UNIVERSIDAD DE GUANAJUATO

Laboratorio de Partículas Elementales
Universidad de Guanajuato

MEASUREMENTS OF NEUTRINO CROSS-SECTIONS ON DIFFERENT NUCLEAR TARGETS IN MINER*v*A

Julian Felix*

Laboratorio de Partículas Elementales. Departamento de Física, División de Ciencias e ingenierías, Campus León, Universidad de Guanajuato
León Guanajuato, México

*On behalf of MINERvA Collaboration.
felix@fisica.ugto.mx

ABSTRACT.

The MINERνA experiment, http://minerva.fnal.gov, has been measuring muon neutrino (muon antineutrino) nuclei interactions in He, C, H_2O, Lead, plastic scintillator, and Fe targets at low energy (~3 GeV) and medium energy (~6 GeV).

The MINERνA experiment is briefly described and some results on different nuclei interaction cross section measurements are presented such as: ν_μ and anti ν_μ induced pion production and Charged-Current ν_μ interaction K^+ production in the ~3.5-GeV region on CH; and neutrino-nucleus charged-current deep inelastic scattering (DIS) on targets as ratios of C, Fe, and Pb to CH.

Outline

1. INTRODUCTION
2. MINER*ν*A EXPERIMENT
3. NEUTRINO CROSS SECTION MEASUREMENTS
4. CONCLUSIONS

1. INTRODUCTION

Neutrino nuclei interaction depends on the energy region

LOW ENERGY CROSS SECTIONS: neutrino energy = ~3.5-GeV.

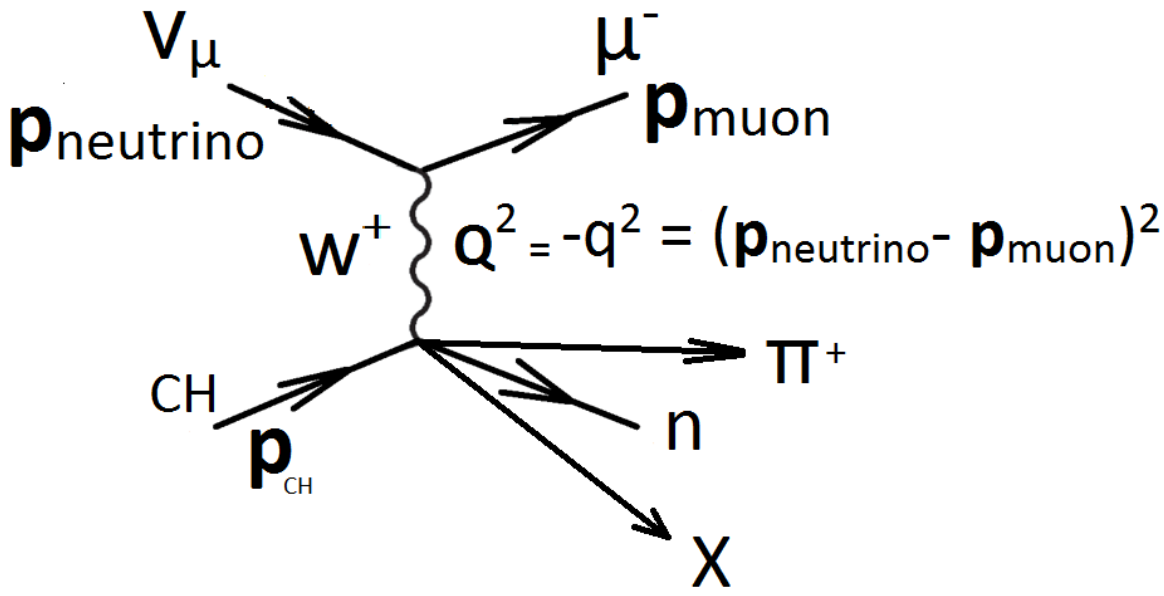
Elastic and quasielastic scattering.

Resonance production.

Deep inelastic scattering.

This is the energy region where MINER*v*A collaboration can contribute.

Charged Current.
Case of neutrino interaction.



To describe neutrino nucleus interactions the following parameter are used:

Differential Cross section

$$\left(\frac{d\sigma}{dX}\right)_i = \frac{1}{T\Phi}\frac{1}{\Delta X_i}\frac{\sum_j U_{ij}\left(N_j^{data} - N_j^{bkg}\right)}{\epsilon_i}$$

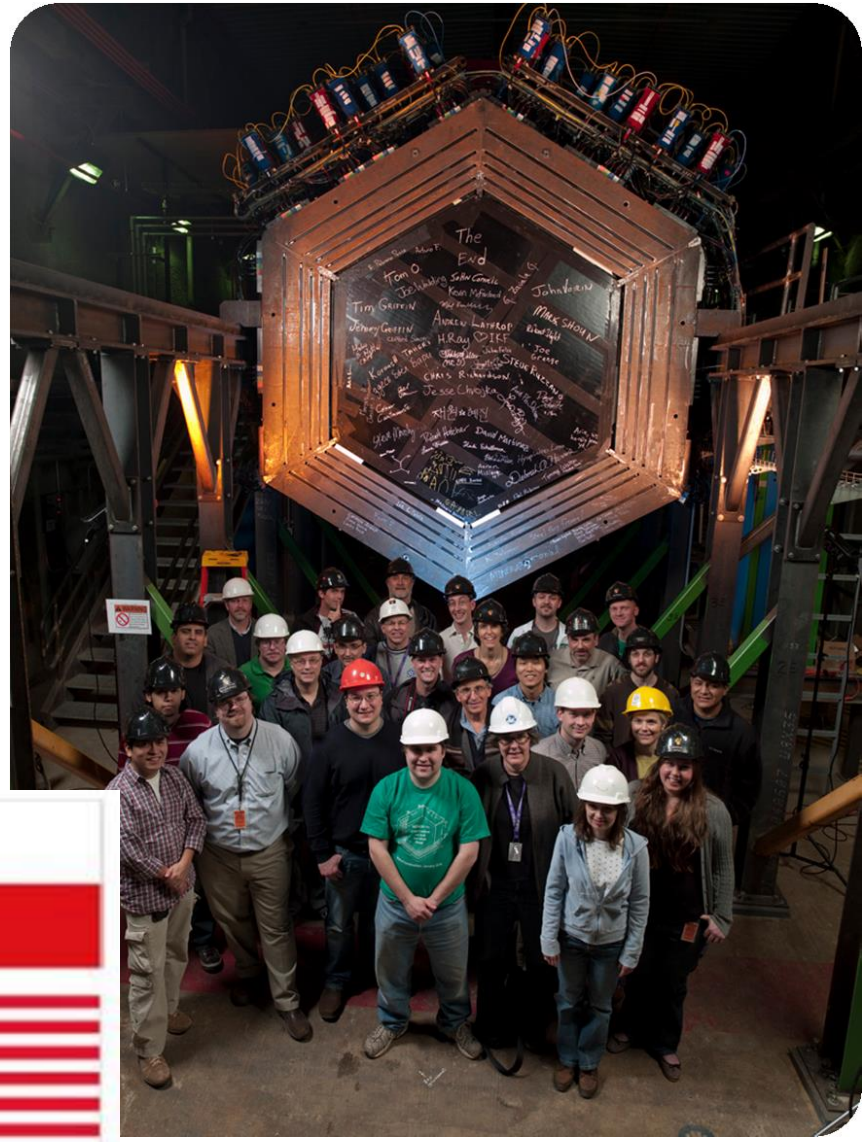
Total Cross section

$$\sigma(E_\nu)_i = \frac{1}{T\Phi_i}\frac{\sum_j U_{ij}\left(N_j^{data} - N_j^{bkg}\right)}{\epsilon_i}$$

