MINERνA

Introduction, Detector Progress and MRI Proposal

Kevin McFarland
University of Rochester
FNAL PAC Meeting
2 April 2004
The Opportunities

• The NuMI beam and its Near Hall
  – at the intensity frontier of neutrino physics for the latter half of the decade, possibly beyond

• The need to understand GeV neutrino interactions for oscillation experiments
  – and rich physics mine in its own right. “JLab West”

• A community of nuclear and particle physics groups excited about making the measurements
  – many users new to FNAL

• Capable University groups willing to start building
Essence of the MINERνA Detector

- 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 ($\pi^0$, $e^\pm$)
  - high momentum hadrons ($\pi^\pm$, $p$, etc.)
  - $\mu^\pm$ from CC (enough to measure momentum)
- Nuclear targets (high $A$, Fe of interest for MINOS)
Detector Overview

• “Chewy center”: active target (5t total, >3t fiducial)
• “Crunchy shell”: surrounded by calorimeters
  – upstream calorimeters are Pb, Fe targets (~1t each)
  – magnetized side and downstream tracker/calorimeter
Active Target Module

• Planes of strips are hexagonal
  – inner detector: active scintillator strip tracker
  – outer detector: frame, HCAL, spectrometer
  – XUXV planes \(\rightarrow\) module

• atom of construction
  and installation

Inner, fully-active
strip detector

Outer Detector
magnetized sampling
calorimeter
Fully-Active Target: Extruded Scintillator and Optics

Basic element: 1.7x3.3cm triangular strips. 1.2mm WLS fiber readout in groove at bottom

Assemble into planes

• MINERvA optical system

• Key questions: light, PMT box design, clear cables, connectors, extrusion, fiber placement
Optical System Development

Lab 5 Production extrusion facility, die simulation (NIU/FNAL)

“Vertical slice” test detector construction (Hampton)

Fiber routing prototype (Rochester)

Plastic fiber routing sheet (50mil polypropylene)

Notched bars

Inner Det. Bar

HCAL Abs.

Outer Det. Bars

Sweating the fringe fields inside the PMT box (Tufts)

M-64 pixel response

5G 7G

Kevin McFarland, MINERvA Detector

2 April 2004

photo courtesy Northern Today
Electronics/DAQ System

- Data rate is modest
  - 100 kBytes/spill
  - but many sources!
    (~37000 channels)
- Front-end board based on existing TriP ASIC
  - sample and hold in up to four time slices
  - few ns TDC, 2 range ADC
- Token Ring readout scheme to VME board
  - existing design
- VME/PVIC to logger PC
  - archive/online by network
Electronics/DAQ Progress

- Progress on Summer Vertical slice test
  - test of charge digitization, buffering for readout and timing on front-end
  - circuit design complete (April); produced boards (May) (FNAL/Rochester)
  - input will be MAPMTs in MINOS MUX box
    - can test complete slice including a mini-detector (summer ’04)

Re-specified slow controls
- change from MIL-1553
- to less costly Ethernet solution (Irvine/FNAL)

TriP ASIC demonstrated buffering! Now default readout scheme (FNAL)
Mechanical Systems

- ECAL and HCAL absorbers are plates, rings
- OD: 4” and 2” steel between radial sampling layers

Assembly:
- OD frame is support; hold strips and fibers in place (Al retainers)
- “layer cake” construction of planes into a single module
Mechanical Progress

“Hanging ECAL test” (Rochester)
attempting to use harder Pb alloys to reduce cost of ECAL, reduce attachments to OD

Plastic fiber routing sheet (50mil polypropylene) Outer HCAL

Pb Absorber (ECAL)

2 meters

Beginning FEA of structural properties of OD as frame. Also study OD assembly techniques. (FNAL, Rochester, Rutgers)

Identified potential vendors for steel with acceptable B-H. This week! (Rutgers)
The Unique Roles of FNAL in MINER\nuA

- Proposed beam use is parasitic
- But… “detector project” as proposed also has places where only FNAL can contribute
  - EDIA for Front-End board
    (TriP-based design builds on work on D0 electronics)
  - Critical safety items
    - magnet coil and its power supply and cooling
    - detector stand. LV supply and distribution
  - Utilities and installation
  - Safety and oversight of on-site activities
  - Space!

impact!
E.g., Model for Installation Procedure

Similar to MINOS Near Detector:
- Assemble “modules” on surface
  - Mostly University Technicians, Fermilab oversight and space.
  - 6 months prototyping
  - 12 months assembly
- Install final stand in MINOS
- Bring modules down the shaft using strongback and cart: max load 5.3 tons
  - 2 “modules” a day for most of detector
  - 1 “module” plus 6 Fe planes/day for µ ranger
  - Physicists commission after each layer installed
- Low voltage, coil, and coil power supply installed by Fermilab folks

