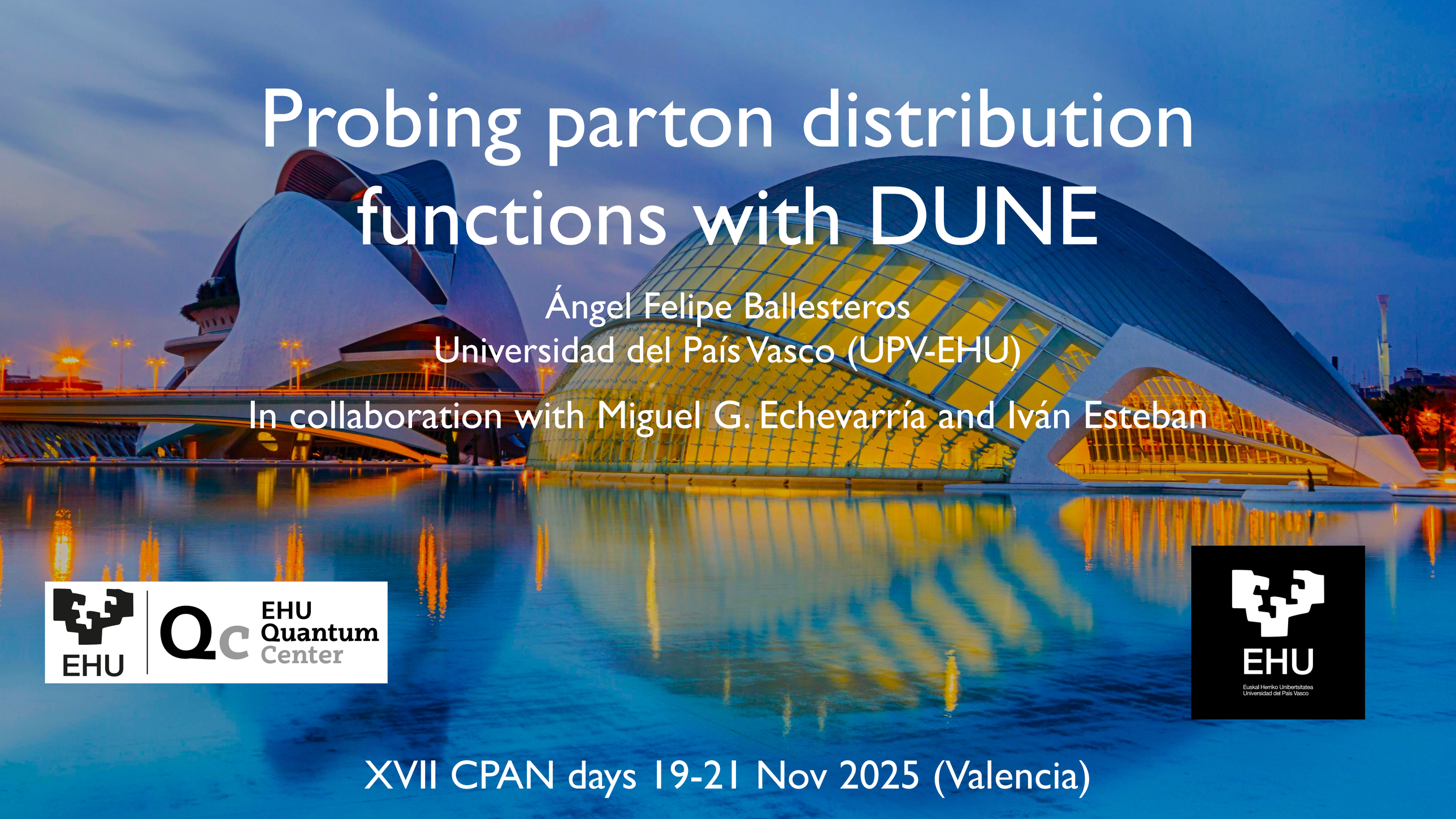

Probing parton distribution functions with DUNE

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XVII CPAN days 19-21 Nov 2025 (Valencia)

