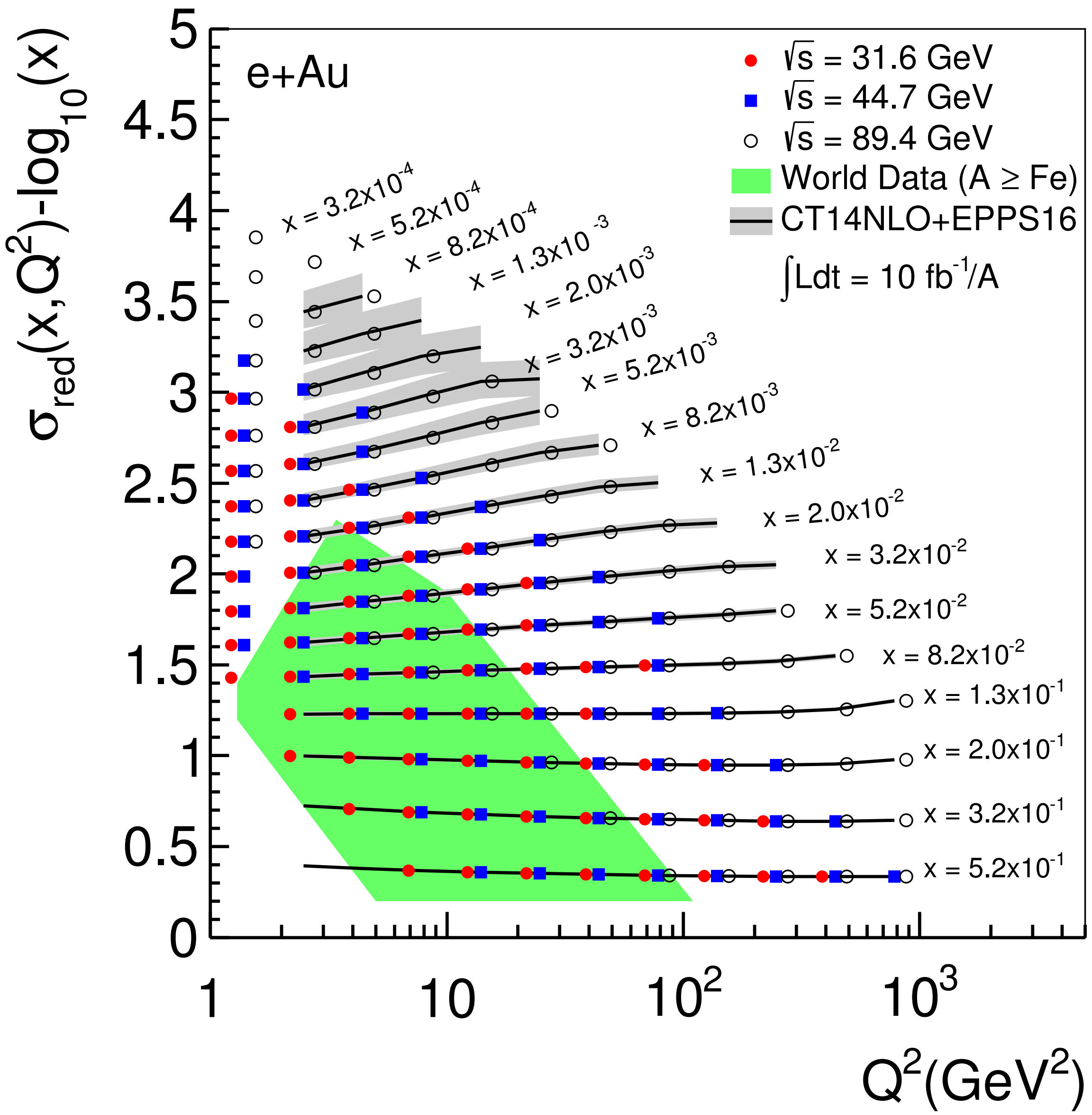
- General overviews of the colliders on Friday by E. Sichtermann (EIC) and N. Armesto (LHeC)
- all based on pseudo data and machine/detector simulations
- using re-weighting techniques or re-fitting
- standard fit observables (inclusive and semi-inclusive DIS, jets, etc)

