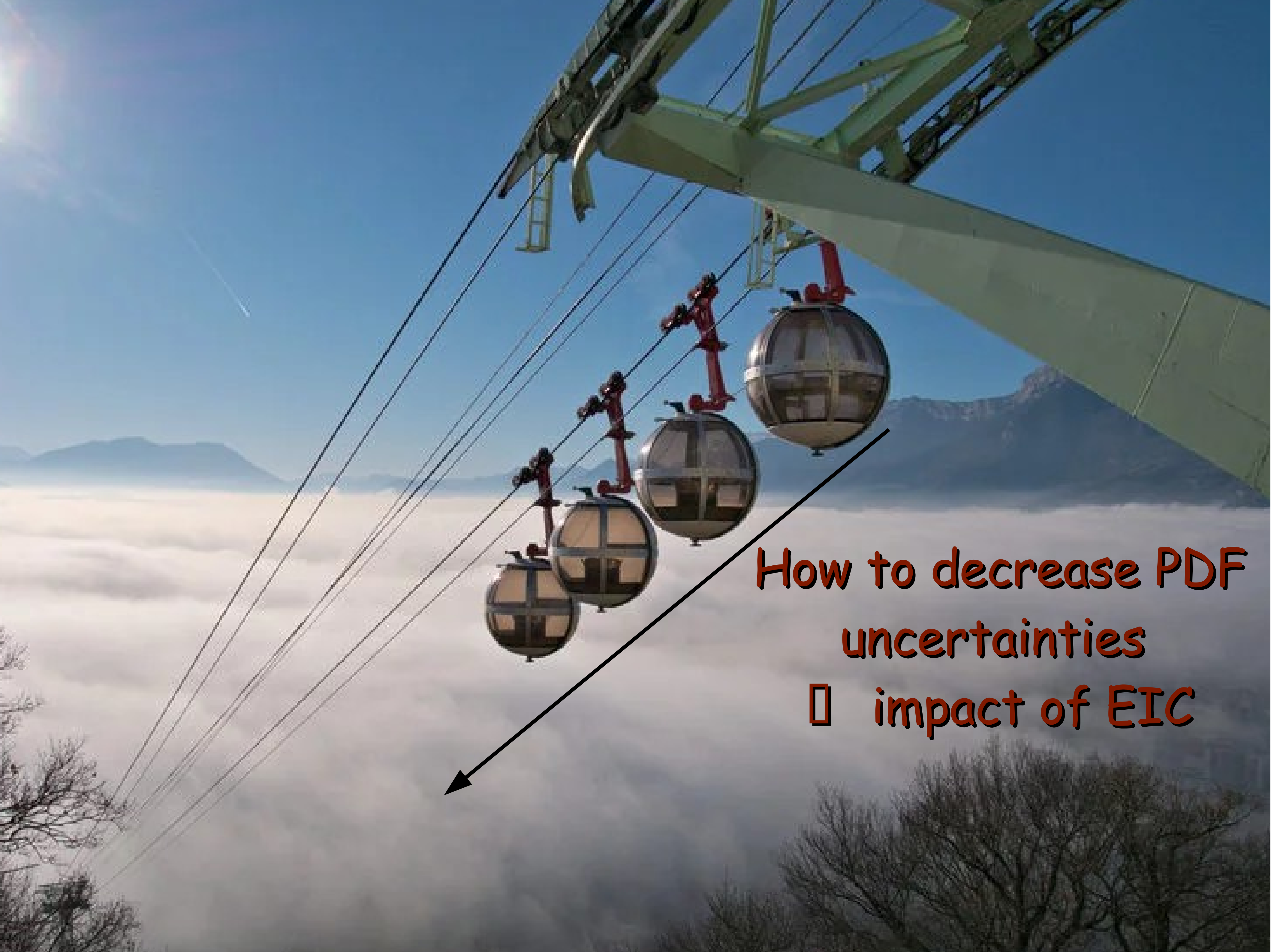

How to decrease PDF uncertainties
impact of EIC

Impact of inclusive electron ion collider data on collinear parton distributions

Néstor Armesto,[1] Thomas Cridge,[2,*] Francesco Giuli,[3] Lucian Harland-Lang,[4] Paul Newman,[5] Barak Schmookler,[6] Robert Thorne,[4] and Katarzyna Wichmann[2]

[1]*Departamento de Física de Partículas and IGFAE, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Galicia, Spain*
[2]*Deutsches Elektronen-Synchrotron DESY, Germany*
[3]*CERN, CH-1211 Geneva, Switzerland*
[4]*Department of Physics and Astronomy, University College, London, WC1E 6BT, United Kingdom*
[5]*School of Physics and Astronomy, University of Birmingham, B15 2TT, United Kingdom*
[6]*Department of Physics and Astronomy, University of California, Riverside, California 92521, USA*

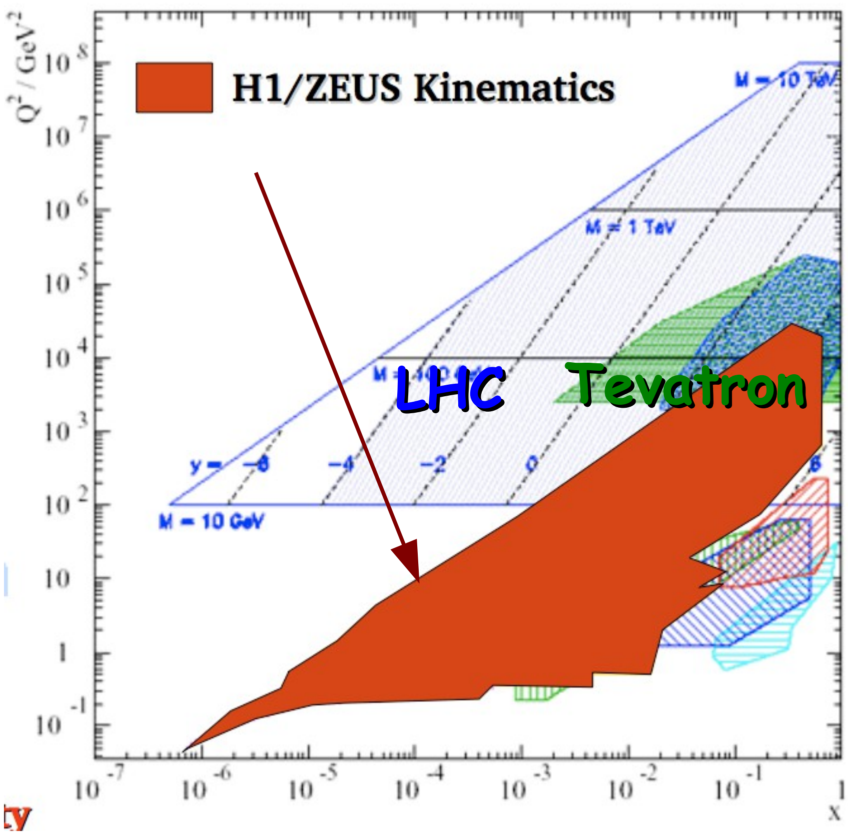
(Received 24 November 2023; accepted 15 February 2024; published 11 March 2024)

