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The MINERνA Experiment

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MINERνA

Main INjector ExpeRiment ν–A*

MINERνA is a compact, fully active neutrino detector designed to study neutrino-nucleus interactions with unprecedented detail.

The detector will be placed in the NuMI beam line, in front of the MINOS near detector.

*Minerva, pictured above, was the Roman goddess of wisdom and technical skill.

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The MINERνA Collaboration

A collaboration of high energy and nuclear experimental groups and theorists from:

Fermilab – **J. Morfin, co-spokesperson**

Rochester – **K. McFarland, co-spokesperson**

Athens, UC-Irvine, Dortmund, Hampton, Ill. Inst. Tech, James Madison, N. Illinois, JLab, JLab, Moscow, Pittsburgh, Rutgers, St. Xavier, Tufts, William & Mary

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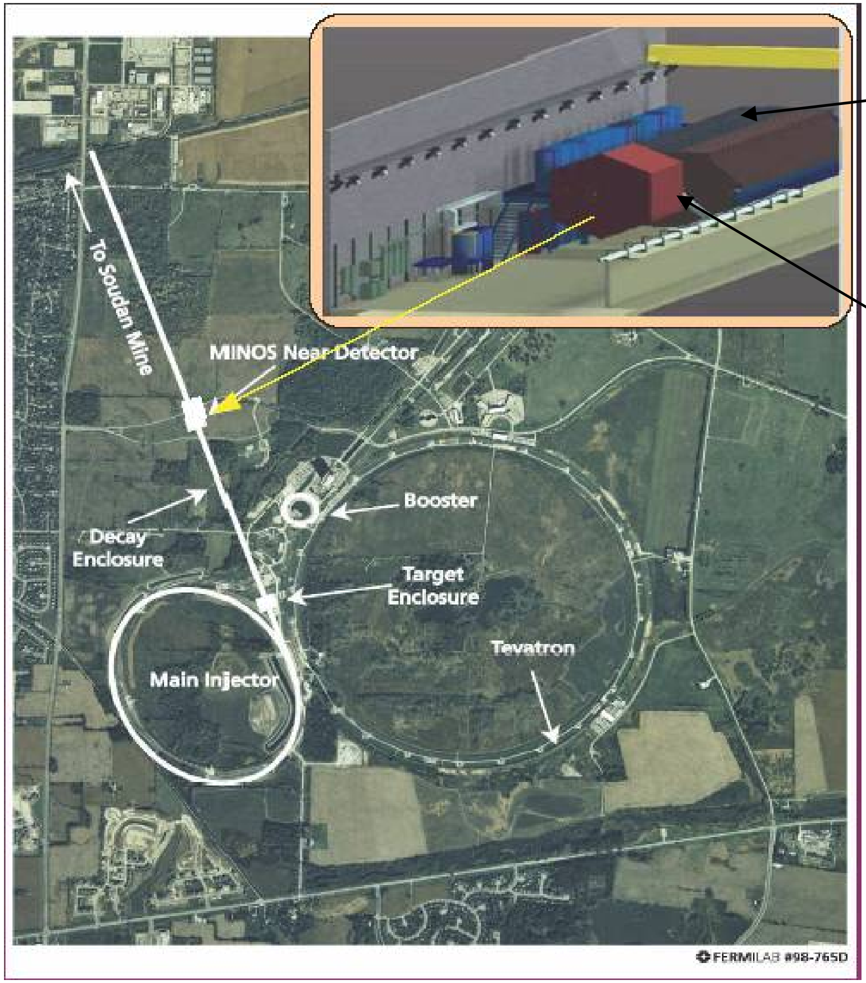
NuMI Beam Line



MINOS

MINERvA

Neutrinos at Main Injector (NuMI) beam line will provide high intensity neutrino beams primarily for oscillation experiments

