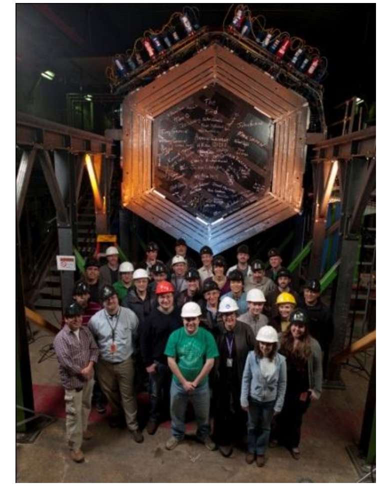
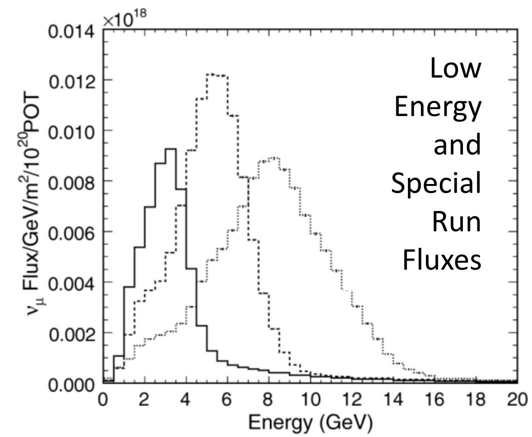
MINERvA Overview

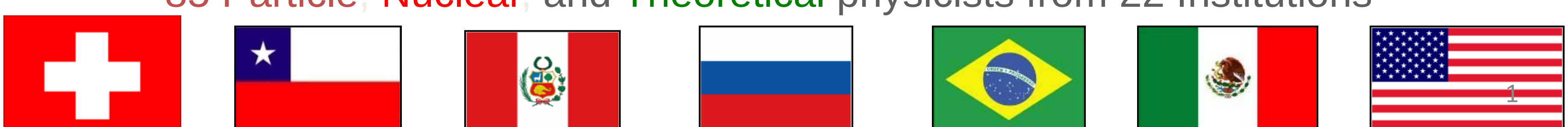
- MINERvA is studying neutrino interactions in unprecedented detail on a variety of different nuclei
- Low Energy (LE) Beam Goals:
  - Study both signal and background reactions relevant to oscillation experiments (current and future)
  - Measure nuclear effects on exclusive final states
    - as function 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

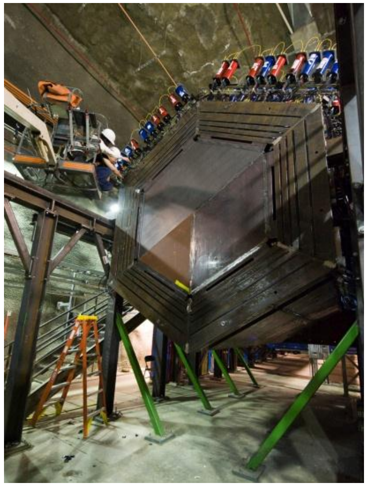


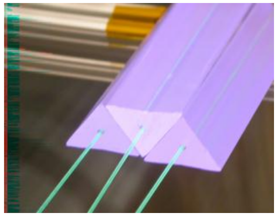
~85 Particle, Nuclear, and Theoretical physicists from 22 Institutions

