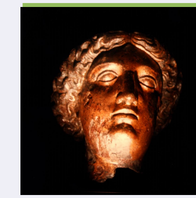
MINERνA

Prospects and Status



NEUTEL 2011

XIV International Workshop on Neutrino Telescopes

15 - 18 March 2011

Venice, Italy

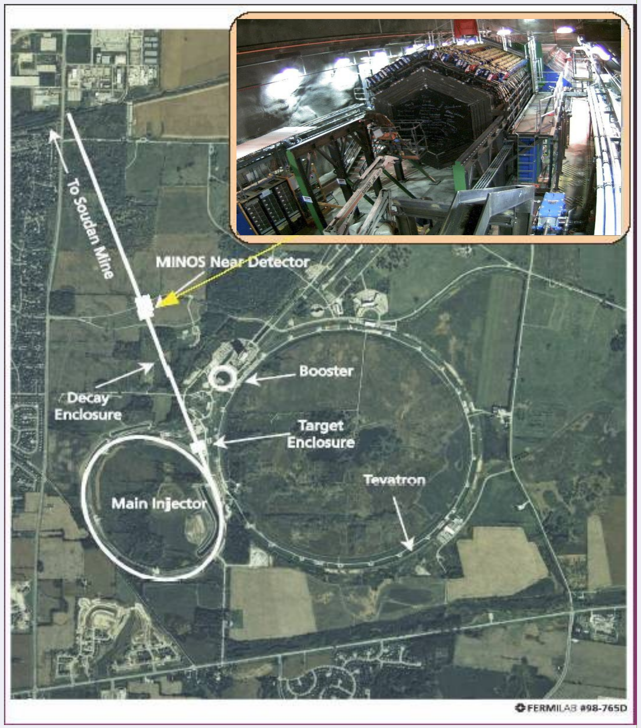
Vittorio Paolone
University of Pittsburgh
(Representing the MINERνA collaboration)

Outline

- What is MINERνA?
- Why MINERνA? - Motivation
- Detector Design and Construction
- NuMI Beam Design
- Detector Status
- Analysis Efforts and Status
- Summary and Outlook

What is MINERνA?

- Dedicated neutrino-nucleus cross-section experiment running at Fermilab in the NuMI beamline.
  - Will perform detailed study of neutrino interactions on a variety of nuclei.
    - Using Low Energy Neutrinos (~Few GeV) and...
    - Visualized with a fully active, high resolution detector and Large statistics

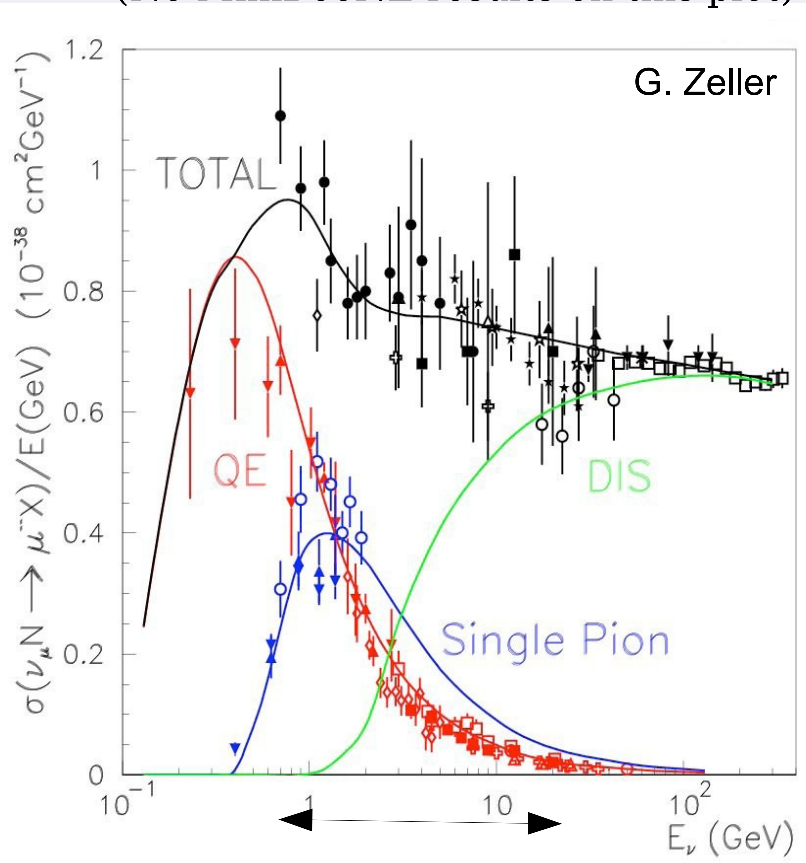


Fermilab, Batavia IL USA

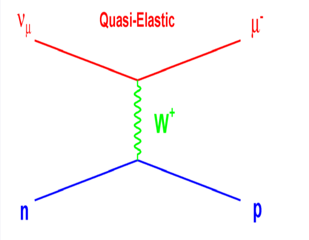
Why is MINERνA Needed?

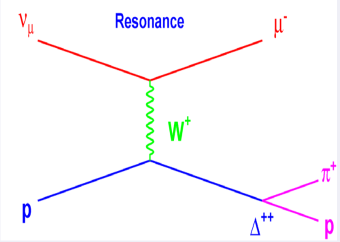
- Existing data between 1-20 GeV poorly understood:
- Mainly Bubble chamber data
- Wide band neutrino beams
  - Low statistics samples
  - Large uncertainty on flux. *i.e.* large systematic errors.

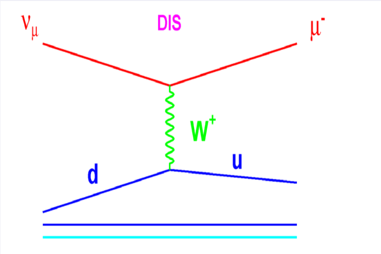
(No MiniBooNE results on this plot)



1-20 GeV







Why do we care that the cross-sections are poorly know?

Motivation (ν Oscillation):

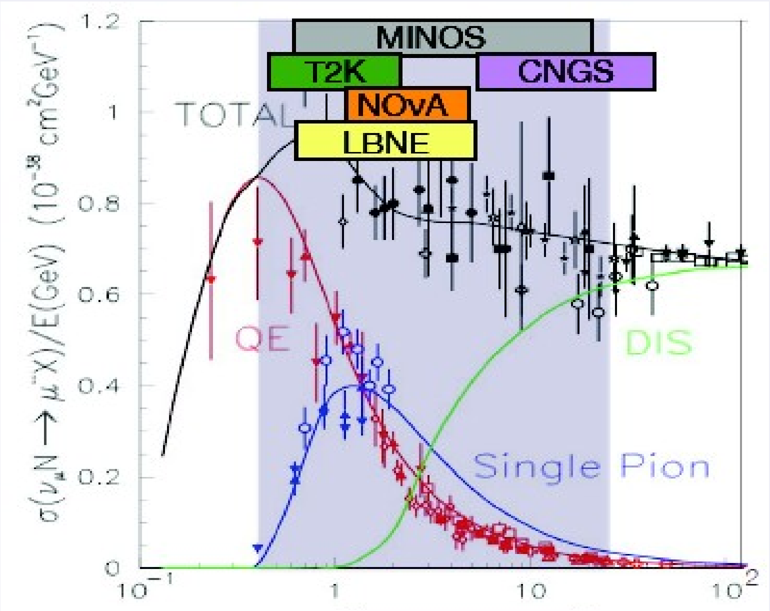
We are now in a period of precision neutrino oscillation measurements

- From oscillation theory: Need $\Delta m^2 \bullet L/E_{beam} \sim 1$ to maximize oscillation effect

- With $\Delta m^2 \sim 2.4 \times 10^{-3}$ eV^2 and
  L's ~several hundreds of km,
  E_{beam} ~few GeV range

- Need Precision understanding of Low energy (Few GeV) neutrino cross sections.

G. Zeller

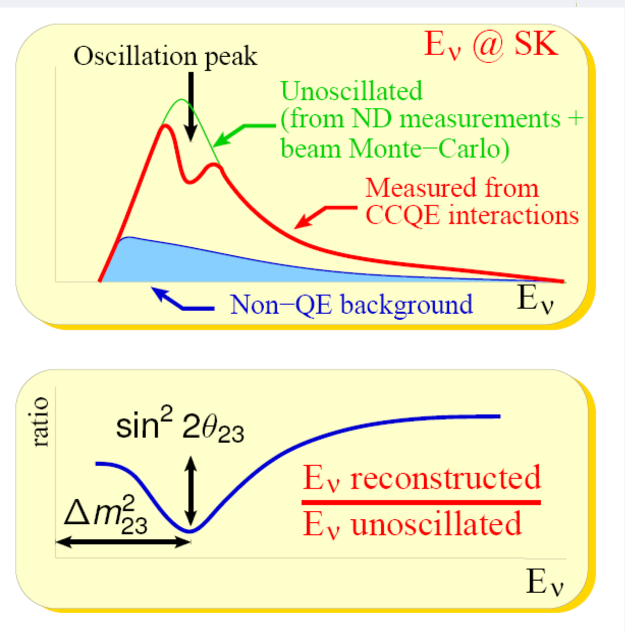


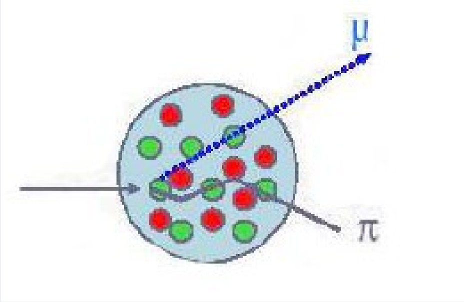
MINERνA Energy Range

Motivation

Disappearance Oscillation Measurement:

- Experiments expect distortion in ν energy distribution for $E_\nu < 5$ GeV
- Recall oscillation probability depends on E_ν
- However Experiments Measure E_{vis}
- E_{vis} depends on Flux, σ, and detector response interaction multiplicities AND particle type produced

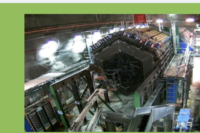




Final State Interactions:

- Intranuclear rescattering
- Energy loss and/or absorption
- Change in direction
- E_{vis} not equal to E_ν

Motivation



Appearance Oscillation Measurements:

Measuring Θ_{13}: Look for ν_e's in a ν_μ beam.

