The MINERνA Detector

NuInt 2012

8th International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region

Rio de Janeiro, Brazil
22 – 27 October 2012

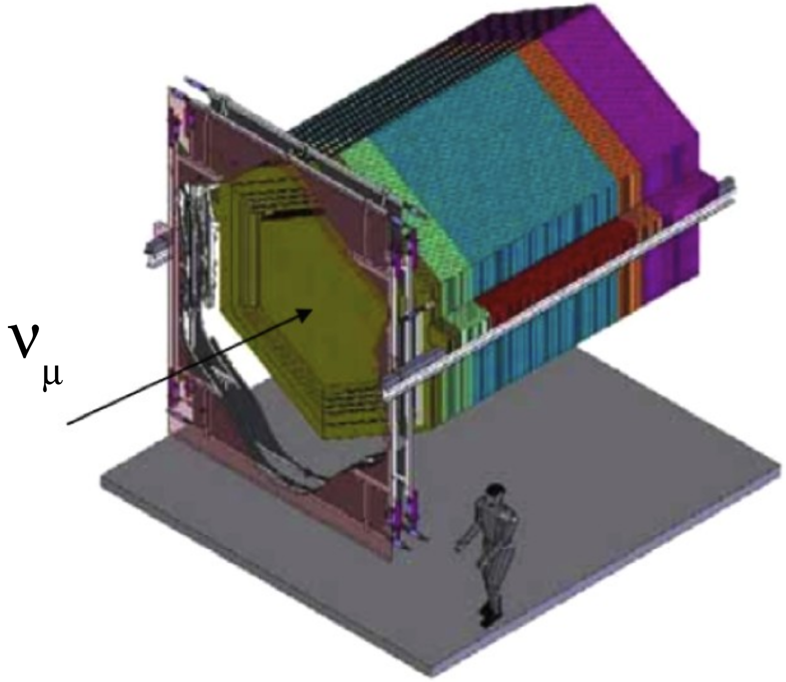
G. Arturo Fiorentini
Centro Brasileiro de Pesquisas Físicas
On behalf of the MINERνA collaboration

Overview

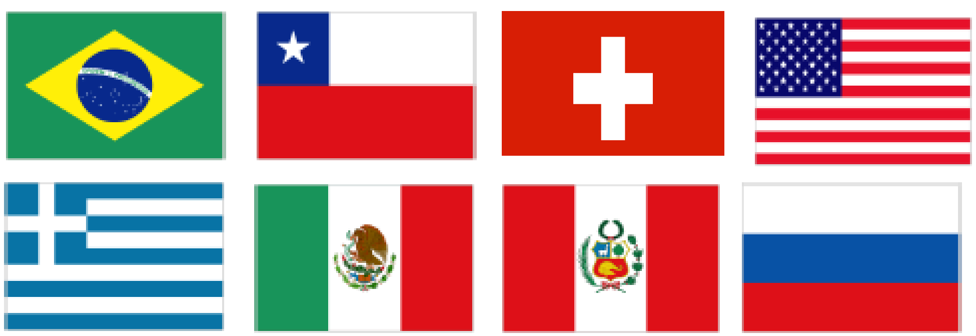
- The MINERvA experiment.
- The neutrino beam (NuMI).
- The MINERVA detector.
- Detector performance.

MINERνA Experiment

- High precision neutrino scattering experiment in the 1-10 GeV energy range.
- Goal is to measure exclusive and inclusive neutrino-nucleus cross section using a high resolution detector.
- Detector was designed to study the A-dependence of neutrino reactions on a variety of nuclei (scintillator, He, C, water, Fe and Pb).



MINERνA Collaboration



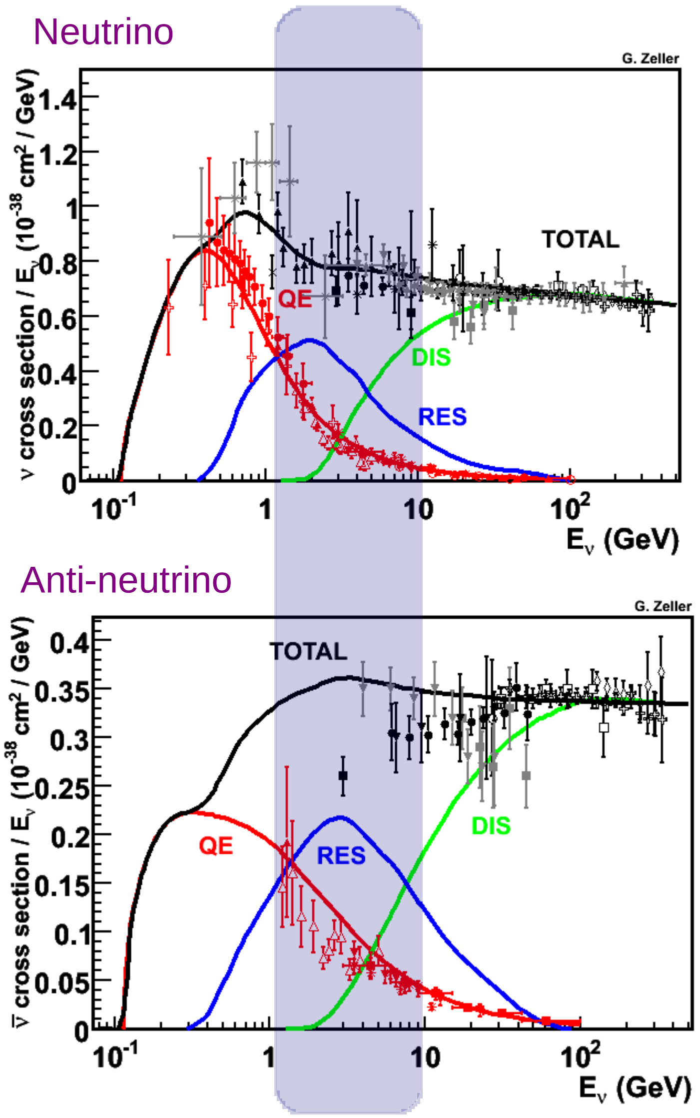
80 nuclear and particle physicists
from 24 institutions

University of Athens
University of Texas at Austin
Centro Brasileiro de Pesquisas Físicas
Fermilab
University of Florida
University of Geneva
Universidad de Guanajuato
Hampton University
Inst. Nucl. Res. Moscow
James Madison University
Mass. Col. Lib. Arts
Northwestern University
Otterbein University
Pontificia Universidad Catolica del Peru
University of Pittsburgh
University of Rochester
Rutgers University
Tufts University
University of California at Irvine
University of Chicago
University of Minnesota at Duluth
Universidad Nacional de Ingeniería
Universidad Técnica Federico Santa María
William and Mary

MINERνA Motivation

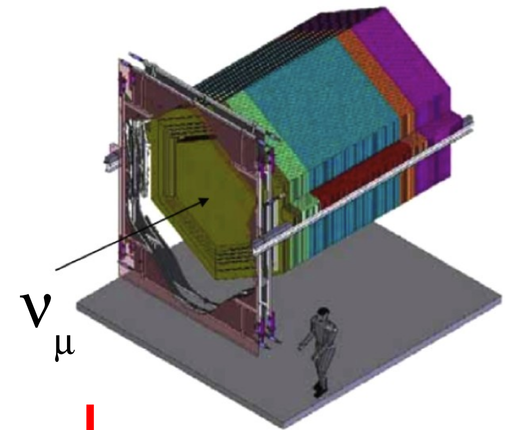
- Neutrino and anti-neutrino interaction cross section are not well measured in 1 – 10 GeV range.

- Cross sections for neutrino and anti-neutrino interactions in nuclear matter important for oscillation experiments.

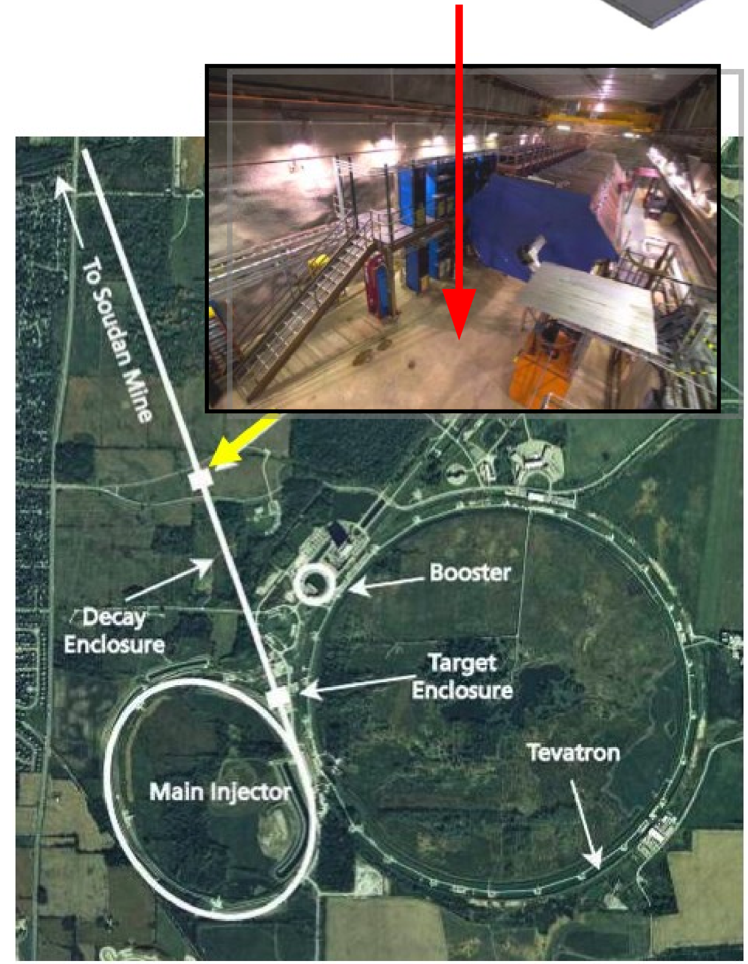


J.A. Formaggio and G.P. Zeller,
"From eV to EeV: Neutrino Cross Sections Across Energy Scales",
Rev. Mod. Phys., 2012.

MINERνA (Main INjector ExpeRiment ν-A)

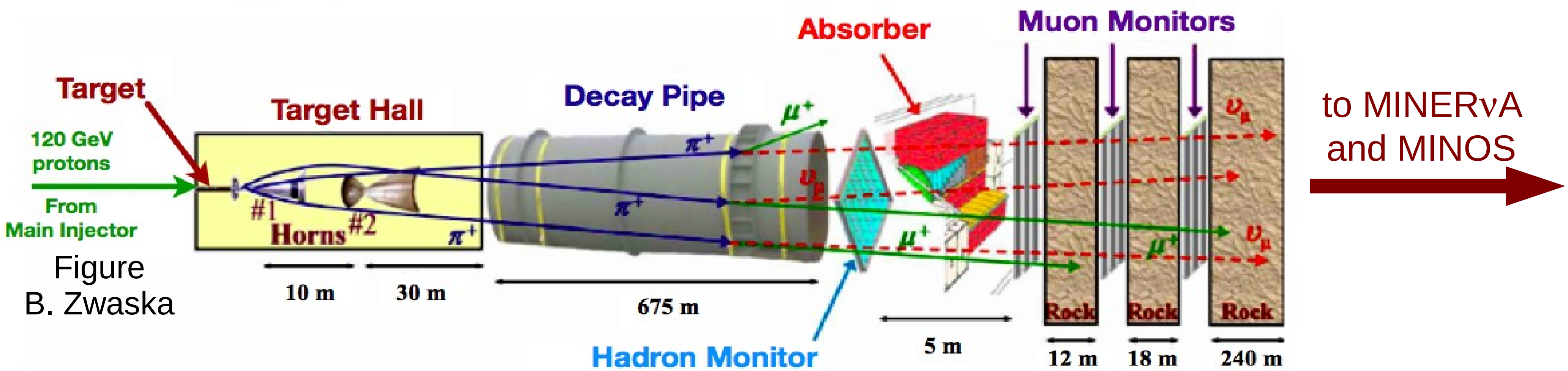


- Located at Fermilab in Batavia, IL, USA.
- Uses NuMI neutrino beamline.
- Detector installed upstream of the MINOS near detector.
- Uses MINOS near detector as muon spectrometer.

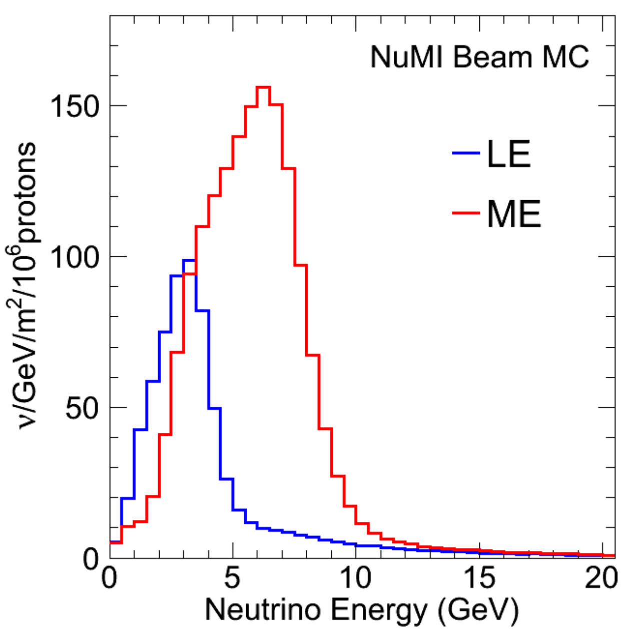


Fermilab, Batavia IL, USA

NuMI (Neutrinos at the Main Injector)



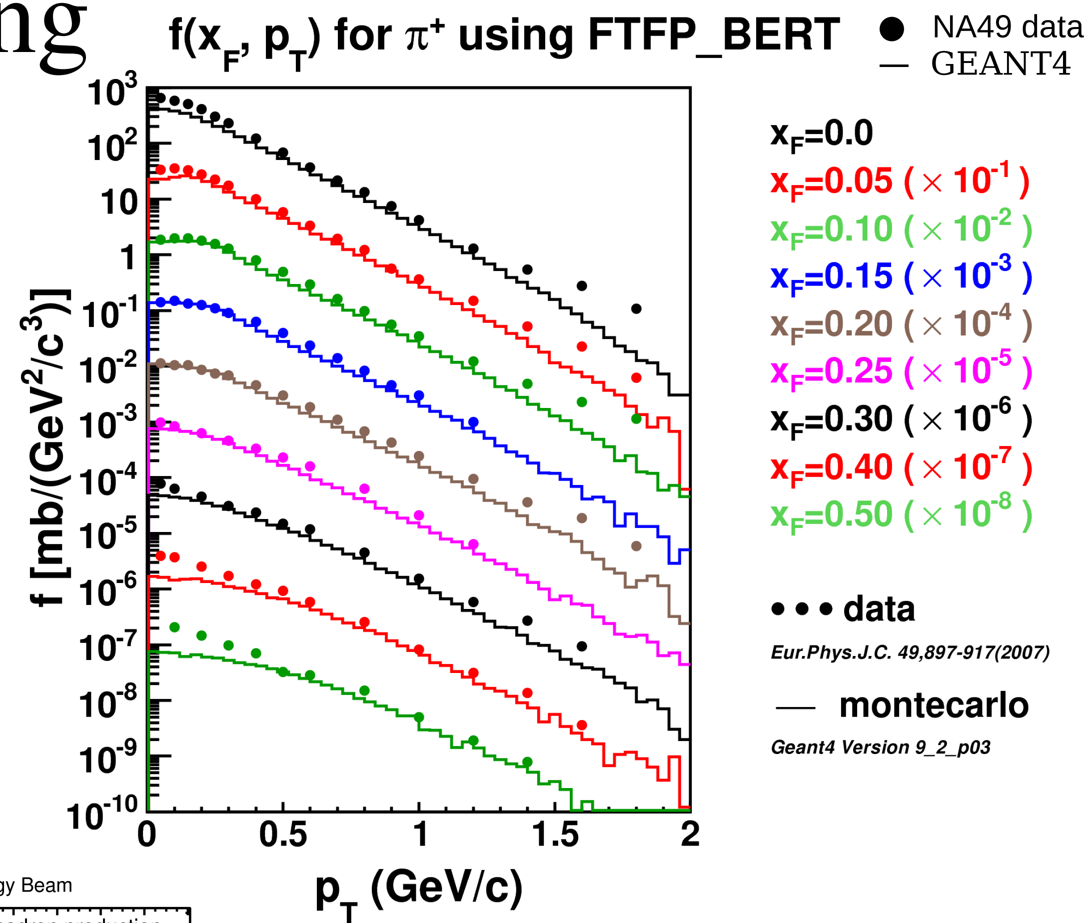
FLUKA: A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

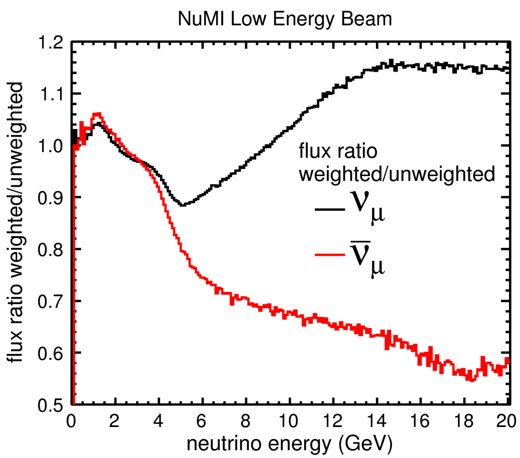


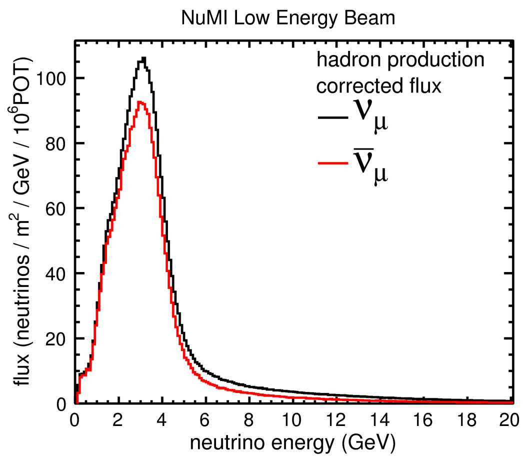
- Very intense neutrino beam with a power of 300 – 350 kW and ~35e12 P.O.T. (Protons On Target) per spill.
  - Spill: 10 μs duration at ~0.5 Hz frequency.
- Energy distribution can be tuned by changing position of target with respect to horns.
- Anti-neutrino beam is obtained by reversing the current in the magnetic horns to focus π^- and instead of π^+ .

Neutrino Flux Tuning

- Tuning the NuMI beam line simulation to reduce flux related uncertainties.
- Hadron production at NuMI target is simulated with Geant4 to predict flux.





