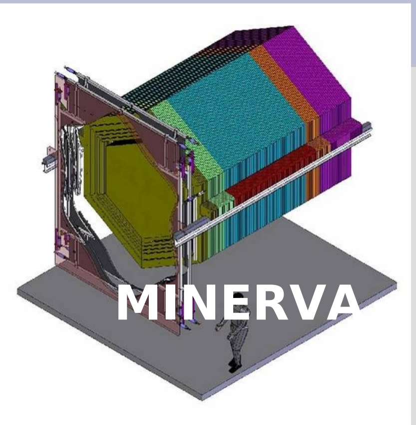
The MINERνA Experiment: precision ν-A cross sections

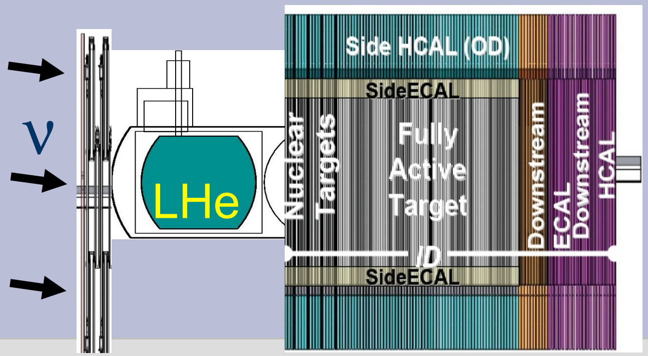


Eric Christy, Hampton University
(for the MINERνA Collaboration)

Elba, 2010

MINERνA

Main Injector ExpeRiment ν-A



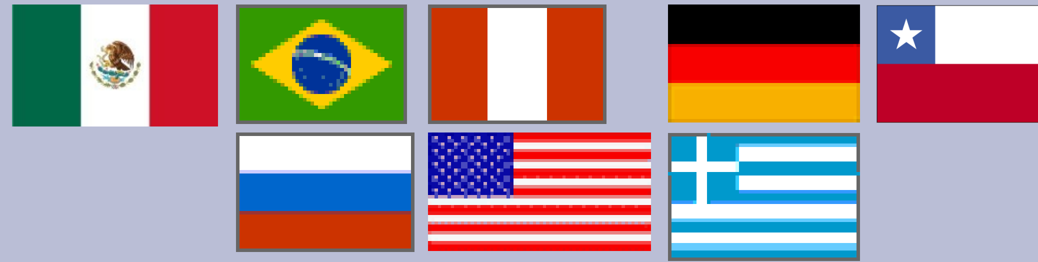
- MINERvA is studying A dependence of neutrino interactions in unprecedented detail, from He to Pb
- Uses high intensity NuMI Beamline at Fermilab and MINOS near detector as muon spectrometer
- ***Nuclear physics goals***
  - High precision measurement of the axial form factor to high Q^2 and search for A dependence of form factor.
  - Studies of quark-hadron duality in neutrino interactions, complementing JLab.
  - Search for x-dependent nuclear effects in neutrino interactions.

(For instance DIS structure functions)

  - Precision cross section measurements and studies of final state (eg. Coherent π production from nucleus)

~70 Particle, Nuclear, and Theoretical physicists from 21 Institutions

Institutions of MINERνA



MINOS

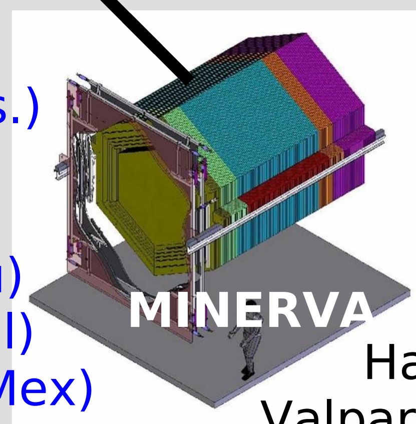
Tufts
William & Mary
FNAL
Duluth
Texas
Athens

NOVA

MiniBooNE

Northwestern

Florida



MCLA (Mass.)
Otterbein
UNI (Peru)
PUCP (Peru)
CBPF (Brazil)
Guanajuato (Mex)

Pitt

Dortmund
INR, Moscow

Theory

Hampton
Valparaiso (Chile)
James Madison
Rutgers

Jefferson Lab

Irvine

T2K

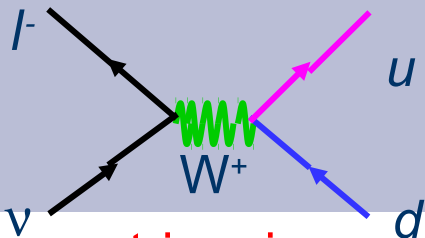
Rochester

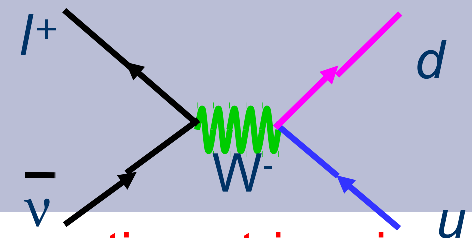
Nuclear

ν-A scattering is complementary to e-A

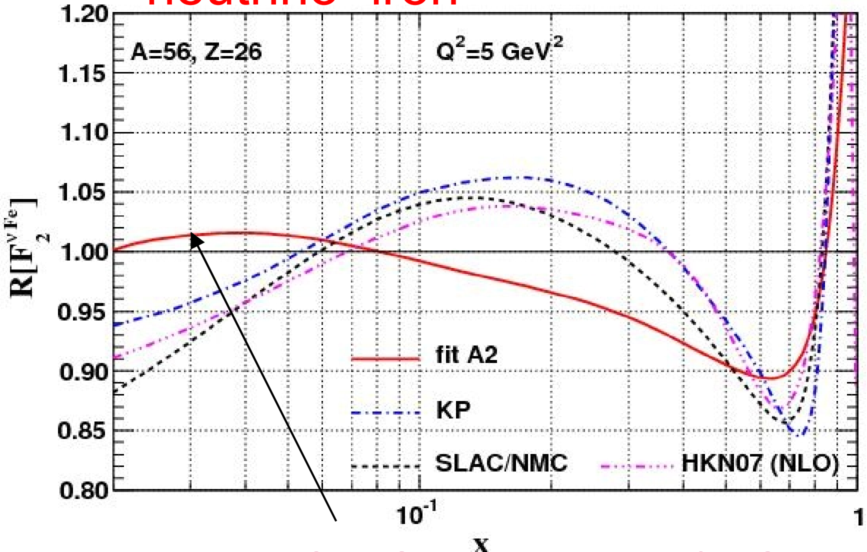
- Can study nucleon **form factors** and **structure functions** and their medium modifications
- Same structure as determined by QCD, but with a different probe than the photon.
- Different sensitivity to parton flavor, strange and weak axial FFs, and medium effects.
- Charged current ν scatting is *flavor* sensitive.
- Combination of ν and anti-ν scattering allows for separation of form factors as valence/sea quark distributions.

Nuclear Modifications in ν-A

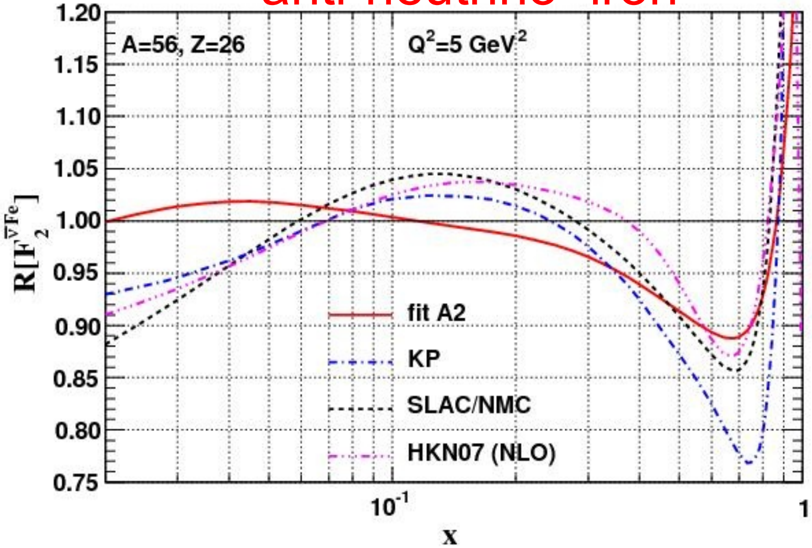




neutrino+iron



anti-neutrino+iron



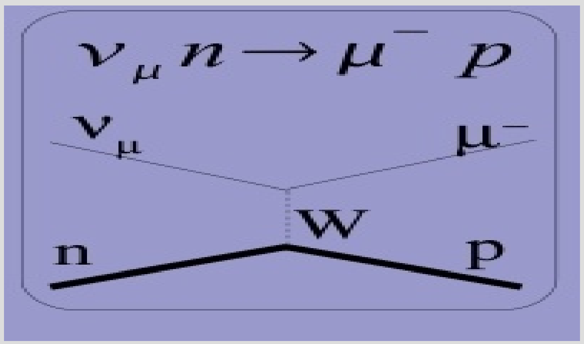
CTEQ nuclear PDF fit, Schienbein *et al.*, PRD77(2008)054013

- Essentially NO data on A dependence of structure functions in ν-A.
- Reasons to believe that these might be different that e-A
(eg. Different shadowing due to presence of axial vector current – S. Kulagin) .
- ***MINERνA will map out the nuclear dependence.***

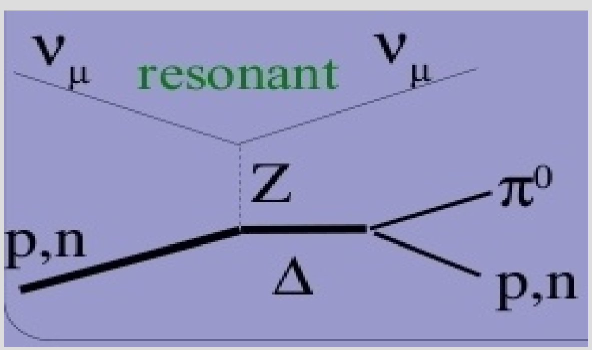
Neutrino – Nucleon Scattering

Exchange W or Z couples to *weak* charge.

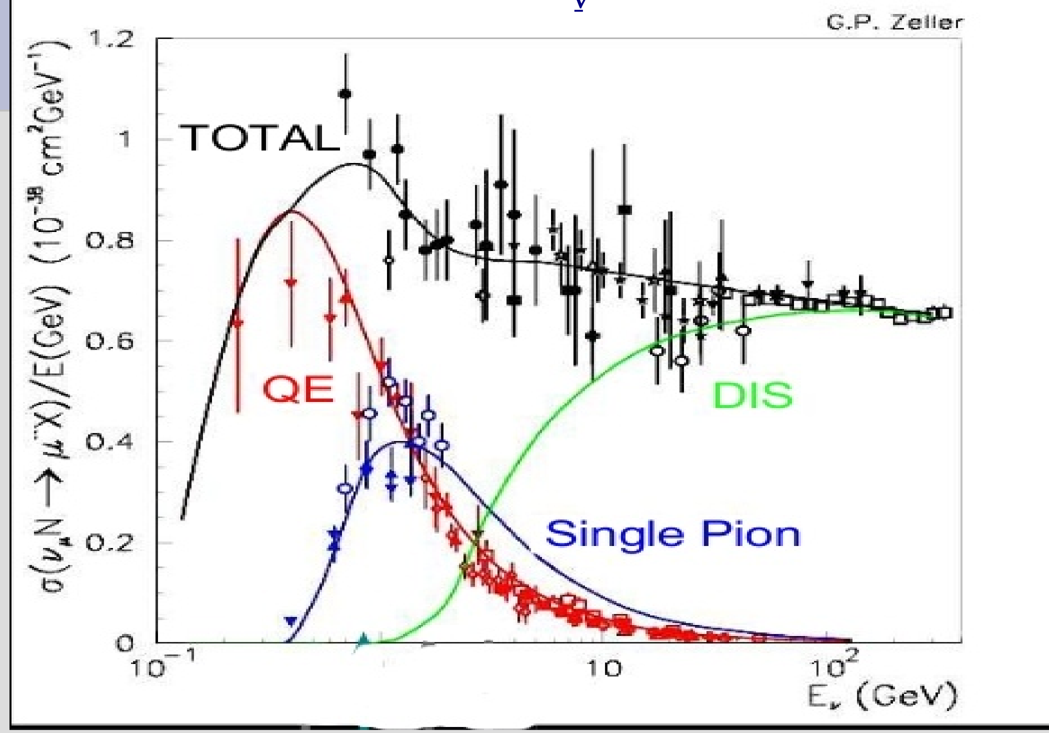
Quasi-elastic



Resonance production



Total cross section/E_ν



- *Current World data has large uncertainties*
- *MINERvA plans to significantly improve this*
- *Wide range of nuclear targets*

Some Experimental differences between e-A and ν-A experiments

(from an electron scattering perspective).