<table>
<thead>
<tr>
<th>Detector Region</th>
<th>Modules</th>
<th>Tons per module</th>
<th>Time to install (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Detector</td>
<td>30</td>
<td>3.6</td>
<td>15</td>
</tr>
<tr>
<td>US ECAL</td>
<td>6</td>
<td>3.8</td>
<td>3</td>
</tr>
<tr>
<td>US HCAL</td>
<td>4</td>
<td>3.9</td>
<td>2</td>
</tr>
<tr>
<td>DS ECAL</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>DS HCAL</td>
<td>5</td>
<td>5.3</td>
<td>5</td>
</tr>
<tr>
<td>Muon Ranger</td>
<td>3+18 Fe Planes</td>
<td>3.6</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>31</strong></td>
</tr>
</tbody>
</table>
## FNAL Impact Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>Design</th>
<th>Fabrication</th>
<th>Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Strongback</td>
<td>2mos, 22k</td>
<td>2wks, 12.5k</td>
<td>n/a</td>
</tr>
<tr>
<td>Transport Cart</td>
<td>n/a</td>
<td>n/i</td>
<td>2k</td>
</tr>
<tr>
<td>Detector Stand+Bookend+Drip</td>
<td>5 wks, 21k</td>
<td>68k</td>
<td>3 wks 73k</td>
</tr>
<tr>
<td>Detector</td>
<td>59k (installation plan)</td>
<td>1.5yr, 95k</td>
<td>7wks 85k</td>
</tr>
<tr>
<td>Magnet Coil and Cooling</td>
<td>n/i</td>
<td>n/i</td>
<td>6 wks 70k</td>
</tr>
<tr>
<td>Electronics (inc. Trip Chip)</td>
<td>1yr, 130k</td>
<td>n/i</td>
<td>(2k FNAL)</td>
</tr>
<tr>
<td>Magnet Power Supply</td>
<td>n/a</td>
<td>Already built</td>
<td>12k+22k</td>
</tr>
<tr>
<td>Quiet Power (low voltage supply)</td>
<td>3 mos, 33k</td>
<td>bought</td>
<td>24k+8k</td>
</tr>
<tr>
<td>Alignment</td>
<td>n/a</td>
<td>3.5k</td>
<td>7k</td>
</tr>
<tr>
<td>Safety Review/Inspection/Managm.</td>
<td>1 mo, 11k</td>
<td>14k</td>
<td>104k</td>
</tr>
<tr>
<td>Total</td>
<td>272k</td>
<td>193k</td>
<td>415k</td>
</tr>
</tbody>
</table>

Design work: engineers, Fabrication: welders, machinists, Installation: Riggers

- Impact review (29 March) concluded, in part, need to add 40% contingency
MRI Submission

- A consortium of MINERvA US Universities submitted an MRI proposal this January
  - Hampton, IIT, Irvine, James Madison, NIU, Pittsburgh, Rochester, Rutgers, Tufts
- Funds all construction costs except FNAL “Unique roles”
- Proposal is to construct only a fraction of MINERvA (limited by $2M MRI cap + University contributions)
  - modules could run standalone with MINOS as both HCAL and muon catcher
  - MRI does fund all EDIA, startup items needed for detector factories
MRI Status

• It is out for review.
  – Expect a decision by summer.

• It is abundantly clear that we will not receive MRI funding to build this detector if there is not a commitment to the experiment by FNAL.

• If it has this commitment, we believe the physics program gives us an excellent chance of success…
The MINERνA Experiment: Physics Topics

Jorge G. Morfín
Fermilab
MINER$\nu$A will have the statistics to cover a wide variety of important $\nu$ physics topics

Assume $9 \times 10^{20}$ POT: $7.0 \times 10^{20}$ in LE $\nu$ beam, $1.2 \times 10^{20}$ in sME $\nu$ beam and $0.8 \times 10^{20}$ in sHE $\nu$ beam

<table>
<thead>
<tr>
<th>$\nu_\mu$ Event Rates per fiducial ton</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>CC</td>
</tr>
<tr>
<td>Quasi-elastic</td>
<td>103 K</td>
</tr>
<tr>
<td>Resonance</td>
<td>196 K</td>
</tr>
<tr>
<td>Transition</td>
<td>210 K</td>
</tr>
<tr>
<td>DIS</td>
<td>420 K</td>
</tr>
<tr>
<td>Coherent</td>
<td>8.4 K</td>
</tr>
<tr>
<td>TOTAL</td>
<td>940 K</td>
</tr>
</tbody>
</table>

