CC Inclusive Pion Production in MINERνA

Brandon Eberly
University of Pittsburgh
April 16, 2012

On behalf of the MINERνA collaboration

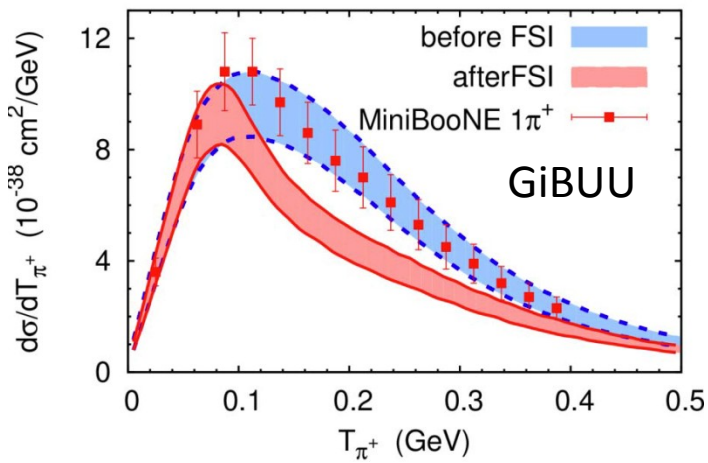
APS April Meeting 2013

Introduction and Motivation

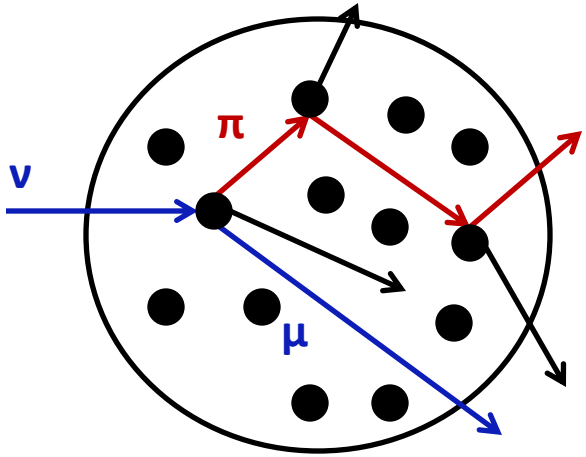
- MiniBooNE recently published a suite of cross section measurements for charged current single pion production by neutrinos on mineral oil:

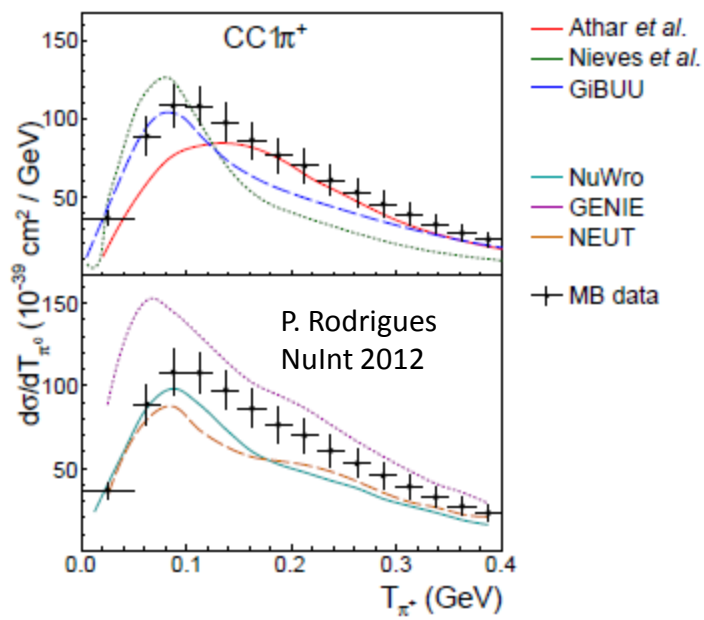
$$\nu_\mu CH_2 \rightarrow \mu^- \pi^+ X$$

- The MiniBooNE data appears to favor models that do not include final state interactions (FSI)



FSI: particle content and kinematics are altered by interactions with bound nucleons





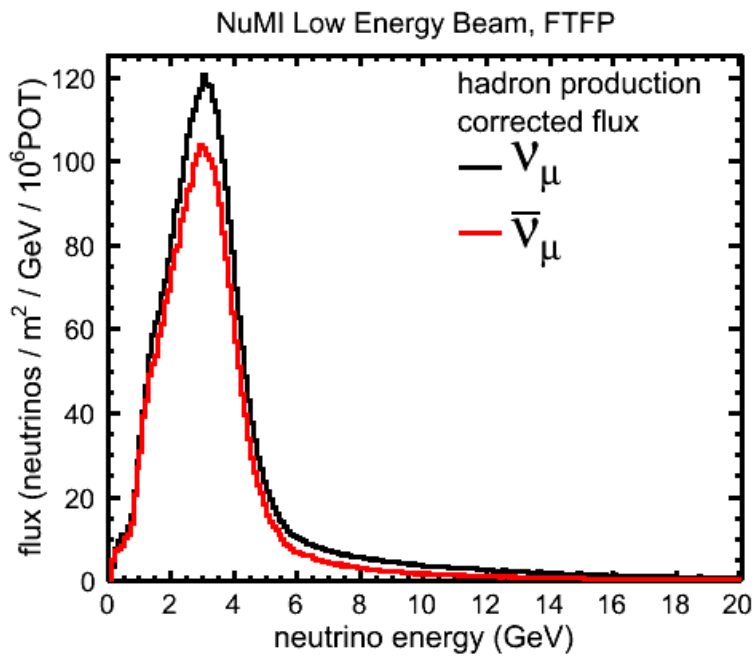
MINERνA and Pion Production

- MINERνA is a dedicated neutrino cross section experiment capable of making measurements that are complimentary to MiniBooNE
  - Higher beam energy (~3 GeV vs. ~0.7 GeV)-> more multi-pion final states and deep inelastic scattering (DIS)
  - Scintillator tracker -> Can reconstruct pions via tracks and dE/dx in addition to Michel electron tagging.

- Today I will show the current status of MINERνA's ν_μ CC inclusive $\pi^\pm$ production analysis on scintillator (CH).
  - Using approximately 25% of the full ν_μ dataset

- Require $\pi^\pm$ in the final state, leading to a nuanced signal definition. For example:

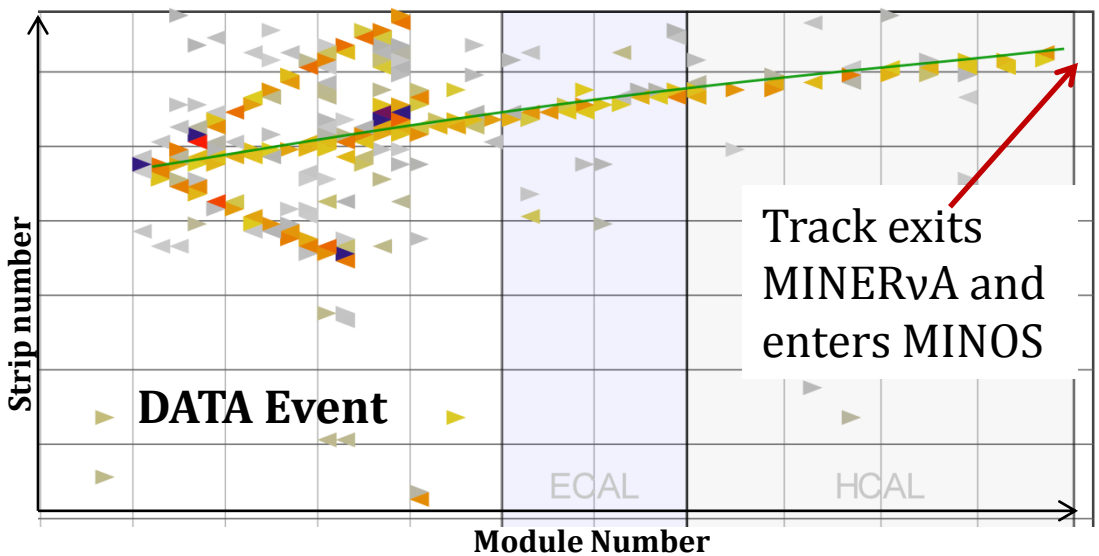
  $\nu_\mu p \rightarrow \mu^- \Delta^{++} \rightarrow \mu^- \pi^+ p$
  - Signal if pion exits the nucleus
  - Background if pion is absorbed inside the nucleus

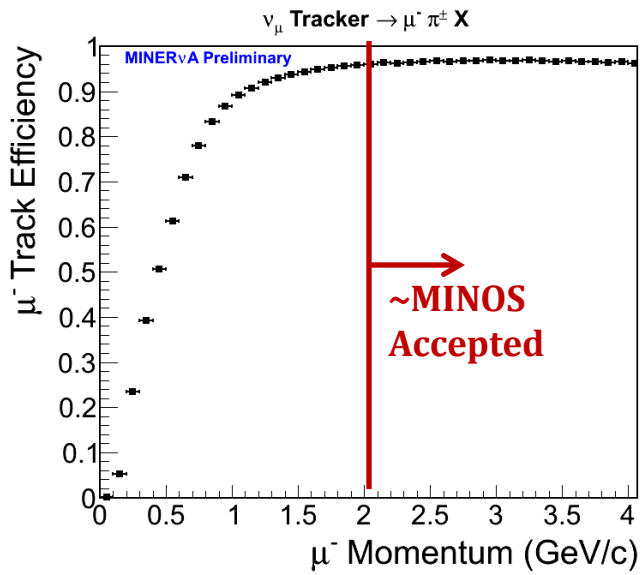


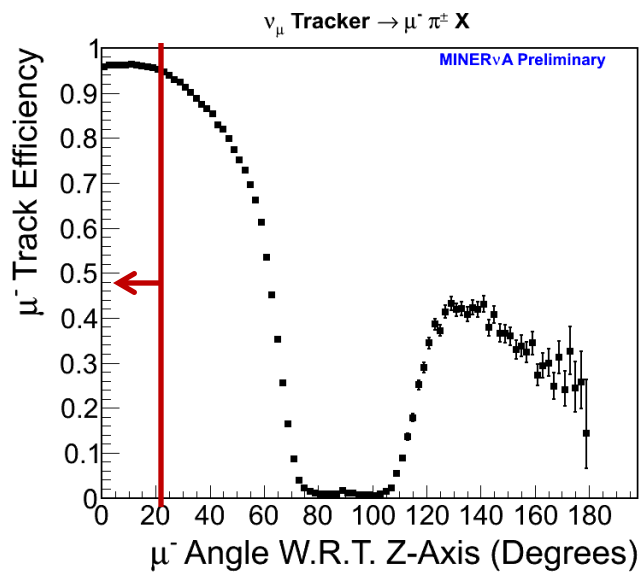
Muon Reconstruction

- Require a reconstructed muon track that matches a track in MINOS with the desired reconstructed charge.

