First Measurements of Differential Cross Sections in Kinematic Imbalance Variables with the MicroBooNE Detector

MANCHESTER 1824
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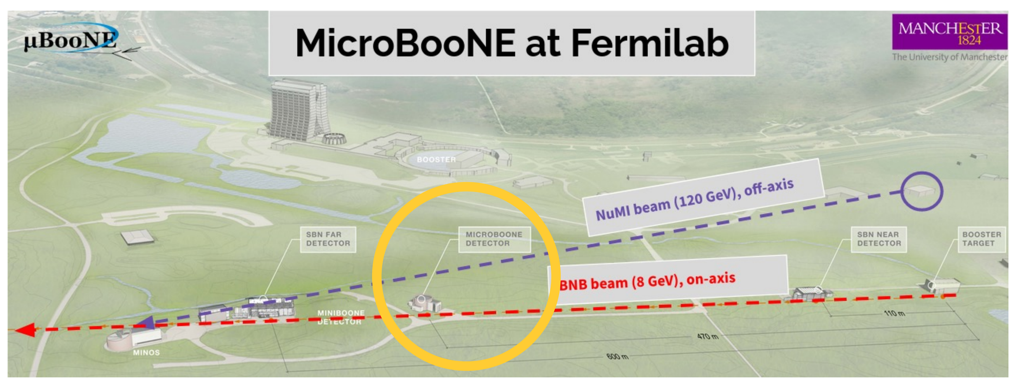
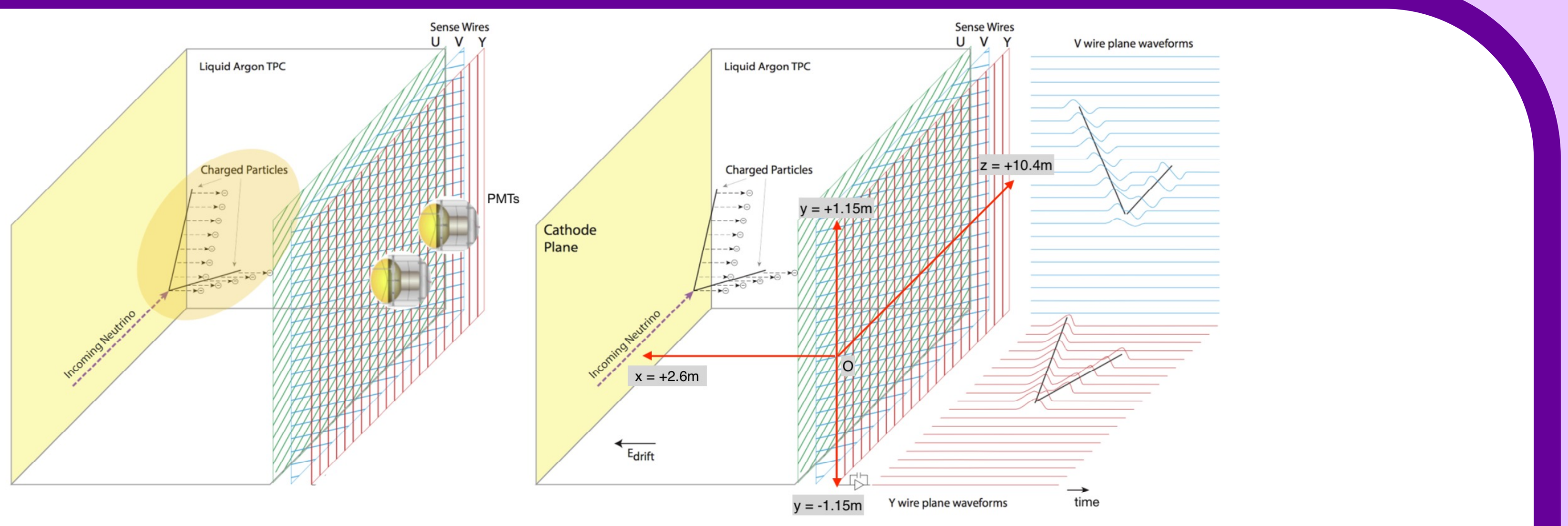
1. Introduction

- The Micro Booster Neutrino Experiment (MicroBooNE) is a Liquid Argon Time Projection Chamber (LArTPC) based at Fermilab.
- MicroBooNE ran from 2015 to 2020, forming the largest dataset of neutrino interactions with argon in the world to date.
- It has been designed for precision neutrino physics measurements.