Typical Fiducial Volume = 3-5 tons CH, 0.6 ton C, $\approx$ 1 ton Fe and $\approx$ 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

Main Physics Topics with Expected Produced Statistics

- **Quasi-elastic** - $\nu+n \rightarrow \mu^-+p$ - 300 K events off 3 tons CH
- **Resonance Production** - e.g. $\nu+N \rightarrow \nu/\mu^-+\Delta$ 600 K total, 450K $1\pi$
- **Coherent Pion Production** - $\nu+A \rightarrow \nu/\mu^-+A+\pi$, 25 K CC / 12.5 K NC
- **Nuclear Effects** - C: 0.6M events, Fe: 1M and Pb: 1 M
- **$\sigma_T$ and Structure Functions** - 2.8 M total /1.2 M DIS events
- **Strange and Charm Particle Production** - ($>60$ K **fully** reconstructed events)
- **Generalized Parton Distributions** - (few K events?)

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**MINER$\nu$A and Oscillation Physics - Debbie Harris**

Fermilab PAC: MINER$\nu$A - 2 April 2004
Quasi-elastic $\nu$ Scattering

MINERvA: 300 K events off CH and over 100 K off of Fe and Pb produced

H. Budd and K. McFarland

Include Selection Criteria
- 1 or 2 tracks for $Q^2 < 1$ GeV$^2$ and 2 tracks for $Q^2 > 1$ GeV$^2$
- 1 long non-interacting track consistent with muon
- $Q^2\mu - 2M\nu / \text{error} < 2.0$ ($x_B$ consistent with 1.0)
- $Q^2$-dependent missing $p_T$ cut
- minimal number of hits in event not associated with $\mu$ or $p$

Errors based on produced statistics
- Fermi Gas, $C_{12}$, $E_{\text{END}} = 25$ MeV

Expected MiniBooNe and K2K measurements

Average: eff. = 74% and purity = 77%

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Extraction of $F_A$ with Selected Sample

Note that, even with the larger errors of the selected sample, MINERvA will have the statistics and $Q^2$ range to distinguish between the two different suggested $Q^2$ behaviors.
Selection criteria reduce the signal by a factor of three - while reducing the background by a factor of ≈ 1000.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Signal</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Visible Charged Tracks</td>
<td>3856</td>
<td>3693</td>
</tr>
<tr>
<td>π^+/π^- &lt; 500 MeV</td>
<td>3124</td>
<td>3360</td>
</tr>
<tr>
<td>Track separation</td>
<td>2420</td>
<td>500</td>
</tr>
<tr>
<td>x&lt;0.2</td>
<td>2223</td>
<td>100</td>
</tr>
<tr>
<td>t&lt;0.2</td>
<td>2223</td>
<td>19</td>
</tr>
<tr>
<td>p_t &gt; 600 MeV</td>
<td>1721</td>
<td>12</td>
</tr>
<tr>
<td>Fudge factor factor</td>
<td>(0.65)</td>
<td>~</td>
</tr>
<tr>
<td>Normalized</td>
<td>5004</td>
<td>4400</td>
</tr>
</tbody>
</table>

Resulting sample is ≈ 5 K CC coherent events
Expected MINERνA Results - Coherent π Production

Errors now include estimated background subtraction

\[ \sigma(\nu_\mu + A \rightarrow \mu^- + \pi^+ + A) \]

Expected MINERνA, MiniBooNe, and K2K measurements

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Resonance Production - $\Delta$

S. Wood and M. Paschos

Total Cross-section and $d\sigma/dQ^2$ for the $\Delta^{++}$ assuming 50% detection efficiency
Errors are statistical only: 175K $\Delta^{++}$
Resonance Production - Nuclear Effects

Adler, Nusinov, Paschos model (1974)

1. **single pion production** in $\nu N$ scattering
   $\rightarrow$ Pauli Principle, Fermi motion
2. **multiple scattering** of pions
   $\rightarrow$ Charge exchange, absorption, Pauli Principle

- charge exchange matrix $M$ for isoscalar targets
  
  $M = M^T, \sum_j M_{ij} = A_p, M_{+0} = M_{-0} \rightarrow 3$ param, $A_p, d, c$

  $M = A_p \begin{pmatrix}
  1 - c - d & d & c \\
  d & 1 - 2d & d \\
  c & d & 1 - c - d
  \end{pmatrix}$

