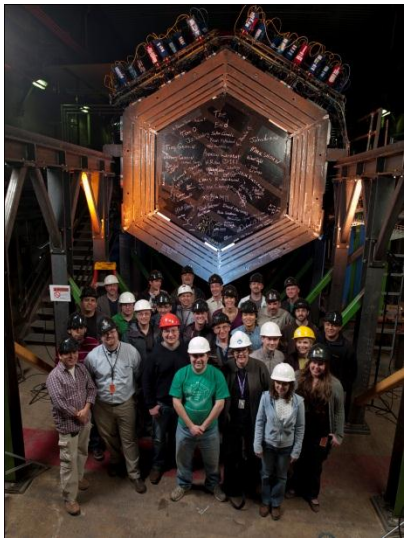
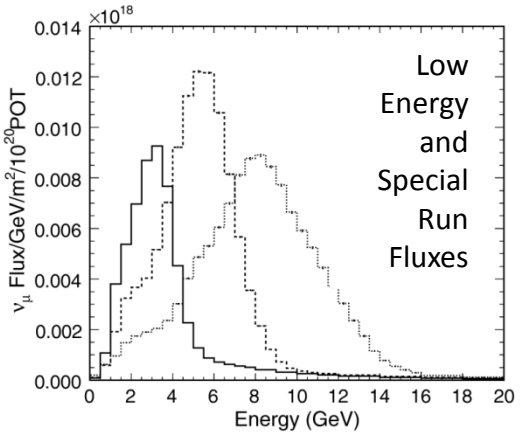
MINERvA Overview

- MINERvA 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 function of a measured neutrino energy
    - Study differences between neutrinos and anti-neutrinos
  - Measure exclusive channel cross sections and dynamics



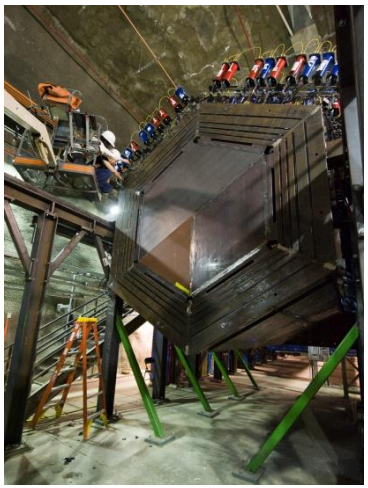
- Medium Energy (ME) Beam (NOvA) Goals:
  - Structure Functions on various nuclei
  - Study high energy feed-down backgrounds to oscillation expt's
- NuMI Beamline Provides
  - High intensity, Wide range of available energies
- MINERvA detector Provides
  - Reconstruction in different nuclei, broad range of final states

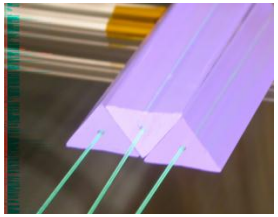


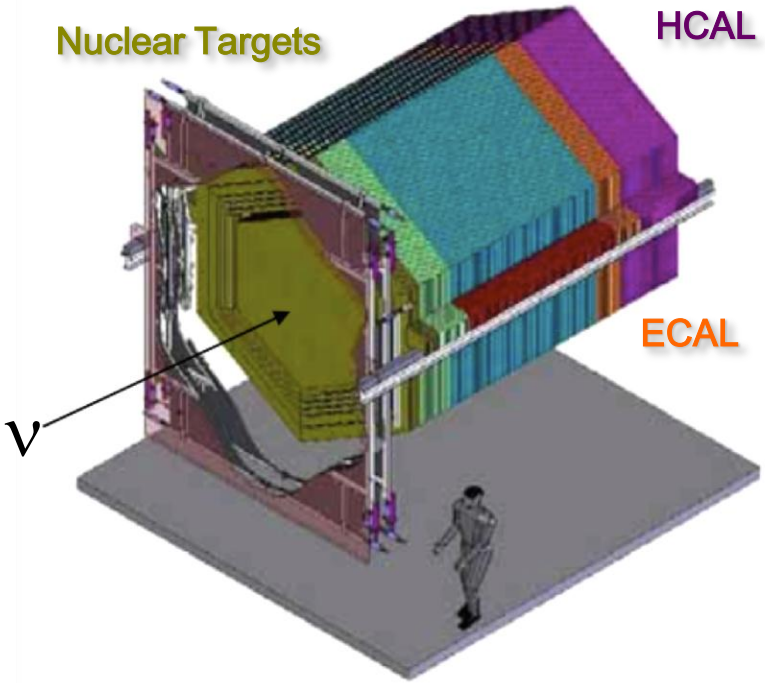
~85 Particle, Nuclear, and Theoretical physicists from 22 Institutions

