Quasi-Elastic Scattering on MINERvA

Kevin McFarland
University of Rochester
NuINT11, Dehradun
8 March 2011

To India *via* Indiana

Thank you to the organizers for adjusting the schedule so I could attend my sister's wedding (54 hours and 7500 miles ago) and give this talk.

Outline

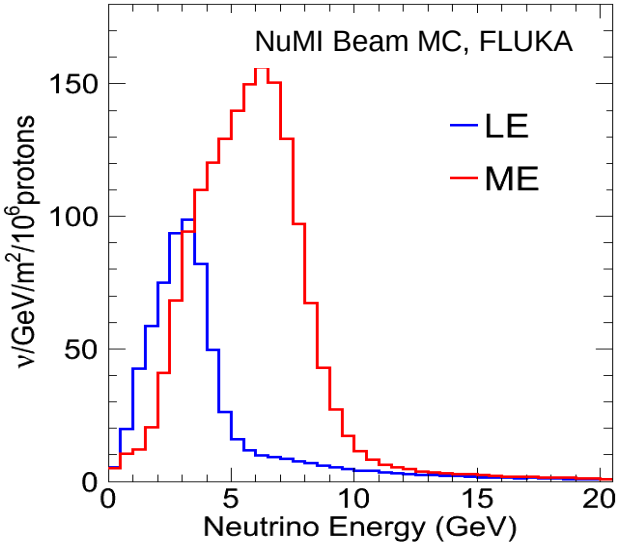
- Goals and Strategies for Studies of (Quasi)-Elastic Scattering at MINERvA
- Scope of Our Initial Study
- Reconstruction and Data Selection
- Comparison with Simulations
- Outlook

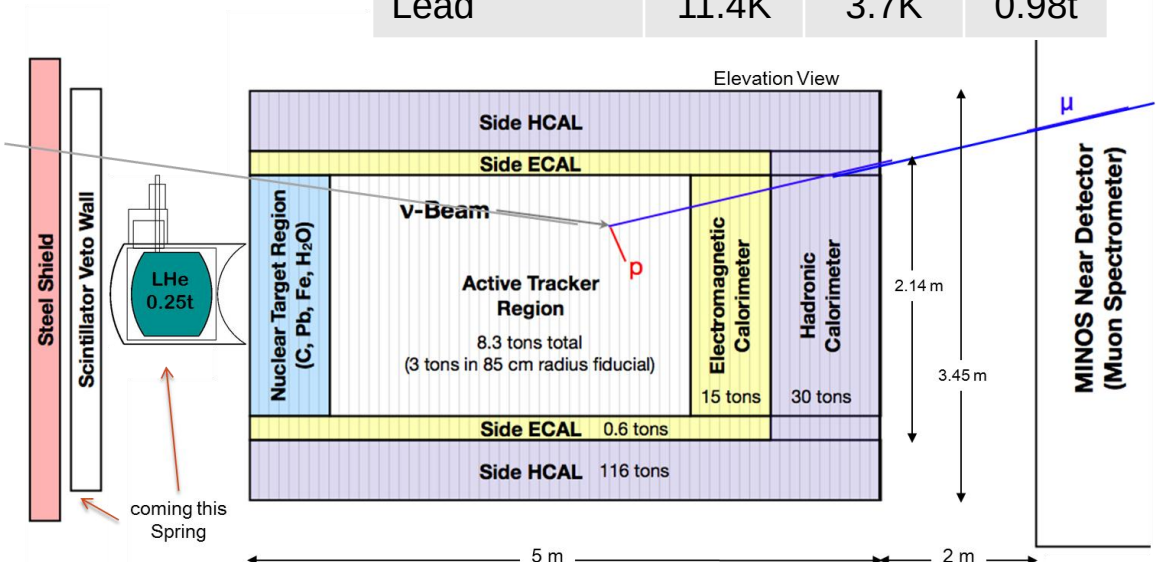
Goals for (Quasi)-Elastic Scattering at MINERvA

- MINERvA was designed in large part to map out features of quasi-elastic cross-sections at moderate energies across a wide range of Q^2
  - Broad range of energies, target nuclei

Fiducial CCQE Interactions/1.2E20 POT

Target	LE ν_μ	LE $\bar{\nu}_\mu$	Mass
Scint. (CH)	58.0K	34.1K	6.4t
Helium	2.6K	1.3K	0.25t
Graphite (C)	1.5K	0.8K	0.17t
Water (H_2O)	3.2K	2.2K	0.4t
Iron (Fe)	9.5K	4.3K	0.97t
Lead	11.4K	3.7K	0.98t



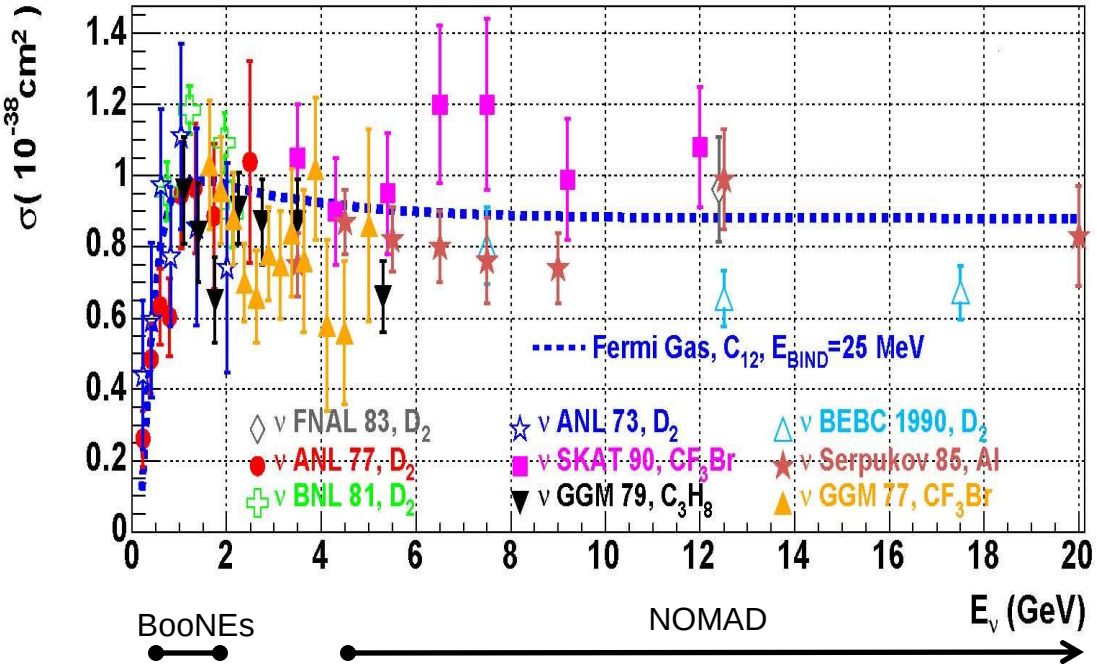


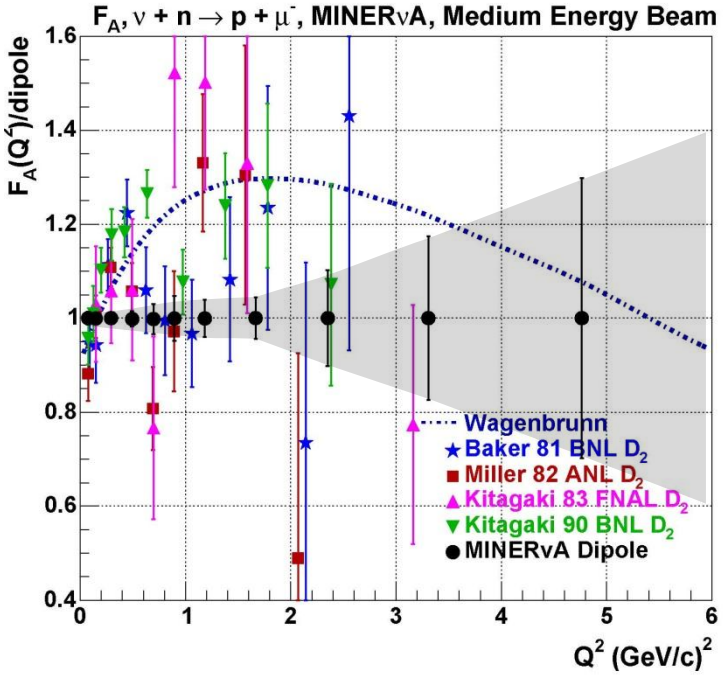
(Q)E Measurements

- Cross section $\left(\sigma \text{ and } d\sigma/dQ^2\right)$ for ν_μ and $\bar{\nu}_\mu$ at low and moderate Q^2.
  - Also model-independent $d^2\sigma/dp_\mu d\theta_\mu$
  - *Do we see similar enhancements at low energy seen by K2K, BooNEs? Agree with NOMAD at high energy?*
- High Q^2 $d\sigma/dQ^2$ to extract axial form factors
  - *Compare with vector form factors. Dipole?*
- A-dependence of σ and $d\sigma/dQ^2$ in nuclear targets
- $d\sigma/dQ^2$ for ν_e, particularly when $m_\mu m_N \ll Q^2$
- NC elastic at moderate Q^2

MINERvA's Prospects

- To illustrate our aspirations, here are our design-era simulation results for measurements with our full low energy data set.





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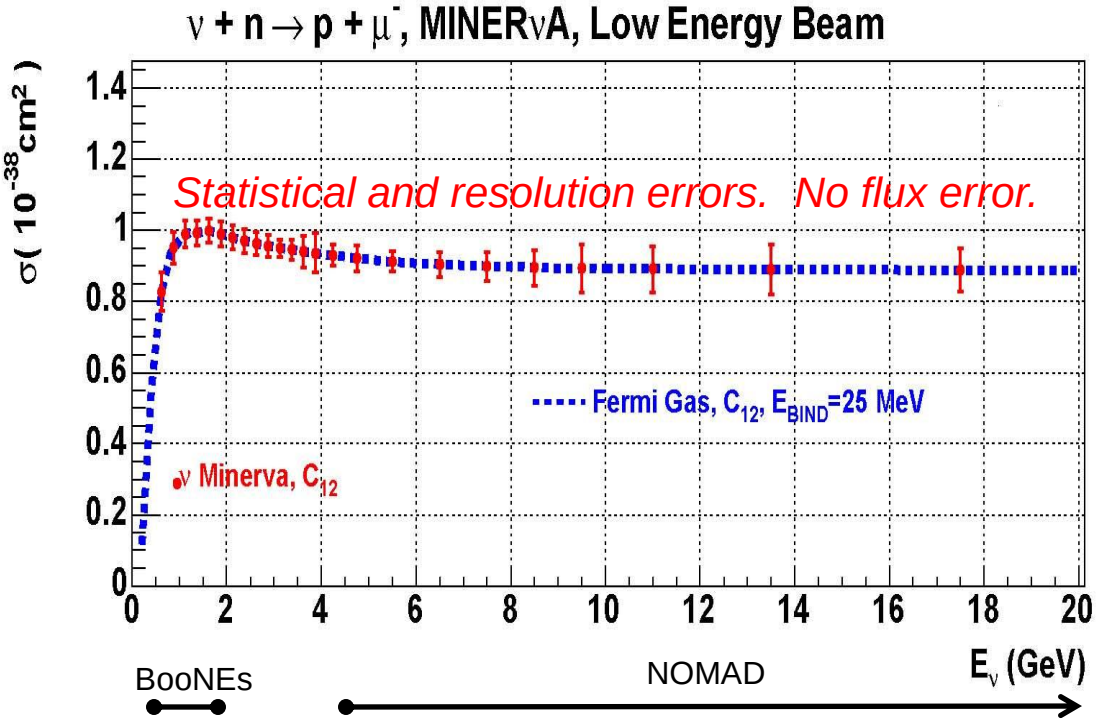
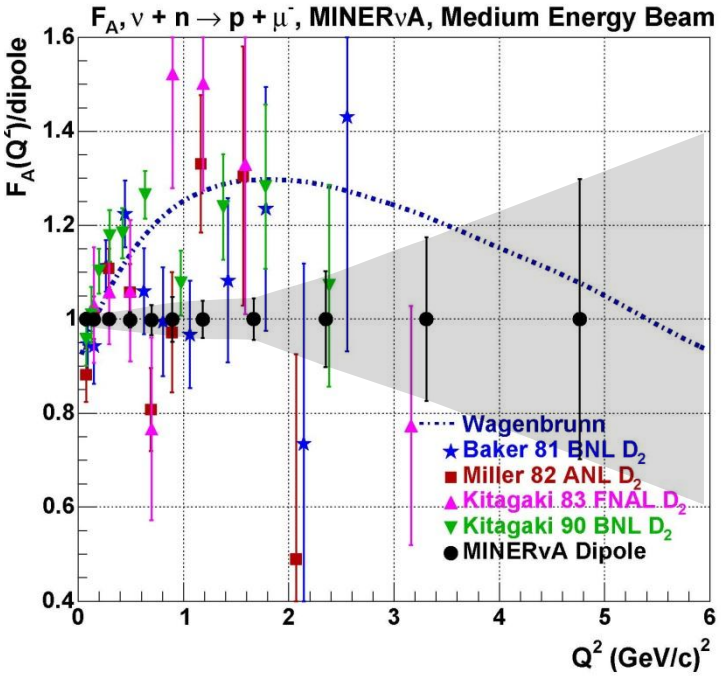