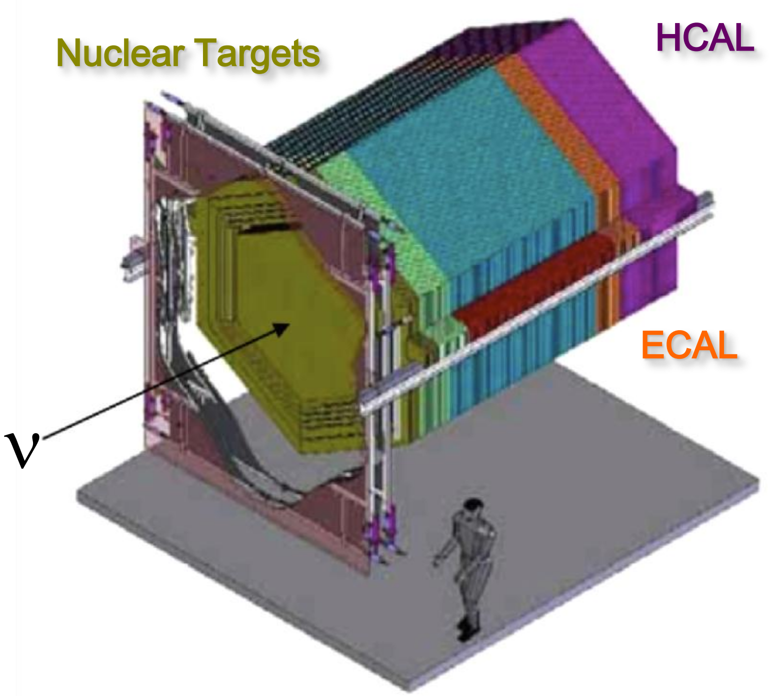


MINERvA Detector Basics

- 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

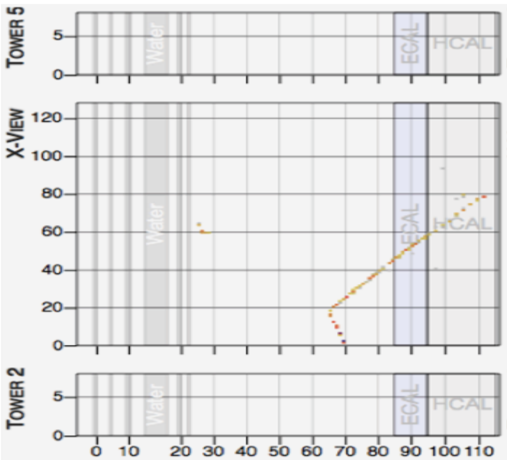




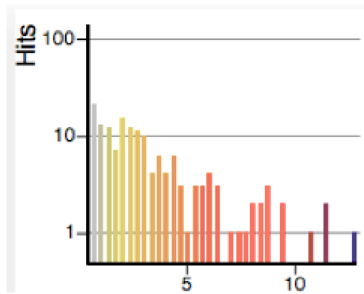


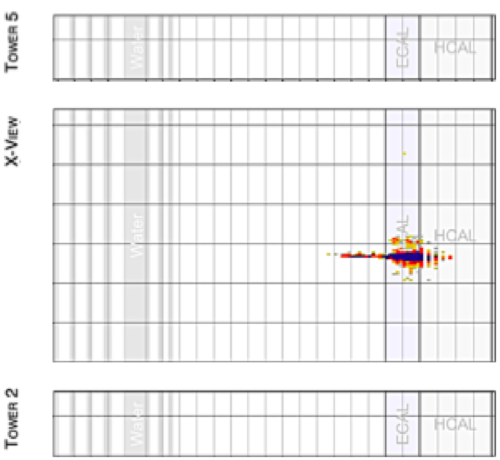
MINERvA Data

- One out of three views shown, color=energy

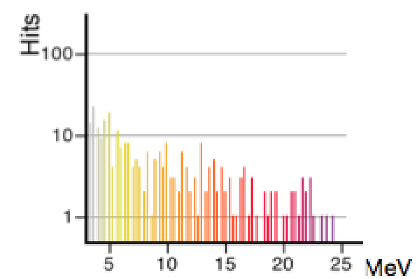


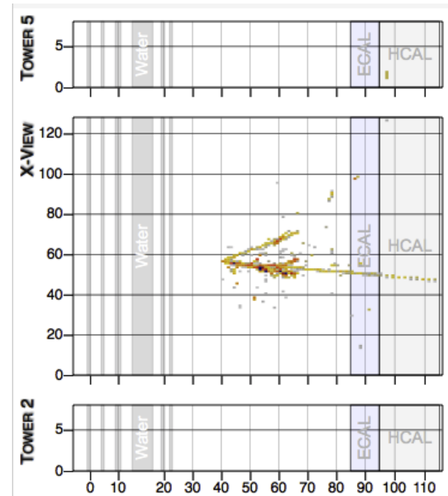
Quasi-elastic candidate



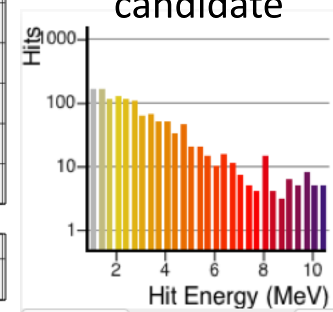


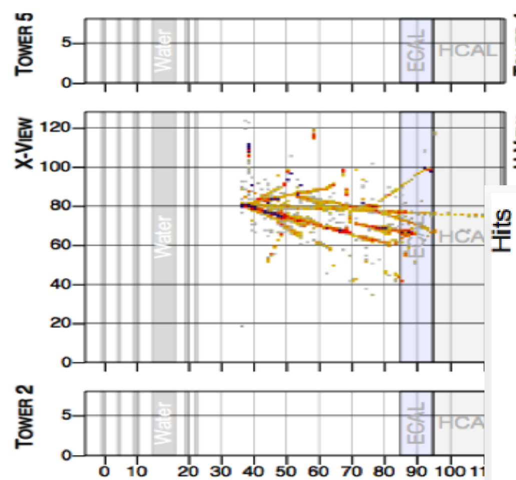