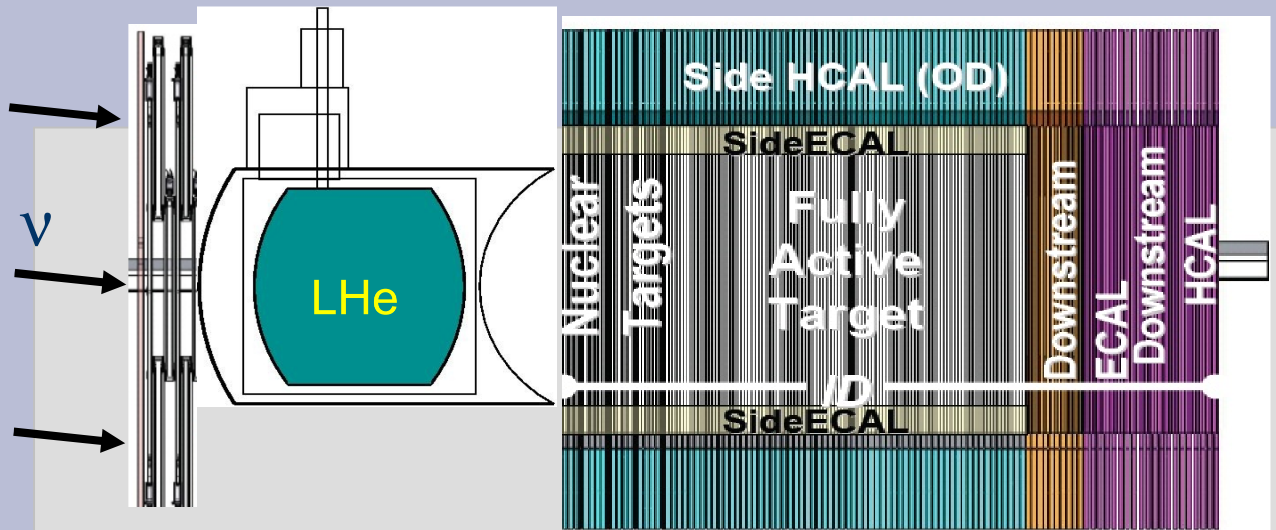
1. Low Rates => Need very large mass target => large detectors
Also means,

- don't need a fast trigger...
- In fact MINERvA doesn't have one!

2. Can not directly monitor beam (indirect monitoring is possible)

3. Typically wide band beam (in energy) => often don't know the neutrino energy event by event without complete calorimetry of final states.

Experiment Configuration



VetoWall

MINOS

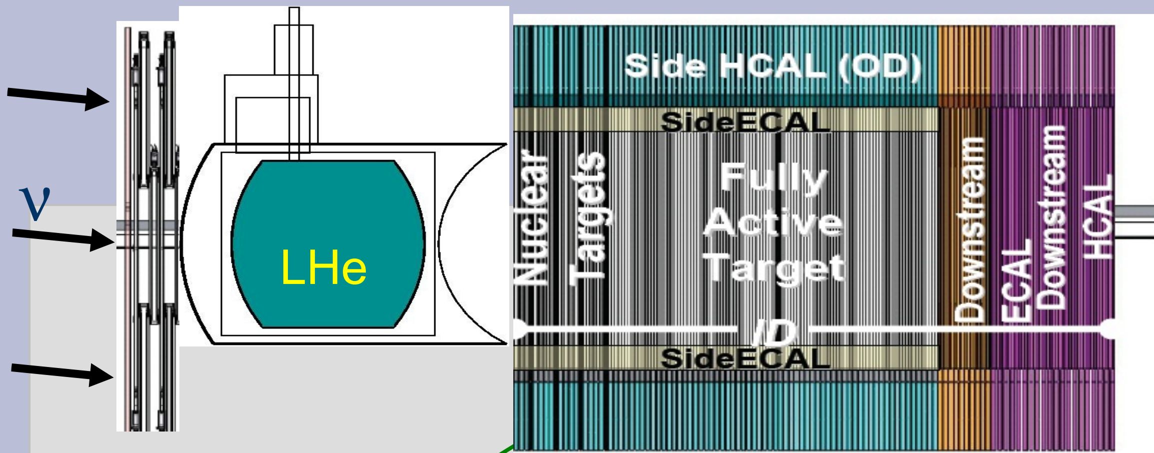
Near Detector

(momentum reconstruction for escaping muons)

- **Downstream Calorimeters:**
  20 modules,, sheets of lead (Electromagnetic Calorimetry) or steel (Hadronic calorimetry) between scintillator planes

- **Side Calorimeters:**
  2 thin lead "rings" for side electromagnetic Calorimetry, 4 layers of instrumented steel frames.

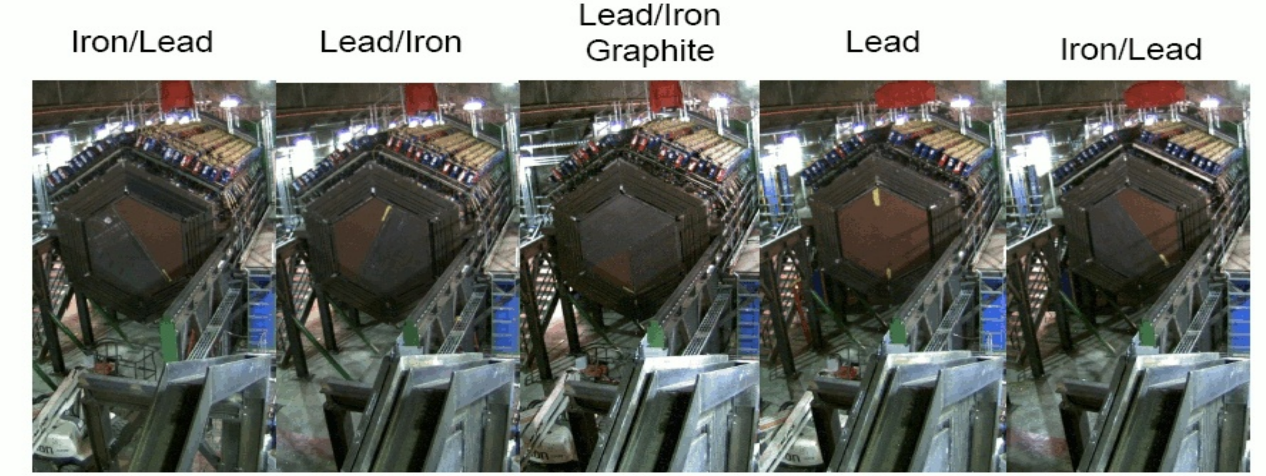
Nuclear Targets



VetoWall

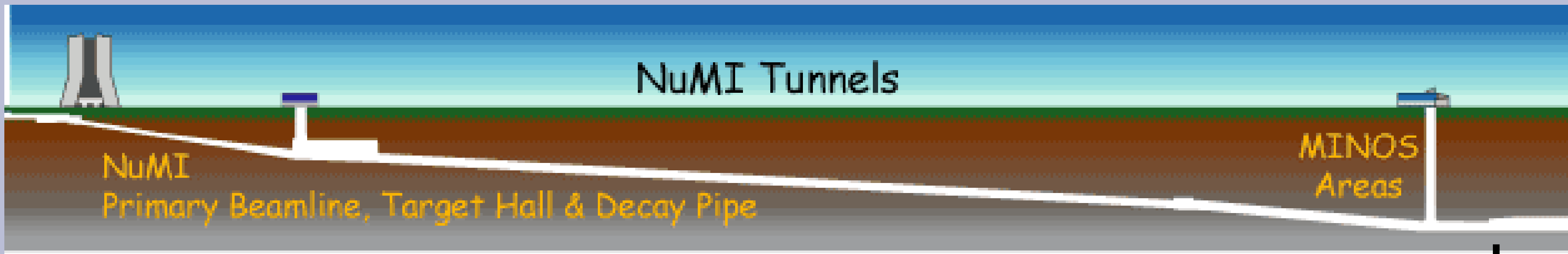
Target Material	Estimated Charged Current Statistics
Helium	0.6 M
Scintillator	9 M
Carbon	1.4 M
Iron	2.9 M
Lead	2.9 M
Water	0.7 M

Target: 1 2 3 4 6 5

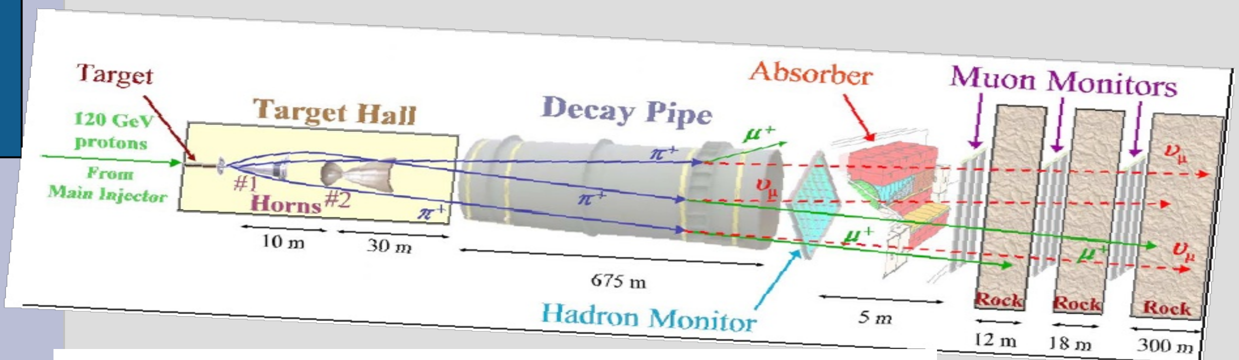


water

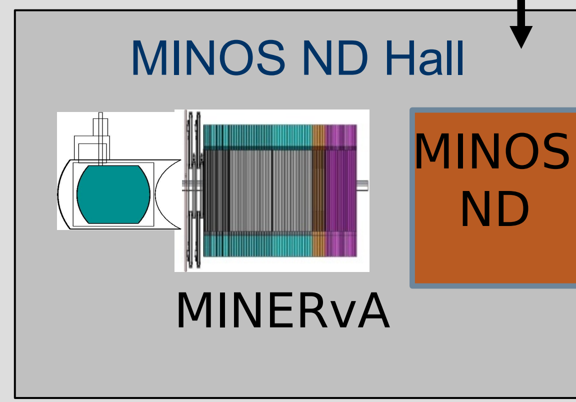
NuMI Beam



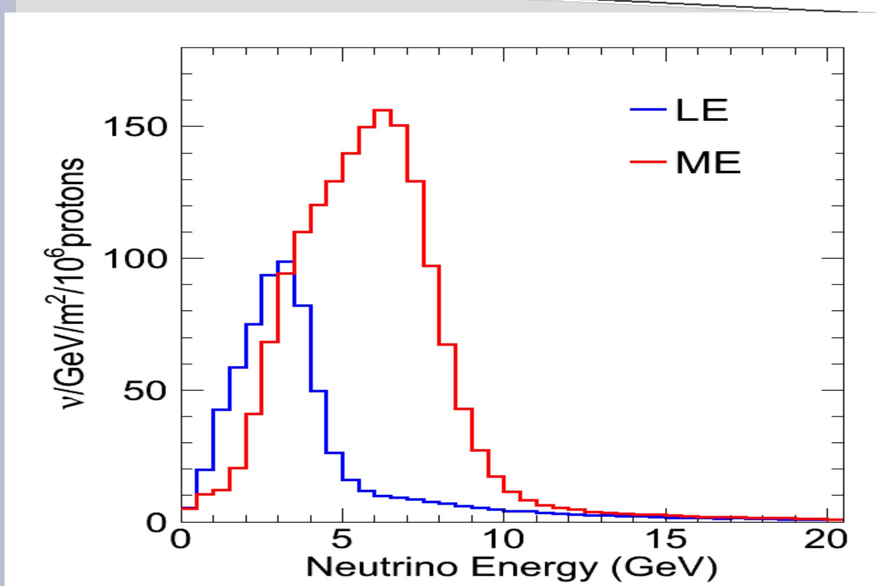
NuMI Tunnels
NuMI
Primary Beamline, Target Hall & Decay Pipe
MINOS
Areas



Target
120 GeV protons
From Main Injector
Target Hall
Horns
#1
#2
10 m
30 m
Decay Pipe
675 m
Hadron Monitor
Absorber
5 m
Muon Monitors
Rock
Rock
Rock
12 m
18 m
300 m



