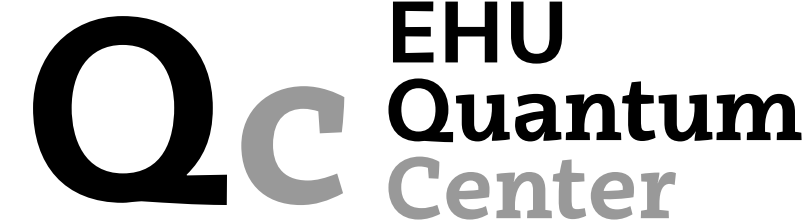


# DUNE as a neutrino DIS experiment

Ángel Felipe Ballesteros  
Universidad del País Vasco (UPV-EHU)

In collaboration with Miguel G. Echevarría and Iván Esteban



QCD Evolution 2026 El Escorial (Madrid)

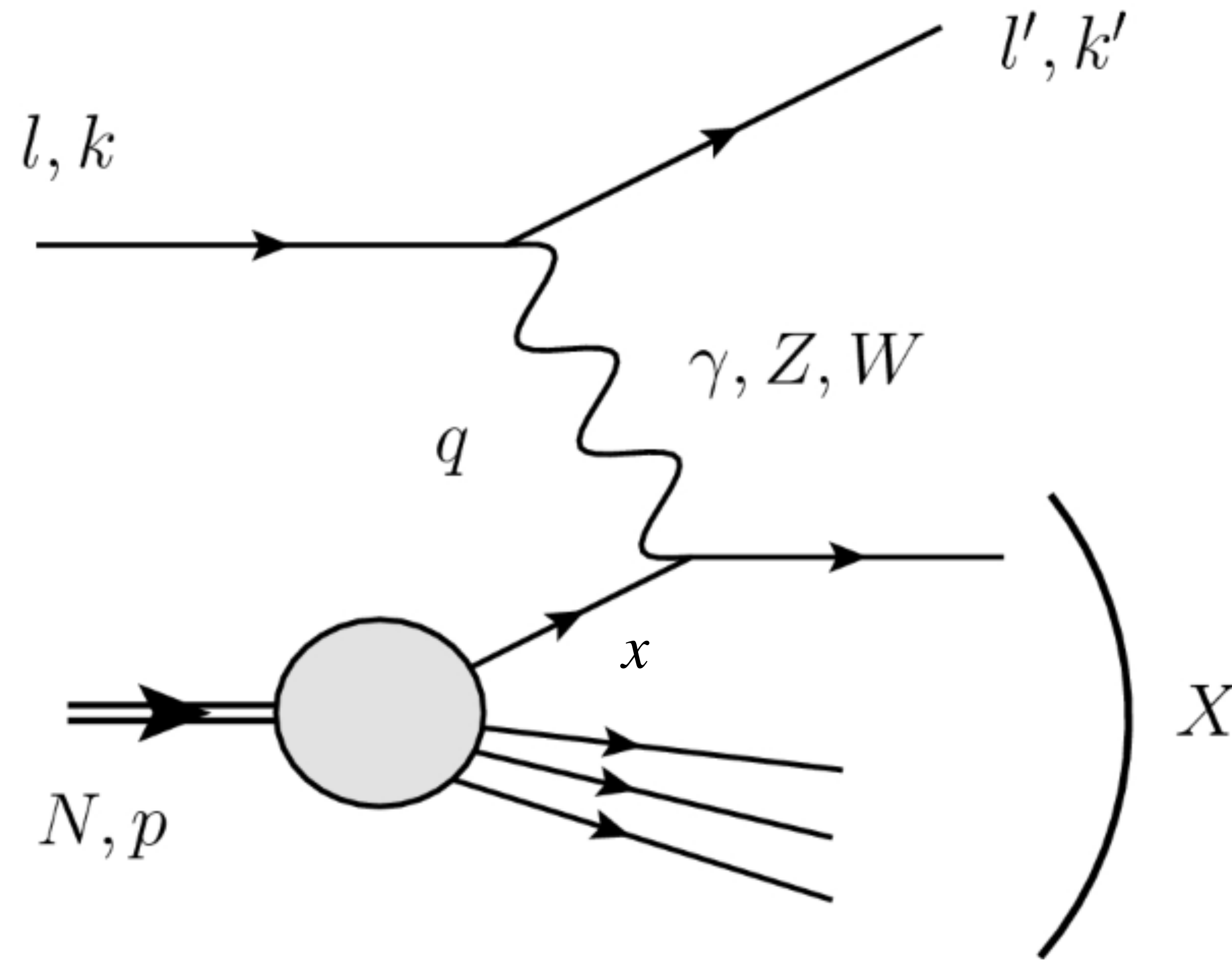


## Introduction

- **PDFs** are key objects to understand hadron structure.
  - **DIS** is a clean tool to measure PDFs
  - $\nu$ **DIS** allows for probing structure functions not available on charged lepton DIS [\[J.M. Cruz-Martinez et al. 2309.09581\]](#)
- GOAL:** Assess the capabilities of DUNE to measure PDFs

## Motivation

- Future neutrino based facilities (DUNE, FPF) will have **improved statistics**, a large number of events and improved final state reconstruction for QCD measurements. [\[DUNE collaboration. 2503.23291, J.Adhikary et al. 2411.04175\]](#)
- **Rising tensions** between neutrino and charged lepton data hint at a lack of understanding of nuclear effects in  $\nu$ DIS [\[K.F. Muzakka et al. 2204.13157\]](#)



