MINERvA

H. Ray

University of Florida

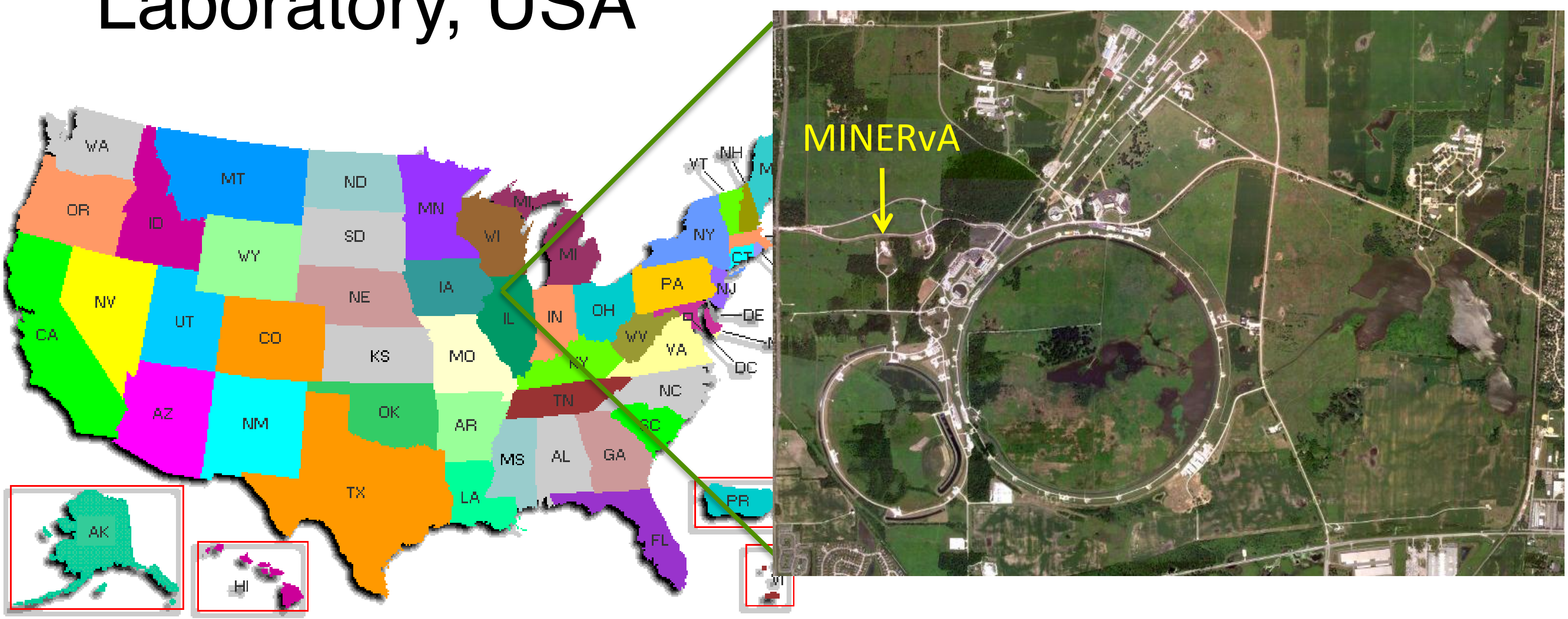
MINERvA's Motivation

- 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

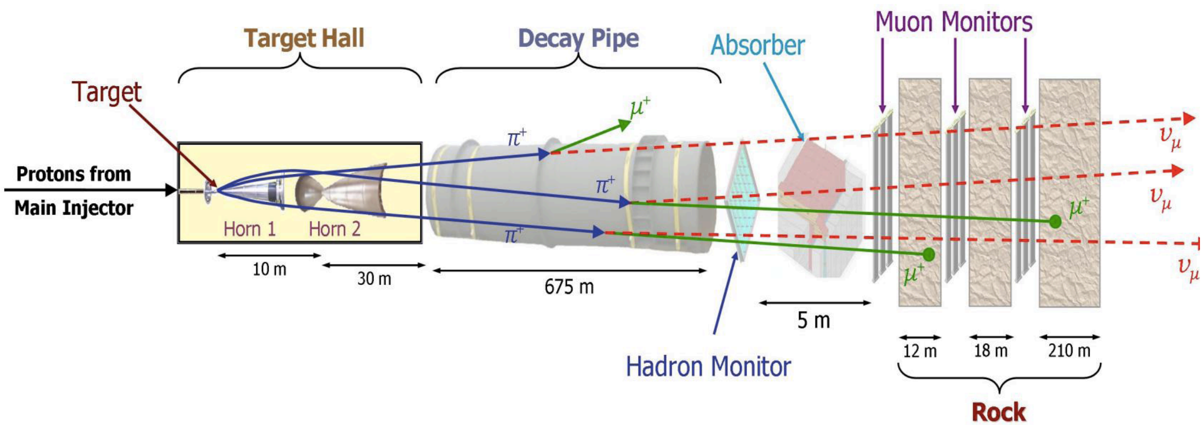
- **No other experiment exists to perform precision measurements in MINERvA's energy range (1-~10 GeV)!**

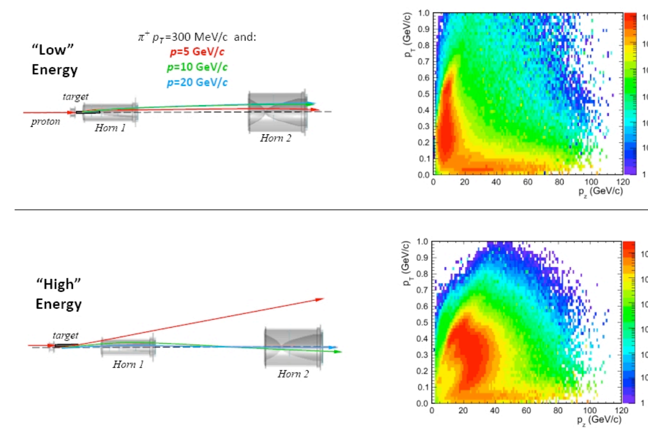
What is MINERvA?

- Accelerator-based neutrino experiment
- Located at Fermi National Accelerator Laboratory, USA

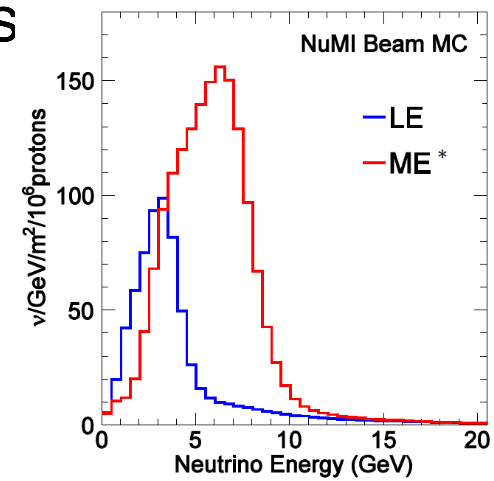


Creating Our Neutrino Beam

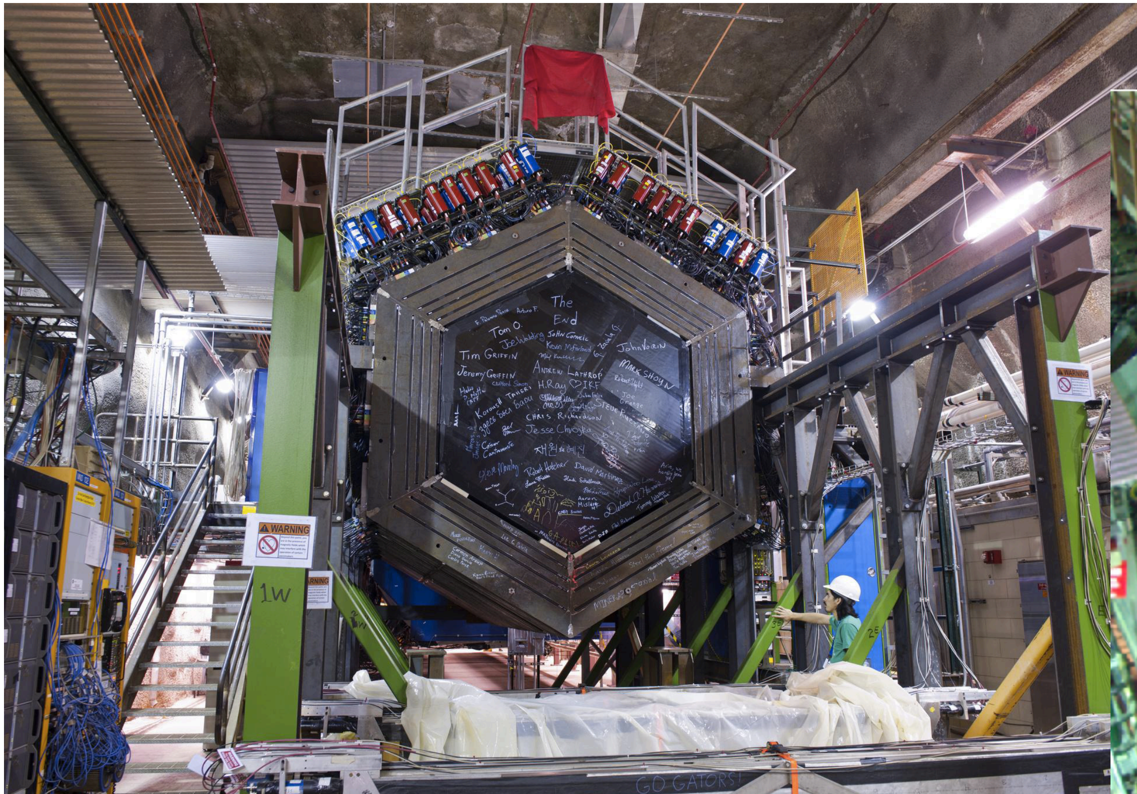


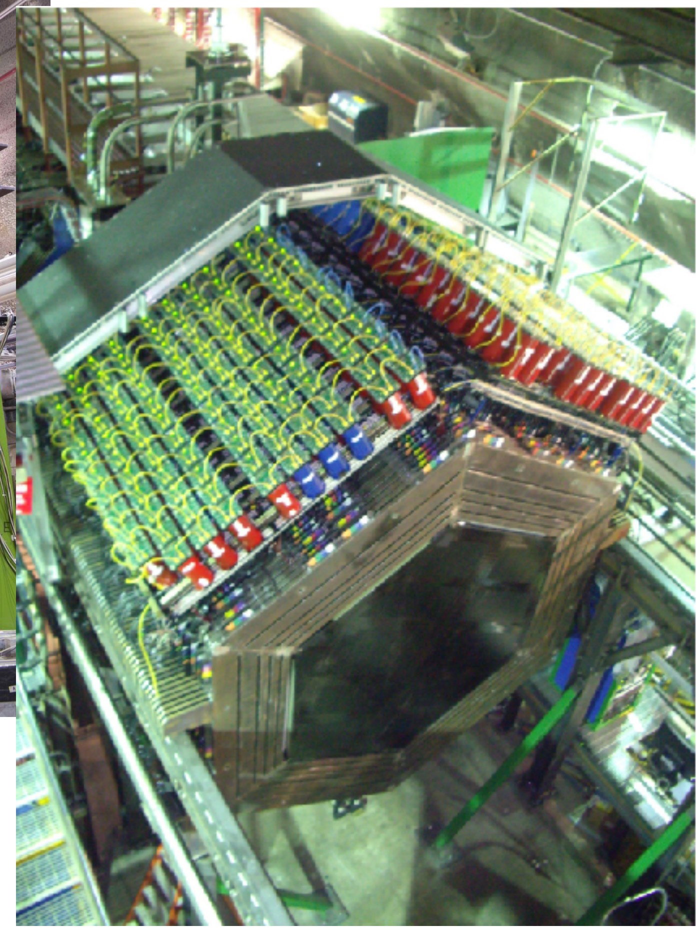


- 120 GeV protons + graphite target = mesons
  - $\pi^{\pm}$, $K^{\pm}$, some K^0
  - Mesons decay in flight to produce neutrino beam
- Magnetic focusing horns
  - Polarity of horns = neutrino or antineutrino beam
  - Movable horn/target = tunable neutrino beam energy



