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# Coherent Neutrino-Nucleus Scattering and the MINER$\nu$A Experiment

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**Abstract.** In this paper we describe the capabilities of the MINER$\nu$A experiment for the measurement of neutrino-nucleus coherent scattering.

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## INTRODUCTION

Coherent neutrino-nucleus reactions leave a relatively clean experimental signature and have been studied in both charged-current ($\nu_\mu + A \rightarrow \mu^- + \pi^+$) and neutral-current ($\nu_\mu + A \rightarrow \nu + \pi^0$) interactions of neutrinos and anti-neutrinos. Coherent interactions are a topic of considerable current experimental interest [1] and have been the subject of theoretical work for over 30 years [2, 3, 4, 5, 6, 7].

MINER$\nu$A's high rates, range of nuclear targets, fine granularity, strong pattern recognition capabilities, and good electromagnetic calorimetry will make it possible to study charged- and neutral-current coherent neutrino-nucleus scattering with unprecedented precision. A unique strength of the experiment is the ability to study both neutral and charged current channels from a variety of nuclear materials ranging from carbon to lead in the same experiment. Kinematic predictions from models can be explored in the charged current sample where the kinematics are fully reconstructed.

## CHARGED CURRENT COHERENT PRODUCTION

To quantify MINER$\nu$A's ability to measure the charged-current coherent cross-section, a Monte Carlo study was carried out using a GEANT detector simulation [8]. Analysis cuts were tuned on a sample of coherent interactions corresponding to a four-year run with the three-ton fiducial volume. Events were generated according to the appropriate mix of low and medium energy beams. This study used the Rein-Sehgal [3] model of coherent production. A low-energy beam sample containing all reaction channels was used for background determination.

To isolate a sample of coherent interactions, a series of cuts are placed on event topology and kinematics. The detector response is parametrized based on measurement smearing of $0.5^o$ angular resolution for reconstruction of muon and pion tracks, $18\%/\sqrt{E_{had}}$ hadronic energy resolution, and 10% muon energy resolution.

*Topological cuts.* An initial set of topological cuts are applied to isolate a sample of events which contain only a muon and charged pion. These cuts are based on the hit-level and truth information as provided by the GEANT simulation.

1. **2 Charged Tracks:** The event is required to have 2 visible charged tracks emerging from the event vertex. A track is assumed to be visible if it produces at least 8 hit strips in the fully active region of the detector.
2. **Track Identification:** The two tracks must be identified as a muon and pion. These identifications are made based on the absence and presence of a hadronic interaction, respectively.
3. **$\pi^0$/neutron Energy:** Events with more than 500 MeV of neutral energy ($\pi^0$ or neutron) produced in the initial neutrino interaction are rejected.
4. **Track Separation:** To make good measurements of the two tracks, the interaction point of the pion must be more than 30 cm from the primary vertex, and at this interaction point, at least 4 strips must separate the two tracks in at least one view.

*Kinematic cuts.* Because coherent and background processes have very different kinematics, cuts on kinematic variables are effective in isolating the final sample. Kinematic quantities are estimated from the smeared measurements of muon energy, pion energy, and muon angle measurement under the assumption that the event is charged-current coherent. Kinematic cuts of $x_{Bj} < 0.2$, $t < 0.2$ (GeV/c)$^2$, and $p_\pi > 600$ MeV are effective at isolating the coherent sample from more numerous quasi-elastic and resonance reactions which tend to occur at higher x, produce less energetic pions, and have larger reconstructed $t$ values. Because the coherence condition requires that the nucleus remain intact, small energy transfers to the nuclear system, $|t|$, are needed.

Applying this set of cuts to our signal sample we find that 25.5k signal events pass all cuts, which gives an overall efficiency of 30%. The expected purity of the sample is 67±3%, where the error bar is the statistical error on the Monte Carlo sample used for the study. Figure 1 shows the expected precision of the MINER$\nu$A measurement as a function of neutrino energy. Here we have only included the statistical error on the signal and assumed that the measured value is that predicted by Rein-Sehgal.

Another task for MINER$\nu$A will be comparison of reaction rates for lead and carbon. The expected yield from lead will be $\approx$ 7200 charged-current events, assuming the same efficiency. The A-dependence of the cross-section depends mainly on the model assumed for the hadron–nucleus interaction, and serves as a crucial test for that component of the predictions. No experiment to date has been able to perform this comparison.

We have carried out a rough calculation of the error budget for this measurement, assuming that the charged current cross section will be measured in 20 bins of energy with equal statistics in each bin. In each bin the statistical error will be 3.4%. The systematic uncertainty (beam-related) is 5%, and the systematic uncertainty (analysis/detector-related) is 5.5% and is dominated by the acceptance correction.

