Neutrino Physics at IUCF

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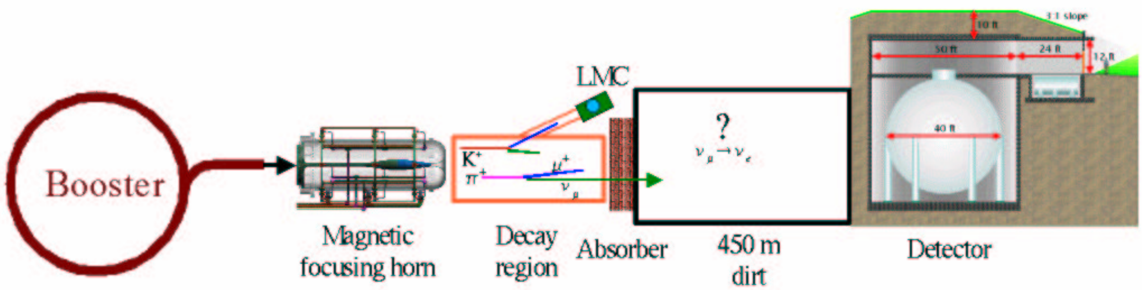
In 2003, our group worked on commissioning, maintaining, and analyzing first data from the MiniBooNE experiment. We have also embarked on design of the FINeSSE experiment. These efforts are described in the following sections.

A. The MiniBooNE Experiment [1]

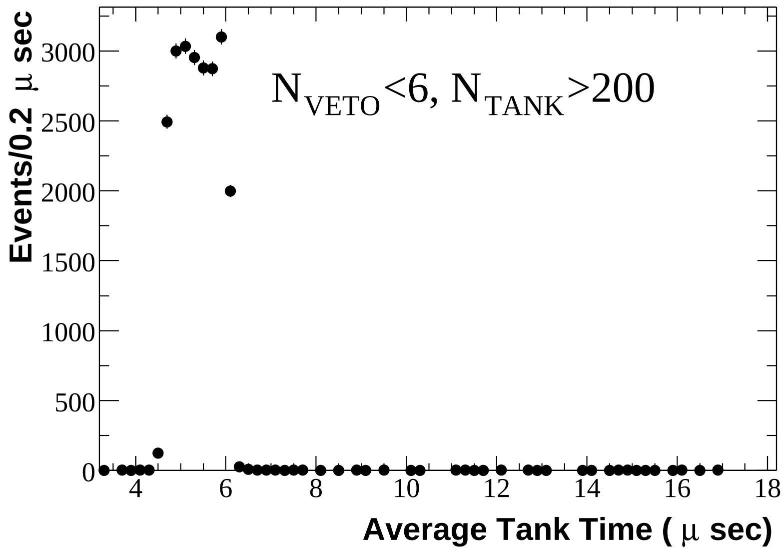
The MiniBooNE [2,3] experiment was approved in 1998 to provide a definitive test of the evidence for $\nu_\mu \rightarrow \nu_e$ oscillations at $\Delta m^2 \approx 1$ eV^2 seen by the LSND experiment [4]. The experiment has been running with beam for one year. The beam and experiment are working well and data analysis is proceeding.



A schematic overview of the MiniBooNE experiment including the booster accelerator, focussing horn, decay region, neutrino flight path, and the MiniBooNE detector.

MiniBooNE will search for neutrino oscillations of the type $\nu_\mu \rightarrow \nu_e$ via appearance of electron-type neutrinos (ν_e) in a beam of muon-type neutrinos (ν_μ). A schematic view of the neutrino source and detector is shown in Figure 1. 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. Oscillations may occur as the neutrinos travel to the detector, located 500m away from the neutrino source. The detector consists of a 12 m spherical tank filled with 807 tons of mineral oil (CH_2) lined with 1280 8 inch PMTs in the fiducial region and 240 8 inch PMTs in the veto region. 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.

MiniBooNE has been running continuously with beam (with the exception of some beam-related downtimes) since September 2002 with a very high beam-on livetime of $> 98\%$. As of October 2003, a total 1.5×10^{20} protons have been delivered to the neutrino production target resulting in approximately 160,000 contained neutrino events



Distribution of event times in the MiniBooNE detector with cuts: number of veto PMTs hit < 6 *and number of main PMTs hit* > 200*. The large excess of events during the 1.6 μs beam spill is visible.*

in the MiniBooNE detector. These events are easily visible in a plot of event time (after some very simple cuts) with respect to the beam spill time (see Figure 2).

In order to perform an unbiased search for $\nu_\mu \rightarrow \nu_e$ oscillations, MiniBooNE has implemented a "blind" analysis scheme. This procedure prevents access to the full data from ν_e candidate events until the analysis procedure and background estimates are finished. In the meantime, work is proceeding on understanding the detector performance, event reconstruction, and other physics channels. These physics channels include:

- ν_μ charged current quasi-elastic scattering.
- Neutral current π^0 production.
- Neutral current neutrino-nucleon elastic scattering.

