A sequential global analysis of Proton and nuclear PDFs at the Electron Ion Collider

XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects

Rabah Abdul Khalek

Thursday 15/04/2021

Outline

1

NNPDF3.1 and nNNPDF2.0

Parameterisation - Constraints

"Parton distributions from high-precision collider data"

— *arXiv:1706.00428*

"nNNPDF2.0: Quark Flavor Separation in Nuclei from LHC Data"

— *arXiv:2006.14629*

2

Electron Ion collider Impact

"Self-consistent determination of proton and nuclear PDFs at the Electron Ion Collider"

— *arXiv:2102.00018*

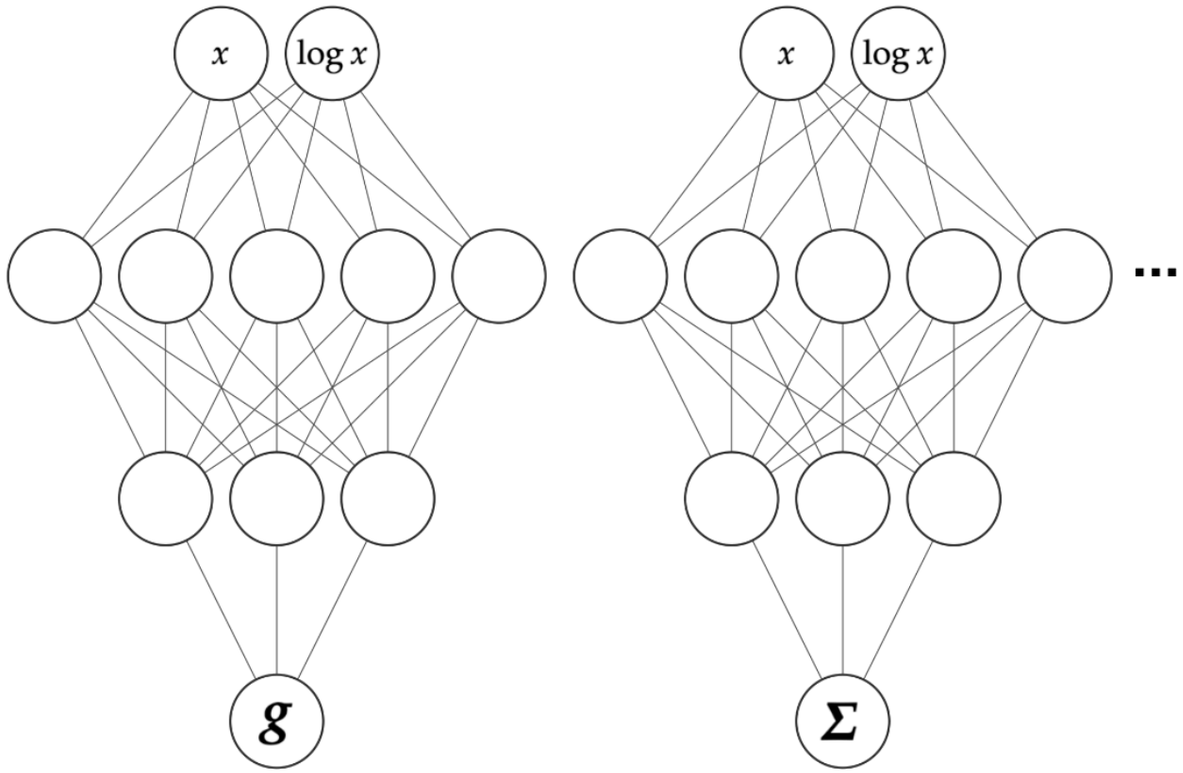
"Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report"

— *arXiv:2103.05419*

NNPDF3.1 Parameterisation

`NNPDF3.1` parameterisation basis: $\{g \quad \Sigma \quad T_3 \quad T_8 \quad V \quad V_3 \quad V_8 \quad (c^+)\}$

and $b = t = 0$ at $Q_0 = 1$ (1.65) GeV



$$\Sigma = \sum_i^{n_f} f_i^+ \text{ (Singlet)}$$

$$T_3 = u^+ - d^+$$

$$T_8 = u^+ + d^+ - 2s^+$$

$$V = \sum_i^{n_f} f_i^- \text{ (Valence)}$$

$$V_3 = u^- - d^-$$

$$V_8 = u^- + d^- - 2s^-$$

$$f_i(x, Q_0) = A_i \hat{f}_i(x, Q_0), \quad \hat{f}_i(x, Q_0) = x^{\alpha_i}(1-x)^{\beta_i} NN_i(x)$$

$$A_g = \frac{1 - \int_0^1 dx x \Sigma(x, Q_0)}{\int_0^1 dx x \hat{g}(x, Q_0)}, \quad A_\Sigma = A_{T_3} = A_{T_8} = 1$$

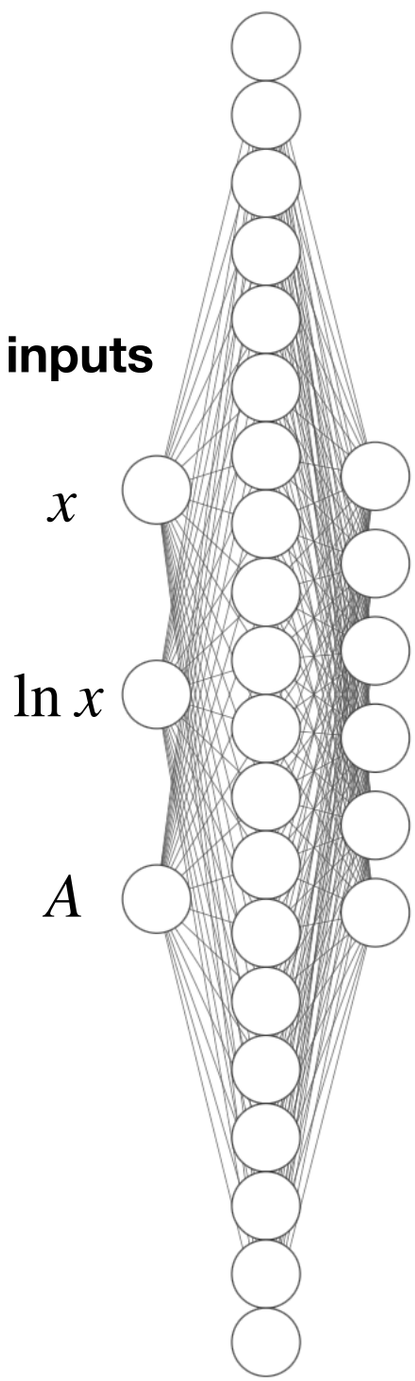
$$A_V = \frac{3}{\int_0^1 dx \hat{V}(x, Q_0)}, \quad A_{V_3} = \frac{1}{\int_0^1 dx \hat{V}_3(x, Q_0)}, \quad A_{V_8} = \frac{3}{\int_0^1 dx \hat{V}_8}$$

nNNPDF2.0 Parameterisation

nNNPDF2.0 parameterisation basis: $\{g \quad \Sigma \quad T_3 \quad T_8 \quad V \quad V_3\}$

and $b = t = 0$ at $Q_0 = 1$ GeV

25 nodes



3 inputs

$$f_i^A = Zf_i^{p/A} + (A-Z)f_i^{n/A} \qquad f_i^{p/A} = N_i x^{\alpha}(1-x)^{\beta} NN_i(x, A)$$

6 independent flavours, 256 free parameters

$$\begin{aligned}
x\Sigma^{(p/A)}(x, Q_0) &= x^{\alpha_\Sigma}(1-x)^{\beta_\Sigma}\mathrm{NN}_\Sigma(x, A)\,, \\
xT_3^{(p/A)}(x, Q_0) &= x^{\alpha_{T_3}}(1-x)^{\beta_{T_3}}\mathrm{NN}_{T_3}(x, A)\,, \\
xT_8^{(p/A)}(x, Q_0) &= x^{\alpha_{T_8}}(1-x)^{\beta_{T_8}}\mathrm{NN}_{T_8}(x, A)\,, \\
xV^{(p/A)}(x, Q_0) &= B_V x^{\alpha_V}(1-x)^{\beta_V}\mathrm{NN}_V(x, A)\,, \\
xV_3^{(p/A)}(x, Q_0) &= B_{V_3} x^{\alpha_{V_3}}(1-x)^{\beta_{V_3}}\mathrm{NN}_{V_3}(x, A)\,, \\
xg^{(p/A)}(x, Q_0) &= B_g x^{\alpha_g}(1-x)^{\beta_g}\mathrm{NN}_g(x, A)\,.
\end{aligned}$$

Sum Rules

$$f^{n/A}_{u(d),\bar{u}(\bar{d})} = f^{p/A}_{d(u),\bar{d}(\bar{u})}$$

SU(2) isospin symmetry

nNNPDF2.0 Constraints

$$\chi^2 = \sum_{i,j=1}^{N_{\rm dat}} (D_i - T_i)(\mathrm{cov}_{t_0})^{-1}_{ij}(D_j - T_j)$$

Common with NNPDF3.1

$$+\lambda_{bc} \sum_m^{n_f} \sum_{l=1}^{N_x} \left(f_m^{(p/A)}(x_l, Q_0, A=1) - f_m^{(p)}(x_l, Q_0) \right)^2$$

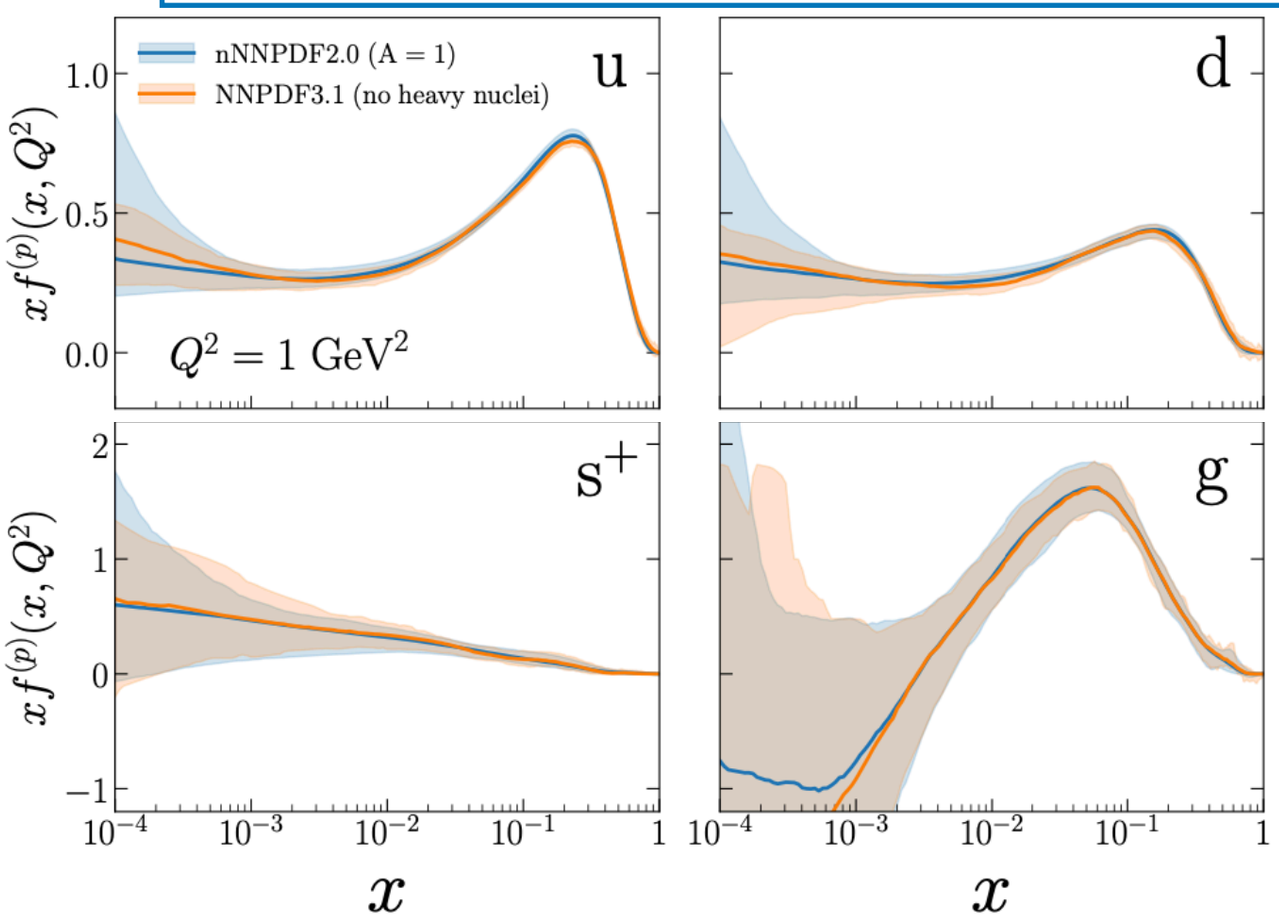
nNNPDF2.0 A=1 Boundary condition
Member-by-member correlation

