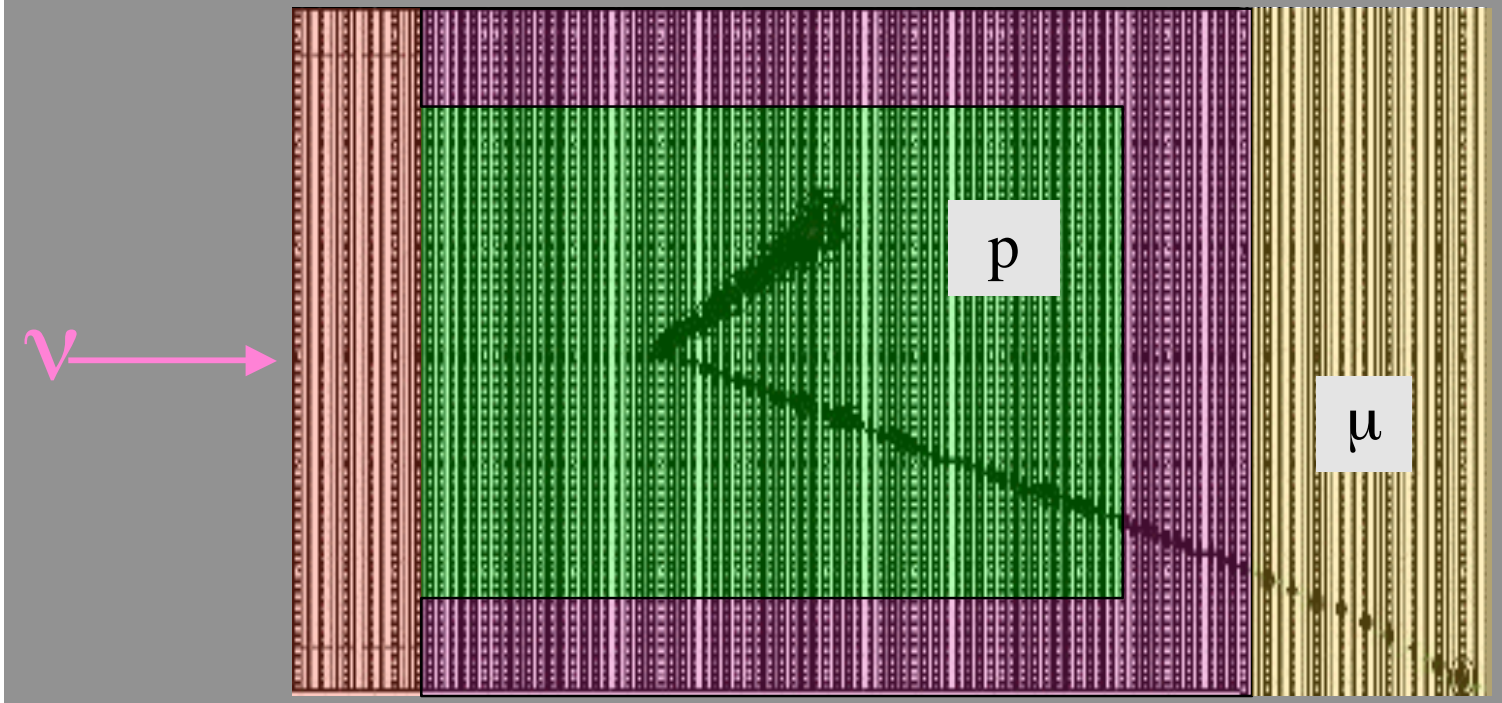
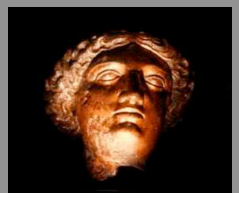
The MINERνA Experiment



Arie Bodek
University of Rochester
Department of Physics and Astronomy





The MINERvA Collaboration

Particle and Nuclear Physics Groups

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K. McFarland, J. Park, W. Sakumoto, J. Seger, J. Steinman
University of Rochester, Rochester, New York

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R. Ransome, E. Schulte
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D. Cherdack, H. Gallagher, T. Kafka, W.A. Mann, W. Oliver
Tufts University, Medford, Massachusetts

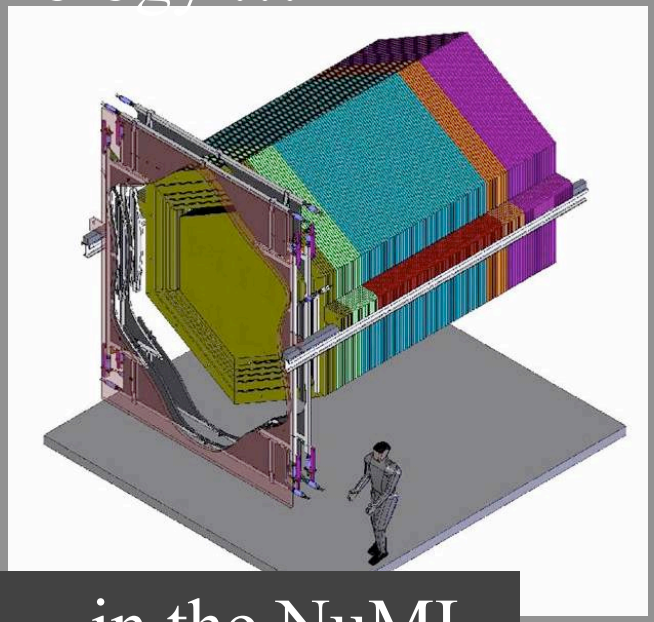
R. Ochoa, O. Pereyra, J. Solano
Universidad Nacional de Ingenieria. Lima, Peru

J.K. Nelson, D.S. Damiani
William and Mary College, Williamsburg, Virginia

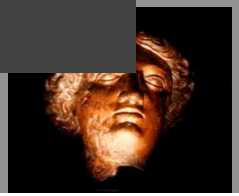
What is MINERνA?

MINERνA is a precision, highly-segmented ν detector with simple, well-understood technology …





… in the NuMI beam just upstream of MINOS's near detector.

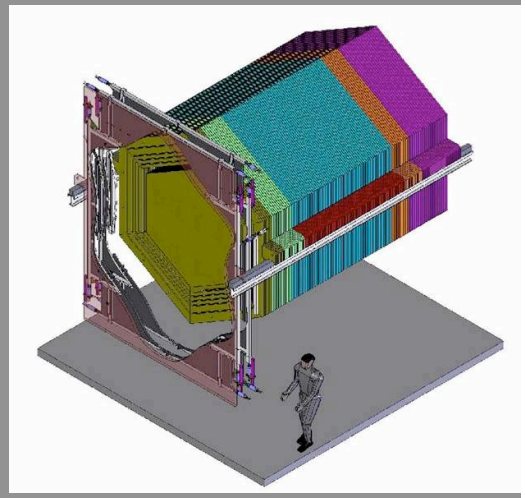


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What is MINERνA?

MINERνA is a precision, highly-segmented ν detector with simple, well-understood technology …



- Active core of segmented solid scintillator
  - tracking (incl. low momentum protons)
  - particle identification
  - few ns timing (track direction, identify stopped $K^{\pm}$)
- Surrounded by electromagnetic and hadronic calorimeters
  - Photon (π^{o}) and hadron ($\pi^{\pm}$) energy and directrion measurement
- LHe, C, Fe, Pb nuclear targets upstream of active solid scintillator core
- MINOS near detector as high energy μ spectrometer downstream

One of the Motivations for MINERνA

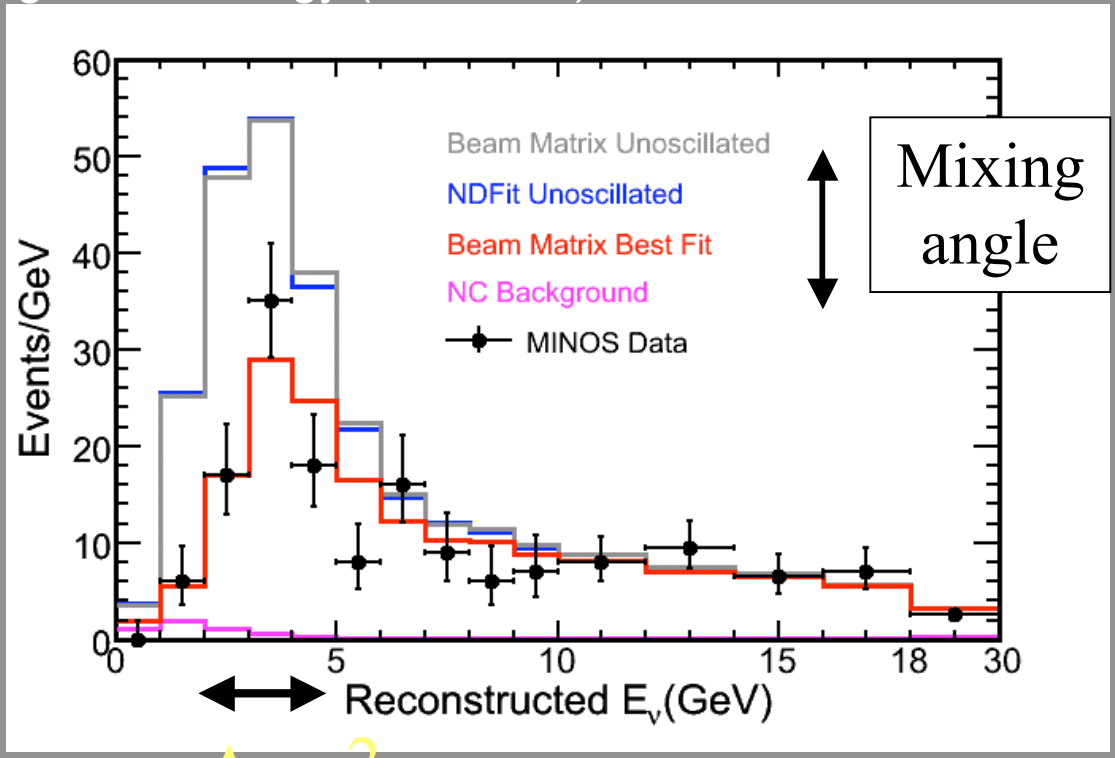
Entering a period of precision neutrino oscillation measurements …

Got E_ν??

- Precision understanding of low energy (Few GeV) neutrino cross sections
- Models
- Nuclear effects
- Final state details

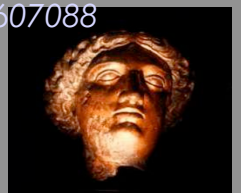
Recent results from MINOS

Neutrino energy calibration => Δm^2



Δm^2

hep-ex/0607088

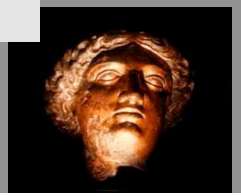


Neutrino oscillations & MINERνA

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.

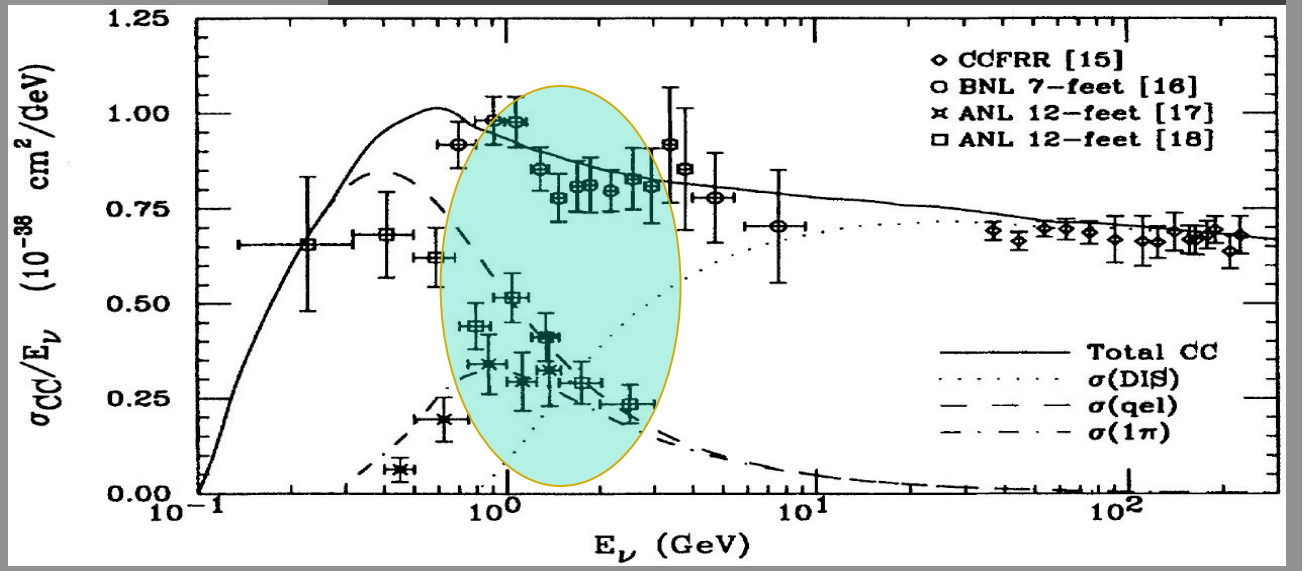




MINERνA Physics: Low Energy Neutrino Scattering

We will be making precision measurements of low energy neutrino cross sections:

Lipari, Lusignoli and Sartogo, PRL 74, 4384 (1995)



Contributions to total cross section: $\sigma_{TOT} = \sigma_{QE} + \sigma_{RES} + \sigma_{DIS}$

σ_{QE}: Quasi-elastic -> $\nu(\overline{\nu})\, n(p) \rightarrow \mu^-(\mu^+)\, p(n)$

σ_{RES}: Resonance -> $\nu N \rightarrow \mu N^*$ Inelastic, Low-multiplicity final states

σ_{DIS}: Deep Inelastic Scattering -> $\nu N \rightarrow \mu X$ Inelastic, High-multiplicity final states

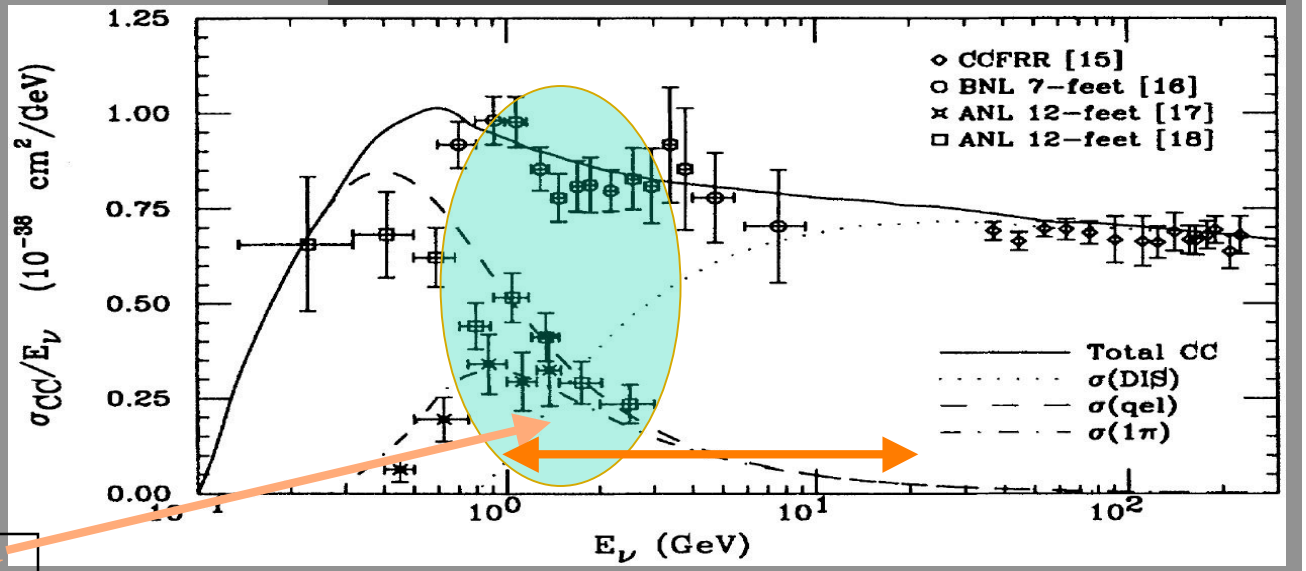




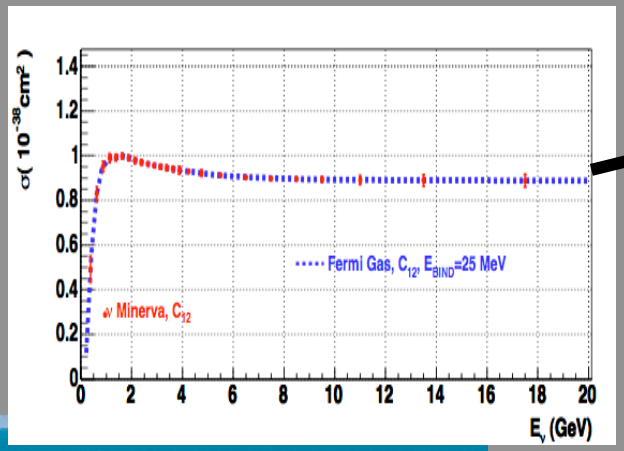
MINERνA Physics: Low Energy Neutrino Scattering

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NuMI flux range 1-20 GeV



Estimated Cross section uncertainties

Process		Current	After MINERνA
QE	~	20%	5%
Res	~	40%	5/10%(CC/NC)
DIS	~	20%	5%
Coh	~	100%	20%





CVC Partnership: NP (e-A Vector - Jlab JUPITER) HEP (vA axial+vector ; Fermilab MINERvA)

K. McFarland-Rochester, J. Morfin, FNAL

MINERvA HEP Spokespersons

significant NP participation in MINERvA because of overlap of physics with Jefferson Lab community





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.

