Elastic scattering with the MINERνA experiment

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Abstract. The Main Injector Experiment ν-A (MINERνA) located at Fermi National Laboratory will measure neutrino cross sections, nuclear effects from a broad range of nuclear targets and a variety of other neutrino interactions. Neutrino elastic scattering will be one of the first focuses of the MINERA collaboration; these measurements will be an important input to current and future neutrino oscillation experiments. Results of the charged current quasi-elastic channel exposure in anti-neutrino NuMI running are presented. Future elastic scattering results, both charged current and neutral current, in anti-neutrino and neutrino exposures are also discussed.

1. Introduction

The future of neutrino physics involves the pursuit of CP violation and precision measurements of the neutrino mixing parameters. Precision measurements of the neutrino's interaction with a range of nuclei are needed before the most accurate physics neutrino factories and beta beams can be extracted. Interactions with anti-neutrinos are becoming increasingly more important. Also, broad physics that can be realized when new, precision neutrino and anti-neutrino data are combined. Clearly, future neutrino endeavours can be aided by a careful study of $\nu_\mu/\overline{\nu}_\mu$ interactions.

2. Neutrino Elastic Scattering

Neutrino nucleon elastic scattering is an important class of interactions that is used extensively in the neutrino community. Hence, it is essential to understand this interaction to a high precision. Presently, there is tension between the higher energy charged current quasi-elastic (CCQE) cross sections measured from the NOMAD experiment [1] and the lower energy BooNE experiments [2]; in addition, there are 20% differences among other experiments' cross sections.

The (quasi) elastic cross section can be written in terms of the well-known leptonic current and a total of six form factors of the hadronic current. Using isospin symmetry, neglecting second class currents and ignoring the factor multiplied by $(m_\mu/m_N)^2$, leaves the only one unknown, the axial form factor. The axial factor can be parameterized via a dipole form:

$$F_A(Q^2) = \frac{g_A(Q^2\!=\!0)}{(1+\frac{Q^2}{M_A^2})^2}$$

where $g_A(Q^2\!=\!0)$ is determined from neutron decay to be roughly -1.26 and M_A is the experimentally determined axial mass parameter. Recent results for the experimentally extracted axial mass parameter have been much higher than measurements obtained in the past (see Figure 1). There are a large range of different targets for these experiments and nuclear effects are still relatively unknown for ν's (as well as for $\overline{\nu}$'s). In addition, there is interest in using theories beyond the impulse approximation, such as meson exchange currents and 2p2h contributions, to describe current CCQE data. Conflicting data make precision physics in this interaction channel difficult at the moment.

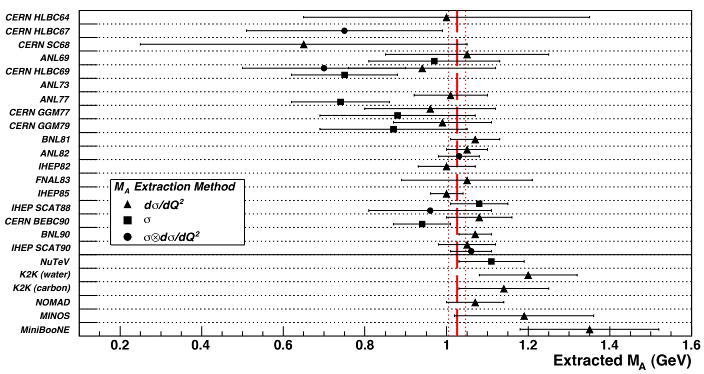

Figure 1. M_A parameters extracted from neutrino experiments with a wide range of targets; data spans 1964-2010. The line represents an average M_A value of 1.026 ± 0.021 GeV/c.