Single Electron candidate



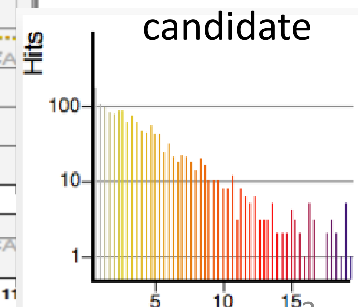


Baryon resonance candidate



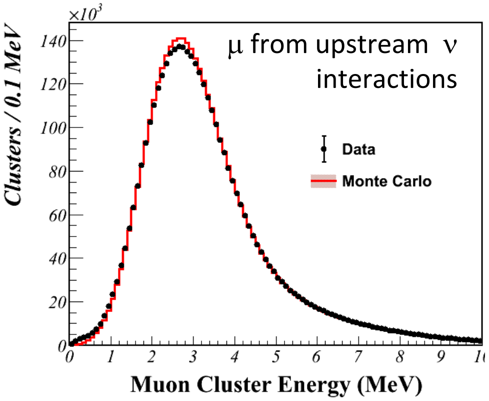


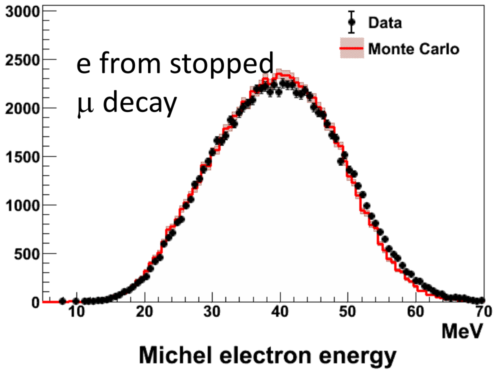
Deep Inelastic Scattering candidate

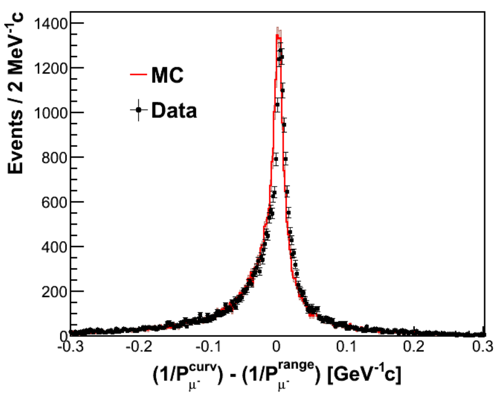


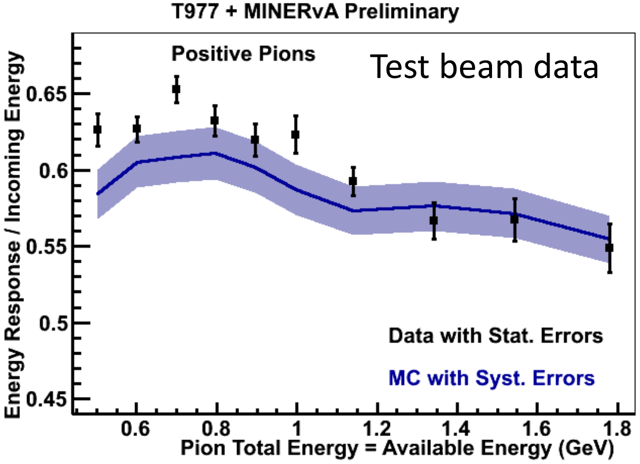
Detector Calibrations

- 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)





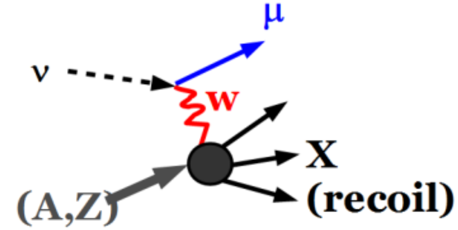




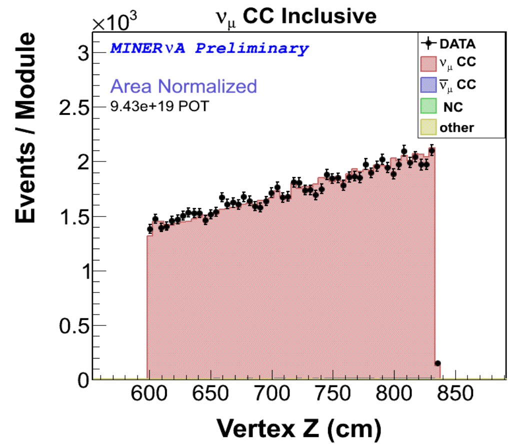
π^+: 5% disagreement with MC (no tuning!)

