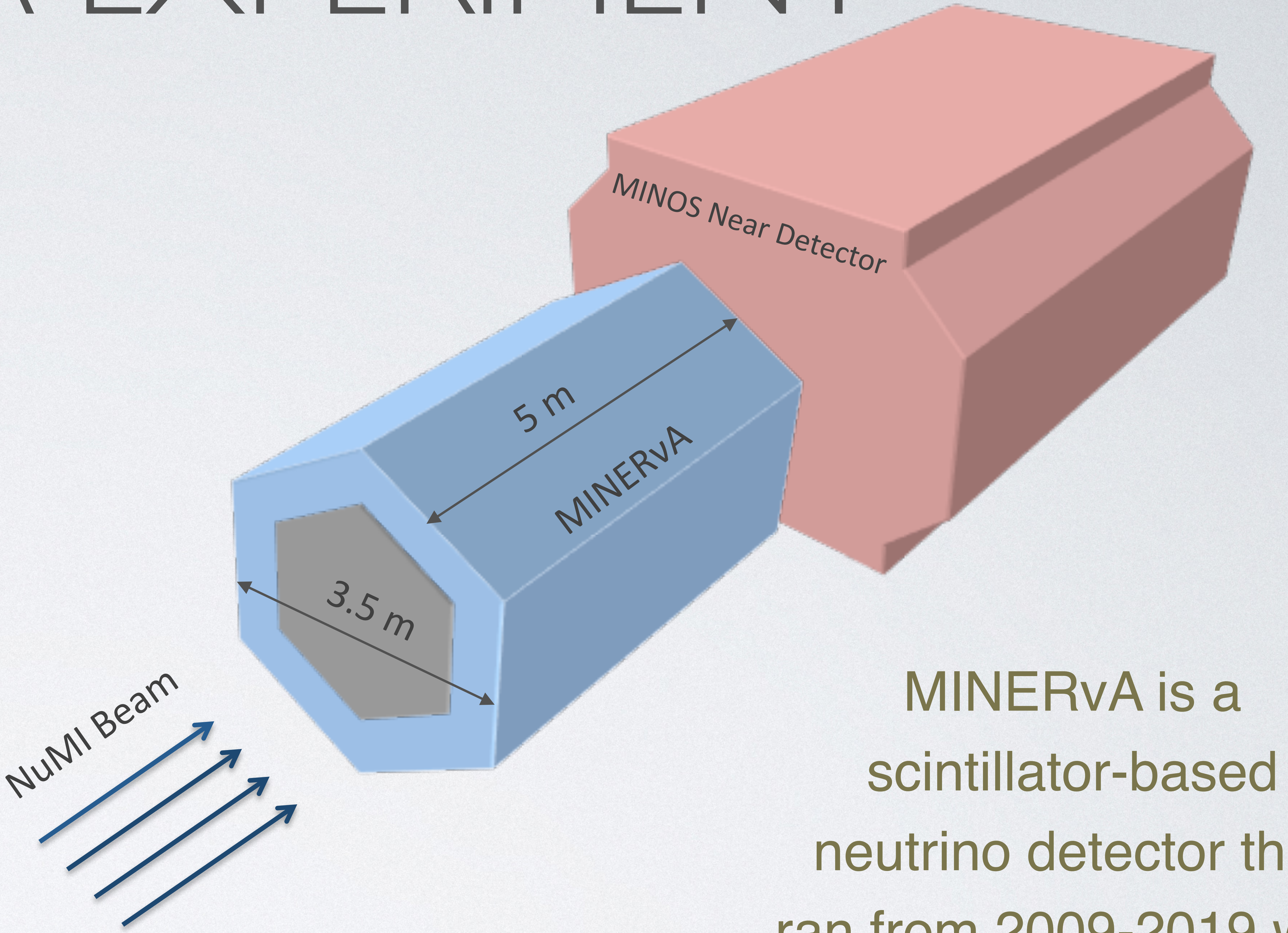
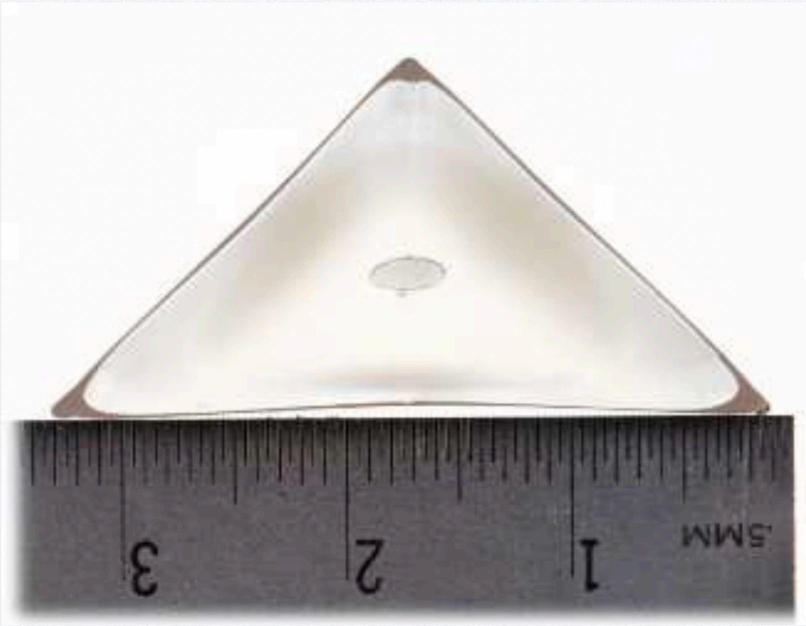
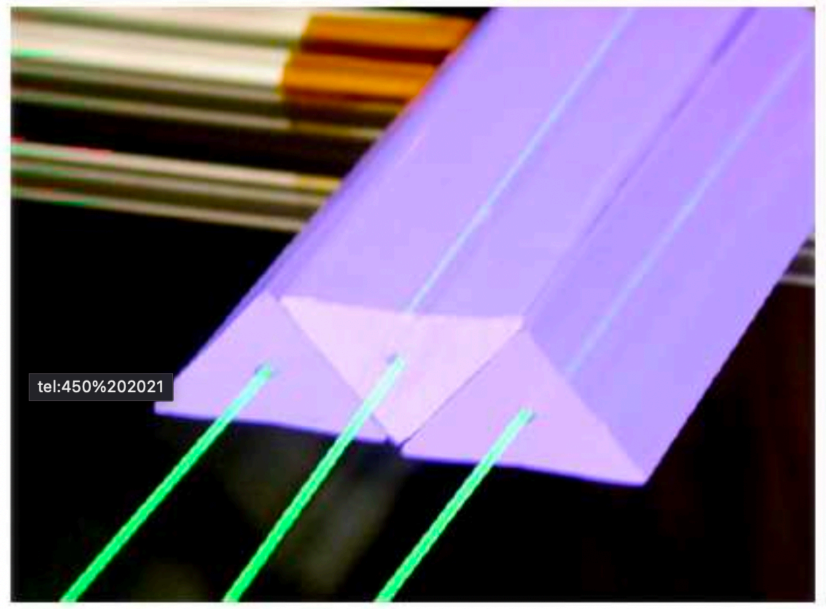
RECENT RESULTS FROM MINERVA

Laura Fields, University of Notre Dame
2023 Fermilab Users Meeting

THE MINERVA EXPERIMENT

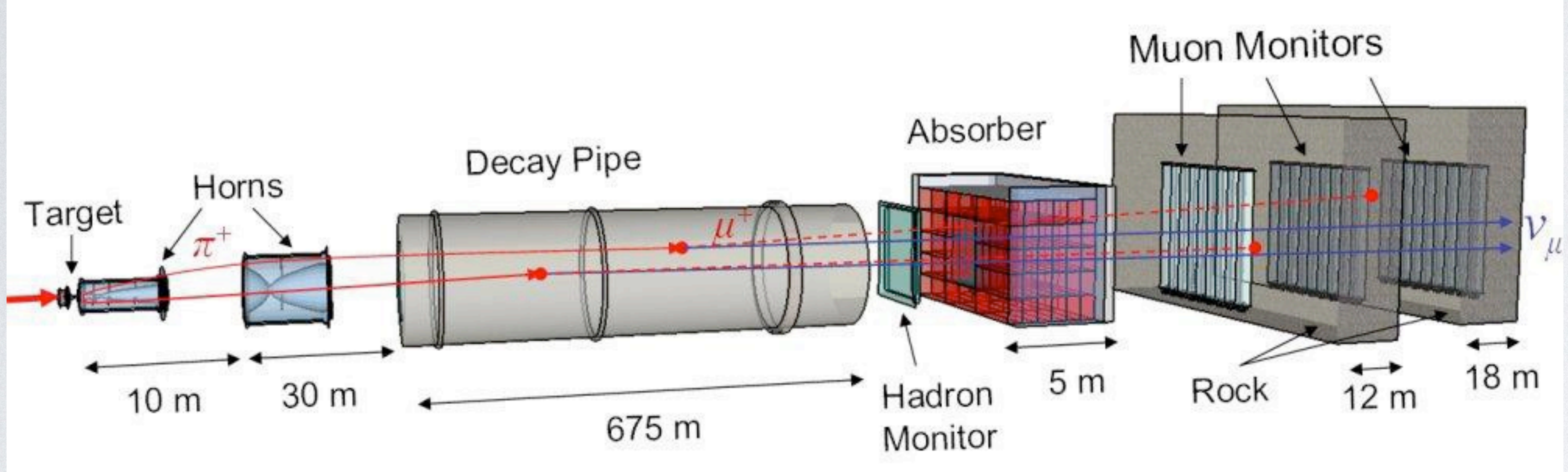


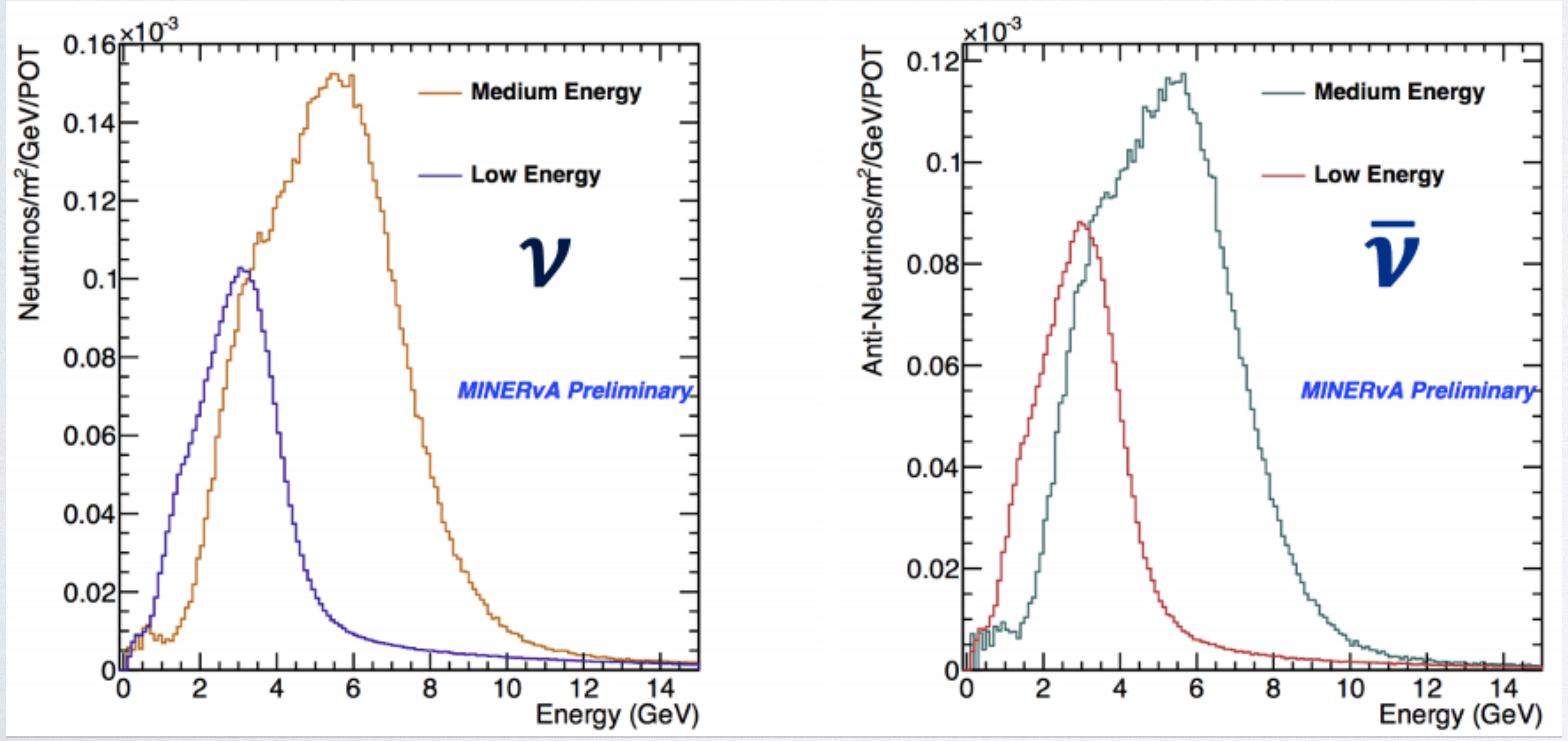




MINERvA is a scintillator-based neutrino detector that ran from 2009-2019 with the primary goal of measuring neutrino interaction cross sections