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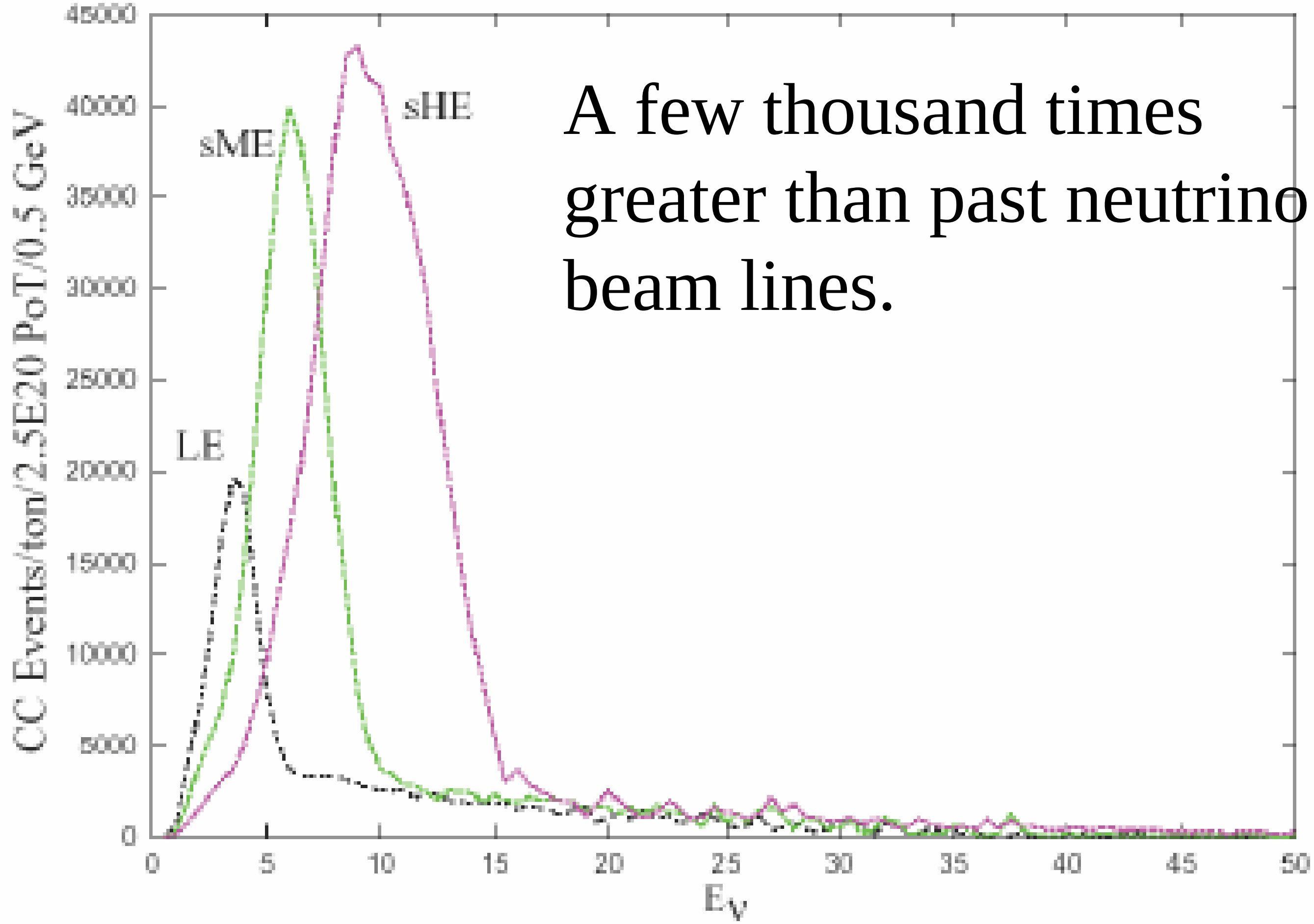
NuMI Neutrino Flux



A few thousand times greater than past neutrino beam lines.