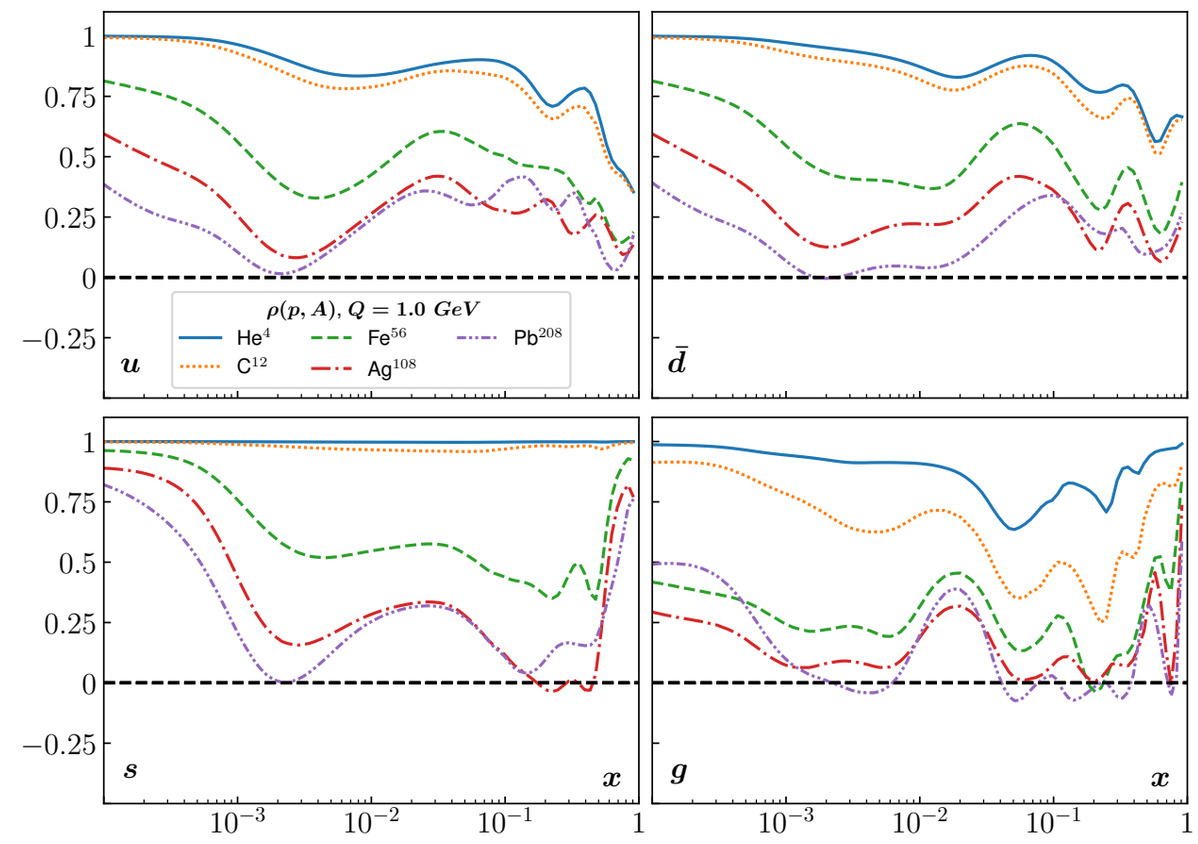
$$+\lambda_{pos} \sum_k^{N_{\rm pos}} \max(0, -O_k^{pos}) \longrightarrow$$

Positivity constraint for $x \in [10^{-7}, 1]$

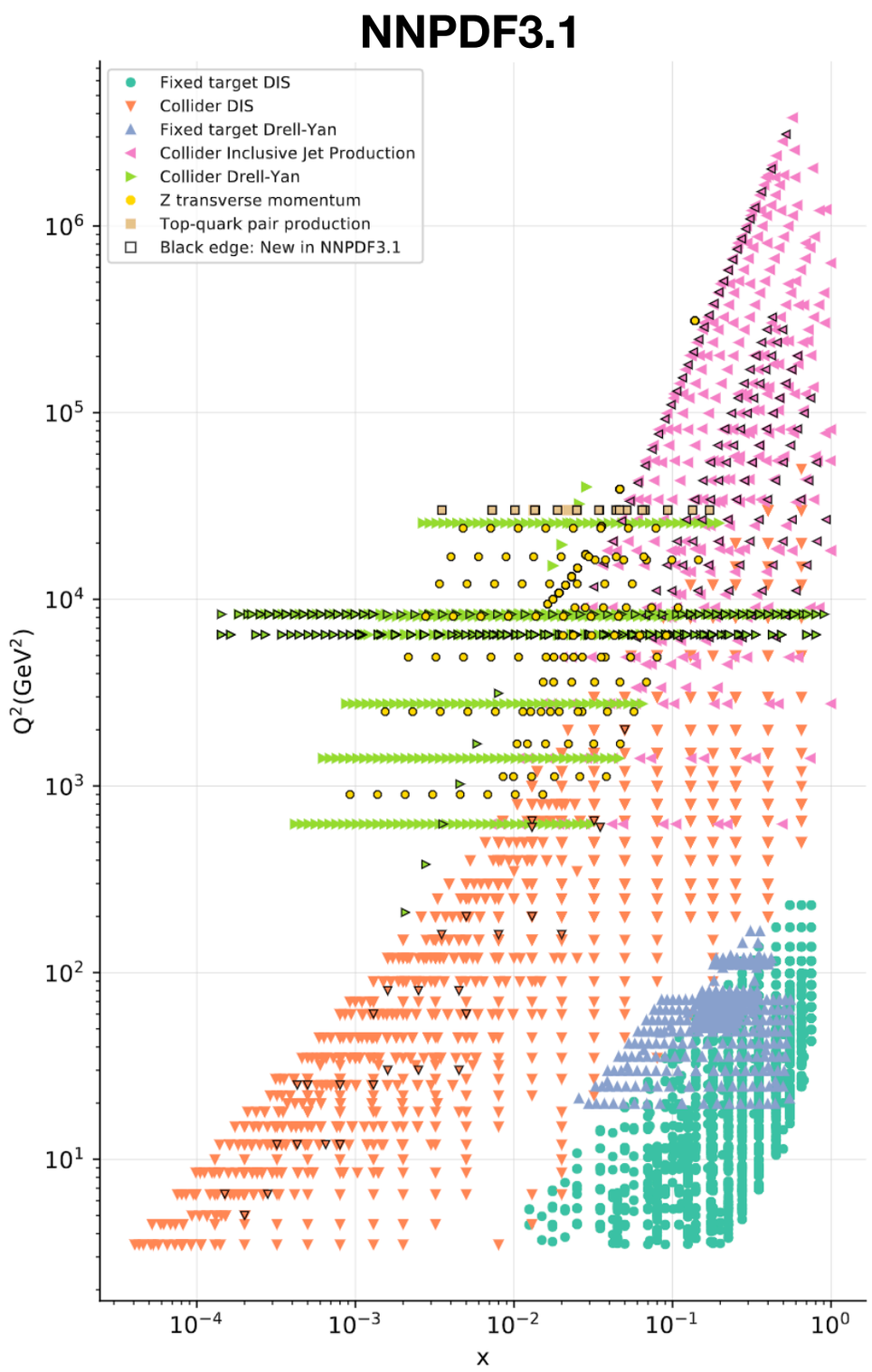
$$F_2^u,\ F_2^d,\ F_2^s,\ d^2_{M^2y}\sigma^{DY}_{u\bar{u}},\ d^2_{M^2y}\sigma^{DY}_{d\bar{d}},\ d^2_{M^2y}\sigma^{DY}_{s\bar{s}},\ F_L^l$$

