MINERνA Status and Results

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Fermilab User's Meeting

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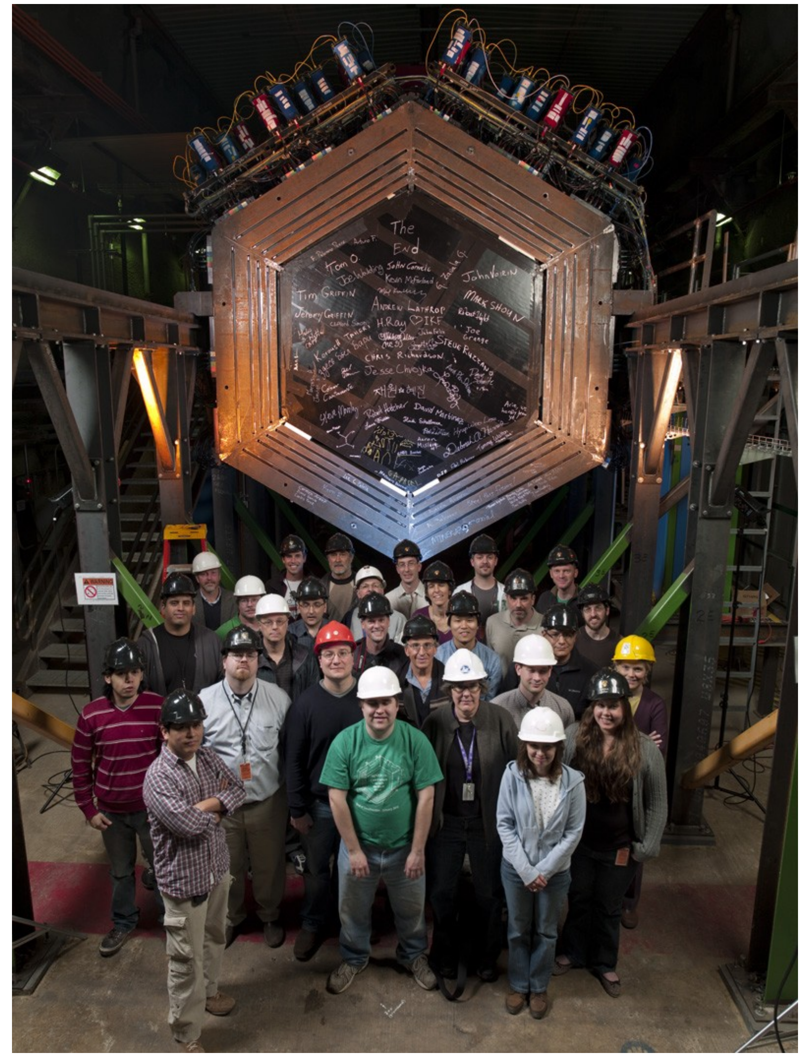
Outline

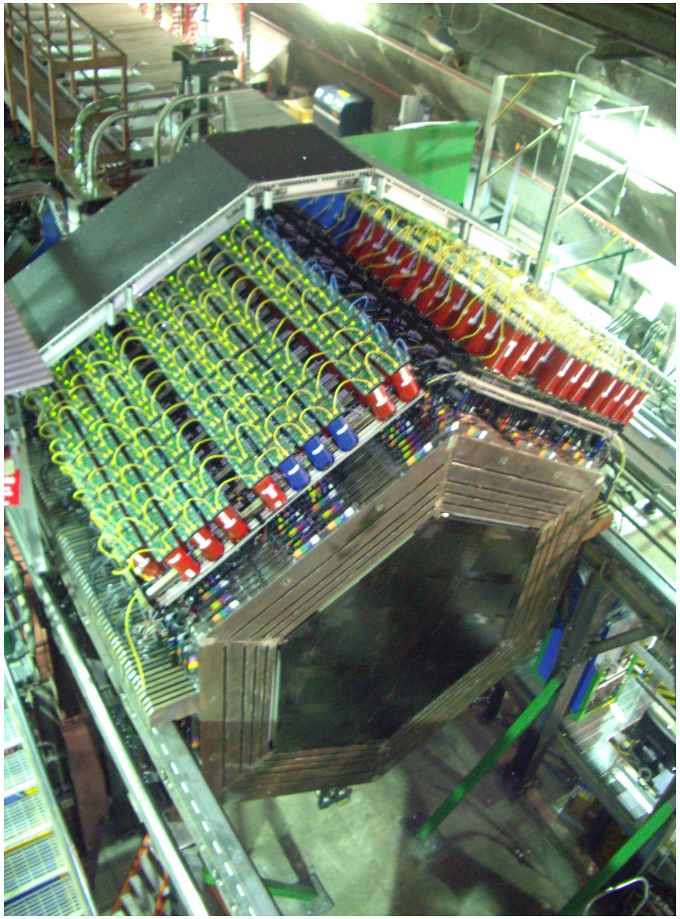
- Overview of MINERνA
- Detector Status
  - Data Taking
  - Flux Determination
  - Nuclear Target Installation
- Reconstruction Status
- Results
  - CC Quasi-elastic
  - CC Inclusive



Overview: MINERνA Goals

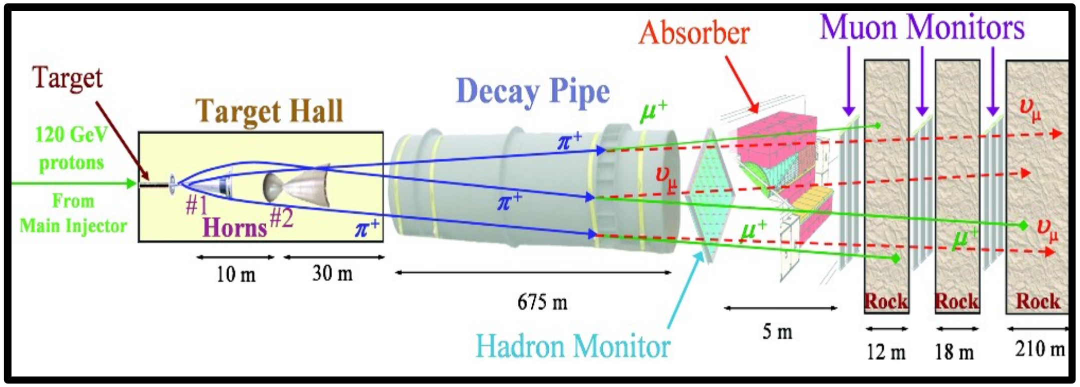
- MINERνA is a high precision neutrino scattering experiment located in the NuMI beamline upstream of the MINOS near detector

- MINERνA Goals:
  - Measure neutrino-nucleus interaction rates for many different exclusive and inclusive final states over a broad energy range
  - Understand how nuclear effects impact these rates
  - Provide inputs to oscillation experiments and increase fundamental understanding of neutrino interactions



Overview: MINERνA Goals

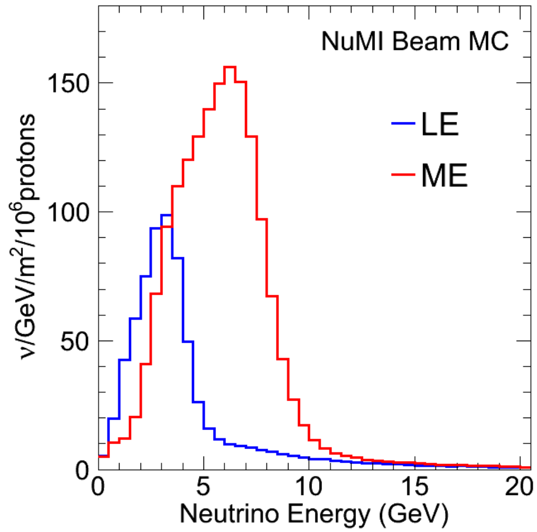
- MINERνA will take advantage of several beam configurations available with the NuMI beamline:



MINERνA

MINOS
Near Detector

*Not To Scale!

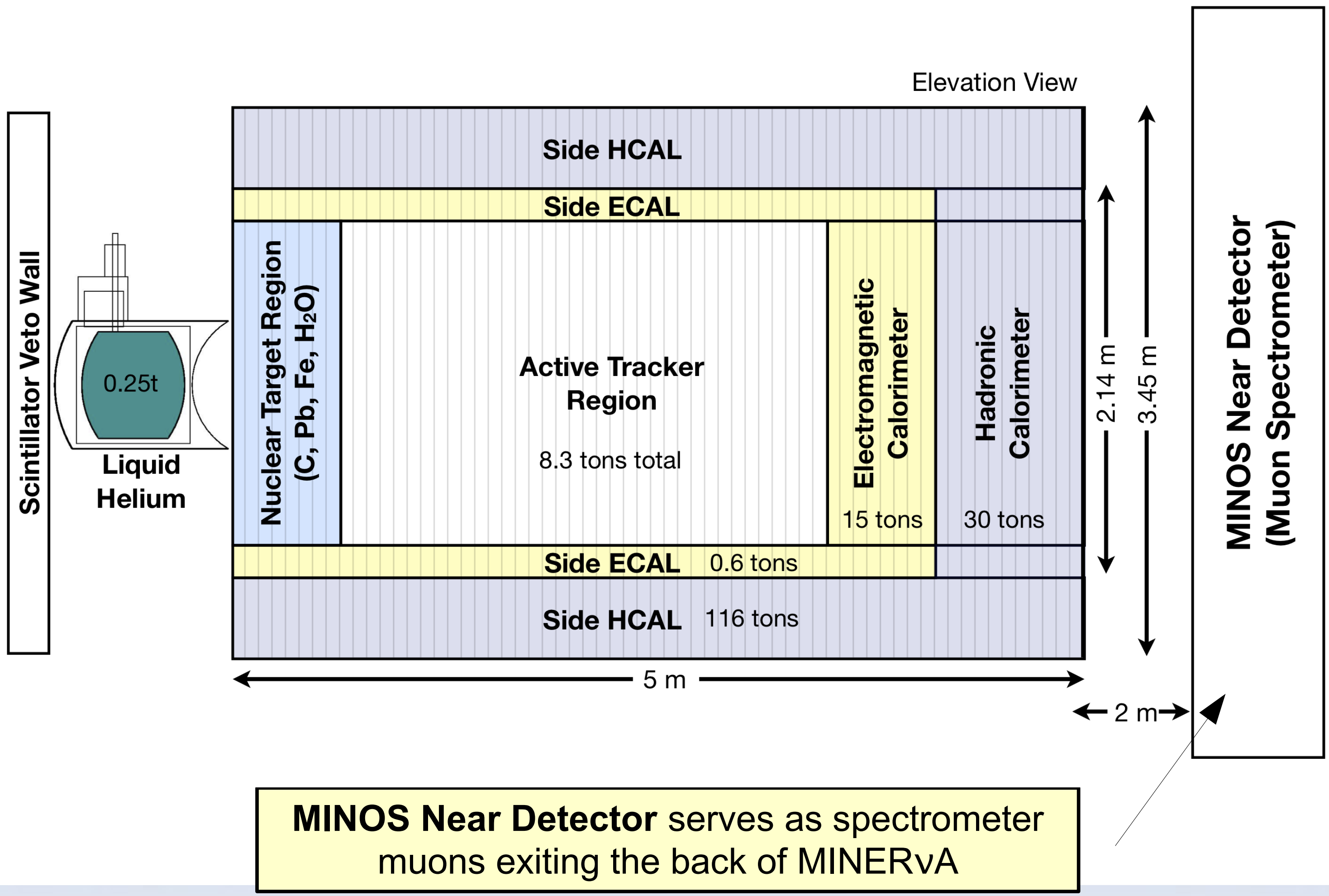


We will take data in two different energy configurations – currently in the low energy (LE) configuration

And with forward horn current (aka FHC or "neutrino mode") and reverse horn current (aka RHC or "anti-neutrino mode")

Overview: The MINERνA Detector

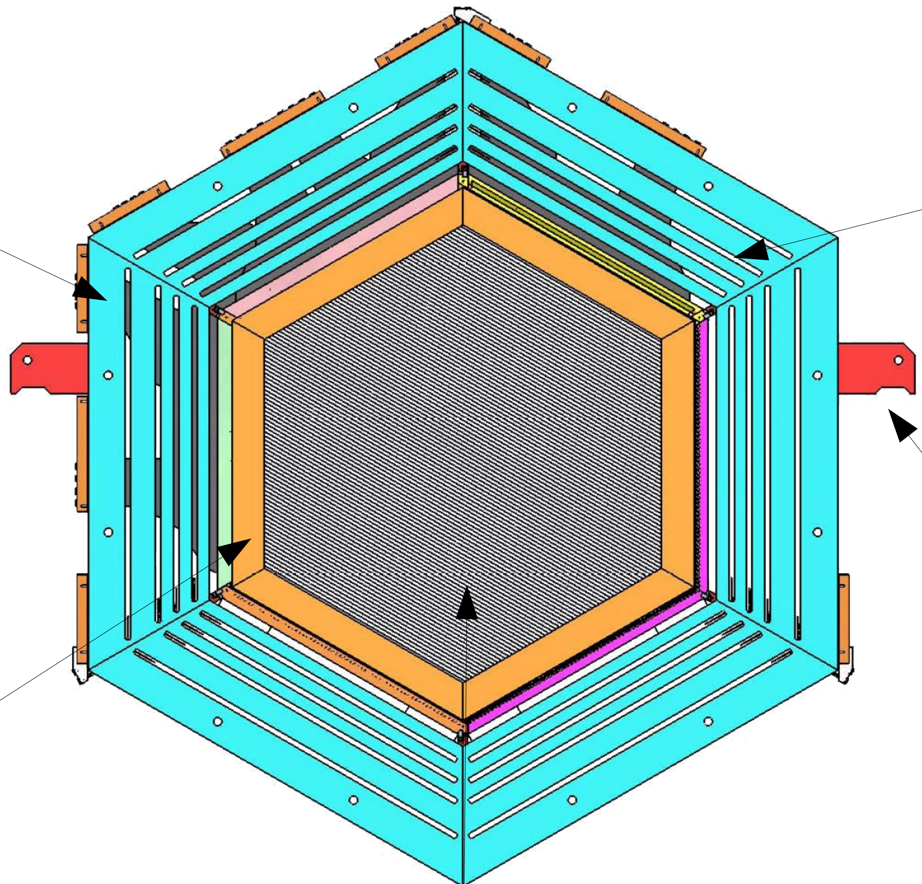
- The MINERνA detector is composed of 120 "modules" of varying composition, including active plastic scintillator and inactive calorimetric and nuclear target materials:



Overview: Structure of a MINERνA Module

Outer Detector Frame: Iron – used for hadron calorimetry

Scintillator bars in Outer Detector (OD): Used to detect side-exiting particles



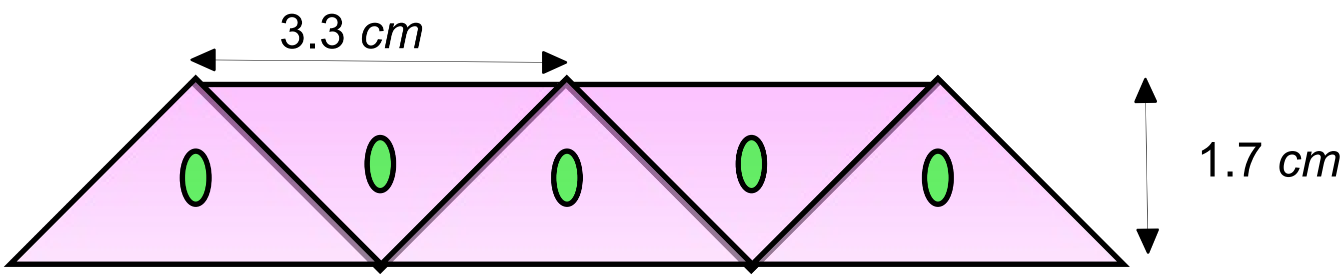
Lead collar: surrounds edge of scintillator strips. Used for EM calorimetry

Steel supports used to hang modules

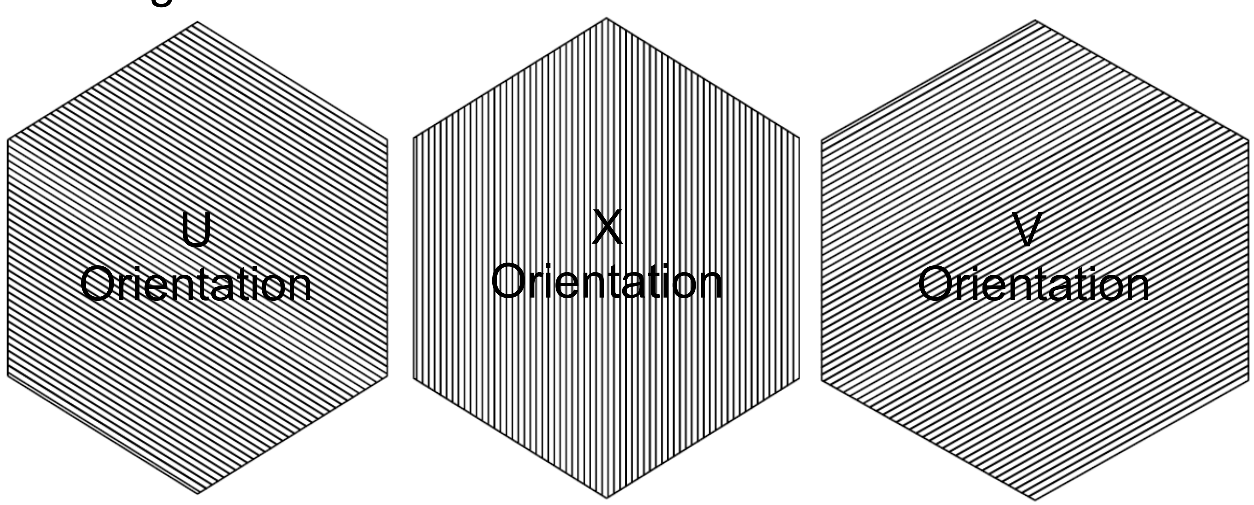
Inner Detector (ID): Plastic scintillator strips create light from moving charged particles

