Inclusive and Exclusive Pionless Cross Section Measurements with MicroBooNE

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ν_μCC Inclusive

arXiv:2307.06413

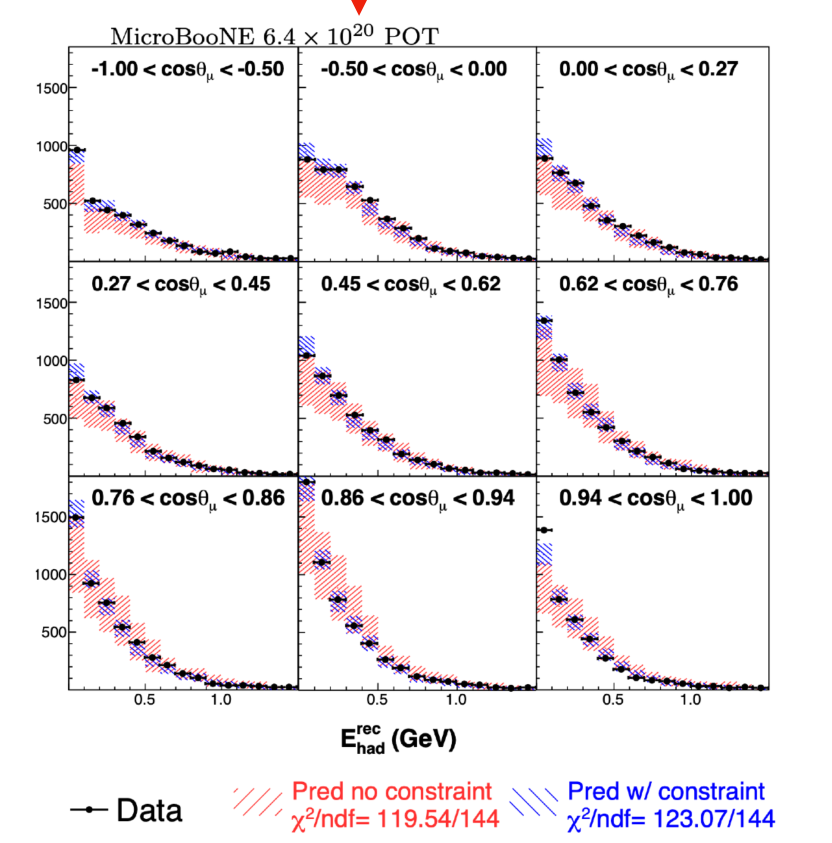
Measured from muon range

Initially unknown (Neutrons, low energy photons, etc.)

