

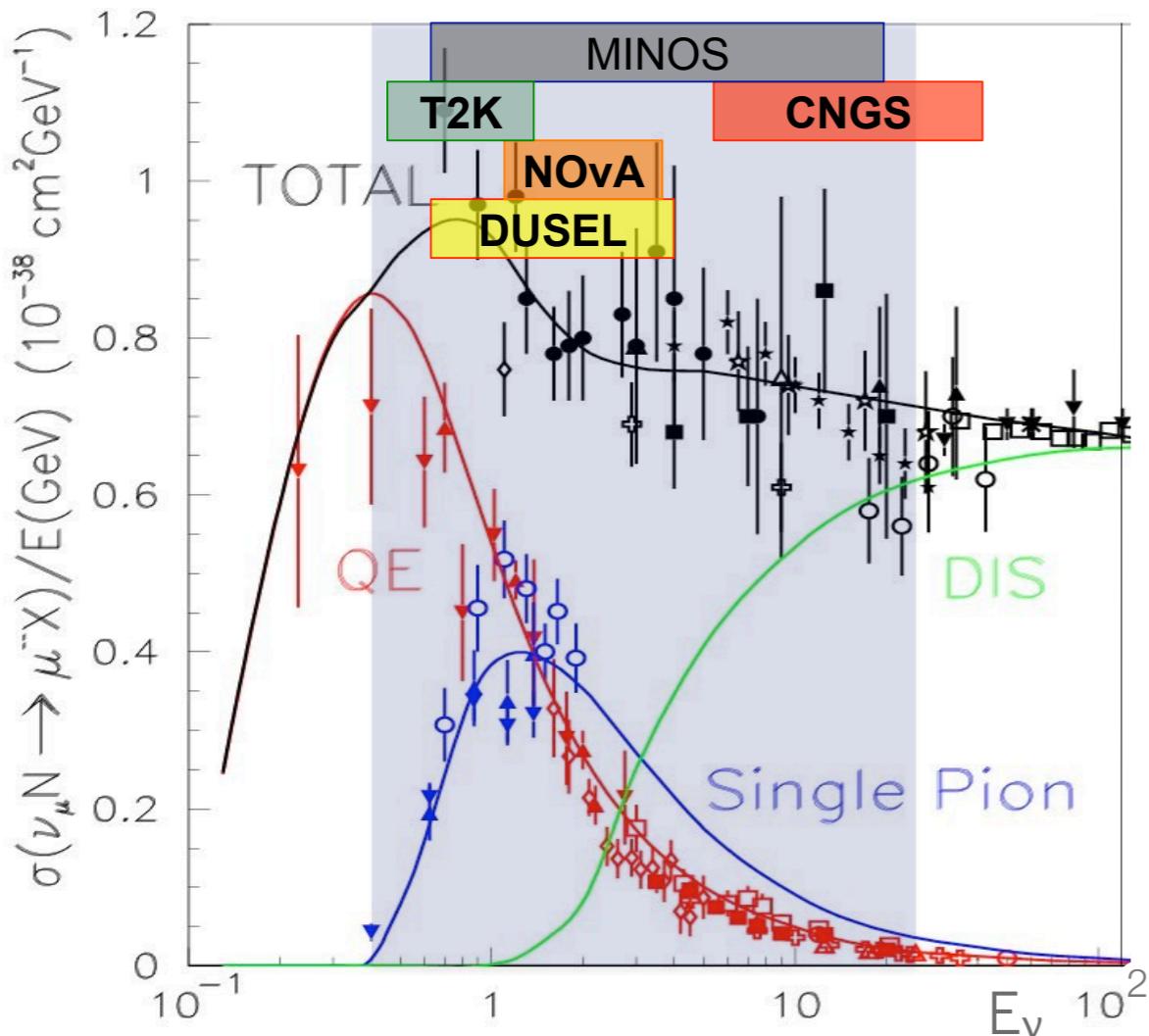
# Neutrino Interaction News: SciBooNE, MiniBooNE, & MINERvA

Rencontres de Moriond  
Electroweak and Unified Theories  
March 5, 2012  
Aaron R. Mislivec  
The University of Rochester

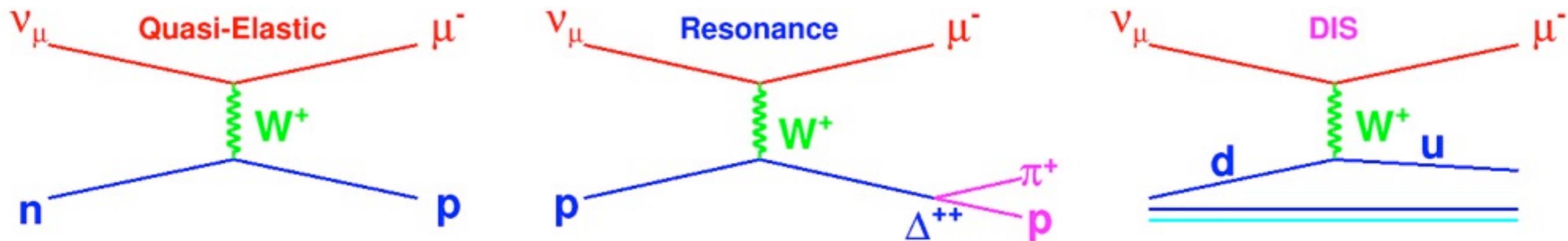
# Outline

- Neutrino cross sections and neutrino oscillation experiments
- Recent MiniBooNE and SciBooNE cross section results
- MINERvA
  - Flux determination
  - Reconstruction stability and tracking efficiency

# Neutrino Cross-Sections

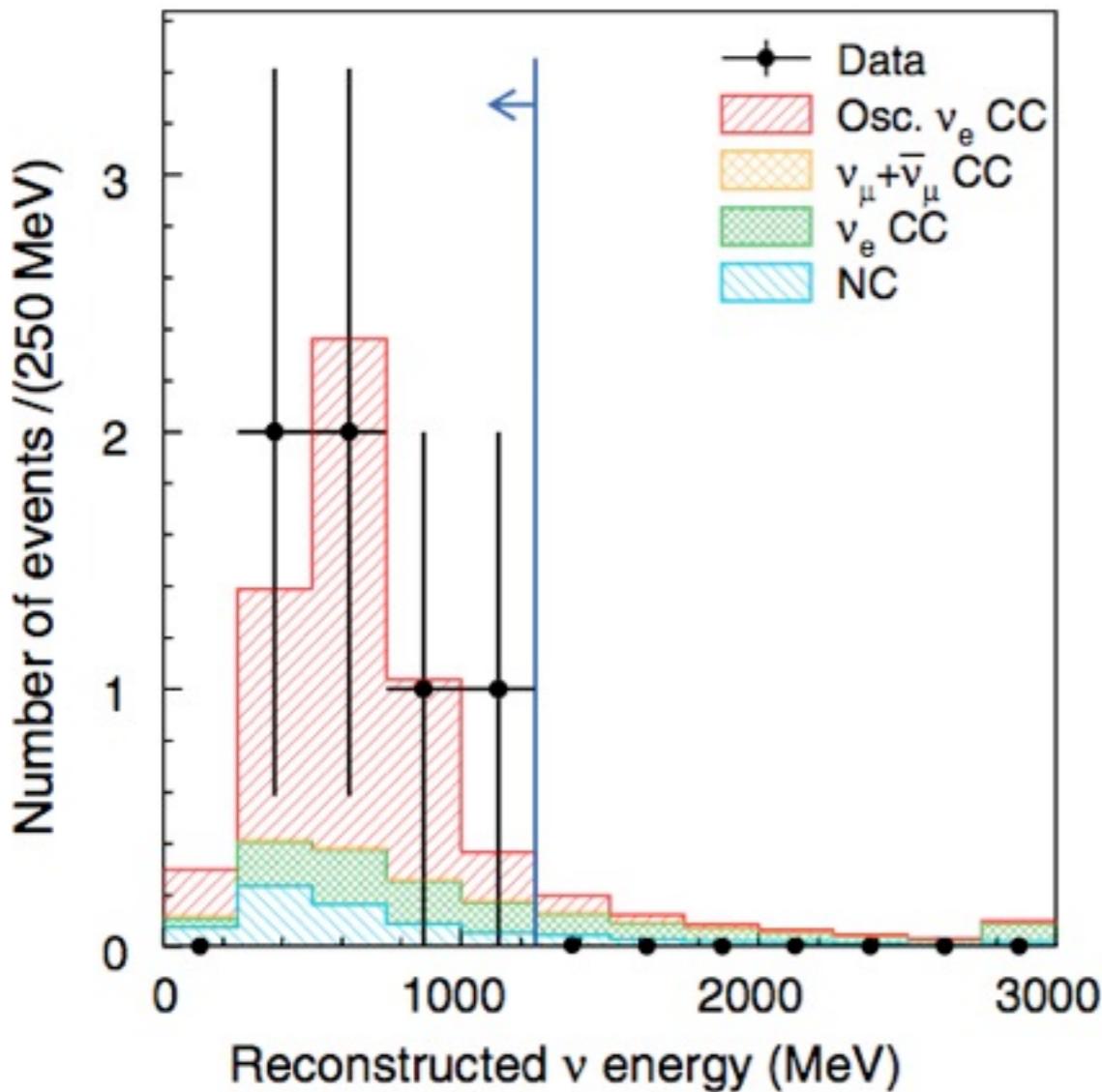


- neutrino oscillation experiments need to understand neutrino-nucleus interactions in the  $< 10 \text{ GeV}$  region
- Older data are problematic:
  - 20-50% uncertainties depending on process
- Nuclear effects are not well understood



# T2K and Neutrino Cross-Sections

PRL 107, 041801 (2011)



T2K  $\nu_\mu \rightarrow \nu_e$  event rate for  
 $1.43 \times 10^{20}$  POT

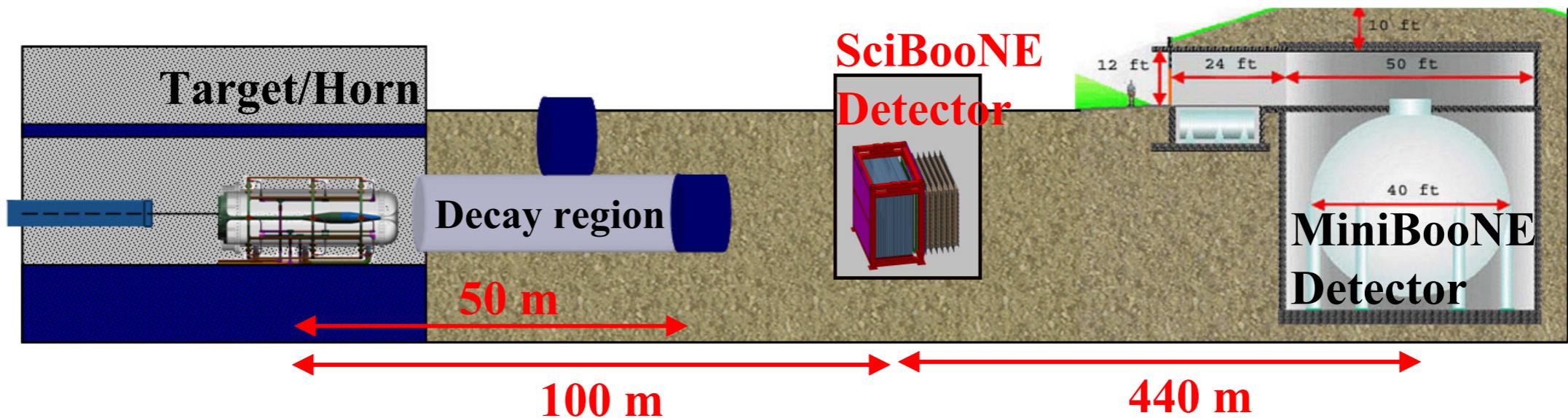
PRL 107, 041801 (2011)

TABLE III. Contributions from various sources and the total relative uncertainty for  $\sin^2 2\theta_{13} = 0$  and 0.1, and  $\delta_{CP} = 0$ .

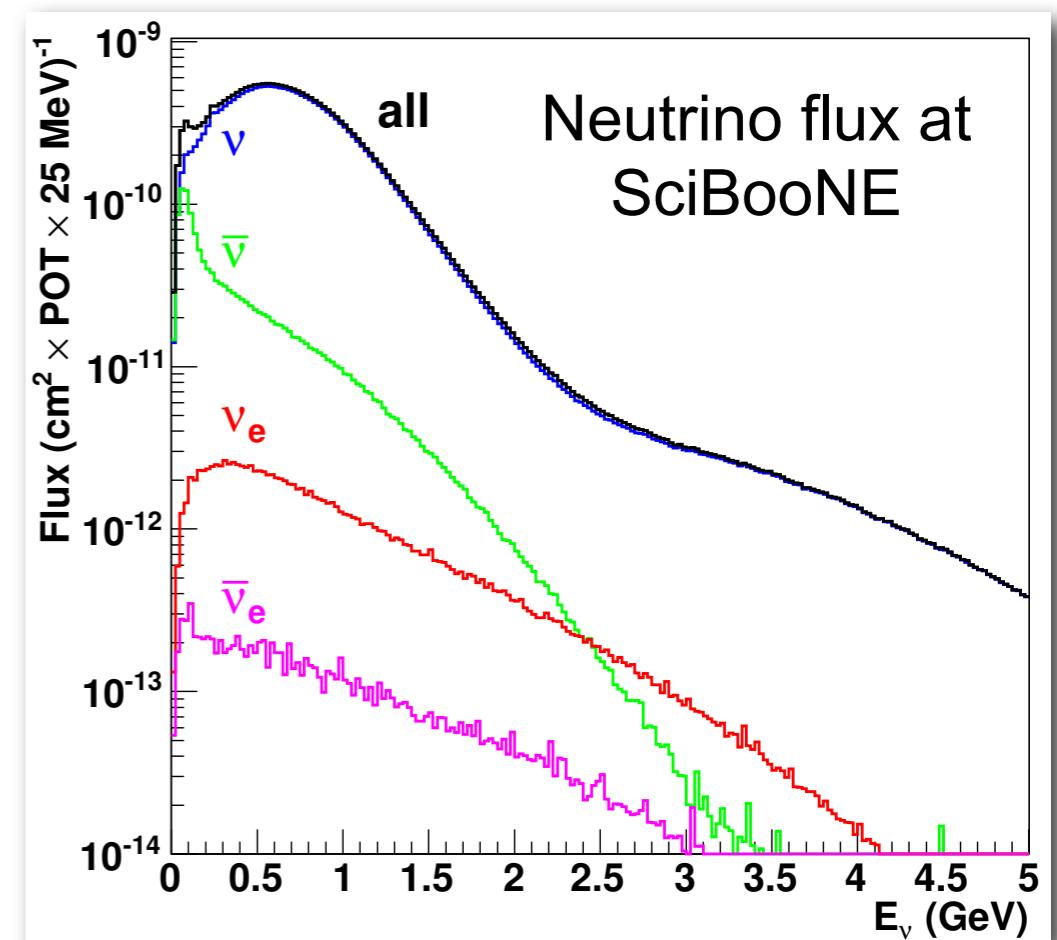
Source	$\sin^2 2\theta_{13} = 0$	$\sin^2 2\theta_{13} = 0.1$
(1) neutrino flux	$\pm 8.5\%$	$\pm 8.5\%$
(2) near detector	$+5.6\%$ $-5.2$	$+5.6\%$ $-5.2$
(3) near det. statistics	$\pm 2.7\%$	$\pm 2.7\%$
(4) cross-section	$\pm 14.0\%$	$\pm 10.5\%$
(5) far detector	$\pm 14.7\%$	$\pm 9.4\%$
Total $\delta N_{SK}^{\text{exp}} / N_{SK}^{\text{exp}}$	$+22.8\%$ $-22.7$	$+17.6\%$ $-17.5$