Nuclear Option: MINERvA Attracts Nuclear Physicists

This is the fourth article in a series on the MINERvA neutrino experiment.



"MINERvA offers us the possibility of making a bridge in our understanding between the longer distance-scale properties of the nuclear force--responsible for the properties of nuclei--and the very short-distance scales explored in particle physics," says Ransome. "And this intermediate distance scale is of great interest to both communities."



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JLab program e-A (JUPITER)Spokespersons

A. Bodek - Rochester HEP

Cynthia Keppel - Hampton/Jlab - NP

Data for neutrino cross-section modeling

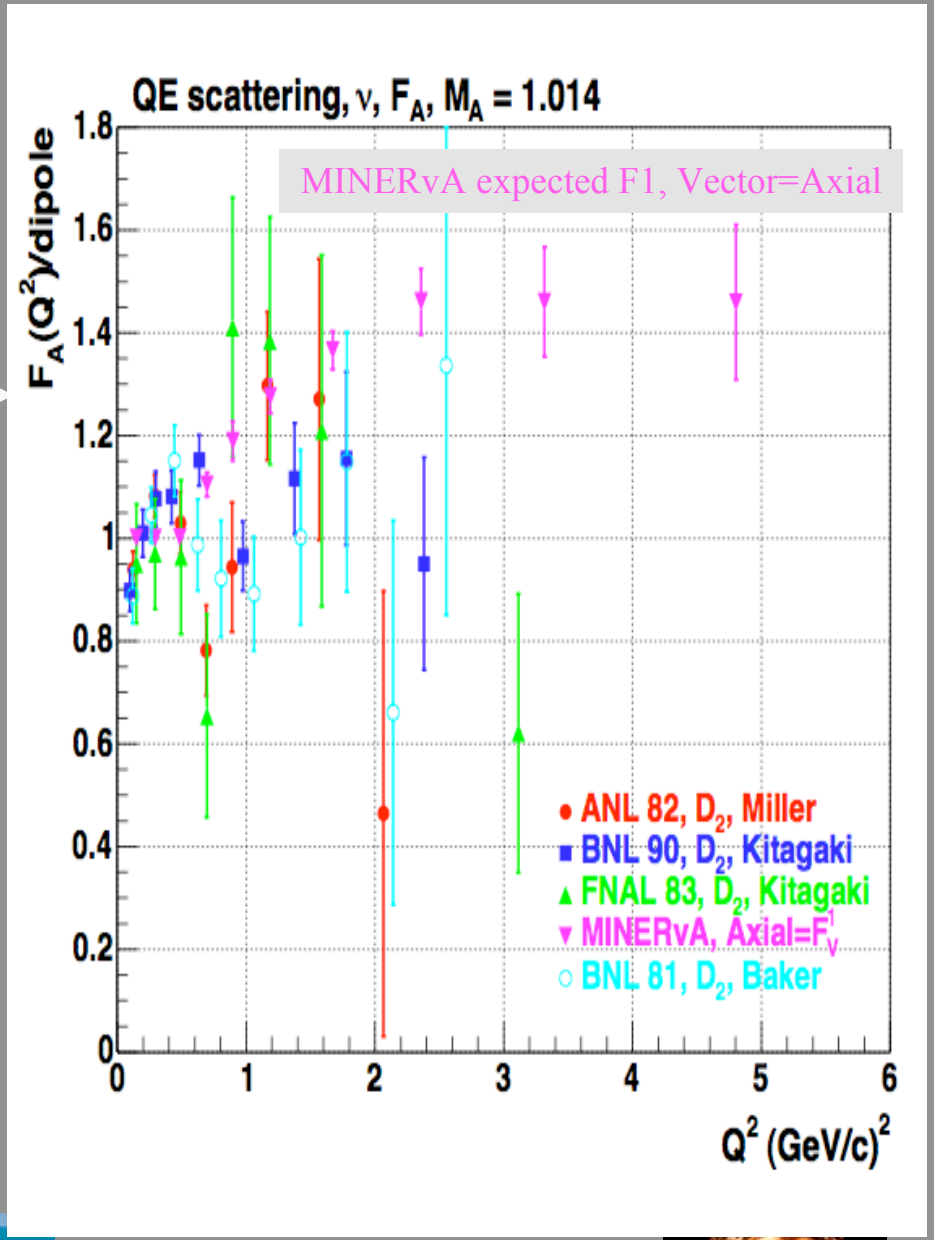
already run one dedicated experiment (Jlab E04-001)- Hall B inclusive

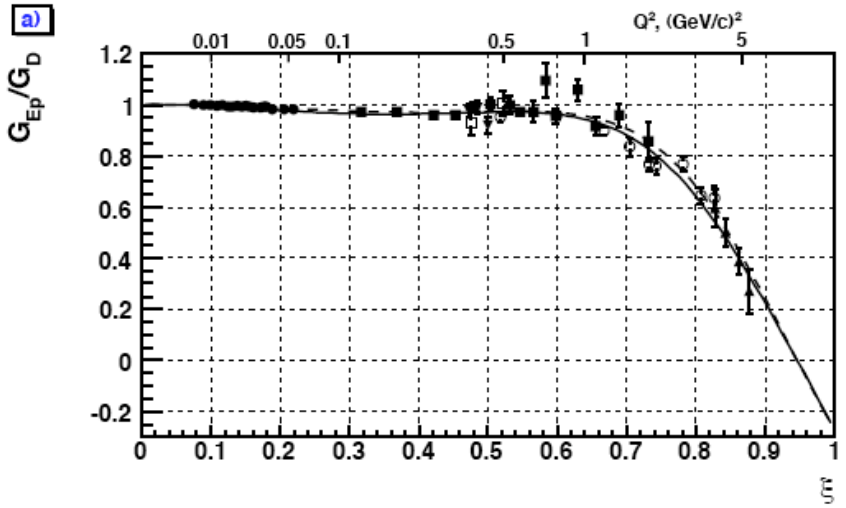
Active program of data mining with neutrinos in mind- Hall C, exclusive

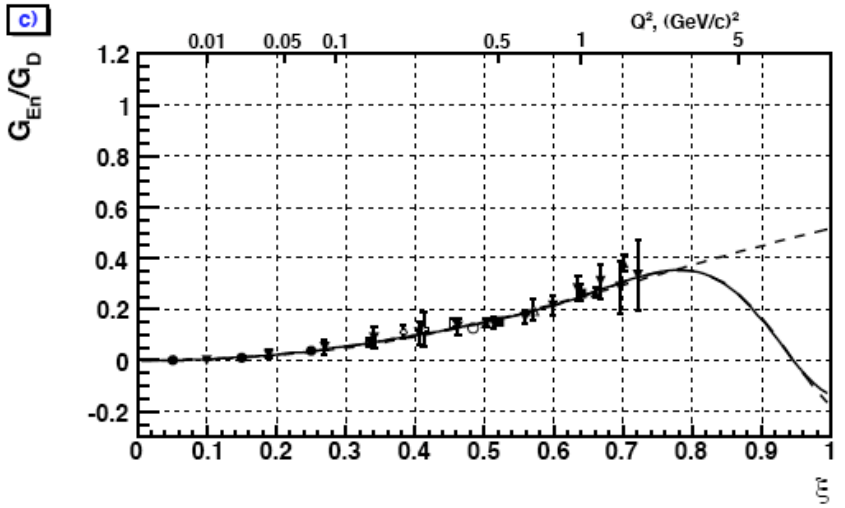
Motivation for MINERvA

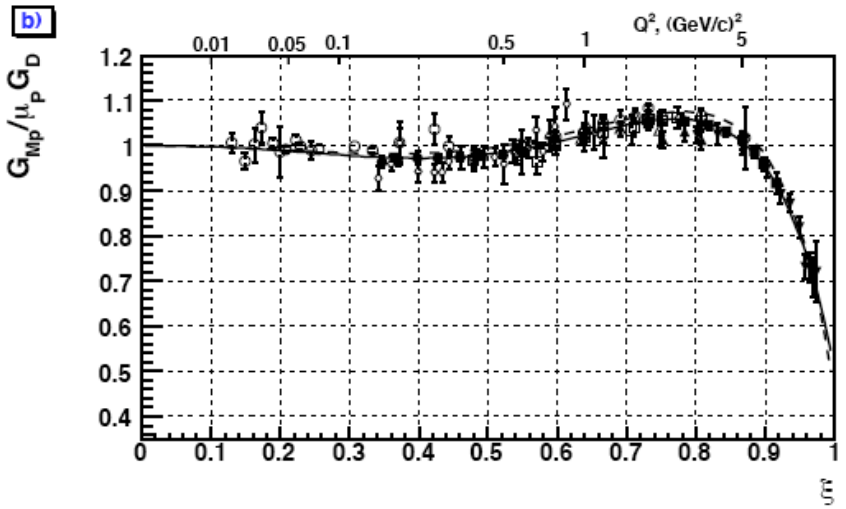
Cross sections interesting in their own right

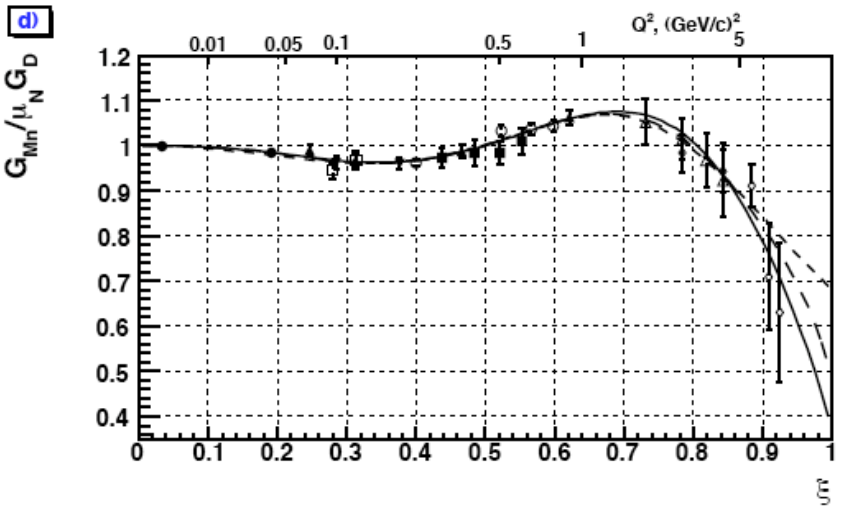
- Determination of axial form factor $F_A(Q^2)$
- Duality in neutrino interactions
  - Do the averaged structure functions in the resonance region agree with extrapolated DIS structure functions?
- Nuclear effects
- Coherent pion production
- DIS and resonance structure functions, high-x PDFs
- Strange & charm production
- Resonance production







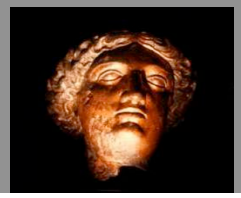




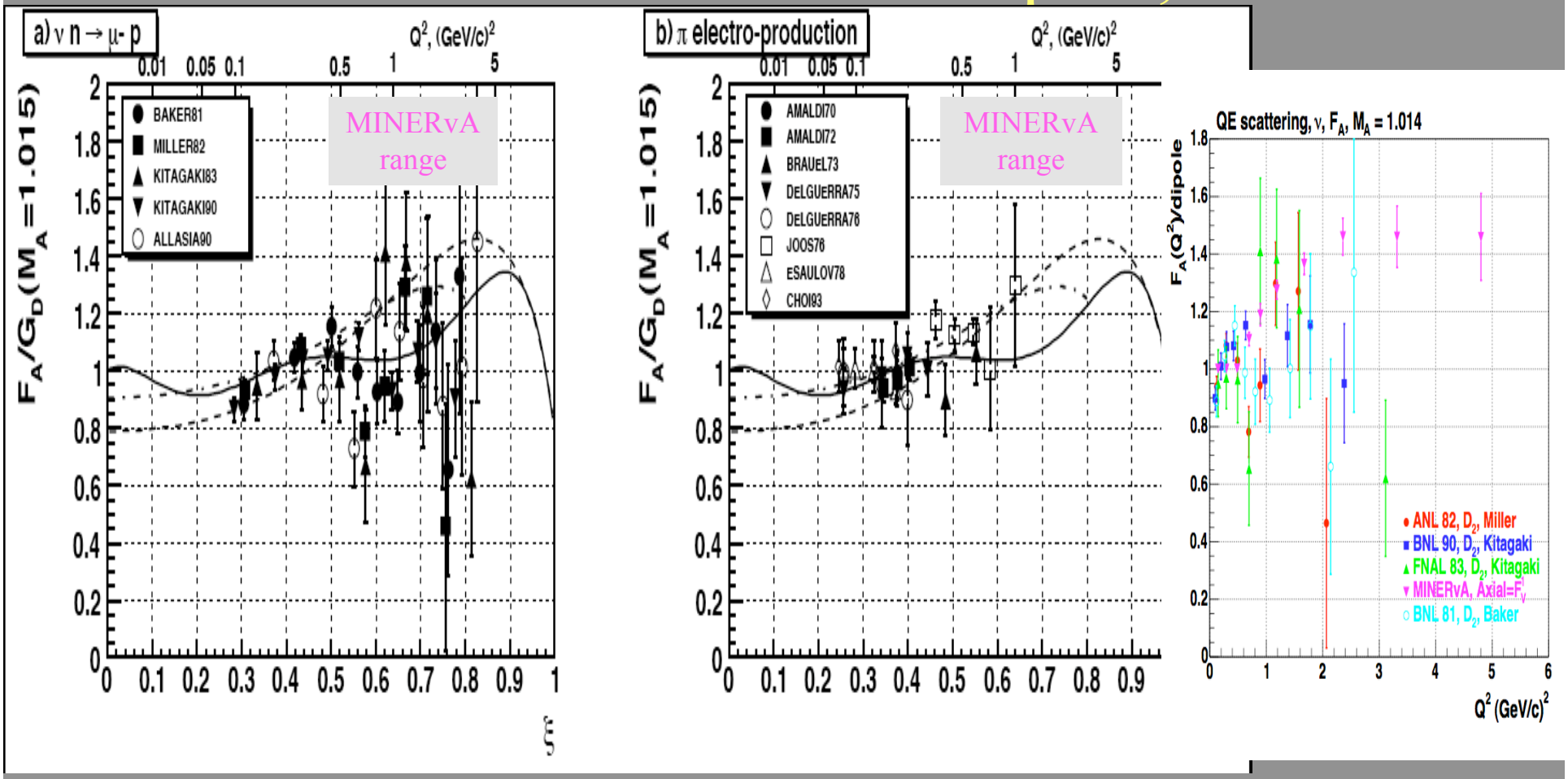
Vector and Axial Nucleon Form Factors:A Duality Constrained Parameterization. A. Bodek, et al. Hep/ex 0708.1946 Ratio to Dipole Mv=0.81 GeV.