MINERvA Detector Basics

- Nuclear Targets
  - Allows side by side comparisons between different nuclei
  - Solid C, Fe, Pb, He, water
- Solid scintillator tracker
  - Tracking, particle ID, calorimetric 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

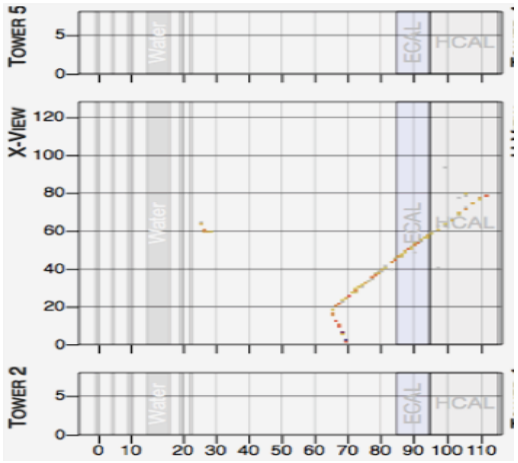




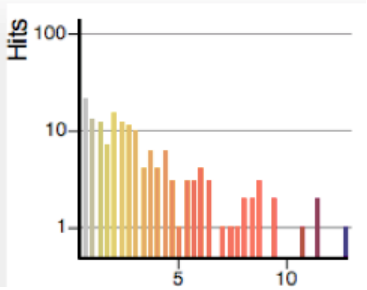


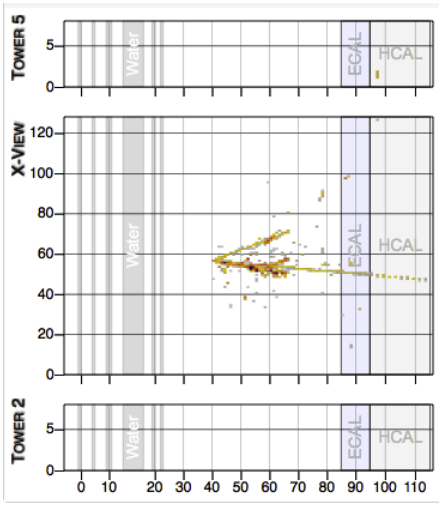
MINERvA Data

- One out of three views shown, color=energy

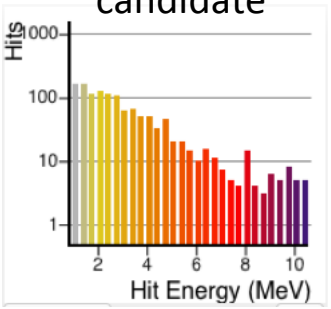


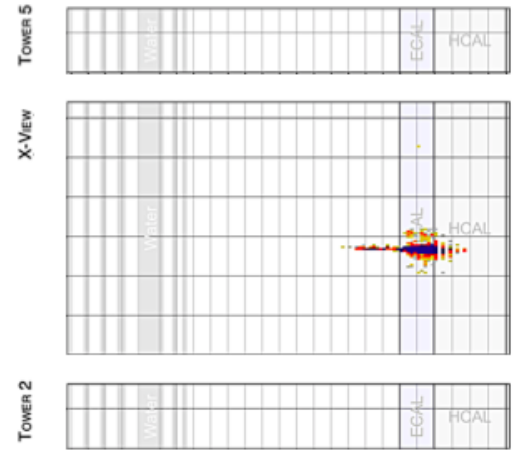
Quasi-elastic candidate



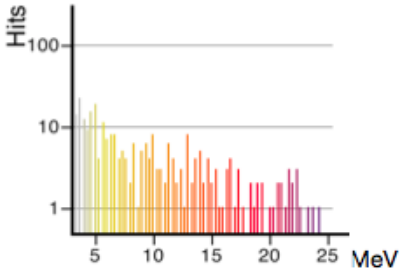


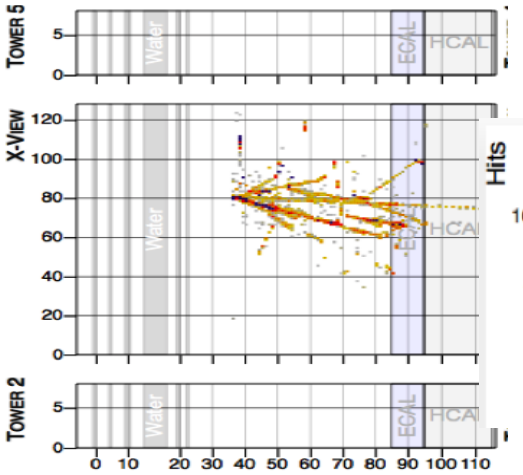
Baryon resonance candidate



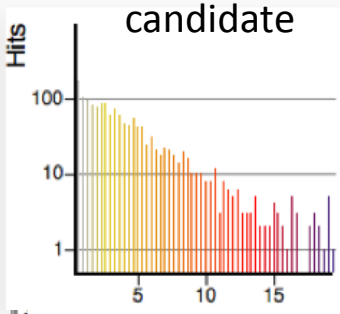


