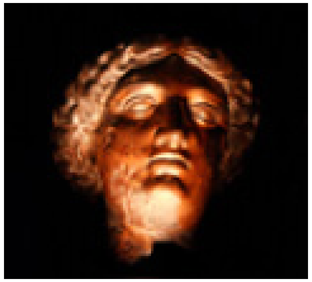


The MINERνA Experiment

What is Minerνa ?

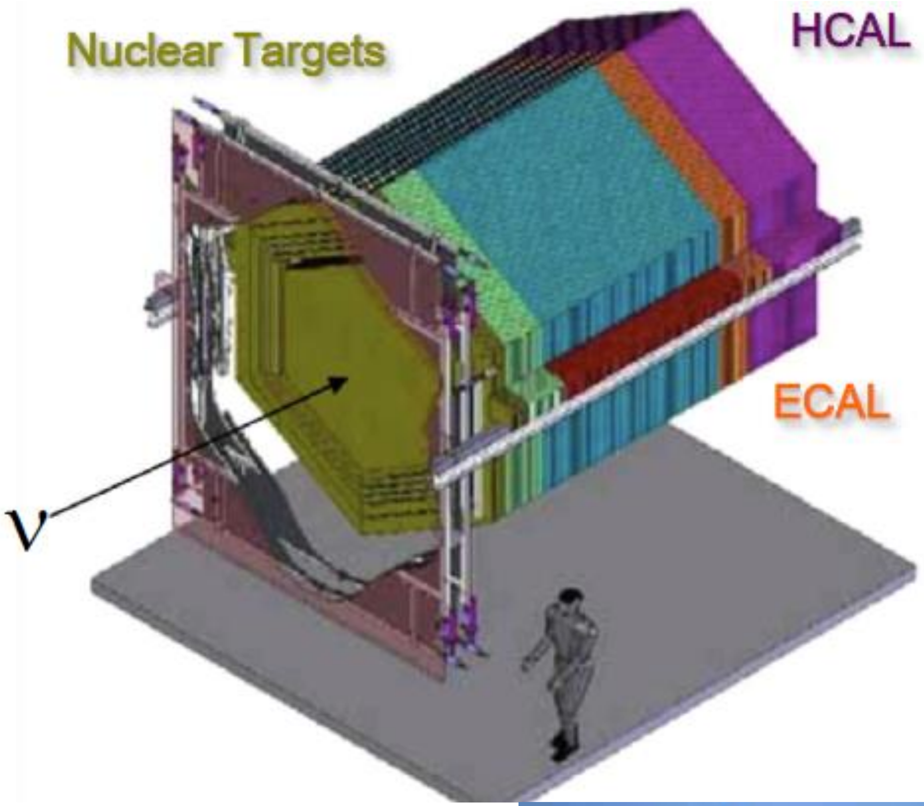
Why Mienrνa ?