MINERVA DATA





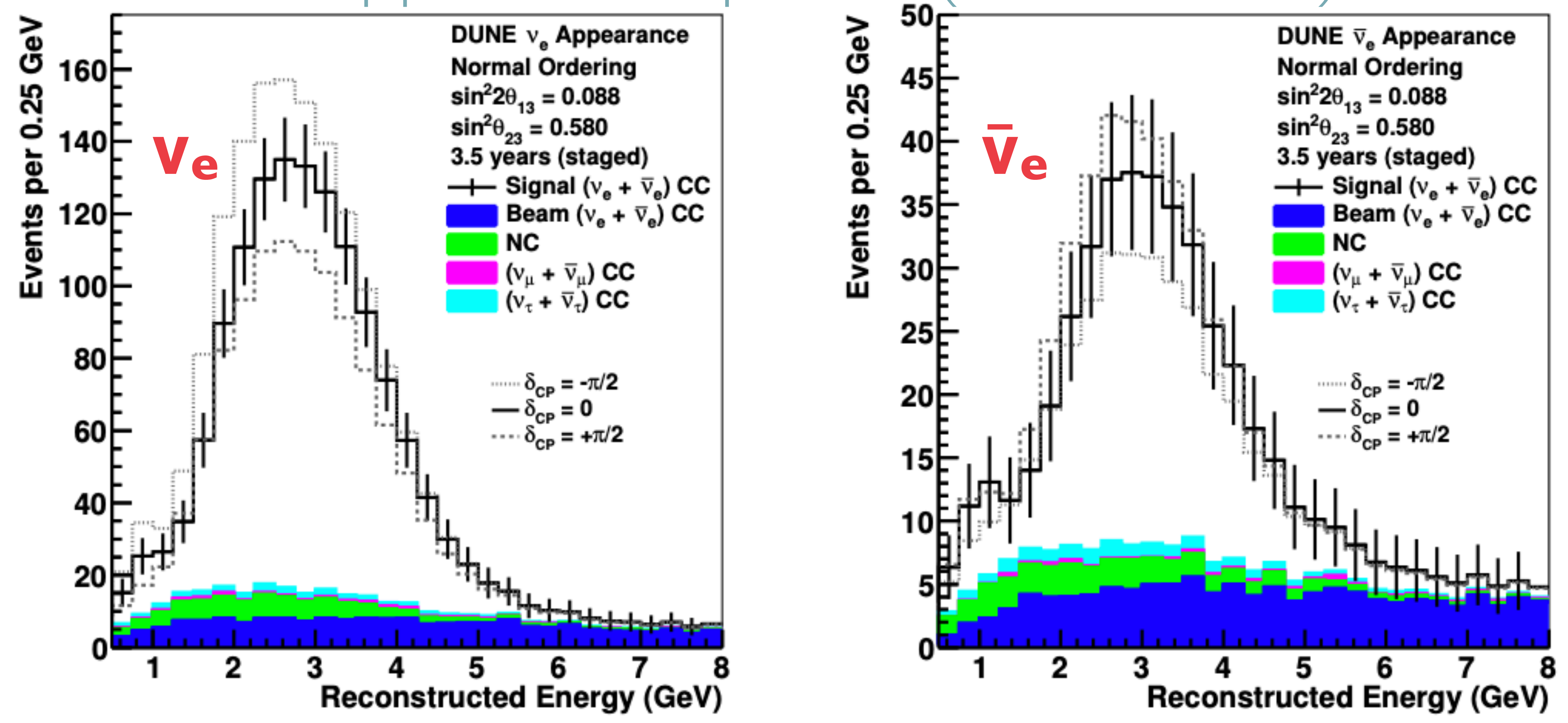
- MINERvA collected a total for 30e20 in two energy configurations and two horn currents.
- More than 30 publications from our "Low Energy" data
- Publications in higher statistics "Medium energy" data rolling out now, including 9 in the last year

Thank you to everyone at Fermilab who provided beam, computing and other infrastructure!

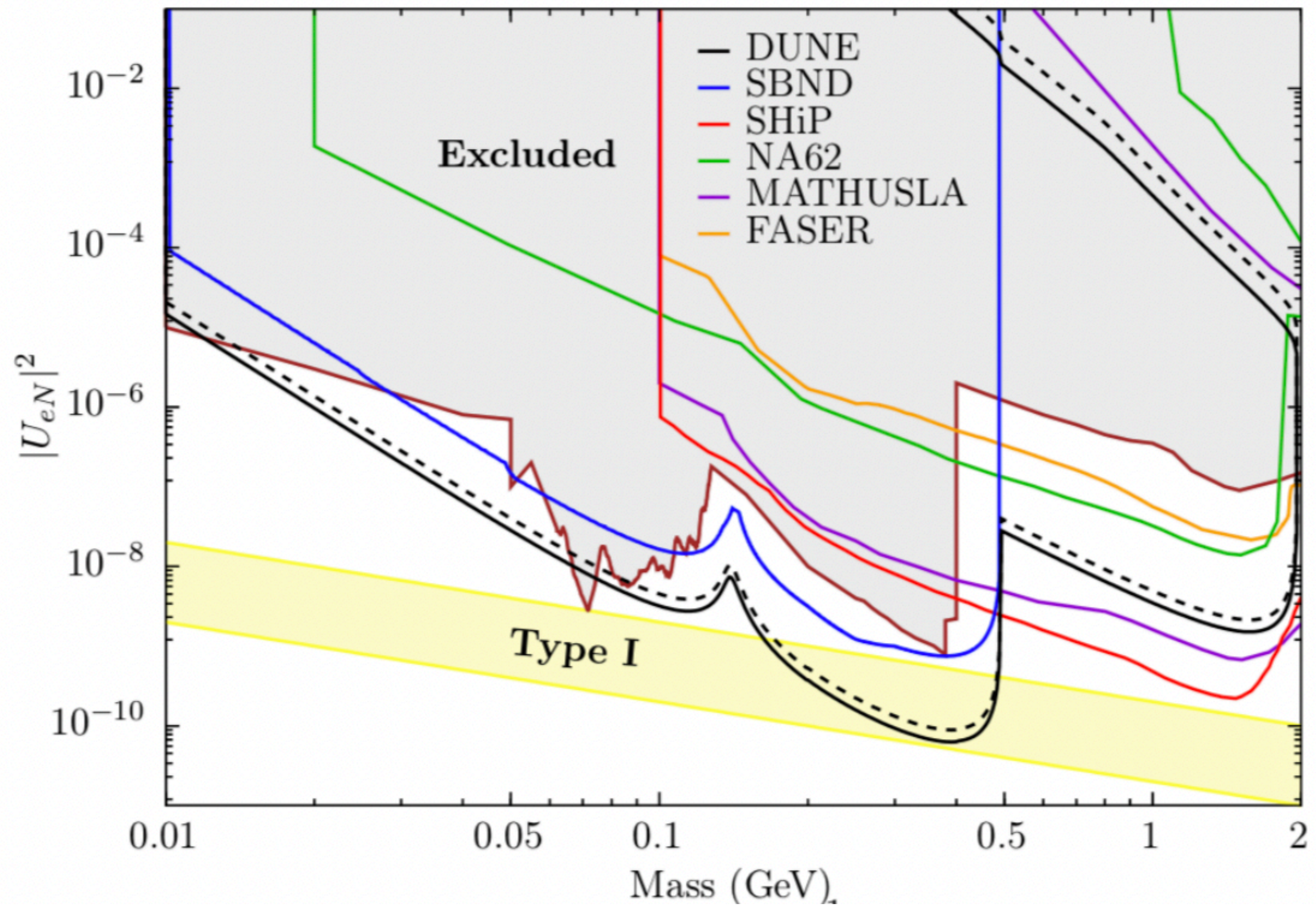
MINERVA MOTIVATION

- Oscillation experiments like DUNE are working on a bunch of cool stuff — e.g. searching for CP violation by neutrinos and Beyond-the-Standard model physics

ν_e appearance spectra (DUNE TDR)

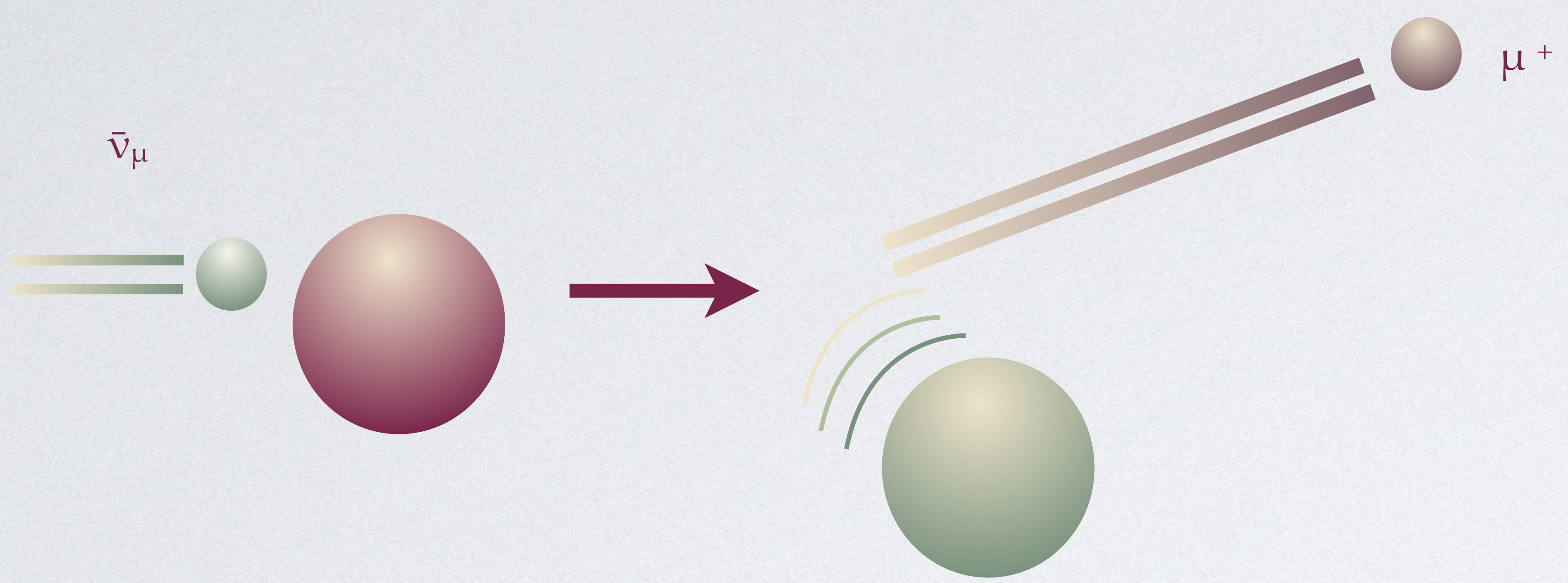


Sensitivities to an HNL scenario (European Physical Journal C 81 (2021) 322)



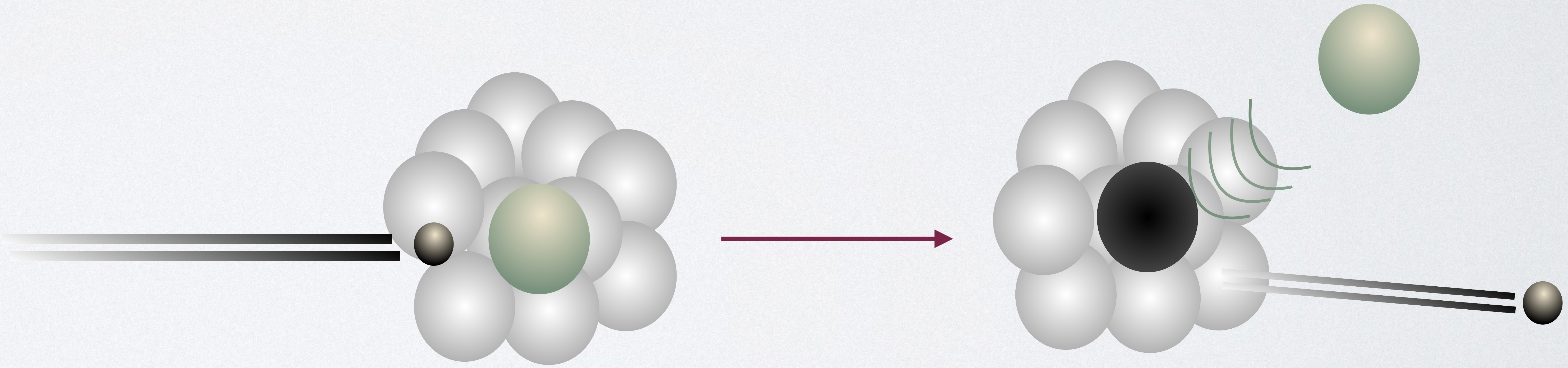
DUNE will do all of this by detecting interactions. To interpret DUNE data we will need very precise models of neutrino interactions.

