Fermi National Accelerator Laboratory

FERMILAB-Conf-98/112

Neutrino Oscillation Physics with BooNE

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April 1998

Published Proceedings of the *Workshop on Physics at the First Muon Collider and at the Front End of a Muon Collider*, Batavia, Illinois, November 6-9, 1997

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

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INTRODUCTION

A proposal [1] was submitted to Fermilab for a Booster Neutrino Experiment (BooNE) to confirm the discovery of neutrino oscillations at LANL using a Liquid Scintillator Neutrino Dtetector (LSND). The location of the experiment at the Fermilab Booster will provide for higher signal rates than were possible at LSND by about an order of magnitude. BooNE will also provide an opportunity for observing the signal under very different conditions and with different systematics than were present at LSND.

The muon collider will provide an opportunity to further explore this region of parameter space with a different set of systematics. Most important will be that the neutrino flux will be accurately known, since the current of the parent muon beam can be measured very precisely. This source will provide a $\nu_\mu(\bar{\nu}_\mu)$ and $\bar{\nu}_e(\nu_e)$ flux equal in magnitude and with easily calculable energy and spatial distributions.

THE BooNE DETECTOR

The proposal to carry out BooNE at Fermilab may have at least two stages, the first stage is MiniBooNE . It will include the construction of a spherical tank, 12 meters in diameter that will be filled with nearly pure mineral oil. The volume of the tank will be observed with an array of about 1250 8″

1) Presented at the Workshop on Physics at the First Muon Collider and at the Front End of a Muon Collider, Fermilab, Batavia IL, November 6-9, 1997.
2) Operated by Universities Research Association, Inc. Under Contract with the United States Department of Energy.

phototubes. Fig. 1 gives a schematic overview of the detector. The detector will be built so that roughly its center will be at grade level, with about a twenty foot earth cover over the top.

The Booster beam will be extracted from the Main Injector tunnel to a target station facing north on the site. An overview of the target station and beam tunnel is given in Fig. 2 and shows the location of the detector just southwest of the Lederman Science Center, and 500 meters from the target. Also shown are potential sites for future extensions of BooNE . Locating the extraction point to BooNE at the injection point of the Main Injector , guarantees that beam can be delivered to BooNE under any future scenario for Booster relocation.

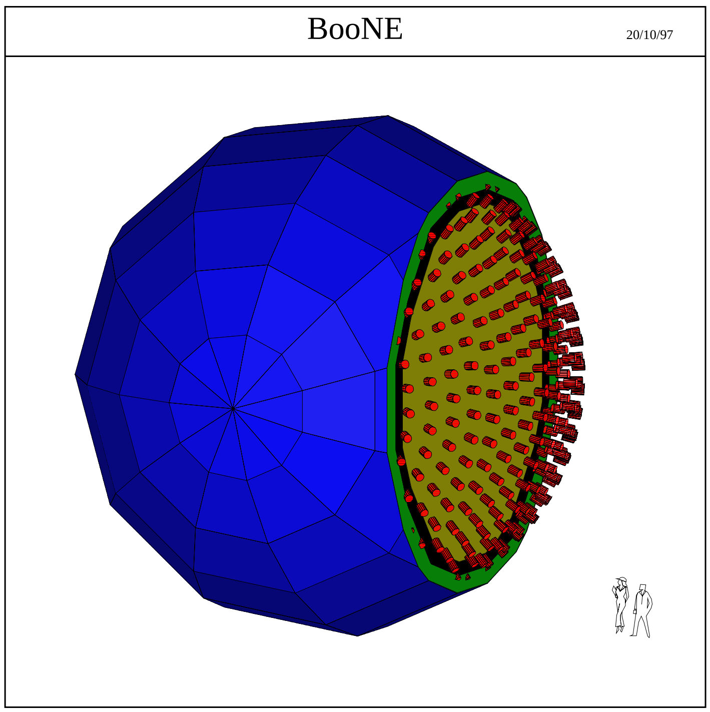

FIGURE 1. Schematic of the proposed detector.

PHYSICS REACH AND NEUTRINO FLUX

MiniBooNE will use a two horn beam [2] similar to the BNL design. The ν_μ flux is presented in Fig. 3. The flux is well matched to the acceptance of the detector, which is optimal roughly between 1/2 GeV and 2 GeV .

