MiniBooNE: The Booster Neutrino Experiment at Fermilab.

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The MiniBooNE experiment at Fermilab is designed to confirm or rule out the LSND observation by looking for $\nu_\mu \to \nu_e$ oscillations. Muon neutrinos are produced by 8 GeV protons from the Fermilab Booster. Neutrino data taking with is currently underway. We describe the experiment and our expected sensitivity to a neutrino oscillation signal.

1. Introduction

The phenomenon of neutrino oscillations, under investigation for the last three decades, seems fairly recently to have been promoted from tantalizing speculation to scientific fact. This is mainly due to the recent confirmation of the solar neutrino deficit by the SNO experiment, and their observation that the flux of neutrinos of all flavors agrees well with the standard solar model prediction [2]. The results from atmospheric neutrinos as reported by Super-Kamiokande [3] and other experiments [4] indicate another type of neutrino oscillations. A third type of oscillation is indicated by evidence from the LSND experiment [5,6] but is yet to be confirmed. If the results from all of these experiments withstand further scrutiny, then not only do neutrinos oscillate, but the standard model scenario of three neutrinos will require modification.

The MiniBooNE experiment [7] will run over the next several years and will provide a definitive test of the LSND evidence for neutrino oscillations. If the LSND oscillation signal is verified and the solar and atmospheric results remain, the standard model will need to allow a fourth neutrino or some other non-standard process to explain these results. This would have far-reaching consequences in many fields, from particle physics to cosmology.

2. The MiniBooNE experiment

The MiniBooNE experiment will make a definitive test of the the LSND results. First, a ν_e appearance search for the process $\nu_\mu \to \nu_e$ will be conducted by running the beam in ν_μ mode. Then, a $\bar{\nu}_e$ appearance search for $\bar{\nu}_\mu \to \bar{\nu}_e$ will be conducted using a $\bar{\nu}_\mu$ beam. A schematic overview of MiniBooNE is shown in Figure 1.

2.1. The MiniBooNE ν Beam

The MiniBooNE neutrino source uses 8 GeV protons from the Fermilab Booster accelerator to create neutrinos. A fraction of the proton spills from the Booster are diverted into a new 8 GeV line that was built for MiniBooNE. These protons are incident on a 70 cm long beryllium target, which is embedded in the magnetic horn focusing system. The protons on the Be target create charged pions which are focused downstream into a 50 meter long region where they decay ($\pi \to \mu\nu$), producing a beam of neutrinos directed toward the MiniBooNE detector.

The goal for the intensity of the proton beam delivered to the MiniBooNE target is 5×10^{12} protons per spill at a rate of 5 Hz. The spills are 1.6 μs in duration; this allows for a very low cosmic-ray background in the detector. A 140 μs, 170 kA current pulse is delivered to the horn in time with the proton spills. This current pulse may be of either sign, to focus π^+ or to focus π^-, allowing a choice of a ν_μ or $\bar{\nu}_\mu$ beam, respectively. In either configuration, the contamination of ν_e or $\bar{\nu}_e$ neutrinos is low. The calculated energy distribution of the neutrino flux for ν_μ and ν_e is shown in Figure 2. The Booster accelerator will operate for approximately two-thirds of the year, which will result in approximately 5×10^{20} protons on the MiniBooNE neutrino target per calendar year.

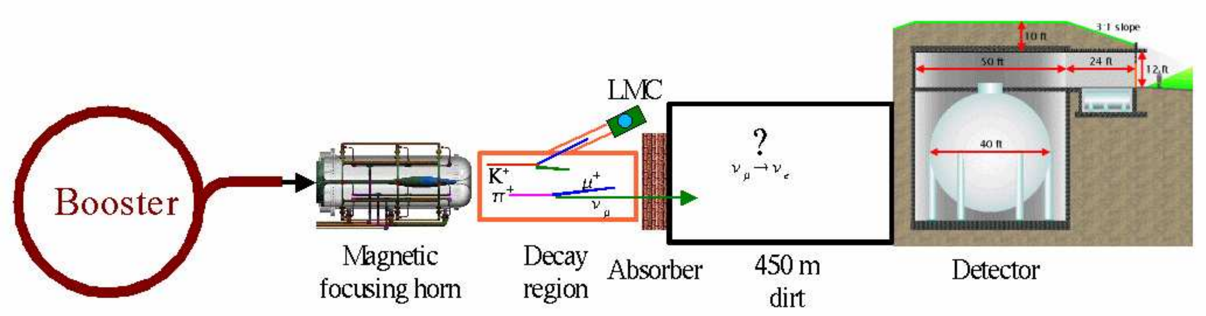

Figure 1. A schematic (not to scale) overview of the MiniBooNE experiment including the booster accelerator, focusing horn, decay region, neutrino flight path, and MiniBooNE detector.