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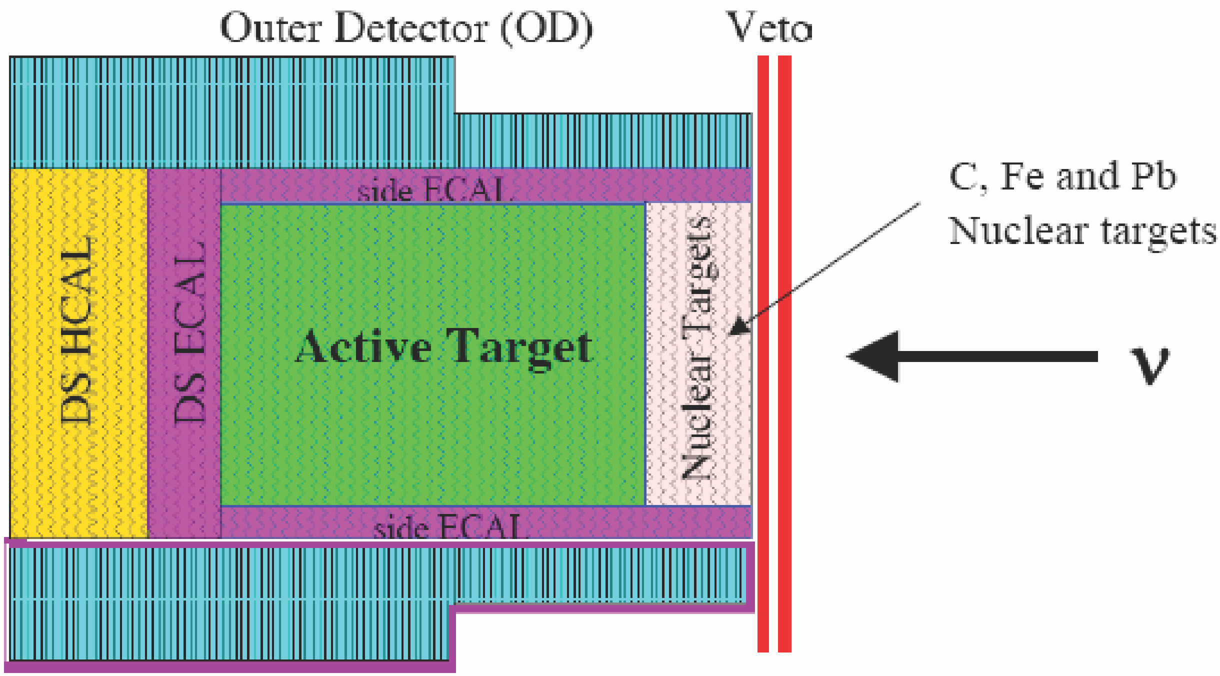
The MINERνA Detector

Length is about 4 m.



- Active target of scintillator bars (6t total, 3 - 5 t fiducial) - M64PMT
- Surrounded by calorimeters
  - upstream calorimeters are Pb, Fe targets (~1t each)
  - magnetized side and downstream tracker/calorimeter

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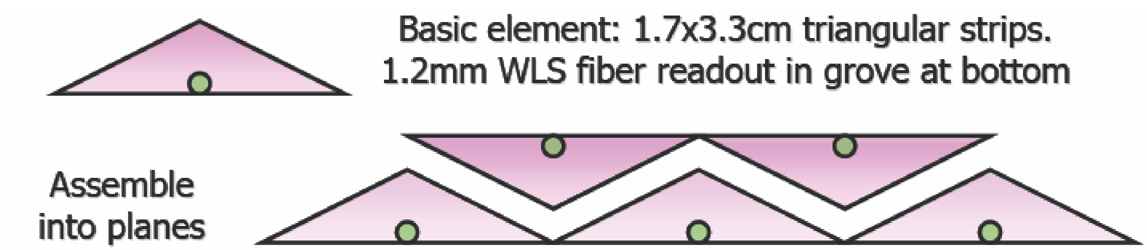
Active Scintillator Target

Triangular scintillators are arranged into planes – Wave length shifting fiber is read out by Mulit-Anode PMT



(Picture from an is an earlier design – fiber is now in center)

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Vertical Slice Test

Prototype readout board built (FNAL, Pittsburgh) and successfully tested summer 2004.

Noise level using MINOS M64 PMT, looks good (less than 2 fC, required level < 3 fC).

A major milestone! With over 37,000 channels and modest data rate, noise is a major concern.

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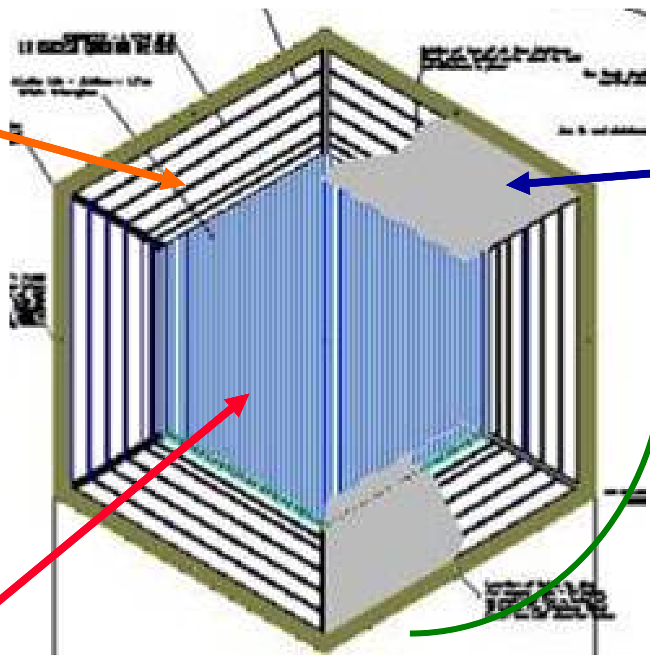
Front View of Detector