3. MINERνA Detector and Physics Capabilities

The basic element of the MINERνA detector is a hexagon with an apothem of $\sim$1.1m made of varying length, repeating scintillator bars read out by fibers connected to a photomultiplier tube. Scintillator planes have three different orientations for 3D track reconstruction. Two scintillator views are stacked together in a tracker module, a 0.2mm sheet of Pb is attached to each plane in an electromagnetic calorimeter (ECAL) module and one plane view is joined with 2.54cm of Fe in a hadronic calorimeter (HCAL) module. A module is surrounded by steel outer detector. The full detector has 60 tracker modules ($\sim$6.5 tons scint.), 10 ECAL modules and 20 HCAL modules. The upstream end of MINERνA has six modules with varying shape solid graphite (C), Pb and Fe targets. A liquid He cryogenic vessel sits in front of MINERνA and there are plans to install a water target module as well. MINERνA lacks a magnetic field; exiting particles are momentum analyzed by the downstream MINOS detector. Position and timing resolutions for the detector are measured to be 2.65mm and 3.0ns, respectively. A more detailed description of the detector can be found in [3].

The MINERνA experiment will collect the largest neutrino data set to date. Charged current events originating the fiducial region are fully contained, except for the muon, for neutrino energies up to 10 GeV. The position and timing resolution will enable studies of busy vertex regions and disentangling of possible multiple neutrino events in the detector. The variety of nuclear targets allows studies of $\nu_\mu/\overline{\nu}_\mu$ interactions in the same beam.

4. MINERνA $\nu_\mu/\overline{\nu}_\mu$ Data Sets

After partial installation of the 20 HCAL modules, the 10 ECAL modules and 30 tracker modules, the detector was fully instrumented and started taking NuMI LE $\overline{\nu}_\mu$ data. After the full detector installation was completed, the NuMI beam switched to the LE ν_μ configuration. The detector has $>98\%$ live time since data taking started (with the partial detector) on 11/2009. The protons on target (POT), NuMI beam mode and the detector configuration for various MINERνA data sets are listed in Table 1.

Table 1. Detector configuration, POT and NuMI beam for MINERνA data sets.

Detector	POT, NuMI mode
partial	$0.8e20\ \overline{\nu}_\mu\ LE$
full	$1.28e20\ \nu_\mu\ LE$
full	$1.5e20\ \overline{\nu}_\mu\ LE$
full (total run plan)	$4.9e20\ \nu_\mu\ LE$
full (total run plan)	$12e20\ \nu_\mu\ ME$

5. MINERνA Elastic Physics

First MINERνA physics results will be Pb/Fe interaction ratios from the most downstream heavy target module and $\overline{\nu}_\mu$ CCQE interactions. The former are reported at this conference [4] and the latter are described here.

Neutrino elastic scattering channels are $\overline{\nu}_\mu \to \mu^+ n$ and $\nu_\mu \to \mu^- p$. The first MINERνA elastic results are $\overline{\nu}_\mu$ scattering with the partial detector. The event selection is a μ^+ momentum analyzed track originating in $\sim$3 ton fiducial volume. Kinematic quantities are derived from the muon alone; the final state neutron is not required to be identified, but a Q^2-dependent vertex recoil energy cut is applied to enhance the CCQE fraction in the sample, see Figure 2.

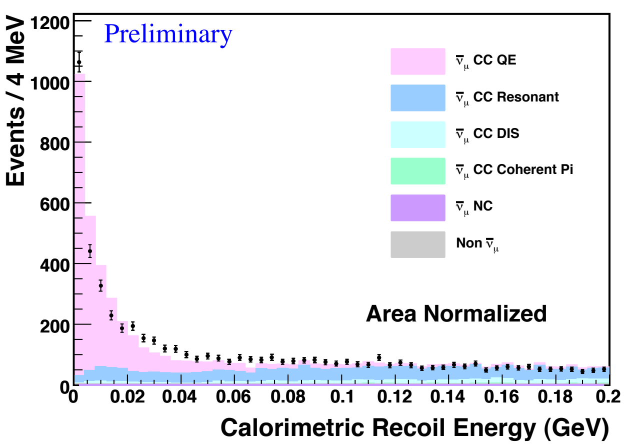

Figure 2. Distribution of the recoil energy of $\overline{\nu}_\mu$ CCQE-like interactions for data and monte carlo.

The area normalized Q^2 and E_ν distributions of data compared to GENIE-generated monte carlo [5] using this event selection are shown in Figures 3 and 4.

