A Unified Study of (Quasi-) Elastic Scattering on the Nucleon

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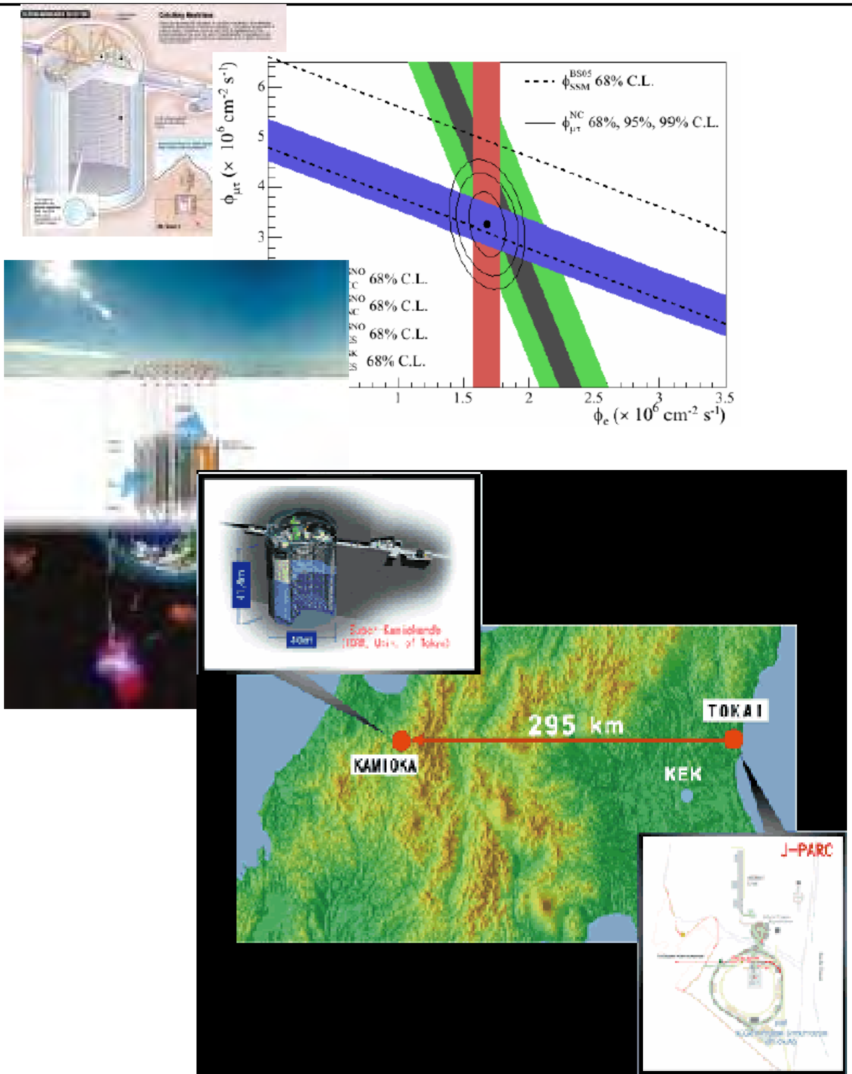
Users Group 2006

We heard this morning...

- Developments in ν physics:
  - Oscillations
  - Solar neutrino flux
  - Neutrino astro-particle physics
  - Talk of ν CP violation...

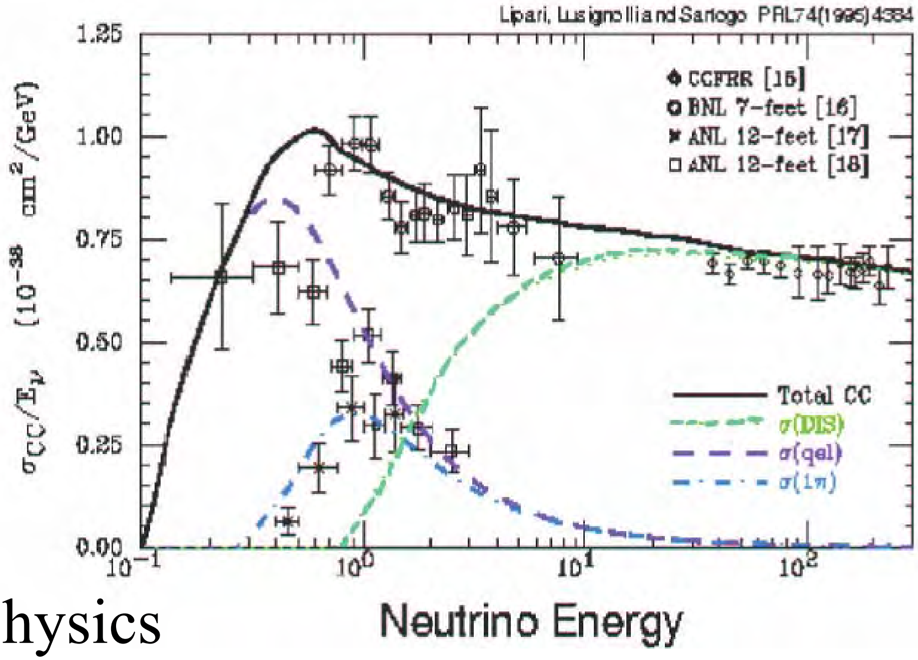


All of this relies on a basic understanding of ν-A physics...

Neutrinos: Interesting physics on a weak foundation...

- Knowledge of ν-A interaction based on data from 70's and 80's
  - Low statistics (~10's of events)
  - High flux uncertainties

Contributions to ν-A CC Total Cross Section



- Weak foundation for ν physics
  - Physics underlying an entire experimental program
  - Experiments will soon be dominate by cross section uncertainties
  - Needs to be revisited
  - Nuclear physics complimentary to JLab program

It’s a lot like e^- scattering, but...

ν-A scattering governed by V-A interaction; both currents contribute to the cross section

$$\sigma_{QE} = \sigma_V + \sigma_A$$

σ_V parameterized by elastic form factors (G_V^E, G_V^M)

σ_A parameterized by axial form factors (G_A or F_A) – roughly ½ of cross section!!

CVC allows us to relate elastic nucleon form factors (G_{ep}, G_{mp}, G_{en}, G_{mn}) to G_V^E and G_V^M, permitting extraction of vector component of σ_{QE}.

→ ν scattering, with help from e^- scattering, can access F_A.

Electron scattering input...

