Neutrino Oscillations, MicroBooNE, and Hand-Scanning

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Neutrino Oscillations

Recent experiments have shown that neutrinos change flavors. Data from the KamLAND, MINOS, Super-Kamiokande, KEK to Kamioka (K2K), and Sudbury Neutrino Observatory (SNO) experiments have all determined that these flavor changes occur in neutrinos produced in the atmosphere, accelerators, reactors, and the sun.

The model put forth describes these flavor changes as the mixing of different mass states. In a simplified version with 2 (instead of 3) flavors, the matrix describing this mixing is:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

where θ is the mixing angle. The probability of a flavor change is then given by:

$$P_{\nu_\mu \to \nu_e}(L, E) = \sin^2 2\theta \, \sin^2\left(1.27 \, \Delta m^2 \frac{L}{E_\nu}\right)$$

where Δm is the mass difference, L is the distance traveled, and E_ν is the energy of the neutrino. This model can be expanded to a situation with three flavors and three distinct mixing angles.

Results

An efficiency trial was conducted with 100 random events of all types. Our algorithmic procedure was able to reject 98% of the background noise and keep all of the ν_e signal. However, several π^0's were misidentified as electrons. Further studies still need to be conducted on π^0 identification as well as on heavier particles, such as $K^\pm$, Σ^+, Λ^0.

Acknowledgements

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Hand-Scanning

Our goal for the summer was to create an algorithmic procedure for identifying ν_e events and rejecting ν_μ events in Monte Carlo simulations of the MicroBooNE data (Figure 1). This was done by examining simulations of various particle types and determining their characteristics. From this information and a knowledge of neutrino interactions, a set of criteria could be developed.

The procedure developed is as follows:

Step 1:
- Discard all events not containing a primary interaction vertex.
- These are intractable and can not be used.

Step 2:
- Discard all events not containing an electromagnetic shower (Figure 2).
- Charged-current ν_e events will always produce an electron, which creates a tell-tale shower.

Step 3:
- Discard all events containing distinctive μ tracks (Figure 3).
- μ's have characteristically long, straight, minimum ionizing tracks.
- μ's are produced in charged-current ν_μ events and as such can be ruled out.

Step 4:
- Determine the shower origin and discard non-electron induced events.
- The candidates are π^0, $\pi^\pm$, γ, and electrons
- γ's leave gaps between the shower and the vertex and can be identified by this (Figure 4).
- $\pi^\pm$'s go through a decay before showering and can be found through bends in their tracks (Figure 6).

