nPDFs @ current and future colliders

Pia Zurita

BNL

Synergies of pp and pA Collisions with an Electron-Ion Collider

June 26-28, 2017, BNL

Outline

- Disclaimer
- Nuclear parton densities and the LHC
- The future: RHIC, LHC, EIC, LHeC, FCC
- What if we find something new?
- Summary

Disclaimer:

- there is much more to show & many topics to discuss on nPDFs
- missing references and results
- only collinear factorized nPDFs

$f_i(x, \mu)$ Parton Density/Distribution Function:

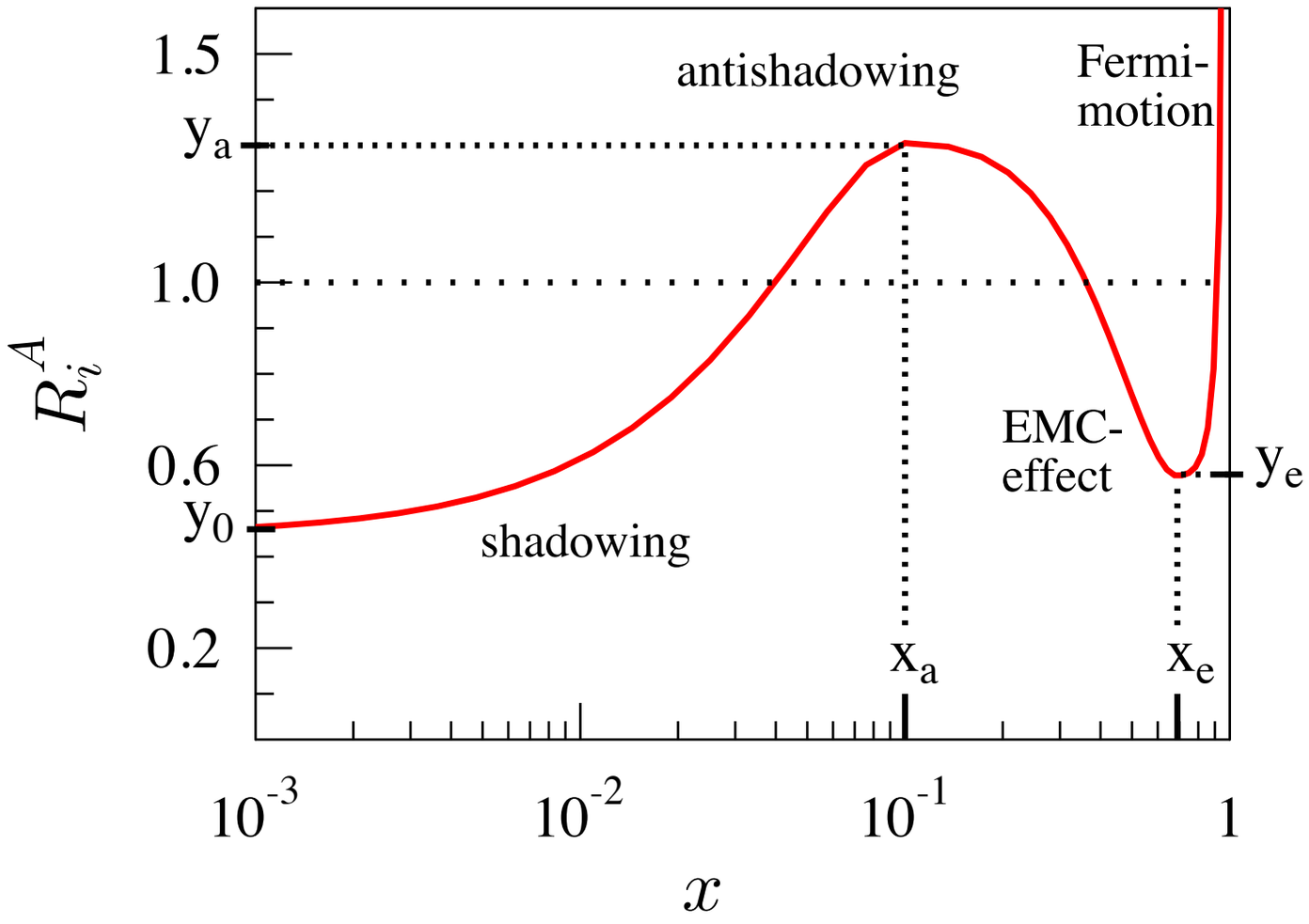
- at LO: probability of finding the parton "i" in the proton, carrying a fraction "x" of its momentum, when the proton is probed with scale μ
- non-perturbative
- UNIVERSAL
- obtained by global fits to the world data

$f_i(x, \mu)$ n Parton Density/Distribution Function:

- ✦ at LO: probability of finding the parton "i" in the nucleus , carrying a fraction "x" of its momentum, when the nucleus is probed with scale μ
- ✦ non-perturbative
- ✦ UNIVERSAL
- ✦ obtained by global fits to the world data

standard procedure for nPDFs:

- ✦ global fit with a proton PDF taken as reference
- ✦ parameterize the nuclear/proton PDF ratio



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

A-dependent parameters

LO

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

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

NLO

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

HKN: Hirai, Kumano, Nagai, Phys.Rev. C76 (2007) —> KEK nuclear physics textbook (2015)

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

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

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

NNLO

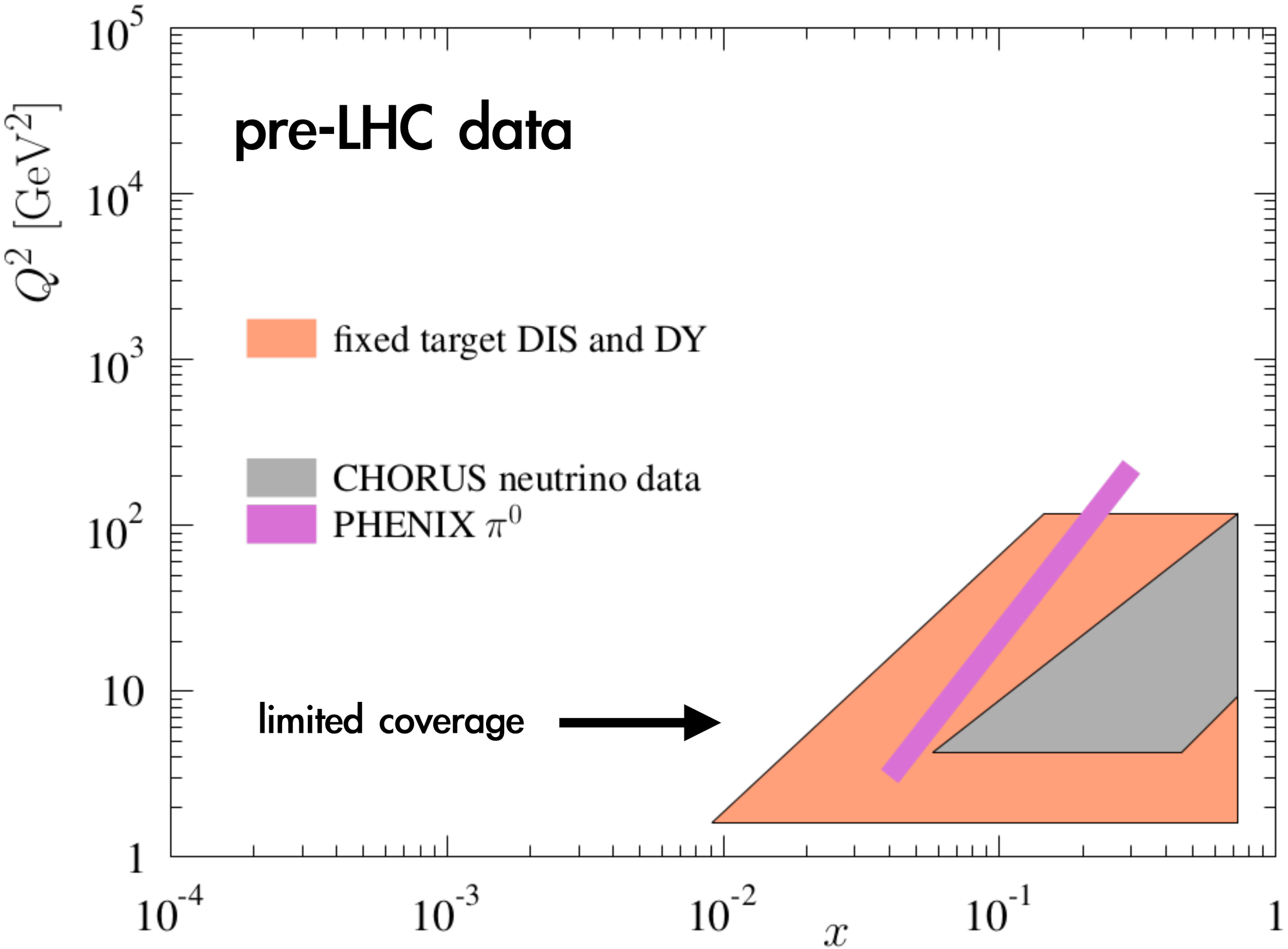
KA15: Khanpour, Tehrani, Phys.Rev. D93 (2016) no.1, 014026

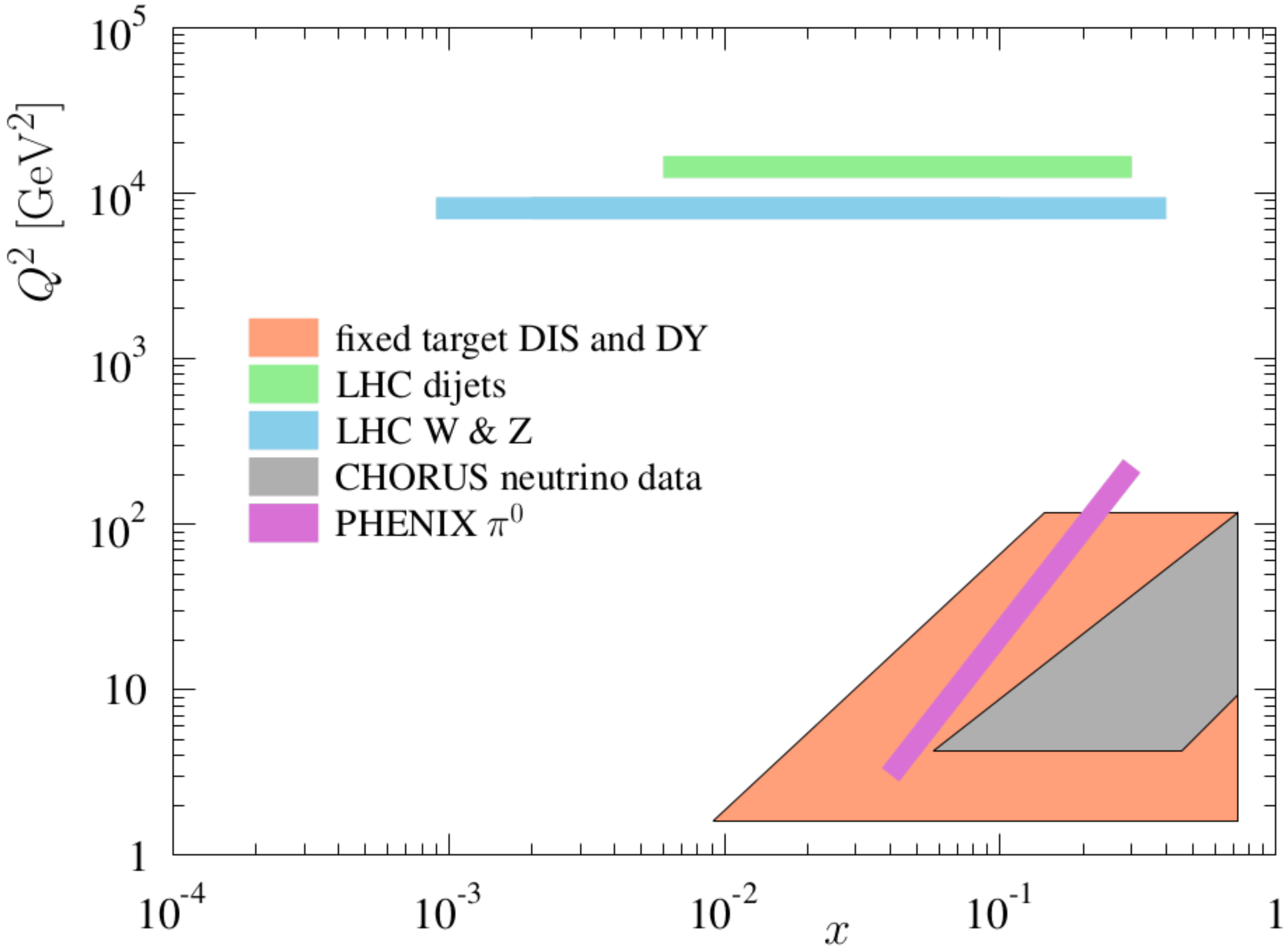
to come

a) A-Z: NNLO
b) NNPDF: Pb nPDFs

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

pre-LHC data


10^5
10^4
10^3
10^2
10
1
Q^2 [GeV^2]
fixed target DIS and DY
CHORUS neutrino data
PHENIX π^0
limited coverage
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

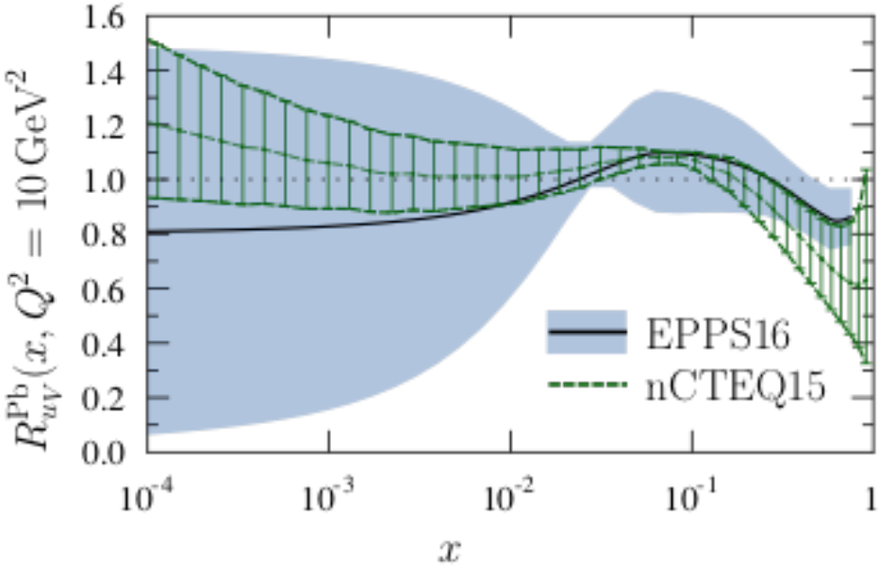

10^5
10^4
10^3
10^2
10
1
Q^2 [GeV^2]
fixed target DIS and DY
LHC dijets
LHC W & Z
CHORUS neutrino data
PHENIX π^0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

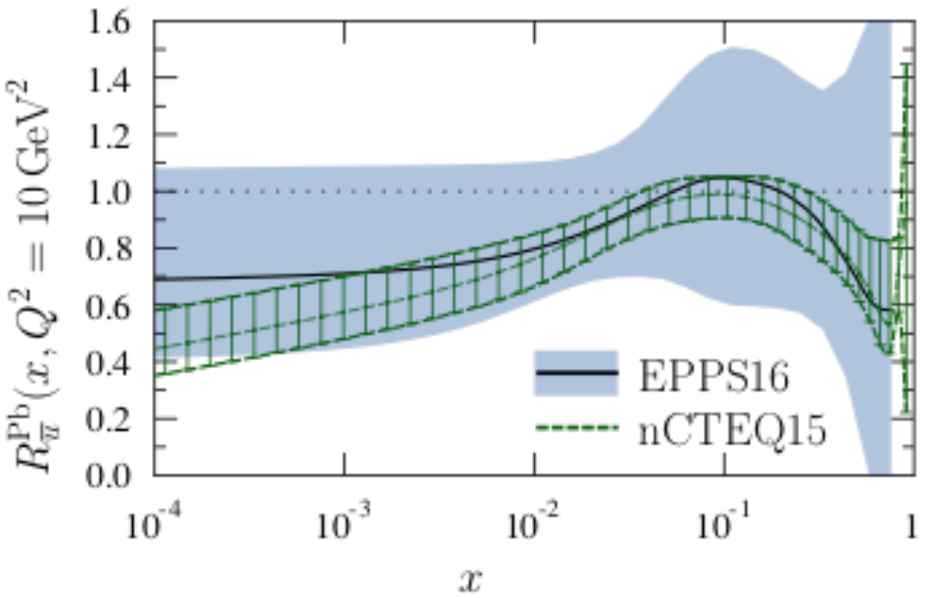
SET		before LHC	
data type	NC-DIS	✔ $\approx \frac{4}{9}u_v + \frac{1}{9}d_v$	
	D-Y	✔	
	pions	✔	
	CC-DIS	✔ $\approx u_v + d_v$	
	EW	✘	
	jets	✘	
accuracy		LO to NNLO	
flavour separation?		not (quite) successful	

LHC data

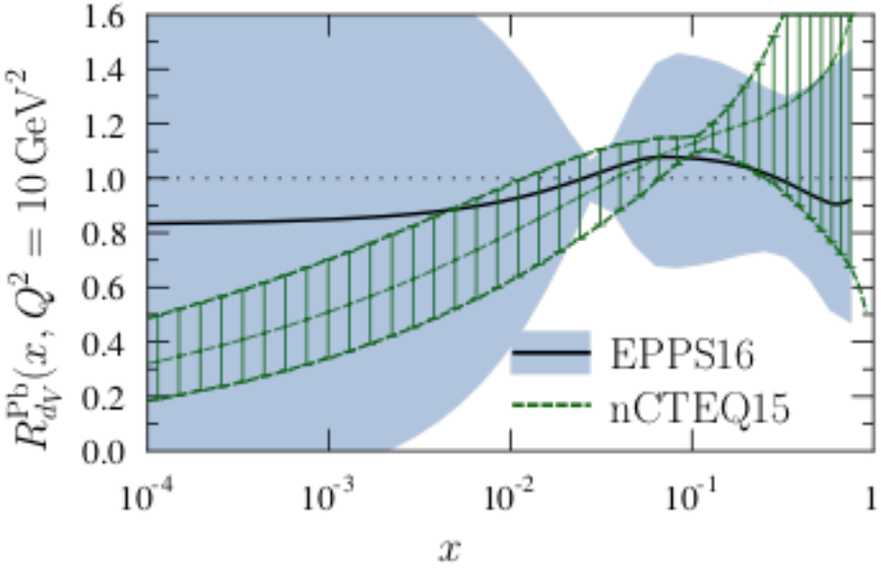
SET		before LHC	EPPS16 Eur.Phys.J. C77 (2017) no.3, 163
data type	NC-DIS	✔ $\approx \frac{4}{9}u_v + \frac{1}{9}d_v$	✔
	D-Y	✔	✔
	pions	✔	✔
	CC-DIS	✔ $\approx u_v + d_v$	✔
	EW	✘	✔
	jets	✘	✔
accuracy		LO to NNLO	NLO
flavour separation?		not (quite) successful	✔

