Inclusive measurements with MINER$\nu$A

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Abstract. MINER$\nu$A is a neutrino scattering experiment in the NuMI beamline at Fermilab
designed to measure neutrino cross-sections, final states and nuclear effects on a variety of targets
in the few-GeV region. MINER$\nu$A is currently running in the NuMI low energy configuration
and will continue in medium energy. We present a preliminary neutrino energy spectra in three
beam configurations and a preliminary comparison of iron and lead event rates.

1. Introduction
MINER$\nu$A [1] is a neutrino scattering experiment in the NuMI beamline at Fermilab, designed
to measure neutrino cross-sections, final states and nuclear effects on a variety of targets. NuMI
is an intense, broad band spectrum, flexible beamline originally developed for the MINOS
oscillation experiment. MINER$\nu$A is currently running in the low energy configuration with
a peak neutrino energy of $\sim$3 GeV and will continue in the NO$\nu$A era as the energy is raised to
$\sim$6 GeV.

2. MINER$\nu$A detector
The MINER$\nu$A detector is constructed of strips of triangular, extruded polystyrene scintillator
assembled into 17 mm thick, 2.5 m point-to-point hexagonal planes. A wavelength-shifting
optical fiber located in the center of the strips transmits light to multi-channel photomultiplier
tubes for readout. The planes are stacked with a 60° rotation between strips in adjacent planes
to form three stereoscopic views. The downstream planes are alternated with sheets of 2 mm
lead to form an electromagnetic calorimeter and 1 in steel to form a hadronic calorimeter. The
MINOS near detector acts as a spectrometer for rear-exiting muons, measuring momentum by
either range or curvature.

The upstream planes of MINER$\nu$A contain targets of iron, lead and carbon. A cryostat
target is currently filled with liquid helium with a proposal to run hydrogen or deuterium in the
NO$\nu$A era. A water target is under development.

3. MINER$\nu$A test beam
To calibrate the absolute energy scale and validate monte-carlo simulations of the MINER$\nu$A
detector, a small, reconfigurable version was constructed and exposed to a measured beam of
low energy hadrons. The test beam detector consists of 40 planes of scintillator of $\sim$1 m$^2$ active
area. These planes can be interleaved with sheets of lead and steel absorber to emulate the
downstream calorimeters of the MINER$\nu$A detector.

The project required the development of a new tertiary beamline at the Fermilab Test Beam
Facility to produce, identify and momentum-analyze low energy hadrons. The beamline consists
of a target and collimator, two pairs of wire chambers upstream and downstream of a pair of
dipole magnets and a time of flight system. In addition to low energy hadrons, the detector was
exposed to a broad spectrum, unmeasured muon beam and cosmics. The project ran during the
Summer of 2010; calibrations and analysis are in progress. The spectrum of beamline particles
is shown in Figures 1 & 2.

4. Calorimetric energy resolution
The calorimetric energy resolution of the detector is determined by a monte-carlo study of neutral
current events with a vertex in the upstream, fully active tracker region. Events are generated
with Genie 2.6 [2] and simulated in Geant4 [3] with the QGSP BERT model. Visible energy is
summed in the tracker and downstream electromagnetic and hadronic calorimeters. The energy
in the calorimeters is weighted to account for the additional passive material. An overall energy
correction is then applied. The true recoil energy is defined as $E_{\text{recoil}} \equiv E_{\nu}^{\text{in}} - E_{\nu}^{\text{out}}$. Using
this simple calorimetry, the energy resolution is $\sigma/E = 0.12 \oplus 0.27/\sqrt{E(\text{GeV})}$ (see Figure 3). The energy resolution will improve with shower reconstruction algorithms and EM/hadronic compensation.
5. Towards charged current inclusive cross-sections
MINERνA is actively working towards producing charged current inclusive cross-sections on plastic scintillator and the iron, lead and carbon targets. To that end, we present the following two preliminary analyses.

5.1. Charged current neutrino energy spectra
The NuMI beamline is reconfigurable; the positions of the target and horns and the horn current can be varied to select the neutrino energy spectra. Figures 4 & 5 show the observed spectra of neutrinos producing a charged current interaction in the MINERνA detector in three beamline configurations: low energy (LE), pseudo medium energy (pME) and pseudo high energy (pHE). Events are restricted to a primary vertex in the upstream, fully active tracker region with a muon track analyzed in the MINOS spectrometer. Tracks identified in the final state products are fit to a dE/dx profile for particle identification. The remaining energy is summed calorimetrically as described in Section 4.

Figure 4. Spectra of neutrinos producing a charged current interaction in the low energy (LE), pseudo medium energy (pME) and pseudo high energy (pHE) beamline configurations in forward horn current (FHC, neutrino-focusing) mode.

Figure 5. Spectra of anti-neutrinos producing a charged current interaction (from the ∼6% ¯ν content of the ν beam).

5.2. Iron/lead charged current event rates
MINERνA is developing analysis techniques for events originating in the passive nuclear targets by studying the most downstream target of iron and lead. Passive target planes are located between active scintillator planes; by requiring muon activity in the first plane downstream of a target, with no activity upstream, a charged current interaction vertex can be localized to the target. The transverse position is determined by projecting the muon track to the center of the target plane. This study requires that the muon is tracked in the MINOS spectrometer.

Backgrounds are introduced from events originating in the scintillator planes upstream and downstream of the target (see Figure 6). Backgrounds and acceptance effects can be studied in data with a scintillator reference target. Eight active planes are declared as a passive target, event selection cuts are applied, then selection purity can be quantified by analyzing the data from within the reference target. The reference target is divided into two regions in the same manner as the passive iron/lead target. A ratio of events originating in these two regions is shown in Figure 7. A data to monte-carlo comparison of events reconstructed in the most downstream target of iron and lead is provided in Figures 8 & 9.
Figure 6. True vertex distribution of charged current interactions reconstructed in the passive and reference targets. Passive target is located at 5760–5800 mm, reference target is 6020–6200 mm.

Figure 7. Mass-corrected ratio of events reconstructed in the lead region of the reference target to those in the iron region. Deviations from unity result from acceptance effects.¹

Figure 8. Data/monte-carlo comparison of events reconstructed in the iron region of the most downstream passive target.¹

Figure 9. Data/monte-carlo comparison of events reconstructed in the lead region of the most downstream passive target.¹

6. Conclusion
MINERνA will measure neutrino cross-sections, final states and nuclear effects on a variety of targets in the few-GeV region to reduce systematic uncertainties in oscillation experiments and provide new understanding of the nucleus.

References
[1] http://minerva.fnal.gov
[2] http://www.genie-mc.org
[3] http://geant4.cern.ch

¹ Discrepancies between data and monte-carlo result from incorrect flux modeling. Flux is Fluka08, prior to tuning, with the Genie 2.6 [2] event generator.