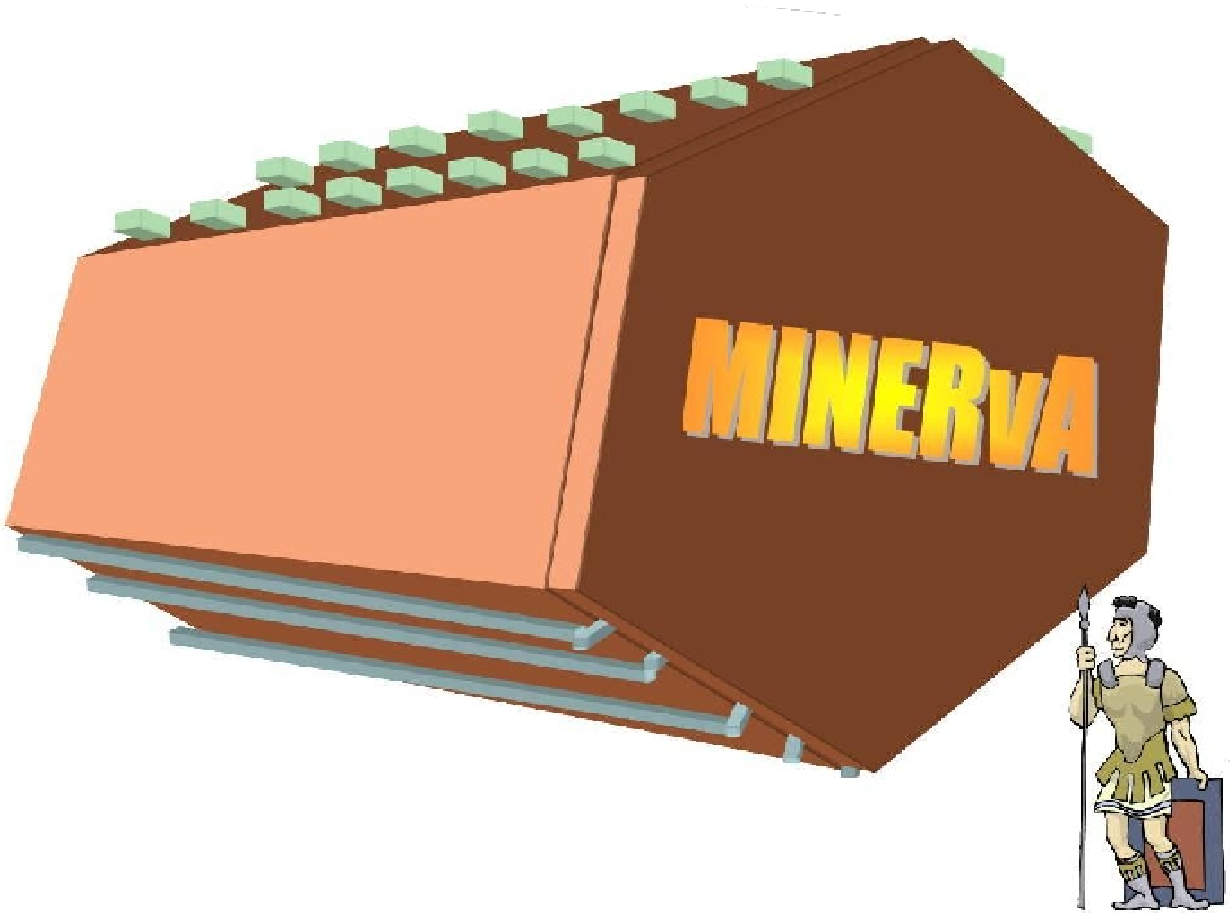
The Design of MINERνA



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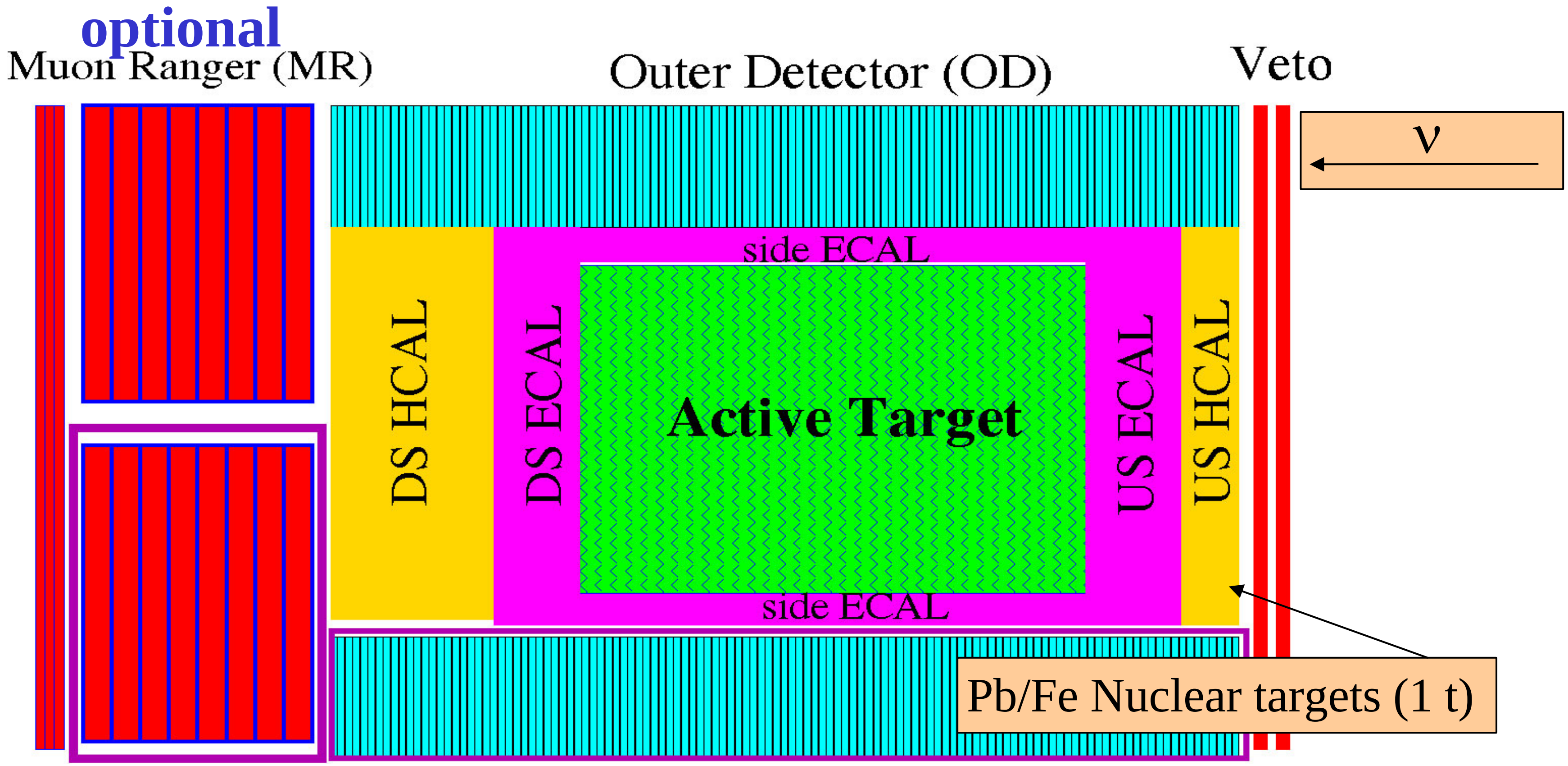
University of Rochester
DPF2004 - August, 2004

What detector properties do we need?

