Status of the MINERνA Neutrino Scattering Experiment at Fermilab

NuInt 2011

The 7th International Workshop On Neutrino-Nucleus Interactions in the Few-GeV Region

March 7-11, 2011 – Dehradun, Uttarakhand, India

David Schmitz
Fermi National Accelerator Laboratory
On behalf of the MINERνA Collaboration

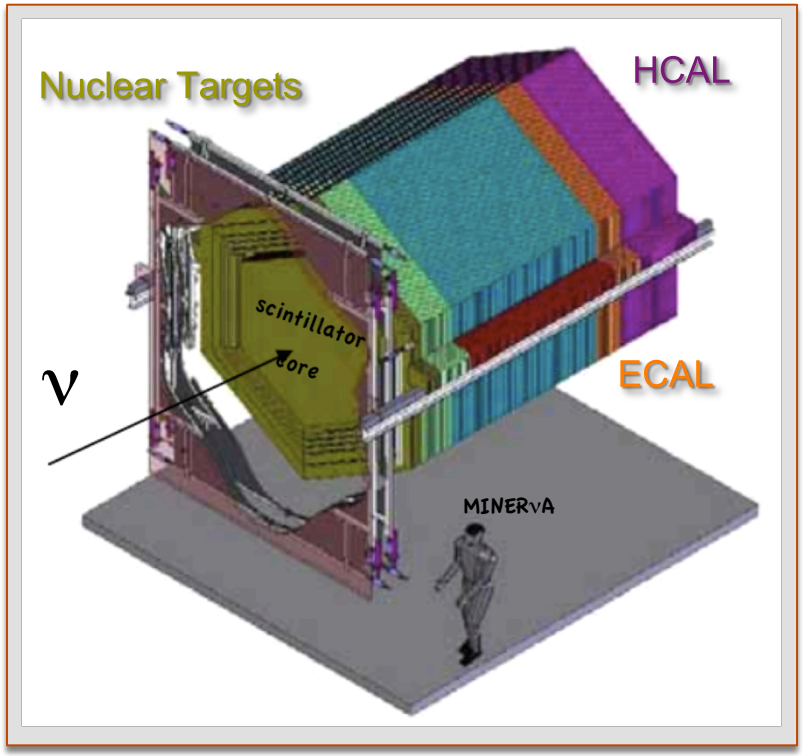
Outline

First and foremost MINERνA is up and running!
Collecting data > 1 year, working toward first results

- **Description of the MINERνA Experiment**
  - Detector components, layout, technology, readout
  - The NuMI facility at Fermilab
- **Status of Data Taking & Future Run Plan**
- **Detector Calibration**
- **Strategy & Status of Event Reconstruction**
  - CC Events: Muon tracking and momentum reconstruction
  - Next steps
- **Advertisements**

MINERνA Basics

- Finely-segmented, fully-active scintillator detector core surrounded by electromagnetic and hadronic calorimetry
  - Ability to fully reconstruct *exclusive final states*
  - Also do the physics of high-energy, high-multiplicity *inclusive event samples*
- Range of nuclear targets in single detector (and flux) for measuring A dependence, studying nuclear effects in neutrino interactions
- Makes use of existing high-intensity NuMI neutrino beamline at Fermilab
- Also uses existing MINOS Near Detector as a muon spectrometer



MINERνA Collaboration

The Collaboration is 100 members from 22 institutions in 7 countries

HEP, Nuclear and Theory

G. Tzanakos
University of Athens

J. Cravens, M. Jerkins, S. Kopp, L. Loiacono, J. Ratchford, R. Stevens IV
University of Texas at Austin

D.A.M. Caicedo, C.M. Castromonte, H. da Motta, G. A. Fiorentini, J.L. Palomino
Centro Brasileiro de Pesquisas Fisicas

J. Grange, J. Mousseau, B. Osmanov, H. Ray
University of Florida

D. Boehnlein, R. DeMaat, N. Grossman, D. A. Harris, J. G. Morfn, J. Osta, R. B. Pahlka, P. Rubinov, D. W. Schmitz, F.D. Snider, R. Stefanski
Fermilab

J. Felix, A. Higuera, Z. Urrutia, G. Zavala
Universidad de Guanajuato

M.E. Christy, C. Keppel, P. Monagham, T. Walton, L. Y. Zhu
Hampton University

A. Butkevich, S.A. Kulagin
Inst. Nucl. Reas. Moscow

G. Niculescu, I. Niculescu
James Madison University

E. Maher
Mass. Col. Lib. Arts

L. Fields, B. Gobbi, L. Patrick, H. Schellman
Northwestern University

N. Tagg
Otterbein College

S. Boyd, I. Danko, S.A. Dytman, B. Eberly, Z. Isvan, D. Naples, V. Paolone
University of Pittsburgh

A. M. Gago, N. Ochoa, J.P. Velasquez
Pontificia Universidad Catolica del Peru

S. Avvakumov, A. Bodek, R. Bradford, H. Budd, J. Chvojka, M. Day, H. Lee, S. Manly, C. Marshall, K.S. McFarland, A. M. McGowan, A. Mislivec, J. Park, G. Perdue, J. Wolcott
University of Rochester

G. J. Kumbartzki, T. Le, R. D. Ransome, E. C. Schulte, B. G. Tice
Rutgers University

H. Gallagher, T. Kafka, W.A. Mann, W. P. Oliver
Tufts University

C. Simon, B. Ziemer
University of California at Irvine

R. Gran, M. Lanari
University of Minnesota at Duluth

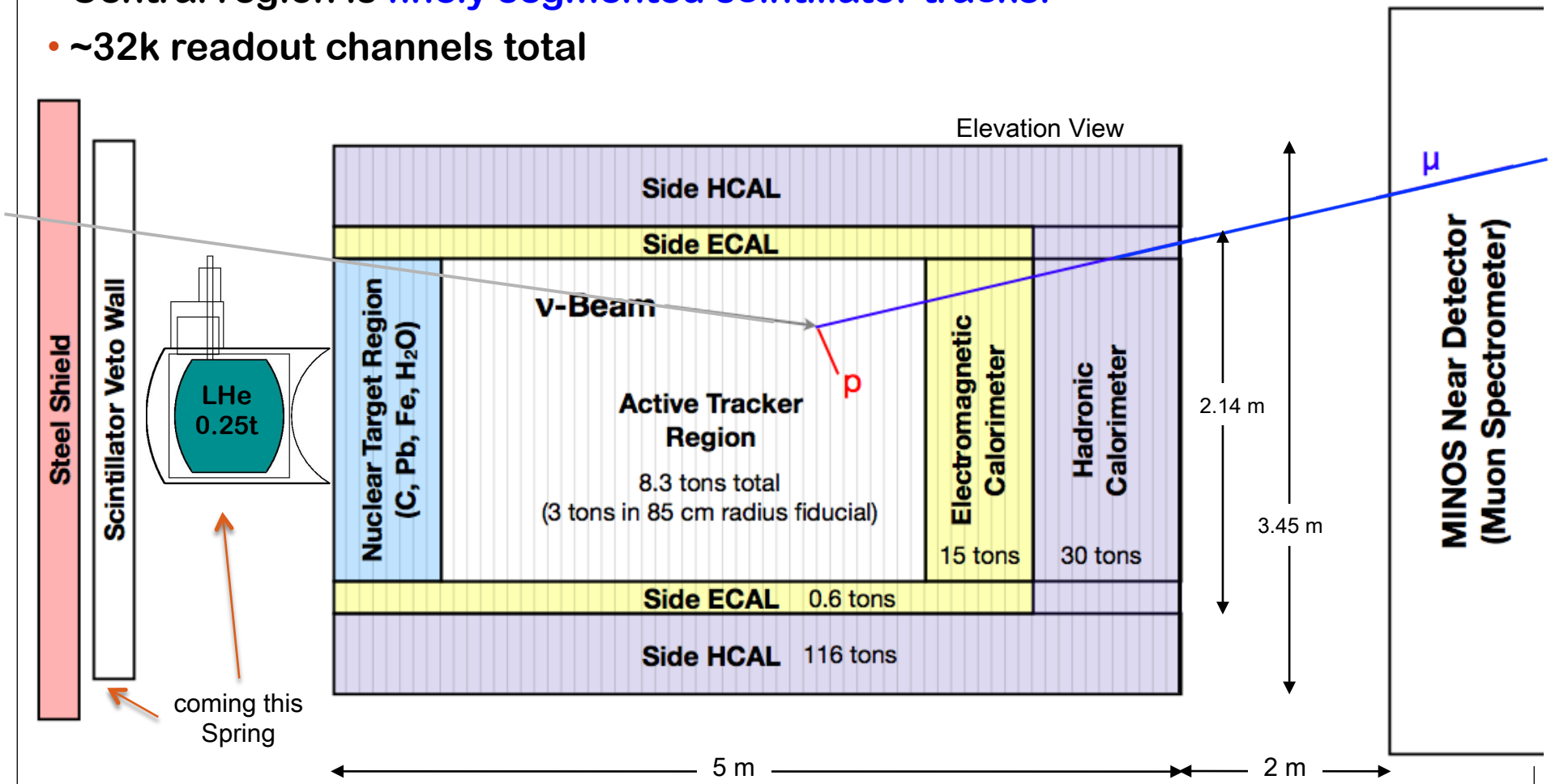
M. Alania, A. Chamorro, K. Hurtado, C. J. Solano Salinas
Universidad Nacional de Ingeniera

W. K. Brooks, E. Carquin, G. Maggi, C. Pea, I.K. Potashnikova, F. Prokoshin
Universidad Tcnica Federico Santa Mara

L. Aliaga, J. Devan, M. Kordosky, J.K. Nelson, J. Walding, D. Zhang
College of William and Mary

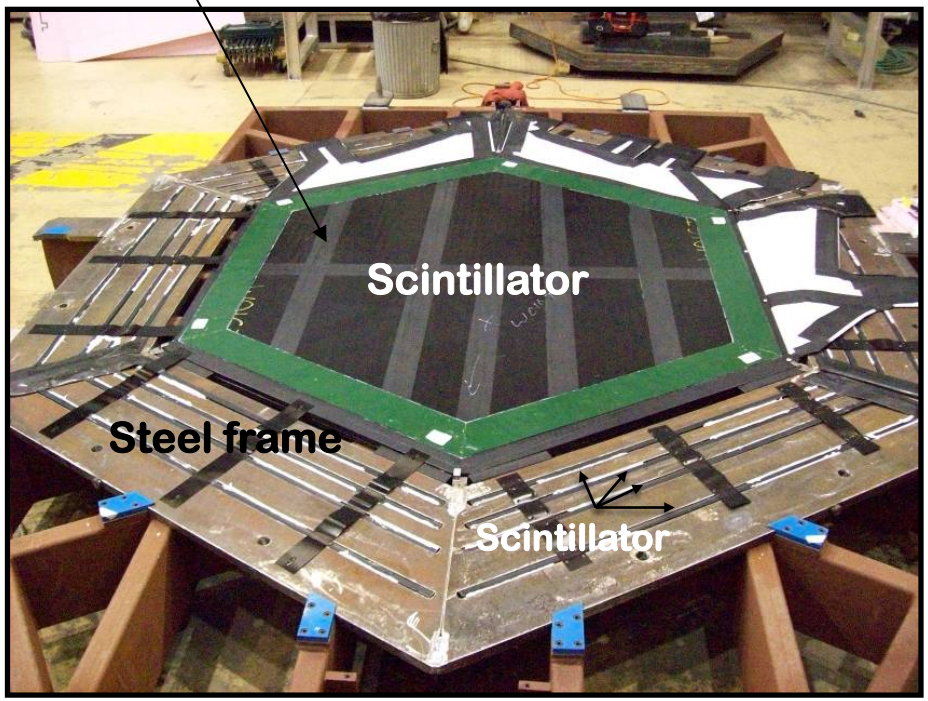
Detector Layout

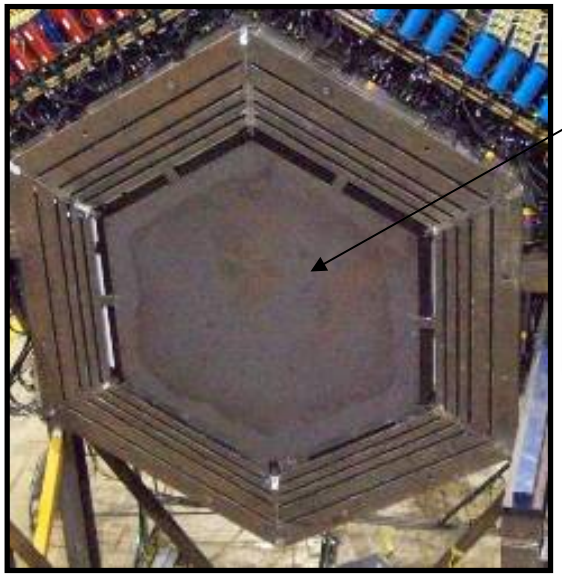
- Detector comprised of 120 "modules" stacked along the beam direction
- Central region is finely segmented scintillator tracker
- ~32k readout channels total



4 Types of Modules

1) Tracker modules have two planes of segmented scintillator measuring two different views (UX or VX)



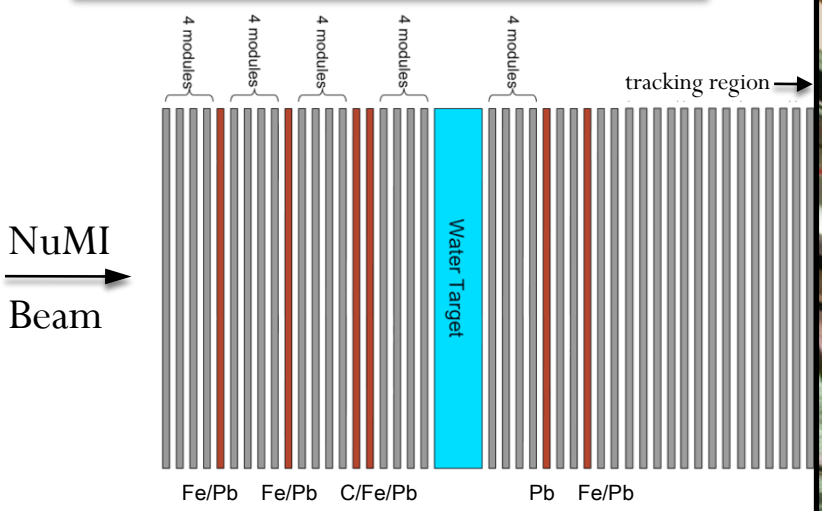


3) Hadronic Calorimeter (HCAL) modules include 1 inch thick steel absorber and one scintillator plane

2) Electromagnetic Calorimeter (ECAL) modules incorporate two 2 mm thick lead absorbers with 2 scintillator planes

4 Types of Modules

4) Nuclear Target modules have no central scintillator. Thin solid sheets welded inside outer steel frame.

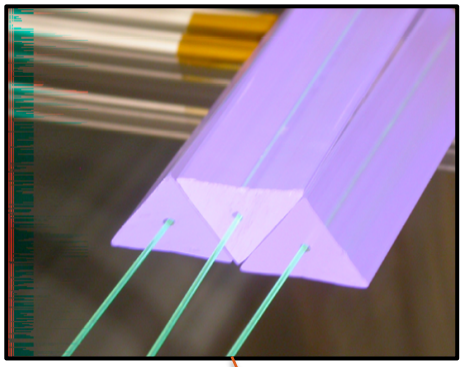


Nuclear Target	Fid .Vol.
CH (tracker)	6.43t
He	0.25t
C	0.17t
Fe	0.97t
Pb	0.98t

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

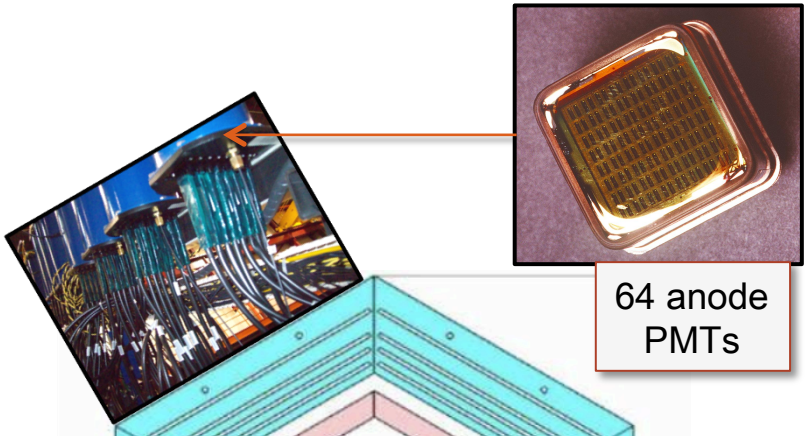
Please see talk from B. Tice on Thursday afternoon

Scintillator Planes & Readout

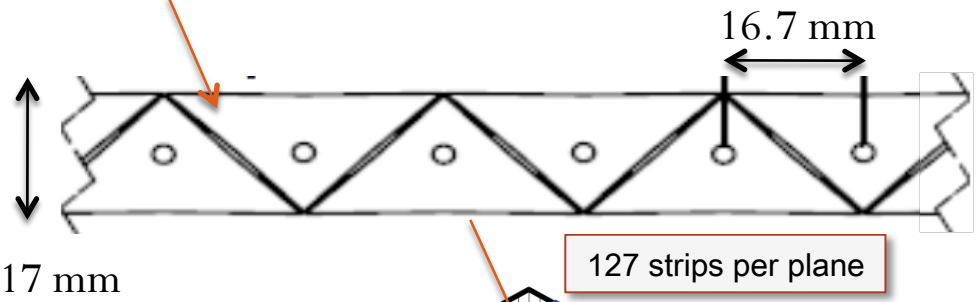


Extruded plastic scintillator & wavelength shifting fibers

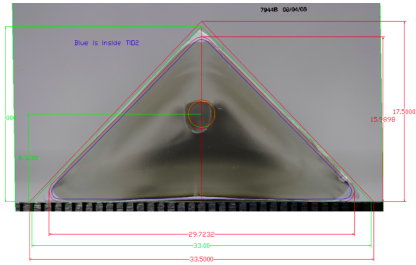
Triangular geometry allows charge sharing for improved position resolution