CC ν_μ backgrounds to ν_e search:

→ NC π^0: $\nu_{\mu/e} + N \rightarrow \nu_{\mu/e} + N + \pi^0$

- $\pi^0 \rightarrow \gamma\gamma$; only one γ detected in final state
  - γ and e are indistinguishable

→ Intrinsic ν_e in beam (Specific to NuMI beam)

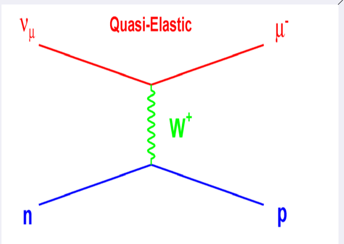
→ Critical to measure these background processes using the same nuclear targets used in oscillation experiments.

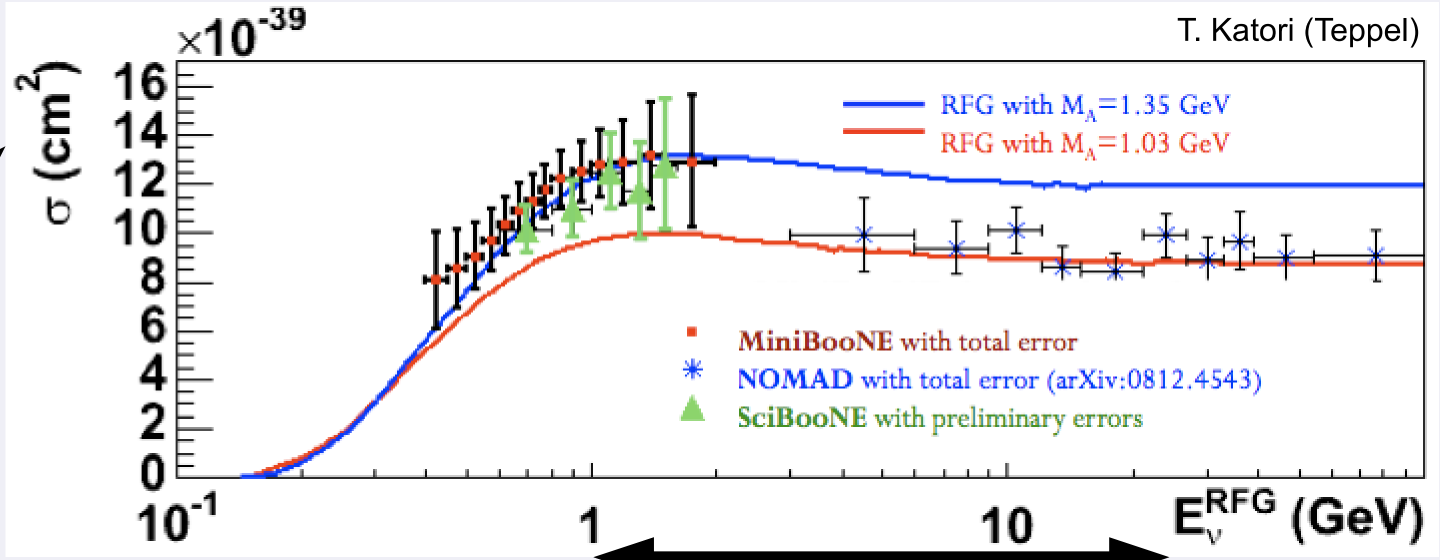
Motivation

ν scattering physics:

MINERvA is positioned to resolve discrepancies between different experiments:

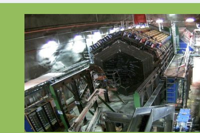
→ MiniBooNE and SciBooNE QE data agree with each other at low energy but conflict with the NOMAD results at higher energies:





Minerva nicely covers region of interest

Motivation



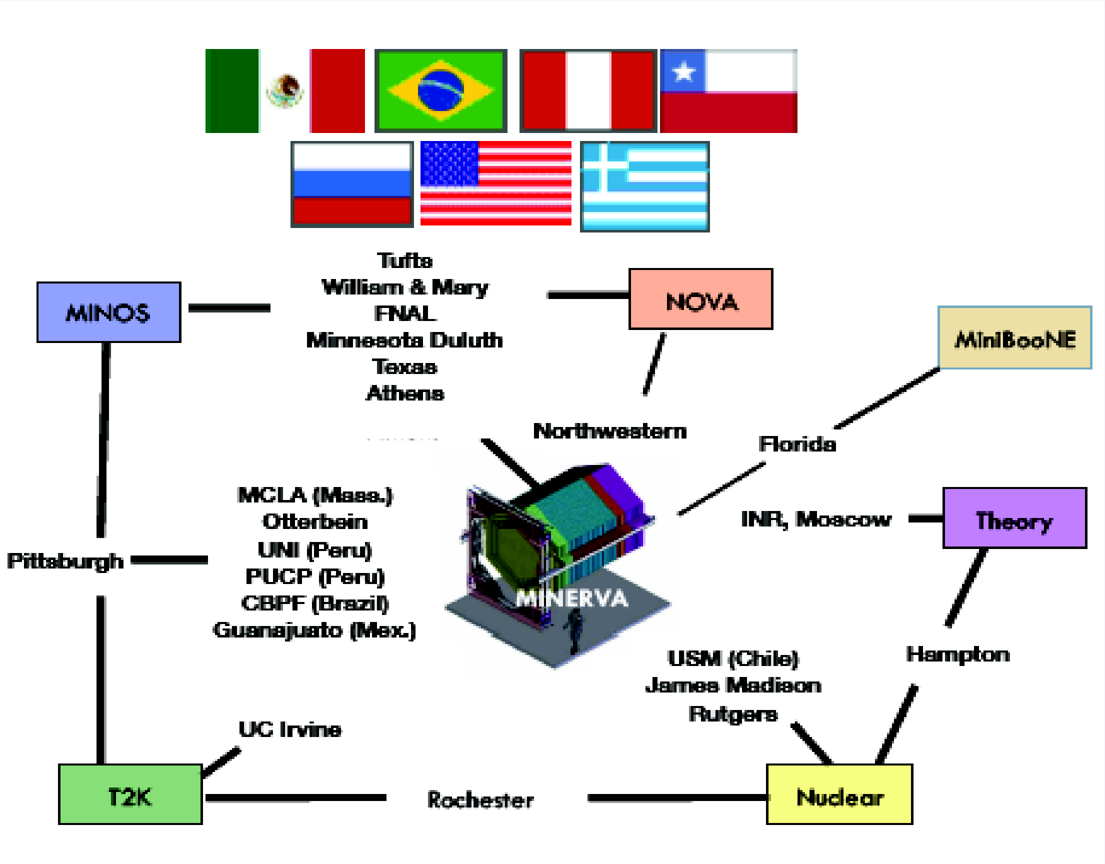
Other ν scattering physics:

- Axial form factor of the nucleon
  - Accurately measured over a wide Q2 range.
- Resonance production in both NC & CC neutrino interactions
  - Statistically significant measurements with 1-5 GeV neutrinos
  - Study of "duality" with neutrinos
- Coherent pion production
  - Statistically significant measurements of A-dependence
- Strange particle production
  - Important backgrounds for proton decay
- Charm particle production at threshold
  - Charm mass
- Parton distribution functions
  - Measurement of high-x behavior of quarks
- Generalized parton distributions using weak probes
- Nuclear effects
  - Expect significant differences for ν-A vs e/μ-A nuclear effects

Collaboration

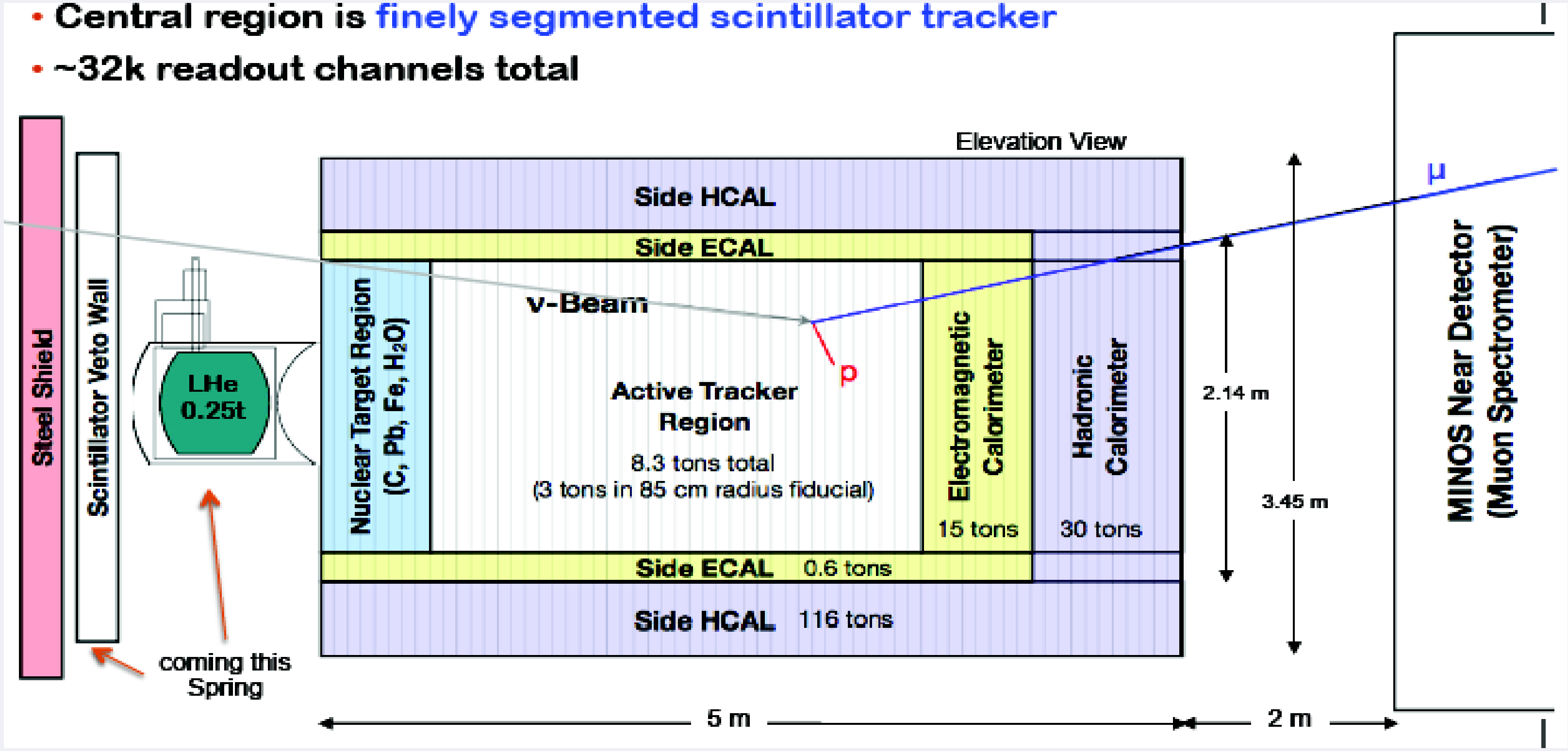
Currently consists of about 100 nuclear and particle physicists from 22 institutions and 7 countries.