- Must reconstruct exclusive final states
  - high granularity for charged tracking, particle ID, low momentum thresholds,
    - e.g. $\nu_\mu n \rightarrow \mu^- p$
- But also must contain
  - electromagnetic showers (π^0, $e^\pm$)
  - high momentum hadrons ($\pi^\pm$, p, etc.)
  - from CC need $\mu^\pm$ (enough to measure momentum)
- Nuclear targets for the study of neutrino induced nuclear effects

Design overview



Fully active scintillating strip target (6 t, 3-5 t fiducial) surrounded by calorimeters and muon rangers

Side and downstream calorimeters are magnetised to provide muon momentum measurements

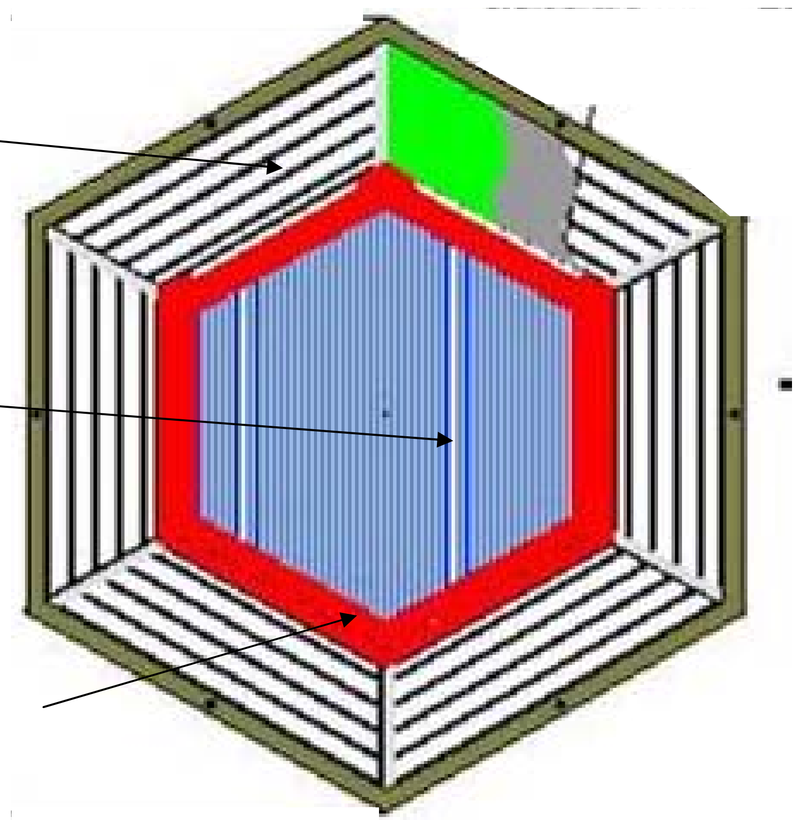
Active target module

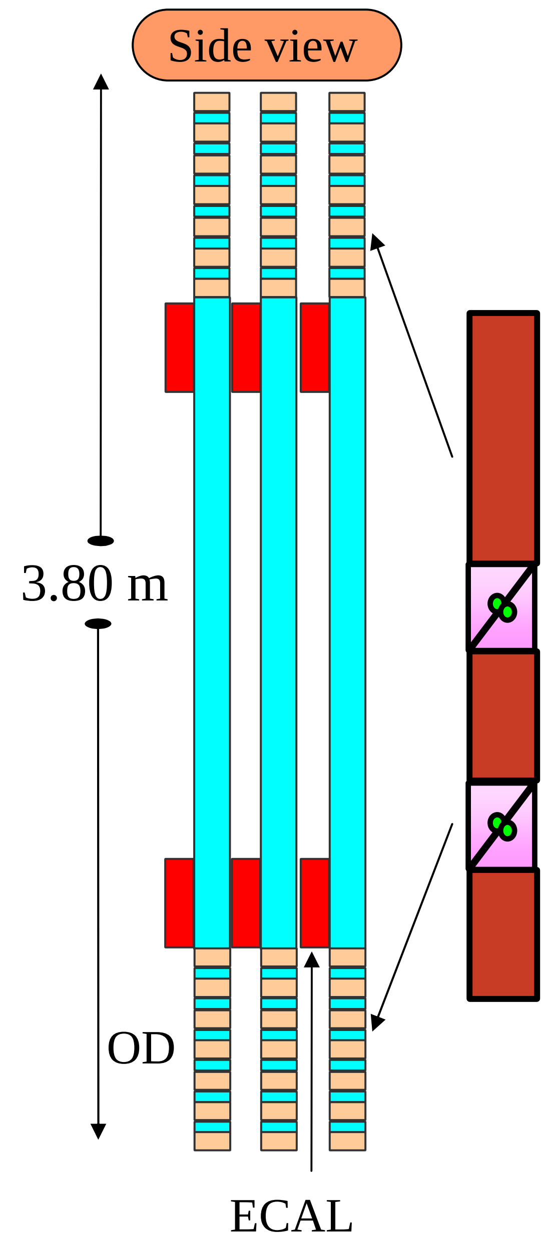
Planes of strips are hexagonal in cross section

Outer detector is a magnetised (1.5T) HCAL, muon spectrometer

Inner detector is totally active scintillator strip detector.

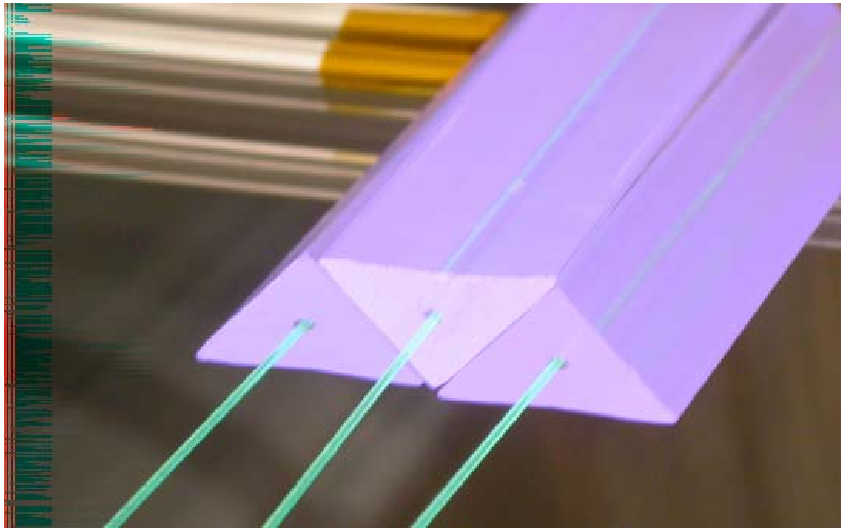
ECAL is a “washer” of lead covering part of the active region