Analysis of elastic $\nu_\mu \to \mu^- p$ scattering is currently underway. Factors from the $\nu_\mu/\overline{\nu}_\mu$ cross section ratio and increased fiducial volume of the full detector will lead to approximately four times the statistics of the $\overline{\nu}_\mu$ partial detector sample for a similar POT exposure. The presence of the highly ionizing proton introduces another signature for the ν_μ CCQE interaction. Using the charge, momentum/range information from the MINOS experiment and knowledge from MINERνA Test Beam detector for proton identification, MINERνA will collect one of the largest samples of this channel to date (with the total POT in the run plan). There is also interest to use knowledge gained from ν_μ CCQE channel analysis to identify single proton tracks originating in the detector; this is the signal for simple neutral current elastic scattering. The $\nu_\mu p \to \nu_\mu p$ interaction can be studied in ratios and combinations to yield a measurement of g_a^s, the strangeness contribution the nucleon spin [6]. The backgrounds in this channel will

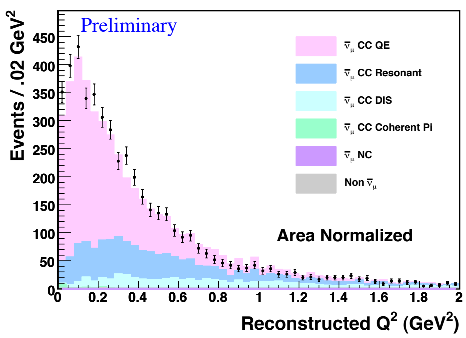

Figure 3. Preliminary Q^2 distribution for CCQE-like $\overline{\nu}_\mu$ candidates.

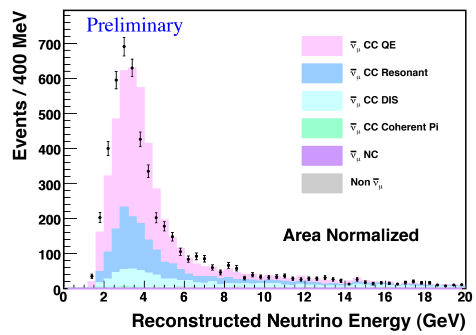

Figure 4. Preliminary E_ν distribution for CCQE-like $\overline{\nu}_\mu$ candidates.

complicate the analysis.

Acknowledgments
The author is very grateful to the organizers for the invitation to speak at the NuFact 2011 and for the financial assistance that, in part, made it possible to attend the venue. The author would also like to extend gratitude, on the behalf of the entire MINERνA Collaboration, to both Alain Blondel and Ilias Efthymiopoulos for their efforts in hosting NuFact 2011.

Appendix A
Kinematic quantities assuming two body $\overline{\nu}_\mu$ CCQE interaction:

$$E_{\overline{\nu}_\mu} = \frac{m_n^2 - (m_p - \epsilon_B)^2 - m_\mu^2 + 2(m_p - \epsilon_B)E_\mu}{2((m_p - \epsilon_B) - E_\mu + p_\mu cos\theta_\mu)}, \quad Q^2 = 2E_{\overline{\nu}}(E_\mu - p_\mu cos\theta_\mu) - m_\mu^2$$

References
[1] Lyubushkin V 2009 A study of quasi-elastic muon neutrino and antineutrino scattering in the NOMAD experiment *AIP Conf. Proc.* **1189** p157-162
[2] Aguilar-Arevalo A 2008 Measurement of muon neutrino quasi-elastic scattering on carbon *Phys. Rev. Lett.* **100** 032301
[3] Budd H 2011 Design of the MINERνA detector *Topics in Part. Phys. Proc.* (Chicago, Elsevier)
[4] Devan J 2012 Charge current inclusive measurements with MINERνA *NuFact Int. Conf. Proc.* (Geneva, JPCS)
[5] Andreopoulos C, *et al.* 2010 The GENIE neutrino monte carlo generator *Nuc. Inst. Meth.* **614** p87-104
[6] Praet C 2009 Modeling quasi-free neutrino-nucleus reactions for accelerator-based experiments PhD. Dissertation (Belgium, Ghent University)