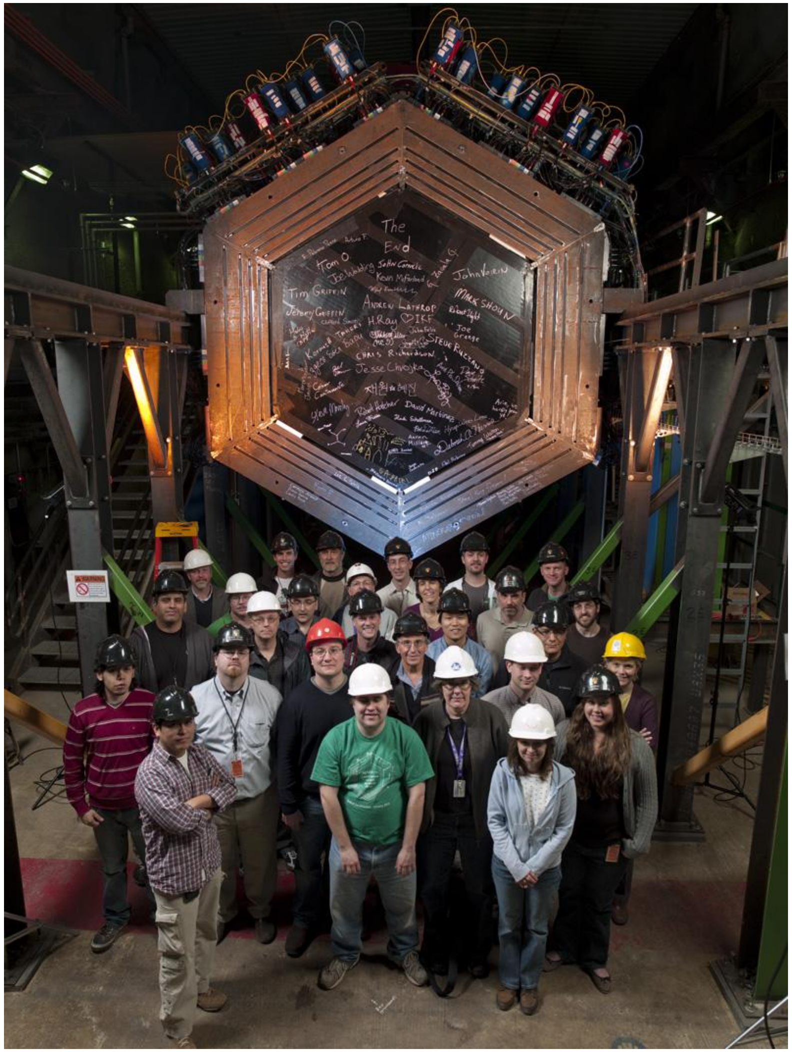
Neutrino cross sections with the MINERνA Experiment

Steven Manly, University of Rochester
NOW 2010, Conca Specchiulla, Italy
September 4-11, 2010

What is MINERνA?

Main Injector ExpeRiment ν-A

- A fully active, high resolution detector designed to study neutrino reactions in detail
- Sited upstream of the MINOS near detector in the FNAL NuMI hall
- Will study neutrino reactions on a variety of nuclei



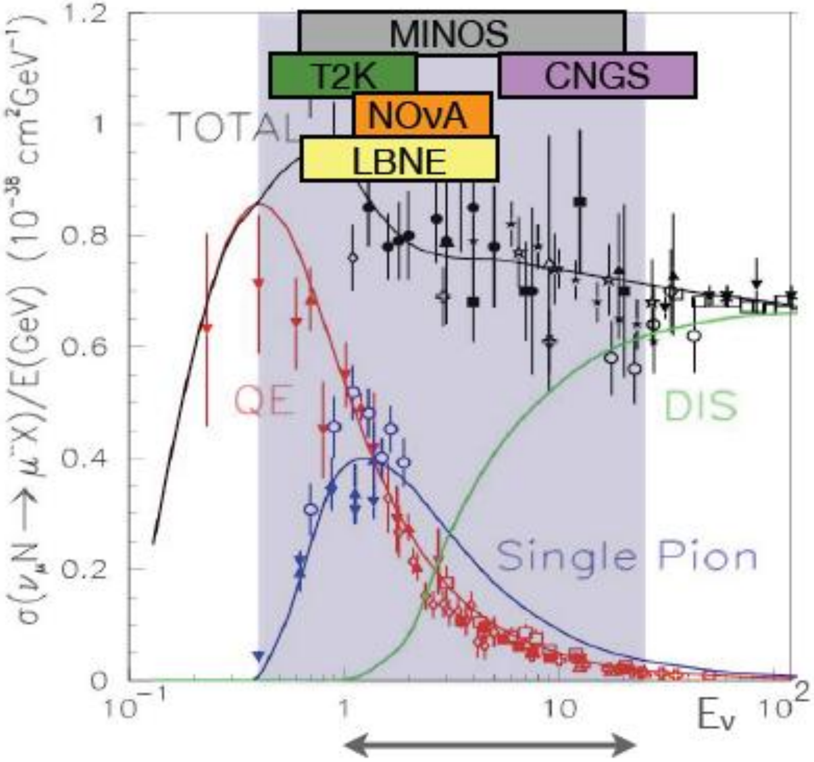
The MINERνA Collaboration
Main Injector ExpeRiment ν-A

- University of Athens, Athens, Greece
- Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
- UC Irvine, Irvine, CA
- Fermi National Accelerator Lab, Batavia, IL
- University of Florida, Gainsville, FL
- Universidad de Guanajuato, Guanajuato, Mexico
- Hampton University, Hampton, VA
- Institute for Nuclear Research, Moscow, Russia
- James Madison University, Harrisonburg, VA
- Mass. Coll. of Liberal 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 Tecnica Federico Santa Maria, Valparaiso, Chile
- University of Texas, Austin, TX
- Tufts University, Medford, MA
- Universidad Nacional de Ingenieria, Lima, Peru
- College of William & Mary, Williamsburg, VA

A collaboration of about 80 nuclear and particle physicists from 21 institutions

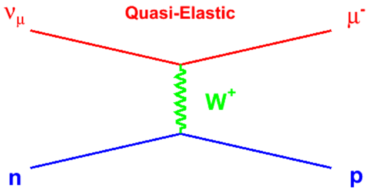
ν interaction physics

Plot from G. Zeller

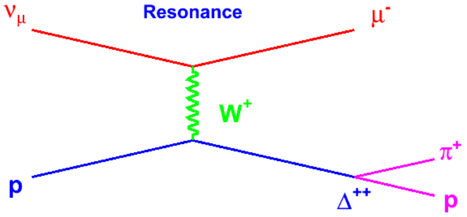


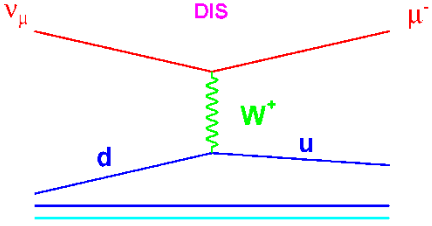
MINERvA Coverage

- ν oscillations need to understand ν reactions on nuclear targets in the 1-10 GeV region
- Older Data Problematic
  - 20-50% uncertainties, depending on process
- The nuclear physics was not well understood
- Causes uncertainty on prediction in far detector

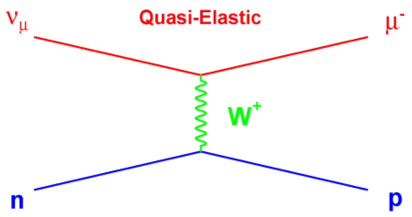


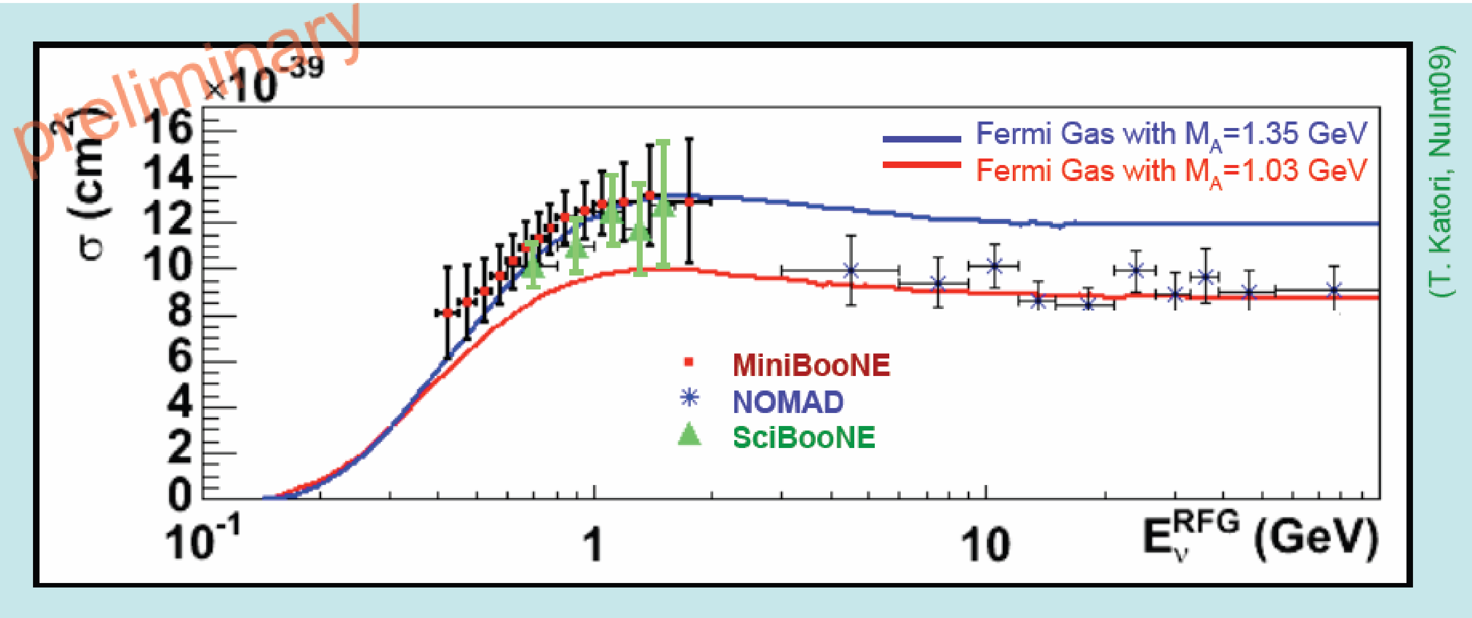
Single p





CCQE – recent results



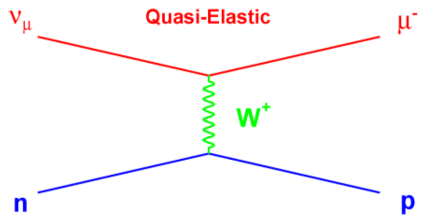


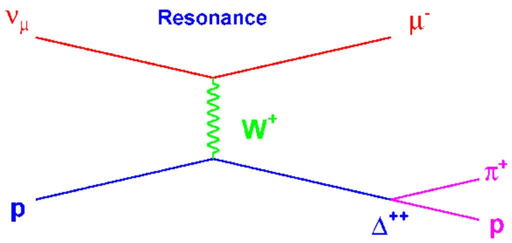
(T. Katori, NuInt09)

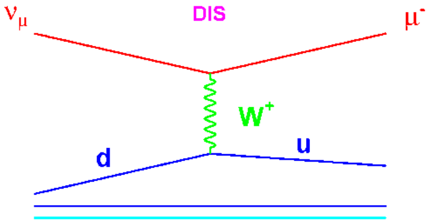
- Inconsistency between MiniBooNE/SciBooNE and NOMAD results
- Gap falls in midst of MINERνA coverage

