MiniBooNE

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MiniBooNE is a short baseline neutrino experiment designed to confirm or refute the LSND observed excess of electron anti neutrinos in a muon anti neutrino beam. The experimental setup, data samples, and oscillation fit method are discussed. Although the result was not public at the time of the talk, MiniBooNE has since published results, which are discussed briefly as well.

1 Purpose

The Liquid Scintillator Neutrino Detector, or LSND, observed an excess of 87.9 ± 22.4 ± 6.0 candidate electron anti neutrino events in a muon anti neutrino beam, consistent with a neutrino oscillation probability of 0.264±0.067±0.045%[1]. The three independent observed mass splittings (atmospheric, solar, and LSND) cannot be explained in a three neutrino standard oscillation framework, and would require new physics explanations. The current favored solution to LSND would include additional 'sterile' neutrinos involved in oscillations[2]. Given that the solar and atmospheric oscillations have been confirmed by multiple experiments, MiniBooNE's goal, then, is to confirm or refute ν_μ to ν_e oscillations at high Δm^2. MiniBooNE has the same ratio of neutrino path to energy, or same probing of Δm^2 as LSND, and complements LSND with a different event signature and different systematics than LSND.

2 Experiment

2.1 Overview

The Fermilab Booster produces protons with kinetic energy at 8.89 GeV/c, and these are directed into a beryllium target placed inside a magnetic focusing horn. The subsequent mesons, predominantly π^+, are focused by the horn and decay to produce neutrinos. Past the decay region and 450 m of dirt sits a ∼ 1kton, mineral oil Cherenkov detector. This 12 m diameter sphere has 1280 photomultiplier tubes (PMTs) on the inner region, providing 10% PMT coverage. The outer 'veto' region has 240 PMTs placed back to back, and these are used to reject the $\sim$ 10kHz cosmic muon background during the beam spill.

2.2 Event Reconstruction

Events within the 1.6μs beam spill, with high enough PMT hits, and no substantial veto activity are neutrino candidate events. PMT hits distinct in time form 'subevents' in each neutrino interaction; a muon decaying in the tank, for example, produces two subevents, one each for the muon and the decay electron.

PMT hit topology, charge, and timing determine event types in MiniBooNE. In a charged current quasi-elastic interaction (CCQE) the incoming neutrino converts to its corresponding lepton partner. The outgoing lepton's flavor implies the flavor of the neutrino, and the Cherenkov ring observed indicates which lepton interacted. Muon events have a sharper Cherenkov cone because they are minimum ionizing particles; electrons and photons have broader rings due to scattering and showering. Basic quantities, such as charge, and timing of the hits, are used in conjunction with reconstructed event properties, such as track length of the lepton, the angle of the lepton with respect to the beam direction, to identify an event.

MiniBooNE's mean neutrino energy is approximately 700 MeV; roughly 40% of all interactions are CCQE. While only about 10% are neutral current single pion production (NC π^0), the π^0 can decay to two photons which appear as electron-like rings. Depending upon the topology of these events, they can be mis-reconstructed as electron neutrino events.

About 25% of the light in MiniBooNE is delayed, isotropic scintillation light. The amount of scintillation light as compared to the prompt Cherenkov light can give additional information distinguishing electron events from background.

3 Appearance Analysis

3.1 Electron neutrino selection

MiniBooNE uses two independent particle identification (PID) algorithms to select electron neutrino events: a likelihood analysis, and a boosted decision tree analysis. These two analyses use different reconstruction algorithms, oscillation fit code and methodology, and are susceptible to different sources of systematic errors.

A simple likelihood based analysis forms three PID variables. First, it compares the hits in the tank to an electron hypothesis and a muon hypothesis to form a PID variable distinguishing electron events from muon ones. Second, it compares hits to an electron hypothesis as compared to a π^0, or, a single electron-like ring to two electron like rings. Finally, cuts are applied to both of these variables and the output pion mass from the assumed two ring hypothesis.

