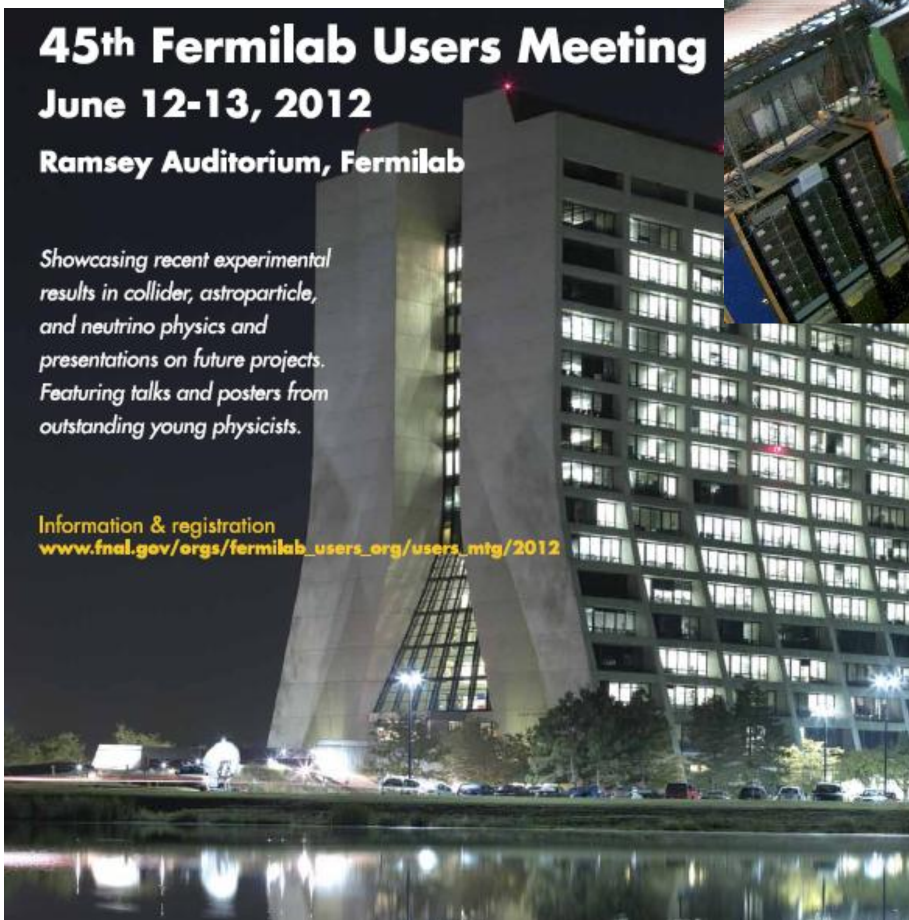
Results from the MINERνA neutrino Experiment (E-938)



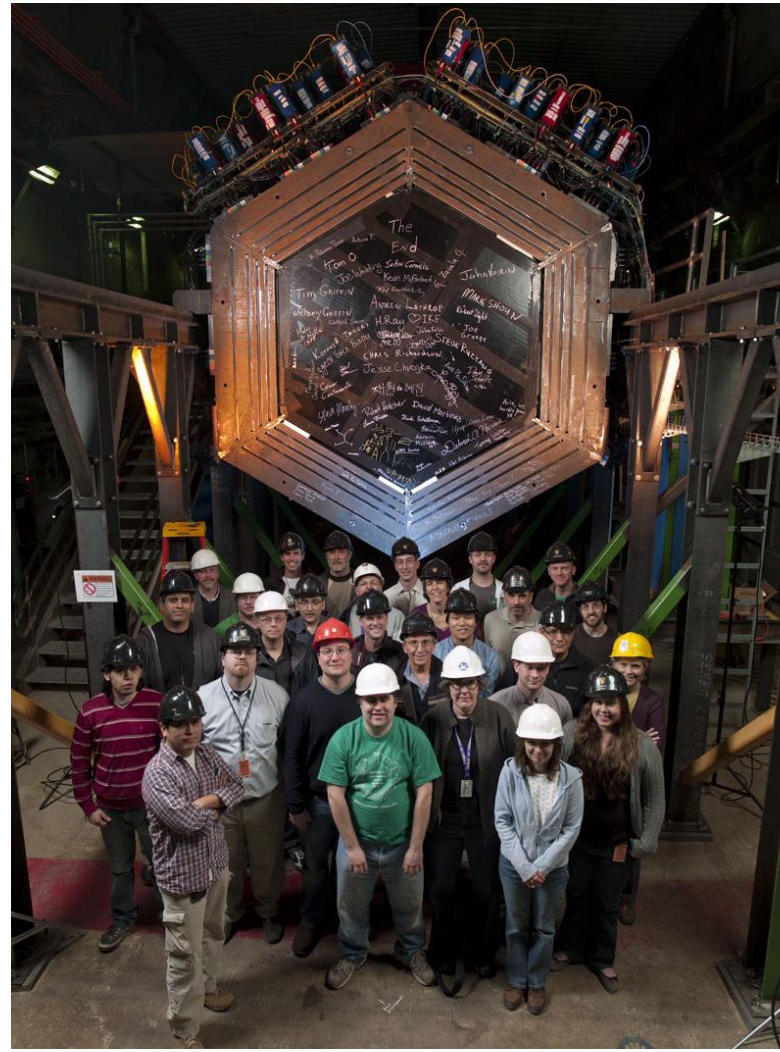
Steven Manly, University of Rochester
Representing the MINERνA collaboration

Fermilab Users' Meeting
June 12-13 , 2012

What is MINERνA?

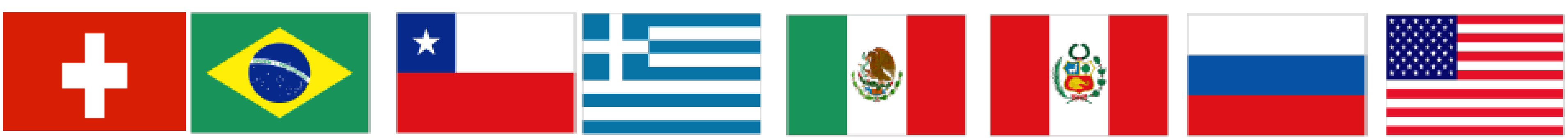
Main Injector ExpeRiment ν-A

- A high resolution detector designed to study neutrino reactions on a variety of nuclei in detail (in the $E_\nu \approx 1$-10 GeV region)
- Sited upstream of the MINOS near detector in the NuMI beam at Fermilab



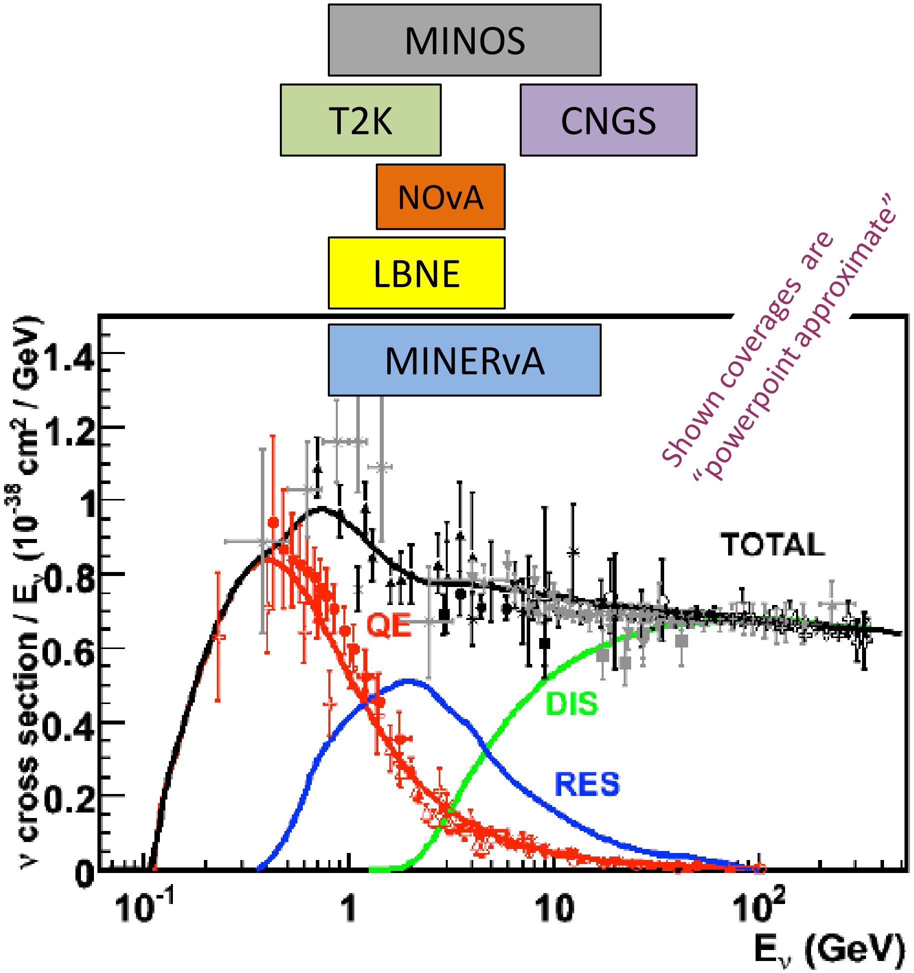
The MINERνA Collaboration
Main Injector ExpeRiment ν-A

University of Athens
University of Texas at Austin
Centro Brasileiro de Pesquisas Físicas
Fermilab
University of Florida
University of Geneva
Universidad de Guanajuato
Hampton University
Inst. Nucl. Res. Moscow
Mass. Col. Lib. Arts
Northwestern University
Otterbein University
Pontificia Universidad Catolica del Peru
University of Pittsburgh
University of Rochester
Rutgers University
Tufts University
University of California at Irvine
University of Minnesota at Duluth
Universidad Nacional de Ingeniería
Universidad Técnica Federico Santa María
William and Mary



A collaboration of about 80 nuclear and particle physicists from 22 institutions

ν interaction physics



J.A. Formaggio and G.P. Zeller, "From eV to EeV: Neutrino Cross Sections Across Energy Scales", to be published in Rev. Mod. Phys. 2012

- ν oscillation experiments need to understand ν reactions on nuclear targets in the 1-10 GeV region
- Situation with data … well …

It's a little bit yucky.

–Allison Manly at age 3

  - 20-50% uncertainties, depending on process
- The nuclear physics not well understood

NuMI Beamline

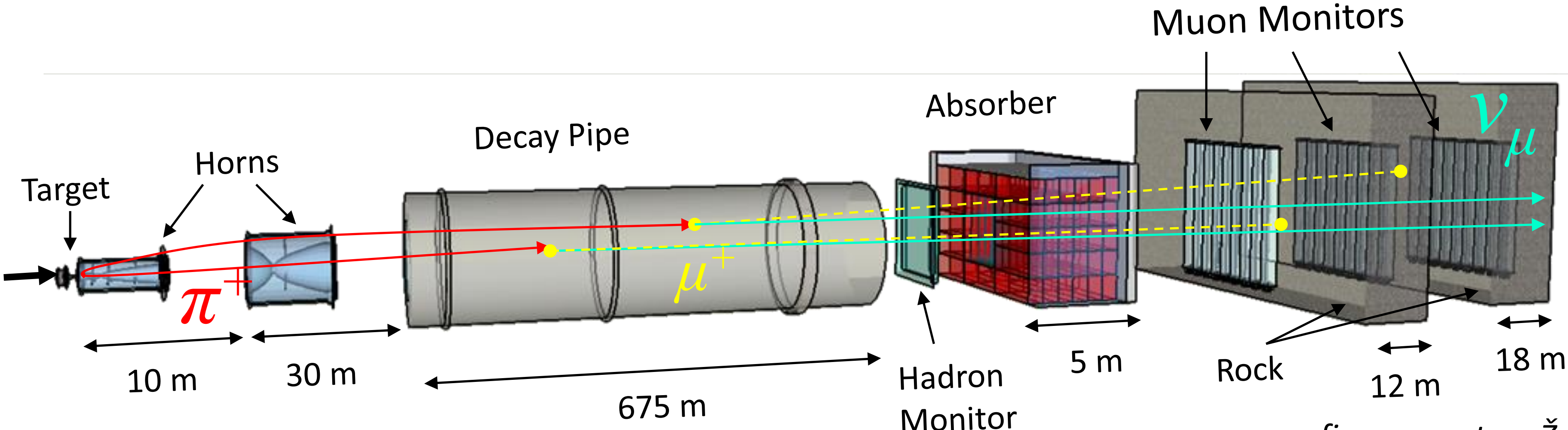
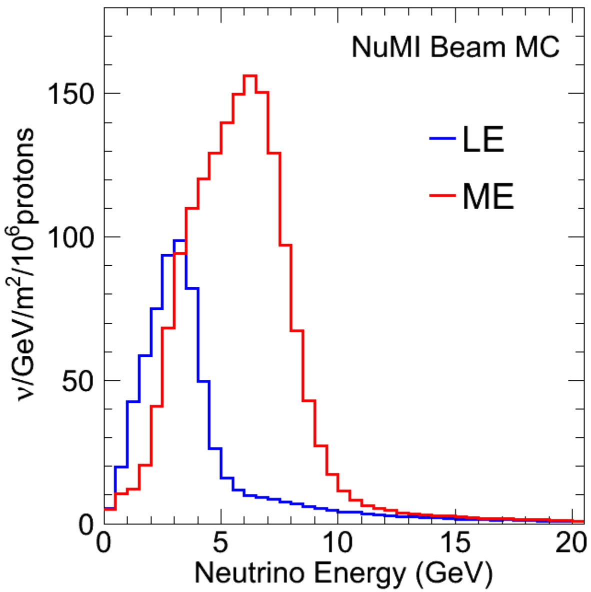
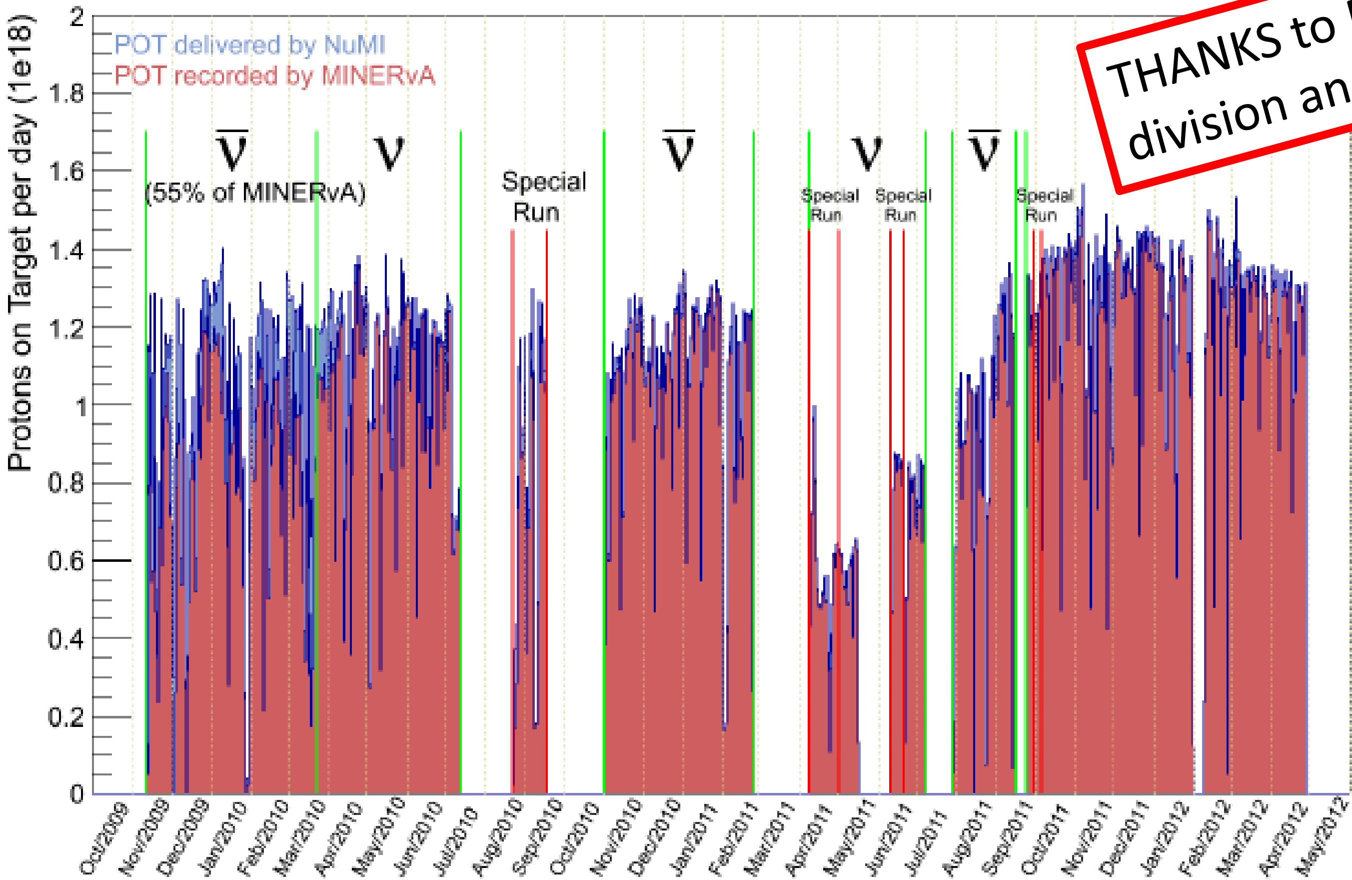


figure courtesy Ž. Pavlović



- 120 GeV P Beam → C target ⟶ π^{+-} & K^{+-}
- ~35x10^{12} protons on target (POT) per spill at 120 GeV with a beam power of 300-350 kW at ~0.5 Hz
- 2 horns focus π^+ and K^+ only (or π^- and K^-)
- Mean E_ν increased by moving target and one horn
- π^+ and K^+ → $\mu^+\nu_\mu$
- Absorber stops hadrons not μ
- μ absorbed by rock, ν ⟶ detector

Without beam, MINERvA's just another pretty detector



THANKS to FNAL accelerator division and NuMI target group!

ν_μ LE
3.98×10^{20} POT

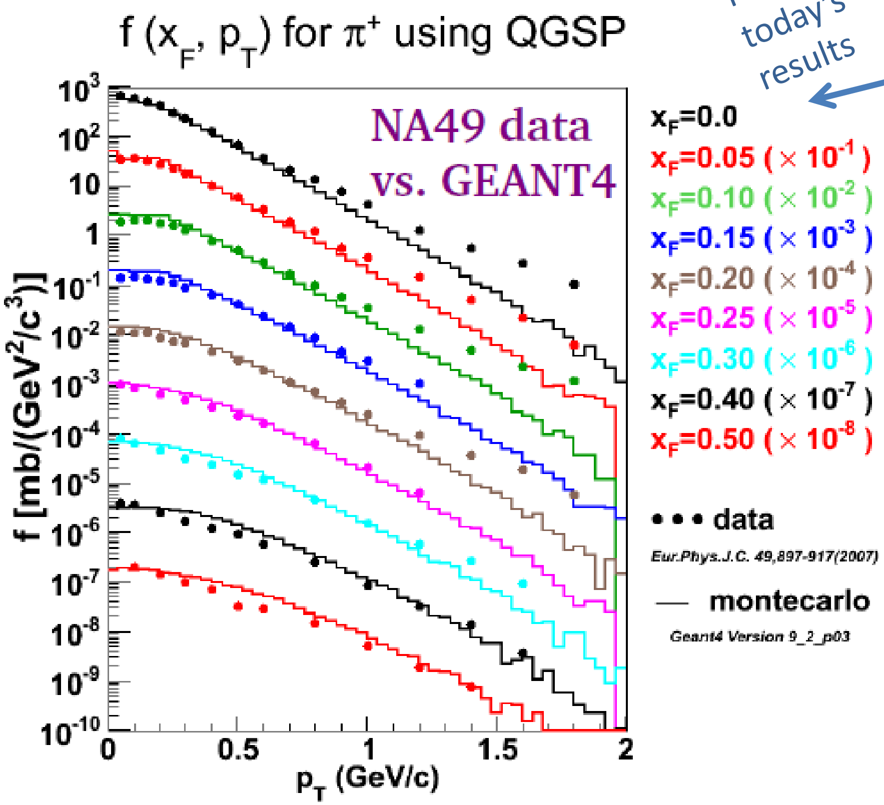
$\bar{\nu}_\mu$ LE
1.7×10^{20} POT

Special runs
4.94×10^{19} POT

Livetime
97.1% MINERvA
93.3% MINOS ND

Numbers for 3/22/2010 – end of run in 4/2012

Flux for these results: GEANT4 + reweighting using external hadron production data from NA49

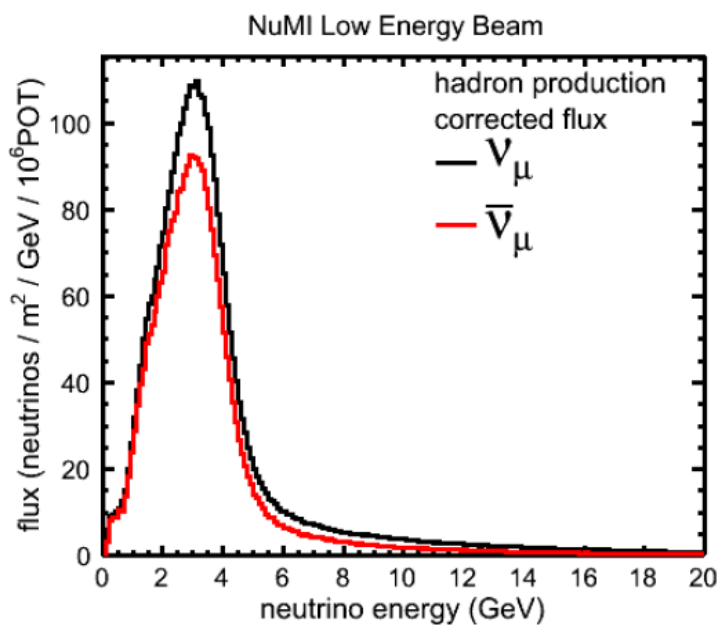


For today's results

Flux tuning handles:

- External hadron production data
- Muon flux from muon monitors
- Data from special runs with different horn current and target position configurations

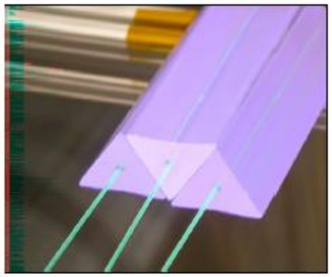
Have data



Uncertainties: 7.5% statistical, 2-10% systematic. Biggest systematic is from reinteractions inside and outside of target.

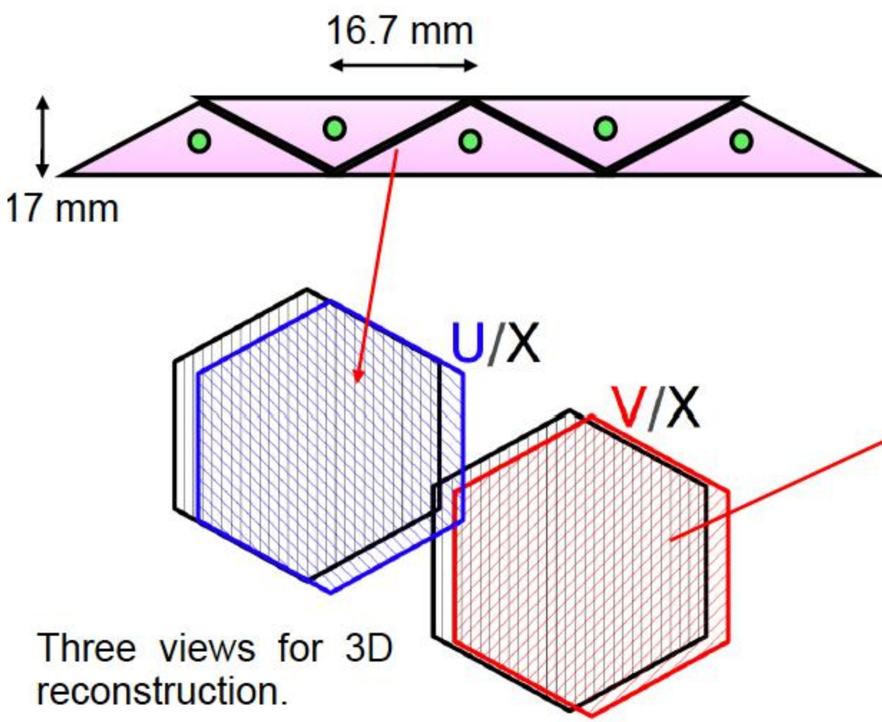
The detector

MINERνA "modules"

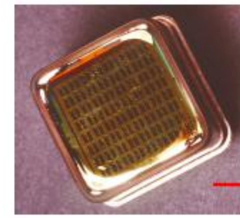


Extruded plastic scintillator
+ wavelength shifters.