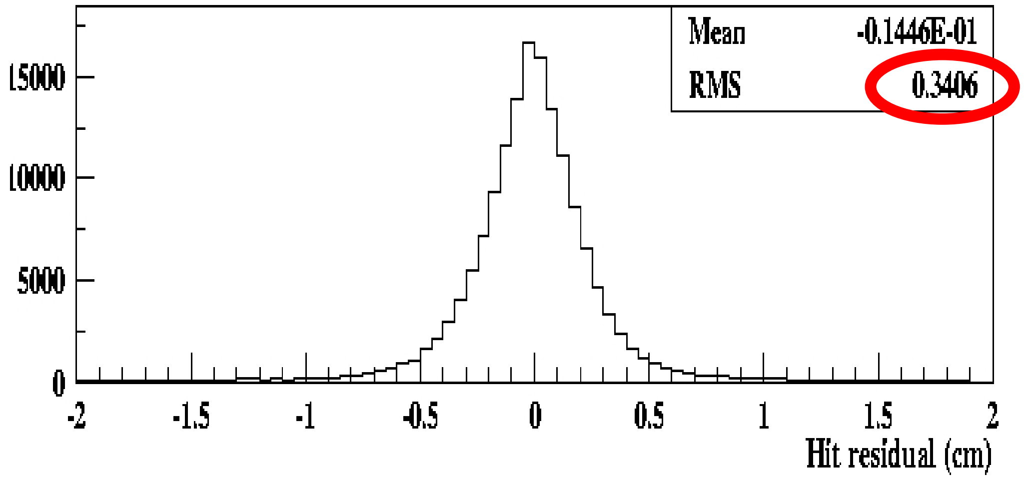
Alternating strip planes rotated by 60 degrees to make 3 views for unambiguous tracking (XUXV)

Active detector elements

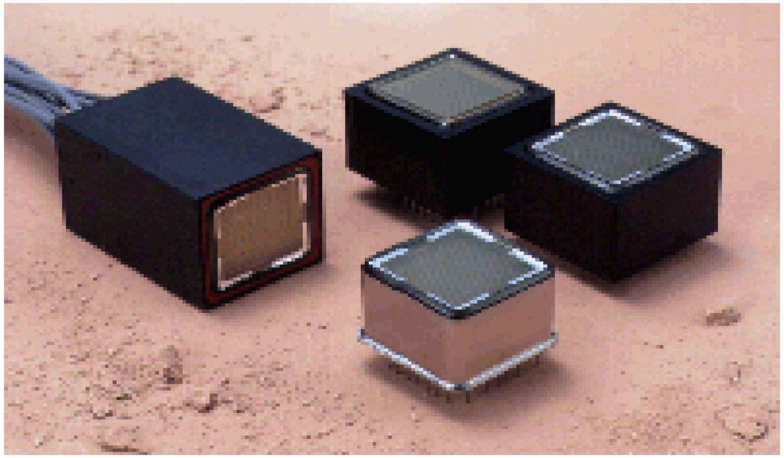


Active elements are triangular bars of extruded scintillator with embedded 1.2 mm WLS fibers

Technique pioneered by D0



Charge sharing across adjacent strips gives excellent position resolution.

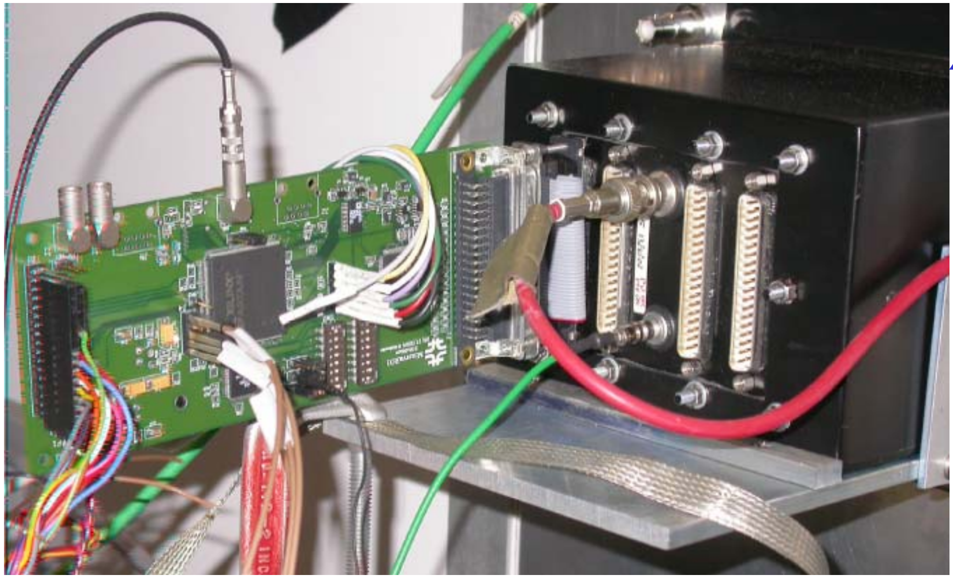


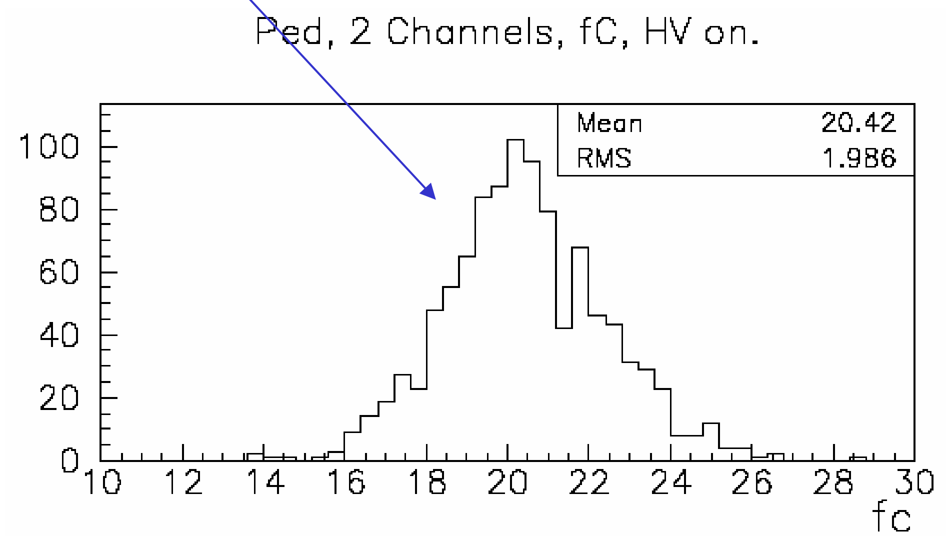
Readout by well understood technology Hamamatsu M64 MAPMTs

Front-End Electronics

- FE Readout Based on existing TriP ASIC
  - builds on FNAL, D0 work. existing submission "free".
  - ADC (dual range) plus few ns resolution timing
- TriP ASIC provides sample and hold slices

Prototype electronics and measured pedestals





  - Four buffers in 8 μsec spill; this is our default
  - each hit has TDC information

