# Charged Current Inclusive Measurements in MINERvA

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**Abstract.** MINERvA is a neutrino scattering experiment stationed in the high intensity NuMI beam line at Fermilab, designed to 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. Here we present the current MINERvA results for inclusive charged current neutrino and anti-neutrino scattering in the active region of the detector and different neutrino cross section ratios with different nuclear targets.

**Keywords:** neutrino interactions, inclusive, nuclear effects

## INTRODUCTION

The MINERvA experiment [1] is a high precision neutrino-nucleus scattering experiment located in the NuMI (Neutrinos at the Main Injector) beamline [2][3] at Fermi National Accelerator Laboratory and is designed to accurately identify events originating in the active plastic scintillator and passive targets carbon, iron, lead, liquid helium and water allowing the experiment to measure inclusive and exclusive cross sections and event kinematics for both neutrino and anti-neutrinos and to study the nuclear dependence of these interactions.

Preliminary results of inclusive neutrino and anti-neutrino measurements on the active scintillator region as well as cross section ratios of iron, lead and carbon to plastic are shown in this proceeding.

## CALORIMETRY

The calorimetric constants, corrections and resolutions in the detector are calculated by fitting calorimetric reconstructed recoil energy to true recoil energy from Monte-Carlo.

True recoil energy is defined as: true $E_{recoil} = E_\nu - E_{lepton}$ and calorimetric reconstructed recoil energy as: calorimetric $E_{recoil} = \alpha \times \Sigma_i c_i E_i$.
Where:

- $\alpha$ is an overall scale
- **i** corresponds to the detector region {tracker,ECAL, HCAL, OD}
- $\mathbf{c}_i$ is the calorimetric constant for sub-detector $i$
- $\mathbf{E}_i$ is the sum of all visible energy in the recoil system in the primary (first) time slice for sub-detector $i$

Figure 1(left) shows the sigma of a gaussian fit to the $\Delta E/E_{recoil} = (\text{calorimetric} - \text{true})/\text{true}$ as a function of the true recoil energy for CC events, resulting in a calorimetric energy resolution of: $\sigma/E = 0.139 \oplus 0.282/\sqrt{E}$.
Figure 1 (right) shows the systematic errors associated for neutrinos and anti-neutrinos.

## CHARGED CURRENT (CC) INCLUSIVE ANALYSIS IN THE TRACKER REGION

The charged current inclusive analysis $\nu_\mu + N \to \mu^- + X$ is the base for understanding a series of fundamental aspects such as the detector performance, reconstruction quality, efficiency, acceptance effects and serve as a reference to compare their kinematic and physics distributions with exclusive topologies. It is also the first step towards deep-inelastic scattering measurements.

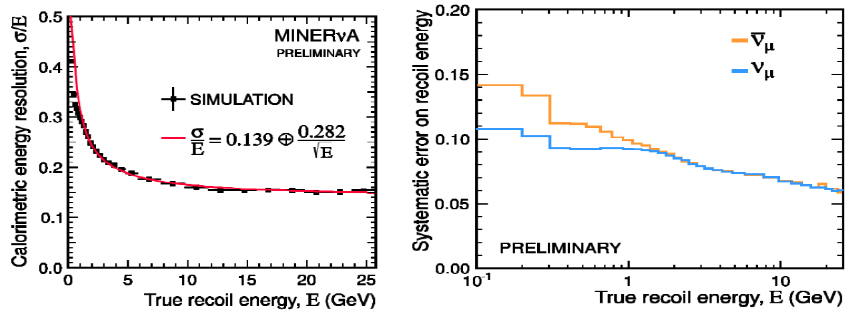


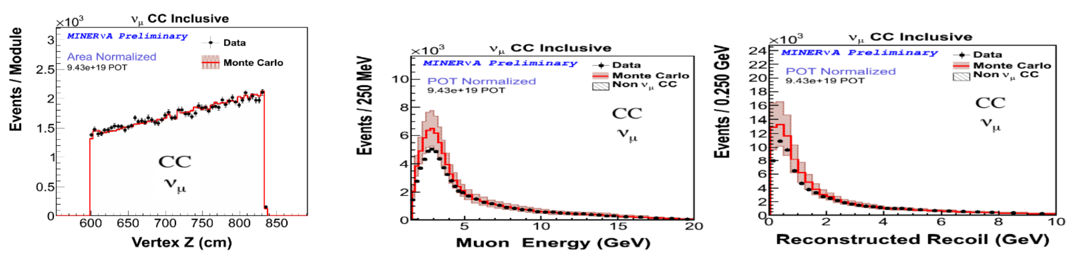

**FIGURE 1.** Calorimetric Energy Resolution for CC events

Neutrino/Anti-neutrino events in this analysis must meet the following criteria:

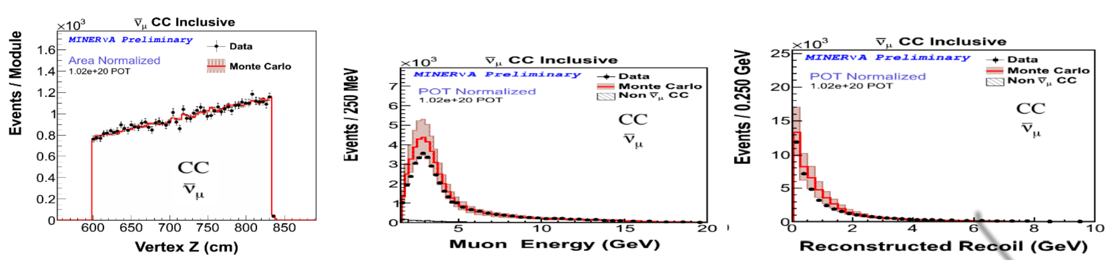
- A single muon track originating in the MINERvA detector and entering the MINOS Near Detector [4] (the track has to be matched between both detectors).
- A reconstructed vertex inside the fiducial tracker region.
- Recoil energy computed calorimetrically.

For neutrinos, muons are defined by a negative track curvature $\rho = \frac{q}{p} < 0$ while for anti-neutrinos, anti-muons are defined by a positive track curvature $\rho = \frac{q}{p} > 0$.

The vertex Z distributions show a good angular acceptance up to scattering angles of about 10 degrees, with limit of about 20 degrees (figure 2 ). The accepted samples right now are restricted in angle because of the requirement that the muons go into MINOS.




a Neutrinos




b Anti-neutrinos

**FIGURE 2.** Reconstucted vertex, muon and recoil for neutrinos and anti-neutrinos

The reconstructed kinematic quantities present a good agreement between Data and Monte Carlo in their shape, although it can be seen that for nominal absolute normalization (figure 2), the data points are about 15% lower than their respective MC prediction, which is why absolute cross sections are not yet ready to show and the efforts in the near term have been focused on studies that cancel out the flux uncertainties like shape comparisons or taking ratios of one cross section to another.

Figure 3 shows the reconstructed neutrino and anti-neutrino energy with their respective statistical and systematic uncertainties following this event selection criteria and a background of about 0.5% for neutrino and 1.5% for anti-neutrino.

