MINERvA

H. Ray

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- Roman goddess (aka Athena)
  - Wisdom incarnate, inventor of music
- Commercial programming system
- Modern-day witch?
- Super-cool neutrino experiment

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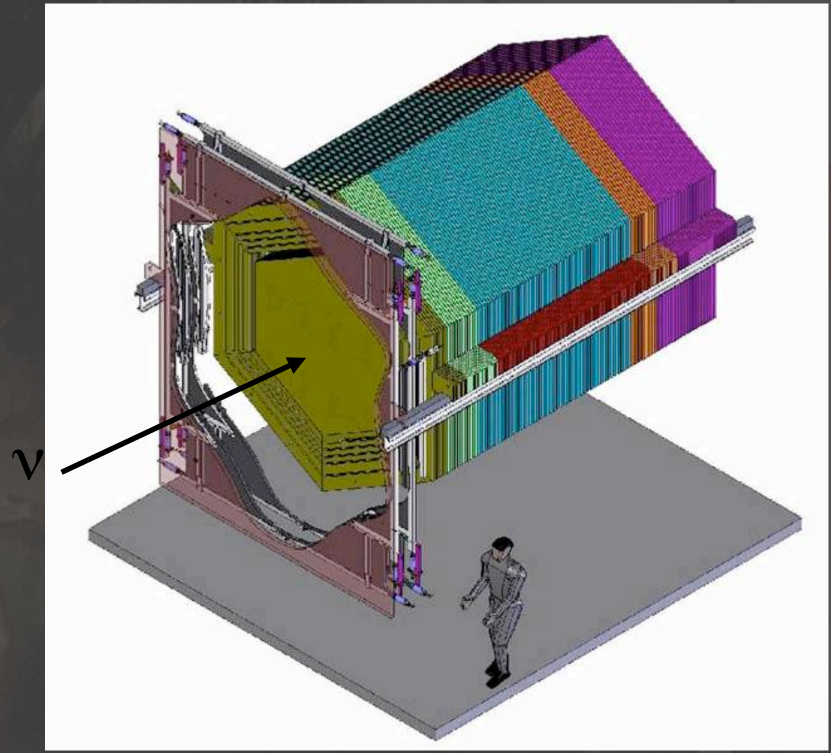

The need for MINERvA

- Entering era of precision neutrino measurements
- Requires precise knowledge of cross sections, final states, and nuclear effects
  - Current cross sections poorly known
    - 20-100% total error
  - Current unresolved discrepancies
    - CCQE, Coherent pion production, nu-Fe nuclear effects
  - 2-det expts depend upon neutrino interaction models to extrapolate backgrounds from near to far detector

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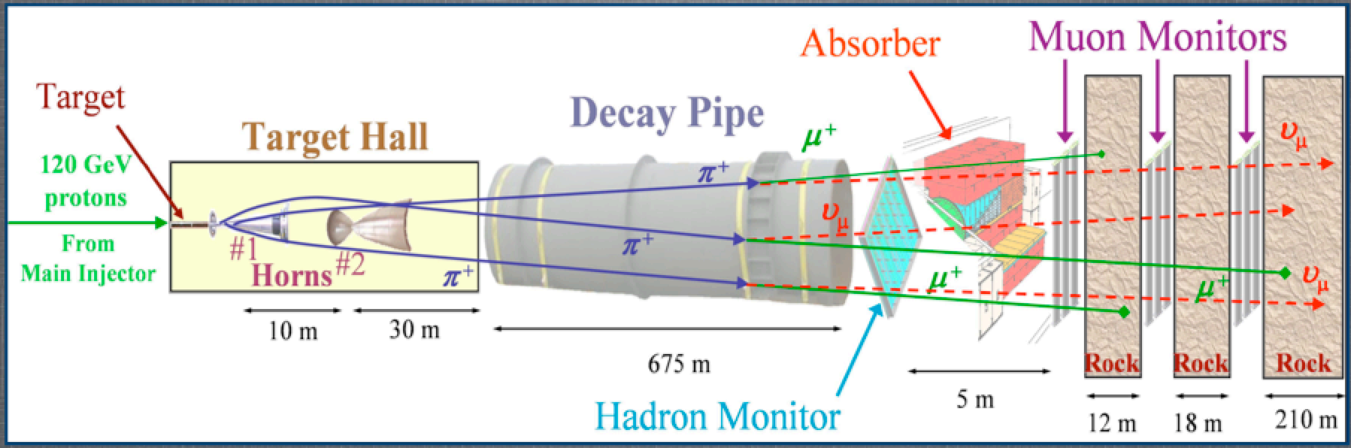
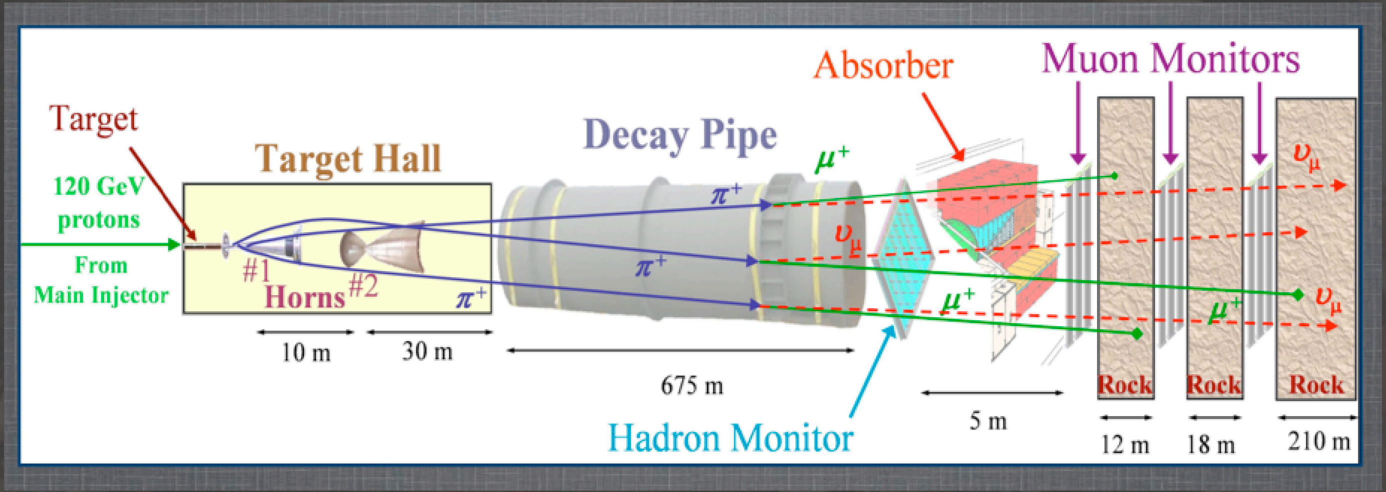
- *No other experiment exists to perform precision measurements in MINERvAs energy range!*

The Neutrino Beam



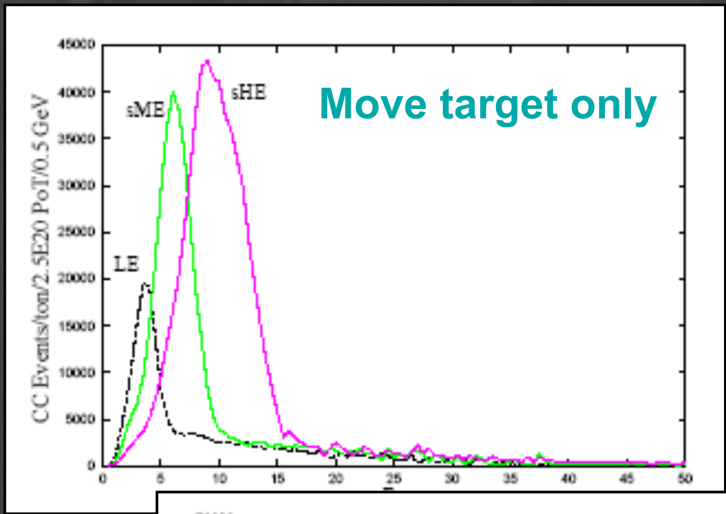
- Accelerator-based experiment
- High-energy protons + target = mesons
  - $\pi^{\pm}$, $K^{\pm}$, some K^0
- Mesons decay to produce neutrino beam
  - Decay At Rest = low energy ν (max ~54 MeV)
  - Decay In Flight = high energy νs

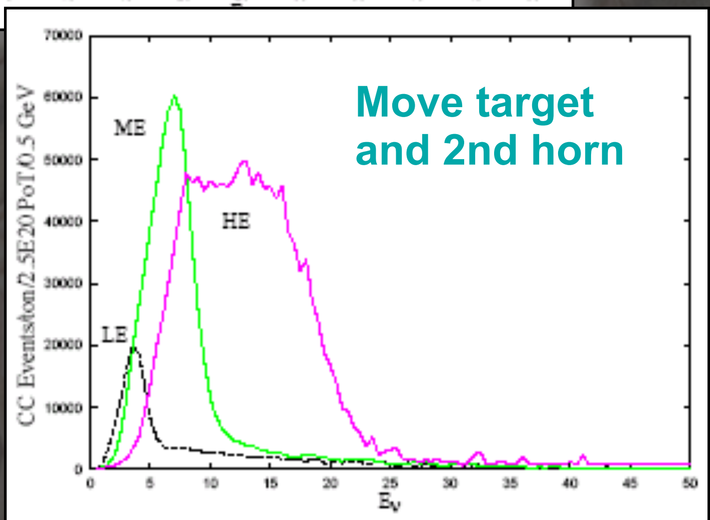
The Neutrino Beam



- 120 GeV protons
- Graphite target
- Magnetic focusing horns
  - Polarity of horns = neutrino or antineutrino beam
  - Movable horn/target = tunable neutrino beam energy

Tunable Neutrino Beam





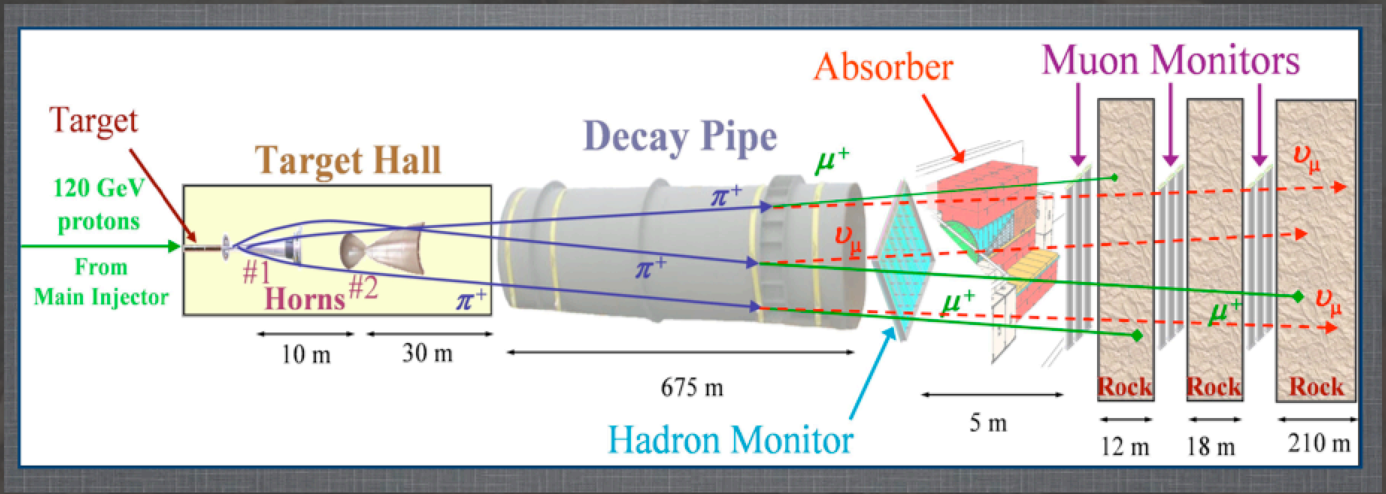
- LE-configuration:
  - E_m >0.35 GeV
  - E_{peak} = 3.0 GeV, $\langle E_\nu \rangle$ = 10.2 GeV
  - rate = **60 K events/ton - 10^{20}** pot
- ME-configuration:
  - E_{peak} = 7.0 GeV, $\langle E_\nu \rangle$ = 8.0 GeV
  - rate = **230 K events/ton - 10^{20} pot**

HE-configuration:

- E_{peak} = 12.0 GeV, $\langle E_\nu \rangle$ = 14.0 GeV
- rate = **525 K events/ton - 10^{20} pot**

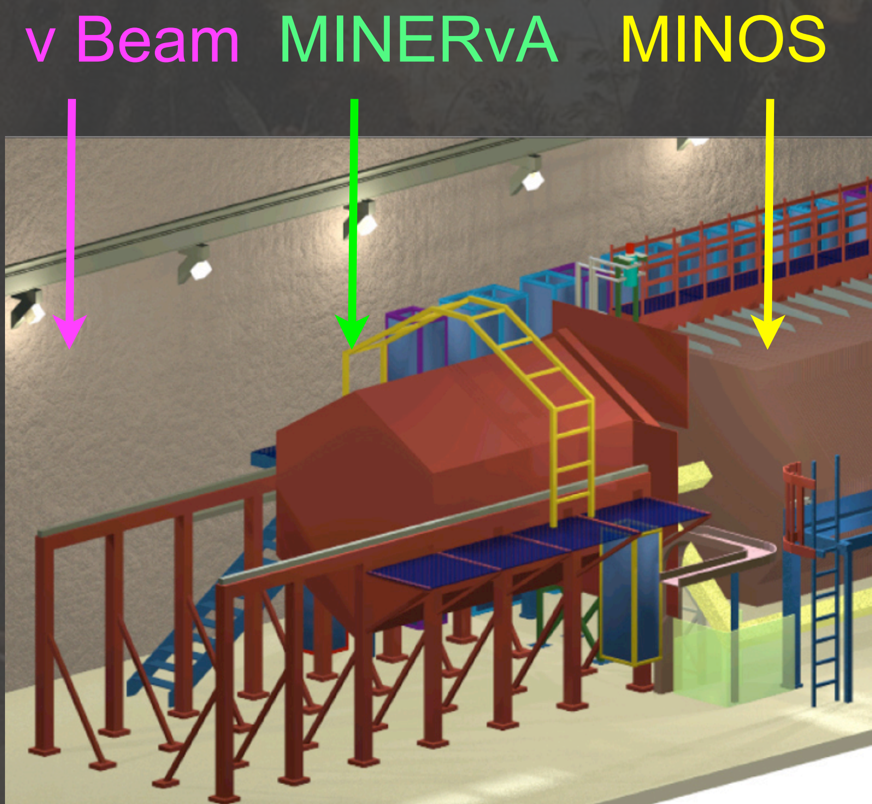
Expect to run with LE (4e20 POT), ME (12e20 POT)

The Neutrino Beam



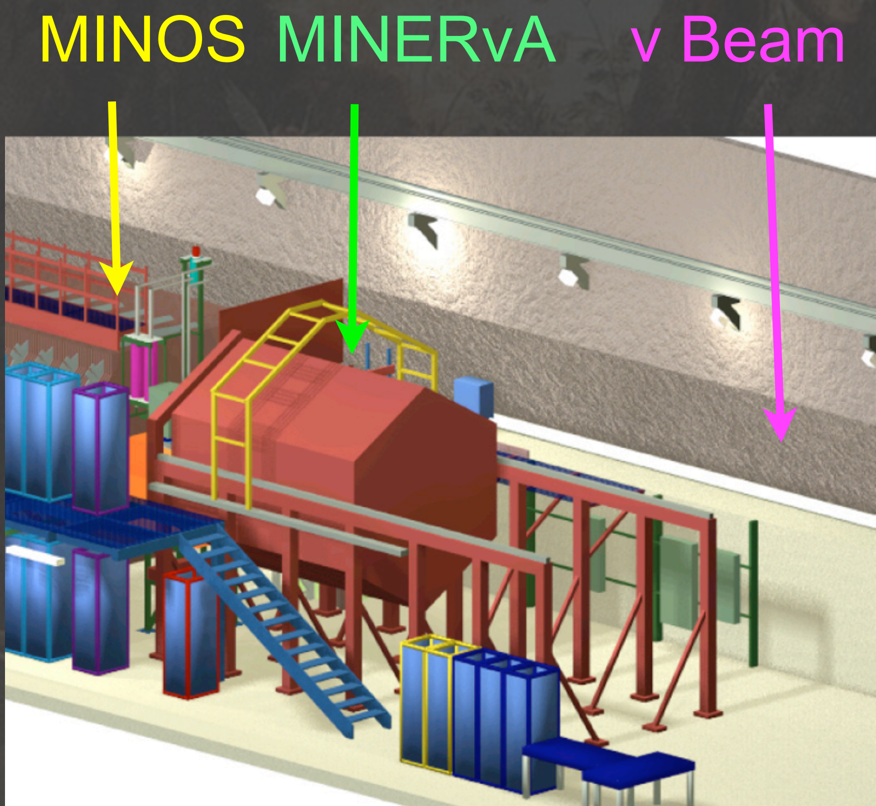
- 675 m long decay pipe
- Hadron absorber stops any undecayed mesons, non-interacting protons from the beam
- 240m of absorber (rock!) stops μs from meson decay