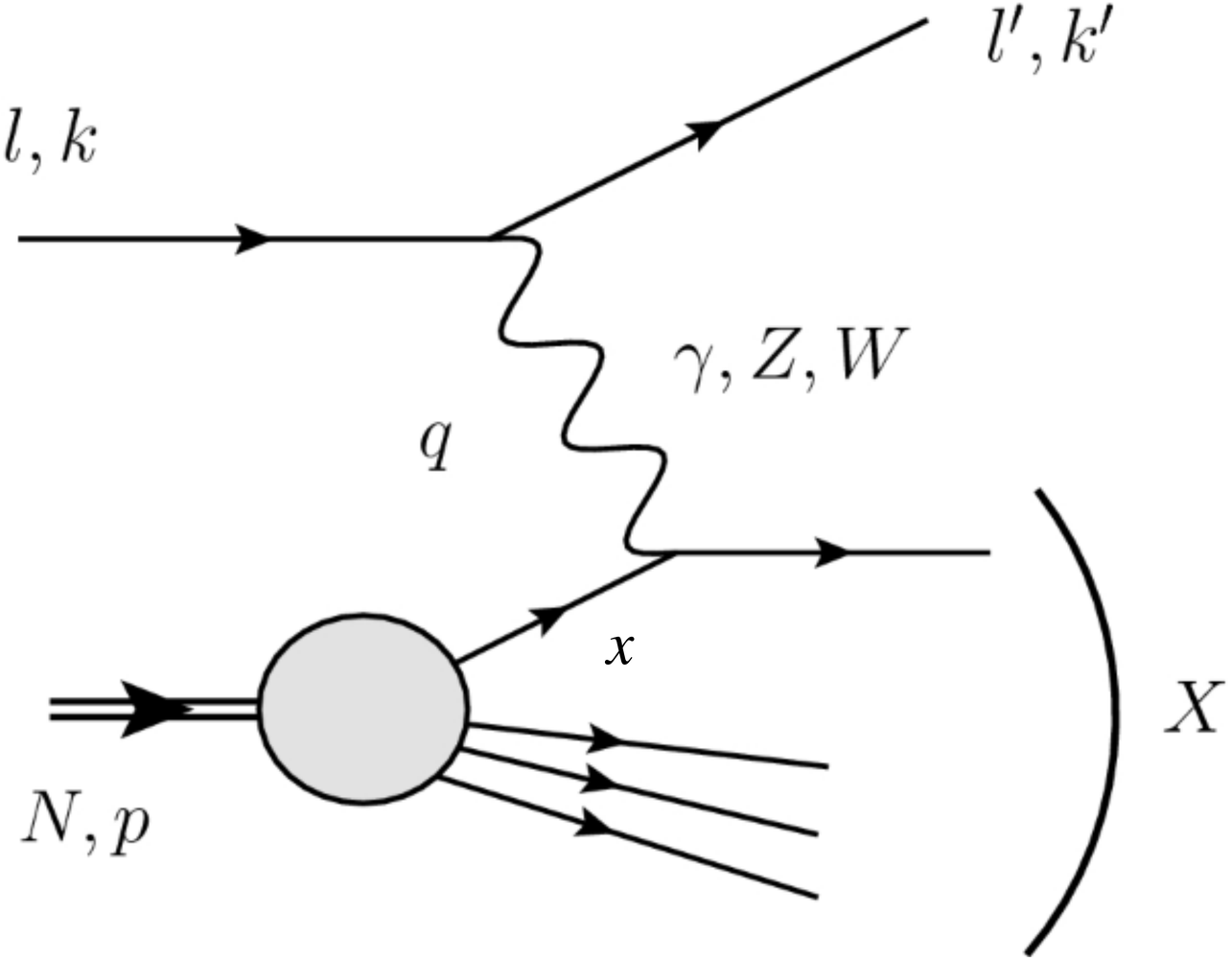
Introduction

- **PDFs** are key objects to understand hadron structure.
- **DIS** is a clean tool to measure PDFs
- ν**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 νDIS [K.F. Muzakka et al. 2204.13157]