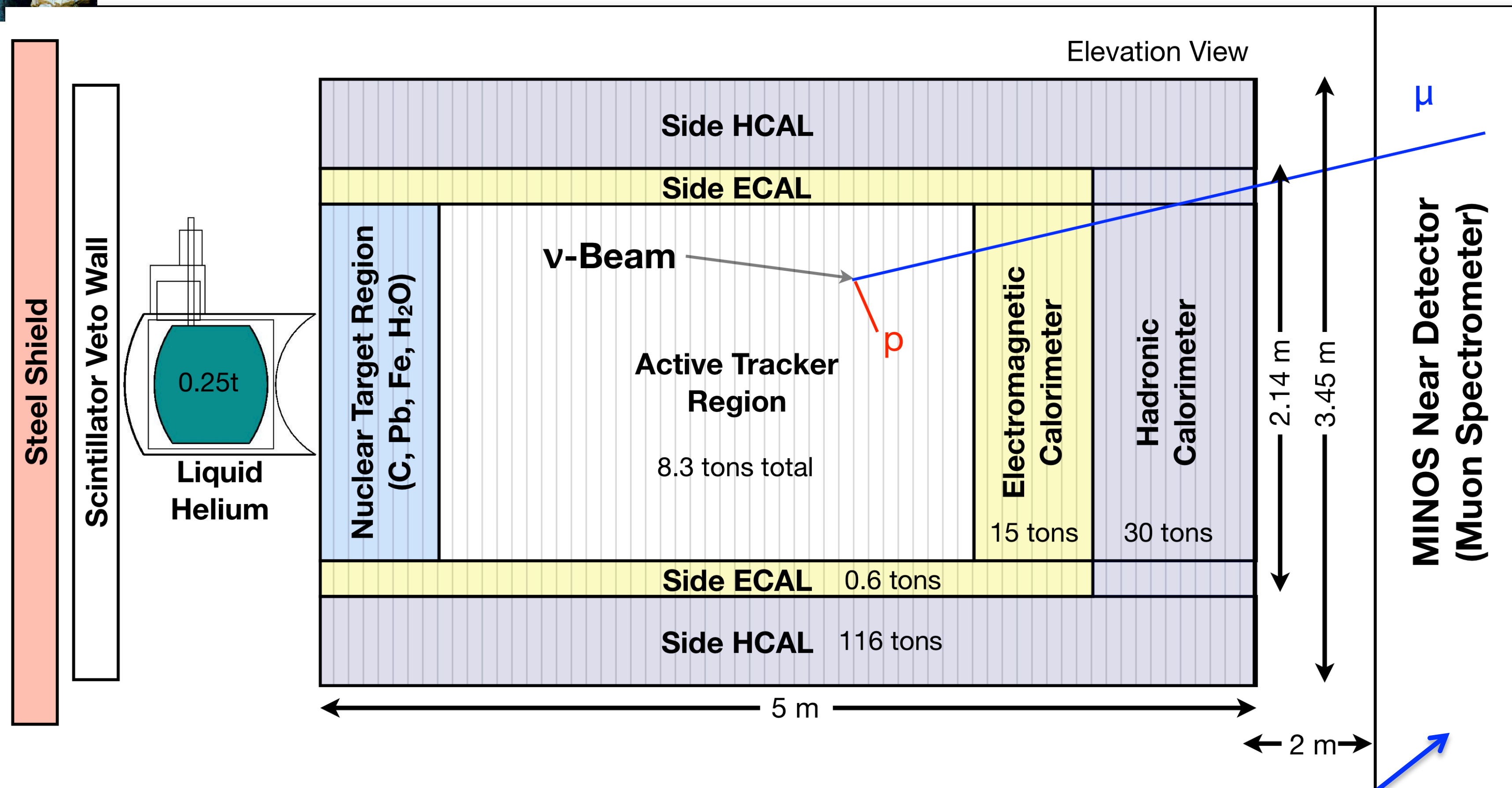
The MINERvA Detector





Composed of 120 modules

The MINERvA Detector

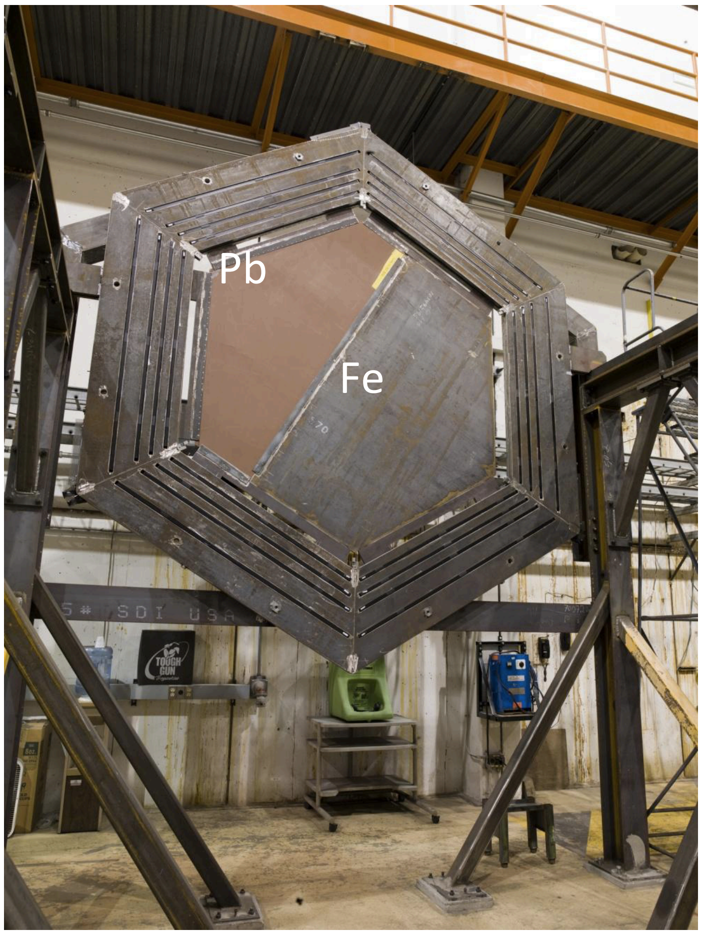


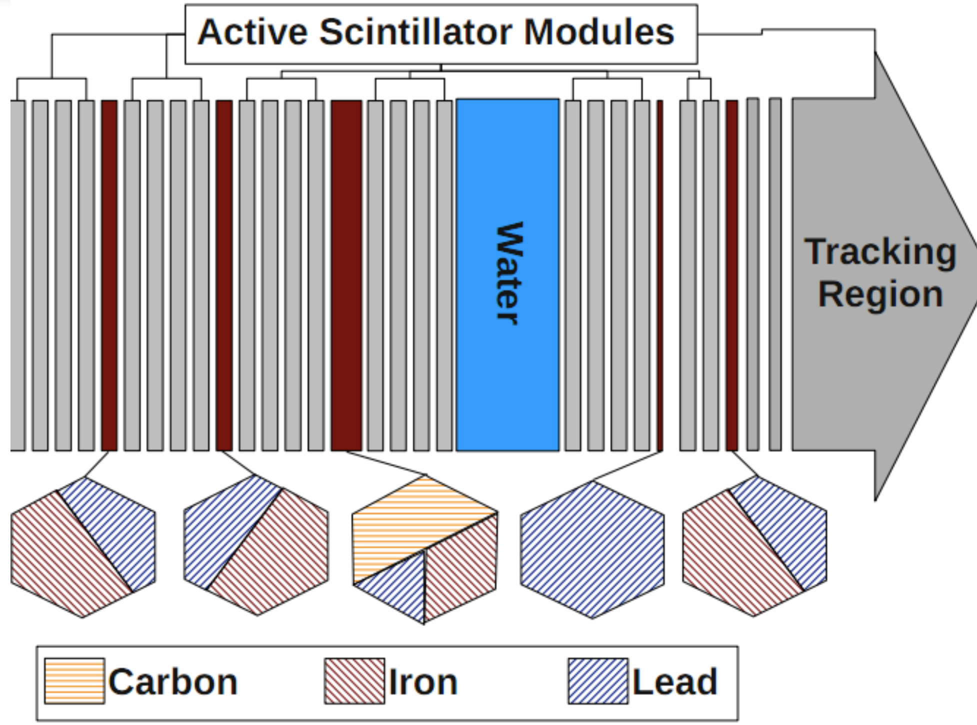
Multiple nuclear targets (C, CH, Fe, Pb, He, H_2O)

MINOS Near Detector acts as a muon spectrometer

The MINERvA Detector

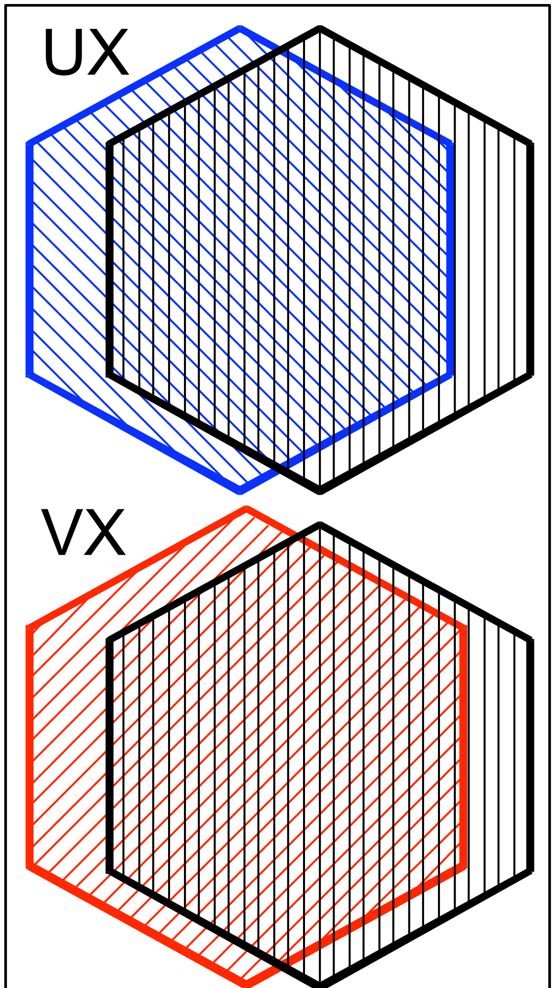
Targets are Fe/Pb, Pb/Fe, C/Pb/Fe, Pb, Fe/Pb



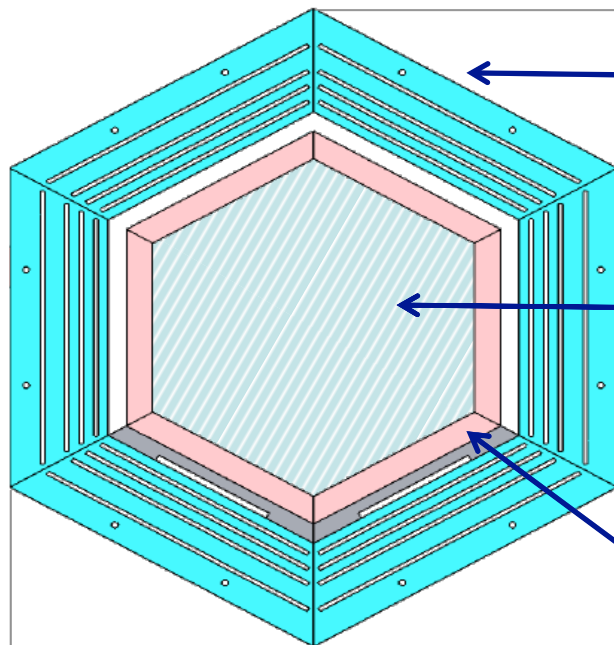


Target	Fiducial Mass
Liquid He	0.25 tons
C	0.17 tons
Fe	0.97 tons
Pb	0.98 tons
CH (tracker)	6.43 tons

The MINERvA Detector



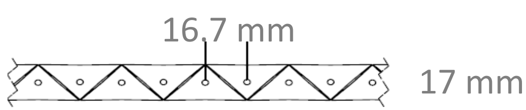
Finely segmented (~32k channels)

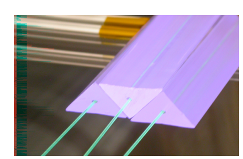


Outer Detector
Fe + Scintillator towers for hadron calorimetery

Inner Detector
UXVX planes for 3D tracking

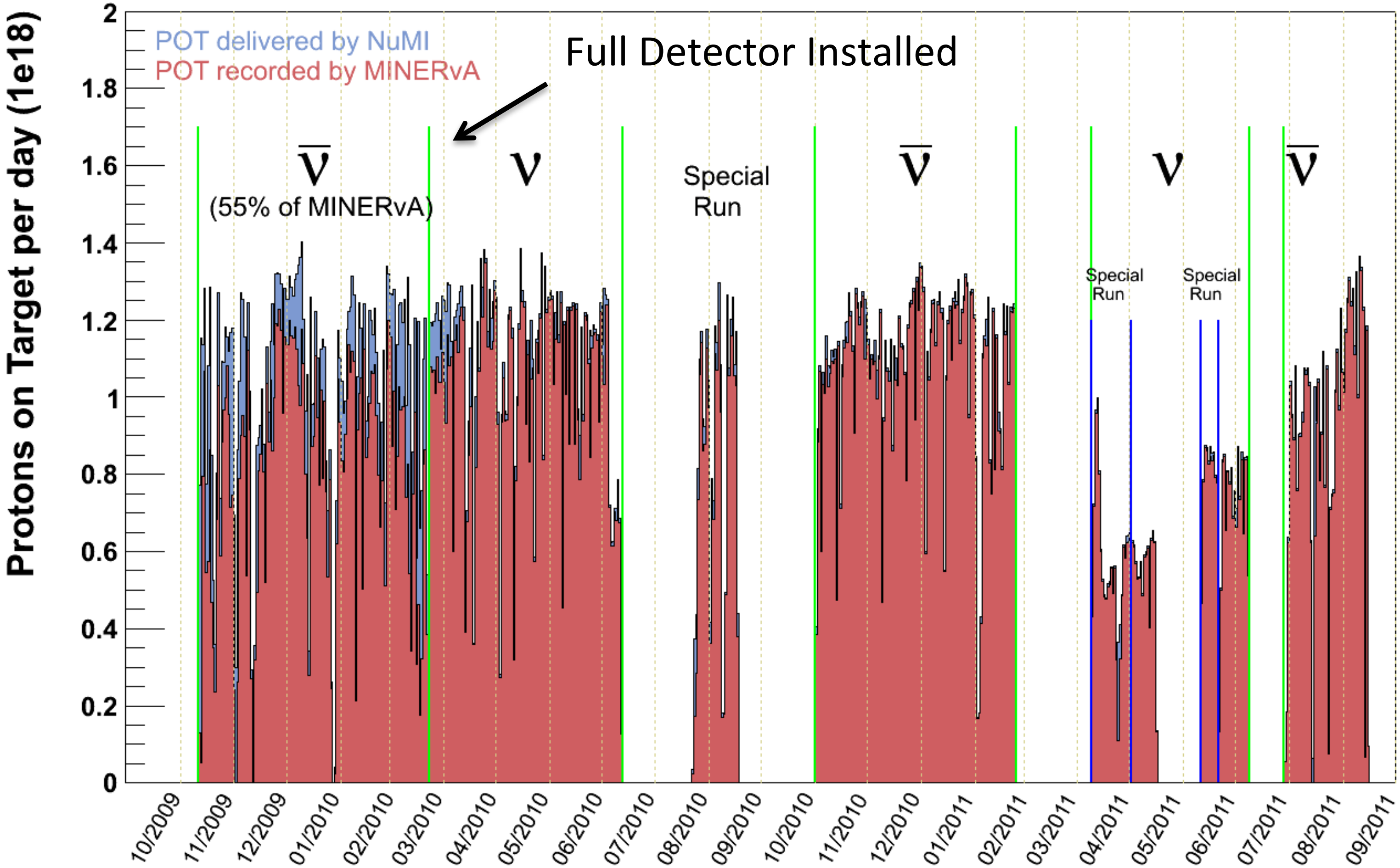
Side ECAL
Pb + Scintillator bars for EM calorimetry





