Measuring Neutrino Interactions at MINERυA (Main Injector Experiment υ-A)

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MINERυA Collaboration
University of Florida
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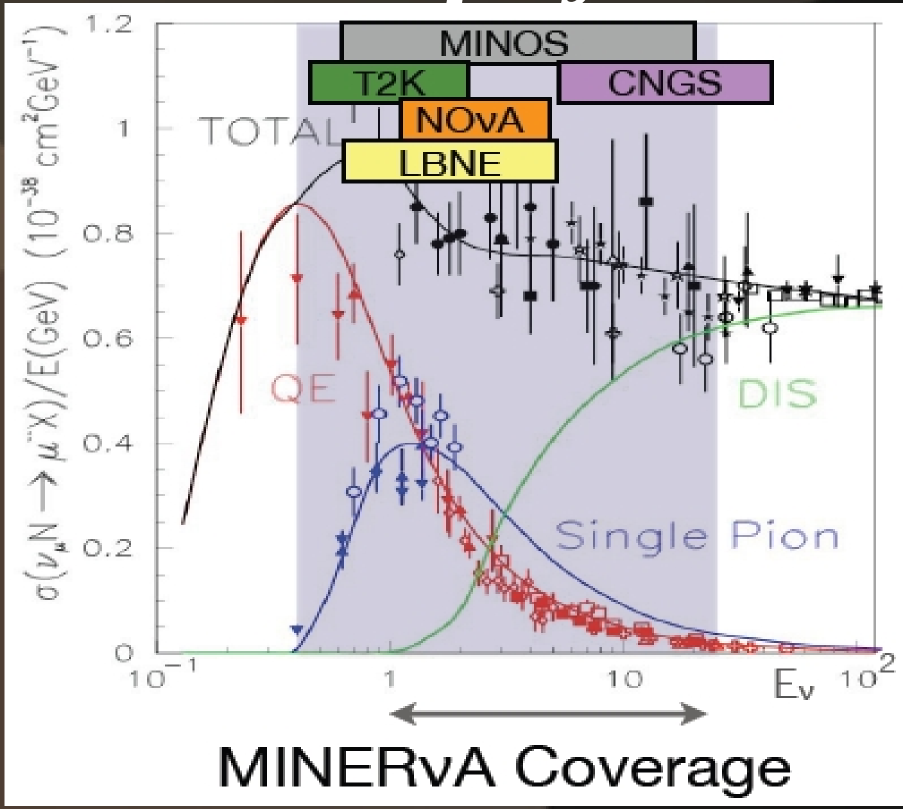
Outline

- Motivation and physics goals of MINERυA.
- Detector and beamline description.
- Reconstruction techniques developed by MINERυA.
- Event displays and kinematic distributions.

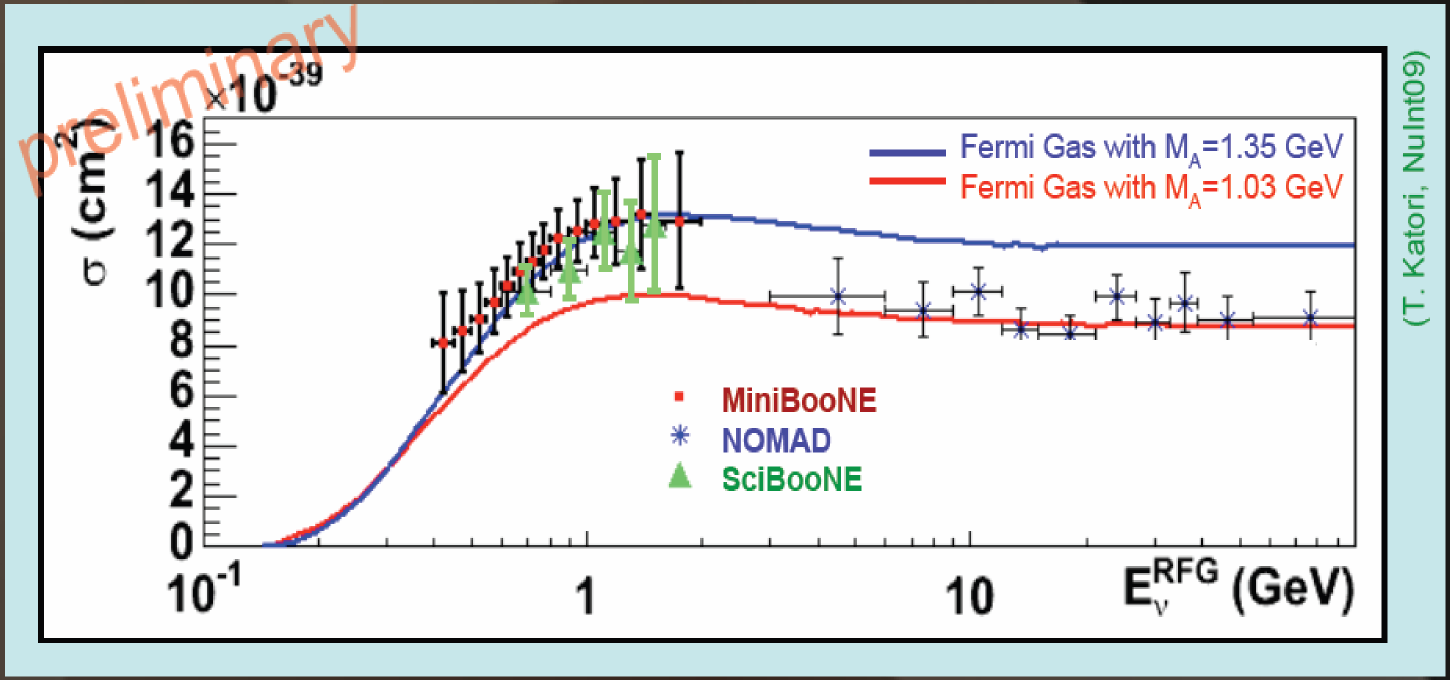
Testing Neutrino Interaction physics



G. P. Zeller

- Older Neutrino scattering experiments suffered from several deficiencies.
- Often bubble chamber experiments suffered from low statistics (~10 – 100 events).
- High-A material used as targets. Introduces poorly understood nuclear effects.
- Beam fluxes not well measured.
- No MiniBooNE or SciBooNE data, however...

MiniBooNE and SciBooNE data not consistent with NOMAD!



MINERυA is sensitive to this gap in energy.

Improving Oscillation Measurements

- Oscillation experiments still report results with larger errors / low significances.
- Part of this is statistics- neutrino interactions are rare.
- Uncertainties on the underlying cross-sections are typically the dominant systematic uncertainty.
- MINERυA is in a position to reduce these uncertainties by measuring these cross-sections with higher precision.

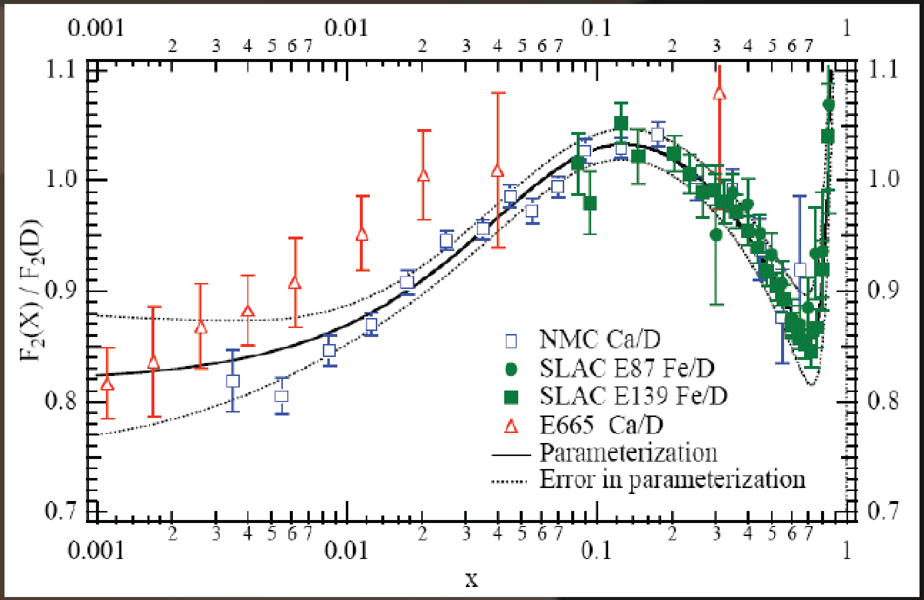
TABLE I. Sources of systematic uncertainties in the measurement of $|\Delta m^2|$ and $\sin^2(2\theta)$. The values are the average shifts for varying the parameters in both directions without imposing the $\sin^2(2\theta) \leq 1$ constraint on the fit. The shift resulting from each systematic effect is evaluated individually. The dominant uncertainties are incorporated as nuisance parameters in the fit of our data to Eq. (1) so as to reduce their effect on the oscillation parameter measurement (see text).

Uncertainty	$\lvert\Delta m^2\rvert$ (10^{-3} eV^2)	$\sin^2(2\theta)$
(a) Absolute hadronic E scale (±10.3%)	0.052	0.004
(b) Relative hadronic E scale (±3.3%)	0.027	0.006
(c) Normalization (±4%)	0.081	0.001
(d) NC contamination (±50%)	0.021	0.016
(e) μ momentum (range 2%, curvature 3%)	0.032	0.003
(f) $\sigma_\nu(E_\nu < 10$ GeV) (±12%)	0.006	0.004
(g) Beam flux	0.010	0.000
Total systematic uncertainty	0.108	0.018
Expected statistical uncertainty	0.19	0.09

Table of Systematic errors from MINOS. Items a, c and d. all contain contributions from event cross-section uncertainty. PRL 101 (13): 130502