- Cross-section uncertainty is a primary systematic error in calculating signal and background rates
- T2K reduced their cross-section uncertainties by normalizing to near detector data

# SciBooNE & MiniBooNE



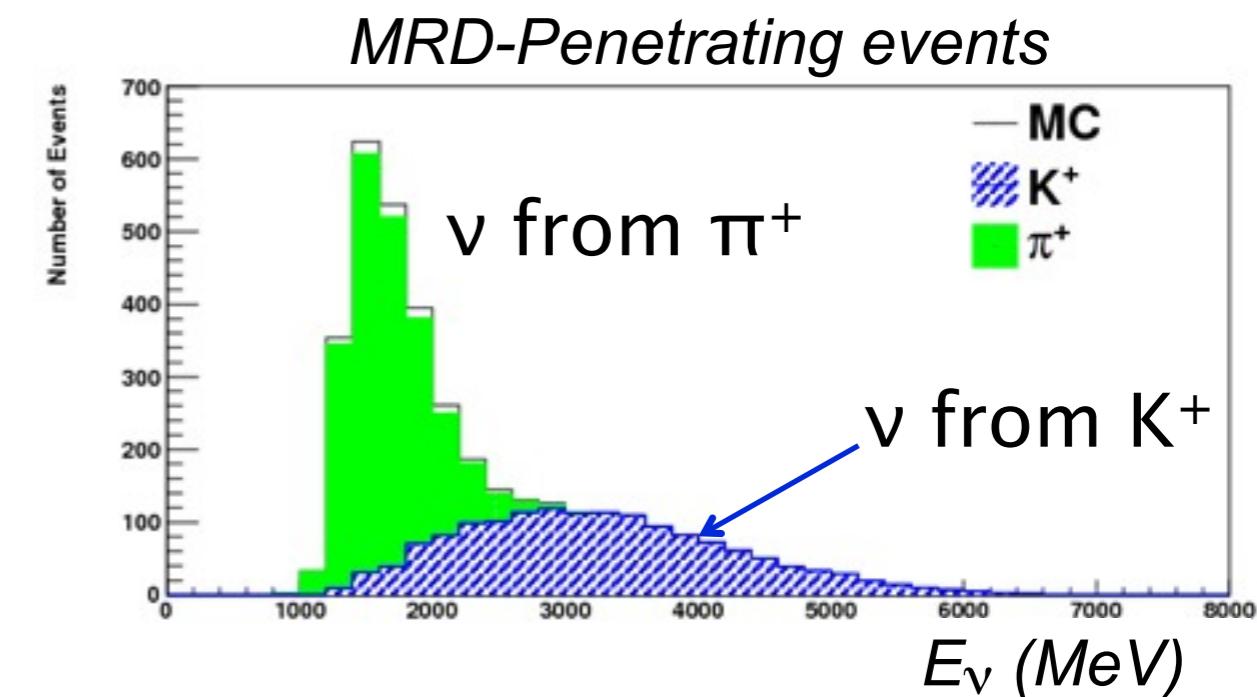
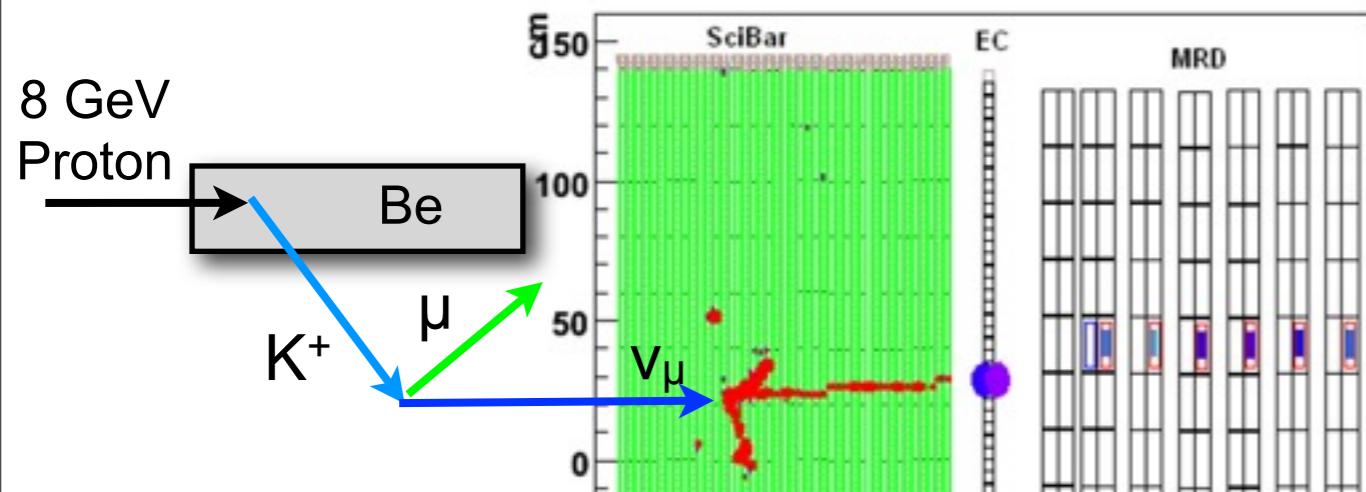
- Located in FNAL's Booster Neutrino Beam
- Precise measurements of neutrino cross sections near 1 GeV
- MiniBooNE/SciBooNE joint  $\nu_\mu$  disappearance
- SciBooNE - scintillator tracking detector
- MiniBooNE - mineral oil Cerenkov detector



# SciBooNE: $\nu_\mu$ 's from Kaon Decays

Gary Cheng & Camillo Mariani

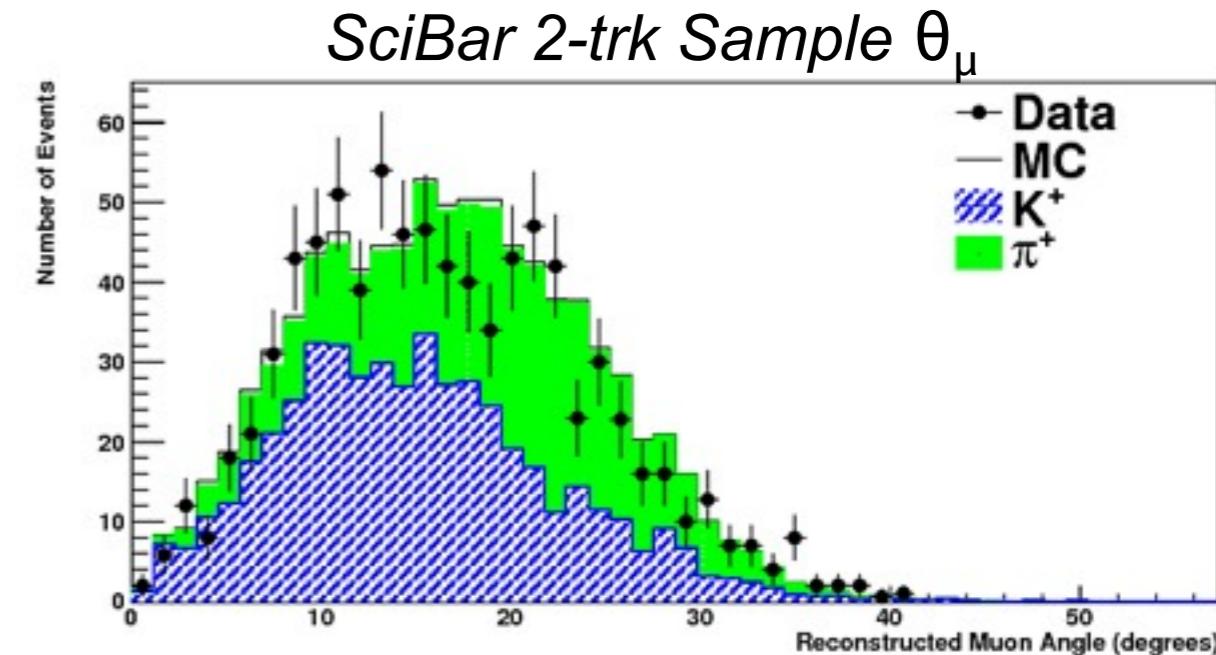
[Phys.Rev.D84, 012009 \(2011\)](#)



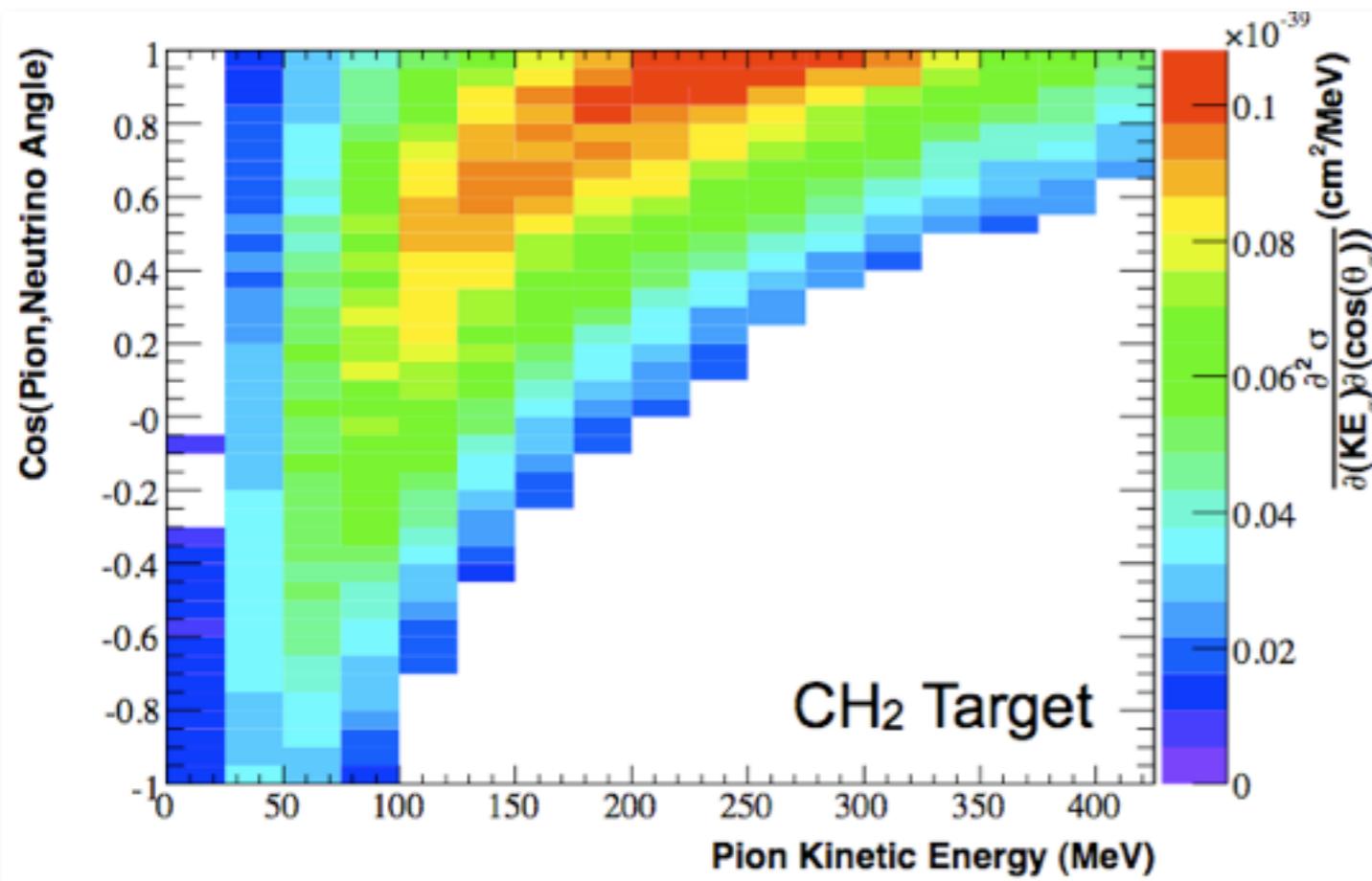
High energy neutrinos predominantly come from kaon decay.

Selecting MRD-penetrating events gives sample of high energy neutrinos.

Fit for kaon fraction, and tune Feynman scaling production model. Reduces model dependence of MiniBooNE  $V_e$  BG prediction.



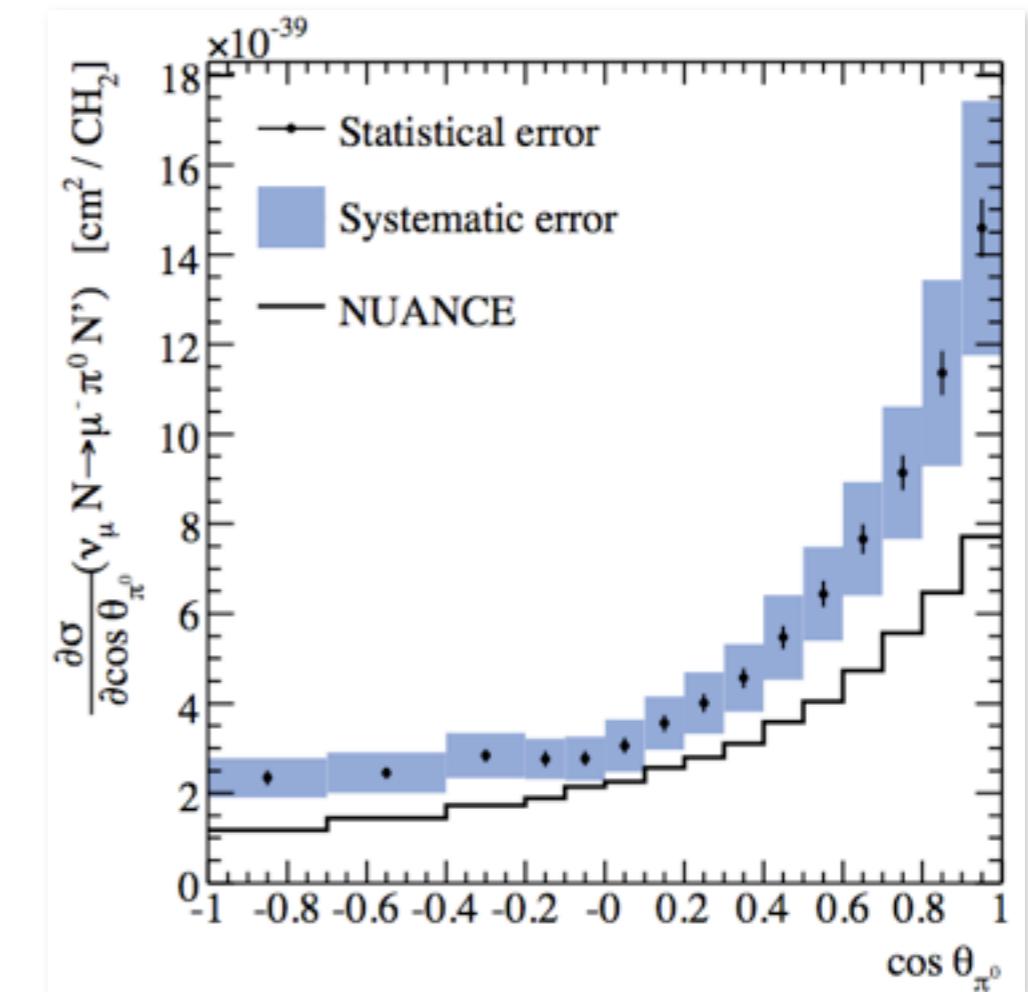
# MiniBooNE Cross Sections



## CC $\pi^+$ production

- Phys. Rev. Lett. 103, 081801 (2009)
- Phys. Rev. D83, 052007 (2011)

- 1<sup>st</sup> time that full kinematics (diff'l & double diff'l cross sections) have been reported for these reactions near 1 GeV
- CC inclusive and additional  $\nu$  analyses in progress now