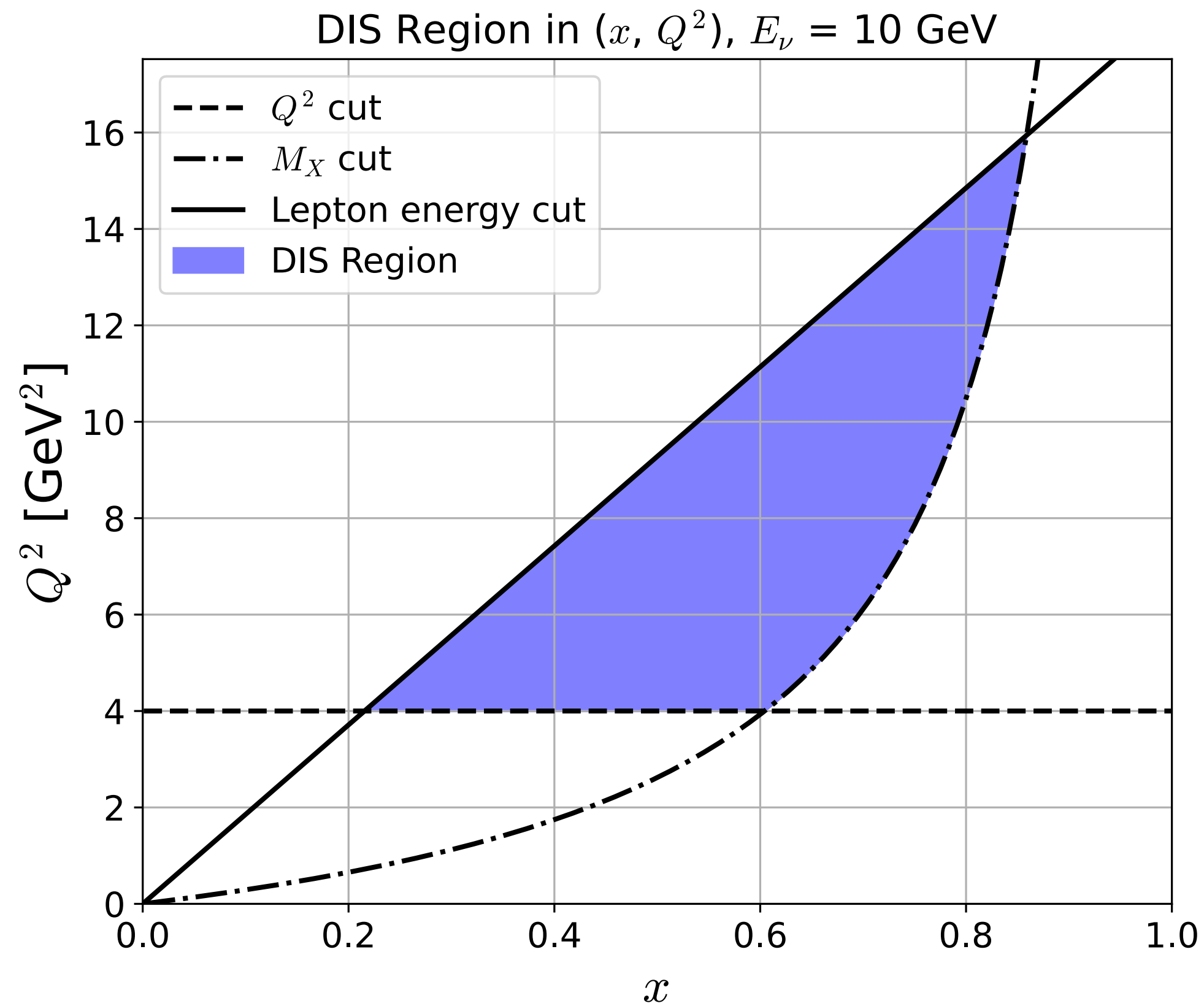
$$-q^2 = Q^2 \geq 4\text{GeV}^2.$$

$$M_X^2 \geq 3.5\text{GeV}^2.$$

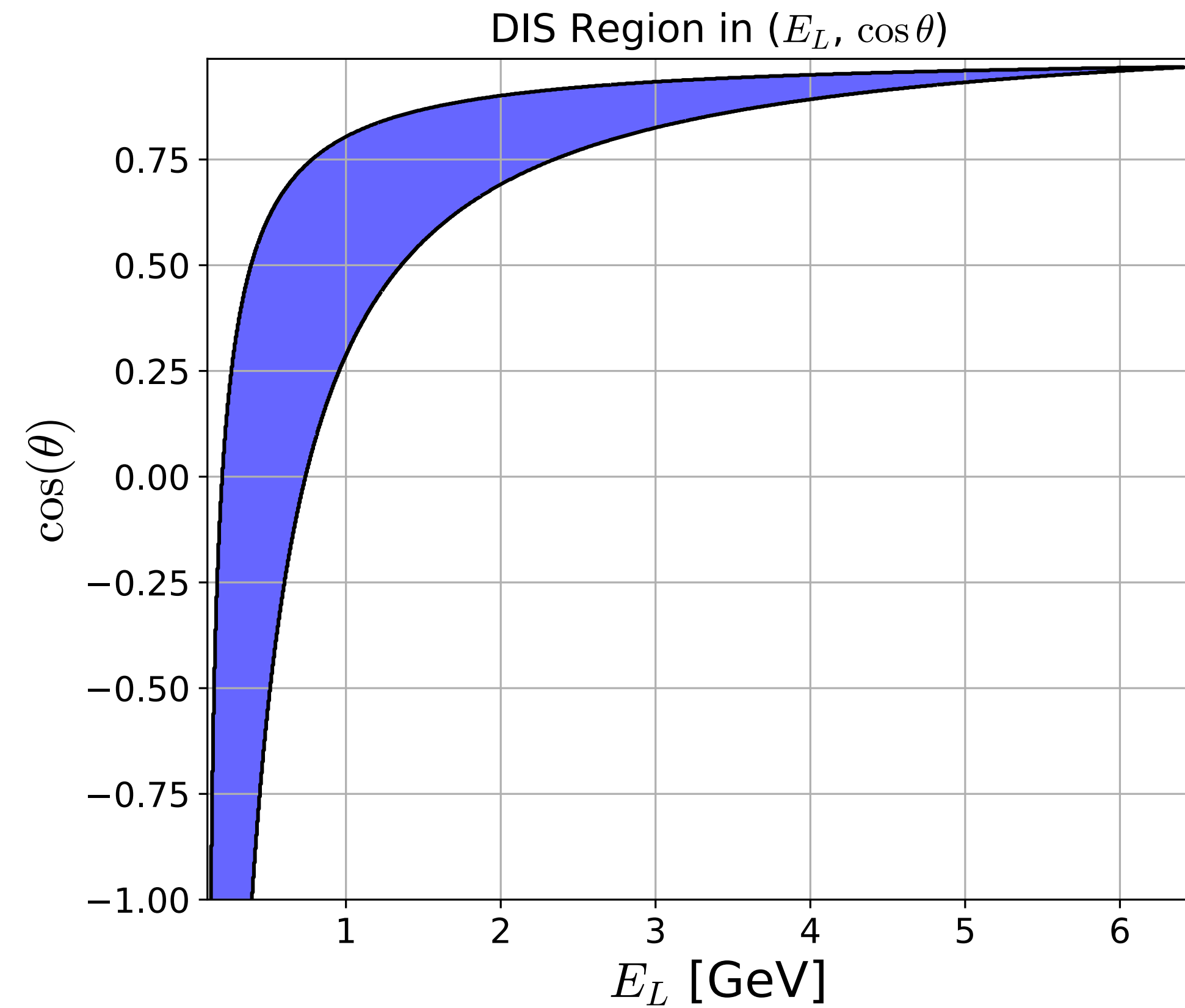
Fig 1. Neutrino DIS diagram

[I. Borsa et al. 2210.12014]

# Neutrino Deep Inelastic Scattering



$$Q^2 = 2E_l E_\nu (1 - \cos \theta)$$

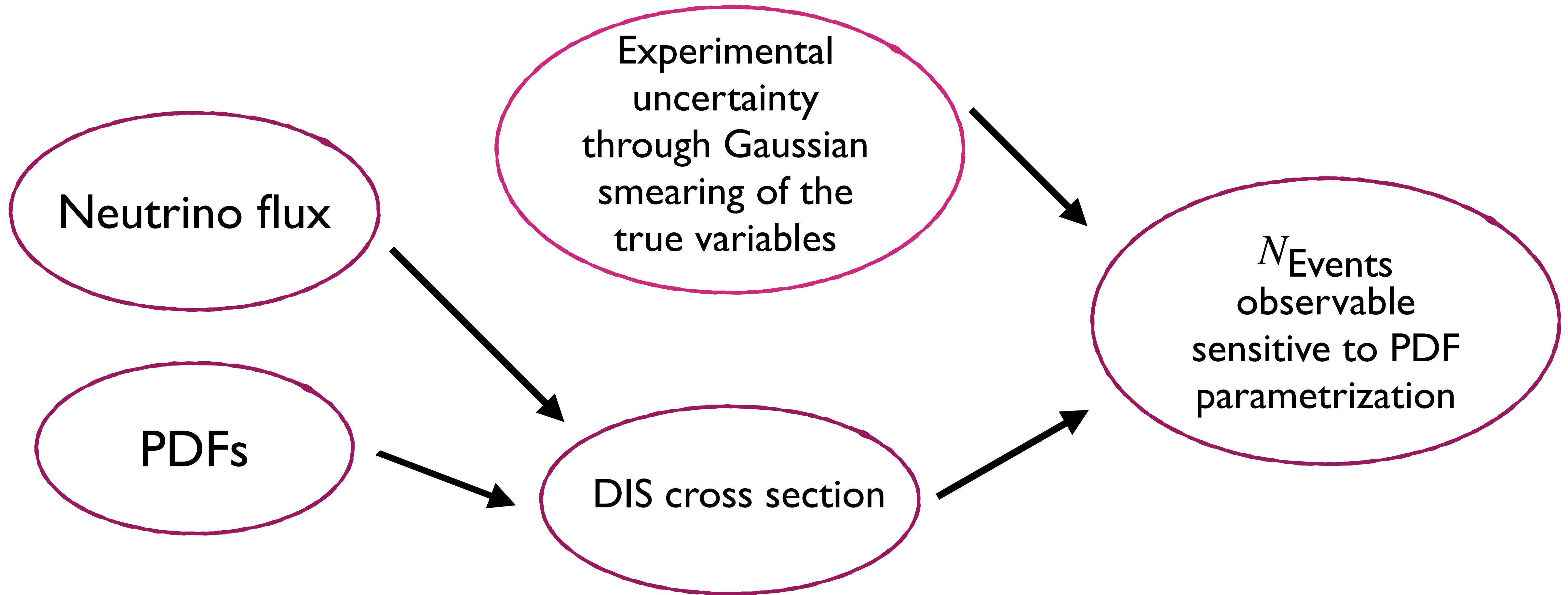


$$x = \frac{Q^2}{2m_N(E_\nu - E_l)}$$

- DUNE is a future neutrino oscillation experiment that will tackle several open questions (CP violation, mass ordering...). Expected to start in 2029-2030 with a  $\sim 10$  year run.