The neutrino flux at the detector will be determined using a variety of methods. Detailed simulations of the neutrino production process have been performed and are ongoing. These simulations are tuned using existing hadron production data, and will use data from the HARP experiment [8] at CERN, which ran with the MiniBooNE Be target. A measurement of the ν_μ charged-current rate in the detector will check the ν_μ flux, and determine the energy distribution of the muons in the decay region, which contribute to the ν_e background via $\mu^+ \to e^+\nu_e\bar{\nu}_\mu$. The ν_e background from $K^+ \to \pi^0 e^+\nu_e$ decays will be determined by measuring the high-transverse-momentum muons from $K^+ \to \mu^+\nu_\mu$ decays with the LMC spectrometer installed in the decay region (shown schematically in Fig. 1). An additional systematic check of an oscillation signal may be made by lowering an intermediate absorber (not shown), installed at the 25 meter position, into the decay region. This will change the signal to background ratio in a known way due to the different decay lengths of the pions and muons.

2.2. The MiniBooNE Detector

The MiniBooNE detector is located on the Fermilab site approximately 500 meters from the neutrino source. It consists of a spherical tank of radius 6.1 m, lined with 1280 8-inch photomultiplier tubes (PMTs) supported on an inner structure of 5.75 m radius (Figure 3). These PMTs point inward and provide 10% photocathode coverage of the inner region of the detector. The PMT support structure also provides an optical barrier to create an outer veto region, which is viewed by 240 8-inch PMTs. The tank is filled with 800 tons of mineral oil, which will provide an inner fiducial region of approximately 500 tons. The detector tank is housed in a cylindrical vault (Figure 1).

The MiniBooNE mineral oil (Exxon/Mobil Marcol 7) was selected with high attenuation length the primary criterion. The attenuation length of this oil was measured to be approximately 26 meters at 450 nm. The calibration data collected so far indicate that the long attenuation length of the oil persists in the MiniBooNE tank. The oil has density 0.836 g/cm^3 and index of refraction 1.46. This mineral oil produces some scintillation light, so both Čerenkov and scintillation light will be produced for particles with $\beta > 0.68$. This total amount of light will provide an energy measurement for a neutrino event; the image of the Čerenkov cone will provide direction information (for $\beta > 0.68$ particles); and the ratio of scintillation to Čerenkov light will provide particle identification information.

A circular room is located above the tank vault and houses the electronics, data acquisition, oil circulation, and calibration systems. The entire structure is covered with a mound of earth to provide some cosmic-ray shielding. A side view of the

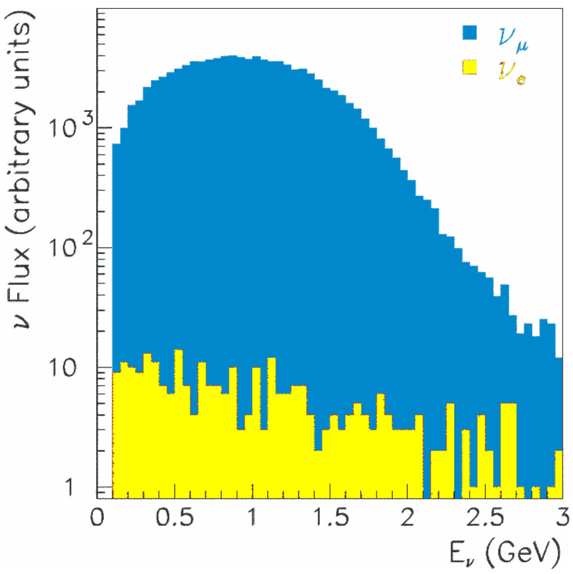

Figure 2. Calculated MiniBooNE neutrino flux energy distribution for ν_μ (dark-shaded region) and ν_e (light-shaded region).

detector structure is shown in Figure 1.

Each PMT is attached to one Teflon-jacketed cable, which both provides high voltage and returns signal. These cables are routed up and out of the tank through ports in the top cylindrical region of the tank, and hence to the data acquisition system, where the signal is picked off the HV cable, amplified, and digitized.

