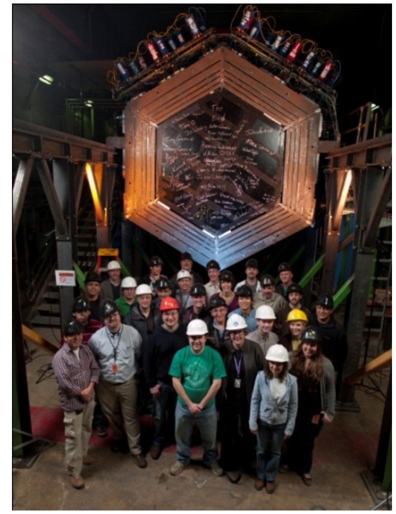
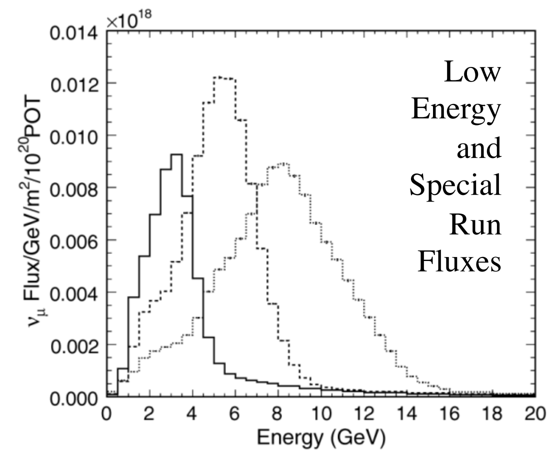
MINERνA Overview



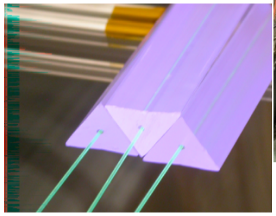
- MINERνA is studying neutrino interactions in unprecedented detail on a variety of different nuclei
- Low Energy (LE) Beam Goals:
  - Study both signal and background reactions relevant to oscillation experiments (current and future)
  - Measure nuclear effects on exclusive final states
    - » as a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

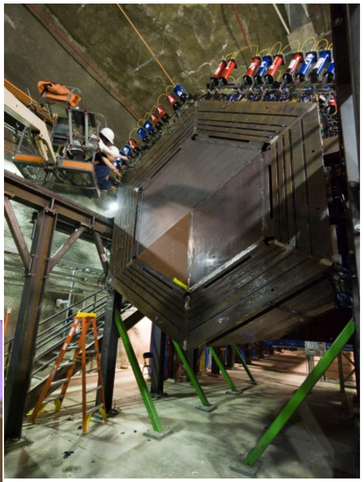


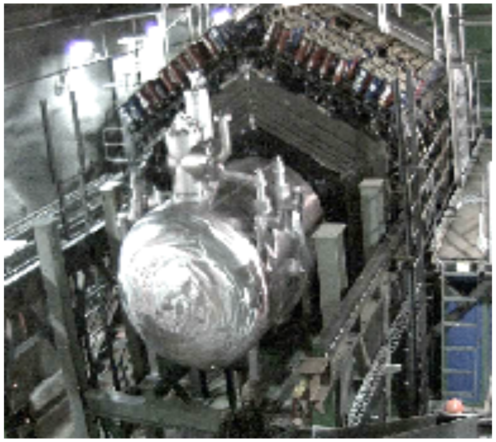
~85 Particle, nuclear and theoretical physicists from 22 institutions

MINERνA Detector Basics

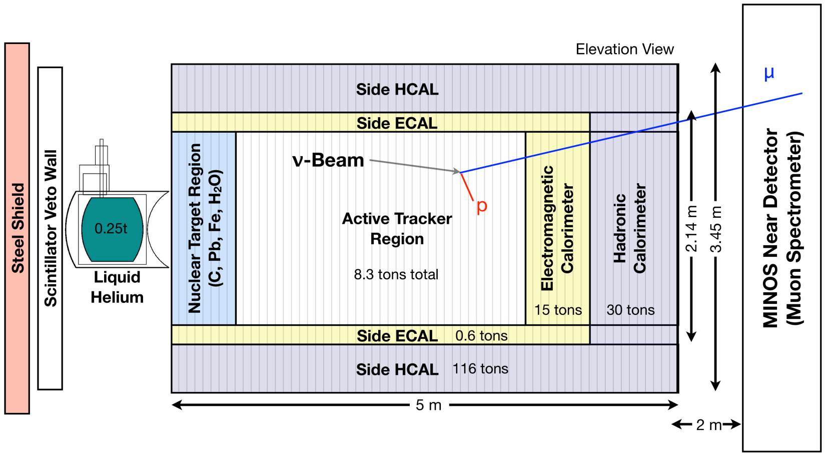
- Nuclear Targets
  - Allows side by side comparisons between different nuclei
  - Pure C, Fe, Pb, LHe, water
- Solid scintillator (CH) tracker
  - Tracking, particle ID, colorimetric energy measurements
  - Low visible energy thresholds
- Side and downstream electromagnetic and hadronic calorimetry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