- For a precise oscillation measurement, it has both a near and far detector.
- **Broadband neutrino beam** with long tail and peak energies of a few GeV.
- The expected number of muon-neutrino events in the ND is of the order of **tens of millions per year**.
- High quality reconstruction of DIS events is done by measuring  $E_H$ ,  $\cos \theta$  and  $E_l$ .

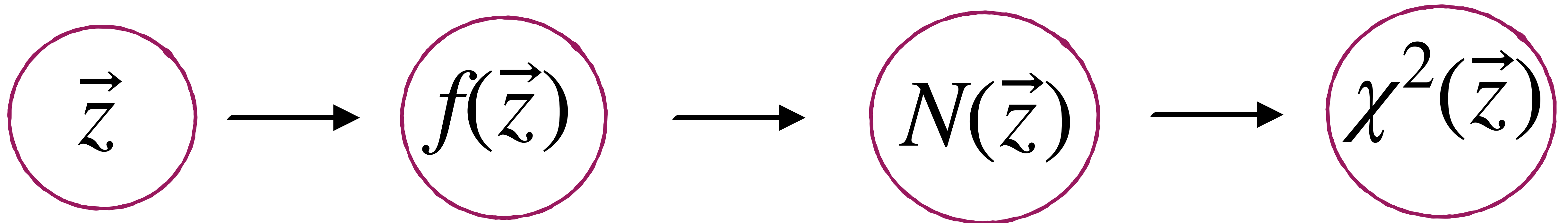
$$\sigma_H = 30\% \sqrt{\frac{E_H}{\text{GeV}}} \quad \sigma_l = 4\% \frac{E_l}{\text{GeV}} \quad \sigma_\theta = 1^\circ$$