The second method, boosted decision trees (BDT), is similar to a neural net[5]. A decision tree takes a sample and applies a cut to a variable with the most signal to background separation possible. Then, it takes the second best variable to cut on, and cuts on it, and so forth. At each cut point, the sample is either cut on again, should more information be extracted, or no more cuts are applied, and the sample is a 'leaf'. If a leaf is predominantly signal, it is a signal leaf; background events on a signal leaf are called mis-classified events. Boosting is an additional method to separate signal from background. Mis-classified events are weighted more, and the tree remade. Hundreds or thousands of trees are produced, and then summed. Events on a signal leaf count as '+1', on a background leaf '-1', and the total gives a PID variable.

Table 1: Breakdown of events passing electron neutrino selection cuts (likelihood method) with systematic error in the signal region (reconstructed neutrino energy between 475 and 1250 MeV).

Process	Number of events
ν_μ CCQE	10 ± 2
$\nu_\mu e \to \nu_\mu e$	7 ± 2
Miscellaneous ν_μ Events	13 ± 5
NC π^0	62 ± 10
NC $\Delta \to N\gamma$	20 ± 4
NC Coherent & Radiative γ	< 1
Out of tank events	17 ± 3
ν_e from μ decay	132 ± 10
ν_e from K^+ decay	71 ± 26
ν_e from $K^0{}_L$ decay	23 ± 7
ν_e from π decay	3 ± 1
Total Background	358 ± 35
0.26% $\nu_\mu \to \nu_e$	163 ± 21

3.2 Electron neutrino sample

The ν_e appearance analysis selection cuts reduce a sample of over 100,000 neutrinos events down to 358 events, as shown in Table 1. The primary backgrounds are NC π^0, and the intrinsic electron neutrinos in the beam, from μ^+ decay and kaon decay.

The rate of NC π^0 induced background is constrained by the NC π^0 events with two well-reconstructed photon rings. The measured rate for the 'clean' π^0 sample is compared to the simulation, and a reweighting factor determined in bins of π^0 momentum. This factor is then used to correct the predicted mis-reconstructed π^0 events in the ν_e sample.

3.3 Sources of uncertainty

The systematic errors included in the table cover primarily: flux, cross section and detector modeling uncertainties. In each case, MiniBooNE's data or external measurements constrain the error.

HARP measured protons producing π^+ off beryllium at exactly MiniBooNE's beam energy[3]. The differential cross section data from HARP is fit to a parameterization function, which is then used in the MiniBooNE beam simulation. For kaon production, external measurements were made with beams of energy spanning 9.5GeV/c to 24 GeV/C [4], these are scaled to 8.9 GeV/c using a Feynman scaling model and then fit as well. Errors cover both the spread of the data as well as parameterization uncertainties.

The differential cross section for quasi-elastic scattering is measured from CCQE ν_μ data. A fit to the shape of the four-momentum transfer (Q^2) distribution fixes an effective axial mass and nuclear effects parameter which is then applied to the ν_e CCQE sample.

In order to model light propagation in oil properly, we use a variety of internal and external measurements. The model includes: scintillation light (yield, spectrum, decay times), fluorescence (rate, spectrum, decay times), scattering (Rayleigh, Raman), absorption, reflection (off the tank walls and PMT faces) and PMT effects (single photoelectron charge response, charge linearity). External measurements such as scintillation light from the oil in a proton beam, from cosmic ray muons, fluorescence spectroscopy, time resolved spectroscopy and attenuation measurements of the mineral oil are also included. Finally, samples in MiniBooNE such as the cosmic ray muons, their decay electrons, and in-situ laser flasks constrain the model.

4 Oscillation Fit

Just as there are two parallel PID selection methods, the fit for oscillation was performed in two different ways. The likelihood analysis uses a CCQE ν_μ sample to constrain the predicted intrinsic ν_e spectrum from muon decay and the predicted ν_e spectrum from ν_μ oscillations. The BDT method performs a χ^2 minimization fit between data and simulation for a χ^2 that includes both ν_μ and ν_e events along with their correlations. The ν_μ data sample is used to reduce the size of the flux and cross section uncertainties. Much like a 'near to far' ratio, this cancels systematics which are the same for the two samples, and also reduces the ν_e uncertainties with the high statistics ν_μ sample. The largest intrinsic ν_e sample comes from μ^+ decay. As the parent π^+ decays to both the μ^+ and ν_μ, and MiniBooNE subtends a small angle of the neutrino beam, the μ^+ spectrum is closely related to the observed ν_μ spectrum, and the additional knowledge of the μ^+ spectrum limits what the ν_e from μ^+ can be.

