MicroBooNE cross section results from muon neutrino inclusive and pionless channels

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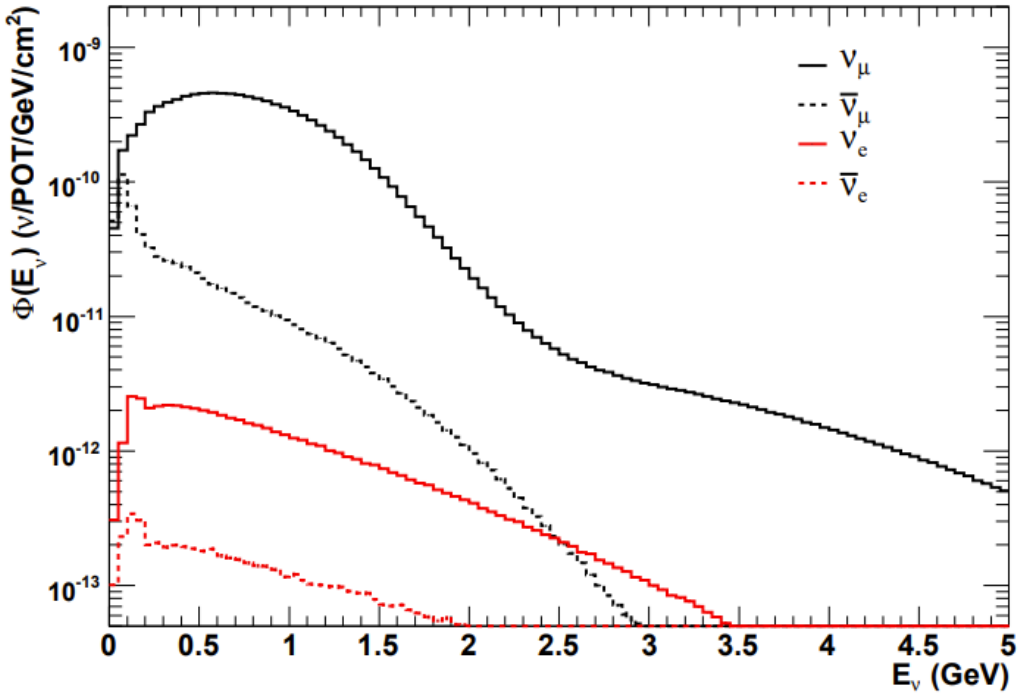
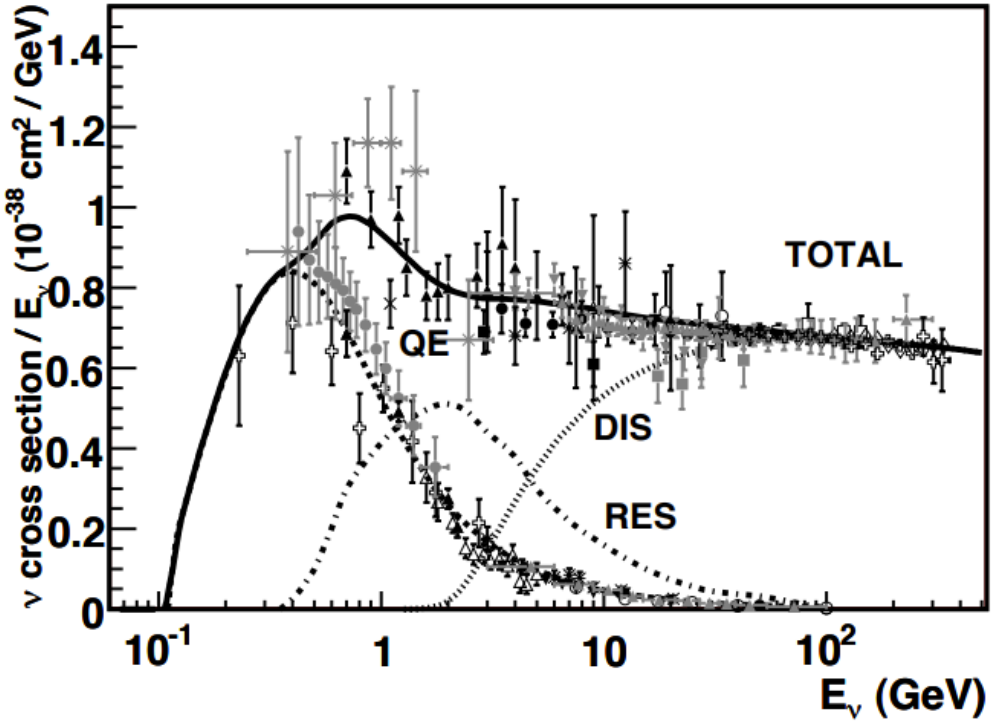
Introduction

- MicroBooNE is exposed to a primarily muon neutrino beam from the Booster Neutrino Beam (BNB).
  - Energy range primarily covers charged-current quasielastic interactions.



BNB neutrino flux (*Phys. Rev. D* 79 (2009) 072002)

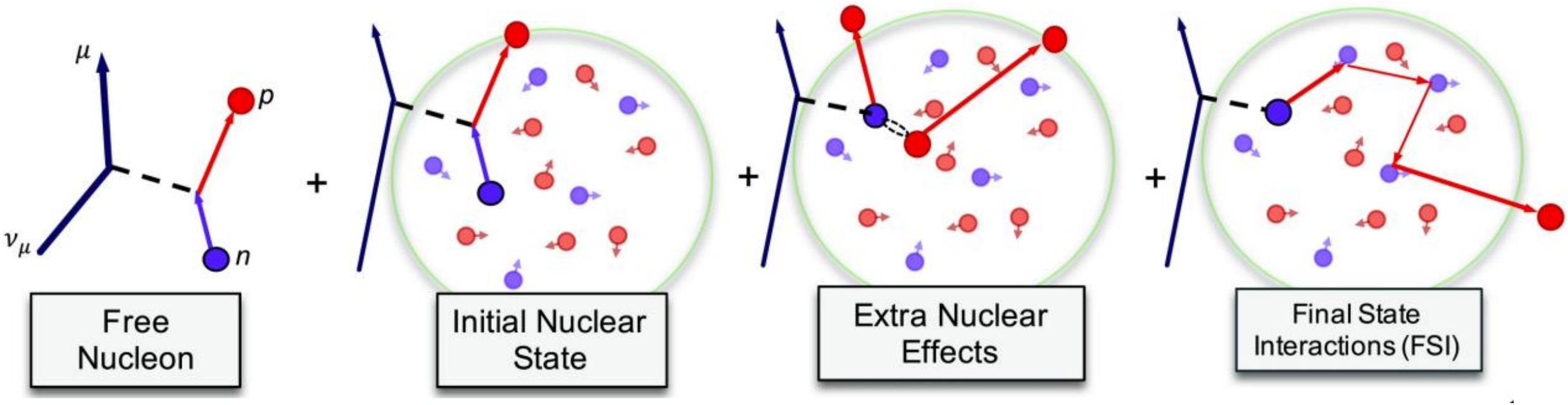


Predicted exclusive channels with historical data overlaid (*Rev. Mod. Phys.* **84**, 1307)

- Presentation will focus on muon neutrino scattering through charged-current (CC) channels.