A study is presented of the impact of updated simulated inclusive electron ion collider deep inelastic scattering data on the determination of the proton and nuclear parton distribution functions (PDFs) at next-to-next-to-leading and next-to-leading order in QCD, respectively. The influence on the proton PDFs is evaluated relative to the HERAPDF2.0 set, which uses inclusive HERA data only, and also relative to the global fitting approach of the MSHT20 PDFs. The impact on nuclear PDFs is assessed relative to the EPPS21 global fit and is presented in terms of nuclear modification ratios. For all cases studied, significant improvements in the PDF uncertainties are observed for several parton species. The most striking impact occurs for the nuclear PDFs in general and for the region of high Bjorken x in the proton PDFs, particularly for the valence quark distributions.

DOI: 10.1103/PhysRevD.109.054019

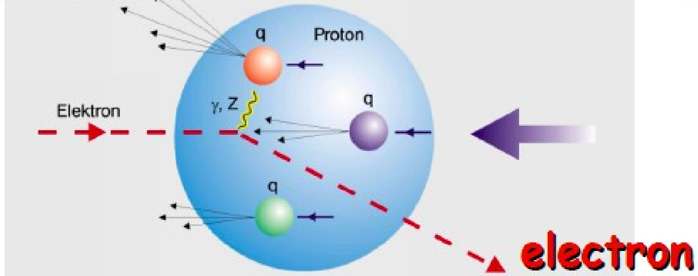
Proton structure

- PDFs used in hadron interactions: LHC, Tevatron, HERA **also EIC!**
- Precision of many measurements often limited by PDF uncertainty