NEUTRINO INTERACTIONS



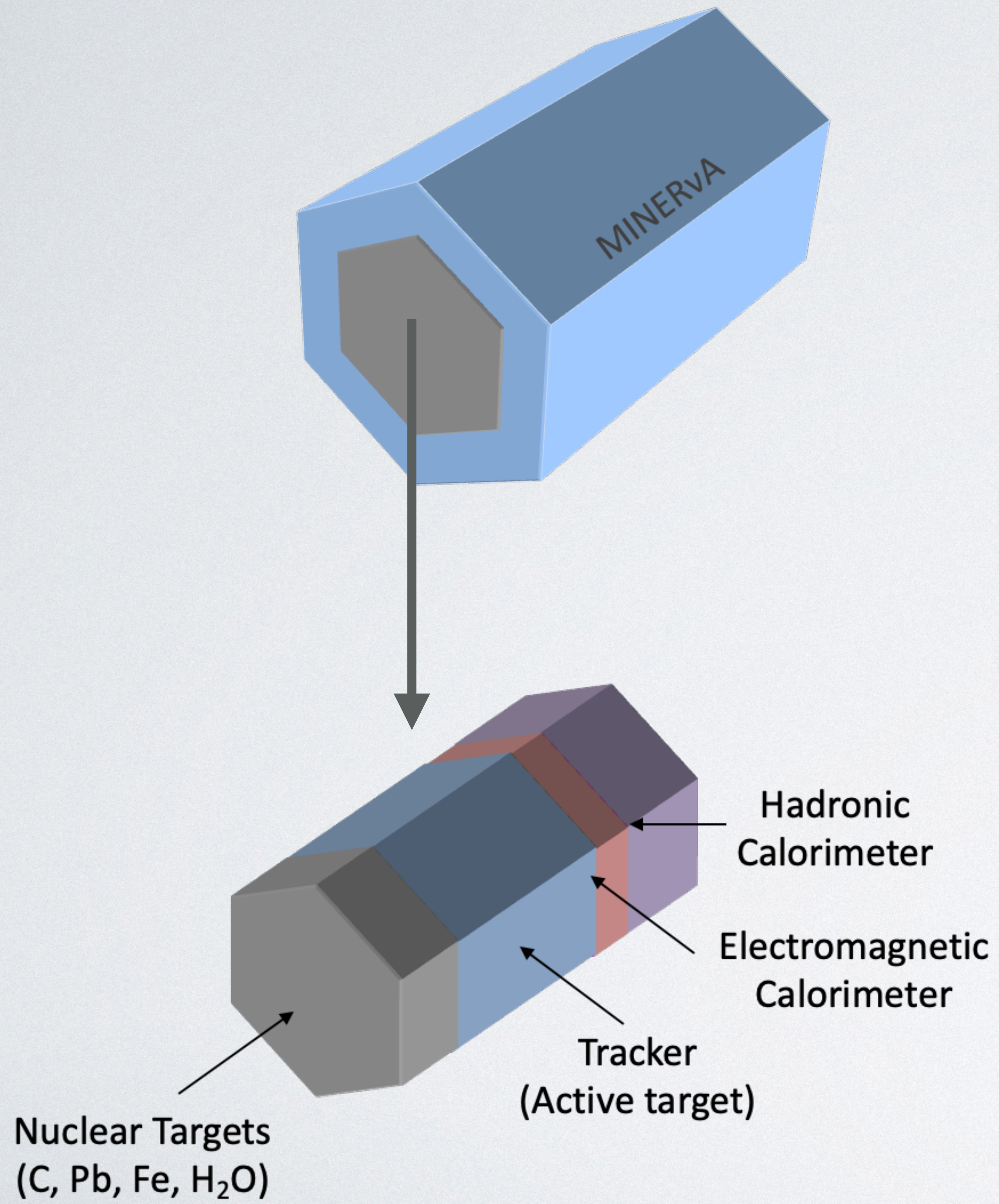
Neutrinos usually interact with protons or neutrons in our detectors. For DUNE (and lots of other experiments) we need models of neutrino interactions with nucleons.

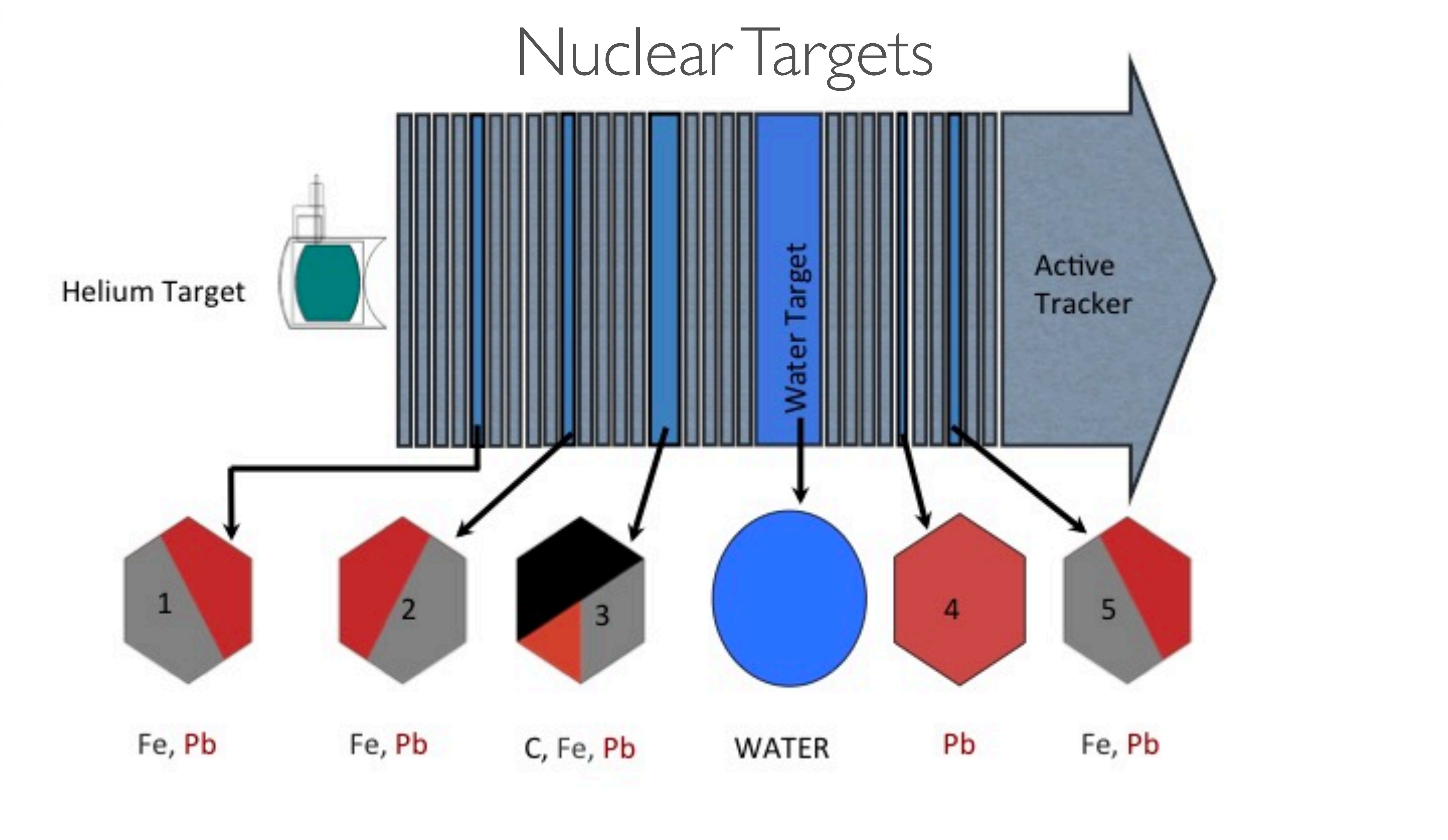
And also models of the nucleus in which the interaction happens, and its impact on the interaction



Untangling nuclear effects is one of MINERvA's primary goals

MINERVA AND NUCLEI



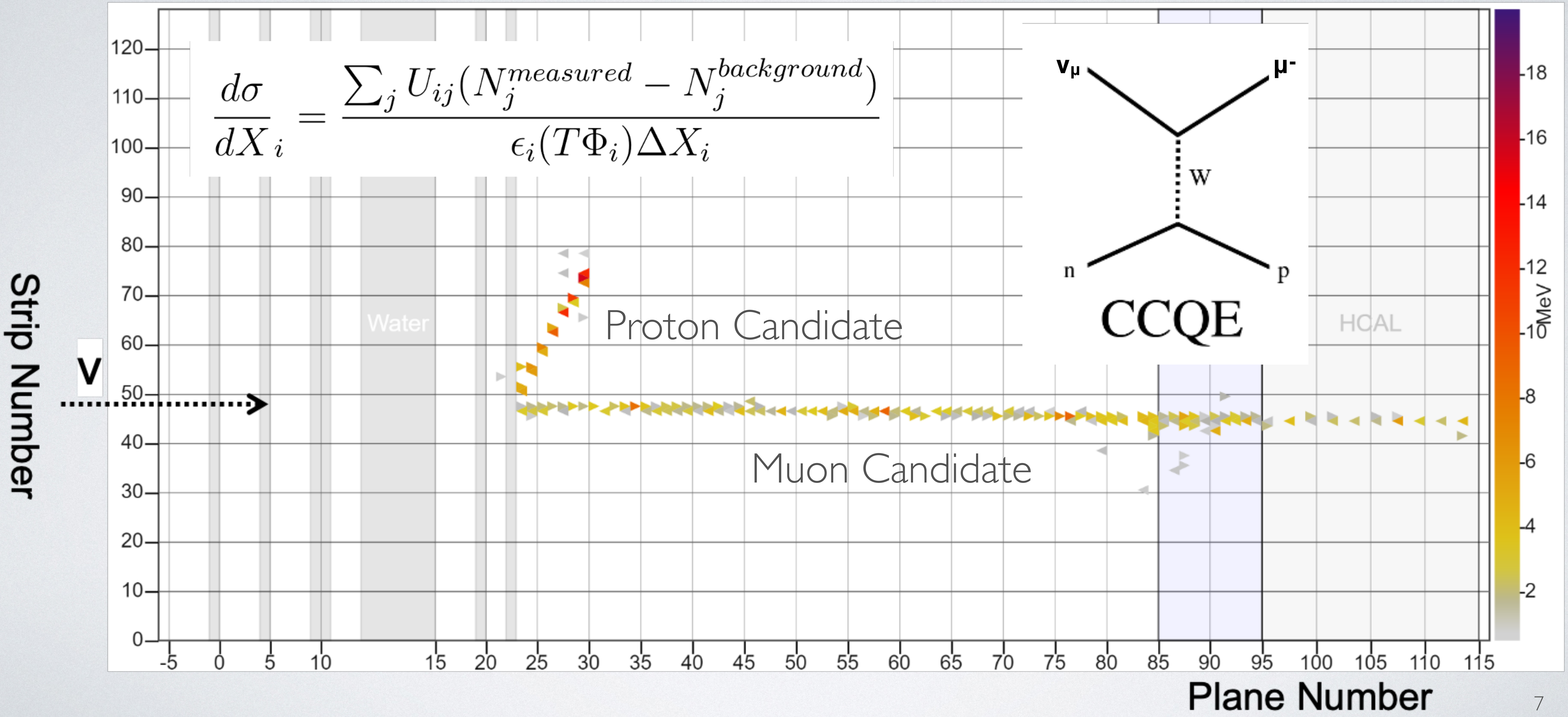


Comparing cross sections across many nuclei highlights impact of nuclear environment