[DUNE Collaboration  
2002.03005 &  
2103.139910]

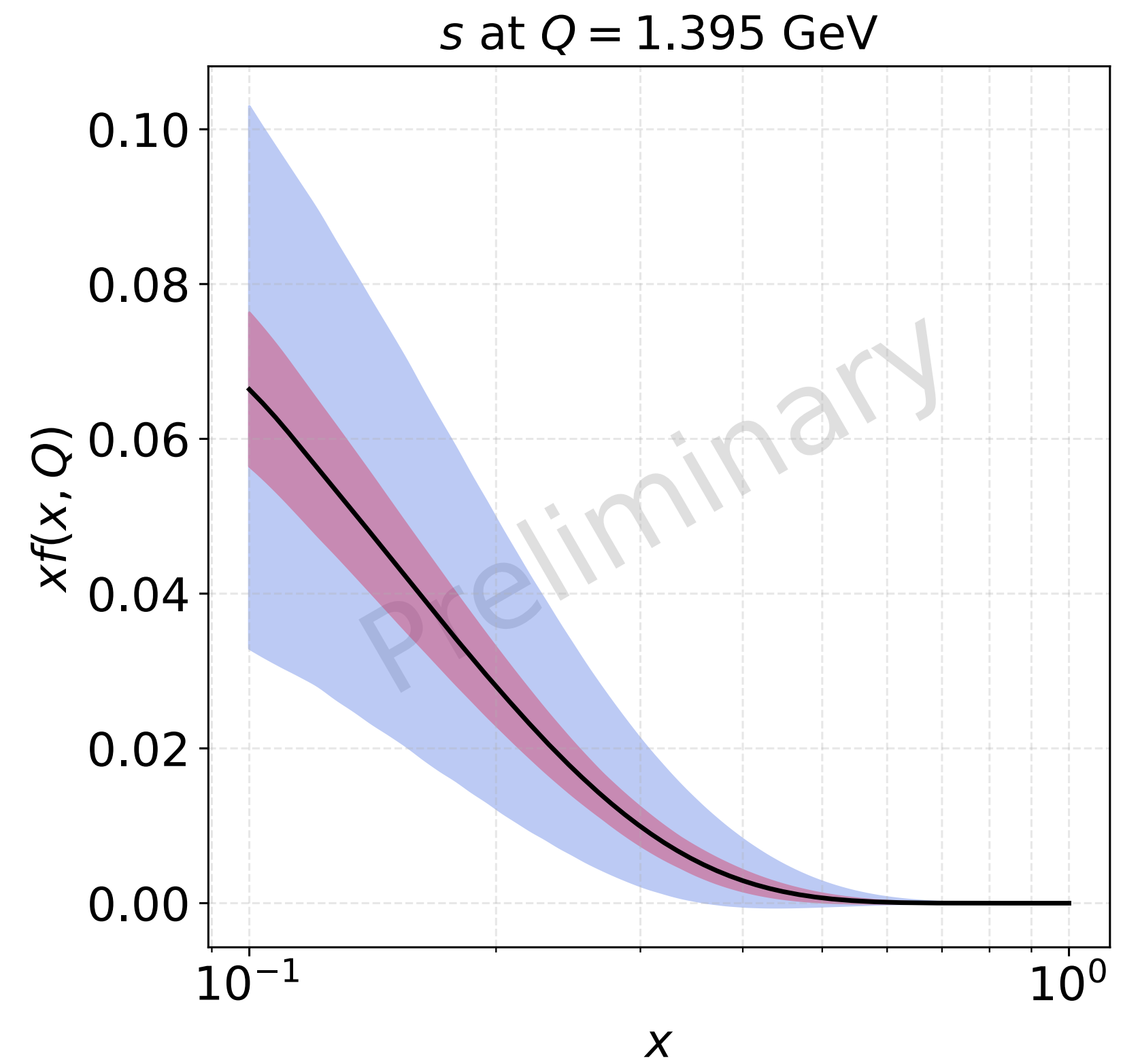