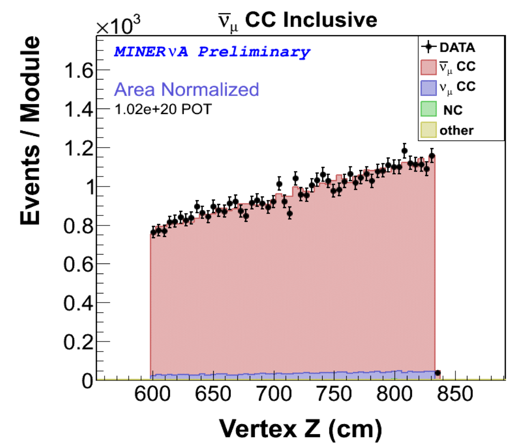
Also have π^- and proton data

Charged Current Events

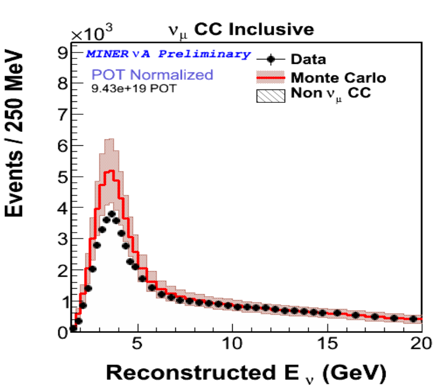


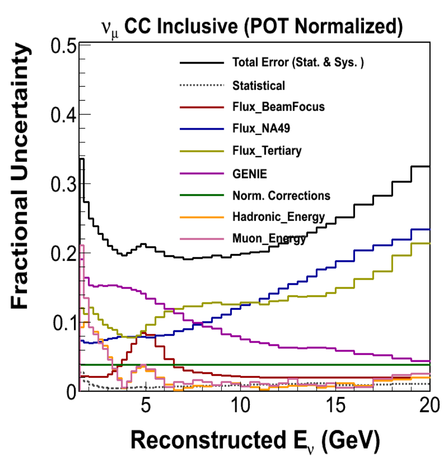
- Abundant sample:
  - Require muon matched with MINOS-analyzed track, measure recoil in MINERvA $E(\nu)=E(\mu)$ + recoil energy
- Useful for cross-checks of detector acceptance modeling and stability
  - Will eventually become total cross section measurement vs. energy
- Currently systematics limited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

