MINERνA (E-938)

Goals, Progress and Project

Kevin McFarland
University of Rochester
FNAL PAC Meeting
7 April 2005
MINERvA in a Nutshell

• MINERvA is a dedicated neutrino cross-section experiment operating in the NuMI near hall
  – in a unique position to provide critical input for world neutrino oscillation program
    • “neutrino engineering” for NuMI program et al.
  – provides an opportunity for studies of proton structure and nuclear effects in axial current
    • “Jefferson Lab west”
  – MINERvA has Stage One approval, and is poised to complete R&D and start construction
HEP/NP Partnership

- This effort has sparked effort in NP community beyond our collaborators…
- JLab approved experiment (JUPITER)
  - data for neutrino cross-section modeling
- Now it’s our turn!!

Neutrino Physics Comes to JLab
The inner workings of the sun, the mysteries of dark matter and dark energy and the structure of the early universe all may be unlocked by one cosmic key: neutrinos. Now, new research carried out in Jefferson Lab's experimental Hall C may help provide insight into neutrinos, the force that governs their behavior and, surprisingly, the structure of the nucleus of the atom.►

from the JLab homepage today…
uniqueness...
NuMI: Unique in the World

- no near hall, limited energy range
- no near hall
- near detectors off-axis in E~700 MeV beam

Tunable, broadband beam energy from resonance to deep inelastic regime, spacious near hall, poised for a long run…
relevance...
MINERvA and Oscillations

The recent *APS Multidivisional Neutrino Study Report* predicated its recommendations on a set of assumptions about current and future programs including: support for current experiments, international cooperation, underground facilities, R&D on detectors and accelerators, and

“determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino-oscillation physics and the neutrino astronomy of astrophysical and cosmological sources. Our broad and exacting program of neutrino physics is built upon precise knowledge of how neutrinos interact with matter.”
Why do we need to know more about neutrino cross-sections?

- At 1-few GeV neutrino energy (of interest for osc. expt’s)
  - Experimental errors on total cross-sections are large
    - almost no data on A-dependence
  - Understanding of backgrounds needs differential cross-sections on target
  - Theoretically, this region is a mess… transition from elastic to DIS
MINERvA and Cross-Sections

- Measurements unique to MINERvA
  - high $Q^2$ axial form factor of nucleon
    (complementary to high $Q^2$ vector FF, hot at JLab)
  - coherent cross-sections vs. energy
    (exploit resolution, fully active containing detector)
  - differential dists. for exclusive final states
    (multi-purpose containing detector, high statistics)
  - A-dependence of:
    - low $Q^2$ elastic (K2K/MiniBooNE “low $Q^2$ problem”?)
    - exclusive final states (nuclear re-interactions)
    - deep inelastic scattering ($F_2^\nu$, $xF_3^\nu$)
Sample Expected Results

Axial Form Factor at high $Q^2$: two models with MINERvA errors

F2, Pb/C, with MINERvA errors

A-dependence of coherent pion production: two models with MINERvA errors
how does this apply to oscillations?
Oscillation Measurements and Neutrino Interaction Uncertainties

• Current Generation’s Primary Goal:
  – Precise $\Delta m^2$ measurement from $\nu_\mu$ disappearance measurements vs. neutrino energy
  – Biggest systematic concern: how do you know you’re really measuring the energy correctly?

• Next Generation’s Primary Goal:
  – Search for $\nu_\mu \rightarrow \nu_e$ transitions at one neutrino energy
  – Biggest systematic concern:
    • Predicting Background accurately
    • At first, claiming discovery based on an excess above background!
    • Later, precision measurements with neutrinos and anti-neutrinos

• Next Generation’s “guaranteed” measurement
  – More precise $\Delta m^2$ measurement, if you can understand the backgrounds in narrow band beam

MINOS

NOvA, T2K
How MINOS will use MINER\(\nu\)A

- Visible Energy in Calorimeter is NOT \(\nu\) energy!
  - \(\pi\) absorption, rescattering
  - final state rest mass

Nuclear Effects Studied in Charged Lepton Scattering, from Deuterium to Lead, at High energies, but nuclear corrections may be different between e/\(\mu\) and \(\nu\) scattering
How NO\(\nu\)A will use MINER\(\nu\)A Measurements

Without MINER\(\nu\)A, NO\(\nu\)A risks being limited by cross section uncertainties

7 April 2005
K. McFarland, Status of MINER\(\nu\)A
How will T2K use MINERvA measurements

Note that as in NOvA, T2K’s near detector will be a very different mix of events than the far detector.

To make accurate prediction, need

- 1 - 4 GeV neutrino cross sections
- Energy Dependence of cross sections

MINERvA can provide these with NuMI beamline Low Energy running!
What about Near Detectors?