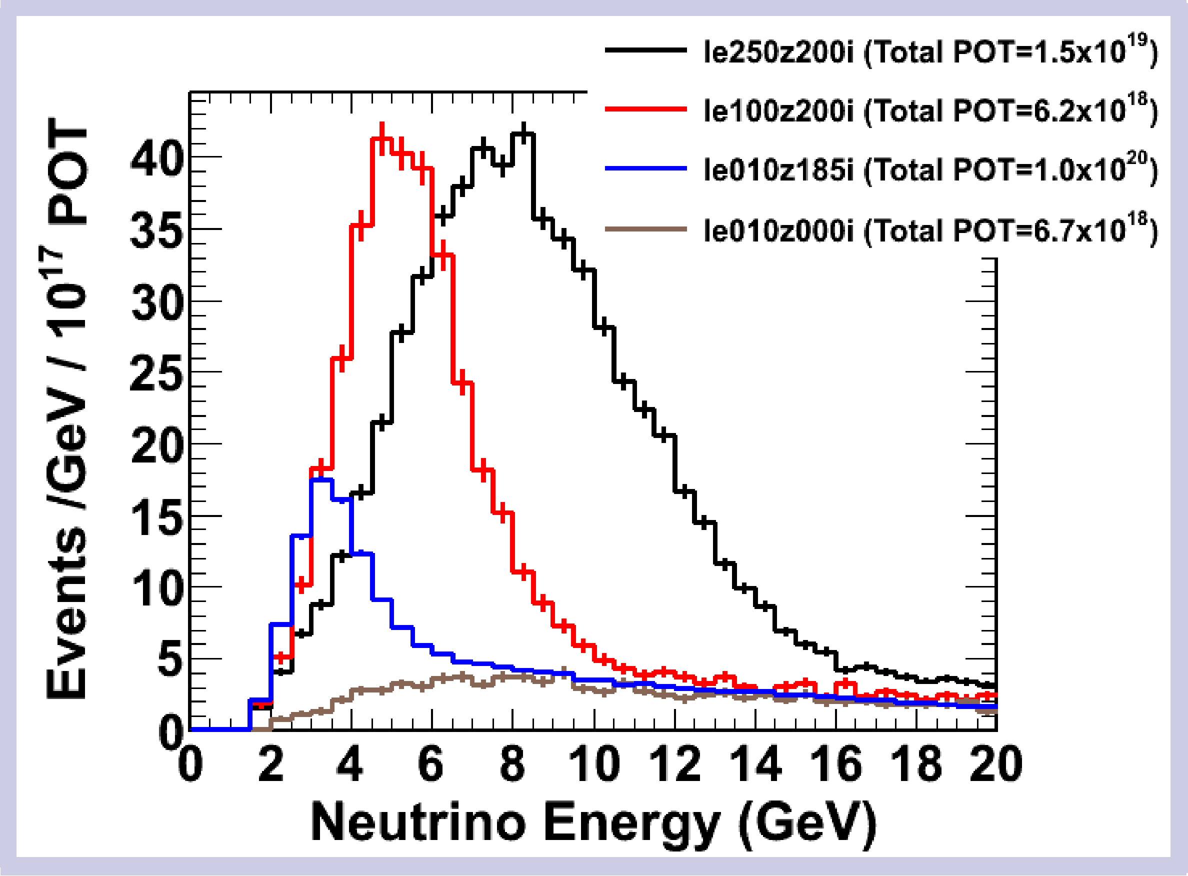


- Flux simulation is re-weighted to match hadron production data from NA49 experiment at CERN.

Neutrino Flux Tuning

- Future flux measurements will be improved by multi-pronged attack:
  - Data with different horn current and target position configurations (special runs).
  - New hadron production data.
  - In situ measurement from muon flux via muon monitors.

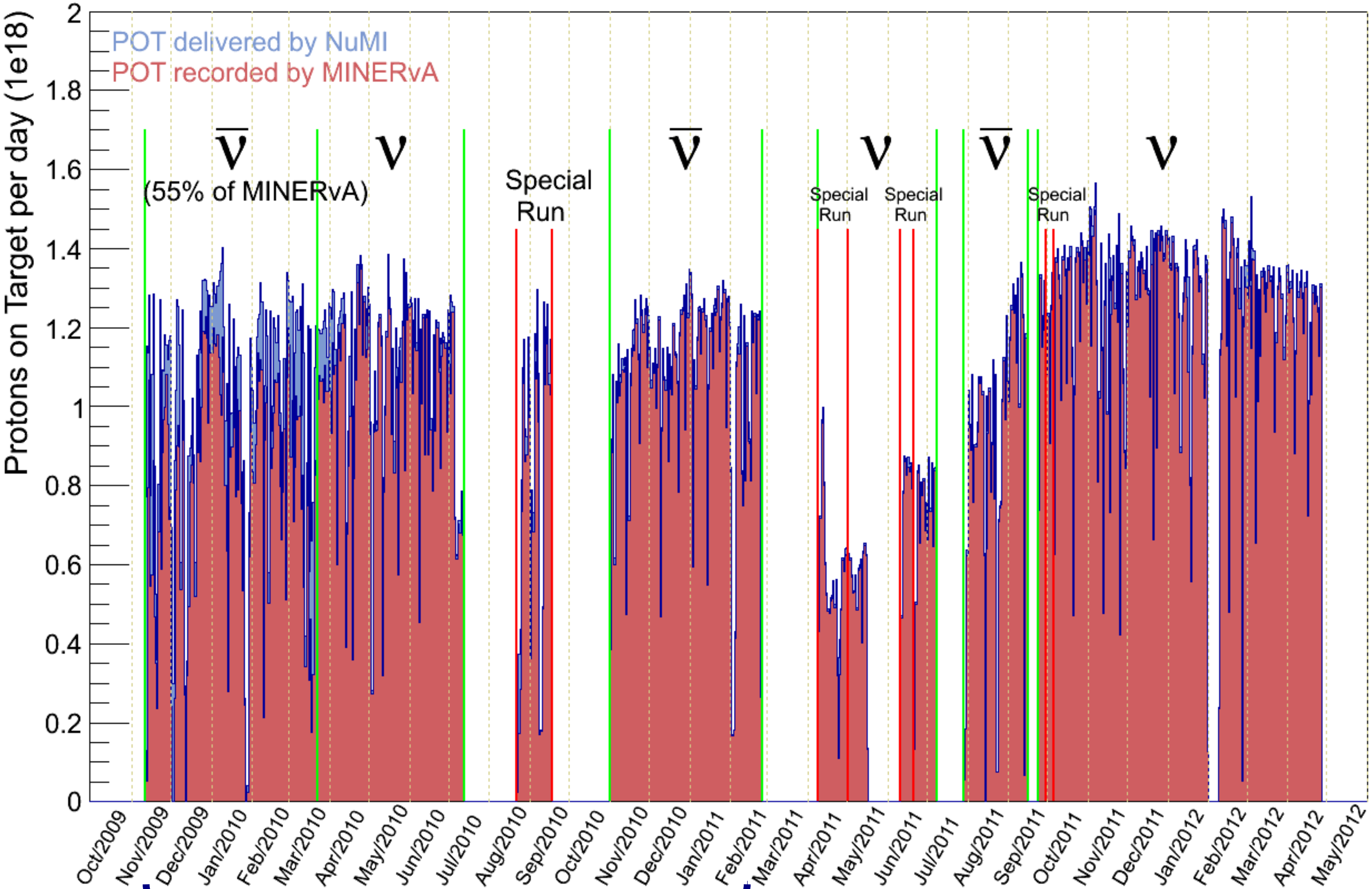
Special Runs



Data already taken!

Please look for more details at D. Harris' poster "Understanding the NuMI Flux for MINERvA".

Total Data Collected



Since 3/22/10

ν_μ LE
3.98e20 POT

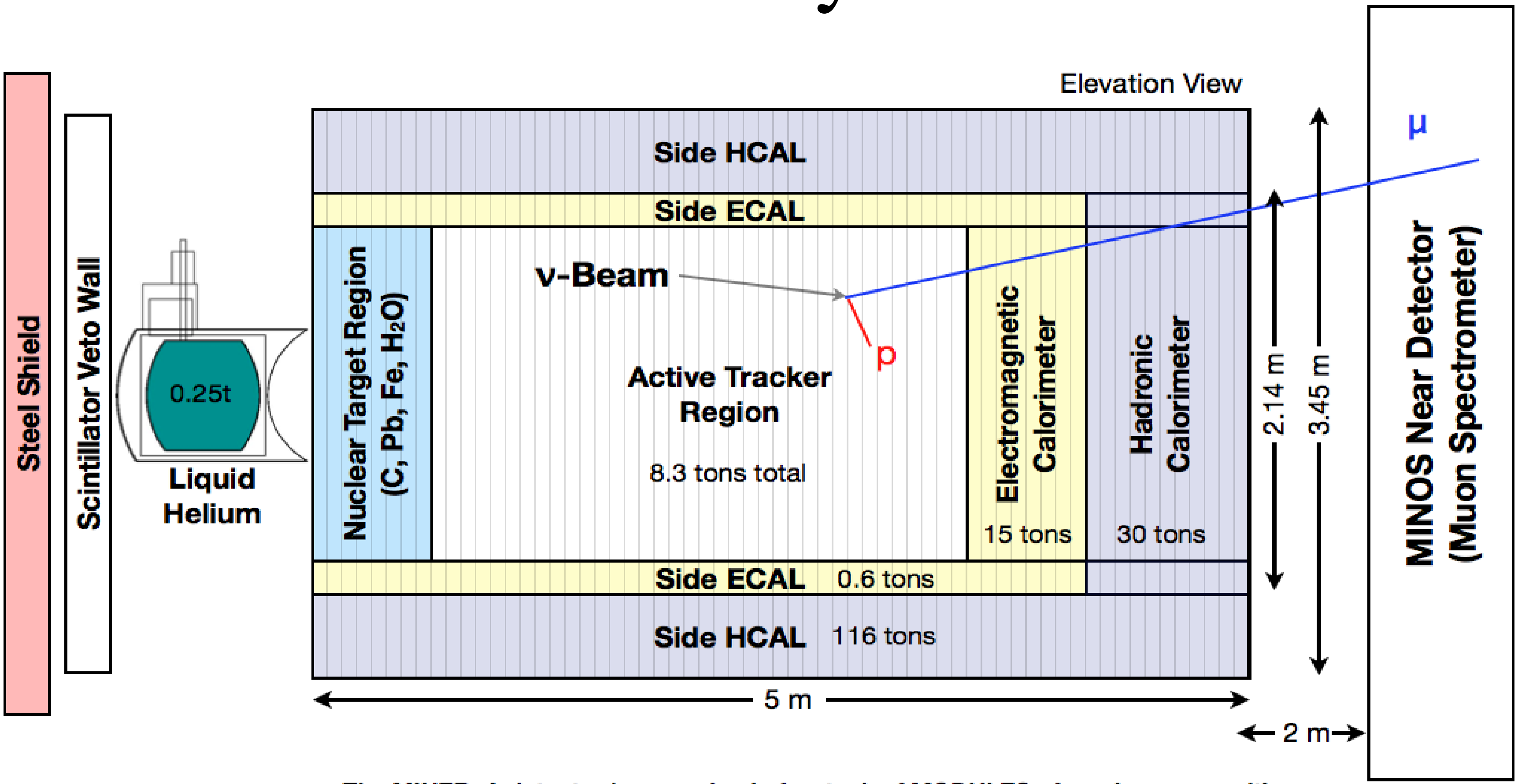
$\bar{\nu}_\mu$ LE
1.70e20 POT

special runs
4.94e19 POT

Analyzed Data
(Nov 2009 – Feb 2011)

Livetime: 97.2% MINERvA, 93.3% MINOS ND
(3/22/10 – end of run)

MINERνA Detector Layout

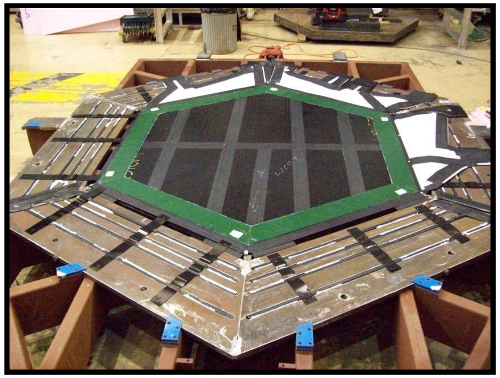


The MINERνA detector is comprised of a stack of MODULES of varying composition, with the MINOS Near Detector acting as a muon spectrometer. It is finely segmented (~32 k channels) with multiple nuclear targets (C, CH, Fe, Pb, He, H_2O).

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

4 types of modules: nuclear targets, tracker, ECal and HCal.

MINERνA Modules



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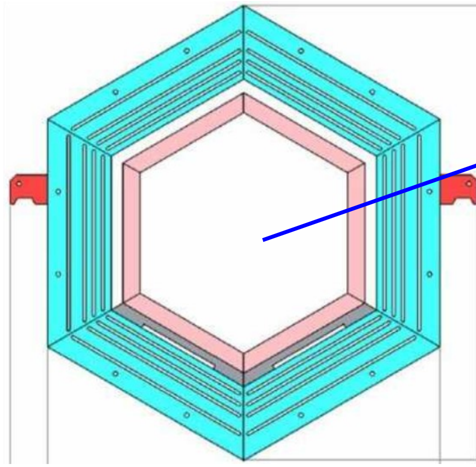
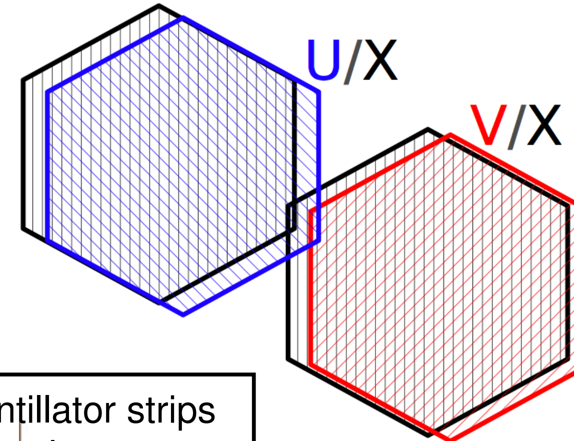
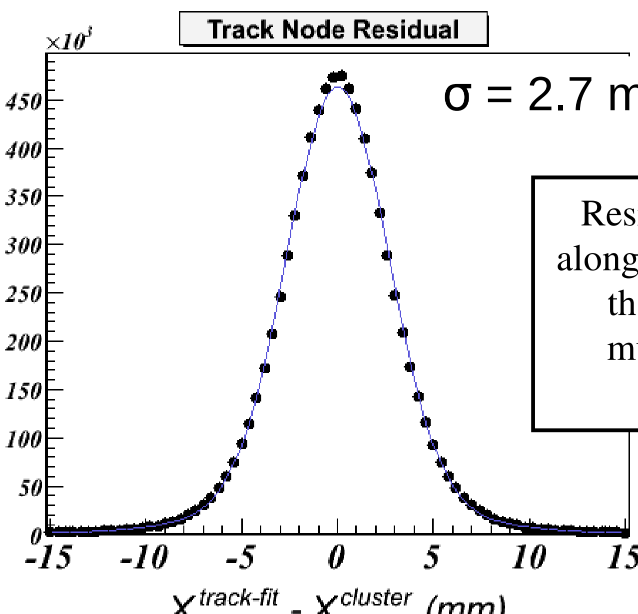


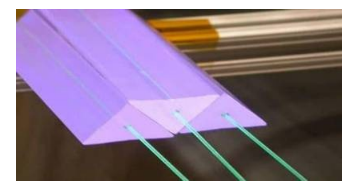


127 scintillator strips per plane.

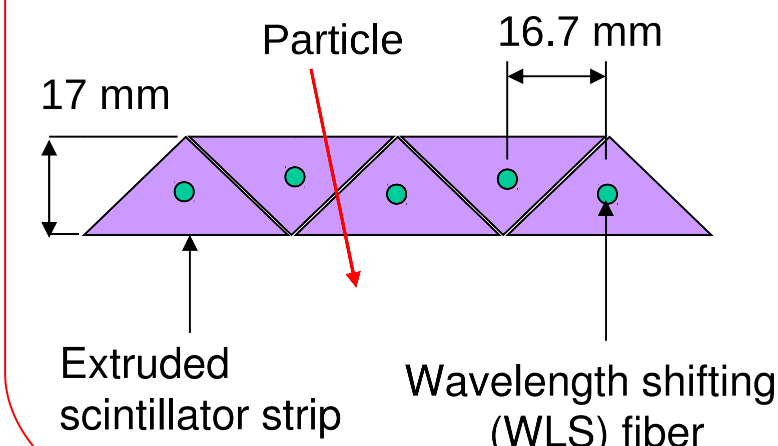
Tracker module = 2 planes
ECAL module = 2 planes + 2 (2 mm thick) sheet of lead
HCAL module = 1 plane + 1 (1 inch thick) sheet of steel