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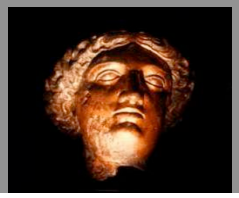


Axial Form Factor: ratio to dipole, Ma=1.014

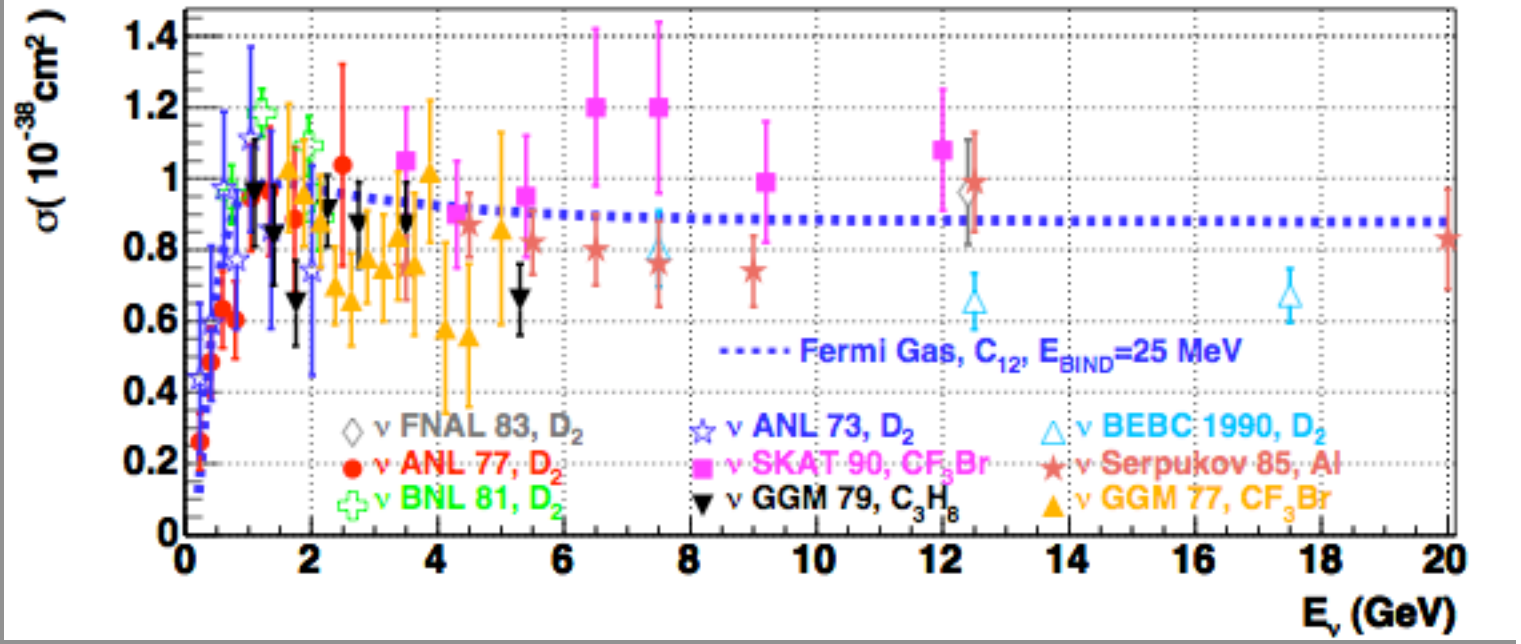


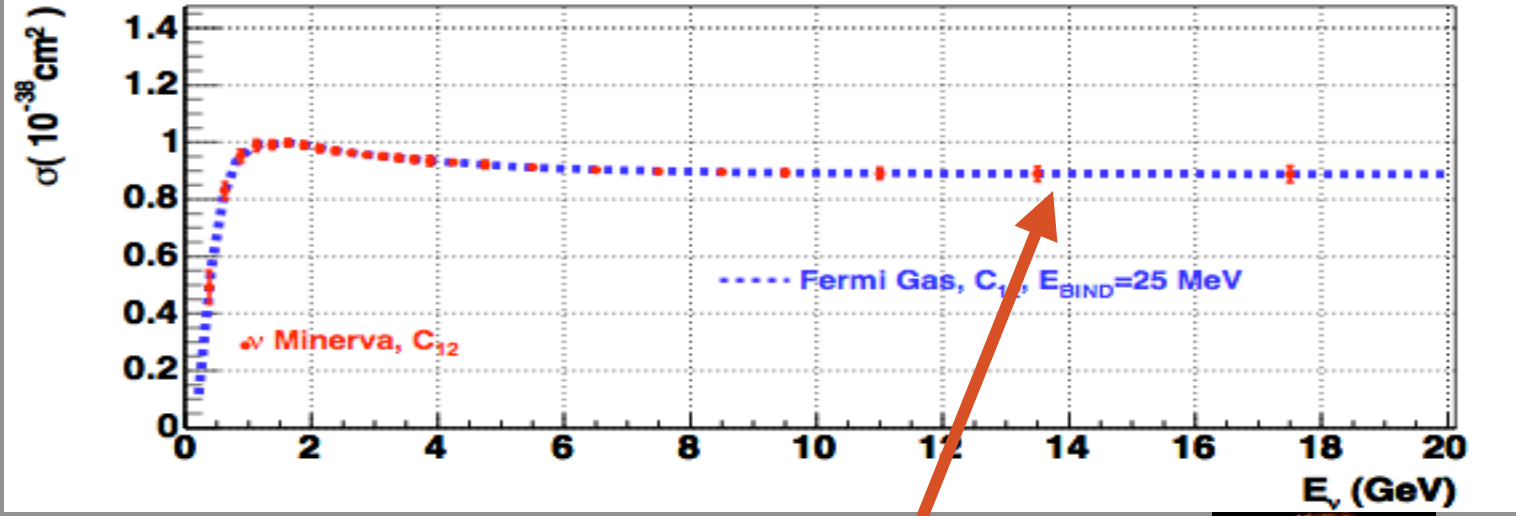
Vector and Axial Nucleon Form Factors:A Duality Constrained Parameterization. A. Bodek, et al. Hep/ex 0708.1946





Motivation for MINERνA

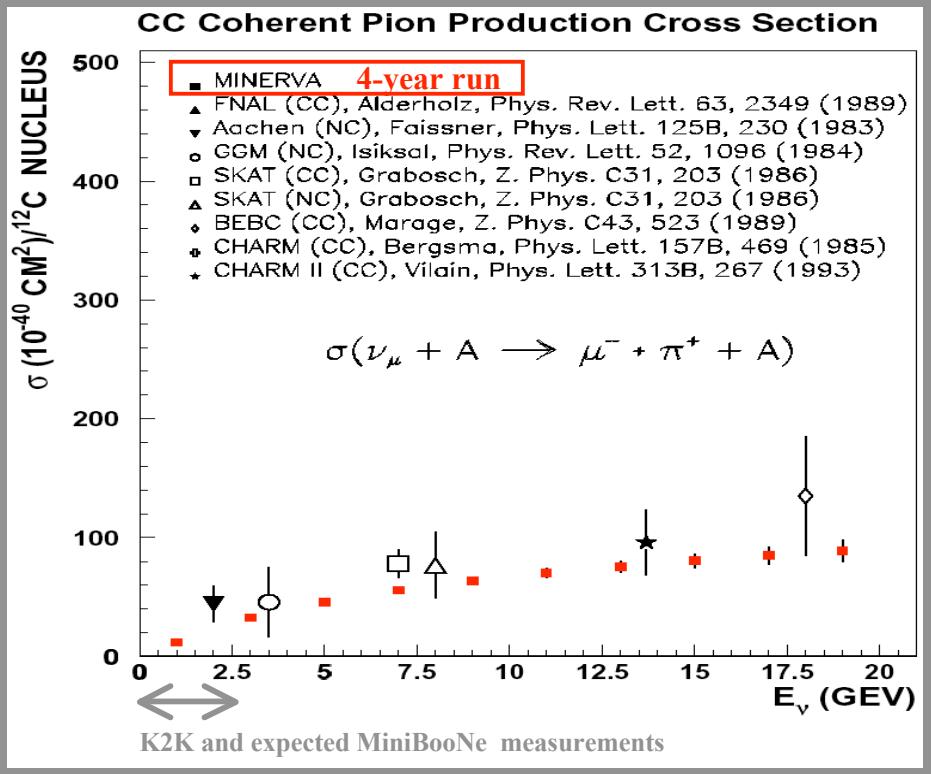


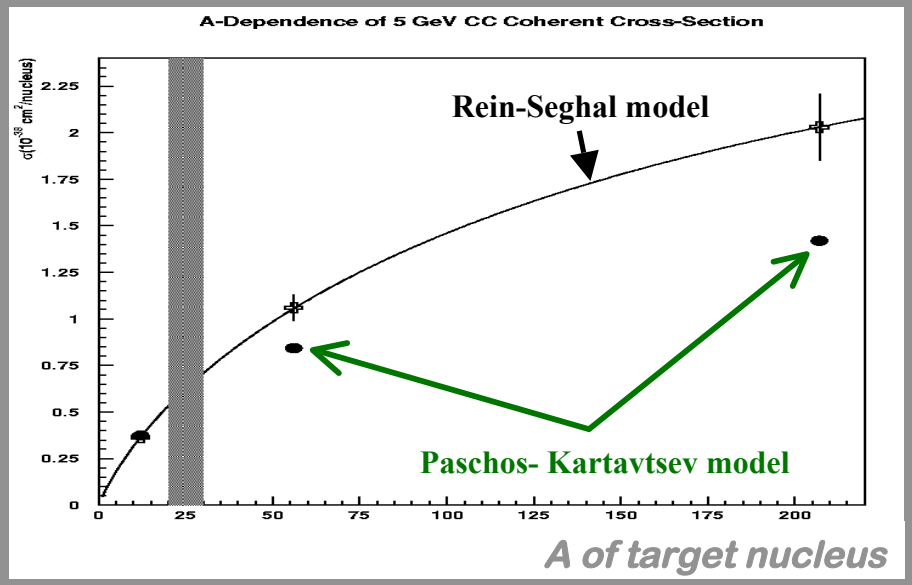


MINERνA Quasielastic



Coherent Pion Production

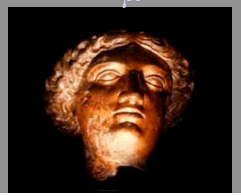




MINERνA's nuclear targets allow the first measurement of the A-dependence of σ_{coh} across a wide A range ➔ Distinguish between models

- Provides a test of the understanding of the weak interaction
  - Cross section can be calculated in various models
- Neutral pion production is a significant background for neutrino oscillations
  - π^0 shower easily confused with an electron shower: $\nu_\mu \rightarrow \nu_e n \rightarrow e^- p$, $\nu_\mu A \rightarrow \nu_\mu \pi^0 A$

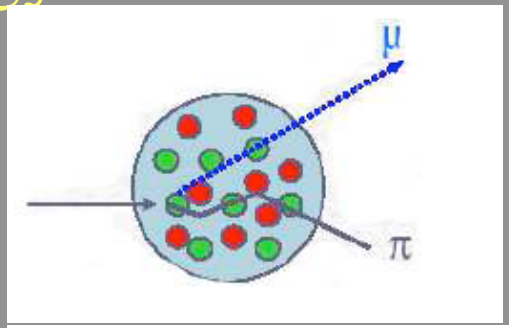




MINERνA and Oscillations- Example: Nuclear Effects on event energy in MINOS

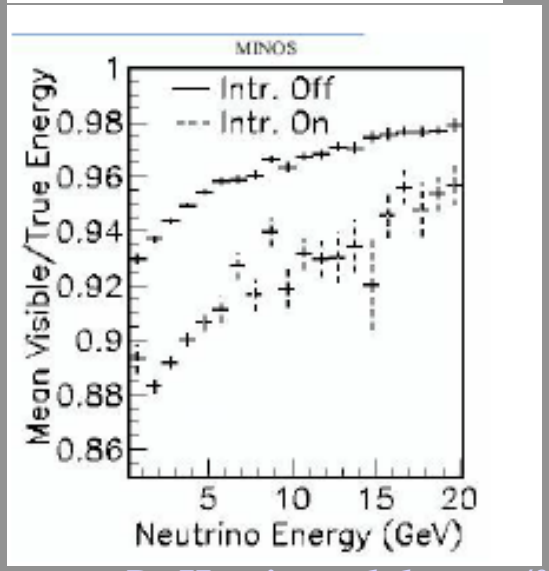
Final State Interactions

- Intranuclear rescattering
- Energy loss and/or absorption
- Change in direction



MINOS Iron Calorimeter - Nuclear effects among the largest systematics

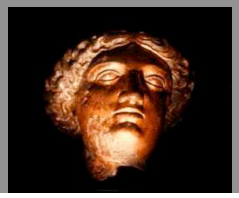
Changes measured visible energy Spectrum: Translate to shift in Far/Near 'dip' location -> Δm^2



D. Harris et al. hep-ex/0410005

MINERνA : measurements with high-A targets and high-statistics

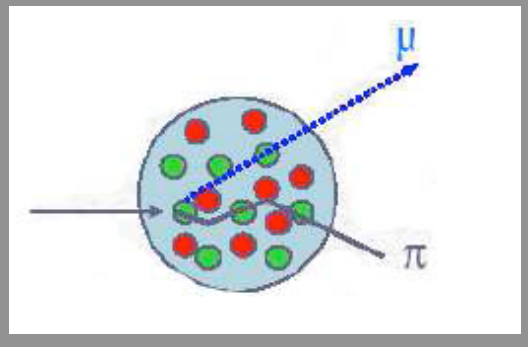




MINERνA and Oscillations- How much is the improvement: Nuclear Effects on MINOS

Final State Interactions

- Intranuclear rescattering
- Energy loss and/or absorption
- Change in direction

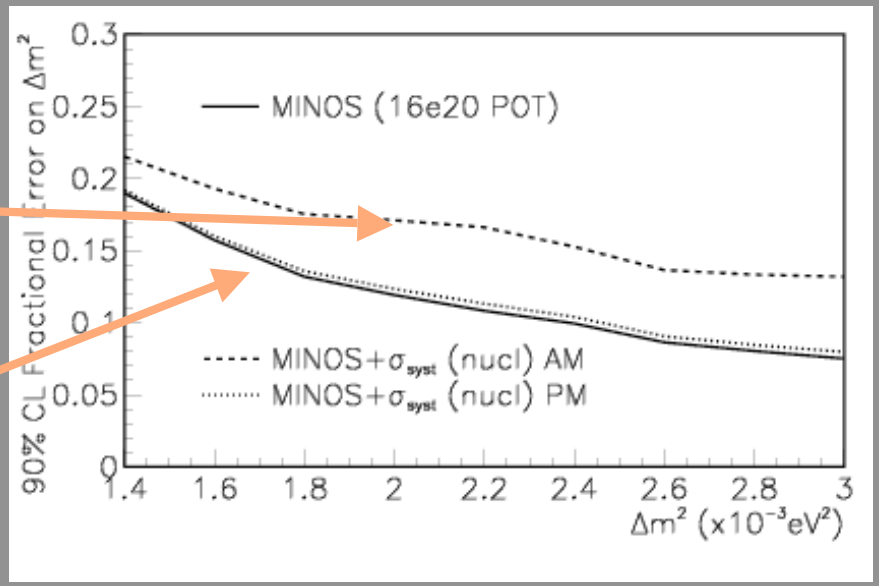


Before MINERνA

$\sigma_{stat} \sim \sigma_{syst}$ (rescattering only)

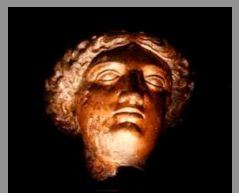
After MINERνA:

$\sigma_{stat} >> \sigma_{syst}$ (rescattering only)

