

Neutrino Nucleon Elastic Scattering in MiniBooNE

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Abstract. Neutrino nucleon elastic scattering $\nu N \rightarrow \nu N$ is a fundamental process of the weak interaction, and can be used to study the structure of the nucleon. This is the third largest scattering process in MiniBooNE comprising $\sim 15\%$ of all neutrino interactions. Analysis of this sample has yielded a neutral current elastic differential cross section as a function of Q^2 that agrees within errors to model predictions.

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Event Selection

Neutral current elastic (NCE) interactions $\nu N \rightarrow \nu N$ can be used to probe the isoscalar structure of the nucleon including contributions from strange quarks [1]. In addition, the Q^2 evolution of the cross section provides information on the nucleon axial mass M_A . These interactions are visible in MiniBooNE [2] mainly via scintillation light produced by protons below Cherenkov threshold and can be isolated with the judicious selections outlined in table 1.

TABLE 1. Neutral current elastic sample selection.

Selection	Purpose	Effectiveness
Veto PMT Hits < 6 1 Subevent 4400 $<$ Time (ns) $<$ 6500 Tank PMT Hits $<$ 150	remove cosmic rays no decaying particles events in beam time low energies	For these first four cuts: Of Monte Carlo simulated neutrino events generated within the detector, these first four cuts isolate a sample that is 80% pure NCE.
Prompt Hits Fraction $<$ 0.55 Reconstructed R $<$ 400 cm	assures protons reduces dirt bkgds	beam unrelated backgrounds from 30% \rightarrow 2%. dirt backgrounds from 25% \rightarrow $(16 \pm 4)\%$ of data.

The PMT multiplicity (hits) distribution of NCE events peaks at low value. Thus according to the Monte Carlo the cut at 150 which was chosen to preserve blindness for the oscillation analysis keeps $\sim 90\%$ of NCE interactions passing the first three cuts.

The “Prompt Hits Fraction” selection provides particle ID for this sample. Scintillation light emitted by low energy protons is delayed with respect to the neutrino interaction time whereas Cherenkov light is prompt. By considering the fraction of prompt hits in an event, MiniBooNE successfully separates low energy nucleons from Cherenkov particles (figure 1(a)). The power of this selection can be quantified by the reduction in

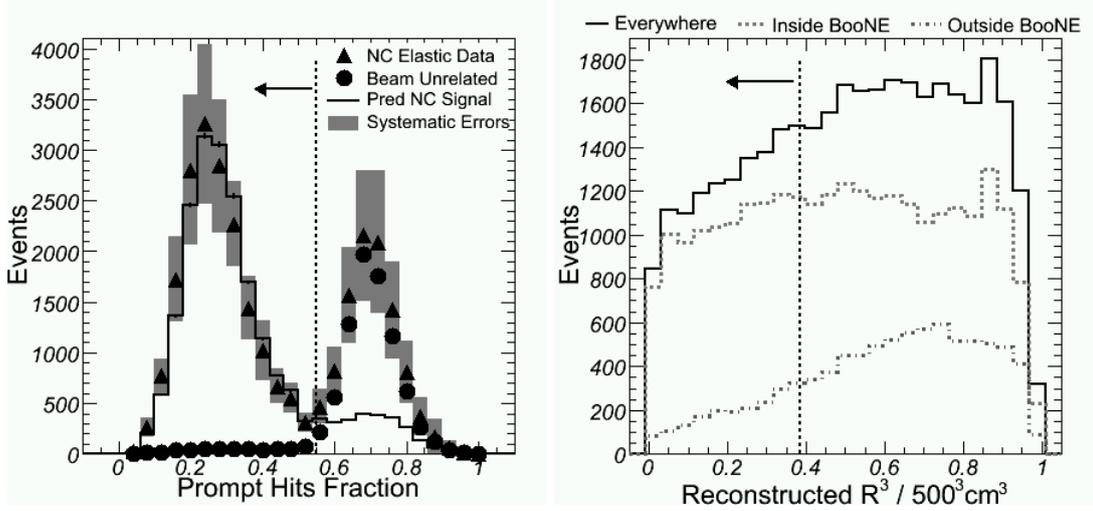


FIGURE 1. Plot (a): PID selection variable. The first four cuts of table 1 have been applied. The dashed line indicates the cut value with protons to the left. Beam unrelated backgrounds are added to the Monte Carlo producing its bump to the right of the cut line. Plot (b): Fiducial volume selection (a Monte Carlo plot, PID selection has been applied). The plot shows reconstructed R^3 for events generated in the different volumes indicated by the plot.