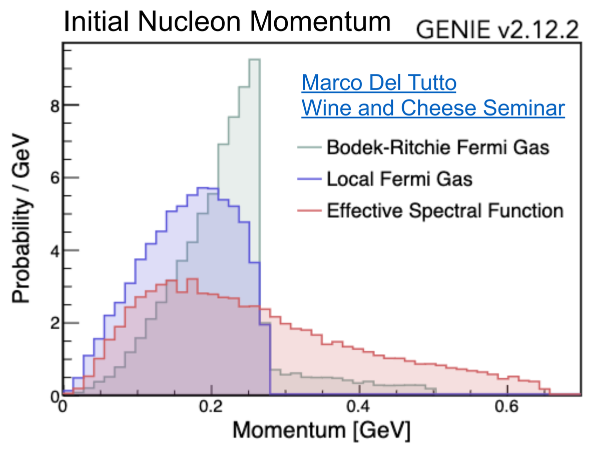


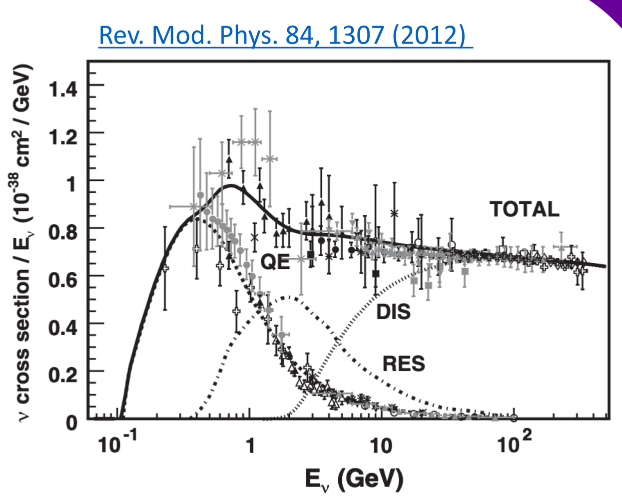


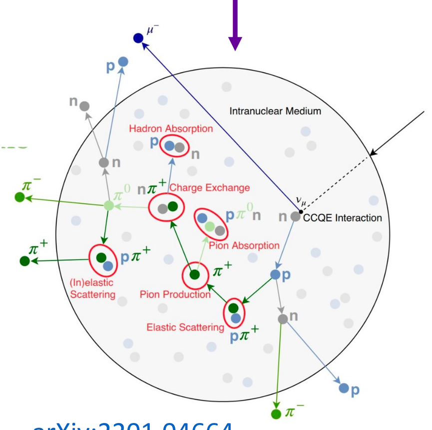
- The scintillation light produced at the time of the interaction is collected by 32 PMTs.
- The ionisation trails are carried to the anode wire planes by the electric field.
- These charged particle trajectories are reconstructed using the known positions of the wires and the recorded drift time of the ionisation.