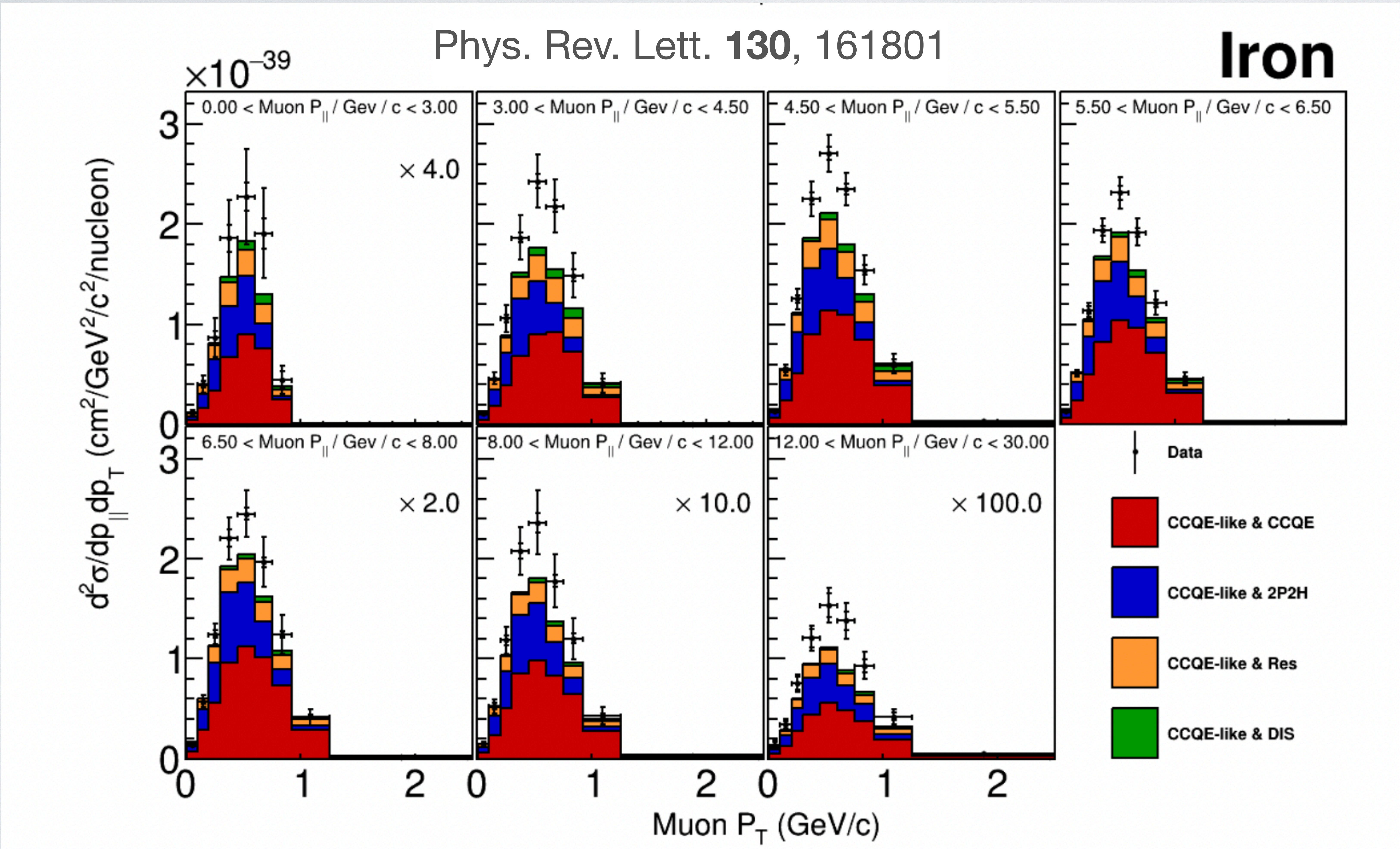
Three papers in the past year on nuclear targets!

A-DEPENDENCE: ν_μ CC 0PI

$$\frac{d\sigma}{dX_i} = \frac{\sum_j U_{ij}(N_j^{measured} - N_j^{background})}{\epsilon_i (T\Phi_i)\Delta X_i}$$

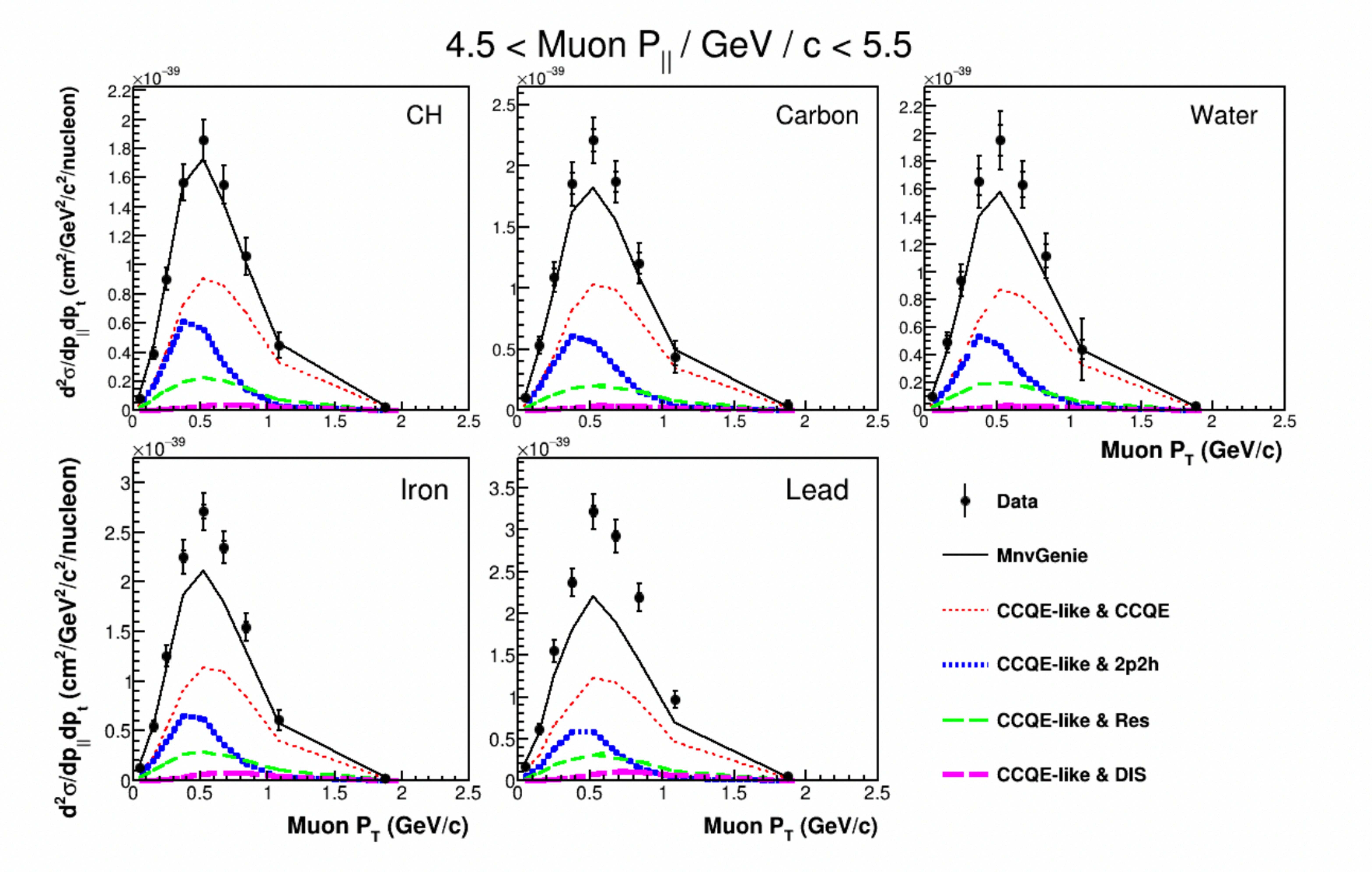


A-DEPENDENCE: ν_μ CC 0PI



- MINERvA has measured this process on five materials and versus many different variables
- Including a two-dimensional cross section versus muon transverse and longitudinal momentum
- MINERvA's GENIE-based simulation under predicts the data on Iron in nearly all bins

A-DEPENDENCE: ν_μ CC 0PI

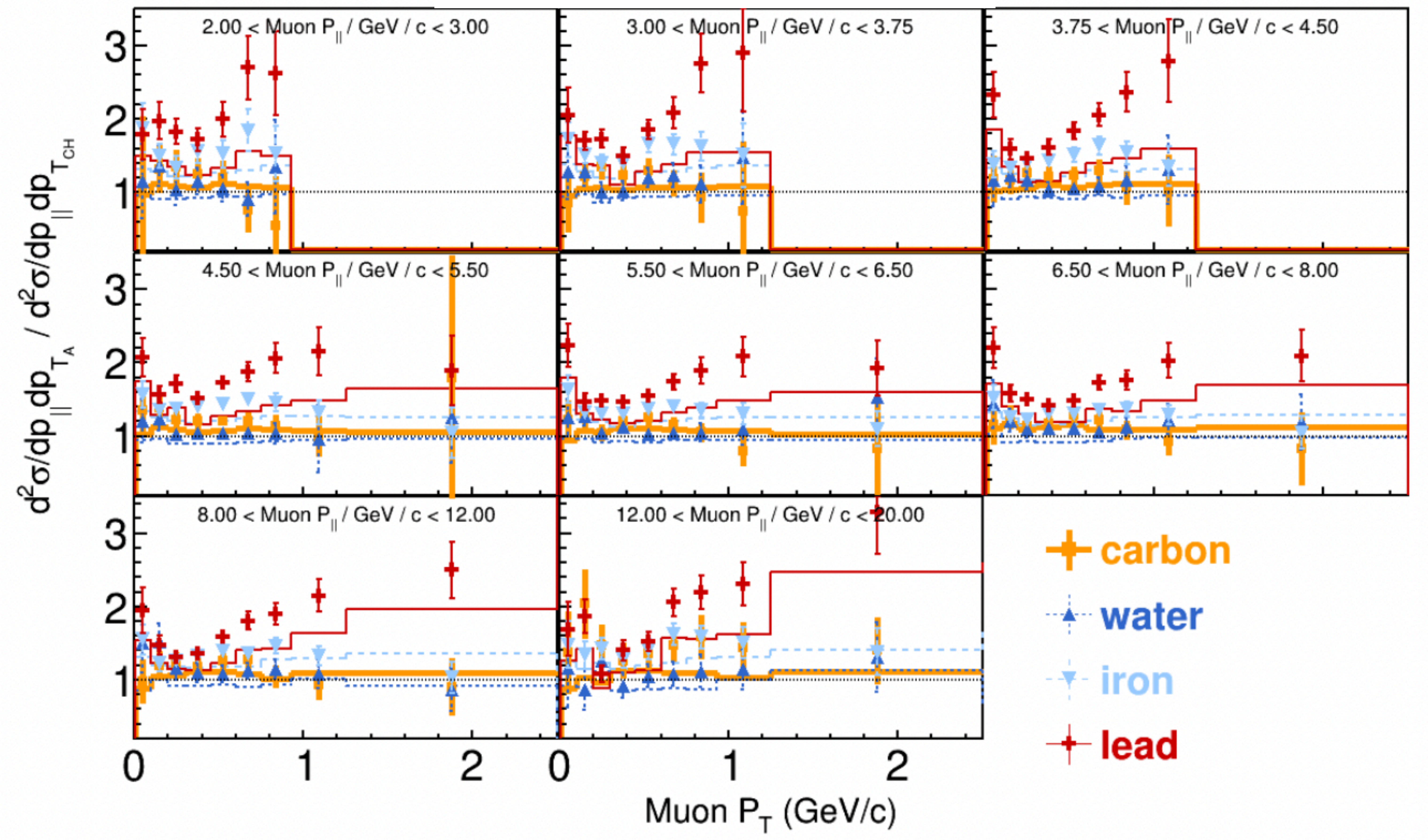


Phys. Rev. Lett. **130**, 161801

- Here we zoom in on the highest-statistics bin of muon longitudinal momentum
- Model agrees fairly well with scintillator data (which it has been tuned to)
- But the underproduction we saw in Iron is present in all heavier targets, and its magnitude increases with A

