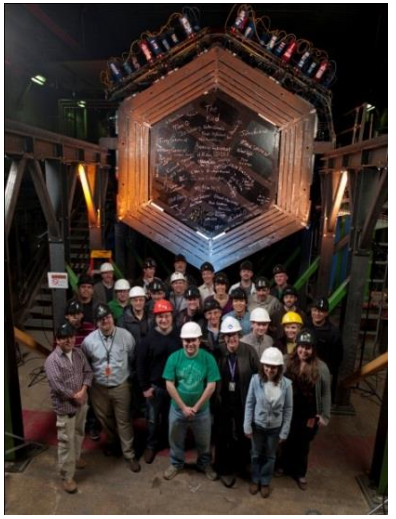
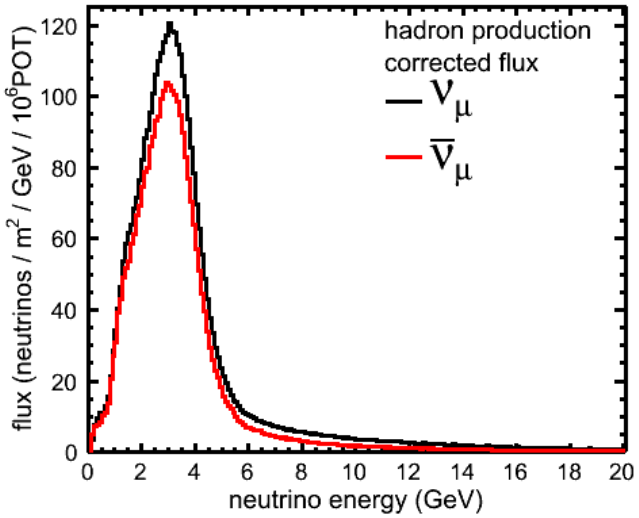
MINERνA Overview



- MINERνA is studying neutrino interactions in unprecedented detail on a variety of different nuclei
- Low Energy (LE) Beam Goals:
  - Study both signal and background reactions relevant to oscillation experiments (current and future)
  - Measure nuclear effects on exclusive final states
    - » as a function of measured neutrino energy
    - » Study differences between neutrinos and anti-neutrinos
- Medium Energy (ME) Beam (NOνA) Goals:
  - Structure functions on various nuclei
  - Study high energy feed-down backgrounds to oscillation expt's
- NuMI Beamline provides
  - High intensity, wide range of available energies
- MINERνA detector provides
  - Reconstruction in different nuclei, broad range of final states