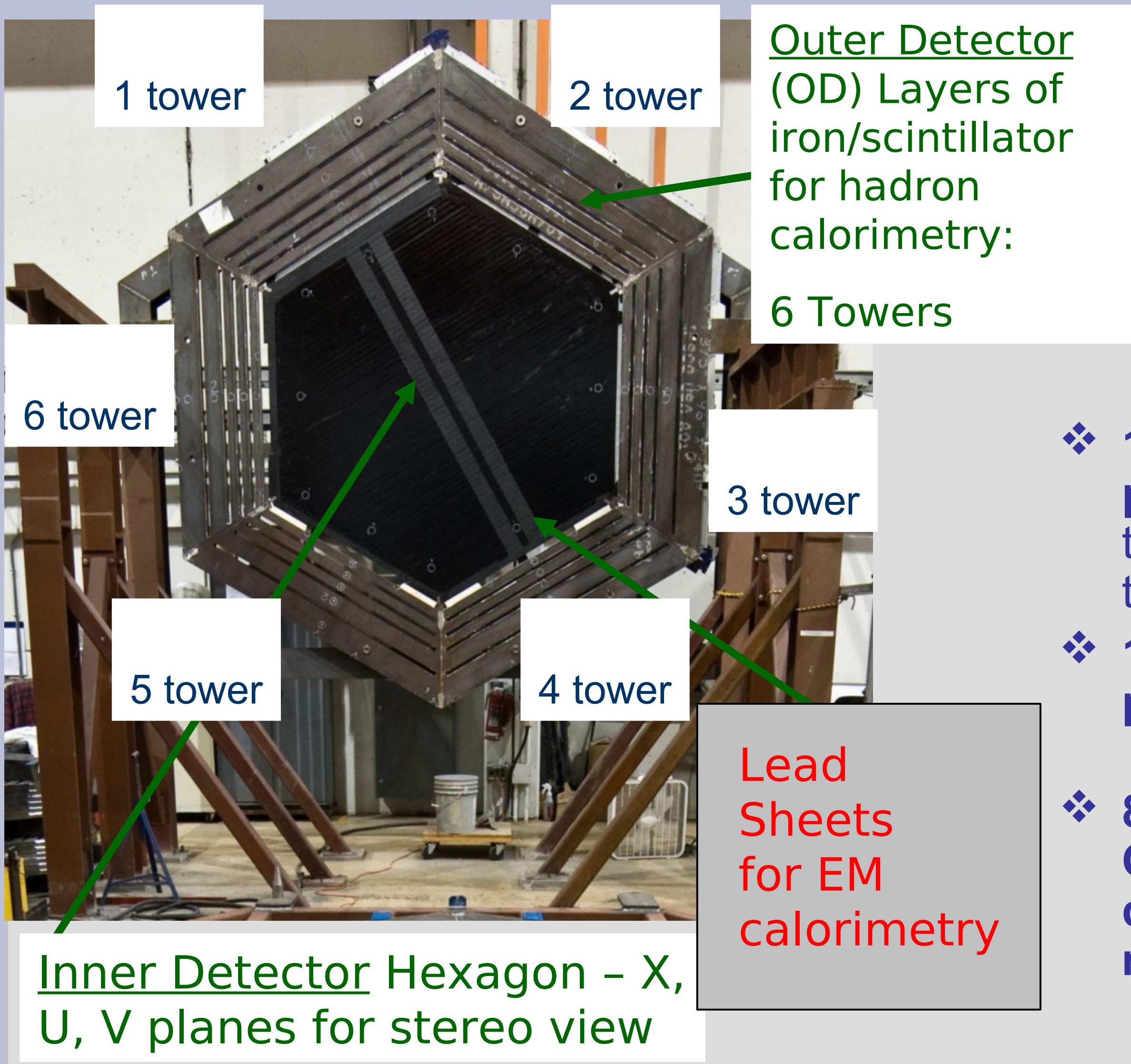
MINOS ND Hall
MINOS
ND
MINERvA



LE
ME
ν/GeV/m²/10⁶protons
Neutrino Energy (GeV)
0
5
10
15
20
50
100
150

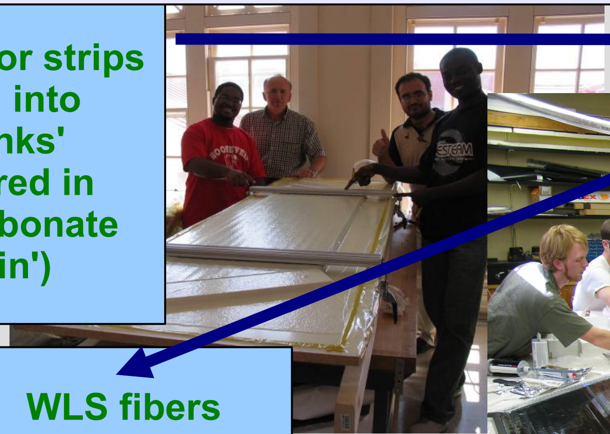
Components of the MINERvA Detector

MINERvA Detector Module



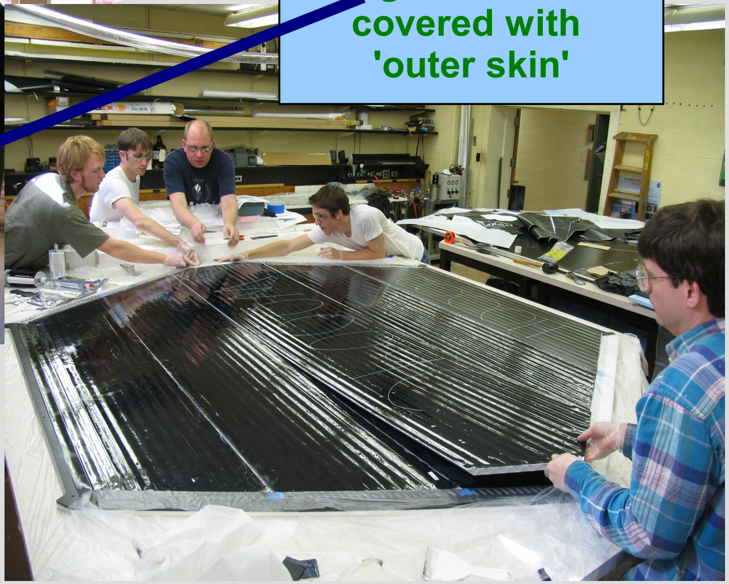
- **~32k channels**
  - 80% in inner hexagon
  - 20% in Outer detector
- **~500 M-64 PMTs** (64 channels)
- **1 wave length shifting fiber per scintillator**, which transitions to a clear fiber and then to the PMT
- **127 pieces of scintillator per Inner Detector plane**
- **8 pieces of scintillator per Outer Detector tower, 6 OD detector towers per module.**

Inner Detector Fabrication (W&M, Hampton U., Fermilab)



Scintillator strips glued into 'planks' (Covered in polycarbonate 'Skin')

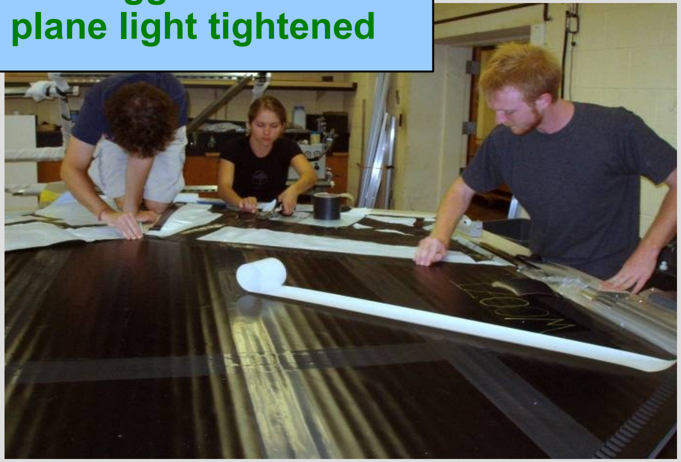
5 Planks assembled into plane, glued and covered with 'outer skin'



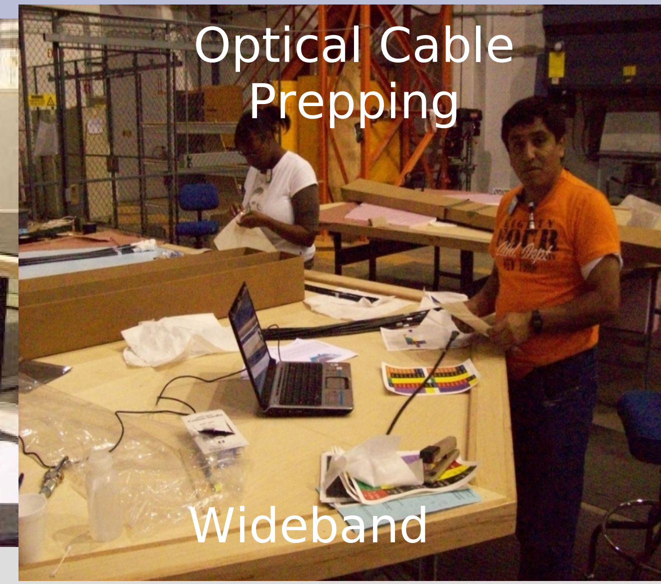
WLS fibers glued Into strips and Routed to optical Connector location

optical Connector Connector glued and then flycut

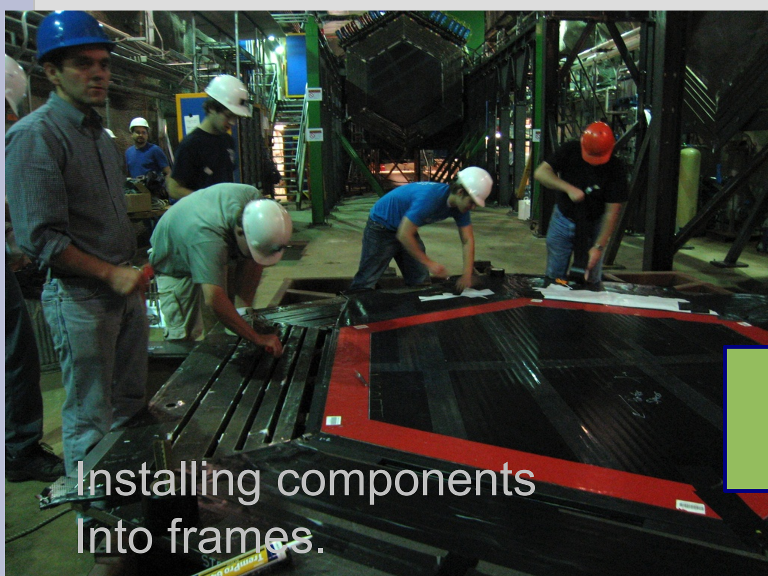
Fiber 'Baggie' sealed and plane light tightened