MINERvA Detector



- Must reconstruct exclusive final states
  - high granularity for charged particle tracking and ID, low momentum thresholds for particle detection such as $\nu_\mu n \rightarrow \mu^- p$ (quasi-elastic, QE)
- Also must contain
  - EM showers (π^0, $e^\pm$)
  - high momentum hadrons ($\pi^\pm$, p, etc.)
  - $\mu^\pm$ from QE, contained well enough to measure momentum
  - nuclear targets to study nuclear effects

MINERvA Detector



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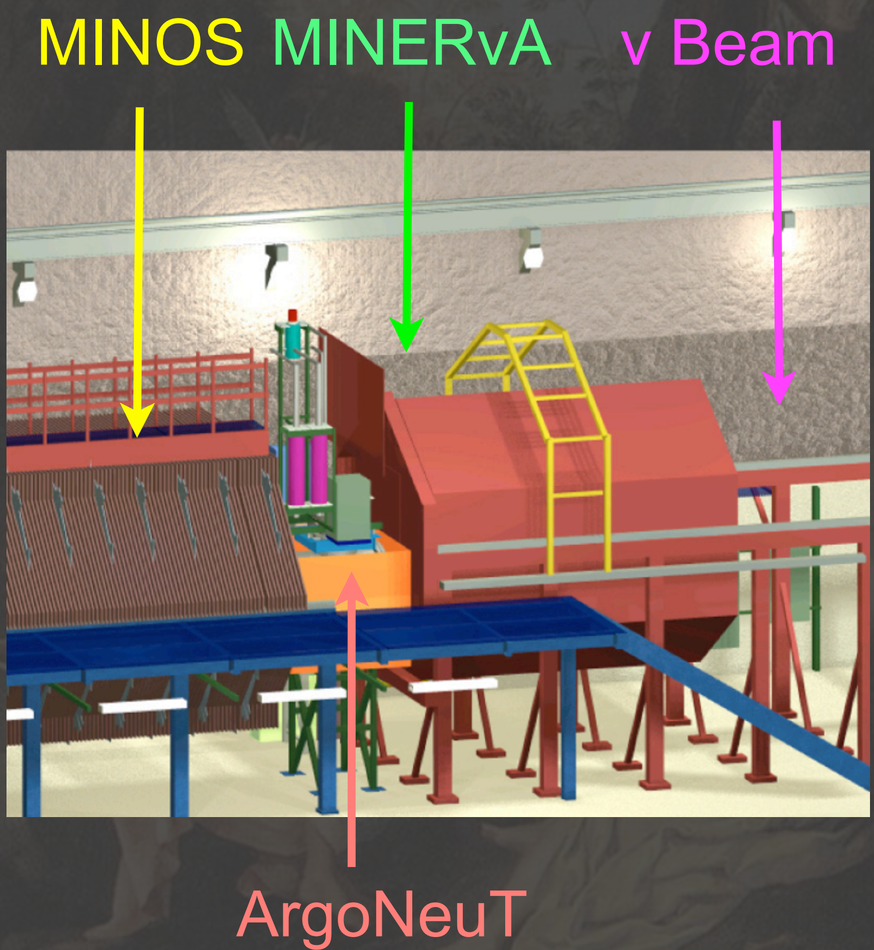

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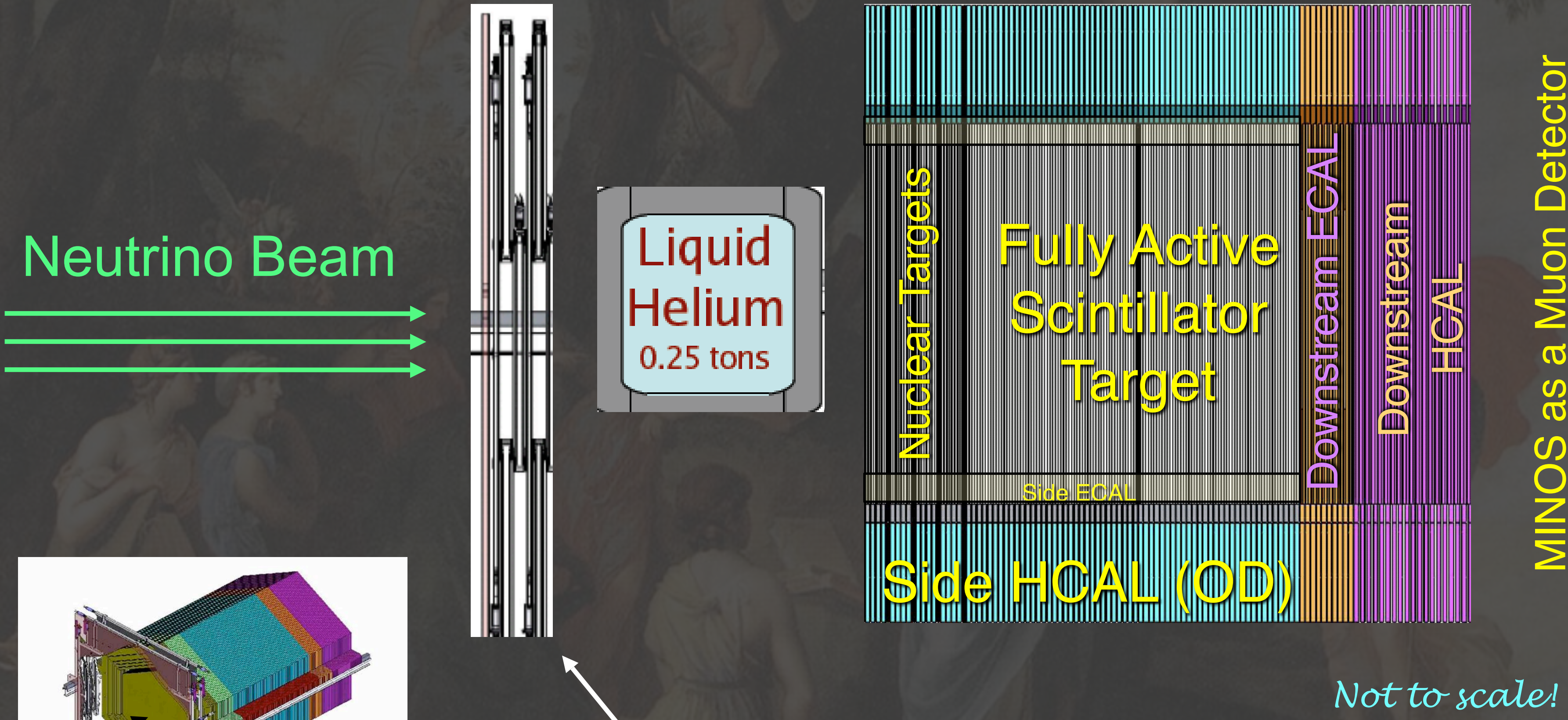
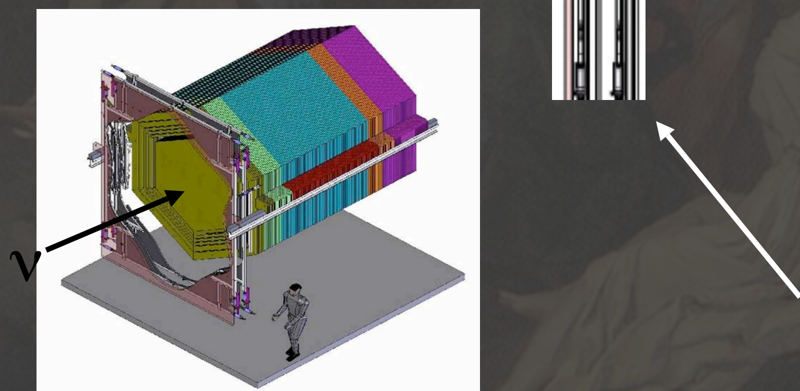
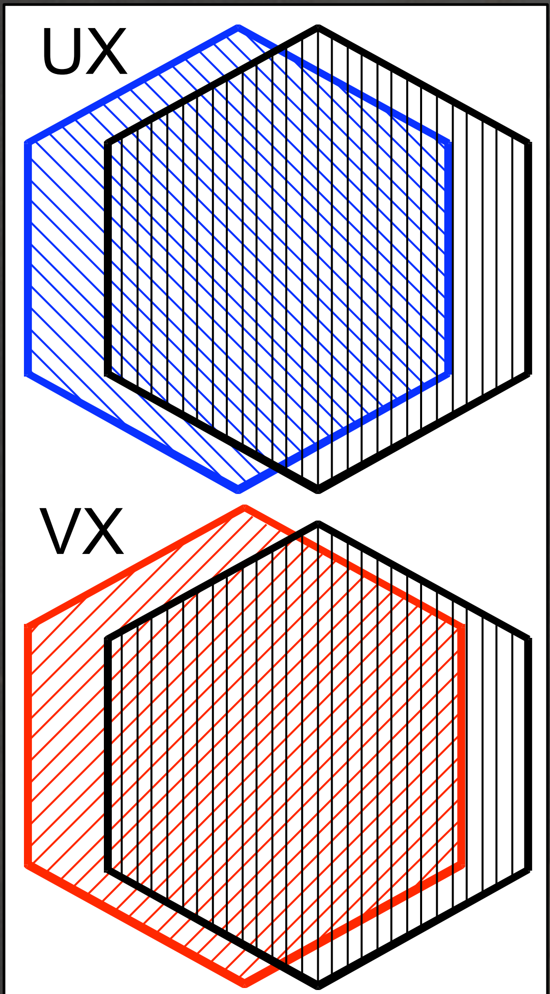


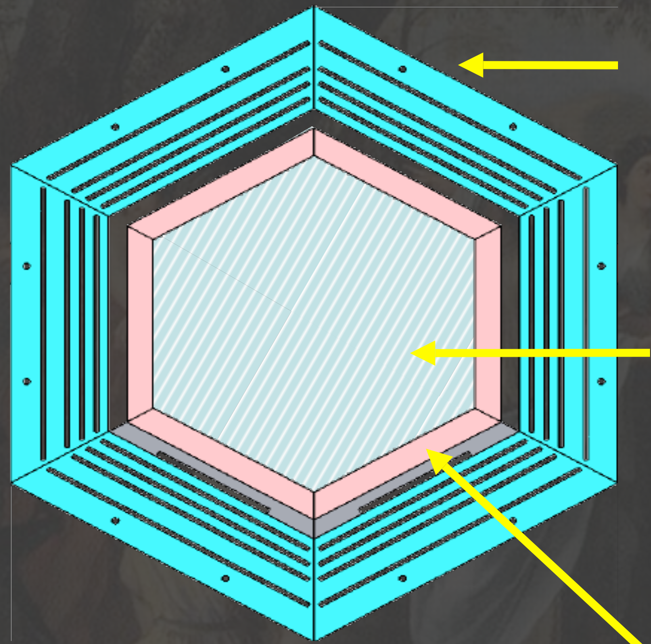


Veto Wall

SIDE: 0.6 tons ECAL, 116 tons HCAL
END: 15 tons ECAL, 30 tons HCAL
ACTIVE: 8.3 tons

Scintillator Planes

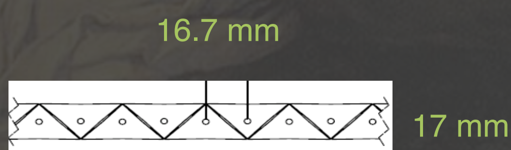




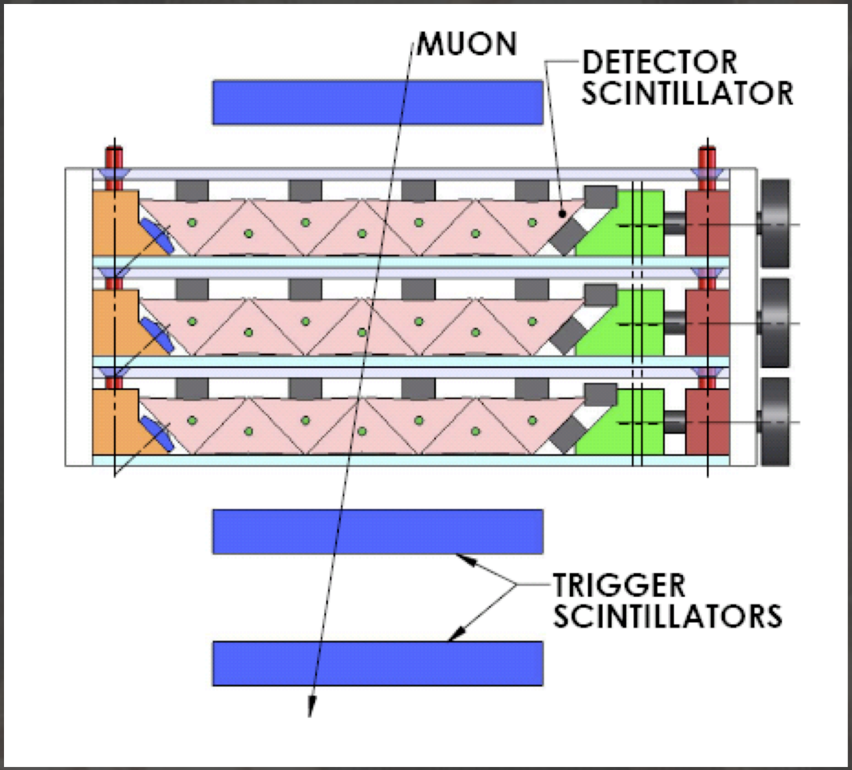
Outer Detector
Fe+scintillator towers for hadron calorimetery

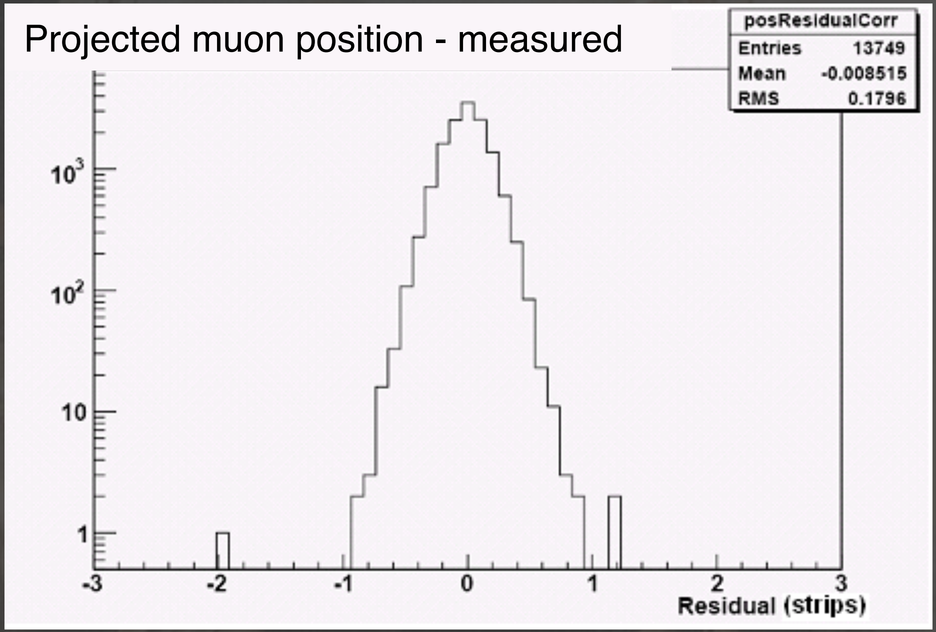
Inner Detector
UXVX planes for 3D tracking

