PROPOSAL

Perform A High-Statistics Neutrino Scattering Experiment Using a Fine-grained Detector in the NuMI Beam

Understanding Low-energy Neutrino - Nucleus Interactions

The MINERνA (Main INjector ExpeRiment ν-A) Collaboration

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Fermilab PAC
12 December 2003

Outline

Bringing together the experts from two communities
To use a uniquely intense and well-understood ν beam
And a fine-grained, fully-active neutrino detector
To collect a large sample of ν and $\bar{\nu}$ scattering events
To perform a wide variety of ν physics studies

The MINERνA Collaboration
Beam and Statistics
Survey of Physics Topics

Kevin McFarland
Description and Performance of the Detector
Cost and Schedule
Summary and Request

… experts from two communities to study low-energy ν - Nucleus Physics

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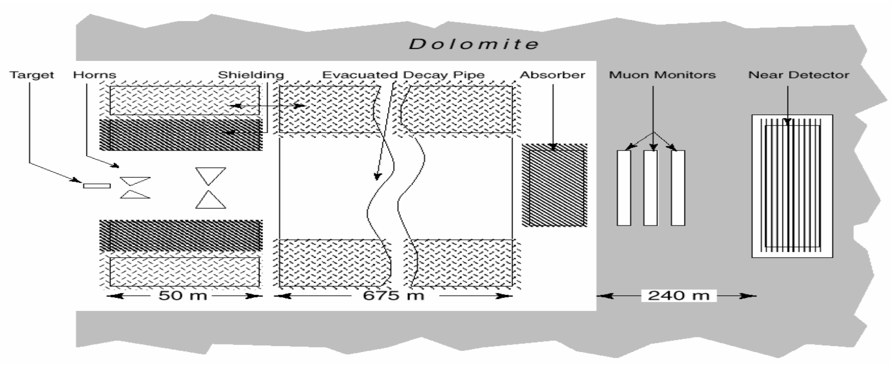
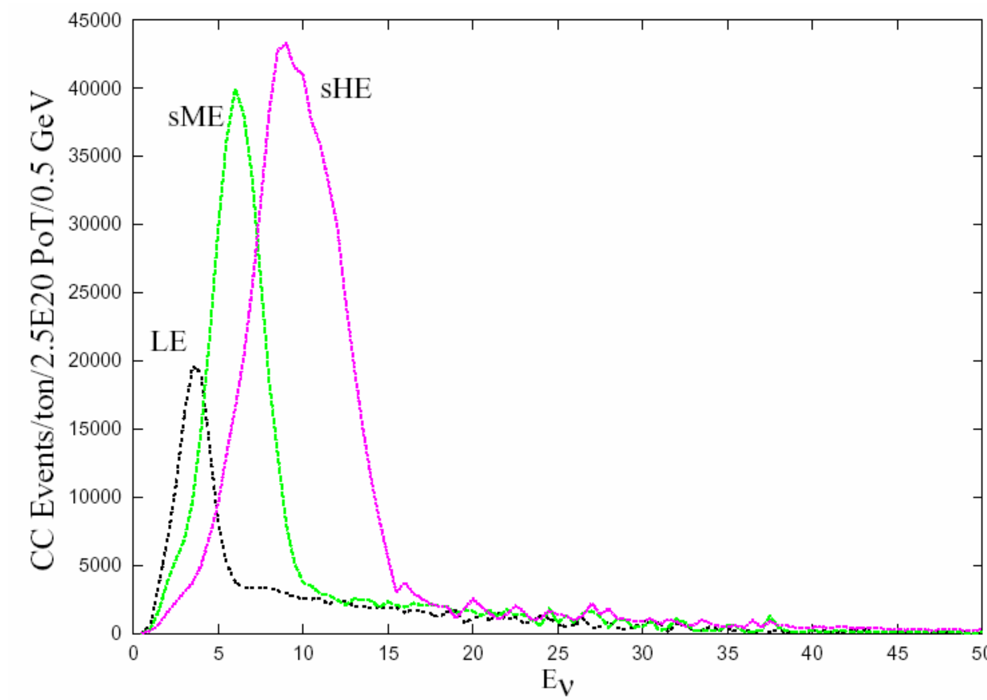
Red = HEP, Blue = NP, Green = Theorist

To use a uniquely intense and well-understood ν beam. The NuMI Beam.