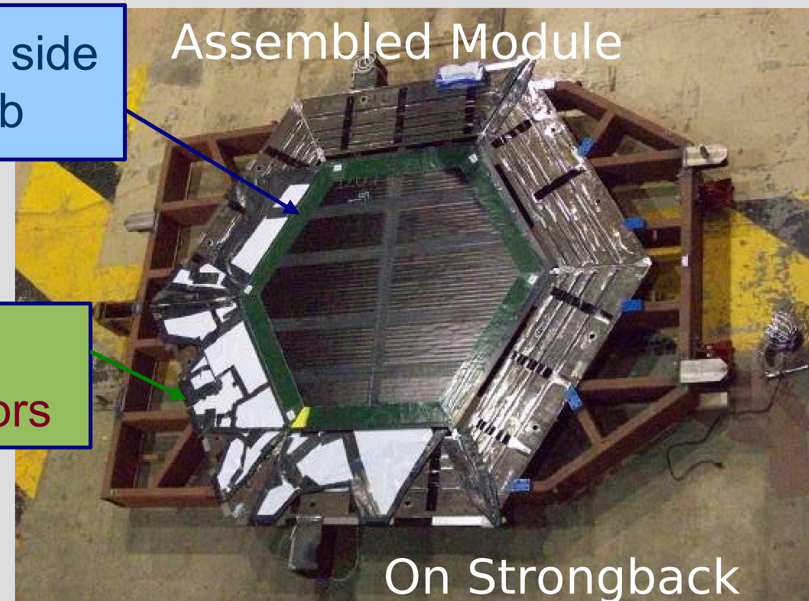
Module Assembly



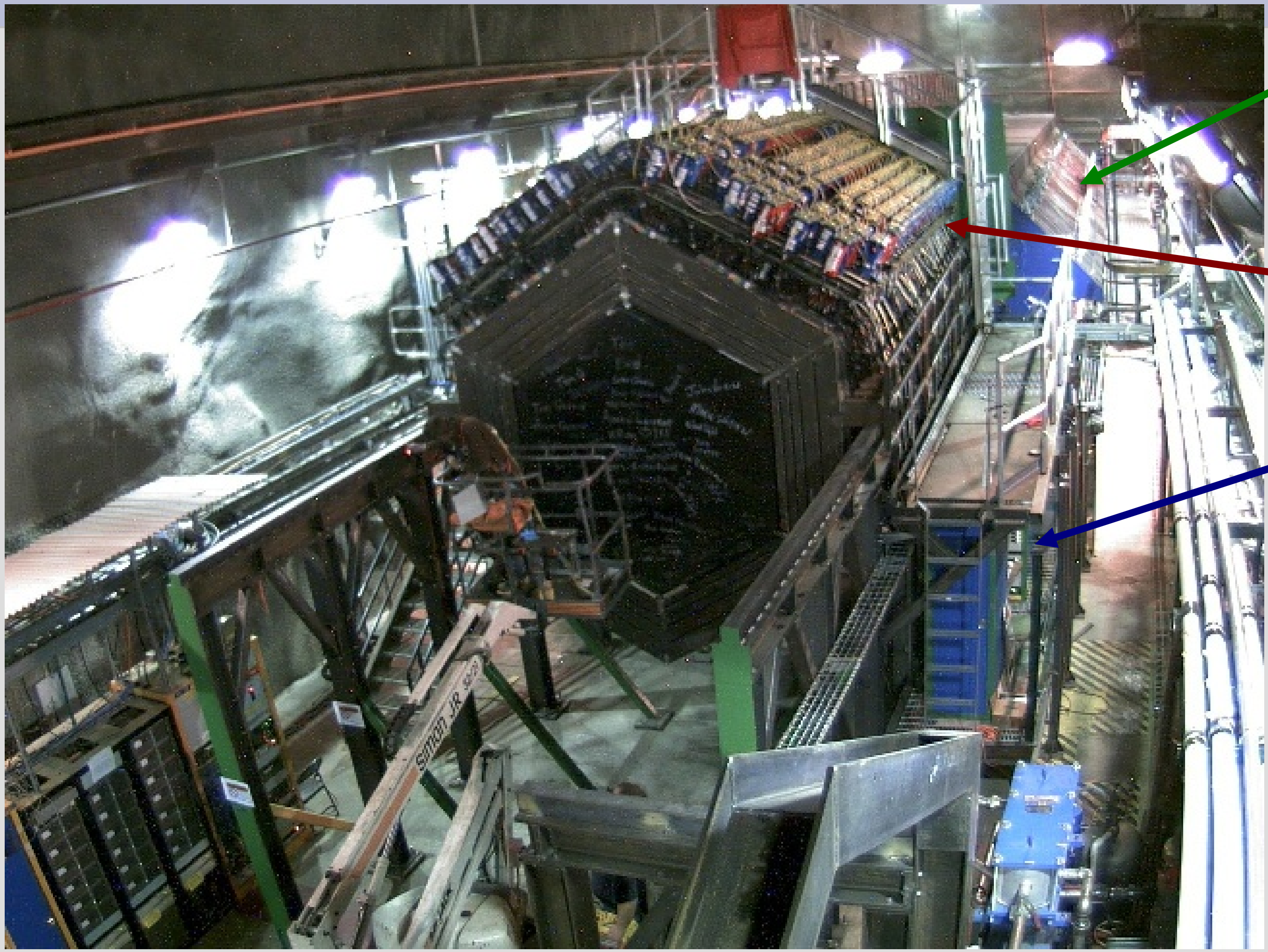
Gluing side
Ecal Pb



Optical
Connectors

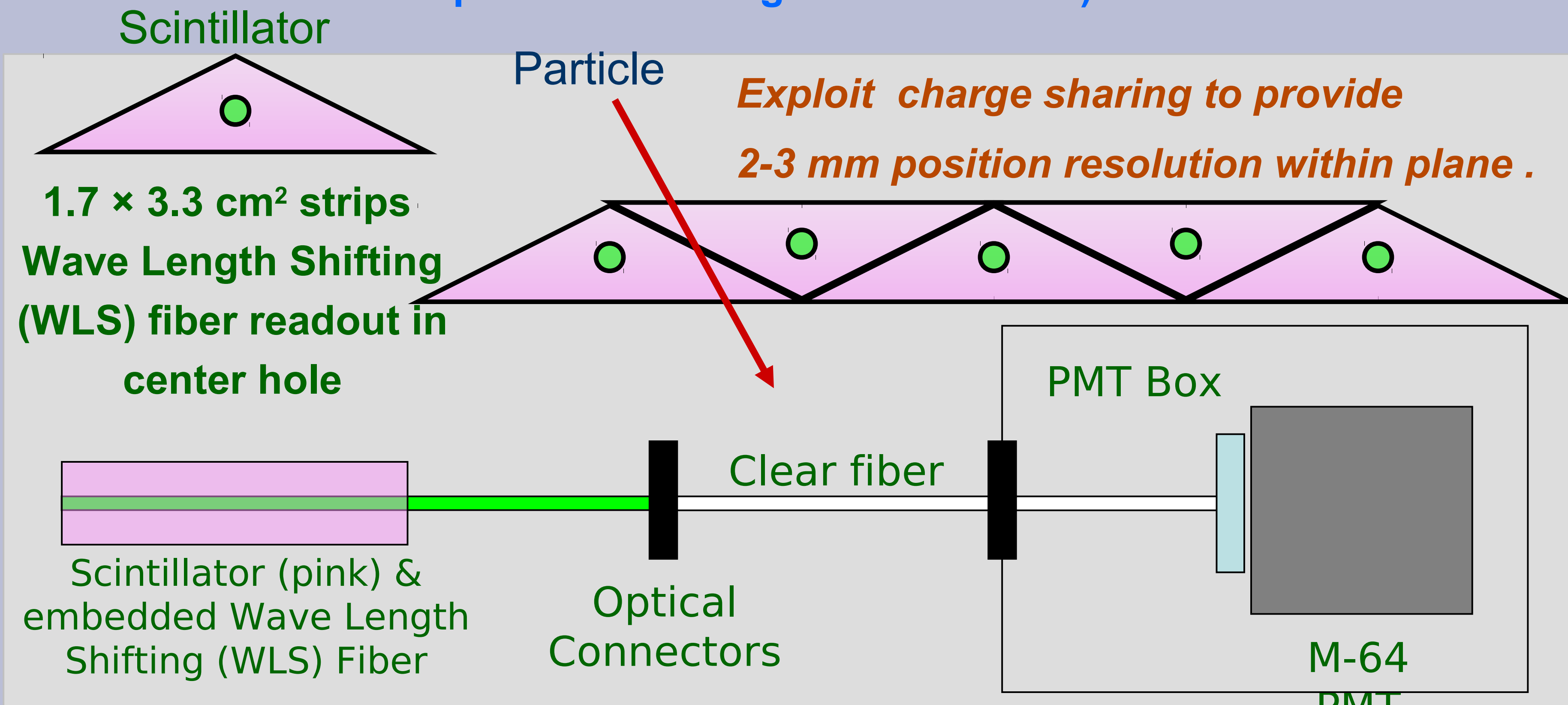


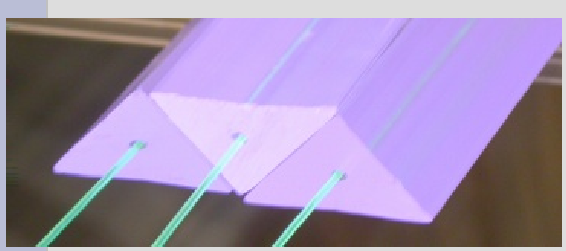
Fully Assembled MINERνA (Sans Cryotarget and Veto Wall)

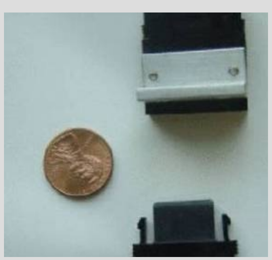


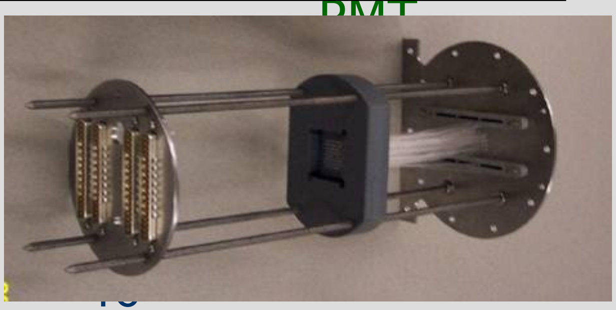
From scintillation to hit position and energy

(Inner detector scintillator and optics shown, Outer Detector has similar optics but rectangular scintillator)









Stages of MINERνA

Frozen Detector (55% of full detector): November 2009 – March 2010

Nov. 2009 – March 2010: Low E anti-ν (~4 GeV average)

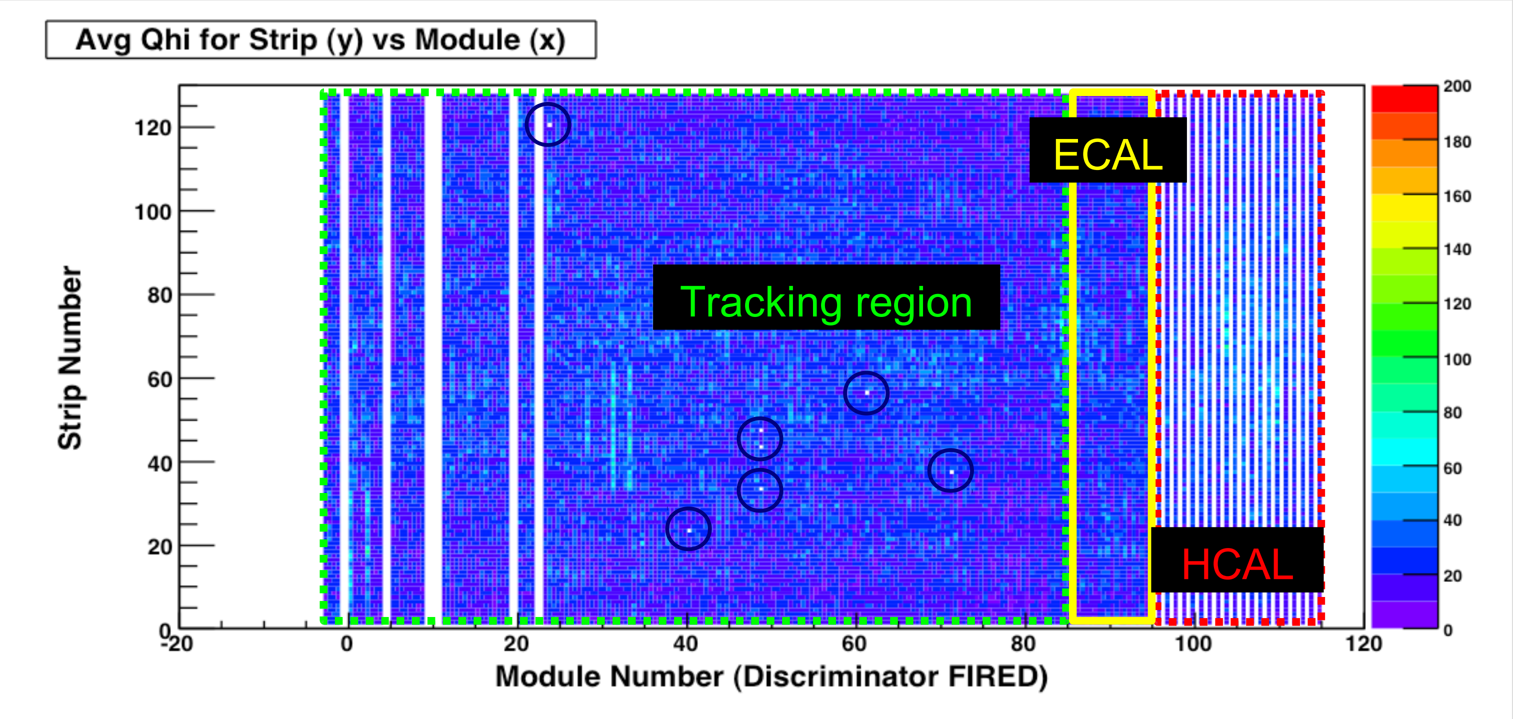
Full Detector:

March 2010 – March 2012: Low E_{ν} (~ 4 GeV average)

Spring 2013 – 2016: Medium E_{ν} (~8 GeV average)

Initial Detector Performance (1)

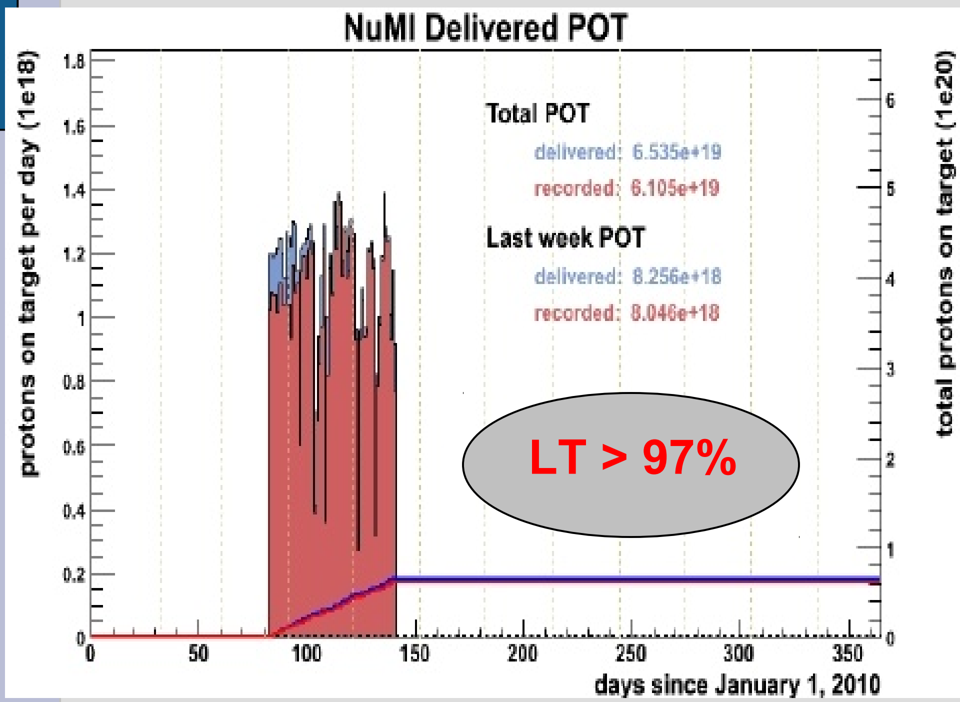
MINERνA detector occupancy plot during beam on



