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Recent Neutrino Cross-section Results from MicroBooNE

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Abstract. MicroBooNE is a liquid argon time projection chamber that operates in the Booster Neutrino Beam at Fermilab. The detector provides high-resolution imaging of neutrino interactions with a low threshold and full angular coverage. Thanks to a high event rate and several years of continuous operation, the MicroBooNE collaboration has obtained the world's largest dataset of neutrino-argon scattering events. A detailed understanding of these interactions, especially the impact of nuclear physics effects, will be critical to the success of future precision neutrino oscillation efforts, particularly the argon-based Deep Underground Neutrino Experiment (DUNE) and the Short-Baseline Neutrino (SBN) program. This talk presents an overview of the latest neutrino-argon cross section measurements in MicroBooNE, including measurements of protons produced in muon neutrino interactions, measurements of the electron neutrino inclusive cross section, and progress towards measurements of rare channels.

1. Introduction

Both the current and next-generation neutrino oscillation experiments, such as Deep Underground Neutrino Experiment (DUNE) [1], and the Short-Baseline Neutrino (SBN) program [2], use argon as the target. Understanding the neutrino-argon interactions is essential for the reconstruction of neutrino energy and estimation of the systematic uncertainty, which are critical for success of precise neutrino oscillation measurements.

The MicroBooNE experiment [3] is the longest running Liquid Argon Time Projection Chamber (LArTPC), with an active mass of 85 tons. It has 3 planes of wires (vertical, +60°, -60°) with 3mm spacing. There are 32 the photomultiplier tubes (PMTs) behind the anode collecting the scintillation light. The high resolution of the detector allows us to achieve very low thresolds for detected particles.

The MicroBooNE detector receives both Booster Neutrino Beam (BNB) and Neutrinos at the Main Injector (NuMI) beam [4] at Fermilab. The main component of the BNB flux is muon neutrinos (ν_μ) and it peaks around 0.7 GeV. We have collected 1.56 $\times 10^{21}$ Protons On Target (POT) BNB data. MicroBooNE also receives off-axis NuMI beam, which has a larger fraction of electron neutrino (ν_e) than the BNB flux. We have collected 2.37×10^{21} POT NuMI data.

In the next two sections, we present some of the recent cross-section results from the MicroBooNE experiment.

2. Recent Cross-section Results from MicroBooNE

2.1. Inclusive Muon Neutrino Charged Current Differential Cross Sections

The inclusive muon neutrino Charged Current (CC) measurement is the highest-statistics measurement at MicroBooNE [5]. The selection has full muon momentum and angular coverage with an overall efficiency of 57.2% and overall purity of 50.4%. It is the first ν_μ-Ar double differential cross section measurement. As shown in Figure 1, the measured double-differential cross sections as a function of muon momentum and muon angle are compared with four different model sets, and our measurement favors the GENIE v3 prediction. This measurement provided valuable information for our cross section model tuning later on.