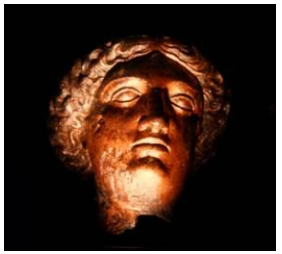


Reconstruction Strategies

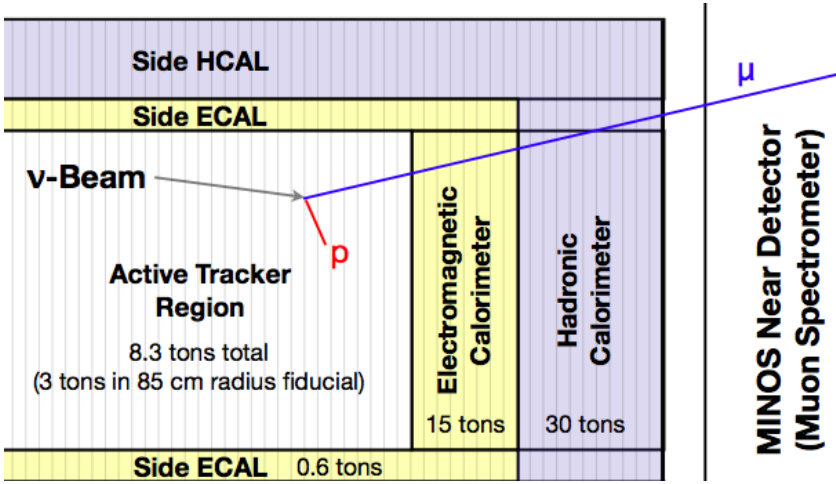
- Many possible approaches to QE reconstruction
  - Experiments choose approaches best suited to detector and beam energy. We hope to try all of these.

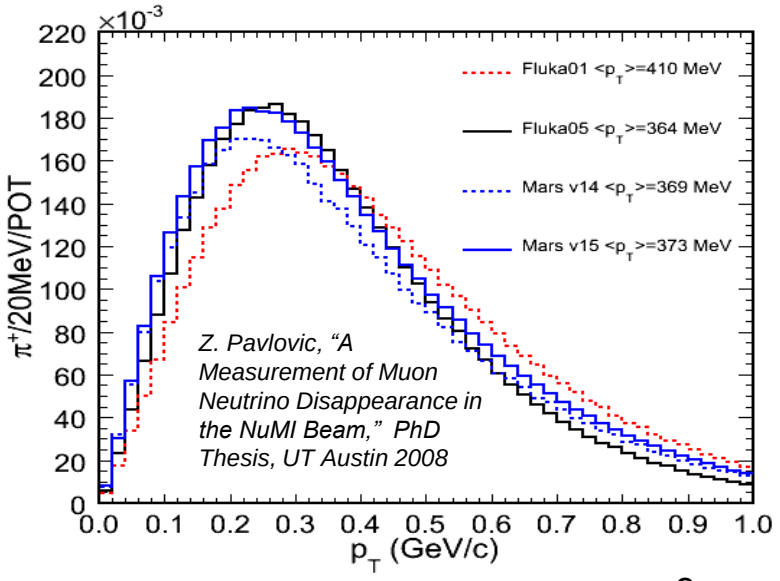
Technique	One and Two-Track [SciBooNE, NOMAD]	Lepton and Michel veto ["MiniBooNE" or Super-K]	One or Two Tracks plus no recoil (calorimetric)
MINERvA-specific comments	• Work to lowest p_p and widest θ_p acceptance • Worse in passive targets	• High energy will be challenging • Only for scint. target	• *Today's analysis from MINERvA*

MINERvA's Challenges



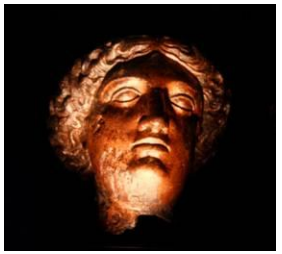
- Dave Schmitz provided a detailed summary of MINERvA's status
  - Increasing muon acceptance at low energy, will be critical for QEL
- Backgrounds
  - Each technique will have different non-elastic contributions
  - Higher energies are more challenging
- Flux uncertainties
  - See talk from Melissa Jerkins
  - We are pursuing techniques using neutrino interaction constraints and constraints independent of neutrinos



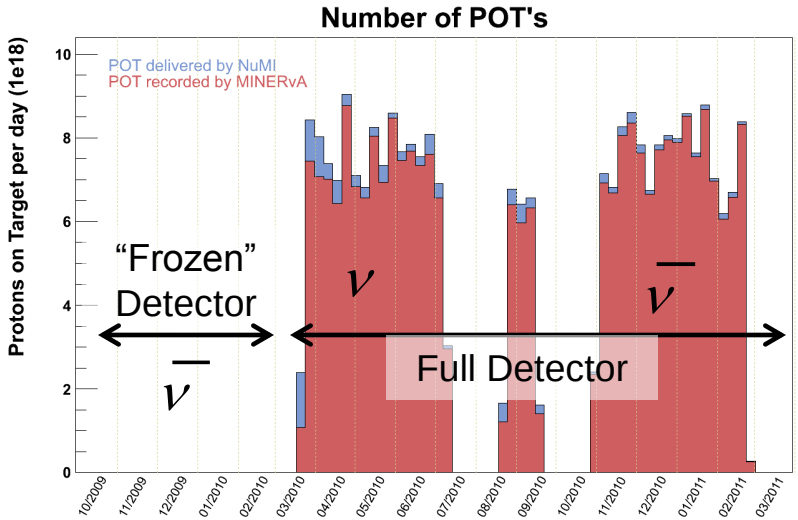


MINERvA's First Quasi-Elastic Studies

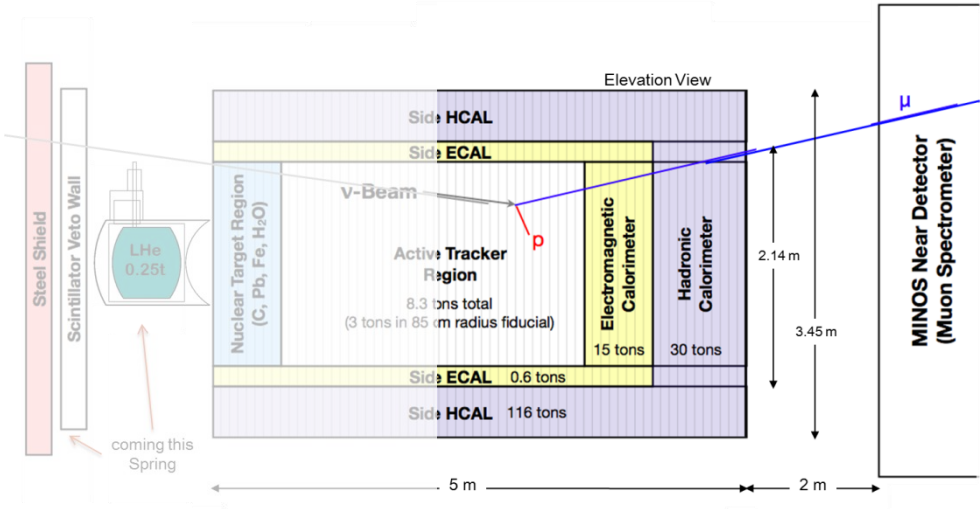
Today's Data Sample



- MINERvA's run to date
  - Accumulated 0.8E20 with partial "frozen" detector in anti-neutrino mode
  - Accumulated 1.2E20 in neutrino and 1.3E20 in anti-neutrino beam with full detector



- This analysis is based on first half of partial detector anti-neutrinos in CH
  - About 10% of expected low energy anti-neutrinos



Sample Events

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

- Muon is a long, penetrating track
- Neutron may or may not appear in the detector

If elastic kinematics,
E_ν=2.8 GeV, Q^2=0.1GeV^2

If elastic kinematics,
E_ν=2.5 GeV, Q^2=0.3GeV^2

ECAL HCAL

ECAL HCAL

30 MeV deposited in single bar. Neutron interaction candidate.

Beam direction

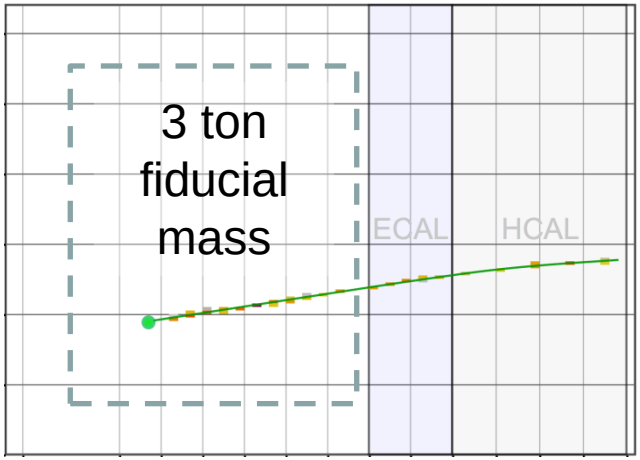
2 4 6
Energy (MeV)

View of detector from above

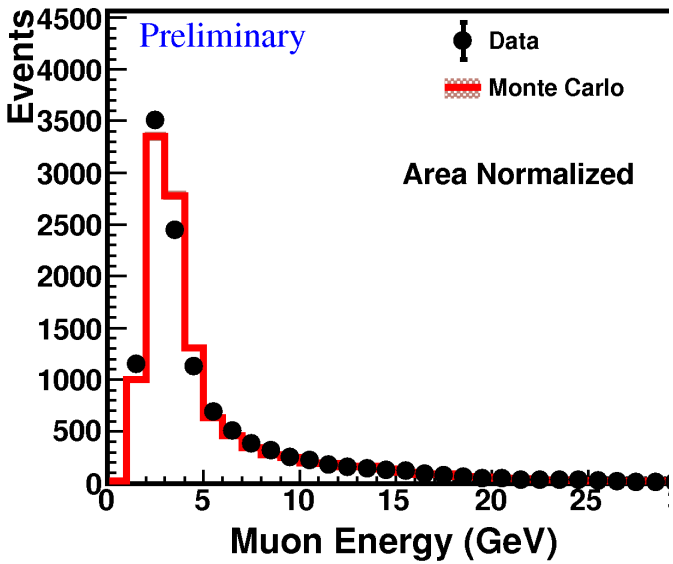
Reconstruction and Data Selection

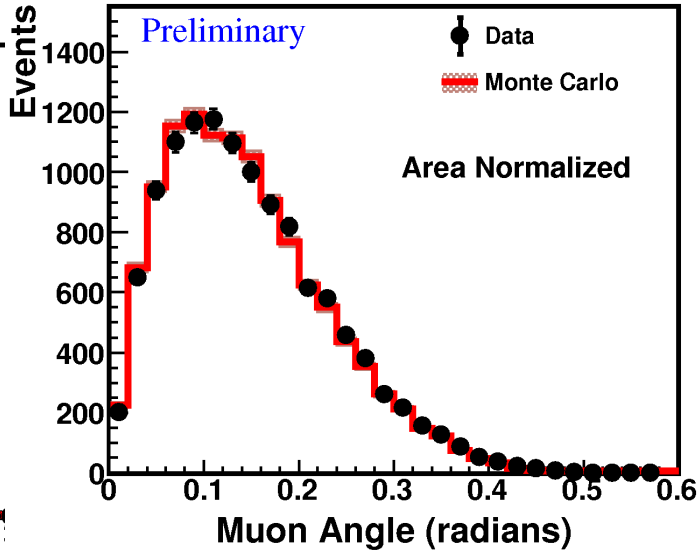
Muon Selection

- Analysis requires momentum analyzed muon in MINOS spectrometer
- Muon track must start in MINERvA detector
- Simulation everywhere is GENIE 2.6.2