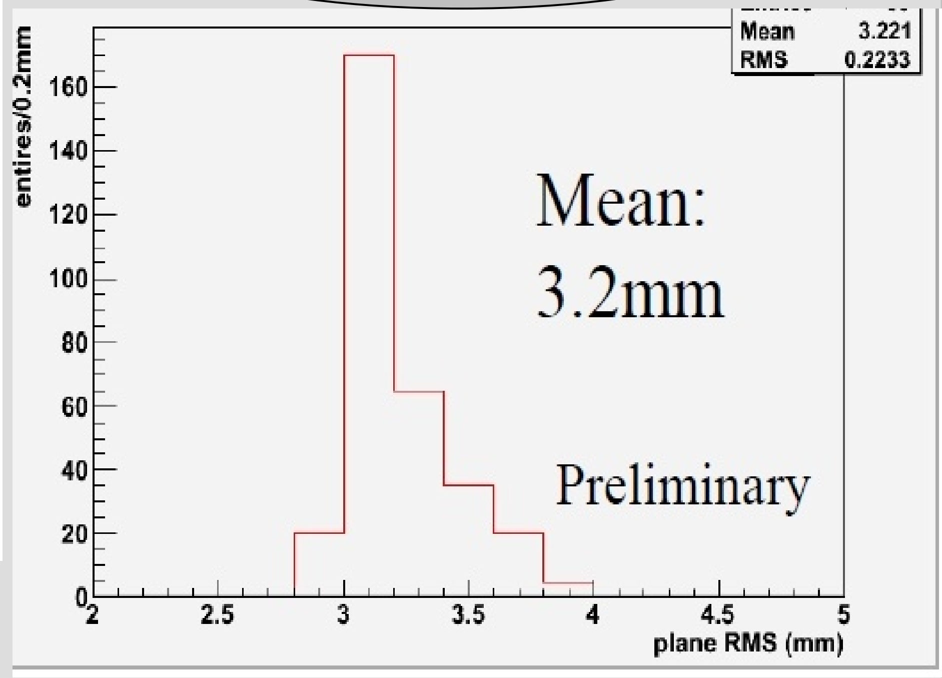
Over 99.9% of channels live!

Initial Detector Performance (2)

Detector availability and Livetime



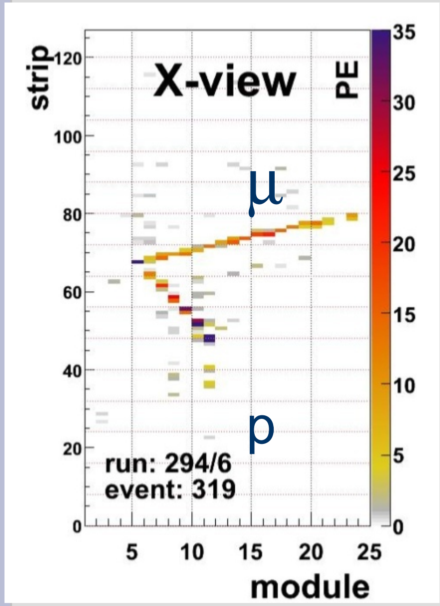
Per plane resolution
From track residuals
~3 mm



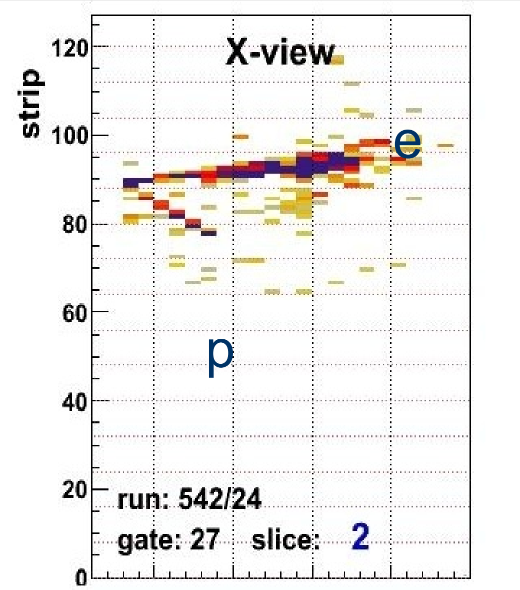
What do real MINERvA event topologies look like?

Sample of **real events** below from tracking prototype in neutrino mode.

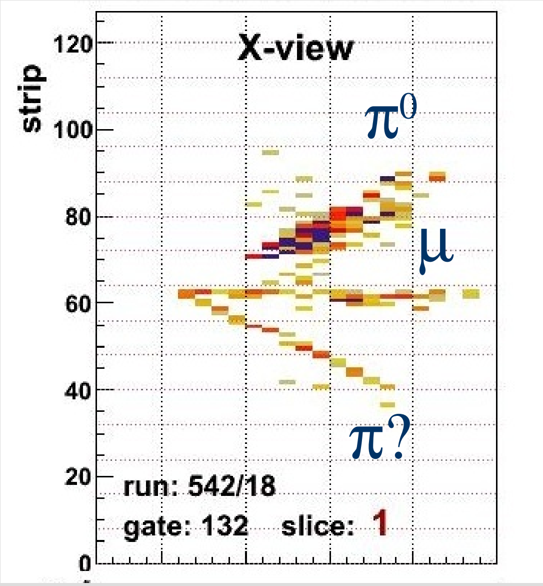
(Candidate process noted below each display)



$\nu_\mu + n \rightarrow \mu^- + p$



$\nu_e + n \rightarrow e^- + p$



$\nu_\mu + n \rightarrow \mu^- + \pi^0 + X$

MINERvA Run Plan Summary

- Low Energy Anti-neutrino beam: November 2009–March 2010.
- Low Energy Neutrino Beam: March 2010 – March 2012, plan for $4x10^{20}$ protons on target.
- Analyze data during long Fermilab accelerator shutdown in 2012.
- Medium Energy Neutrino beam with NOvA after 2012 shutdown: plan for 3 year run, plan for $12x10^{20}$ protons on target.

Kinematic Reconstruction Tools

Scattering / production angles:

Tracking/vertexing utilizing MINERvA segmented scintillator planes

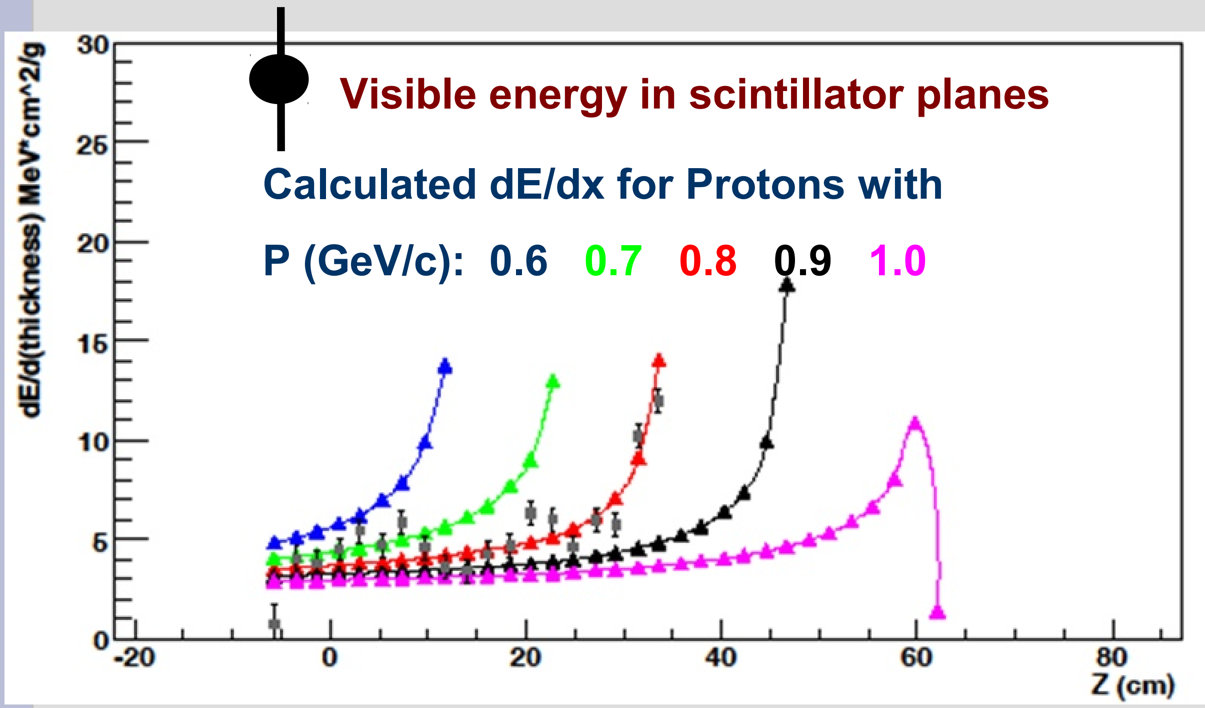
Momentum/energy:

- High energy leptons tracks exiting minerva use momentum reconstructed from MINOS.
- Contained single tracks use fit of dE/dx profile (specifically protons and pions which range out before the HCAL).
- Larger energy hadrons use total energy from HCAL corrected for non-visible energy.
- $e/\gamma/\pi^0$ use ECAL corrected for non-visible energy.

Momentum from dE/dx

We wish to use all the information on energy deposition available to us and not just range or average dE/dx.

=> Fit the entire (visible) energy deposition profile in z to that expected for various momenta and particle mass.