Investigating Nuclear Effects

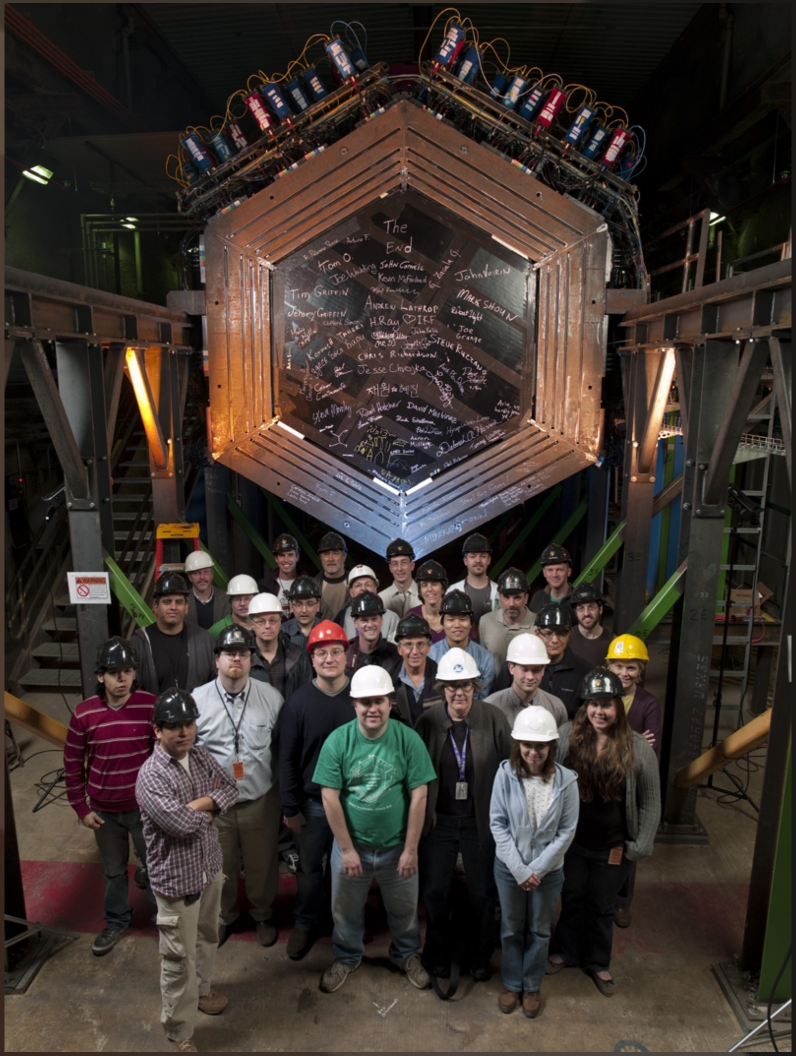
- Neutrinos provide a unique probe of nuclear structure because they only interact via weak.
- Nuclear shadowing predicted to be different for neutrinos vs. charged leptons.
- Nuclear effects are A dependent. MINERυA will measure the A dependence using multiple nuclear targets.



EMC effect well known for charged lepton DIS. Well known effect for neutrino DIS is ???

MINERνA to the rescue

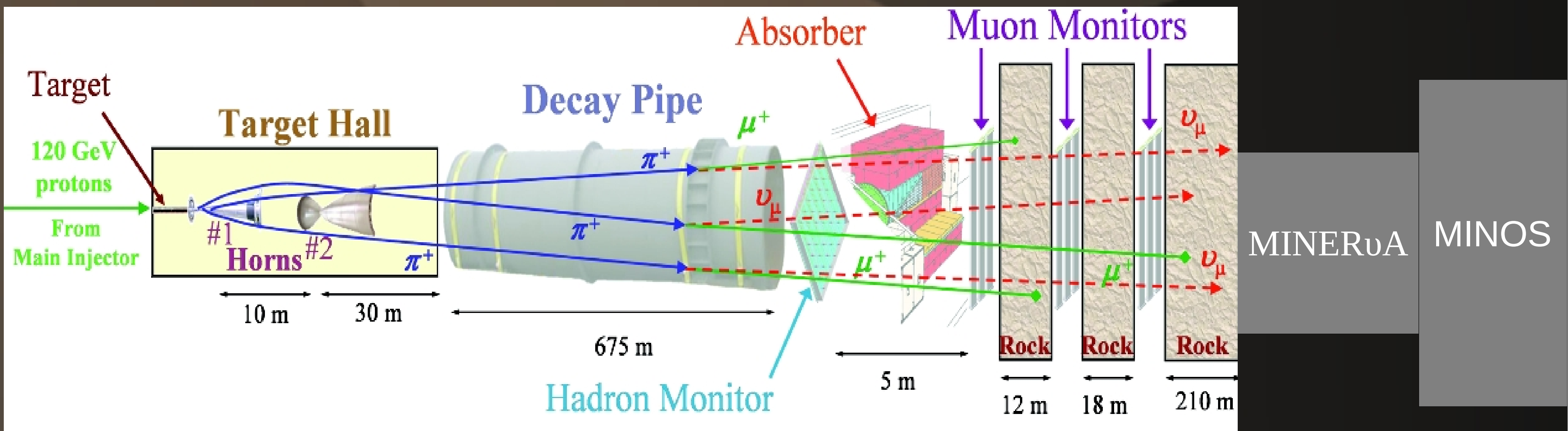
- MINERνA is designed to measure neutrino-nuclear cross sections on a variety of materials (C, Fe, Pb, He, H_2O).
- MINERνA rests in the high intensity NuMI neutrino beam at Fermilab in Batavia, IL.
- The high intensity beam + high resolution detector = high precision measurements.
- Over 80 scientists from 7 different countries.



Time Line of MINERνA

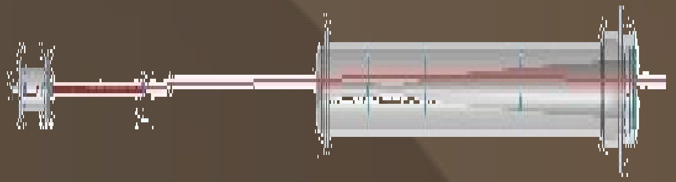
- 11/2009: Accumulated ~0.8x1020 POT of low energy (LE) anti-neutrino beam with 55% of detector commissioned.
- 2/2010: Installed remaining 45% of detector. Ran LE neutrino beam from 3/2010 -9/2010.
- 11/2010-Spring 2011: Run in LE anti-neutrino beam.
- Spring 2011-3/2012: Accumulate at least 4x1020 POT, plus 0.9x1020 POT in special runs to determine neutrino flux.
- 3/2012: Fermilab accelerator shutdown, switch to Medium Energy (~6 GeV average). Accumulate more than 12x1020 POT with NOνA.

NuMI (Neutrinos at the Main Injector) beamline

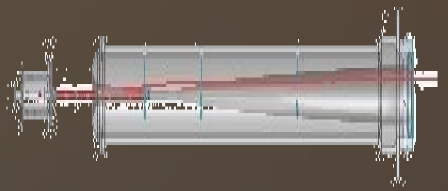


NuMI produces neutrinos by smashing 120 *GeV* protons from the FNAL Main Injector on to a graphite target, and allowing the resultant mesons to decay in the decay pipe. Magnetic horns let us sign select positive/negative mesons, which translates to muon/antimuon neutrinos in the beamline. Muon monitors count number of muons at three different locations inside the rock.

NuMI Beamline:

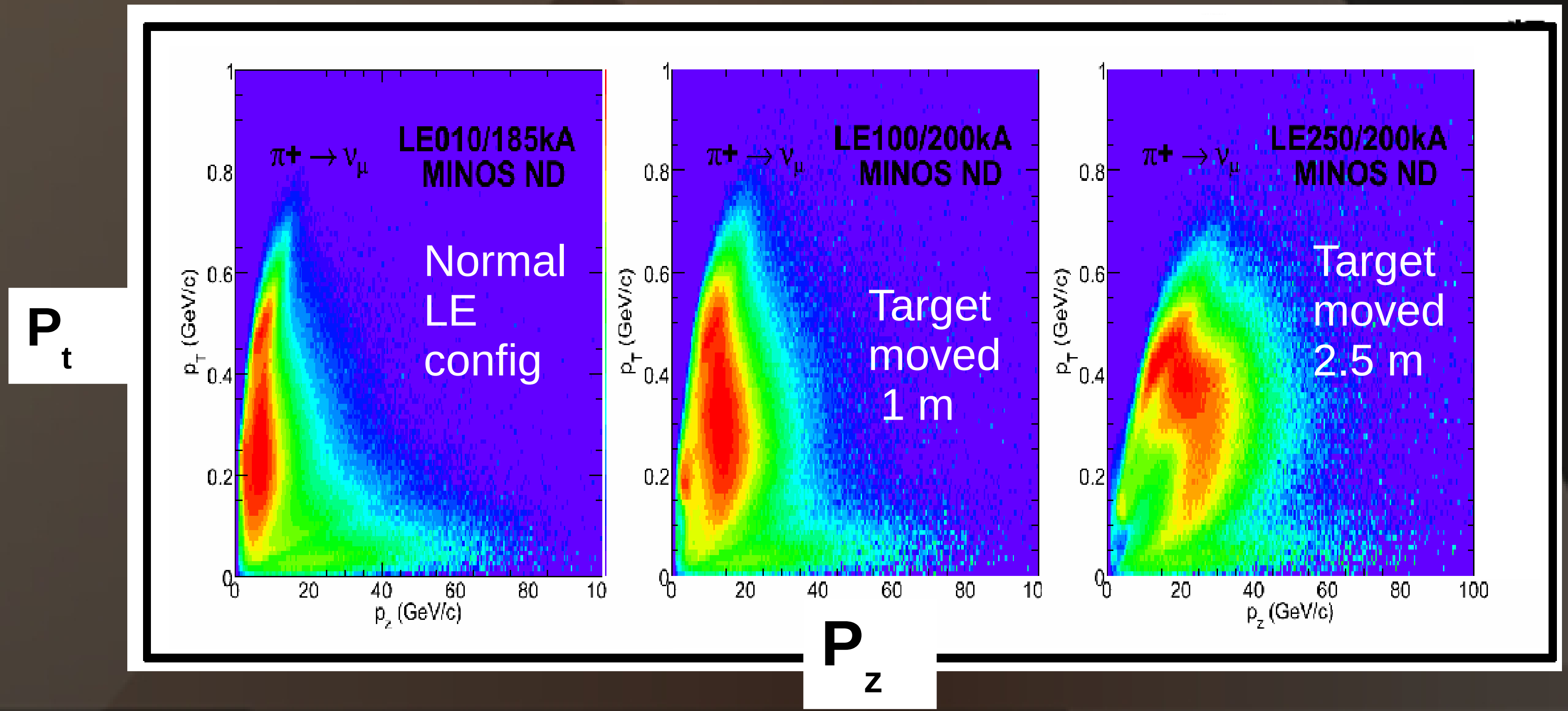


"High Energy" Configuration



"Low Energy" Configuration

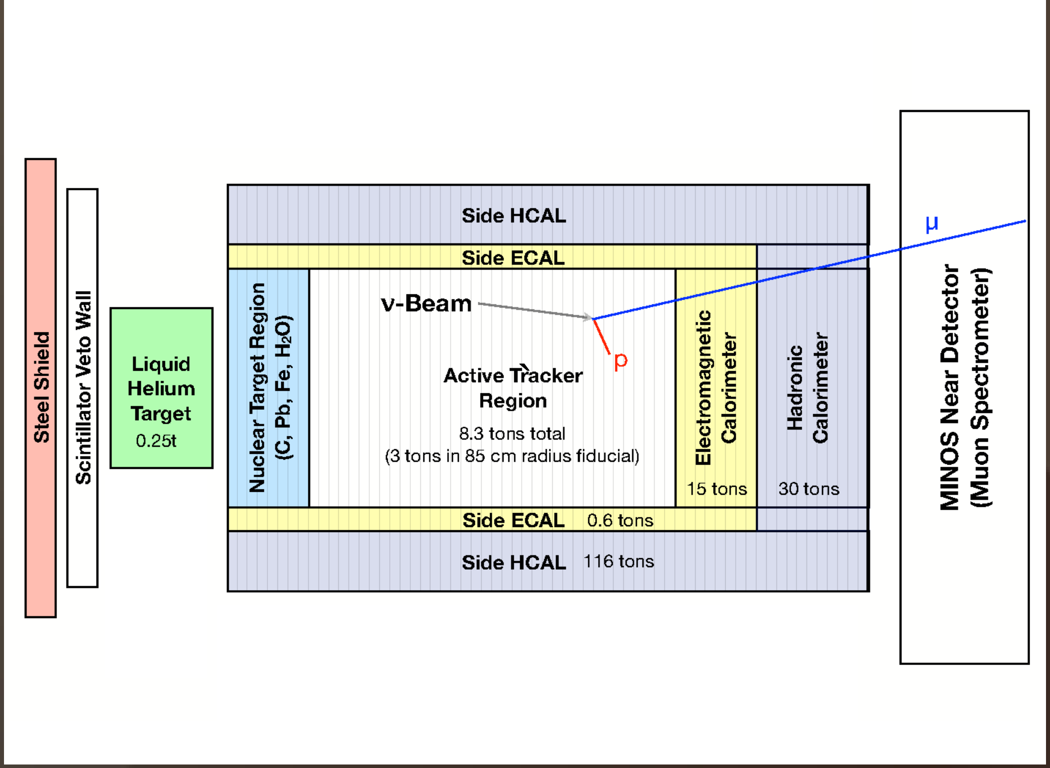
- The Graphite NuMI target is mounted on rails to allow different neutrino energy spectra.
- Target pulled out: only focus very low angle, high energy pions = higher neutrino energy.
- Use different horn configurations and muon monitor data to tune flux MC.
- Goal: understand flux normalization to ~10%.

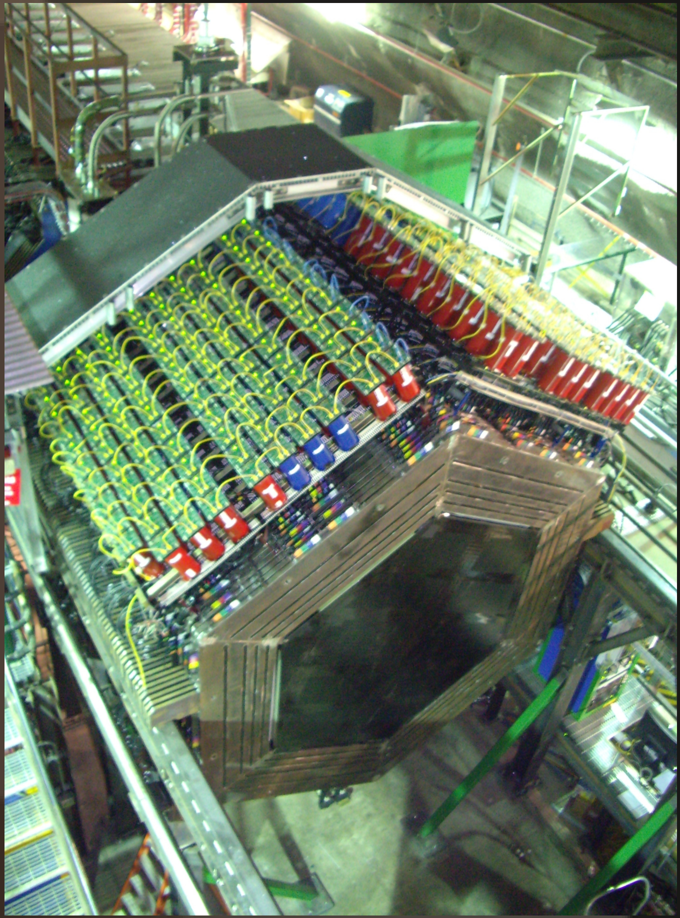


Structure of MINERνA

MINERνA consists of 120 hexagonal shaped "modules", each stacked one in front of the other in the direction of the neutrino beam.
Modules come in one of four types: nuclear target, tracker, EM calorimeter, and hadronic calorimeter.

Other detector elements: Veto Wall and cryogenic target.

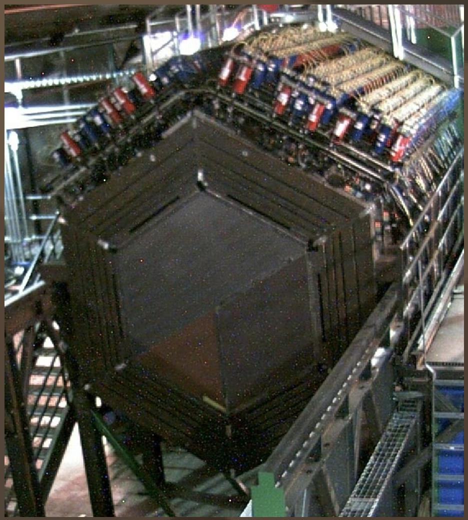




MINERνA under construction

Nuclear Targets

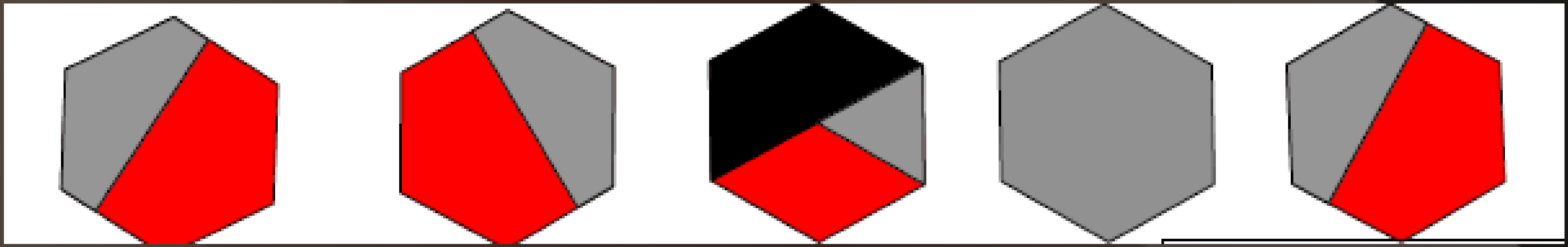
MINERυA employs nuclear targets of Fe, Pb, and C.
One of the goals of MINERυA is to study nuclear effects as a function of A.
C: Common material in scintillators.
Fe: Common material in calorimeters.
Pb: Stable, high A.



Key:
Gray = Pb
Red = Fe
Black = C

Target	Mass in tons	CC Events (Million)
Scintillator	3	9
He	0.2	0.6
C (graphite)	0.15	0.4
Fe	0.7	2.0
Pb	0.85	2.5
Water	0.3	0.9

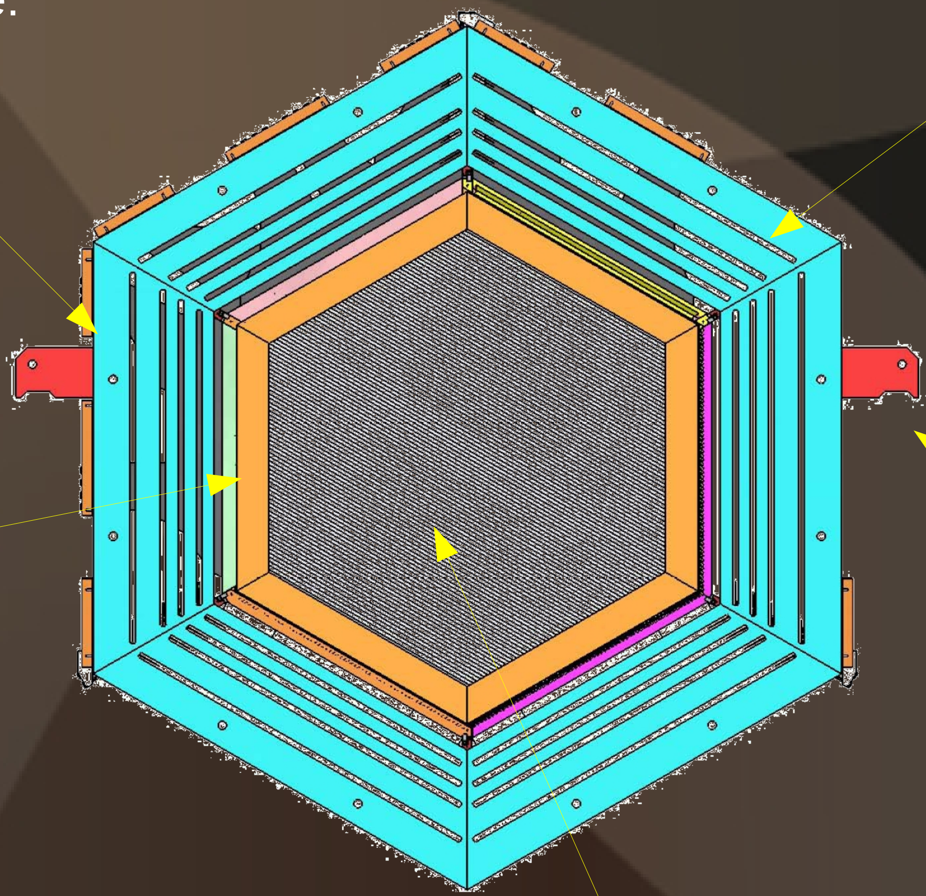
4×10^{20} POT LE beam + 12×10^{20} POT ME beam



Structure of a Module

Outer Detector Frame:
Fe, used for hadron calorimetry.

Scintillator bars in OD: Used to detect particles escaping out the side.

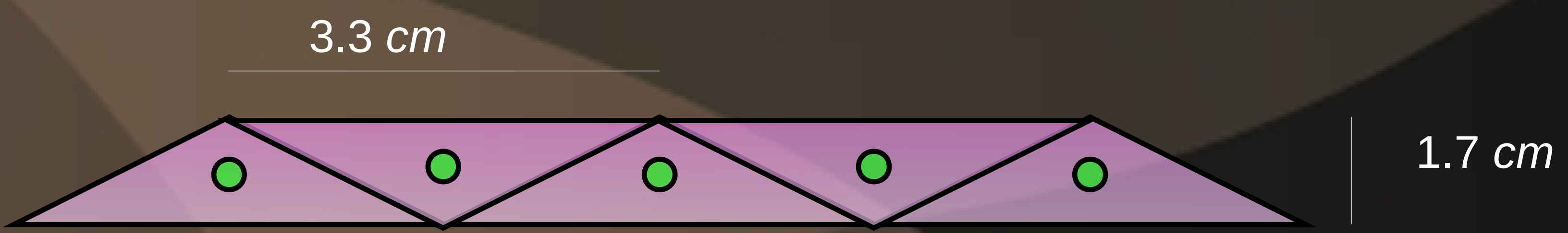


Lead collar:
surrounds edge of scintillator strips. Used for EM calorimetry.