→Members are also collaborators on other experiments where MINERνA results can make a significant contribution.

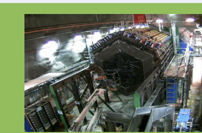


Detector

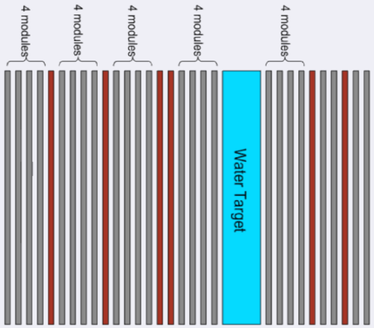
- An active segmented scintillator detector with nuclear targets of C, Fe, and Pb (H_2O and He coming soon)
- All targets in same detector reduces systematic errors between different A targets
- 120 modules of four types: nuclear target, tracker, ECal and Hcal
  - **Total Mass: ~ 200 tons**



Detector: Nuclear Targets



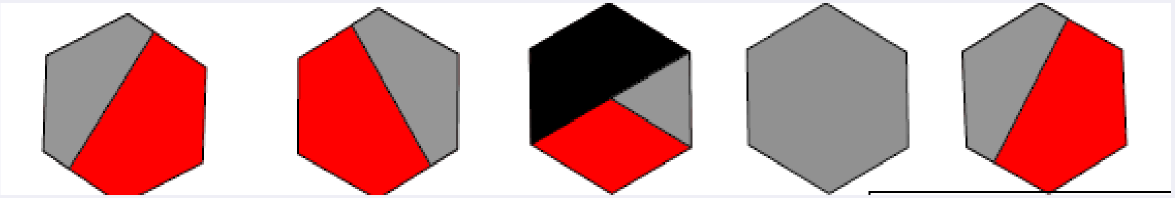
- Water target



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

- Helium target upstream of detector:

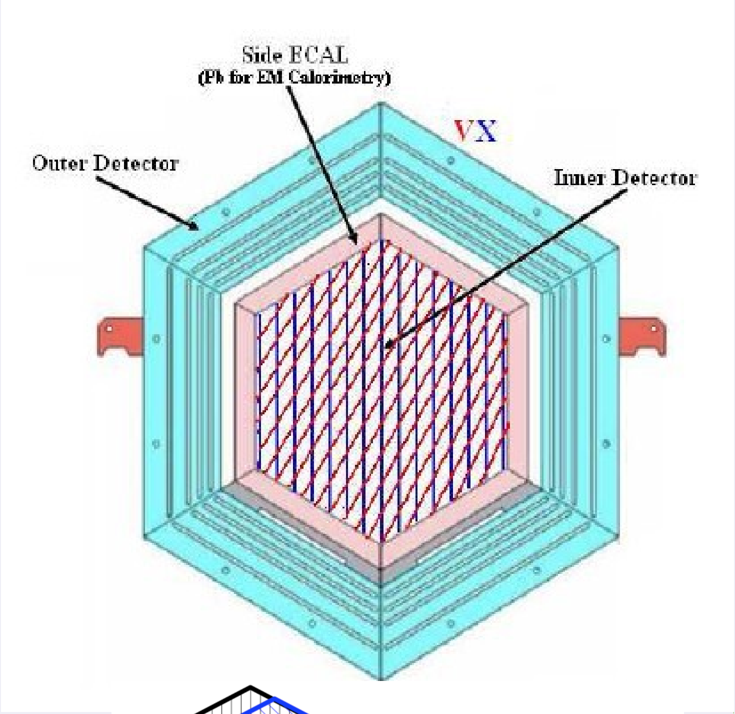
- 5 Nuclear Targets: Fe Pb C:

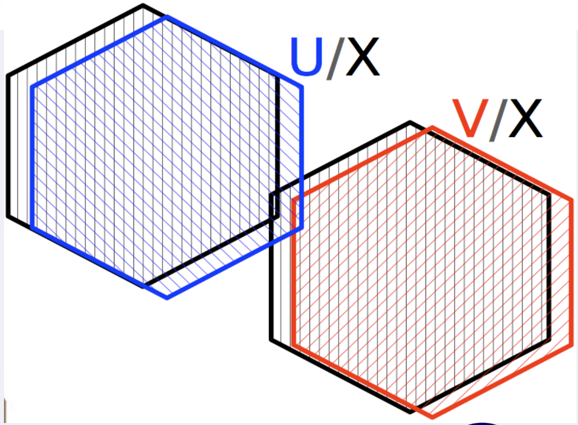


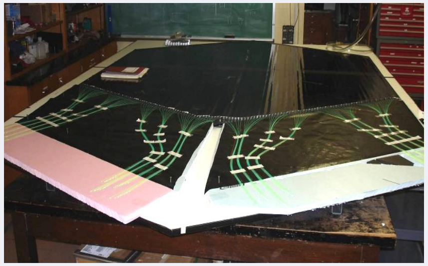
Detector Elements: Modules

Each Tracker Module composed of:

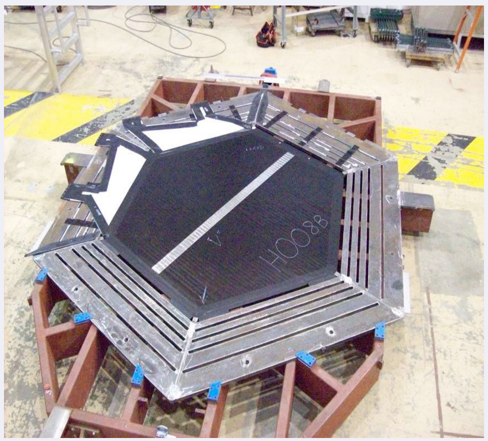
- An inner detector is made of two layers of scintillator bars:
  - X layers are vertical and U and V layers are rotated 60 degrees in either clockwise or counterclockwise direction
  - A lead collar acts as a side ECal
  - An outer detector for hadron calorimetry made of iron and interleaved with scintillator bars to detect exiting particles