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

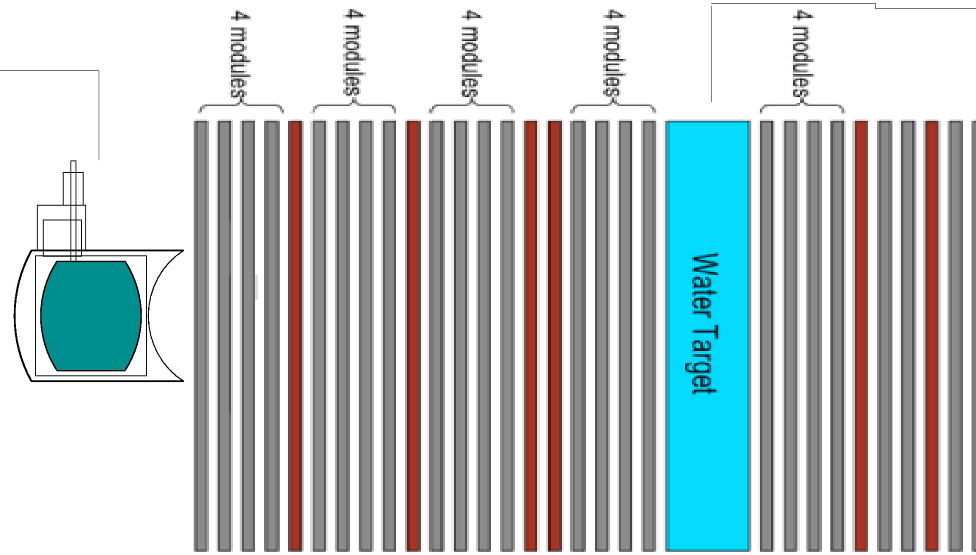


Triangular strip to allow charge sharing

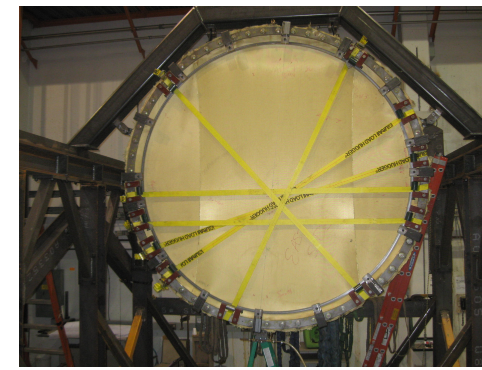


MINERνA Nuclear (Passive) Targets

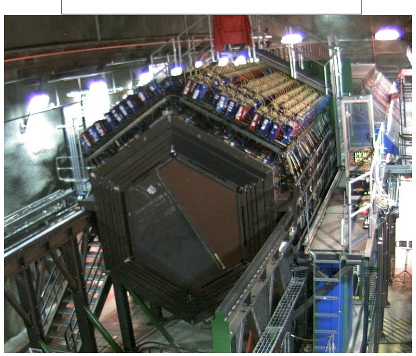
Liquid Helium



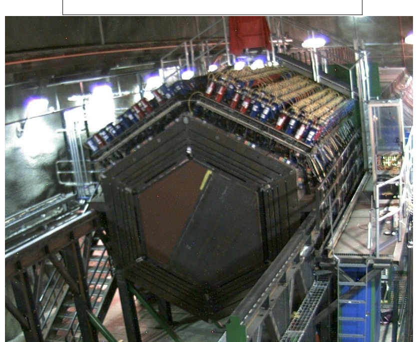
Prototype Water Target



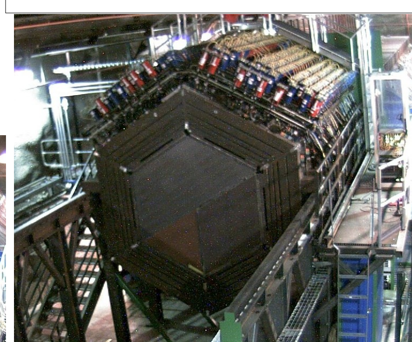
Iron / Lead



Lead / Iron



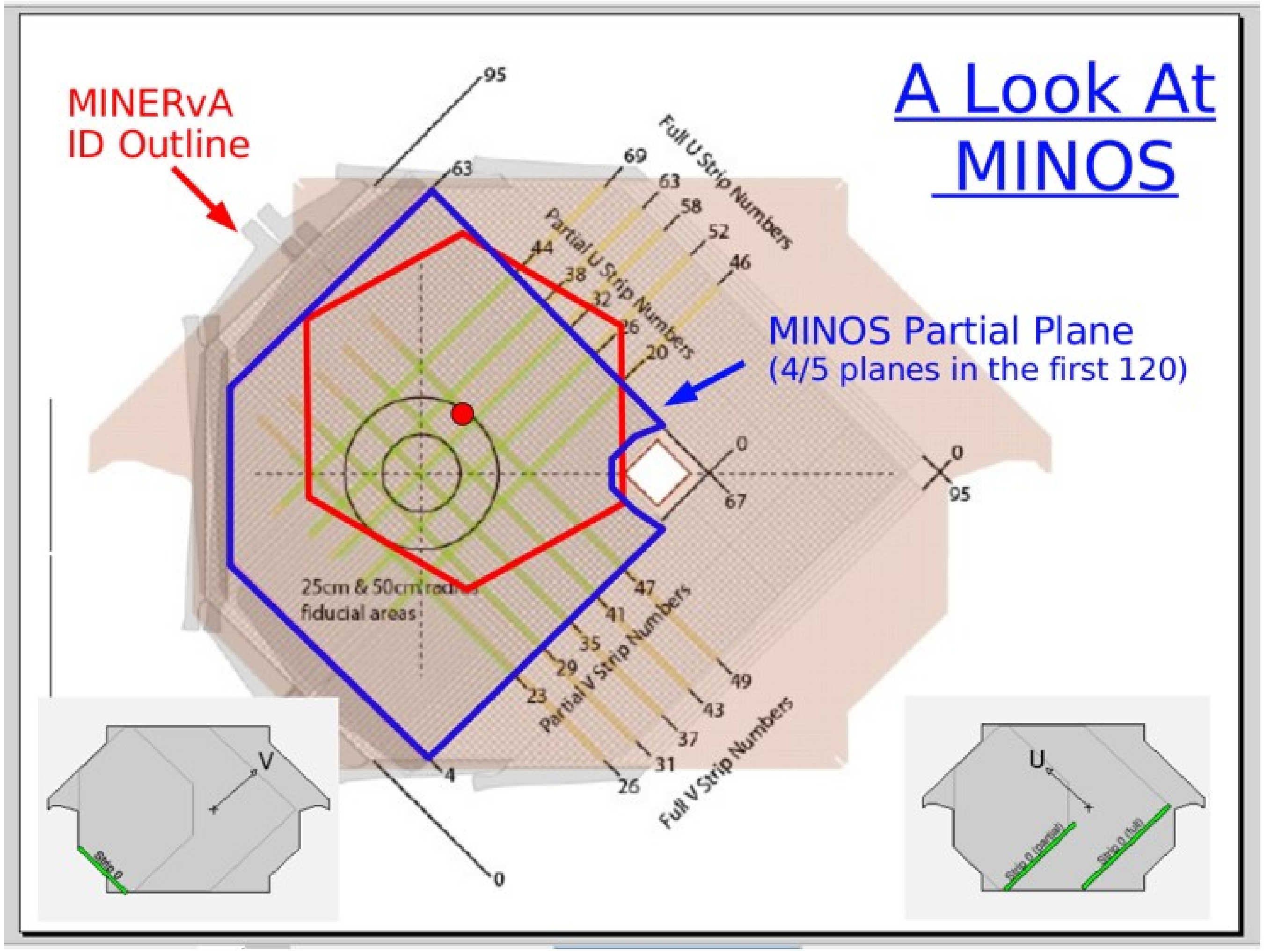
Carbon / Lead / Iron



Lead

Iron / Lead

MINERνA's Muon Spectometer (a.k.a. MINOS Near Detector)

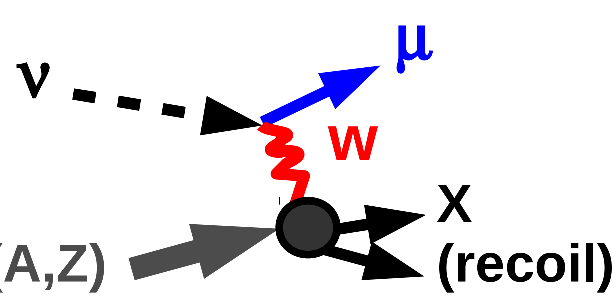


MINOS' near detector is used as a forward muon spectometer

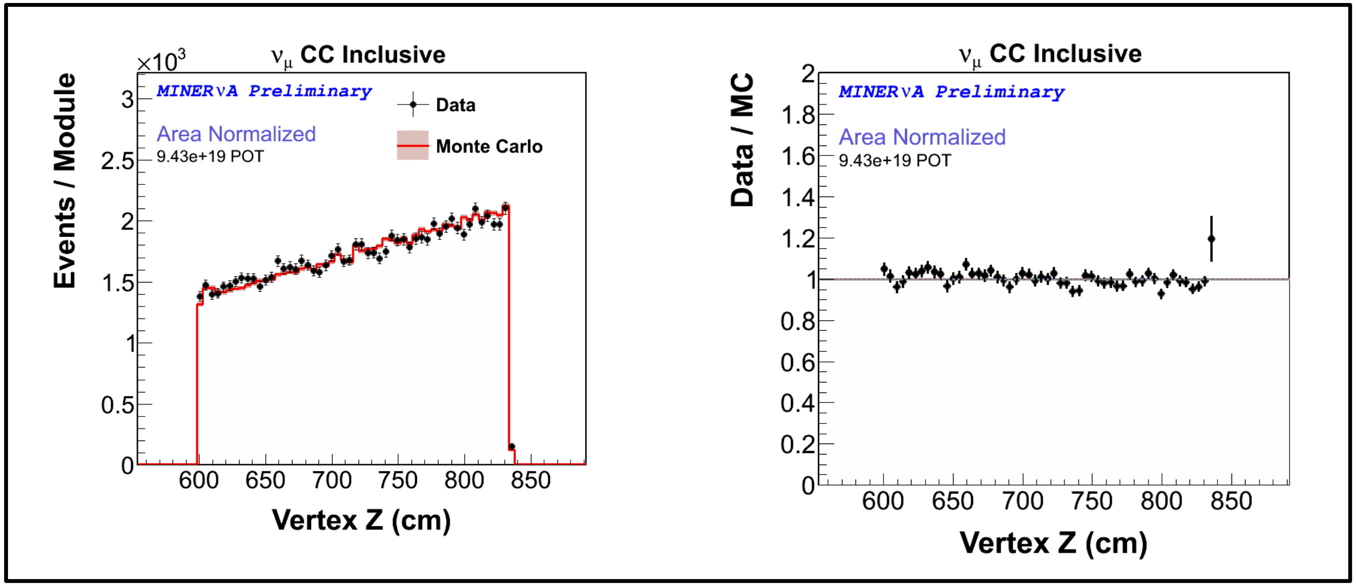
MINOS' magnet allows charge and momentum reconstruction

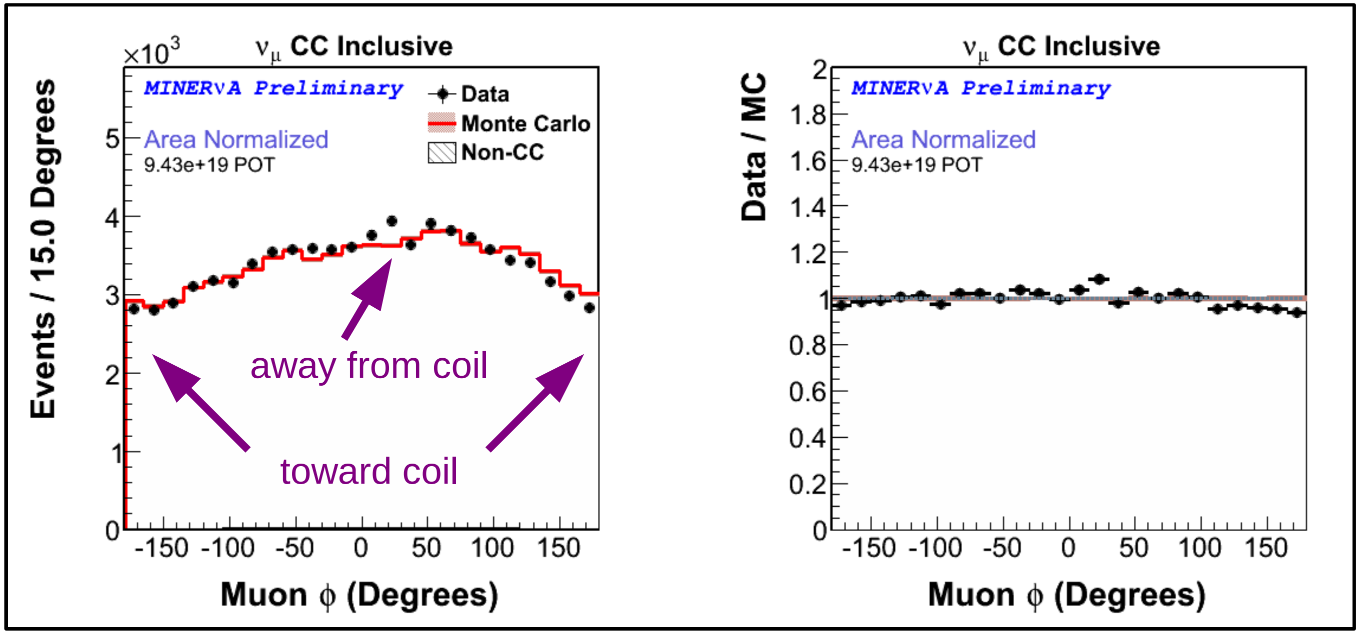
MINOS Acceptance - Where do the μ's go?

ν_μ CC inclusive sample



For much more on ν_μ CC inclusive analysis, see Kenyi Hurtado's talk later today.

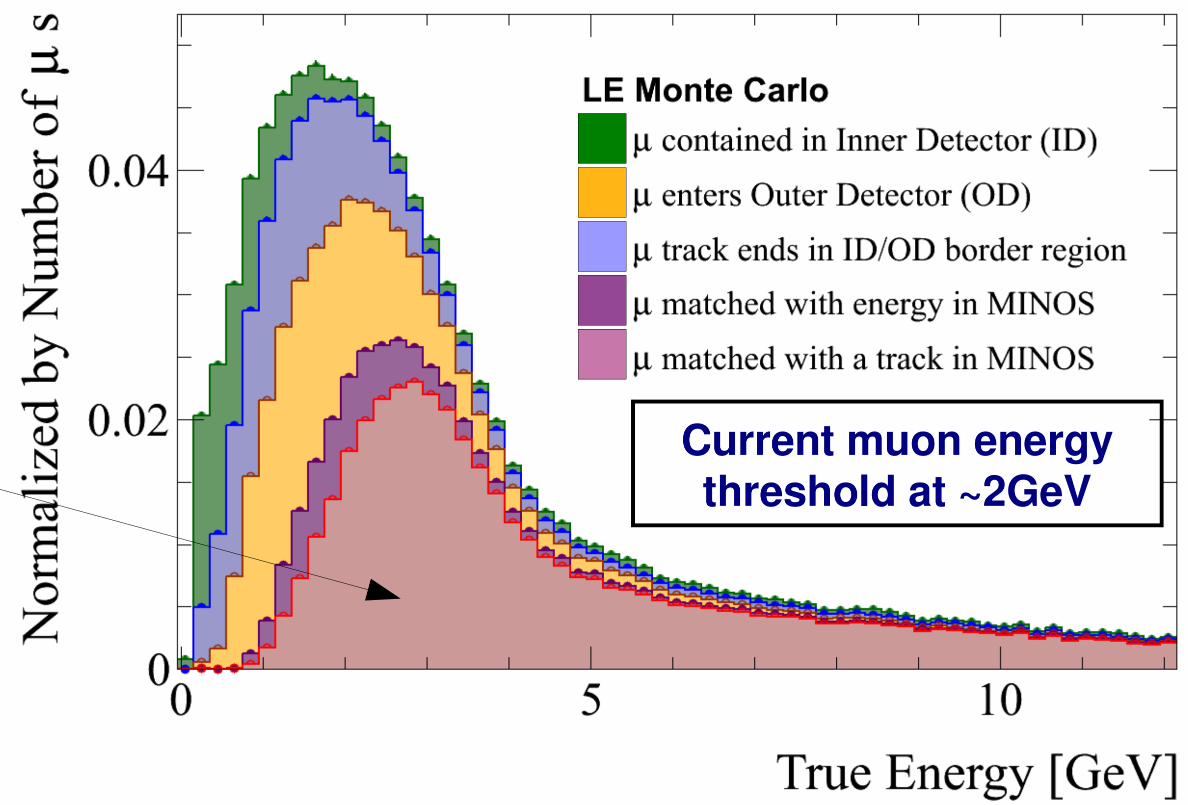




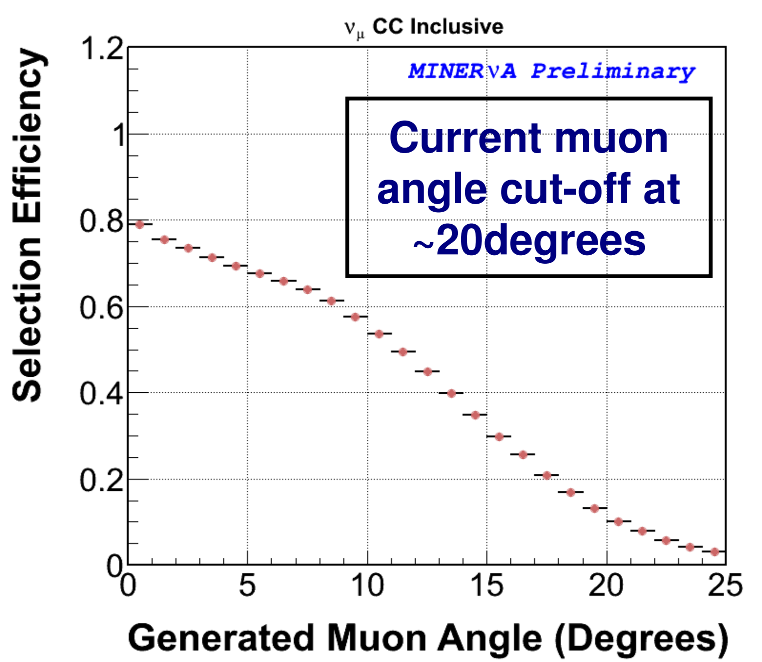
MINOS Acceptance - Where do the μ's go?

Due to the relative position between MINOS and MINERvA, acceptance is complicated but well understood

Muons reaching MINOS



Current muon energy threshold at ~2GeV

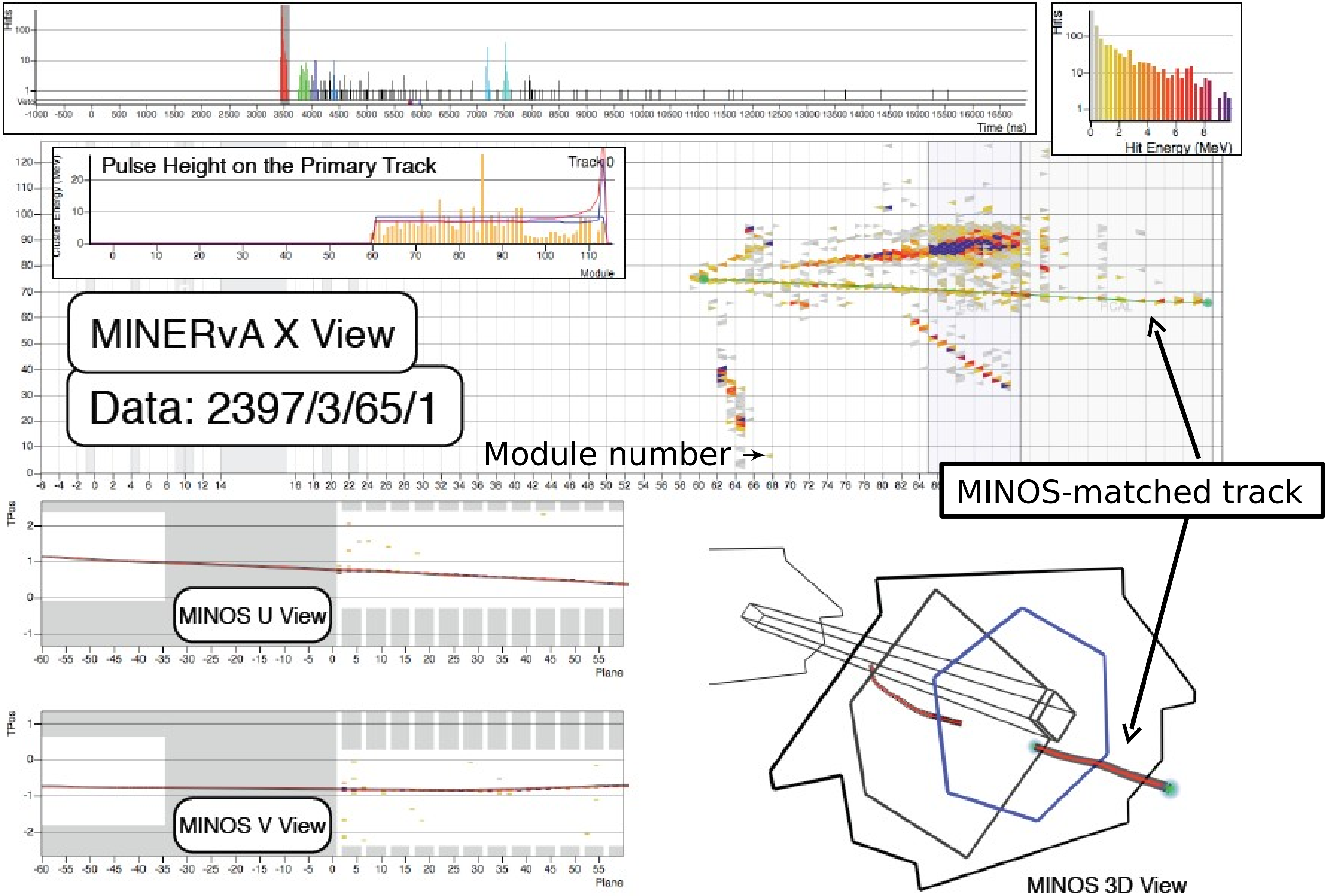


Current muon angle cut-off at ~20degrees

Muons that doesn't reach MINOS can also be analyzed, but no charge measurement is possible