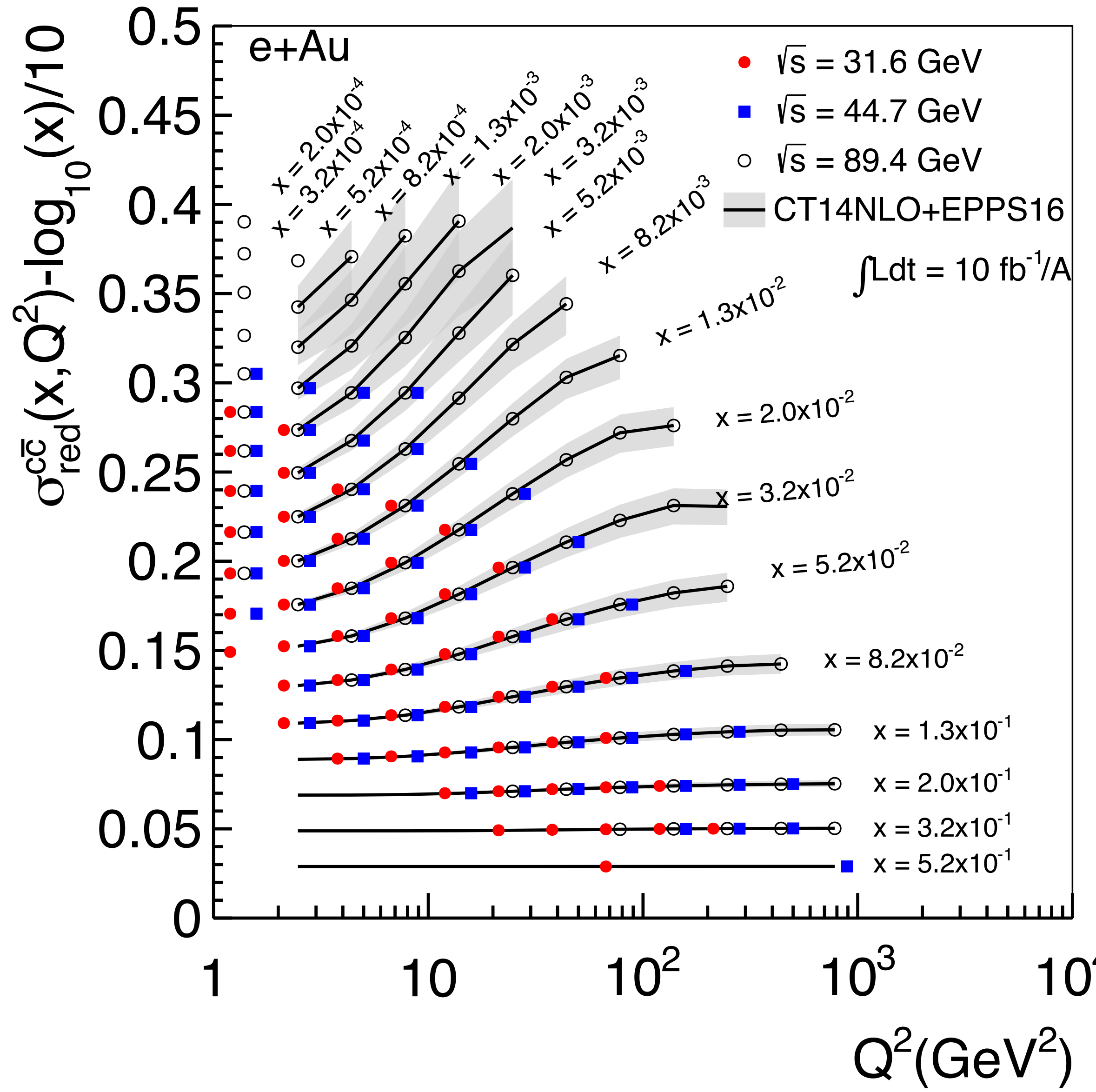
Impact studies for EIC



Aschenauer et *al.*,
Rept.Prog.Phys. 82 (2019) no.2, 024301

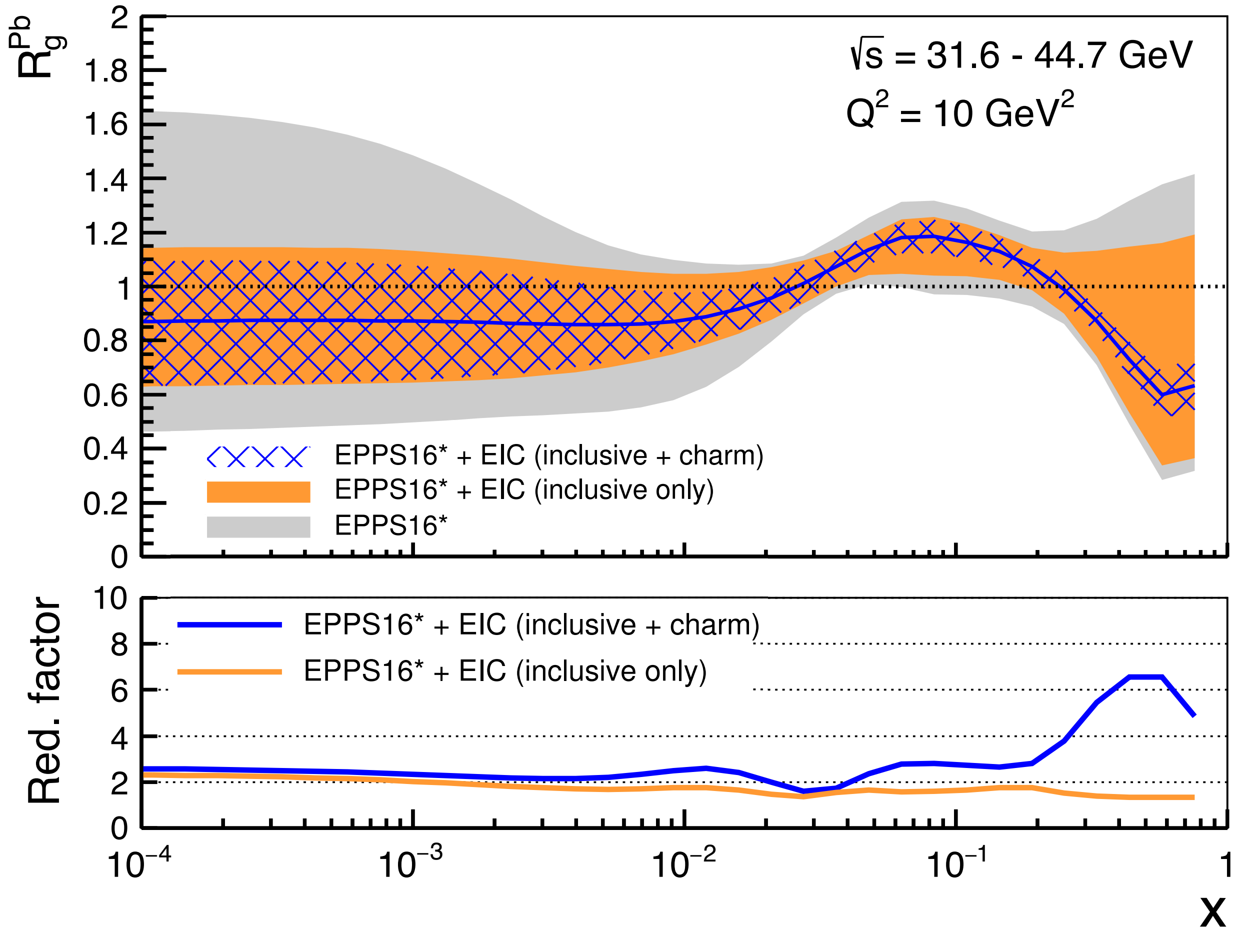
- observables: reduced cross-section
- pseudo-data using CT10 NLO proton PDFs + EPS09 nPDFs