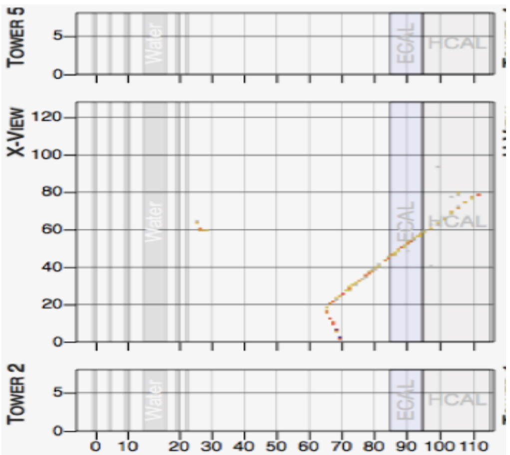


LHe cryotarget

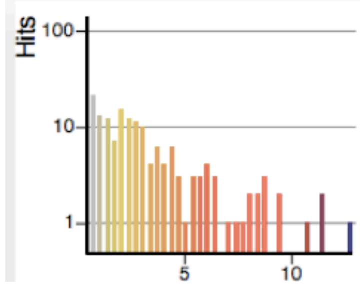


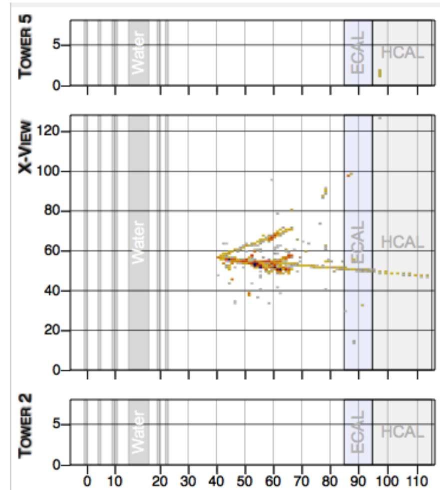
MINERνA Data

One out of three views shown, color = energy

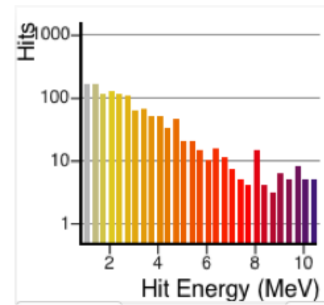


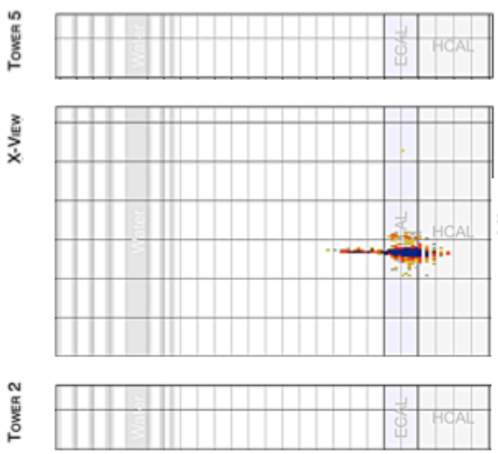
Quasi-elastic candidate



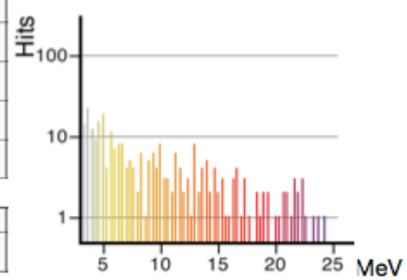


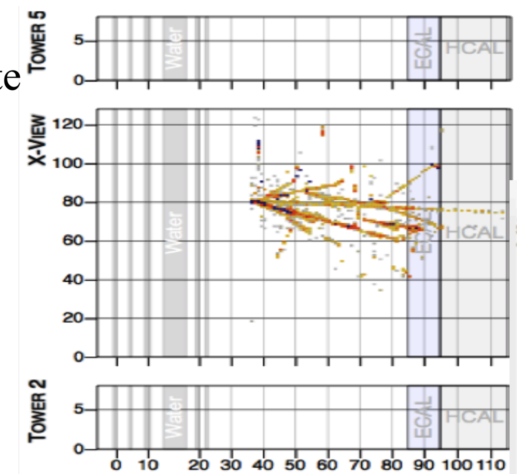
Baryon resonance candidate



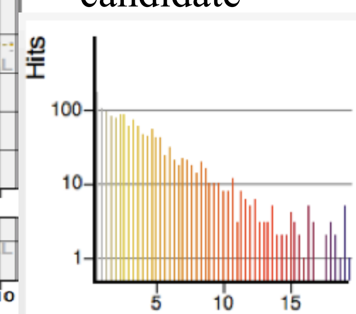