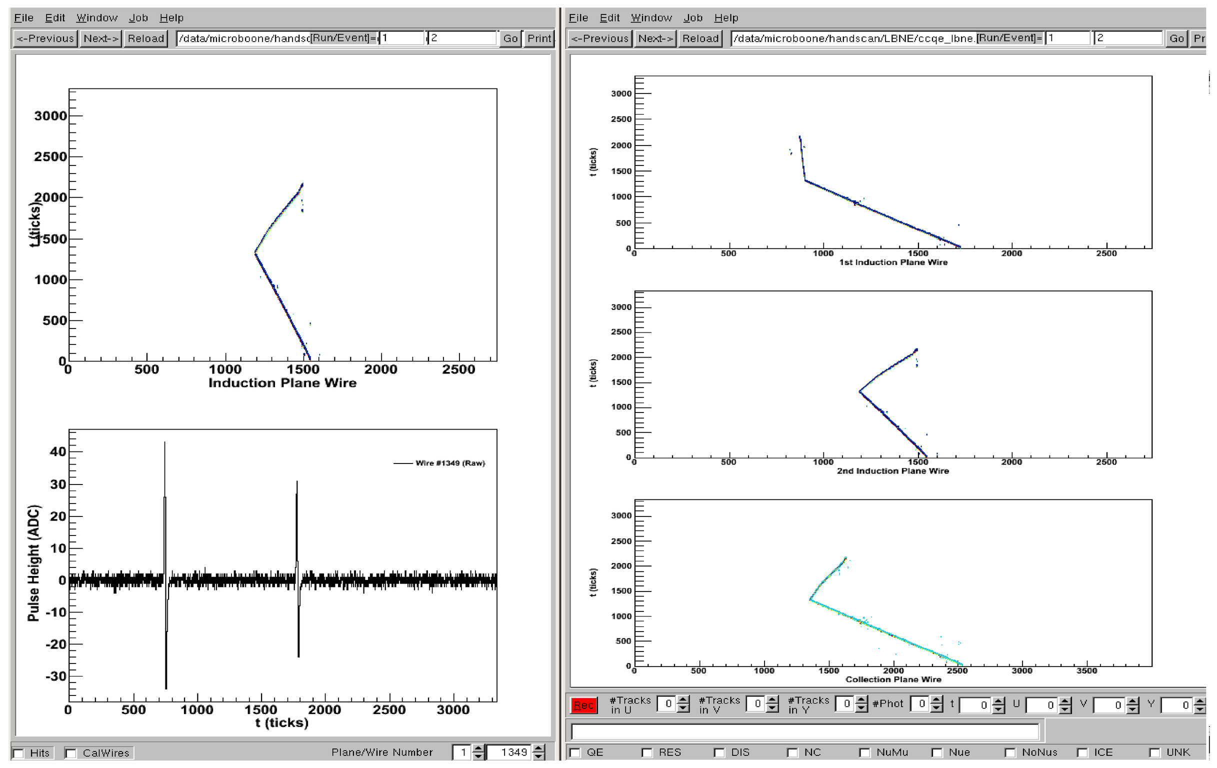

Figure 1: The LArSoft event display

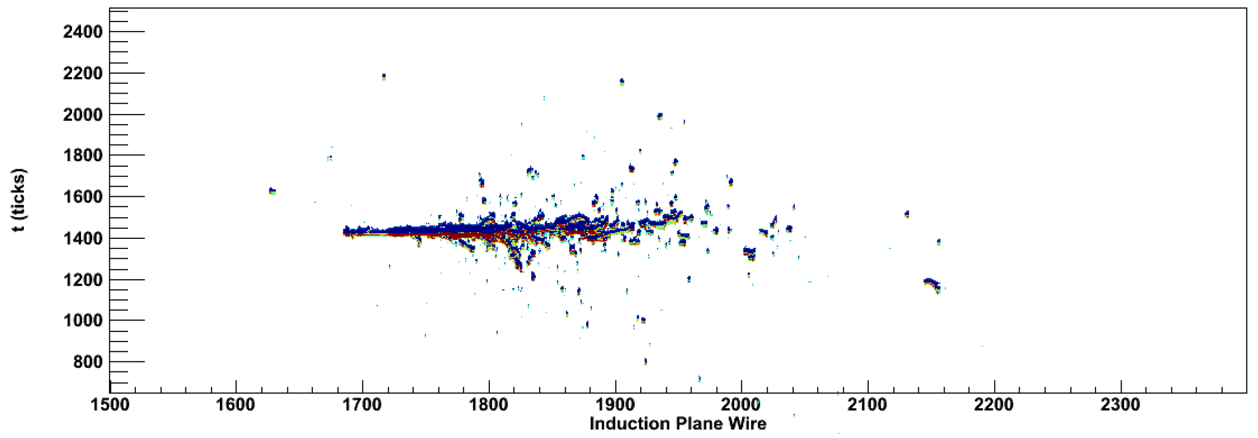

Figure 2: An electromagnetic shower

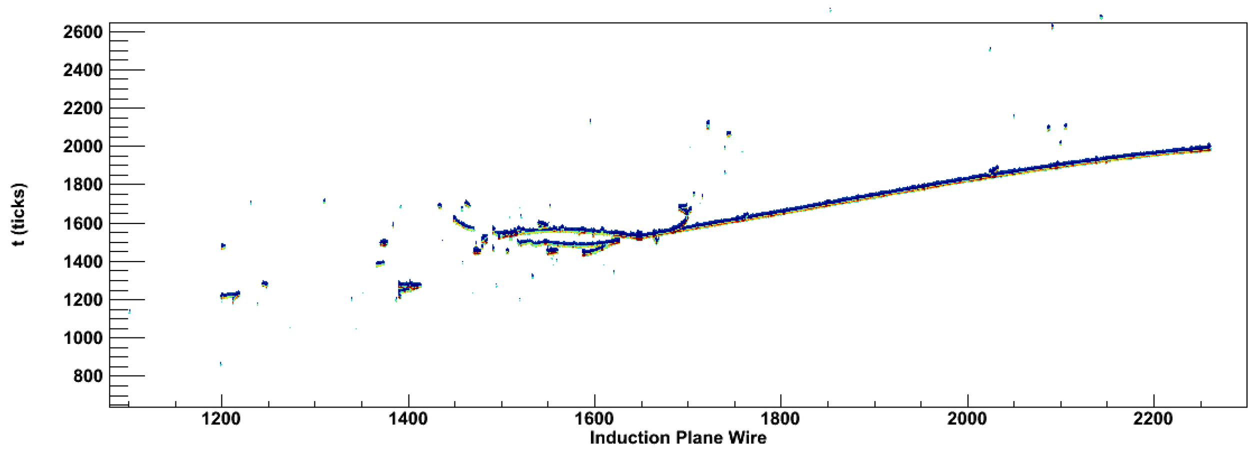

Figure 3: A typical μ track

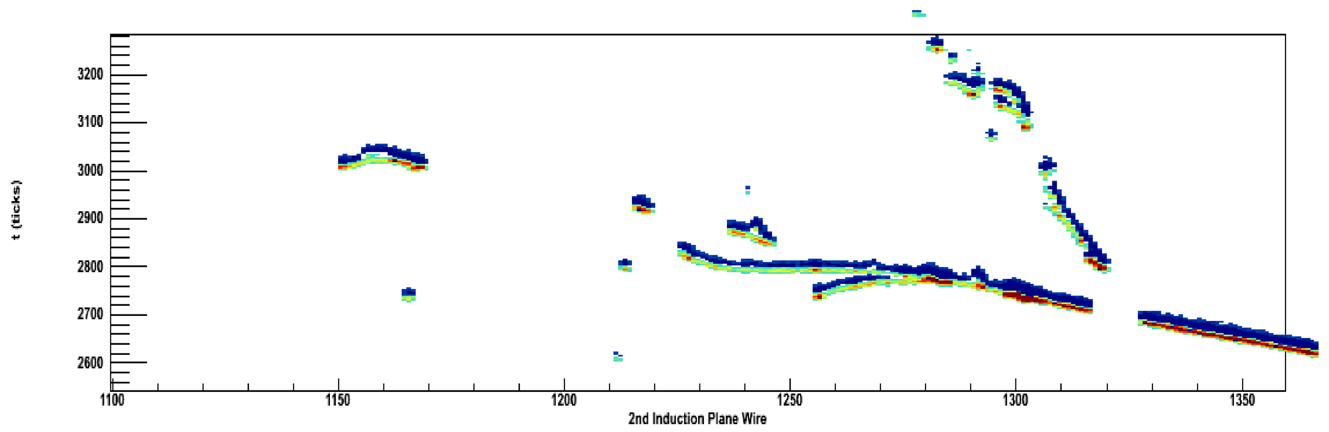

Figure 4: A showering π^0 (decay to γ's)

The MicroBooNE Detector

MicroBooNE is a liquid argon based detector to be built at Fermilab (Figure 5). Its goal is to detect events arising from neutrinos, determine their flavors, and compare the frequencies to the calculated probabilities to measure the mixing angle.

Charged particles traveling through the detector ionize the argon atoms as they pass by. The ions then drift to wire detection planes under the influence of a strong electric field (500 V/cm). The information collected at the wires can then be used to reconstruct the event with extreme resolution.