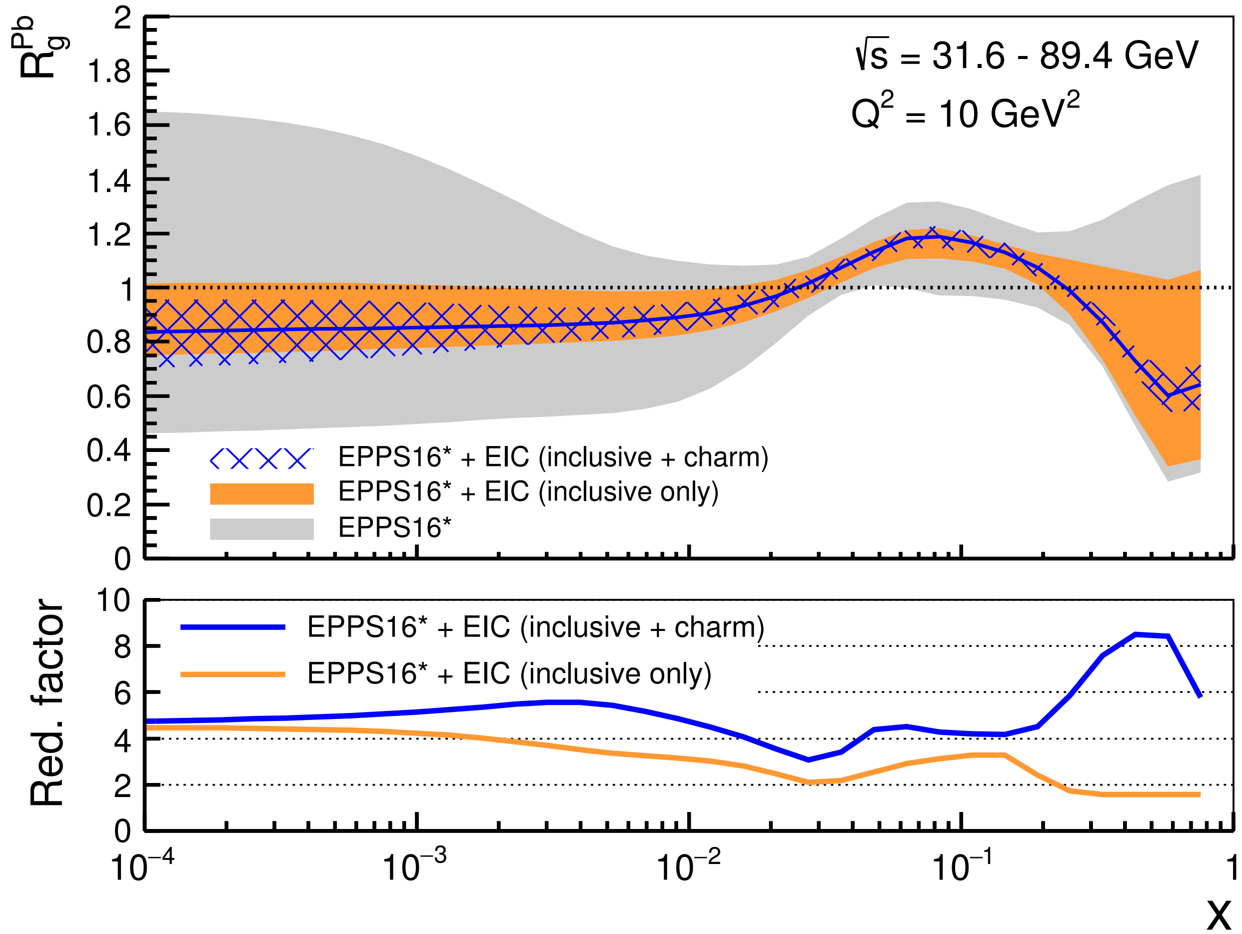




Aschenauer, Fazio, Lamont, Paukkunen, PZ, PRD96 (2017) no.11, 114005

✦ check impact on **EPPS16*** nPDFs: charm, high energy

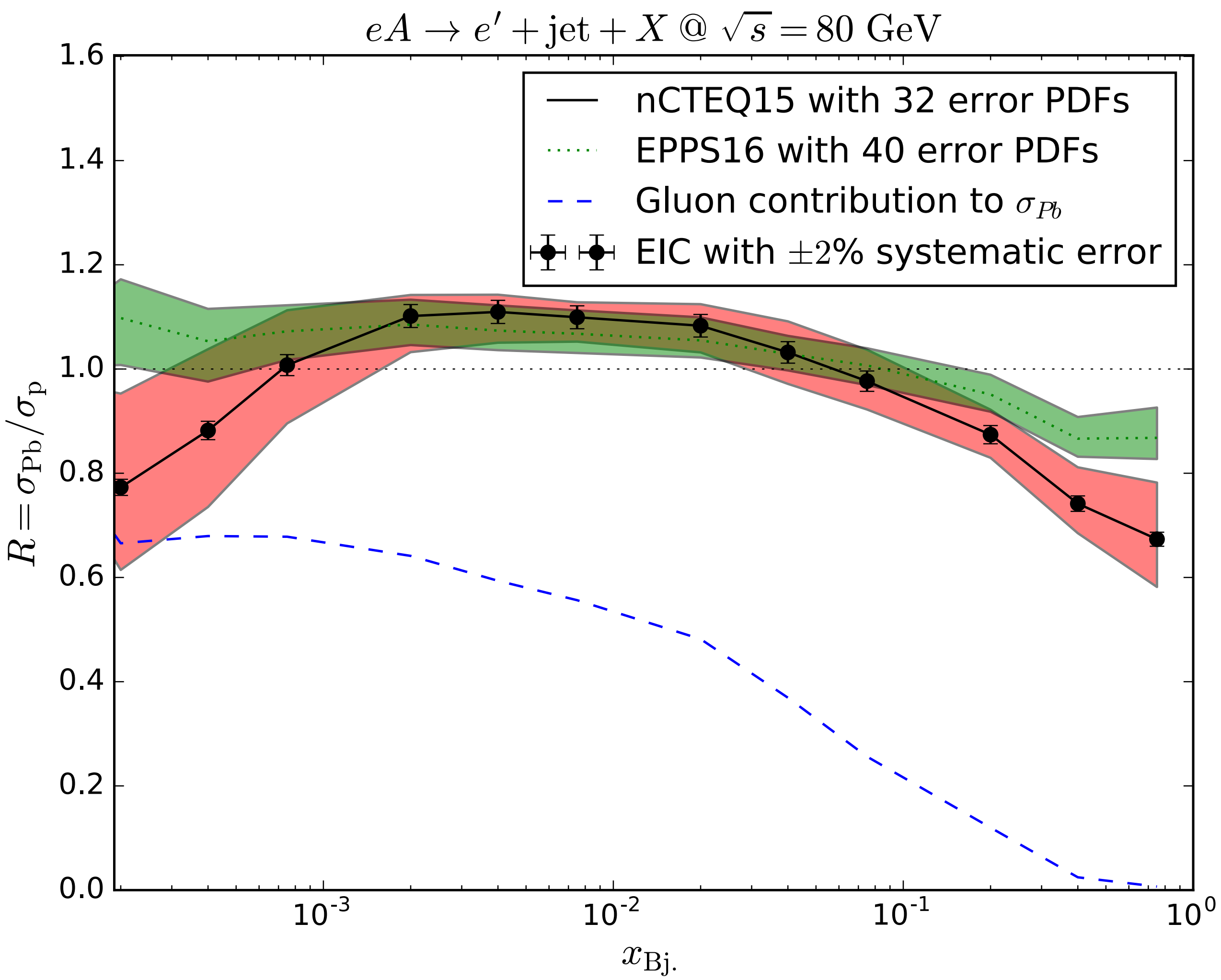


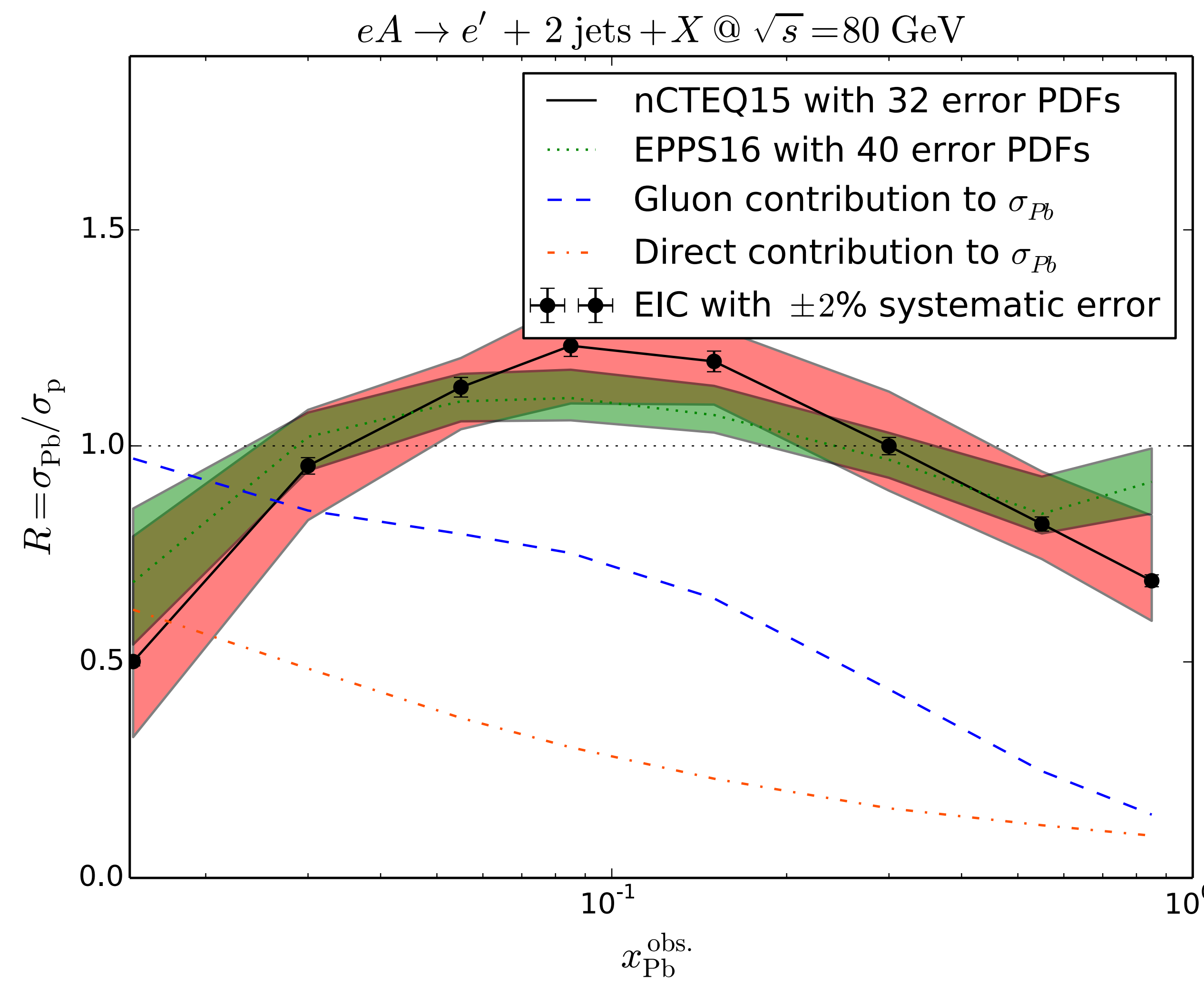