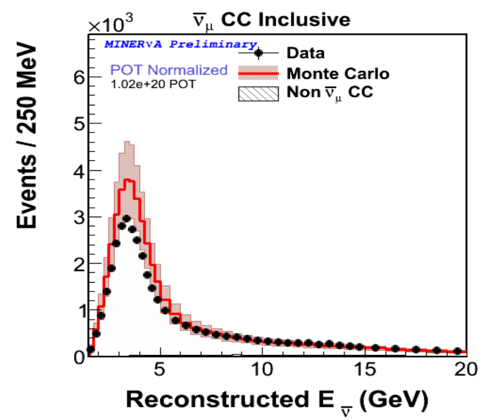


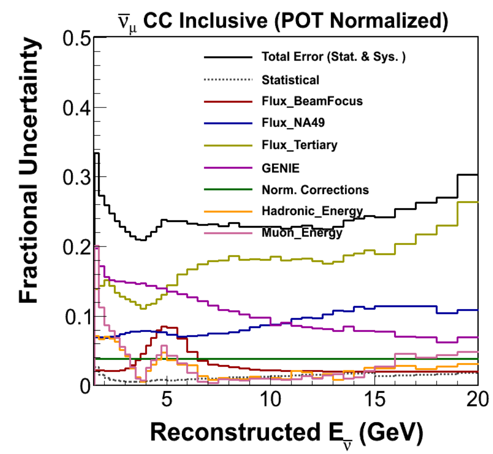


Neutrinos: 1×10^{20} POT, Anti-Neutrinos: 1×10^{20} POT



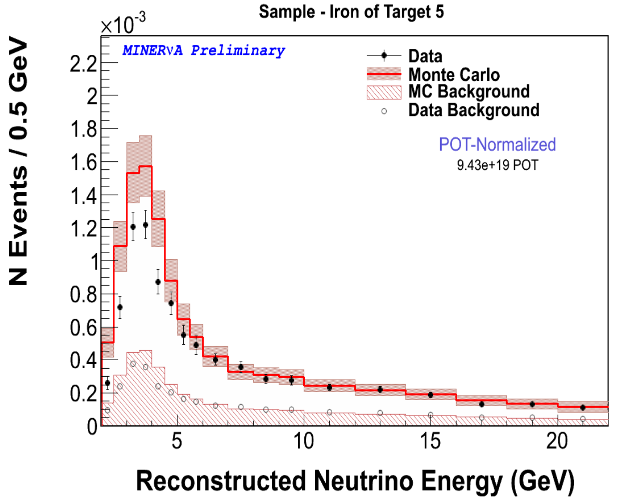


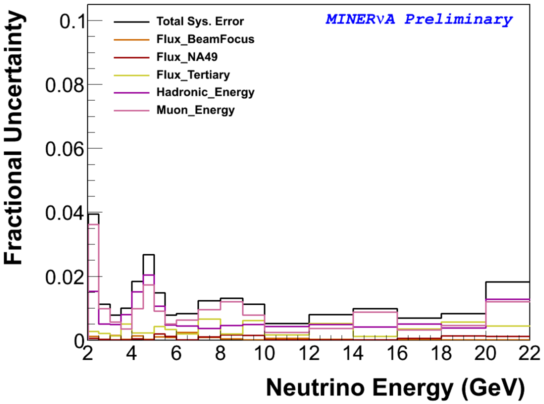


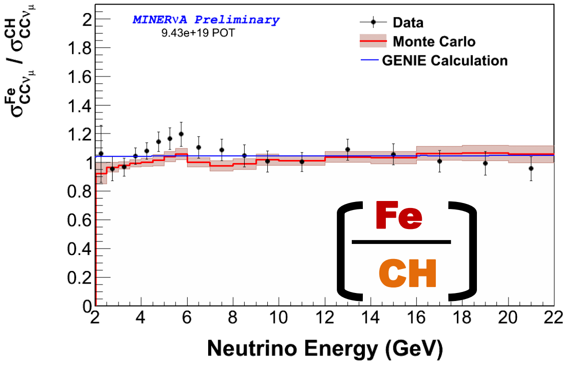


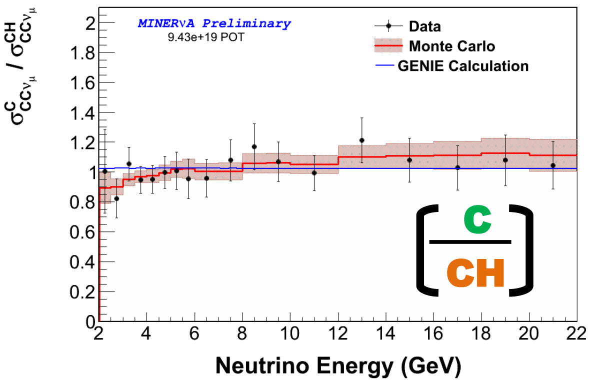
Inclusive Nuclear Target Ratios

- 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 mis-reconstructions
- Results with 4 targets: allows for ratios of Pb/CH, Fe/CH, C/CH
  - Double ratio cancels out acceptance uncertainties
- Systematic errors on ratios are already <2%
- Have factor ~4 more data to add to this proof of principle.