$\bar{\nu}$ / ν CCQE $\times$ sections

Inclusive ν $\times$ sections

ν beam and ν flux

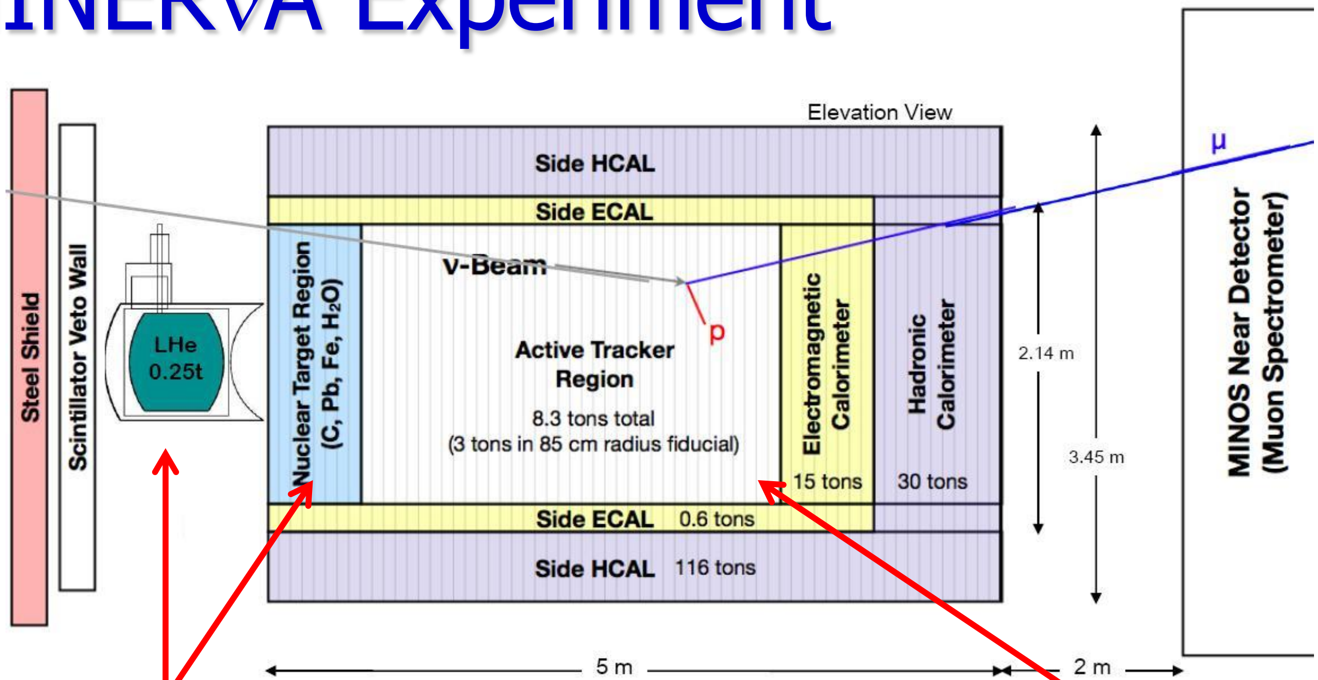
Outlook



Alessandro Bravar
for the Mienrνa Collaboration

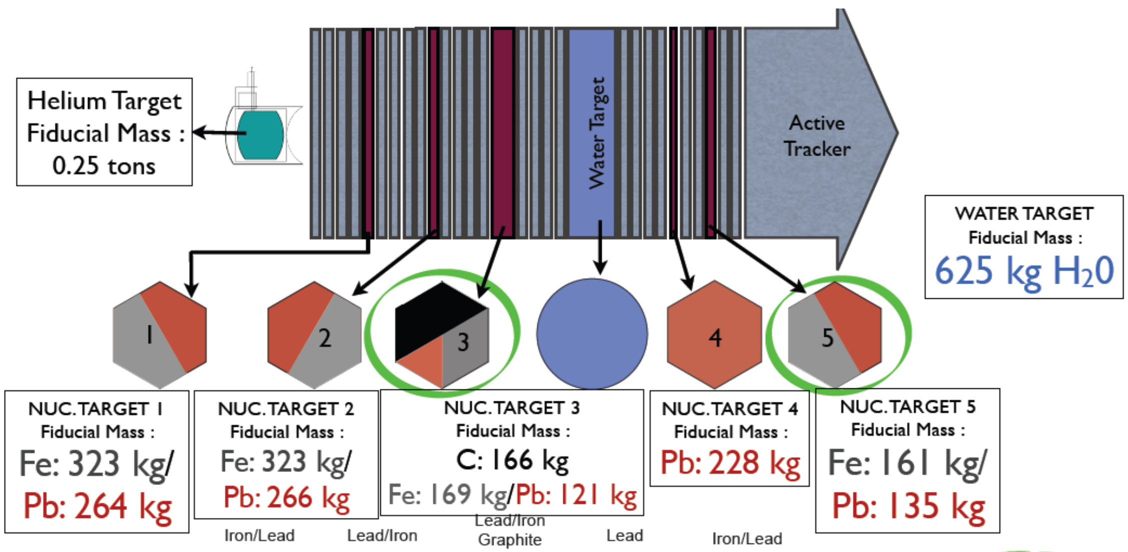
INPC 2013
June 4^{th} '13

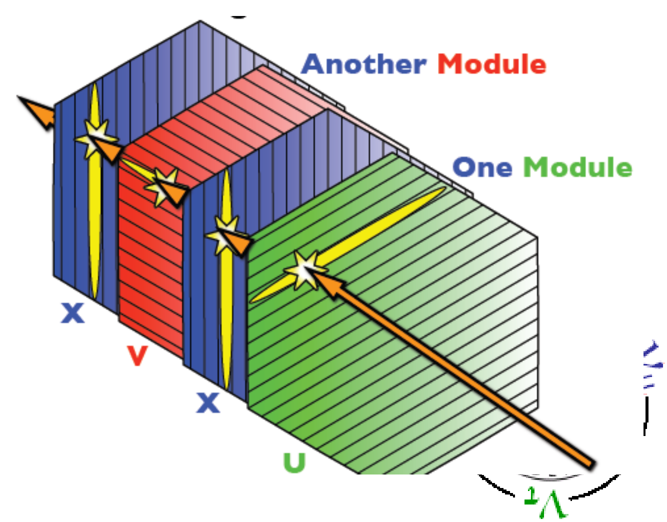
The MINERνA Experiment



nuclear targets: He, C, H_20, Fe Pb

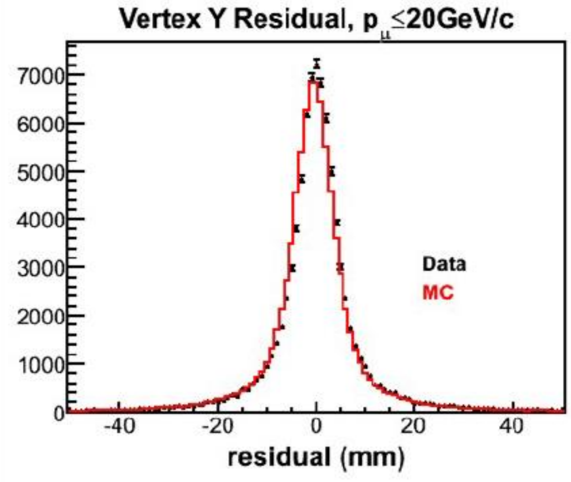
fully active scintillator tracker



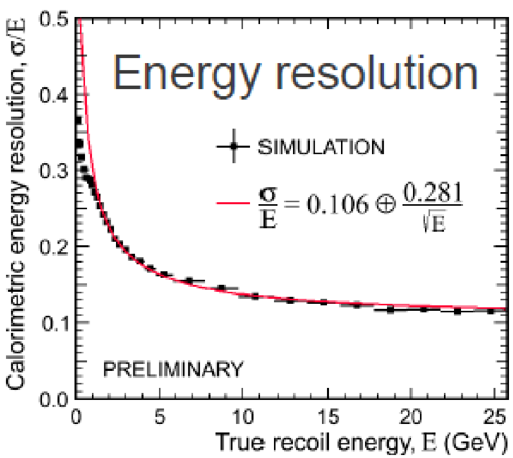


Detector Performance

Good tracking resolution (~3mm)



Calorimetry for charged hadrons and EM showers



Timing information (few ns)

pileup: several "rock" muons and several ν interactions per spill

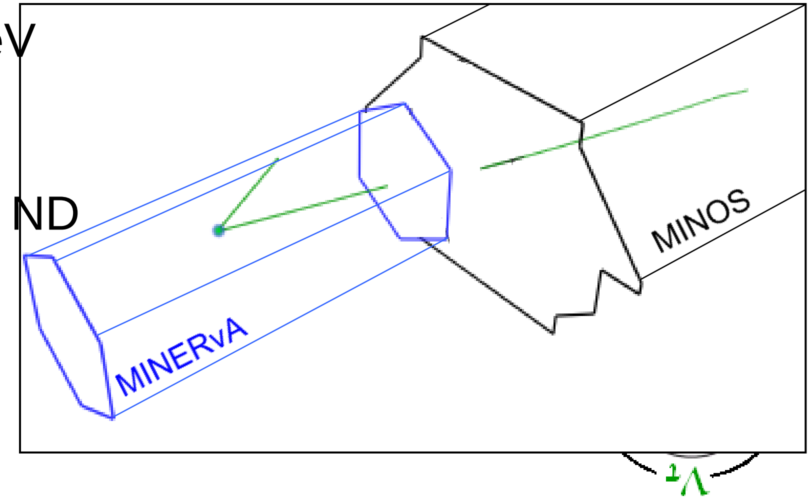
Containment of ν-induced events up to several GeV (except for muons)