In Fig. 4 the parameter space covered by MiniBooNE for the $\nu_\mu \rightarrow \nu_e$ is given, including anticipated results from future experiments. The figure gives the allowed region for the LSND effect, and the coverage anticipated by

FIGURE 2. An aerial view suggesting the location of MiniBooNE , future extensions of BooNE , and the targeting station located near the Main Injector .

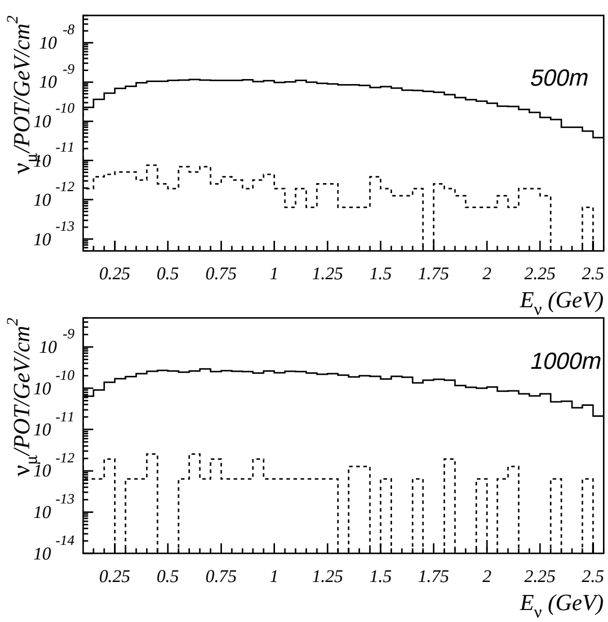

FIGURE 3. Flux of ν_μ (solid histogram) and ν_e (dashed histogram) from a 50m decay length beam line at 500 m and 1000 m from the target.

MiniBooNE . Fig. 5 gives the Δm^2 and $\sin^2 2\theta$ plot for the ν_μ disappearance experiment. It can be seen that a MiniBooNE detector at one km has good reach into the region of the atmospheric neutrino effect.

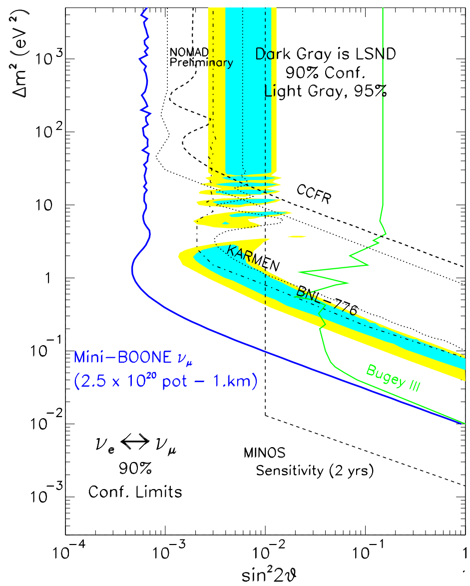

FIGURE 4. 90% C.L. limit expected for MiniBooNE for $\nu_\mu \to \nu_e$ appearance after one year of running, including systematic and statistical error, if LSND signal is not observed (solid line). Summary of results from past experiments and expectations for the future MINOS experiment are also shown.

FUTURE PROSPECTS WITH THE MUON COLLIDER FRONT END

A first step toward the development of the muon collider might be a low energy facility capable of storing 1.5 GeV muons in a small storage ring. A ten GeV muon collider using superconducting magnets will provide 1.5 GeV in the same ring circumference with conventional magnets [3]. The size of the storage ring can be seen in Fig. 6. The facility would fit nicely within the footprint of the Pbar Source. Operating at 1.5 GeV , the ring would provide neutrinos from muon decay for a low energy facility that could include MiniBooNE , and other high resolution detectors.

The neutrino flux and event distributions from decays from muons in a storage ring of μ^+ is given in Fig. 7 [4]. By comparison with Fig. 3, and assuming 2×10^{20} protons per year from the Booster accelerator, we can see that the integrated yearly flux is similar between the two beams. More important, however, is that the muon generated beam provides an opportunity for greater control of systematics than the Booster generated beam.