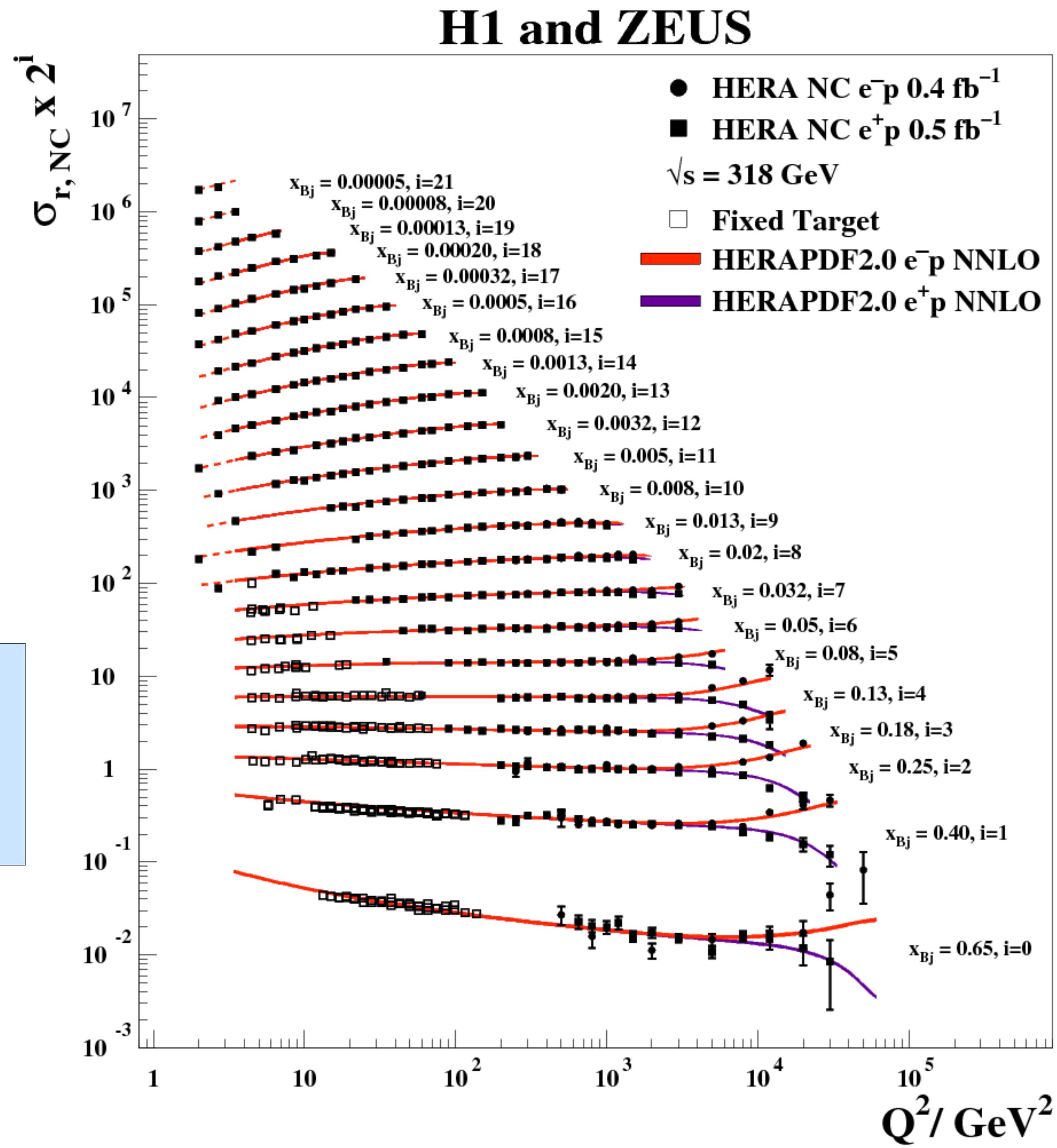


Inclusive measurements from HERA are core of every parton density extraction

K. Wichmann @ DIS 2024



HERA combined inclusive DIS



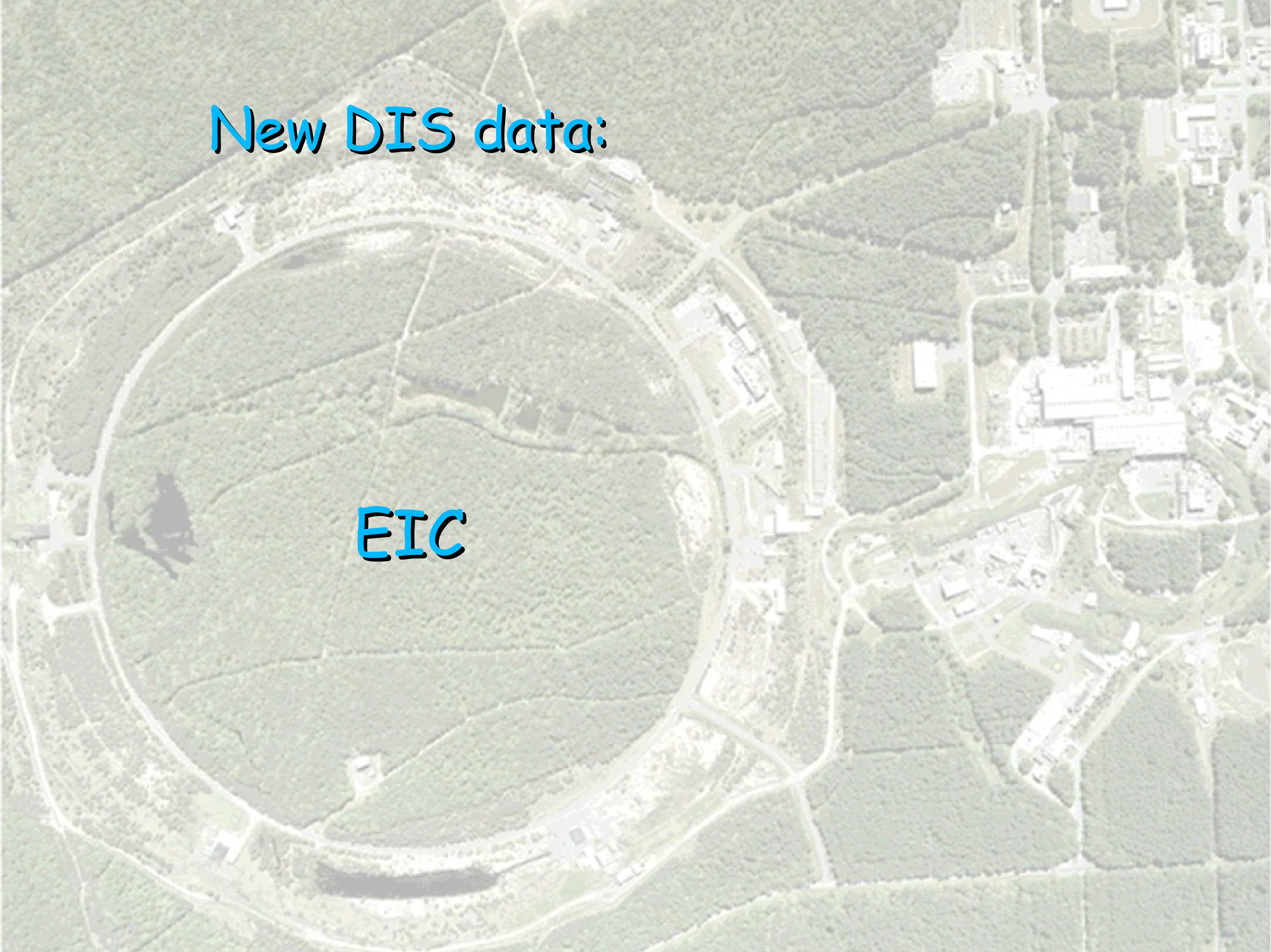
HERAPDF philosophy

HERAPDF approach uses only HERA data in global QCD fit

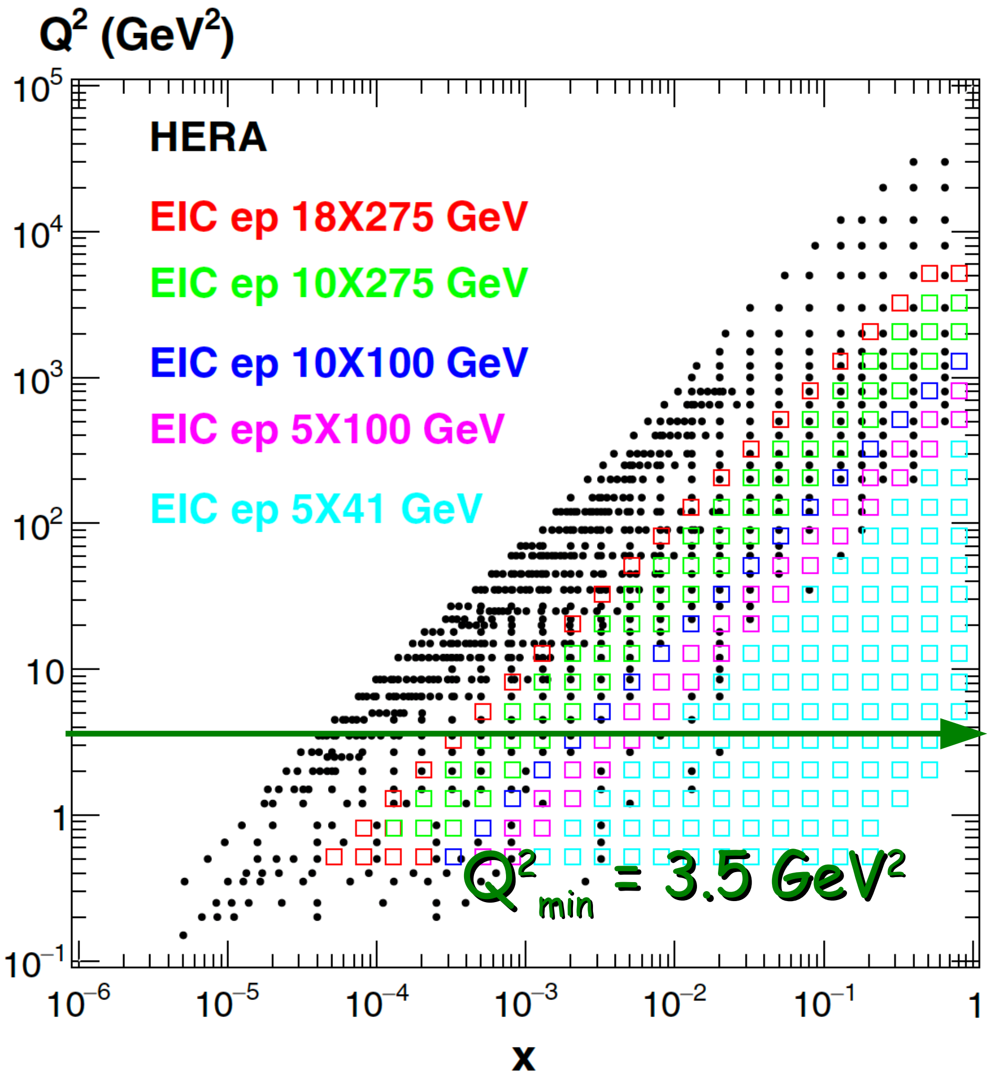
⇒ extend it to only DIS data ...

