The MINERνA Experiment

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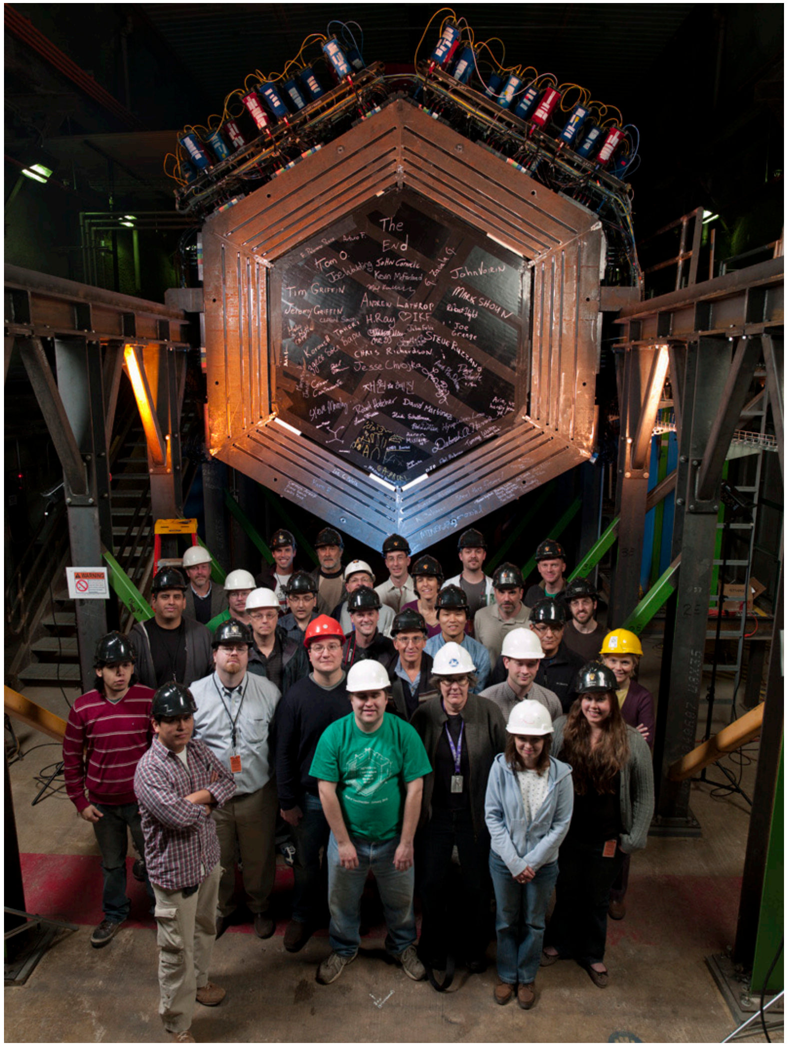
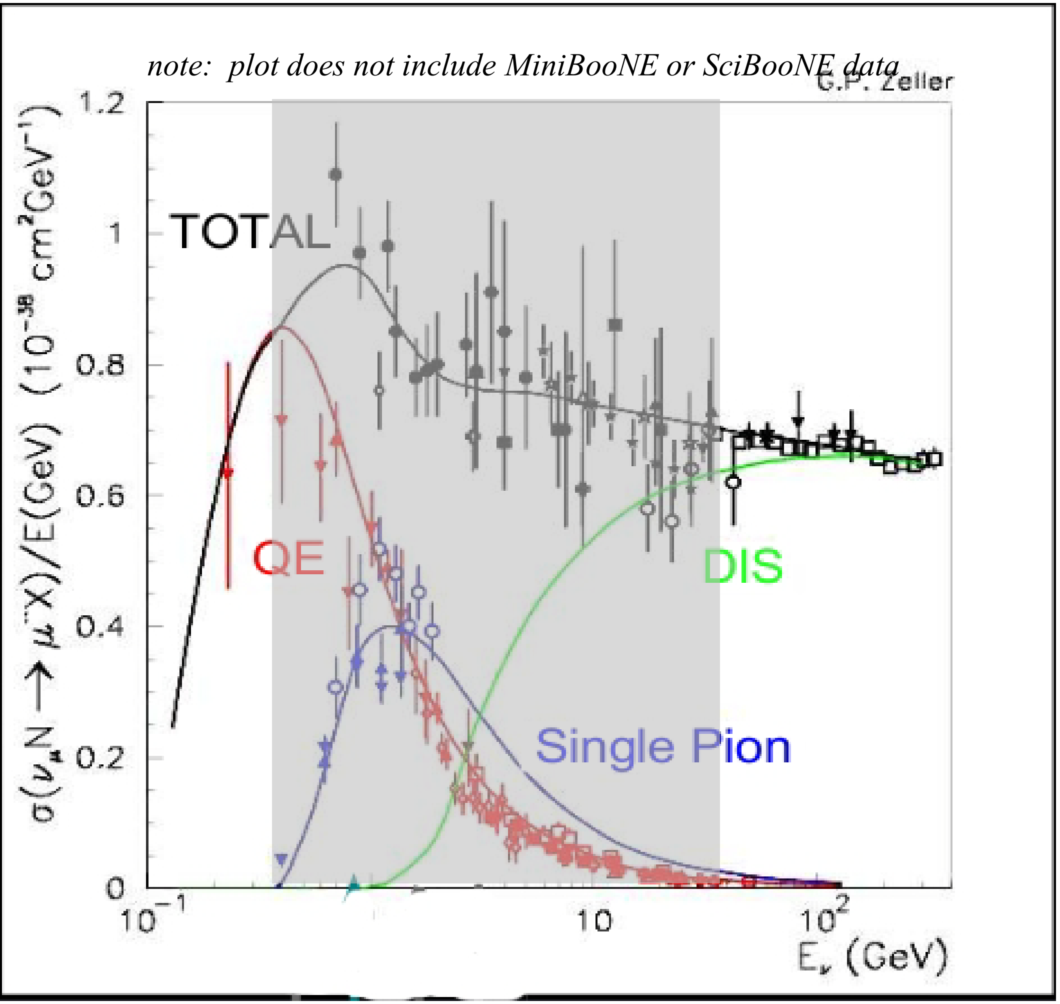
on behalf of the Minerva Collaboration

Outline

- Previous ν Results
- NuMI Beam & measuring the flux
- MINERνA Detector
- MINERνA Event Displays
- Kinematic Distributions
- Summary



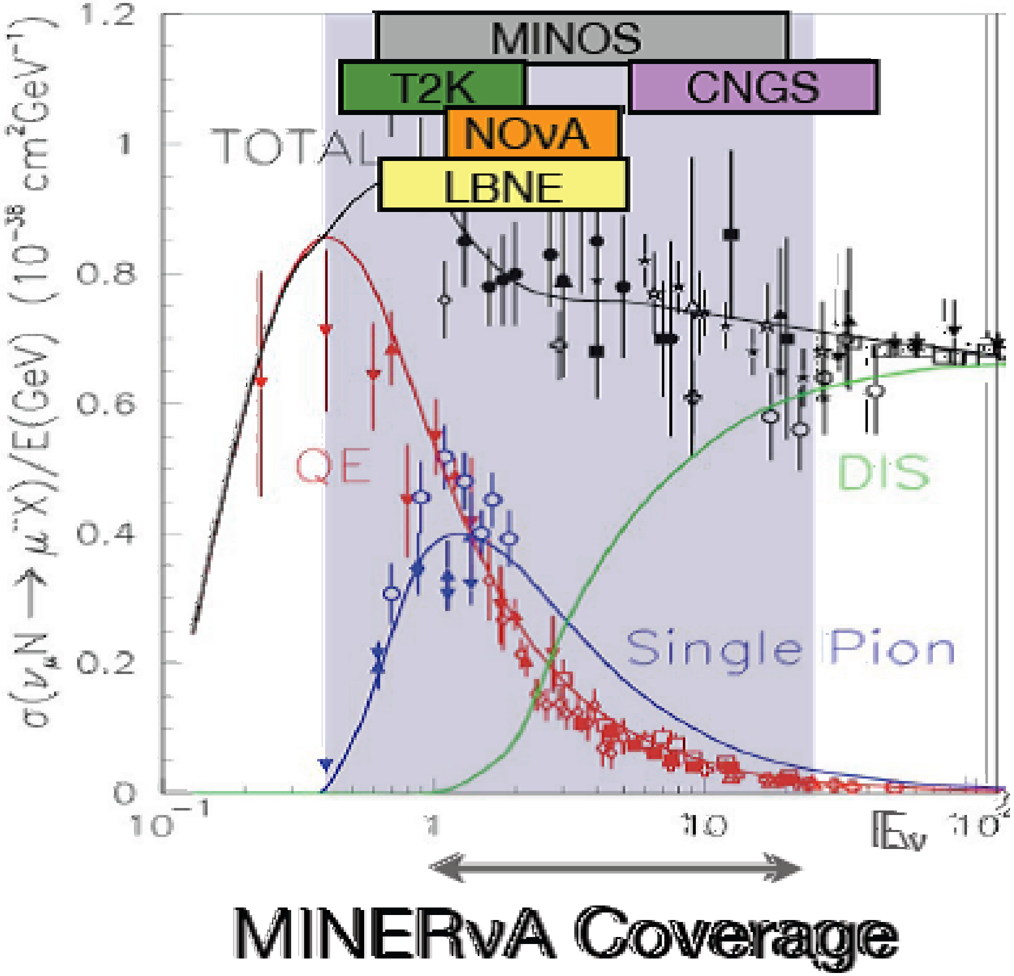
ν interaction physics



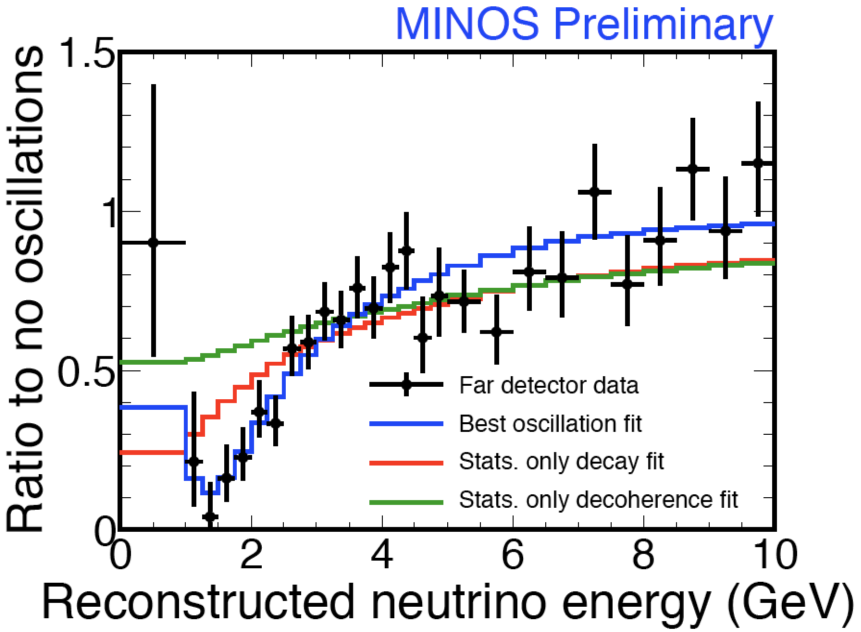
- Past measurements
  - bubble chambers
  - wide band neutrino beams at low energy
  - NBB for >20 GeV
- Limitations on measurement accuracies
  - low statistics samples
  - significant uncertainty on flux in wide band neutrino beams
- In many cases the nuclear physics effects not well-understood