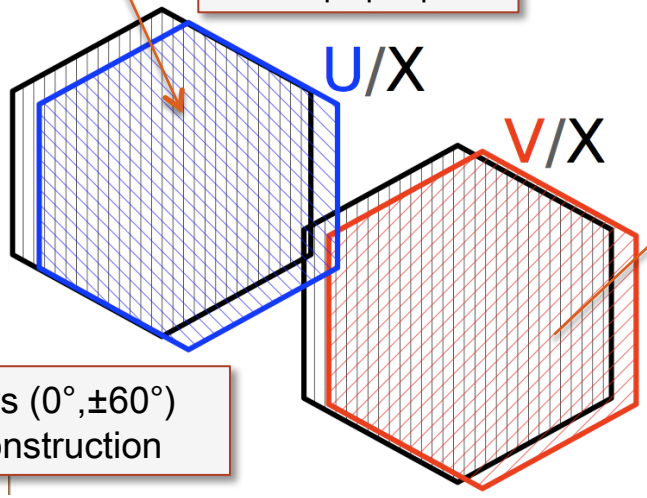


64 anode PMTs

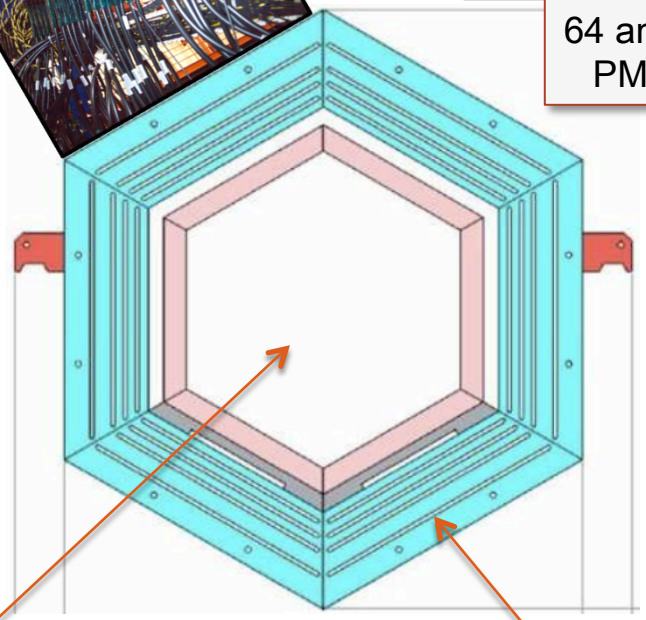


127 strips per plane



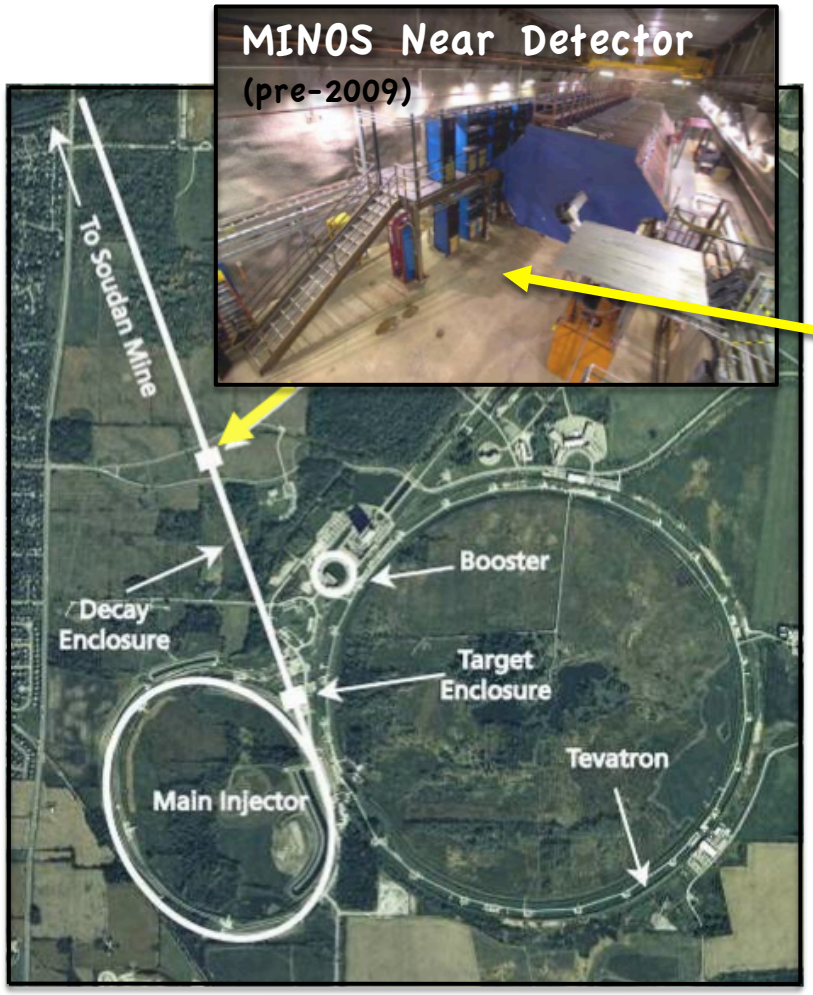


Three views (0°,±60°) for 3D reconstruction

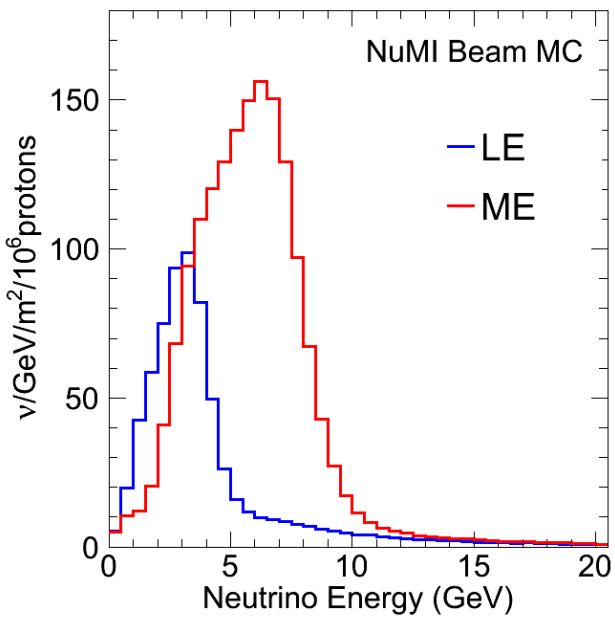


Iron outer detector instrumented for calorimetry

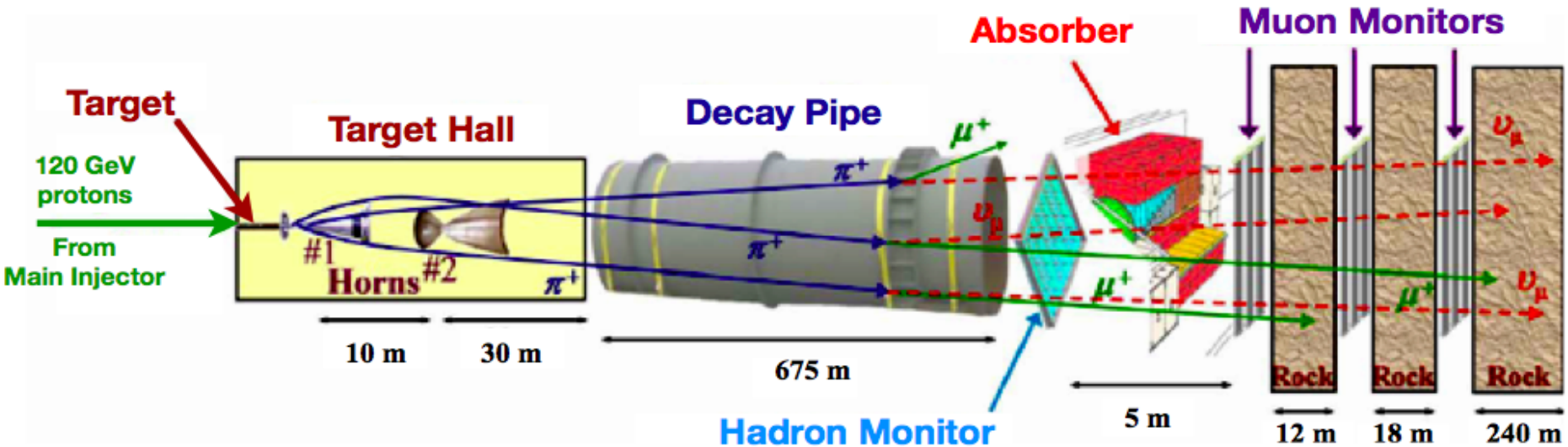
MINERνA in Her Home



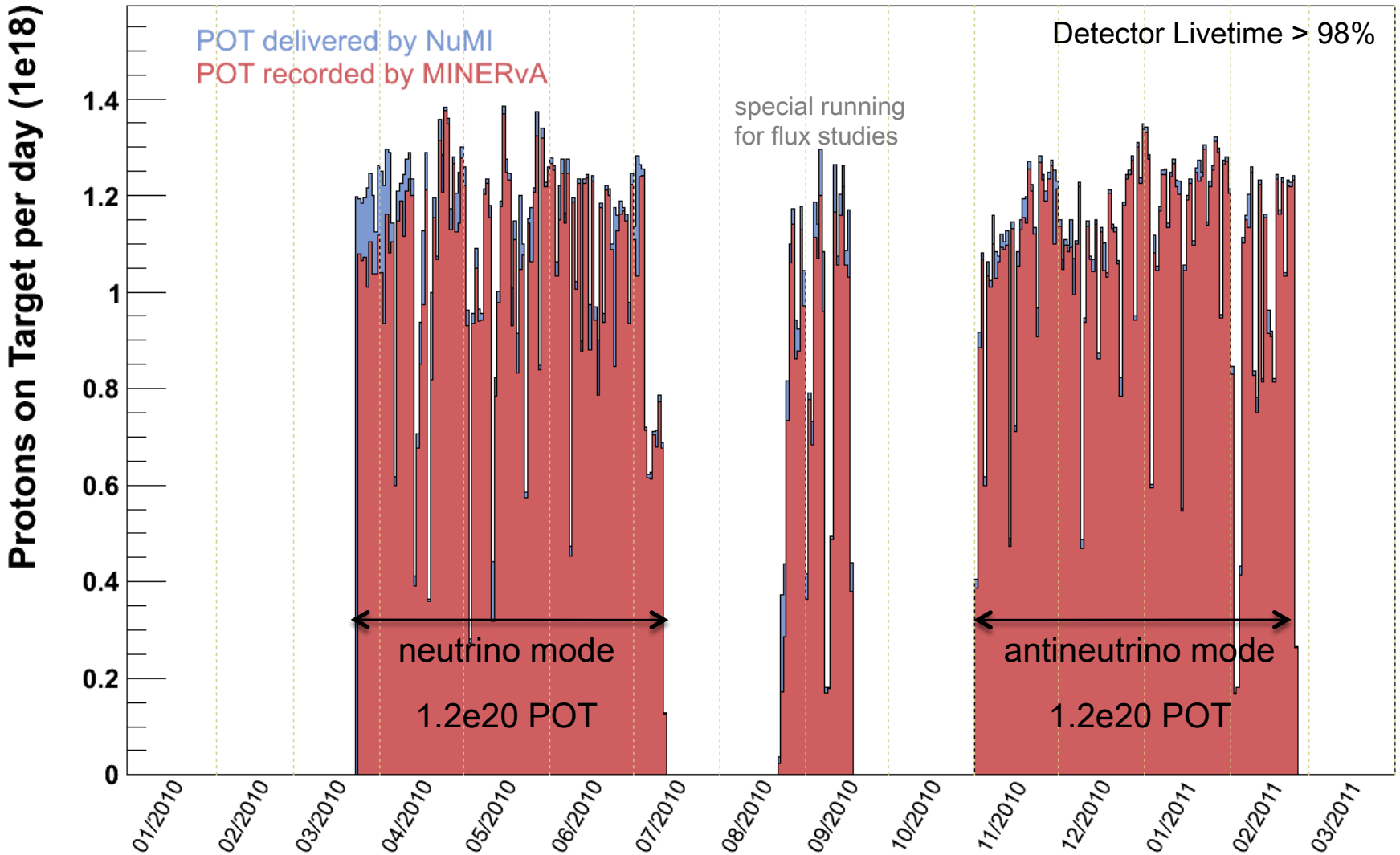
NuMI Beam Facility



- Intensity: ~35e12 P.O.T per spill
  - about 1 ν event and a few rock muons in MINERνA per spill
- Spill length/frequency: 10μs / ~0.5 Hz.
- Beam power: 300 – 350 kW
- Mean energy of NuMI ν beam can be tuned by changing longitudinal positions of the target and horns
- Reversing current in focusing horns changes beam from mostly neutrinos to mostly antineutrinos
- Please see talk from M. Jerkins on Friday afternoon



Data Collected So Far



Expected Event Rates

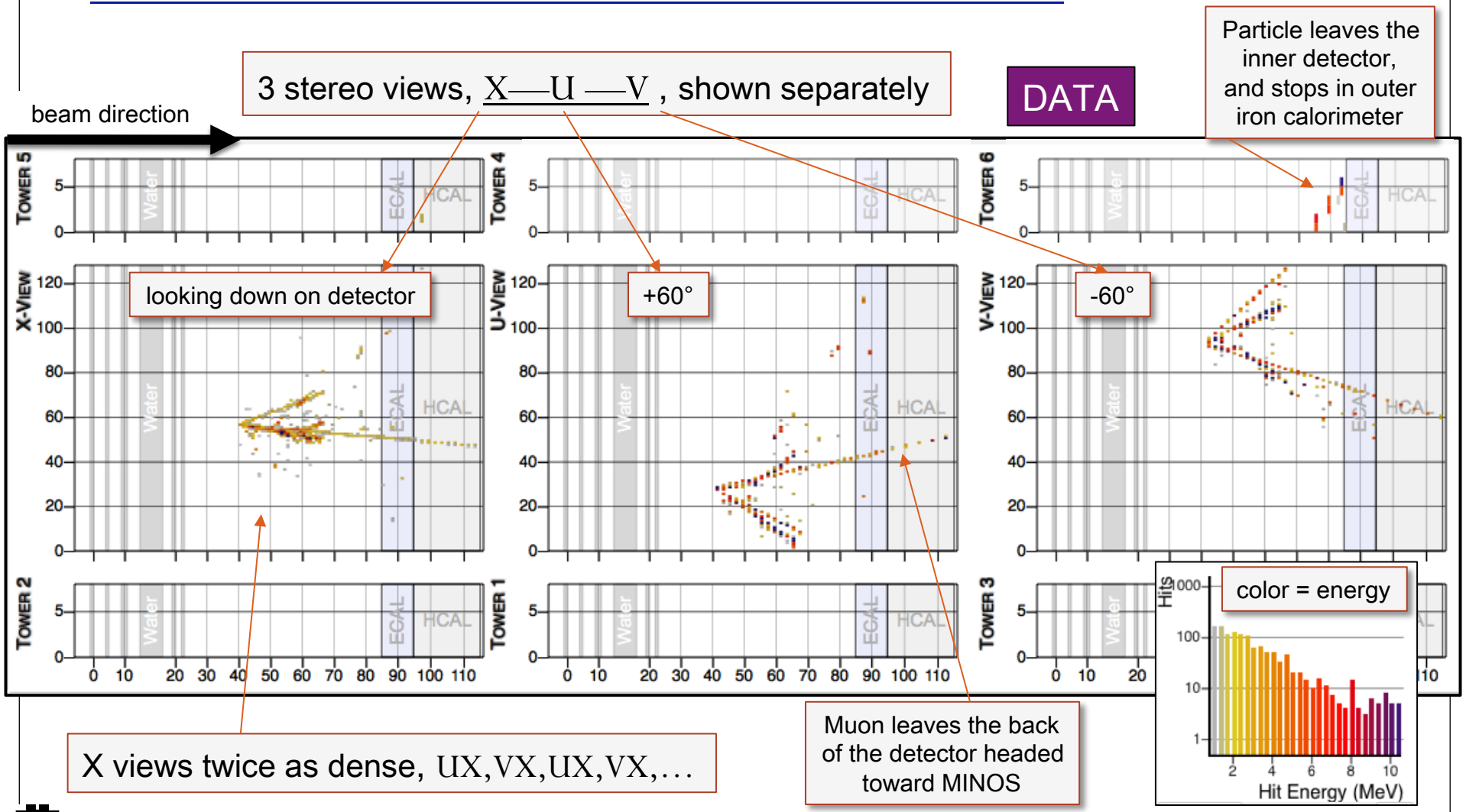
Generator Level CC Event Numbers in Current Neutrino Data Set

	1.2e20 POT LE ν mode	1.2e20 POT LE anti-ν mode
Coherent pion production	4k	3k
Quasi-elastic	84k	46k
Resonance production	146k	62k
DIS, structure functions, high-x PDFs	167k	19k
C target	11k	5k
Fe target	65k	20k
Pb target	68k	17k
Scintillator Tracker	409k	134k

- **Total MINERνA run plan in neutrino mode:**
  - 4.9e20 P.O.T. in low-energy (LE) mode (March, 2010 – mid 2012)
  - 12e20 P.O.T. in medium-energy (ME) mode (beginning in 2013)