- **MINOS Near Detector:**
  - Can’t test nuclear effect models with only one nucleus!

- **NOvA and T2K Near Detectors:**
  - Can’t measure energy dependence with only one energy
  - If near design is same as far, can’t separate backgrounds any better near than far

*MINERvA design solves all three of these problems*
the MINERvA detector
To Accomplish its Goals…

- MINERvA proposes to build a low-risk detector with simple, well-understood technology
- Active core is segmented solid scintillator (K2K SciBar)
  - tracking (including low momentum recoil protons)
  - particle identification
  - few ns timing (track direction, identify stopped $K^\pm$)
- Surrounded by electromagnetic and then hadronic calorimeters
  - photon ($\pi^0$) and hadron ($\pi^\pm$) energy measurement
  - magnetized for charge, momentum measurement of escaping muons at wide angles
Basic Detector Geometry

- Active segmented scint. detector 5.87 tons
- ~1 ton of US nuclear target planes (C, Fe, Pb)

- DS Cals, Nucl. Targets just add absorber to scintillator planes
- Magnetized OD (HCAL) frames
Extruded Scintillator and Optics

Basic element: 1.7x3.3cm triangular strips. 1.2mm WLS fiber readout in center hole

Assemble into planes

- MINERvA optical system

Scintillator and embedded WLS

DDK Connectors

Clear fiber

PMT Box

Cookie

M-64 PMT
can one build it?
MINERvA R&D Progress

• Completed a vertical slice test (VST1)
  – Inner detector scintillator extrusions
    • FNAL, NIU
  – WLS fibers to PMT Box (MINOS) and similar PMT
    • Rochester, Tufts, FNAL (MINOS)
  – Prototype MINERvA Front-End electronics
    • FNAL, Irvine, Pittsburgh, Rochester

• Mechanical Design “complete” at concept level
  • Rochester, FNAL, Tufts
  – Prototyping cables, steel, PMT box: Tufts, Rutgers, Rochester

• Hit-Level Simulation
  • Irvine, Pittsburgh

support for this work from FNAL-PPD, DOE HEP university funds, and funds from collaborating universities
Vertical Slice Test (VST1)

VST1 array, electronics and DAQ

8 PE/MIP per doublet

7 April 2005

K. McFarland, Status of MINERvA
Current Prototyping

- Refining scint. extrusion
- First “trapezoid” of OD steel
- Prototype PMT box
- Prototype clear fiber cables in progress
- 2nd Prototype front-end and prototype readout electronics
the MINERvA project
Status of MINERvA Project

• We have developed a detailed costing and schedule model
  – basis for our design report and DOE/NSF proposals
  – costs down to Level-3 at worst, usually Level-4 or -5
• First FNAL director’s (“Temple”) review 1/05
  – generally positive report… they were impressed with our level of detail in design, cost, safety, etc.
  – recommended: formal project management plan, cost vs. physics optimization studies, development of more detailed resource-loaded cost and schedule model
## MINERvA Costs

### as presented to Temple review, Jan ‘05

- These costs include contingency (~40%), all University G&A
  - there is significant missing FNAL G&A. ~$0.5M in model where costs all flow through FNAL
- Assumes specific task distributions by institution and funds FY05-07

<table>
<thead>
<tr>
<th>Project</th>
<th>WBS Code</th>
<th>Materials and Supplies</th>
<th>Salaries, Wages, Engineering and Design</th>
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<td>$0</td>
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<td><strong>Total</strong></td>
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<td><strong>$3,398,257</strong></td>
<td><strong>$1,071,757</strong></td>
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MINERvA Schedule

- Have identified critical paths, spending profile
- Time to complete:
  - roughly 24 months from start of “R&D” phase
  - roughly 18 months from start of “construction funding”
Project Management

- Experiment has proposed and Fermilab directorate approved
  - Project Manager: Deborah Harris
  - Two co-Deputy Project Managers
    - KSM overseeing University efforts
    - Jorge Morfin overseeing Fermilab efforts
- Project Management Plan has been drafted by the executive committee
- Plan has had first reading by Ed Temple and Dean Hoffer, iterating with Project Manager and co-Deputy Project Managers
- WBS has been refined since Temple Review:
revisiting cost vs. physics optimization
Importance of Longitudinal Granularity
Proton Detection Efficiency

- Proton candidates from quasi-elastic and 1-pi production defined as hits in 3x, 1u and 1 v planes. Triangular extrusions, with light sharing, already considerably more efficient than rectangular extrusions

- Proton detection efficiency shows minimal dependence to transverse granularity but significant dependence to longitudinal granularity