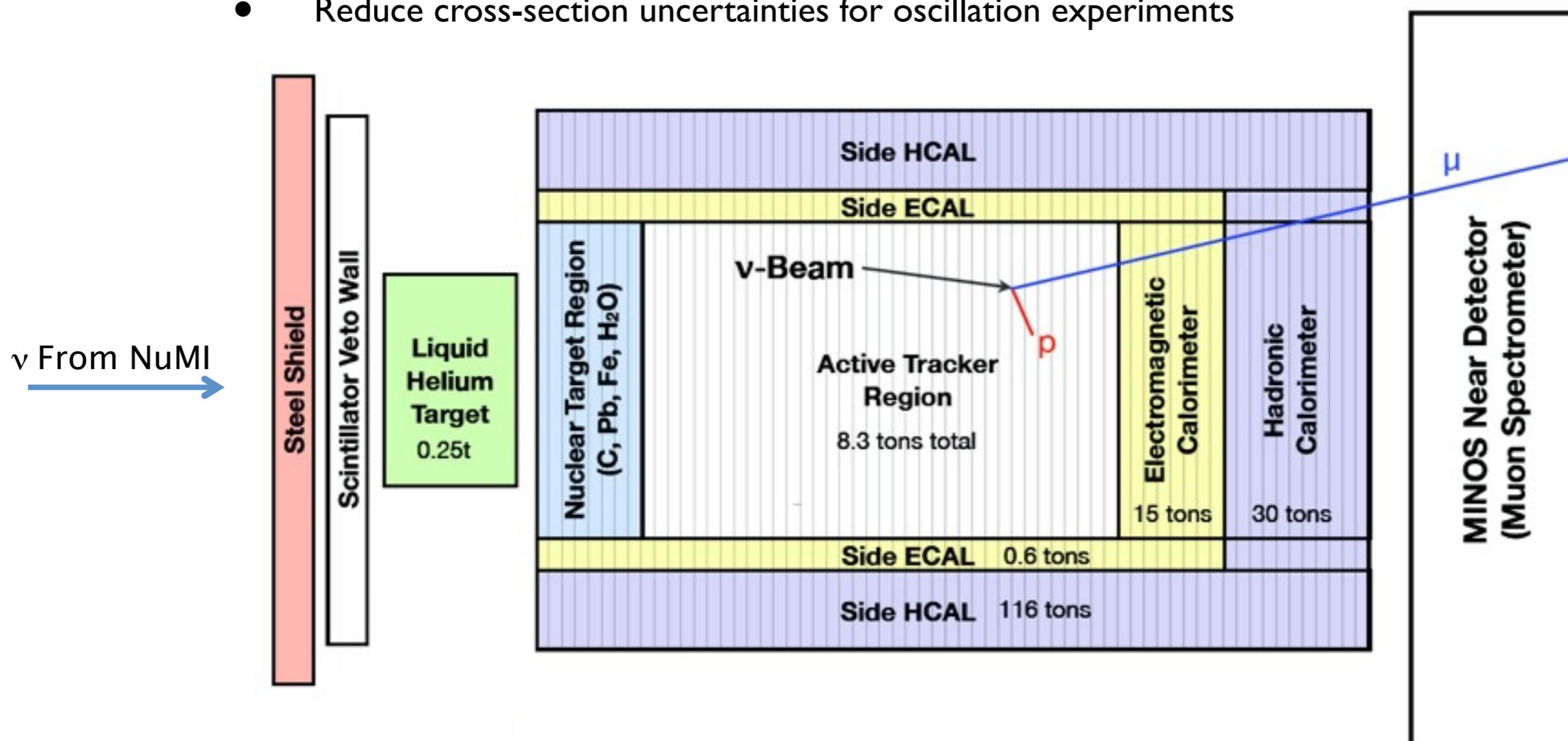


## CC $\pi^0$ production

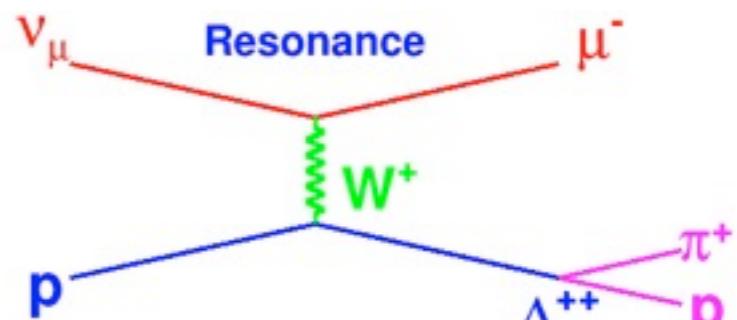
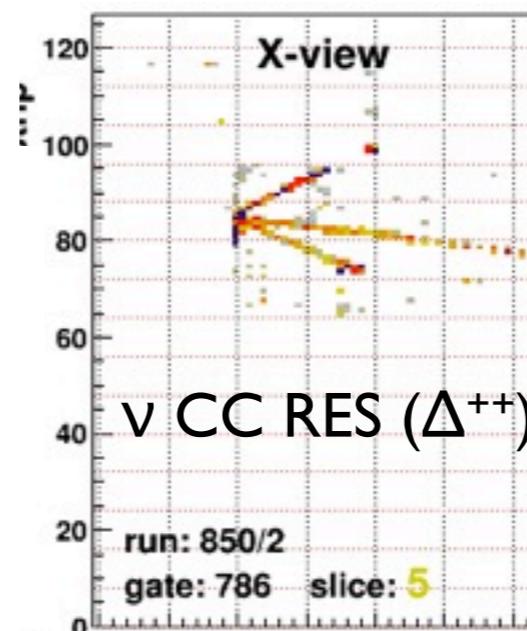
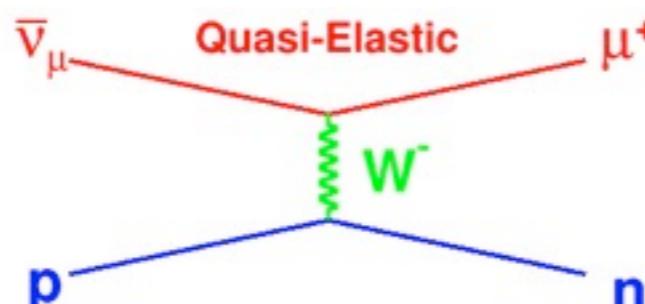
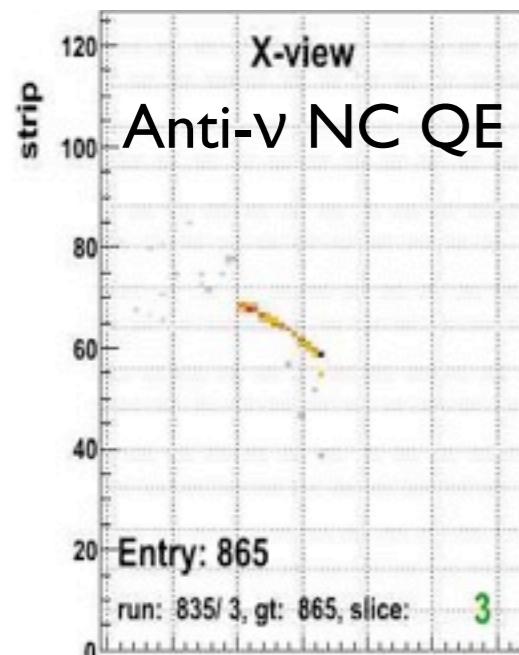
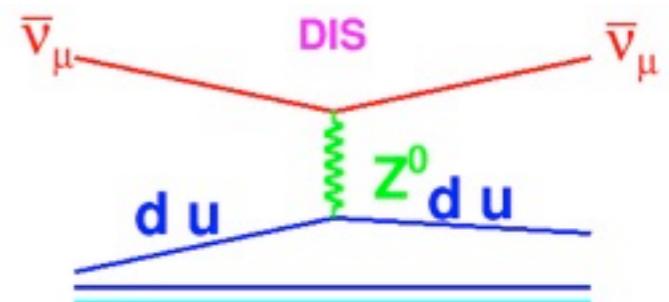
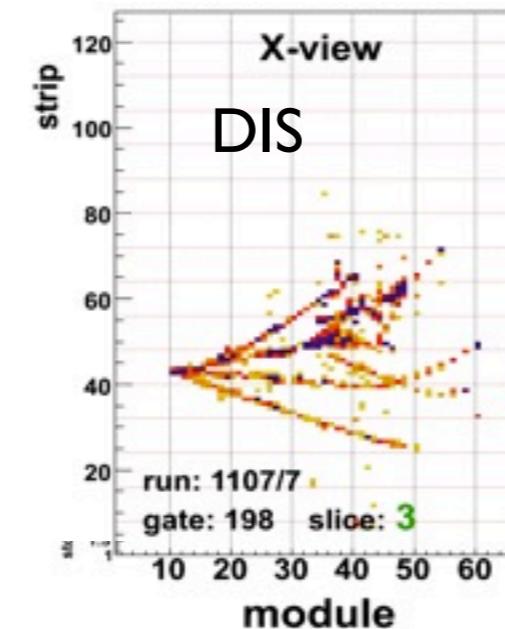
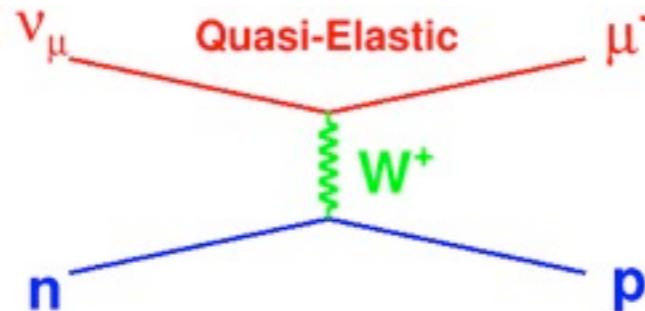
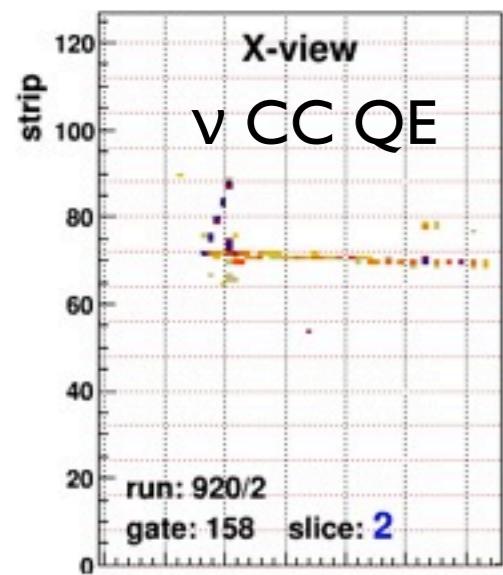
- Phys. Rev. D83, 052009 (2011)

# MINERvA

- MINERvA is a high precision neutrino scattering experiment located in the NuMI beamline upstream of the MINOS near detector
- MINERvA goals:
  - Measure neutrino-nucleus interaction rates for many different exclusive and inclusive final states in the 1-10 GeV region
  - Measure these rates on a variety of nuclei to better understand nuclear effects
  - Reduce cross-section uncertainties for oscillation experiments

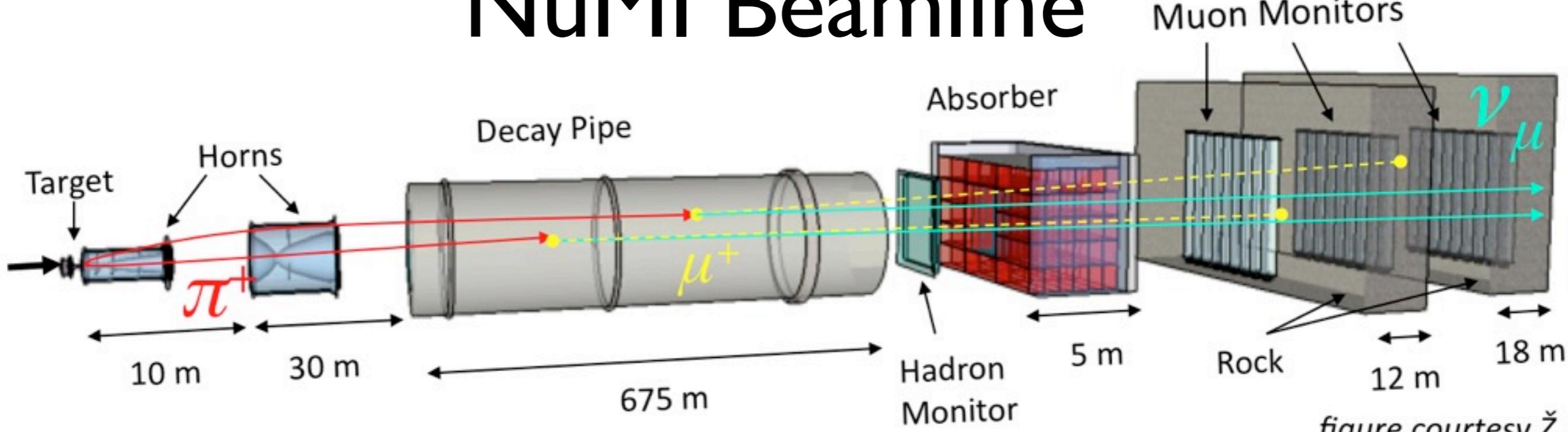


# MINERvA Events



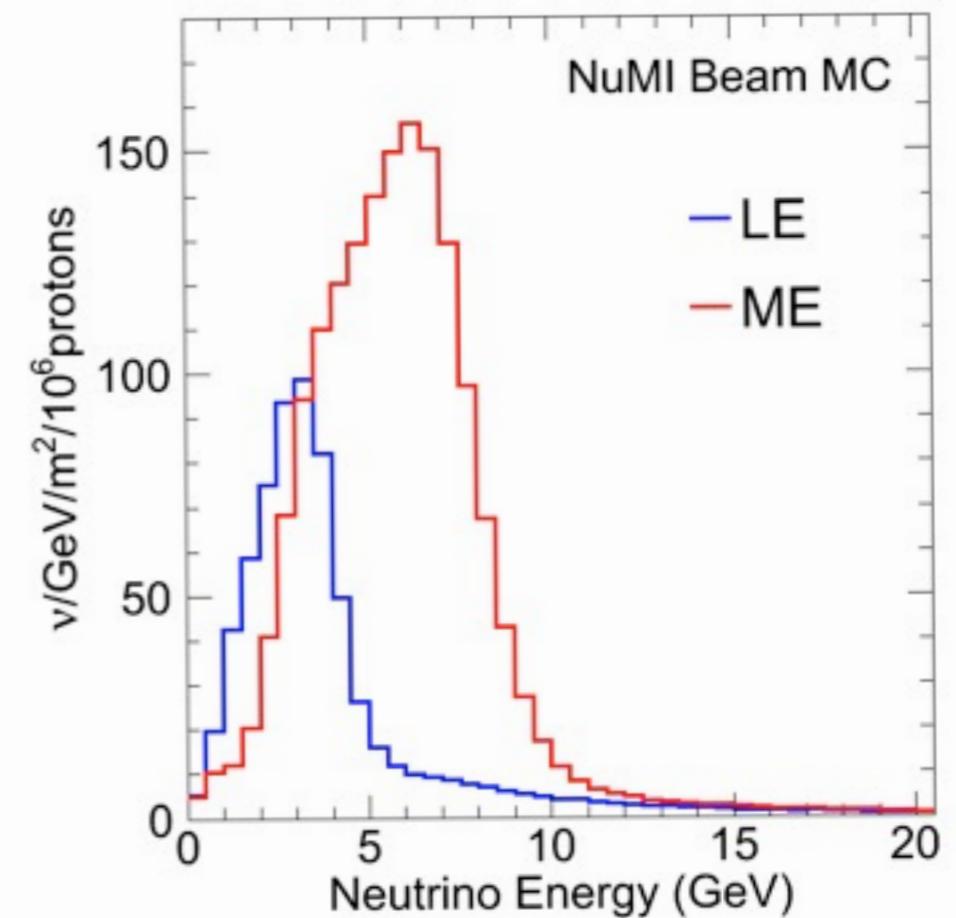
Exclusive final states are distinguished in MINERvA's fine grained detector