Single electron candidate



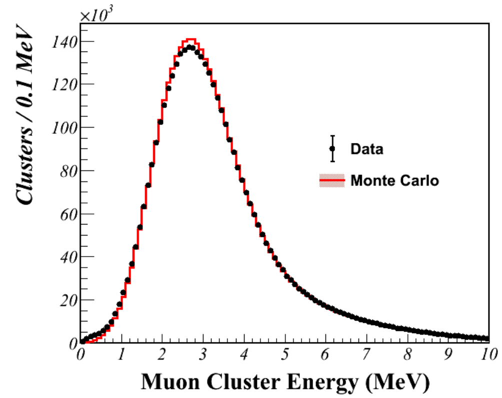


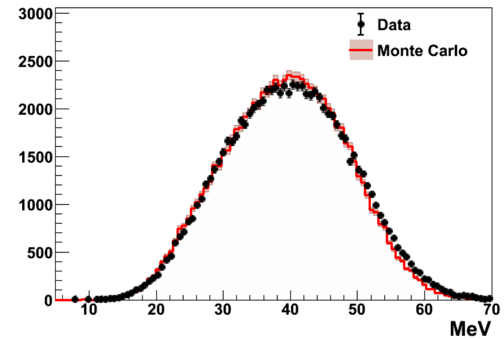
Deep Inelastic Scattering candidate

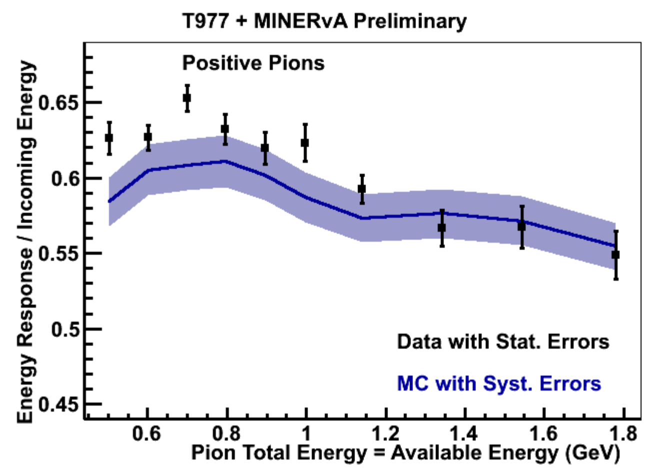


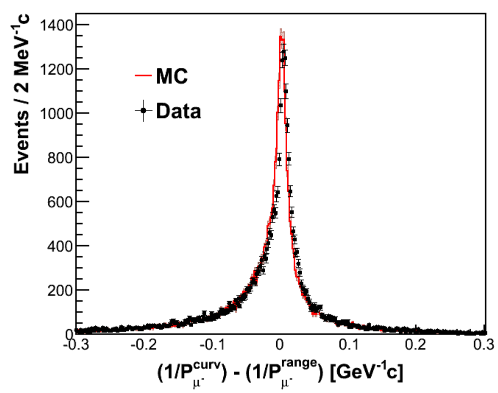
Detector Calibrations

- Have calibrated first 18 months of data written to tape: ¼ of total ν exposure, all of anti-ν exposure
- MINERνA
  - 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
  - MINERνA uses much looser fiducial cuts on MINOS ND