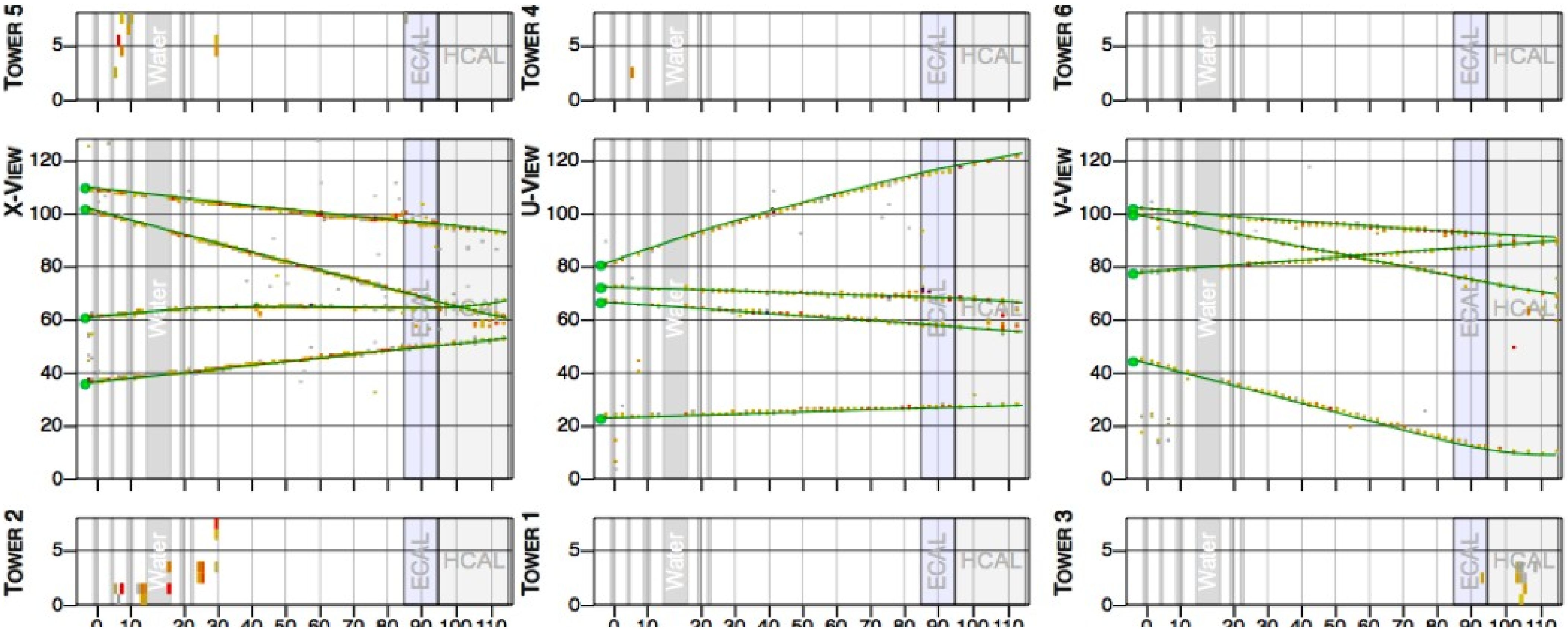
MINERvA will be showing in this conference for the first time muons not reaching MINOS for QE analysis
(See Laura Fields' QE talk)

MINERνA Event Display (ν interaction)



MINERνA Event Display (Rock Muons)

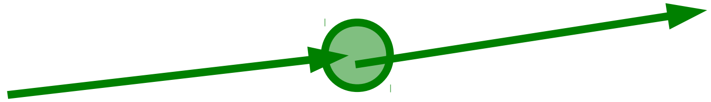
Muons generated in the rock upstream the detector

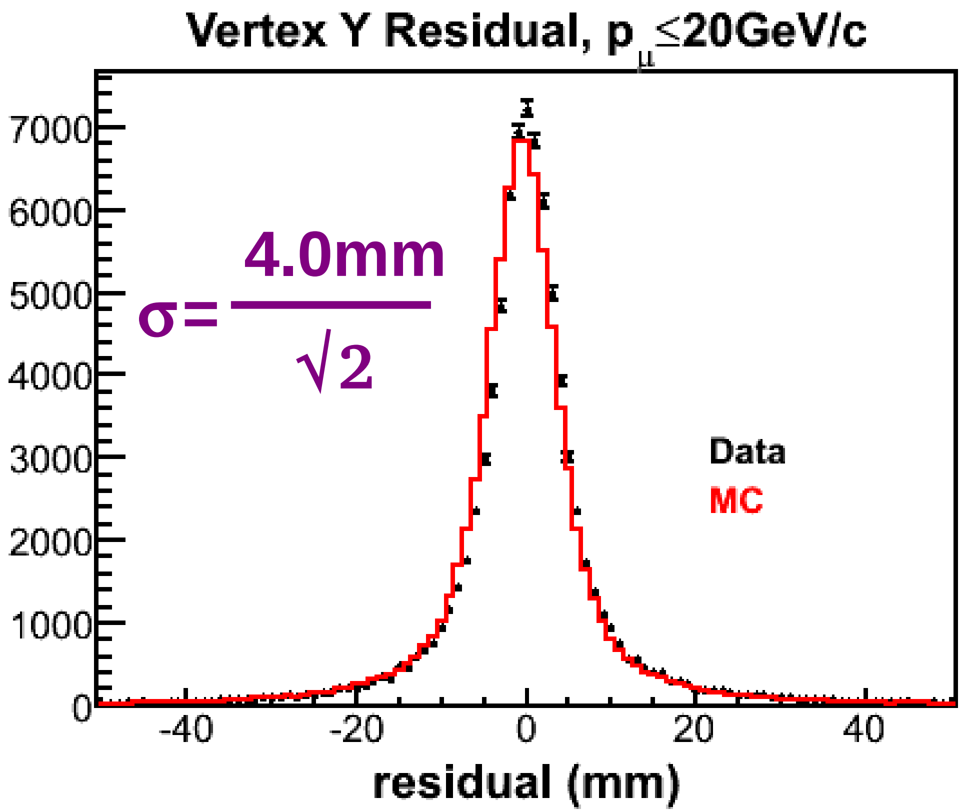


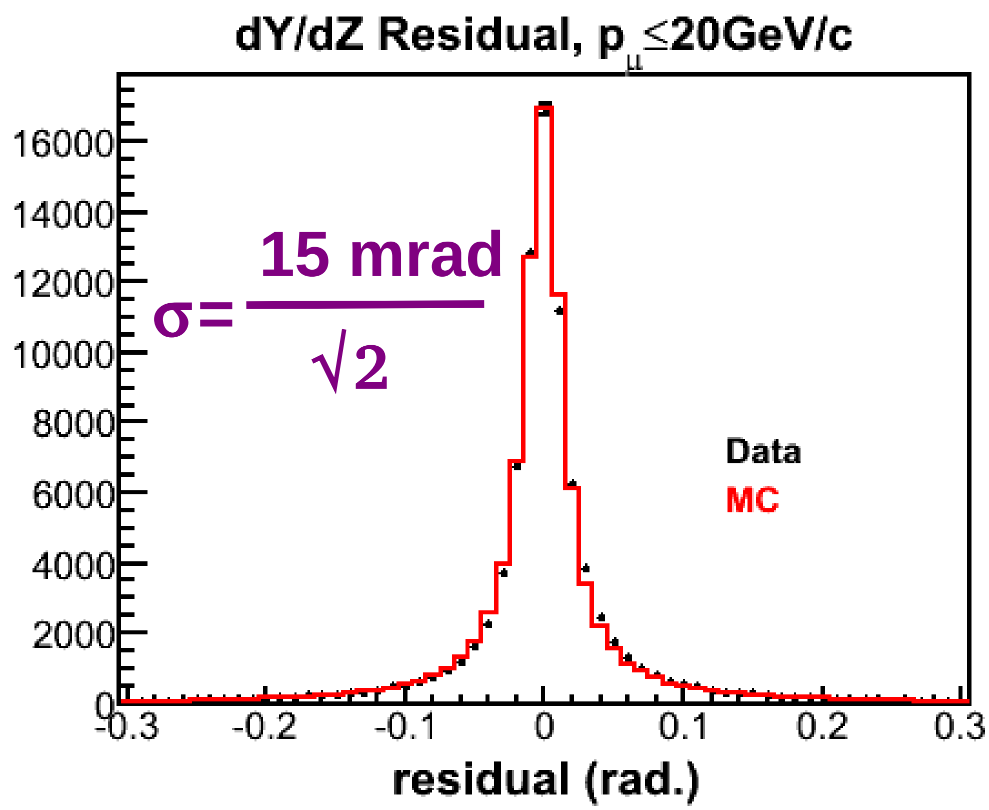
Very useful sample for detector calibration and reconstruction checks

Tracking Resolutions

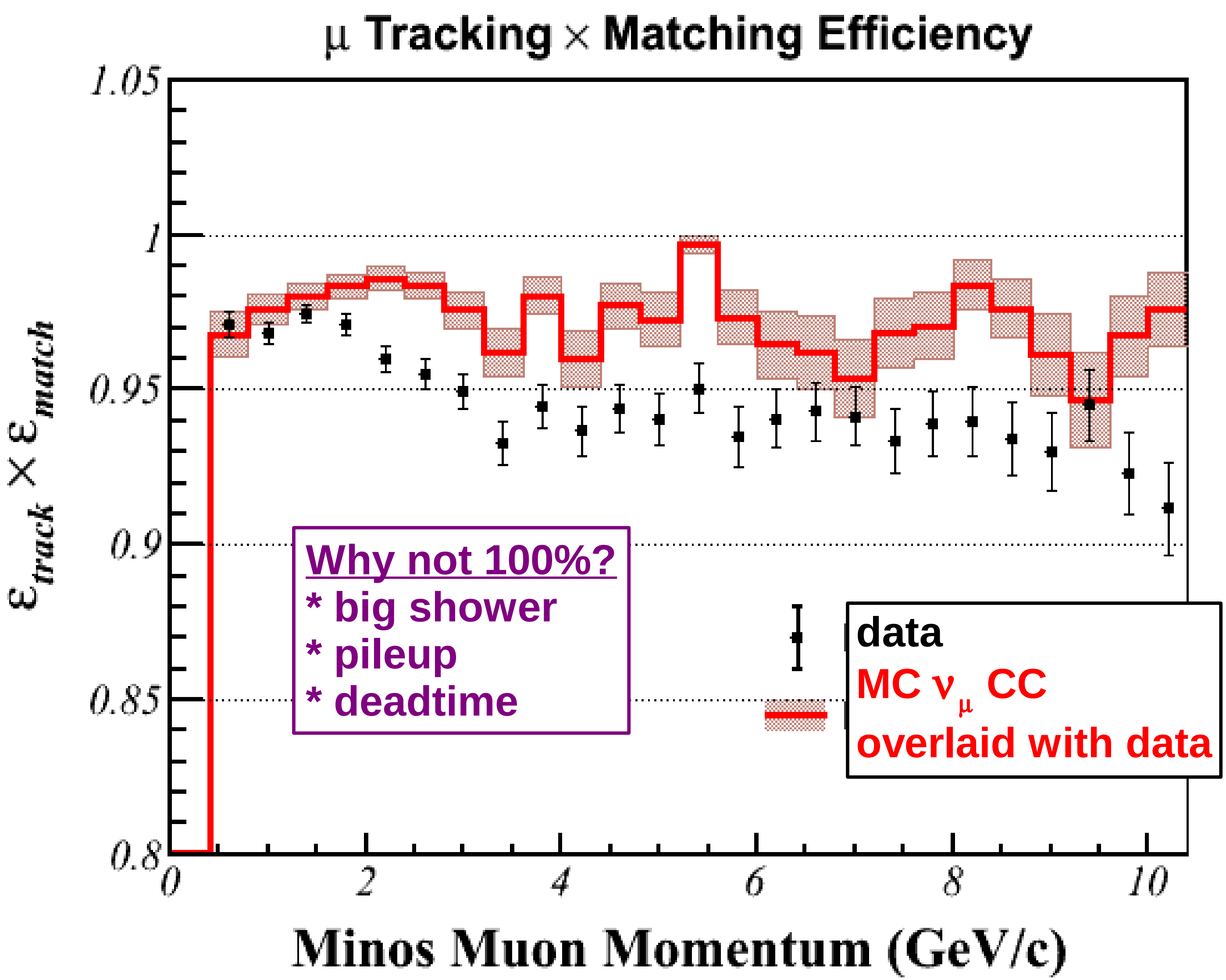
Vertex and track slope residuals from split- rock muon tracks in tracker region







Muon's Tracking x Matching Efficiency

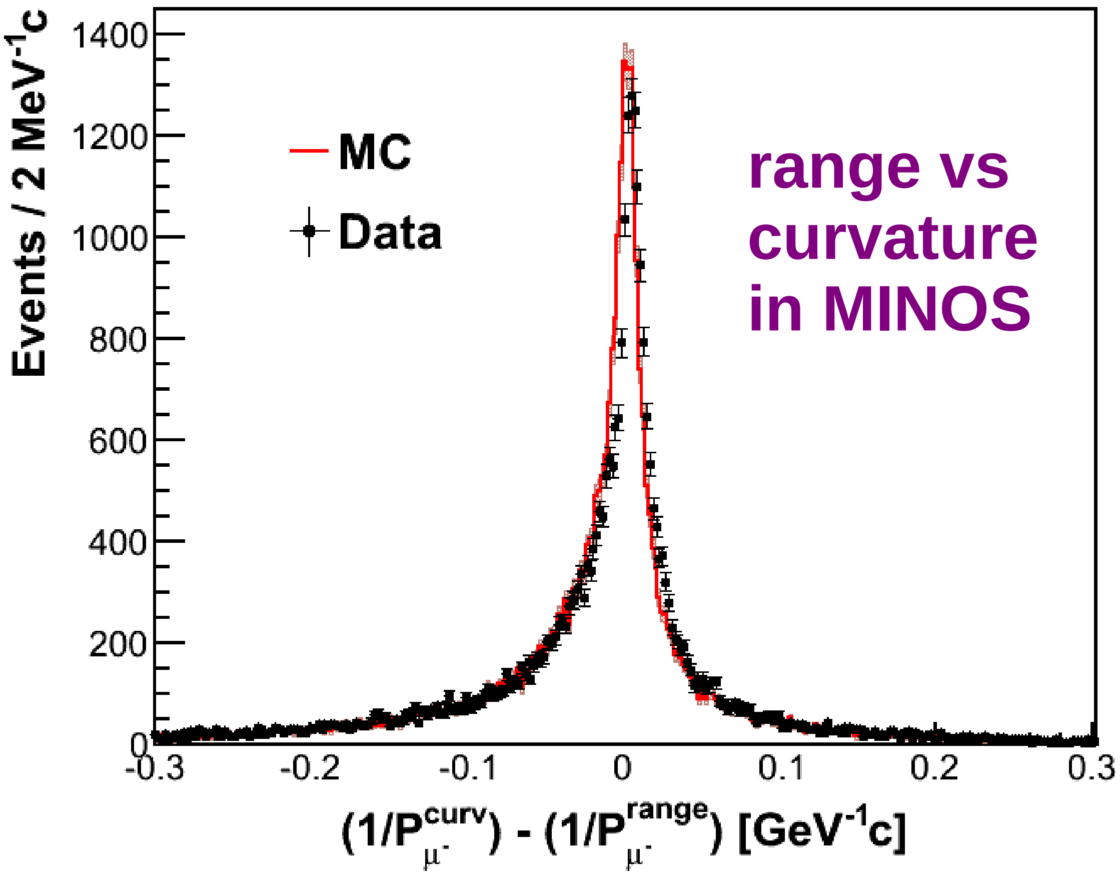


Method

Use μ in MINOS that point backs to MINERvA and try to find a match in MINERvA

Muon energy uncertainty

Additional muon momentum uncertainties from dE/dX and mass models in MINOS and MINERνA



MINOS
dE/dX + mass model = 2%
[MINOS, NIM A 596, 190 (2008)]

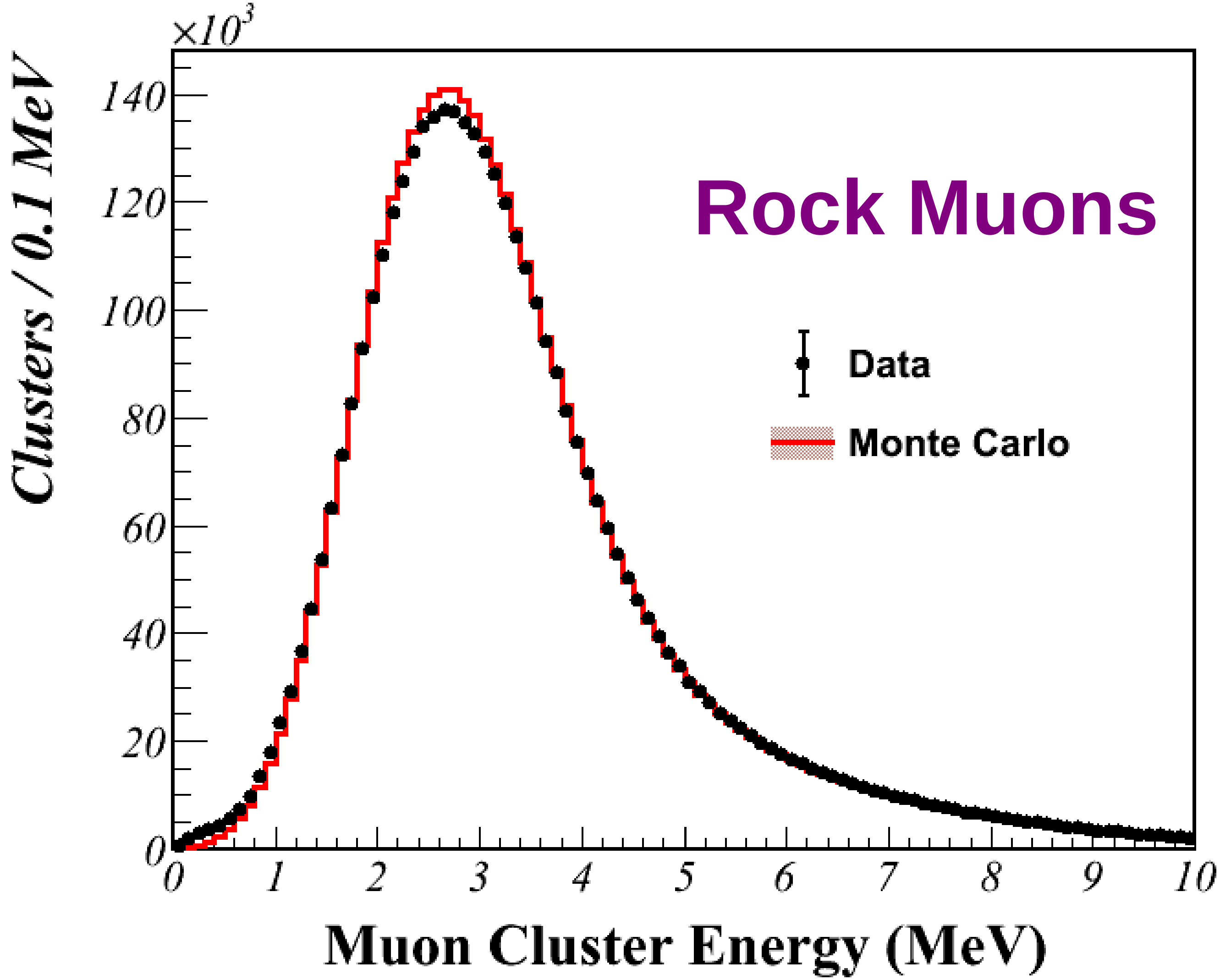
range vs. curvature
|data-MC|~25 MeV

Total: ±3% p> 1.5 GeV
±5% p<1.5 GeV

MINERvA
mass model = 11 MeV tracker
= 17 MeV Nucl. Tgts.