Single Electron candidate



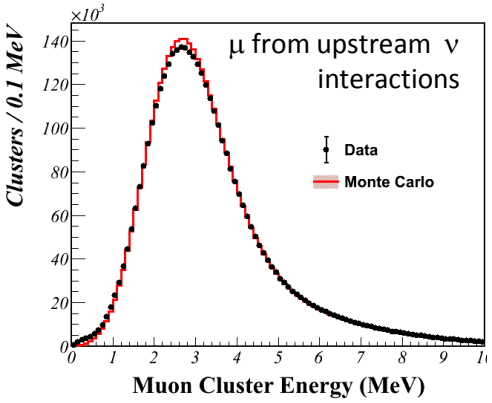


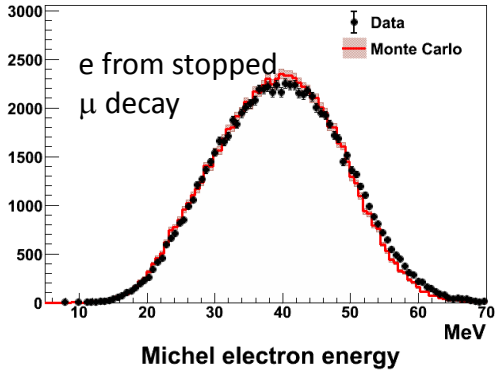
Deep Inelastic Scattering candidate

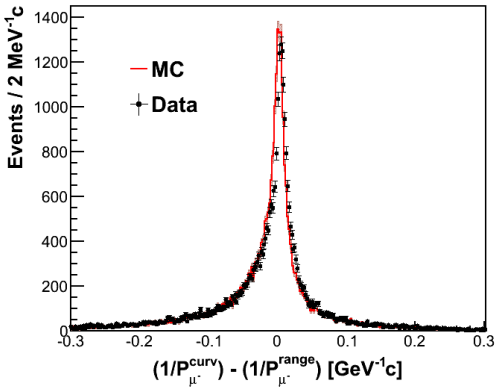


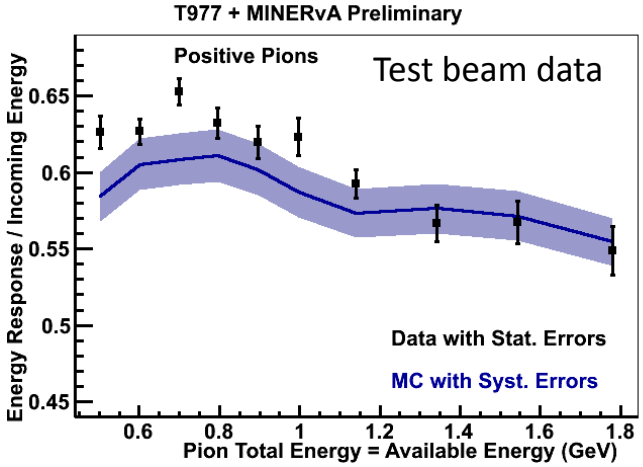
Detector Calibrations

- Have calibrated first 18 months of data written to tape: ¼ of total ν exposure, all of anti-ν exposure
- MINERvA:
  - use μ from upstream interactions to set energy scale, check with e's from stopped μ decay
  - Set hadronic energy scale relative to muon energy deposits using test beam data and equivalent calibration procedure
- MINOS:
  - compare muon tracks where measurement from both range and curvature are available
  - (MINERvA uses much looser fiducial cuts on MINOS ND)