- $\pi^+$ cross section is **largely reduced** (up to 40%) $\leftrightarrow$ charge exchange $M$
- $\pi^0$ cross sections is **slightly increased** by the nuclear corrections

One obvious omission, this model does not include **hadron formation length corrections**

MINER$\nu$A can measure $L_H$ off of C, Fe and Pb

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Nuclear Effects

MINERvA: 2.8 M events off CH, 600 K off C and 1 M events off of Fe and Pb

S. Boyd, JGM, R. Ransome

All “known” nuclear effects taken into account: Pauli suppression, Fermi Motion, Final State Interactions

They have not included low-ν shadowing that is only allowed with axial-vector (Boris Kopeliovich at NuInt04)

\[ L_c = \frac{2\nu}{m_\pi^2 + Q^2} \geq R_A \quad (\text{not } m_A^2) \]

\[ L_c \text{ 100 times shorter with } m_\pi \text{ allowing low } \nu-\text{low } Q^2 \text{ shadowing} \]

ONLY MEASURABLE VIA NEUTRINO - NUCLEUS INTERACTIONS! MINERvA WILL MEASURE THIS ACROSS A WIDE ν AND Q² RANGE WITH C : Fe : Pb
Example: MINERvA Sensitivity to Nuclear Effects

Use NEUGEN Monte Carlo model to study π intranuclear scattering and absorption

D. Harris

Study effects of π absorption

\[
\frac{E_{\text{Had}} (+3\sigma) - E_{\text{Had}} (-3\sigma)}{E_{\text{Had}} (-3\sigma)}
\]

E. Had (Fe) vs. Reconstructed \(E_{\text{Re}} \text{(GeV)} \) (Lead target)

Study π rescattering as \( f(A) \)

\[
\begin{align*}
\text{Fe} & : 0.1 \pm 0.01 \\
\text{Pb} & : 0.07 \pm 0.005
\end{align*}
\]
If we take the projected MINERvA results, how could it improve Neutrino Oscillation Experiments?

Deborah Harris
Fermilab
Challenges of Oscillation Measurements

- MINOS measurement of $\Delta m^2$
  - need a wide band beam to do this
  - need to understand the relationship between the incoming neutrino energy and the visible energy in the detector
- NOvA search for $\nu_\mu \rightarrow \nu_e$
  - Must have accurate prediction for backgrounds
  - Once a signal is seen, it’s extracting a probability
- NOvA precision measurement of $\sin^2 2\theta_{23}$
  - Have to predict NC background
How Nuclear Effects enter $\Delta m^2$ Analyses

**Measurement of $\Delta m^2$ (e.g. MINOS)**

- Need to understand the relationship between the incoming neutrino energy and the visible energy in the detector

  - Improve understanding of pion and nucleon absorption
  - Understand intra-nuclear scattering effects
  - Understand how to extrapolate these effects from one A to another
  - Improve measurement of pion production cross-sections
  - Understand low-$\nu$ shadowing with neutrinos
How Nuclear Effects enter MINOS $\Delta m^2$ Measurement

**Before MINERvA:**
- pion absorption measured on Neon
- All nuclear effects extrapolated from low A

**After MINERvA:**
- pion absorption and rescattering measured on steel,
- No extrapolation necessary!
Measuring $\nu_\mu \rightarrow \nu_e$ at NOvA

Assuming 50kton, 5 years at $4 \times 10^{20}$ POT, $\Delta m^2 = 2.5 \times 10^{-3}$ eV$^2$

<table>
<thead>
<tr>
<th>Process</th>
<th>Events</th>
<th>QE</th>
<th>RES</th>
<th>COH</th>
<th>DIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta \sigma/\sigma$</td>
<td>20%</td>
<td>40%</td>
<td>100%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Signal $\nu_e$</td>
<td>175</td>
<td>55%</td>
<td>35%</td>
<td>n/i</td>
<td>10%</td>
</tr>
<tr>
<td>At $\sin^2 2\theta_{13} = 0.1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>15.4</td>
<td>0</td>
<td>50%</td>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>$\nu_\mu$ CC</td>
<td>3.6</td>
<td>0</td>
<td>65%</td>
<td>n/i</td>
<td>35%</td>
</tr>
<tr>
<td>Beam $\nu_e$</td>
<td>19.1</td>
<td>50%</td>
<td>40%</td>
<td>n/i</td>
<td>10%</td>
</tr>
</tbody>
</table>

For large $\sin^2 2\theta_{13}$, statistical = 8%
For small $\sin^2 2\theta_{13}$, statistical = 16%

ND sees very different fluxes
Compared to FD, regardless of Off axis angle of ND!