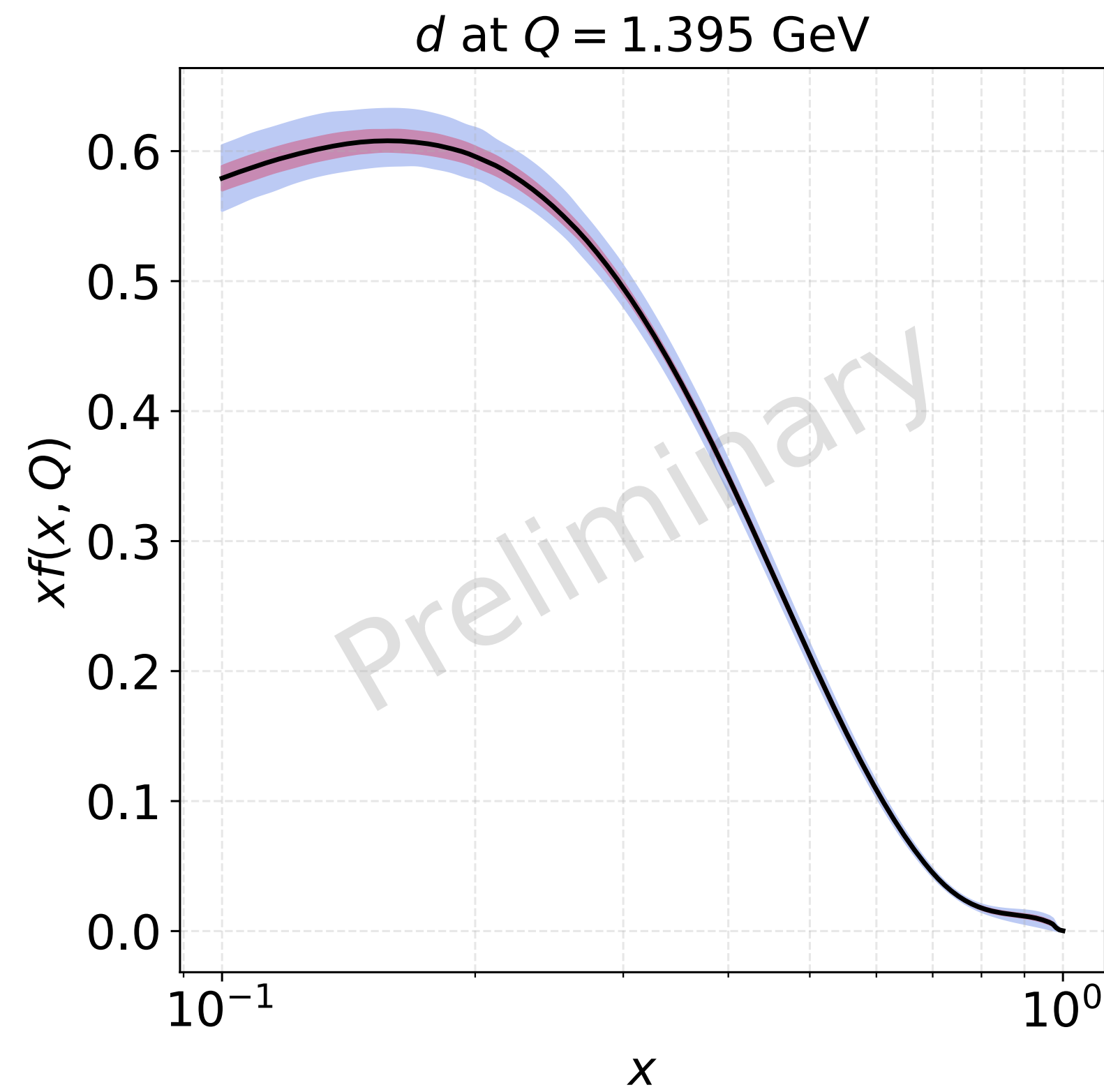
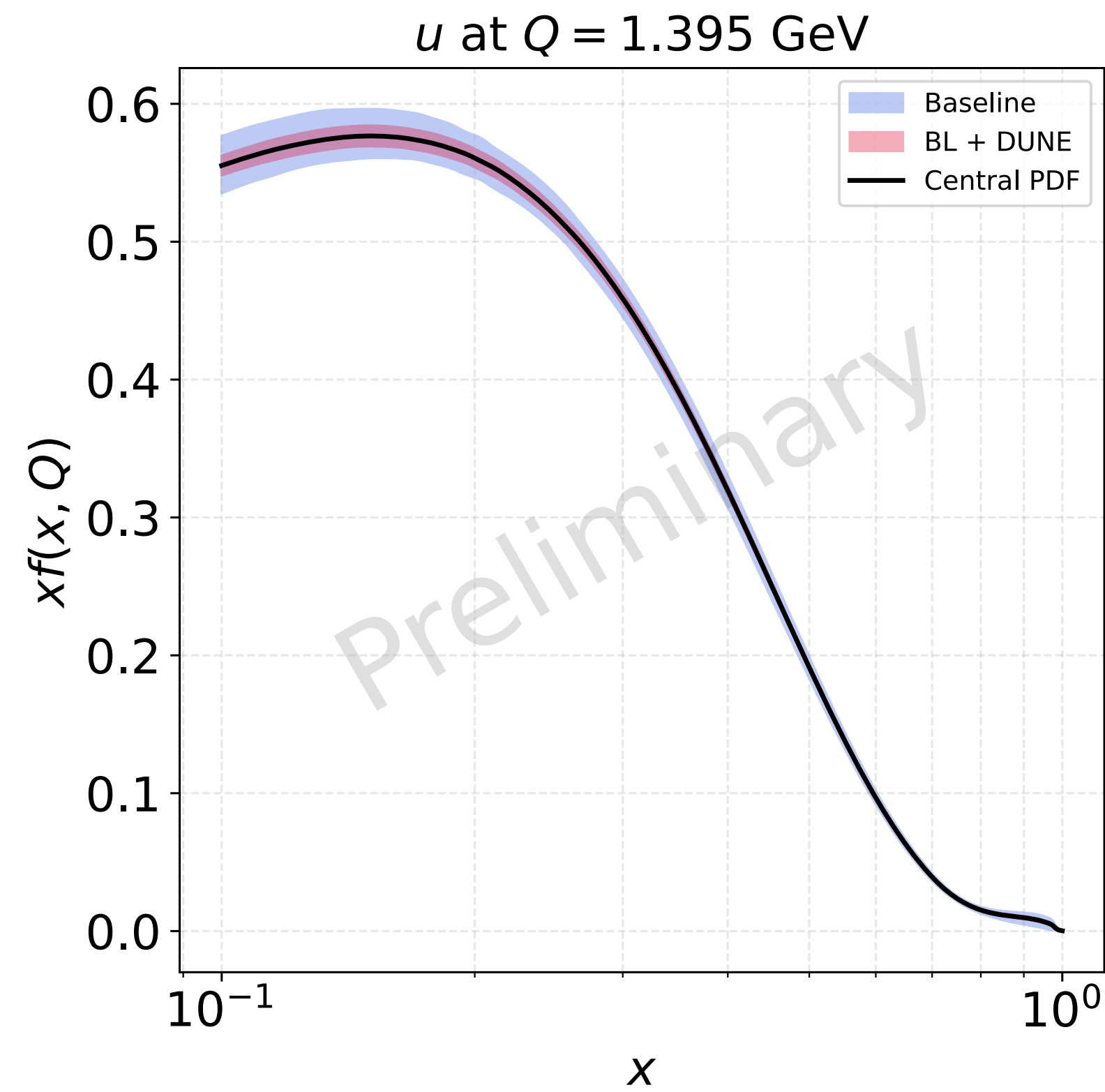