- CVC allows us to determine $G^V{}_E(q^2)$ and $G^V{}_M(q^2)$ from the elastic nucleon form factors:

$$G_E^V\left(Q^2\right) = G_{ep}\left(Q^2\right) - G_{en}\left(Q^2\right),$$
$$G_M^V\left(Q^2\right) = G_{mp}\left(Q^2\right) - G_{mn}\left(Q^2\right)$$

- e^-N scattering allows to σ_A

It's a l like e$^-$ scattering, but...

ν-A (MINERνA)

verned by V-A interaction; both currents
o the cross section

$$\sigma_{QE} = \sigma_V + \sigma_A$$

σ_V ar eri d

^{M})

σ_A parameterized by axial form factors (G_A or F_A) – roughly ½ of cross section!!

e$^-$N (JLab)

CVC a late elastic nucleon form factors (G_{ep}, G_{mp}, G_{en}, G_{mn}) to G_V^E and G_V^M, erm ting xtraction of vector component of σ_{QE}.

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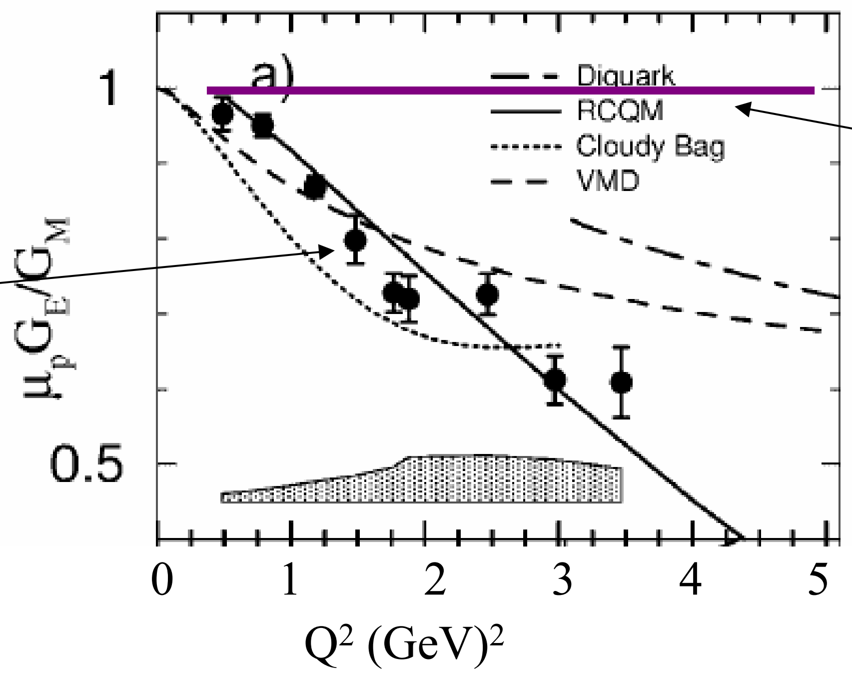
Overview

- Extraction of F_A requires parameterization of nucleon elastic form factors valid to high Q^2
    - Background on parameterizations
    - Duality constrained form factors fits
    - Done with J. Arrington, A. Bodek, and H. Budd
- MINERνA
    - Detector
    - Experimental program
    - QE cross sections and F_A

Suddenly, G_D is no longer in vogue..

For years, we parameterized form factors with $G_D=(1+Q^2/\Lambda^2)^{-2}$, but that has changed with the new recoil polarization data.



Newer data exhibits linear drop in ratio.

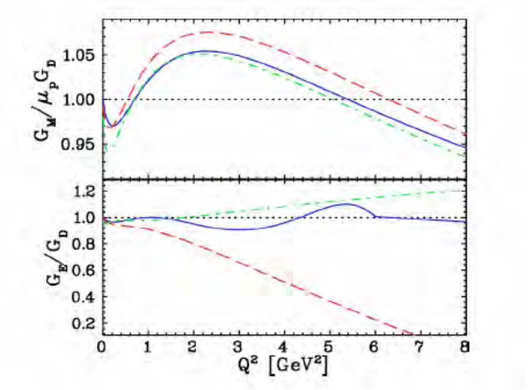
If form factor scaling were valid.

Source: M.K. Jones *et al*, PRL **84**, 1398 (2000)

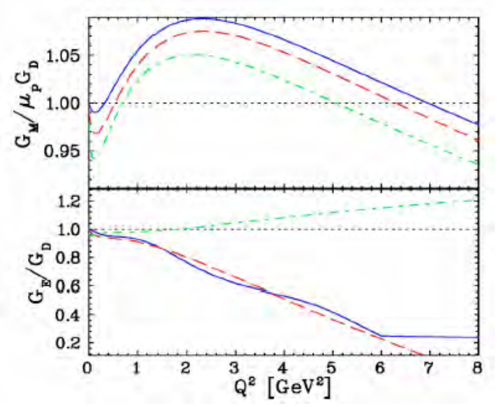
Parameterizations

- Criteria
  - Simplicity – few parameters
  - Reasonable asymptotic behavior - fall off like Q^4
  - Reasonable low-Q^2 behavior
- Past work:
  - Many parameterizations introduced after discrepancy published
  - Brash, Kozlov, Li, Huber, Phys. Rev. C 65, 051001(R) (2004).
  - Arrington

Rosenbluth Fits



Polarization Fits



Source: J. Arrington, Phys. Rev. C 69 022201(R), (2004.

Kelly Parameterization –
J. Kelly, PRC **70** 068202 (2004)

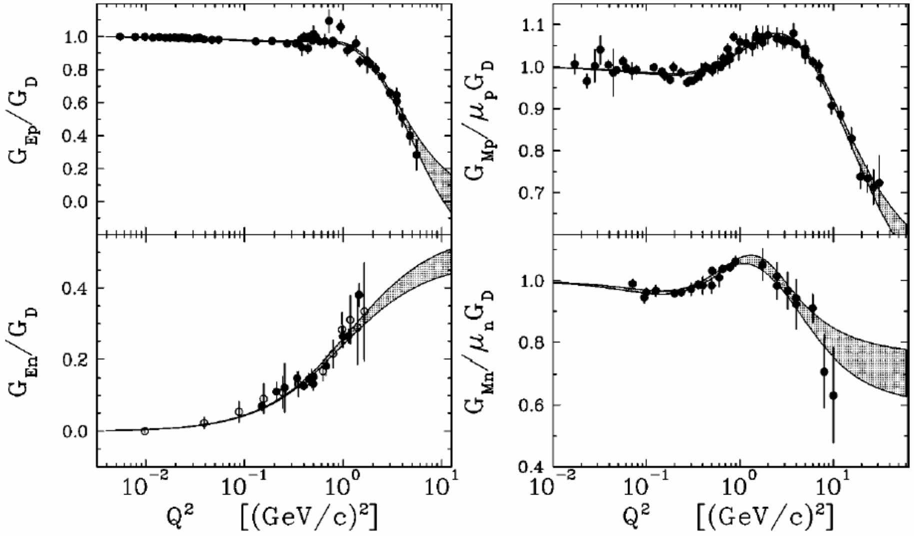
- Fit to sanitized dataset favoring polarization data.
- Employs the following form:

$$G(Q^2) = \frac{\sum_{k=0}^{n} a_k \tau^k}{1 + \sum_{k=1}^{n+2} b_k \tau^k}$$

G_{ep}, G_{mp}, and G_{mn}

$$G_{en}(Q^2) = \frac{a\tau}{1+b\tau} G_D(Q^2)$$

$\tau = Q^2/4m_p^2$



BBBA2005*

- Fit based largely on polarization transfer data.
  - Dataset similar to that used by J. Kelly.
- Functional form similar to that used by J. Kelly:

$$G\left(Q^2\right)=\frac{\sum_{k=0}^{n} a_k \tau^k}{1+\sum_{k=1}^{n+2} b_k \tau^k}$$

4 parameters for G_{ep}, G_{mp}, and G_{mn}. 6 parameters for G_{en}.

use $a_0=1$ for G_{ep}, G_{mp}, G_{mn}, and $a_0=0$ for G_{en}.

- Employs 2 additional constraints.

*Bradford, Bodek, Budd and Arrington

Duality constraints

- From local duality, $R_n = R_p$ at high Q^2,

$$\Rightarrow \quad \left(\frac{G_{ep}}{G_{mp}}\right)^2 = \left(\frac{G_{en}}{G_{mn}}\right)^2$$

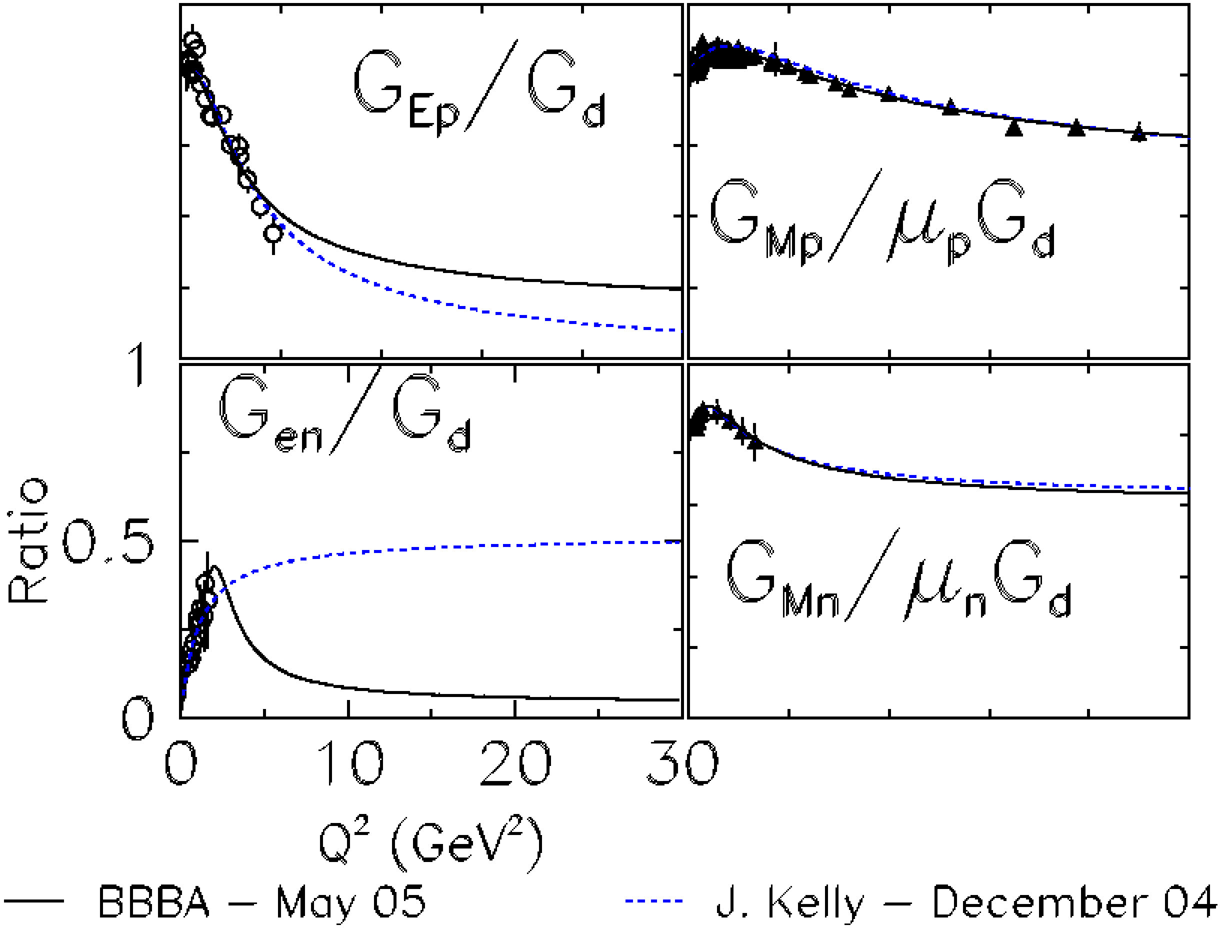
- In the elastic limit: $(F_{2n}/F_{2p})^2 \rightarrow (G_{mn}/G_{mp})^2$

$$\Rightarrow \quad \left(\frac{G_{mn}}{G_{mp}}\right)^2 \approx \left(\frac{F_{2n}}{F_{2p}}\right)^2 \approx \frac{1+4\frac{d}{u}}{4+\frac{d}{u}}$$