Layers of iron/scintillator for hadron calorimetry

Lead Sheets for EM calorimetry



Toroidal magnetic field

Inner Detector – X, U, V planes for stereo view

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Rates

Assume $9x10^{20}$ POT: MINOS chooses $7.0x10^{20}$ in LE ν beam, $1.2x10^{20}$ in sME and $0.8x10^{20}$ in sHE

ν_μ Event Rates per fiducial ton

Process	CC	NC
Quasi-elastic	103 K	42 K
Resonance	196 K	70 K
Transition	210 K	65 K
DIS	420 K	125 K
Coherent	8.4 K	4.2 K
TOTAL	**940 K**	**305 K**

Typical Fiducial Volume =
3-5 tons CH, 0.6 ton C, ≈ 1 ton Fe and ≈ 1 ton Pb

3 - 4.5 M events in CH
0.5 M events in C
1 M events in Fe
1 M events in Pb

Expect ~ 5 million CC events in 4 year run

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Physics of MINERνA

MINERνA will provide information helpful to oscillation experiments and study a number of physics topics interesting in their own right.

- Determination of Axial Form Factor
- Duality with Neutrinos
- Nuclear Effects (Shadowing)
- Coherent Pion Production
- GPD’s (maybe)

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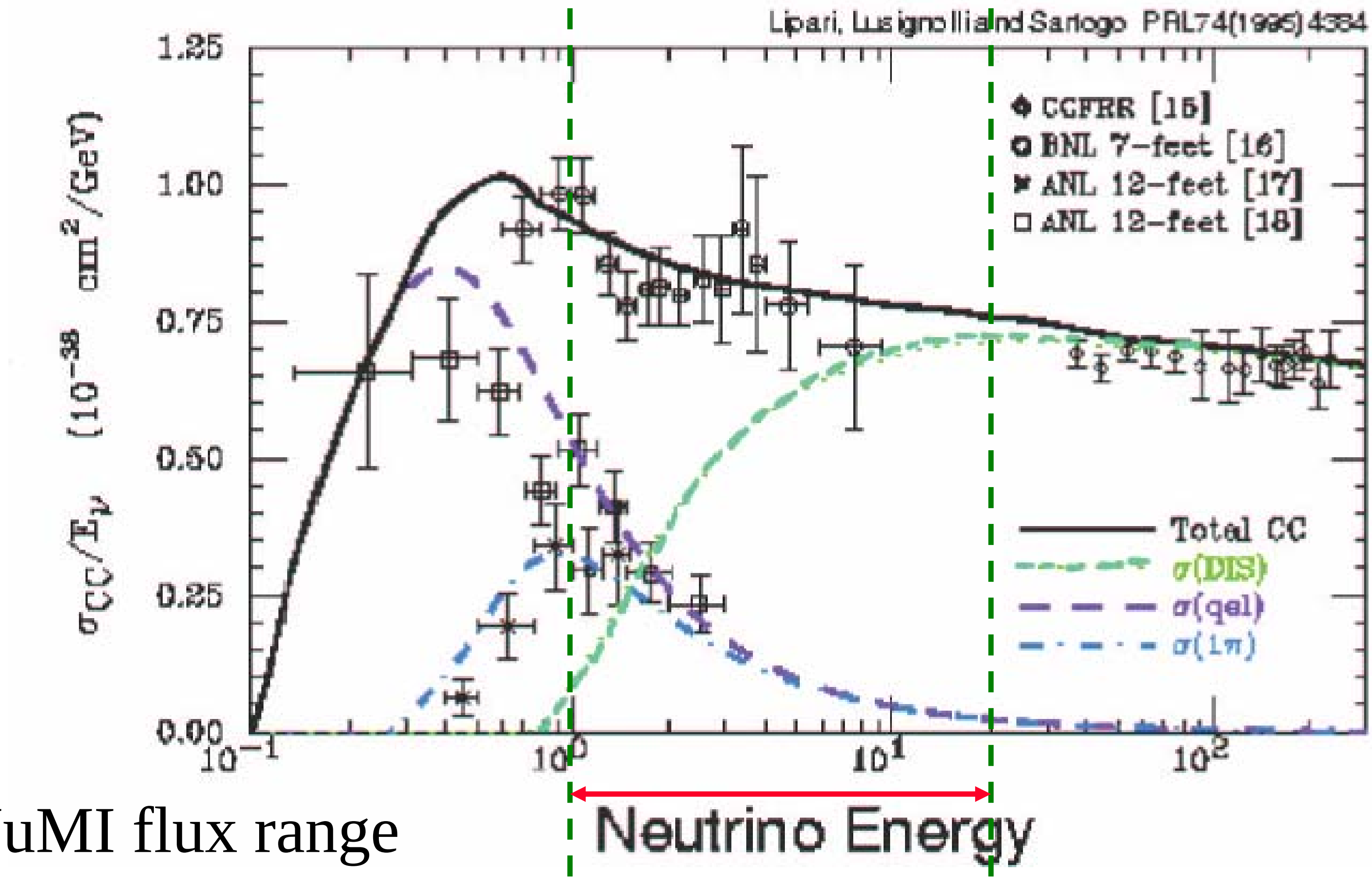
Neutrino-Nucleon Cross section