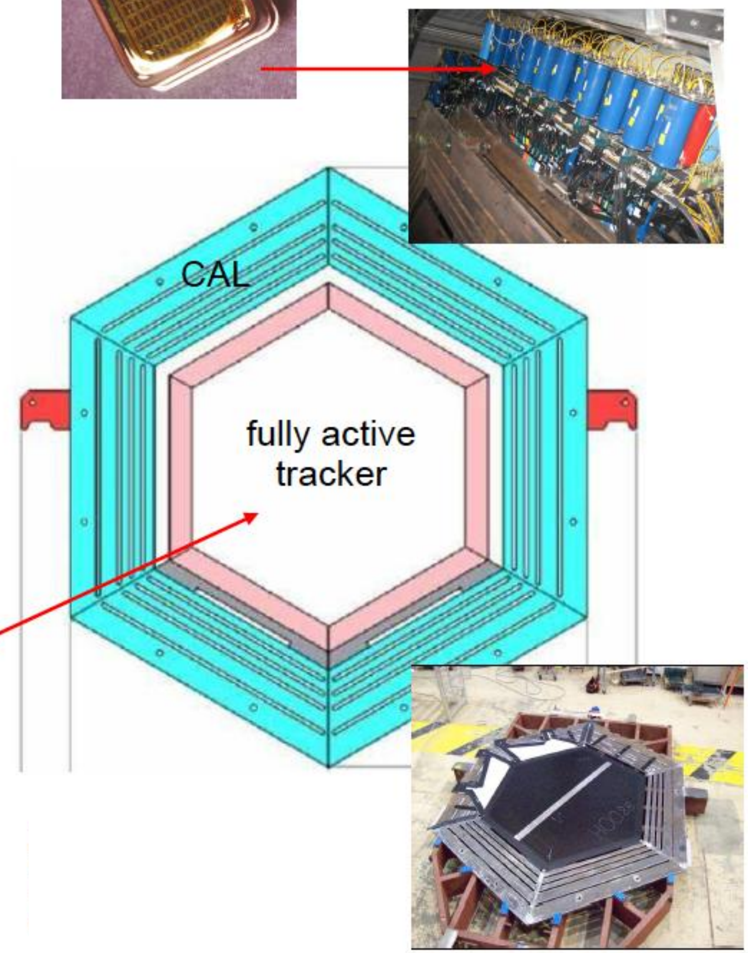
Triangular geometry allows charge sharing for better position resolution.



Three views for 3D reconstruction.

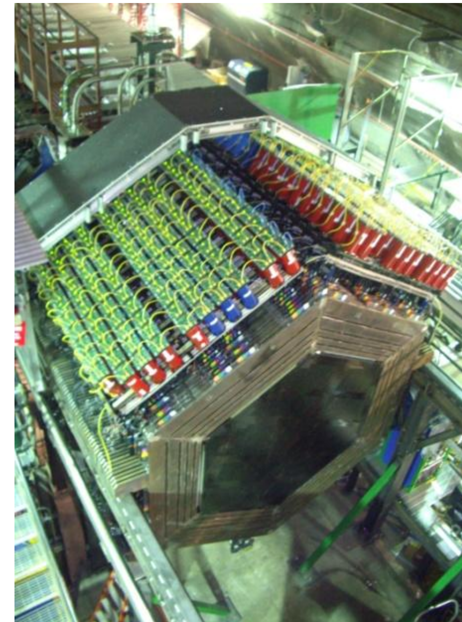


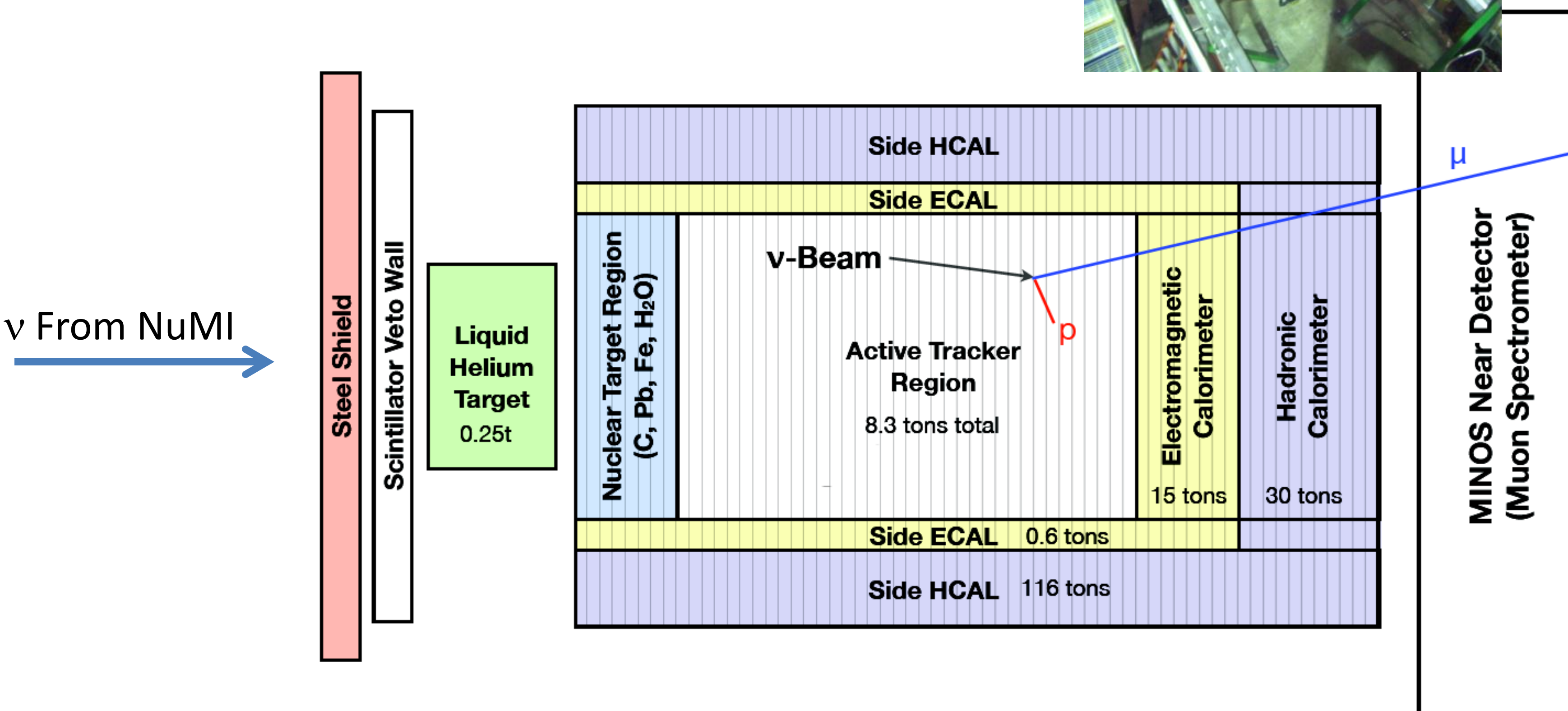
64 anode
PMT's



The detector

- MINERνA received US DOE "CD-3 approval" in Nov. 2007
- Construction of the full detector completed in spring 2010
- He and H_2O targets added in 2011 (funded by an NSF MRI)



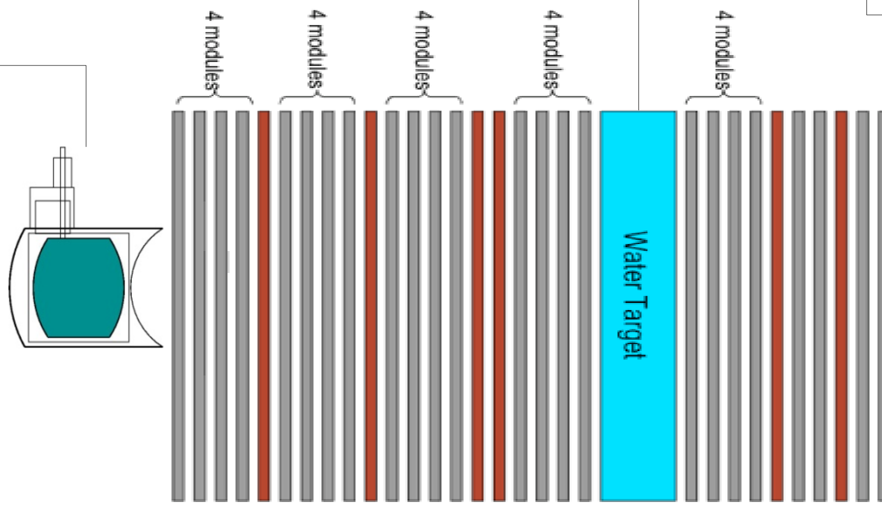


Since the last users meeting

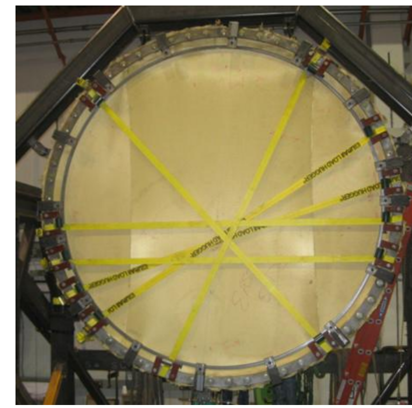
Roof to help shield detector

Nuclear target region

250 kg Liquid He



500kg Water



- Filled and run successfully He target (full and empty)

  ↘ 1.9×10^{20} POT ↘ 5.5×10^{19} POT

- Completed installation /commissioning of veto wall
- Complete design/construction and run with water target
- Constructed protective "roof"
- New cooling system in tunnel

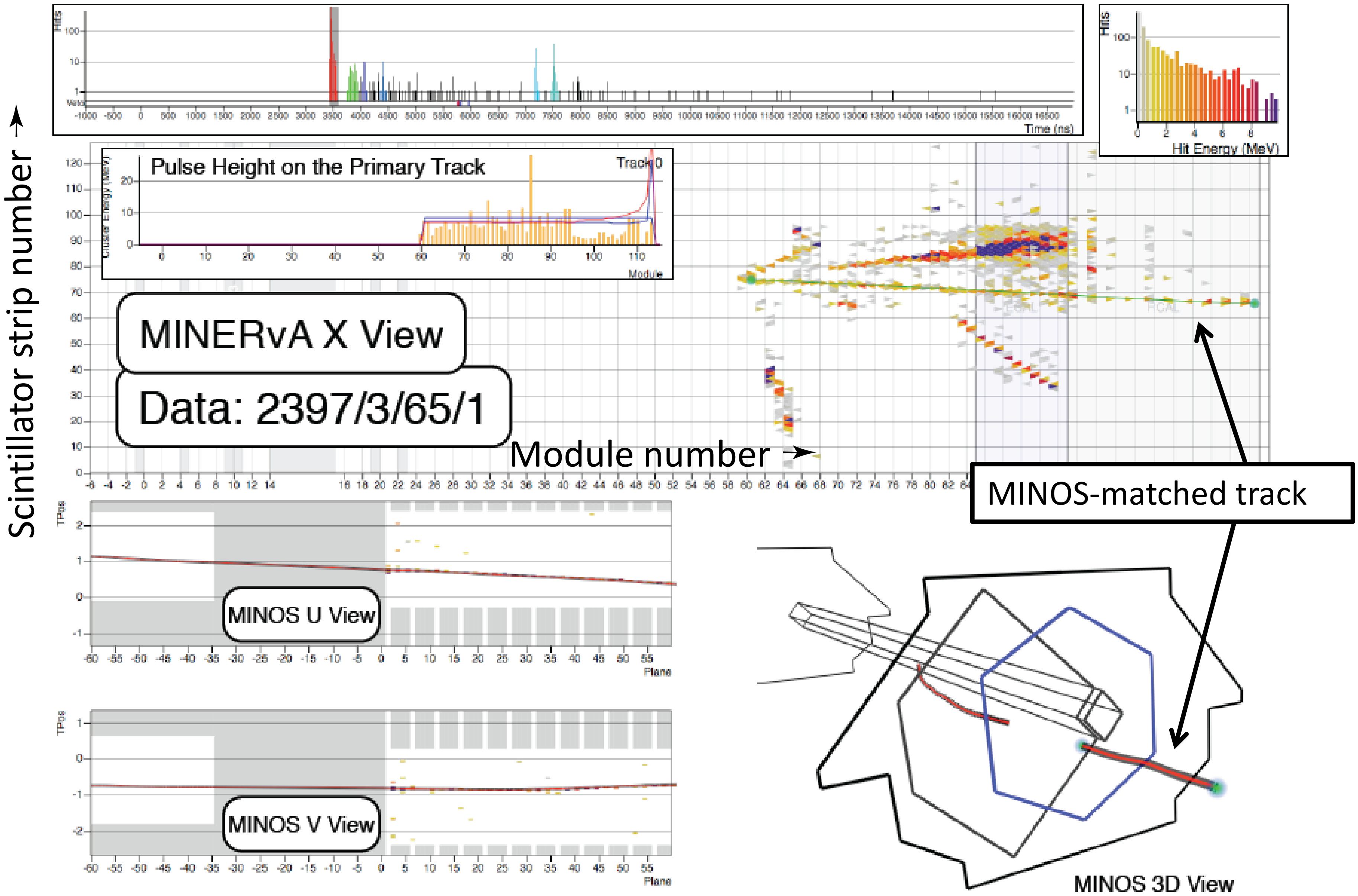
THANKS to PPD (esp. the Mechanical Installation Group) and FESS!

MINERνA μ Spectrometer

Installed and tested long ago ☺

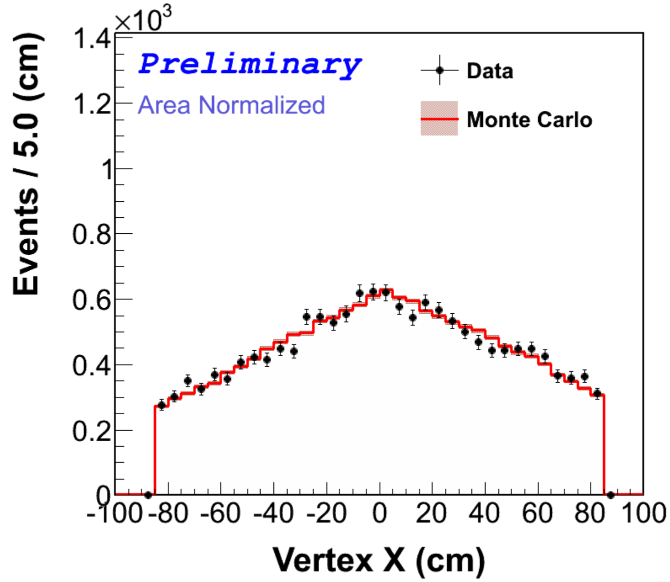
Thanks to the MINOS collaboration for access to their data!

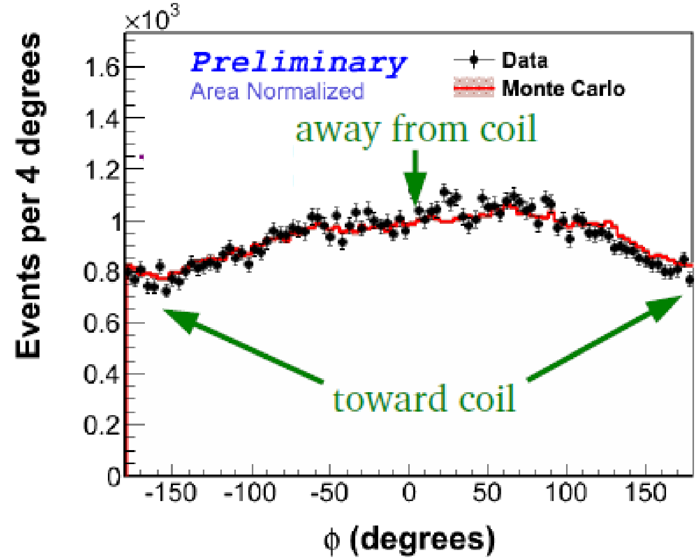
(Also known as the MINOS Near Detector)

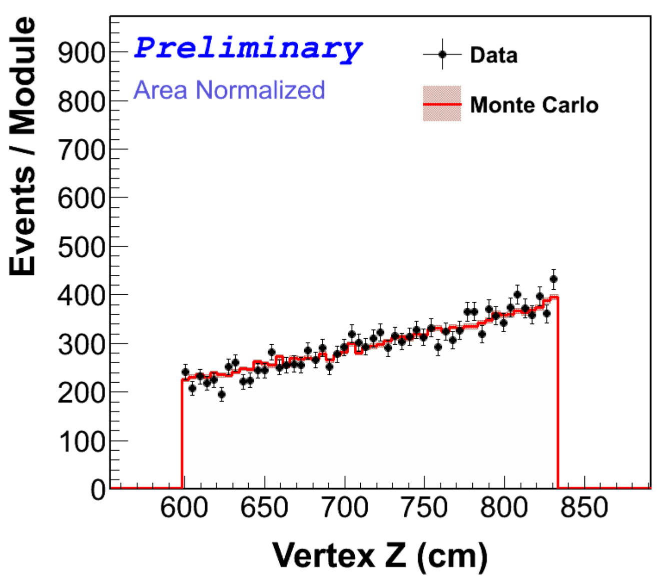


Scintillator strip number →
Pulse Height on the Primary Track
Track 0
MINERvA X View
Data: 2397/3/65/1
Module number →
MINOS-matched track
MINOS U View
MINOS V View
MINOS 3D View
Time (ns)
Hit Energy (MeV)
Module
Plane

MINOS-matching affects acceptance



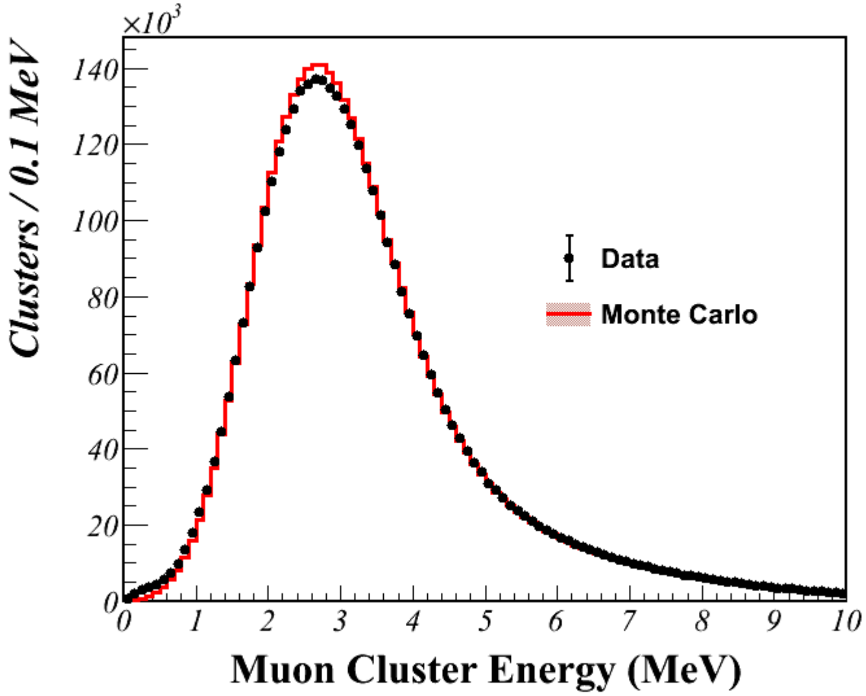


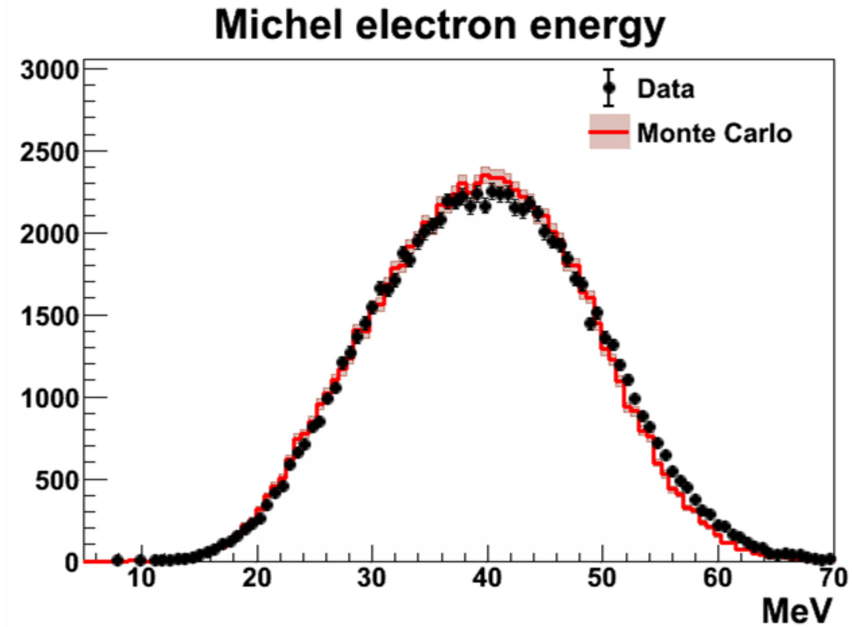


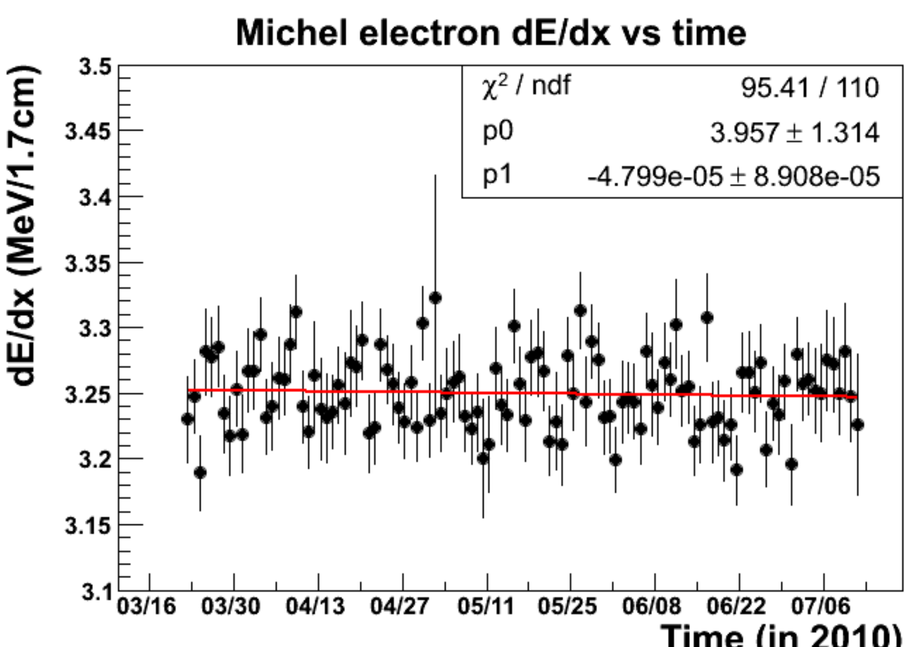
"MINOS-matched" muons
(for CC ν_μ inclusives sample)

- Energy threshold ~2 GeV
- Good angular acceptance up to scattering angles of about 10 degrees, with limit of about 20 degrees
- Bias is complex but well understood

