CC Inclusive Pion Production in MINERνA

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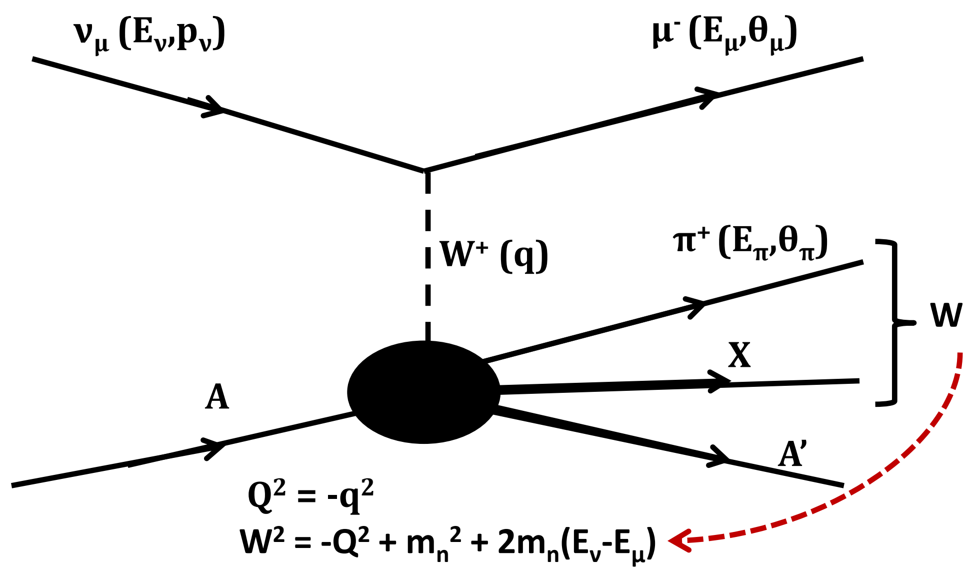
On behalf of the MINERνA collaboration

NuInt 2012

CC Inclusive Pion Production

$\nu_\mu A \rightarrow \mu^- \pi^\pm X A'$

$\bar{\nu}_\mu A \rightarrow \mu^+ \pi^\pm X A'$



• A' is the outgoing nucleus and X represents any other particles in the final state, perhaps even other pions

•Pion must exit nucleus and is not necessarily created at interaction point; nuclear final state interactions (FSI) are folded into the channel definition

•Inclusive final state reduces model dependence in measurement, providing strong constraints on neutrino event generators and theoretical calculations

MINERνA Inclusive Pion Goals

•MINERνA's multiple nuclear targets allow us to measure A-dependence of neutrino pion production.

•Data collected in neutrino and antineutrino beam configurations – comparisons will be interesting.

•Measure single and double-differential cross sections in E_ν, Q^2, KE_μ, θ_μ, KE_π, and θ_π

•Absolute cross sections and ratios with CC-inclusive sample

•Study exclusive final states selected from inclusive sample

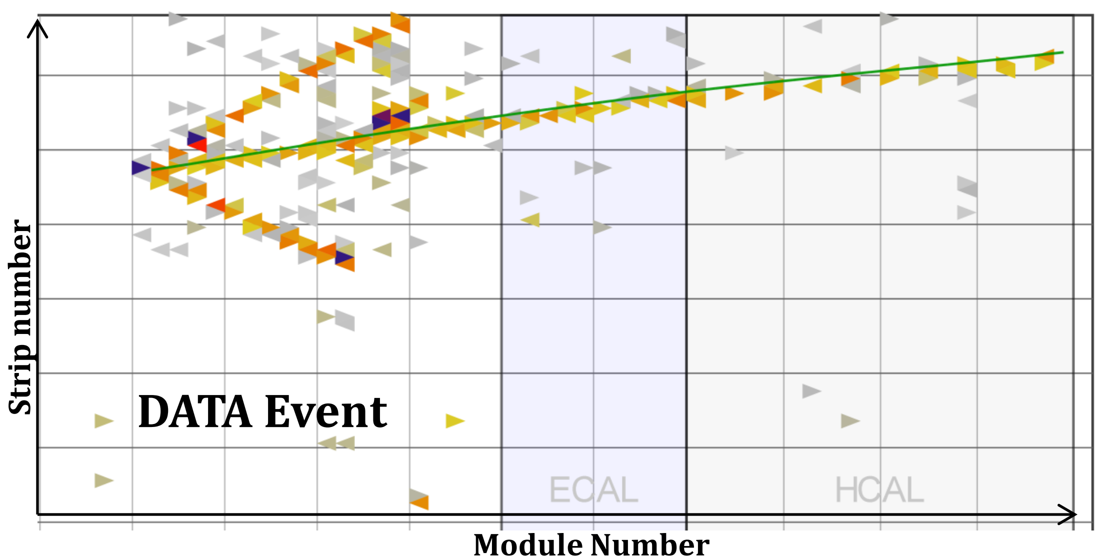
  •e.g., low W resonances to measure resonance form factors and m_A

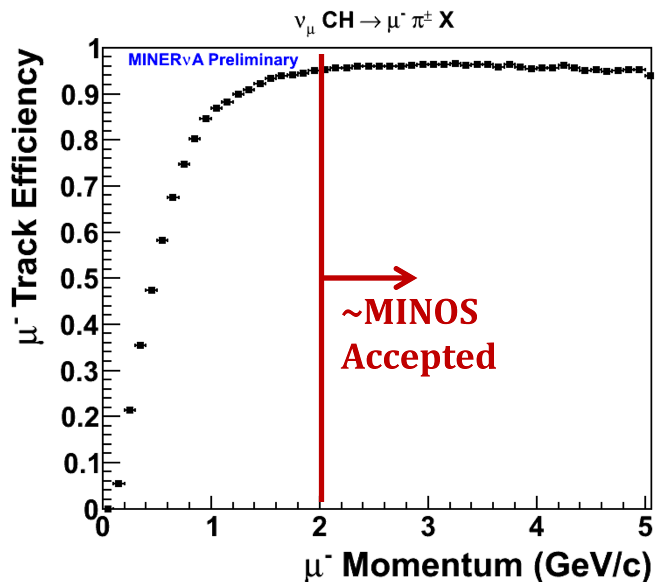
•Today I will show the current status of MINERνA's ν_μ & $\bar{\nu}_\mu$ CC inclusive pion production analyses on scintillator

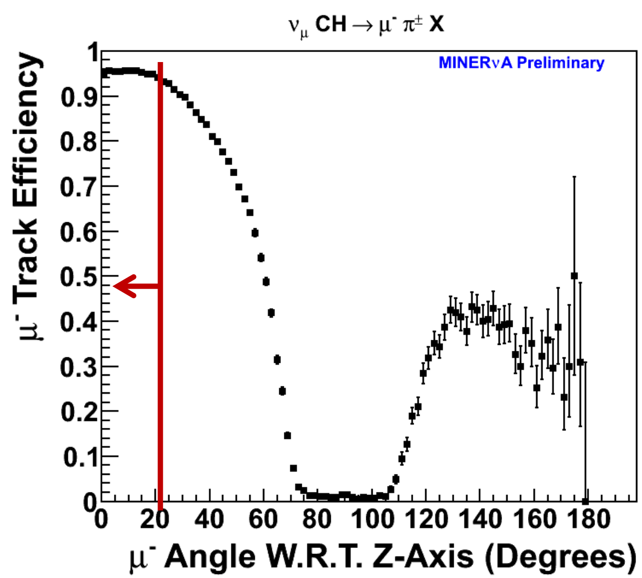
  •Results using ~1/4 ν_μ events and majority of $\bar{\nu}_\mu$ events on tape

Muon Reconstruction

•Both analyses require a reconstructed muon track that matches a track in MINOS with the desired reconstructed charge.





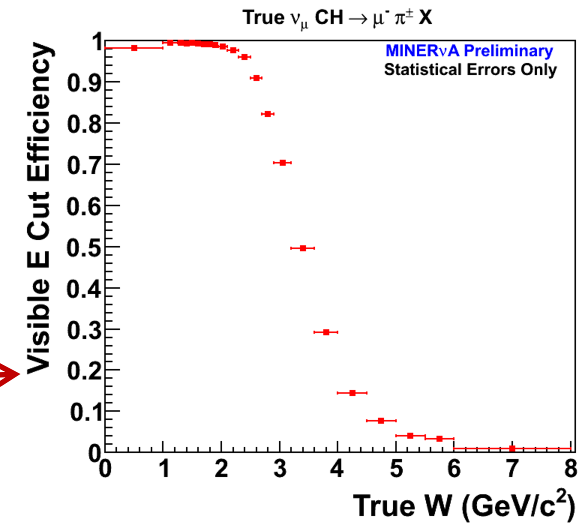


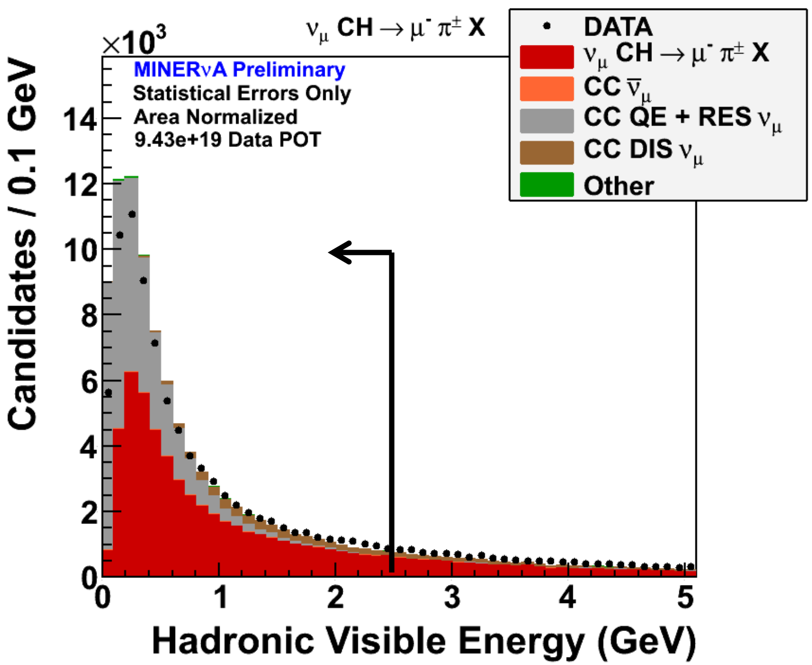
•Additional quality cuts applied to remove muon background (from neutrino interactions outside the detector) that fakes signal due to detector dead time or reconstruction failures

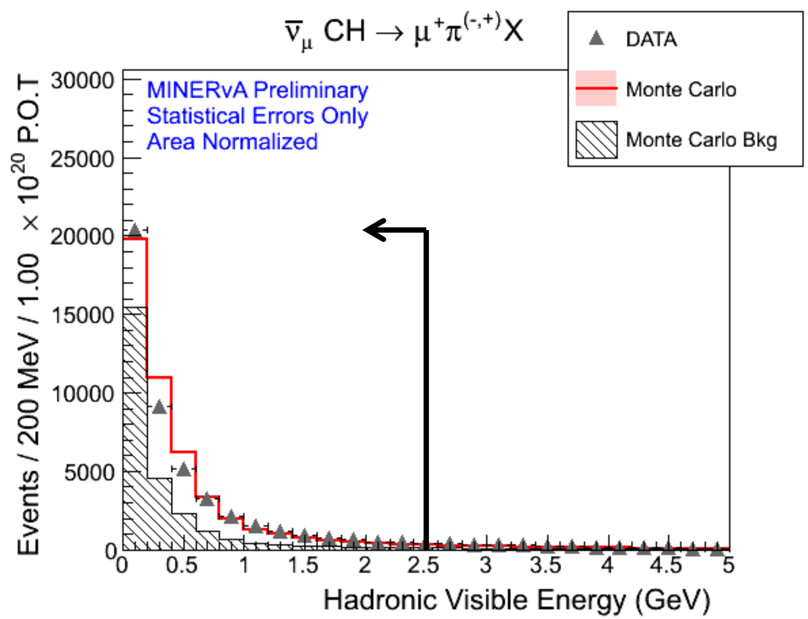
Hadronic Energy Cut

- It is difficult to reconstruct pion tracks in events with large hadronic showers (large W).

- Both analyses select events that likely contain a trackable pion by cutting on total visible hadronic energy.
  - This is effectively a cut on W.





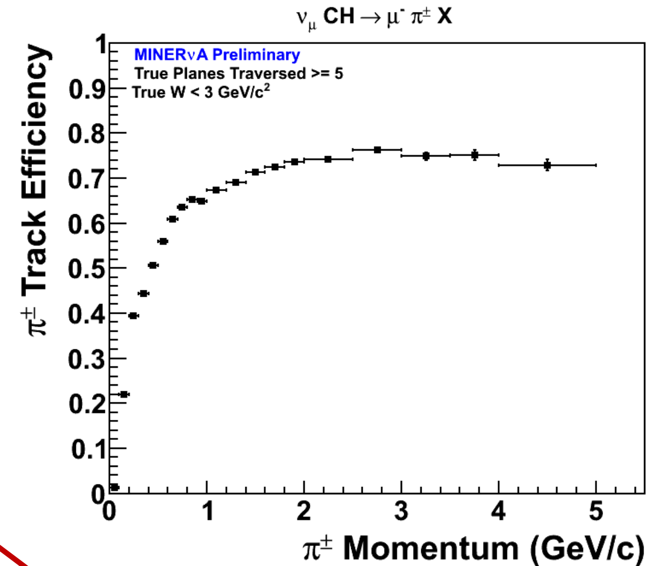


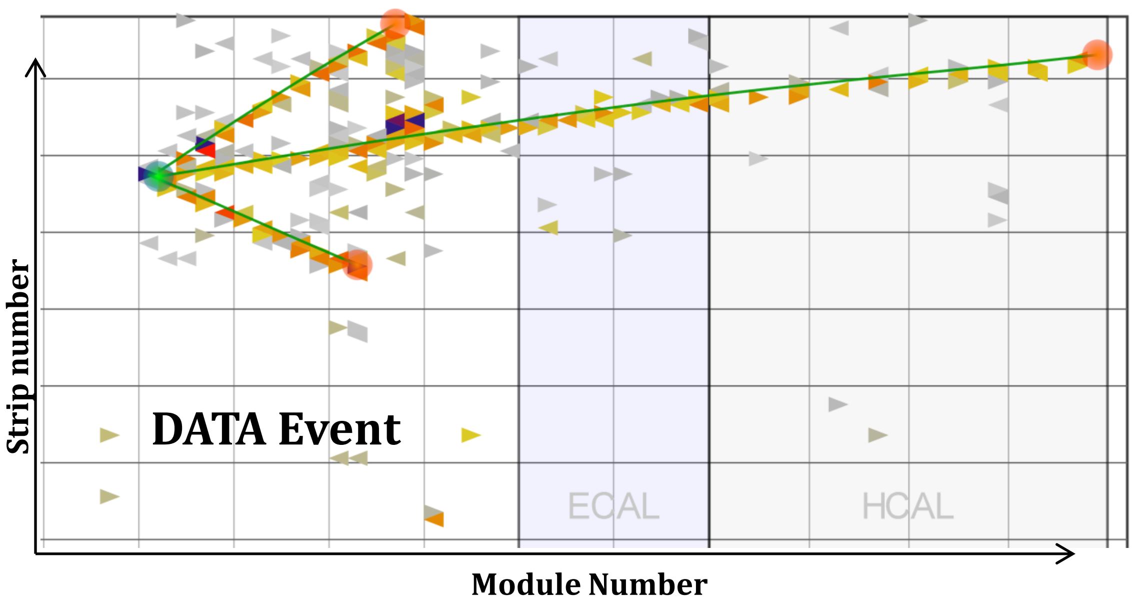
Pion Track Reconstruction

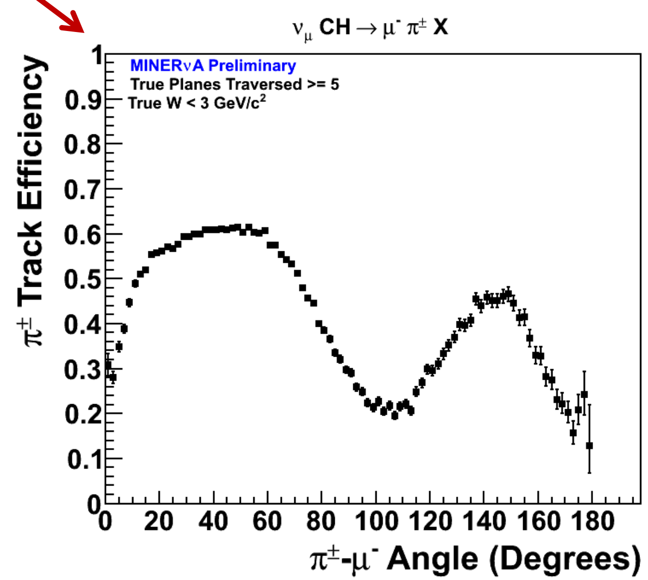
•Remove muon activity from event and search for additional tracks consistent with the muon vertex