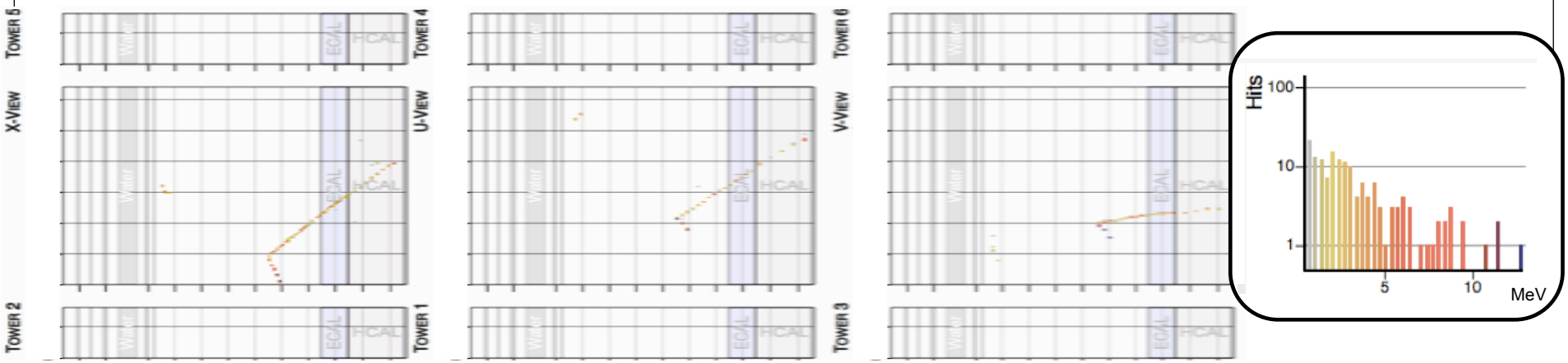
ν Events in MINERνA

- **So what does an event look like in MINERνA…**



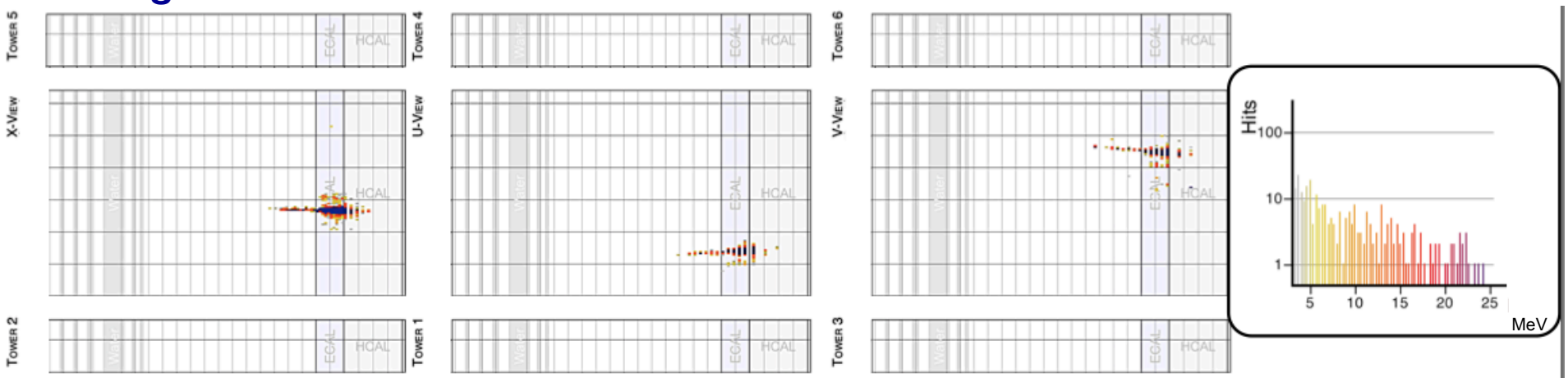
ν Events in MINERνA

- **Charged-current Quasi-elastic candidate**



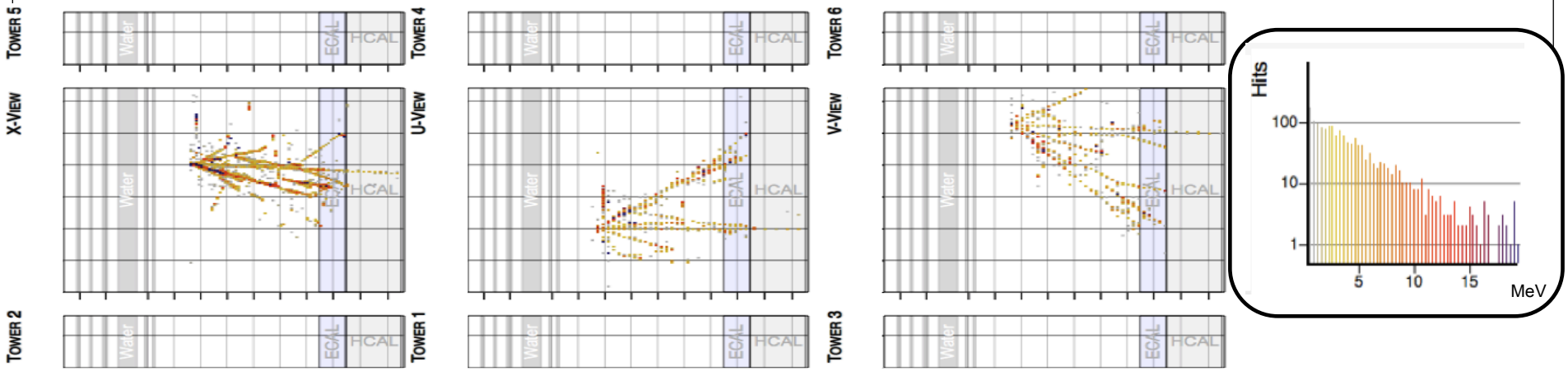
DATA

- **Single Electron Candidate**



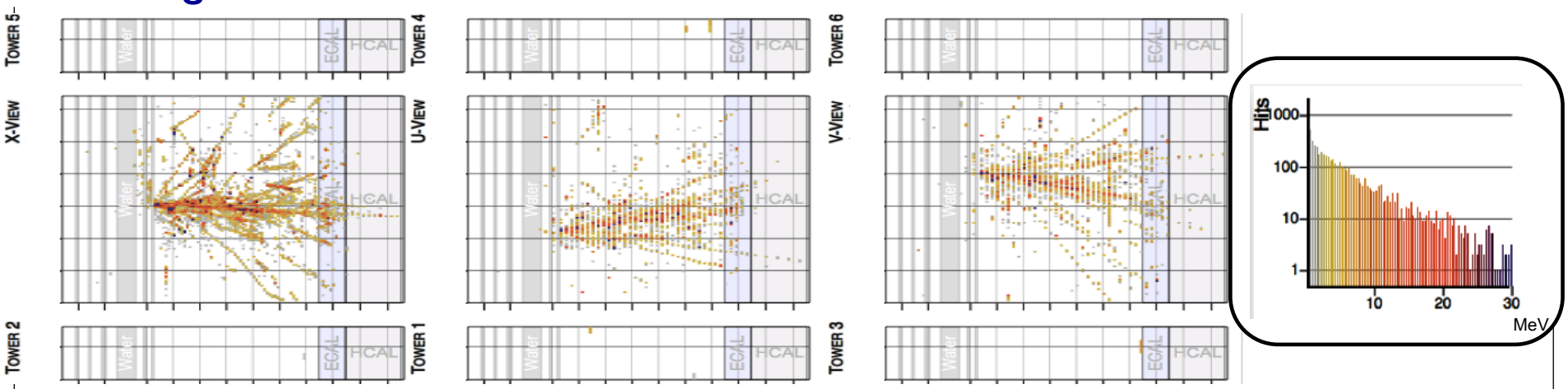
ν Events in MINERνA

- **Charged-current DIS candidate**

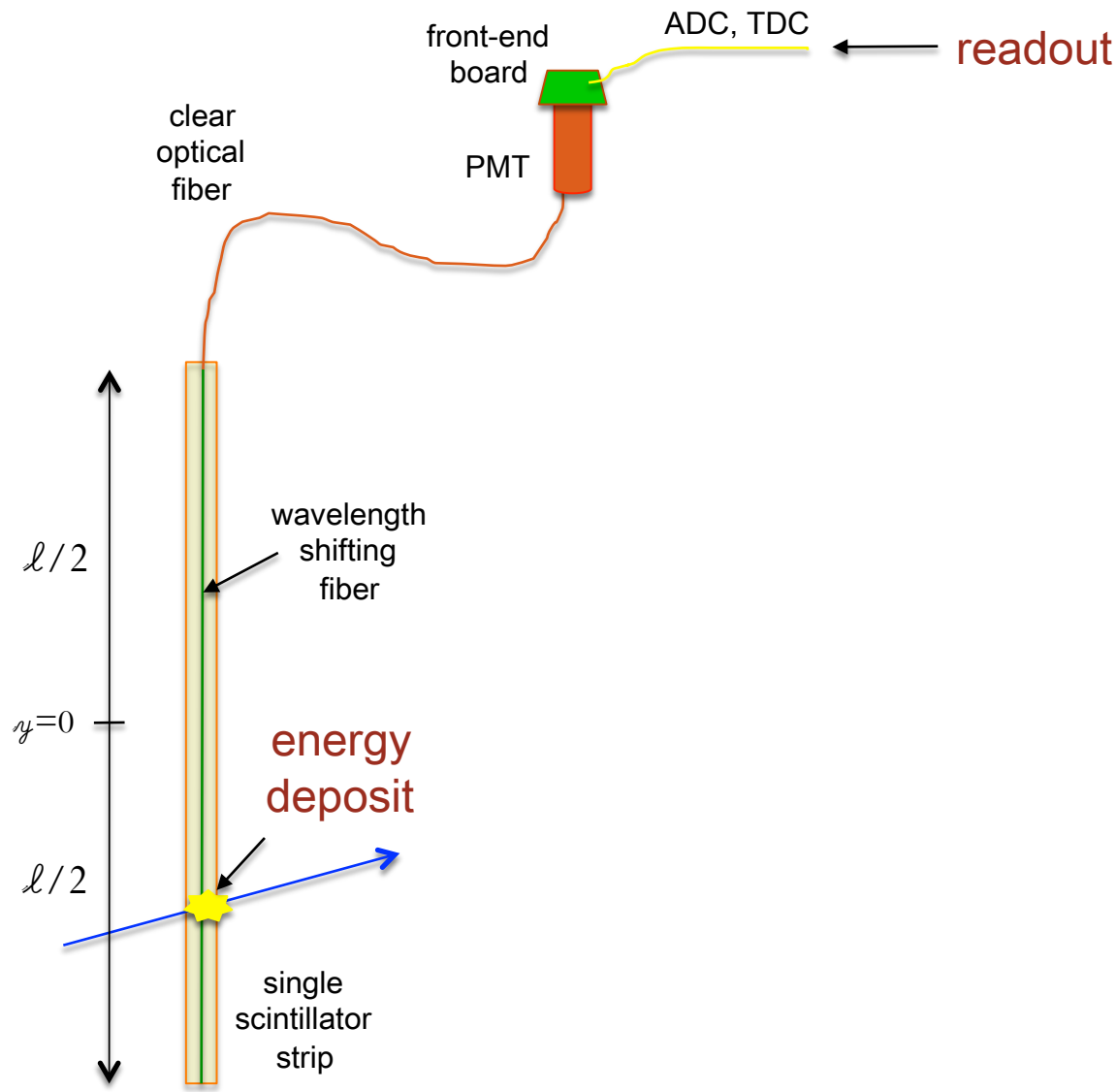


DATA

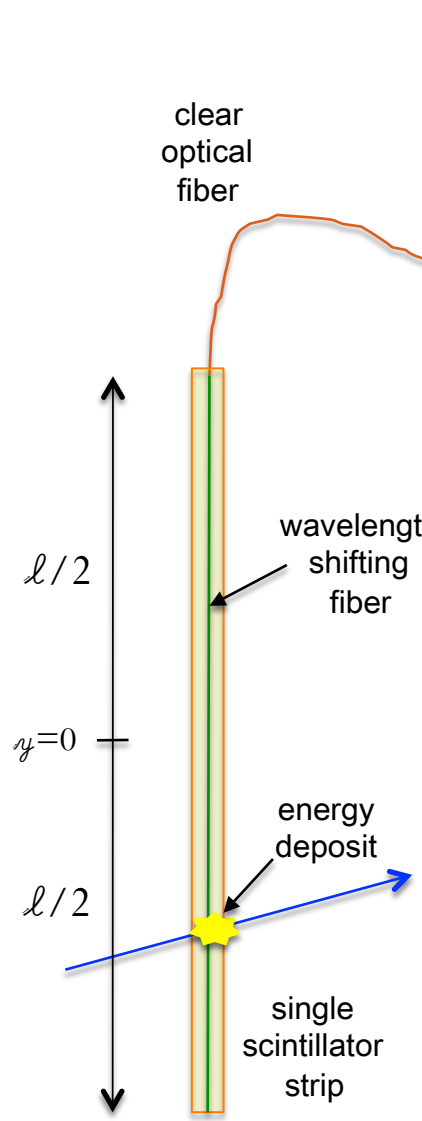
- **Charged-current DIS candidate**



Detector Calibration

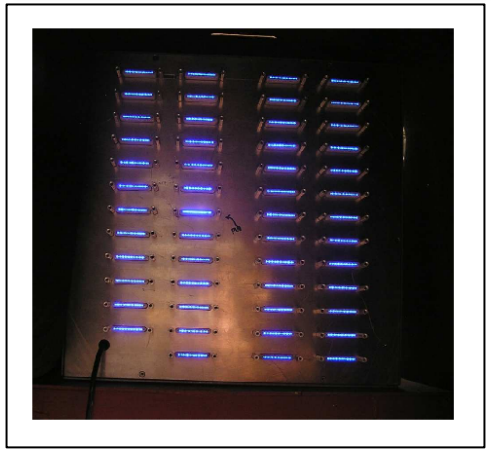


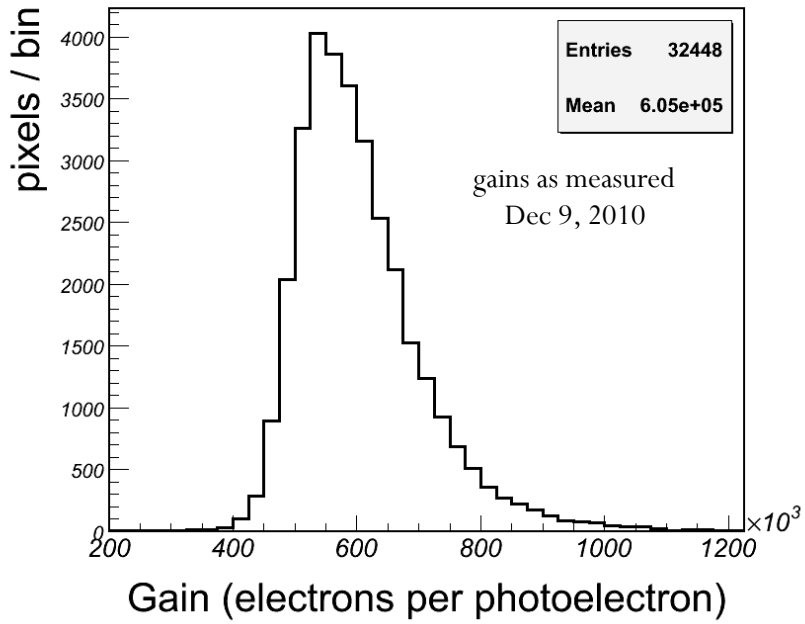
Detector Calibration



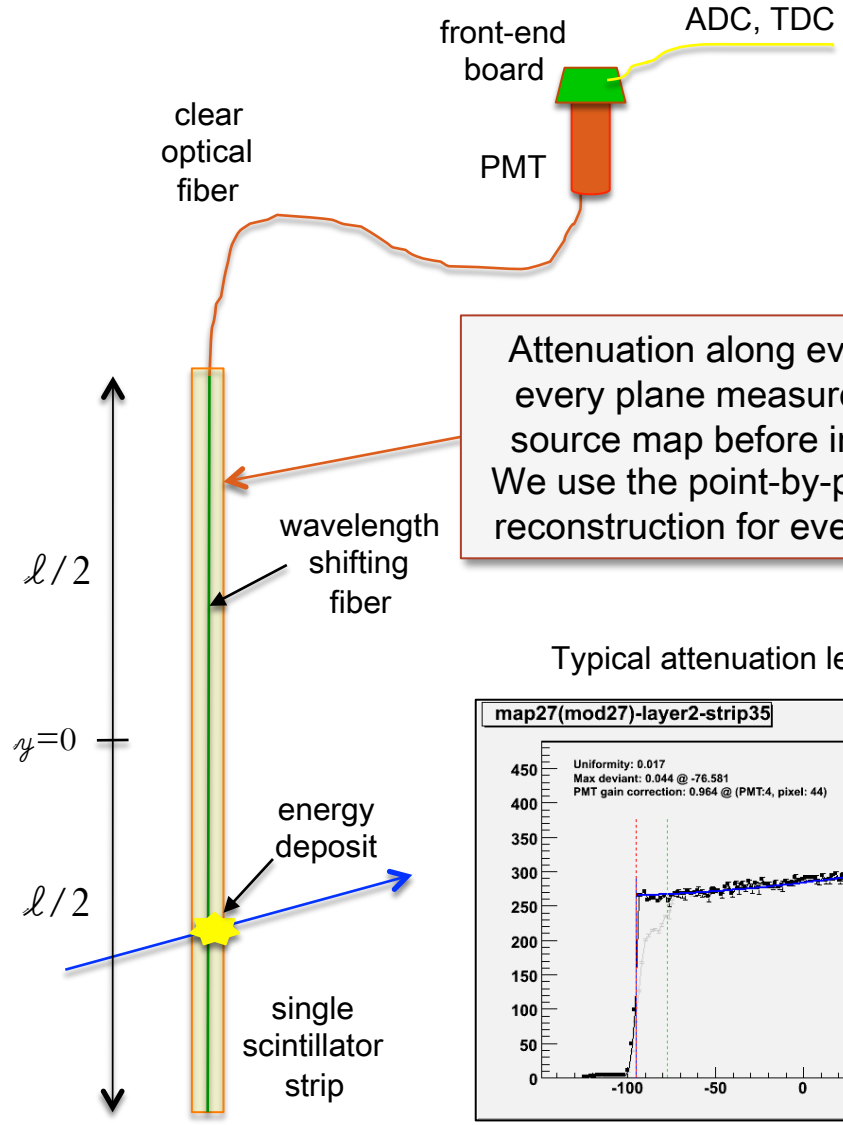
Charge to ADC conversion function measured on a test stand for every channel on every board before installation on the detector

PMT gains measured continuously *in-situ* using Light Injection system

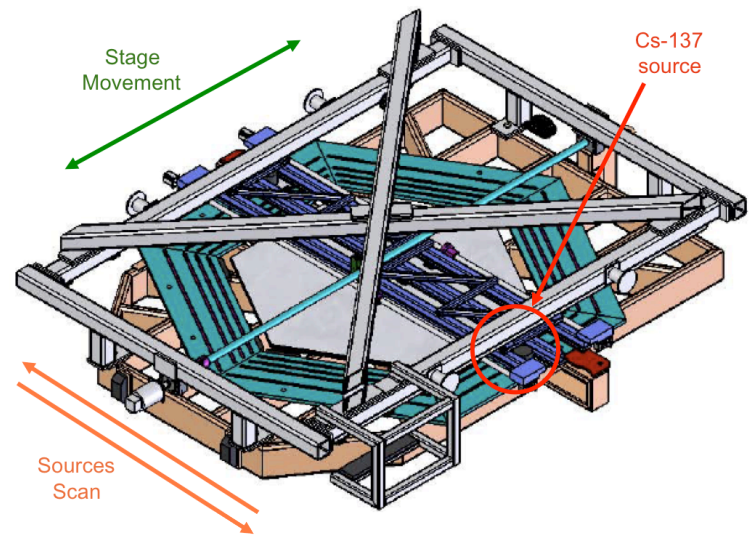




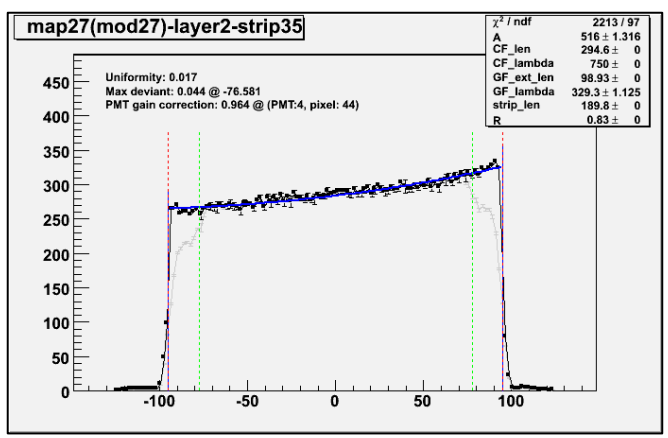
Detector Calibration



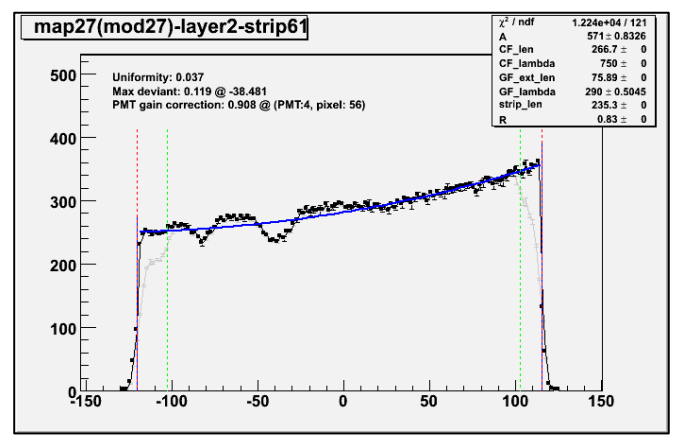
Attenuation along every strip in every plane measured using a source map before installation. We use the point-by-point map in reconstruction for every channel.



Typical attenuation length ~300 cm.

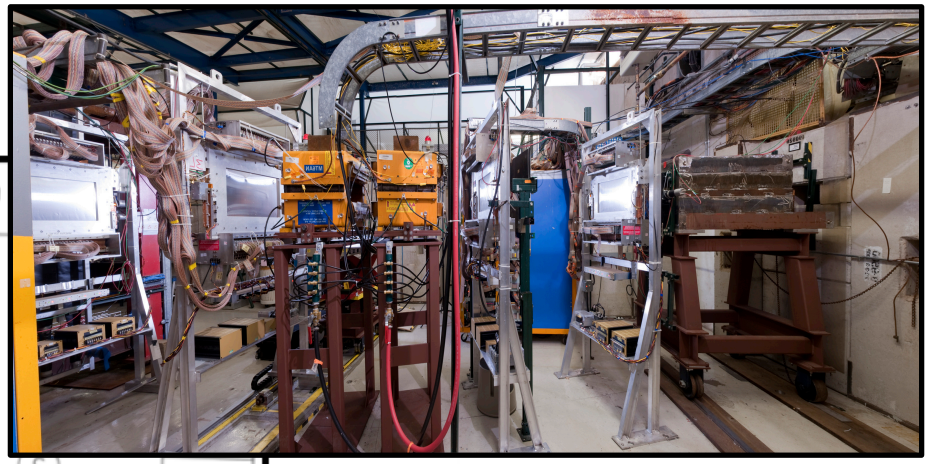


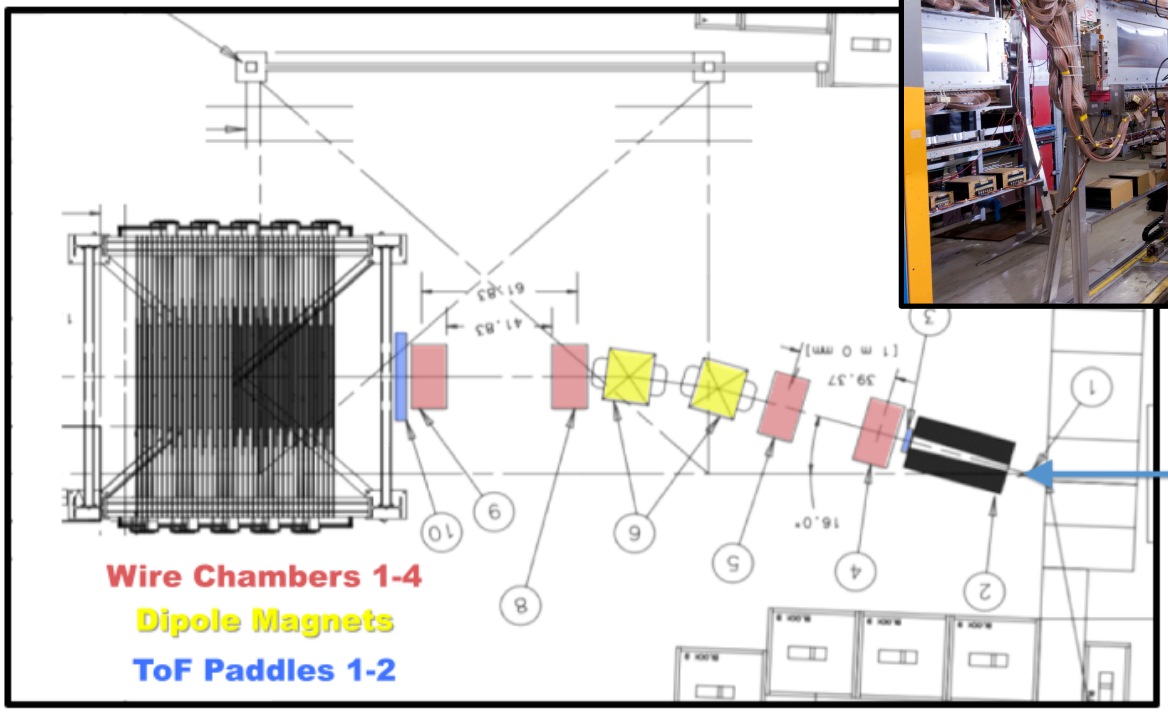
Map can find non-uniformities along the strip (e.g. air pockets in glue)



Detector Calibration

- **MINERνA Test Beam Project**
  - Very important to calibrate the absolute energy response of the MINERνA detector
  - 16 GeV incident pion beam produces a tertiary beam between 400-1200 MeV/c
  - 4 wire chambers, 2 dipole magnets, ToF





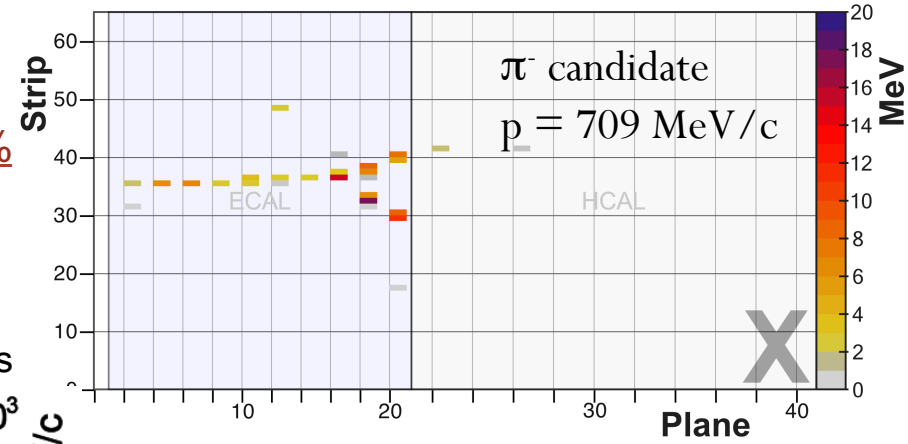
16 GeV incident pion beam

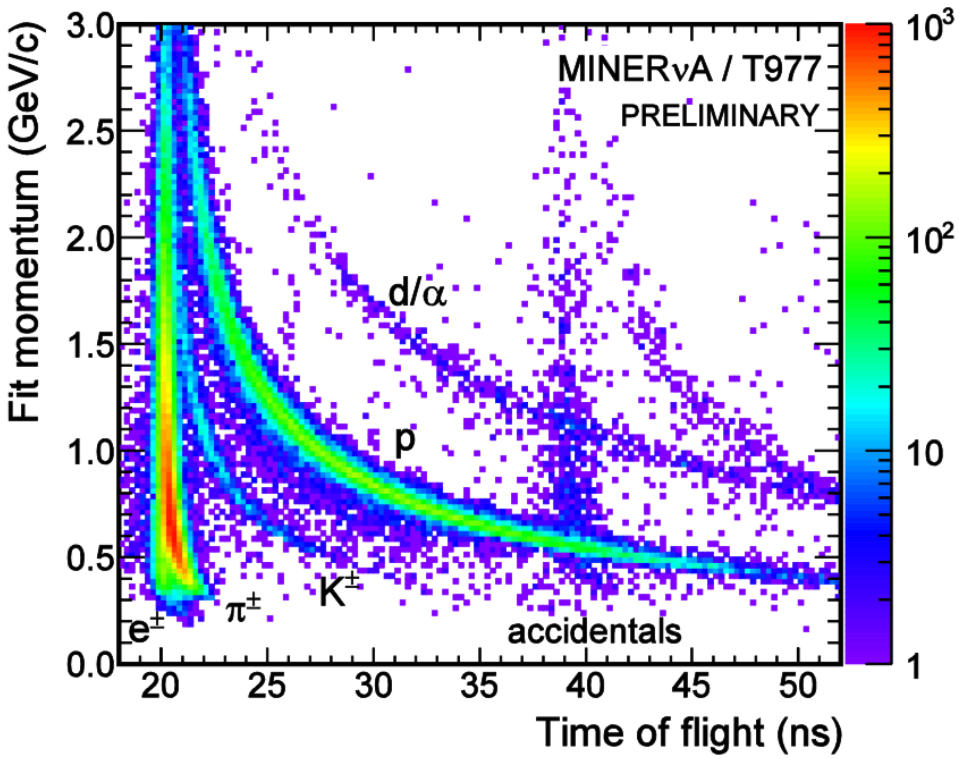
Copper target

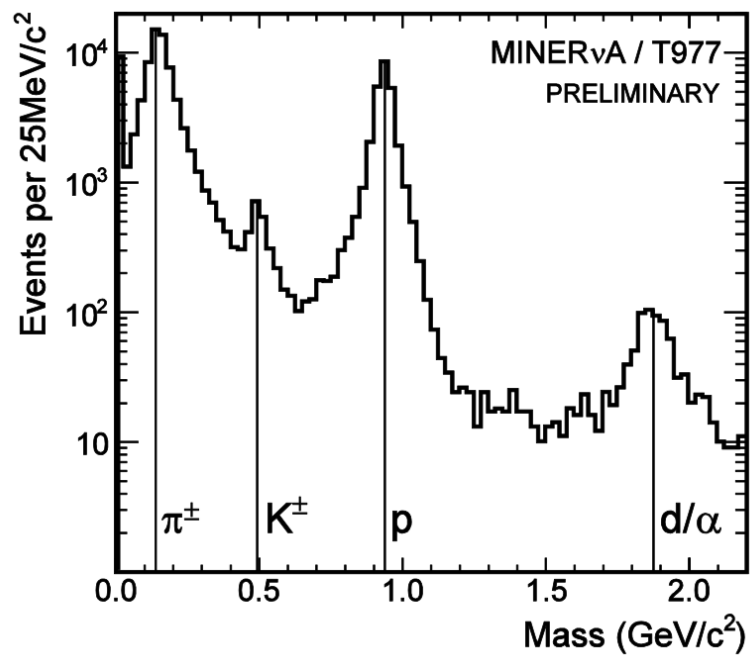
This beamline is now a permanent part of the Fermilab test beam facility!