2. MINERvA EXPERIMENT

~65 collaborators from particle and nuclear physics

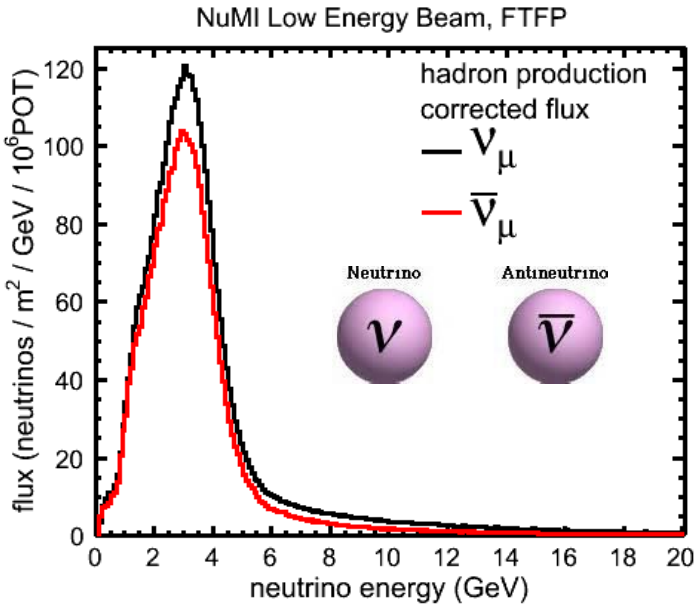
Centro Brasileiro de Pesquisas Físicas
University of Florida
Universidad de Guanajuato
University of Oxford
Northwestern University
Otterbein University
University of Pittsburgh
Rutgers University
University of California at Irvine
University of Minnesota at Duluth
Universidad Nacional de Ingeniería
Universidad Técnica Federico Santa María
College of William and Mary
Fermilab
Université de Genève
Hampton University
Mass. Col. Lib. Arts
University of Chicago
Pontificia Universidad Catolica del Peru
University of Rochester
Tufts University



MINERvA stands for Main Injector Neutrino ExpeRiment v(neutrino) A(nucleus).

This is, a designed experiment to study the interactions between neutrino (antineutrino) -both, electron neutrino and muon neutrino- with different nuclei -He, H_2O, Pb, C, Fe, CH-.

This experiment has no precedent in the detailed studies, in variety of used targets, and in providing data to present and future neutrino oscillation experiments.



The MINERvA beam energy distribution

The main goals established for low energy run are as follows:

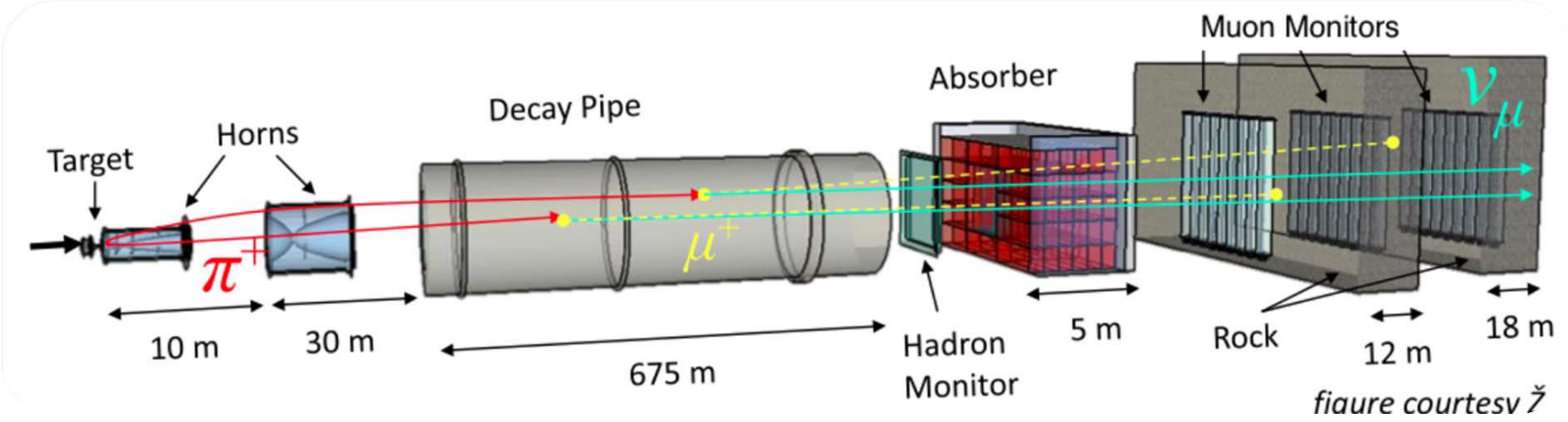
---Study, both signal and background, reactions important to present and future neutrino oscillation experiments;

---study nuclear effects in inclusive reactions;

---measure nuclear effects on exclusive final states as function of measured neutrino energy;

---study differences between neutrinos (anti neutrinos) nuclei interactions.

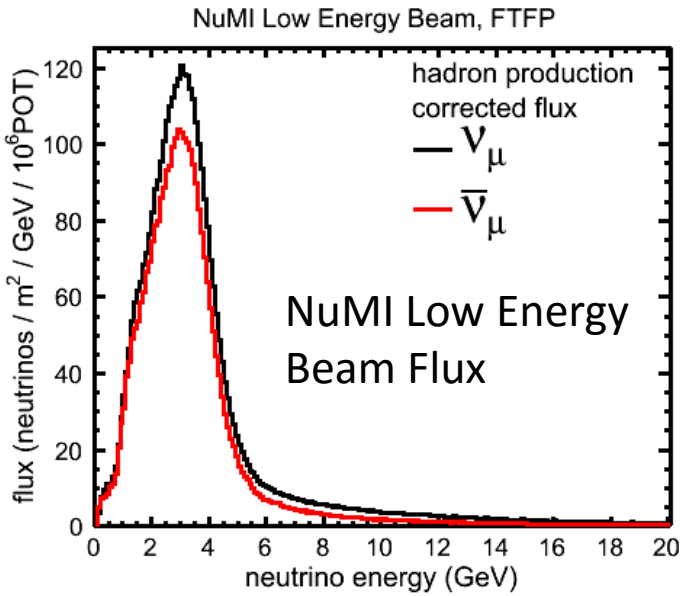
NuMI Beam line (~same for MINOS, NOvA)



