Prospects for Antineutrino Running at MiniBooNE

M.O. Wascko[a], for the MiniBooNE Collaboration

[a]Department of Physics and Astronomy, Louisiana State University,
Baton Rouge, LA 70803-4001, U.S.A.

We outline a program of antineutrino cross-section measurements necessary for the next generation of neutrino oscillation experiments, that can be performed with one year of data at MiniBooNE. We describe three independent methods of constraining wrong-sign (neutrino) backgrounds in an antineutrino beam, and their application to the MiniBooNE antineutrino cross section measurements.

1. Introduction

Future off-axis neutrino experiments will attempt to measure CP violation by comparing oscillation probabilities for $\nu_\mu \to \nu_e$ versus $\bar{\nu}_\mu \to \bar{\nu}_e$. To accomplish this, one needs control of the ratio of $\nu/\bar{\nu}$ cross sections to a better precision than the size of the expected oscillation asymmetry.

While published low energy neutrino cross section data are hardly copious [1], measurements of low energy antineutrino cross sections are even *more* scarce. Additional antineutrino data on nuclear targets are clearly needed so that interaction spectra and background rates for antineutrino oscillation experiments can be estimated with confidence.

Table 1 lists the expected antineutrino event statistics for one year of antineutrino running (2×10^{20} POT) at MiniBooNE [3]. Rates are listed for both right-sign (antineutrino) and wrong-sign (neutrino) interactions. Note that wrong-sign represent about 30% of the total events. To address the wrong-sign backgrounds, we have developed three independent methods of constraining the neutrino content of the anti-neutrino beam. We describe these methods below, and also describe their application to antineutrino cross section measurements at MiniBooNE.

2. Constraining Wrong Sign Events

For charged current (CC) interactions, neutrino events are typically distinguished from antineutrino events by identifying the charge of the outgoing muon. Without a magnetic field to provide such event-by-event identification, we have developed several novel techniques for measuring wrong-sign backgrounds in antineutrino mode data, allowing more precise antineutrino cross section measurements. The wrong-sign content is constrained by three measurements: muon angular distributions in quasi-elastic (CC QE) events, muon lifetimes, and the measured rate of CC single π^+ events.

2.1. Muon Angular Distributions

The most powerful wrong-sign constraint comes from the observed direction of outgoing muons in CC QE interactions. Neutrino and antineutrino events exhibit distinct muon angular distributions. Due to the antineutrino helicity and the V-A nature of the weak charged current operator, the final state muons in antineutrino QE interactions predominantly follow the initial neutrino direction — they are more forward peaked than muons from neutrino interactions.

MiniBooNE's angular resolution allows one to exploit this difference and fit the angular distributions to extract the wrong-sign contribution. Analysis of Monte Carlo data sets determined the accuracy with which the wrong-sign content can be measured using this technique to be 5% of itself. Including systematic uncertainties and (non-QE) backgrounds increases the uncertainty only to 7%. We have also studied fits to Q^2 distributions and achieved similar results.

Reaction	$\bar{\nu}_\mu$ (RS)	ν_μ (WS)
CC QE	32,476	11,234
NC elastic	13,329	4,653
CC resonant $1\pi^-$	7,413	0
CC resonant $1\pi^+$	0	6,998
CC resonant $1\pi^0$	2,329	1,380
NC resonant $1\pi^0$	3,781	1,758
NC resonant $1\pi^+$	1,414	654
NC resonant $1\pi^-$	1,012	520
NC coherent $1\pi^0$	2,718	438
CC coherent $1\pi^-$	4,487	0
CC coherent $1\pi^+$	0	748
other (multi-π, DIS)	2,589	2,156
total	71,547	30,539

Table 1
Event rates expected in MiniBooNE $\bar{\nu}$ running with 2×10^{20} POT assuming a 550 cm fiducial volume, before cuts. Listed are the expected right-sign (RS) and wrong-sign (WS) events for each reaction channel. These event estimates do not include the effects of final state interactions in carbon which can alter the composition of the observed final state, and do not include effects from reconstruction.

2.2. Muon Lifetimes

A second constraint results from measuring the rate at which muons decay in the MiniBooNE detector. Due to an 8% μ^- capture probability in mineral oil, positively and negatively charged muons exhibit different effective lifetimes ($\tau \sim 2.026\,\mu s$ for μ^- [4] and $\tau \sim 2.197\,\mu s$ for μ^+ [5]). Solely using this difference, we find that the wrong-sign contribution can be extracted with a 30% statistical uncertainty based solely on this lifetime difference and negligible systematic uncertainties. While not as precise as fits to the muon angular distributions, this particular constraint is unique, as it is independent of kinematics.