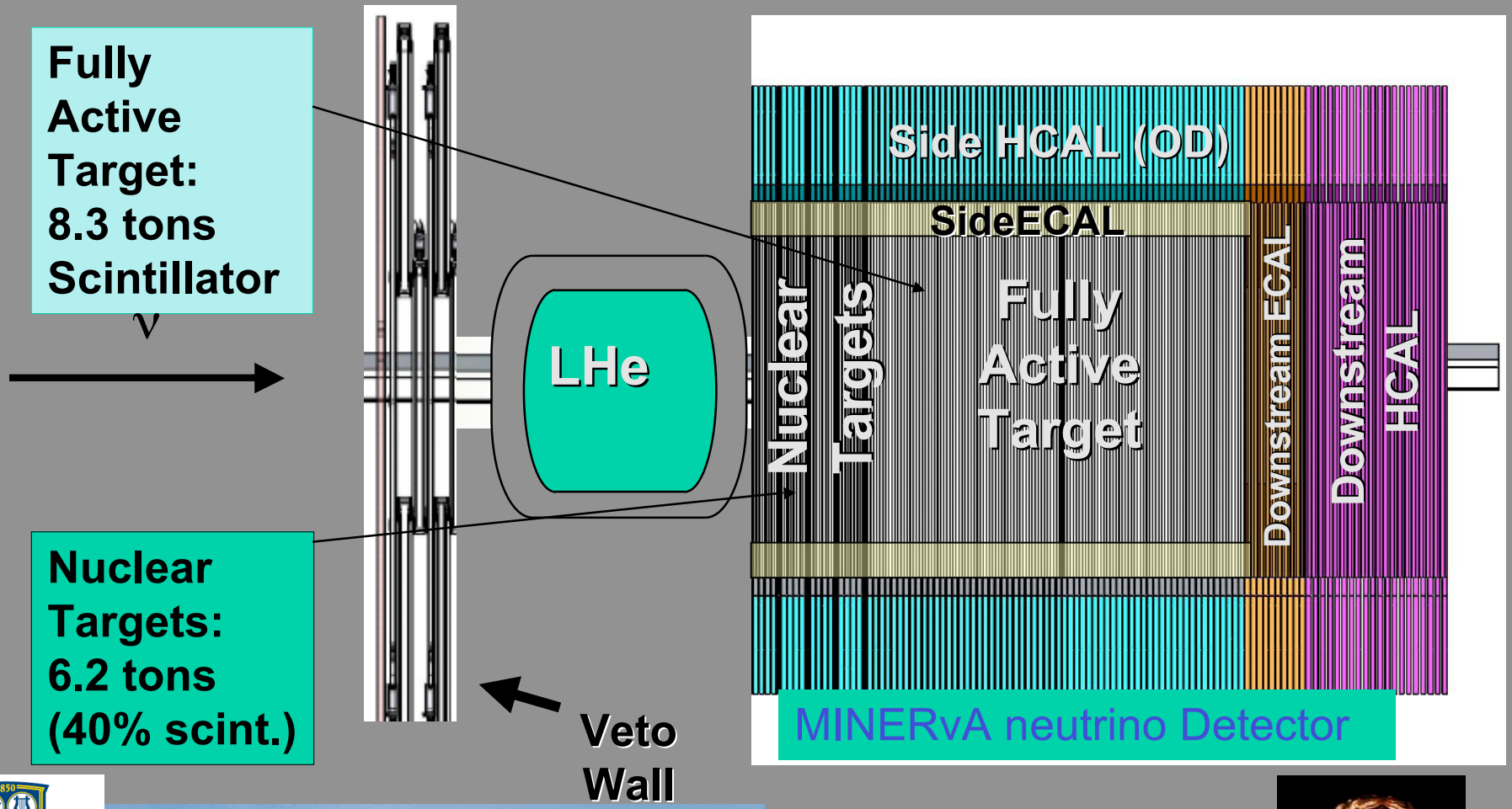


MINERνA: measurements with high-A targets and high-statistics

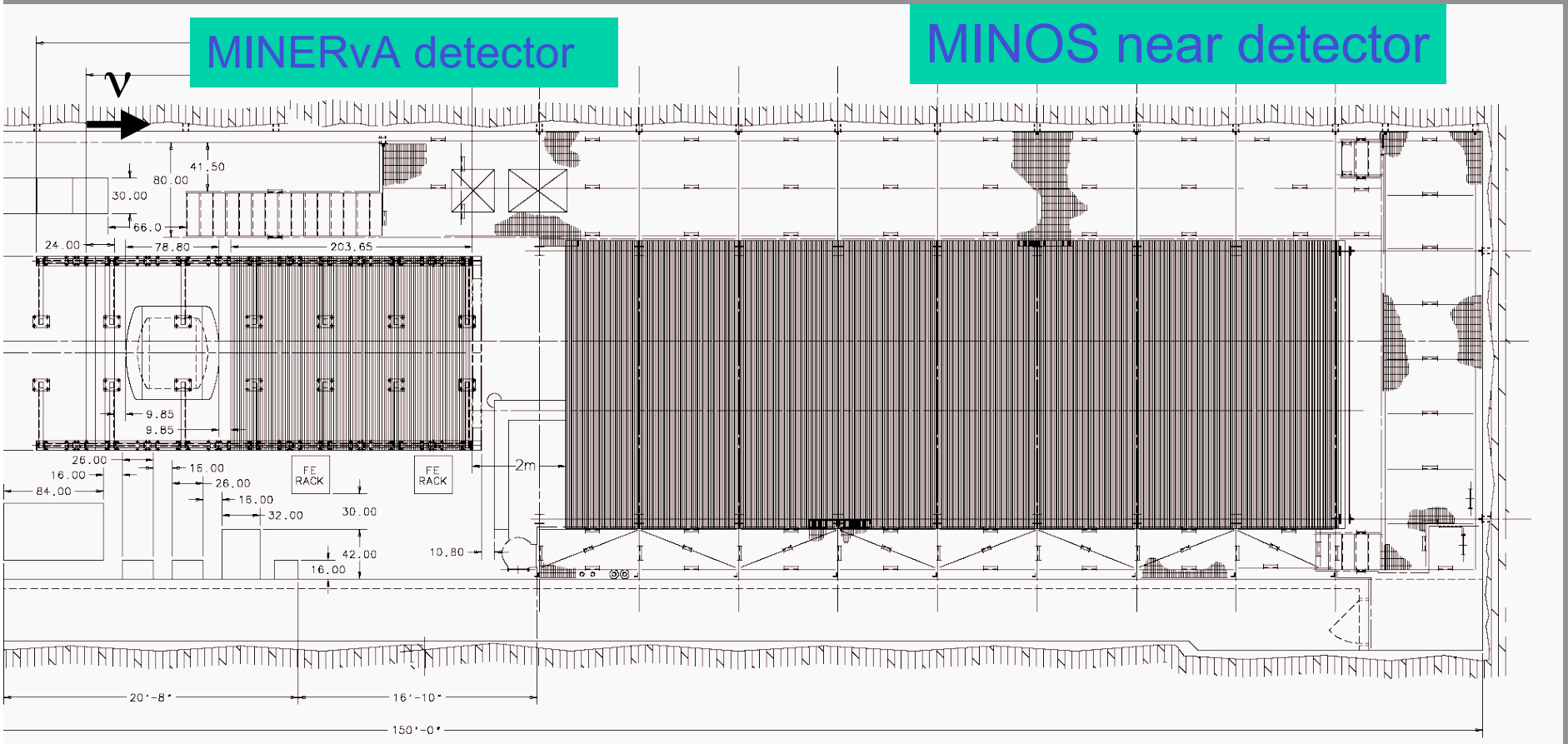




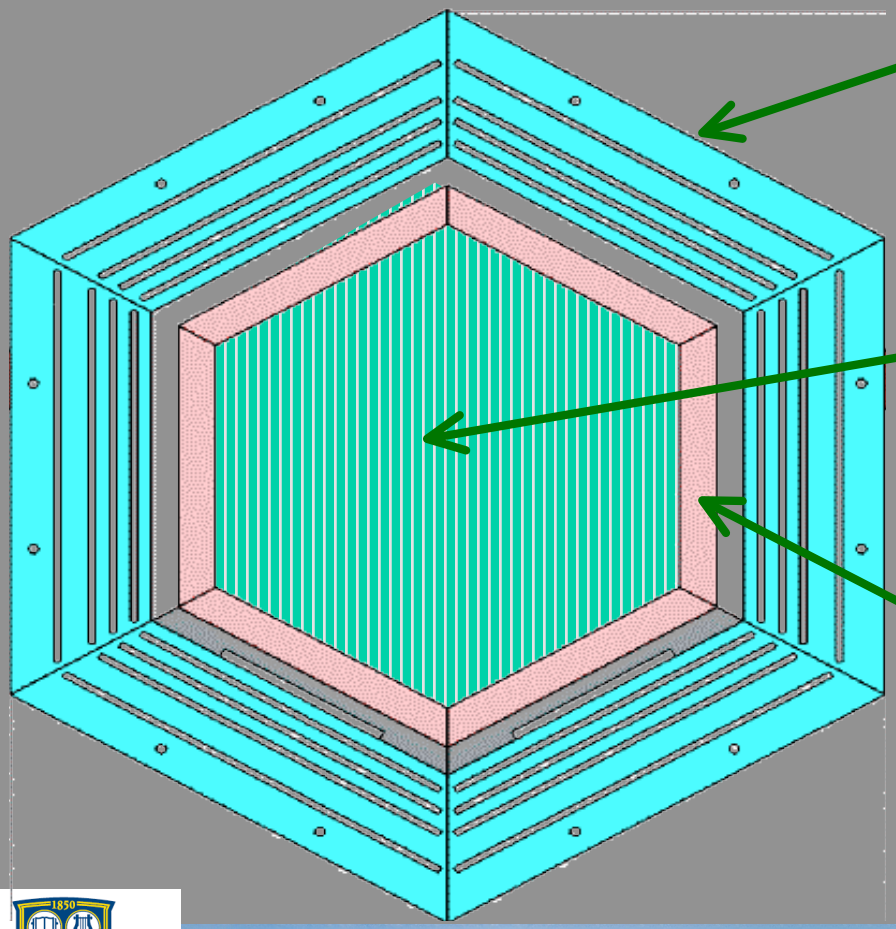
MINERvA Structure



MINERvA & MINOS



MINERvA Detector Module

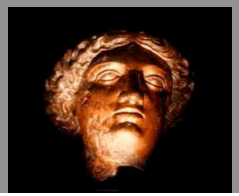


Outer Detector (OD)
"Towers" of iron & scintillator for hadron calorimetry

Inner Detector (ID)
Hexagonal X, U, V planes for 3D tracking, Active Scintillator Target

Lead for EM calorimetry



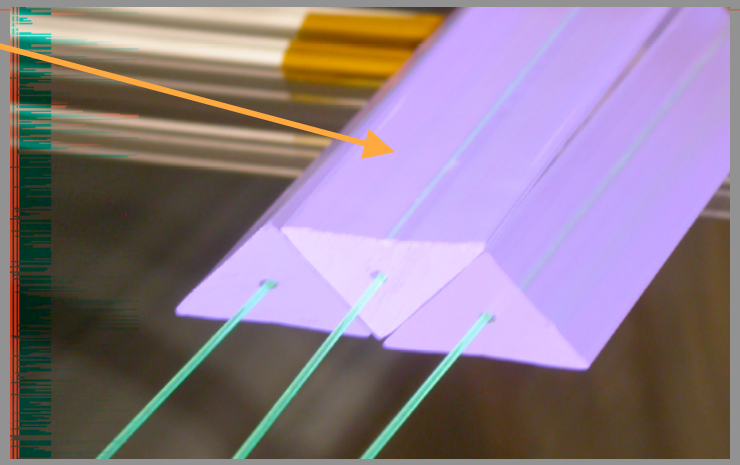


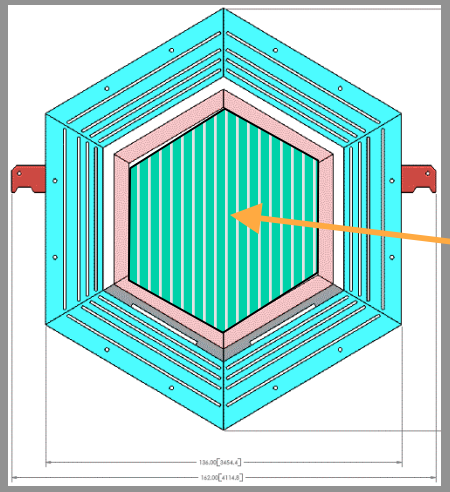
MINERvA Detector

Detector Channel Count:

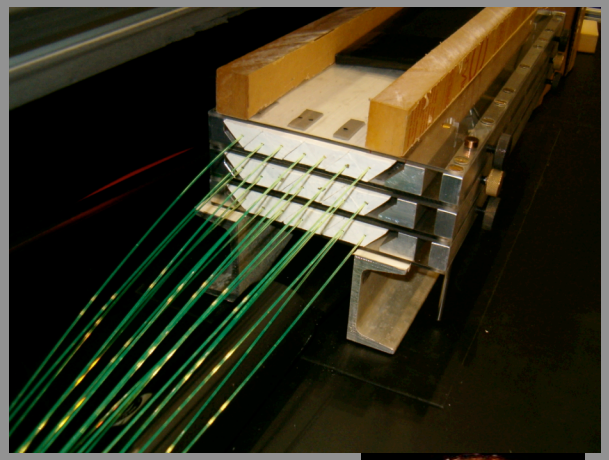
- **31,000 channels**
  - 80% in inner hexagon
  - 20% in Outer detector
- **503 M-64 PMTs** - 64 channels
- **128 pieces of scintillator per Inner Detector plane**

Active elements are 1.7x3.3 cm triangular bars of extruded scintillator with embedded 1.2 mm WLS fibers



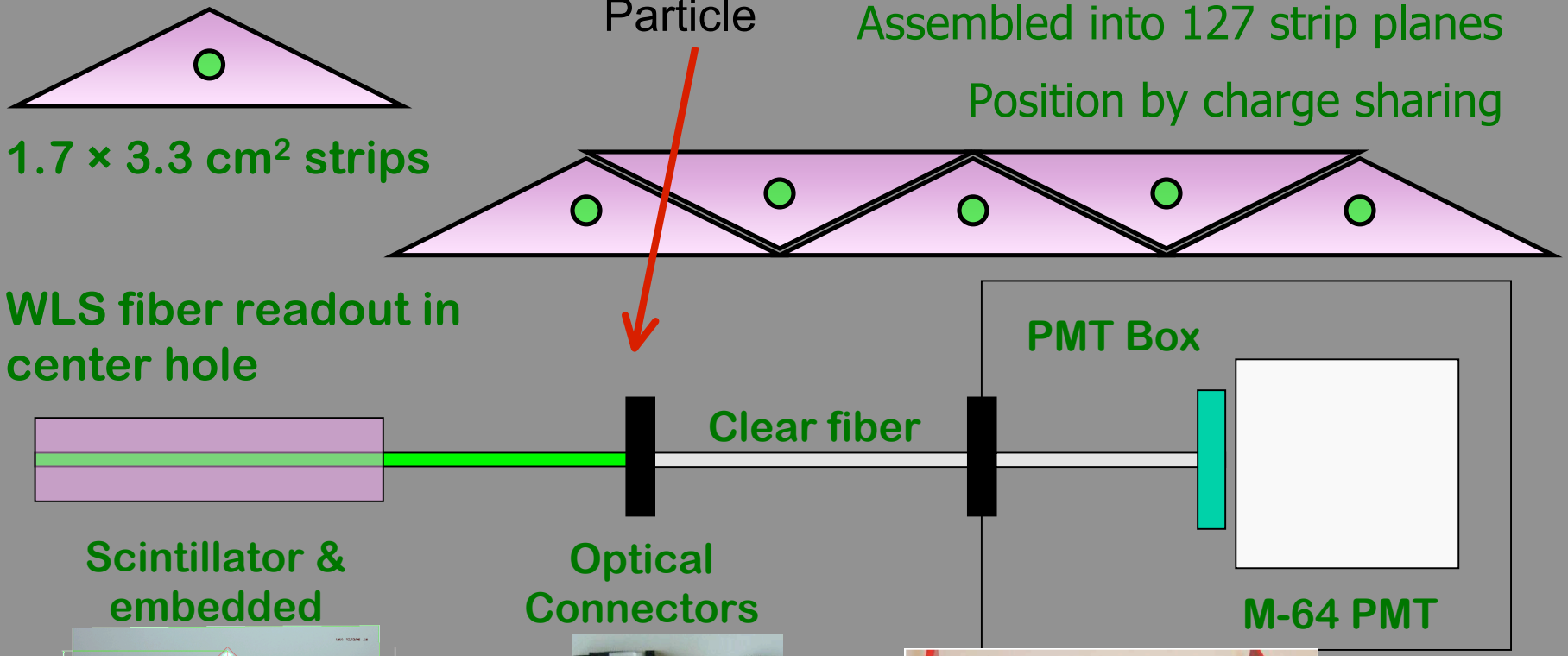


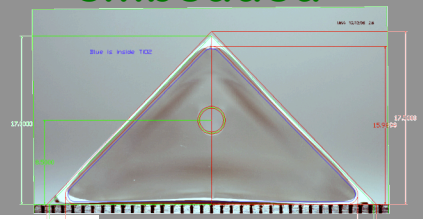
Inner detector is totally active scintillator strip detector. Alternating planes rotated by 60 degrees to make 3 views (XUXV)