ν interaction physics

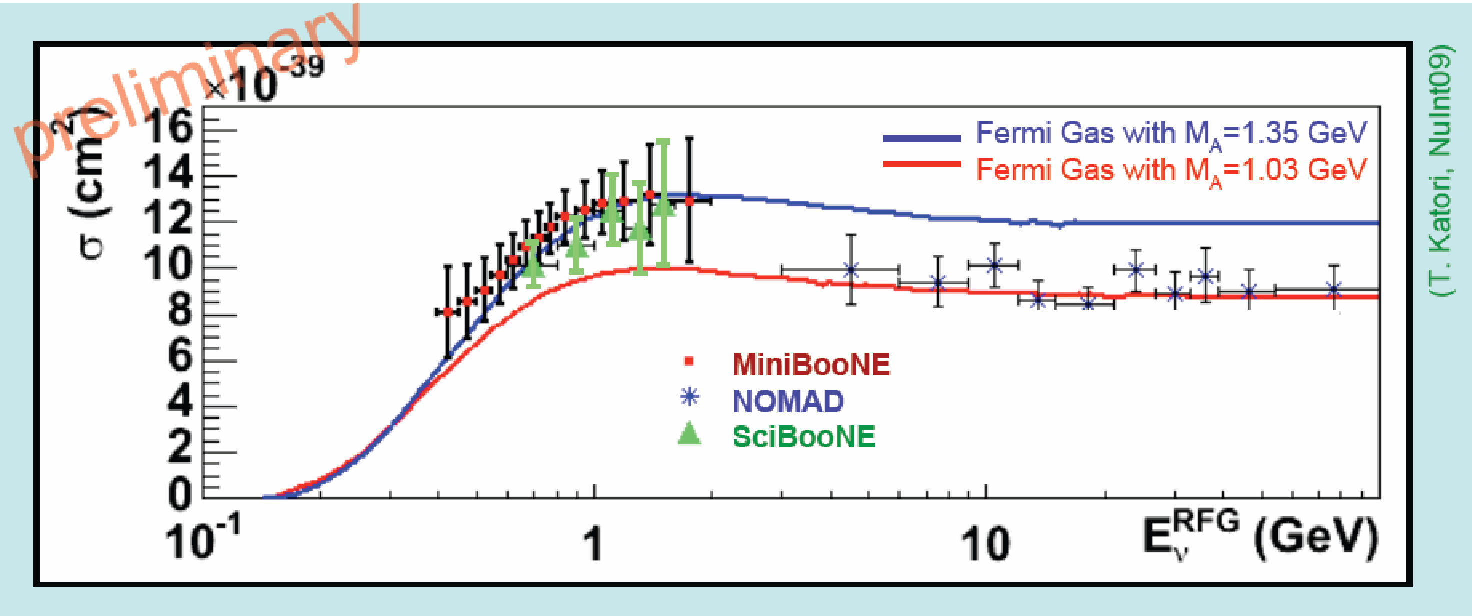
note: plot does not include MiniBooNE or SciBooNE data



- Renewed interest for En reconstruction in oscillation experiments
  - calorimetric exp’ts
  - Water Cherenkov QEL



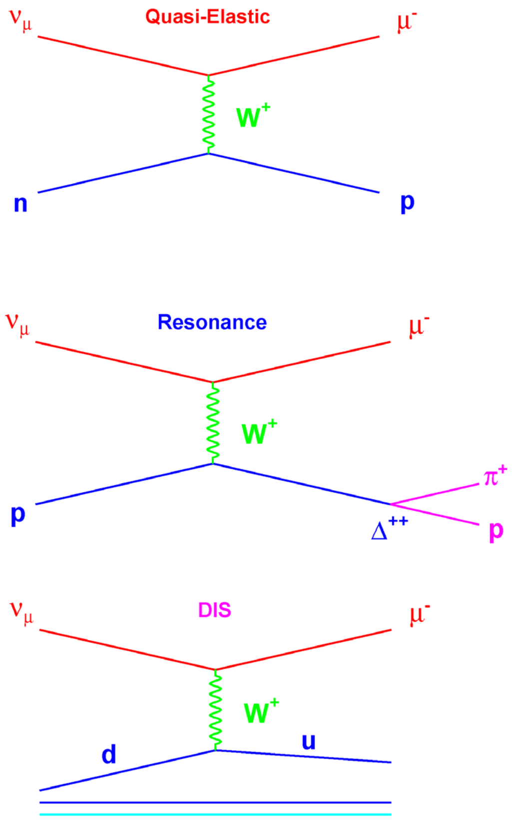
New Data, Still Inconsistent



- New Data
- Clear inconsistency between MiniBooNE/SciBooNE and NOMAD results

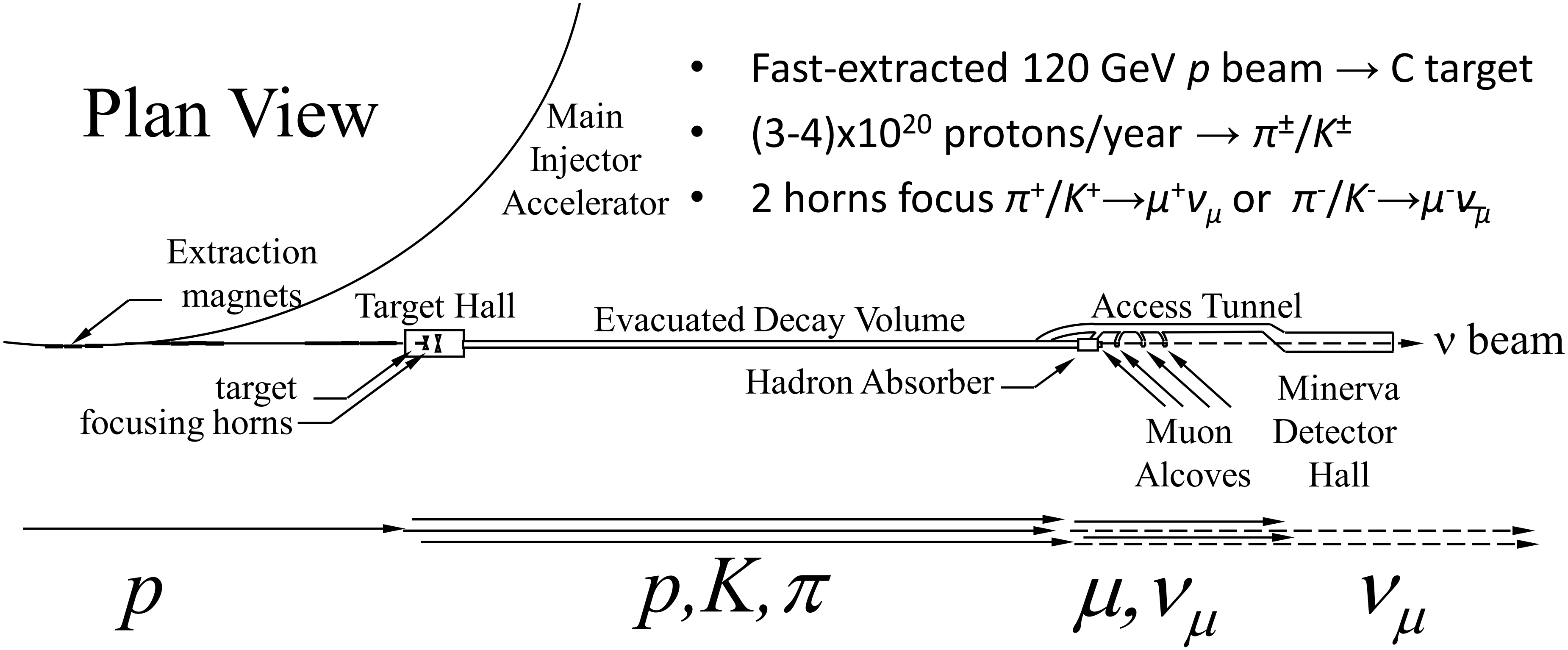
MINERνA

- Precision measurement of cross sections in the 1-10 Gev region
  - – Understand the various components of cross section both CC and NC
    - CC & NC quasi-elastic
    - Resonance production, $\Delta(1232)$
    - Resonance↔deep inelastic scatter, (quark-hadron duality)
    - Deep Inelastic Scattering
- Study A dependence of ν interactions in a wide range of nuclei