- MINOS muon acceptance (approximate):
  - Greater than 2 GeV/c
  - Less than 20°

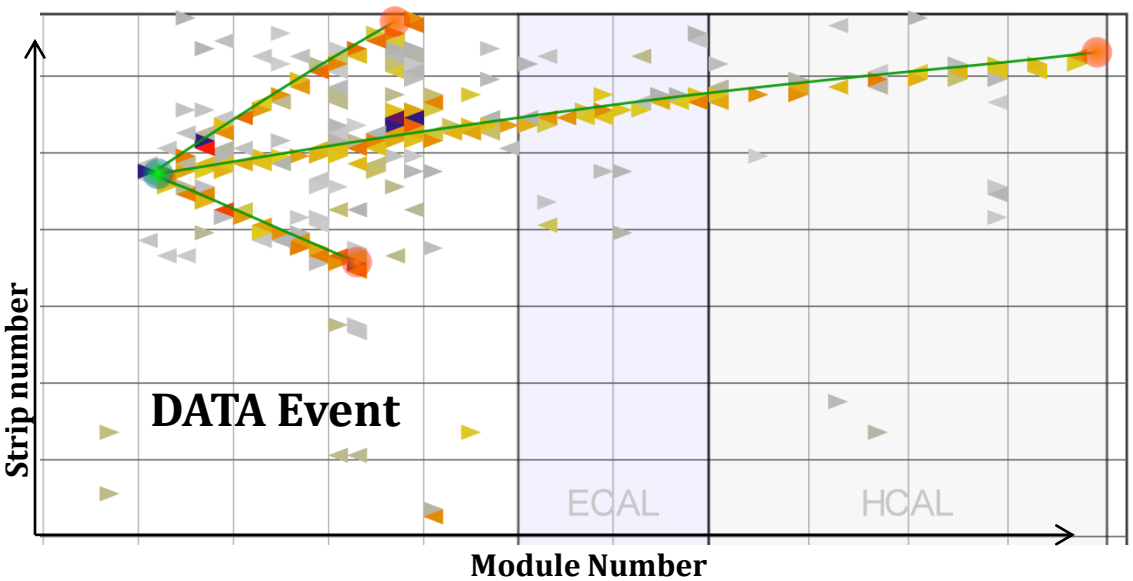


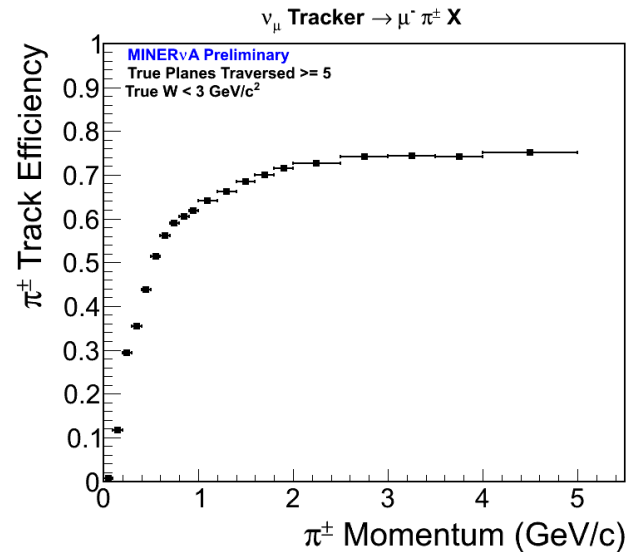


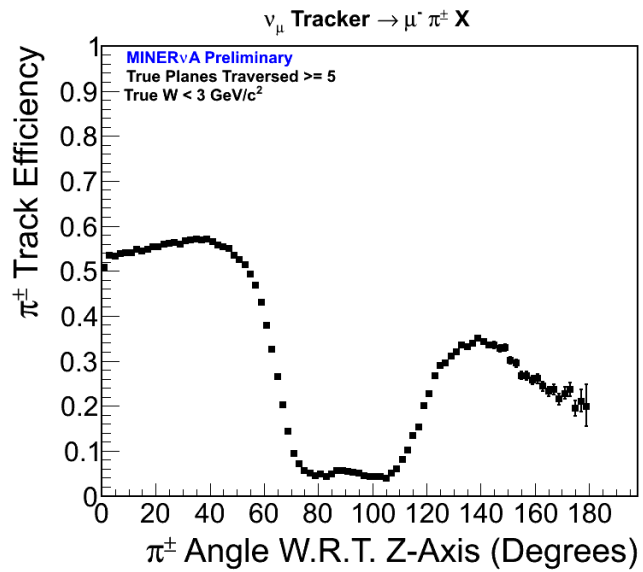


Hadron Track Reconstruction

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

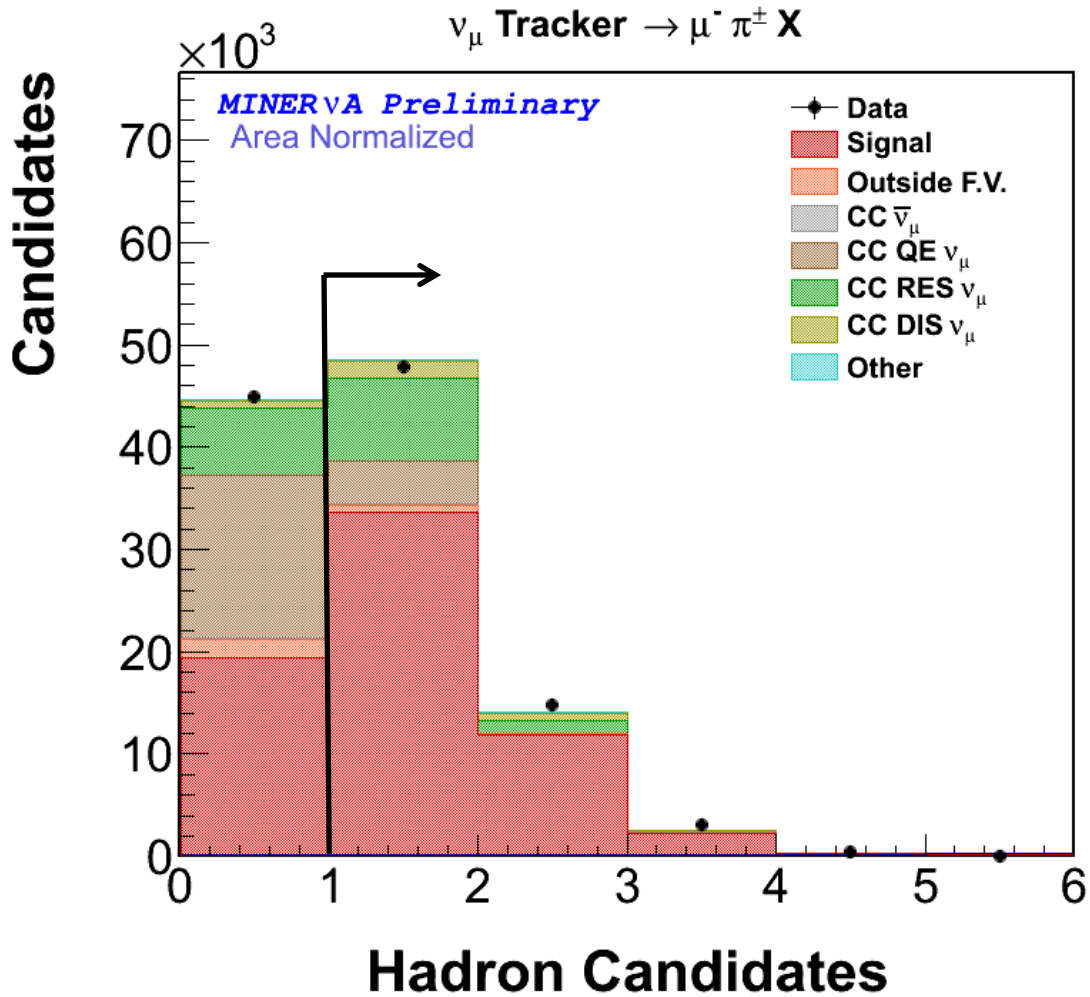






Hadron Track Reconstruction

- Require at least one hadron track at the primary vertex

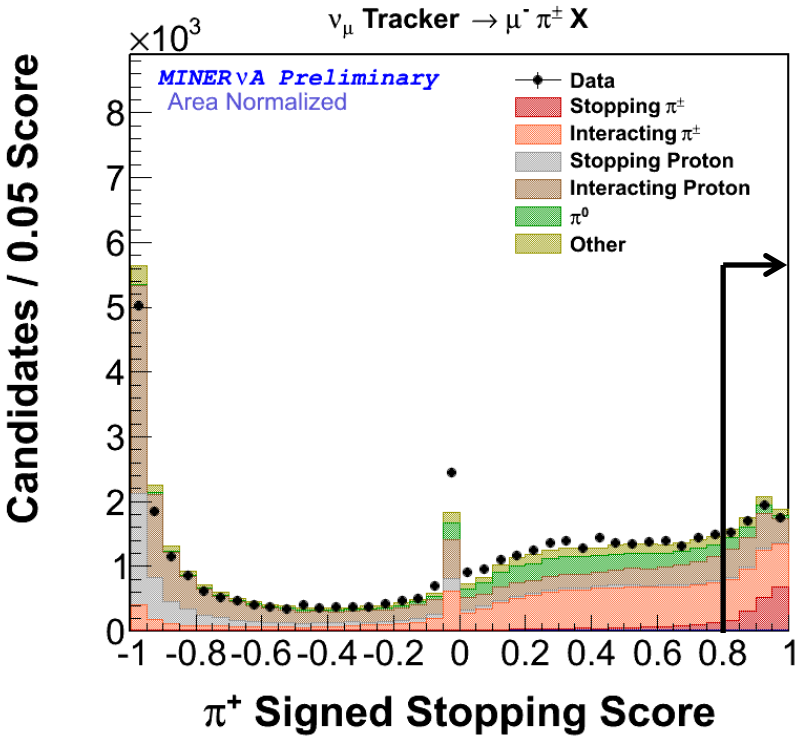


Particle Identification (PID)

•Stopping ID: Compare the energy deposited at the end of each reconstructed hadron track to templates generated from simulation.