MINERνA

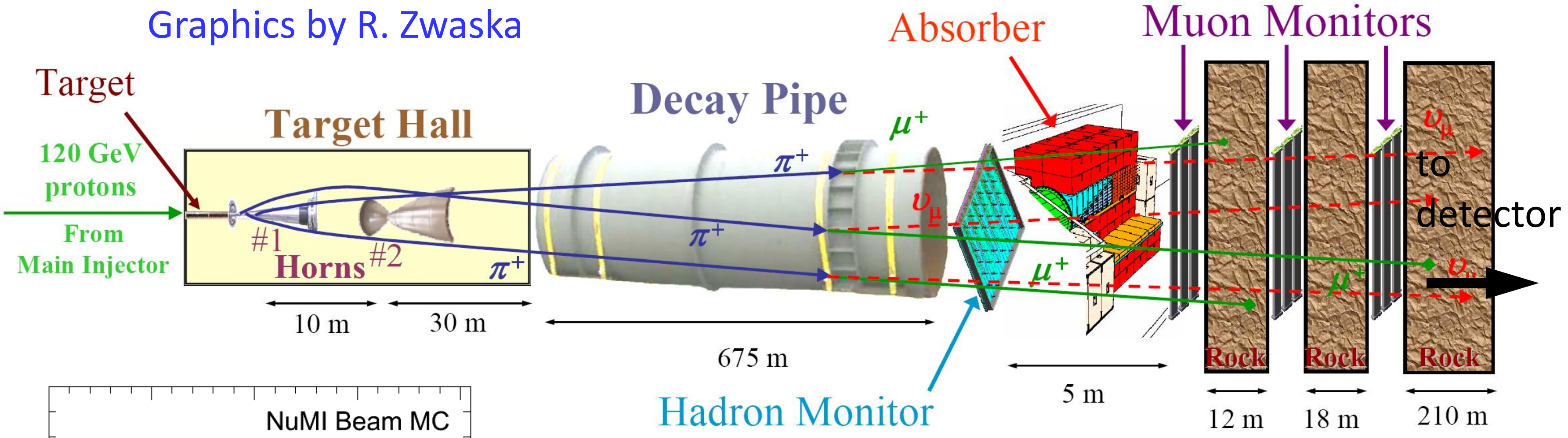
- Precision measurement of cross sections in the 1-10 Gev region
  - Understand the various components of cross section both CC and NC
    - CC & NC quasi-elastic
    - Resonance production, $\Delta(1232)$
    - Resonance↔deep inelastic scatter, (quark-hadron duality)
    - Deep Inelastic Scattering
- Study A dependence of ν interactions in a wide range of nuclei
- Need high intensity, well understood ν beam with fine grain, well understood detector.

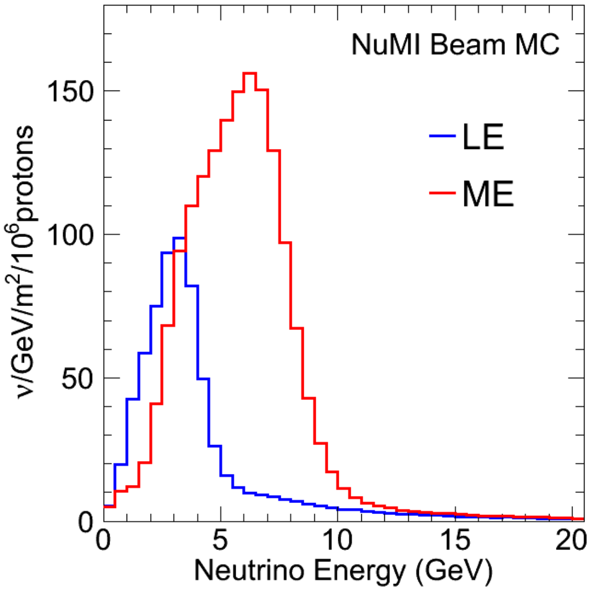






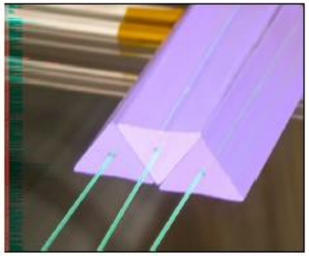
NuMI Beamline


Graphics by R. Zwaska



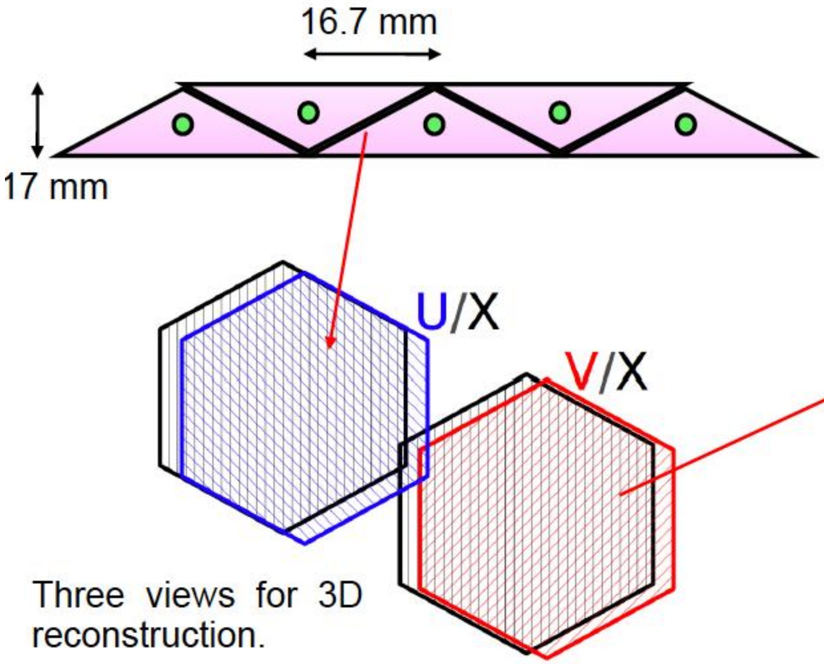
- 120 GeV P Beam → C target ⟶ π^{+-} & K^{+-}
- 2 horns focus π^+ and K^+ only
- Mean E_ν increased by moving target upstream
- π^+ and $K^+ \rightarrow \mu^+\nu_\mu$
- Absorber stops hadrons not μ
- μ absorbed by rock, ν ⟶ detector
- Before Mar 2012 LE beam, After 2012 ME beam

Tracking detectors

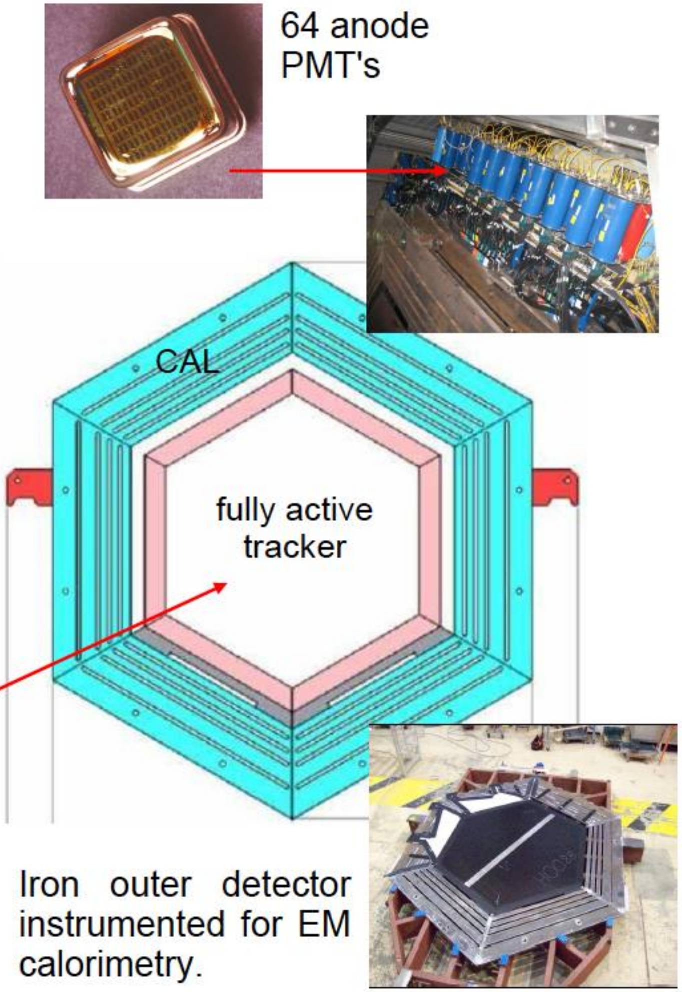


Extruded plastic scintillator + wavelength shifters.

Triangular geometry allows charge sharing for better position resolution.



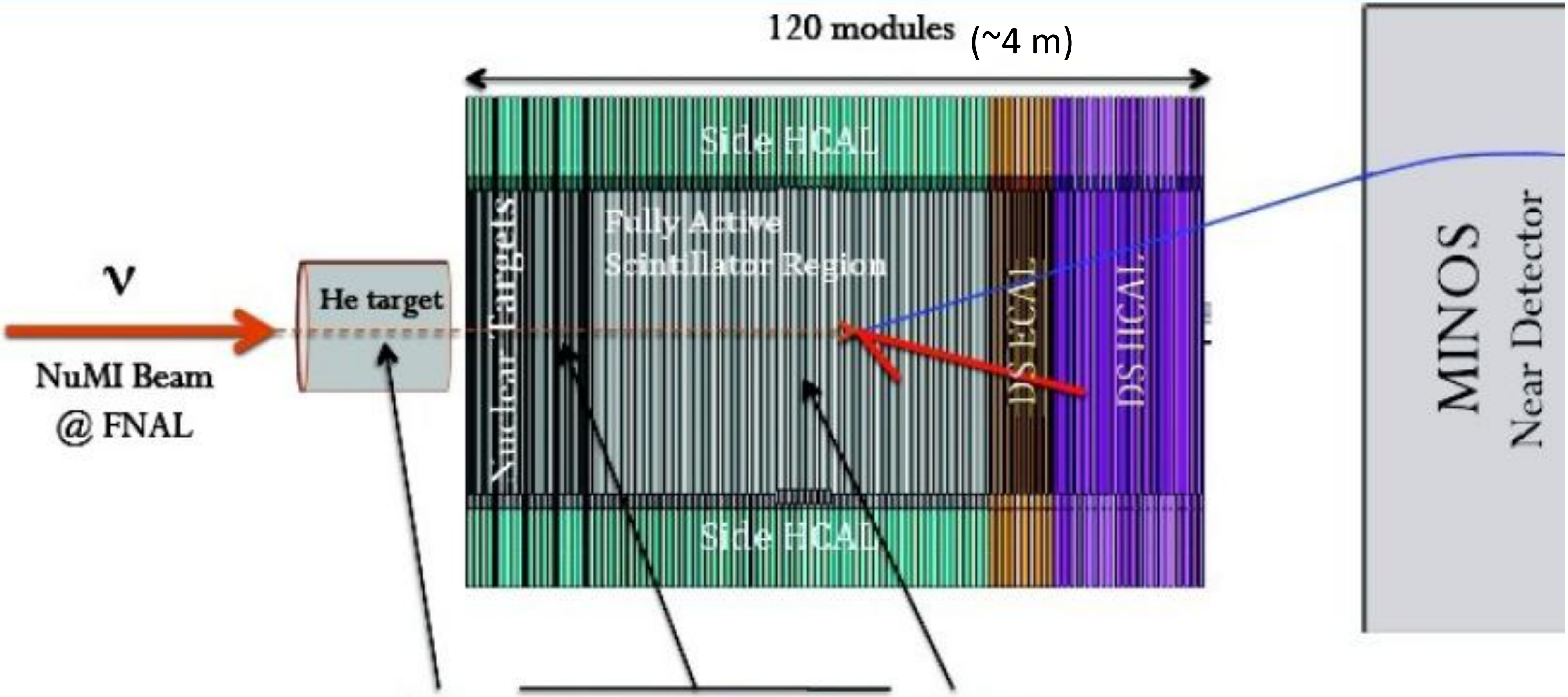
Three views for 3D reconstruction.



64 anode PMT's

Iron outer detector instrumented for EM calorimetry.

