The MINERνA Experiment and Neutrino DIS

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MINERνA is a dedicated cross-section experiment in the NuMI neutrino beam at Fermi National Accelerator Laboratory. MINERνA will reduce the errors on neutrino cross sections across energy ranges of interest to current and future oscillation experiments. Both inclusive and exclusive channels will be measured with this detector. MINERνA will have four distinct nuclear targets and excellent detector resolutions will allow extraction of the A-dependence of neutrino interaction probabilities and final state effects. The full detector is in the final stages of construction and will see data in early 2010.

1 NuMI Neutrino Beam

Pions and kaons are produced from the collision of 120GeV protons on a graphite target. These particles are selectively focused downstream and allowed to decay to yield neutrinos as they travel roughly 700 meters to the detector. Secondary and non-interacting particles are removed from the beam by various absorbers and remaining particles pass several beam monitors before reaching the experimental hall where the MINERνA detector resides. The relative position between the NuMI target and focusing horns can be changed to produce neutrinos with three different energies ranges: low energy peaked at 3GeV, medium energy peaked at 7GeV and high energy peaked at 12GeV. Anti-neutrino running is possible by changing the focusing current. Extraction of absolute cross-sections requires knowledge of the beam flux. MINERνA will use the experience of MINOS in this area. Using multiple NuMI beam configurations it is possible to disentangle the flux from a cross-section model [2]. There was also a dedicated experiment that measured hadron production off of the NuMI target. Information may also be obtained by the muon monitors from the decay particles that produced the neutrino that could provide constraints on the flux. When all this data is applied to the analysis, the error from the flux should be at the 4-5% level.

2 MINERνA Detector

Neutrinos first pass through a veto wall that serves to shield the detector from low energy particles and tag unabsorbed charged particles. Immediately behind the veto wall is a 0.25 ton liquid helium cryostat. The MINERνA detector sits after this light nuclei target. The entire MINERνA detector is modular and made of hexagonal planes of varying composition depending on location. Each plane consists of the inner detector about 2m across surrounded by an outer detector frame. A side view of the detector is shown in Figure 1.

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The first section of the MINERνA detector has five heavy nuclei target plates that are each followed by four of the scintillating tracking planes to seed particle tracks that enter into the main MINERνA tracking region. These plates are made of combinations of carbon, iron and lead and are further described in Section 5.2. The fiducial volume of the detector follows the heavy target region. This volume is comprised of planes of 17x33mm triangular scintillator extrusions in three different orientations and serves as the main tracking region of the detector. The last two sections are the electromagnetic and hadronic calorimeters that have 2 and 25.4mm Pb and Fe absorbers, respectively, between the scintillating tracker planes. There are also lead absorbers along the perimeter of the inner detector tracking planes and the iron outer detector that serve to contain transverse electromagnetic and hadronic energy. The MINOS detector is approximately 2m downstream of the MINERνA detector. MINOS will measure momentum of tracks exiting the rear of the MINERνA via curvature in the MINOS magnetic field.

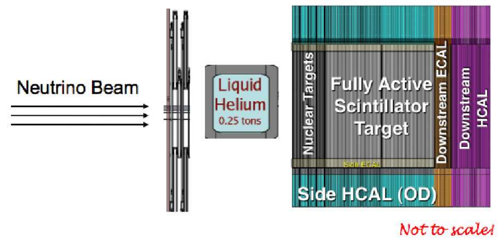

Figure 1: The detector profile showing: veto wall, cryogenic liquid helium dewar and segmented MINERνA structure.

3 MINERνA Performance

The base element of the MINERνA detector is the 17x33mm triangular scintillator extrusions. The triangular shape was chosen because this allows charge sharing between adjacent extrusions; square extrusions immediately degrade resolutions. Tracks in MINERνA will have coordinate resolutions on the order of 3mm and angular resolutions of less than a degree. Muon tracks that stop inside of the MINERνA detector will have $\frac{\Delta P_\mu}{P_\mu} \simeq 5\%$ and muons tracks that are measured in MINOS will have $\frac{\Delta P_\mu}{P_\mu} \simeq 10 - 12\%$. A preliminary Monte Carlo study found that 85%, 90% and 95% of stopping kaons, pions and protons (respectively) were correctly identified via dE/dX along the track. Electromagnetic and hadronic shower energy resolution can be parameterized by $1\% + \frac{2.7\%}{\sqrt{E}}$ and $4\% + \frac{18\%}{\sqrt{E}}$ (or by $\frac{5\%}{\sqrt{E}}$ and $\frac{23\%}{\sqrt{E}}$), respectively. Around the $\Delta(1232)$ peak, energy resolution on W and Q^2 are $0.1GeV$ and $0.2(GeV/c)^2$ [3]. Initial pattern recognition and tracking algorithms have shown good efficiency. Tracks that exit the back of MINERνA have been matched to tracks found by MINOS with extrapolated coordinate residuals (between the two detectors) of $\sim$10mm.