beam unrelated backgrounds (mainly electrons from muon decay) from 30% \rightarrow 2% in the sample.

Finally, neutrino events generated in material surrounding the detector (called “dirt” here) can produce particles (e.g. neutrons) that enter the detector and produce light via secondary interactions. Template fits to the data confirm a 25% Monte Carlo predicted dirt background to NCE events that is reduced to $(16 \pm 4)\%$ with the 400 cm fiducial volume cut (figure 1(b)).

After all these selections, the Monte Carlo predicts that the composition of neutrino events interacting in the detector is 84% NCE, 14% NC- 1π , 1% multi- π , and 1% charged-current quasi-elastic (CCQE) [3]. The majority (80%) of the NC- 1π survive these cuts because they have no pion in the final state (the pion is absorbed by the nucleus) and are therefore indistinguishable from NCE interactions. Such events are an irreducible background.

Reconstructed Kinetic Energy

The goal of this analysis is to measure the differential NCE cross section as a function of the momentum transfer Q^2 for which only one previous measurement exists [4]. For elastic interactions, $Q^2 = 2m_N T_N$, where m_N is the nucleon rest mass and T_N is the final nucleon kinetic energy. Thus to determine Q^2 the kinetic energy measurement must be calibrated.

In this analysis, kinetic energy is calibrated using the total radiation flux (the combination of measured scintillation and Cherenkov light). The flux is fit against the Monte Carlo generated nucleon kinetic energy to determine the reconstructed T_N . Figure 2(a)

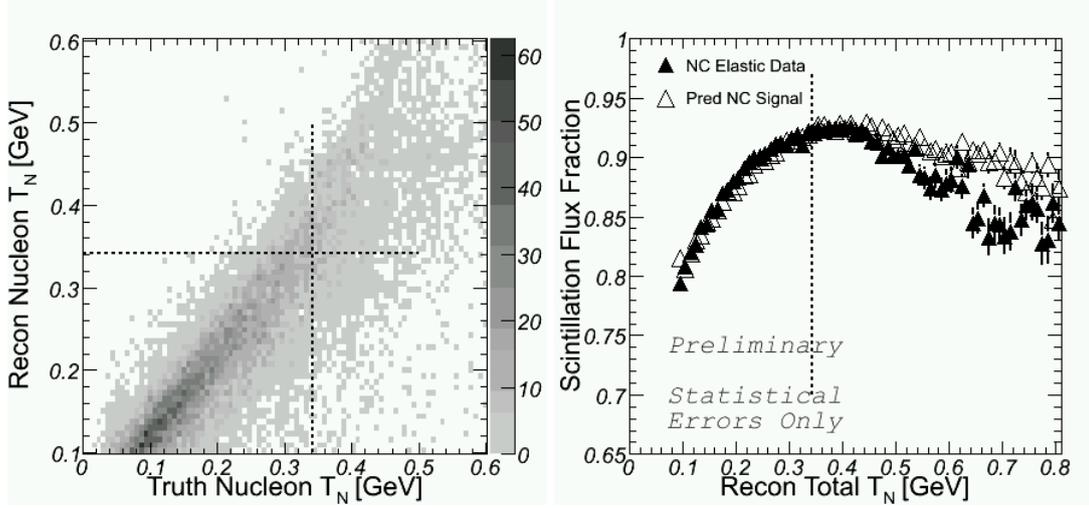


FIGURE 2. Plot (a): Calibrated reconstructed nucleon T_N vs Monte Carlo generated true T_N . The dashed lines indicate Cherenkov threshold (342 MeV). The majority of events are contained within the dark diagonal band in the center. Plot (b): Scintillation light fraction as a function of reconstructed T_N comparing data and Monte Carlo. The shape of the plots agree indicating no need to adjust calibrated T_N scale for data.

shows how well this calibration works for Monte Carlo events.