The Detector

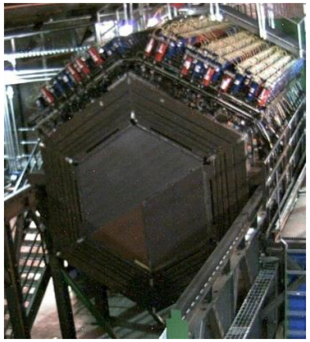


nuclear targets (He, C, Fe, Pb, H_2O, CH)

Nuclear Targets

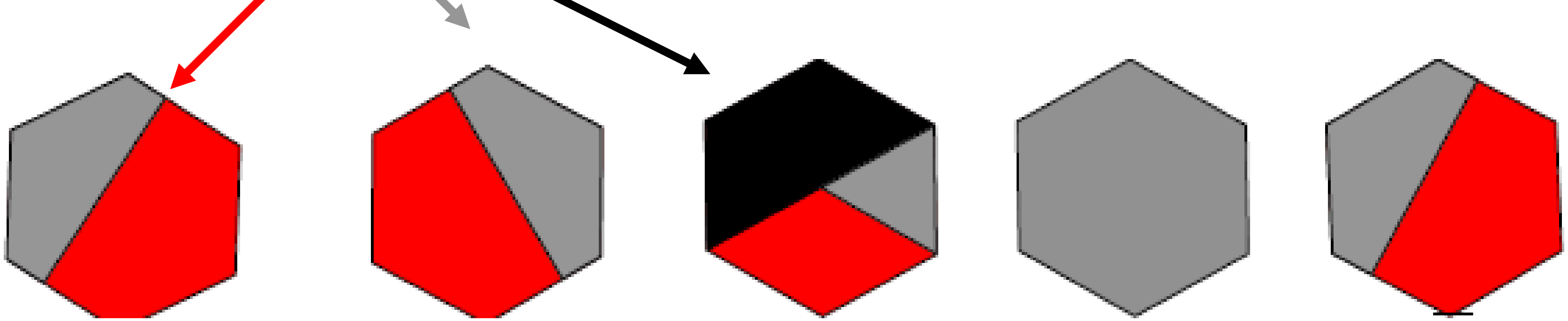
- 5 nuclear targets + water target
- Helium target upstream of detector
- Near million-event samples
  (4×10^{20} POT LE beam + 12×10^{20} POT in ME beam)

Target	Mass in tons	CC Events (Million)
Scintillator	3	9
He	0.2	0.6
C (graphite)	0.15	0.4
Fe	0.7	2.0
Pb	0.85	2.5
Water	0.3	0.9



Water target

5 Nuclear Targets
Fe Pb C



MINERνA μ Spectrometer installed and tested ☺

(Also known as the MINOS Near Detector)

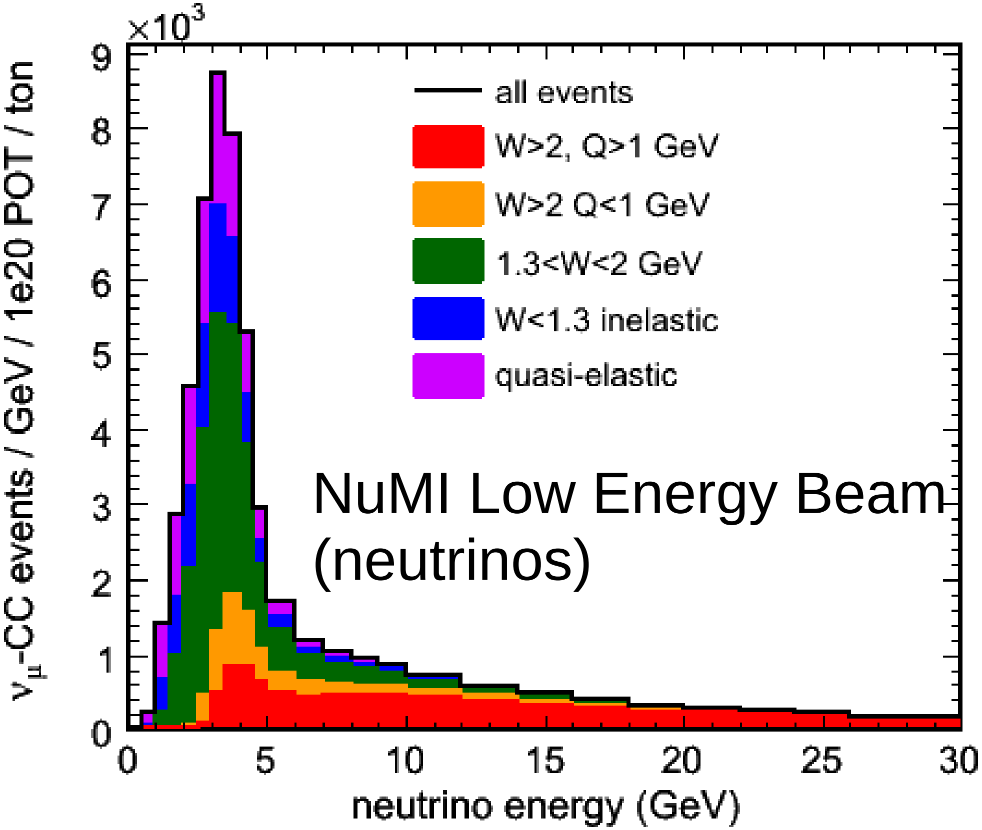
CC Sample

- Current run plan (Aug. 2010)
  4 × 10^{20} POT LE beam
  12 × 10^{20} POT ME beam
- Yield: ~14M (CC events)

  9M in scintillator

Quasi-elastic	**0.8 M**
Resonance production	**1.7 M**
Resonance to DIS transition region	**2.1 M**
DIS Low Q^2 region and structure functions	**4.3 M**

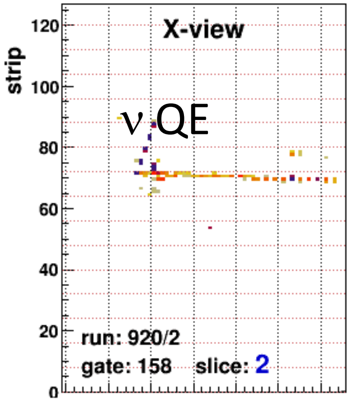
Coherent Pion Production	**CC 89k, NC 44k**
charm / strange production	**230 k**

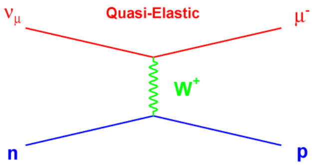


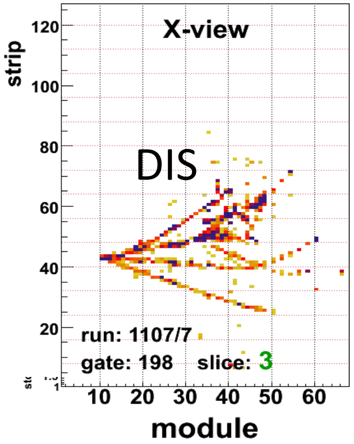
NuMI Low Energy Beam (neutrinos)