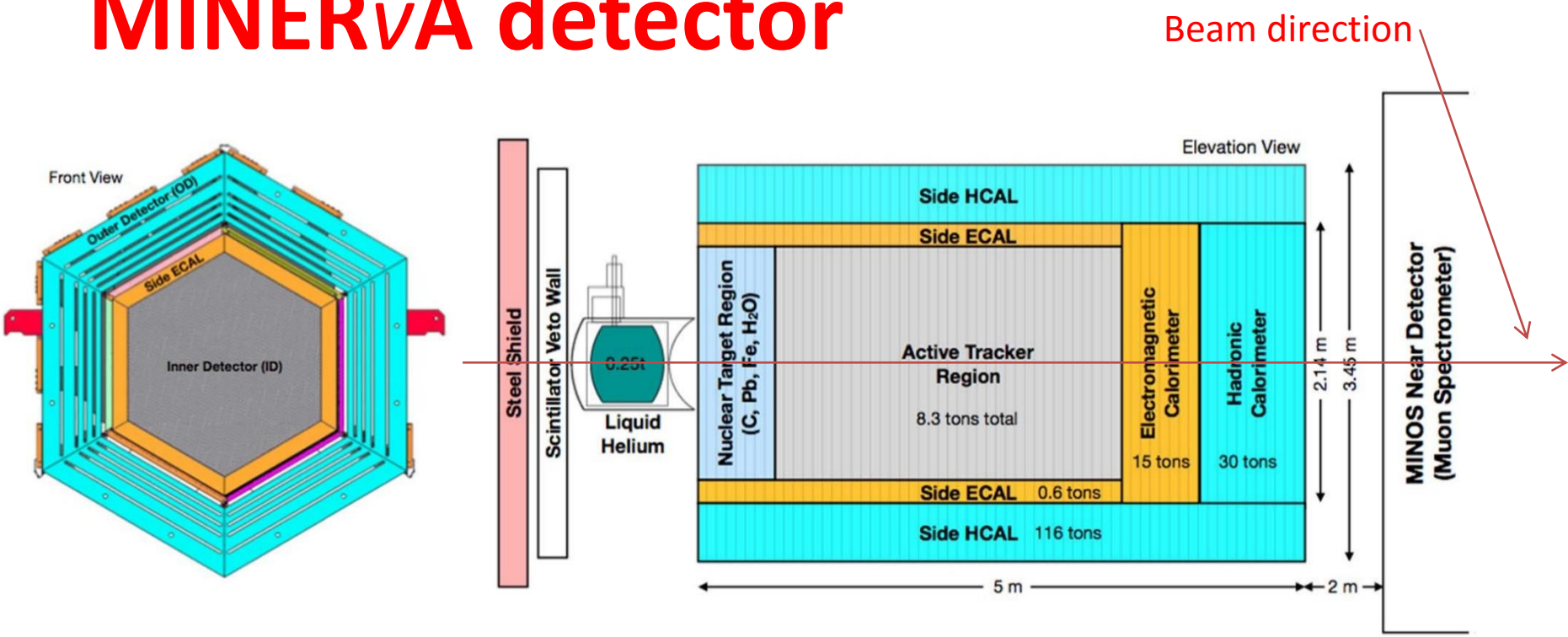
NuMI is a "conventional" neutrino beam, neutrinos from focused pions.

For MINERνA, flux must be calculated, use hadron production data.

Protons on target (POT) to MINERνA,
--neutrino (LE): 3.9E20 POT.
--anti-neutrino (LE): 1.0E20 POT.



MINERvA detector



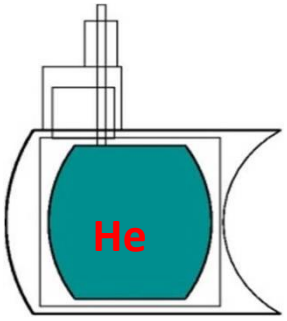
Detector comprised of **120 "modules"** stacked along the beam direction.

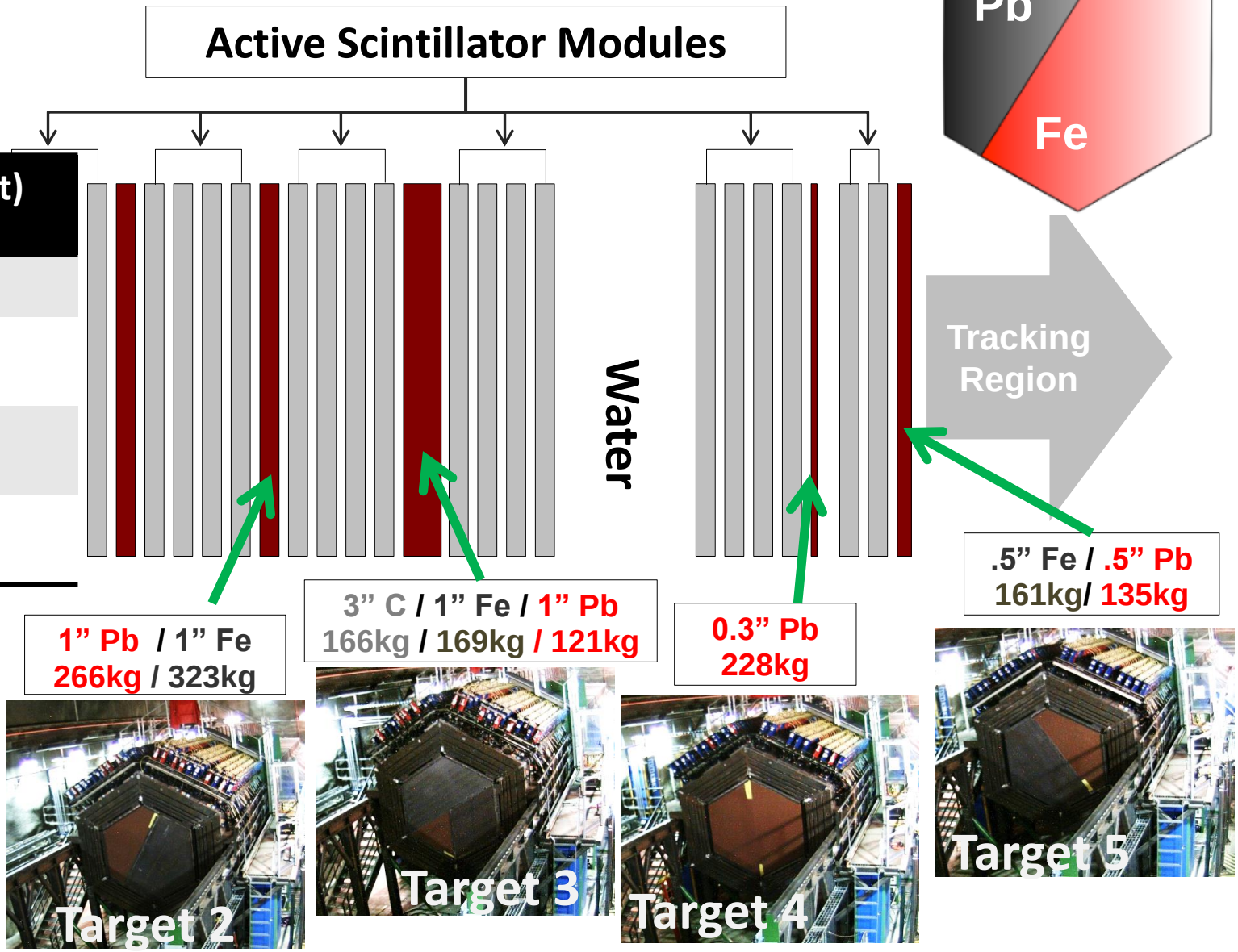
Central region is **finely segmented scintillator tracker.**

~32k plastic scintillator strip channels total.

