MINERνA, a Neutrino – Nucleus Interaction Experiment

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Abstract. With the fantastic results of KamLAND and SNO for neutrino physics, a new generation of neutrino experiments are being designed and build, specially to study the neutrino oscillations to resolve most of the incognita still we have in the neutrino physics. At FERMILAB we have the experiments MINOS and, in a near future, NOvA, to study this kind of oscillations. One big problem these experiments will have is the lack of a good knowledge of the Physics of neutrino interactions with matter, and this will generate big systematic errors. MINERνA, also at FERMILAB, will cover this space studying with high statistics and great precision the neutrino – nucleus interactions.

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INTRODUCTION

There exist open questions in Neutrino Physics like: what are the masses of the neutrinos?, what is the pattern of mixing among different types of neutrinos? are neutrinos their own anti-particles? and other more. To solve the pattern mixing question there exist a new generation of long-baseline neutrino oscillation experiments at the atmospheric $\delta m^2$, like MINOS[4]. The answer to almost every one of these open questions in Neutrino Physics involves understanding how neutrinos interact with matter.

For NuMI/MINOS [5], beamline expected distorsion in $\nu$ energy distribution occurs for $E_\nu < 3 GeV$. Recall oscillation probability depends on $E_\nu$, however $E_\nu(measured)$ depends on Flux, $\sigma$, and detector response. The complications are that Near/Far fluxes are different (cross section don’t cancel in the ratio) and that low energy neutrino cross sections are not well understood (little data exists [6]). The solution was the MINERνA experiment [1, 2, 3], which put fine grained detector in high rate neutrino beam - NuMI beamline.

MINERνA DETECTOR

MINERνA detector [2, 3] is a low mass compact fully-active device interspersed with passive nuclear targets, designed to make use of the wide-band, high intensity NuMI neutrino beam with energy ranges from $E_\nu = 1 – 20 GeV$. The fiducial volume in which most events will be analyzed is the inner “active target” which is made almost entirely of scintillator strips. The strips are assembled into hexagonal planes with distinct
FIGURE 1. Schematic side view of the MINERvA detector with sub-detectors labeled. In the figure the neutrinos enter from the left and the MINOS near detector, which serves as the MINERvA muon detector analyzer, is to the right.

FIGURE 2. Scintillator strips with WLS fibers

orientations of strips offset by $60^\circ$. The structure of the MINERvA detector is modular. Each plane is made of two components: 1) sheet of segmented polystyrene scintillator, 2) a surrounding iron and scintillator hadronic calorimeter.

Inner detector:
1. nuclear targets: lead, iron, carbon
2. active target
3. electromagnetic calorimeter (ECAL)
4. hadronic calorimeter (HCAL)

Surrounding ECALs are the HCAL and the outer detector (OD) which intersperse scintillator with steel absorber. Downstream of MINERvA is the MINOS [4] near detector, which will measure the energy of muons which do not exit through the OD.

The active element of the inner scintillator detector consists of extruded polystyrene scintillator strips of triangular cross-section [2]. The polystyrene is mixed with 1% PPO and 0.01% POPOP in a continuous in-line extrusion process, and an accompanying co-extruder places a $\sim 0.2 mm$ reflected layer of $TiO_2$ loaded polystyrene on the outside of
the strips. In the center of the triangle, the extruder also leaves a $\sim 2 \text{mm}$ diameter hole in which is placed a 1.2 mm diameter Kuraray multi-clad S-35 fiber doped at 175 ppm of Y-11 waveshifter 2.

**LHCb/GAUDI FOR MINERvA SOFTWARE**

We distinguish between four layers of software:

1. **LCG** [7] is the set of libraries and toolkits maintained by the CERN Linear Computing Grid project. LCG includes essential utilities like ROOT and Geant4, but is not experiment- or framework-specific. It is used by all LHC experiments and MINERvA (among others). It is maintained by a combination of external authors and the LCG project, and managed (for purposes of LHC experiments and MINERvA) by LCG personnel.

2. **GAUDI** [8] is the framework on which higher layers are built. It supports considerable essential functionality like job steering, histogramming, Ntuples, and persistence, but does not actually perform any specific physics task (like simulating data, displaying the detector, etc). GAUDI depends on a subset of the full LCG software libraries and is used by LHCb, ATLAS, GLAST, HARP, and MINERvA. It is maintained and managed by the GAUDI developers at CERN.

3. The LHCb software [9] is based on GAUDI and LCG, and includes libraries and complete applications to perform end-user physics tasks. While written for LHCb, this software contains an architecture and a large number of reusable components that can be adapted or modified for use in MINERvA. It is maintained and managed by the LHCb computing group.

4. The MINERvA software is built on all of the above layers. Only this layer is subject to modification by MINERvA developers. When MINERvA-specific modifications are required in LCG, GAUDI and/or LHCb layers, we “override” the externally maintained software by creating and modifying a copy of the package in question, rather than the original. If the changes are extensions or bug fixes which are compatible with the designed behavior of the external software in other experiments, we ask the appropriate maintainers to incorporate them in a future release, so the amount of MINERvA-specific code is minimized.

**MINERvA SOFTWARE PROJECT**

The project encompass all internally developed software to operate, simulate, reconstruct, analyze and visualize MINERvA data. The project also encompass deployment of software, management of the environment for using it, and accessibility of the data for processing and physics analysis.