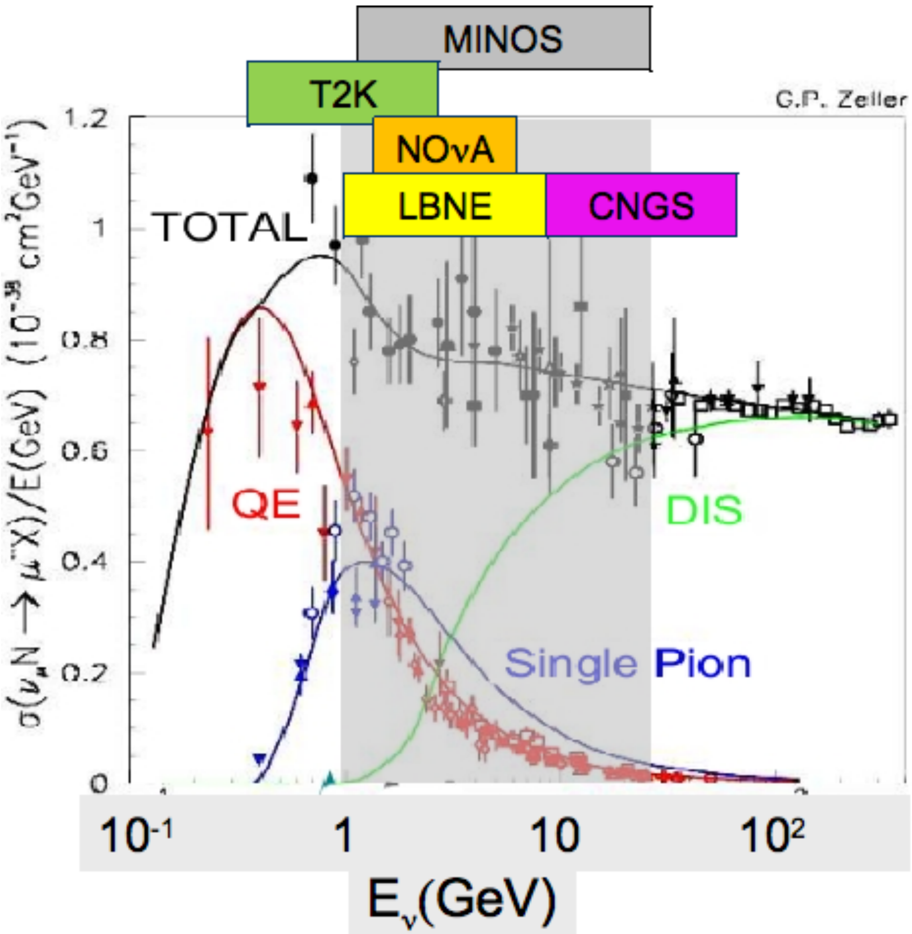
Data Collection To Date

Accelerator based neutrino experiments quantify their data set size in terms of the number of protons directed onto the target (POT)



MINERvA's Impact

Run plan: Approved for 4.9e20 POT in LE, 12e20 POT in ME beam configurations



To date: 1.5e20 POT LE neutrino
1.3e20 POT LE anti-nu (full detector)

Target	CC in LE 4e20 POT	Expected Total CC
Liquid He	56k	0.6M
C	36k	0.4M
Fe	215k	2.7M
Pb	228k	2.7M
CH (Plastic)	1363k	
Water	81k	1.0M

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

Other Stuff

Strange particle production

Important backgrounds for proton decay

Nuclear effects as f(Bjorken x)

Expect some significant differences for ν-A vs e/μ-A nuclear effects

Final State Interactions (ex: pion absorption in the nucleus)

Parton distribution functions

Measurement of high-x behavior of quarks

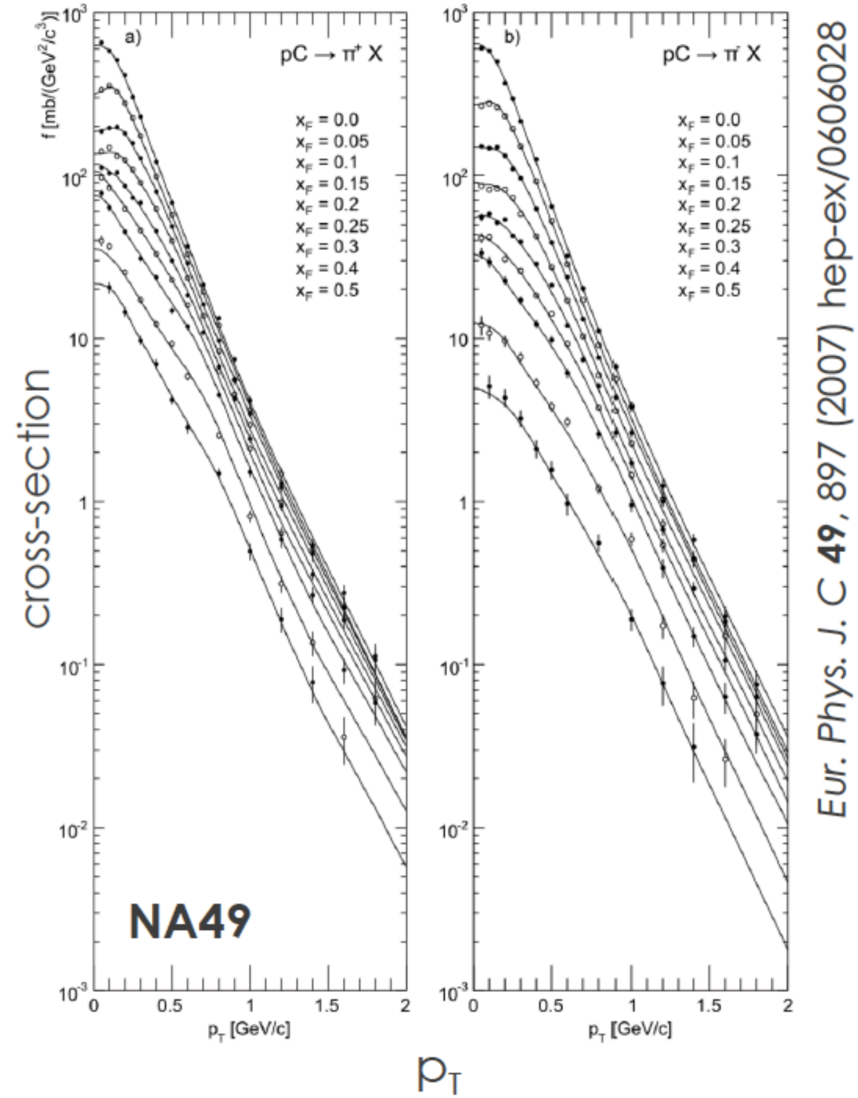
Generalized parton distributions

Analyses Currently In Progress

- Inclusive Analyses
  - Single pion production
  - CC ratios as f(Z)
- Exclusive States with Tracks
  - NCE
  - CCQE: 1 track, 2 track
  - Resonant and Coherent pion production
- EM Final States
  - Resonant CC π^0
  - NC π^0
  - ν_e scattering and ν_e CCQE

Understanding the Flux

- External measurements: hadron production data on thin carbon targets
- Internal measurements: muon monitors placed in the rock absorber downstream of target, special runs with varying target position and horn current
- Tunable beam MC, match spectra of observed hadrons in data



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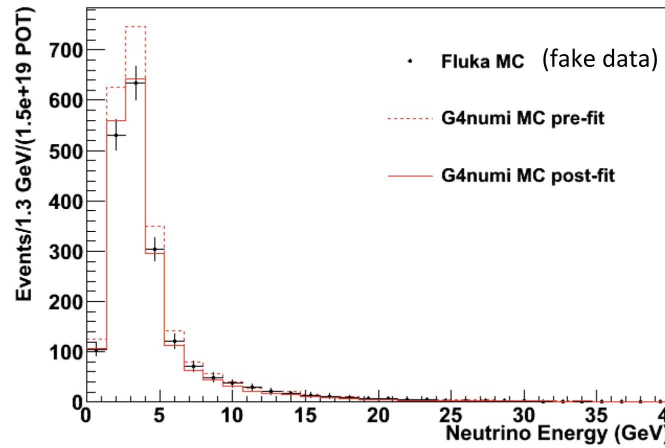
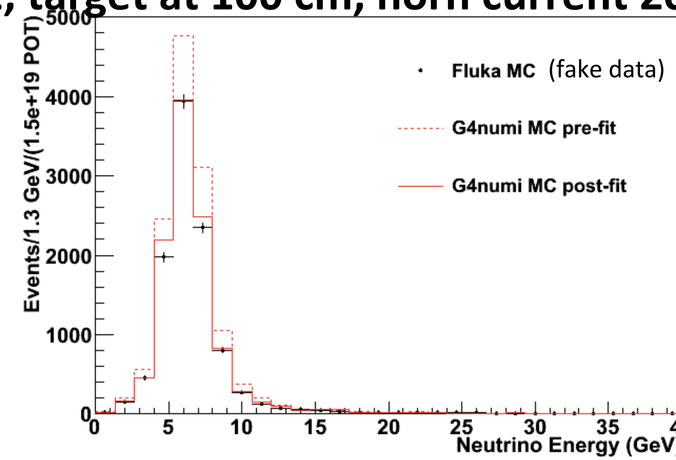
LE, target at 10 cm, horn current 185 kA

