

Study of Quasi-Elastic Scattering in the NOvA Near Detector Prototype

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Abstract. NOvA is a 14 kTon long-baseline neutrino oscillation experiment currently being installed in the NuMI off-axis neutrino beam produced at Fermilab. A 222 Ton prototype NOvA detector was built and operated in the neutrino beam for over a year to understand the response of the detector and its construction. Muon neutrino interaction data collected in this test are being analyzed to identify quasi-elastic charged-current interactions and measure the behavior of the quasi-elastic muon neutrino cross section.

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INTRODUCTION

The NOvA experiment is the next generation long-baseline experiment that will look for ν_e appearance. The experiment built a Near Detector Prototype to obtain a better understanding of the performance of the hardware and the response of detector before building the NOvA Far and Near Detectors. This Near Detector Prototype is a 222 Ton detector located on the surface at Fermilab. The detector is placed 110 mrad off-axis of the NuMI beam and collected data for more than one year in the NuMI neutrino beam with partial instrumentation.

The NOvA detector is made of plastic PVC modules; each module is made of 32 cells and those cells are filled with liquid scintillator. Each cell has a wavelength shifting fiber with a single sided readout. Both ends of the fiber are connected to one pixel on an Avalanche PhotoDiode (APD) which converts light to an electrical signal. The figures 1 (a) and (b) show the prototype detector and detector components.

The Prototype Detector collected data using two different detector configurations, configuration 1 and configuration 2. These configurations are shown in the cartoon figure 1 (c), different colors on the blocks represent the instrumentation for each configuration. In addition, figure 1 (d) shows charged current candidate events from the data.

For the study of the quasi-elastic interactions we use Monte Carlo simulations. Starting with the simulation of the production of the neutrino flux, NOvA uses FLUGG simulation (FLUGG 2009.4). The generation of neutrino interactions in the detector prototype uses GENIE event generator (GENIE 3665). GENIE uses a dipole form factor approximation with an axial-vector mass equal to $M_A = 0.99 GeV/c^2$. The final states of the neutrino interactions are propagated using GEANT4 simulations.

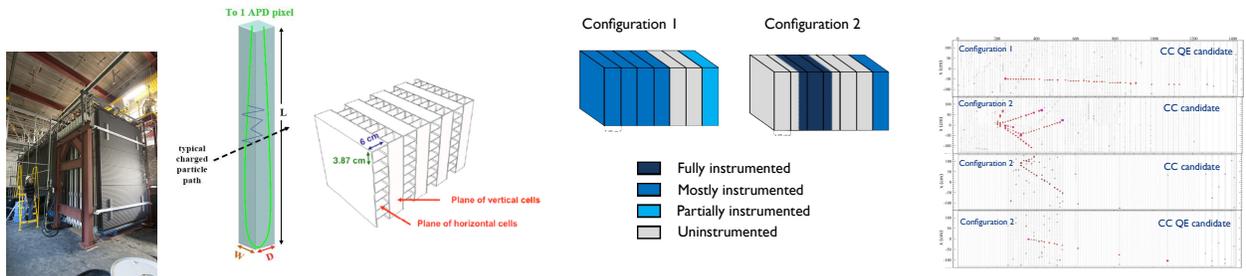


FIGURE 1. (a) shows the NOvA Detector Prototype. This detector is constructed from 6 blocks of 31 planes each plus a muon catcher. The dimensions of the detector are: 2.9 m wide, 4.2m high, and 14.3m long. (b) Detector components. (c) Cartoon shows the detector configurations. (d) Examples of the charged current and charged current quasi-elastic candidates from data.

CC QUASI-ELASTIC EVENT SELECTION

The charged current quasi-elastic (CC QE) sample is selected using two selection criteria: first we apply preselection cuts, second we use a k Nearest Neighbour classifier (kNN) for the ν_μ charged current quasi-elastic selection.

The preselection cuts are defined as follows: (i) event within 10 microsecond beam spill, (ii) interaction point 50cm from the edge of the detector, (iii) one and only one reconstructed track, (iv) the slope of the tracks is not near vertical to reject cosmic background events, (v) track does not exit the detector.

The kNN is built using three input quantities shown in figure 2; number of planes, ratio of mean energy per plane to track length and energy around the vertex. In the distributions, the Monte Carlo has been normalized to the data (area normalized). The shapes of the data and Monte Carlo distributions are generally in good agreement.

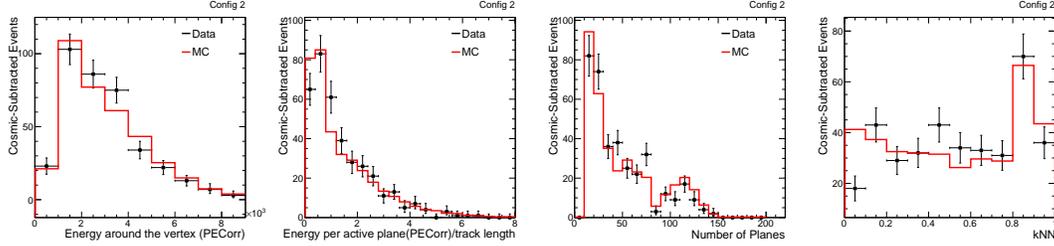


FIGURE 2. Comparison of the input variables for the beam candidates after cosmic background subtraction and Monte Carlo Simulation of preselected events. The first three plots are: (a) the energy around the vertex, (b) the ratio energy per plane to track length and (c) the number of planes. The last plot (d) shows the selector variable (kNN). All distributions are MC normalized to data number of events.