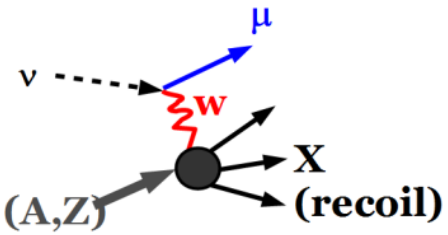




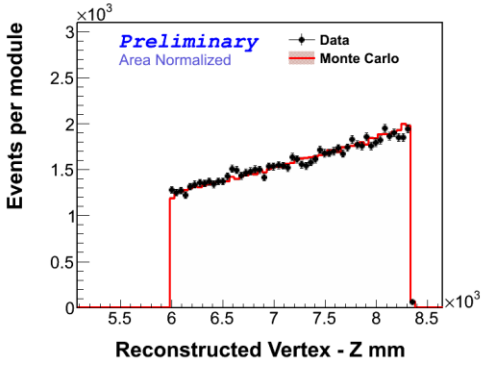


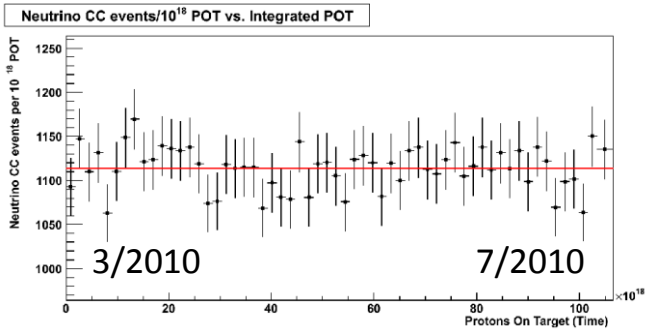
π^+: 5% disagreement with MC (no tuning!)
Also have π^- and proton data

Charged Current Events

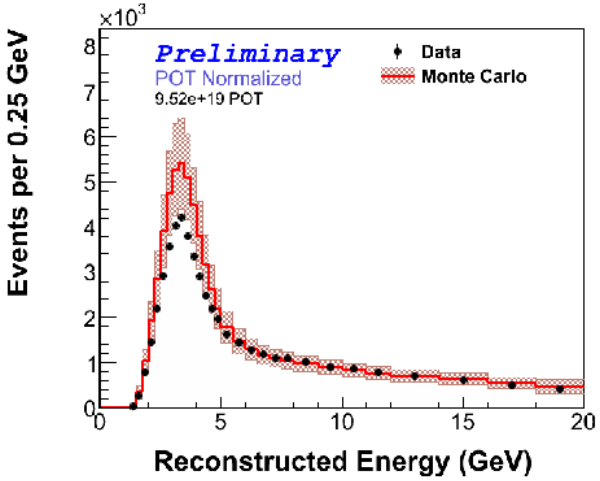


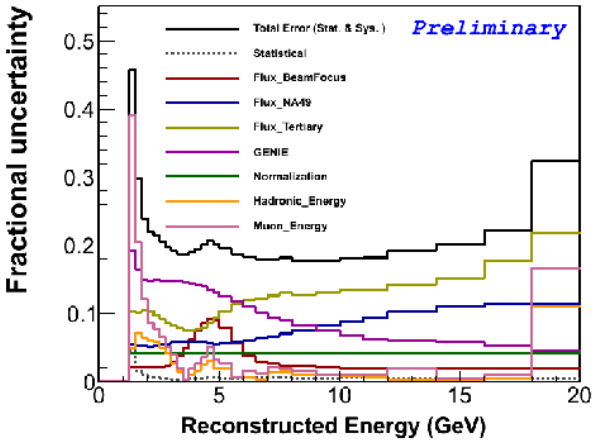
- Abundant sample:
  - Require muon matched with MINOS-analyzed track, measure recoil in MINERvA $E(\nu)=E(\mu)$ + recoil energy
- Useful for cross-checks of detector acceptance modeling and stability
  - Will eventually become total cross section measurement vs. energy
- Currently systematics limited