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How MINERνA Would Help NOνA: 
Once a Signal is seen...

Assume Energy Dependence
Perfectly known….vary σ levels

Regardless of NOνA Near Detector
Location, large errors in extrapolation
To far detector....
How MINERνA Would Help NOνA:
Once a Signal is seen…

Total fractional error in the predictions as a function of Near Detector off-axis Angle

Current Accuracy of Cross-sections
\[ \Delta QE = 20\% \]
\[ \Delta RES = 40\% \]
\[ \Delta DIS = 20\% \]
\[ \Delta COH = 100\% \]

With MINERνA Measurements of \( \sigma \)
\[ \Delta QE = 5\% \]
\[ \Delta RES = 5, 10\% (CC, NC) \]
\[ \Delta DIS = 5\% \]
\[ \Delta COH = 20\% \]

Without MINERνA measurements of \( \sigma \),
oscillation probability measurement could be limited by systematics!

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Summary

◆ MINERνA brings together the expertise of the HEP and NP communities to address the challenges of low-energy ν-A physics.

◆ MINERνA will accumulate significantly more events in important exclusive channels across a wide $E_\nu$ range than currently available.

◆ MINERνA will enable a systematic study of nuclear effects in ν-A interactions, known to be different than well-studied e-A channels.

◆ MINERνA results will dramatically improve the systematic errors of current and future neutrino oscillation experiments.
Backup Slides
How MINERνA Helps NovA Background Predictions

Assume Energy Dependence
Perfectly known….vary σ levels

Same study, but with MINERνA precision

Regardless of NOνA Near Detector location, large errors in extrapolation to far detector.
How MINERνA Helps NovA
Background Predictions

Total fractional error in the background predictions as a function of Near Detector off-axis Angle

Current Accuracy of Cross-sections
\[ \Delta \text{QE} = 20\% \]
\[ \Delta \text{RES} = 40\% \]
\[ \Delta \text{DIS} = 20\% \]
\[ \Delta \text{COH} = 100\% \]

With MINERνA Measurements of \( \sigma \)
\[ \Delta \text{QE} = 5\% \]
\[ \Delta \text{RES} = 5, 10\% \text{ (CC, NC)} \]
\[ \Delta \text{DIS} = 5\% \]
\[ \Delta \text{COH} = 20\% \]

With MINERνA measurements of \( \sigma \), decrease fractional error on background prediction again by a factor of FOUR
Strange and Charm Particle Production

- Theory: Initial attempts at a predictive phenomenology stalled in the 70’s due to lack of constraining data.

- MINERvA will focus on exclusive channel strange particle production - fully reconstructed events (small fraction of total events) but still.

- Important for background calculations of nucleon decay experiments

- With extended ν running could study single hyperon production to greatly extend form factor analyses

- New measurements of charm production near threshold which will improve the determination of the charm-quark effective mass.

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Existing Strange Particle Production
Gargamelle-PS - 15 Λ events. FNAL - ≈ 100 events
ZGS - 7 events BNL - 8 events
Larger NOMAD inclusive sample expected

MINERvA Exclusive States
100x earlier samples
3 tons and 4 years

ΔS = 0

\[
\begin{align*}
\mu^- K^+ \Lambda^0 & : 10.5 \text{ K} \\
\mu^- \pi^0 K^+ \Lambda^0 & : 9.5 \text{ K} \\
\mu^- \pi^+ K^0 \Lambda^0 & : 6.5 \text{ K} \\
\mu^- K^- K^+ p & : 5.0 \text{ K} \\
\mu^- K^0 K^+ \pi^0 p & : 1.5 \text{ K}
\end{align*}
\]

ΔS = 1

\[
\begin{align*}
\mu^- K^+ p & : 16.0 \text{ K} \\
\mu^- K^0 p & : 2.5 \text{ K} \\
\mu^- \pi^+ K^0 n & : 2.0 \text{ K}
\end{align*}
\]

ΔS = 0 - Neutral Current

\[
\begin{align*}
v K^+ \Lambda^0 & : 3.5 \text{ K} \\
v K^0 \Lambda^0 & : 1.0 \text{ K} \\
v K^0 \Lambda^0 & : 3.0 \text{ K}
\end{align*}
\]
High-$x_{Bj}$ Parton Distribution Functions

- The particular case of what is happening at high-$x_{Bj}$ is currently a bit of controversial with indications that current global results are not correct.

- Drell-Yan production results (E-866) may indicate that high-$x_{Bj}$ (valence) quarks **OVERESTIMATED**.

