PRAMANA — journal of physics | © Indian Academy of Sciences | Vol. 62, No. 3 March 2004 pp. 611–614

MiniBooNE overview and status

P KASPER (for the BooNE Collaboration)
Fermilab, P.O. Box 500, Batavia, IL 60510-0500, USA

Abstract. Recent discoveries in the neutrino sector have opened a new frontier in high-energy physics and cosmology. Evidence from neutrino oscillation experiments from around the world indicate that neutrinos oscillate between their different flavours and therefore may have mass. In addition, results from solar and atmospheric neutrino experiments as well as the accelerator neutrino experiment, LSND, cannot all be explained with the three standard model neutrinos. Is this new physics or is there some other explanation? The MiniBooNE experiment presently taking data at Fermilab is designed to address the LSND signal and answer this question. Progress on the MiniBooNE experiment will be presented and prospects for the future will be discussed.

Keywords. MiniBooNE; LSND; neutrino; oscillations.

PACS No. 14.60.Pq

1. Introduction

The goal of the MiniBooNE experiment is to unequivocally confirm or refute the neutrino oscillation signal observed by the LSND experiment [1]. The LSND experiment observed a roughly 4σ excess of $\overline{\nu}_e$s in a predominantly $\overline{\nu}_\mu$ beam produced from an 800 MeV proton beam at the LANCE accelerator in Los Alamos. This result was not confirmed by the very similar KARMEN experiment [2]. However the KARMEN detector was located closer to their neutrino source than the LSND detector and had a less intense proton beam. Consequently their exclusion limit does not fully cover the full parameter space allowed by the LSND signal. In fact a combined analysis of the two data sets [3] resulted in two distinct regions of the oscillation parameter space that were allowed at the 64% confidence level.

When put into the context of other oscillation signals, the LSND result has profound implications. The allowed LSND signal region implies a Δm^2 range between 0.1 and 1 eV^2. Atmospheric neutrino oscillations observed by the Super-Kamiokande [4] and Kamiokande [5] experiments, and confirmed (albeit weakly) by K2K [6], require a Δm^2 between 10^{-2} and 10^{-3} eV^2. The SNO [7] and Kamland [8] experiments have produced convincing evidence that neutrinos from the sun are oscillating with a Δm^2 of about 10^{-4} eV^2. Taken together, these results are incompatible with a simple 3-neutrino flavour model.

A variety of theoretical models have been proposed to explain these data. The most favoured models invoke bimaximal mixing in a 3 + 1 [9] neutrino hierarchy with a heavy mass state which is composed of a sterile neutrino flavour weakly mixing with the three active flavours. The alternate $2+2$ models are however also still viable [10]. There is even a model, motivated by branes with extra dimensions [11] that accounts for the data by assuming maximal CPT violation in the neutrino mass terms. This gives rise to separate mass scales for neutrinos and anti-neutrinos and is thus able to account for all the data without invoking sterile neutrinos. The Kamland result does not rule out this model [12], though it does become somewhat contrived in that one of the anti-neutrino mass differences would coincidently match the solar neutrino data.

1.1 *The MiniBooNE experiment*

As stated earlier, the goal of MiniBooNE is to unequivocally refute or confirm the LSND result. Consequently, the parameter L/E_ν which determines the region of Δm^2 to which the experiment is sensitive, has been chosen to match that of LSND. (L is the distance from the neutrino source to the detector and E_ν is the average neutrino energy.) However, the average MiniBooNE neutrino energy is about 1 GeV which is an order of magnitude higher than LSND and hence the detector is correspondingly further from the source. This means that the MiniBooNE event signatures and analysis will be completely different, thereby providing a truly independent test of their result.

MiniBooNE's neutrino beam will be produced using 8 GeV protons from Fermilab's booster accelerator. The proton beam impinges on a 65 cm Be target impeded inside a magnetic horn which focuses the positively charged interaction products. The horn is followed by a 50 m long decay pipe in which the predominantly ν_μ beam is produced from the decay of π^+s. A small number of ν_es are also expected primarily from kaon and muon decays. This background is anticipated to be about 0.1% and needs to be well understood. To this end, the decay region has been equipped with a removable absorber that can effectively halve the decay length. This produces a bigger reduction in the neutrino flux from muon decays than that from pions and hence provides a handle on the number of ν_es produced by muons. In addition, a muon range stack has been installed to detect wide angle muons from the decay region. This detector can clearly distinguish muons produced by Ks from those produced by πs and therefore provides a check on the kaon production rates and hence the ν_es resulting from their decays. Members of the BooNE Collaboration are also working with the HARP experiment to measure pion and kaon production cross-sections from 8 GeV protons incident on a section of the actual MiniBooNE target in order to enable us to accurately simulate our neutrino fluxes.

The MiniBooNE detector is located 500 m from the target and consists of a 12 m diameter spherical tank containing 800 tons of pure mineral oil and is instrumented with 1530 8$''$ PMTs. 1280 of the PMTs view an inner sphere 11.8 m in diameter which is optically separated from a 35 cm thick outer shell which is instrumented with the remaining PMTs to form a veto region.

