NUE Working Group Internal Note
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Scan Rules for Assignment of Type and Topology to Events in MINOS

Scanning rules and auxiliary event evaluation criteria are proposed, for the purpose of classifying candidate neutrino events in MINOS using reaction flavor and final state topology characterizations. The event types considered are distinguished by observation of candidate final state leptons. In the MINOS detectors, one can straightforwardly distinguish charged current muon flavor (via a visible muon track) and electron flavor (via a prompt electromagnetic shower), and neutral current reactions as well (via absence of a charged lepton prong). In scanning however, there remains a level of ambiguity with distinguishing among these three event types, and so two ambiguous categories are also allowed, namely mu/NC and e/NC types. There remains the possibility of mu/e ambiguity and of three-way mu/e/NC ambiguity, however in actual practice these seldom arise, and events of these types are identified using the comment field.

Each event – in addition to its neutrino event type as above – is assigned to a final state topology event type. At present, three topology types are used: There are ``Quasi-Elastic" (QE) events; there are events which have low multiplicity hadronic systems (e.g. a single charged pion or a pion plus recoil proton) which are predominantly instances of nucleon resonance production (RES); and there are events having multiprong final states which are usually instances of deep inelastic scattering (DIS). In MINOS data, non-neutrino events arising from cosmic ray muons or their interactions, or arising from detector noise (e.g. remnant LI pulses) can also occur. Currently these non-neutrino backgrounds are identified using the label "???" for both type and topology. (The `label' is available as a NueAna recording button.) The comment field is also useful for identifying an event as a non-neutrino background.

Neutrino Event Type Assignment

Identification of neutrino flavor (mu or e) type is of course based upon observation of the charged lepton produced in the reaction or else, in the case of neutral current (NC) reactions, it is based upon the apparent absence of a lepton track or prompt shower. For assignment of neutrino reaction type, the scanner must carefully examine the hits of an event and their relative pulse heights (PH) in the U and V projections on canvases 1 and 2 of the NueAna display. These canvases should be examined initially for the presence of a muon track. If a candidate muon is not readily discernible, the event vertex region should be zoomed and judicious use made of pulse height threshold settings. Canvases 3, 4, and 5 can be useful in event type discrimination as well, especially with separation of electron type from NC event type.

Muon-Flavor Reaction Type:

An event is to be assigned to muon-flavor event type if a candidate muon track is observed in the final state. Neutrino-induced final state muons in the MINOS detectors are usually distinctive because of their length (usually much longer than the extent of hadronic showers) and because of their narrow widths, which are typically one strip wide. Muon tracks are comprised of relatively low pulse height hits. Candidate muon tracks should be clearly discernible in both U and V views.

Electron-Flavor Reaction Type:

An event is to be assigned to electron-flavor type if there is a candidate electromagnetic shower which emerges promptly from the primary vertex region of the event. A candidate EM shower is to be recognized by the size and shape of the pattern of hits in the shower prong. Characteristic detector response patterns have been inferred from study of CalDet data. As is elaborated below, it is important to consider the relative positions of hits in a candidate shower together with the corresponding PH at each position along the shower's transverse and longitudinal profiles (relative to detector scintillator planes, which are nearly orthogonal to the beam axis).

Shower Shape:

The general shape of an EM shower is that of an elongated oval, resembling a sine curve, from 0 the π, of low amplitude and long wavelength, and rotated about the axis of the shower direction. An energetic shower will have a central core, accompanied by hits which are peripheral to it – a ``halo". The core is comprised of hits of largest PH arranged along the shower axis of travel. In the halo, which consists of hits outside, but directly adjacent to the core, the PH should fall off sharply, and surround the core somewhat uniformly. The width of both the core and the halo should increase (and decrease) with core PH. The overall topology should be fairly regular, without large jumps in PH in neighboring planes, or strips. Along the shower core, and after the shower max-PH has been reached and the PH subsequently diminishes, no resurgence of PH should be observed. Appearance of PH resurgence is evidence for occurrence of tracks within the (apparent) shower. It is useful to examine the longitudinal and transverse energy per plane displays when evaluating shower profiles. One should observe a relatively smooth rise and fall in longitudinal energy, and a relatively compact PH profile in transverse energy.

Shower Size:

The size, unlike the general shape, is a function of the electron energy. This can be gauged by the reconstructed shower energy, but the correlation between the two is fairly rough. As the shower energy increases so will the length, width, and PH of the event.
Listed below are some guidelines in the forms of minimums/maximums that should be scaled with energy, but are reasonably descriptive for events in the 2-10 GeV reconstructed shower energy range.