- By changing the position of the easily-movable target with respect to the horns, the energy of the neutrino beam can be quickly changed.

- For MINOS, the majority of the running will be in the “low-energy” (LE) configuration. There will be shorter runs in the ME and HE.configuration as well.



With E-907 at Fermilab to measure particle spectra from the NuMI target, expect to know neutrino flux to ≈ ± 3%.

To collect a **large** sample of ν and $\bar{\nu}$ scattering events…

- LE-configuration: **Events-** (E_μ >0.35 GeV)
  E_{peak} = 3.0 GeV, $\langle E_\nu \rangle$ = 10.2 GeV, rate = 80 K events/ton - 10^{20} pot
- ME-configuration: **Events-**
  E_{peak} = 6.0 GeV, $\langle E_\nu \rangle$ = 8.0 GeV, rate = 160 K events/ton - 10^{20} pot
- HE-configuration: **Events-**
  E_{peak} = 9.0 GeV, $\langle E_\nu \rangle$ = 12.0 GeV, rate = 260 K events/ton - 10^{20} pot

Typical Fiducial Volume =
3 tons CH, 1 ton Fe and 1 ton Pb

Units of 10^{20}

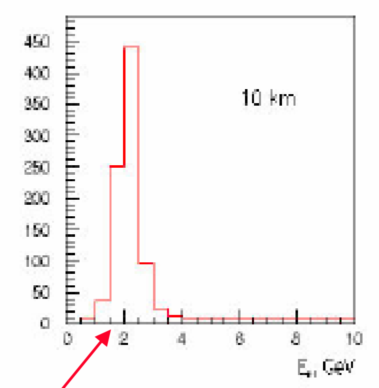
Year	total POT	LE	ME	HE	LEB	MEB	HEB
2006	3.0	3.0					
2007	4.0	3.0	0.7	0.3			
2008	4.0				2.5	1.0	0.5
2009	4.0	1.0	0.5	0.5	0.5	0.5	1.0
TOTAL	**15.0**	**7.0**	**1.2**	**0.8**	**3.0**	**1.5**	**1.5**

ν_μ Event Rates per ton

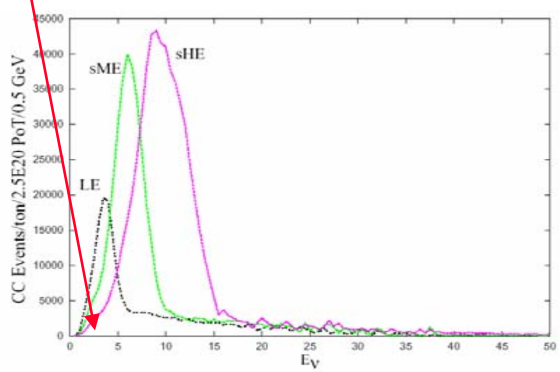
Process	CC	NC
Quasi-elastic	103 K	42 K
Resonance	196 K	70 K
Transition	210 K	65 K
DIS	420 K	125 K
Coherent	8.4 K	4.2 K
TOTAL	**940 K**	**288 K**

To perform a wide variety of ν physics studies…WHY?

NuMI Off-axis Neutrino Beam

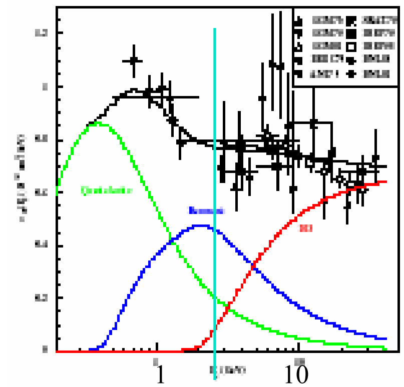


We need to improve our understanding of **low energy ν-Nucleus interactions** for oscillation experiments!



MINOS: Neutrino Beam

Inherent interest in the phenomena of low-energy neutrino-nucleus scattering!