The Complications of Neutrino Interactions

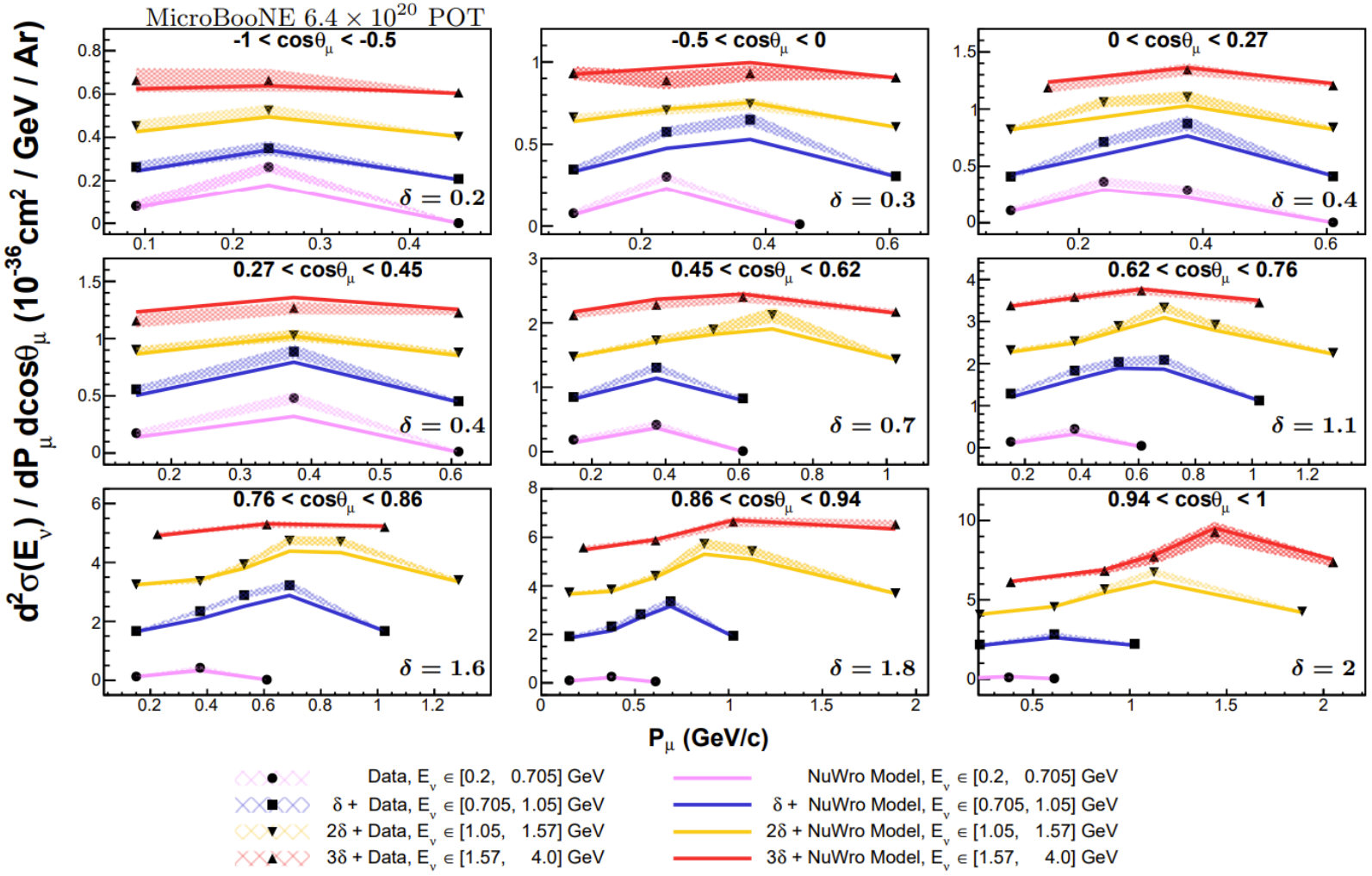
- Neutrinos interact with nucleons within nuclei



Cartoons of various nuclear effects in neutrino interactions (From C. Wilkinson at NuXTract)

Triple-Differential CC Inclusive Cross Section

- Select all muon neutrino events and bin in muon kinematics and reconstructed neutrino energy.

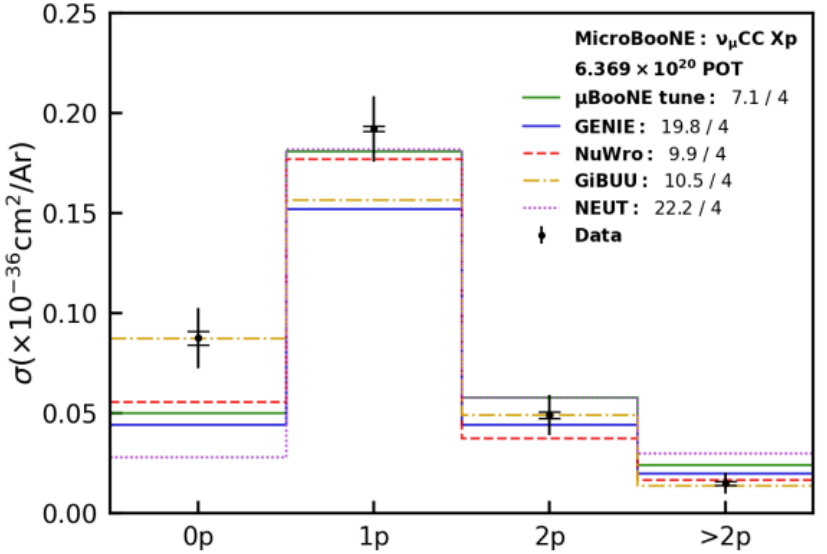


Triple-differential cross section, note that δ is an offset to the numerical value in units of 1E-36.

arXiv:2307.06413

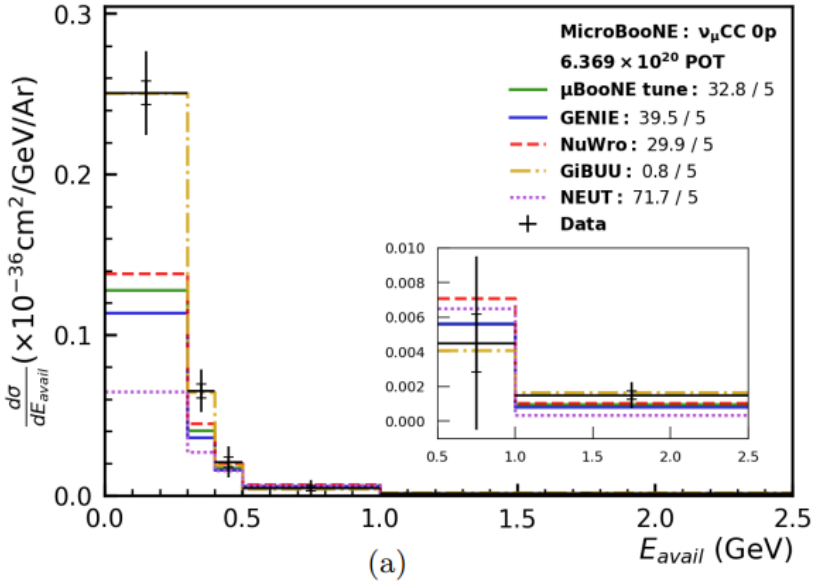
CC Inclusive with and without Protons

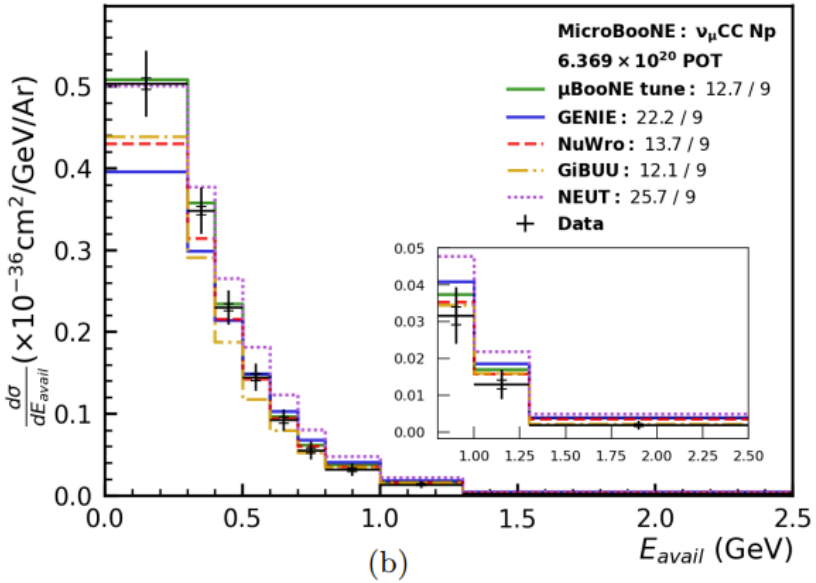
- Using an inclusive neutrino cross section selection and separate to events without and with protons in the final state.
- Models disagree with the data significantly for events with no protons in the final state, except for GiBUU.