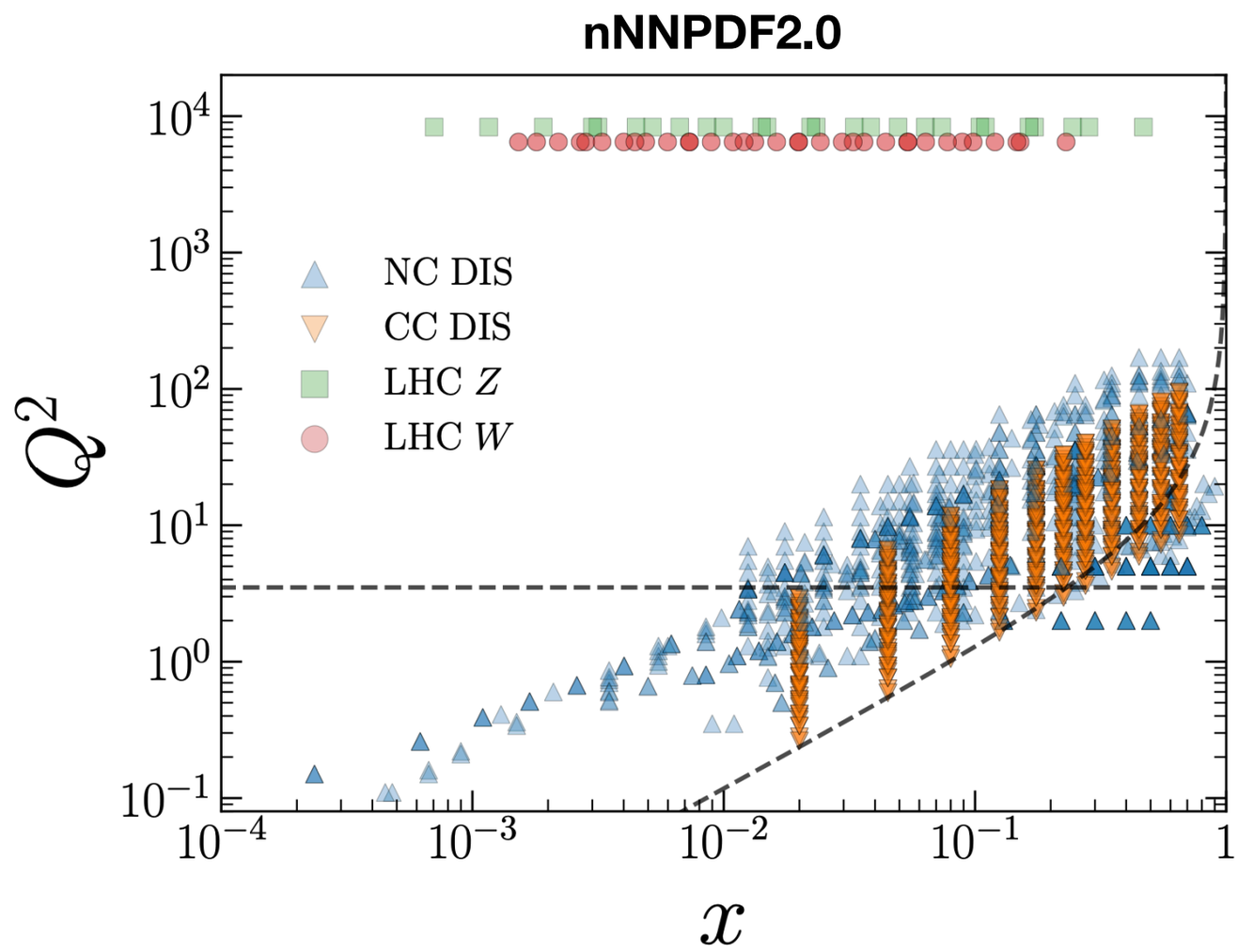
Common with NNPDF3.1



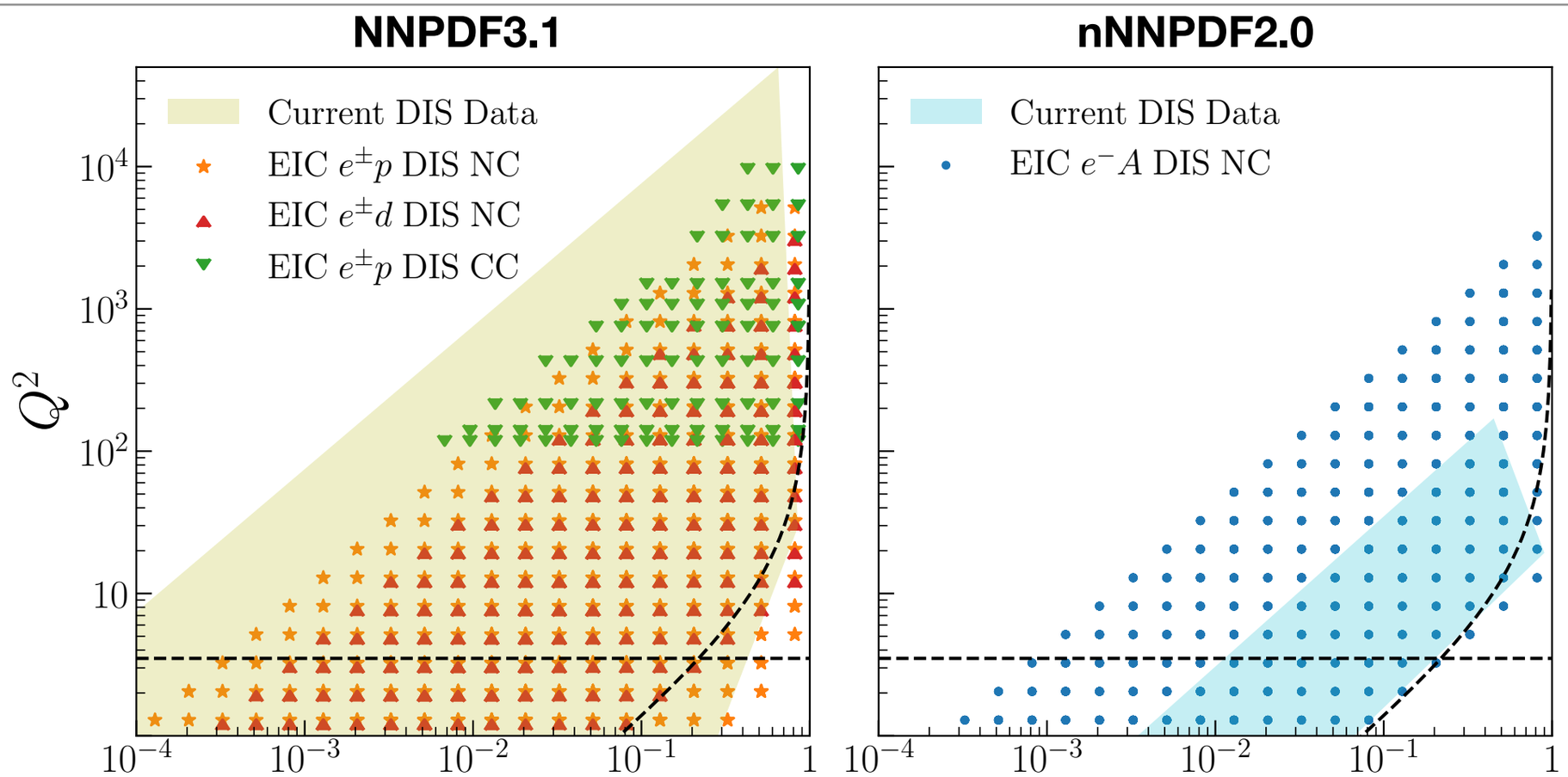


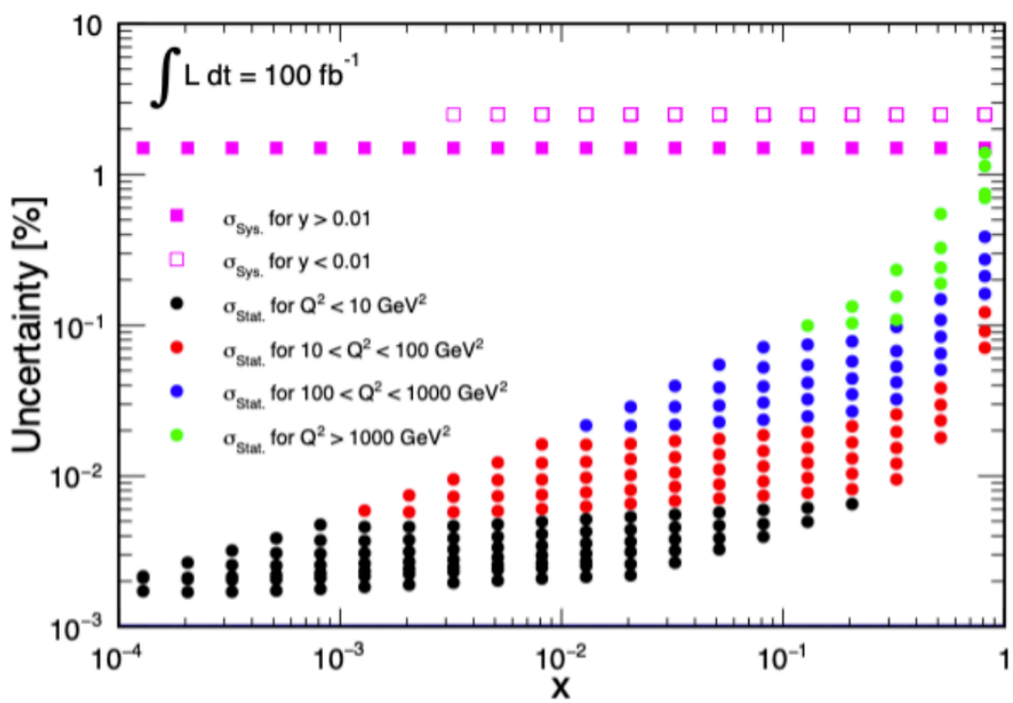
Kinematic coverage



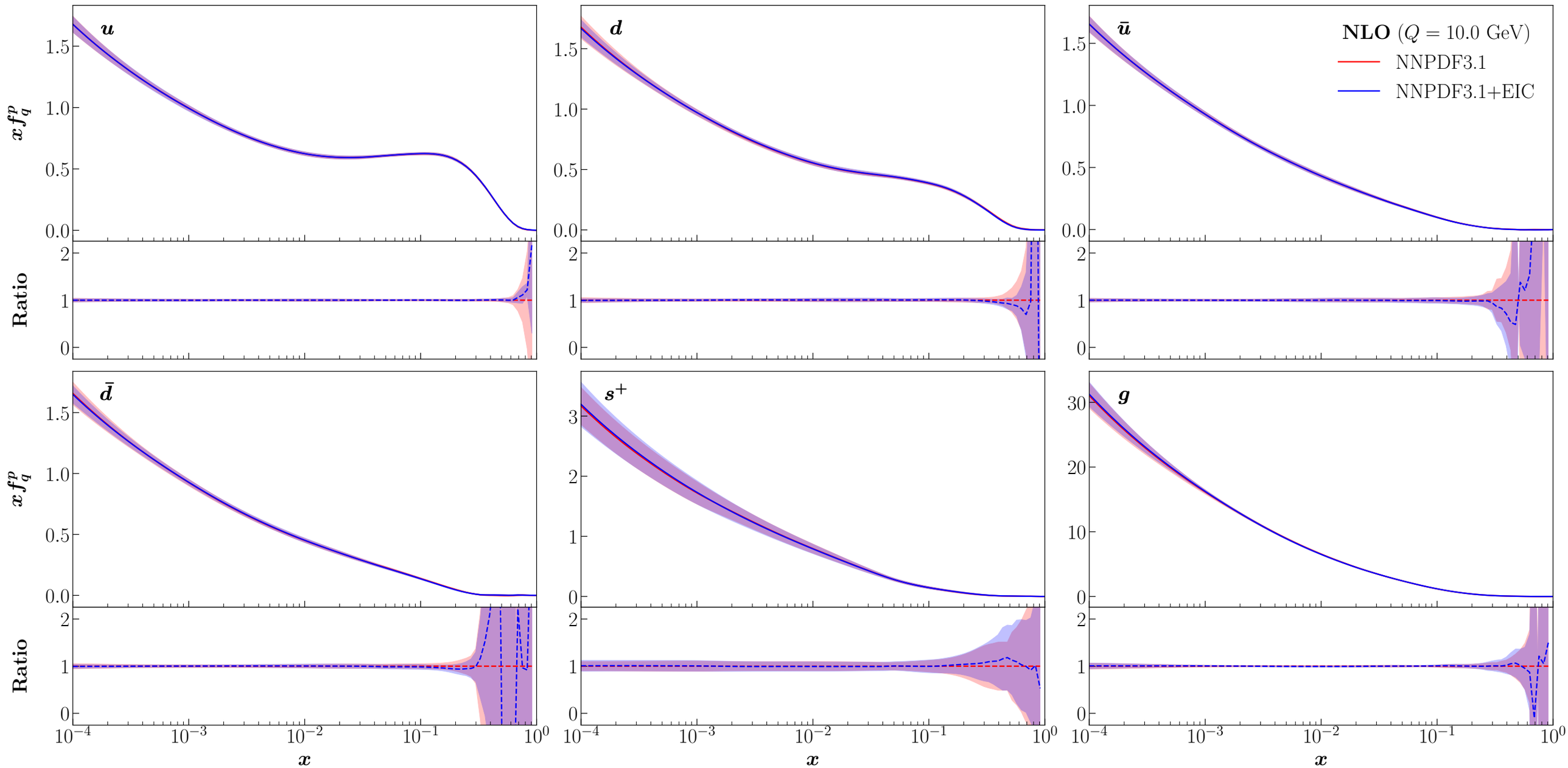


EIC Kinematic coverage



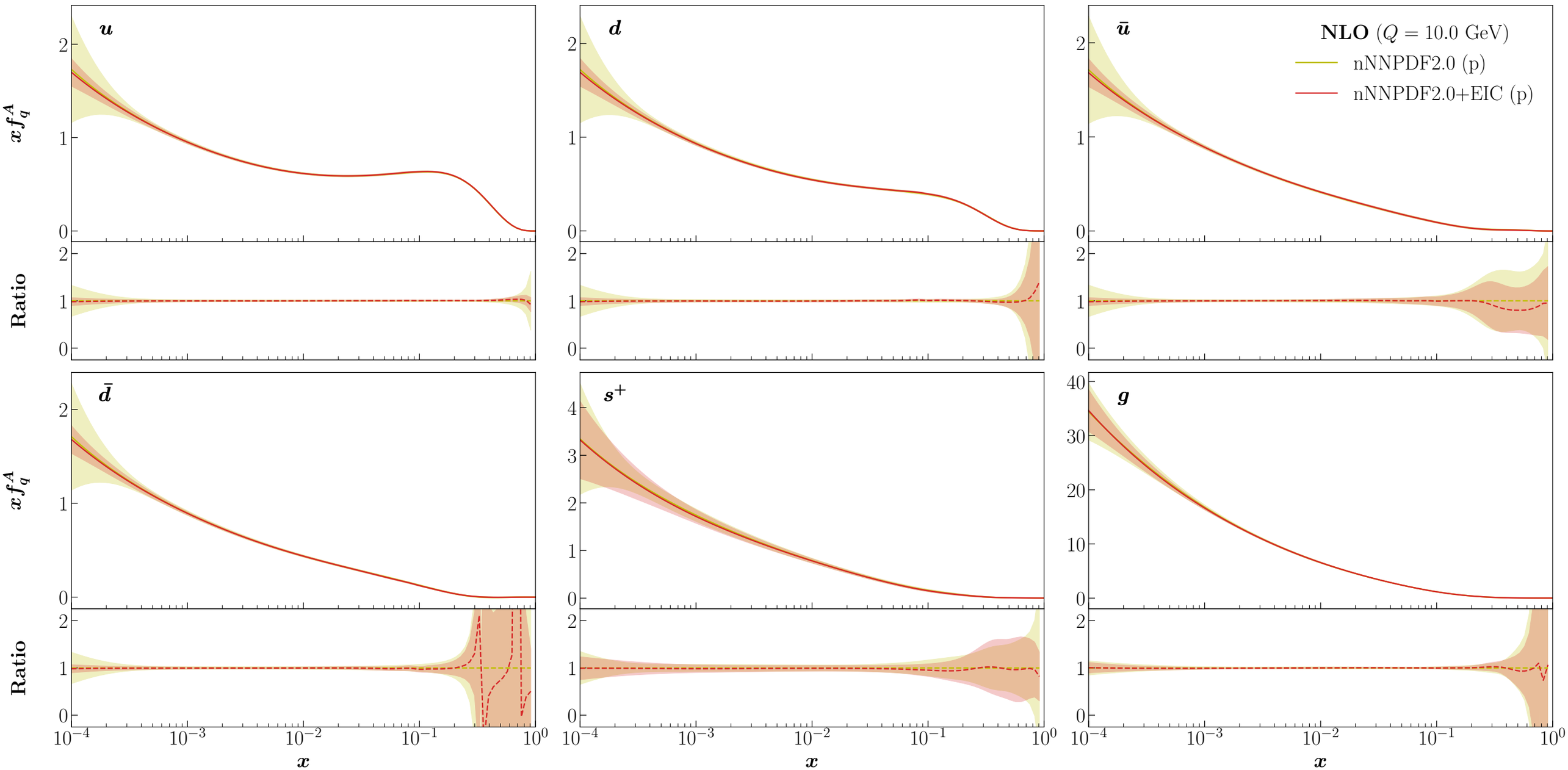


Impact on NNPDF3.1

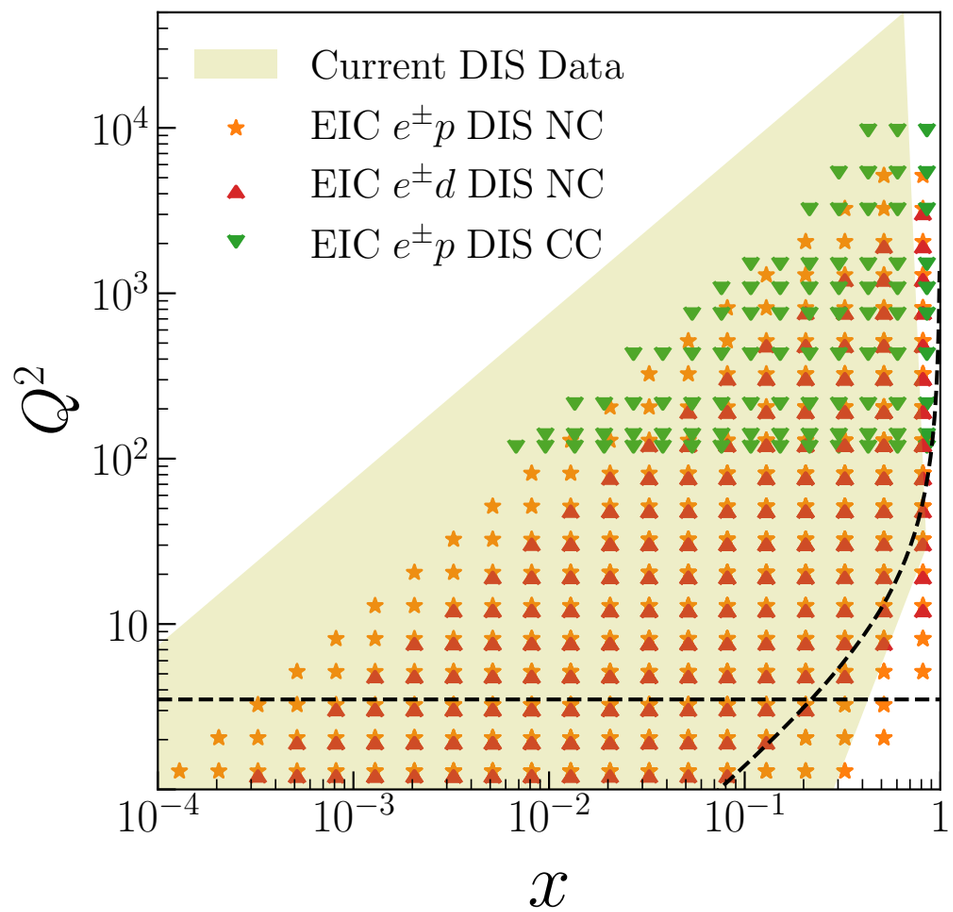


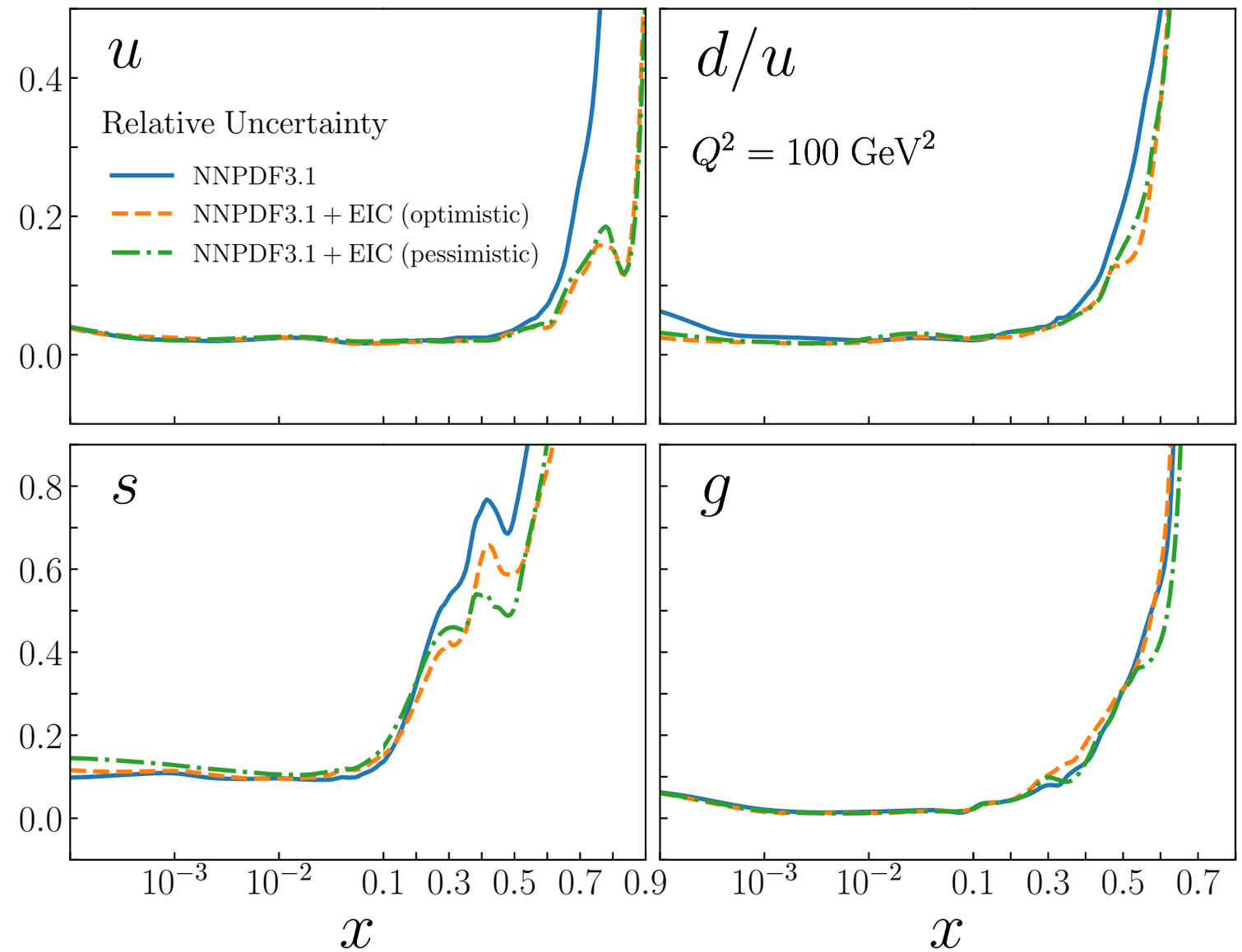
Impact on NNPDF3.1*

***NNPDF3.1 without CHORUS nor NuTeV**



EIC impact on PDFs

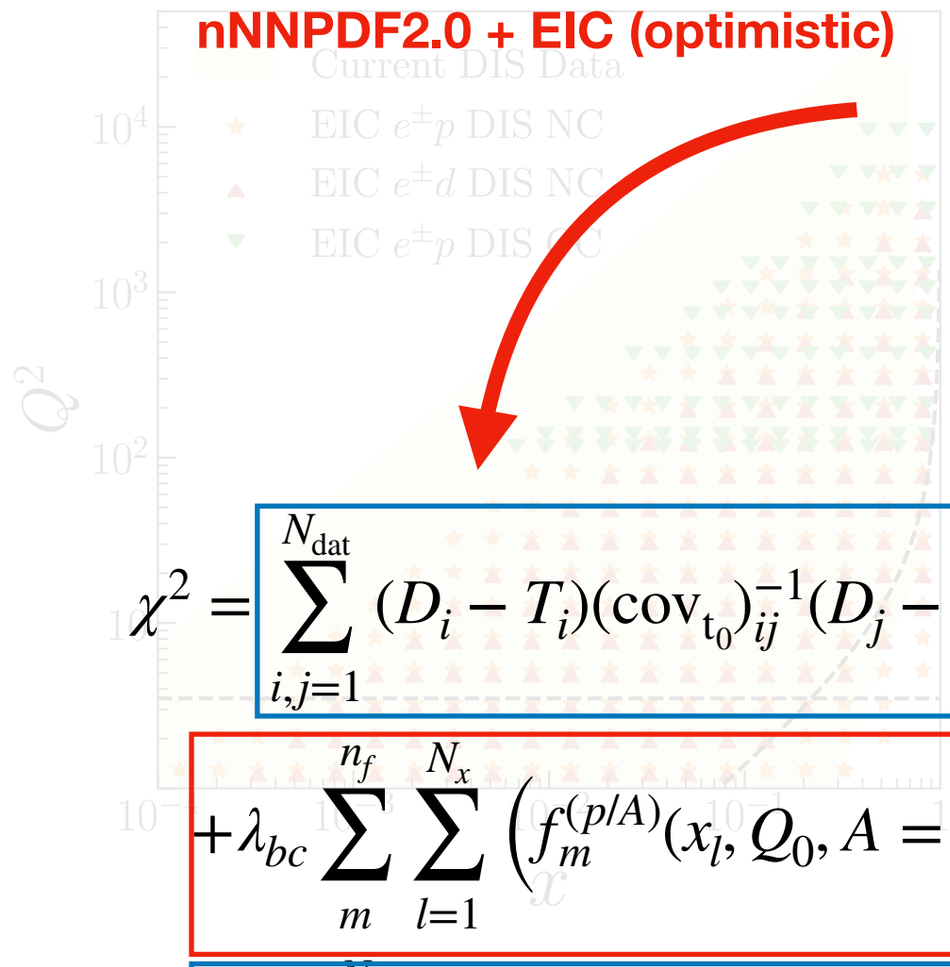