Require that the track is contained in the scintillator tracker and is consistent with a stopping pion template.

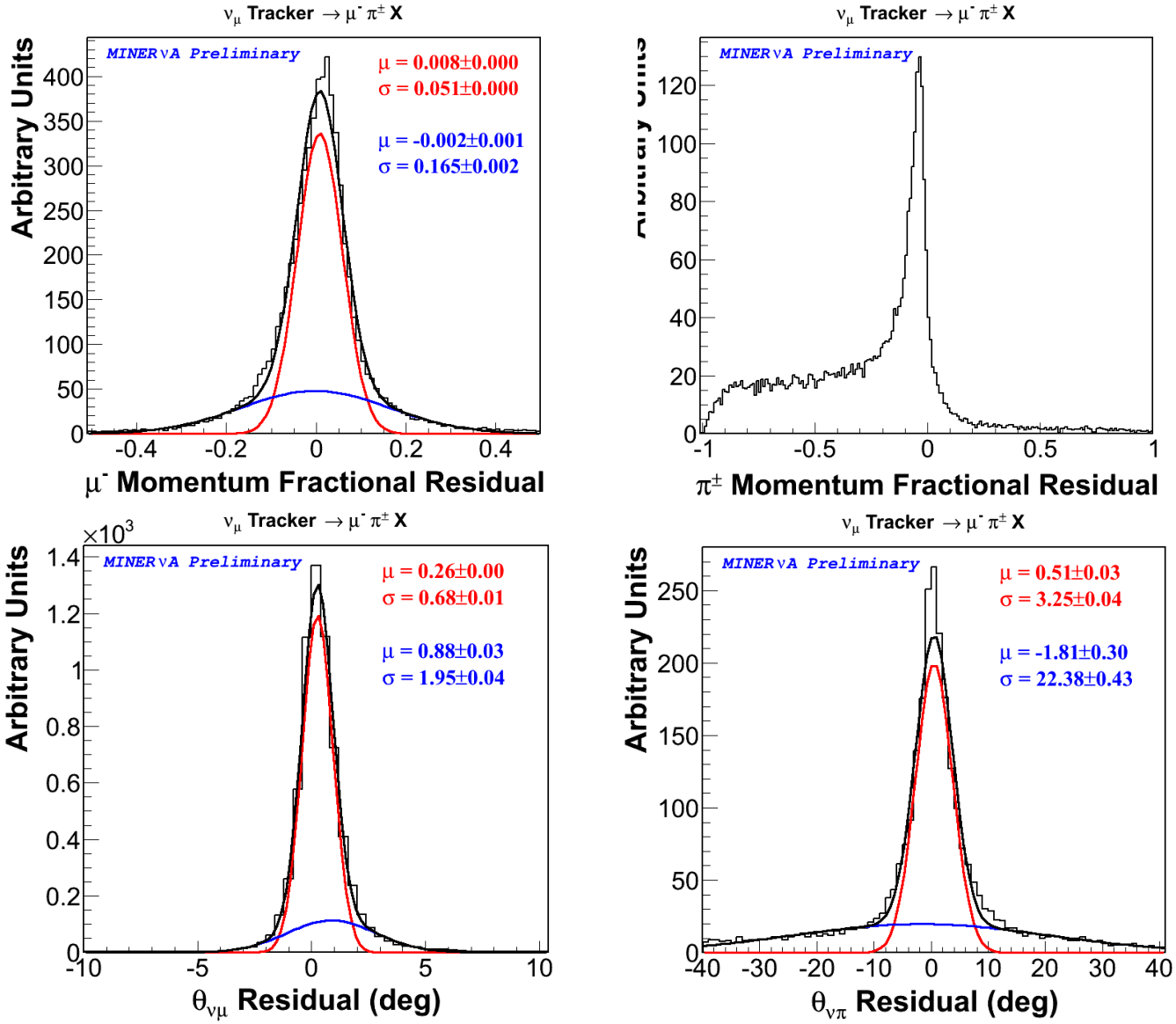
•Stopping ID rejects most protons, retains most stopping pions, and provides a sample that allows good energy reconstruction by range.



•Working to improve PID by using the entire dEdX profile.

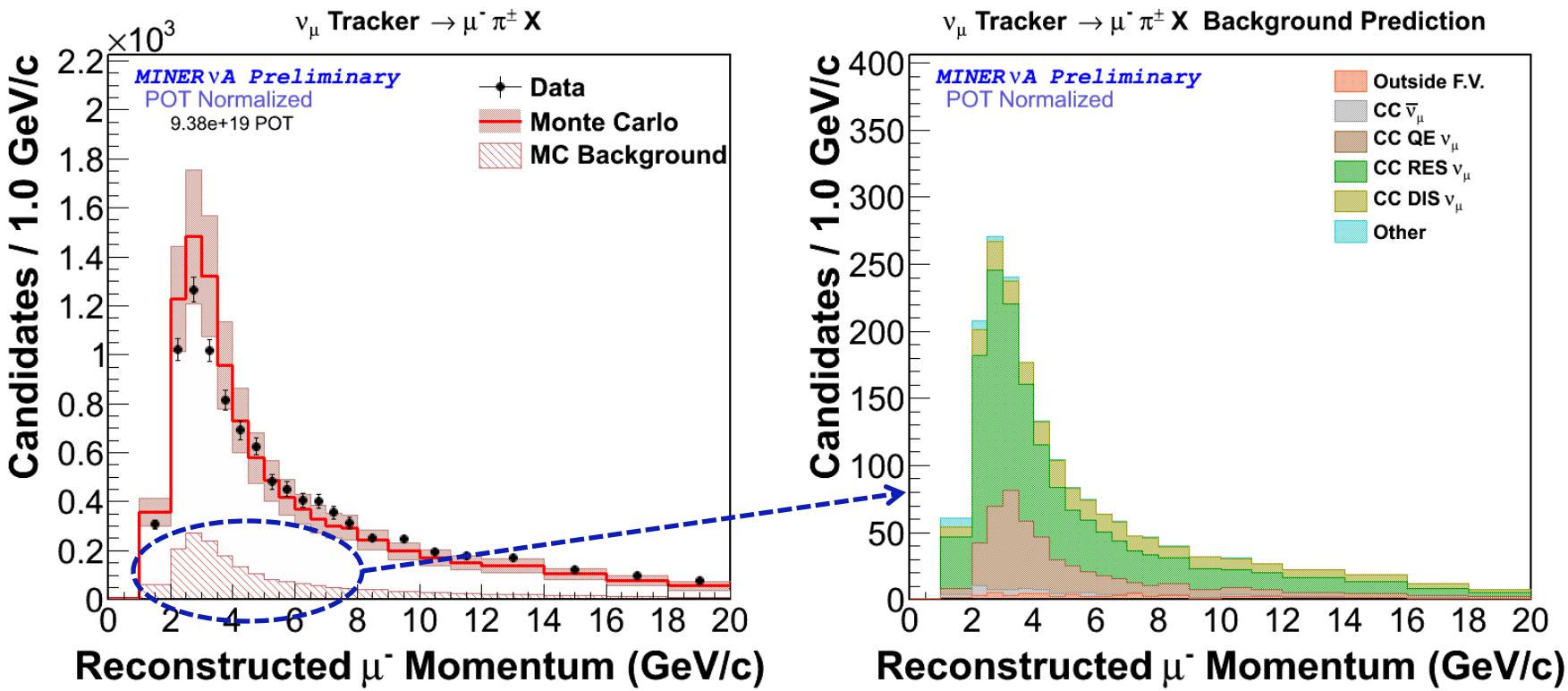
•Overlapping particles in high multiplicity interactions leads to difficulties.