Muon energy and charge measurement in MINOS ND

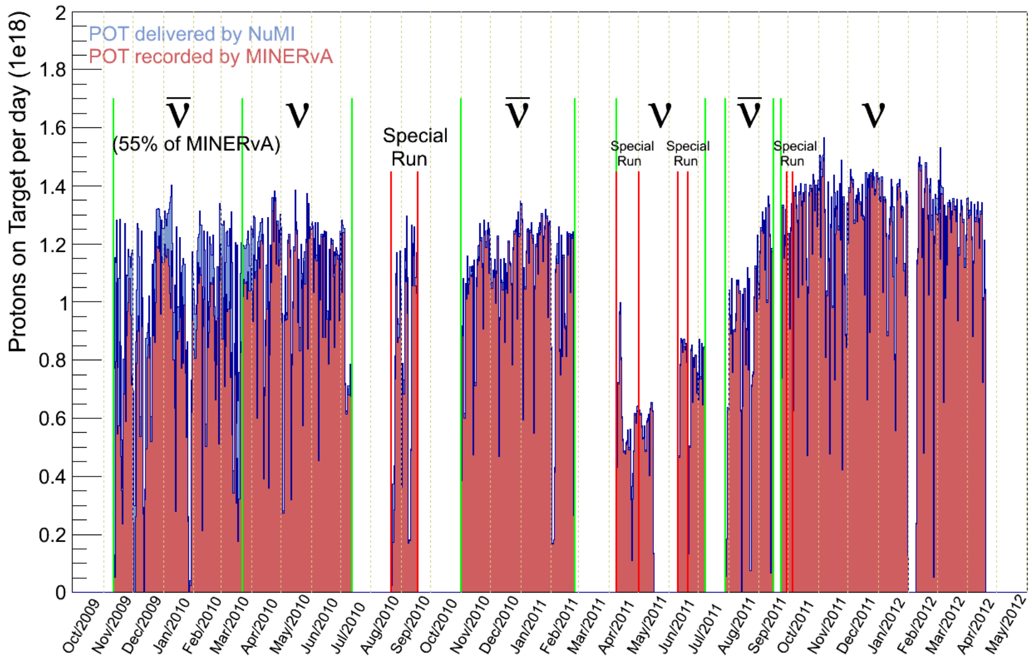
PID from dE/dx and energy/range

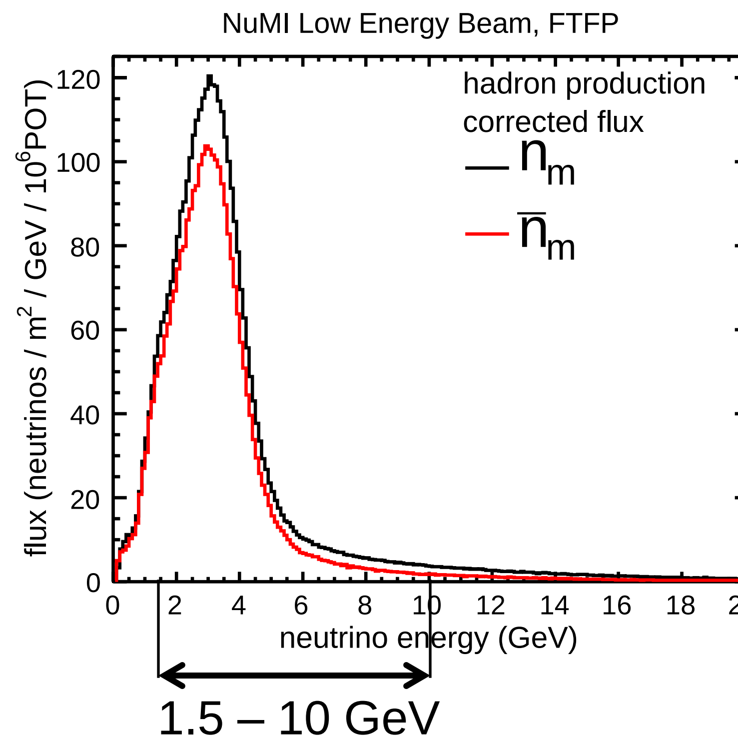
no charge determination

except for muons entering MINOS ND



Collected Data





Low Energy (LE, peak ~3 GeV) run
? 2010 – ? 2120

LE ν mode 3.9×10^{20} POT
LE anti-ν mode 1.7×10^{20} POT
flux-calibration 4.9×10^{20} POT

Medium Energy (ME, peak ~6 GeV) run
about to start → 2018 ? (NOνA era)
ν and anti-ν running

Target	Fiducial Mass	ν_μ CC Events in 4×10^{20} POT
Plastic	6.43 tons	1363k
Helium	0.25 tons	56k
Carbon	0.17 tons	36k
Water	0.39 tons	81k
Iron	0.97 tons	215k
Lead	0.98 tons	228k

Why MINERνA ?

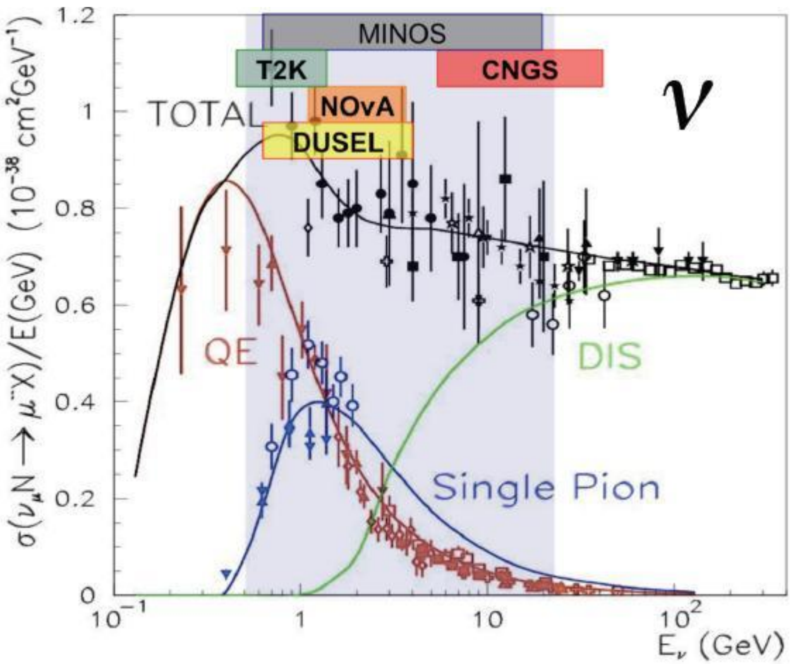
existing data (~1 – 20 GeV) poorly understood
- mainly (old) bubble chamber data
- low statistics samples
- large uncertainties of ν flux

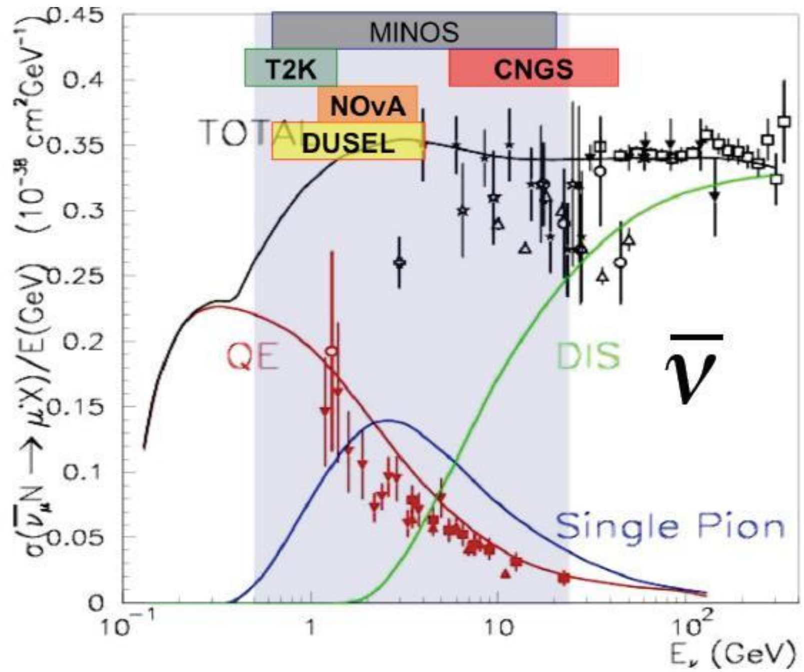
need detailed understanding of ν_μ and anti- ν_μ $\times$-sections

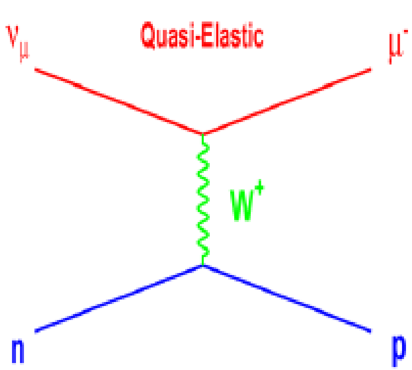
ν oscillation
- precision neutrino oscillation measurements
- all experiments use nuclear targets (C, $H_2$0, Ar, Fe)
  - $\rightarrow$ additional complication whose impact needs to be understood
- oscillation parameters: ν energy E_{vis} not equal E_ν
  appearance / disappearence need to know precisely σ
- backgrounds for ν_e appearance studies (including searches for CP in ν sector)
  - CC events with π^0, lost μ
  - NC π^0 production: $\nu + N \rightarrow \nu + N + \pi^0 \rightarrow$ electrons
  - ν_e content of accelerator ν beams

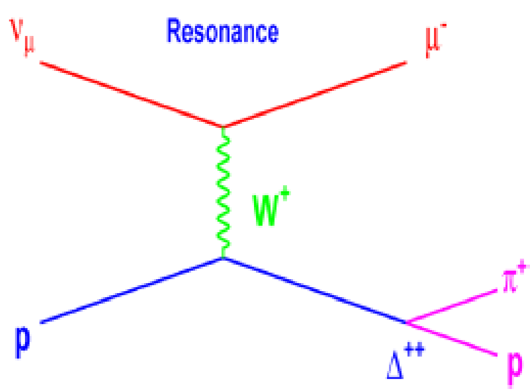
neutrinos – weak probe of nuclear (LE) and hadronic (ME) structure
- axial form factors of the nucleon
- parton distribution functions (DIS)
- nucleons are confined in nuclei and are not free
  - $\rightarrow$ expect deviations from ν – nucleon interactions
  - $\rightarrow$ modifications of nucleon (hadron) structure, like EMC effect (DIS)