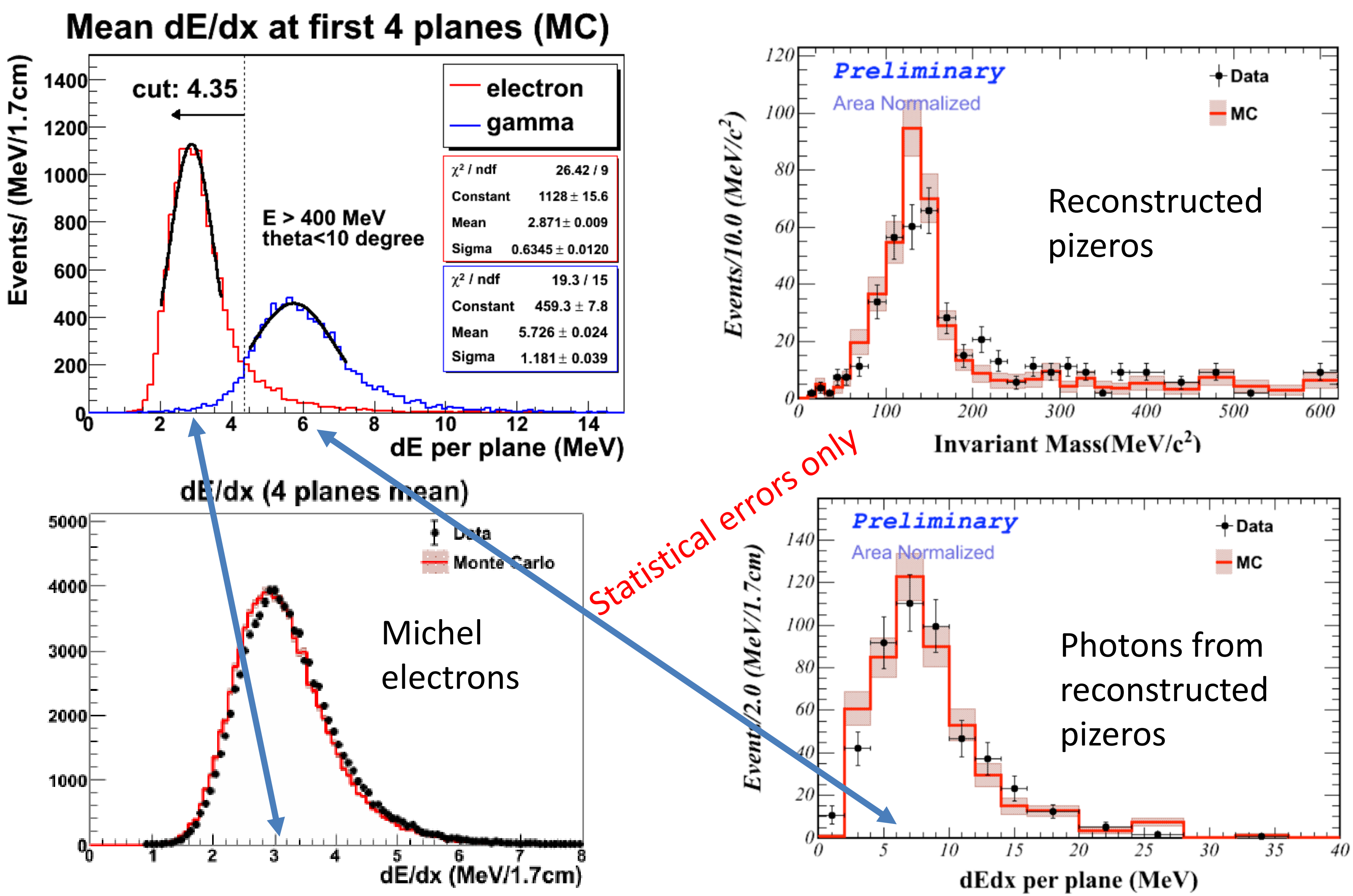
Energy scale and stability





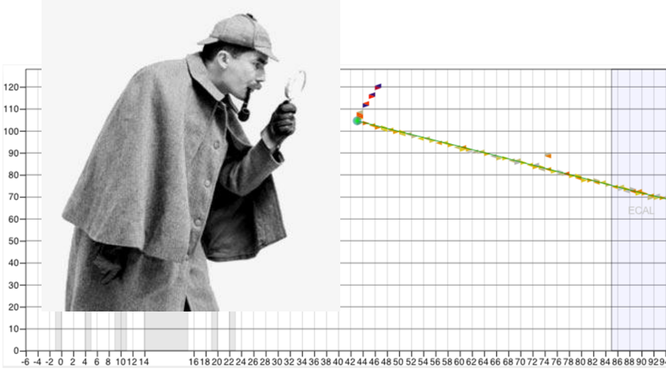


Michels, pizeros and e/γ separation



Physics analysis

- Many analyses underway.
- Only time for a few highlights in this talk.



For more on MINERνA, see the following recent talks and presentations/posters at this meeting:

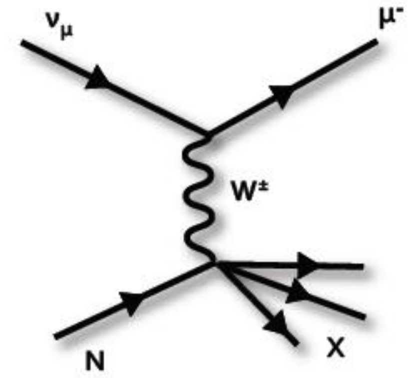
- M. Kordosky, FNAL Wine & Cheese (joint experimental-theoretical seminar), June 1, 2012
- J. Osta, CIPANP, St. Petersburg, June 1, 2012
- New Perspectives talks, this meeting
  - A. Higuera, MINERνA test beam
  - G. Maggi , Pizero reconstruction in neutral current events
  - J. Palomino, CCpizero reconstruction in MINERνA
  - J. Park, Elastic scattering of muon neutrinos from electrons
  - G. Diaz, MINERνA-MINOS muon energy scale
  - J. Chvojka, Status of MINERνA CCQE measurements
- Posters at this meeting
  - B. Tice, Nuclear physics with MINERνA
  - C. Marshall, MINERνA test beam experiment
  - J. Chvojka, Status of MINERνA CCQE measurements

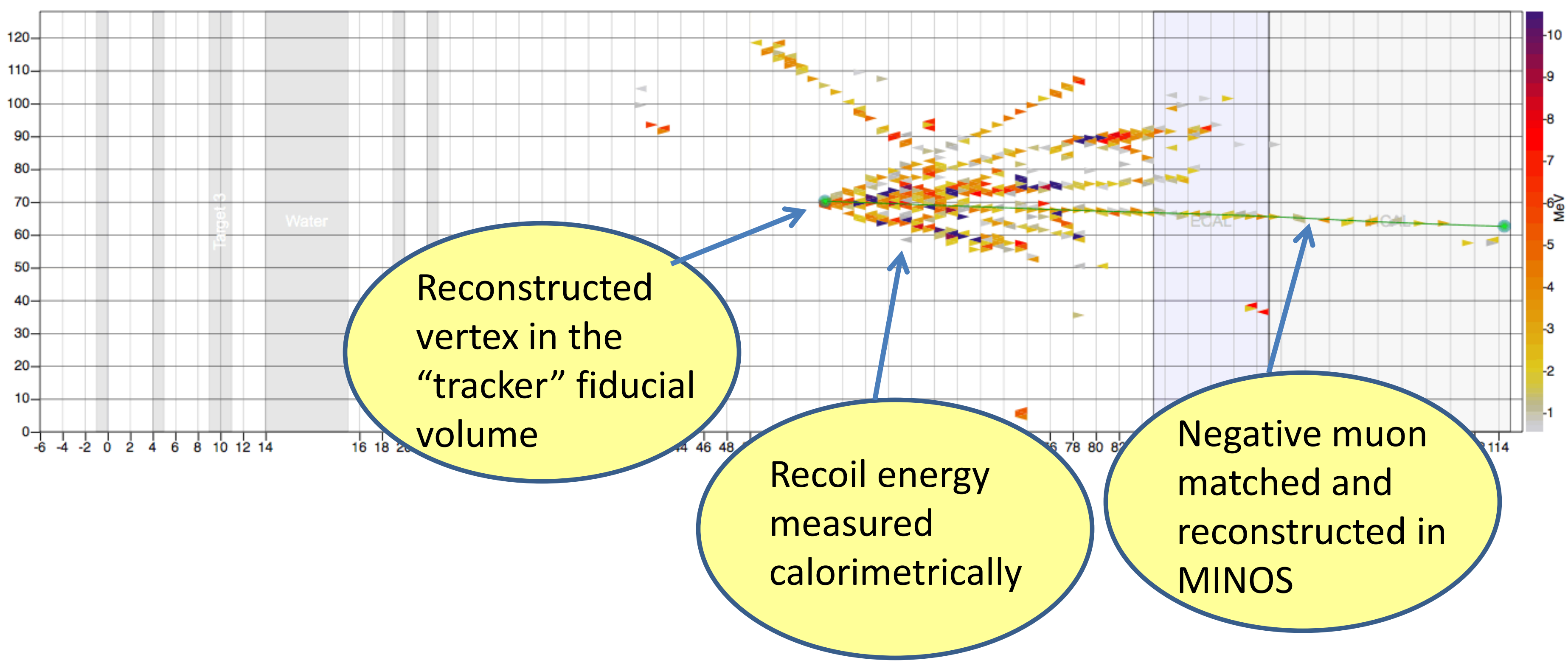
Feynman diagrams from G. Perdue

(charged-current)

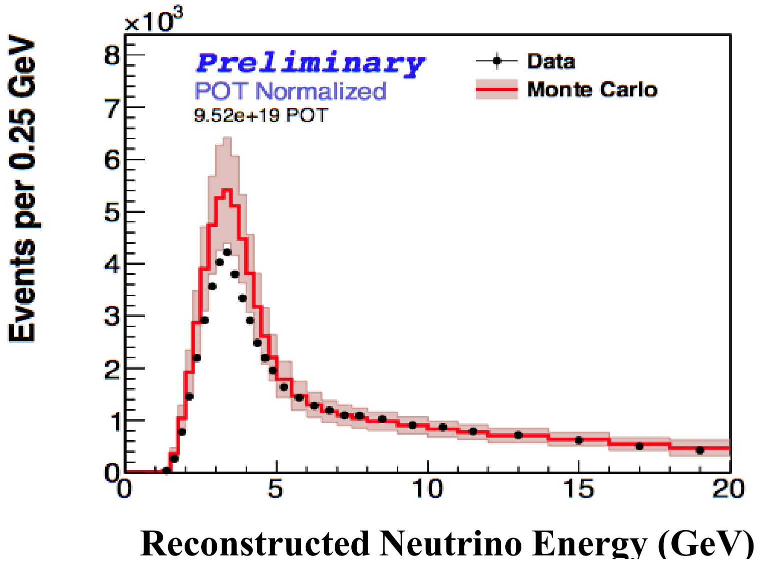
ν_μ CC inclusive analysis

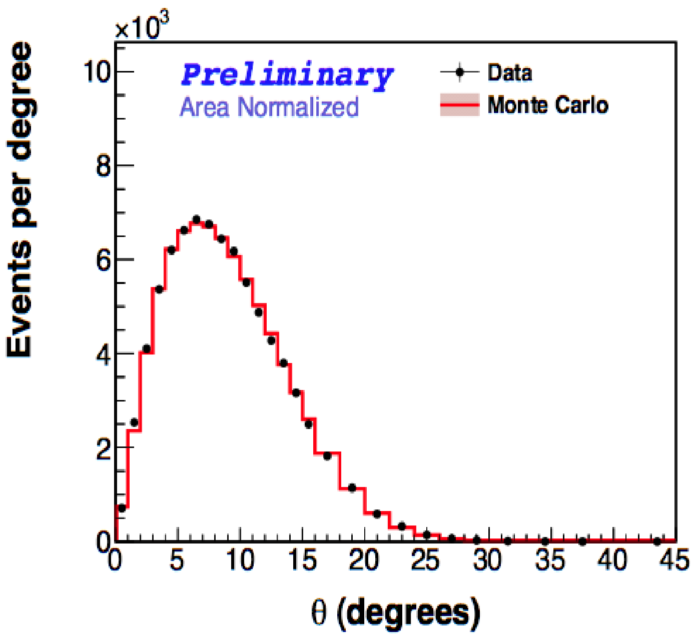
- Uses 25% of available data

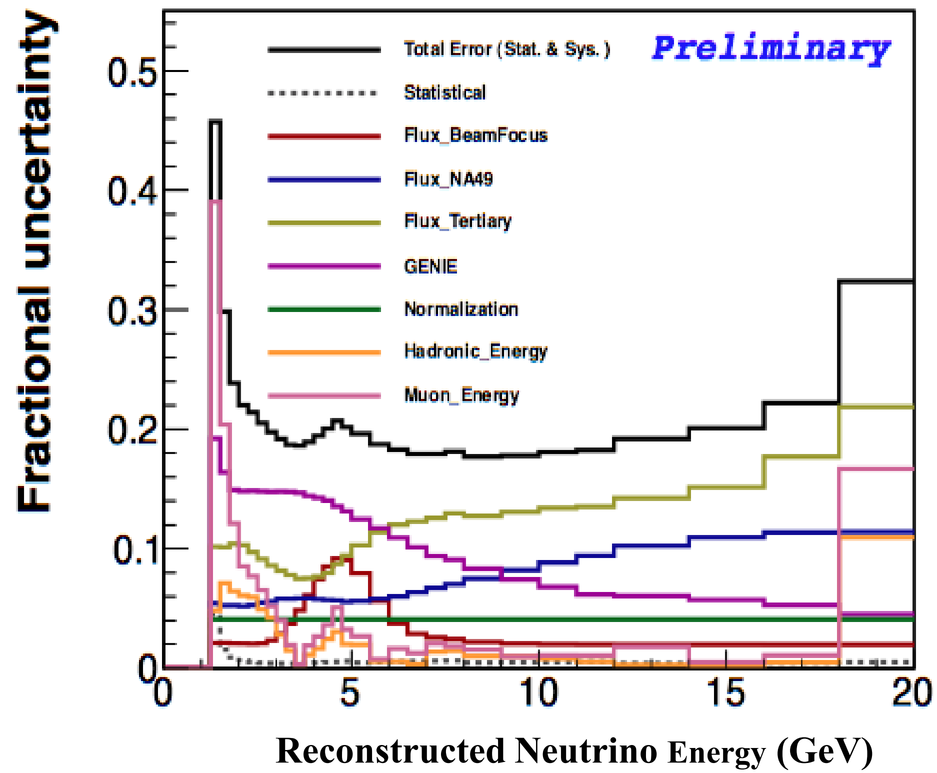




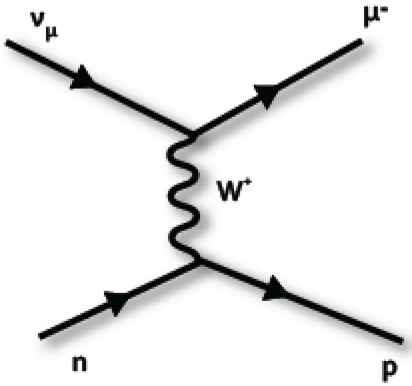
ν_μ CC inclusive analysis – kinematic distributions



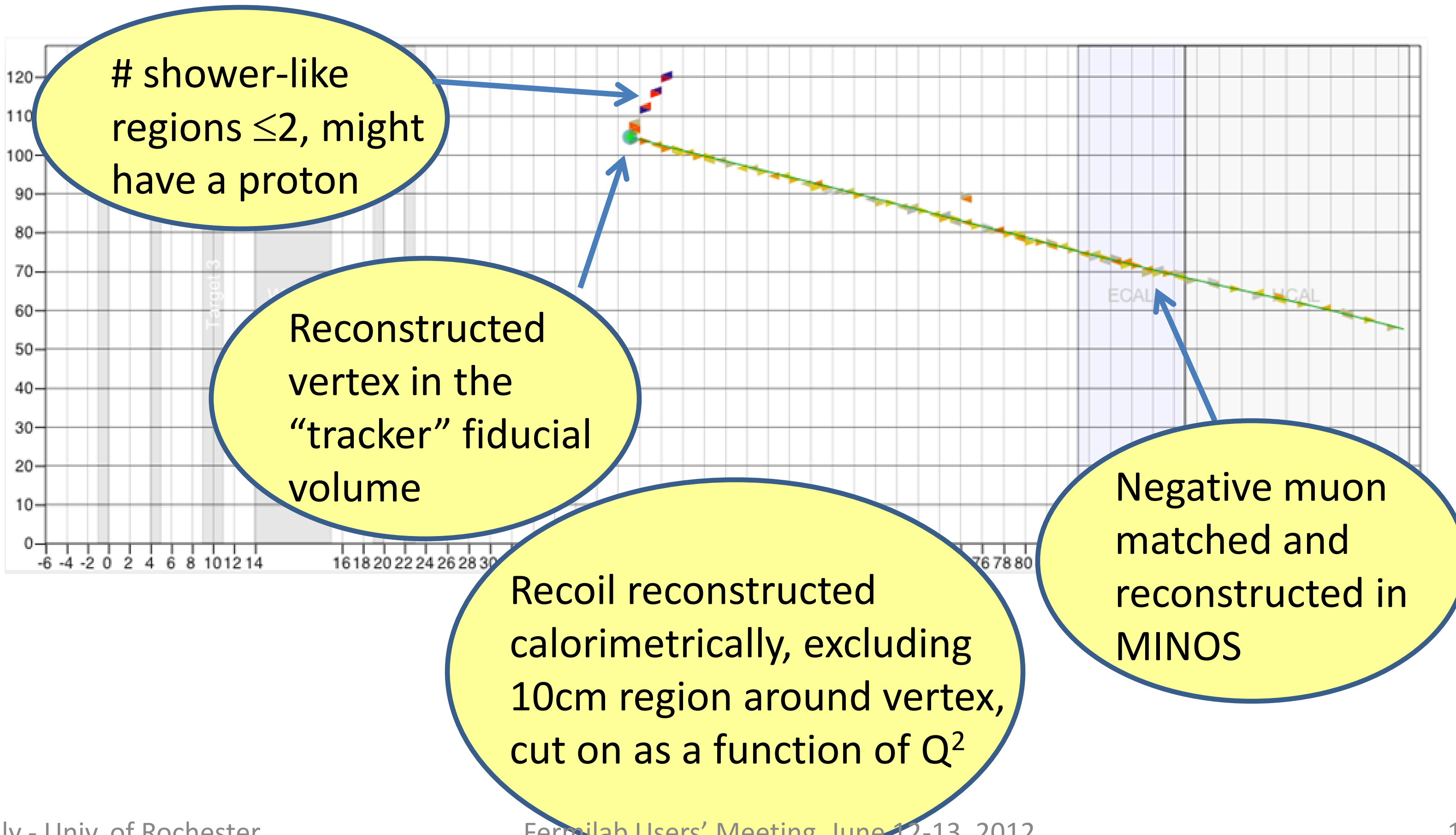




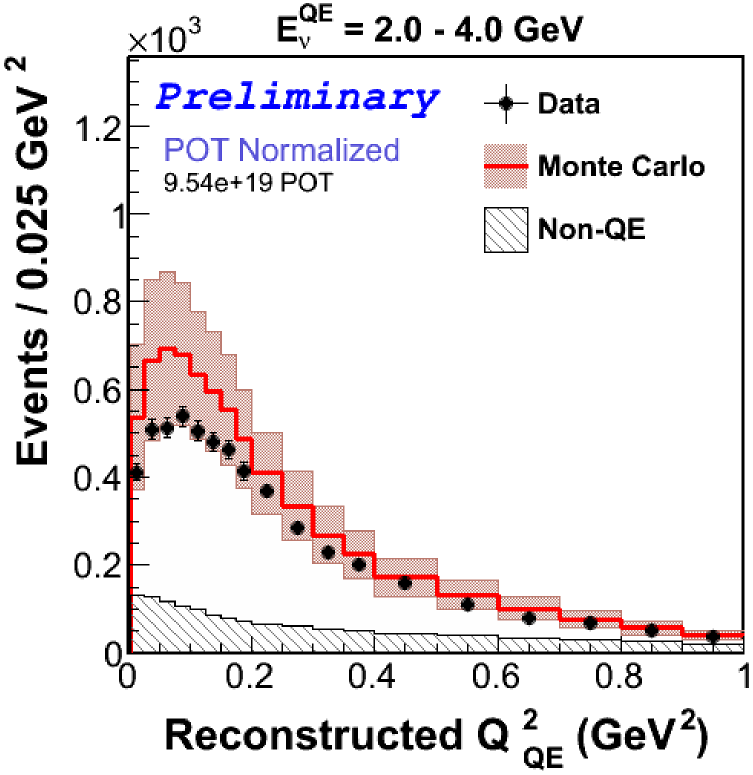
ν_μ CC quasi-elastic analysis

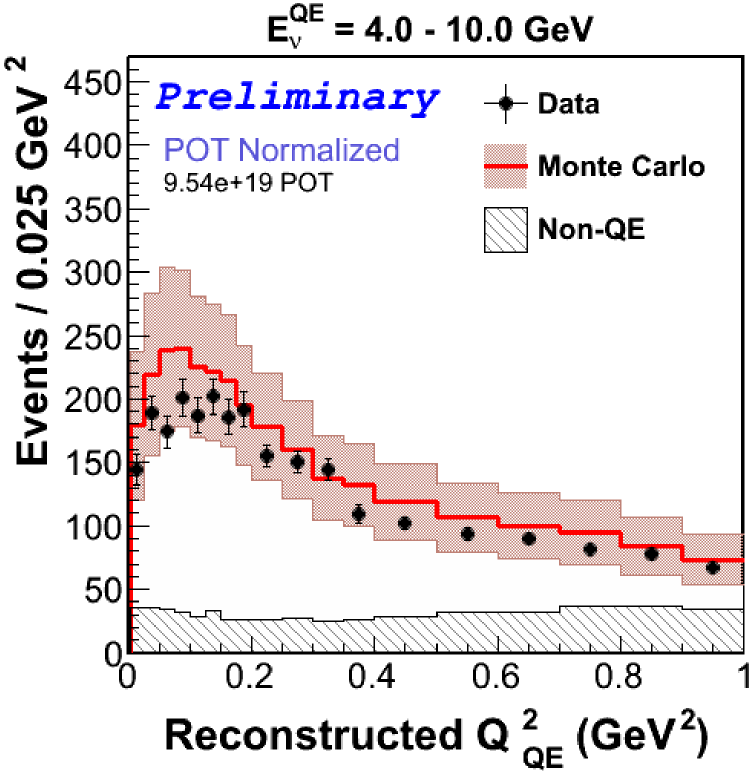


- Uses 25% of available data
- Currently treating as 1-track event in reconstruction



