Paper of the month: Search for an anomalous excess of inclusive charged-current ν_e interactions in the MicroBooNE experiment using Wire-Cell reconstruction

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The observation of the neutrino oscillation phenomenon [1, 2, 3, 4] provides unquestionable evidence for the existence of non-zero neutrino masses. Upon combining all available data from different experiments, we have established the existence of two mass squared differences, Δm^2_{31} and Δm^2_{21}, which drive neutrino oscillations over distances $L \sim E_\nu/\Delta m^2_{3(2)1}$, where E_ν is the neutrino energy. Given the small values for these mass square differences and the typical neutrino energies studied in oscillation experiments, $E_\nu >$ MeV, one would expect to observe oscillations only when placing the detector far away enough, at least some kilometers away from the neutrino source for $E_\nu \sim 1$ MeV.

Surprisingly, the LSND experiment [5] studying a ν_μ neutrino beam with a detector 30 m away from the source found a larger amount of ν_e events than expected, pointing to an oscillation $\nu_\mu \to \nu_e$ at short baselines driven by $\Delta m^2 \sim 1$ eV$^2 \gg \Delta m^2_{3(2)1}$. One possible explanation for this would be the existence of a new kind of neutrino, the so-called "sterile" neutrinos, which are present in many neutrino mass models. Given the relevance of the LSND result, the MiniBooNE experiment [6, 7] was designed to test the "sterile neutrino hypothesis" and check whether new physics had been discovered or not. MiniBooNE's results were again surprising, and an excess of ν_e events at low energies in the detector was found, as shown in Fig. 1 for energies below 600 MeV.

Several possible explanations were found for MiniBooNE's electron low-energy excess (eLEE), among which one can highlight two:

- Electron neutrino appearance in a muon neutrino beam which will lead to the conclusion that the eLEE is indeed a result of oscillations of an unknown kind of eV-scale sterile neutrino [9].
- SM background processes producing photons which cannot be easily distinguished from electrons in the MiniBooNE detector. The identified dominant process would be the neutral current radiative decay of the Δ baryon into a single photon (NC $\Delta \to N\gamma$).

MicroBooNE's first round of eLEE analyses addresses these two hypotheses using the Booster Neutrino Beam (BNB) flux and taking MiniBooNE's previous observations to build a data-driven LEE model. The MicroBooNE experiment uses the liquid argon time projection chamber (LArTPC) technology, which allows to unequivocally distinguish between electrons and photons, in contrast to MiniBooNE. This separation power is based on a calorimetric distinction that relies on the ionization pattern at the beginning of the particle shower.

The NC $\Delta \to N\gamma$ radiative decay is studied from ν_μ charged-current (CC) or NC interactions with a single photon and a proton track or a single photon in the final state. After performing

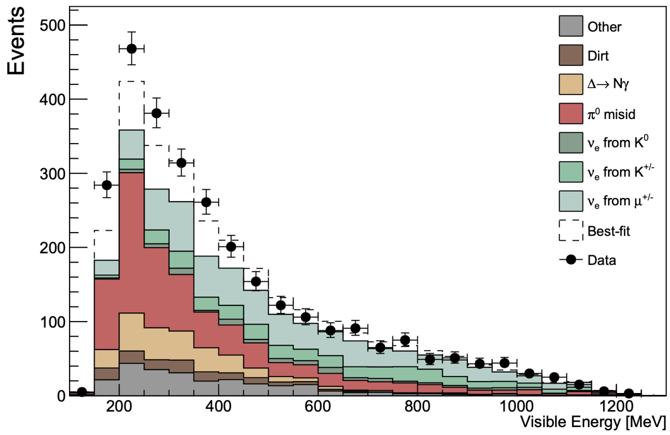

Figure 1: Event number in the MiniBooNE detector (black dots) as a function of the visible energy. The different shaded regions correspond to different contributions to the expected event rate.

statistical tests, the NC $\Delta \to N\gamma$ radiative decay hypothesis is disfavored as an interpretation for MiniBooNe's eLEE at 94.8% C.L. [8].

On the other hand, the electron neutrino hypotheses is analysed measuring three independent final state topologies: quasielastic-like, pionless and inclusive CC electron neutrino. To perform a quantitative comparison of the results between MicroBooNE and MiniBooNE, a prediction with an eLEE signal is developed taking the MinibooNE excess, unfolding it through MiniBooNE's simulation and applying the excess directly to the intrinsic electron neutrino spectrum expected in the MicroBooNE detector.

The results from such a search are shown in Fig. 2, where the different contributions to the signal (black dots) are shown as the coloured shaded regions. The light-grey regions correspond to the predicted uncertainty in each energy bin. Additionally, the LEE expected events in MicroBooNE are shown as a red-dashed line. The lower panel shows the ratio between the data and the prediction without an eLEE, together with the expected uncertainty. Given that MicroBooNE's data is in well agreement with the lack of an electron low-energy excess, the eLEE hypothesis can be rejected using this first round of data at 3.75 σ.

MicroBooNE has provided the first test for the longstanding MiniBooNE low-energy excess, and found no evidence for it so far. Nonetheless, more data will be collected in the future, and together with future experiments we will be able to fully test the existence of a sterile neutrino oscillation signal.

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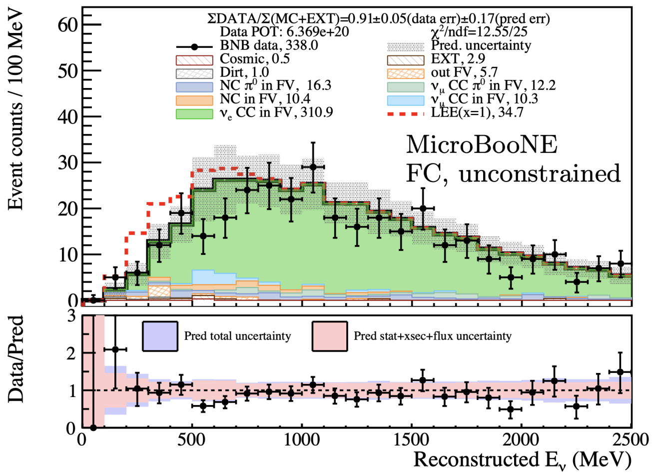

Figure 2: Event number in the MicroBooNE detector (black dots) as a function of the reconstructed neutrino energy (upper panel), together with the eLEE prediction (red-dashed lines). The lower panel corresponds to the ratio between the data and the prediction without eLEE.

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