CT18 QCD analysis at small x

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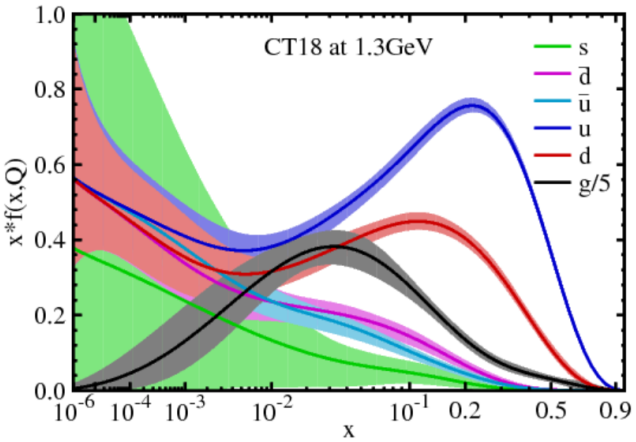

CTEQ-TEA (Tung et al.) working group

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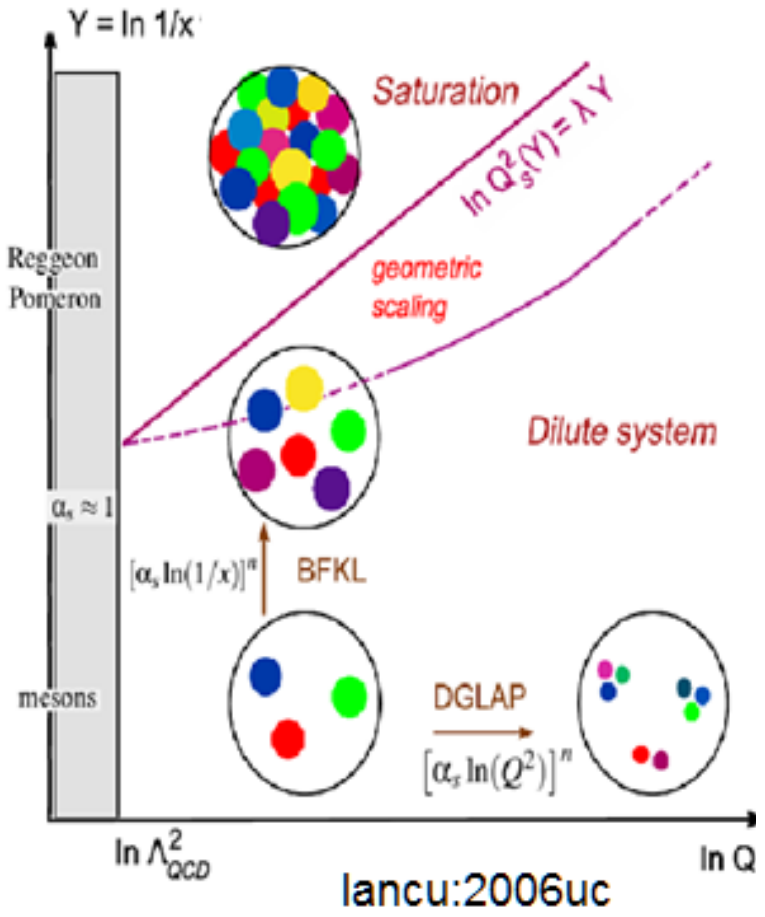
University of Pittsburgh: K. X.