R&D Goals - Electronics / Vertical Slice Test

Phase 1: Testing the TriP Chip

Test board being designed by (PPD/EE); piggy back on D0 work

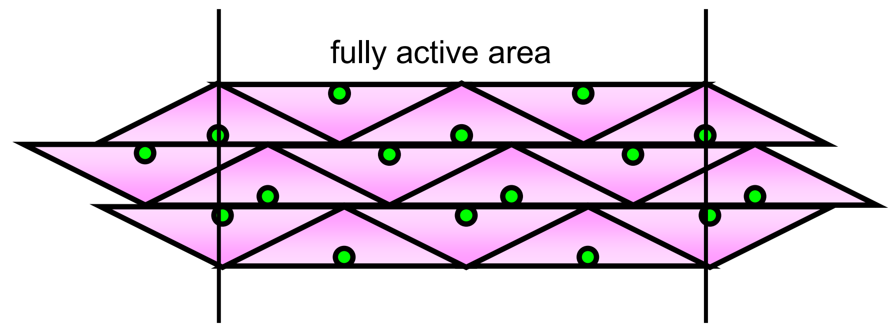
Reads out 16 channels of a MINOS M64 using a MINOS CalDet PMT box

Questions:

1. Noise and signal when integrating over 10 μs.
   2 fc pedestal rms
2. Test self-triggering and external triggering mode for storing charge.
   successful
3. Test the dynamic range (2 TriP Channels / PMT channel)
   successful
4. Procedure to get timing from the TriP chip.
   underway

Phase 2: Test our full system

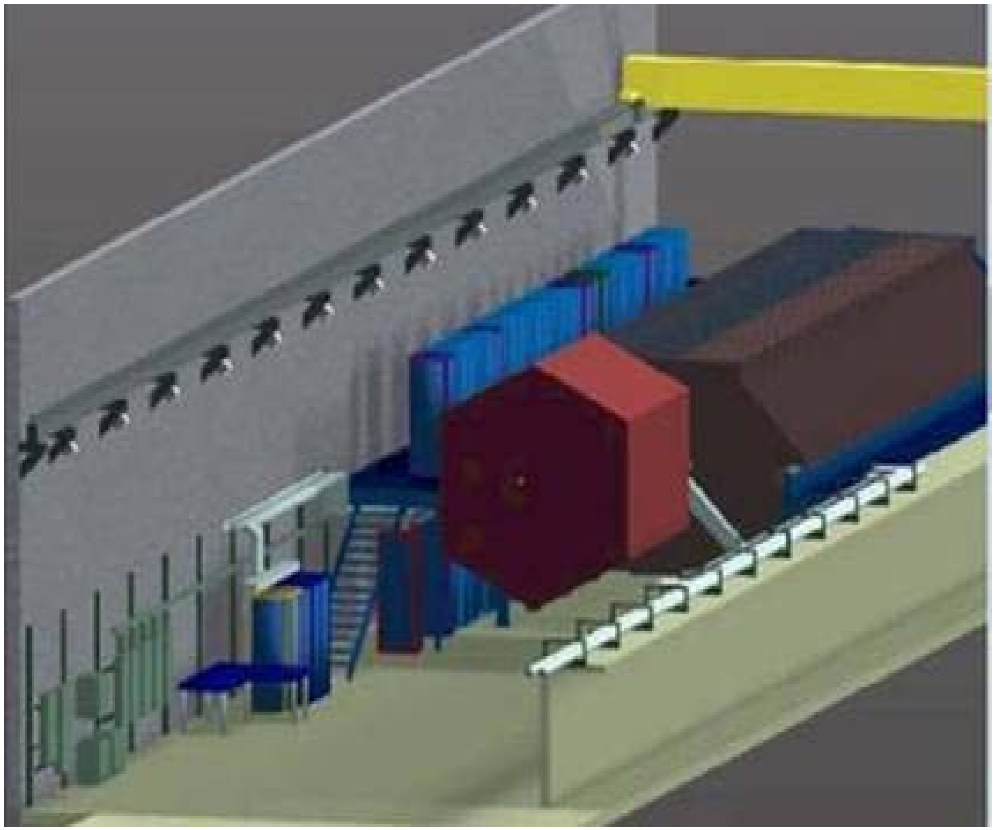
Build a small tracking array in the new muon lab using strips and fibers of the proposed design and the readout system from Phase 1.
Use CR and β sources.

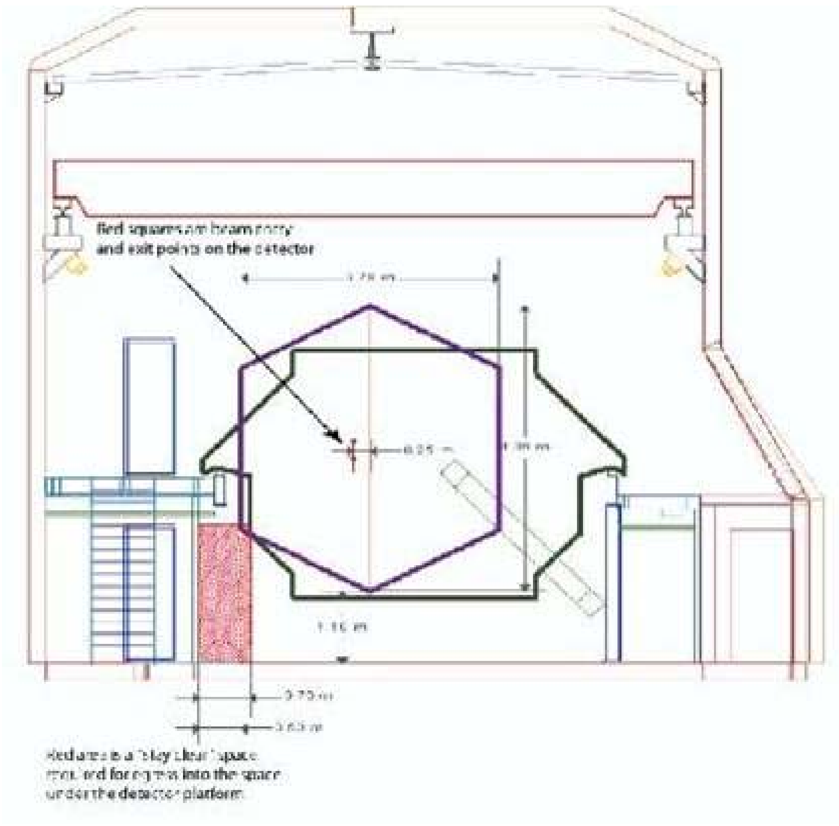


Questions:

1. Light yield – does it match our expectations?
   First look is promising
2. Spatial resolution via light sharing in a plane
3. Timing
4. Uniformity

