Simple Introduction to Discriminating ν_μ vs $\overline{\nu}_\mu$ in MINOS

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Abstract

This note summarises the event reconstruction in MINOS. The classification of events and background is defined and the reconstruction of tracks and showers is briefly explained. Then the extraction of $\overline{\nu}_\mu$ events is stressed: studies have been made to build discriminators between ν_μ and $\overline{\nu}_\mu$ events, and the main five (three of them being used in the official analysis) are detailed. This note is a summary, one should refer to [1] and the public MINOS documents listed the bibliography for further details.

1 Event Topologies

Three kinds of Charged Current (CC) neutrino events can be distinguished:

- Those induced by ν_μ, with a track from a muon and/or a hadronic shower at the vertex. In the forward magnetic field polarity, the μ^- bends towards the center of the detector and can either stop inside or exit the back.
- Those induced by $\overline{\nu}_\mu$, with a muon track and/or a hadronic shower. The μ^+ bends towards the outside of the detector and often exits. In this case the track is only partially detected.
- Those induced by ν_e and $\overline{\nu}_e$, with, most of the time no track, but a electromagnetic and/or a hadronic shower.

Neutral Current (NC) events, concerning all flavours, result in principle in observing only a shower, but sometimes a hadron can leave a track. It is important to note that a track has to be seen to distinguish between NC and $\nu_\mu/\overline{\nu}_\mu$ CC.

2 Backgrounds

The first maximum for the ν_μ and $\overline{\nu}_\mu$ oscillation is around 1.5 GeV for MINOS. At this energy, two kinds of background dominate:

- Wrong Sign events (WS): the tracks of the muons (whether μ^- or μ^+) can be short, thus making it difficult to extract their curvature. A μ^+ can be reconstructed as a μ^- and vice-versa. The muon tracks (especially if they are short) can be obscured in the hadronic showers. It is then difficult to reconstruct a track at all. Finally, a reconstruction error can occur for any track length, leading to a wrong estimate of the curvature.

- Neutral Current events: a hadron track can be mistaken for a muon. This category also includes the ν_e CC events, which occasionally have a track reconstructed. However, the fraction of events that are ν_e is much less than the number of NC, so they do not contribute to a significant background for $\overline{\nu}_\mu$.

3 Event Reconstruction in a nutshell

3.1 Tracks

The track reconstruction has two steps: finding and then fitting [2, 3].

Finding the track(s) in an event is an iterative process. The reconstruction is done in 2D first by considering the two independent plane views [4]. For each projection, all the possible segments of 3 hits over 3 to 5 consecutive planes are formed. The neighbouring segments are then matched by overlapping hits or finding segments with similar directions. A chain of segments is formed that can have branches: the longest and the straightest branch is kept as the 2D track. The two 2D tracks are matched to make a 3D track.

The track fitting uses a Kalman filter and outputs the curvature as q/p, the ratio of the charge over the momentum.

3.2 Showers

Like the track finding, the shower search works by treating the 2D views before matching them up to create a 3D object. Hits are clustered on a plane, then on groups of planes, according to their space and time correlations. An additional correlation looks for the position of the peak, within the shower, of the calorimetric response.

The reconstruction of the shower energy is basically the sum of each hit energy in the shower, but also depends on the nature of the event itself. For example, if the event has been identified as a ν_μ event and a long track has been found, then the fraction of the energy of the muon in the shower is evaluated and removed. This step thus happens after the event has been identified [3].

3.3 Events

An event is built by matching tracks and showers in space and time. The space matching is a search for a common vertex. If several tracks and showers have been associated to one event, then a primary shower (highest energy) and a primary track (most strips hit) are chosen [3].

4 Extracting $\overline{\nu}_\mu$

The identification of a $\overline{\nu}_\mu$ event relies on identifying the muon and determining its sign. Five variables that can be used to extract a pure $\overline{\nu}_\mu$ sample are described below.

- One of the most powerful ways to purify the $\overline{\nu}_\mu$ sample is to use the algorithms originally developed to reject NC events. These algorithms are good at rejecting both NC and WS events. The WS events tend to have a poorly identified track, often a high-y event where the track is buried in the shower to some extent. A selector has been built based on the event topology [5]. Three parameters have been chosen and their probability density functions (PDF) have been determined separately for signal and background events using Monte-Carlo. These parameters are:
  - the event length, in units of detector planes;
  - the fraction of the total event energy (calorimetric response) in the reconstructed track;

  - the average calorimetric response per plane for the reconstructed track.

The three signal (background) PDFs are multiplied, giving the probability of an event to be signal (background). The two probabilities for signal and background are then combined in a selection parameter centered around 0. Most of the background is located on the negative side of the selector distribution, and a cut keeping the selector values above 0.25 is applied to obtain a good purity data sample of $\overline{\nu}_\mu$. Figure 1 shows the selection parameter and the PDFs for events with positive curvature tracks and after the cuts on relA and q/p have been applied (see below). The MC background in the plots is the NC and WS events. See [5] for more detailed explanation on the PDFs and the selector (note that in [5] the data shown are for all events regardless of the track curvature).