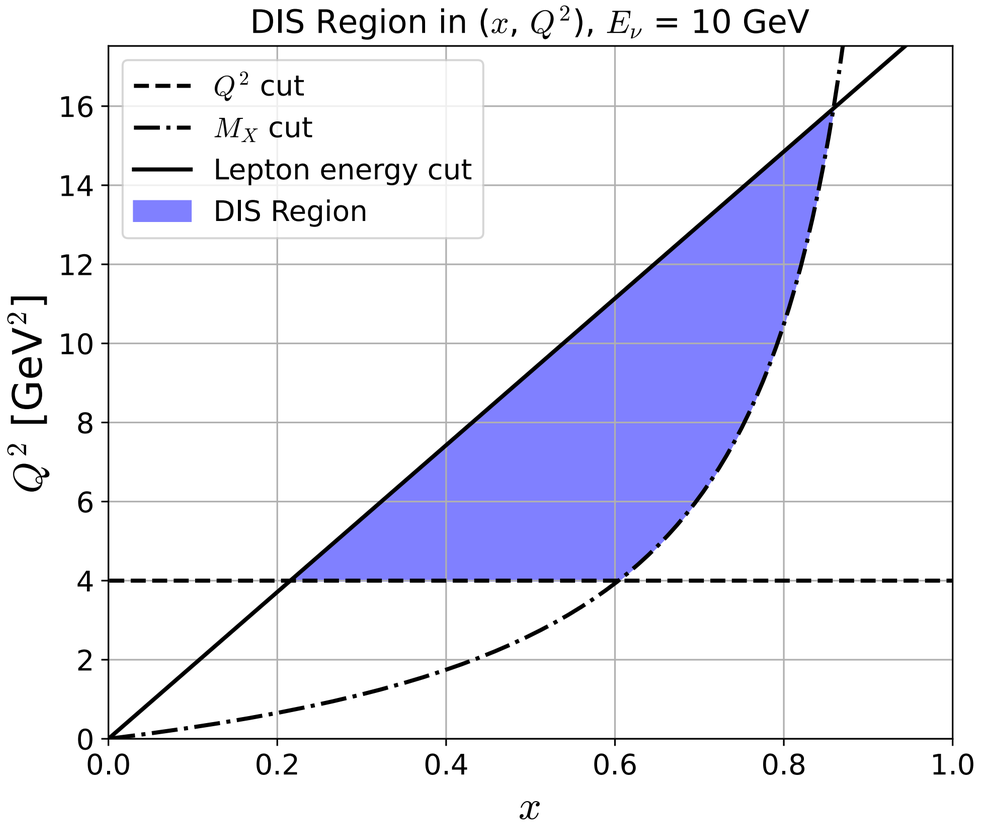


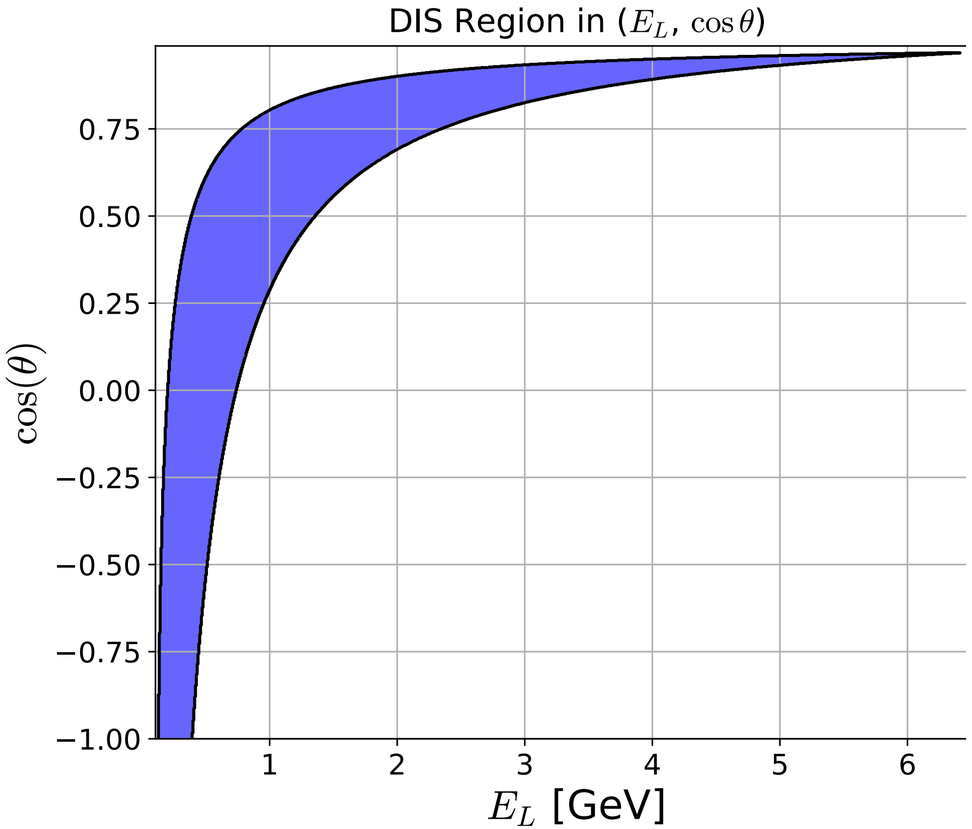
$$-q^2 = Q^2 \geq 4\text{GeV}^2 .$$

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

Fig 1. Neutrino DIS diagram
[I. Borsa et al. 2210.12014]