NuMI Beamline

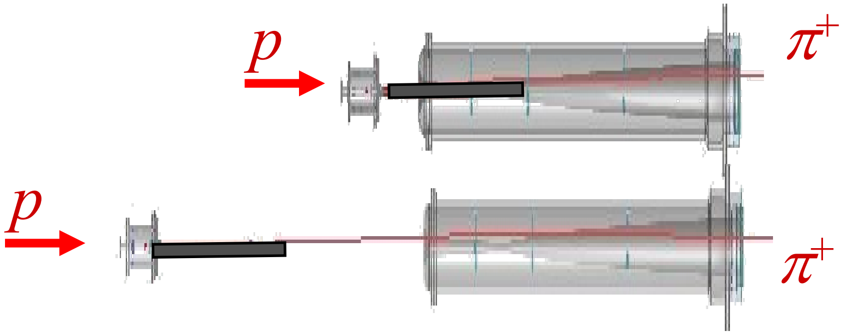
- Fast-extracted 120 GeV p beam → C target
- (3-4)x10^{20} protons/year → $\pi^{\pm}/K^{\pm}$
- 2 horns focus $\pi^{+}/K^{+} \rightarrow \mu^{+}\nu_{\mu}$ or $\pi^{-}/K^{-} \rightarrow \mu^{-}\nu_{\mu}$

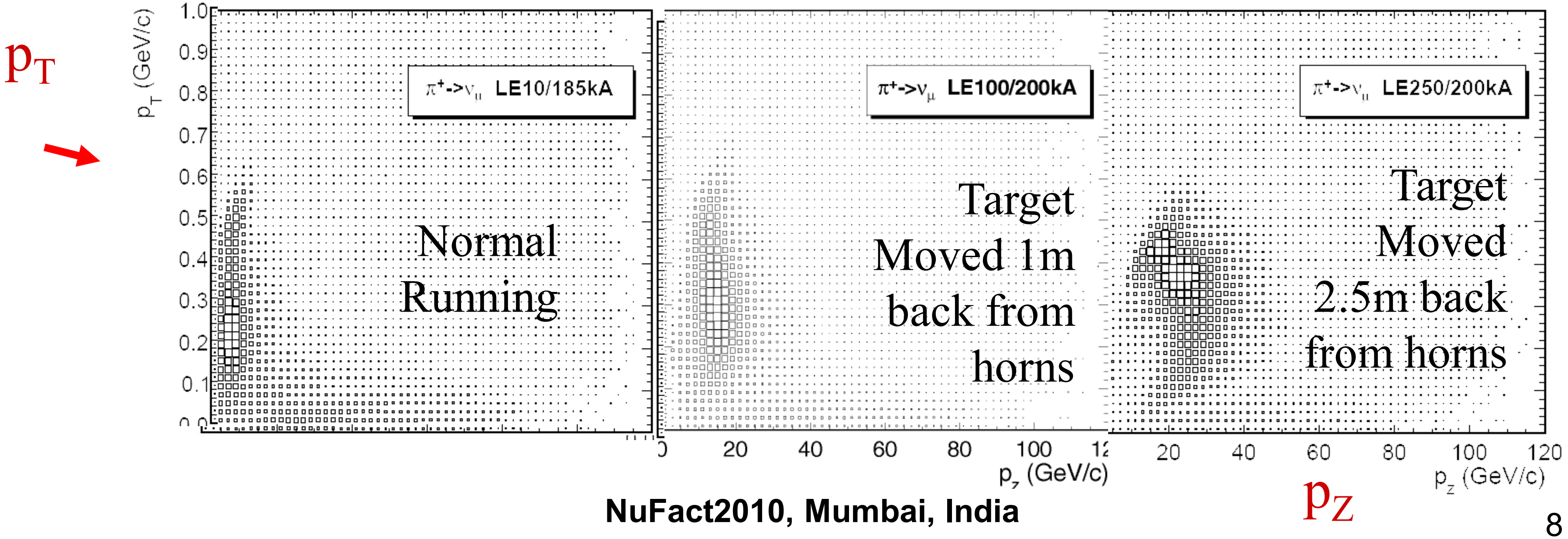


- Absorber stops hadrons not μ
- μ absorbed by rock, ν → detector
- Extensive instrumentation to monitor p, hadron, muon beams

NuMI Variable Energy Beam

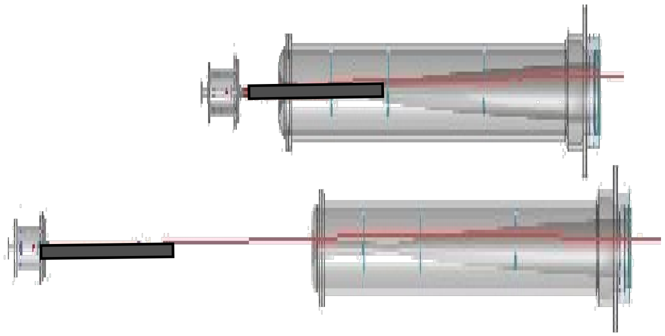
- NuMI target mounted on a rail drive for remote positioning
- Provides *in situ* method to measure flux
- Vary (p_z ,p_T) of π^+ contributing to ν flux.
  - Horn current (p_T kick supplied to π's)
  - Target Position (p_z of focused particles)

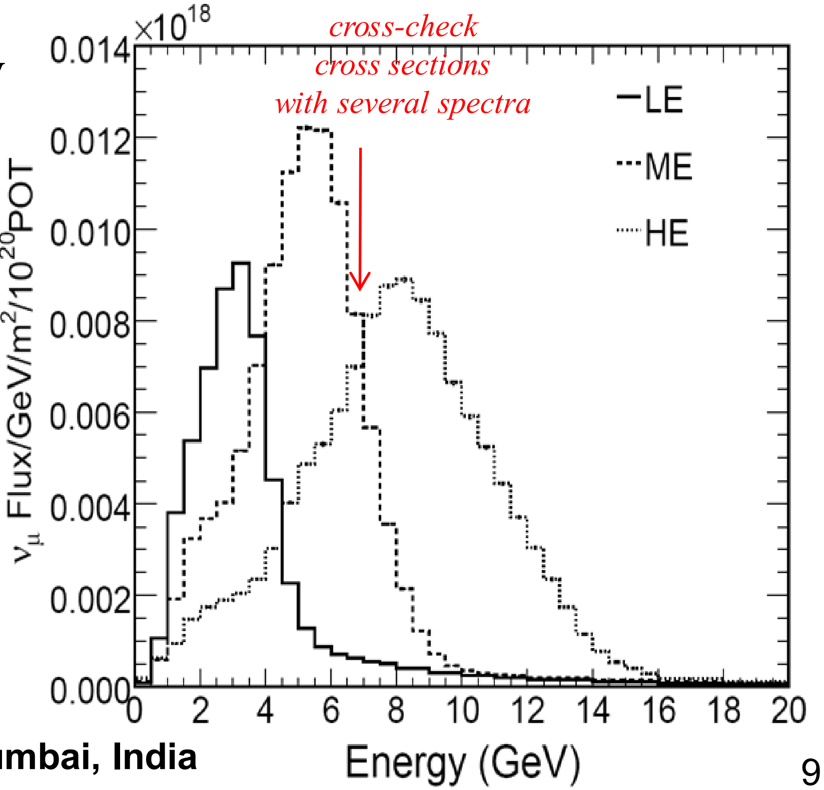




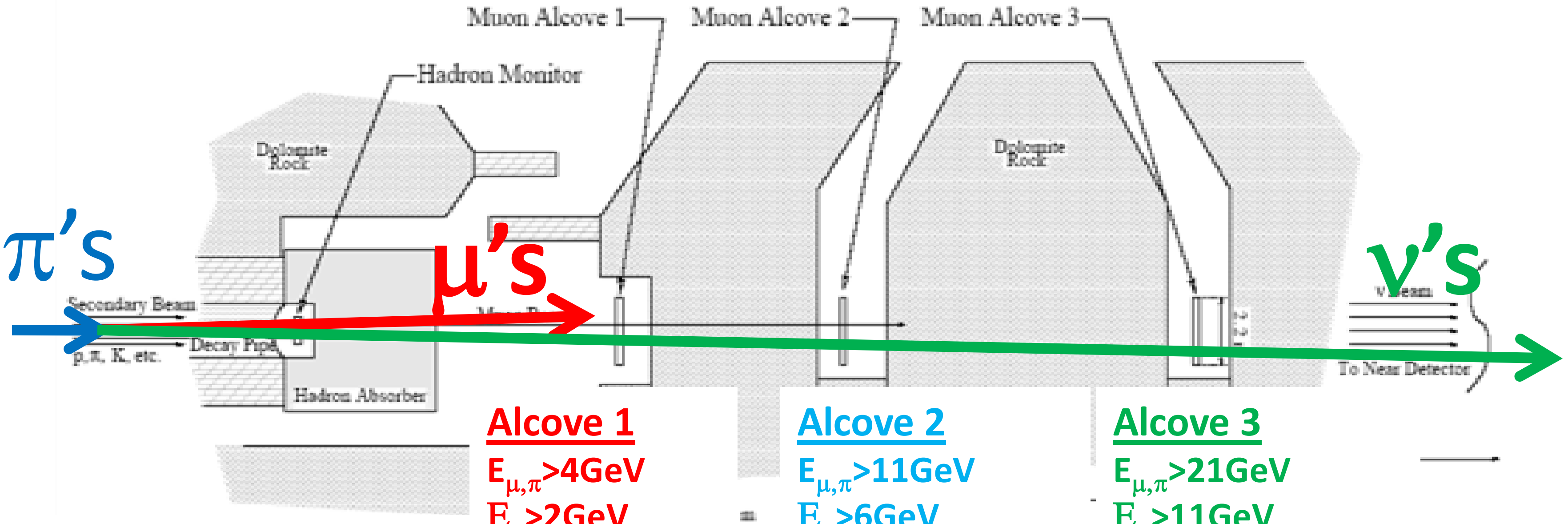
In Situ Flux Measurement

- 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 E_ν using several beam configurations
- Measure event spectrum with QEL's
- Normalize to NBB (CCFR) at high energy
- Goal is 7% error flux shape, 10% norm