NuMI Low Energy Beam Flux



~65 Particle, nuclear and theoretical physicists from 20

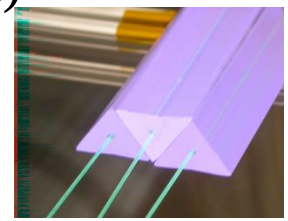


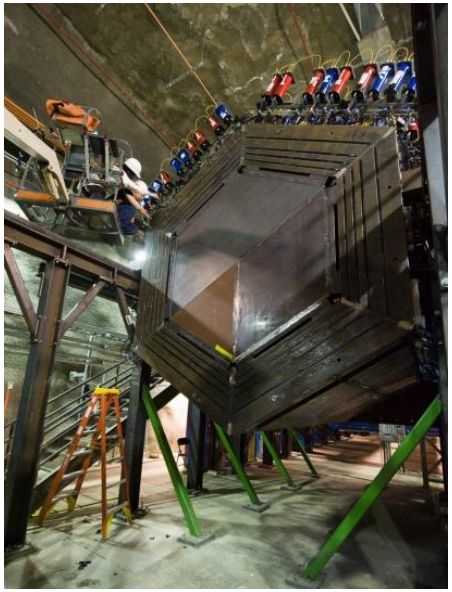




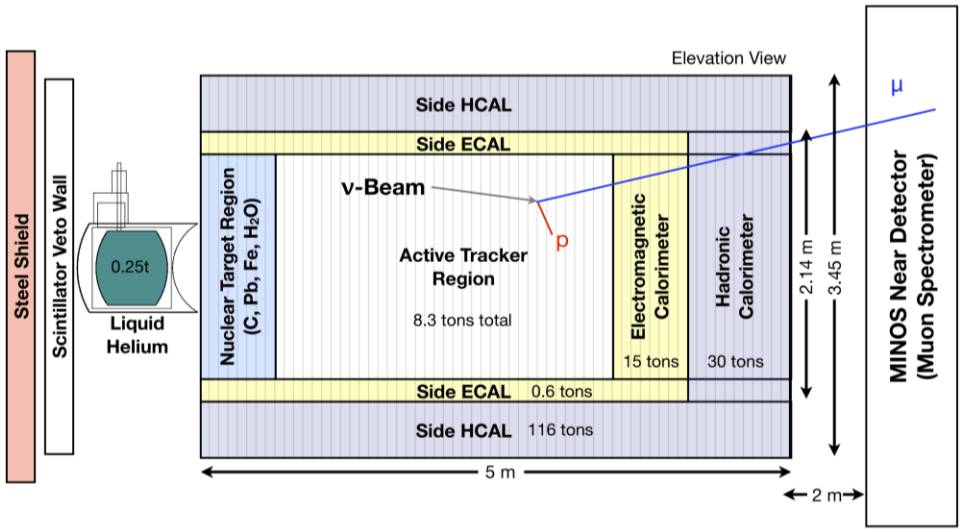
MINERvA Detector Basics

- Nuclear Targets
  - Allows side by side comparisons between different nuclei
  - Pure C, Fe, Pb, LHe, water
- Solid scintillator (CH) tracker
  - Tracking, particle ID, colorimetric energy measurements
  - Low visible energy thresholds
- Side and downstream electromagnetic and hadronic calorimetry
  - Allow for event energy containment
- MINOS Near Detector
  - Provides muon charge and momentum