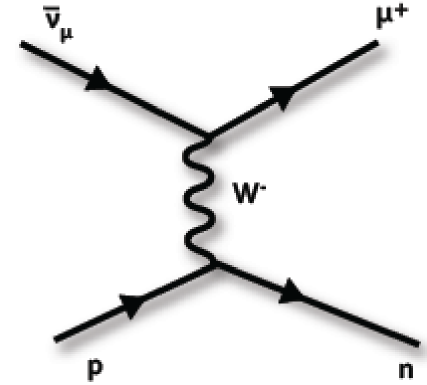
ν_μ CC quasi-elastic analysis

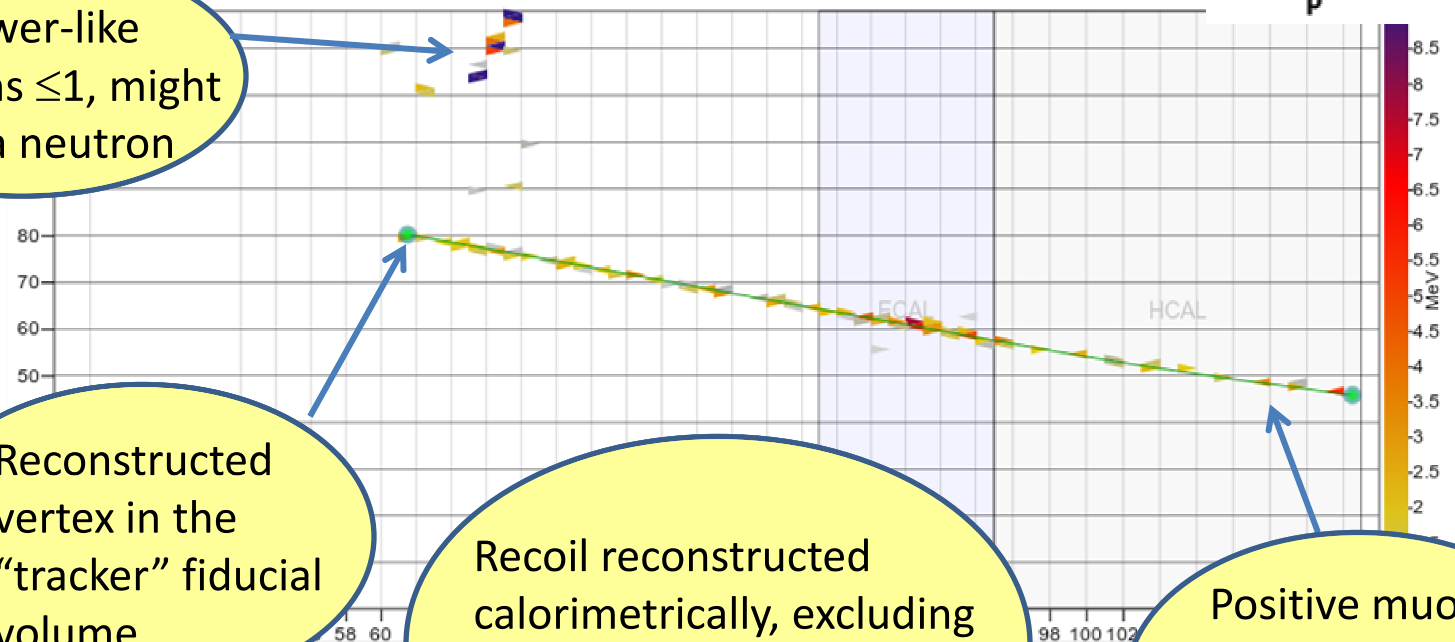




$\overline{\nu}_\mu$ CC quasi-elastic analysis

- Uses 16% of available data
- Data accumulated with partially built MINERvA (55%)





shower-like regions ≤1, might have a neutron

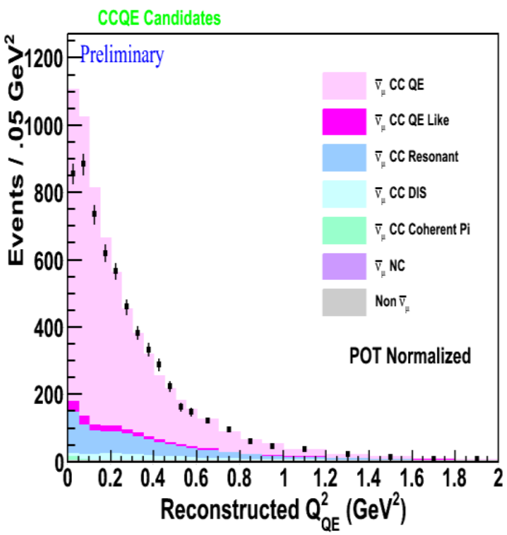
Reconstructed vertex in the "tracker" fiducial volume

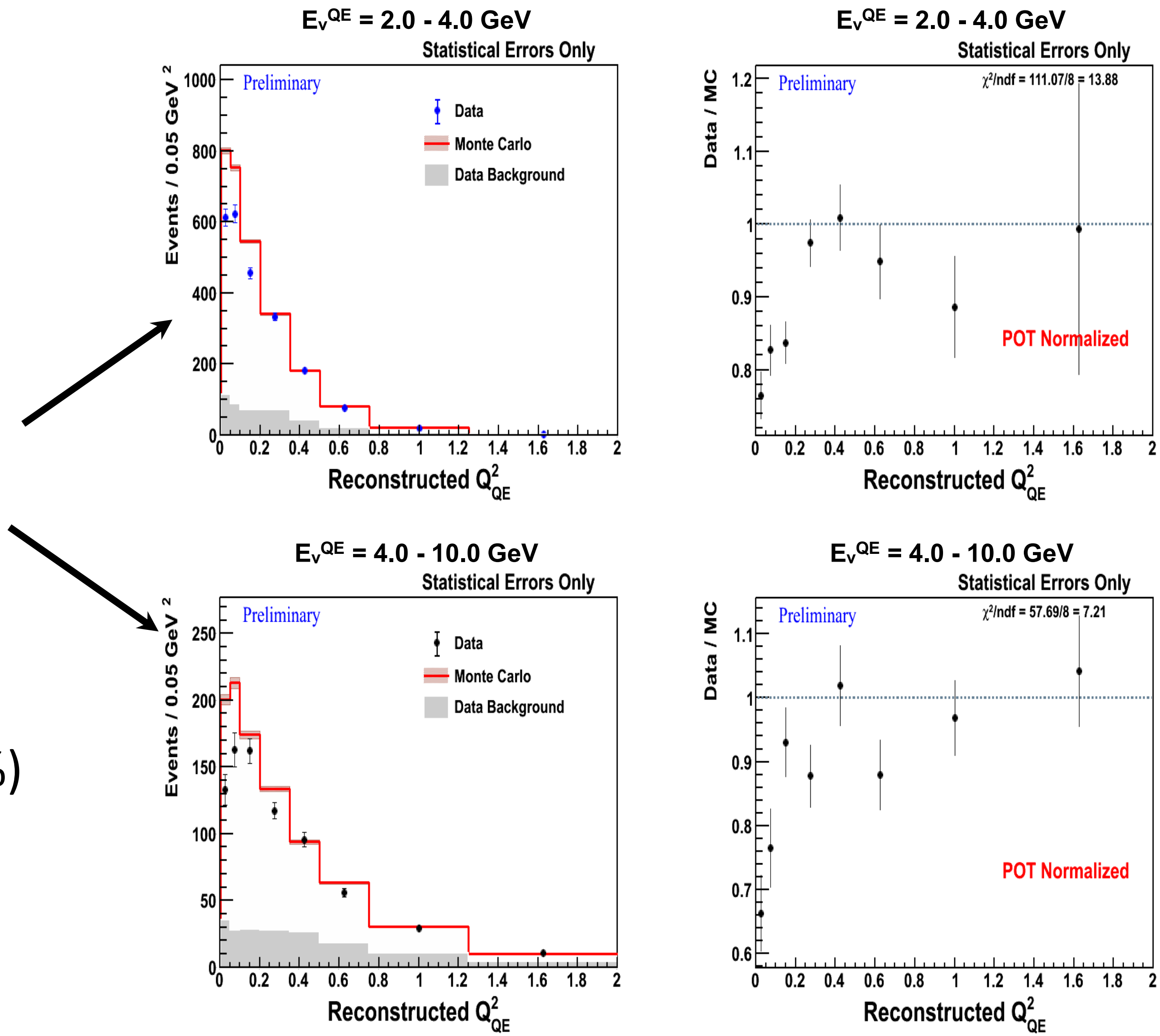
Recoil reconstructed calorimetrically, excluding 10cm region around vertex, cut on as a function of Q^2

Positive muon matched and reconstructed in MINOS

E_ν<10GeV

Four-momentum transfer in bins of anti-neutrino energy

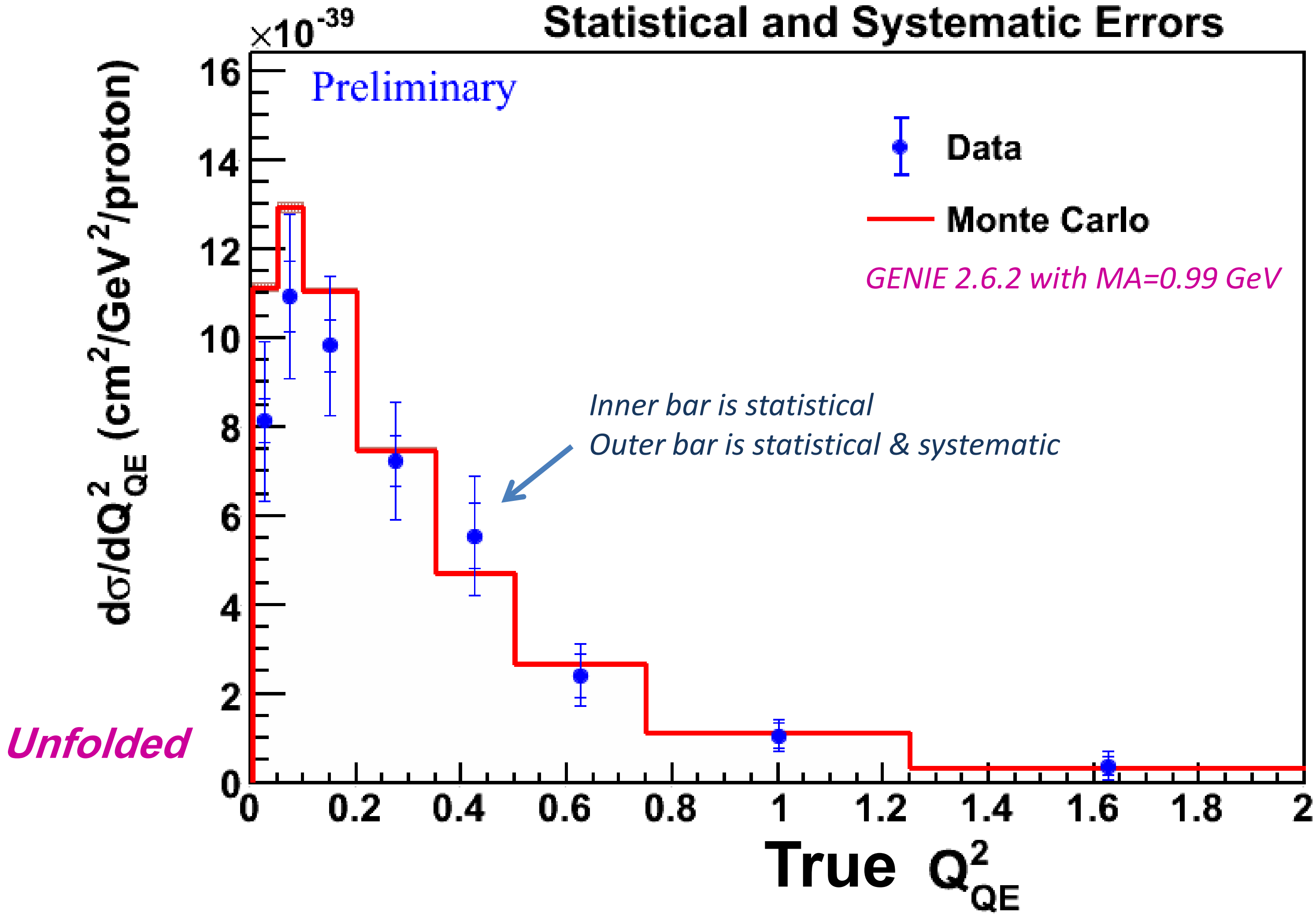




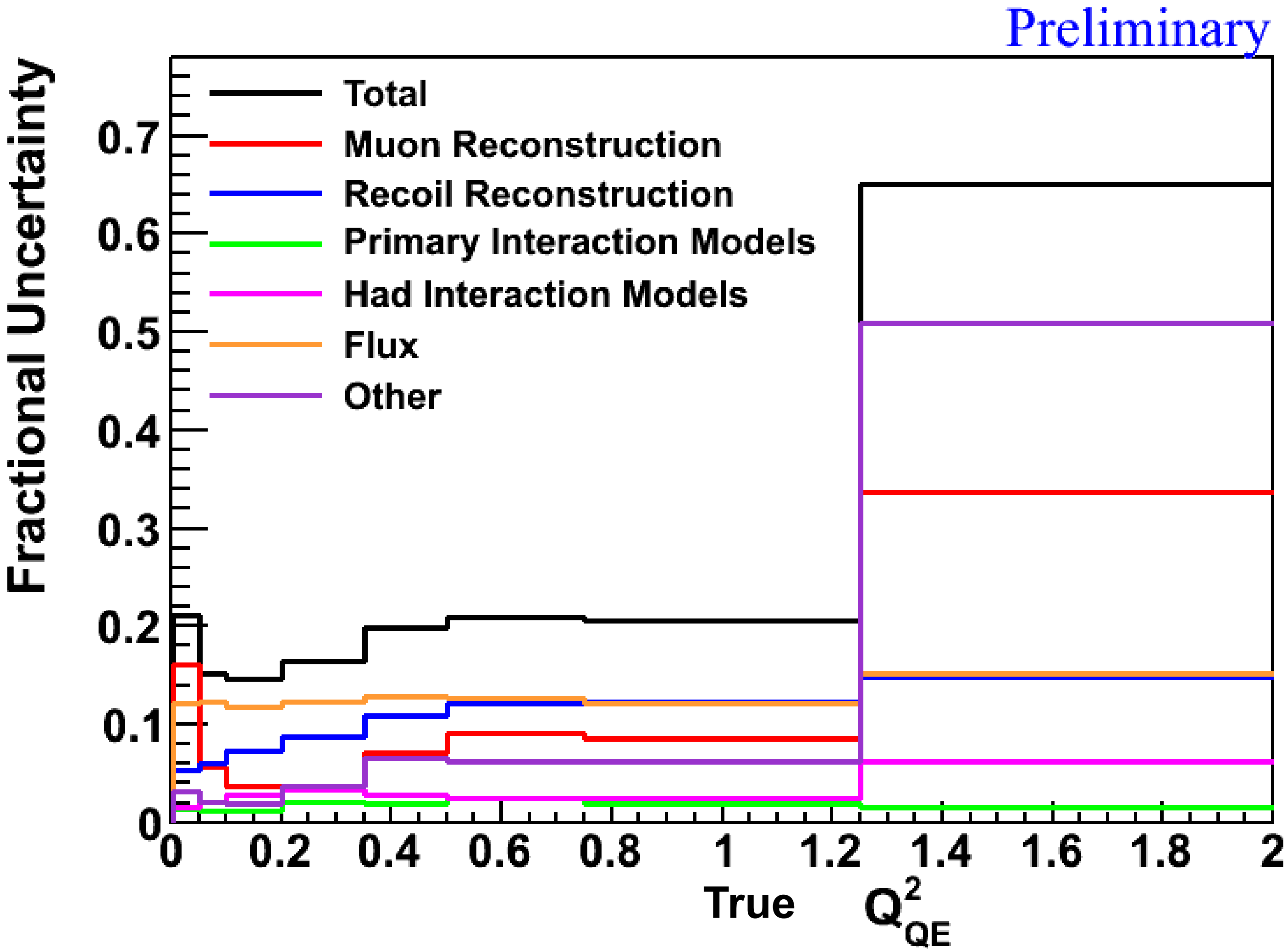
High purity (80%) even before background subtraction

Differential cross-section ($d\sigma/dQ^2$)

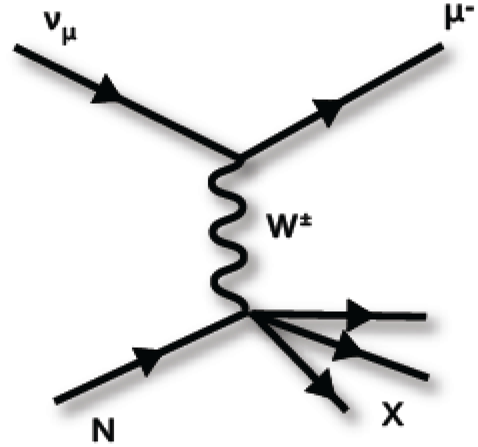
$$\left(\frac{d\sigma}{dQ^2}\right)_i = \frac{1}{\epsilon_i\,(\Phi T)\,\Delta Q_i^2} \times \sum_j \left(M_{ij}\left(N_{\mathrm{data},j} - N^{\mathrm{bkdg}}_{\mathrm{data},j}\right)\right)$$



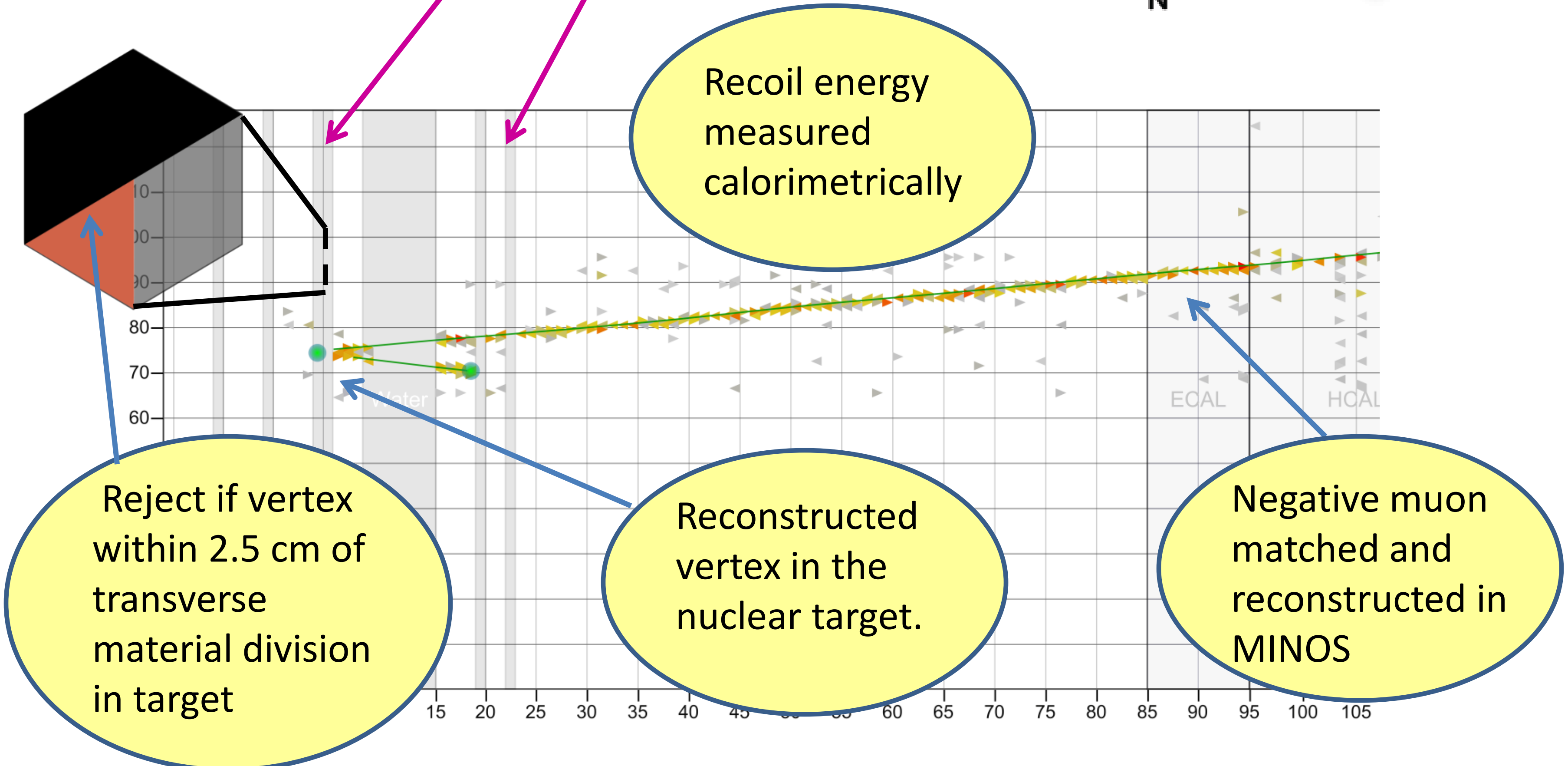
dσ/dQ^2 Systematic Uncertainties on *Data*



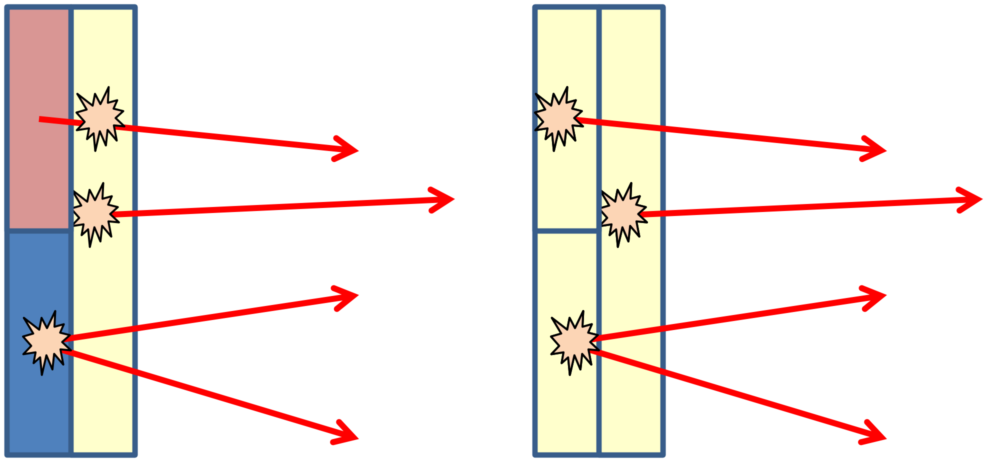
ν_μ CC inclusive analysis on nuclear targets



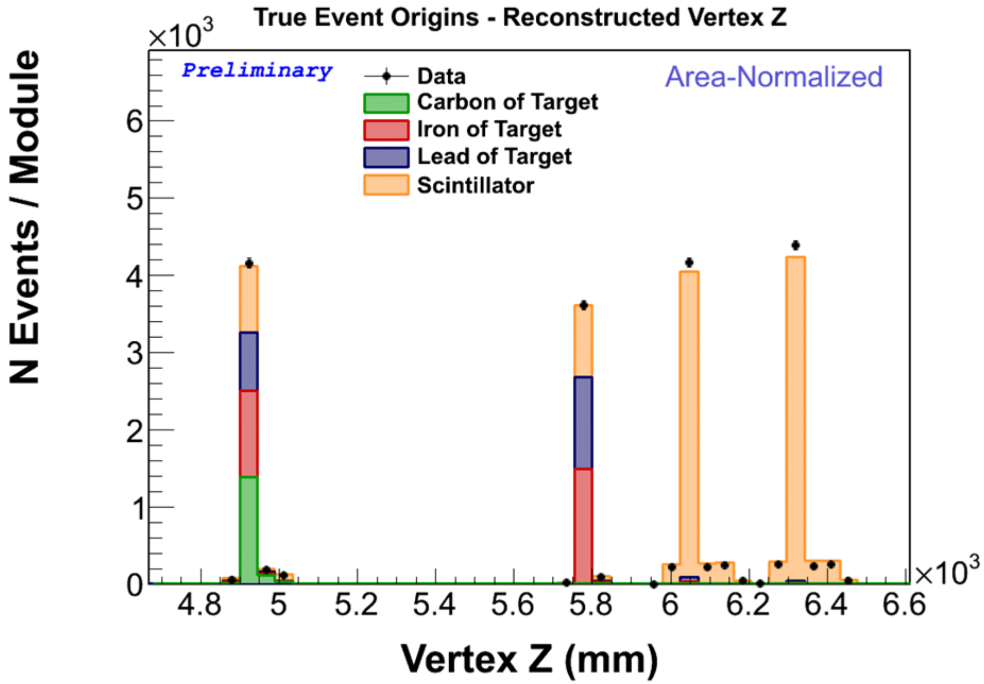
- Uses 25% of available data
- Used only targets "3" and"5" (gotta start somewhere)
- Fe, Pb, C



ν_μ CC inclusive analysis on nuclear targets

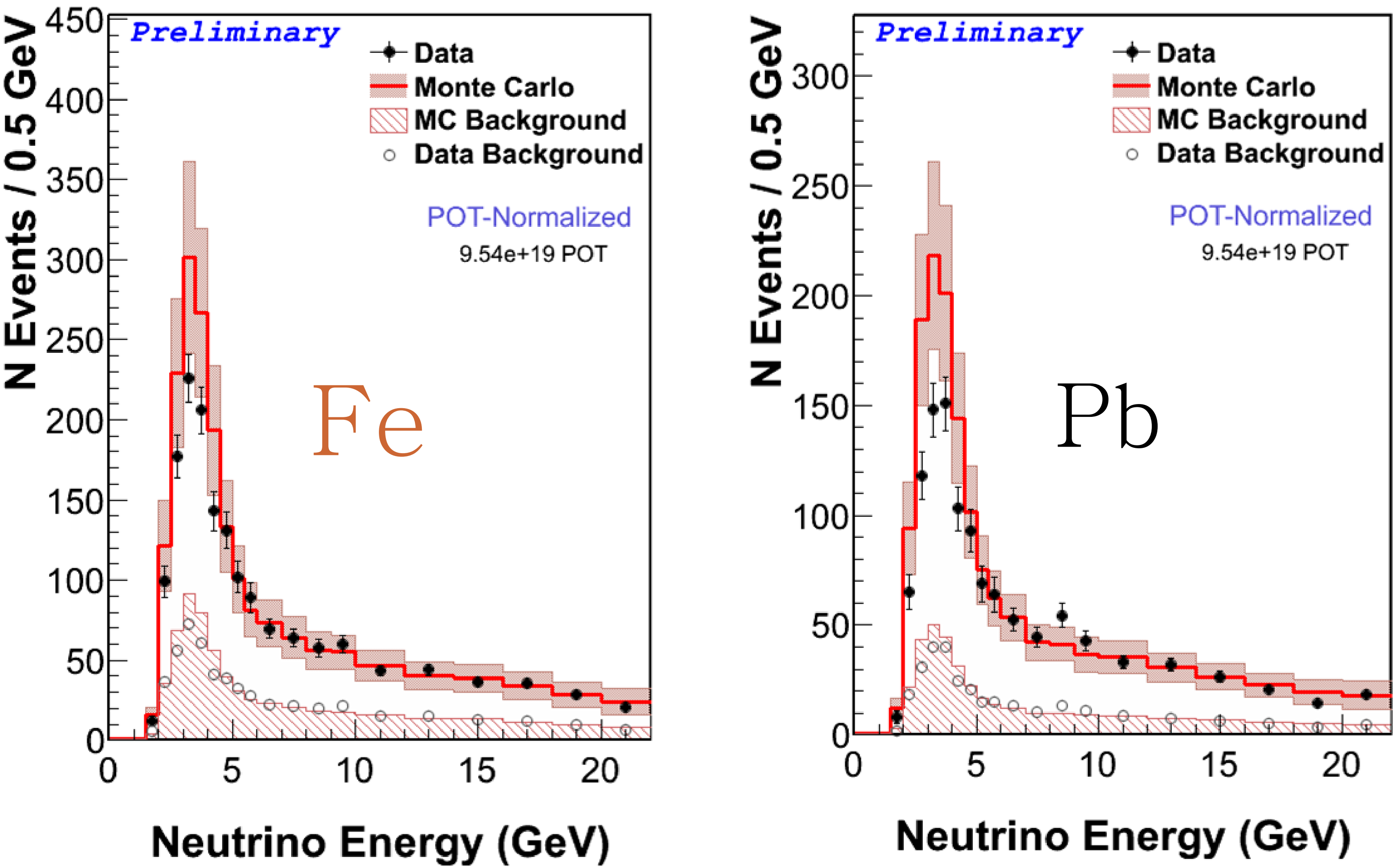


Use plastic "faux" targets in a data-driven analysis to estimate backgrounds, reduce the flux uncertainty, and cancel (largely) the acceptance and efficiency corrections.