•Energy on the muon track inconsistent with MIP activity is removed from the track and used in hadronic tracking

- •Increases tracking efficiency at small opening angles
- •Better vertex activity measurement

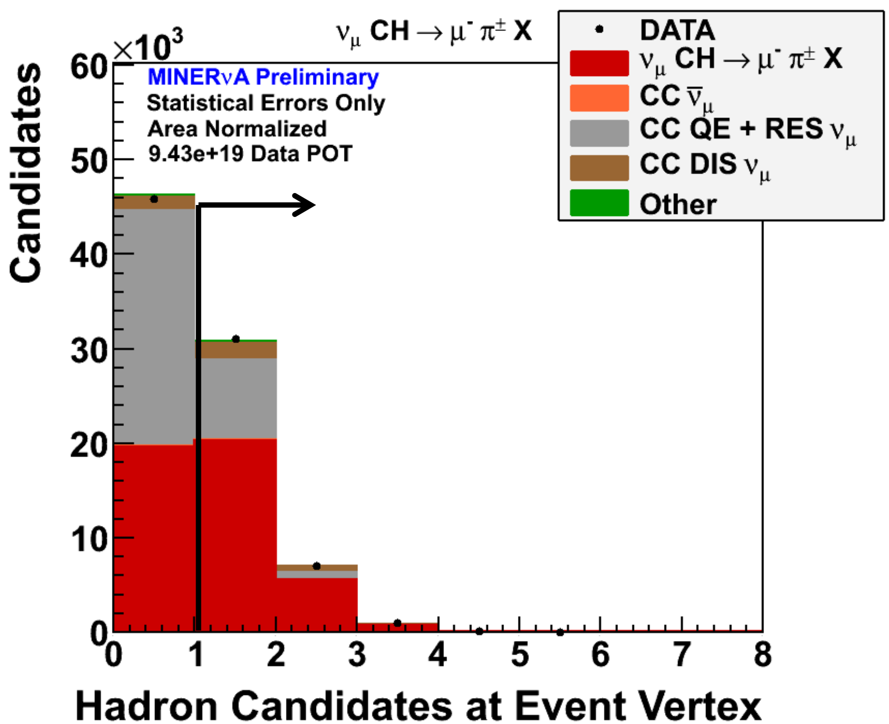


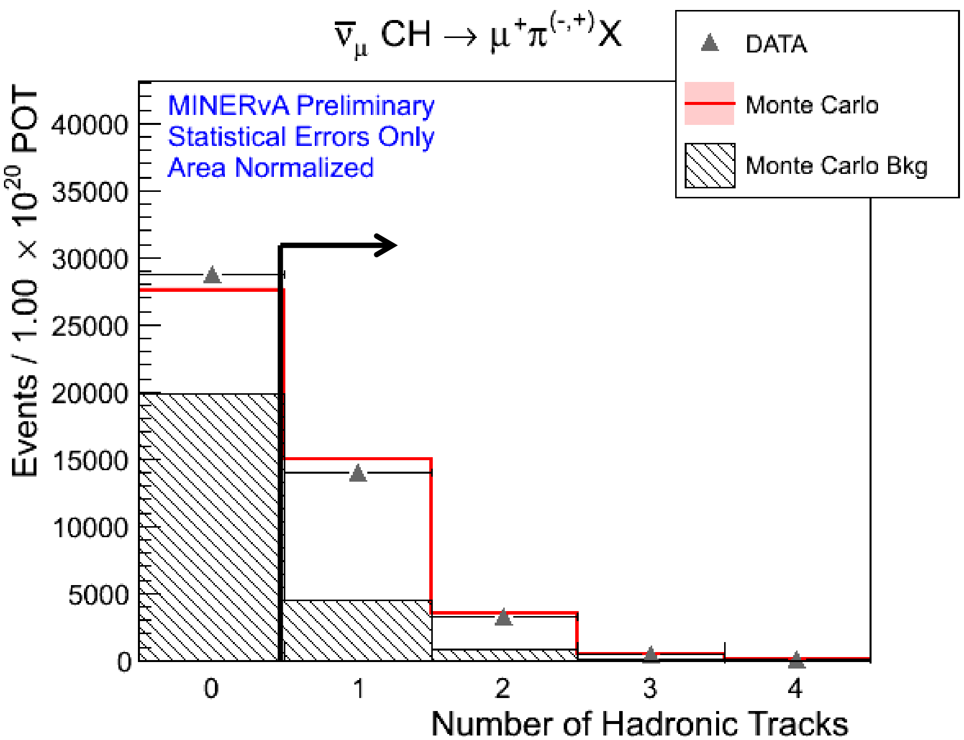




Pion Track Reconstruction

•Both analyses require at least one hadron track at the primary vertex





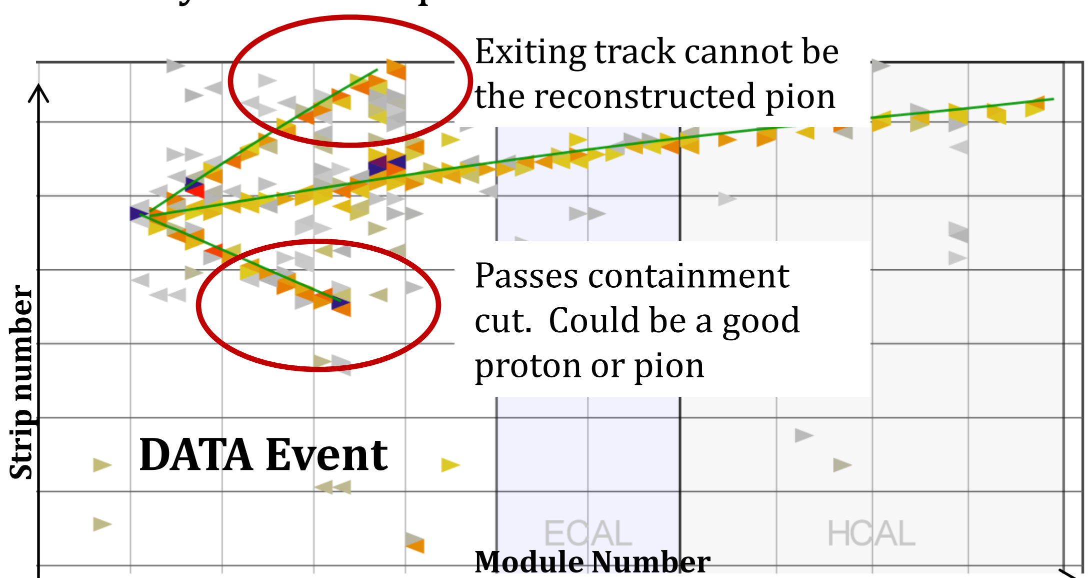
Particle ID (PID)

- Fit the track's dE/dx profile to the best momentum under proton and π hypotheses

- Calculate pion score as a function of the proton and pion fit χ^2

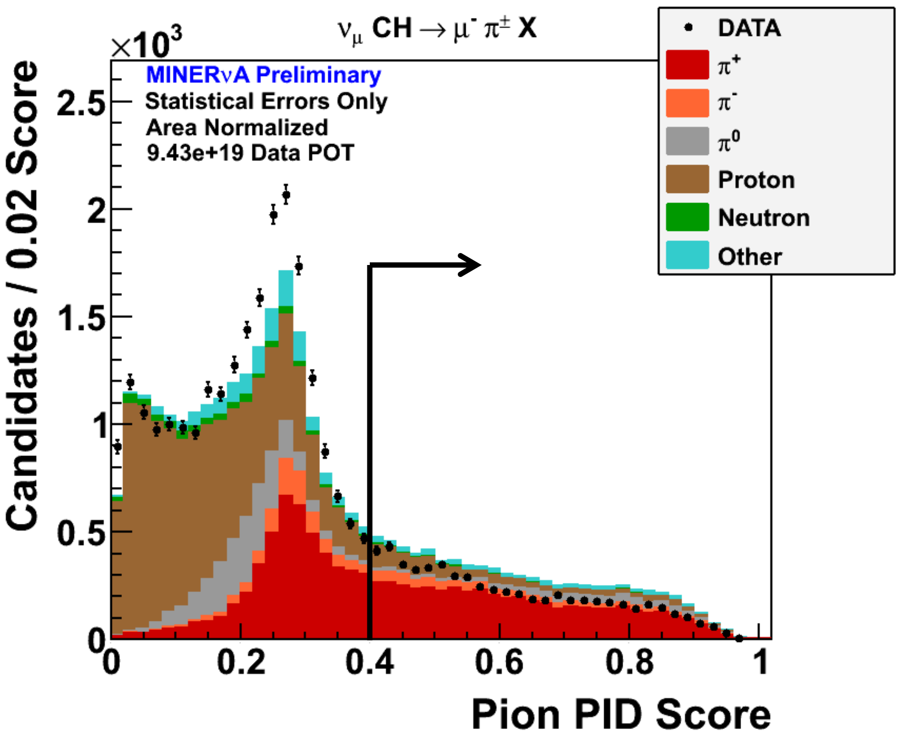
- No charge ID for now (try to use Michel electrons?)– that's why both analyses count $\pi^{\pm}$ as signal

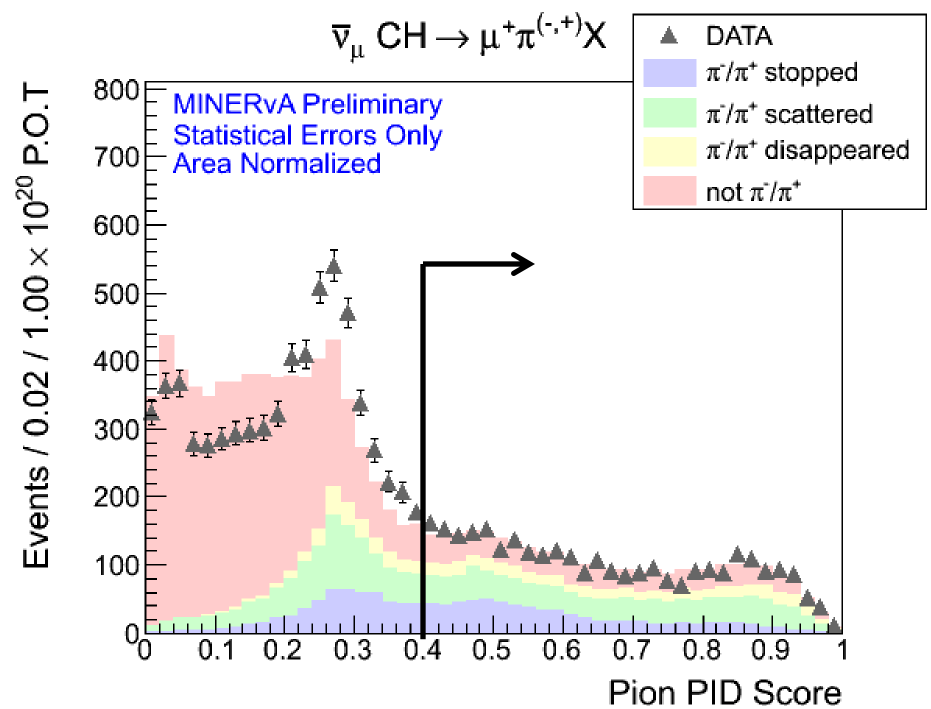
- Both analyses require a converging pion hypothesis fit on a hadron track that is contained in the MINERνA detector
    - Antineutrino analysis also requires the hadron does not enter the calorimeter



Particle ID (PID)

- Both analyses require that pion score is greater than 0.4
  - pion and proton hypotheses have equal fit χ^2 at score = 0.3



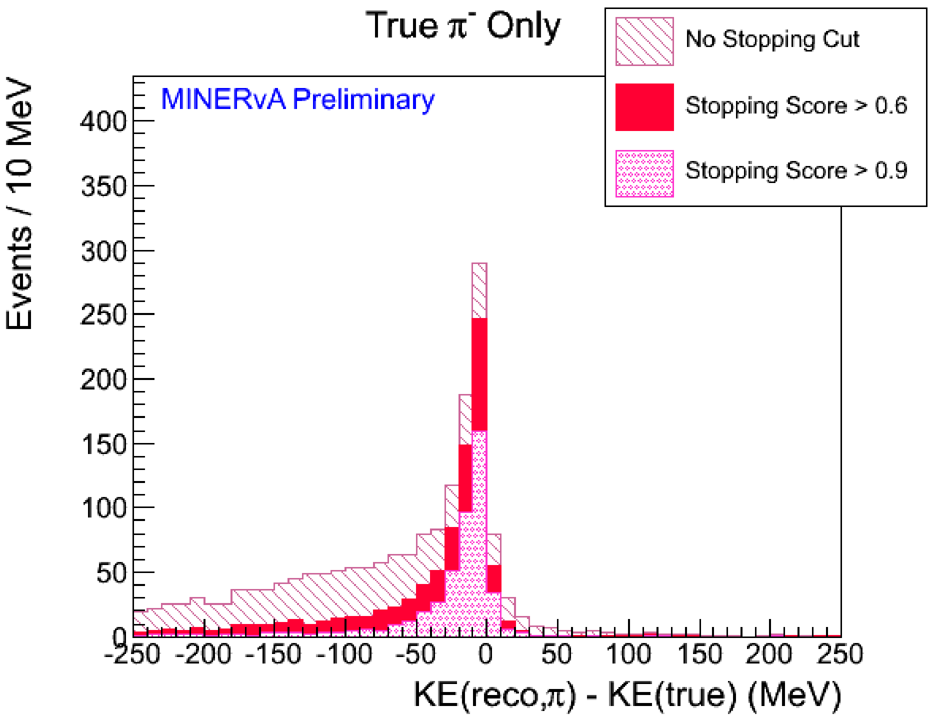


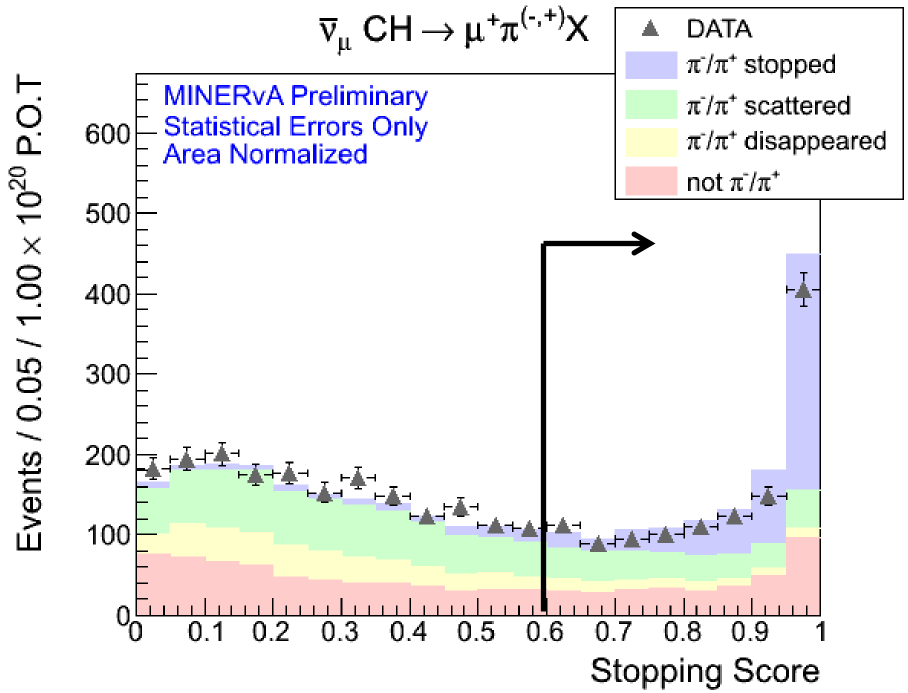
- Pions that scatter or absorb tend to have score ~ 0.3. We will need to develop alternative PID techniques for such pions

Stopping ID ($\bar{\nu}$ Analysis Only)

•Antineutrino analysis uses a "stopping ID" that identifies tracks consistent with a particle that ranges out without scattering or absorbing in the detector.