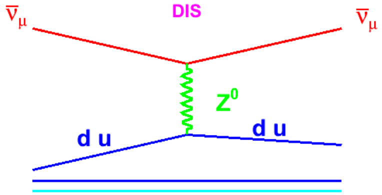
MINERνA Events

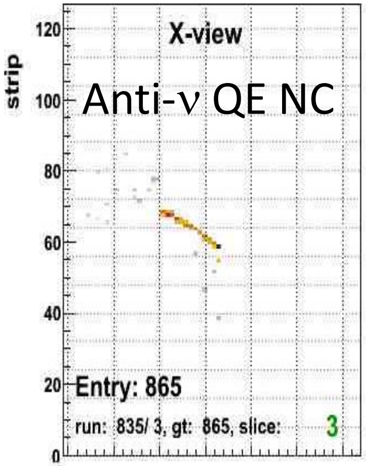
- Showing X view

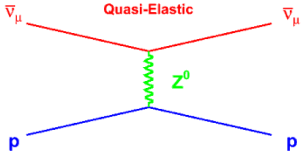


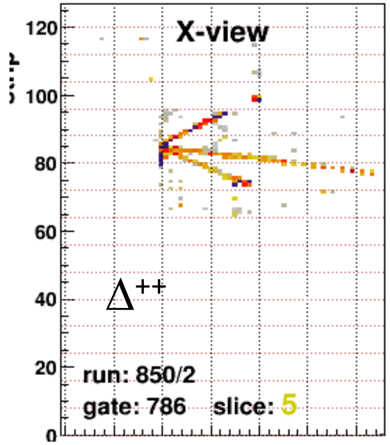


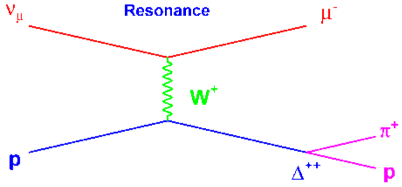






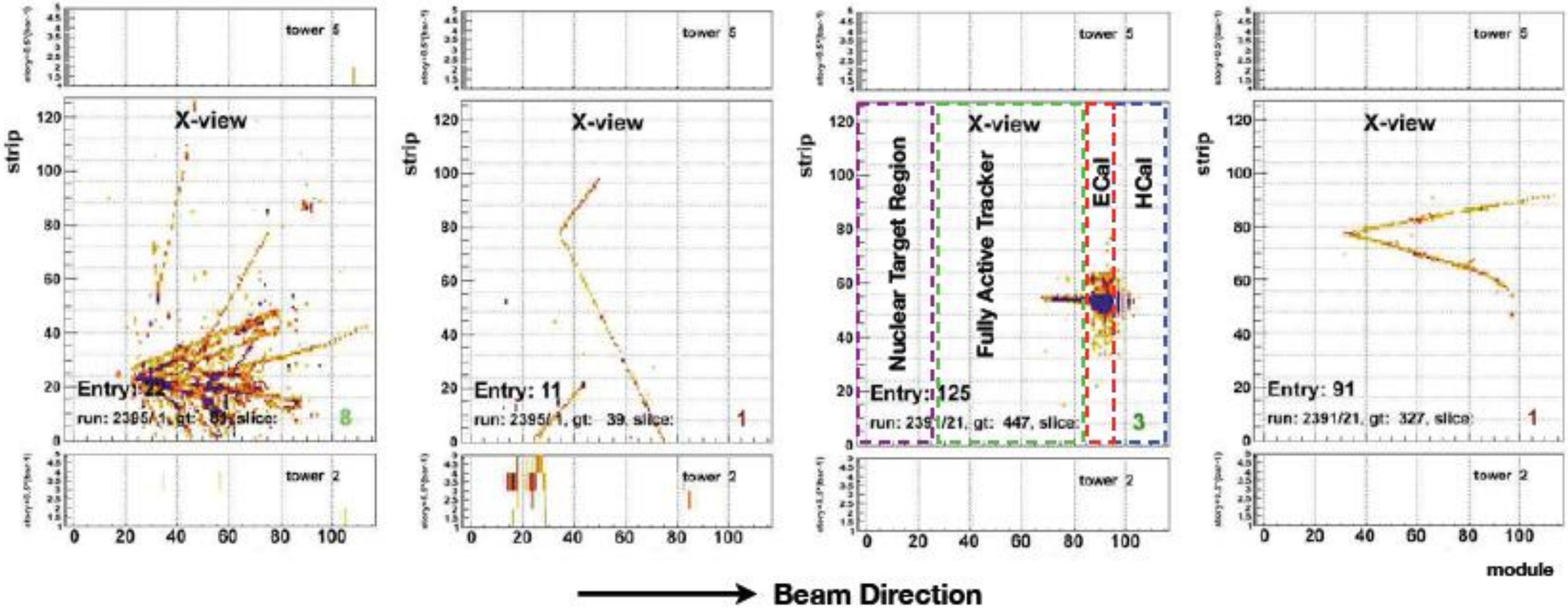




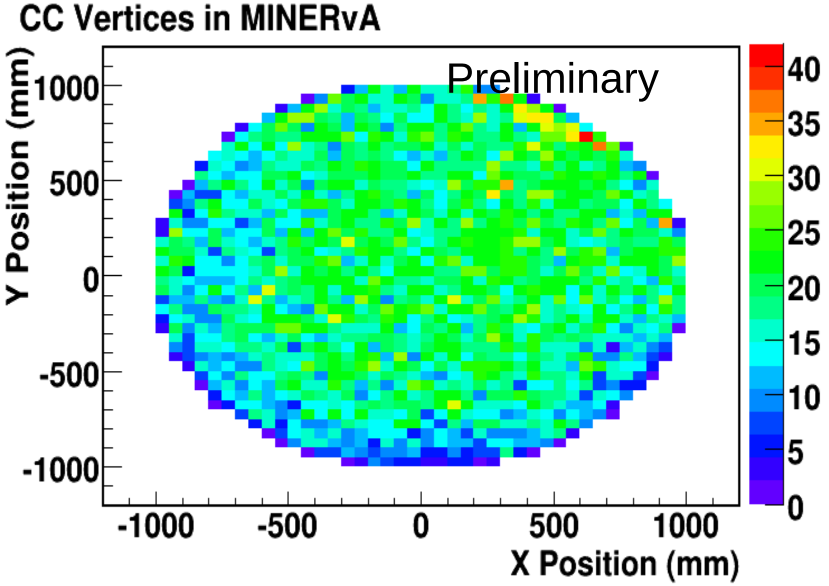


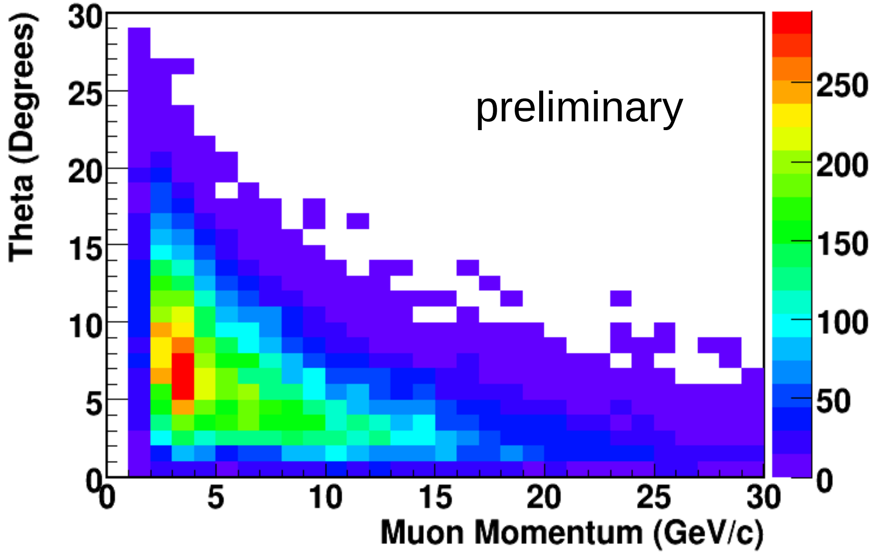
Summary of detector capability

- Good tracking resolution (~3 mm)
- Calorimetry for both charged particles and EM showers
- Containment of events from neutrinos < 10 GeV (except muon)
- Muon energy and charge measurement from MINOS
- Particle ID from dE/dx and energy+range
  - But no charge identification except muons into MINOS



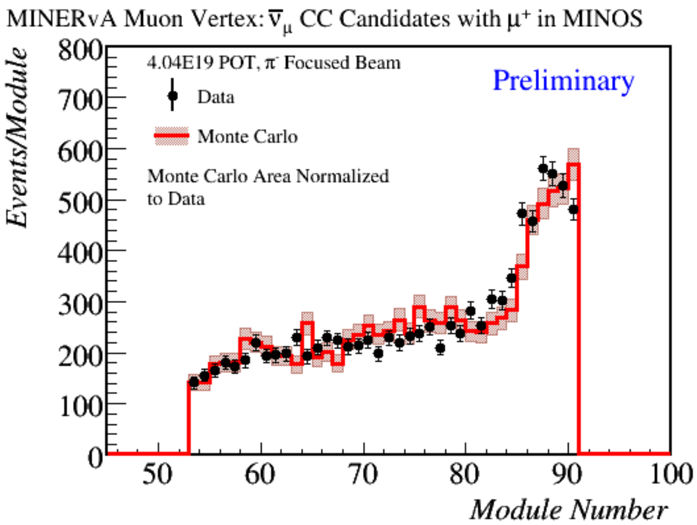
Anti-ν Inclusive CC Data

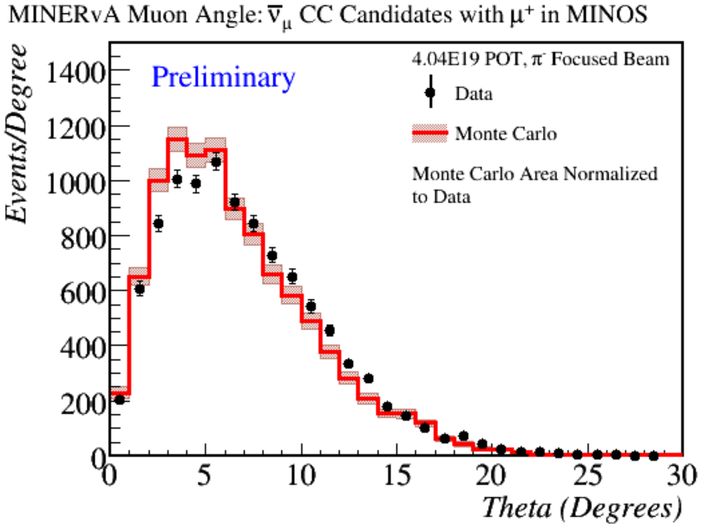




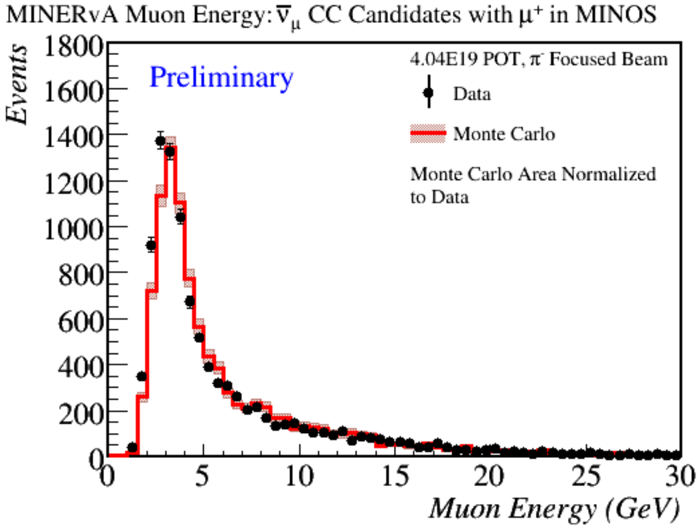
- Track in MINERνA which matches a track in MINOS, this imposes few GeV cut
  - Requires hits < 1m radius
  - X Y vertex distribution
  - Momentum from MINOS + de/dx in MINERνA

Distributions in Anti-ν Beam
Anti-ν CC, Data vs MC

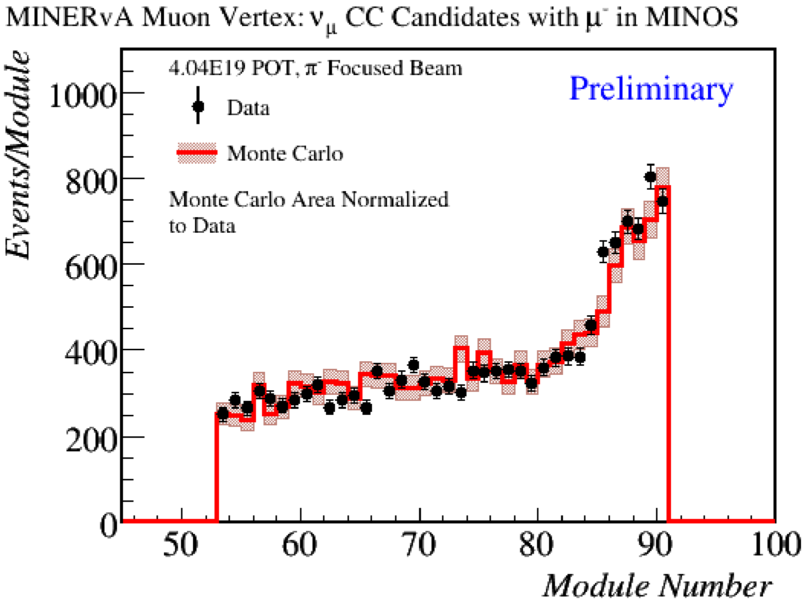


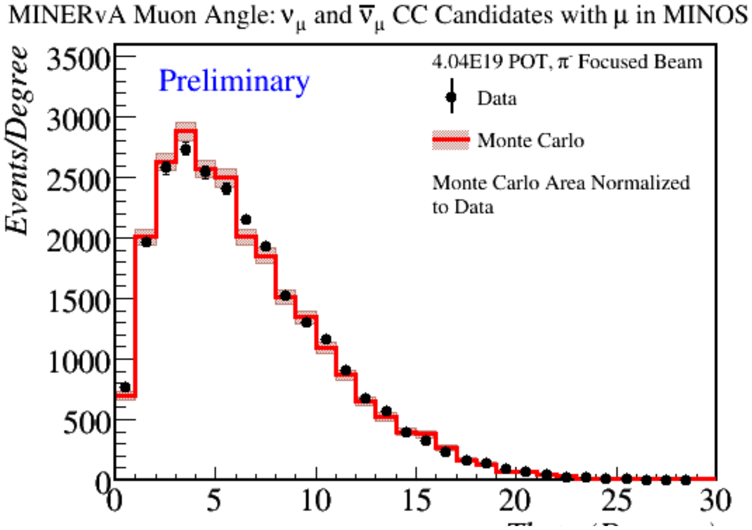


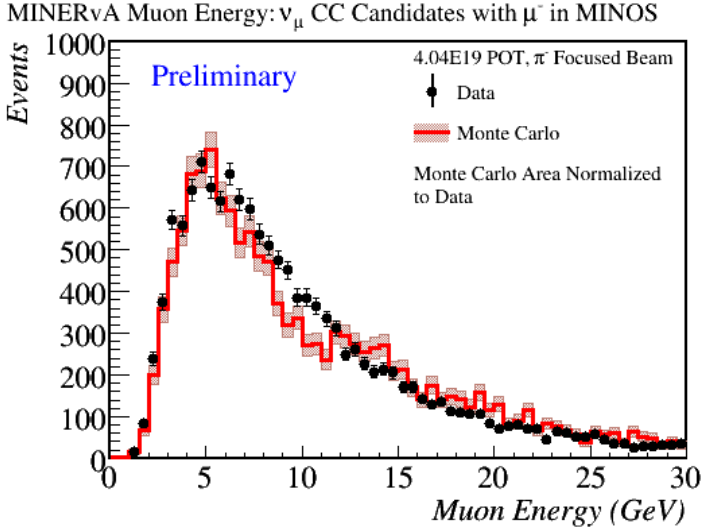
- 4.04×10^{19} POT in anti-ν mode
- MC generator GENIE v 2.6.0
  - GEANT4 detector simulation
  - 2×10^{19} POT MC , LE Beam MC anti-ν flux, untuned
  - Area normalized
- Require reconstructed muon in MINOS



Distributions in Anti-ν Beam
ν CC, Data vs MC

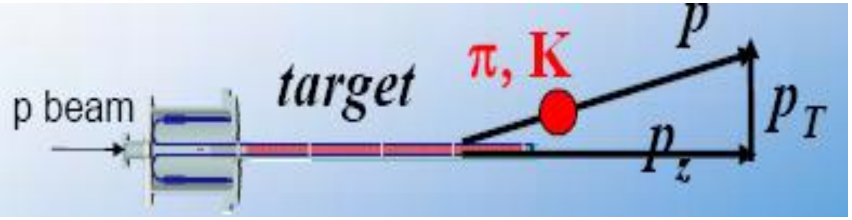

MINERvA Muon Vertex: ν_μ CC Candidates with μ^- in MINOS


MINERvA Muon Angle: ν_μ and $\bar{\nu}_\mu$ CC Candidates with μ in MINOS

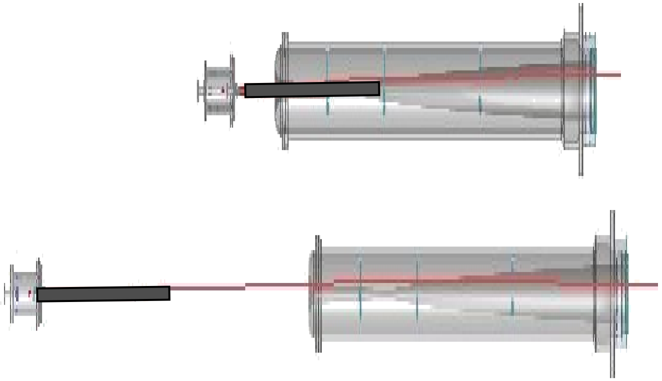

MINERvA Muon Energy: ν_μ CC Candidates with μ^- in MINOS

- ν Distributions same conditions as before
- Very good agreement between Data and MC