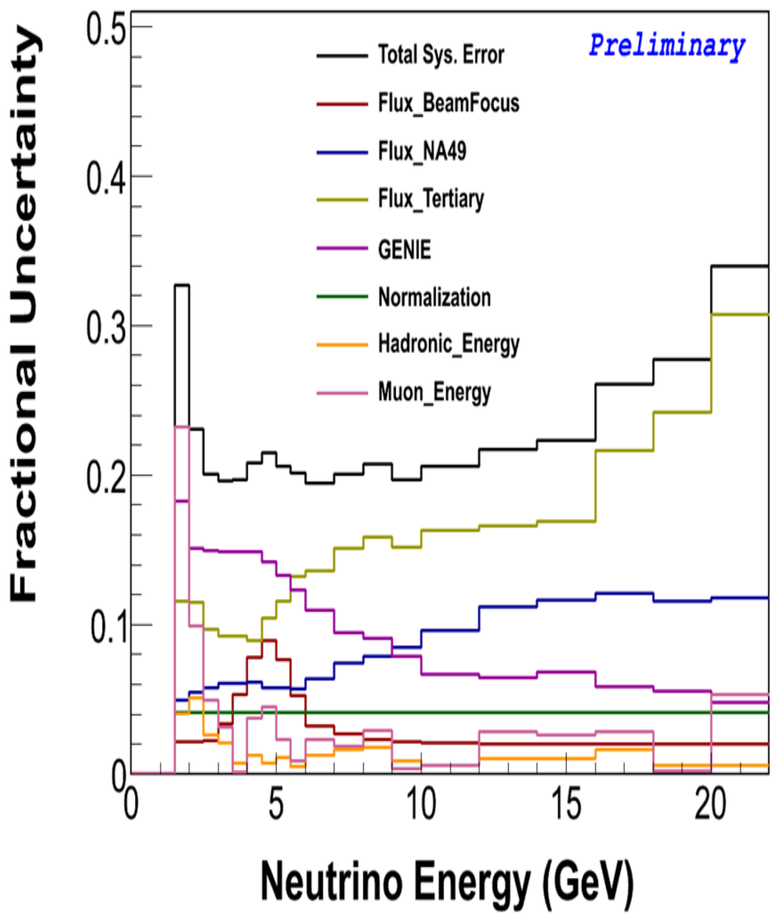
$$\frac{\left(\dfrac{\frac{d\sigma^{Pb}}{dX_i}}{\frac{d\sigma^{CH}}{dX_i}}\right)}{\left(\dfrac{\frac{d\sigma^{Fe}}{dX_i}}{\frac{d\sigma^{CH}}{dX_i}}\right)}$$

ν_μ CC inclusive analysis on nuclear targets

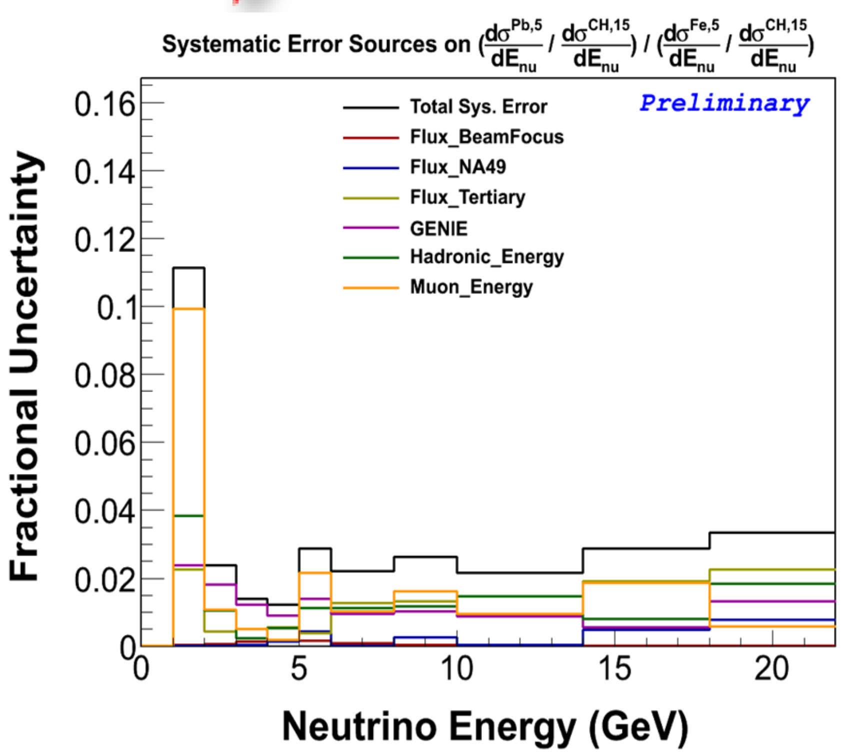


ν_μ CC inclusive analysis on nuclear targets

Iron

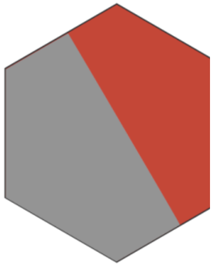


Lead/Iron

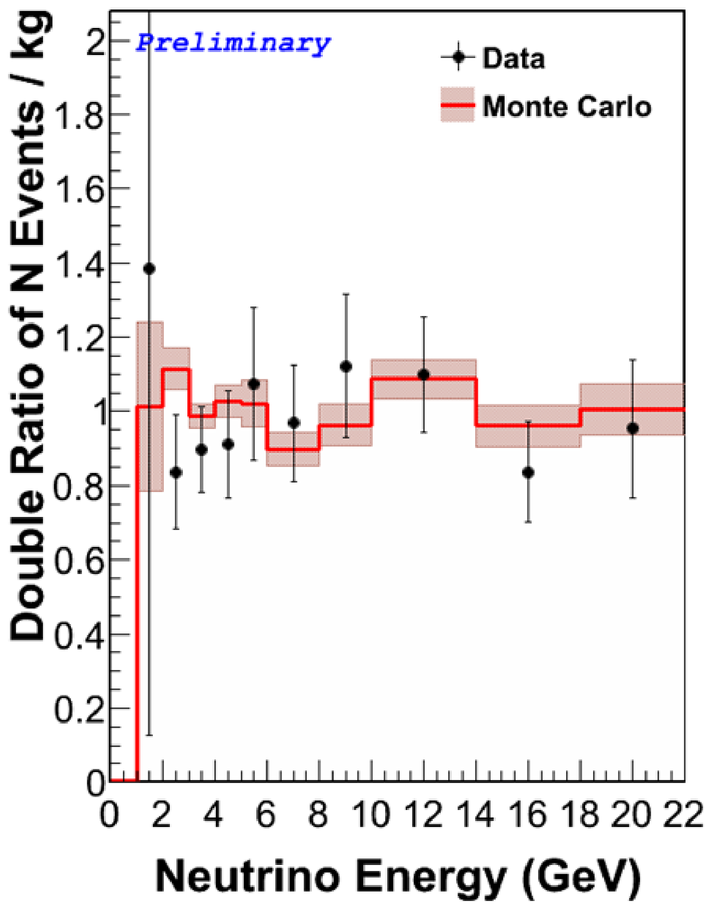


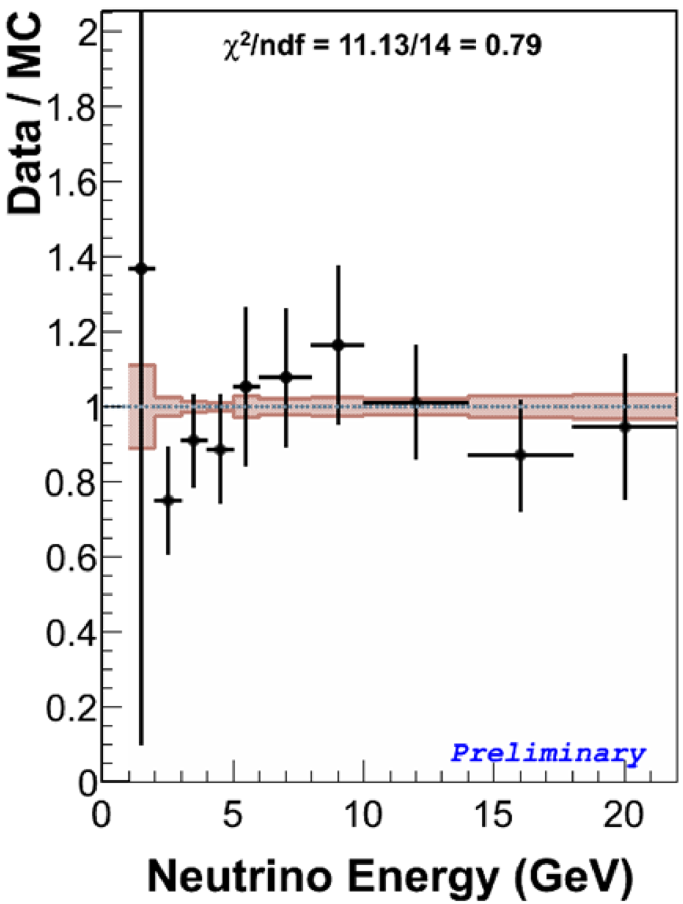
ν_μ CC inclusive analysis on nuclear targets

Lead of Target 5/Iron of Target 5



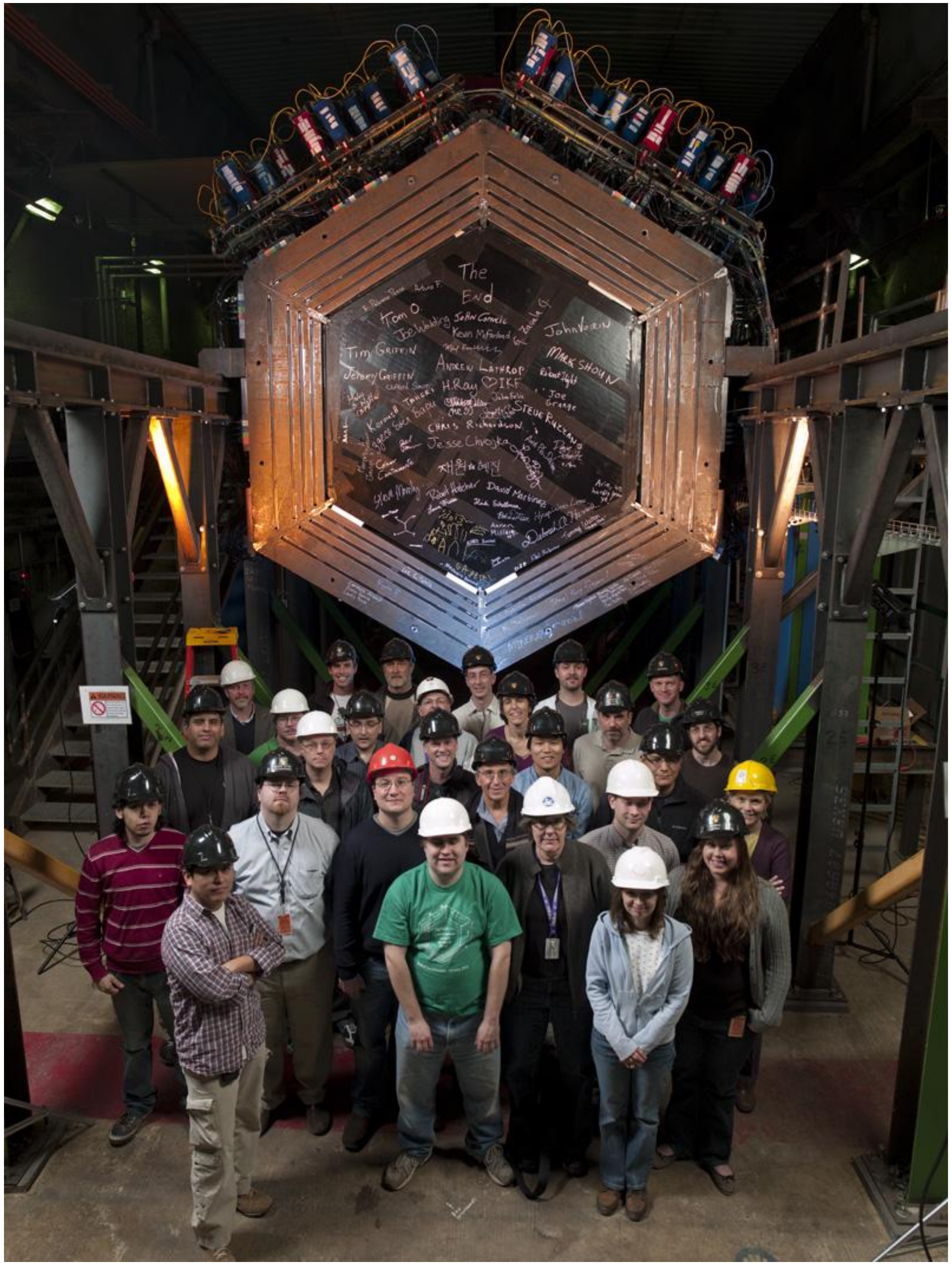
(Pb/CH)/(Fe/CH)





Conclusions

- A big thank you to FNAL/accelerator division/NuMI target group for a successful run in spite of some difficulties … and to MINOS for the muon data.
- MINERνA physics program off to a good start
  - Portfolio of systematic errors explored (significant room for improvement in the future)
- Smallish fraction of data to date included in analyses so far
- Many other analyses underway!



The end?
No. It's more like the beginning.
Stay tuned.

Backup slides

The MINERvA Collaboration

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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

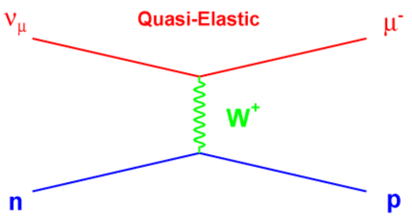
R. Gran, M. Lanari
University of Minnesota at Duluth

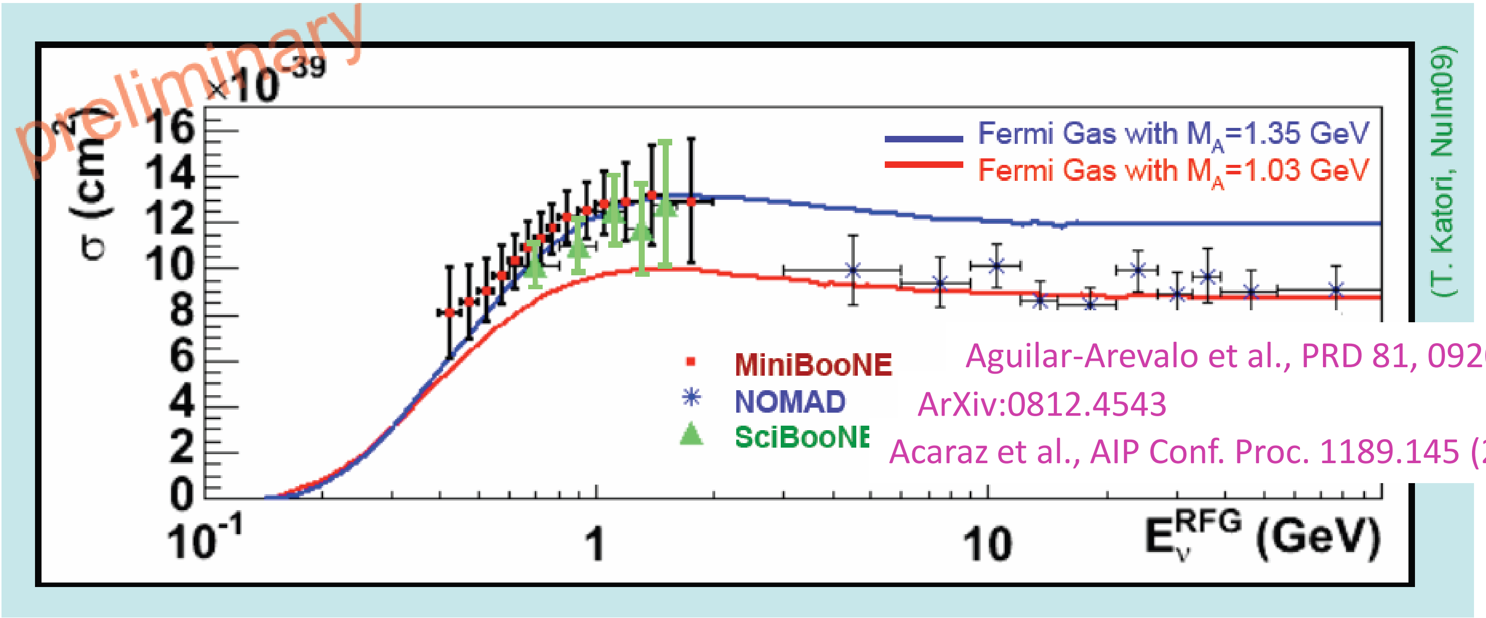
M. Alania, A. Chamorro, K. Hurtado, C. J. Solano Salinas
Universidad Nacional de Ingeniera

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

CCQE – recent results





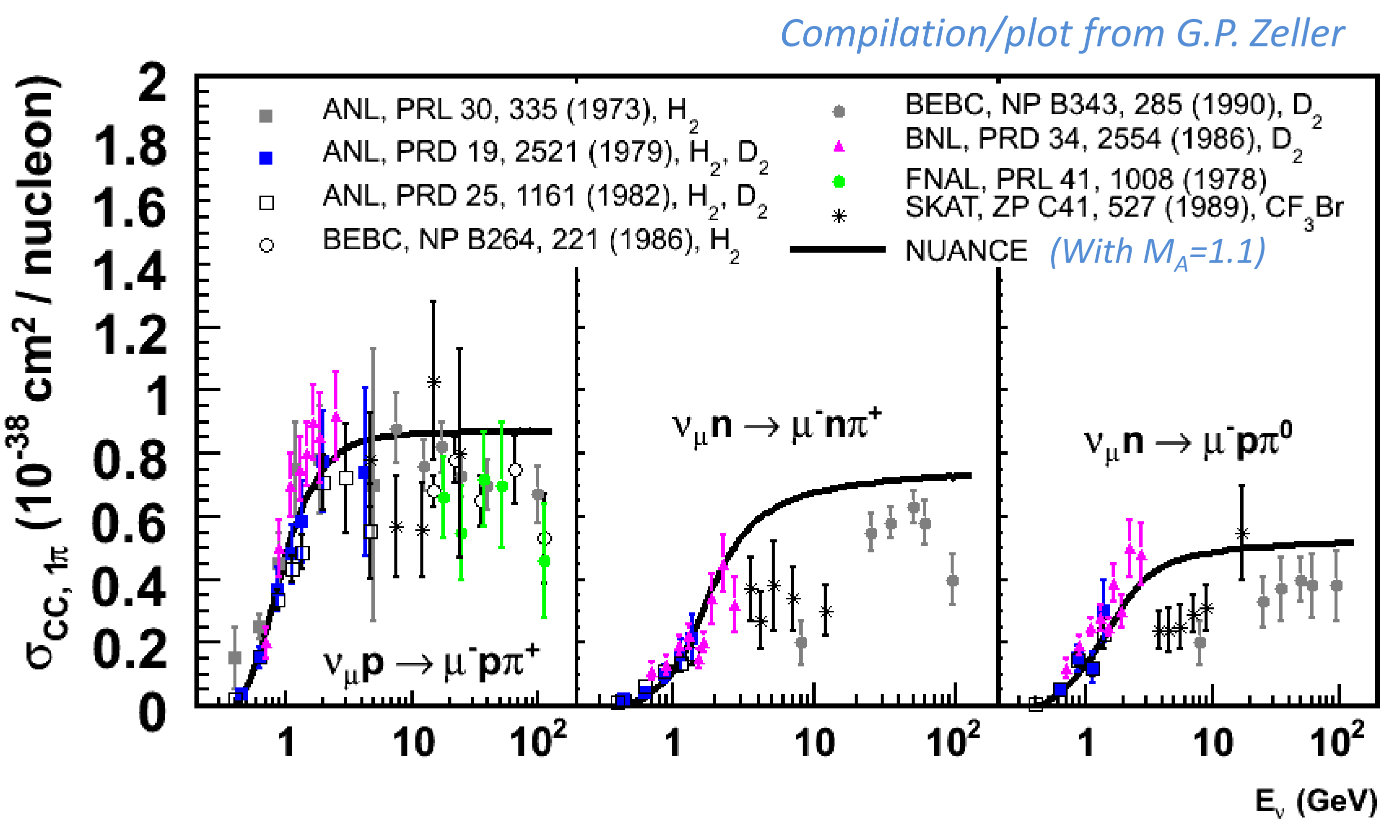
Aguilar-Arevalo et al., PRD 81, 092005 (2010)

ArXiv:0812.4543

Acaraz et al., AIP Conf. Proc. 1189.145 (2009)

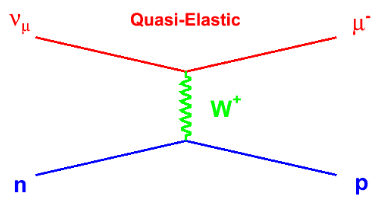
- Inconsistency between MiniBooNE/SciBooNE and NOMAD results
- Gap falls in midst of MINERνA coverage

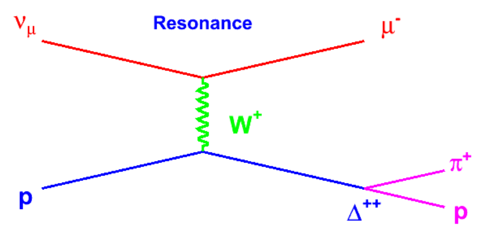
CC resonant single pion results

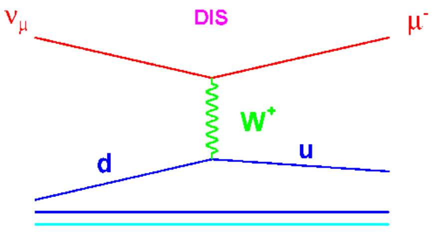


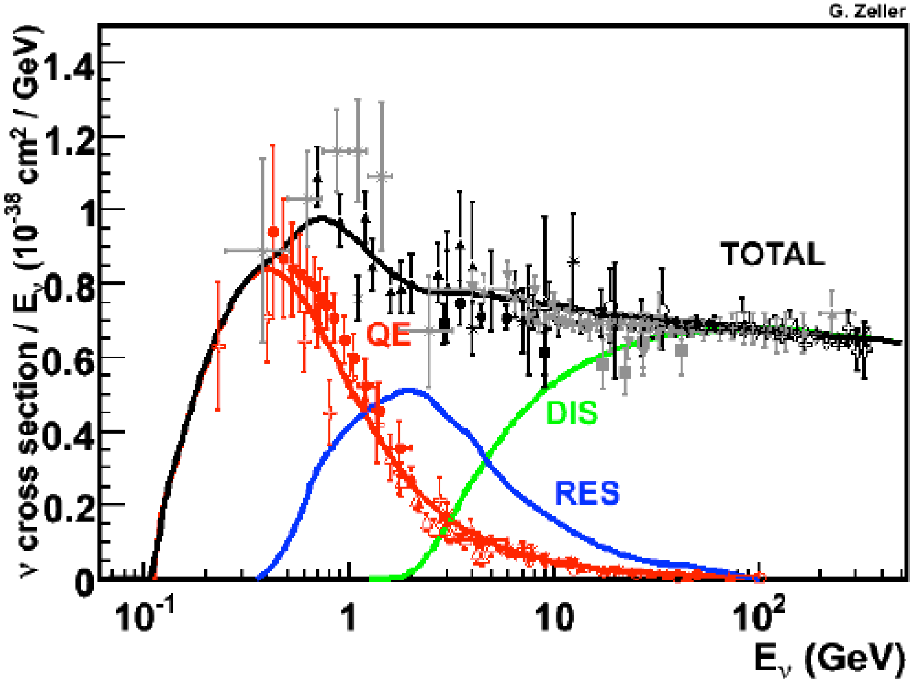
MiniBooNE has released pion production results not shown here because they are more inclusive.

