Neutrino cross section measurements at MiniBooNE

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MiniBooNE (Booster Neutrino Experiment) is accumulating a large sample of $\mathcal{O}(1\,\mathrm{GeV})$ ν_μ interactions in the neutrino beam produced by the 8 GeV Booster synchrotron at Fermilab. Analyses of ν_μ charged current quasi-elastic scattering and neutral current π^0 production, as well as neutral current elastic scattering and charged current π^+ production are in progress.

1. Introduction

1.1. The MiniBooNE Detector

The MiniBooNE detector at Fermilab is a 800 ton sphere of mineral oil instrumented with 1520 photomultiplier tubes (PMTs). Neutrino interactions are detected by the Cherenkov radiation and scintillation produced by charged particles traversing the mineral oil. The detector is divided into two concentric regions at 550 cm radius by an optical barrier: an outer veto region and an inner "tank" region instrumented by 240 and 1280 PMTs, respectively.

The neutrino beam is produced by protons from the 8 GeV Booster synchrotron at FNAL. The beam is dominated by ν_μ and has average energy $\sim 800\,\mathrm{MeV}$. More details are provided in Reference [1]. Over two years of running, over 3×10^{20} protons on target and four hundred thousand neutrino interactions in the detector have been accumulated, providing a valuable sample to study $\mathcal{O}(1\,\mathrm{GeV})$ neutrino physics.

Neutrino interactions are identified by PMT hits that occur within the expected 1.6 μsec time window of the beam spill. Hits in the veto PMTs are used to eliminate cosmic rays, while tank PMT hits are analyzed to identify Cherenkov rings and scintillation produced in the event. Electrons produced by the decays of stopped muons following the primary interactions are used to identify the production of charged pions and muons.

Process	Fraction of Events
ν_μ CC Quasi-Elastic	0.40
ν_μ NC Elastic	0.15
ν_μ CC Resonant π	0.25
ν_μ NC Resonant π	0.10

Table 1
The dominant neutrino interaction processes and their expected contribution in the MiniBooNE neutrino beam.

1.2. Neutrino Interactions at $\mathcal{O}(1\,\mathrm{GeV})$:

The dominant neutrino interaction processes in the MiniBooNE neutrino beam are charged-current quasi-elastic scattering (CCQE), neutral current elastic scattering (NCEL), and charged and neutral current resonant single pion production (CCRE/NCRE). The expected fraction of each type of interaction in the MiniBooNE detector is shown in Table 1. Contributions from coherent pion production and deep inelastic scattering comprise most of the remainder. A survey of neutrino cross section measurements at $\mathcal{O}(1\,\mathrm{GeV})$ shows that most of the measurements have large uncertainties resulting from low statistics, systematic corrections translating data from nuclear targets to free nucleon cross sections, or inconsistent results from different experiments [2]. Even for the CCQE process, where measurements with larger statistics and deuterium targets are available, uncertainties are $\sim 20\%$.

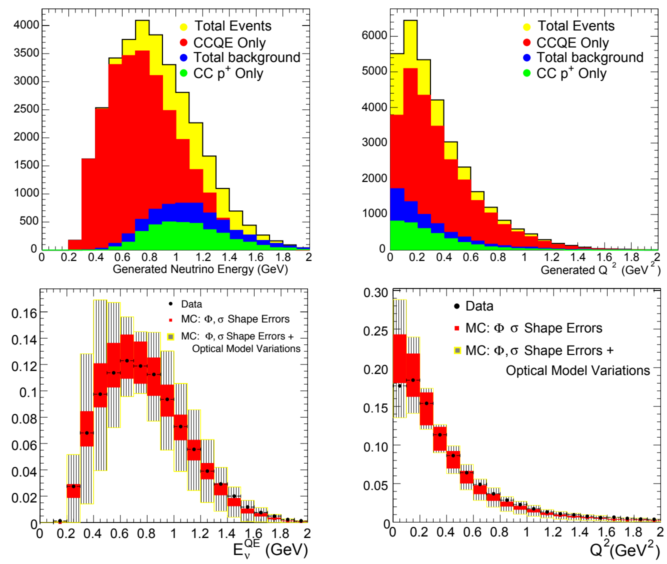

Figure 1. Top: Reconstructed E_ν and Q^2 distribution for CCQE events selected in MiniBooNE data. Bottom: Corresponding generated quantities and event composition for Monte Carlo events satisfying the CCQE selection.