Series of Workshops on this topic (organized by MINERνA collaborators) to bring HEP and NP physicists together:

<u>Workshops on Neutrino Nucleus Interactions in the Few GeV Region</u>

NuInt01 - Japan, December 2001

NuInt02 - U.S.A, December 2002

NuInt04 - Italy, March, 2004

To perform a **wide variety** of ν physics studies

- Physics Monte Carlos - NEUGEN (H. Gallagher) and NUANCE (D. Casper)
- Quasi-elastic ($\nu + n \dashrightarrow \mu^- + p$, 300 K events off 3 tons CH) - A. Bodek and H. Budd
  - Precision measurement of $\sigma(E_\nu)$ and $d\sigma/dQ$ important for neutrino oscillation studies.
  - Precision determination of axial vector form factor (F_A), particularly at high Q^2
  - Study of proton intra-nuclear scattering and their A-dependence (C, Fe and Pb targets)
- Resonance Production (e.g. $\nu + N \dashrightarrow \nu / \mu^- + \Delta$, 600 K total, 450K 1π) - S. Wood
  - Precision measurement of σ and $d\sigma/dQ$ for individual channels
  - Detailed comparison with dynamic models, comparison of electro- & photo production, the resonance-DIS transition region -- duality
  - Study of nuclear effects and their A-dependence e.g. $1\pi \longleftrightarrow 2\pi \longleftrightarrow 3\pi$ final states
- Coherent Pion Production ($\nu + A \dashrightarrow \nu / \mu^- + A + \pi$, 25 K CC / 12.5 K NC) - H. Gallagher
  - Precision measurement of $\sigma(E)$ for NC and CC channels
  - Measurement of A-dependence
  - Comparison with theoretical models

To perform a wide variety of ν physics studies - continued

- Nuclear Effects (C, Fe and Pb targets)- A. Bruell and J. G. M.
  - Final-state intra-nuclear interactions. Measure multiplicities and E_{vis} off C, Fe and Pb.
  - Measure NC/CC as a function of E_H off C, Fe and Pb.
  - Measure shadowing, anti-shadowing and EMC-effect as well as flavor-dependent nuclear effects and extract nuclear parton distributions.
- MINERνA and Oscillation Physics - H. Gallagher and D. A. Harris
  - MINERνA measurements enable greater precision in measure of Δm, $\sin^2\theta_{23}$ in MINOS
  - MINERνA measurements important for θ_{13} in MINOS and off-axis experiments
  - MINERνA measurements as foundation for measurement of possible CP and CPT violations in the ν–sector
- σ_T and Structure Functions (2.8 M total /1.2 M DIS events) - C. Keppel and J. G. M.
  - Precision measurement of low-energy total and partial cross-sections
  - Understand resonance-DIS transition region - duality studies with neutrinos
  - Detailed study of high-x_{Bj} region: extract pdf's and leading exponentials over 1.2M DIS events

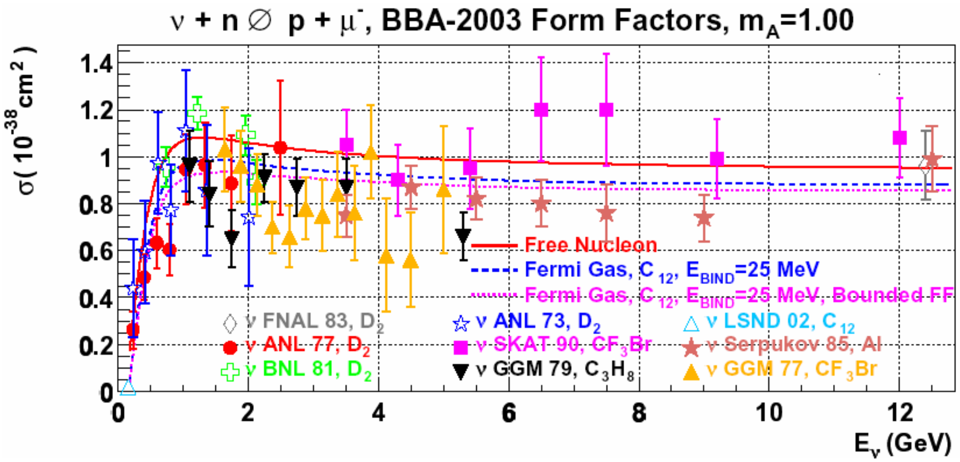
To perform a wide variety of ν physics studies - continued