# NuMI Beamline



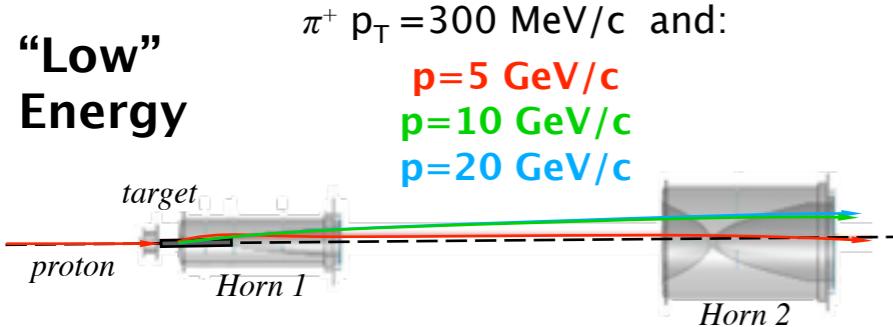
*figure courtesy Ž. Pavlović*

- 120 GeV/c proton beam  $\rightarrow$  C target  $\rightarrow \pi^{+/-}, K^{+/-}$
- $E_\nu$  spectrum changed by moving target and one horn
- MINERvA will take data in two different energy configurations
  - low energy (LE) running will finish Spring '12
  - medium energy (ME) running will begin Spring '13
- Forward horn current (FHC) for neutrino mode
- Reverse horn current (RHC) for anti-neutrino mode

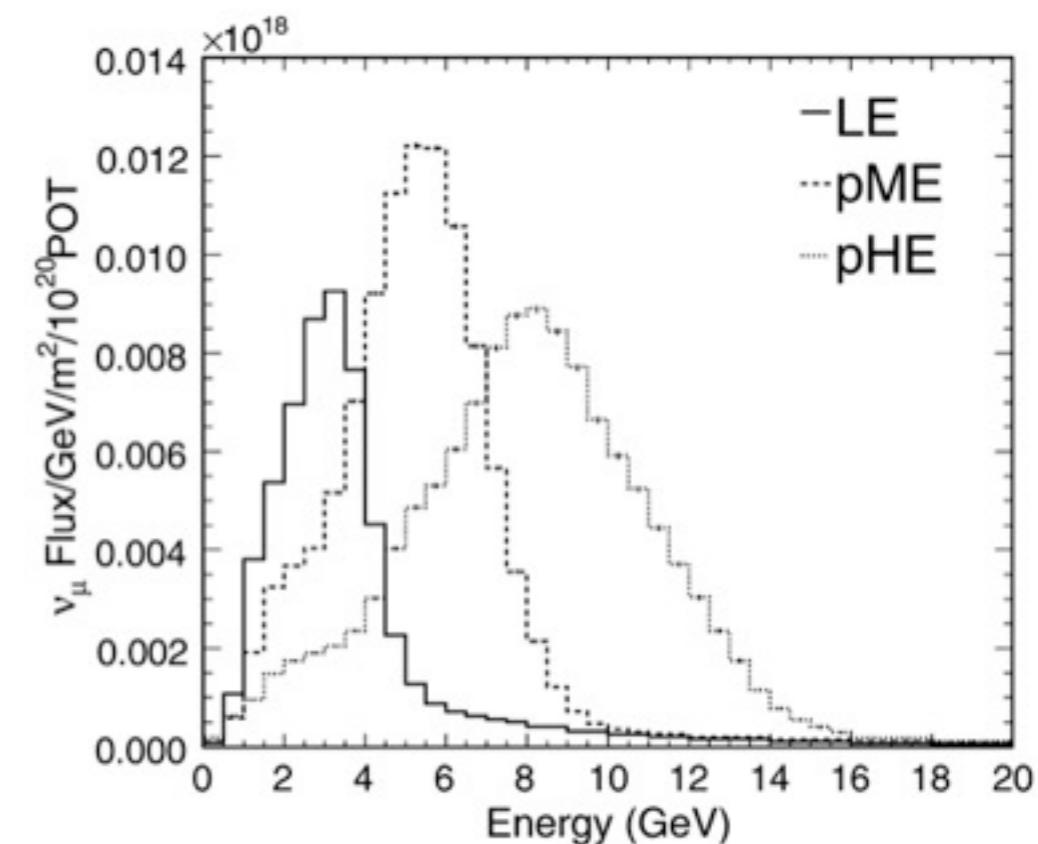
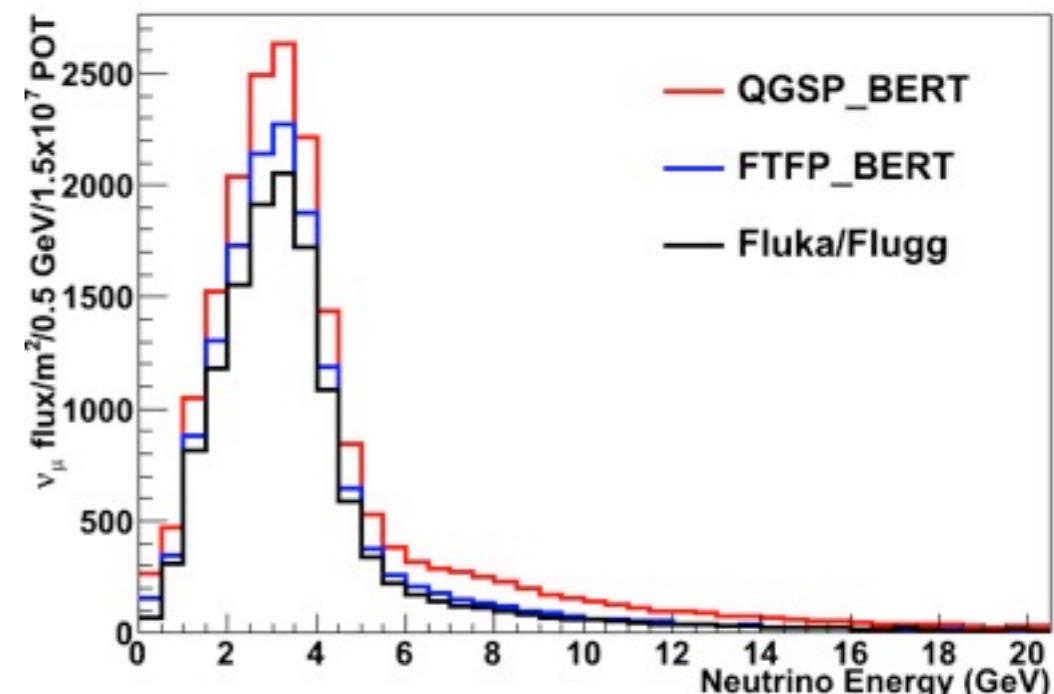
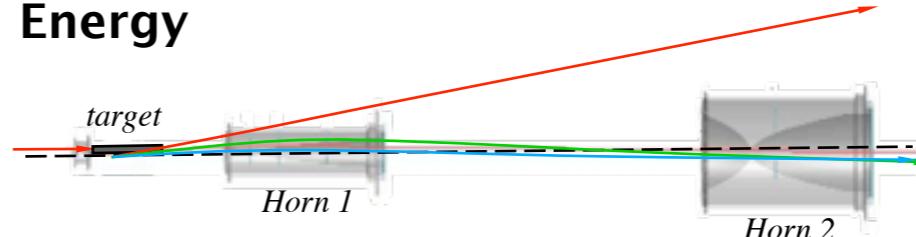


# Flux Determination

- MINERvA must understand its  $\nu$  flux very well to make precise measurements of absolute  $\nu \sigma$ 's
- Monte Carlo flux predictions have large uncertainties, especially due to hadron production uncertainties
- MINERvA's program for reducing its flux uncertainty:
  - tune its model of hadron production in the NuMI target to external hadron production data
  - Tune flux prediction to *in situ* flux measurements taken from special runs data - multiple beam configurations produced by varying target position and horn current

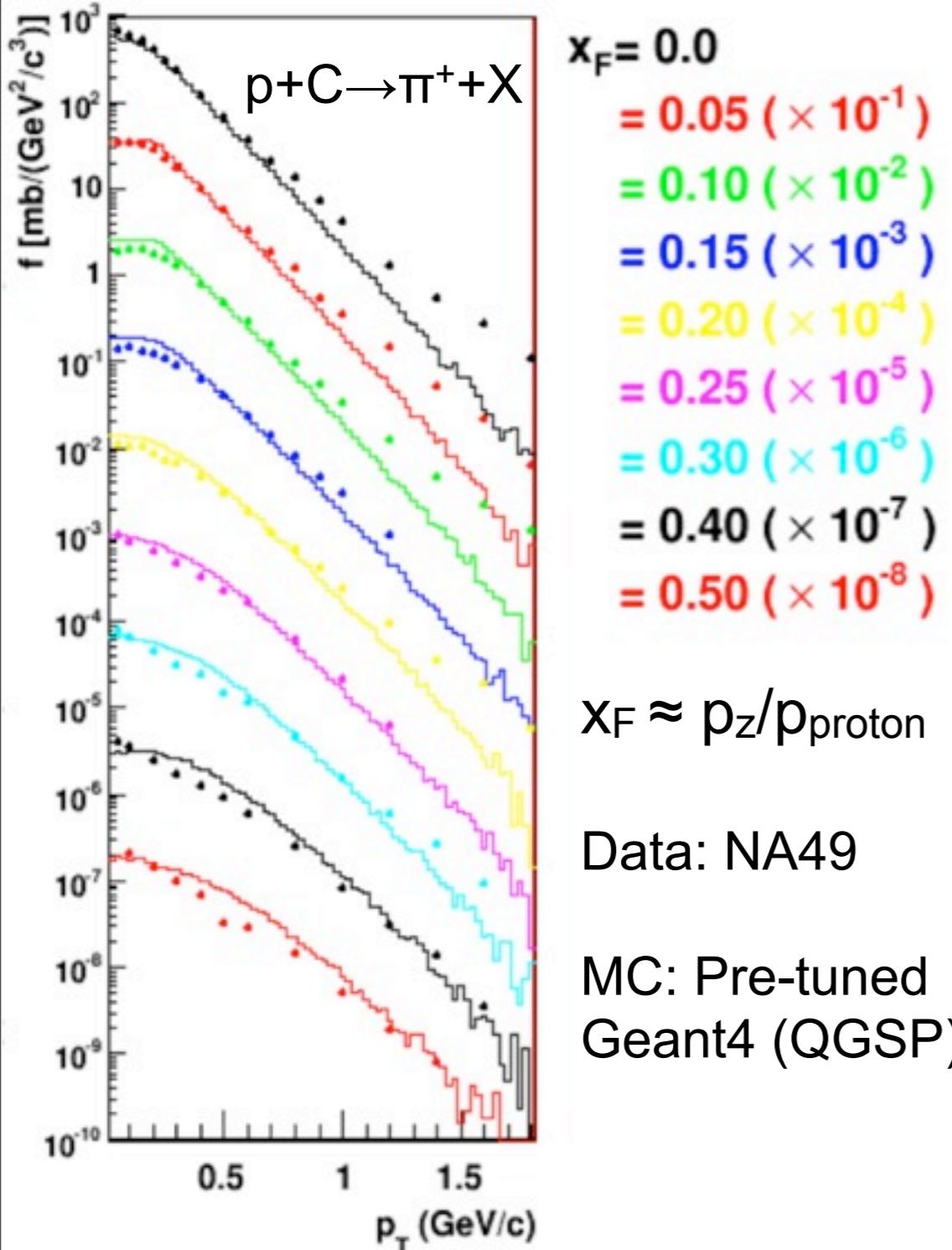


**“High” Energy**



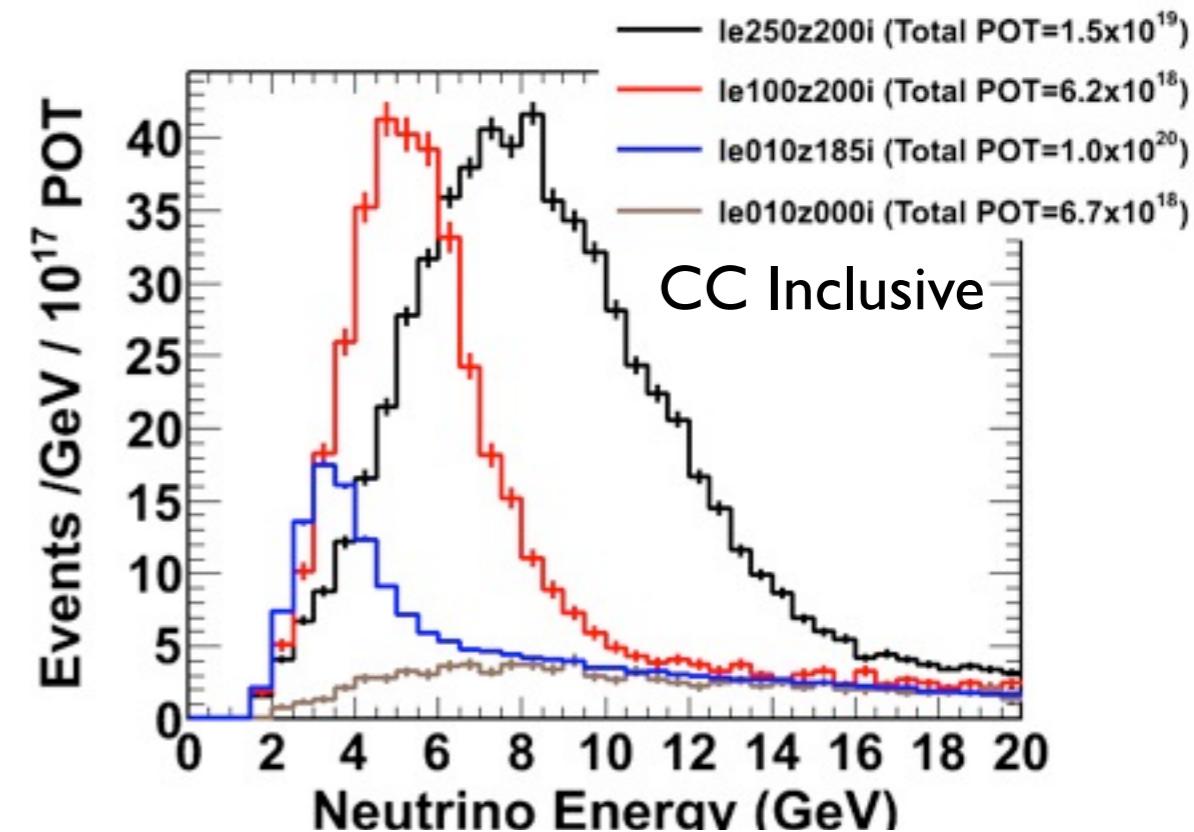
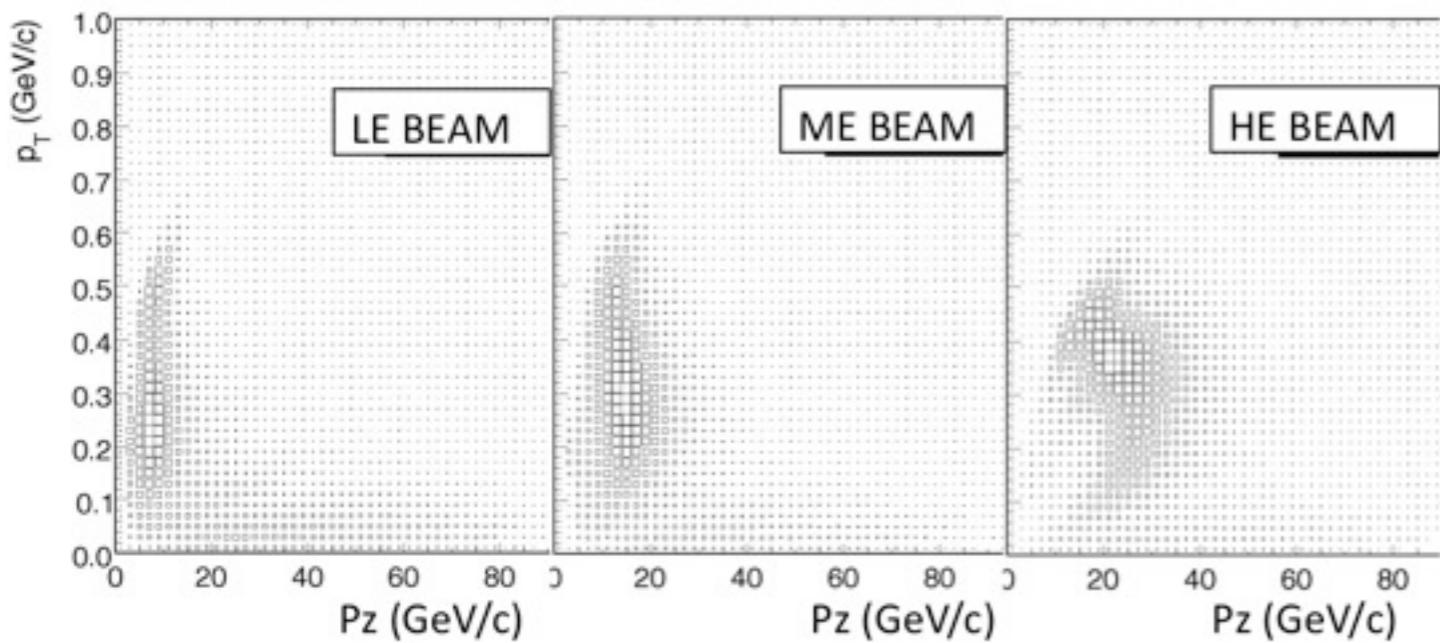
# Flux Determination: Hadron Production