Absolute Flux with μ Monitors



Alcove 1

$E_{\mu,\pi}$>4GeV

E_{ν}>2GeV

Alcove 2

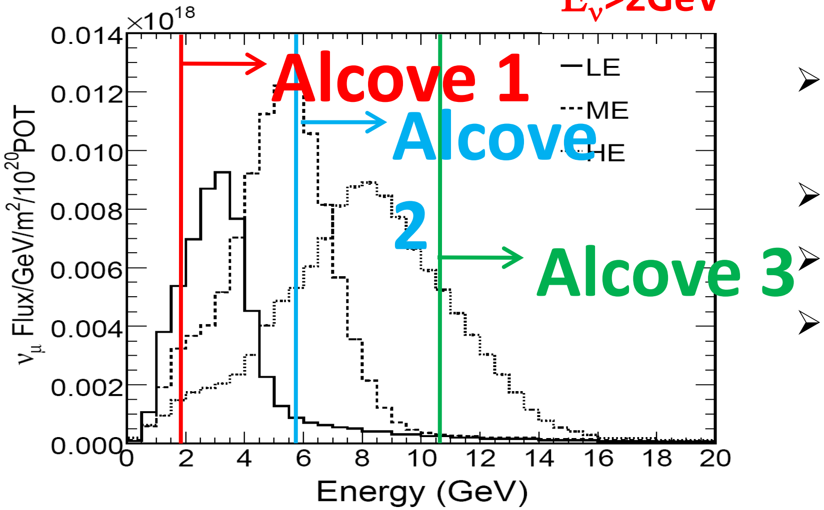
$E_{\mu,\pi}$>11GeV

E_{ν}>6GeV

Alcove 3

$E_{\mu,\pi}$>21GeV

E_{ν}>11GeV

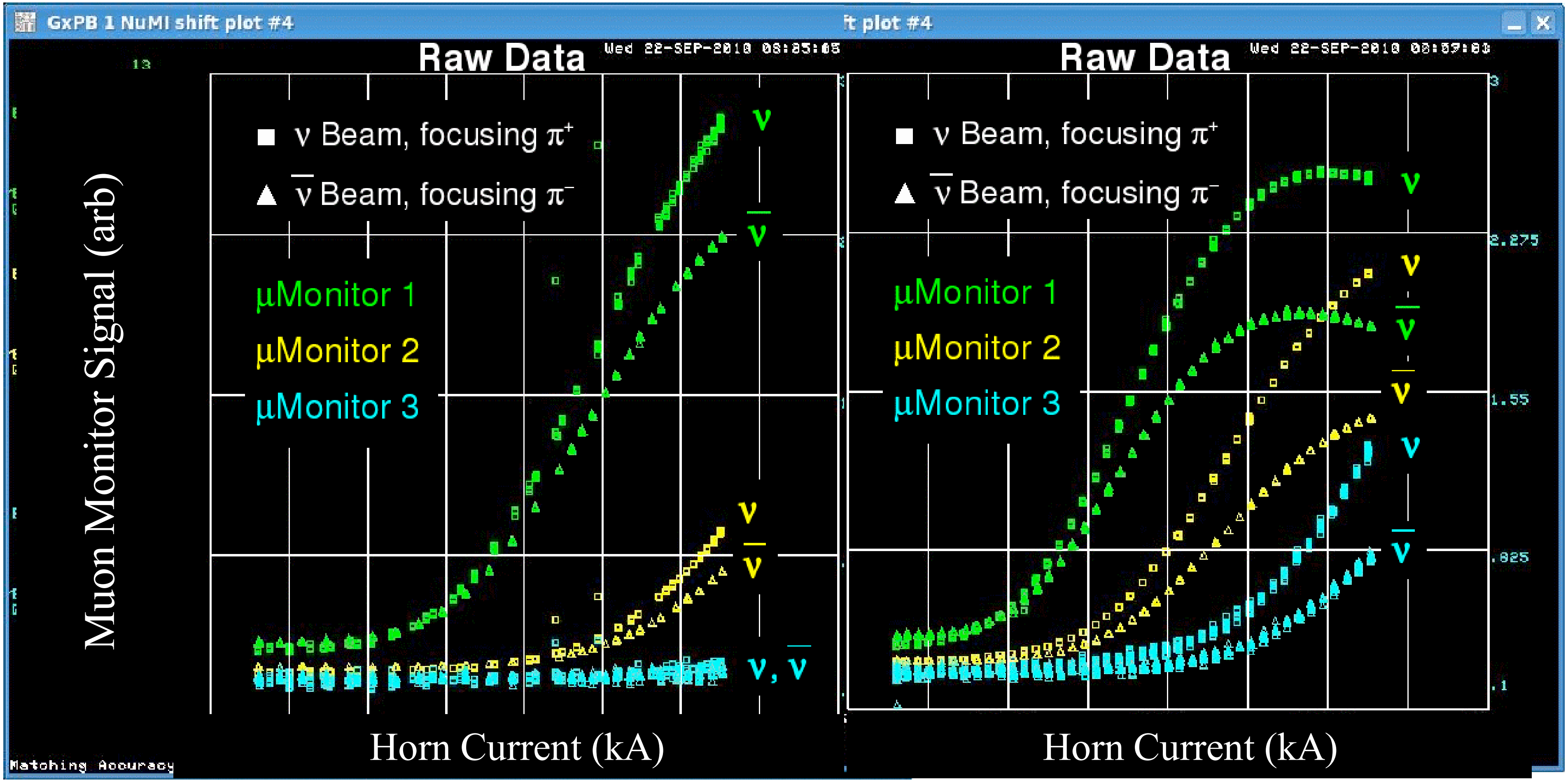


- Sampling μ flux = Sampling hadrons off target = Sampling ν flux.
- Sample different energy regions of the flux.
- Several beam settings → differential flux
- Goal of μ monitors is to understand flux shape and normalization to 10%