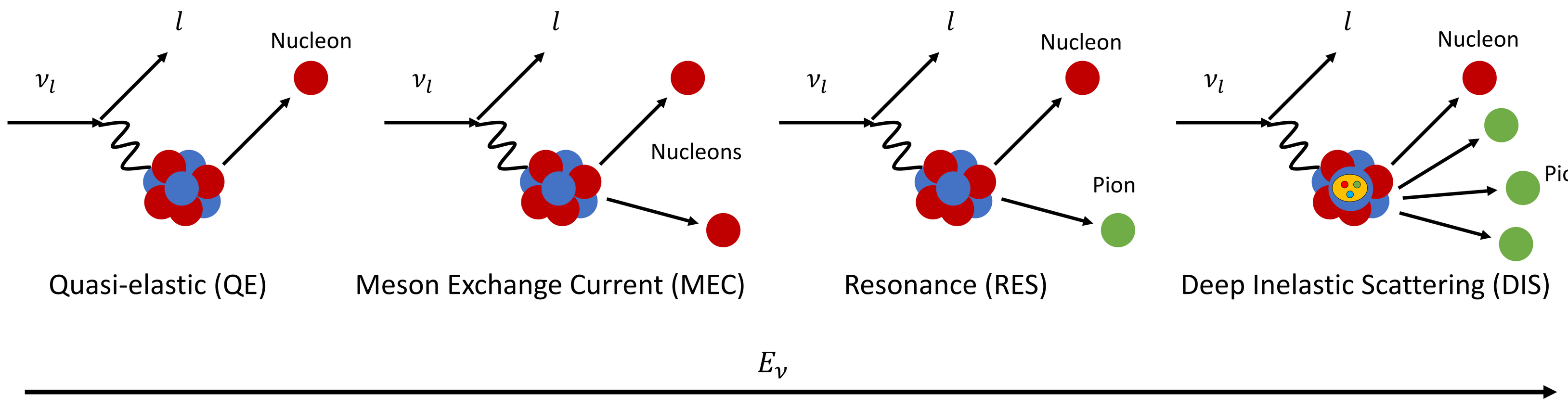
2. Neutrino Interaction Modeling Challenge

- Broad range of neutrino fluxes
- Many known unknowns that must be accurately simulated:
  - Ground states, Fermi motion
  - Neutrino interaction mechanisms
  - Final state interactions (FSI)
  - …





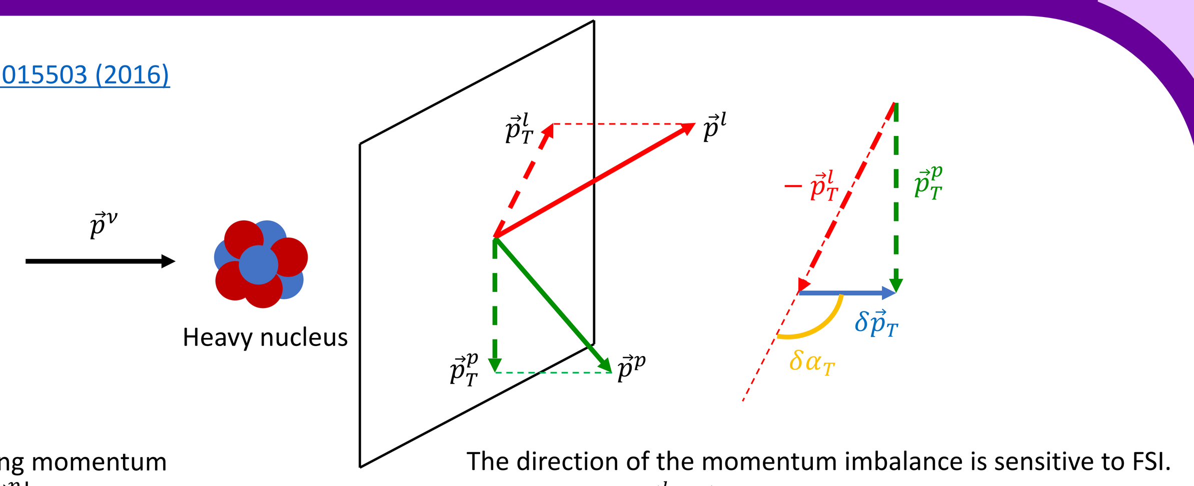




Any mismodeling can limit experimental sensitivity → Issue for future flagship experiments like DUNE.