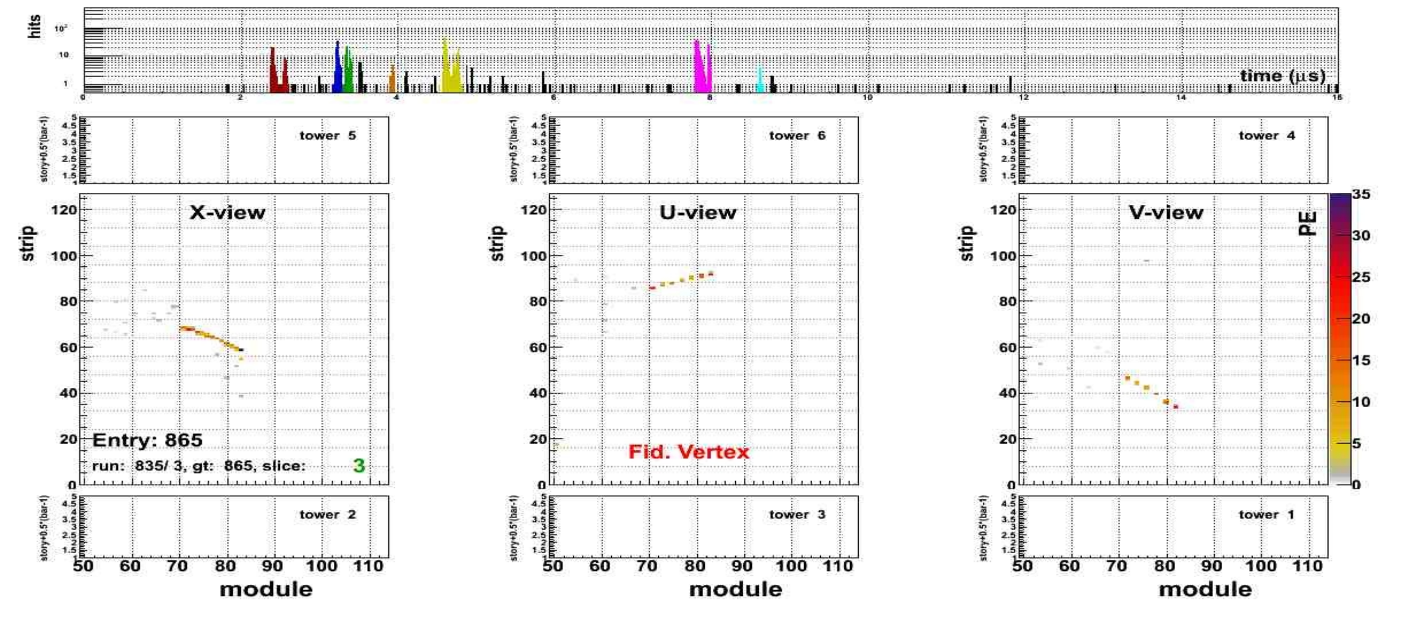


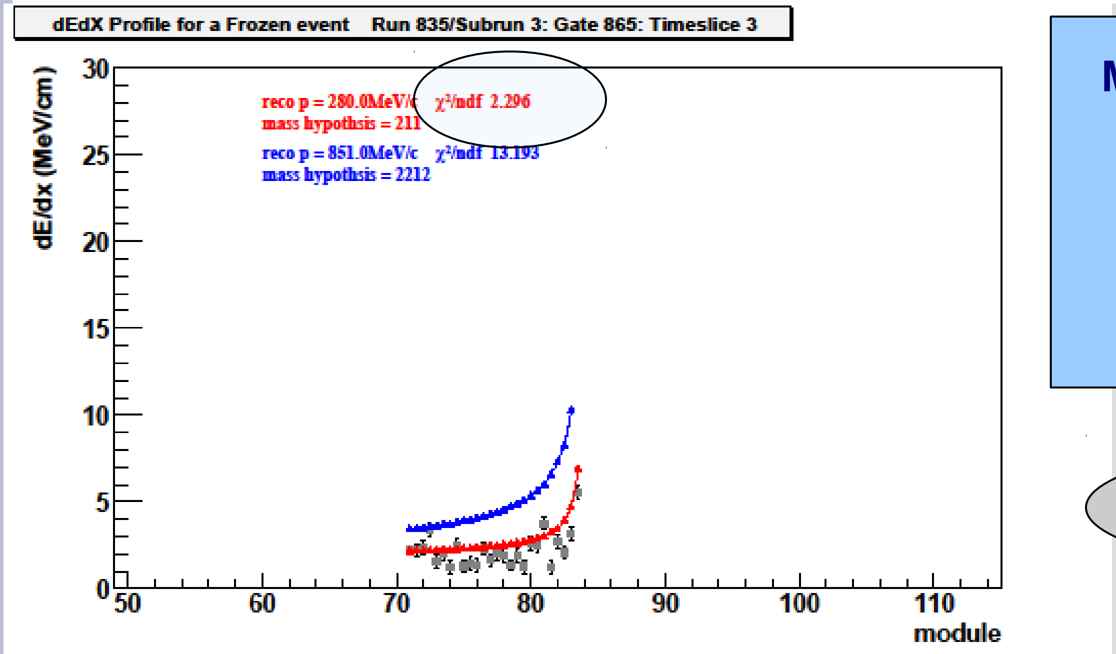
Calculated profiles based on

1. vertex,
2. angle of track
3. material dbase

Best fit profile from χ^2

Candidate π / μ track





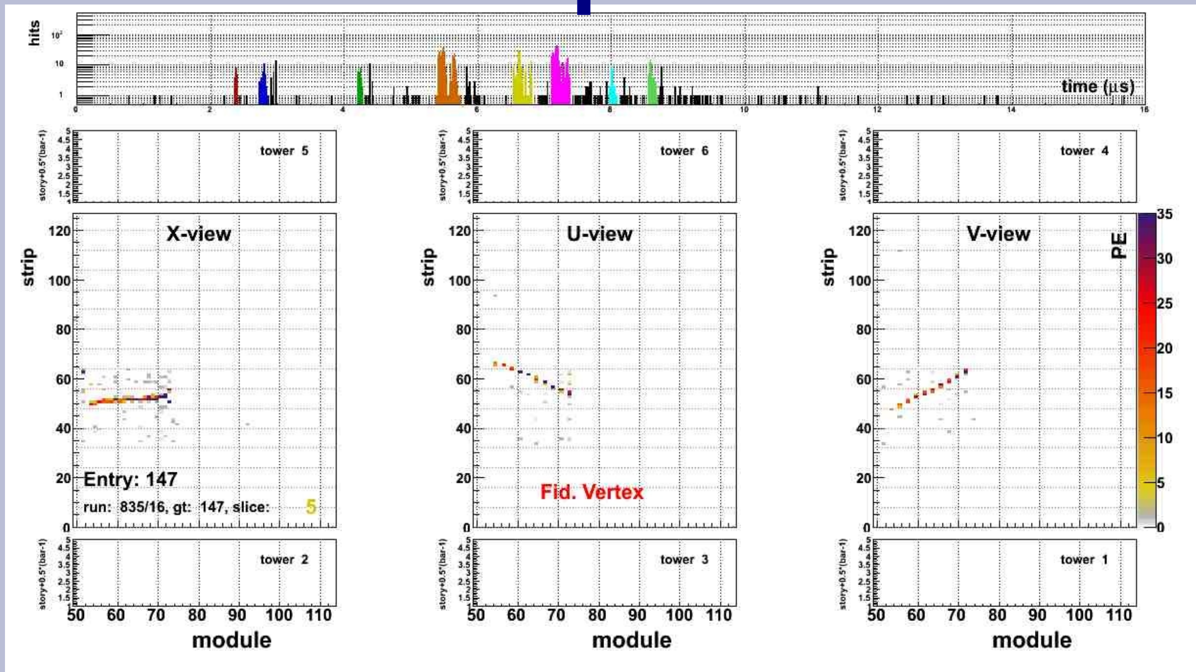
Method allows good determination of the momentum

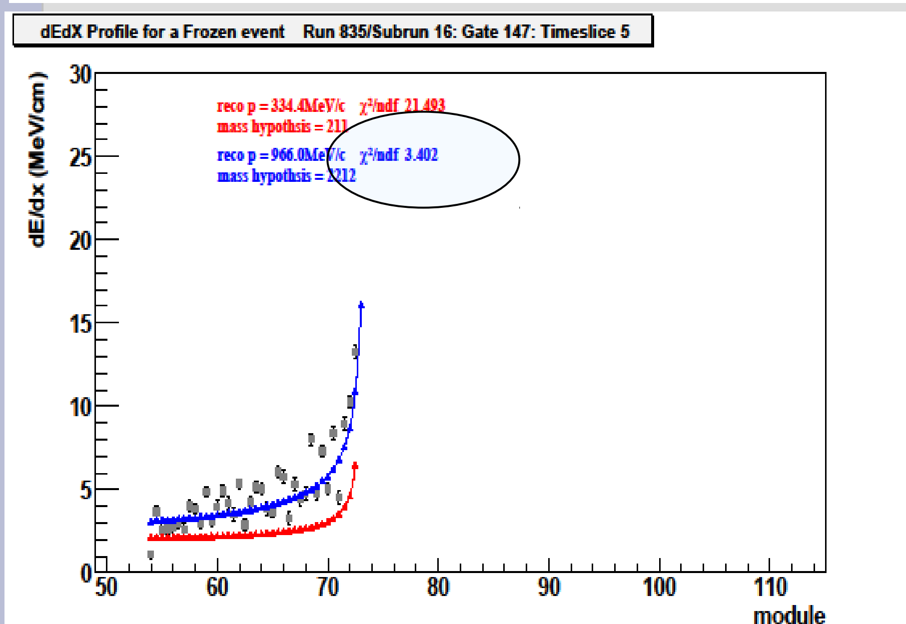
AND

Most probable mass

Monte Carlo indicates effective PID method

Candidate proton track





Expected physics capability of MINERνA

MINERνA Event Rates

14.5 Million total CC events in the current run-plan

7 Million NC events

Run-plan assumes 4.0×10^{20} **in LE and** 12.0×10^{20} **ME NuMI beam configurations**

Main CC Physics Topics (Statistics in CH)

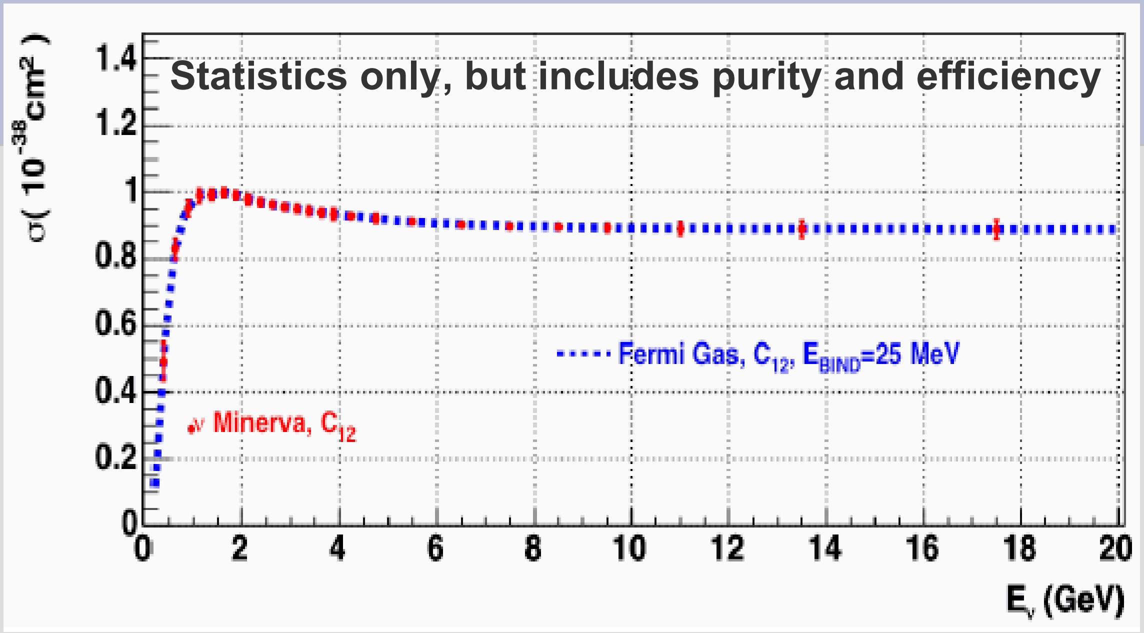
- **Quasi-elastic** **0.8 M events**
- **Resonance Production** **1.7 M total**
- **Transition: Resonance to DIS** **2.1 M events**
- **DIS, Structure Funcs. and high-x PDFs** **4.3 M DIS events**
- **Coherent Pion Production** **89 K CC / 44 K NC**
- **Strange and Charm Particle Production** **> 240 K fully reconstructed events**
- **Generalized Parton Distributions** **order 10 K events**
- **Nuclear Effects** **He: 0.6 M, C: 0.4 M, Fe: 2.0 M and Pb: 2.5 M**

Quasi-elastic in MINERνA

Recent nuclear target
Indicate axial radius larger than from ν-d, Fermi decay, and Threshold electroproduction
M_A~1.05

K2K SciFi (16O, Q^2>0.2)
Phys. Rev. D74, 052002 (2006)
M_A=1.20 ± 0.12 GeV

- **K2K SciBar (12C, Q^2>0.2)**
  AIP Conf. Proc. 967, 117 (2007)
  M_A=1.14 ± 0.11 GeV
- **MiniBooNE (12C, Q^2>0)**
  paper in preparation
  M_A=1.35 ± 0.17 GeV
- **MINOS (Fe, Q^2>0.3)**
  NuInt09, preliminary
  M_A=1.26 ± 0.17 GeV



Given what we know from measuring 'nucleon' form factors In e-A scatting, perhaps this shouldn't be too surprising.