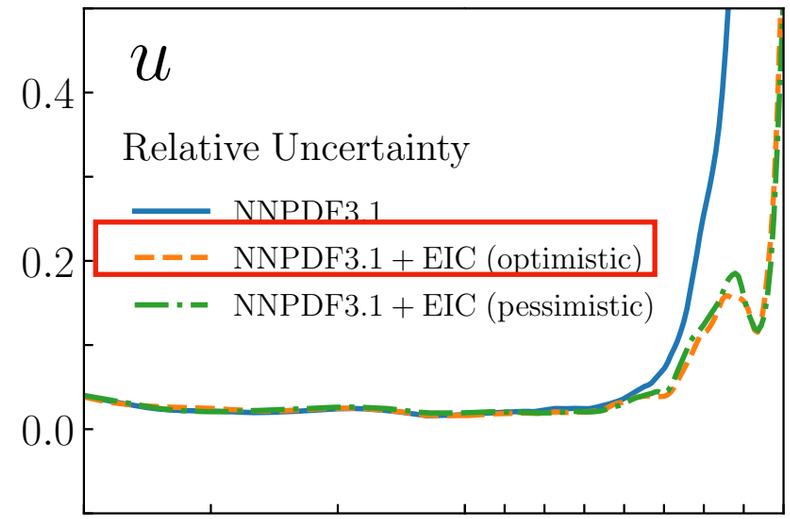


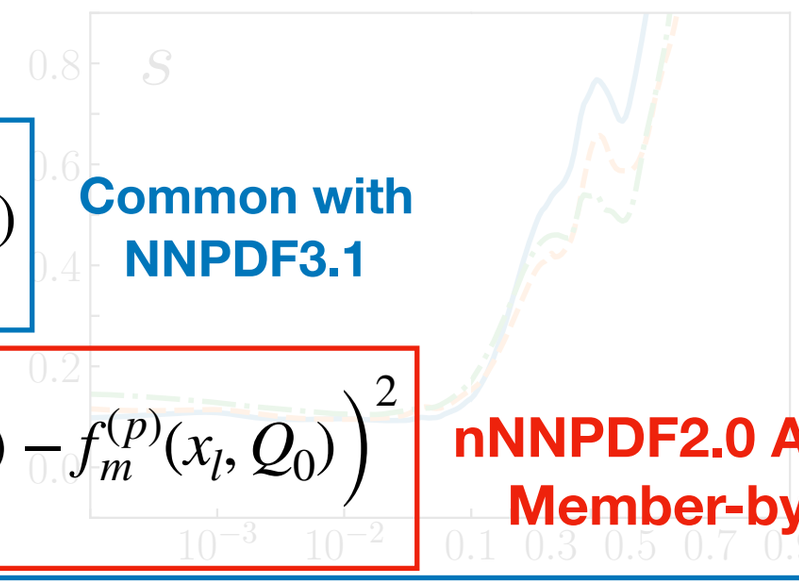
- **EIC could reduce the uncertainty of the light quark PDFs of the proton at large x**
- **Size of this reduction is similar for both the optimistic and pessimistic scenarios.**

EIC impact on PDFs

We take NNPDF3.1 + EIC (optimistic)
To be the boundary condition in
nNNPDF2.0 + EIC (optimistic)







$$\chi^2 = \sum_{i,j=1}^{N_{\rm dat}} (D_i - T_i)(\mathrm{cov}_{t_0})^{-1}_{ij}(D_j - T_j)$$