Aschenauer, Fazio, Lamont, Paukkunen, PZ, PRD96 (2017) no.11, 114005

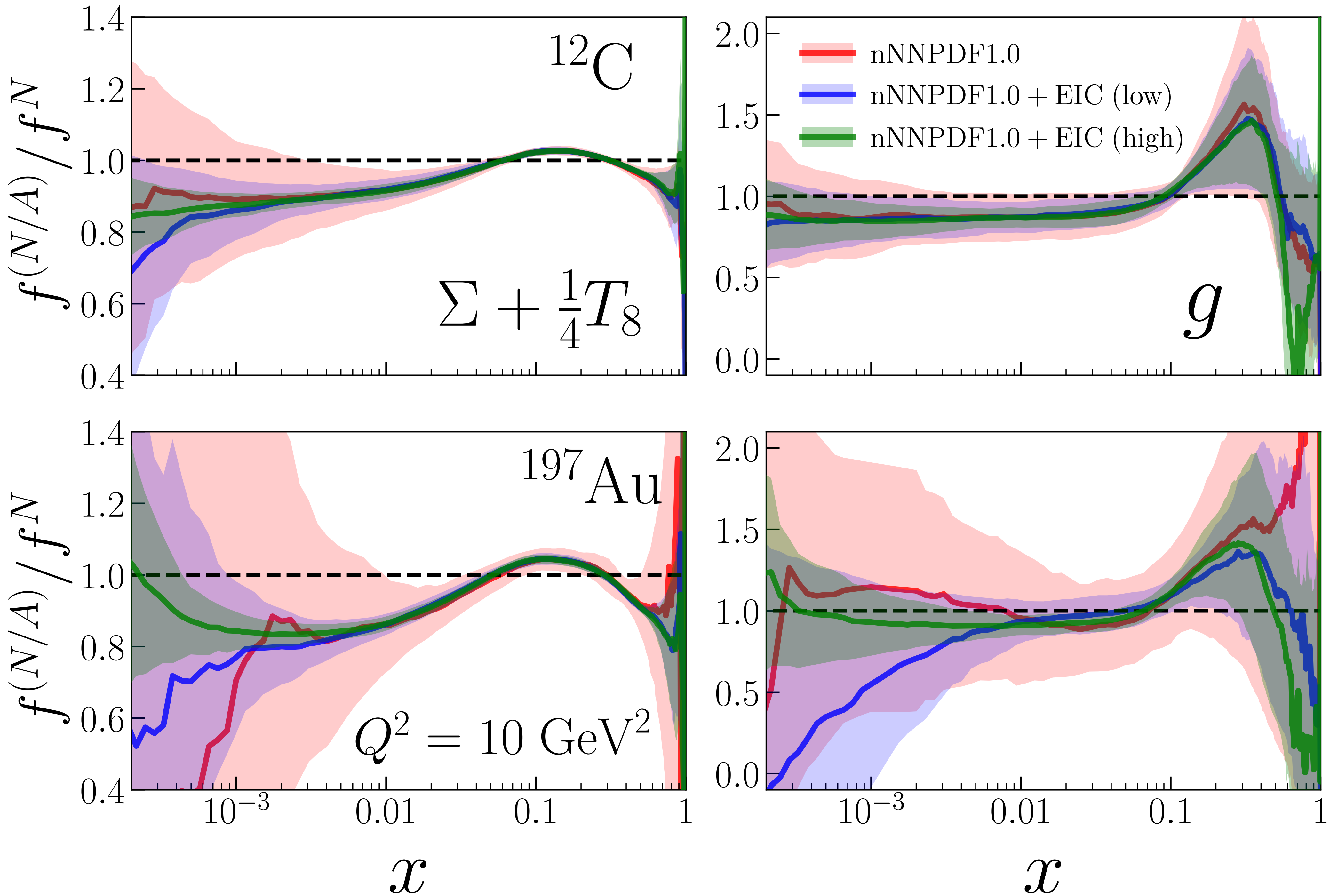
Impact studies for future colliders: EIC

Klasen and Kovarik, PRD97 (2018) no.11, 114013





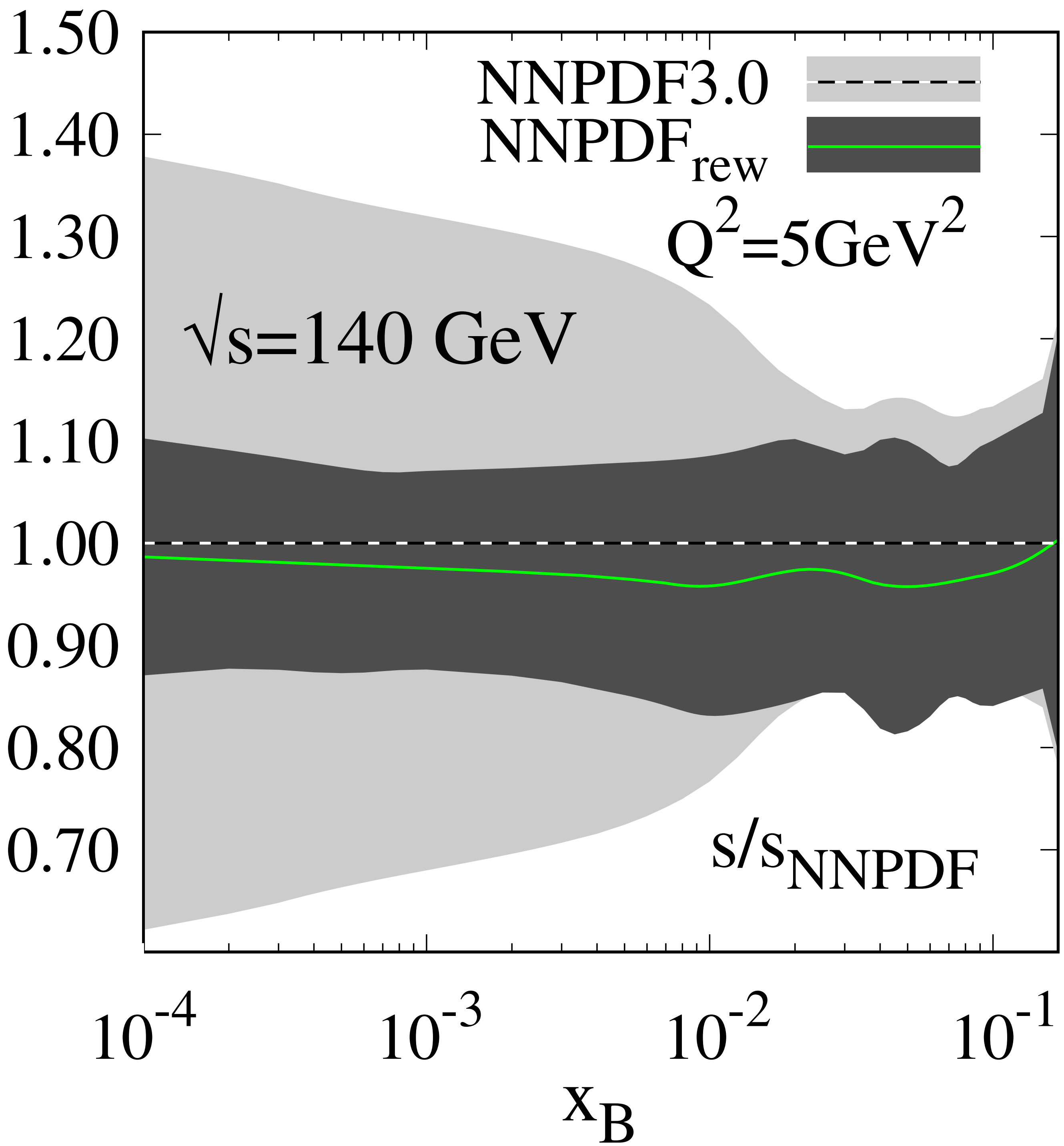
Klasen, Kovarik, Potthoff, PRD95 (2017) no.9, 094013