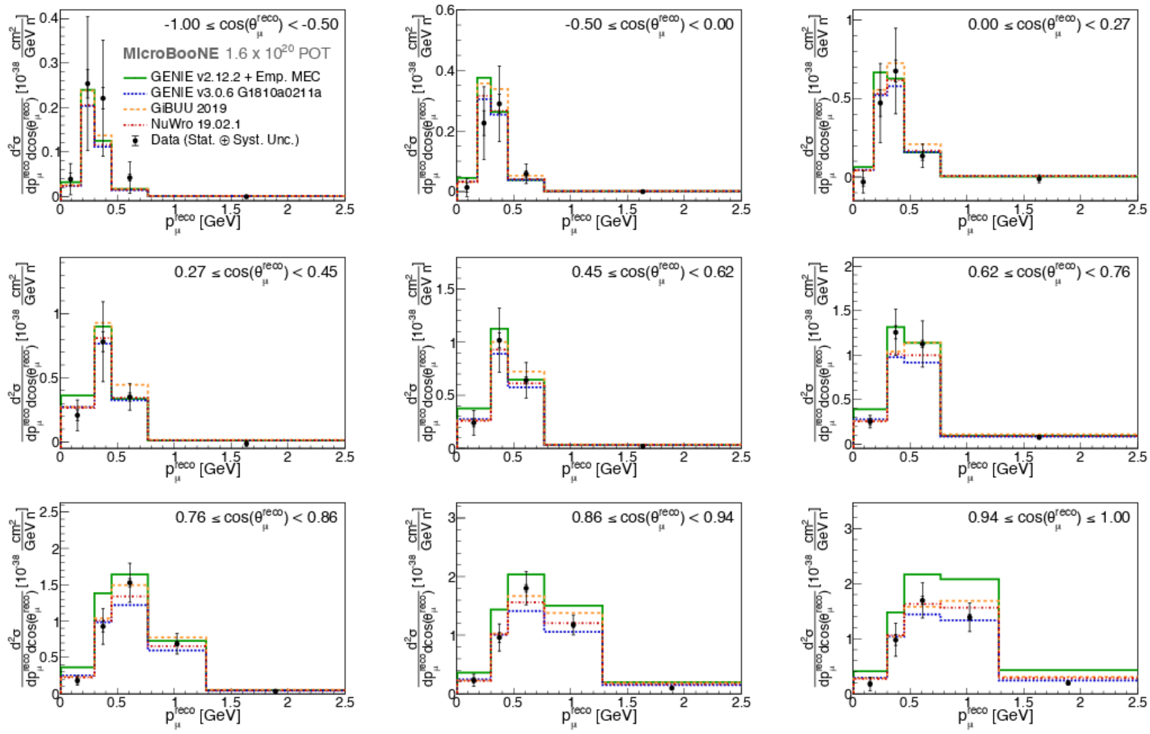

Figure 1. CC inclusive double-differential cross section on argon per nucleon as a function of the measured muon momentum and cosine of the measured muon polar angle (angle with respect to the incoming neutrino direction). The data (black) are compared to a GENIE v2 with empirical meson exchange current (MEC) prediction (green), a GENIE v3 prediction (blue), a GiBUU prediction (orange), and a NuWro prediction (red). The vertical bars show statistical and systematic uncertainties.

2.2. Inclusive Charged-current Electron Neutrino and Antineutrino Cross Section

The single-differential $\nu_e + \bar{\nu}_e$ CC inclusive cross sections [6] is measured using the data collected from the NuMI beam, which has a higher fraction of electron neutrinos. We select CC interaction by looking for single shower, we then utilize the energy loss per cm (dE/dx), as shown in Figure 2, to separate electrons from photons. 214 events are selected from $2.4{\times}10^{20}$ POT data. The selection achieves an overall purity 40% and overall efficiency of 10%. The final value of the electron neutrino and antineutrino CC inclusive cross section on argon is

$$\langle\sigma\rangle = 6.84 \pm 1.51(stat.) \pm 2.33(sys.) \times 10^{-39} \frac{\text{cm}^2}{\text{nucleon}}, \quad (1)$$

which is in good agreement with model predictions.

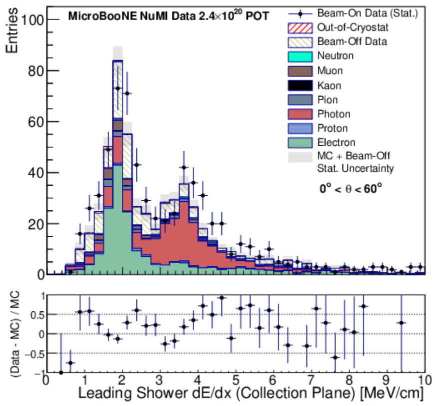

Figure 2. dE/dx of leading showers for neutrino candidates broken down by particle type. This plot is made for leading shower θ between 0° and 60° where the reconstruction of showers is good. Electrons are gathered in the MIP peak,while most photons are around 4 MeV/cm.

2.3. Charged-current Interactions with Protons and No Pions in the Final State

In this measurement [7], we select events that have one muon, no pions and N>=1 proton(s) with momentum above 300 MeV/c in the final state. Protons are identified using the Bragg peak at the end of the track. The overall selection purity is 70%, efficiency is 30%. The single-differential cross sections are reported as a function of muon momentum, muon angle, leading proton momentum and leading proton angle. Proton kinematics show good agreement with various models, while disagreement is seen in the forward going muons as shown in Figure 3.