Overview: MINERνA Scintillator Strips

- Inner hexagon of each active MINERνA plane contains 127 scintillator strips:

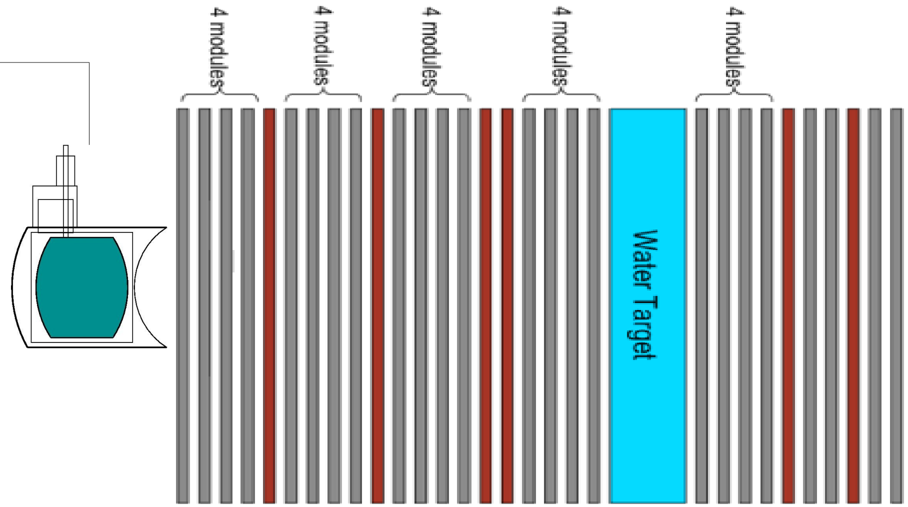


  - The strips are made of doped polystyrene
  - Wavelength-shifting fibers run through the center of each strip
  - Strips are aligned in one of three directions for 3D reconstruction:

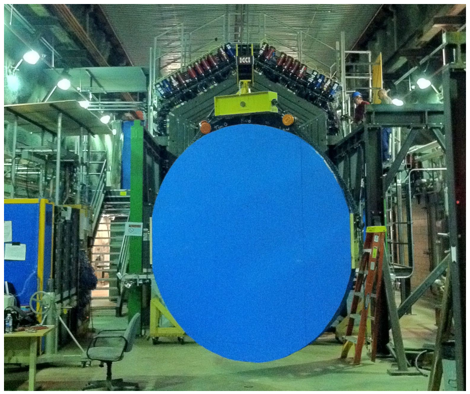


MINERνA Results: Passive Targets

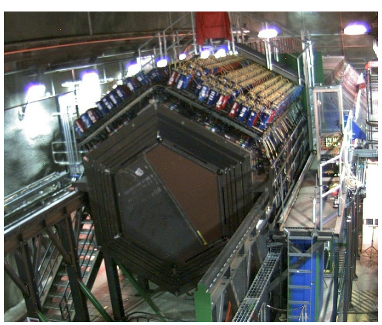
Liquid Helium



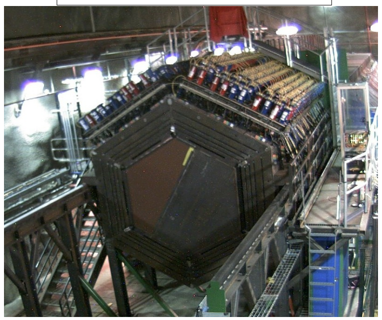
Water



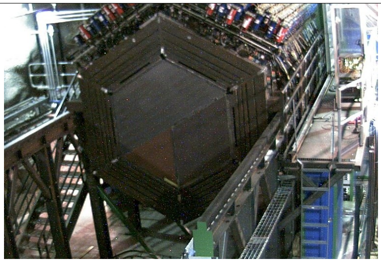
Iron / Lead



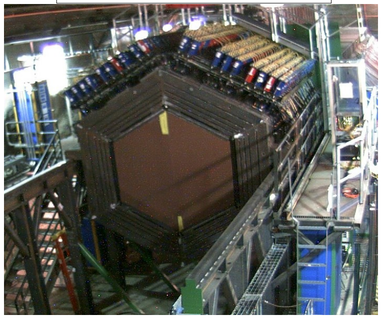
Lead / Iron



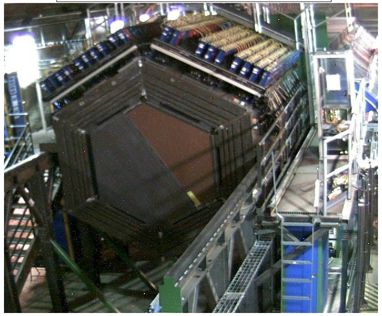
Carbon / Lead / Iron



Lead



Iron / Lead



Nuclear Targets → measurements of ν interaction cross sections vs nucleon number
More targets in the future? A liquid deuterium Letter of Intent was recently submitted

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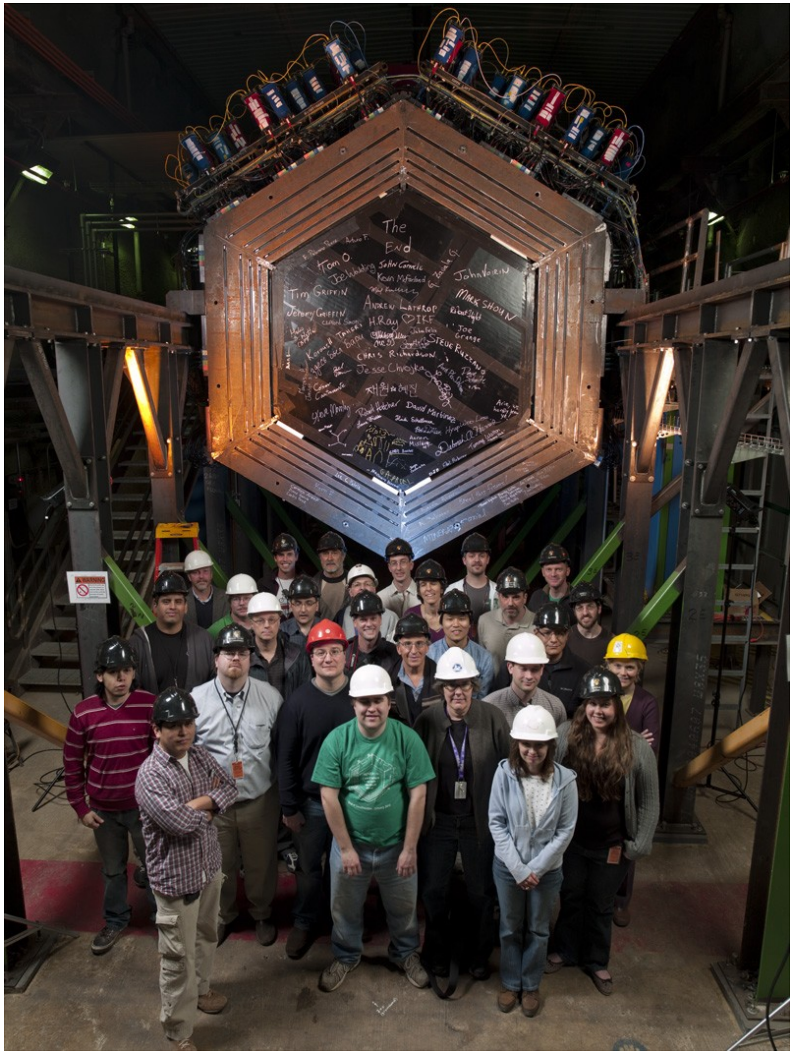
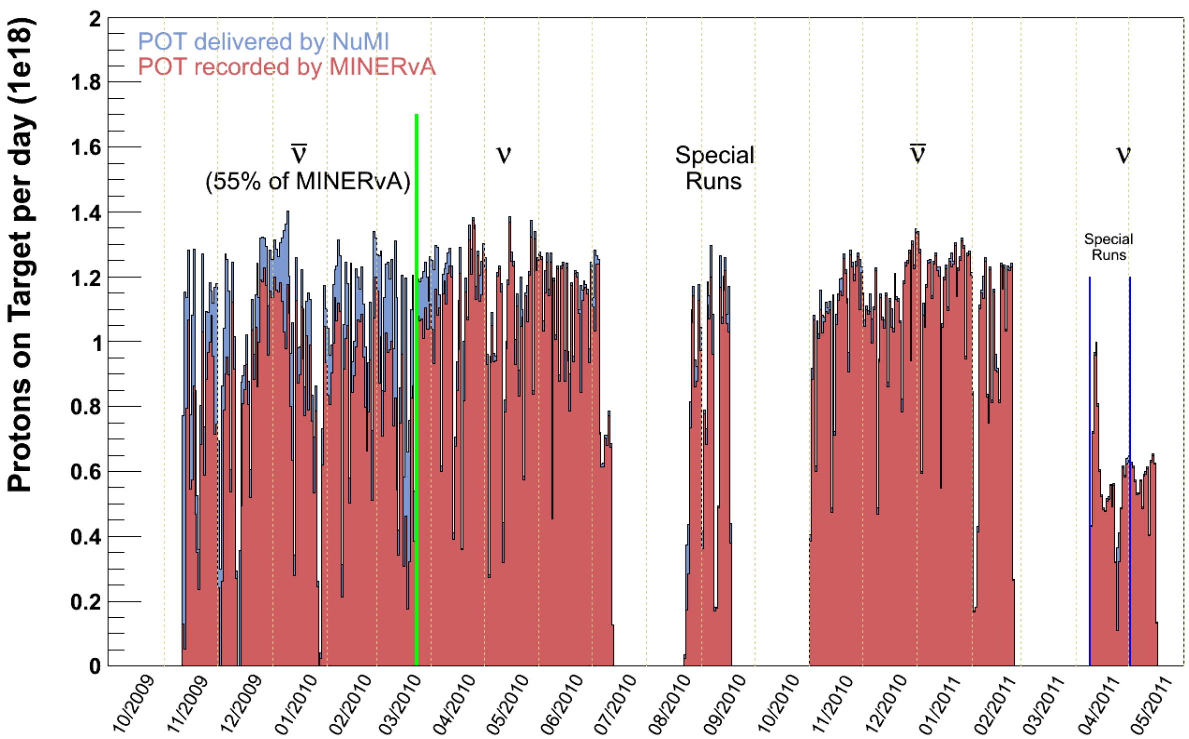


MINERνA Status: Data Taking

- MINERνA has been collecting data using our full detector since March 2010 with excellent efficiency:

- Data collection in the last year has been in the "Low Energy" configuration, divided between neutrino and antineutrino mode

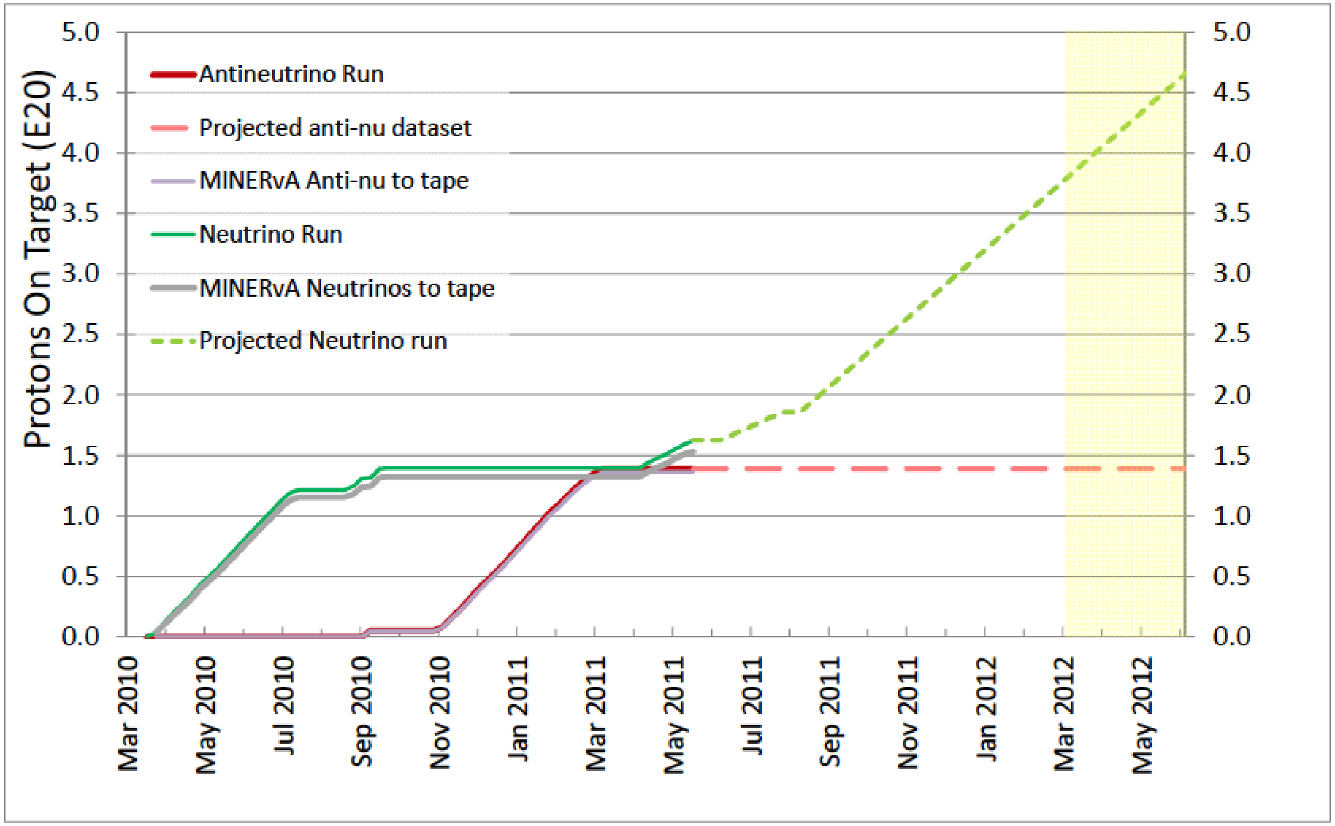
- Also took a series of "special runs" for flux determination



Full Detector anti-nu POT: 1.3 e20
Full Detector nu POT: 1.5e20

MINERνA Status: Data Taking

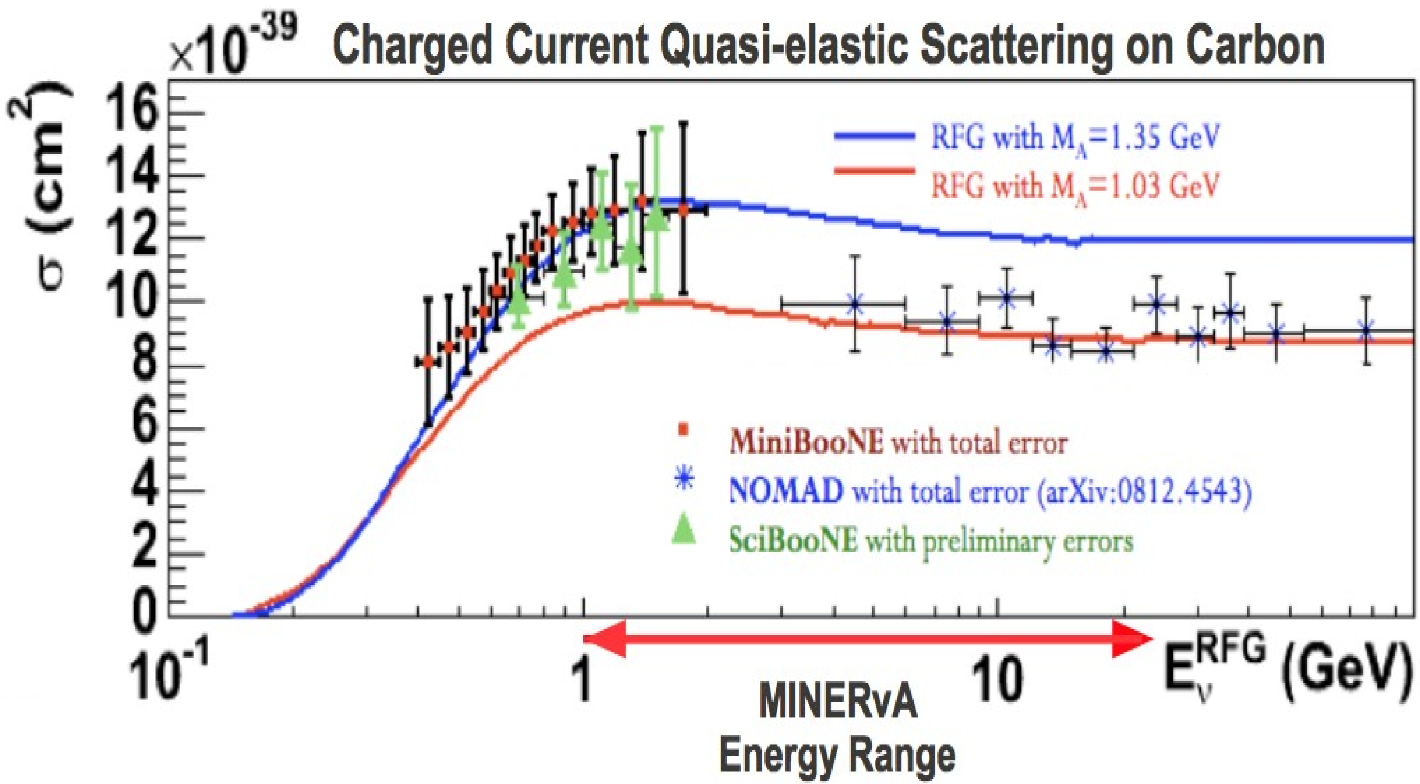
- MINERνA will have 3.75e20 neutrino mode POT by March 2012, assuming 5 weeks of downtime for target transitions
- This is 75% of our planned LE run



Full Detector anti-nu POT: 1.3e20
Full Detector nu POT: 1.5e20

MINERνA Status: Flux Determination

- To measure cross-sections, we have to know our incoming neutrino flux!