Abdul Khalek, Ethier, Rojo [NNPDF Collaboration], EPJ C79 (2019) no.6, 471

“low” E_e = 5 GeV

“high” E_e = 20 GeV

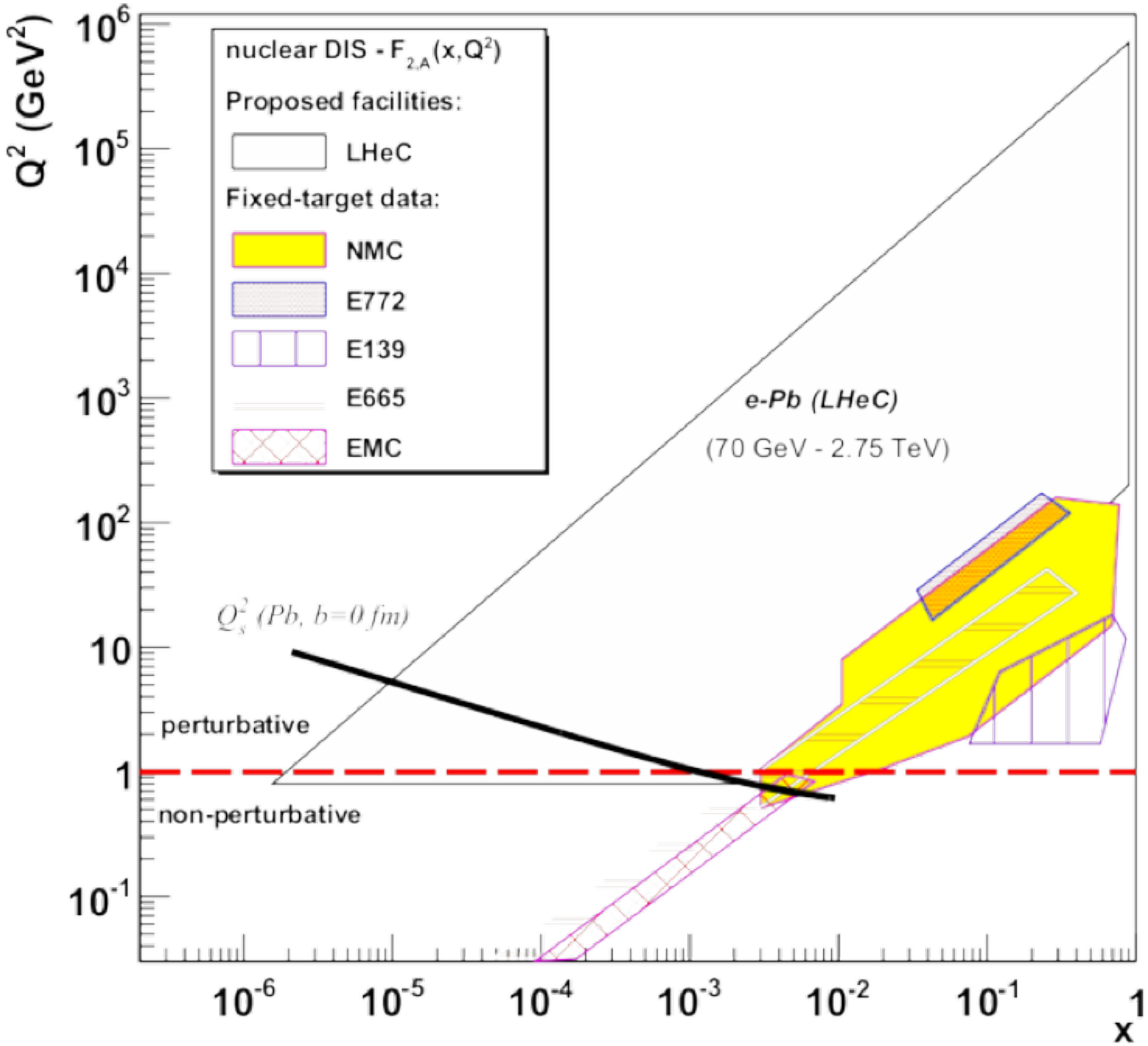


Aschenauer, Borsa, Sassot, Van Hulse, PRD99 (2019) no.9, 094004

Great for e+p, maybe we can do this for e+A?*

*check I. Borsa's talk (Wednesday afternoon)