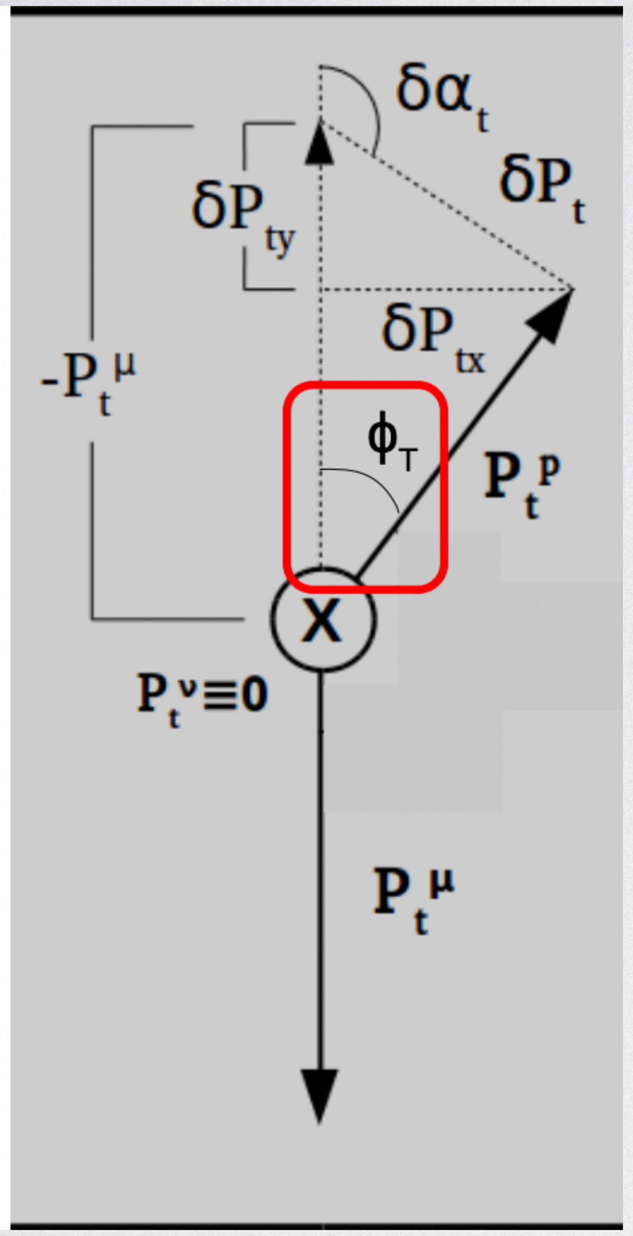
A-DEPENDENCE: ν_μ CC 0PI

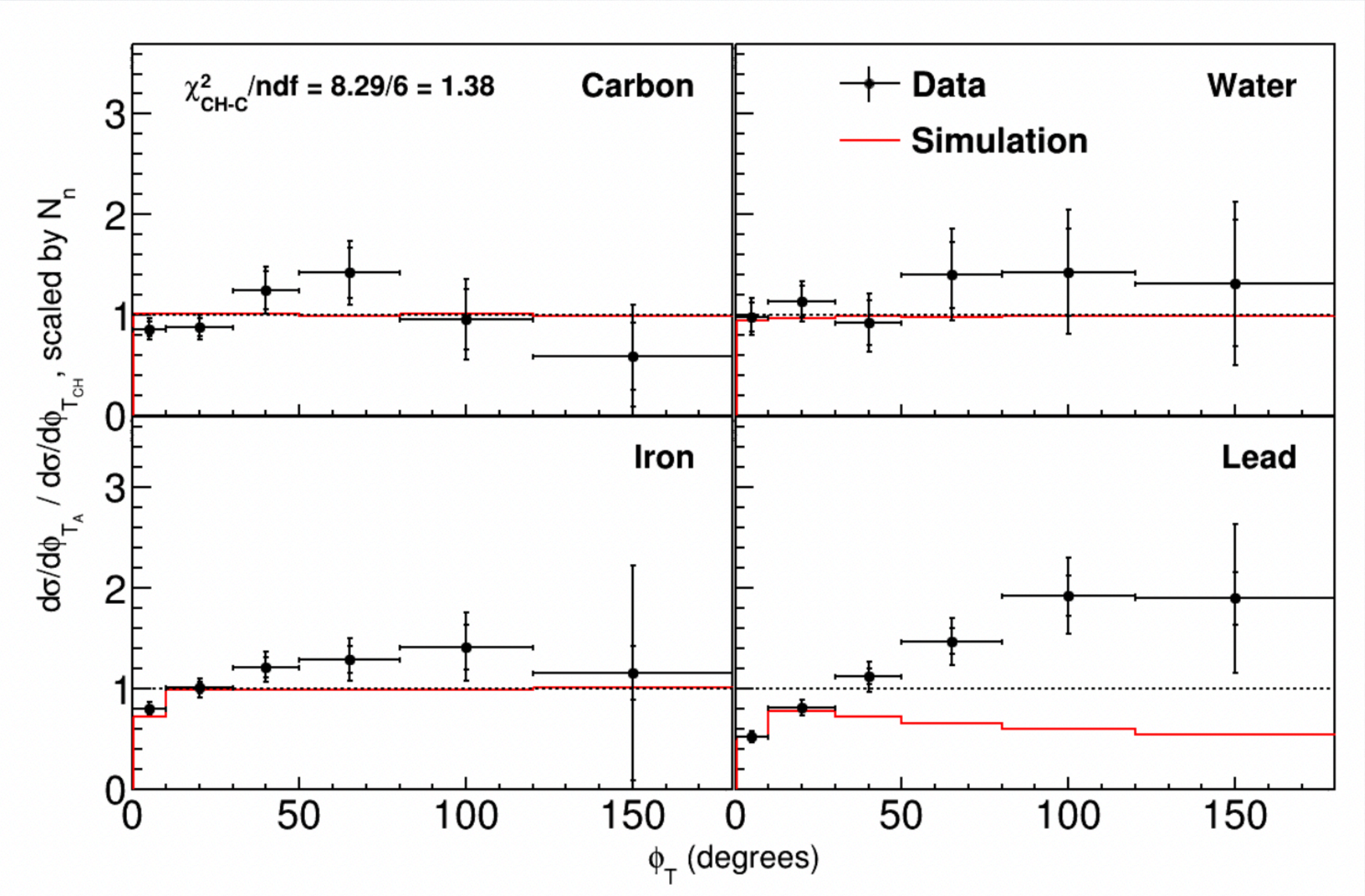
Phys. Rev. Lett. **130**, 161801



- Double ratios of cross section on various targets to cross section on scintillator minimize systematic uncertainties
- Previous trend holds — model performs increasingly poorly for heavier nuclei

A-DEPENDENCE: ν_μ CC 0PI

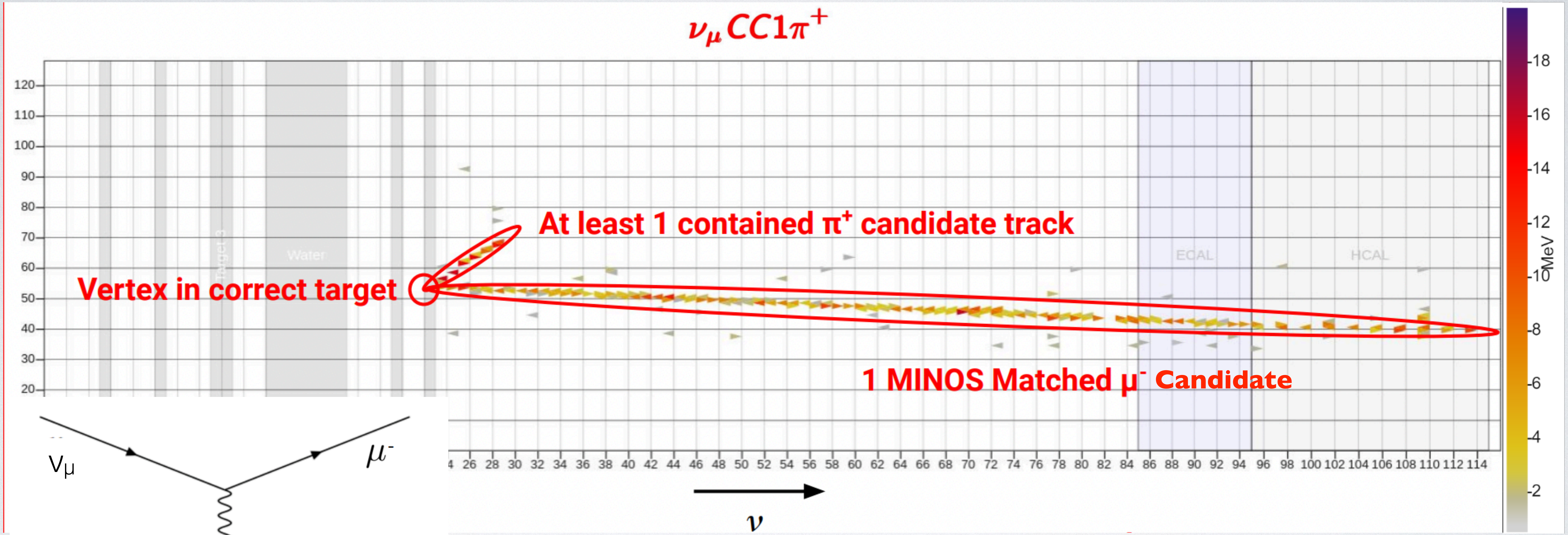


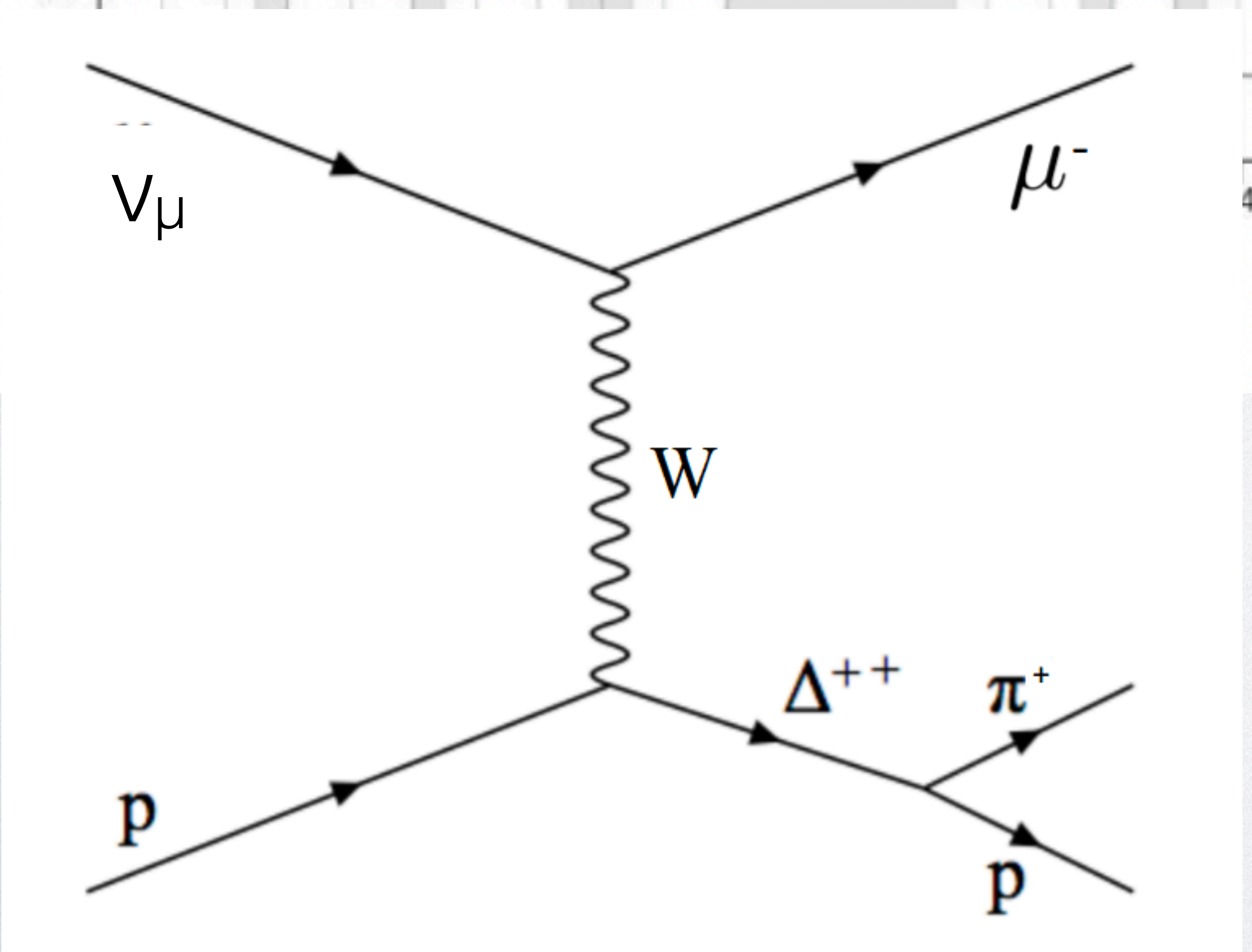


Jeffrey Kleykamp, FNAL Wine and Cheese Seminar 3-24-23
(Paper in Preparation)

- Transverse kinematic variables look at various quantities in plane transverse to neutrino beam direction — help isolate nuclear effects
- ϕ_T measures proton deflection with respect to expectation for free nucleon scattering