Side ECAL
Pb+scintillator bars for EM calorimetery



Position Resolution





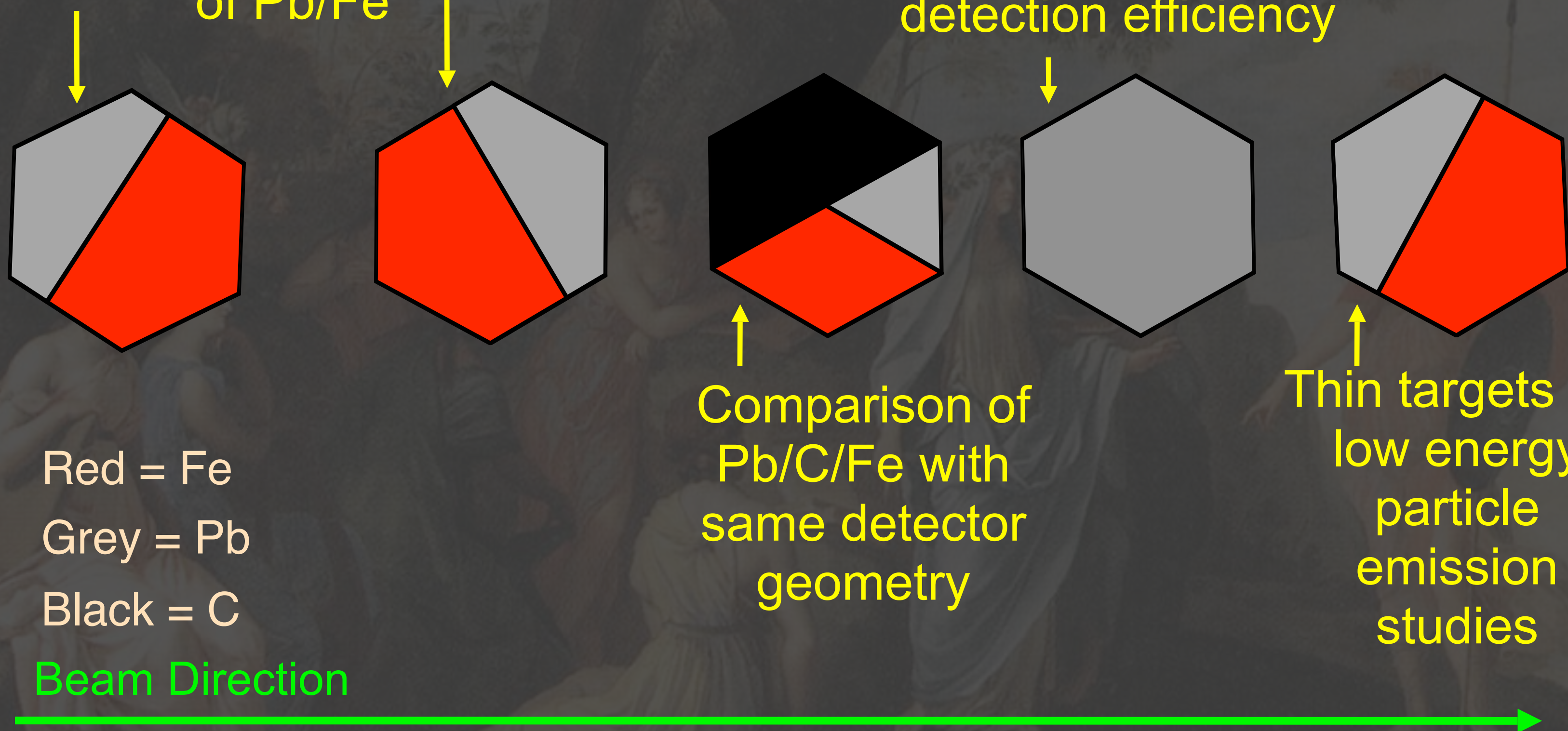
Vertical Slice Test

- Position resolution = 2.5 mm (MIP)
- Distance between the center of strips is 1.7 cm

Nuclear Targets

High statistics comparison of Pb/Fe

Thin Pb target serves to insure good photon detection efficiency



Comparison of Pb/C/Fe with same detector geometry

Thin targets for low energy particle emission studies

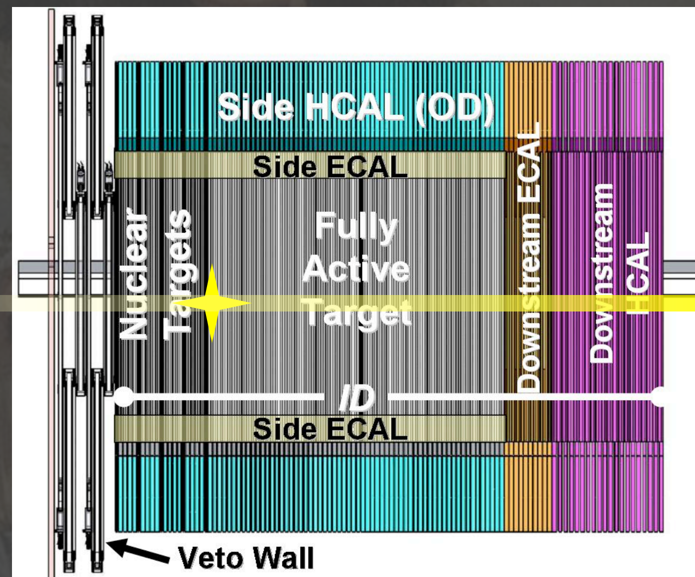
- Red = Fe
- Grey = Pb
- Black = C

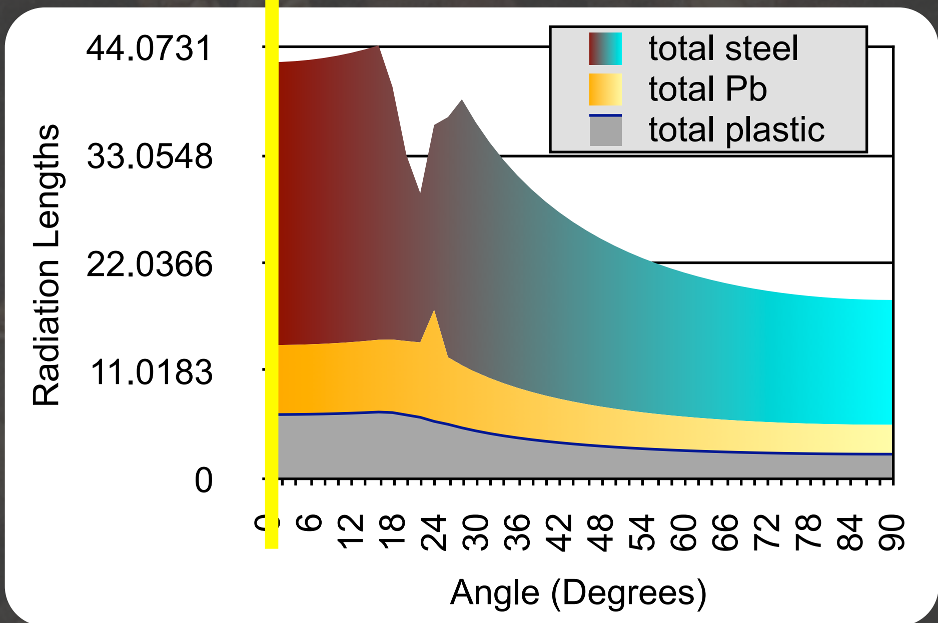
Beam Direction

4 scintillator frames (ux vx ux vx) between targets

MINERvA as Calorimeter

- Material thickness in radiation lengths (γ, $e^{\pm}$)
  - Side & downstream ECALs have 2mm Pb plates





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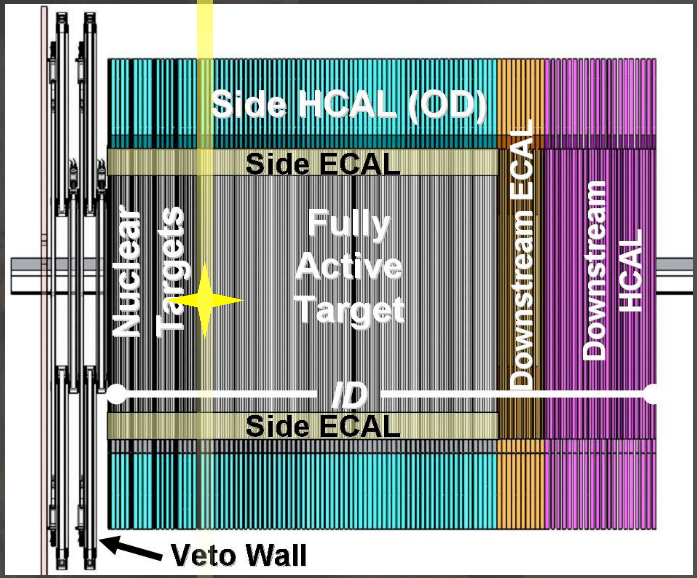
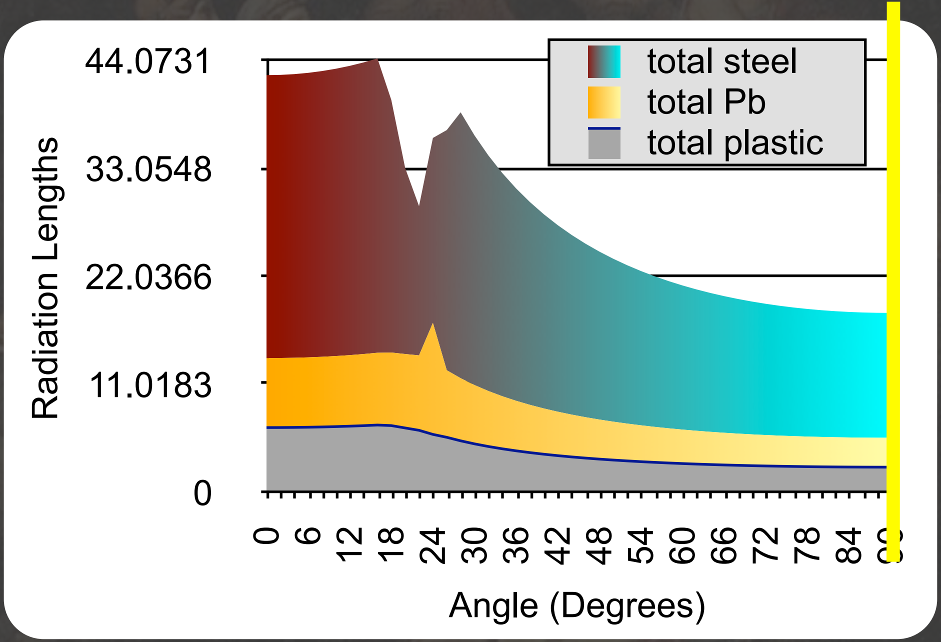
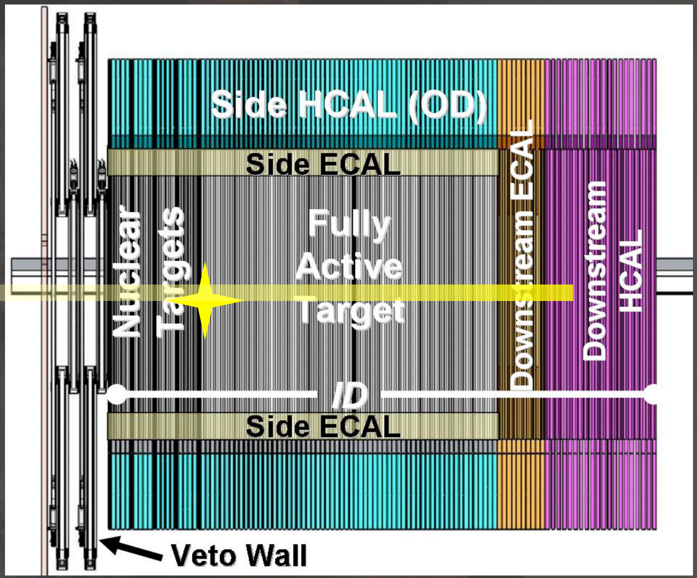
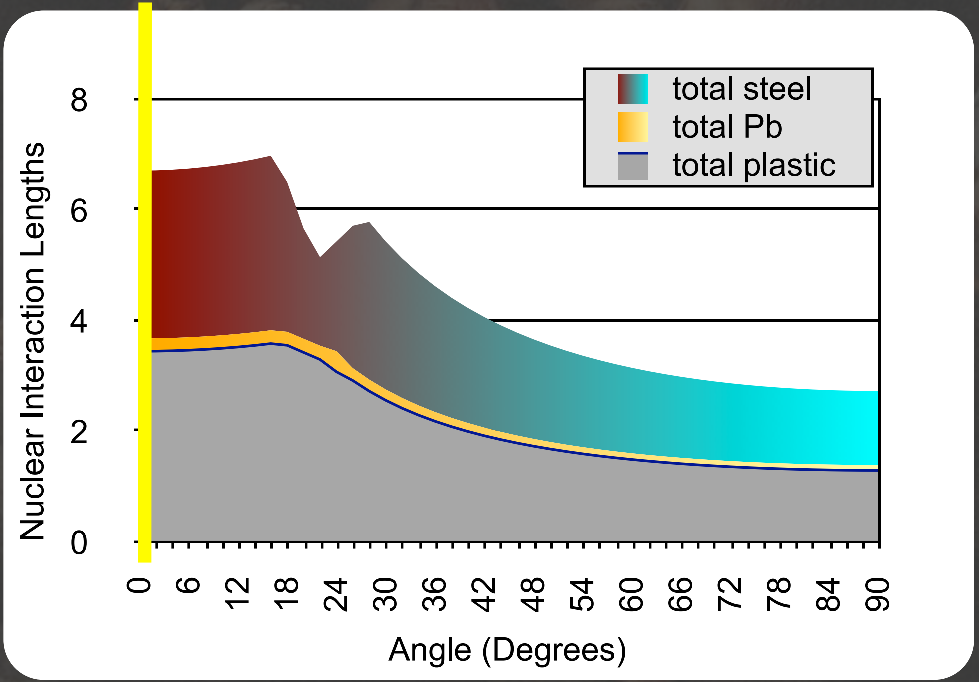




MINERvA as Calorimeter

- Material thickness in nuclear interaction lengths (hadrons)