Location

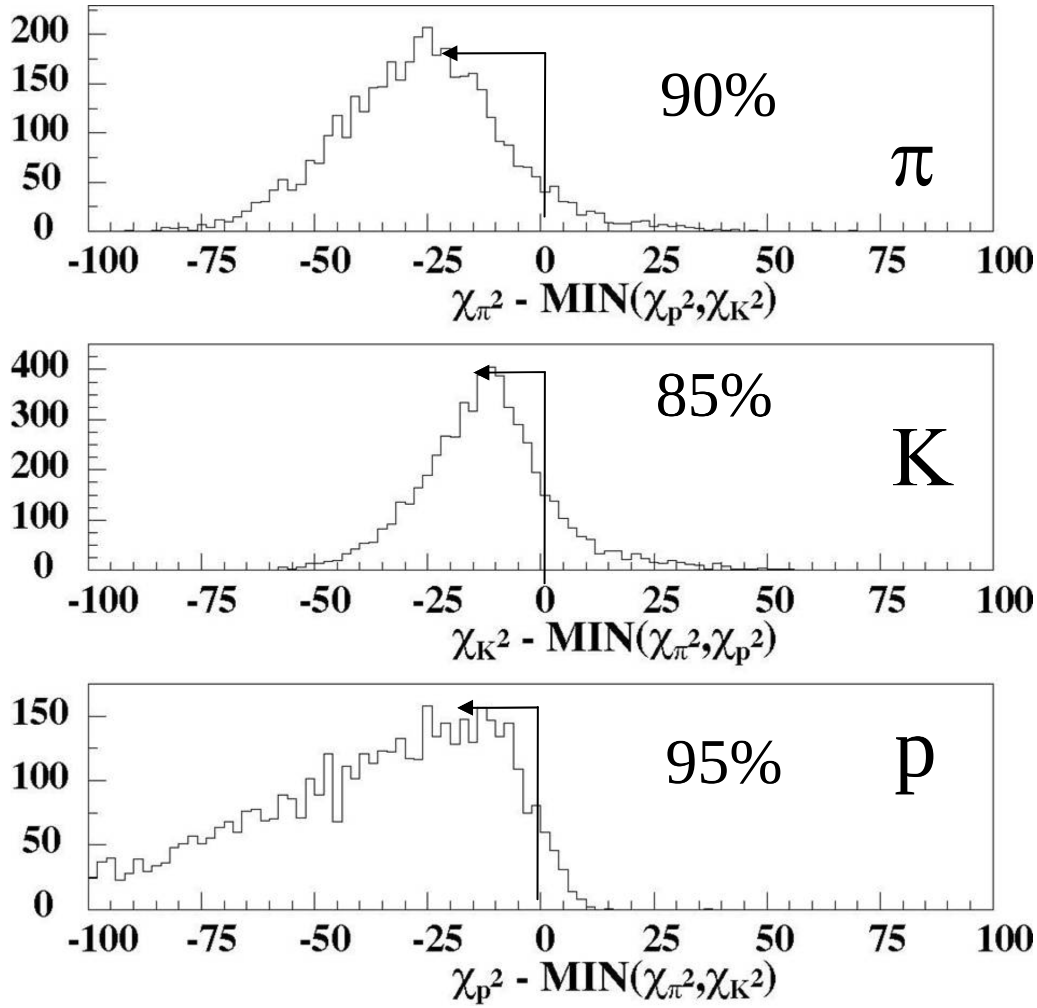




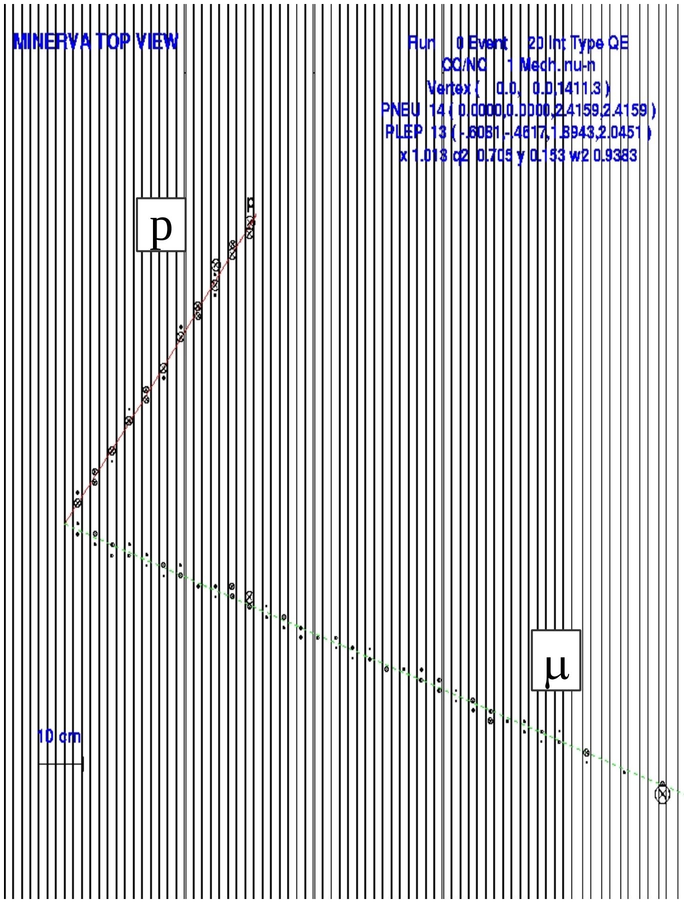
MINERνA runs parasitically to MINOS - MINOS chooses the beam
Use MINOS as the forward muon spectrometer.
Studies show minimal impact on MINOS
Backup plan to add a stand-alone muon ranger if necessary

