Charge Current Anti-Neutrino Quasi-Elastic Scattering in MINERvA

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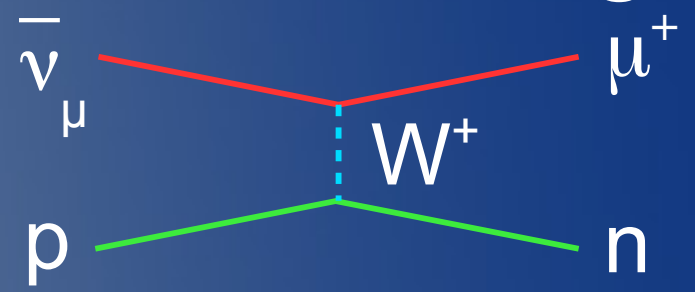
Overview

- Description of Charge Current Quasi-Elastic (CCQE) Scattering
- Physics Motivation
- The NuMI Beam and MINERvA Detector
- Selecting CCQE Events
- Results
- Conclusions

What is Quasi-Elastic Scattering?

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$$



- Neutron is ejected from the nucleus, but not necessarily observed
- Incoming neutrino or anti-neutrino energy and momentum transfer squared (Q^2) can be reconstructed with just the muon kinematics

$$E_{\bar{\nu}_\mu}^{QE} = \frac{2M_p' E_\mu - \left(M_p'^2 + m_\mu^2 - m_n^2\right)}{2\left(M_p'^2 - E_\mu + p_\mu \cos\theta_\mu\right)}$$

$$Q^2 = 2E_{\bar{\nu}_\mu}^{QE}\left(E_\mu - p_\mu \cos\theta_\mu\right) - m_\mu^2$$

$$M_p' = m_p - \varepsilon_B$$

$$\varepsilon_B = 30\ MeV$$

Uses Relativistic Fermi Gas Model (RFGM)

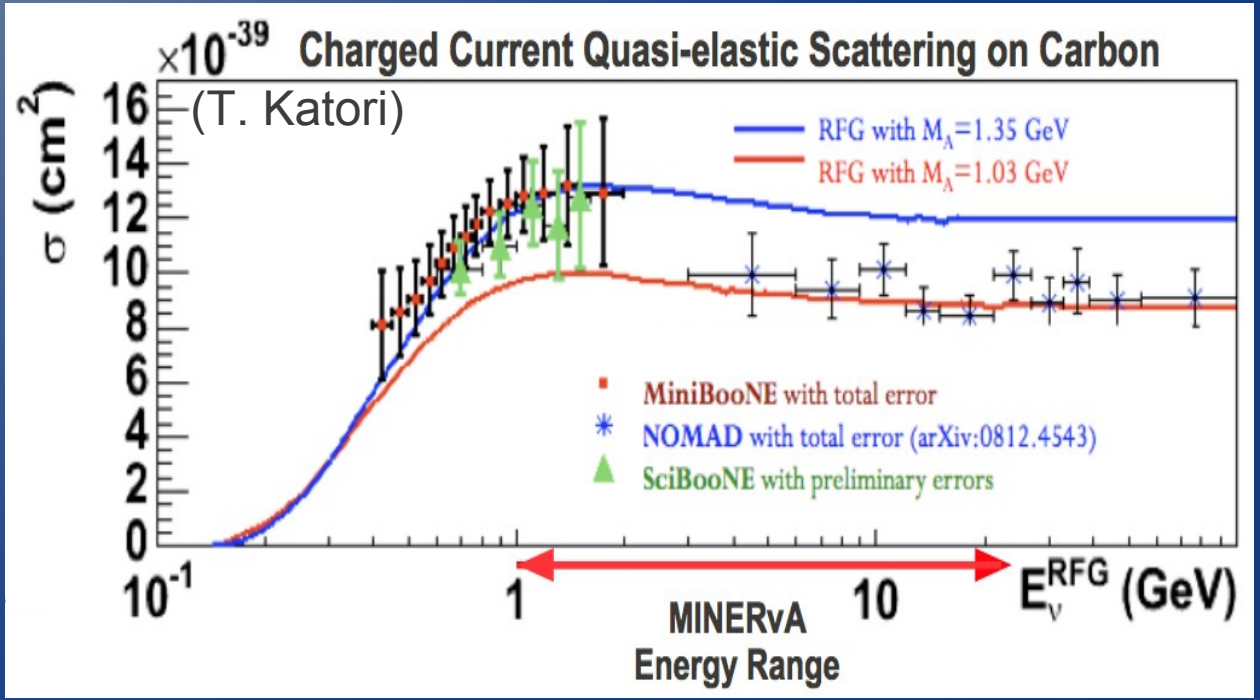
CCQE Cross Section

- Cross section calculated using a variety of form factors (vector and axial vector)
  - Vector form factors extracted from electron-proton scattering
  - Axial vector form factor (Dipole Approximation shown below) must be extracted from neutrino-nucleus scattering

$$F_A(Q^2) = \frac{-g_A}{\left(1+\frac{Q^2}{M_A^2}\right)^2} \qquad M_A = Axial\,Vector\,Mass$$

Motivation

- Cross-sections are a big systematic error for oscillation experiments
- Contradictory measurements
- Experiments looking for CP violation by measuring differences in oscillations between neutrinos and anti-neutrinos will be systematics dominated due to the size of θ_{13}



The NuMI Beam Line

- Neutrinos created from pion and kaon decays
- Ability to predict pion and kaon production off the target is the largest uncertainty in determining our flux

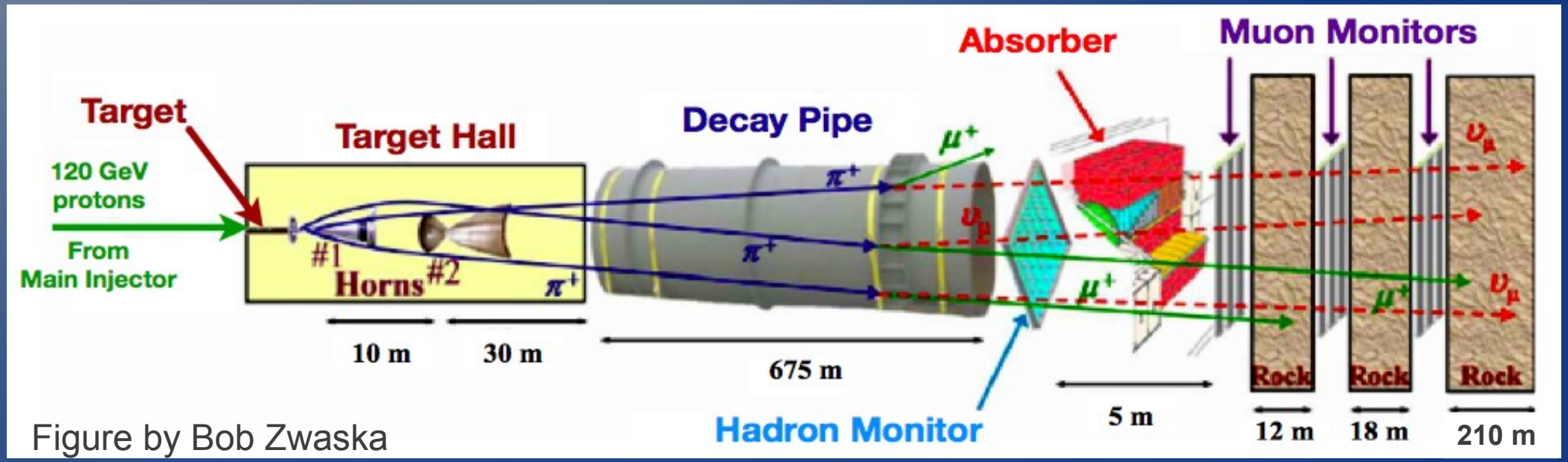
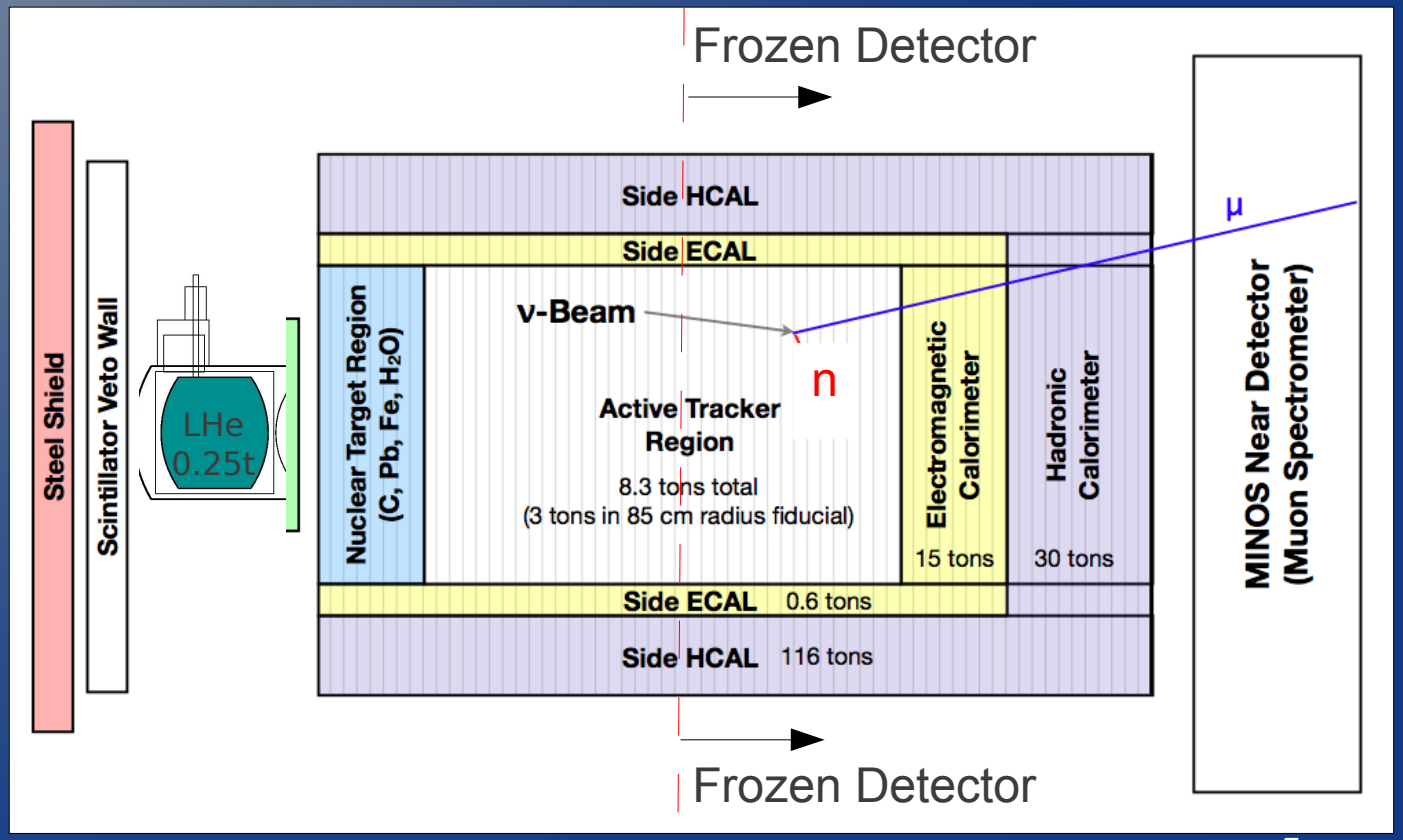