Detector Calibration

- **MINERνA Test Beam Project**
  - Test beam to measure Energy scale to ~2%
  - Analysis is on-going
  - Plots show real beam data
    - 107k accepted events, positives and negatives



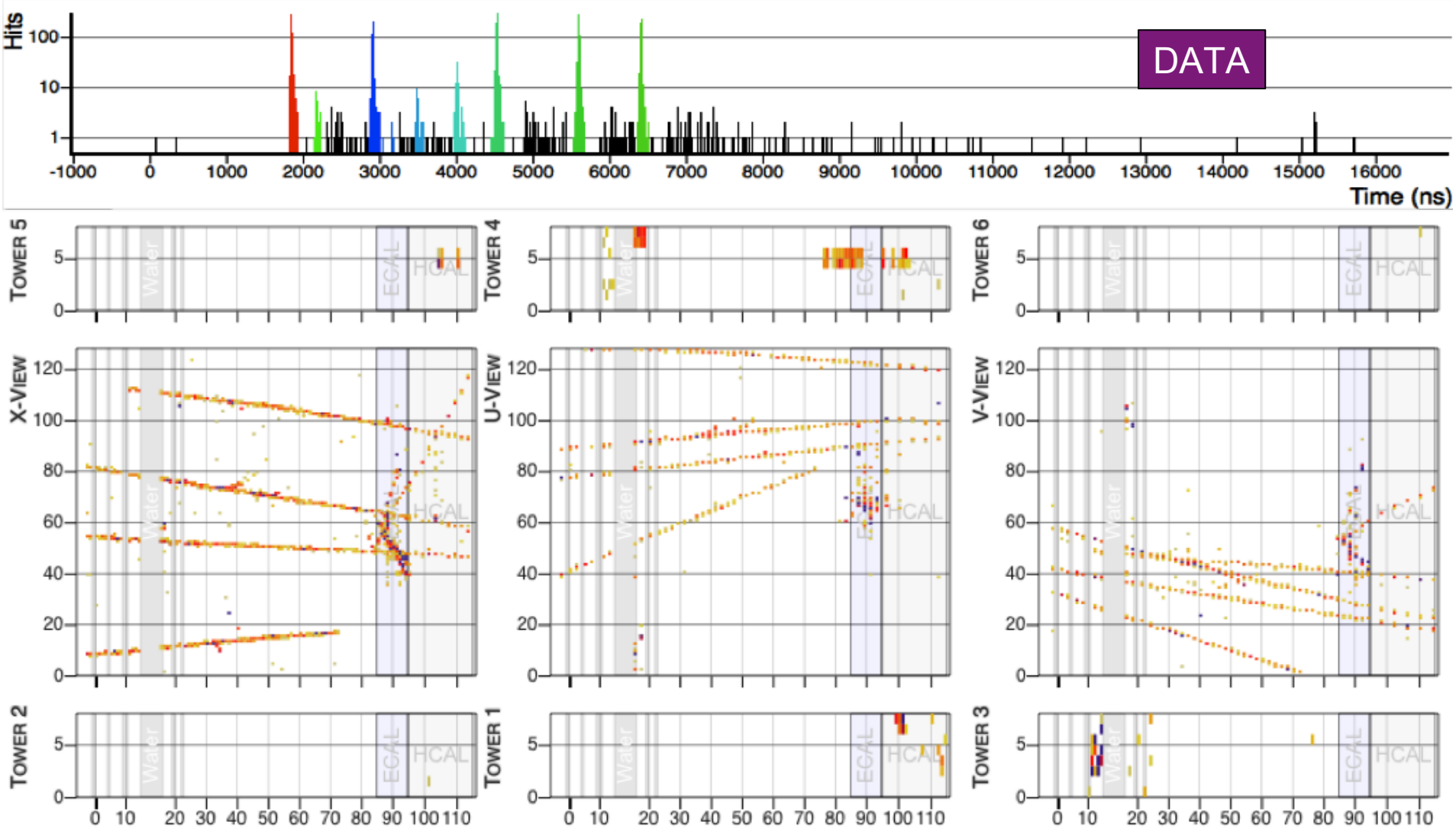




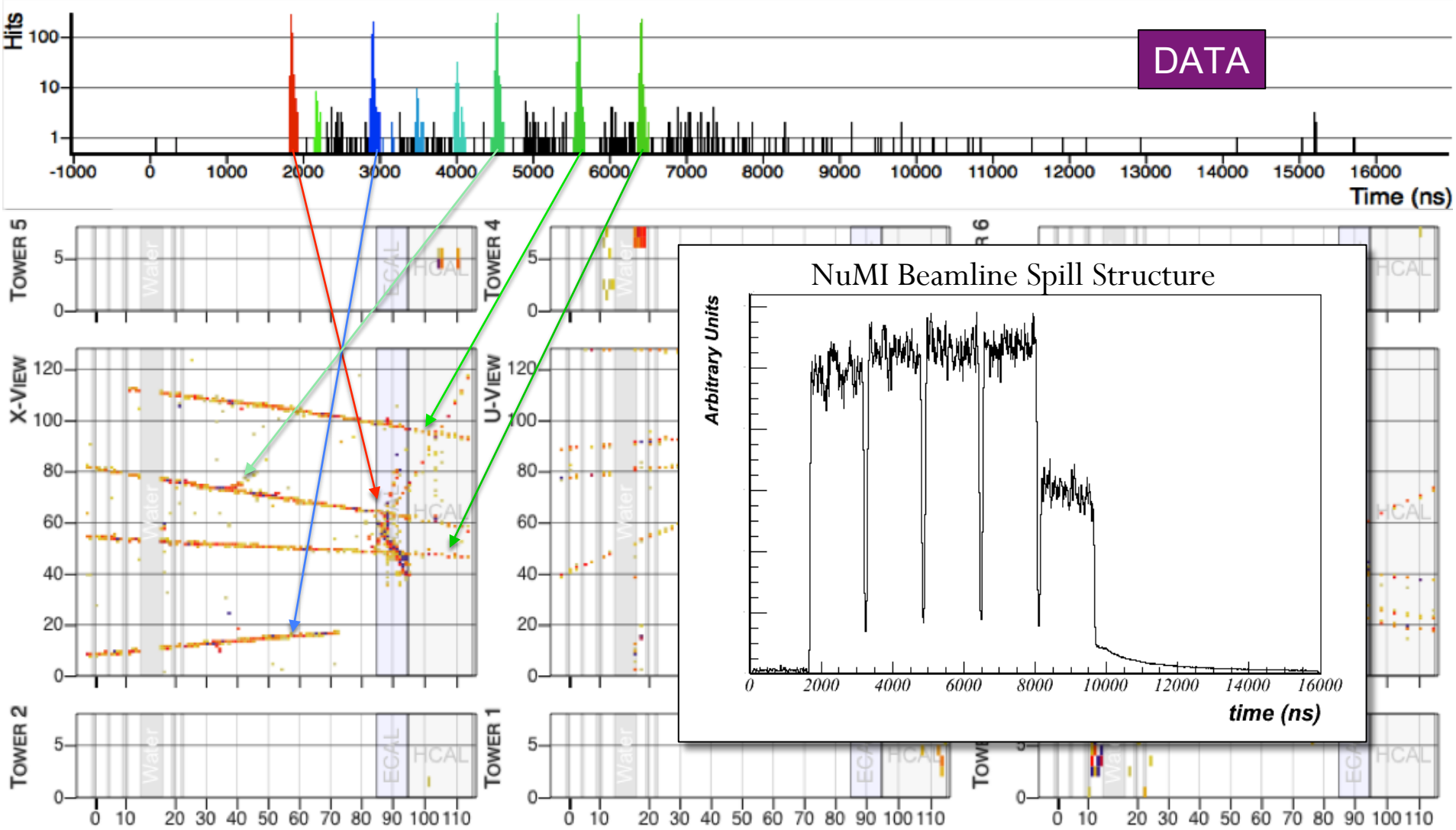
Event Reconstruction

- **Hard things first…**
  - Time separate activity in the detector (NuMI beam is intense; multiple events per spill)
  - Cluster neighboring hits within each plane in the inner detector region
  - Find and fit tracks for muons and higher-energy pions and protons
  - Match muon tracks in MINERνA with tracks reconstructed in MINOS
  - Estimate initial muon energy by range
  - Sum non-trackable shower energy near/displaced from the μ vertex
- **Really hard things next… all on-going work**
  - Electromagnetic/hadronic shower ID and reconstruction
  - Deal with obfuscation of tracks by showers, charge sharing
  - Inclusive, DIS interactions
  - Neutral current interactions

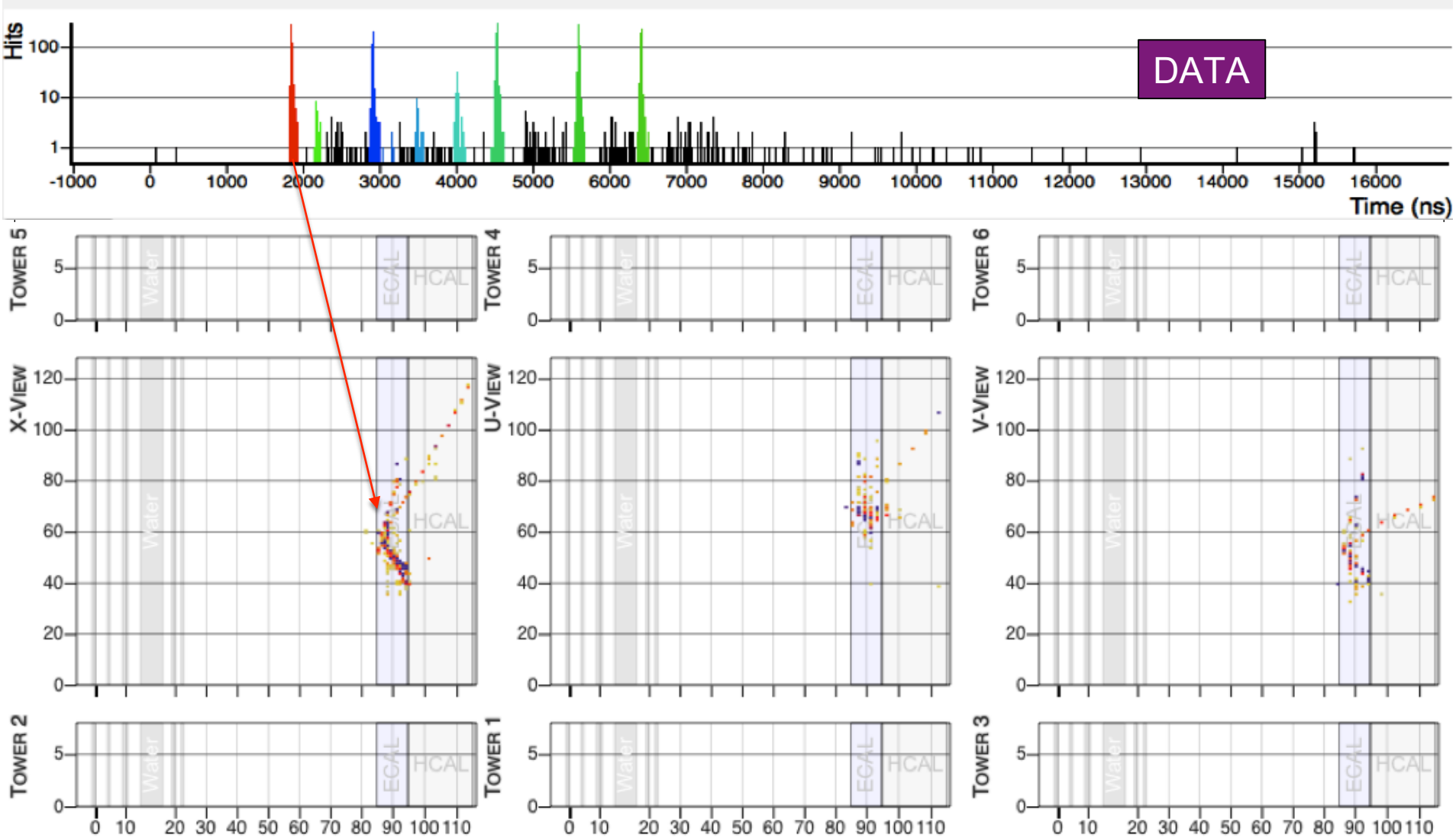
Time Separation



Time Separation

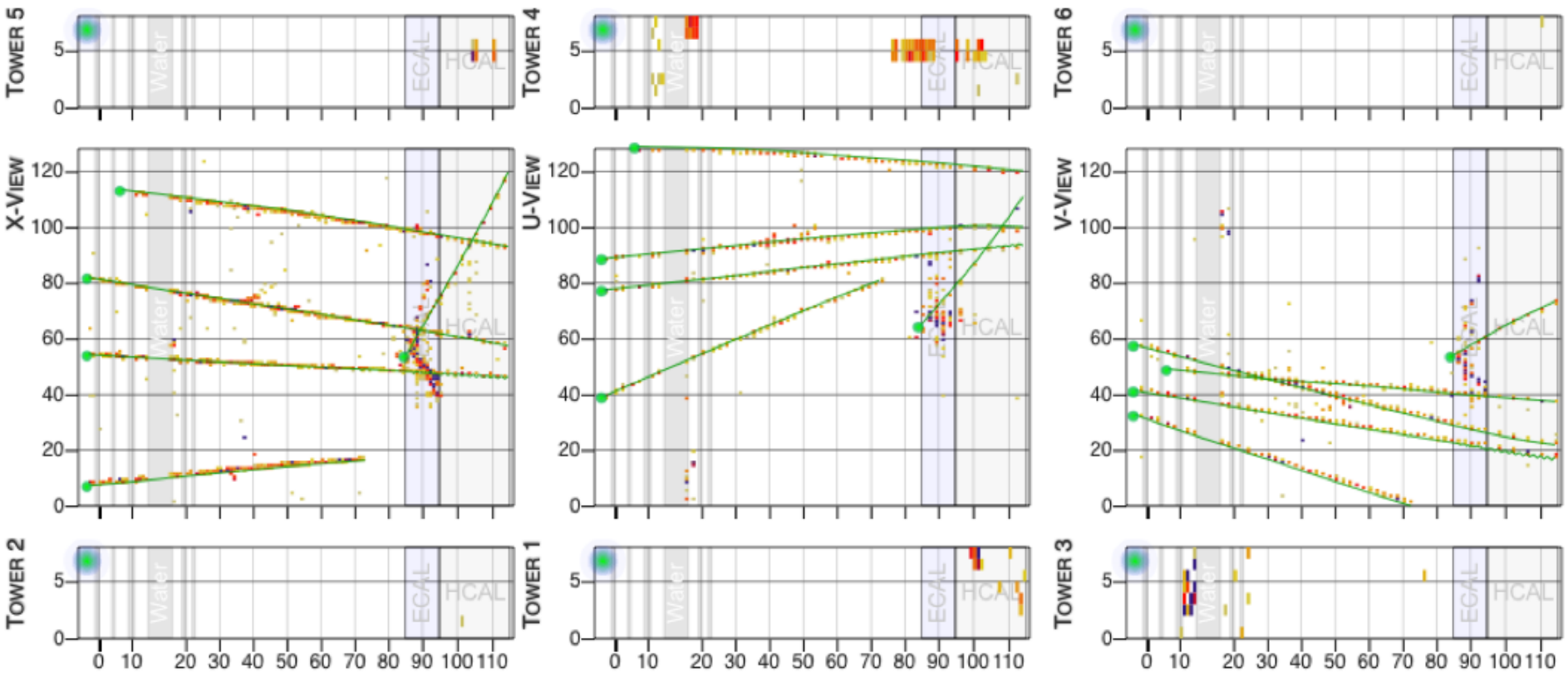


Time Separation



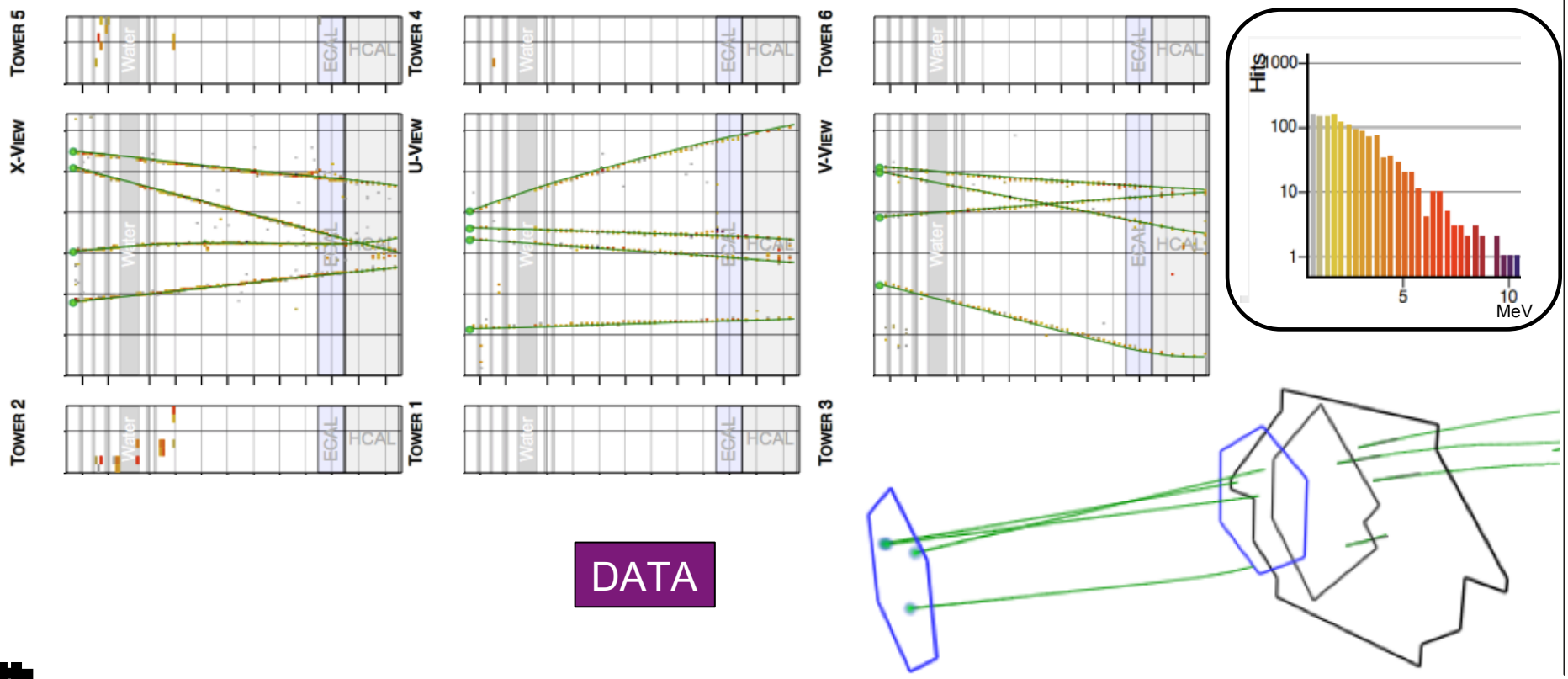
Track Finding

- Pattern recognition finds 2-D tracks in each view (X,U,V), then combines into a 3-D track
- Kalman Filter used to fit 3-D track parameters, allow for multiple scattering
- Currently optimized for muons and longer hadron tracks; work on short track finding algorithms is on-going

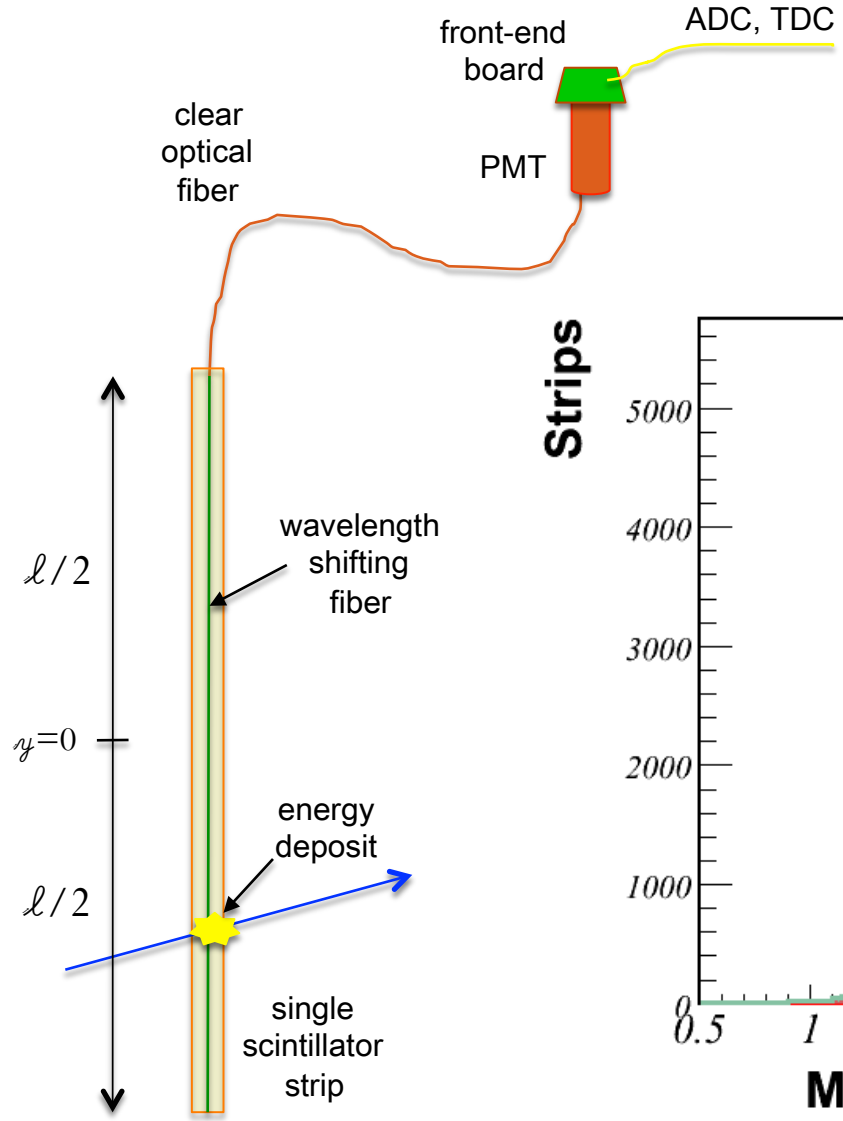


“Rock Muons” in MINERνA

- Most of the activity in the detector is muons produced by neutrinos, but <u>NOT</u> in the detector, rather in the rock upstream of MINERνA
- Far from being a nuisance, they provide a continuous, high-statistics, *in-situ* detector calibration source

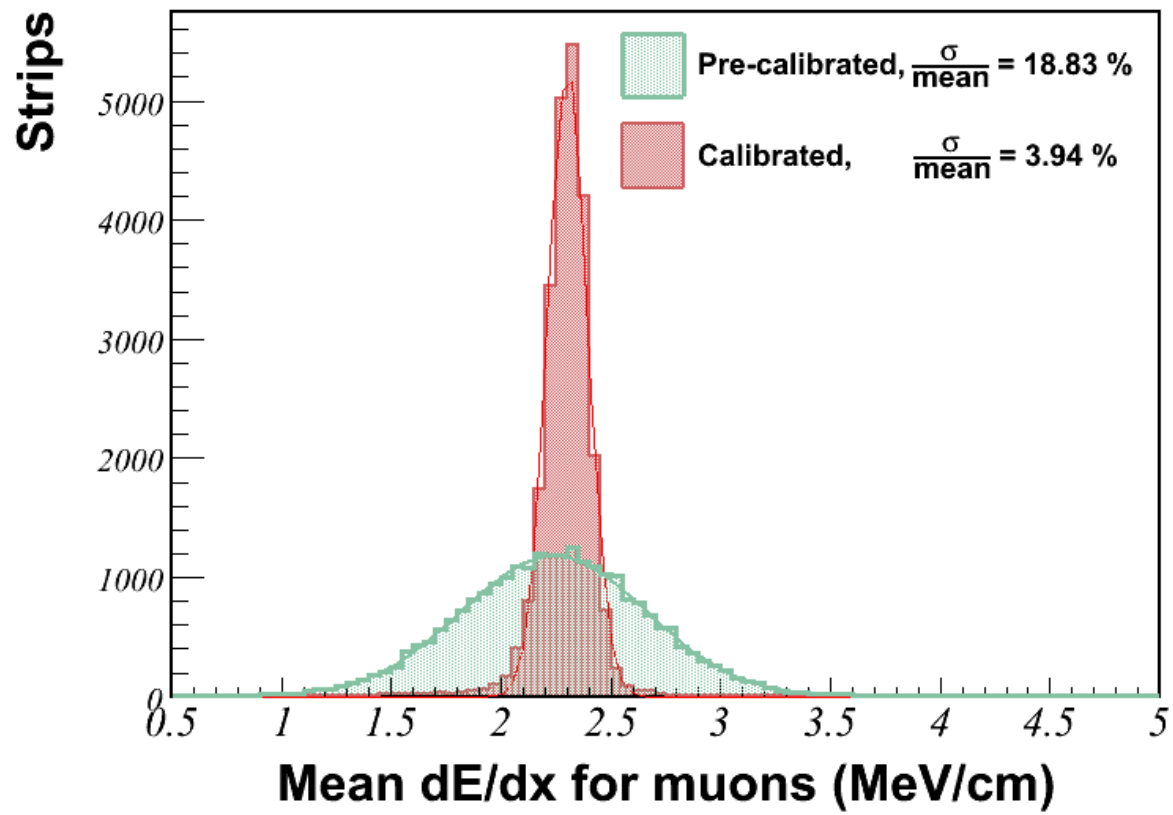


Detector Calibration



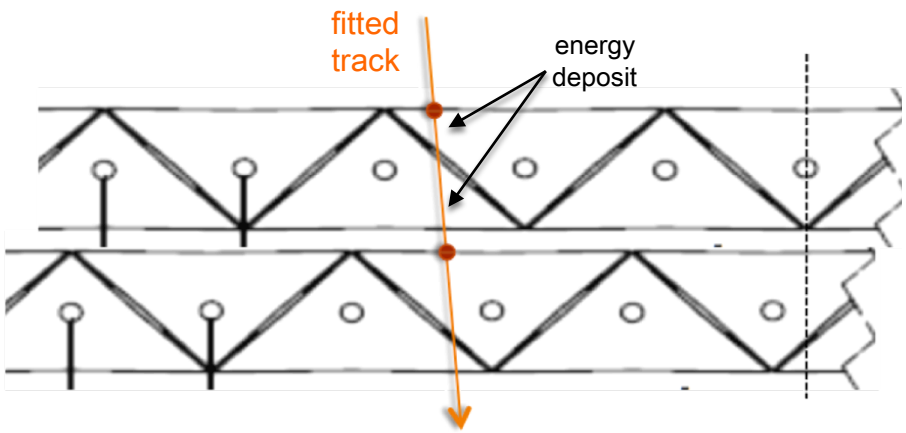
Channel-to-channel variations can be calibrated out with calibration sample of rock muons.