3. Transverse Kinematic Imbalance (TKI)

Phys. Rev. C 94, 015503 (2016)

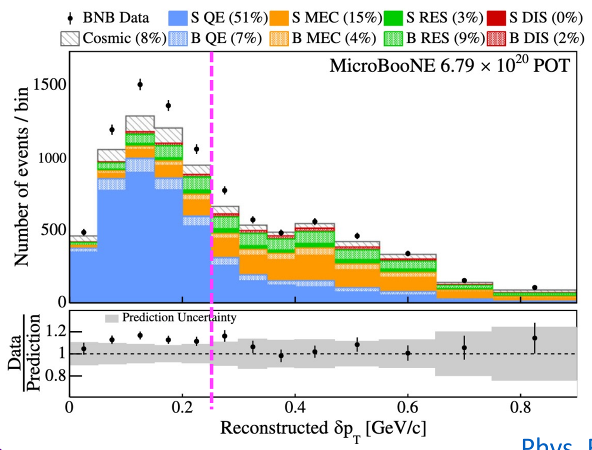


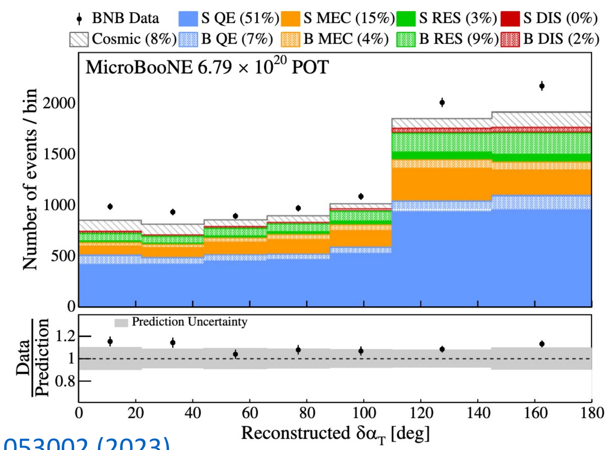
Transverse missing momentum
$|\delta\vec{p}_T| = |\vec{p}_T^{\,l} + \vec{p}_T^{\,p}| > 0$

- Sensitive to Fermi motion of initial nucleon.
- Further smeared by FSI and non-QE interactions.
- → Both result in a broad distribution.

The direction of the momentum imbalance is sensitive to FSI.
$\delta\alpha_T = \cos^{-1}\left(\frac{-\vec{p}_T^{\,l}\cdot\delta\vec{p}_T}{p_T^l|\delta\vec{p}_T|}\right)$

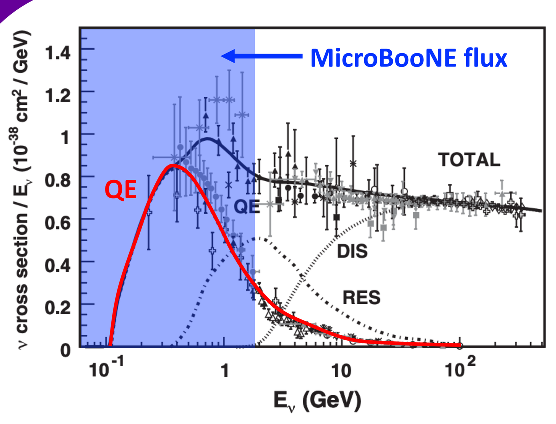
- Uniform distribution in the absence of FSI due to isotropic nature of Fermi motion.
- With FSI, proton momentum $\vec{p}_T^{\,p}$ reduces, so $\delta\alpha_T$ increases.