This calibration is then tested on the data by comparing the predicted Monte Carlo Cherenkov threshold with the observed data threshold using the fraction of scintillation flux across energy. Naively, the scintillation fraction should be exactly 1.0 until threshold and then decrease. However, de-excitation photons, other prompt light, and reconstruction effects give the distribution in figure 2(b). Yet since the shape is the same for both data and Monte Carlo within errors, there is no need to adjust the energy scale. This calibration will be assigned a systematic error in the final analysis.

Once calibrated, the energy evolution of the data and backgrounds are examined. Figure 3(a) shows the data with beam unrelated background as well as the predicted dirt backgrounds. Here data and backgrounds peak at low energies. However, in figure 3(b), the predicted neutrino backgrounds (shown with partial systematic errors) peak at higher energies, consistent with the prediction that they are mainly NC- 1π interactions.

Figure 4(a) shows the data overlaid by absolutely normalized Monte Carlo where the dirt and neutrino backgrounds have been included in both distributions. The data and Monte Carlo agree within the partial systematic errors shown.

Unfolding the Differential Cross Section

There is enough information in the results of figure 4(a) to extract certain physics (such as M_A) via data–Monte Carlo comparisons. However to report model and detector independent observables the information must be converted to a differential cross section. The standard method for conversion is to multiply the reconstructed data (from figure 4(a)) by the inverse of the efficiency matrix (a more coarsely binned version of

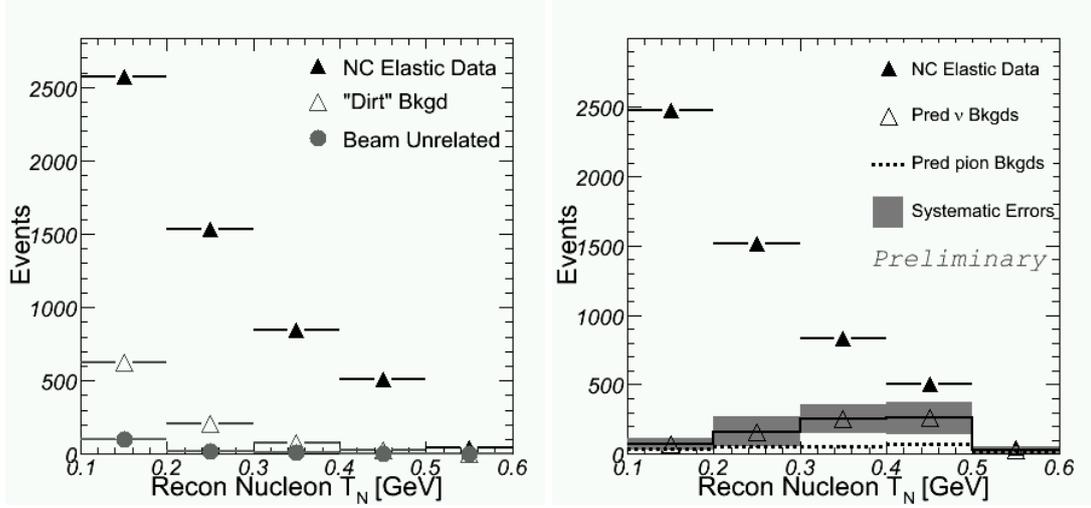


FIGURE 3. Plot (a): T_N evolution of NCE data as well as dirt and beam unrelated backgrounds. All distributions decrease with energy. Plot (b): T_N evolution of data (beam unrelated backgrounds subtracted) and predicted neutrino backgrounds. The dotted line shows the portion of these backgrounds that are not irreducible. Neutrino backgrounds increase with energy.

figure 2(a)) to remove detector effects. Unfortunately, there is considerable smearing in the NCE efficiency matrix which results in an unstable inversion.