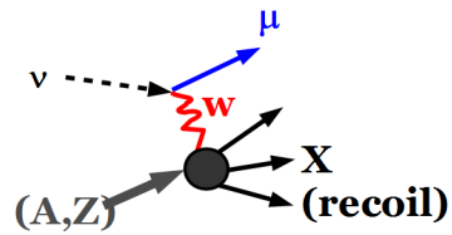




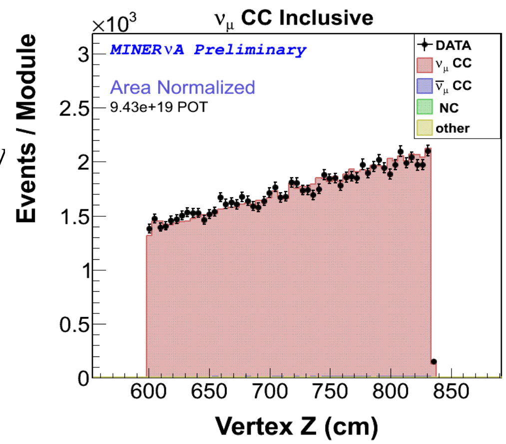
π^+: 5% disagreement with MC (no tuning!)

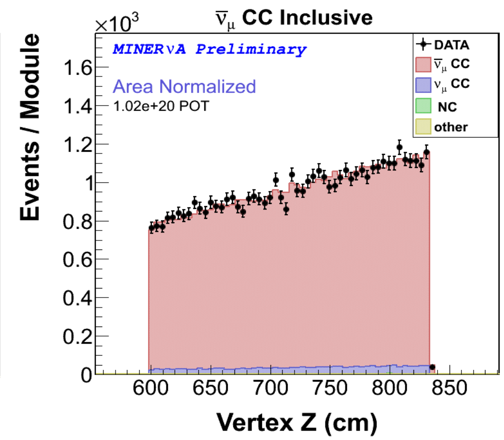
Also have π^- and proton data

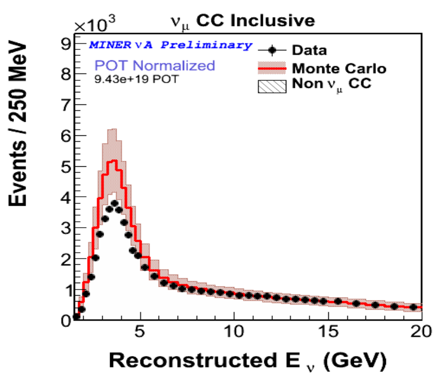
Charged Current Events

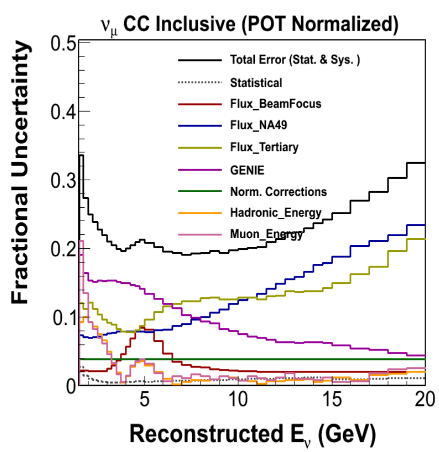


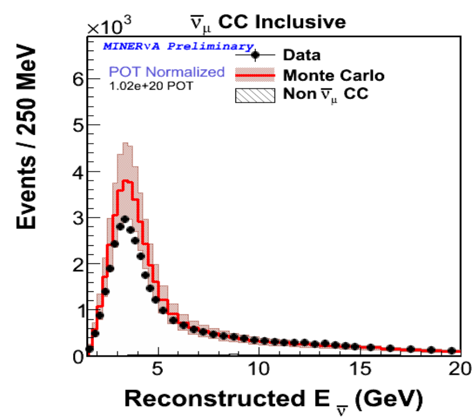
- Abundant sample:
  - Require muon matched with MINOS -analyzed track, measure recoil in MINERνA E(ν) = E(μ) + recoil energy
- Useful for cross checks of detector acceptance modeling and stability
  - Will eventually become total cross section measurement vs energy
- Currently systematics limited in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