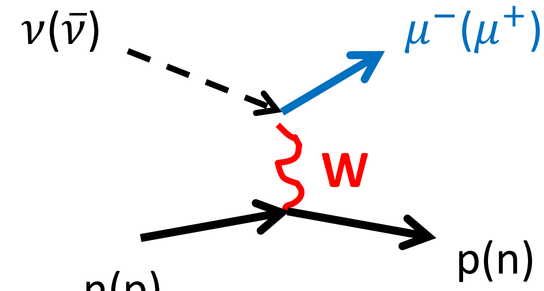


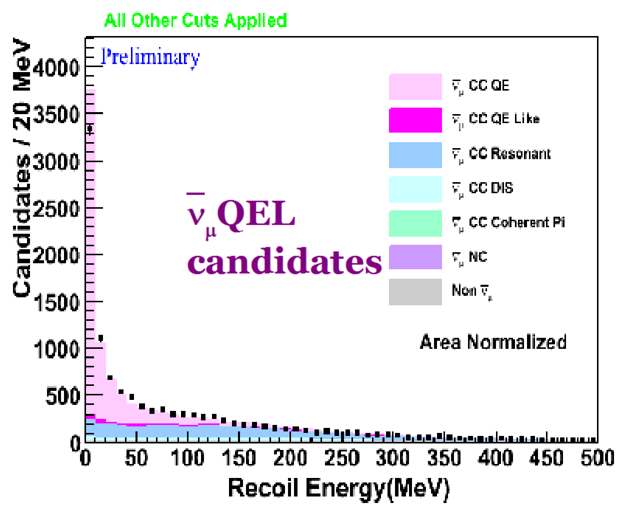


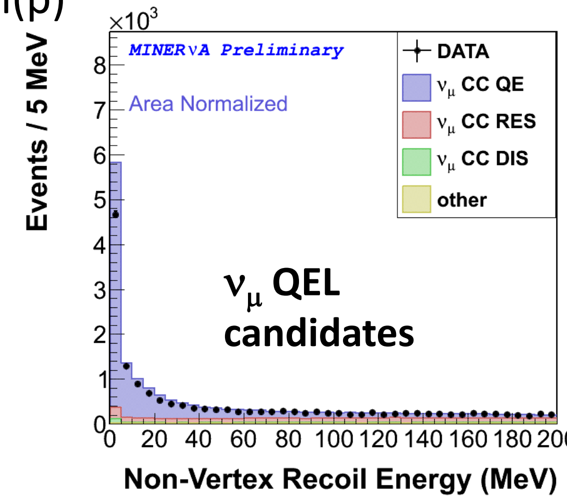


Quasi-Elastic Scattering

- “Golden” signal for oscillation experiments
  - Low backgrounds
  - Estimate neutrino energy by measuring muon angle and momentum
- Physics question is how nucleus modifies these backgrounds and energy estimates
  - Big systematics for T2K and presumably NOvA and LBNE
- To identify, look for muon with low recoil energy, consistent with recoiling nucleon
- New since summer: Neutrino QE in plastic, and 2-track QE events in nuclear targets

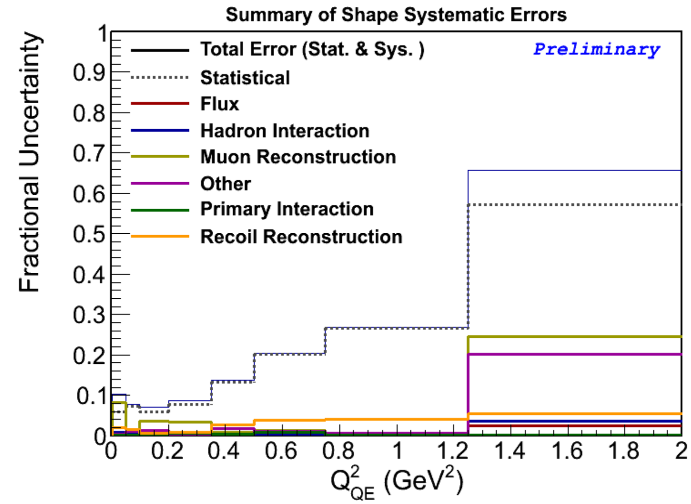