NuMI flux range

1-20 GeV

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Axial Form Factor

CC cross section ~ $c_1 G_E^2 + c_2 G_M^2 + c_3 G_A^2$

Where c's are constants depending on kinematics

For both protons and neutrons, the axial form factor contributes about half the cross section

This is in sharp contrast to electron scattering, where the axial form factor is measured through parity violation

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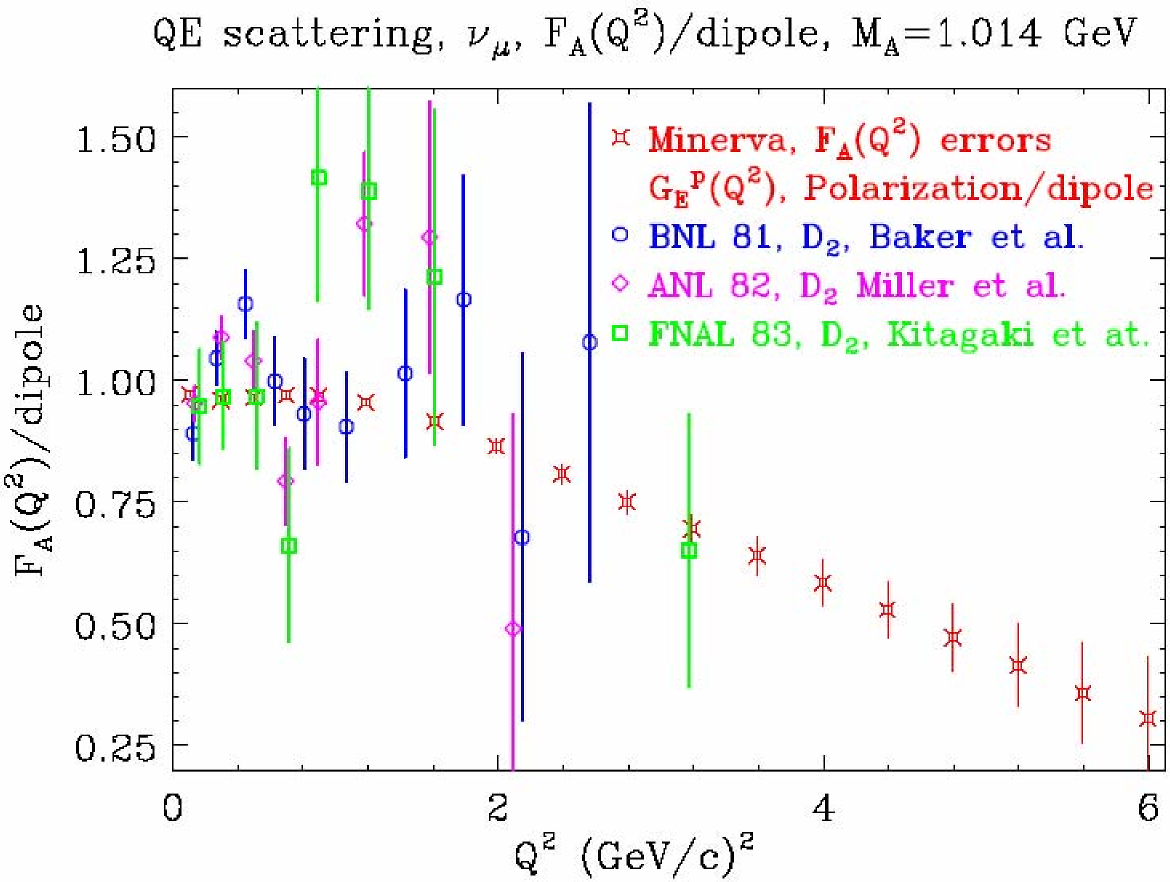
Anticipated Axial FF



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Duality

Inclusive electron scattering is a function of two form factors.