Common with NNPDF3.1

$$+\lambda_{bc} \sum_m^{n_f} \sum_{l=1}^{N_x} \left(f_m^{(p/A)}(x_l, Q_0, A=1) - f_m^{(p)}(x_l, Q_0) \right)^2$$

nNNPDF2.0 A=1 Boundary condition
Member-by-member correlation

$$+\lambda_{pos} \sum_k^{N_{\rm pos}} \max(0, -O_k^{pos}) \longrightarrow$$

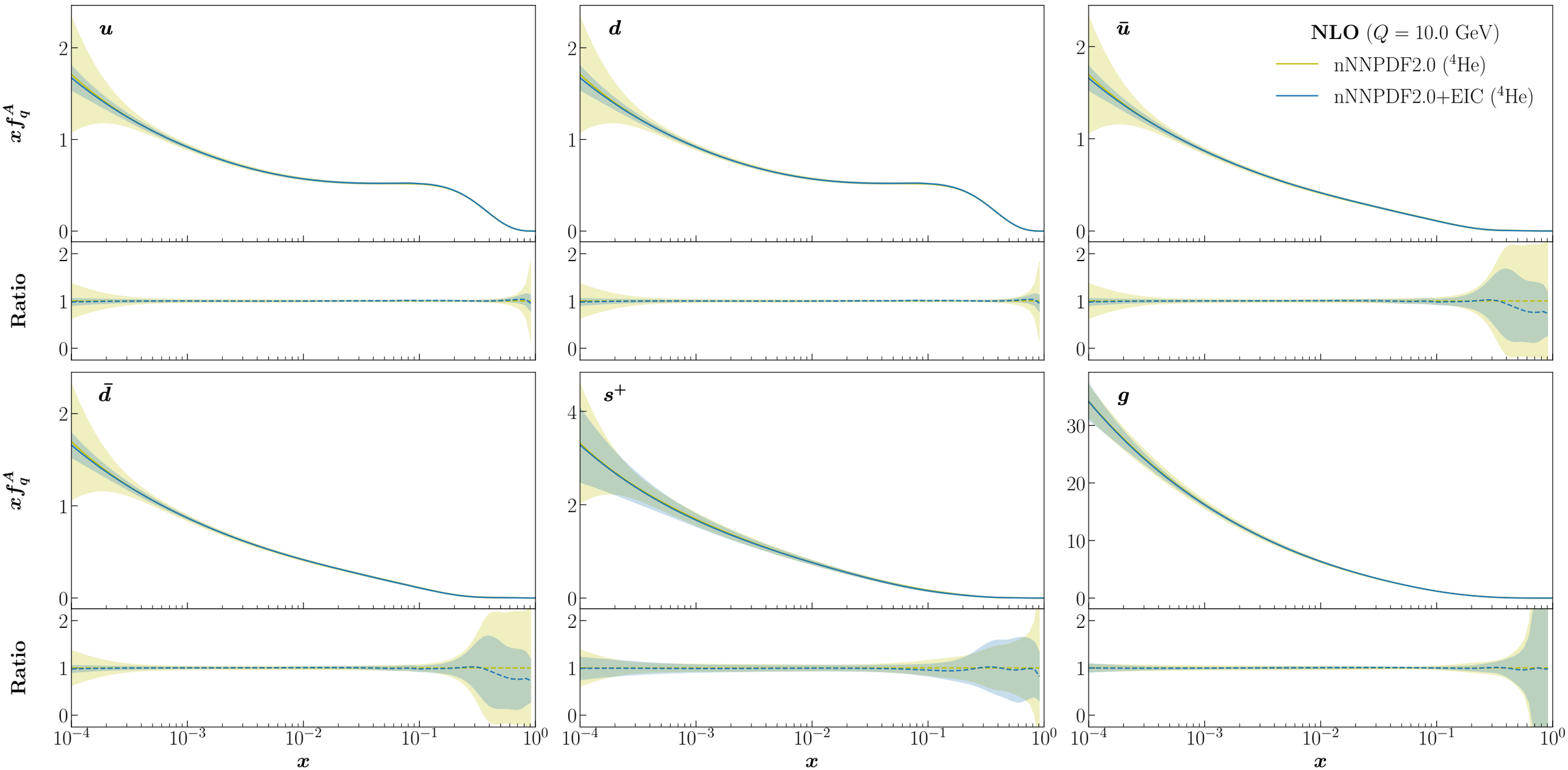
Positivity constraint for $x \in [10^{-7}, 1]$

$$F_2^u,\ F_2^d,\ F_2^s,\ d^2_{M^2y}\sigma^{DY}_{u\bar{u}},\ d^2_{M^2y}\sigma^{DY}_{d\bar{d}},\ d^2_{M^2y}\sigma^{DY}_{s\bar{s}},\ F_L^l$$

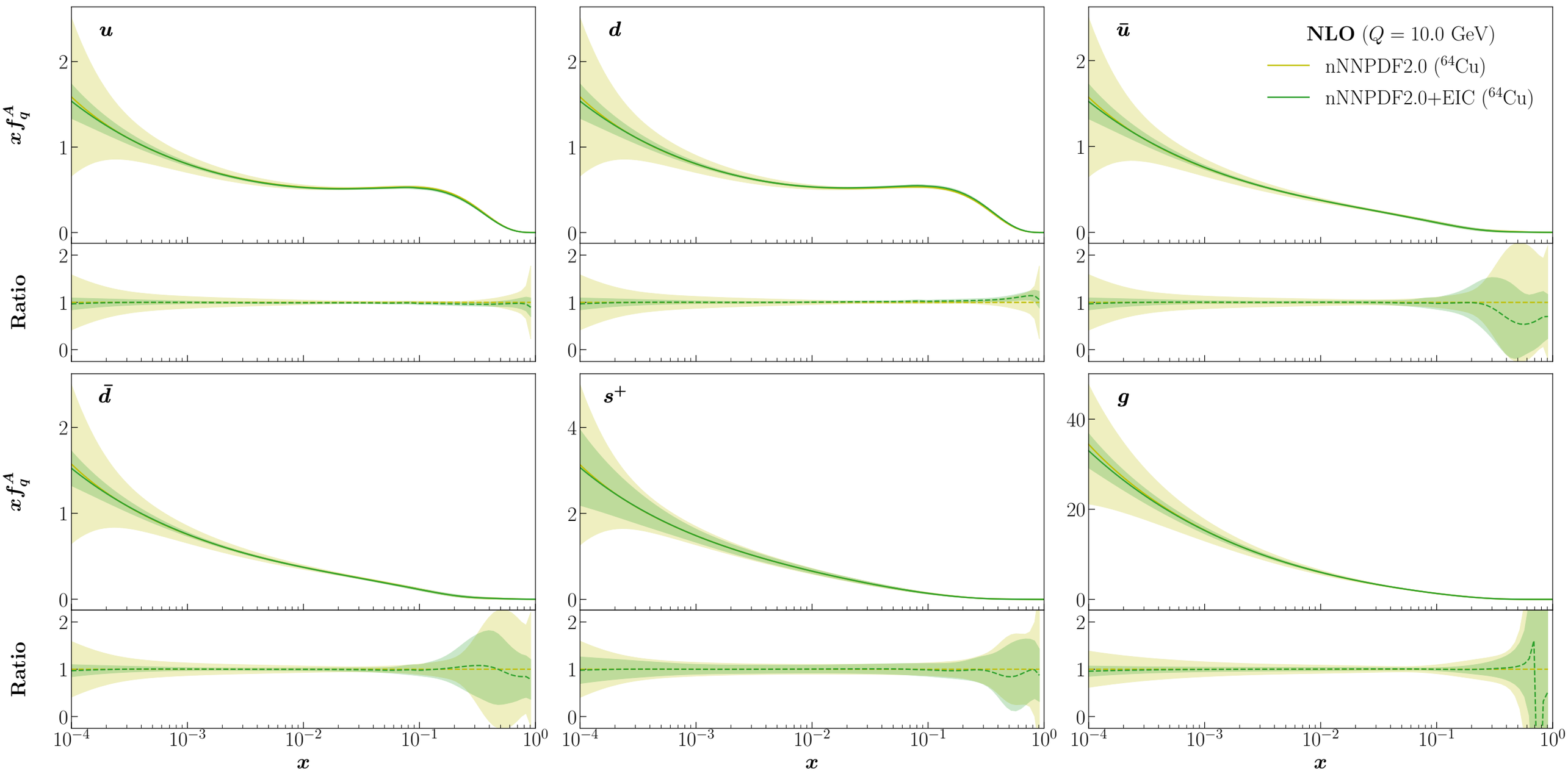
Common with NNPDF3.1

- EIC could reduce the uncertainty of the light quark PDFs of the proton at large x
- Size of this reduction is similar for both the optimistic and pessimistic scenarios.

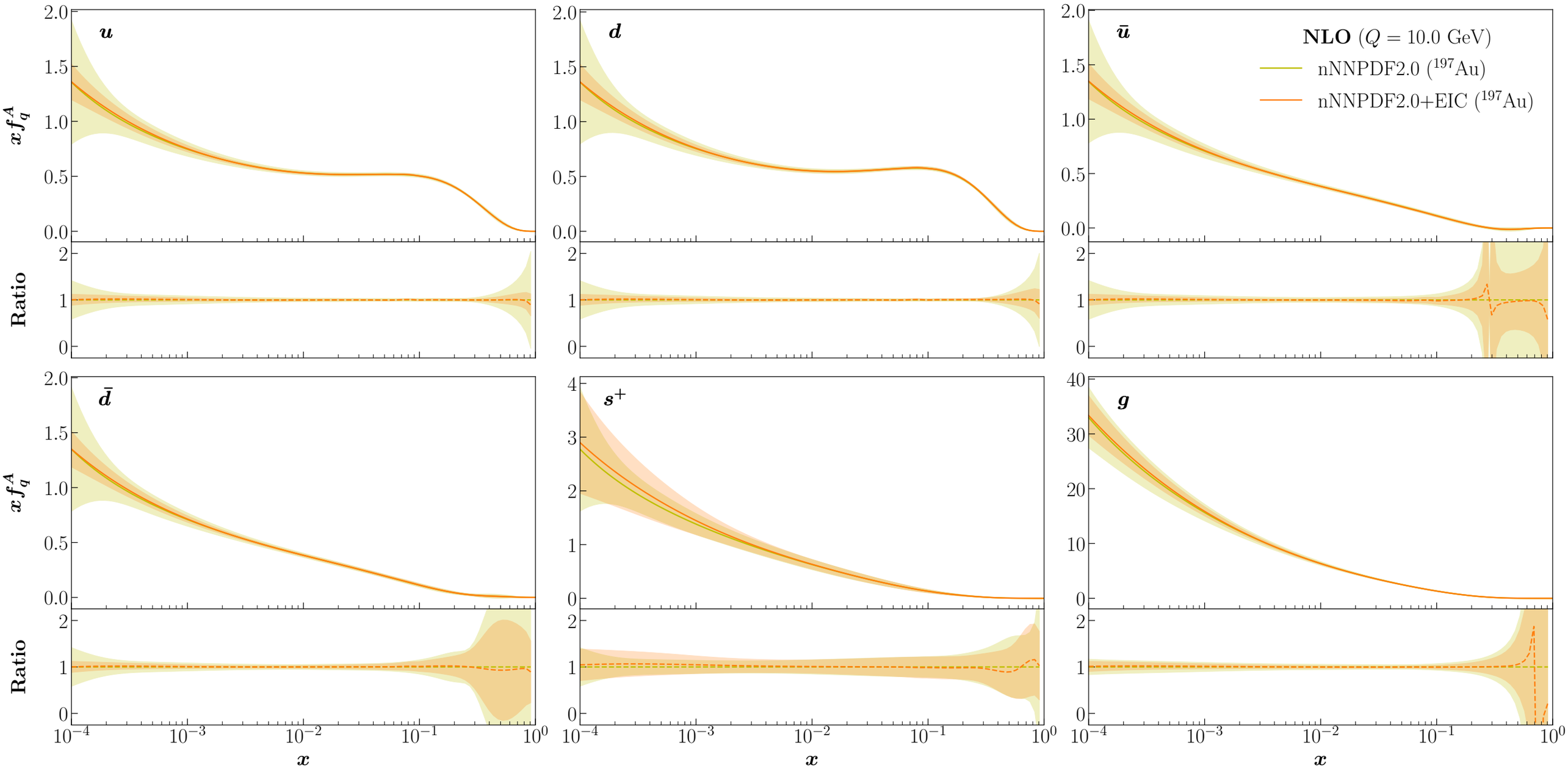
Impact on nNNPDF2.0 [He]