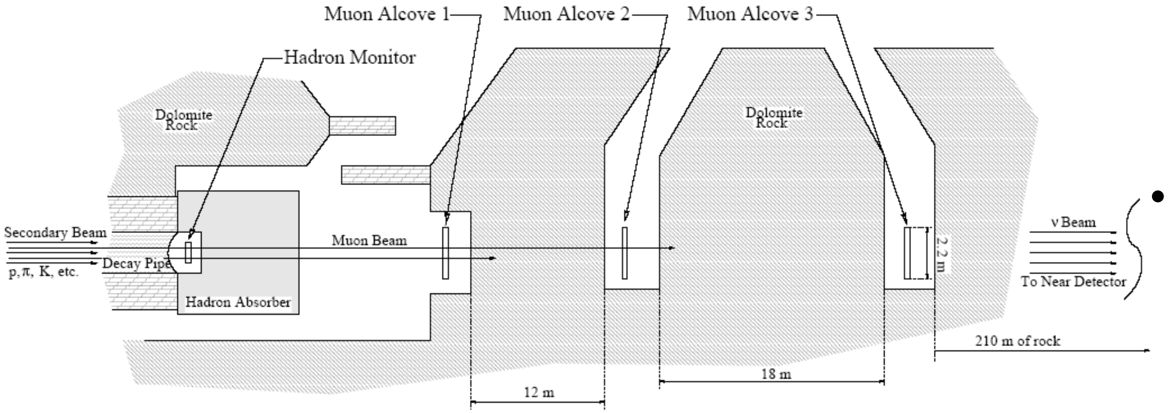
Understanding the Flux



- FNAL MIPP experiment measures hadron production using 120 GeV/c P on NUMI target replica

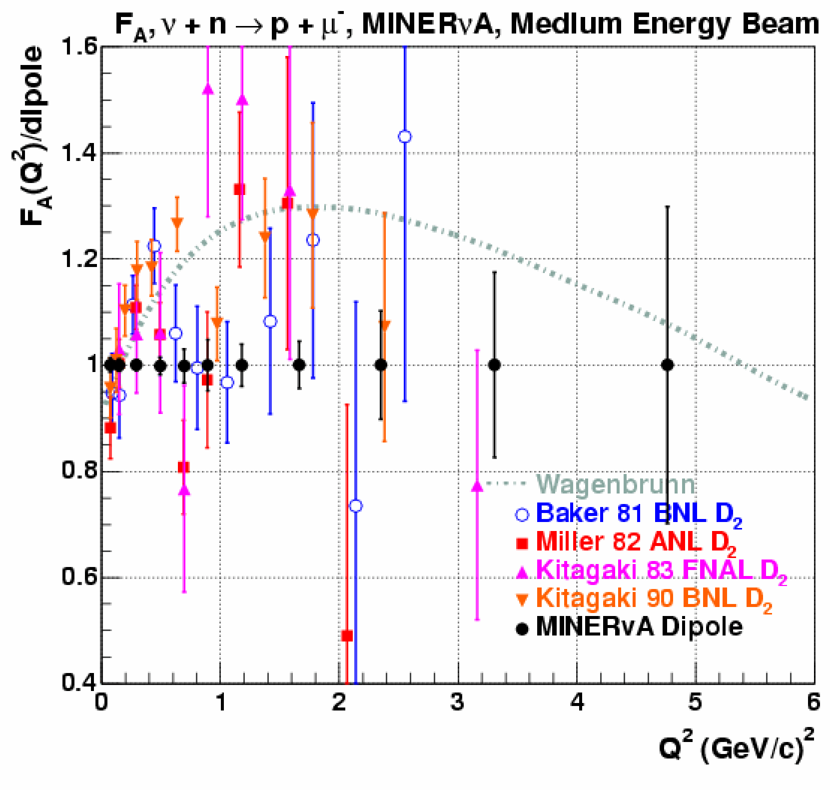


- Measure flux with 8 different beam configurations where horn current and the target position are varied
- Goal is 7% error in flux shape and 10% on flux normalization



- Use muon monitors in alcoves downstream of the hadron absorber in the beam to measure the muon flux.
- Hope to achieve 10% error in absolute flux normalization.

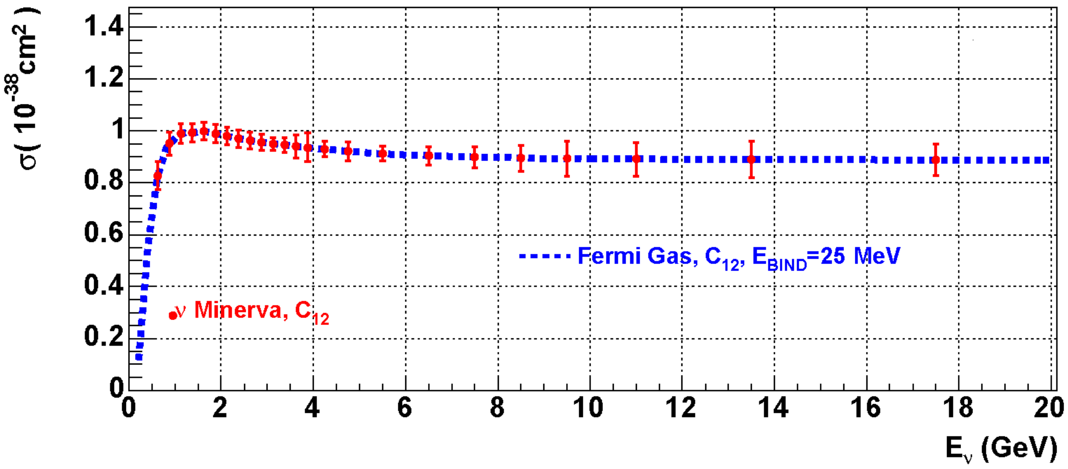
Extraction of F_A , ME Beam

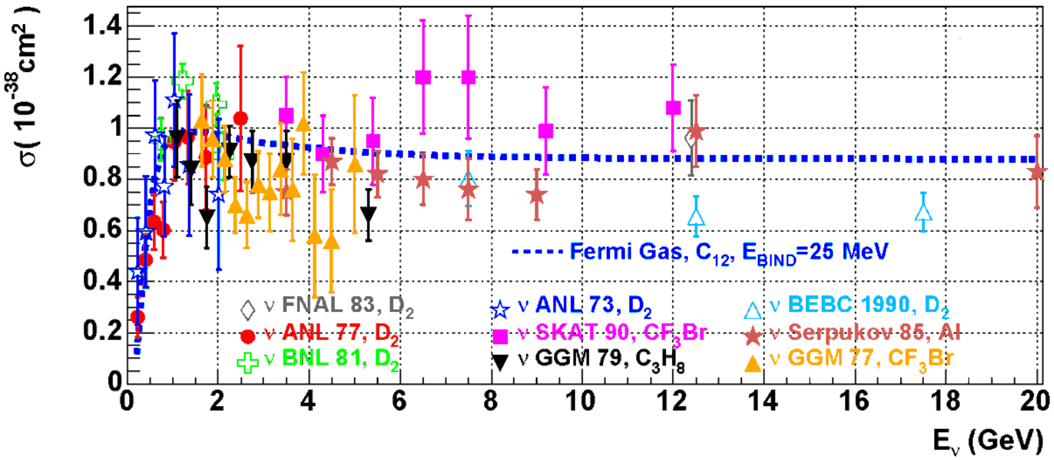


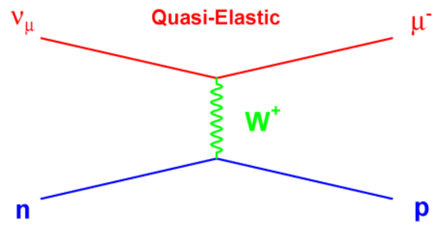
- Experiments assume dipole form for axial form factor, (F_a) & determine M_A by fit and/or normalization
- We can extract F_A directly
  - $\sigma = aF_A{}^2 + bF_A + c$
- Hence, with the high statistics ME data we can extract F_A in bins of Q^2
  - 12 × 10^{20} POT
  - Expected errors with GEANT3 and NEUGEN & include detector resolution effects
  - The statistics give sensitivity for F_A at the few % level at moderate Q^2

The range of nuclear targets will allow us to study the nuclear dependence of the extracted F_A

CCQE Cross Section, LE beam

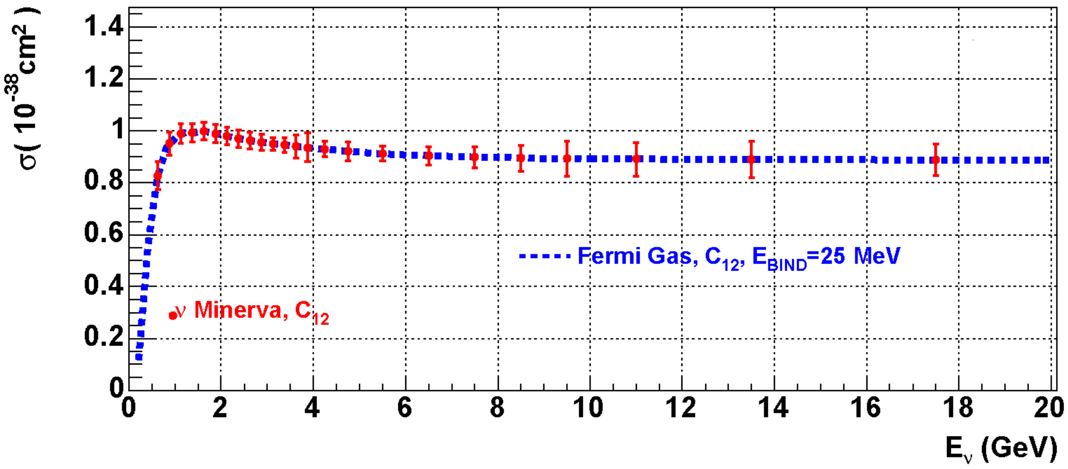


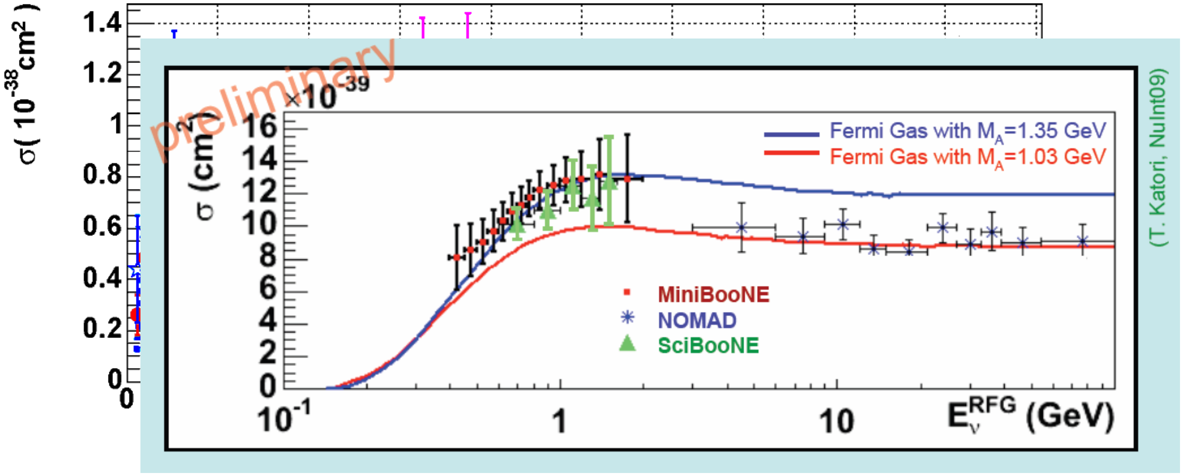


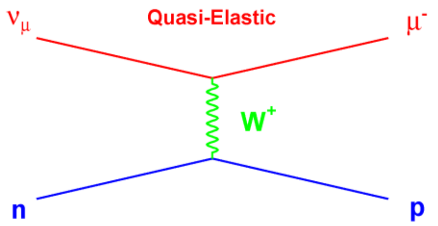


- Expected statistical errors in cross section for the LE ν beam
  - 4 × 10^{20} POT
- Include efficiencies and purities using NEUGEN and a GEANT 3 MC and includes detector resolution effects
- Goal of 7% flux errors on shape and 10% on absolute normalization