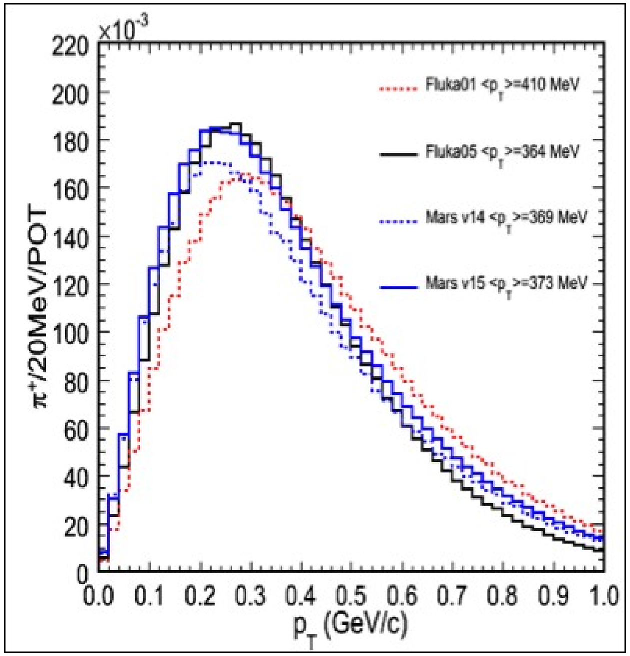


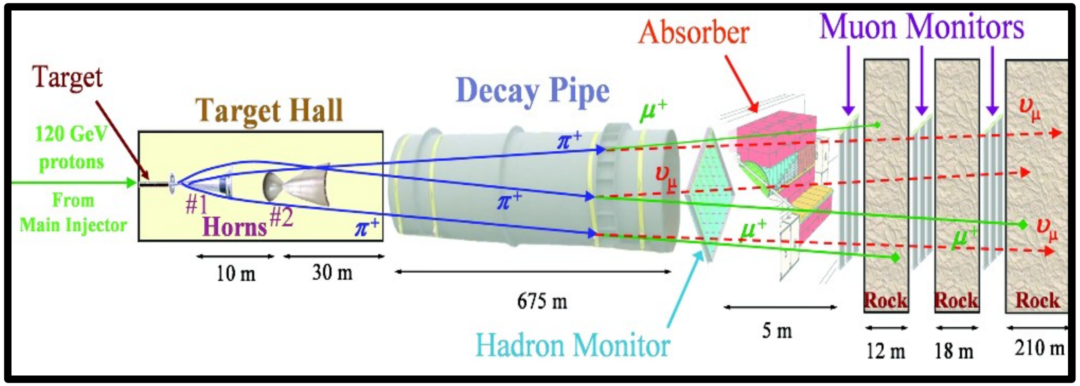
MINERνA can help sort this out!
But only if we have an accurate normalization of our cross-sections

- The “special runs” taken over the past year are designed to reduce MINERνA's flux uncertainties

MINERνA Status: Special Runs

- Monte Carlo simulations of flux have large uncertainties, especially from hadron production off the NuMI target
- Uncertainties can be reduced by tuning hadron production parameters to match observed spectra in data





- Parameter tuning is very successful at NuMI, where multiple target positions and horn currents produce multiple beam energy spectra that can be fit simultaneously

MINERνA Status: Special Runs

- MINERνA plans a series of six LE neutrino-mode special runs in various beam configurations:

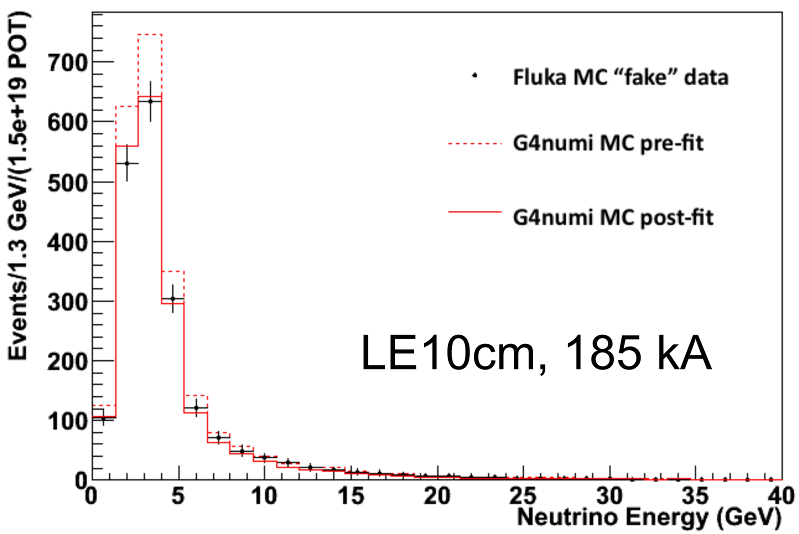
Target Position	Horn Current	POT Requested	POT on Tape
LE10cm	150kA	0.15e20	-
LE10cm	200kA	0.15e20	-
LE10cm	0kA	0.15e20	0.07
LE100cm	200kA	0.15e20	-
LE150cm	200kA	0.15e20	0.07
LE250cm	200kA	0.15e20	0.07

- We've also collected data in one antineutrino-mode special run:

Target Position	Horn Current	POT Requested	POT on Tape
LE150cm	-200kA	0.15	0.07

MINERνA Status: Special Runs

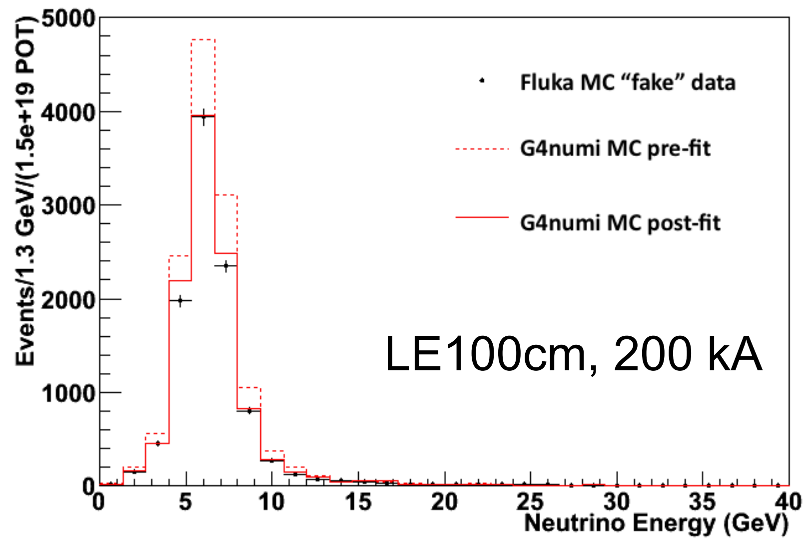
- While we await completion of the special runs, we are building and tuning the infrastructure needed to analyze them



Results of a fit to a pseudo-data sample equivalent to 0.15e20 in 6 beam configuration

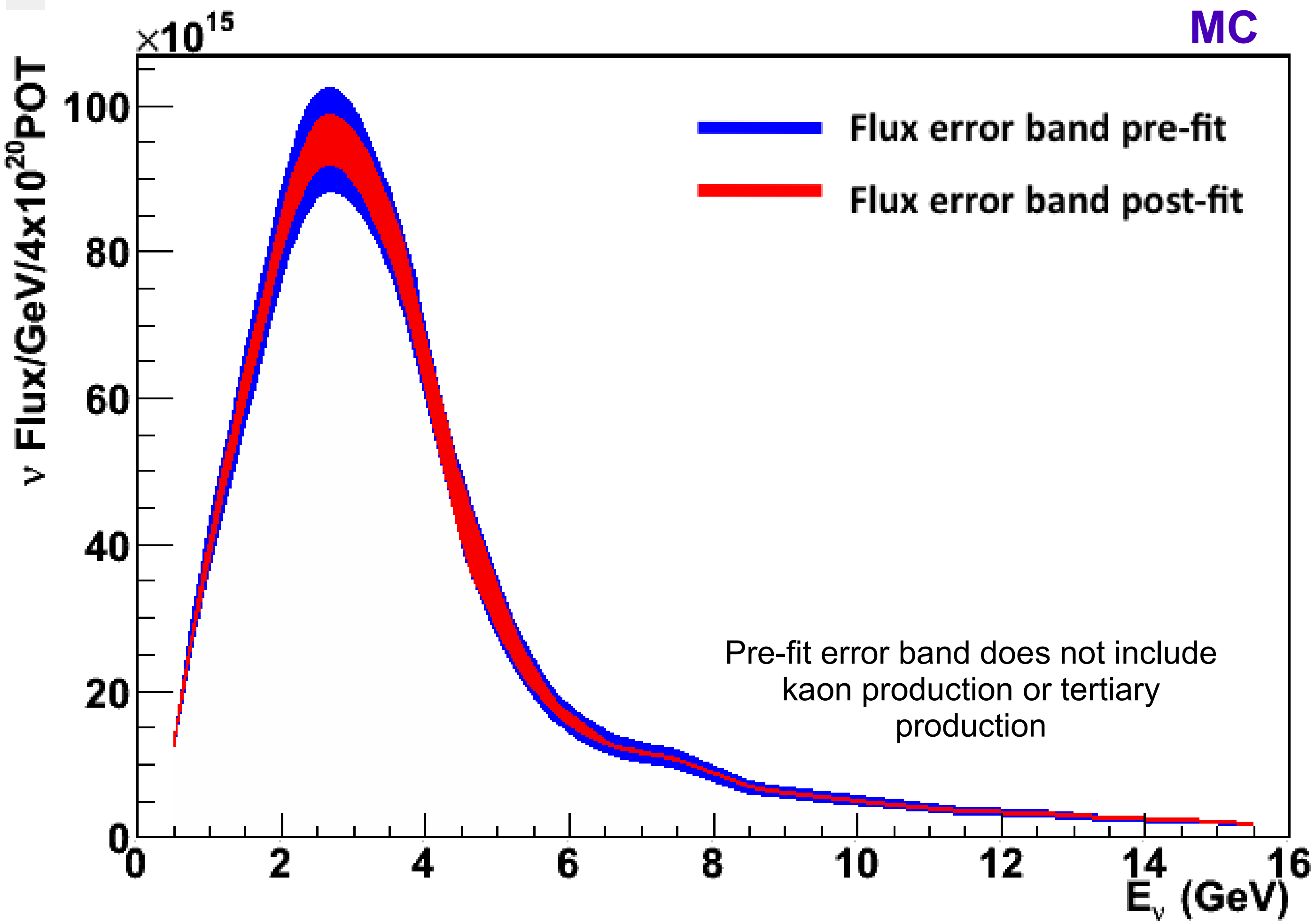
1. **Estimate our post-fit errors by treating MC as 'data'**

- e.g reweight Geant4 Monte Carlo to agree with Fluka 'data'
- means fitting infrastructure will be nearly ready-to-go when special runs data are available



MINERνA Status: Special Runs

- Estimated uncertainties after fit to pseudo-data sample equivalent 0.15e20 POT in six beam configurations:

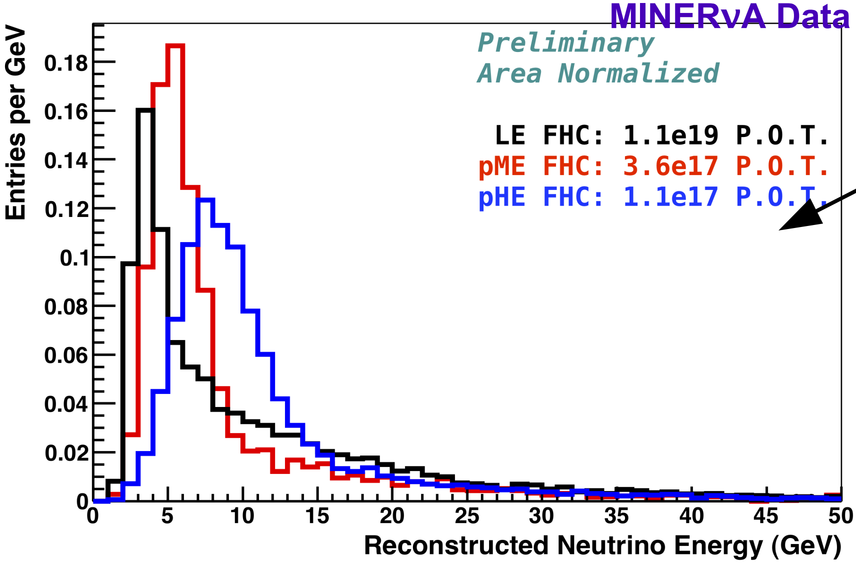


A work in progress!

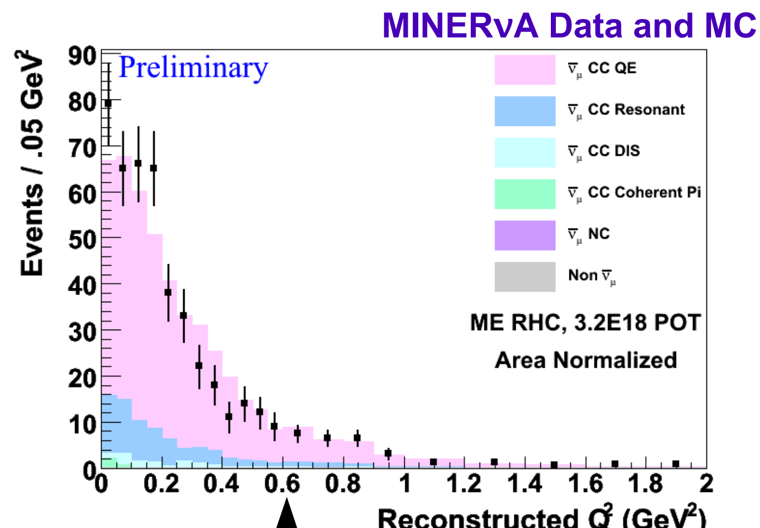
For example, constraints on π/K production ratios have not yet been included

MINERνA Status: Special Runs

- While we await completion of the special runs, we are building and tuning the infrastructure needed to analyze them.