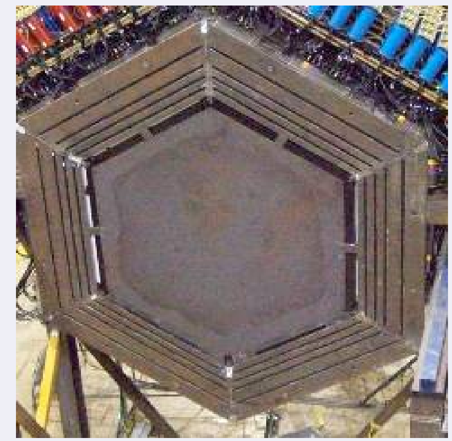


Detector Modules



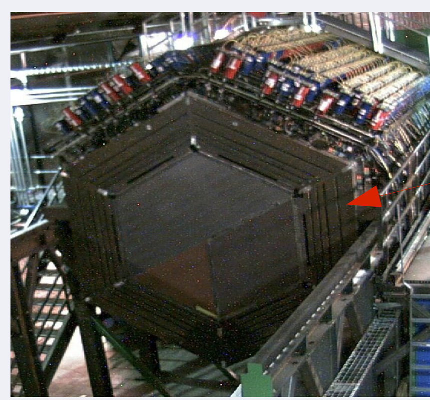
Tracker module

ECAL modules incorporate Pb absorber



HCAL modules include 1” steel absorber

Modules hung onto rails using frame “ears” to assemble detector



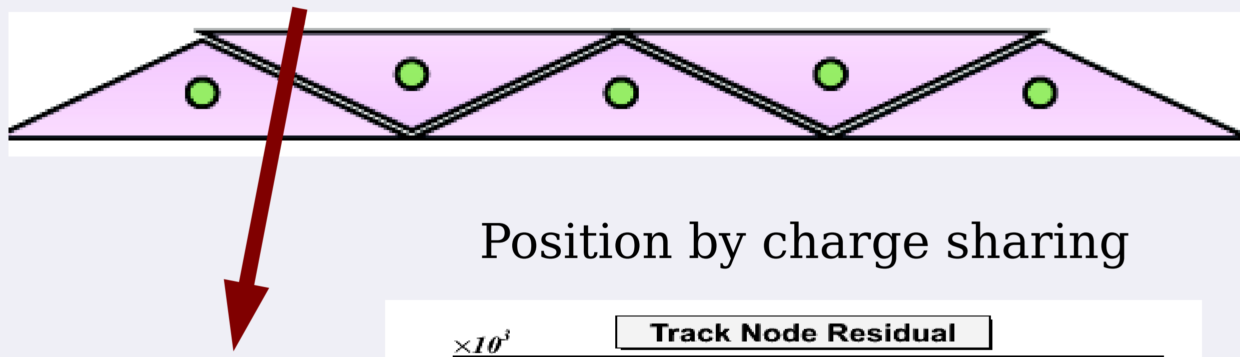
Example Target module

Detector Elements: Scintillator Bars

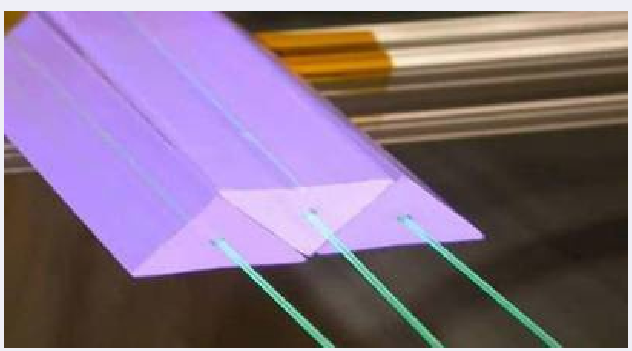
1.7 x 3.3 cm^2 strips

WLS fiber readout in center hole

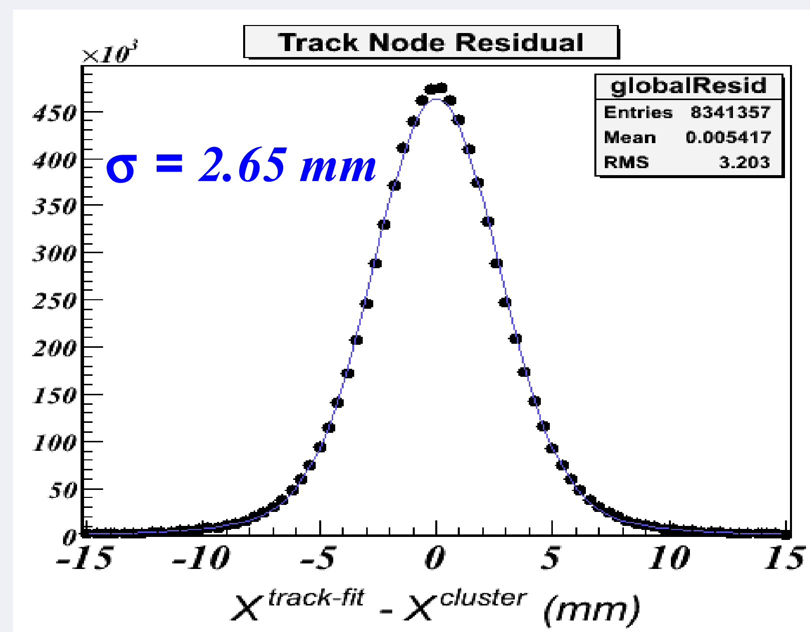
Particle



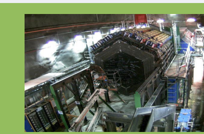
Position by charge sharing



~32K channels

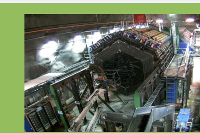


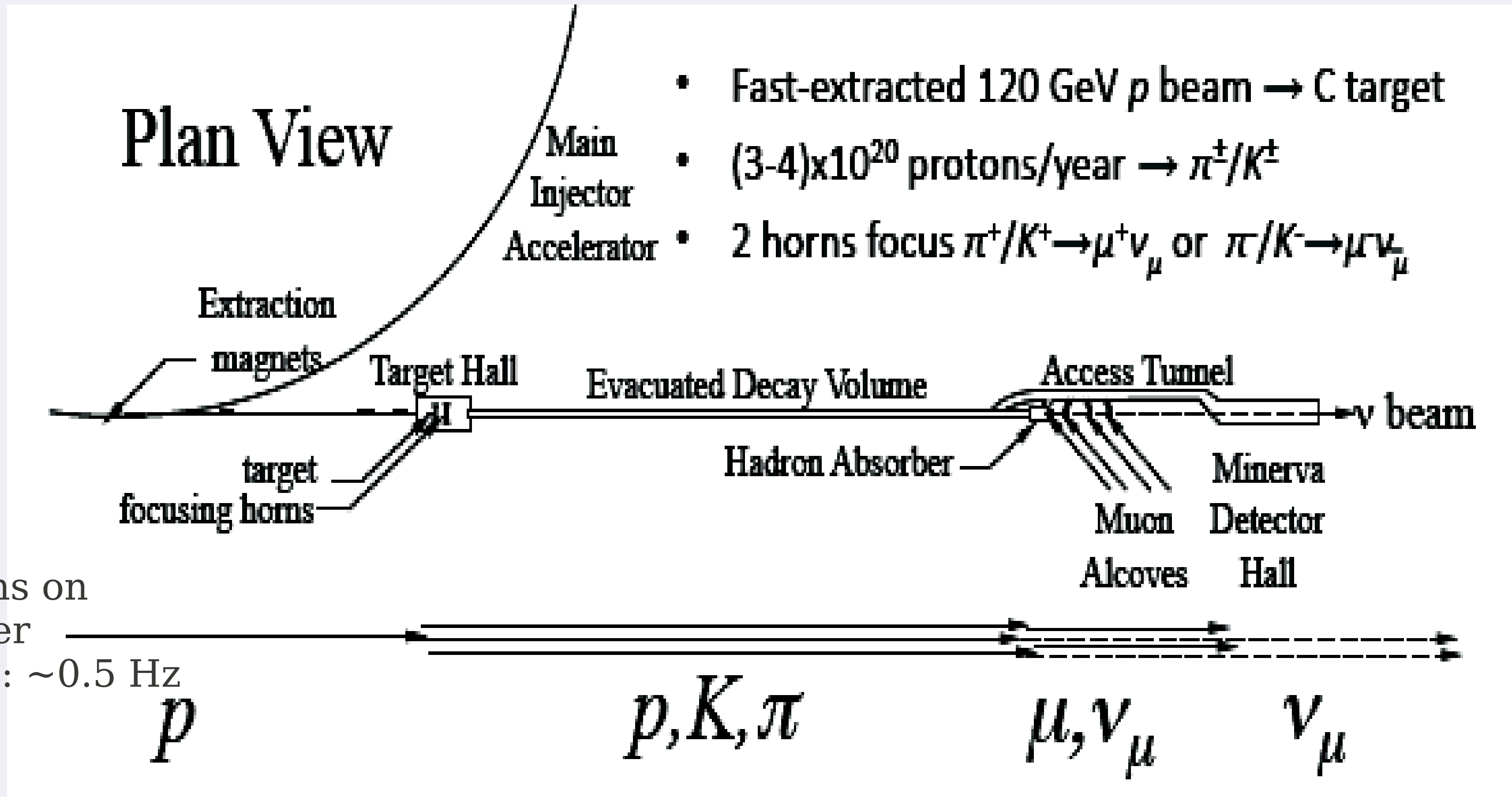
Detector Capabilities



- Good tracking resolution (~3 mm)
- Calorimetry for both charged hadronic particles and EM showers
- Timing information (few ns resolution)
- Containment of events from neutrinos < 10 GeV (except muon)
- Muon energy and charge measurement from MINOS
- Particle ID from dE/dx and energy+range
  - But no charge determination except muons entering MINOS

FNAL NuMI Beamline

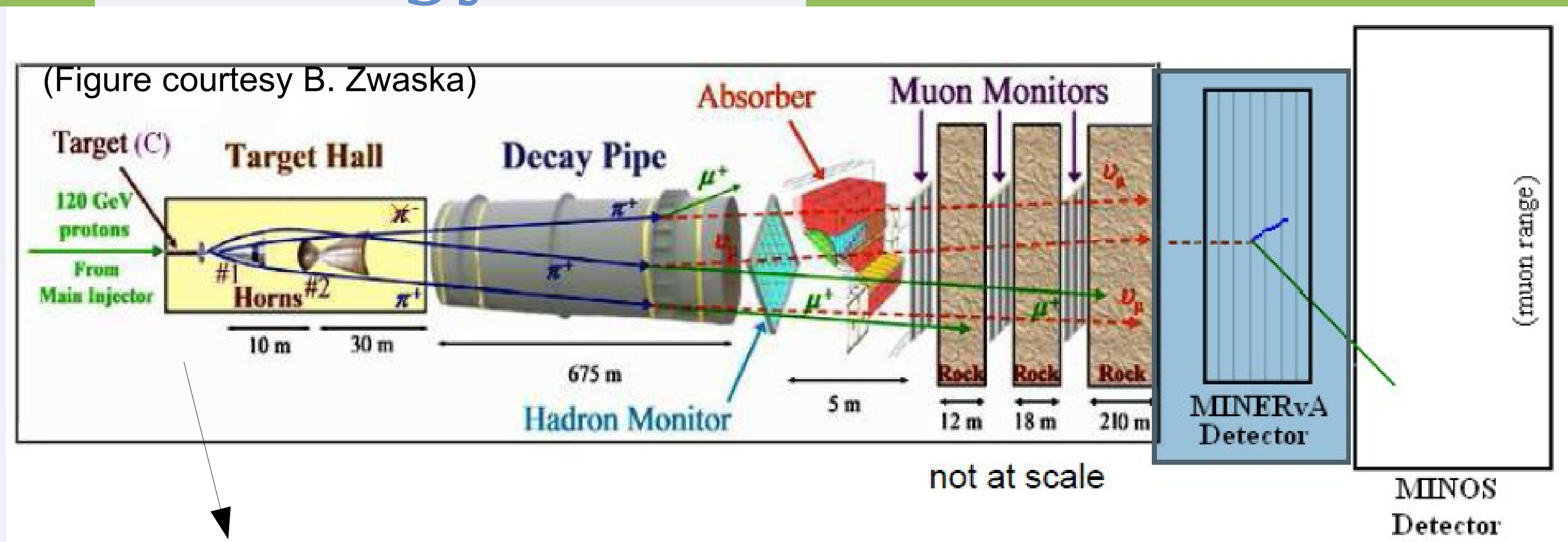


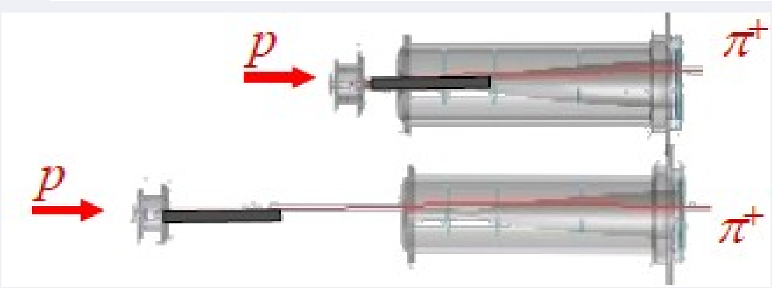


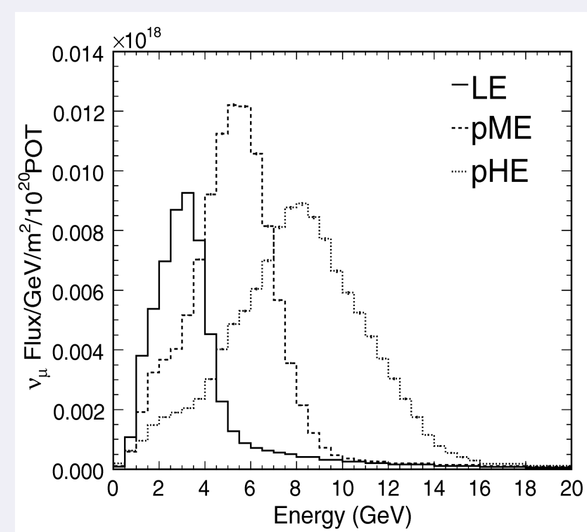
35x10^{12} protons on target(POT) per Spill. Rep rate: ~0.5 Hz (300-350 kW)

- Absorber stops hadrons not μ
- μ absorbed by rock, ν → detector
- Extensive instrumentation to monitor p, hadron, muon beams

NuMI Variable ν Energy



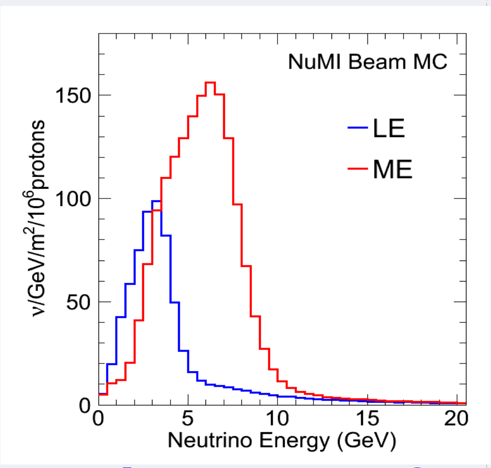




- NuMI target mounted on a rail drive for variable positioning – Allows easy ν energy tuning
- NuMI provides either ν_μ or anti-ν_μ beam by sign selecting pions using magnetic horn current direction.