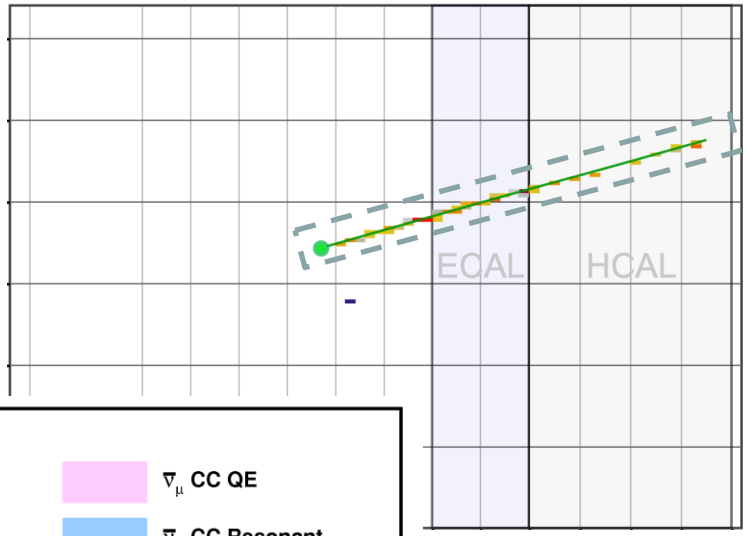
Inclusive μ^+ originating in MINERvA, momentum analyzed in MINOS

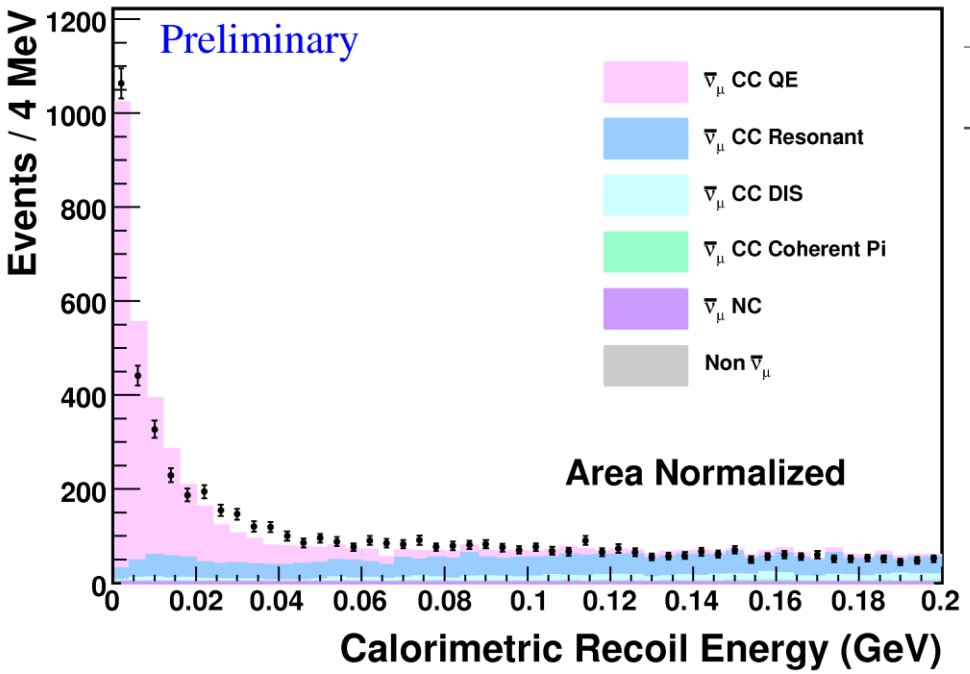




Recoil Selection

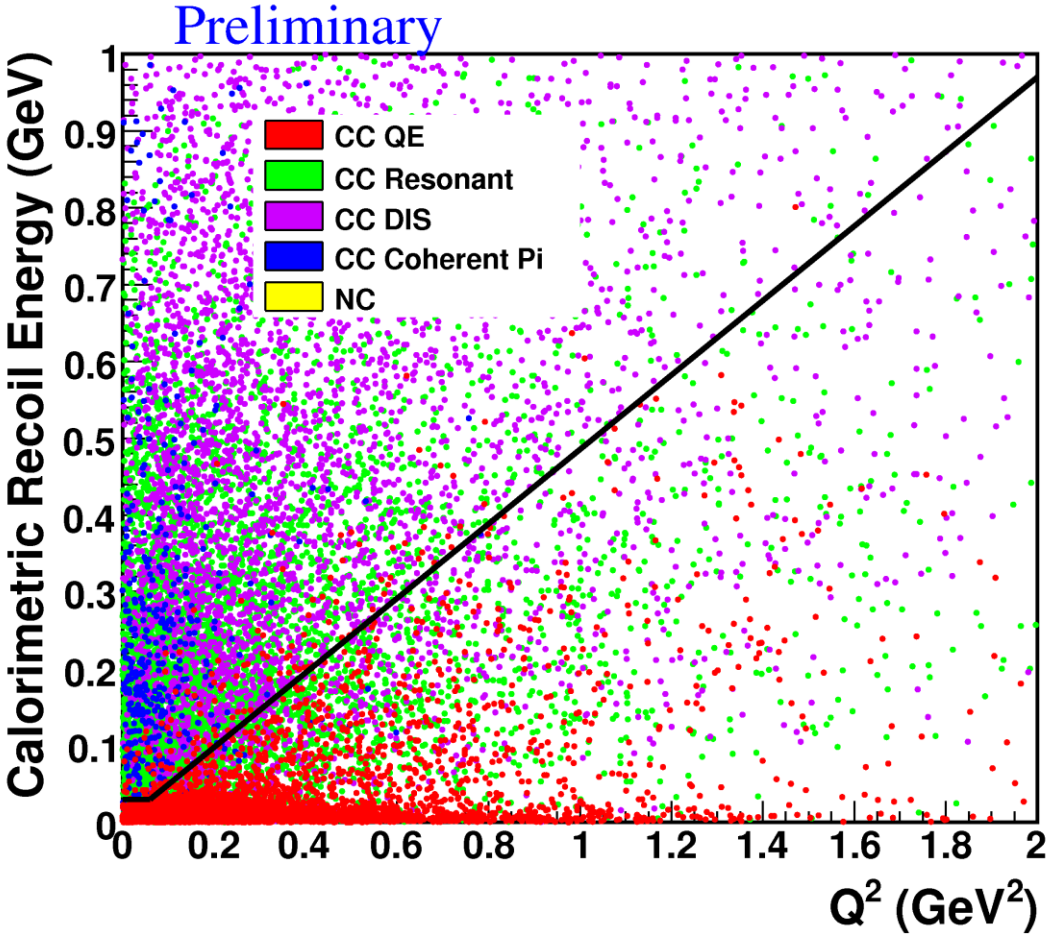
- Look at energy in the detector, outside of a region very close to the track (5cm)
  - Reduces contribution from δ-rays
- Form a calorimetric energy sum
- As expected, elastic events dominate at low recoil





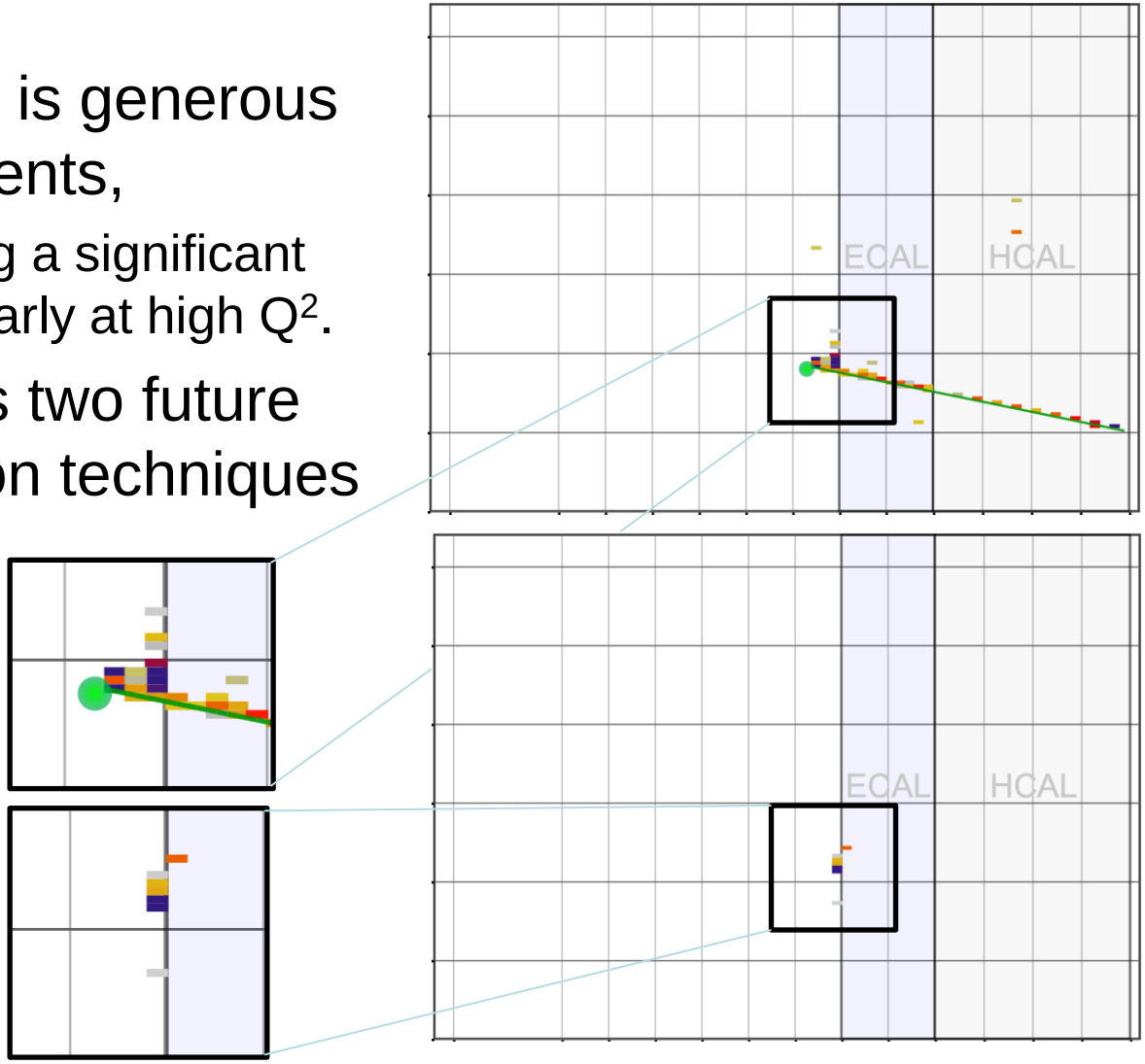
Recoil vs Q^2

- If the neutron interacts, may still see visible energy, particularly at high Q^2 (neutron energy)
- Our current selection varies with Q^2
- Another option would be to require low recoil, eliminating signal with interacting neutrons



Backgrounds after Recoil

- The current strategy is generous in keeping signal events,
  - at the price of leaving a significant background, particularly at high Q^2.
- This event illustrates two future background reduction techniques
  - Recoil energy near the track
  - Michel electron veto to remove $\pi^{\pm}$