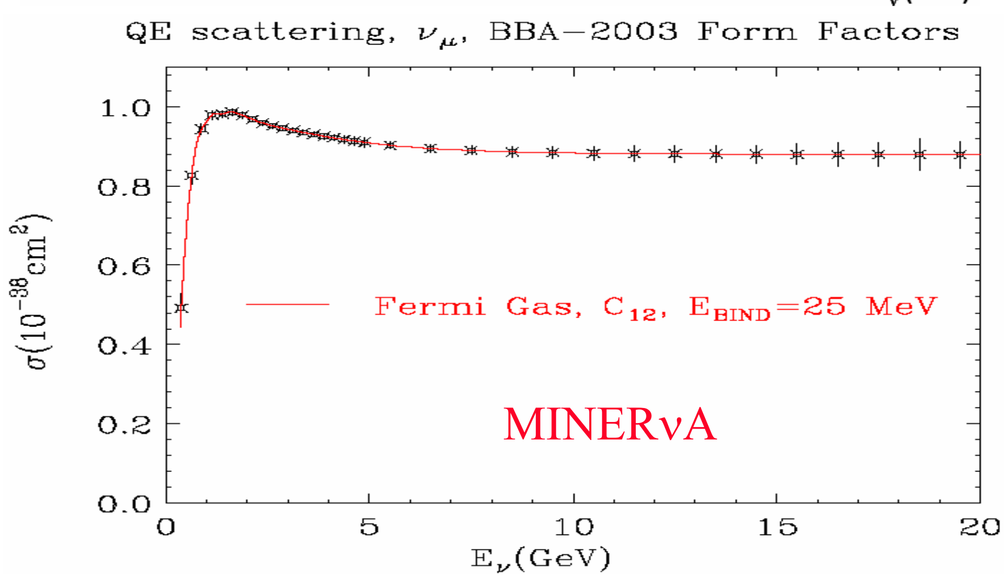
- Strange and Charm Particle Production (> 60 K **fully** reconstructed exclusive events) - A. Mann, V. Paolone and N. Solomey
  - Exclusive channel $\sigma(E_\nu)$ precision measurements - importance for nucleon decay background studies.
  - Statistics sufficient to reignite theorists attempt for a predictive phenomenology
  - Exclusive charm production channels at charm threshold to constrain m_c

- Generalized Parton Distributions (few K events) - W. Melnitchouk and R. Ransome
  - Provide unique combinations of GPDs, not accessible in electron scattering (e.g. C-odd, or valence-only GPDs), to map out a precise 3-dimensional image of the nucleon. MINERνA would expect a few K signature events in 4 years.
  - Provide better constraints on nucleon (nuclear) GPDs, leading to a more definitive determination of the orbital angular momentum carried by quarks and gluons in the nucleon (nucleus)
  - provide constraints on axial form factors, including transition nucleon --> N* form factors

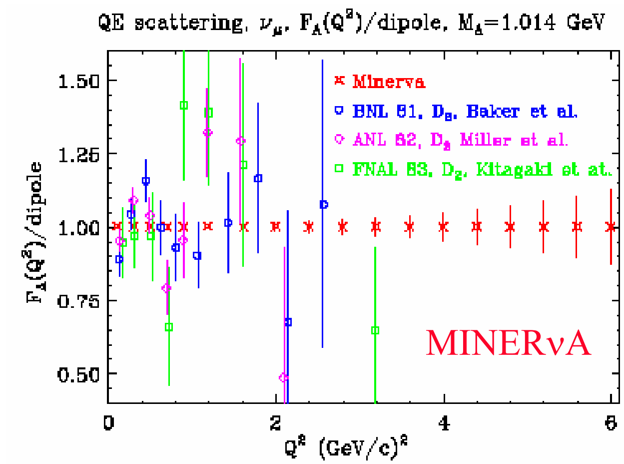
Quasi-elastic ν and $\bar{\nu}$ Scattering

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





- Theory: Reliable expression of cross-section in terms of nucleon vector and axial-vector form factors (F_A). F_A very poorly known, particularly at high Q^2.



- Cross-section important for understanding low-energy neutrino oscillation results and Needed for all low energy neutrino monte carlos used in neutrino oscillation analyses.
- Constrained kinematics help measure final state interactions.