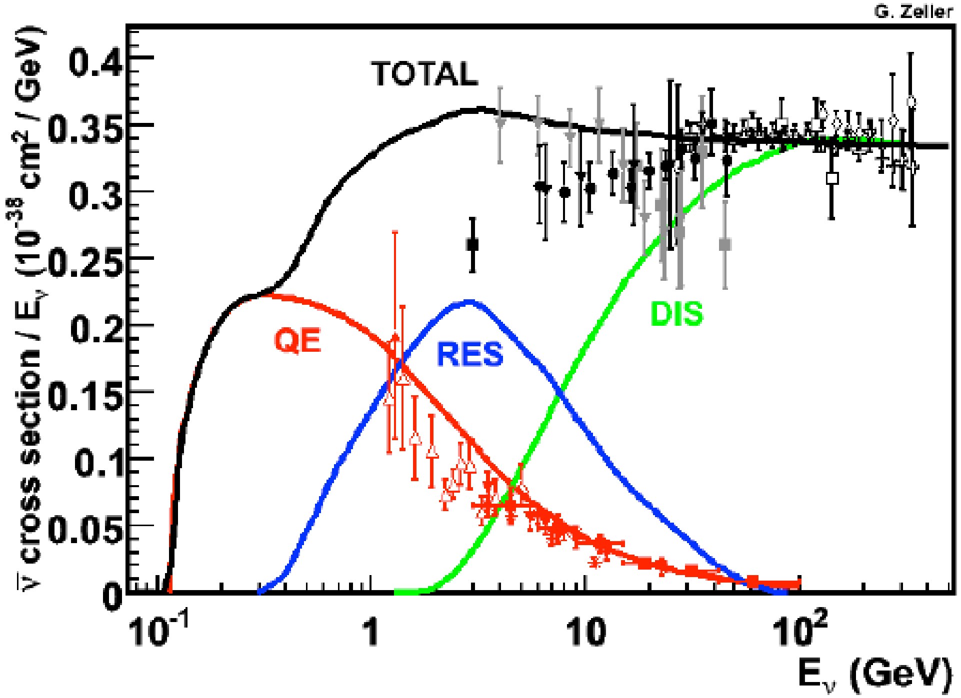
ν interaction physics



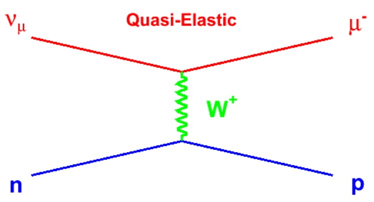


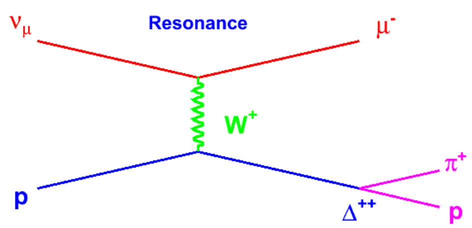


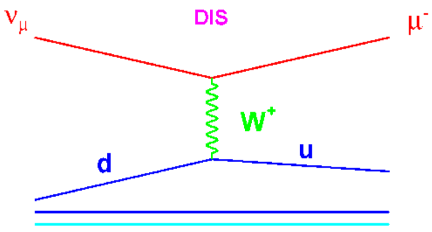


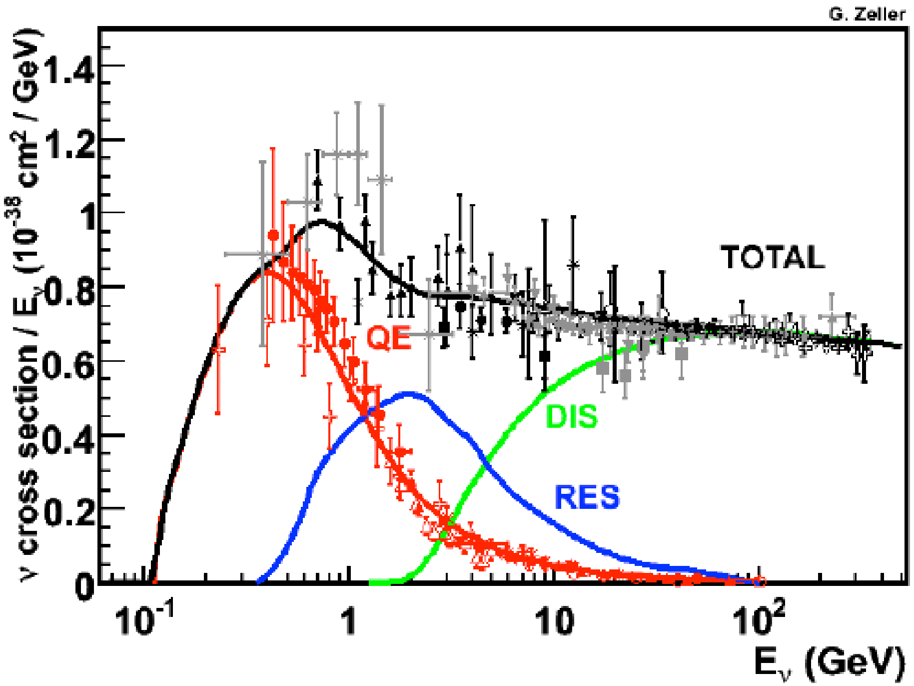


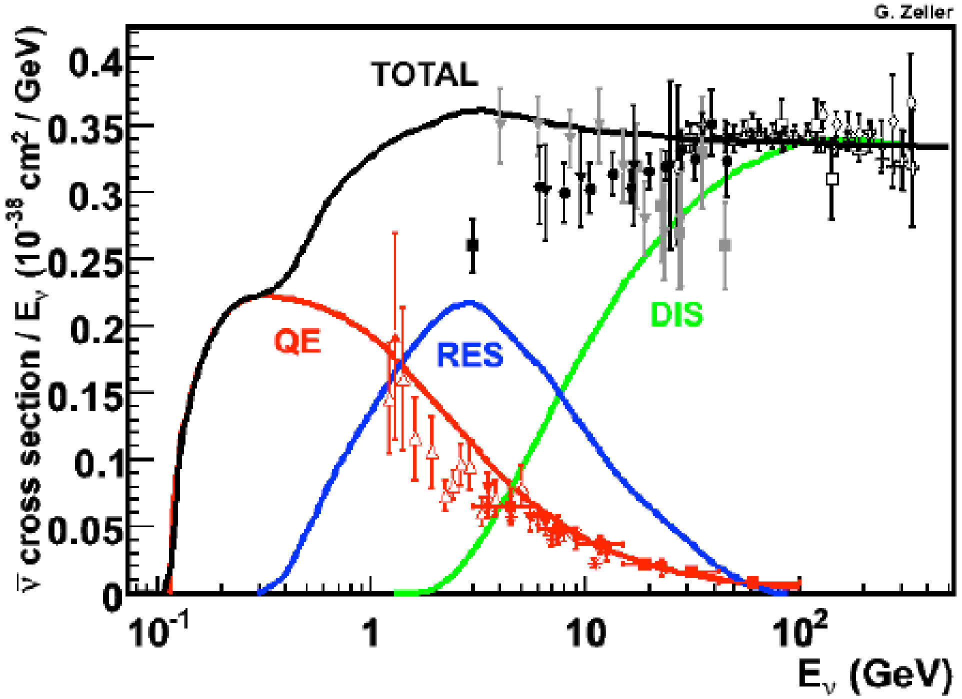
ν interaction physics











Flux determination

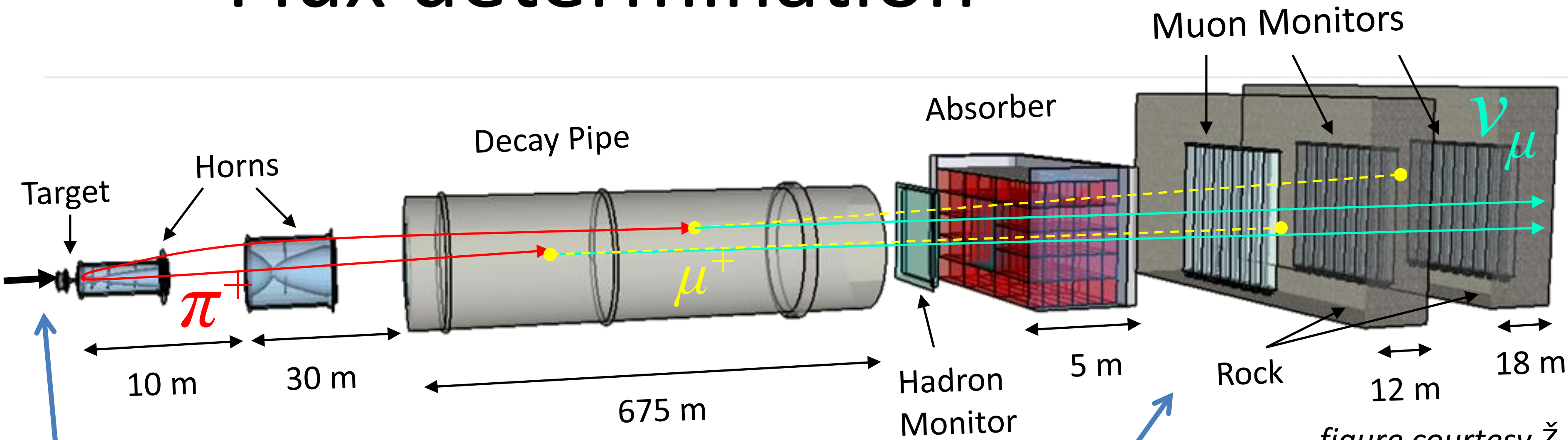
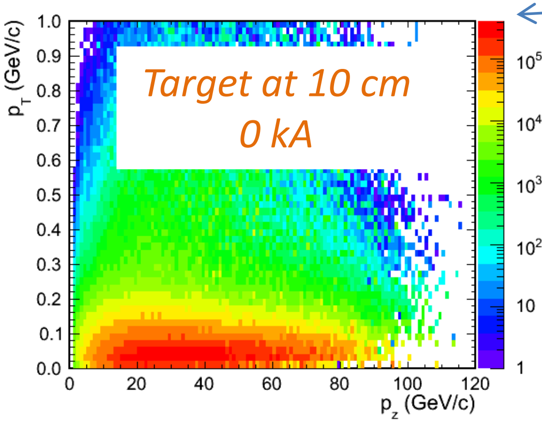


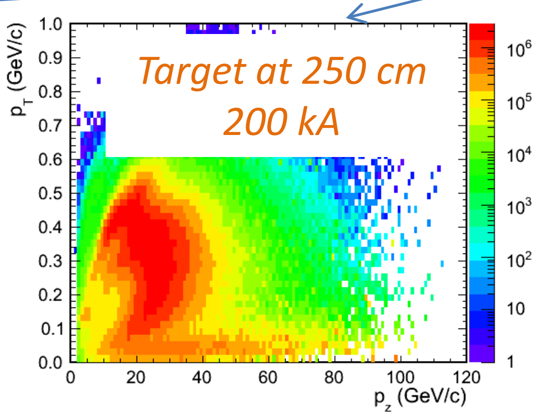
figure courtesy Ž. Pavlović

Use external hadron production data

Monitor the muon flux

examples

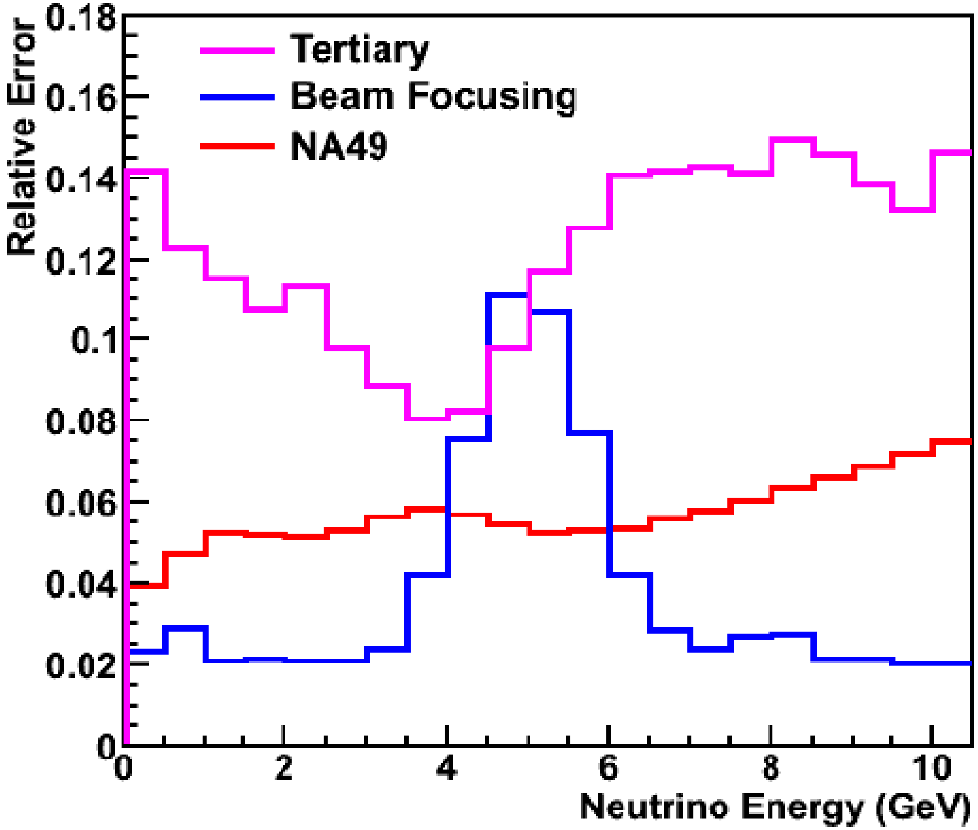




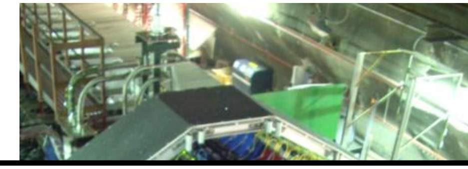
Use flexible beam design, take data in special runs with different beam configurations (vary target position and horn currents)

- Goal is better than 10% in absolute flux and 7% on shape

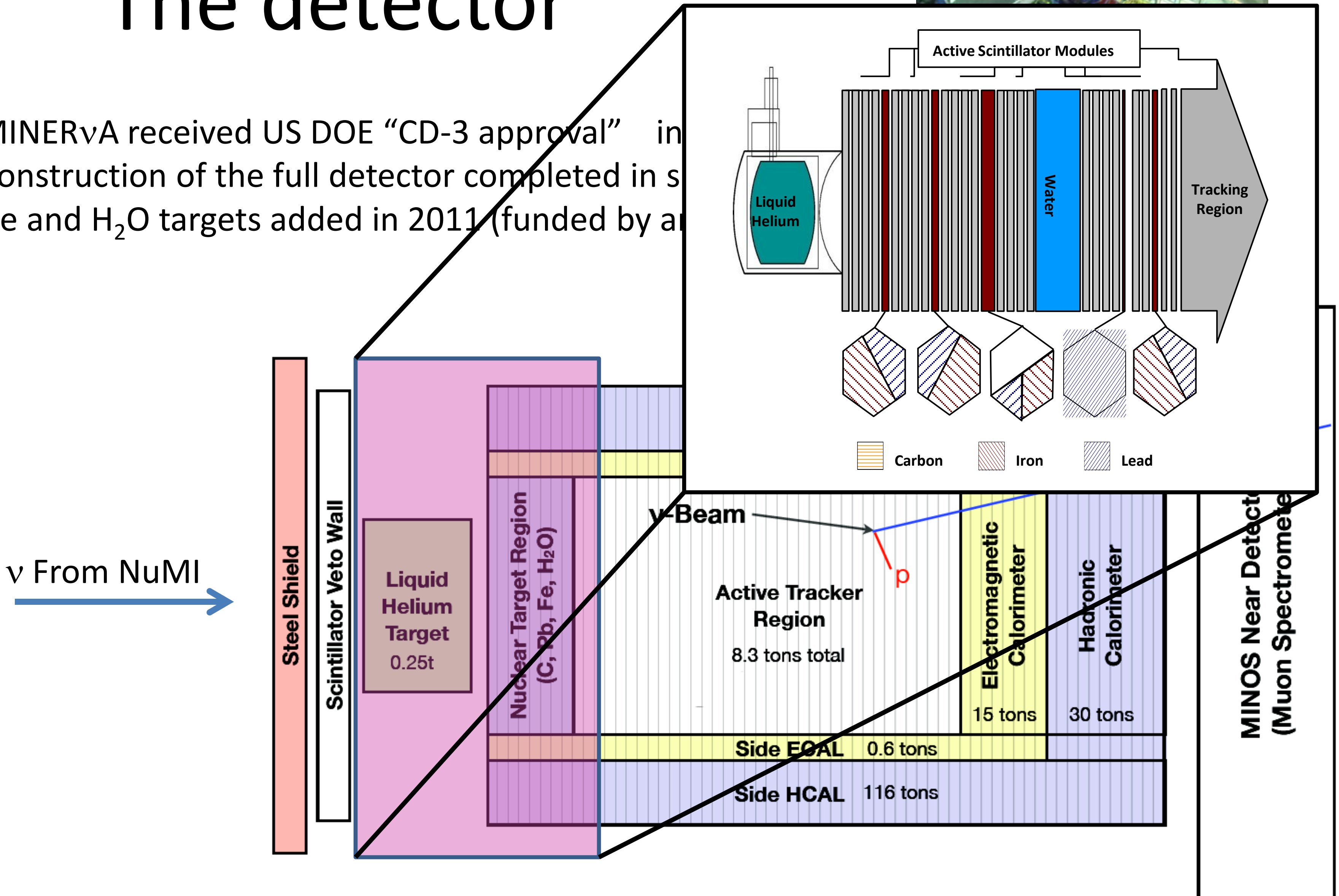
Preliminary flux uncertainties



The detector



- MINERνA received US DOE “CD-3 approval” in
- Construction of the full detector completed in s
- He and H_2O targets added in 2011 (funded by a

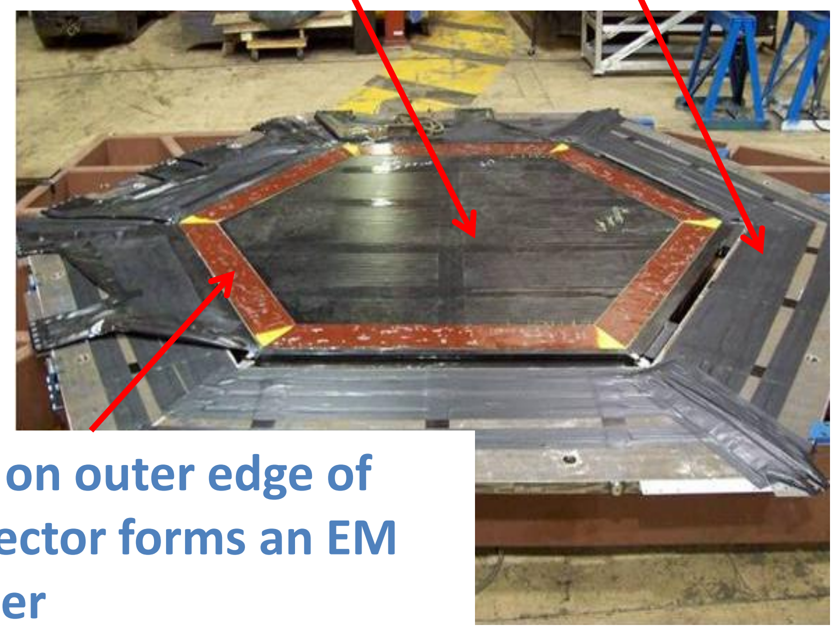


The detector (types of modules)

- Target Module (5 total):
  - Layer of target material (Fe, C or Pb)
  - Layer of scintillator
- Tracker Module(84 total):
  - 2 layers scintillator
  - 3.71 interaction lengths
- ECal module (10 total):
  - 2 sheets of lead
  - 2 layers of scintillator
  - 8.3 rad lengths.
- HCal module (20 total):
  - Layer of Fe
  - Layer of scintillator
  - 3.7 interaction lengths.

Inner detector

Outer detector – slots instrumented with scintillator (HAD calorimetry)



Lead ring on outer edge of inner detector forms an EM calorimeter

MINERvA module under construction

The detector (nuclear targets)

- 5 nuclear targets + water target interspersed in target region with tracking modules between
- Helium target upstream of detector
- Approved (for Physics) near million-event samples (4×10^{20} POT LE beam + 12×10^{20} POT in ME beam)

in hand!