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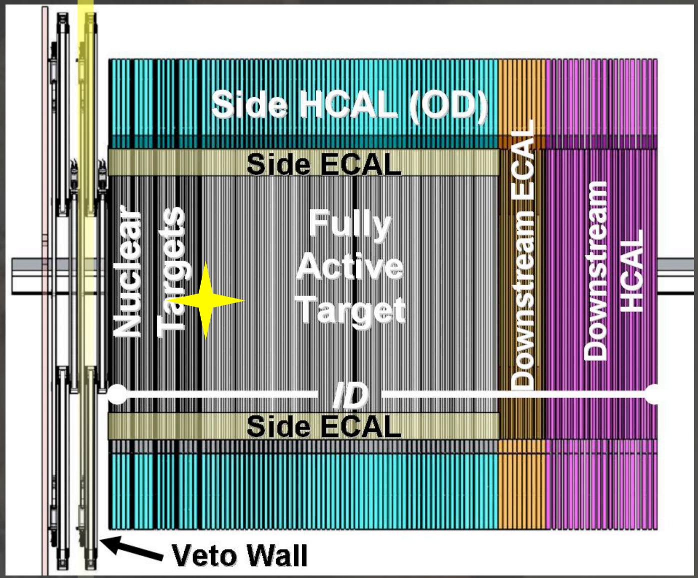
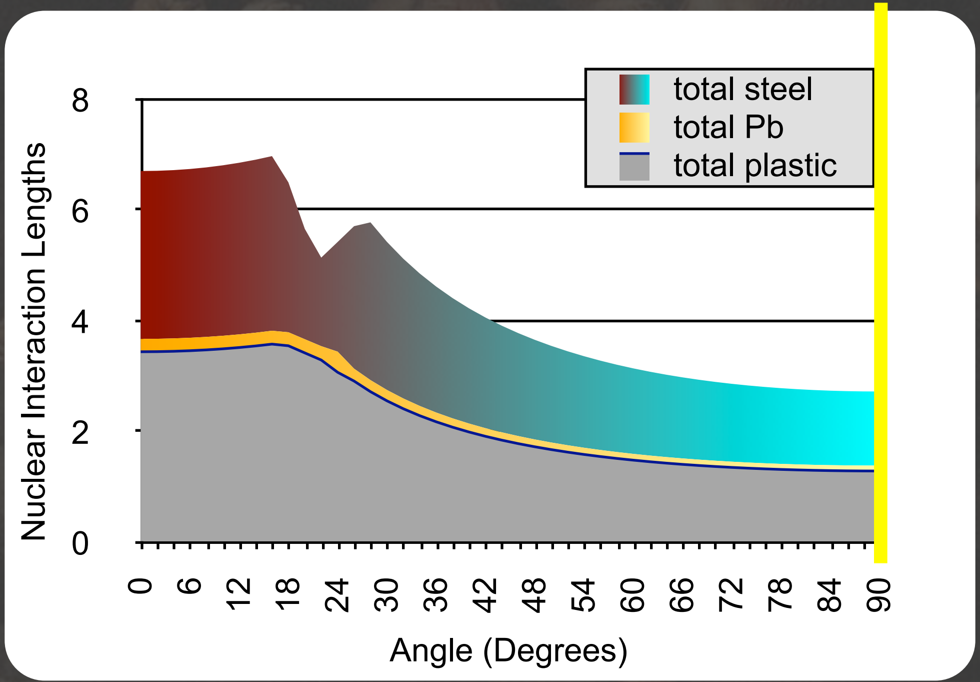
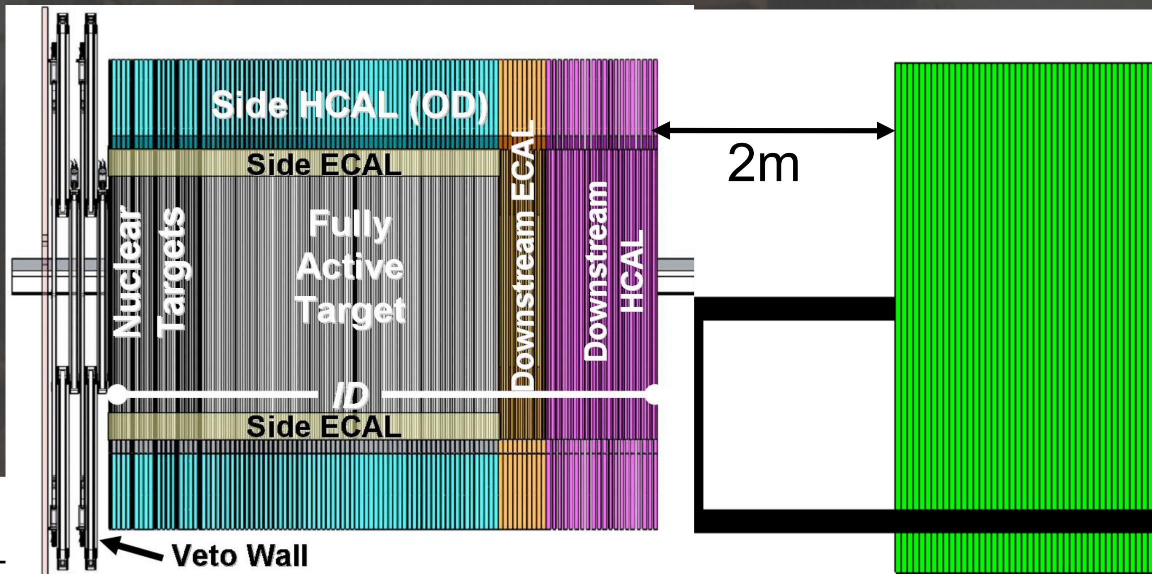
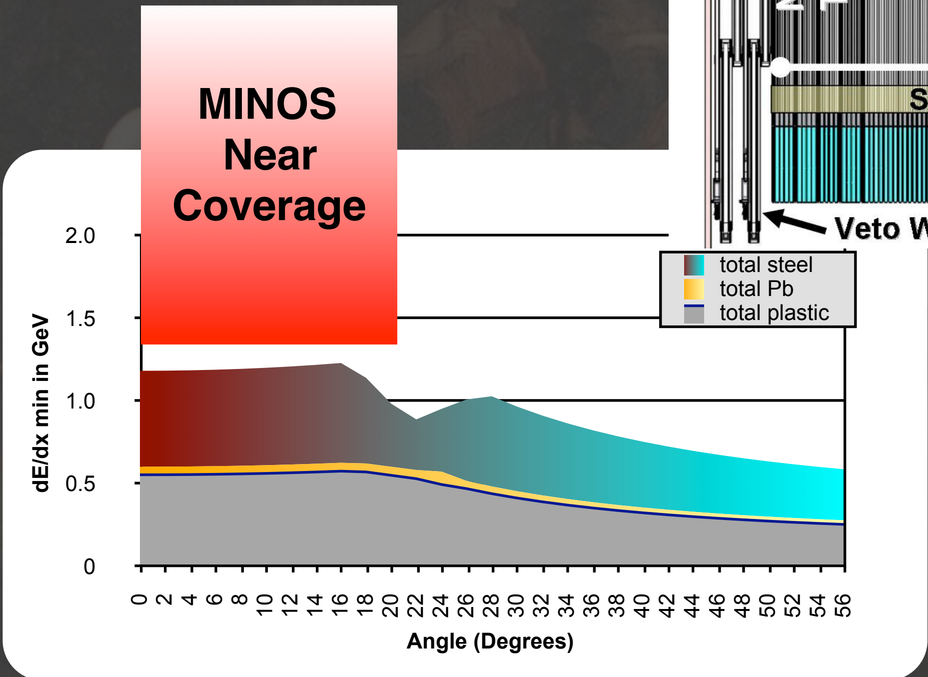




MINERvA as Range Tracker

- Material thickness in $(dE/dx)_{min}$ (low E particles)

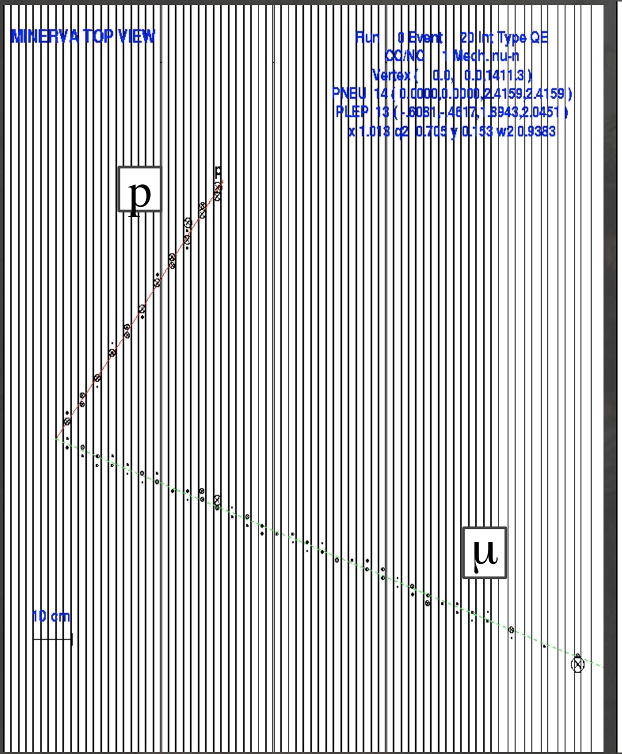


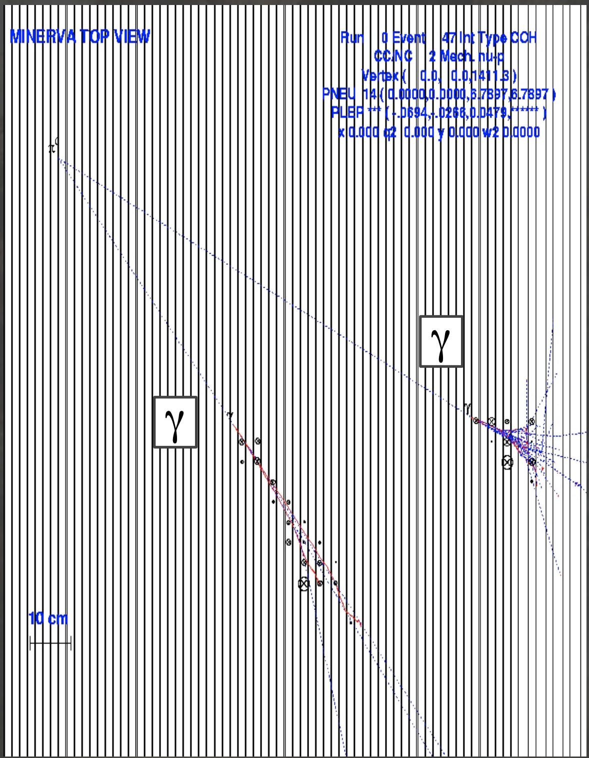


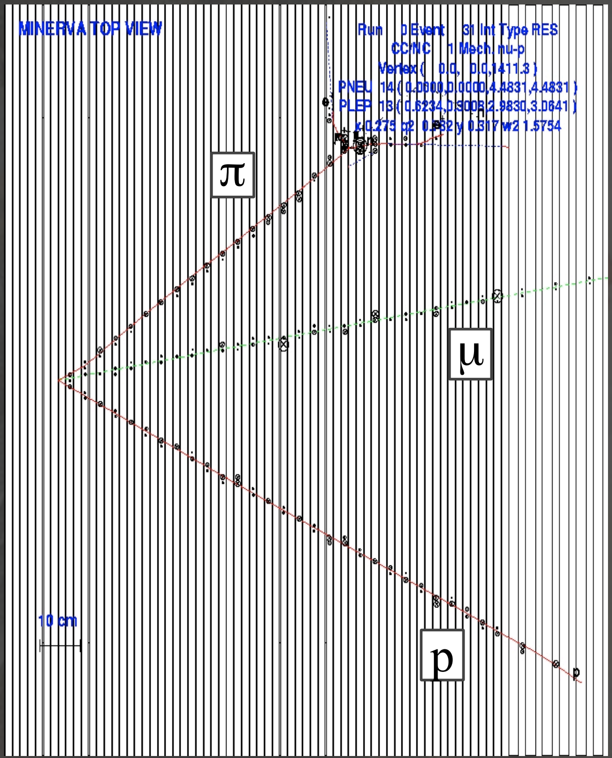
Largely rely on MINOS near detector

- Analyze by
  - Range for lower energy muons
  - Curvature in the magnetics field for higher energy muons (δp/p~12%)

Monte Carlo Events







Quasi-elastic event

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

Neutral Current π^0

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

Resonance production

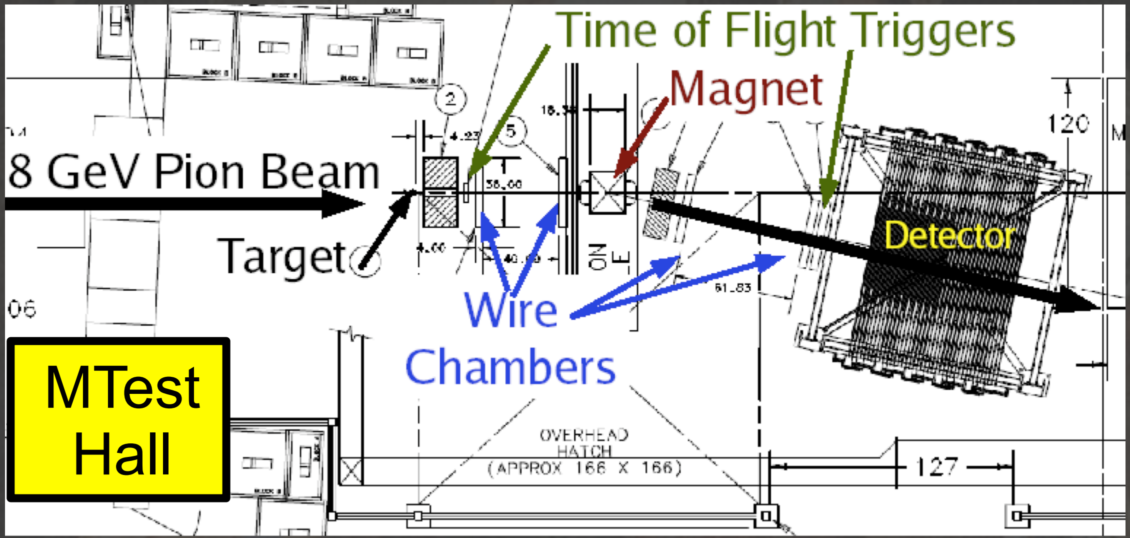
$\nu_\mu\, p \rightarrow \mu^-\, \Delta^{++} \rightarrow \mu^-\, p\, \pi^+$

Detector Response Studies

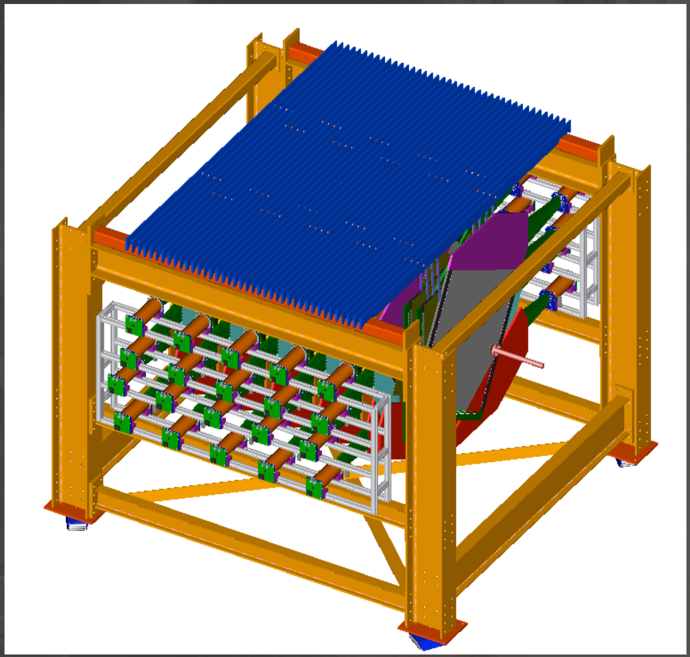
- Precision measurements require thorough understanding of detector response, neutrino beam

- Test Beam
  - Characterize detector response to single mesons
- Tracking Prototype
  - Study neutrino interactions in scintillator in simple environment (only 1 nuclear target)