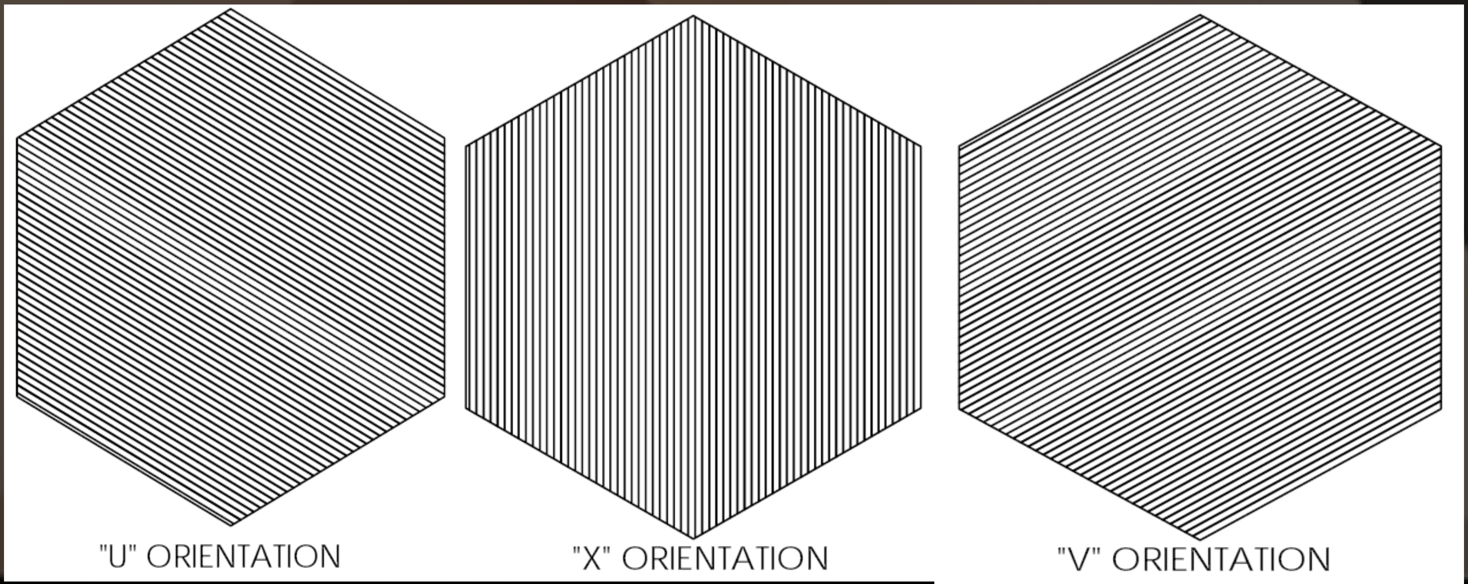
Steel supports used to hang modules on rail.

Inner Detector:
Plastic scintillator strips create light from moving charged particles.

Scintillator strips:



- Doped Polystyrene with WLS fiber running through the center.
- Triangular design of scintillator strips allows greater position resolution via charge sharing (transverse resolution about 3 mm).
- 127 strips makes up one plane.
- Strips orientation allows for a 3D view (see diagram).



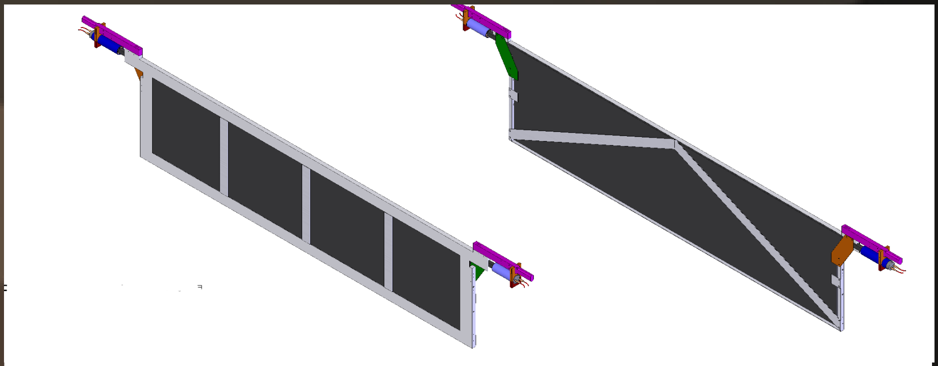
MINOS: MINERυA's Muon Spectrometer

- MINERυA cannot range out all high energy μ^- (too little mass).
- Muons are the most important particles in reconstructing υ_μ events, we need to know their energy and momentum.
- Solution: use MINOS, which is directly downstream of MINERυA. MINOS is equipped with a 1.1 - 1.5 T magnet.
- MINOS provides extra mass, so the muon energy can be measured by range.
- If the muon does not range out in MINOS, resort to measuring momentum by curvature.

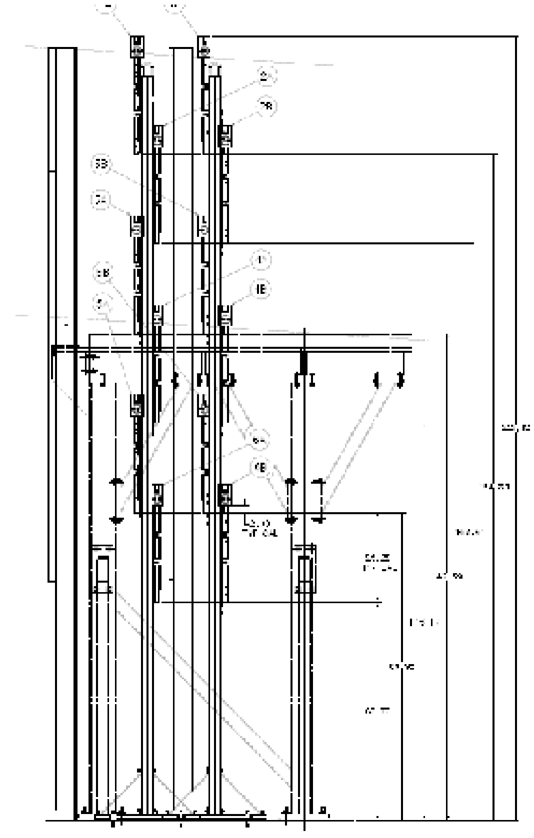
- MINOS magnetic field also lets us determine the sign of the muon, and if the event was neutrino or anti-neutrino.

Veto Wall

- Veto wall is designed to tag neutrino rock events which produce muons.
- Muons are vital to reconstructing our events; we need to make sure they originate in the target area and not the rock which surrounds the detector.
- Most important for upstream target and He analysis.
- Composed of two walls of 6 10' x 2.5' panels of scintillator + steel shielding.
- Each panel is read out by two one-channel PMTs. One on each side of the paddle.



Top: Graphic of veto panel
Bottom: Eng. Diagram of veto wall



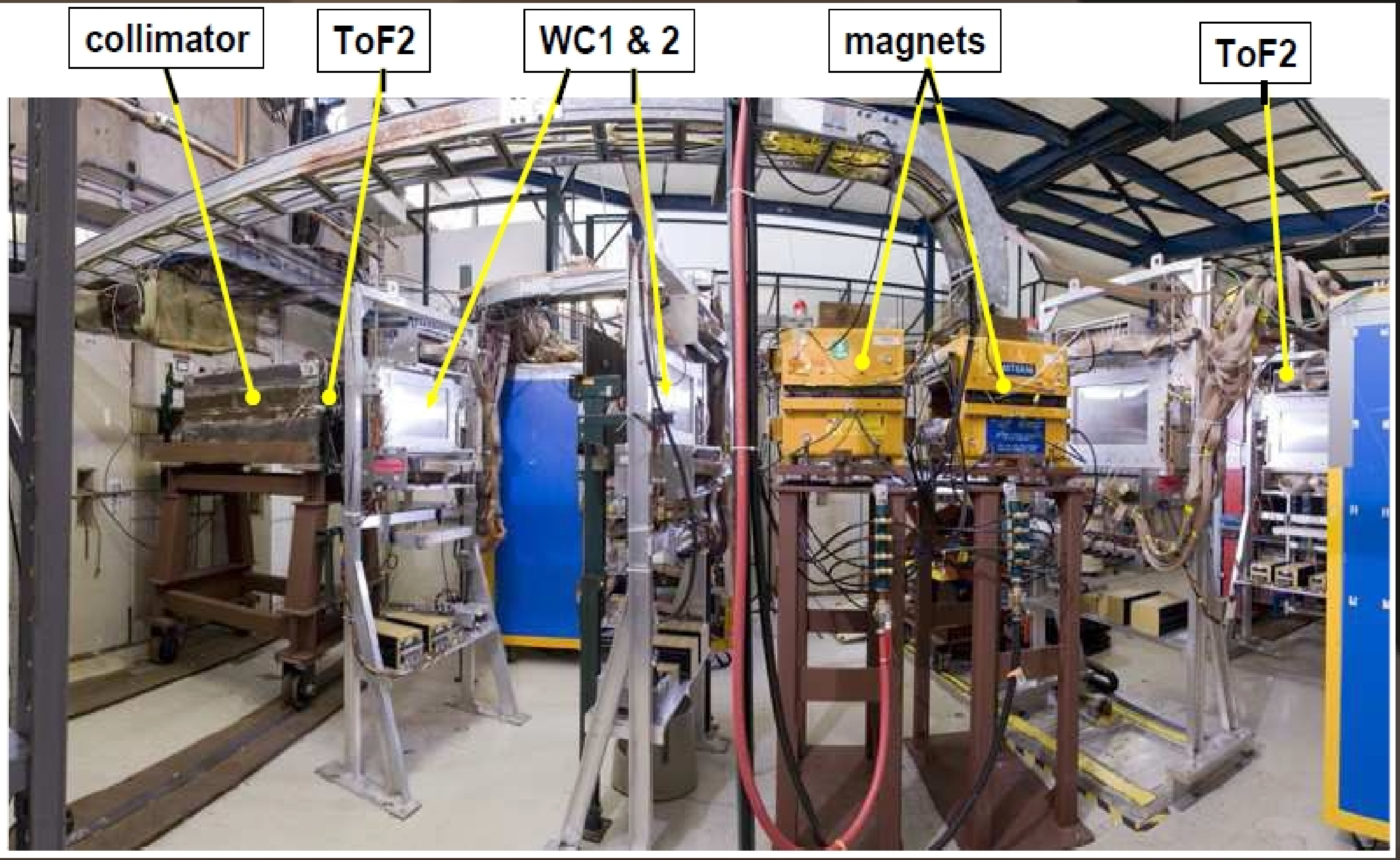
MINERνA Test Beam

Goal: To assist in reconstruction and simulation algorithms using beams of known particles and momenta (*p*, μ, π).