arXiv: 1912.10053

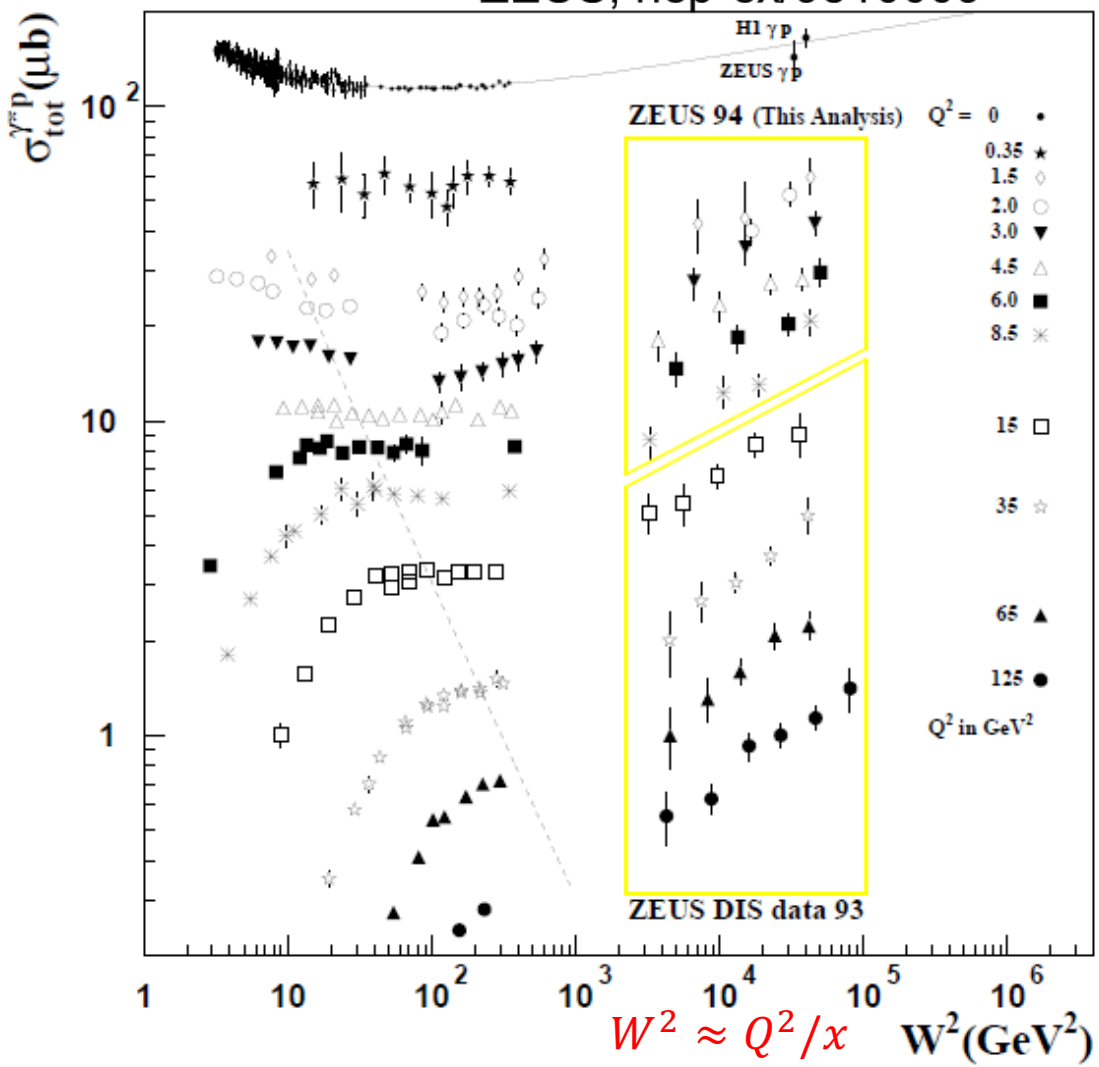
Available on

https://ct.hepforge.org

QCD dynamics vs. Q and x



$\gamma^* p$ total cross sections
ZEUS, hep-ex/9510009



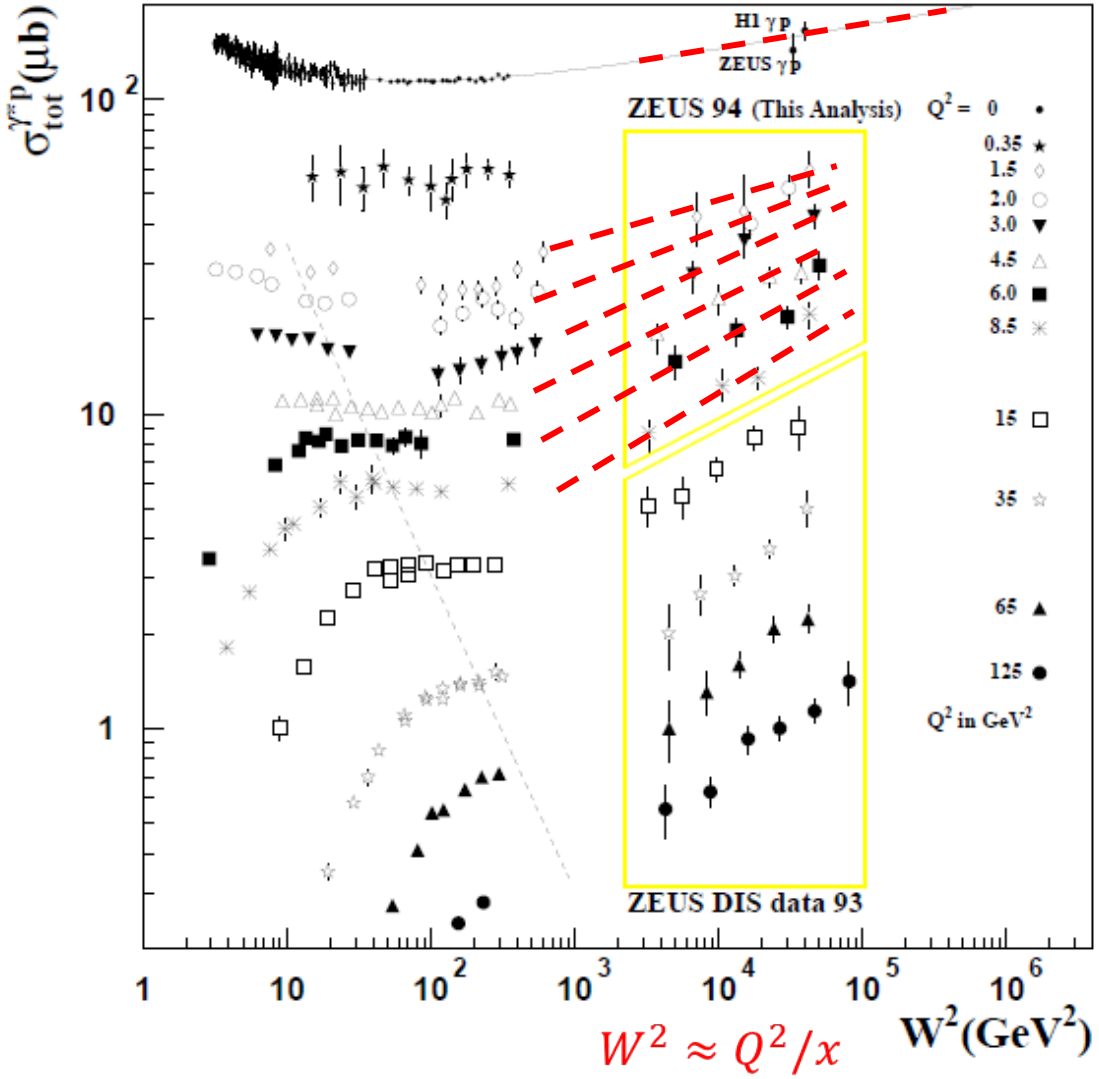
Slide from P. Nadolsky @ DIS 2016

QCD dynamics vs. Q and x

Red lines "fit" $\sigma_{tot}^{\gamma^* p} \sim \sigma_{reduced}$ for a fixed Q

The slope of $\sigma_{tot}^{\gamma^* p} \sim \sigma_{red}$ vs. $1/x$ changes as a function of x and Q, predicting rapid growth of PDFs at $x \to 0$

$\gamma^* p$ total cross sections
ZEUS, hep-ex/9510009



Slide from P. Nadolsky @ DIS 2016

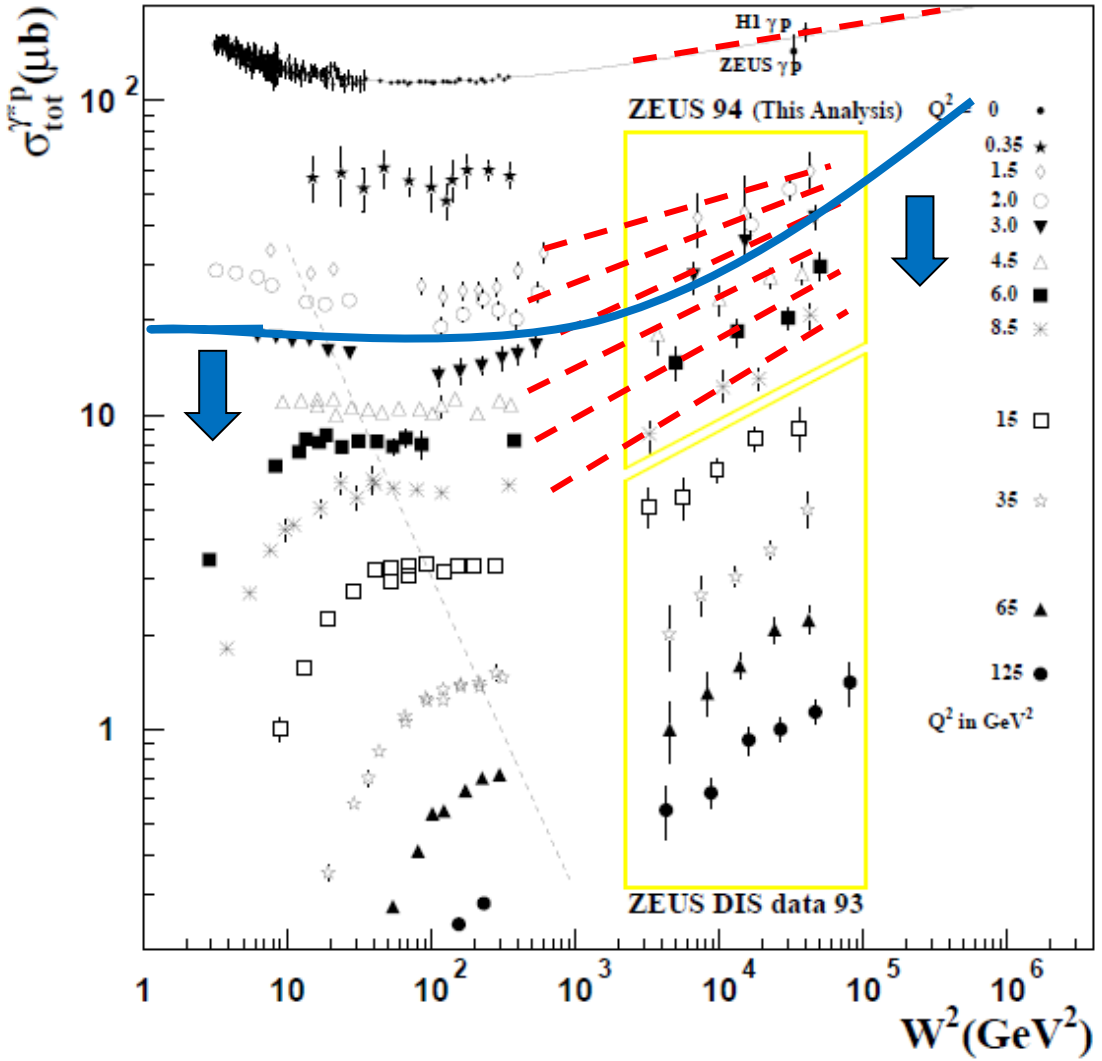
QCD dynamics vs. Q and x

$\gamma^* p$ total cross sections
ZEUS, hep-ex/9510009

For points below the blue line, expectations are consistent with DGLAP collinear factorization at NNLO

Above, we see deviations

The boundary has not been located precisely. We can try to establish it using PDF fits.