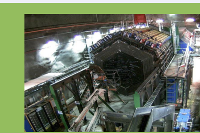
Timeline

- 11/2009: ~0.8 x 10^{20} POT of low energy (LE) anti-ν beam using 55% of detector.
- 2/2010: Installed remaining 45% of detector.
  - Ran LE ν beam from 3/2010-9/2010 - 1.2 x 10^{20} POT.
- 11/2010-May 2011: LE anti-ν beam, roughly 1.2 x 10^{20} POT already recorded.
- Spring 2011 – Spring 2012: Run in LE ν beam. Expect in excess of 4 x 10^{20} POT.
- Summer 2012: Fermilab accelerator shutdown, switch to ME.
  - Expect 12 x 10^{20} POT running with NOνA.



- Expect ~9 million CC events in the fully active target region over the course of full Run Plan (LE+ME, NEUGEN prediction).

CC Sample Sizes



Current Data Sample (GENIE* 2.6.2 Generator Raw Events)

(Target Masses: CH Fiducial = 6.43 tons, C = 0.17 tons, Fe = 0.97 tons, Pb = 0.98 tons w/ 90 cm vertex radius cut.)

	1.2e20 POT Low Energy Neutrino Mode	1.2e20 POT Low Energy Anti-neutrino Mode
Coherent Pion Production	4k	3k
Quasi-Elastic	84k	46k
Resonance Production	146k	62k
Deep Inelastic Scattering, Structure Functions, High-x PDFs	168k	19k
Carbon Target	10.8k	3.4k
Iron Target	64.5k	19.2k
Lead Target	68.4k	10.8k
Scintillator (CH) Tracker	409k	134k

Total MINERνA Exposure: Run plan in neutrino mode:

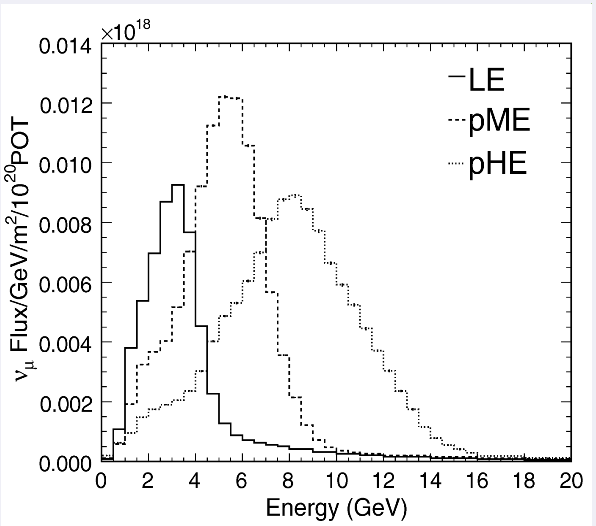
- 4.9 x 10^{20} P.O.T. in low-energy (LE) mode (March, 2010 – mid 2012)
- 12 x 10^{20} P.O.T. in medium-energy (ME) mode (beginning in 2013)

Cross-section Errors

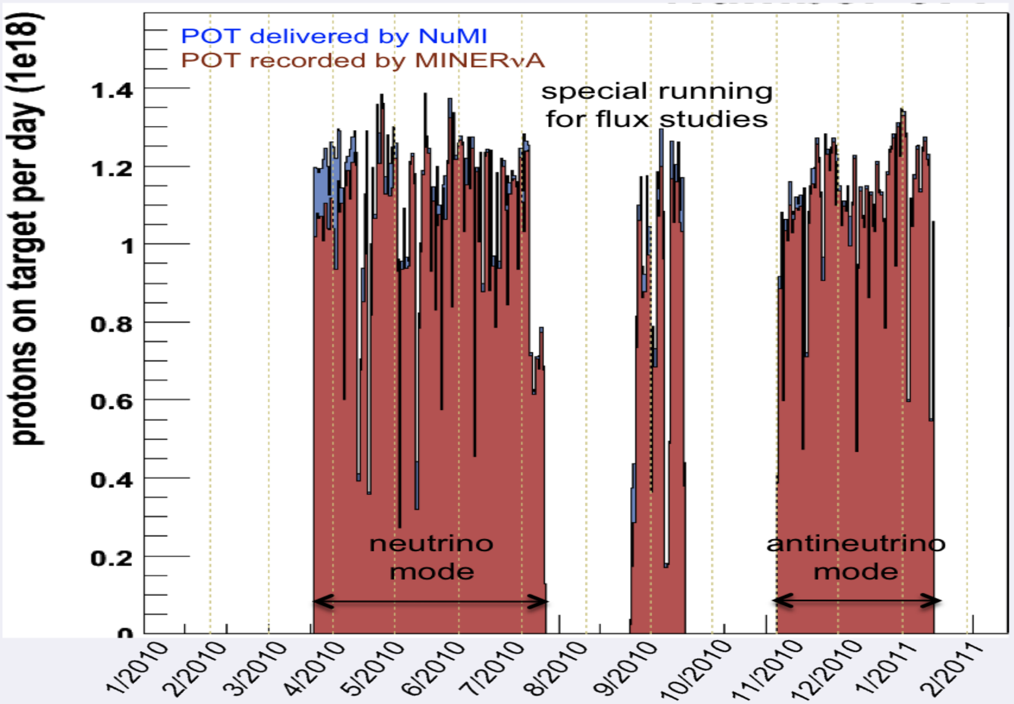
- Statistical errors are expected to be very small.

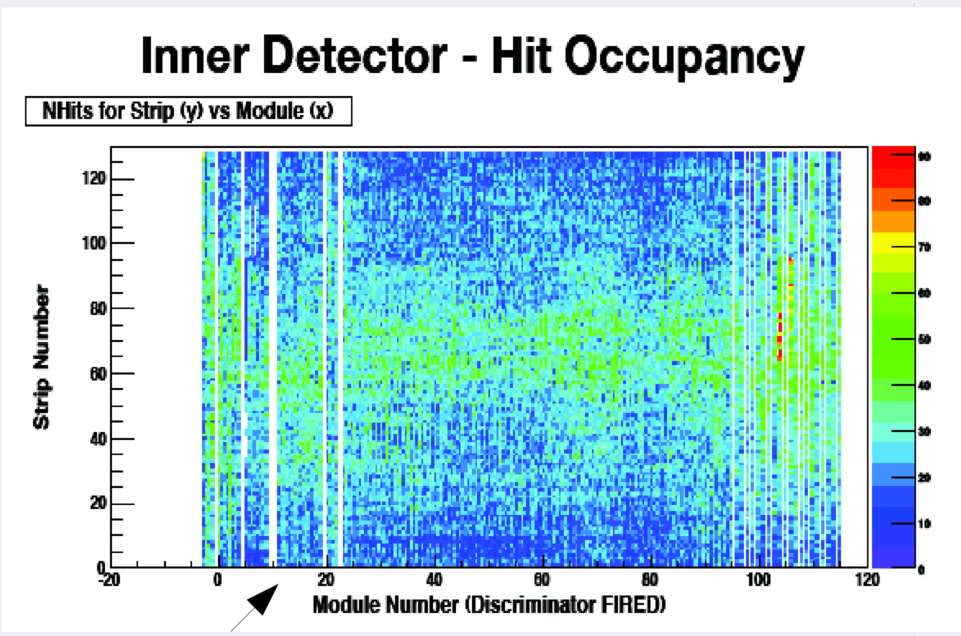
- The total error on absolute cross section measurements will be dominated by the systematic error on the determination of the neutrino flux:
  - Past experiments in wide band beams limited to ~30% uncertainty in flux
  - External hadron production data sometimes inconsistent, or leaves no opportunity for in situ check of the flux.
  - Variable beam configurations offer in situ flux method
    - Can check cross sections at single Eν using several beam configurations
      - Each configuration samples different pion kinematics at the same neutrino energy

  - Measure event spectrum with QE's
  - Normalize to NBB (CCFR) at high energy
  - **Goal is 7% error flux shape, 10% norm**