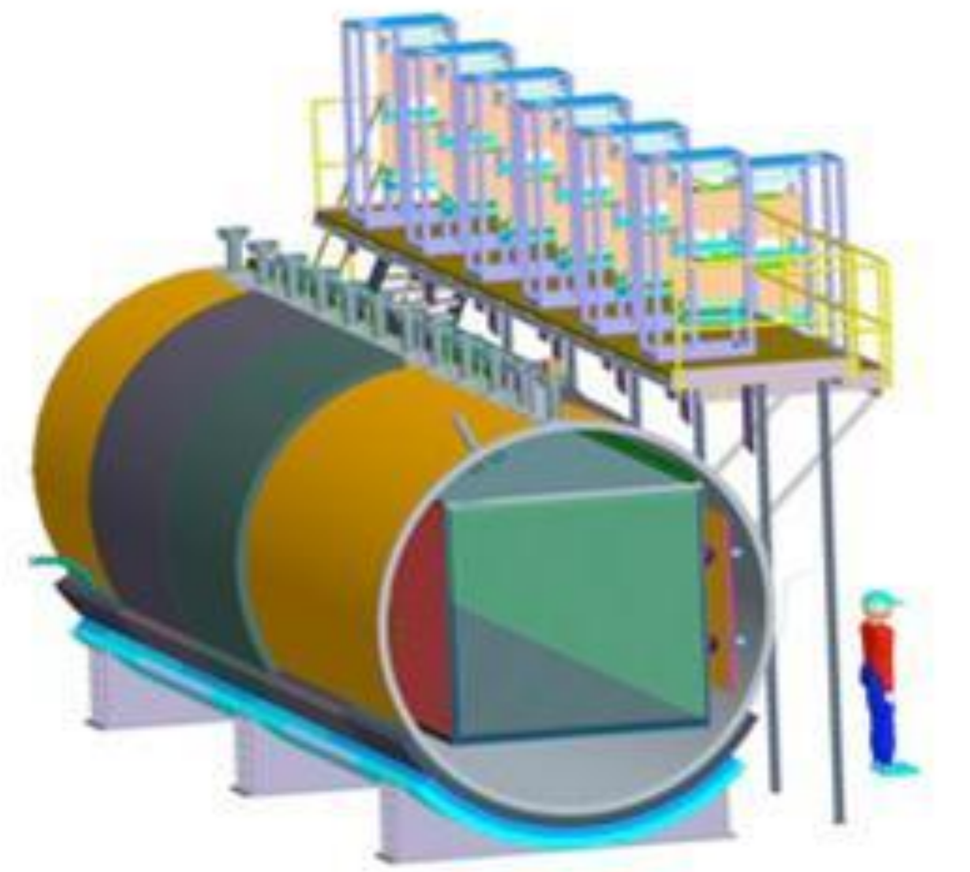

Figure 5: The MicroBooNE detector

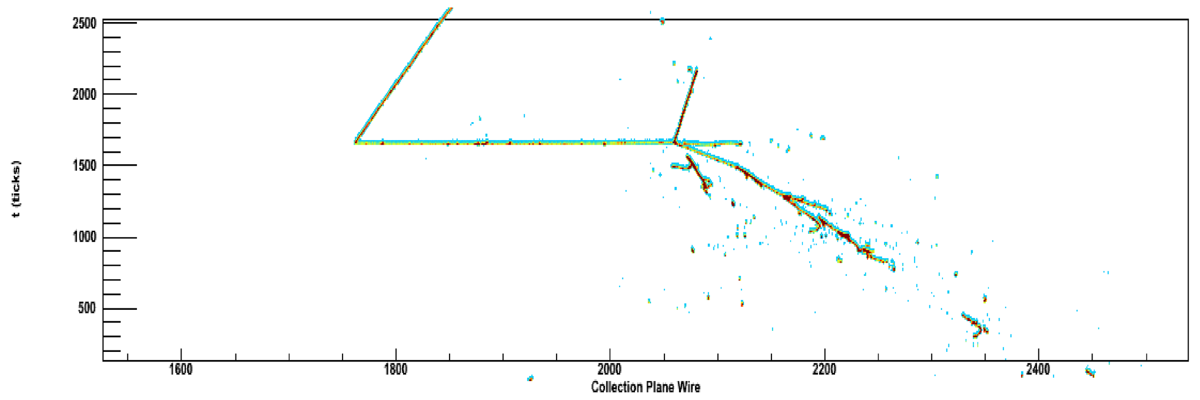

Figure 6: A $\pi^\pm$ induced shower