Targets used

A	Mass (t)
C	0.16
Fe	0.63
Pb	0.71
CH	5.48





Coherent Production of $\pi^{\pm}$ in Neutrino and Anti-Neutrino Beams on Carbon from Eν of 1.5 to 20 GeV;

Ratios of $\nu\mu$ Charged-Current Cross Sections on C, Fe, and Pb to CH at Neutrino Energies 2–20 GeV;

Pion Production in $\nu\mu$ Interactions on Hydrocarbon at <Eν>= 4.0 GeV;

Muon Plus Proton Final States in $\nu\mu$ Interactions on Hydrocarbon at <Eν> = 4.2 GeV;

Single Neutral Pion Production by Charged-Current anti-$\nu\mu$ Interactions on Hydrocarbon at <Eν> = 3.6 GeV;

Electron Neutrino Quasielastic and Quasielastic-like Scattering on Hydrocarbon at <Eν> = 3.6 GeV;

Nuclear Effects in Neutrino-Carbon Interactions at Low Three-Momentum Transfer;

Partonic Nuclear Effects in Deep-Inelastic Neutrino Scattering;

Muon Neutrino (Antineutrino) Quasi-Elastic Scattering on a Hydrocarbon Target at Eν ~ 3.5 GeV;

Muon Quasi-Elastic Scattering on a Hydrocarbon Target at Eν ~ 3.5 GeV;

Neutrino-nucleus charged-current deep inelastic scattering (DIS) on targets as ratios of C, Fe, and Pb to CH.

K^+ production in Charged-Current $\nu\mu$ Interactions;

$\nu\mu$ and anti $\nu\mu$ induced pion production;

And many others.

3. NEUTRINO CROSS SECTION MEASUREMENTS

MINERvA Physics publications

The differential cross sections for muon production angle, muon momentum, and four-momentum transfer Q^2 are reported, and total cross sections as function of neutrino energy are obtained.
In preparation for publication.

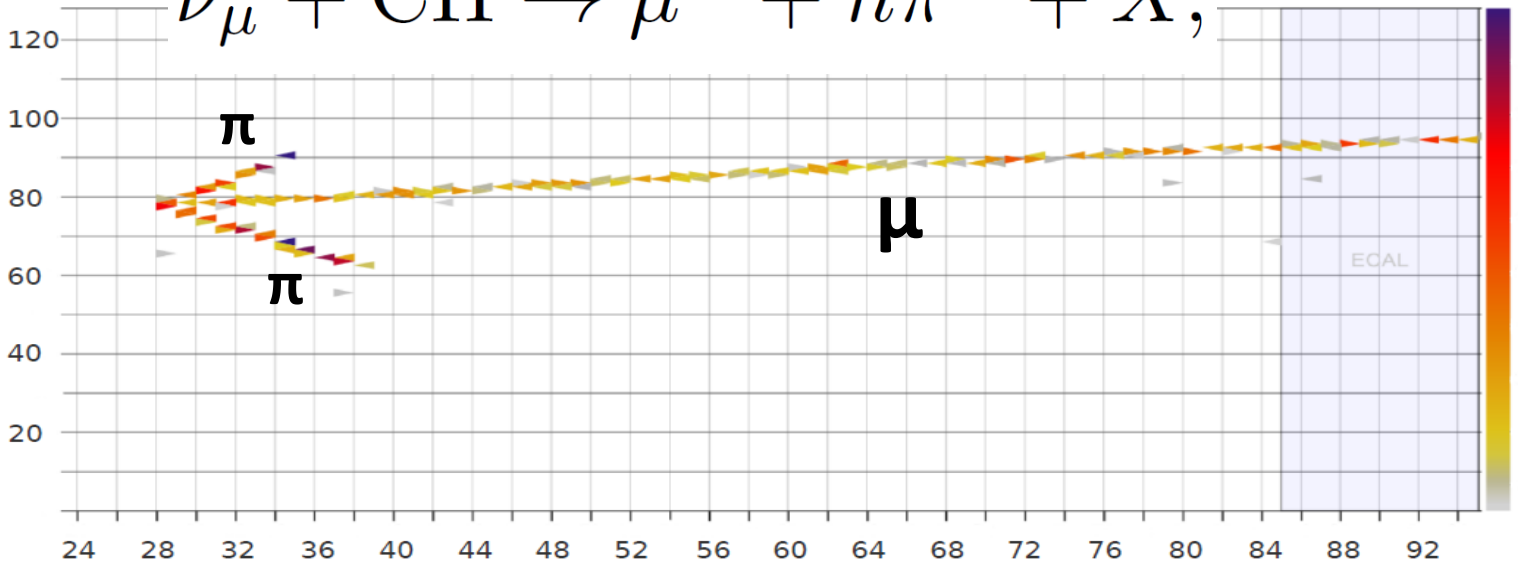
Measurement of K^+production in charged-current $\nu\mu$ interactions **Phys.Rev. D94 no.1, 012002 (2016).**

Neutrino-nucleus charged-current deep inelastic scattering (DIS) on targets as ratios of C, Fe, and Pb to CH. **Phys. Rev. D 93, 071101 (2016).**

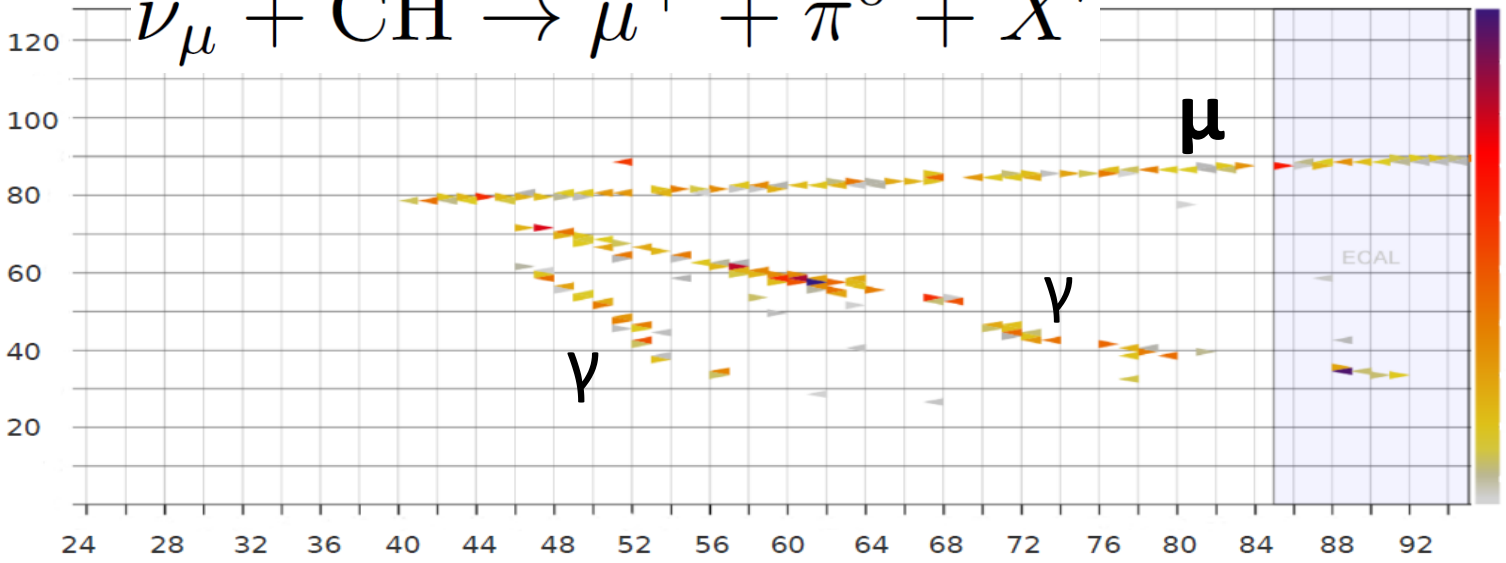
Each analysis follows a particular procedure, depending on the particular physics topic.