Inclusive cross section (electron scattering)

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2 \sin^4 \frac{\theta}{2}} \left(\frac{2F_1}{M} \sin^2 \frac{\theta}{2} + \frac{F_2}{\nu} \cos^2 \frac{\theta}{2} \right)$$

For DIS, form factors are related to each other and depend only on the scaling variable *x*, (they are independent of Q^2). This is evidence that the DIS process is due to scattering off point-like spin ½ particles.

Neither of these aspects is expected to be true in the resonance region.

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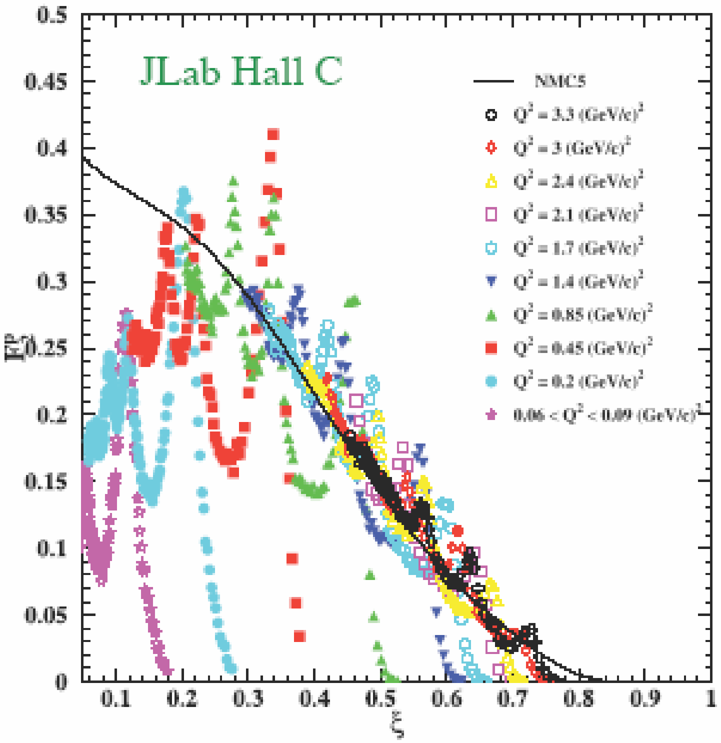
Duality

Quark-hadron duality

Oddly enough though, the structure function measured in the resonance region "averages" to the DIS measurement (black line)



Niculescu et al., Phys. Rev. Lett. 85 (2000) 1182

$$\xi = 2x/(1+\sqrt{1+4M^2x^2/Q^2})$$

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Duality

- Origins of duality not well understood
- MINERvA should be able to do measurements with neutrinos and anti-neutrinos
- Should duality hold (and if its origins are understood) this would also allow measurements of structure functions in the high-x region, which is difficult to access in DIS
- Monte Carlo studies underway to estimate how well these measurements can be made

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Coherent Pion Production

Although the weak interaction is a point interaction …

It is still possible to interact with the whole nucleus to produce pions in a coherent fashion.

$$\nu_\mu A \rightarrow \nu_\mu \pi^0 A \quad \text{or} \quad \nu_\mu A \rightarrow \mu^- \pi^+ A$$

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Coherent Pion Production

This occurs because the exchanged boson, the $W^{+/-}$ or Z^0, can fluctuate into a meson, which can travel a distance:

$$l = \frac{\nu}{Q^2 + m^2}$$

from the uncertainty principle, for a meson of mass m. The meson interacts strongly and over longer distances, allowing it to interact with several nucleons.

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Coherent Pion Production

This of interest for two reasons: It provides a test of the understanding of the weak interaction (the cross section can be calculated in various models), and neutral pion production is a significant background for neutrino oscillations.