Coherent Pion Production

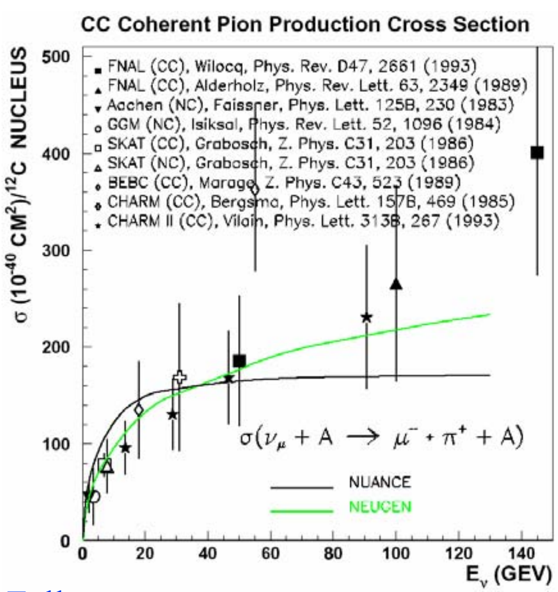
MINERνA: 25 K CC / 12.5 K NC events off C - 8.3 K CC/ 4.2 K NC off Fe and Pb

•Characterized by a small energy transfer to the nucleus, forward going π. NC (π^0 production) significant background for ν_μ --> .ν_e oscillation search

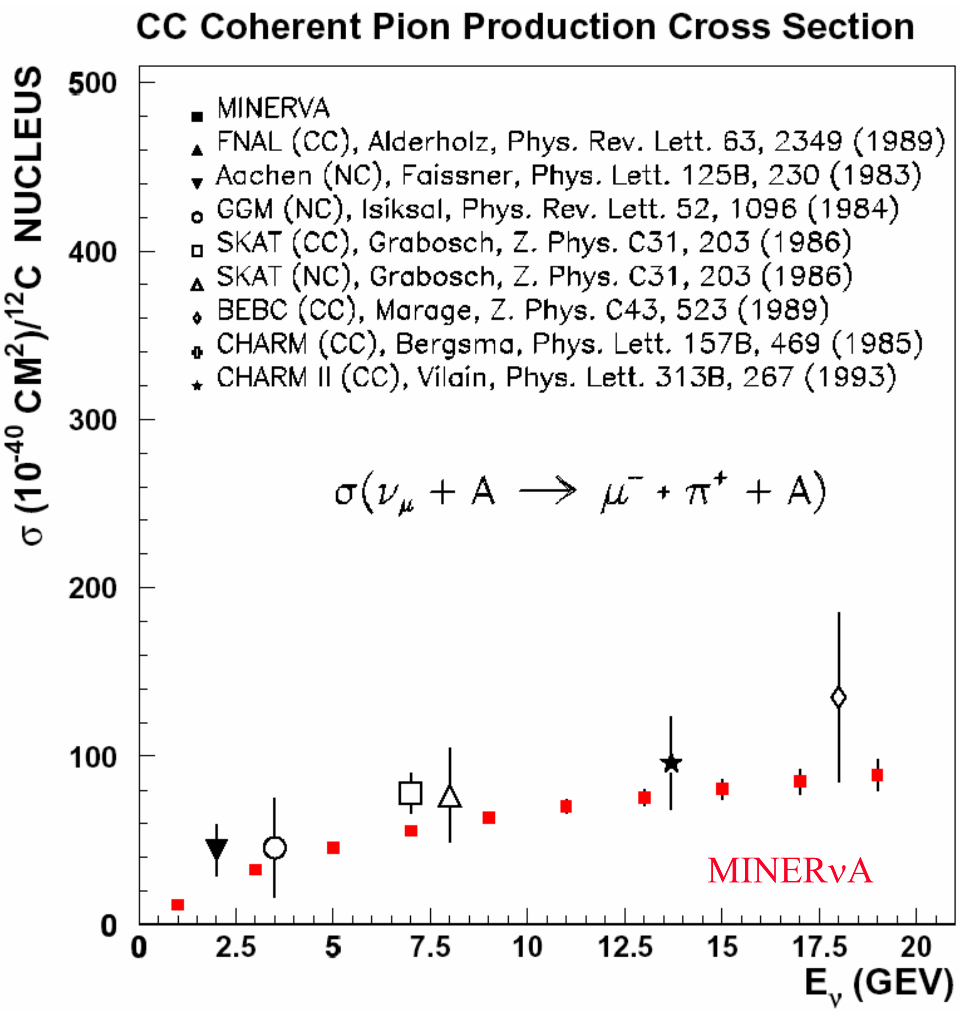
•Data has not been precise enough to discriminate between several very different models.