Proton multiplicity

0pNp χ^2 (ndf = 14): μBooNE tune = 43.3, GENIE = 56.8, NuWro = 40.4, GiBUU= 14.3, NEUT = 85.1



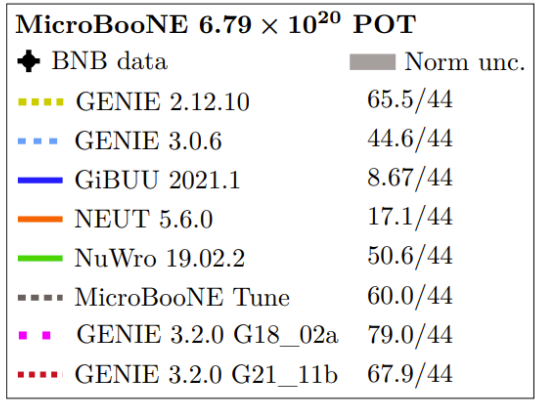


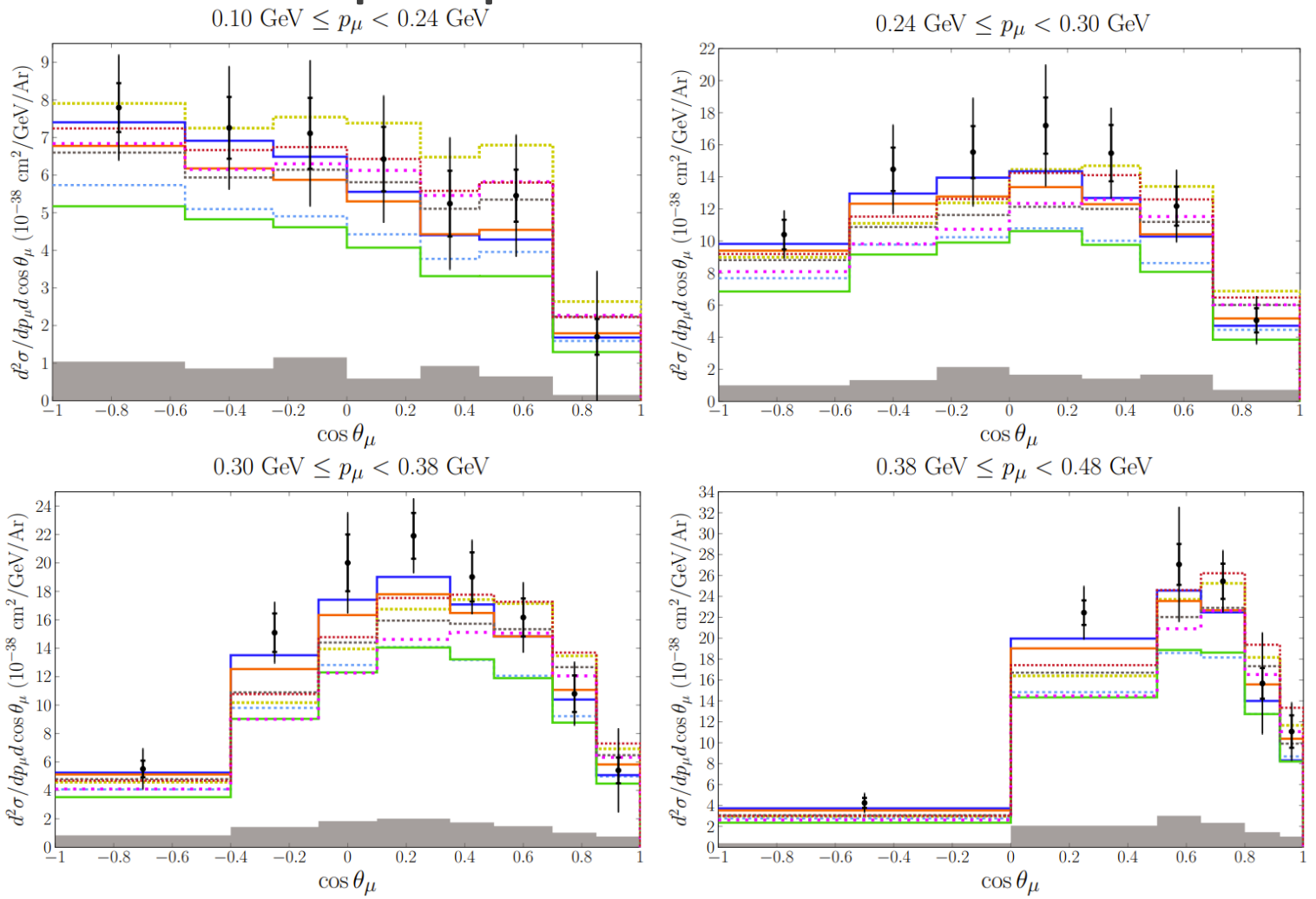
Available (visible) energy without and with protons in the final state.

arXiv:2402.19216

Cross Section of CC1μNp0π Events

- Extremely important for tuning DUNE-like energies, which are predominately CC1μNp0π.
- Multi-differential measurement for muons, protons, and kinematic imbalances.
  - Employs a method called block-wise unfolding.





Double-differential cross section in muon kinematics (continued on next slide).

arXiv:2403.19574

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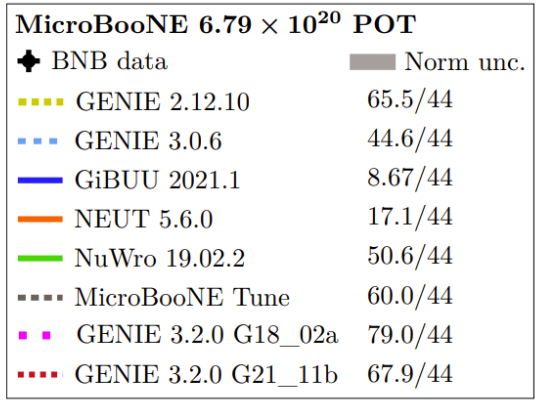