Neutrino Deep Inelastic Scattering: DIS conditions





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

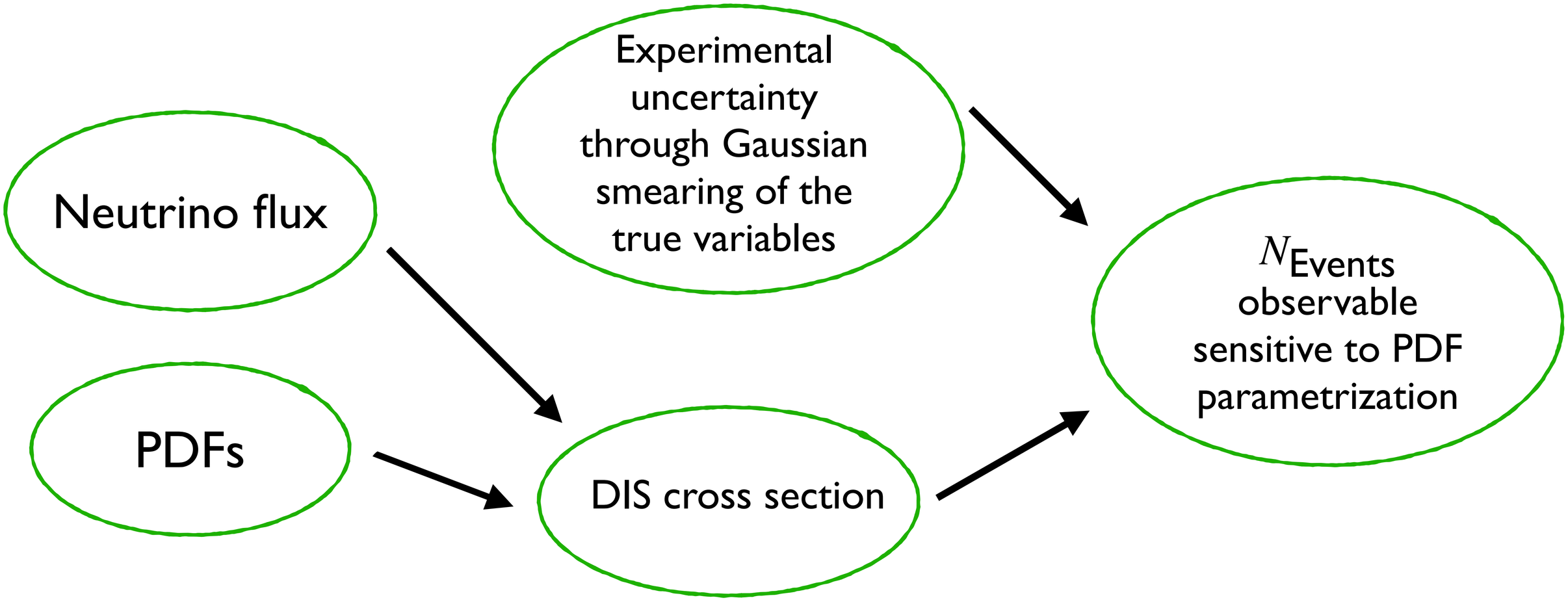
$$x = \frac{Q^2}{2m_N(E_\nu - E_l)}$$

- DUNE is a future neutrino oscillation experiment that will tackle several open problems (CP violation, mass ordering…).
- 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.
- Reconstruction of DIS events is done by measuring E_H, $\cos\theta$ and E_l .

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

[DUNE Collaboration 2002.03005 & 2103.139910]

Number of events



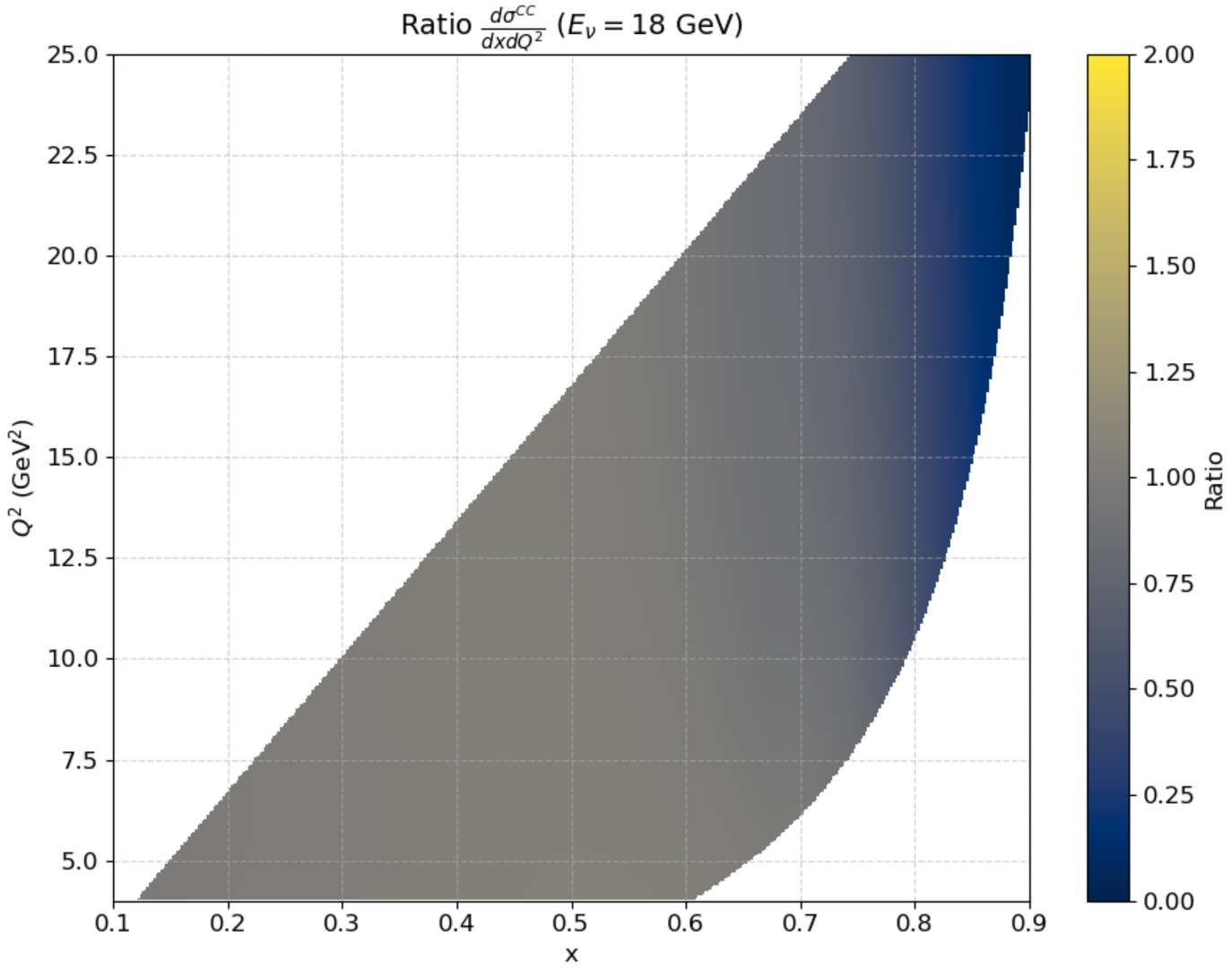
PDF constraints on number of events EPPS vs NNPDF

There is a mild tension between EPPS and nNNPDF Argon-40 datasets in the high-x region

Can DUNE explore this by reconstructing events?