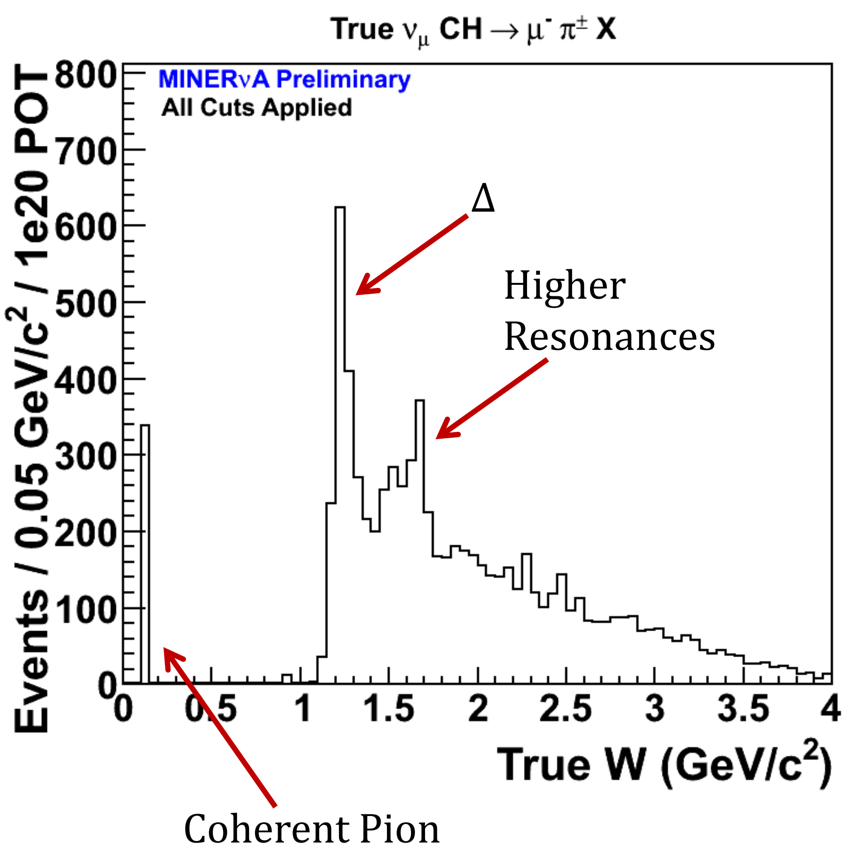
•Procedure: Create templates of the energy loss at the end of the track under different particle hypotheses. Require that the track is consistent with one of the templates.

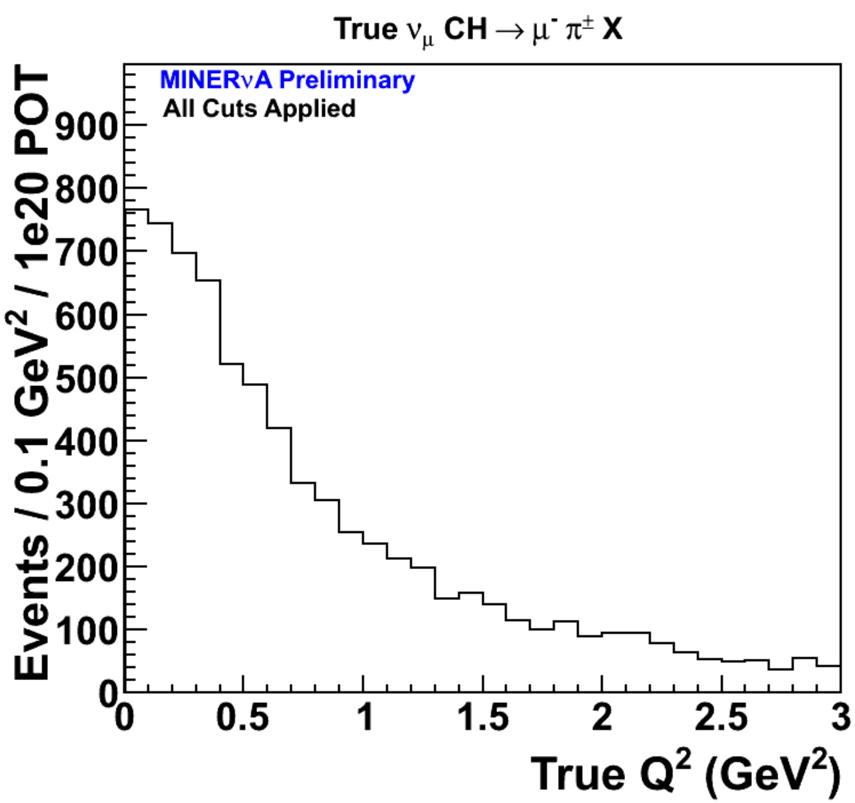




Kinematics Reach (ν)

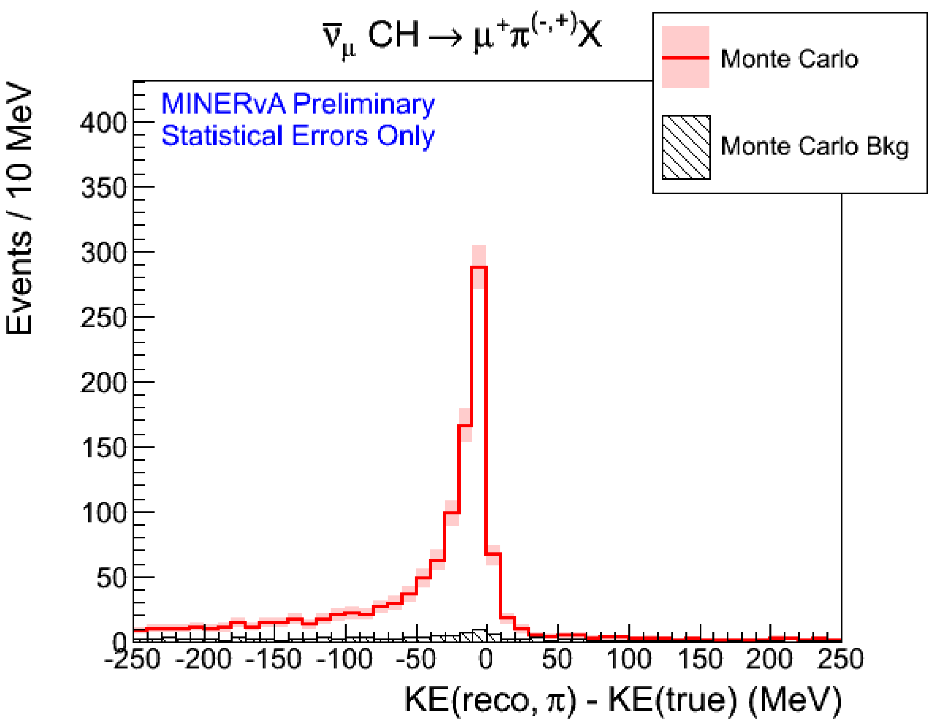
•True (MC) W and Q^2 after all cuts applied, for true signal events only

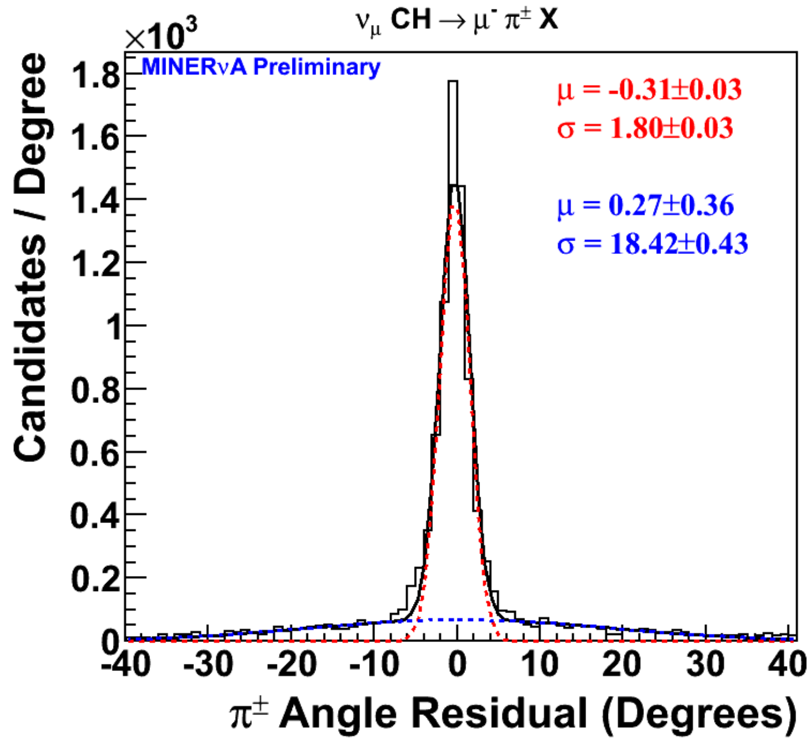




Kinematics Residuals

- Muon resolutions: 0.7° (Angle) and 5% (Momentum)
- $\bar{\nu}$ analysis p_π residual has a small tail due to stopping ID cut
- Pion Angle residual tail: mis-ID protons and pions that scatter near vertex

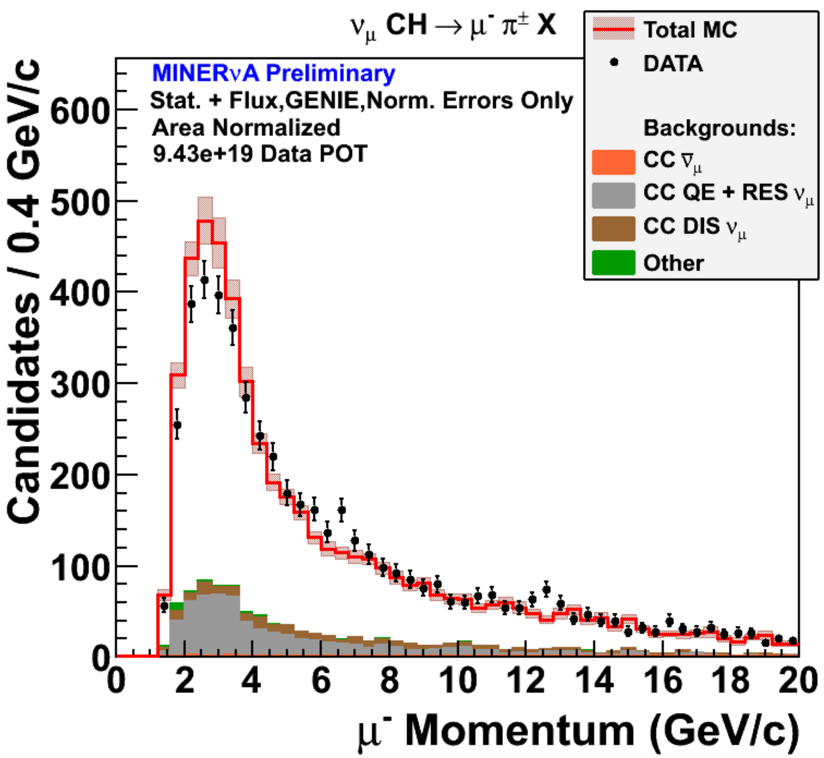


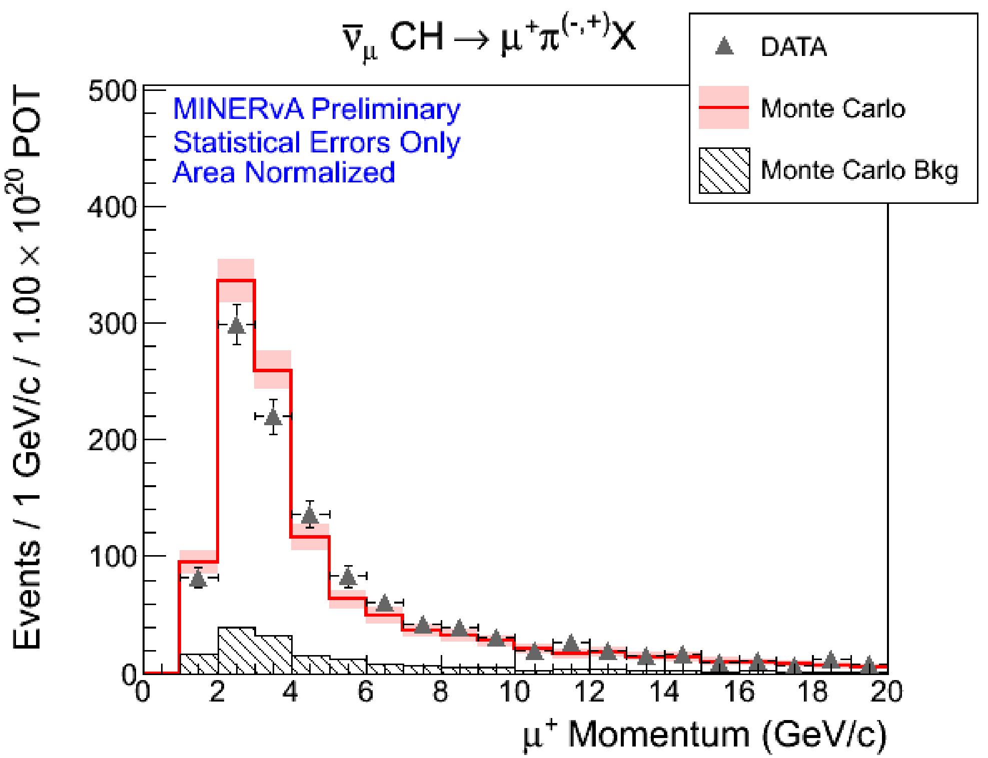


Reconstructed Muon Momentum

•Both analyses have large sample purities, > 80%.

•Partial shape systematic error bars on ν analysis plots – both analyses working towards absolutely-normalized distributions with full systematic errors

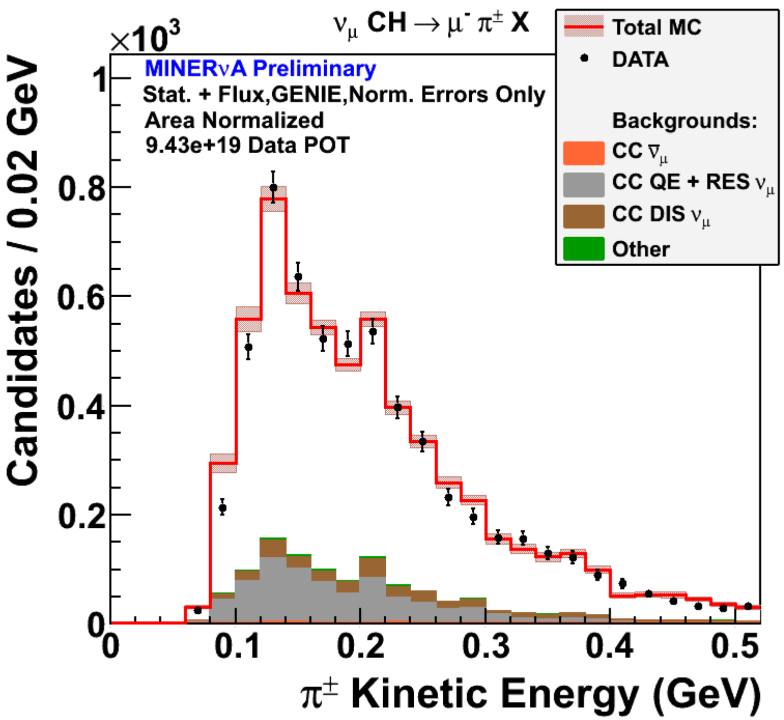


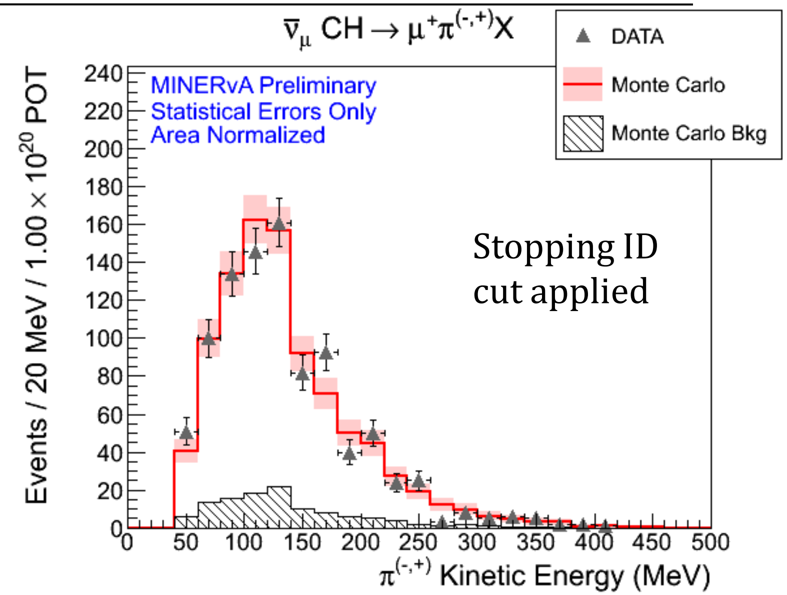


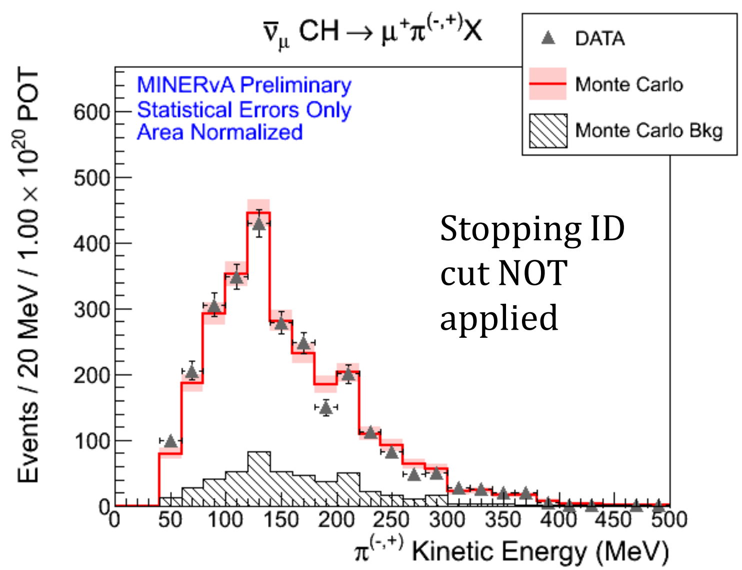
Reconstructed Pion KE

- Show $\bar{\nu}$ analysis with and without stopping ID cut - the analyses still differ in the pion containment cut!