Eur. Phys. J. C 49, 897–917 (2007)

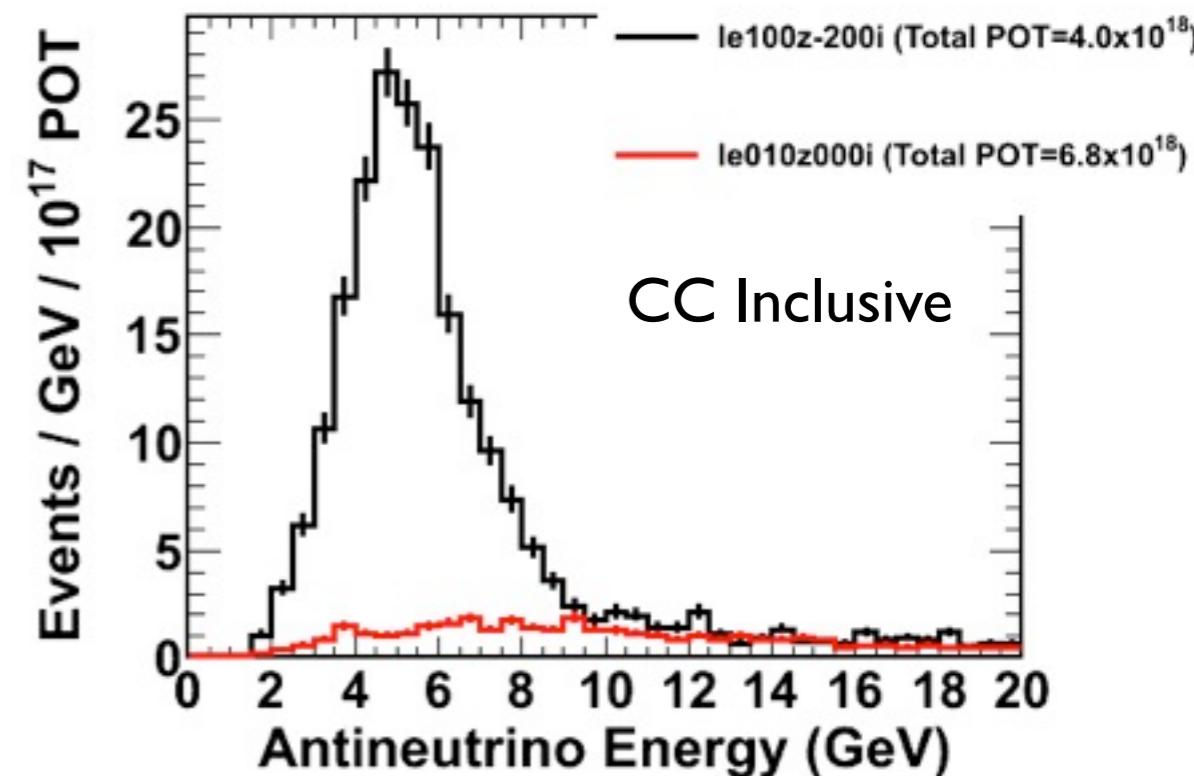


- MINERvA is using NA49  $p+C \rightarrow \pi/K + X$  data to tune its hadron production model at the NuMI target
- Similar proton beam energies
  - NA49: 158 GeV/c
  - NuMI: 120 GeV/c
- Additional corrections that need to be made:
  - Thick target effects:
    - NA49 data taken on a thin target
    - NuMI target is  $\sim 2\lambda_{\text{int}}$  length
    - Reinteractions are a 20-30% effect
  - Downstream interactions in horns, shielding, etc.
  - Temporal variations including target degradation and target swaps

# Flux Determination: Special Runs

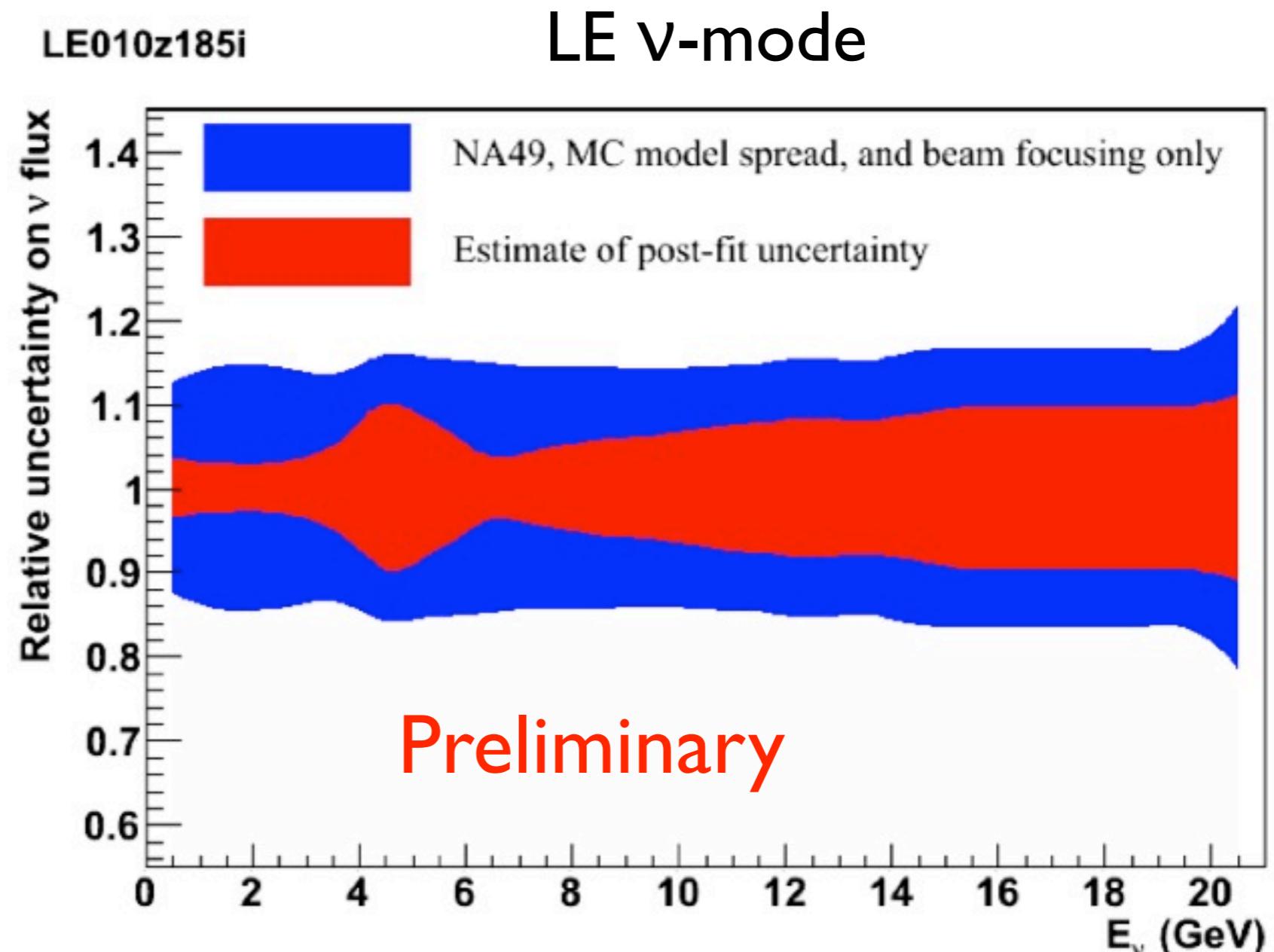


- MINERvA is performing an *in situ* measurement of  $\Phi(p_T, x_F)$  using several different beam configurations
- Fitting these data sets simultaneously allows us to deconvolve systematics:
  - $\pi, K$  production off the target
  - Neutrino beam focusing
  - Neutrino cross sections
- From this fit we will generate a set of weights which will be used to correct our  $\Phi(p_T, x_F)$  prediction

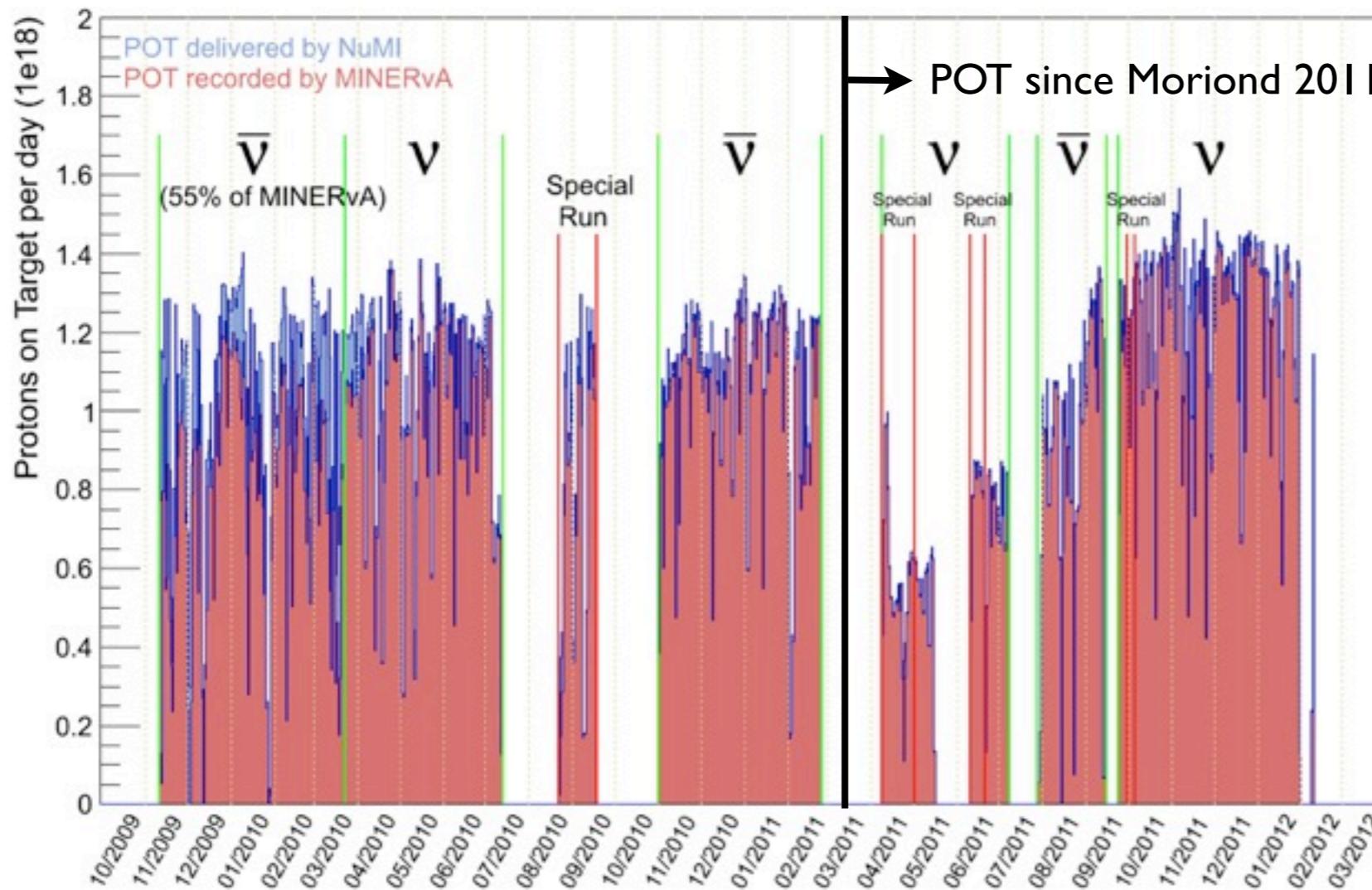


# Flux Determination: Uncertainty

- To estimate post-fit flux uncertainty, the reweighting procedure is used to warp hadron production in Geant4 MC to bring simulated Geant4 “data” into agreement with simulated Fluka “data”
  - **Blue:** pre-fit flux uncertainty estimate:
    - NA49 uncertainties
    - MC Model Spread: maximum difference between relevant Geant4 hadronic physics models in describing reinteractions in the target and downstream interactions is taken to be  $1\sigma$
    - Focusing uncertainties
  - **Red:** post-fit flux uncertainty estimate