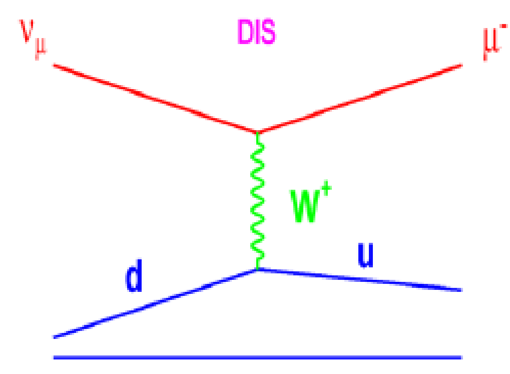
ν ×-sections


MINOS
T2K
CNGS
NOvA
DUSEL
TOTAL
QE
DIS
Single Pion
ν
σ(ν_μN → μ⁻X)/E(GeV) (10⁻³⁸ cm²GeV⁻¹)
E_ν (GeV)
0
0.2
0.4
0.6
0.8
1
1.2
10⁻¹
1
10
10²


MINOS
T2K
CNGS
NOvA
DUSEL
TOTAL
QE
DIS
Single Pion
ν̄
σ(ν̄_μN → μ⁺X)/E(GeV) (10⁻³⁸ cm²GeV⁻¹)
E_ν (GeV)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
10⁻¹
1
10
10²


Quasi-Elastic
ν_μ
μ⁻
W⁺
n
p


Resonance
ν_μ
μ⁻
W⁺
p
Δ⁺⁺
π⁺
p

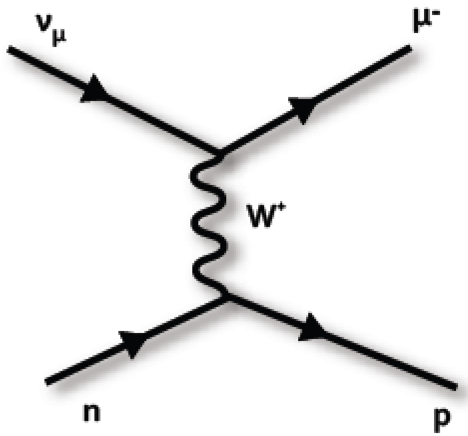

DIS
ν_μ
μ⁻
W⁺
d
u

ν CCQE scattering

considered a possible standard for ν oscillation experiments

E_ν can be determined from outgoing μ energy and angle

$$E_\nu^{QE} = \frac{m_n^2 - (m_p - E_b)^2 - m_\mu^2 + 2(m_p - E_b)E_\mu}{2(m_p - E_b - E_\mu + p_\mu \cos\vartheta)}$$

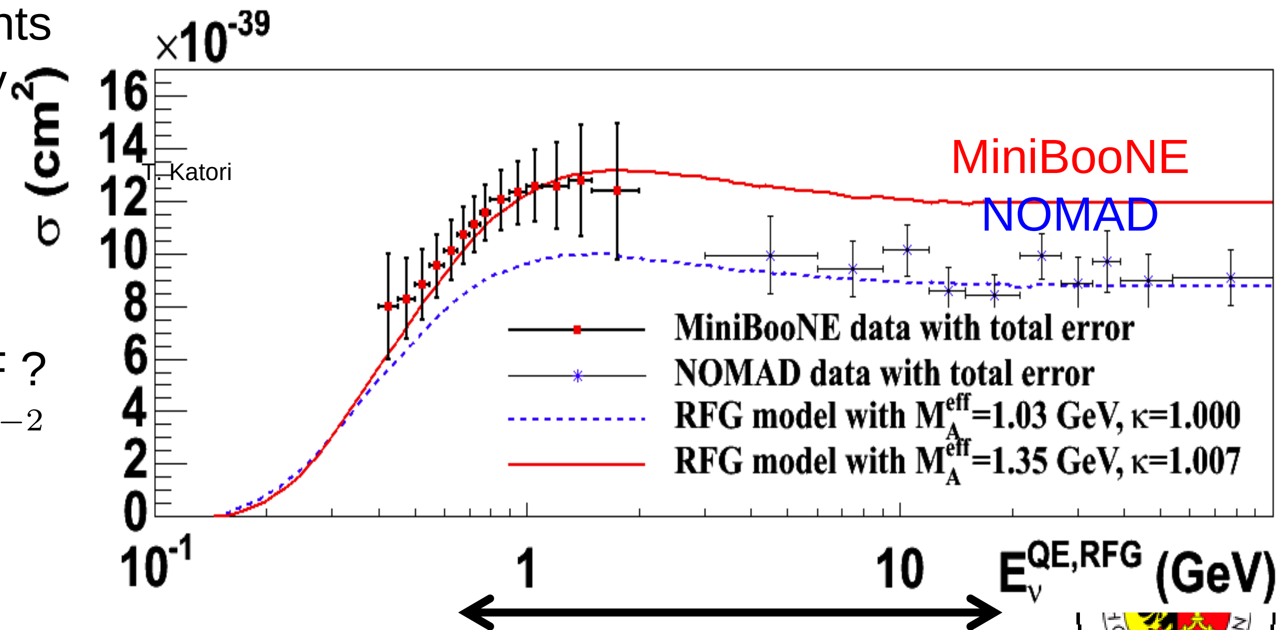


~30% discrepancy in the QE ×-section measurements between recent experiments

- axial mass M_A
- nuclear effects
- identification of QE events
- reconstructed E_ν energy