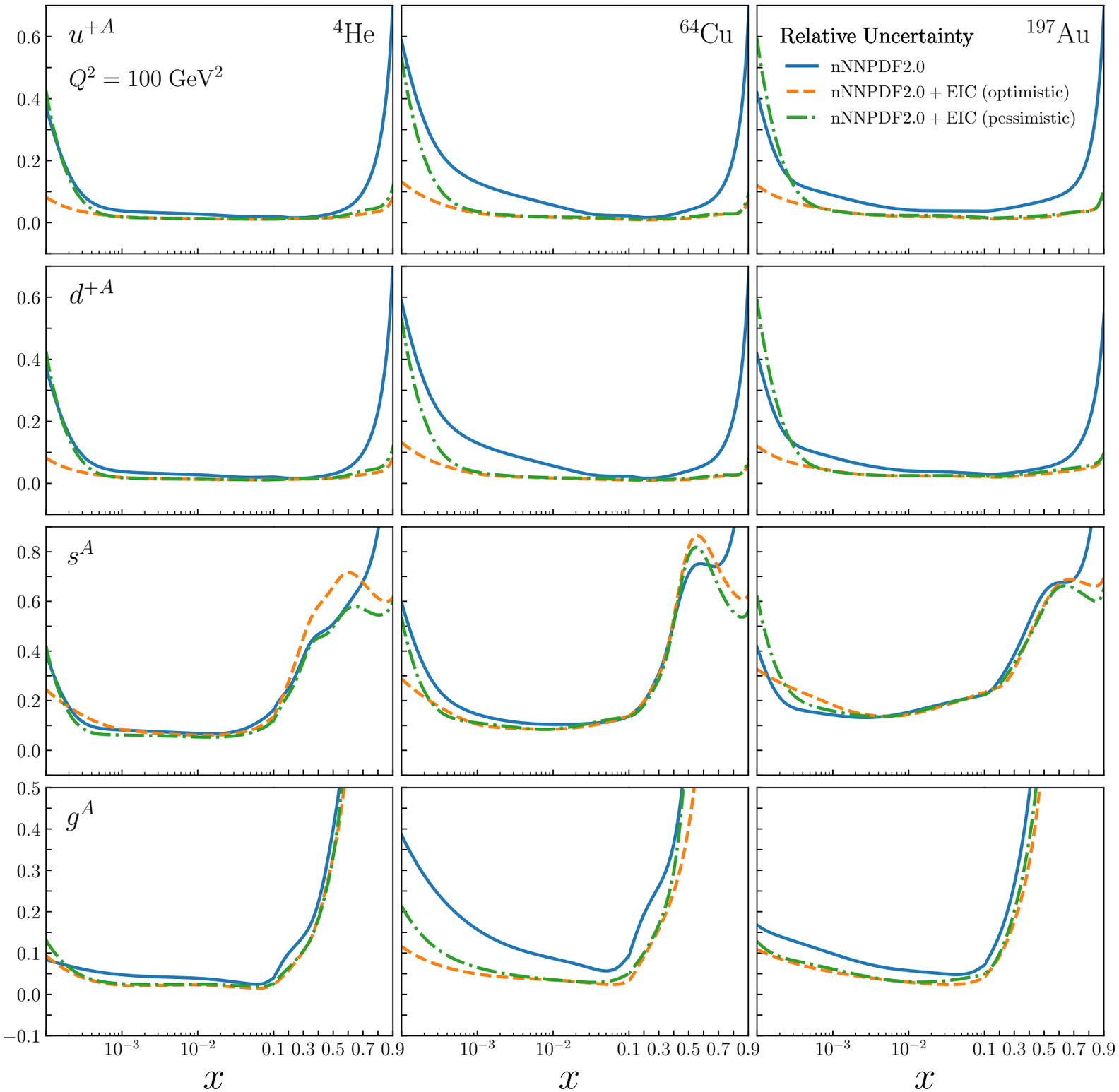
Impact on nNNPDF2.0 [Cu]

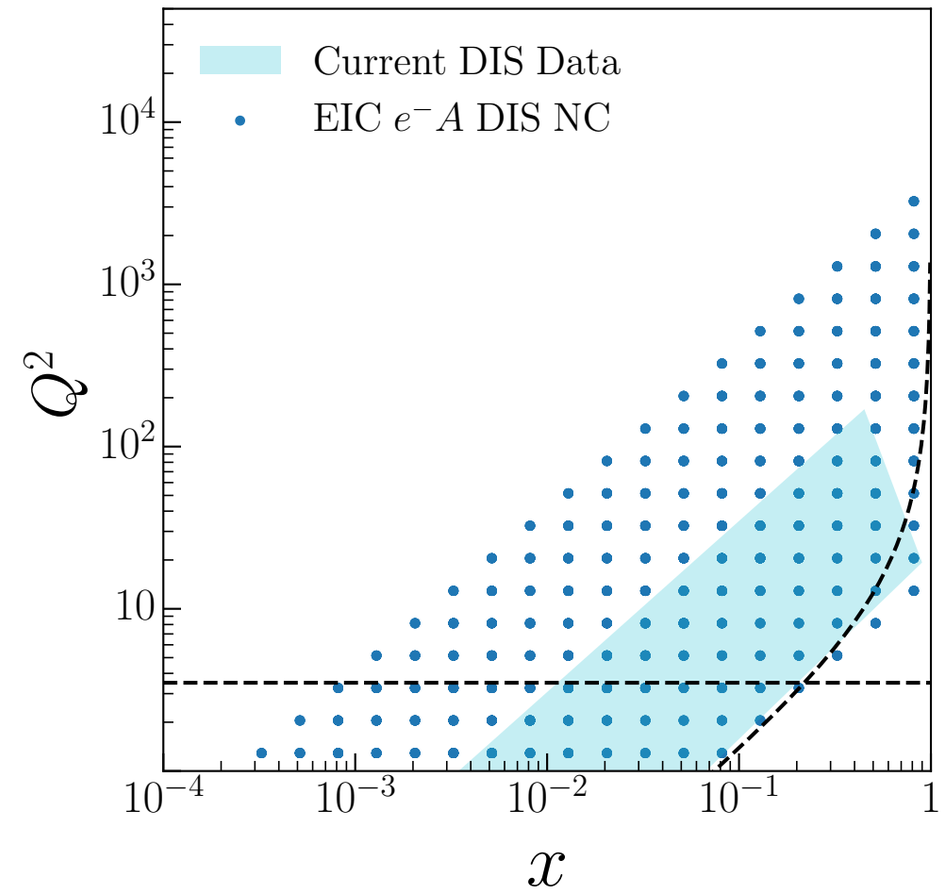


Impact on nNNPDF2.0 [Au]



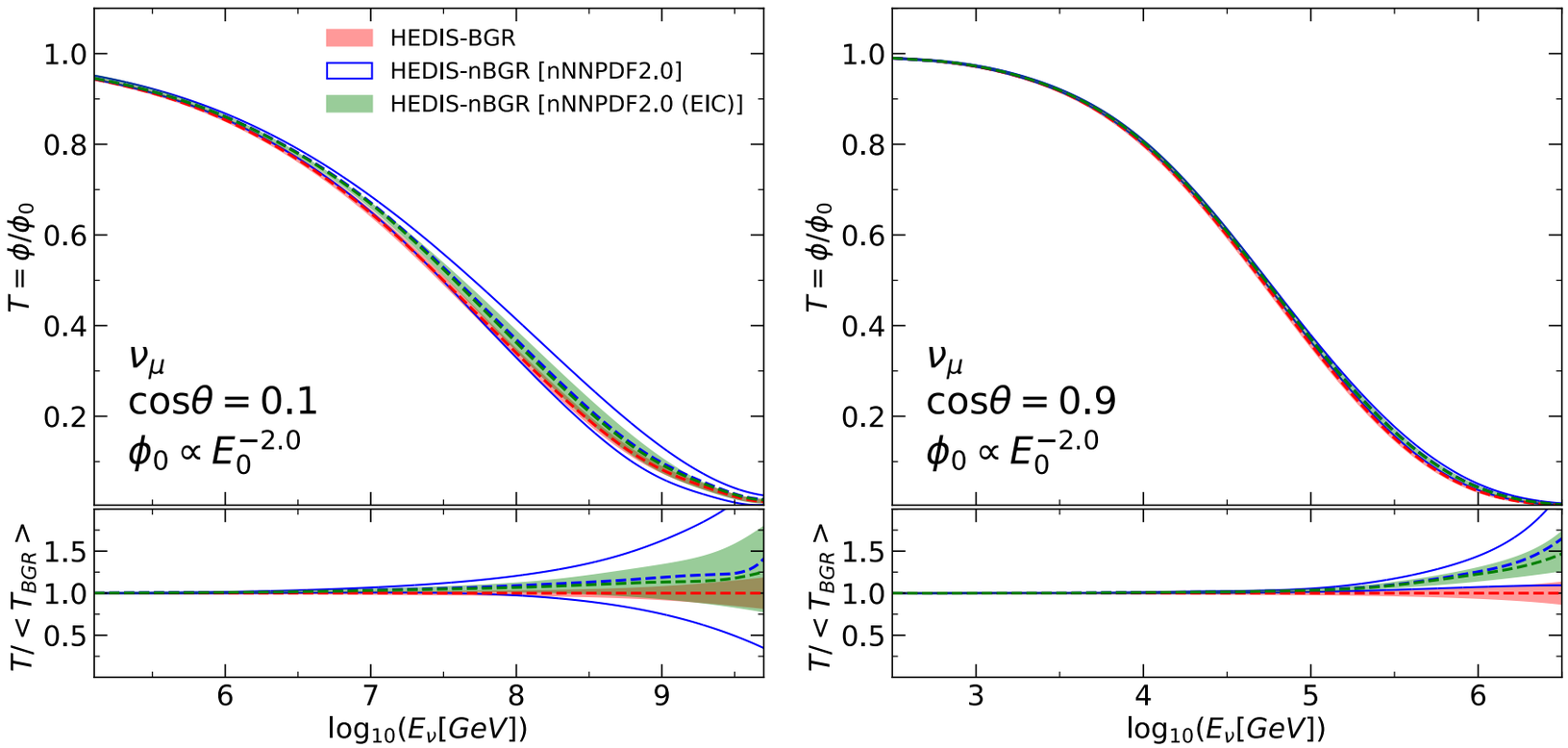
EIC impact on nPDFs

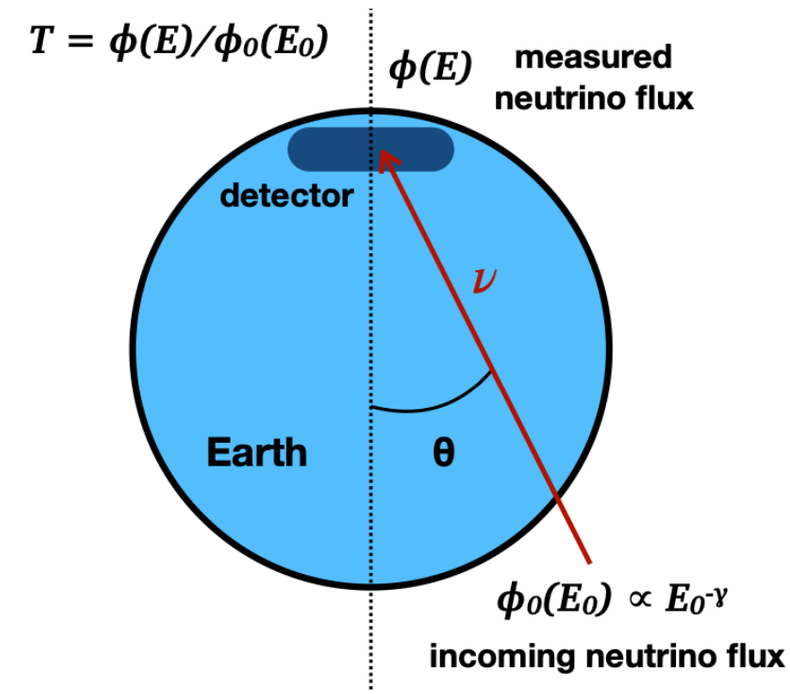


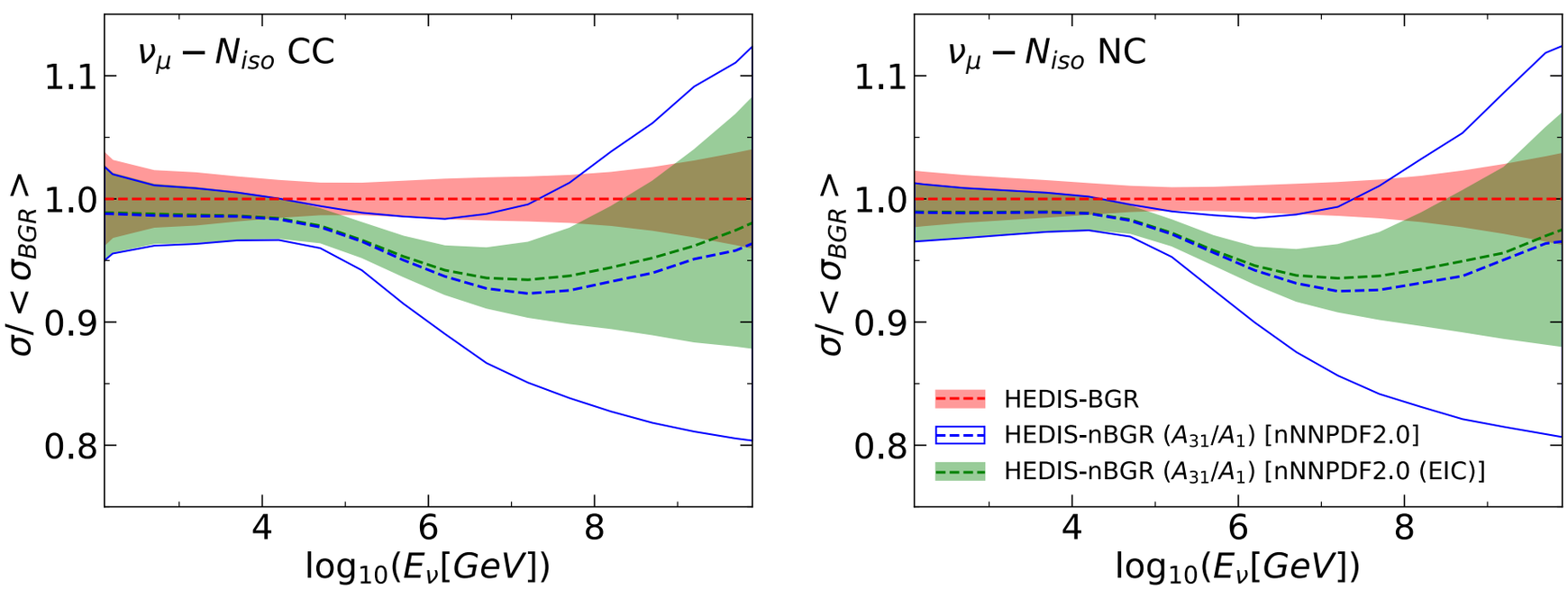


- **Reduction of nPDF uncertainties for nuclei in a wide range of atomic mass A values both at small and large-x.**
- **At large-x region, nPDF benefit from the increased precision of the baseline proton PDFs.**