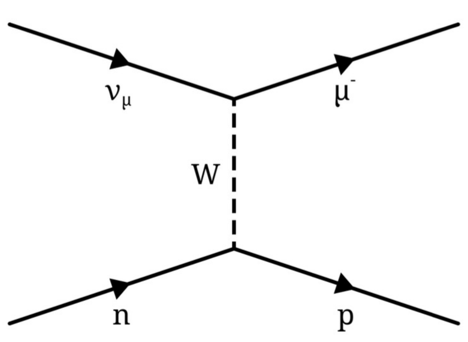




Phys. Rev. D 108, 053002 (2023)

4. CC1μ1p0π Differential Cross Section Results





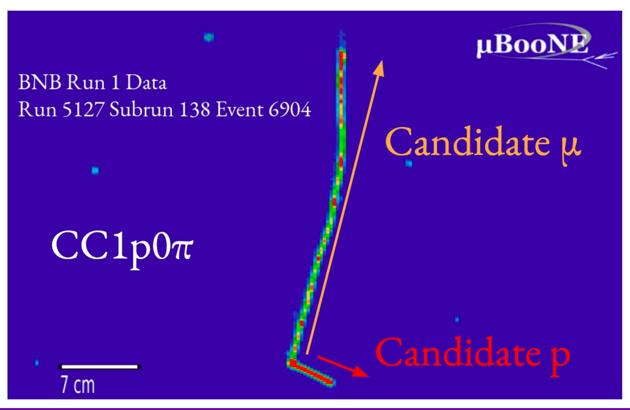
Can use the MicroBooNE detector to set constraints:

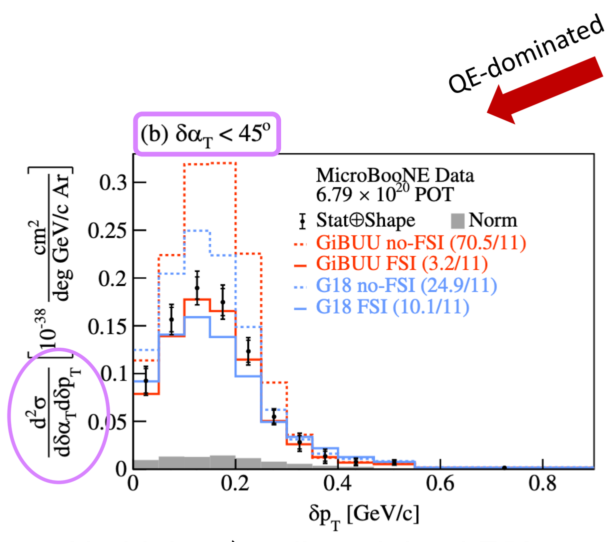
- First double-differential single-proton cross section measurement on argon.
- Uses ~ 50% of available dataset and the Booster Neutrino Beam (BNB) at Fermilab.
- Identified phase-space regions that are separately sensitive to Fermi motion and FSI.

QE-like Signal Definition:

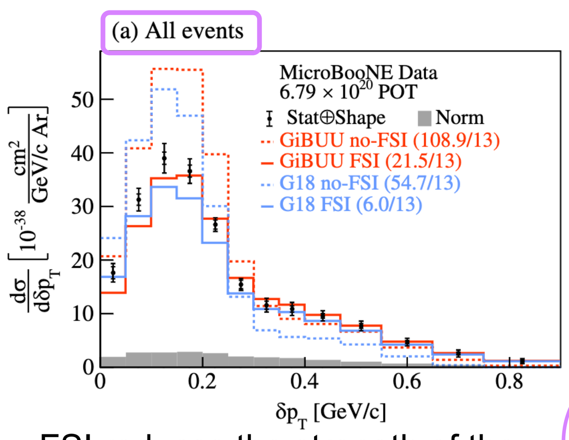
- 1 muon with $1 < P_\mu < 1.2$ GeV/c
- 1 proton with $0.3 < P_p < 1$ GeV/c
- No $\pi^\pm$ with $P_\pi > 70$ MeV/c
- No π^0 or heavier mesons
- Any number of neutrons