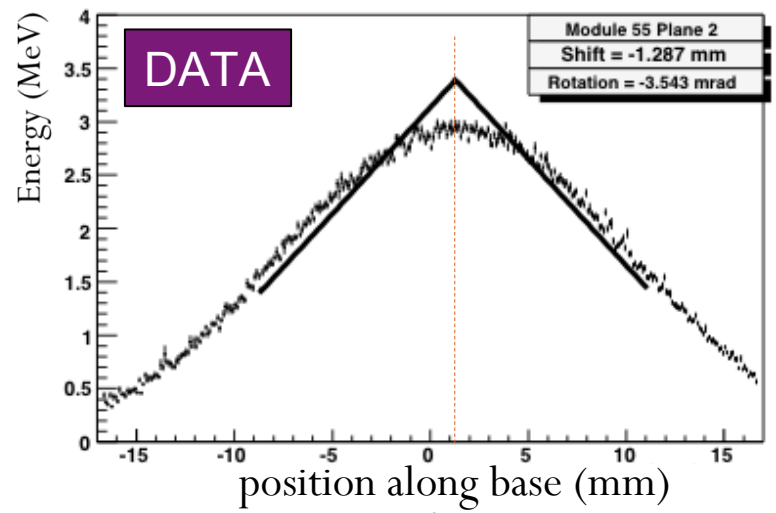
High statistics allow comparison of the mean mip response for all channels to extract a scaling parameter for each inner detector channel

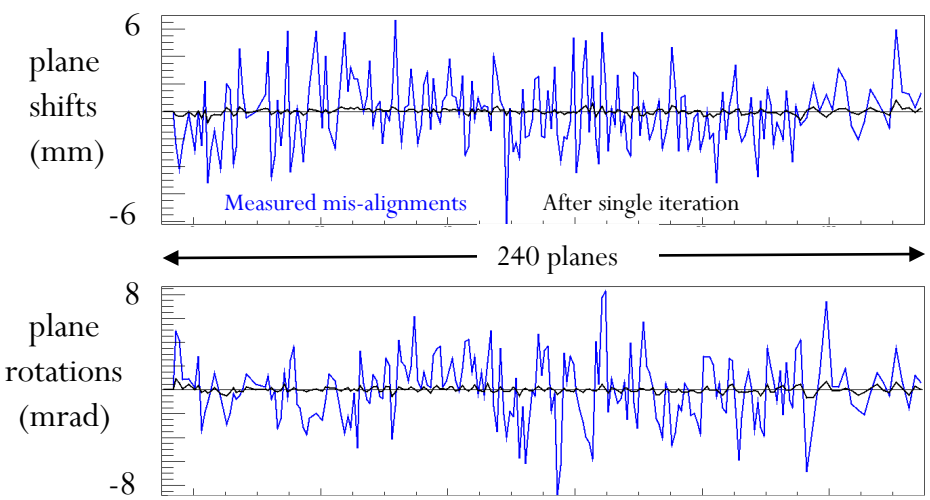


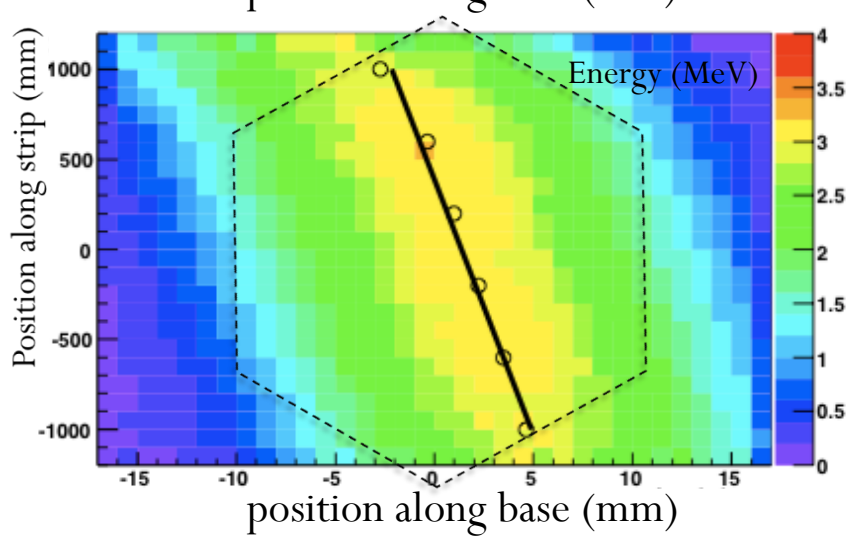
Detector Alignment

- **Rock Muons also used for measuring plane mis-alignments**



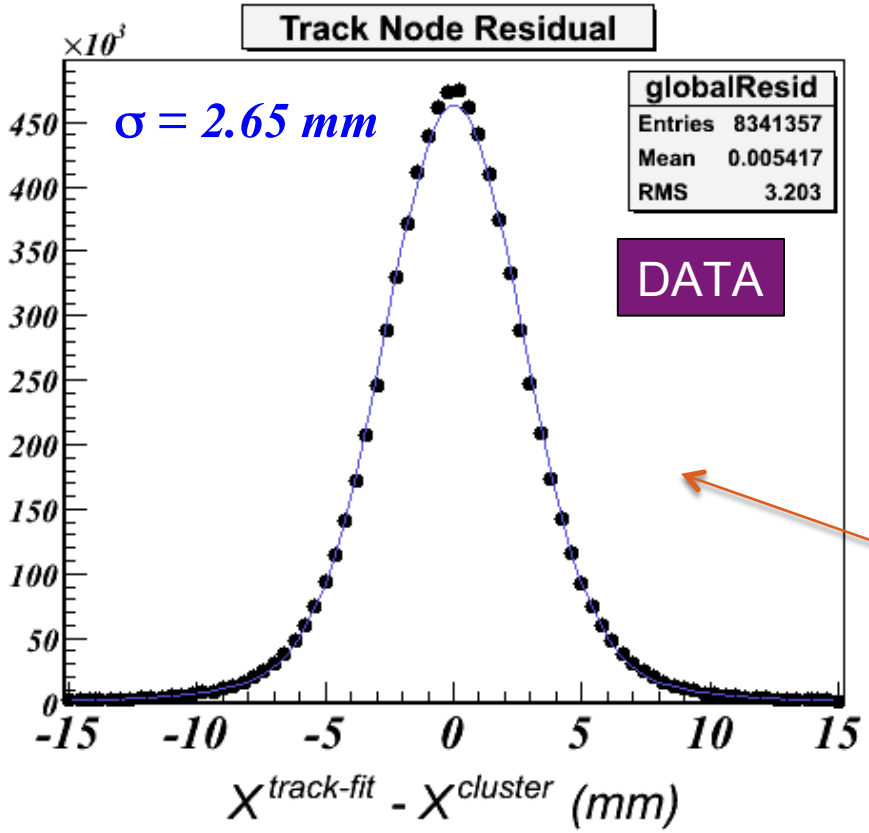


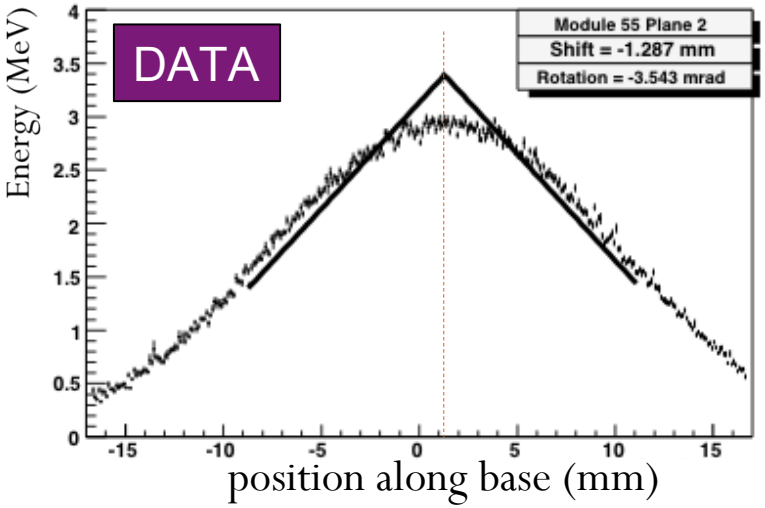




Detector Alignment

- **Rock Muons also used for measuring plane mis-alignments**

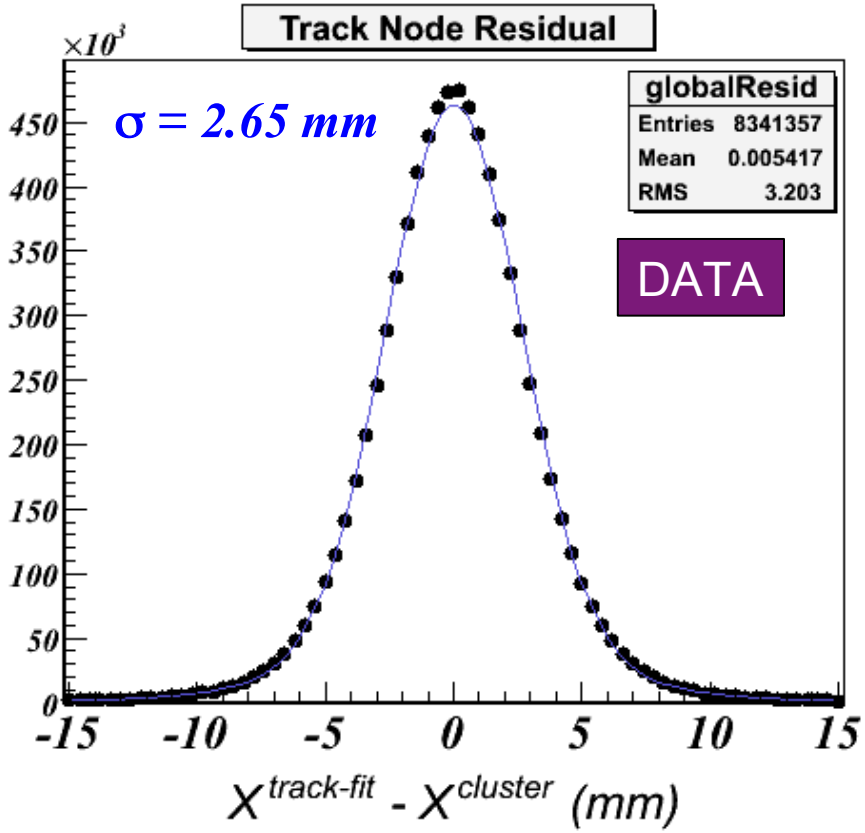


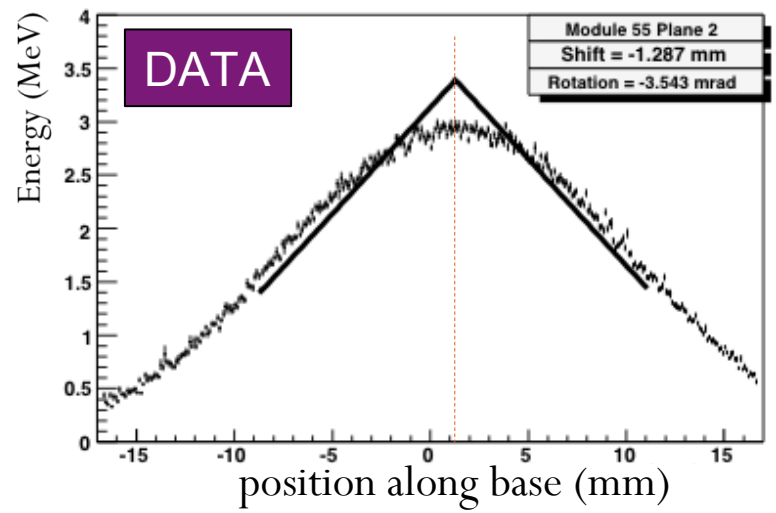


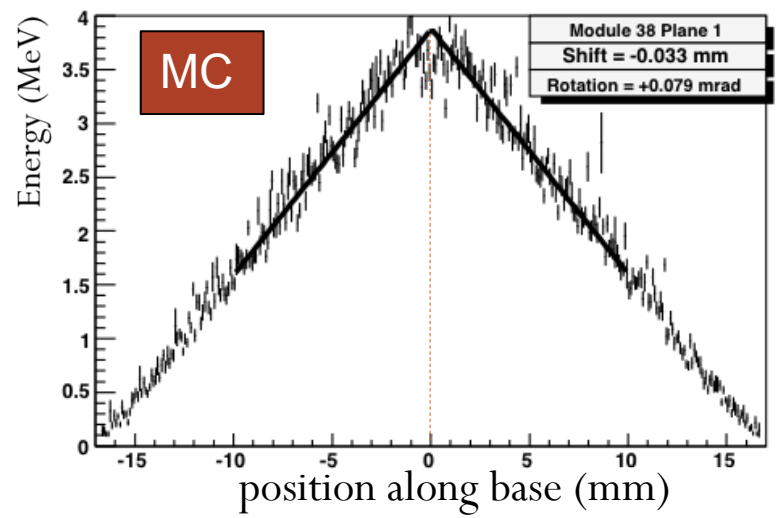
Residual between a fitted position along a track and the measurement in that plane for a sample of rock muons

Detector Alignment

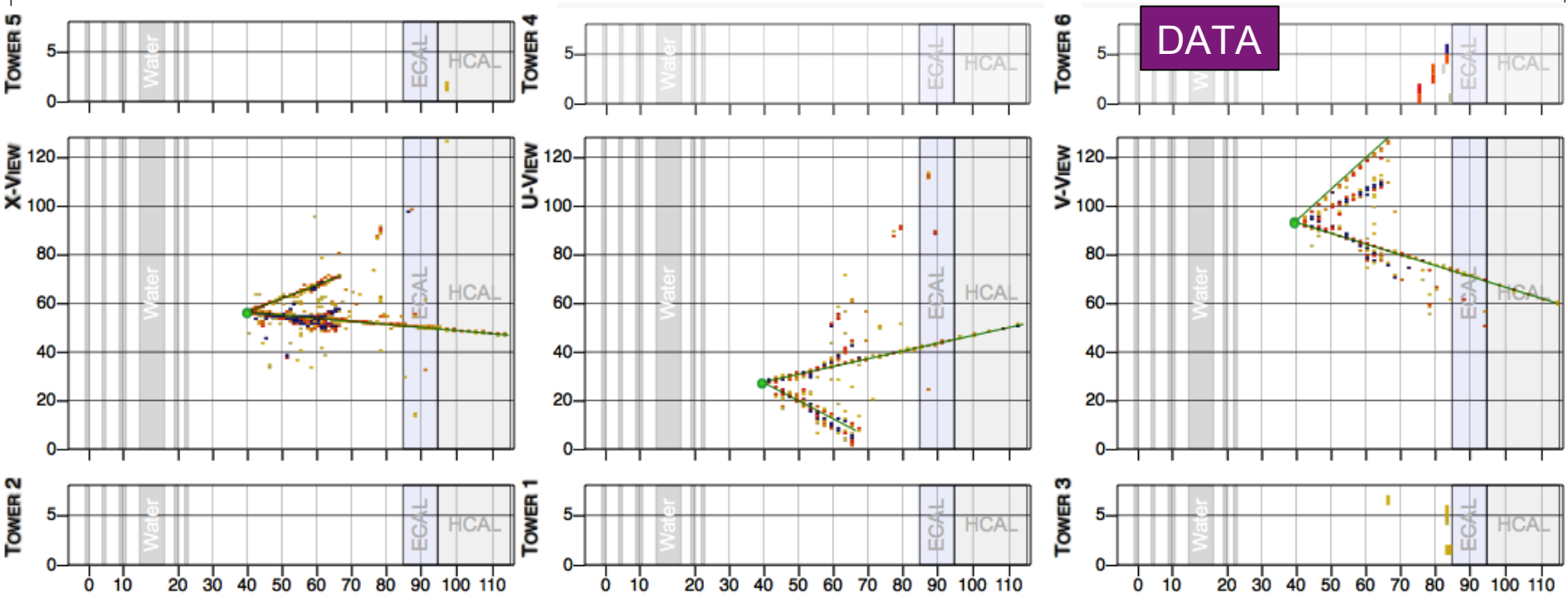
- **Rock Muons also used for measuring plane mis-alignments**