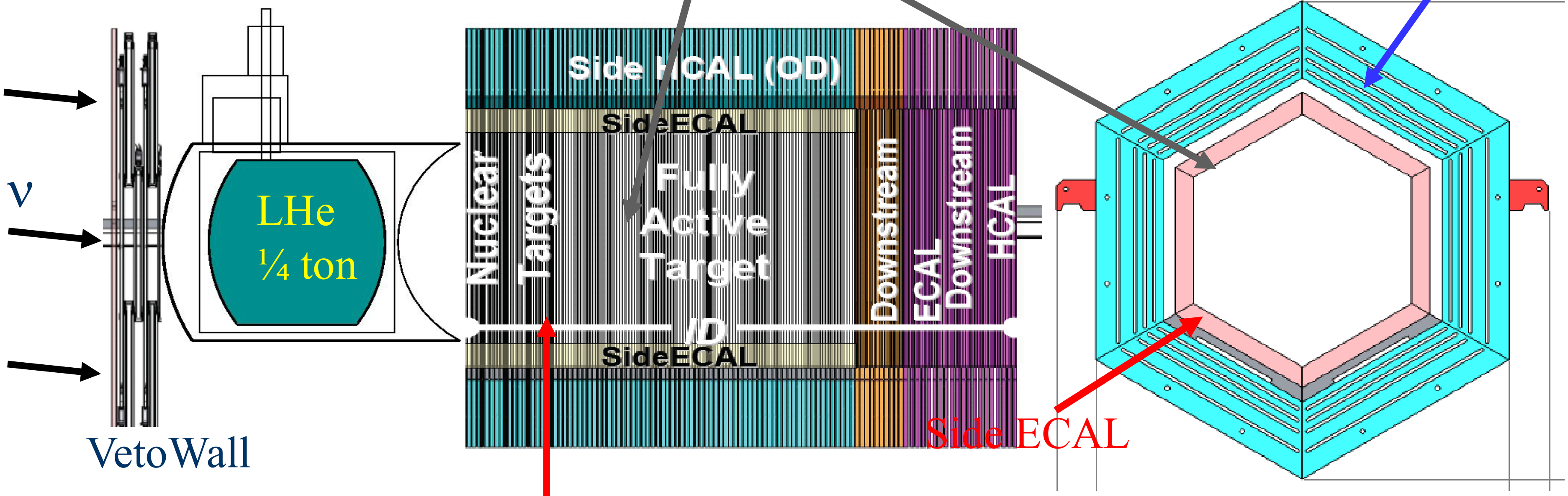
Early Data from μ Monitors

Target 100cm upstream of horn

Target 250cm upstream of horn



MINERνA Detector

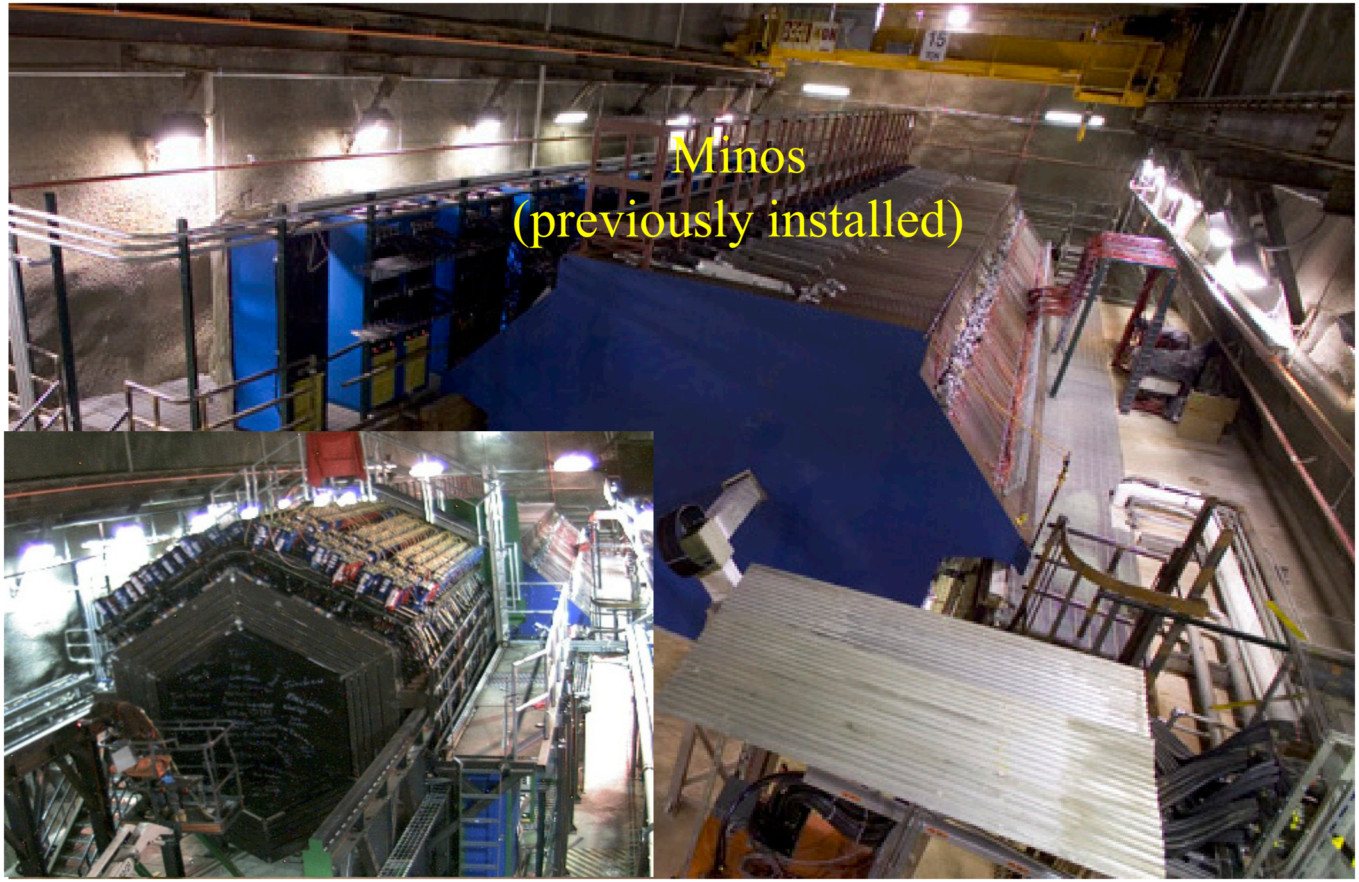


Fully Active Fine Segmented Scintillator Target
8.3 tons, 3 tons fiducial

Nuclear Targets with Pb, Fe, C, H_2O,CH
In same experiment reduces systematic errors between nuclei

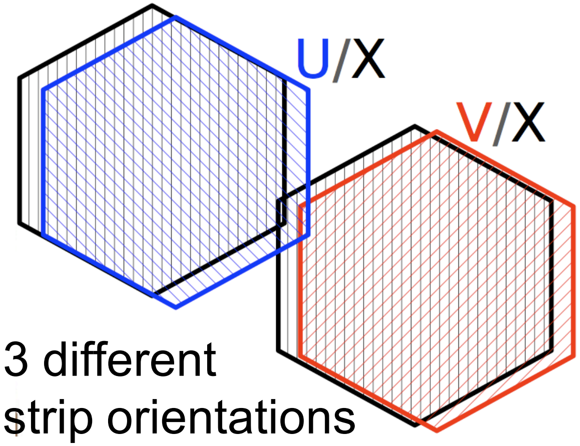
- Made of 120 planar “modules”.
  - Total Mass: 200 tons
  - Total channels: ~32K

MINERνA μ Spectrometer

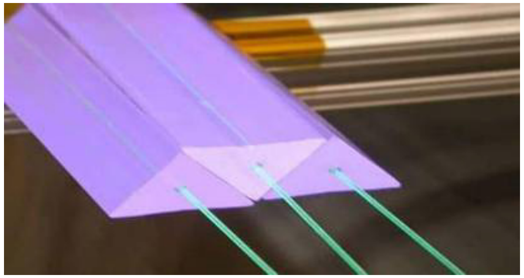


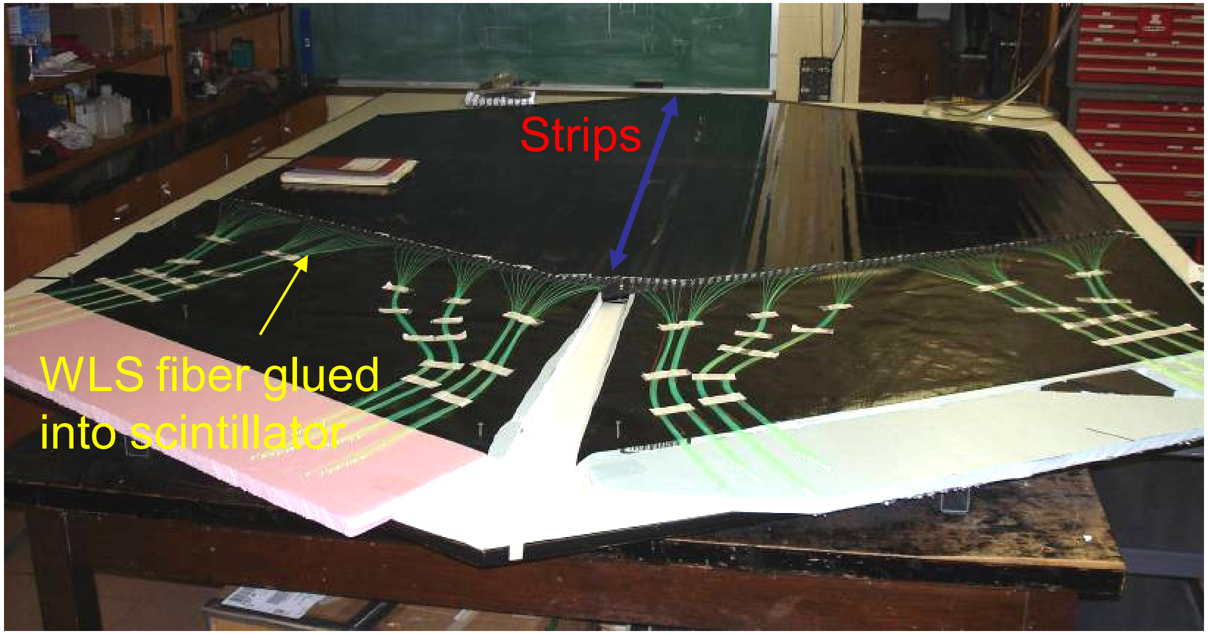
The MINOS Near Detector is MINERνA μ Spectrometer

Tracking Scintillator Planes



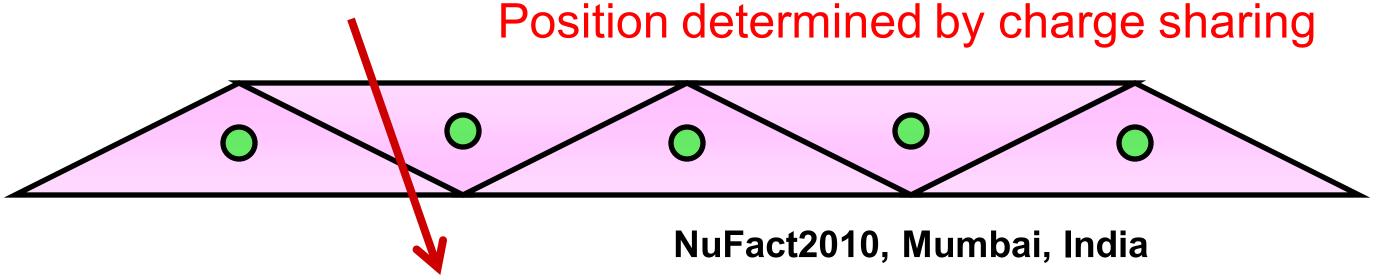
3 different strip orientations





Particle

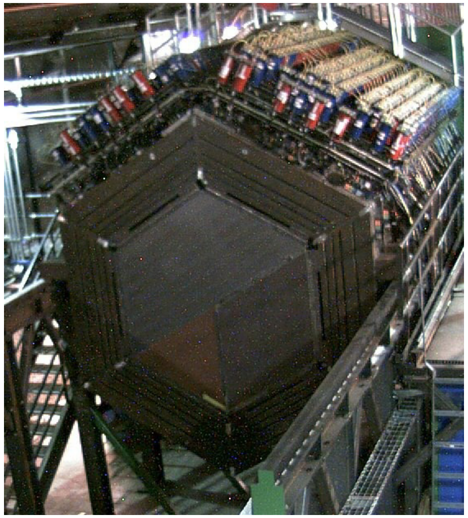
Position determined by charge sharing



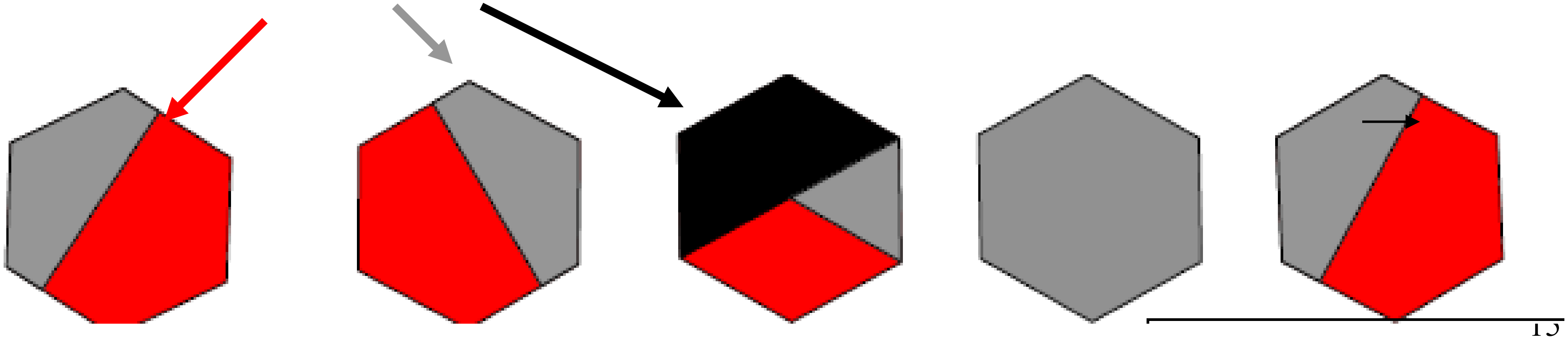
Fibers mirrored on far end. Near end terminated in optical connector, polished, and light-tightened.