9051 CC1μ1p0π candidate data events
~ 10% efficiency
~ 70% purity



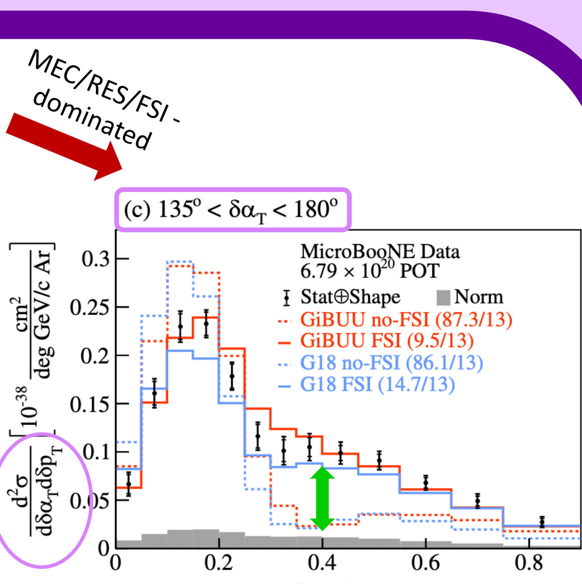


- No high $\delta\vec{p}_T$ tail – minimal FSI.
- Great region of phase-space to study Fermi motion.
- Results are consistent with the local Fermi gas distribution.



- FSI reduces the strength of the peak.
- Small changes in the tail.
- Data favours FSI predictions.

G18 = GENIE v3.0.6 G18_10a_02_11b + tune*
GiBUU = GiBUU 2021
Phys. Rev. Lett. 131, 101802 (2023)
* Phys. Rev. D 105, 072001 (2022)



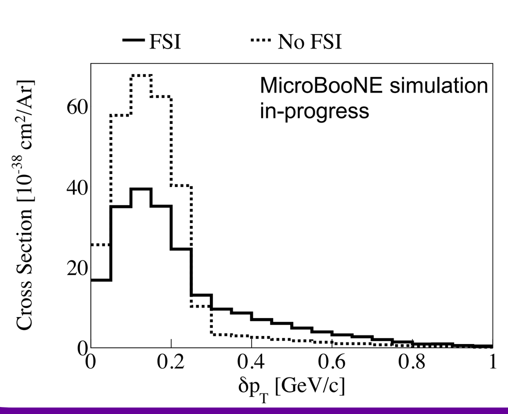
- FSI predictions in good agreement with data.
- The "no-FSI" predictions are minimal at high $\delta\vec{p}_T$.
- High $\delta\vec{p}_T$ and high $\delta\alpha_T$ phase-space is ideal to test FSI.

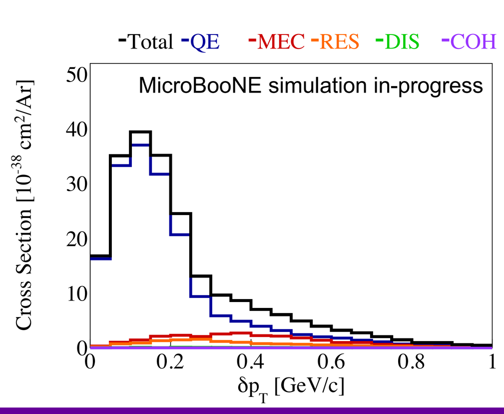
5. CC1e1p0π Cross Section Analysis - Ongoing

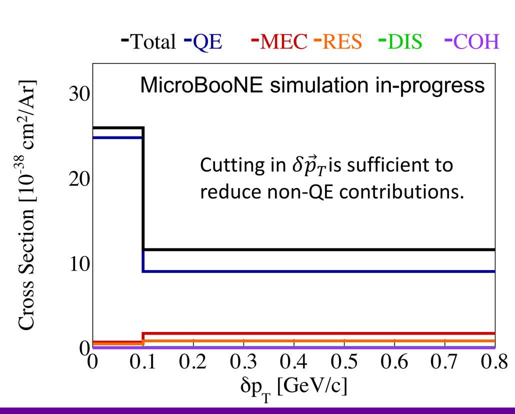
Similar ongoing analysis with ν_e (the appearance signal)!

