Neutrino Physics

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1 The MiniBooNE Experiment

with the University of Alabama; Bucknell University; the University of California, Riverside; the University of Cincinnati; the University of Colorado; Columbia University; Embry Riddle Aeronautical University; Fermi National Accelerator Laboratory; Indiana University; Los Alamos National Laboratory; Louisiana State University; the University of Michigan; and Princeton University.

The phenomenon of neutrino oscillations, which has been under investigation for the last three decades, seems to have, fairly recently, 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 [1]. The results from atmospheric neutrinos as reported by Super-Kamiokande [2] indicate another type of neutrino oscillations. A third type of oscillation is indicated by evidence from the LSND experiment [3] 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 (FNAL-E898) [4] will run at Fermilab 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.

MiniBooNE will search for neutrino oscillations of the type $\nu_\mu \to \nu_e$ via appearance of electron-type neutrinos (ν_e) in a beam of muon-type neutrinos (ν_μ). The ν_μ are created by 8 GeV protons from the FNAL booster accelerator impinging on a beryllium target rod embedded in an electrically pulsed horn system. The miniBooNE detector is located 500m away from the neutrino source and consists of a 12m spherical tank filled with 807 tons of mineral oil (CH_2) (see Fig. 1). A thin optical barrier divides the tank into a 445 ton inner fiducial region and an outer, 35cm-thick, veto region. Particles with $\beta > 1/n_{\rm oil}, n_{\rm oil} \sim 1.47$ will produce Čerenkov light which is viewed by 1280 8in PMTs in the fiducial region and 240 8in PMTs in the veto region. The veto region allows particles entering or exiting the main volume to be tagged. Neutrino interactions in the detector are identified by the pattern of hit tubes that result from the light created by the final-state charged particles.

If the LSND result is correct, miniBooNE will approximately 1000 ν_e-induced events over background after two calendar years. At that time, the beam will be switched to antineutrino mode and data will be collect for another 2 years. This strategy will allow for both an neutrino and antineutrino oscillation with adequate sensitivity to make a definitive check of the LSND result.

The MiniBooNE detector and neutrino beam line are operational and data-taking has begun. The MiniBooNE detector has been full of oil and taking cosmic-ray and calibration data since May 2002. The initial energy and timing calibrations have been performed and the detector is operating well. The MiniBooNE neutrino source has been delivering neutrinos since August 2002. Studies of the proton beam line and horn are still underway and the intensity is being increased gradually. However, even with this low neutrino intensity, the first neutrino events ($\nu_\mu C \to \mu^- X$) have been seen. The neutrino source will be up to full intensity by the end of 2002.

The IUCF group has and continues to make crucial contributions to the miniBooNE experiment. These contributions include the following items.

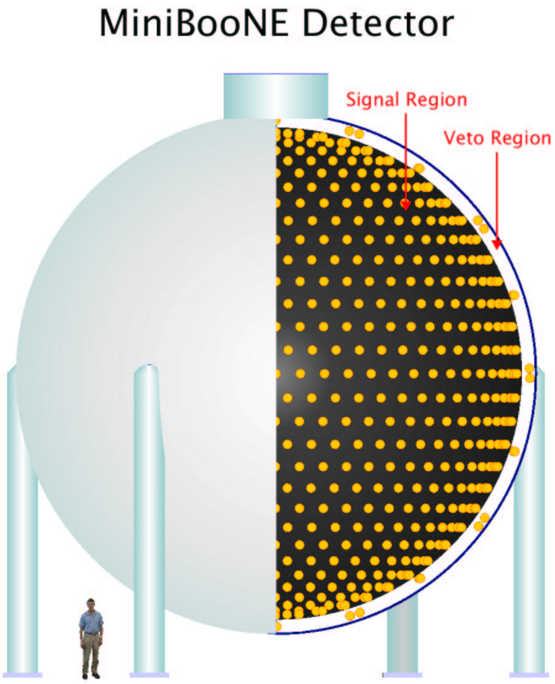

Figure 1: A schematic picture of the MiniBooNE detector showing the signal region, viewed by 1280 8-inch PMTs (represented as spheres), and the veto region, viewed by 240 8-inch PMTs.

- Project management for the detector installation phase. Now complete.
- Management of detector operations. Ongoing.
- Creation and maintenance of the data acquisition and trigger software. The system is complete, maintenance is ongoing.
- Design, installation, and maintenance of the slow monitoring system for the miniBooNE detector. The system is installed and working. Maintenance is ongoing.
- Testing of the miniBooNE mineral oil using the IUCF 200 MeV cyclotron beam in the RERP facility. The light output strength and time distribution has been measured. Tests on the wavelength distribution are ongoing.
- Data Analysis. This project has just begun.