Broad Range of Nuclear Targets

- 5 nuclear targets + water target
- Helium target upstream of detector
- Near million-event samples (4×10^{20} POT LE beam + 12×10^{20} POT ME beam



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

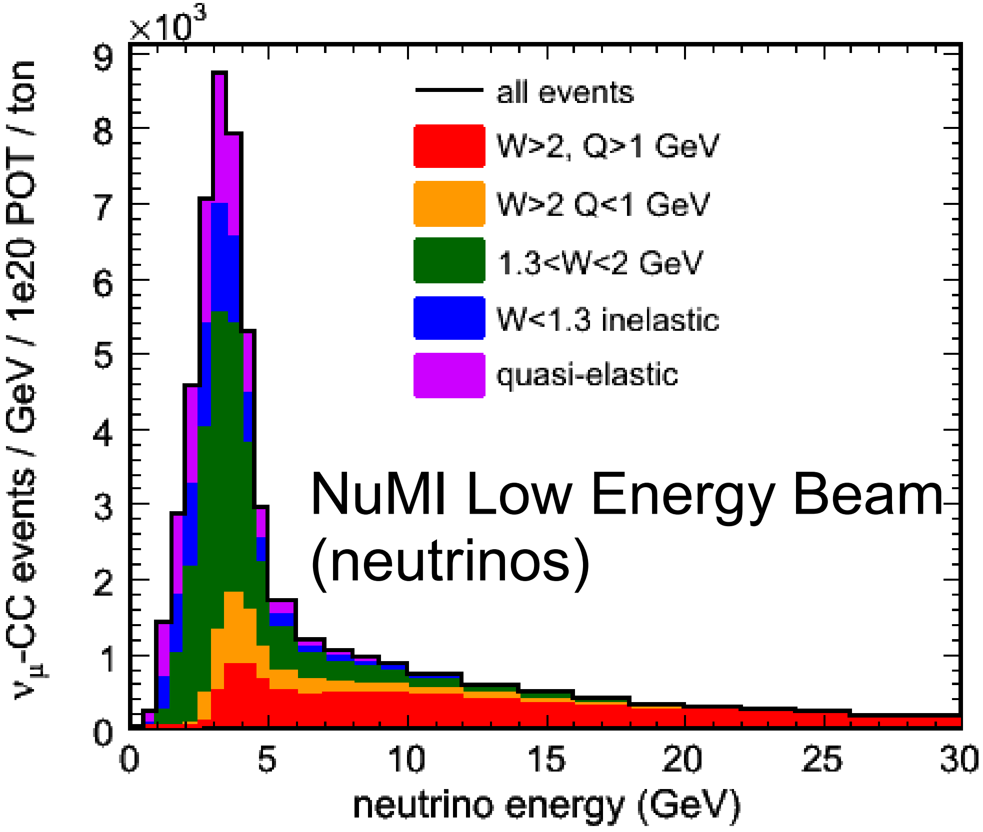


5 Nuclear Targets: Fe Pb C

Charged Current Sample

- Current run plan
  4 × 10^{20} POT LE beam
  (10^{20} POT accum. so far)
  12 × 10^{20} POT ME beam
  0.9 × 10^{20} POT special runs
- Yield: ~14M CC events
  - 9M in scintillator

Quasi-elastic	**0.8 M**
Resonance production	**1.7 M**
Resonance to DIS transition region	**2.1 M**
DIS Low Q^2 region and structure functions	**4.3 M**

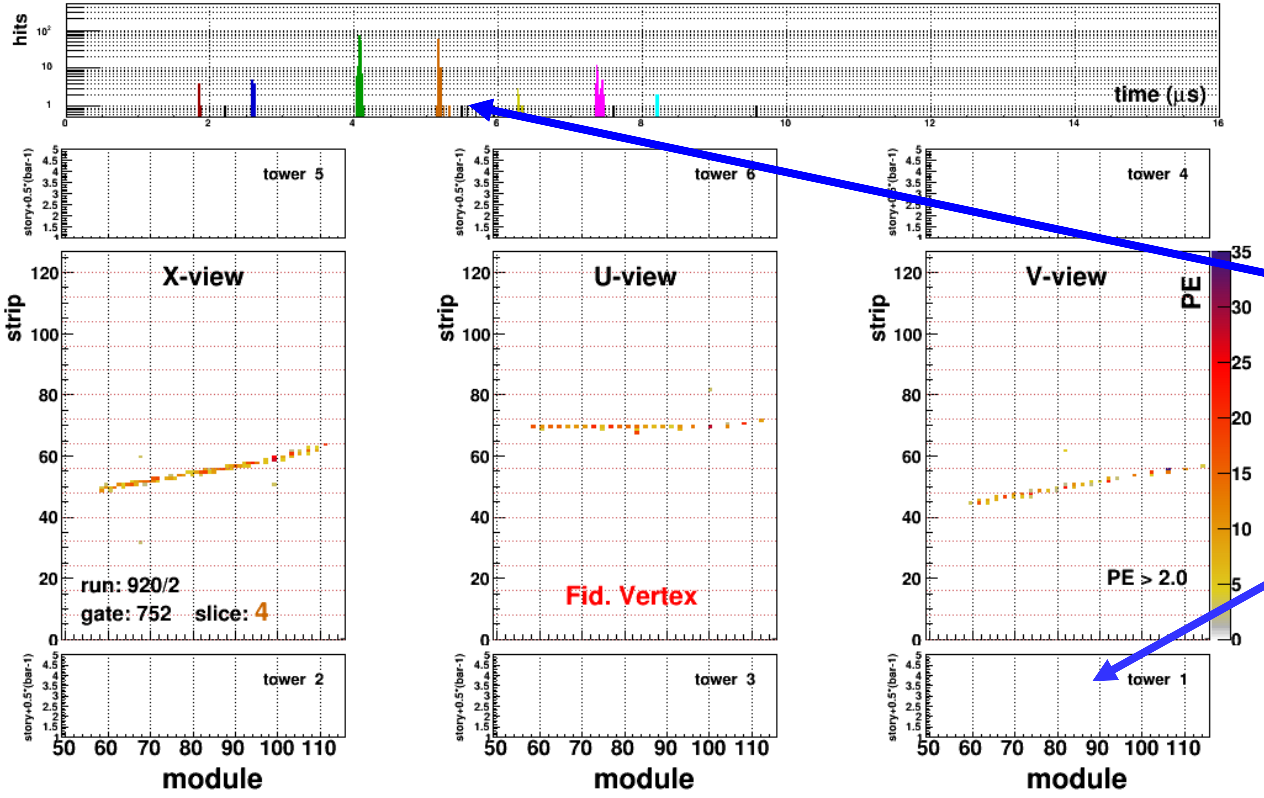


Coherent Pion Production	**CC 89k, NC 44k**
charm / strange production	**230 k**

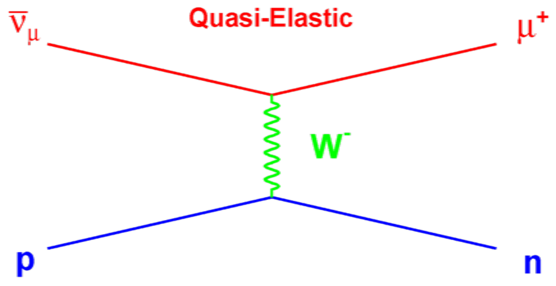
MINERvA Run Plan: History and Summary

- Low Energy Anti-neutrino beam: 11/2009 – 3/2010
  - 55% of detector commissioned by 11/09
  - Installation of remaining 45%
  - Accumulated ~0.8×10^{20} protons on target
- Low Energy Neutrino Beam: 3/2010 – 3/2012
  - 4×10^{20} protons on target in “standard” ν beam
  - 0.9×10^{20} in special runs to understand ν flux
- Fermilab accelerator shutdown, switch to Medium Energy Beam configuration: 3/2012—2/2013
- Medium Energy Neutrino beam with NOvA after 2/2013
  - 12×10^{20} protons on target in neutrino mode
  - Would be interested in antineutrinos too, of course

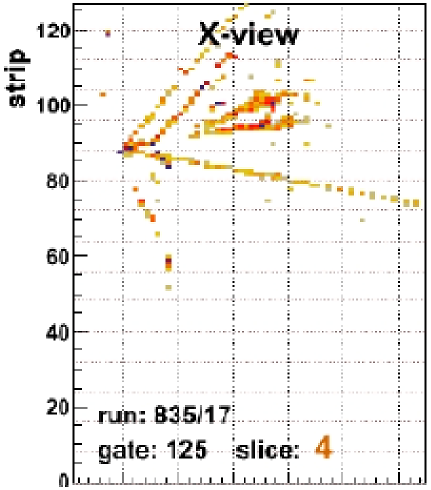
MINERνA Events in $\bar{\nu}$ Beam



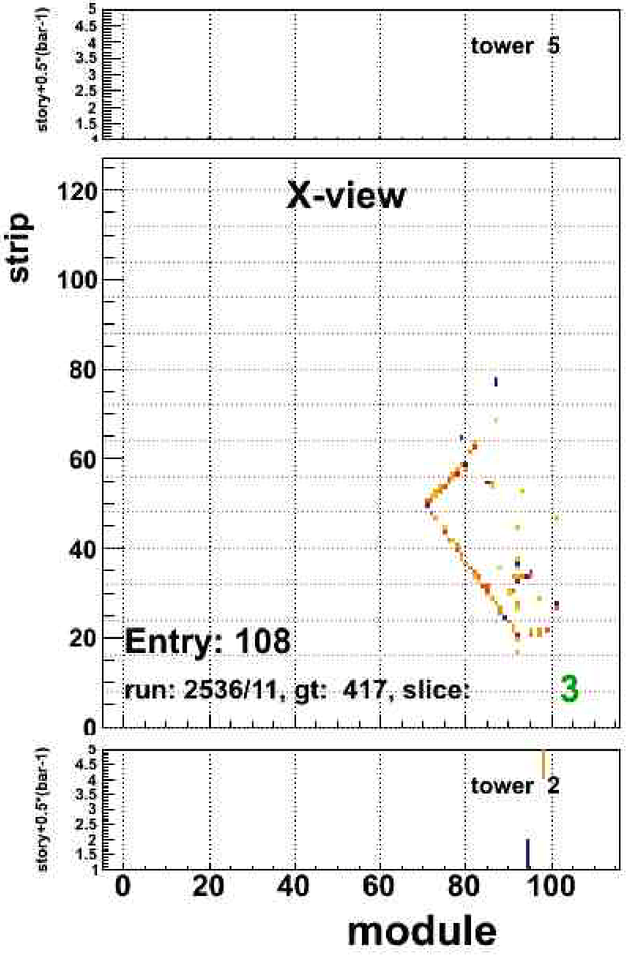
- CCQE anti-event
  - Information buffered in the ν spill and read out at end of spill
  - Timing for different slices (events)
  - 4th slice
  - 3 view, x (top), & V
  - Outer calorimeter
- X view of other events



