Scan Rules for Assignment of Type and Topology to Events in MINOS

In this note we specify rules and auxiliary criteria for categorizing events in MINOS according to neutrino event types. The events types to be considered are characterized by the final state lepton. Functionally, one can distinguish charged current μ flavor (muon track) and e flavor (electromagnetic shower) events, as well as neutral current (no charged lepton) events. There is a level of ambiguity in distinguishing among these neutrino event types. The ambiguous categories mu/NC, and e/NC allow for these events to be cataloged. The mu/e ambiguity and three way ambiguity (mu/e/NC) are rare, and to be accommodated using comments.

Each event is to be labeled by a neutrino flavor type as above, additionally each event is to be labeled by a topology descriptor. At present three topologies are distinguished: "Quasielastic" (QE) events; events with a low multiplicity hadronic systems (eg single pion or pion plus proton), ie nucleon resonance event (RES); and finally events that have energetic multi prong systems, are labeled as "Deep inelastic scattering" (DIS). MINOS data can also include non-neutrino events, such as detector noise, or cosmic ray induced events. Currently these background events are identified using "???" labels for type and topology. The comment field is also useful in tagging these backgrounds.

RULES FOR EVENT TYPE IDENTIFCATION

Identification of neutrino flavor is of course based on identification of the charged lepton produced in the reaction, or in the case of neutral current reactions the absence of a lepton track. For assignment of event type it is imperative that the scanner examine hits and their relative pulse heights in the U and V projections on canvases 1 and 2 of NueAna. These canvases should be studied with the event vertex region zoomed in and with judicious usage of pulse height threshold settings. Additional canvases may prove useful in event identification as well.

Muon Flavor (ν_μ)

An event is muon type if a candidate muon track is observed in the final state. Muon tracks in MINOS produce (comparatively) long tracks typically of one strip wide, and are comprised of relatively low pulse height hits. A candidate muon track should be discernible in both U and V views.

Electron Flavor (ν_e)

An event is electron flavor type if there is a candidate electromagnetic (EM) shower. An EM shower must be recognized by the size and shape of the pattern of hits in the event. It is important to consider relative positions, and the corresponding pulse height (PH) at each position for hits in the shower.

Shower Shape

The general shape of an EM shower is that of an elongated oval, (resembling a sine curve, from 0 th πι, of low amplitude and long wavelength, and rotated about the axis

of the shower direction). The event can be characterized by what can be defined as a central core, and by the hits peripheral to this core, or "halo". The core will be defined as the hits of largest PH closest to the axis of travel. In the halo, consisting of the 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 smooth, and without large jumps in PH in neighboring planes, or strips. Also, as distance increases from the core and the PH falls, it should not begin to re-increase. These increases are evidence of other tracks. It is useful to examine the longitudinal and transverse energy per plane displays when evaluating shower profiles. One should find evidence of the smooth energy distribution in these displays.

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 far from perfect. As the shower energy increases so will the length, width, and PHs of the event. What follows are some guidelines, in the forms of minimums/maximums, that should be scaled with energy, but should suffice for events in the (roughly) 3-10 GeV reconstructed shower energy range.

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

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.

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.

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 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 that the spacial extent of the final state hadronic system may 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 (sightings) 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 eg mu/NC e/NC. In scanning, which focuses on the ν_e flavor search, situations which require the e/NC type are common.

RULES FOR EVENT TOPOLGY IDENTIFCATION

Scanners are required to distinguish among the three topology classes. Roughly these classes reflect the charge particle multiplicity of final state hadronic systems. A recoil proton is associated with each event, however, in a coarsely sampled iron medium, such as MINOS, the final state proton is rarely discernible. When it is, it appears as one or a few high pulse height hits at the interaction vertex. In addition to the lepton, and recoil proton the three classes can be describe as those with: no hadronic components, "Quasielastic" (QE); events with a single pion track, nucleon resonance event (RES); and finally events that have energetic multi prong systems, "Deep inelastic scattering" (DIS).