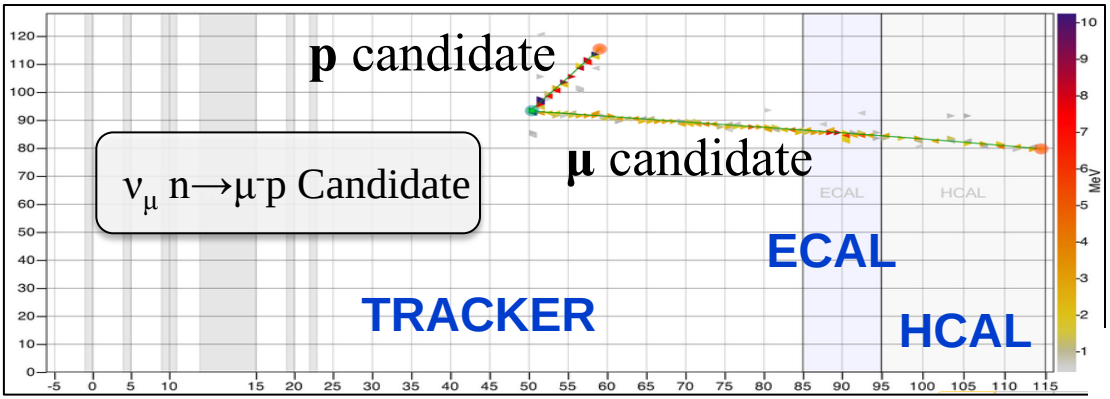


LHe cryotarget

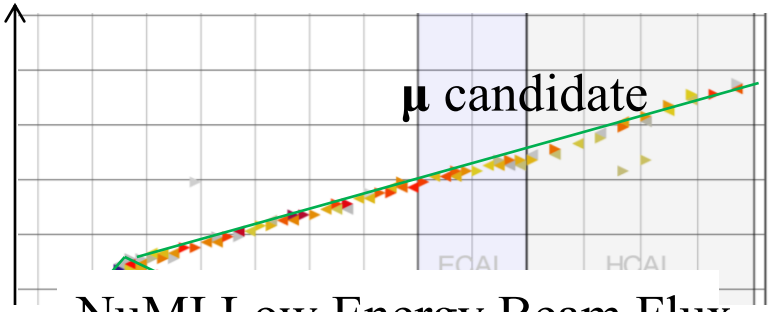


Events in MINERvA

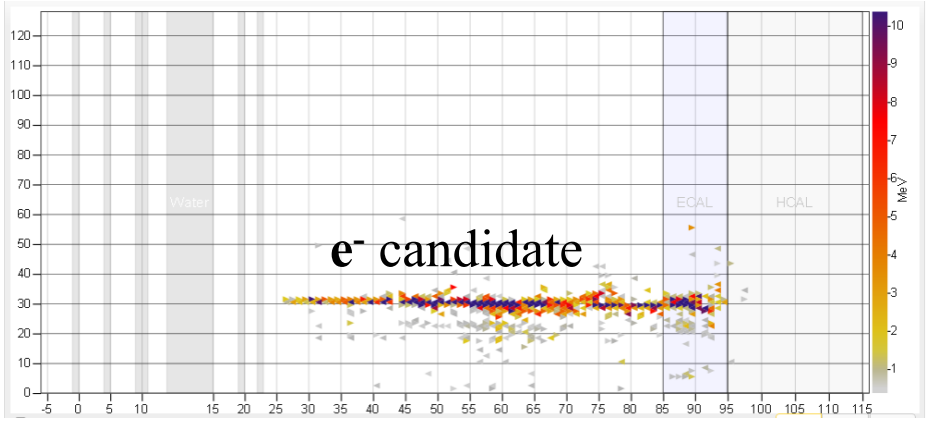
One out of three views shown, color = energy