5 Result

Two weeks after the presentation at Moriond, the collaboration agreed to 'open the box', and unblind the ν_e sample. Less than a month later, the oscillation result paper was posted to the preprint server and submitted for publication[6]. Although the presentation of this talk lacked any reference to the result, it is summarized here for completeness.

MiniBooNE did not observe an excess of events consistent with a two-neutrino oscillation explanation of the LSND observation. The final sensitivity is shown in Fig. 1. Within the main energy fit region of reconstructed neutrino energy between 475 MeV and 1275 MeV, the ν_e sample was consistent with no oscillation (see Fig. 2). However, an excess at lower than 475 MeV has been observed, but is still under investigation, and is not consistent with a simple oscillation model.

Acknowledgments

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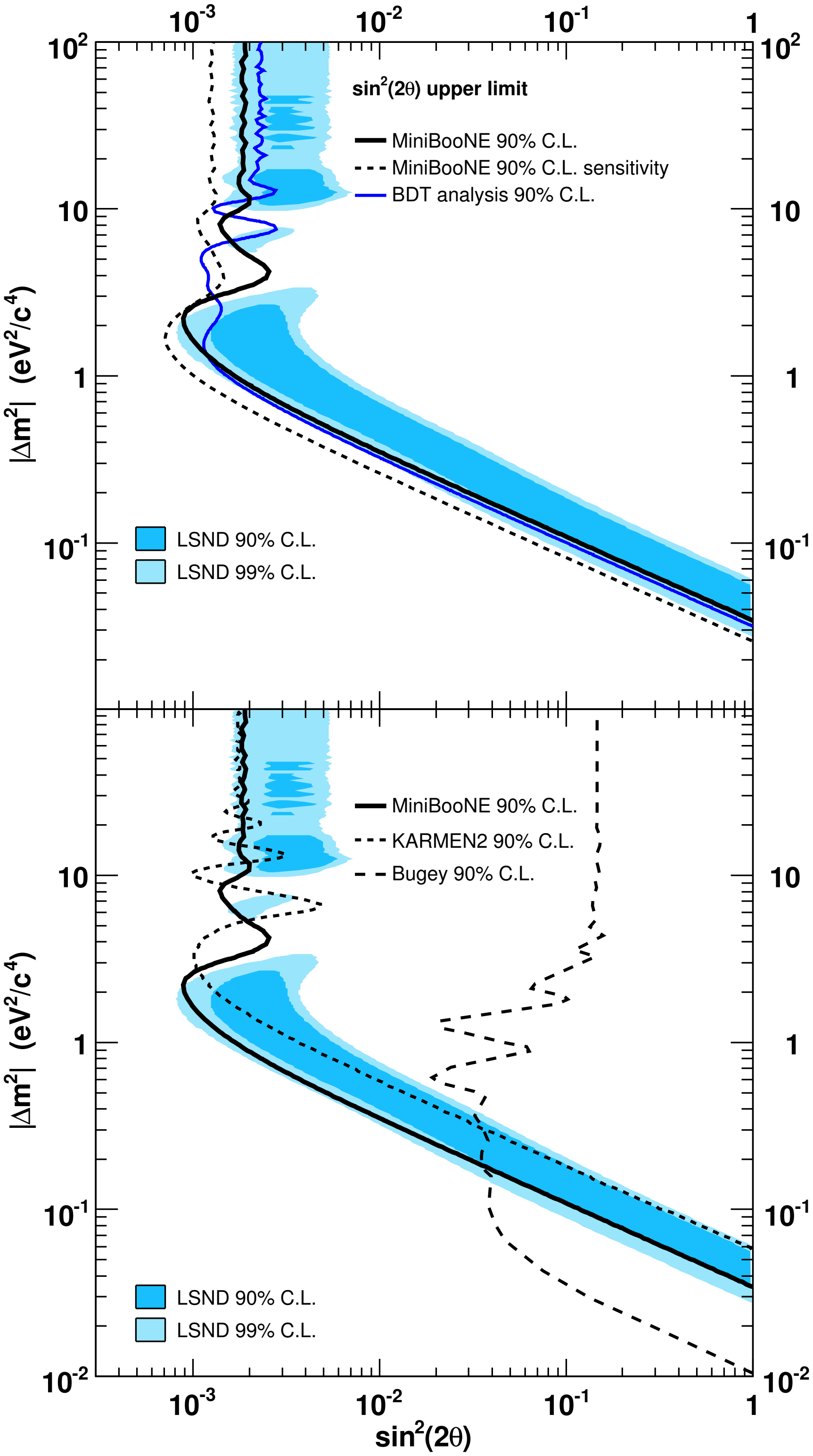