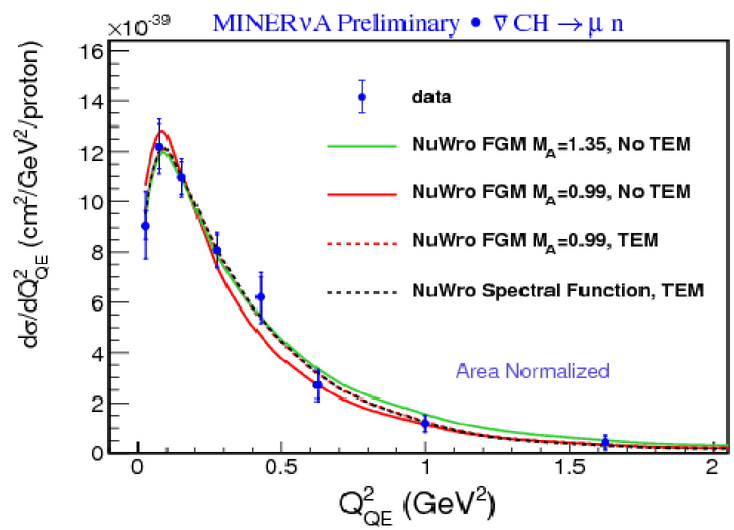




Quasi-Elastic Cross Section

- Anti-neutrino Quasi-elastic analysis has results for shape-only $d\sigma/dQ^2$
  - Background subtraction from sidebands
  - Unfold detector resolution in Q^2
  - Full suite of syst. errors evaluated
- Result that we publish will have uncertainties 2 or 3 times smaller than this preliminary result
  - More data, better unfolding, improve leading systematics
  - Power to distinguish between "effective M_A" model of MiniBooNE and multi-nucleon correlations
  - Latter effects disrupt neutrino energy reconstruction in oscillation experiments