Test Beam Effort



1-10 GeV/c in secondary beam
200 - 1000 MeV/c in new tertiary beam

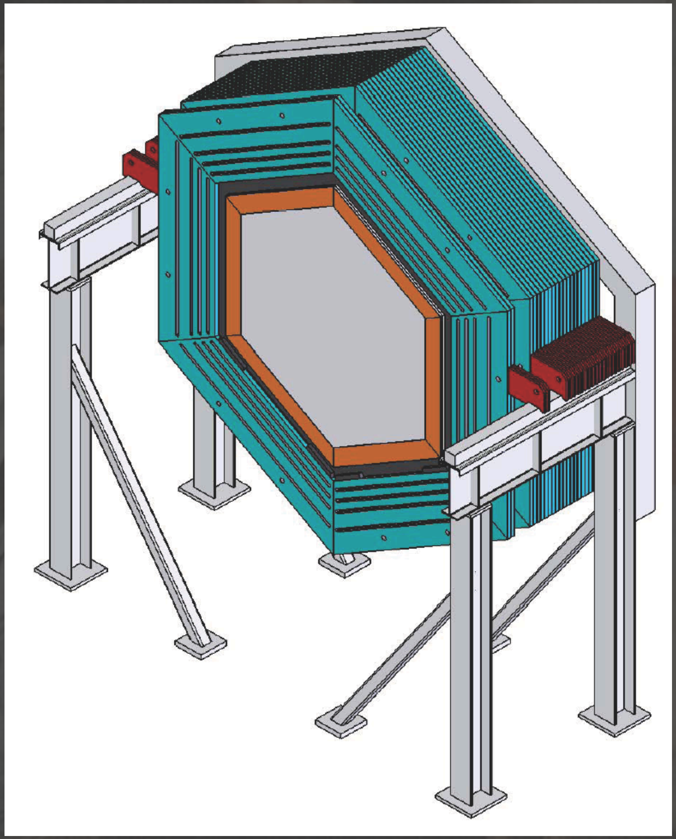


- Reconfigurable scintillator, Fe, Pb modules emulate different detector sections
- Full UX VX plane readout to test tracking
- Benchmark detector response to single particles (charged π, K)
- New tertiary beam designed by MINERvA to get down to 200 MeV/c

Tracking Prototype

- Fe target
- Scintillator modules
- ECAL, HCAL

- Fully integrated test of all detector systems
  – detector design, assembly
  – component production, integration
  – calibration chain
  – event reconstruction
  – etc …



Currently collecting cosmic ray data
Installed in beam March

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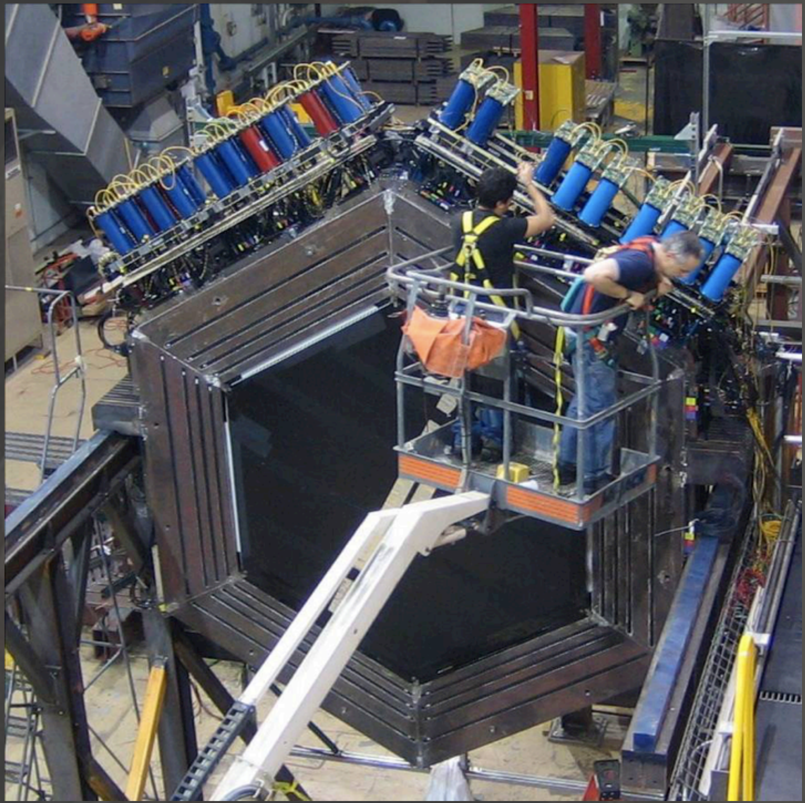

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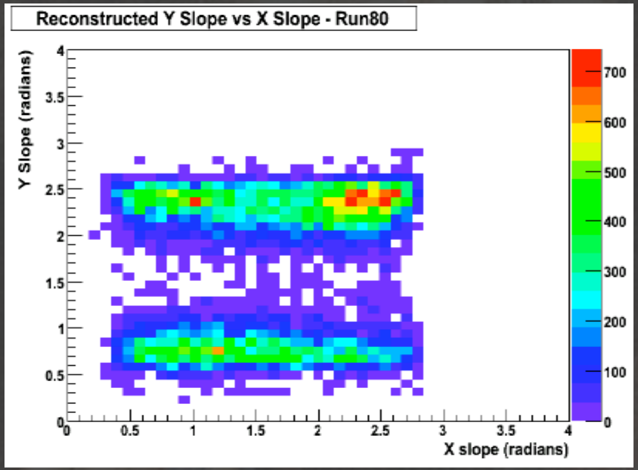
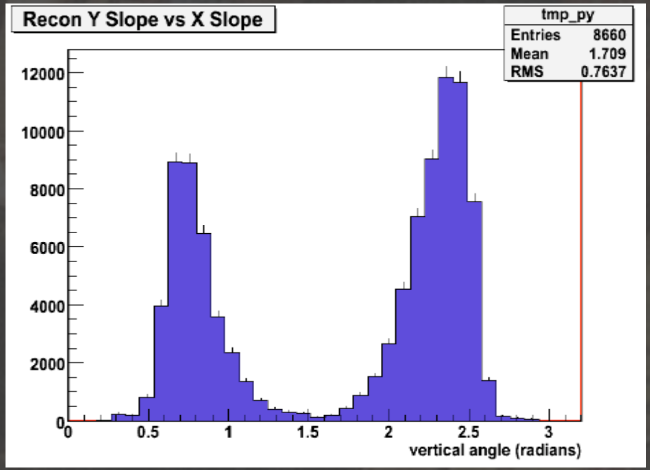
Cosmic Ray Muons





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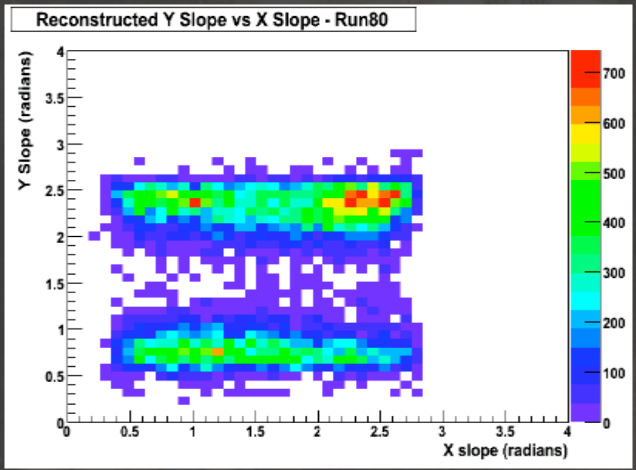
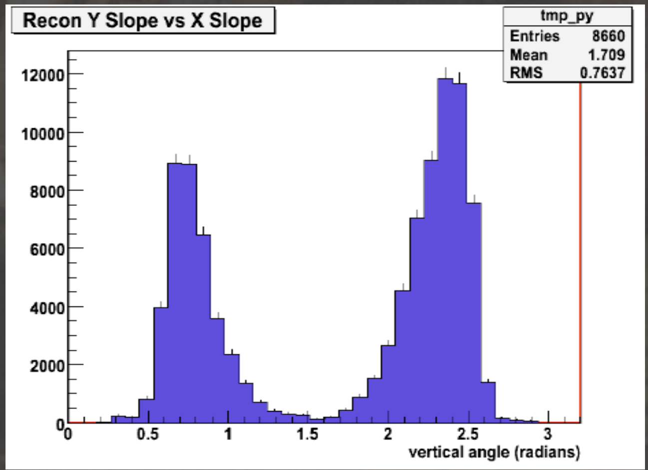
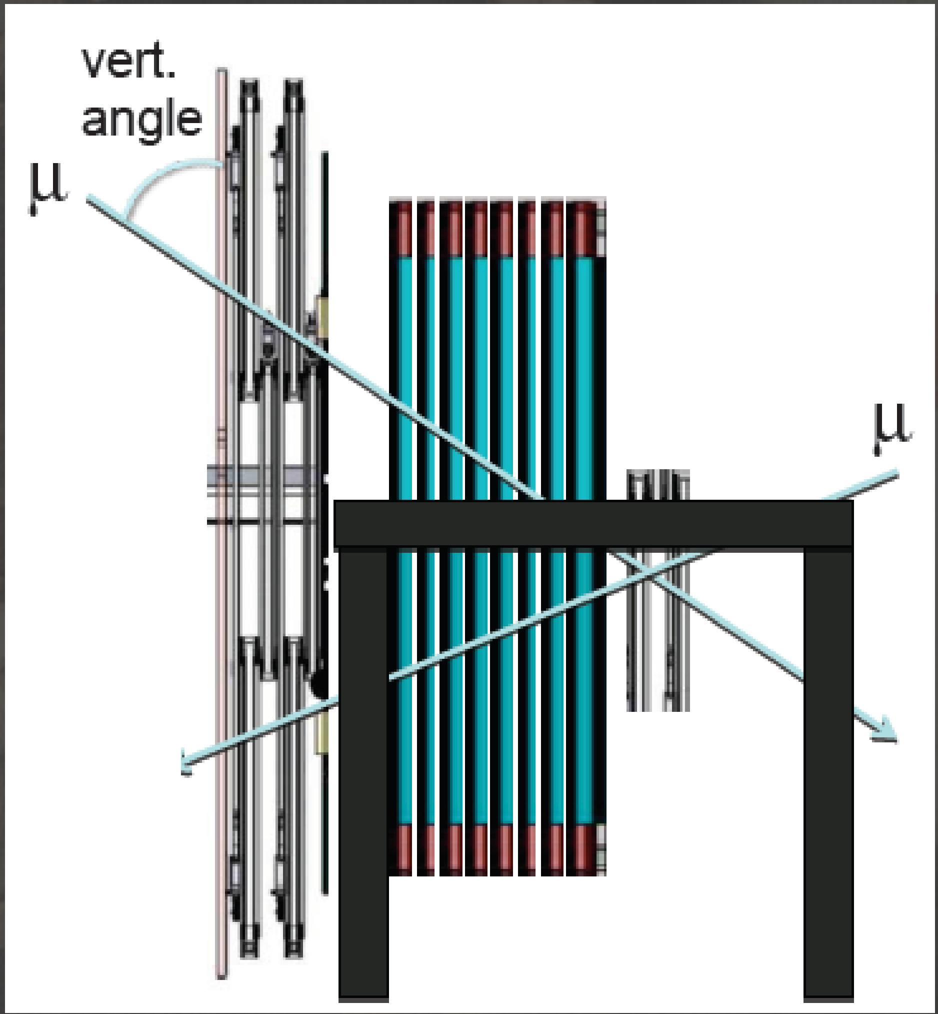






Analysis Goals

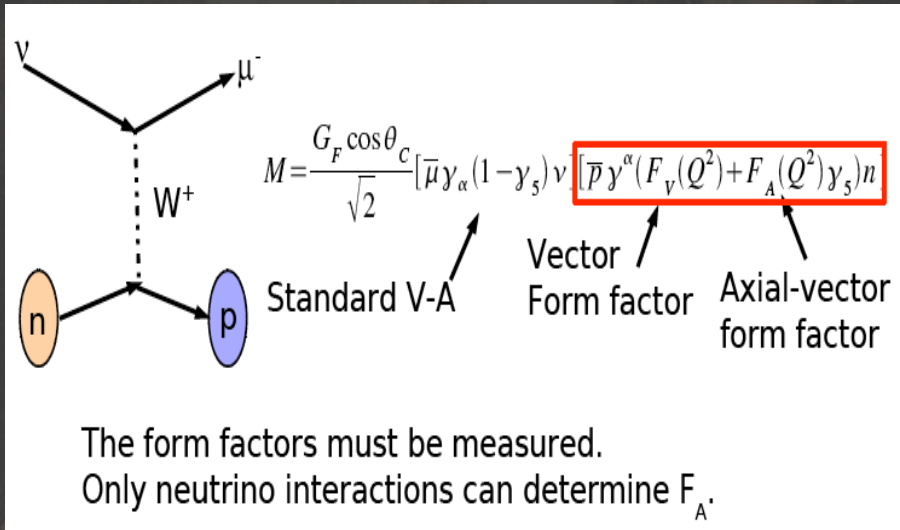
Cross Section Measurements

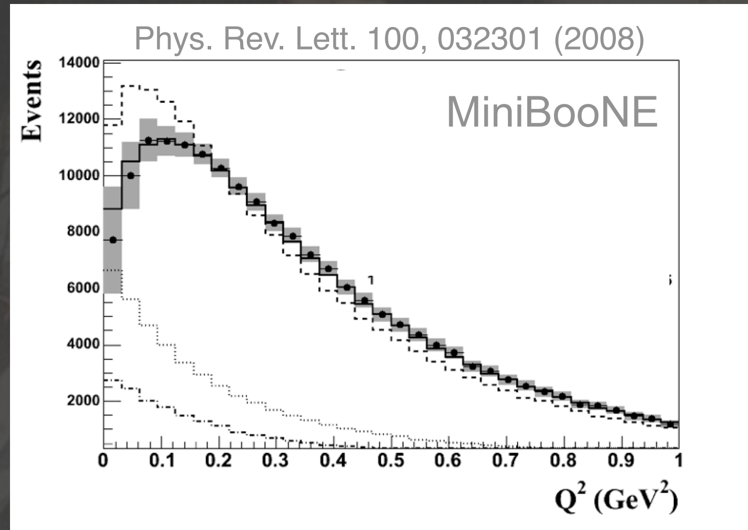
- Axial form factor of the nucleon
  - Accurately measured over a wide Q^2 range
- Coherent pion production
  - Statistically significant measurements of atomic mass dependence
- Resonance production in both NC & CC neutrino interactions
  - Statistically significant measurements with 1-5 GeV neutrinos
  - Study of “duality” with neutrinos

Other Stuff

- Strange particle production
  - Important backgrounds for proton decay
- Nuclear effects
  - Expect some significant differences for ν-A vs e/μ-A nuclear effects
- Parton distribution functions
  - Measurement of high-x behavior of quarks
- Generalized parton distributions

Quasi-Elastic Analysis





- Nuclear effects play a huge role in modeling these events
  - Fermi momentum (target nucleon has momentum in nucleus), modifies scattering angle, p spectra of outgoing final state particle
  - Nuclear re-interaction (outgoing nucleon can interact with target nucleus), modifies outgoing nucleon p, direction
  - ~20% theoretical uncertainty on these events!
- Experimental evidence indicates a lack of understanding!
  - MiniBooNE, K2K observe unexpected turn-over of data at low Q2

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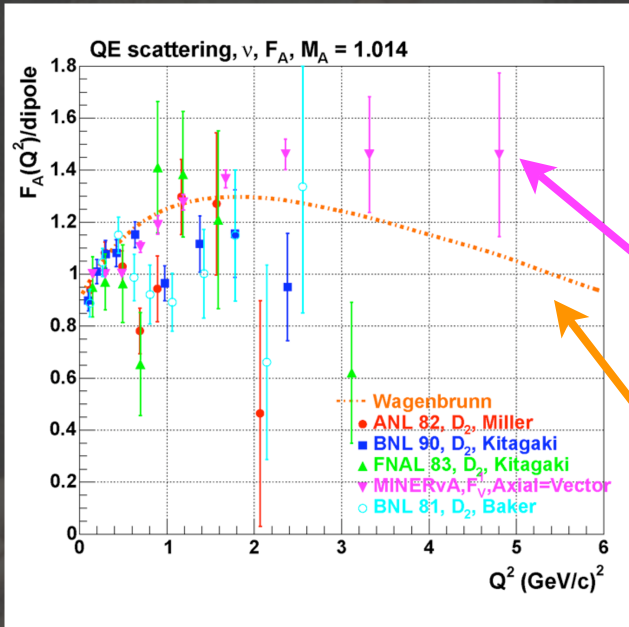