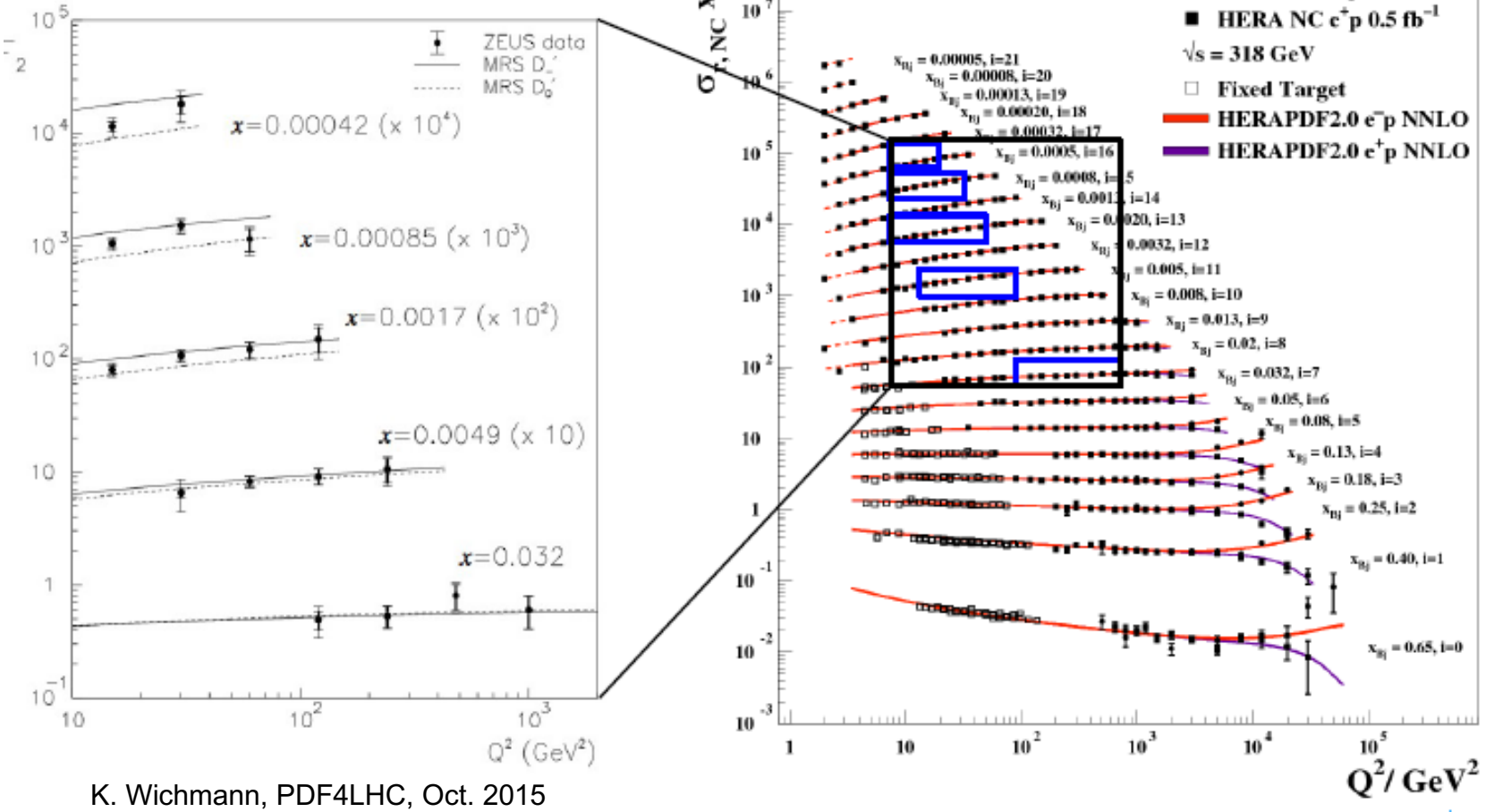


Slide from P. Nadolsky @ DIS 2016

we can test DGLAP/BFKL/Saturation with combined HERAI+II data!

1993

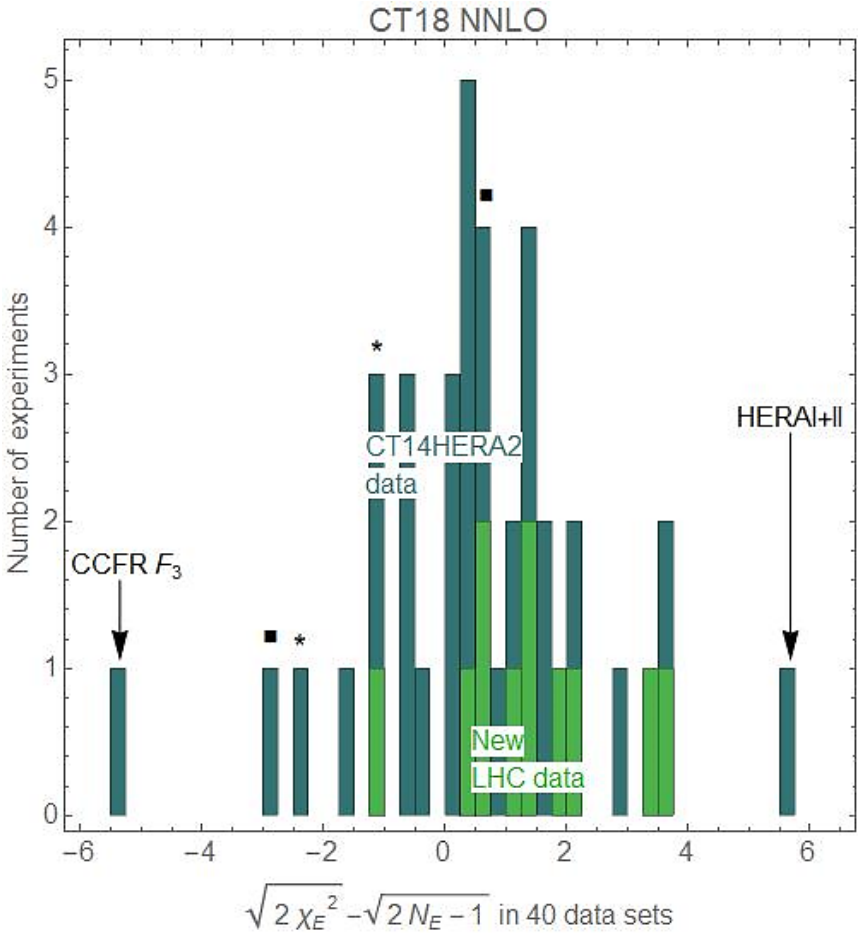
arXiv:1506.06042



K. Wichmann, PDF4LHC, Oct. 2015

HERAI+II data in global fits

e^+p data are fitted fine
e^-p data are fitted poorly



Separate the four HERA2 DIS processes;
($Q_{cut} = 2$ GeV)

	N_{pts}	$\chi^2_{red.} / N_{pts}$
NC e^+p	880	1.11
CC e^+p	39	1.10
NC e^-p	159	1.45
CC e^-p	42	1.52
totals		
[reduced χ^2] /N	1120	1.17
χ^2 / N	1120	1.25
R^2 / N	1120	0.08

CT14HERA2

← reduced χ^2 values

← χ^2 = [reduced χ^2] + R^2

← The quadratic penalty for 162 systematic errors = 87.5

Fair (not perfect) agreement; can be mildly improved!