CCQE Cross Section, LE beam

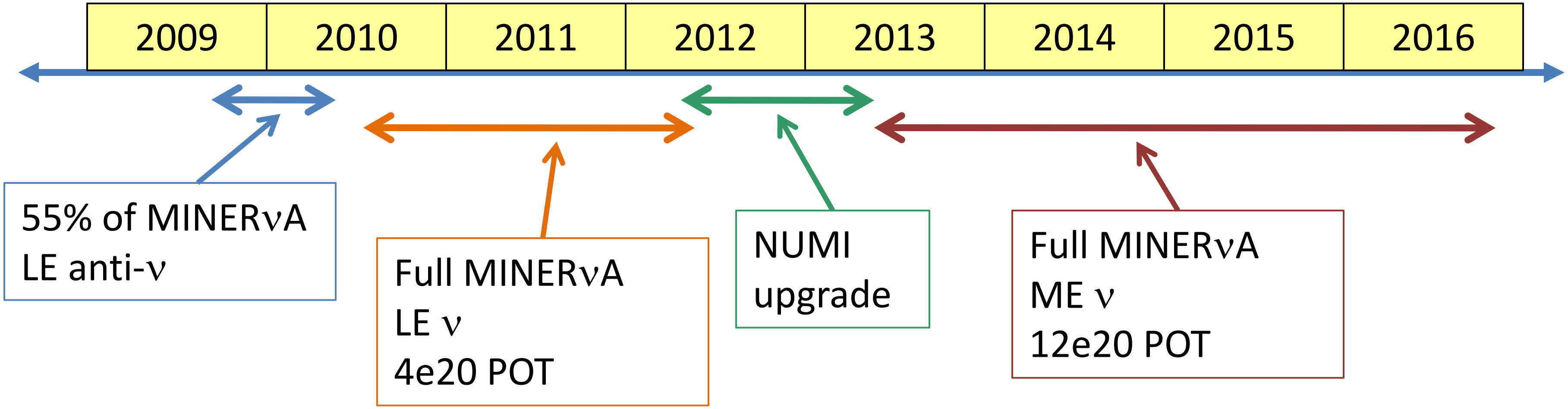






- Expected statistical errors in cross section for the LE ν beam
  - 4×10^{20} POT
- Include efficiencies and purities using NEUGEN and a GEANT 3 MC and includes detector resolution effects
- Goal of 7% flux errors on shape and 10% on absolute normalization

MINERνA Schedule



55% of MINERνA
LE anti-ν

Full MINERνA
LE ν
4e20 POT

NUMI
upgrade

Full MINERνA
ME ν
12e20 POT

- MINOS request for more anti-neutrino running and some impact from potential Tevatron run extension – may change things a little

  (Jeff Hartnell’s talk on Tuesday)

Summary

- MINERvA is a high statistics neutrino experiment
- Greatly improved statistics on all neutrino-nucleus cross sections
- Precision measurements of A dependence of axial form factor
- Data coming in now! Results soon!

Backup slides

CCQE, Measuring F_A

The hadronic current for QE neutrino scattering is given by:

$$< p(p_2)|J_\lambda^+|n(p_1) >= \overline{u}(p_2)\left[\gamma_\lambda F_V^1(q^2) + \frac{i\sigma_{\lambda\nu}q^\nu \xi F_V^2(q^2)}{2M} + \gamma_\lambda\gamma_5 F_A(q^2)\right]u(p_1) \qquad (1)$$

The Dirac/Pauli form factors $F_V^1(q^2)$ and $\xi F_V^2(q^2)$ are given in terms of the Sachs form factors by:

$$F_V^1(q^2) = \frac{G_E^V(q^2) - \frac{q^2}{4M^2}G_M^V(q^2)}{1 - \frac{q^2}{4M^2}}, \xi F_V^2(q^2) = \frac{G_M^V(q^2) - G_E^V(q^2)}{1 - \frac{q^2}{4M^2}}.$$

CVC used to determine G_E^V and G_M^V from the electron scattering form factors G_E^p, G_E^n, G_M^p, and G_M^n:

$$G_E^V(q^2) = G_E^p(q^2) - G_E^n(q^2), G_M^V(q^2) = G_M^p(q^2) - G_M^n(q^2).$$

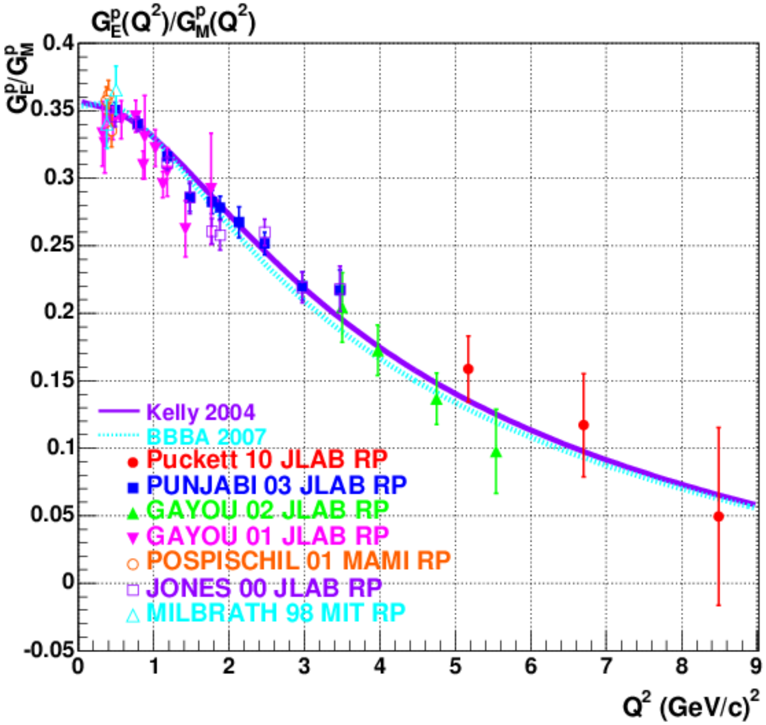
The dipole approximation:

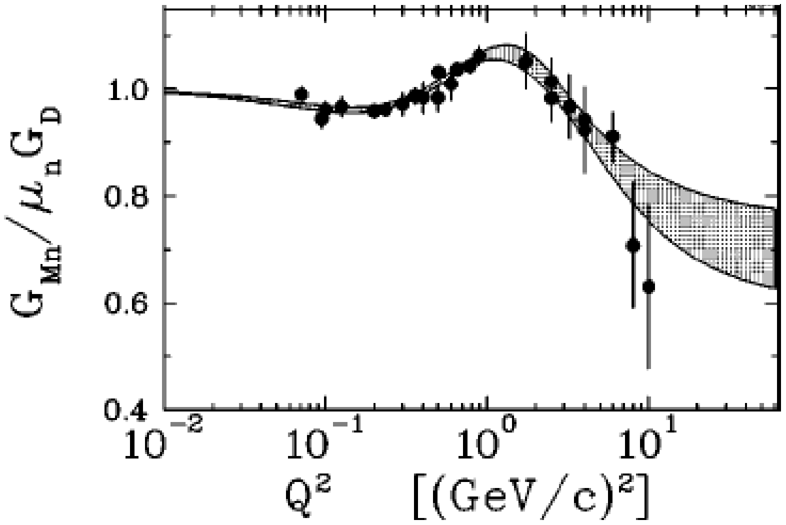
$$G_D(q^2) = \frac{1}{\left(1 - \frac{q^2}{M_V^2}\right)^2}, \quad M_V^2 = 0.71\ (GeV/c)^2, \quad F_A(q^2) = \frac{g_A}{\left(1 - \frac{q^2}{M_A^2}\right)^2}$$

$$G_E^p = G_D(q^2), \quad G_E^n = 0, \quad G_M^p = \mu_p G_D(q^2), \quad G_M^n = \mu_n G_D(q^2).$$

G_E^V and G_M^V are related in the non-relativistic limit to the charge and magnetic distribution. In the dipole approximation, $\rho(r) = \rho_0 e^{-r/r_0}$, rms of radius ~ 0.81 fm.

Form Factors Dipole?



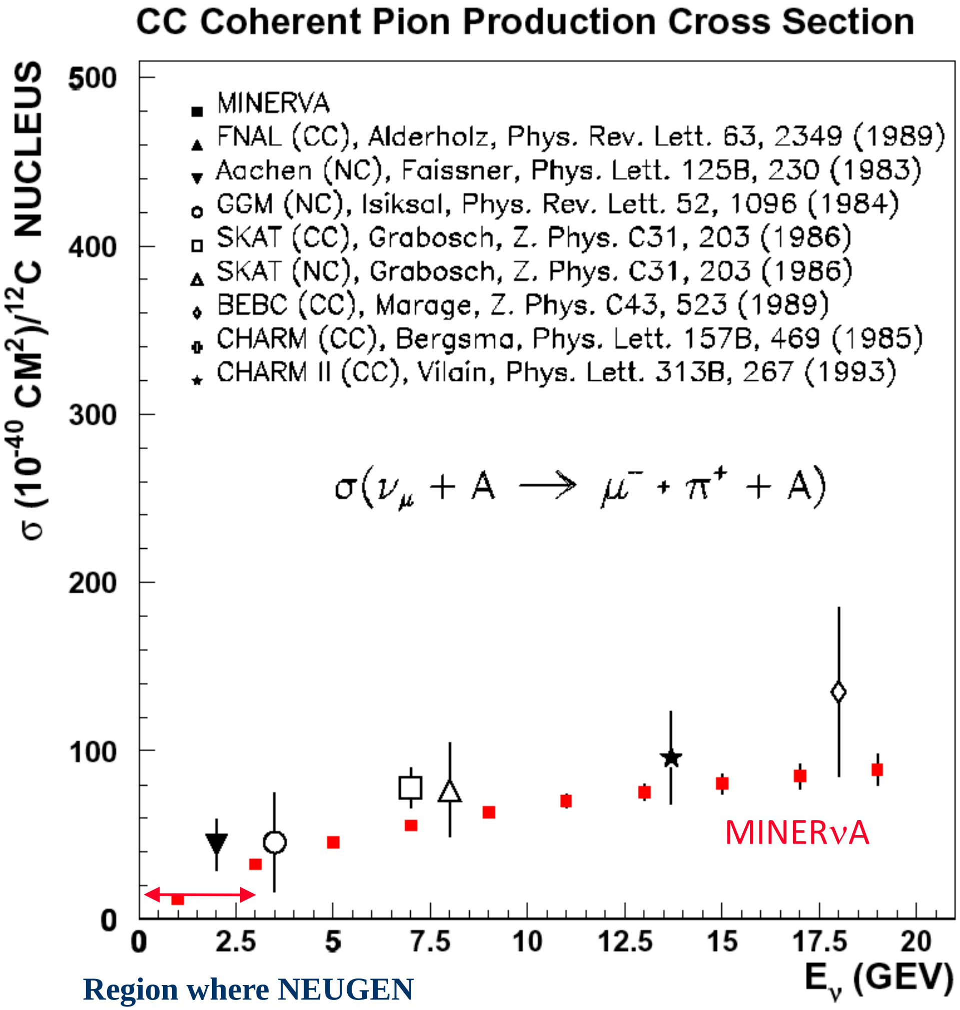


- Previously, the vector factors form factors were assumed to be a dipole form
- However, there is no reason why they should be dipole
- During the last 10 years, the EM form factors have been measured with impressive accuracy
- Plot of G_E^P / G_M^P
  - From data compilation of JJ Kelly
  - Added lastest data from Puckett et al.PRL 104,242310 (2010)
  - If G_E^P and G_M^P were dipole with same M_V, this ratio would be flat.
- G_M^n/dipole- JJ Kelly, PRC 70, 068202 (2004)
- Hence, we can't assume F_A is dipole either.
- F_A is a major contribution to the cross section