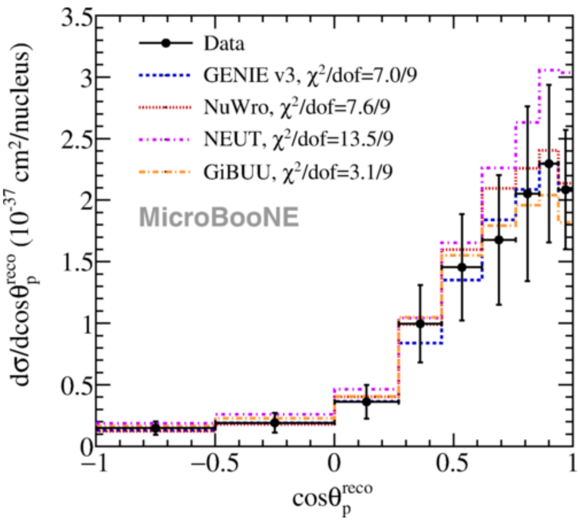

Figure 3. Measured cross section as a function of $\cos\theta_\mu$ compared with various model predictions.

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2.4. Charged Current Quasielastic-like Scattering Cross Sections

The CC Quasielastic-like (CCQE-like) measurement [8] selects pion-less events with one muon, one proton and no pions in the final state. Additional angle requirements are also applied to the signal to reduce the cosmic background and enhance the quasi-elastic contribution. The overall purity for CCQE is about 80%. The differential cross section are reported as a function of muon momentum, muon angle, proton momentum and proton angle. Our data shows good agreement with models, except at very forward muon scattering angles, as shown in Figure 4. Figure 5 shows the differential cross sections as a function of measured muon momentum, proton scattering angle, and proton momentum. Improved data and model agreement is seen with the most forward going muons removed.

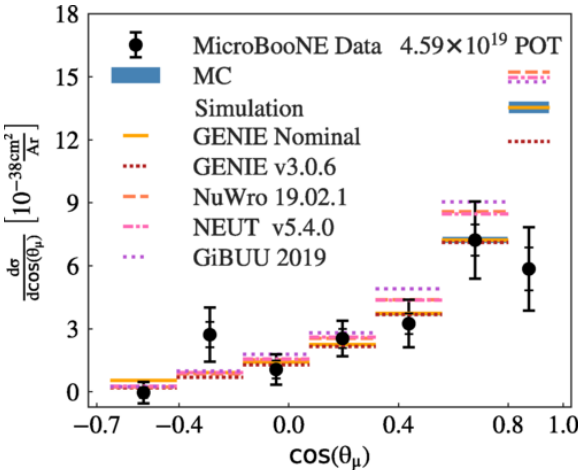

Figure 4. The flux-integrated single differential cross sections as a function of $\cos\theta_\mu$. Inner and outer error bars show the statistical and total (statistical and systematic) uncertainty at the 1 σ, or 68%, confidence level.