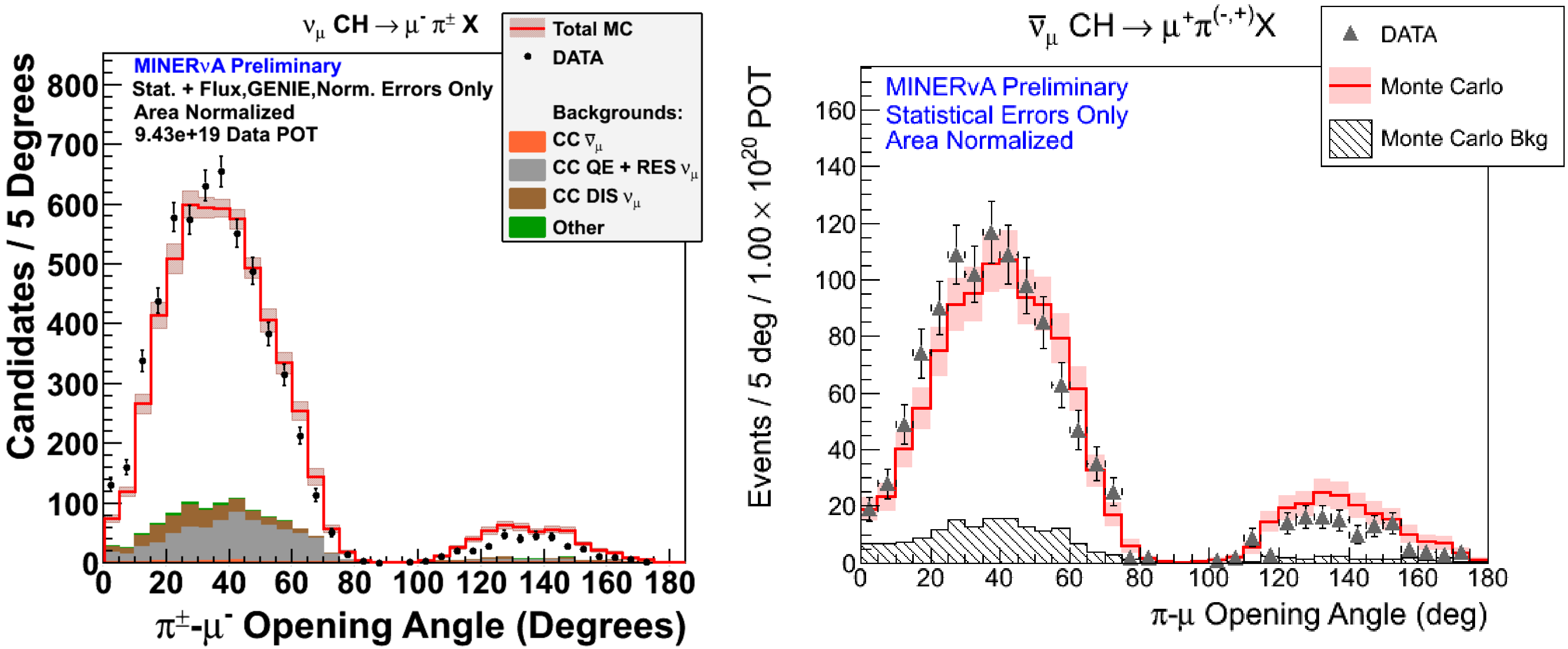
Odd bump near 200 MeV not understood, but is modeled







Reconstructed Opening Angle



Conclusions, Next Steps

•MINERνA CC inclusive pion analyses have developed selection criteria that yield > 80% sample purity.

•Stopping ID is a powerful new tool to select a sample of range-out pions with good momentum reconstruction – sacrifice statistics

Next Steps Towards Cross Sections:

•Reconstruction refinements – can modifications to tracking and PID yield increased efficiencies without sacrificing purity?

•Reconstruct hadronic shower energy by calorimetry – calculate E_ν, Q^2, W

•Examine background subtracted, unfolded, and efficiency-corrected distributions

•Evaluate systematic errors related to hadron reconstruction

Our goal is to show cross section results in 2013!

Backup Slides

CC Inclusive Pion Measurements

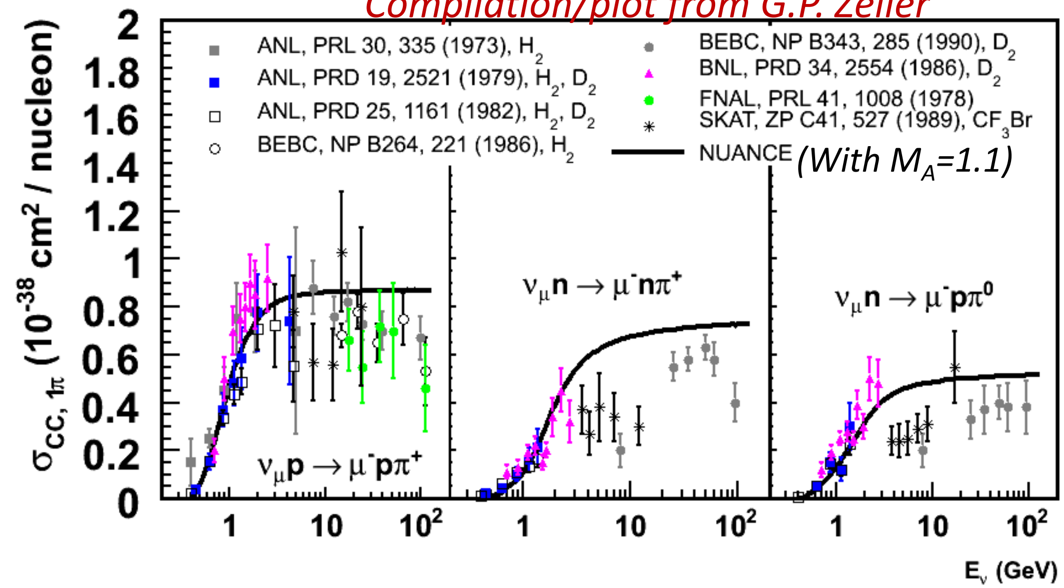
- Early experiments measured exclusive final states on H and D bubble chambers

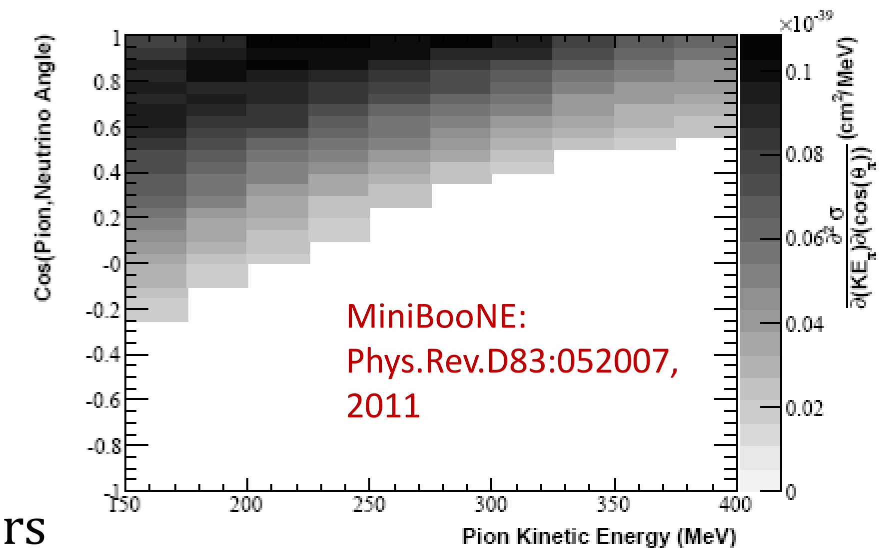
- The only high-statistics measurement is single π^+ inclusive by MiniBooNE on CH_2 at ~ 1 GeV (~48k candidates)

- Need to probe A-dependence to understand nuclear effects - ratio to other CC processes is useful

- Δ-rich sub-sample could be used to measure resonance form factor parameters

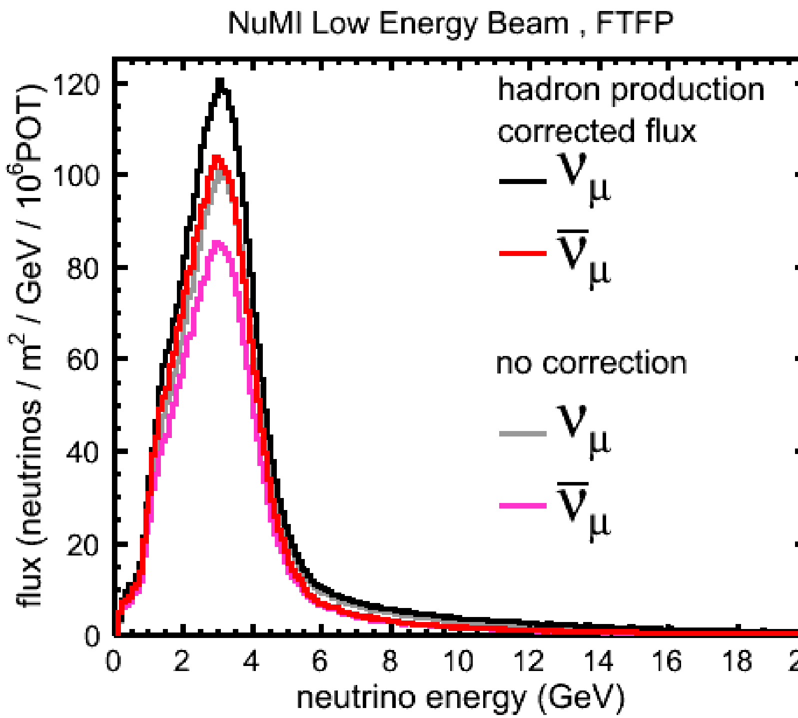
Compilation/plot from G.P. Zeller

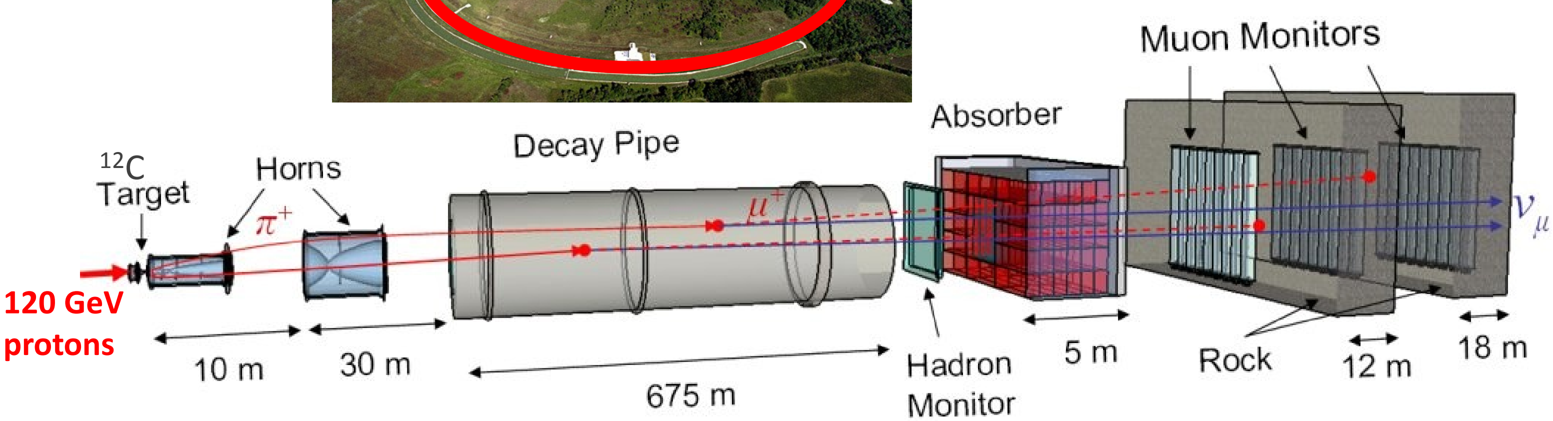




NuMI Beam

- Delivers ~35e12 protons on target (POT) per spill at ~0.5 Hz
- Moveable target for flux studies
- Magnetic horns focus + or – charged particles

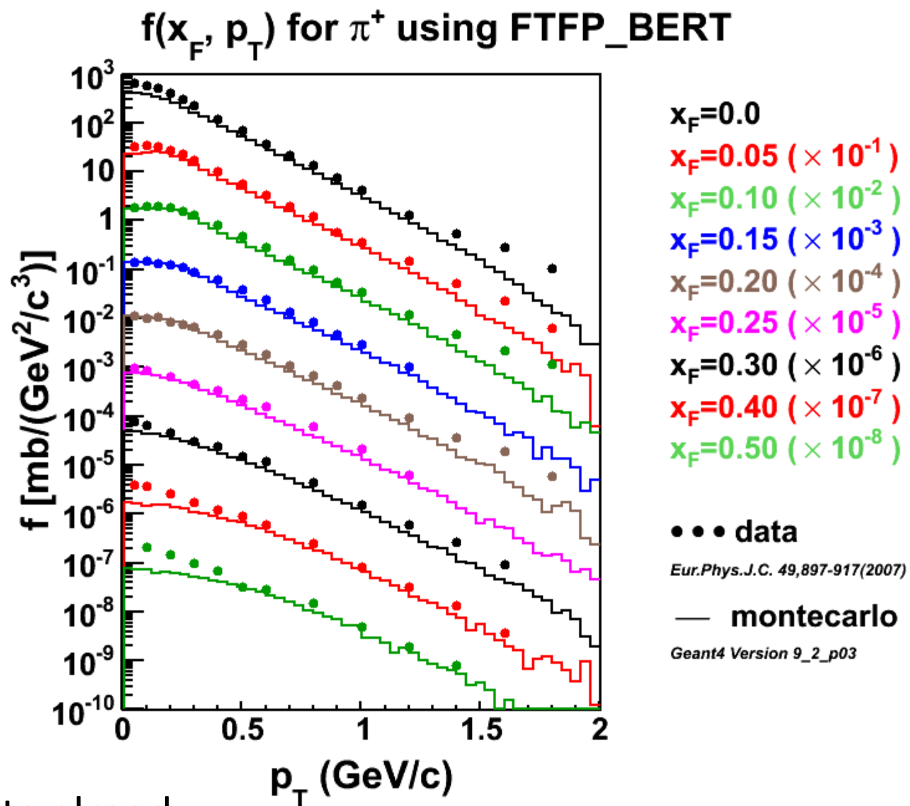




MINERvA

Beam Knowledge and Flux

- Today's results: Flux simulated by GEANT4 and reweighted to match hadron production data from NA49.
  - 7.5% statistical, 2-10% systematic uncertainties