From flux simulation

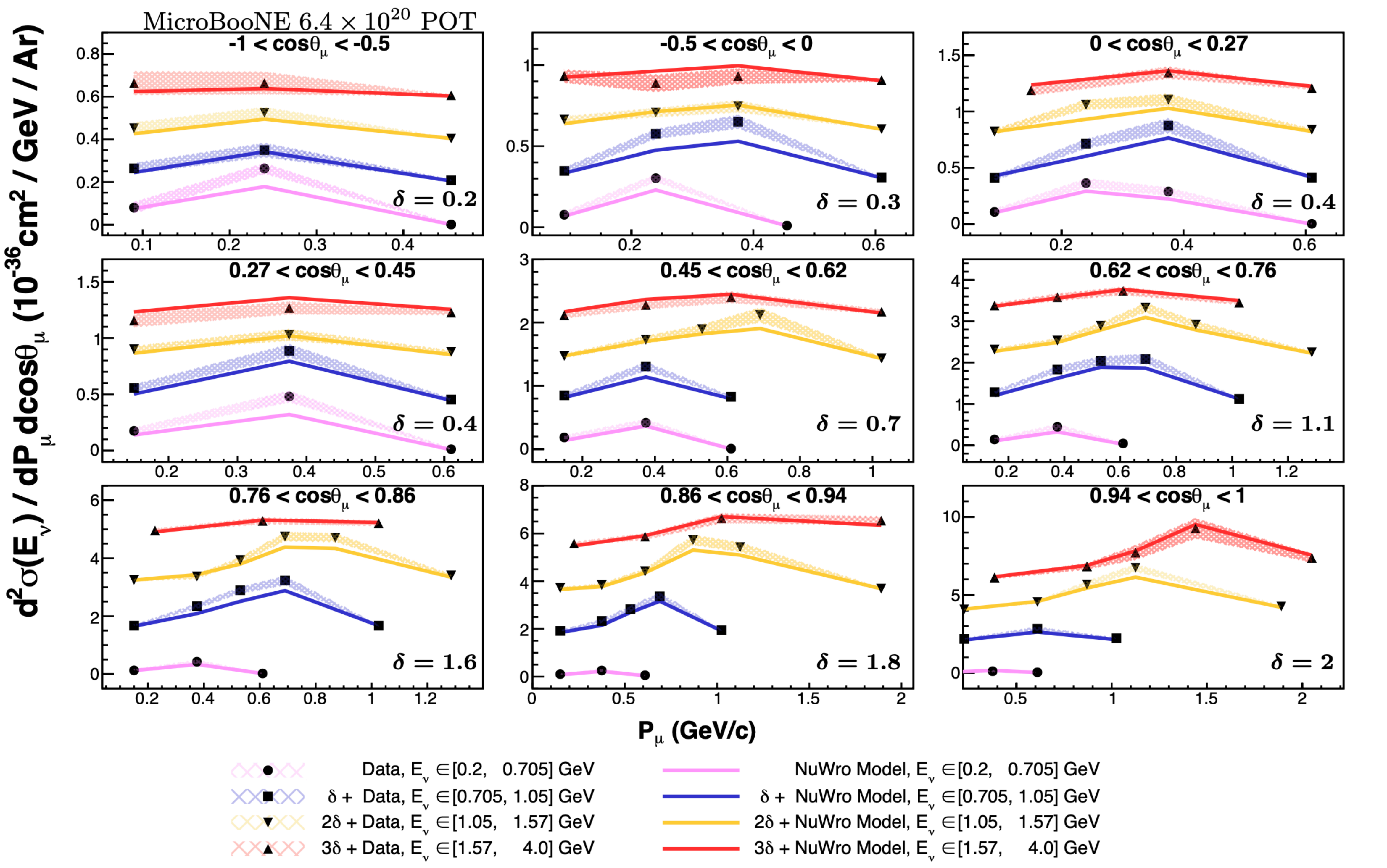
Measured from hadronic ionization

$$E_\nu^{true} = E_\mu + E_{had}^{vis} + E_{had}^{invis}$$



2D E_{had}^{rec} and $\cos\theta_\mu^{rec}$ constrained by 2D E_μ^{rec} and $\cos\theta_\mu^{rec}$

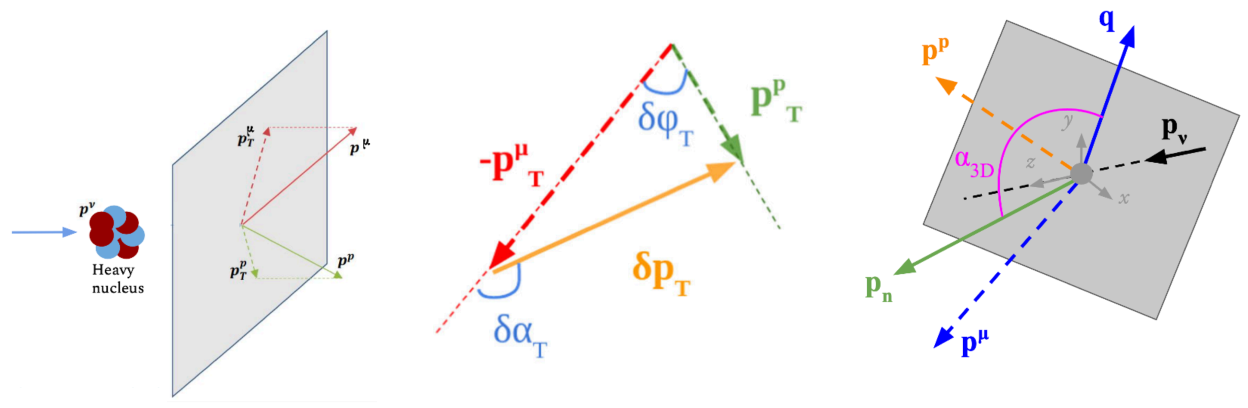
- Correctly modeling invisible energy is critical for current and future neutrino oscillation experiments
- Use energy conservation to infer information about invisible energy (for the distribution, not event-by-event) using a conditional constraint test
- Fake data studies show that this test is sensitive to ~15% missing energy mis-modeling
- The observed hadronic energy is consistent with the simulation after a constraint from muon kinematics
- With this increased confidence in our modeling, we unfold to true neutrino energy and extract 3D cross sections
- All tested model central values are disfavored