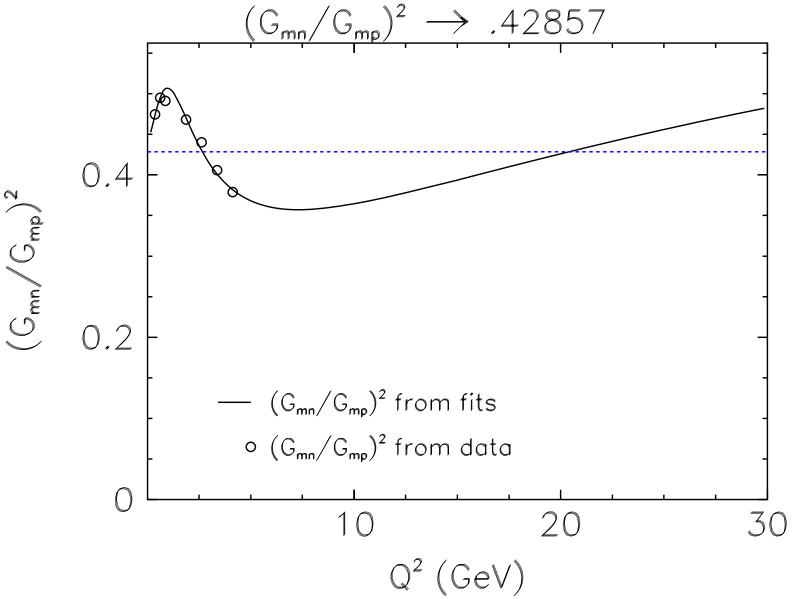
At high Q^2, high ν and fixed x. We use d/u=.2

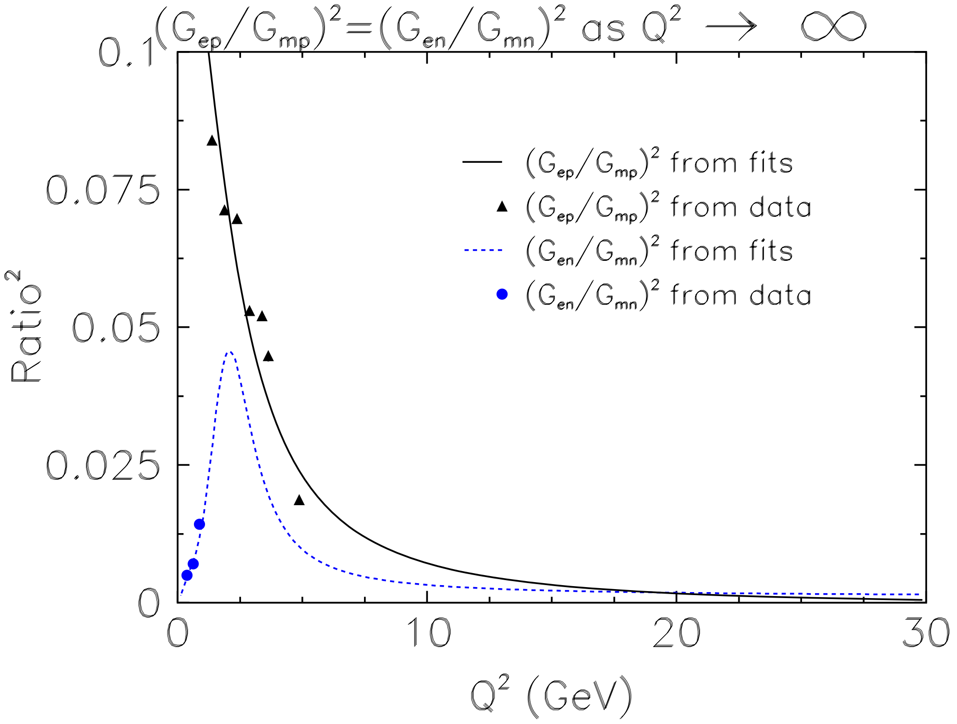
- Constraints applied to fits for G_{en} and G_{mn}.