- A Jlab analysis of Jlab and SLAC high $x$ DIS indicate high-$x_{Bj}$ quarks **UNDERESTIMATED**.

- CTEQ / MINERvA working group to investigate high-$x_{Bj}$ region.

- MINERvA will have over 1.2 M DIS events to study high-$x_{Bj}$ Close examination of the non-PQCD and pQCD transition region, in context of quark-hadron duality, with axial-vector probe.
Nuclear Effects

◆ Modified Interaction Probabilities

♦ Shadowing Region ($x_{Bj} < 0.1$): Expect a difference in comparison to $e/\mu$ - nucleus results due to axial-vector current and quark-flavor dependent nuclear effects.

♦ EMC-effect ($0.2 < x_{Bj} < 0.7$): depends on explanation of the effect

♦ Fermi Motion Effect ($x_{Bj} > 0.7$): should be the same as $e$-nucleus scattering

♦ With sufficient $\bar{\nu}$: measure flavor dependent effects.

◆ NC/CC off C, Fe and Pb

♦ Over 100 K CC and 30 K NC with $E_H > 5$ GeV on Fe and Pb, times 3 for Carbon.

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Modular Design

• a necessary part of installation in NuMI near hall is that detector should be constructed in thin modules
  – each module consists of *four planes* of active inner detector, absorbers and outer detector

• flexibility in design
  – MINERvA can run stand-alone
  – or can use MINOS as long muon catcher
Active Target Module

- Rotate 60° to get U,V views
  - X+U+X+V make a module, bolted together
  - module is unit of construction and installation
Calorimeters

• Three types of calorimeters in MINERνA
  – ECAL: between each sampling plane, 1/16” Pb laminated with 10mil stainless ($\chi_0/3$)
  – HCAL: between each sampling plane, 1” steel ($\lambda_0/6$)
  – OD: 4” and 2” steel between radial sampling layers

• ECAL and HCAL absorbers are plates, rings
Calorimeters (cont’d)

- OD: 4” and 2” steel between radial sampling layers
  - coil at bottom of the detector provides field in steel
Extruding Scintillator

- Process is inline continuous extrusion
  - improvement over batch processing (MINOS)

- Tremendous capacity at Lab 5
  - the 18 tons of MINERνA in < 2 months, including startup and shutdown time
Extruding Scintillator (cont’d)

• Design of the die in order to achieve the desired scintillator profile
  – collaboration with NIU Mech. E. department (Kostic and Kim)

2x1cm rect. die developed at NIU for Lab 5

Simulation of performance (design tool)
PMT Boxes

• Design is similar to MINOS MUX boxes
  – but no MUX!
• Mount on detector
  – minimizes clear fiber length
Fiber Routing

- Downside of design: getting fibers from inner detector to outside is complicated
  - built a 1/6 hexagon prototype to study (Rochester)
Fiber Routing (cont’d)

- Fibers are not infinitely flexible
  - but must route outer and inner detector fibers around the absorber/frame

fibers must bend up (out of plane) and to outside of detector
Front-End Electronics

• FE Readout Based on existing TriP ASIC
  – builds on FNAL work. existing submission “free”.
  – ADC (dual range) plus few ns resolution timing

• TriP ASIC provides sample and hold slices
  – four-sample mode works on bench; this is our default
  – each time over threshold also recorded in spill
Electronics / Vertical Slice Test

Phase 1: Testing the TriP Chip

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

Reads out 16 channels of a MINOS M64 in a spare MINOS PMT box (coming from MINOS CalDet)

Questions:

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

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?
2. Spatial resolution via light sharing in a plane
3. Timing
4. Uniformity

Early summer
Late summer

2 April 2004
Kevin McFarland, MINERvA Detector
**Light Yield**

- **Critical question:** does light yield allow for low quantum efficiency photosensor?
- **Study:** use MINOS light MC, *normalized to MINOS results*, MINERνA strips
- **Need** roughly 5-7 PEs for reconstruction
- **Must mirror fibers!**
Fiber Processing

• Mirrors are clearly necessary
  – Lab 7 vacuum deposition facility (E. Hahn)

• Fibers (WLS, clear) bundled in connectors
  – working with DDK to develop an analog to MCP-10x series used in CDF plug upgrade
  – polishing also most effectively done at FNAL

• MRI proposal included costs for contracting FNAL effort through Universities
Magnet Coil

- Design: using ARMCO specialty steel (MINOS)
  - B of 1.6T, H ~ 30 Gauss

- 48 turn coils
  - 700 Amps in OD
  - 1200 Amps in MR
  - Assume 1cm$^2$ wire
    (with hole for cooling)
Location in NuMI Near Hall