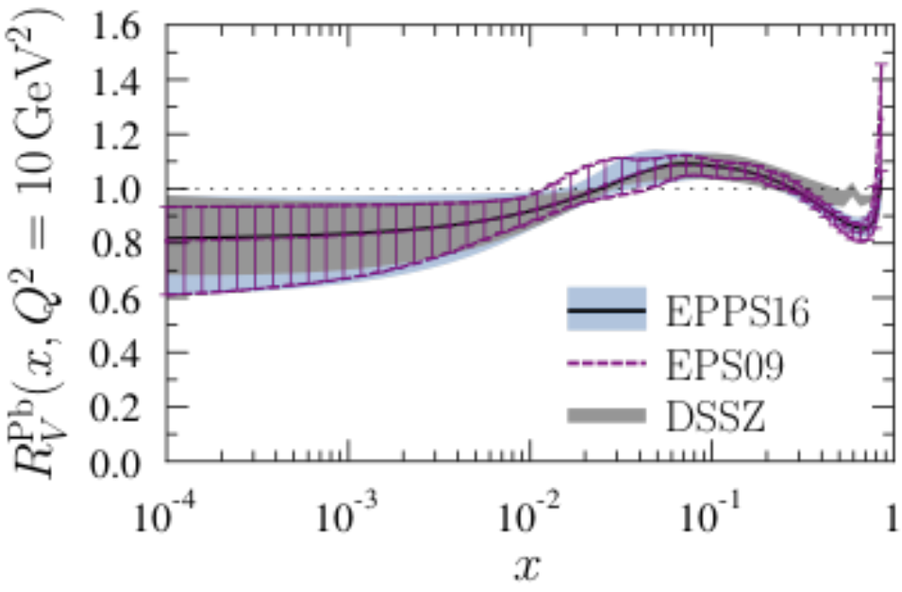
LHC data



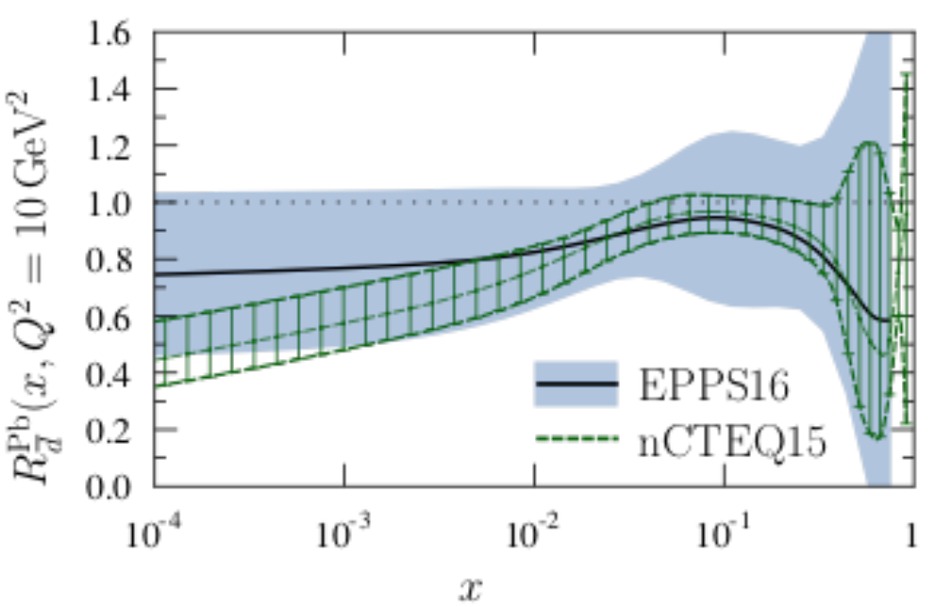


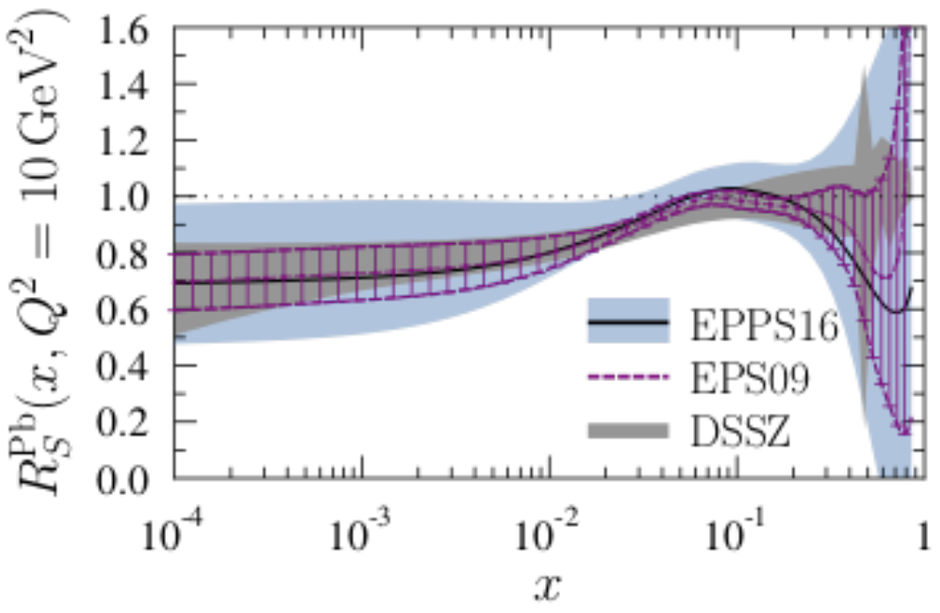
$R_{valence}$





R_{sea}

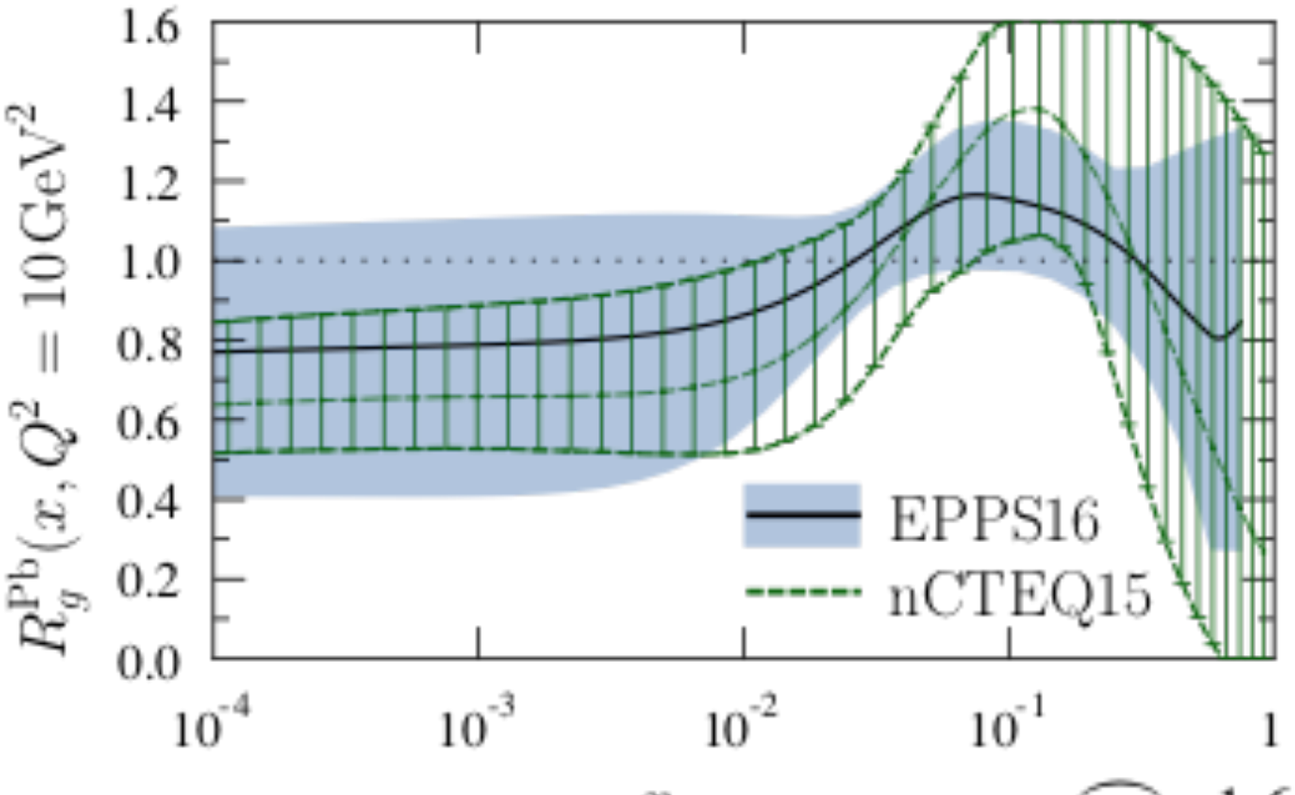


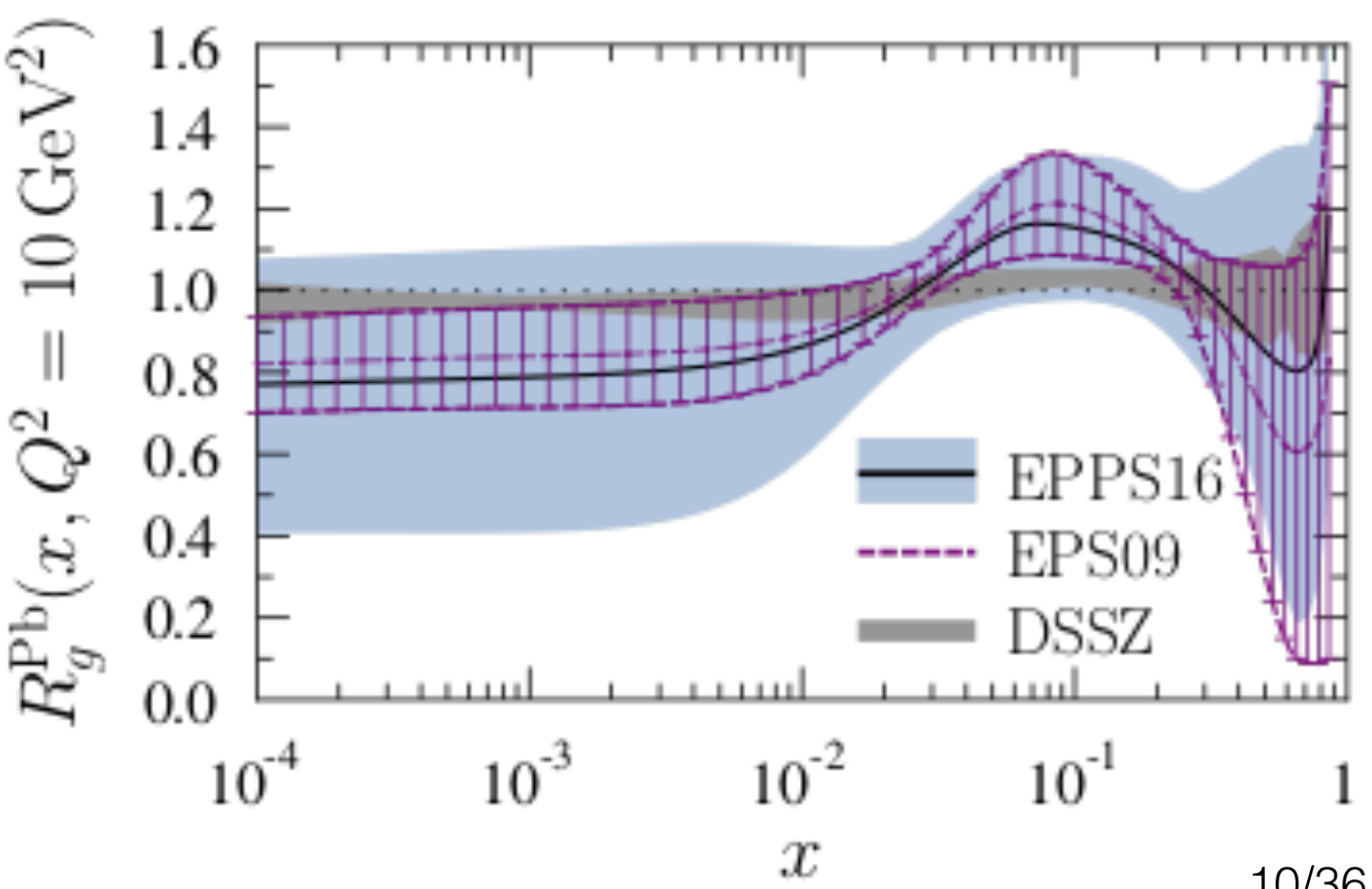


Eur.Phys.J. C77 (2017) no.3, 163

R_{gluon}

Eur.Phys.J. C77 (2017) no.3, 163





The Future

(from data perspective)

- the right-now-and-near future: RHIC & LHC

not talking more about this one

- the not-so-near future: EIC
- the further-away future: LHeC
- the fairytale future: FCC

not really talking about this one

a few remarks:

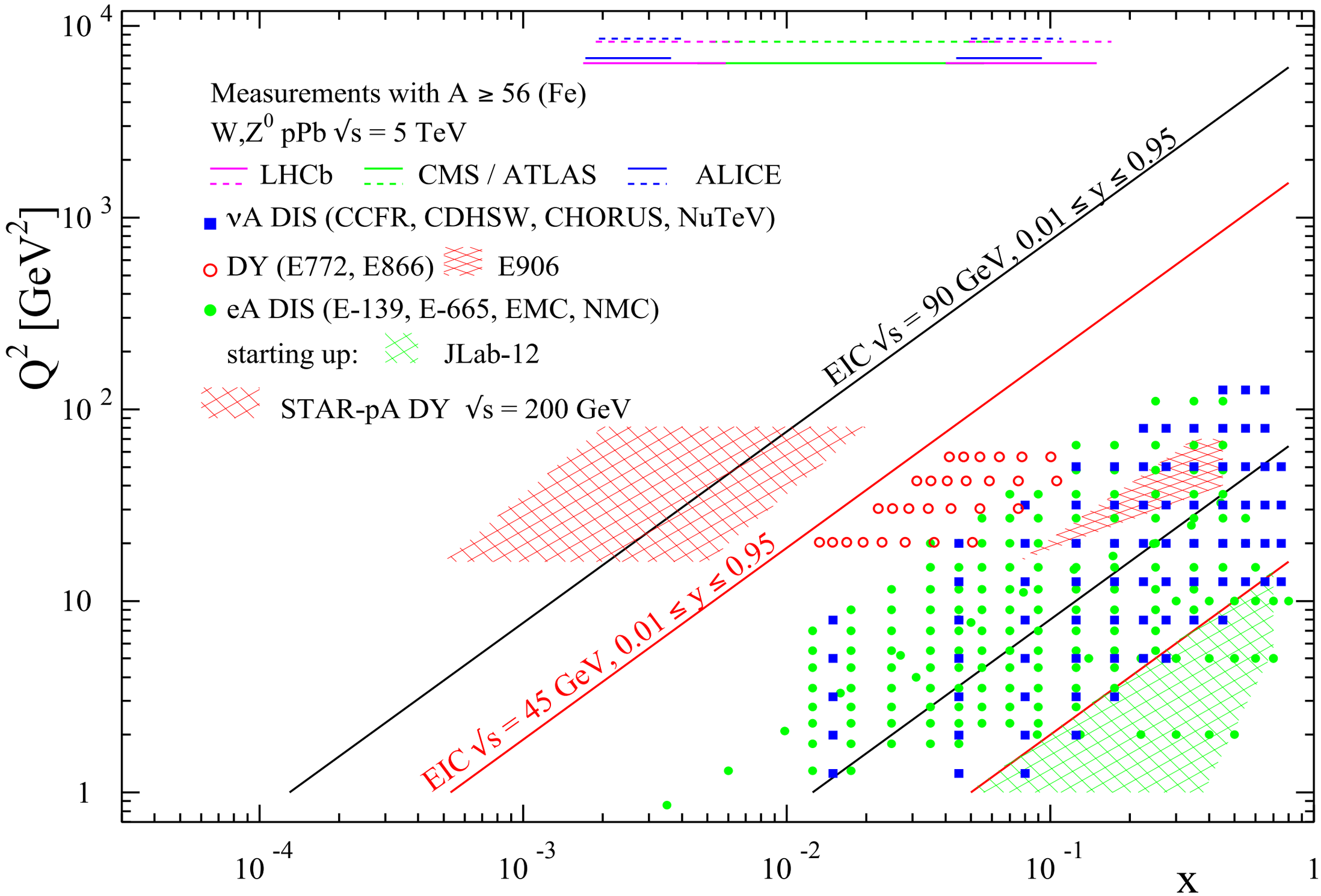
- pseudo-data ("data") used, with assumed experimental uncertainties

- two equivalent methods used to analyze the "data" (re-weighting and re-fit)

- impact estimations are tied to the initial parameterizations & below $x \sim 10^{-2/-3}$ the theoretical curves are extrapolations: there is always a bias

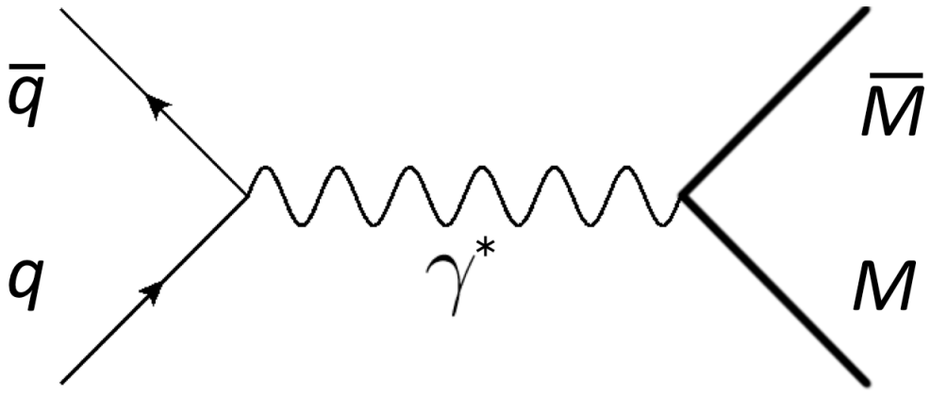
- no joint analysis of all the experiments shown next

- mostly focused on the nightmare (a.k.a. gluon)

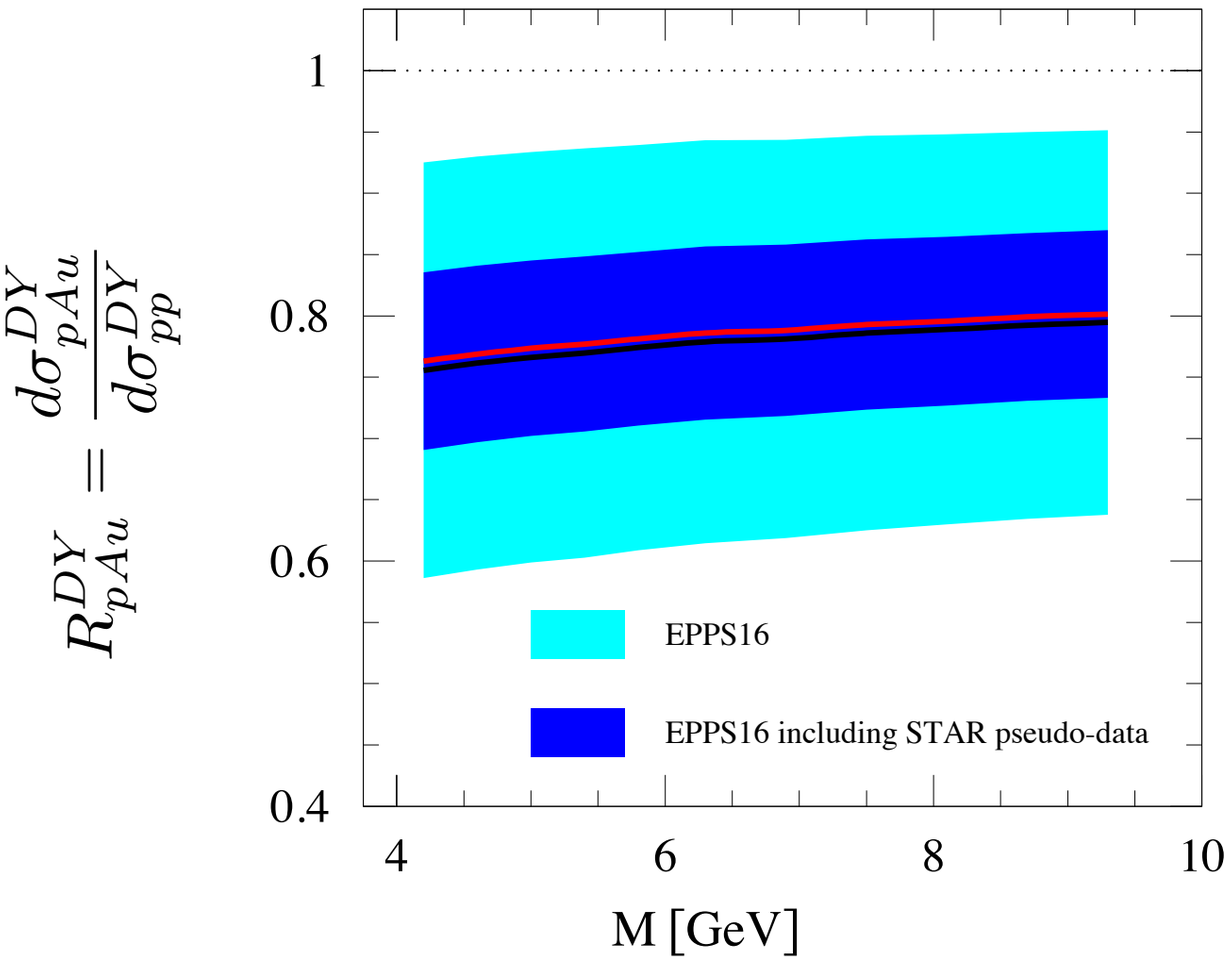

Measurements with A ≥ 56 (Fe)
W,Z^0 pPb √s = 5 TeV
LHCb
CMS / ATLAS
ALICE
νA DIS (CCFR, CDHSW, CHORUS, NuTeV)
DY (E772, E866)
E906
eA DIS (E-139, E-665, EMC, NMC)
starting up:
JLab-12
STAR-pA DY √s = 200 GeV
EIC √s = 90 GeV, 0.01 ≤ y ≤ 0.95
EIC √s = 45 GeV, 0.01 ≤ y ≤ 0.95
Q^2 [GeV^2]
x
10^4
10^3
10^2
10
1
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1