Reconstruction Resolutions



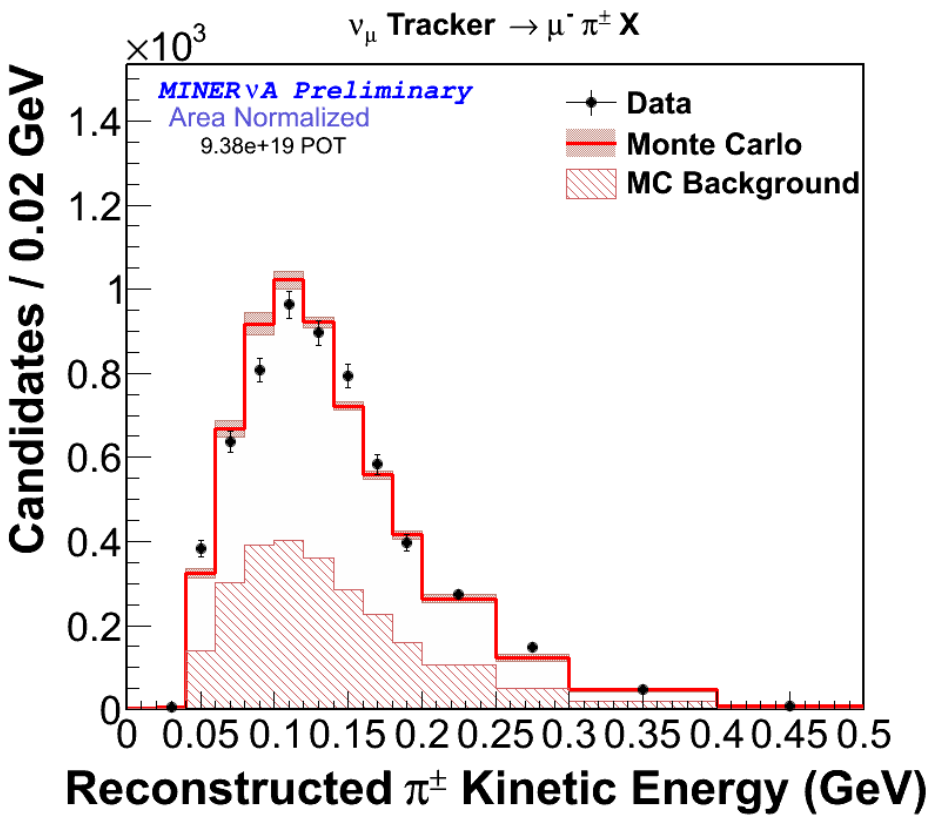
Reconstructed Muon Momentum

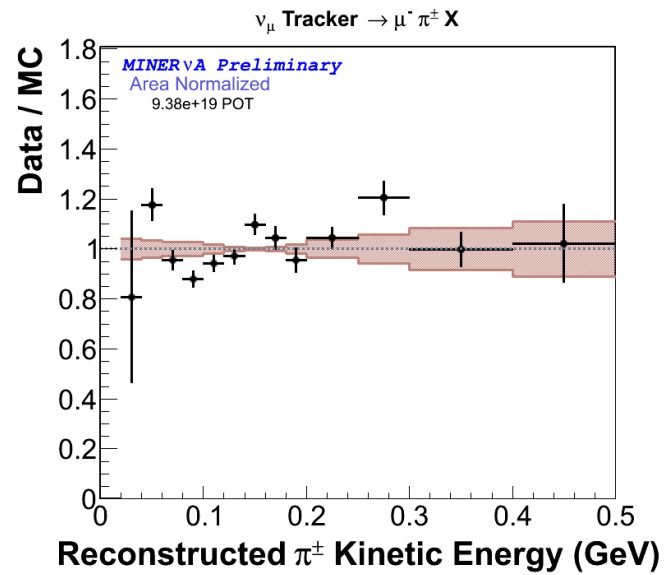
- Selection purity is ~83%, with a pion mis-ID rate of ~25%
- Large flux systematic errors on the MC prediction

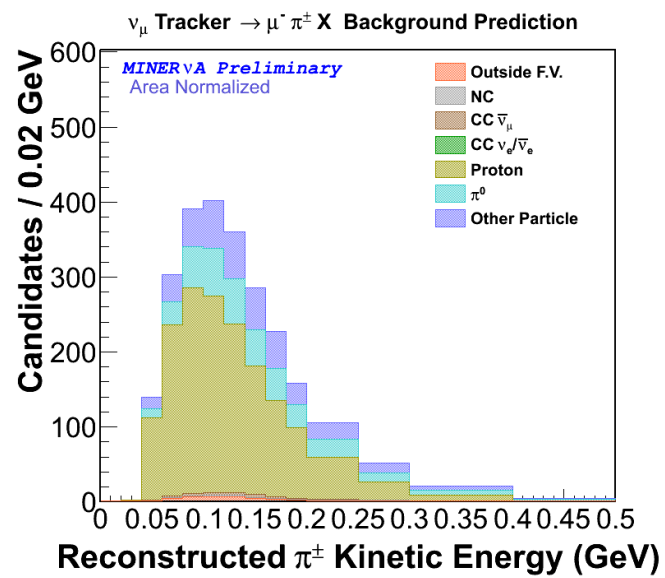


Reconstructed Pion KE

- Area normalize to reduce flux systematic errors
  - Can still look for FSI strength in the shape
- Background prediction includes mis-ID pions





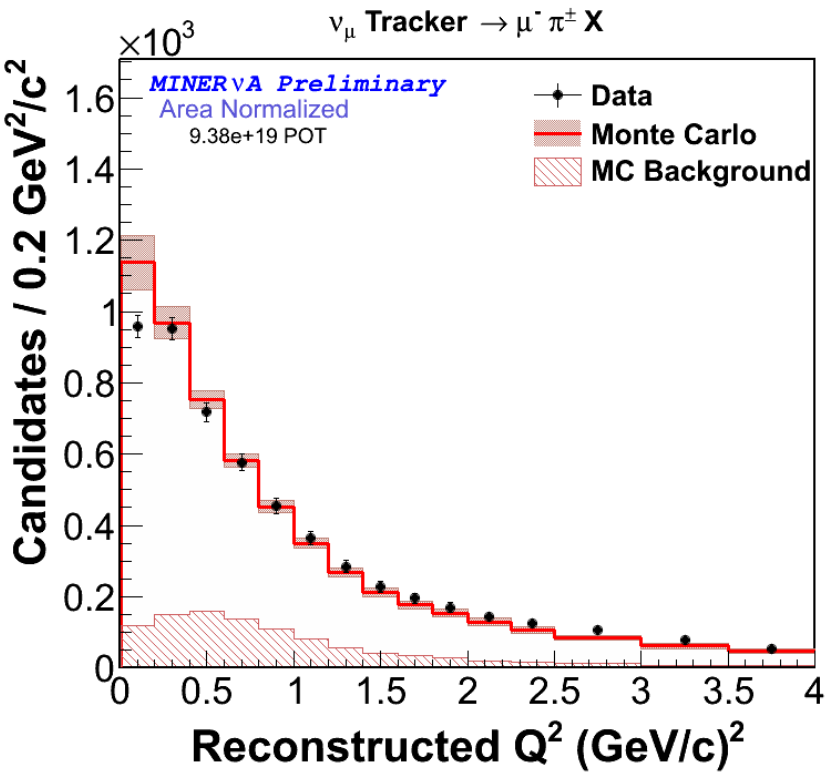


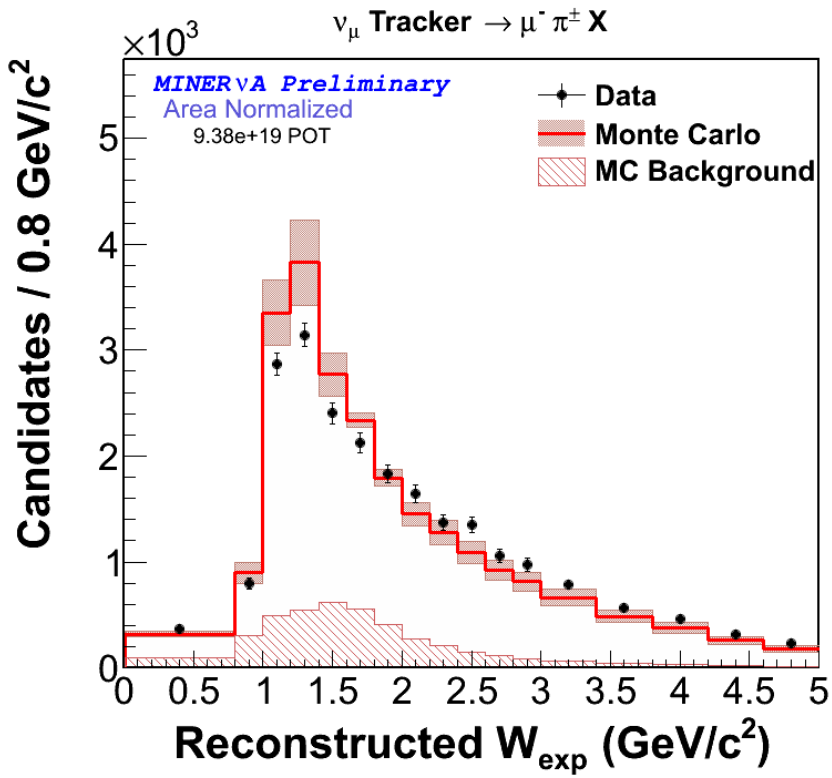
Reconstructed Q^2 and W_{exp}

- Q^2 resolution is ~ 25%
- W_{exp} resolution is ~ 10%

$$E_\nu = E_\mu + E_{recoil}$$
$$Q^2 = 2E_\nu(E_\mu - p_\mu \cos\theta_{\mu\nu}) - m_\mu^2$$
$$W^2_{exp} = -Q^2 + m_n^2 + 2m_n(E_{recoil})$$

- Good kinematic coverage into high Q^2 and W_{exp} regions





Conclusions, Next Steps

•The consistency of MiniBooNE's pion cross section data with no-FSI models is a mystery that requires additional measurements to be solved

•The MINERνA CC inclusive pion analysis has developed selection criteria with ~83% sample purity, a ~25% pion mis-ID rate, and good reconstruction resolutions.

Next Steps:

•Use the sidebands of the PID distributions to constrain the background prediction

•Apply detector resolution corrections ("unfolding") to background-subtracted distributions. Apply efficiency corrections

•Evaluate systematic errors related to hadron reconstruction

Backup Slides

CC Inclusive Pion Measurements

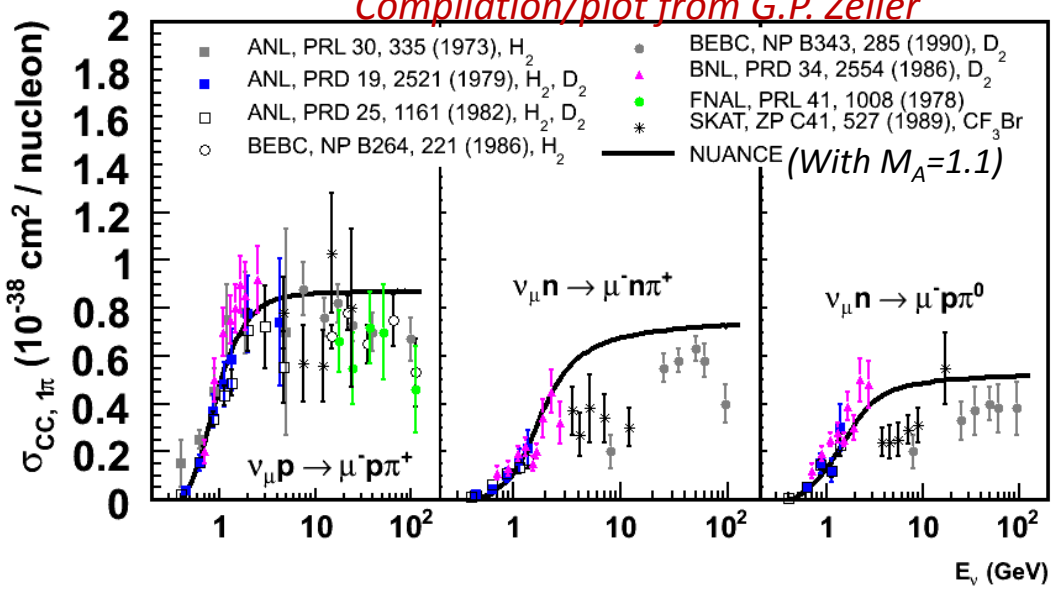
- Early experiments measured exclusive final states on H and D bubble chambers