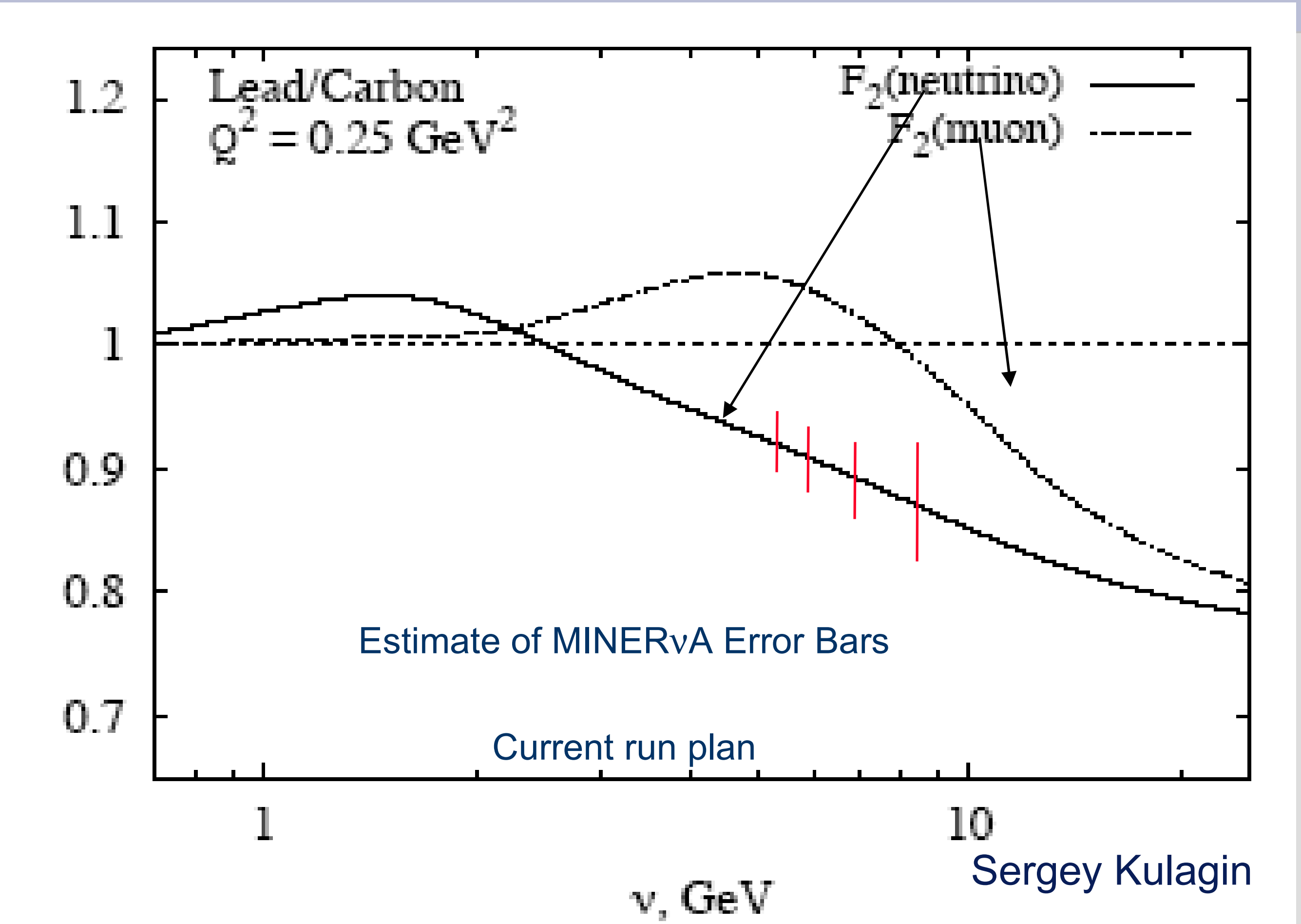
MINERνA will measure CC / NC

- $d\sigma/dQ^2$ and
- Total cross sections for

4 < A < 208

MINERνA Measurement of Nuclear Effects

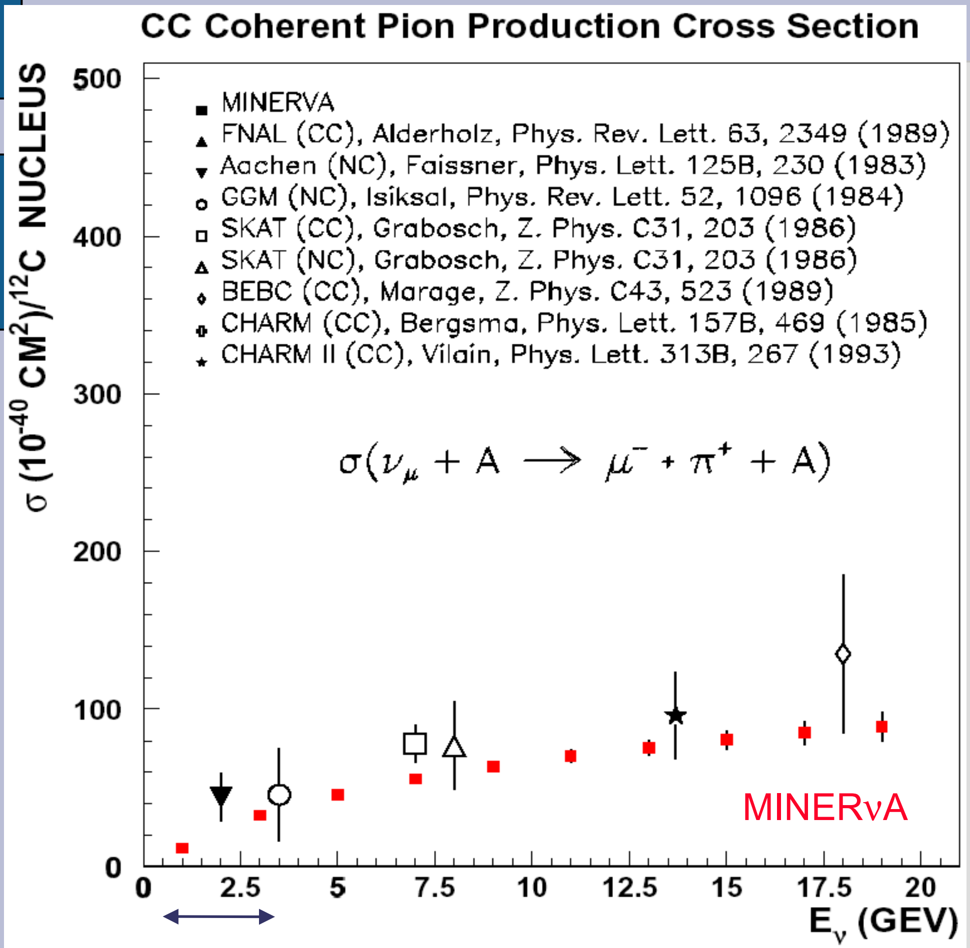
The Axial-vector Current and Shadowing in DIS

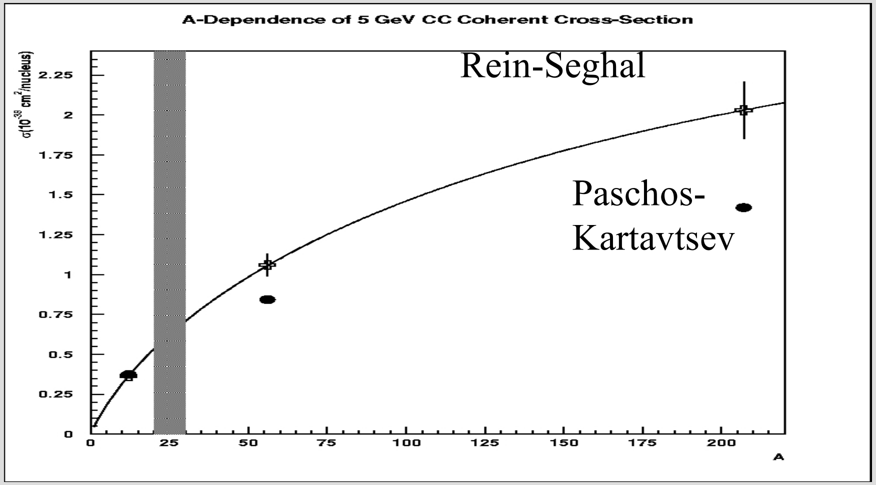


MINERνA data Could allow first Observation of differences due to probe.

Coherent Pion Production

ν + A --> ν /μ⁻ + A + π





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

- ✔ Estimate **85 K CC / 37 K NC** events produced
- ✔ Test nuclear models

Region where NEUGEN event generator overestimates the cross sections

Summary

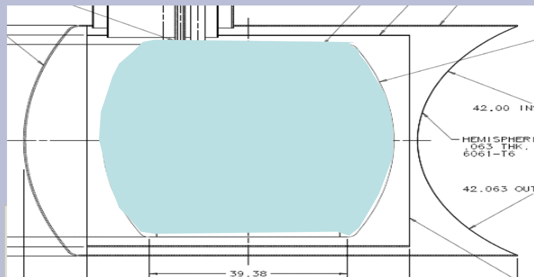
- MINERvA will measure **ν-A** cross sections to unprecedented precision
- This will allow studies complementary to **e-A** scattering such as:

DIS structure functions, Elastic form factors, resonance production, duality studies, and more.