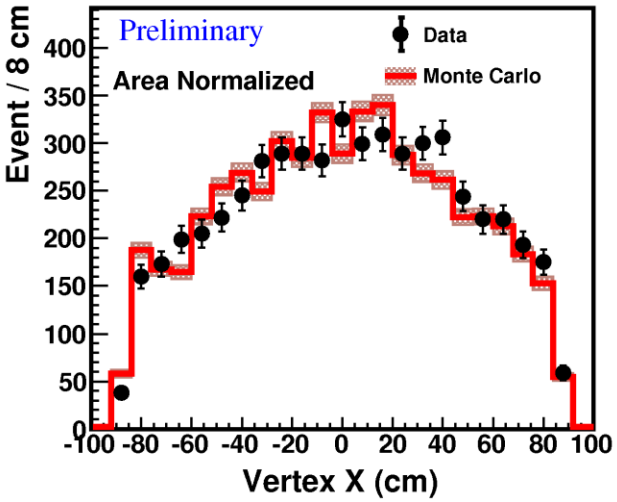


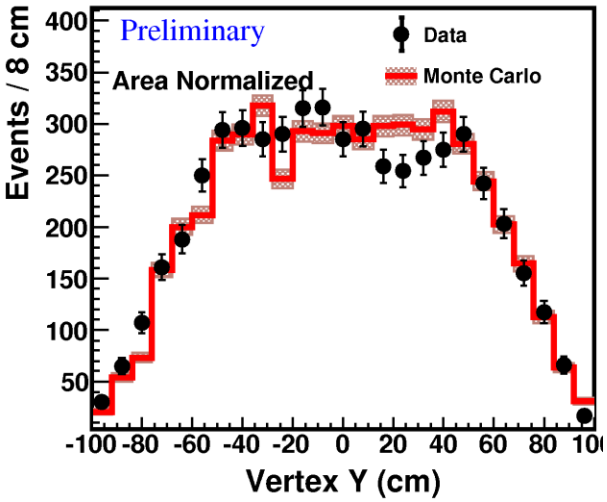
Comparisons with Simulation

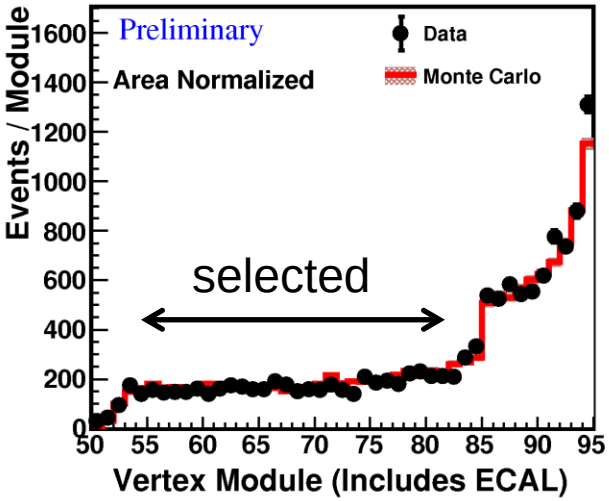
Technique for Comparison

- Uncertainties shown are from two sources
  - Data statistics and Simulation Statistics
    - Simulation is approximately 2.5x the statistics of data
  - Flux uncertainties
    - These uncertainties and the techniques for reducing them will be discussed in Melissa Jerkins' talk
    - Range from 7% at focusing peak to 16% at high energy
  - Other uncertainties (resolution, reconstruction efficiencies, material composition, etc.) not included
- Will show absolutely normalized comparisons
  - Except in plots to demonstrate agreement in "nuisance" variables, such as spatial distributions

Event location @ vertex

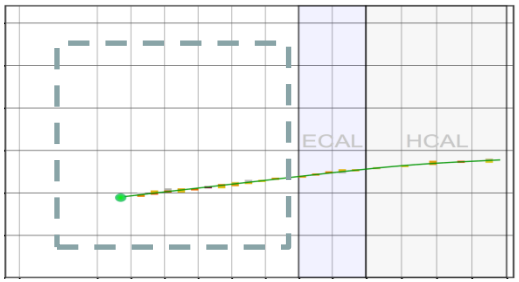




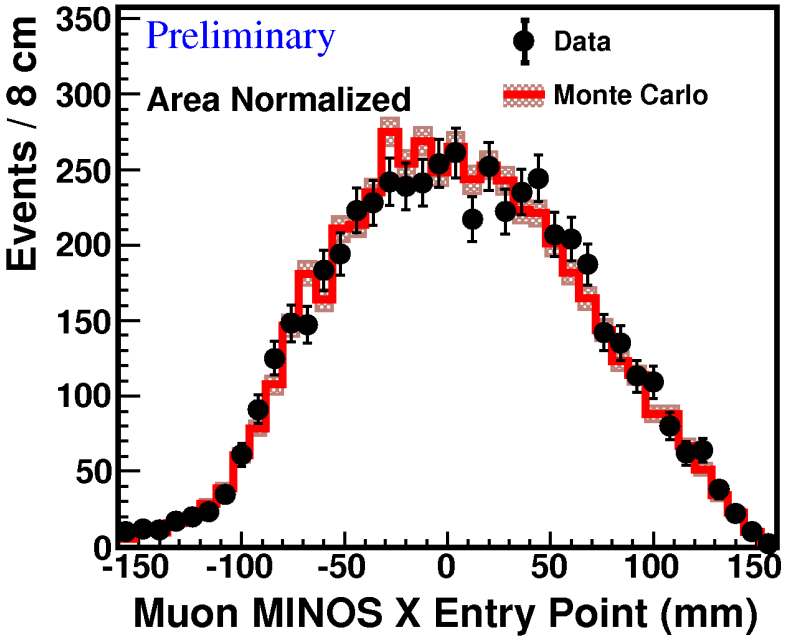


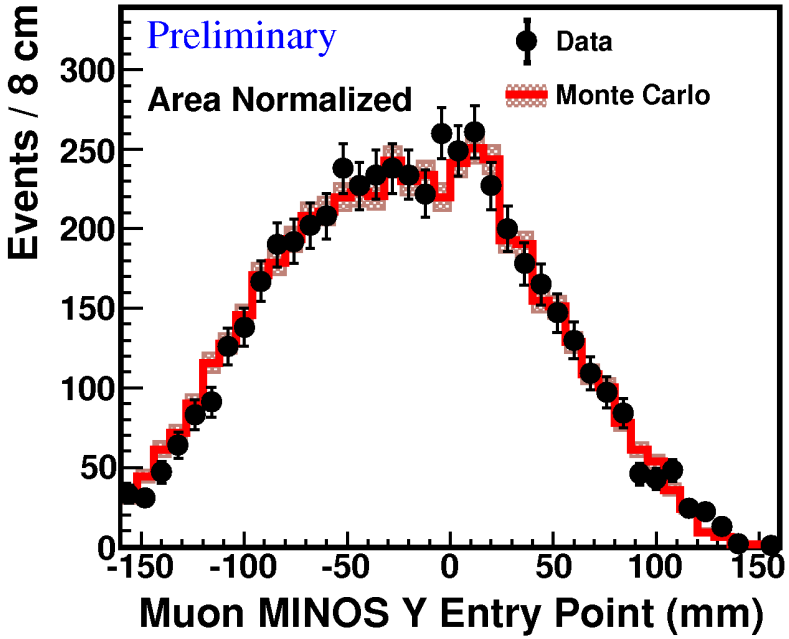
$\bar{\nu}_\mu p \rightarrow \mu^+ n$ candidates

0.4E20 POT, partial detector



Muon location @ MINOS



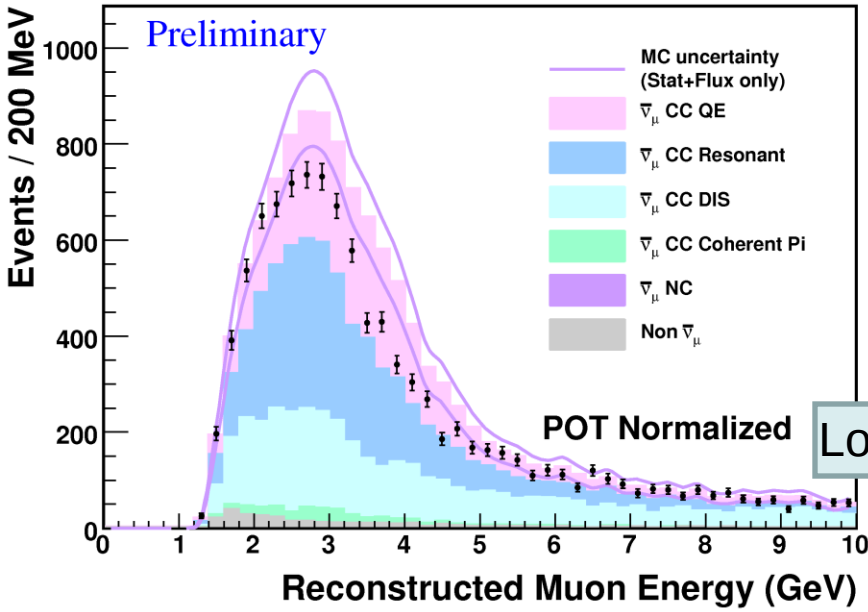


$\bar{\nu}_\mu p \rightarrow \mu^+ n$ candidates

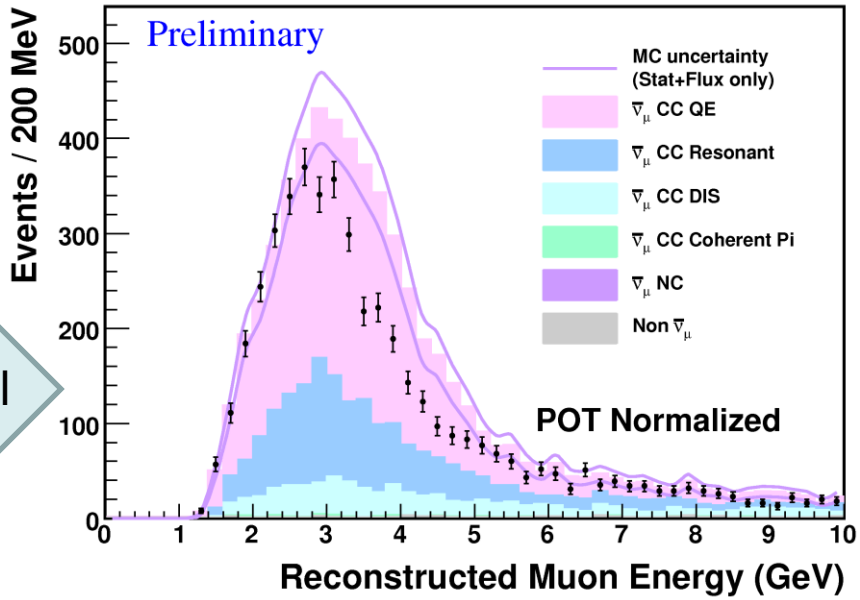
0.4E20 POT, partial detector

- Good agreement in spatial distributions across detectors gives us confidence in our muon acceptance modeling