Detector Performance

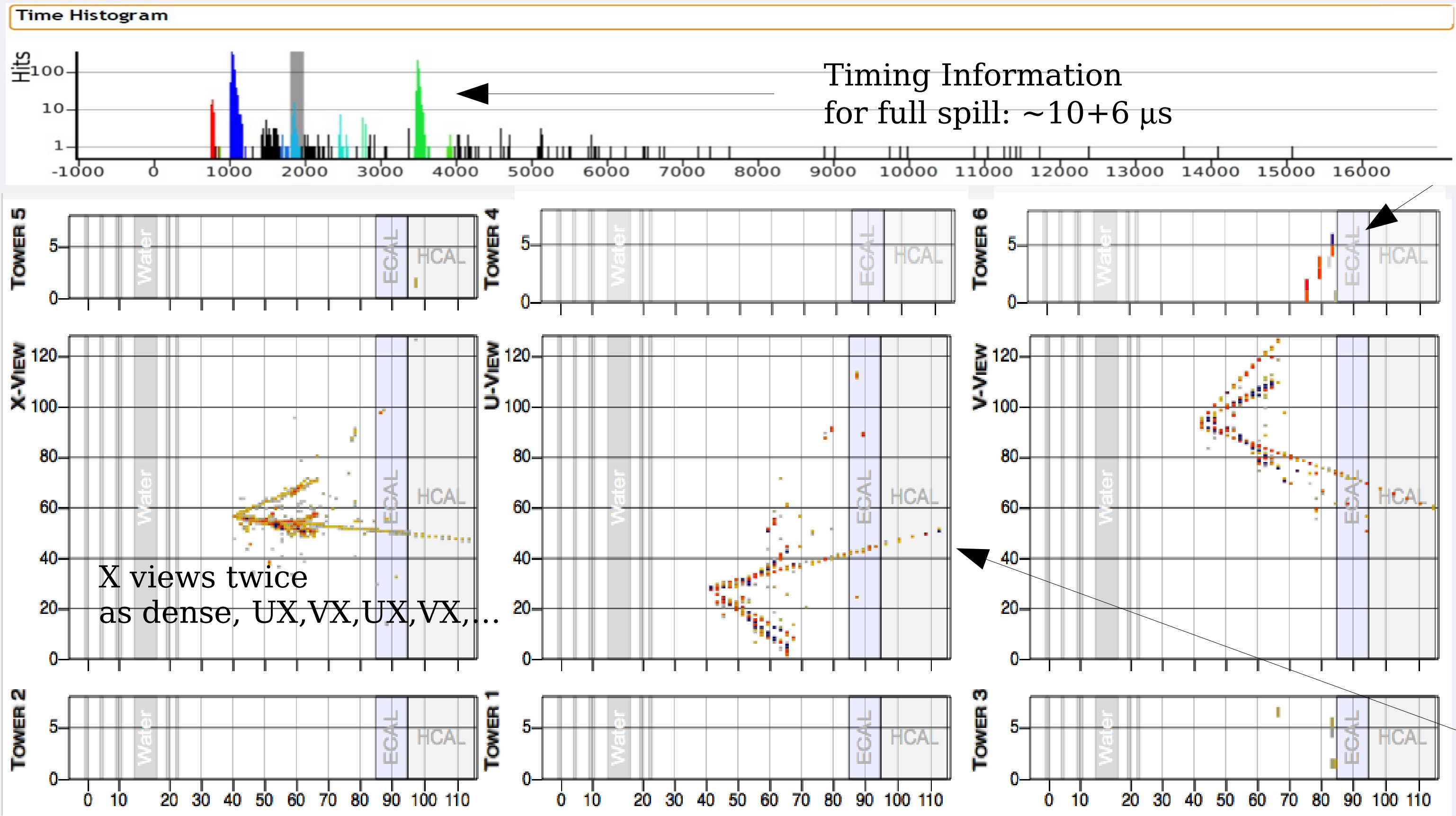




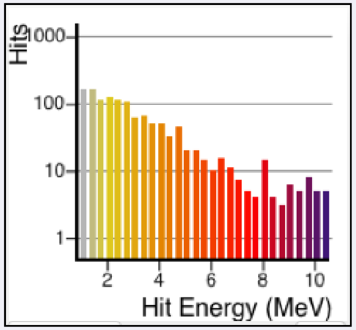
Vertical white stripes: passive target locations

- >98% live-time since November
- From live channel and occupancy plots
  - ~20(inner) and ~10(outer) dead channels (out of ~32K): <0.1%

Example Event (Data)



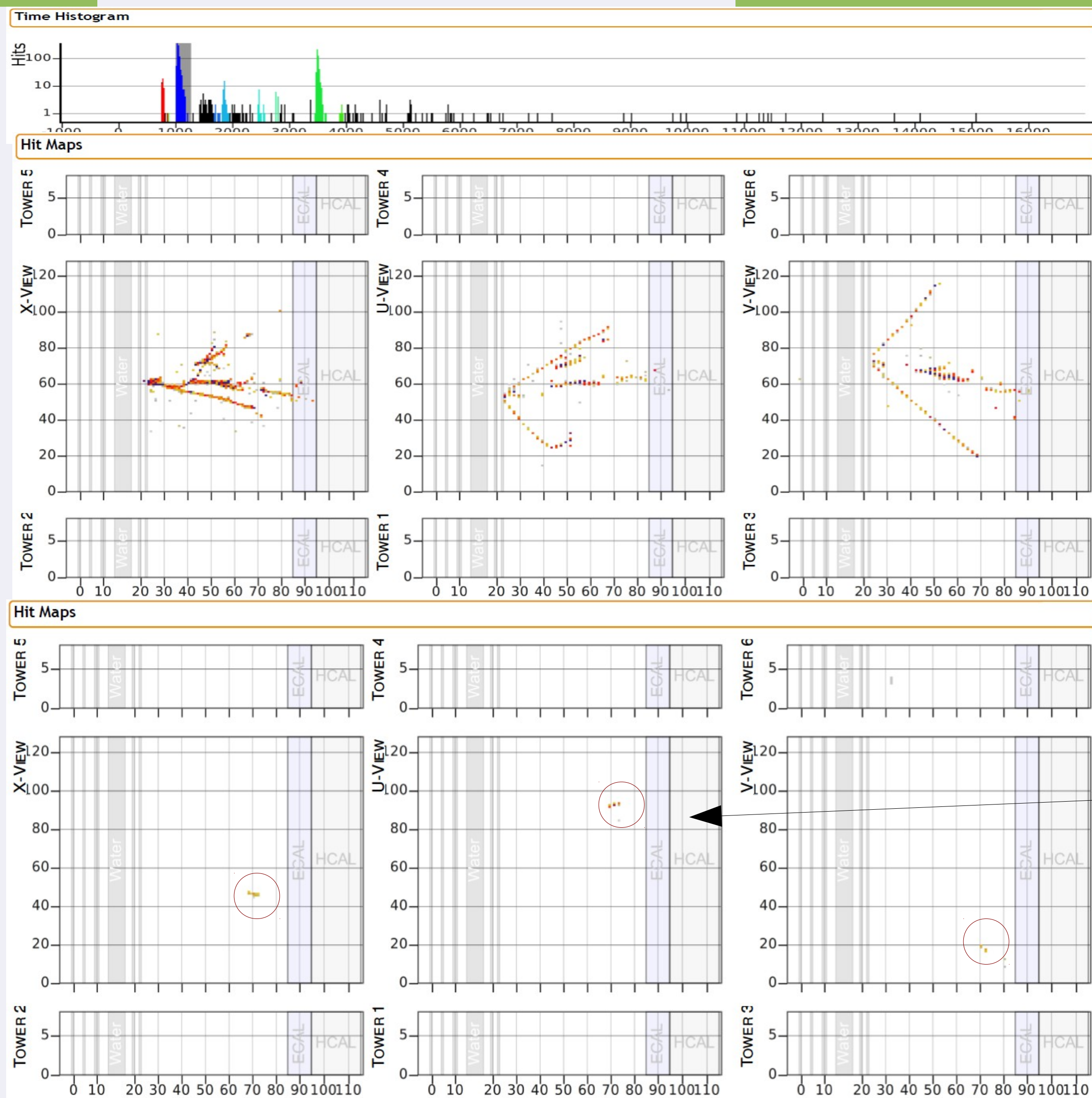
Particle leaves the inner detector, and stops in outer iron calorimeter



Muon leaves the back of the detector headed toward MINOS

- Information buffered in the ν spill and read out at end of spill: ADC and TDC
- Similar Times bunched for different slices (events)
- 3 views: X, U & V + Outer calorimeter, color of hits $\propto$ to deposited energy

Example Data Event (anti-ν)

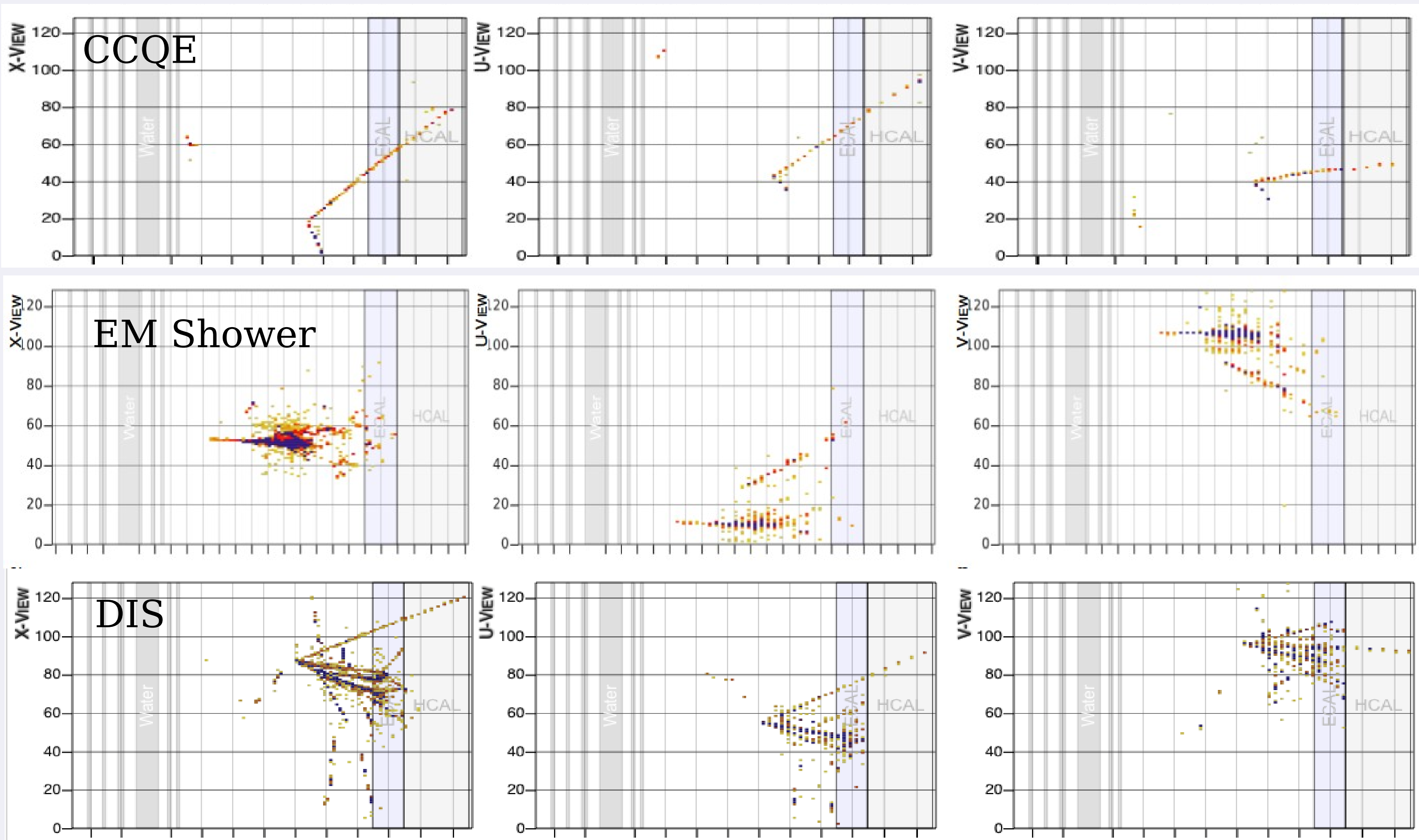


CC anti-ν Low Multiplicity Interaction with π^0.