40 planes of Scintillator.

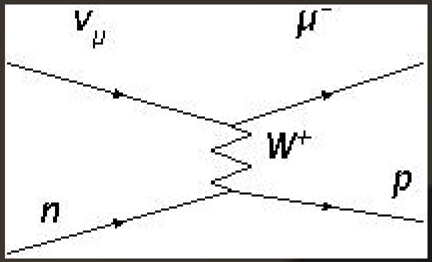
20 planes Fe, and 20 planes Pb acting as absorber materials for Electromagnetic and Hadronic Calorimeters respectively. Can configure to mimic any part of the main detector.

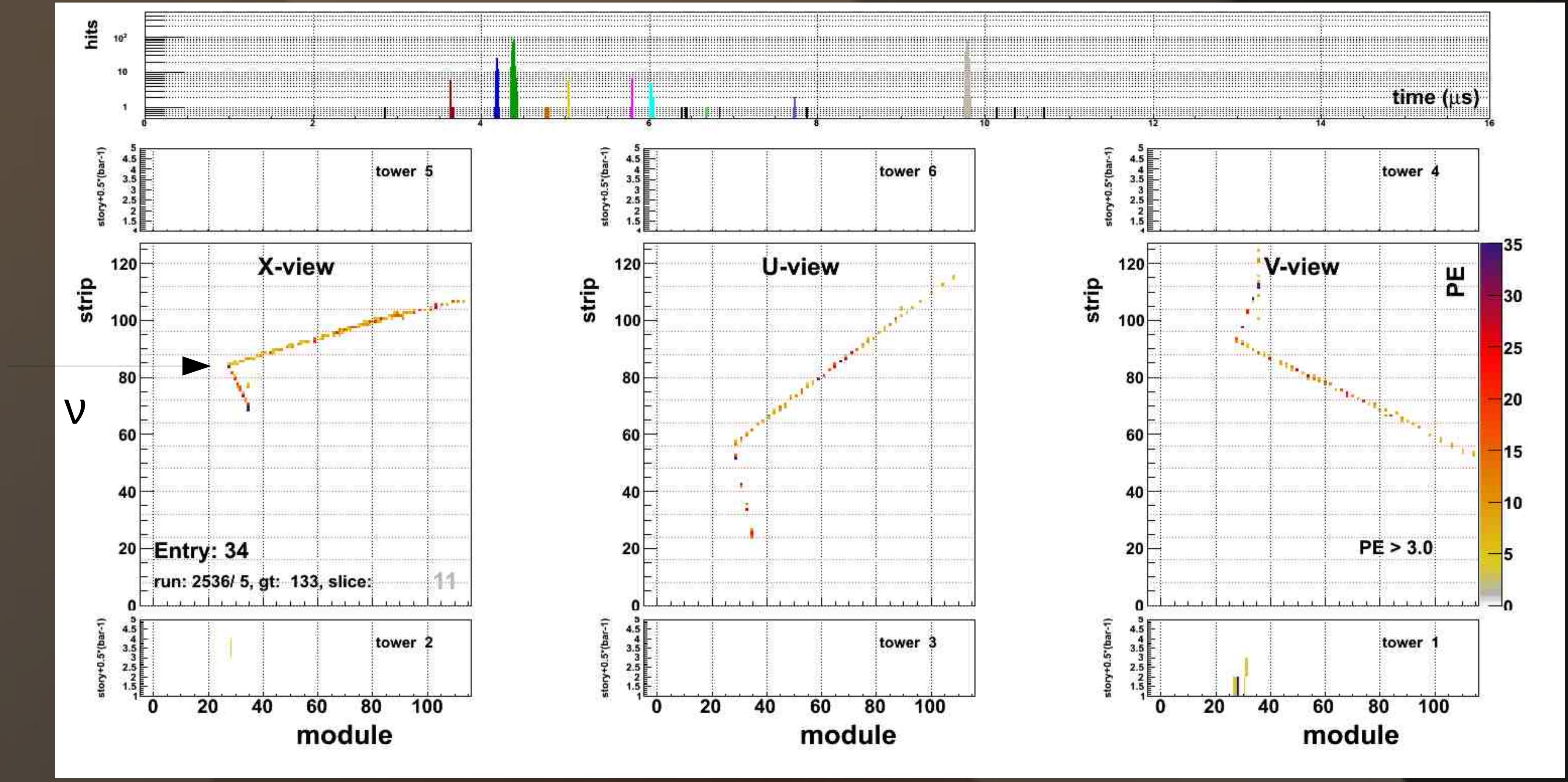
Took data Summer of 2010



The Test Beam detector, with scintillator modules and absorbers visible.

CCQE in MINERνA

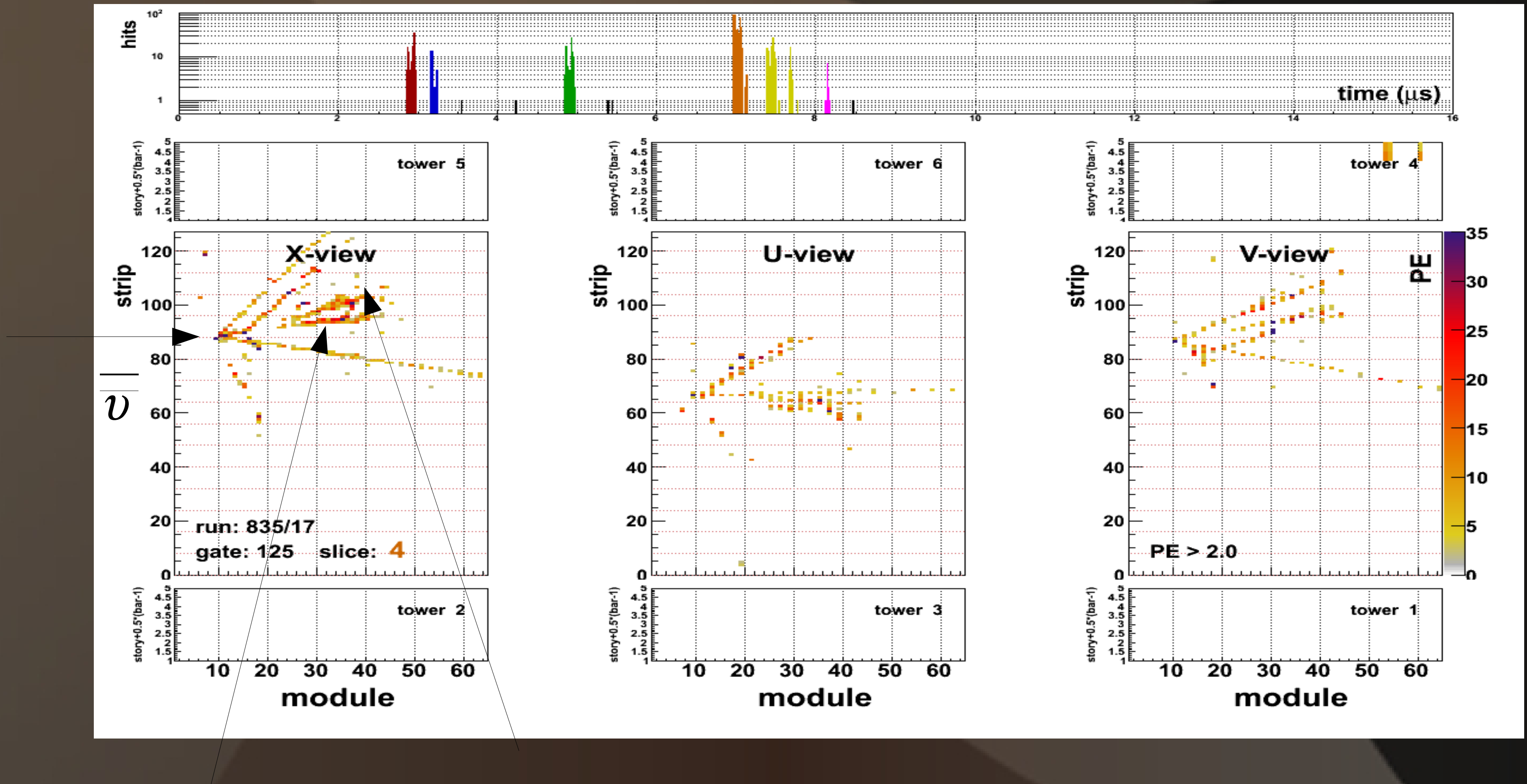




Hits are bunched into "Time Slices." (colored histogram on top) A time slice is a collection of hits occurring in the same (variable) time window.