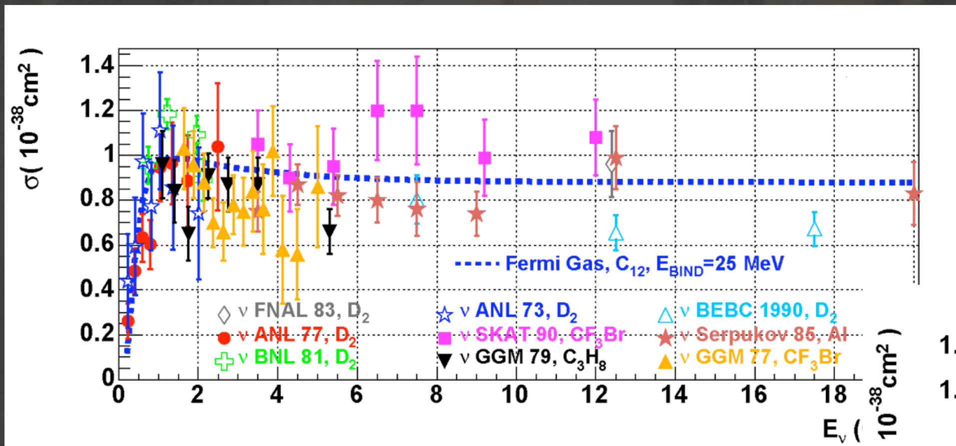
Expected ability to measure high Q^2 behavior and sensitivity to non-dipole F_A form factor

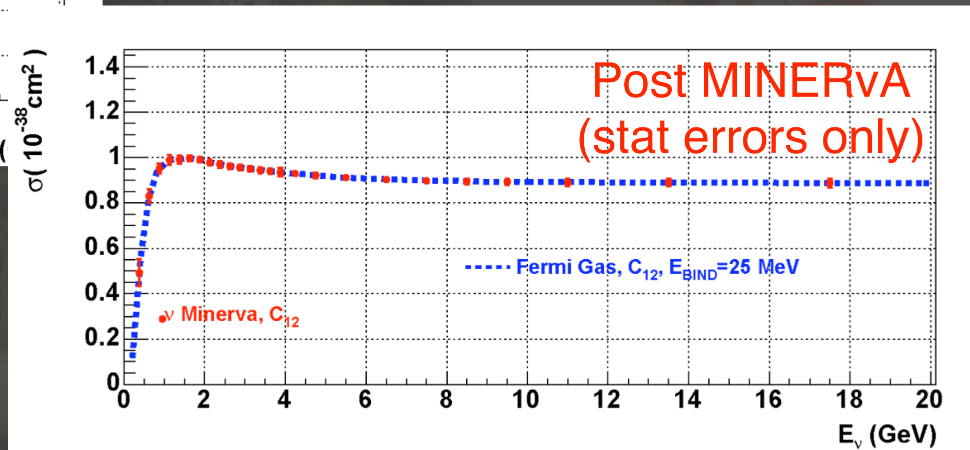
Simulated MINERvA Axial-Vector hypothesis (stat only)

Wagenbruun, et al (hep-ph/0212190)

- First expt to systematically study F_A in range of $Q^2 = 0$ to ~6 GeV^2
- First expt to systematically study xsec across a range of atomic mass in same expt environment
- Sensitive to three models of F_A
  - Dipole approx (current assumption), constituent quark model, duality model (dipole breaks down @ $Q^2 = 0.5$)

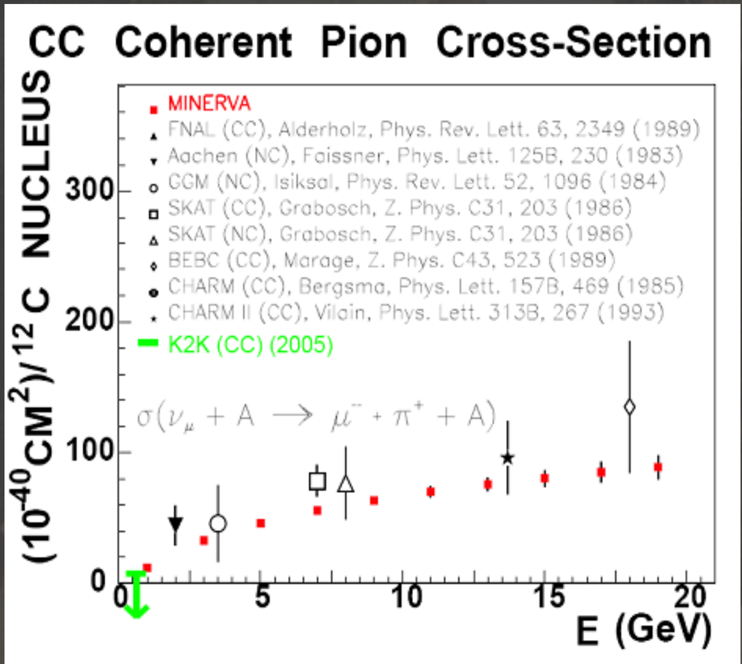
Quasi-Elastic Analysis



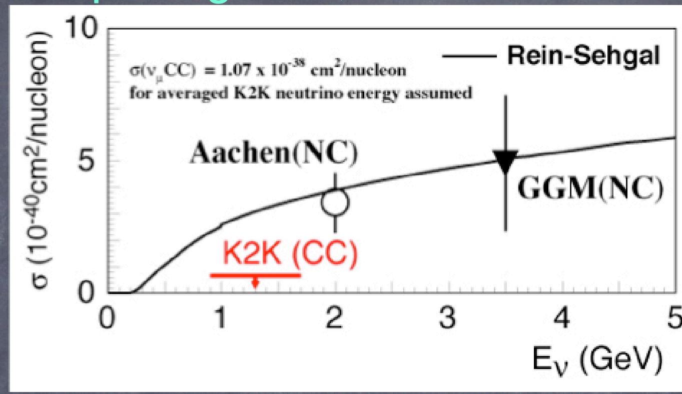


- >800K total events in 4 year run time
- Expect to achieve 5% total error on xsec measurement!
- Refined CCQE model used to re-analyze MB CCQE data

Coherent Pion Production



Surprising K2K, SciBooNE results!

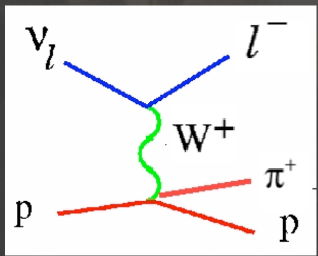


Expect 470, find 7.6 ± 50.4 !

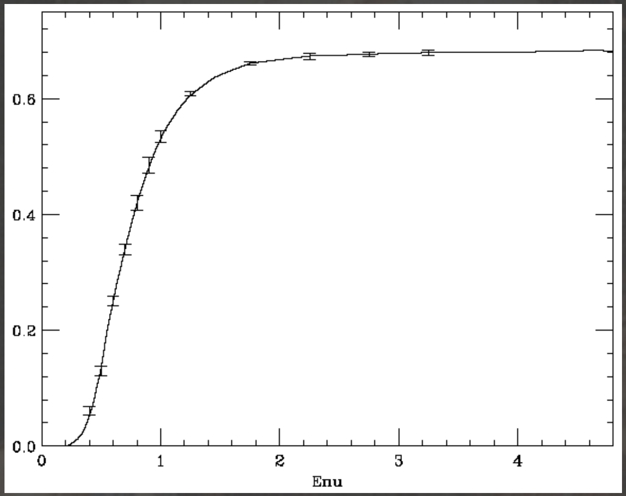
- Assumptions:
  - σ(CC)=2σ(NC) (isospin relations)
  - σ proportional to $A^{1/3}$ for different nucleus
  - σ(total CC) in NEUT MC

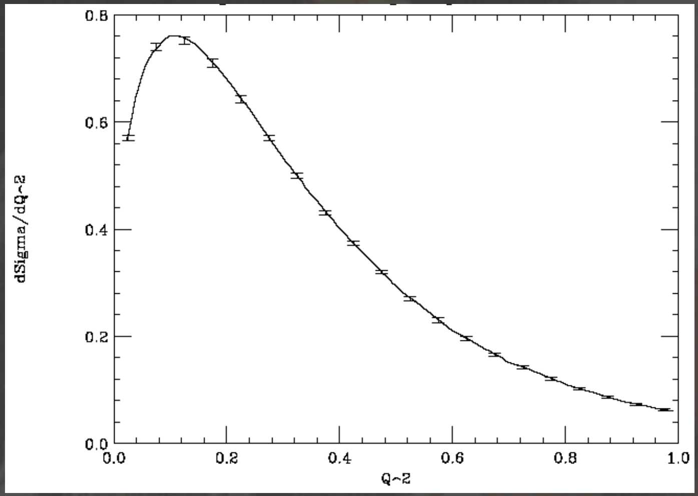
Phys. Rev. Lett. 95, 252301 (2005)
arXiv:0811.0369

- ν scatters from entire nucleus, nucleus remains intact
- First measurement of atomic mass dependence across a wide atomic mass range
- Factor of >100 increase in world's current sample



Resonant Production





Total Cross-section and $d\sigma/dQ^2$ for the Δ^{++}. Errors are statistical only

- ν scatters from nucleon, nucleon resonance is excited, decays back to ground state via emission of 1 or more mesons
- $\nu + N \rightarrow \nu/\mu^- + \Delta$
- Study nuclear effects and atomic mass dependence for multi-pi final states

Cross Section Summary

- Constrain charged-current channels to ~5% total, dominated by beam/flux error
  - CCQE, coherent pion, resonant, DIS
- NC more difficult, expect 10% total error

Estimated Cross section uncertainties

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

Strange Particles

- Focus on exclusive channel strange particle production
- Important for bgd calculations of nucleon decay expts
- Extended anti-nu running = single hyperon production, greatly extend form factor analyses

MINERνA Exclusive States

400 x earlier samples

3 tons and 4 years

$\Delta S = 0$

$\mu^- K^+ \ \Lambda^0$ 42 K

$\mu^- \pi^0 K^+ \ \Lambda^0$ 38 K

$\mu^- \pi^+ K^0 \ \Lambda^0$ 26 K

$\mu^- K^- K^+ p$ 20 K

$\mu^- K^0 K^+ \pi^0 p$ 6 K

$\Delta S = 1$

$\mu^- K^+ p$ 65 K

$\mu^- K^0 p$ 10 K

$\mu^- \pi^+ K^{0n}$ 8 K

$\Delta S = 0$ - Neutral Current

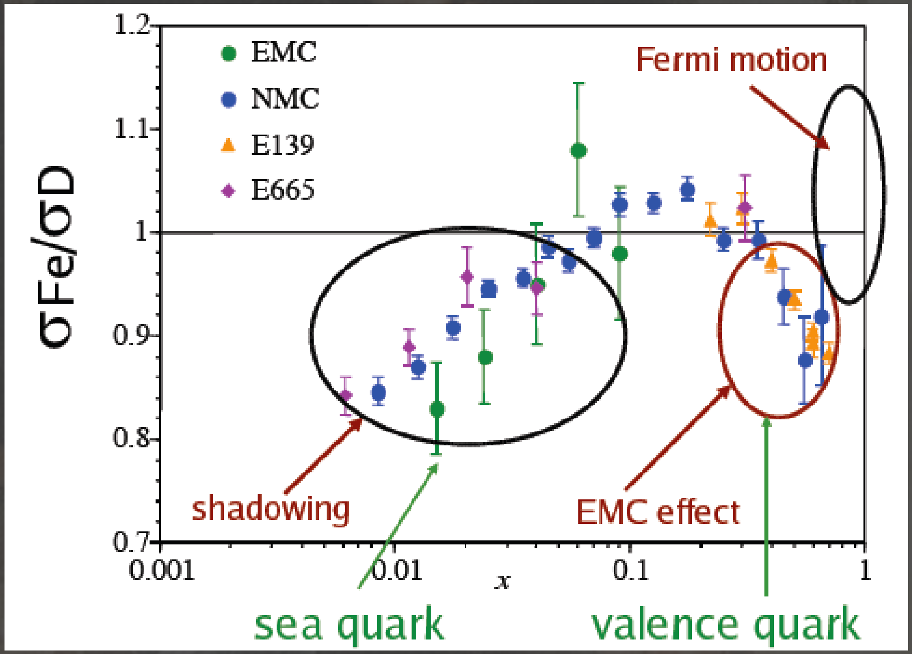
$\nu \ K^+ \Lambda^0$ 14 K

$\nu \ K^0 \Lambda^0$ 4 K

$\nu \ K^0 \Lambda^0$ 12 K

Nuclear Effects & DIS

- Dependence on atomic mass observed in e/μ DIS
- Could be different for neutrinos
  - Presence of axial-vector current
  - Different nuclear effects for valence and sea
  - leads to different shadowing for xF_3 compared to F_2

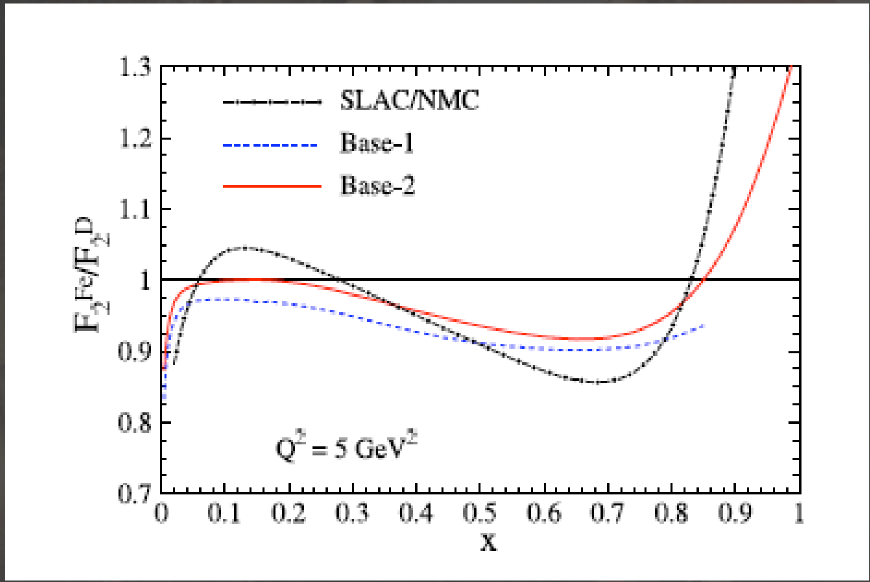


Can we extrapolate 10-20 GeV to 100 GeV? Compare to JLAB results…

Neutrino-Fe

- Nuclear correction factors for CC ν-Fe and NC e/μ-Fe appear to differ in behavior as $f(x_{Bj})$
- Use CC DIS, high-multiplicity events
- Resolution necessary for neutrino and HEP expts!
  - Use ν-nuclear data to develop free-proton PDFs at high x_{Bj}

Fe PDFs extracted from NuTeV nu, anti-nu data, compared to SLAC/NMC parameterization



arXiv:0710.4897

Event Rates

Assume 16.0×10^{20} **in LE and ME beam configurations**

• 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 reco. events
• Generalized Parton Distributions	order 10 K events
• Nuclear Effects	He: 0.6 M, C: 0.4 M, Fe: 2.0 M and Pb: 2.5 M

Fiducial Volume
- 3 tons CH (scintillator)
- 0.2t He - 0.15t C
- 0.7t Fe - 0.85t Pb