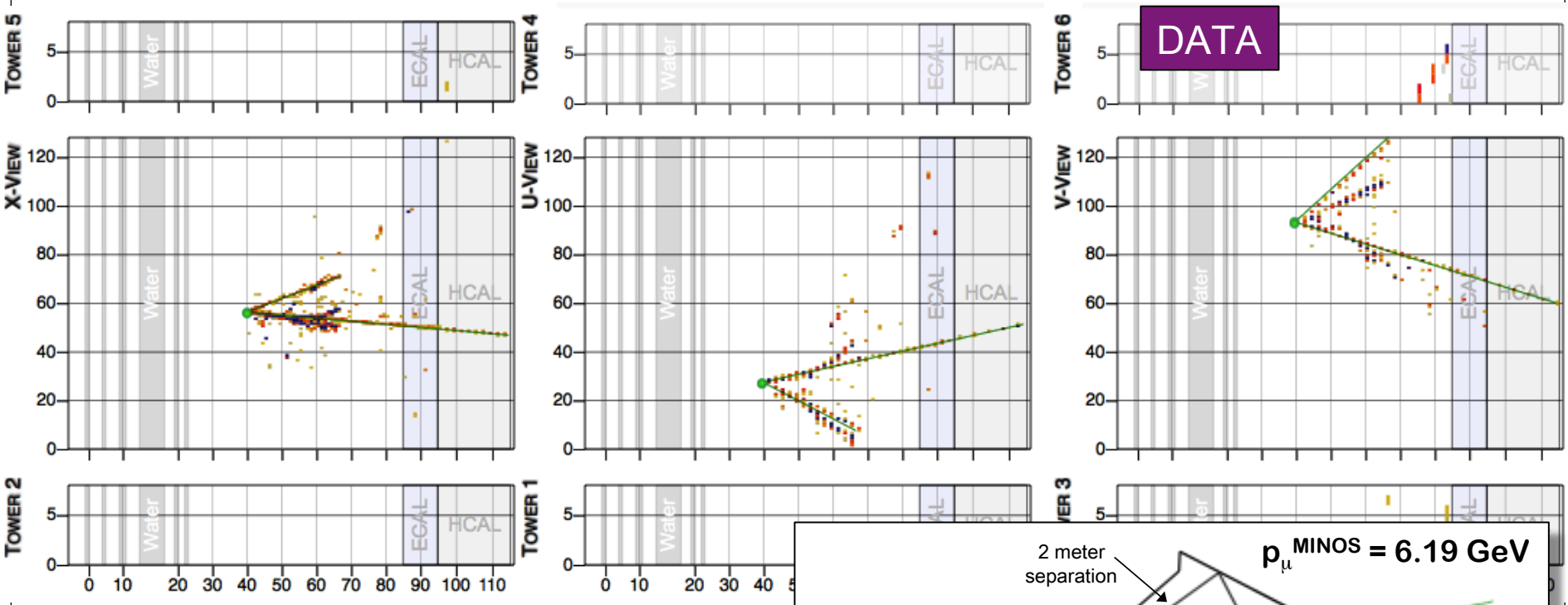


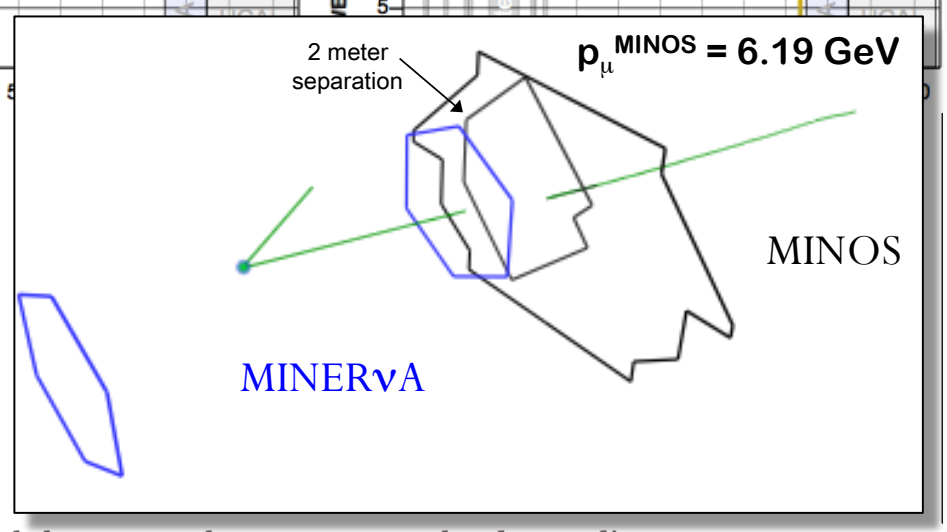


Matching tracks into MINOS



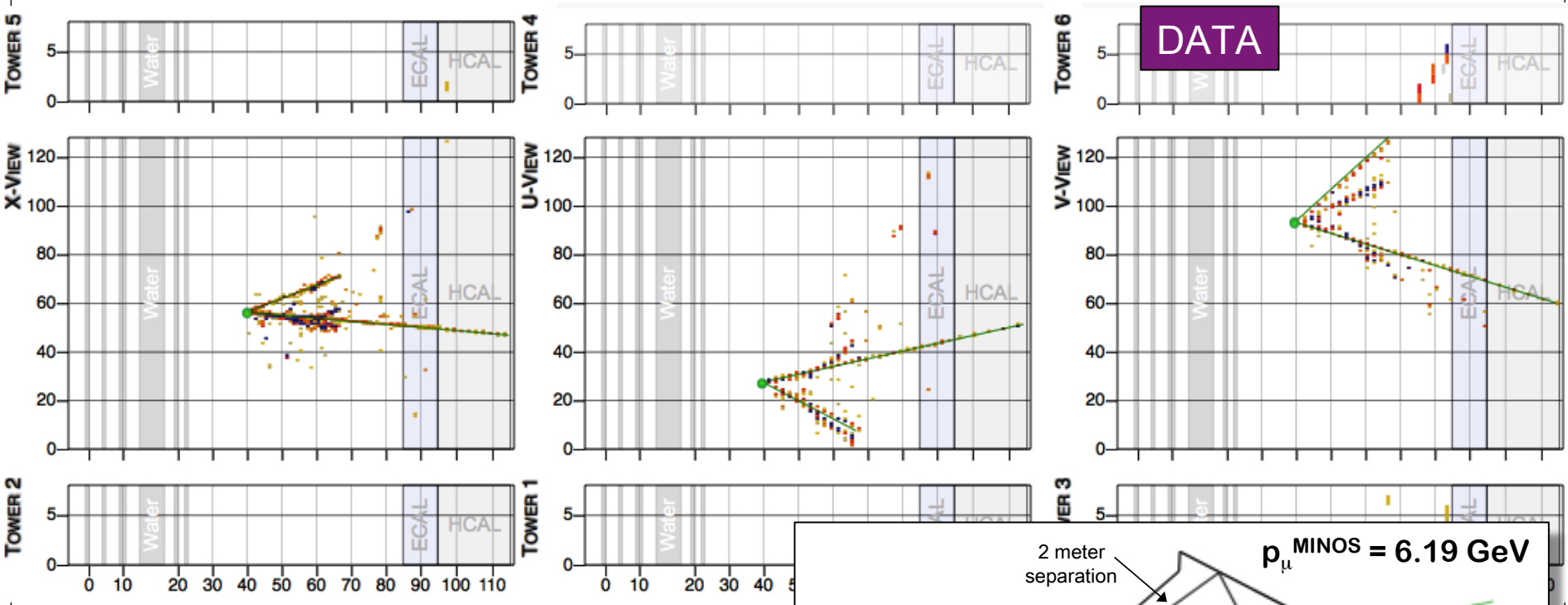
Matching tracks into MINOS



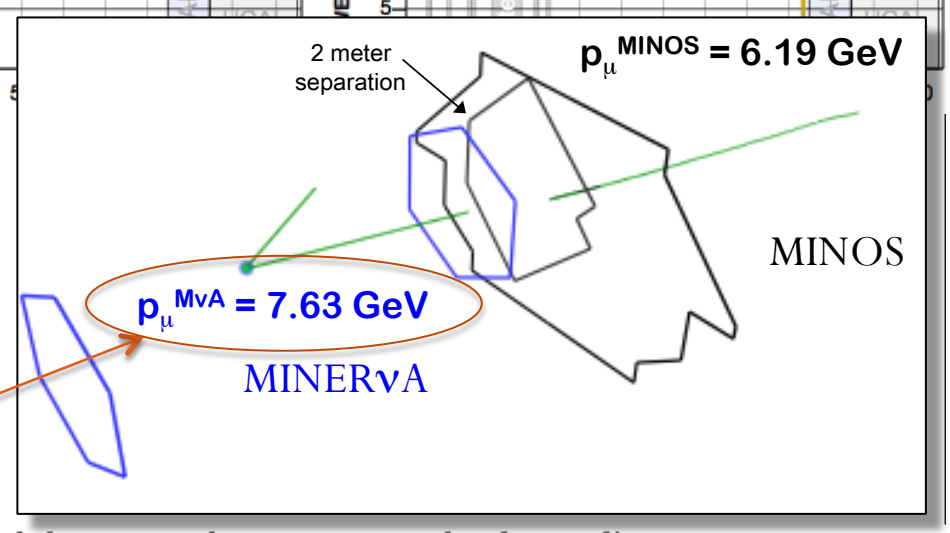


- Higher momentum muons penetrate into MINOS and are reconstructed by curvature or by range
- Data merged spill-by-spill; Matching of tracks done using timing and spatial information

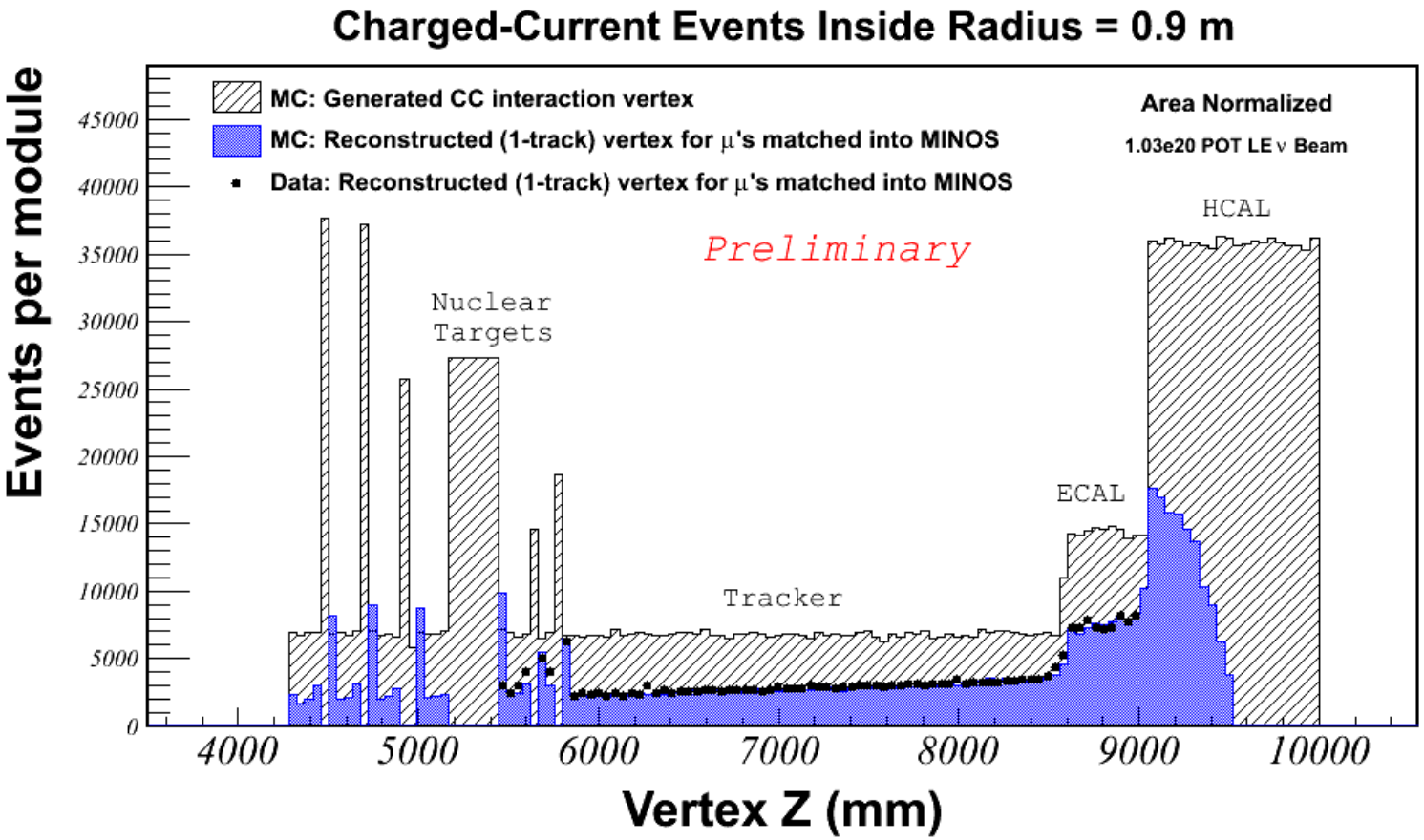
Matching tracks into MINOS



- Higher momentum muons penetrate into MINOS and are reconstructed by curvature or by range
- Propagate back to vertex in MINERνA, adding energy lost in detector material to estimate iniatial muon momentum



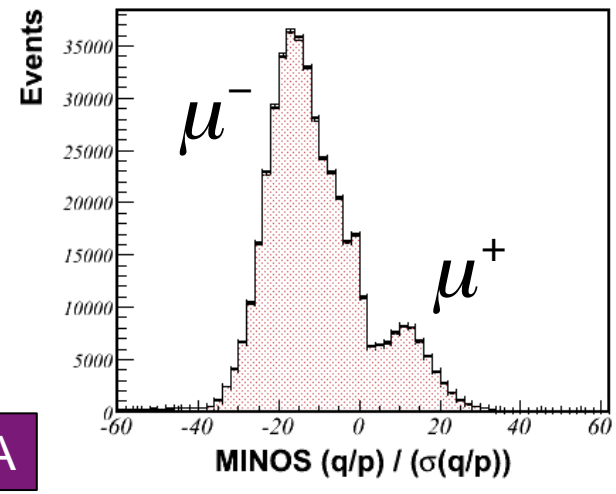
Muon Vertex for CC Events



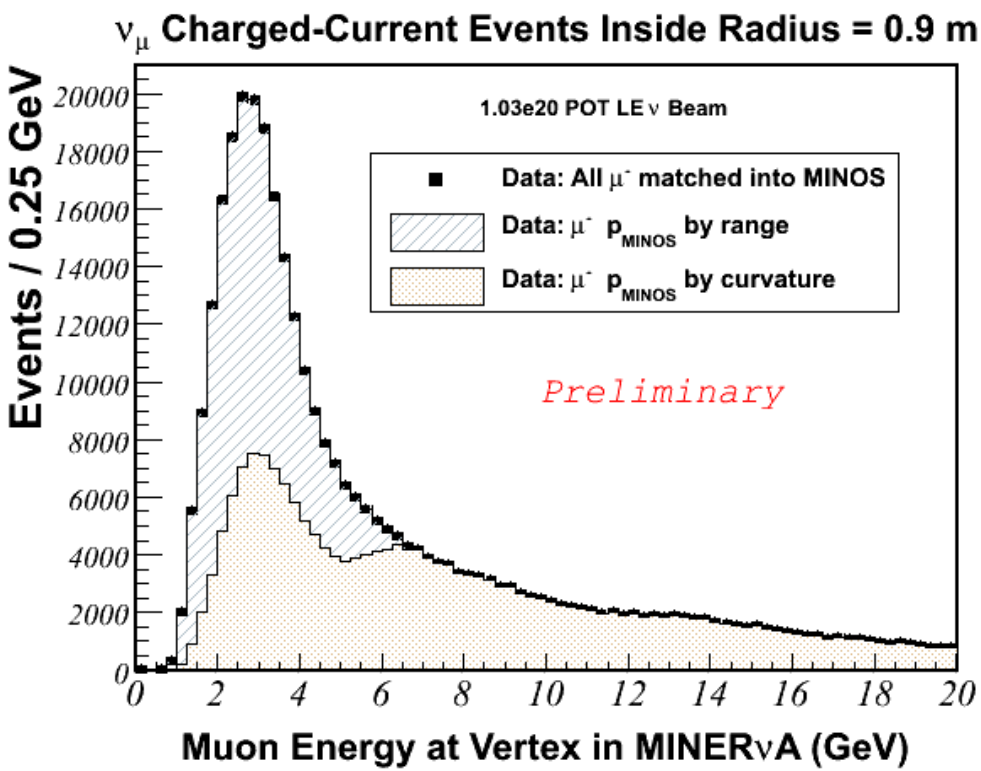
- Current analyses use muons which enter into MINOS only
- On-going efforts <u>to identify and reconstruct muons which range out in MINERνA</u> important for extending acceptance in E_μ, θ_μ for CC analyses

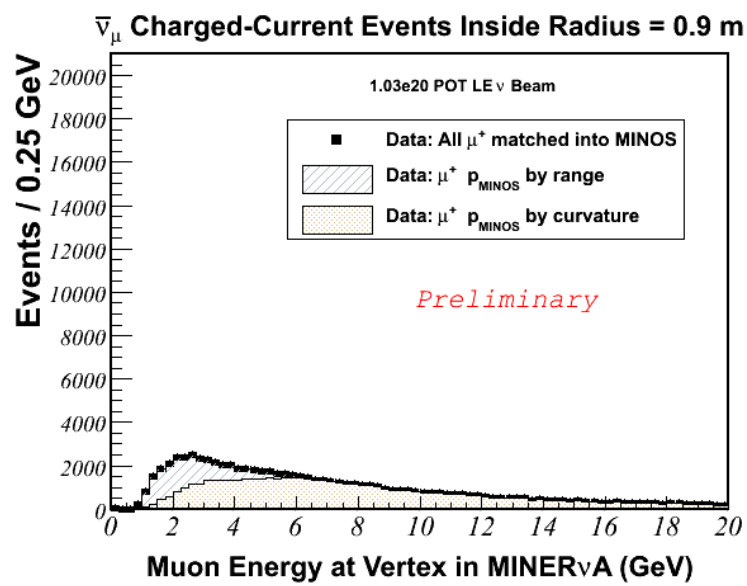
Muon Energy for CC Events

- Muon energy distributions in 1.03e20 POT of low-energy neutrino beam data
- Events in MINERνA inner detector region (all targets)
- Muon charge determined in MINOS



DATA





Advertisements

- **The MINERνA collaboration is presenting the preliminary status of three analyses at this workshop:**
  - Kevin McFarland will present a study of CCQE candidates in a sample of early data taken with ~50% of the full detector and an antineutrino beam on Tuesday
  - Brian Tice will discuss the plan for studying nuclear effects with the MINERνA detector on Thursday
  - Melissa Jerkins will present the strategy for constraining the neutrino flux prediction from the NuMI beamline on Friday
- **MINERνA has transitioned from a start of operations phase to a focus on analysis and preliminary results**
- **And MINERνA will be back with much more for NuINT 2013!**

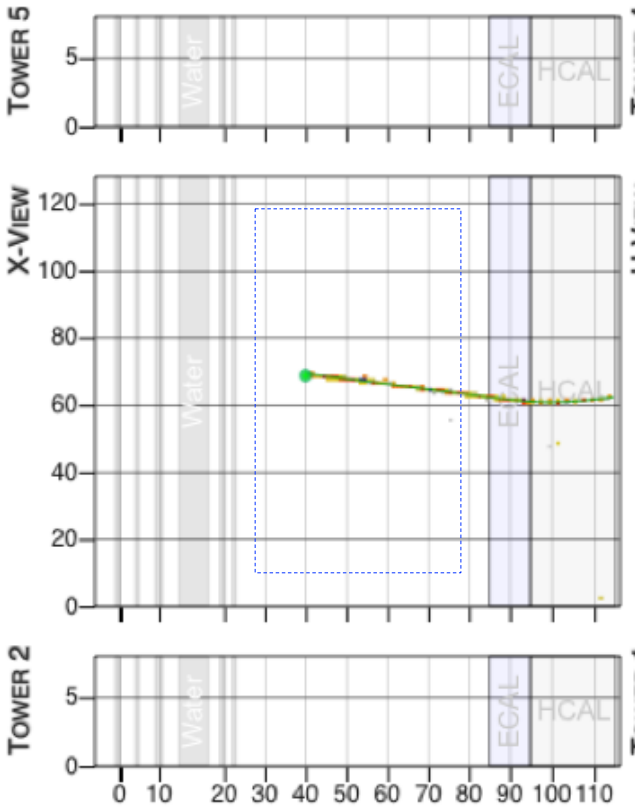
Thank You!

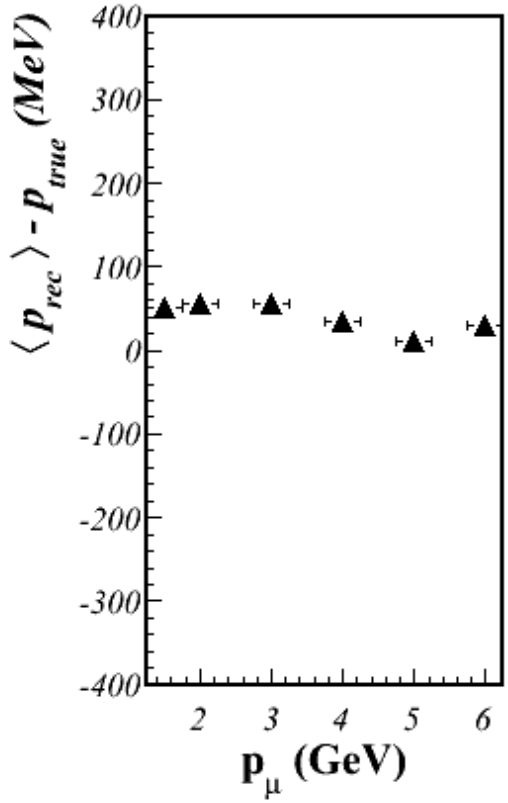
- **The MINERνA Collaboration would like to sincerely thank many groups who have been critical to our progress so far:**
  - Fermilab Particle Physics Division for all their help installing the MINERνA detector in the NuMI Near Detector Hall
  - Fermilab Accelerator Division for their tireless efforts to keep the NuMI facility running and to provide intense beam since the detector was commissioned
  - 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 important to MINERνA's success, and for the significant effort required on the part of many collaborators to process, calibrate, and reconstruct the Near Detector samples which we use in our analysis
  - Finally, we thank the Organizing Committee for NuInt 2011 for the opportunity to report on our progress and the status of our initial physics studies at this workshop!

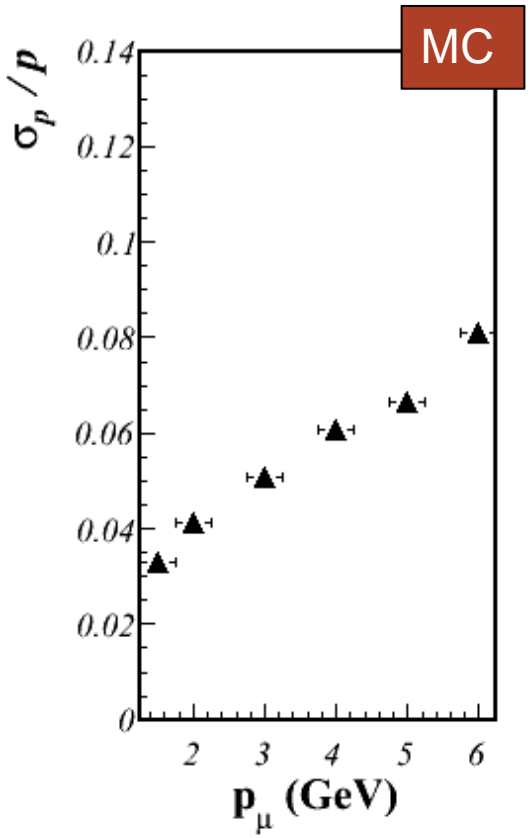
Extras

Muon Energy Resolution

- **Generate muons in Monte Carlo in the central tracking detector to map out momentum resolution and bias**
- **σ_p/p 3-8% below 6 GeV**







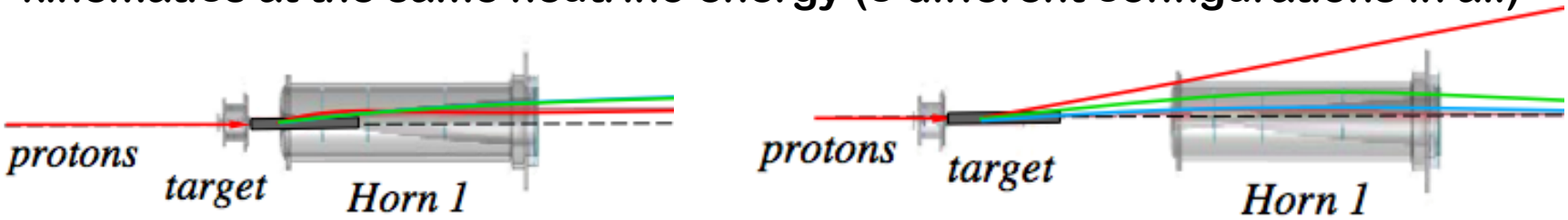
Neutrino Flux

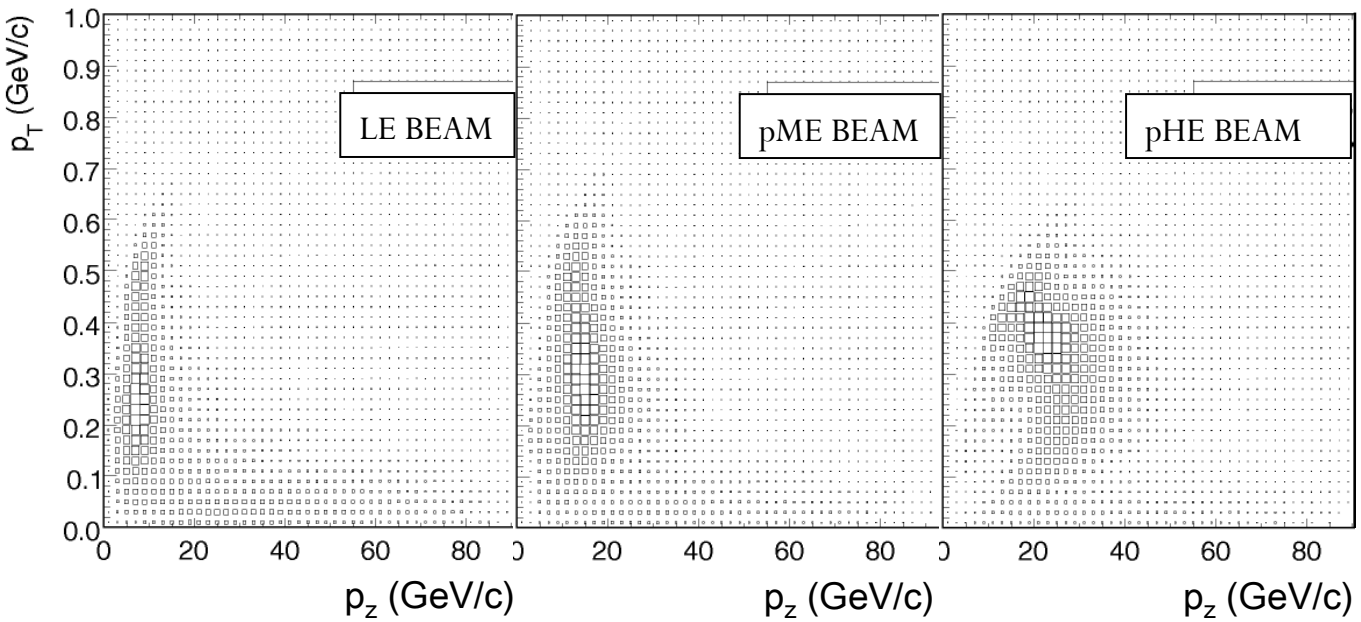
- Understanding the neutrino flux
  - Clearly important for any absolute cross-section measurements
  - Traditionally a very difficult problem in neutrino experiments. Past wide band beams limited to ~30% uncertainty in flux calculations. Often relied on knowing neutrino cross-section to measure neutrino flux…
  - Largest uncertainty comes from primary hadron production in the target by incident proton beam
  - MINERνA's goal is 7% in flux shape and 10% in normalization
  - MINERνA will take a multi-faceted approach to reducing flux uncertainties