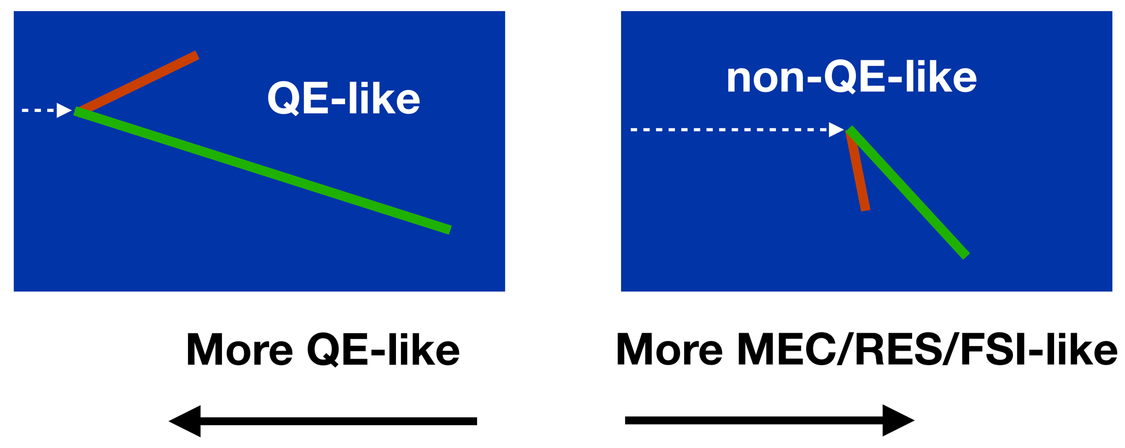


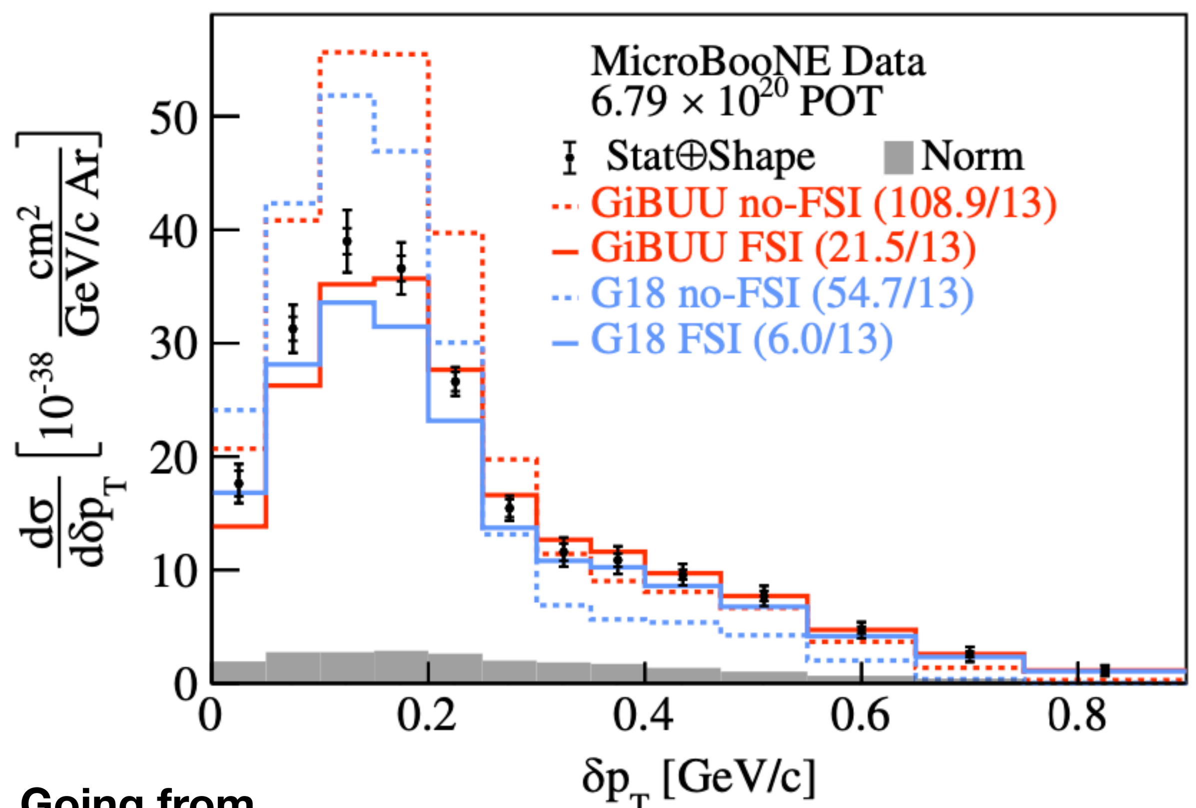
ν_μCC $1\mu 1p 0\pi$ Kinematic Imbalance

Phys. Rev. Lett. 131, 101802 (2023)
Phys. Rev. D 108, 053002 (2023)
Phys. Rev. D 109, 092007 (2024)

- Kinematic imbalance is a way to study initial nucleon momentum and final state interactions (FSI)
- To further separate different types of interaction processes:
  - Expand to double differential cross sections
  - Expand the kinematics to 3D, using the total visible energy to estimate the neutrino energy and thus the initial longitudinal momentum