7 April 2005
K. McFarland, Status
The Importance of Barrel Calorimetry
Transverse Energy Containment

- Varying the nominal MINERνA outer detector thickness from 30 cm thinner to 10 cm thicker results in a factor of five change in the percentage of DIS events with greater than 5% of the hadronic energy leaking out of the outer detector. For the nominal MINERνA design, only 5% of DIS events lose more than 5% of their hadronic energy.
conclusions
MINERvA…

- Opportunity for unique and critical FNAL role in world neutrino efforts in a modest-scale project
  - construction funds in FY07 means running in FY09
  - only possible because of investment in NuMI

- On track technically to build and use detector
  - R&D and prototyping progressing

- We are doing what projects do…
  … including waiting for funding
backup slides
Example Events

- Quasi-elastic $\nu_\mu n \rightarrow \mu^- p$
  - proton and muon tracks are clearly resolved
  - observed energy deposit is shown as size of hit; can clearly see larger proton dE/dx
  - precise determination of vertex and measurement of $Q^2$ from tracking
Example Events (cont’d)

- $\pi^0$ Production
  - two photons clearly resolved (tracked). can find vertex.
  - some photons shower in ID,
    some in side ECAL (Pb absorber) region
  - photon energy resolution is $\sim 6%/\sqrt{E}$ (average)
Old NOvA vs New (TASD) NOvA

What about the change from old NOvA design to new design?
Old: FD background was ½ beam $\nu_e$, ½ other
New: FD background is 2/3 beam $\nu_e$, 1/3 other
New: Signal has more resonance contributions, more poorly known process
Extrapolating near to far will be easier, but probably by ~30%...
Statistical error is about the same (same FOM)
MINER$\nu$A statistics and running

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

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<th>Process</th>
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<tr>
<td>Quasi-elastic</td>
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<tr>
<td>Resonance</td>
<td>196 K</td>
<td>70 K</td>
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<td>Transition</td>
<td>210 K</td>
<td>65 K</td>
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<td>DIS</td>
<td>420 K</td>
<td>125 K</td>
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<tr>
<td>Coherent</td>
<td>8.4 K</td>
<td>4.2 K</td>
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<tr>
<td>TOTAL</td>
<td>940 K</td>
<td>305 K</td>
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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)

2 April 2004
MINERvA Costs
(Alternate Roll-up)

as presented to Temple review, Jan ‘05

- These costs include contingency (~40%), all University G&A
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- Assumes specific task distributions by institution and funds FY05-07

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### MINERvA Costs

<table>
<thead>
<tr>
<th>WBS</th>
<th>Items</th>
<th>M&amp;S</th>
<th>SWF</th>
<th>Total</th>
<th>M&amp;S Total</th>
<th>M&amp;S Cont%</th>
<th>SWF Total</th>
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<th>Total Cont%</th>
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<td>403,700</td>
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<td>51%</td>
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Project Totals: 3,721,501 3,226,437 6,947,938 5,071,560 4,449,404 9,520,963
Vital Statistics of MINERvA

- Number of Channels: 30992
- Channels in ID+CALS: 25088
- Channels in OD: 5904
- Volume of Scintillator (m³): 22.5
- WLS Fiber (km): 90.7
- Clear Fiber (km): 41.6
- Number of M-64 PMTs: 503
- Mass of ID (metric tons): 10.8
- Mass of OD in ID region (metric tons): 98.0
- Mass of CALS, Nuclear Targets (metric tons): 27.2
- Mass of OD in CAL region (metric tons): 62.9
- Total MINERvA Mass (metric tons): 199
- Plastic Region Mass (metric tons): 5.87
- Data Rate (bits/spill): 7.9E+6
A Brief History of MINERvgA

- December 2002 - Two EOIs for neutrino scattering experiments using the NuMI beam and similar detector concepts presented to the PAC. PAC suggests unifying efforts and preparing proposal.
- December 2003 - MINERvgA proposal presented to PAC. PAC requests more quantitative physics studies and details of MINERvgA’s impact on Fermilab.
- January 2004 - Submit proposal for MRI funding support (maximum $2M) of partial detector to NSF. Rejected due to no guarantee for funding rest of detector.
- April 2004 - Proposal addendum containing additional physics studies and report from the Impact Review Committee presented to PAC. Receive Stage I approval.
- Summer 2004 - R&D Program concentrating on front-end electronics, scintillator extrusions and a “vertical slice test”
- October 2004 - Proposal to NP and EPP of NSF to fund bulk of MINERvgA.
- December 2004 - Proposal to NP and HEP of DOE to fund bulk of MINERvgA.
- January 2005 - First Director’s Review of MINERvgA
- February 2005 – With release of FY06 budget, DOE of budget process crystallizes; decision that MINERvgA must be primarily funded by FNAL budget.
Fiber Testing and Qualification (pre-VST1)

- Fiber testing and qualification (Rochester)
  - attenuation and light yield of WLS fiber for different dopant concentrations
  - fiber flexibility and light loss tests