Reconstructed neutrino energy of CC inclusive candidates in standard running and a neutrino mode special run



2. Use existing runs to identify samples of interest

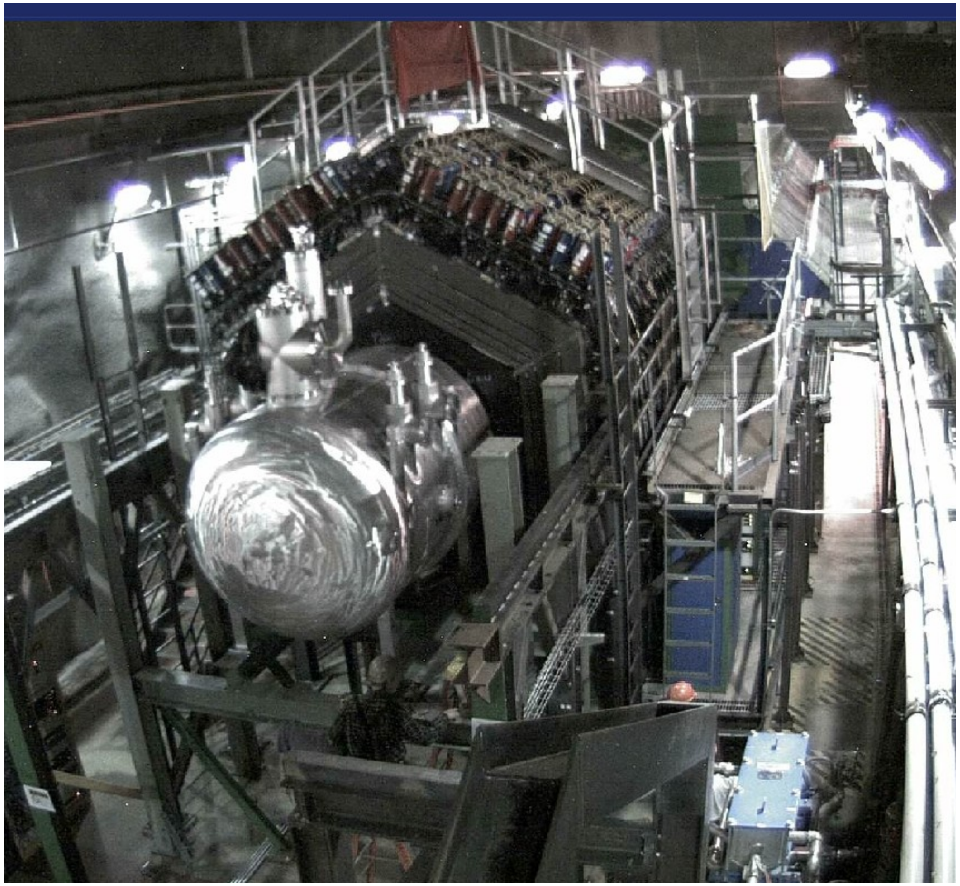
Can soon move on to using these and other samples to do the flux tuning fits

Reconstructed Q^2 of CC quasi-elastic candidates in the anti-neutrino mode special run

Nuclear Target Installations

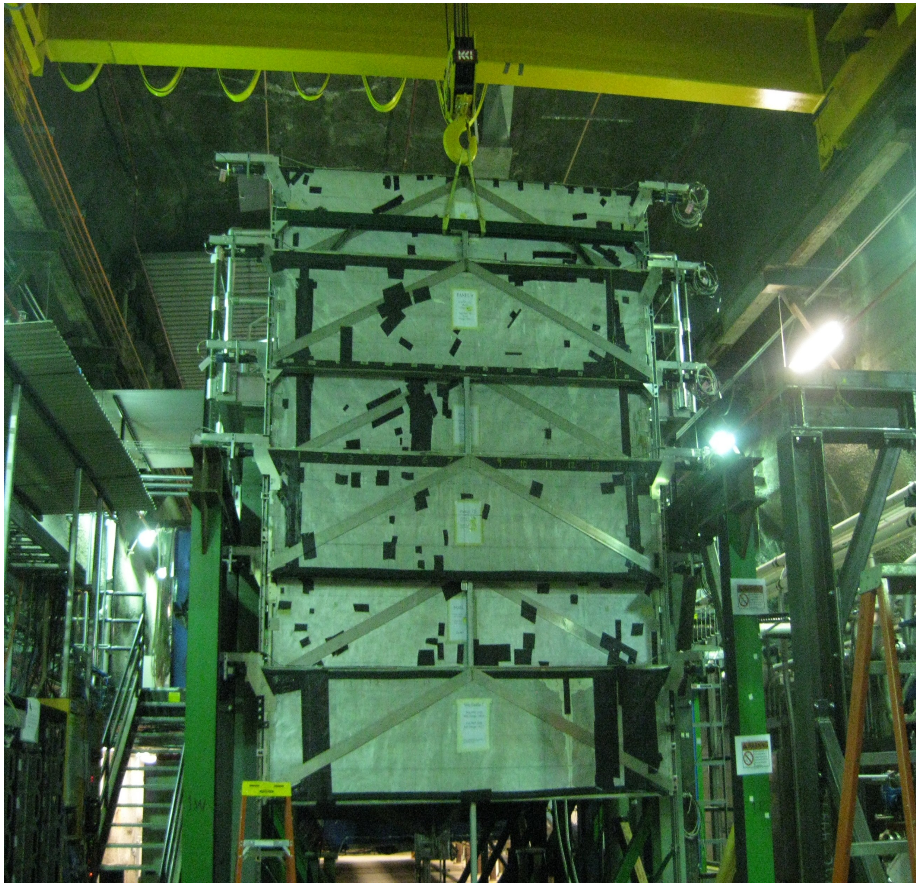
- While data proceeds with the main detector, we are continuing installation of other elements of the detector

- The liquid helium target was installed in March 2010



Veto Wall Installation

- The "veto wall" designed to tag particles entering the front of the detector is currently being installed
  - Wall consists of two planes of scintillators and two planes of steel shielding
  - First scintillator + steel planes have been installed and commissioned
  - Second scintillator plane has been installed; will be commissioned upon return of beam



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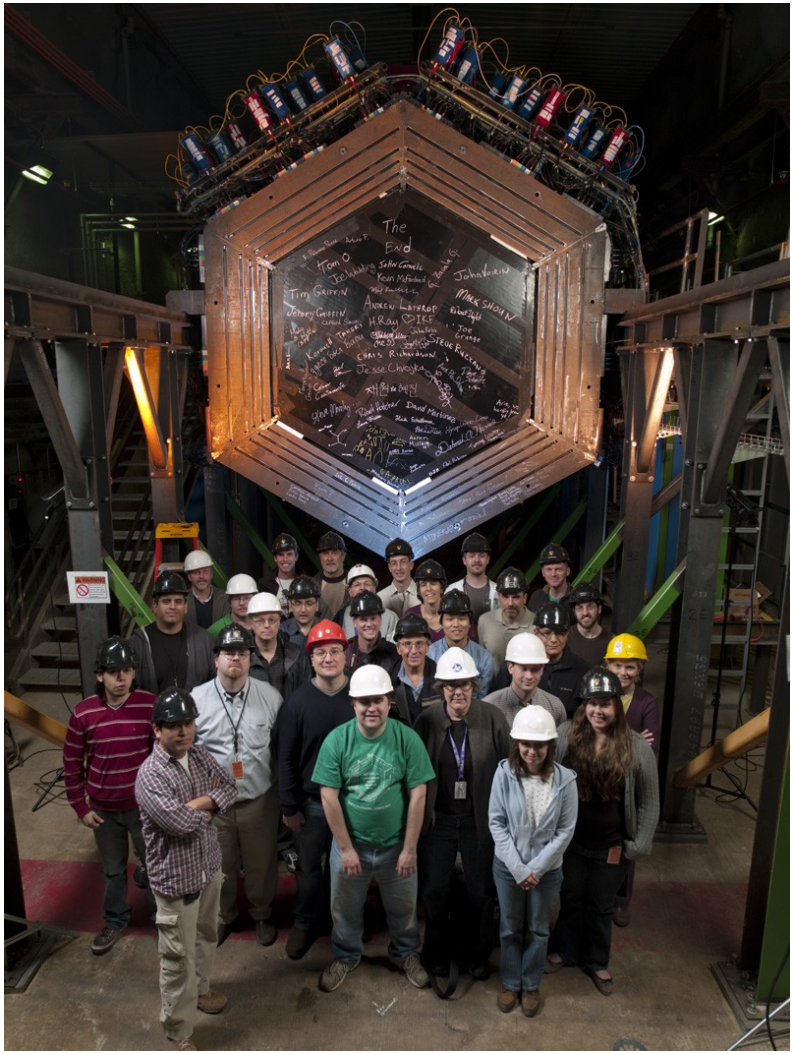
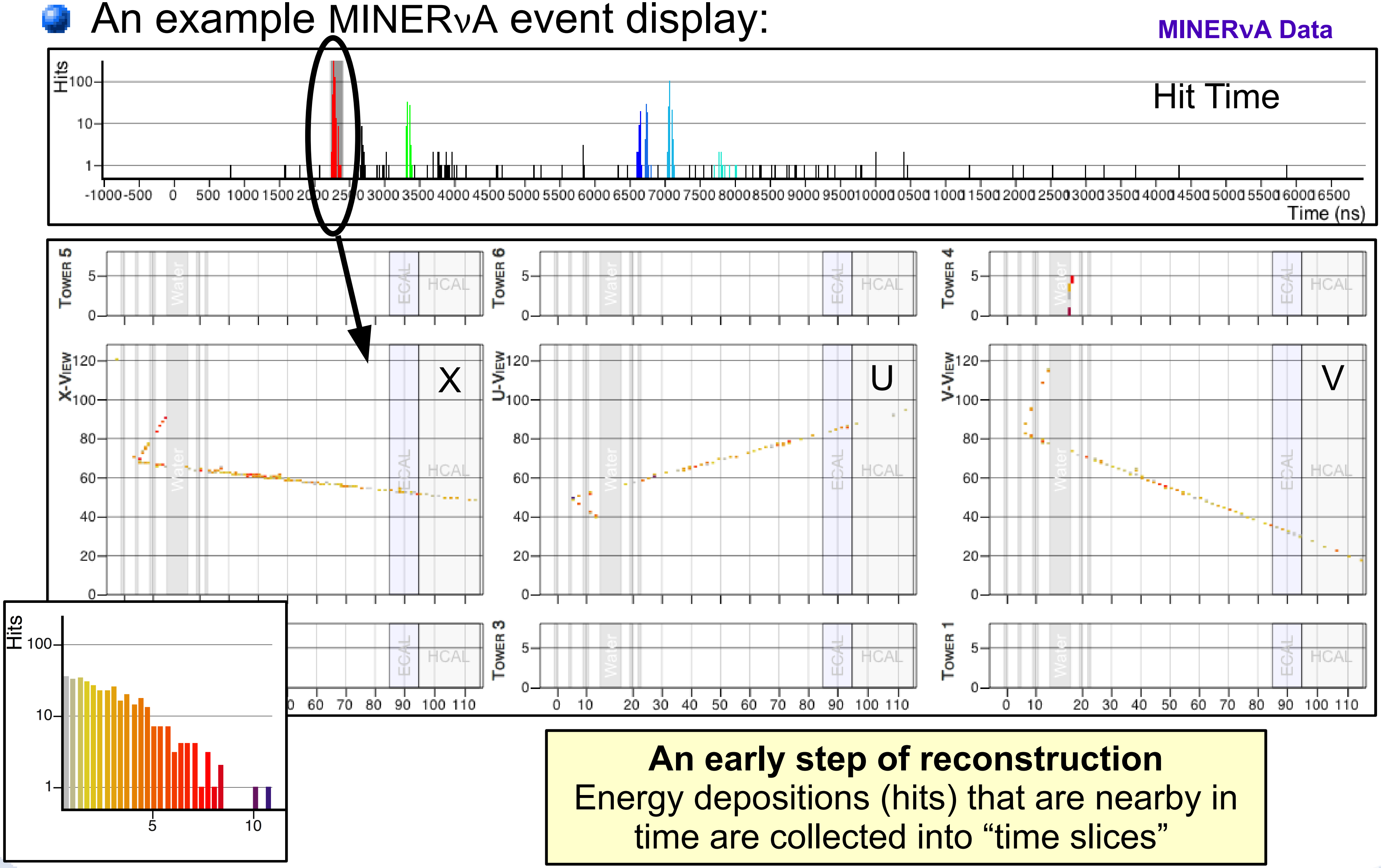


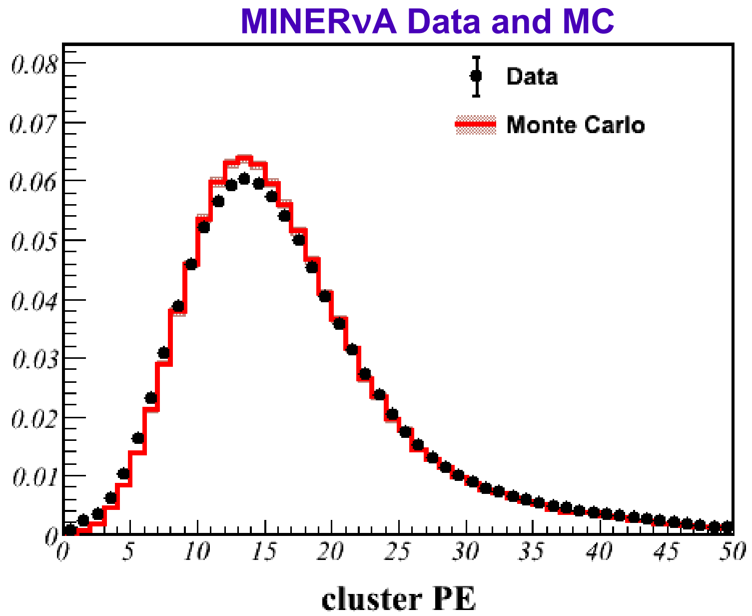
Reconstruction Status

- An example MINERνA event display:



An early step of reconstruction
Energy depositions (hits) that are nearby in time are collected into “time slices”

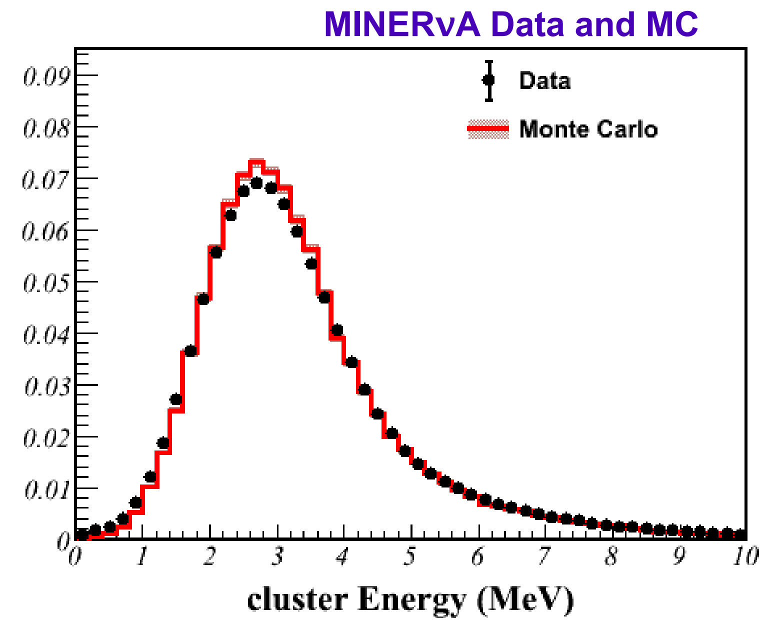
Reconstruction Status



Another early step of reconstruction
Formation of “clusters”, or hits within the same plane and time slice on adjacent strips

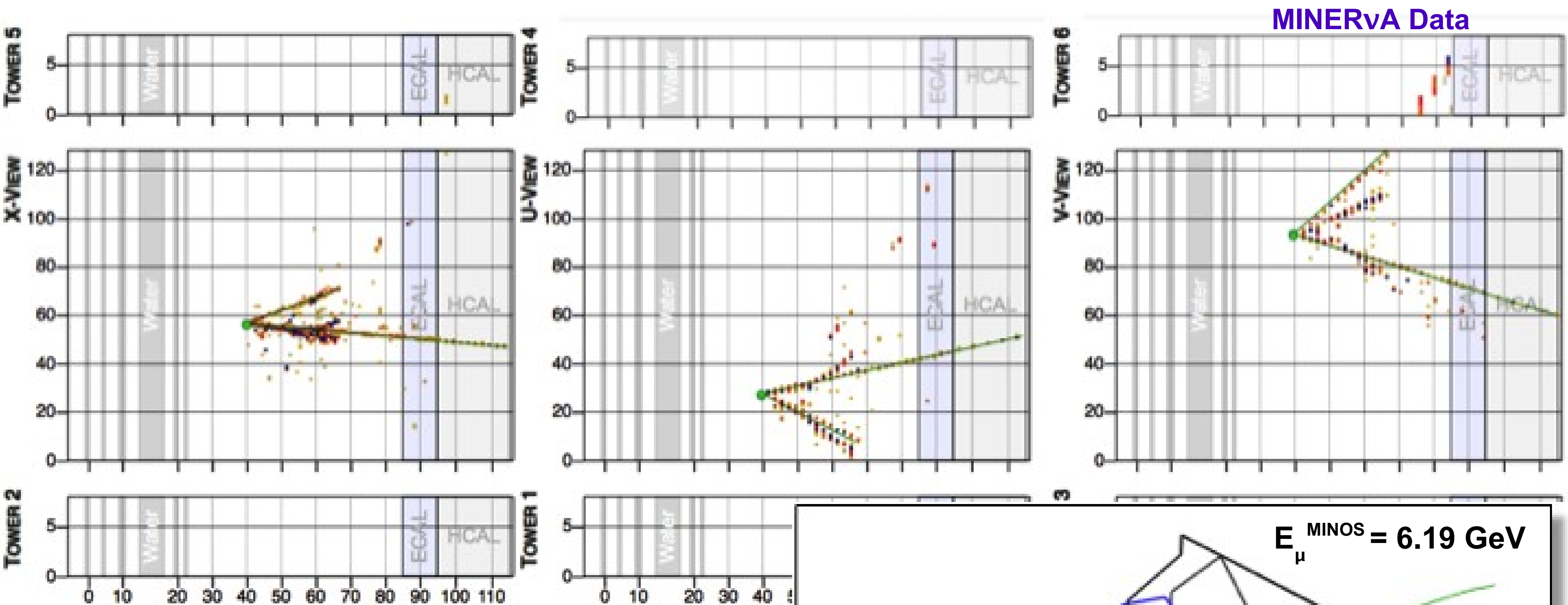
Raw Photoelectron Count

Calibrated Cluster Energy



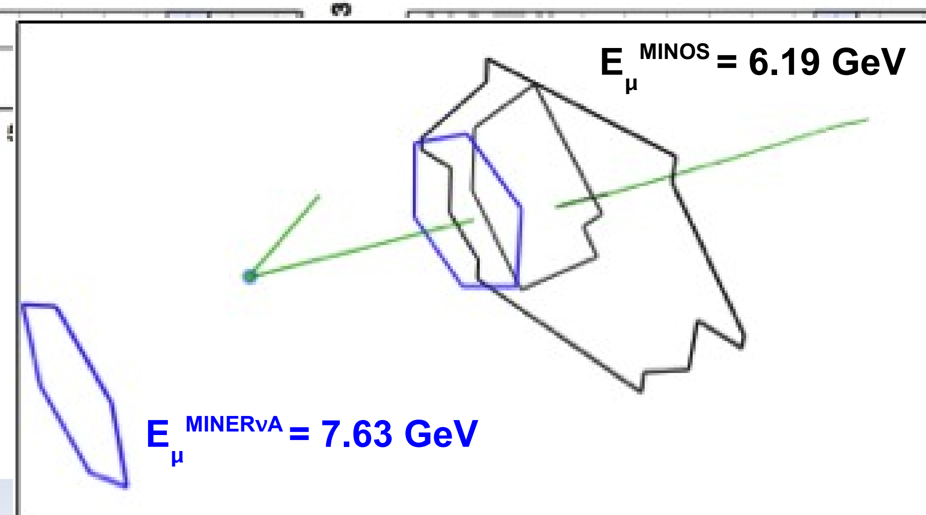
Reconstruction Status

- A first reconstruction priority: high energy muon tracks matched to the MINOS near detector