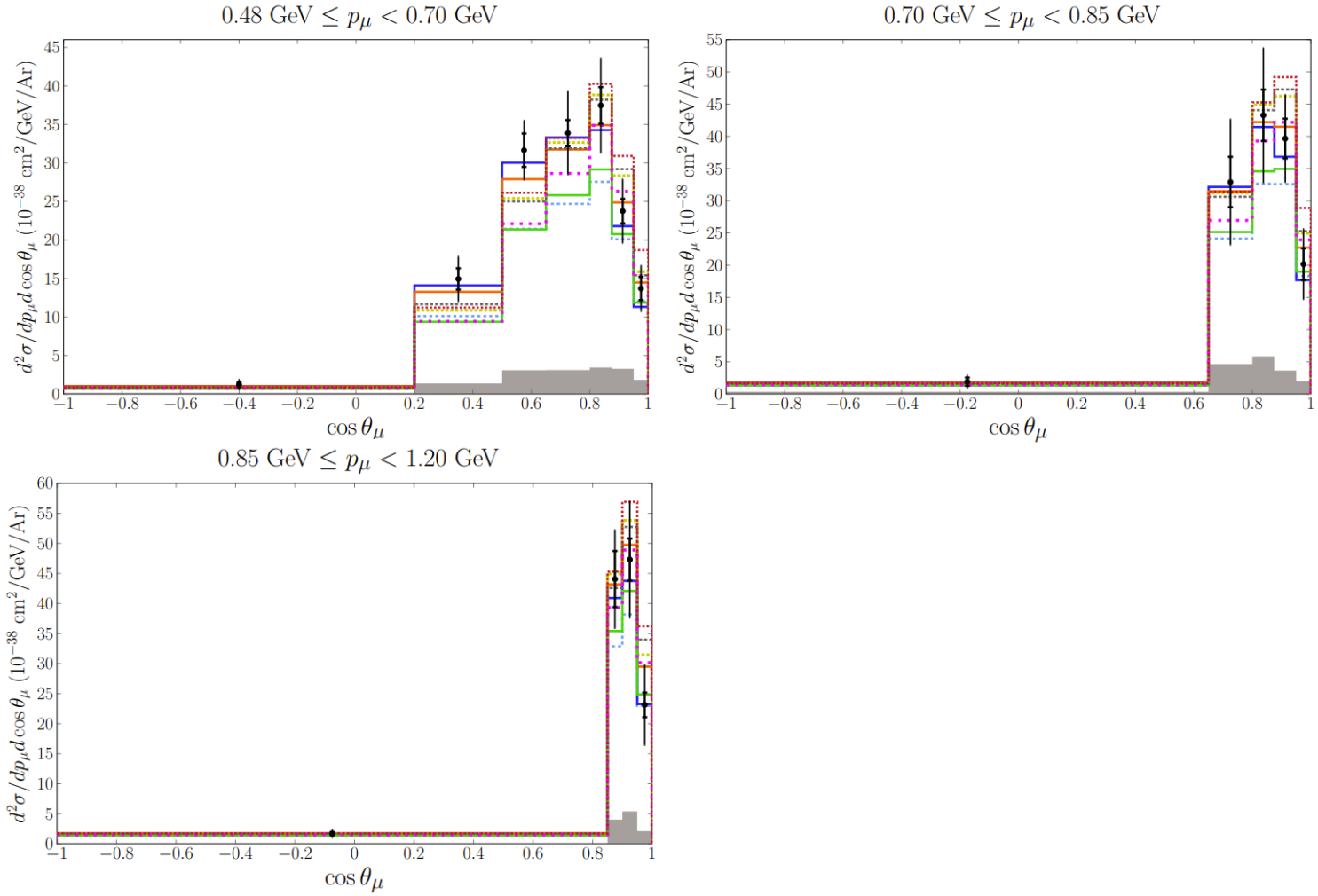

Double-differential cross section in muon kinematics.

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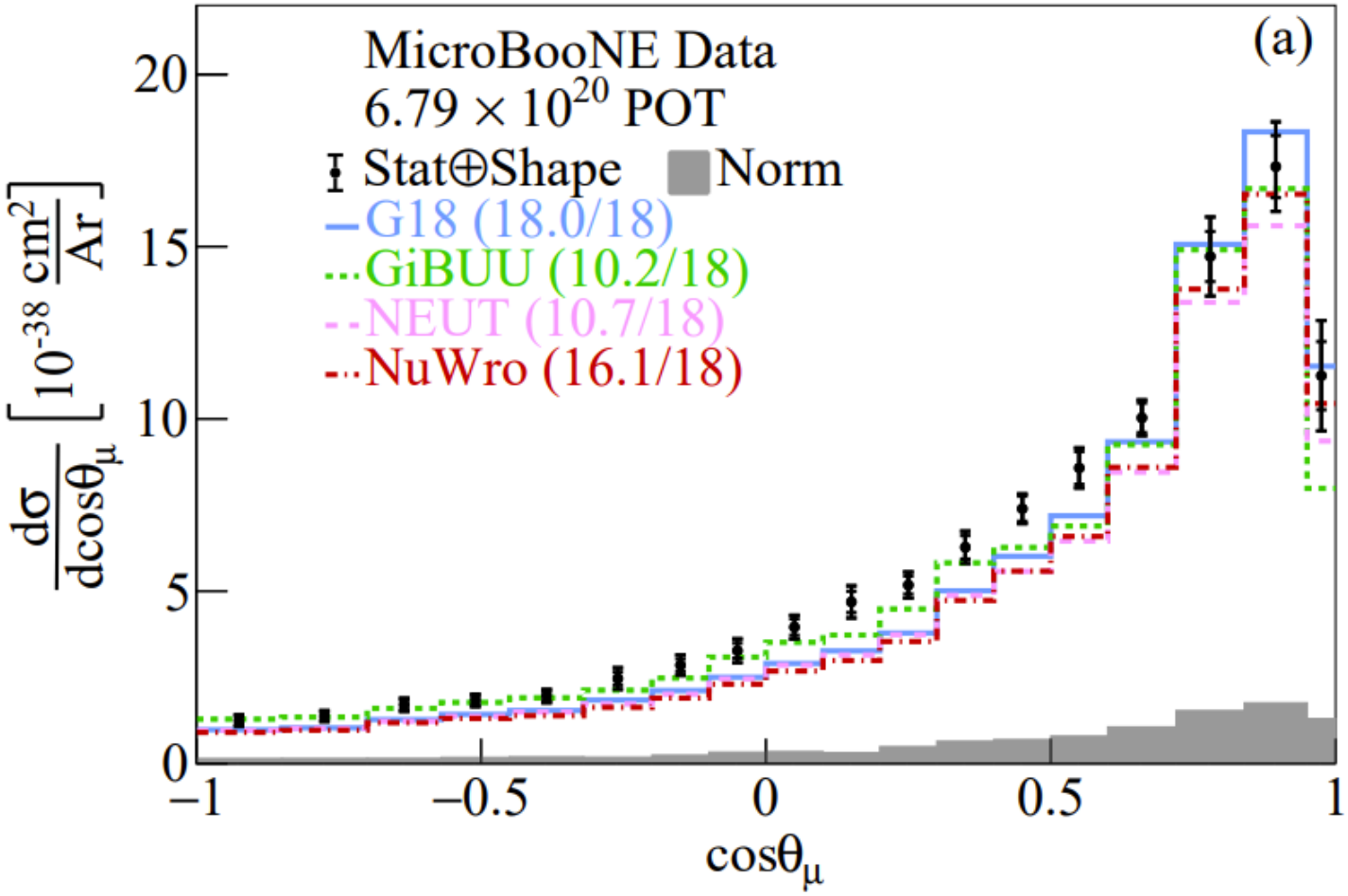
Muon Neutrino CC1μ1p0π

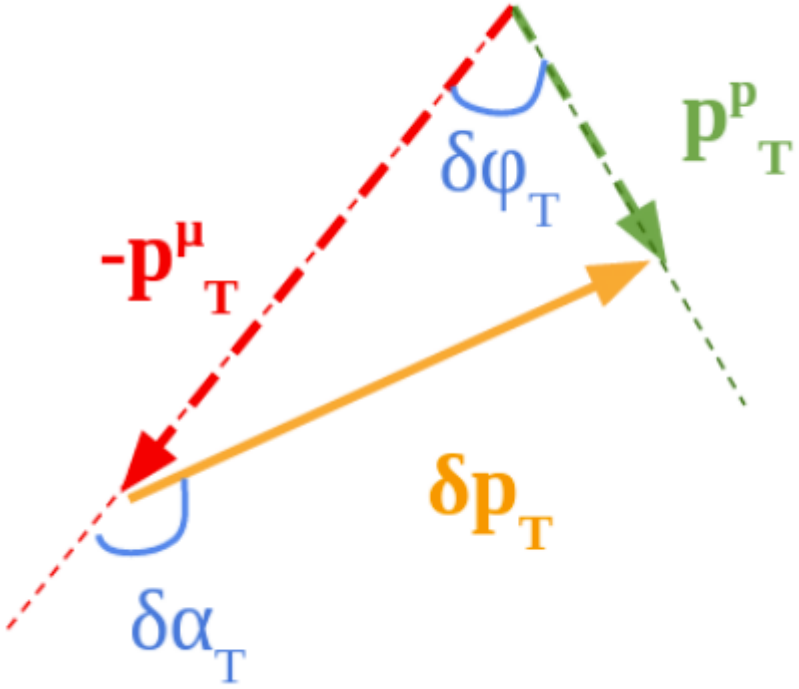
- The simplest observable is 1 muon and 1 proton (quasielastic-like).