In separate samples of charged-current pion production events representing two semi-inclusive channels $\nu\mu$-CC(π^+) and - $\nu\mu$-CC(π^0) have been obtained using neutrino and antineutrino exposures of the MINERνA detector. The differential cross sections for muon production angle, muon momentum, and four-momentum transfer Q^2, are reported, and cross sections versus neutrino energy are obtained.

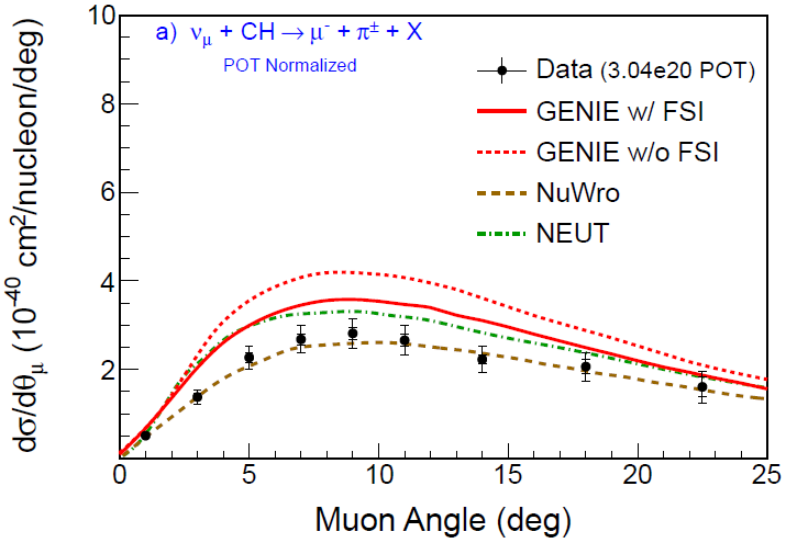
$$\nu_\mu + \mathrm{CH} \rightarrow \mu^- + n\pi^\pm + X,$$

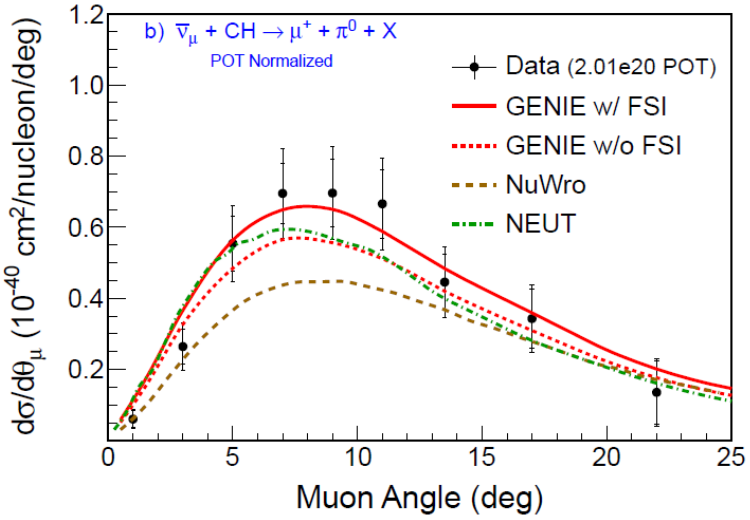


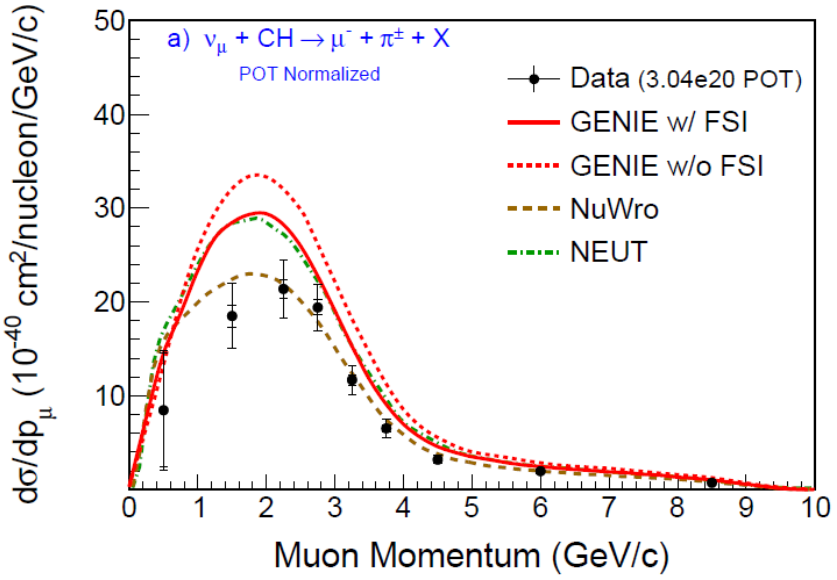
$$\bar{\nu}_\mu + \mathrm{CH} \rightarrow \mu^+ + \pi^0 + X'$$