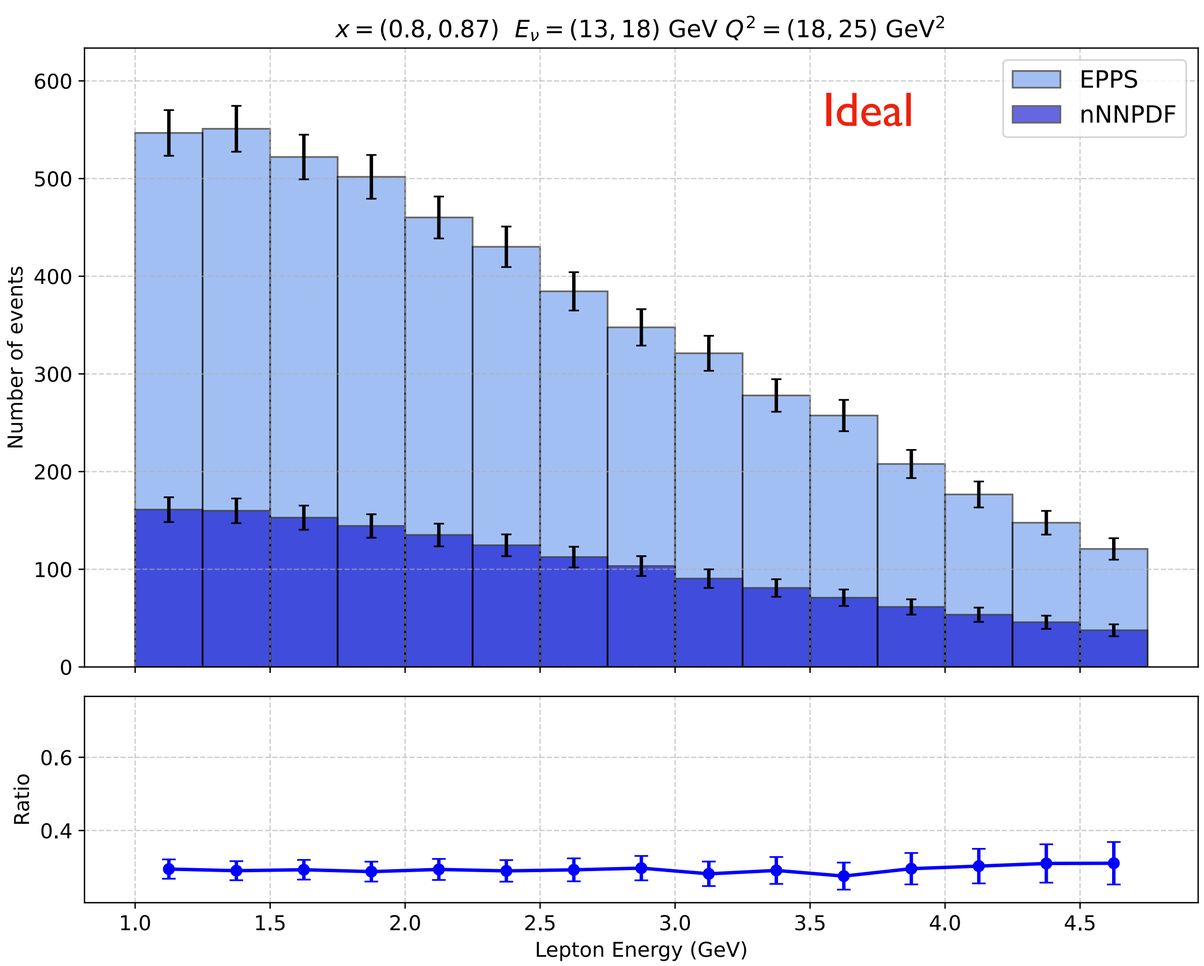
[K.J. Eskola et al. 2112.12462]