A variety of techniques exist to deal with unstable efficiency matrices. The technique used here is to unfold the data using a correction factor \vec{C}

$$\vec{T}_{physics}^{data} = \vec{C} \cdot \vec{T}_{reconstructed}^{data} \cdot$$

where \vec{C} is determined from the Monte Carlo [5]

$$\vec{C} = \vec{T}_{predicted}^{MC} / \vec{T}_{reconstructed}^{MC} \cdot$$

The elements of the denominator can be calculated from the efficiency matrix ϵ_{ij}

$$T_{i reconstructed}^{MC} = \sum_j T_{j predicted}^{MC} \epsilon_{ij} \cdot$$

The inverse of the correction factor acts like a generalized efficiency $\vec{\epsilon}'$. So the unfolded kinetic energy distribution can be written

$$\vec{T}_{physics}^{data} = \vec{T}_{reconstructed}^{data} / \vec{\epsilon}' \cdot$$

Unfolding with this method incurs a bias if the Monte Carlo energy shape differs from the data energy shape

$$bias_i = \left(\frac{T_{i pred}^{MC}}{T_{i recon}^{MC}} - \frac{T_{i physics}^{data}}{T_{i recon}^{data}} \right) T_{i recon}^{data} \cdot$$

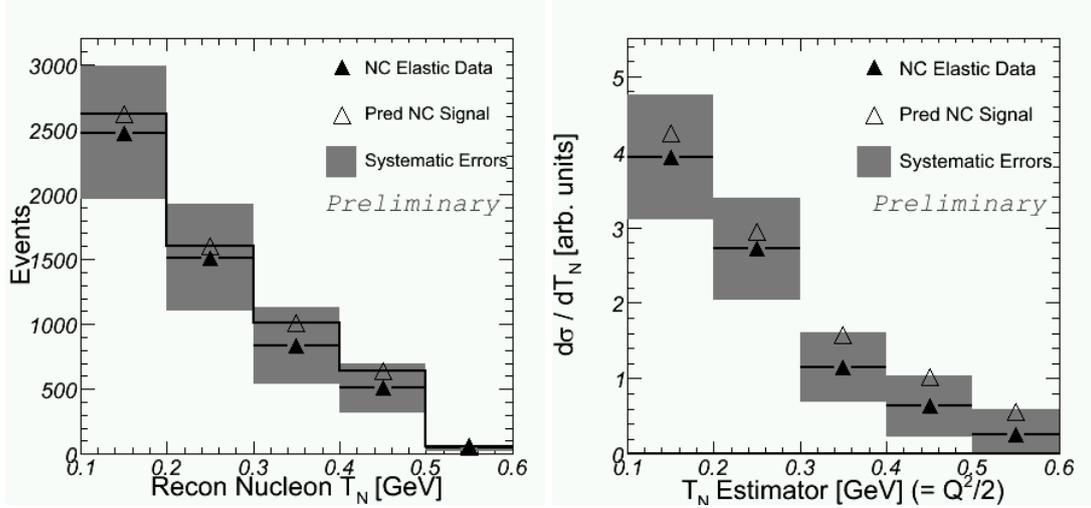


FIGURE 4. Plot (a): T_N evolution of the NCE data (beam unrelated backgrounds subtracted) and Monte Carlo predicted NCE signal (with dirt and neutrino backgrounds included). Partial systematic errors are included on the data. Plot (b): Differential cross sections for NCE data and the predicted Monte Carlo NCE signal. Partial systematic errors have been applied to the data. Data and prediction agree within errors.

The bias can be reduced by correcting the Monte Carlo to have a more data-like distribution (which amounts to a single iteration of the correction factor procedure). Tests on fake data samples indicate that this bias is not large.

The results of unfolding the data with this method and converting to a differential cross section are shown in figure 4(b). Here the data with partial systematic errors are compared with the absolutely normalized Monte Carlo prediction and found to agree. These results are preliminary and do not include all systematic errors. Future publications will include fits to the final cross section to extract M_A .

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