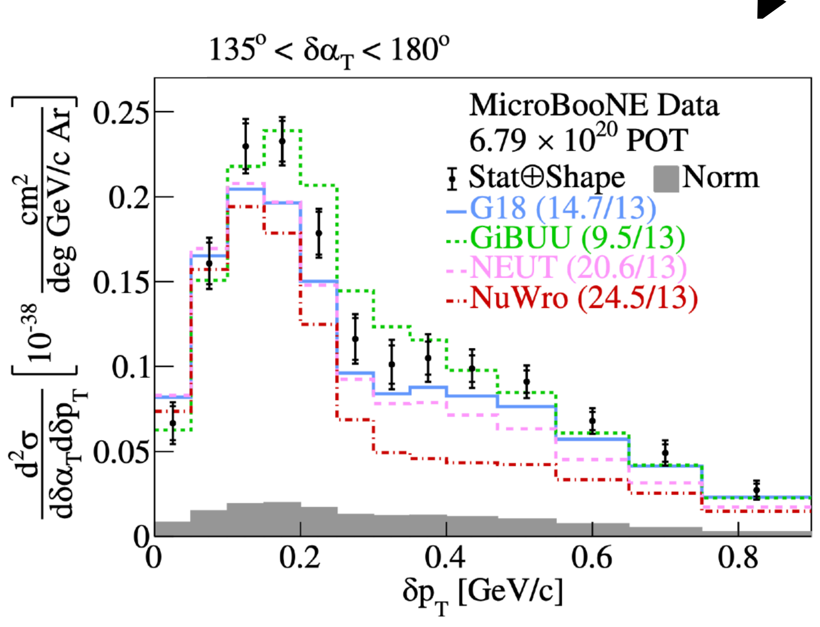


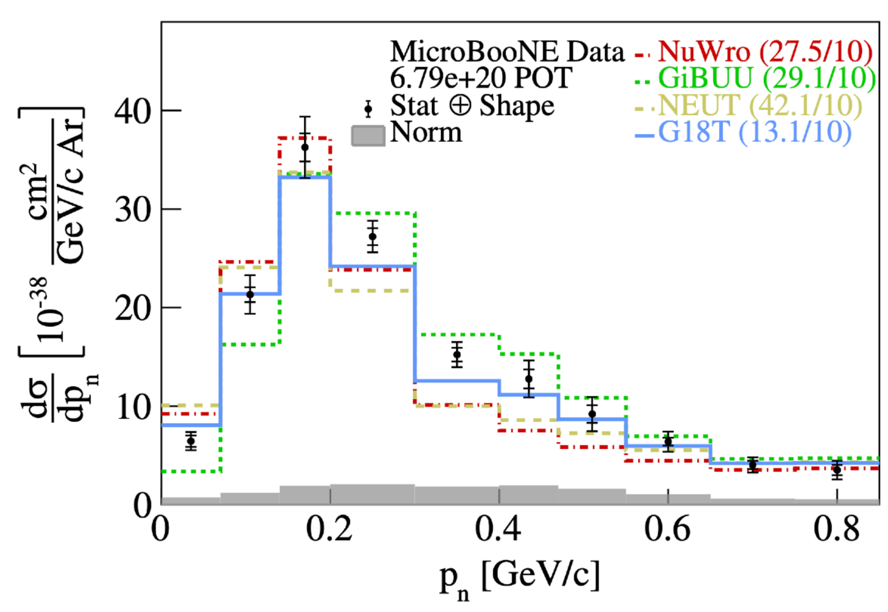




Going from 1D → 2D