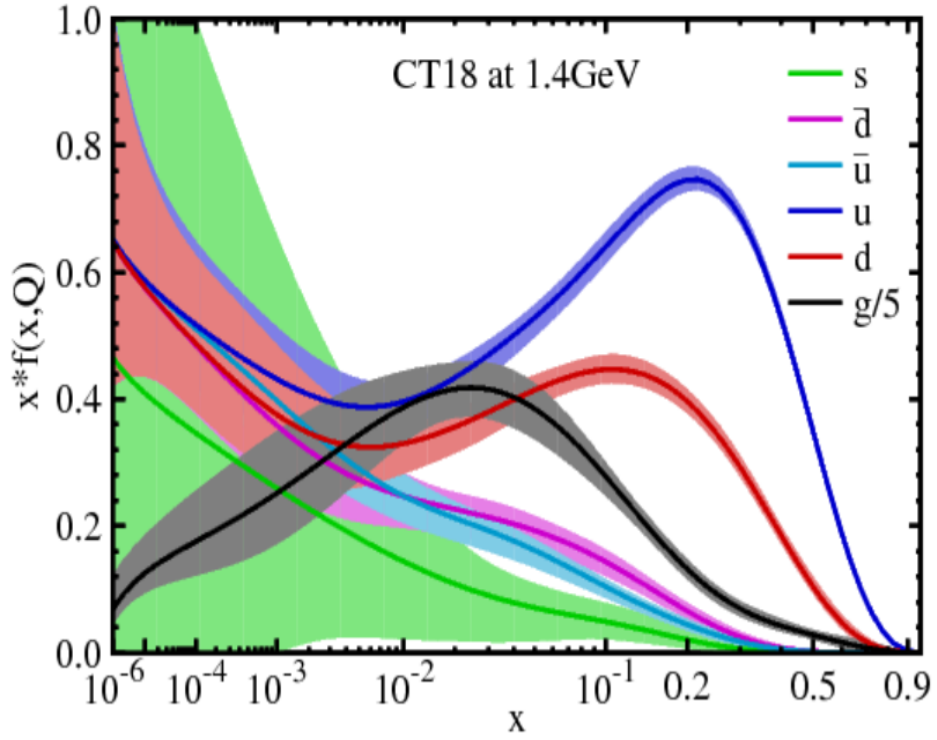
How to treat the DIS low-Q and small-x data?

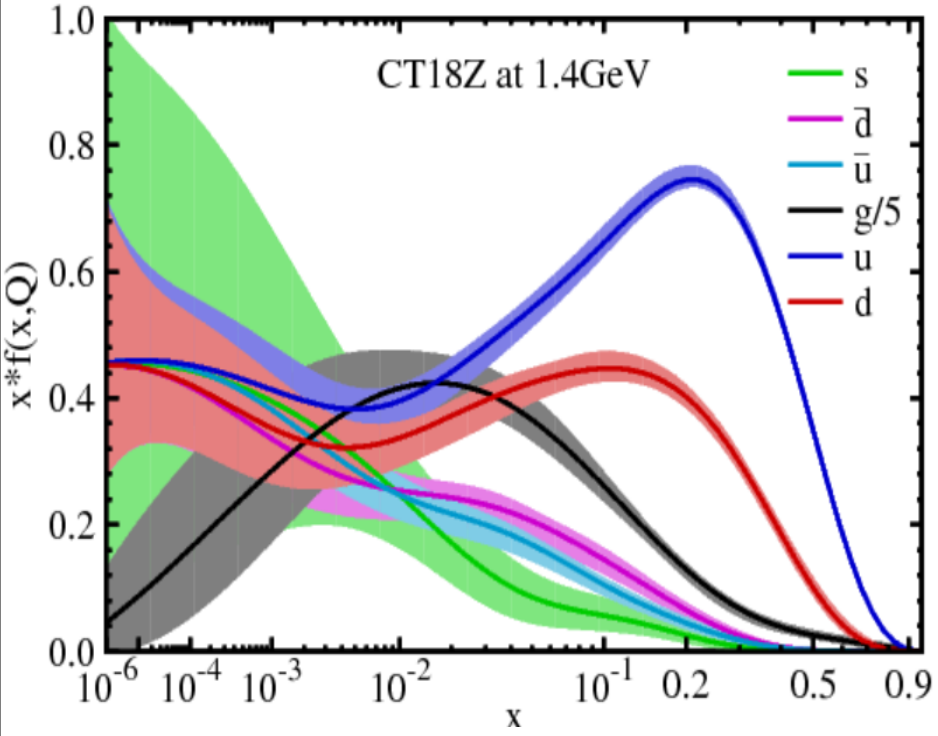
- NNPDF: BFKL to resum the small-x
- CT: an x-dependent DIS scale, motivated by saturation models.

PDF ensemble	Factorization scale in DIS	ATLAS 7 Z/W data included?	CDHSW $F_2^{p,d}$ data included?	Pole charm mass, GeV
CT18	$\mu_{F,DIS}^2 = \mathrm{Q}^2$	No	Yes	1.3
CT18X	$\mu_{F,DIS}^2 = 0.8^2\left(Q^2 + \frac{0.3\ GeV^2}{x^{0.3}}\right)$	No	Yes	1.3
CT18A	$\mu_{F,DIS}^2 = \mathrm{Q}^2$	Yes	Yes	1.3
CT18Z	$\mu_{F,DIS}^2 = 0.8^2\left(Q^2 + \frac{0.3\ GeV^2}{x^{0.3}}\right)$	Yes	No	1.4

CT18 parton distributions

Four PDF ensembles: CT18 (default), A, X, and Z



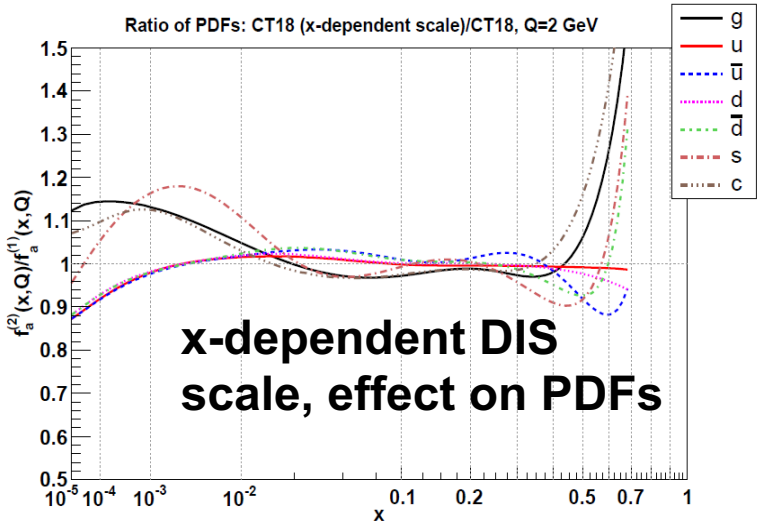


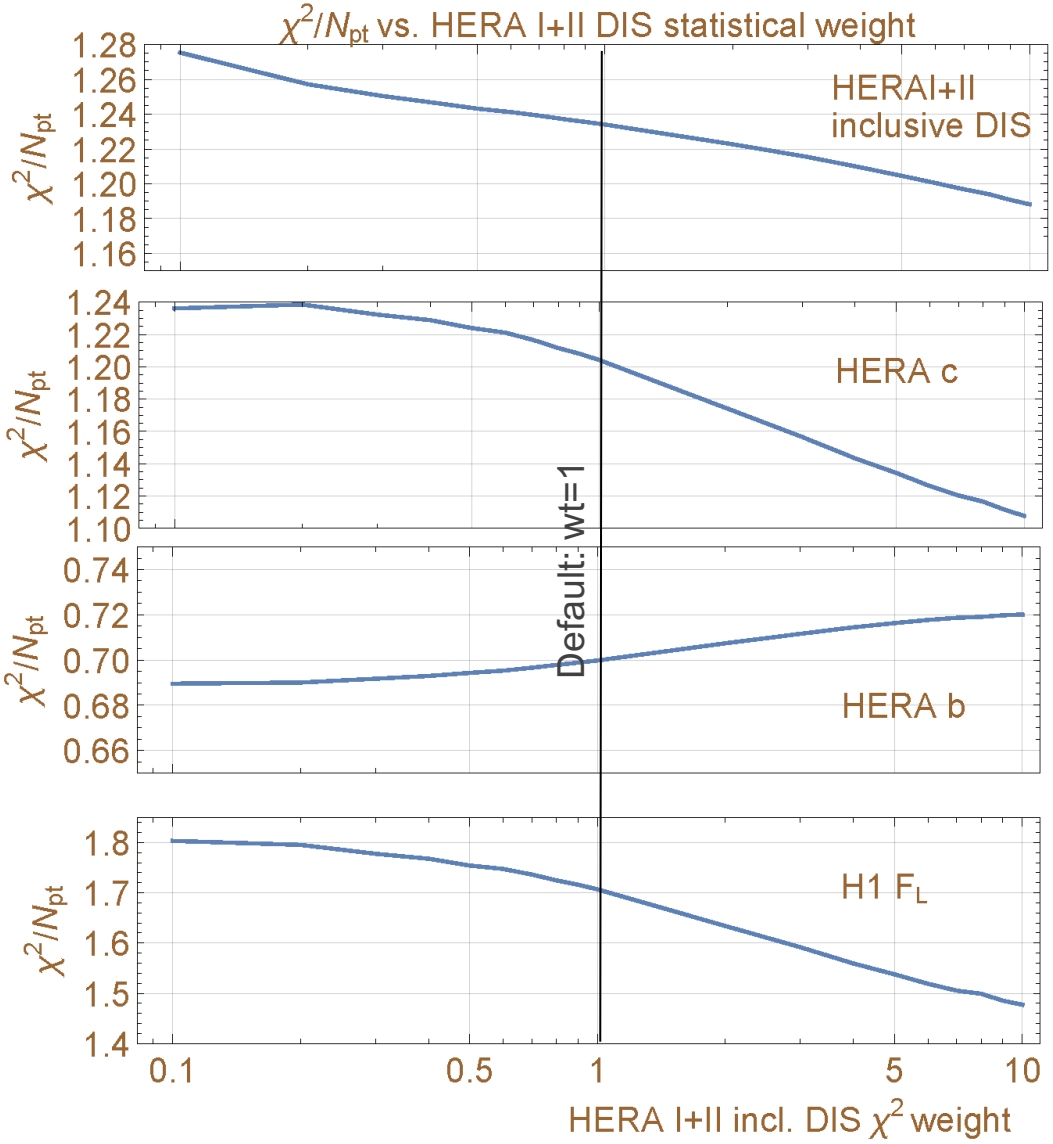
CT18Z has enhanced gluon and strange PDFs at $x \sim 10^{-4}$, and reduced light-quark PDFs at $x < 10^{-2}$. The CT18Z fit is performed so as to maximize the differences from CT18 PDFs, while preserving about the same goodness-of-fit as for CT18. CT18A and CT18X include some features of CT18Z