- MINERvA preferred initial running is as close to MINOS as possible
  - if this is not possible, we can run initially stand-alone elsewhere in the hall with muon ranger necessary
Utilities

- Quiet Power
  (3kW draw, add 175kVA transformer)
- Magnet Coil Power (240kW PEI supply)
- Cooling (c.f., MINOS 120kW)
  - Magnet coil heat loss expected: 30kW
  - Magnet power supply 10kW
  - Electronics: Rack 2kW, PMT boxes: 4kW
## Summary of Design Tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Division</th>
<th>Personnel</th>
<th>Time</th>
<th>Cost (k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Procedure</td>
<td>PPD</td>
<td>Mech. Eng. Drafting</td>
<td>4 months</td>
<td>45</td>
</tr>
<tr>
<td>Detector Stand for Near Hall (incl. Bookend and Drip protection)</td>
<td>PPD</td>
<td>Engineer Draftsman</td>
<td>5 weeks</td>
<td>13</td>
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<tr>
<td>Strongback for module transport</td>
<td>PPD</td>
<td>Mech. Eng. Drafting</td>
<td>1 month</td>
<td>11</td>
</tr>
<tr>
<td>Review of Module Assembly procedure</td>
<td>PPD</td>
<td>Mech. Eng.</td>
<td>1 month</td>
<td>11</td>
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<tr>
<td>Low Voltage System (5kW)</td>
<td>PPD</td>
<td>Elec. Eng.</td>
<td>3 months</td>
<td>33</td>
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<tr>
<td>TriP-chip front-end board</td>
<td>PPD</td>
<td>Elec. Eng.</td>
<td>12 months</td>
<td>130</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>272</strong></td>
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</table>
# Fabrication

Modules would be assembled on site (NMS)

<table>
<thead>
<tr>
<th>Task</th>
<th>Division</th>
<th>Personnel</th>
<th>Time</th>
<th>Cost (k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Stand for Near Hall</td>
<td>PPD</td>
<td>See statement table 4</td>
<td>See statement table 4</td>
<td>52</td>
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<tr>
<td>(incl. Bookend and Drip protection)</td>
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<td></td>
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<tr>
<td>Detector Stands Material (≈ 16 tons)</td>
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<tr>
<td>Installation Strongback Fabrication</td>
<td>PPD</td>
<td>Technicians</td>
<td>2 weeks</td>
<td>11</td>
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<tr>
<td>Strongback Material</td>
<td></td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Strongback safety oversight</td>
<td>ES&amp;H</td>
<td>Engineer</td>
<td>2 days</td>
<td>1</td>
</tr>
<tr>
<td>Module Assembly Prototyping</td>
<td>PPD</td>
<td>Safety oversight</td>
<td>0.1FTE x 6 months</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Welder</td>
<td>0.2FTE x 6 months</td>
<td>15</td>
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<tr>
<td></td>
<td></td>
<td>Crane Operator</td>
<td>0.2FTE x 6 months</td>
<td>8</td>
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<tr>
<td>Module Assembly</td>
<td>PPD</td>
<td>Same at prototype</td>
<td>12 months</td>
<td>72</td>
</tr>
<tr>
<td>Internal Alignment</td>
<td>PPD</td>
<td>Survey Crew</td>
<td>1 week</td>
<td>3.5</td>
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<tr>
<td>Total</td>
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<td>193</td>
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<tr>
<td>Task</td>
<td>Division</td>
<td>Personnel</td>
<td>Time</td>
<td>Cost (k$)</td>
</tr>
<tr>
<td>-----------------------------------------</td>
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<td>------------</td>
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</tr>
<tr>
<td>Installation Manager</td>
<td>PPD</td>
<td>1 engineer</td>
<td>4 months</td>
<td>44</td>
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<tr>
<td>Bookend</td>
<td>PPD</td>
<td>2+1 Riggers</td>
<td>2 days</td>
<td>4</td>
</tr>
<tr>
<td>Transport Cart</td>
<td>PPD</td>
<td>2+1 Riggers</td>
<td>1 day</td>
<td>2</td>
</tr>
<tr>
<td>Detector Stand</td>
<td>PPD</td>
<td>See Impact table 4</td>
<td>Table 4</td>
<td>52</td>
</tr>
<tr>
<td>Module Installation</td>
<td>PPD</td>
<td>2 + 1 riggers, 2 technicians</td>
<td>7 weeks, 7 weeks</td>
<td>77</td>
</tr>
<tr>
<td>Electronics rack</td>
<td>PPD</td>
<td>1 rigger</td>
<td>0.5 day</td>
<td>0.7</td>
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<tr>
<td>PMT Boxes down shaft</td>
<td>PPD</td>
<td>1 rigger</td>
<td>0.5 day</td>
<td>0.7</td>
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<tr>
<td>PMT Boxes on Detector</td>
<td>Experimenters</td>
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<td></td>
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<tr>
<td>Magnet Coil and Cooling</td>
<td>PPD</td>
<td>4 tech crew</td>
<td>6 weeks</td>
<td>70</td>
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<tr>
<td>Refurbish Magnet PS</td>
<td>PPD</td>
<td>Techs, riggers</td>
<td>1 week</td>
<td>22</td>
</tr>
<tr>
<td>Install Magnet PS</td>
<td>PPD</td>
<td>2 tech crew, riggers</td>
<td>1 week</td>
<td>12</td>
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<tr>
<td>Quiet Power Panel Boards</td>
<td>PPD</td>
<td>Techs &amp; electricians (2)</td>
<td>2-4 weeks</td>
<td>24</td>
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<tr>
<td>Install M&amp;S</td>
<td>PPD</td>
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<td>8</td>
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<tr>
<td>Accelerator Controls/GPS</td>
<td>AD</td>
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<tr>
<td>Possible Readout Platform Mod. M&amp;S</td>
<td>PPD</td>
<td>4 techs</td>
<td>3 days</td>
<td>1.2</td>
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<tr>
<td></td>
<td>PPD</td>
<td></td>
<td></td>
<td>8.7</td>
</tr>
<tr>
<td>Survey</td>
<td>PPD</td>
<td>Survey crew (3)</td>
<td>2 weeks</td>
<td>7</td>
</tr>
<tr>
<td>Safety Reviews</td>
<td>PPD</td>
<td>6 Safety officers (engineers)</td>
<td>1 week</td>
<td>60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>415</strong></td>
</tr>
</tbody>
</table>
Detector Cost Summary