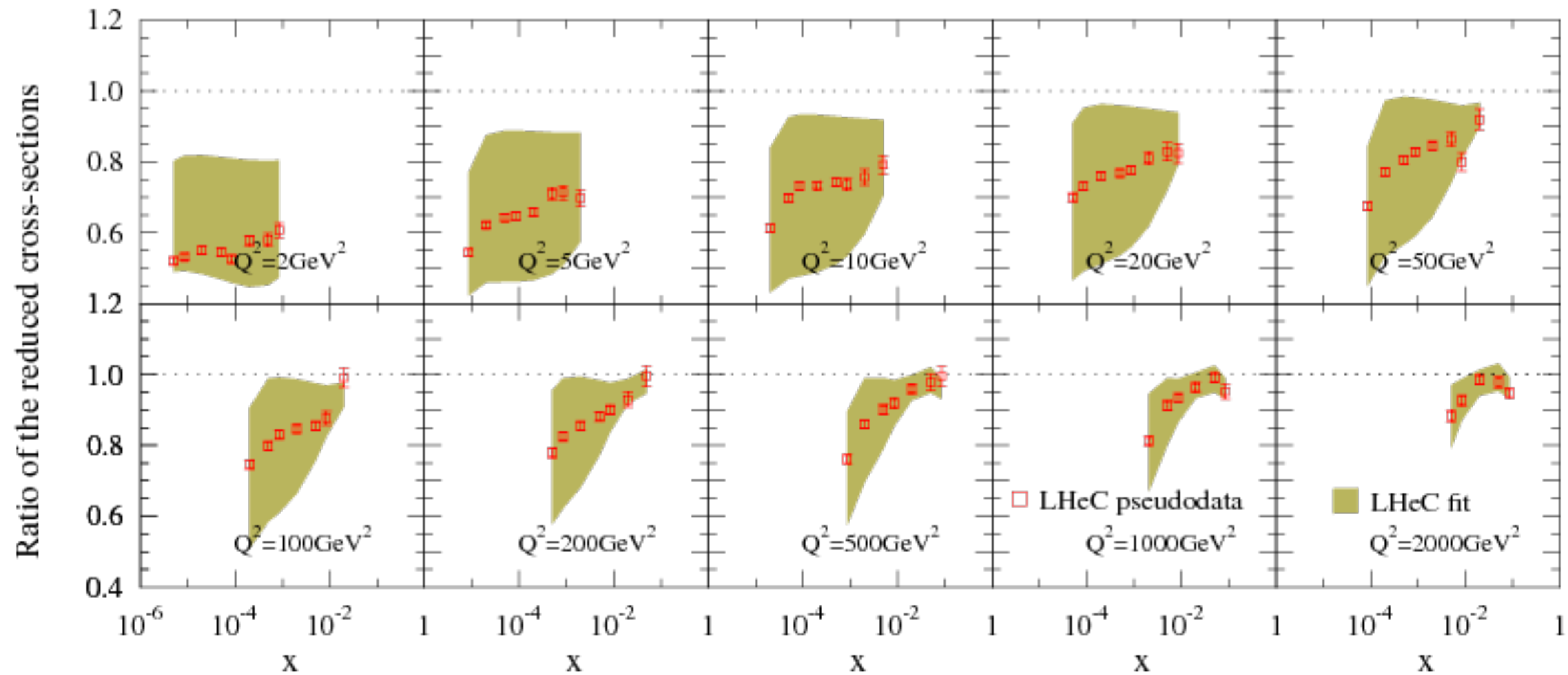
Impact studies for LHeC



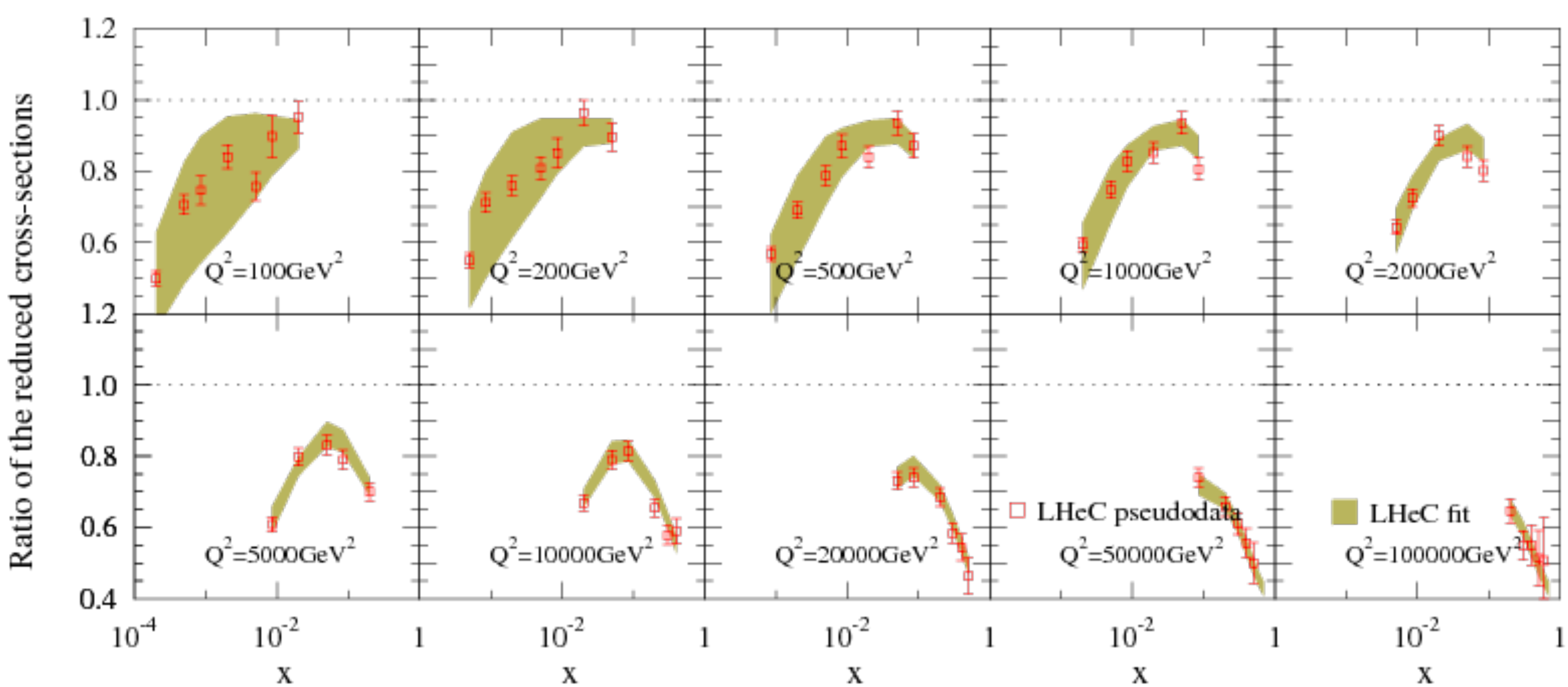
J.Phys. G39 (2012) 075001

Impact studies for future colliders: LHeC

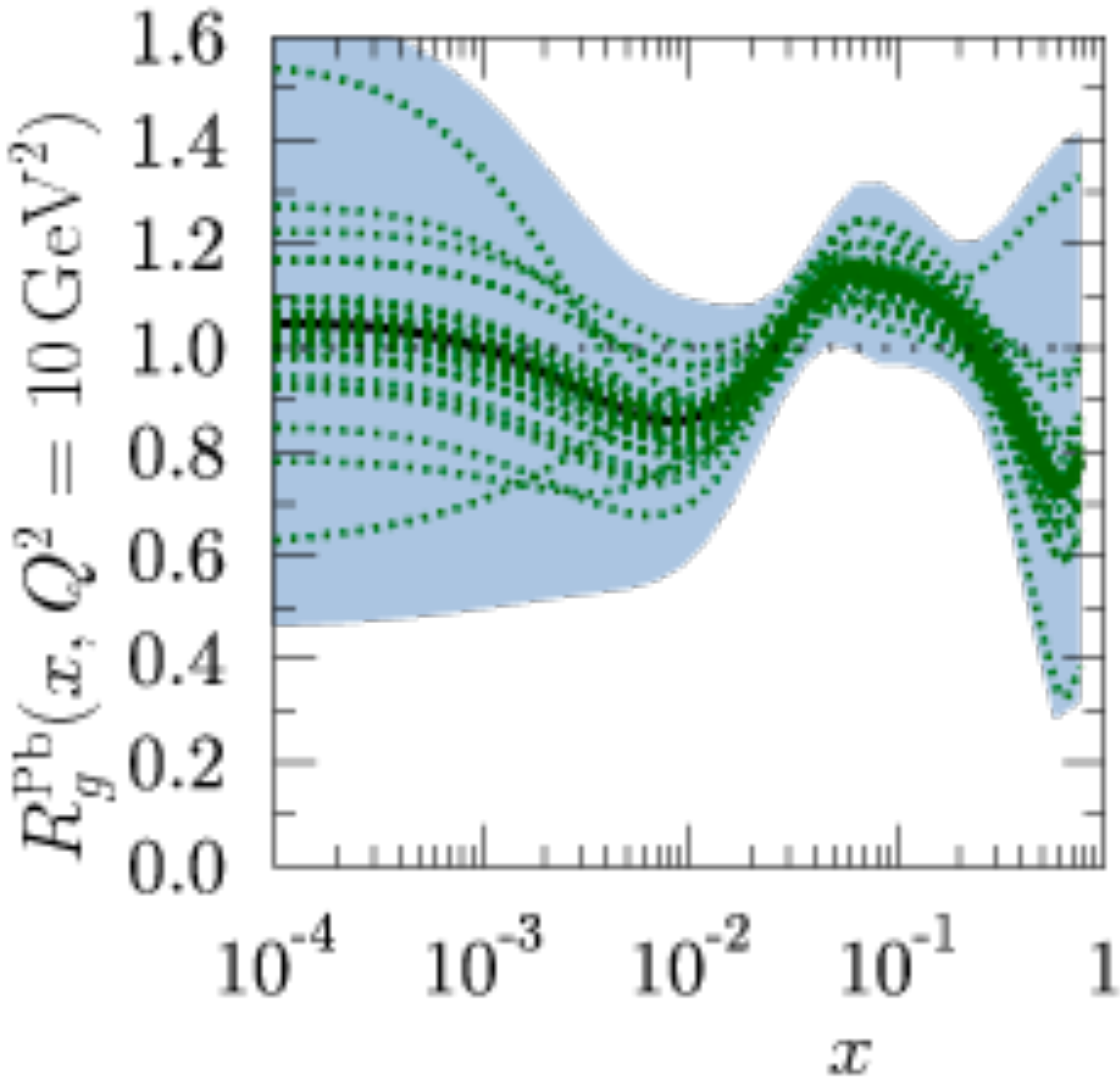
NC



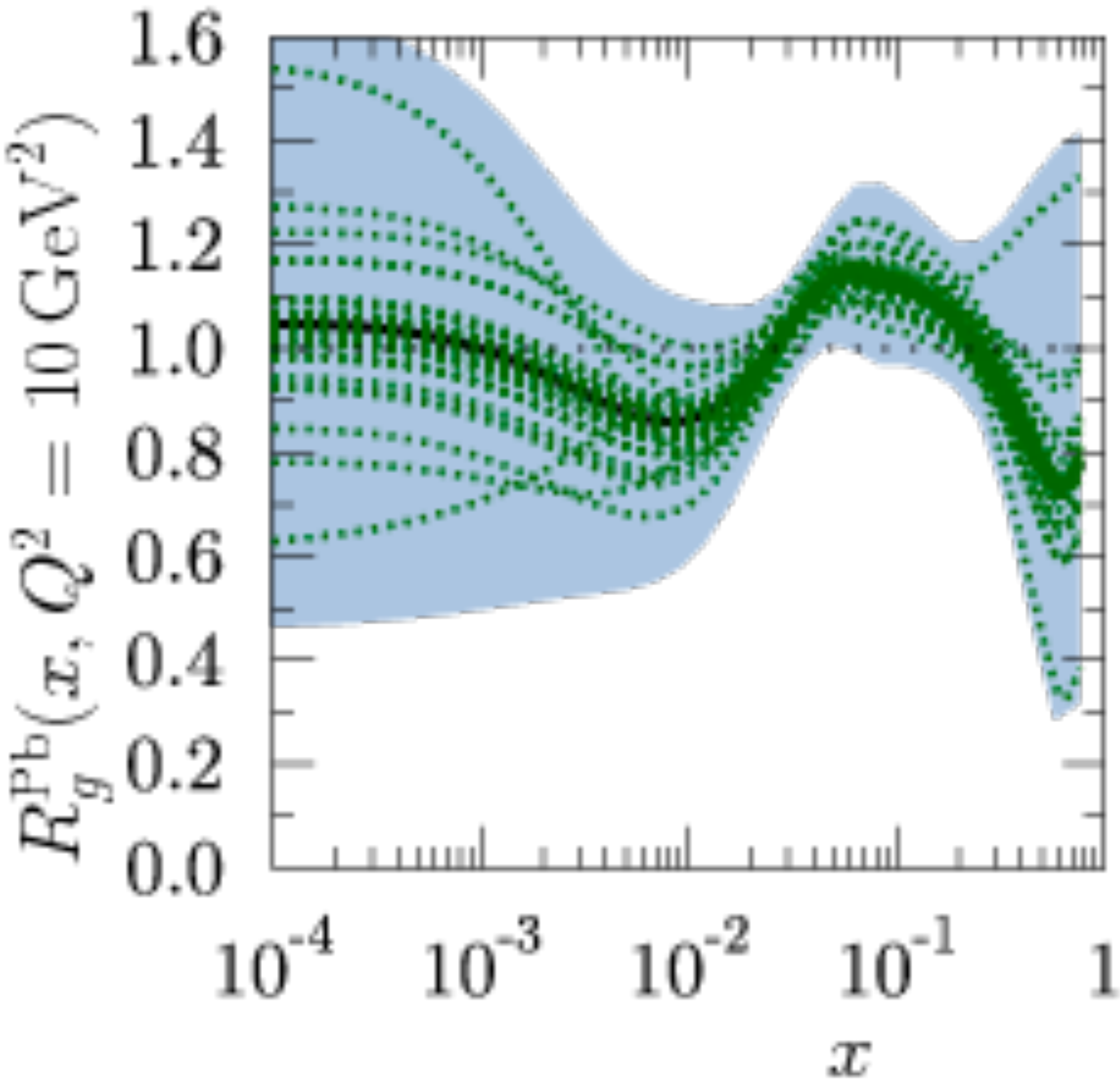
