PROCEEDINGS OF SCIENCE

Measurement of Neutral Current Elastic Cross Section in MicroBooNE

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The MicroBooNE experiment is an 85 ton active volume liquid-argon time projection chamber located in the Fermilab Booster Neutrino Beamline. MicroBooNE's ability to detect low-energy protons allows us to study single proton events with a four-momentum transfer squared, Q^2, as low as 0.10 GeV^2. We present a measurement of the flux-averaged neutral-current elastic differential cross sections for neutrinos scattering on argon as a function of Q^2, proton momentum and proton angle with respect to the direction of the neutrino beam. This is our first step towards extracting the strange quark contribution to the axial form factor, which is not only the least-constrained contribution to the neutral-current elastic scattering cross section but is also crucial for understanding the strange quark contribution to the proton spin.

**** The 22nd International Workshop on Neutrinos from Accelerators (NuFact2021) ****
*** 6–11 Sep 2021 ****
*** Cagliari, Italy ****

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PoS(NuFact2021)205

1. Introduction

Neutrino-proton neutral-current elastic (NCE) scattering can be used to probe the nuclear effects inside the interaction target, as well as the property of strange quarks of the nucleon via the isoscalar weak current. The NCE cross section has been previously measured by two neutrino experiments, E734 at BNL [1] and the MiniBooNE experiment [2] at Fermilab. They measured the NCE interactions with four-momentum transfer squared, Q^2, as low as $Q^2 = 0.45$ GeV^2. In the MicroBooNE experiment, we are able to extend the Q^2 range down to 0.1 GeV^2, which is more sensitive to the value of Δs.

2. MicroBooNE Experiment

The MicroBooNE [3] experiment is an 85 ton active mass liquid-argon time projection chamber (LArTPC) located at the Fermilab Booster Neutrino Beamline (BNB). The BNB is a predominantly ν_μ beam with peak energy around 600 MeV. MicroBooNE's active region is $2.3 \times 2.5 \times 10.4$ m^3. Figure 1 shows a schematic of the MicroBooNE TPC [4]. Charged particles produced from neutrino interactions ionize the argon along their path. The ionization electrons drift in a 273 V/cm electric field along the x axis, towards the vertical (y, z) anode plane for readout.

In addition to the wire chamber, the experiment employs a set of 32 8-inch cryogenic photomultiplier tubes (PMTs) located directly behind the anode plane, in order to take advantage of the excellent scintillation properties of argon that it produces a large amount of light per unit energy deposited and is transparent to its own scintillation. Light detected by the PMTs is used as a trigger for the presence of neutrino interactions, as well as for rejecting cosmic-ray events. This trigger looks at light activity on the PMTs in time-coincidence with the 1.6 μs beam-spill reaching the detector, which may be caused by a neutrino interaction or coincident cosmic activity. In

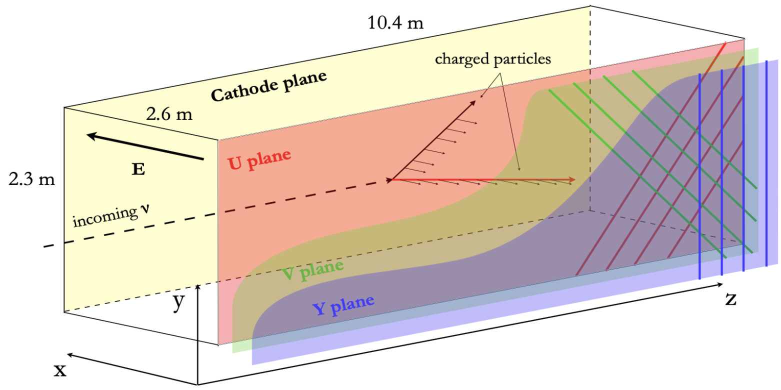

Figure 1: A schematic of the MicroBooNE TPC system from [4].

MicroBooNE, two different data streams are used. The on-beam data stream ("BNB") is triggered by BNB neutrino spills that last for 1.6 μs. The off-beam data stream ("EXT") is taken during periods when no beam is received. The off-beam data sample is used to measure the cosmic-ray backgrounds, which are appreciable due to the location of MicroBooNE near the surface and without substantial overhead shielding. We use a cosmic-data-overlaid Monte Carlo (MC) sample to develop the analysis. The neutrino interactions are generated using the GENIE neutrino event generator version 3.0.6 [5, 6, 7]. MicroBooNE employs signal processing [8, 9] to convert 2D raw data into Gaussian-shaped signals (known as "hits"). We then employ the Pandora multi-algorithm pattern recognition framework [10] to convert these 2D hits into 3D objects and create a set of "Particle Flow Particles" ("PFParticles") hierarchies, each of which corresponds to a track or shower, and their parent-daughter relationships between tracks and showers.

3. Signal Definition

Our signal is defined as neutral current elastic events that produce a single proton above 300 MeV/c, no muons above 100 MeV/c, and no pions above 65 MeV/c . First of all, it is required to be 'NCE-like", which means it is a muon neutrino interaction that happens inside the fiducial volume (FV), with one and only one proton in the final state with a momentum greater than 300 MeV/c. Additionally, for this measurement we require that the event is also classed as NCE and the struck nucleon was a proton according to truth information. The main sources of our background are NCE-like events that are not also NCE, other neutrino-induced NC and charged-current (CC) protons, interactions happen outside of the fiducial volume, as well as the cosmic rays.

4. Event Selection

We require tracks to be contained in the FV. Any candidate tracks that are in or across any dead region of the detector are removed. We remove events that have more than one object in the particle-flow hierarchy, as reconstructed by Pandora, and obvious cosmic backgrounds based on the light information. We only keep track candidates that are going forward along the beam direction ($\cos\theta > 0$), since the low-energy protons we are interested in tend to be forward-going. To enrich our sample in protons we only select tracks that have a deposited energy profile consistent with a proton [11].