Implications







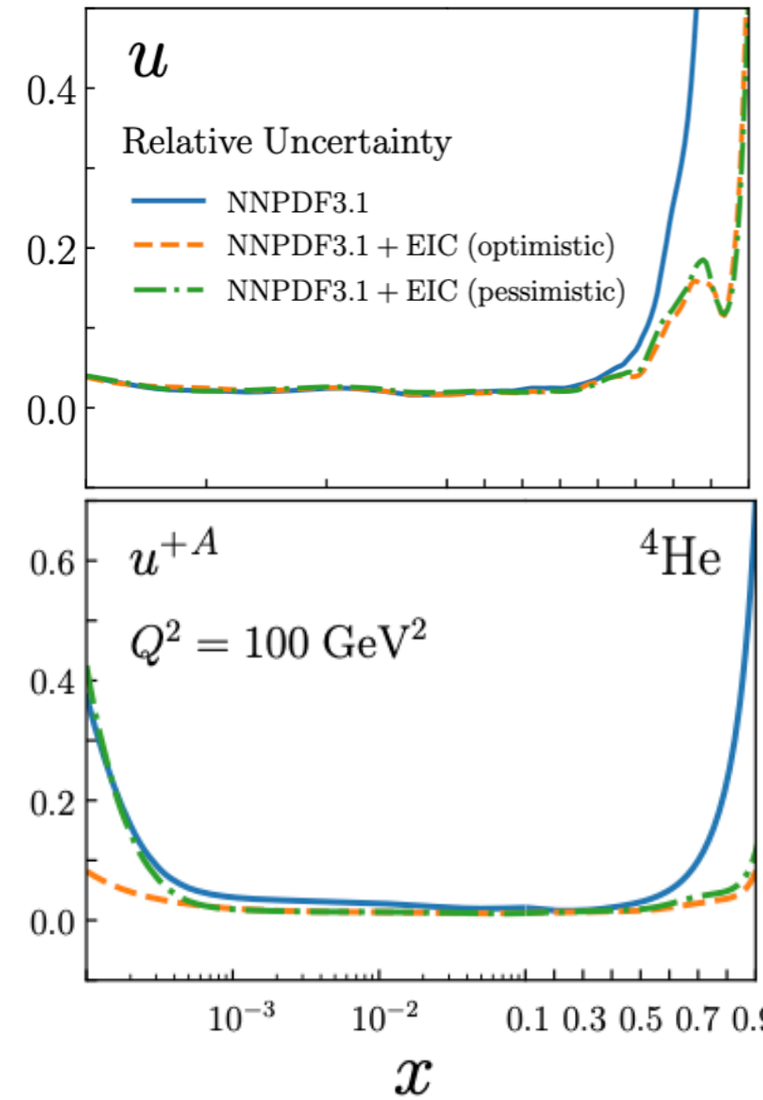
We average the earth nuclei by
$A \sim 31,\ Z \sim 15$

For the HEDIS-BGR proton a variant of NNPDF3.1 used

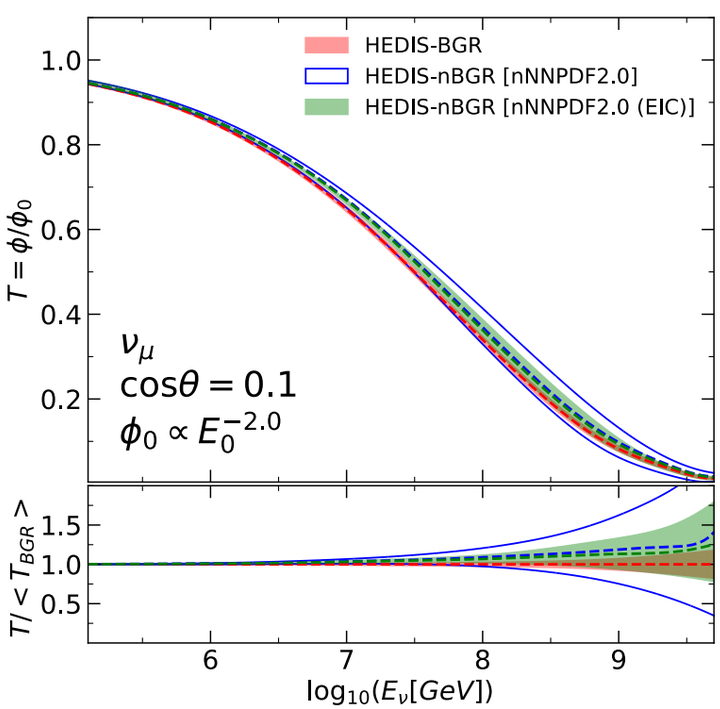
the EIC pseudodata is seen to reduce the uncertainty of the prediction for a nuclear target by roughly a factor of two for
$E_\nu \simeq 10^6$ GeV

Conclusions

- EIC could reduce the uncertainty of the light quark PDFs of the proton at large x
- Size of this reduction is similar for both the optimistic and pessimistic scenarios.



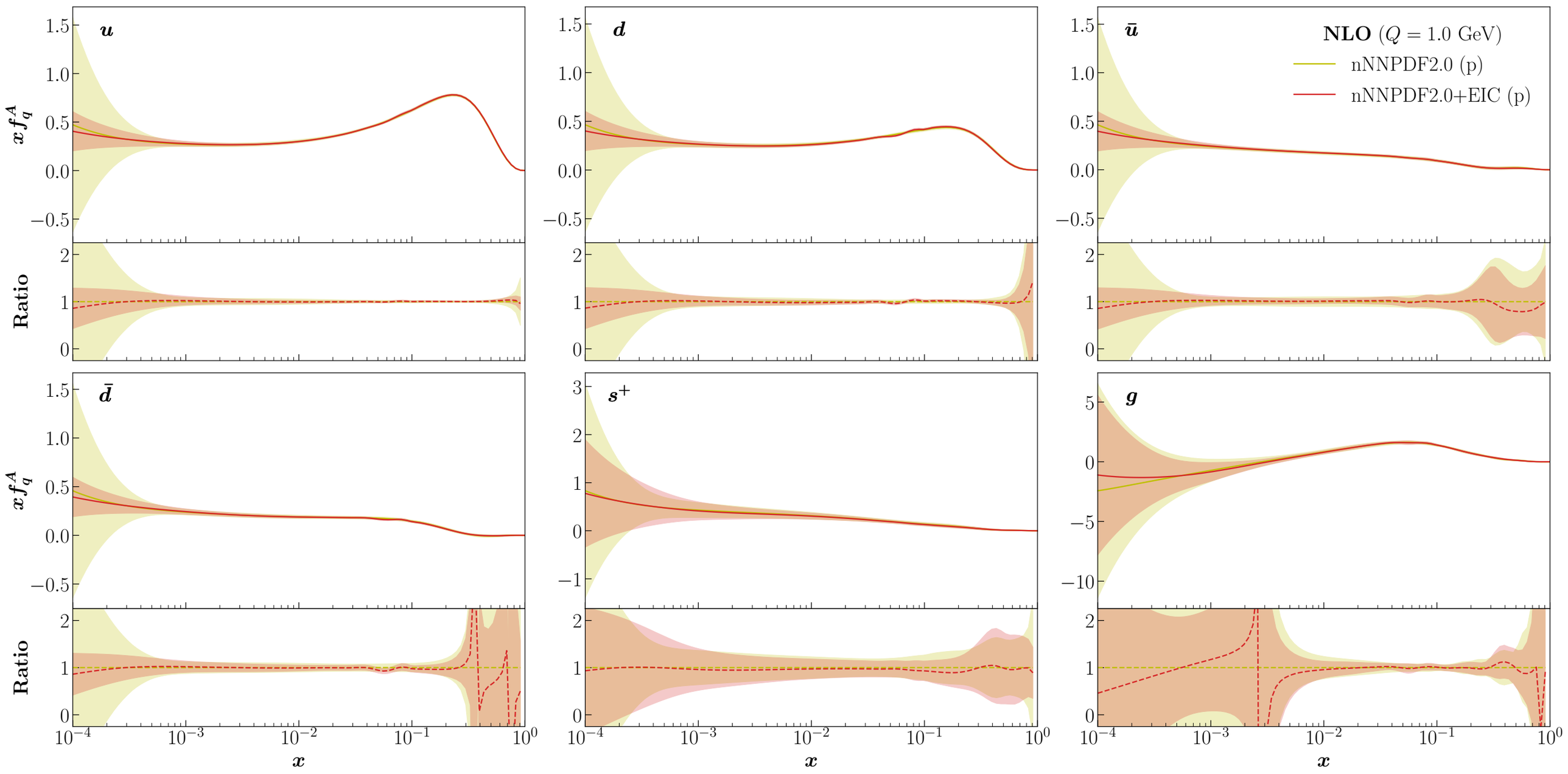
- Reduction of nPDF uncertainties for nuclei in a wide range of atomic mass A values both at small and large-x.
- At large-x region, nPDF benefit from the increased precision of the baseline proton PDFs.



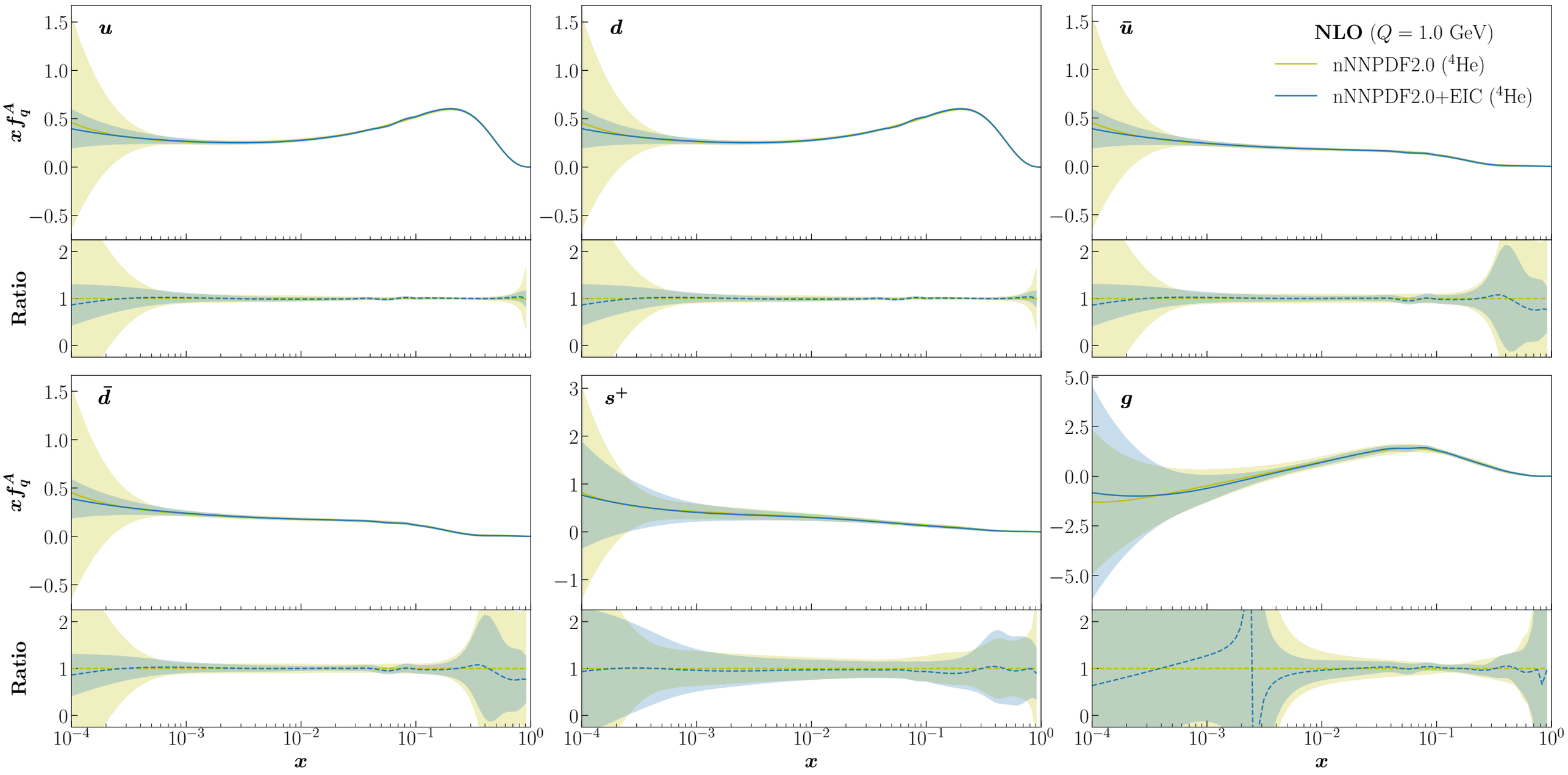
- Improve the modelling of the interactions of ultra-high energy cosmic neutrinos with matter.
- nuclear PDF uncertainties may no longer encompass the difference between νApredictions obtained on a proton and on a nuclear target.
- importance of carefully accounting for nuclear PDF effects in high-energy neutrino astrophysics.