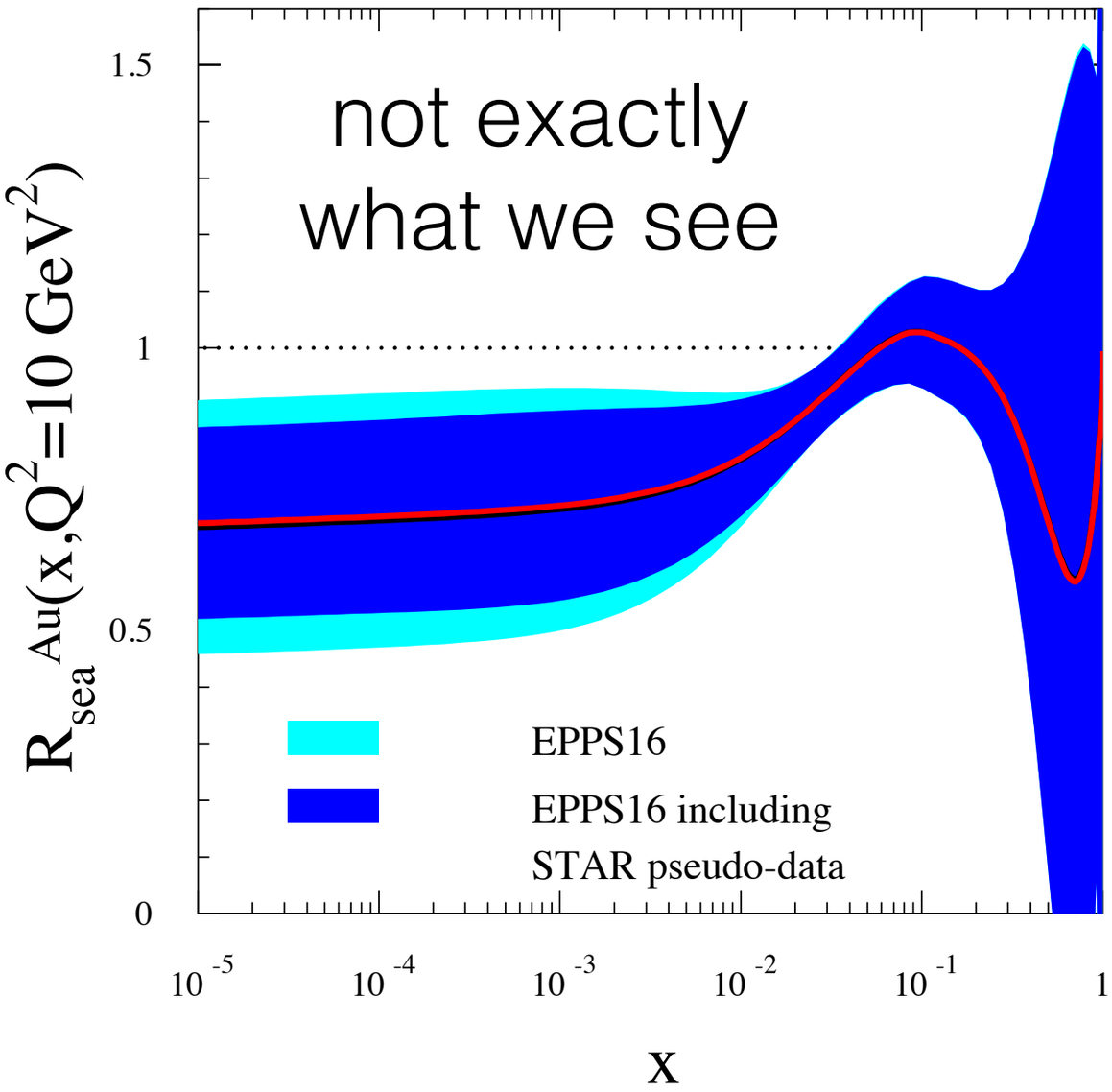
Drell-Yan

update of the cold-QCD plan: Aschenauer et al., arXiv:1602.03922 [nucl-ex]



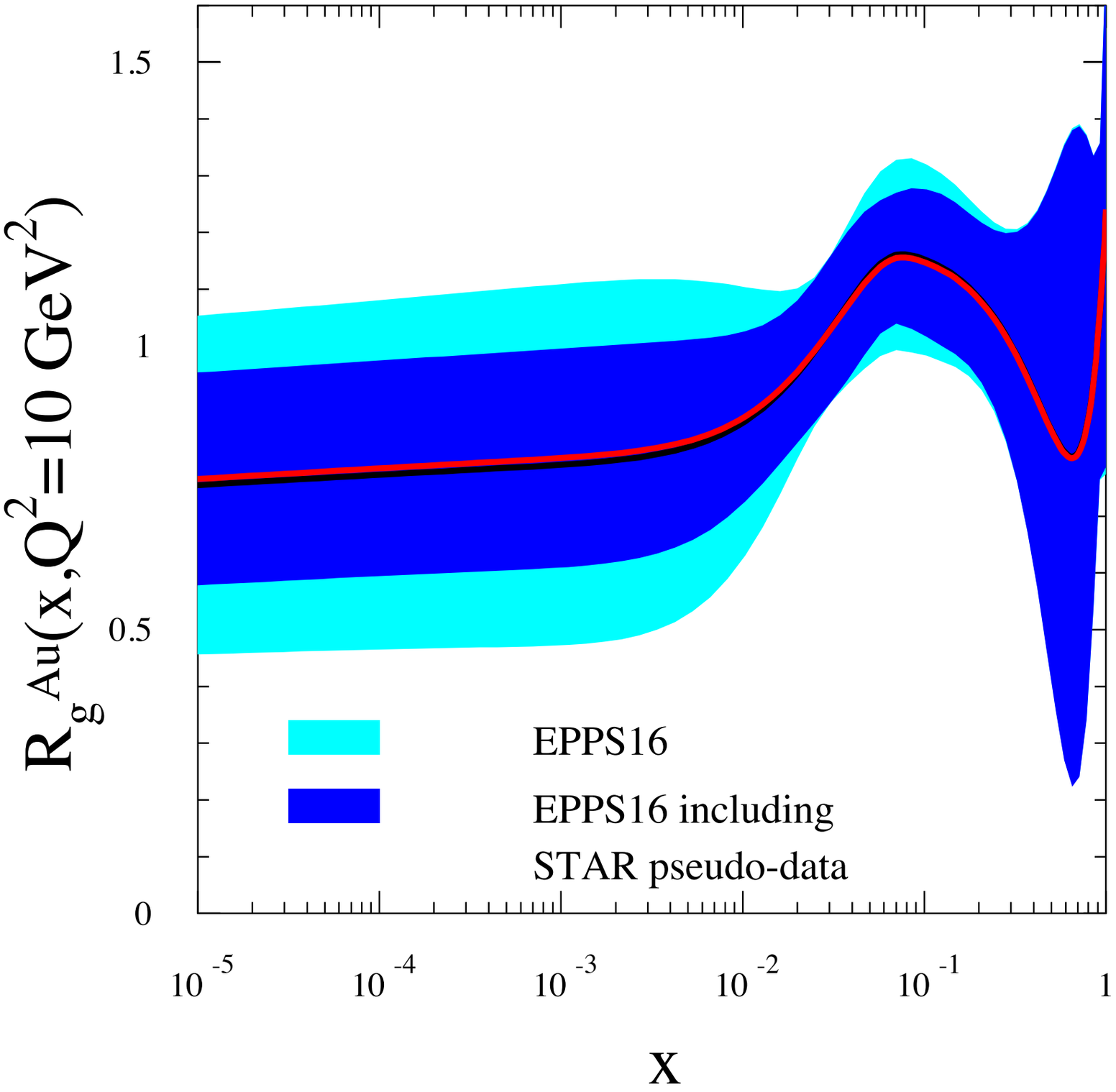
impact **expected** on both quark/anti-quark nPDFs



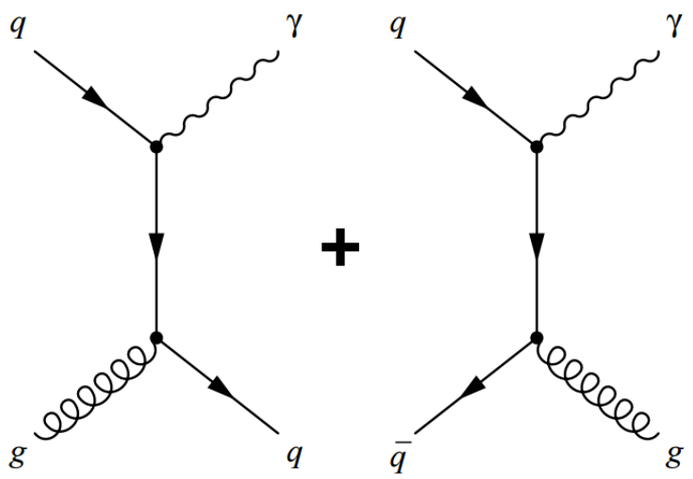


Drell-Yan

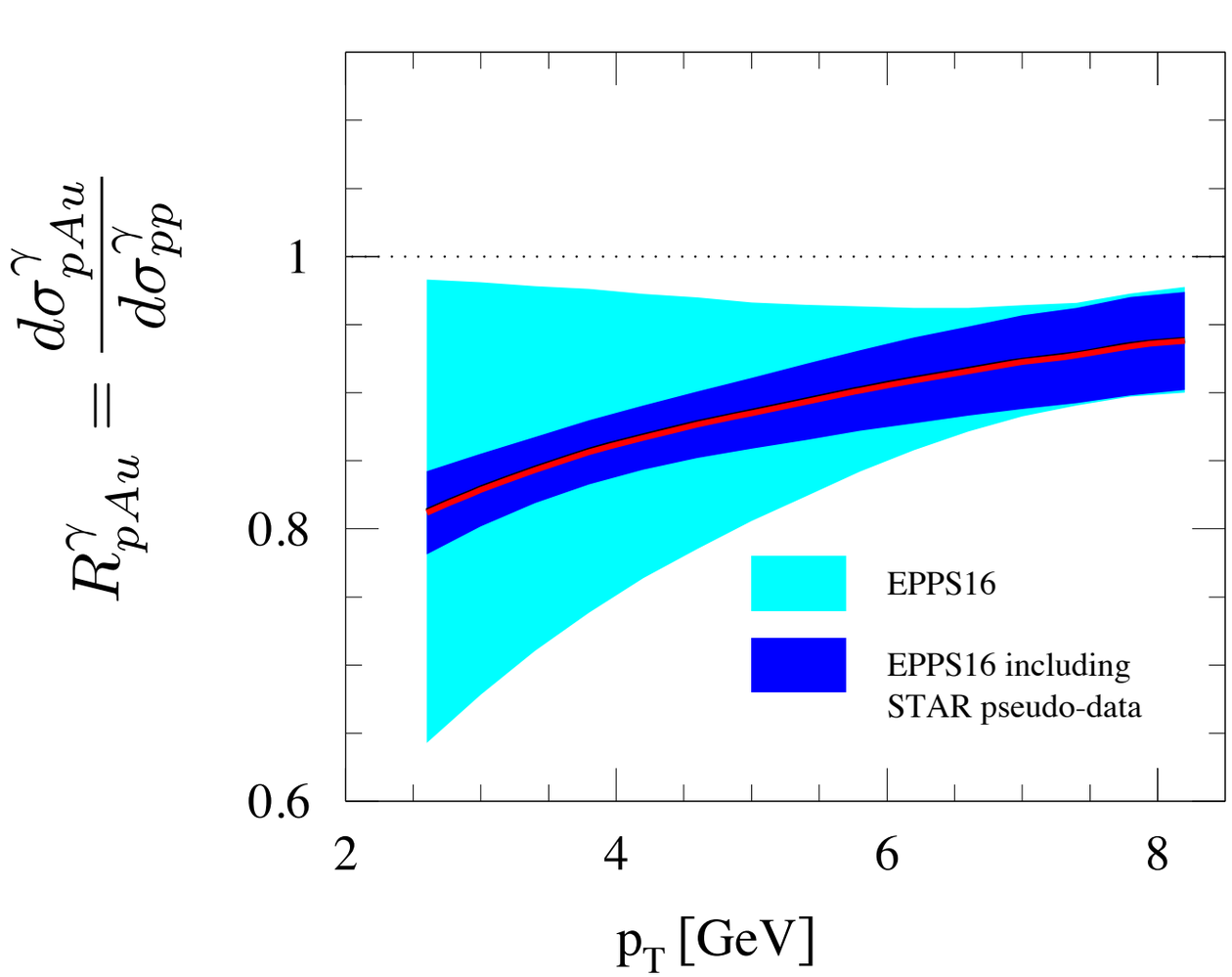
Somehow the impact seems to be more relevant for the gluon (but they're tied by the evolution)