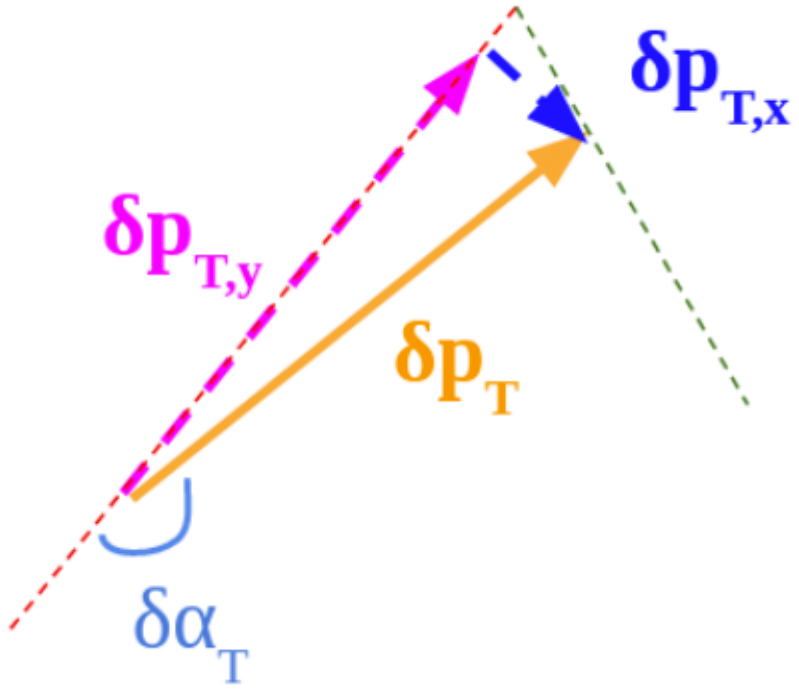


Phys. Rev. D 108 (2023) 5, 053002

Kinematic Imbalance of CCQE-like

- The neutrino travels in one direction, so there should be no momentum in the transverse plane.
  - However, due to the nuclear ground state and nuclear medium effects there is an imbalance.

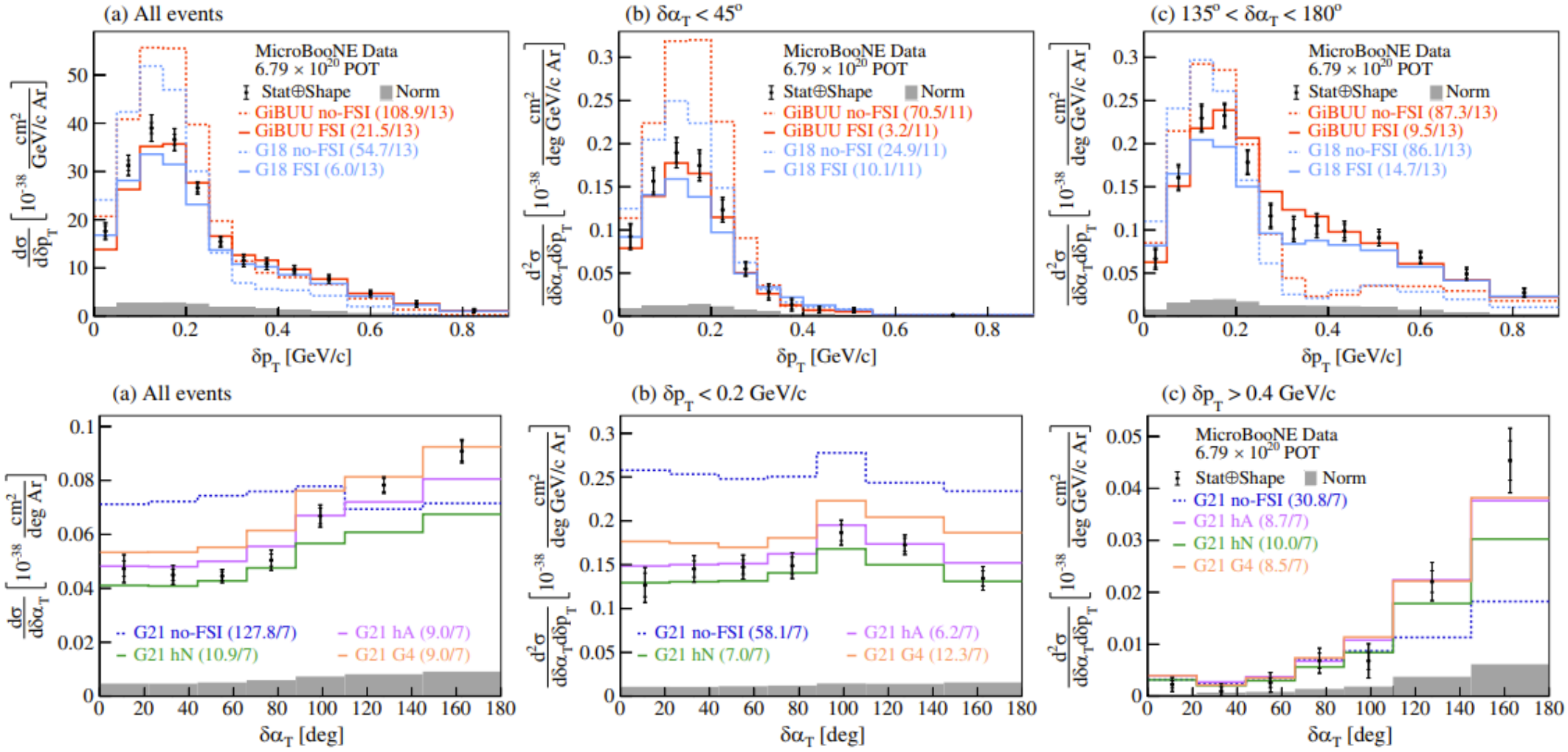




Phys. Rev. D 108 (2023) 5, 053002

Kinematic Imbalance of CC1μ1p0π Events

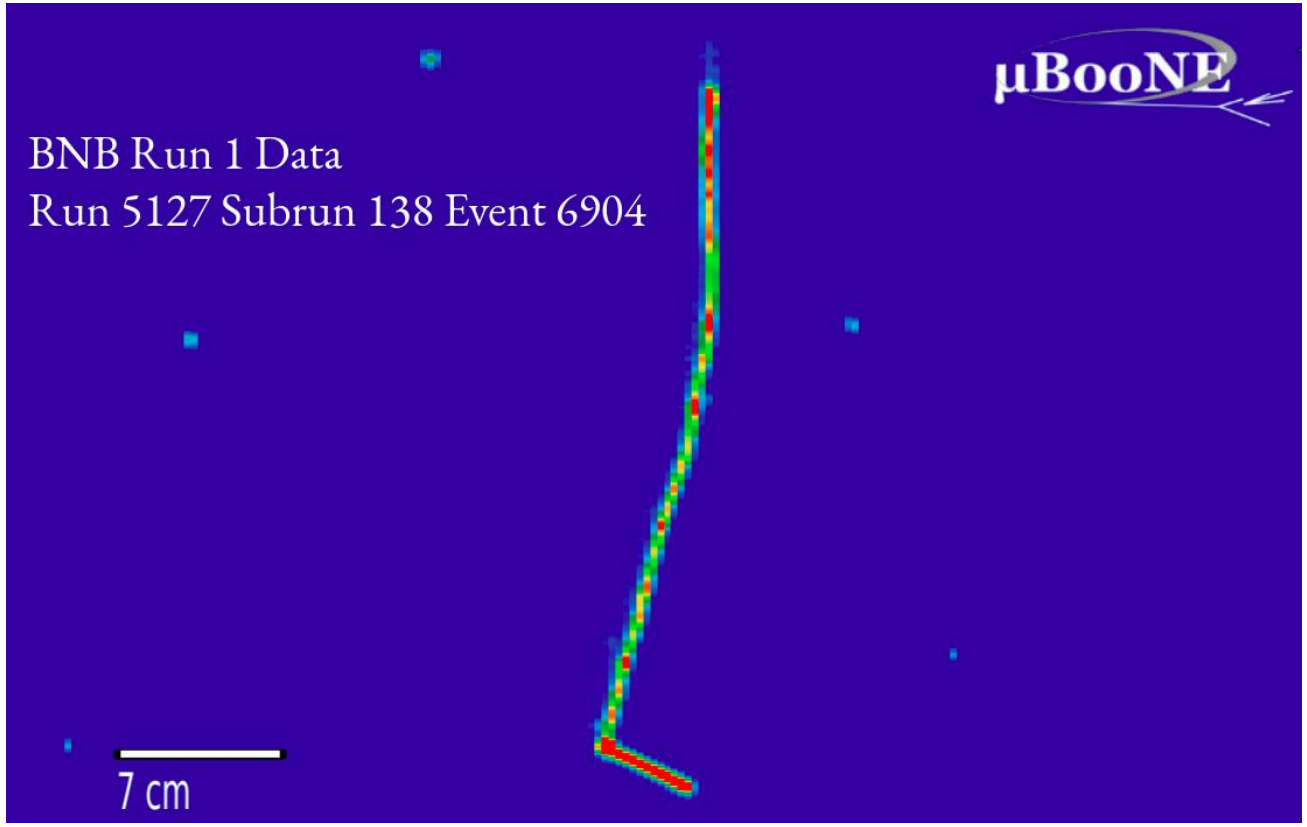
- Probing nuclear effects in-depth using a multi-differential measurement of the kinematic imbalance.