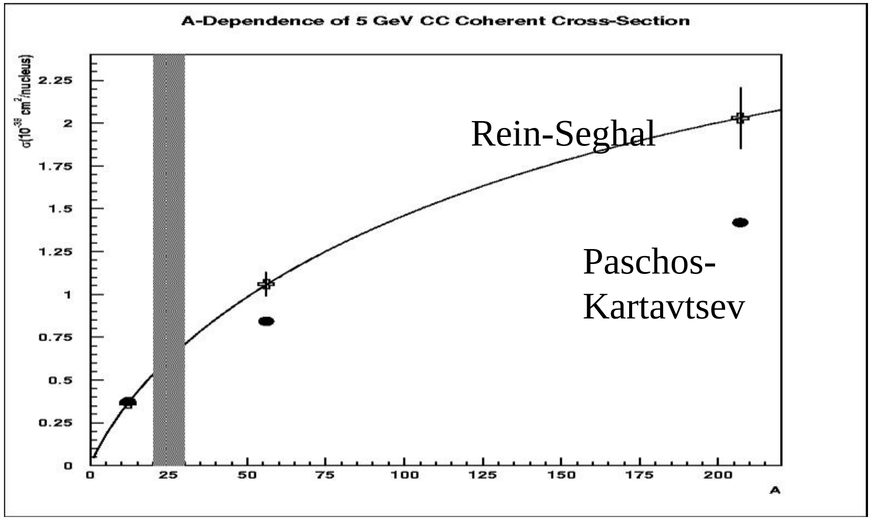
A dependence of form factor

- The form factor may be modified in the nuclear medium
  - Model predictions that form factor will be modified by a few percent, (Saito, Tsushima, Thomas, Progress in Particle and Nuclear Physics **58,** 1 (2007)
  - Extraction of form factor may be influenced by conventional effects – final state interactions, for example, which effect identification of QE
- We anticipate sufficient statistics to study final states and potential changes in the form factor at low Q^2 at the percent level
  - Estimated total interactions, no efficiency or solid angle correction ~800 K in CH, ~300 K in Pb/Fe, ~100 K in H_2O in 4 year run

Coherent Pion Production

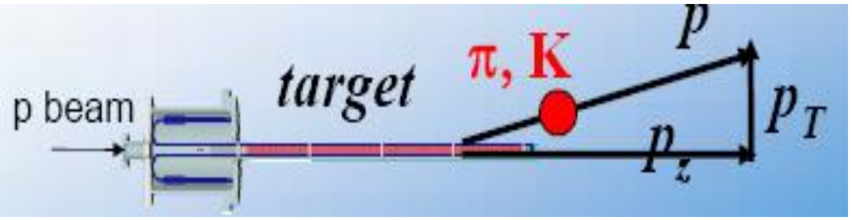


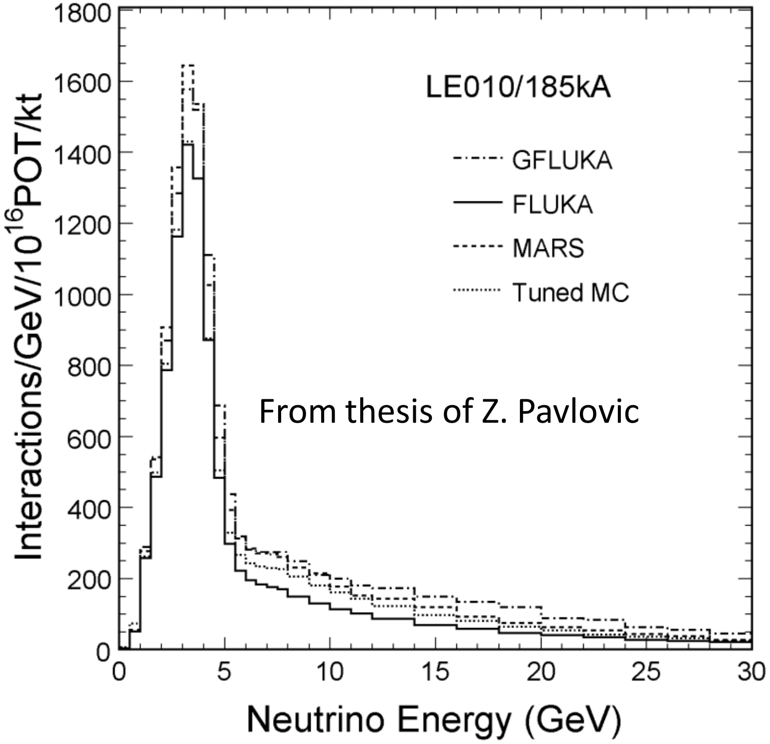
Region where NEUGEN overestimates the cross sections



MINERνA's nuclear targets allow the first measurement of the A-dependence of σ_{coh} across a wide range of nuclei.

Understanding the Flux



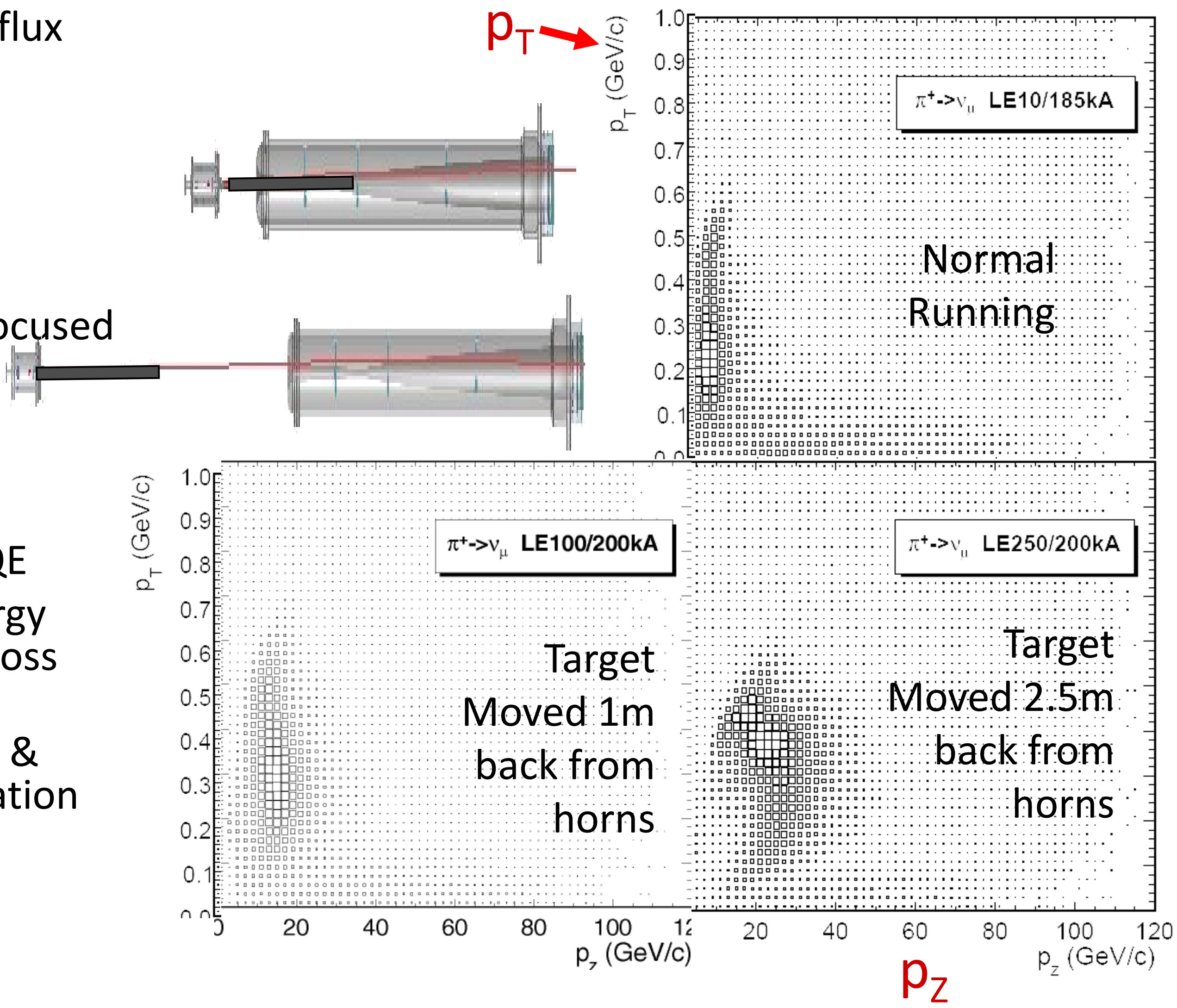


From thesis of Z. Pavlovic

- Most ν experiments use a MC of beamline tuned to existing hadron production to simulate the production of the neutrinos in the beam line
- External hadron production data
  - Atherton 400 Gev/c p-Be
  - Barton 100 GeV/c p-C
  - SPY 450 Gev/c p-C
- New FNAL MIPP experiment uses 120 Gev/c P on replica of NuMI target
- Not easy to get flux precisely this way
- Plot shows prediction of CC interactions on MINOS with different production models each consistent with experimental production data.
  - Variations 15 to 40%
- In additional 2 to 10% error from horn angle offset &current errors and scrapping

Measure Flux, Special Runs

- In situ method to measure flux
- Plots show (p_z ,p_T) of π^+ contributing to ν flux.
- "Special Runs" vary
  - Horn current (p_T kick supplied to π's)
  - Target Position (p_z of focused particles)
- Minerva will acquire data from total of 8 beam configurations
  - Measure events with QE
- Normalize flux at high energy using CCFR/CHARM total cross section
- Goal is 7% error flux shape & 10% error on flux normalization