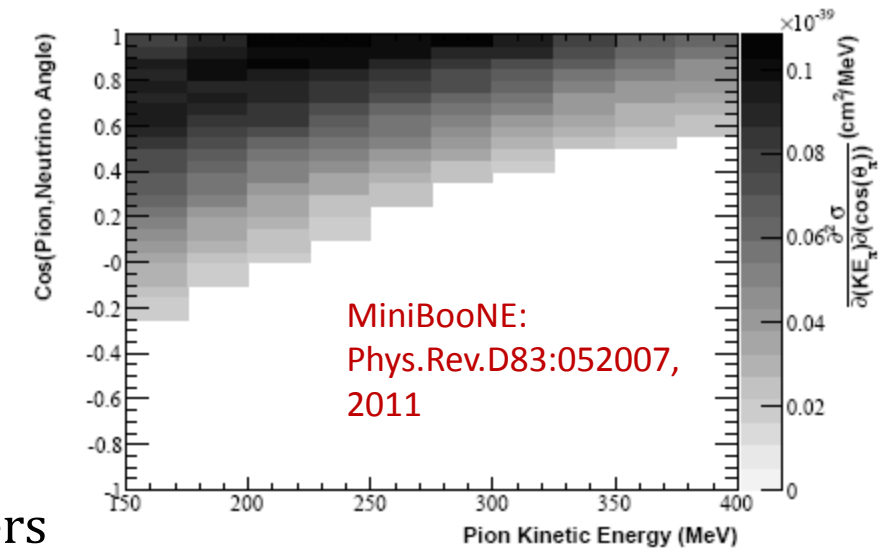
- The only high-statistics measurement is single π^+ inclusive by MiniBooNE on CH_2 at ~ 1 GeV (~48k candidates)

- 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

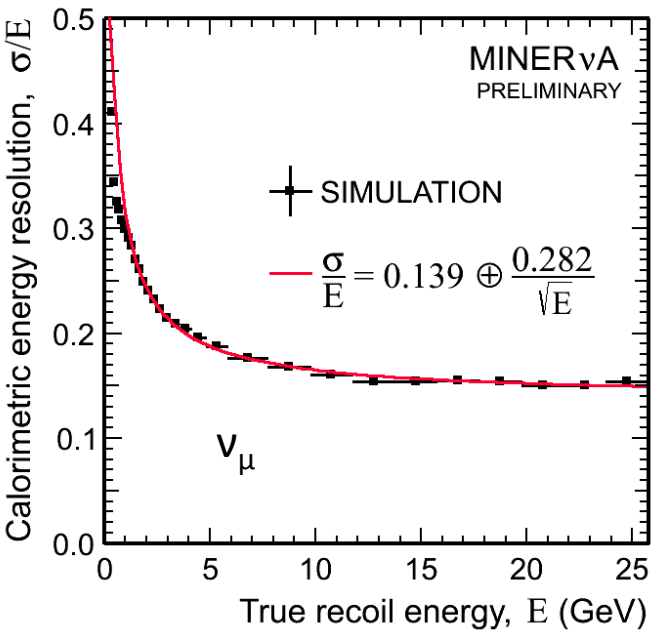


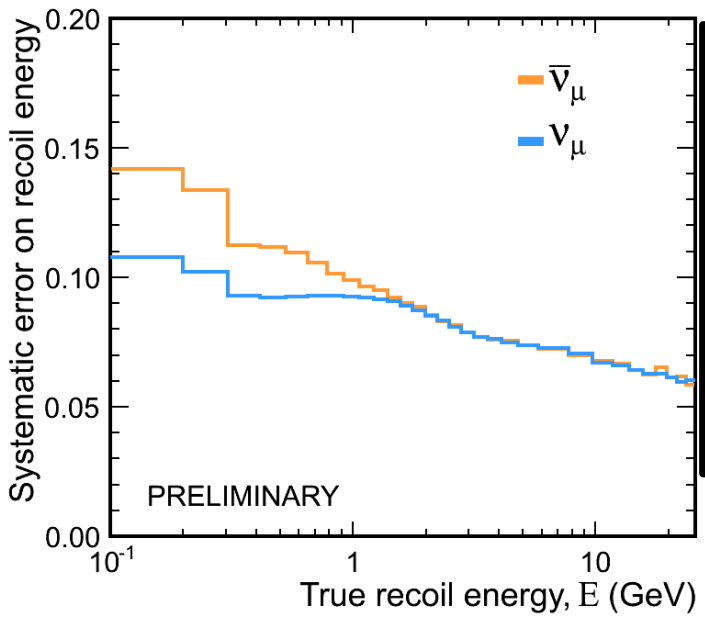


Hadronic Recoil Reconstruction

- Retrieve all reconstructed hadronic energy in the event and weight the energy deposit according to passive material fraction at its location

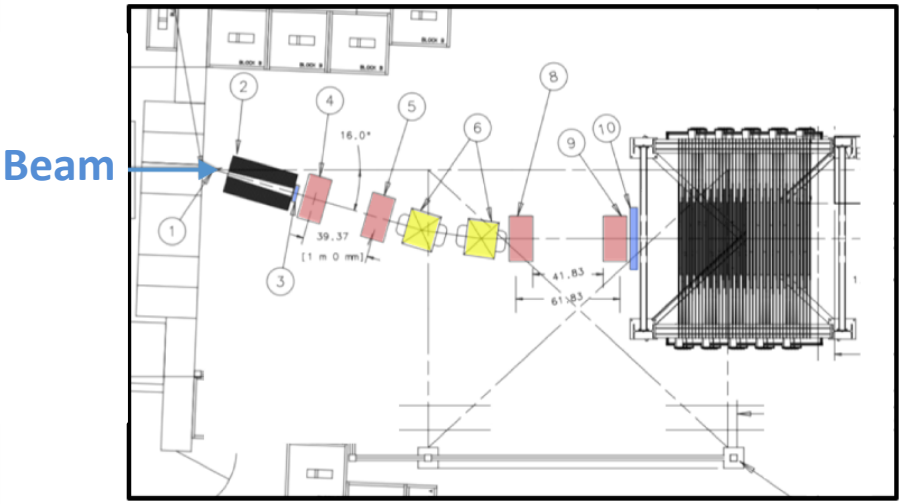
- For CC-Inclusive events, apply an additional energy-dependent correction to better match true recoil in MC
  - This correction also works very well for CC-Inclusive pion events