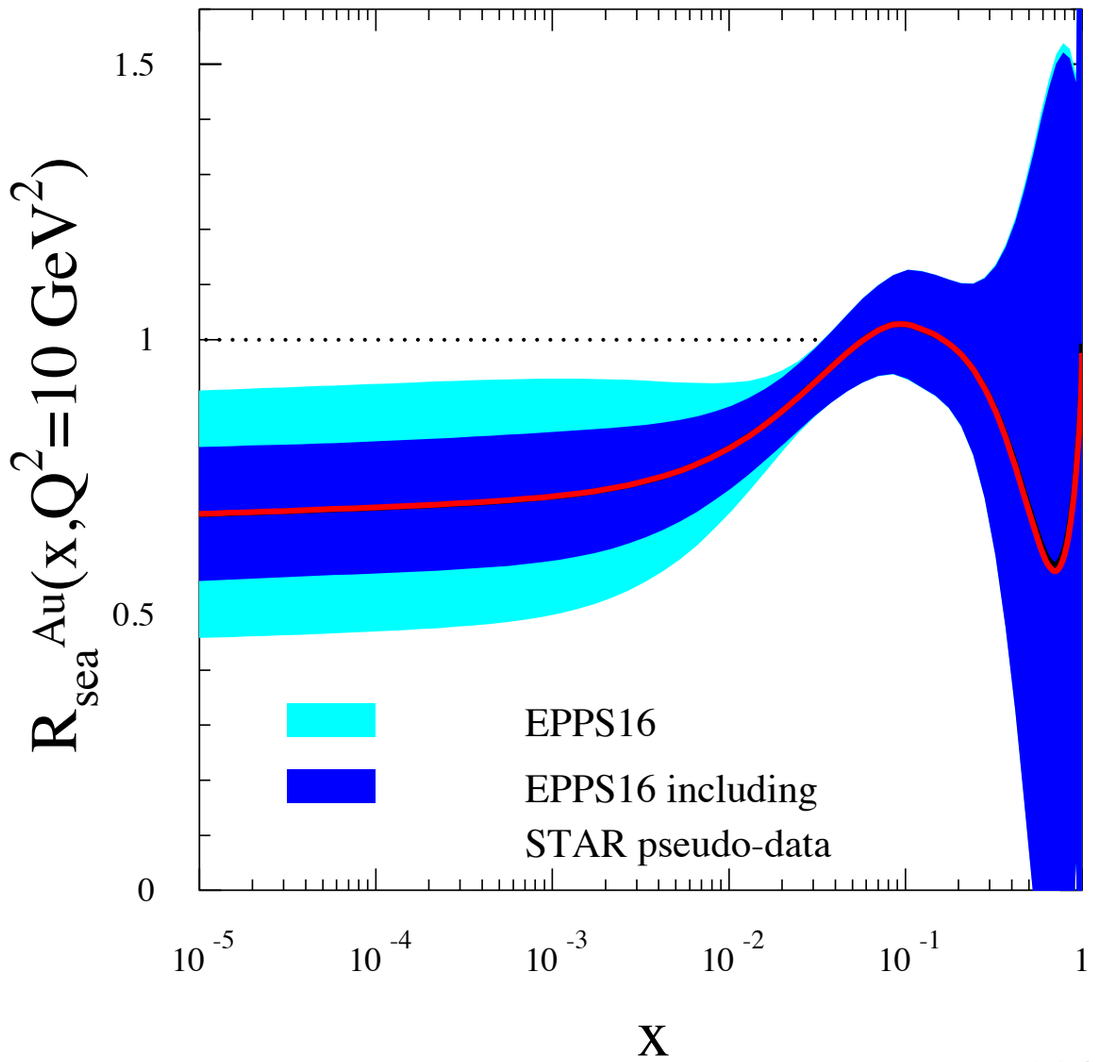


direct photon $g + q \rightarrow q + \gamma$

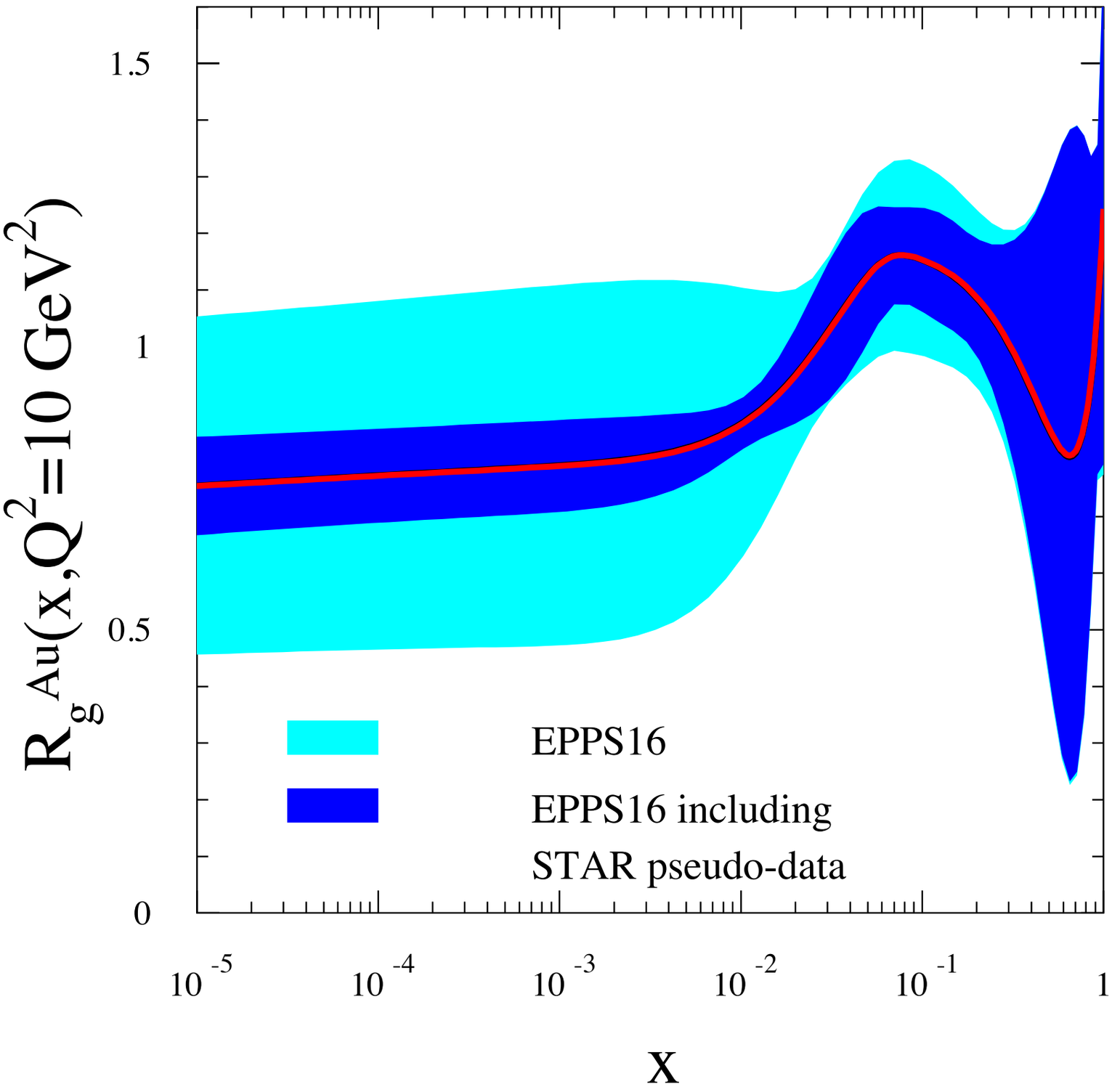


impact expected on both quark/ anti-quark and gluon nPDFs

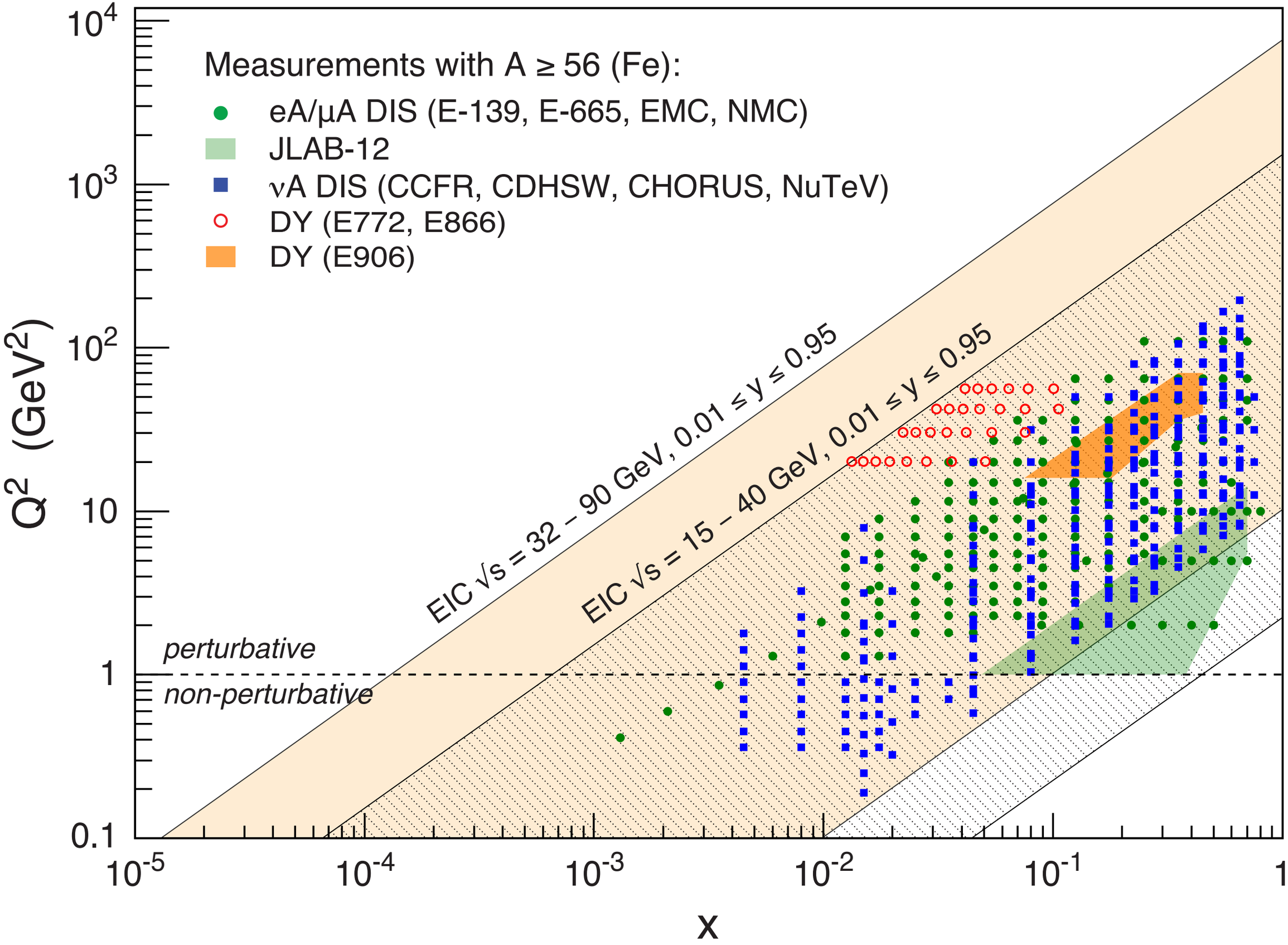




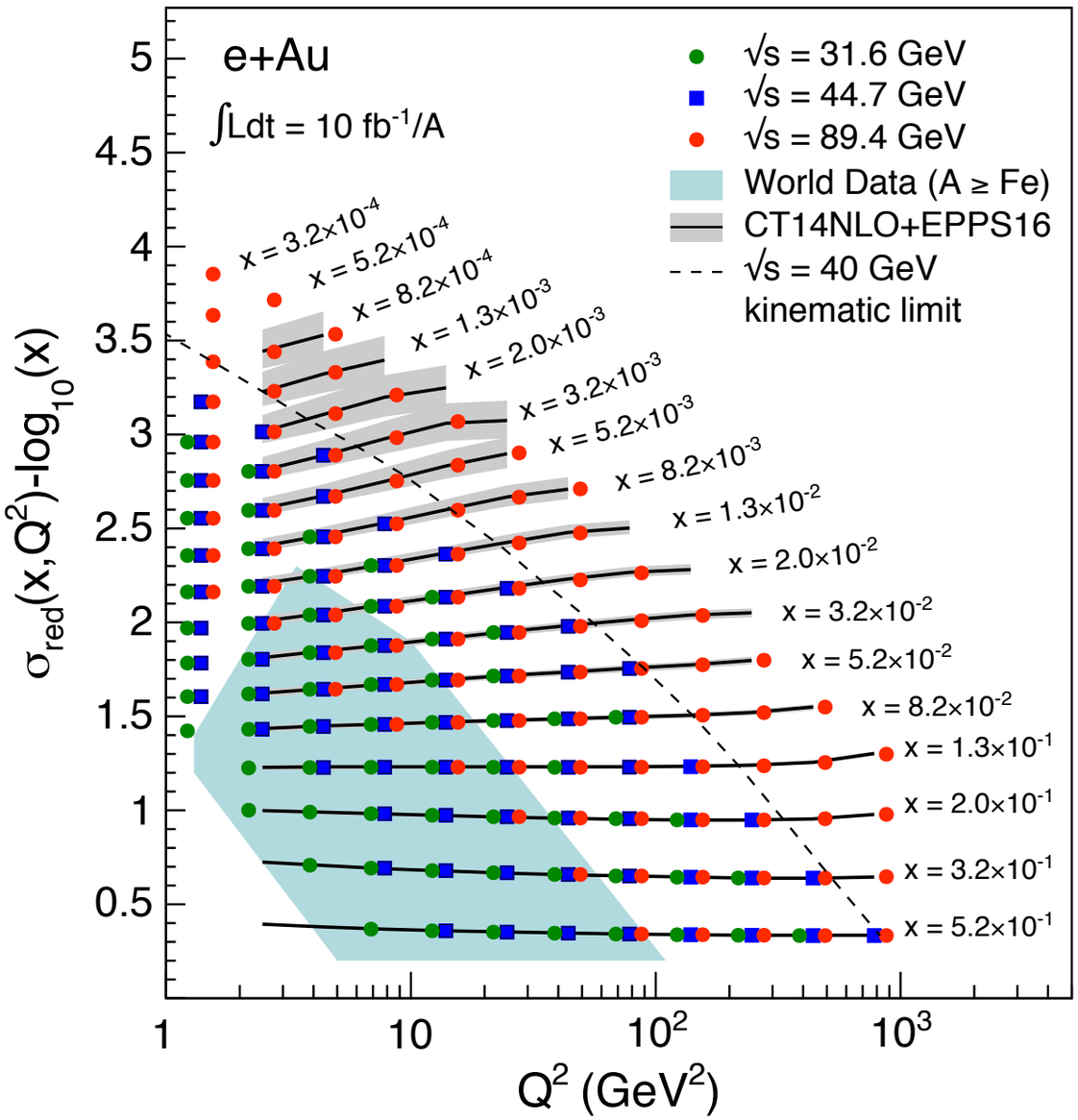
direct photon



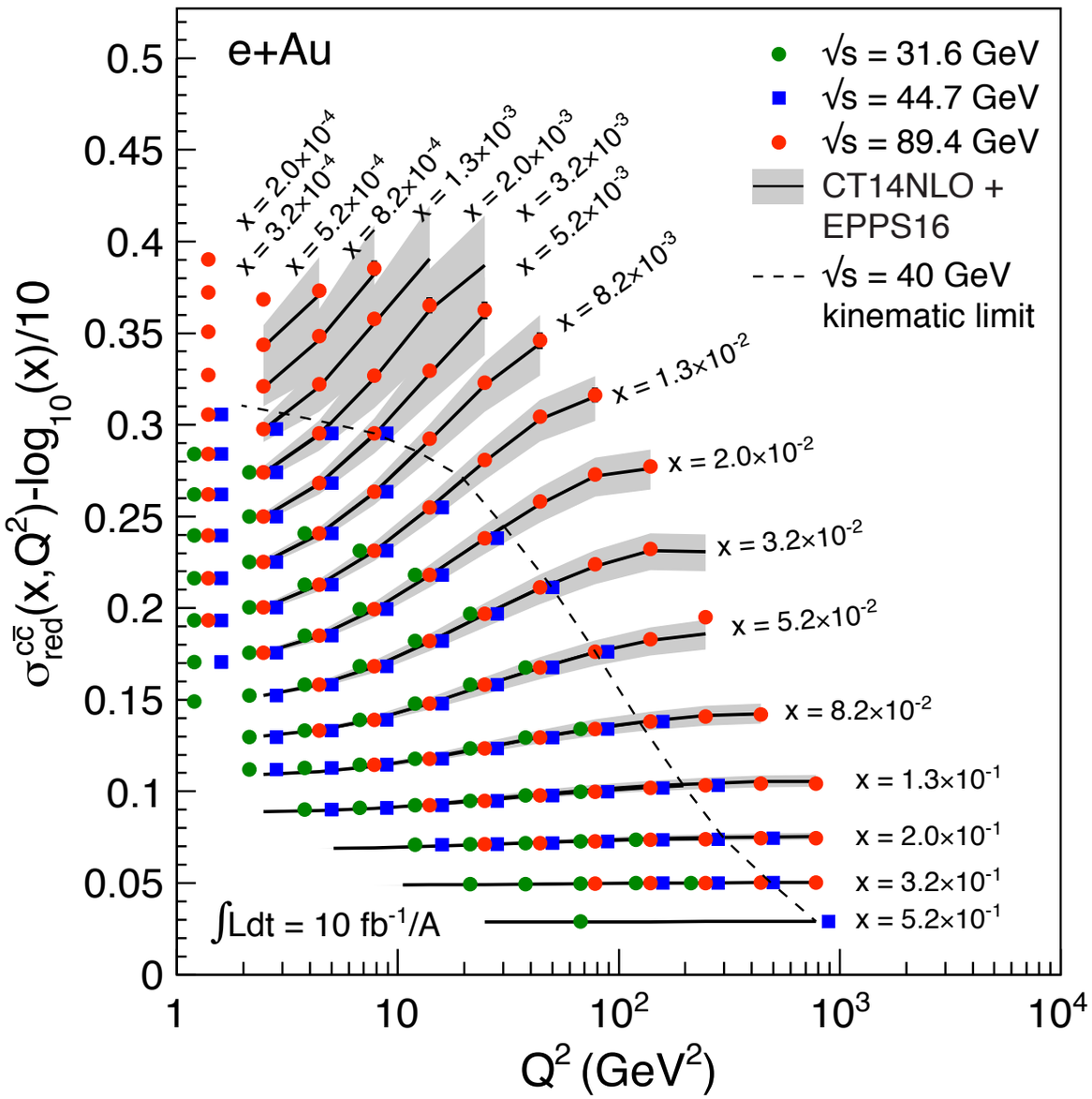
Eur.Phys.J. A52 (2016) no.9, 268

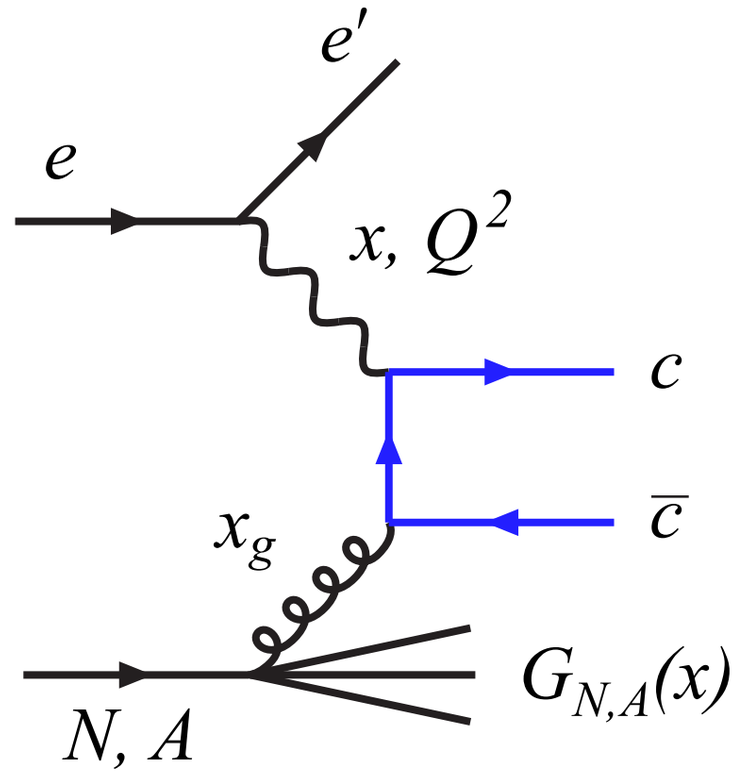


EIC: not only more explored space,



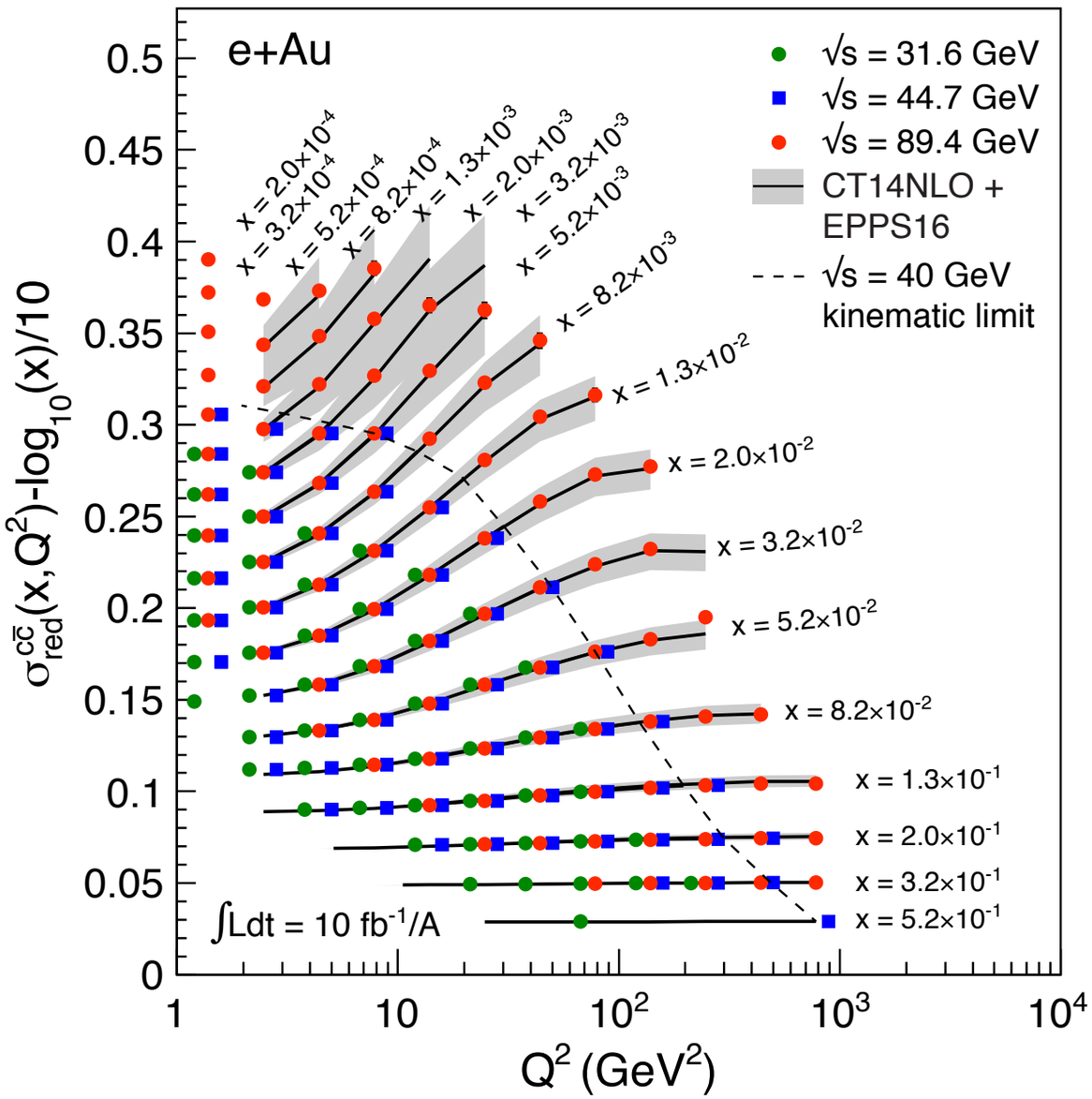
EIC: not only more explored space, also new observables!