Muons in Selected Events



Low Recoil



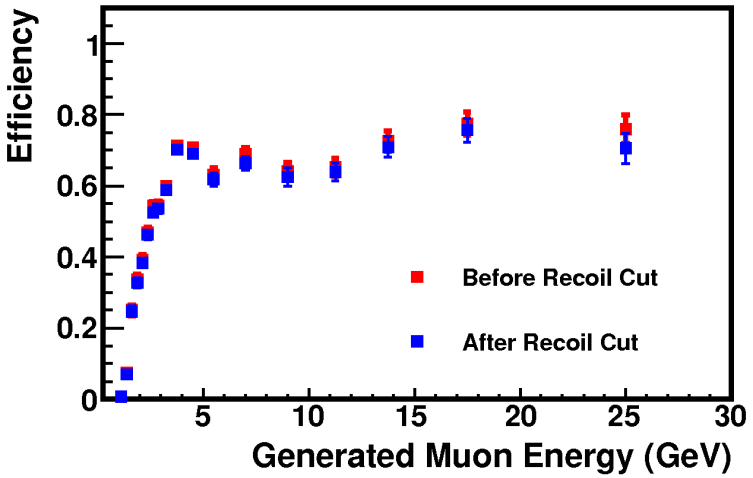
Inclusive μ^+

0.4E20 POT, partial detector

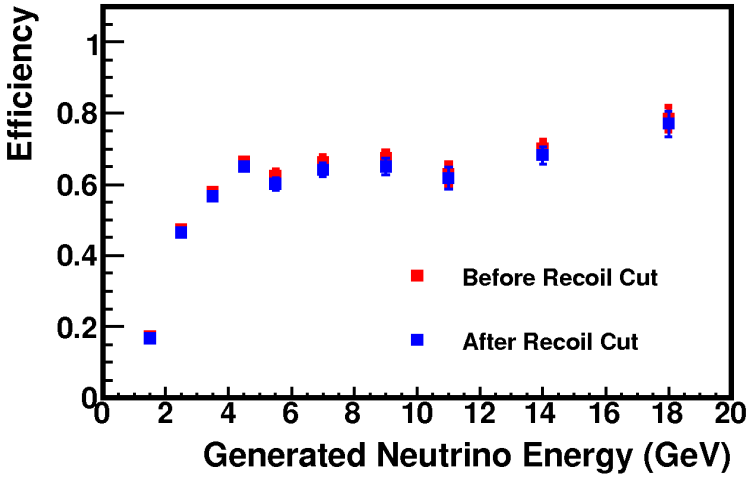
$\bar{\nu}_\mu p \rightarrow \mu^+ n$ candidates

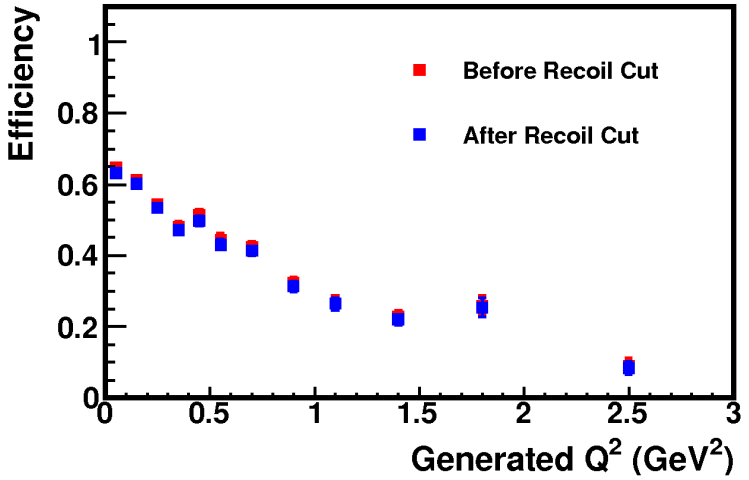
- Absolute normalization: protons + flux + cross-sections
- Recoil cut leaves Quasi-Elastic sample largely untouched, but reduces backgrounds significantly

Efficiency of Reconstruction



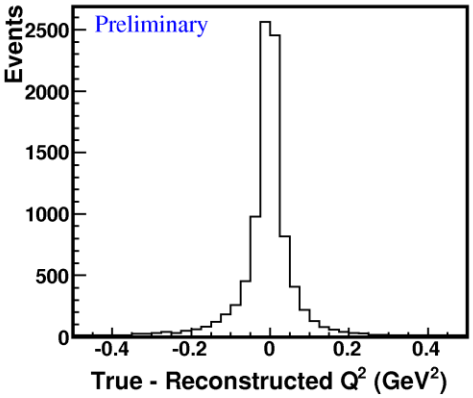
- Reconstruction efficiency for true (generator) Quasi-Elastic
  - Biggest is loss of low energy muons
  - Slow fall of efficiency at high Q^2

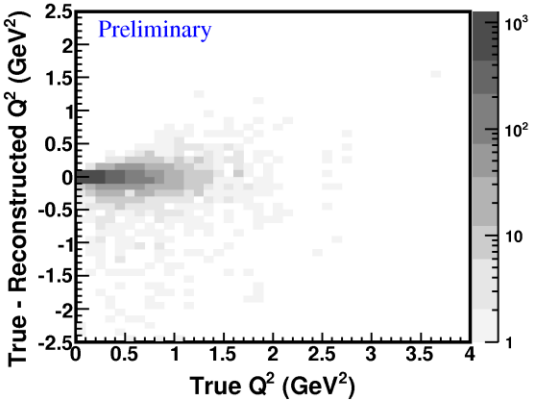


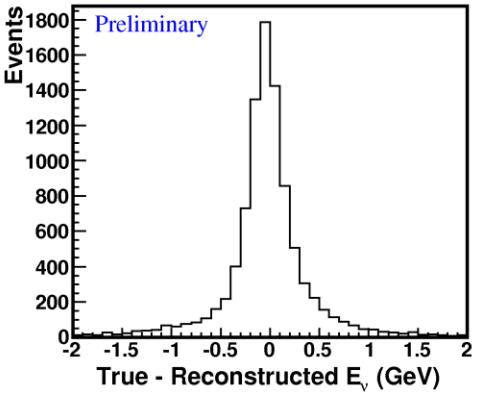


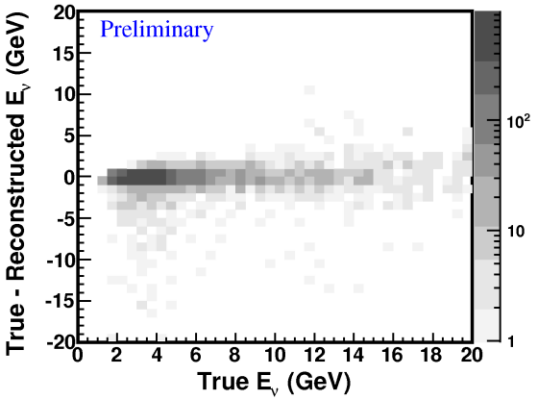
Event Kinematics: Resolution

- For true (generator) Quasi-Elastic events, look at resolution of event kinematics
- Derive neutrino energy and Q^2 from muon kinematics solely