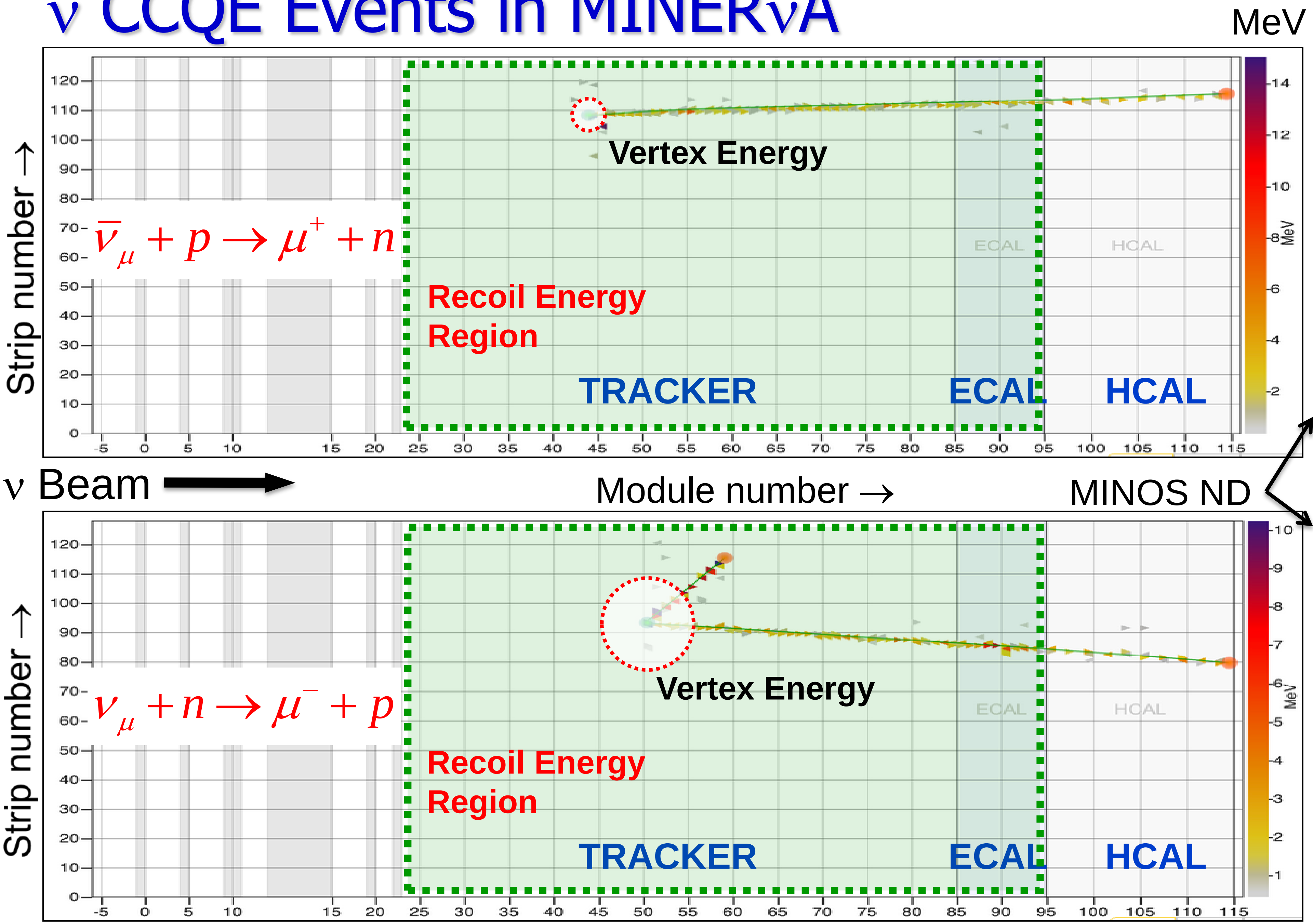
tension between datasets and RFG model :
increase MA in the axial FF ?

$$F_A(Q^2) = F_A(0)\left(1 + \frac{Q^2}{M_A^2}\right)^{-2}$$



MINERνA covers region of interest

ν CCQE Events in MINERνA

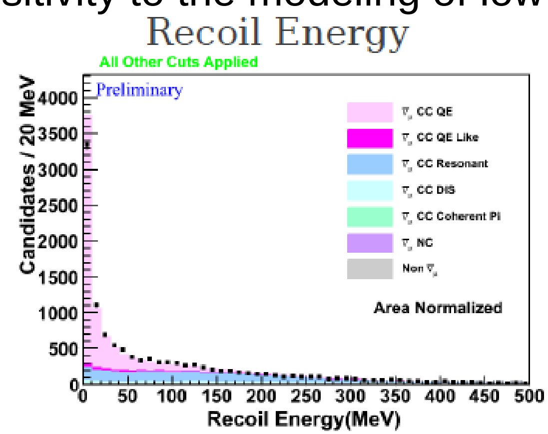


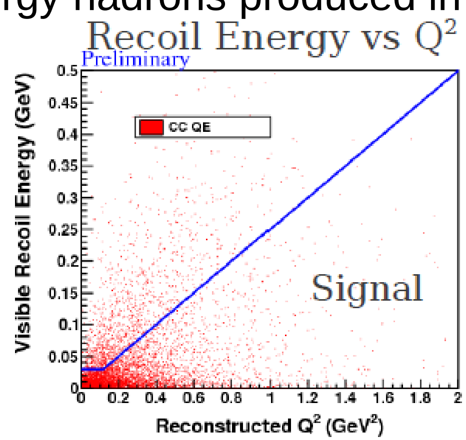
Selecting anti–ν / ν CCQE Events

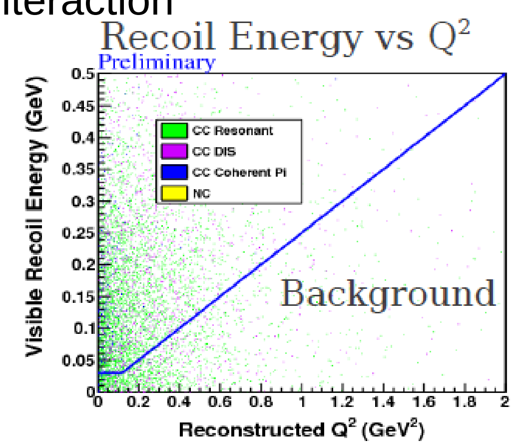
1. single MIP track in MINERνA matched in MINOS ND
   momentum and charged analyzed
2. low energy recoil hadronic system
   recoil energy measured in tracker and ECAL excluding a region around the vertex

10 g/cm^2 vertex region $\bar{\nu}_\mu$	30 g/cm^2 vertex region ν_μ
Contains <120 MeV KE protons	Contains <225 MeV KE protons
Contains <65 MeV KE pions	Contains <100 MeV KE pions
≤ 1 isolated energy showers outside	≤ 2 isolated energy showers outside
Q^2_{QE} dependent total recoil energy cut	Q^2_{QE} dependent total recoil energy cut

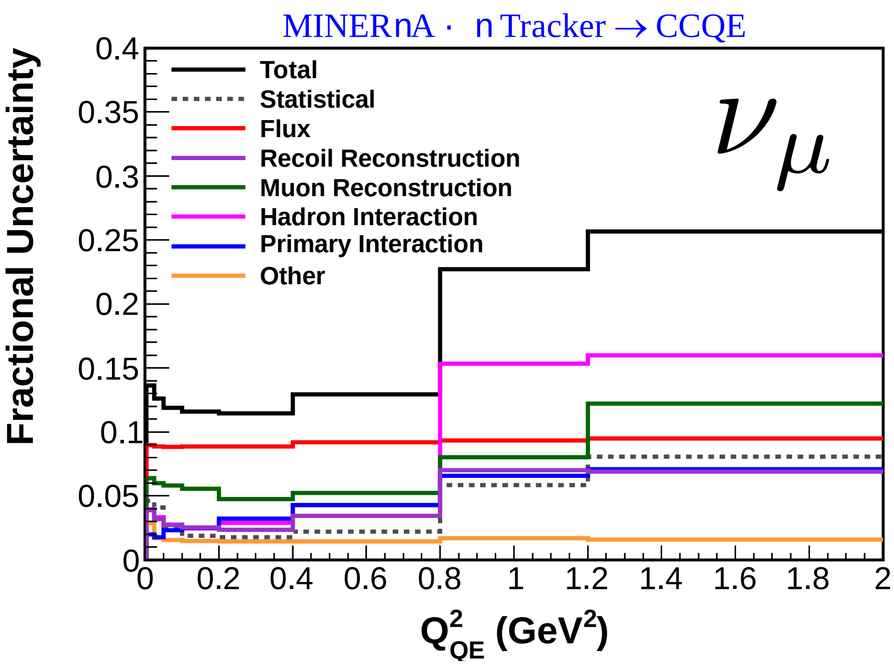
This region is sensitive to low energy protons which could arise from correlations among nucleons in the initial state or interactions of the outgoing hadrons inside the target nucleus, and limits sensitivity to the modeling of low energy hadrons produced in the interaction