Neutrino Mode: 1×10^{20} POT

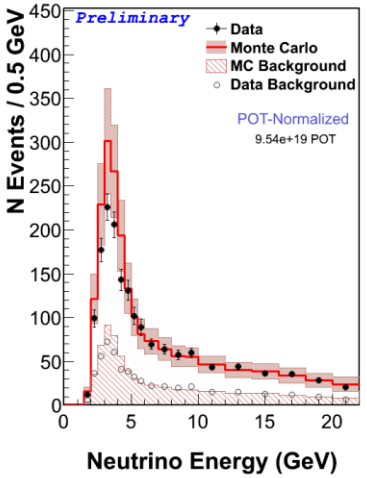


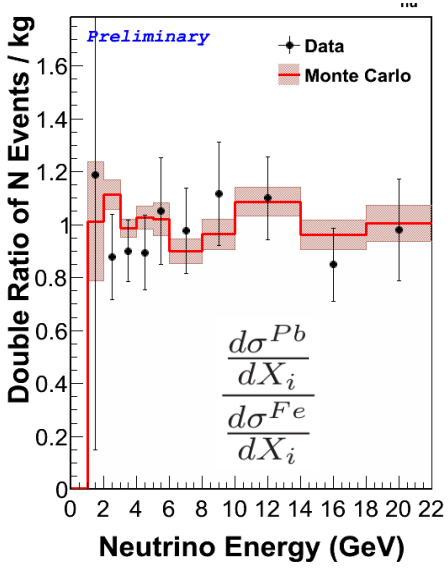


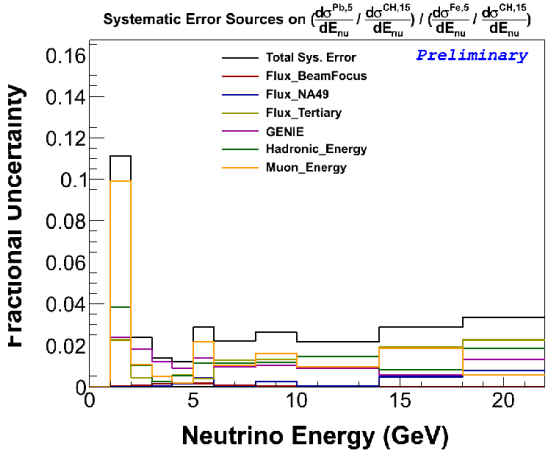
Inclusive Nuclear Target Ratios

- Significant reduction in systematic errors when taking ratios of events: MINERvA designed to do this
  - Same cuts as inclusive analysis. Vertex must be in solid targets. Subtract backgrounds from vertex misreconstructions
- First results with 2 targets: allows for ratios of Pb/Fe, Pb/C, Fe/C
  - Double ratio cancels out acceptance uncertainties
- Systematic errors on ratios are already at few per cent level
- Have factor ~20 more data to add to this proof of principle.

Target	Fiducial Mass	ν_μ CC Events in 4×10^{20} POT
Plastic	6.43 tons	1363k
Helium	0.25 tons	56k
Carbon	0.17 tons	36k
Water	0.39 tons	81k
Iron	0.97 tons	215k
Lead	0.98 tons	228k