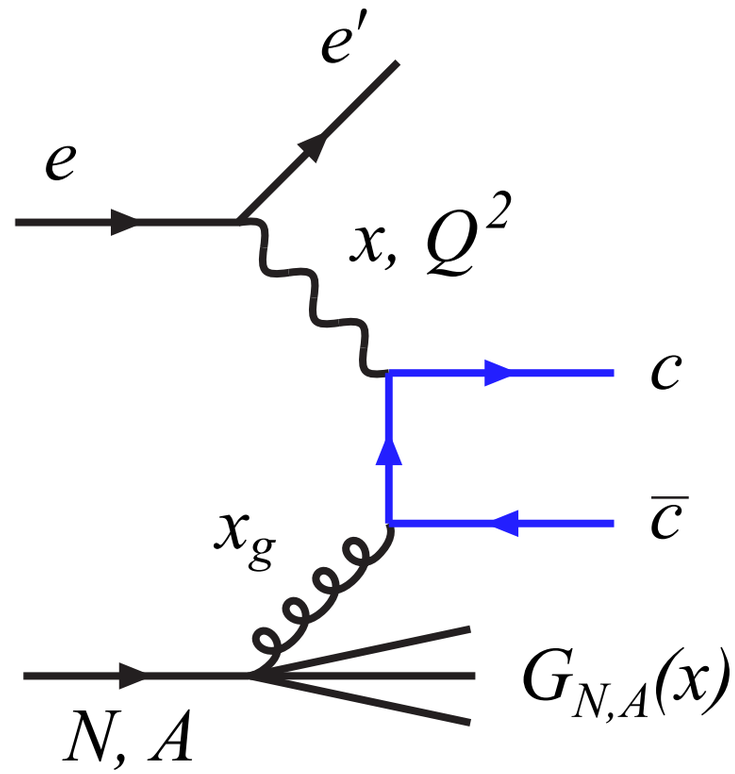




VERY sensitive to the gluon

EIC: not only more explored space, also new observables!

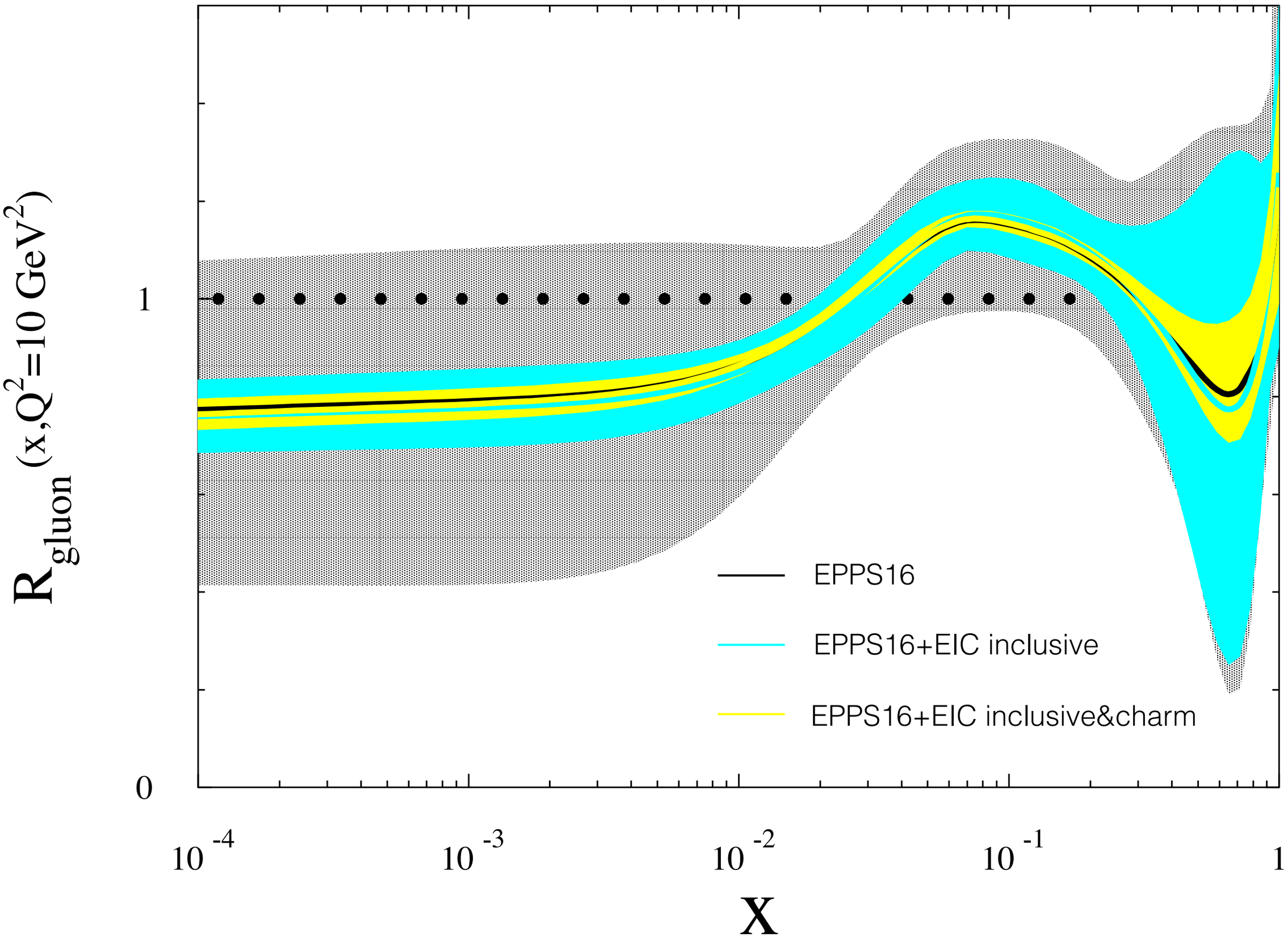




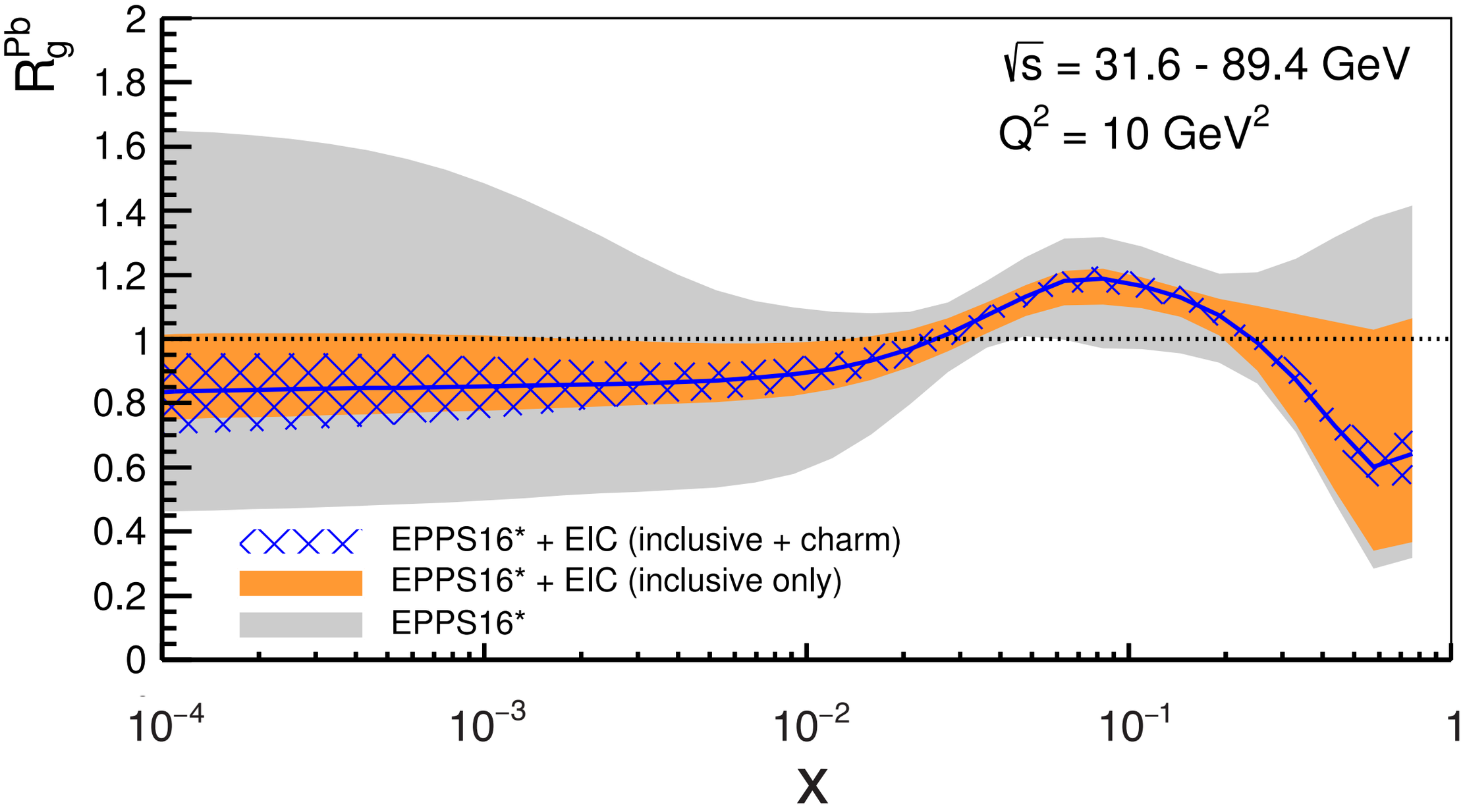
VERY sensitive to the gluon

Thorough jets in e-A analysis:
Klasen, Kovarik, Potthoff,
Phys.Rev. D95 (2017) no.9, 094013

impact of the EIC
σ_{red} on EPPS16



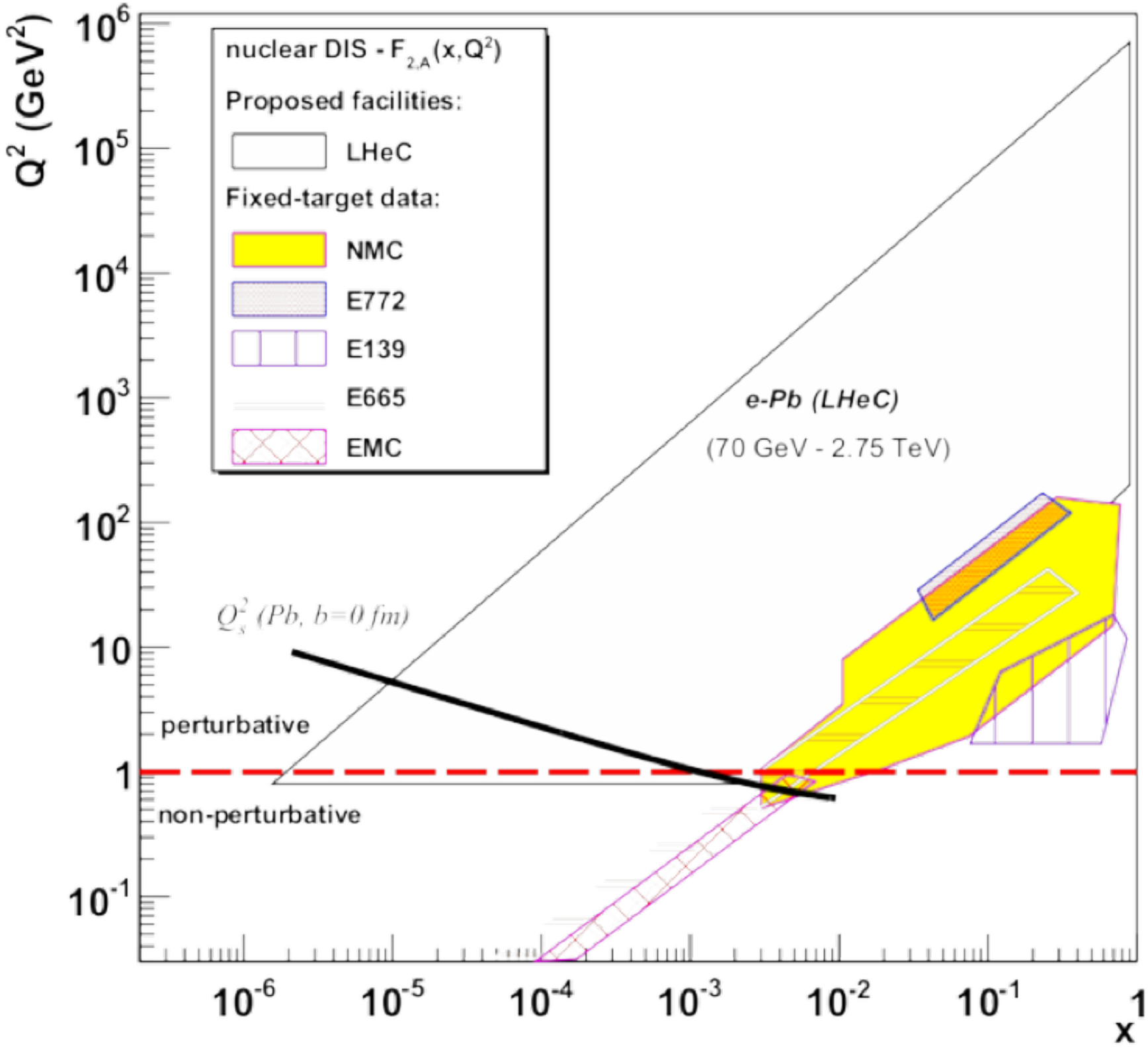
impact of the EIC
σ_{red} on EPPS16*



EPPS16 is a bit stiff at low x

EPPS16* cures this

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)
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