•Expect roughly (30-40)% detection efficiency with MINERνA.

•Can also study A-dependence with MINERνA



Sam Zeller

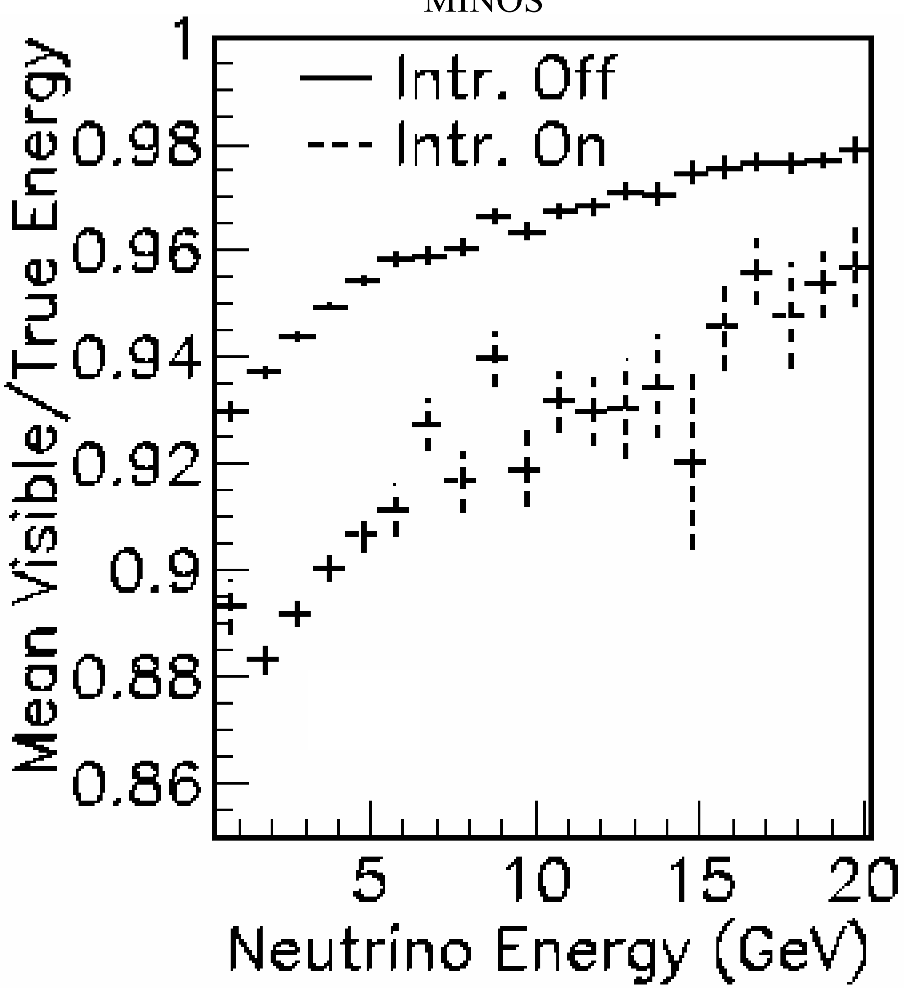


Nuclear Effects

MINERνA: 2.8M events off Carbon and 940 K events off of Fe and Pb

- Neglecting initial target nucleon state, two types of nuclear effects to consider:
  - Final State Interactions
  - Modified Interaction Probabilities
- **Final State Interactions**
  - Intranuclear scattering causing change in direction and energy loss (absorption) of secondary pions and nucleon. Not as well known as needed.
  - Will cause $E_{vis} < E_\nu$
  - **Important for neutrino oscillation analyses**
  - **MINERνA will measure multiplicities and E_{vis} off of C, Fe and Pb targets**