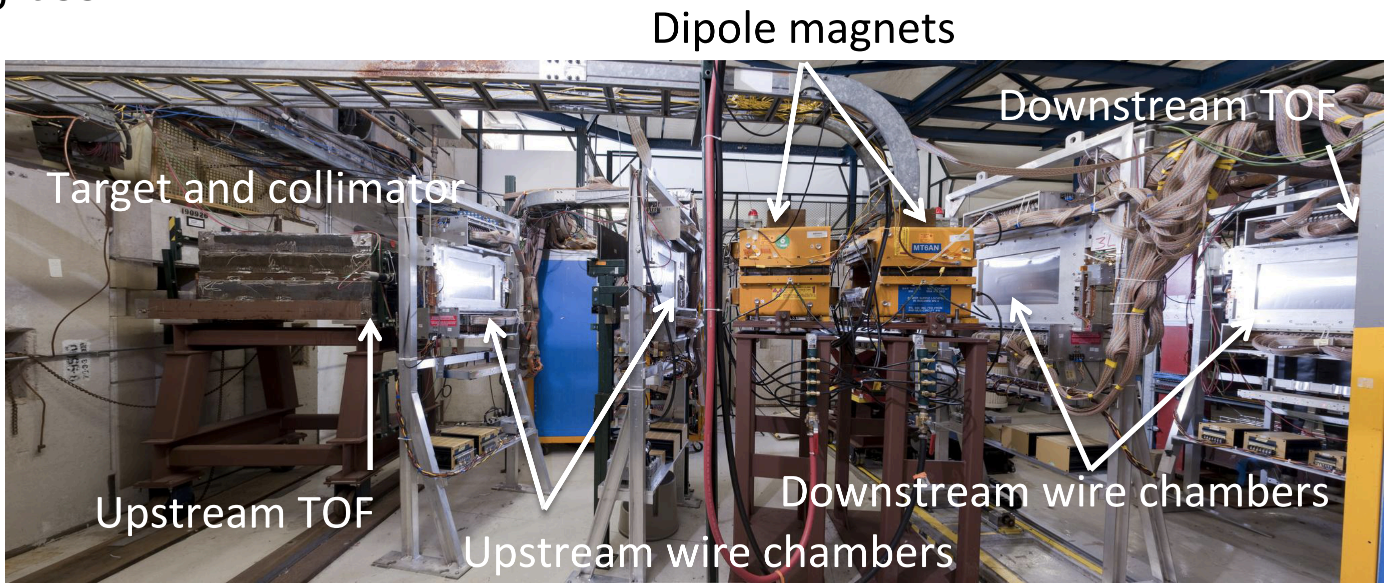


LE, target at 100 cm, horn current 200 kA



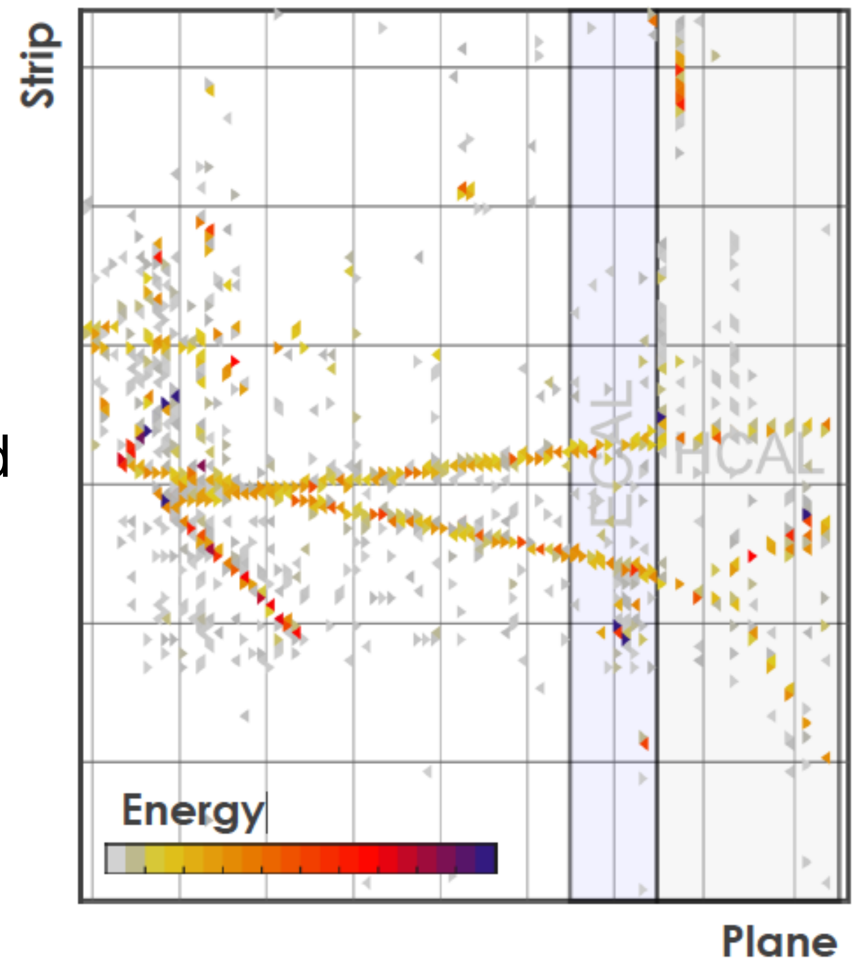
Calibrating Energy Scale

- Test Beam Detector: small, reconfigurable version of our detector, collected data at Fermilab's Test Beam Facility
- Study identification and momentum separation of low energy hadrons, hadronic energy scale
- Ran Summer 2010, used 2 different detector configurations, analysis in progress



Event Reconstruction

- Group hits within a single spill by timing
- Muons identified and measured in MINOS by range or curvature (6%, 12% resoultion)
- Working to include contained and side-exiting muons
- Pion and proton tracks are identified through energy loss profile
- Showers are identified, visible E found calorimetrically



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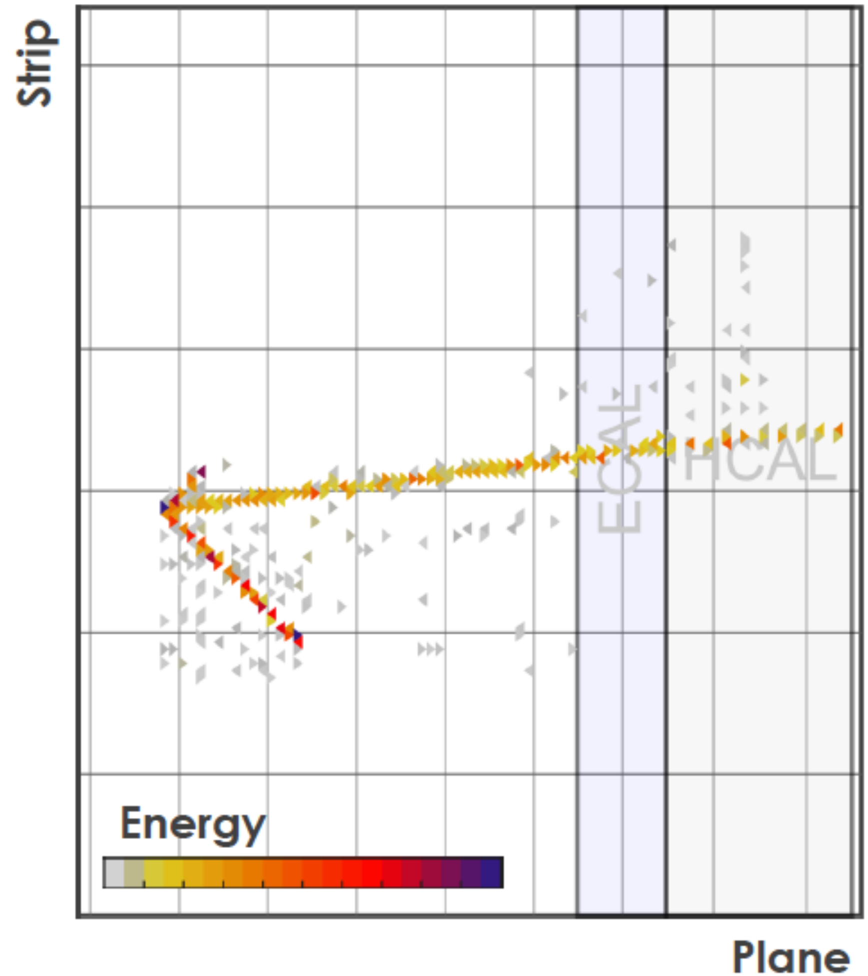

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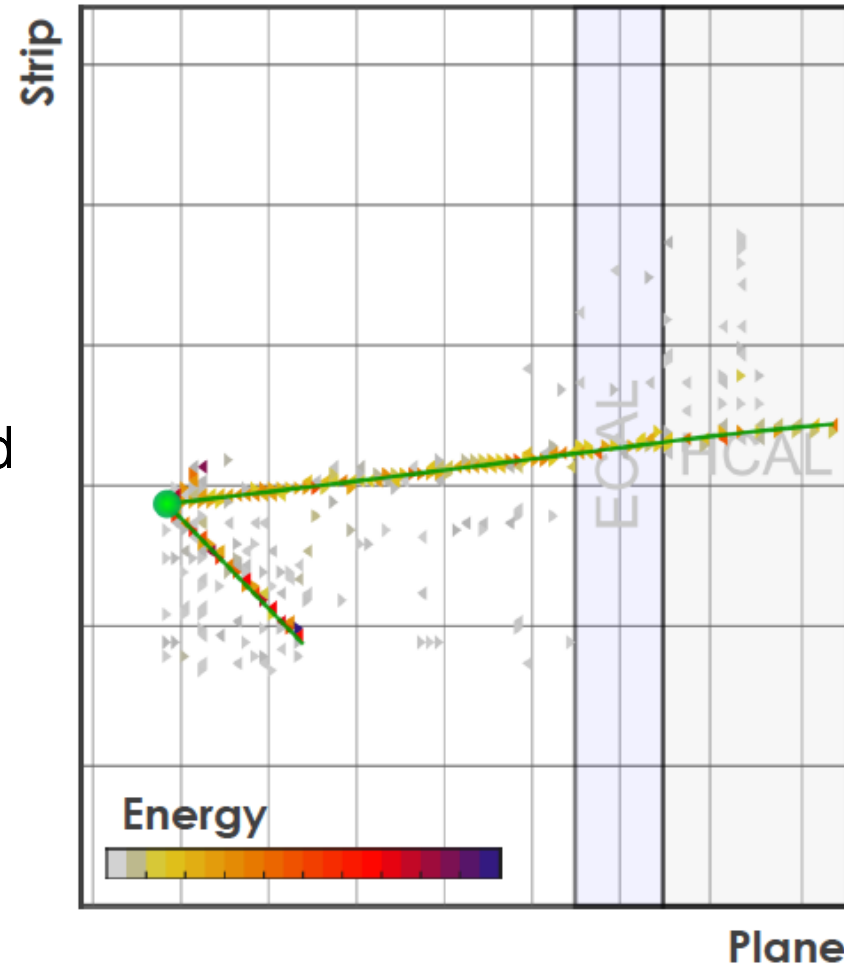

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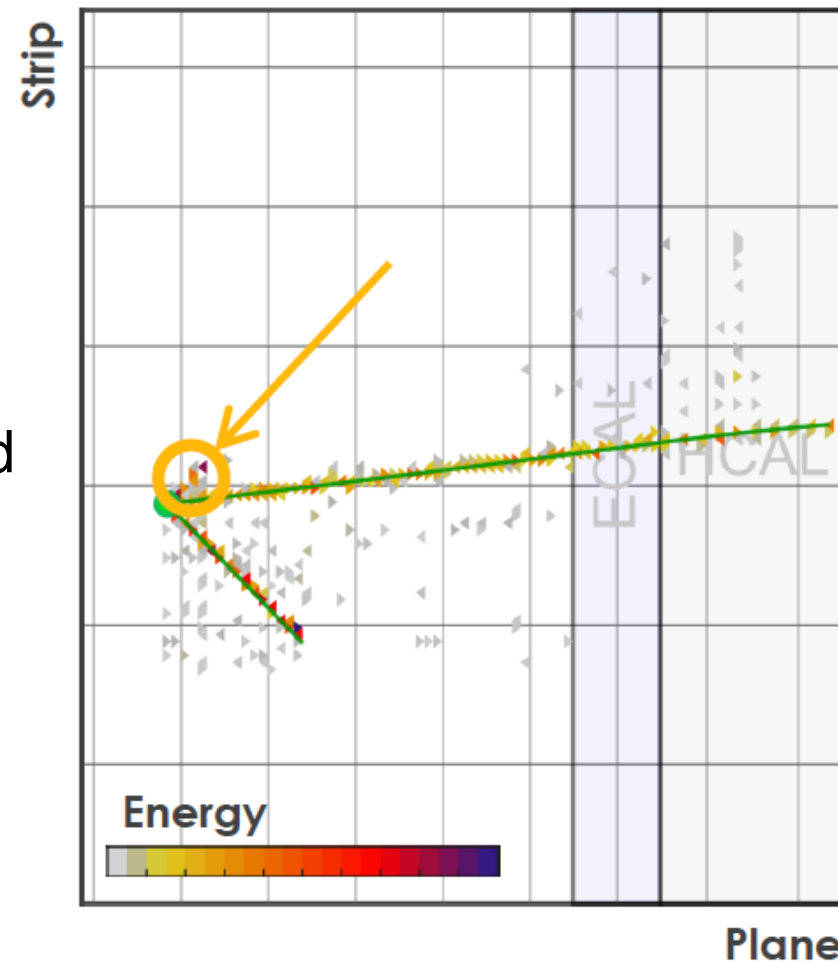


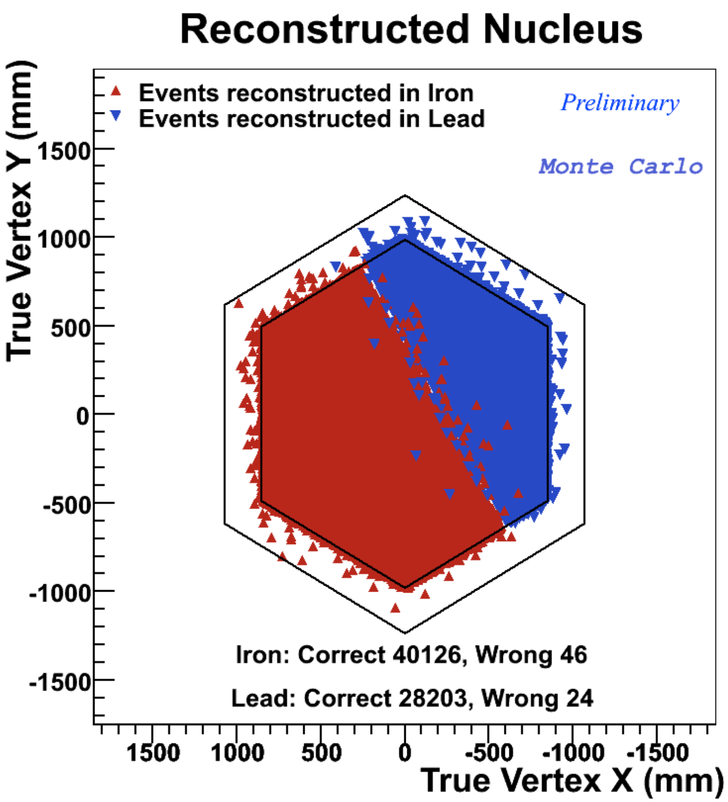
Latest Results: CC Inclusive

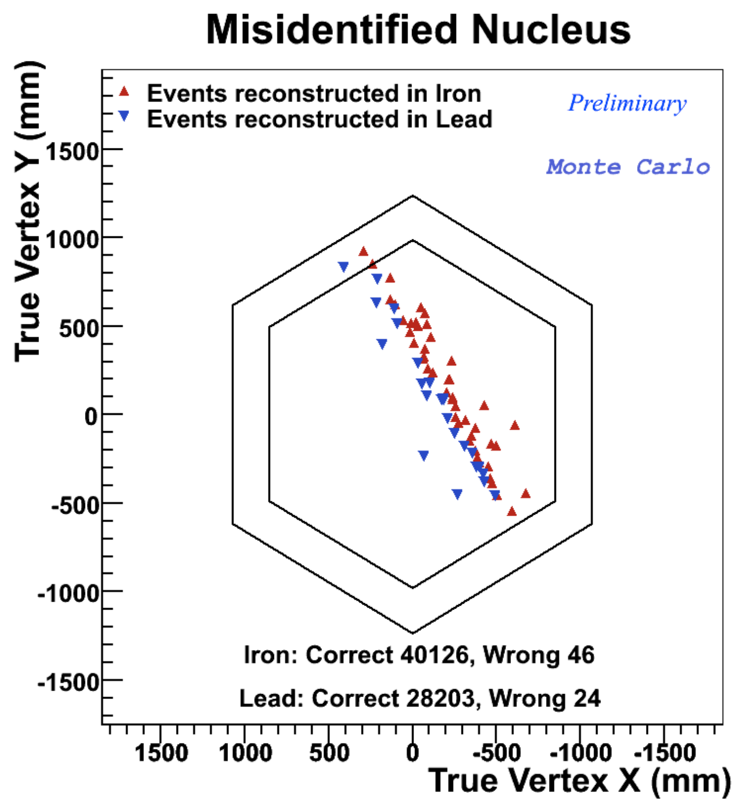
- ν_μ CC in Fe, Pb, CH, measure Fe/Pb CC rates