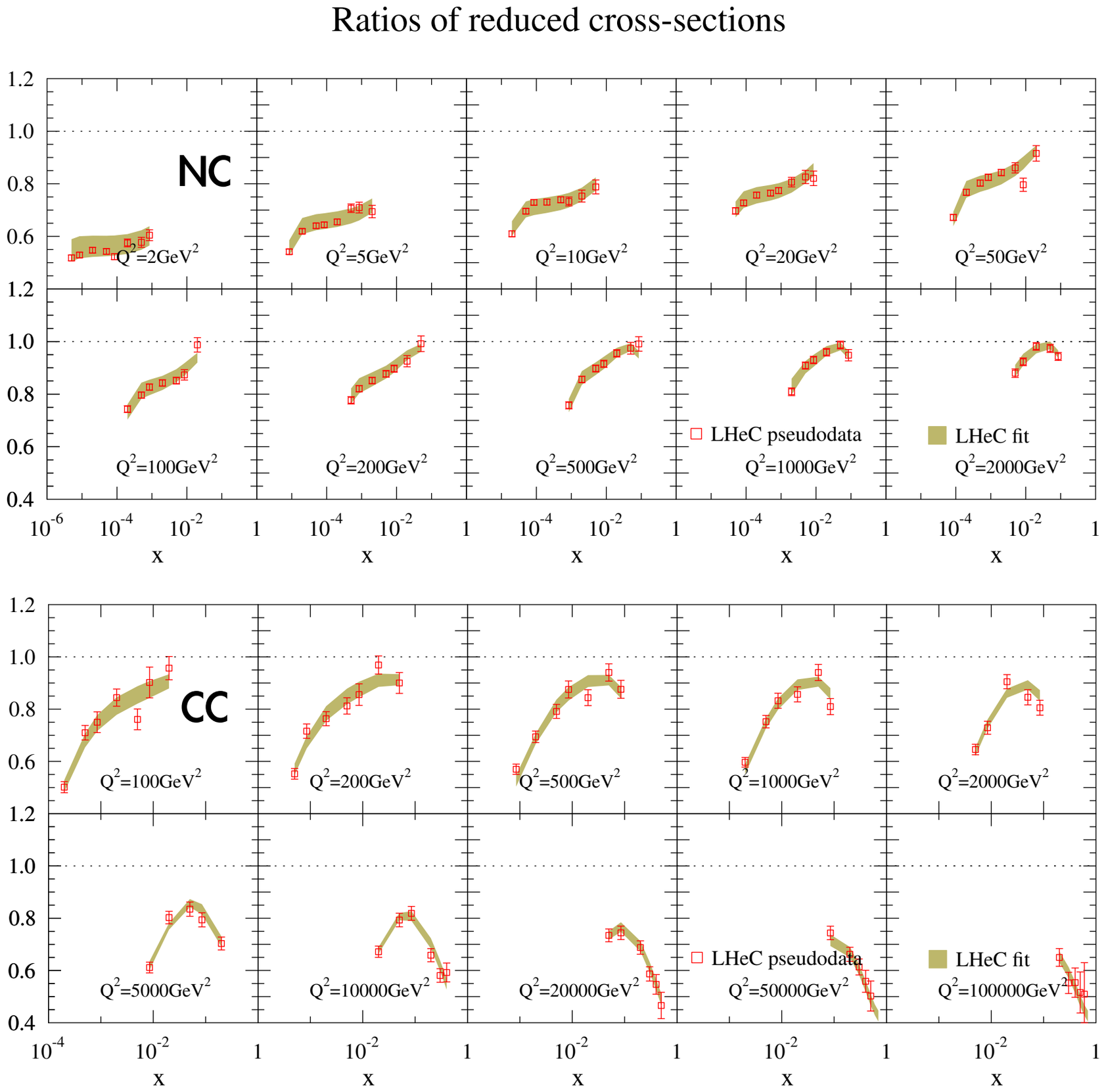
from H. Paukkunen's talk in DIS17

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

- "data" from EPS09

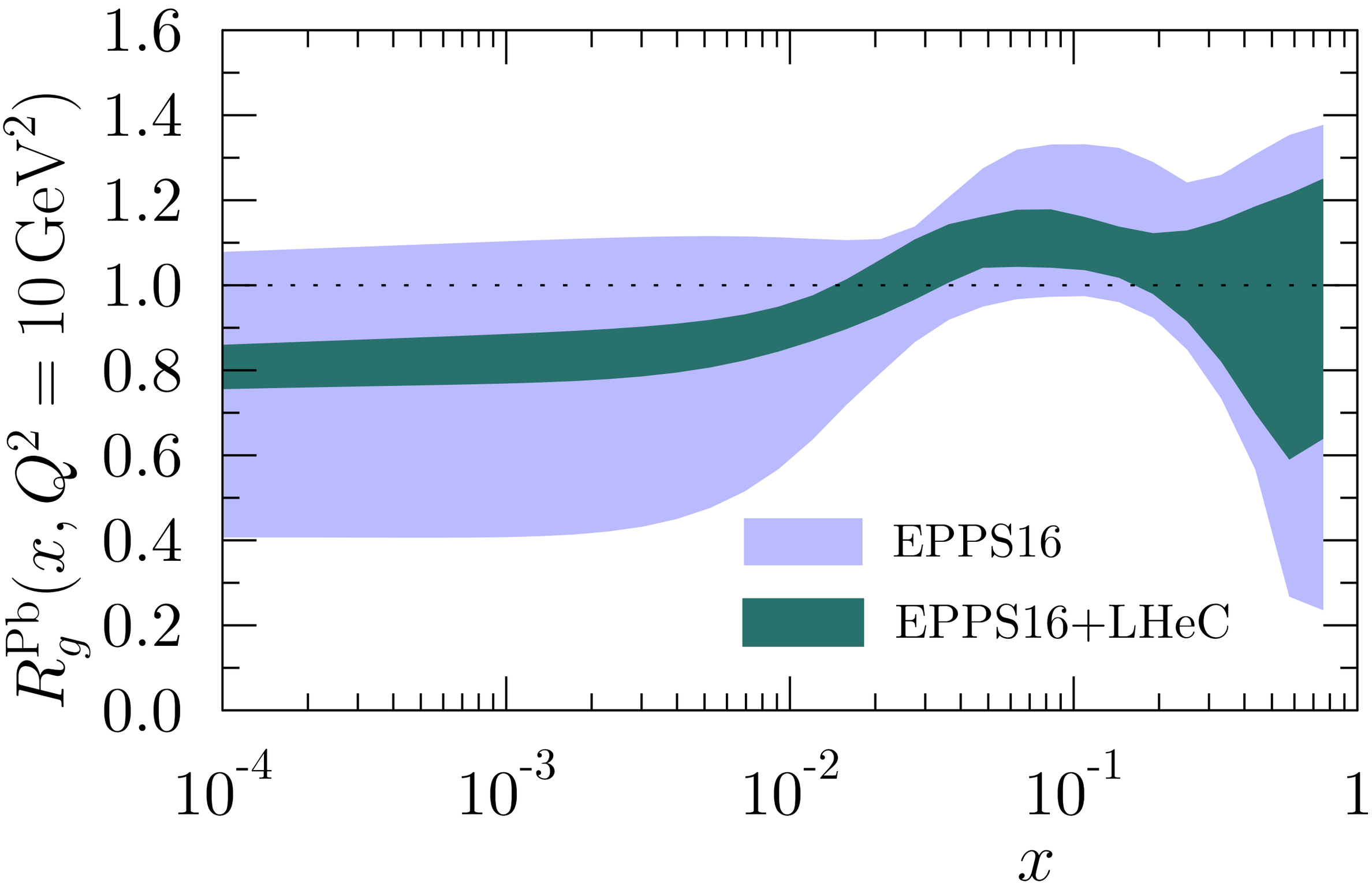
- joint analysis NC and CC σ_{red}

$$u_v + d_v$$

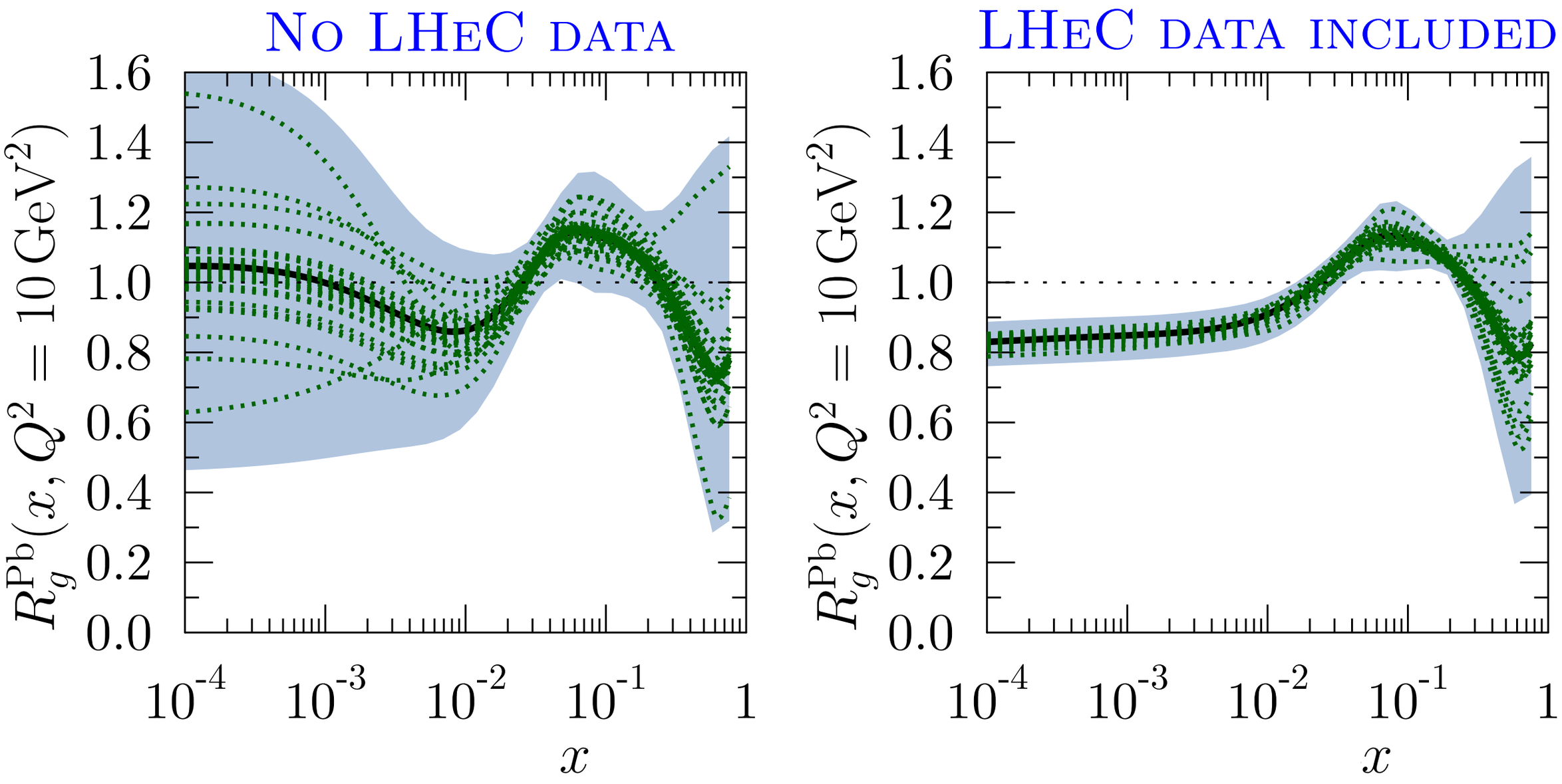


from H. Paukkunen's talk in DIS17

impact of the LHeC σ_{red} on EPPS16



if the tight low-x shape is released (like EPPS16* shown for an EIC)



WHAT IF...

WHAT IF...

... something DIFFERENT

and/or NEW and/or

UNEXPECTED shows up?

a few points:

in a global fit individual features tend to be suppressed, so

- could we actually tell IT apart?
- wouldn't IT be hidden in a fit?
- what if IT is already there and we're missing IT?

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- what if IT is already there and we're missing IT?

We gave IT a go!

We gave IT a go! Let's see

C. Marquet, M. Rodriguez-Moldes and P.Z., arXiv:1702.00839

- we generated "data" for F_2 (quark) and F_L (gluon) with AAMQS

Albacete, Armesto, Milhano, Quiroga-Arias and Salgado, Eur.Phys.J. C71 (2011) 1705

  - σ_r from the combined analysis of the H1 and ZEUS collaborations
  - F_L from the H1 and ZEUS collaborations NOT included
  - $x \leq 10^{-2}$ and $0.045\ \text{GeV}^2 \leq Q^2 \leq 50\ \text{GeV}^2$

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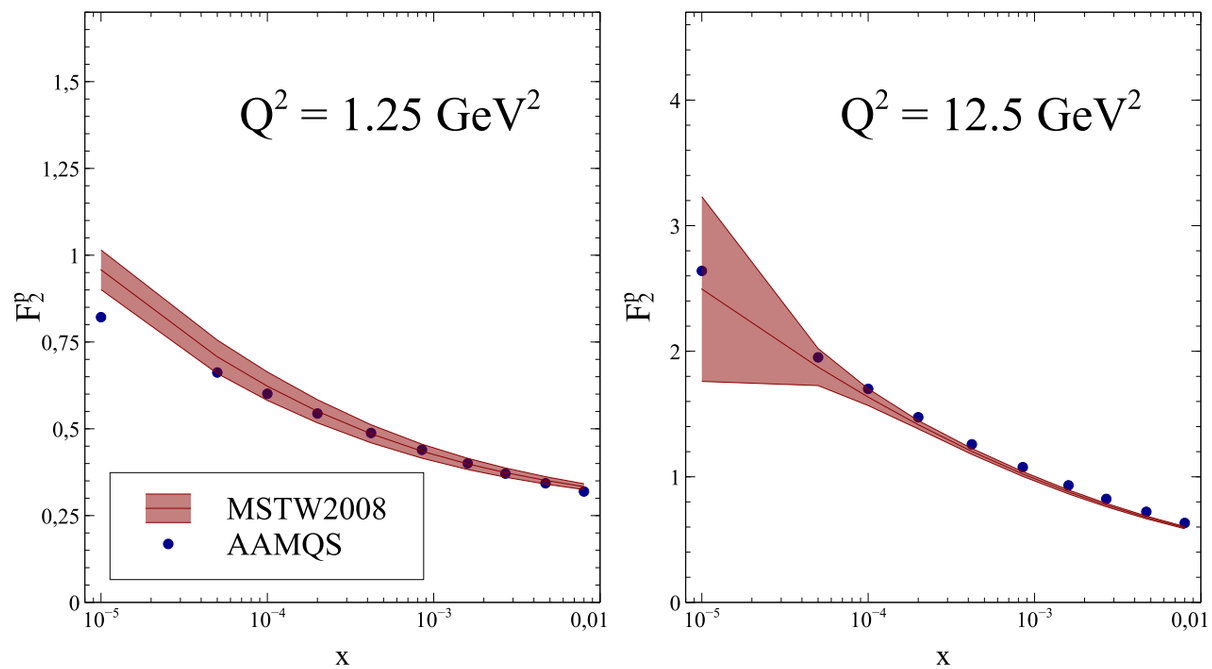
  - F_L from the H1 and ZEUS collaborations NOT included
  - $x \leq 10^{-2}$ and $0.045\ \text{GeV}^2 \leq Q^2 \leq 50\ \text{GeV}^2$

- theoretical predictions from MSTW2008 + EPS09/DSSZ
  - world data
  - $2\ \text{GeV}^2 \leq Q^2$



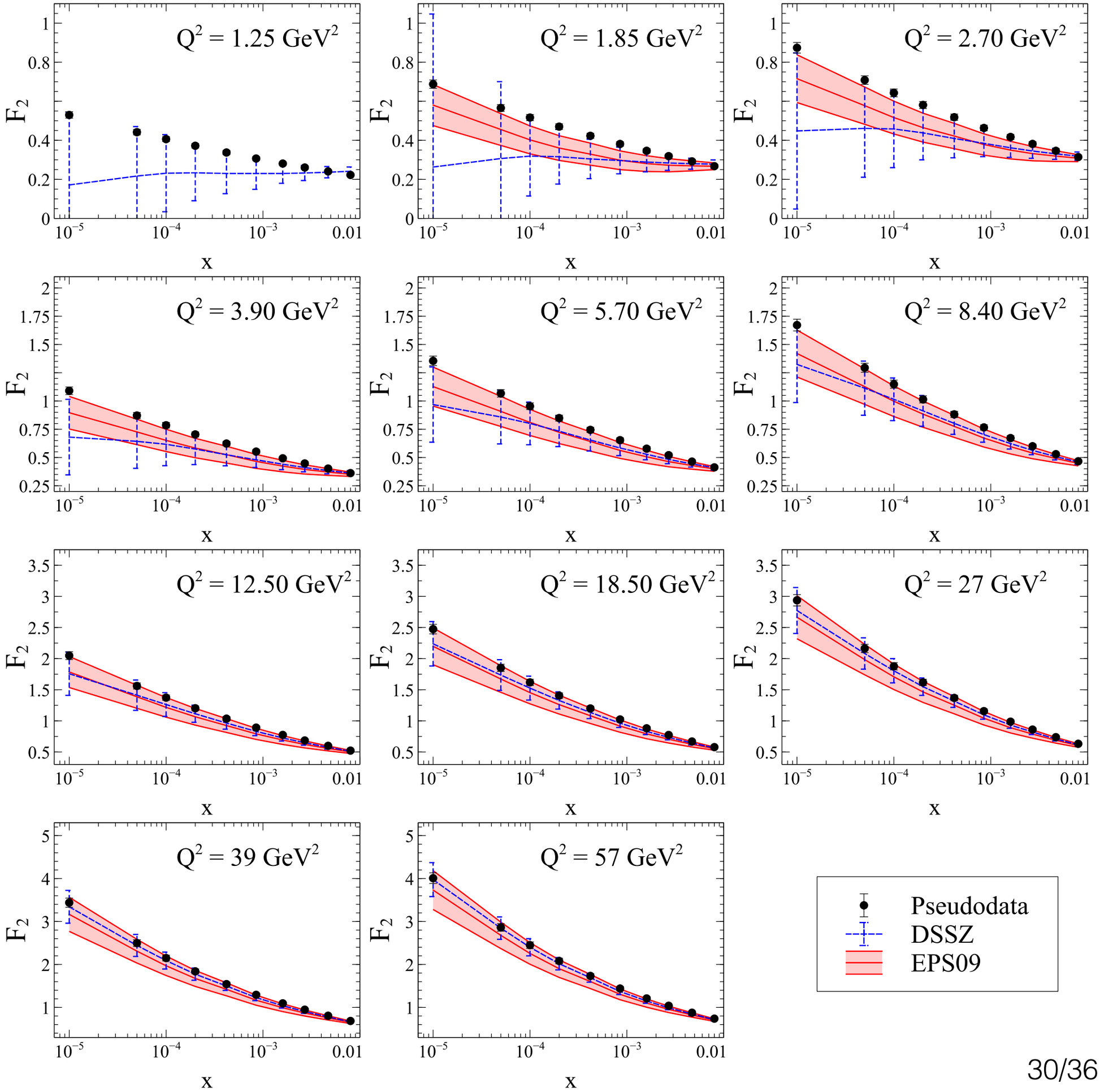
We gave IT a go! Let's see

C. Marquet, M. Rodriguez-Moldes and P.Z., arXiv:1702.00839

- used a re-weighting technique to check the impact on two nPDFs sets (EPS09 and DSSZ)

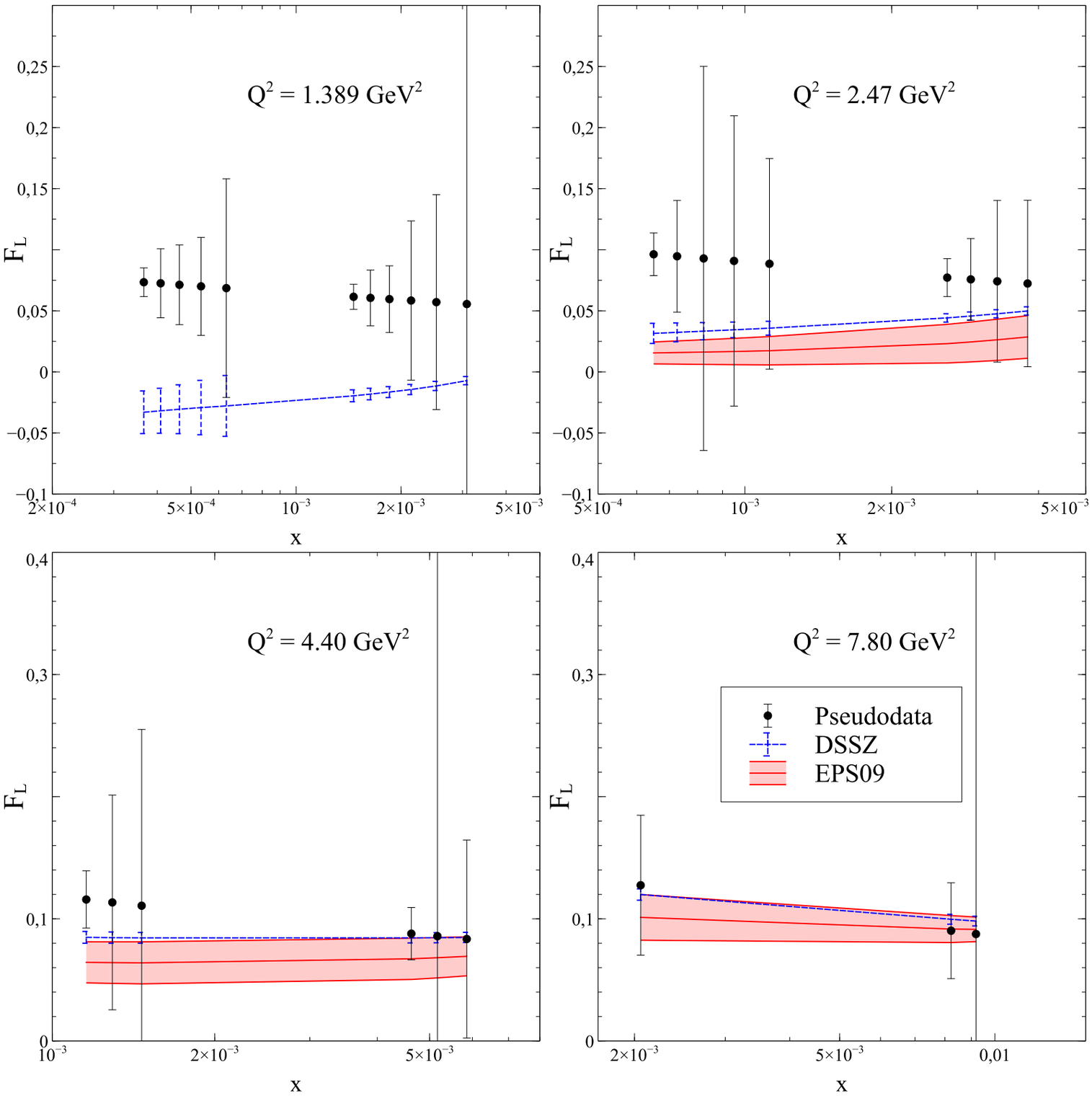
- and we've got some results to show

DGLAP predictions for F_2 in e-Au collisions are (more or less) in agreement with the "data"



What if...?

but F_L ... oh my!