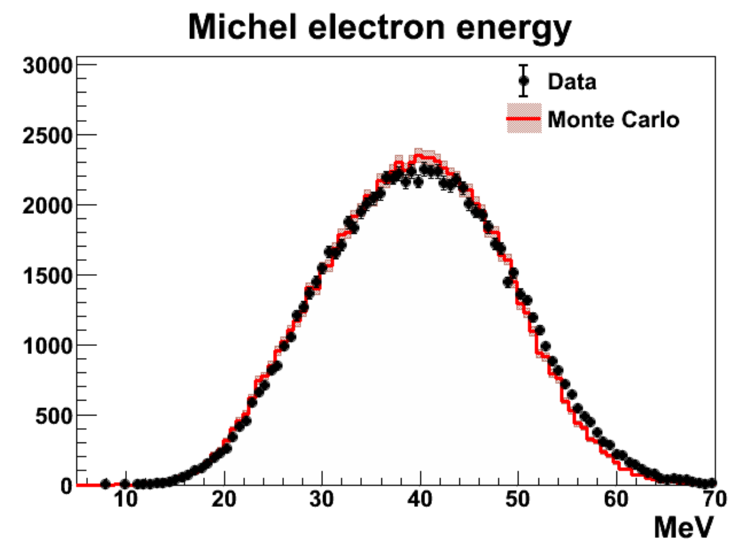
μ energy loss = 30 MeV

Energy Scale



dE/dx from rock muons (MIPs) set the energy scale

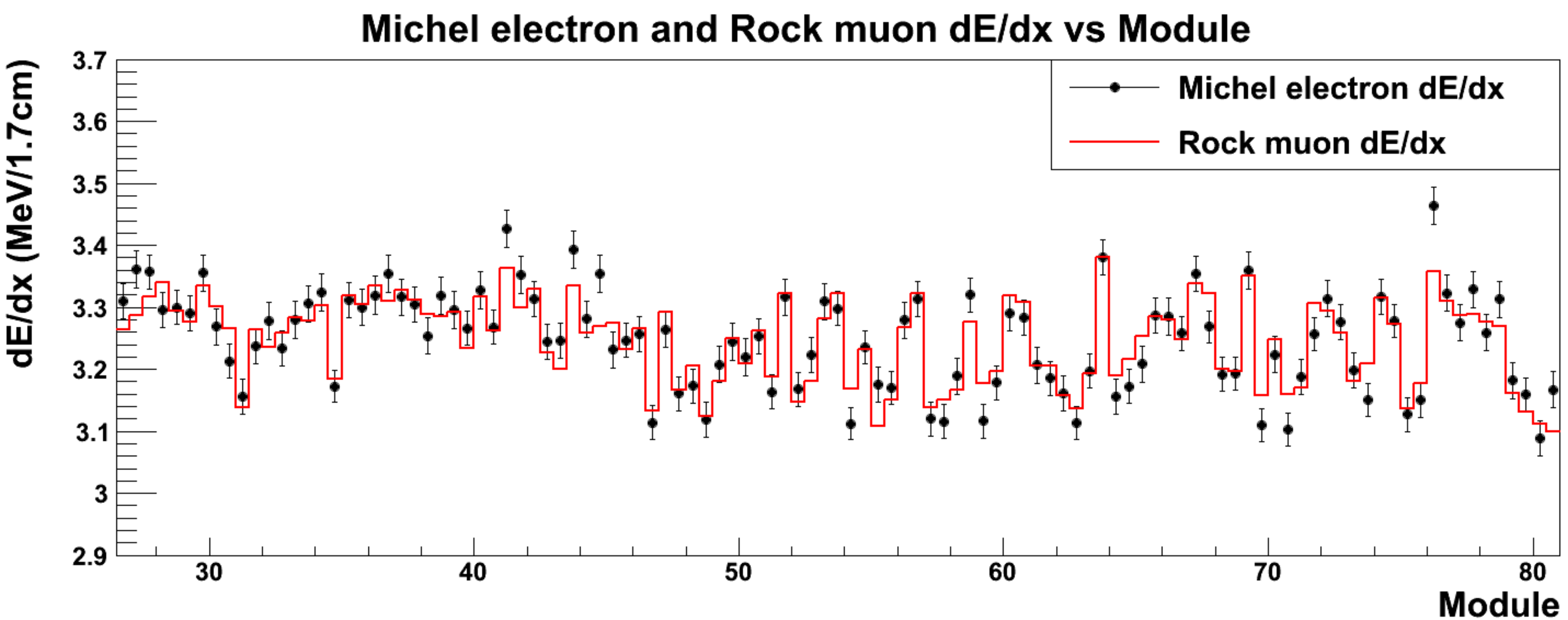
Energy Scale



Michel Electrons: $\mu \rightarrow e\, \nu \bar{\nu}$

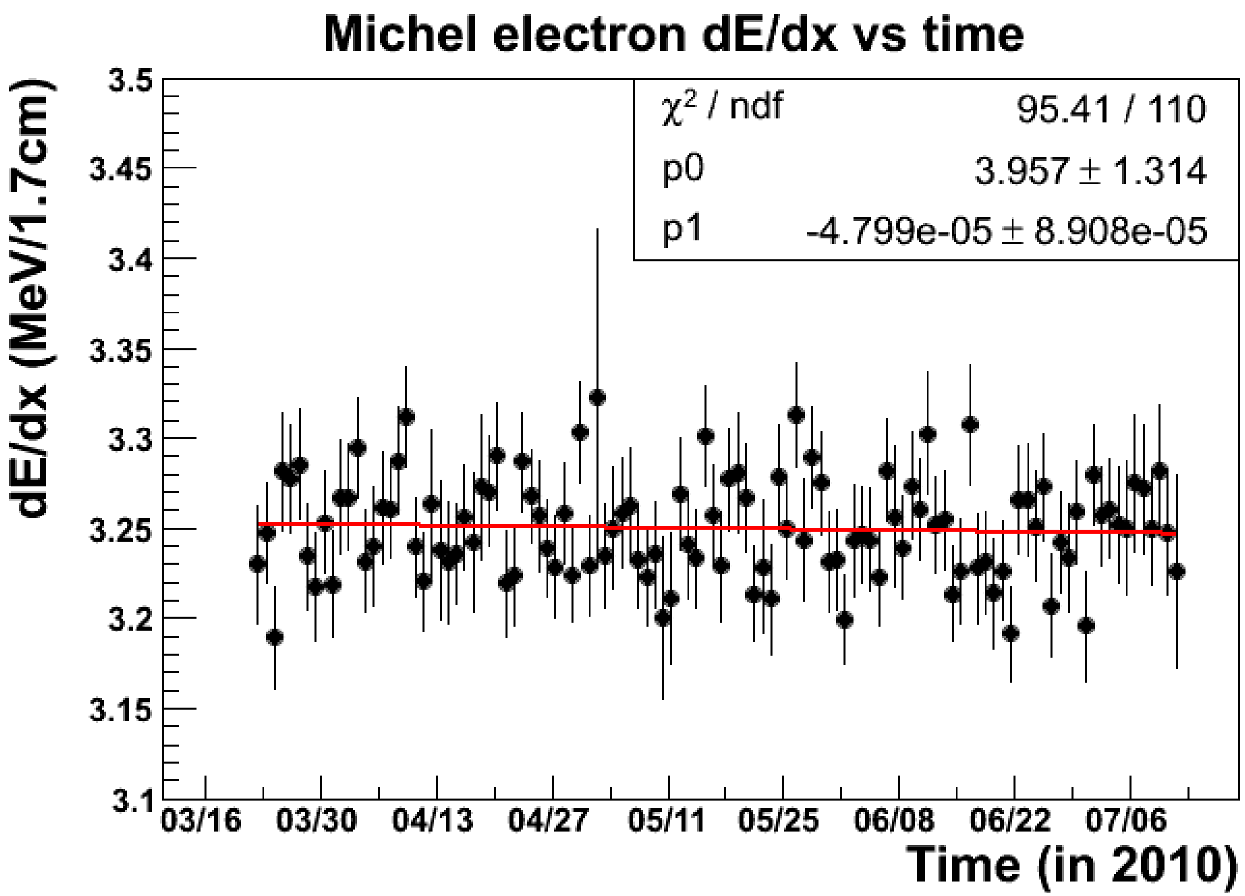
Cross-check on μ derived energy scale

EM response uncertainty = 3%.



Detector Stability

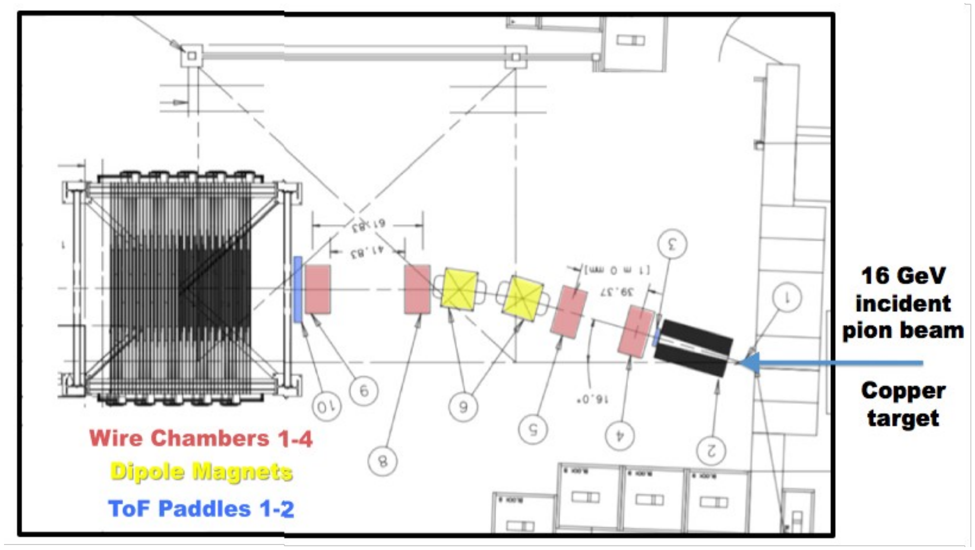
Slope (dE/dx)/day = $(-4.8 \pm 8.9) \times 10^{-5}$
shows energy scale is constant vs time

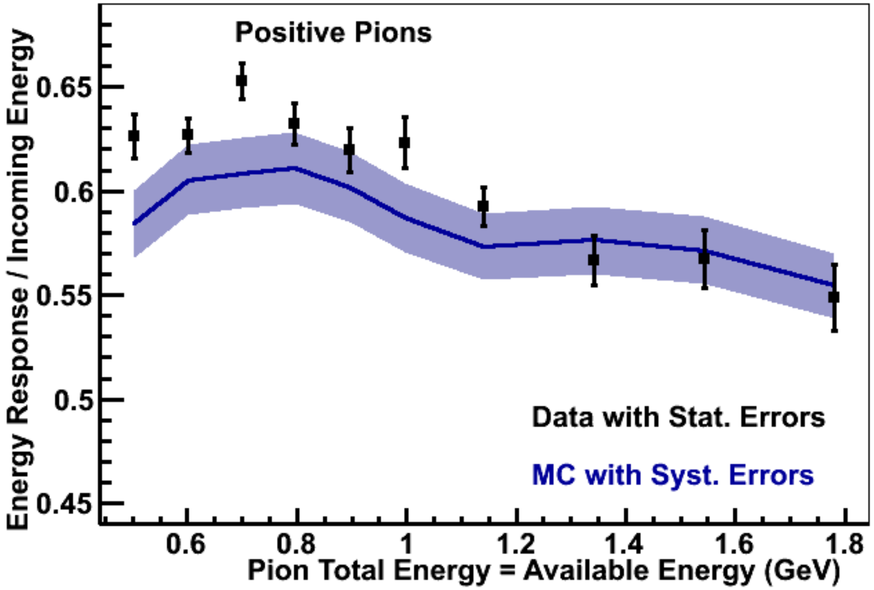


A nice stable detector!

See more details on Sheryl Patrick's poster "MINERvA Detector Calibration"

FNAL-T977 Test Beam





Mini-MINERvA + Mtest Tertiary Beam

16 GeV incident pion beam produces a tertiary beam of 0.4 – 2.0 GeV/c

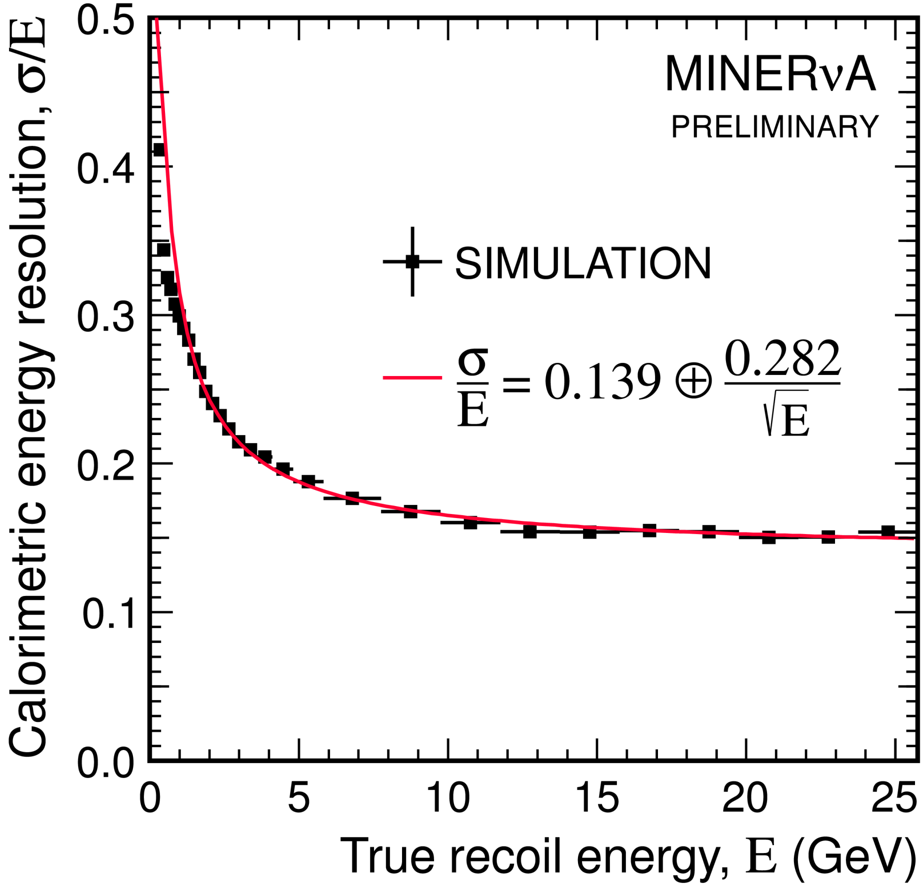
Very important project to **calibrate absolute energy response** (hadron calibration) of the MINERvA detector

Pi+ Data/MC agreement is ~ 5%
pi- is a little better
Protons a little worse (~10%)

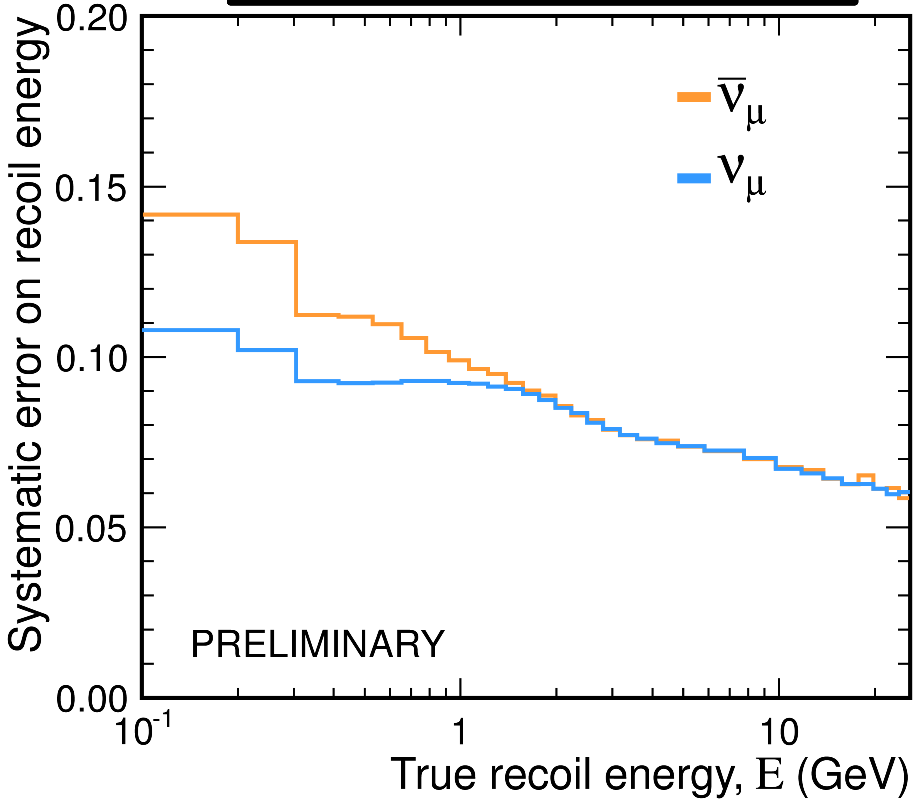
These values are what constrain the systematic error on the analysis that you will hear during the conference

See more details on Richard Gran's poster "MINERvA test beam preliminary results"

Shower Energy Resolution



Convolution of single particle uncertainties
π,K = 5%
e,γ = 3%
p = 10%
n = 20%



Conclusions

- MINERνA's detector is working well and meeting its design specifications.
- MINERνA has all its Low Energy (LE) data and is very busy analyzing it.
- MINERνA is preparing to start running in the Medium Energy (ME) run next year.
  - One goal is to have an additional Deuterium target
- Stay tuned for the exciting incoming talks about MINERνA in this conference.

Other MINERνA talks

- Here is a preview of what are you going to see later this week:

  - **Inclusive ν and anti-ν CC distributions** and **ratios of nuclear targets cross sections** by **Kenyi Hurtado** later today.

  - **Inclusive charged π production** for ν and anti-ν by **Brandon Eberly** on Thursday.

  - Advanced analysis of **charge current production of neutral π** by **Jose Palomino** on Thursday.

  - **ν and anti-ν QE** analysis by **Laura Fields** on Thursday.