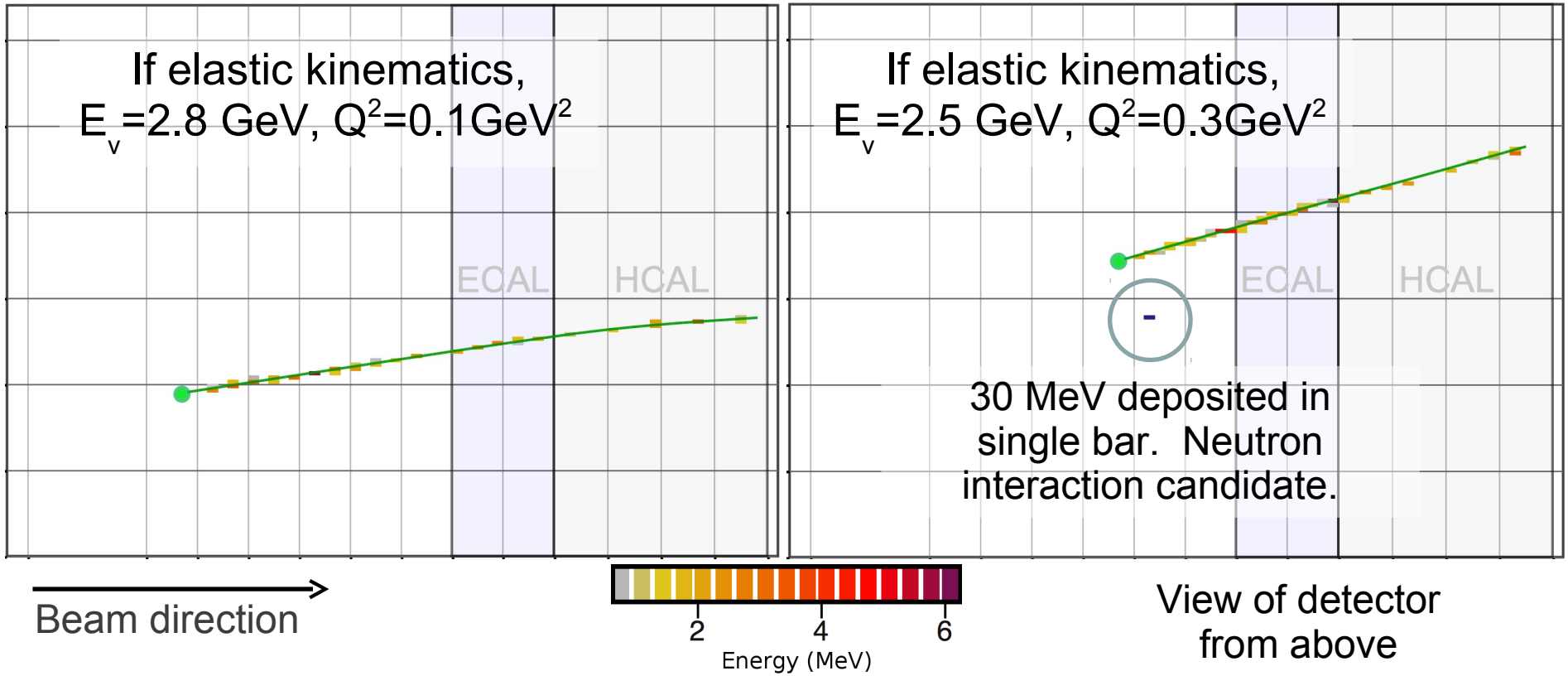
Figure by Bob Zwaska

The MINERvA Detector

- Fine grained detector that lies upstream of the MINOS Near Detector (our muon spectrometer)
- Data that we show is from our partially constructed detector
- We show ~9e19 Protons on Target (POT) worth of anti-neutrino data

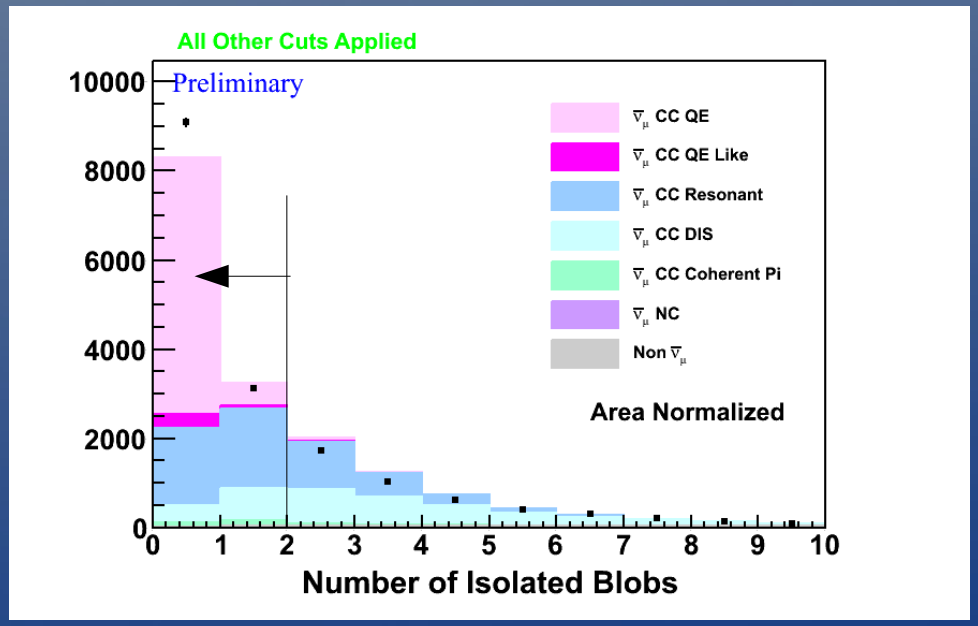


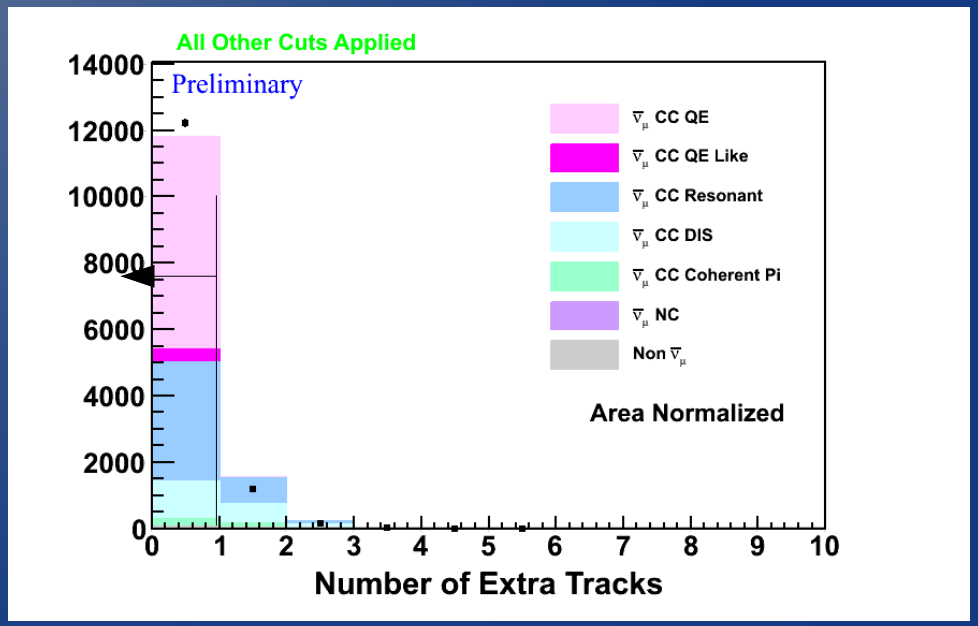
Example of CCQE Candidate Events in MINERvA (data)