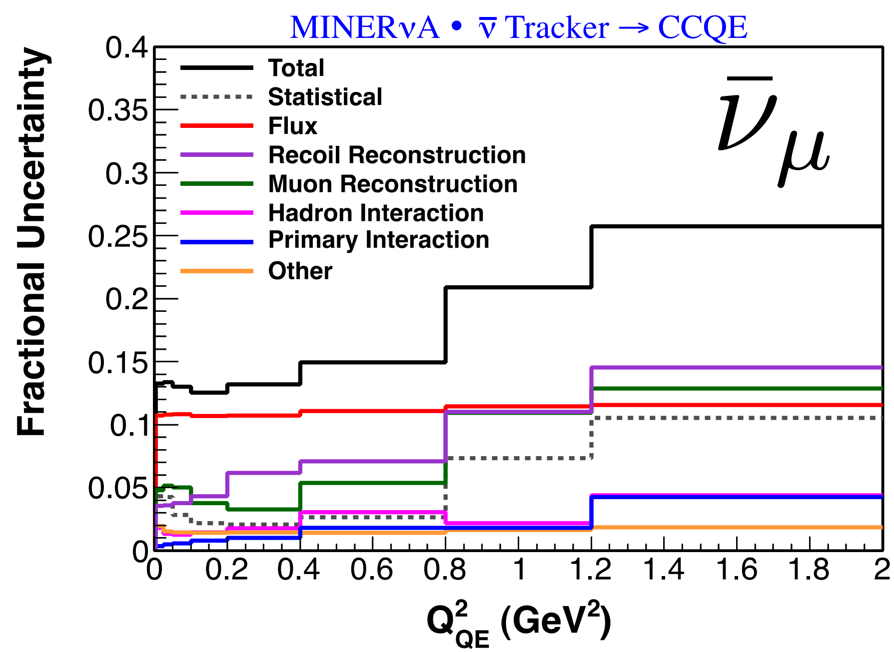






anti-ν / ν CCQE Systematics

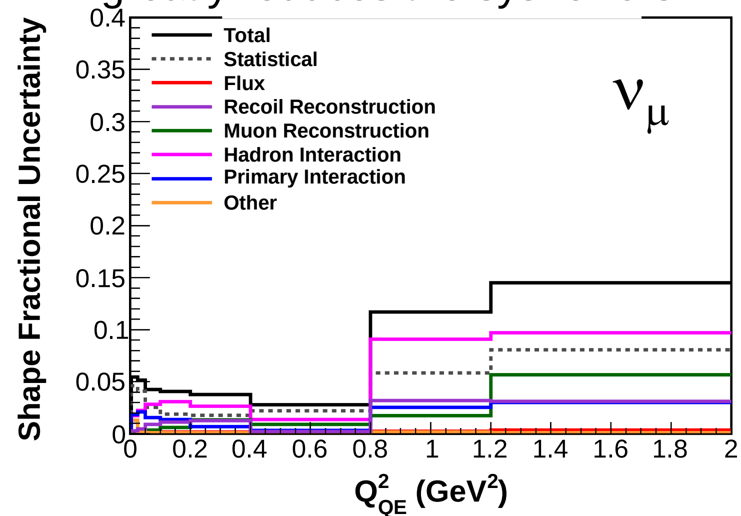




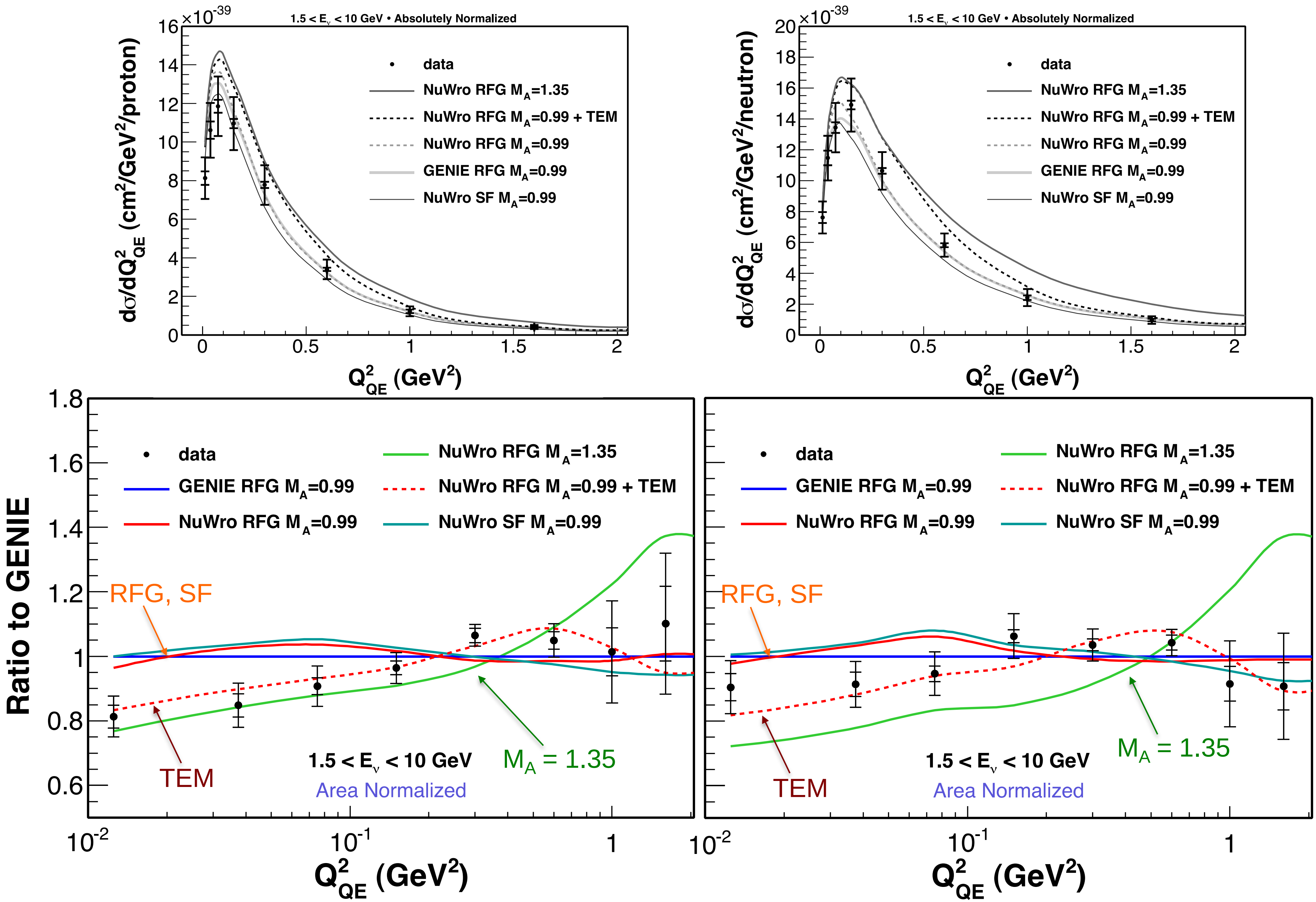
dominant systematical errors:

- normalization (i.e. ν flux)
- hadron interactions
- muon reconstruction
- recoil reconstruction
- primary interaction models