CT18X and Z: a special factorization scale in DIS

The CT18Z fits uses a $\mu_{DIS,X}$ scale that reproduces many features of NNLO-NLLx fits with $\ln(1/x)$ resummation by the NNPDF [arXiv:1710.05935] and xFitter [1802.0064] groups.

$$\mu^2_{DIS,X} = 0.8^2 \left(Q^2 + \frac{0.3\ GeV^2}{x^{0.3}} \right)$$

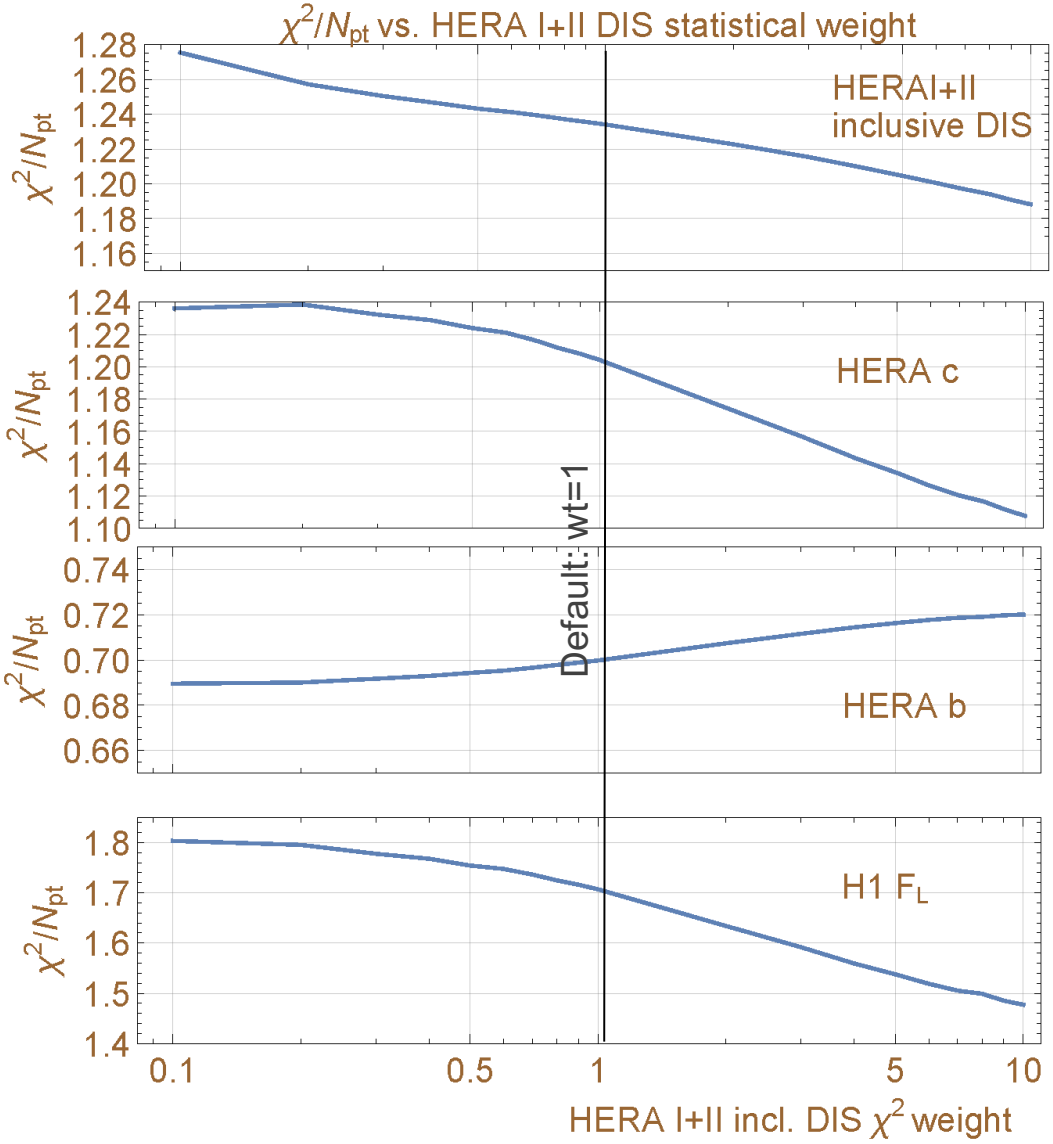




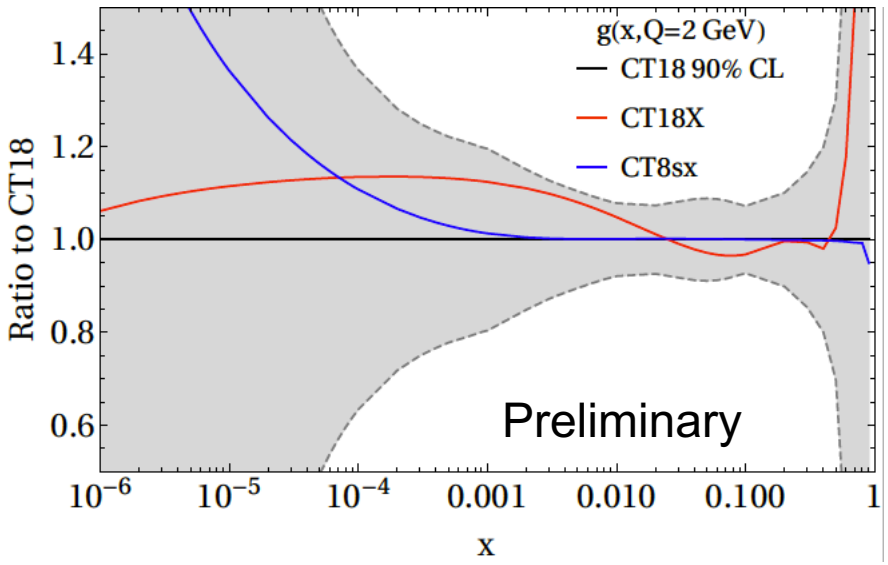
CT18X and Z: a special factorization scale in DIS