- *Data taking in progress.... Stayed tuned!*

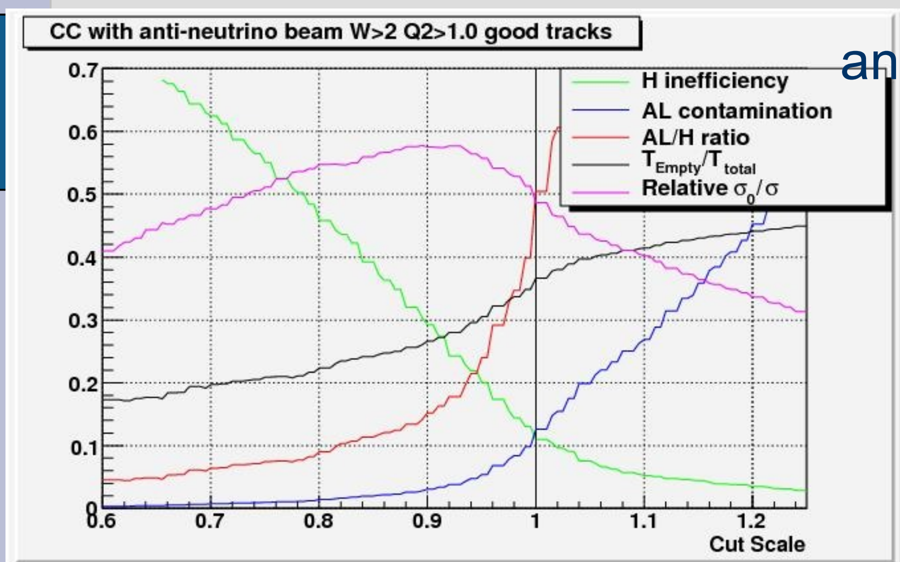
Backup Slides

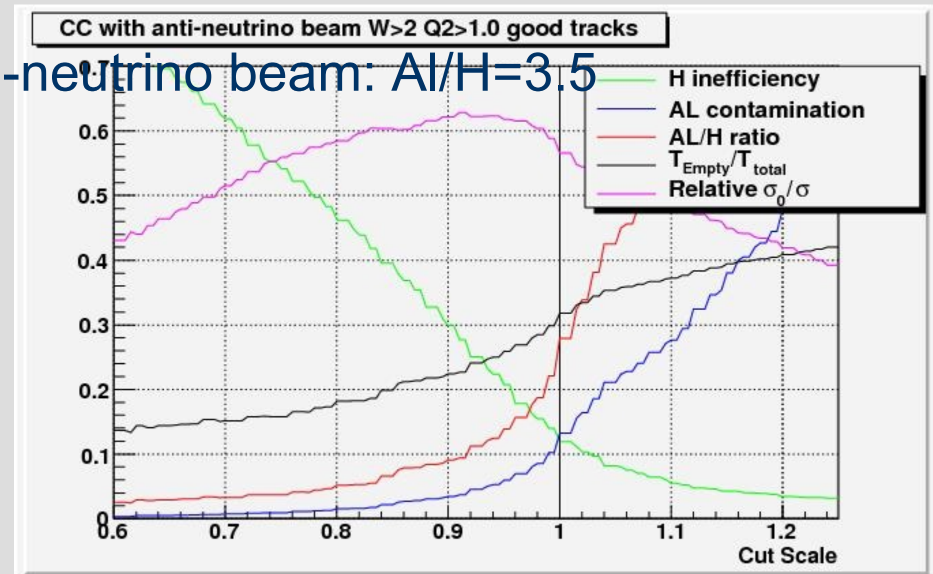
Empty Taret Background

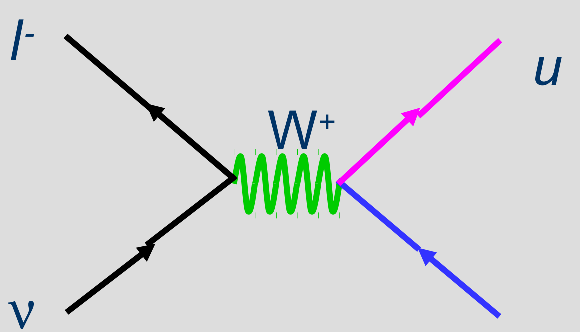


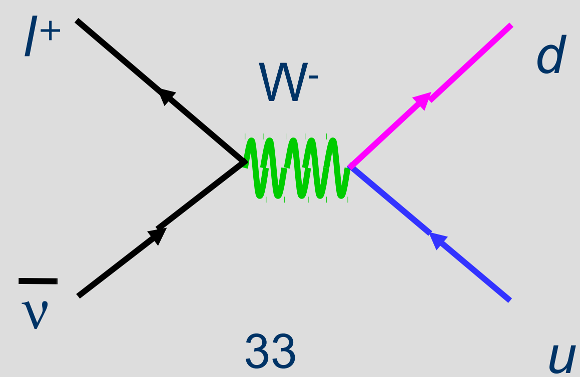
neutrino beam: Al/H=6.7

anti-neutrino beam: Al/H=3.5

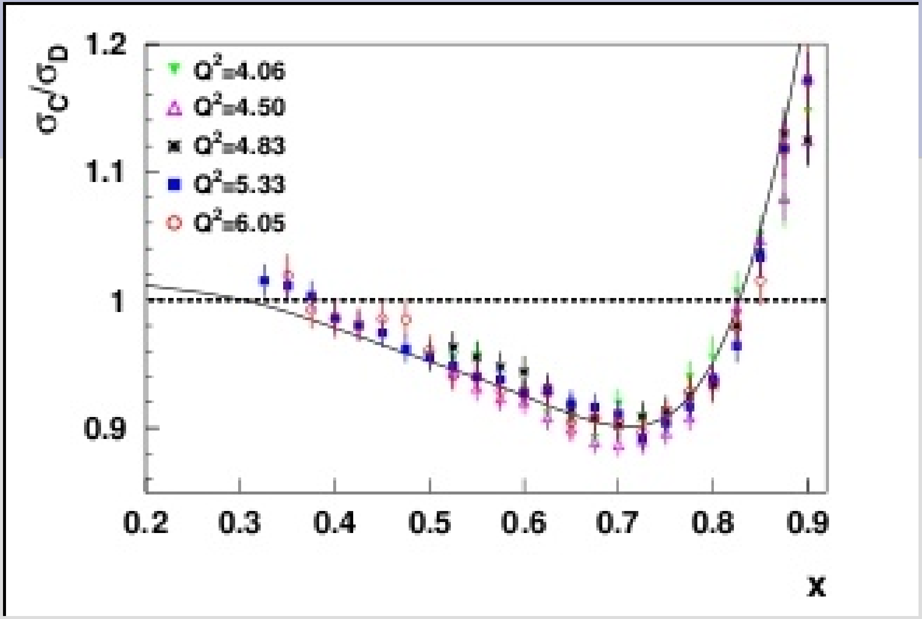


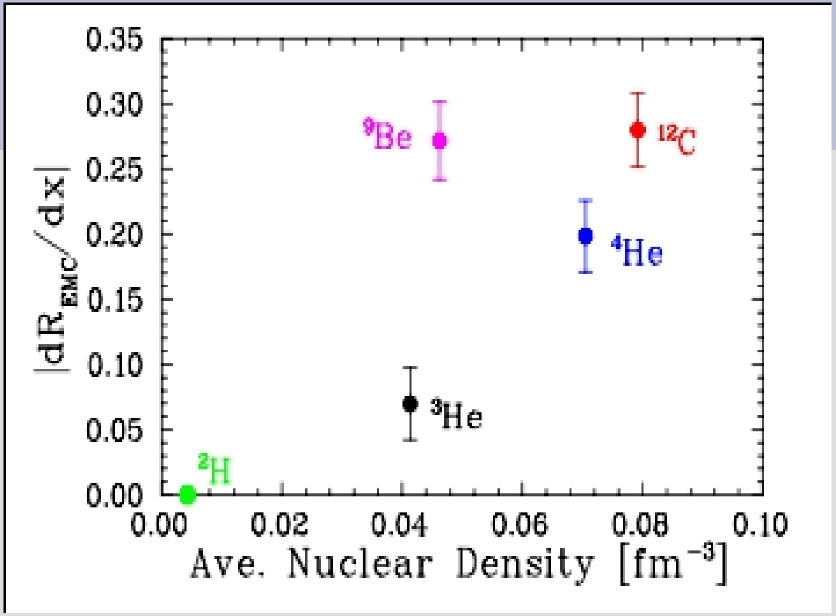






New Jlab results on EMC effect in light Nuclei





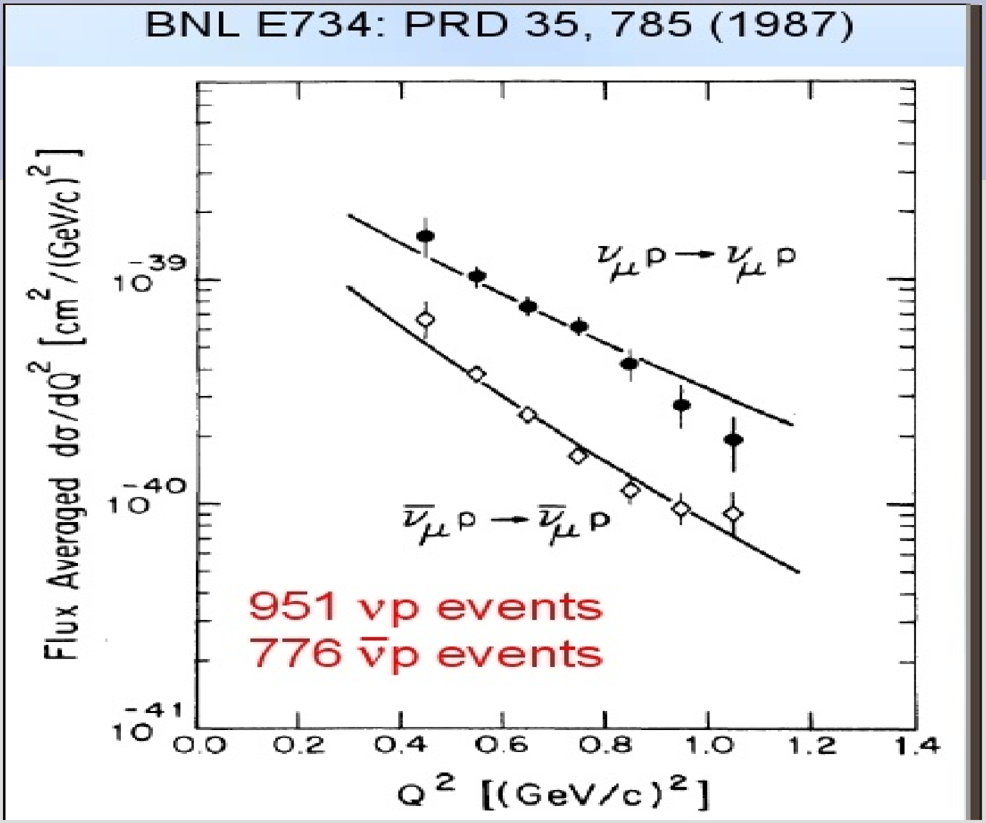
- Data show no simple scaling with average nuclear density for light nuclei
- ^{9}Be and ^{3}He have similar average densities but very different EMC ratios.

=> Correcting from nucleus to nucleon using nuclear density questionable

Neutral Current Quasi-elastic

Current World data set from

BNL E734



The follow ratios can be used to isolate form factors with reduced systematics.

$$R_\nu = \frac{\langle\sigma\rangle_{(\nu p\to\nu p)}}{\langle\sigma\rangle_{(\nu n\to\mu^- p)}} = 0.153 \pm 0.007 \pm 0.017$$

$$R_{\bar{\nu}} = \frac{\langle\sigma\rangle_{(\bar{\nu} p\to\bar{\nu} p)}}{\langle\sigma\rangle_{(\bar{\nu} p\to\mu^+ n)}} = 0.218 \pm 0.012 \pm 0.023$$

$$R = \frac{\langle\sigma\rangle_{(\bar{\nu} p\to\bar{\nu} p)}}{\langle\sigma\rangle_{(\nu p\to\nu p)}} = 0.302 \pm 0.019 \pm 0.037 ,$$

where $\langle\sigma\rangle_{\nu(\bar{\nu})}$ is a total cross section integrated over the incident neutrino (antineutrino) energy and weighted by the $\nu(\bar{\nu})$ flux. The first error is statistical and the second is the systematic one.

Requires neutron target (Deuterium)

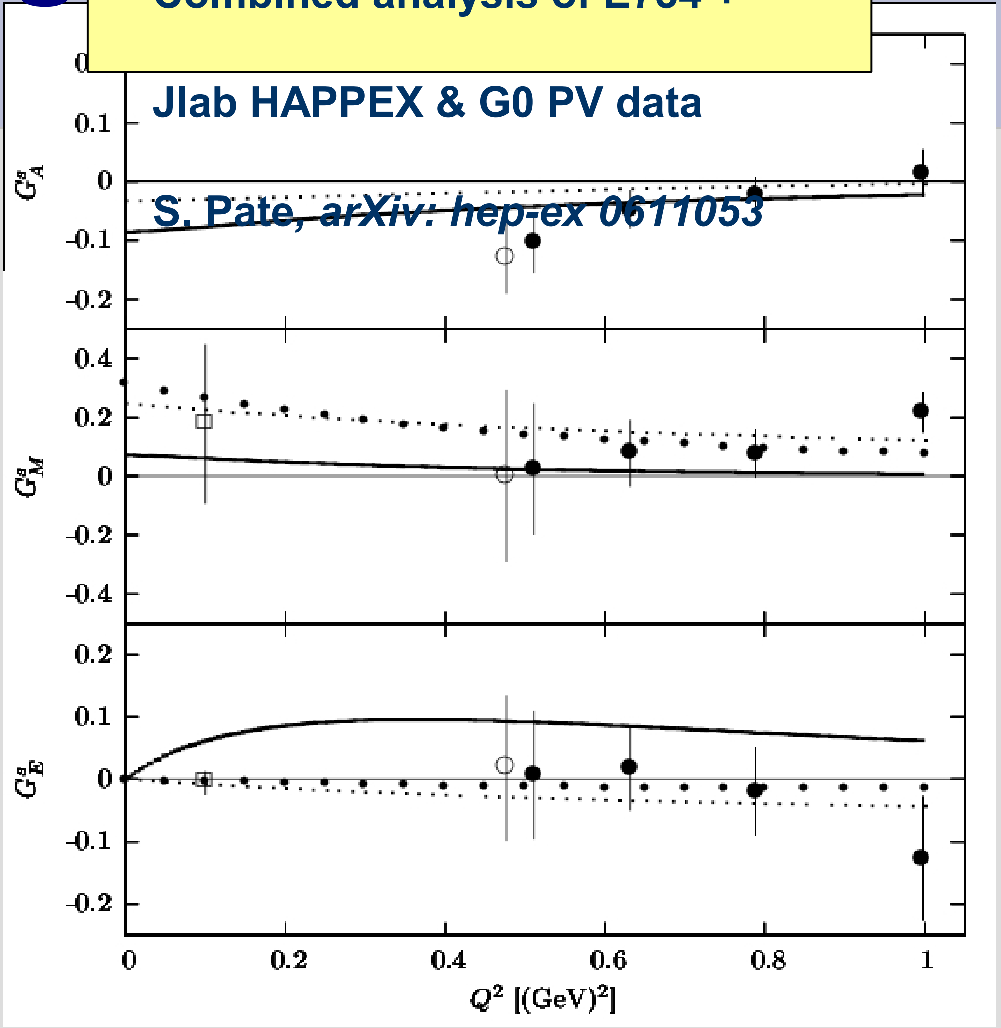
Systematic uncertainty is dominated by flux

ν−p elastic sensitive to strangeness

Combined analysis of E734 +

Jlab HAPPEX & G0 PV data

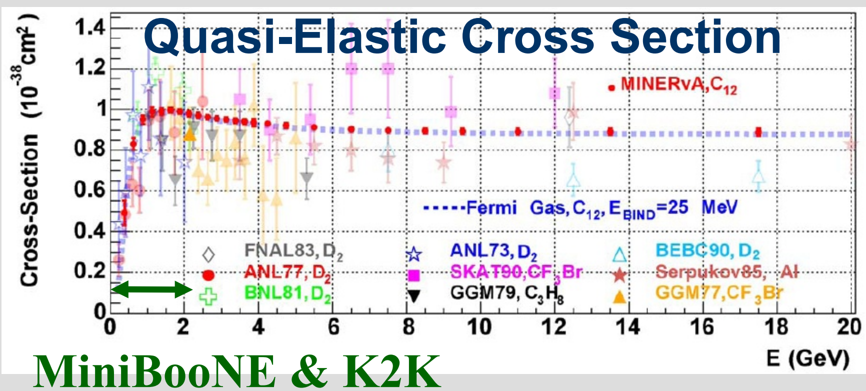
S. Pate, *arXiv: hep-ex 0611053*



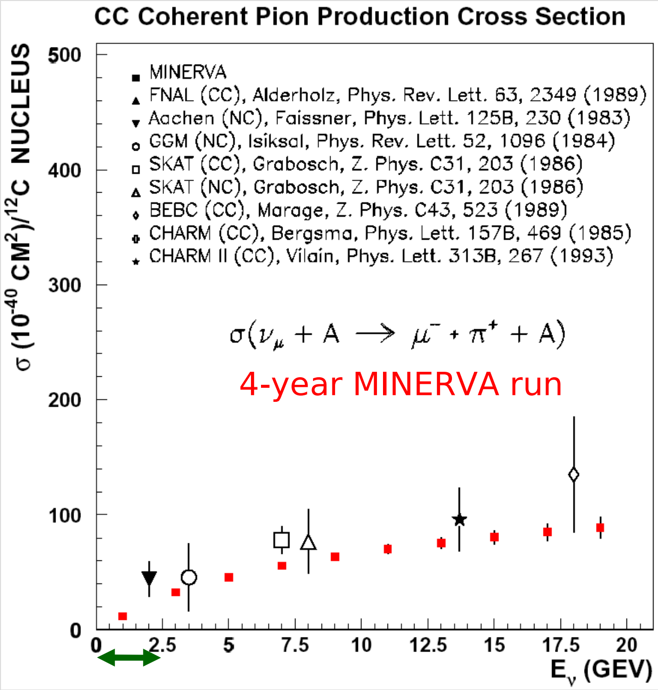
- Combining e-p parity violating elastic measurements with ν−p elastic measurements allows extraction of strange axial form factors.
- Uncertainties are dominated by E734 systematics.

MINERvA and Cross Section Measurements (examples)

- Quasi-elastic Cross Section
  - First precise measurements at high Q^2 of proton axial form factor
  - First study in nuclear modification of form factors conjectured at low Q^2
- Coherent π production Cross Section
  - Overwhelming statistics (> 100 increase)
  - Wide energy range
  - Range of nuclear targets (C, Fe, Pb, H_2O, He)
  - MINERvA is in a position to measure this important background for ν_e appearance and to check recent surprising K2K null result



MiniBooNE & K2K measurements



MiniBooNe & K2K