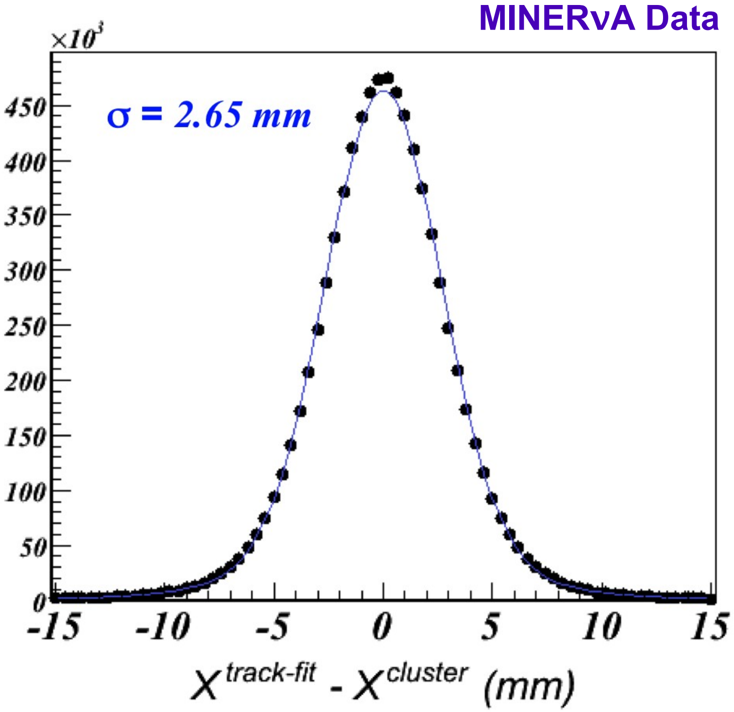


Momentum/charge measured in MINOS detector.

Corrected with energy depositions in MINERνA to estimate momentum at vertex

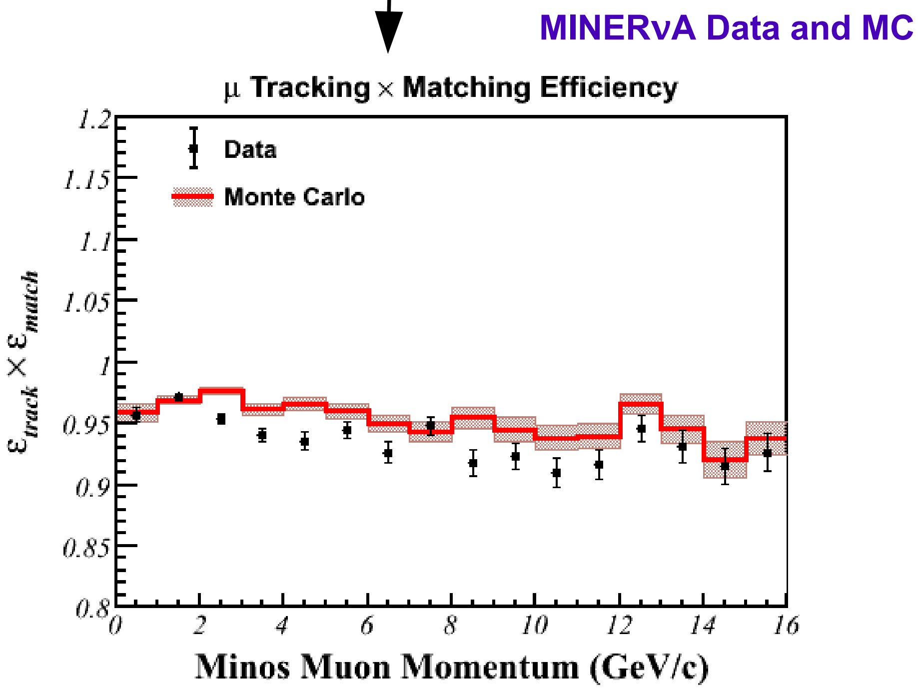


Reconstruction Status



Tracking Residual

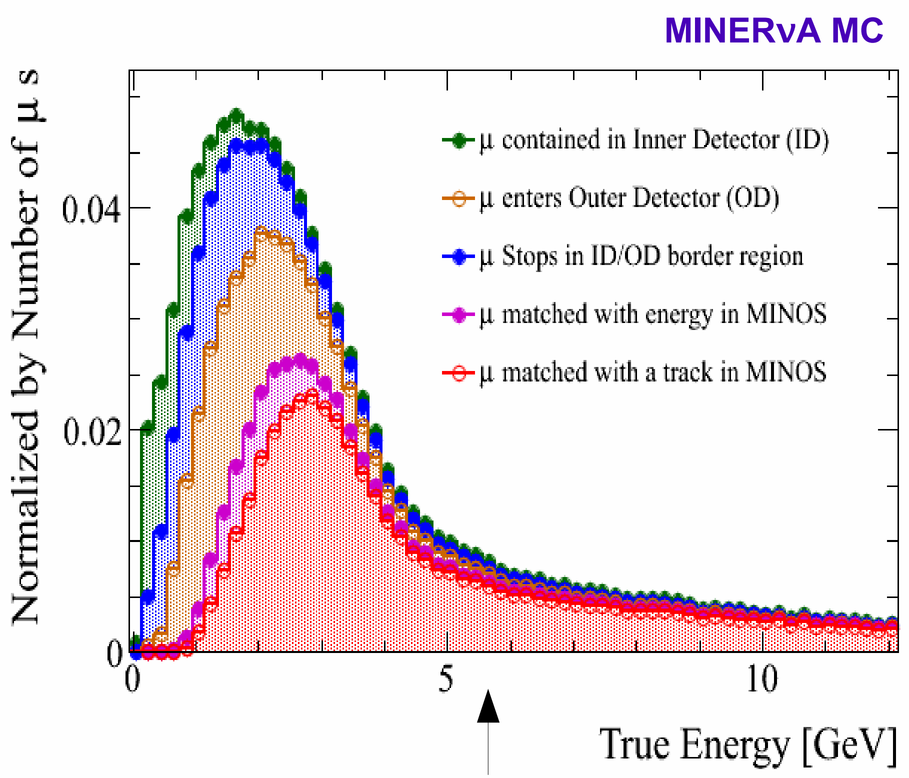
Tracking and Matching Efficiency



Efficiency Definition

Fraction of tracks in MINOS with energy in front and back of MINERνA that are matched to MINERνA tracks

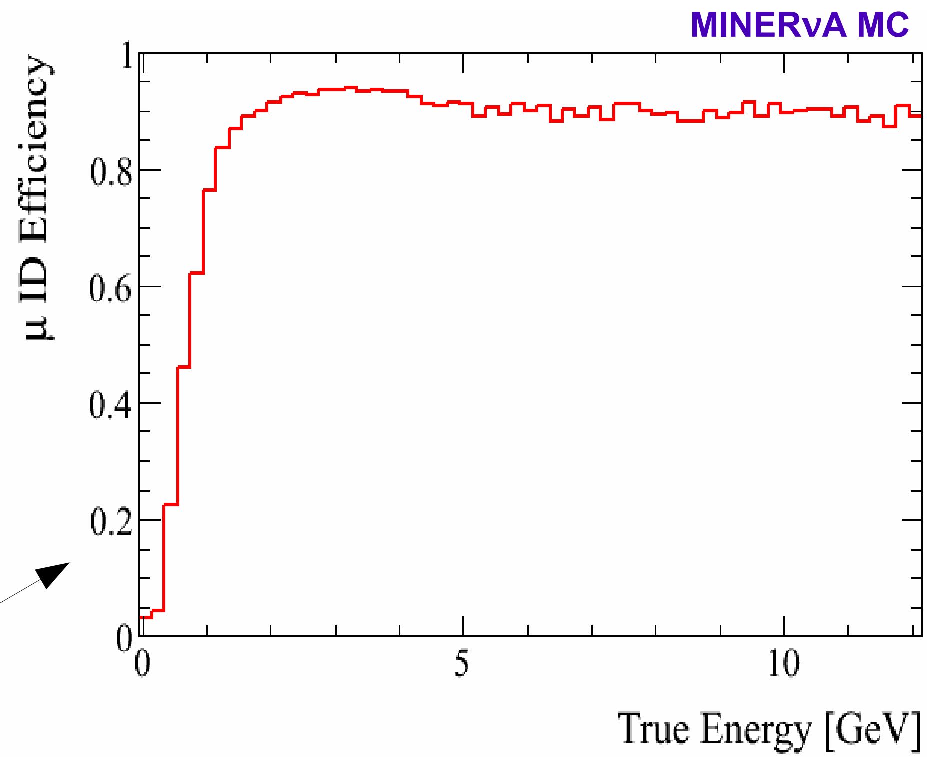
Reconstruction Status



Stacked energy distribution of muons matched and not matched to MINOS

Muon efficiency

- Next step: reconstruct hadrons and lower energy muons not matched to MINOS



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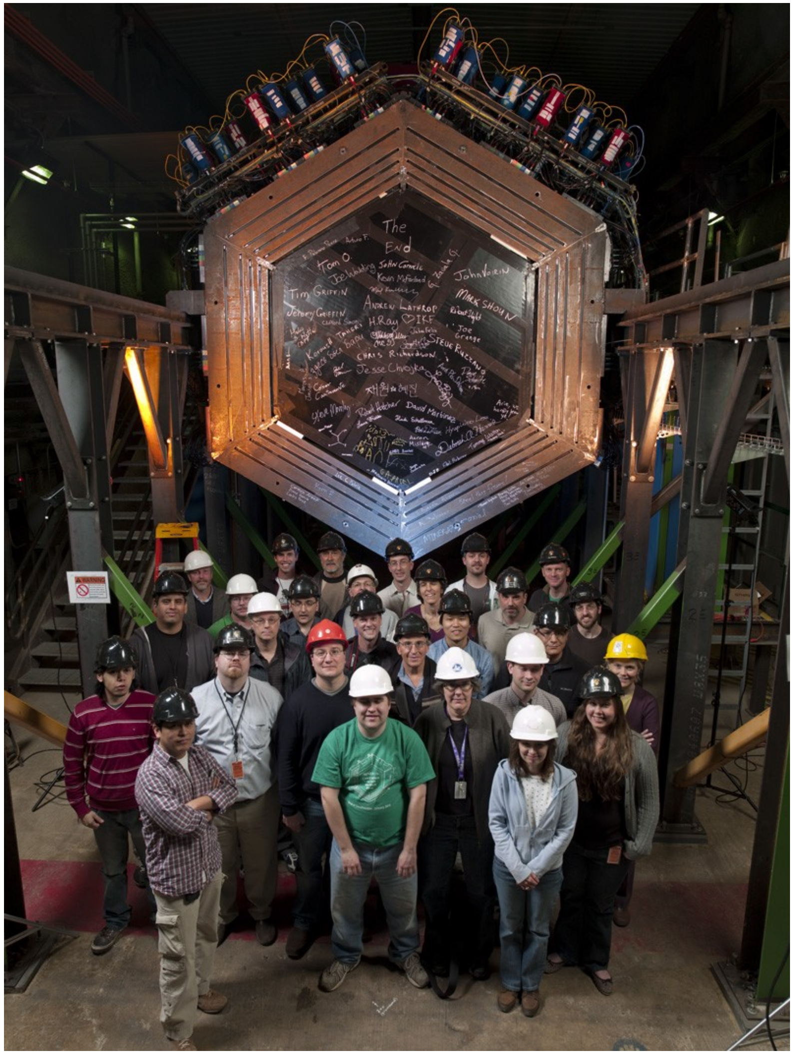
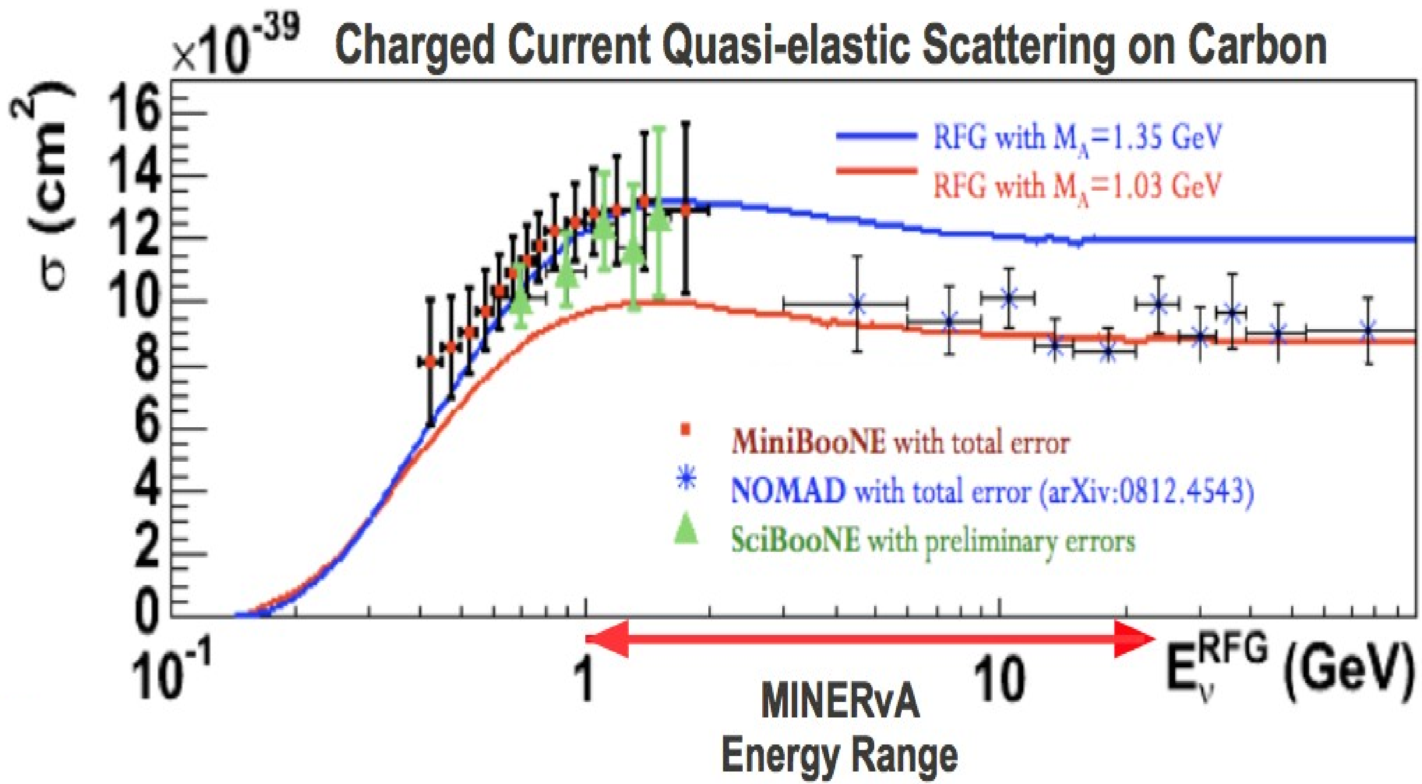


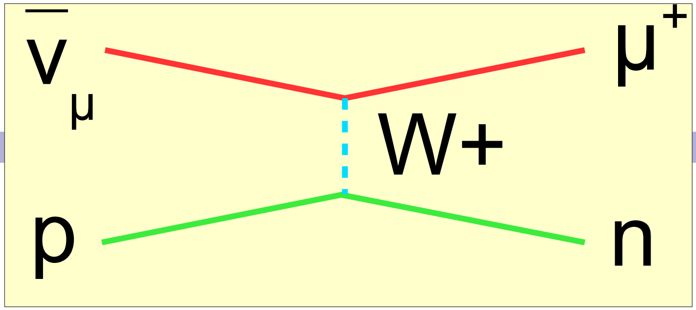
MINERνA Results: CCQE

CCQE
= Charged Current Quasi-Elastic

- We've already mentioned the importance of quasi-elastics... recall this plot from a few slides ago:



MINERνA Results: CCQE



- Measuring muon energy and angle energy and angle (wrt beam) completely reconstructs a quasi-elastic interaction:

$$E_{\bar{\nu}_\mu}^{QE} = \frac{2M'_p E_\mu - (M'^2_p + m_\mu^2 - m_n^2)}{2(M'^2_p - E_\mu + \sqrt{E_\mu^2 - m_\mu^2}\cos\theta_\mu)}$$

$$M'_p = m_p - \varepsilon_B$$

$$\varepsilon_B = 30\ MeV$$

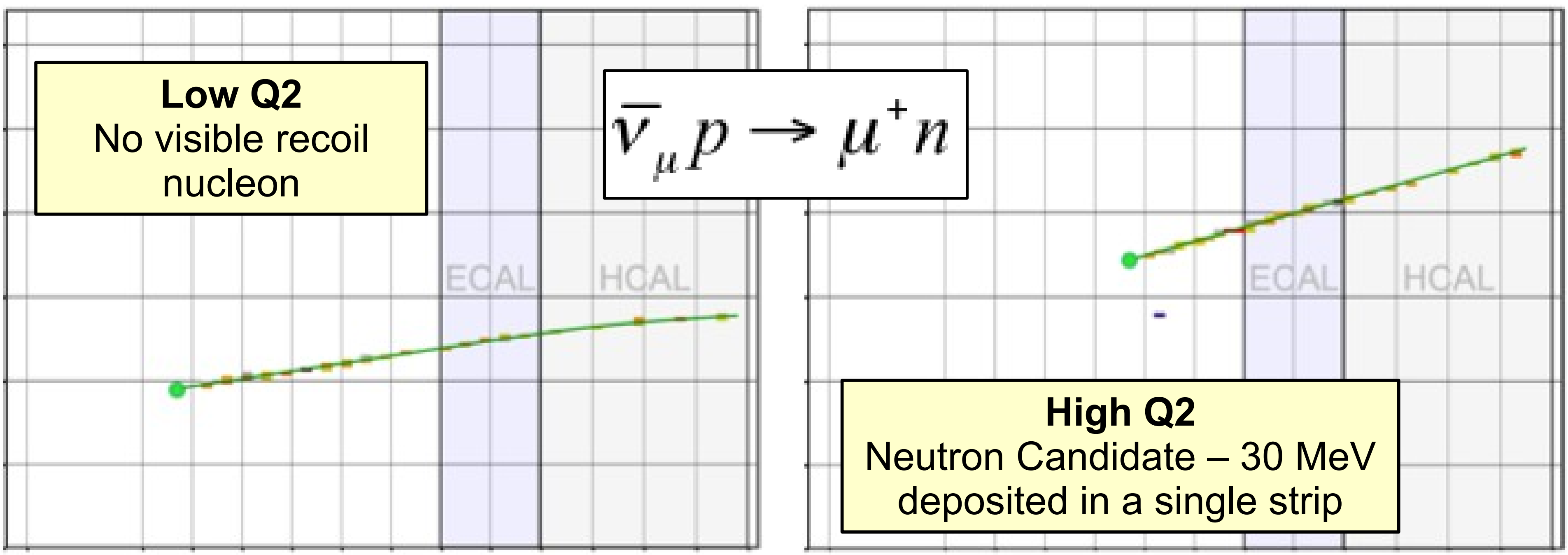
$$Q^2 = 2E_{\bar{\nu}_\mu}^{QE}(E_\mu - p_\mu cos(\theta_\mu)) - m_\mu^2$$

Q^2 is the 4-momentum transfer squared from the neutrino to the neutron

MINERνA Results: CCQE

- Charged Current Quasi-elastic interactions are among the simplest to reconstruct in the MINERvA detector:

MINERνA Data



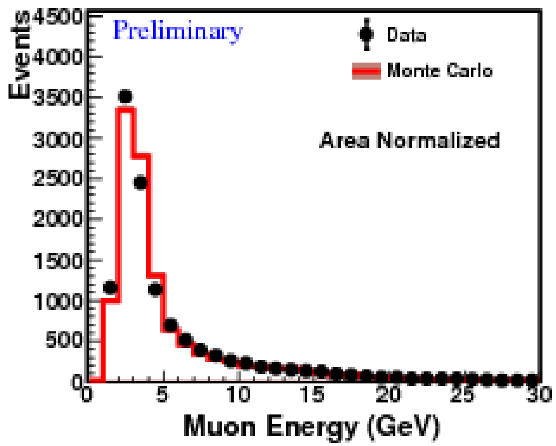
If elastic kinematics,
E_ν=2.8 GeV, Q^2=0.1GeV^2

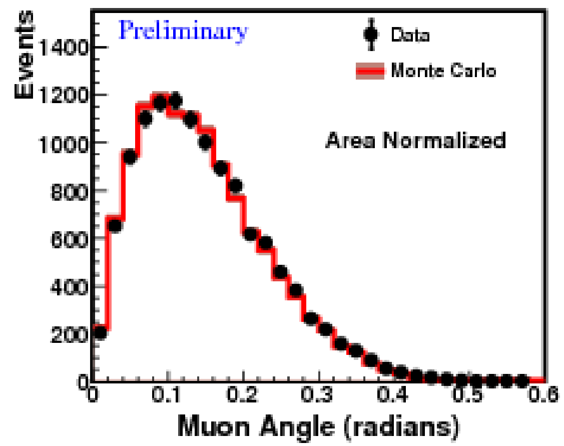
If elastic kinematics,
E_ν=2.5 GeV, Q^2=0.3GeV^2

MINERνA Results: CCQE

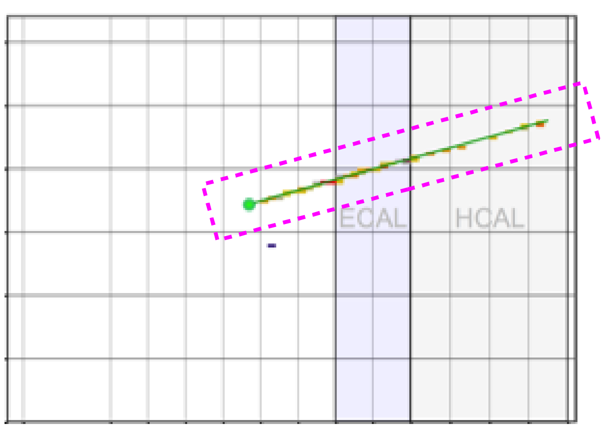
- First step: reconstruct a minos-matched muon in the fiducial volume

MINERνA Data and MC



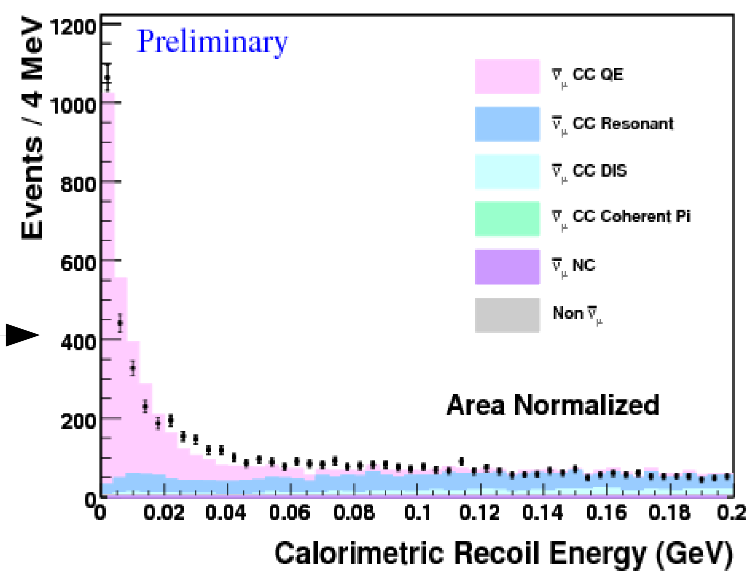


- Next: consider non-track energy



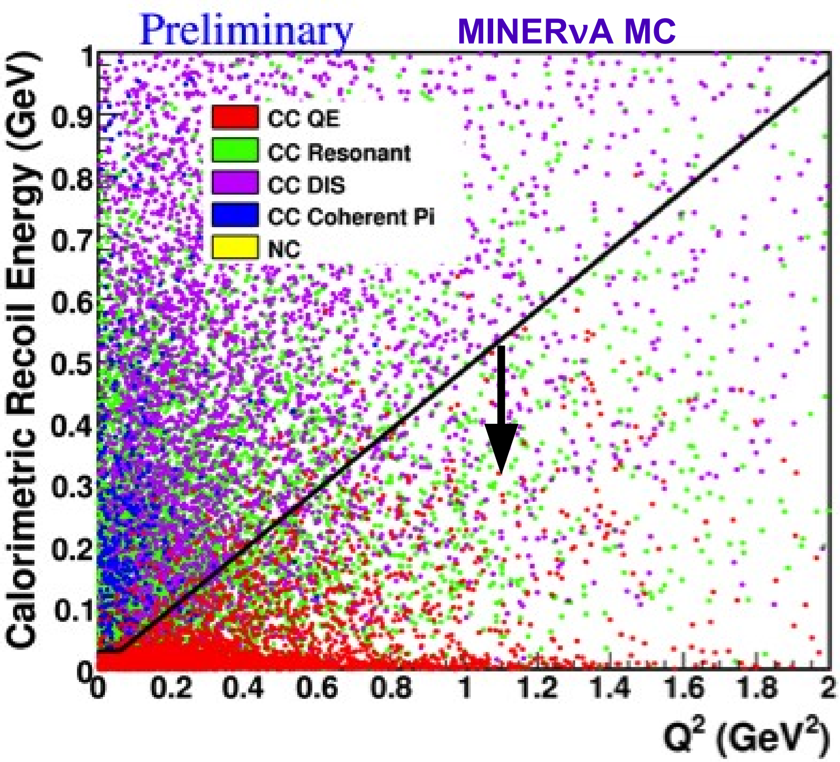
Count energy outside of cylinder in tracker + ecal

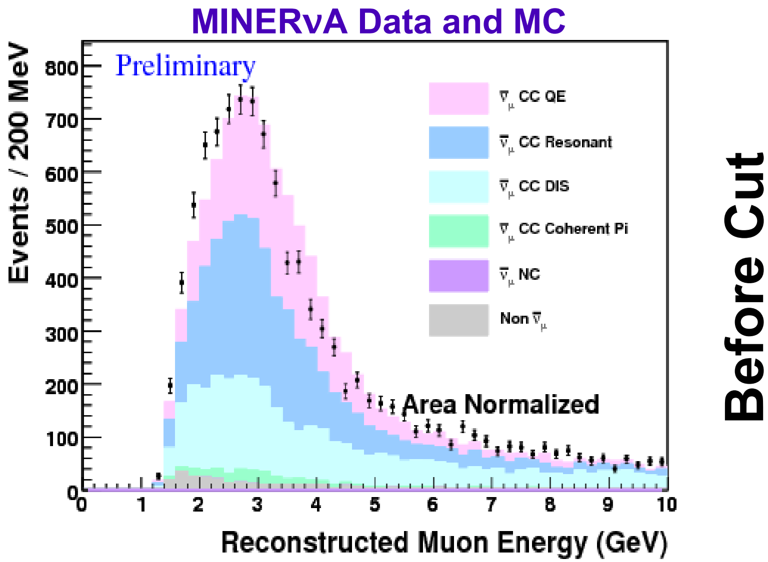
MINERνA Data and MC

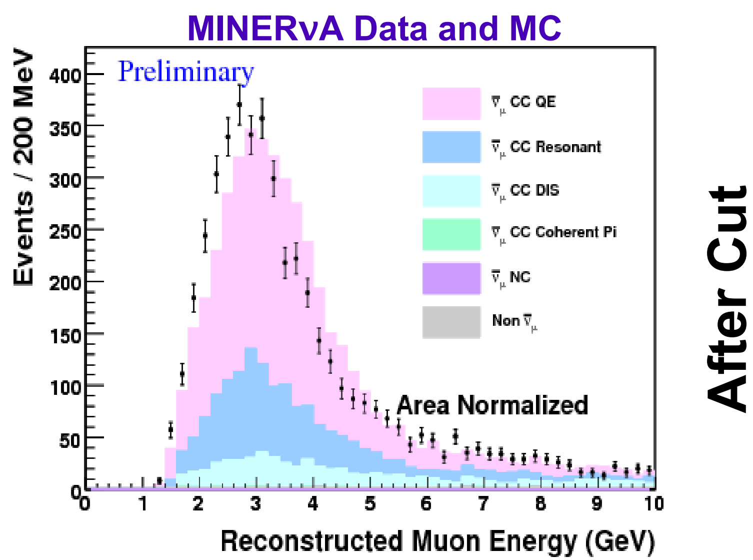


MINERνA Results: CCQE

To Identify QE Candidates:
Apply Q^2 dependent cut on calorimetric recoil

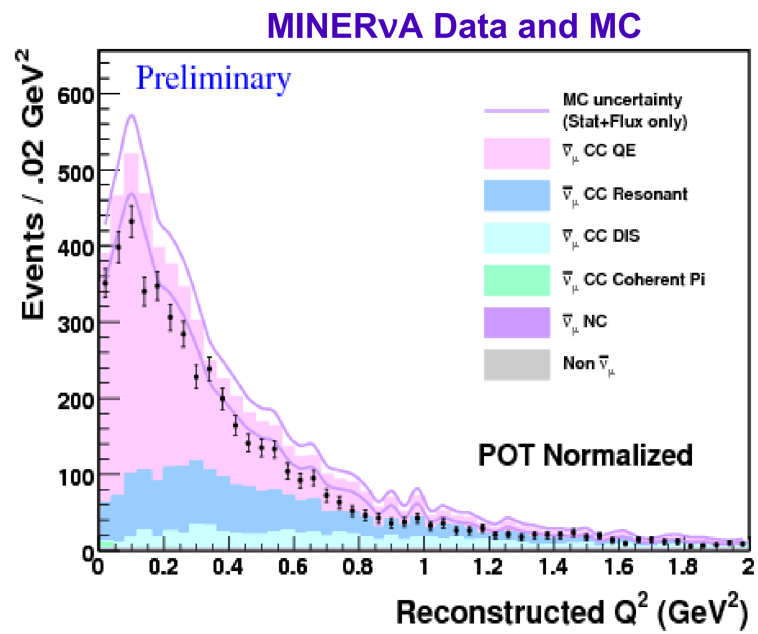


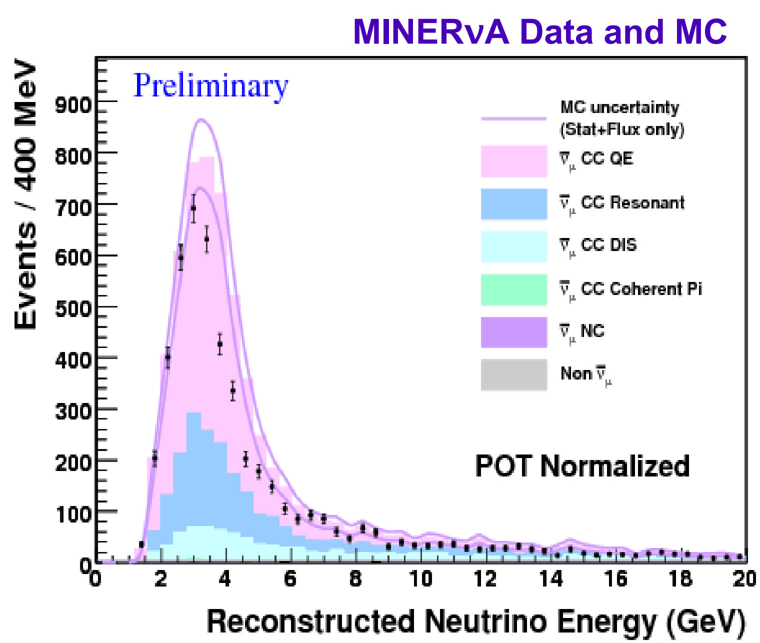




MINERνA Results: CCQE

- Quasi-elastic next-steps:
  - Better background suppression
  - Michel veto
  - Lower energy muon reconstruction



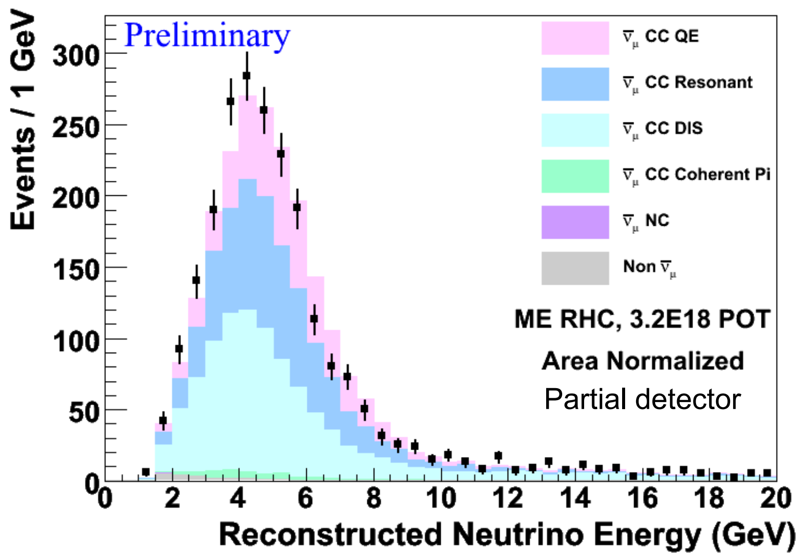


- This analysis uses ~1/5 of the anti-neutrino data sample and a partial detector

  → more statistics to come!