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Conclusions

- MINERvA is uniquely positioned to provide precision neutrino measurements over a wide range of energies
- Tracking Prototype installed in 1-2 mths
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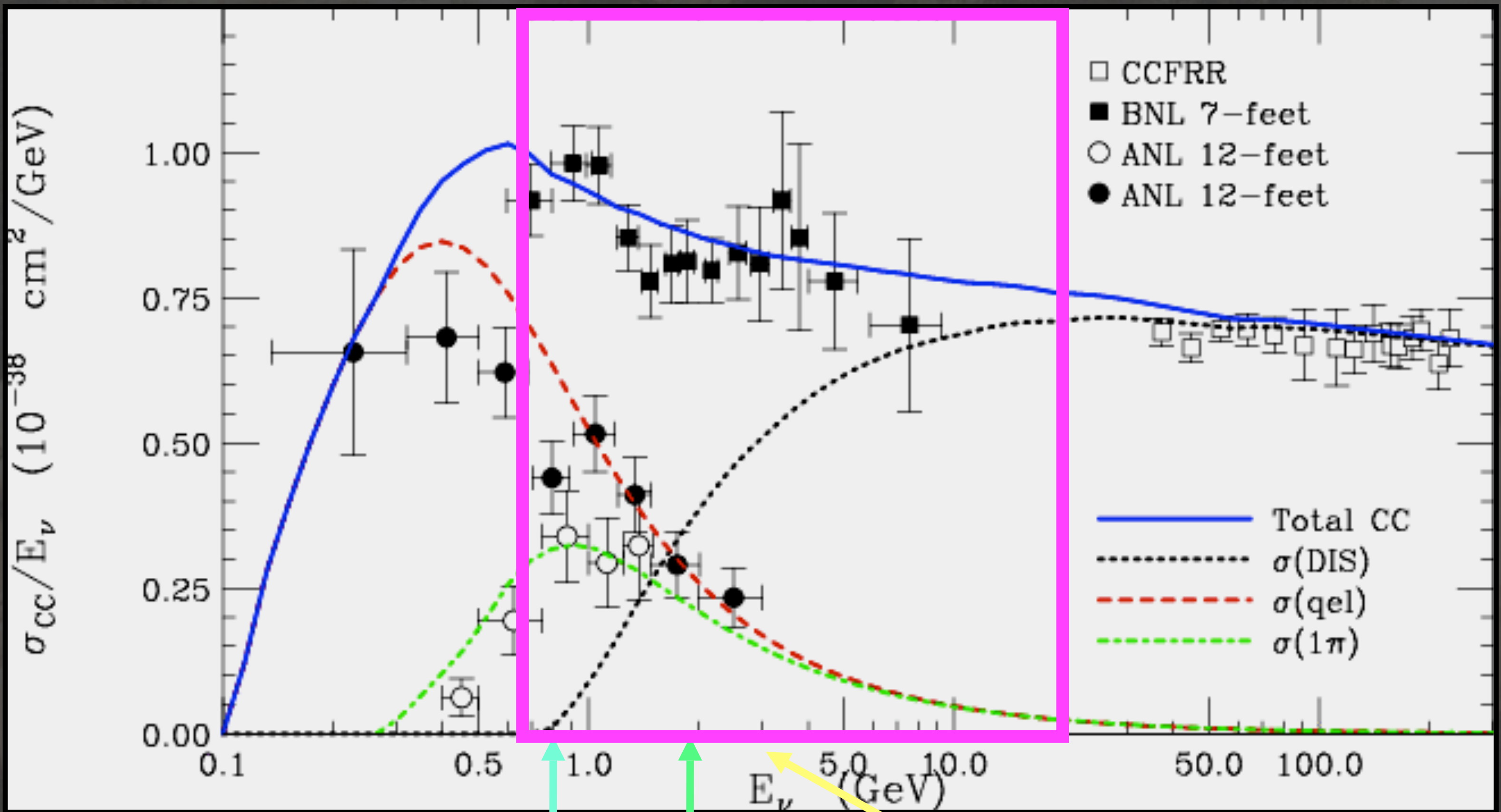
World Domination!

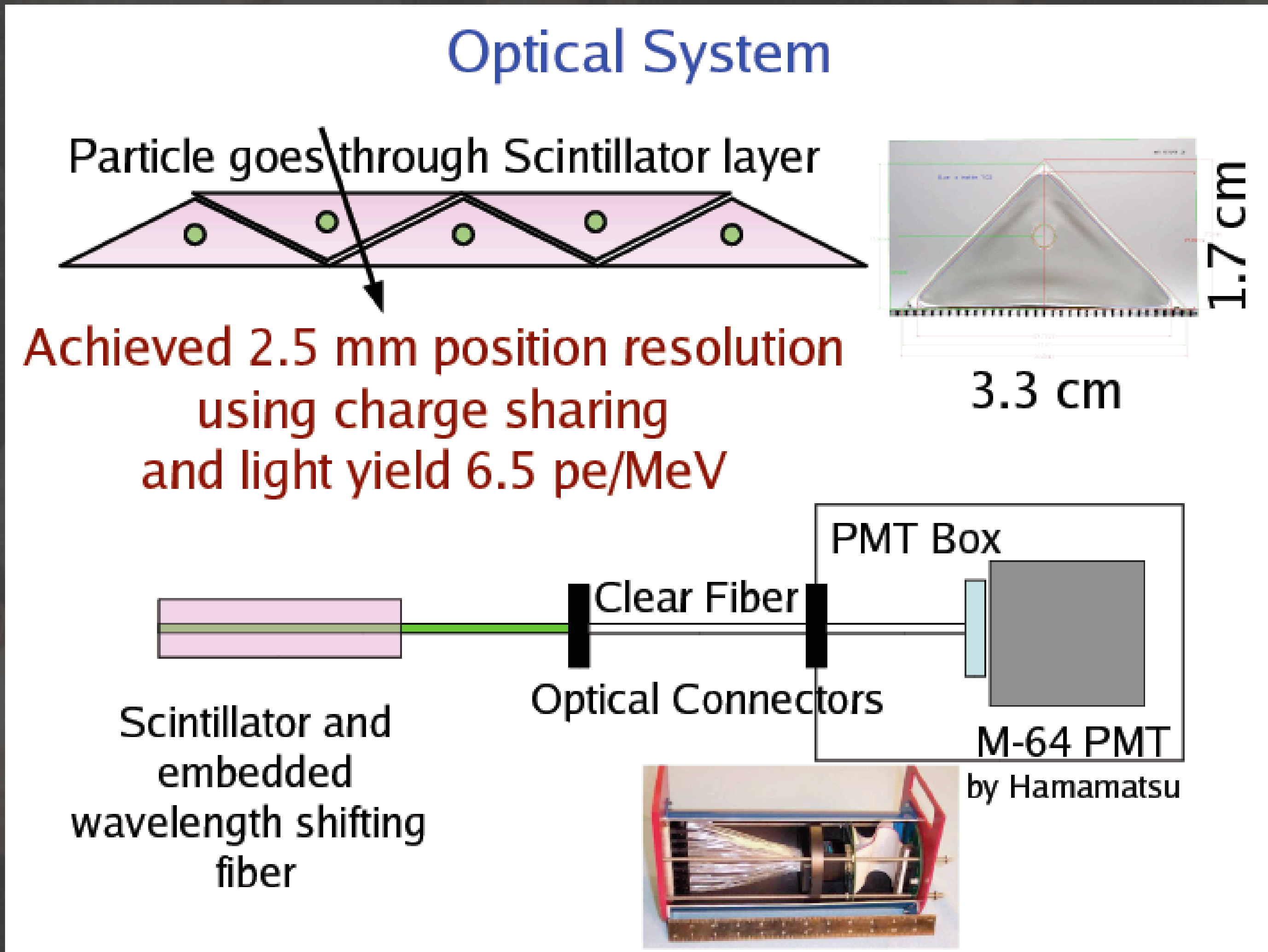
Backup Slides

MINERvAs Impact

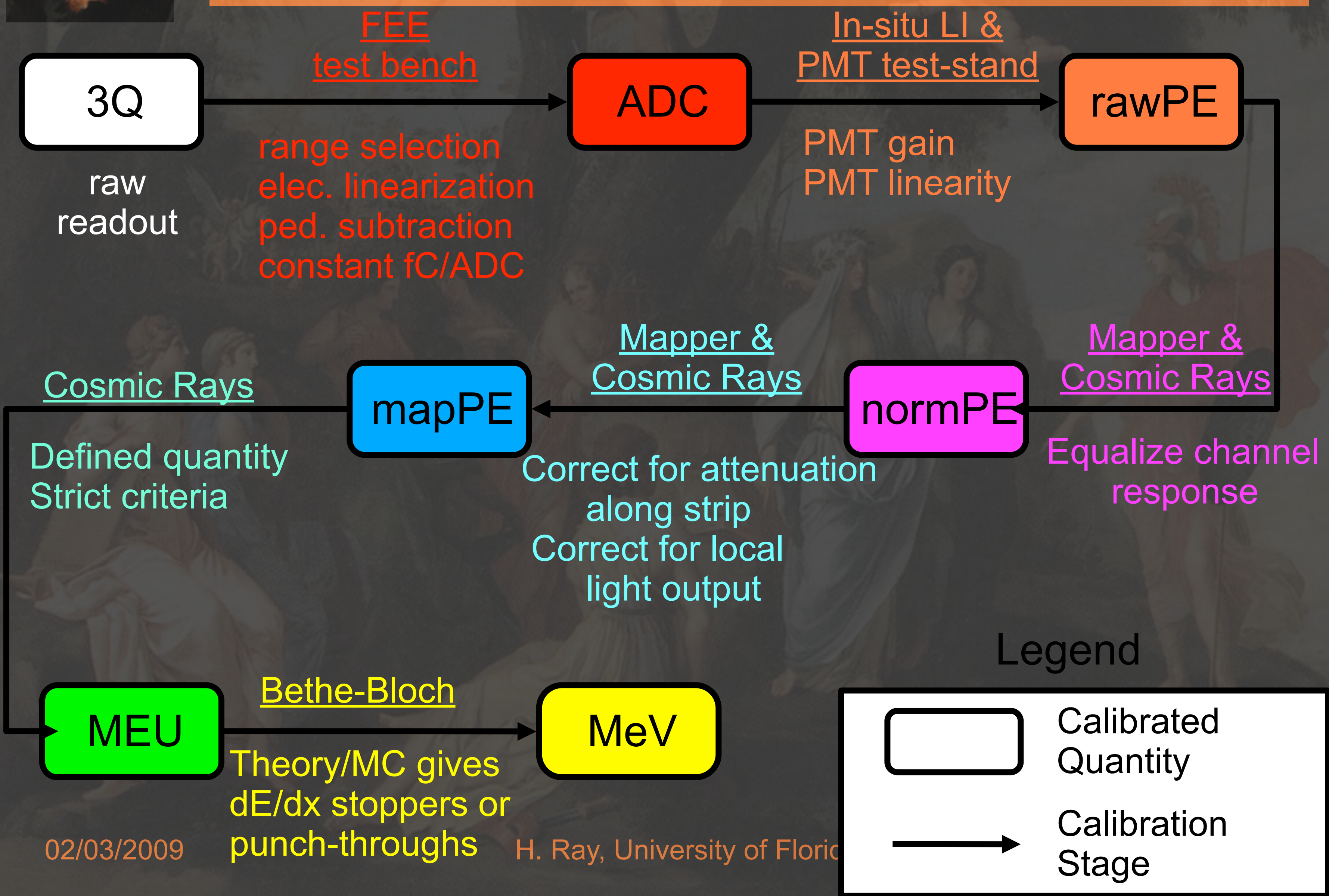


T2K, SciBooNE NOvA, MINERνA MINOS, MINERνA

Tracking System

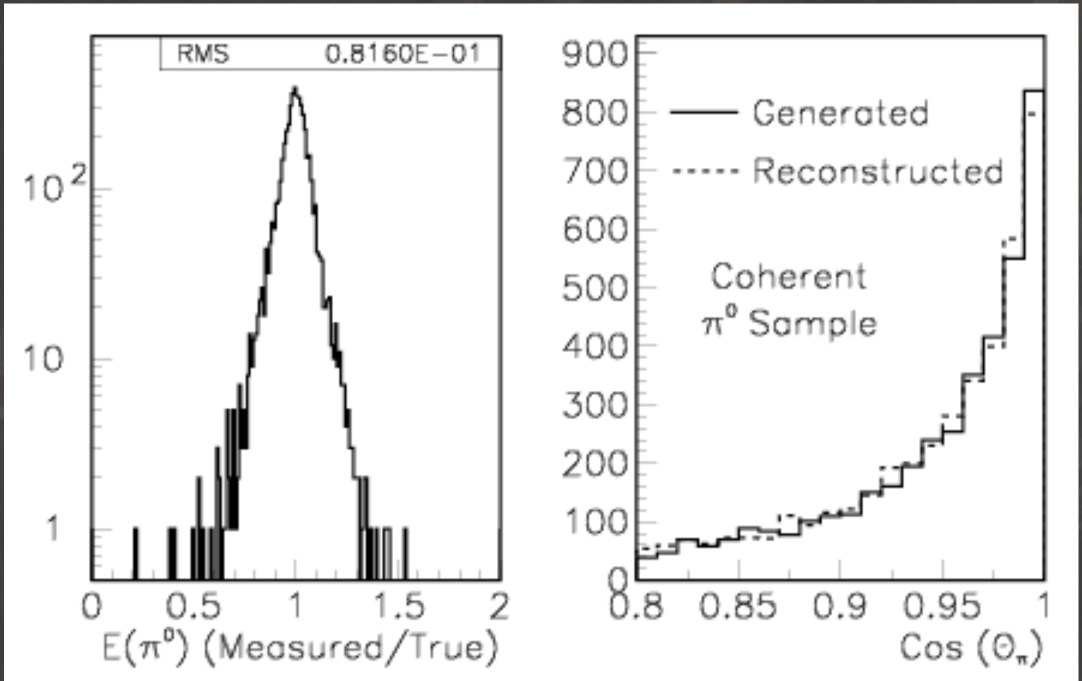


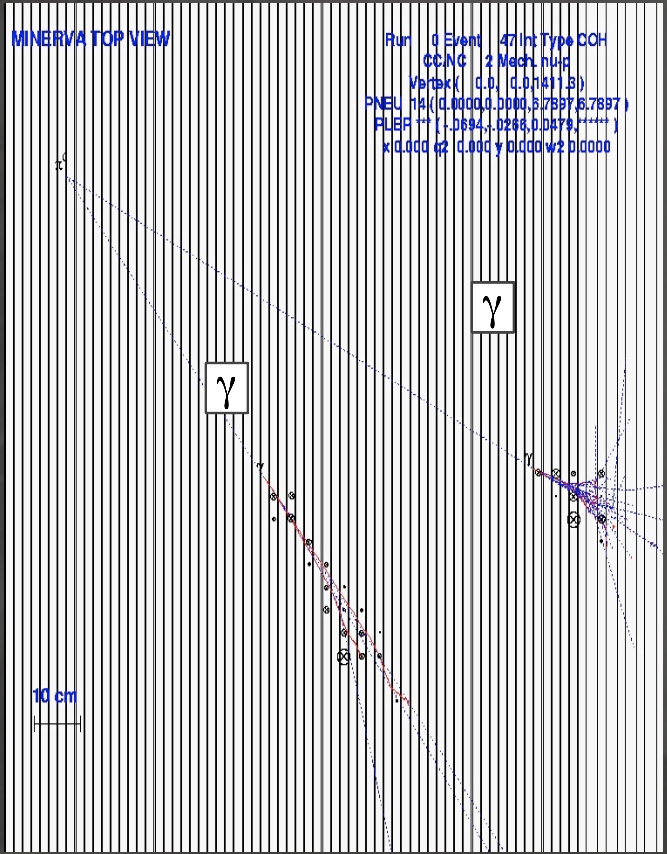
Calibration Scheme



Neutral Pions

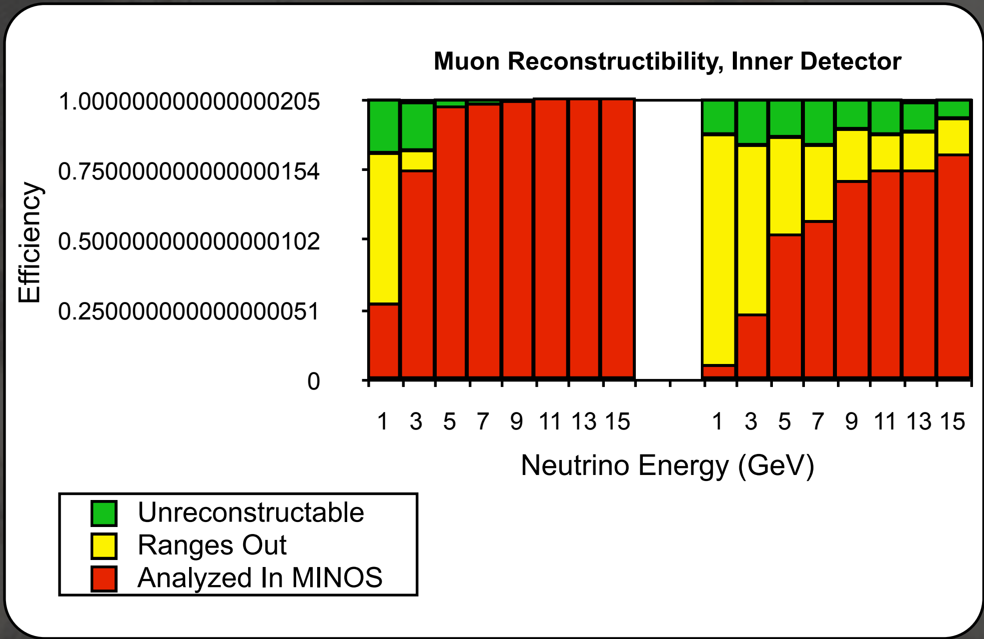
- Photons cleanly identified and tracked
  - π^0 energy res.: 6%/√E (GeV)
- For coherent pion production, angular resolution < physics width