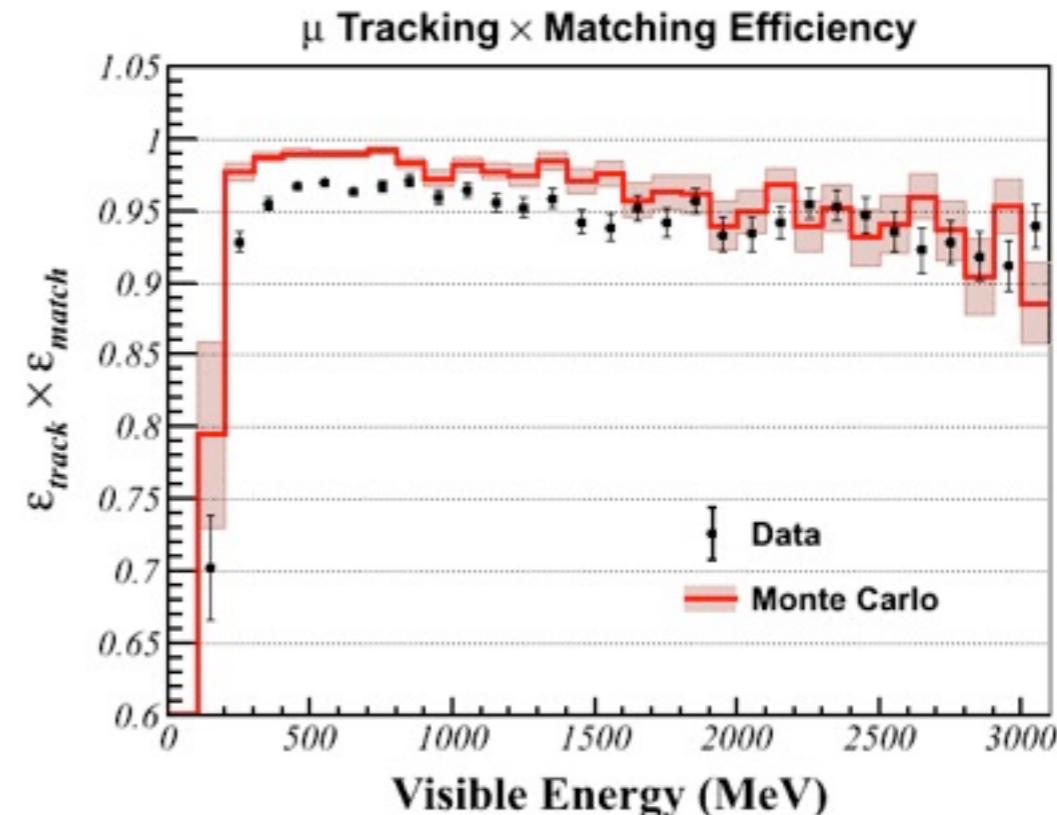
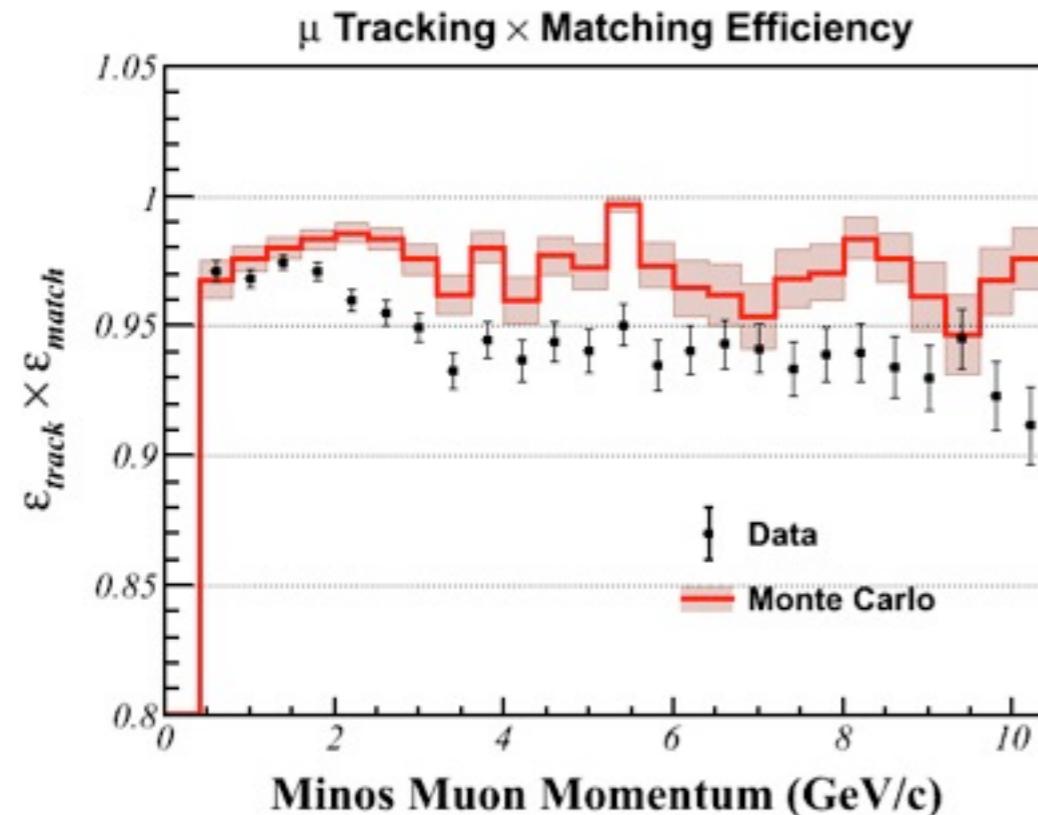


# MINERvA Data Collection & Processing



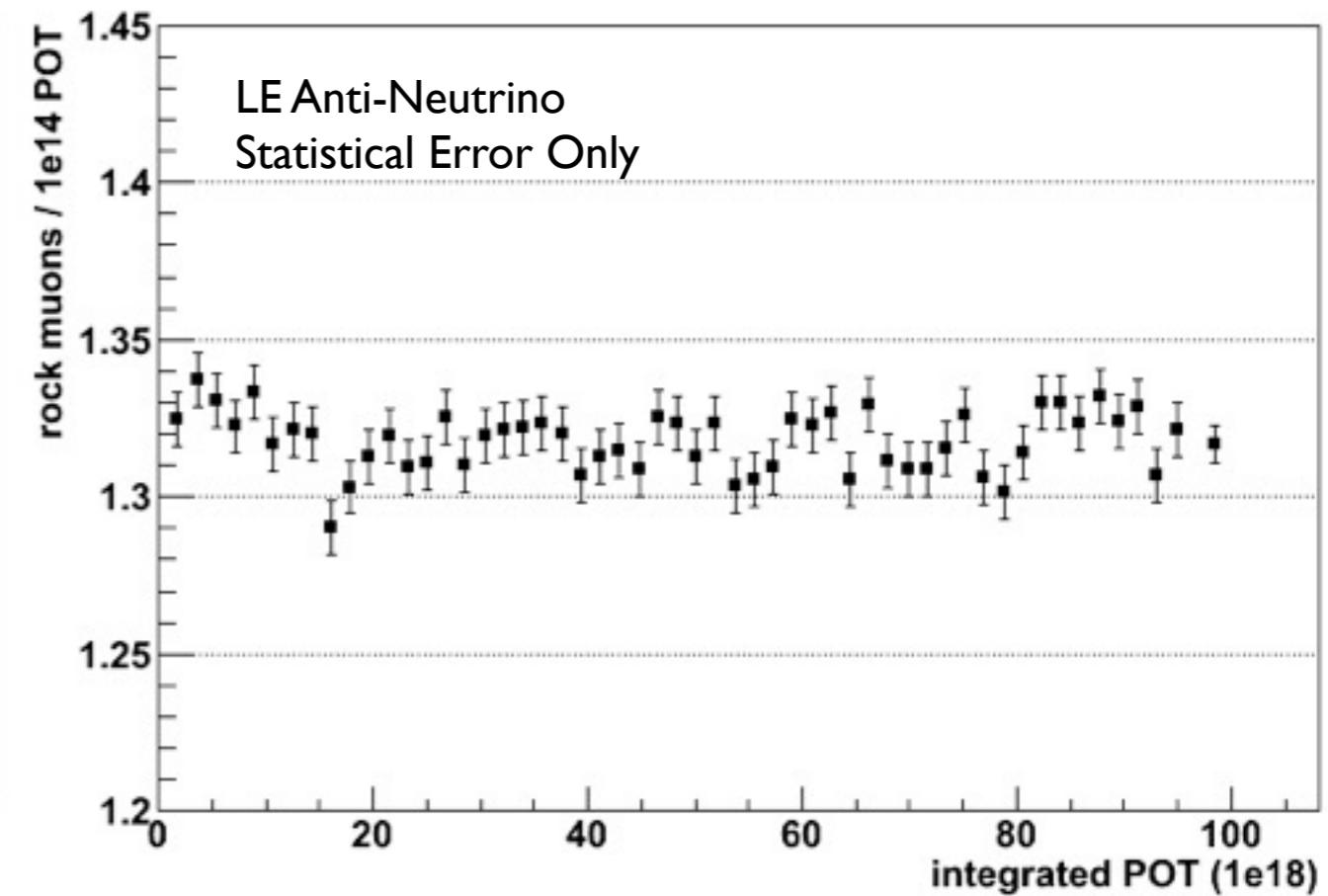
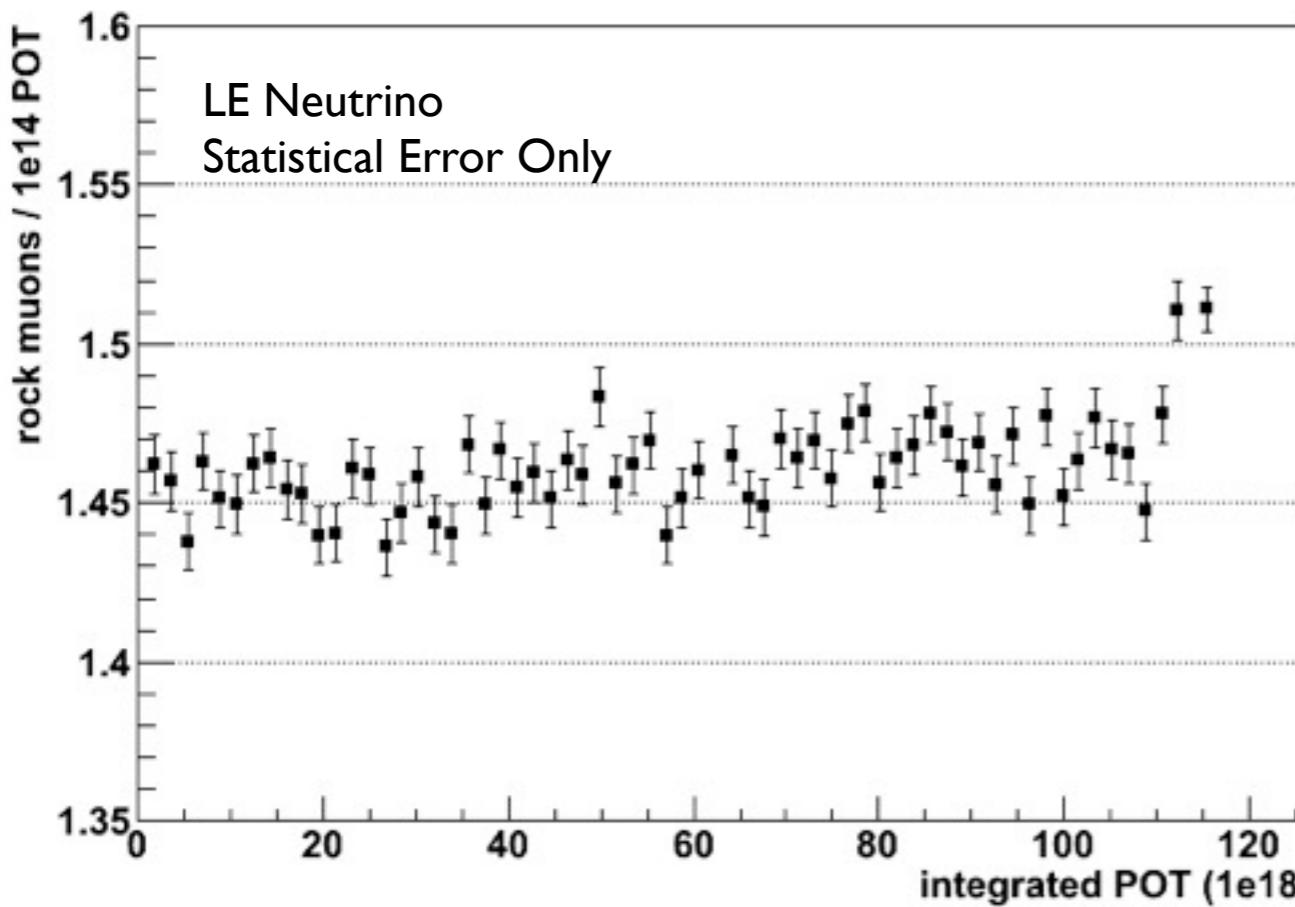
- MINERvA has fully calibrated and processed its first 19 months of data (Nov '09 through Jun '11)

# Muon Tracking Efficiency



- Tracking muons from MINERvA into MINOS is critical to MINERvA's CC analyses
- Events in denominator satisfy
  - cuts on MINOS track: well reconstructed, front entering, points back to MINERvA's tracker
  - cuts on visible energy in MINERvA falling within MINOS track's time window
- Events in numerator have a matching MINERvA track
- Data and Monte Carlo differences attributed to PMT afterpulsing and particles from neutrino interactions outside the detector not yet simulated in Monte Carlo