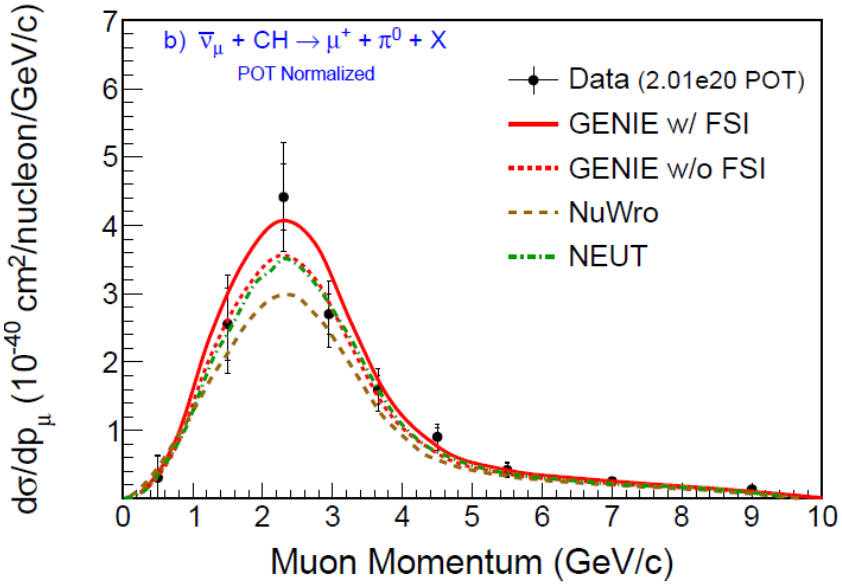


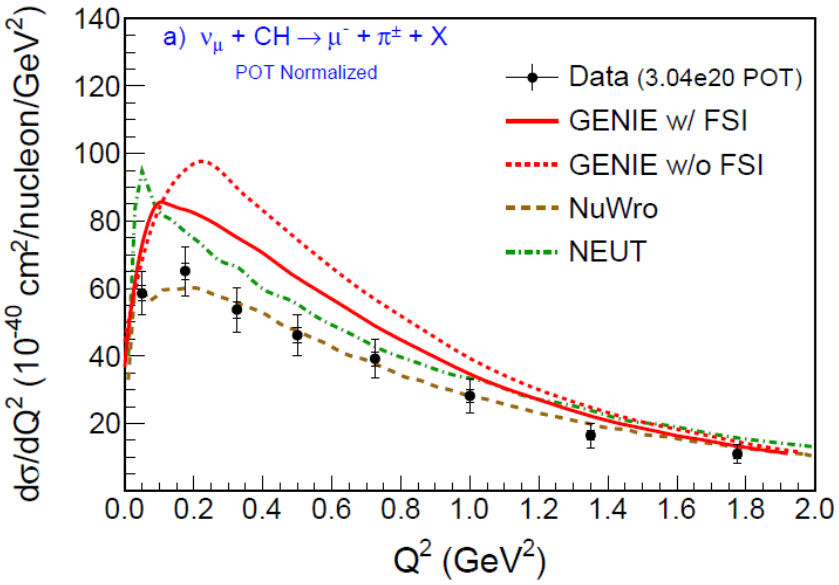
Cross sections for ν_μ and $\bar{\nu}_\mu$ induced pion production on hydrocarbon in the few-GeV region using MINERvA

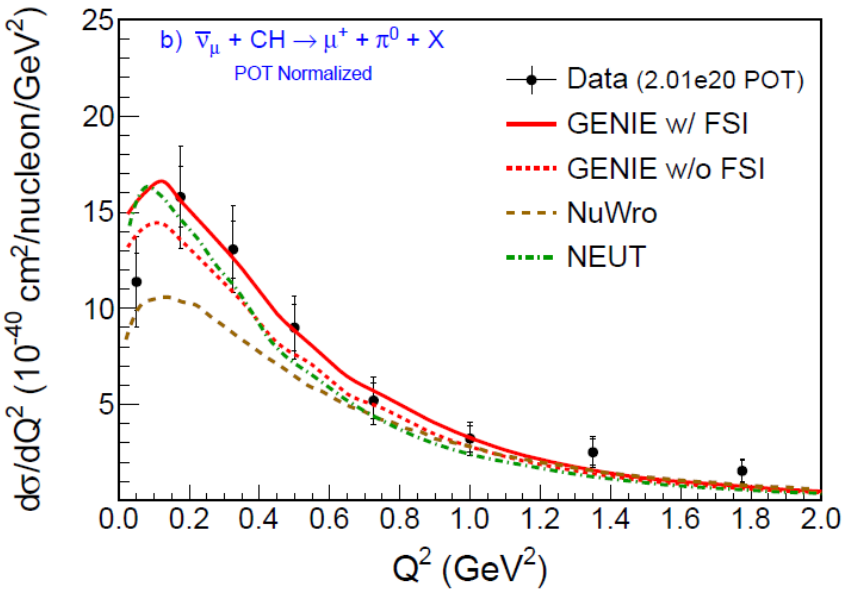


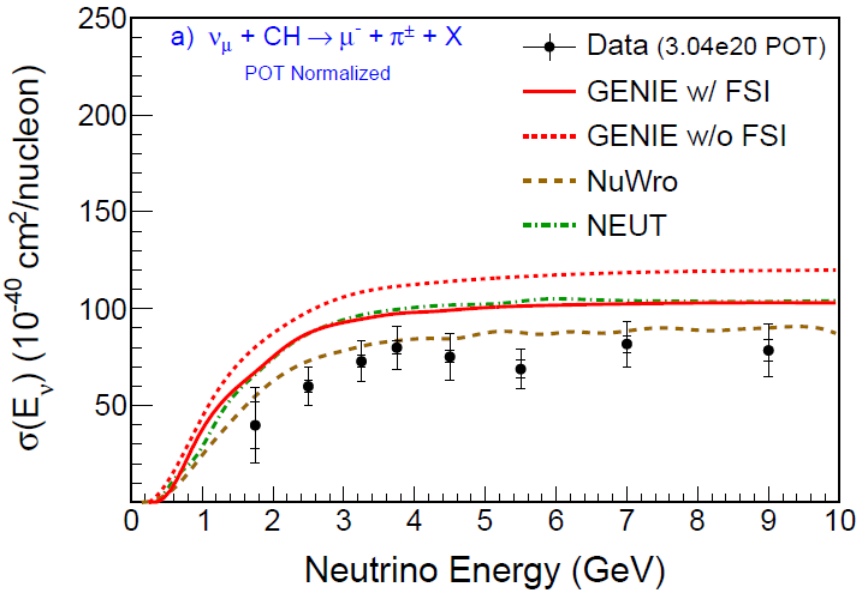


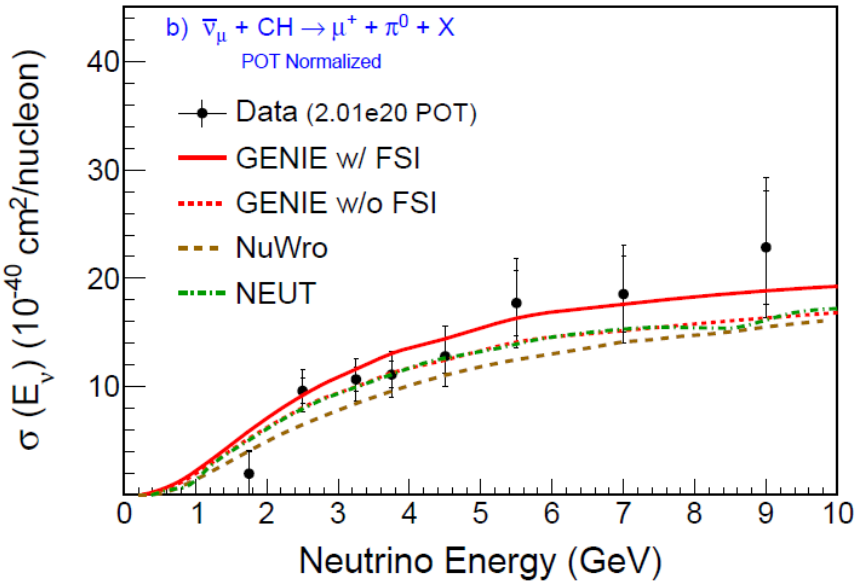





a) $\nu_\mu + CH \rightarrow \mu^- + \pi^\pm + X$
POT Normalized
Data (3.04e20 POT)
GENIE w/ FSI
GENIE w/o FSI
NuWro
NEUT
$d\sigma/dQ^2$ (10^{-40} cm^2/nucleon/GeV^2)
Q^2 (GeV^2)


b) $\bar{\nu}_\mu + CH \rightarrow \mu^+ + \pi^0 + X$
POT Normalized
Data (2.01e20 POT)
GENIE w/ FSI
GENIE w/o FSI
NuWro
NEUT
$d\sigma/dQ^2$ (10^{-40} cm^2/nucleon/GeV^2)
Q^2 (GeV^2)