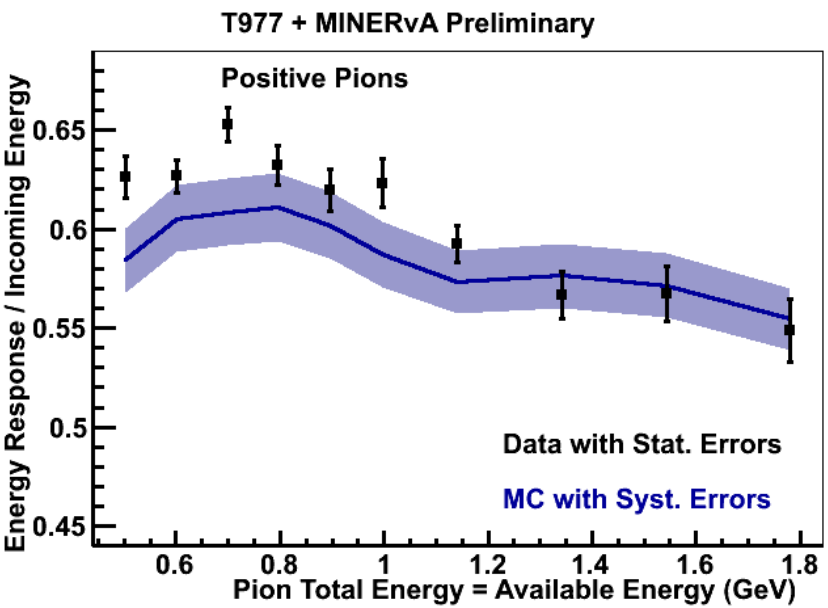




Convolution of single particle uncertainties
π,K = 5%
e,γ = 3%
p = 10%
n = 20%

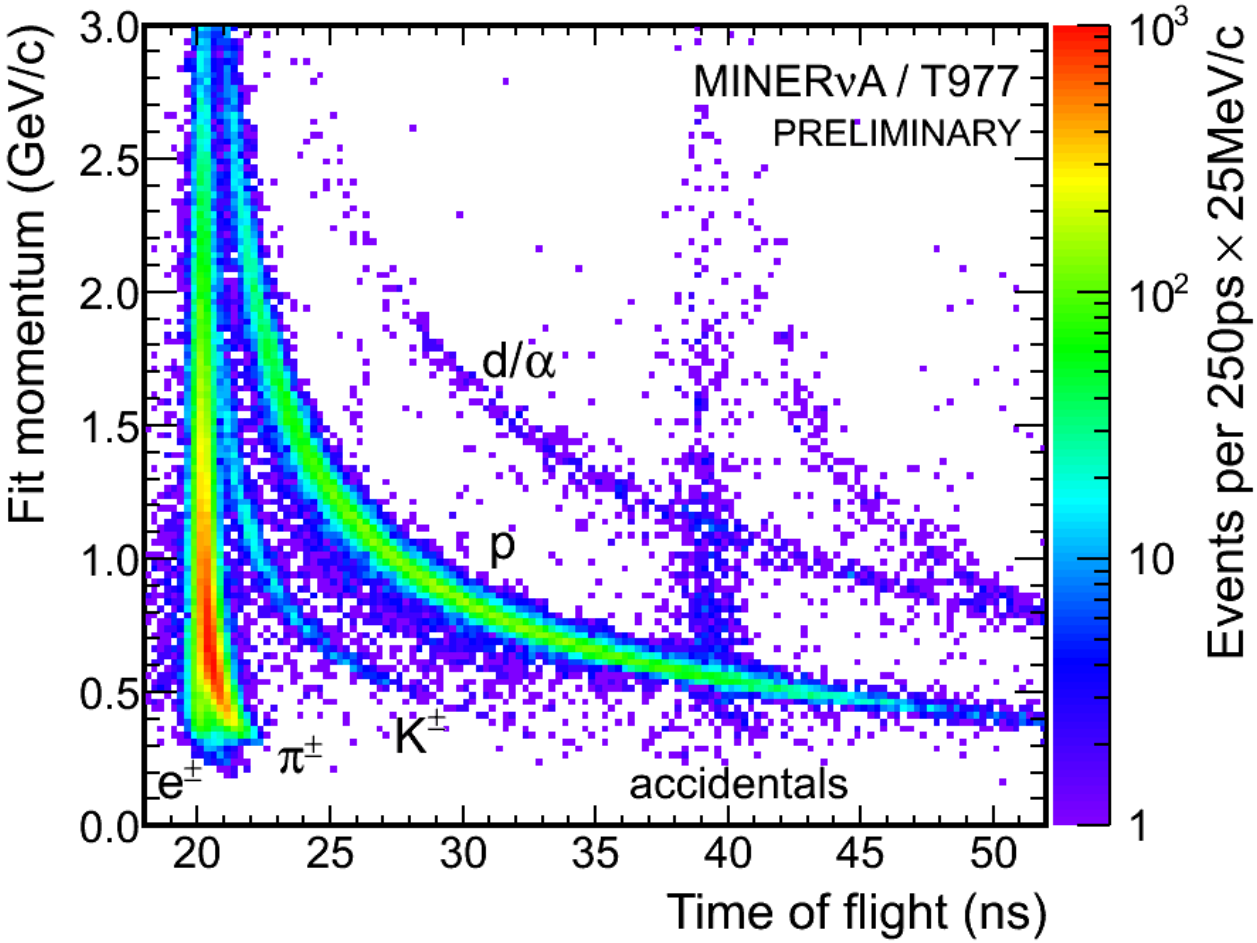
MINERνA TestBeam





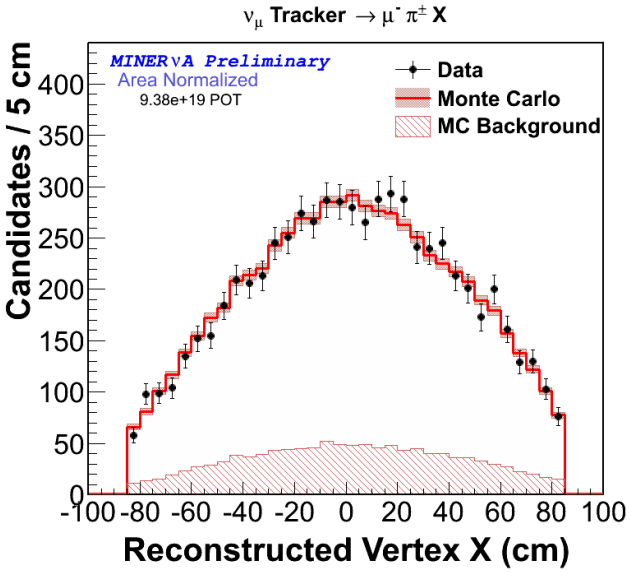
- Mini-MINERνA planes installed in MTEST tertiary beamline
- 0.4-1.2 GeV pions for hadron response calibration
- Reconfigurable – collected data for:
  - 20ECAL-20HCAL
  - 20Tracker-20ECAL
- Current data/MC agreement for π^+ response is ~5% with well-modeled resolution.
  - π^- is slightly better
  -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