The optimized kNN cut was chosen to be $kNN > 0.3$, using the criterion of having the maximum figure of merit ($Signal / \sqrt{Signal + Background}$). The kNN selector is shown in figure 2 (d). This selection produces a signal efficiency of 85% and a purity of about 60%.

RECONSTRUCTED NEUTRINO ENERGY AND FOUR MOMENTUM TRANSFER

The neutrino energy is reconstructed using the kinematics of the event, the scattering angle and momentum measurement. The momentum is obtained using the range of the tracks. Estimation of neutrino energy and four momentum transfer is obtained using

$$E_\nu = \frac{2(M')E_\mu - ((M')^2 + m_\mu^2 - M_p^2)}{2[(M') - E_\mu + \sqrt{E_\mu^2 - m_\mu^2} \cos \theta_\mu]}, \quad Q^2 = -m_\mu^2 + 2E_\nu(E_\mu - \sqrt{E_\mu^2 - m_\mu^2} \cos \theta_\mu), \quad (1)$$

where $E_\mu = T_\mu + m_\mu$ is the total muon energy, M_p is the proton mass, m_μ is the muon mass, and M' is the adjusted neutron mass: $M' = M_n - E_B$, where E_B is the binding energy ($E_B = 25MeV$). Figure 3 shows neutrino energy and the four momentum transfer for the ν_μ CC QE selected events after cosmic background subtraction and the Monte Carlo simulation for each detector configuration. Plots on the left correspond to configuration 1 and plots on the right to configuration 2. In the distributions, MC has been normalized to the data (area normalized).

BACKGROUND STUDY

A sample dominated by background interactions is used to cross check the Monte Carlo modeling. For this sample we require two reconstructed tracks in both views, where a track is made with a minimum of 4 hits in each view.

The reconstructed energy and four momentum transfer is obtained using the longest track of the event as the muon candidate in equation 1. The left distribution in figure 4 shows the four momentum transfer distribution for the background events using the Monte Carlo predictions. The largest contribution is from resonance interactions and the right distribution shows the comparison of the four momentum transfer for two track selected events after cosmic background subtraction and Monte Carlo simulation. This distribution shows data agreement with the Monte Carlo simulation for the background events.

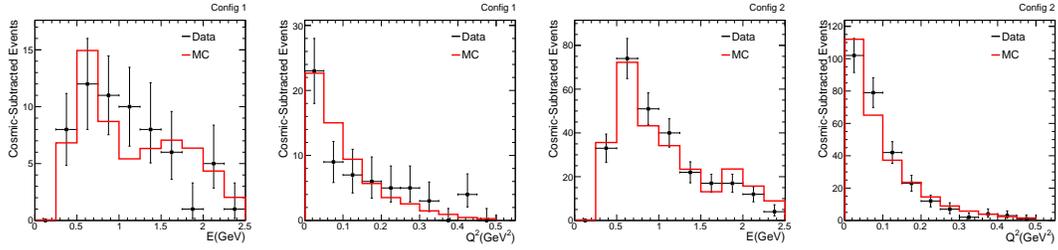


FIGURE 3. Neutrino Energy and four momentum transfer for ν_μ CC QE selected events after cosmic background subtraction for both configurations. Left distributions correspond to configuration 1 and right to configuration 2. MC has been normalized to Data.

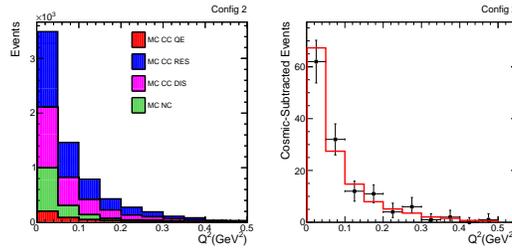


FIGURE 4. Four momentum transfer for events with 2 reconstructed tracks. The left plots shows the Monte Carlo prediction and the right distribution shows data and Monte Carlo simulation comparison. MC has been normalized to Data.

FOUR MOMENTUM TRANSFER AND BACKGROUND PREDICTION

Figure 5 shows the Monte Carlo prediction for the selected ν_μ CC QE selected events for the detector prototype of the four momentum transfer variable for both configurations. The biggest contribution from background is from the resonance interactions which have a single visible muon. In addition, we show the ν_μ CC QE selected events after cosmic background subtraction, the total Monte Carlo prediction and the background prediction.

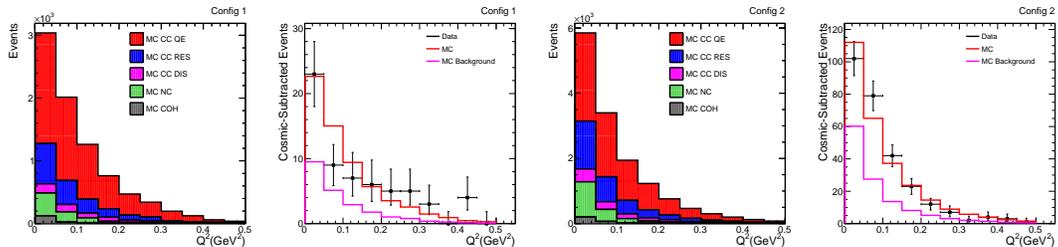


FIGURE 5. Monte Carlo predictions and data after the ν_μ CC QE selection for both detector configurations, left distributions shows the event rates as function of Q^2 for configuration 1 and right distributions correspond to configuration 2. MC has been normalized to Data.

SUMMARY

Using the data collected in the Near Detector Prototype a sample of selected ν_μ CC QE events and background is studied. The comparisons of data and Monte Carlo show good shape agreement. We continue to study neutrino data from the Near Detector Prototype to test analysis procedures for NOvA.

NOvA will begin taking data with a partially constructed Far Detector starting in spring 2013. The detector construction will be completed in early 2014.