A-DEPENDENCE: ν_μ CC 1PI

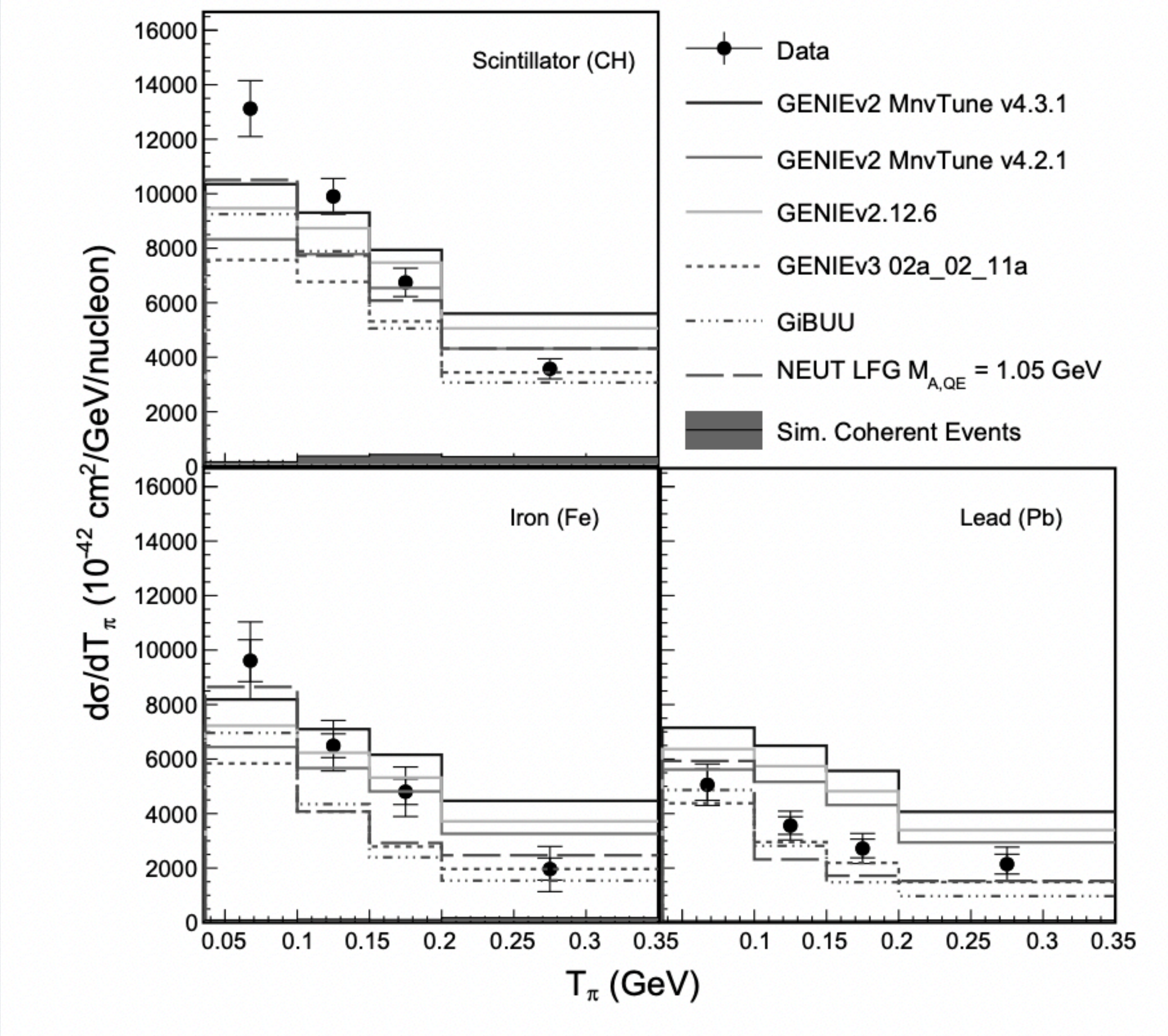


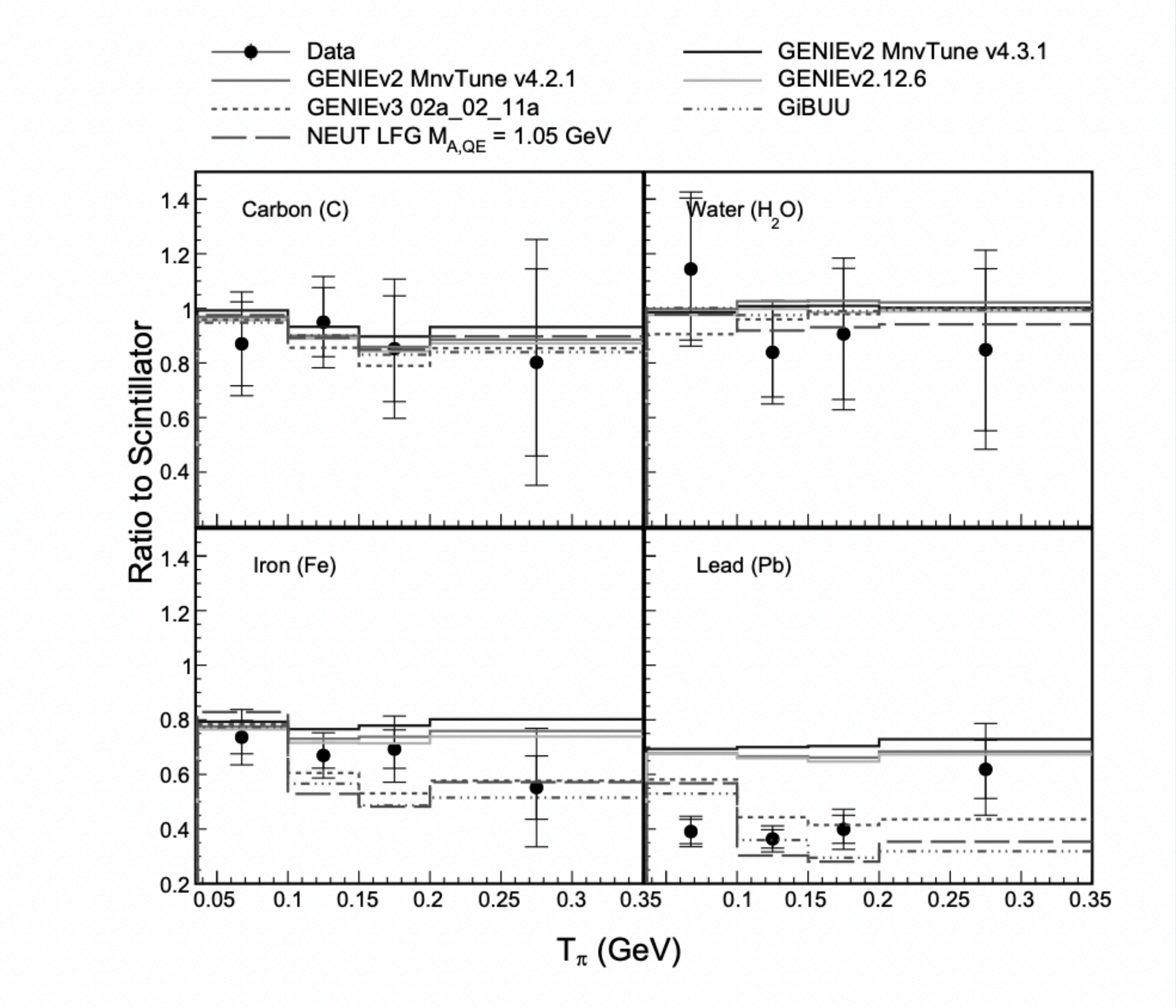


Most events at DUNE will contain a pion!

A-DEPENDENCE: ν_μ CC 1PI

arXiv:2209.07852 (Accepted by PRL)

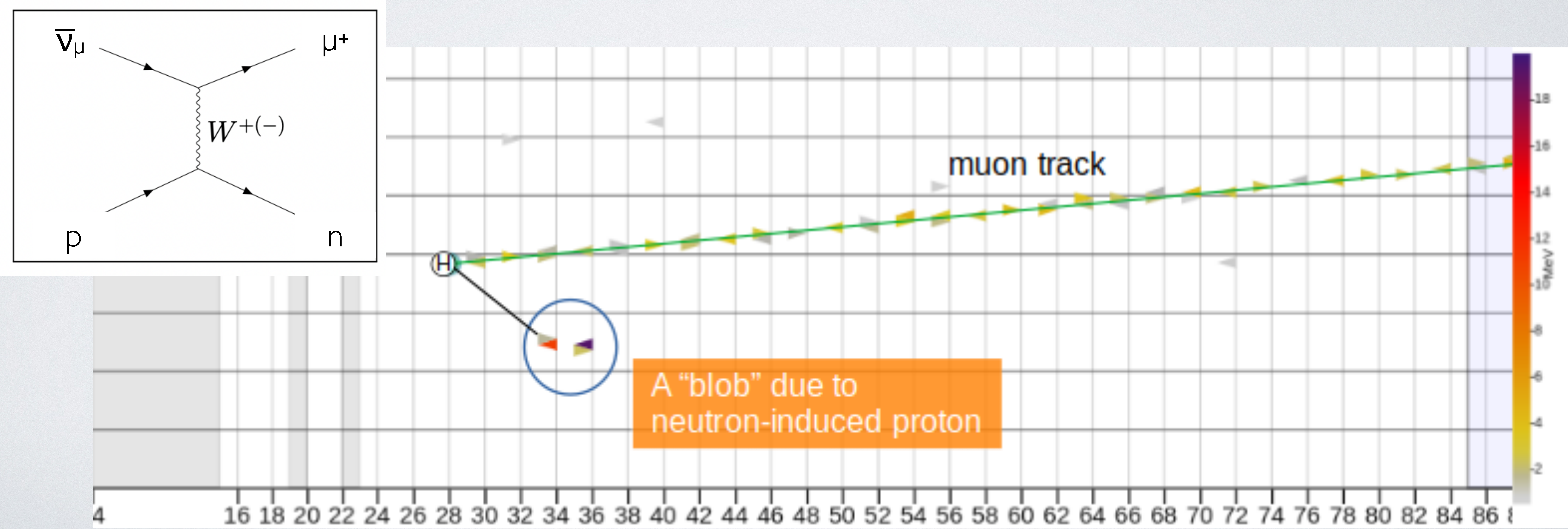




- Over prediction of pions in heavy nuclei combined with underprediction of 0-pi points to pion absorption as potential source of mismodeling

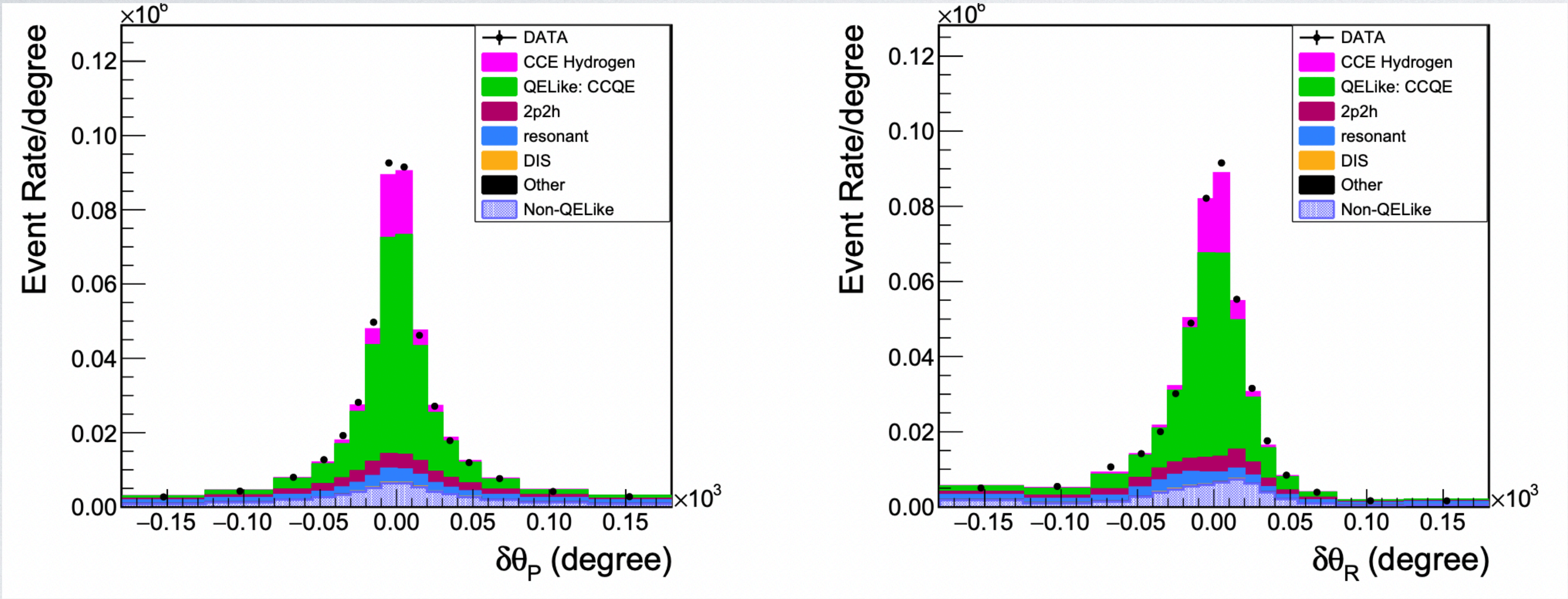
$\bar{\nu}_\mu$ CC 0PI ON HYDROGEN

- Measurements across many materials is the next best thing to measurements on free nucleons
- But it turns out MINERvA has free nucleons — the hydrogen in our CH tracker

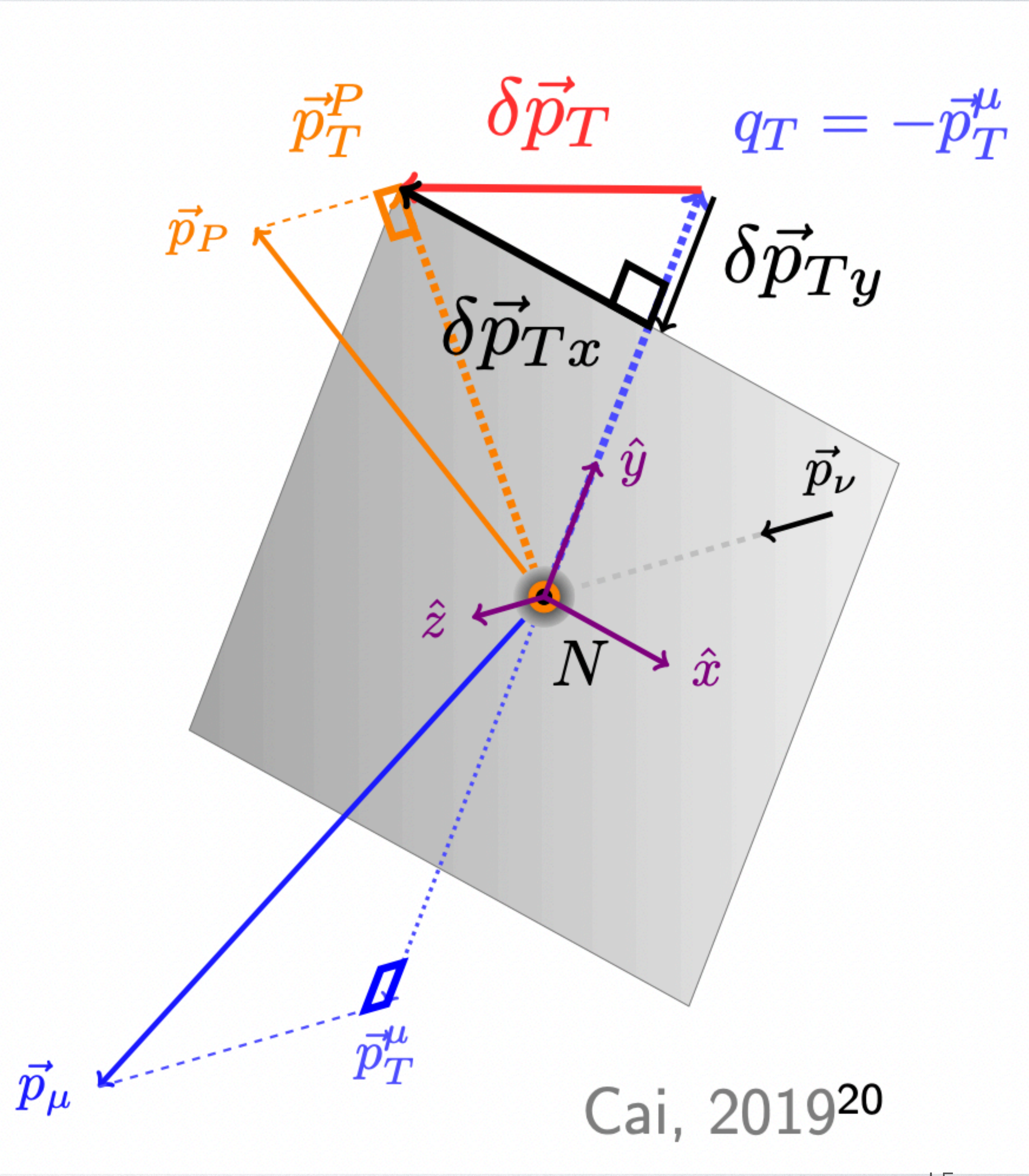


$\bar{\nu}_\mu$ CC 0PI ON HYDROGEN

Nature **614**, 48-53 (2023)