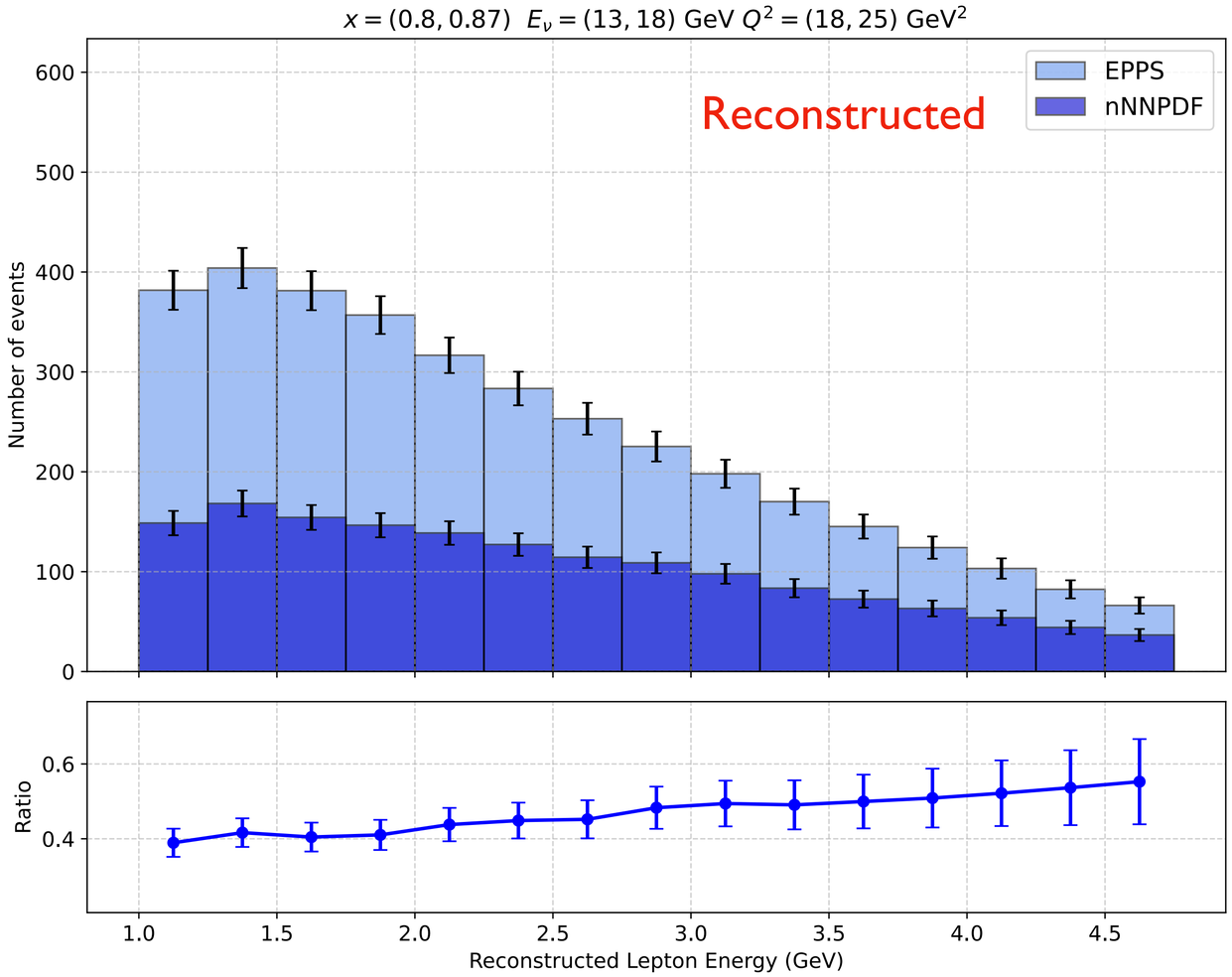
[R. Abdul Khalek et al. 2201.12363]



Results on number of events

*Statistical uncertainty only





- Charm tagging refers to identifying a charm jet in an event through various techniques and algorithms that exploit c-meson lifetimes and decay products.

[ATL-PHYS-PUB-2015-001]

$$c\tau_{D^{\pm}} \sim 309\mu m \qquad c\tau_{\pi^{\pm}} \sim 7.8m$$

$$c\tau_{D^{0}} \sim 123\mu m \qquad c\tau_{\pi^{0}} \sim 25.3nm$$

[S. Navas et al. (PDG) PhysRevD.110.030001]

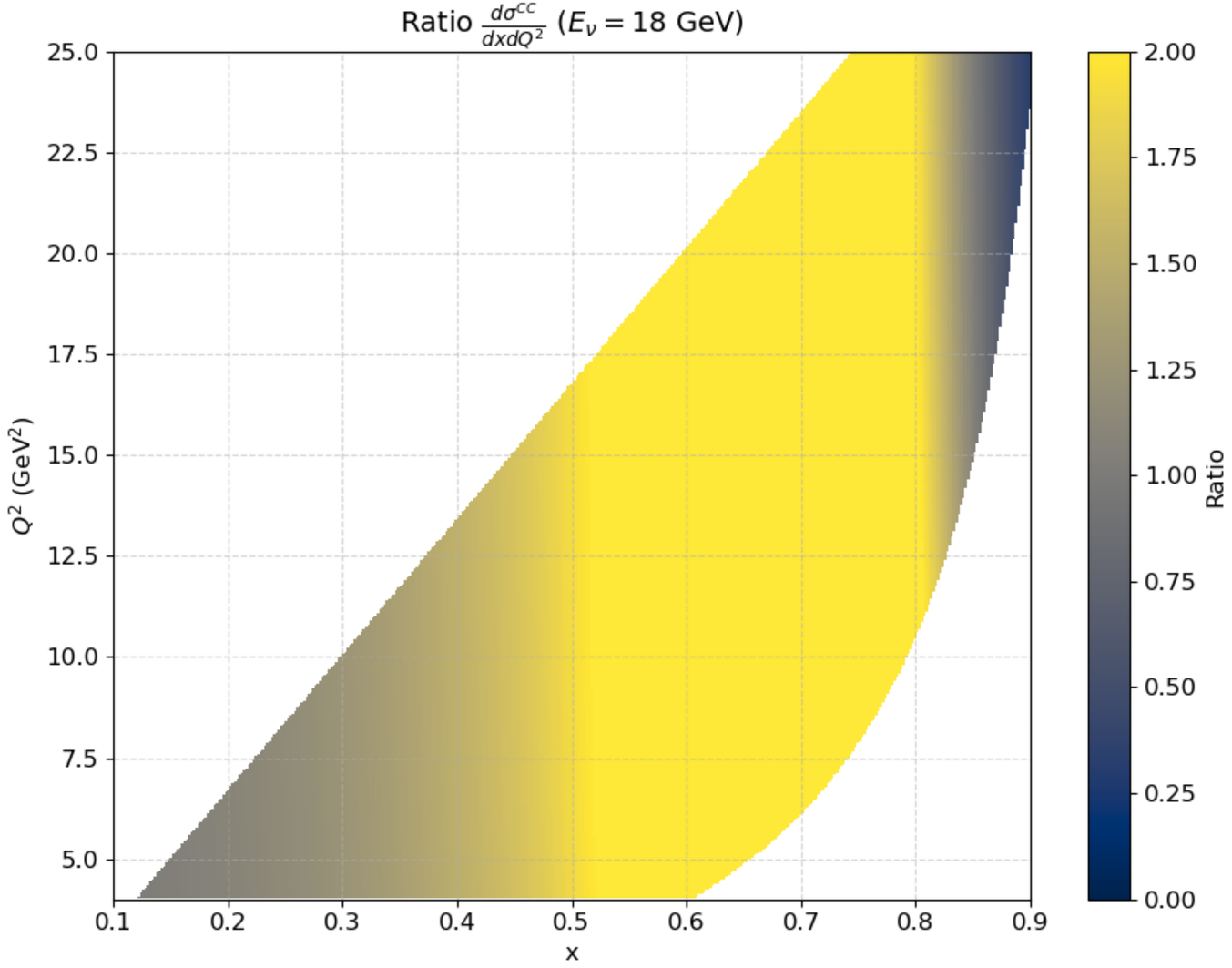
- Evaluating if and how effectively DUNE can c-tag through its TPC is an ongoing work.