Require:
1 muon track, matched to a negative charge MINOS track

Z position of muon vertex in nuclear target/ first module downstream of target

Fiducial cut on muon vertex





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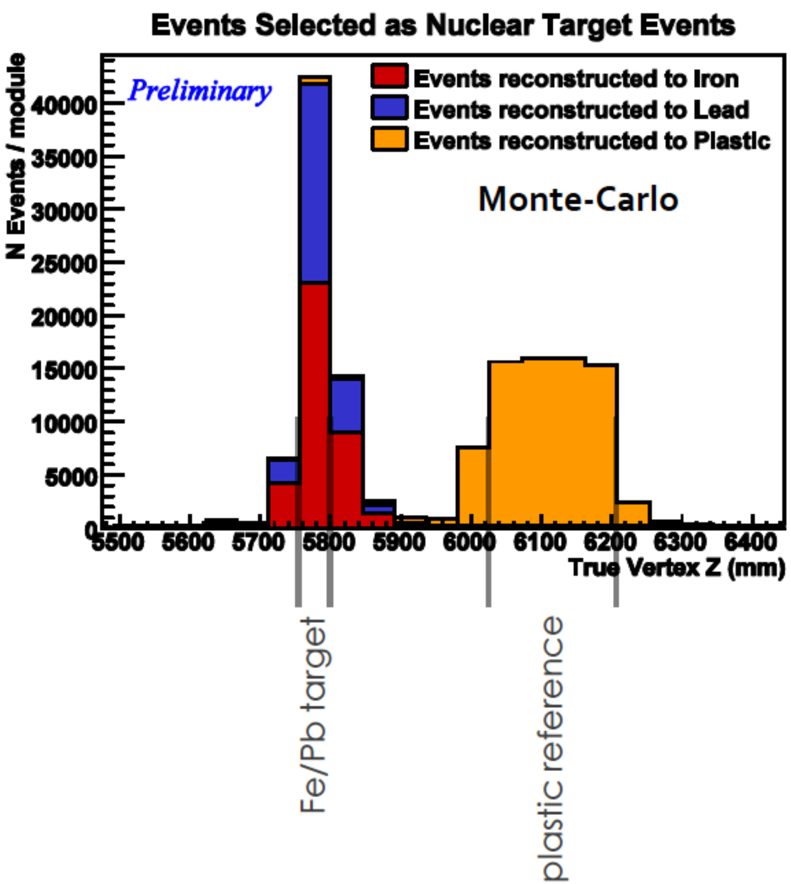
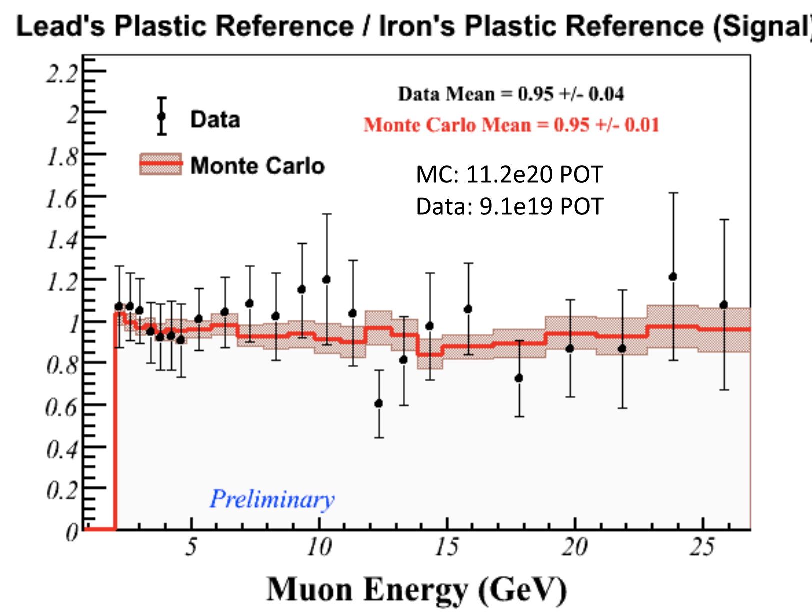


Backgrounds originate from neutrino interactions in scintillator upstream and downstream of the target

Use active plastic scintillator reference target for background, acceptance studies



Uni

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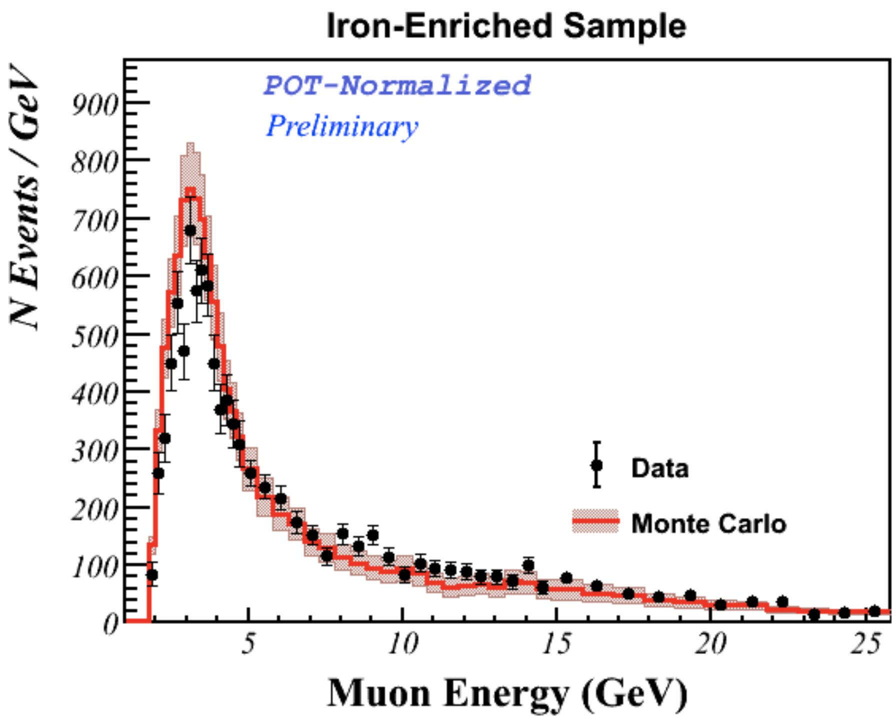
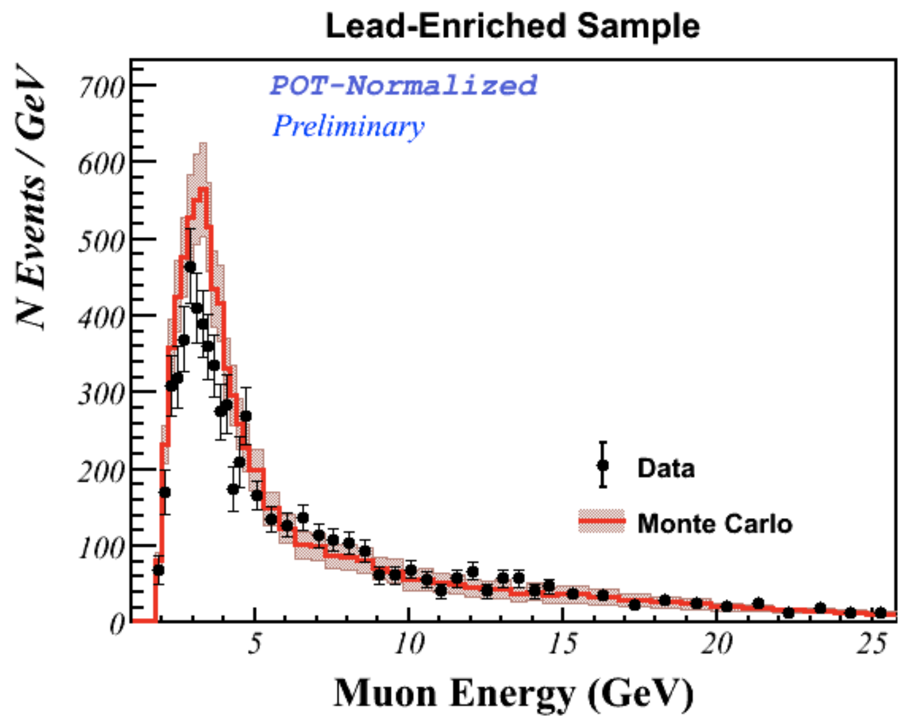


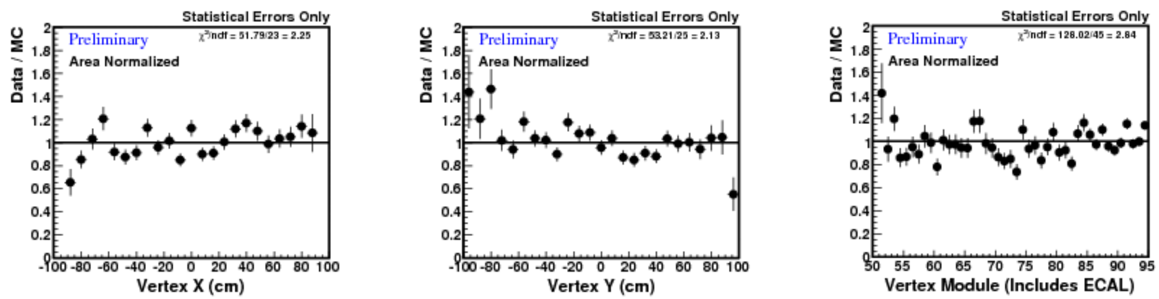


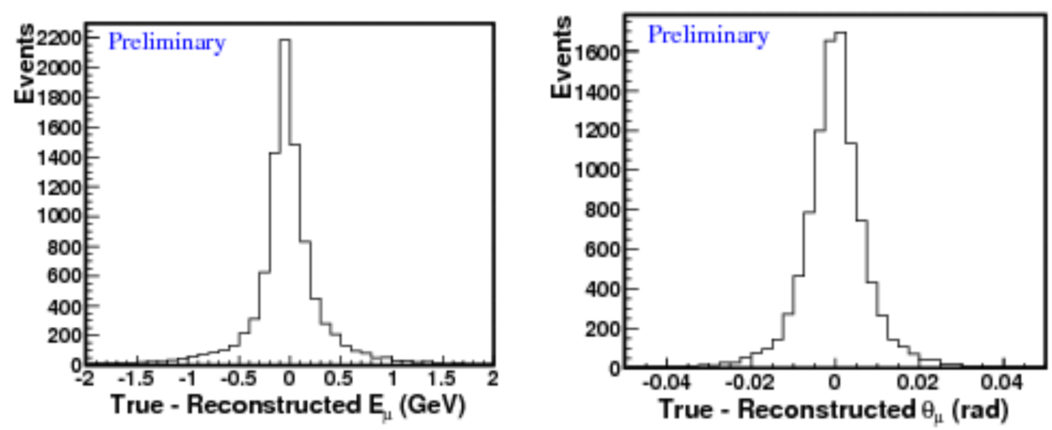
Discrepancies between data and MC result primarily from untuned flux model

MC: 11.2e20 POT
Data: 9.1e19 POT

Latest Results: CCQE

- Event selection:
  - MINOS matched muon track
  - Vertex in tracker region
  - No significant energy deposition in target region
  - Radial position of all track nodes < 87 cm