[K. J. Eskola, C. Salgado et al.  
2112.12462]

- EPPS21 is one of the state of the art nuclear PDF sets, using CT18 as free proton baseline
- Parameter space can be explored via computing number of events in DUNE

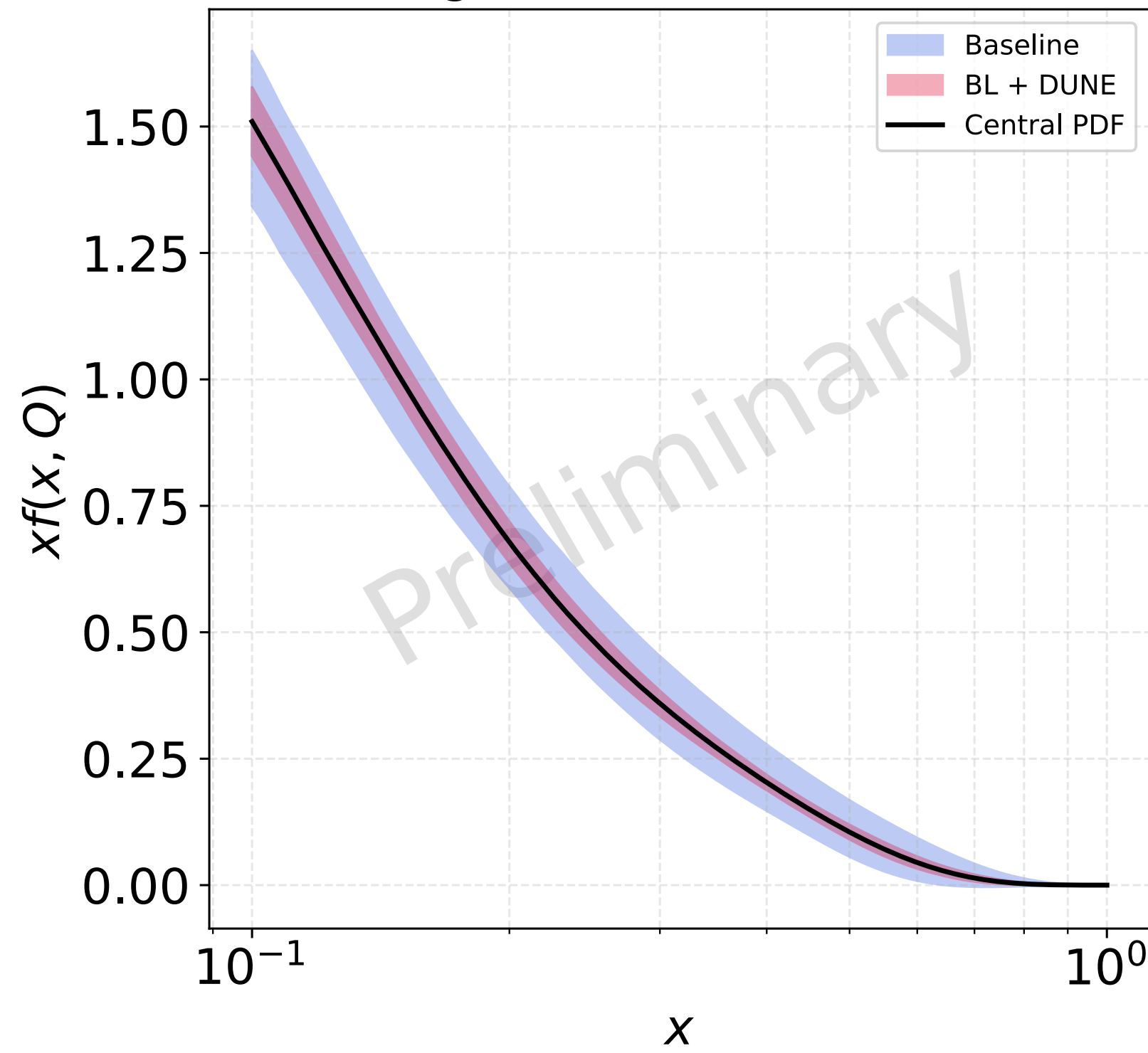


# Results: nPDF constraints

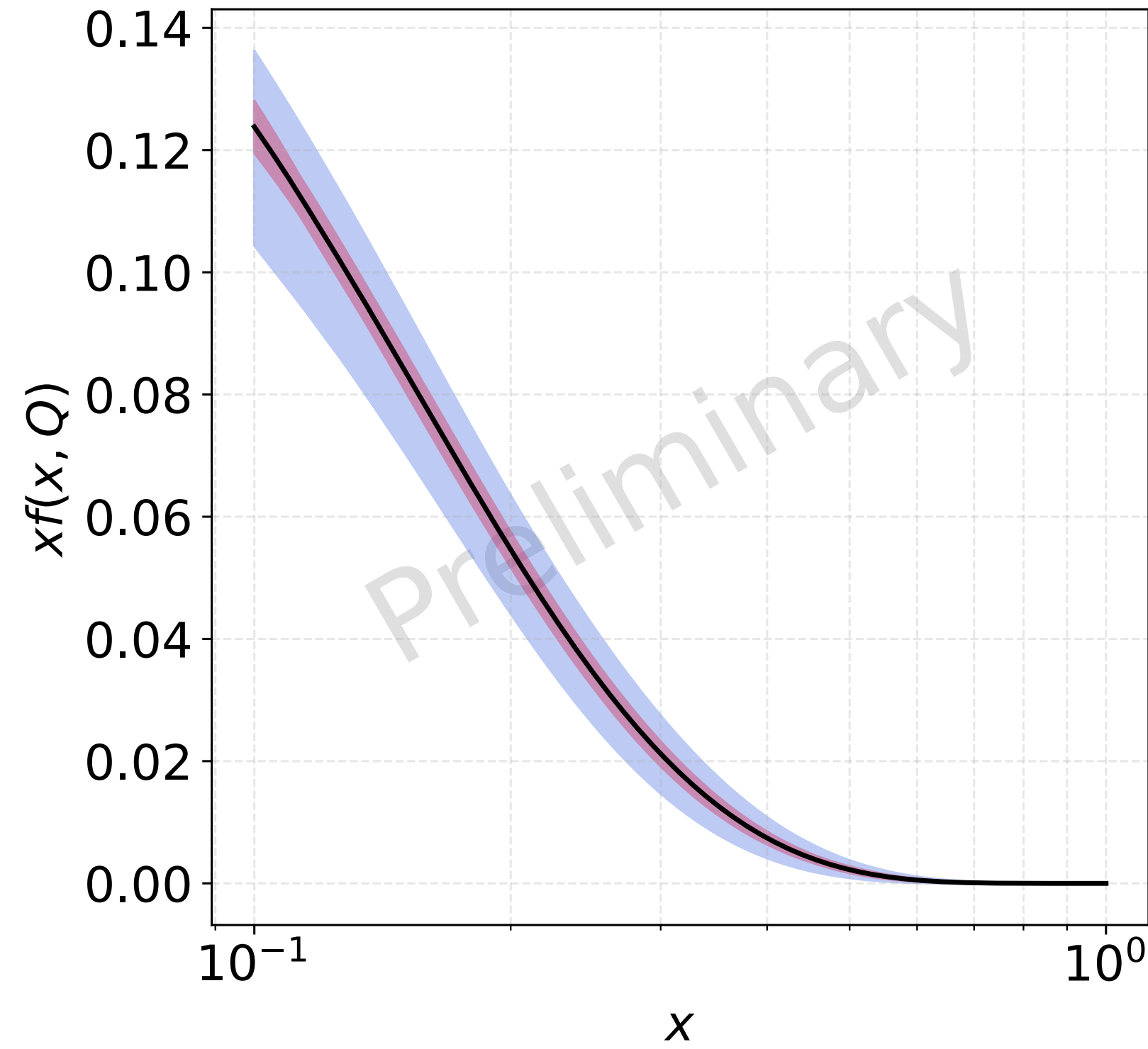


# Results: nPDF constraints

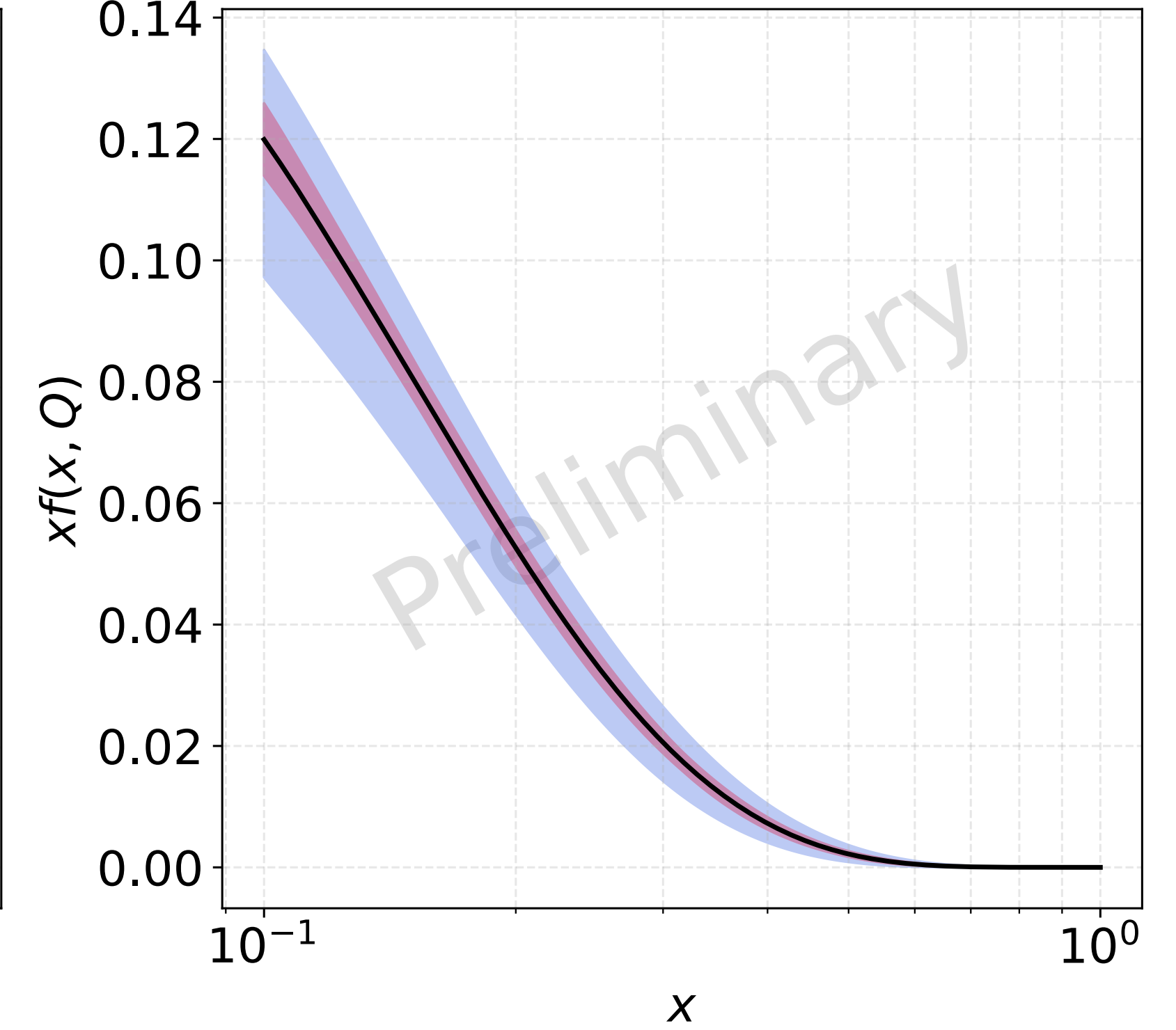
$g$  at  $Q = 1.395$  GeV



$\bar{u}$  at  $Q = 1.395$  GeV



$\bar{d}$  at  $Q = 1.395$  GeV

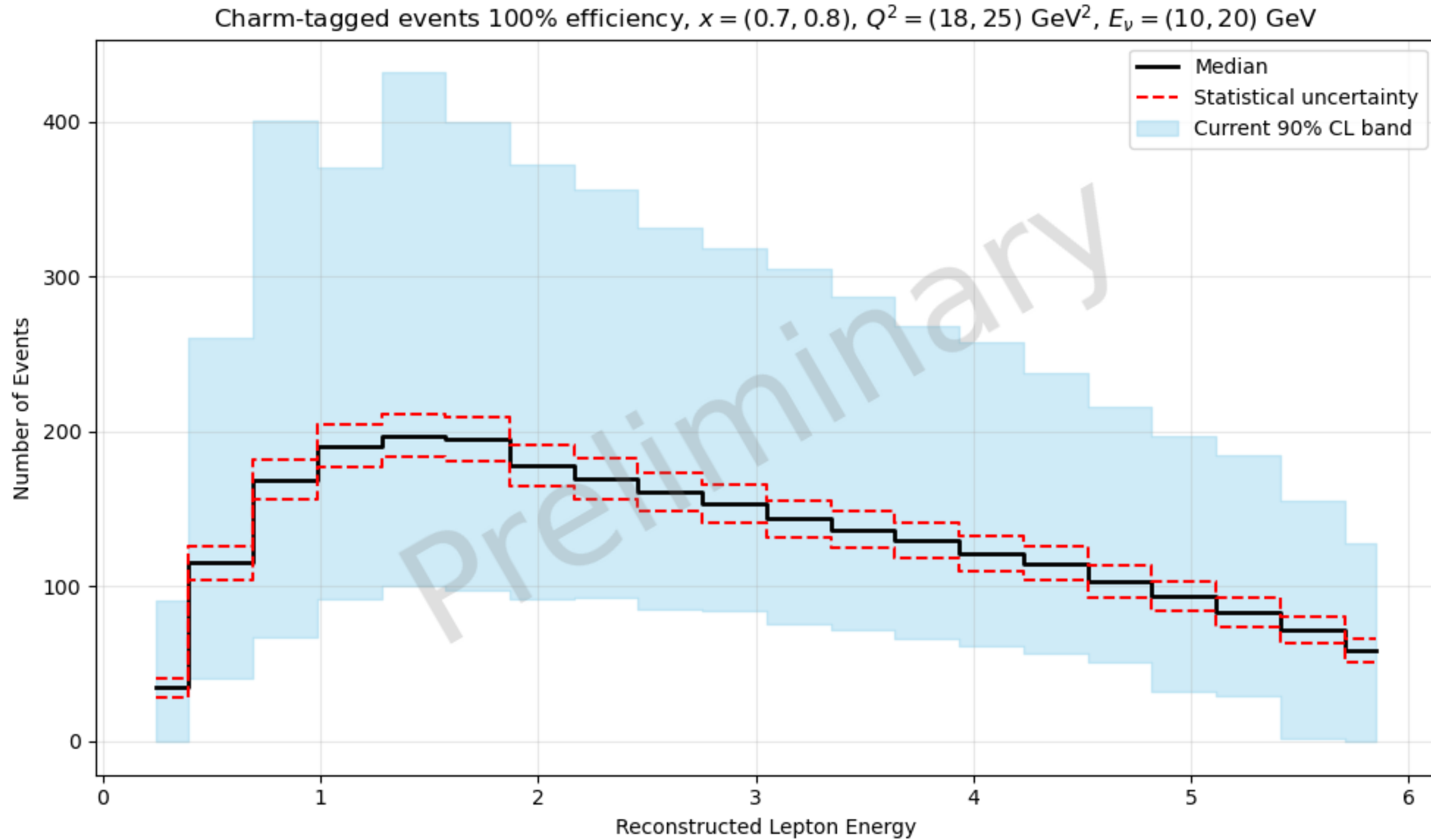


- Charm-tagged events can constrain the poorly understood strange PDF.

$$s + W^+ \rightarrow c$$

- TPCs have very good final-state reconstruction and spatial resolution (e.g. MicroBooNE). This may grant DUNE c-tagging capabilities via measuring c-meson decay products.