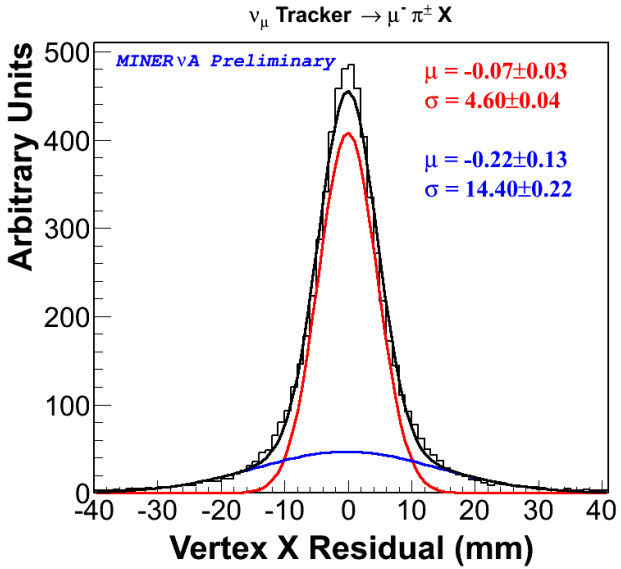
MINERνA Test Beam

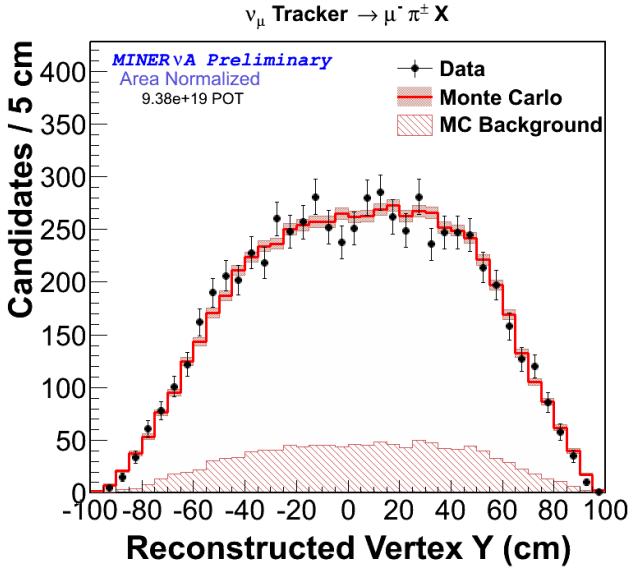


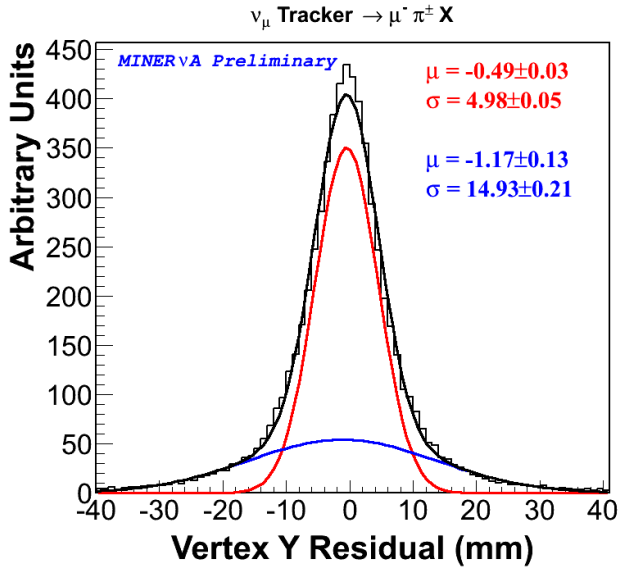
*slide from S. Manly

Reconstructed Vertex XY

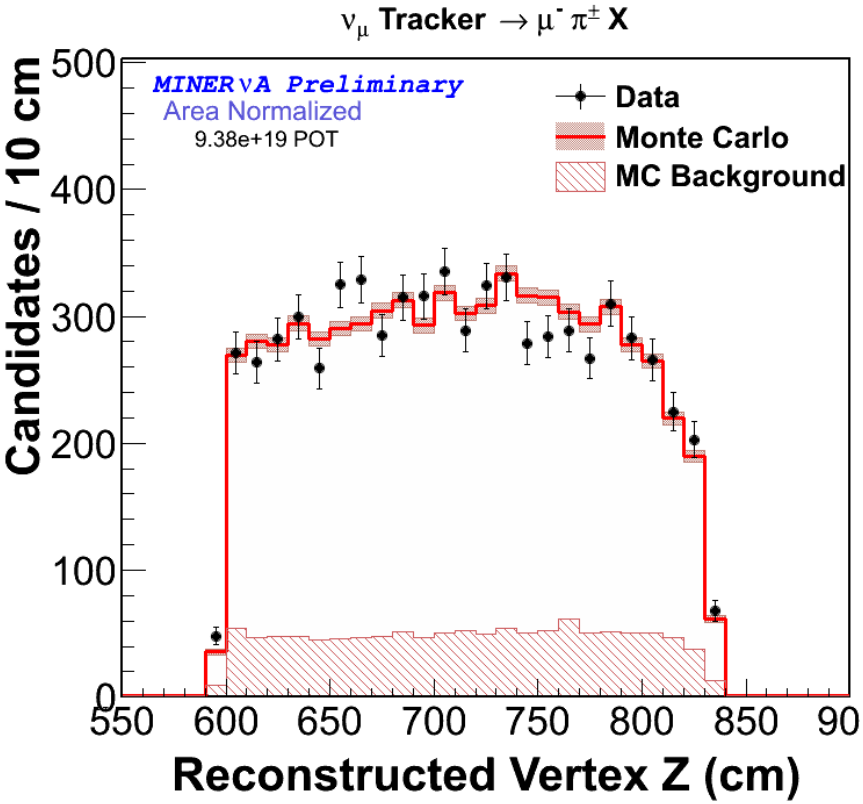


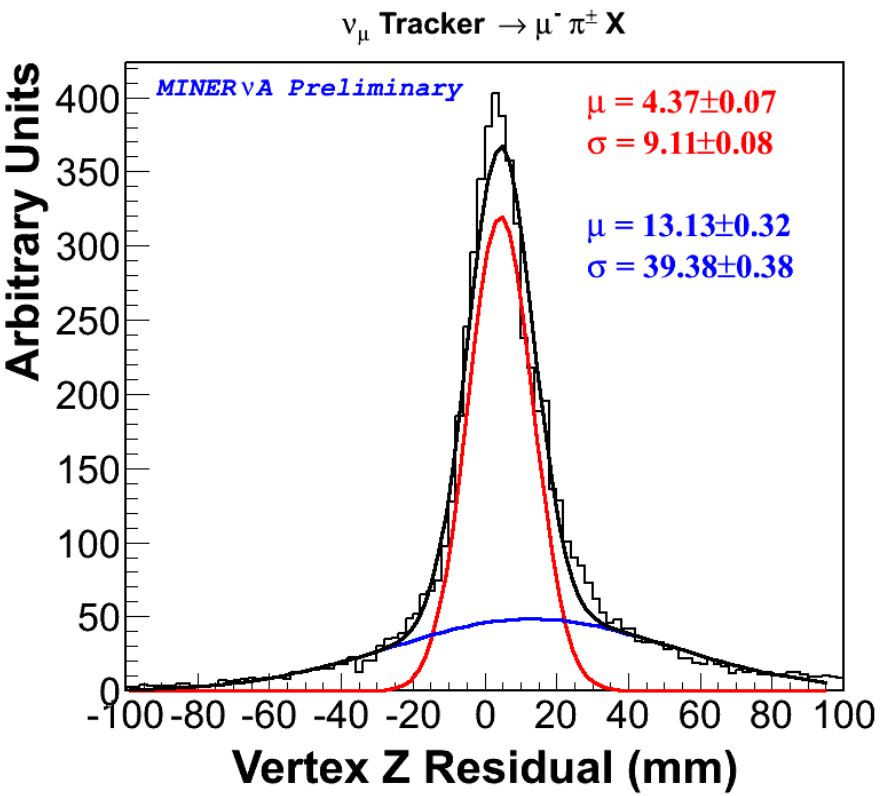






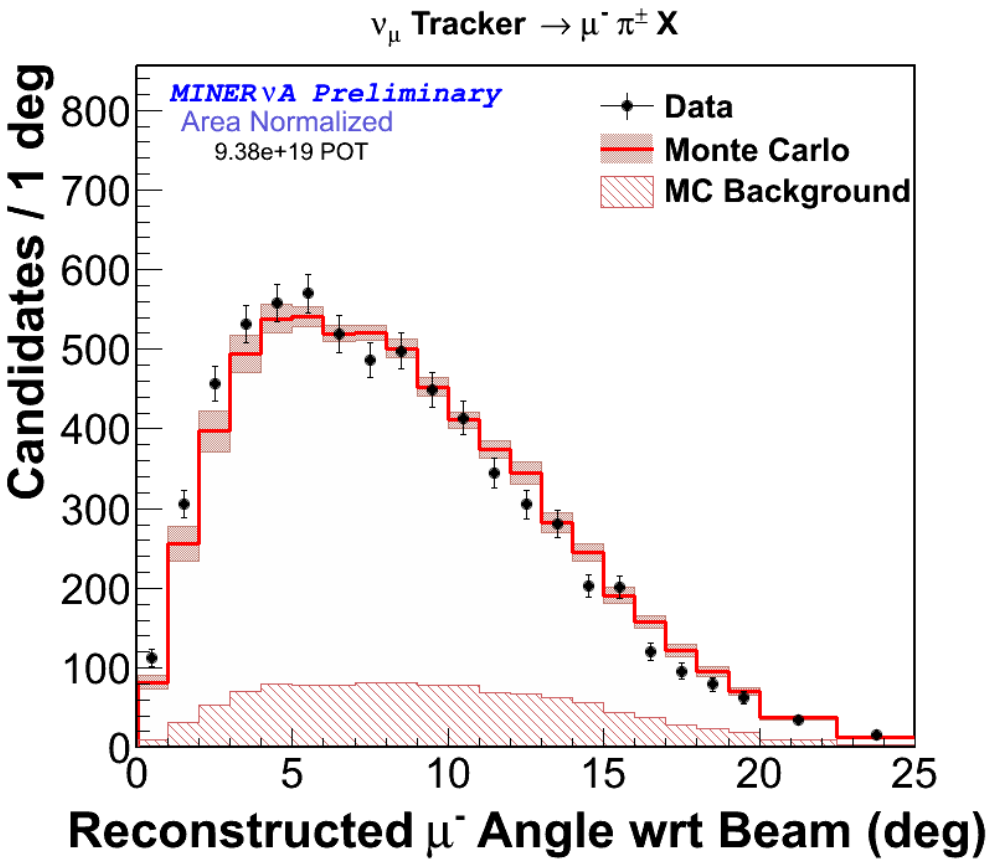
Reconstructed Vertex Z

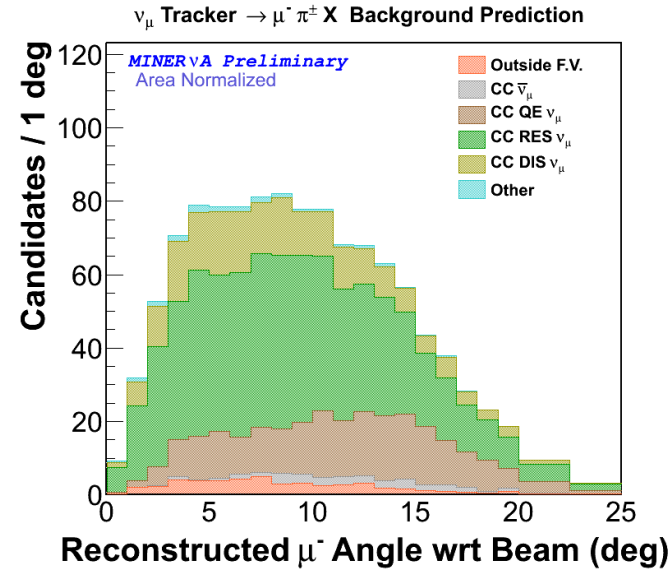


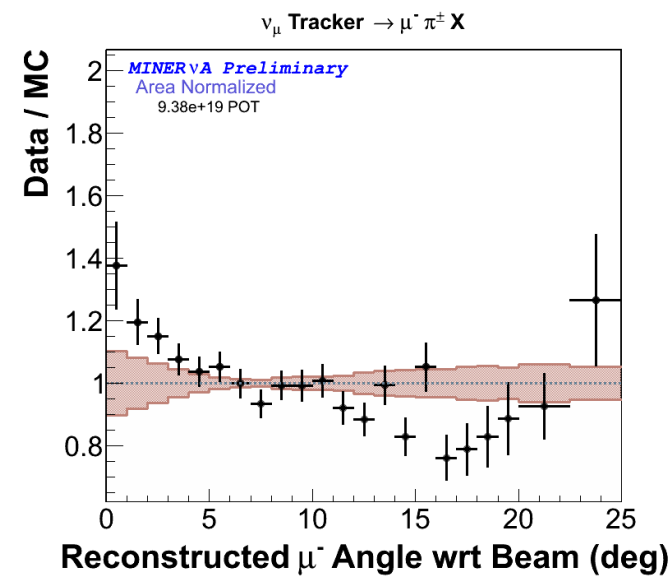


Reconstructed Muon Angle