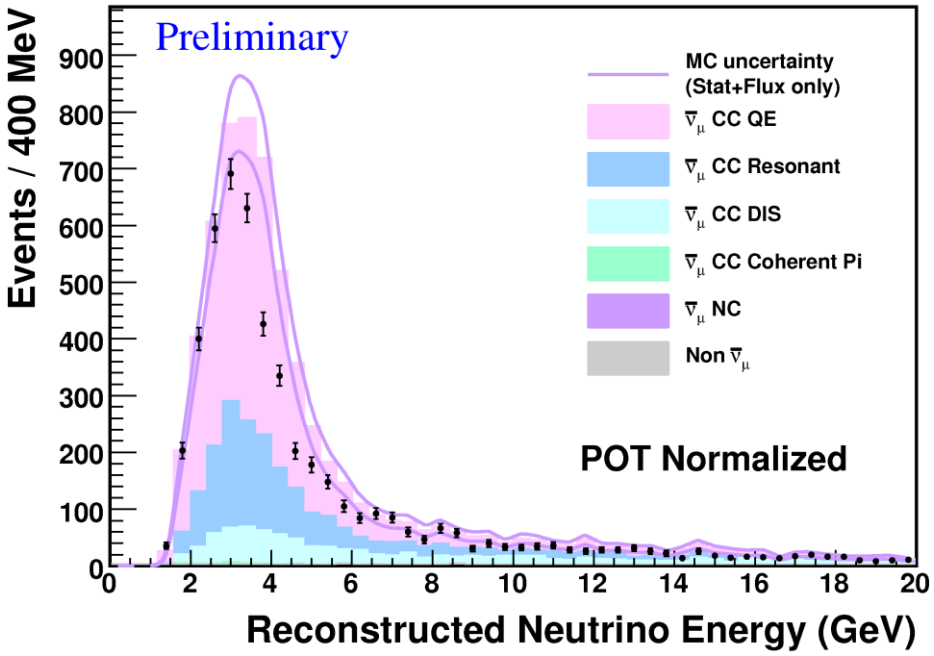


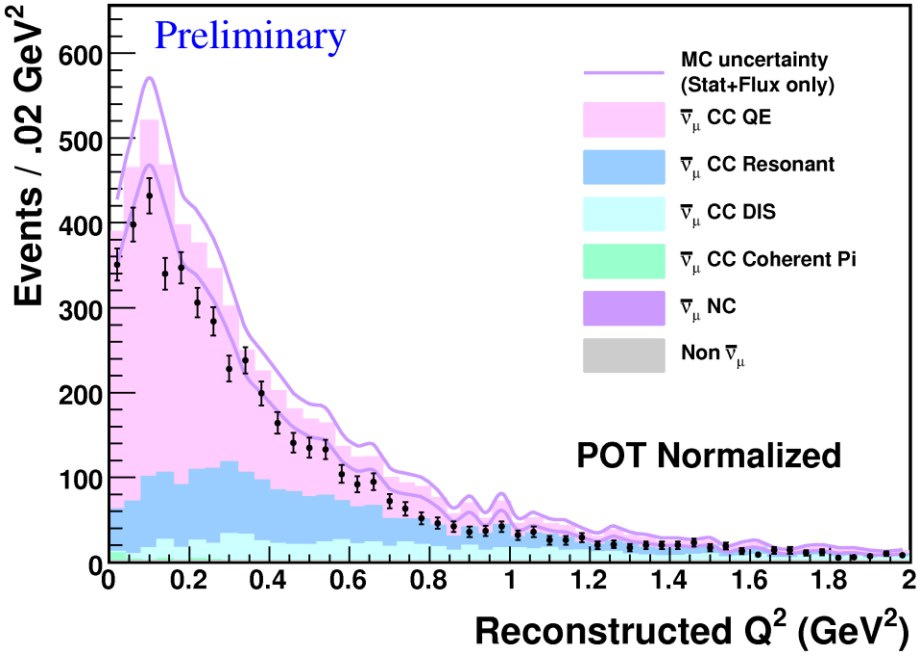


Event Kinematics

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

0.4E20 POT, partial detector

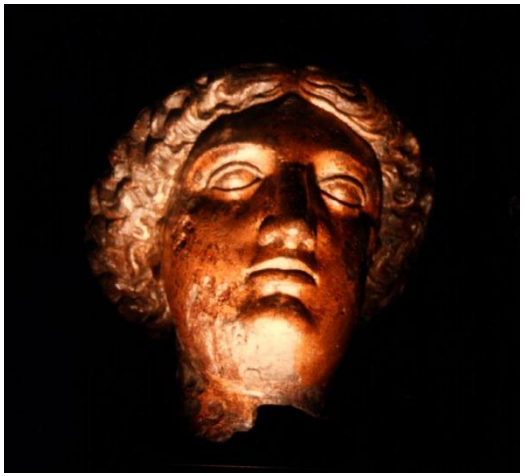


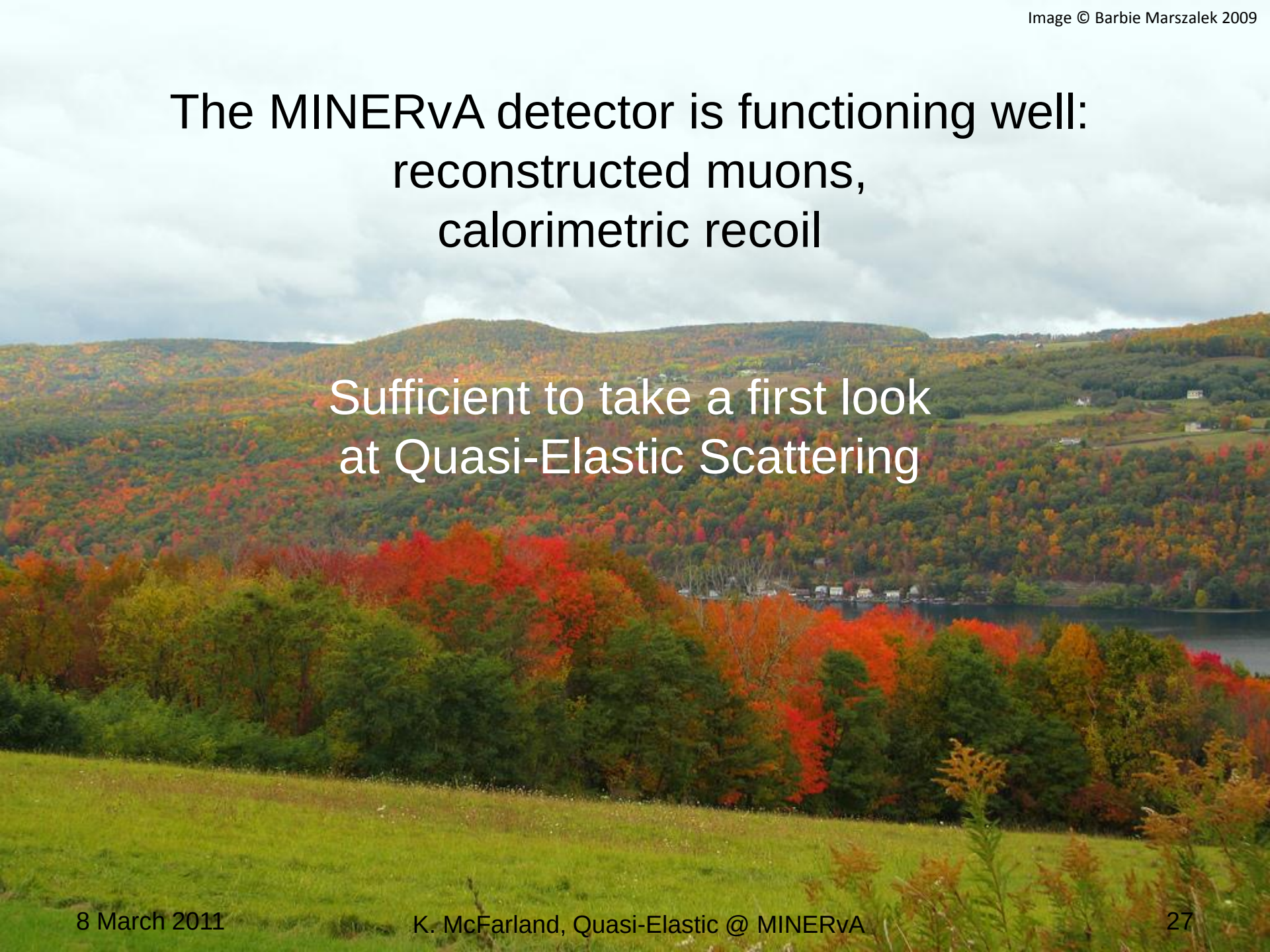


- Reminder: absolute predictions from flux simulation, GENIE 2.6.2, MINERvA simulation
- Event deficit is flat in Q^2 and not flat in E_ν

Outlook

(Backdrop of beautiful vistas from much smaller hills)





The MINERvA detector is functioning well: reconstructed muons, calorimetric recoil

Sufficient to take a first look at Quasi-Elastic Scattering

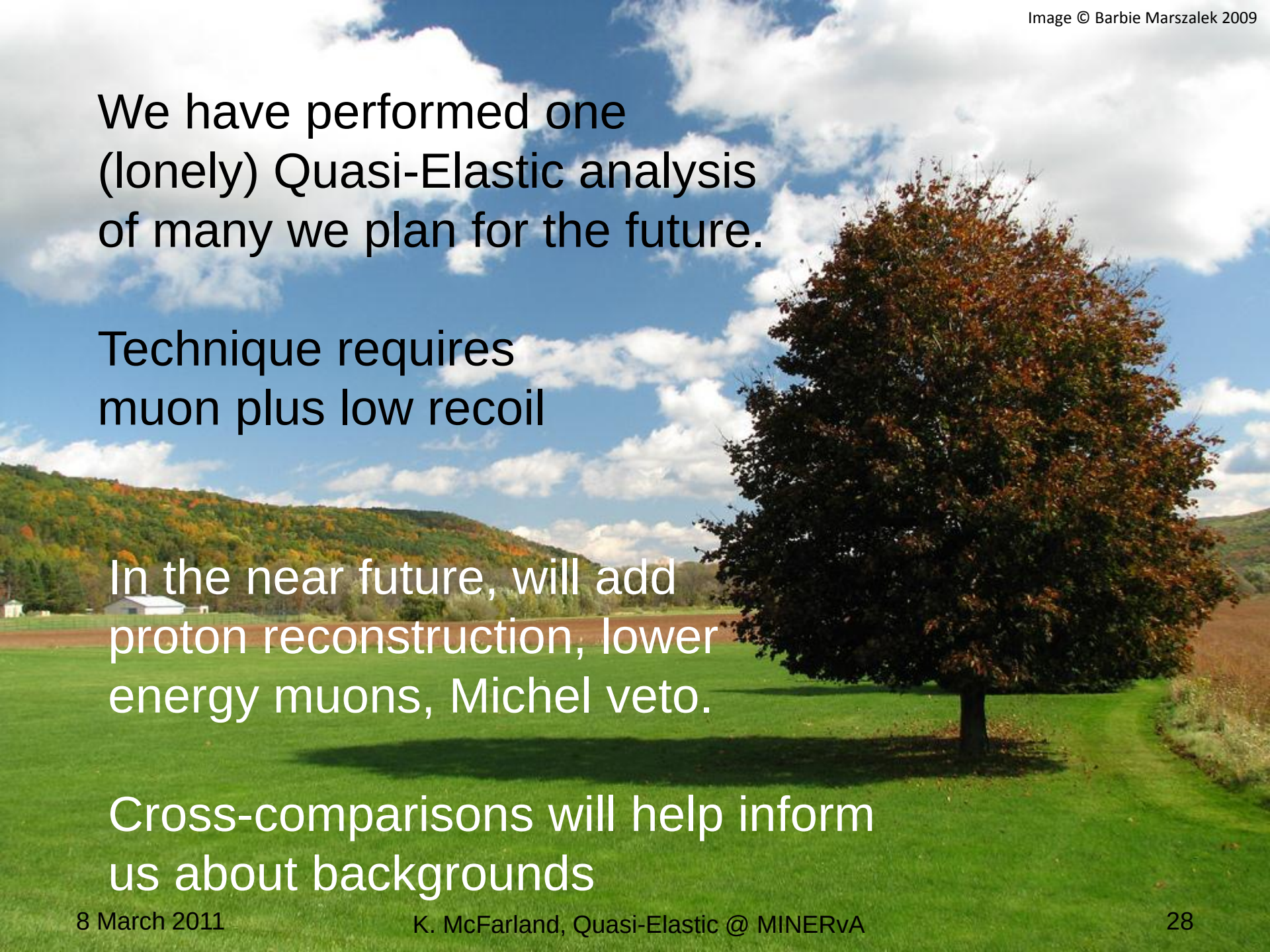
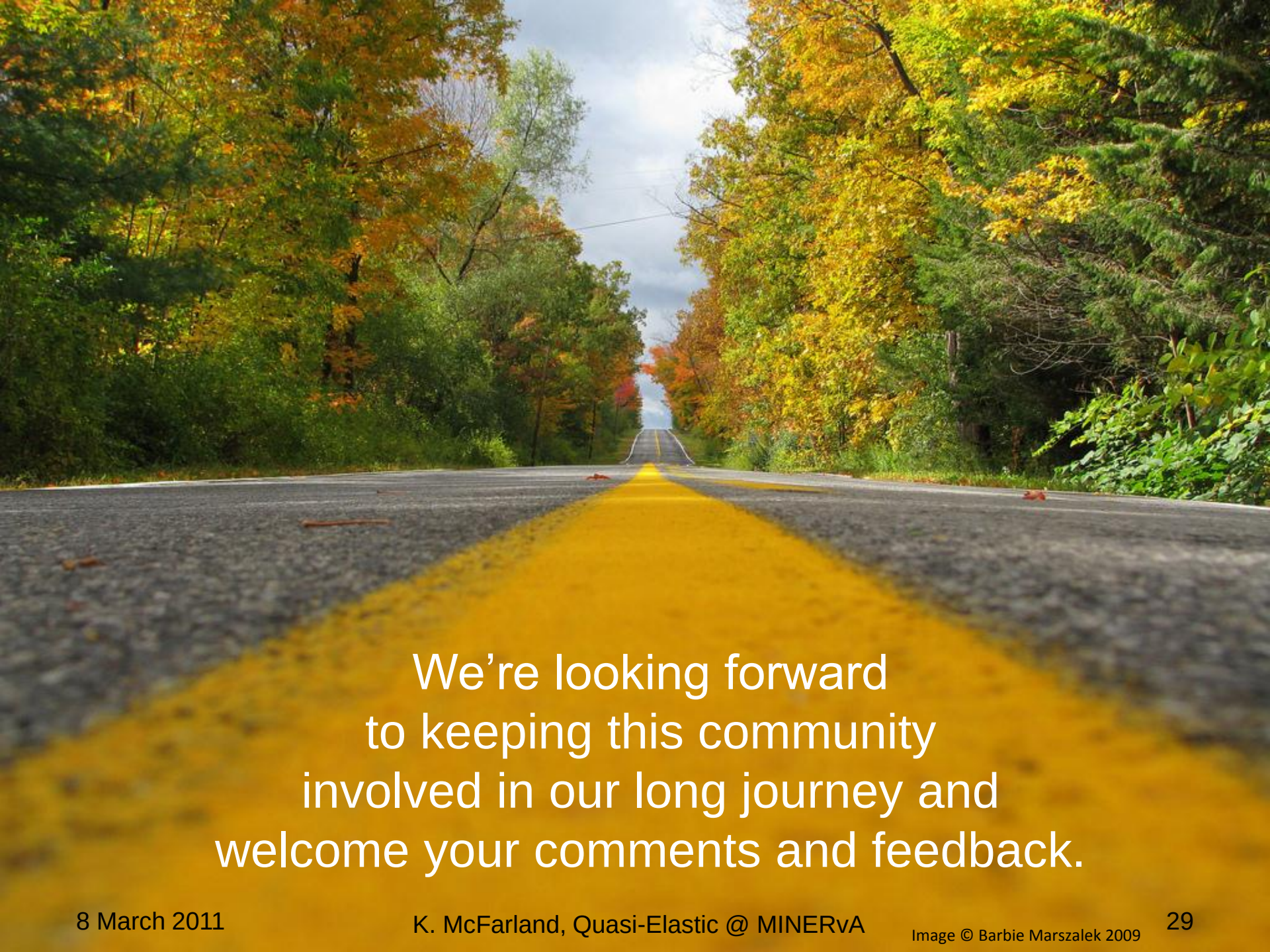


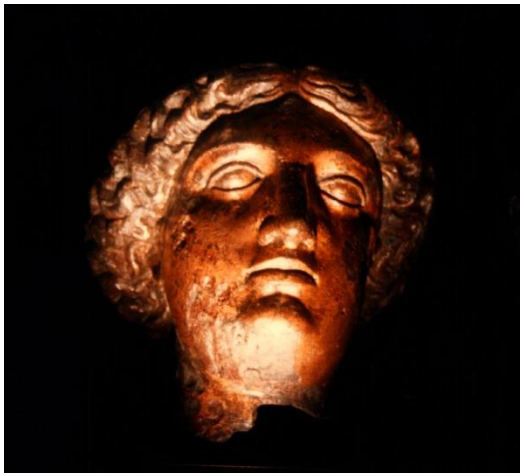
Image © Barbie Marszalek 2009
We have performed one (lonely) Quasi-Elastic analysis of many we plan for the future.
Technique requires muon plus low recoil
In the near future, will add proton reconstruction, lower energy muons, Michel veto.
Cross-comparisons will help inform us about backgrounds



We're looking forward
to keeping this community
involved in our long journey and
welcome your comments and feedback.

Acknowledgments

(from Monday's MINERvA talk by Dave Schmitz)



Thank You!