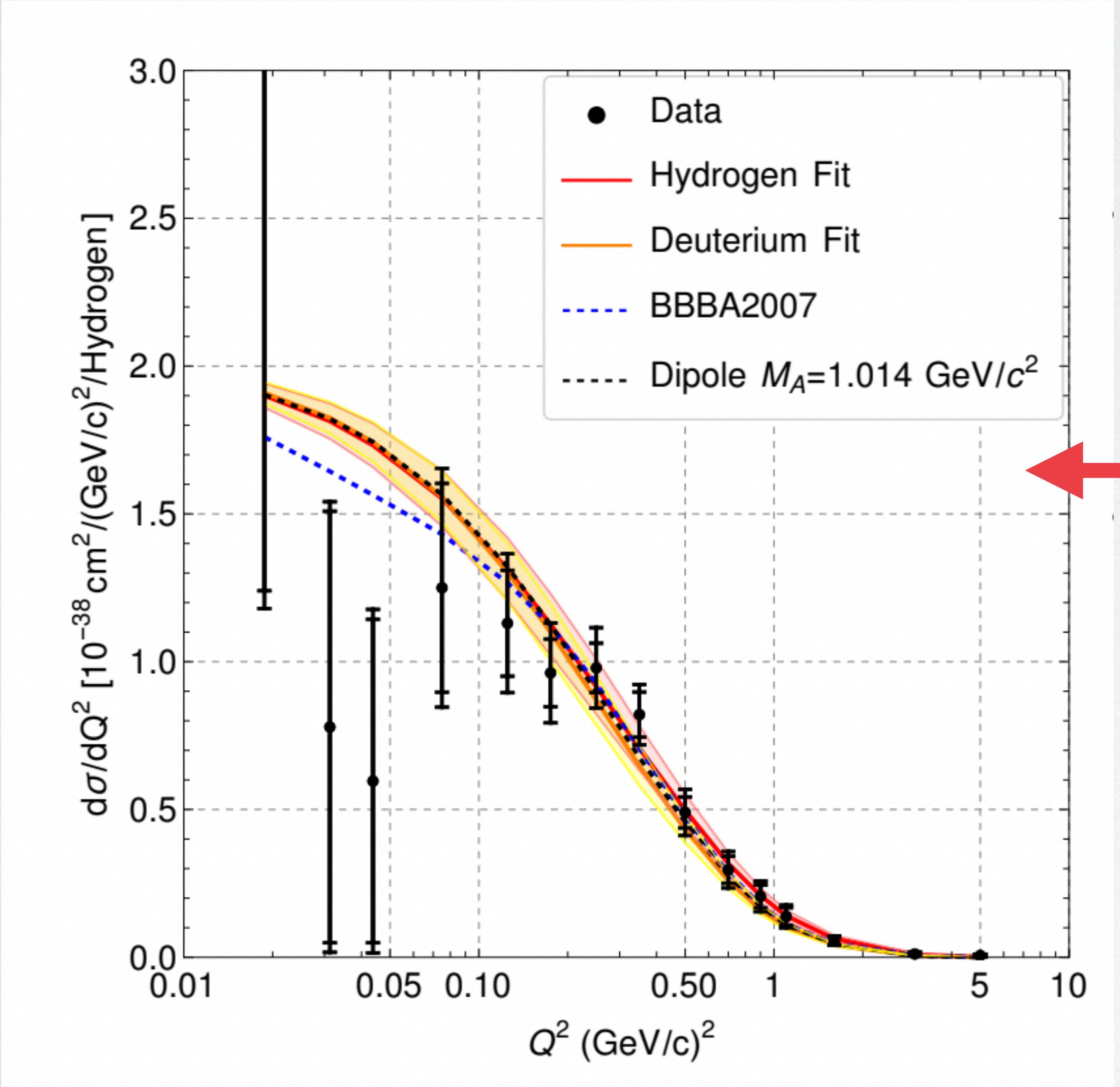


- Transverse kinematic variables help separate interactions on hydrogen from large carbon background
- Tune and subtract carbon background using TKI sidebands

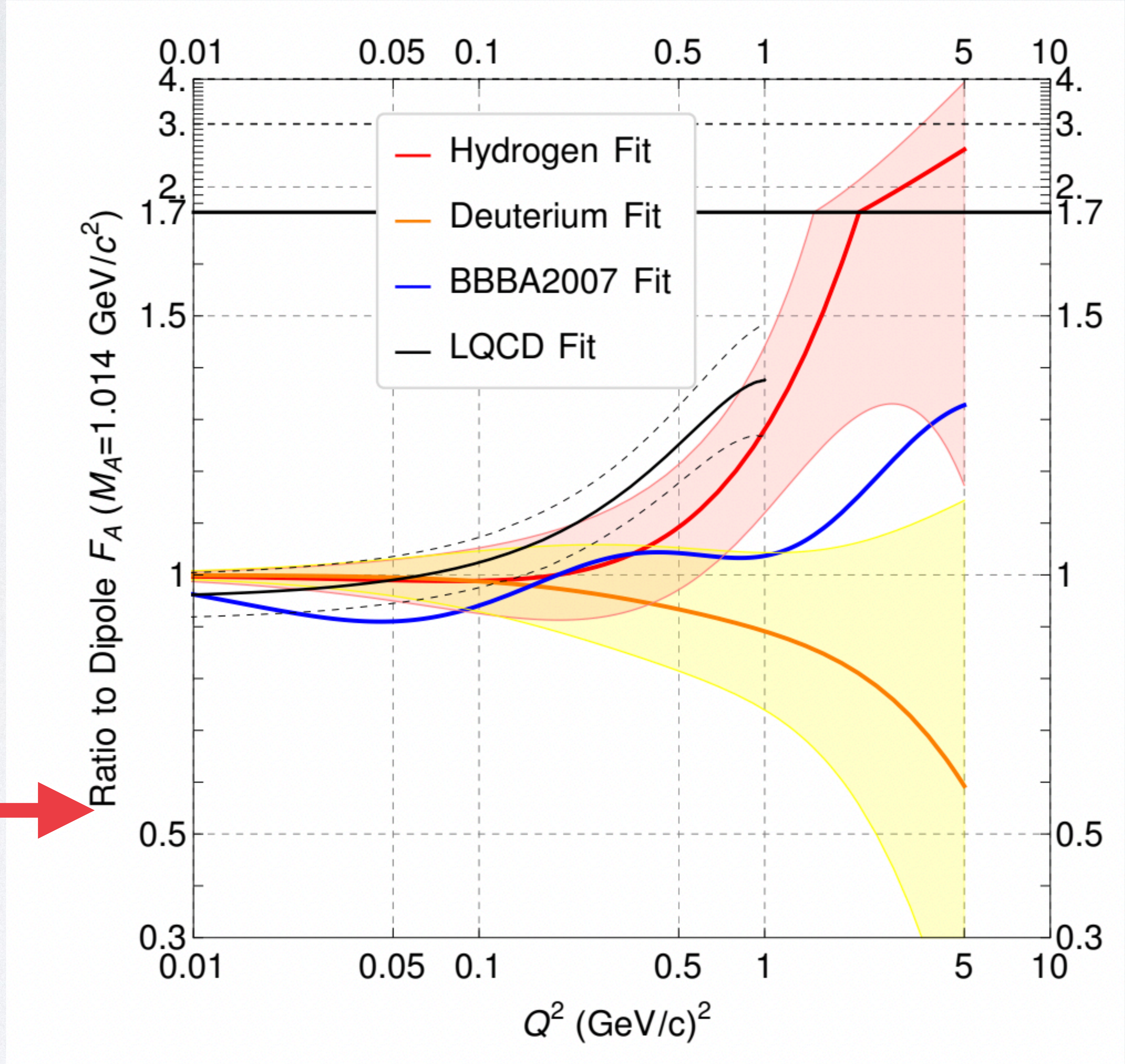


$\bar{\nu}_\mu$ CC 0PI ON HYDROGEN

Nature **614**, 48-53 (2023)

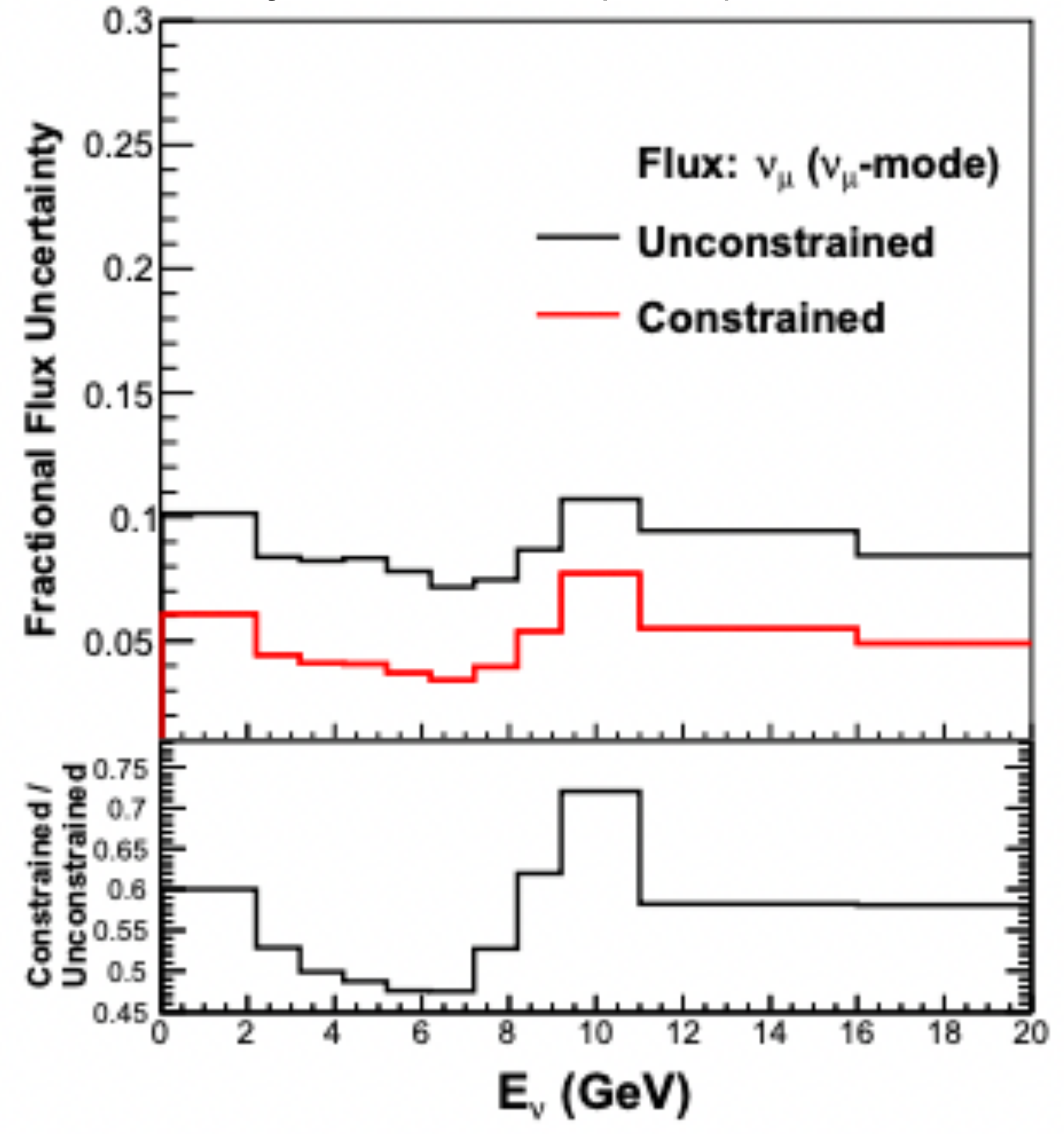


- Cross section vs Q^2 (4-momentum transfer squared)
- Axial form factor, ratio to dipole