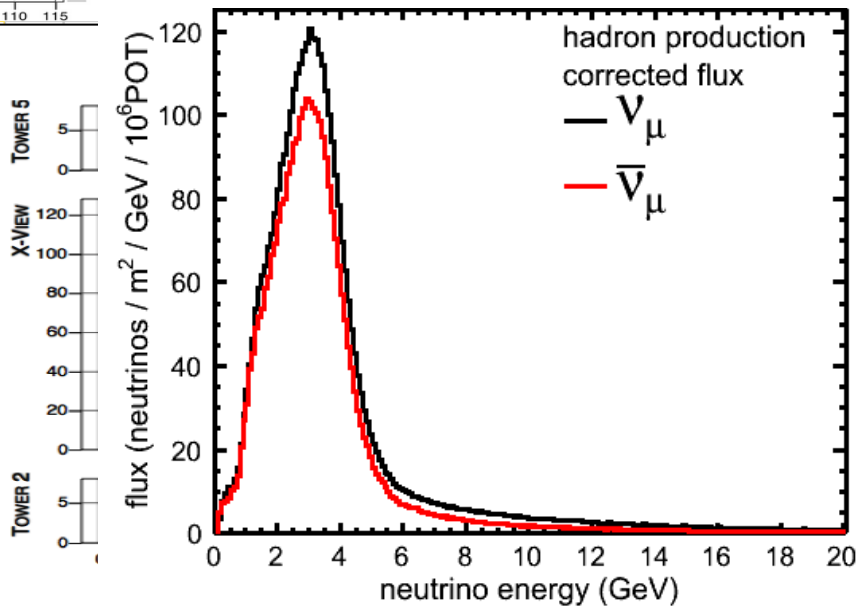
νμ p→μ-Δ++, Δ++→pπ+ Candidate



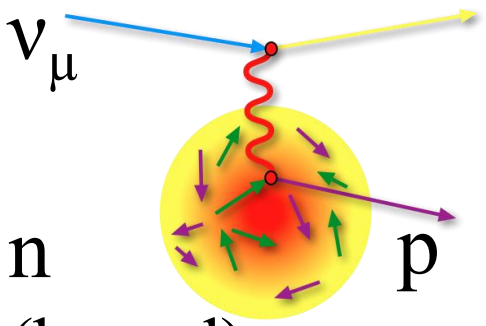
νμ e-→ νμ e- Candidate



NuMI Low Energy Beam Flux



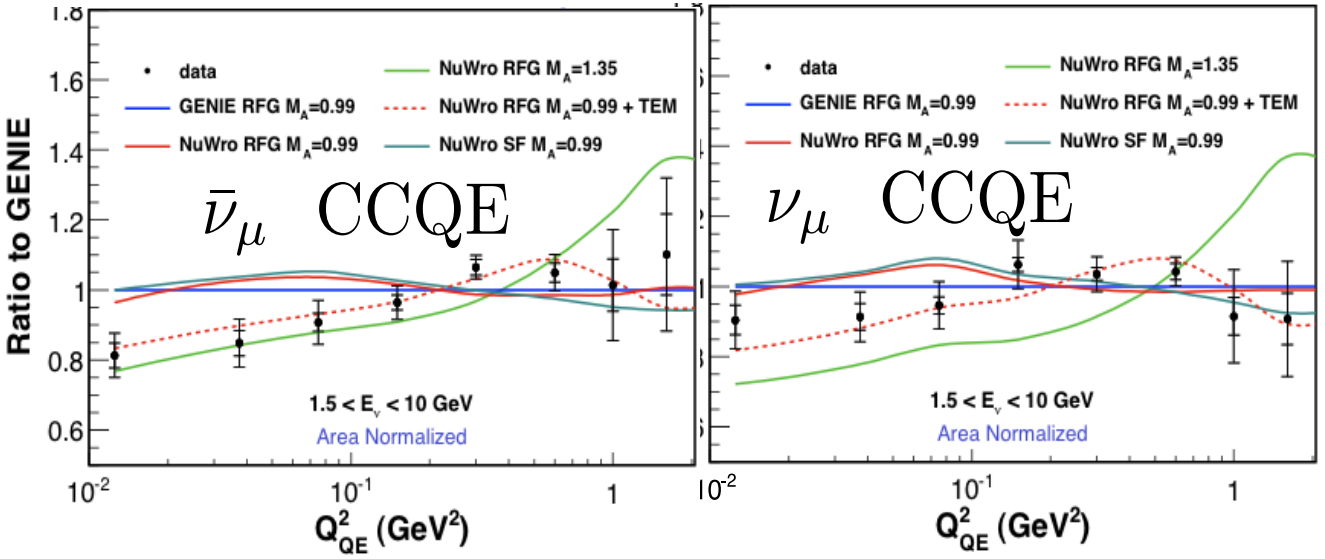
Neutrino & Anti-Neutrino CCQE

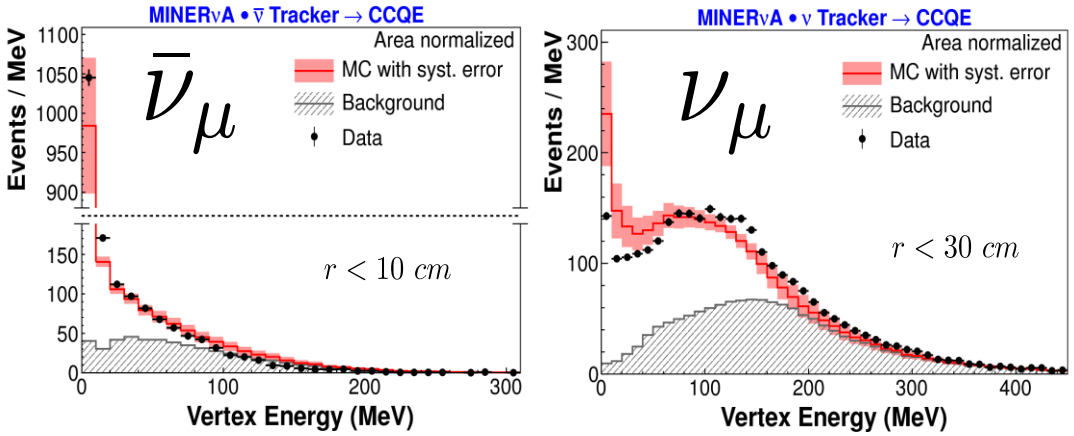


Phys Rev. Lett. 111, 002051 and 002052 (2013)

What is effect of nucleus?

Compare shape of $d\sigma/dQ^2$ to models



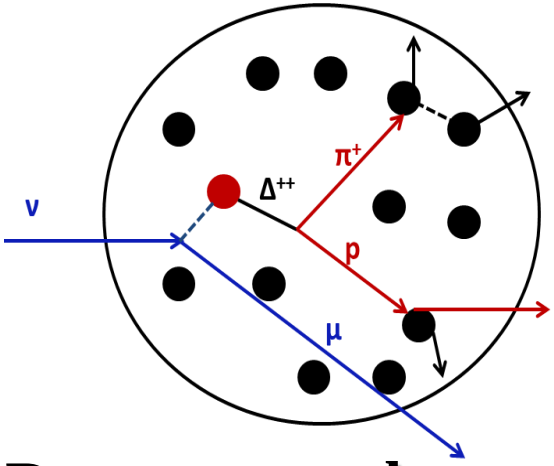


Look for energy near vertex consistent with extra nucleons

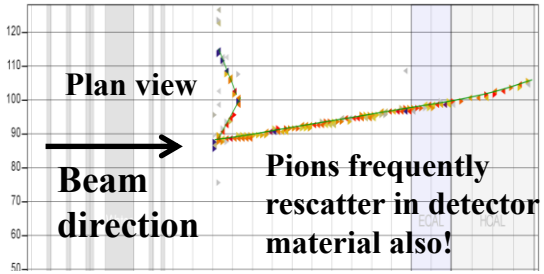
Data would prefer if 25±9% of events ejected initial state np pairs (final state nn or pp)