differential XS

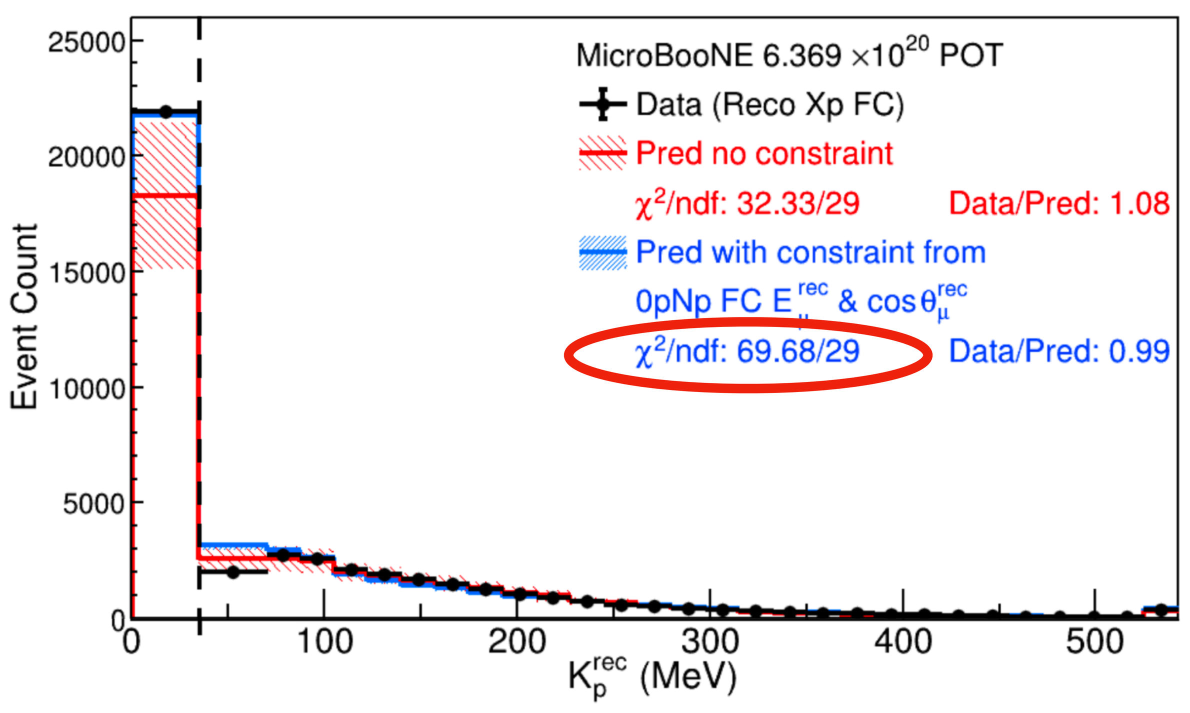
Going from transverse → 3D momentum imbalance