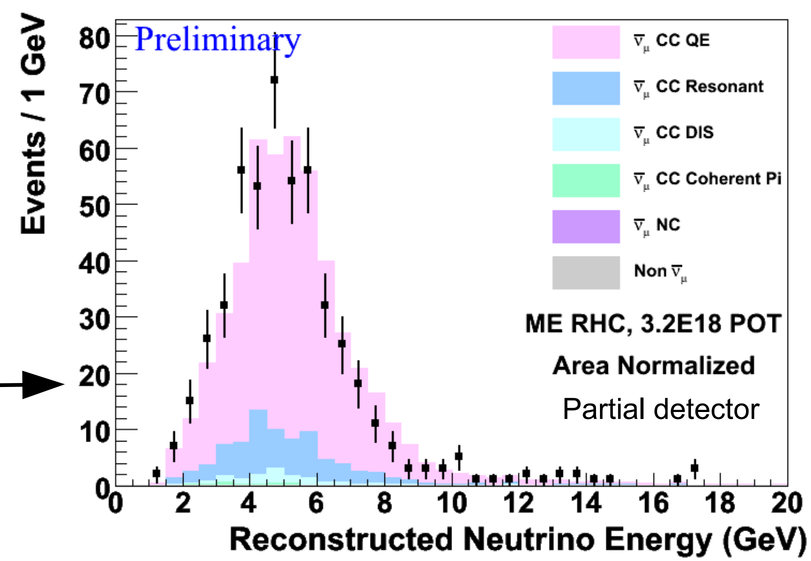
MINERνA Results: CCQE in the Special Runs

- We have used this anti-nu CCQE analysis infrastructure for the single special run taken in anti neutrino mode:



CC Candidates
(Before Recoil Energy Cut)

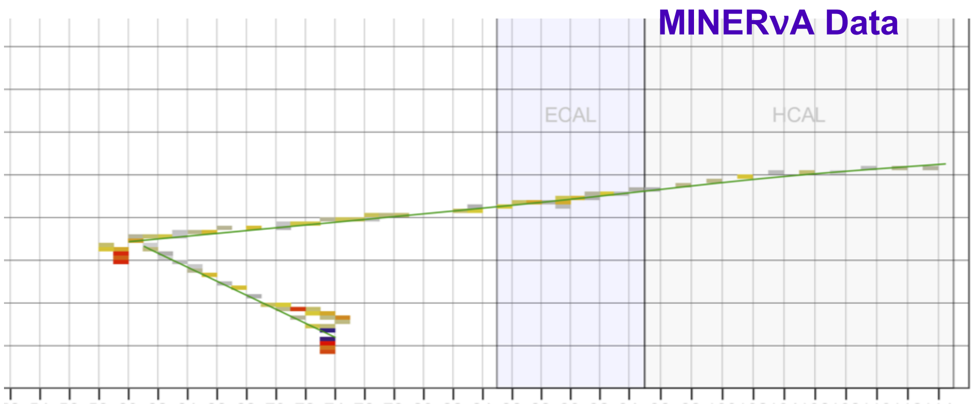
CCQE Candidates
(After Recoil Energy Cut – harsher than in standard analysis)

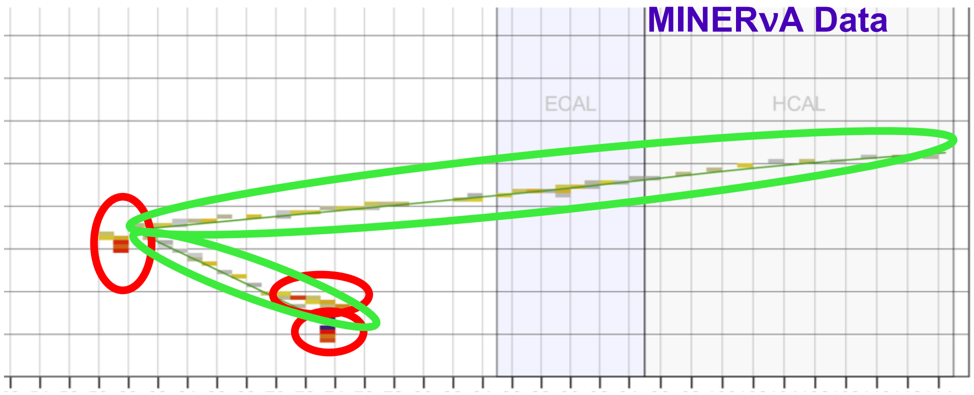


This sample corresponds to roughly ¼ of statistics on disk

MINERνA Results: CC Inclusive

- Another analysis: Charged Current inclusive
  - Similar to CCQE analysis, but without recoil energy cut
  - The challenge: can't assume elastic kinematics → must sum energy in detector to measure neutrino momentum





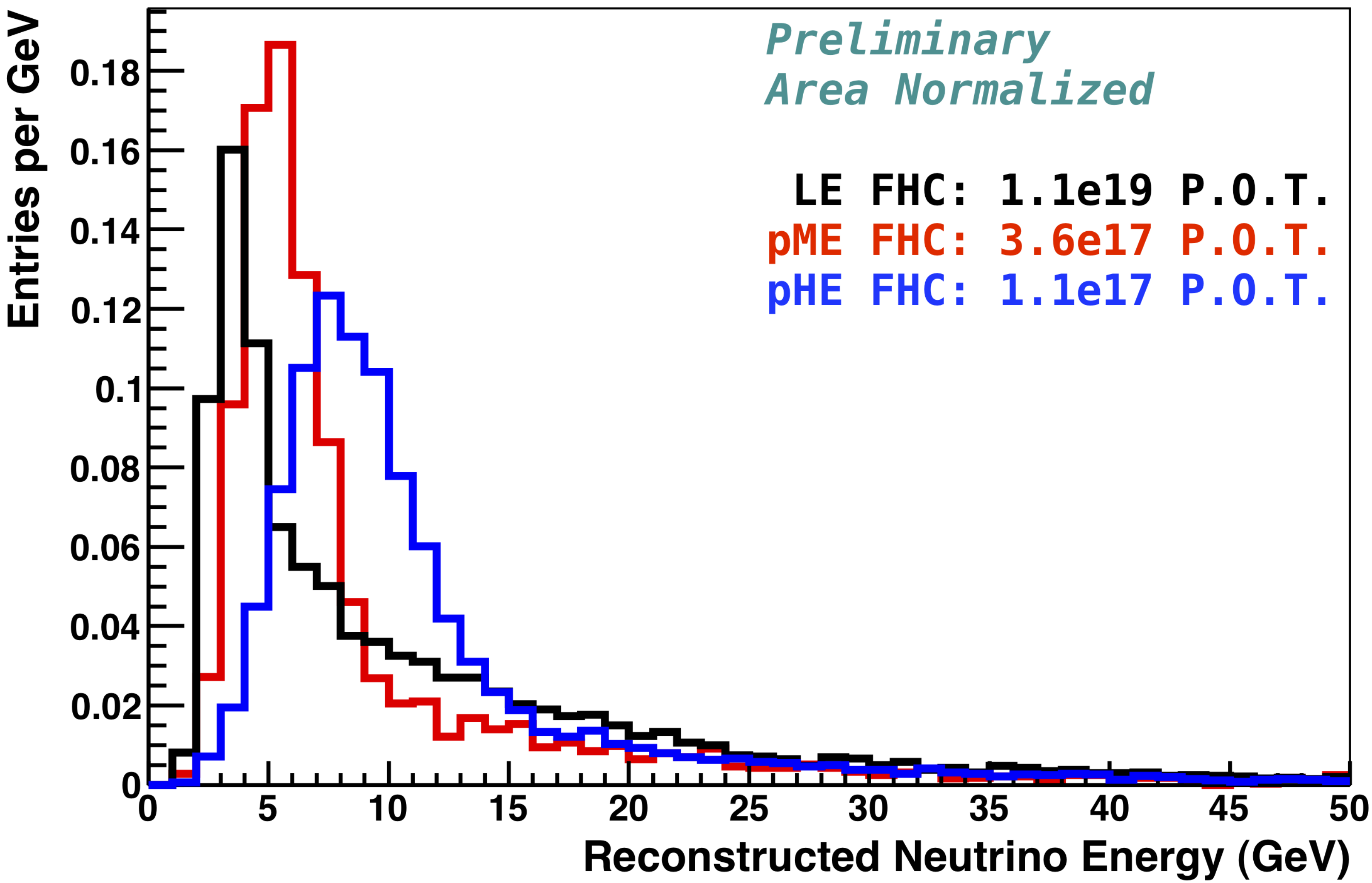
Neutrino Energy
Estimated by summing everything in a time slice

Both tracks (reconstructed in MINOS and contained in MINERνA)

And everything else "blobs"

MINERνA Results: CC Inclusive

- First MINERνA CC Inclusive Neutrino Energy Distributions:

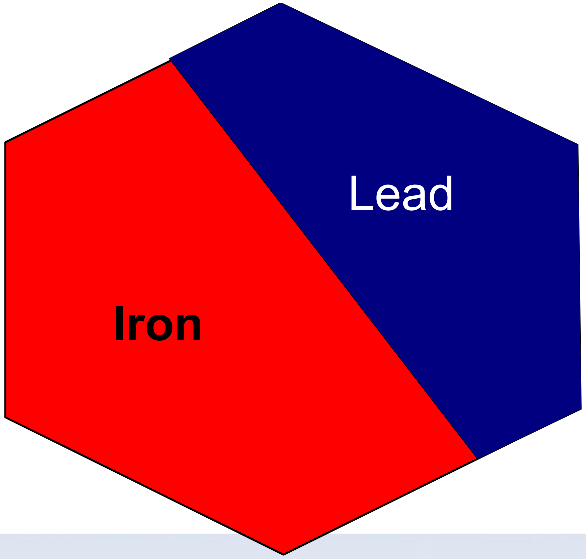


MINERνA Results: CC Inclusive in Nuclear Targets

- CCQE and CC Inclusive (and many others!) will be studied in plastic as well as nuclear targets
- Our first attempt at studying nuclear targets is with a CC Inclusive sample in “Target 5” – a combination of lead and iron

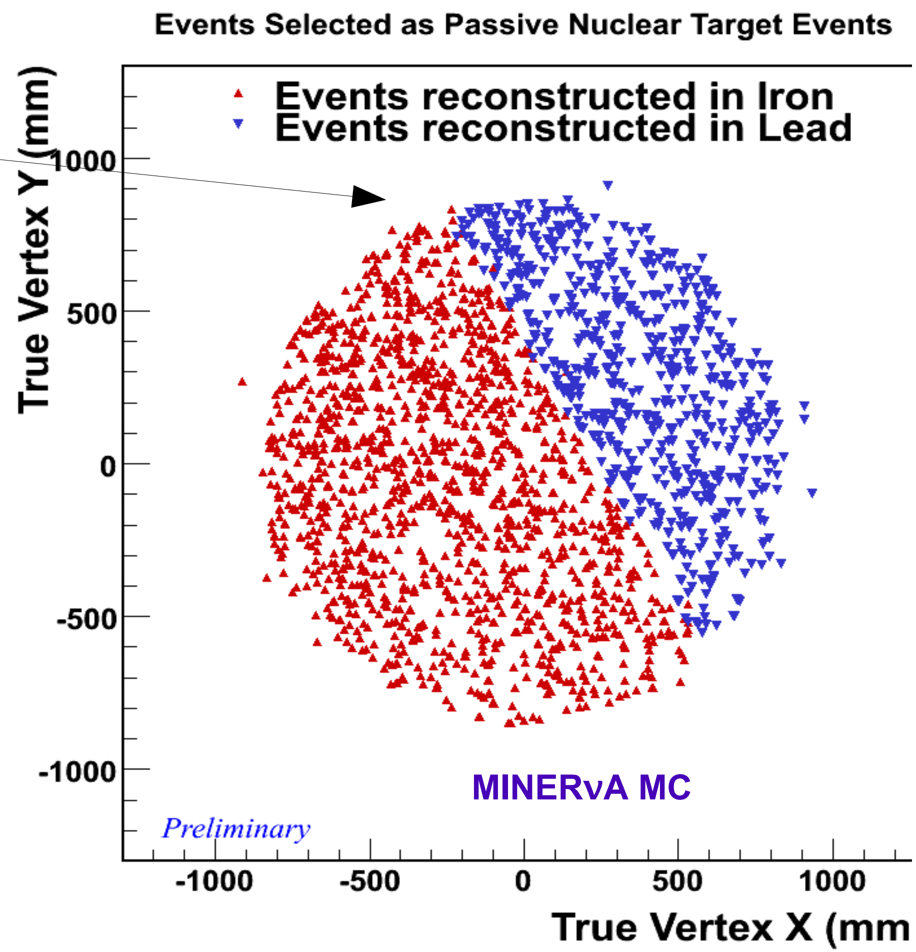
Expected Event Rates for Low Energy Neutrino beam

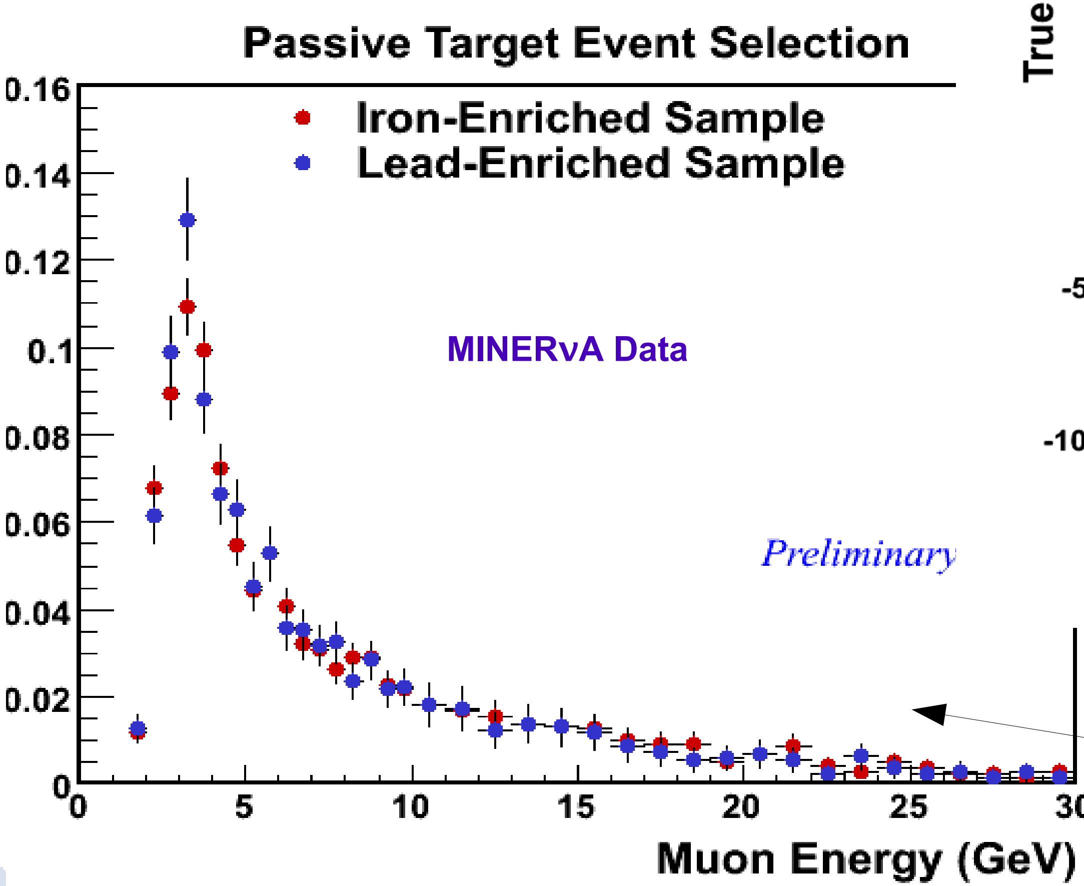
Target	Fiducial Mass	ν_μ CC Events in 4e20 P.O.T.
Plastic	6.43 tons	1363k
Helium	0.25 tons	56k
Carbon	0.17 tons	36k
Water	0.39 tons	81k
Iron	0.97 tons	215k
Lead	0.98 tons	228k



MINERνA Results: CC Inclusive in Nuclear Targets

Monte Carlo shows good vertex separation at material boundary



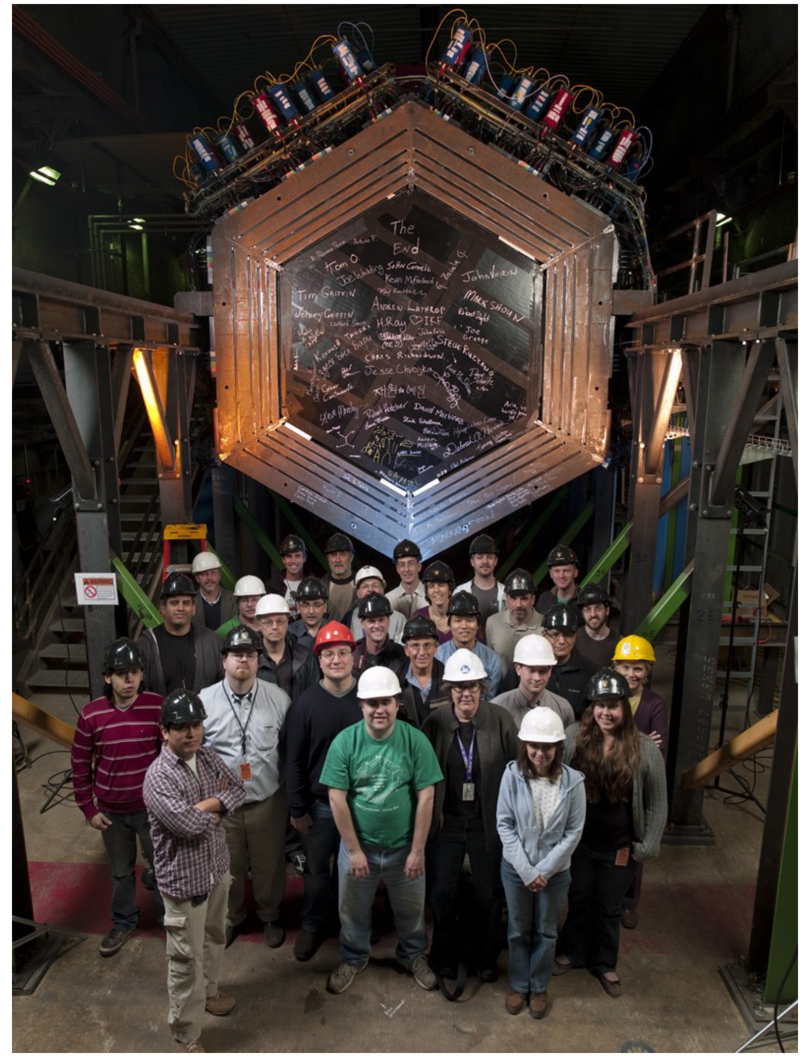


First muon energy spectra in targets; ratios coming soon!