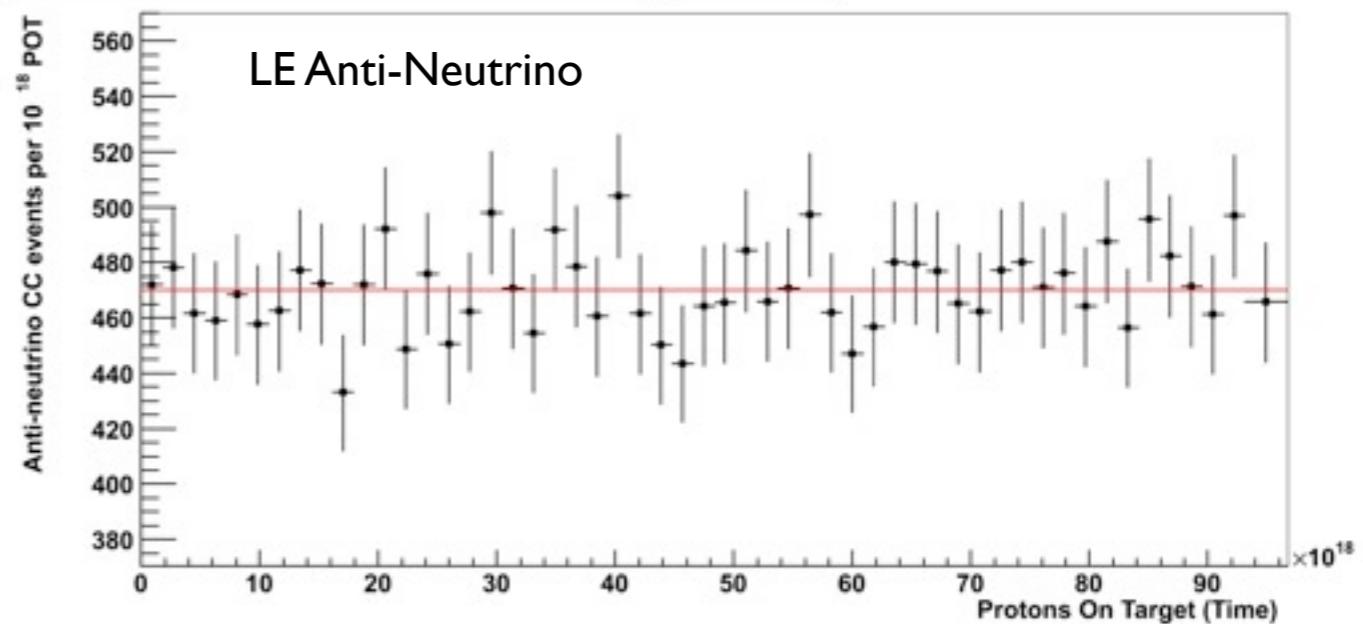
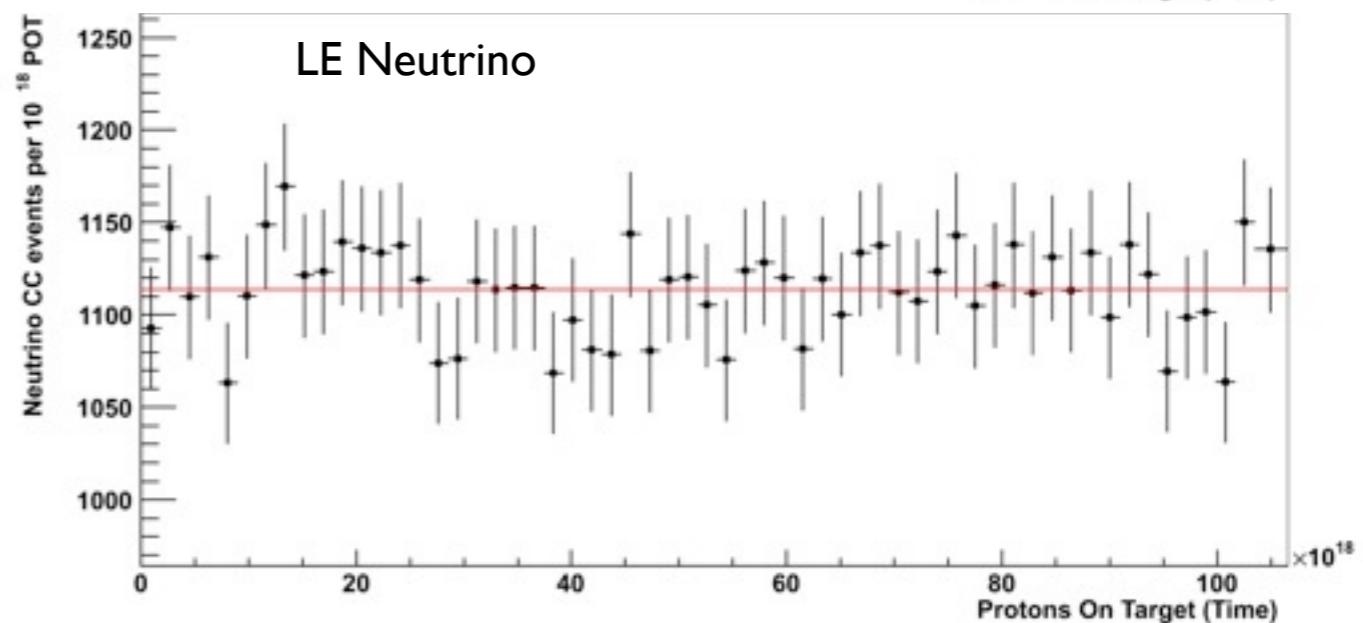
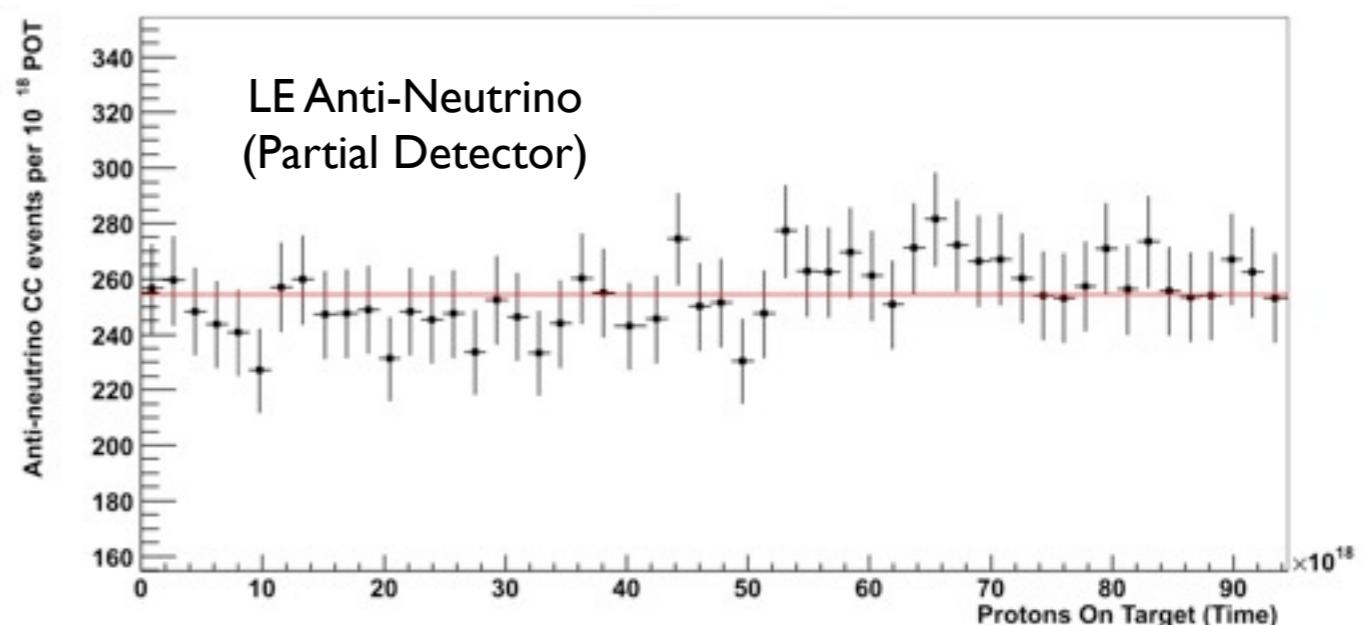
# Reconstruction Stability: Rock Muons



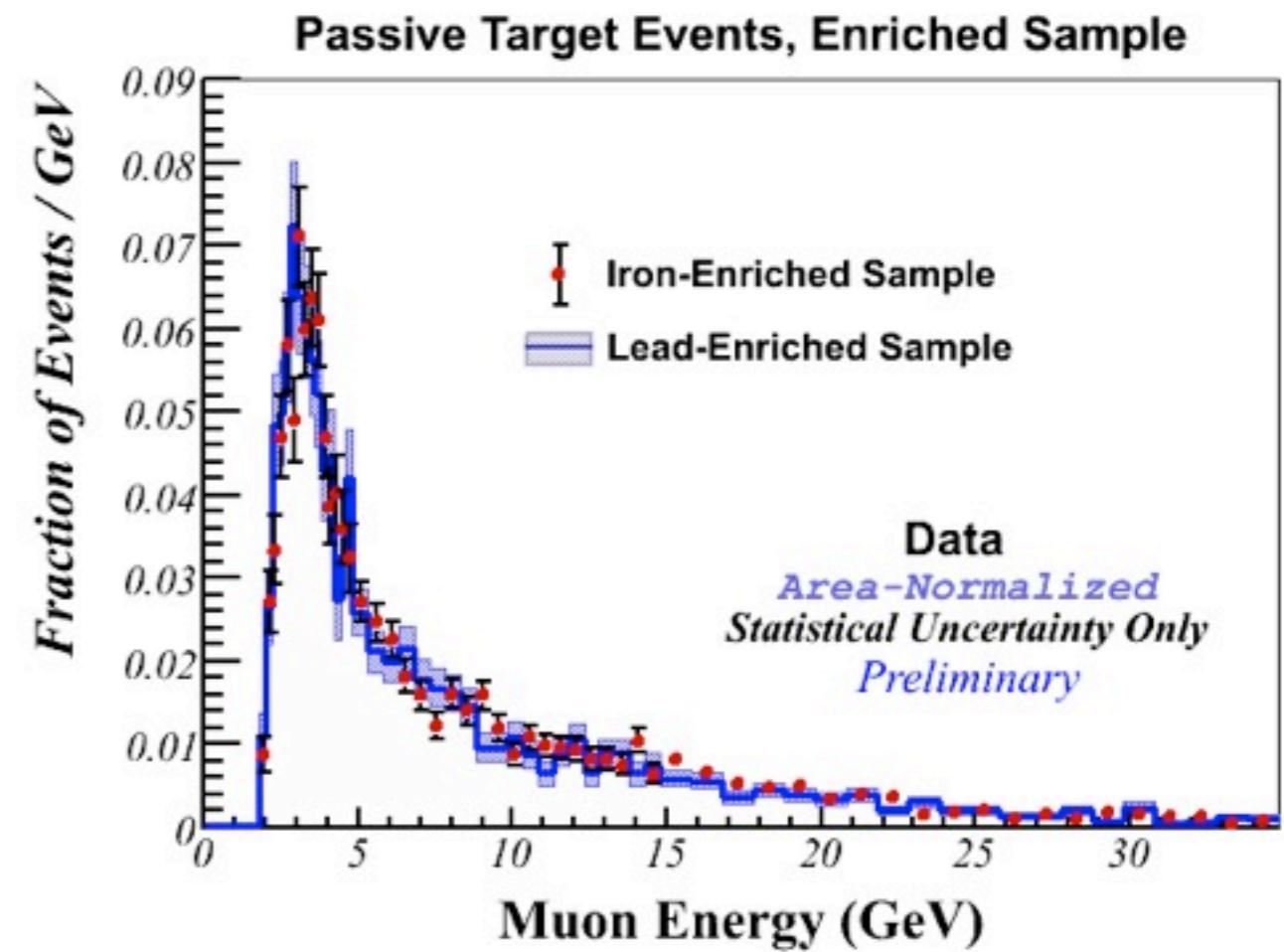
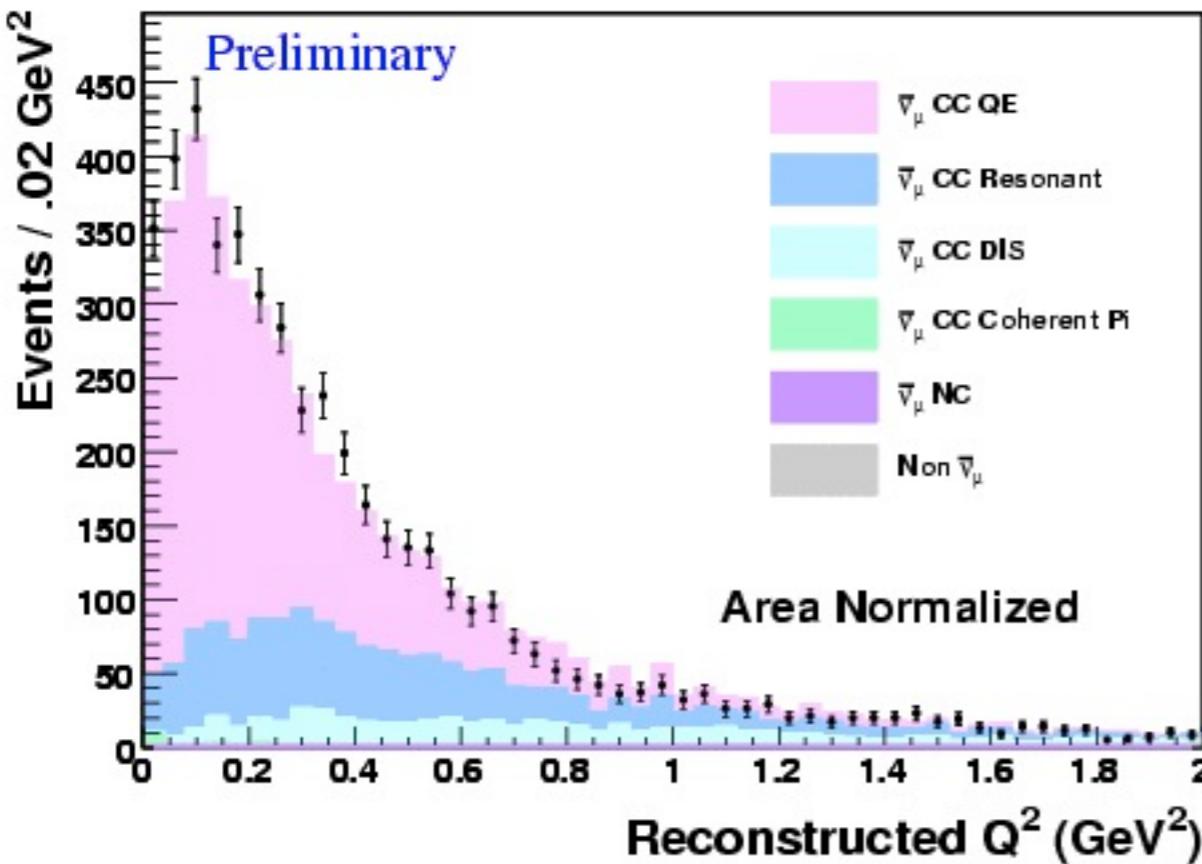
- Rock muons - muons from neutrino interactions in rock in detector hall
- Above plots show rock muons/POT vs. integrated POT for muons that enter the front of MINERvA and are tracked in both MINERvA and MINOS
- Rock muons/POT are sensitive to the state of
  - proton beam, target, and horns
  - MINERvA & MINOS readout, MINOS magnetic field

# Reconstruction Stability: CC Events

- CC event selection
  - exactly one MINOS-matched muon track
  - muon track originates inside MINERvA's tracker region



# Upcoming MINERvA Results



- Summer 2012 - updated results for increased statistics and improved calibrations and reconstruction
  - CC QE
  - CC inclusive nuclear target event rates and ratios
- Many other analyses in the works!

# On Behalf of the MINERvA Collaboration, Thank You

G. Tzanakos

*University of Athens, Athens, Greece*

D.A.M. Caicedo, C. Castromonte, G.A. Fiorentini, H. da Motta, J.L. Palomino  
*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*

C. Simon, B. Ziemer

*University of California, Irvine, California*

L. Bagby, D. Boehlein, R. DeMata, D.A. Harris\*, J. Kilmer, J.G. Morfin, J. Osta, A.  
Pla-Dalmau, P. Rubinov, D. Schmitz, R. Stefanski  
*Fermi National Accelerator Laboratory, Batavia, Illinois*

J. Grange, J. Mousseau, R. Napora, B. Osmanov, H. Ray  
*University of Florida, Gainesville, Florida*

J. Felix, A. Higuera, Z. Urrutia, G. Zavala

*Universidad de Guanajuato, Division de Ciencias e Ingenierias, Leon Guanajuato,  
Mexico*

M.E. Christy#, R. Ent, C.E. Keppel, P. Monaghan, T. Walton, L. Zhu  
*Hampton University, Hampton, Virginia*

A. Butkevich, S. Kulagin

*Institute for Nuclear Research, Moscow, Russia*

I. Niculescu, G. Niculescu

*James Madison University, Harrisonburg, Virginia*

E. Maher

*Massachusetts College of Liberal Arts, North Adams, Massachusetts*

R. Gran, M. Lanari

*University of Minnesota-Duluth, Duluth, Minnesota*

L. Fields, H. Schellman

*Northwestern University, Evanston, Illinois*

N. Tagg

*Otterbein College, Westerville, Ohio*

A. M. Gago, N. Ochoa, C. E. Perez, J. P. Velasquez  
*Pontificia Universidad Católica del Perú, Lima, Peru*

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

A. Bodek, R. Bradford, H. Budd, J. Chvojka, M. Day, R. Flight, H. Lee, S. Manly,  
K.S. McFarland\*, A. McGowan, A. Mislivec, J. Park, G. Perdue, J. Wolcott  
*University of Rochester, Rochester, New York*

G. Kumbartzki, T. Le, R. Ransome#, B. Tice  
*Rutgers University, New Brunswick, New Jersey*

M. Jenkins, S. Kopp, L. Loiacono, R. Stevens IV  
*University of Texas, Austin, Texas*

H. Gallagher, T. Kafka, W.A. Mann#, W. Oliver  
*Tufts University, Medford, Massachusetts*

M. Aliana, C.J. Solano Salinas  
*Universidad Nacional de Ingeniería, Lima, Peru*

W. Brooks, E. Carquina, G. Maggi, C. Peña, I. Potashnikova, F. Prokoshin  
*Universidad Técnica Federico Santa María, Valparaíso, Chile*

