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MINERνA : High Statistics Neutrino Scattering Using a Fine-grained Detector

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MINERνA Collaboration

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The MINERvA experiment at Fermilab will use a fully-active scintillator based fine grained neutrino detector and the high rate NuMI neutrino beam. MINERνA will measure low energy neutrino interaction properties and cross sections to a new level of precision. These measurements will be critical input to present and future accelerator-based neutrino oscillation experiments in this energy range.

Keywords: neutrinos; oscillations

1. MINERνA Overview and Motivation

Our current understanding of neutrino interactions in the energy range less than 20GeV is mostly based on bubble chamber data taken in the late 70's and early 80's which has large statistical and systematic uncertainty. A primary motivation for MINERνA is to improve the precision in low energy cross section measurements to the level required to understand the data in the current and future accelerator-based neutrino oscillation experiments. In particular, improvements in statistical precision are possible because of the high-rate NuMI neutrino beam facility.

The MINERνA detector[1] is designed to provide the fine-granularity required to perform exclusive final state tracking and particle Id. The detector incorporates three nuclear targets carbon, iron and lead.

2. Physics Summary

MINERνA will run parasitically using the NuMI beam in the MINOS near detector hall. The current MINOS run plan involves primarily low-energy beam running which peaks at an energy of about 3 GeV and has a long high-energy tail. MINOS is currently approved for a total integrated intensity of 7.4×10^{20} protons on target (PoT). Table 1 shows a breakdown by process of MINERνA event rates per ton for a particular run scenario with 9×10^{20} PoT. The detector fiducial mass for each target is 3-5tC, 1t Fe, and 1t Pb.

Table 1. MINERνA event rates per ton for selected physics processes assuming 9×10^{20} PoT. The detector fiducial mass is 3-5tC, 1t Fe, and 1t Pb.

Process	CC/ton	NC/ton
Quasi-Elastic	82 K	27 K
Resonance	156 K	48 K
Transition	164 K	52 K
DIS	336 K	98 K
Coherent	7 K	3.3 K
Total (ν)	745 K	228 K

Charged-current Neutrino scattering at low energy is usually described in terms of three contributions. Listed here in order of increasing hadronic mass, they are; quasi-elastic, resonance, and deep-inelastic scattering (DIS). The Quasi elastic contribution rises fastest and dominates below 1GeV. Resonance and deep inelastic processes become comparable at energies of a few GeV. MINERνA covers the kinematic region where all three contributions are important. Here we outline MINERνA 's sensitivity for cross section measurements in this energy range. More details are available in our proposal[2].

2.1. *Charged-current Neutrino Cross Sections*

MINERνA 's measurement of the quasi-elastic scattering process , $\nu\ n \rightarrow \mu^-\ p$, will result in a factor of four improvement in precision over current measurements[1]. MINERνA can uniquely measure the Q^2 dependence of the process over a wide range in Q^2 by identifying and reconstructing the proton track.

Resonance processes can be described as the low Q^2 limit of deep-inelastic scattering. The Rein-Seghal model[3] describes the cross section for low-multiplicity exclusive final states in terms of excited baryon resonances decays. The transition region where the "resonance" contribution is artificially separated from the higher-Q^2 description, DIS, can be thoroughly explored by MINERνA . MINERνA will have a large statistical sample of exclusive resonance channels and can reduce the current level of uncertainty (40%) on resonance production cross section by better