$$\nu_\mu \to \nu_e n \to e^- p$$

The electron showers and can be easily confused with a π^0

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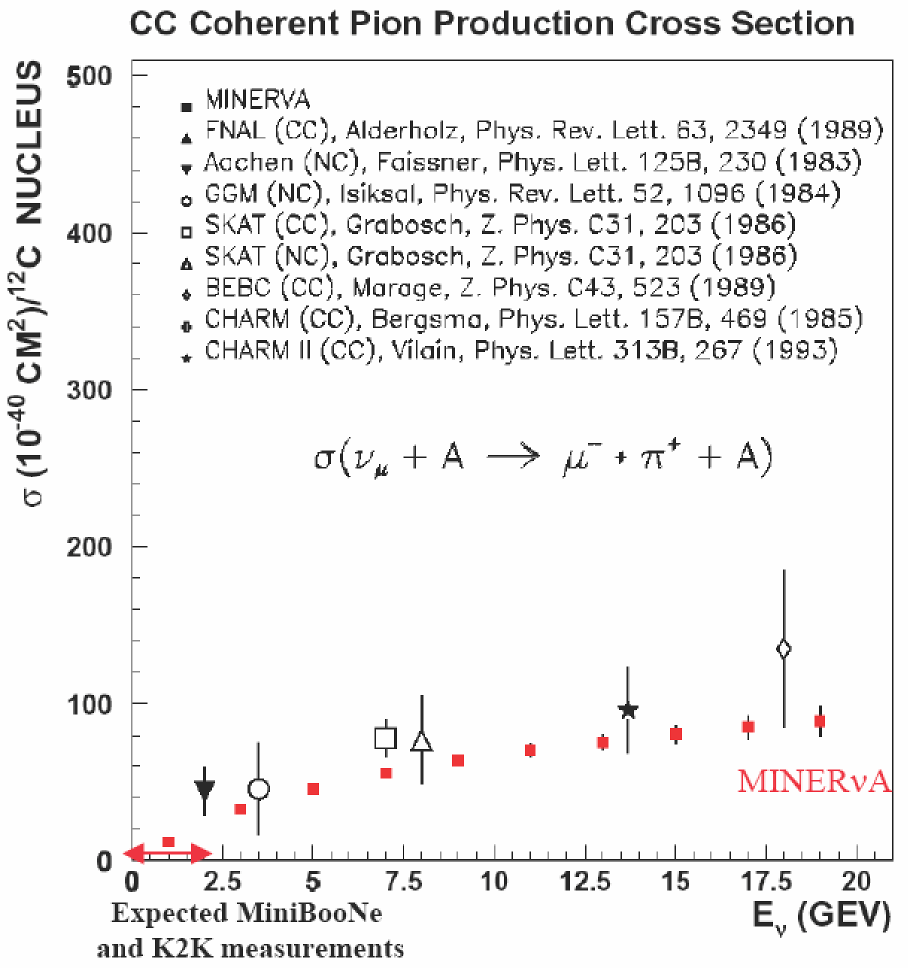
Coherent Pion production



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Nuclear Effects

Most measurements of neutrino interactions have been on heavy nuclei. The statistics have generally been so poor that any changes to measured quantities due to nuclear effects could be safely neglected. No longer!

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Nuclear Effects

As with coherent pion production, oscillation of the W/Z into mesons can cause interactions with the nuclear medium that differ with A. This can cause shadowing effects which are substantial under certain kinematical conditions.

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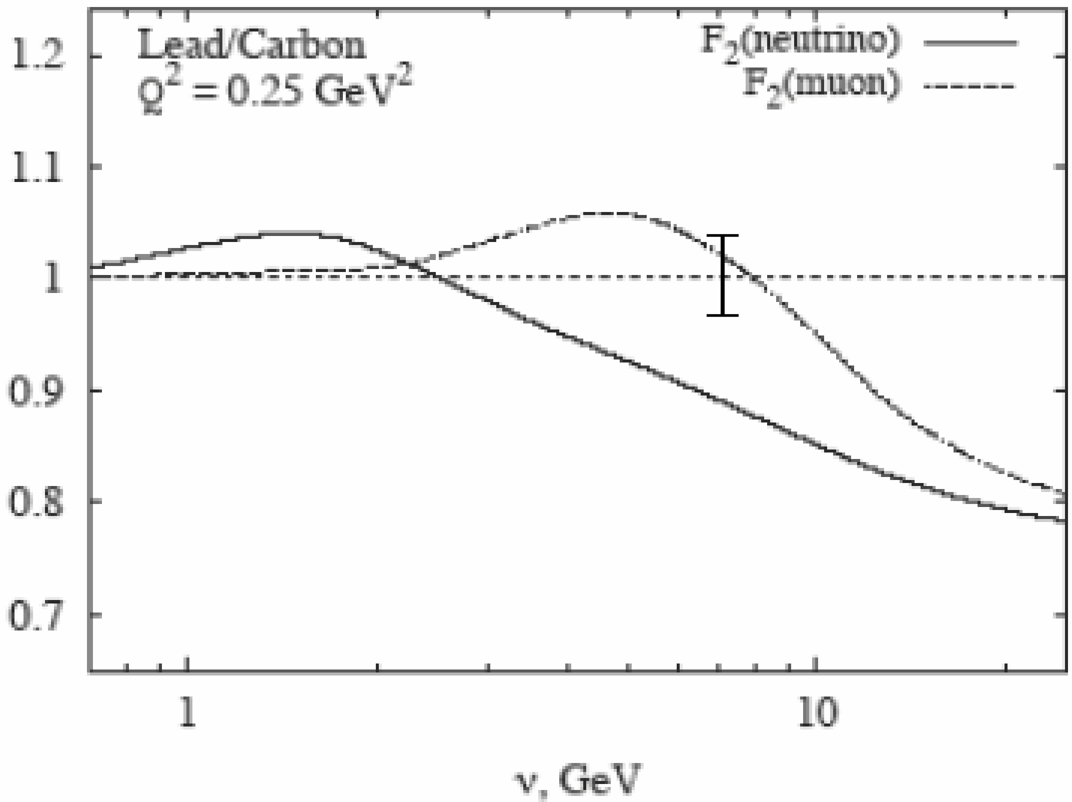
Nuclear Effects