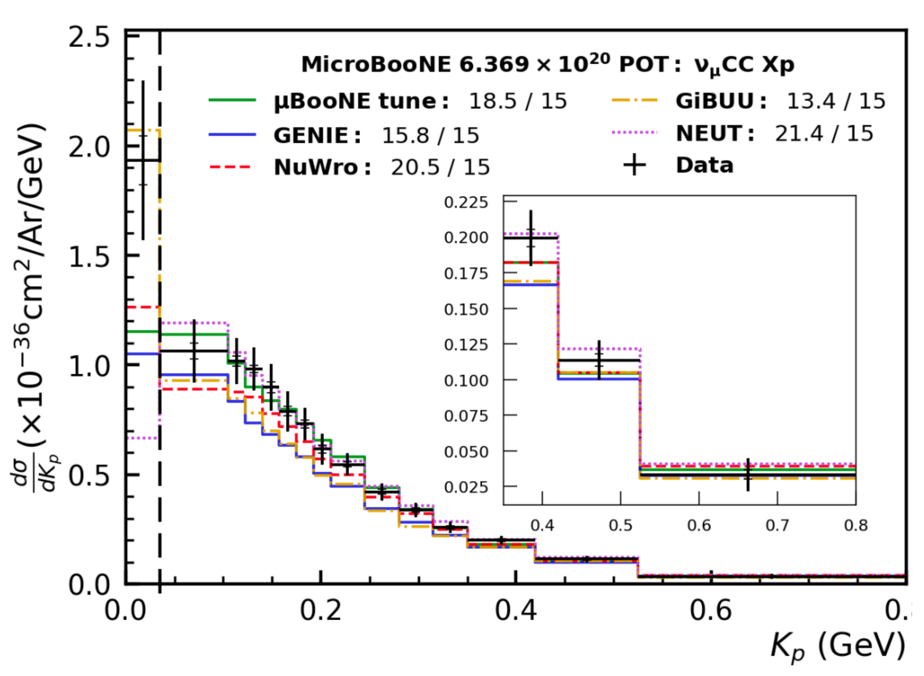


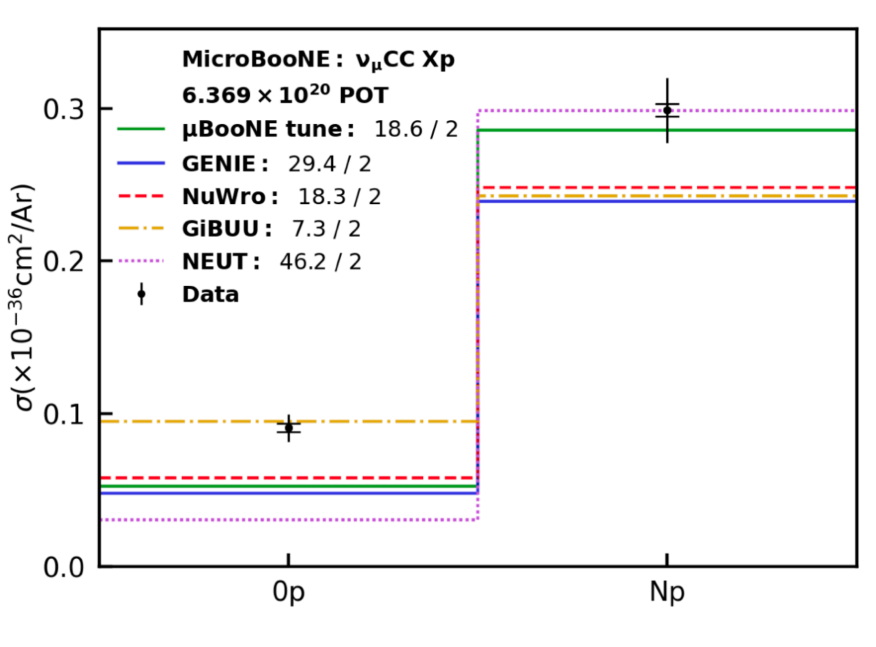
ν_μCC Inclusive, With and Without Protons