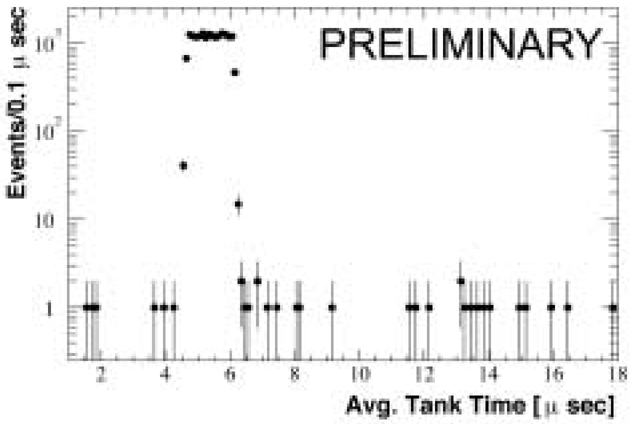

Figure 1. Reconstructed event times with respect to the start of the beam trigger window, for events reconstructed within 500 cm of the center of the detector and with <6 veto hits and >200 signal region hits.

1.2 *Status*

The experiment started taking data in September of 2002 albeit at a modest rate. The current beam rate is still well below the experiment's goal of 9×10^{16} protons/h and is limited by radiation from beam losses in the Booster. A variety of accelerator improvements are being implemented which we anticipate will enable us to approach our goals by the end of this year. At full intensity, MiniBooNE should get 5×10^{20} protons/year and can reach its proposed sensitivity in two years.

The detector has been operational from early 2002 and is now clearly seeing neutrino interactions from the beam. This is dramatically demonstrated by figure 1 in which the arrival times of contained events with respect to the beam trigger is plotted. A clear peak of width 1.6 μs (the expected length of the beam spill) is located at the correct time within the 19.2 μs beam trigger window. This plot is generated with very simple cuts to reject cosmic ray backgrounds and Michel electrons. The precision with which the experiment is able to reconstruct event times is demonstrated in figure 2 which shows the distribution of the event times with respect to the 53 MHz RF structure of the beam. One can clearly resolve the beam RF structure which may be useful in separating neutrinos produced from slow kaons from those produced by the faster pions.

2. Conclusion

In summary, MiniBooNE has started taking data and the detector and reconstruction algorithms are working well. It is hoped that by the end of this year we will reach our full data taking rate and will shortly thereafter be able to resolve the LSND question. However, the physics available to the experiment is not restricted to neutrino oscillations.

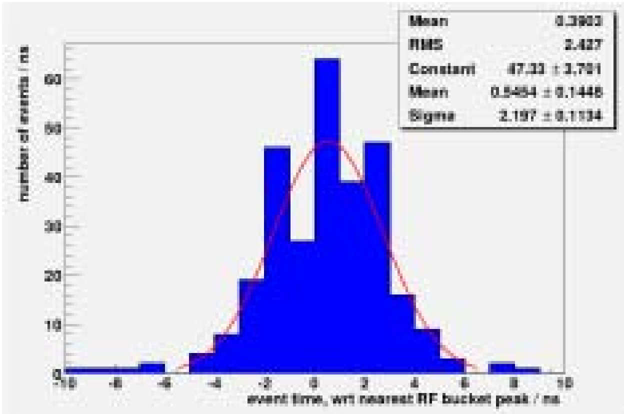

Figure 2. Reconstructed event times with respect to the 53 MHz RF structure of the beam.

The MiniBooNE detector can function as a supernovae detector [13]. If a supernovae occurs within 10 kpc, it has been estimated that we will detect approximately 200 neutrino interactions in a 10 s period. This is to be compared to an expected background of about 5 intereactions per second. We will also be able to make major improvements in our knowledge of exclusive neutrino cross-sections in the energy range below 1 GeV. In addition, we will be able to set competitive limits on exotic processes such as neutrino magnetic moments and the Karmen timing anomaly [14].

References

[1] A Aguilar *et al*, *Phys. Rev.* **D64**, 112007 (2001)
[2] B Armbruster *et al*, *Phys. Rev.* **D65**, 112001 (2002)
[3] E D Church, K Eitel, G B Mills and M Steidl, *Phys. Rev.* **D66**, 013001 (2002)
[4] Y Fukuda *et al*, *Phys. Rev. Lett.* **81**, 1562 (1998)
[5] Y Fukuda *et al*, *Phys. Lett.* **B335**, 237 (1994)
[6] S H Ahn *et al*, *Phys. Lett.* **B511**, 178 (2001)
[7] Q R Ahmad *et al*, *Phys. Rev. Lett.* **89**, 011301 (2002)
[8] K Eguchi *et al*, *Phys. Rev. Lett.* **90**, 021802 (2003)
[9] For example: K S Babu and R N Mohapatra, *Phys. Lett.* **B532**, 77 (2002)
[10] For example: H Päs, L Song and T J Weiler, hep-ph/0209373
R Foot, hep-ph/0210393
[11] G Barenboim, L Borissov and J Lykken, *Phys. Lett.* **B534**, 106 (2002)
[12] G Barenboim, L Borissov and J Lykken, hep-ph/0212116
[13] M K Sharp, J F Beacom and J A Formaggio, *Phys. Rev.* **D66**, 013012 (2002)
[14] S Case, S Koutsoliotas and M L Novak, *Phys. Rev.* **D65**, 077701 (2002)