Eur. Phys. J. **C75** (2015), 12, 580

New DIS data:



HERA & ATHENA phase-space



High-x region not covered by HERA

 impact on high-x PDFs expected

e-beam energy (GeV)	p-beam energy (GeV)	$\sqrt{s}$ (GeV)	Integrated lumi (fb^{-1})
18	275	141	15.4
10	275	105	100
10	100	63	79.0
5	100	45	61.0
5	41	29	4.4

NNLO QCD analysis with DIS data

- EIC pseudo-data created using HERAPDF2NNLO with $\alpha_s(M_Z) = 0.118$
- HERAPDF procedure used

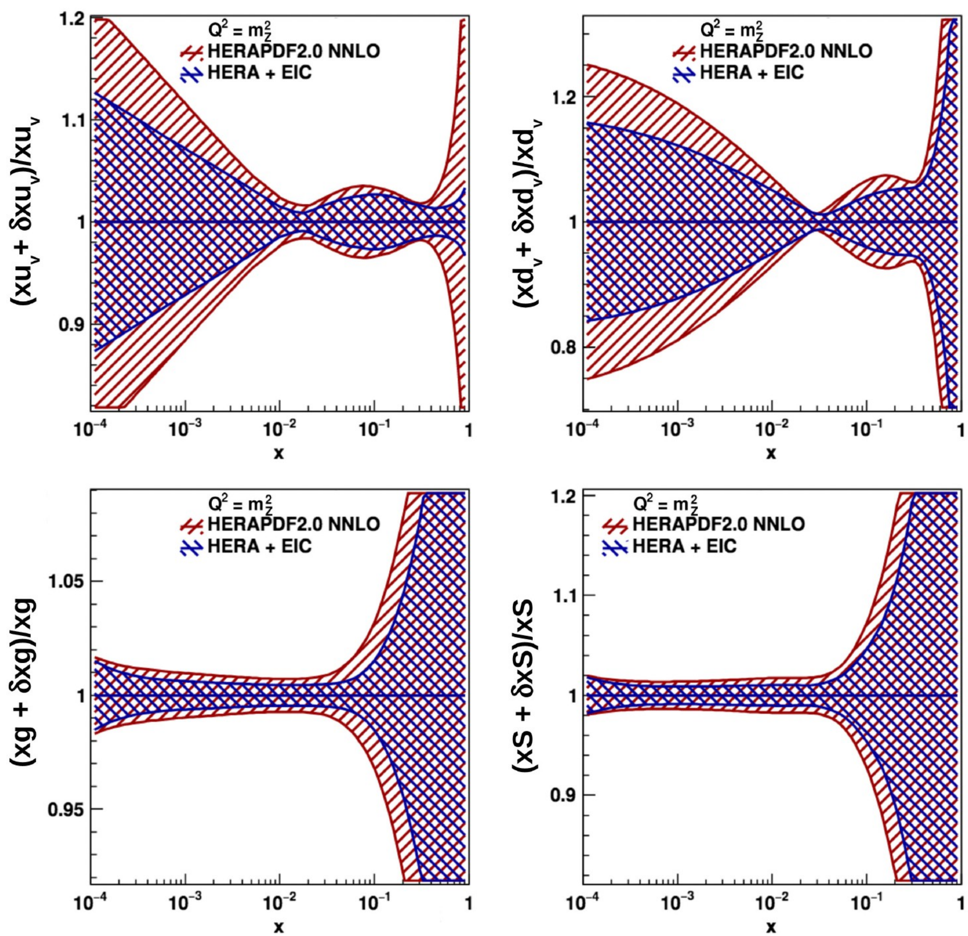
$$
\begin{aligned}
xg(x) &= A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{25};\\
xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} \left(1 + E_{u_v} x^2\right);\\
xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}};\\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} (1 + D_{\bar{U}} x);\\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

- Cuts
  - $Q^2 > 3.5$ GeV^2
  - $W^2 = Q^2(1-x)/x > 10$ GeV
  - $0.001 < y < 0.95$

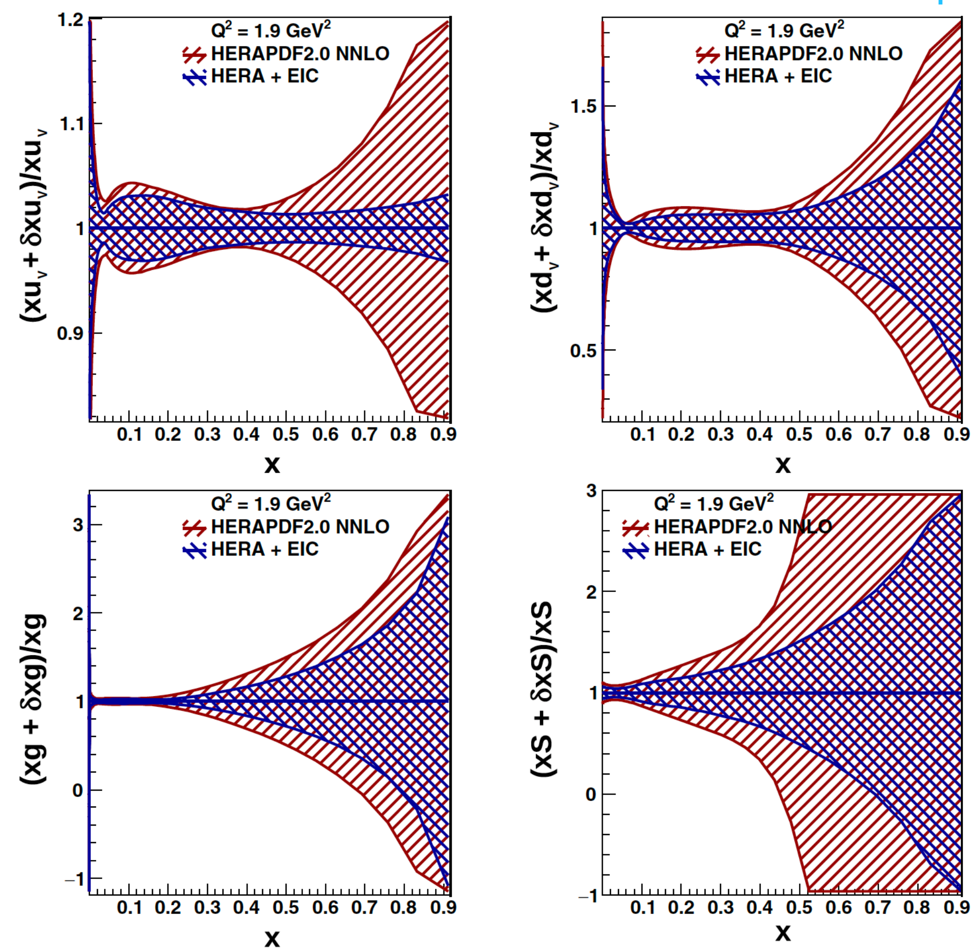
- Pseudodata uncertainties
  - Most data points have uncorrelated systematic uncertainty of 1.9%, extending to 2.75% at lowest y values
  - Additional normalisation uncertainty of 3.4% taken to be fully correlated between data at each CME, and fully uncorrelated between different CMEs