- MC disagrees in shape at small angles

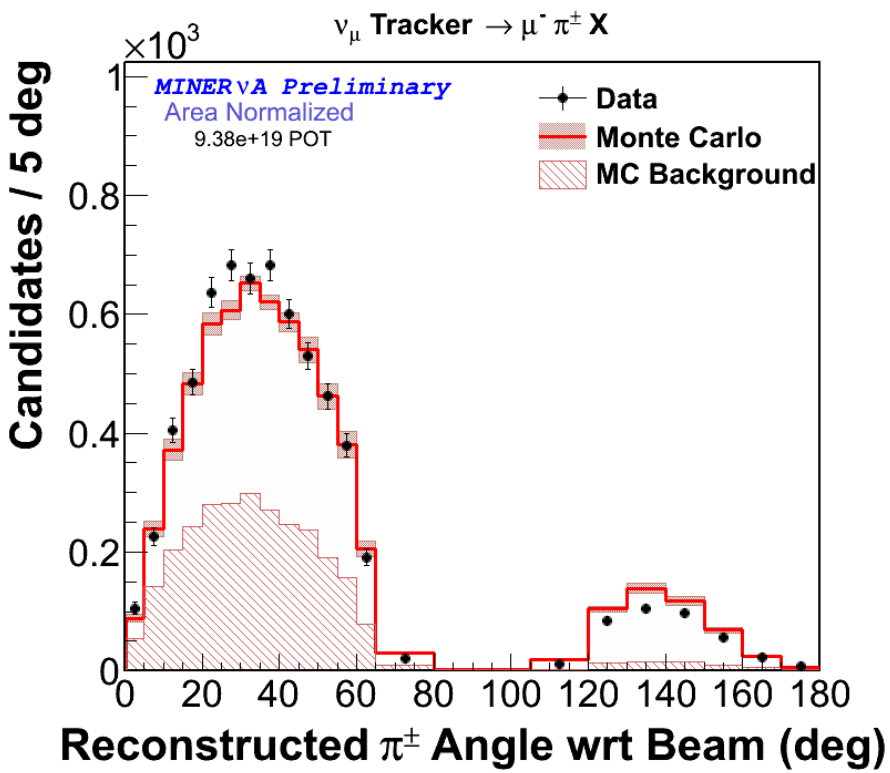


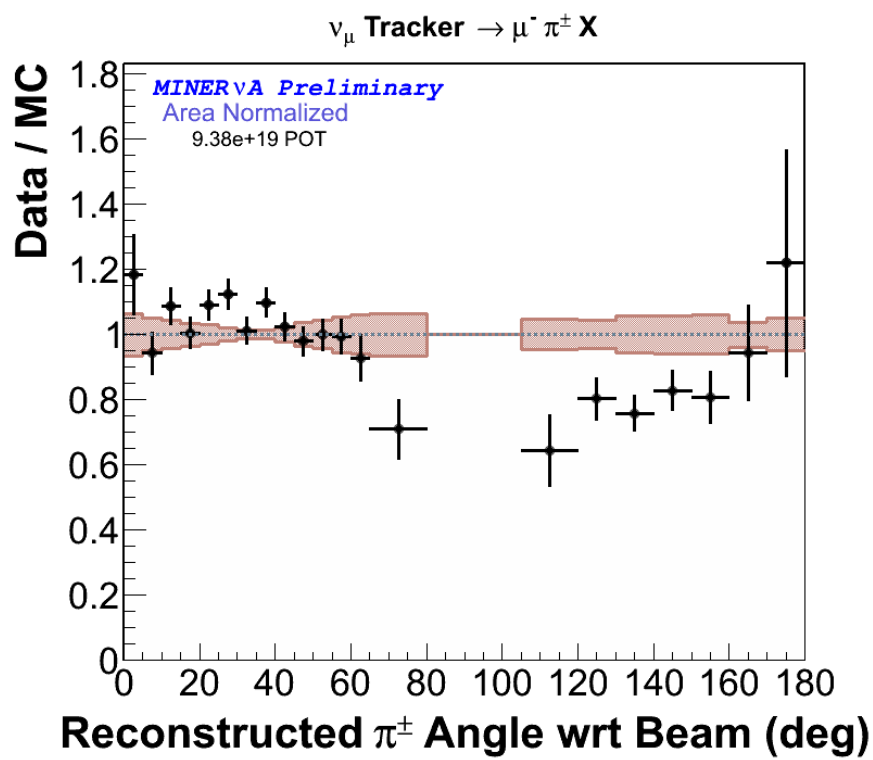




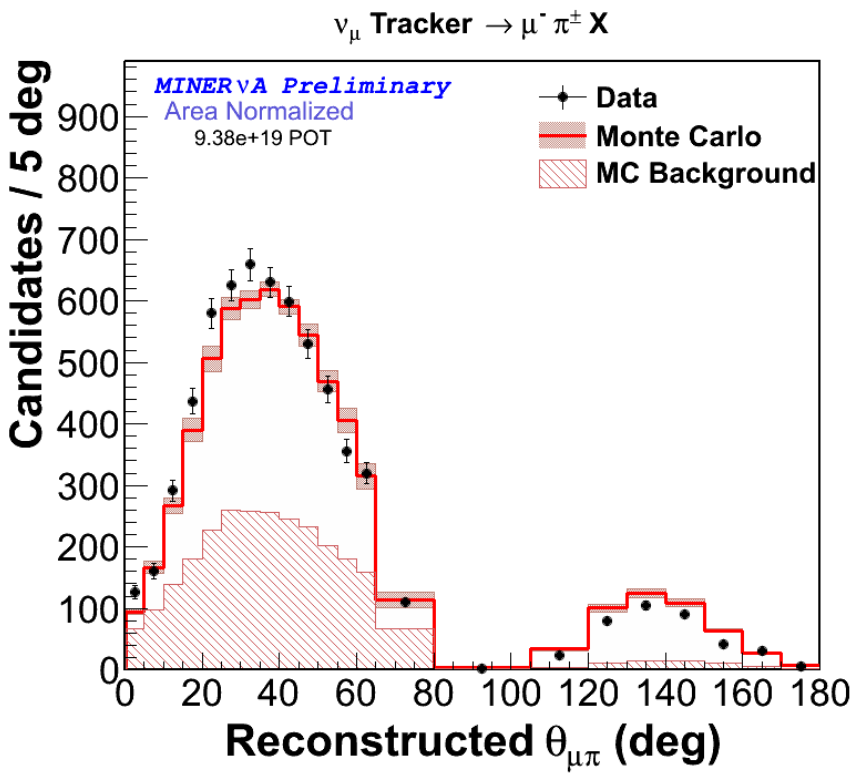
Reconstructed Pion Angle

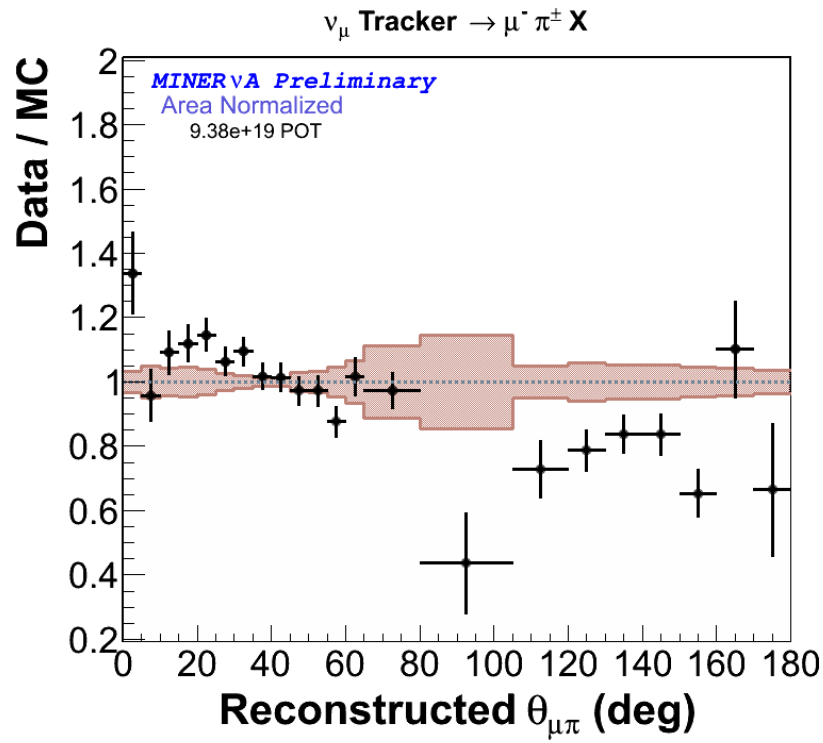
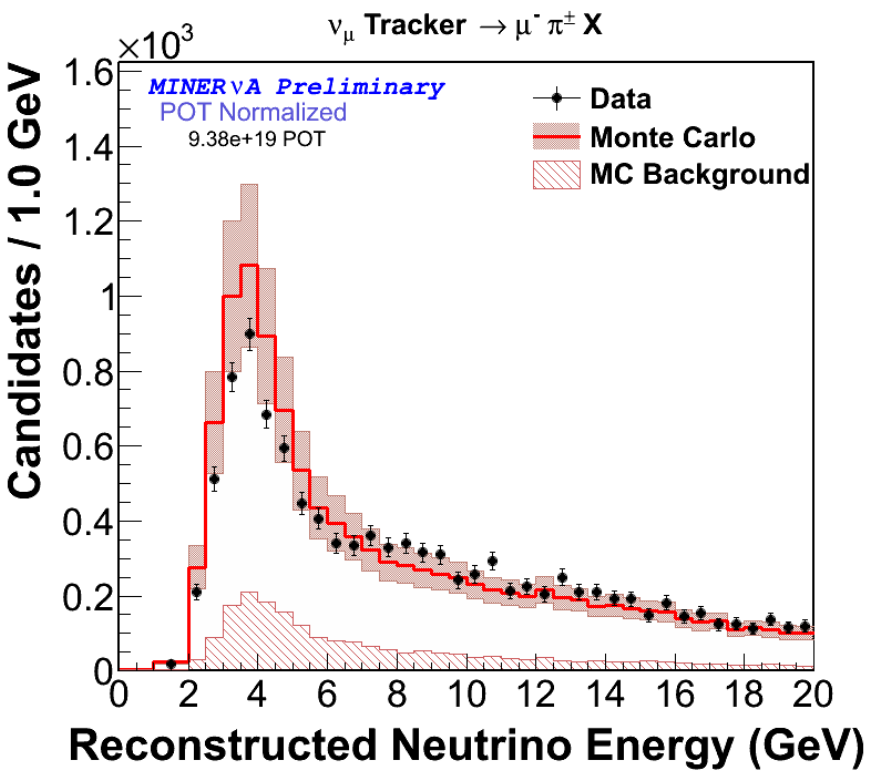
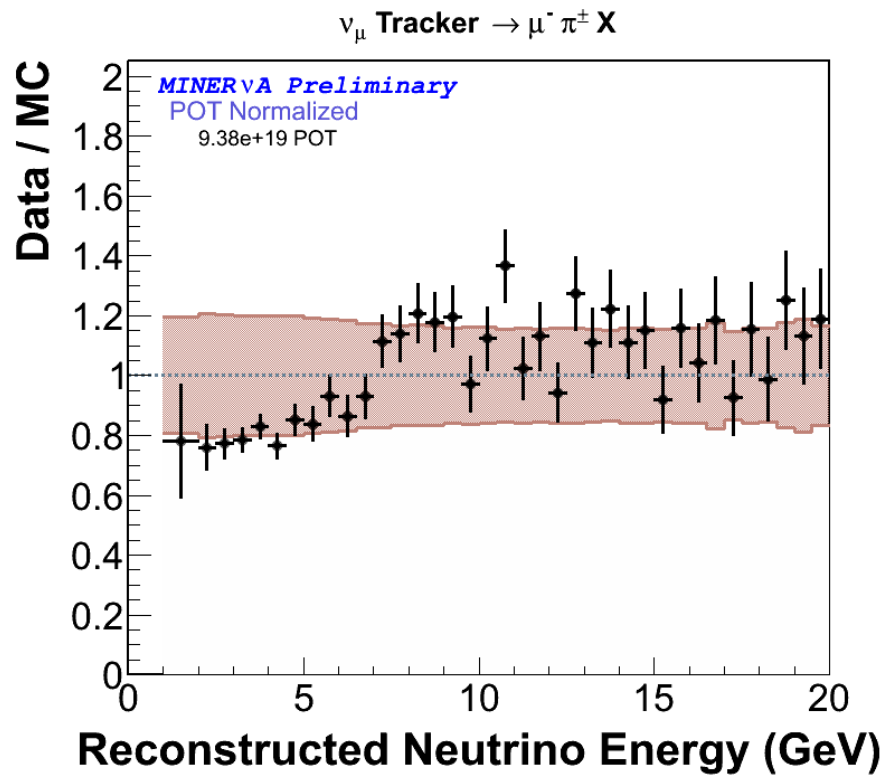
- It will be interesting to see the relative sizes of forwards and backwards peaks after correcting for detector efficiency





Reconstructed Opening Angle





Reconstructed E_ν