Introduction

1. What physics topics are accessible to MINERνA?

2. Why are these topics important?

3. How will MINERνA address this physics?
## Physics Topics Accessible to Minerva

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<th>Experimental Need</th>
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<td>Deeply-Inelastic Scattering:</td>
<td>Improved statistics with better determination of final states</td>
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<td>Quasi-Elastic Scattering:</td>
<td>Improved Precision over a wide $Q^2$ Range</td>
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<td>Axial Form Factor of Nucleon</td>
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<td>Coherent Scattering:</td>
<td>1) Improved statistical precision of total cross section</td>
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<td>Single Pion Production</td>
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<td>Resonance Production:</td>
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<td>Both Neutral Current (NC) and Charged</td>
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<td>Current (CC)</td>
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<tr>
<td>Nuclear Physics</td>
<td>Precision studies of neutrino-nucleus scattering as compared to charged lepton-</td>
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<tr>
<td></td>
<td>nucleus scattering.</td>
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### Existing Measurements of Neutrino-Nucleon Cross Section

*Graph showing existing measurements of neutrino-nucleon cross section.*
Quasi-Elastic Neutrino Scattering
\[ \nu \mu (\bar{\nu} \mu) n(p) \rightarrow \mu^+ (\mu^-) p(n) \]

\[ \langle p | J^\mu \rangle = \pi \left( y_3 F_\nu^1 (q^2) + i \sigma_{3 \nu} q^2 \frac{2 M}{F_\nu^1 (q^2)} \right) + \]

\[ y_3 y_5 F_\mu (q^2) + y_3 \frac{F_\mu (q^2)}{M} \mu \]

\( F^1_v (q^2) \) & \( F^2_v (q^2) \) are the Vector Form Factors
(extractable from \( G^N_E, G^N_M \))

\( F^A_A (q^2) \) is the Axial Form Factor
(extractable from neutrino scattering!)

**Form Factor Measurements**

**MINER\( \nu \)A Measurement of Axial FF**

QE scattering, \( \nu \mu \), \( F^A_A (Q^2) \)/dipole, \( M_A = 1.014 \) GeV

Minerva estimated \( F^A_A (Q^2) \) statistical precision based on Monte Carlo simulation attached to the electric form factor, \( G^p_E (Q^2) \), for the nucleon to indicate scale.

The \( G^p_E (Q^2) \) scales used in this plot are based on polarization transfer measurements performed at Jefferson Lab (red) and measurements of the total elastic electron-nucleon scattering cross section (magenta).

The Axial Form Factor of the Nucleon is poorly known...
Coherent Neutrino Scattering

\[ \nu_\mu (\bar{\nu}_\mu) N \rightarrow \mu^+ (\mu^-) \pi N \text{ Charged Current} \]

\[ \nu_\mu (\bar{\nu}_\mu) N \rightarrow \nu_\mu (\bar{\nu}_\mu) \pi N \text{ Neutral Current} \]

Coherent Pion Production: A Window on the Weak Interaction

A-Dependence of 5 GeV CC Coherent Cross-Section

- Rein-Seghal model
- Paschos- Kartavtsev model
- Data points: MINER\nu A

XX Max Born Symposium
December 7-10, 2005, Wroclaw, Poland
Example of MINERvA’s Analysis
Potential Coherent Pion Production

Resonance Production

\[ \nu_\mu (\nu_\mu) n (p) \rightarrow \mu^+ (\mu^-) R \text{ Charged Current} \]
\[ \nu_\mu (\bar{\nu_\mu}) n (p) \rightarrow \nu_\mu (\bar{\nu_\mu}) R \text{ Neutral Current} \]

Form Factors are needed to describe the N-Resonance transitions.
- electron scattering probes vector component of these form factors
- neutrino scattering will probe axial component

Cross sections, thus the form factors, for neutrino excitation of resonances are virtually unknown.
**Quark-Hadron Duality**: The relationship between the DIS structure function $F_2$ and the average resonance cross section as measured in electron scattering.

The cause of quark-hadron duality is not well known...

Neutrino scattering will help untangle this phenomena since neutrino interactions explicitly provide insight into flavor dependent behavior.

**Nuclear Effects**

The Past: Neutrino interactions were measured on heavy nuclei with low statistical precision; nuclear effects could be ignored...but...

The present: interactions are being measured with increasing precision; nuclear effects are now important...so...

The future: precision $A$-dependence studies must be performed!
MINERνA should be able to determine this ratio to a few percent for $n > 6$ GeV.

**Physics Topic**

**Observed energy in detectors can be obscured by final state interactions in nuclear media.**

- **Deeply-Inelastic Scattering:**
  - Observed energy in detectors can be obscured by final state interactions in nuclear media.