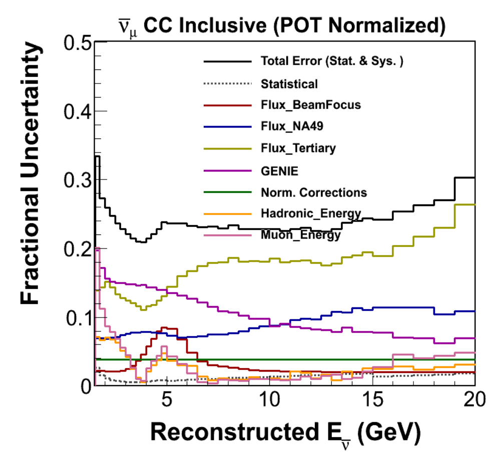






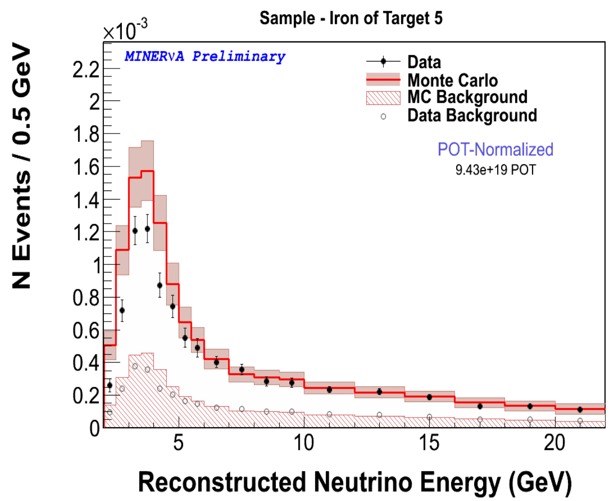


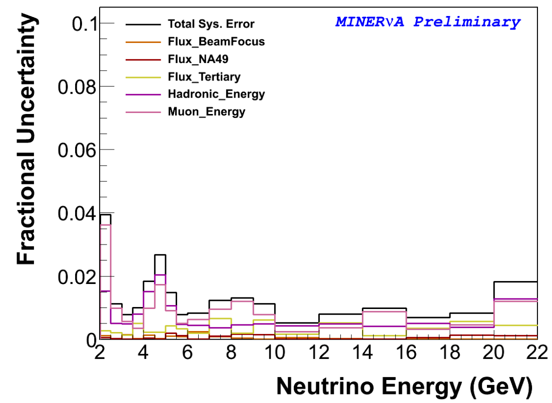


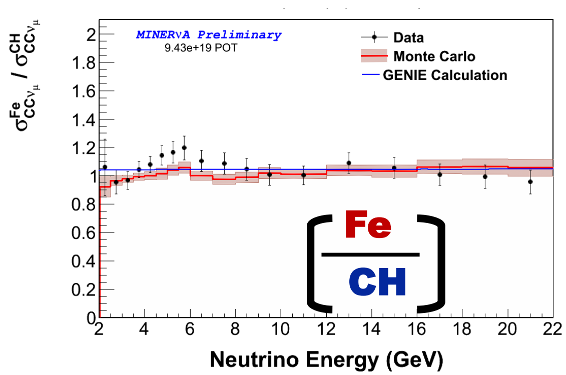


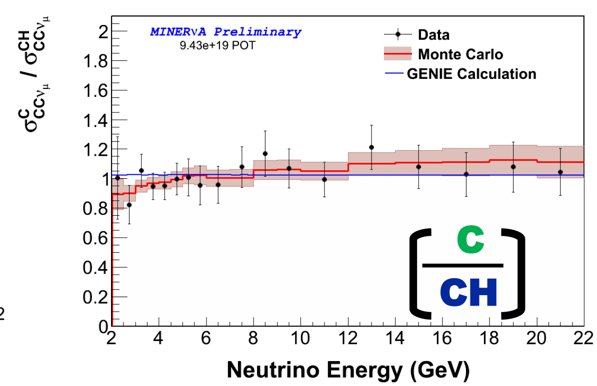
Inclusive Nuclear Target Ratios

- Significant reduction in systematic errors when taking ratios of events: MINERνA designed to do this
  - Same cuts as inclusive analysis. Vertex must be in solid targets. Subtract backgrounds from vertex mi -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