Selecting a CCQE Sample

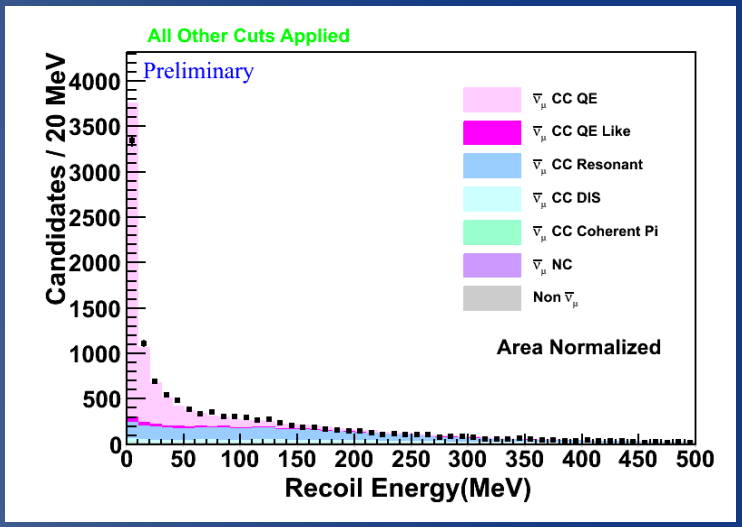
- Require event in fiducial volume with low activity and limited dead time upstream of the muon track
- ≤ 1 recoil shower deposit (blob)
- No extra tracks
- Cut on overall recoil energy

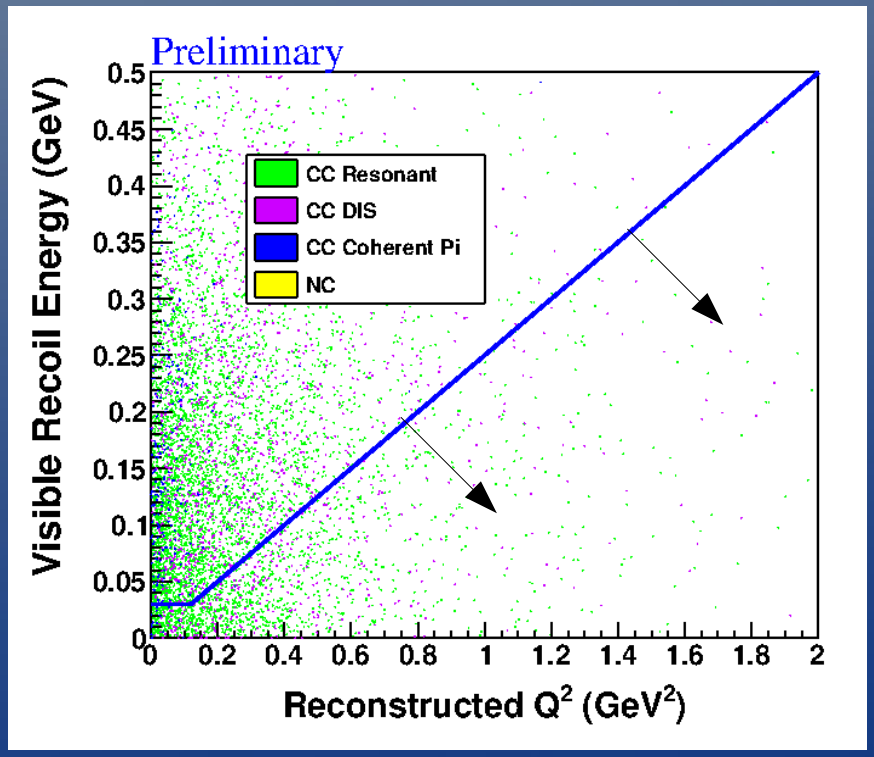


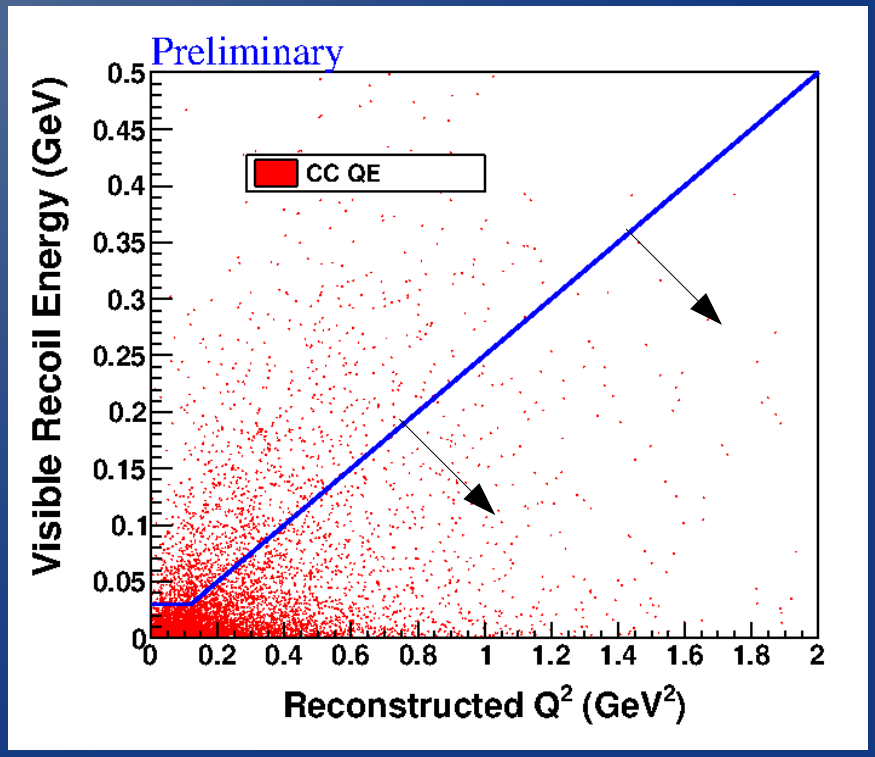


Selecting a CCQE Sample

- Expect higher Q^2_{QE} events to have more recoil energy
- Made a recoil cut that scales with Q^2_{QE}