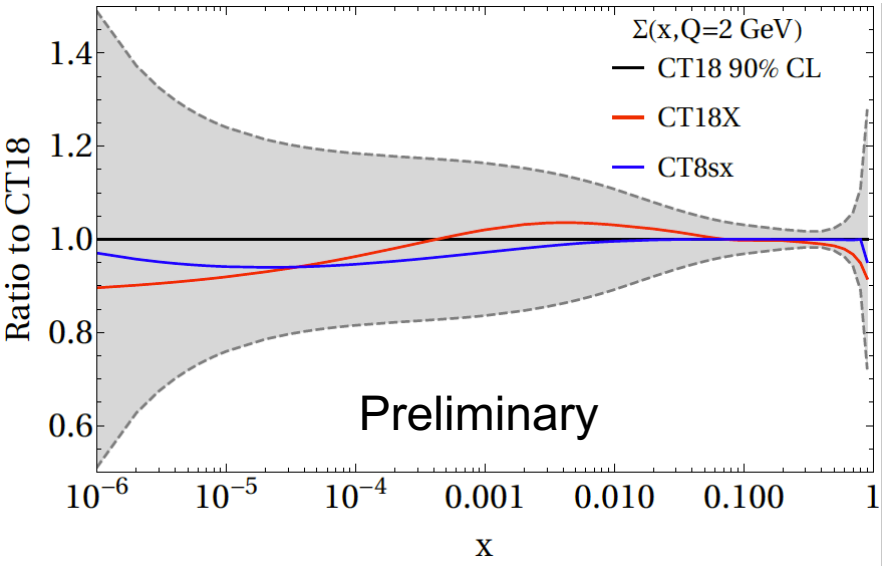
Right: when the χ^2 weight for the **inclusive** HERA I+II DIS is increased to $wt = 10$ to suppress pulls from the other experiments, χ^2_{CT18Z}/N_{pt} for HERA I+II DIS **and** HERA charm production decreases to about the same levels as in HERA-only NNLO+NLLx fits by other groups.

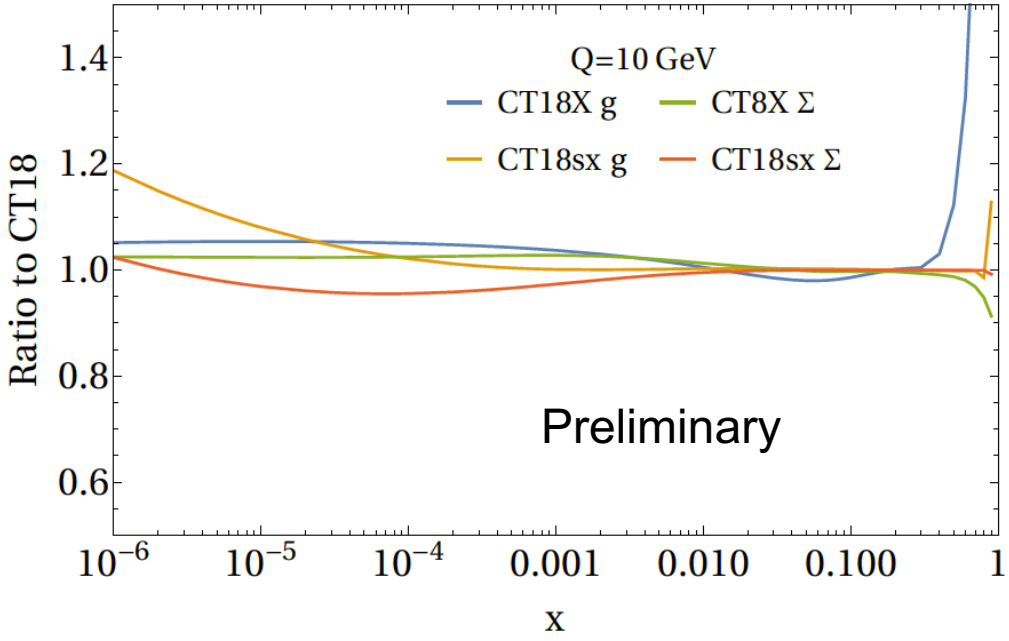
- **NNLO with an x-dependent scale is statistically indistinguishable from BFKL resummation in the CT18 x-Q region (Q > 2 GeV)**