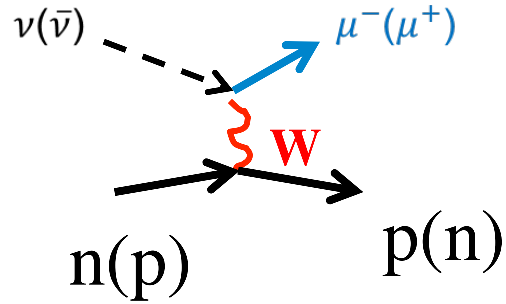






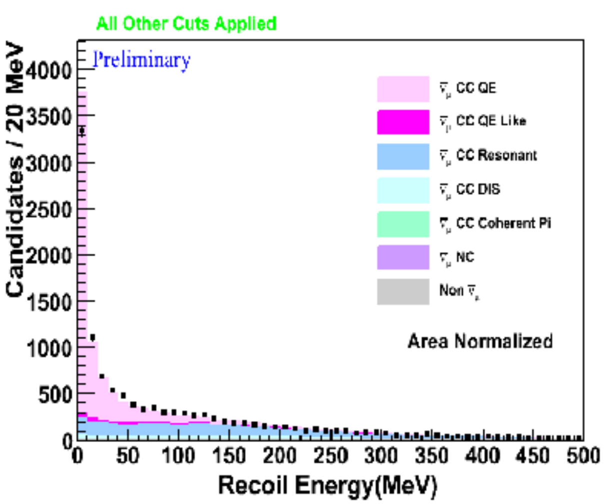


Quasi-Elastic Scattering



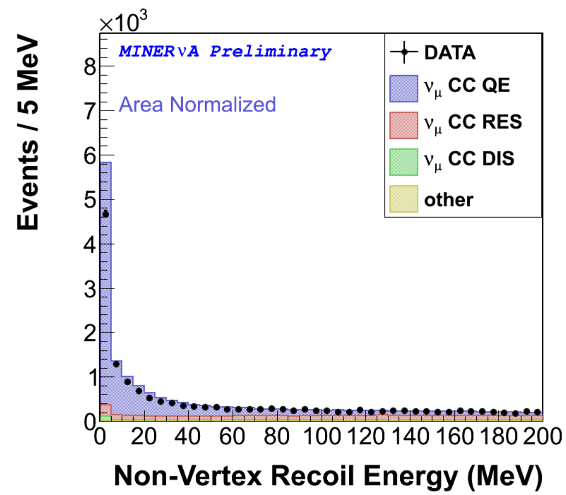
- "Golden signal for oscillation experiments
  - Low backgrounds
  - Estimate neutrino energy by measuring muon angle and momentum
- Physics question is how nucleus modifies these backgrounds and energy estimates
  - Big systematics for T2K and presumably NOvA, LBNE

- Identified by muon with low recoil energy, consistent with recoiling nucleon
- Anti-ν and ν in plastic, plus 2 -track QE in nuclear targets studies studied to date



