Updated Search for Electron Antineutrino Appearance at MiniBooNE

E. D. Zimmerman

University of Colorado, Boulder, Colorado 80309
For the MiniBooNE Collaboration

Abstract. The MiniBooNE experiment at Fermilab has updated its search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations with data collected through May 2011. This represents a statistics increase of 52% over the result published in 2010. The data favor LSND-like oscillations over a background-only hypothesis at the 91.1% confidence level. While the new result remains equally consistent with LSND, the compatibility with the background-only hypothesis is improved. An excess of $38.6 \pm 18.5 \bar{\nu}_e$-like events below 475 MeV is observed, consistent with the observation of such an excess in neutrino mode.

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MINIBOONE

The MiniBooNE experiment (E898/944) at Fermi National Accelerator Laboratory is a short-baseline neutrino oscillation experiment whose main purpose is to test the LSND oscillation results [1]. MiniBooNE uses an 8 GeV proton beam from the Fermilab Booster to produce pions, which then decay in flight to produce a nearly pure $\nu_\mu$ flux at a mineral oil Cherenkov detector 500 m away. The detector uses Cherenkov ring shape information to distinguish charged-current $\nu_\mu (\bar{\nu}_\mu)$ from $\nu_e (\bar{\nu}_e)$ interactions, searching for an excess of $\nu_e$ which would indicate oscillations. Data collection began in late 2002 with the beam configured to produce neutrinos; since 2007 most operations have been with the focusing polarity reversed to produce antineutrinos. Antineutrino studies are important for a complete test of LSND, which was primarily a $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ search.

OCCILATION RESULTS FROM MINIBOONE

MiniBooNE has three previous appearance-mode oscillation results. The general technique is similar in all of them: events with a single electron-like Cherenkov ring are selected as charged-current quasielastic (CCQE) candidates. Cuts are designed to remove neutral-current $\pi^0$ events as well as fragments from neutrino interactions that occurred outside the detector (“dirt”). The reconstructed neutrino energy $E_{\nu\text{QE}}$ is computed assuming the process was $\nu N \rightarrow e N'$ with the nucleon unobserved and the neutrino originating from the beam direction. Significant backgrounds are intrinsic $\nu_e$ in the beam, neutral-current $\pi^0$ and $\Delta \rightarrow N\gamma$, and dirt. Neutrinos and antineutrinos cannot be distinguished on an event-by-event basis.

In 2007, the main search for LSND-like oscillations in neutrino mode was published [2] based on $5.7 \times 10^{20}$ protons on target (POT). This result excluded a CP-conserving two-neutrino oscillation explanation for LSND at the 98% confidence level. At the same time, an unexplained excess of $\nu_e$-like events below 475 MeV was seen; further studies of this low-energy excess were published in 2009 [3].

In 2010, a search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ from $5.66 \times 10^{20}$ POT in antineutrino running mode was published [4]. That paper indicated an excess of $20.9 \pm 14.0 \nu_e / \bar{\nu}_e$ candidates in the 475-1250 MeV range where MiniBooNE is most sensitive to LSND-like oscillations and contributions from the neutrino-mode low-energy excess are minimized. However, a likelihood-ratio fit to the energy distributions of both the $\nu_e$ and $\bar{\nu}_e$ candidates preferred the oscillation hypothesis over the background-only hypothesis with 99.4% probability. In the low-energy region of 200-475 MeV, the data excess over the background prediction was $18.5 \pm 14.3$ events. Scaling the neutrino-mode low-energy excess by the expected neutrino contamination in the antineutrino flux gives a predicted low-energy excess of 12 events.
TABLE 1. Preliminary predicted low-energy excess from scaling neutrino-mode excess by various factors. The value observed in data is $38.6 \pm 18.5$.

| Scaling basis             | Predicted excess | Scaling basis             | Predicted excess |
|---------------------------|------------------|---------------------------|------------------|
| Total background          | 50               | Neutrino contamination    | 17               |
| $\Delta \to N\gamma$ decays | 39               | Dirt                      | 46               |
| Protons on target*        | 165              | $K^+$ in secondary beam   | 67               |
| Neutral-current $\pi^0$   | 48               | Inclusive charged-current | 59               |

* Excess would scale this way if due to neutral particles in secondary beam.