- **The MINERνA Collaboration would like to sincerely thank many groups who have been critical to our progress so far:**
  - Fermilab Particle Physics Division for all their help installing the MINERνA detector in the NuMI Near Detector Hall
  - Fermilab Accelerator Division for their tireless efforts to keep the NuMI facility running and to provide intense beam since the detector was commissioned
  - The ArgoNeuT Collaboration for paving the way for the use of cryogenic vessels in the underground area
  - A very special thanks to the MINOS Collaboration for their willingness to share their data, so important to MINERνA's success, and for the significant effort required on the part of many collaborators to process, calibrate, and reconstruct the Near Detector samples which we use in our analysis
  - Finally, we thank the Organizing Committee for NuInt 2011 for the opportunity to report on our progress and the status of our initial physics studies at this workshop!
  -

MINERvA Collaboration

The Collaboration is 100 members from 22 institutions in 7 countries

HEP, Nuclear and Theory

G. Tzanakos
University of Athens

J. Cravens, M. Jerkins, S. Kopp, L. Loiacono, J. Ratchford, R. Stevens IV
University of Texas at Austin

D.A.M. Caicedo, C.M. Castromonte, H. da Motta, G. A. Fiorentini, J.L. Palomino
Centro Brasileiro de Pesquisas Fisicas

J. Grange, J. Mousseau, B. Osmanov, H. Ray
University of Florida

D. Boehnlein, R. DeMaat, N. Grossman, D. A. Harris, J. G. Morfn, J. Osta, R. B. Pahlka, P. Rubinov, D. W. Schmitz, F.D. Snider, R. Stefanski
Fermilab

J. Felix, A. Higuera, Z. Urrutia, G. Zavala
Universidad de Guanajuato

M.E. Christy, C. Keppel, P. Monagham, T. Walton, L. Y. Zhu
Hampton University

A. Butkevich, S.A. Kulagin
Inst. Nucl. Reas. Moscow

G. Niculescu, I. Niculescu
James Madison University

E. Maher
Mass. Col. Lib. Arts

L. Fields, B. Gobbi, L. Patrick, H. Schellman
Northwestern University

N. Tagg
Otterbein College

S. Boyd, I. Danko, S.A. Dytman, B. Eberly, Z. Isvan, D. Naples, V. Paolone
University of Pittsburgh

A. M. Gago, N. Ochoa, J.P. Velasquez
Pontificia Universidad Catolica del Peru

S. Avvakumov, A. Bodek, R. Bradford, H. Budd, J. Chvojka, M. Day, H. Lee, S. Manly, C. Marshall, K.S. McFarland, A. M. McGowan, A. Mislivec, J. Park, G. Perdue, J. Wolcott
University of Rochester

G. J. Kumbartzki, T. Le, R. D. Ransome, E. C. Schulte, B. G. Tice
Rutgers University

H. Gallagher, T. Kafka, W.A. Mann, W. P. Oliver
Tufts University

C. Simon, B. Ziemer
University of California at Irvine

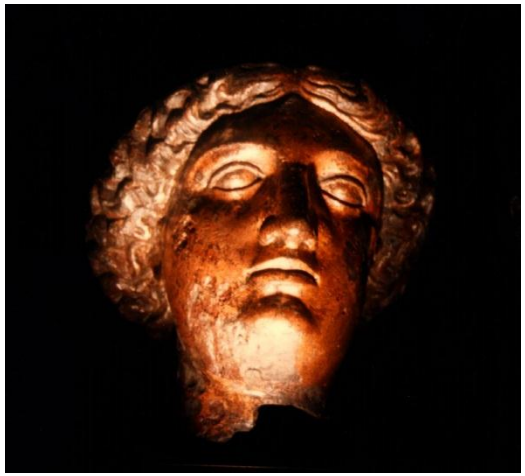
R. Gran, M. Lanari
University of Minnesota at Duluth

M. Alania, A. Chamorro, K. Hurtado, C. J. Solano Salinas
Universidad Nacional de Ingeniera

W. K. Brooks, E. Carquin, G. Maggi, C. Pea, I.K. Potashnikova, F. Prokoshin
Universidad Tcnica Federico Santa Mara

L. Aliaga, J. Devan, M. Kordosky, J.K. Nelson, J. Walding, D. Zhang
College of William and Mary

Backup Slides



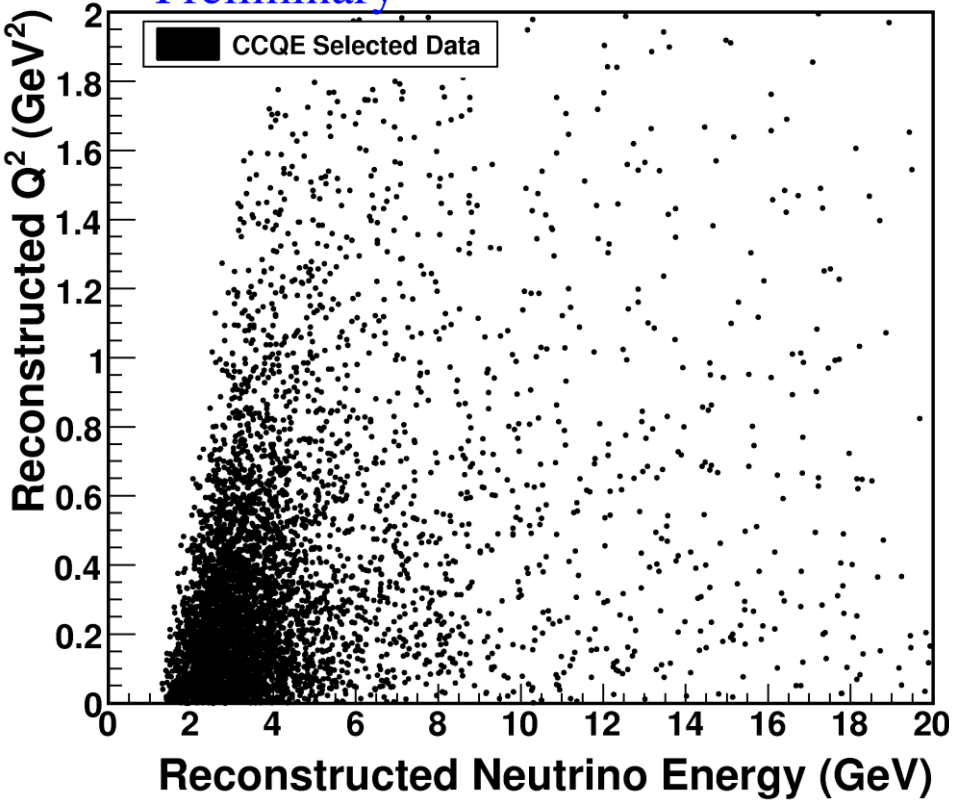
Generator Details

- GENIE 2.6.2 (tagged ~Jan 2011)
- Details of nucleon cross-section
  - General equation is Llewellwyn-Smith with lepton mass terms
  - The pseudo-scalar form factor is from PCAC.
  - Electromagnetic form factors are BBBA2005 (*hep-ex/0602017*)
  - Axial form factor has a dipole form, and M_A=0.99 GeV/c^2.
- Nuclear effects (for carbon)
  - The nuclear model is a Fermi gas, with a high momentum component (*Bodek and Ritchie, Phys.Rev. D23 (1981) 1070*).
  - Pauli blocking is applied by requiring the outgoing nucleon has momentum above the Fermi momentum, 221 MeV/c for carbon.