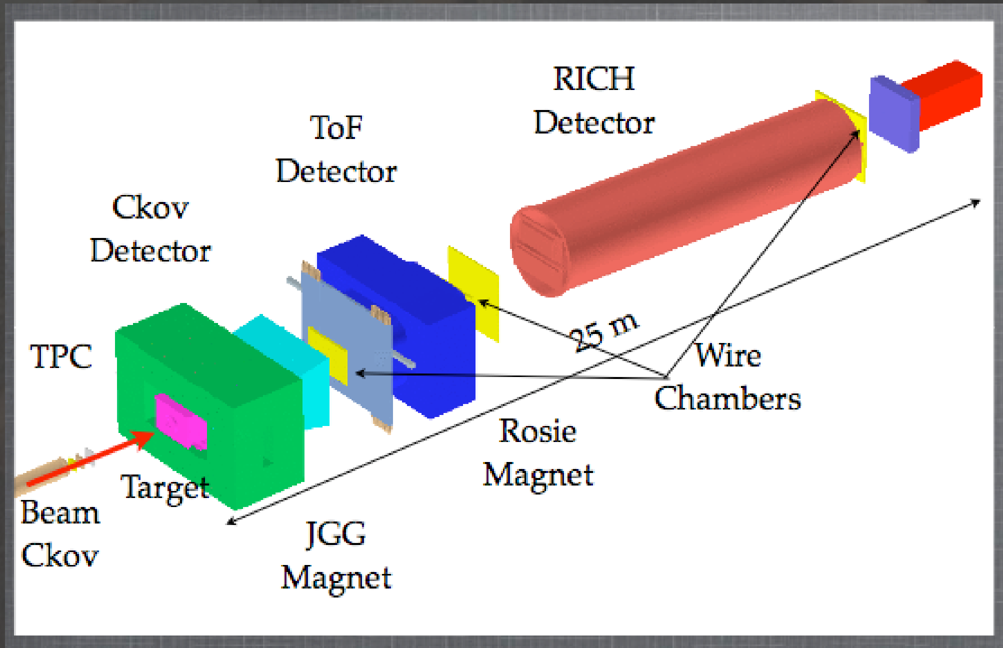


Muon Acceptance

- Look at acceptance for muons
  - High x DIS (x > 0.7)
    - Analyzed in MINOS: >90% active TGT, >80% nucl target
  - High Q^2 Quasi-Elastic
    - Analyzed in MINOS: >99% active TGT, >86% nucl. target



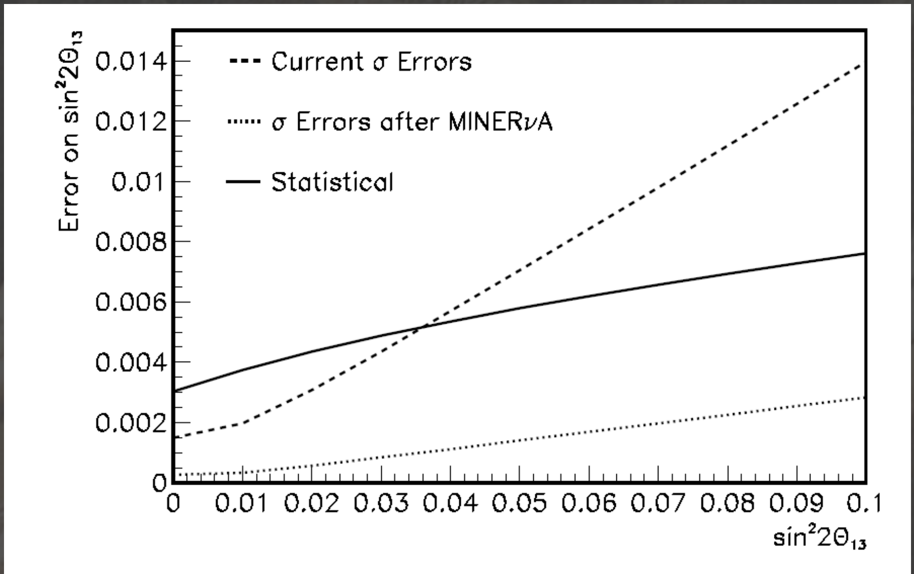
MIPP (E-907)

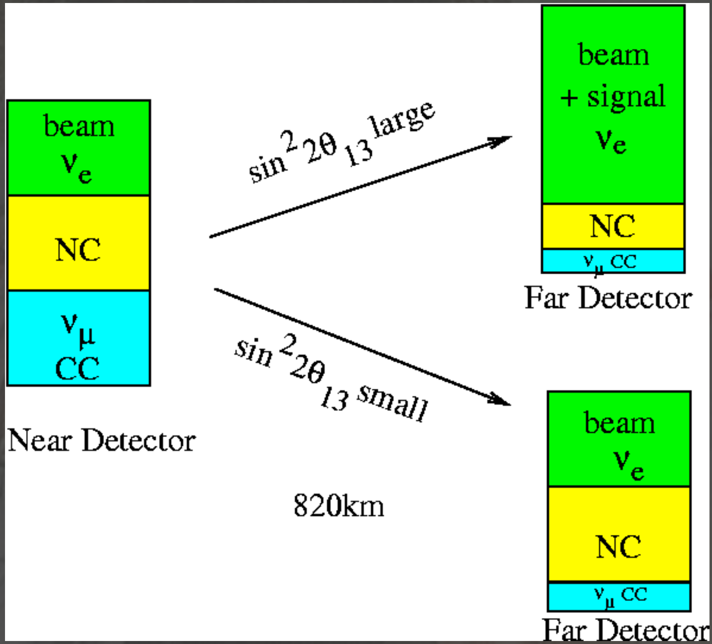


- Dominant systematic error for MINERvA will be characterization of the neutrino beam
- Main Injector Particle Production (MIPP)
  - fixed target expt, beams of π, K, p from 5 to 120 GeV
- 1.6e6 events of 120 GeV protons + our graphite target

MINERvA & NOvA

Total fractional error in the predictions as a function of reach (NOvA)

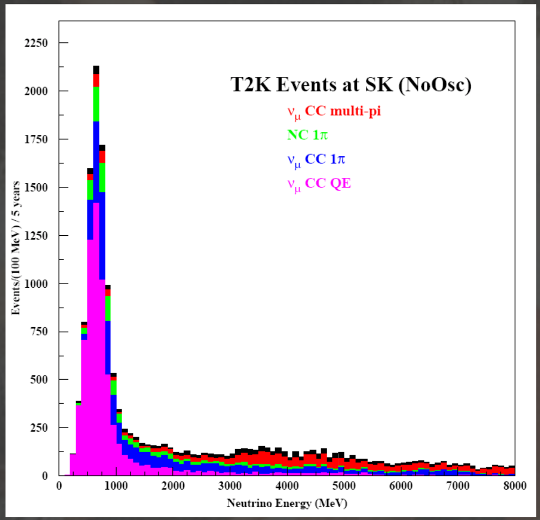


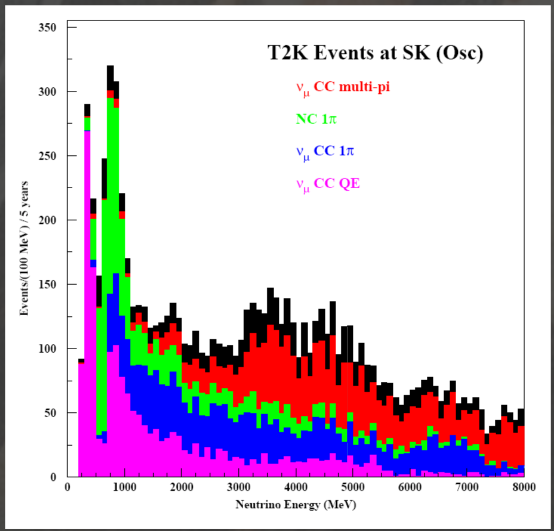


Process	QE	RES	COH	DIS
δσ/σ NOW (CC,NC)	20%	40%	100%	20%
δσ/σ after MINERνA (CC,NC)	5%/na	5%/10%	5%/20%	5%/10%

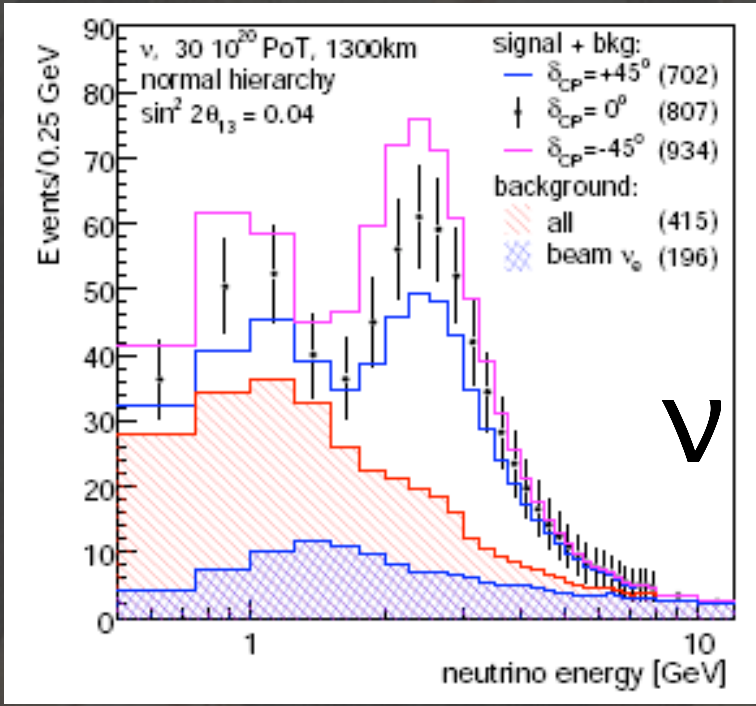
MINERvA & T2K

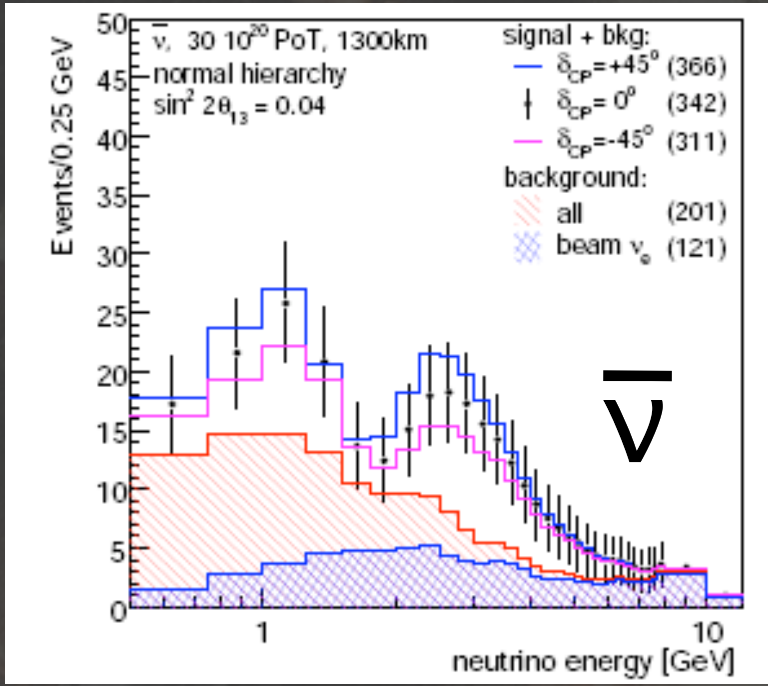
- T2K's near detector will see different mix of events than the far detector
- To make an accurate prediction one needs
  - 1 - 4 GeV neutrino cross sections (with energy dependence)
- MINER*v*A can provide these with low energy NuMI configuration





MINERvA & DUSEL





arXiv: 0705.4396
300kt Water Cerenkov

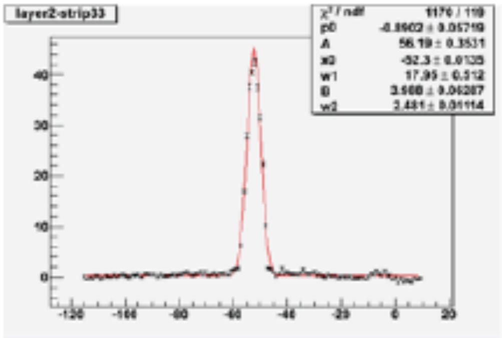
Backgrounds from NC p^0 production feed down
Study above assumes 5% knowledge of background
Basic cross-sections have large uncertainties (30-100%)

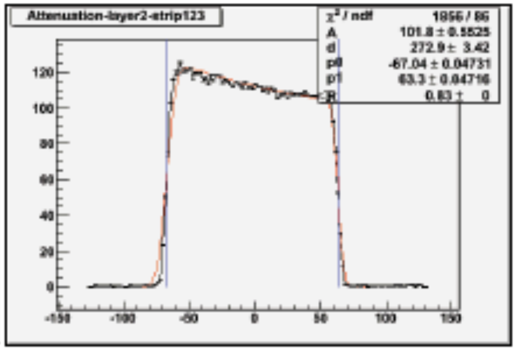
Note: MiniBoone coherent / all p^0 = 19.5 +/- 2.7% @ 1 GeV
arXiv: 0803.3423

Module and PMT Calibration

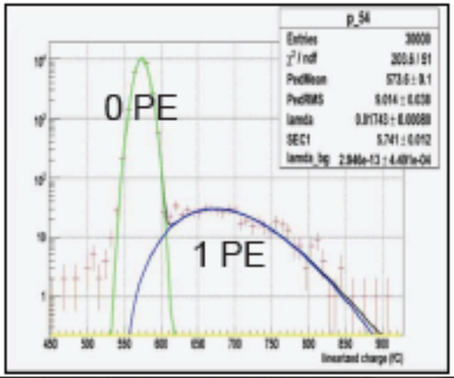
- Modules 3 and 6+ source mapped in Wideband before being hung

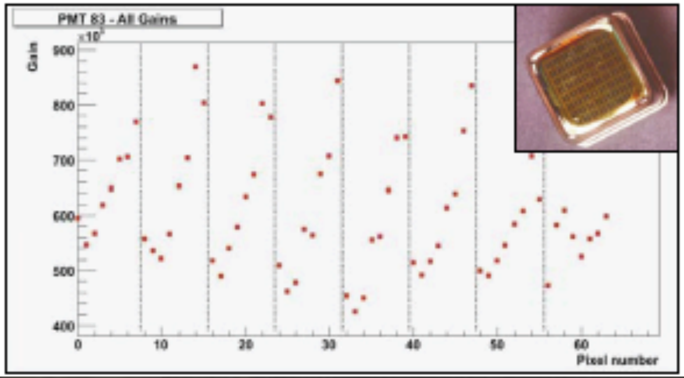
  strip position, attenuation along strips





- Light injection system installed for PMT gain calibration
  - needed for measurements of light yield





LI

Fiber Attenuation

- We scan at many points along each fiber
- Expect fiber attenuation length to be ~350cm and mirror reflectivity of 81% on far end of fiber
- Graph of “typical” attenuation in a scintillator plane from mapper (TP13, X view)