Cross-section vs Q^2 and vertex energy support multi-nucleon hypothesis

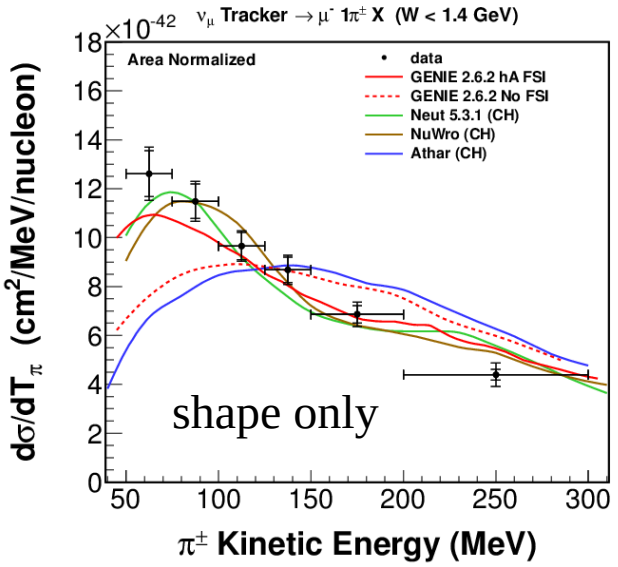
Charged Pion Production

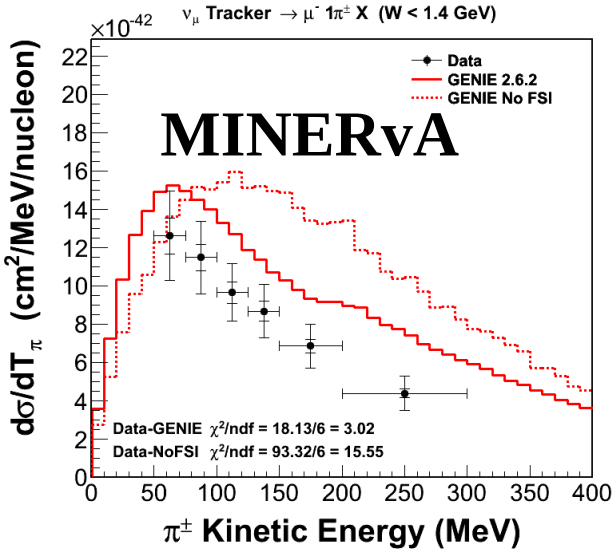


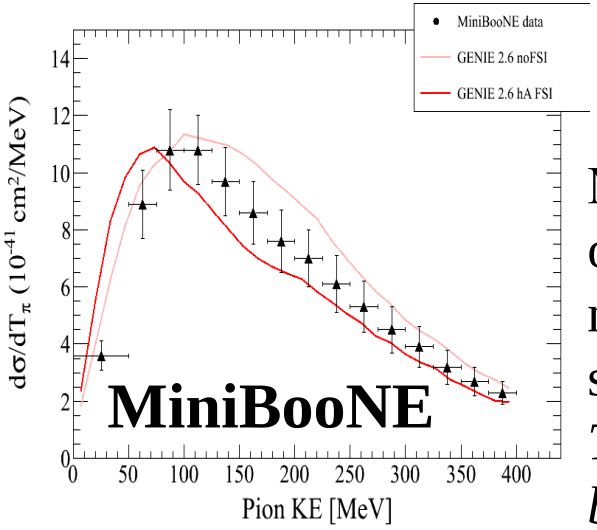
Do we correctly model nuclear rescattering, "final state interactions"?