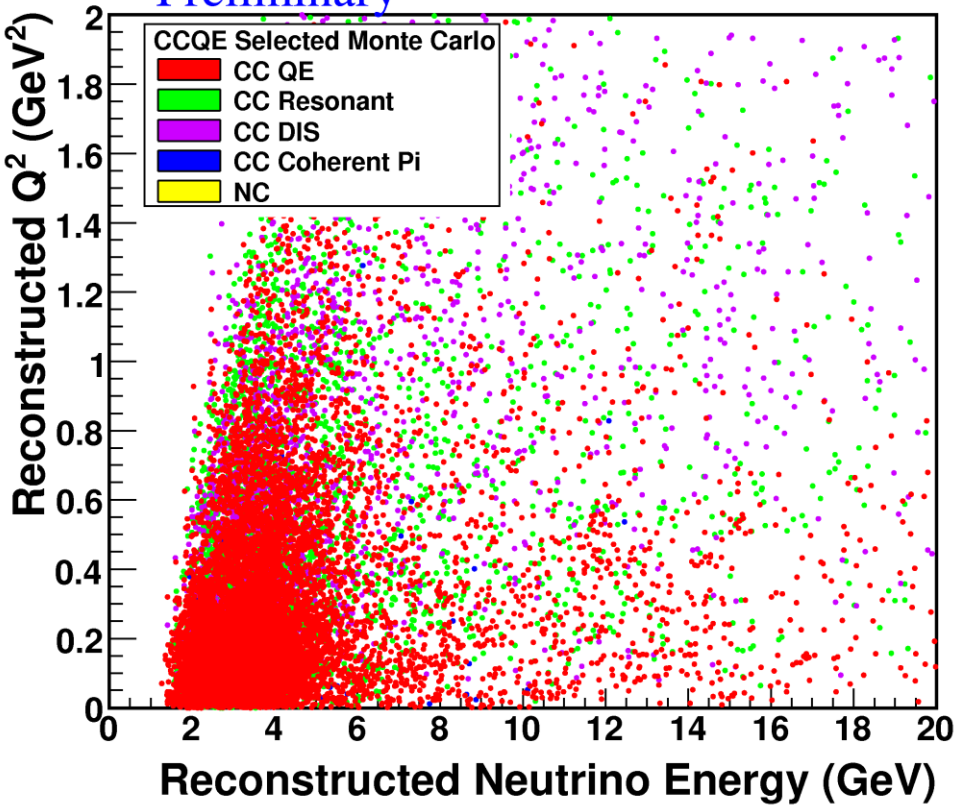
Event Kinematics

$\bar{\nu}_\mu p \rightarrow \mu^+ n$ candidates, 0.4E20 POT, partial detector

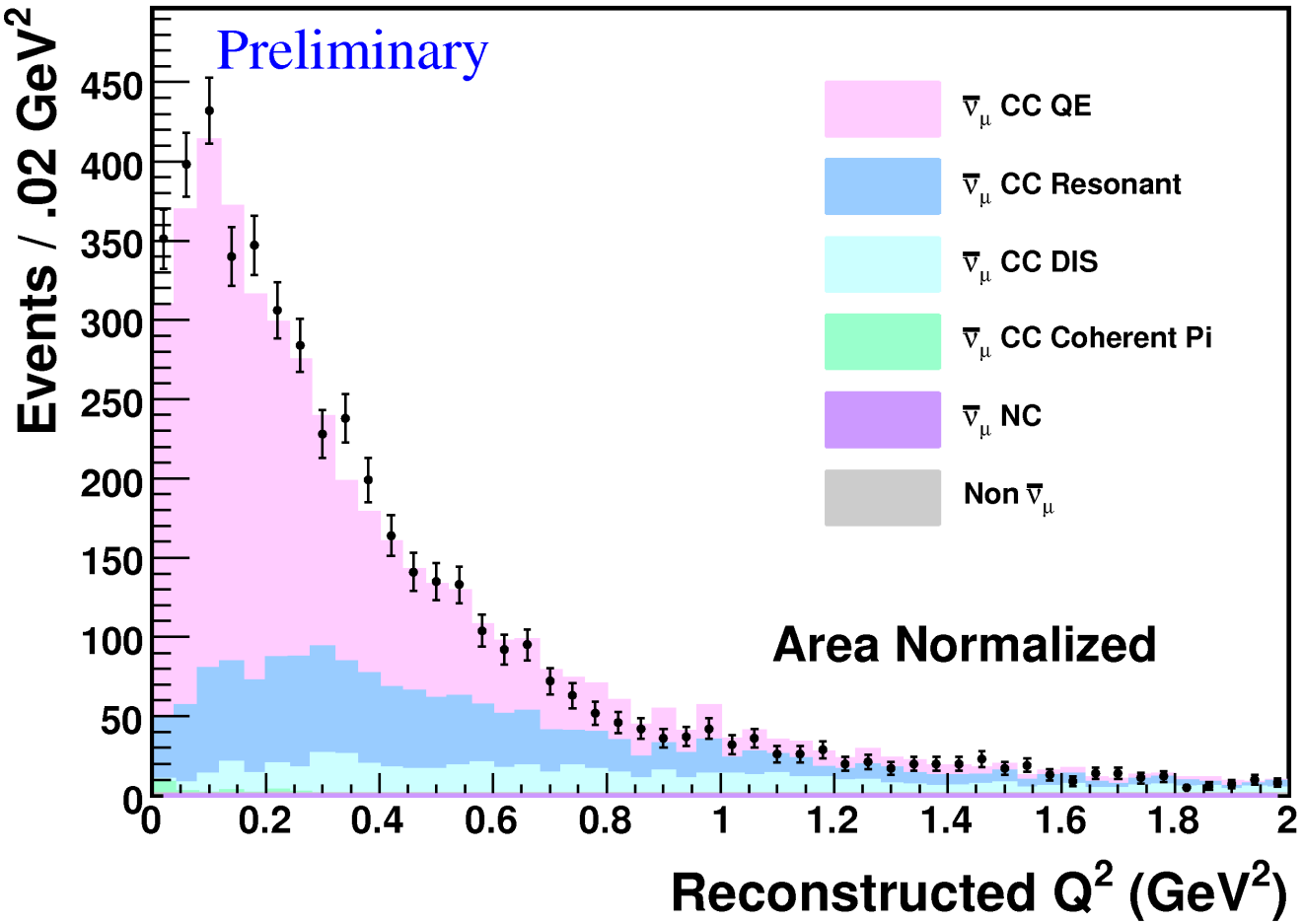
Preliminary



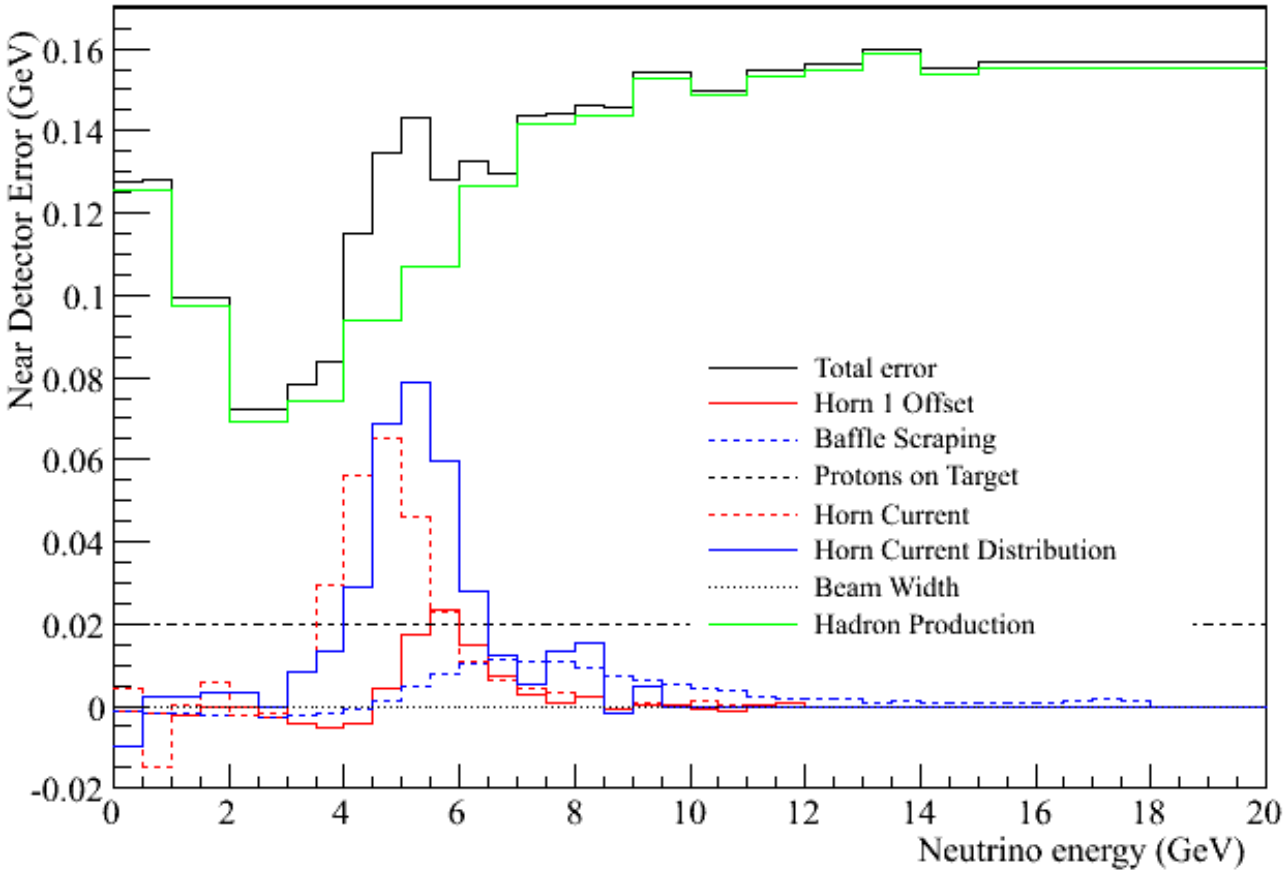
Preliminary



Relatively Normalized Q^2 Distribution

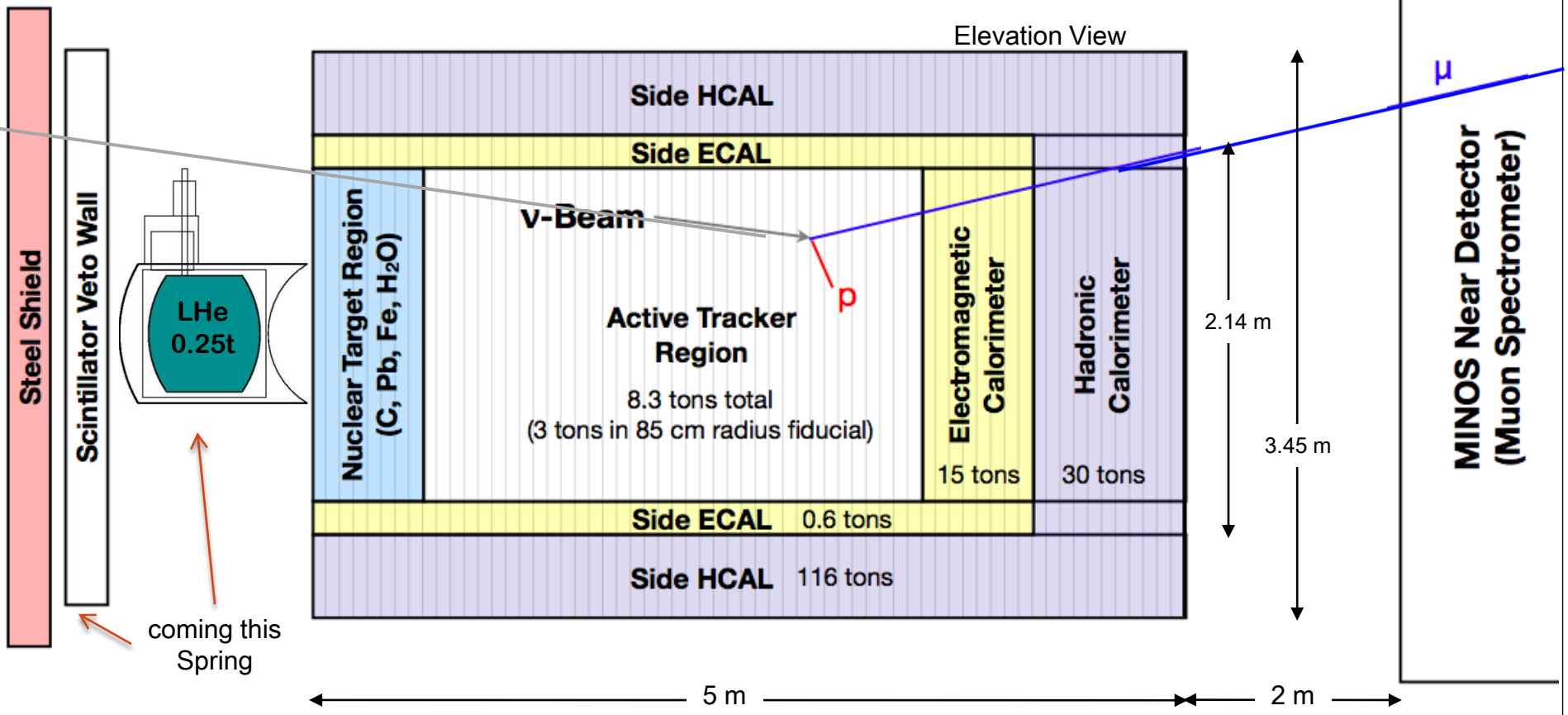


Flux Uncertainty Detail

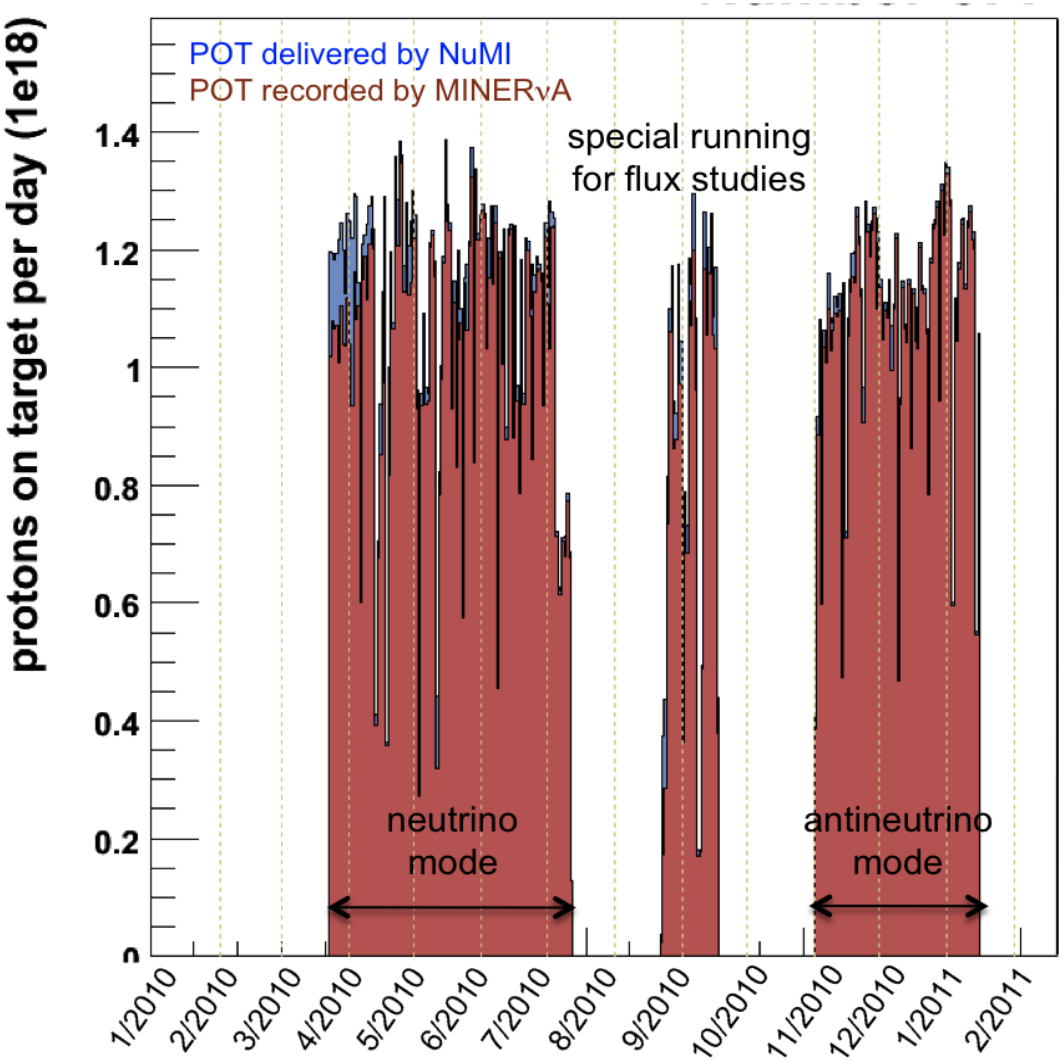


Full-Sized Detector Layout

- Detector comprised of 120 "modules" stacked along the beam direction
- Central region is finely segmented scintillator tracker
- ~32k readout channels total



Data Collected So Far



- **Full detector installation completed in March, 2010**
- **NuMI beamline in low-energy configuration**
  - 1.2e20 P.O.T. in neutrino mode
  - 1.2e20 P.O.T. in antineutrino mode
  - Detector live-time > 98%