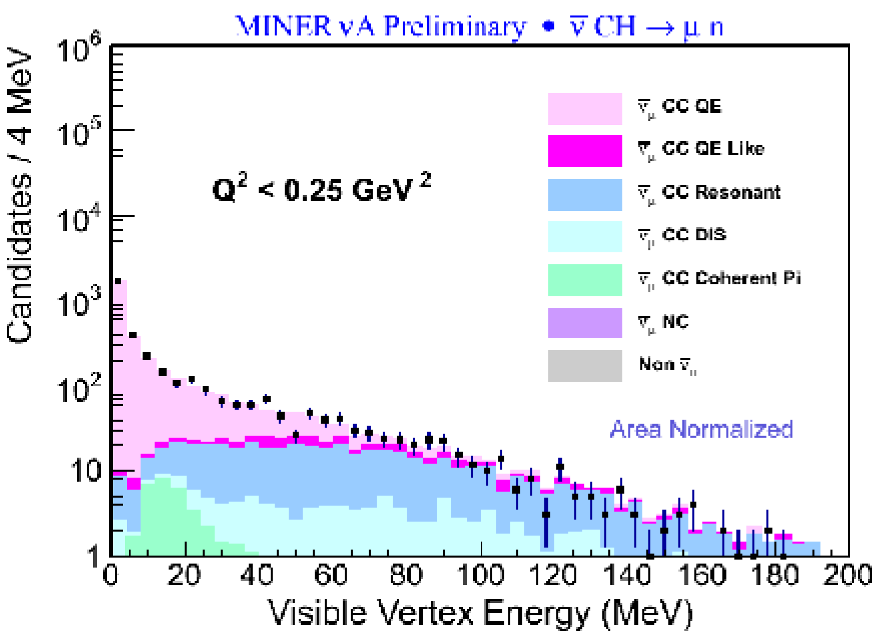


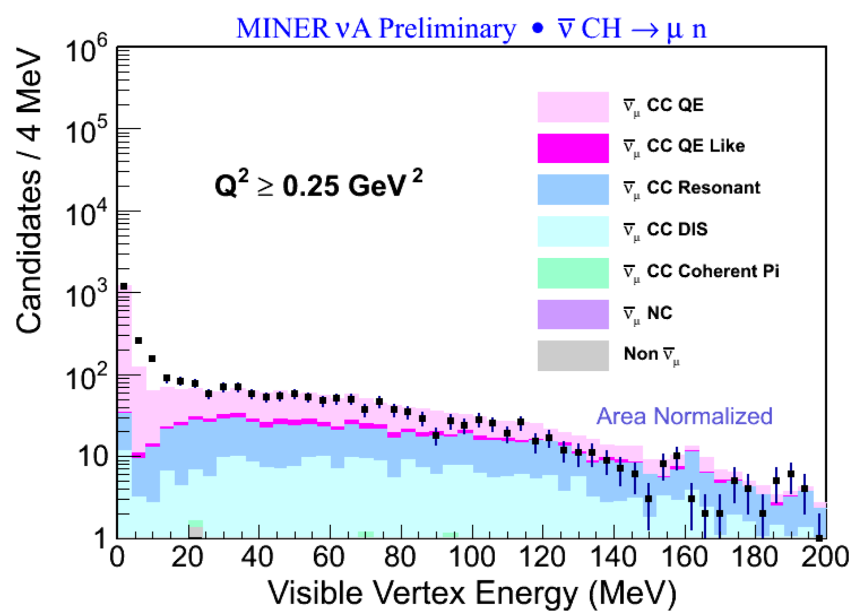


NuWro: T.Golan, C.Juszczak, J.Sobczyk, arXiv: 1202:4197

Another Signature of Nuclear Effects in QE: "Vertex Energy"

- Multi-nucleon models which predict disruption of energy reconstruction from nucleus also predict correlated recoil of nucleons in "quasi-elastic" events
- Cross-section analysis doesn't look at energy near vertex to avoid bias due to such effects
- First glimpse at anti-neutrino data: no excess energy at low Q^2 but some excess at moderate and high Q^2 where multi-nucleon effects are important
  - Certainly not yet conclusive, but an interesting hint





Summary of 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