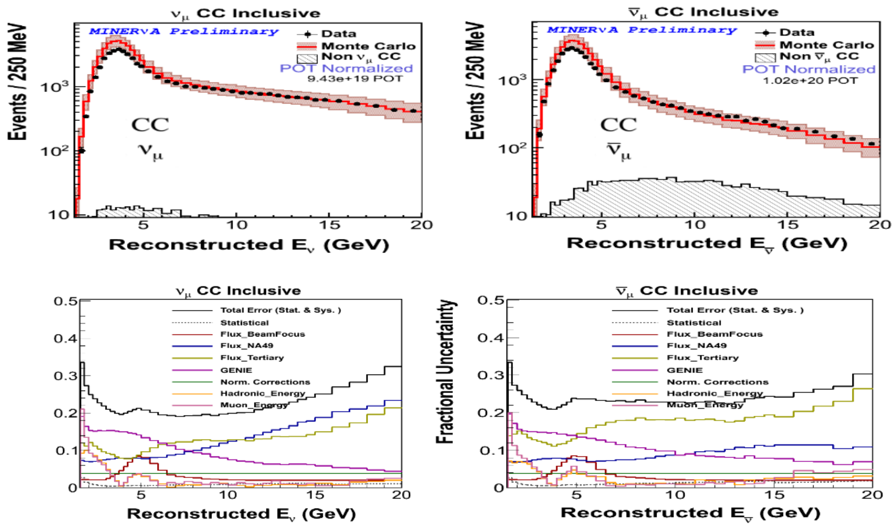
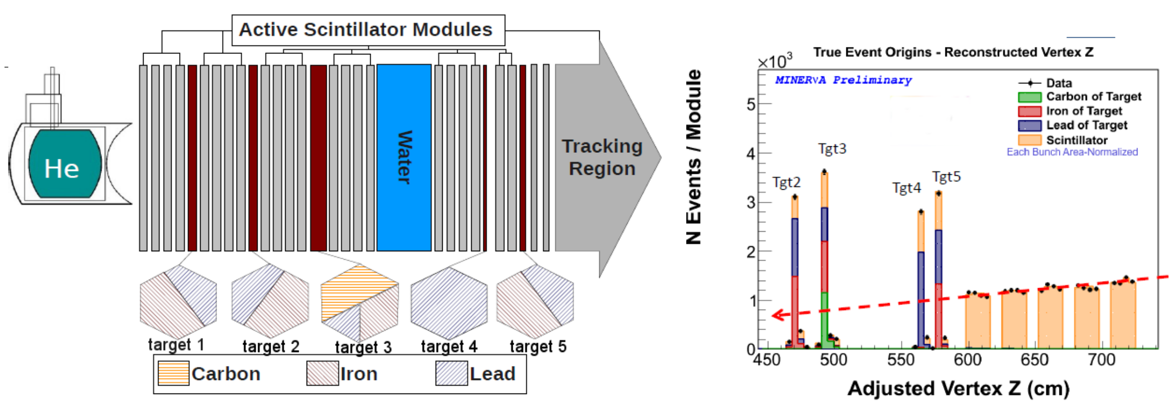



**FIGURE 3.** Neutrino and anti-neutrino reconstructed energy

## CHARGED CURRENT (CC) INCLUSIVE ANALYSIS IN THE NUCLEAR TARGETS

The goal of this analysis is to study the nuclear dependence of the inclusive cross section. The MINERvA detector has a large variety of nuclear targets. It has passive nuclear targets of lead, carbon, iron, helium and water in addition to the active scintillator target.

Carbon, iron and/or lead are combined to form each of the solid passive target modules (see figure 4(a)) and having either four or eight active scintillator planes separating them in order to measure final state multiplicities and near-vertex activity.




a MINERvA nuclear targets schematic

b Tracker modules are used to predict and subtract the plastic background

**FIGURE 4.** Nuclear targets at MINERvA and the data-driven plastic background subtraction technique for targets 2,3 and 4 used for the present results of this analysis

The event selection criteria is similar to the inclusive analysis in the tracker, but requiring for the vertex z-position to be near a nuclear target and for the vertex point to be more than 2.5 cm away from the material partition in the

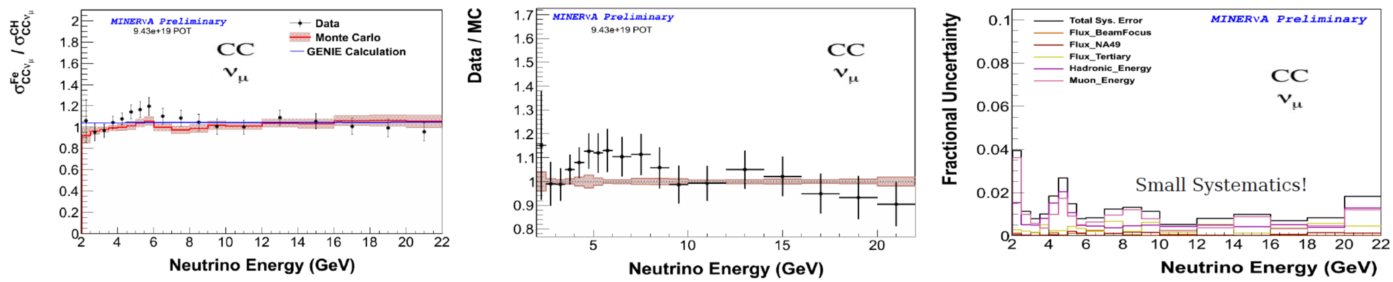



**FIGURE 5.** Left: $\sigma^{Fe}_{CC_{\nu_\mu}}/\sigma^{CH}_{CC_{\nu_\mu}}$ ratio comparison. Center: $Data/MC$ ratio, Right: Fractional sistematic uncertainties