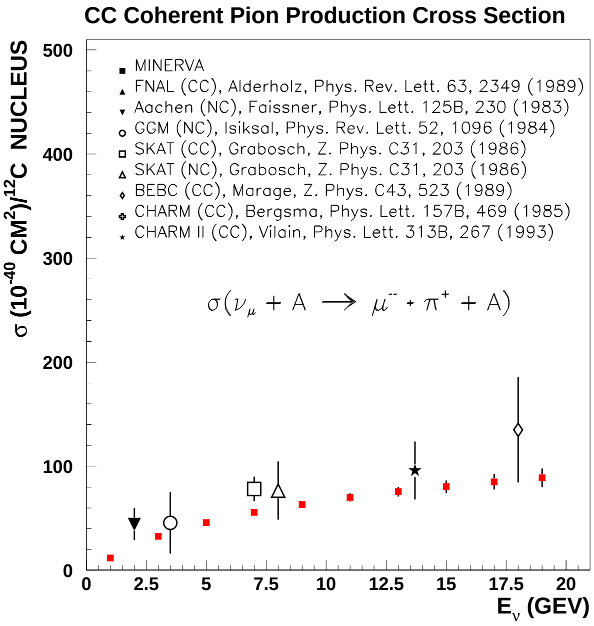

**FIGURE 1.** MINER$\nu$A CC coherent cross sections (statistical errors only) compared with existing published results.

## NEUTRAL CURRENT COHERENT PRODUCTION

Because the outgoing pion generally follows the incoming neutrino direction, this reaction is an important background to searches for $\nu_\mu \rightarrow \nu_e$ oscillation, as these events can easily mimic the oscillation signature of a single energetic electron shower.

By requiring two well-separated electromagnetic clusters that shower in the scintillator target, and extend at least 6 scintillator planes, about 30% of the coherent $\pi^0$ events produced in the detector are retained. Furthermore, by requiring the ratio of the energy in the two clusters to that of the total event energy to be above 90%, and requiring any extra energy to be less than 100 MeV, reduces both the $\nu_e$ ($\nu_\mu$) charged-current contamination to a few (less than one) events. The resulting sample in this simple analysis (1000 events per year in 3 tons of fiducial mass) is roughly half resonant $\pi^0$ production and half coherent $\pi^0$ events, which can be separated by studying the angular and energy distribution of the events, as well as the presence or absence of additional particles at the production vertex identified by the two photon showers.

Coherent and resonant interactions can be cleanly separated by cutting on the $\pi^0$ angle to the beam direction, as shown in Figure 2, which also highlights MINER$\nu$A's excellent $\pi^0$ angular resolution. The overall efficiency for selecting coherent neutral-current $\pi^0$ is about 40%. With this efficiency we expect around 17k NC coherent events in the analysis sample from the four-year run.

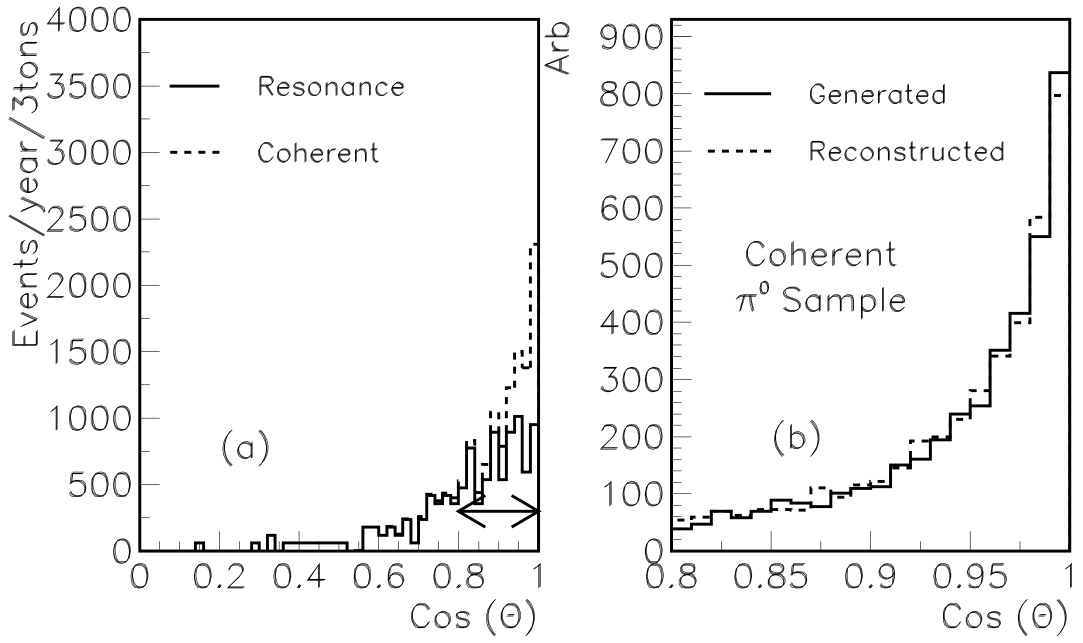

**FIGURE 2.** Angular distribution of neutral-current single-$\pi^0$ sample. The plot at left shows all events passing the cuts on $E_\pi/E_{tot}$ and $E_{tot} - E_\pi$ described in the text, broken down into coherent and resonant reactions. The coherent sample is strongly forward-peaked. The plot at right is a close-up of the forward region comparing the true and reconstructed $\pi^0$ angular distributions from the beam direction. The distributions are nearly identical, highlighting the MINER$\nu$A detector's excellent angular resolution.

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