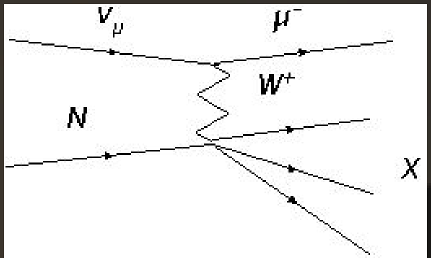
π^0 Event

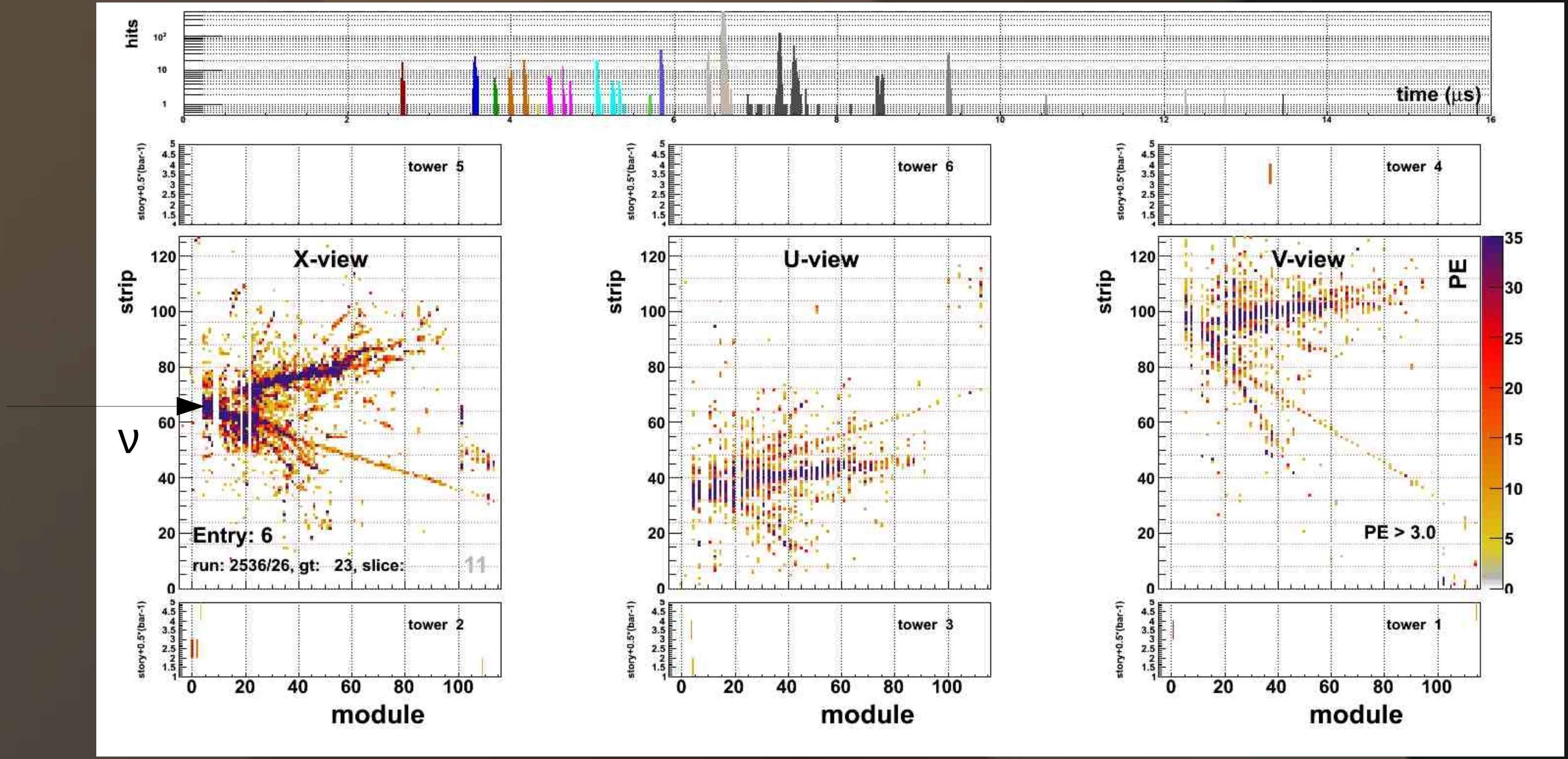
$\overline{\upsilon} + p \rightarrow \mu^{+} + \pi^{0} + X$



High resolution tracker allows us to distinguish two photon tracks from π^0 decay.

DIS Event in MINERνA

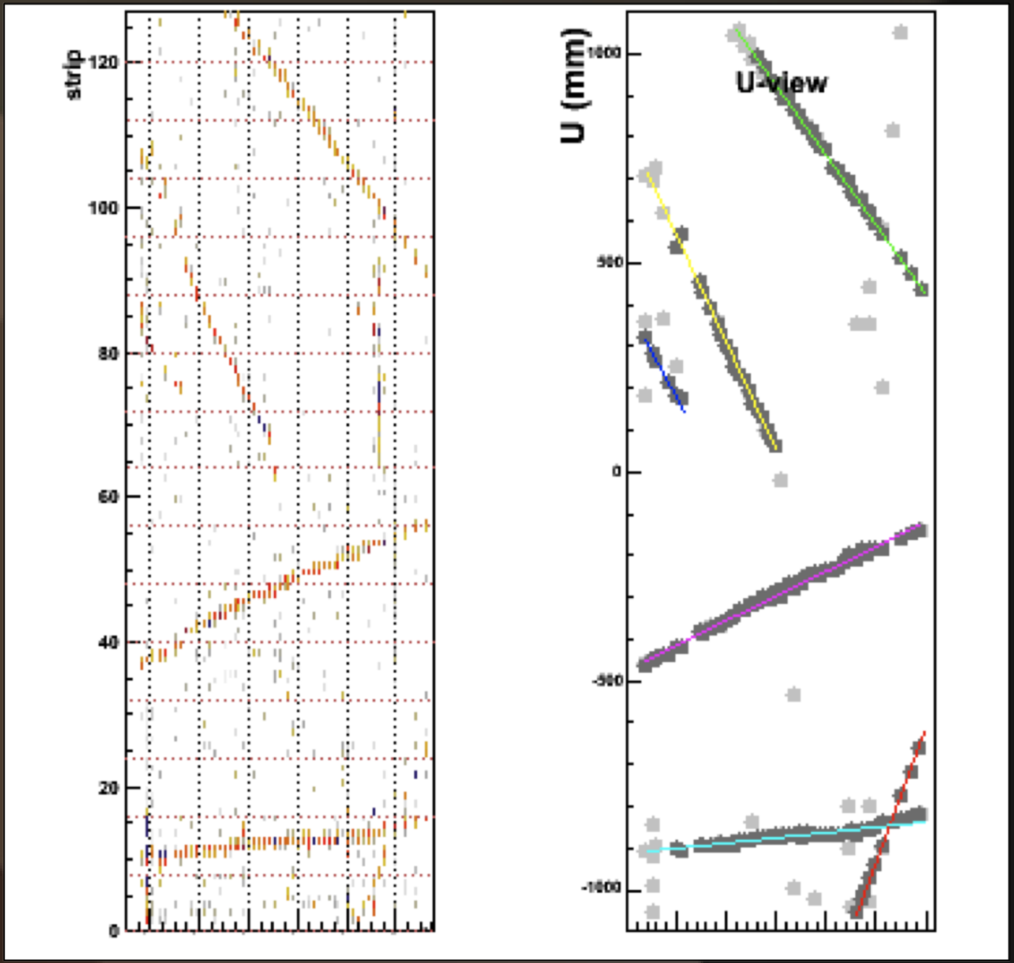




- Complex final states.
- Develop algorithms which decide which hits to track, and which to classify by calorimetry.

Pattern Recognition based tracking

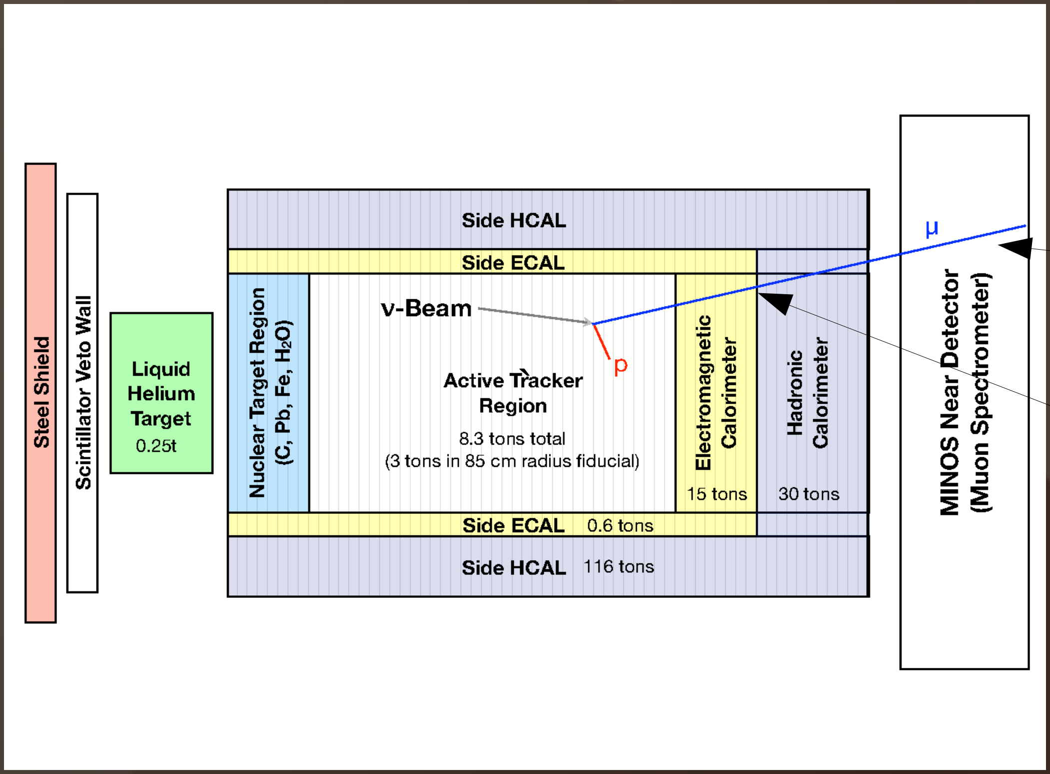
- Clustering algorithm takes nearby hits, forms into clusters.
- Clustering algorithim is "smart:" only picks out clusters which could have come from a muon.
- Clusters form 2D track candidates, which are merged across three views to form 3D track candidates.
- Track parameters are fit to a Kalman Filter.



Left: Hits seen in MINERυA
Right: Gray dots are clusters. Colored lines are tracks found by filter.

Muon Reconstruction

- For muons that escape the back of MINERυA, we use MINOS and their magnetic field to measure the momentum of the muon.
- From this measurement of the *final* momentum in MINOS, the MINERυA reconstruction walks the muon track backward through the MINERυA detector, adding back in a mips worth of energy at each step.



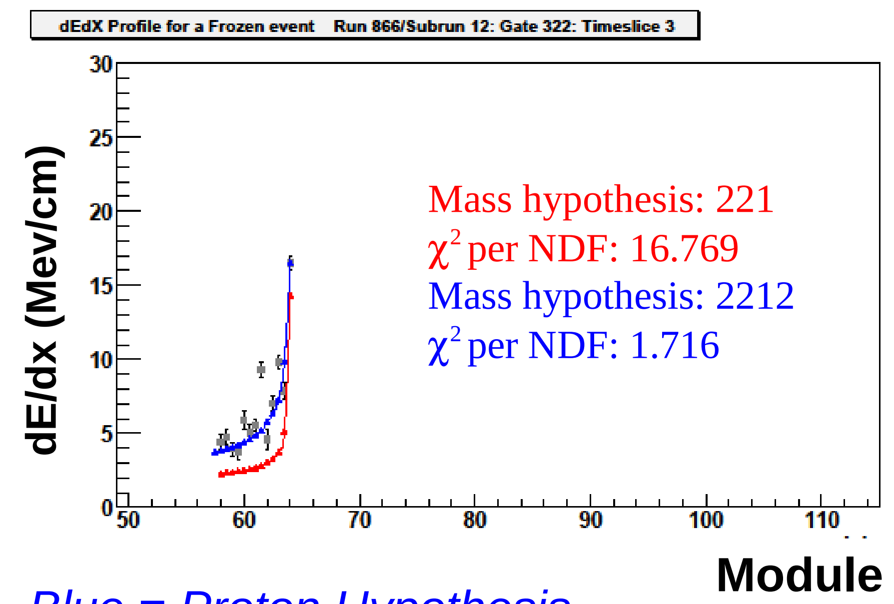
$$E_{initial.} = E_{MINOS} + \Sigma E_i$$