Our data on pion momenta requires this FSI

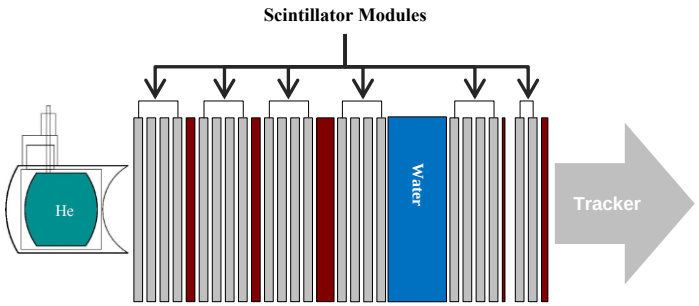




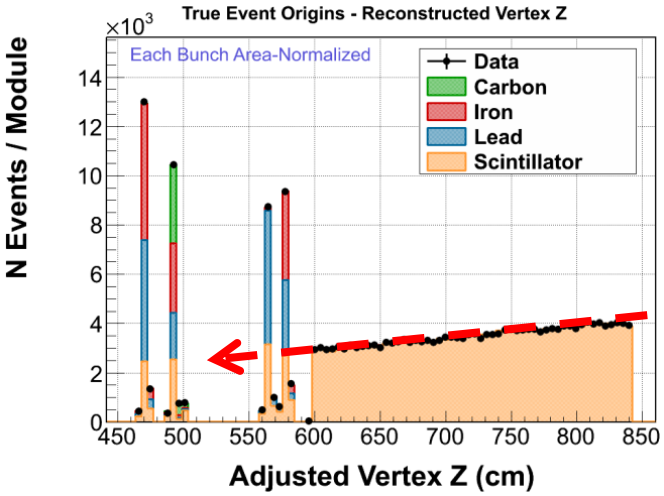


MiniBooNE's measurement of same reaction sees harder momenta, more events and suggest less FSI.
There is significant tension between the experiments.

Ratios of CC Reactions on Nuclei

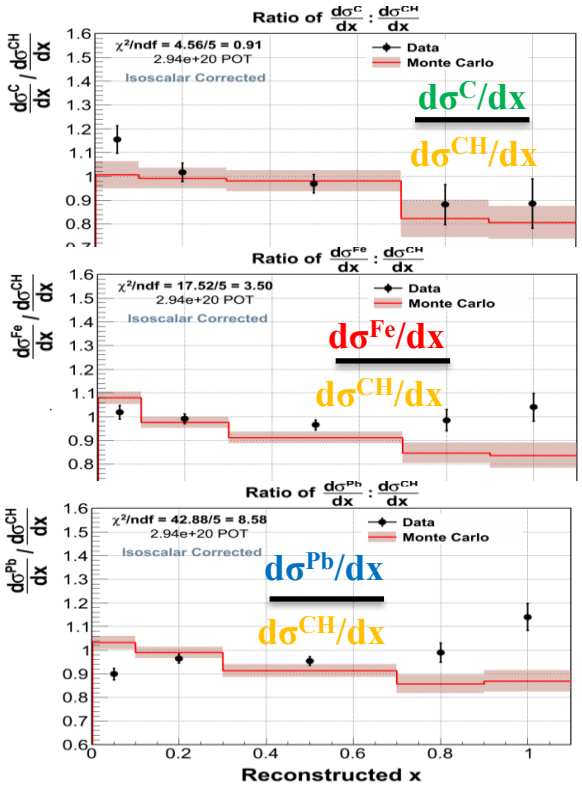


How are inclusive charged current reactions modified by nucleus?
"EMC effect in neutrinos"



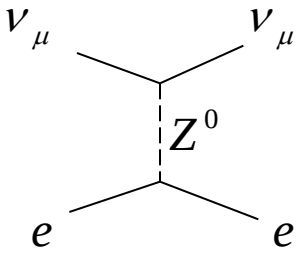
Targets are passive and there is background from nearby scintillator.

Use events in the tracker modules to predict and subtract the plastic background



We observe two primary effects not predicted in models used in oscillation experiments:

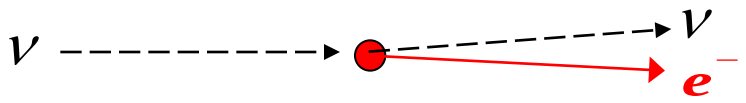
1. *At low x, "shadowing" is large and increases with heavier nuclei*
   (Large shadowing at our low Q^2? Axial current?)
2. *At high x, see higher rate for heavy nuclei*
   (Inadequate modeling of initial state momenta? Pauli blocking poorly modeled?)