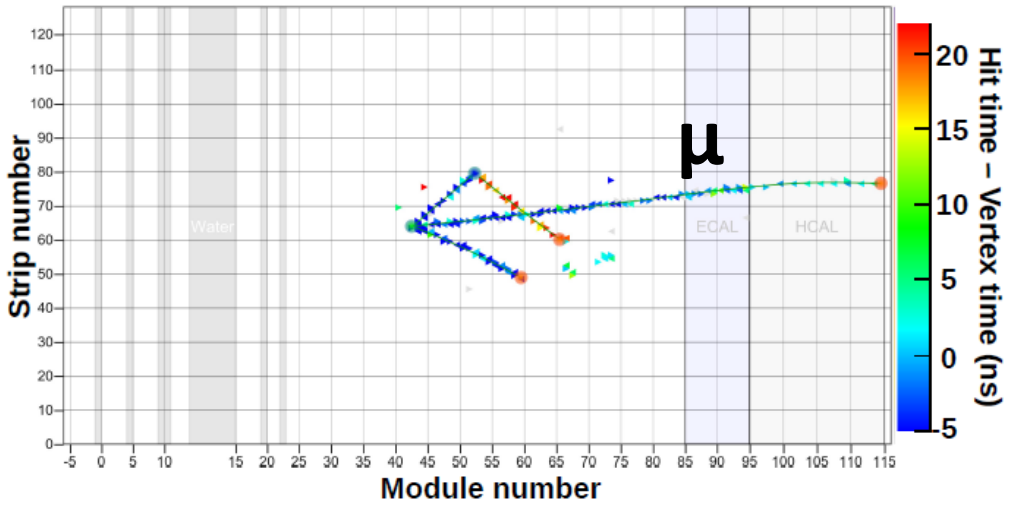

a) $\nu_\mu + CH \rightarrow \mu^- + \pi^\pm + X$
POT Normalized
Data (3.04e20 POT)
GENIE w/ FSI
GENIE w/o FSI
NuWro
NEUT
$\sigma(E_\nu)$ (10^{-40} cm^2/nucleon)
Neutrino Energy (GeV)


b) $\bar{\nu}_\mu + CH \rightarrow \mu^+ + \pi^0 + X$
POT Normalized
Data (2.01e20 POT)
GENIE w/ FSI
GENIE w/o FSI
NuWro
NEUT
$\sigma(E_\nu)$ (10^{-40} cm^2/nucleon)
Neutrino Energy (GeV)

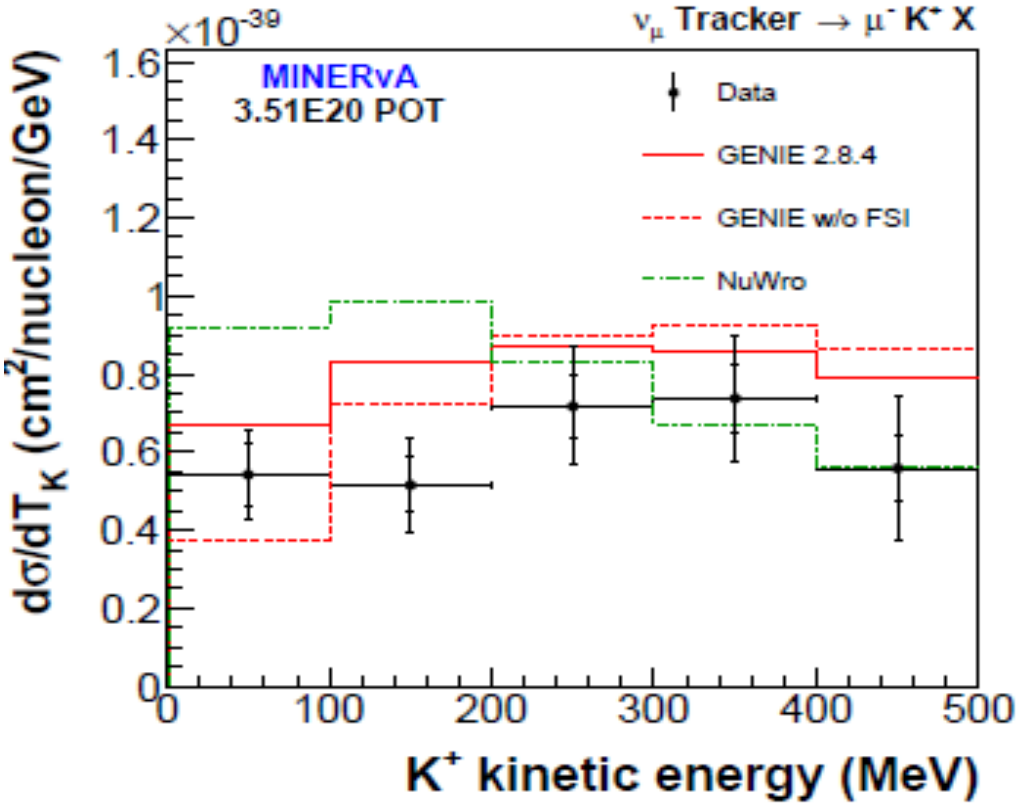
Measurement of K^+ production in charged-current ν_μ interactions
Published in Phys.Rev. D94 (2016) no.1, 012002

ν_μ Tracker $\rightarrow \mu^- K^+ X$

Production of K^+ mesons in charged-current ν_μ interactions on plastic scintillator (CH) is measured using MINERvA exposed to the low-energy NuMI beam at Fermilab. Timing information is used to isolate a sample of 885 charged-current events containing a stopping K^+ which decays at rest. The differential cross section in K^+ kinetic energy, $d\sigma/dT_K$, is observed to be relatively flat between 0 and 500 MeV. Its shape is in good agreement with the prediction by the genie neutrino event generator when final-state interactions are included, however the data rate is lower than the prediction by 15%.