The data acquisition hardware consists of custom built cards in 13 VME crates and read out via MVME2304 single-board computers (SBC) running LINUX. The data is zero suppressed by the SBC and shipped, via ethernet, to a single Intel-based computer running LINUX. This computer assembles the data and ships it to the Fermilab computer center where it is written to tape.

The trigger system consists of an additional VME crate housing custom built cards that collect PMT multiplicity and beam information to form event triggers. The primary MiniBooNE trigger is simply a "beam-on-target" signal from the accelerator, which initiates a data read out in a 20 μs window around the 1.6 μs beam spill (regardless of PMT multiplicity). Additional triggers are formed for calibration purposes and for a supernova search [9] using the detector multiplicity information. The data acquisition hardware and software is built with data buffering capability at all levels to create a virtually dead-time-free system.

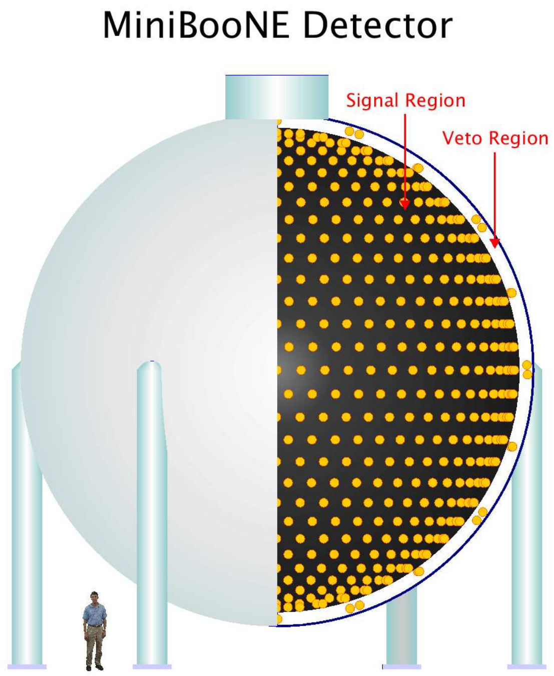

Figure 3. A schematic picture of the MiniBooNE detector showing the signal region, viewed by 1280 8-inch PMTs (represented as spheres), and the veto region, viewed by 240 8-inch PMTs.

3. The MiniBooNE Neutrino Oscillation Search

The $\nu_\mu \rightarrow \nu_e$ oscillation search will be conducted by measuring the event rate for the ν_e induced reaction, $\nu_e C \rightarrow e^- X$, and comparing to the rate expected from background processes. If the LSND result is indeed due to neutrino oscillations, approximately 1000 ν_e-induced events

Process	Reaction	Number of Events
LSND-based $\nu_\mu \to \nu_e$ Signal	$\nu_e C \to e^- X$	1000
Intrinsic ν_e Background	$\nu_e C \to e^- X$	1500
Mis-ID μ^- Background	$\nu_\mu C \to \mu^- X$	500
Mis-ID π^0 Background	$\nu_\mu C \to \nu_\mu \pi^0 X$	500
$\nu_\mu C$ charged-current scattering	$\nu_\mu C \to \mu^- X$	500,000
$\nu_\mu C$ neutral-current π^0 production	$\nu_\mu C \to \nu_\mu \pi^0 X$	50,000
$\nu_\mu e$ elastic scattering	$\nu_\mu e \to \nu_\mu e$	100

Table 1
Estimated number of neutrino oscillation signal and background events after 2 years (10^{21} protons on target) of data taking with neutrinos. Also shown are the number of events from other neutrino reactions in MiniBooNE.

are expected due to $\nu_\mu \to \nu_e$ oscillations in two calendar years (10^{21} protons on target).

The three main backgrounds to this search are: intrinsic ν_e background in the beam from μ and K decay in the decay pipe, mis-identification of μ events ($\nu_\mu C \to \mu^- X$), and mis-identification of π^0 events ($\nu_\mu C \to \nu_\mu \pi^0 X$). The number of events for signal and backgrounds are listed in Table 1.