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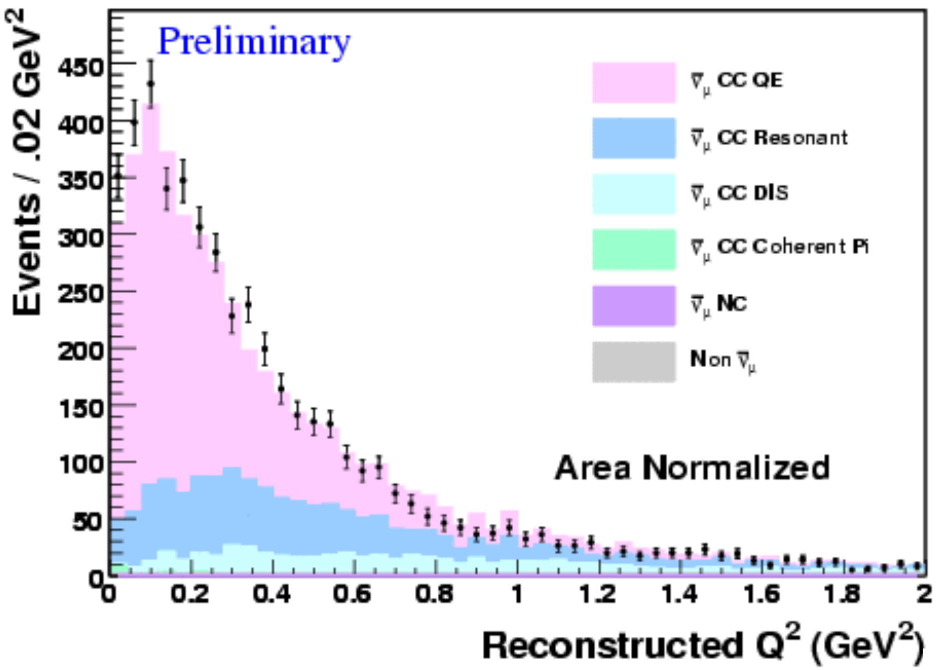
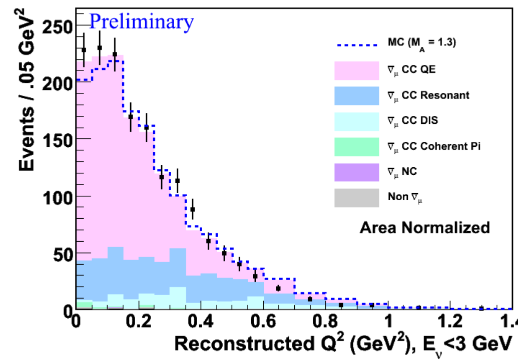
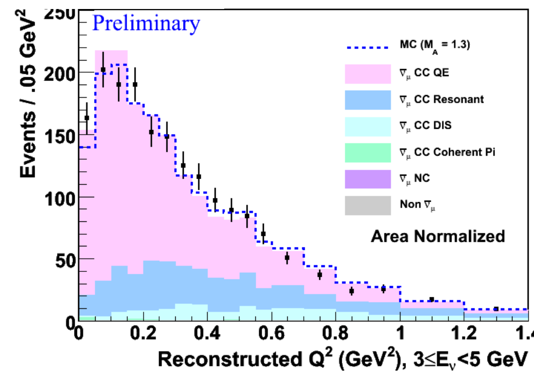
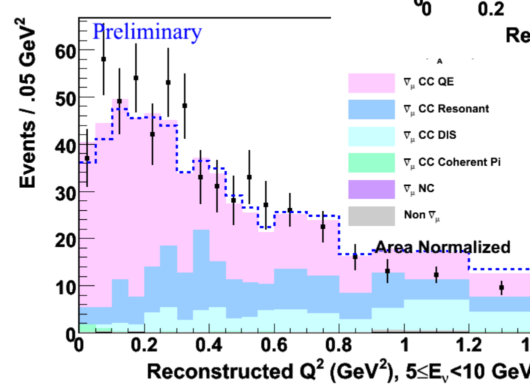








Near Future

- To reach our goals of high precision measurements we require:
  - Strong characterization of flux and flux uncertainties
  - Calibration and energy scale of the detector
  - Precise reconstruction algorithms

- Focusing our effort on these tasks, as they are necessary for all our analyses to move forward

- Next major analysis update: Spring 2012

Backup Slides

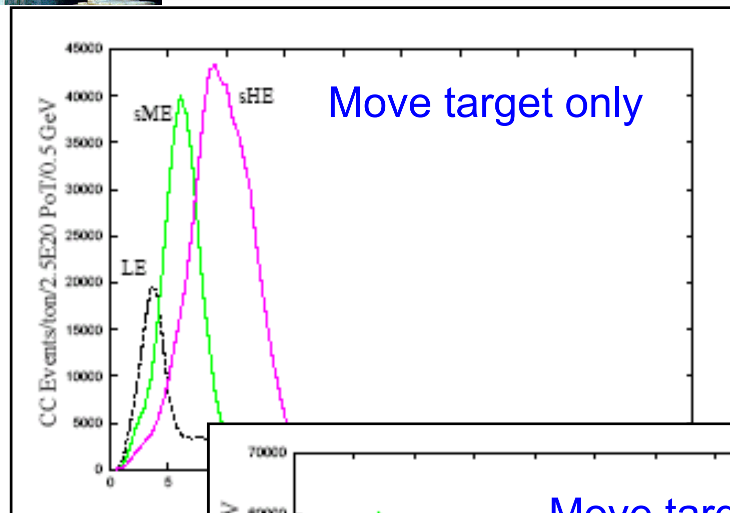
Expected Event Rates

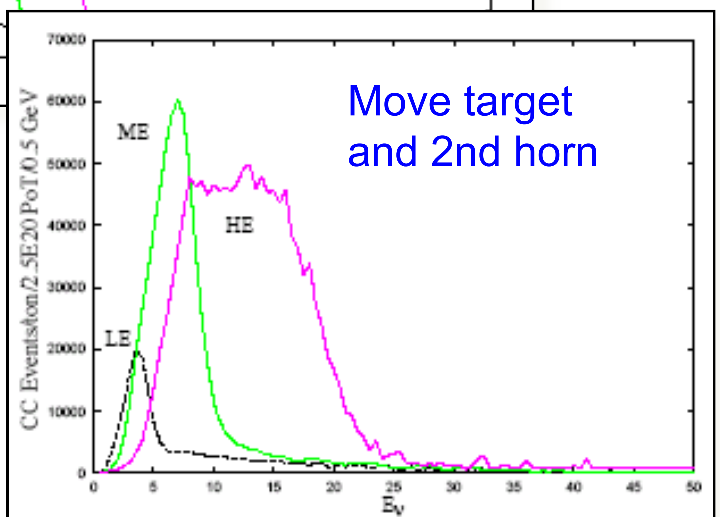
Assume 16.0×10^{20} in LE and ME beam configurations

• 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

NEED TO UPDATE

The Neutrino Beam





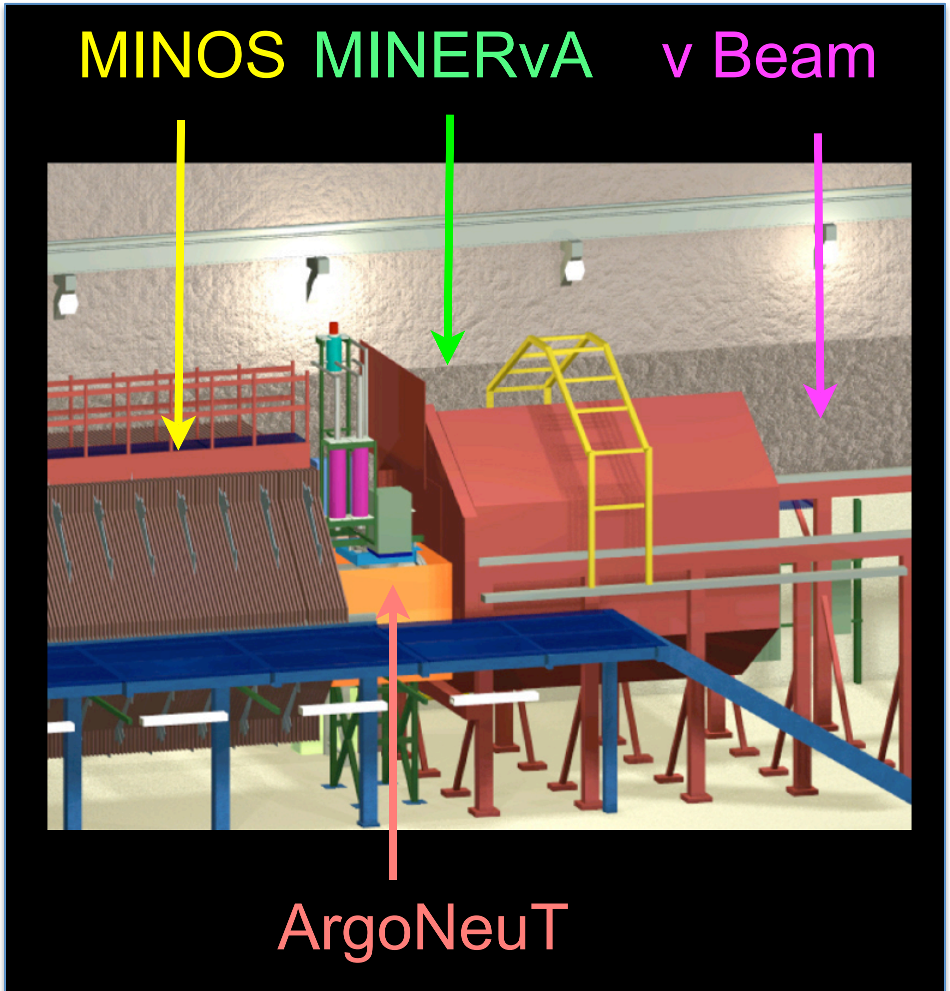
- LE-configuration:
  - E_m >0.35 GeV
  - E_{peak} = 3.0 GeV, $\langle E_\nu \rangle$ = 10.2 GeV
  - rate = 60 K events/ton - 10^{20} pot

  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

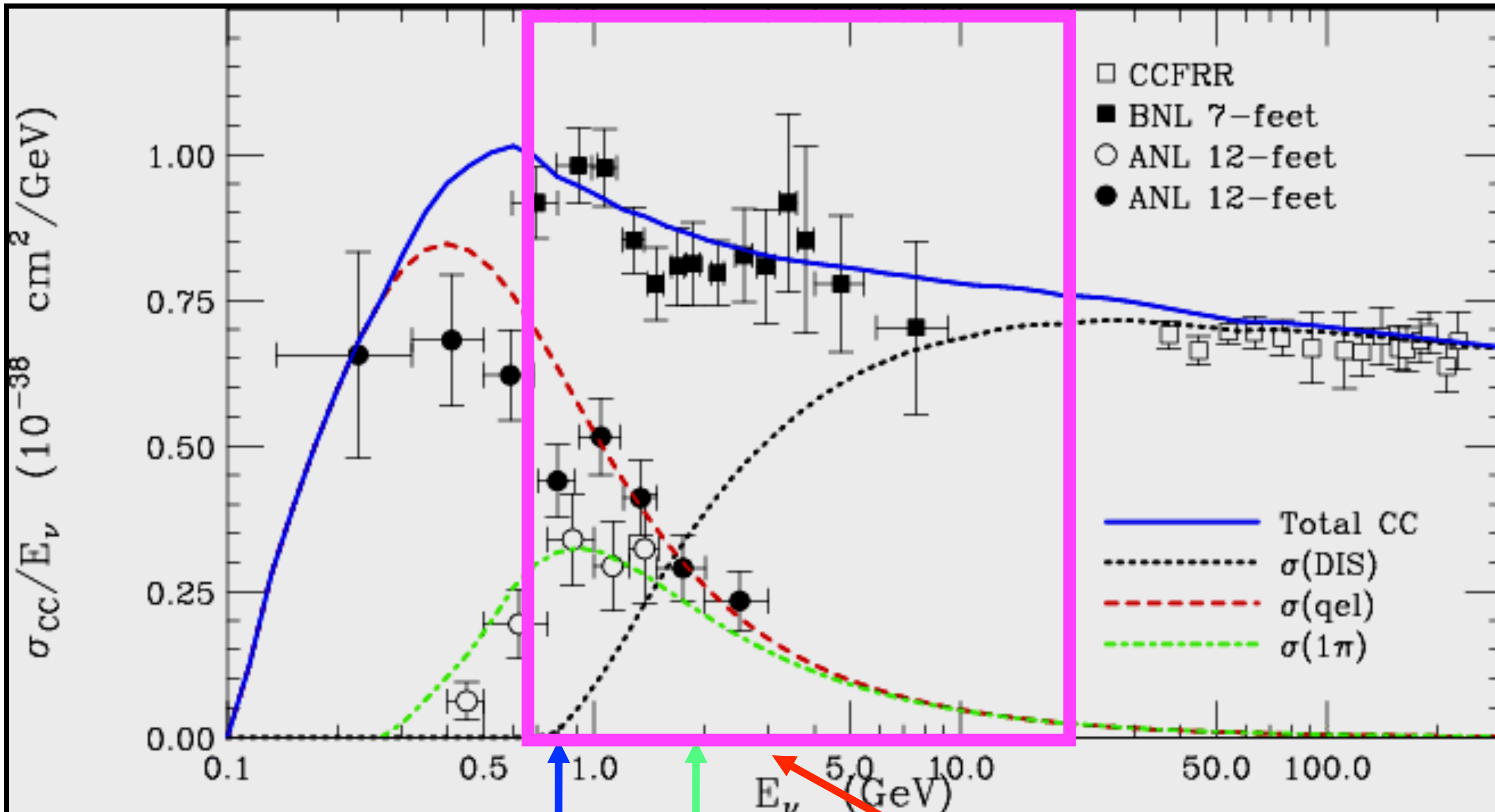
Expect to run with LE (4e20 POT), ME (12e20 POT)