Cross section measurements in this energy region are interesting for three reasons. First, the next generation of long baseline experiments (NuMI, T2K) will be performed in this energy range; cross sections are necessary to accurately predict signal and background rates. Second, interesting effects from nuclear physics, related to such phenomenon as Fermi motion, Pauli exclusion and shadowing in the nucleus, are expected in this energy range. The availability of new data in this energy region from MiniBooNE and K2K has prompted renewed interest in theoretical models and predictions for these effects [3]. Third, this energy region is where the interference from vector and axial amplitudes, which has opposite signs for ν and $\overline{\nu}$, is maximum.

2. Neutrino Data

2.1. ν_μ CCQE Events

A selection for ν_μ CCQE events utilizing the ring and time information of PMT hits has been developed, yielding a sample of twenty thousand events with $\sim 80\%$ purity. The event reconstruction determines the momentum of the muon. Assuming a two-body interaction, the incident neutrino energy and Q^2 in the interaction can be determined after correcting for the average binding energy and Fermi momentum of the struck nucleon. The generated distribution for these quantities in a Monte Carlo simulation using the NUANCE event generator [4] are shown in the top two plots of Figure 1, with the contribution of the signal process and dominant background from CC π^+ production also shown. The corresponding distributions from the data are shown in the bottom two plots.

2.2. ν_μ NC π^0 production

The rate of neutral current π^0 production is of particular interest for neutrino oscillation searches involving ν_e appearance, since they often constitute a significant background to the signal process. In MiniBooNE, NC π^0 candidates are selected with the requirement that there are no decay electrons identified in the event. This suppresses the dominant charged current processes, where the primary muon is expected to produce

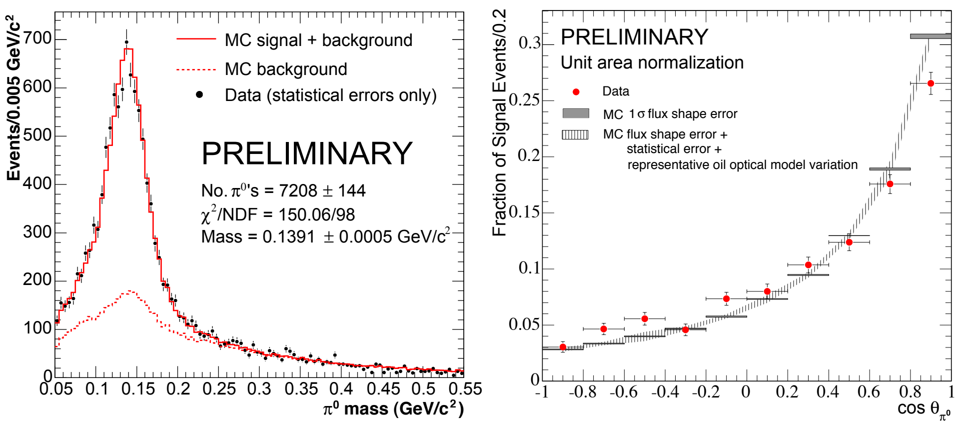

Figure 2. Reconstructed invariant mass (left) and polar angle distribution (right) for π^0 candidates.

a decay electron. A two-ring reconstruction algorithm determines the momentum of each of the rings, allowing the kinematics (momentum and invariant mass) of the two rings to be determined.

Of these kinematic quantities, the angle θ between the π^0 momentum and incident neutrino is of particular interest, as the two dominant processes, resonant and coherent production, have different distributions in this quantity. In particular, the coherent process has a sharp forward-peaked distribution, whereas the resonant contribution has a more isotropic distribution. The reconstructed invariant mass and $\cos\theta$ distributions for the selected events are shown in Figure 2, along with the expectations from Monte Carlo simulations.

3. Future Prospects:

MiniBooNE continues to accumulate neutrino events at a rapid rate. In addition to the studies presented here, analyses of neutral current elastic scattering and charged current π^+ production are also in progress. MiniBooNE is investigating the anti-neutrino cross section measurements that can be made if the polarity of the horn is reversed. The status of anti-neutrino cross sections in this energy range is even worse than it is for neutrinos. MiniBooNE may be able to make a substantial contribution in measuring these cross sections, thereby providing valuable input for future searches for CP-violation in neutrino oscillations.

4. Acknowledgments

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