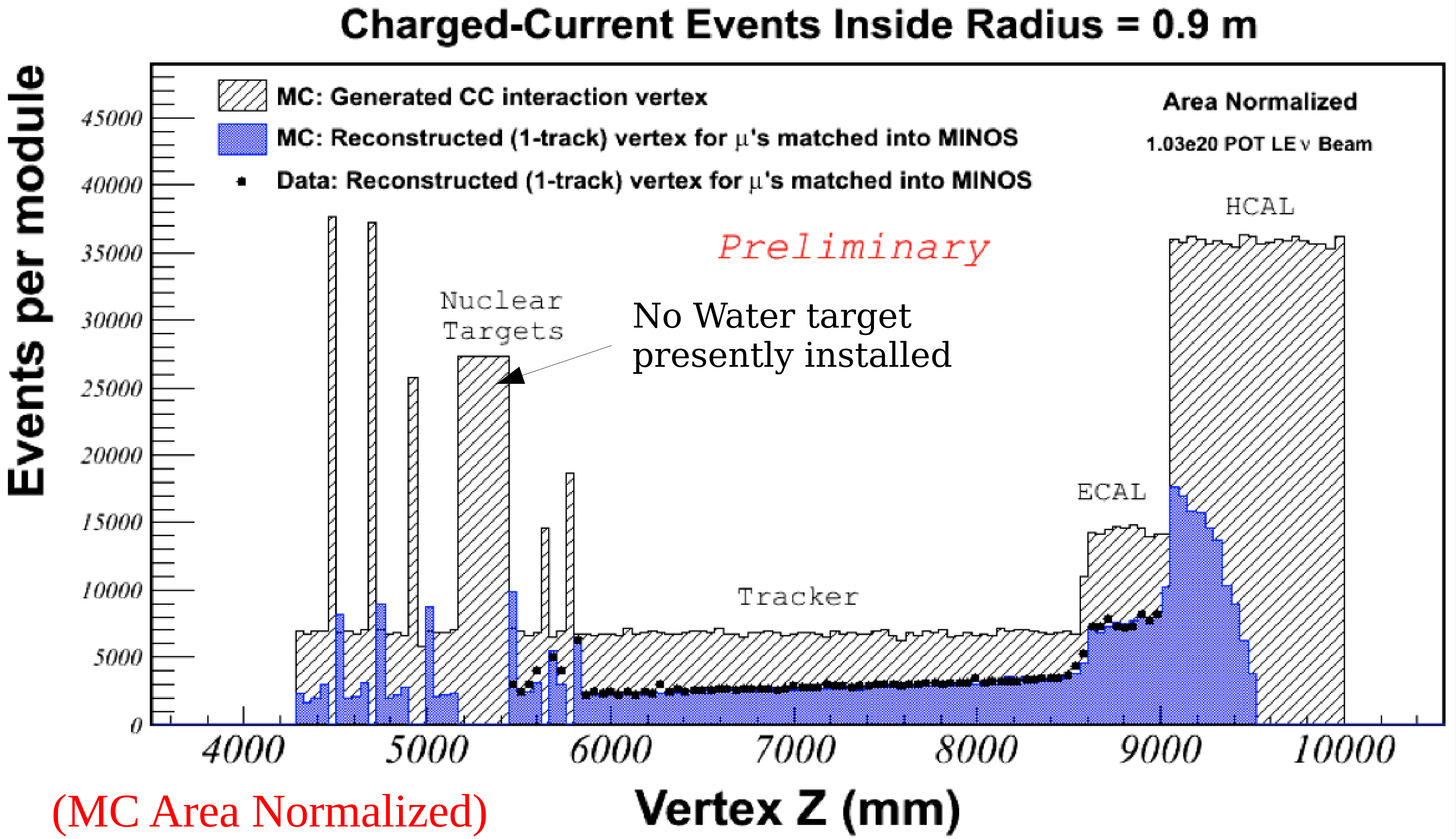
Later Time Slice

Stopping muon – Michel Electron

Sample Events Candidates



Vertex Distribution for ν CC Events

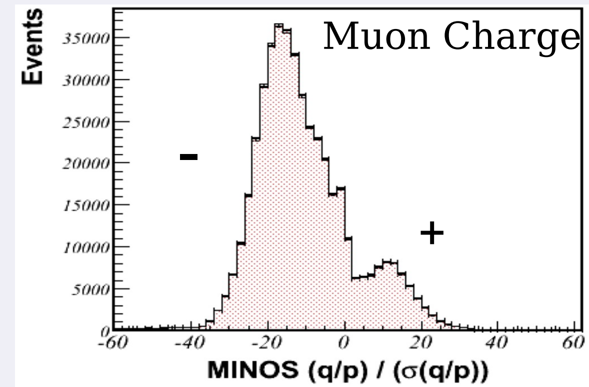


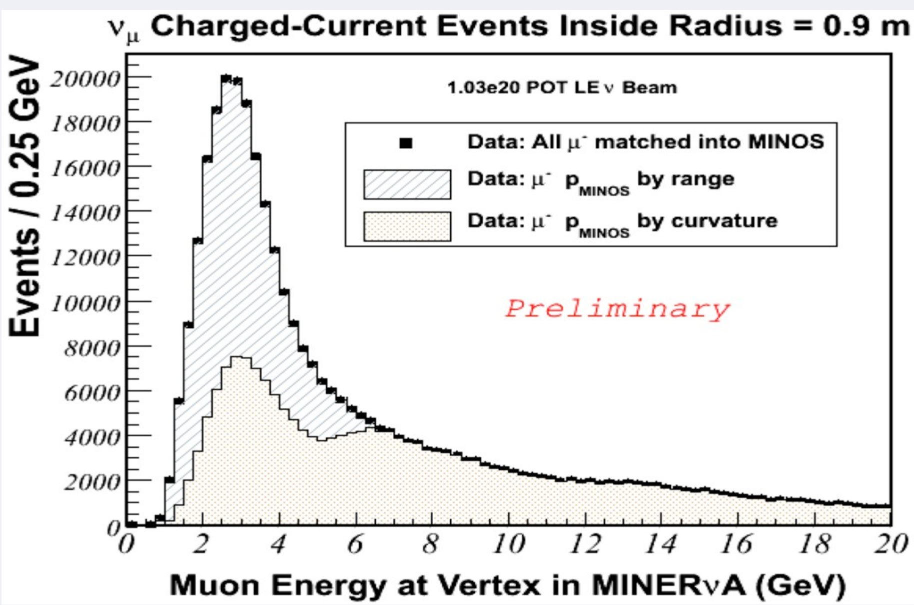
(MC Area Normalized)

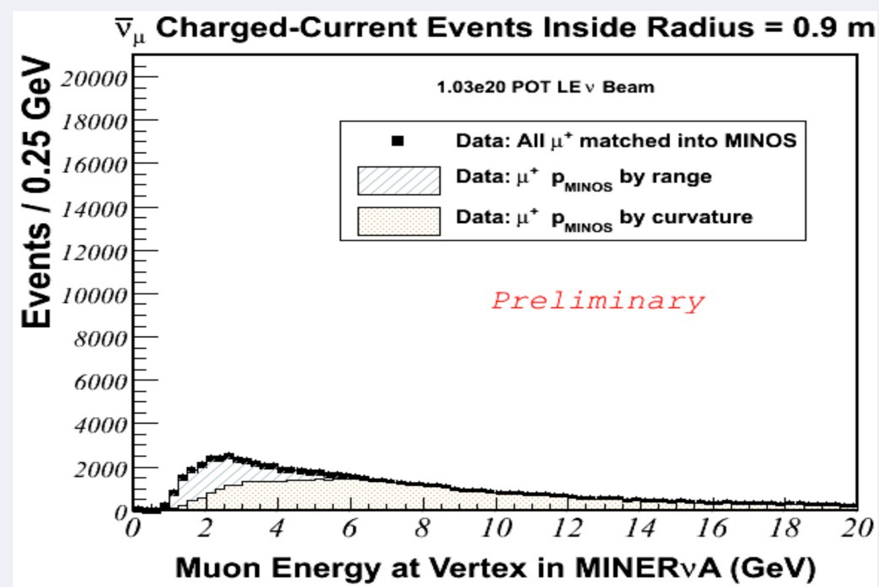
ν CC: Muon Energy Distributions

DATA: 1.03e20 POT Low Energy ν Mode

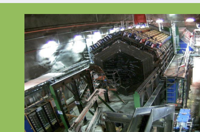
- Presently only muons entering MINOS used
- Will extend to momentum measurement in MINERνA using range



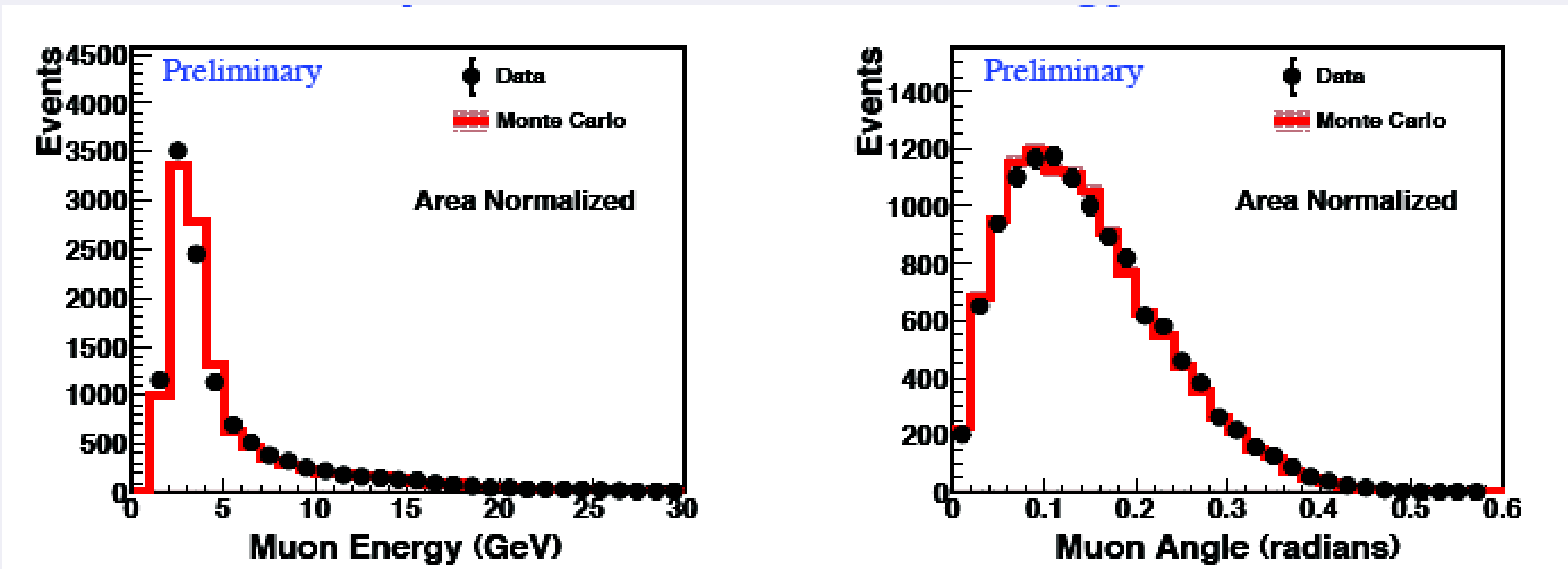




Anti-ν Charged Current (CC)