Target	Mass in tons	CC Events (Million)
Scintillator	3	9
He	0.2	0.6
C (graphite)	0.15	0.4
Fe	0.7	2.0
Pb	0.85	2.5
Water	0.3	0.9

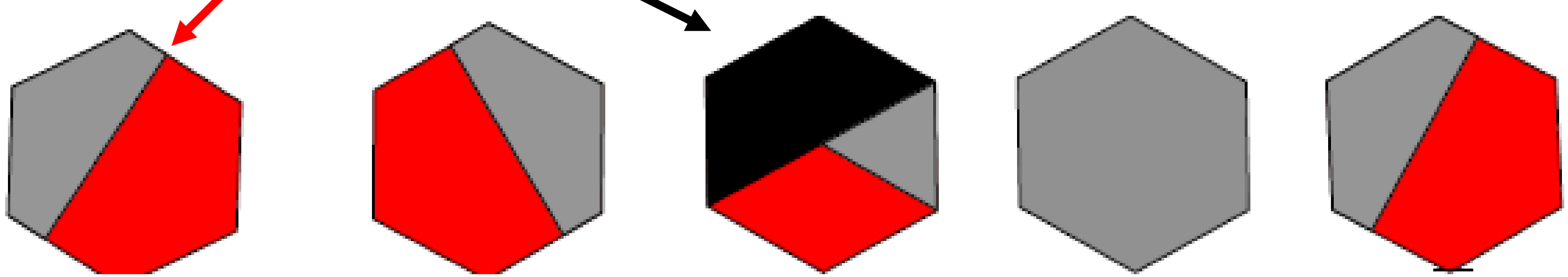
- NUGEN MC
- Only ν
- not acceptance corrected
- inside fiducial volume

Water target

He target

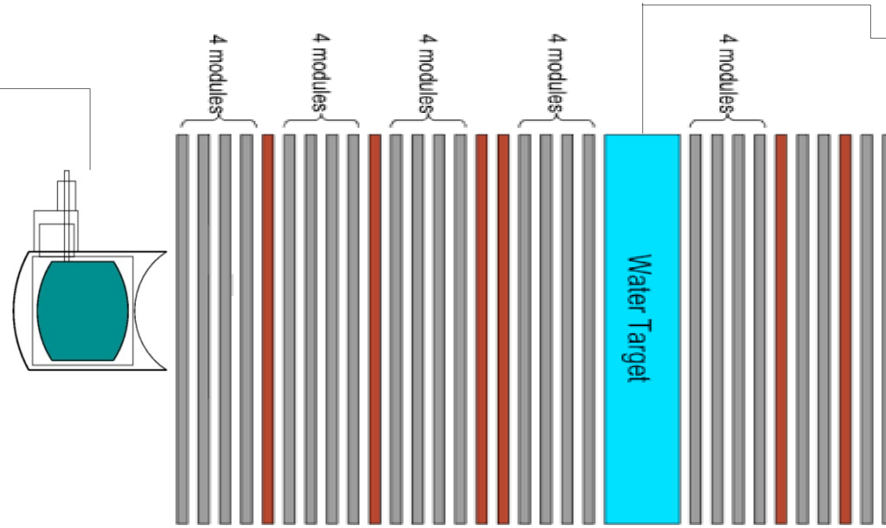
5 Nuclear Targets

Fe Pb C

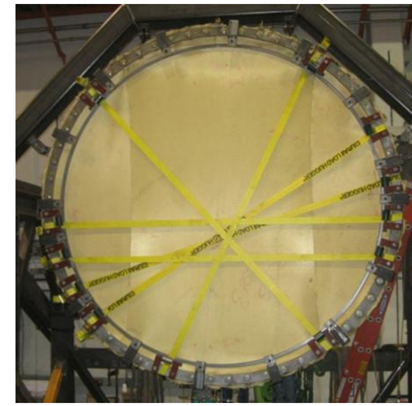


nuclear targets

250 kg
Liquid He



500kg
Water



1.0" Fe / 1.0" Pb

1.0" Pb / 1.0" Fe

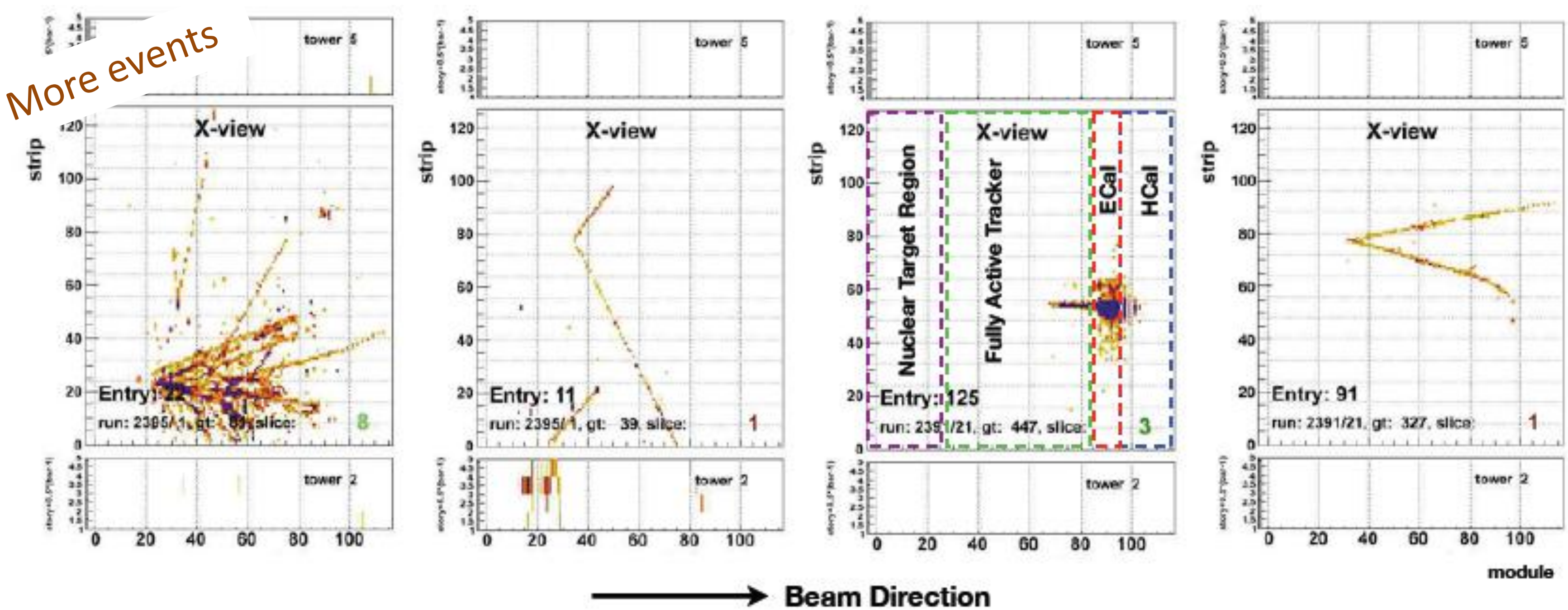
3.0" C / 1.0" Fe / 1.0" Pb

0.3" Pb

0.5" Fe / 0.5" Pb

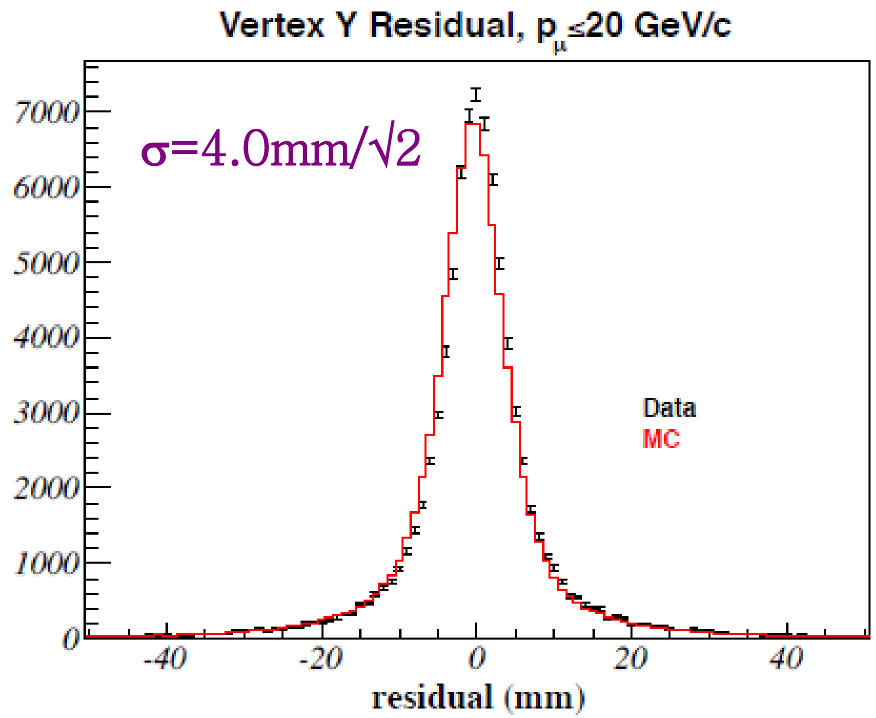
Summary of detector capability

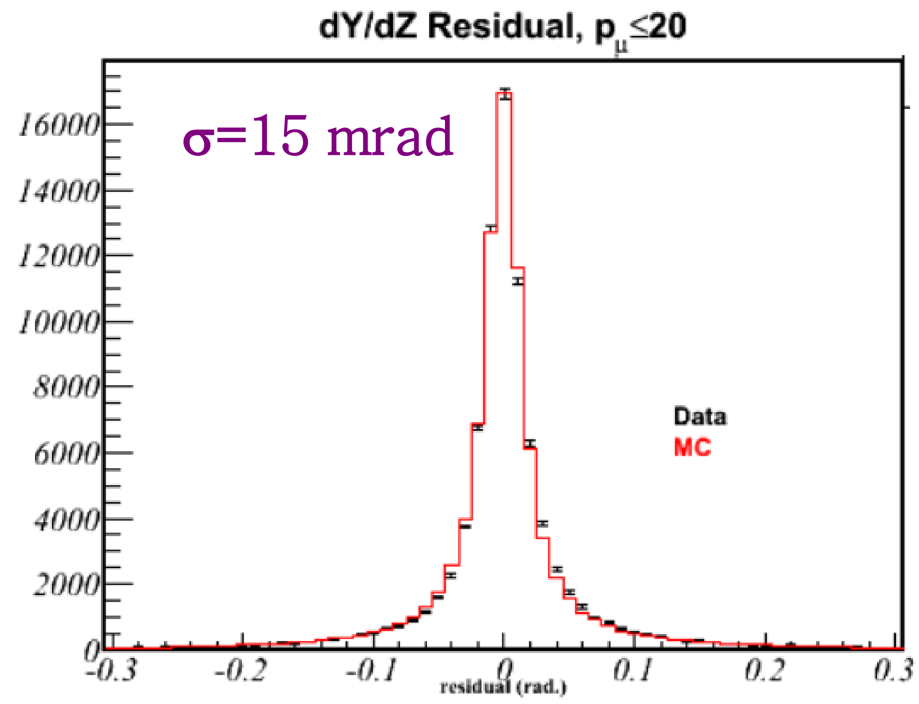
- Good tracking resolution (~3 mm)
- Calorimetry for both charged particles and EM showers
- Containment of events from neutrinos < 10 GeV (except muon)
- Muon energy and charge measurement from MINOS
- Particle ID from dE/dx and energy+range
  - But no charge identification except muons into MINOS



Tracking resolution

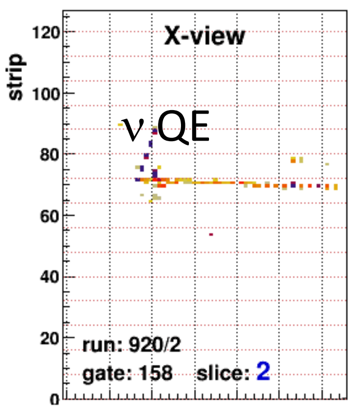
From study of rock muons passing through tracker

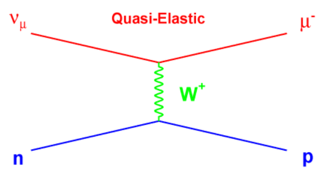


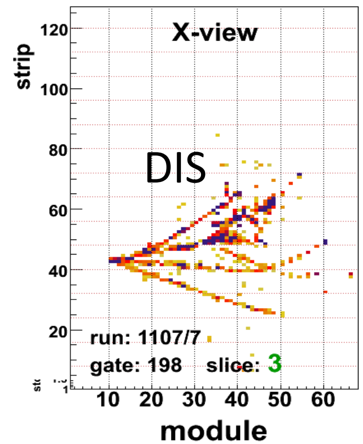


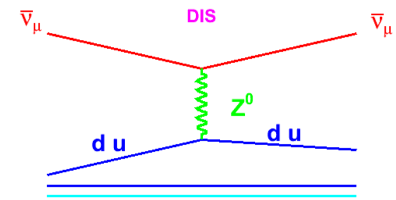
MINERνA Events

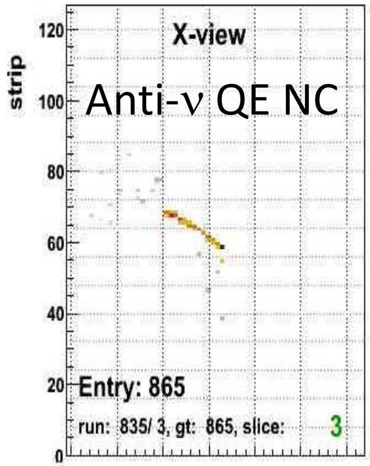
- Showing X view

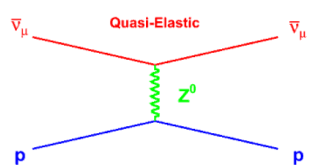


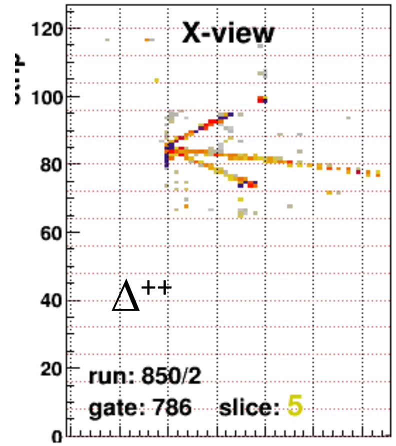


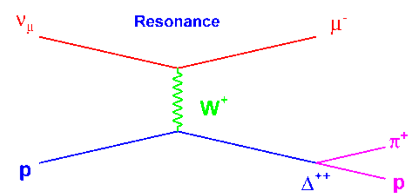




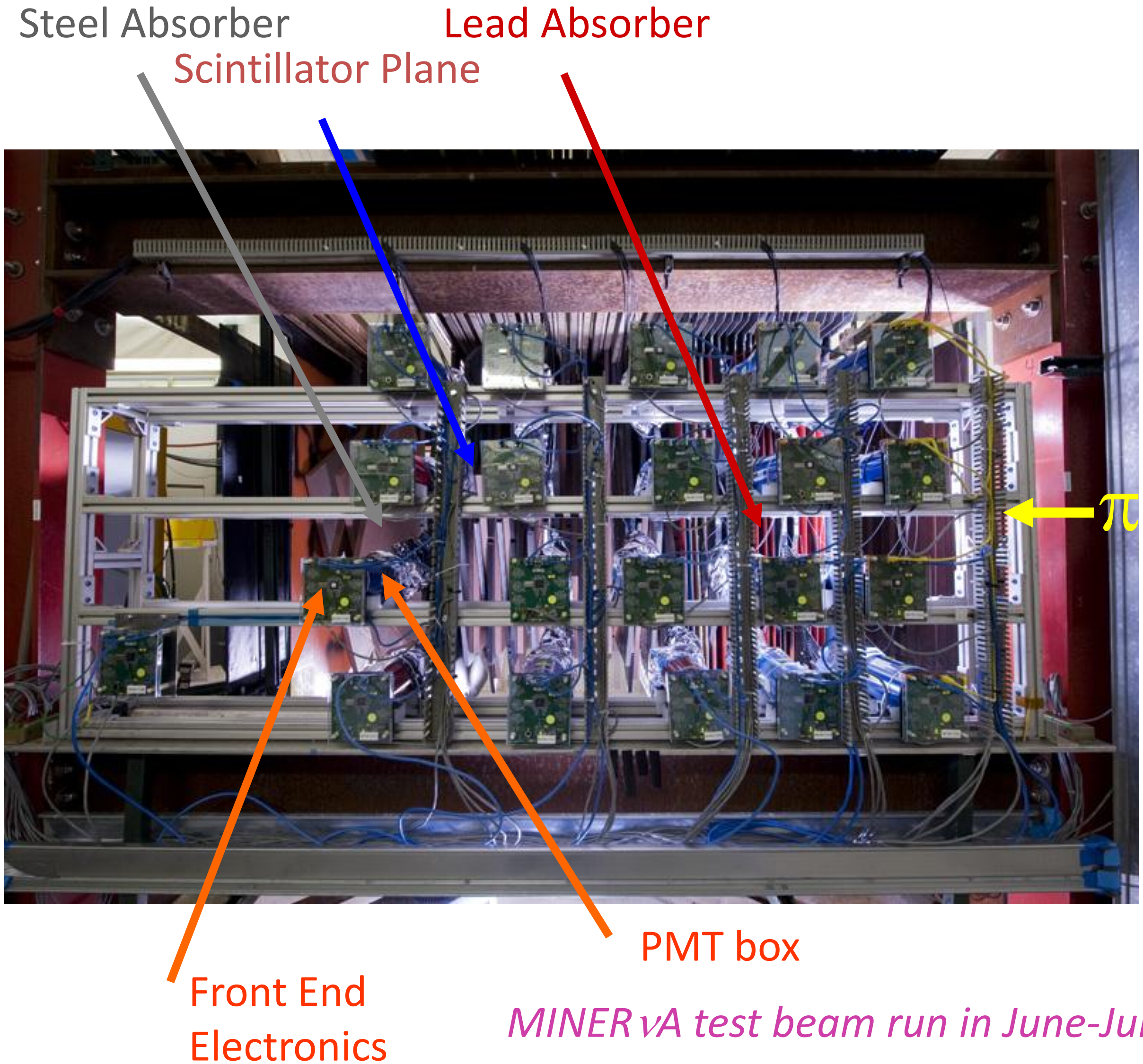








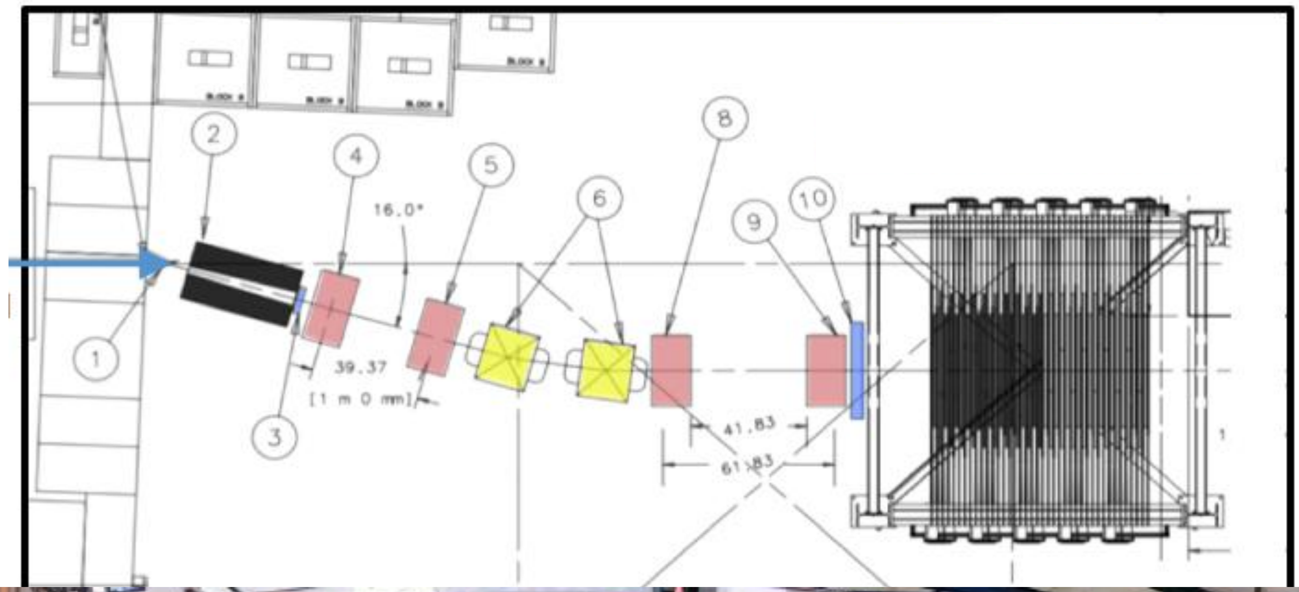
MINERνA Test Beam



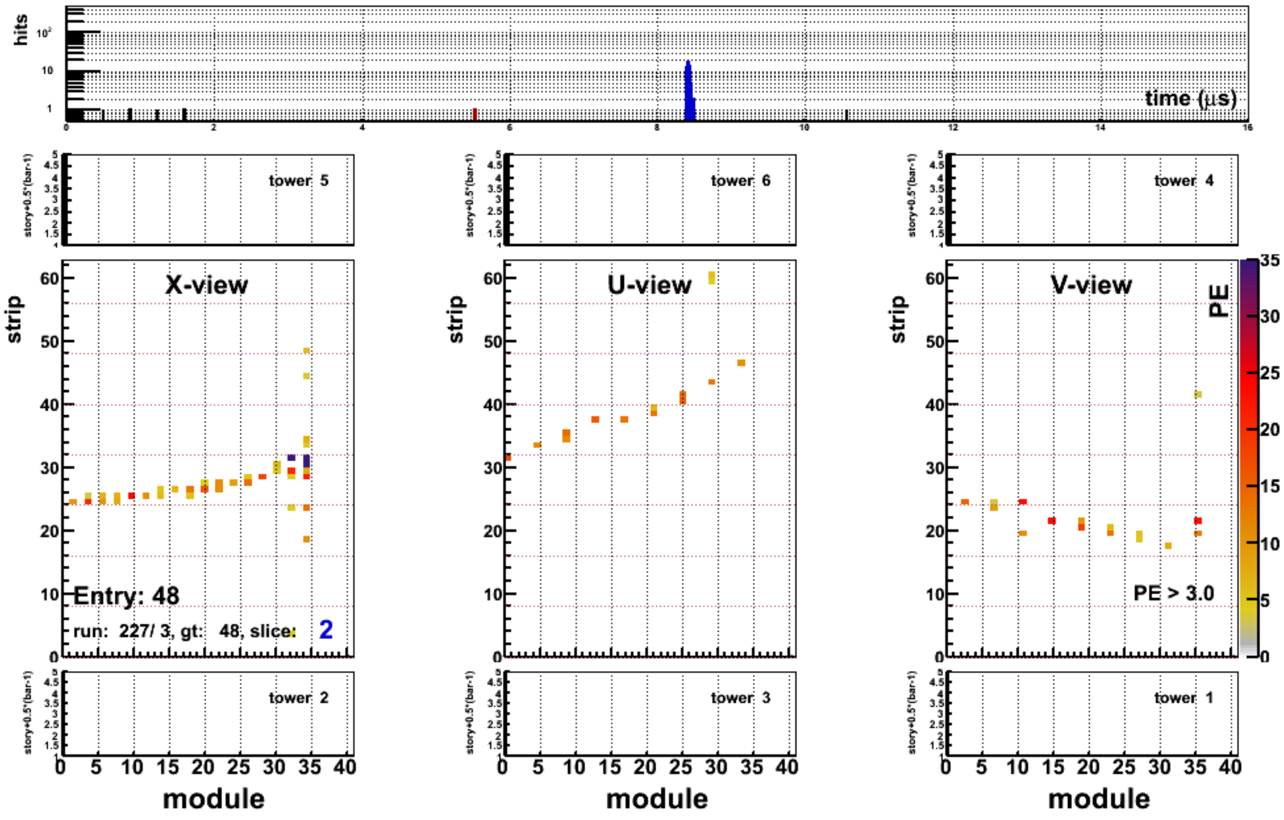
- In order to make precise measurements we need a precise low energy calibration
- 40 planes, XUXV,1.07 m square
- Reconfigurable can change the absorber configuration. Plane configurations:
  - 20ECAL-20HCAL
  - 20Tracker-20ECAL
- Test beam has 0.4 to 1.2 GeV pions for LE hadron calibration
- Am told test beam is available if needed