Thanks for listening
The MINERvA collaboration

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Universidad Técnica Federico Santa María, Valparaíso, Chile

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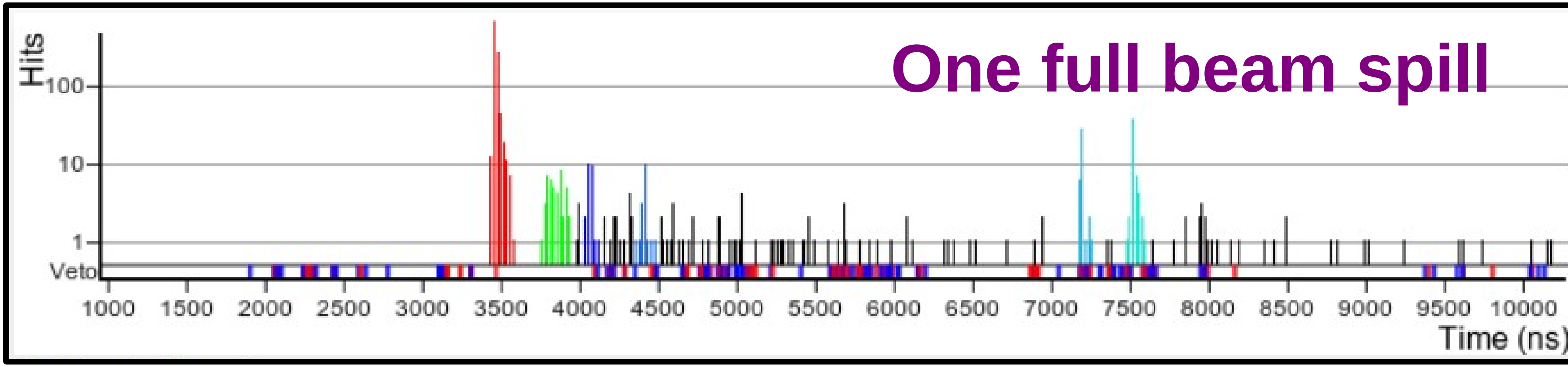
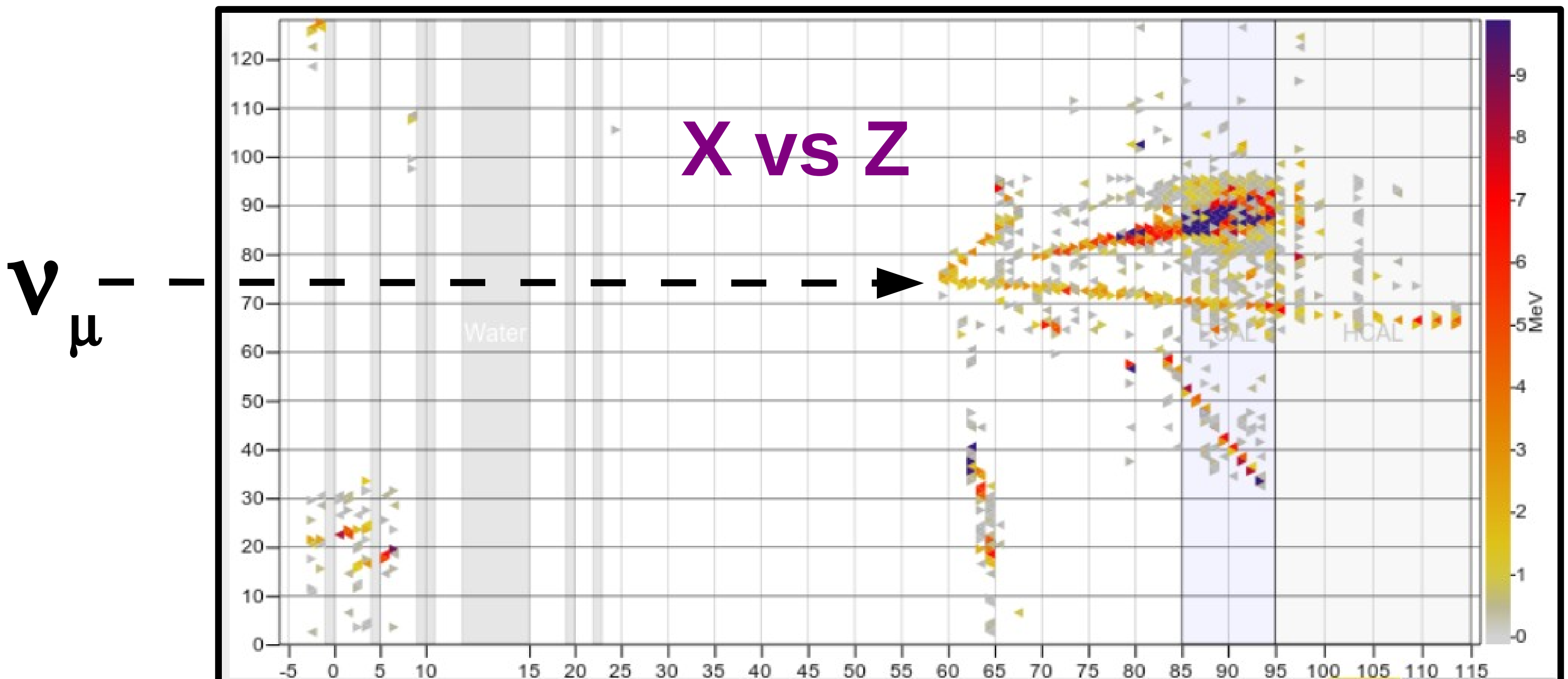
The College of William and Mary, Williamsburg, Virginia