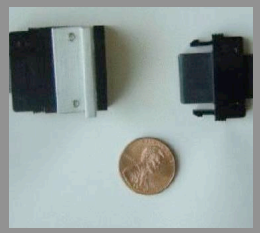


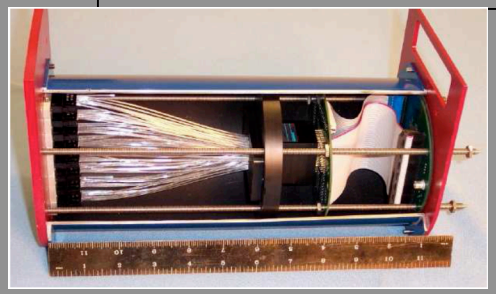


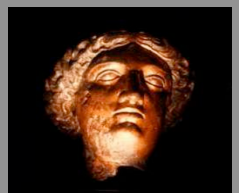
MINERvA Active Scintillator Target







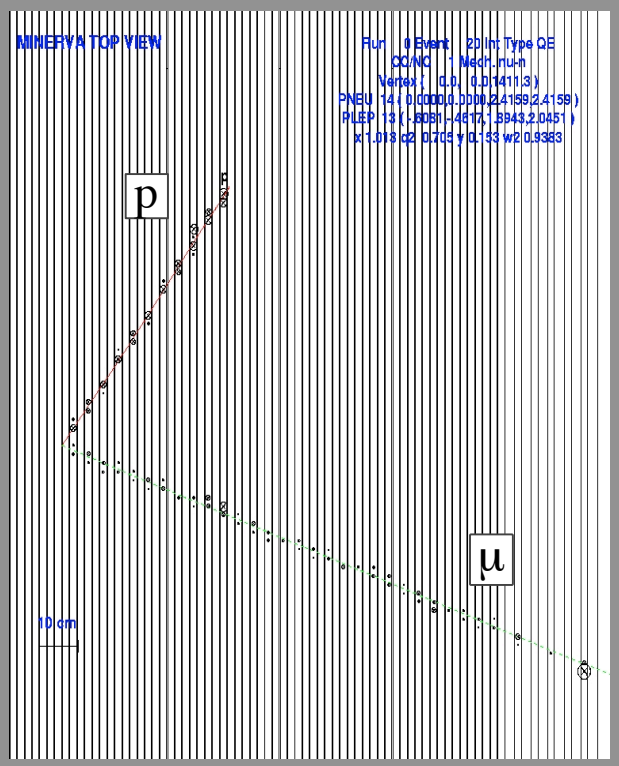


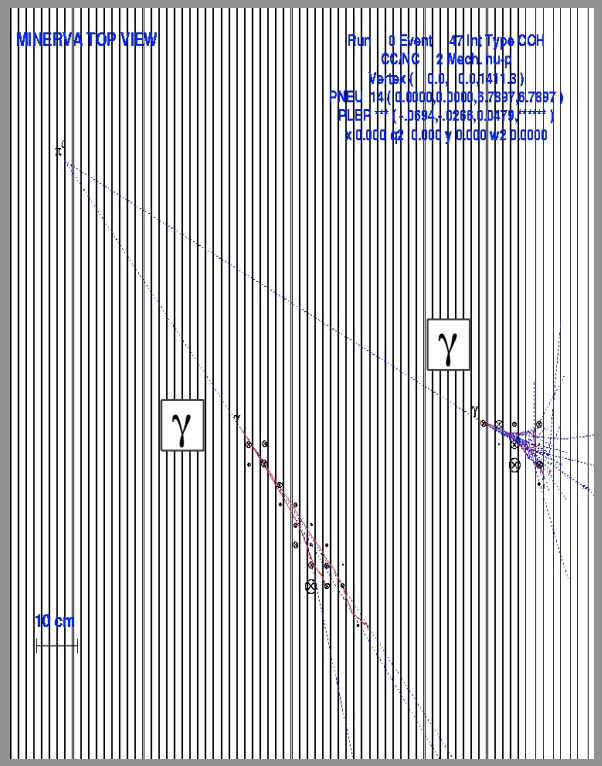


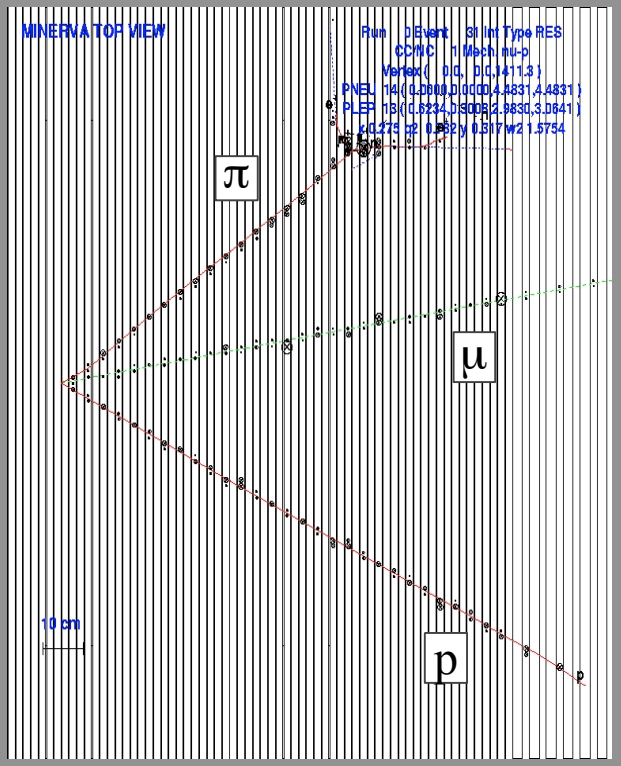


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MINERνA Events







Quasielastic event

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

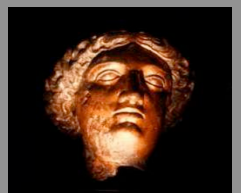
Neutral Current π^0

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

Resonance production

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

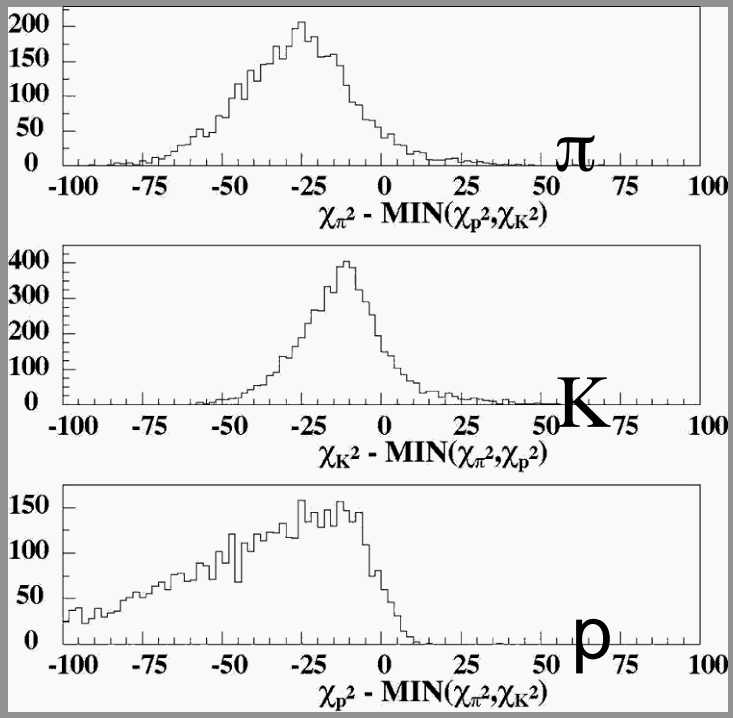




Particle Identification

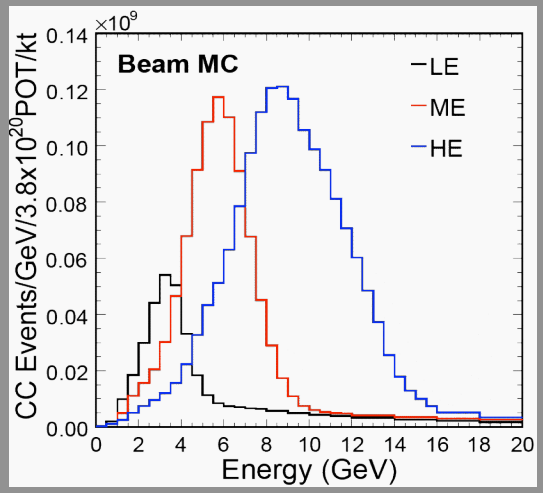
- Particle ID by dE/dx in strips and endpoint activity
- Many dE/dx samples for good discrimination
  - Sensitive to light yield

X^2 differences between right and best wrong hypothesis



Event Sample with 4 10^{20} Protons on Target (LE) & 12 10^{20} POT ME beam

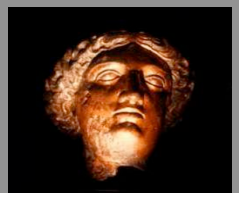
Target	Fiducial Vol. (tons)	Expected CC Yields (10^6)
CH (scintillator)	3	9.0
He	0.2	0.6
C	0.15	0.4
Fe	0.7	2.0
Pb	0.85	2.5



Main CC Physics Topics (Statistics in active target only - CH)

• Quasi-elastic	0.8 M events
• Resonance Production	1.7 M total
• Transition: Resonance to DIS	2.1 M events
• DIS, Structure Funcs. and high-x PDFs	4.3 M DIS events
• Coherent Pion Production	89 K CC / 44 K NC
• Strange and Charm Particle Production	> 240 K fully reconstructed events
• Generalized Parton Distributions	~ 10 K events



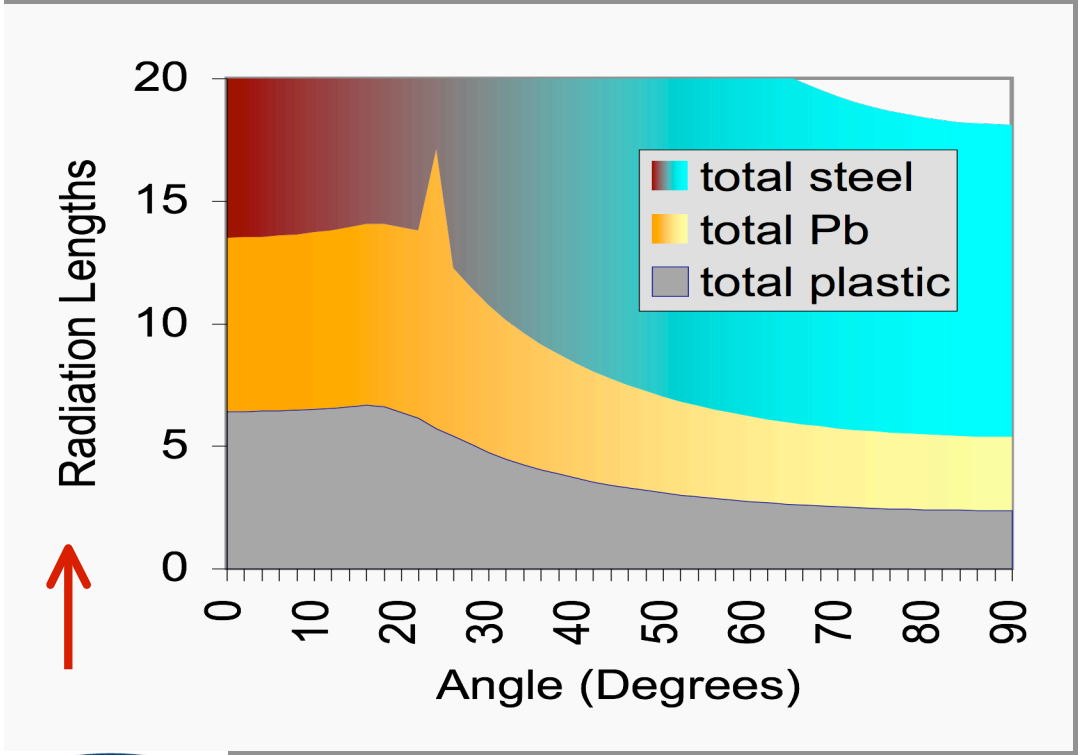


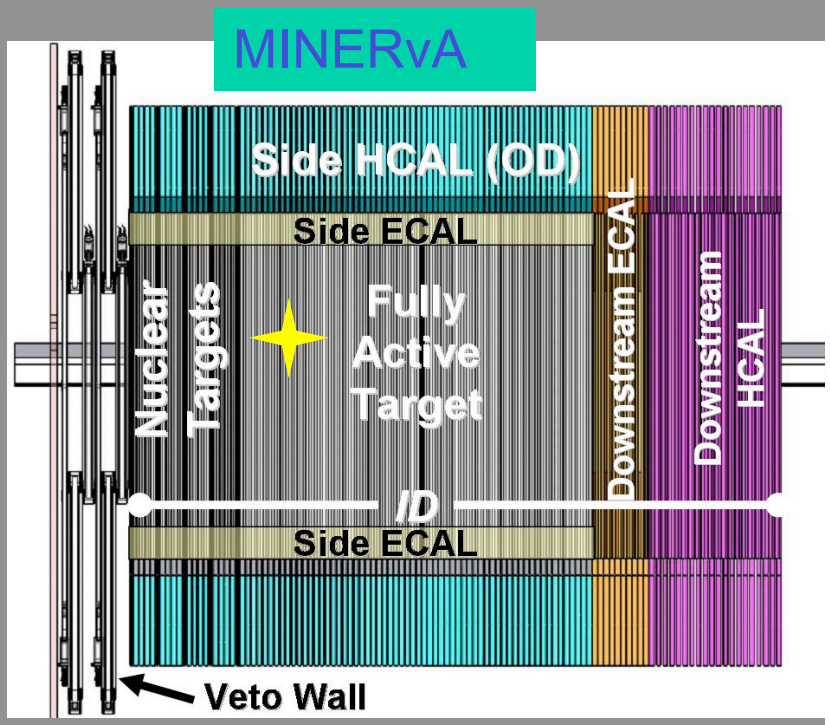
Physics Goals

- Axial form factor of the nucleon
  - **Accurately measured over a wide Q2 range.**
- Resonance production in both NC & CC neutrino interactions
  - **Statistically significant measurements with 1-5 GeV neutrinos**
  - **Study of "duality" with neutrinos**
- Coherent pion production
  - **Statistically significant measurements of A-dependence**
- Strange particle production
  - **Important backgrounds for proton decay**
- Parton distribution functions
  - **Measurement of high-x behavior of quarks**
- Generalized parton distributions
- Nuclear effects
  - **Expect some significant differences for nu-A vs e/m-A nuclear effects**

MINERvA as an Electromagnetic Calorimeter

- Material thickness in radiation lengths
  - Side & downstream ECALs have 2mm Pb plates