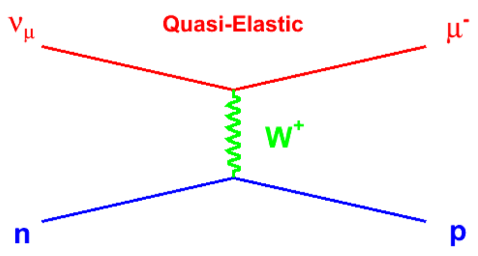
Event with π^0



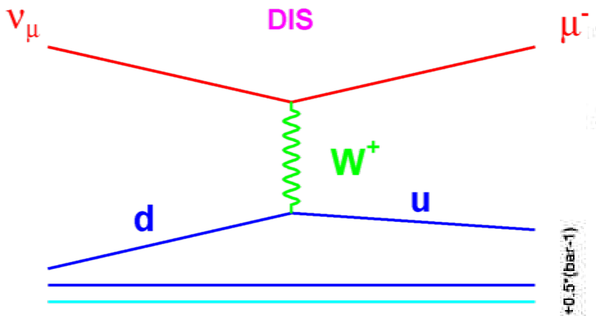
MINERνA Events in ν Beam

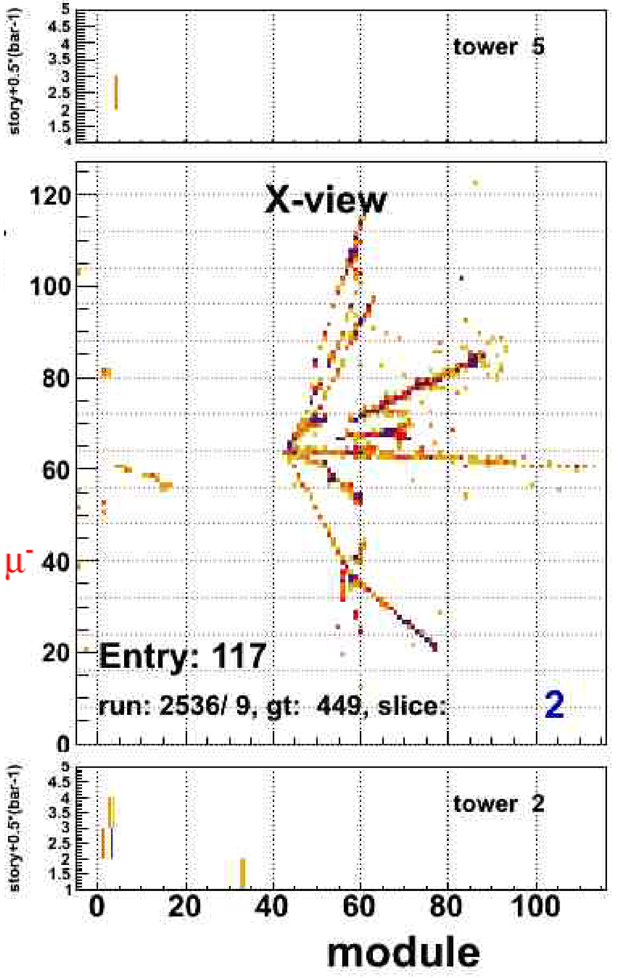


From



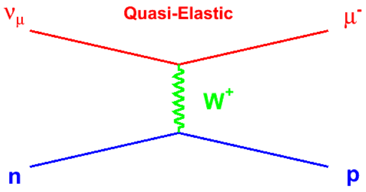
to

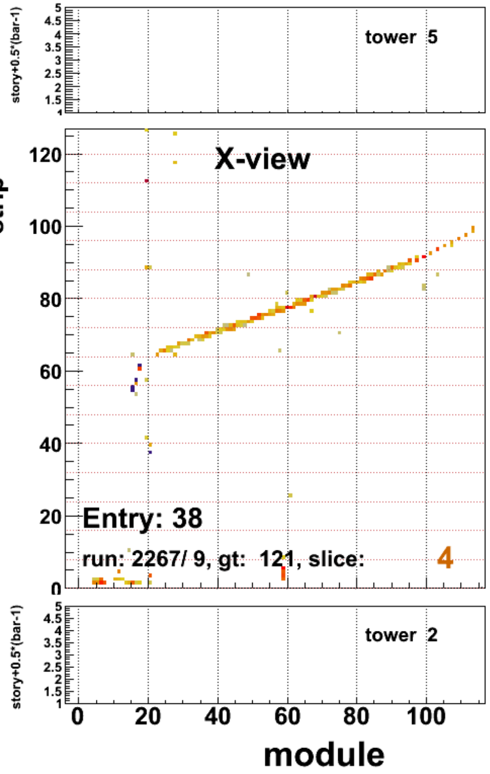


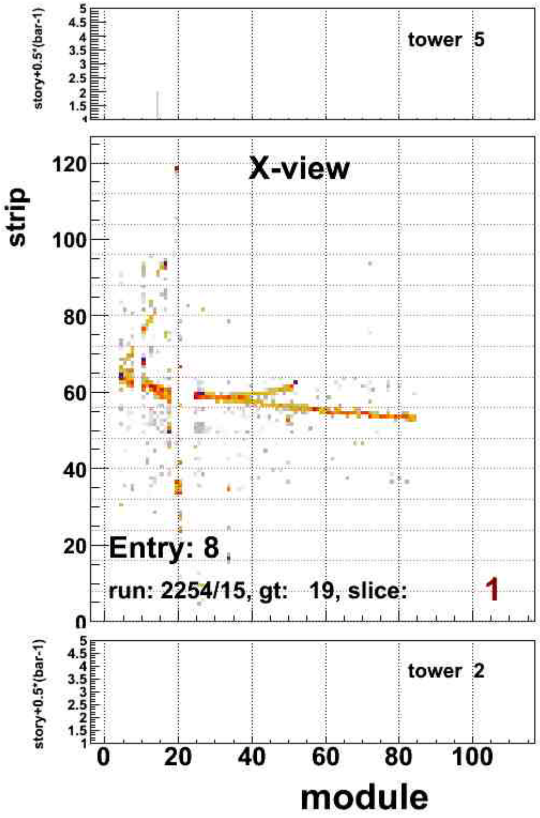


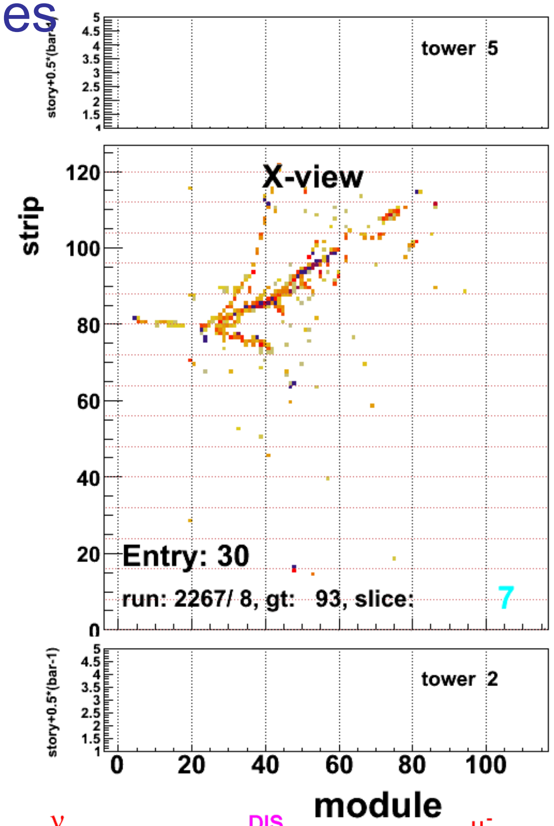
Candidate Nuclear Target Events

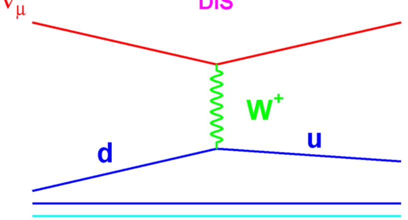
- Upstream region of detector has 5 different planes of nuclear targets and gap for water target, separated by 4 modules