UPDated ANTINEutrino RESULTS

In this section we present preliminary updates to the antineutrino oscillation search reported in Ref. [4] using $8.58 \times 10^{20}$ POT, using a nearly unchanged analysis. The most significant change is an improved constraint on kaon-decay $\nu_e$ in the beam from the SciBooNE experiment [5], reducing the prediction for that background source by 3% and its error by a factor of three. Detector and beam monitoring have indicated no significant changes over the entire run period, and Kolmogorov-Smirnov tests of neutrino control samples are consistent with a constant event rate.

The reconstructed energy distribution of $\bar{\nu}_e$ candidates is shown in Fig. 1a. In the augmented data set, 168 events are observed in the 475–1250 MeV region, corresponding to an excess of $16.3 \pm 19.4$ over predicted background. The excess in this region is thus reduced when the new data are added.

In the low-energy region, the excess has grown to $38.6 \pm 18.5$ events. We can compare this excess to predictions from scaling the observed neutrino-mode low-energy excess by various factors (see Table 1). This can exclude some possible phenomena as primary sources of the low-energy excess, though it should be noted that none of these processes can be scaled by a large enough factor to explain the low-energy excess without disagreeing strongly with control samples.

The primary test of LSND’s result is the simultaneous fit to the $\nu_\mu$ and $\bar{\nu}_e$ candidates in the $475 < E_{\nu}^{\text{QE}} < 3000$ MeV range. The updated confidence-level contours are shown in Fig. 1b. The fit prefers the oscillation hypothesis to the background-only hypothesis at 91.1% confidence level. The best-fit point moved from the high-$\sin^2(2\theta)$, low-
$\Delta m^2$ region to the high-$\Delta m^2$ “island” solution, however the $\chi^2$ minimum is quite broad so this does not represent a significant change. In the signal bins, the $\chi^2$ probability is 14.9% for background-only and 35.5% for the oscillation fit. (These numbers were 0.5% and 10% before the statistics update.) The 68% confidence level contour still covers most of the LSND allowed region. This result is therefore still consistent with LSND, but the evidence for LSND-like oscillations is no longer as strong.

As in the published result, fits have been performed under other sets of assumptions. First, a fit to the entire energy range ($200 < E_{\nu}^{QE} < 3000$ MeV) yields similar contours, with oscillations preferred with 97.6% probability. The fit $\chi^2$ probabilities for background-only and the best oscillation fit are 10.1% and 50.7% respectively. However, it should be noted that there is a large known neutrino contamination in antineutrino running (22% of the $\bar{\nu}_\mu$ candidates and 44% of the total background to the $\bar{\nu}_e$ oscillation signal). A low-energy excess from neutrinos may be expected to contribute to the 200-475 MeV bins in this fit, but has not been subtracted because its origin and scaling are unknown. Therefore, this fit cannot be interpreted as a pure antineutrino physics result.

Another alternative fit is done with additional background subtraction, assuming that the low-energy excess contribution from neutrinos simply scales with the neutrino-induced event rate in each bin. This model’s validity may be poor, however, if the excess is due to feed-down from misreconstructed higher-energy neutrinos with unobserved particles in the final state (since the neutrino spectrum differs between neutrino and antineutrino running). The fit under this background subtraction model prefers oscillations with 94.2% probability. The fit $\chi^2$ probabilities for background-only and the best oscillation fit are 28.3% and 76.5% respectively.

The contours and best-fit points for the fits to the full energy spectrum are available in the slides from this presentation.

CONCLUSION AND NEXT STEPS

MiniBooNE presents a preliminary update to its 2010 electron antineutrino appearance search with 52% more integrated flux. Adding the new data reduces the significance of the apparent LSND-like oscillation signal, and reveals a low-energy excess of $\bar{\nu}_e$ candidates similar to that observed in neutrino mode. In the higher-energy region, the new data are consistent with both LSND and a background-only hypothesis.

The experiment will continue to take data at least until the 2012 shutdown. The collaboration’s goal is a total of $1.5 \times 10^{21}$ POT – nearly doubling the current data set. This statistically-limited result should benefit greatly from the additional data. If either our best-fit value or LSND’s central value is correct, the expected exclusion of the background-only hypothesis (relative to the oscillation fit) with a data set that large is at the 98-99% confidence level.

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