Paukkunen [LHeC study Group], PoS DIS 2017 (2018) 109



CC

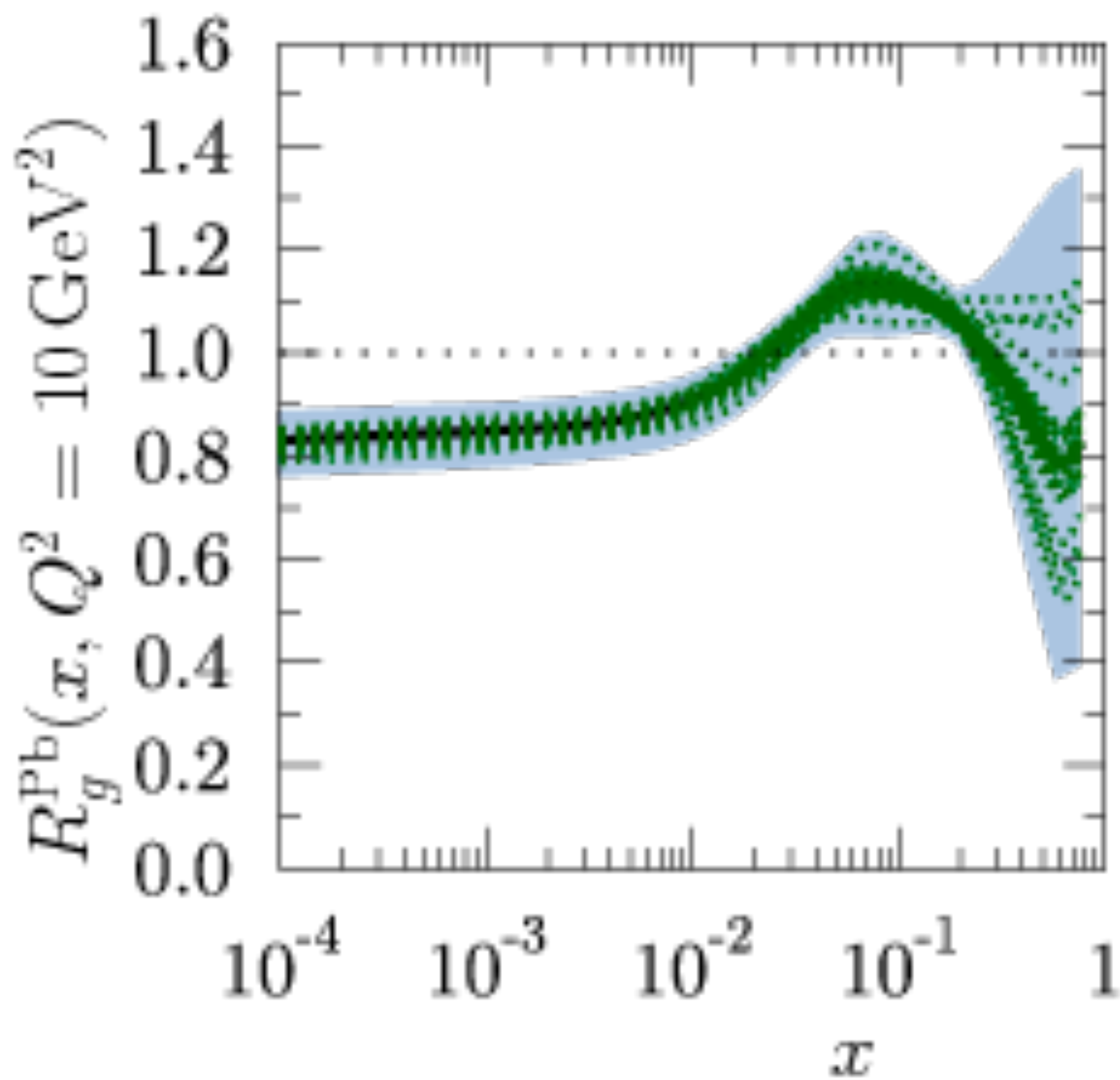


EPPS16 with
more flexible
shape at low x



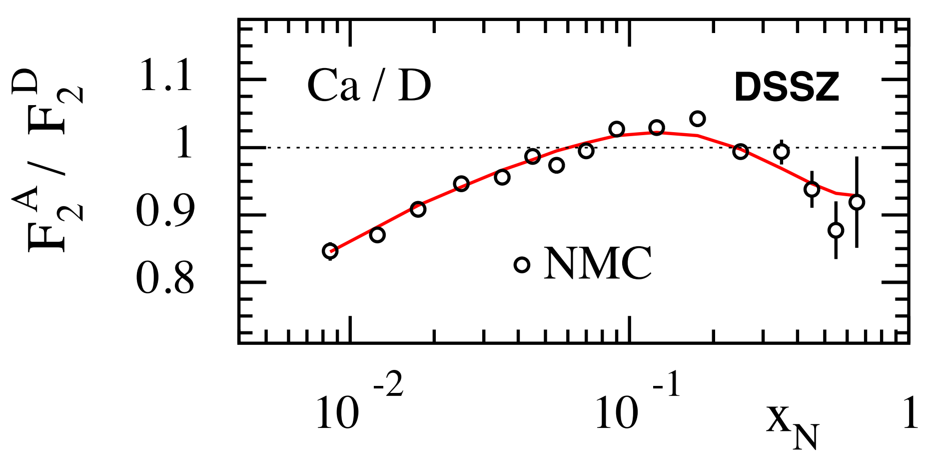
EPPS16 with
more flexible
shape at low x