Muon track in MINOS

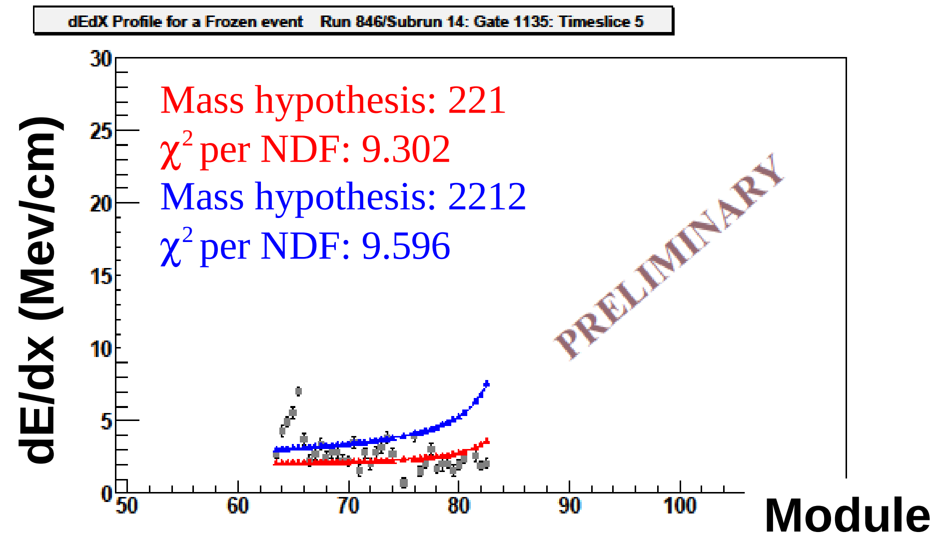
Muon track in MINERυA

PID via dE/dx

- Particle Identification is done by matching dE/dx profiles of tracks.
- Fit dE/dx to Bethe-Bloch model with a given mass hypothesis (K, p^+, π).
- Calculate χ^2 of fit to Bethe-Bloch each different mass hypothesis.
- Assign a particle identity based on χ^2 per NDF minimization.
- Classify profiles with analysis tags. Reco tags this as “vertex activity.”

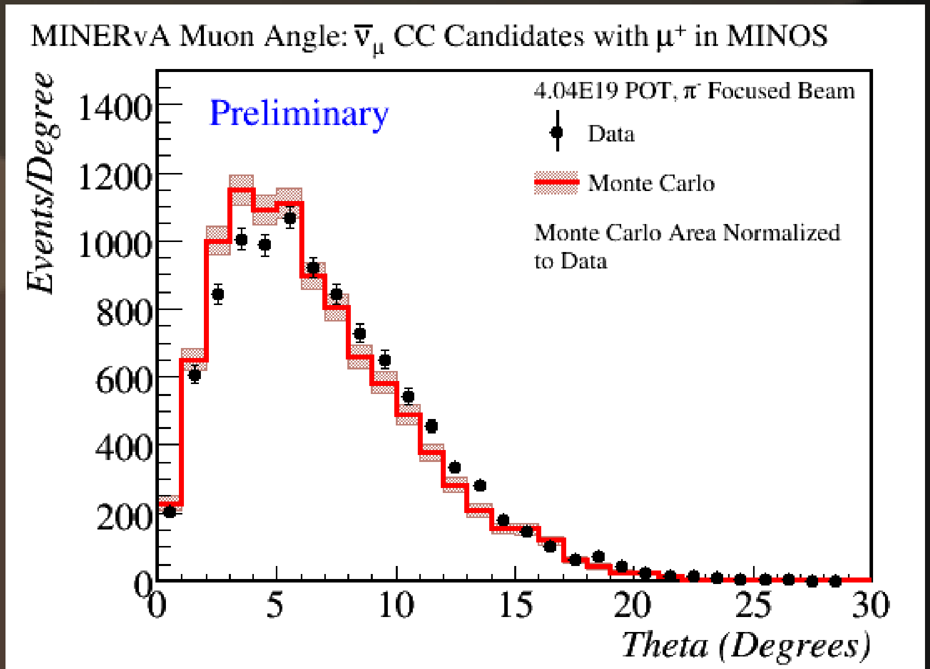


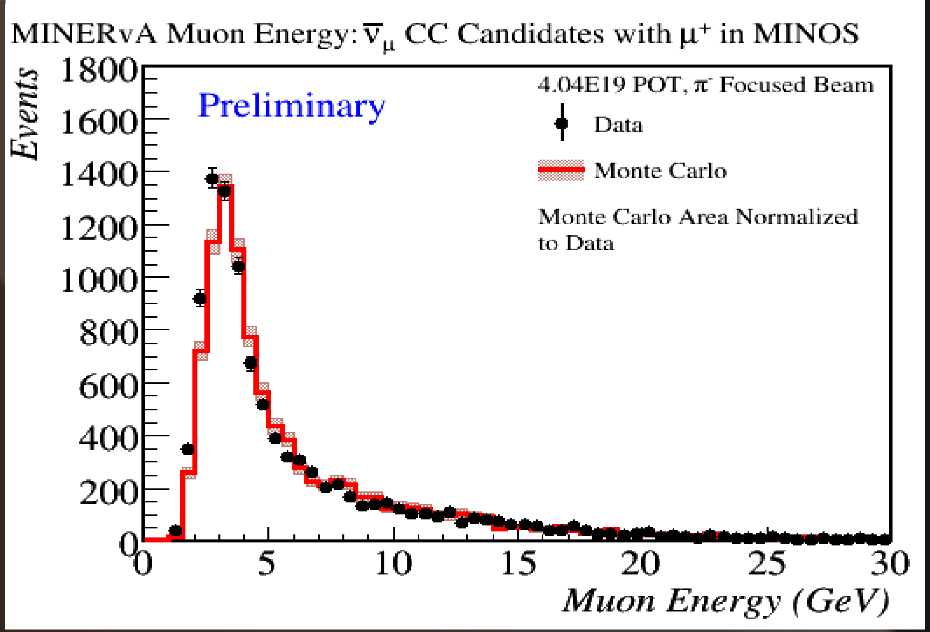
Blue = Proton Hypothesis
Red = Pion Hypothesis



Reconstruction at Work

- We tested our reconstruction on data and MC. Using CC like events.
- Data: 4.04×10^{19} POT in anti-ν mode.
- MC: MC generator GENIE v 2.6.0
  - GEANT4 detector simulation.
  - 2×10^{19} POT MC , LE Beam MC flux, untuned.
  - Plots Area Normalized.
- Reconstruction code has been improved recently.





All signs point to working reconstruction!

Summary

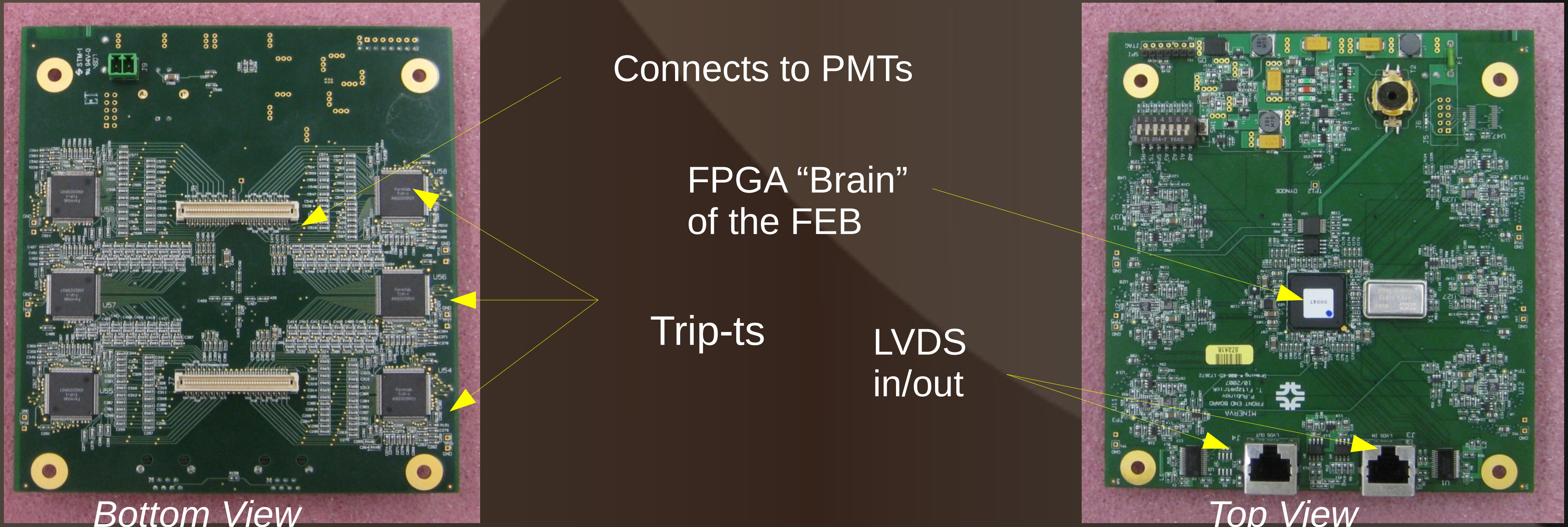
- MINERυA is constructed, running and going strong.
- MINERυA will make valuable contributions to neutrino and nuclear physics.
- Reconstruction has been Tested, is working well.
- *Physics results are coming soon!*

Thank you for listening!