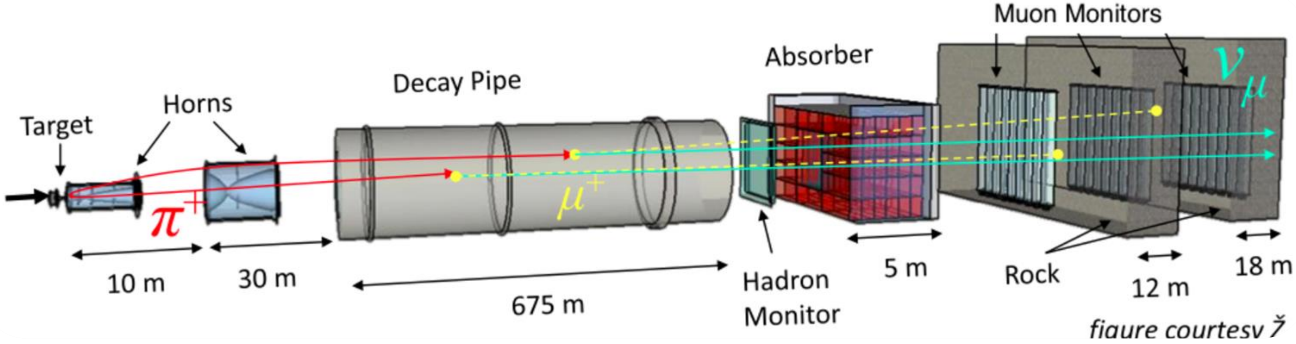
restricting the study to the shape greatly reduces the sys. errors



anti-ν / ν CCQE × section Results



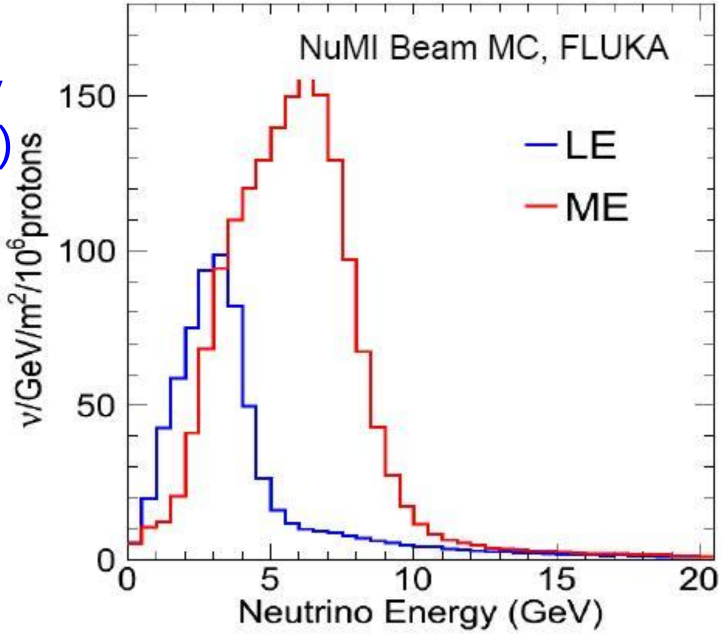
The NUMI Beam



NuMI (Neutrinos at the Main Injector)

- 120 GeV protons from Main Injector
- 90 cm graphite target
- 675 m decay tunnel

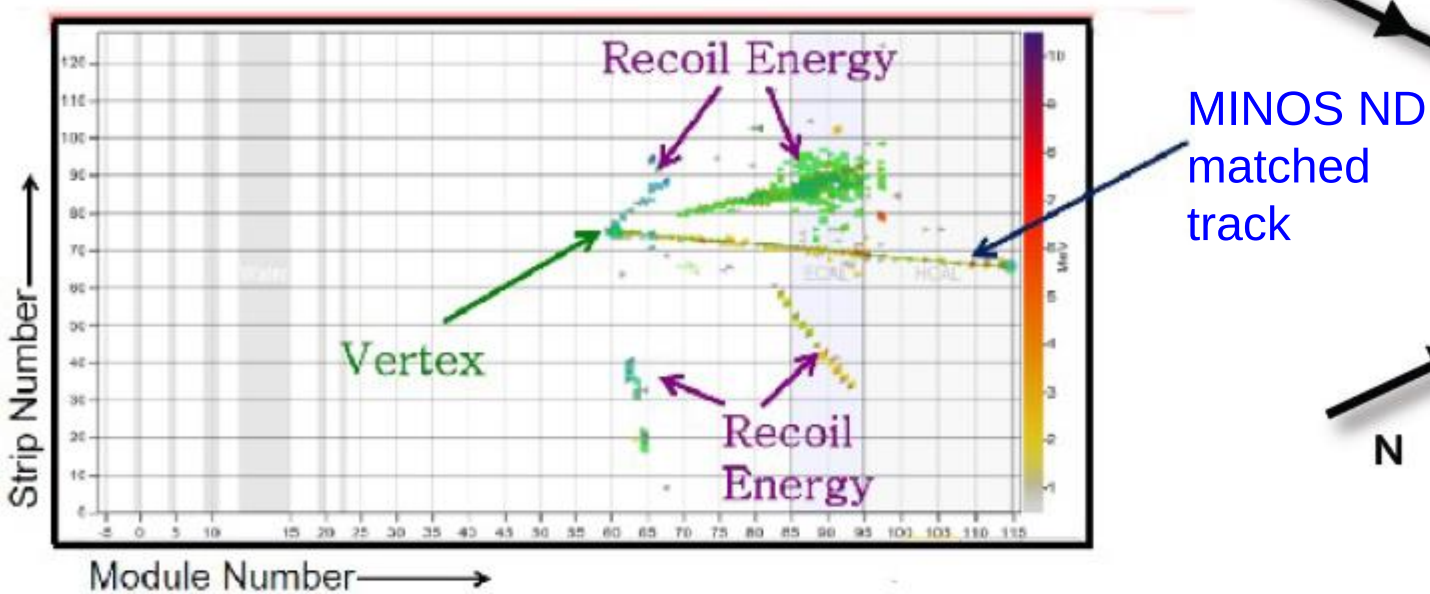
by moving production target w.r.t. 1st horn can modify ν spectrum : LE (peak ~3 GeV) $\rightarrow$ ME (peak ~6 GeV)

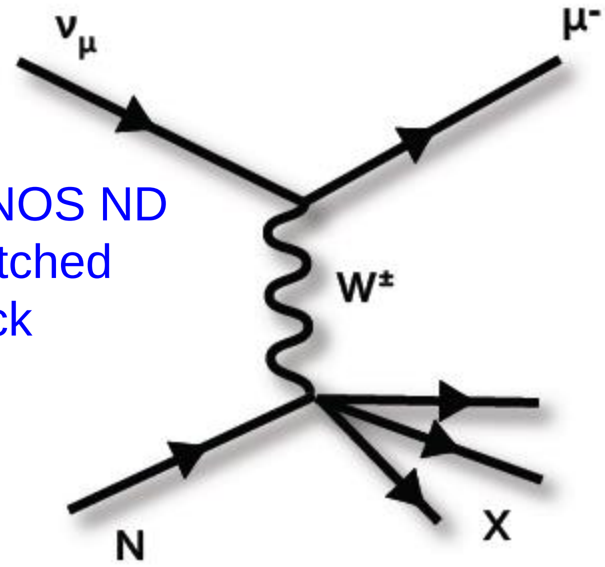


Flux determination

- muon monitor data
- special runs (vary beam parameters)
- ν_μ–electron scattering
- low–ν method
- external hadron–production data