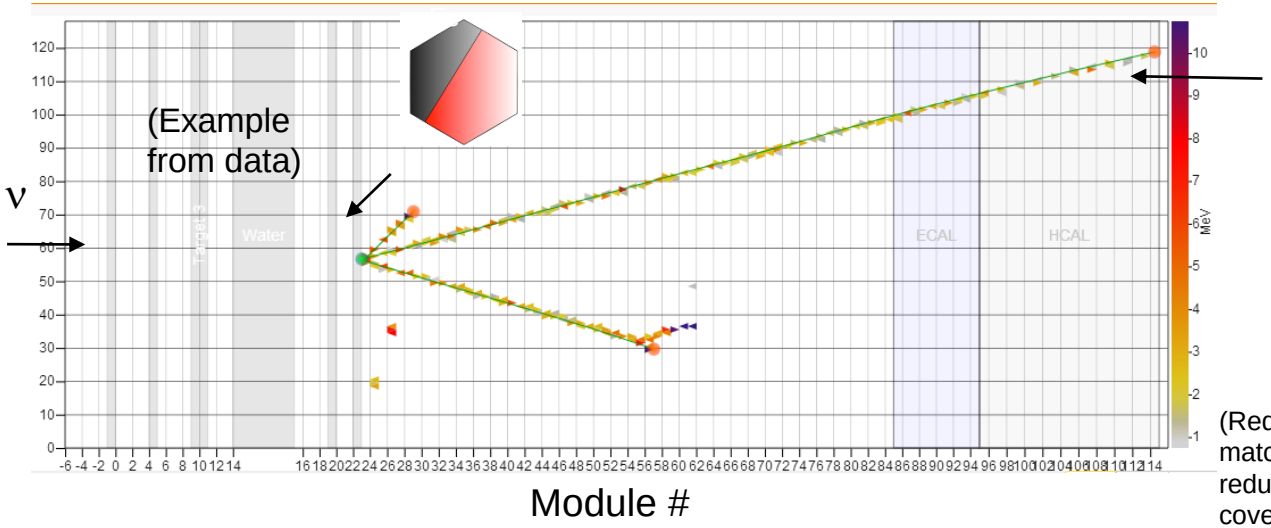
ν_μ Tracker $\rightarrow \mu^- K^+ X$

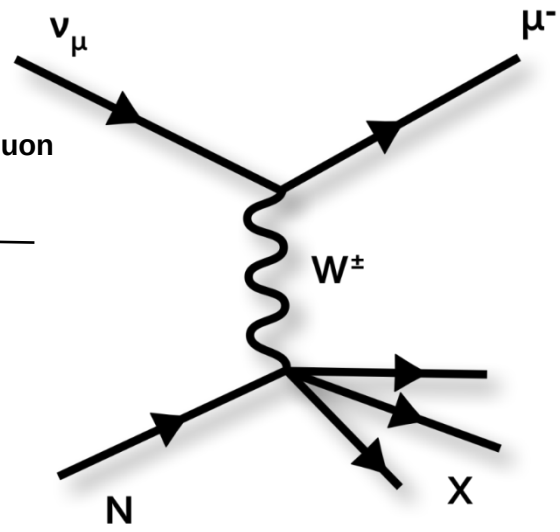


Neutrino-nucleus charged-current deep inelastic scattering (DIS) on targets as ratios of C, Fe, and Pb to CH.
Phys. Rev. D 93, 071101 (2016).

Report of a novel study of neutrino-nucleus charged-current deep inelastic scattering (DIS) on targets of polystyrene, graphite, iron, and lead. Total DIS cross sections are presented as ratios of C, Fe, and Pb to CH as a function of neutrino energy.

CC ν DIS Inclusive



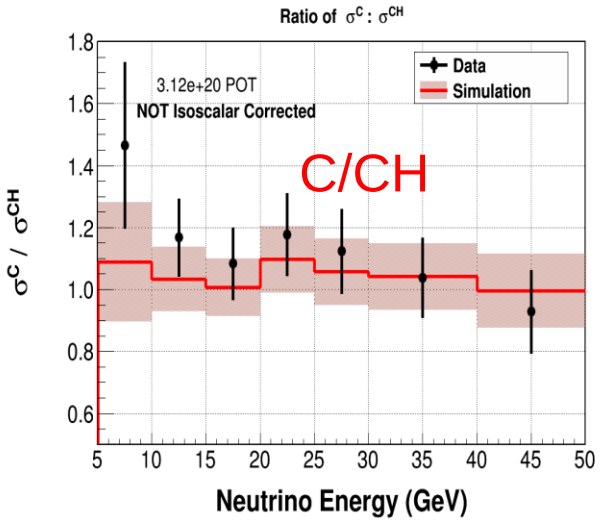


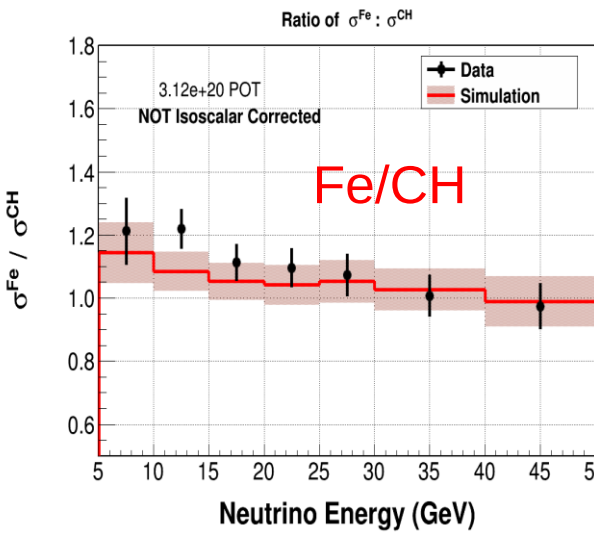
(Requiring a MINOS match somewhat reduces our energy coverage – If sign of muon not critical can use range and extend our coverage)

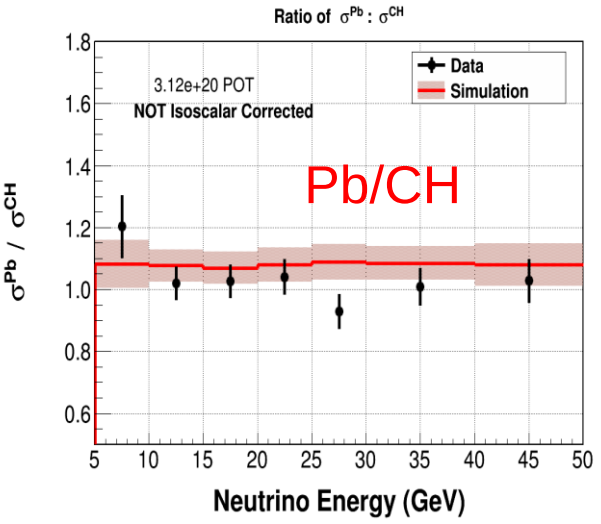
Event selection:

- Muon must be matched in MINOS Near Detector
- Vertex in passive nuclear target

DIS Ratios, $\sigma(E_\nu)$







- Ratios of the heavy nuclei (Fe, Pb) to lighter CH are evidence of nuclear effects.
- There is a general trend of the data being below the MC at high energy.
- This trend is larger in the lead than in the iron.

4. CONCLUSIONS

1. We measure differential cross sections for muon production angle, muon momentum, four-momentum transfer Q^2, and total cross section as function of neutrino energy in neutrino (antineutrino) CH CC (single pion) at few GeV and compare them.

2. We measure the flux-averaged differential cross section, d(sigma)/dTk, of K^+ production and compare to several theoretical models of QE scattering. Agreement with GENIE is quite good.

3. We measure the cross sections for neutrino-nucleus charged-current deep inelastic scattering (DIS) on targets as ratios of C, Fe, and Pb to CH as function of neutrino energy.

4. Better models of neutrino (antineutrino) nuclei interactions are very much needed.