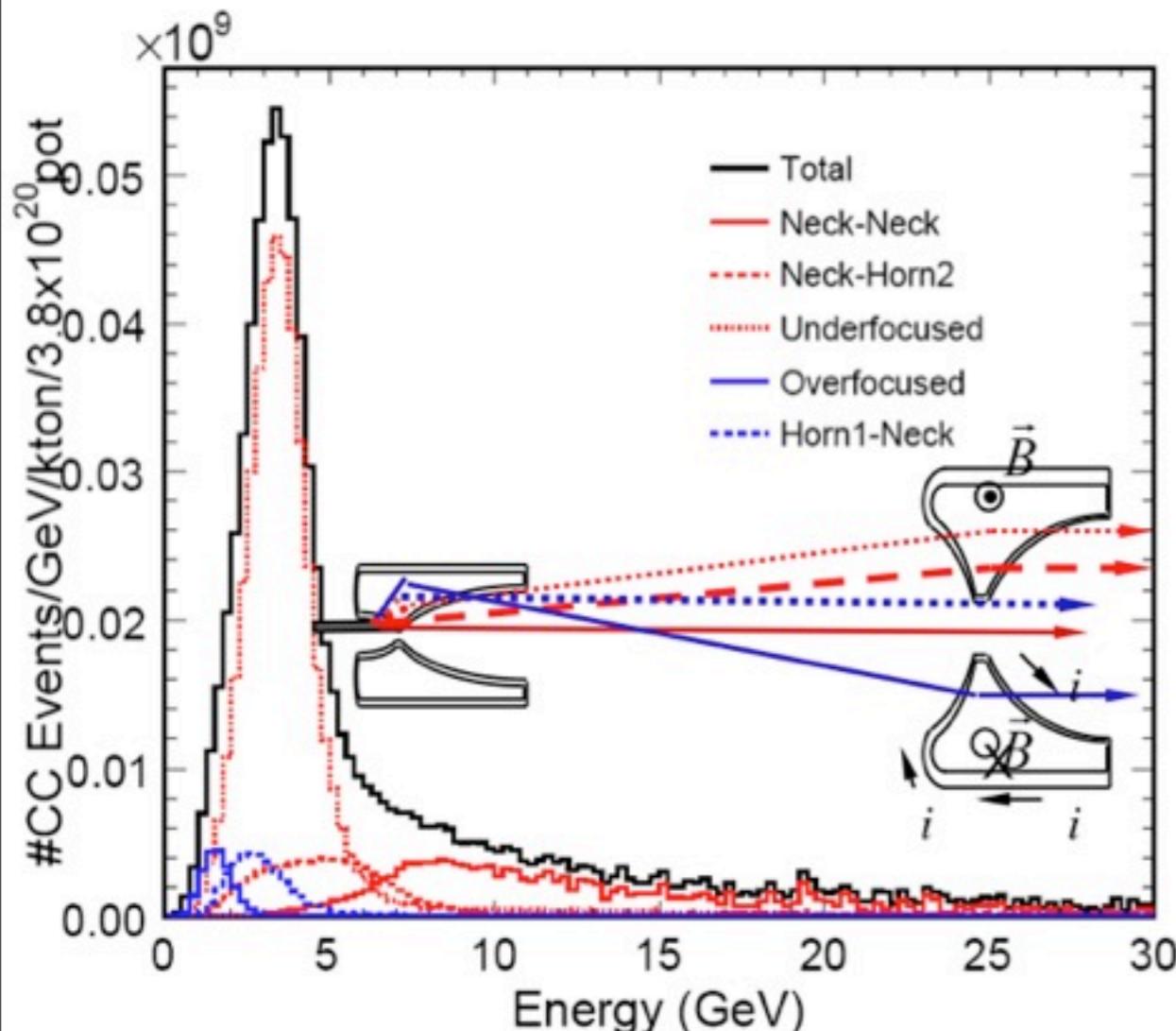
L. Aliaga, J. Devan, M. Kordosky, J.K. Nelson, J. Walding, D. Zhang  
*The College of William and Mary, Williamsburg, Virginia*



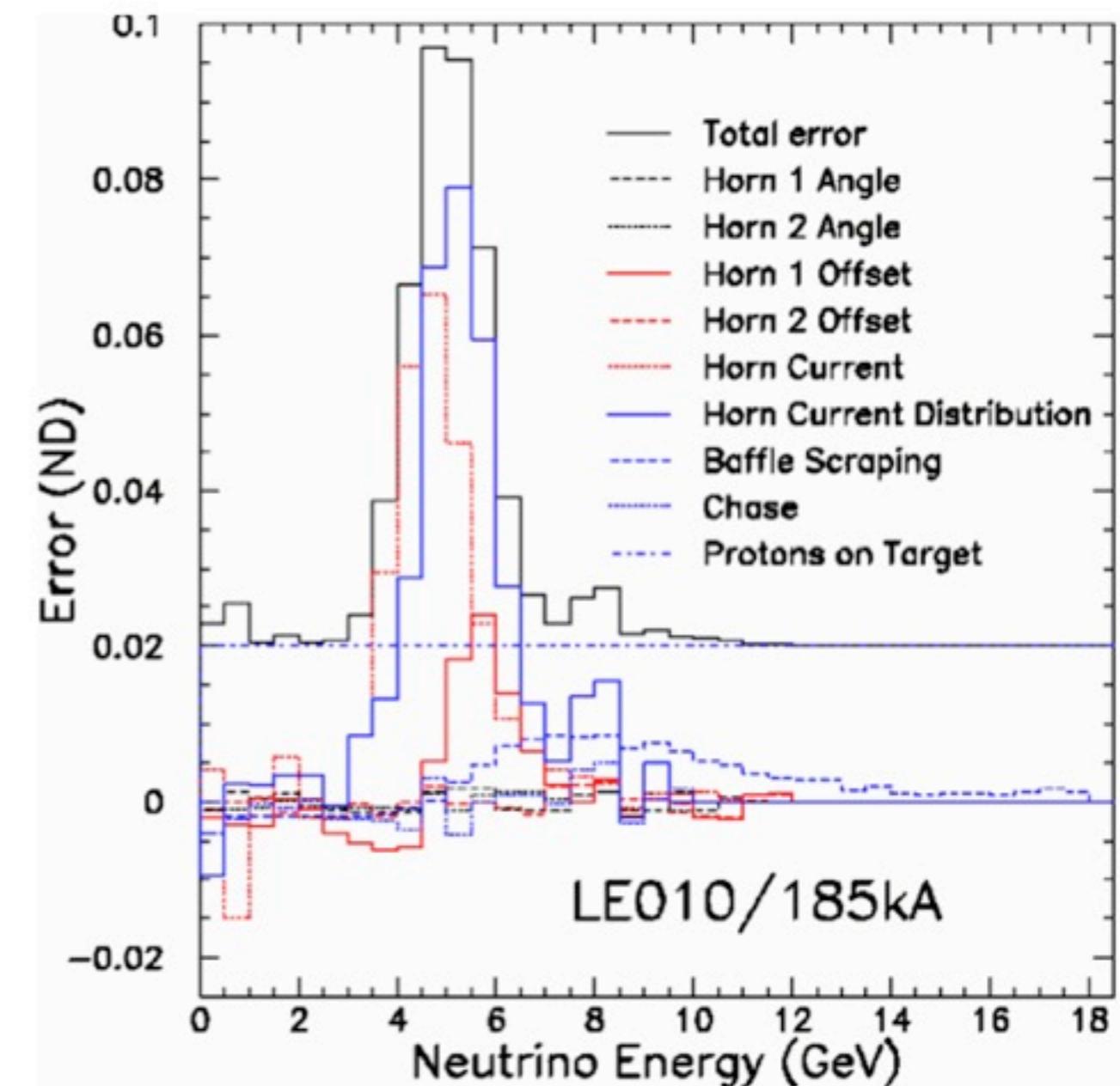
# Backup

# Focusing Uncertainties

Z. Pavlovic, PhD Thesis, University of Texas, 2008



Z. Pavlovic, PhD Thesis, University of Texas, 2008



# Hadron Production

Yields of secondaries off of target are parameterized:

$$\frac{d^2N}{dx_F dp_T} = [A + Bp_T] * \exp(-Cp_T^{3/2})$$

A( $x_F$ )  
determines  
low  $p_T$  yields

B( $x_F$ ) determines  
how fast  
distribution  
rises

C( $x_F$ )  
determines  
high  $p_T$  fall off

Linear warpings of A, B, C:

$$A'(x_F) = (p_1 + p_2 x_F) A(x_F)$$

$$B'(x_F) = (p_3 + p_4 x_F) B(x_F)$$

$$C'(x_F) = (p_5 + p_6 x_F) C(x_F)$$

For  $\pi^+$ ,  $K^+$ :  
6 parameters

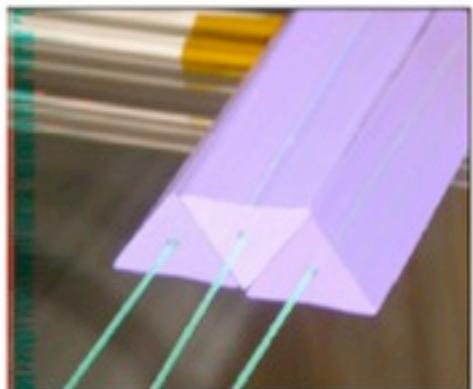
$$W(ptype, p_T, x_F) = \frac{[A' + B'p_T] \times \exp(-C'p_T^{3/2})}{[A + Bp_T] \times \exp(-Cp_T^{3/2})}$$

For  $\pi^-$ ,  $K^-$ :  
2 parameters

$$W(\pi^-) = (p_{13} + p_{14} x_F) W(\pi^+)$$

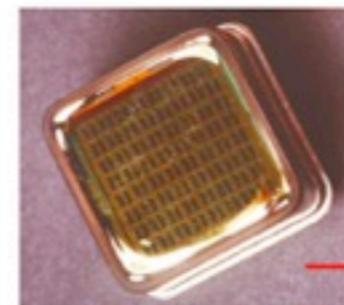
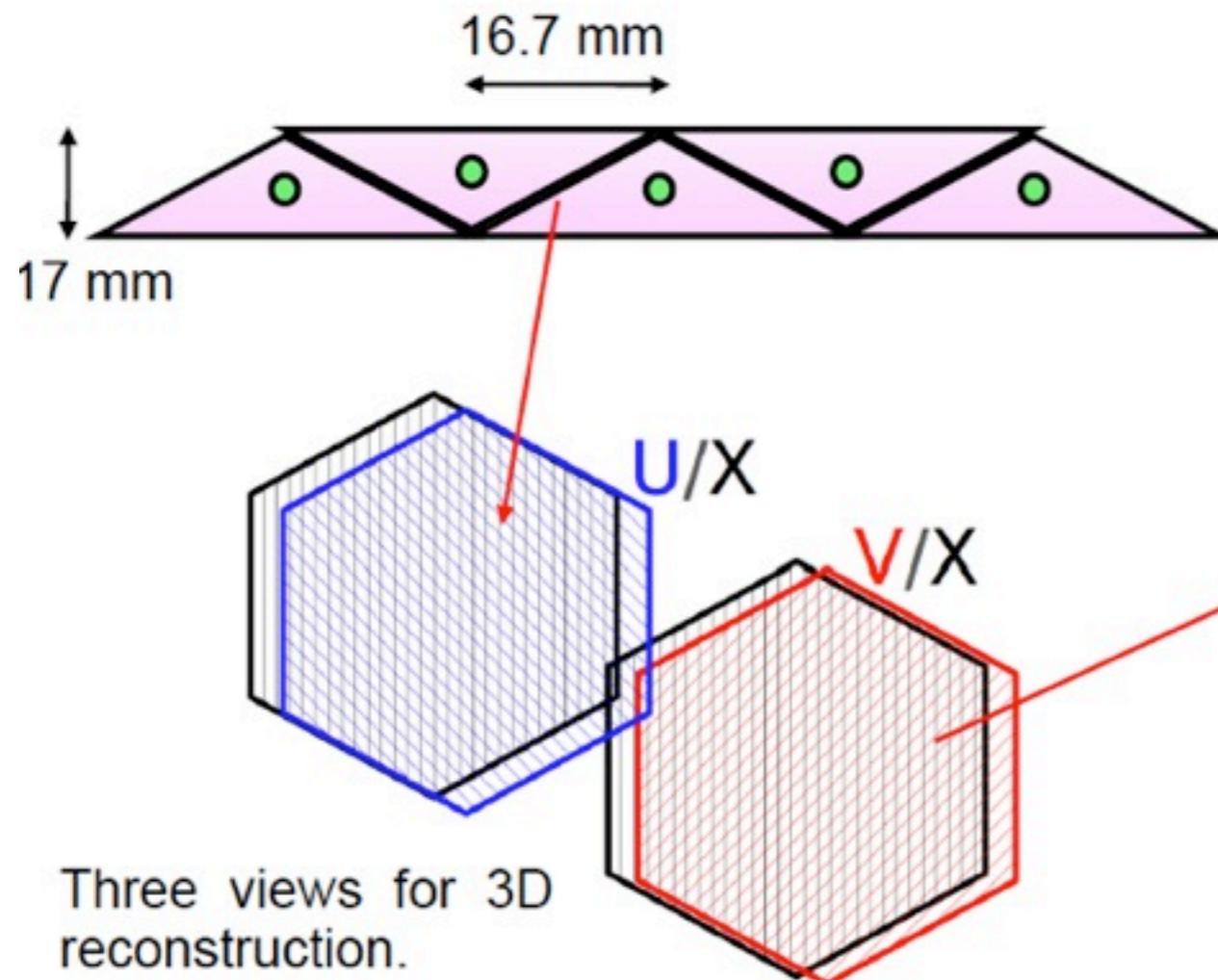
16 total parameters to tune MC hadron  
target production to match observed data

# MINERvA Detector

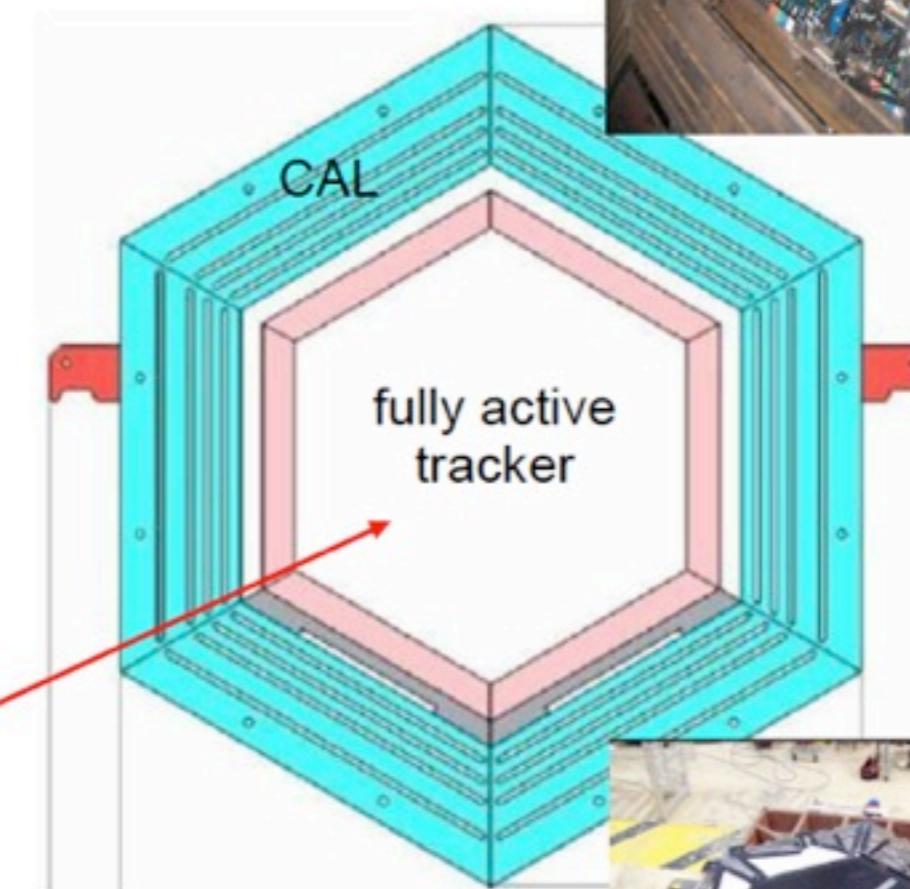


Extruded plastic scintillator  
+ wavelength shifters.

Triangular geometry allows  
charge sharing for better  
position resolution.



64 anode  
PMT's



Iron outer detector  
instrumented for EM  
calorimetry.