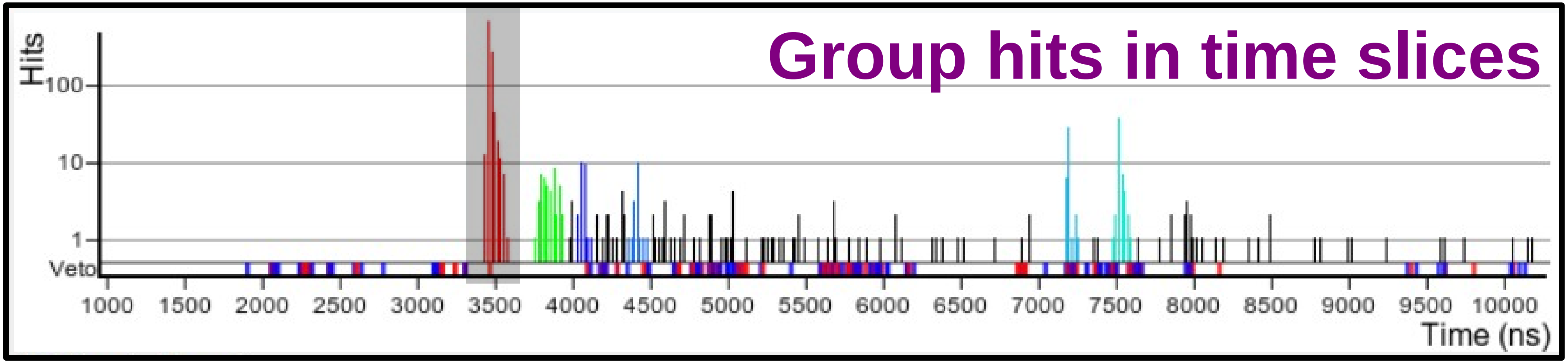
Backups

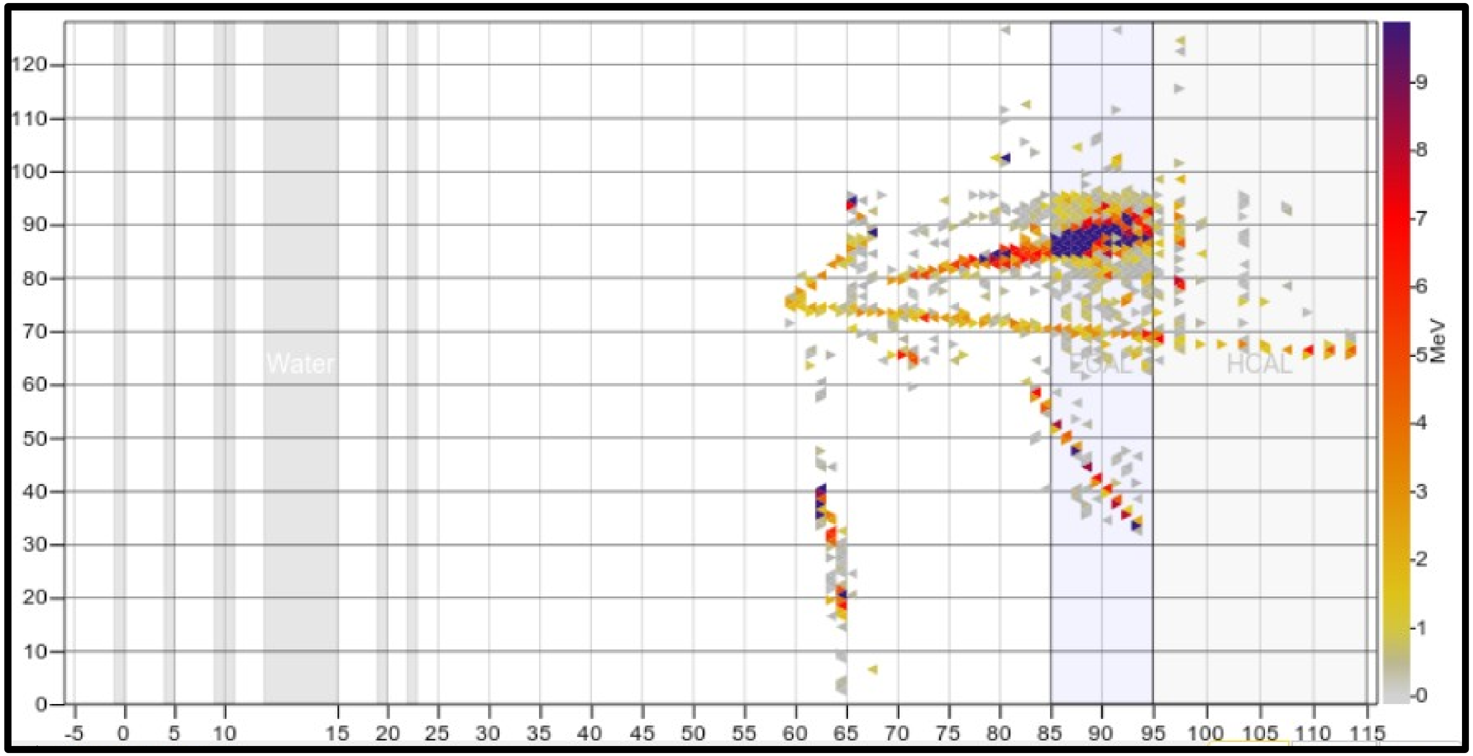
Event reconstruction



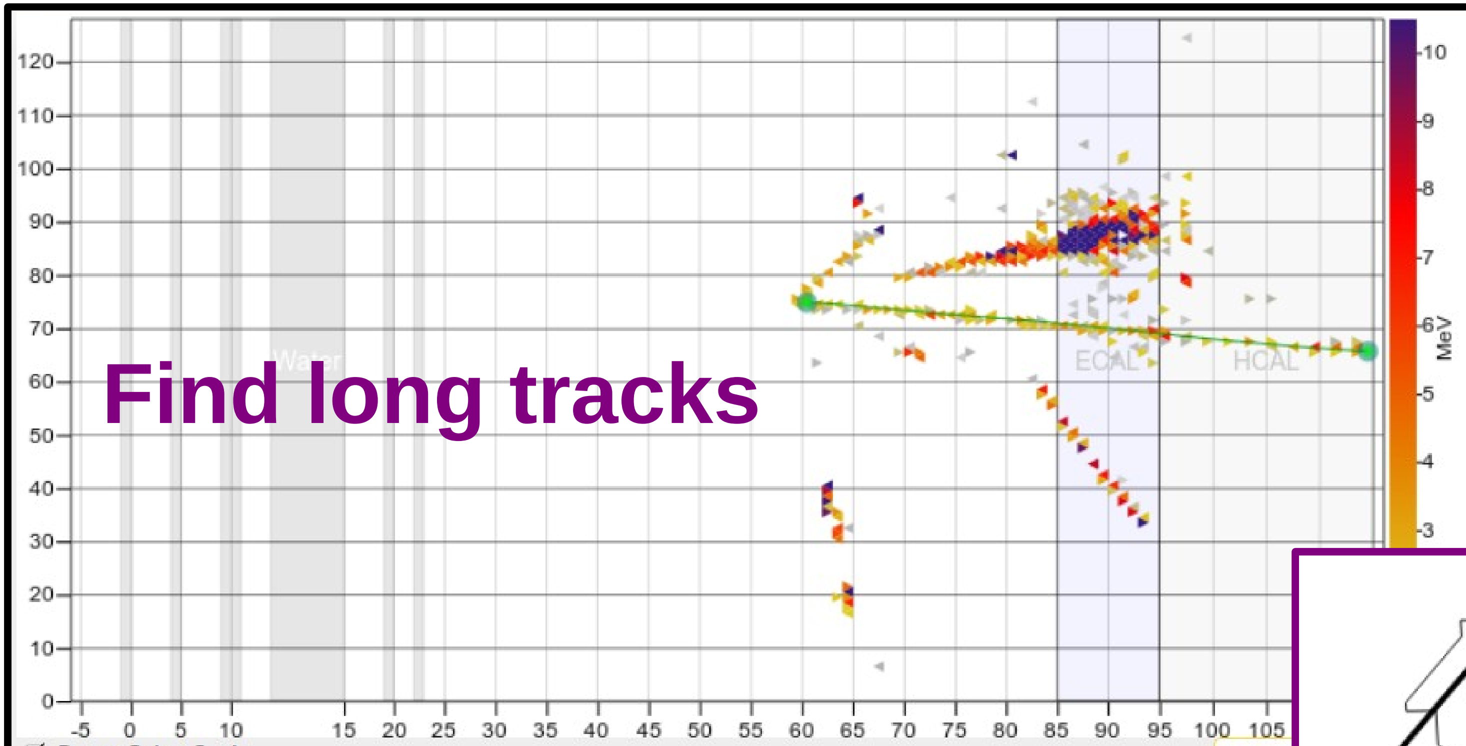


Event reconstruction



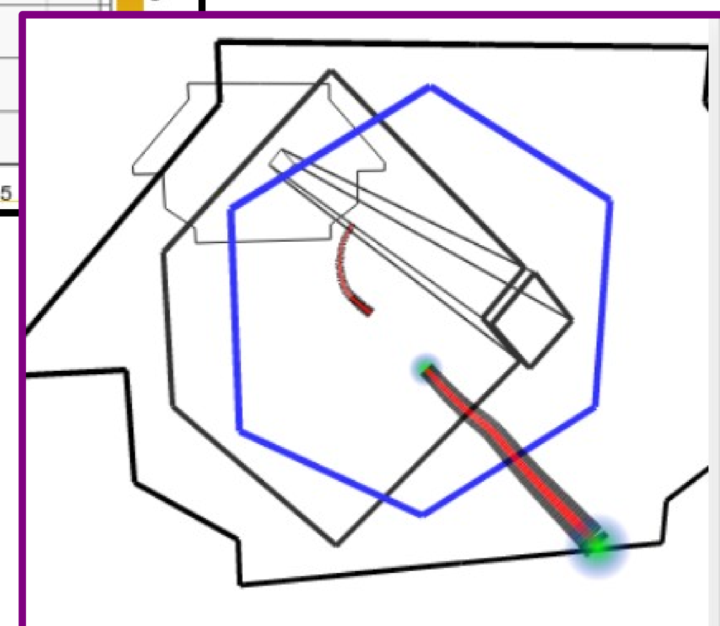


Event reconstruction



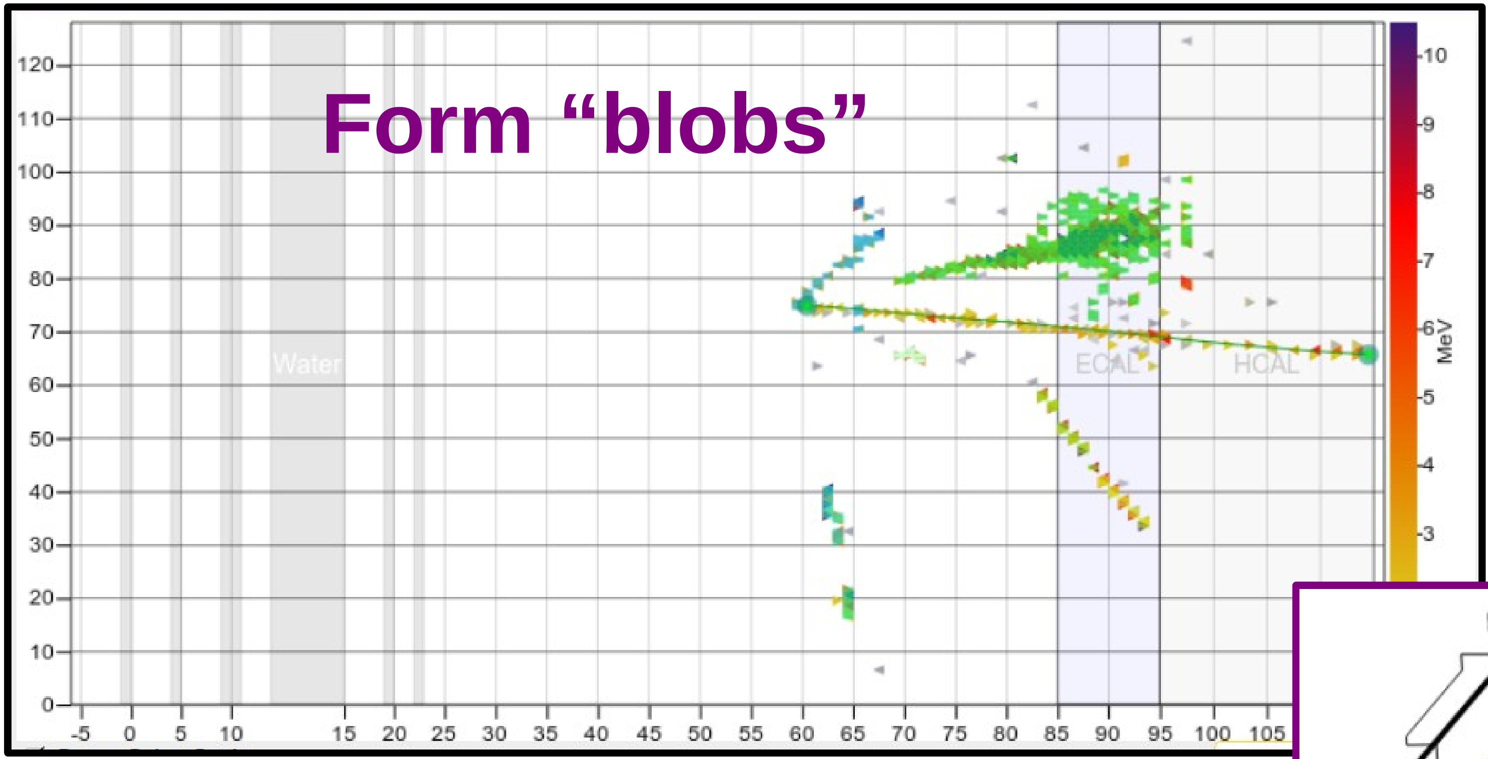
Find long tracks

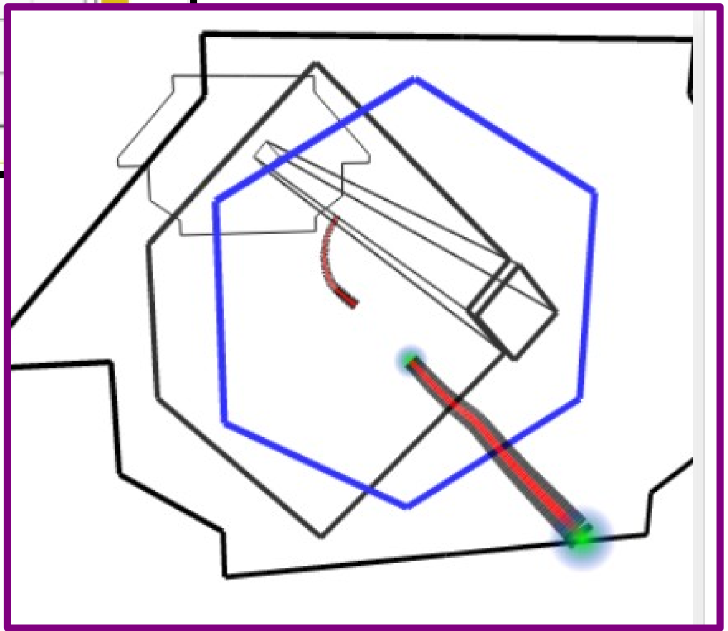
Match to MINOS



Use MINOS matched μ to define event vertex

Event reconstruction

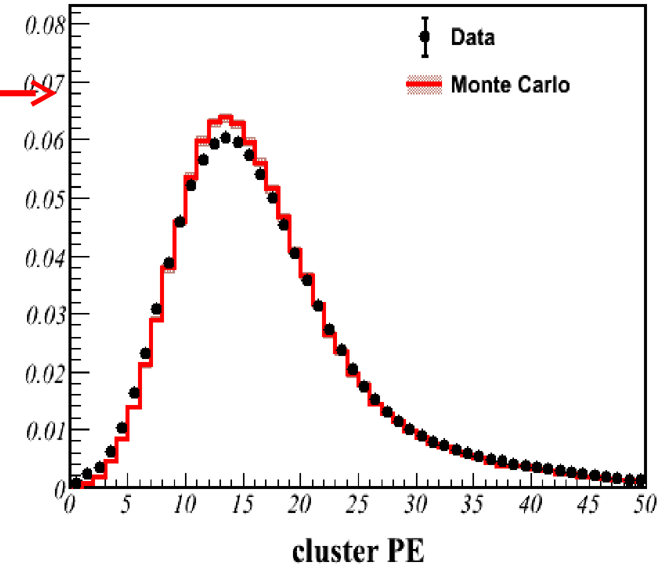


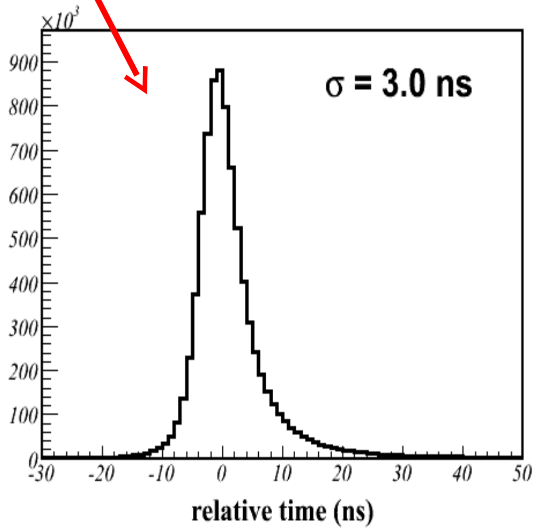


<u>Reconstructed objects</u>
MINOS tracks, other tracks, vertices, endpoints, blobs

Detector Performance

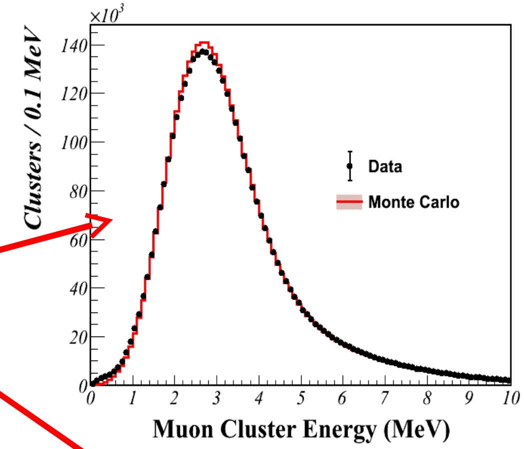
- PE/ layer for MIP, 1.7 cm scintillator
  - MC tuned to detector light level
- Hit Cluster resolution – 2.65 mm σ
  - Design σ = 3.0 mm
- Timing resolution – 3 ns σ
  - Design σ = 3 ns
  - Track time – time in a layer
  - Resolution determined by light

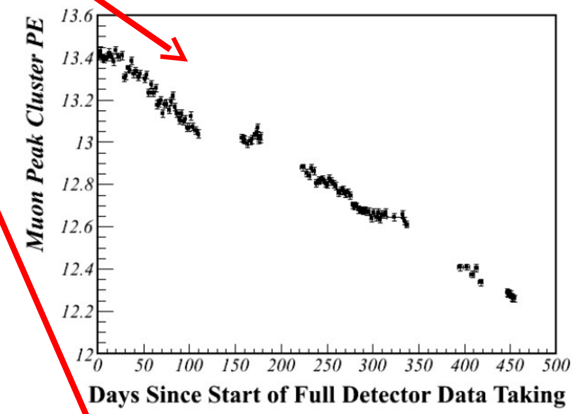


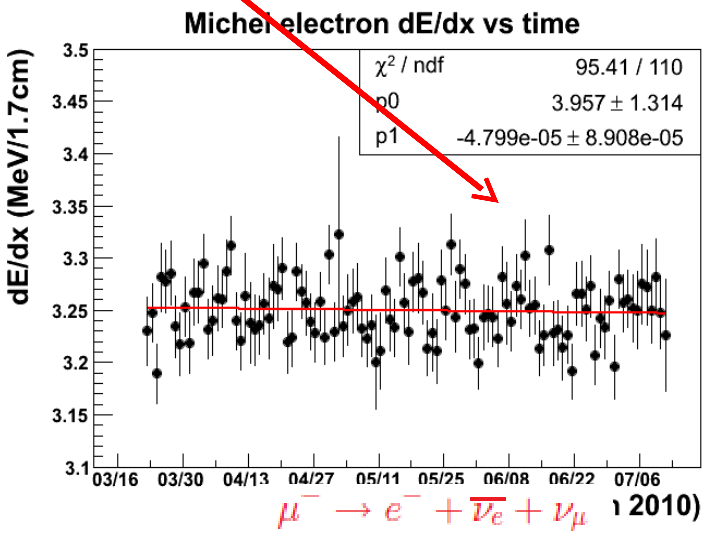


Energy Scale

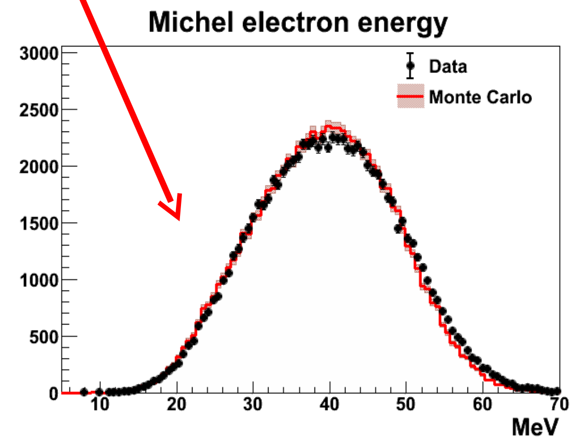
- dE/dx from rock μ sets the energy scale
- Scintillator aging light loss of 7-10%/year at 80F
  - Temp reduced to 72F after chiller installation
- Michel electrons provide check of energy scale
- Slope (dE/dx)/day = $(-4.8 \pm 8.9)\times 10^{-5}$ shows energy scale is constant vs time







$$\mu^- \rightarrow e^- + \overline{\nu_e} + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$



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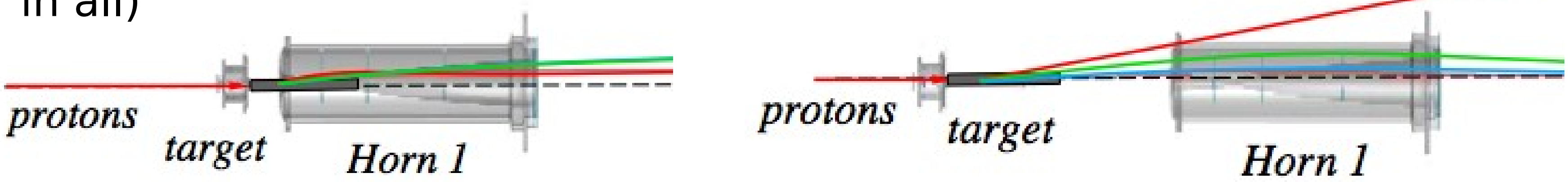
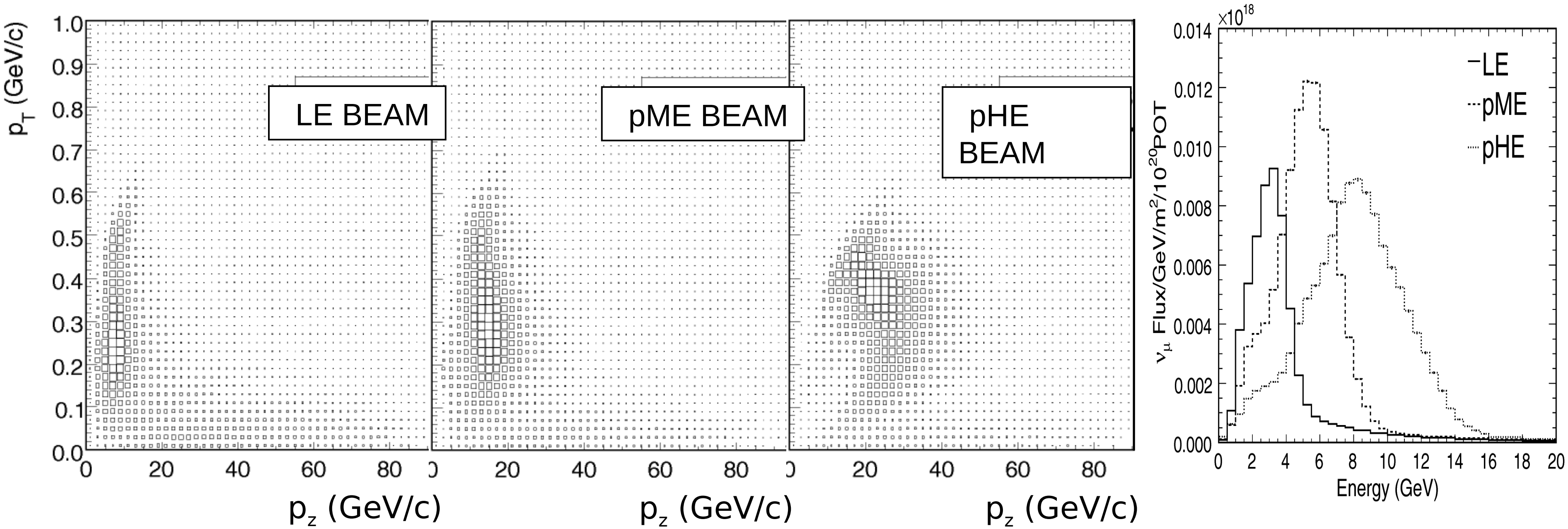
Neutrino flux

- [Understanding the neutrino flux]

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)





Event Rates

MC

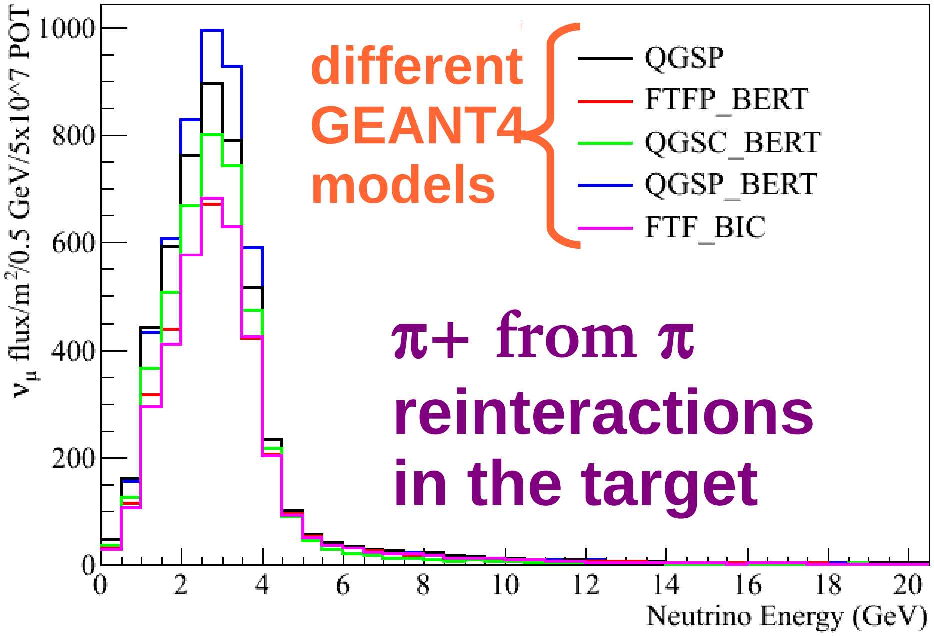
Expected Event Rates for Low Energy Neutrino-tuned beam

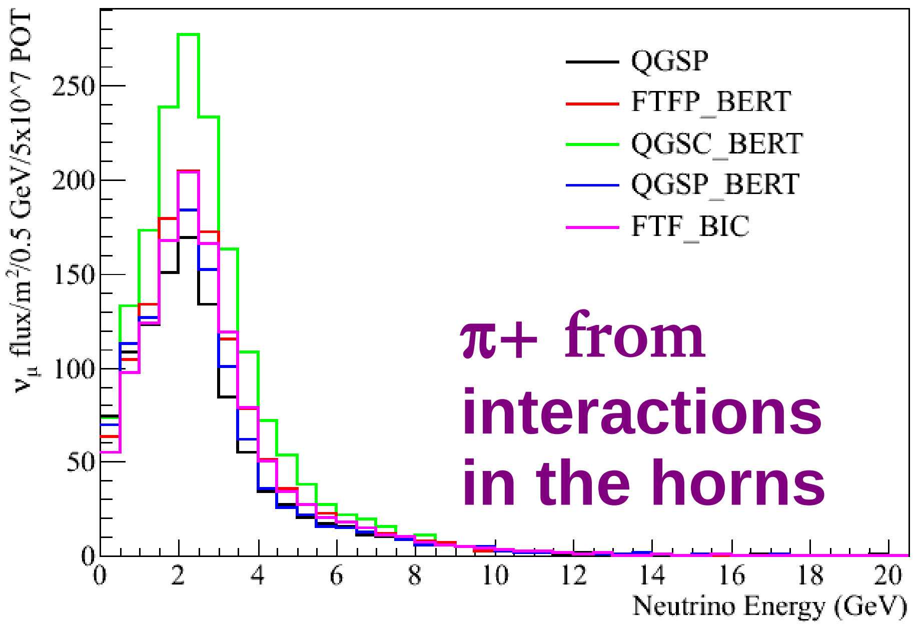
Target	Fiducial Mass	ν_μ CC Events in 1.0e20 P.O.T.
Plastic	6.43 tons	340k
Helium	0.25 tons	14k
Carbon	0.17 tons	9.0k
Water	0.39 tons	20k
Iron	0.97 tons	54k
Lead	0.98 tons	57k

GENIE 2.6, FLUKA08, 90cm radius, 116 tracker modules

Model Spread Uncertainties

Non-NA49 uncertainties from maximum model spread





Categories

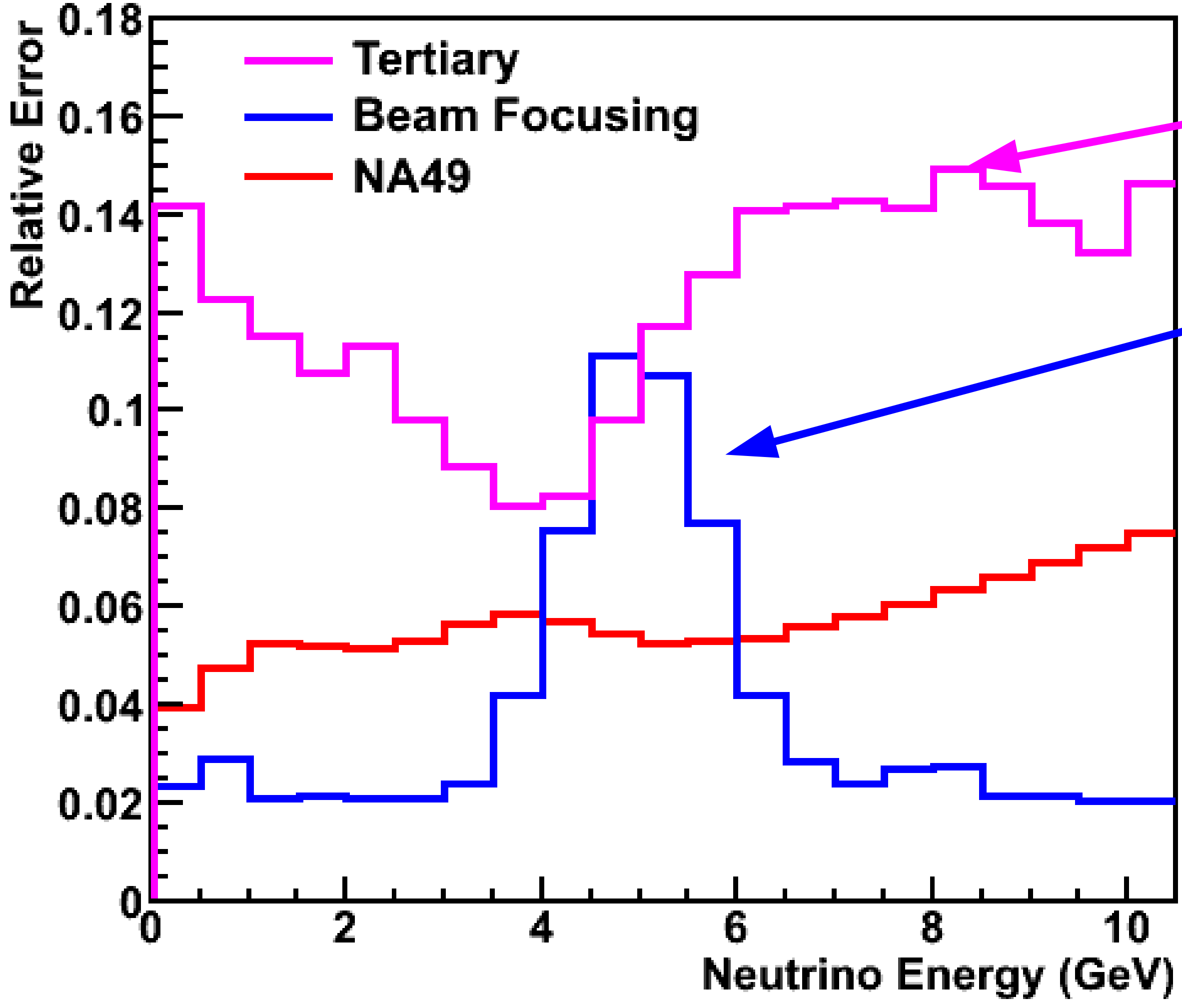
π,K,p,n,other secondary interactions in target

production in horns, decay pipe walls& He, target hall chase

Large project to
(a) add more models
(b) gradually replace model spread with existing and new data

Current Flux Uncertainties

Preliminary!