DIS-only fits

- Dramatic improvement of valence quarks at large x
- Improvement also for gluons/sea



Log-x scale



Lin-x scale

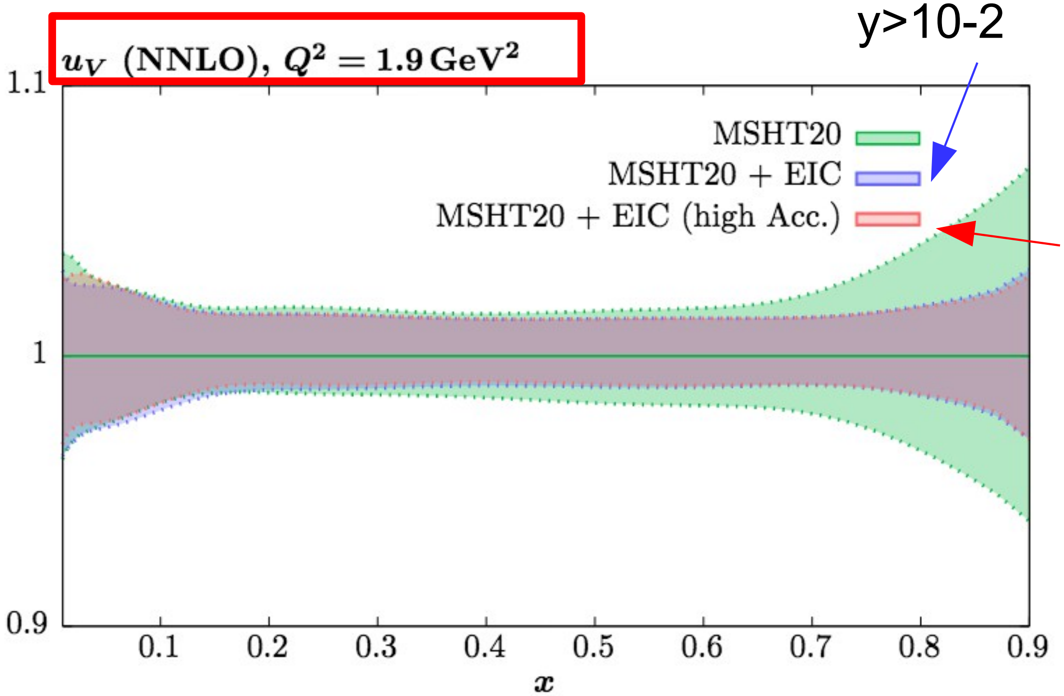
Impact of EIC data on global fits

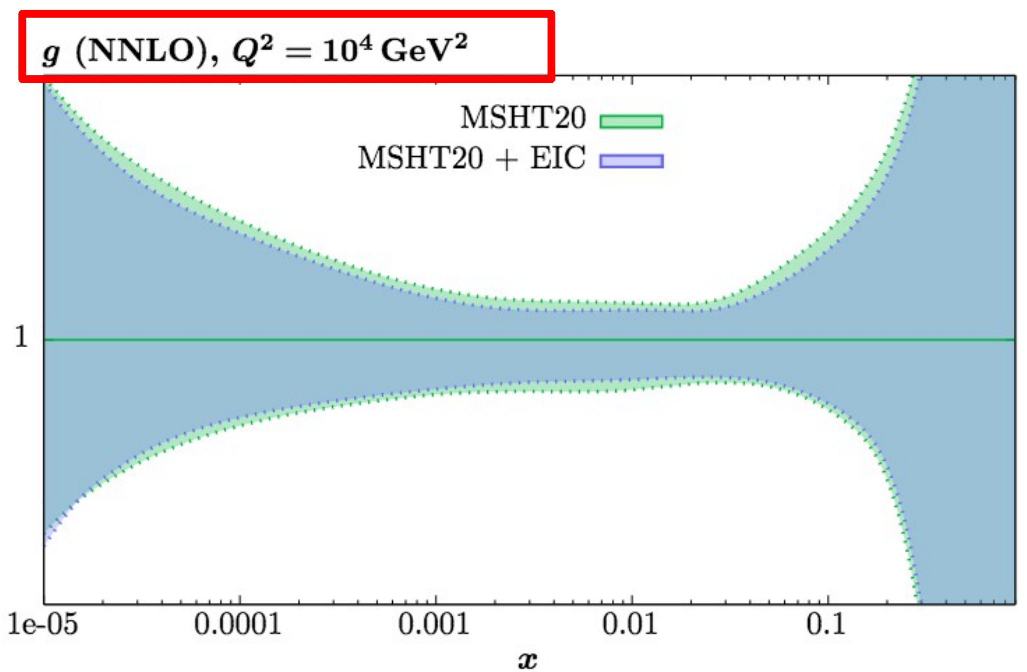
- Studies using MSHT20 approach
  - Parameterisations using Chebyshev polynomials (52 parameters in total)

$$xf(x,Q_0^2) \;=\; A(1-x)^{\eta}x^{\delta}\left(1+\sum_{i=1}^{n}a_i T_i^{\mathrm{Ch}}(y(x))\right)$$

  - Data with $Q^2 > 2$ GeV^2, $W^2 > 15$ GeV^2
- Pseudo-data created with MSHT20 with uncertainty assumptions
  - Most data points have uncorrelated systematic uncertainty of 1.9%, extending to 2.75% at lowest y values
  - Additional normalisation uncertainty of 3.4% taken to be fully correlated between data at each CME, and fully uncorrelated between different CMEs
- DIS data with $Q^2 > 2$ GeV^2, $W^2 > 15$ GeV^2