- **Quasi-Elastic Scattering:**
  - The axial form factor of the nucleon is poorly known.
  - Cross section uncertainties are a major portion of oscillation experiment error budgets.

- **Coherent Scattering:**
  - Coherent scattering is, in general, a good probe of the weak interaction.
  - Coherent scattering is expected to be a large background for future precision neutrino oscillation experiments.

- **Resonance Production:**
  - Improved understanding of the transition from quasi-elastic processes to deeply-inelastic scattering processes in the weak sector.

- **Nuclear Physics**
  - Nuclear medium dependence of neutrino interactions is important for interpretation of future neutrino oscillation studies.
  - Differences are expected between charged and neutral lepton structure functions.
For Example: Helping MINOS and NOνA/T2K

**Measurement of $\Delta m^2$ with MINOS:**
*Needed:* detailed understanding of the relationship between the incoming neutrino energy and the visible energy in the detector
*From:* precision cross section measurements and neutrino-initiated nuclear reactions

**Measurement of $\sin^2 \theta_{13}$ with NOνA:**
*Needed:* absolute cross sections of signal & background reactions
*From:* precision cross section measurements

*see: D. A. Harris, et al., hep-ex/041005 for further info...*

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**How will Minerva Achieve these Physics Goals?**

- **Lots of Neutrinos**
  - Provided by the NuMI Beam at FNAL
  - approximately $10^3$ times more intense than previously available beams!

- **Massive Detector with:**
  - Good Tracking Resolution
  - Good Momentum Resolution
  - Low Momentum Particle Detection Threshold
  - Particle Identification Capabilities

- **Array of Nuclear Targets**
  - Carbon
  - Iron
  - Lead
What is MINER$\nu$A?
Main INjector ExpeRiment $\nu$-A$^*$

MINER$\nu$A is a compact, fully active neutrino detector designed to study neutrino-nucleus interactions with unprecedented detail.

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

The MINER$\nu$A Collaboration

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* Co-Spokespersons
# Members of the MINERvA Executive Committee
Lots of Neutrinos-NuMI Beam Line

MINOS

MINERνA

The MINERνA Detector

- **Nuclear Targets:**
  - 1/2 Ton each carbon, iron, and lead

- **Active Target:**
  - 5.78 Tons segmented scintillator planes

- **Electromagnetic Calorimeter:**
  - Interleaved lead sheet (0.2 cm thick) with segmented scintillator planes

- **Hadronic Calorimeter:**
  - Interleaved Iron sheet (2.54 cm thick) with segmented scintillator planes
Active Detector Elements

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

Assemble into planes

MINERνA optical system

Scintillator and embedded WLS
DDK Connectors
Clear fiber
PMT Box
Cookie
M-64 PMT

Front View of Detector
Fiducial Volume:
3 tons Polystyrene, ≈ 0.6 t C, ≈ 1/2 t Fe and ≈ 1/2 t Pb
Expected CC event samples:
8.6 M ν events in Polystyrene
1.4 M ν events in C
1.4 M ν events in Fe
1.4 M ν events in Pb

Charged-Current Physics Topic

<table>
<thead>
<tr>
<th>Expected Statistics</th>
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<tbody>
<tr>
<td>3 Tons of Polystyrene</td>
</tr>
<tr>
<td>Quasi-Elastic</td>
</tr>
<tr>
<td>Resonance</td>
</tr>
<tr>
<td>Transition: Resonance to DIS</td>
</tr>
<tr>
<td>DIS and Structure Functions</td>
</tr>
<tr>
<td>Coherent Pion Production</td>
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</tbody>
</table>

MINERνA is an established project and approved by FermiLab.
Component research and development, and prototyping, are well underway at our member institutions.
Summary

1. What physics topics are accessible to Minerva?
   A. Minerva will provide improved precision neutrino-nucleus cross section measurements at neutrino energies from 1 to 15 GeV.
   B. Minerva will be able to investigate DIS, quasi-elastic, coherent, and resonance processes with precision much improved over most present neutrino cross section measurements.

2. Why are these topics important?
   A. Coherent processes comprise a significant source of background for neutrino future neutrino oscillation studies.
   B. Cross sections for resonance production in neutrino scattering are relatively unknown.
   C. Nuclear medium effects from neutrino interactions are expected to differ from their charged-lepton counterparts.
   D. Neutrino-nuclear effects have not been studied in high-mass targets.
   E. The axial form factor of the nucleon is poorly known.

3. How will Minerva address this physics?
   A. Minerva is a multi-ton detector designed specifically for precision cross section measurements.
   B. Minerva will make use of the high-intensity neutrino beam from NuMI.
   C. Minerva is outfitted with an array of nuclear targets for the express purpose of high-precision studies of nuclear medium effects in neutrino interactions.