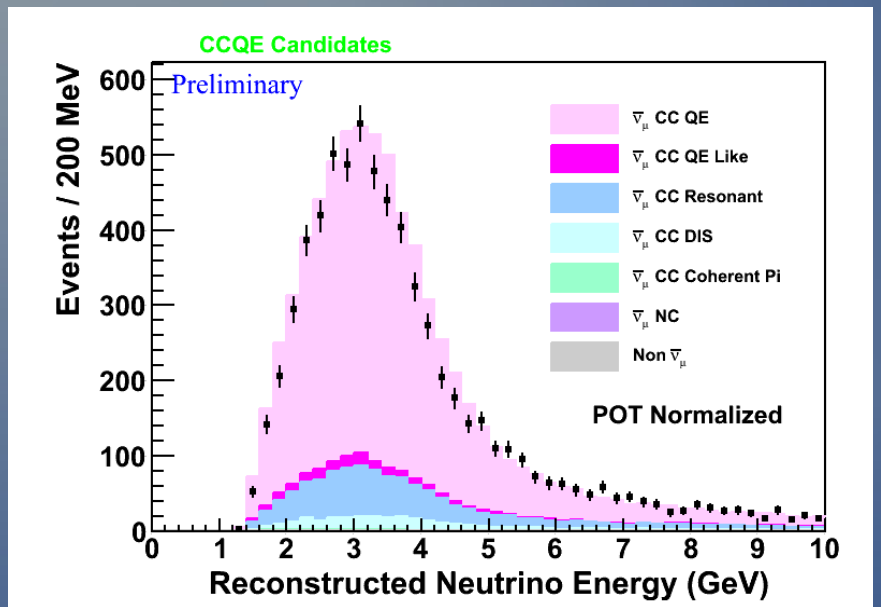


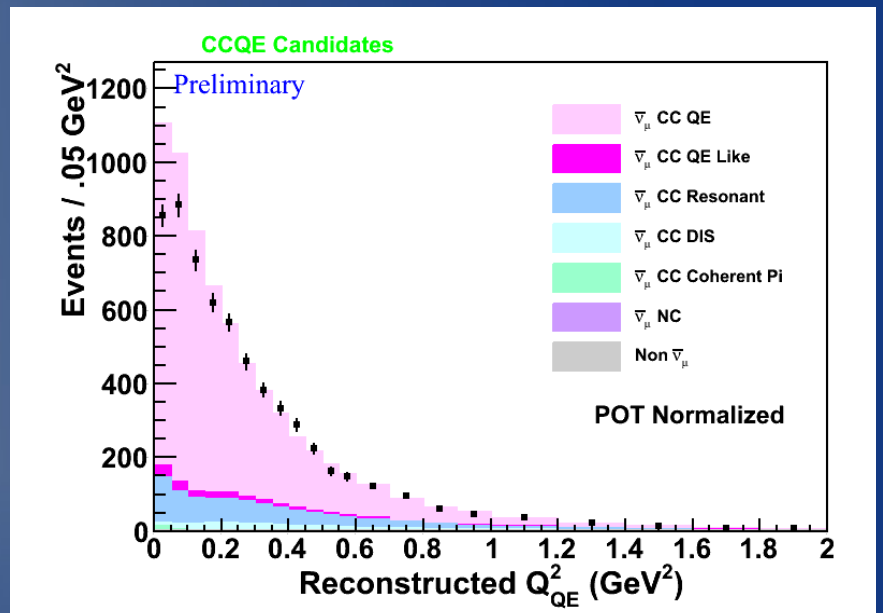


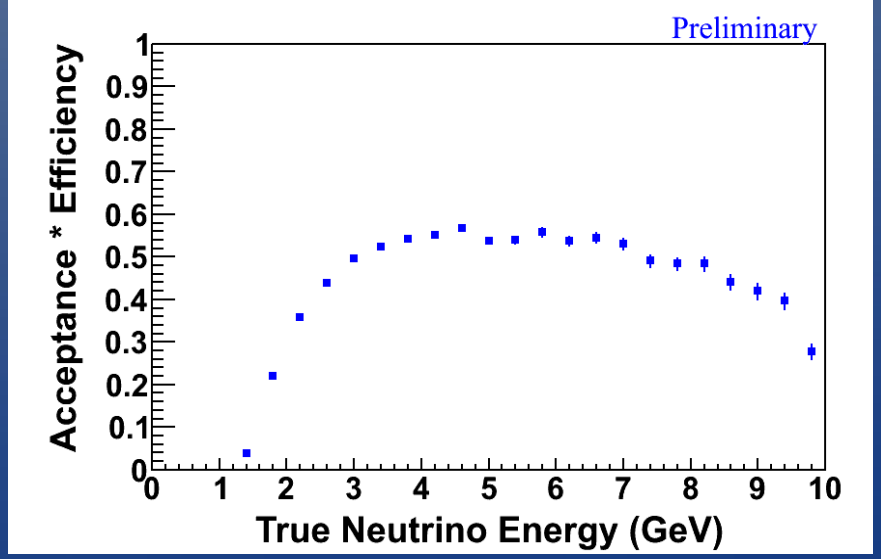


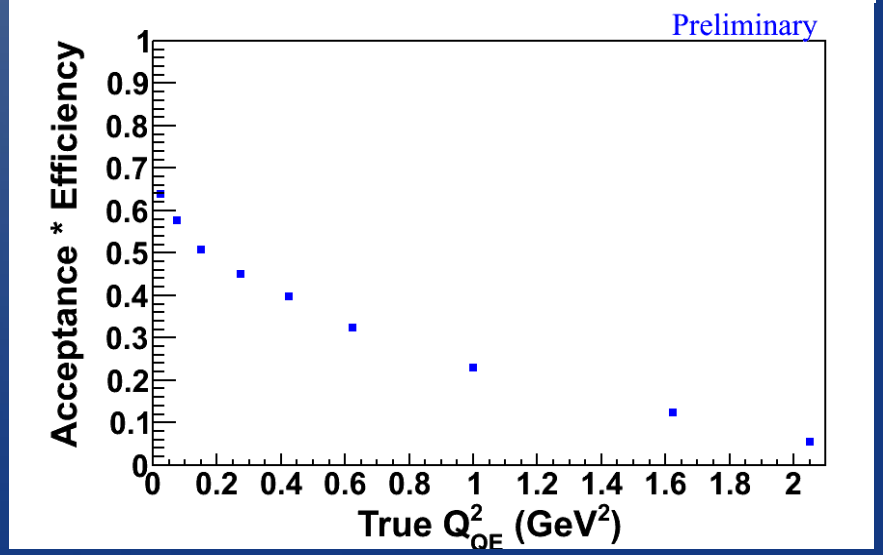
Neutrino Energy and Q^2_{QE}

- After all cuts are applied, sample has ~80% purity

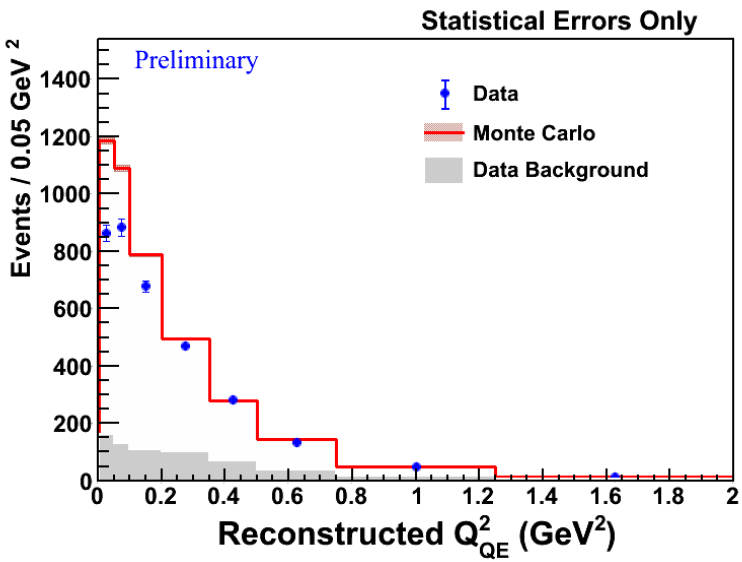




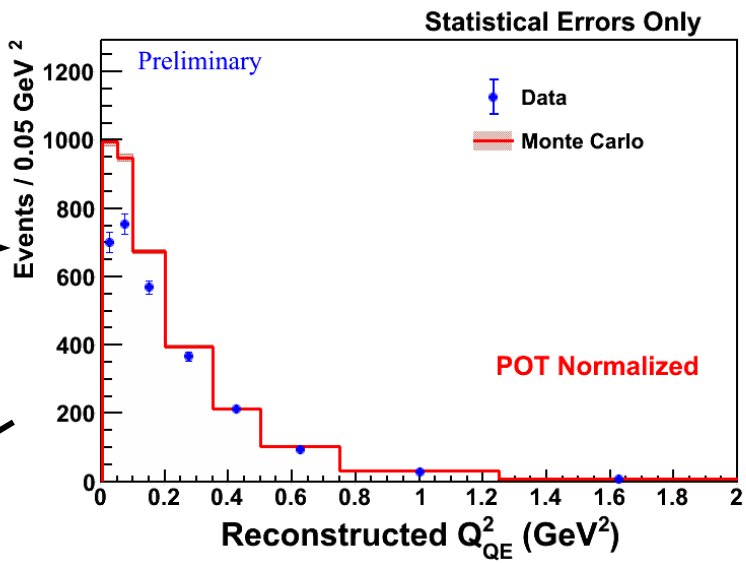




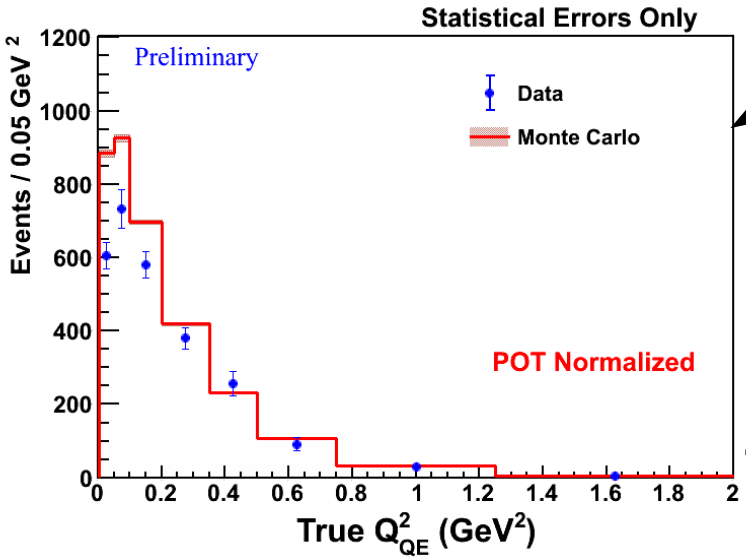
Finding $d\sigma/dQ^2_{QE}$



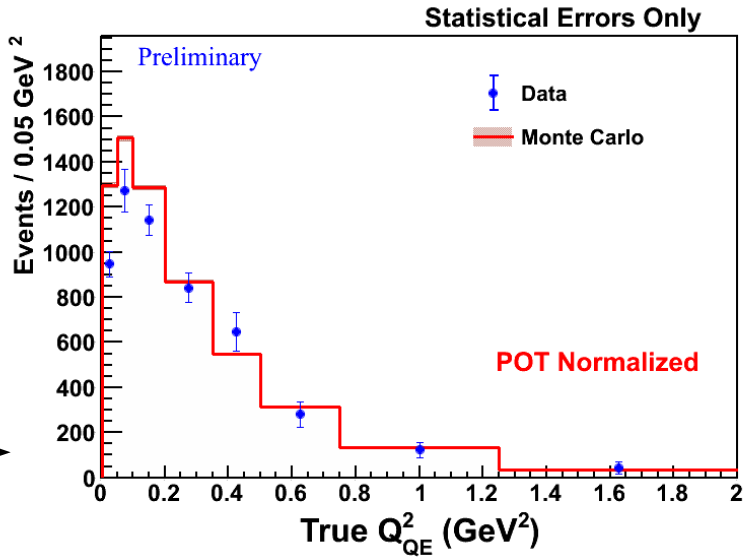
Background subtraction



Unfolding detector smearing