Constraints on charm-tagged events

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

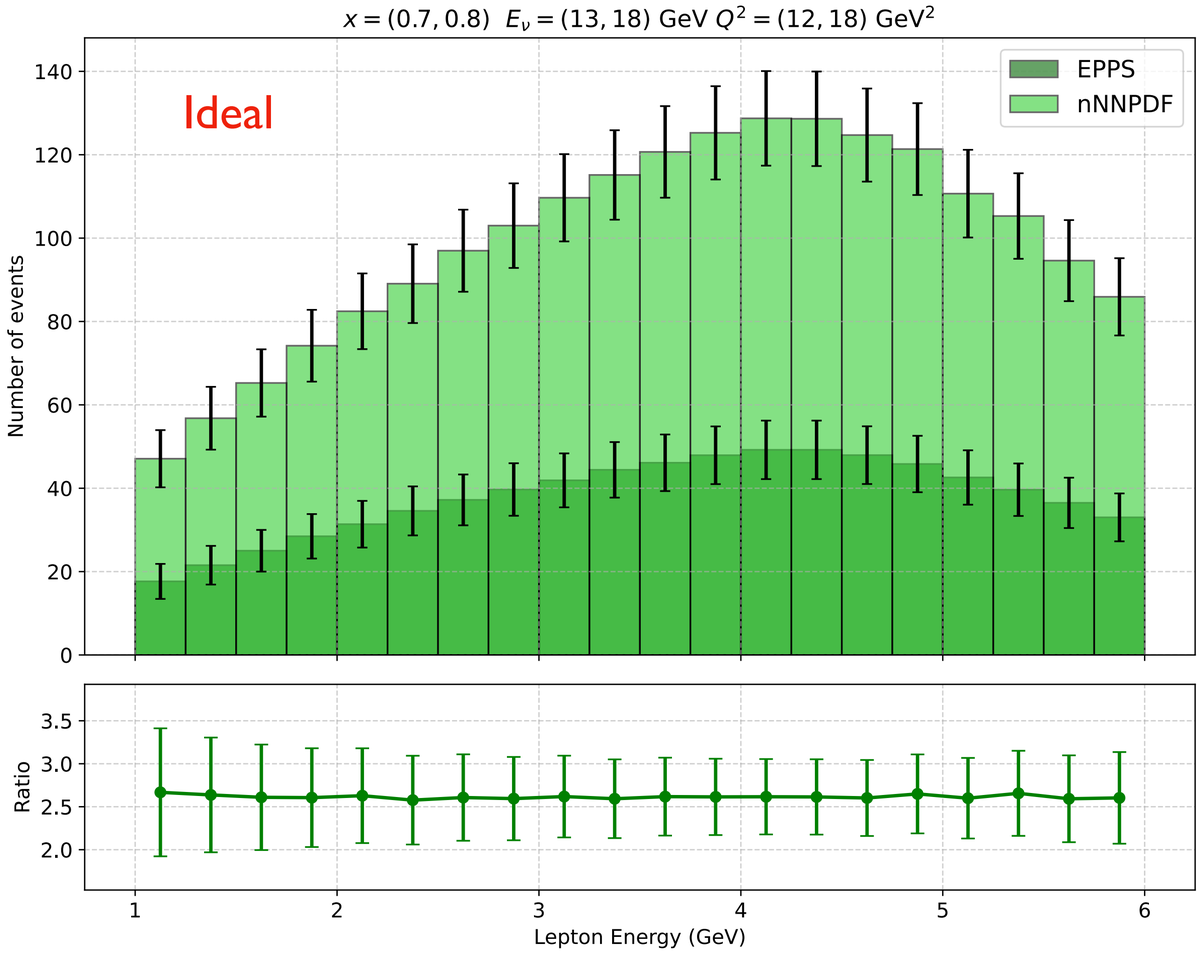
$$s + W^+ \rightarrow c$$

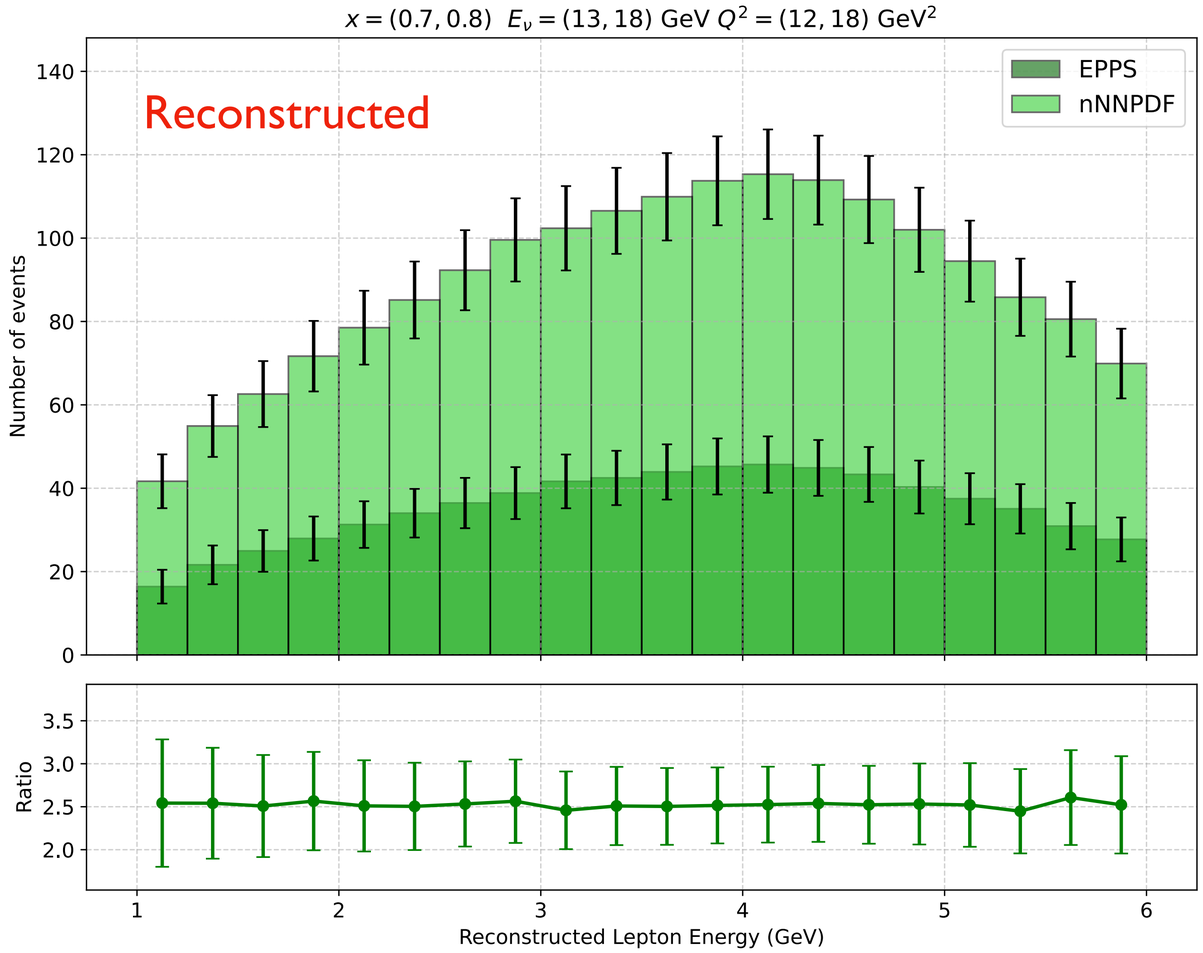
- Tensions are more present as the cross section gets more sensitive to the strange PDF.



Constraints on charm-tagged events

*Statistical uncertainty only





Main takeaways

- Preliminary results show that DUNE could be capable of constraining PDFs 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.

Future lines of research

- Extend calculations beyond leading power (WIP).
- Study the advantages of neutrino usage and their role in TMDs, FFs, … (WIP)
- Compare different nuclei datasets to look for exclusive neutrino nuclear effects.


Thank you!
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Backup slides

DIS formulae relating physical variables

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

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

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

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

$$F(x,Q^2) = \sum_j \int_1^x \frac{dz}{z} \mathrm{d}z \; C_j\left(z, \alpha_s(Q^2)\right) \; f_j\left(\frac{x}{z}, Q^2\right) .$$

[A. Candido et al. 2401.15187]

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

Applying these modules to the Argon 40 neutrino DIS case of DUNE is an ongoing work