Phys. Rev. Lett. 131 (2023) 10, 101802

Conclusion

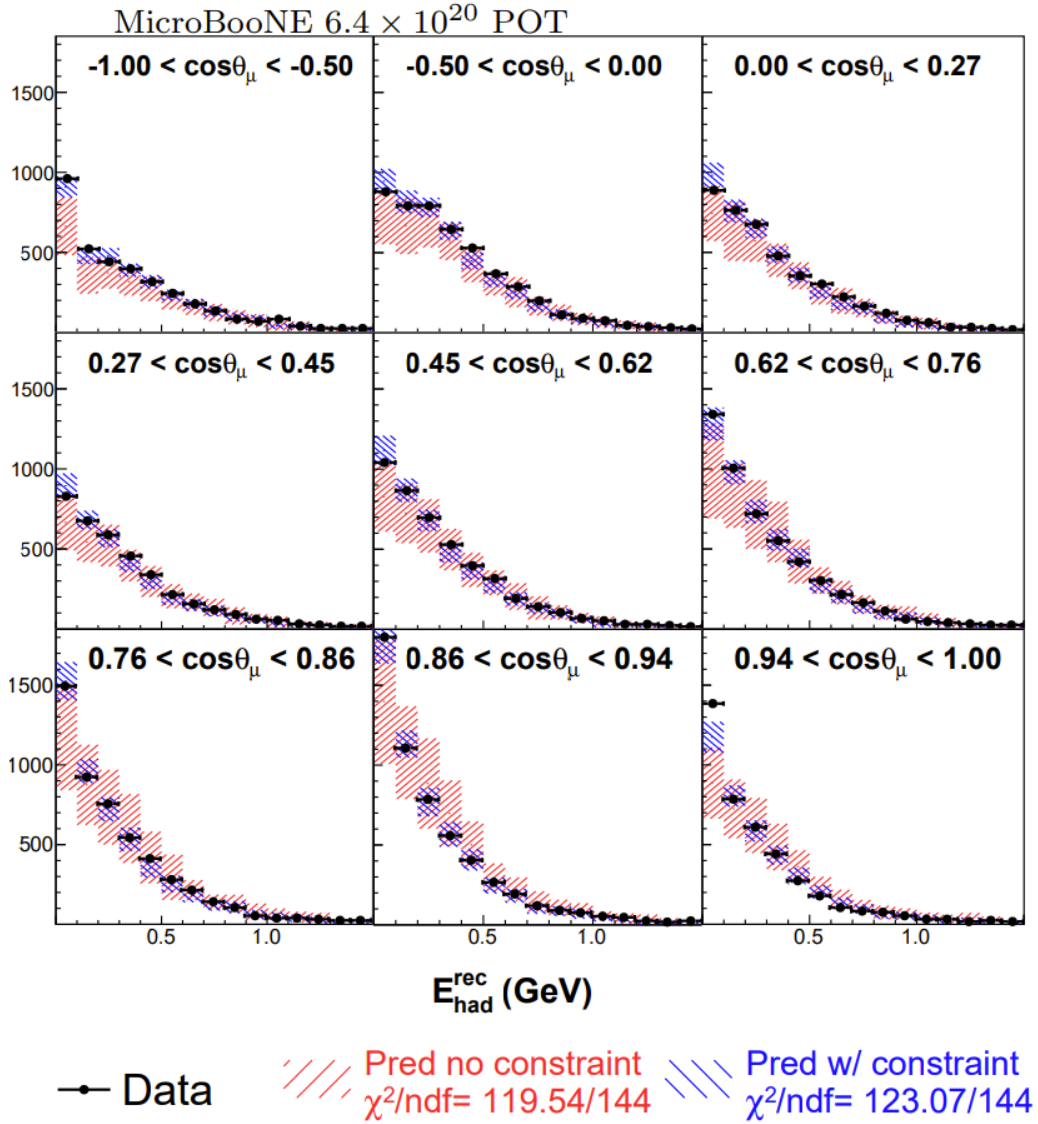
- MicroBooNE has published the cutting-edge of neutrino cross sections on argon for:
  - CC1μ
  - CC1μ0/Np
  - CC1μNp0π
  - CC1μ1p0π
- Slight preference for GiBUU for distributions modeling kinematic imbalances or without protons.
- Numerous ongoing analyses in addition to plans for re-releasing results over the full dataset planned in the near future.