- Costs are primarily scaled from experience of MINERvA collaborators on CMS HCAL, MINOS
  - $2.55M equipment (no F&A)
  - $1.41M labor, EDIA
  - $1.54M contingency (39% avg.)
- Full project costs not updated since proposal
  - MRI exercise was consistent with this costing (ex: steel)
Construction Model

- Our goal is that detector construction be managed and carried out by University collaborators.
Known Technical Risks

• Light Yields
  – we are not swimming in light
  – problem may be exacerbated by need to use center hole with air coupling
  – larger diameter fiber

• Steel
  – have not located a vendor for MINOS quality magnetic steel
  – global steel costs have “gone mad”
  – it’s just $$$, but may be significant
Known Technical Risks (cont’d)

• Fringe Field at PMT
  – need to keep field at PMT to <5 Gauss
  – *increase shielding for optical boxes.*

• TriP multiple time slices could fail
  – *fallback is to integrate over spill.* Survivable.
Schedule

• Schedule for MRI detector: ~20 months from start
  – MRI schedule is our only schedule exercise with “contingency”

• Scaling to full detector…
  – schedule dominated by module assembly
  – we believe that stretches from six months to twelve months
    • with larger crew
  – PMT boxes may also vie for critical path
Costing Methodology

- most of our costs could be scaled from similar construction products in MINOS or CMS HCAL where *MINERνA collaborators have hands-on experience*
  - FE electronics boards. TRiP bottoms-up costs were significantly lower than analogous MINOS board costs. Used MINOS
  - PMT box costs scaled from MINOS far MUX boxes
  - MINOS costs for most electronics infrastructure, LV, slow
  - Optical cable, connectors, fiber mirroring from CMS HCAL
  - Gluing, extrusion costs from MINOS
  - Absorber costs based on preliminary sketches from Rutgers machine shop
  - Fiber, MAPMTs quoted from vendors (Kurary, Hamamatsu)

- Contingency: 40-50%
  - except Rutgers shop (30%) and vendor quotes (20%)
Schedule Comments

• Schedule estimates are still tentative
  – assembly schedule is more difficult to scale from past projects than M&S costs
• Module assembly is most uncertainty
  – estimate ~6 months of prototyping and one year of assembly
  – need to improve model for assembly procedure
  – this is focus of EDIA work at Rochester
• PMT boxes
  – Tufts group has scaled from MINOS; should be OK.
• FE electronics
  – scaling from D0 TriP project is probably accurate. Need EDIA and prototyping now (underway, FNAL PPD/Rochester)
• Only obvious resource limit in critical path is ability to expend money at the start of the project for fixed costs and absorber M&S
  – and, of course, the flow of cash…