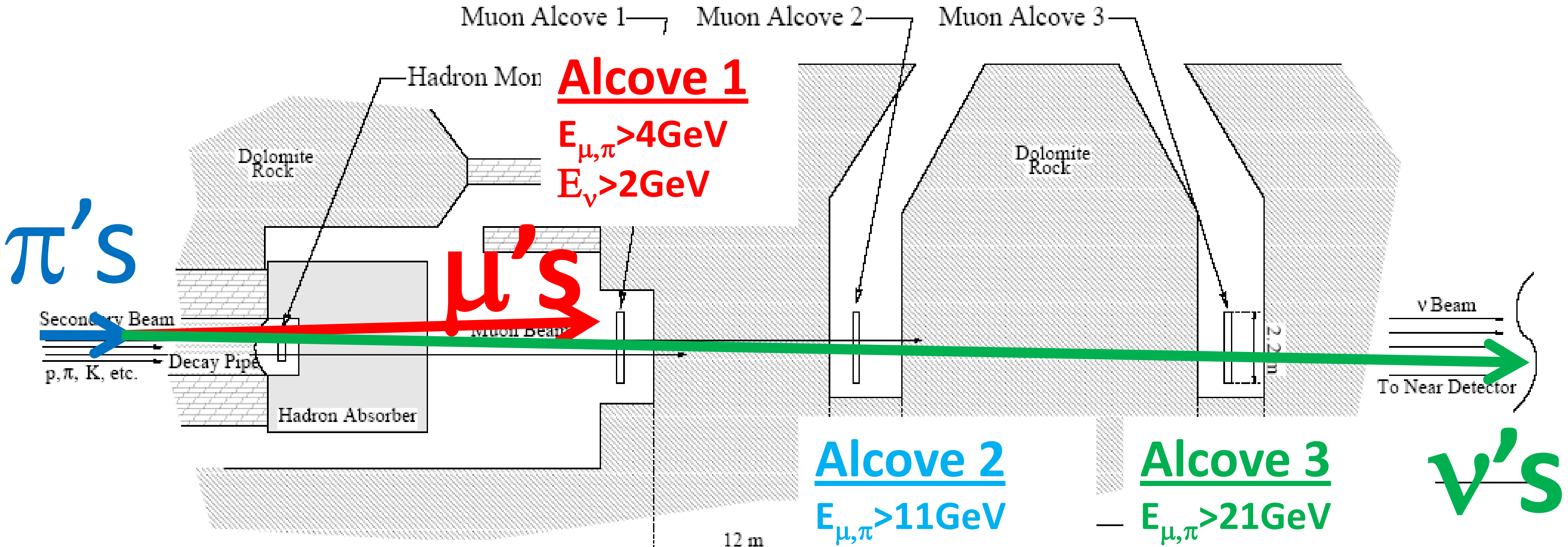


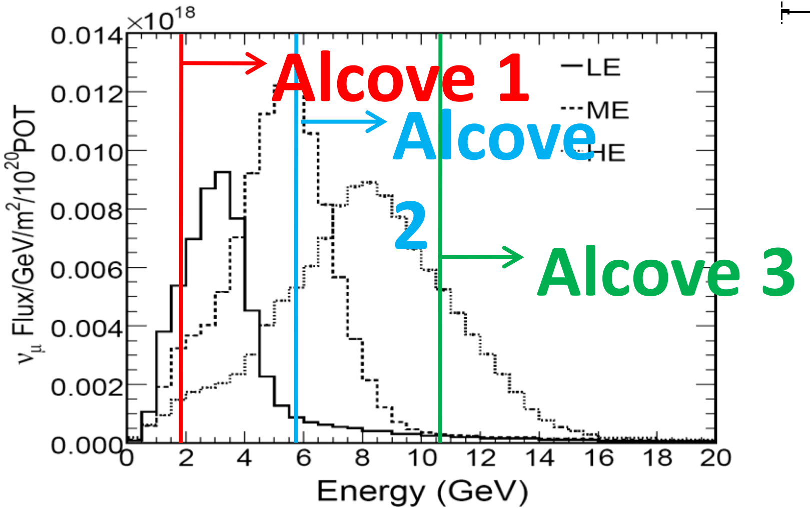
Normal Running

Target Moved 1m back from horns

Target Moved 2.5m back from horns

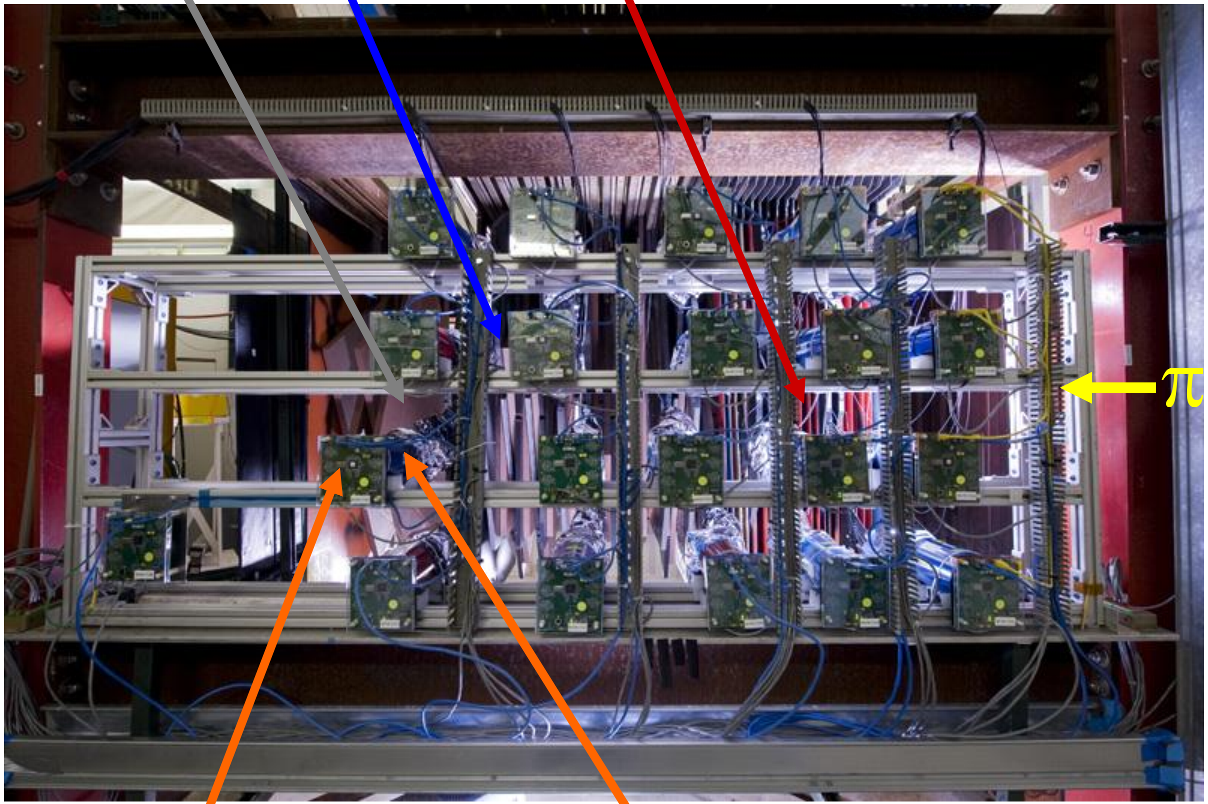
Absolute Flux with μ Monitors





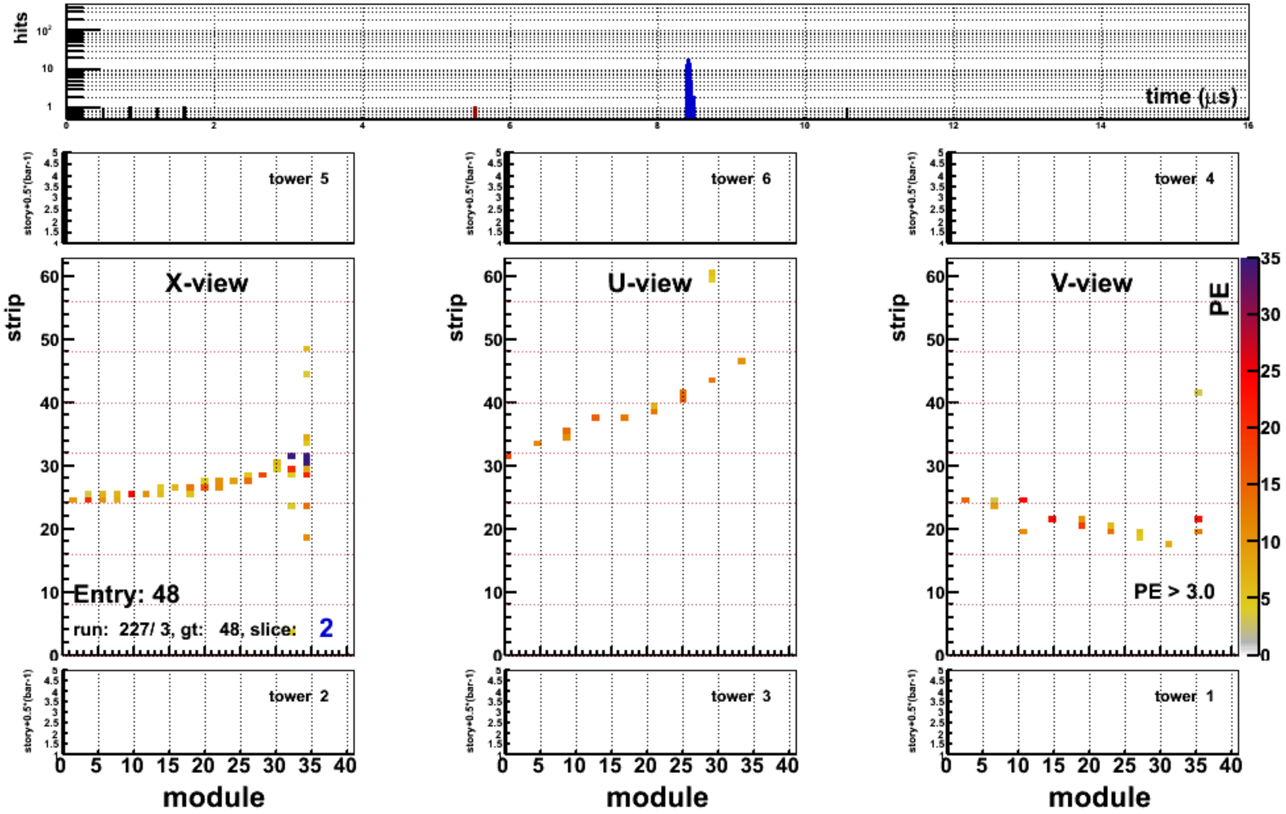
- 3 arrays of ionization chambers, 4th chamber being added;
- Signal = ionized electrons.
- Sampling μ flux = Sampling hadrons off target = Sampling ν flux.
- Sample different energy regions of the flux.
- Goal of μ monitors is to understand flux normalization to 10%

MINERνA Test Beam



- In order to make precise measurements we need a precise a calibration
  - Low energy calibration
- 40 planes, XUXV,1.07 m square
- Reconfigurable can change the absorber configuration. Plane configurations:
  - 20ECAL-20HCAL
  - 20Tracker-20ECAL
- Just finished 1st run – Jun 10-Jul 16

Test Beam π

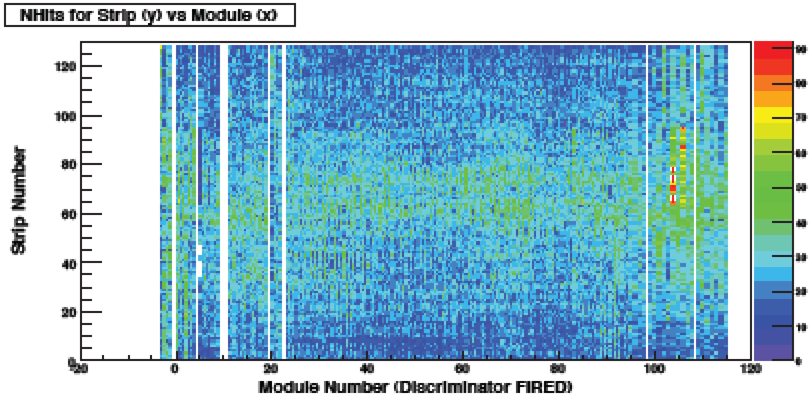


- 20 ECAL 20 HCAL configuration
- 1.35 GeV interacting in HCAL

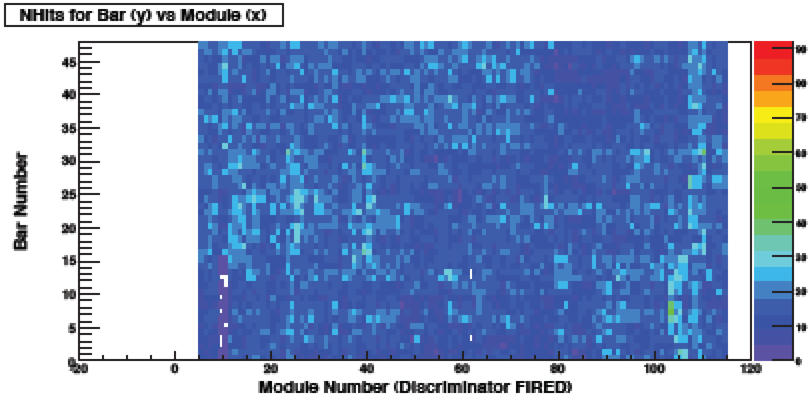
MINERνA Running Status

- Accumulated 0.84x10^{20} POT of anti-ν beam with 55% of detector and Fe/Pb target
- Accumulated >1.21x10^{20} POT in Low Energy neutrino beam running with full detector
- Detector Live times typically above 95%
- Less than 20 dead channels out of 32k channels

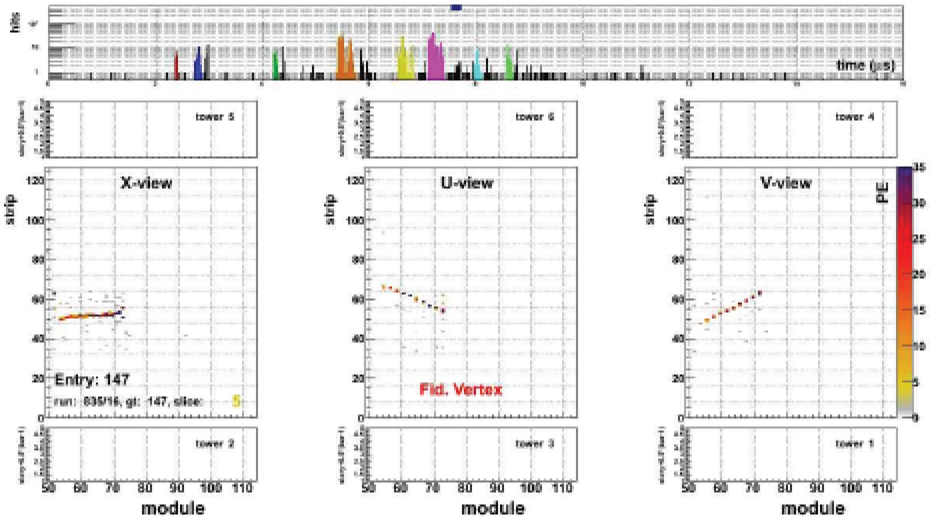
Inner Detector - Hit Occupancy



Outer Detector - Hit Occupancy



PID with dE/dX



Candidate proton track from the anti-ν data set.

MC indicates this will be a successful method.