1) The central core should reach a PH of at least 5 MEUs.

2) The central core should be at least 2 planes long in each view.

3) The total length (defined as the number of continuous occupied planes along the core, but including halo, added for the 2 views) should be less than or equal to 12

planes.

4) The peak core width should be 1 to 2 strips across (3 at higher energies), and fall sharply (<1/2 max) at either side.

5) The average width (defined as the average from the two views of the number of consecutive strips, where the PH is decreasing from the core, in the plane with the most of these consecutive strips) should be less than 6 hits.

Shower Direction:
The axis of the shower should align to within 45 degrees of the beam/detector direction. Note that ν_e candidates having low multiplicity topologies (QE or RES) will generally align very well with the beam direction, consequently these events will have narrow profiles centered near zero in the U and V view transverse energy per strip profiles (Canvas 4).

Neutral Current (NC) Type:
An event is of NC type if it is devoid of either a candidate muon track or electron shower. Events of this type are comprised entirely of final state hadronic shower(s). The hadronic system may be of high or very low multiplicity (eg a single proton, single pion, proton plus pion, etc). These systems may contain regions of high pulse height and may even include small EM showers (from $\pi 0$ decay), however, these regions should not be arranged in a way which is compatible with an evolving shower core, otherwise the event would be assigned ν_e type (or e/NC ambiguous).

Ambiguous Types (e/NC, mu/NC):
In neutrino events it is possible for the spacial extent of the final state hadronic system to be comparable to that of a final state charged lepton. This situation is not uncommon with low energy CC events and/or high-y CC events. For events of this kind the scanner must discern the charged lepton amidst the surrounding hits of the final state hadrons and ambiguous sighting can occur. For example, a hit sequence may appear as a plausible candidate lepton in one view but obscured or else indiscernible in the other view. In such cases the scanner can record the event using an ambiguous event type e.g. mu/NC or e/NC. In recent scanning, which has focused upon the ν_e flavor search, situations which require the e/NC type are common.

Event Topology Classification

Scanners are required to distinguish among the three topology classes which distinguish according to particle multiplicity of final state hadronic systems. While recoil protons are frequently produced in neutrino interactions, in the coarsely sampled iron media of MINOS detectors these are often invisible. When a final state proton is visible, it appears as one or a few high pulse height hits at the interaction vertex. For each event, the hits which are in addition to the final state lepton (and recoil proton) are used to classify it in one of three ways: If the event has no hadronic prongs, it is recorded as a "Quasielastic" (QE); an event which has a single candidate pion track is taken to be a nucleon resonance event (RES); otherwise, the an event has a multiprong hadronic system and it is recorded as an instance of "deep inelastic scattering" (DIS).

QE Topology:

Among charge current neutrino interactions, the reaction with the lowest production threshold and largest exclusive channel cross section is the CC QE reaction. In such reactions the final state is comprised of the charged lepton together with a recoil proton which may or may not yield detector hits. Events which appear to be single muon or single shower events either with or without a recoil proton at the vertex, are to be recorded as QE. (These reactions can occur as NC events, in which case they are truly elastic; in MINOS these NC QE events will appear as one or few high PH hits.)

RES Topology:

An event which has a candidate single charged pion track in addition to a charged lepton (and possible recoil proton) hits is to be assigned the RES topology. In many cases a candidate pion track will be comprised of a few low pulse height hits and its track-like character may not be obvious. Events of the RES category include hadronic systems with very modest energy. Charge current events which have a clearly discernible track accompanying the muon are worthy of note and a comment should be made. As rare occurrences, but occasionally seen, are RES events in which the second track is sufficiently long to qualify as a muon candidate. Such events are dimuon candidates, and may be of interest to the study of threshold charm production.

DIS Topology:

Events which plausibly have more than one final state hadronic track (in addition to the recoil proton) are to be recorded as DIS. Most high energy CC events fall into this category.

Scanning Tip:

Cross-talk and other noise in the detectors can give the events a very low PH "halo" surrounding the actual event activity. To remove low energy hits, thus making it easier to discern structures using the primary hits having significant PH, one may use the “buttons” provided on the second NueAna canvas to eliminate the lowest PH hits from view. (The buttons initiate a re-scaling of the canvas color axis.)