Results – hep-ex/0602017

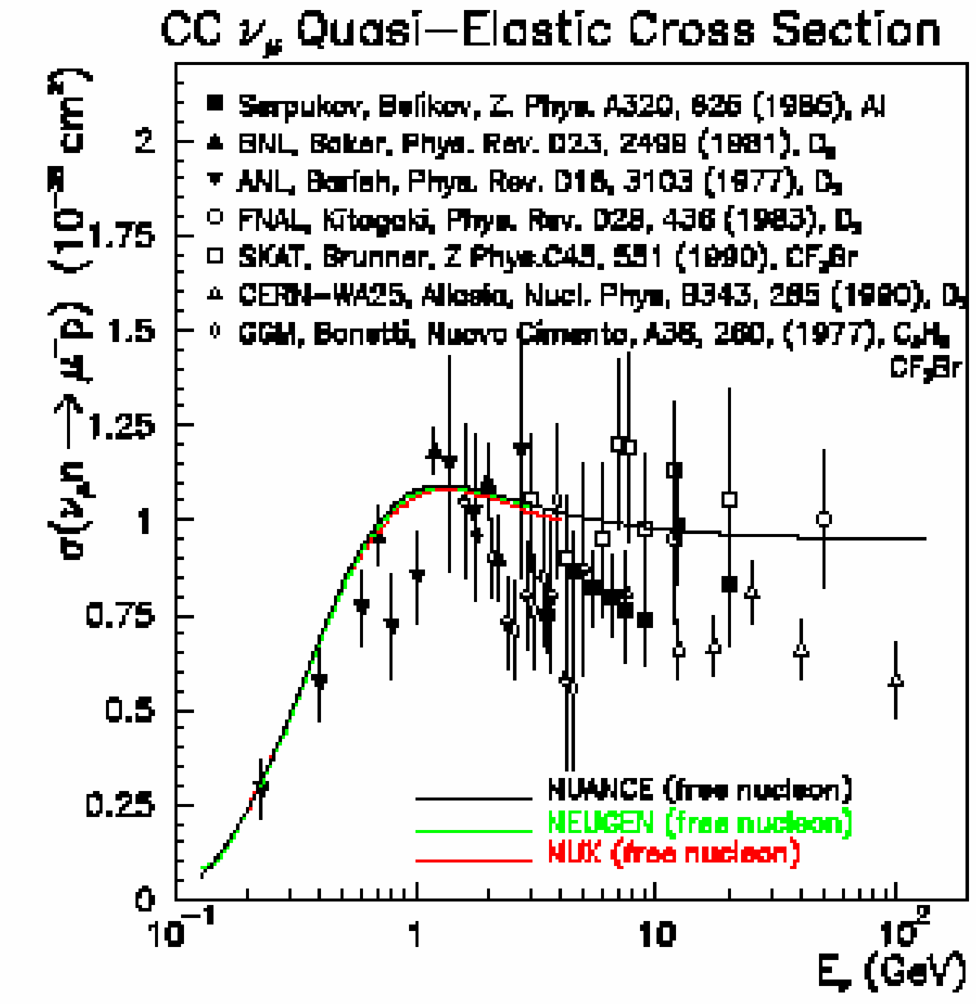


Constraints



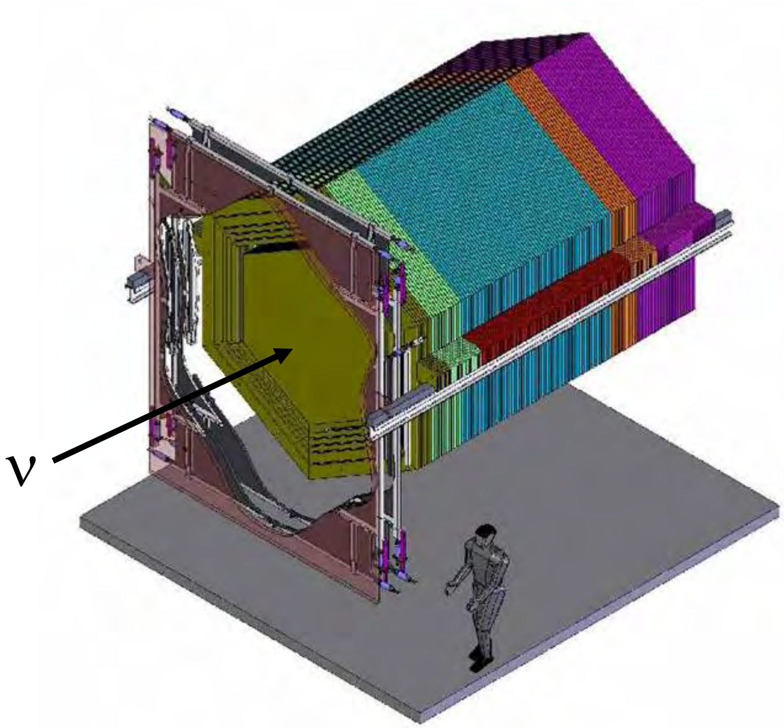


If only we had good ν-A cross sections...



MINERνA

- MINERνA is high precision a ν-A scattering experiment that will run at Fermilab.
  - Will re-measure cross sections
    - total cross sections
    - differential cross sections
  - Variety of physics topics
  - Broad range of nuclear targets



Will re-measure QE cross section, permitting extraction of F_A over a broad range of Q^2.