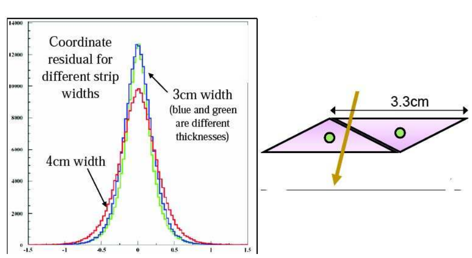

Figure 2: Coordinate resolutions obtained by varying the extruded scintillator dimensions.

4 MINERνA Event Rates

The current MINERνA run plan is for $4x10^{20}$ protons on target (POT) in the low energy NuMI configuration and $12x10^{20}$ POT in the medium energy configuration. The full detector will have approximately a 3 ton fiducial volume in the scintillator with an additional 0.2, 0.15, 0.7 and 0.85 tons of liquid helium, carbon, iron and lead present in the nuclear targets. This detector mass and POT run plan yields a total of 14.5 million charged current neutrino events. The breakdown of events in each of the specific detector locations is given in Table 1.

Detector Location	CC Events
scintillator	$9x10^6$
liquid helium	$6x10^5$
carbon	$4x10^5$
iron	$2x10^6$
lead	$2.5x10^6$

Table 1: Four year event yield by location

The fine-grained nature of the MINERνA detector will allow the measurement of exclusive final states. The breakdown of several of the specific neutrino channels is shown in Table 2. MINERνA will also collect around $8.9x10^4$ coherent pion events and $2.4x10^5$ fully reconstructed events with a strange or charm particle produced. This last sample will increase neutrino produced strange particle data set by roughly a factor of 400.

Event Channel	CC Events
quasi-elastic	$8x10^5$
resonance	$1.7x10^6$
transition	$2.1x10^6$
DIS	$4.3x10^6$
gen.parton dist.	$\sim 1x10^3$

Table 2: Four year event yield by channel

5 MINERνA and DIS

MINERνA will collect about $7x10^6$ deep inelastic scattering events in the above listed run plan. This will increase the data set of important exclusive channels across a wider neutrino energy than is currently available. Because of flavor specificity, a neutrino and an anti-neutrino data set would allow extraction of all six structure functions. There are several other interesting DIS topics that MINERνA will address as well.

5.1 Quark Hadron Duality

Low energy physics processes are described by hadronic form factors while high energy processes are described by partonic structure functions. Quark hadron duality is an attempt to relate these two. If isoscalar form factors and structure functions are written as a function of $\xi = 2x/\sqrt{1 + (\frac{2Mx}{Q})^2}$ and the quotient of their integrals is taken over a range of ξ, then this quantity should be equal to one (if duality holds). Duality has been shown to hold for charged leptons within 20% across a range of Q^2. Model indicate that neutrino duality holds better and across a wider range of Q^2 [4] than for charged leptons. Duality for neutrinos still is dependent on the axial form factor model used and the number of terms (resonance peaks or higher twist corrections) included in the above mentioned integral. MINERνA will collect millions of events in the resonance, transition and DIS energy regions. Form factors and structure functions will be extracted and to test neutrino quark hadron duality.

5.2 Nuclear Effects

The presence of multiple nuclei in the nucleus changes the interactions between neutrinos and heavy atoms with respect to free protons (or deuterium). This can show up as modifications to the interaction probability or modifications to the final state particles. These modifications have been studied for charged leptons, but a detailed study for neutrinos has not been done. The axial vector current and flavor specificity prevents the same description for neutrino nuclear effects. Nuclear effect models have accurately described experimental data on some nuclei, but show 15-20% deviations and shape distortions on other nuclei [5, 6] (see Figure 3). The structure of the nuclear targets region in MINERνA (shown in Figure 4) has been chosen so that neutrinos can pass the same number of interaction lengths in C, Fe and Pb regardless of where it enters the face of the detector.

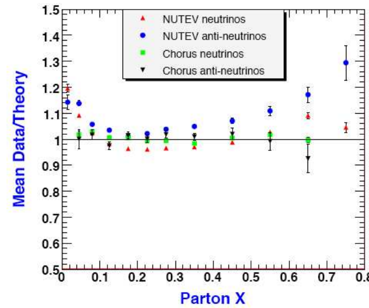

Figure 3: Experimental data over a theoretical model for two different nuclei.

Particles can also be absorbed or re-interact upon exiting the nucleus. This is especially true for the energy range of particles produced by NuMI neutrinos. These effects change the particle multiplicities (absorption), kinematic variables (re-interaction) and therefore the extracted experimental quantity. MINERνA will measure these effects by studying shower energies and multiplicities from the heavy nuclear targets.

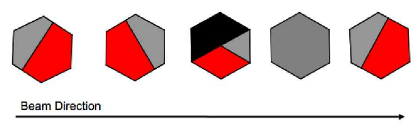

Figure 4: Nuclear target region plates: carbon - black, iron - red, lead - grey.

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