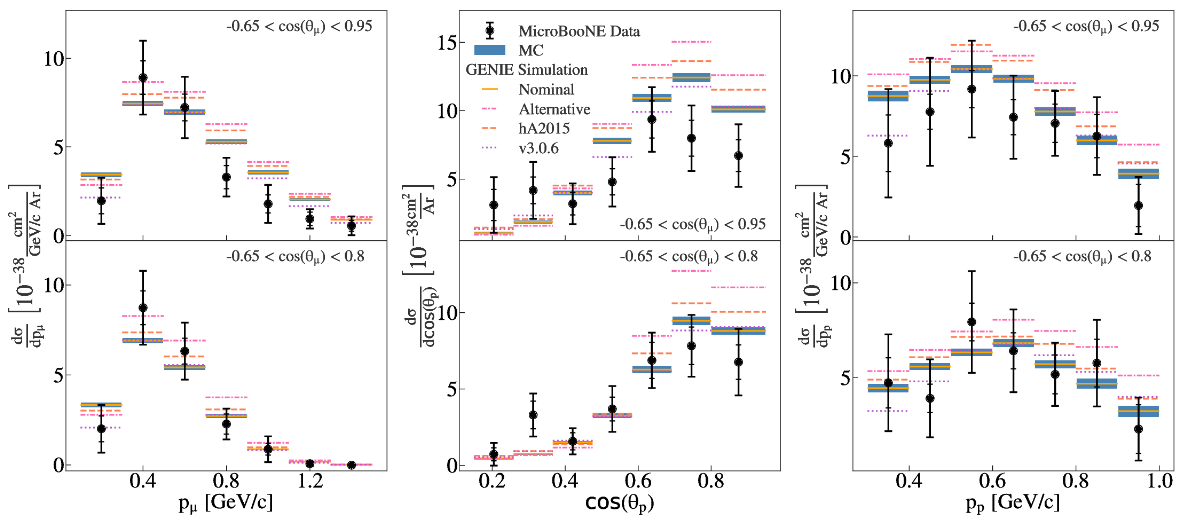

Figure 5. The differential cross sections as a function of measured muon momentum (left) and measured proton scattering angle (middle) and momentum (right). Cross sections are shown for the full measured phase space (top) and for events with $cos\theta < 0.8$ (bottom).

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2.5. Neutral Current Quasielastic-like Scattering Cross Sections

The signal for neutral current (NC) quasielastic-like (or NC1p) measurement [9] is defined as NC events with one and only one proton above 200 MeV/c in the final state, of which the main component is NC elastic scattering events. The overall selection efficiency is 29.8%, overall purity is 42.1%. The flux-averaged single-differential cross section as a function of proton kinetic energy is shown in Figure 6. This measurement includes NC interactions down to $Q^2 = 0.1$ GeV^2, which is significantly lower than previous measurements in neutrino experiments. This measurement is the first step towards a NC elastic scattering cross section measurement.

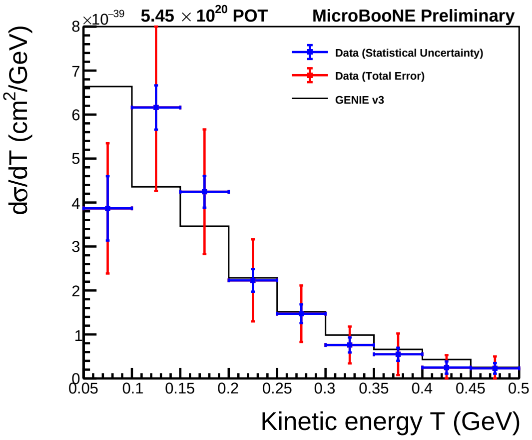

Figure 6. The differential cross section for NC1p as a function of proton kinetic energy.

3. Progress towards Measurements of Rare Channels

CC kaon production is a rare process with few existing measurement. We have developed a selection [10] with 67.7% purity and 7% efficiency. A total of 12 candidate events are expected from 1.3 $\times 10^{21}$ POT BNB data.

We also have the ability to detect and reconstruct activity as low as 100 keV [11], which is photons produced by gamma nuclear de-excitations or neutron scattering. This reconstruction technique has been used to reconstruct simulated Supernova and muon-decay-at-rest (μDAR) neutrino events.

4. Conclusion

Neutrino-argon cross section measurements play an important role in the success of future neutrino oscillation experiments. The MicroBooNE experiment has made huge progress on precise neutrino-argon cross section measurements in the last two years using both the BNB and NuMI data. More exciting cross section results from MicroBooNE will come soon.

References

[1] Abi B *et al.* (DUNE) 2018 (*Preprint* 1807.10327)
[2] Antonello M *et al.* (MicroBooNE, LAr1-ND, ICARUS-WA104) 2015 (*Preprint* 1503.01520)
[3] Acciarri R *et al.* (MicroBooNE) 2017 *JINST* **12** P02017 (*Preprint* 1612.05824)
[4] Adamson P *et al.* 2016 *Nucl. Instrum. Meth. A* **806** 279–306 (*Preprint* 1507.06690)
[5] Abratenko P *et al.* (MicroBooNE) 2019 *Phys. Rev. Lett.* **123** 131801 (*Preprint* 1905.09694)
[6] Abratenko P *et al.* (MicroBooNE) 2021 *Phys. Rev. D* **104** 052002 (*Preprint* 2101.04228)
[7] Abratenko P *et al.* (MicroBooNE) 2020 *Phys. Rev. D* **102** 112013 (*Preprint* 2010.02390)
[8] Abratenko P *et al.* (MicroBooNE) 2020 *Phys. Rev. Lett.* **125** 201803 (*Preprint* 2006.00108)
[9] MicroBooNE Public Note 1067
[10] MicroBooNE Public Note 1071
[11] MicroBooNE Public Note 1076