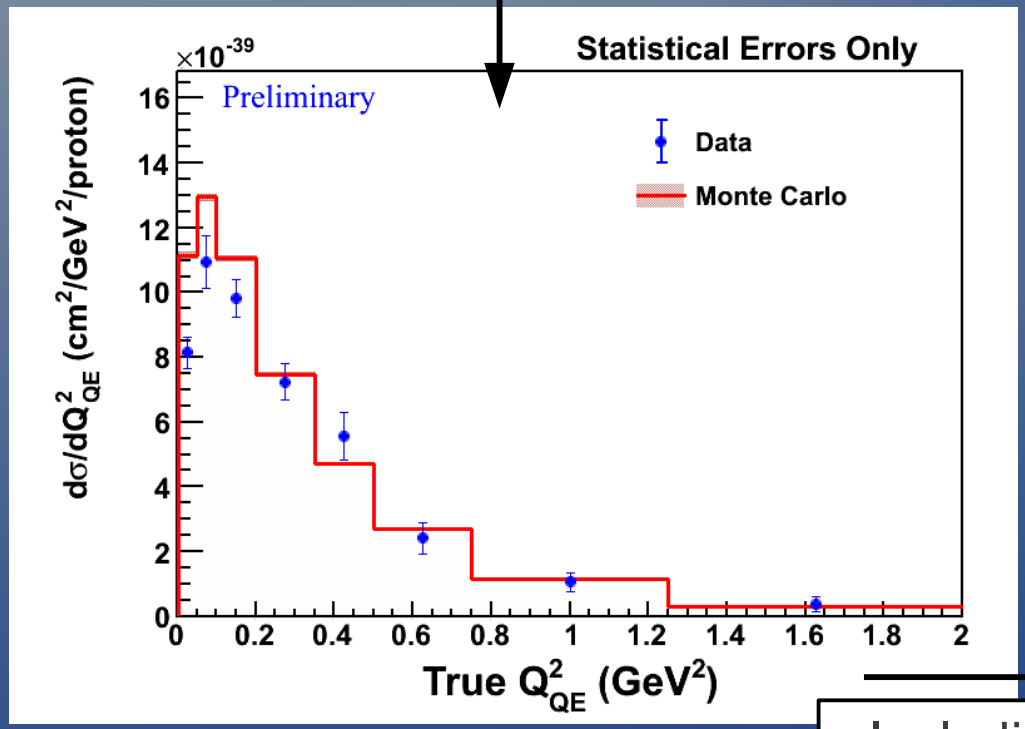


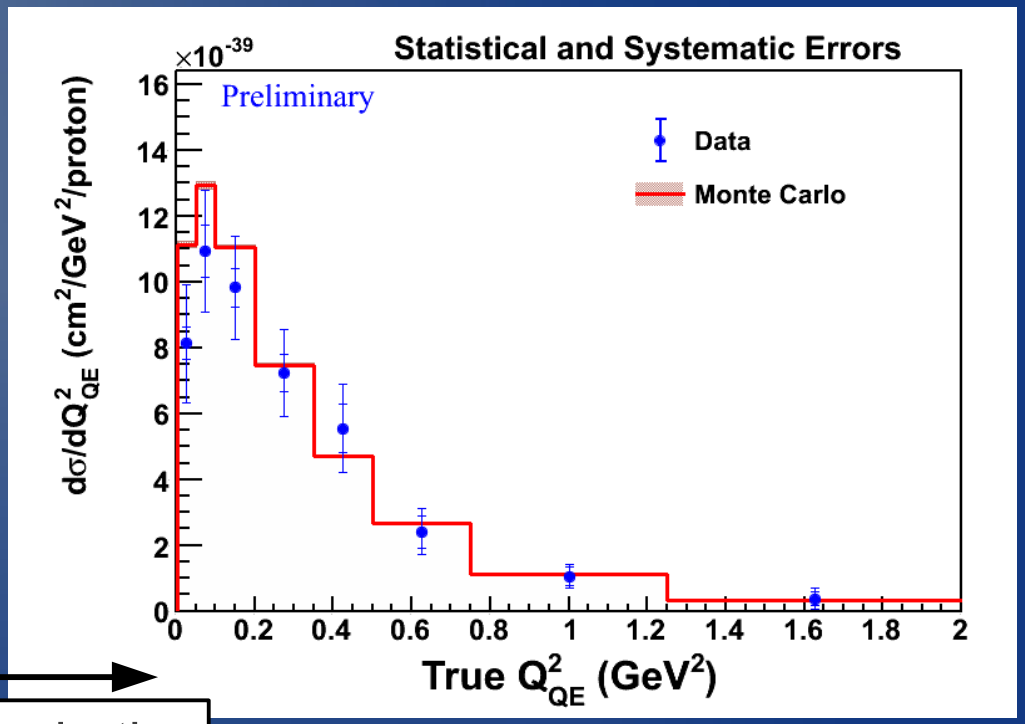
Efficiency correction



Finding $d\sigma/dQ^2_{QE}$

Divide by flux and number of target protons to get $d\sigma/dQ^2_{QE}$

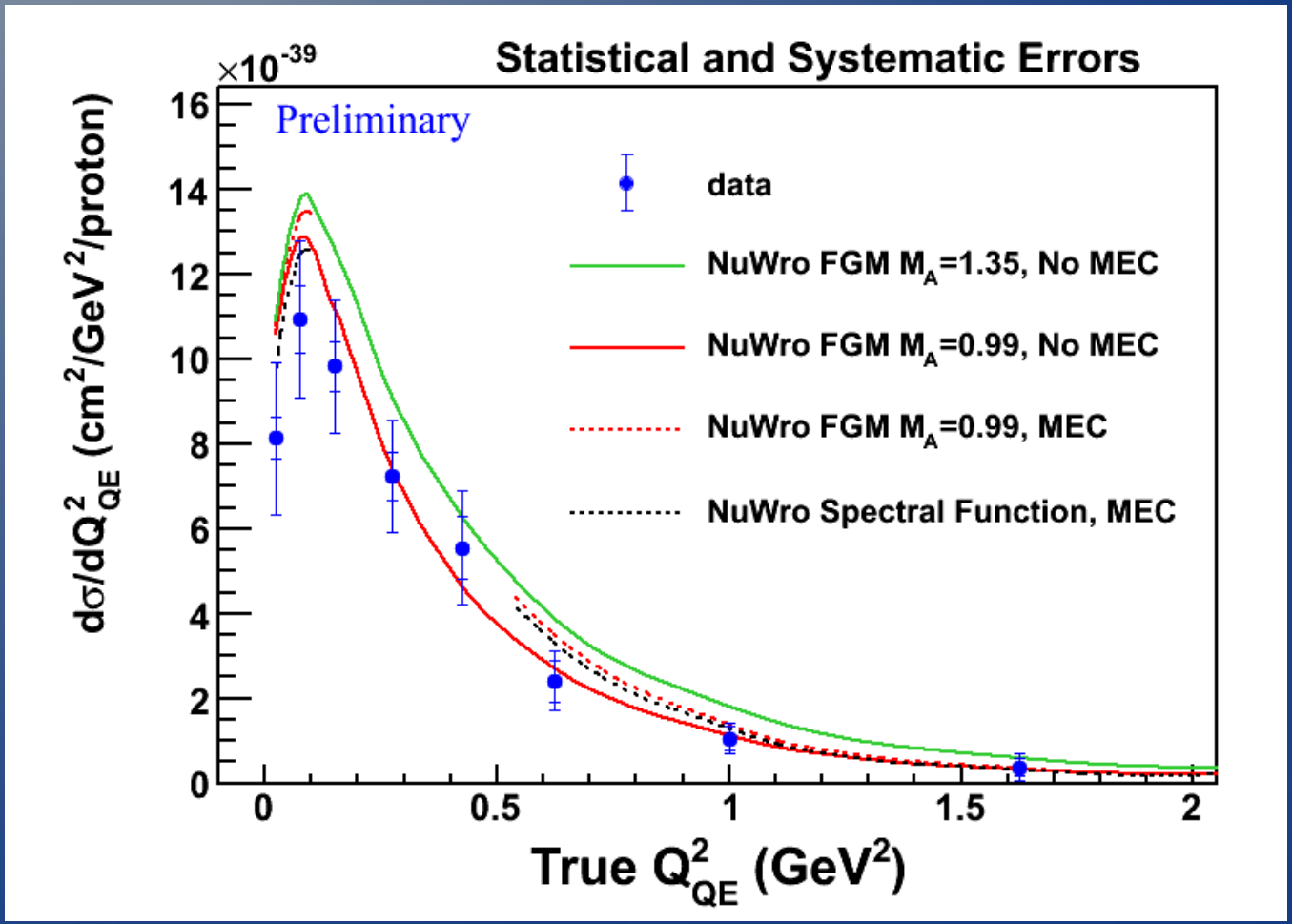




Including both systematic and statistical errors

Comparisons to Other MC Models

- We find our data is consistent with an MC sample with M_A = 0.99 GeV



NuWro: Acta Phys.Polon.B40:2507-2512,2009 (http://arxiv.org/abs/0909.1492)