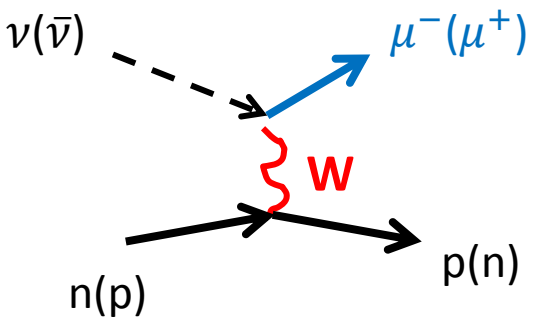


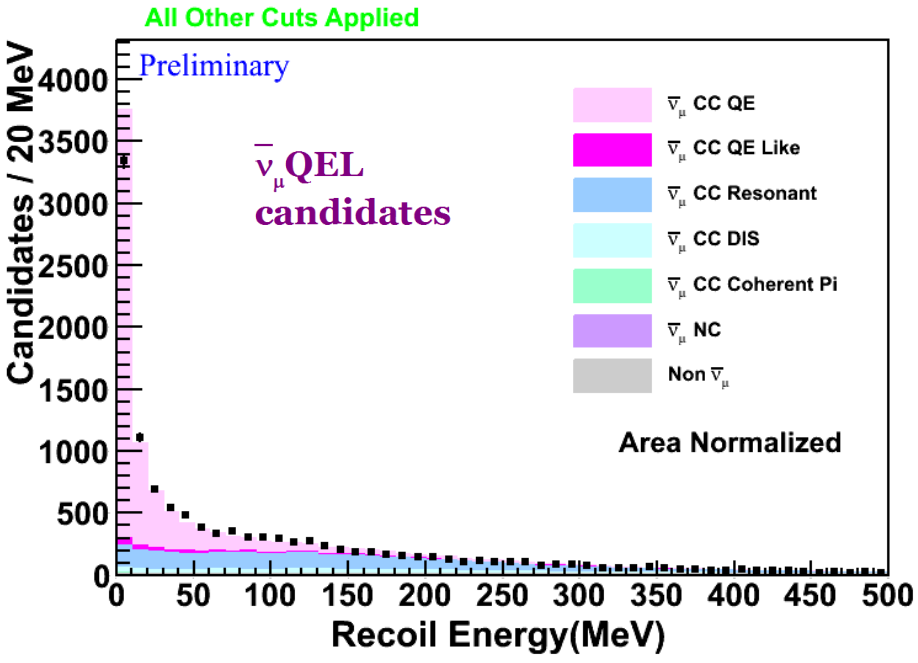


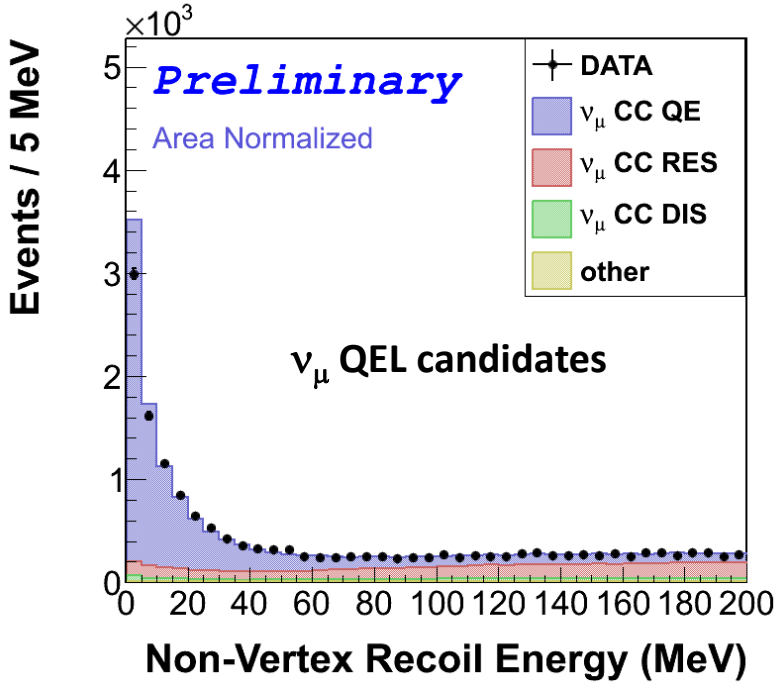


Quasi-Elastic Scattering

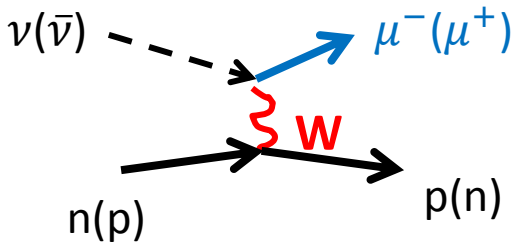
- This interaction is one of the most important in oscillation experiments because backgrounds are low and can estimate neutrino energy simply by measuring muon angle and momentum
- To identify, look for muon and low recoil energy, consistent with recoiling nucleon