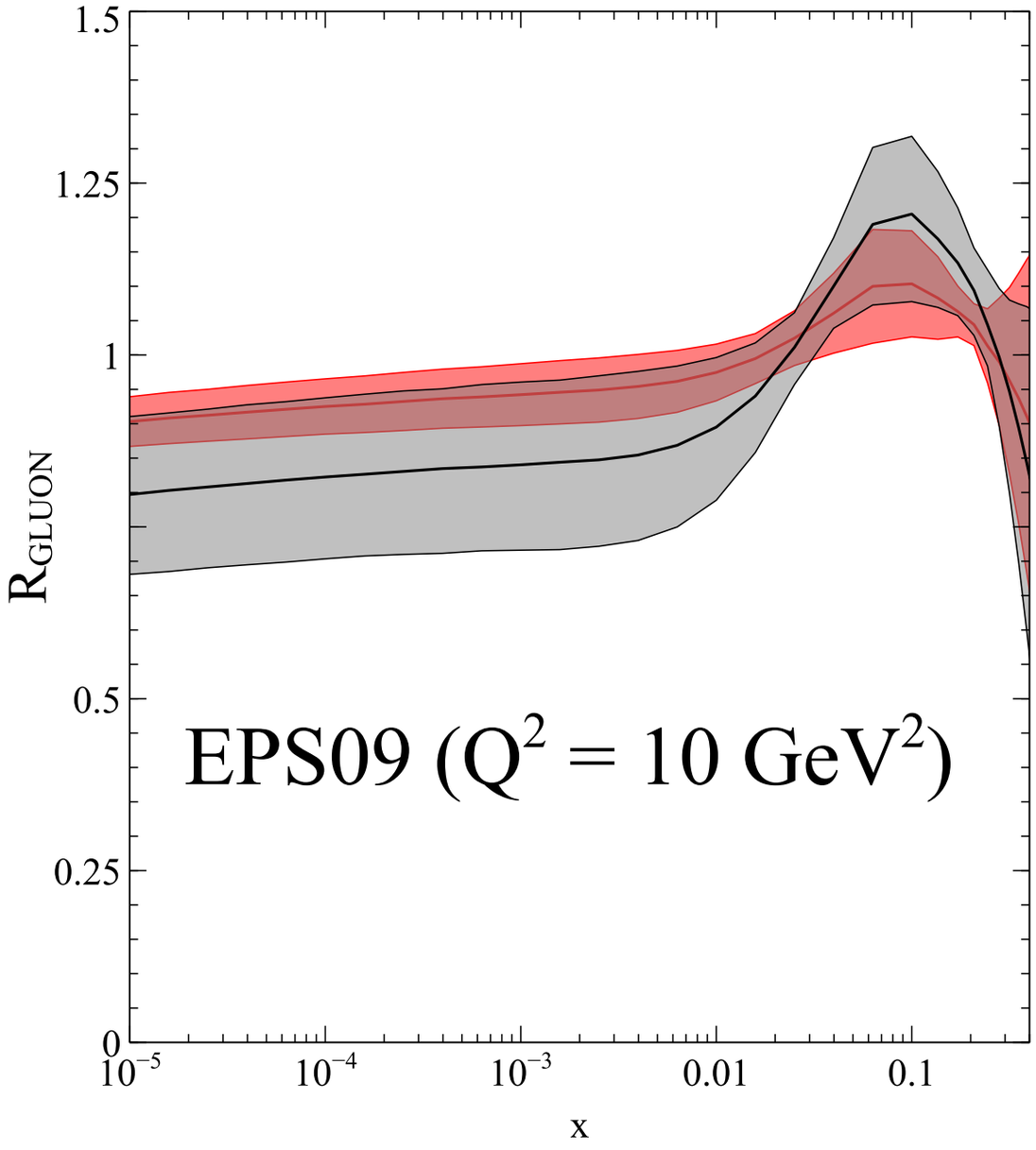


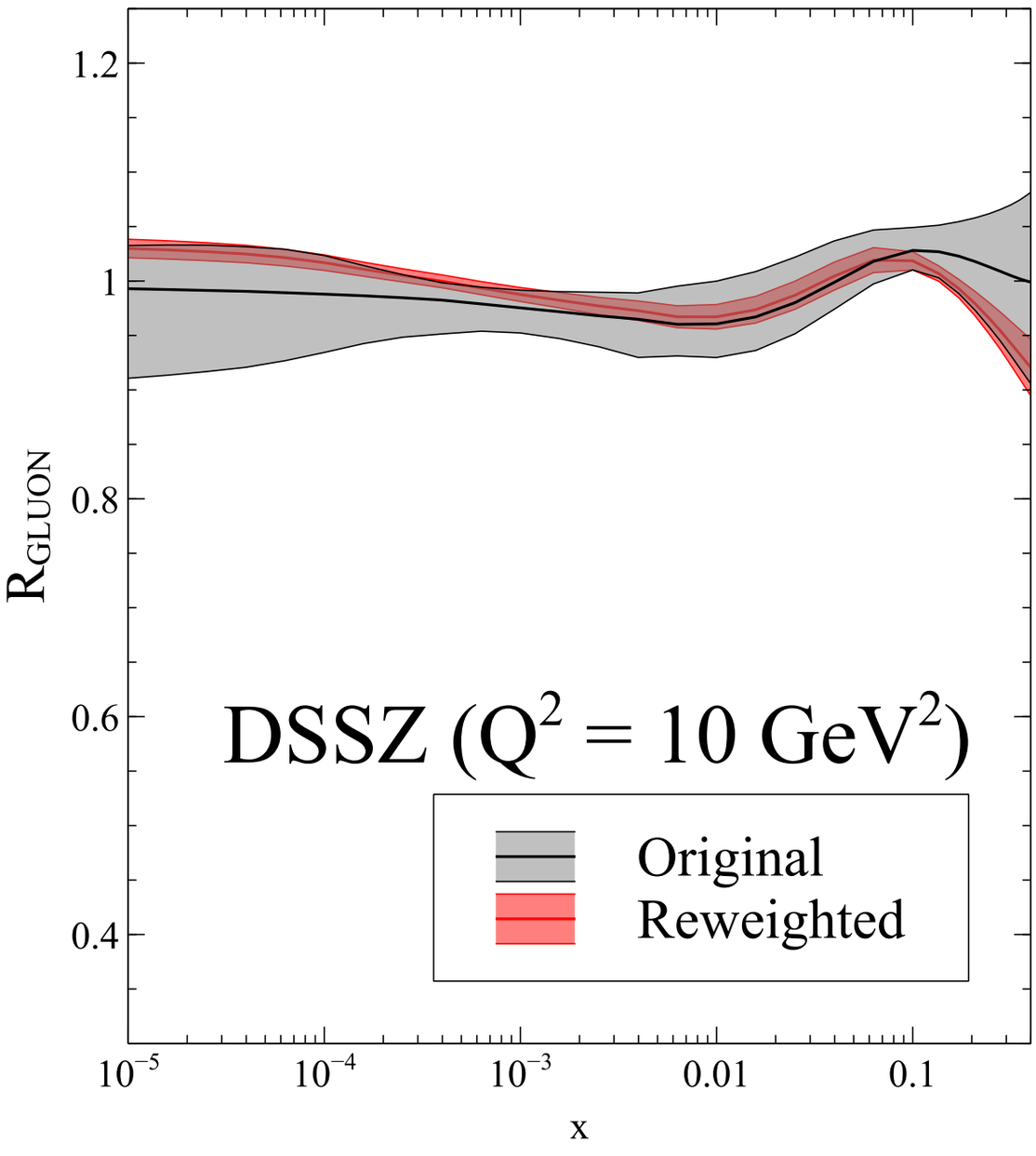
drive the

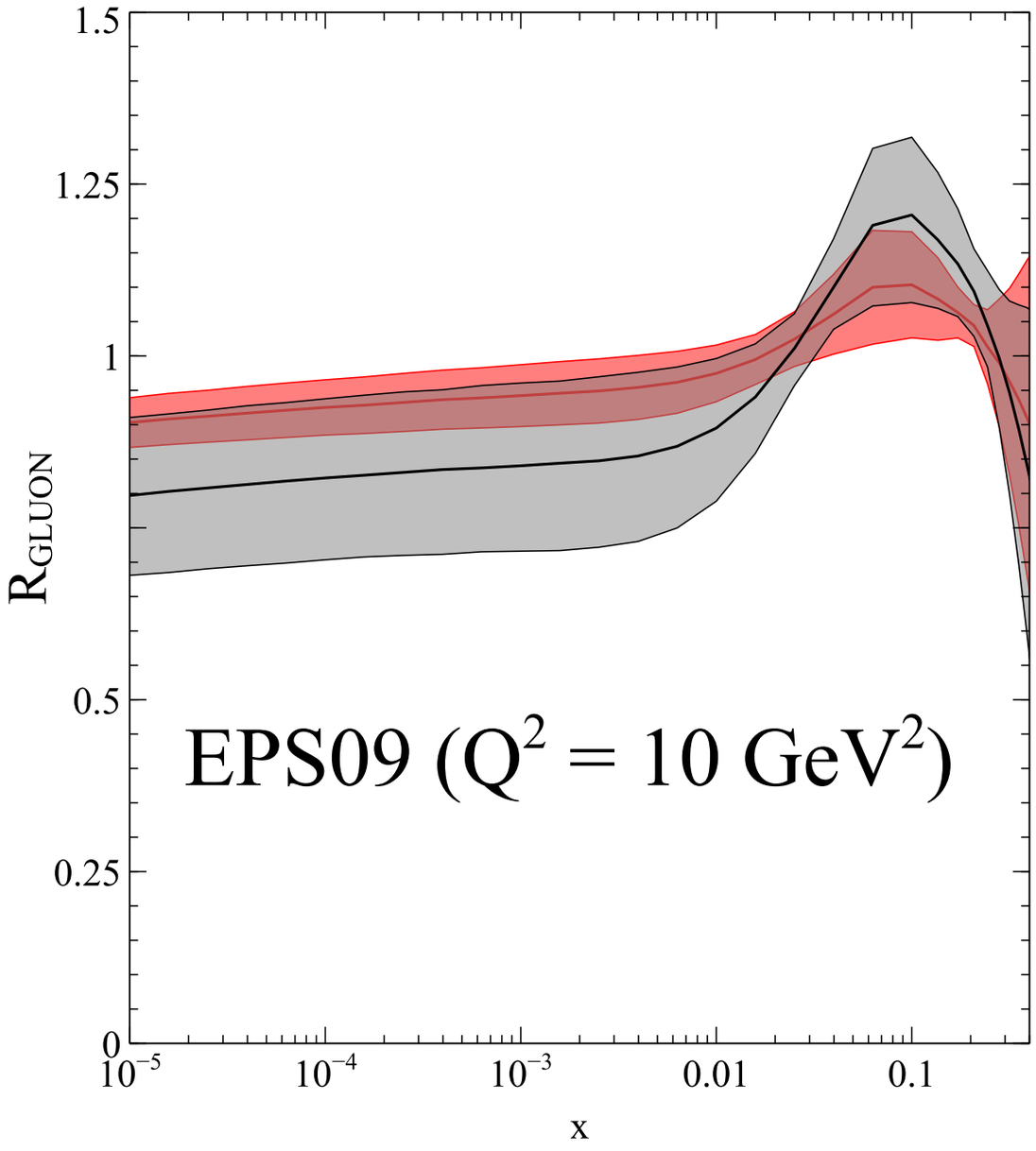
impact at

low x

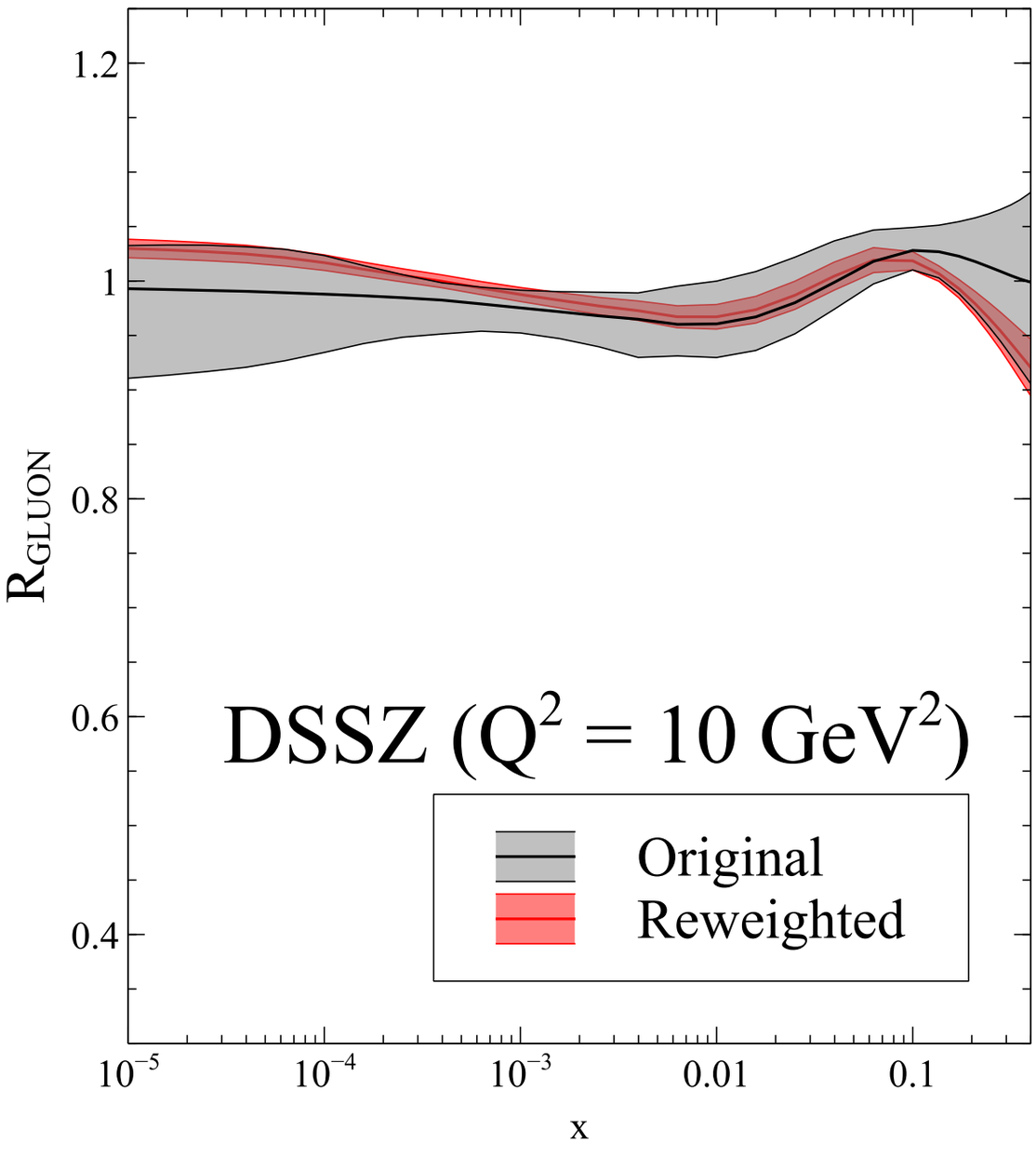
What if...?


EPS09 ($Q^2 = 10$ GeV^2)
R_{GLUON}
x
1.5
1.25
1
0.5
0.25
0
10^{-5}
10^{-4}
10^{-3}
0.01
0.1


DSSZ ($Q^2 = 10$ GeV^2)
R_{GLUON}
x
Original
Reweighted
1.2
1
0.8
0.6
0.4
10^{-5}
10^{-4}
10^{-3}
0.01
0.1



every other gluon impact plot I have shown prefers shadowing at low-x



the "data" seems to like a higher gluon

the plots tell us that the impact

on nPDFs are dramatic

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but

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but

the tension is just

TOO HIGH

	nPDF	$\chi^2/n\|_{before}$	
F_2	DSSZ	84.22	
	EPS09	26.51	
F_L	DSSZ	197.63	
	EPS09	42.03	
$F_2 + F_L$	DSSZ	109.06	
	EPS09	29.66	

	nPDF	$\chi^2/n\|_{before}$	$\chi^2/n\|_{after}$
F_2	DSSZ	84.22	2.24
	EPS09	26.51	1.38
F_L	DSSZ	197.63	**162.96**
	EPS09	42.03	**39.05**
$F_2 + F_L$	DSSZ	109.06	**38.15**
	EPS09	29.66	**5.67**

2-15% of replicas remaining

Summary

- we have many nPDFs sets available, and we’re getting better at extracting them

- we had high hopes for the pPb run, but the truth is… LHC is not the best machine to constrain partons in the nuclear medium, at least with these observables (sad lesson from EPPS16)

- studies show a significant tension between DGLAP predictions and saturated models… maybe we can even make a discovery

- we really need to understand proton/nuclear PDFs (and FFs/nFFs?) in case something new shows up

- future colliders have a huge potential to help us improve (see EIC white paper and LHeC CDR)

- a first step while we wait is to use the current colliders... but we need DATA

- we really need to understand proton/nuclear PDFs (and FFs/nFFs?) in case something new shows up

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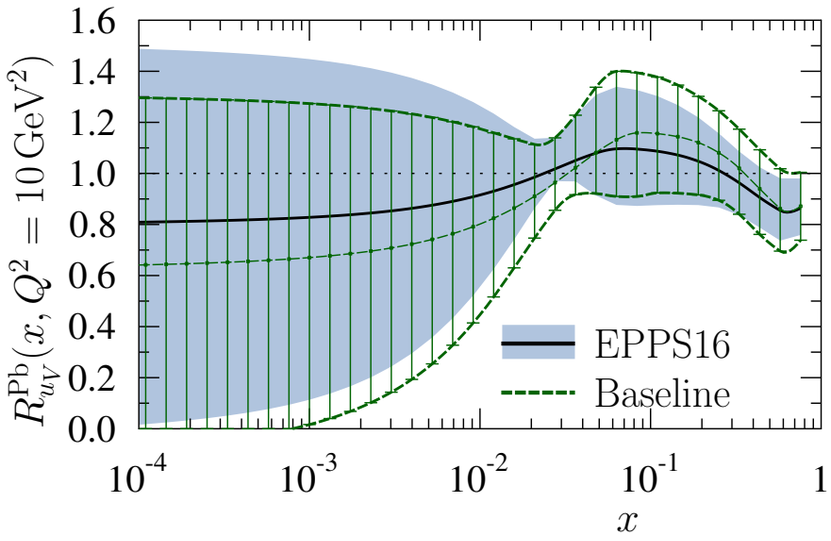
- a first step while we wait is to use the current colliders... but we need DATA