Figure 1: Top: The final sensitivity curves of MiniBooNE in $sin^2(2\theta) - \Delta m^2$ space within a two neutrino oscillation model. Black shows the MiniBooNE 90% C.L, dash shows the sensitivity for the likelihood analysis. Blue shows the BDT analysis 90% C.L. Bottom: MiniBooNE's 90% C.L. is shown in solid black, along with KARMEN2 (dot) and Bugey (dash).

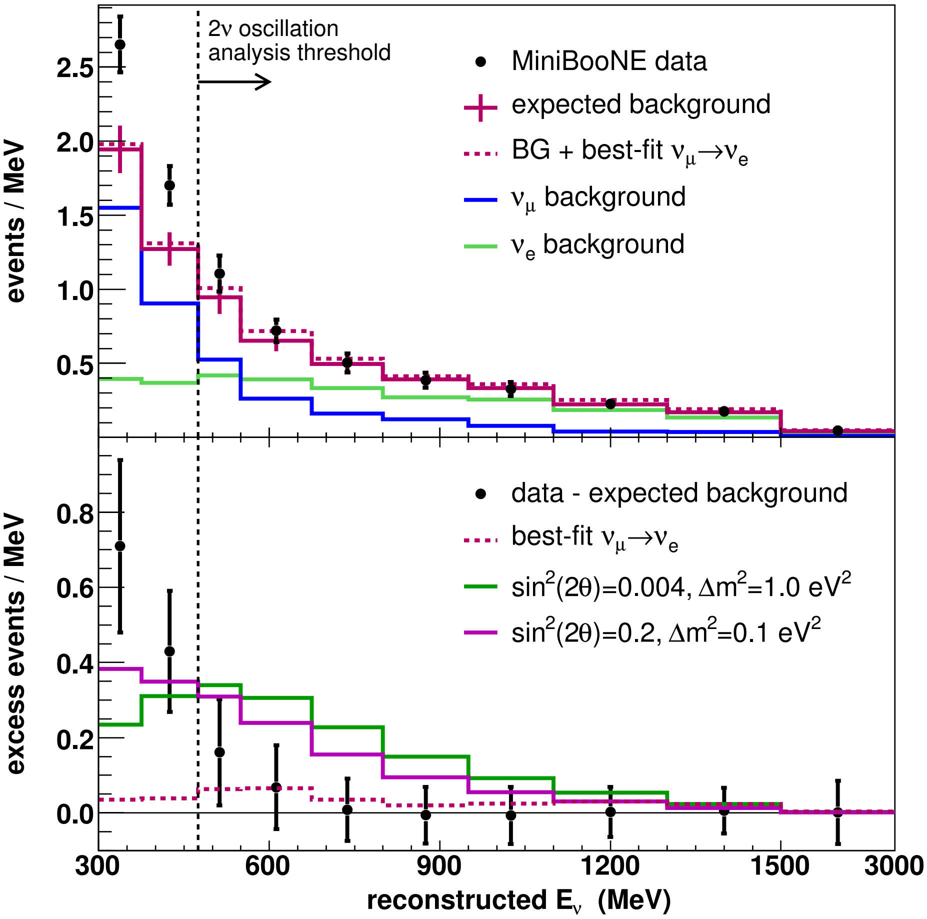

Figure 2: Events passing ν_e selection criterion as a function of reconstructed neutrino energy for the likelihood analysis. Top: Data is shown in black, expected background in solid red. Dashed shows the background with the best fit oscillation hypothesis. Intrinsic electron neutrino induced events are shown in solid green, and solid blue shows events from muon neutrinos. Bottom: Data, background subtracted shown in black, best fit oscillation shown in dashed red, solid green shows $sin^2(2\theta) = 0.004, \Delta m^2 = 1.0eV^2$, and solid purple shows $sin^2(2\theta) = 0.2, \Delta m^2 = 0.1eV^2$.