The MINERvA Detector



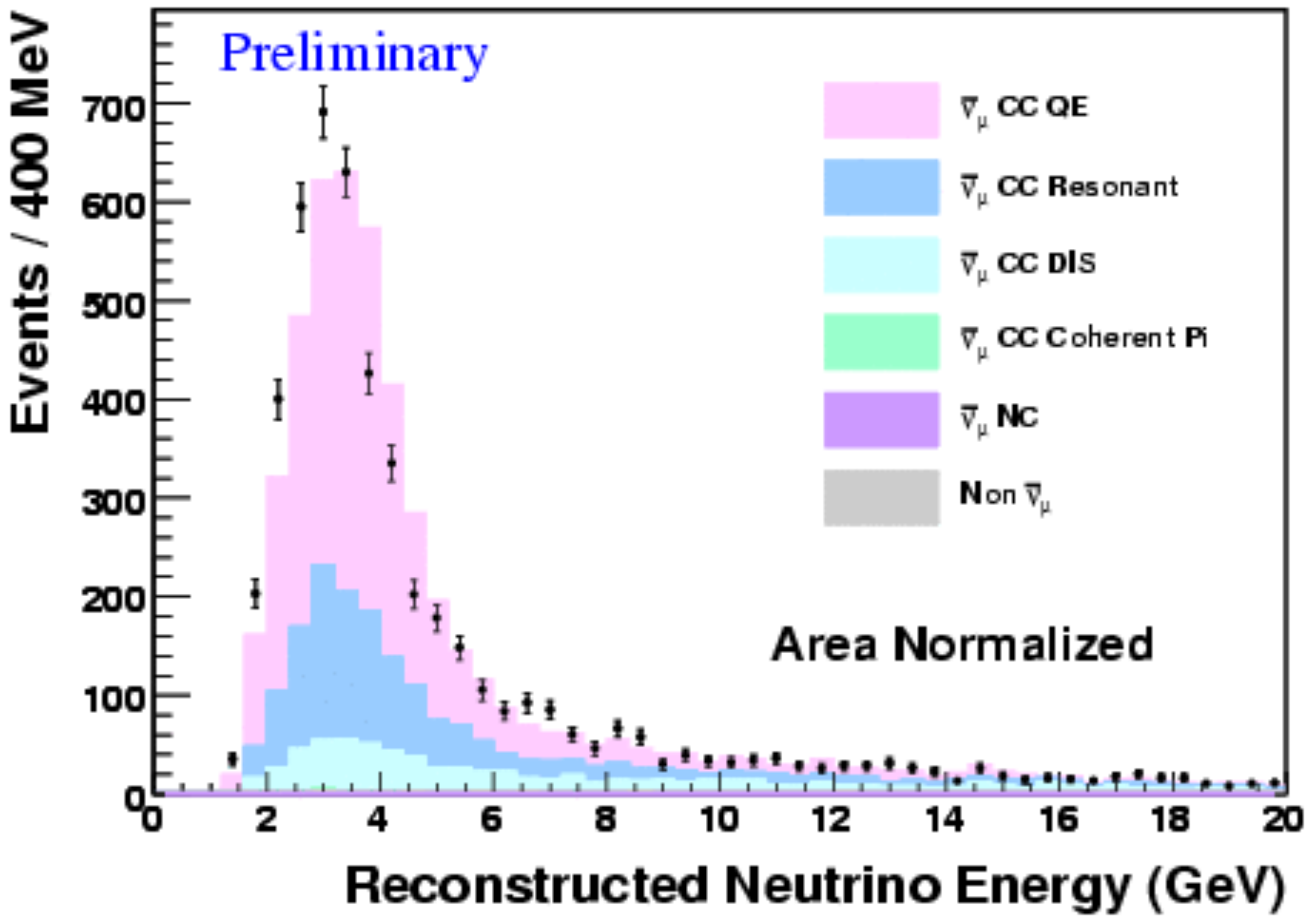
- Must reconstruct exclusive final states
  - high granularity for charged particle tracking and ID, low p thresholds for particle detection
- Also must contain
  - EM showers
  - High momentum hadrons
  - Muons from QE, contained well enough to measure momentum
  - Nuclear targets to study nuclear effects

MINERvAs Impact

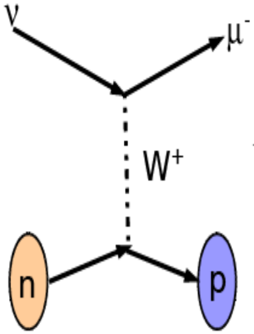


T2K, SciBooNE NOvA, MINERνA MINOS, MINERνA

Latest Results: CCQE



Quasi-Elastic Analysis



$$M = \frac{G_F \cos\theta_c}{\sqrt{2}} [\bar{\mu}\gamma_\alpha(1-\gamma_5)\nu] [\bar{p}\gamma^\alpha(F_V(Q^2) + F_A(Q^2)\gamma_5)n]$$

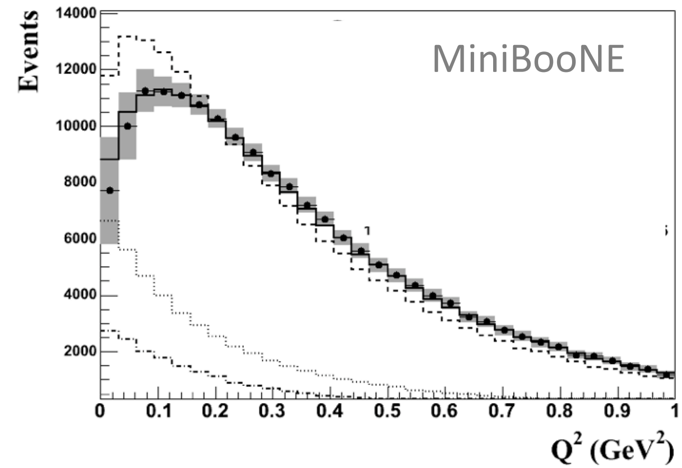
Standard V-A

Vector Form factor

Axial-vector form factor

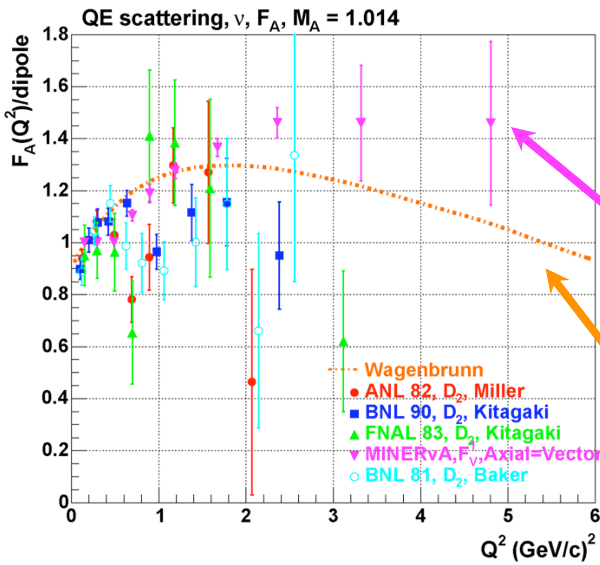
The form factors must be measured.
Only neutrino interactions can determine F_A.

Phys. Rev. Lett. 100, 032301 (2008)



- 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

Quasi-Elastic Analysis



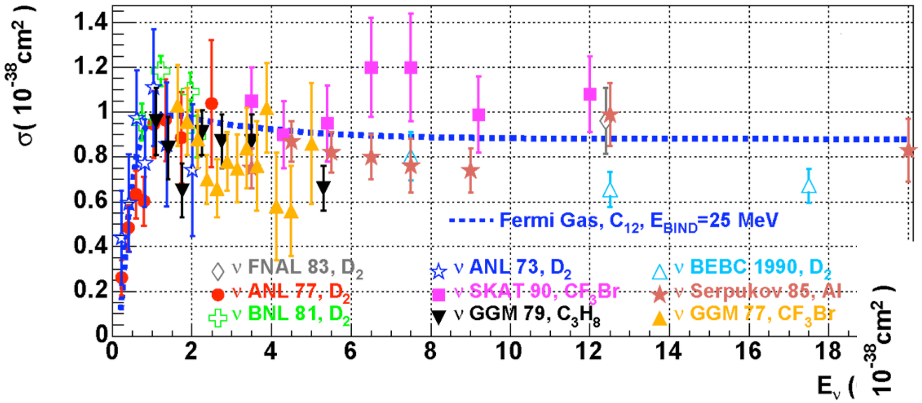
Expected ability to measure high Q^2 behavior and sensitivity to non-dipole F_A form factor

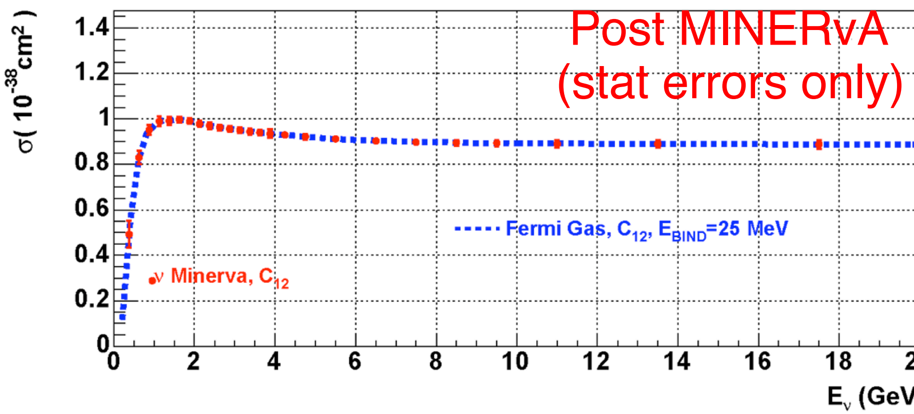
Simulated MINERvA Axial-Vector hypothesis (stat only)

Wagenbruun, et al (hep-ph/0212190)

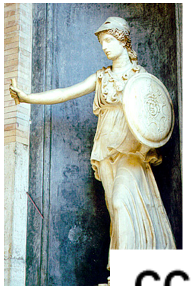
- First expt to systematically study F_A in range of Q^2 = 0 to ~6 GeV^2
- First expt to systematically study xsec across a range of atomic mass in same expt environment
- Sensitive to three models of F_A
  - Dipole approx (current assumption), constituent quark model, duality model (dipole breaks down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

Quasi-Elastic Analysis



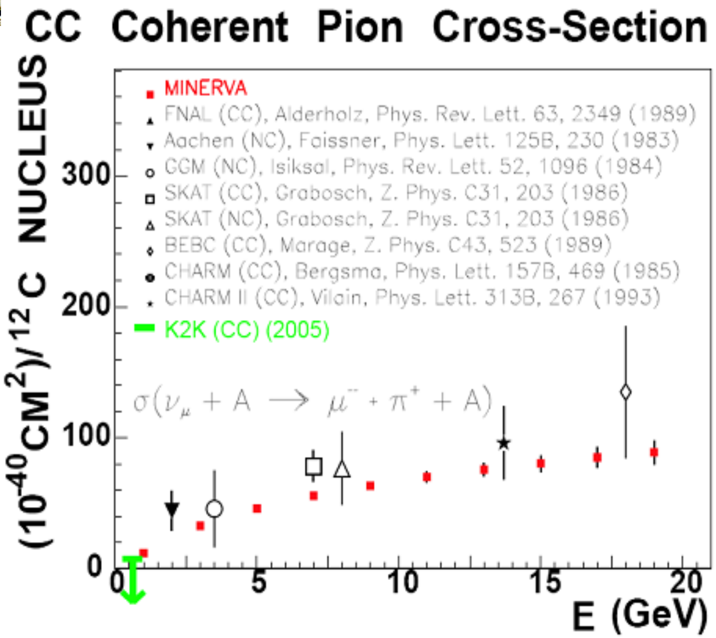


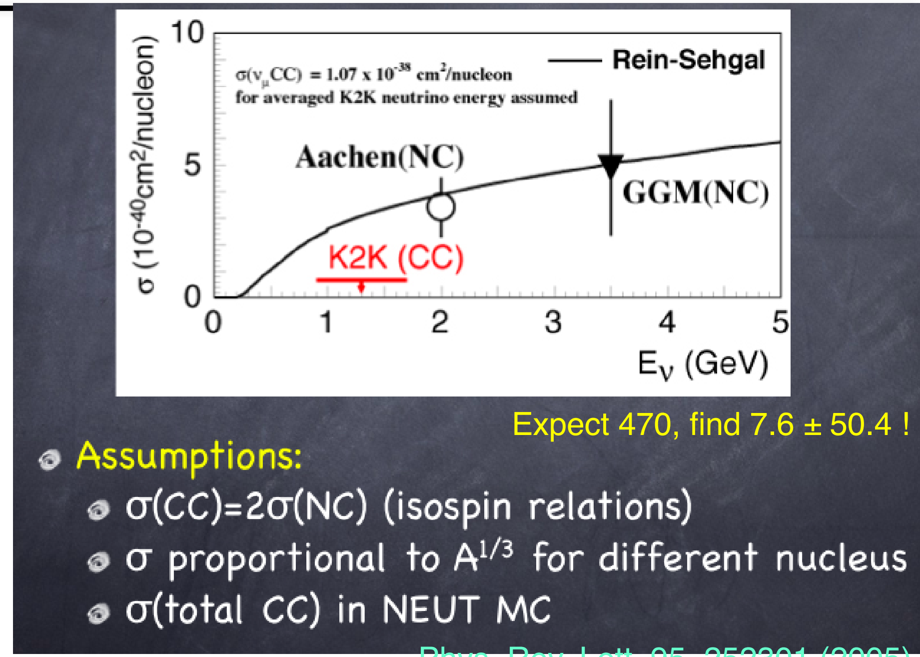
- >800K total events in 4 year run time
- Expect to achieve 5% total error on xsec measurement!
- Refined CCQE model used to re-analyze MB CCQE data



Coherent Pion Production

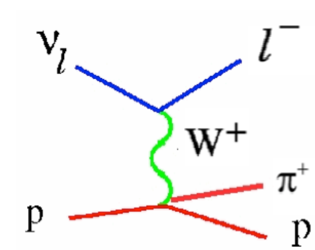
Surprising K2K, SciBooNE results!