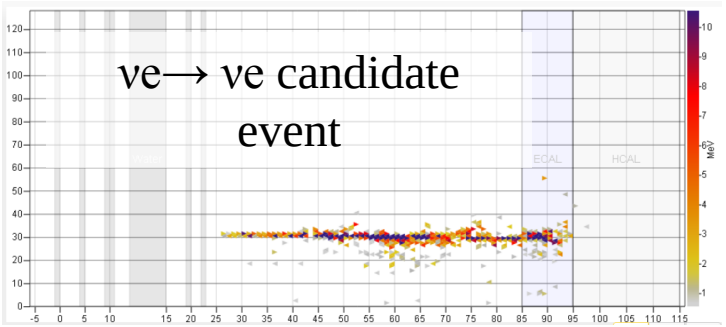


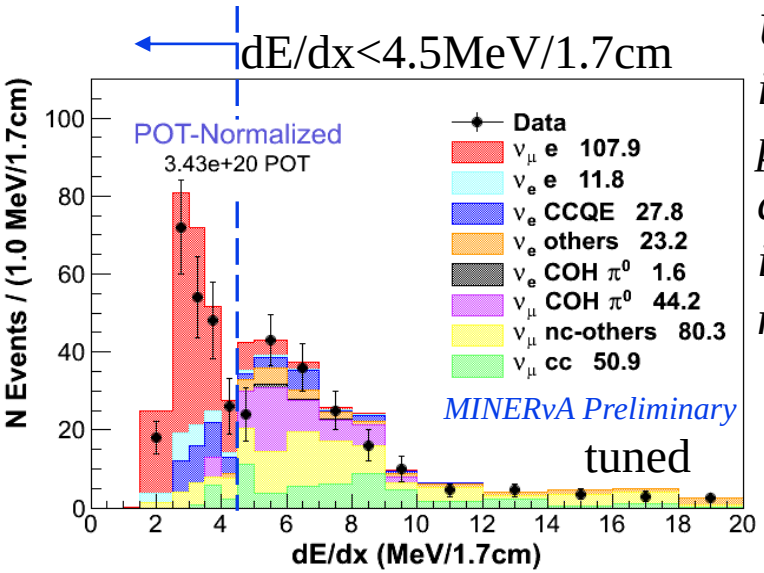
Neutrino-Electron Scattering

Can we isolate a sample of these well-predicted events to directly measure neutrino flux?

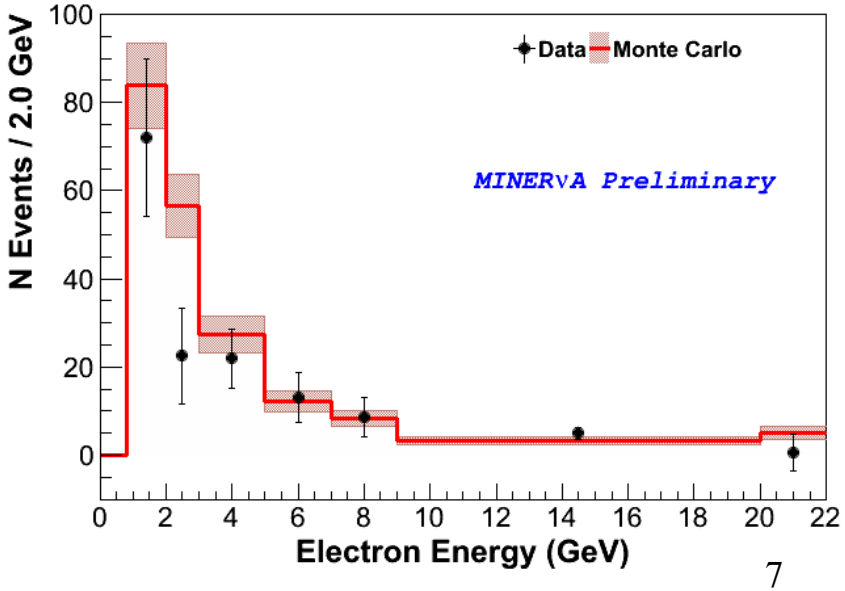
Very forward single electron final state







Use early ionization to reject photons and direction to reject interactions on nucleons



Measurement in LE NuMI beam constrains flux at precision similar to hadroproduction uncertainties

Technique will be even more powerful in NOvA era beam with higher energy and rate

What's Next for MINERvA?