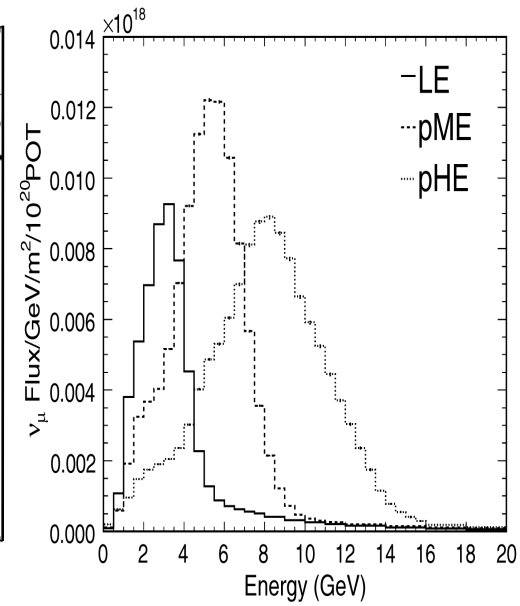
Neutrino Flux

- **Understanding the neutrino flux**

1. **Comparing ν event rates when varying beamline configuration (target z-position and horn current). Each configuration samples different pion kinematics at the same neutrino energy (8 different configurations in all)**



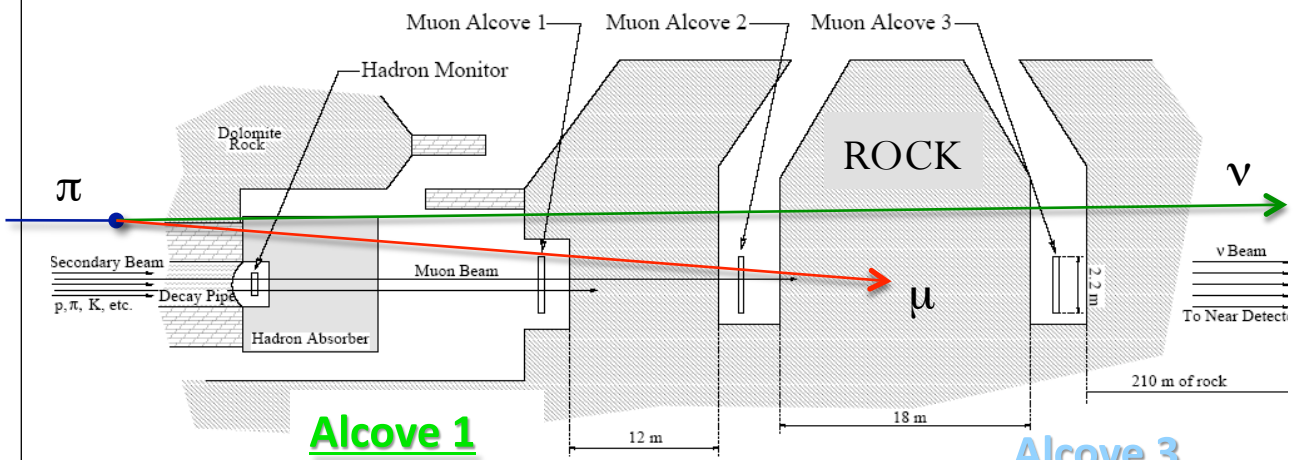




Neutrino Flux

- **Understanding the neutrino flux**

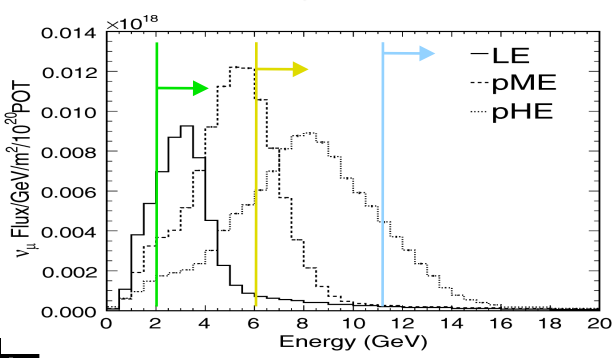
2. **In situ measurements using muon monitor system**



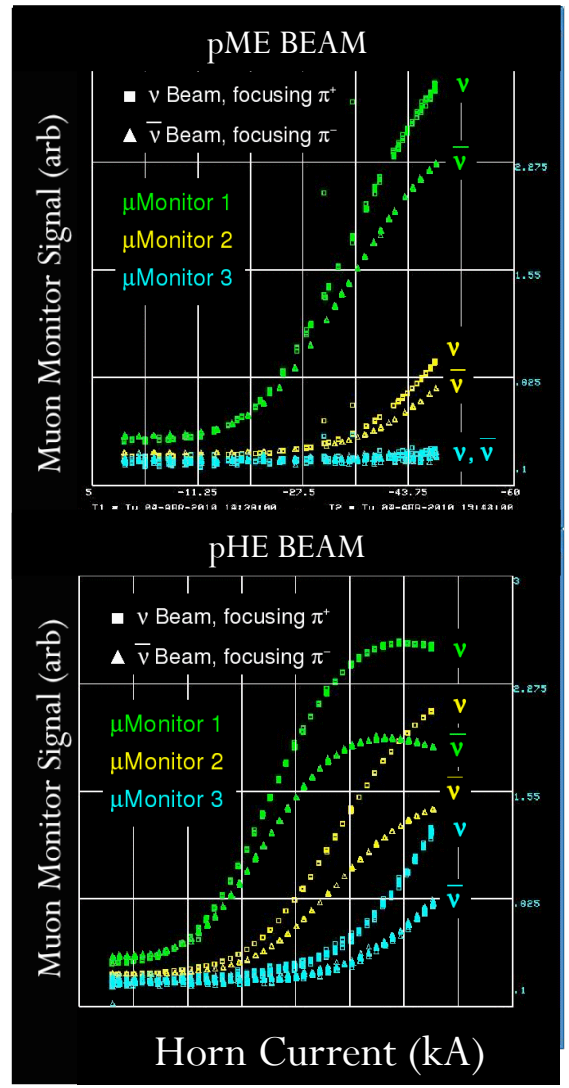
Alcove 1
$E_{\mu,\pi}$ > 4 GeV
E_{ν} > 2 GeV

Alcove 2
$E_{\mu,\pi}$ > 11 GeV
E_{ν} > 6 GeV

Alcove 3
$E_{\mu,\pi}$ > 21 GeV
E_{ν} > 11 GeV



- A large matrix of such data each sampling different hadron phase space
- Global fit to constrain hadron production



Neutrino Flux

- Understanding the neutrino flux

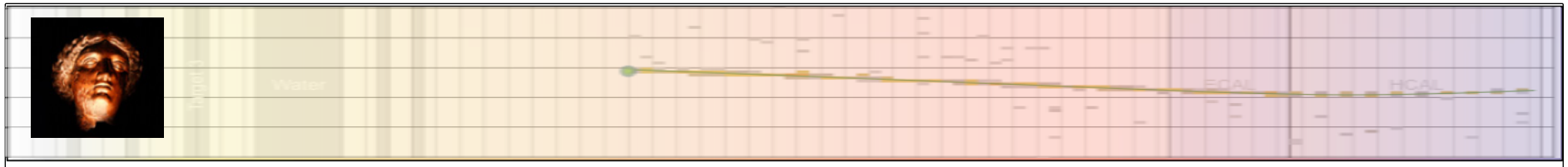
3. Ex situ hadron production data

   - Expected to be less precise than above approaches

   - Use world's data for protons on thick targets (SPY, MIPP, NA49,etc.) for "secondary beam", but requires extrapolations in energy, target thickness and target composition

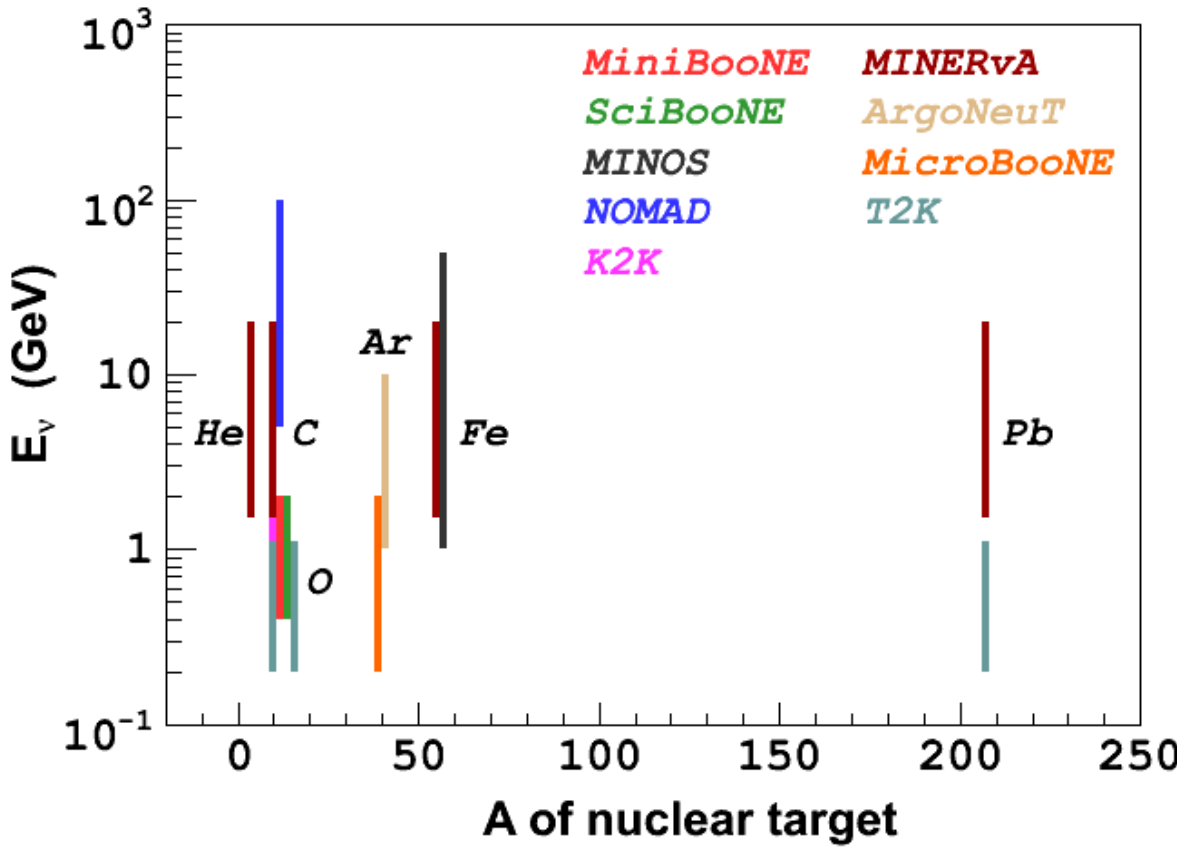
   - Use world's data to better model "tertiary beam", pion production in other materials in the beamline by lower energy protons and pions

   - The most comprehensive example of this bottom-up approach to neutrino flux prediction is MiniBooNE's flux calculations [Phys. Rev. D79, 072002 (2009)] where a total error of ~9% in the peak is achieved

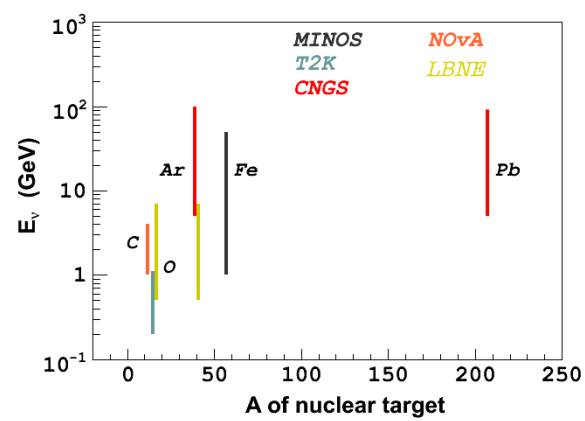


Nuclear targets
Neutrino energies
Interaction channels

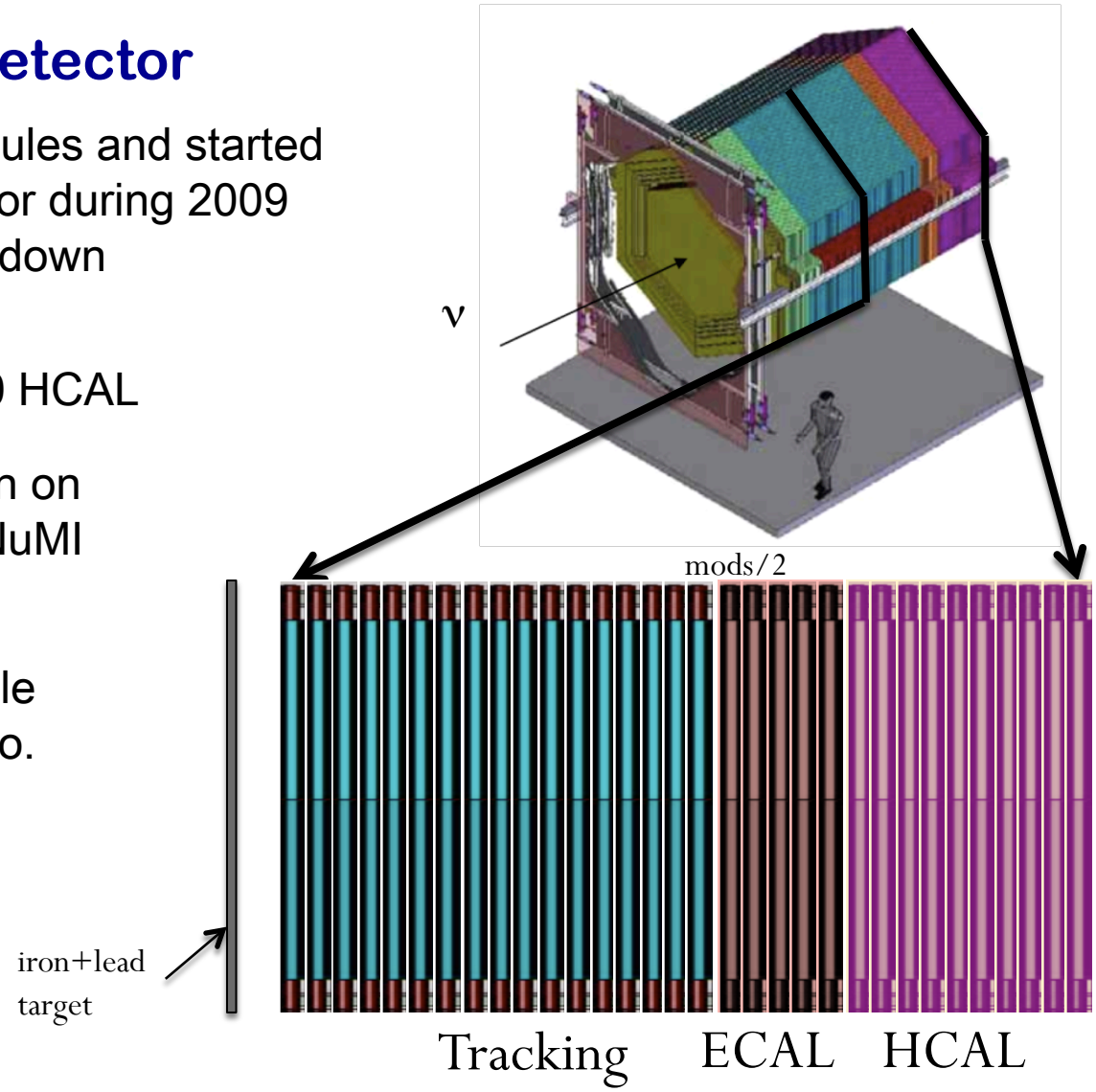
Modern Neutrino Cross-Section Experiments



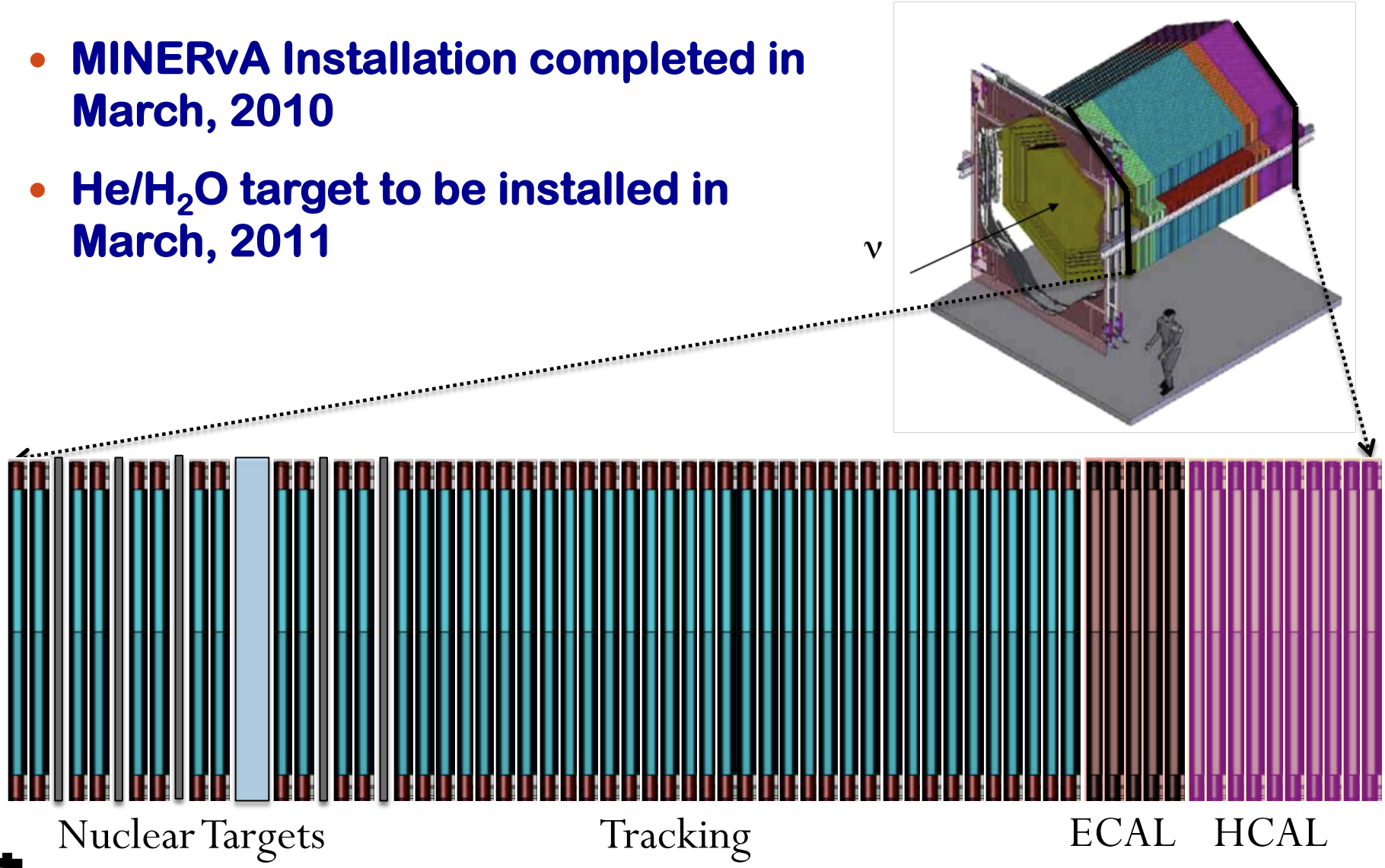
LBL Neutrino Oscillation Experiments



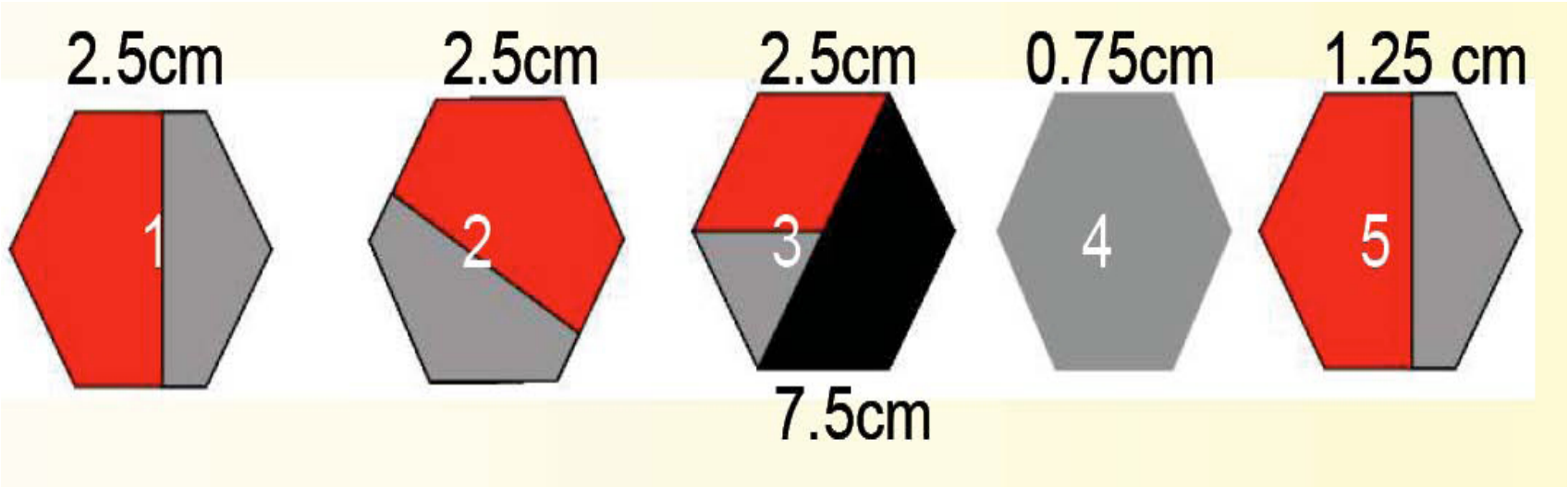
- **MINERvA "Frozen" Detector**
  - Removed Prototype modules and started installation of final detector during 2009 summer accelerator shutdown
  - Installed **64 modules**
    34 tracking+10 ECAL+20 HCAL
  - Froze detector installation on November 12 to collect NuMI **antineutrino beam data**
  - One nuclear target module (Fe, Pb) included for 2 mo.