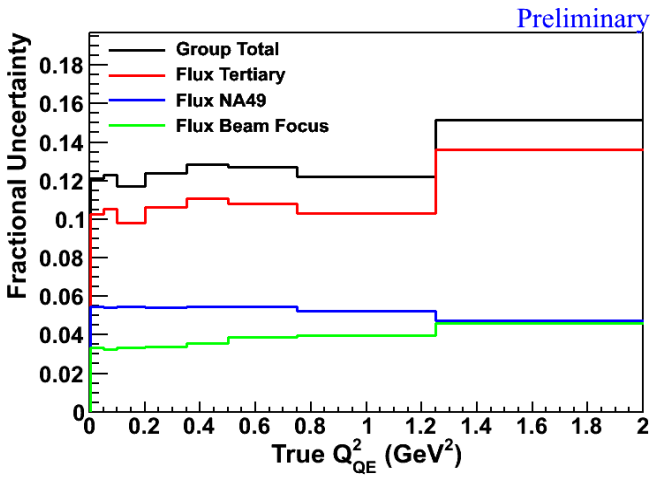
Conclusions

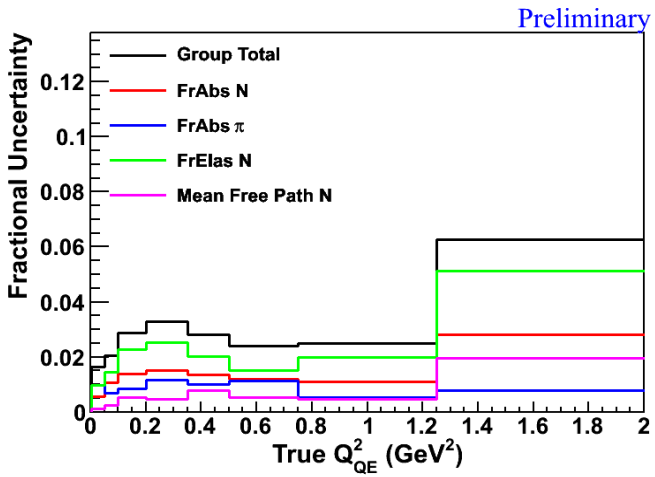
- We have a CCQE anti-neutrino sample with ~80% purity
- We have extracted $d\sigma/dQ^2_{QE}$ for this sample
- We have found our results are consistent with models with M_A = 0.99 GeV, but that we are not yet sensitive to other effects such as Meson Exchange Currents (MEC)

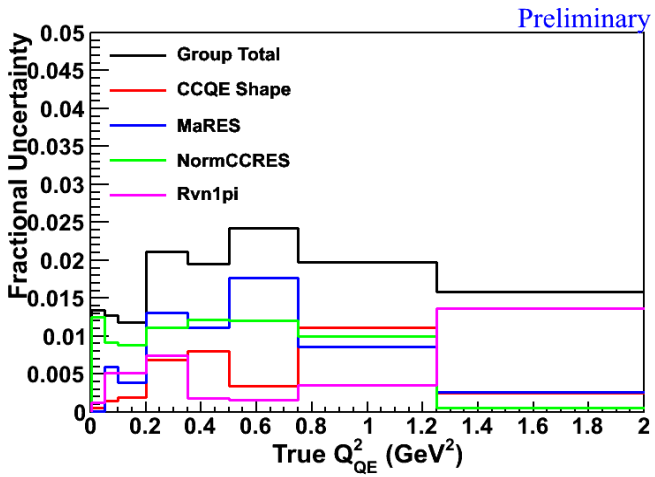
Back Up

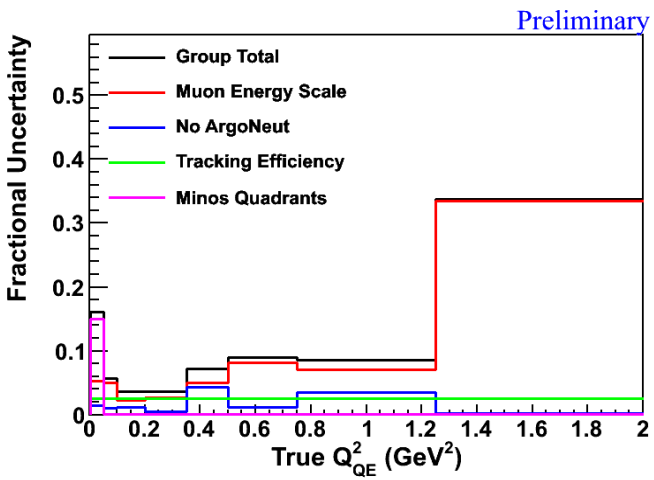
Systematic Errors

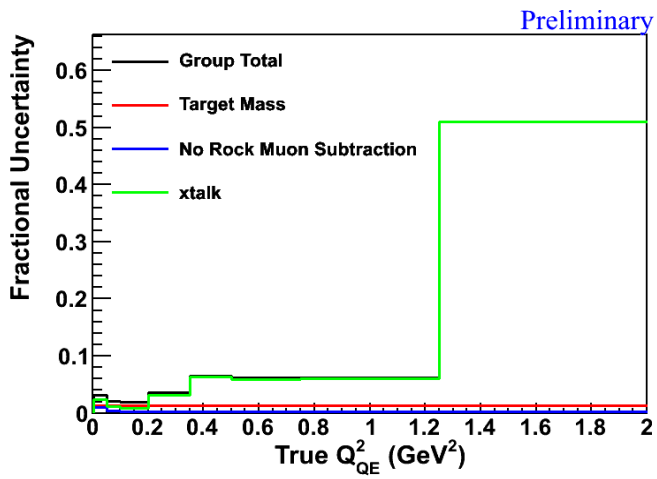
- Breakdown of different error components