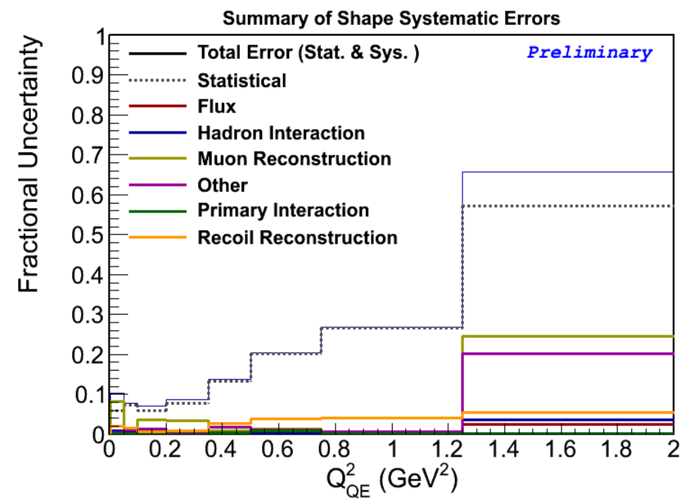
$\bar{\nu}_\mu$QEL candidates

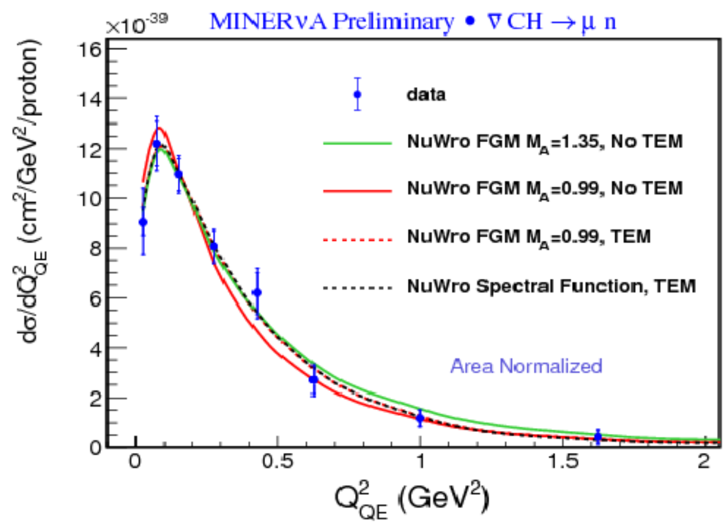
ν_μ QEL candidates



Quasi-Elastic Cross section

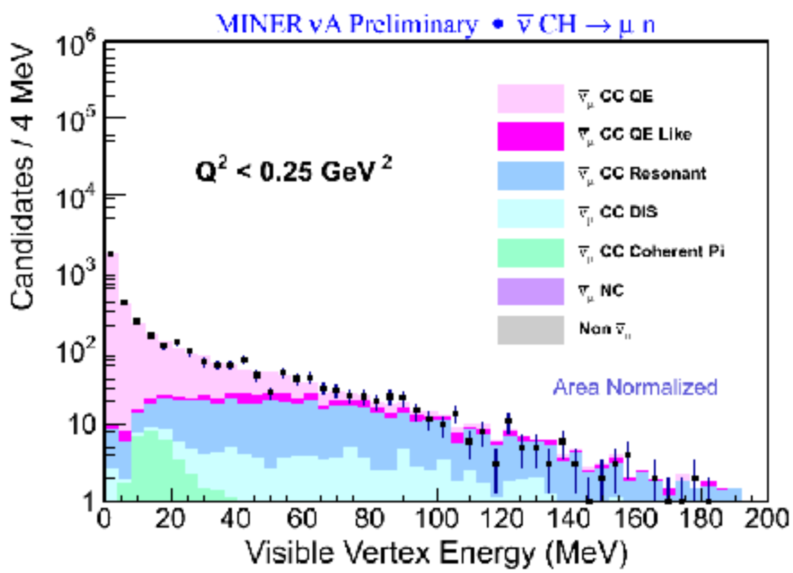
- Anti-ν Quasi-elastic analysis has results for shape-only dσ/dQ²
  - Background subtraction from sidebands
  - Unfold detector resolution in Q²
  - Full suite of syst. errors evaluated
- Result that we publish will have uncertainties 2 or 3 times smaller than this preliminary result
  - More data, better 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

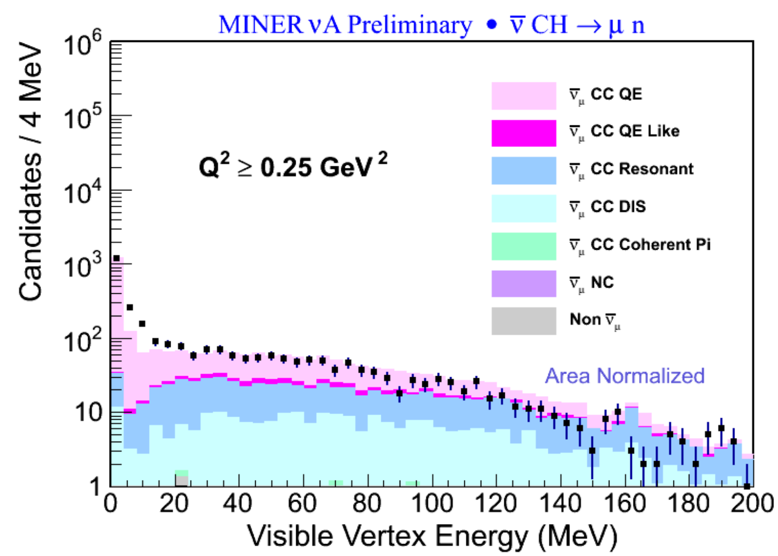




Search for Nuclear Effects in QE "vertex energy"

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





Summary of 2012 results

- Preliminary $d\sigma/dQ^2$ for anti-ν 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 anti-ν
- Identified portfolio of systematics
  - Clear path for improvement