Performance : Stopping Particle Identification

Chi2 difference between the right and best wrong particle hypothesis

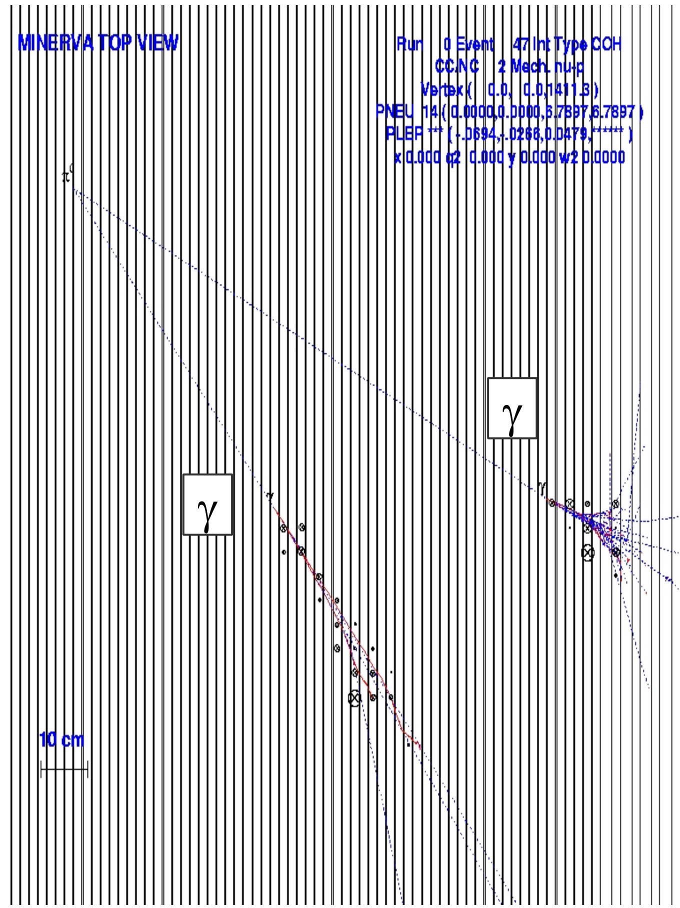


Some event displays



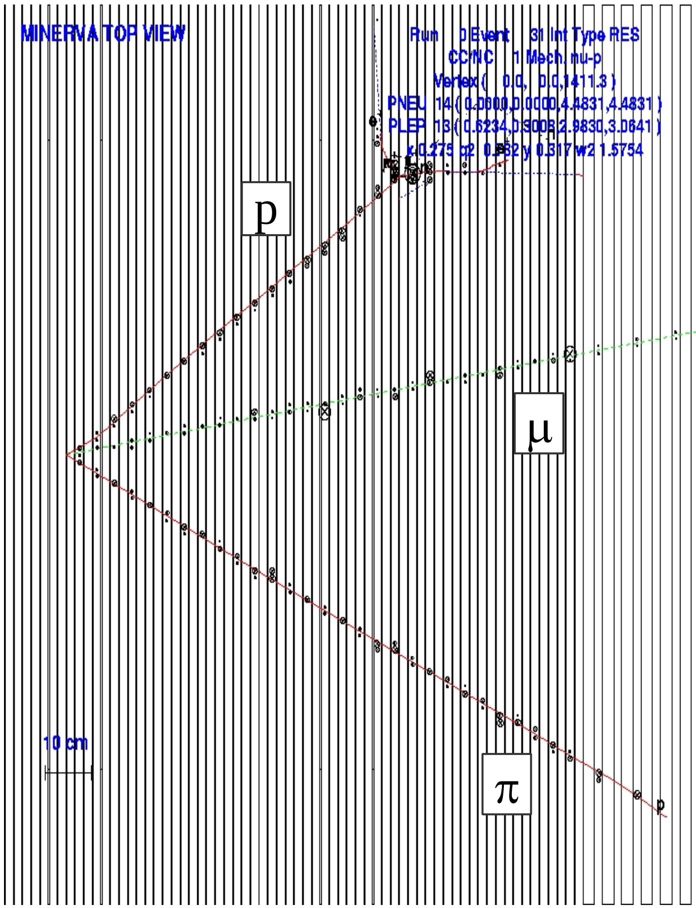
Quasielastic event

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



Neutral Current π^0

$\nu_\mu\, A \rightarrow \nu_\mu A\, \pi^0$



Resonance production

$\nu_\mu\, p \rightarrow \mu^- \, \Delta^{++} \rightarrow \mu^- \, p\, \pi^+$

Quasi-elastic Scattering

The hadronic current for QE neutrino scattering is given by [2]

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

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

We use the CVC to determine $G_E^V(q^2)$ and $G_M^V(q^2)$ from the electron scattering form factors $G_E^p(q^2)$, $G_E^n(q^2)$, $G_M^p(q^2)$, and $G_M^n(q^2)$:

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

The axial form factor F_A and the pseudoscalar form factor F_P (related to F_A by PCAC) are given by

$$F_A(q^2) = \frac{g_A}{\left(1-\frac{q^2}{M_A^2}\right)^2}, \quad F_P(q^2) = \frac{2M^2F_A(q^2)}{M_\pi^2 - q^2}.$$

Electron Scattering measurements of G^p_E

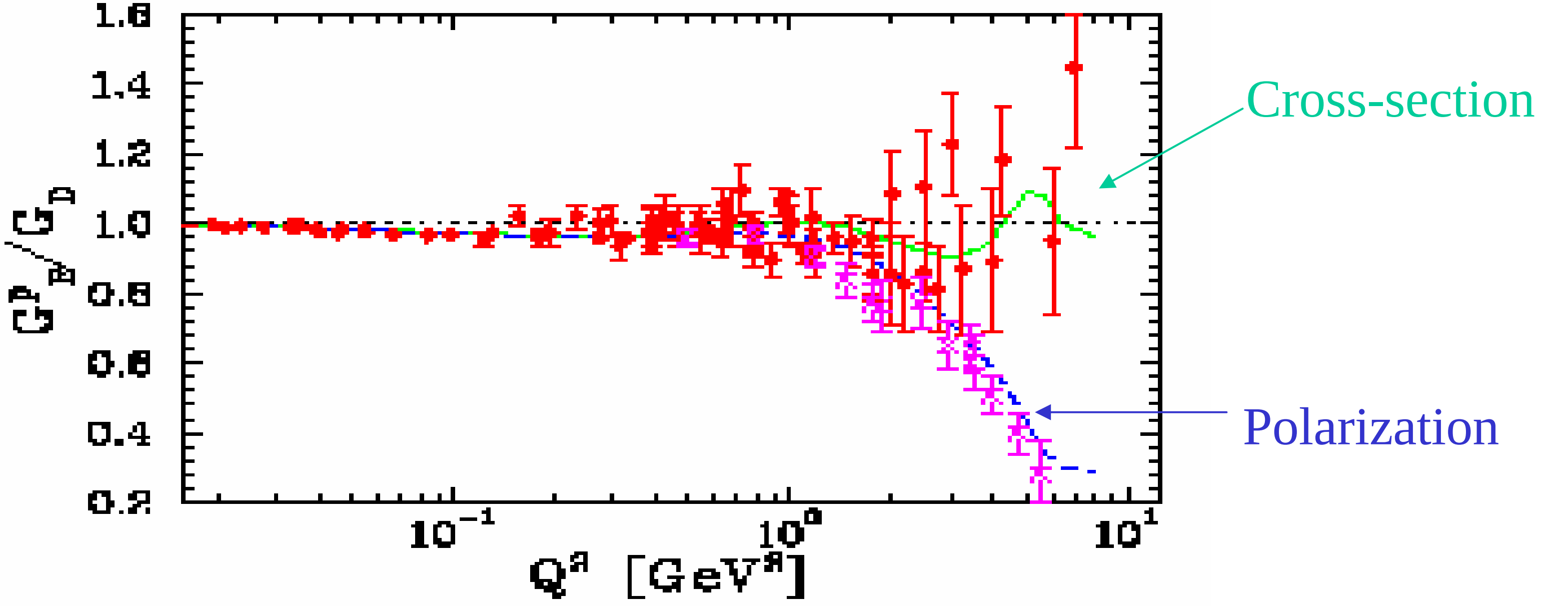
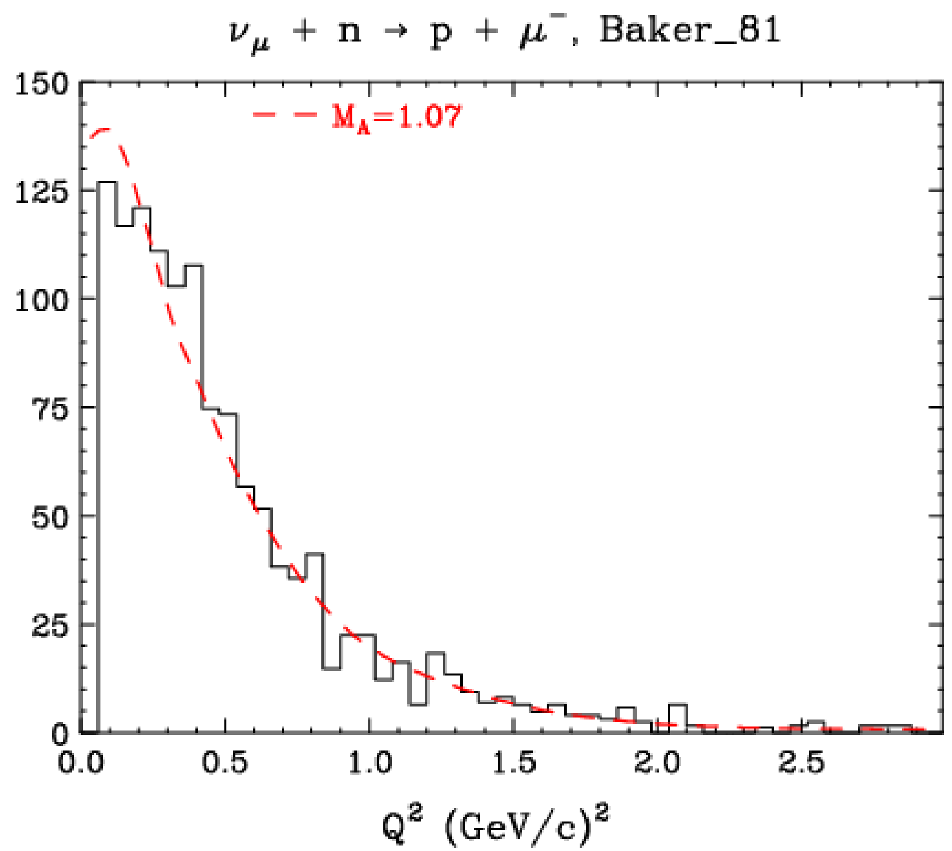