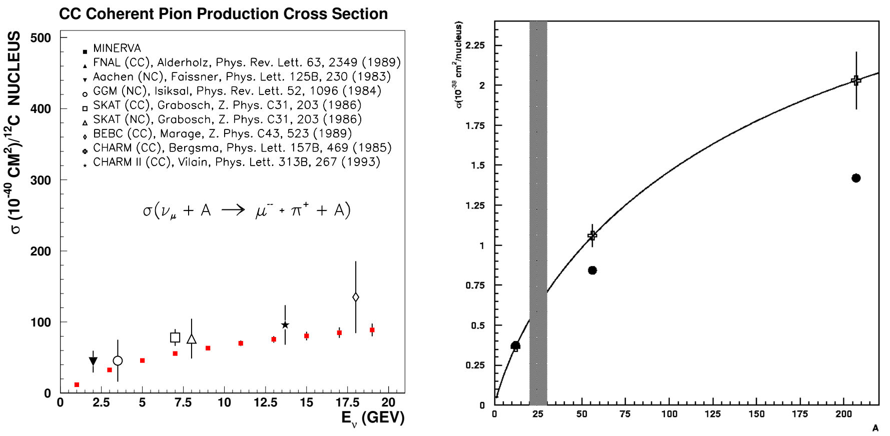

Fig. 1. MINERνA sensitivity for charged-current coherent single pion production (left). (Right) Nuclear dependence of coherent single pion production cross section. (crosses:MINERνA , models: curve and solid dots). The band represents coverage of previous measurements.

than a factor of four.

Deep-inelastic scattering interactions will comprise the largest data sample in MINERνA . The NuMI beam allows access to regions at high Bjorken-x and low Q^2 that have not been previously covered by neutrino scattering experiments. The x range extends from 0.01-1 and Q^2 up to 20GeV^2. Measurements of $F_2(x, Q^2)$ and $xF_3(x, Q^2)$ in this kinematic range will help constrain non-perturbative (higher-twist) contributions to structure functions. In addition, MINERνA will be uniquely sensitive to the nuclear dependence of neutrino deep-inelastic scattering by comparing cross sections measured from all three nuclear targets, Carbon, Iron and Lead.

2.2. *Coherent Pion Production*

Coherent pion production processes occur when a neutrino scatters off a nucleon producing a single forward pion and leaving the nucleon undisturbed. This process occurs in both neutral-current ($\nu A \rightarrow \nu\pi^o A$) and charged-current ($\nu A \rightarrow \mu^-\pi^+ A$) channels. These rare processes have only been observed in sample sizes of handfuls in the energy range below 10 GeV. MINERνA will have good reconstruction efficiency for both charged-current (30-40%) and neutral-current (∼40%) channels. For example, the expected sample size for charged-current coherent pion production will be on the order of 5000 events in MINERνA (this represents two orders of magnitude increase in statistics for this process). Figure 1 shows the MINERνA sensitivity for charged-current coherent single pion production. The sensitivity of MINERνA to measure, for the first time, the nuclear dependence of this process is also shown. It should also be noted that knowledge of neutral current pion production is a large

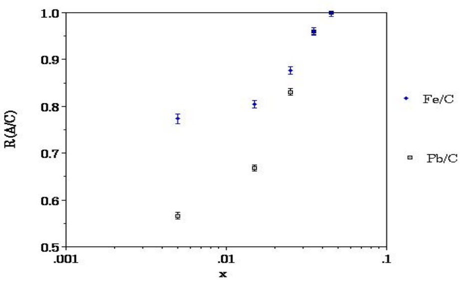

Fig. 2. Sensitivity for measurement of Fe/C and Pb/C ratios as a function of x in MINERνA .

uncertainty for future planned ν_e appearance experiments such as NOνA[4].

2.3. *Nuclear Effects*

Nuclear effects have long been established in charged-lepton scattering. The main mechanism for nuclear dependence at low and moderate x is shadowing, which depends on the virtual probing particle. Because neutrinos interact via the weak axial-vector current this mechanism predicts a different behavior for nuclear dependence in deep inelastic scattering for neutrino probes than is seen in charged-lepton scattering. Figure 2 shows predicted ratio of scattering off of heavy nuclear targets (Fe and Pb) to light (Carbon) in the MINERνA kinematic range[5].

An additional mechanism for nuclear effects that is particularly important at low energy is re-interactions of outgoing final state particles. Final state particles produced at the primary vertex, such as pions, can change direction, lose energy, or be absorbed by re-interaction with the nuclear medium. These effects must be understood and quantified to address neutrino energy reconstruction issues that are most relevant to oscillations experiments being performed in this energy range which use a nuclear target-detector, (for example, MINOS). MINERνA will be able to make systematic measurements of scattering particle multiplicities and energies and comparisons for three nuclear targets. More information about how this will help neutrino oscillation measurements can be found in reference[4].

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