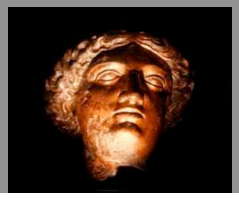


Fe for Hardron calorimetry

Pb for EM calorimetry

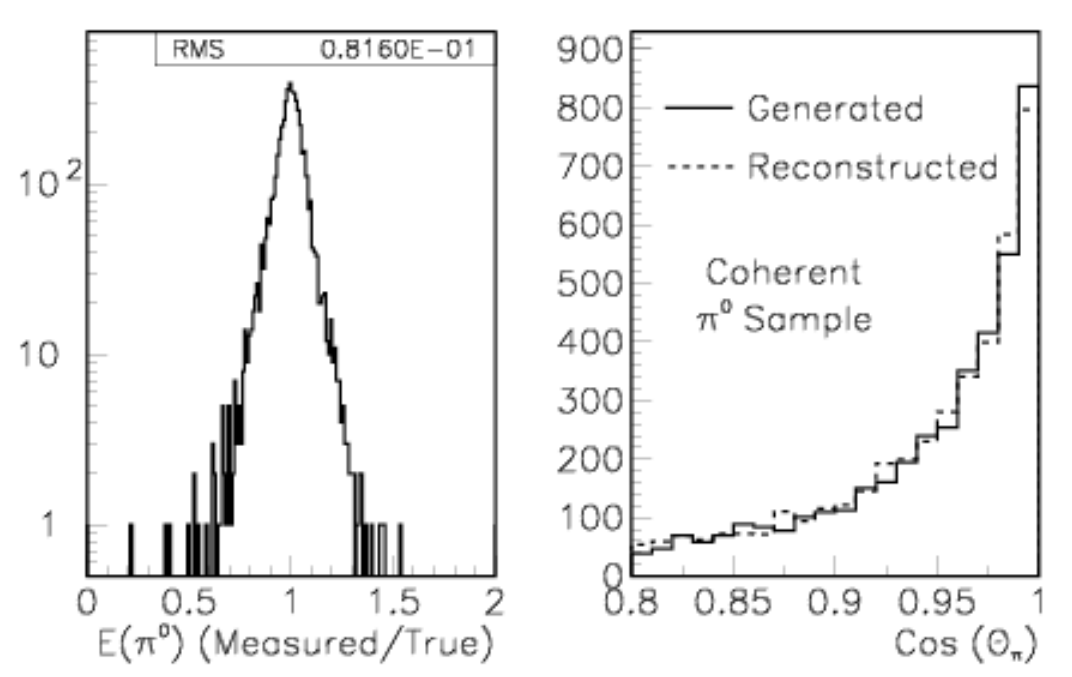
Active Scintillator Target

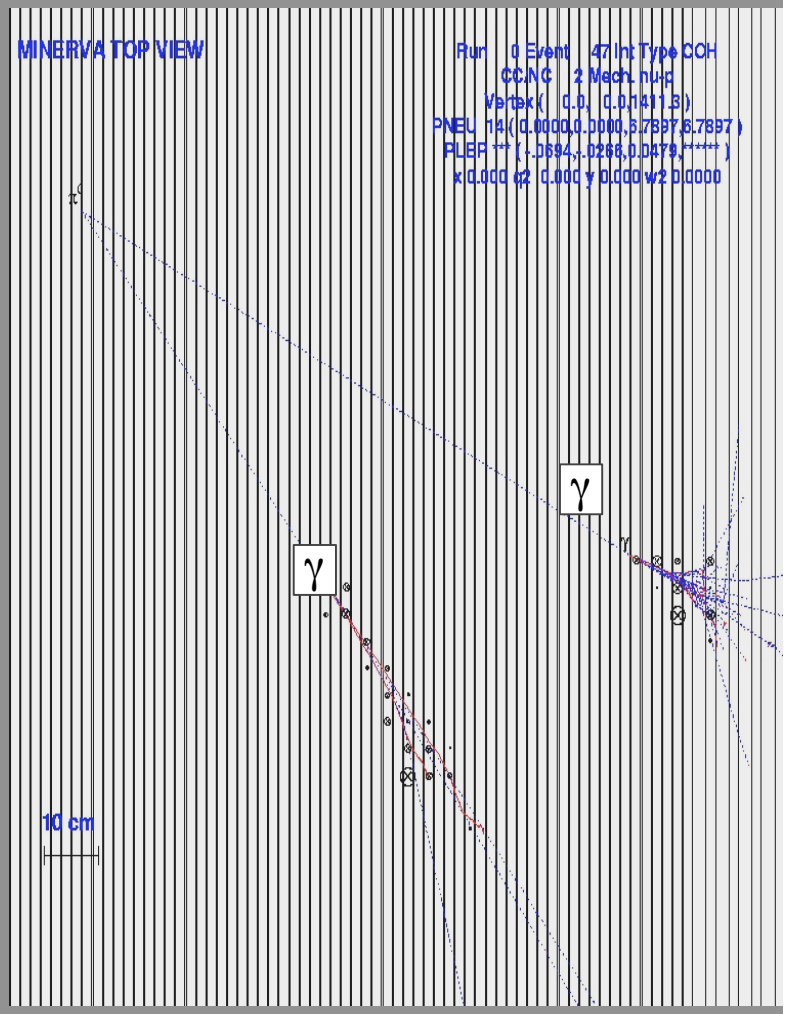




Neutral Pions

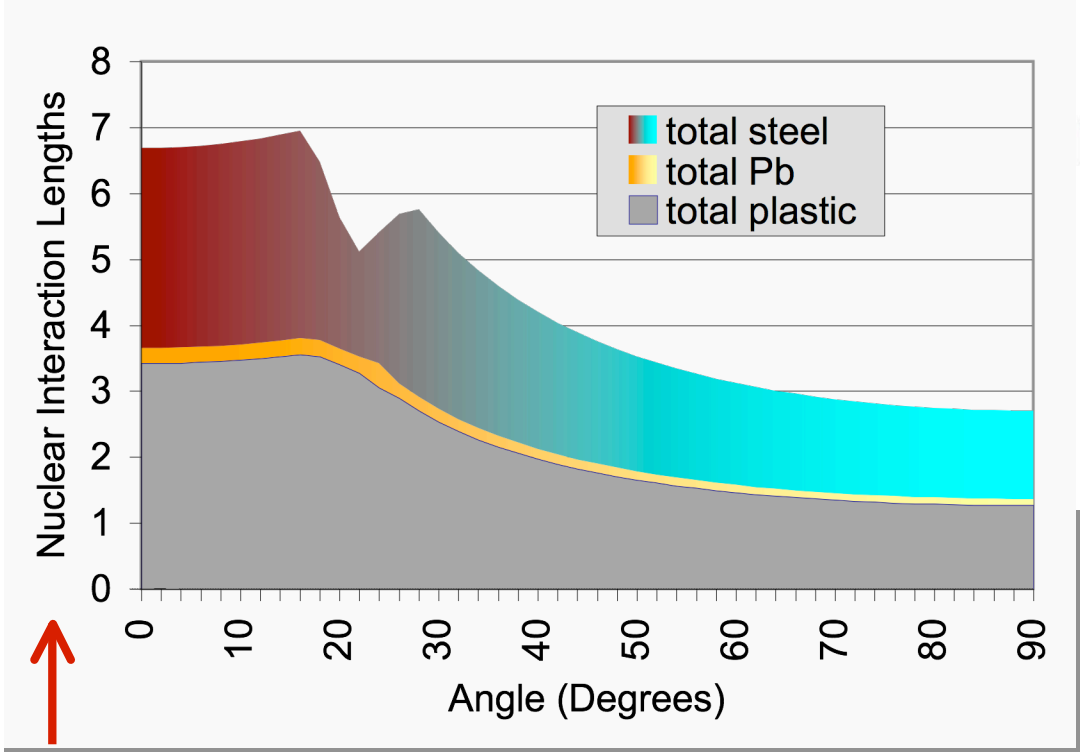
- Photons cleanly identified and tracked
  - π^0 energy res.: 6%/√ E (GeV)
- For coherent pion production, angular resolution < physics width

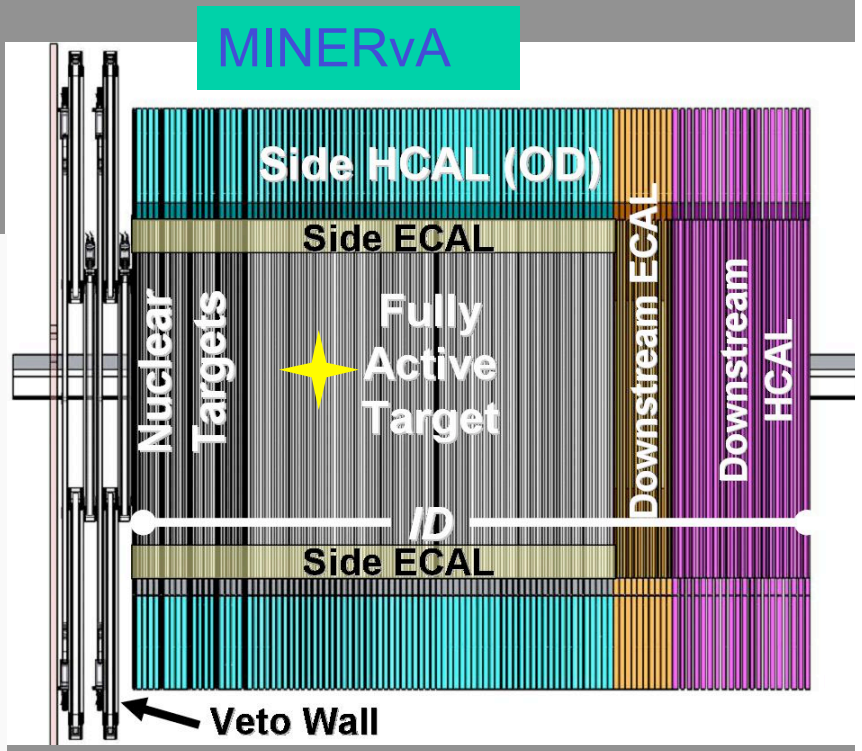




MINERvA as Calorimeter

- Material thickness in nuclear interaction lengths



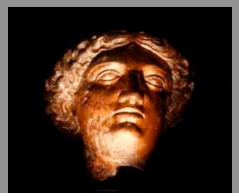


Fe for Hardron calorimetry

Pb for EM calorimetry

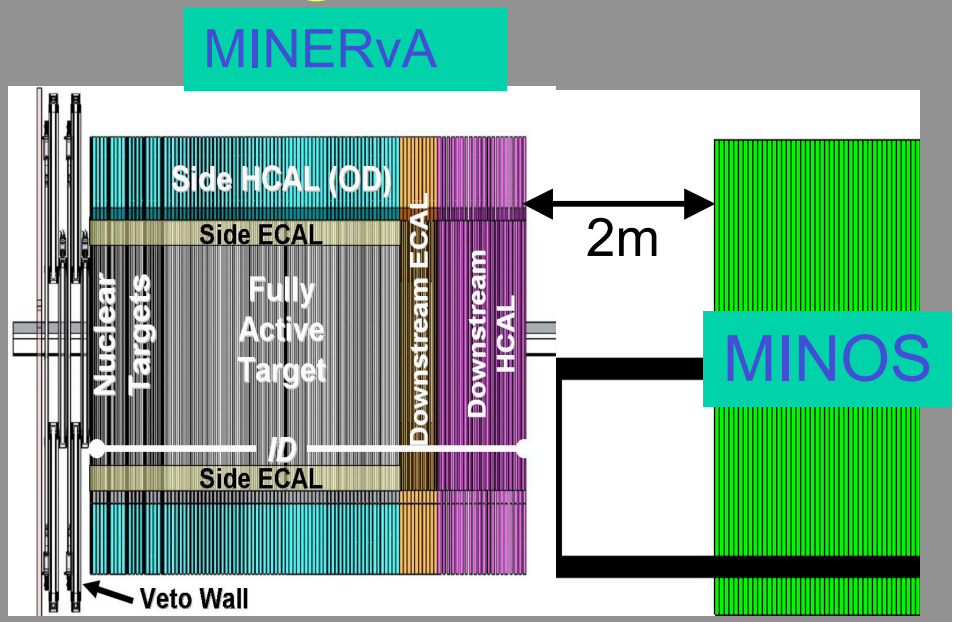
Active Scintillator Target



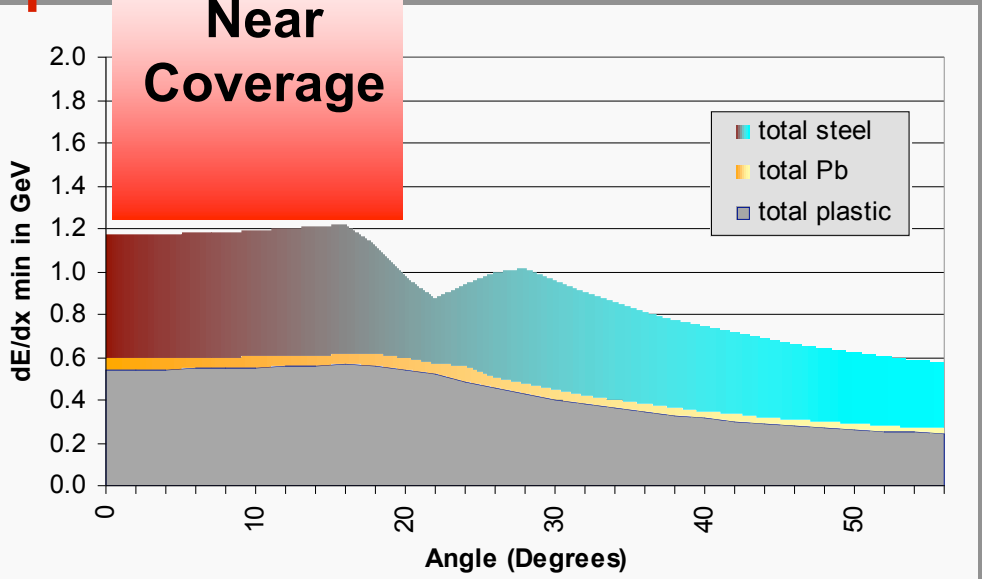


MINERvA as muon range tracker

- Largely rely on MINOS near detector
  - For high momentum
  - Analyze by
    - Range for lower energy muons
    - Curvature in the magnetics field for higher energy muons (δp/p~12%)



MINOS Near Coverage



Material thickness in $(dE/dx)_{min}$

Fe for Hardron calorimetry

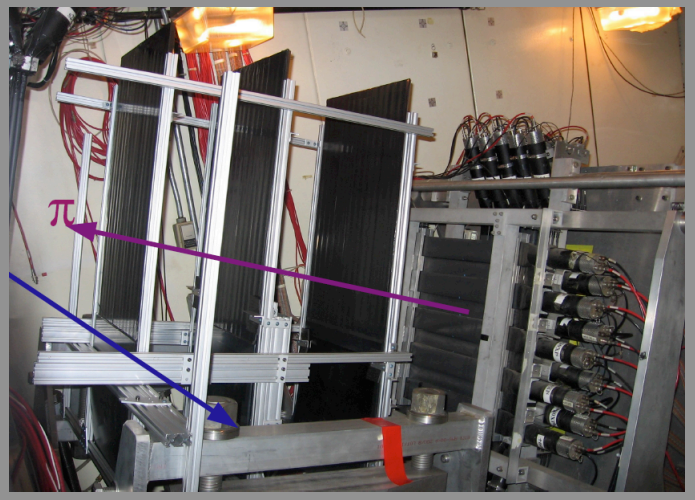
Pb for EM calorimetry

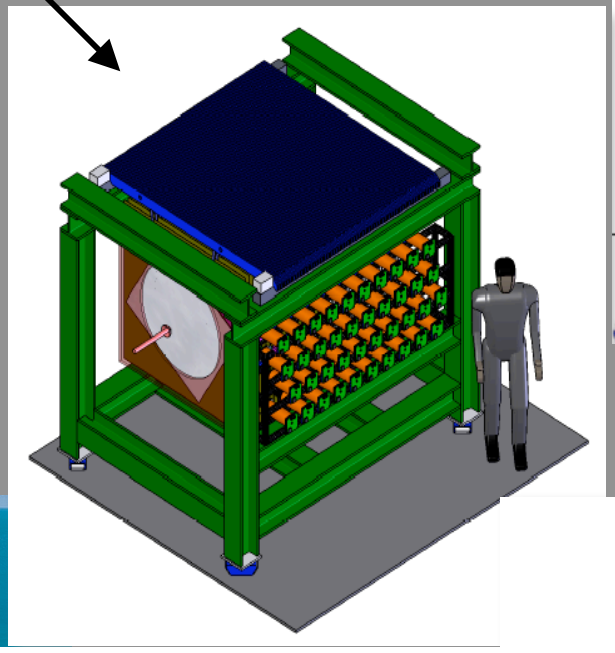
Active Scintillator Target

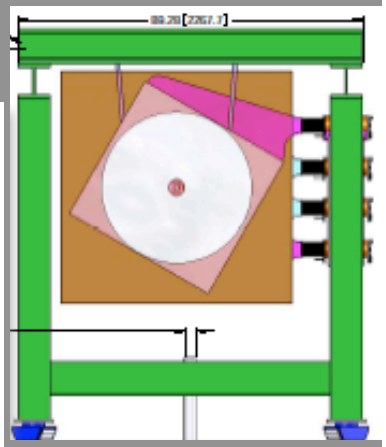


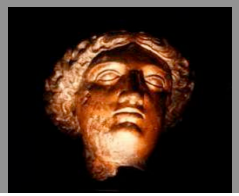
Test beam program at Jlab and FNAL

- 2 phases
- Small array in the SOS spectrometer at Jlab
  - 150 to 450 MeV pions
  - Spectrometer tracking
  - 3 planes with a steel plate
- Larger detector in the MTEST at Fermilab
  - 40 planes of target
    - 1 m^2 active area
    - Full XUXV tracking structure
  - Removable Pd and Fe plates
  - Planning a new tertiary beam for sub GeV particles
  - Run plan in 2008





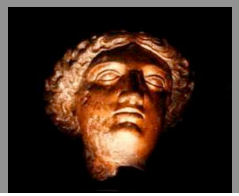




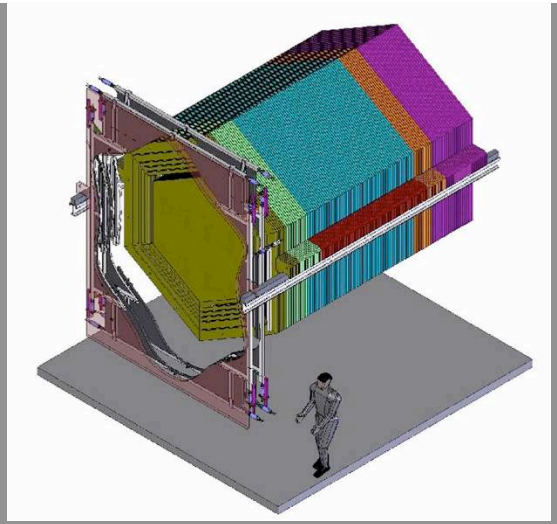
MINERvA schedule

- MINERvA received DOE critical decision (CD) 3a approval Spring 07
  - Authorization for advanced purchases
  - Bulk purchases being executed for PMT's, WLS fiber, Clear fiber, PMT box components, steel and lead
- Approved for full construction authorization (CD 3b) Fall 07
  - Included in FY08 Presidential Budget for Department of Energy
- Construction begun
- Detector installation and commissioning in 2009





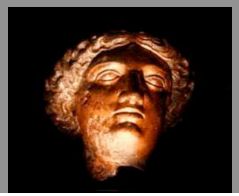
Summary



- MINERvA
  - Precision neutrino interaction measurements over a wide range of neutrino energies
  - Several different nuclear targets --> study of nuclear effects
  - Important input to current and future oscillation measurements
  - Physics - Axial form factors, high x PDFs, Resonances, Nuclear effects, low energy cross sections

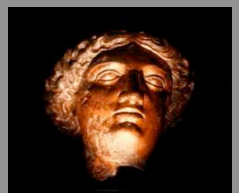
data in 2009!