Inclusive ν ×–sections





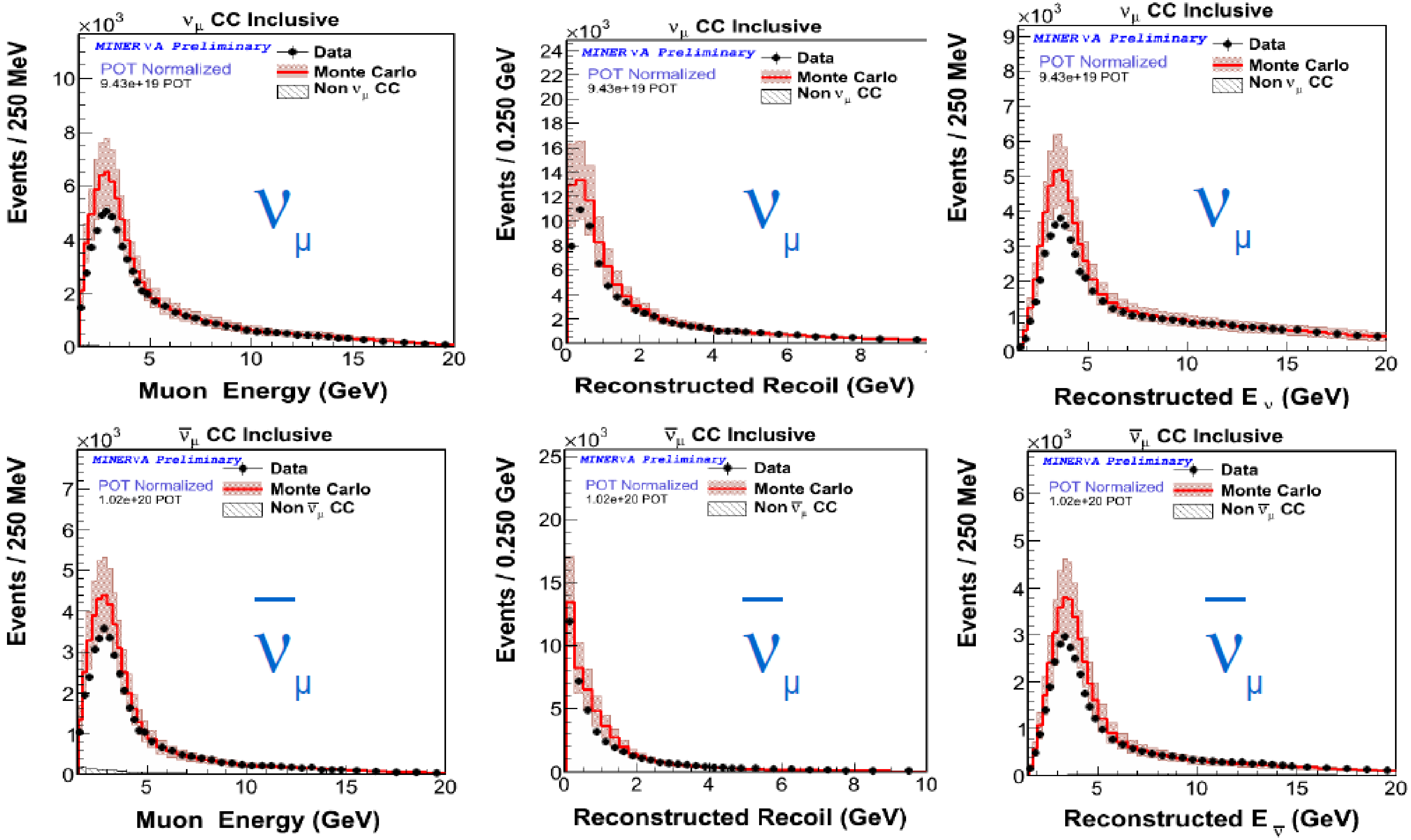
Event selection criteria:

- single muon track in MINERνA, well reconstructed and mathced into MINOS ND
- reconstructed vertex inside fiducial tracker region
- nuclear targets : z position near nuclear target
- recoil energy E_{REC} reconstructed calorimetrically
- $E_\nu = E_\mu + E_{REC}$

study: absolute cross section of scintillator tracker (HC)
cross section ratios of nuclear targets
DIS region: quark densities modifications in nuclei

work in progress

The Inclusive ν and anti–ν Kinematics

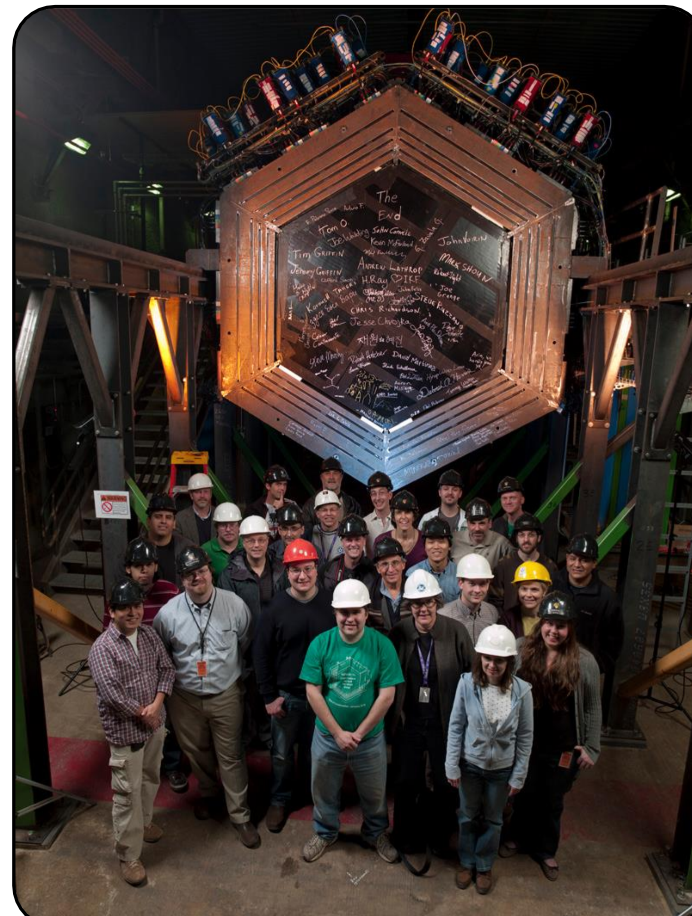


all distributions are absolutely normalized

The MIENRνA Collaboration

University of Athens, Athens, Greece
Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
UC Irvine, Irvine, CA
University of Chicago, Chicago, IL
Fermi National Accelerator Laboratory, Batavia, IL
University of Florida, Gainsville, IL
Université de Genève, Genève, Switzerland
Universidad de Guanajuato, Ganajuato, Mexico
Hampton University, Hampton, VA
Inst. Nucl. Reas. Moscow, Russia
Mass. Col. Lib. Arts, North Adams, MA
University of Minnesota-Duluth, Duluth, MN
Northwestern University, Evanston, IL
Otterbein College, Westerville, OH
University of Pittsburgh, Pittsburgh, PA
Pontificia Universidad Catolica del Peru, Lima, Peru
University of Rochester, Rochester, NY
Rutgers University, Piscataway, NJ
Universidad Técnica Federico Santa María, Valparaiso, Chile
University of Texas, Austin, TX
Tufts University; Medford, MA
Universidad Nacional de Ingeniería, Lima, Peru
College of William & Mary, Williamsburg, VA

~80 collaborators



Outlook

MINERνA studies neutrino interactions in the 1 – 20 GeV region with high precision

- using a variety of nuclear targets (He, C, $H_2$0, Fe, Pb)
- using a fine-grained, high resolution fully active scintillator detector

MINERνA has measured the flux averaged differential cross-section $d\sigma/dQ^2$ for neutrinos and antineutrinos on a hydrocarbon (CH) target.

- The shape of both of these cross-sections disfavor a simple RFG modeling of the carbon nucleus for scattering at these energies, strengthening the call for improved modeling in (anti)neutrino scattering.

Studies of quasi-elastic scattering are being extended to different nuclear targets (A-dependence)

Soon to come:

- Inclusive cross-section measurements
- Single pion production

Data taking with a “medium energy” n beam to start soon, E_ν peak ~6 GeV.

The higher neutrino beam energy will allow us to access the DIS region and study quark distributions at high x, x > 0.1