Preliminary results on all of these topics have been presented and details may be seen in Reference [5].

While the first year of MiniBooNE running has provided a large number of neutrino scattering events and the detector has performed well, the average proton intensity delivered to the neutrino production target must be increased in order to complete a definitive test of the LSND result in the desired timeframe. To accomplish this, a series of upgrades to the FNAL booster accelerator have been installed during the August 2003 shutdown. These upgrades should bring the proton intensity up to the level required to allow MiniBooNE to receive 1×10^{21} protons on the production target by July 2005. This is the number required for a definitive test of the LSND signal. A detailed plan and beam request has been submitted to FNAL and may be found in Reference [5].

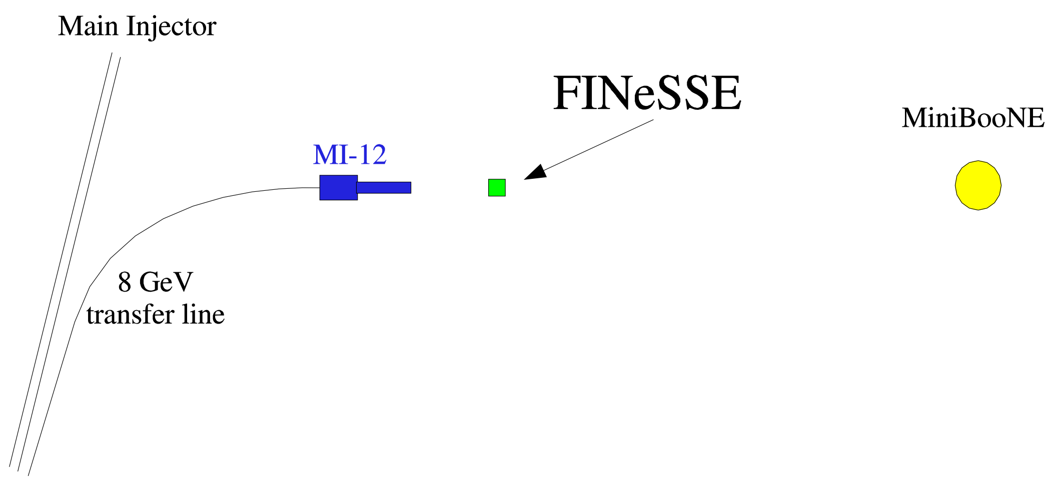
The IUCF group has made and continues to make crucial contributions to the miniBooNE experiment. These contributions include the following items.

- Creation and maintenance of the data acquisition and trigger software. This system has ran with 98% beam-on livetime during the first year of running. 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 have been measured. Additional tests have been performed in the last year to calibrate a new device that was designed to measure scintillation light from cosmic-ray muons.
- Data Analysis. Our group has concentrated on the neutral current elastic scattering analysis.

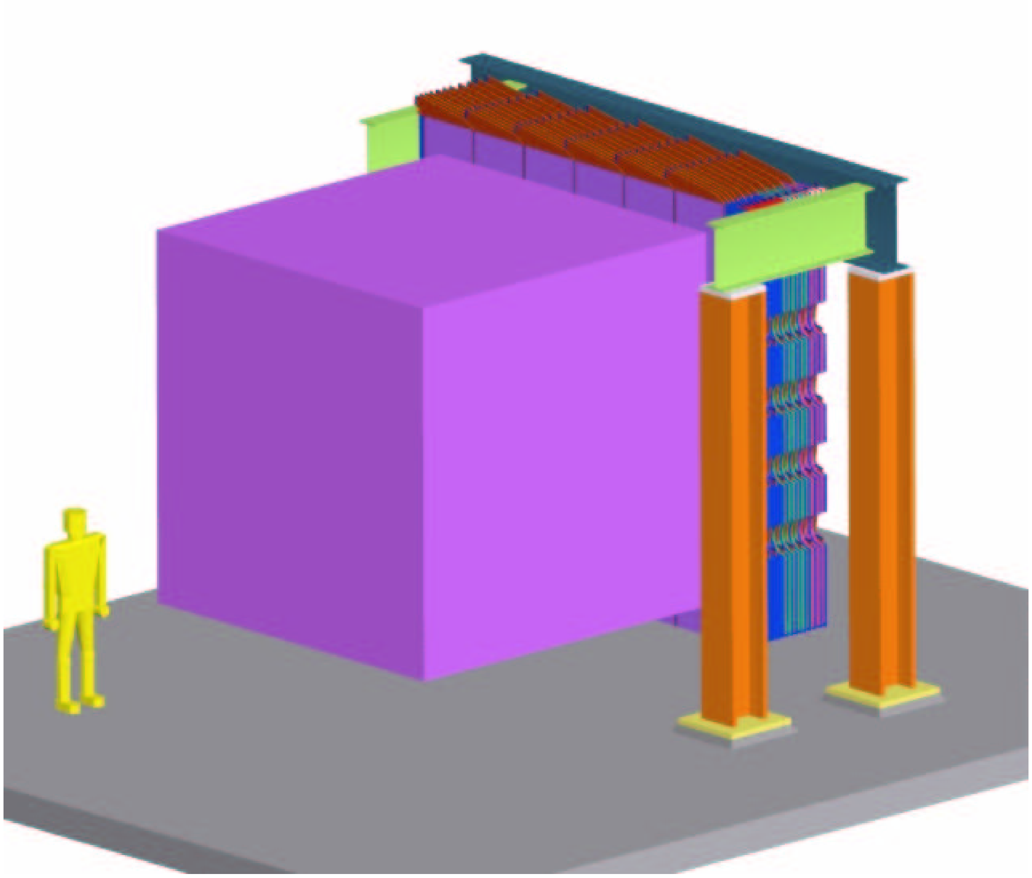
B. The FINeSSE Experiment [6]