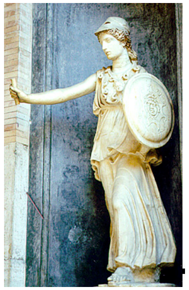




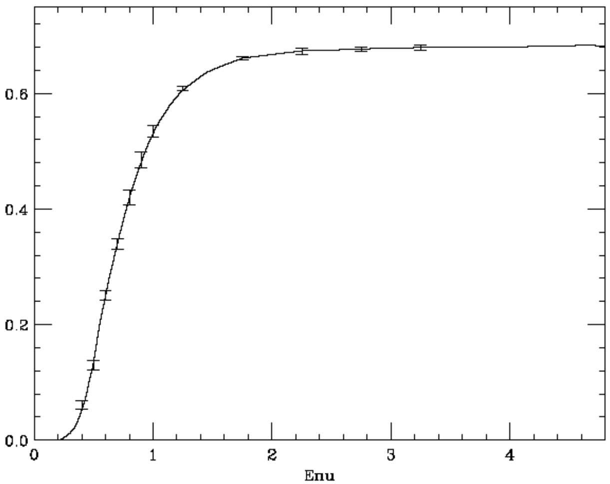
Phys. Rev. Lett. 95, 252301 (2005)
arXiv:0811.0369

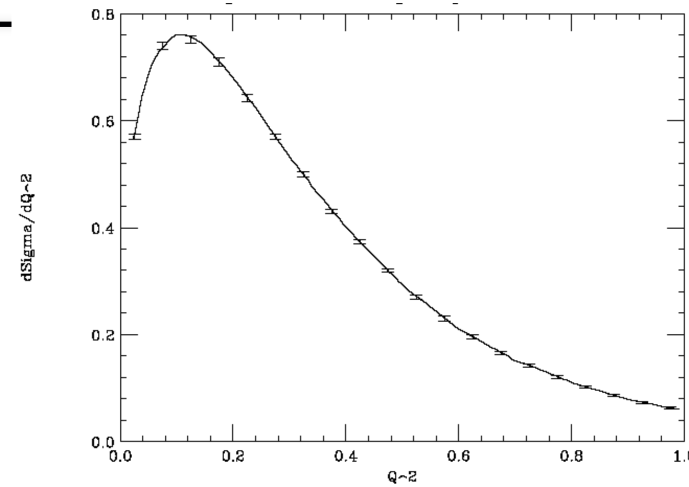
- ν scatters from entire nucleus, nucleus remains intact
- First measurement of atomic mass dependence across a wide atomic mass range
- Factor of >100 increase in world's current sample





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

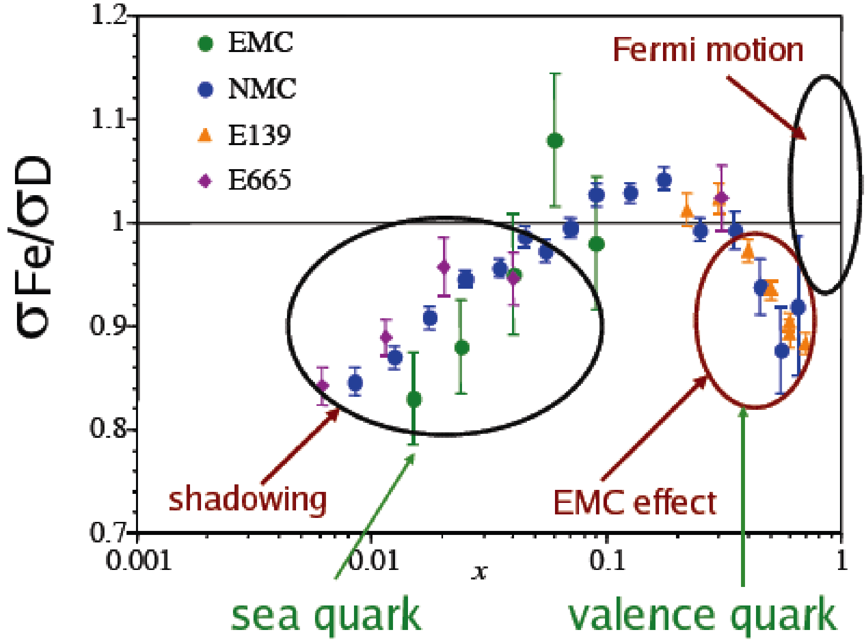
- Focus on exclusive channel strange particle production
- Important for bgd calculations of nucleon decay expts
- Extended anti-nu running = single hyperon production, greatly extend form factor analyses

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

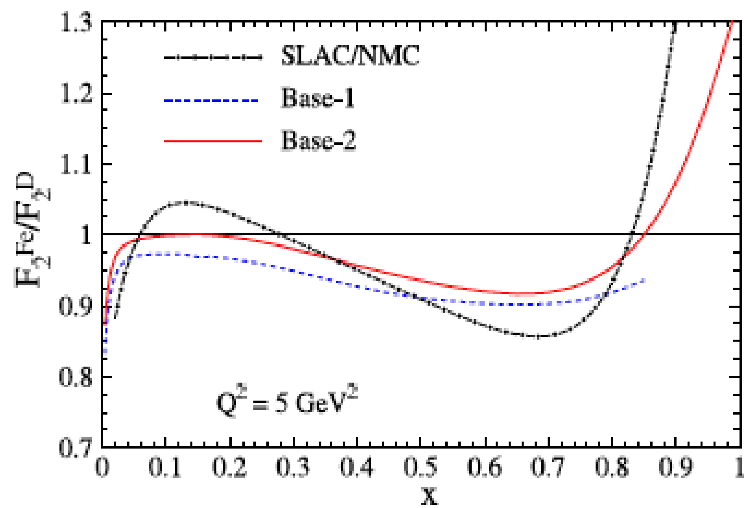


Can we extrapolate 10-20 GeV to 100 GeV? Compare to JLAB results…

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}

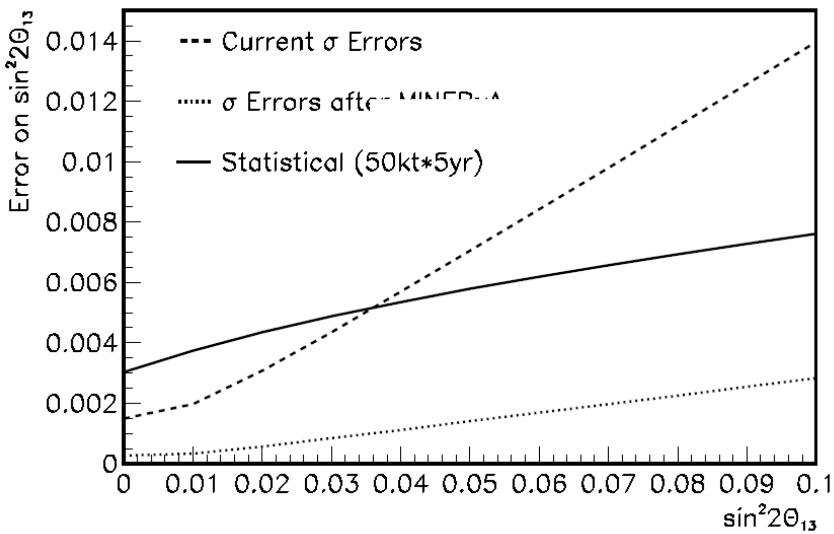
Fe PDFs extracted from NuTeV nu, anti-nu data, compared to SLAC/NMC parameterization

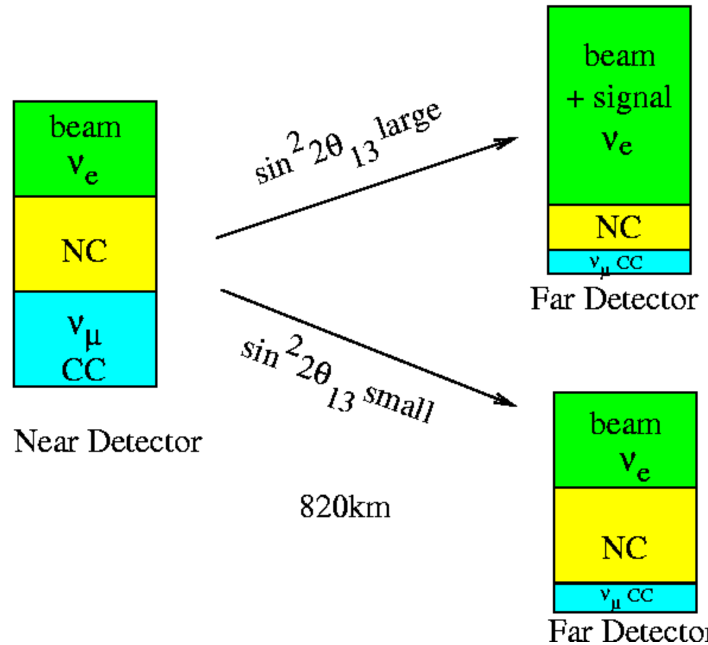


arXiv:0710.4897

MINERνA & NOνA

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

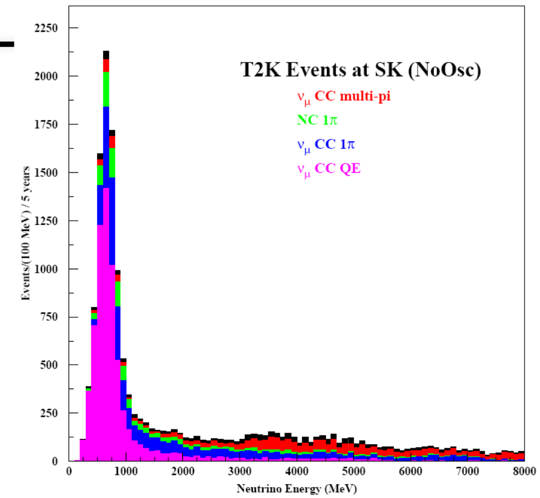


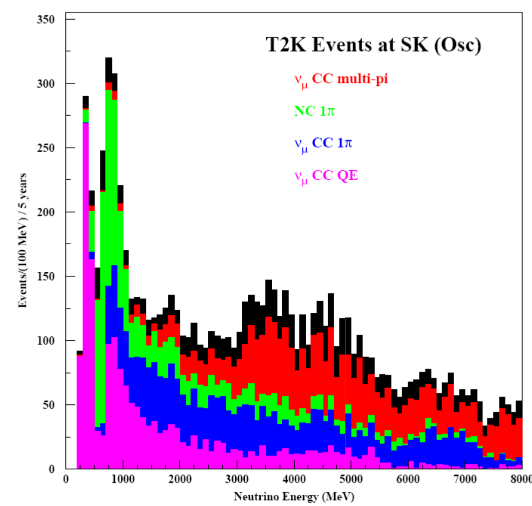


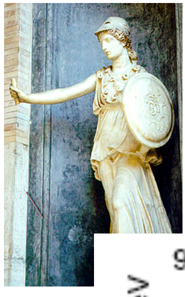
Process	QE	RES	COH	DIS
δσ/σ NOW (CC,NC)	20%	40%	100%	20%
δσ/σ after MINERνA (CC,NC)	5%/na	5%/10%	5%/20%	5%/10%

MINERvA & T2K

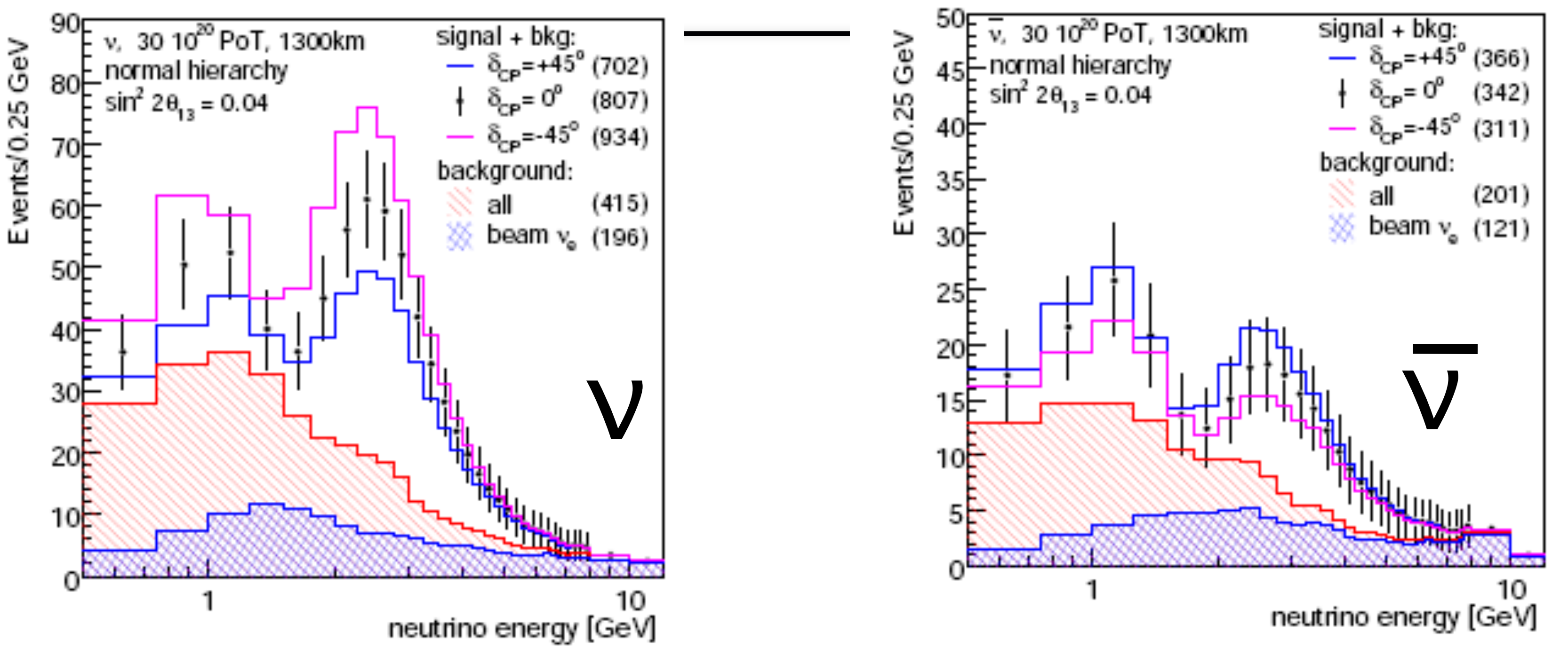
- T2K’ s near detector will see different mix of events than the far detector
- To make an accurate prediction one needs
  - 1 - 4 GeV neutrino cross sections (with energy dependence)
- MINER*v*A can provide these with low energy NuMI configuration







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