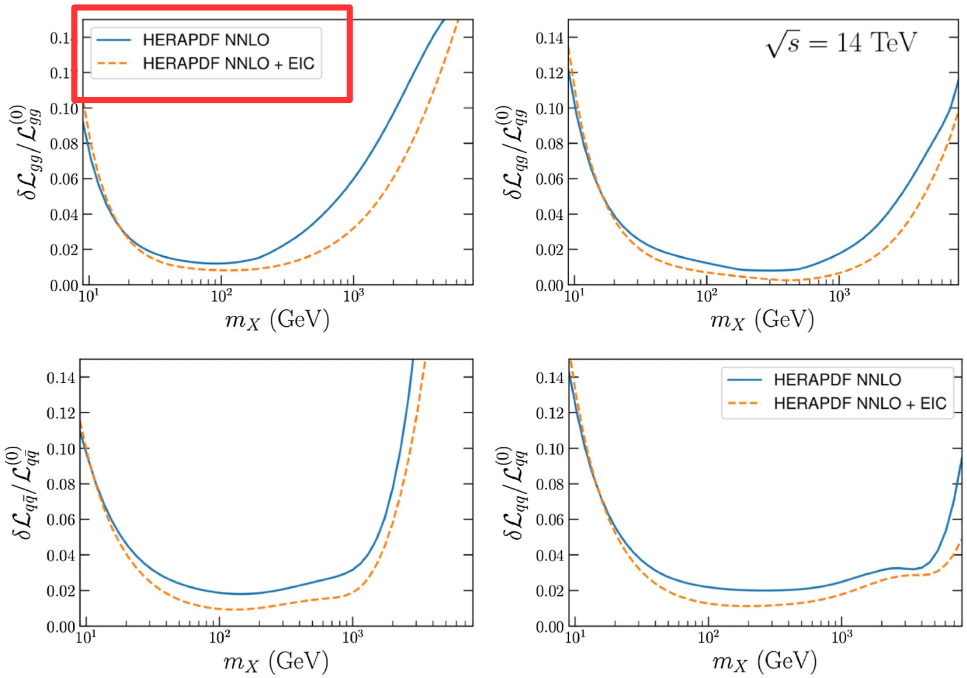
Impact of EIC data on global fits @NNLO

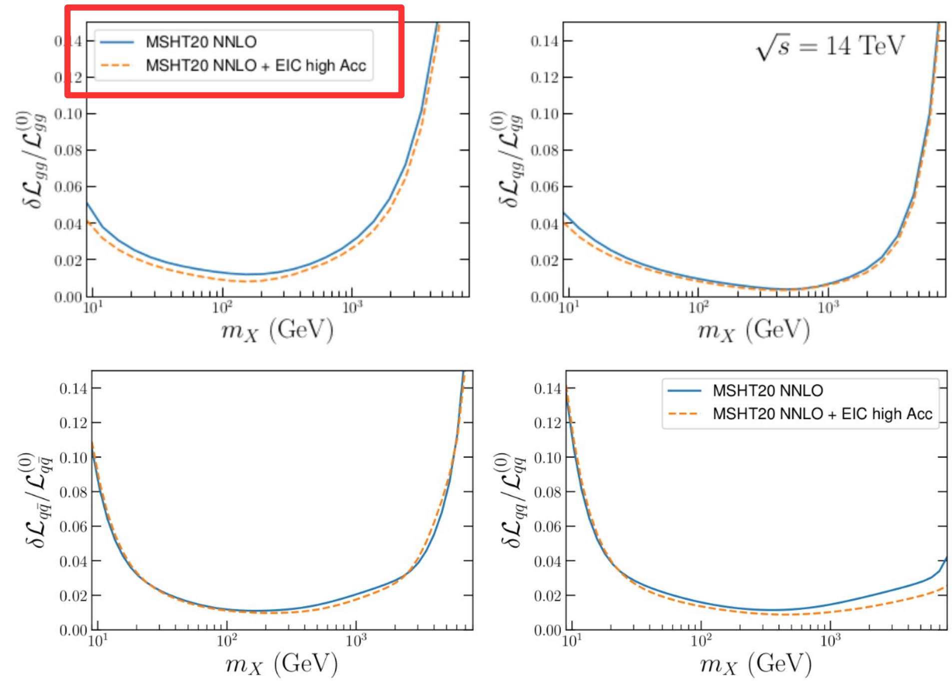




- Improvement significantly reduced compared with HERAPDF2.0
- Still significant effects present
  - biggest impact on up-valence distribution
  - small but valuable improvement on all parton species visible at all x and Q^2 values

Parton luminosities

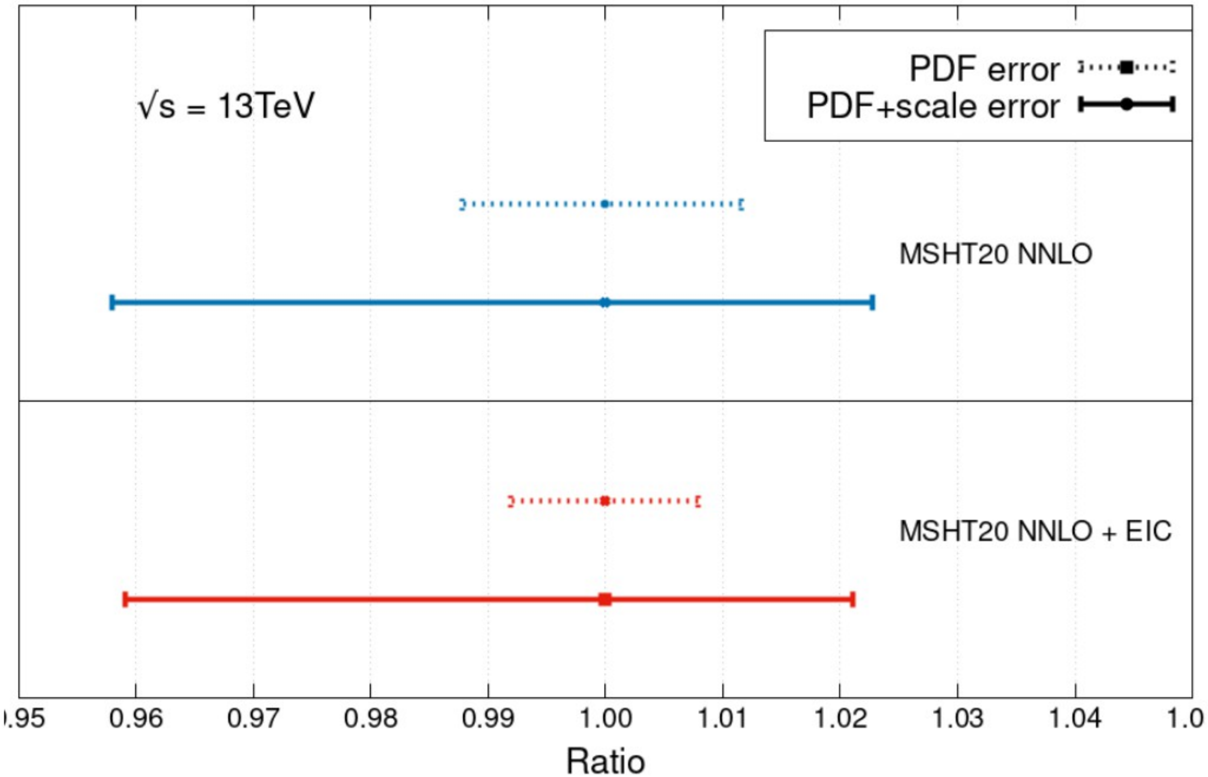




- Reduced uncertainties
  - Largest impact at high m_X coming from PDF constraints at high x
  - gluon-gluon luminosity shows largest reduction in uncertainty, up to ħ50% at larger invariant masses