Calculation from S. Kulagin

MINERνA should be able to determine this ratio to a few % for ν > 6 GeV

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Generalized Parton Distributions

Usual parton distributions are sensitive to longitudinal momentum distributions.

GPD's (formalism developed in mid 1990's by Ji and Radyushkin) gives a 3 dimensional picture of nucleon structure.

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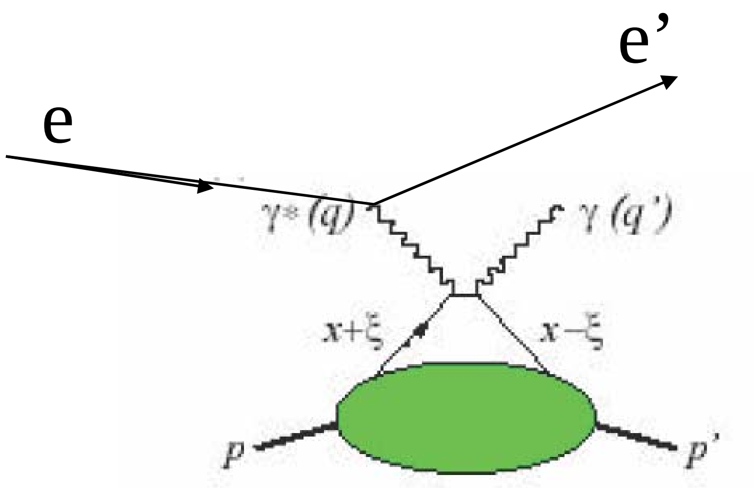
GPD

GPD’s measured through exclusive reactions.

Being measured at JLab via DVCS



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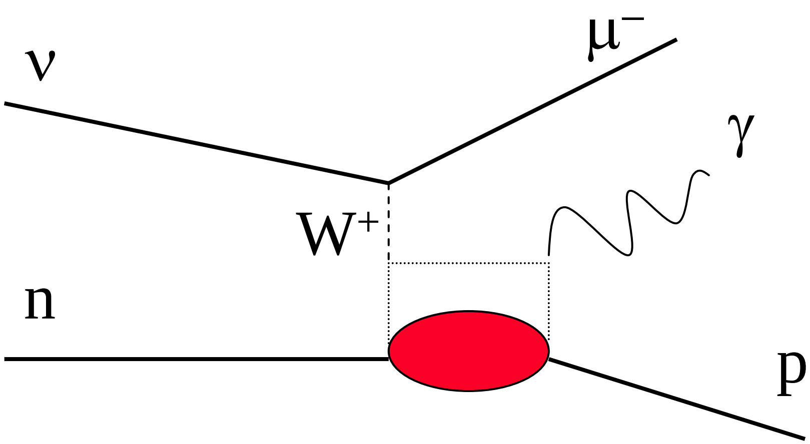
GPD – Weak DVCS



W> 2 GeV, t small, E_γ large - Exclusive reaction

Weak DVCS would allow flavor separation of GPD's. Not clear how well MINERvA can measure this, but estimates of cross section by A. Psaker (ODU) indicate a few thousand events could be detected.

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Conclusions

- Neutrinos provide a unique probe of nucleon structure
- New beams have sufficient intensity to do experiments with good statistics (10-100 times better than previous expts)
- Numerous physics topics, both fundamental and important input to oscillation experiments
- MINERνA will provide greatly improved statistics for fundamental measurements (we just need $, new collaborators welcome!)
- An exciting new area of physics