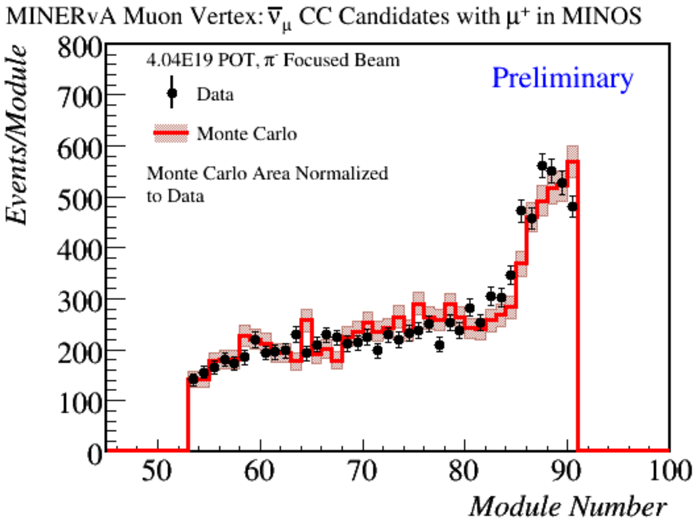


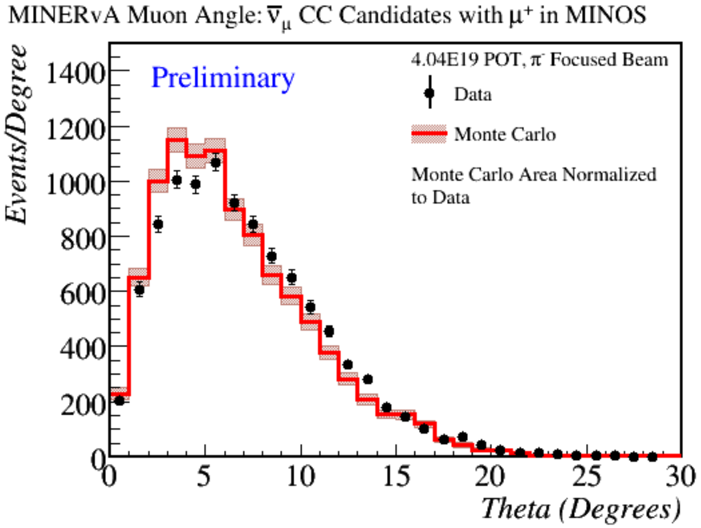




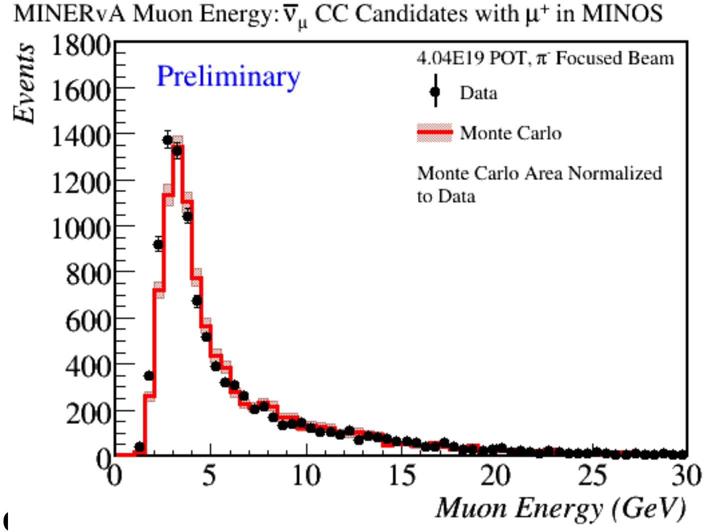


$\bar{\nu}$ Beam Data

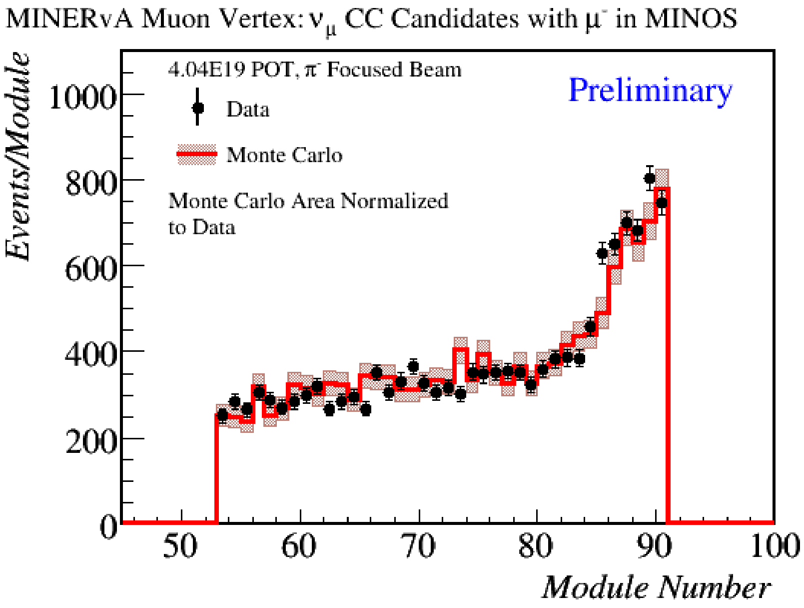


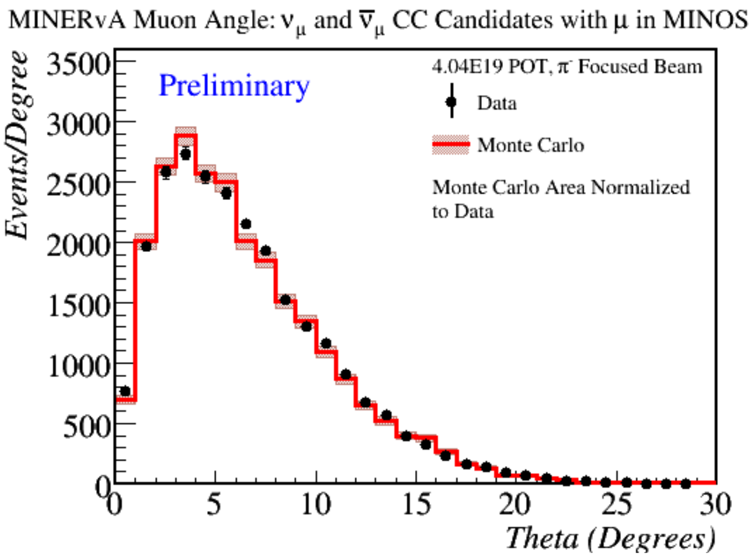


- 4.04 × 10^{19} POT in anti-ν mode
- MC generator GENIE v 2.6.0
  - GEANT4 detector simulation
  - 2 × 10^{19} POT MC , LE Beam MC anti-ν flux, untuned
  - Area normalized
- Require reconstructed muon in MINOS

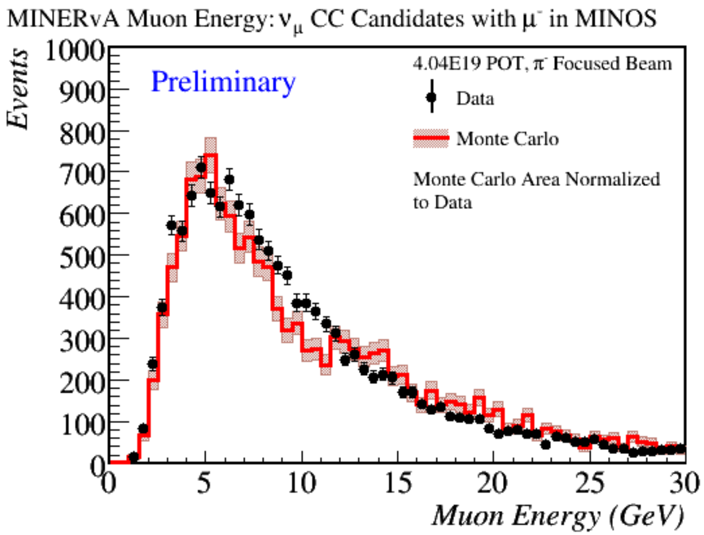


ν Data in $\bar{\nu}$ Beam


MINERvA Muon Vertex: ν_μ CC Candidates with μ^- in MINOS


MINERvA Muon Angle: ν_μ and $\bar{\nu}_\mu$ CC Candidates with μ in MINOS

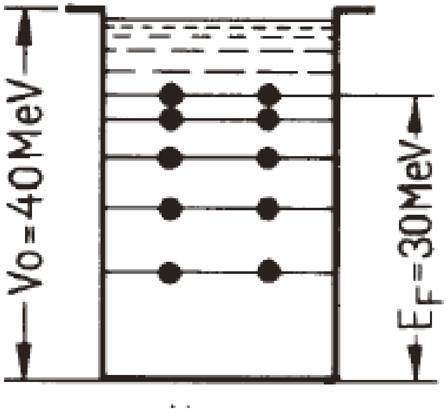
- ν Distributions same conditions as before
- Very good agreement between Data and MC


MINERvA Muon Energy: ν_μ CC Candidates with μ^- in MINOS

Summary

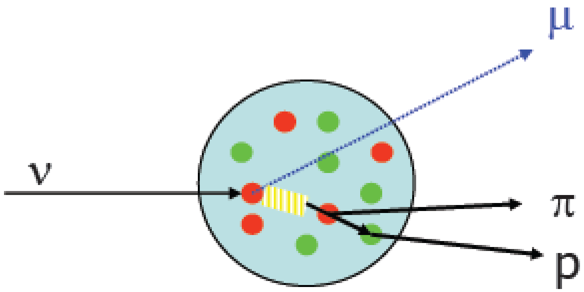
- The high statistics MINERνA is on the air !
  - Have ~25% of the needed Low Energy beam so far
- Using various techniques to understand the ν flux
  - Have first glance at 2 of 6 special neutrino beam runs
- Precision Measurement of various cross section and support current and future ν experiments
  - QE, Resonance, DIS,
- Detector working very well
- Analysis of data is proceeding
- Expect preliminary results in the near future.
- My gratitude to colleagues H.Budd, E.Christy, G.Perdue, R.Ransome, from whose slides I've drawn.

Nuclear Effects, FGM & FSI

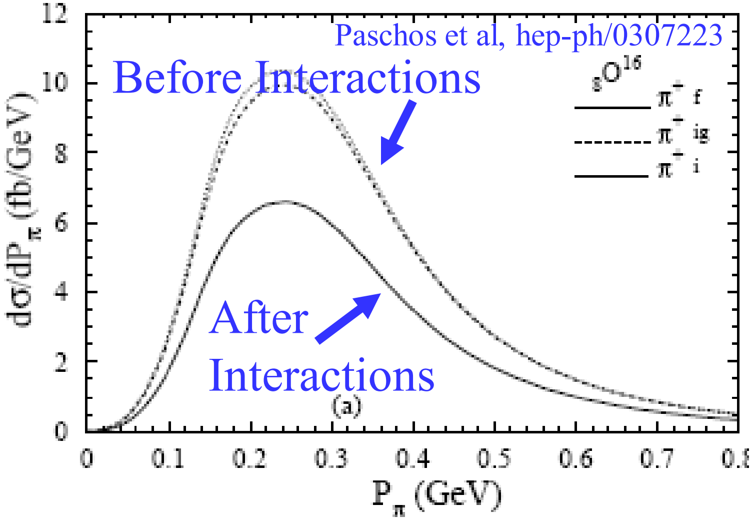


- Fermi gas model, nucleons obey Pauli exclusion principle
  - –Nucleons fill up states to some Fermi momentum
  - –Maximum momentum $k_F \sim 235$ MeV/c
- •Nuclear binding, additional binding energy which in simple models is treated as a constant.
- •Pauli blocking for nucleons not escaping nucleus, as states are already filled with identical nucleons

- Rescattering/Absorb in nuclear media
  - –Resonance →QE, π is lost
  - –Kinematics of event are modified



Resonance production in Oxygen


Paschos et al, hep-ph/0307223

Before Interactions

After Interactions

NuFact2010, Mumbai, India