CT18X compared to small-x resummation

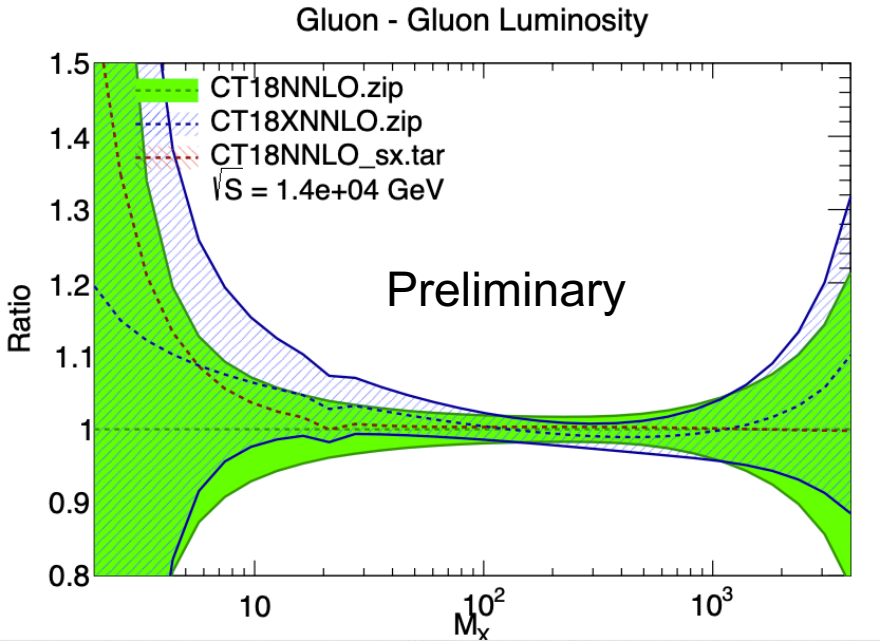


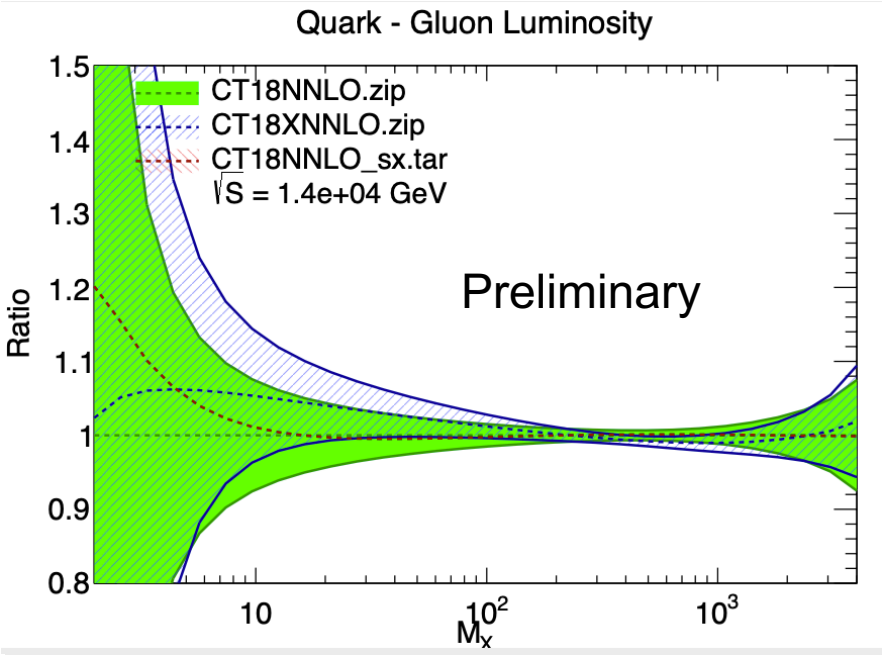


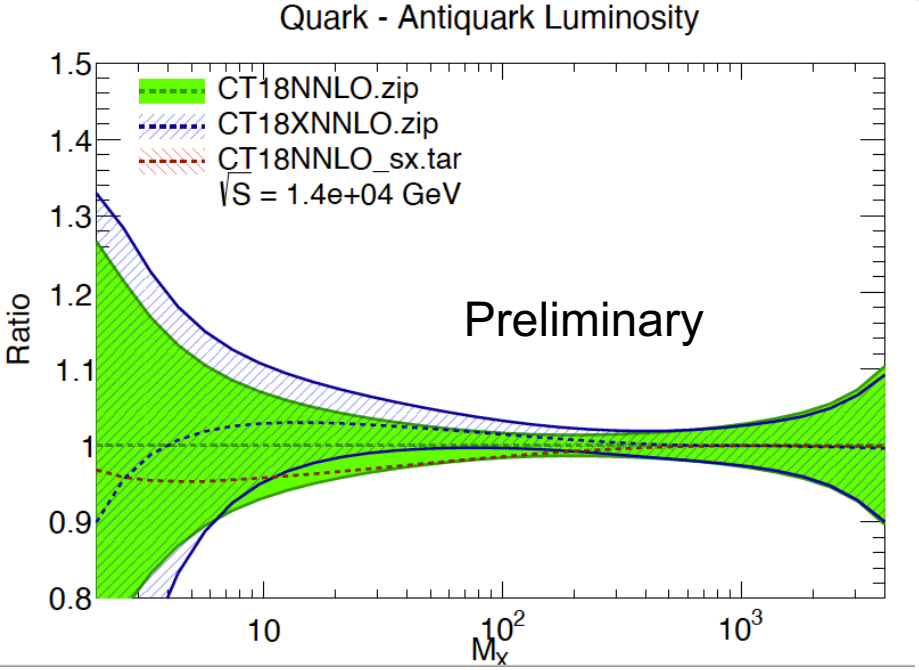


- Both x-dependent scale and small-x resummation enhance (reduce) the gluon (singlet) PDF at low Q and low x.
- At high Q or high x, the impact of both the x-dependent scale and small-x resummation die out.

Parton luminosity

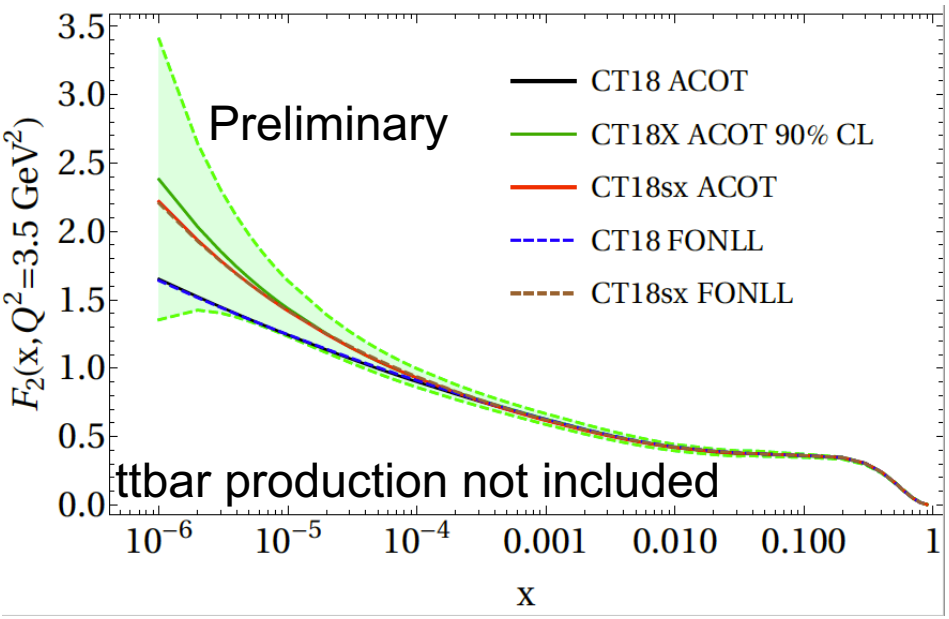


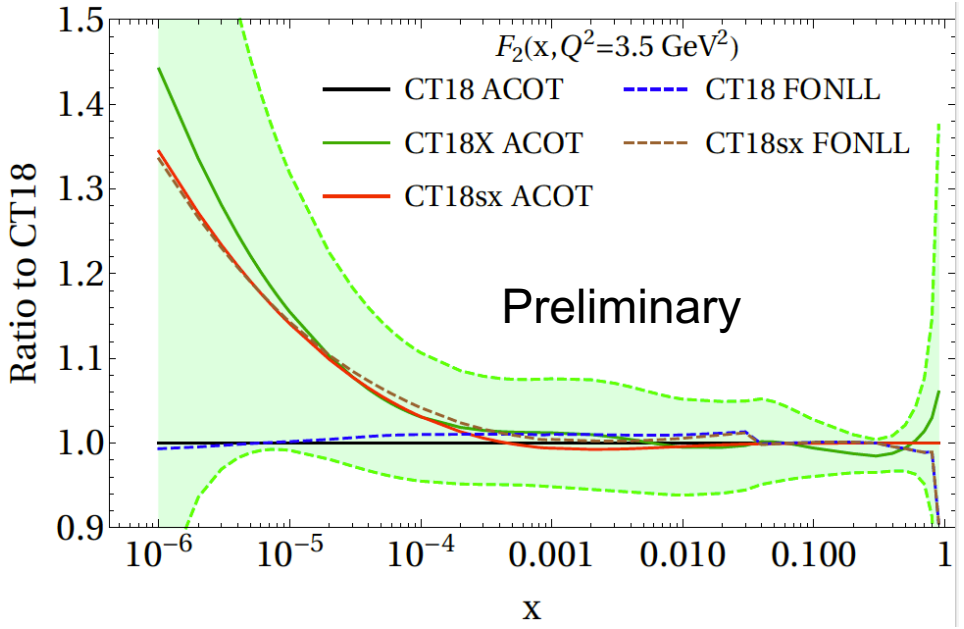




- The small-x effect impacts the parton luminosity at small invariant-mas region significantly.
- It enhance the gluon-gluon, quark-gluon parton luminosity.
- For the q-qbar luminosity at intermediate invariant mass, the x-dependent scale and small-x resummation pull to the opposite directions.