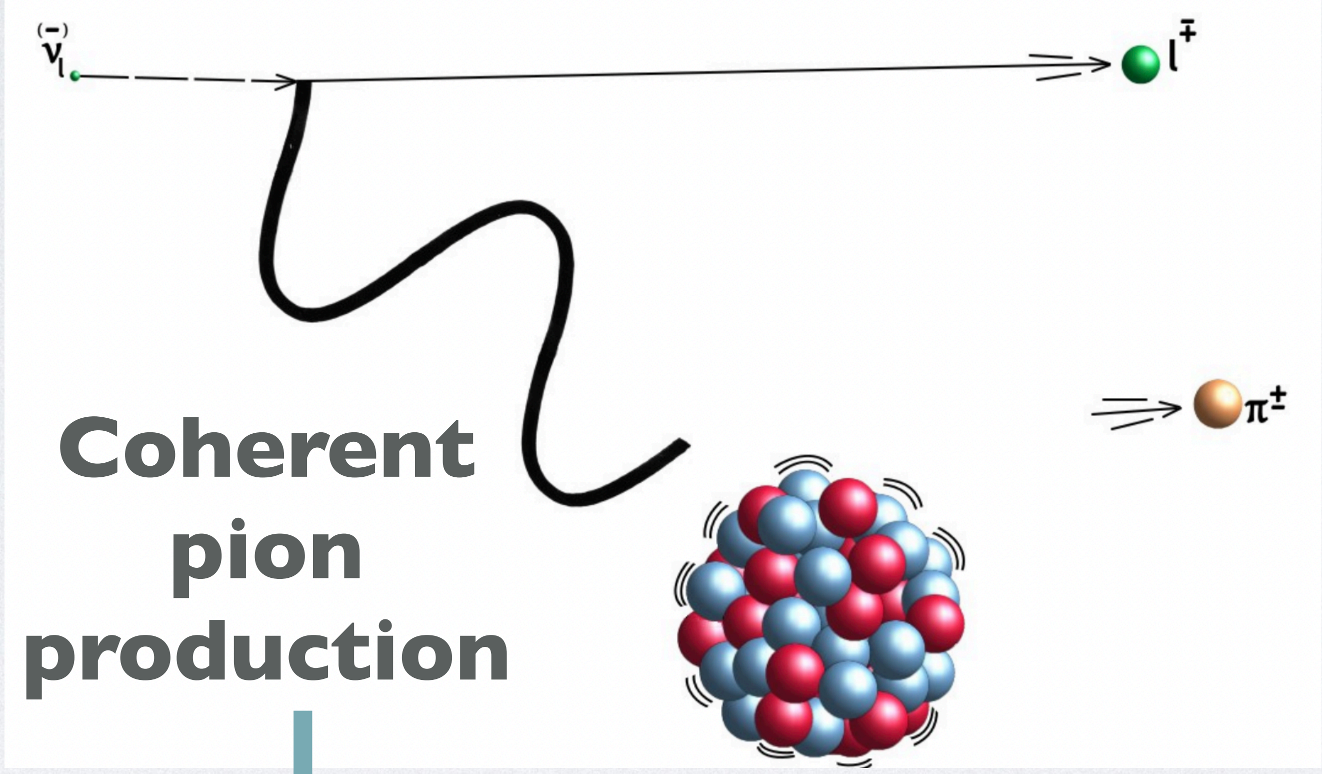


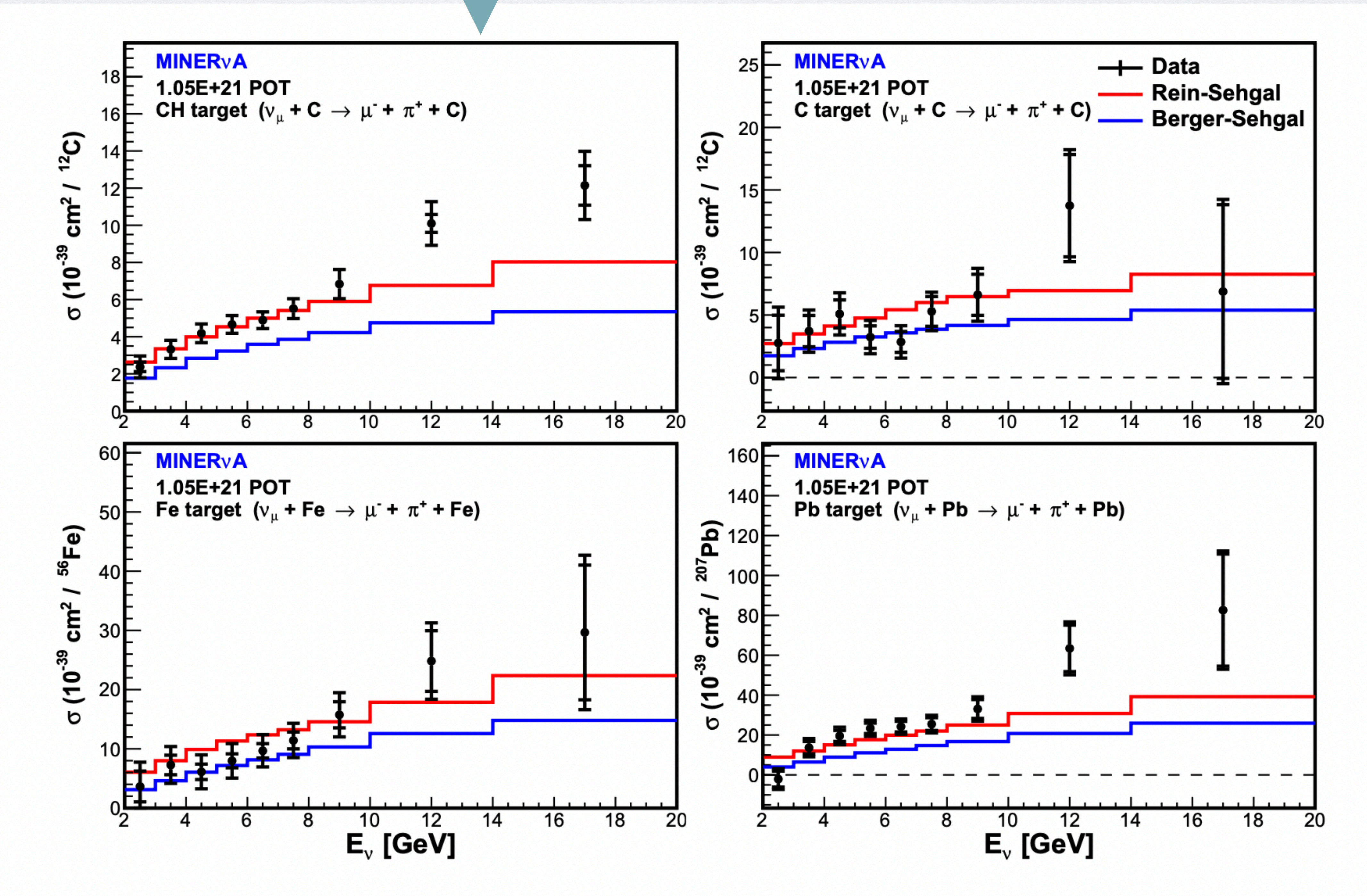
EVEN MORE FROM THE PAST YEAR

Phys.Rev.D 107 (2023) 1, 012001



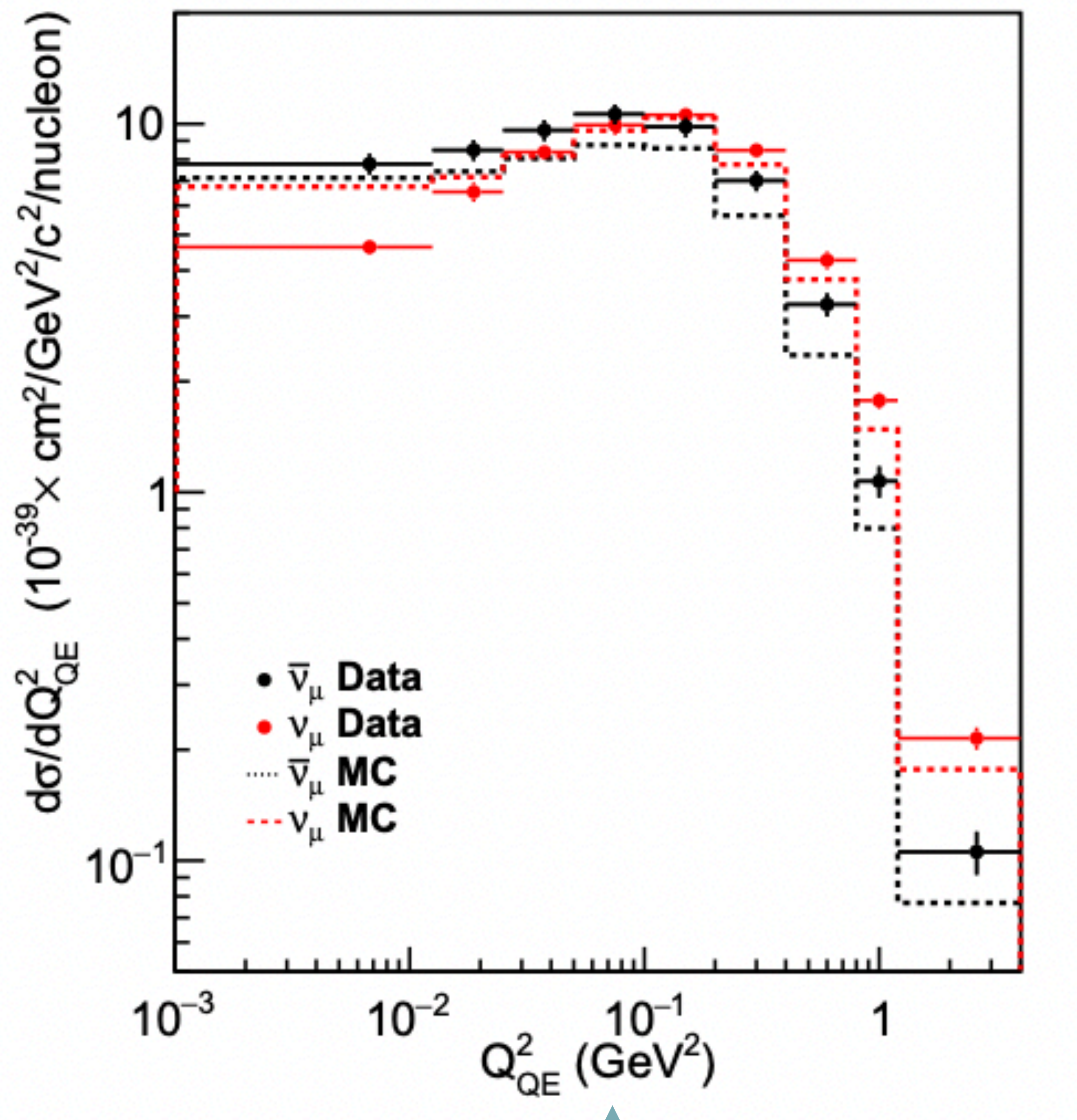
Flux measured using neutrino and antineutrino scattering on electrons and inverse muon decay





arXiv:2210.01285 (Accepted by PRL)

arXiv:2211.11402



High statistics antineutrino 0 pi on scintillator

And much more

STILL TO COME

- Quasi-elastic
  - 3D vs **transverse kinematic imbalance** variables
  - Nu/Antinu **ratios**
  - **Neutron** tagging

- Low hadronic recoil
  - Interactions with **2+ neutrons**
  - **Electron neutrinos** and Electron antineutrinos
  - Interactions with **charged pions**

- Inelastic
  - Many **Deep Inelastic Scattering** (DIS) results
  - Also **Shallow Inelastic Scattering** (SIS)
  - Interactions on **Helium**

And more!

Also: MINERvA has produced a data preservation product that will enable mining MINERvA data into the DUNE era

https://github.com/MinervaExpt/MAT

https://arxiv.org/abs/2009.04548

THANKS FOR LISTENING!

MINERvA planes repurposed for DUNE 2x2!

BACKUP

ACKNOWLEGEMENTS

This document was prepared by members of the MINERvA Collaboration using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359. These resources included support for the MINERvA construction project, and support for construction also was granted by the United States National Science Foundation under Award No. PHY-0619727 and by the University of Rochester.

MODEL

Simulation

Model prediction

MnvGENIE-v2.5.1

1. Nieves 2p2h[10] and low-recoil tune[11]
2. RPA tune[12]
3. Non-resonant pion reduction[13]
4. Low-Q^2 resonant pion suppression[14]
5. Carbon elastic FSI reweight[15]
6. CCQE carbon NuWro SF[16,17] reweight

A GEANT4 neutron reweight[18,19]

Slide Courtesy Tejin Cai