Figure 1. Our fits to G^p_E/G_D, using cross section data only (solid), and with both the cross section and polarization transfer data (dashed). The diamonds are the from Rosenbluth extractions and the crosses are the Hall A polarization transfer data. Note that we fit to cross sections, rather than fitting directly to the extracted values of G^p_E shown here.

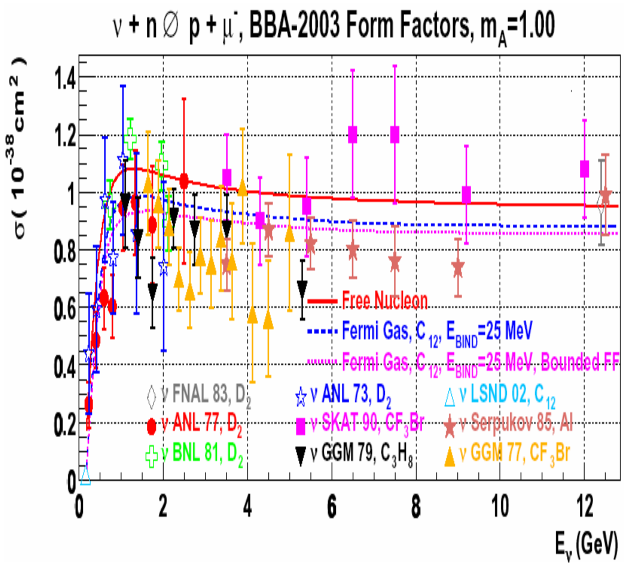
Jefferson Lab has measured all vector form factors precisely

Determining m_A , Baker et al. – BNL D_2

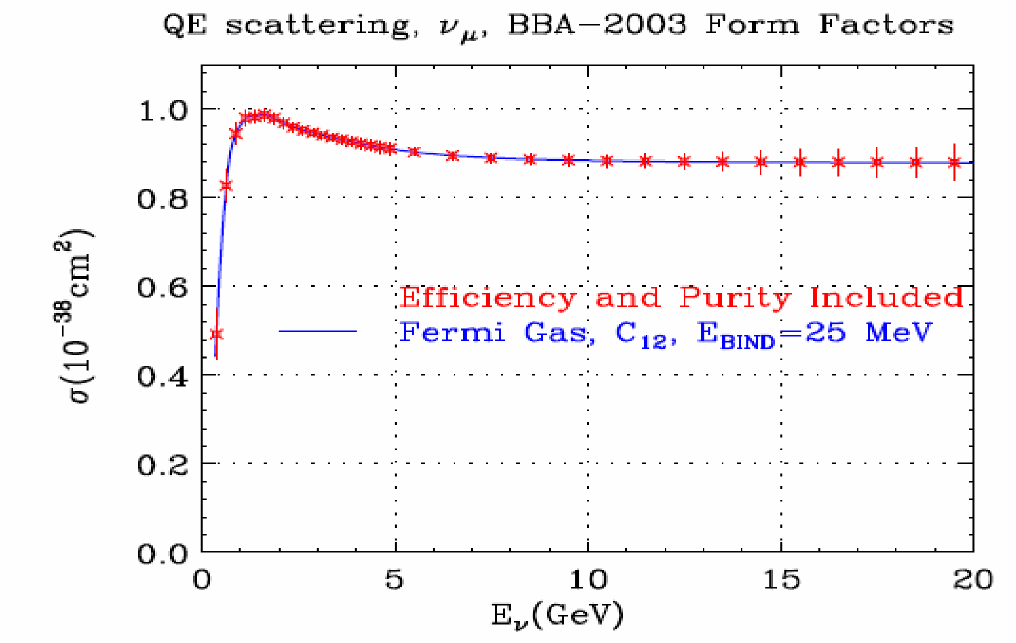
- The dotted curve shows Baker's measurement, not assuming a pure dipole, of M_A with fit value of 1.07 GeV
- If we fit with new values of the vector form factors, we find a shift downward of - .024 GeV.
- The difference between recent form factors and dipole form factors in M_A is -0.049 GeV
- Therefore, recent Jlab data gives accurate vector form factor input to the extraction of the axial vector form factor from MINERνA data



Neutrino Quasi-elastic Cross-sections



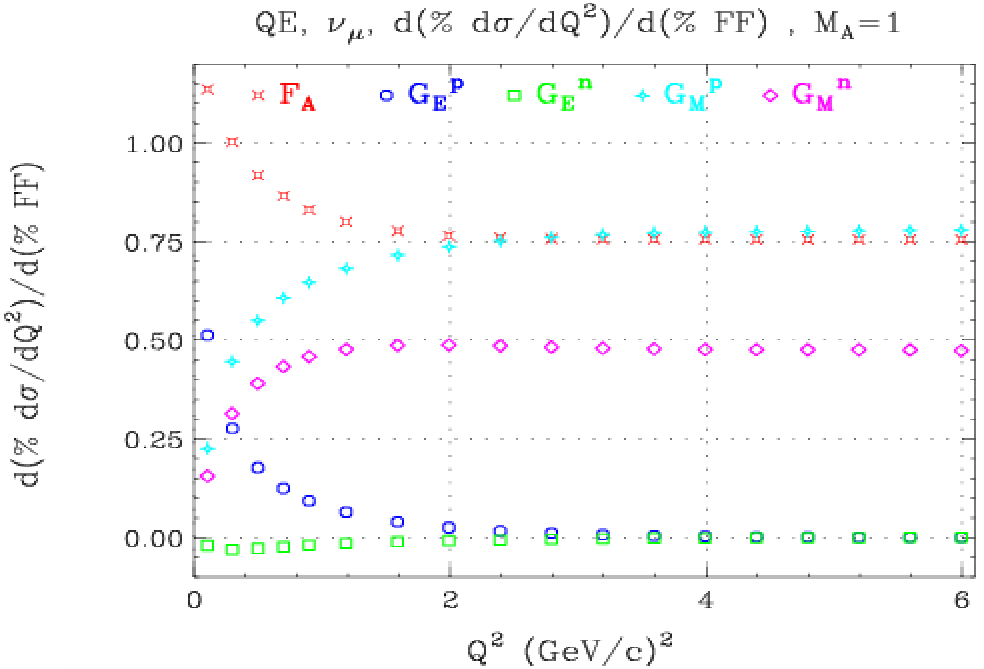
Most of the cross-section measurements for nuclear targets are low