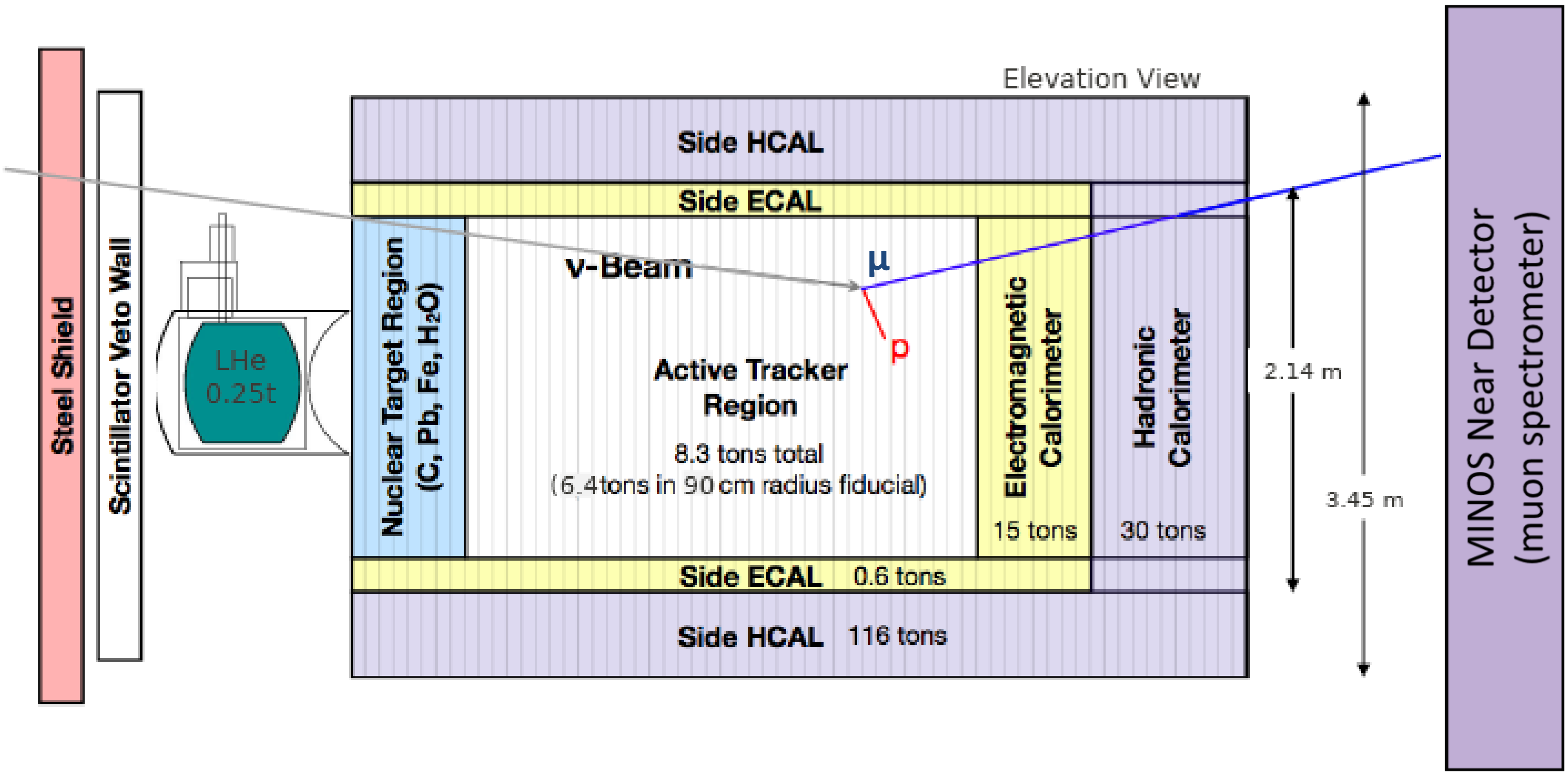
- Future flux measurements will be improved by multi-pronged attack:
  - In situ measurement from muon flux via muon monitors
  - Data with different horn current and target position configurations
  - New hadron production data

Data already taken!

- See Leo Aliaga's talk at this conference!

MINERνA Diagram

- Nuclear targets to study A dependence and nuclear effects
- Fully active, finely segmented scintillator tracking region
- MINOS Near Detector is our muon spectrometer

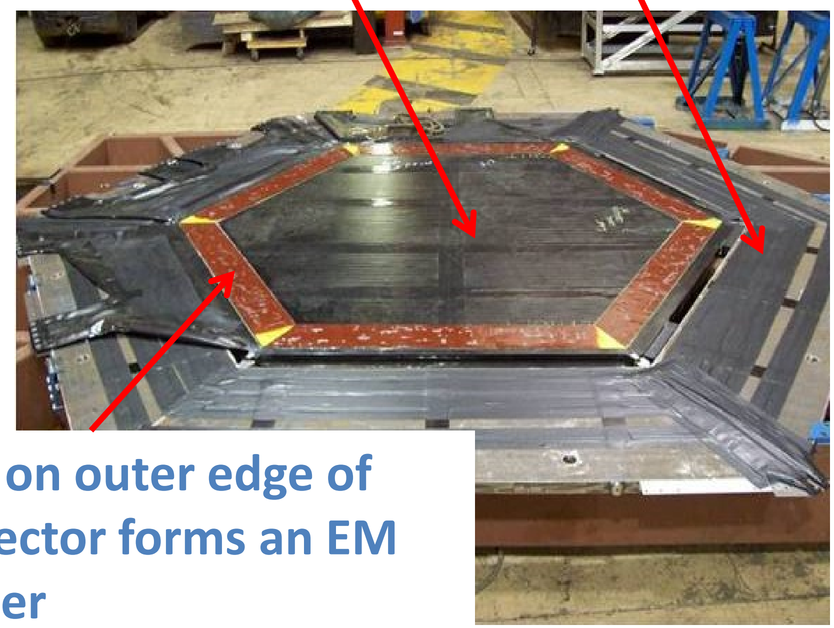


The detector (types of modules)

- 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 lengths.

Inner detector

Outer detector – slots instrumented with scintillator (HAD calorimetry)

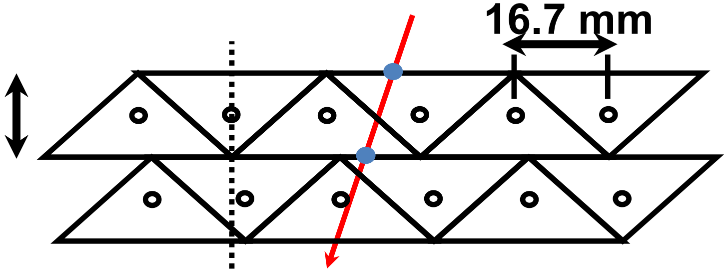


Lead ring on outer edge of inner detector forms an EM calorimeter

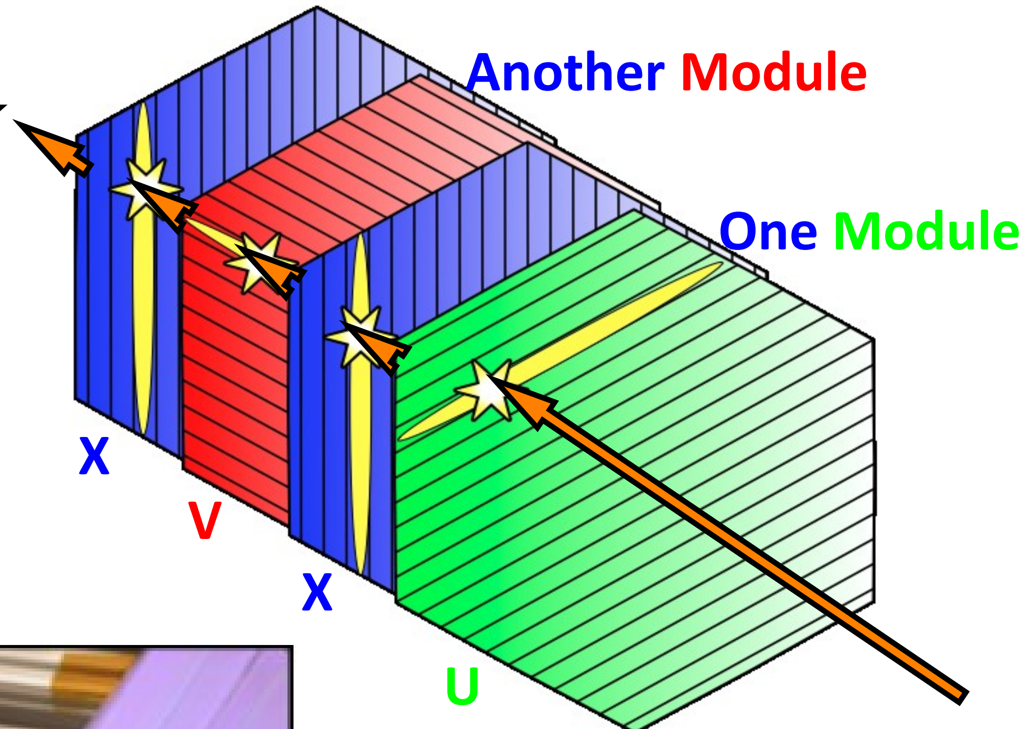
MINERvA module under construction

*slide from S. Manly

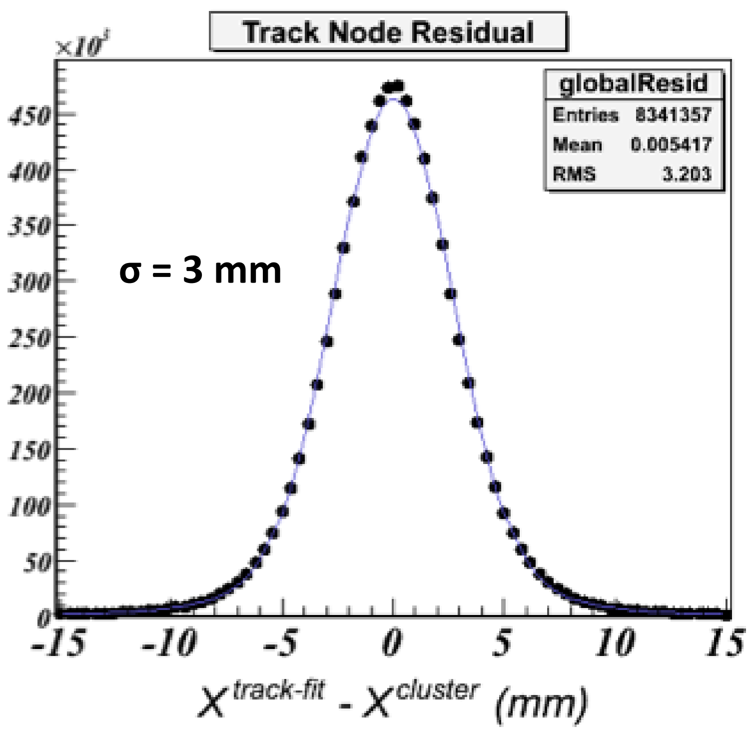
Planes and Optics

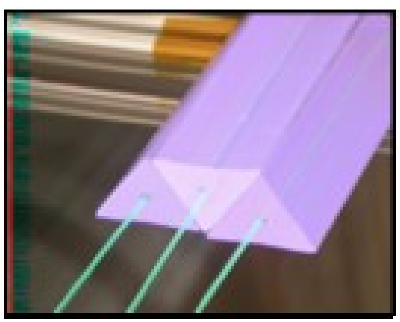


Triangular scintillator strips allows charge-sharing for good position resolution (3 mm)



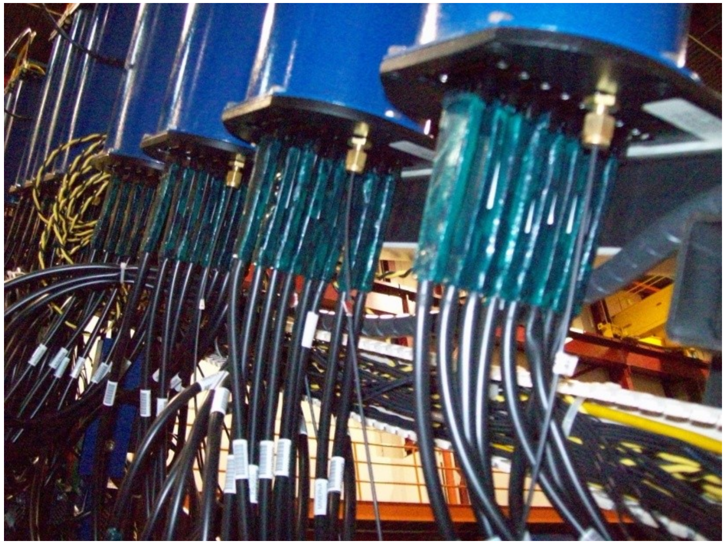
3 different rotated plane views to resolve high-multiplicity events