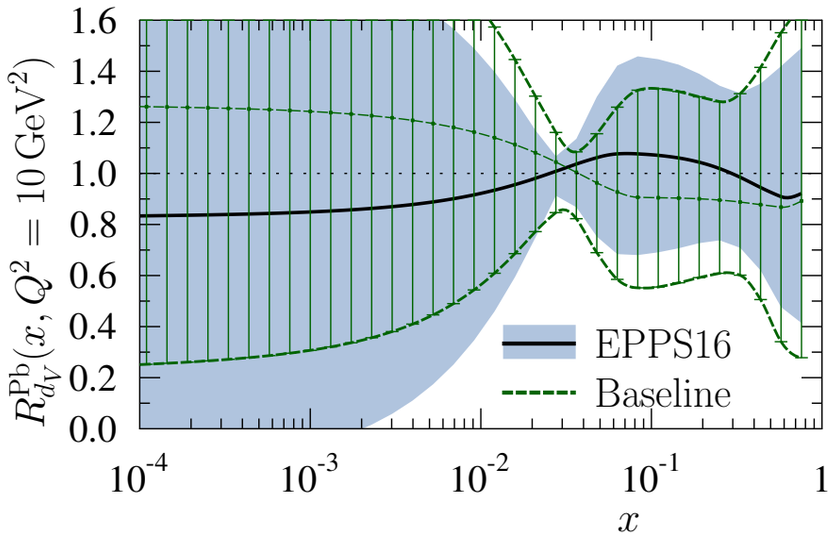
and no, not

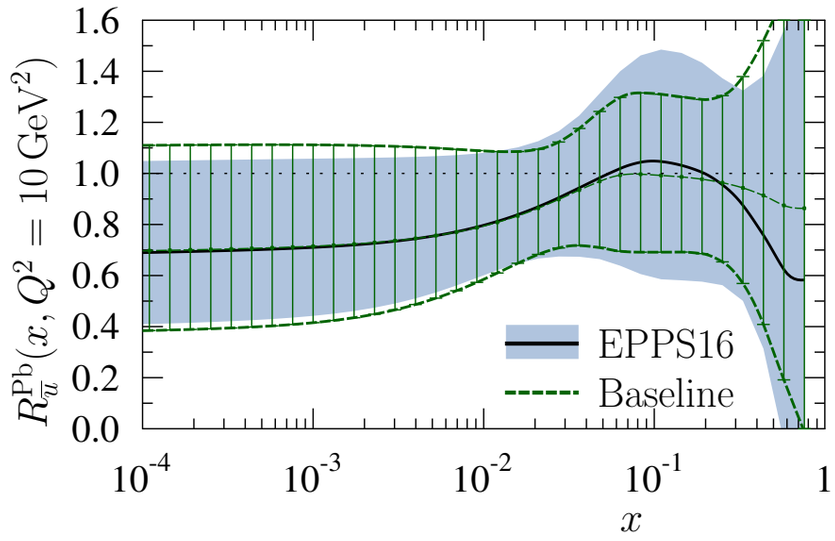
THIS Data

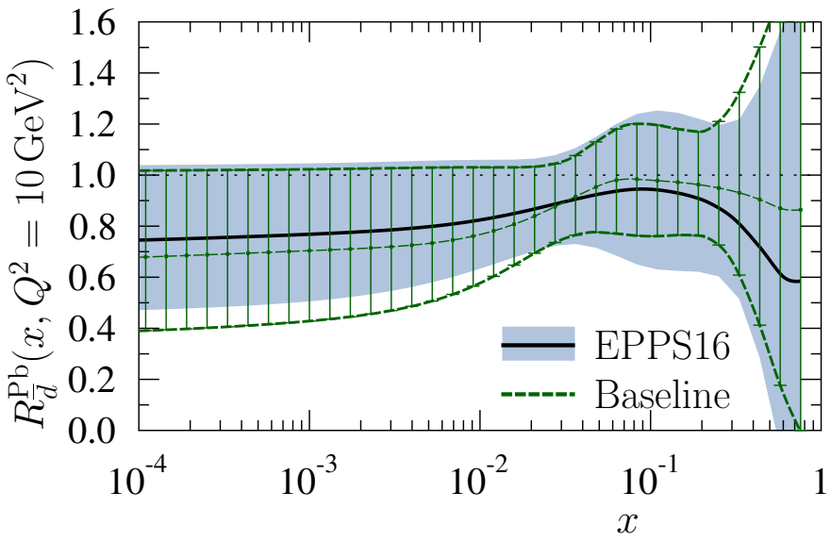
BACK UP SLIDES

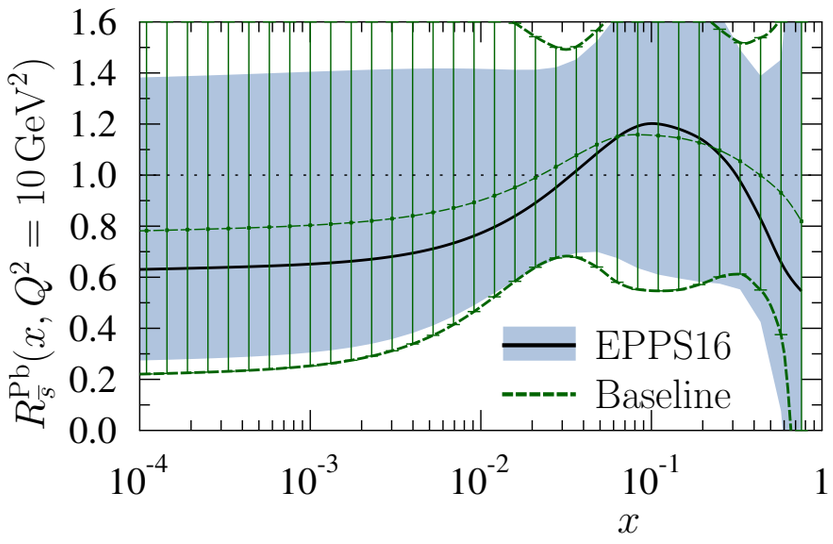
The impact of LHC data

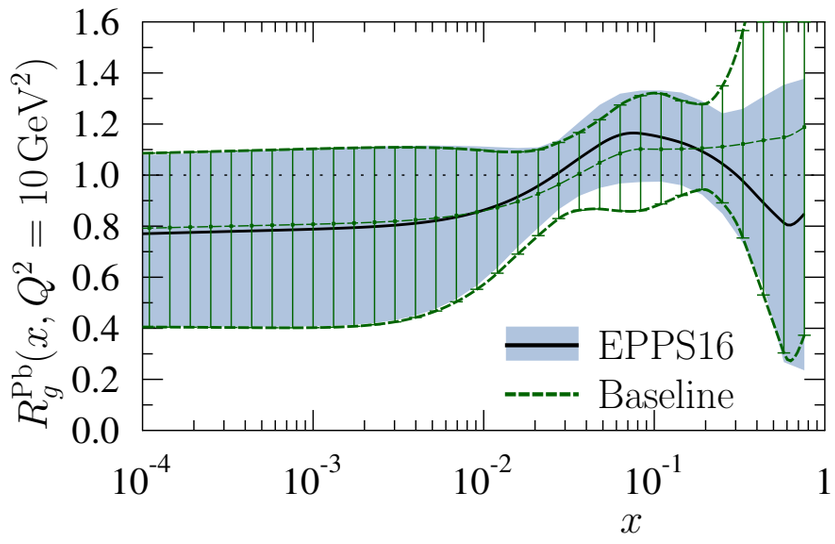












- few points (30 out of 1811, ~ 1.7%)
- not very precise (correlation not included in general)
- ratios taken, information lost
- very high Q^2 (2 o.o.m. away from DIS and DY data)
- DGLAP evolution washing away effects

In collinear factorized pQCD:

$$\mathcal{O} = \sum_{i,j} \hat{\mathcal{O}}_{i,j}(x,\mu) \otimes f_i(x,\mu)$$

where

$\mathcal{O}$: physical observable

i,j : initial/final state particles

x : fraction of the proton's momentum carried by the initial particles

μ : hard scale(s) of the process

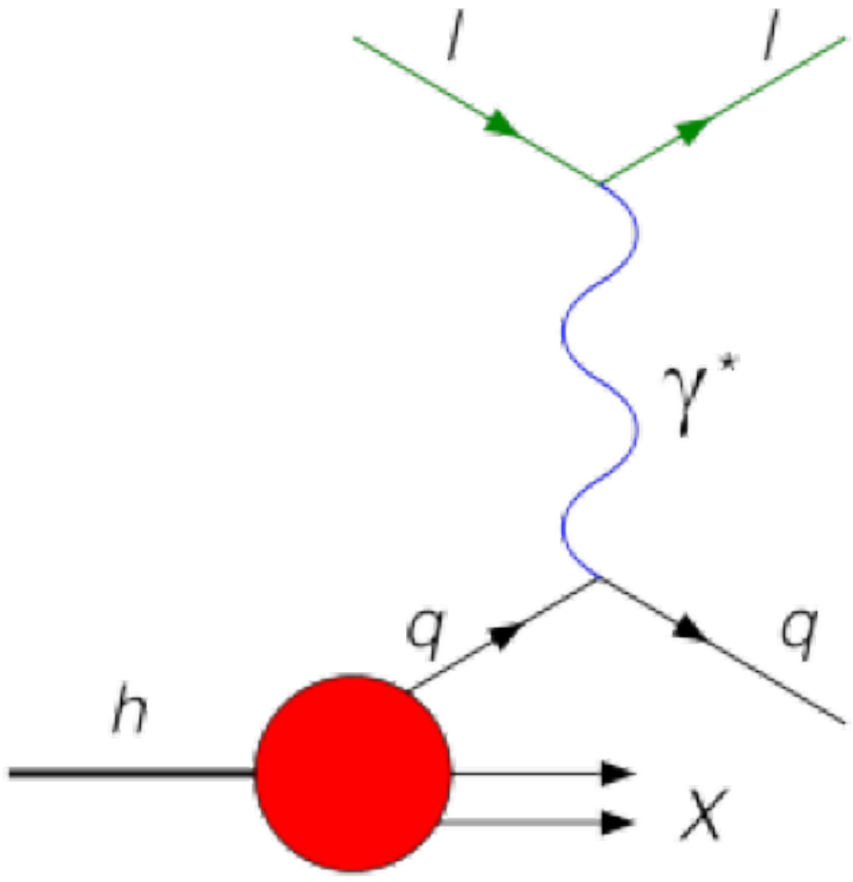
$\hat{\mathcal{O}}_{i,j}$: observable at the partonic level

$f_i(x,\mu)$: PDF

$$A \otimes B(x) = \int_x^1 \frac{dy}{y} A(y/x) B(y)$$

The key experiment for PDFs determination is

Deeply Inelastic Scattering



One parton from the proton, with

$$p^{\mu}_{parton} = x * p^{\mu}_{proton}$$

interacts with the electron via the exchange of a virtual photon

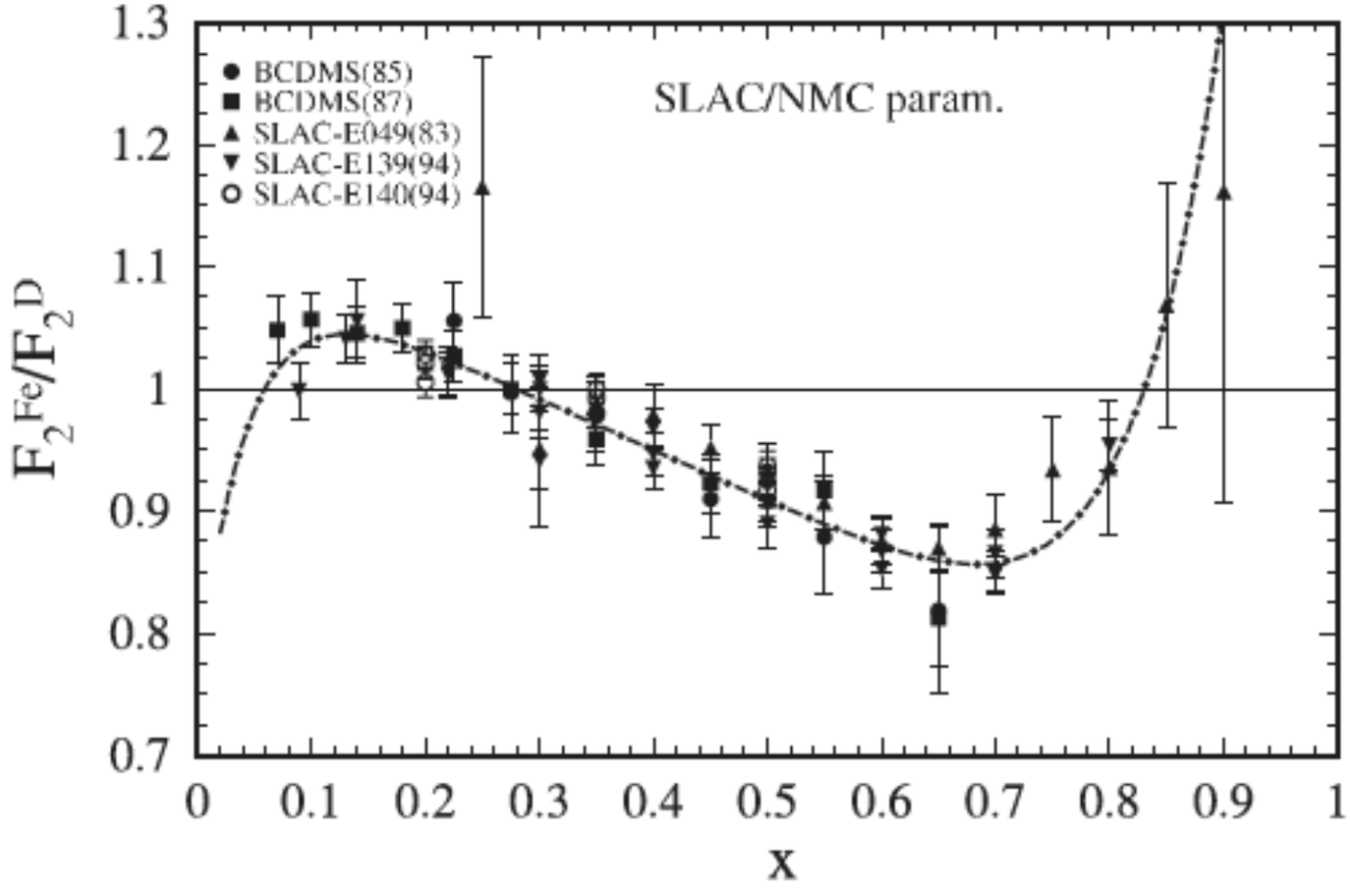
We sum over all possible initial partons

$$\frac{d^2\sigma^{lh\to lX}}{dxdQ^2} = \frac{4\pi\alpha^2_{e.m.}}{xQ^4}\left[\left(1-y+y^2\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

In the early 80's, DIS experiments with nuclei began measurements in a region where

$$\frac{d^2\sigma^{lh\to lX}}{dxdQ^2} \propto F_2(x,Q^2)$$

is a good approximation

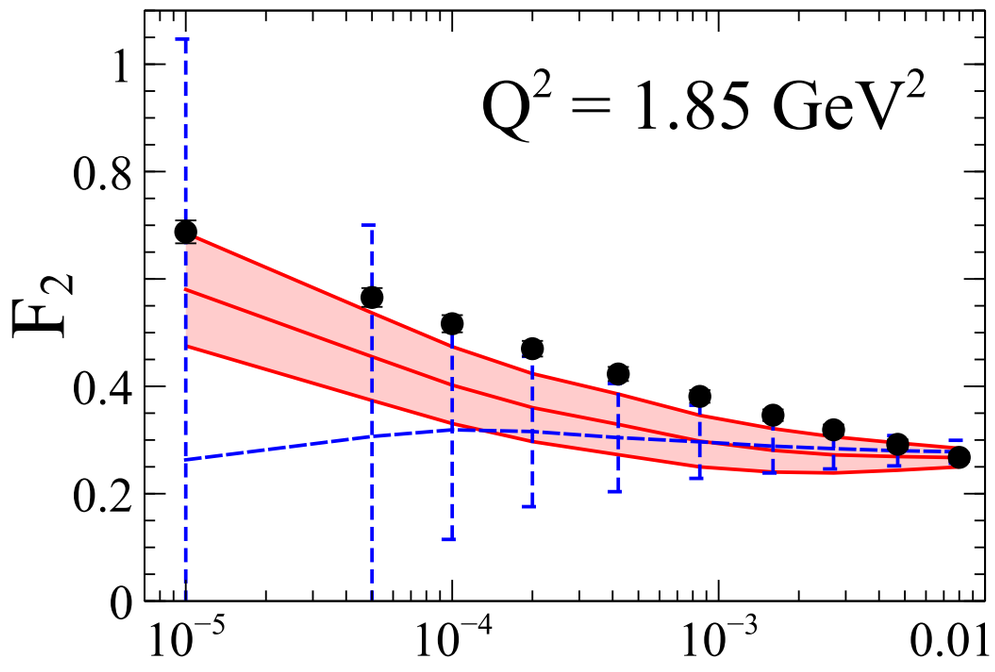


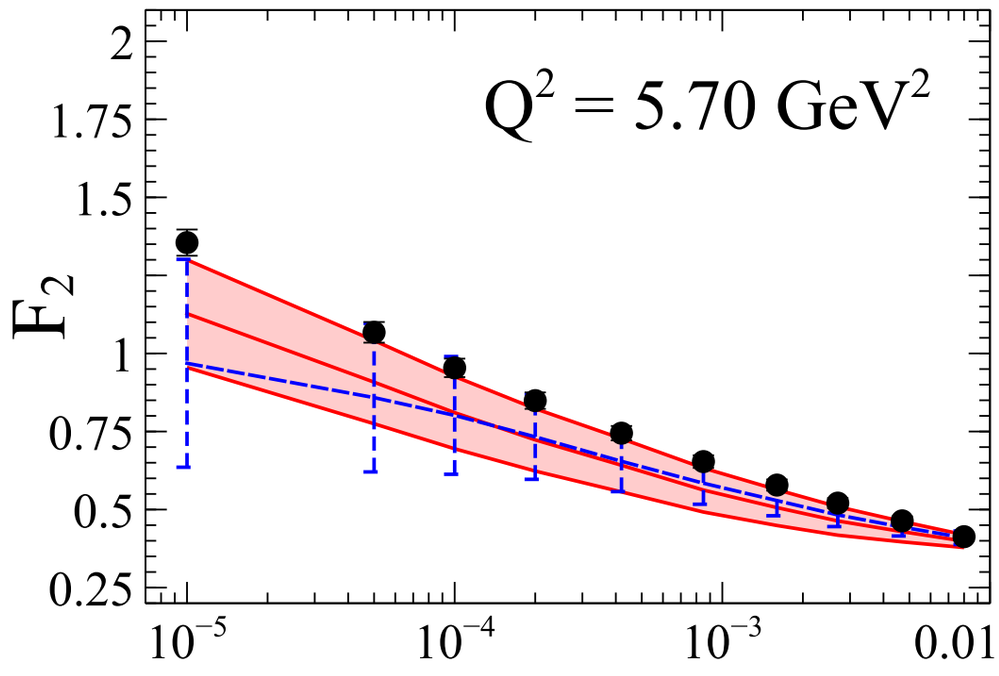
is this a:

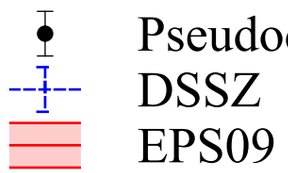
a) hard
b) soft
c) hard and soft

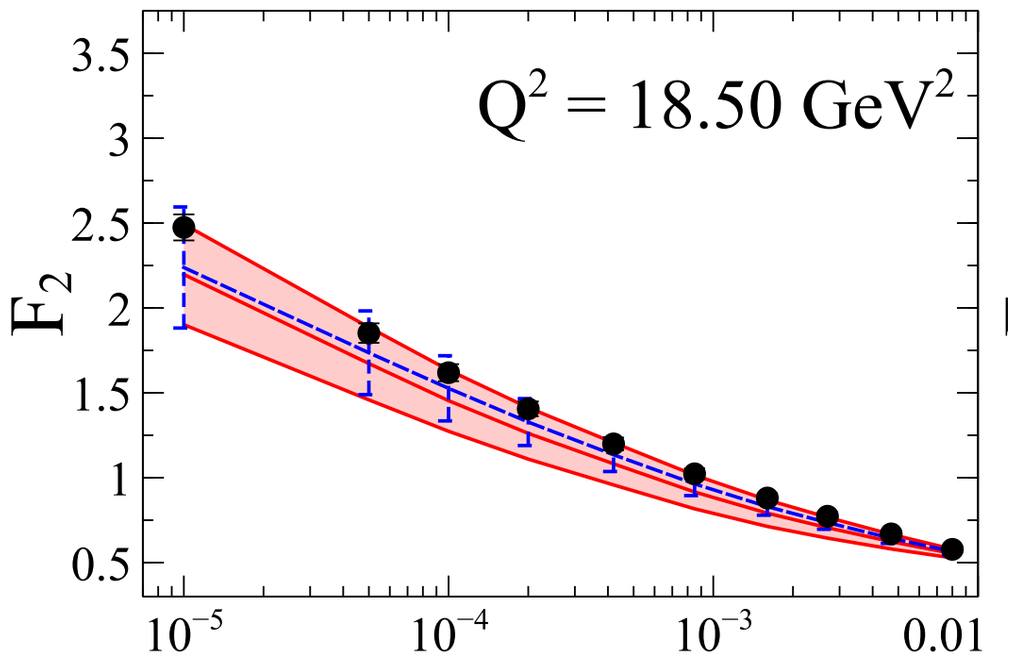
effect?

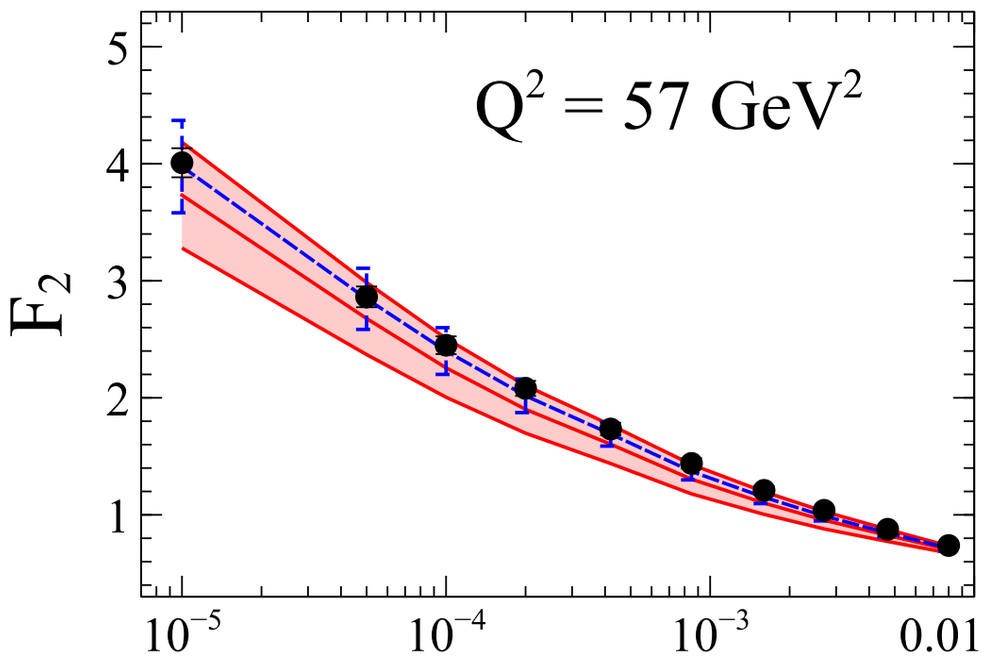
DGLAP predictions for F_2 in e-Au collisions is (more or less) in agreement with the "data"











What if...?