- The track fit probability (in ROOT: TMath::Prob(χ^2,n)) is computed for each fit from the reduced χ^2. It offers better rejection power than the simple reduced χ^2.
- The curvature of the muon track is obtained from the fit as the q/p value. The ratio $\frac{q/p}{\sigma(q/p)}$ gives the charge confidence in units of sigma, and the value used for the cut in MINOS is 3.5.
- Another variable with discriminating power is called majority curvature. This variable is based on parabolic fits of successive segments of the track, giving successives values of the curvature. They can be positive or negative depending on the track segment, e.g. because of scattering. The number of segments with a positive curvature and those with a negative one are calculated and used to build the majority curvature. This variable thus expresses the general curvature of the track against the possibility of scattering. Here the cut is made to reject negative values [7] [1].
- The last variable looks at the amount of deflection of the track in the toroidal magnetic field and is called the relative angle, relA. The direction of the track at the vertex is projected in a straight line on to the last plane of the track (point P). Because of the curvature of the

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[1] This variable is not currently used in the official analysis of the $\overline{\nu}_\mu$ oscillation and the reference has been yet published in the public MINOS database, see [7] to contact the author.

track, P is at a different position than the actual end of the track E. On the last plane, P is made the center of a reference frame that has its x-axis going through the center of the detector and pointing outwards (perpendicular to the magnetic field lines). The angle between the x-axis and the segment PE is another way to describe the curvature of the track. It is expected that the μ^+ have an angle between $-\pi/2$ and $\pi/2$ and the μ^-, between $\pi/2$ and $3\pi/2$. The cut is made on the variable $\mid \mathrm{relA} - \pi \mid$ and rejects values below 2.08 [6].

References

[1] http://minos-docdb.fnal.gov/cgi-bin/DocumentDatabase/

[2] J.Marshall, *A study of muon neutrino disappearance with the MINOS detectors and the NuMI neutrino beam*, DocDB 4849-v1.

[3] A.Culling, *An Optimised Oscillation Analysis of MINOS Beam Data*, DocDB 3673-v1, 2007.

[4] MINOS Coll., NIM A 596 (2008) 190-228.

[5] MINOS Coll., Phys.Rev.D 77, 072002 (2008).

[6] R.Ospanov, *A measurement of muon neutrino disappearance with the MINOS detectors and NuMI beam*, DocDB 5544-v1, 2008.

[7] J.Evans, *Measuring Antineutrino Oscillations with the MINOS Experiment*, evansj@hep.ucl.ac.uk

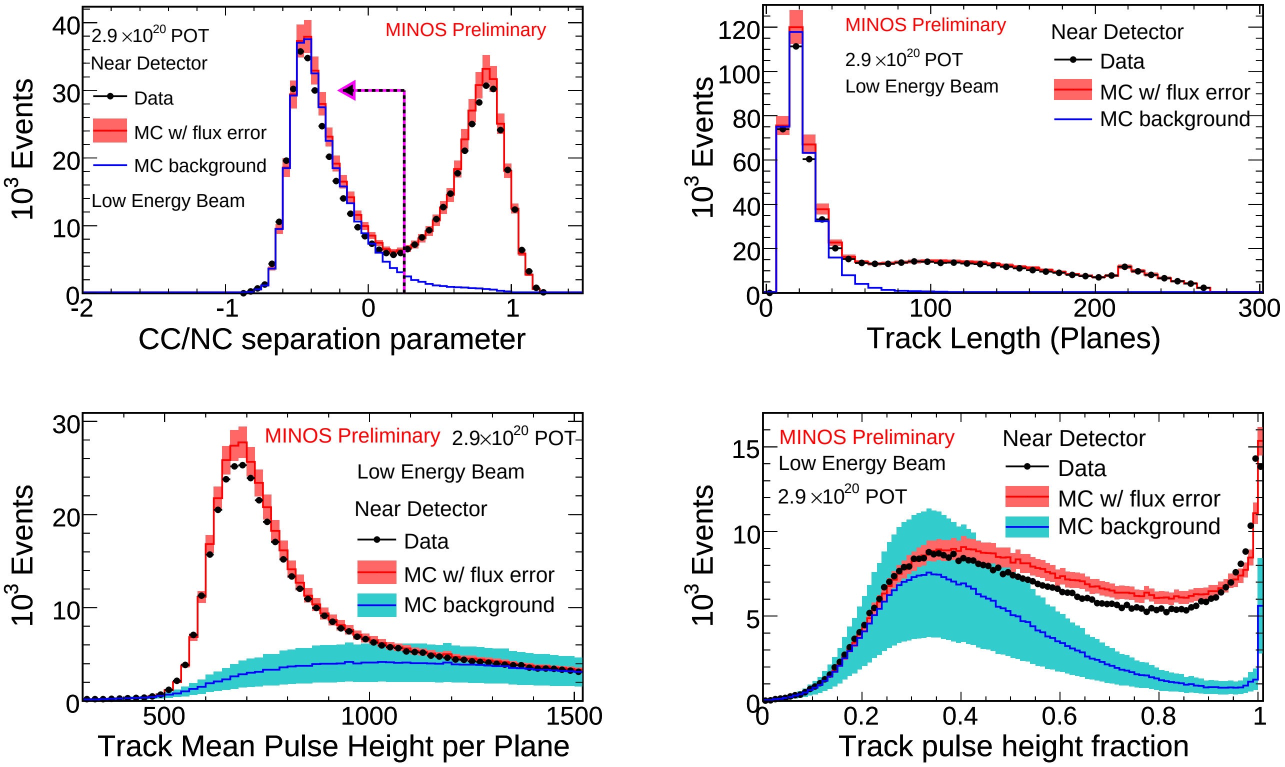

Figure 1: On the top left, the selection parameter built from the 3 PDF for the signal and background. The data shown are for positive curvature tracks and after the cuts on relA and q/p have been applied. The MC background shown in blue is the NC and WS events. The arrow shows the rejection cut at 0.25. On the top right and on the bottom, the three PDFs: the track length (top right), the average calorimetric response per plane (bottom left) and the track pulse height fraction (bottom right) [5].