To further reduce the cosmic background, we created a multi-class gradient-boosted decision tree (BDT) classifier using the TMVA [12] package in ROOT. The variables used for the training include the total and track-end dE/dx on the collection plane, track start and end positions in cartesian coordinates, Particle Identification (PID) variables on all planes [11], track angles, and track length. Figure 2 shows the selected NCE events as a function of reconstructed Q^2, momentum and $\cos\theta$. We achieve an overall efficiency of 38% and overall purity of 23%.

5. Differential Cross Section Extraction

We extract differential cross section $d\sigma/d\alpha$ in true α (with α stands for kinetic energy T, Q^2, momentum p or $\cos\theta$) using unfolding method. We unfold using the D'Agostini iterative unfolding algorithm as found in the RooUnfold [13] package. We find that one iteration is sufficient to produce a stable result so a single iteration is used for all differential cross sections.

The differential cross section can be written as

$$(\frac{d\sigma}{d\alpha})_i = \frac{S_i^{\text{unfolded}}}{\varepsilon_i \cdot N_{\text{target}} \cdot \Phi_{\nu_\mu} \cdot (\Delta\alpha)_i}, \tag{5.1}$$

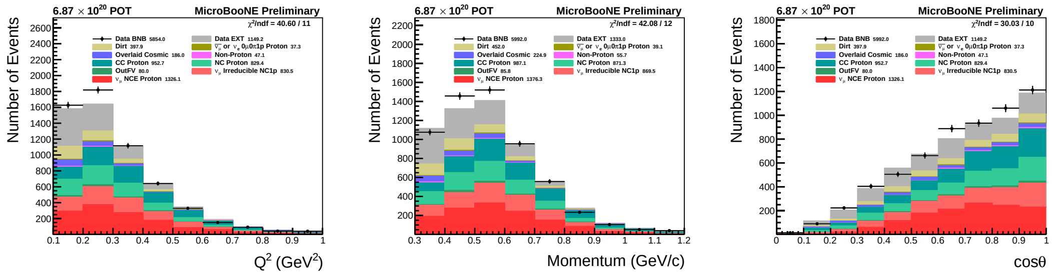

Figure 2: Event rate of the selected NCE sample from data and MC, as functions of reconstructed Q^2 (left), reconstructed momentum (middle), and $\cos\theta$ (right). The stacked histograms are broken down to highlight the NCE signal and backgrounds.

in which i is the i-th true α bin, S_i^{unfolded} is the unfolded background-subtracted event rate that is produced from $N_j - B_j$ in the reconstructed space. N_j is the event rate in the j-th reconstructed bin, B_j is the background in bin j, ε_i is the efficiency correction in bin i. The number of target protons N_{target} is defined as

$$N_{\text{target}} = \rho_{\text{Ar}} \cdot V_{\text{Ar}} \cdot N_A \cdot N_{\text{protons}} / m_{\text{mol}}, \tag{5.2}$$

in which

$$\rho_{\text{Ar}} = 1.3836 \text{ g/cm}^3,$$

$$N_A = 6.022140857(74) \times 10^{23} \text{ molecules/mol},$$

$N_{\text{protons}} = Z = 18$, V_{Ar} is the fiducial volume, and $m_{\text{mol}} = 39.95$ g/mol .
The integrated flux is calculated to be $\Phi_{\nu_\mu} = 3.87 \times 10^{11}$ cm^{-2}. The bin width $(\Delta\alpha)_i$ is 0.1 GeV^2 for Q^2, 0.1 GeV/c for momentum p, or 0.1 for $\cos\theta$ in all bins.

6. Results

Figure 3 shows the final differential cross sections with all uncertainties added in quadrature, with the total uncertainty ranging from 50% to 100% at high energies. Four main sources of

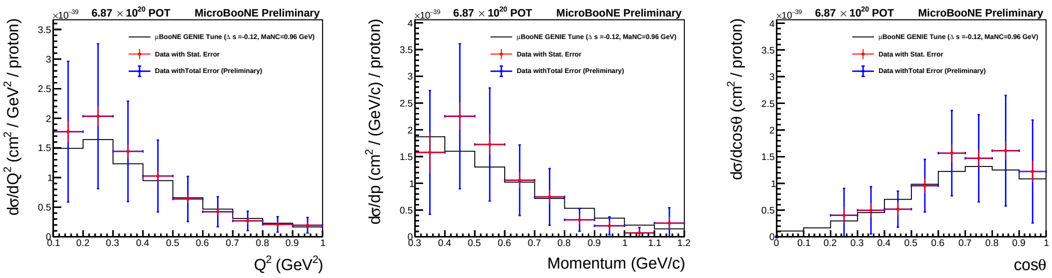

Figure 3: Final differential cross sections $d\sigma/dQ^2$ (left), $d\sigma/dp$ (middle) and $d\sigma/d\cos\theta$ (right) with both statistical and systematic uncertainties.

systematic uncertainties are considered in this measurement: neutrino beam flux predictions, neutrino interaction modeling, detector modeling and modeling of secondary hadronic interaction that happens after the primary neutrino interaction. The dominant uncertainty on the measured cross sections comes from the neutrino interaction modeling.

These are the first measured NCE differential cross sections on argon. The differential cross section $d\sigma/dQ^2$ goes as low as $Q^2 = 0.1$ GeV^2, which is significantly lower than previous measurements [1, 2] in neutrino experiments. In the near future, we will try to improve the selection purity, as well as finalize the systematic uncertainty.

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