The IUCF group have been heavily involved with the assembly of the miniBooNE detector at Fermilab over the past year. The slow monitoring system continuously senses and records and array of temperature, pressure, and relative humidity data from detector tank and surrounding enclosure. The data acquisition and trigger system is performing well, the miniBooNE detector data is collected 24 hours per day with virtually no human intervention.

The tests of the miniBooNE oil using 200 MeV protons from the cyclotron in the RERP test area provided a measurement of the amount and time distribution of the isotropic scintillation light produced by charged particles in the the miniBooNE detector. This is important information to understand the response of the the detector. In 2002, a total of approximately 72 hours of beam was used in 3 separate times. Both undergraduate and graduate students participated in the tests. An example of the response of the miniBooNE oil as measured at the IUCF is shown in Figure 2.

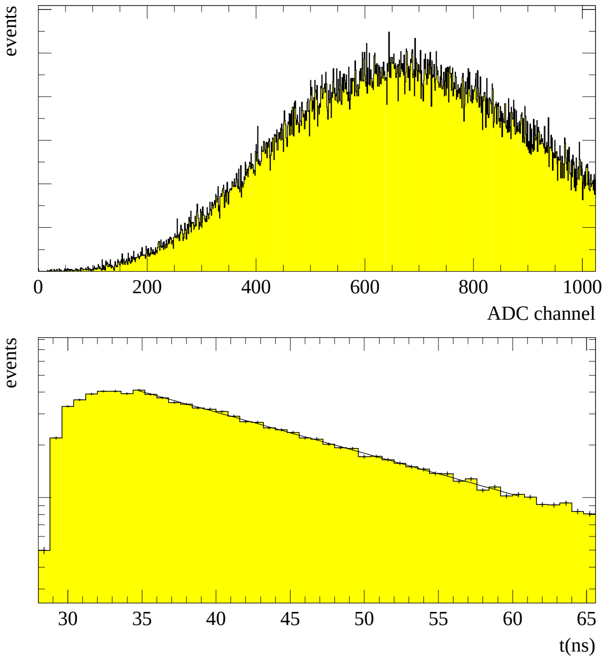

Figure 2: Data from the RERP miniBooNE oil tests. The top plot is the ADC spectrum obtained from a PMT that collects the light produced in an oil sample in coincidence with a passing proton. The bottom plot is the time distribution of this light.

2 A Future Neutrino Detector

A detector on the miniBooNE beam line at a near location (100m from the neutrino source) would be capable of measuring the strange quark contribution to the proton spin [5]. Work on a prototype detector to make this measurement has begun at IUCF. The idea is to image individual charged particle tracks in a large volume of liquid scintillator using image intensifiers and CCD cameras. This technology has the potential to provide high resolution tracking data for a large ($\approx$ 10 tons) detector quite economically.

In the summer of 2002, the first tests were performed as a "proof of principle" of this technology. This work was the project of an REU student and a high school summer student. An image-intensified CCD camera was used to capture images of an ensemble of proton tracks in the RERP test beam. An example of the images obtained are shown in Figure 3. This technology shows promise and work to build a prototype device is underway.

References

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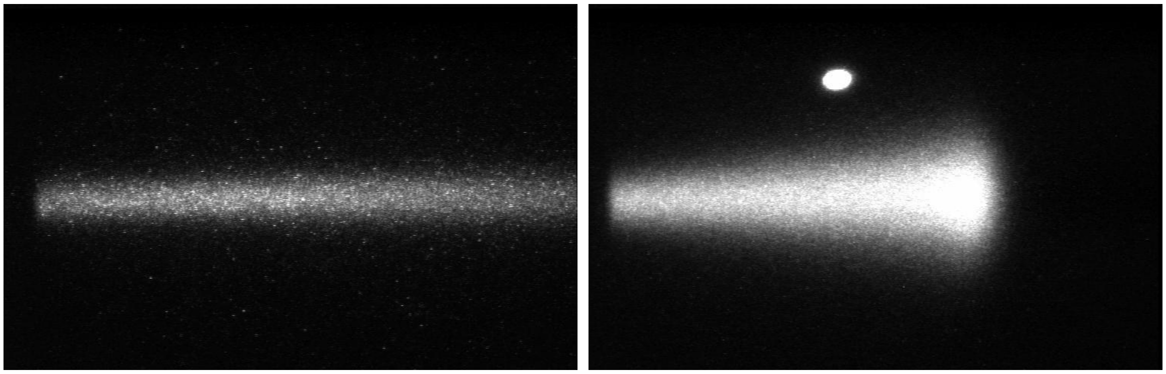

Figure 3: Two images of preliminary tests of a scintillation imaging detector. These pictures show a collection of 200 MeV protons crossing a 6 inch wide volume of liquid scintillator. The picture on the left shows a shows the protons passing through the volume. In the picture on the right, the protons have been degraded with a 1 inch block of Copper and range out in the scintillator volume.