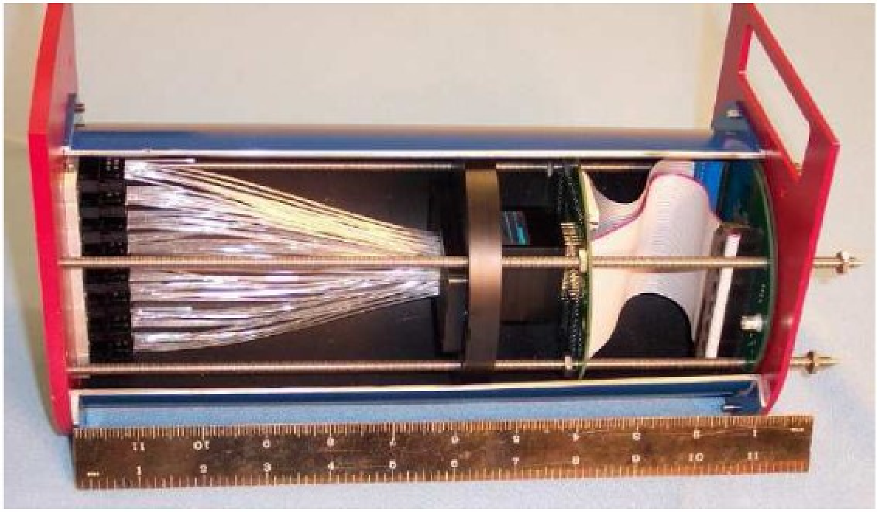




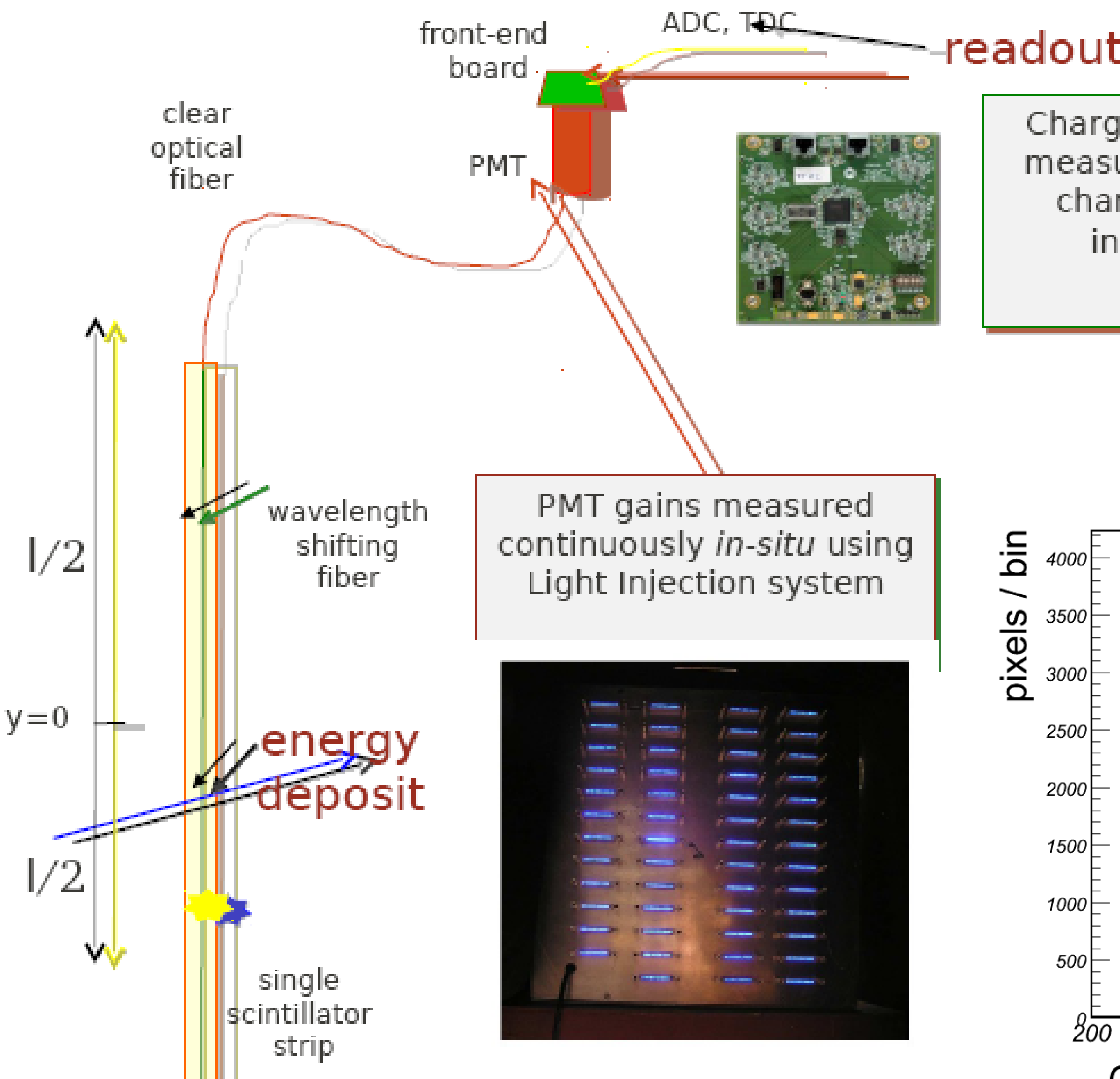
Electronics

•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



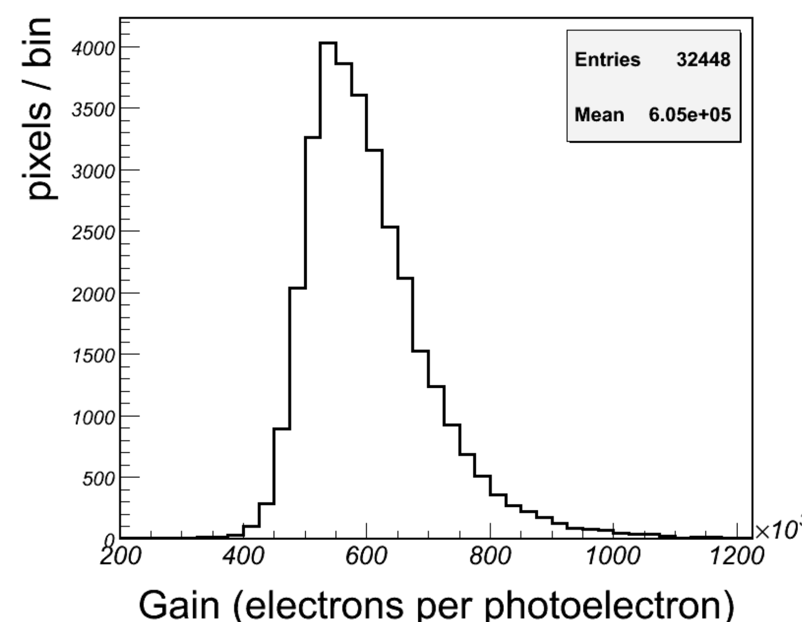


Detector Calibration



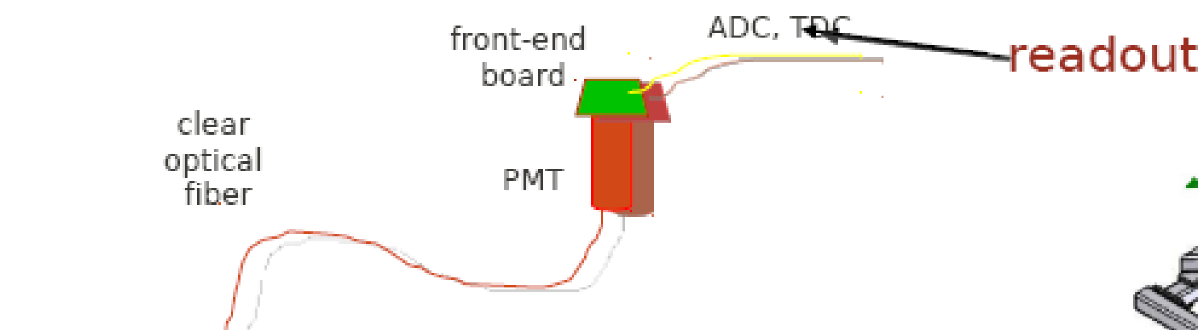
Charge to ADC conversion function measured on a test stand for every channel on every board before installation on the detector

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

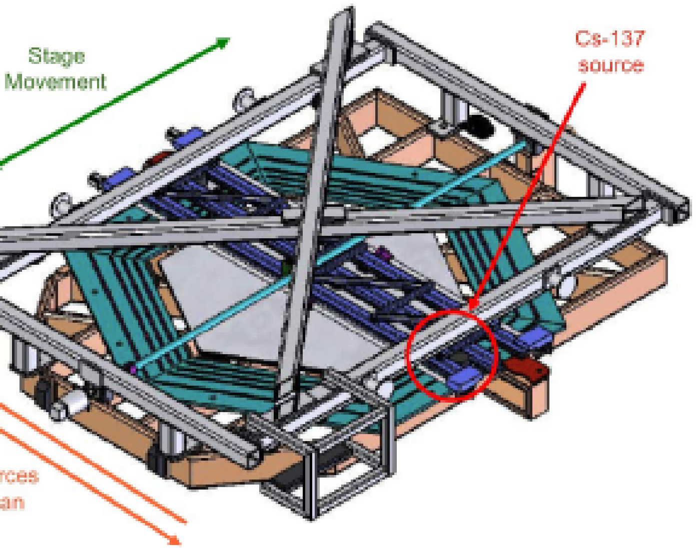


*slide from M. Kordosky

Detector Calibration

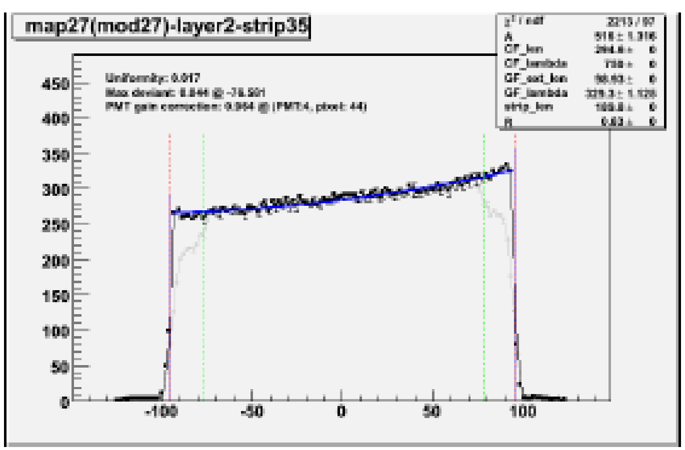


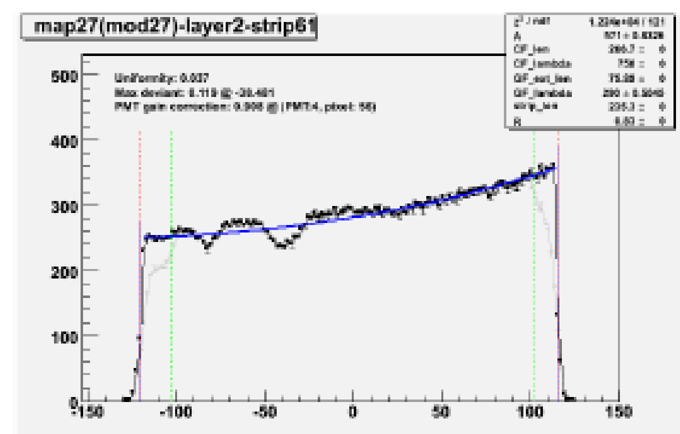
Attenuation along every strip in every plane measured using a source map before installation. We use the point-by-point map in reconstruction for every channel.



Typical attenuation length ~300 cm.

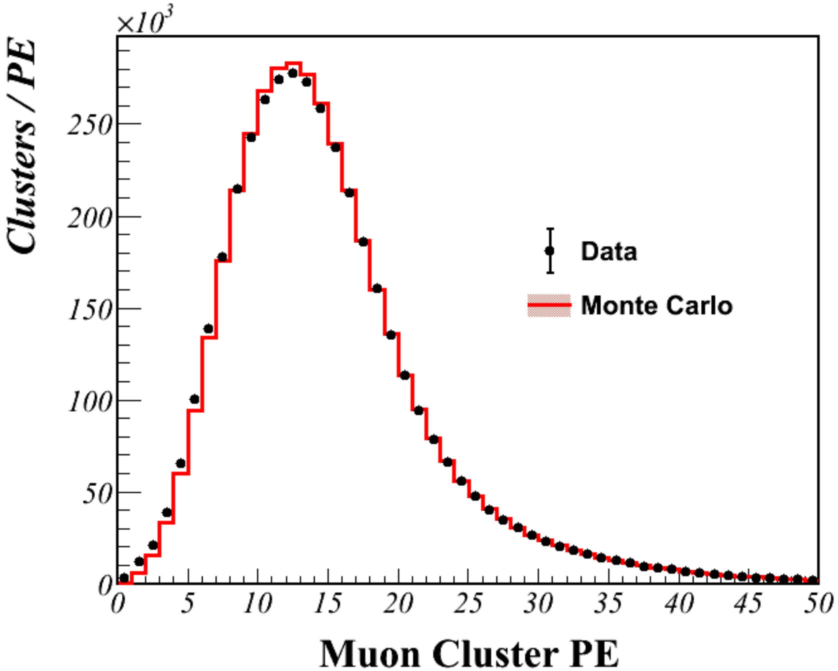
Map can find non-uniformities along the strip (e.g. air pockets in glue)