# Exploratory work, charm events



## Main takeaways

- Results show that DUNE will be capable of constraining PDFs, specially nuclear parameters, owing to the large available number of neutrino interactions and good final state reconstruction.
- Neutrino data can be a window to existing tensions among different PDF datasets and a new probe for nuclear effects.
- Charm tagging in DUNE, if possible to implement, can be a great tool to access the strange content of nuclei.

## Conclusions and ways forward

- Study the advantages of neutrino data and their role in TMDs, FFs, ...
- Improve determination of axial nucleon structure.
- Explore mutual feedback between neutrino and QCD experiments.

# Thank you!



# Backup slides

## DIS formulae relating physical variables

$$Q^2 = 2E_l E_\nu (1 - \cos \theta)$$

$$x = \frac{Q^2}{2m_N E_H} \quad E_H + E_l = E_\nu$$

$$M_x^2 = m_N^2 + \frac{Q^2(1-x)}{x}$$

The number of events is computed via:

$$N = \int_{\text{BIN}} dE_l^R \int_{\text{BIN}} dE_\nu^R \int_{\text{BIN}} d \cos \theta^R \int_{E_0}^{E_f} dE_\nu^T \int_{\text{DIS}} dE_l^T \int_{\text{DIS}} d \cos \theta^T \times$$

$$\times \frac{d\sigma}{dE_l^T d \cos \theta^T} \frac{d\phi}{dE_\nu^T} P_\theta P_l P_\nu T N_{\text{targets}}$$

Sensible to PDF parametrization

Experimental dependance (Gaussian smear)

Structure functions in neutrino DIS can be computed through collinear factorization

$$F(x, Q^2) = \sum_j \int_1^x \frac{dz}{z} dz C_j(z, \alpha_s(Q^2)) f_j\left(\frac{x}{z}, Q^2\right). \quad [\text{A. Candido et al. 2401.15187}]$$

Libraries for the computation of structure functions and cross sections beyond leading power already exist (YADISM, PineAPPL,...)