The Fermilab Intense Neutrino Scattering Scintillator Experiment ("FINeSSE") is designed to measure the strange quark contribution to the spin of the proton, and to search, in conjunction with the MiniBooNE experiment, for ν_μ disappearance. FINeSSE will be located 100 m from the Booster neutrino beamline production target, and 441 m upstream of the currently-running MiniBooNE experiment as shown in Figure 3. The detector will be a novel liquid scintillator fiber tracking detector of 9 ton fiducial volume combined with a solid scintillator/iron muon detector as shown in Figure 4. This experiment will be proposed to FNAL in December 2003 [7].



Proposed FINeSSE location with respect to the existing neutrino target building (MI-12) and MiniBooNE detector. North is to the right in this drawing.

Neutral-current neutrino proton elastic scattering ($\nu p \to \nu p$) is uniquely sensitive to the strange-sea quark contribution to the spin of the proton. This quantity, known as Δs, has been measured to be non-zero in deep-inelastic polarized lepton scattering and is a piece of the "proton-spin puzzle" [8]. The theoretical assumptions inherent in the extraction of Δs from this data have been questioned and a measurement via neutrino scattering is needed. In addition, a measurement of the charged current neutrino scattering



A schematic drawing of the FINeSSE detector. The cubic volume is the (3.5 m)^3 Vertex Detector. It is a (2.4 m)^3 signal region surrounded by a veto, filled with scintillator oil. The larger volume is the Muon Rangestack.

($\nu n \to \mu^- p$), combined with this measurement in the MiniBooNE detector will allow a significant improvement in the search for $\nu_\mu \to \nu_x$ oscillations ("ν_μ disappearance").

The IUCF neutrino group has been a leader in this project from its inception. The idea for liquid scintillator fiber tracker detector originated at IUCF. A prototype was tested in the summer of 2003 in the IUCF 200 MeV proton beam and shown to perform well. In addition, the full-sized version of this detector, including the mechanical aspects and electronics, was designed at IUCF. If FINeSSE is approved by FNAL, funding to build a large part of the experiment at IUCF will be pursued.

1. The MiniBooNE collaboration consists of the following institutions: the University of Alabama; Bucknell University; 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. Additional information about MiniBooNE may be found at: `http://www-boone.fnal.gov/`.
2. E. Church *et al.*, FERMILAB-P-0898 (1997); `http://library.fnal.gov/archive/test-proposal/0000/fermilab-proposal-0898.shtml`.
3. R. Tayloe, Nucl. Phys. Proc. Suppl. **118**, 157 (2003).

4. A. Aguilar *et al.*, Phys. Rev. D **64** (2001) 112007.
5. "The MiniBooNE Run Plan", A. A. Aguilar-Arevalo *et al.*, submitted to the FNAL PAC, 11/03, and available at: `http://www-boone.fnal.gov/publicpages/runplan.ps`.
6. The FINeSSE collaboration consists of the following institutions: Columbia University; Fermi National Accelerator Laboratory; University of Illinois at Urbana-Champaign; Indiana University; Los Alamos National Laboratory; Louisiana State University; New Mexico State University; University of Virginia. Additional information about FINeSSE may be found at: `http://home.fnal.gov/~bfleming/finese.html`.
7. `http://home.fnal.gov/~bfleming/TheFINeSSEProposal.html`.
8. B. W. Filippone and X. D. Ji, Adv. Nucl. Phys. **26**, 1 (2001) [arXiv:hep-ph/0101224].