- Relatively mild improvement for luminosities
- Impact of EIC pseudodata on MSHT20 smaller than that of HERAPDF2.0
  □ consistent with changes seen in PDF uncertainties

Impact of EIC data on Higgs production



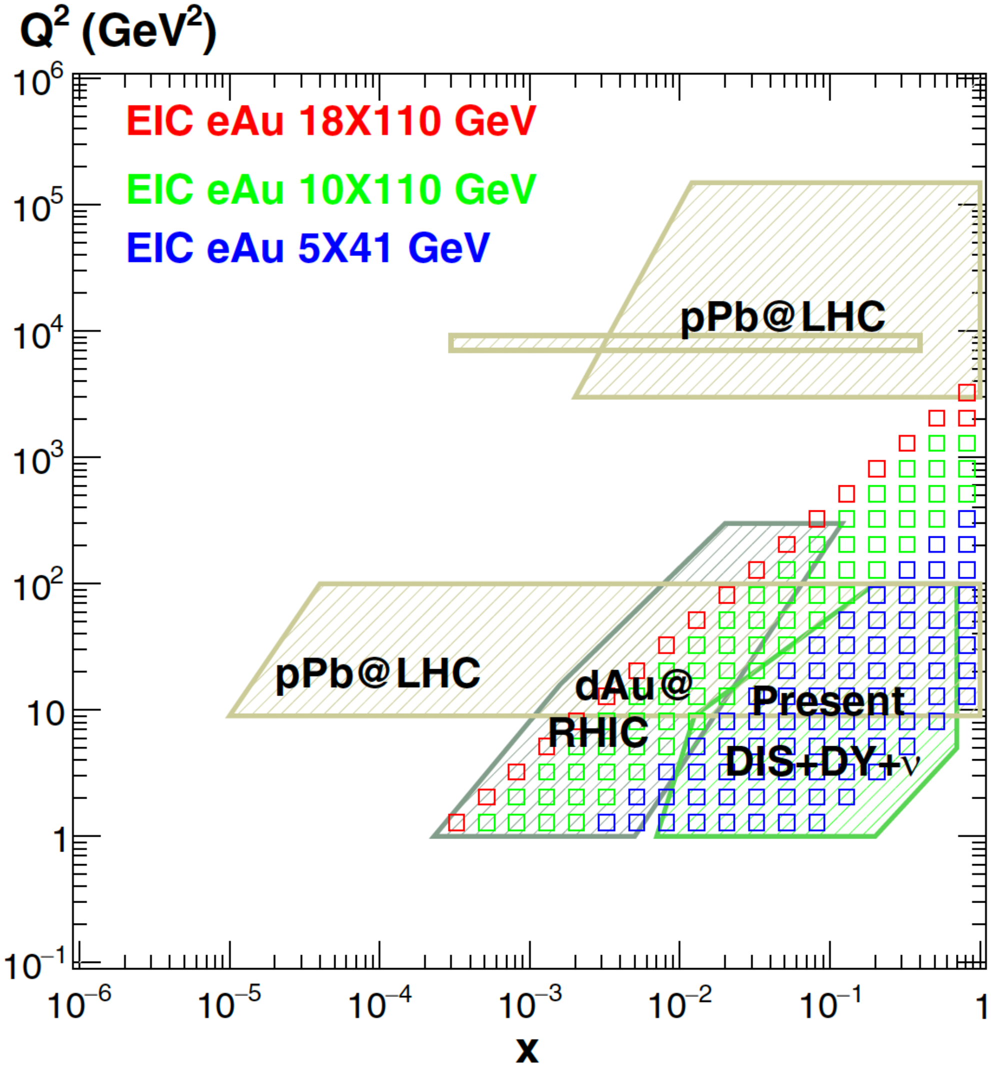
• Reduction in gluon-gluon luminosity uncertainty directly affects precision of predictions for Higgs production from gluon-gluon fusion

 with EIC uncertainty in gg luminosity at m_H 125 GeV goes from 1.2% to 0.8%

 same for PDF uncertainty

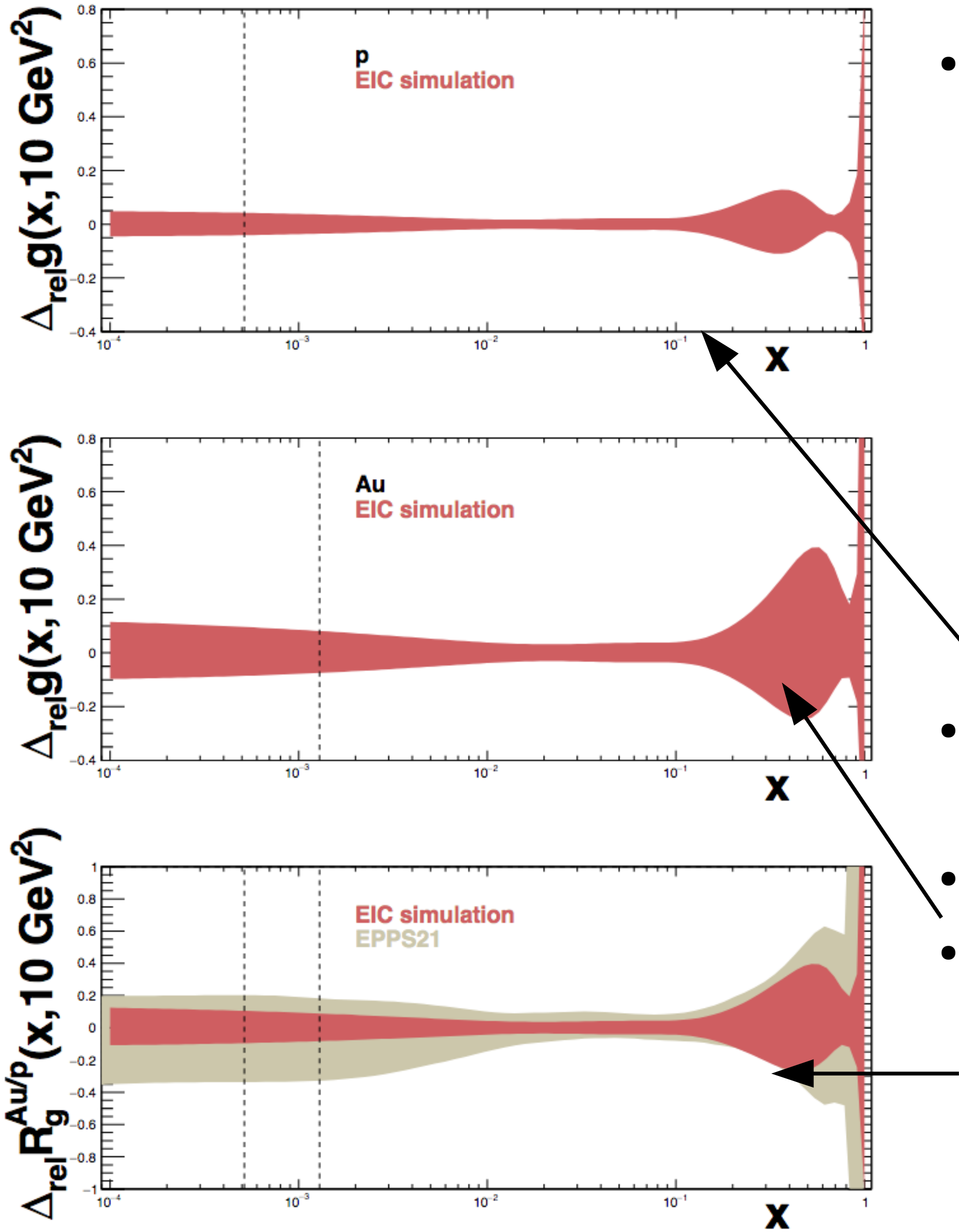
 however large scale variations make overall impact smaller