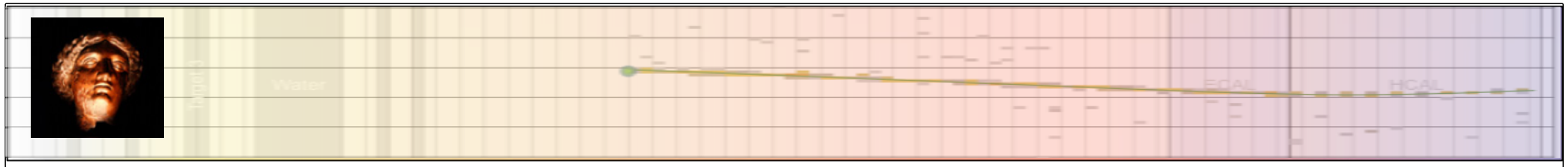
- **MINERvA Installation completed in March, 2010**
- **He/H_2O target to be installed in March, 2011**



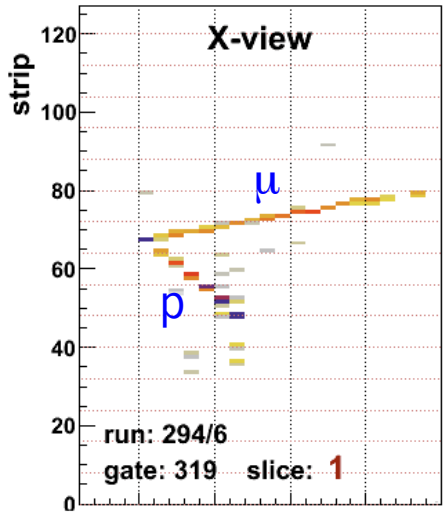
- Red = Iron, Grey = Lead, Black = Carbon



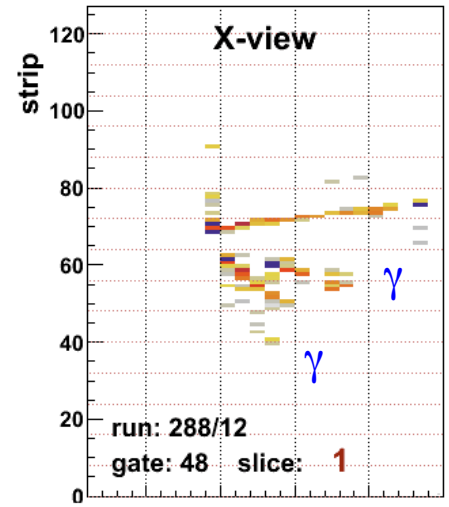
- First two targets: High statistics, compare lead and iron
- Third target: Compare lead, iron, and carbon with same detector geometry
- Last targets: Thin for low energy particle emission studies, high photon detection
- ^{4}He cryogenic target in front of detector



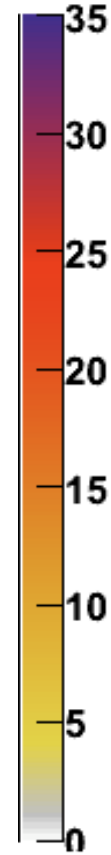
ν_μ CCQE candidate event



ν_μ CC π^0 candidate event



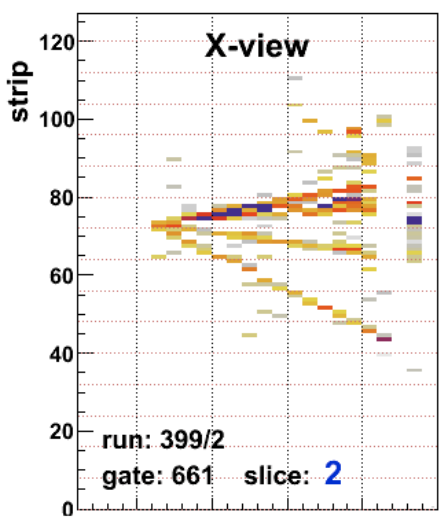
p.e. scale



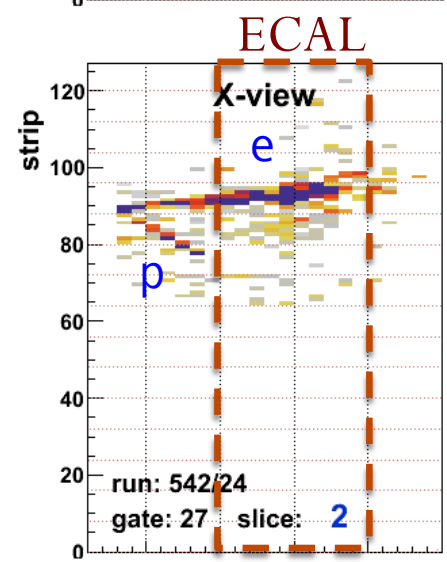
MINOS

NuMI Beam

DIS candidate event

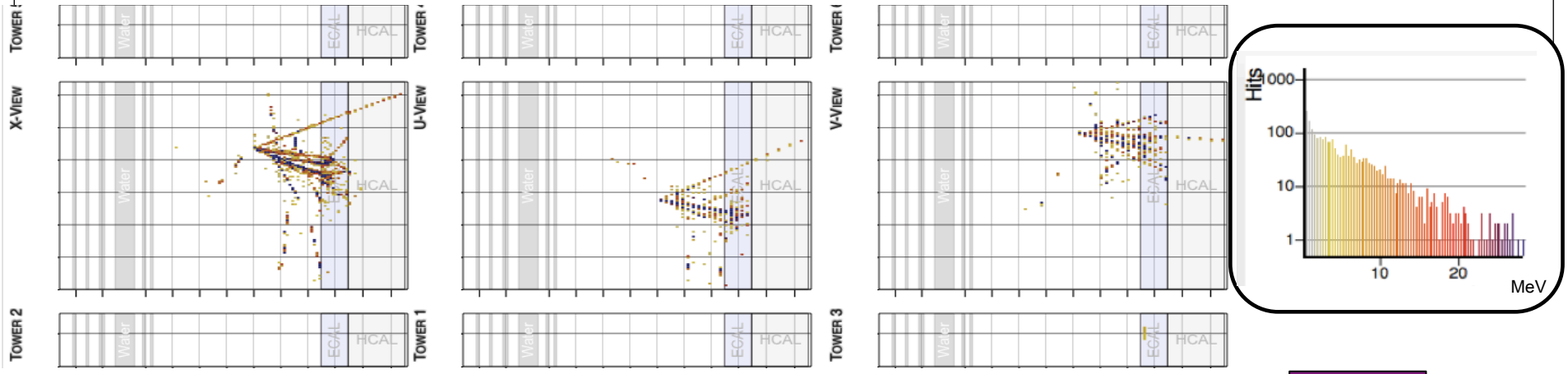


ν_e CCQE candidate event



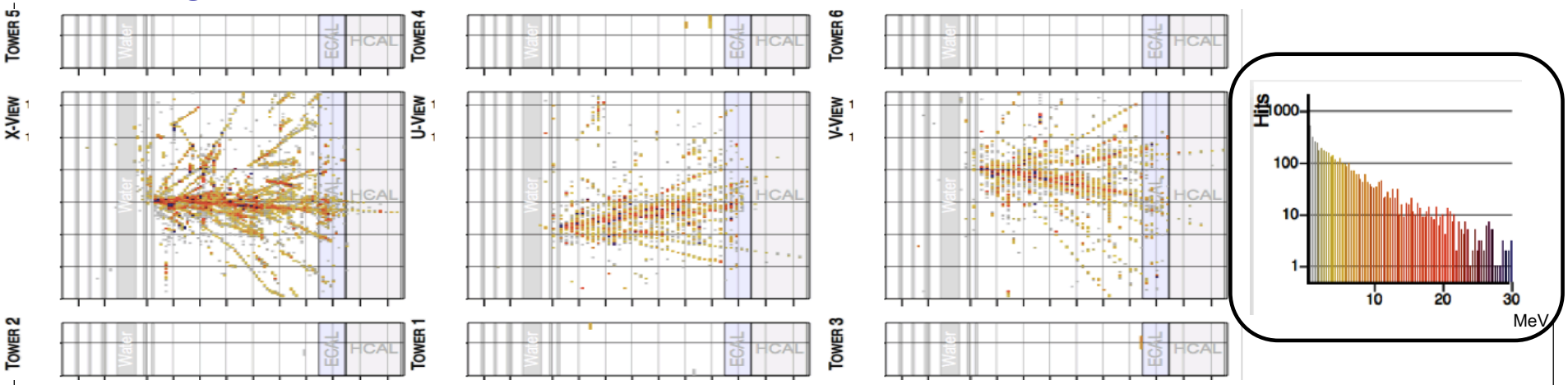
ν Events in MINERνA

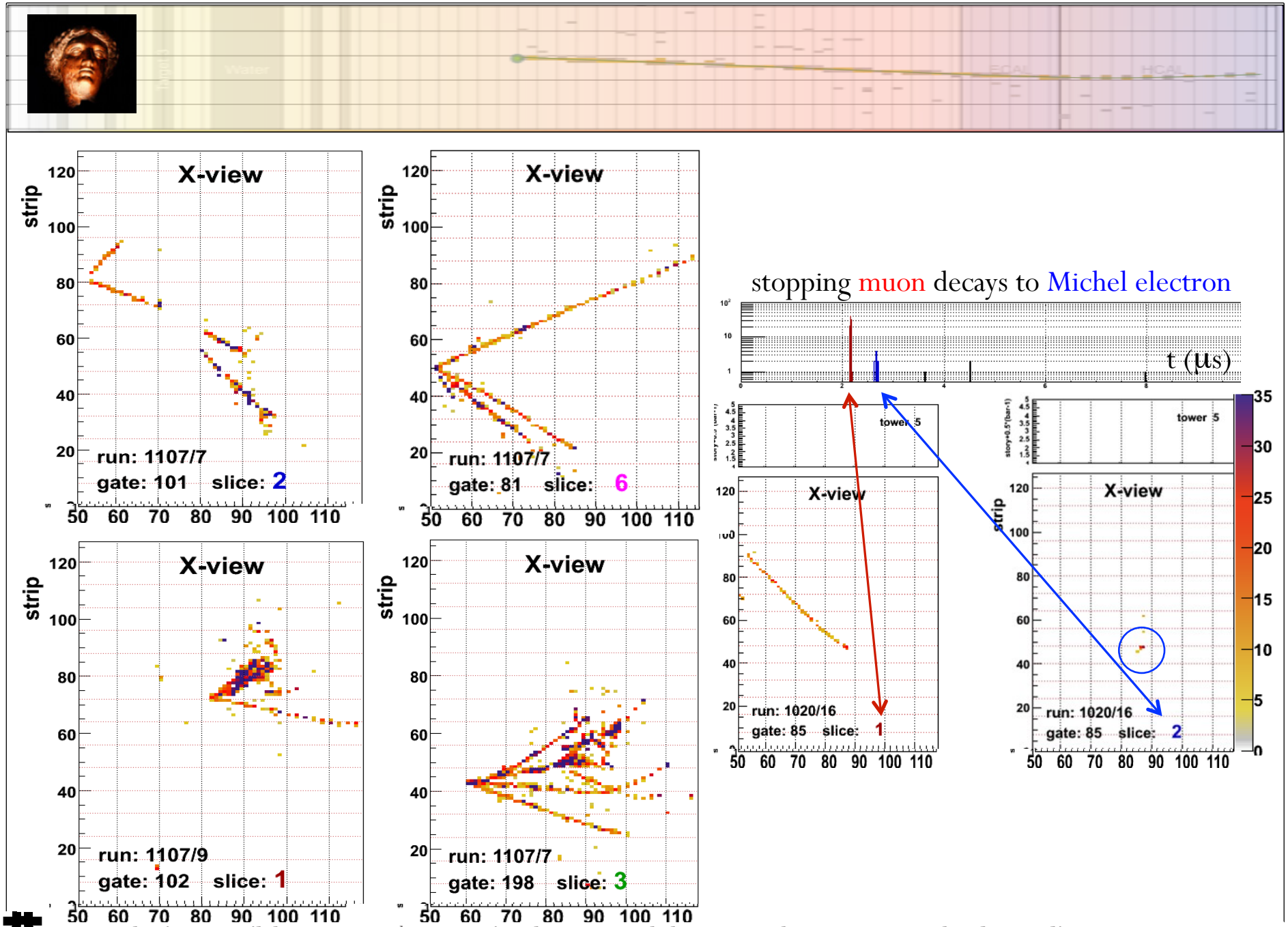
- **Charged-current DIS candidate**



DATA

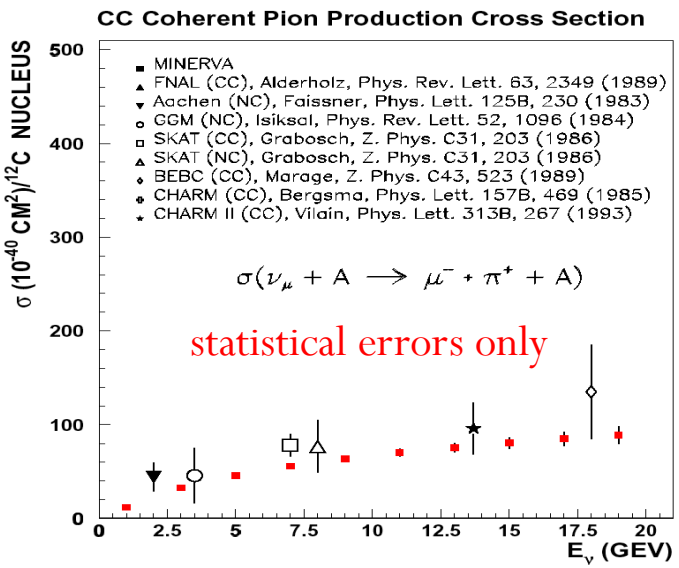
- **Charged-current DIS candidate**

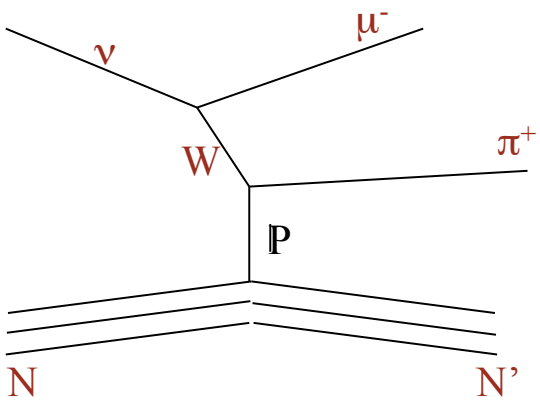


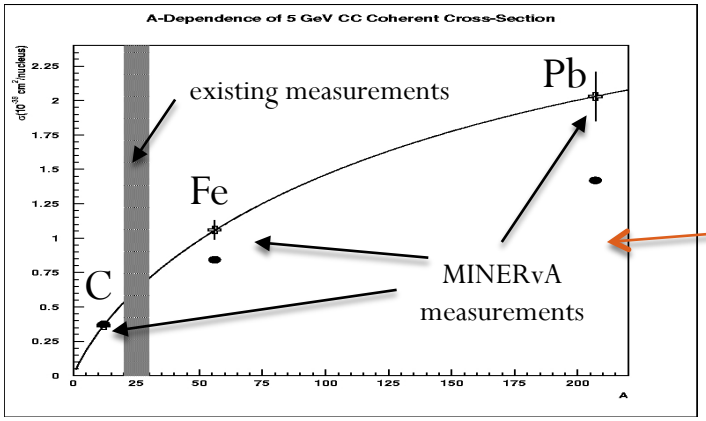

X-view
strip
run: 1107/7
gate: 101 slice: 2
run: 1107/7
gate: 81 slice: 6
run: 1107/9
gate: 102 slice: 1
run: 1107/7
gate: 198 slice: 3
stopping muon decays to Michel electron
t (μs)
tower 5
run: 1020/16
gate: 85 slice: 1
run: 1020/16
gate: 85 slice: 2

Coherent Scattering

- **Coherent pion production (CC/NC) off the nucleus**







- Scatters off the nucleus as a whole, leaving nucleus in the ground state.
- Comparison with theoretical models
- MINERνA's nuclear targets allow the first measurement of the A-dependence of σ_{coh} across a wide range in a single experiment

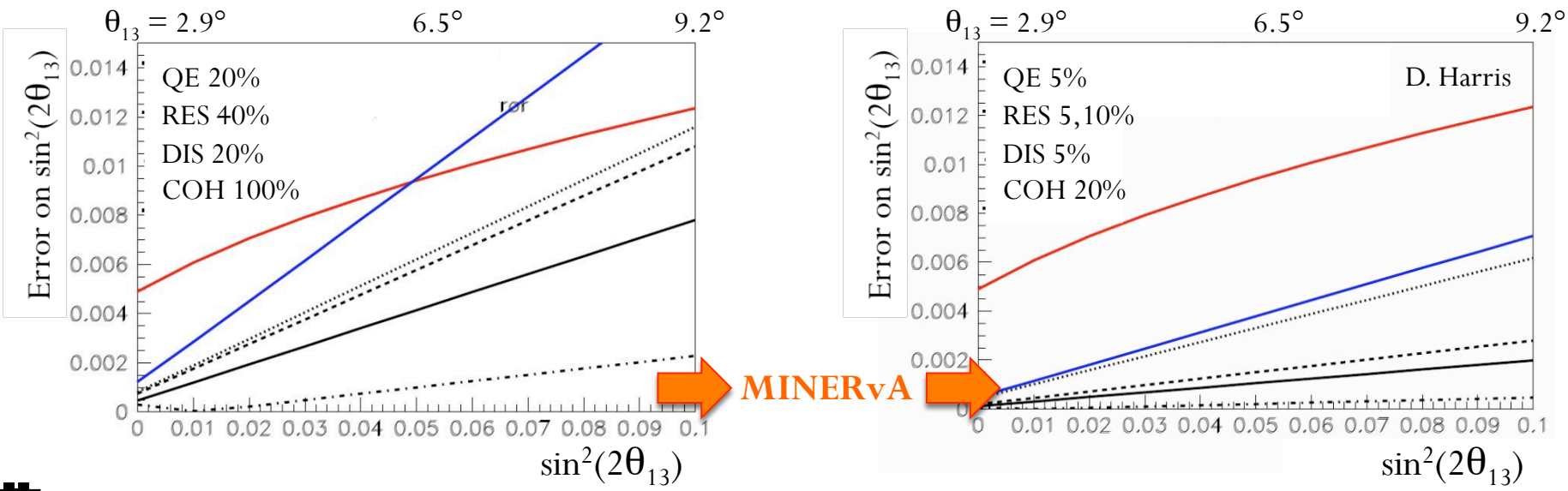
Impact on Oscillation Exp

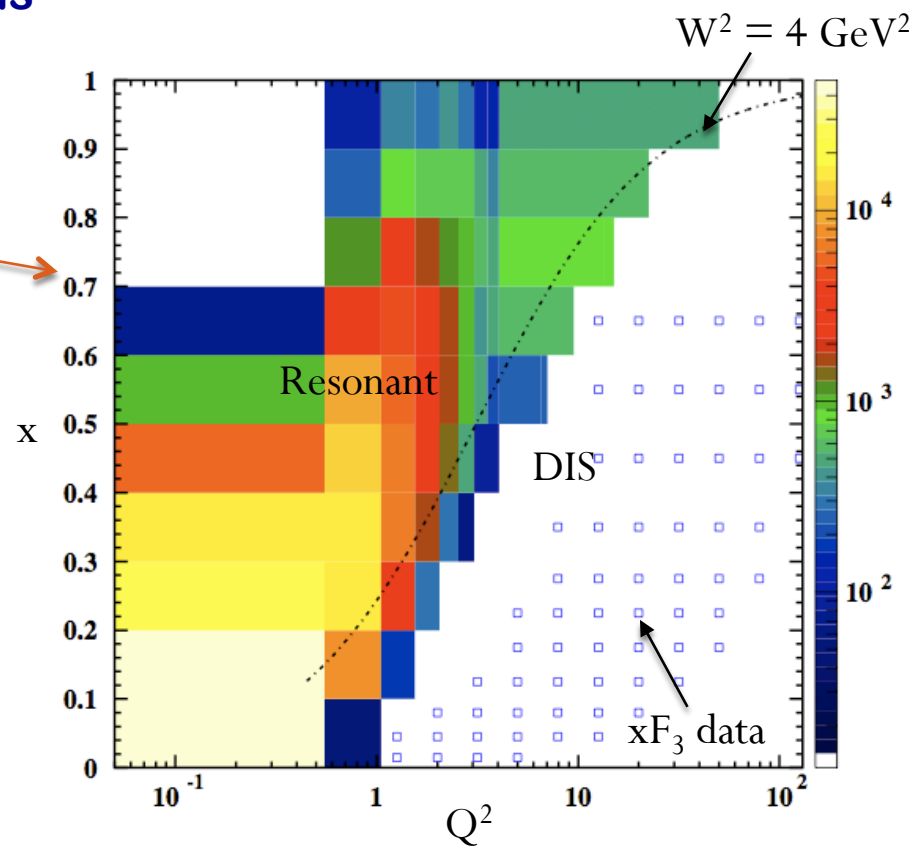
- **NOvA $\sin^2\theta_{13}$ sensitivity**
  - Toy MC study
  - Expected cross-section uncertainties after MINERvA make s systematic negligible for all values of $\sin^2\theta_{13}$

Process	Stats	QE	RES	DIS	COH
Signal ν_e	78 ($\sin^2\theta_{13}$=0.1)	50%	40%	1%	9%
NC	6.6	1%	10%	11%	78%
ν_μ CC	0.7	0%	7%	0%	93%
Beam ν_e	7.2	52%	37%	1%	10%

statistical error on a signal of that size

total systematic error from cross-section uncertainties of the given size



DIS Physics

- **Deep Inelastic Scattering Physics: PDFs and Nuclear Effects**
- **The intense NuMI broad-band neutrino beam and the fine-grained high-resolution MINERvA detector provide an opportunity for a lot of physics beyond cross-sections for oscillations**
  - Expected numbers of events in (x,Q^2) for ~4 years of running in the Resonant → DIS transition region
  - Study transition between perturbative and nonperturbative QCD regimes
  - High statistics at high x