MINOS

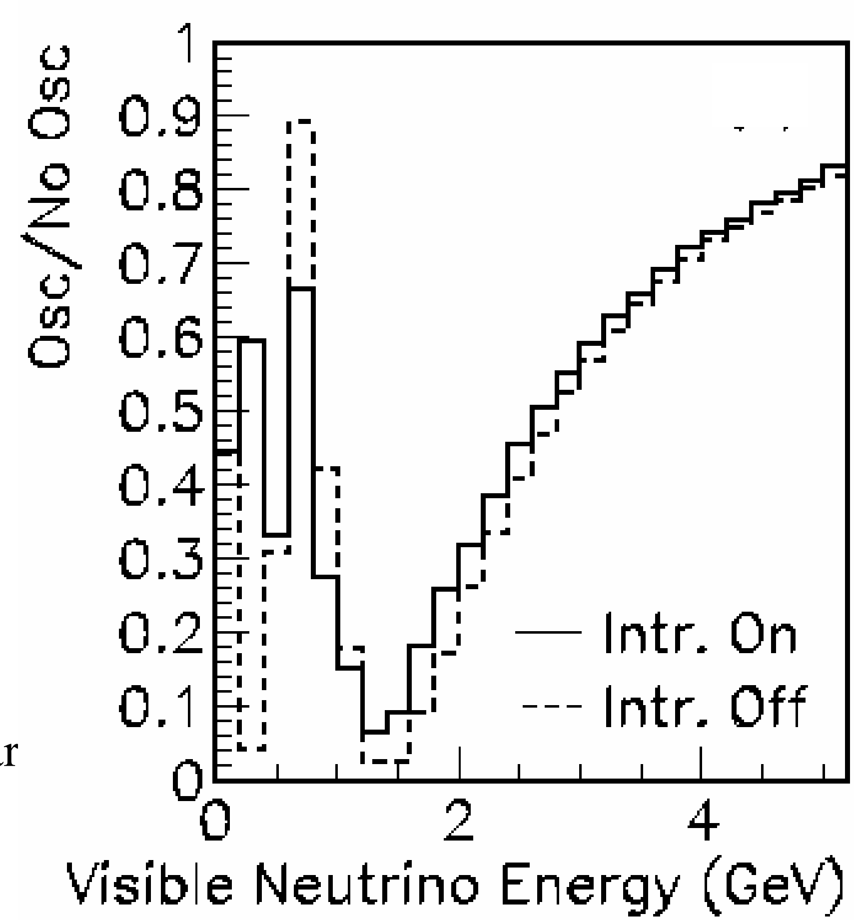


How MINERνA Helps Oscillation Analyses

(summary of individual channel contributions)

- Measurement of Δm^2 (e.g.MINOS)
  - Understanding intra-nuclear scattering effects
  - Improved measurements of pion / nucleon absorption
  - Improved measurement of pion production cross-sections
  - These combine with absorption probability to produce further uncertainties in plot at right
- Measurement of θ_{13} (e.g.MINOS/Off-axis)
  - Precision measurement of coherent pion, and resonant pion cross-sections and angular distributions.
  - Measurement of ν_e content of NuMI beams

MINOS : $\Delta m^2 = 2.5 \times 10^{-3}$



Strange and Charm Particle Production

- Theory: Initial attempts at a predictive phenomenology stalled in the 70's due to lack of constraining data.
- MINERνA 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 $\overline{\nu}$ 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.

Existing Strange Particle Production

Gargamelle-PS - **15** Λ events. FNAL - ≈ 100 events
ZGS - 7 events BNL - 8 events
Larger NOMAD **inclusive** sample expected