Thank you

Backup Slides

Model Validation for Energy-Dependent Results

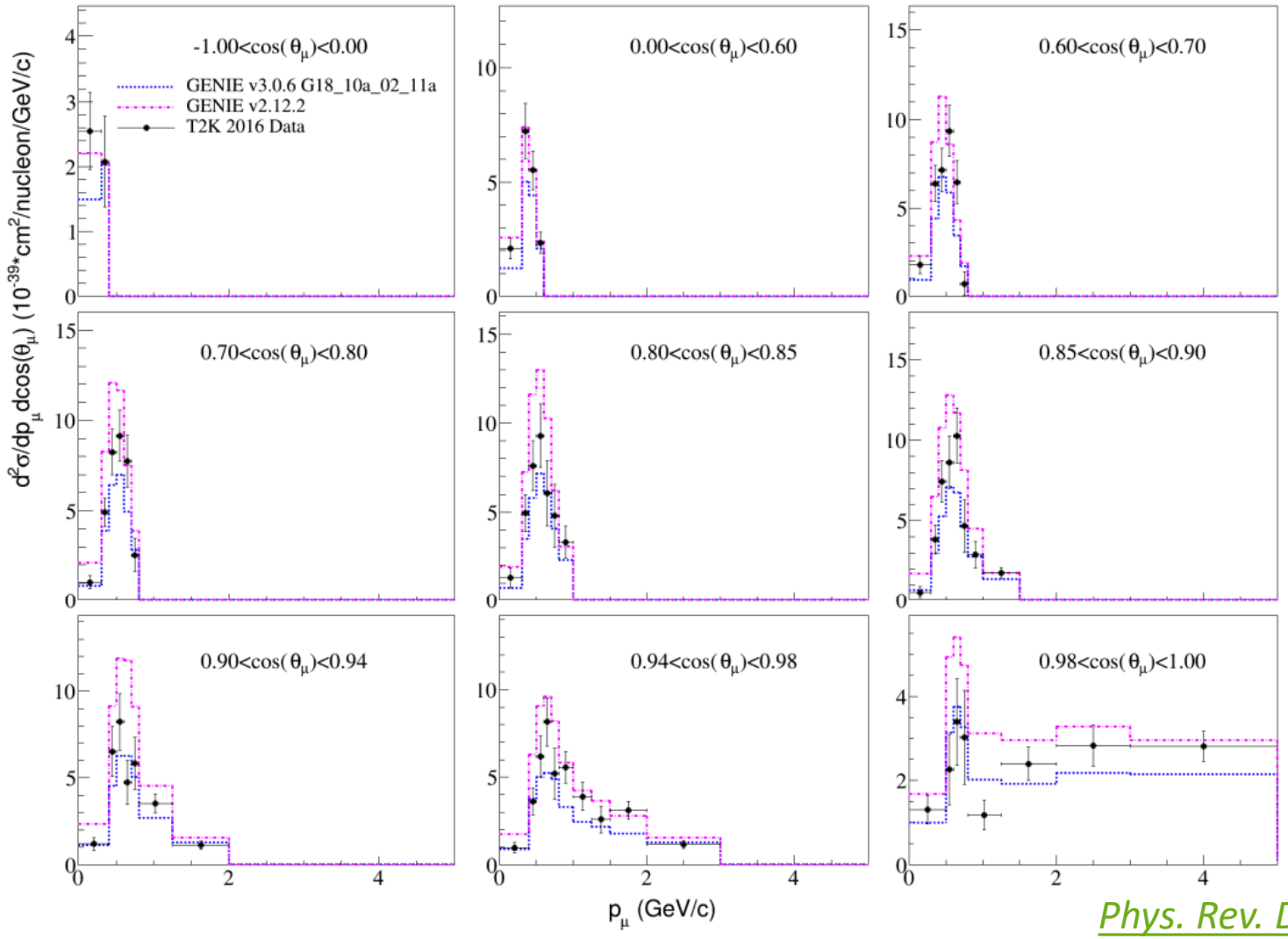


Scale based on visible hadronic energy reconstructed.

arXiv:2307.06413

MicroBooNE GENIE Tune

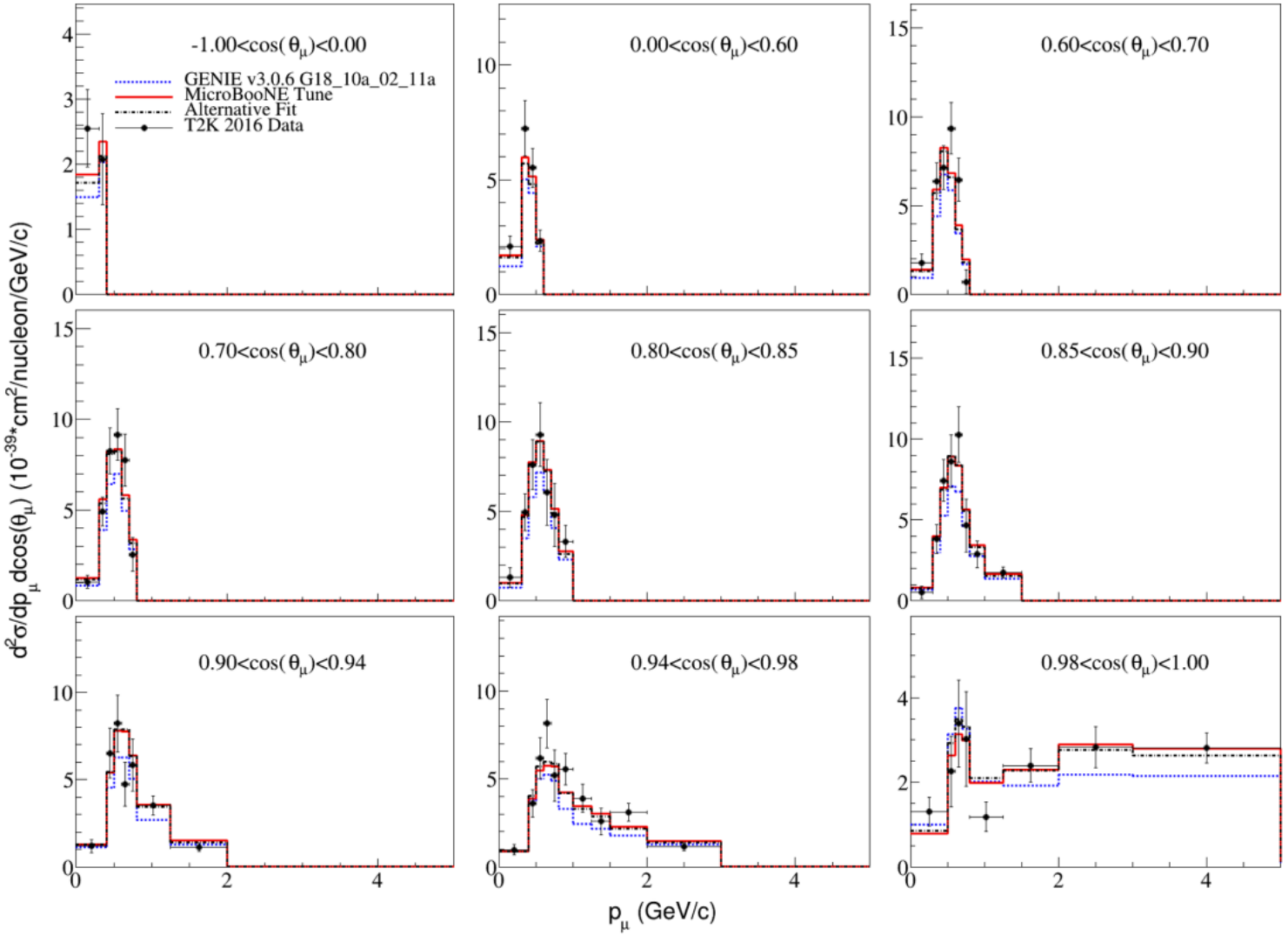
- Differences observed between world data with GENIEv2 and GENIEv3.



Phys. Rev. D 105 (2022) 7, 072001

MicroBooNE GENIE Tune

- Tune selects theory-driven parameters and tunes to the T2K CC0π data.



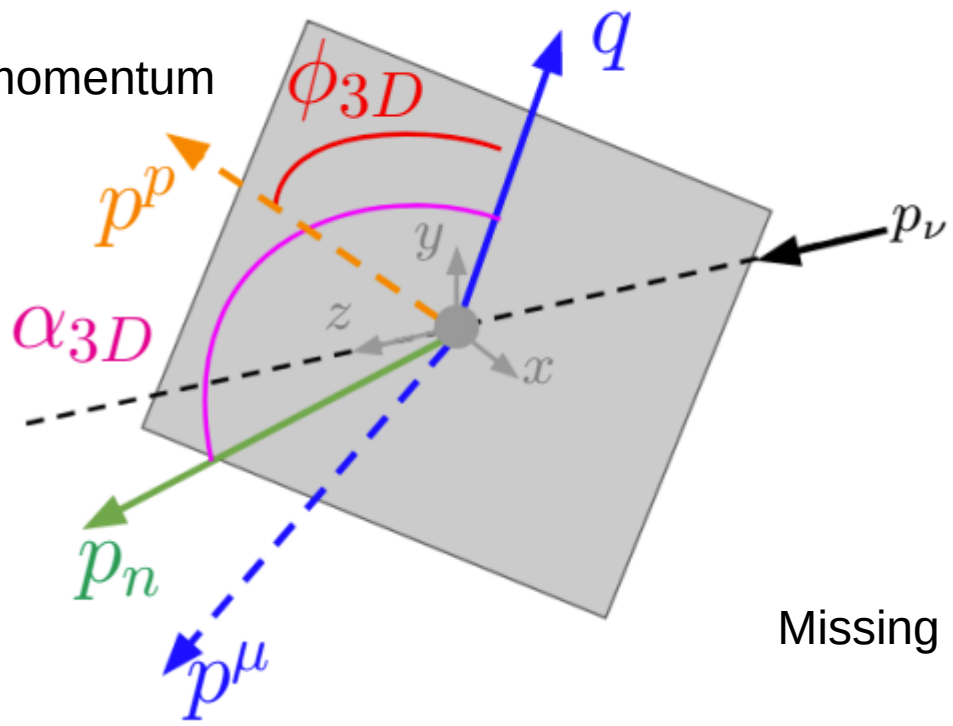
	MaCCQE fitted value	CC2p2h Norm. fitted value	CCQE RPA Strength fitted value	CC2p2h Shape fitted value
Nominal (untuned)	0.961242 GeV	1	100%	0
"MicroBooNE tune"	1.10 ± 0.07 GeV	1.66 ± 0.19	$(85 \pm 20)\%$	$1^{+0}_{-0.74}$
"Alternate fit"	1.04 ± 0.10 GeV	1.44 ± 0.42	$(67 \pm 16)\%$	$0.91^{+0.09}_{-0.18}$