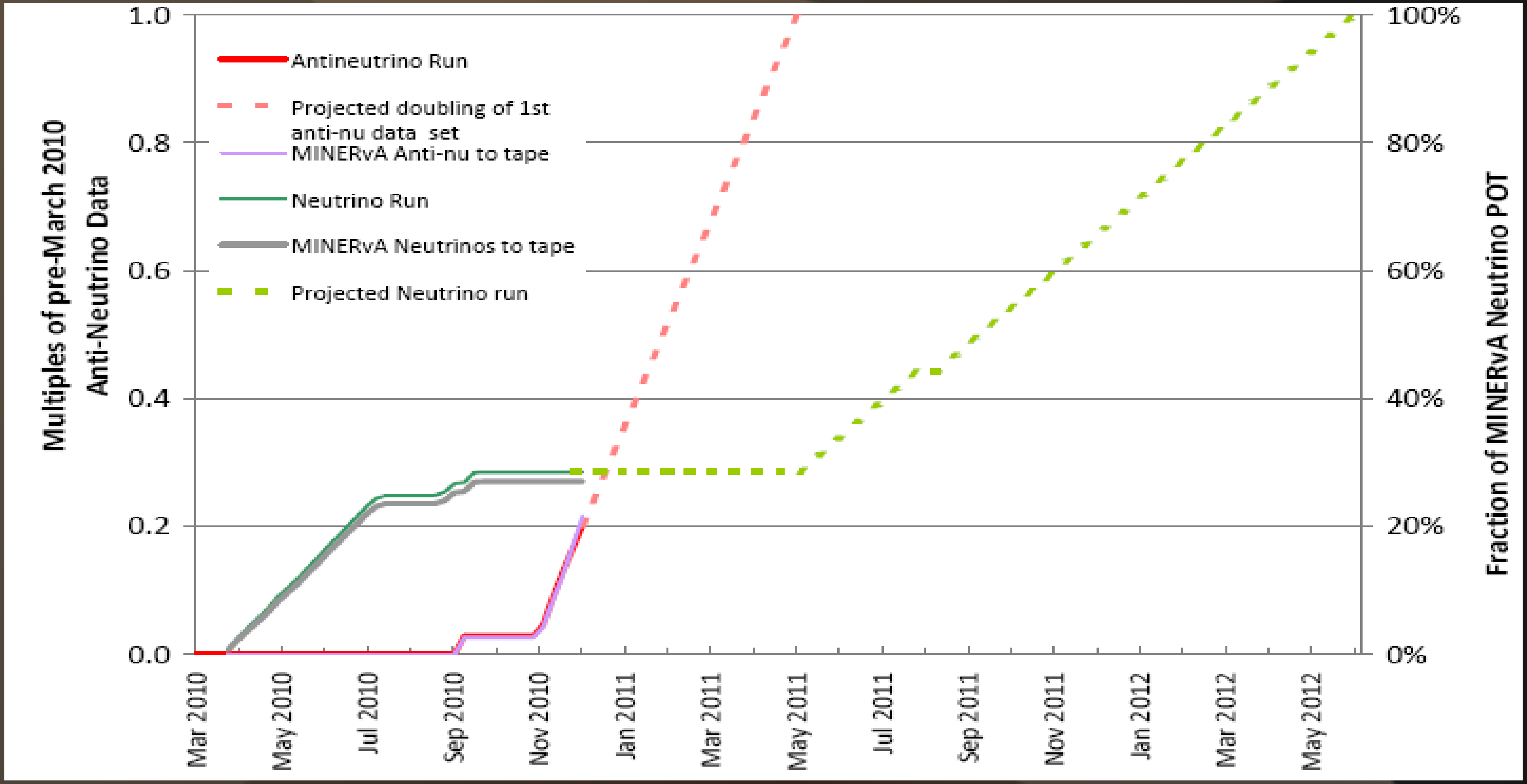
Backup Slides

Readout electronics

- Each MINERυA PMT box is connected to a front end electronics board (FEB).
- FEBs are responsible for controlling PMT high voltage, digitizing PMT signals, and environmental monitoring.
- Digitization is handled by 6 Trip-t chips (technology developed by D0) using pipeline ADCs.



MINERνA Run Plan + POT to Date



Data Acquisition

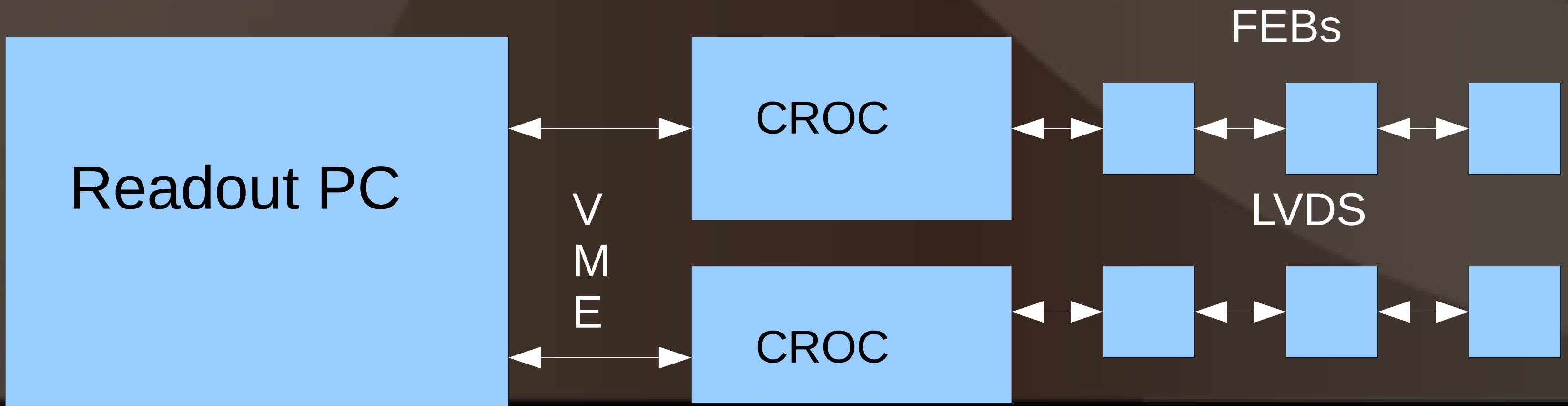
12 FEBs are daisy-chained together to form a chain.

Chains read out in series to a VME module Chain Read Out Card (CROC).

Each CROC is responsible for four chains.

CROCs issue command to chains (open gate, readout ADC blocks, close gate, etc.)

CROCs talk to main DAQ computer via VME for slow control, data storage etc.



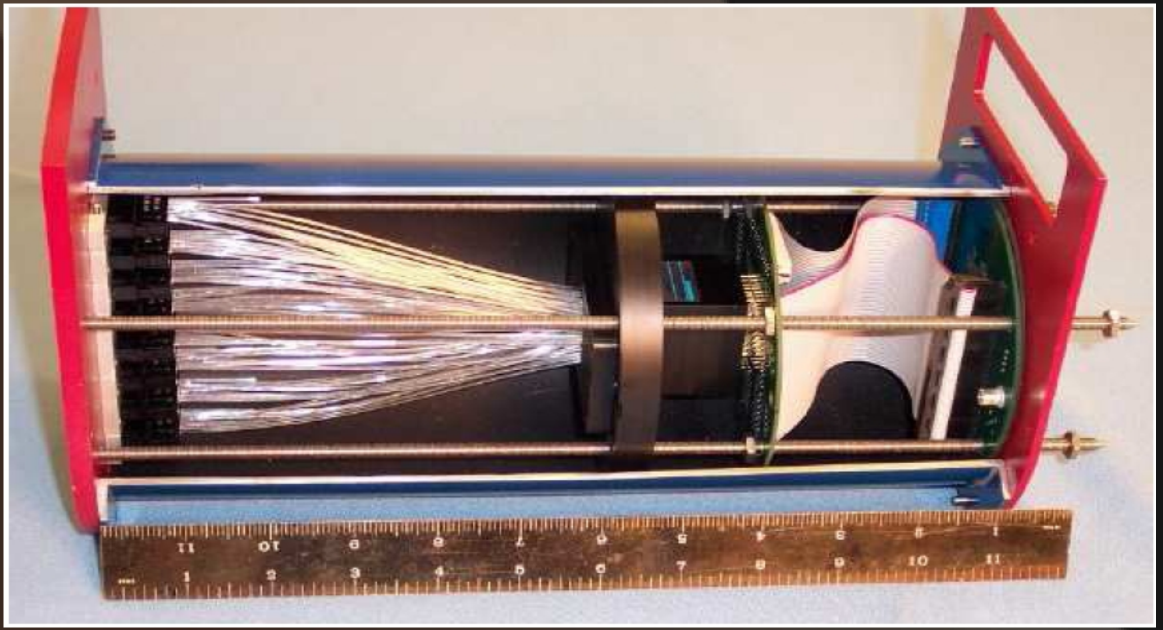
MINERυA PMTs

Light from the scintillator travels through the green WLS fiber, until it exits the plane.

Clear optic fibers carry the light from the plane to MINERυA PMT boxes (bottom right). Fibers inside the box carry the light to a Hamatsu M-64 PMT.

Fiber weave separates adjacent scintillator strips to non-neighboring PMT pixels to reduce optical cross talk.

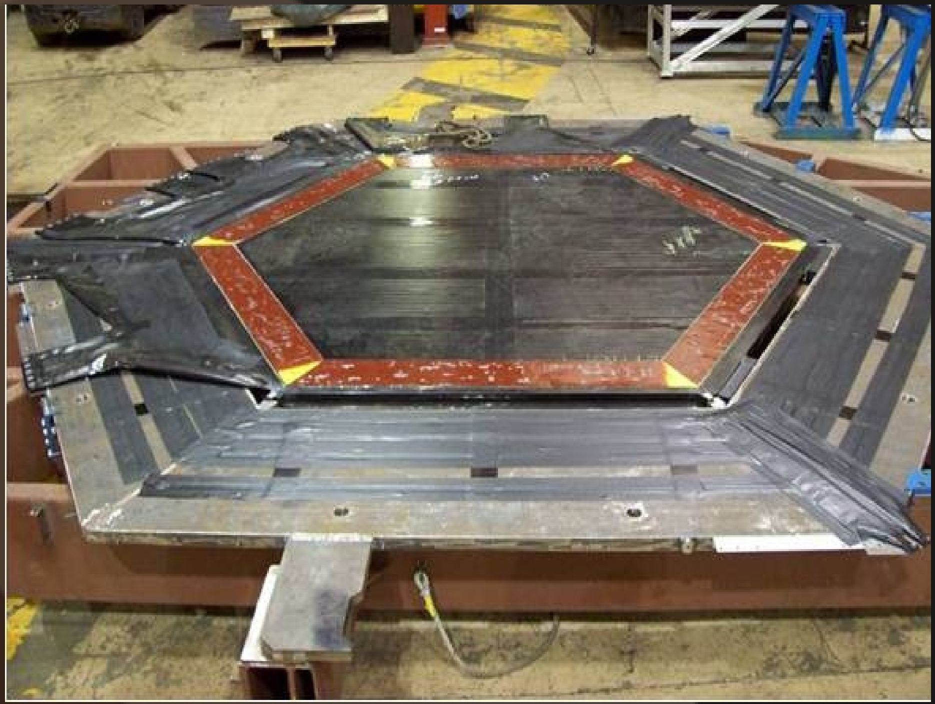
Fibers terminate on a plastic “cookie” which mechanically mates with PMT base.



Cut away of a PMT box, showing the weave, cookie, and PMT. MINERυA has 507 PMT boxes installed.

Structure of Modules (cont'd)

- Target Module: One layer of target material (Fe, C or Pb) and one layer of scitntillator (5 modules).
- Tracker Module: Two layers of scintillator (84 modules) 3.71 interaction lengths.
- ECal module: Two sheets of lead, surrounding two layers of scintillator (10 modules) 8.3 rad lengths.
- HCal module: One layer of Fe + one layer of scintillator (20 modules) 3.7 interaction lengths.



MINERνA module under construction

In Situ *Flux Measurement*

- Variable beam configurations offer *in situ* flux method.
- Can check cross sections at single E_ν using several beam configurations.
- Measure event spectrum with QEL's.
- Normalize to high energy DIS
- Goal is 7% error flux shape, 10% norm.