Detector Layout

Side ECAL Ring (Pb) 0.6 tons

Side HCAL Tower (Fe) 116 tons

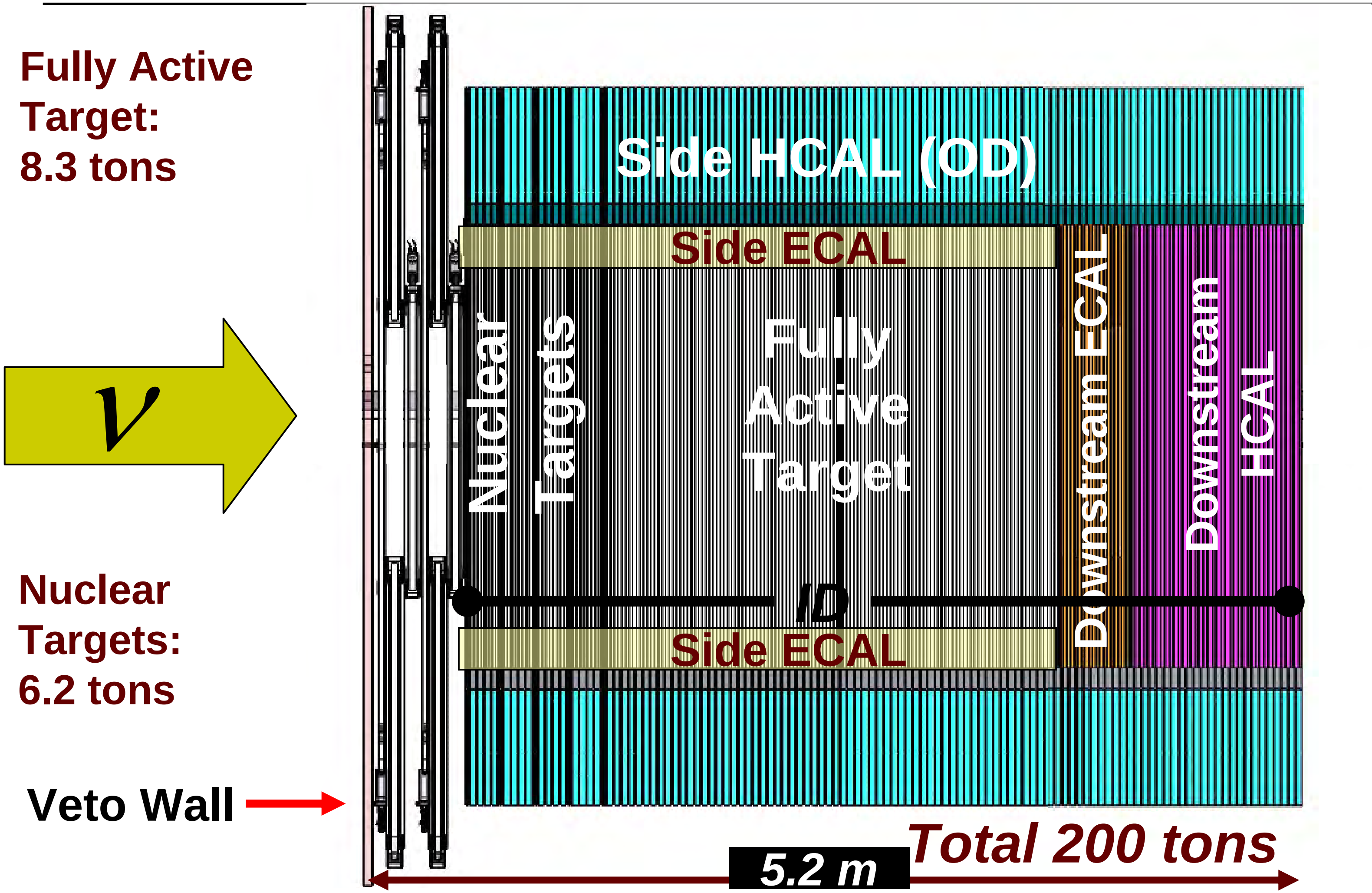
Fully Active Target: 8.3 tons

Nuclear Targets: 6.2 tons

Veto Wall

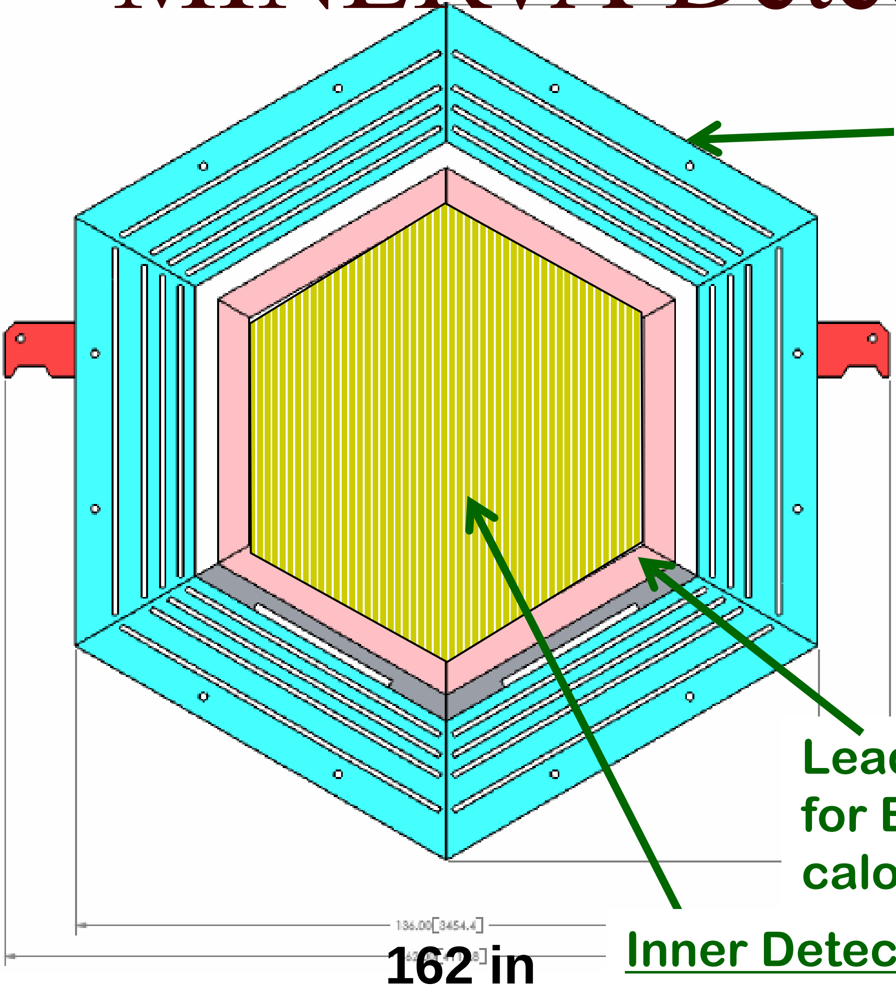
DS ECAL: 15 tons

DS HCAL: 30 tons



Total 200 tons

MINERvA Detector Module



Outer Detector (OD)
Layers of iron/scintillator for hadron calorimetry.

Lead Sheets for EM calorimetry

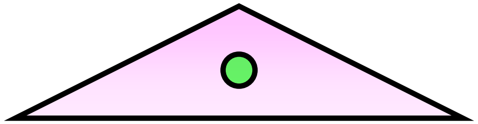
Inner Detector (ID)
Hexagonal X, U, V planes for 3D tracking

- A frame with two planes of scintillator has 304 channels
  - 256 in inner detector
  - 48 in outer detector (two per slot)
- Module construction varies with type
  - Ecal – steel and one plane scintillator
  - Hcal – lead sheets and 2 planes scintillator
- 108 modules in full detector
  - 30,372 total channels