Nuclear PDFs from EIC



- EIC will have revolutionary impact on eA phase space → most promising environment to observe novel low-x effects
- Studies performed @ NLO in xFitter & HERAPDF framework to assess sensitivity of EIC relative to EPPS21 (<u>representative current global fit</u>)
  - EPPS21 includes
    - Fixed target DIS and DY
    - p+A at LHC
    - π^0 from PHENIX

Impact on Nuclear PDFs: Gluon

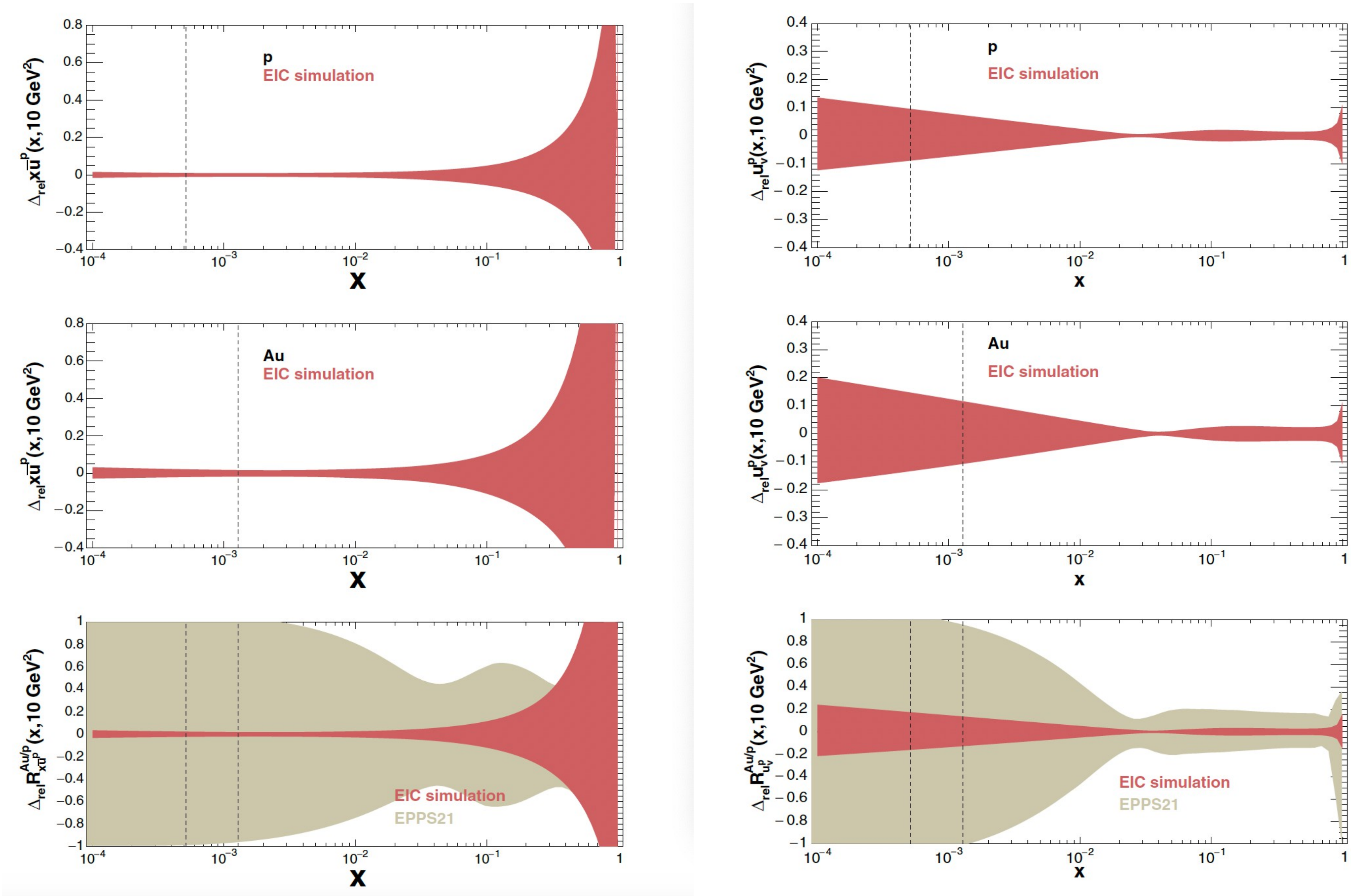


- Nuclear PDFs studied in terms of nuclear modification factor R:

It encodes deviations of nPDFs from simple scaling of free nucleon PDFs with atomic mass A after accounting for varying proton-to-neutron ratios using isospin symmetry

- Relative uncertainty of gluon in proton EIC-only fits
- Uncertainty of gluon in gold nucleus
- Nuclear modification factor formed from ratio of gluon in gold and proton

Impact on Nuclear PDFs: sea and valence u quarks



Precision largely improved <u>with EIC data only</u>

⇒ factor of 2 @ x ~ 0.1

Message to take home

Using EIC data will make tremendous difference in proton and nuclear PDFS, especially at high x