arXiv:2402.19216
arXiv:2402.19281



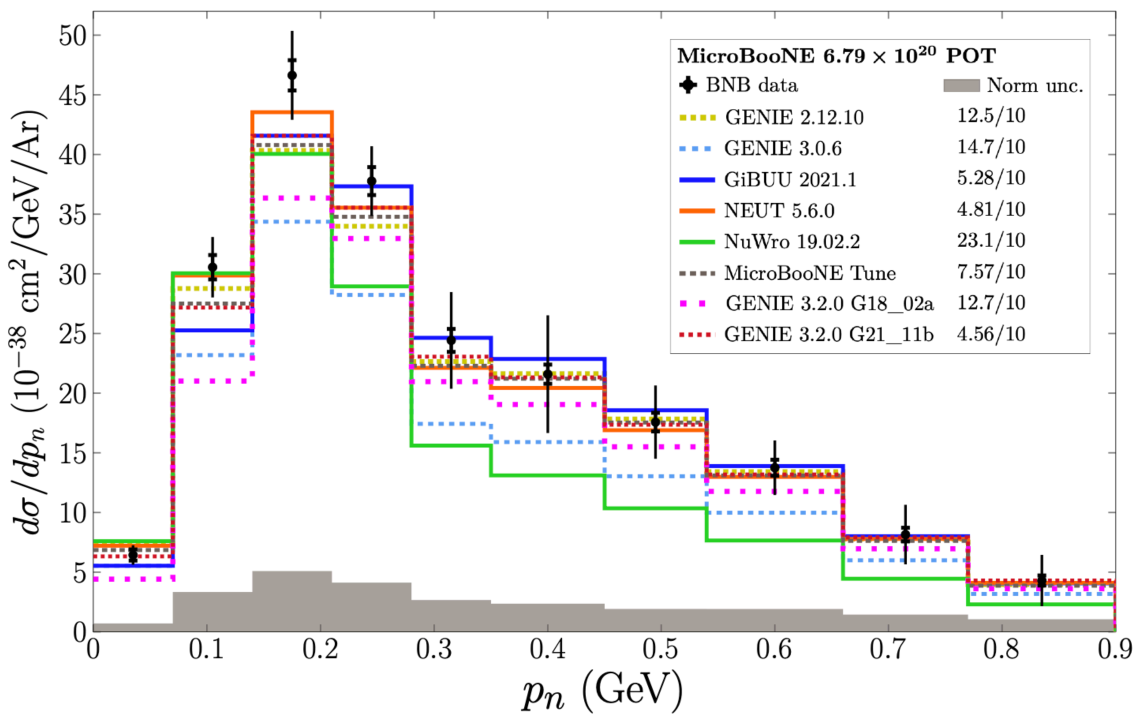
- Expand the inclusive analysis to different hadronic final states
- 35 MeV proton kinetic energy threshold
- Our model is unable to describe low energy protons consistently within uncertainties. We expand our GENIE uncertainties before unfolding
- Model central values are unable to describe the 0p/Np split, but GiBUU performs notably better





ν_μCC $1\mu Np 0\pi$

arXiv:2403.19574



- Extract single and double differential cross sections across many observables, including kinematic imbalance variables
- Report all correlations between all extracted cross sections
- All tested model central values are disfavored

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