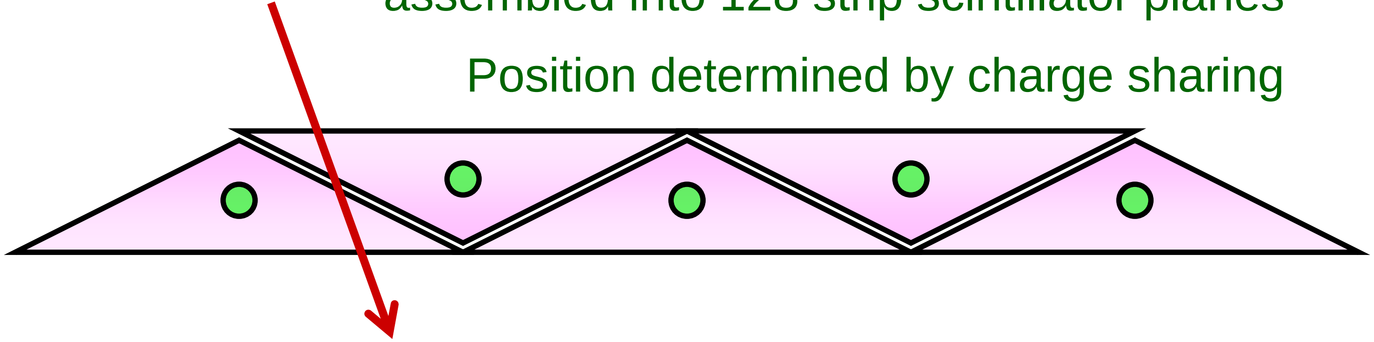
MINERvA Optics

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

Scintillator

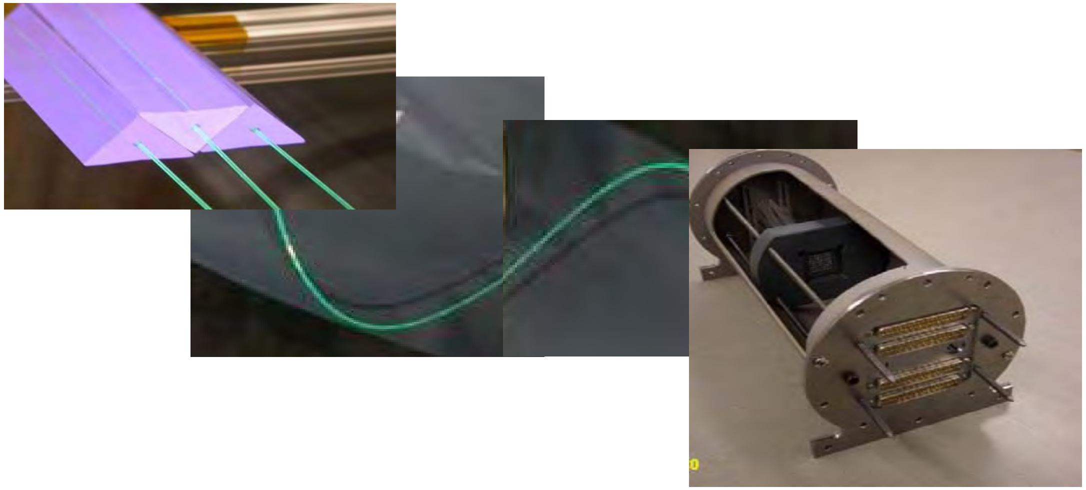


1.7 × 3.3 cm^2 strips
Wave Length Shifting (WLS) fiber readout in center hole



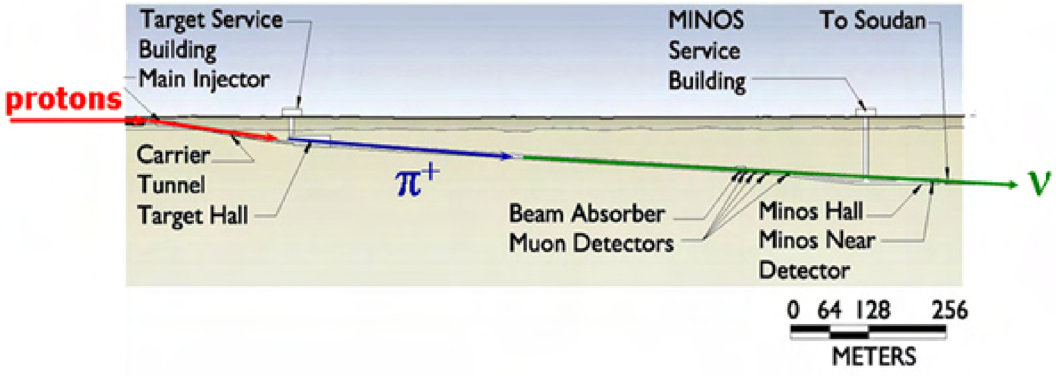
For the Inner Detector, scintillator is assembled into 128 strip scintillator planes

Position determined by charge sharing

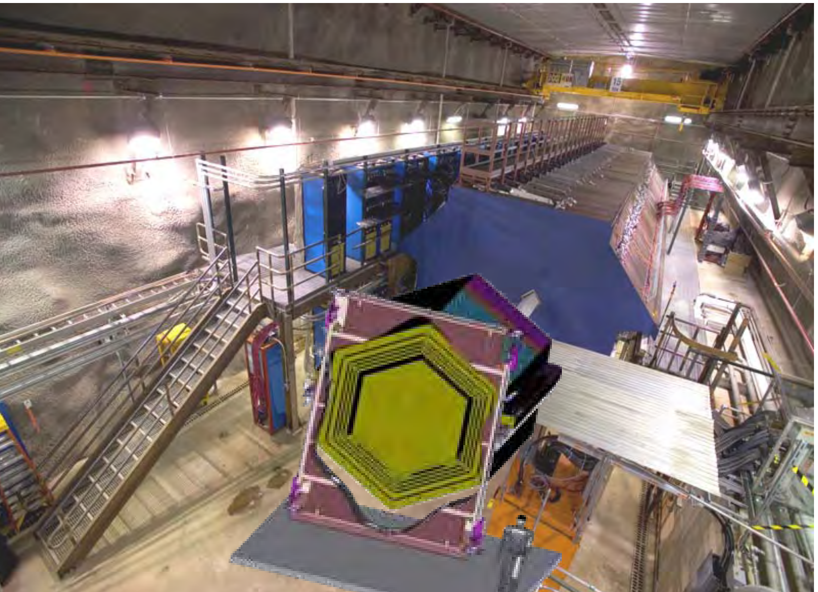


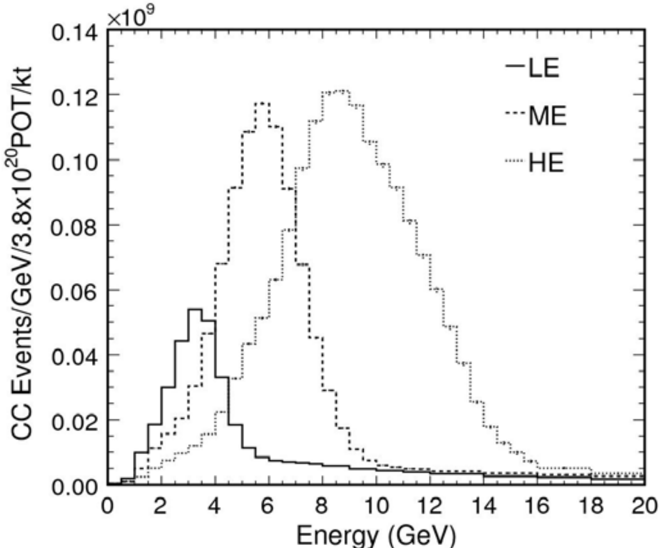
WLS fibers read out by Hammamatsu 64-anode PMT

Numi Beamline



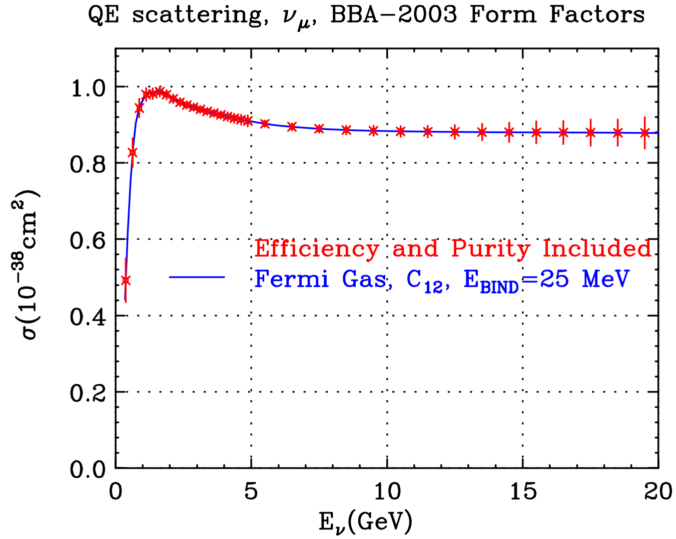
- High intensity beam (~4X10^{20} p.o.t./year) gets 120 GeV protons from FNAL main injector
- Coverage in E_ν ~ 10 GeV
- Well understood flux – known to ~4% via MIPP experiment.