1. **Detector Simulation.** MEGA is the simulation program of the MINERvA experiment, based on the Gaudi Framework and on the LHCbSys Classes. MEGA makes use of the Geant4 toolkit for the tracking of the particles in the detector and simulating the physics processes occurring in the experimental setup. The MINERvA soft-
ware group is currently implemented the event generators, such as NEUGEN, Nu-
ance and GENIE, these both were created for experiment specific applications, but
are used widely in the neutrino community.

2. Digit Simulation.- The digitization application will be the final stage of the
MINERνA detector simulation. It will apply the detector response to hits previously
generated in sensitive detectors by the Geant4 based simulation application
(MEGA). The digitization step includes simulation of the detector response and
of the readout electronics, as well as of the L0 trigger hardware. The output will
be digitized data that mimics the real data coming from the real detector. It is
currently under development.

3. Reconstruction.- Currently under development, the reconstruction program will
naturally rely heavily on the software framework for steering, event data and detector
data management. The global reconstruction algorithm will be composed from
smaller and more manageable sub-algorithms, each responsible for a single, spec-
cific function. It is highly desirable that each sub-algorithm be independent of the
details of any other, and that algorithms appear as interchangeable components that
can be combined at will.

4. MINOS [5] Interface.- MINERνA will rely heavily on data from the MINOS near
detector, which serves as a range/spectrometer and is necessary to reconstruct the
momentum of most muons produced in MINERνA, whether by range or curva-
ture. This necessitates not only access to certain MINOS event data, but sufficient
knowledge of the relevant geometry and field information to interpret them. Since
the momentum of the lepton produced in a charged-current neutrino interaction is
required to determine the neutrino energy and momentum transfer, our experiment
is predicated on the availability of this information. Currently we are working im-
plemented onto the simulation the MINOS detector geometry.

EVENT GENERATORS AT MINERνA

The MINERνA simulation software interfaces with two event generators that model
neutrino interactions with matter: NEUGEN [10] and NUANCE [11]. NEUGEN was
originally designed for the Soudan 2 experiment and is now the primary neutrino gen-
erator for the MINOS experiment. NUANCE was developed for the IMB experiment and
is used by the Super-Kamiokande, K2K, MiniBooNE and SNO collaborations. Both
have evolved from “proprietary” programs designed for atmospheric neutrino studies
into freely-available, general-purpose utilities that aim to model neutrino scattering over
a wide range of energies and for different nuclear targets. Total charged-current cross
sections calculated by NUANCE and NEUGEN (Fig. 3) are shown below.

As the results of the two generators agree with each other (to within the depressingly
large range of uncertainties in available data) [12], they have been used interchange-
ably for the present studies. As in the past, future studies of neutrino oscillation and
searches for nucleon decay will rely heavily on the best possible description of neu-
trino interactions with matter. Neutrino event generators are tools which encapsulate our
understanding of this physics in an easily usable and portable form. Practically, they
serve two related functions: to allow the rates of different reactions with the experimen-
otal target to be calculated, by providing total exclusive and inclusive cross-sections, and to simulate the dynamics of individual scattering events, by sampling the differential cross-sections. Many comparable packages are available to the collider physics community, and have been incrementally improved for decades, forming a common basis for discussion of different models and phenomena. One important goal of MINERvA is to improve the quality of neutrino Monte Carlo event generators, and thereby enhance the physics reach of many future experiments.

MINERvA will attack this problem from both experimental and theoretical directions. Experimentally, MINERvA will make definitive measurements of dozens of exclusive and inclusive cross-sections, across the range of energies most important for future oscillation and nucleon-decay experiments, with a well-controlled flux, and on a variety of nuclear targets. The era of 25% uncertainties and marginally consistent cross-section data for even the simplest neutrino reactions will end with MINERvA; for the first time it will be possible to validate the details, and not merely the gross features, of competing models. At the same time, MINERvA will be a natural focus of attention for theorists and phenomenologists developing these models. NEUGEN and NUANCE are two of the most sophisticated neutrino-physics simulations in the world, but NUANCE models quasi-elastic scattering with the 1972 calculation of Smith and Moniz [13], and both programs use the Rein-Sehgal [14] resonant production model which dates from 1981. That no other widely-accepted models for these, the most fundamental neutrino-nucleon reactions, have emerged in the last quarter century is sobering evidence that an experiment like MINERvA is long overdue. New, high-quality data is the surest way to catalyze theoretical ingenuity, and MINERvA will provide the former in abundance. Through our contacts with these theorists, and ability to translate well-tested, state-of-the-art models into universally-available and widely-adopted software, MINERvA will serve as a conduit for expertise from a diverse collection of disciplines into the high-energy neutrino physics community.

FIGURE 3. Total neutrino cross section ($\sigma/E_\nu$) as a sum of quasi-elastic, resonant, and inelastic contributions compared with data from a number of experiments.
CONCLUSIONS

• The MINERνA experiment brings together the expertise of the HEP and NP communities to study low-energy ν – A physics.
• MINERνA will accumulate significantly more events in important exclusive channels across a wider $E_\nu$ range than currently available as well as a huge sample of DIS events. With excellent knowledge of the beam, $\sigma$ will be well-measured.
• With C, Fe and Pb targets MINERνA will undertake a systematic study of nuclear effects in $\nu – A$ interactions, known to be different than well-studied e-A channels.
• The MINERνA results will dramatically improve the systematic errors of current and future neutrino oscillation experiments.
• The most advanced software architecture, like the Object Oriented framework Gaudi and event generator NEUGEN/GENIE, are used in MINERνA.
• MINERνA has Stage I approval and is an established Fermilab project, with an evolving (Fermilab/DOE) funding scenario, that should be completed in Fall of 2008 with physics data-taking starting end CY2008 or start of CY2009.

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REFERENCES