Appendix

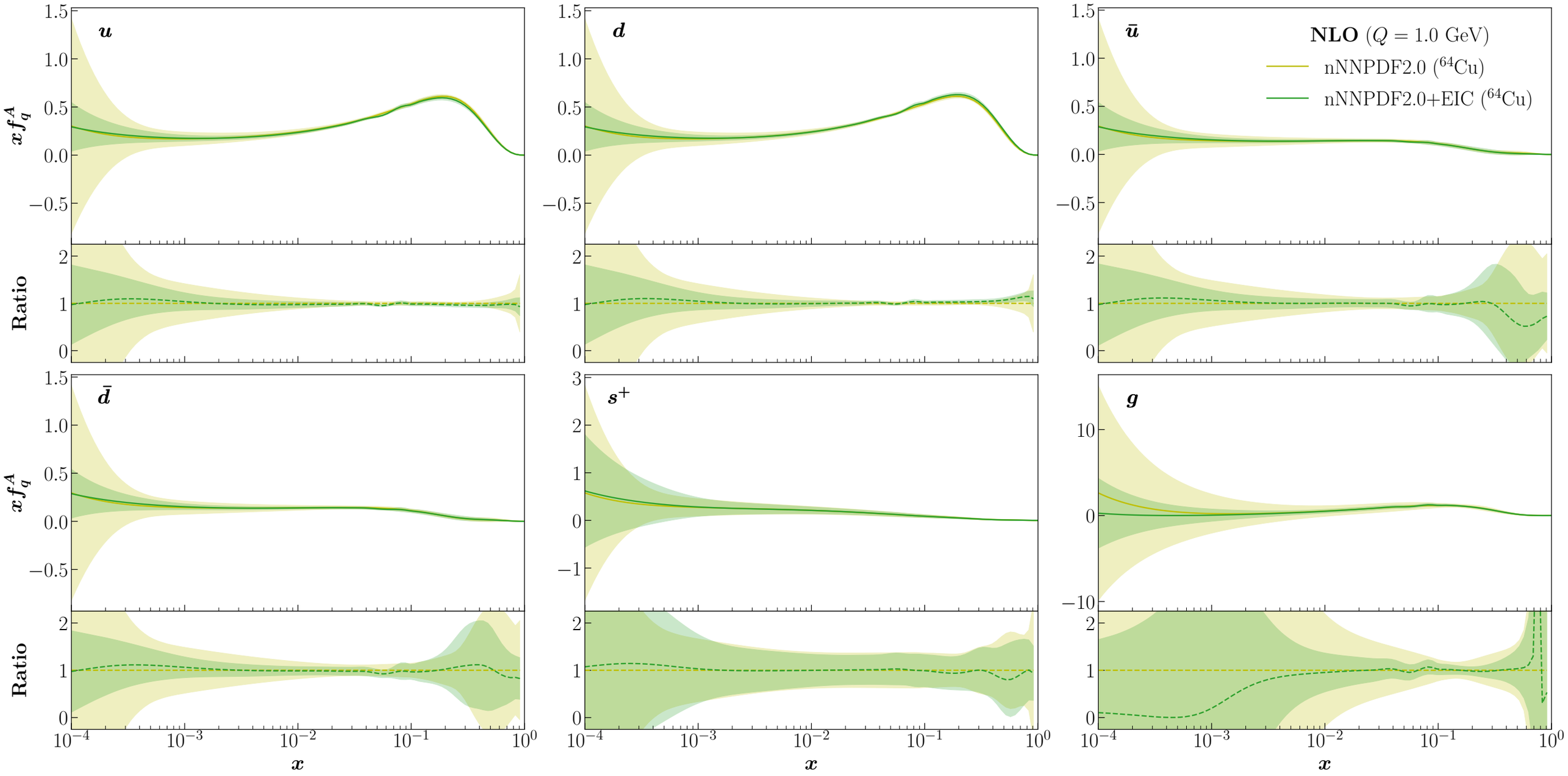
nNNPDF2.0 Results



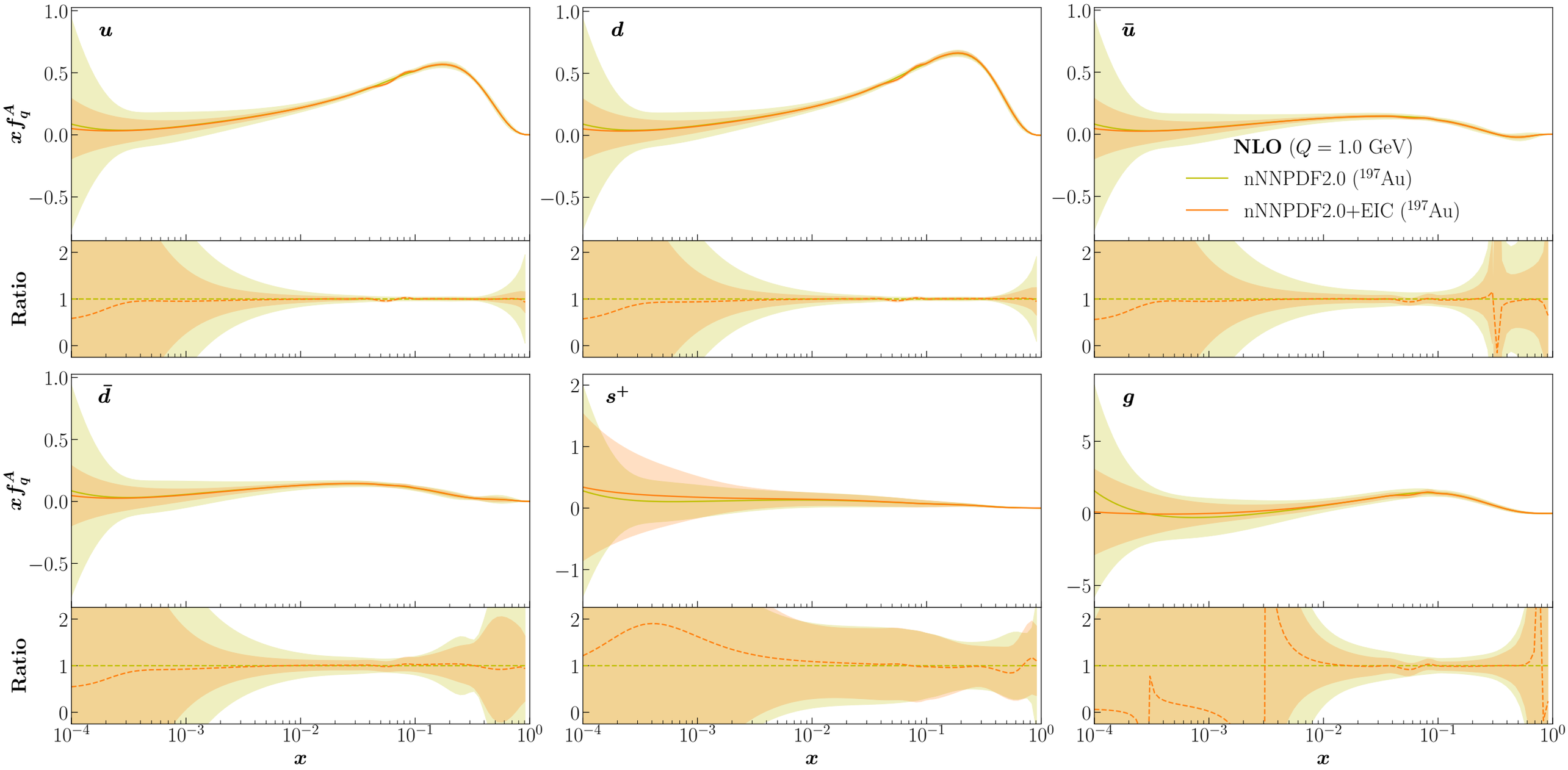
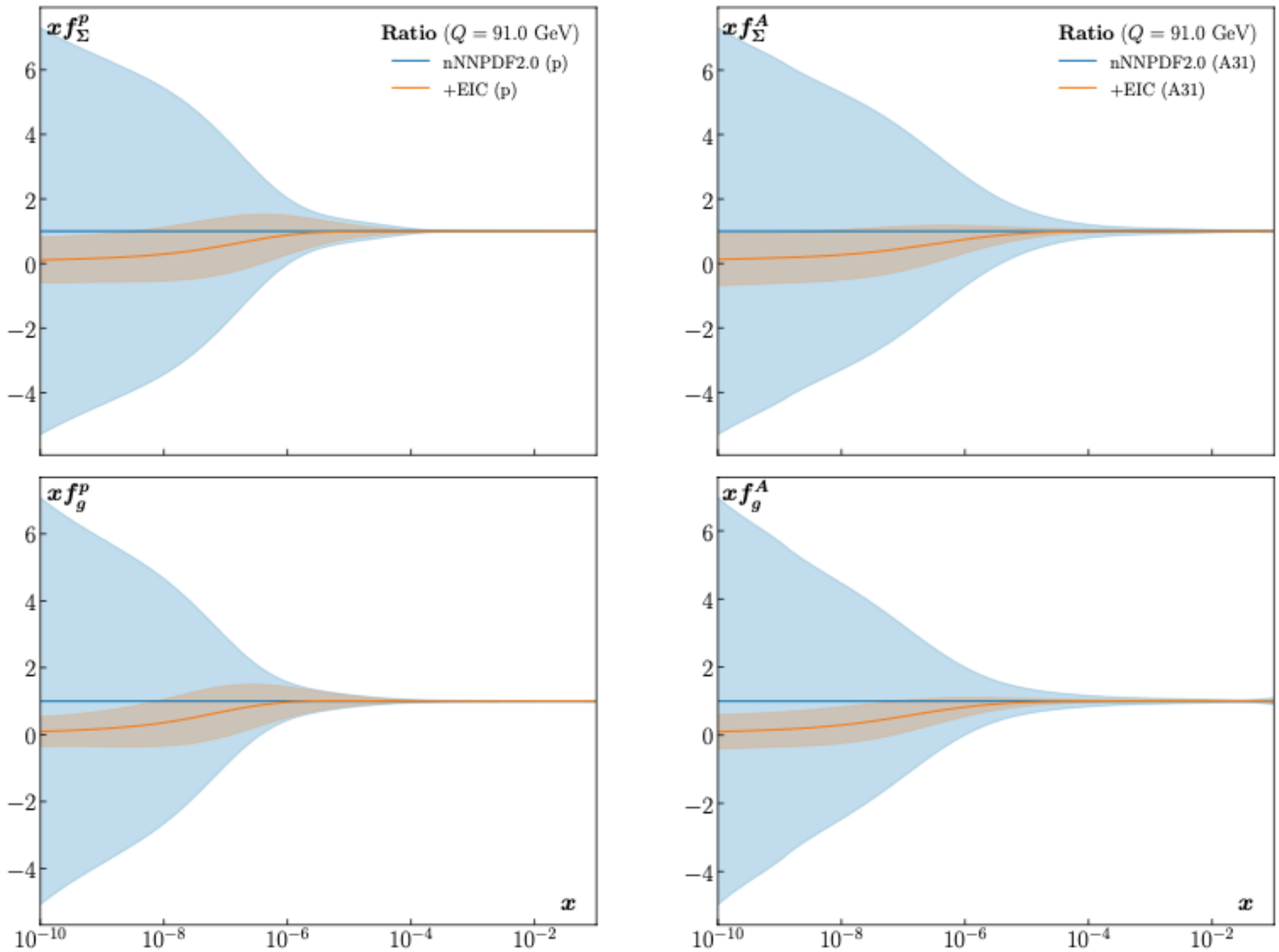
nNNPDF2.0 Results



nNNPDF2.0 Results



nNNPDF2.0 Results



Implications