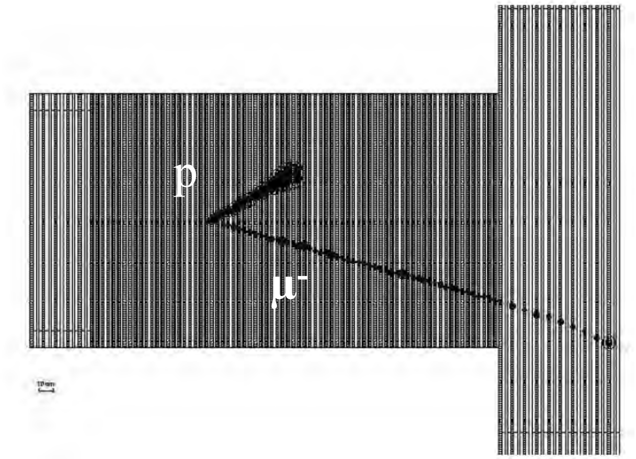




QE Event Sample

- MINERvA will collect 800K QE events
- Event reconstruction yields clean QE sample
- Measurements of total and differential cross sections

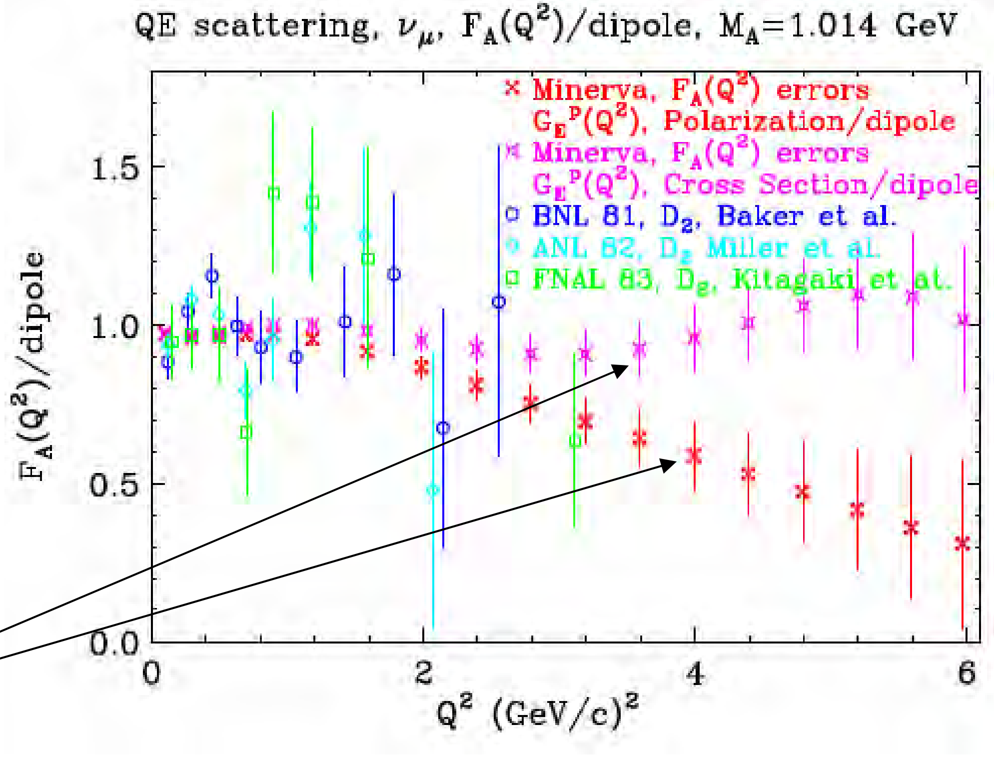




Typical **$\nu_\mu n \rightarrow p\mu^-$** CCQE event in MINERvA detector

Axial Form Factor

- MINERvA will extract axial form factor
  - First determination of high Q^2 behavior
  - 2 predictions shown for 2 models of G_{ep}



MINERvA: Status and Timeline

- December 2005: CD-1 Review at FNAL
- Fall 2006: CD-2 Review, detector R&D
- 2007: Prototype detector components and modules constructed
- 2008: Detector construction
- 2009: Turn on...

Summary/Conclusions/Future Work

- Both e^- and ν scattering are key to understanding elastic nucleon structure
  - e^- measurements
    - Vector interaction
    - Accurate parameterizations permit extraction of axial contribution
  - ν scattering allows access to the axial current
- MINERνA will revisit ν cross sections with unprecedented precision
- Coming soon: F_A

Supplemental Slides

MINERνA Collaboration

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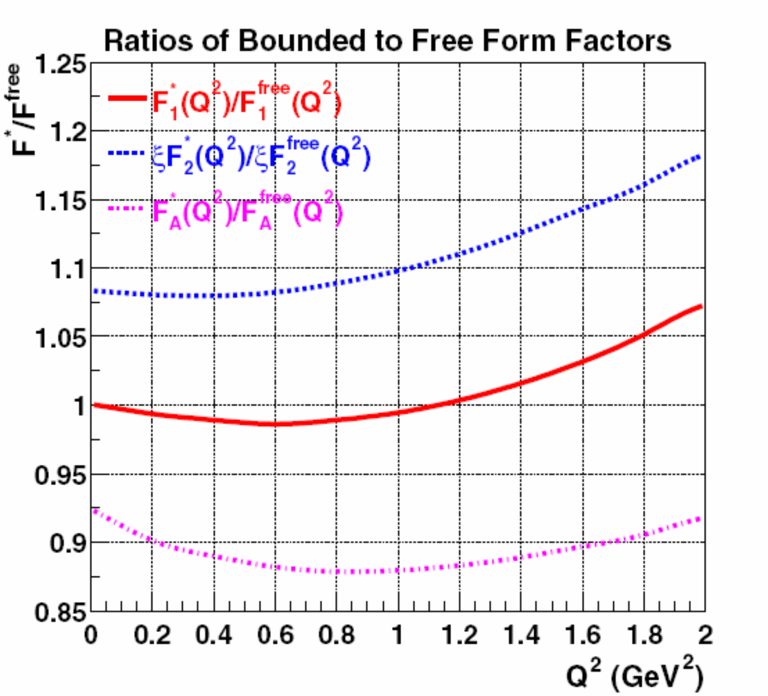
**** Co-Spokespersons***

 # Members of Executive Committee

A collaboration of HEP, Nuclear, and Theoretical physicists

What about nuclear targets?

- MINERvA will largely extract F_A on carbon target
    - Nucleus will effect cross section, F_A
- MINERvA will conduct systematic study over wide range in A to determine extent of nuclear effects on QE cross section
    - C, Fe and Pb targets



Calculation from Tsushima, Kim, and Saito, nucl-th/0307013.