Inclusive μ^+ Data & MC: Low Energy Anti-ν Beam

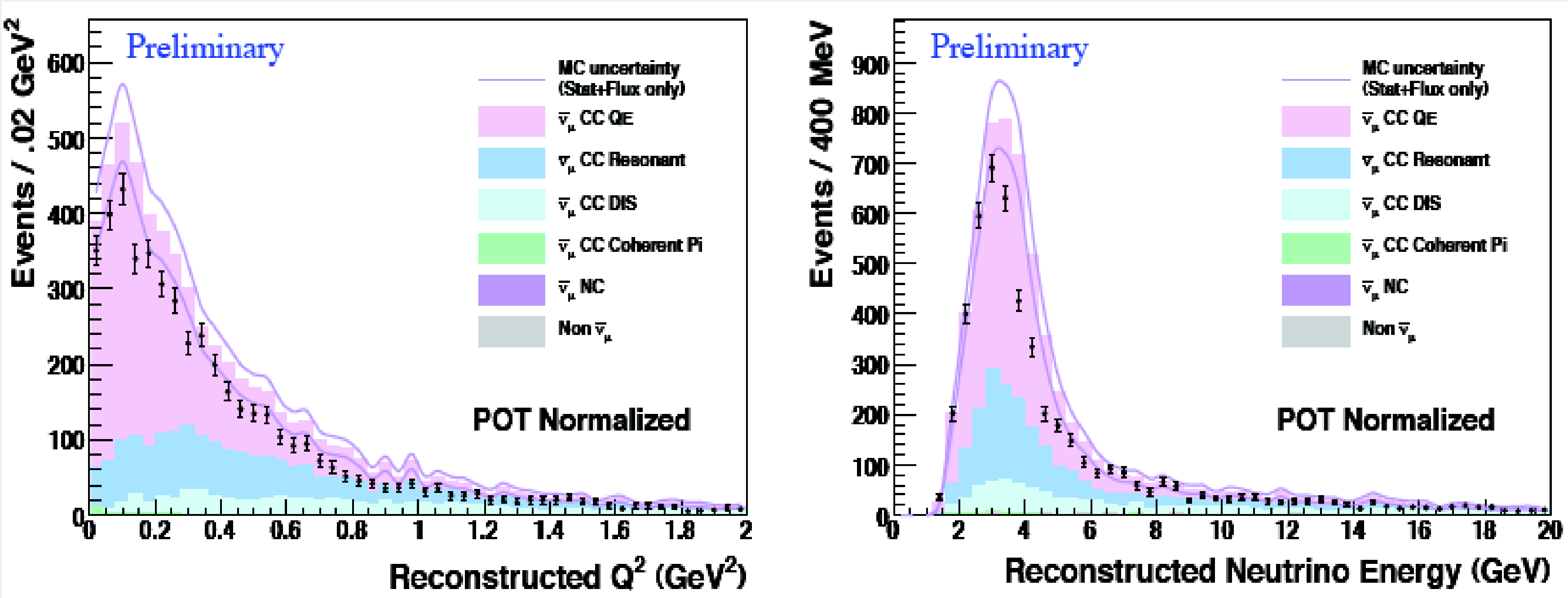


Tracks originated in the MINERνA tracker fiducial volume:

- Muon momentum and charge analyzed in MINOS.
  - MINERνA energy loss computed using range.

Anti-ν CCQE

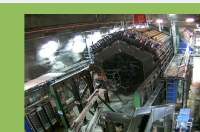
Anti-νp → μ^+n Event Candidates: Low Energy Anti-ν Beam
DATA(0.4E20 POT, partial detector) & MC



→ Absolute predictions from our flux simulation (GENIE 2.6.2, GEANT4)

→ Event deficit is flat in Q2 and not in E_ν

Conclusions



- MINERνA will precisely study neutrino interactions in 1-20 GeV:
  - Using a fine-grained, high-resolution, detector
  - Using the high flux NuMI beam.

- MINERνA will improve our knowledge of:
  - Neutrino cross sections at low energy, low Q2.
  - A-Dependence in neutrino interactions (Targets He, C, Fe, Pb and H_2O)

- These data will be interesting in there own right and will be important for minimizing systematic errors in oscillation experiments.

- First studies are starting to mature, Stay tuned.

The Collaboration Thanks You

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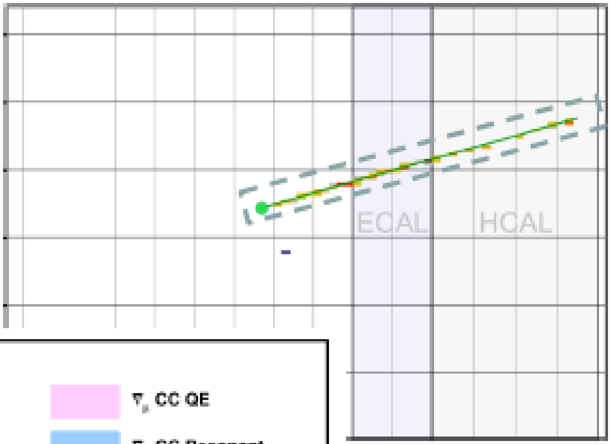
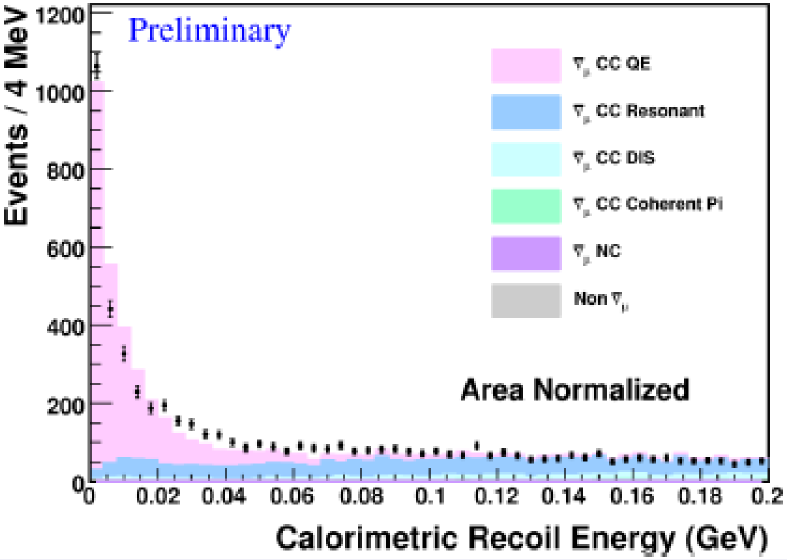
Recoil Selection

- Look at energy in the detector, outside of a region very close to the track (5cm)
  - Reduces contribution from δ-rays
- Form a calorimetric energy sum
- As expected, elastic events dominate at low recoil

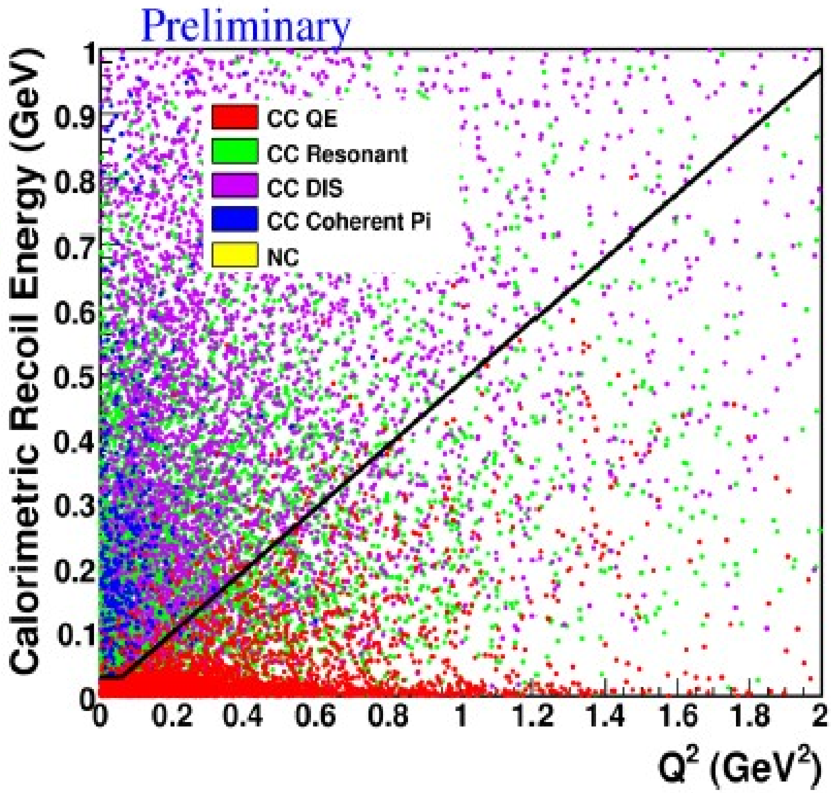




Backup

Recoil vs Q^2

- If the neutron interacts, may still see visible energy, particularly at high Q^2 (neutron energy)
- Our current selection varies with Q^2
- Another option would be to require low recoil, eliminating signal with interacting neutrons



Backup

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