Electron Neutrino Background Analysis with the MINOS Near Detector

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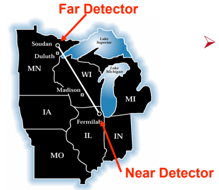
Motivation



Baseline = 735 km

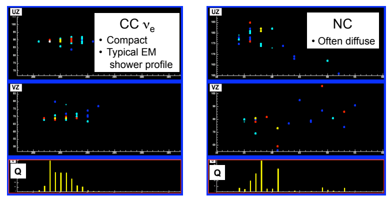
➢ The opportunity:

- **MINOS has a chance of making the first measurement of a non-zero θ_{13},** if this mixing angle lies in the vicinity of the current experimental limit set by the CHOOZ experiment.
- As muon neutrinos from the NuMI beam travel from Fermilab to Minnesota a very small fraction of them can oscillate to electron neutrinos:

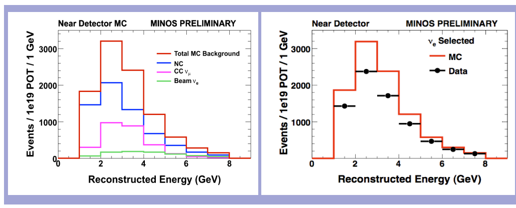
$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2\frac{\Delta m^2_{32} L}{4E} \quad \text{(to leading order)}$$

➢ The challenge:

- The MINOS detectors are designed for Charged -Current (CC) ν_μ identification and thus lack the optimal granularity for electromagnetic vs. hadronic shower separation.
- The CC ν_e selections are dominated by a background comprised of Neutral Current (NC), CC ν_μ and intrinsic beam ν_e events.



➢ The key:



- **The key lies in the precise determination of the backgrounds**, as the extrapolation to the Far Detector is dependent on the event type.

The Data/MC disagreement is not unexpected as hadronic showers are hard to model and occur in a kinematic region where little experimental data is available.

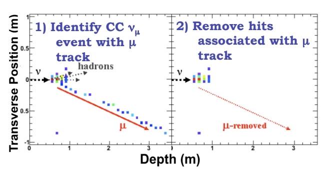
The Muon Removal (MRCC) Method

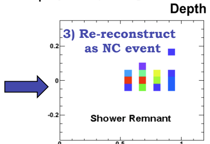
➢ The premise:

- Data/MC discrepancy originates primarily from imperfect hadronic shower modeling.
- Showers from NC and CC ν_μ interactions are to first order very similar in the MINOS detectors.

→ Use CC ν_μ showers from data to model NC events.

➢ The MRCC procedure:

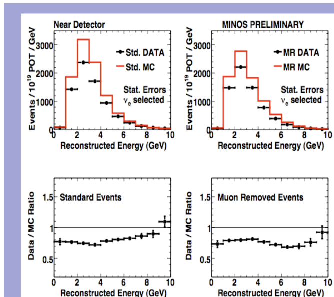




and the CC ν_e selection is then applied to the MRCC samples (both data and MC)

➢ The correction:

- The ratio of ($MRCC^{Data}$ / $MRCC^{MC}$) is used to correct the NC component in the standard MC, which cancels out the systematics in the MRCC procedure.
- The remaining Data-MC discrepancy is absorbed by the correction to the CC ν_μ component.

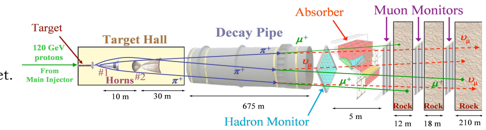


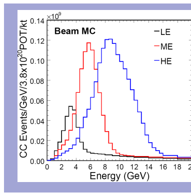
Data-MC discrepancy is very similar between standard and MRCC samples.

The NuMI Beam and the MINOS Near Detector

➢ The beam:

- The beam is obtained from 120 GeV Main Injector protons impinging on a graphite target.



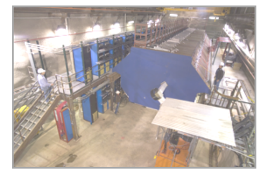


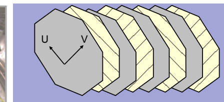
- The particles produced in the target are focused by two magnetic "horns" into a 675 m long, 2 m diameter steel pipe.
- The decays of the particles in the decay pipe produce an almost pure ν_μ beam.

It is possible to modify the neutrino energy spectrum by changing the horn current and its separation with the target. Most of the MINOS data is taken in the 'low energy' (LE) beam configuration, composed of 98.5% ν_μ and 1.5% ν_e.

➢ The Near Detector:

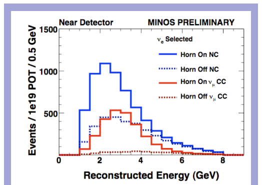
- The Near Detector is located 1km downstream of the target at Fermilab and is used to **study the unoscillated beam composition and energy spectrum**.
- Planes of steel and scintillator alternate in a 1.2 T toroidal magnetic field.
- The scintillator planes are segmented into 4.1 cm wide parallel strips.





Alternating scintillator planes have strips perpendicular to one another allowing reconstruction of events in 3D

The Horn On/Off (HOO) Method



Data taken in the horn-off configuration provides us with an NC enriched sample

➢ The premise:

- When the horns in the NuMI beam are turned off pions coming off the target are no longer focused.
- The data taken in the horn-off configuration results in a distinctive visible energy spectrum with a very different composition from the one obtained in the LE configuration.

➢ The method:

- The number of events selected in the horn-on/off configurations can be described by a system of two equations that can be solved for the two unknown CC ν_m (N_{CC}) and NC (N_{NC}) components:

$$\begin{cases} N^{on} = N_{NC} + N_{CC} + N_e \\ N^{off} = r_{NC}{*}N_{NC} + r_{CC}{*}N_{CC} + r_e{*}N_e \end{cases} \quad \text{where} \quad r_x = N_x^{off} / N_x^{on}$$

- The ratios of events in the two configurations r_x are determined from simulation and are robust against modeling uncertainties.
- As in the MRCC method, the intrinsic beam ν_e component N_e is taken from simulation. Electromagnetic showers are well modeled, and the rate and spectrum of beam electron neutrinos are well known as most of them originate from μ^+ decay. Furthermore, a cross-check is done by measuring the number of anti-neutrinos from μ^+ decay.

The Results

- **The MRCC and HOO data-driven methods produce consistent results:**

Method	Total	NC	CC	Beam ν_e
Raw MC	9668 ± 22	6230 ± 18	2651 ± 11	788 ± 118
HOO	7303 ± 41	4491^{+233}_{-224}	2025^{+244}_{-220}	788 ± 118
MRCC	7303 ± 41	4899 ± 176	1617 ± 202	788 ± 118

(all errors are statistical except for MRCC and Beam ν_e)

- After being extrapolated to the Far Detector these numbers constitute the total background for the ν_e appearance analysis.