Structure function F2 at low Q



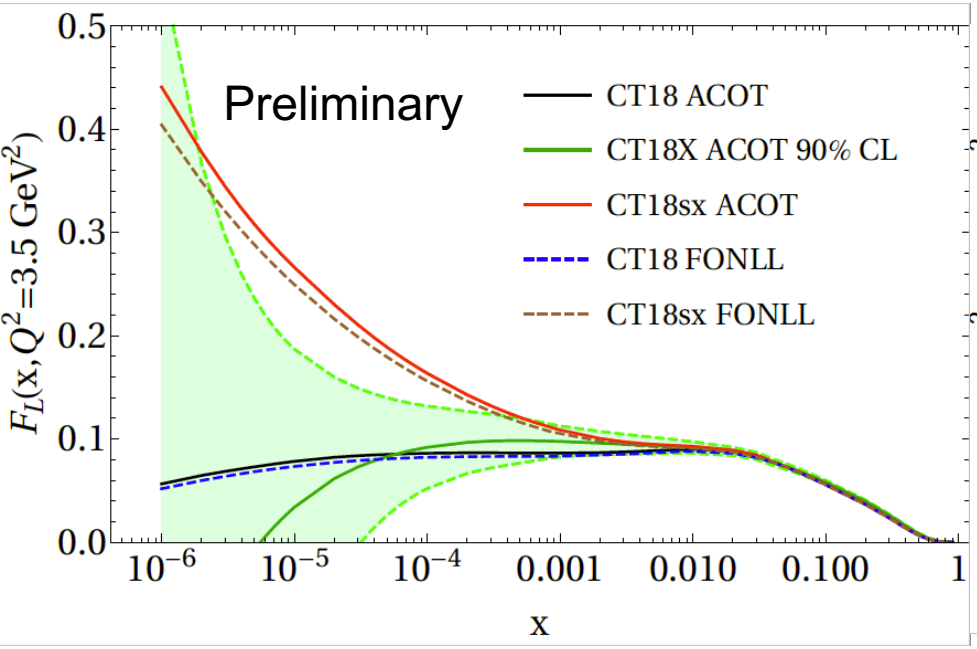


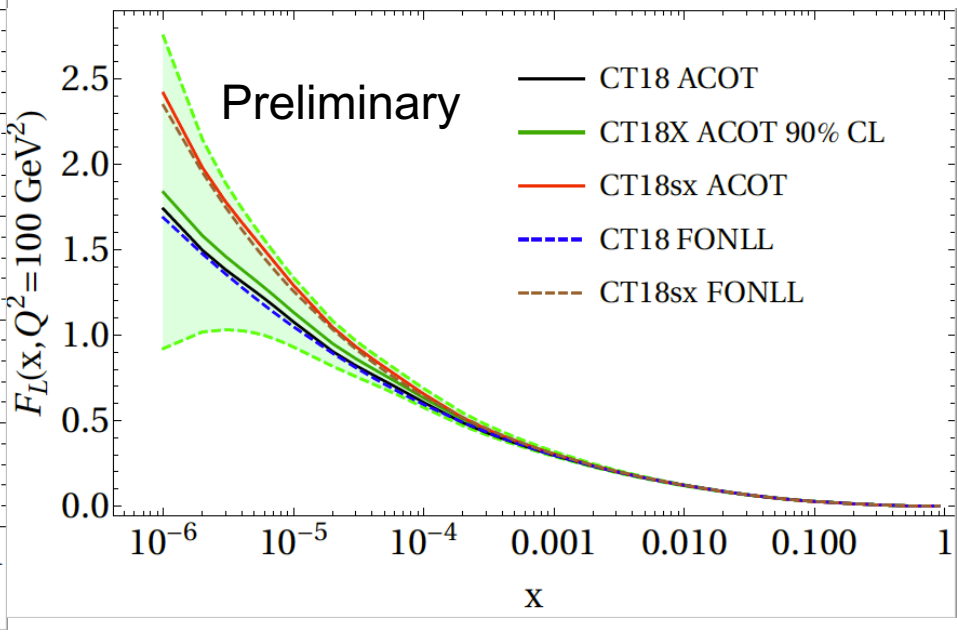
- CT uses the SACOT heavy-quark scheme. Small-x resummation is performed in the FONLL scheme that close to the SACOT.
- The small-x resummed F2 is obtained with a K-factor approach:

$$CT18sx\ ACOT = CT18\ ACOT\ \frac{CT18sx\ FONLL}{CT18\ FONLL}$$

- For F2, the CT18X is indistinguishable with CT18sx down to $x \sim 10^{-5}$. It only takes off below this x value.
- At higher Q, the impact of CT18X and CT18sx on F2 is comparably small (see backup slides).

Structure function FL



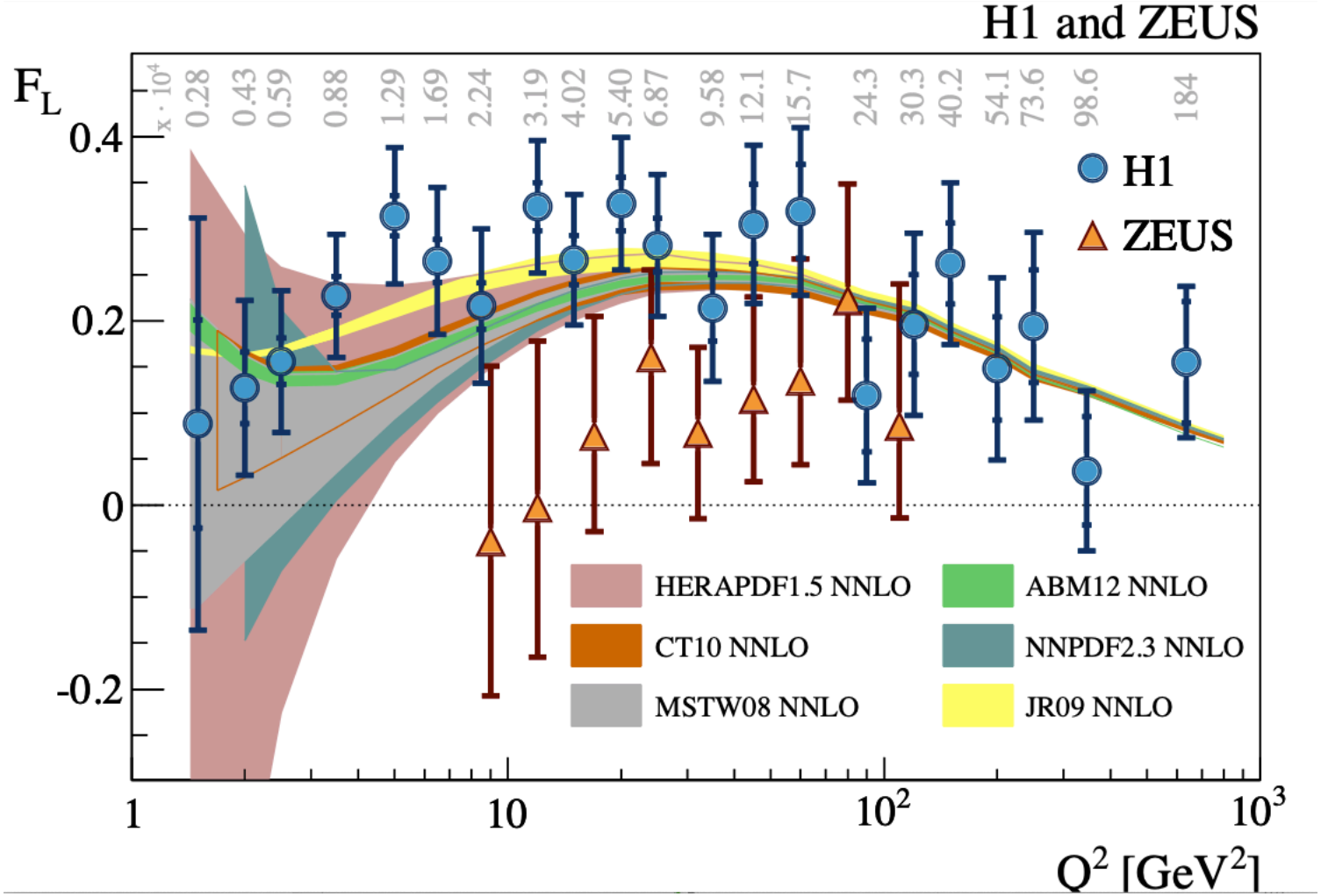


- At low Q, CT18X prediction agrees better than CT18 with the H1 FL data. At $x < 5 \cdot 10^{-5}$, CT18X (CT18sx) predicts reduction (enhancement) of FL.
- At high Q, both gives enhancement to FL, while the CT18X prescription is sizably smaller.
- It would be very interesting to see which is preferred by LHeC.

Conclusion

- At low x and low Q, both the small-x resummation and the x-dependent DIS scale prescription enhance the gluon and reduce the singlet PDF.
- At high x or high Q, they become indistinguishable within PDF errors.
- Both the small x resummation and the x-dependent scale give a comparable description of the HERA I+II DIS data.
- At x<10^-5 and Q<2 GeV, NLLx and NNLO+saturation scale may predict different FL behavior.

Backup


H1 and ZEUS
F_L
$x \cdot 10^4$
0.28
0.43
0.59
0.88
1.29
1.69
2.24
3.19
4.02
5.40
6.87
9.58
12.1
15.7
24.3
30.3
40.2
54.1
73.6
98.6
184
0.4
0.2
0
-0.2
H1
ZEUS
HERAPDF1.5 NNLO
ABM12 NNLO
CT10 NNLO
NNPDF2.3 NNLO
MSTW08 NNLO
JR09 NNLO
1
10
10^2
10^3
Q^2 [GeV^2]

The F2 at high Q