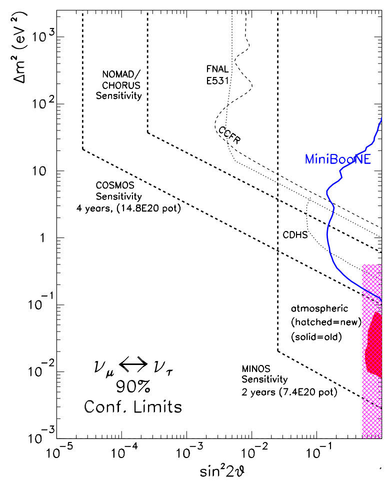

FIGURE 5. Summary of results from past experiments (narrow-dashed and dotted), future approved experiments (wide-dashed) and 90% C.L. limit expected for MiniBooNE (solid) for ν_μ disappearance. Solid region indicates the favored region for the atmospheric neutrino deficit from the Kamioka experiment. No zenith angle dependence would extend the favored region to higher Δm^2 as indicated by the hatched region.

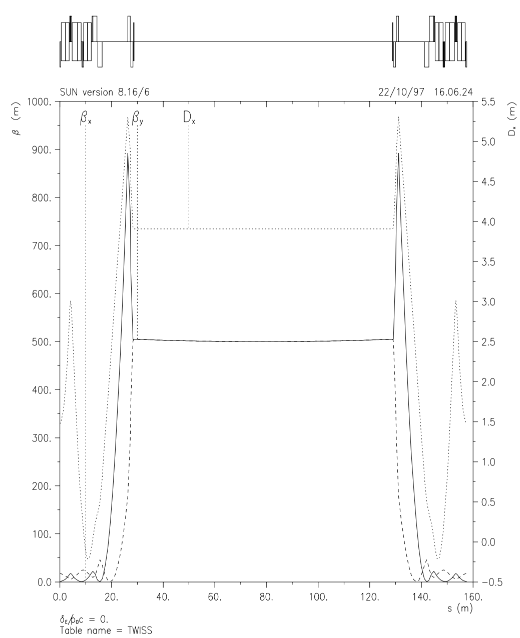

FIGURE 6. Half ring configuration for a Muon Storage Ring. Ring energy is 10 GeV if superconducting magnets are used, and about 1.5 GeV if conventional magnets are used.

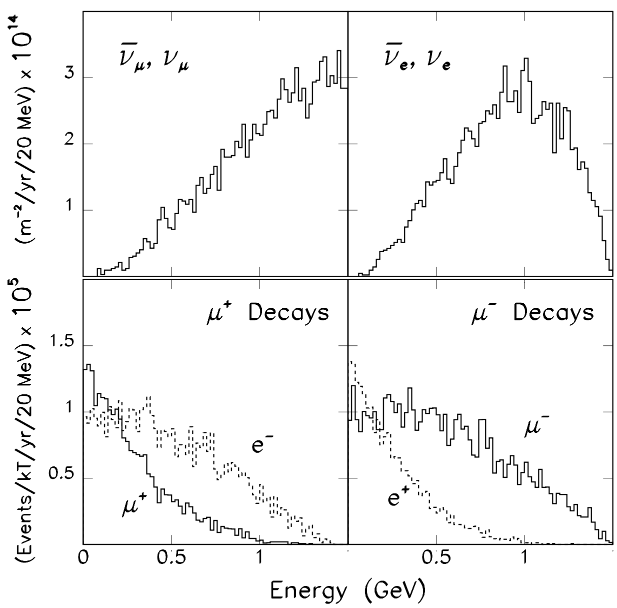

FIGURE 7. Expected neutrino flux and event rates from a 1.5GeV muon storage ring. The half-ring configuration is given in Fig. 6.

CONCLUSION

The Muon Collider would benefit from a program that would permit an intensive R&D effort on a small, low energy facility. Low energies can be of physics interest as well. We've described here an approach to developing a low energy (1.5 GeV) muon storage ring that would test most of the concepts associated with capture and storage of a muon beam, with a goal of providing neutrinos for oscillation experiments.

The BooNE program, as outlined in the proposal, will continue into the year 2005. Construction of a small storage ring and muon collection facility on this time scale may be feasible. The facility could become part of a program to verify and extend our understanding of neutrino oscillations within the later phases of the BooNE program.

REFERENCES

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2. L. A. Ahrens *et. al.* , Phys. Rev. D **34**, 75 (1986)
3. The half ring design was provided by Carol Johnstone.

4. Steve Geer, submitted to PRD (Fermilab-pub-97/389).