MINERνA Exclusive States

100x earlier samples

3 tons and 4 years

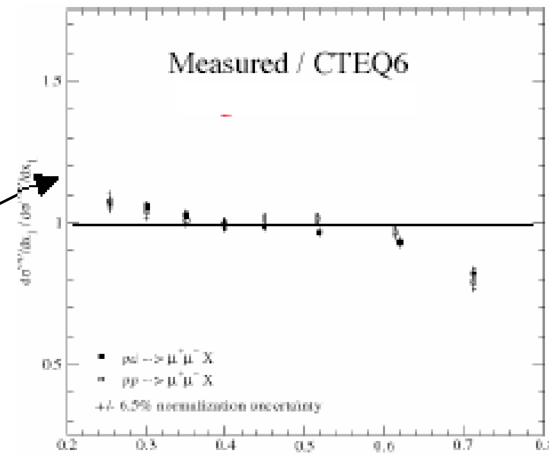
$\Delta S = 0$	
$\mu^- K^+ \Lambda^0$	10.5 K
$\mu^- \pi^0 K^+ \Lambda^0$	9.5 K
$\mu^- \pi^+ K^0 \Lambda^0$	6.5 K
$\mu^- K^- K^+ p$	5.0 K
$\mu^- K^0 K^+ \pi^0 p$	1.5 K
$\Delta S = 1$	
$\mu^- K^+ p$	16.0 K
$\mu^- K^0 p$	2.5 K
$\mu^- \pi^+ K^{0n}$	2.0 K
$\Delta S = 0$ - Neutral Current	
$\nu K^+ \Lambda^0$	3.5 K
$\nu K^0 \Lambda^0$	1.0 K
$\nu K^0 \Lambda^0$	3.0 K

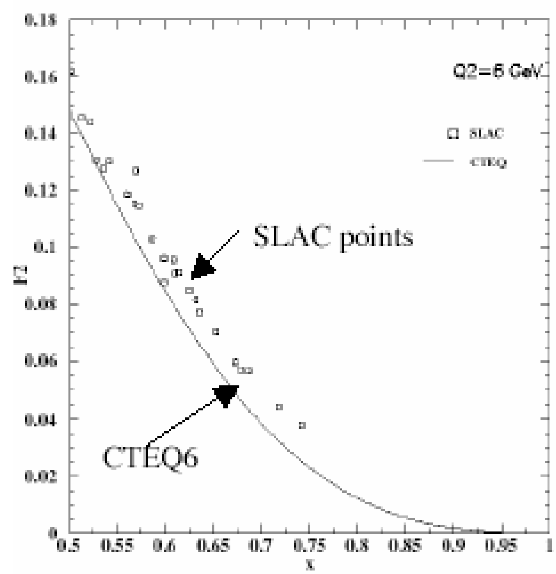
Summary and Detector Requirements

- The MINERνA experiment will produce a sample of quasi-elastic, resonant pion, coherent pion and exclusive strange particle events **significantly larger** than earlier experiments. With excellent knowledge of the beam, σ will be well-measured.
- With C, Fe and Pb targets, the MINERνA experiment will perform the first dedicated neutrino experimental study of nuclear effects.
- These MINERνA results will significantly **improve neutrino Monte Carlos** and, consequently, **neutrino oscillation analyses**.
- What kind of detector do we need to successfully study these large produced samples:
  - Must identify μ and precisely measure the momentum vector.
  - Identify individual hadrons and π^0 and measure direction and energy with precision.
  - Measure the energy and direction of hadronic and em showers with precision.
  - Contain a significant portion of the energy from events within the detector
  - Accommodate a selection of nuclear targets

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 / MINERνA working group to investigate high - x_{Bj} region.
- MINERνA 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.

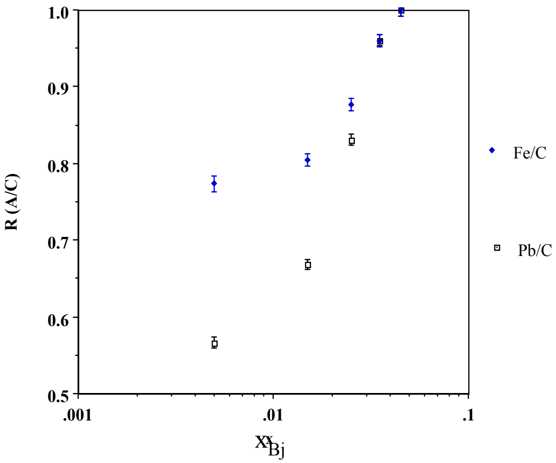




Nuclear Effects

- **Modified Interaction Probabilities**
  - Shadowing Region ($x_{Bj} < 0.1$): Expect a difference in comparison to e/μ - 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.

S. Kulagin prediction for shadowing region



Kumano fit for flavor-dependent effects