QE Topology

Among charge current neutrino interactions the reaction with the lowest energy threshold and the highest exclusive channel cross section is the CC QE reaction. In such reactions the final state is just the charged lepton together with the recoil proton. Events which the scanner believes are single muon or single shower events either with or without a recoil proton at the vertex are to be labeled QE. (These reactions can occur as NC events, in which case they are truly elastic, but leave little or no trace.)

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 need not be obvious. Events of the RES category include hadronic systems with very modest energy. Charge current events with a clearly discernible track which accompany the lepton are worthy of note and a comment should be made. As rare occurrences, but occasionally seen, are RES events in which the 2nd 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 labeled DIS. Of course many high energy CC events fall into this category.

Scanning Tip

Crosstalk and other noise in the detectors can give the events a very low PH "halo" surrounding the actual event activity. To remove this and thus, make it easier to concentrate on the higher PH hits, use the buttons to remove (by rescaling the color axis) the lowest PH hits.

Appendix A -Physics Review for non-MINOS scanners

The MINOS detectors were designed to induce and detect neutrino interactions. There are several types of neutrinos, and neutrino interactions that are expected. What follows is a descriptive review the physics involved.

Neutrino Types (flavors)
Electron neutrino (ν_e)
Muon neutrino (ν_μ)
Tau neutrino (ν_μ)

Interaction Types
Charge Current (CC)
Neutral Current (NC)

Interaction Topologies
Elastic/Quasielastic (QE)
Resonance production(RES)
Deep inelastic scattering (DIS)
Coherent (COH)

To understand the ways in which the neutrinos interact one must first understand the properties of the neutrino, and what quantities must be conserved in the reactions. First of all neutrinos are neutral leptons, meaning they only interact weakly, exchanging either charged W bosons (CC), or neutral Z bosons (NC). In the reaction momentum, energy, and charge are all conserved. Additionally, lepton flavor is conserved, meaning that the particle produced will be a lepton in the same family as the interacting neutrino, although further decays may occur. (ie a ν_μ will produce either another ν_μ, or a muon.) In a NC reaction, no charge is exchanged and the resultant particle is the same as the ingoing particle. In a CC reaction the exchange particle carries a +/-1 charge meaning the resulting particle must have charge opposite to the the exchanged W. (For matter (antimatter) a neutrino (antineutrino) emits a W+ (W-), and becomes an e-,mu-,tau- (e+,mu+,tau+).) For CC interactions identification of the charged lepton allows for flavor determination, while in NC events flavor detection is impossible.

The identification of the neutrino flavor in CC events is based on the identification of the charged lepton produced in the reaction. The muon (easiest to detect) produce a (comparatively) very long track with a width of one strip. Electrons (more difficult to detect) produce an electromagnetic shower, which will be discussed in greater detail later. Tuas (hardest to detect) decay almost immediately and must be detected by signatures in the decay products.

The interaction topology is defined by what the neutrino interacts (exchanges the W/Z) with. If the neutrino interacts with the entire nucleus (exchanging momentum equally with each nucleon) the event is termed coherent. These events are characterized by a single $\pi 0$, and are quite rare. If the interaction is between the neutrino, and a single nucleon the event can be elastic, quasielastic, or resonance production. An elastic

collision must be NC, while a quasielastic is CC. In either case the product is the recoil nucleon (one hit with a large pulse height), along with either the undetectable neutrino (NC), or charged lepton (CC) track/shower present. If the correct amount of energy is transferred to the nucleon it can create an excited state known as a delta resonance. When the nucleon returns to its ground state it usually emits a pion. Therefore, an elastic/quasielastic like event, with an extra pion track is the signature of a RES event. Finally, if the neutrino resolves an individual quark inside of a nucleon it is referred to as DIS. This can happen with either NC or CC events, and usually creates many particles additional to the lepton. These events are the most difficult to classify, because of the large number of tracks involved. If a long muon track is identified, it can be classified as a CC ν_μ event. However, discrimination between an NC and CC ν_e, or CC ν_τ, can prove to be difficult.