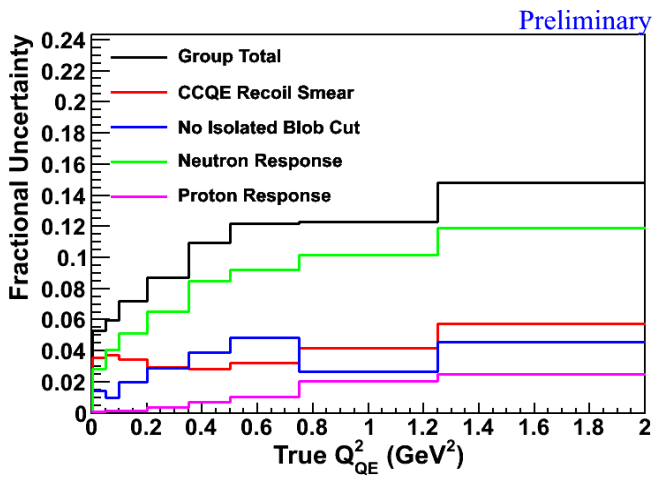






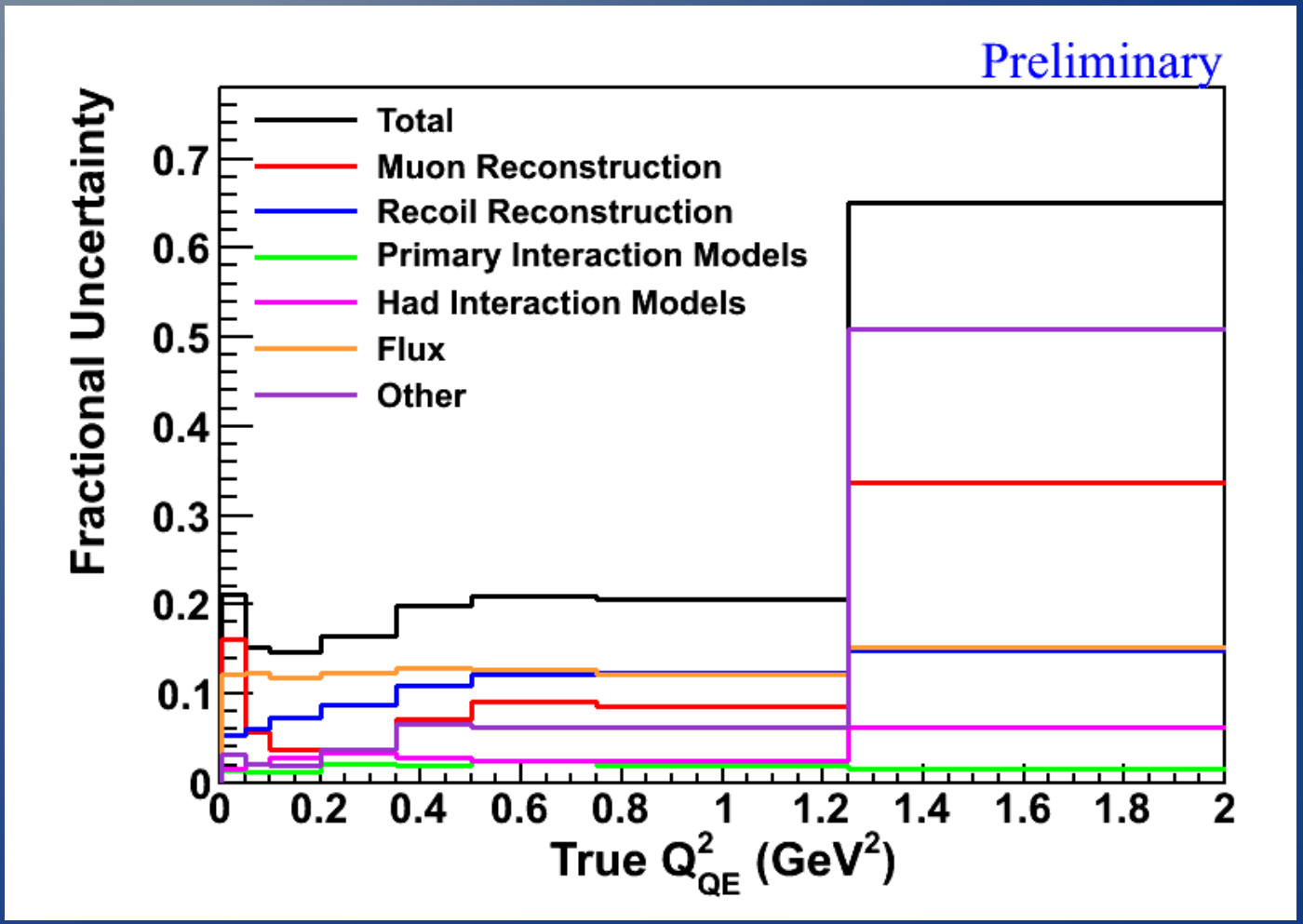






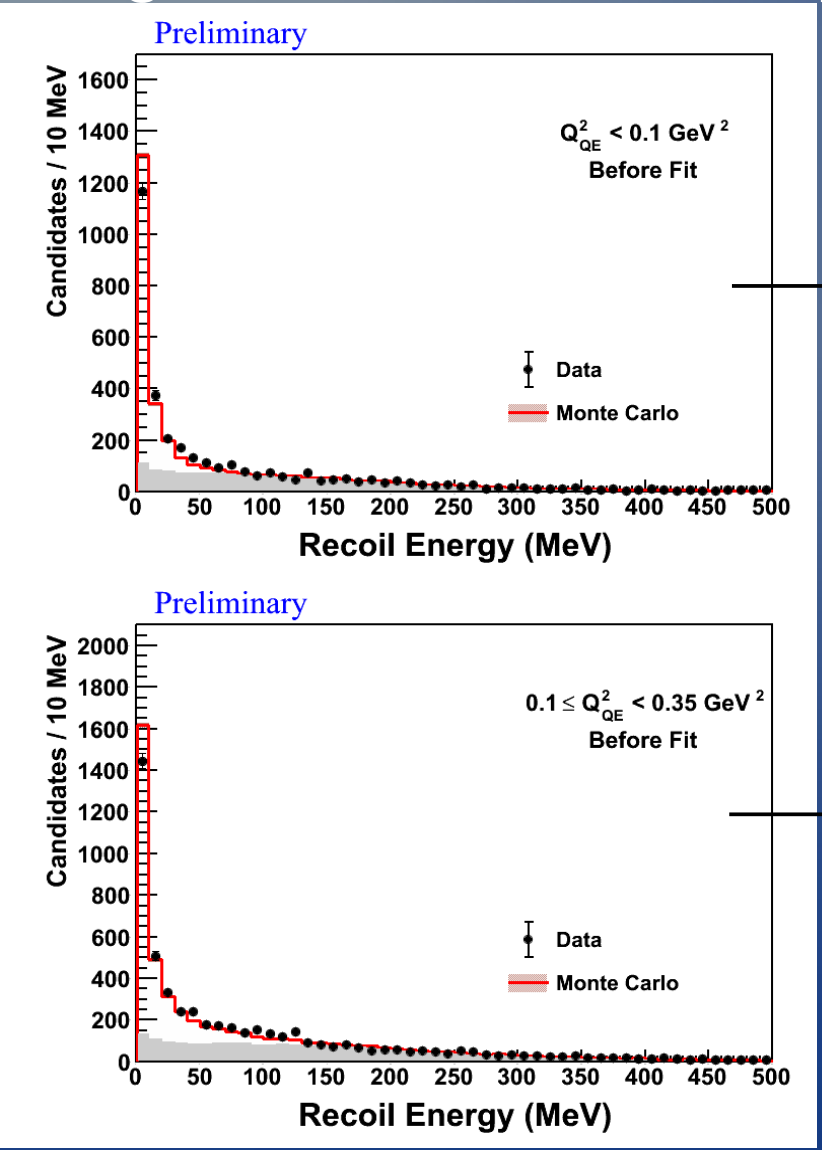
Systematic Errors

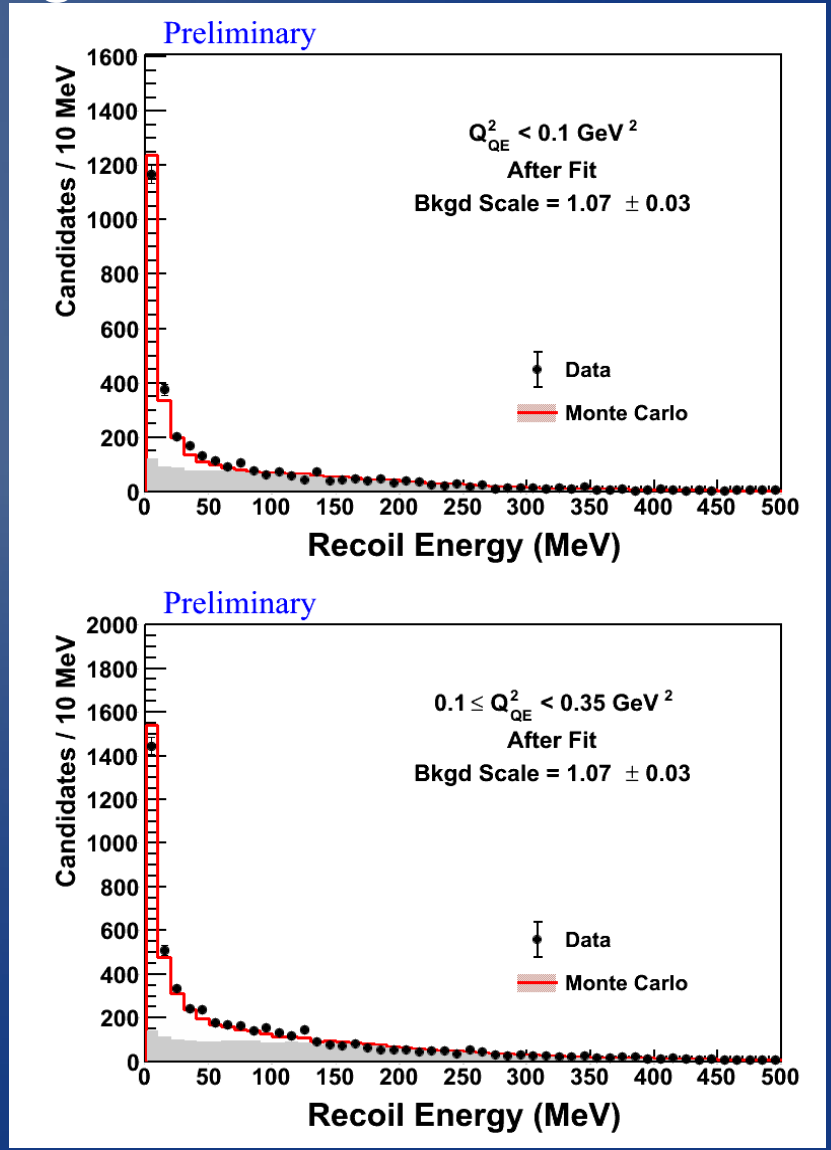
- Summary of error by general type



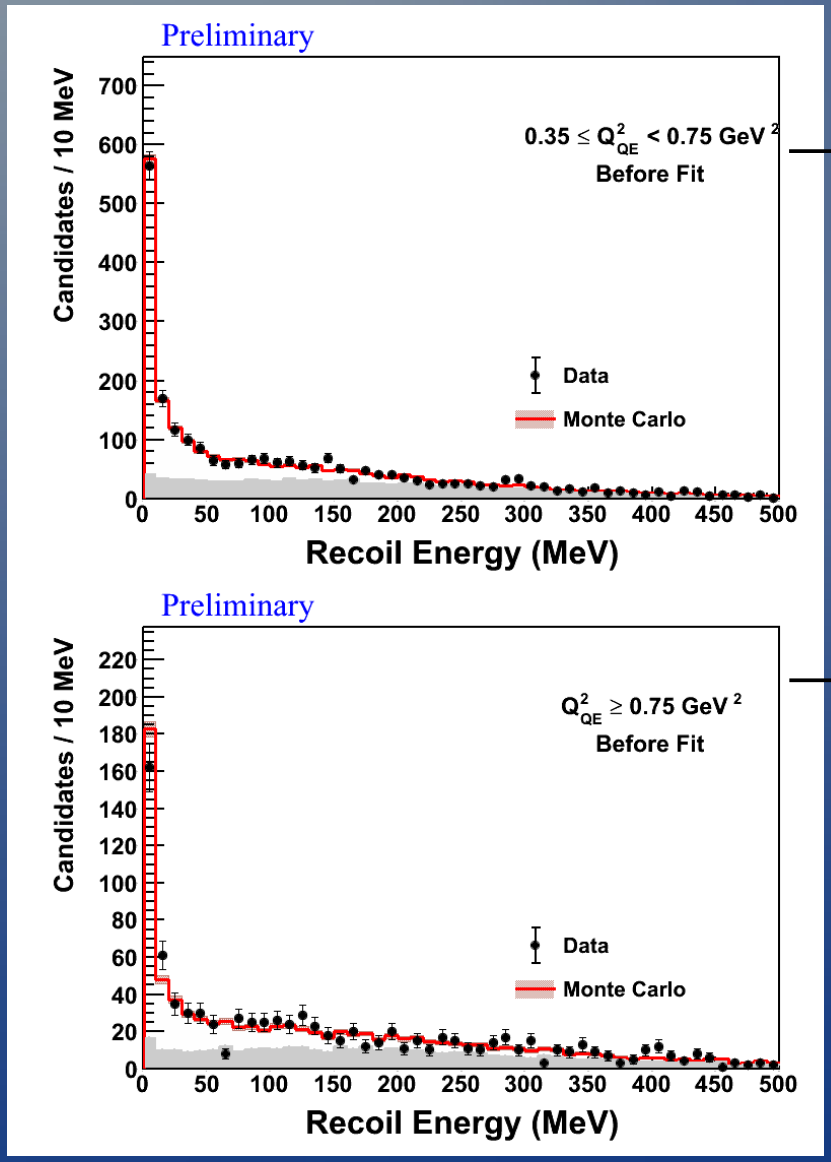
Fitting Background

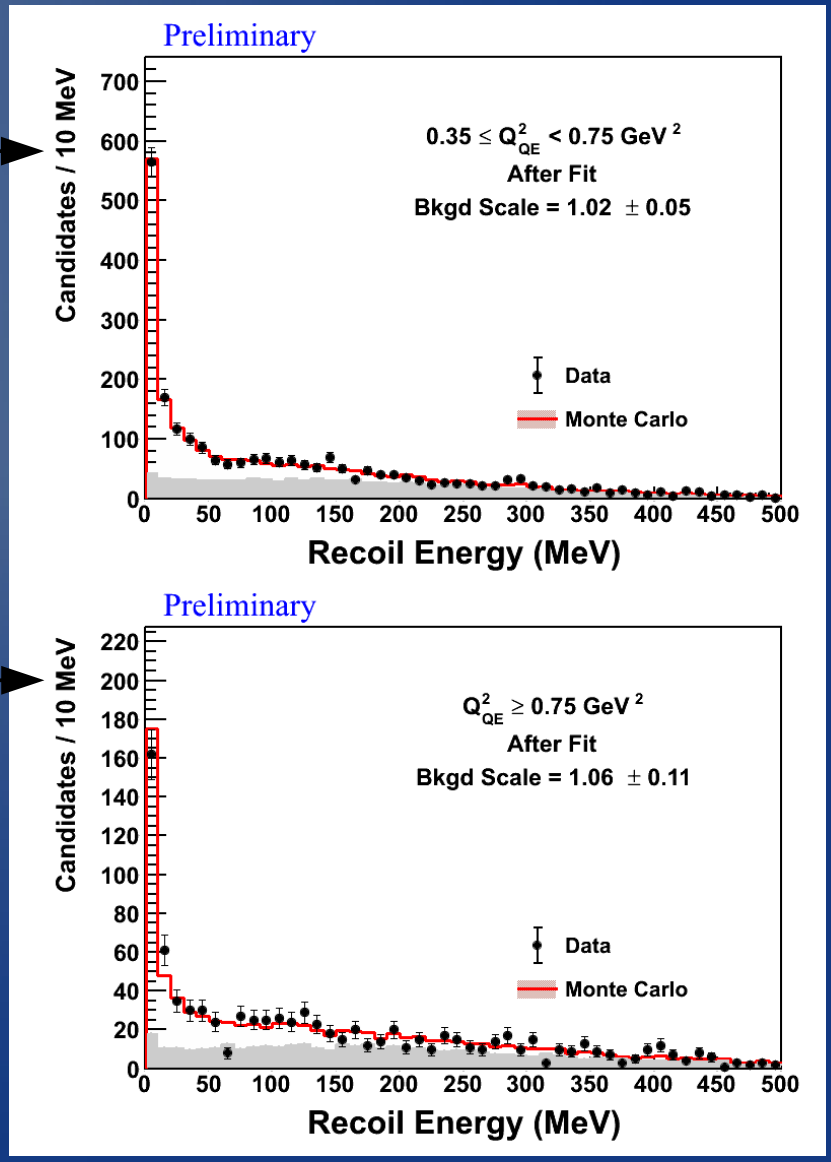
- Background is found by doing a template fit to data using the TFractionFitter package in ROOT





Fitting Background

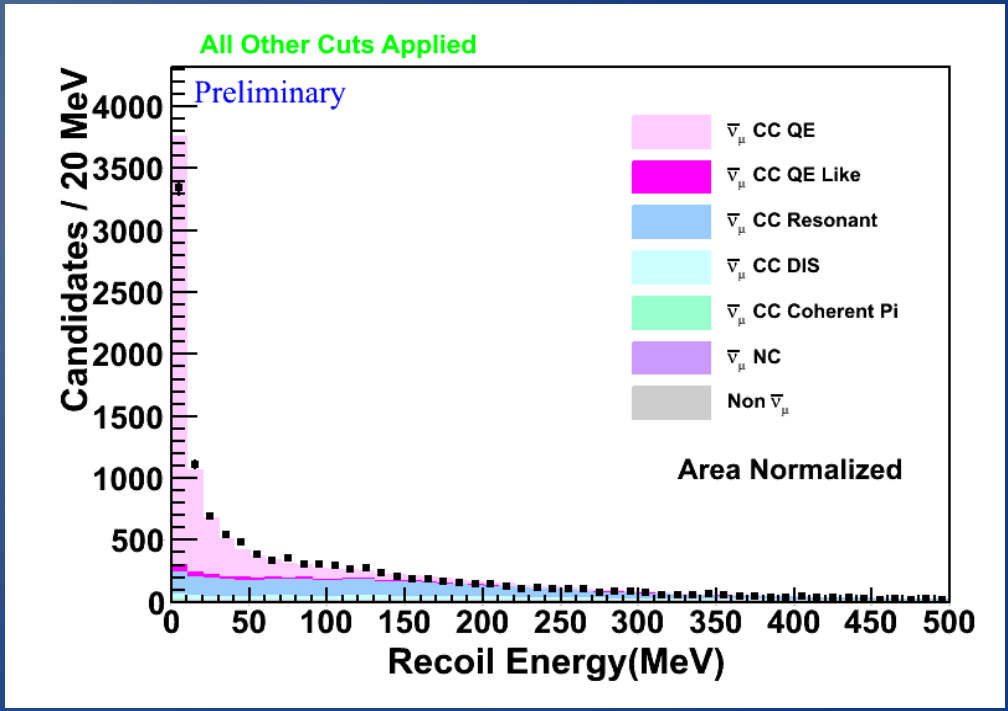




Selecting a CCQE Sample

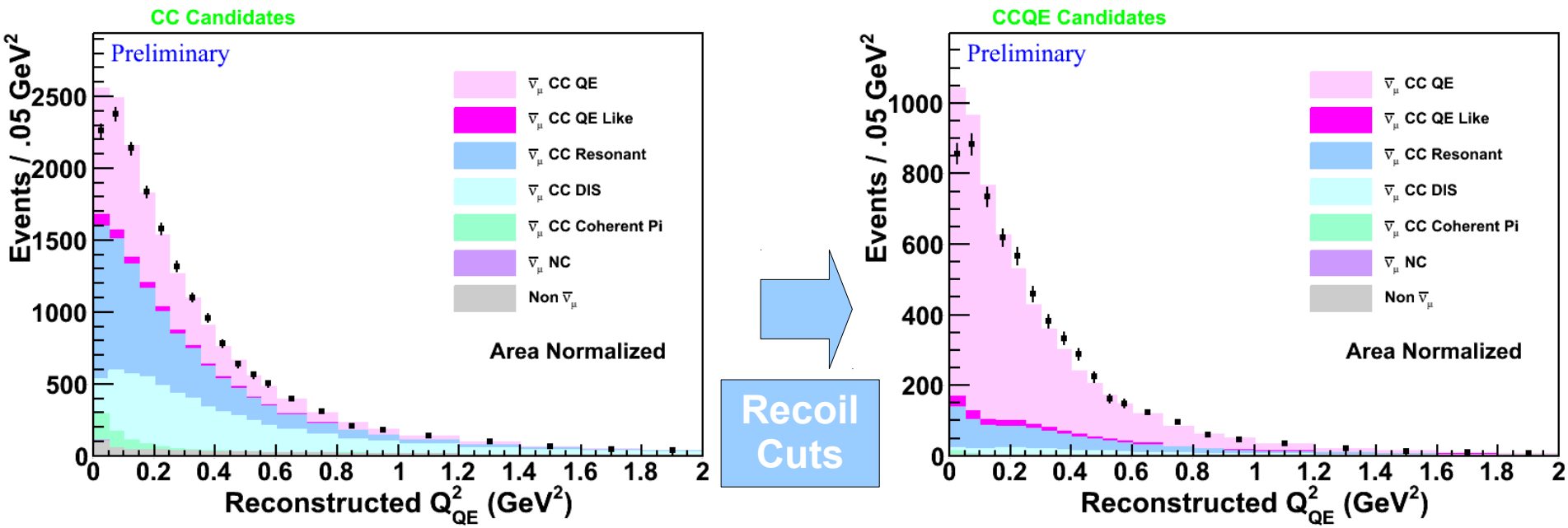
Recoil energy is defined as visible energy in the tracker and ECAL regions of the detector, but excluding:

- Energy near the vertex
- Cross-talk energy deposits
- Energy deposits < 1 MeV
- Energy deposits more than 25 ns away from the muon track time



CCQE Sample Before and After Recoil Cut

- Recoil cut is very effective at selecting a very rich quasi-elastic sample



NuMI Beam Flux Details

- ~35 E12 POT per spill
- Spill length/frequency = 10 μs/0.5 Hz
- Beam power: 300-350 kW

GENIE Generator Details

For QE Generation, specific details of model are:

- Used GENIE 2.6.2 with M_A = 0.99 GeV
- General equation is Llewellwyn-Smith (with lepton mass terms)
- The pseudo-scalar form factor is taken from PCAC
- Eletromagnetic form factors are BBBA2005 (hep-ex/0602017)
- The nuclear model is a fermi gas, with a high momentum component included (taken from Bodek and Ritchie - Phys.Rev. D23 (1981) 1070)
- Pauli blocking is applied by requiring the outgoing nucleon has momentum above the fermi momentum for the nucleus in question, 221 MeV/c for carbon

Meson Exchange Currents

- Proposed to account for cross-section disagreement between MiniBooNE/SciBooNE and NOMAD

  (A. Bodek, H.S. Budd, M. E. Christy, 2011: http://arxiv.org/abs/1106.0340)

- Alters cross-section due to a correction to magnetic form factors in the cross-section calculation