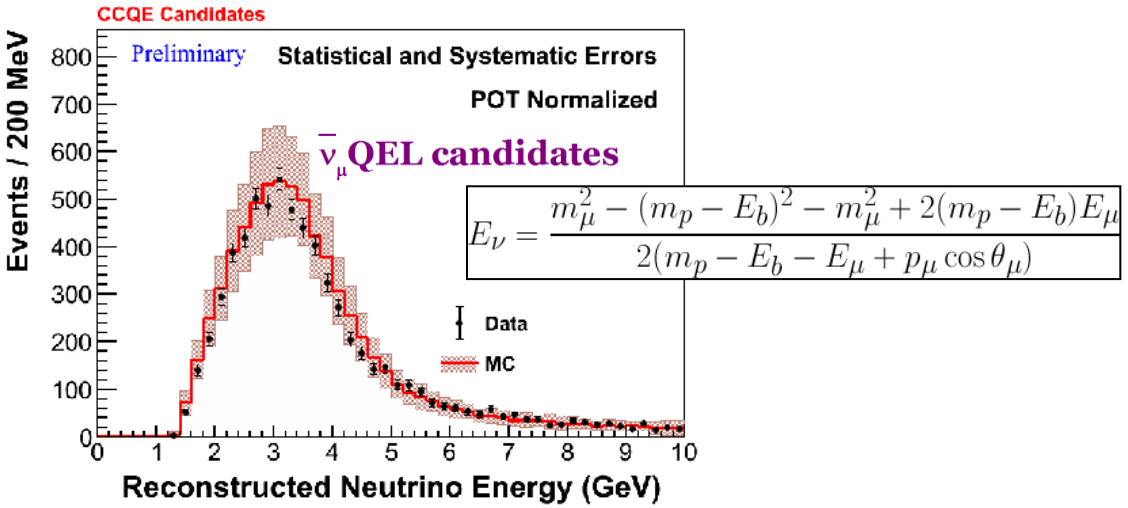




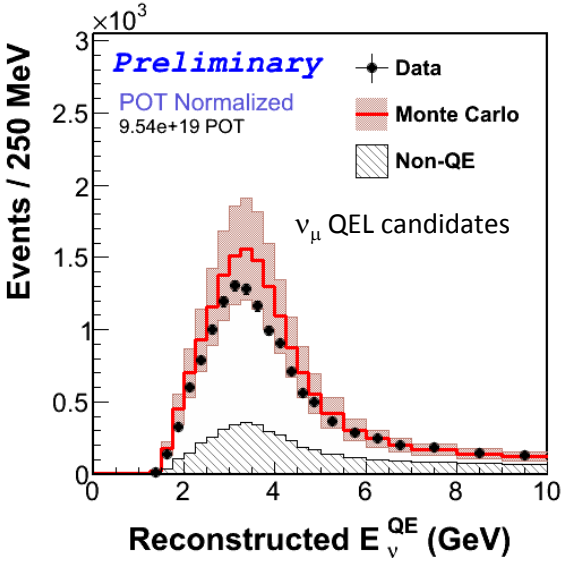


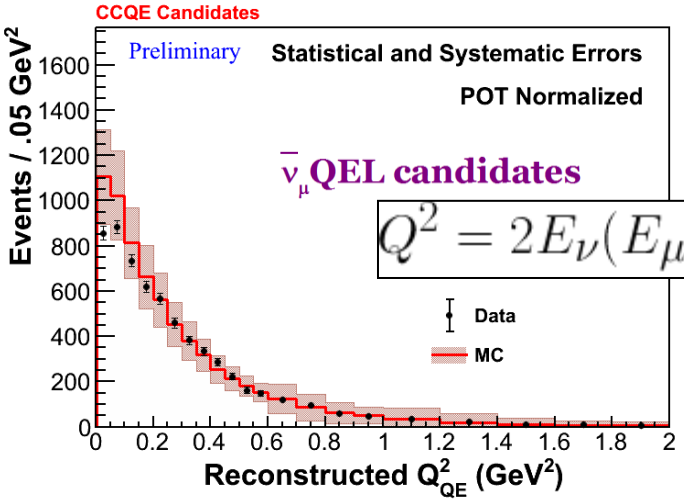
Quasi-Elastic Kinematics



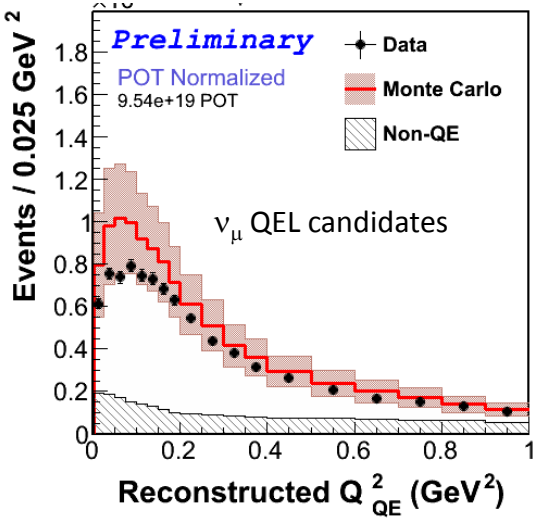


$$E_\nu = \frac{m_\mu^2 - (m_p - E_b)^2 - m_\mu^2 + 2(m_p - E_b)E_\mu}{2(m_p - E_b - E_\mu + p_\mu \cos\theta_\mu)}$$



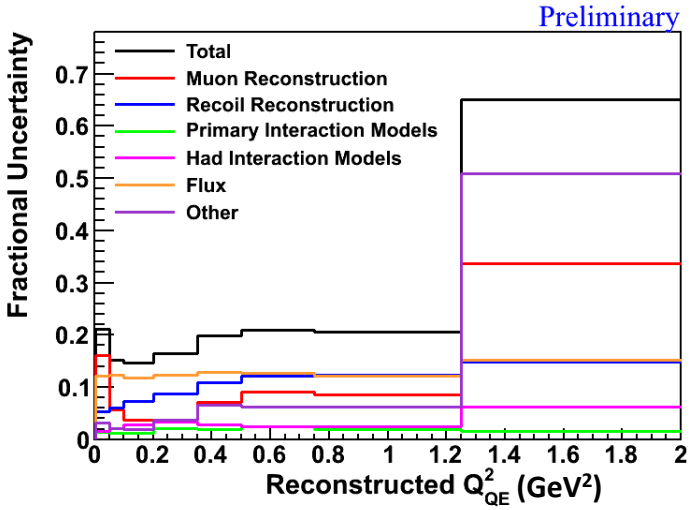


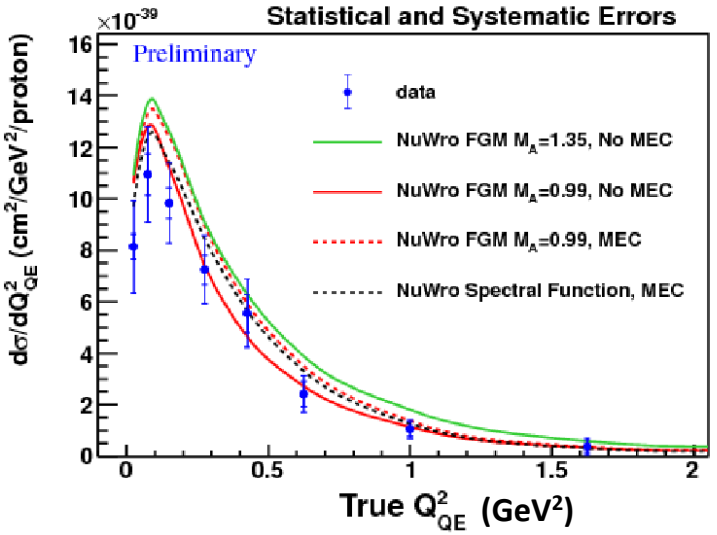
$$Q^2 = 2E_\nu(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2$$



Quasi-Elastic Cross Section

- Anti-neutrino Quasi-elastic analysis has results for $d\sigma/dQ^2$
  - Background subtraction uses data in sidebands
  - Unfold detector resolution in Q^2
  - Full suite of syst. errors evaluated
  - Result is something that can be compared with several different models, in search of meson exchange currents (MEC)
- Result will be improved: add more data (x5) and reduce conservative systematic uncertainties





NuWro: T.Golan, C.Juszczak, J.Sobczyk, arXiv: 1202:4197

Summary of Summer 2012 Results

- Preliminary $d\sigma/dQ^2$ for antineutrino quasi-elastics, neutrino mode not far behind!
- We have the statistics to inform/constrain models
- Promising nuclear target ratios method
  - small systematics
  - data hungry, additional targets available
    - NOvA era run with higher (on axis) neutrino energy
- Many other analyses in progress
  - Total exposure past what has been shown: 3x more data for ν and 5x more for $\bar{\nu}$
- Identified portfolio of systematics
  - clear path for improvements