Phys. Rev. D 105 (2022) 7, 072001

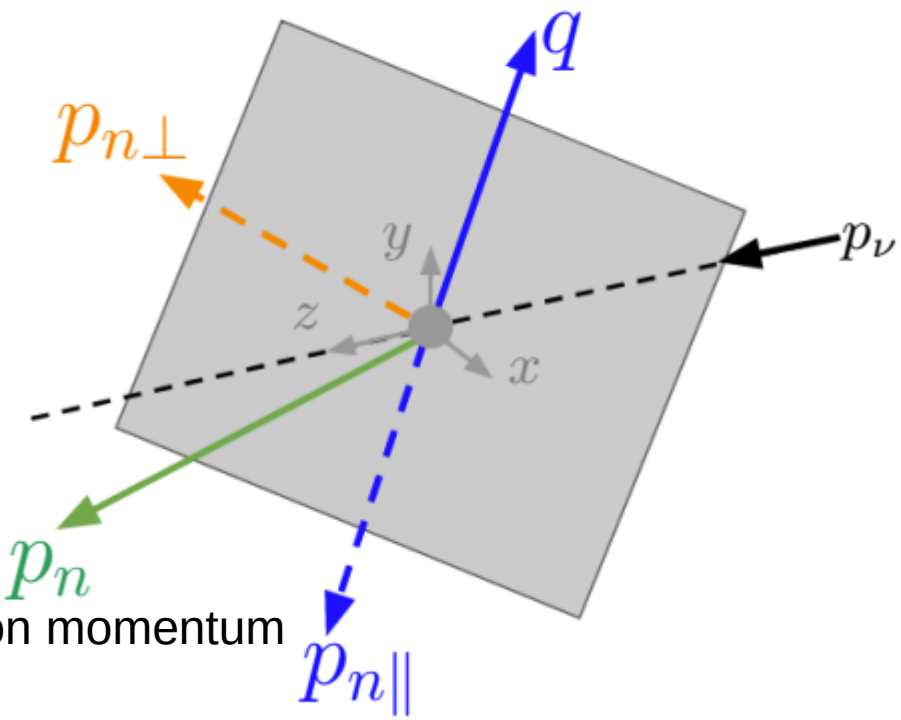
Generalized Kinematic Imbalance for CC1μ1p0π

- Could we simply this to the missing momentum and the momentum of the nucleon?

Proton momentum



Momentum transfer

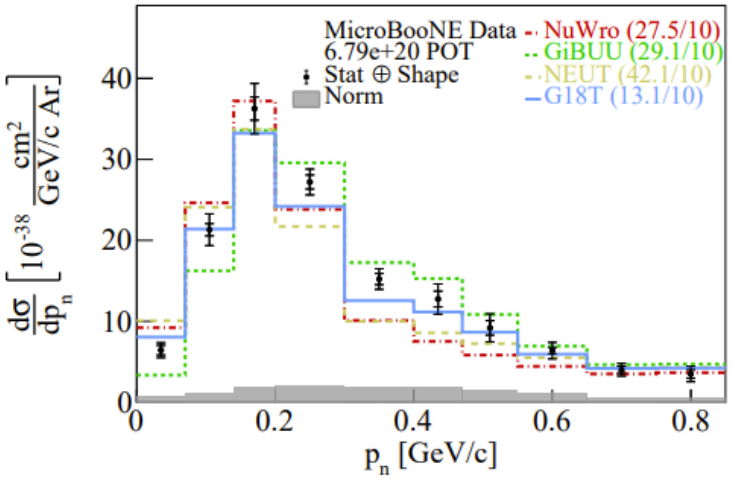


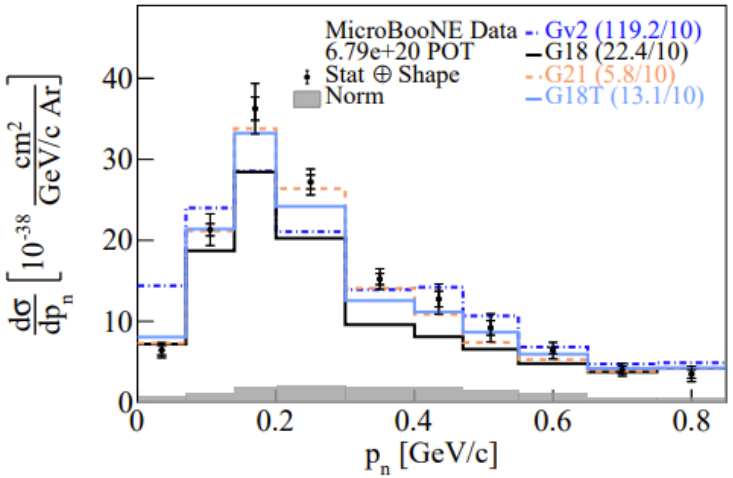
Missing nucleon momentum

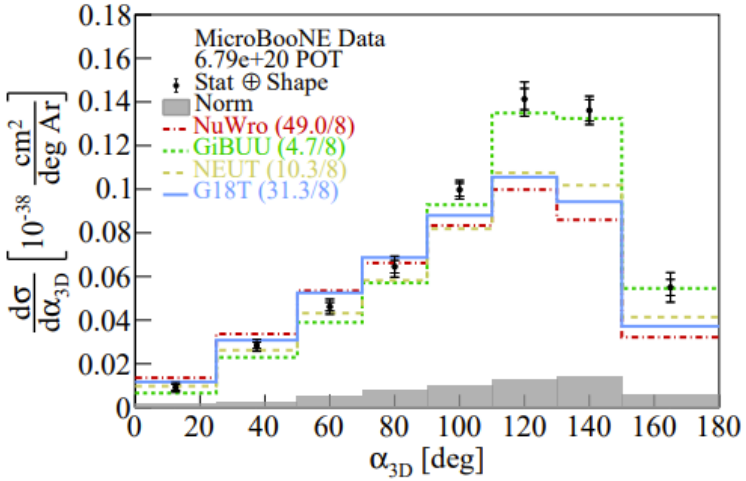
Phys. Rev. D 109 (2024) 9, 092007

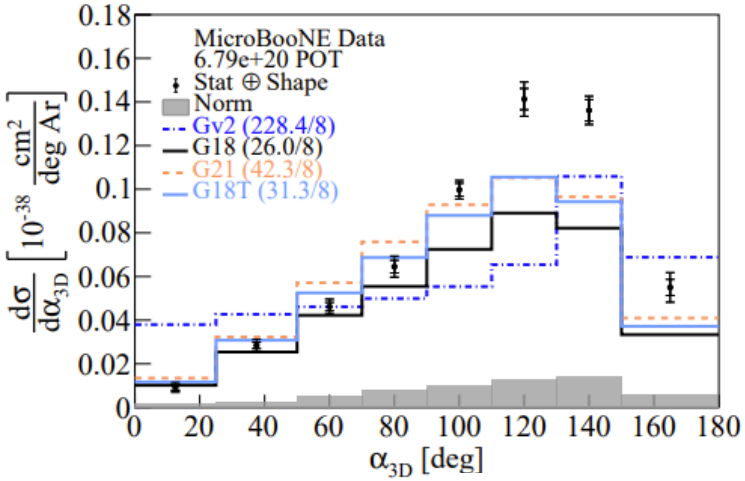
Generalized Kinematic Imbalance for CC1μ1p0π

- Comparisons with the same data as the CCQE-like data release:









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