MINERνA test beam run in June-July, 2010

16 GeV pion beam on copper target

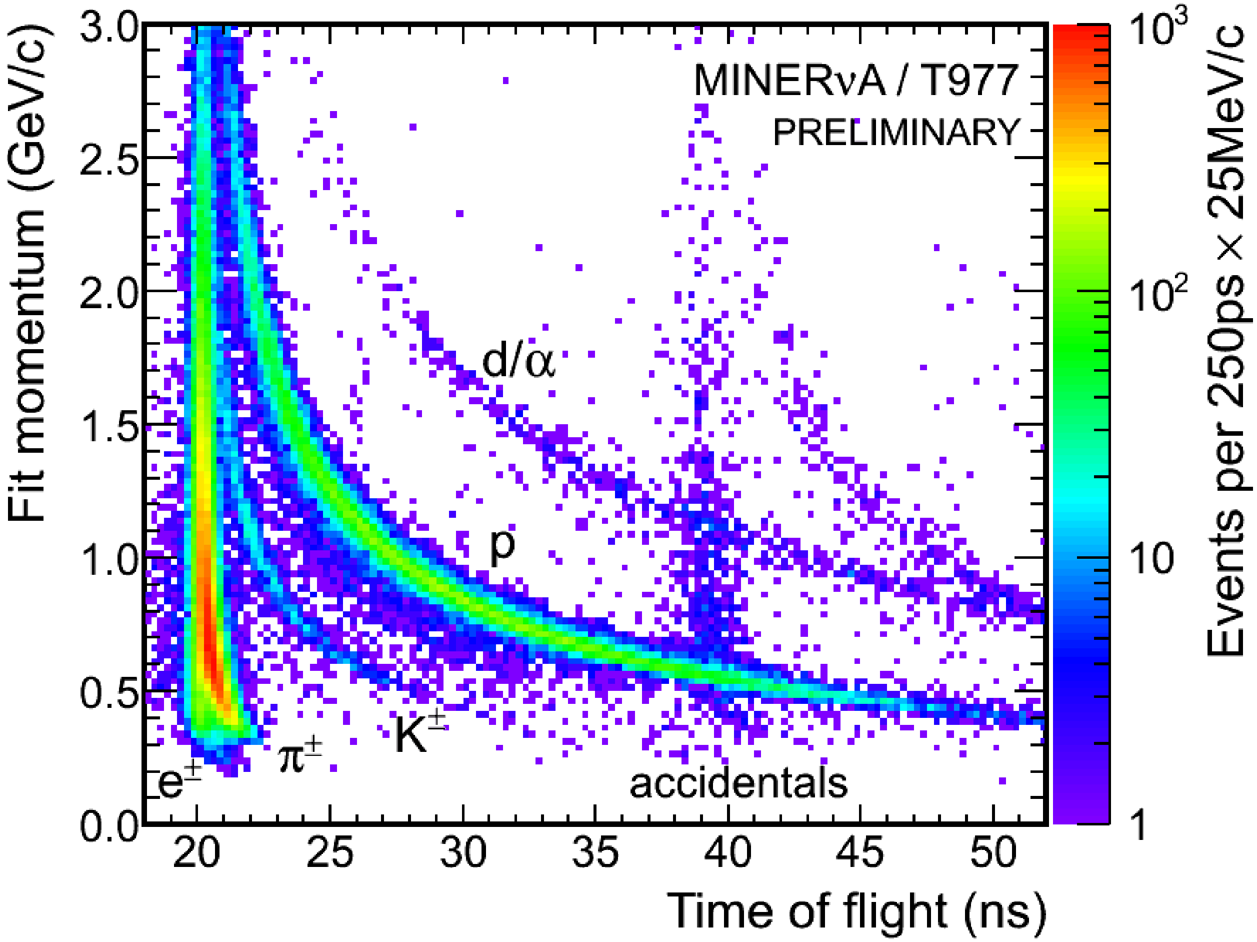


Test Beam π

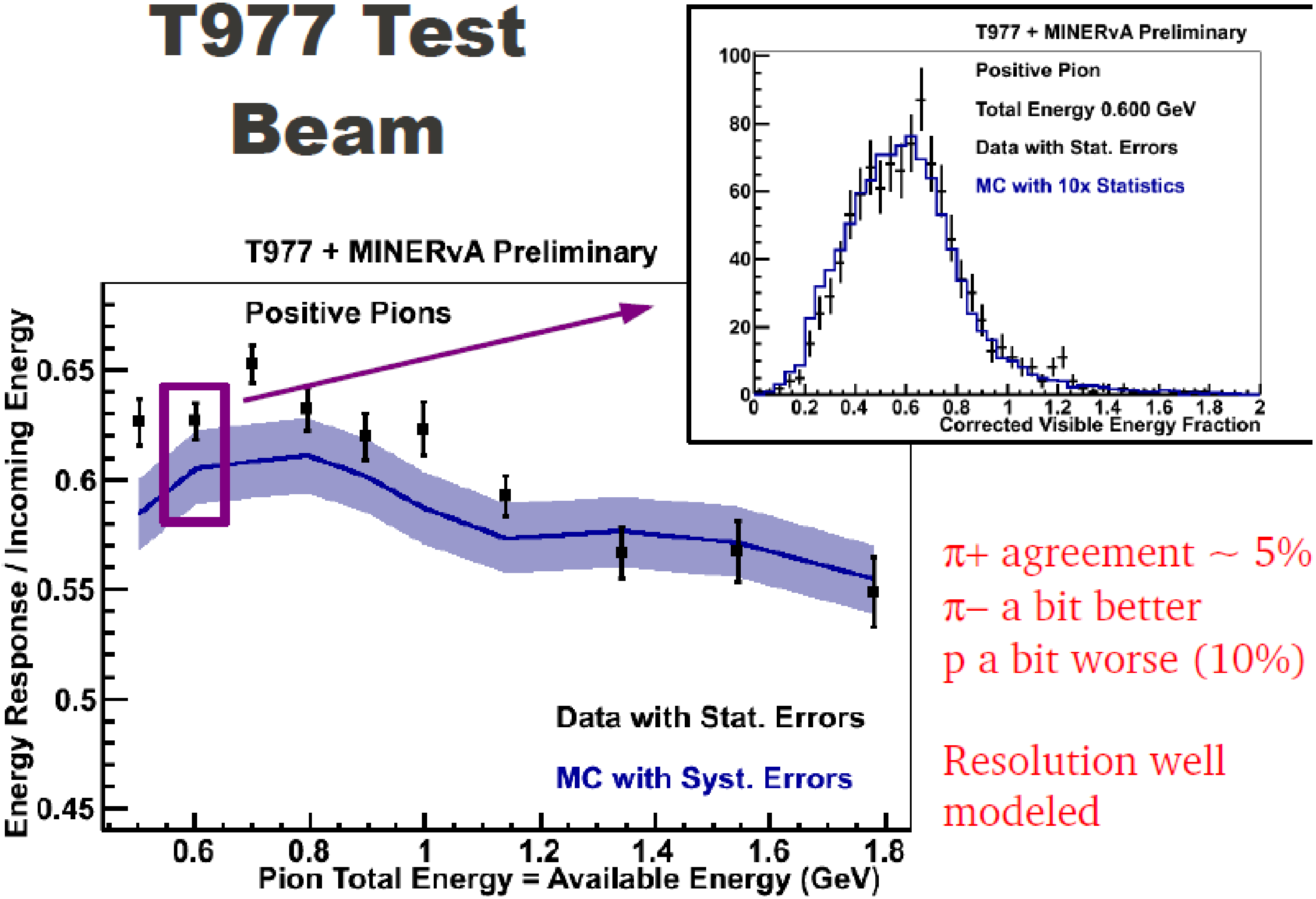


- 20 ECAL 20 HCAL configuration
- 1.35 GeV interacting in HCAL

MINERνA Test Beam



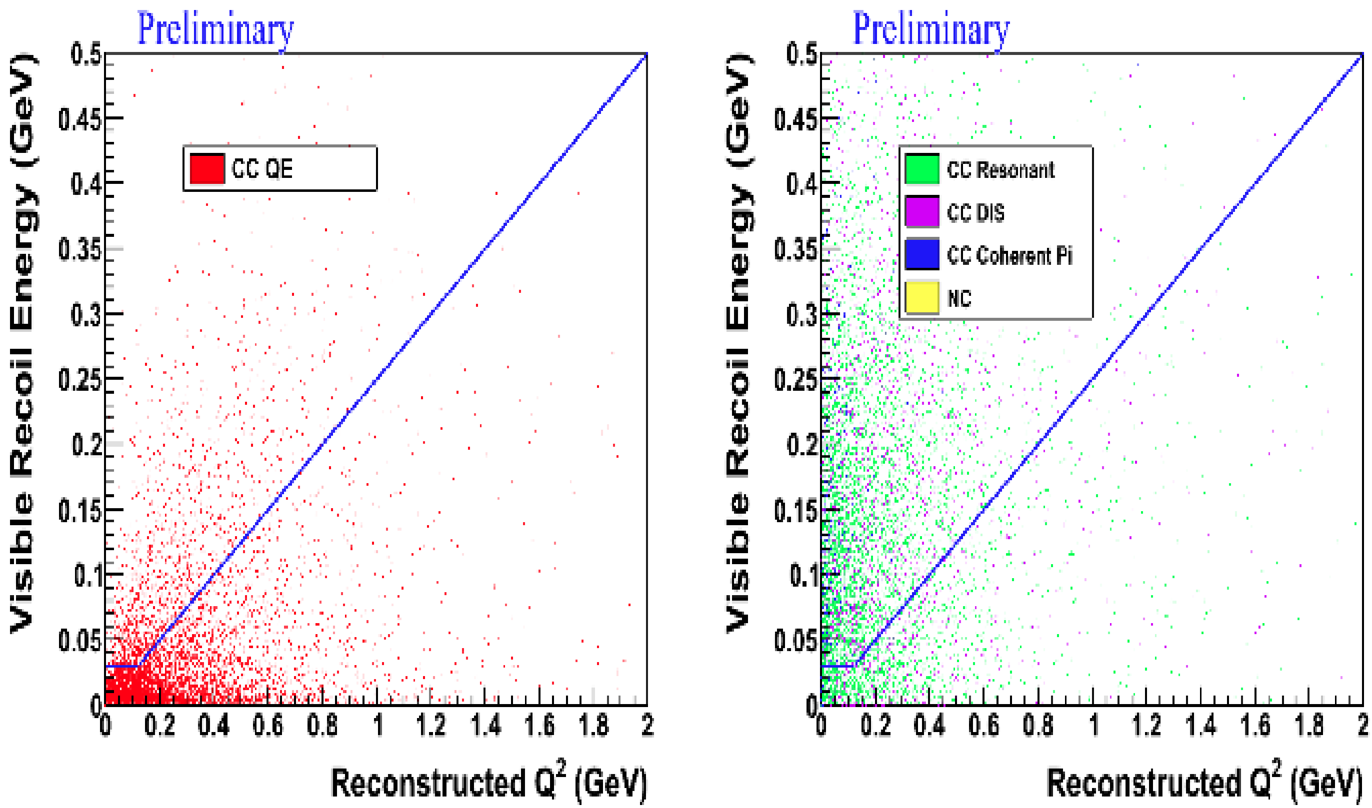
T977 Test Beam



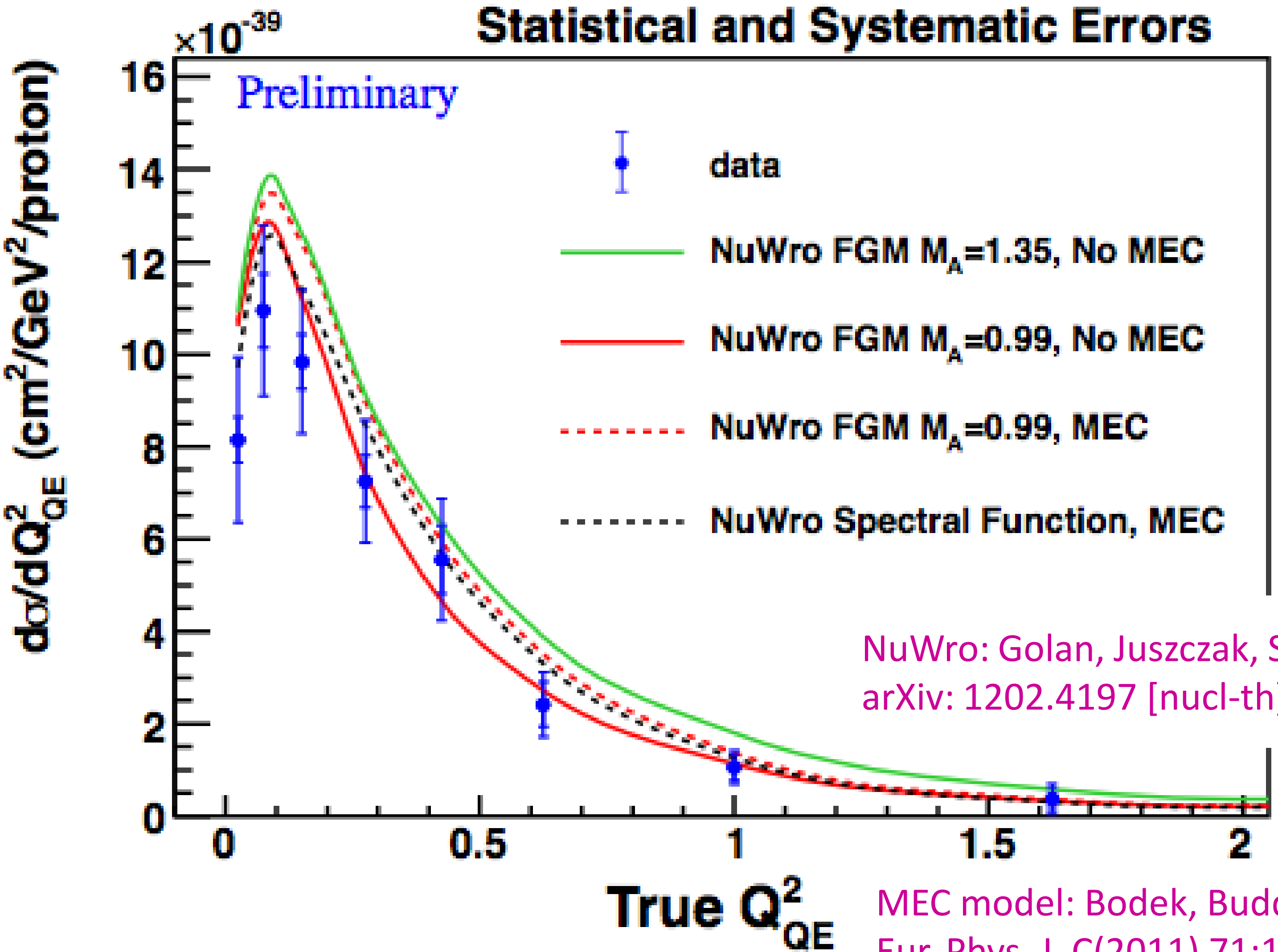
π+ agreement ~ 5%
π– a bit better
p a bit worse (10%)

Resolution well modeled

$\overline{\nu}_\mu$ CC quasi-elastic analysis



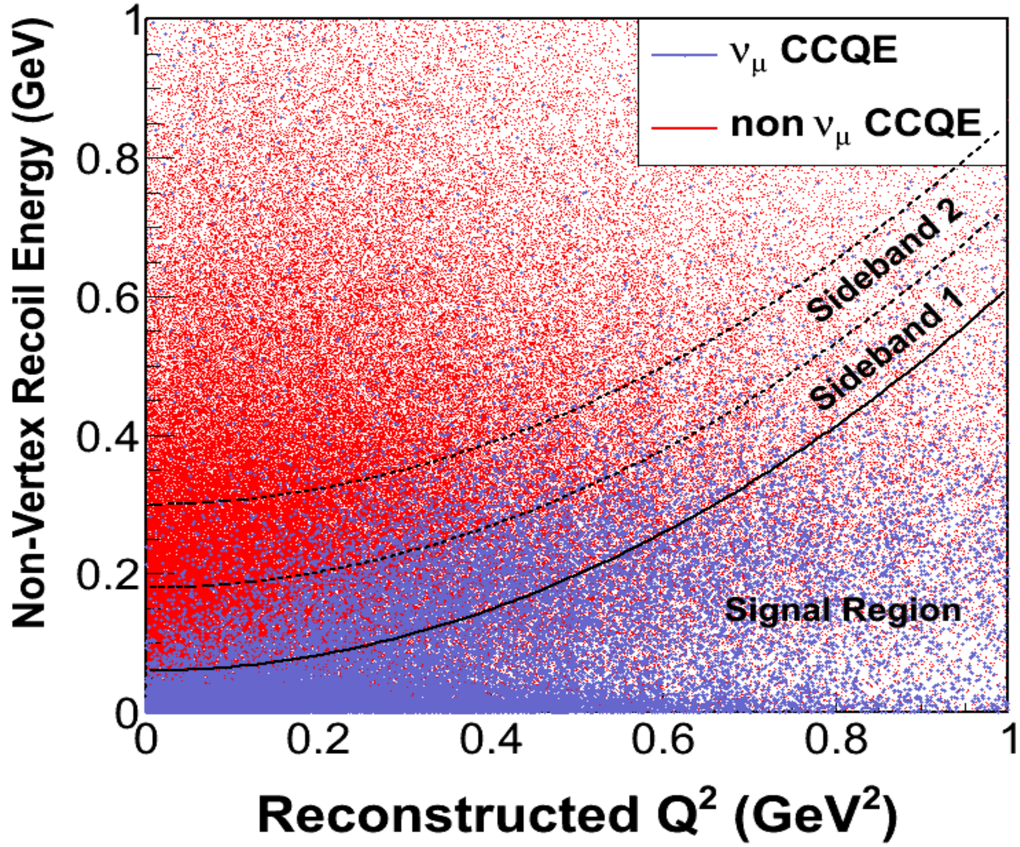
Data compared to NuWro event generator



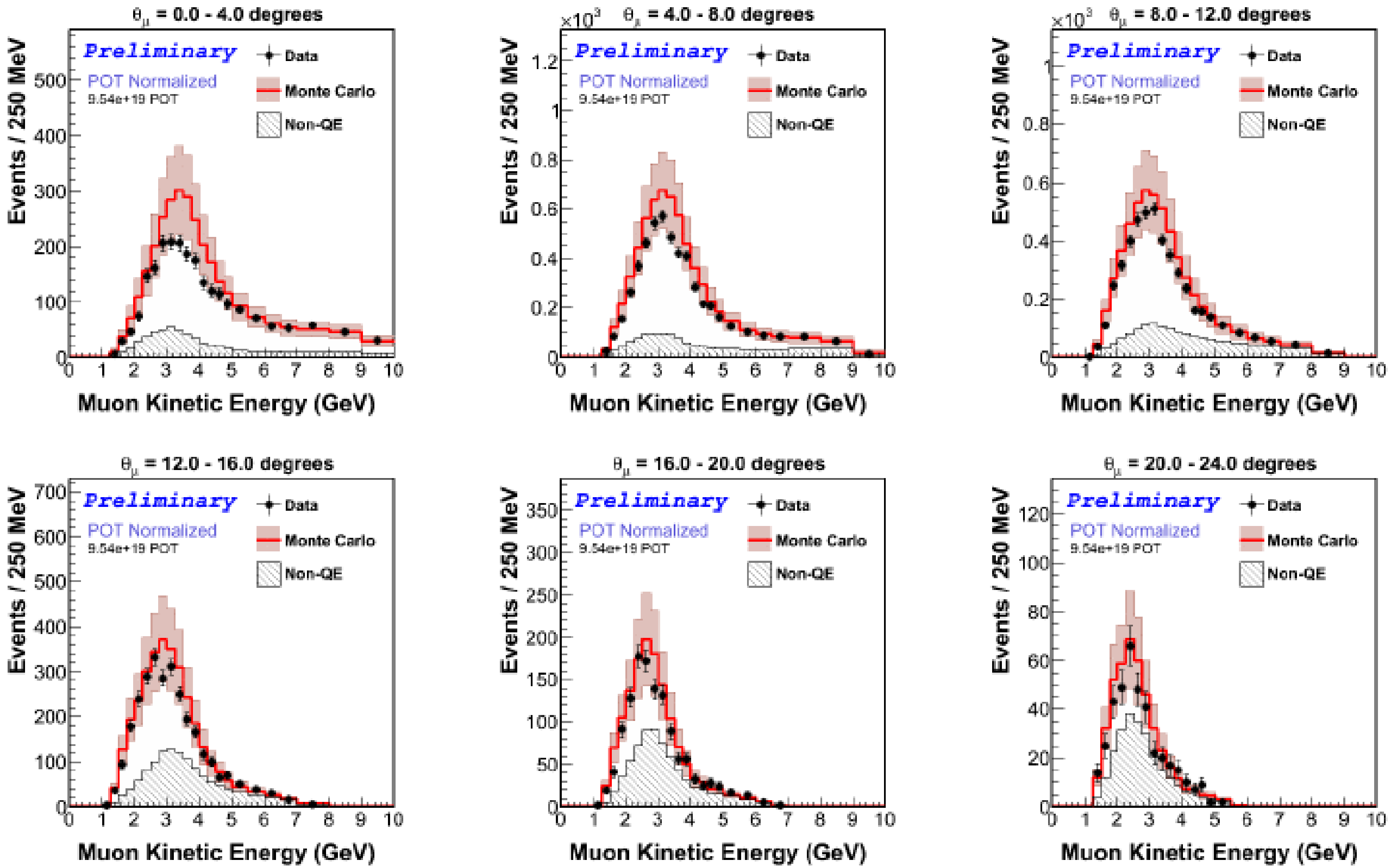
NuWro: Golan, Juszczak, Sobczyk, arXiv: 1202.4197 [nucl-th]

MEC model: Bodek, Budd, Christy, Eur. Phys. J. C(2011) 71:1726

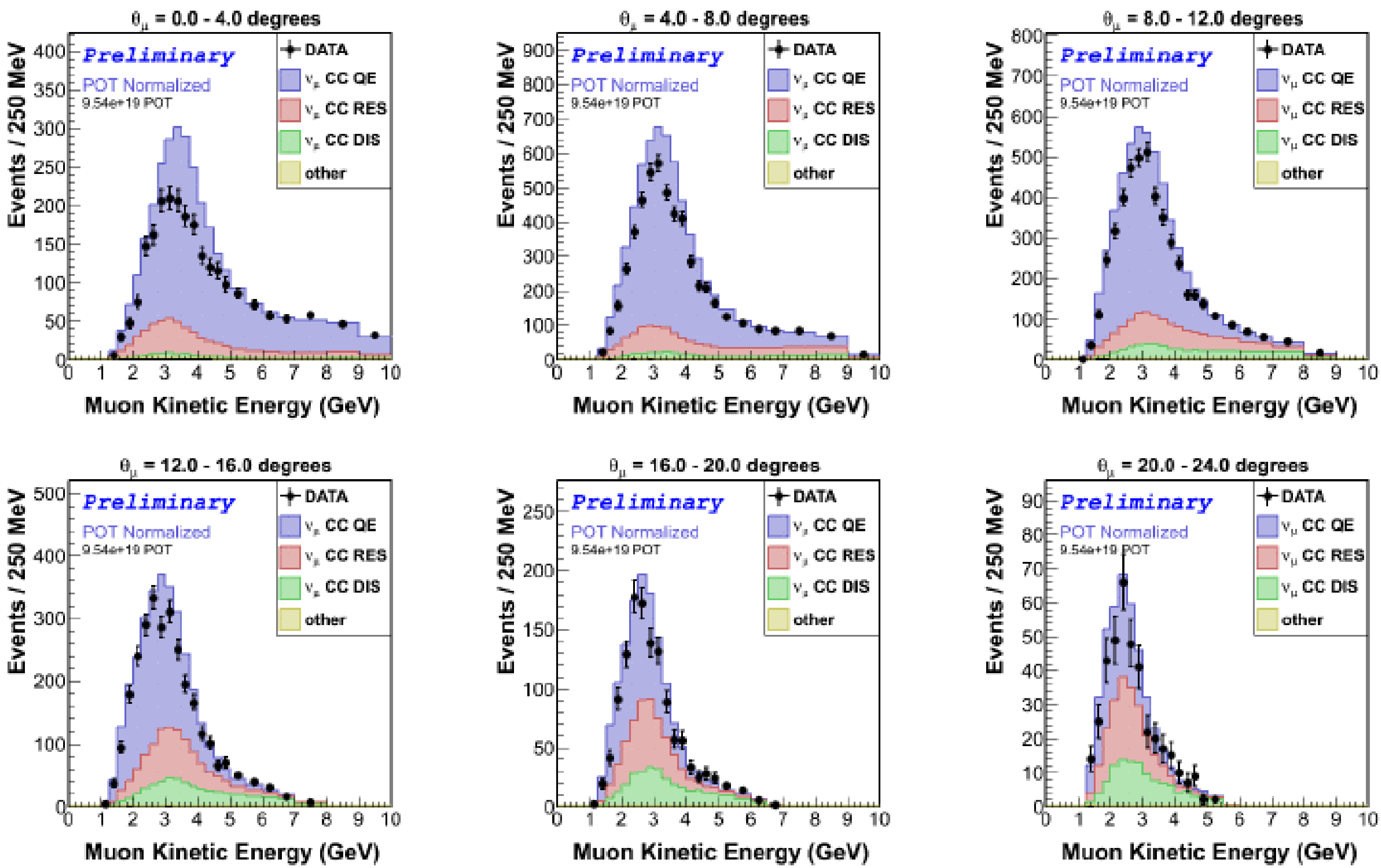
ν_μ CC quasi-elastic analysis



ν_μ CC quasi-elastic analysis



ν_μ CC quasi-elastic analysis



ν_μ CC quasi-elastic analysis