These backgrounds will be measured. As described in Section 2.1, the number of events from intrinsic ν_e that are produced from μ^+ decays in the target region will be determined from ν_μ charged-current scattering in the detector. Also, the number of intrinsic ν_e from K^+ decays will be determined from the μ detected with the off-axis LMC spectrometer. The number of μ^- and π^0 events mis-identified as e^- events will be measured via the large number of correctly identified $\nu_\mu C \to \mu^- X$ and $\nu_\mu C \to \nu_\mu \pi^0 X$ events. Figure 4 shows the estimated sensitivity to neutrino oscillations for 10^{21} protons on target with the horn in ν_μ and $\bar{\nu}_\mu$ configuration.

4. First Glance at the Data, and Future Plans

The MiniBooNE detector and beamline are operational, and data-taking has begun. The initial energy and timing calibrations have been performed and the detector is operating well. Good progress on understanding the beamline has been made since MiniBooNE started taking data late August. However, challenges remain to acquire the neccessary proton intensity. Nevertheless, the first neutrino candidate events ($\nu_\mu C \to \nu_\mu X$) have been seen. Figure 5 shows the reconstructed event times with respect to the beam trigger. These events are simply required to have at least 200 PMT hits, and < 6 hits in the veto region. No timing requirement is imposed.

The current plan is to run ν_μ mode until MiniBooNE collects 5×10^{20} protons on target, with the possibility of changing to $\bar{\nu}_\mu$ mode afterwards. First results are expected by 2005; if the LSND signal is confirmed, MiniBooNE will be upgraded to the BooNE experiment (two detectors).

5. Acknowledgements

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REFERENCES

1. The MiniBooNE Collaboration consists of scientists from the following institutions: University of Alabama; Bucknell University; University of California, Riverside; University of Cincinnati; University of Colorado; Columbia University; Embry-Riddle Aeronautical University; Fermi National Accelerator Laboratory; Indiana University; Los Alamos National Laboratory; Louisiana State University; University of Michigan; and Princeton University. More information may be found at http://www-boone.fnal.gov/.
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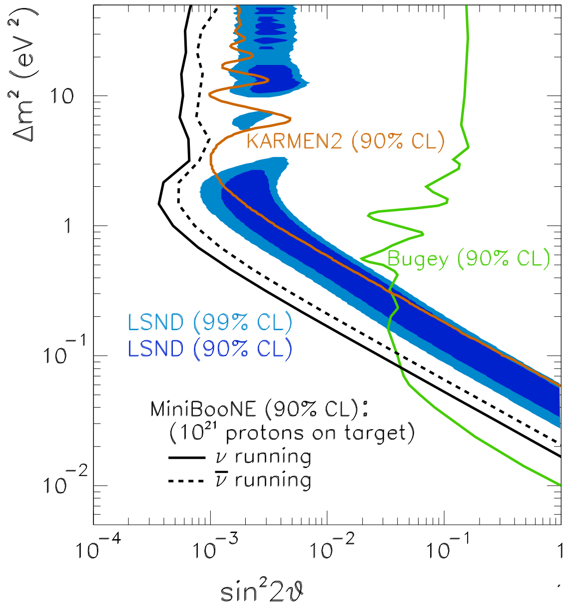

Figure 4. Estimated sensitivity to $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations after 2 years of running. Shown separately are the ν_μ and $\bar{\nu}_\mu$ running modes with 5×10^{20} protons each.

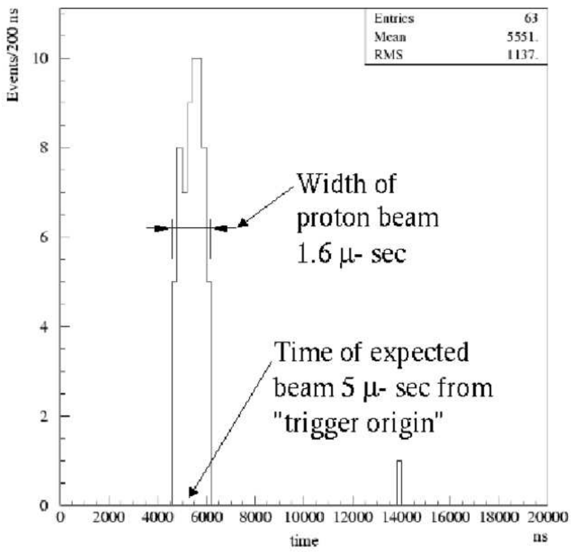

Figure 5. ν_μ candidate event times with respect to the beam trigger. The beam trigger starts the event window 5 μs before the beam is expected to arrive.

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