2.3. CC Single Pion Event Sample

A third measure makes use of the fact that CC single pion (CC$1\pi^+$) events in antineutrino mode almost exclusively result from neutrino interactions in the detector (Table 1). MiniBooNE cleanly identifies CC$1\pi^+$ events by tagging the two decay electrons that follow the primary neutrino interaction, one each from the μ^- and π^+ decay chains [6]. CC$1\pi^-$ events are largely rejected by this requirement because most of the π^-'s come to rest and are captured by carbon nuclei, resulting in no decay electrons. Starting from a sample that is 70% *right-sign* antineutrino interactions, this simple two decay electron requirement yields an 85% pure sample of *wrong-sign* neutrino events.

Assigning very conservative uncertainties to the antineutrino background events and the CC$1\pi^+$ cross section, which will be well-measured by the MiniBooNE neutrino data, yields a 15% uncertainty on the wrong-sign content in the beam given 2×10^{20} POT. This measurement is complementary to the muon angular distribution determination because CC$1\pi^+$ events predominantly result from resonance decays, and therefore constrain the wrong-sign content at larger neutrino energies.

Measurement	WS uncertainty	resultant error on $\sigma_{\bar{\nu}}$
CC QE $\cos\theta_\mu$	7%	2%
CC $1\pi^+$ cuts	15%	5%
muon lifetimes	30%	9%

Table 2
Wrong-sign extraction uncertainties as obtained from various independent sources in the $\bar{\nu}$ data. The resultant systematic uncertainty on $\bar{\nu}$ cross section measurements is obtained by assuming that wrong-signs comprise 30% *of the total events.*

2.4. Summary of Wrong Sign Constraints

We have described three separate techniques to measure the wrong-sign content in the antineutrino data. This will both lend confidence to the antineutrino cross section measurements and greatly reduce their associated systematics. Combined, these three independent measurements (each of which have different systematics) offer a very powerful constraint on the neutrino backgrounds in antineutrino mode (Table 2).

3. CC Quasi-Elastic Scattering

MiniBooNE expects approximately 40,000 QE interactions in antineutrino mode with 2×10^{20} POT before cuts (to be compared to 766 events from the next most sensitive measurement). Applying the same QE event selection criteria as in the MiniBooNE neutrino analysis [7] yields a sample of $\sim 19,000$ events, 75% of which are pure QE interactions ($\nu_\mu + \bar{\nu}_\mu$ QE).

Assuming the wrong-sign constraint from Section 2 along with conservative errors on the incoming neutrino flux, the background contributions, and event detection together imply that MiniBooNE can measure the antineutrino QE cross section to better than 20% with 2×10^{20} POT.

4. NC Single Pion Production

To date, there is only one published measurement of the absolute rate of antineutrino NC π^0 production, the single largest background to future $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation searches; this measurement was reported with 25% uncertainty at 2 GeV [8].

Using the same cuts as in neutrino mode with no further optimization results in a clean sample of antineutrino NC π^0 events with a similar event purity and efficiency [9]. After this selection, we expect 1,650 $\bar{\nu}_\mu$ resonant NC π^0 events and 1,640 $\bar{\nu}_\mu$ coherent NC π^0 events assuming an exposure of 2×10^{20} POT [3,10]. The relative contribution of $\sim$ 1000 WS events will be well predicted given the constraints on the wrong-sign content in the beam as described in Section 2 and the measurement of the ν_μ NC π^0 cross section from MiniBooNE neutrino data.

5. CC Single Pion(CC1π^-) Production

At MiniBooNE, roughly 7,000 resonant CC $1\pi^-$ are expected with 2×10^{20} POT before cuts. Although most of the emitted π^-'s will be captured by carbon nuclei, and will therefore not be selected by the CC1π^+ events selection cuts, such events still produce a signature: two Cherenkov rings (one each from the μ^+ and π^-) and one Michel electron from the muon decay. While promising, the selection efficiency and purity of such events is unknown at this time. Further investigation is currently underway.

6. Conclusions

We have developed three techniques for determining the wrong-sign background in antineutrino mode. The resulting systematic on any antineutrino cross section measurement is at the 2% level, which is remarkable for a detector which does not possess event-by-event sign selection. Given this redundant approach, the wrong-sign contamination should not be considered prohibitive to producing meaningful antineutrino cross section and oscillation measurements at MiniBooNE. These techniques may also be useful for other experiments without magnetized detectors which have plans to study antineutrino interactions (*e.g.* T2K, NOνA, Super-K).

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REFERENCES

1. G. P. Zeller, NuInt02, *hep-ex/0312061.*
2. I. Stancu, these proceedings.
3. D. Casper, Nucl. Phys. Proc. Suppl. **112**, 161 (2002), *hep-ph/0208030.*
4. T.Suzuki *et al.*, Phys. Rev. **C35**, 2122 (1987).
5. S.Eidelman *et al.*, Phys. Lett. **B592**, 33 (2004).
6. M. O. Wascko, DPF04, *hep-ex/0412008.*
7. J. Monroe, Moriond 2004, *hep-ex/0406048.*
8. H.Faissner,*et al.*, Phys. Lett. **126B**, 230 (1983).
9. J. L. Raaf, NuInt04, *hep-ex/0408015.*
10. D. Rein and L. M. Sehgal, Nucl. Phys. **B223**, 29 (1983).