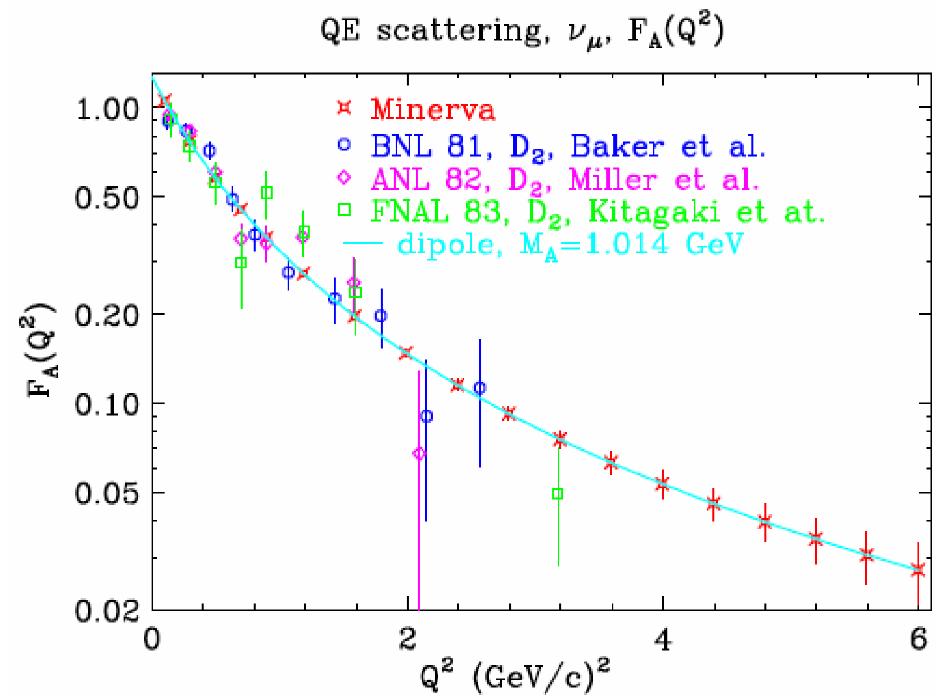
MINERνA

Extracting the axial form factor

- This plot shows the contributions of the form factors to the cross section
  - % change in the cross section vs % change in the form factors
- F_A is a major component of the cross section.

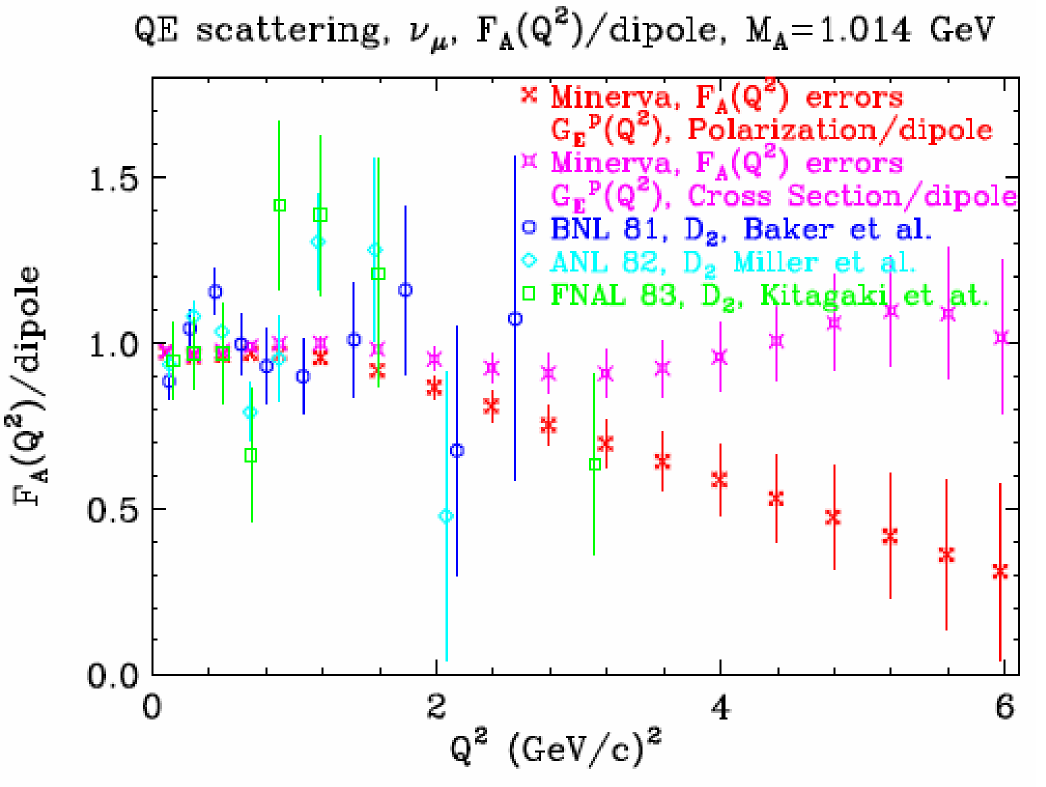


- This plot shows extracted values of F_A for the previous D_2 experiments and -
- The Minerva result for a 4 year run
  - Efficiencies and Purity of sample is included.



Discriminating Power of MINERνA's Extraction of F_A

- For Minerva - show G_E^P for polarization/dipole and G_E^P for cross section/dipole, F_A errors.
  - Including efficiencies and purities.
- Showing also the extraction of F_A from the deuterium experiments.
- Shows that Minerva can determine:
  - if F_A deviates from a dipole
  - Whether the "cross-section" or "polarization" Q^2 form is correct



Summary

- Minerva is a low risk, flexible, modular design that fulfills the physics requirements.
  - Design uses existing technologies.
- Excellent coordinate resolution and particle identification.
- MINERνA can makes precise measurement of axial form factor using vector form factors from JLAB.
- From the previous talk, MINERνA can also measure resonance and coherent cross-sections, study the resonance-DIS transition region, study neutrino-induced nuclear effects and help neutrino oscillation experiments reduce their systematic errors.

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- We welcome additional collaborators.