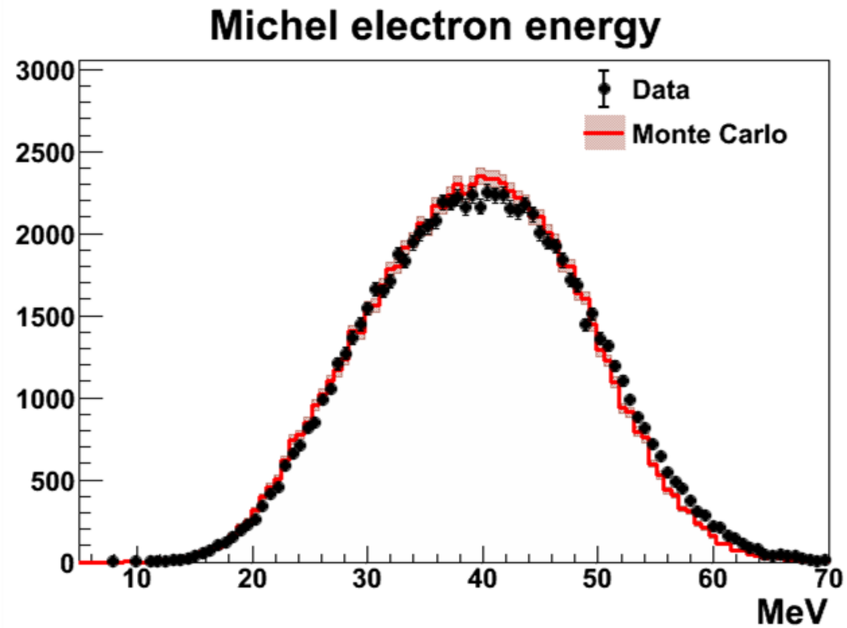


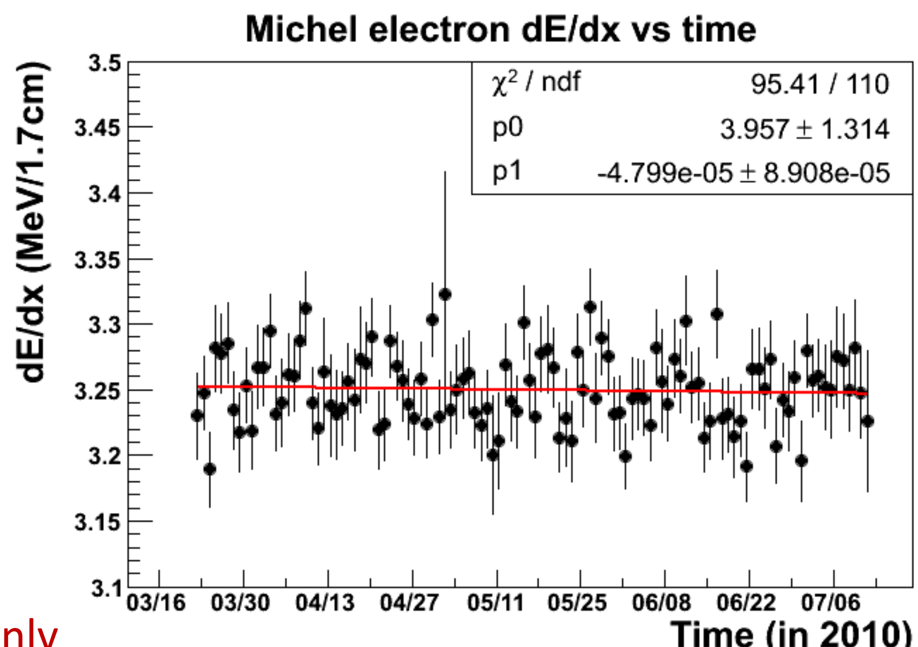


*slide from M. Kordosky

Energy scale and stability

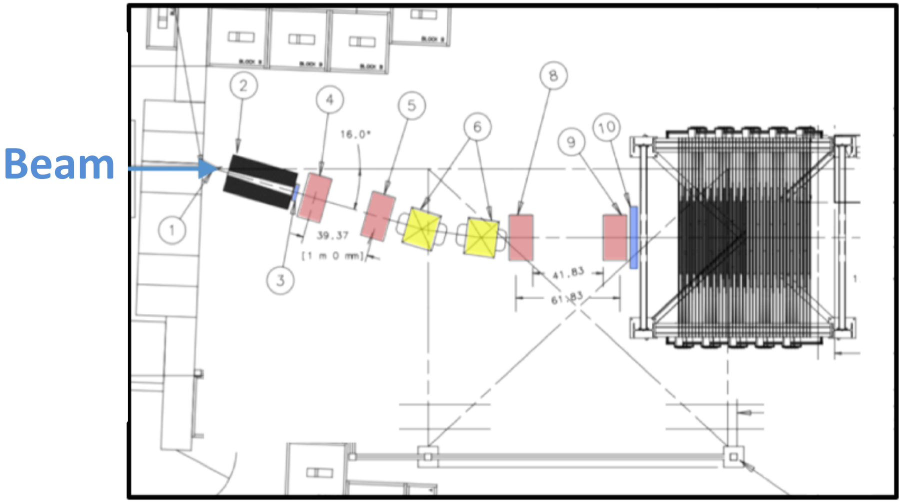


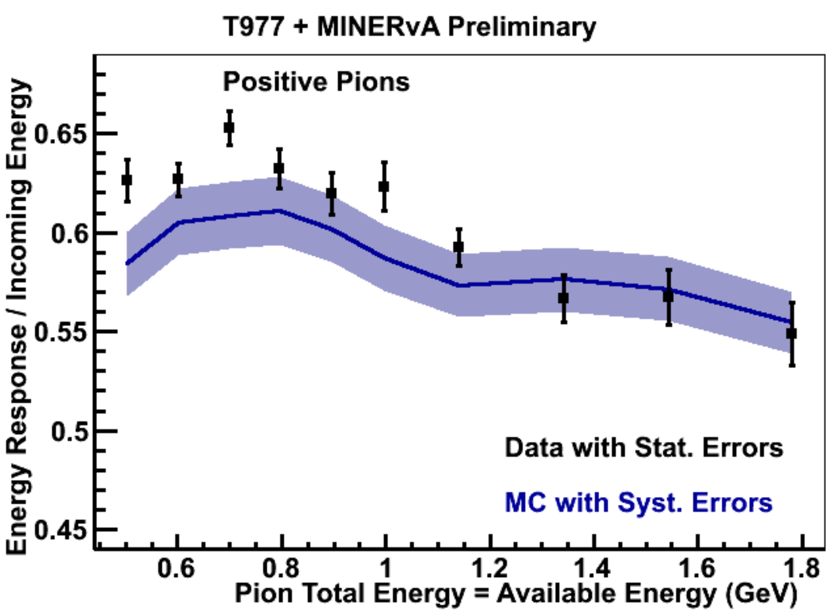




*slide from S. Manly

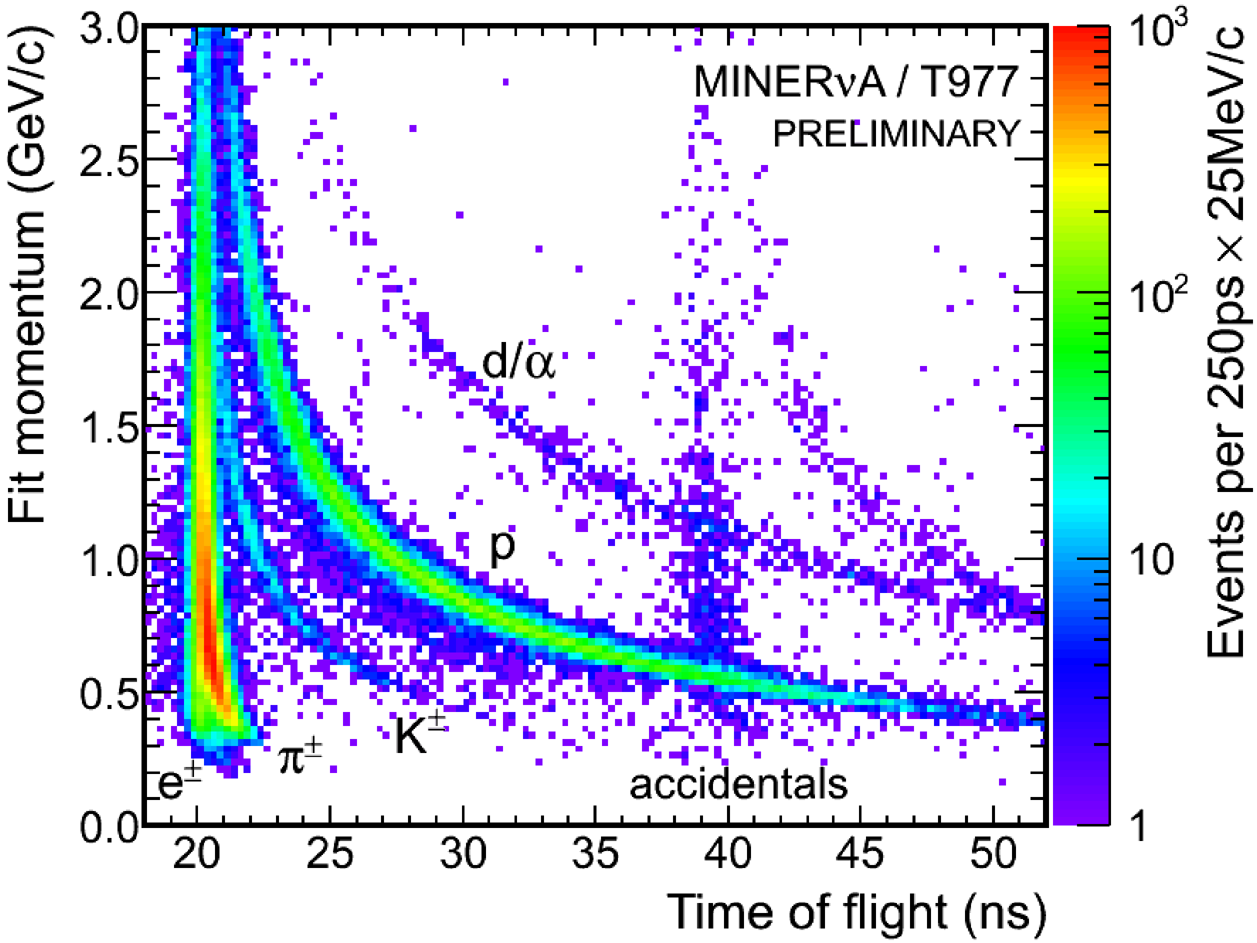
MINERνA TestBeam





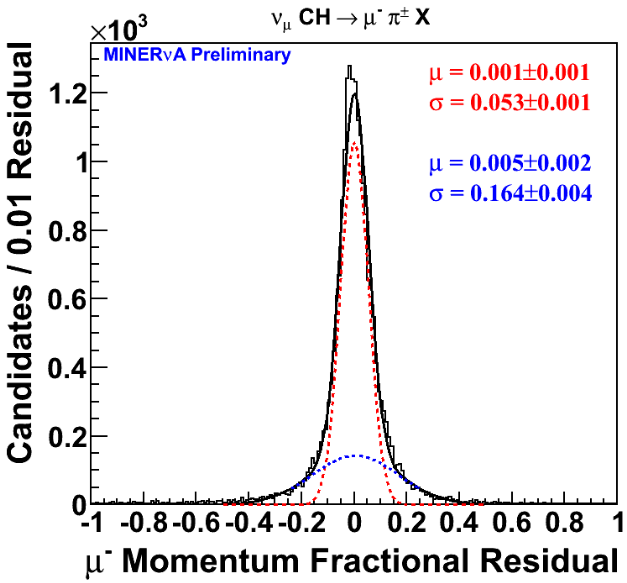
- Mini-MINERνA planes installed in MTEST tertiary beamline
- 0.4-1.2 GeV pions for hadron response calibration
- Reconfigurable – collected data for:
  - 20ECAL-20HCAL
  - 20Tracker-20ECAL
- Current data/MC agreement for π^+ response is ~5% with well-modeled resolution.
  - π^- is slightly better
  - proton response ~10%

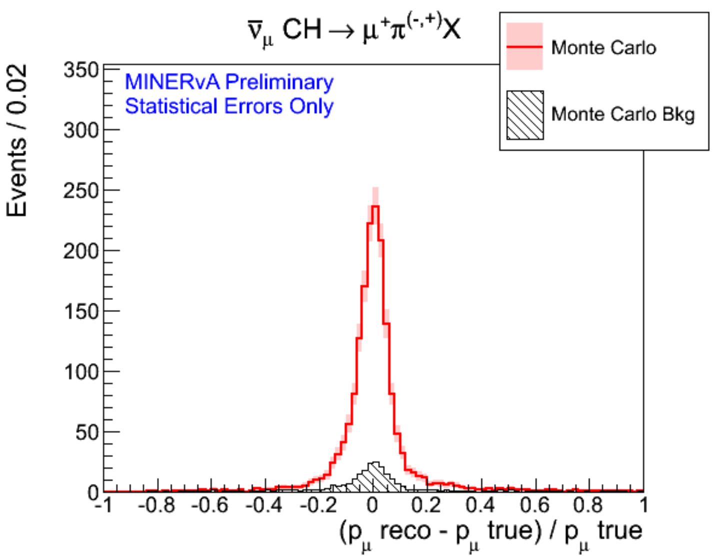
MINERνA Test Beam

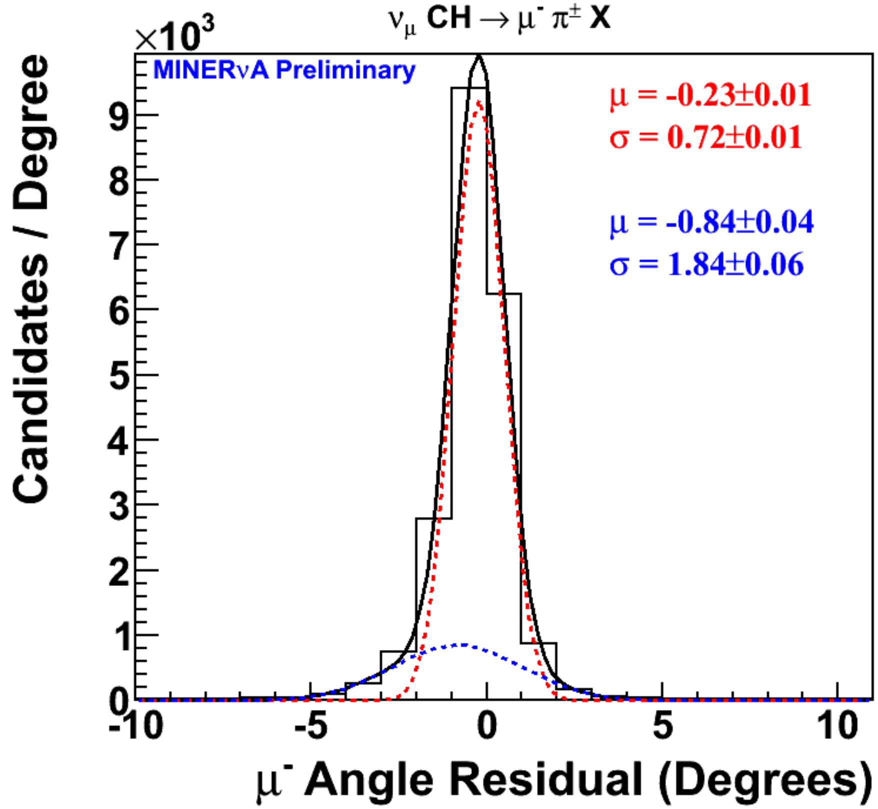


*slide from S. Manly

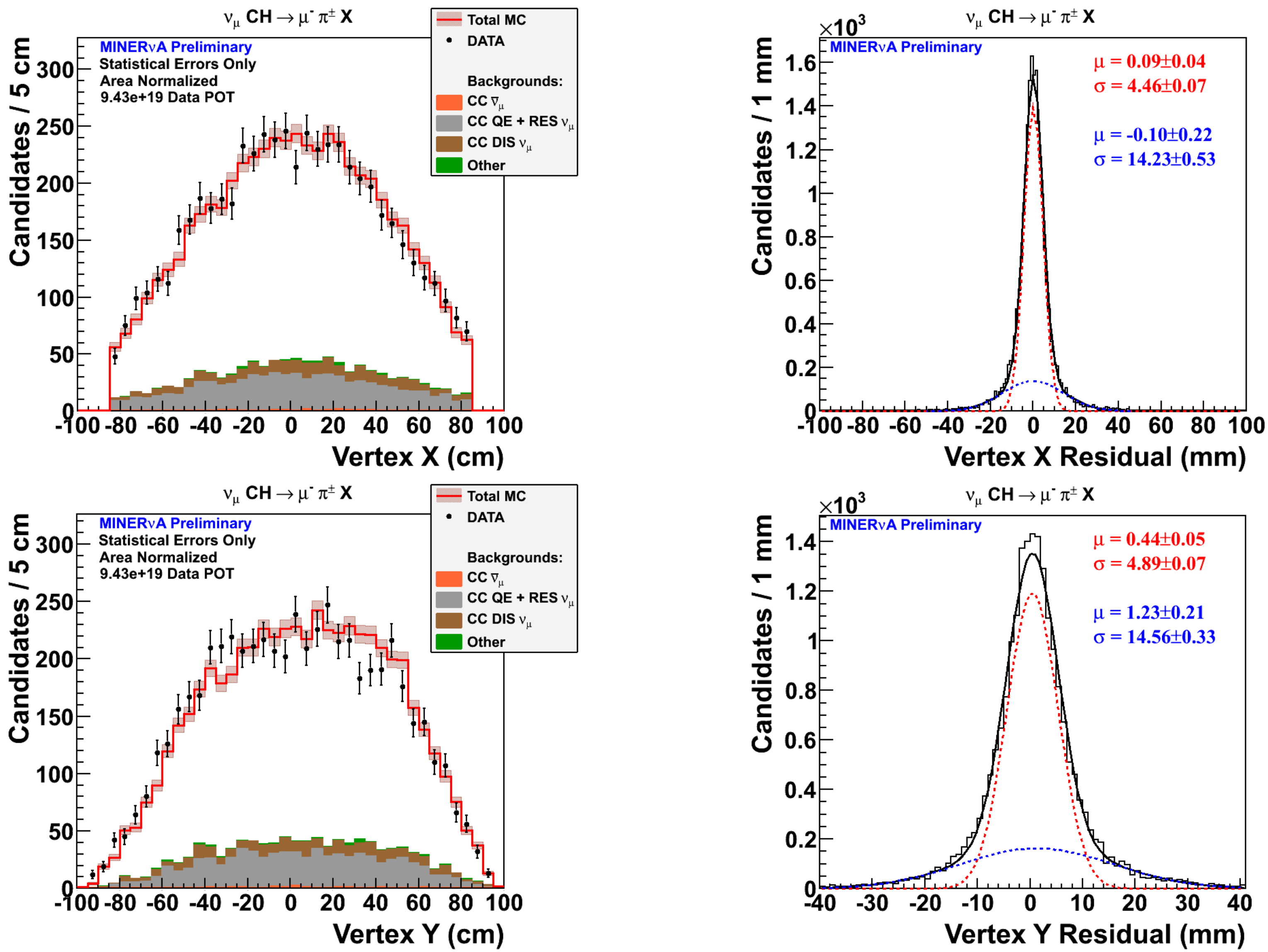
Muon Kinematics Residuals



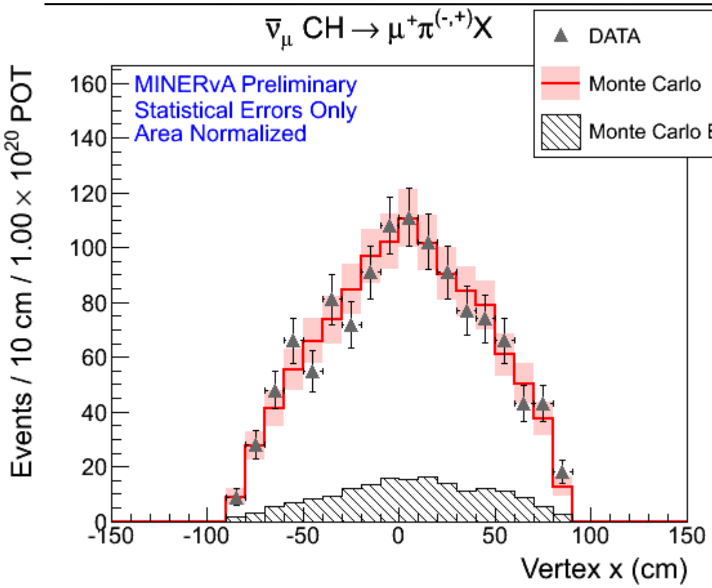


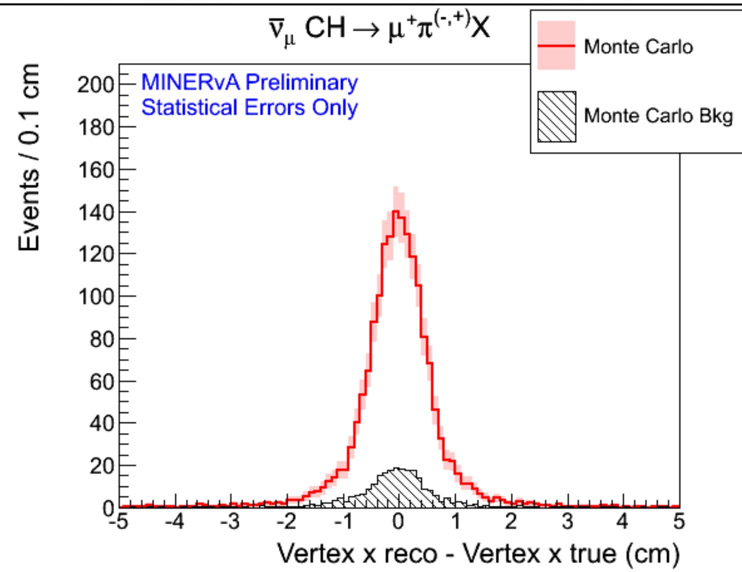


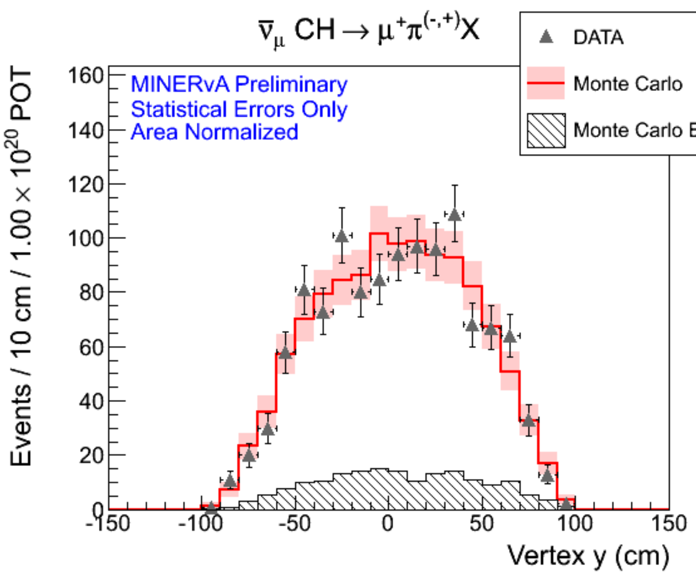
Reconstructed Vertex XY (ν)