<u>"Tertiary"</u>
= non-NA49

Z. Pavlovic,
PhD Thesis,
Texas (2008)

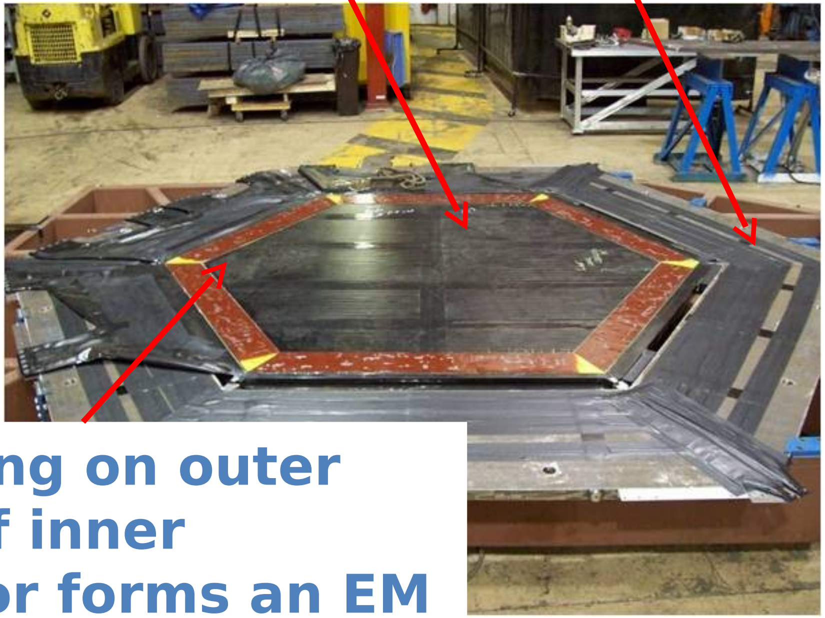
Can be improved with work!

The detector (types of modules)

- Target Module (5 total):
  - Layer of target material (Fe, C or Pb)
  - Layer of scintillator
- Tracker Module(84 total):
  - 2 layers scintillator
  - 3.71 interaction lengths
- ECal module (10 total):
  - 2 sheets of lead
  - 2 layers of scintillator
  - 8.3 rad lengths.
- HCal module (20 total)
  - Layer of Fe
  - Layer of scintillator
  - 3.7 interaction lengt

Inner detector

Outer detector – slots instrumented with scintillator (HAD calorimetry)



Lead ring on outer edge of inner detector forms an EM calorimeter

ıder construction

*slide from S. Manly

Module Construction

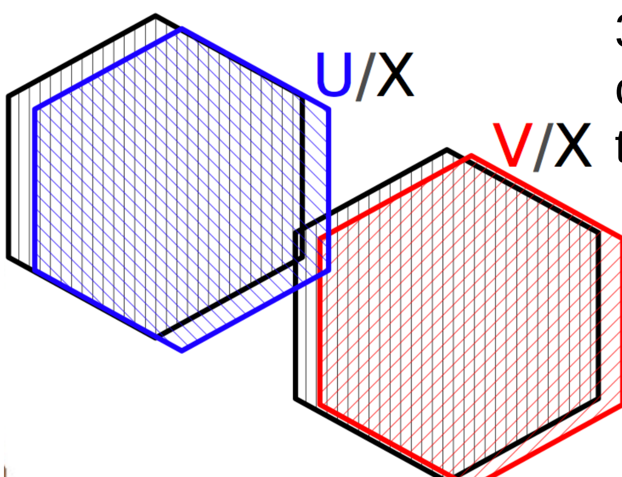
Steel + scintillator = module

Typical module:

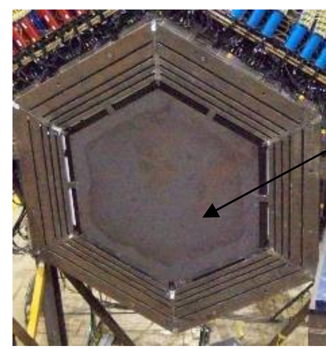
- has 302 scintillator channels
- weighs 3,000 lbs
- 3 types of modules

Full detector:

- 120 modules; ~32K channels.



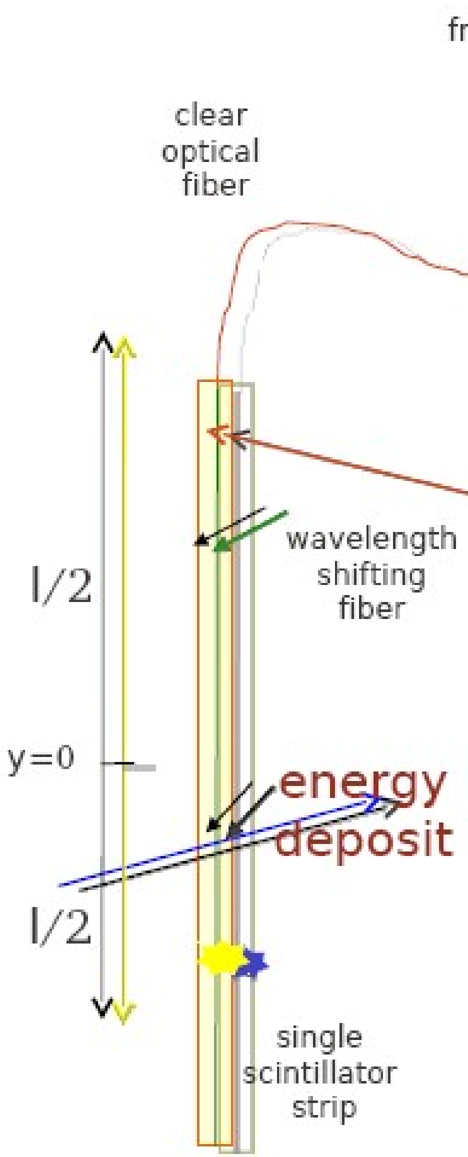
3 different strip orientations for 3D tracking



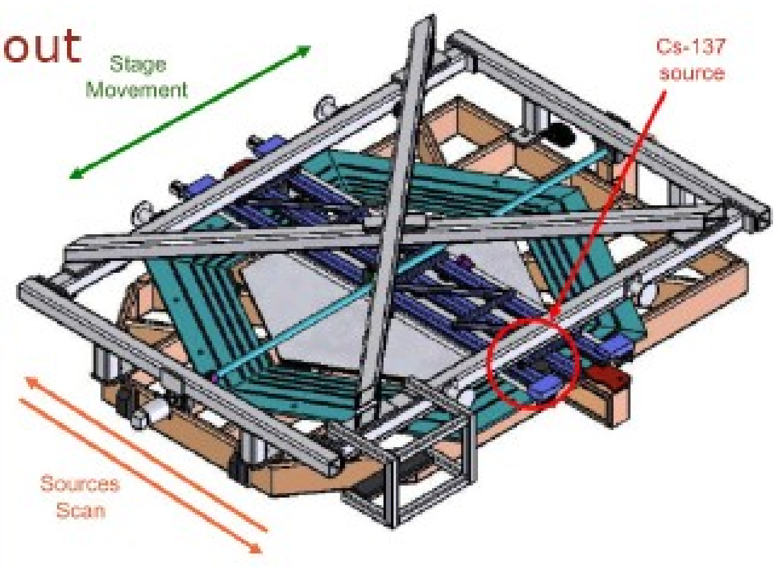
HCAL modules include 1” steel absorber

ECAL modules incorporate 2mm-thick Pb absorber

Detector Calibration

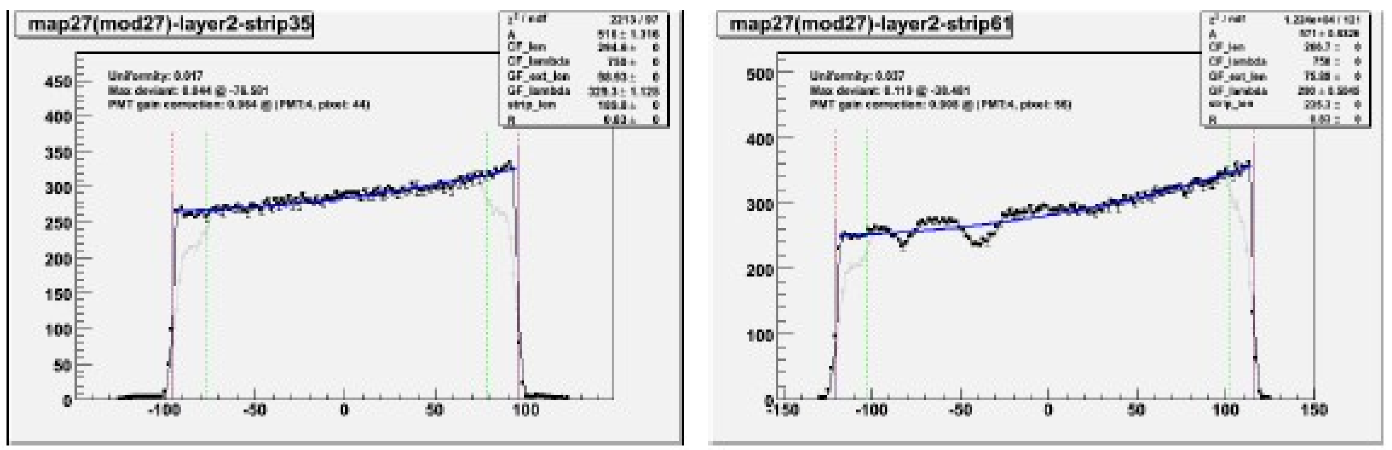


Attenuation along every strip in every plane measured using a source map before installation. We use the point-by-point map in reconstruction for every channel.



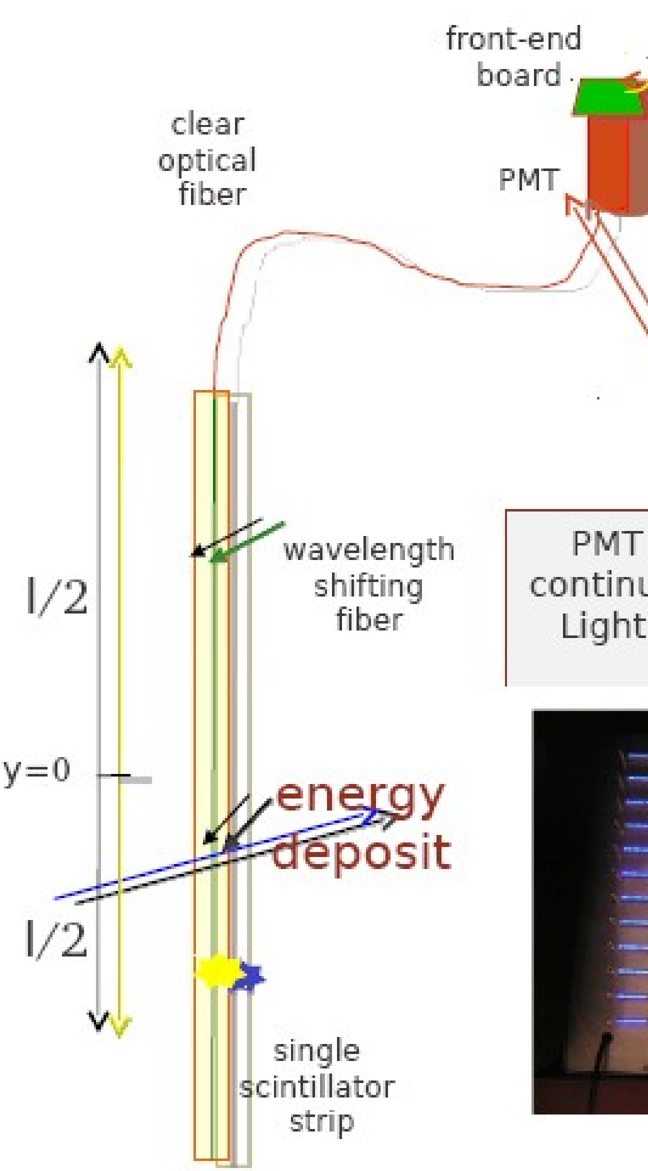
Typical attenuation length ~300 cm.

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



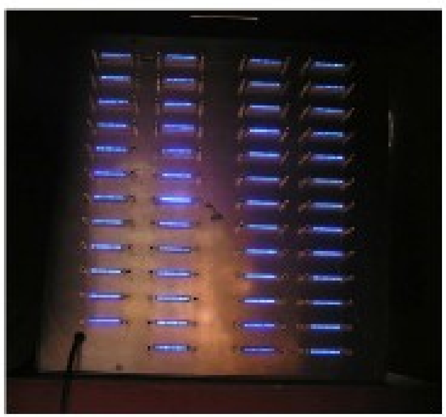
*slide from M. Kordosky

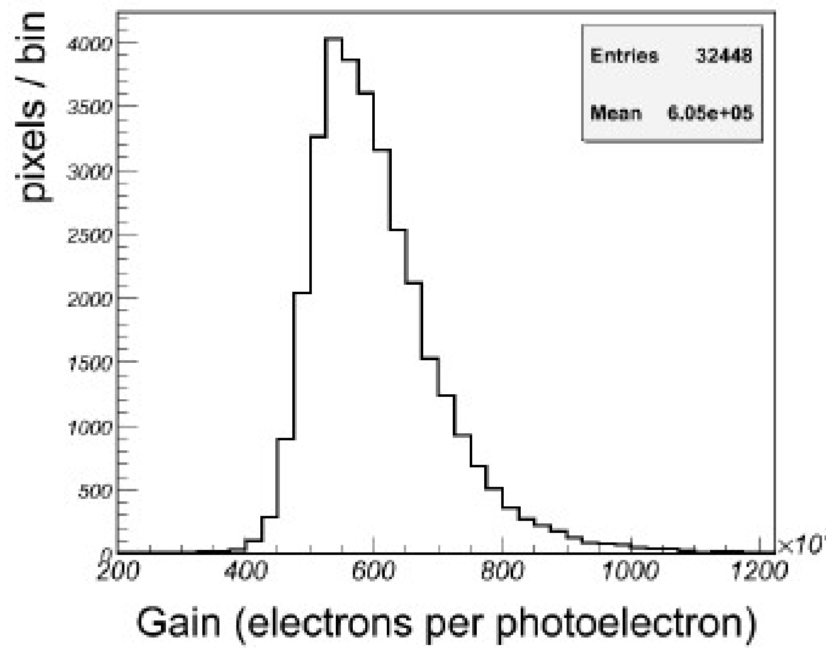
Detector Calibration



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

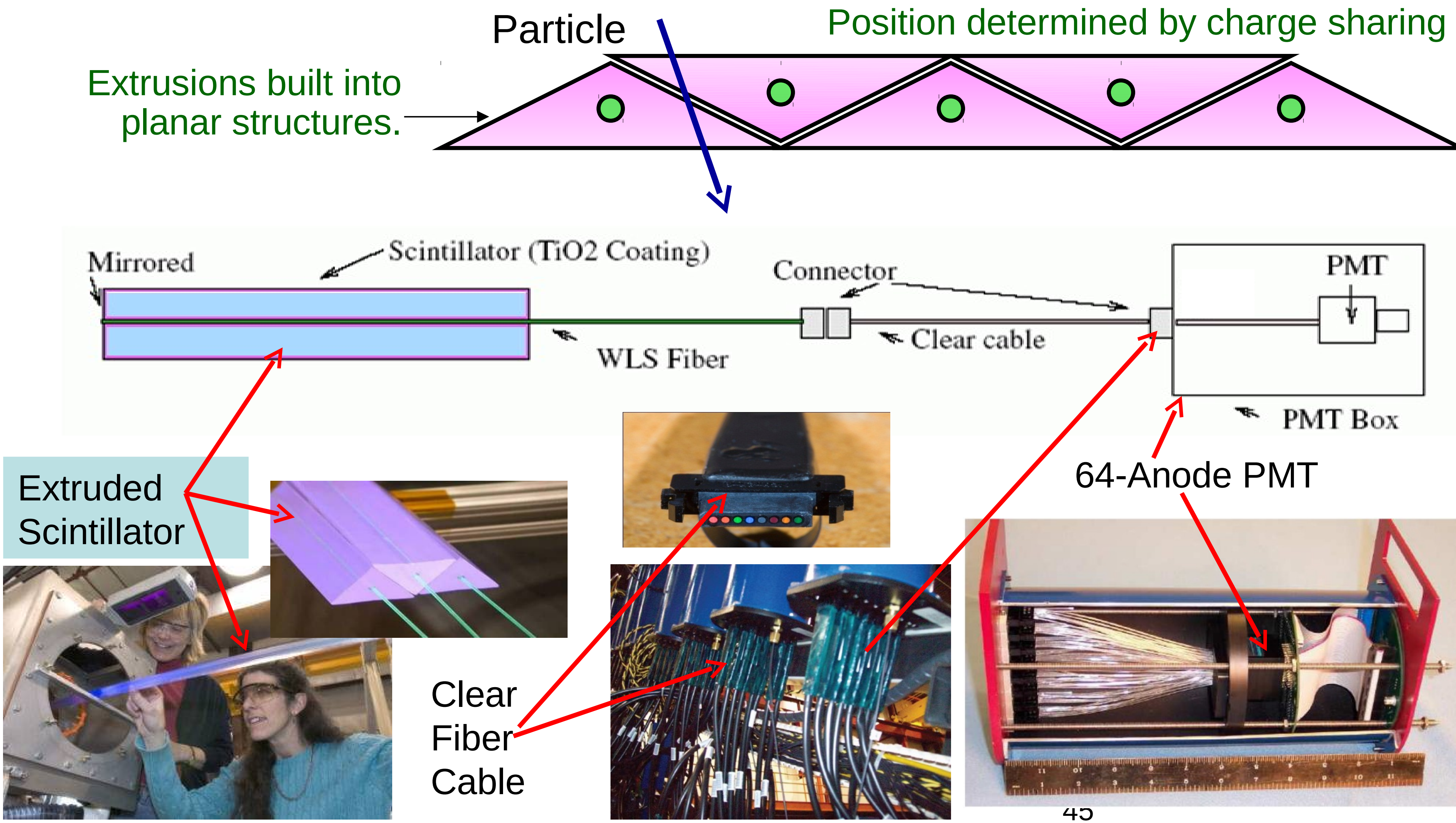
PMT gains measured continuously *in-situ* using Light Injection system





*slide from M. Kordosky

MINERνA Optics



MINERνA Electronics

- Light measured by Hamamatsu 64 anode PMTs (newer version of MINOS model)
- Front end board (FEB) with Trip-t chips interface the PMTs
- Discriminators allow us to trigger at 1PE and resolve overlapping events during a spill