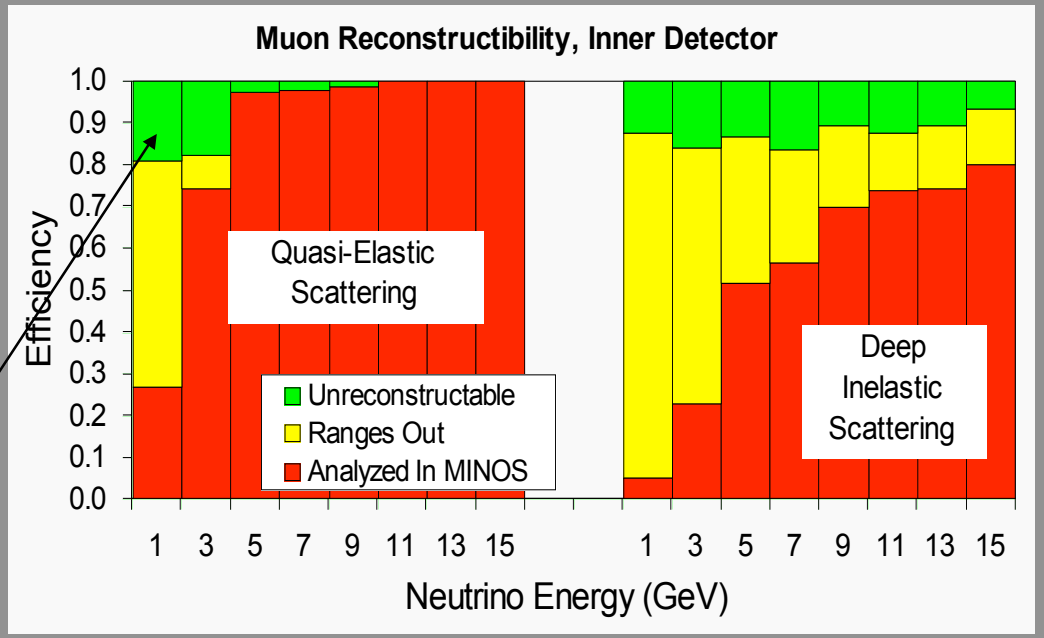
Backup Slides





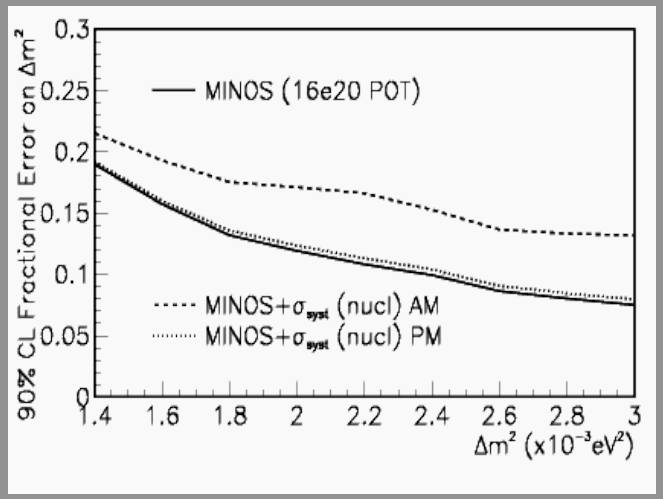
Muon Acceptance

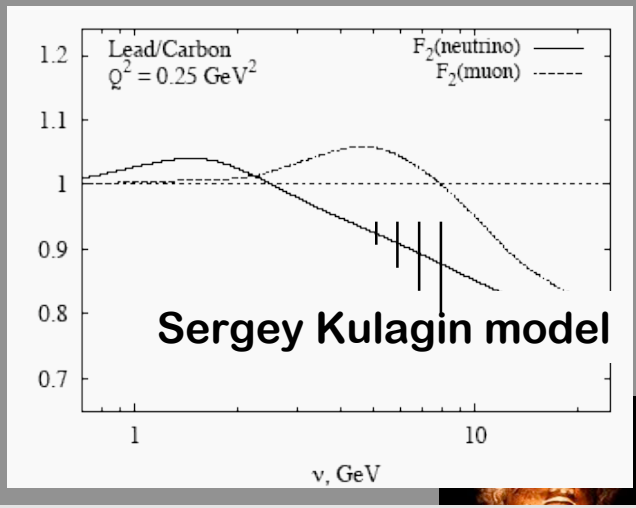
- Look at acceptance for muons
  - High x DIS (x > 0.7)
    - Analyzed in MINOS: >90% active TGT, >80% nuclear targets
  - High Q^2 Quasi-Elastic
    - Analyzed in MINOS: >99% active TGT, >86% nucl. Target
    - Even "un-reconstructable" can be reconstructed by resolving two fold neutrino energy ambiguity for QE events by using muon angle and Pmin for large angle muons

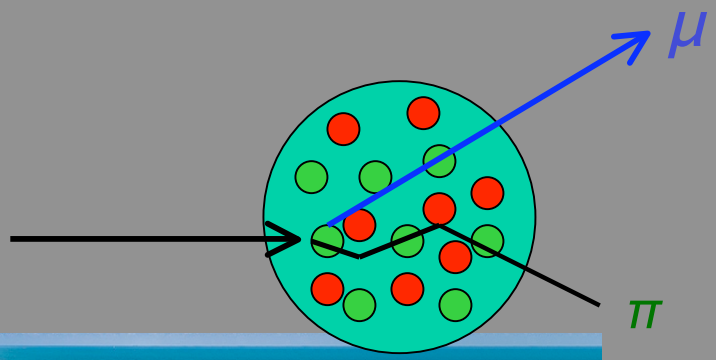


Impact on Δm^2 Measurement

- MINOS statistical errors & systematic errors due to nuclear correction
  - Shown
    - Pre-MINERvA (AM)
    - Post-MINERvA (PM)
  - Pion / nucleon absorption
  - Intra-nuclear scattering effects
  - Shadowing with neutrinos
- Extrapolation of nuclear effects from Low *A* to high *A* (e.g. He → Fe)







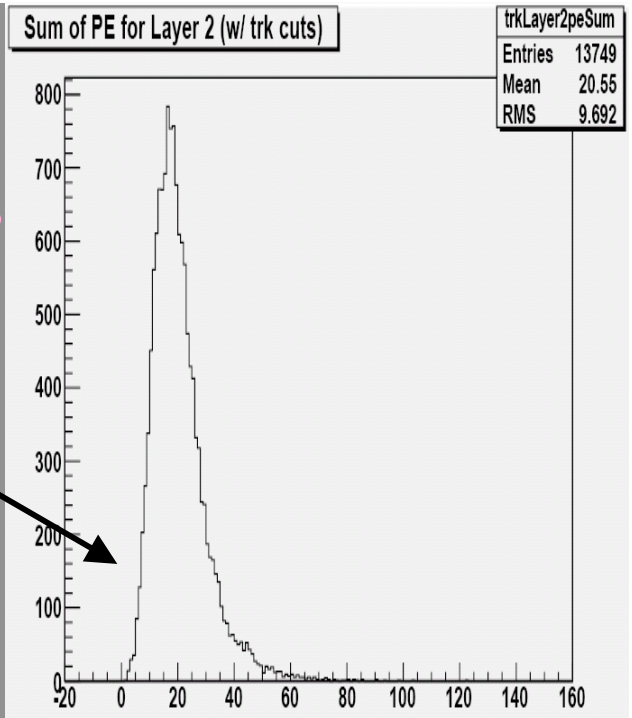
F_2, Pb/C (MINERvA stat. errors)



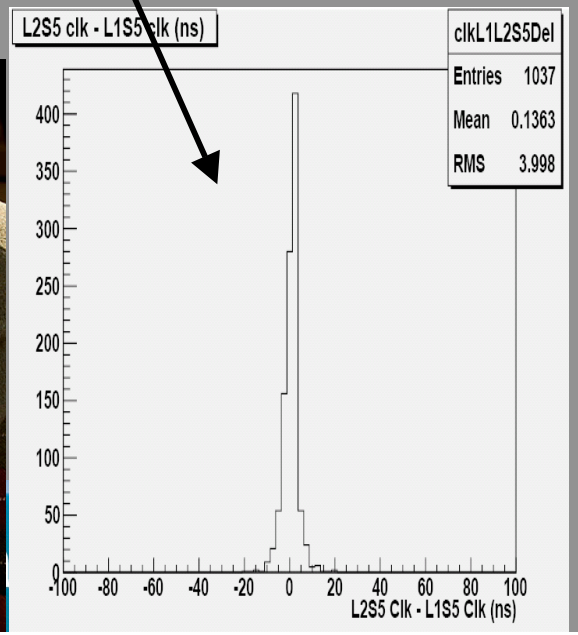
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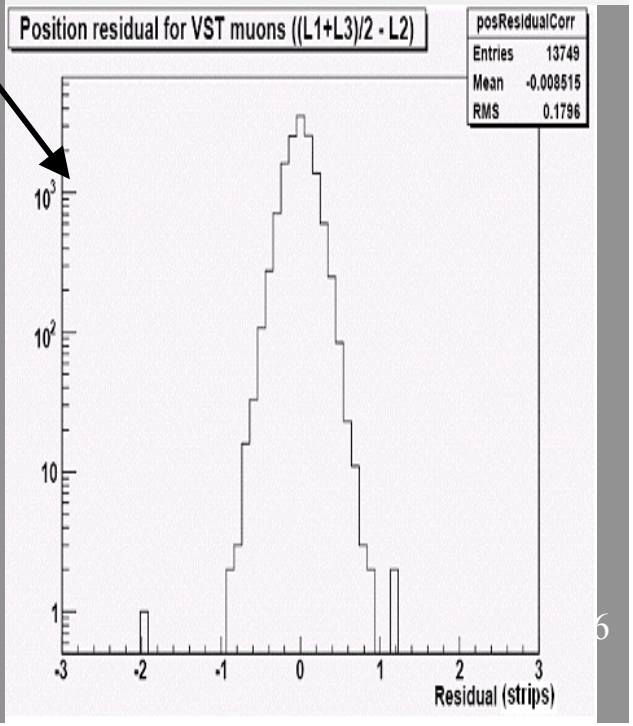
Vertical Slice Test

- Small test detector with cosmic muons
- Light Yield: 6.5 pe/MeV
  - Specification is > 4 pe/MeV
- Position Resolution: 2.5 mm
  - Spec is 3.0 mm
- Timing Resolution: 2.8 ns
- Overall: Everything works as required









MINERvA readout

- Completed a long series of R&D test over the last two years
- Full tests with readout chain
- Light injection calibrations system tested
- PMT housing production well underway
- 40 PMTs delivered for testing



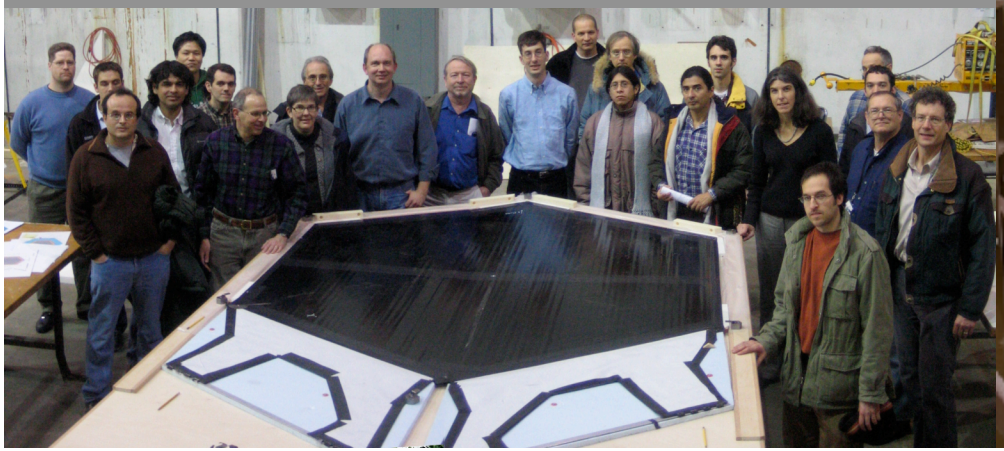


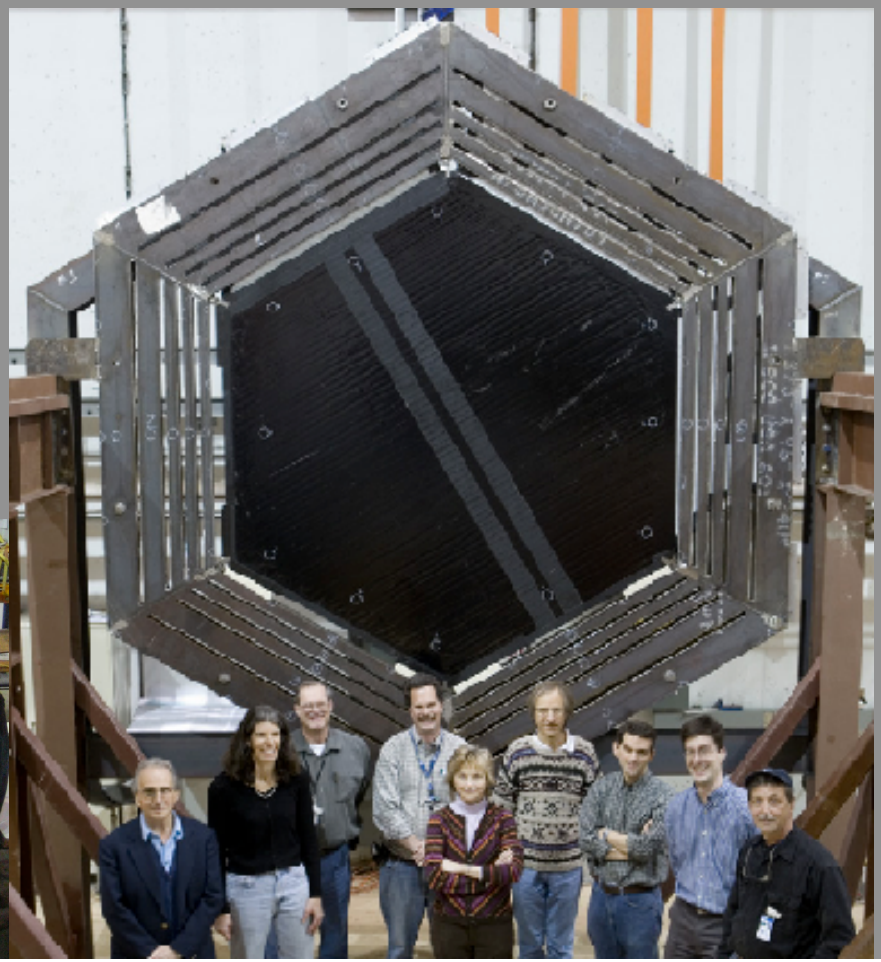


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Full Module Prototype

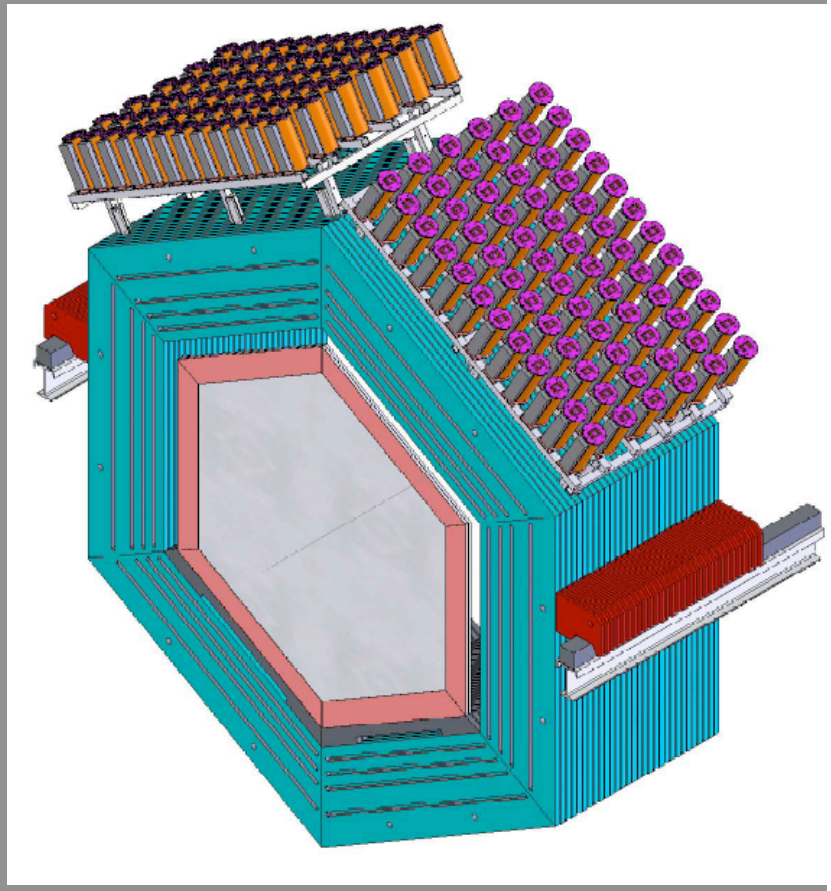
- 1st full assembly of a MINERvA module
  - Test mechanical structure
    - Integrated of inner and outer detectors
  - Two planes of scintillator
    - Two stereo views
  - Planes tested with source for uniformity
  - Completed Spring 07