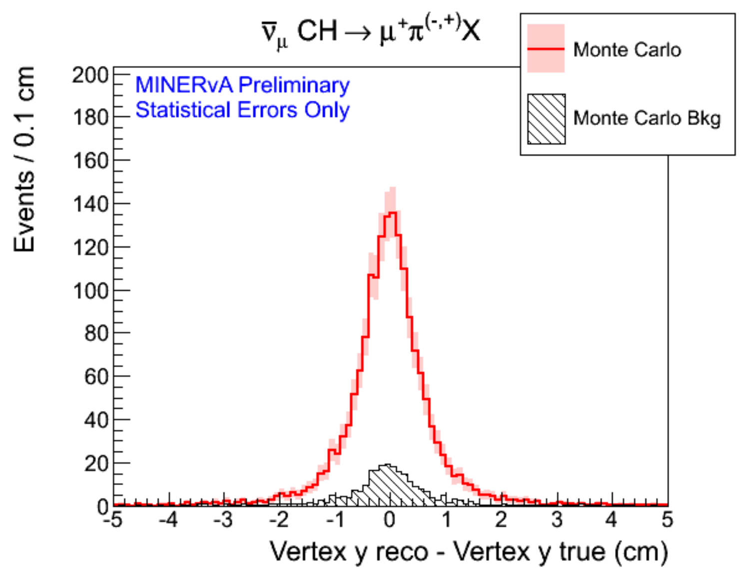


Reconstructed Vertex XY ($\bar{\nu}$)

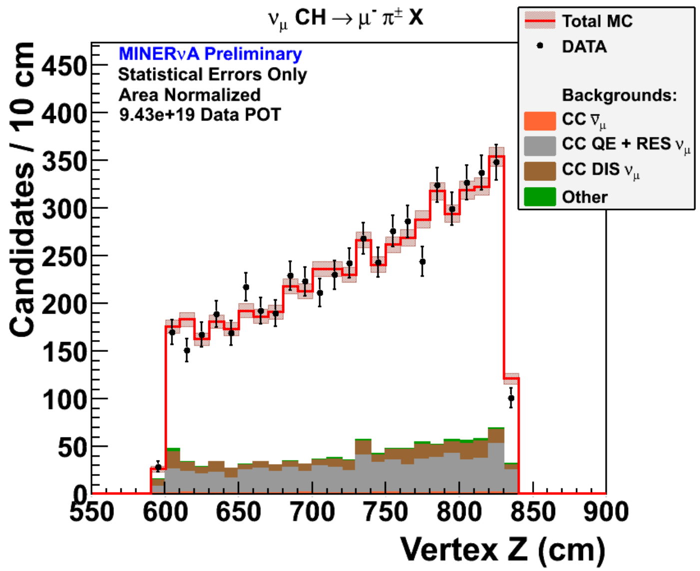


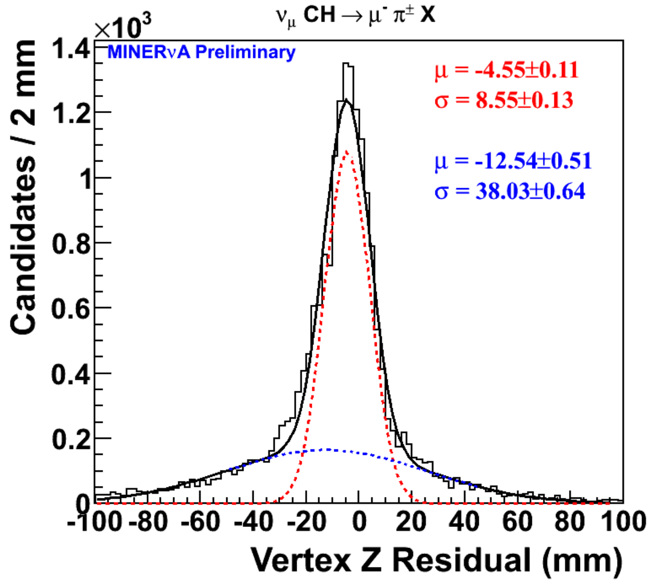


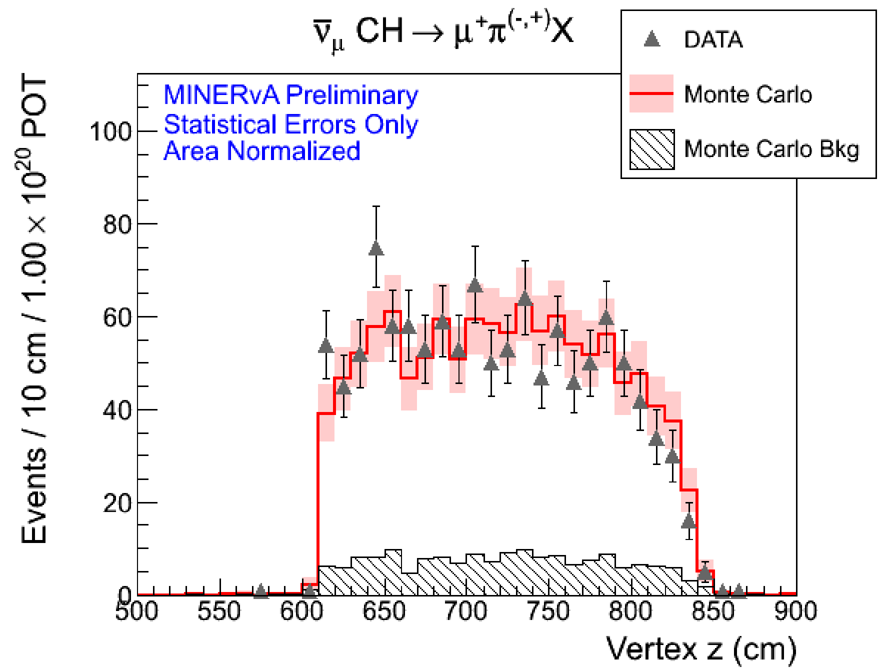




Reconstructed Vertex Z

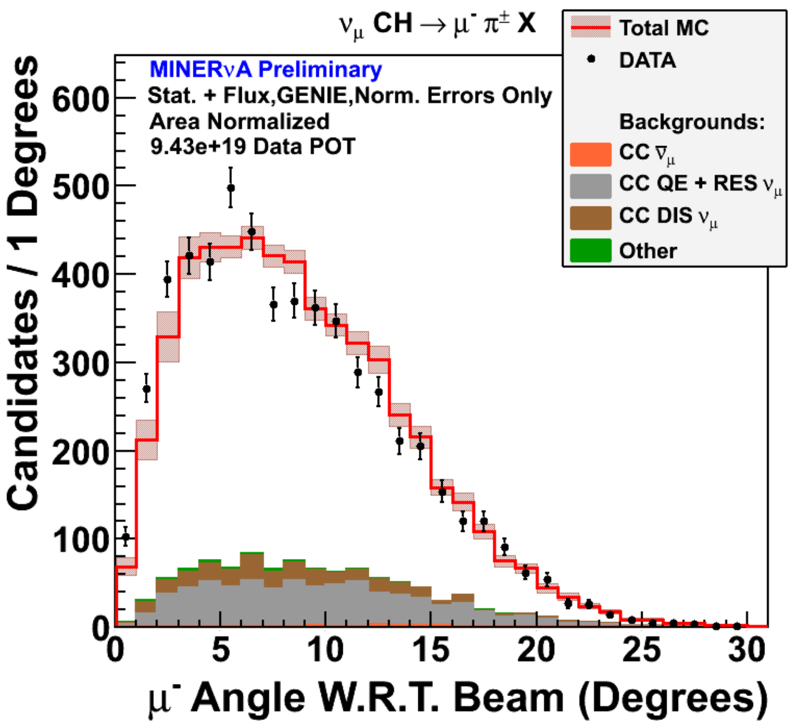


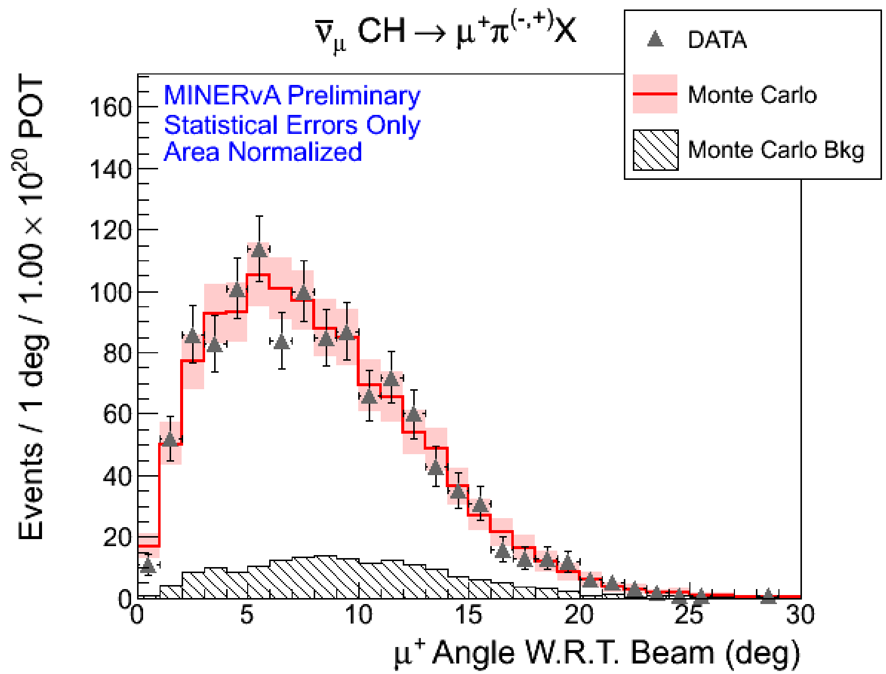




Reconstructed Muon Angle

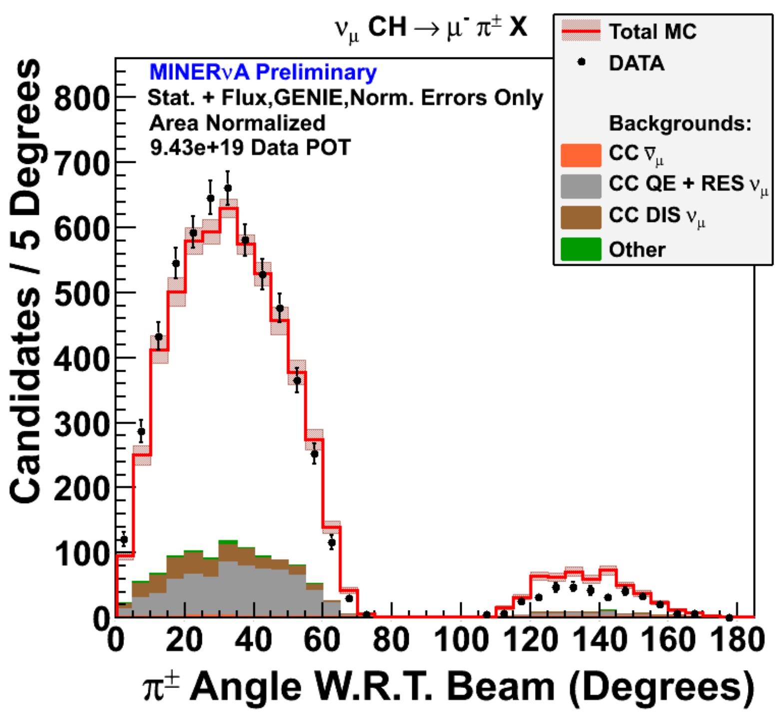
•Observe some shape difference in neutrino analysis. Good shape agreement in antineutrino analysis

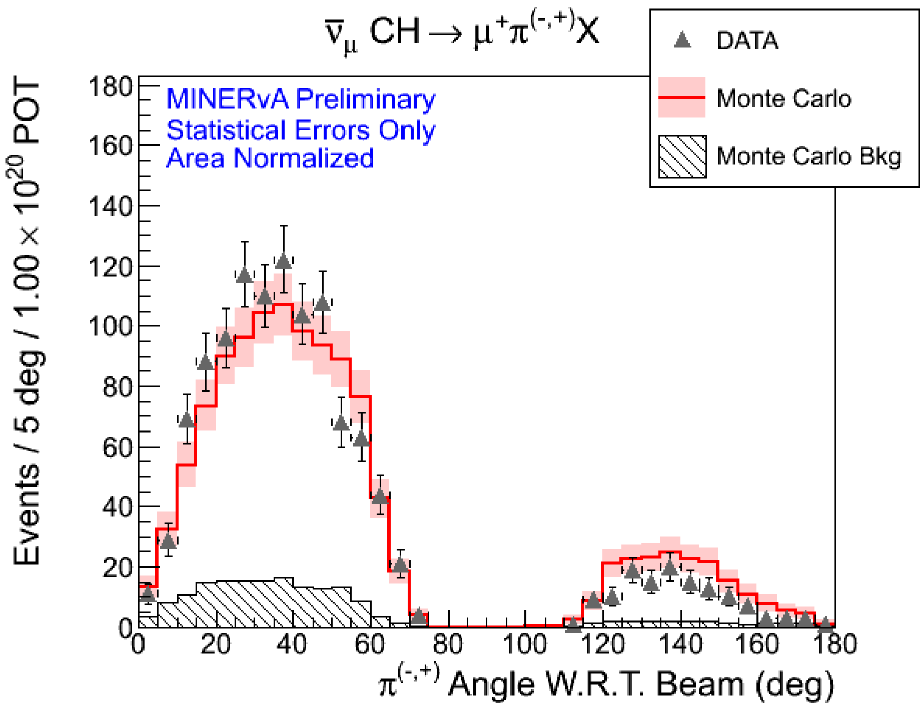




Reconstructed Pion Angle

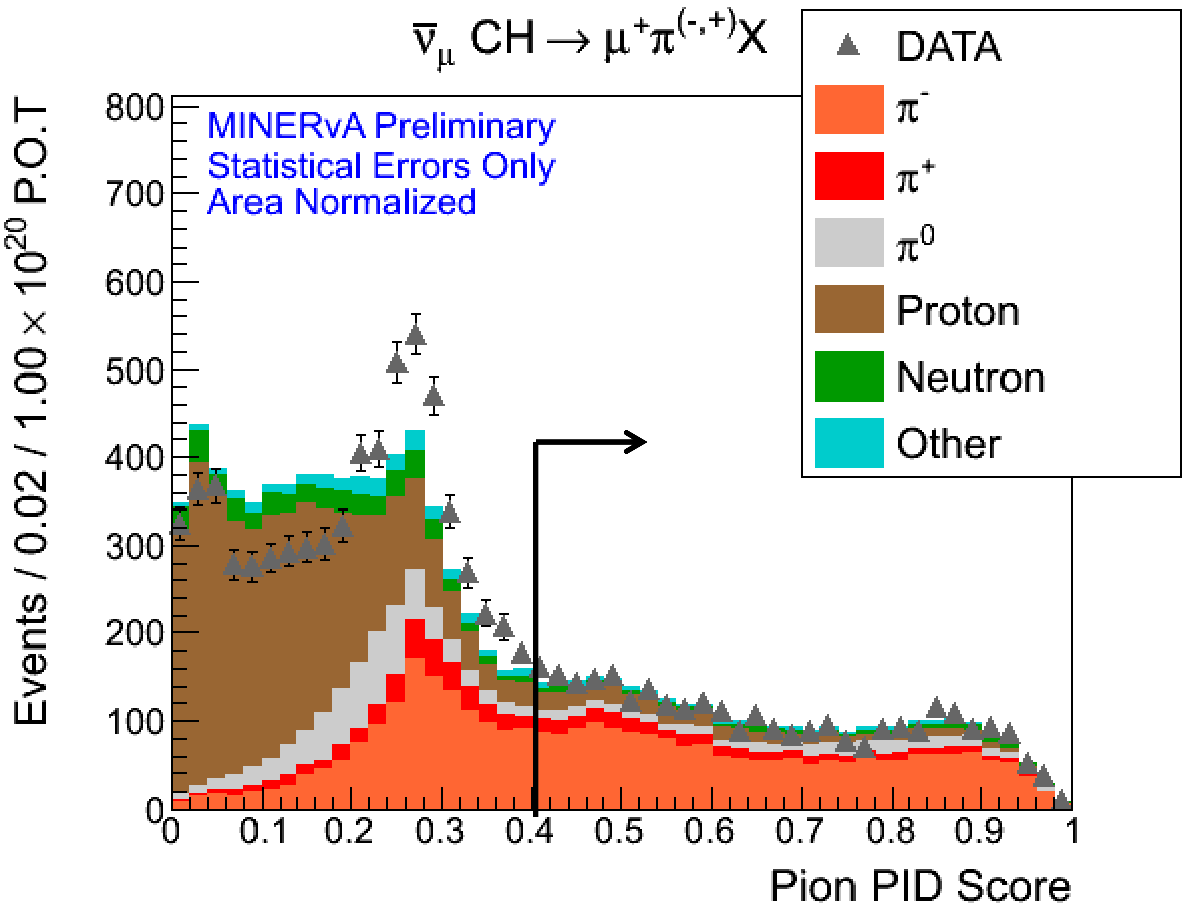
- It will be interesting to see the relative sizes of forwards and backwards peaks after correcting for detector efficiency





PID Cut (Particle Content)

- Non-pion content is mostly proton, just like neutrino analysis



Stopping ID Cut

•Stopping ID does not significantly change sample purity; it is most helpful in selecting pions with good reconstructed KE