Conclusion

MINERνA is making lots of progress!

- We have sizable chunks of data on disk in neutrino mode & antineutrino mode
- Nuclear targets and veto wall are nearly complete; water target (and maybe Deuterium?) soon
- Special runs and execution of flux determination plans are underway
- Cluster formation, Tracking, MINOS-matching, PID are all working well
- First CC Quasi-elastic and CC Inclusive spectra are public
- Much, much more to come



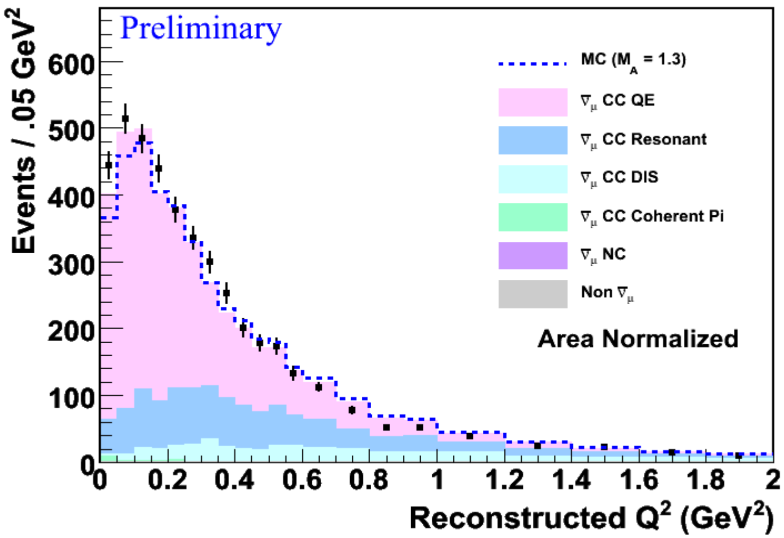
Thanks!

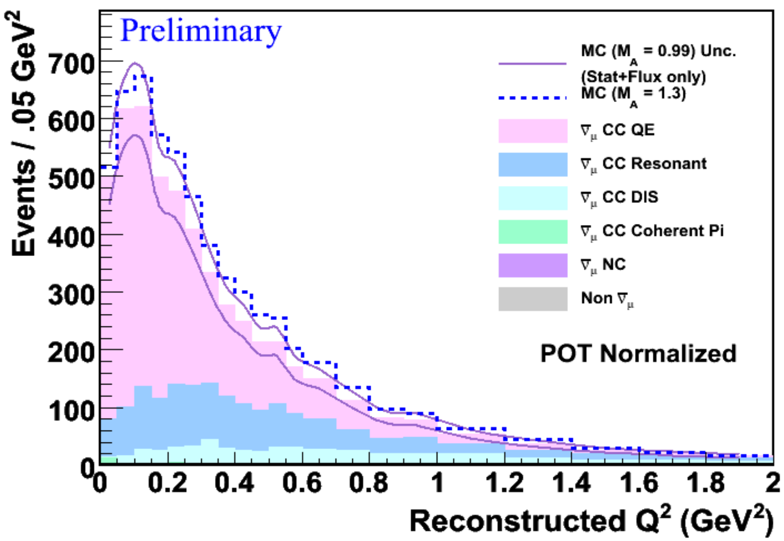
The MINERνA collaboration would like to to thank the many groups that have been critical to our progress so far:

- **Fermilab Particle Physics Division** for all their help installing the MINERvA detector in the NuMI near detector hall
- **Fermilab Accelerator Division** for their tireless efforts to keep the NuMI facility running and to provide intense beam since the detector was commissioned
- **Fermilab Computing Division** for providing our computing infrastructure and a lot of valuable expertise
- **The ArgoNeut Collaboration** for paving the way for the use of cryogenic vessels in the underground area
- A very special thanks to the **MINOS Collaboration** for their willingness to share their data, so significant to MINERνA's success, and for the significant effort required to process, calibrate and reconstruct the Near Detector data

Backup Slides

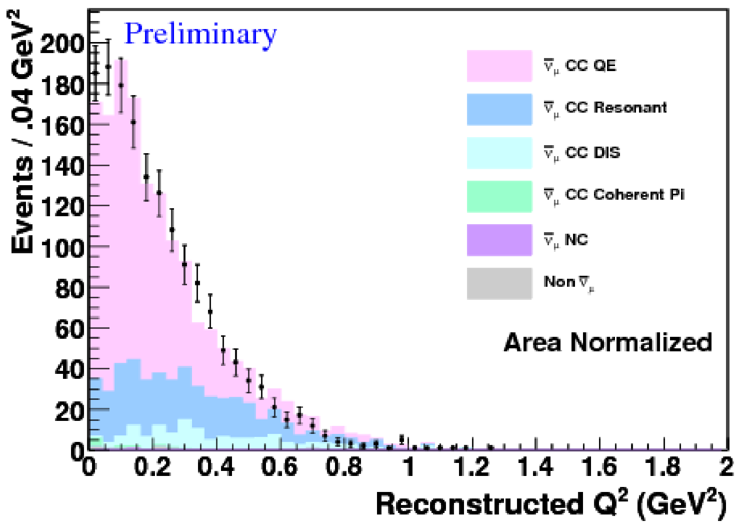
Backup Slides



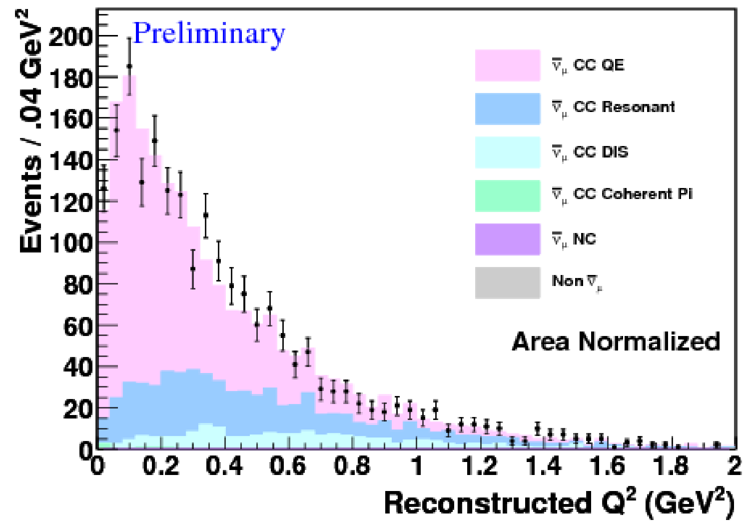


CCQE Q^2 spectra, with standard Monte Carlo (shaded histograms) and reweighted so that CCQE component uses M_A=1.3. Our standard Monte Carlo uses M_A = 0.99

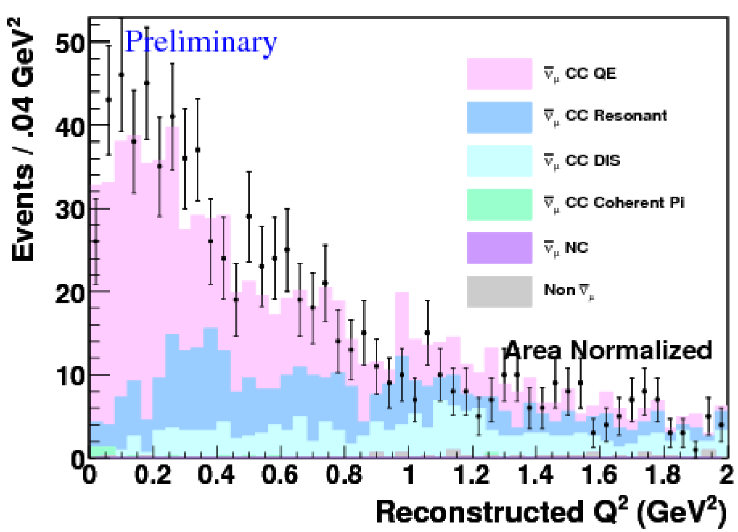
Backup Slides



$E_\nu < 3$ GeV



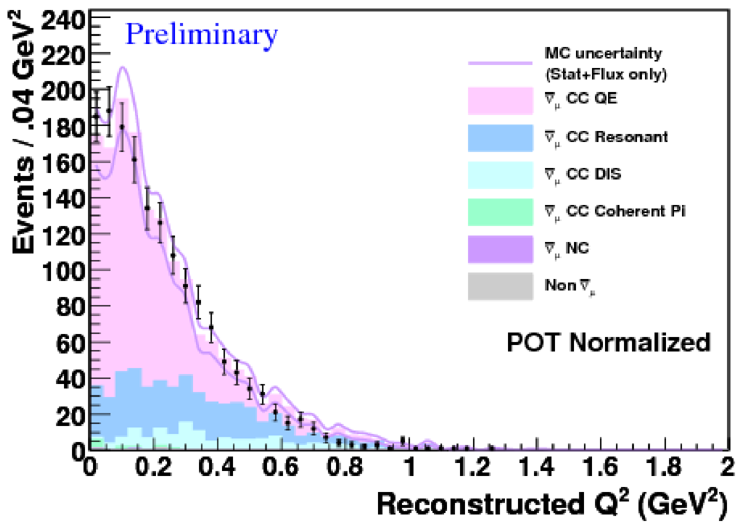
3 GeV $< E_\nu < 5$ GeV



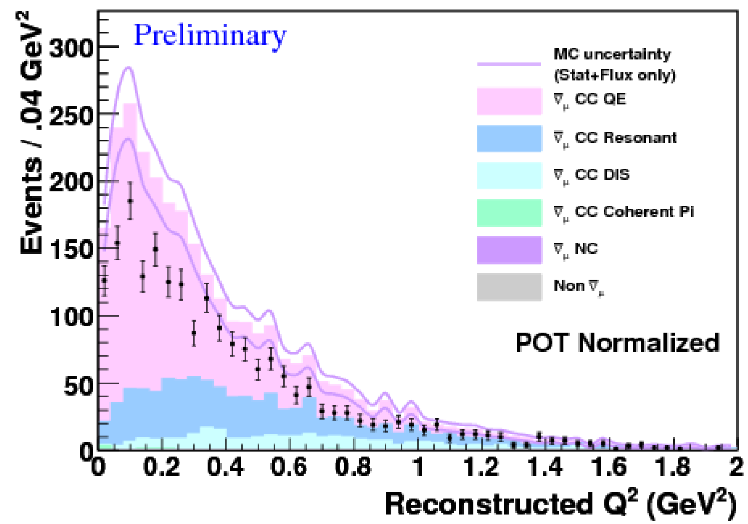
5 GeV $< E_\nu < 10$ GeV

Area normalized CCQE Q^2 spectra, divided into three reconstructed neutrino energy bins

Backup Slides

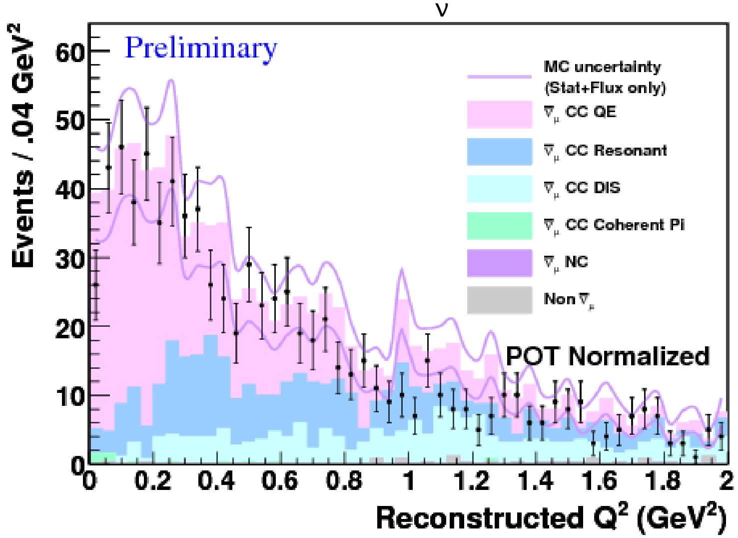


$E_\nu < 3$ GeV



3 GeV $< E_\nu < 5$ GeV

5 GeV $< E_\nu < 10$ GeV

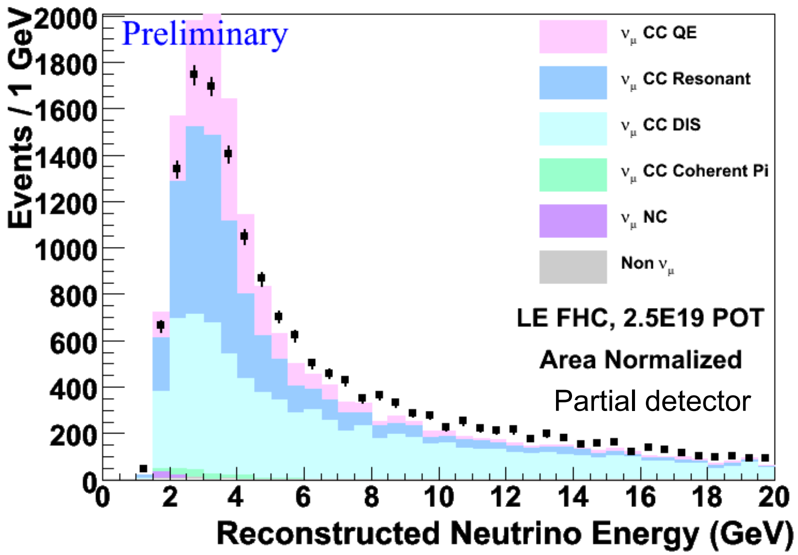


5 GeV $< E_\nu < 10$ GeV

POT normalized CCQE Q^2 spectra, divided into three reconstructed neutrino energy bins

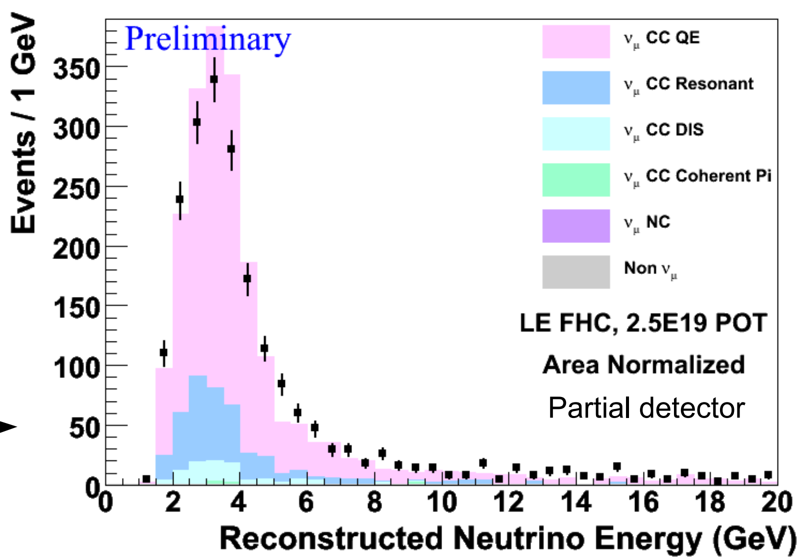
MINERνA Results: CCQE in the Special Runs

- Next special run steps: apply similar procedure to neutrino mode data:



CC Candidates
(Before Recoil Energy Cut)

CCQE Candidates
(After Recoil Energy Cut – harsher than in standard analysis)



This sample size is roughly equivalent to our POT request for a single special run