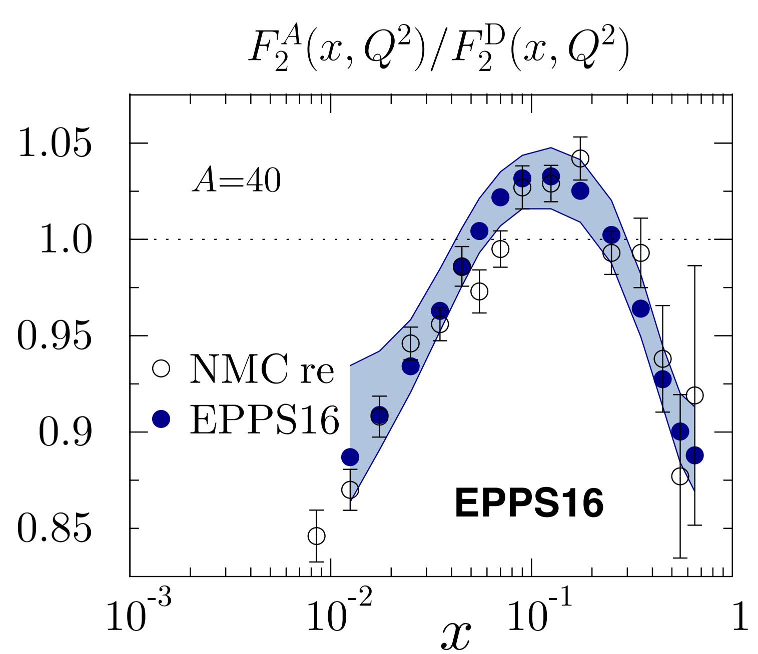
adding LHeC
pseudo data



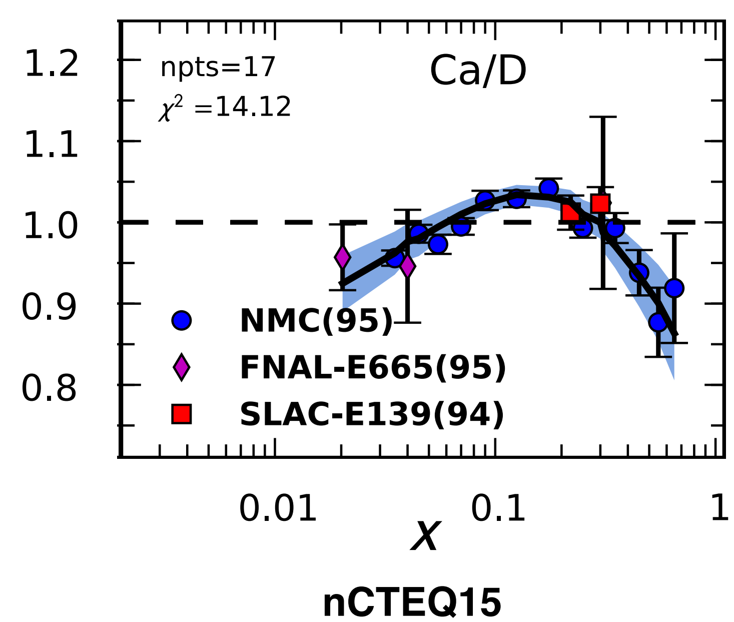
Summary

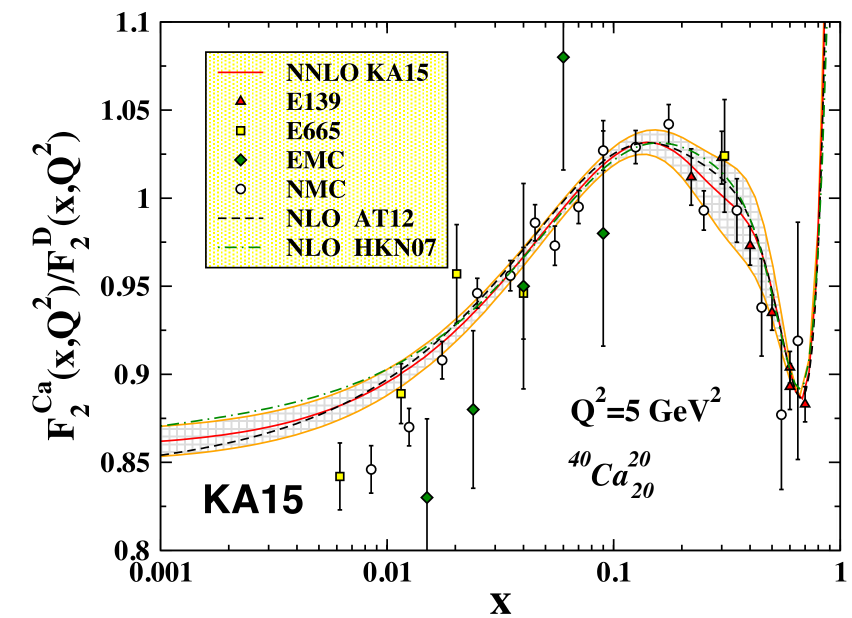
all sets give **NICE** descriptions of the data

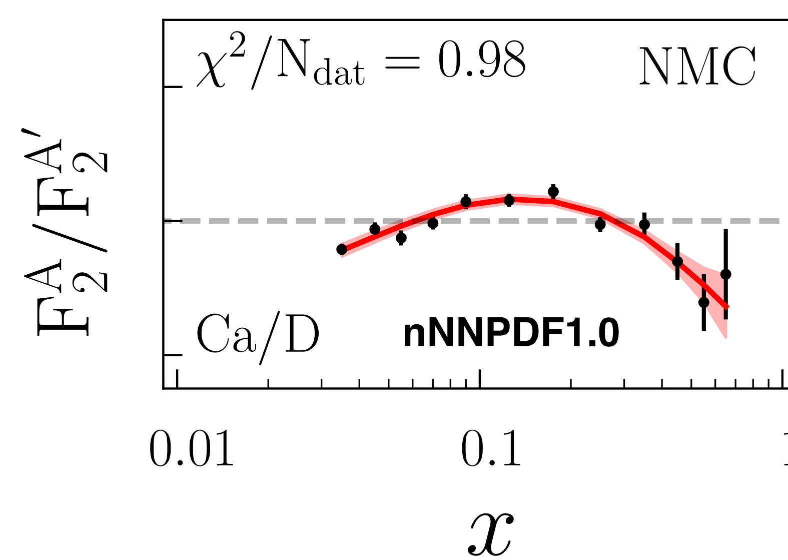




F_2^A / F_2^D







- several nPDFs sets available, comparing them is tricky
- far from the precision of proton PDFs due to the available data
- “new” data coming into the game
- many observables not included
- active work to include other data
- waiting for new results to include!
- future experiments have a huge potential to improve nPDFs

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- A Fixed Target ExpeRiment using the LHC beams (**AFTER@LHC**)

For more information see I. Schienbein’s talk:

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

Proposal for a DFG* Research Unit

Next Generation Perturbative QCD for Hadron Structure: Preparing for the Electron-Ion Collider

Aim: Matching the precision achievable at the EIC and other high luminosity accelerators

Topics:

higher precision QCD evolution
(n)PDFs and (n)FFs
multiparton interactions & HT effects
TMDs
MCEGs and detector design

Evaluation: May 2019 (positive review from the panel)

Resolution: mid-end of September 2019

*Deutsche Forschungsgemeinschaft (German Research Foundation)