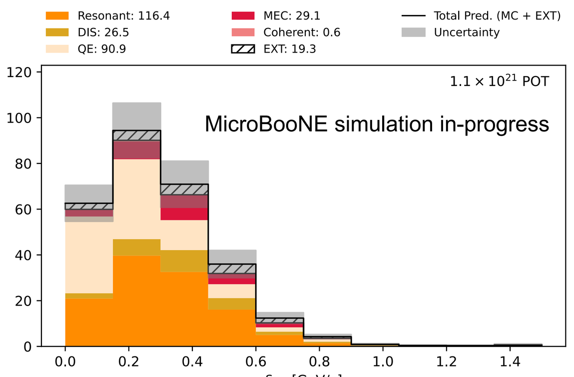
Interesting regions of QE-dominated phase-space identified using TKI truth variables:

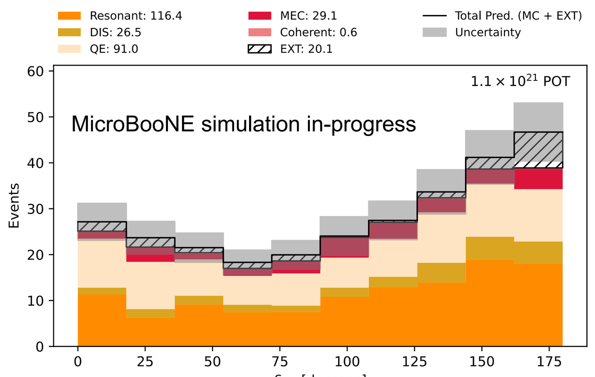
- Cross section measurement in such a "non-FSI region" is likely to yield small uncertainties.
- Can we leverage this to perform an oscillation analysis and to reduce the overall systematic uncertainty?

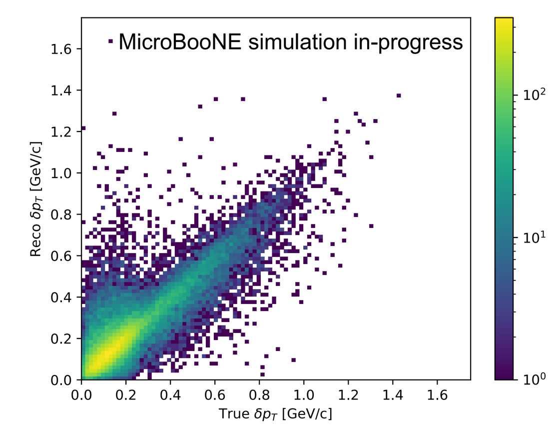


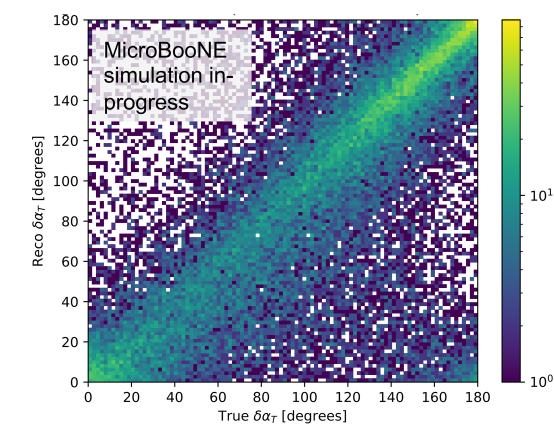












QE-like Signal Definition:

- 1 electron
- 1 proton with $P_p > 0.3$ GeV/c
- No $\pi^\pm$ with $P_\pi > 70$ GeV/c
- No π^0 or heavier mesons
- Any number of neutrons

More resonant events passed the reco selection cuts than expected.
→ Still under investigation.

Purity ~ 28.12%
Efficiency ~ 24.37%

Need sufficient resolution (and statistics) to perform an oscillation measurement.
→ especially for the electron showers (harder to reconstruct).

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