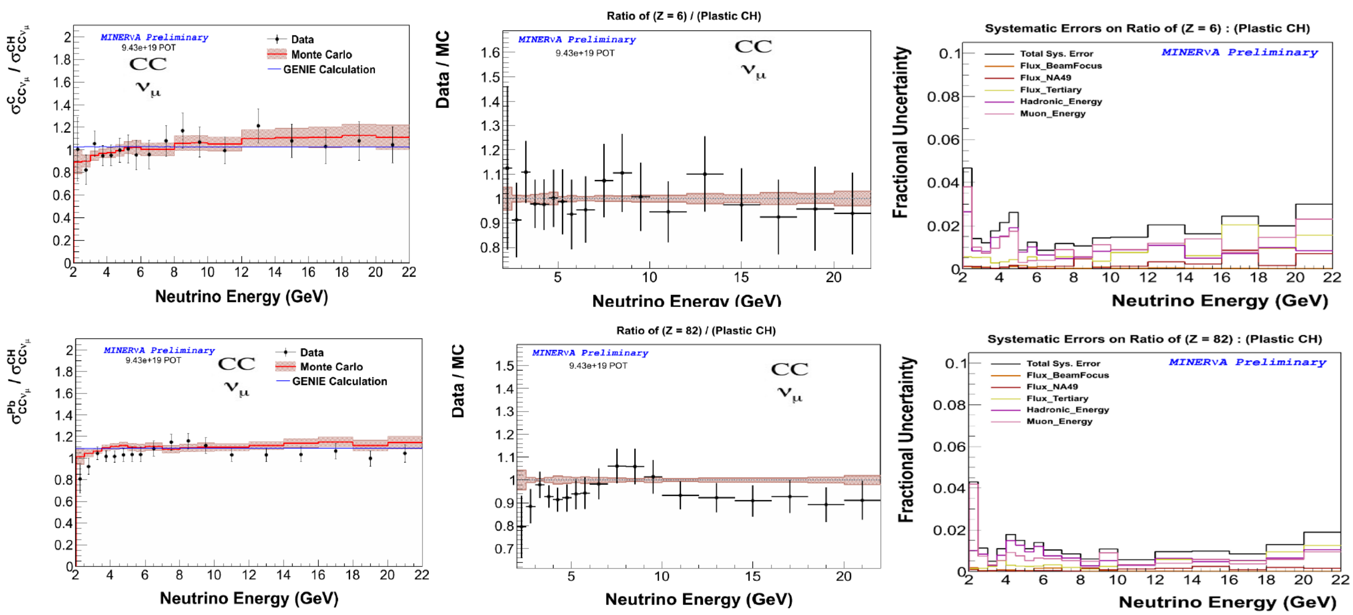



**FIGURE 6.** $\sigma^{C}_{CC_{\nu_\mu}}/\sigma^{CH}_{CC_{\nu_\mu}}$ (Top) and $\sigma^{Pb}_{CC_{\nu_\mu}}/\sigma^{CH}_{CC_{\nu_\mu}}$ (Bottom) cross section ratios (left) , Data/MC comparisons (center) and fractional systematic uncertainties (right)

nuclear target.

The passive target vertex estimation is done by first considering the vertex in the first plane downstream of the target and then projecting the one track events to the passive target's center in Z. There are scintillator modules downstream of the passive targets used as control targets to predict and subtract the plastic background (see figure 4(b)).

After the background subtraction, the bayesian unfolding method with 2 iterations, acceptance correction and flux normalization are applied in order to get the cross sections.

Figure 5 shows the cross section ratio between iron and plastic, systematics are considerably small since both targets are exposed to the same beam, hence having most of the systematics cancelled out when doing the ratio measurements. Figure 6 shows the cross section ratio measurements for $C/CH$ and $Pb/CH$.

## CONCLUSIONS

The MINERvA experiment is performing well and is making significant progress towards its first charged current inclusive cross sections results. It is the first time for MINERvA showing CC anti-neutrino inclusive samples. Preliminary measurements of neutrino cross section ratios on different targets in the few-GeV region have been presented, the plastic background subtraction in this analysis is improving and there is still more data available to analyze. The systematic errors are being explored and significant improvement can be expected in the future. A DIS analysis will be driven in the near future based on the CC Inclusive Analysis.

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