

Understanding CCQE events in MicroBooNE*

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Abstract

Understanding nuclear effects in neutrino interactions, particularly on argon, will be critical for the future success of neutrino oscillation experiments. One channel that potentially allows these effects to be probed is the CCQE-like channel where a single muon and no pions are produced. Liquid argon time projection chambers allow unprecedented resolution of the hadronic side of neutrino interactions on heavy nuclei. Different models and generators make very different predictions for the kinematics and multiplicity of protons in these interactions, and MicroBooNE will be able to collect enough data in the first year of running to begin probing this previously unmeasured part of phase space.

MICROBOONE

MicroBooNE is a 170 ton (87 ton active) liquid argon TPC in the Booster Neutrino Beam at Fermilab. The bubble-chamber quality images allow for extremely good particle identification, calorimetry, and a low threshold for tracking heavy particles such as protons. This makes it the ideal place to study nuclear effects in neutrino interactions. Figure 1 shows a schematic of the MicroBooNE detector.

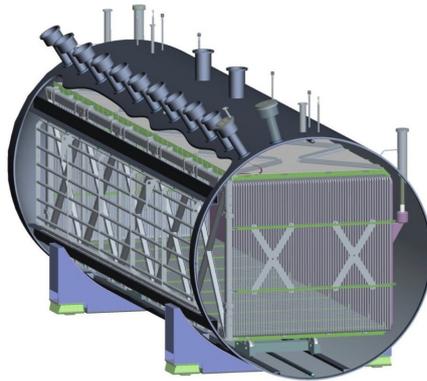


FIG. 1: Schematic showing the MicroBooNE cryostat with the TPC placed inside. The booster neutrino beam enters from the far end of the detector.

PREVIOUS EVIDENCE FOR CORRELATIONS

From electron scattering experiments, there is significant evidence for correlations between nucleons in nuclei. Recently ArgoNeuT observed a number of interesting “hammer” events [1] - a single muon accompanied by a pair of back-to-back protons (shown in figure 2). The observation of back-to-back protons is indicative of nucleon-nucleon correlations being observed for the first time in neutrino scattering. Unfortunately due to the small size and short exposure of ArgoNeuT the results are very statistically limited. MicroBooNE will collect an order of magnitude more events than ArgoNeuT in the CCQE regime.

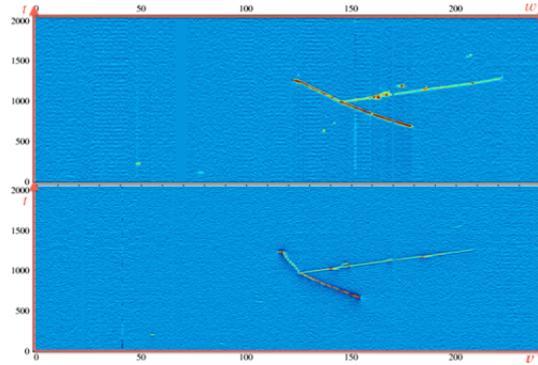


FIG. 2: An event display from the ArgoNeuT [1] experiment, showing a single muon and a pair of back-to-back protons. This is known as a “hammer” event.

GENERATORS AND MODELS

Two generators are considered in this study. The first is GENIE version 2.8.6 [2, 3], which is commonly used in the neutrino physics community. All GENIE parameters were left at their default values. Importantly, the default GENIE settings use the Bodek-Ritchie Relativistic Fermi Gas nuclear model and no nucleon-nucleon correlations.

The second generator considered was NuWro version 11q [4]. NuWro has many options for nuclear models. For this study, the Benhar Spectral Function nuclear model was selected, as this model includes nucleon-nucleon correlations. In addition the Nieves model for meson-exchange current (MEC) interactions was enabled. Other parameters were left at their default values.

PREDICTED EVENT RATES

Figure 3 shows the predicted muon momentum spectrum for the two models. The distributions are very similar. However figures 4 and 5 show the predictions for the number of protons and the angle between 2 protons (for the topology with exactly 2 protons). Large differences are seen in these variables.

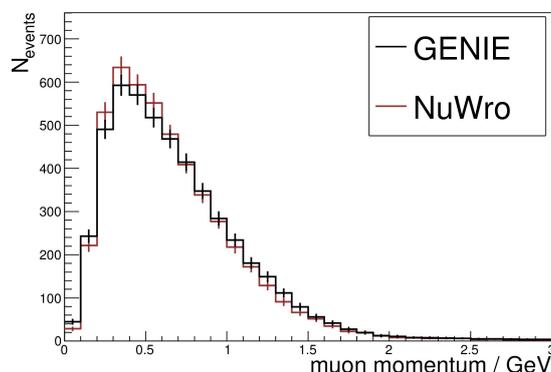


FIG. 3: Muon momentum distribution for all $CC0\pi$ events. The distributions are very similar despite large differences in the models used.

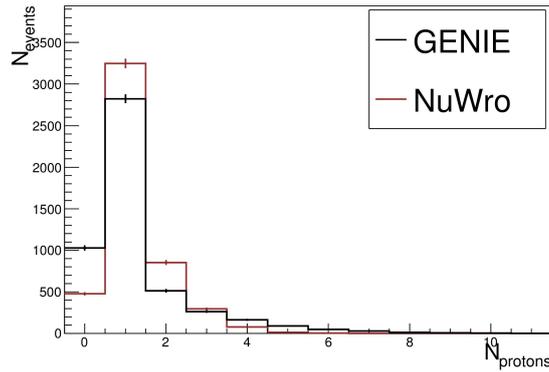


FIG. 4: Number of protons above 200 MeV/c momentum for all CC0 π events. Large differences can be seen in all bins.

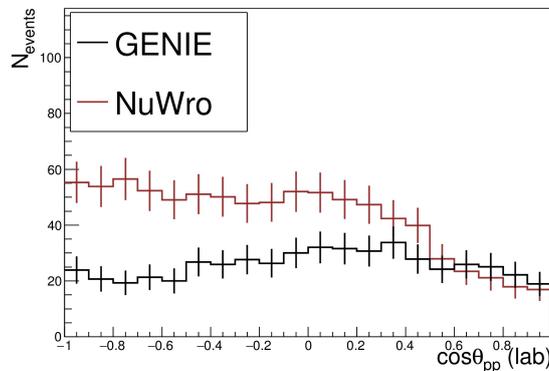


FIG. 5: Proton-proton angle for CC0 π events with exactly two protons above 200 MeV/c momentum. NuWro shows enhancement in the back-to-back region, due to MEC events.

CONCLUSIONS

Nuclear effects, such as nucleon-nucleon correlations, can have a large effect on the multiplicity and kinematics of protons leaving the nucleus in a neutrino interaction, even when the muon kinematics are relatively unchanged. In particular, models which incorporate nucleon-nucleon correlations and multinucleon interactions tend to predict larger proton pair opening angles than those models without these effects. Using a high-statistics event sample in a liquid argon TPC such as MicroBooNE, it will soon be possible to begin to explore these effects in neutrino interactions.

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