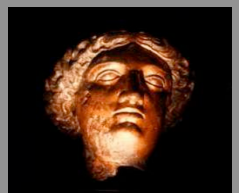


Looking forward

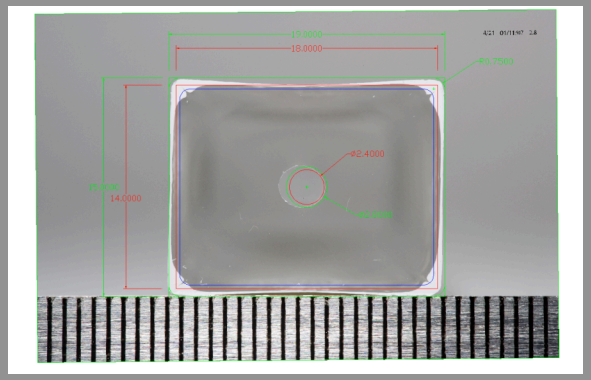
- Tracking prototype
  - Large scale systems integration
    - 10 target modules
    - 10 ECAL module
  - Currently under construction
    - To be completed in early 2008
  - Initially deployed on surface for cosmic tests
    - Plan to install in NuMI for a beam test
- Fully integrated test of all detector systems
  - Measure uniformity across many planes
  - Full installation tests and post-installation testing and calibration
  - Test tracking capability



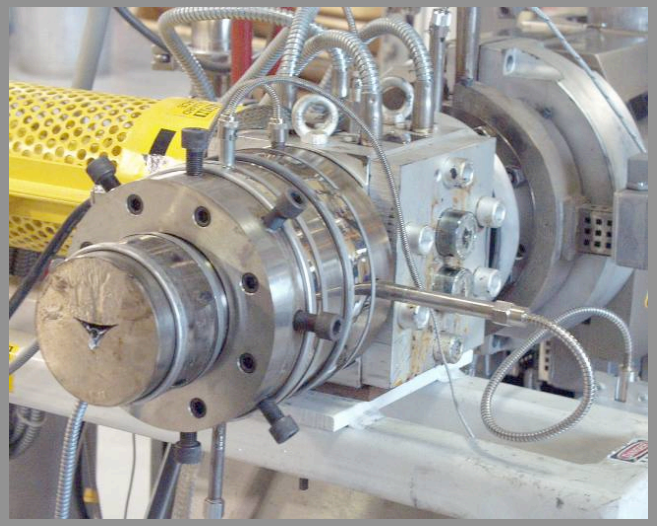


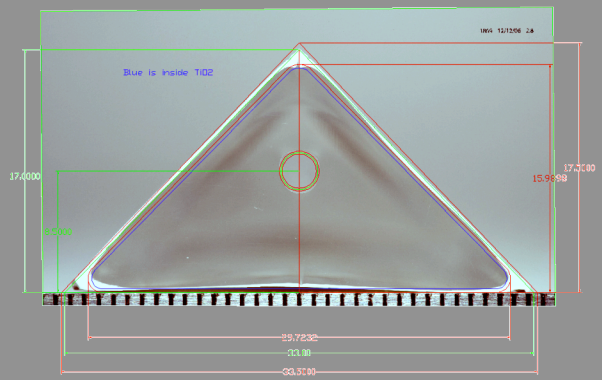


Scintillator Prototypes

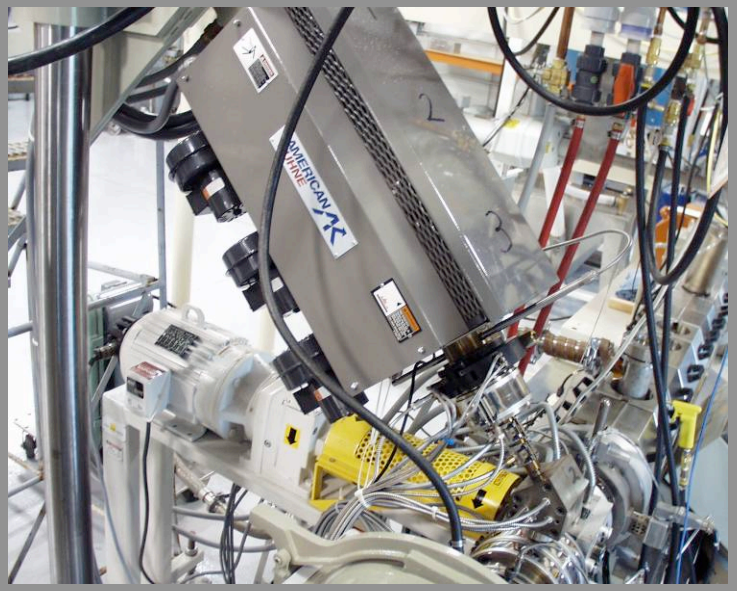


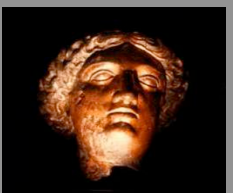
ID Triangle Die





Co-Extruder





Nuclear Targets

Red=Fe, Grey=Pb, **Black = C**

4 frames (uxvxuxvx) between targets

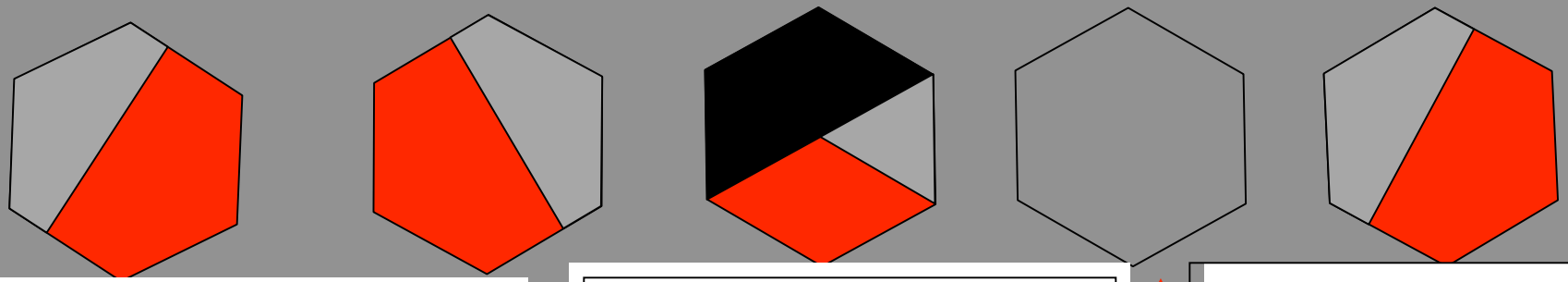
2.5 cm thick
230 kg Fe/Pb

2.5 cm thick
230 kg
Fe/Pb

2.5 cm Fe/Pb
110 kg each
7.5 cm C
140 kg

0.75 cm Pb
170 kg

1.5 cm thick
115 kg Fe/Pb



High statistics comparison of Pb/Fe

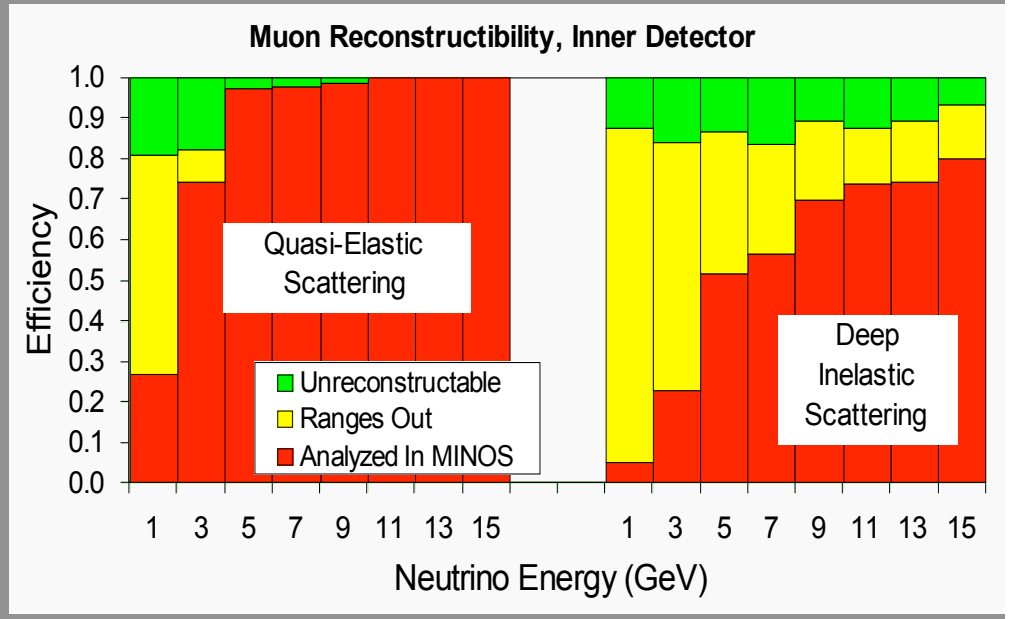
Comparison of Pb/C/Fe with same detector geometry

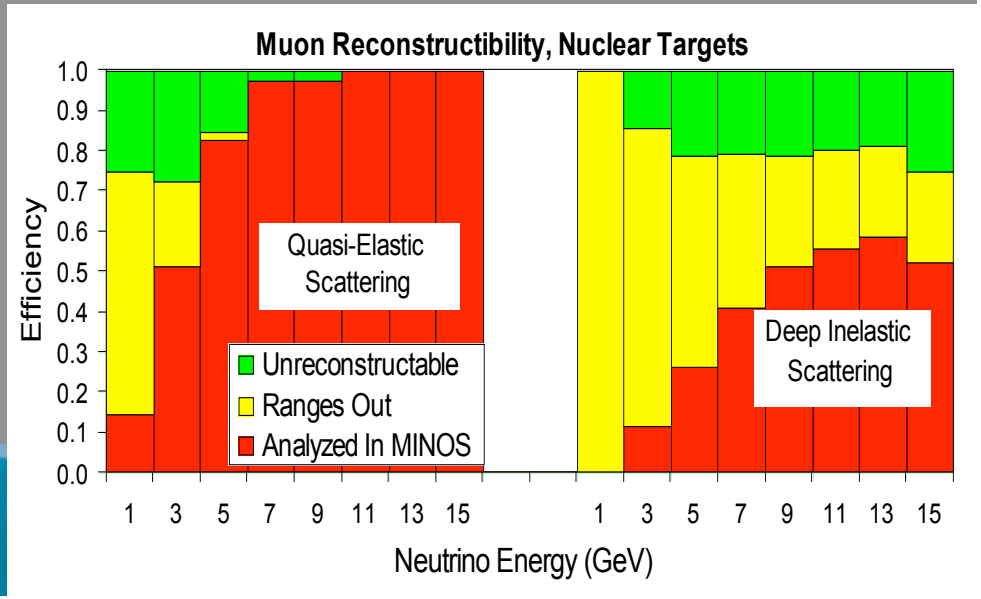
Thin targets for low energy particle emission studies

Thin Pb target also serves to insure good photon detection efficiency

Muon Acceptance Study

- Fiducial Volume Cuts: radius<75cm
- Look at acceptance for muon
  - Active Target (>50cm from DS ECAL)
  - Nuclear Target Region
- In kinematic extrema of interest:
  - High x DIS: (x>.7)
    - Analyzed in MINOS: >90% active TGT, >80% nucl target
    - Remainder escape the sides
  - High Q^2 Quasi-Elastic:
    - Analyzed in MINOS: >99% active TGT, >86% nucl. target

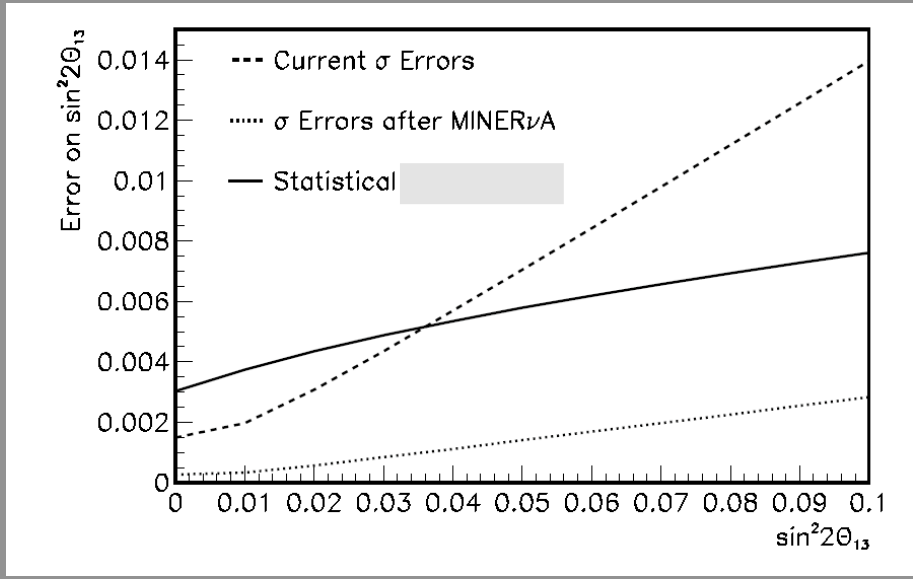


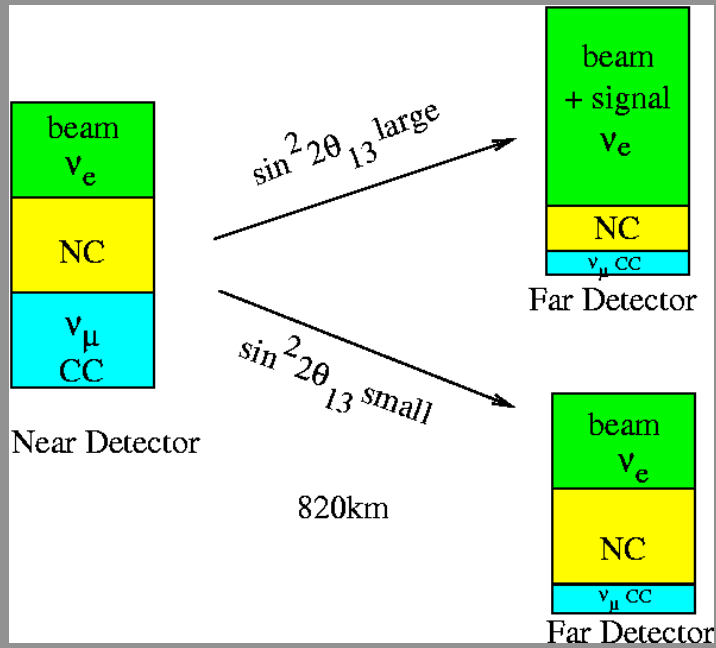




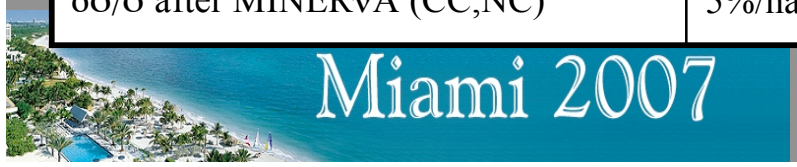
MINERvA & NOvA

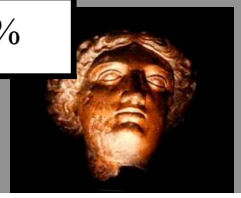
Total fractional error in the predictions as a function of reach (NO*v*A)





Process	QE	RES	COH	DIS
δσ/σ NOW (CC,NC)	20%	40%	100%	20%
δσ/σ after MINERνA (CC,NC)	5%/na	5%/10%	5%/20%	5%/10%





MINERvA & T2K

- T2K's near detector will see different mix of events than the far detector
- To make an accurate prediction oune needs
  - 1 - 4 GeV netrino cross sections (with energy dependence)
- MINER*v*A can provide these with low energy NuMI configuration

