



Neutrinos Induced Pion Production in MINERvA

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On behalf of the MINERvA collaboration

NuFact 2013, Beijing, China

Outline



Neutrinos Induced Pion Production

MINERvA Experiment E-938

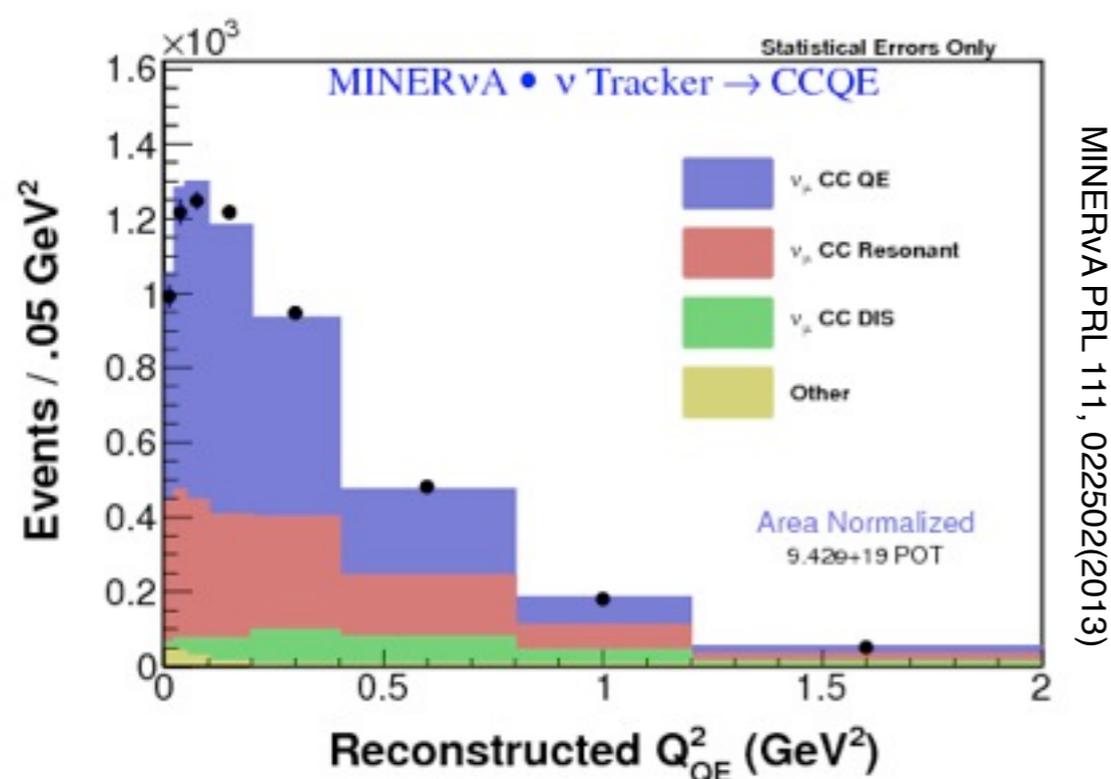
CC Inclusive Pion Production

CC Exclusive Pion Production (Coherent)

Summary

Neutrinos Induced Pion Production

- Why measuring π production on nuclei is important?
 - Test of production and final state interaction models
 - Background to oscillation
 - NC $1\pi^0$ background to ν_e appearance
 - CC $1\pi^+$ background to CCQE

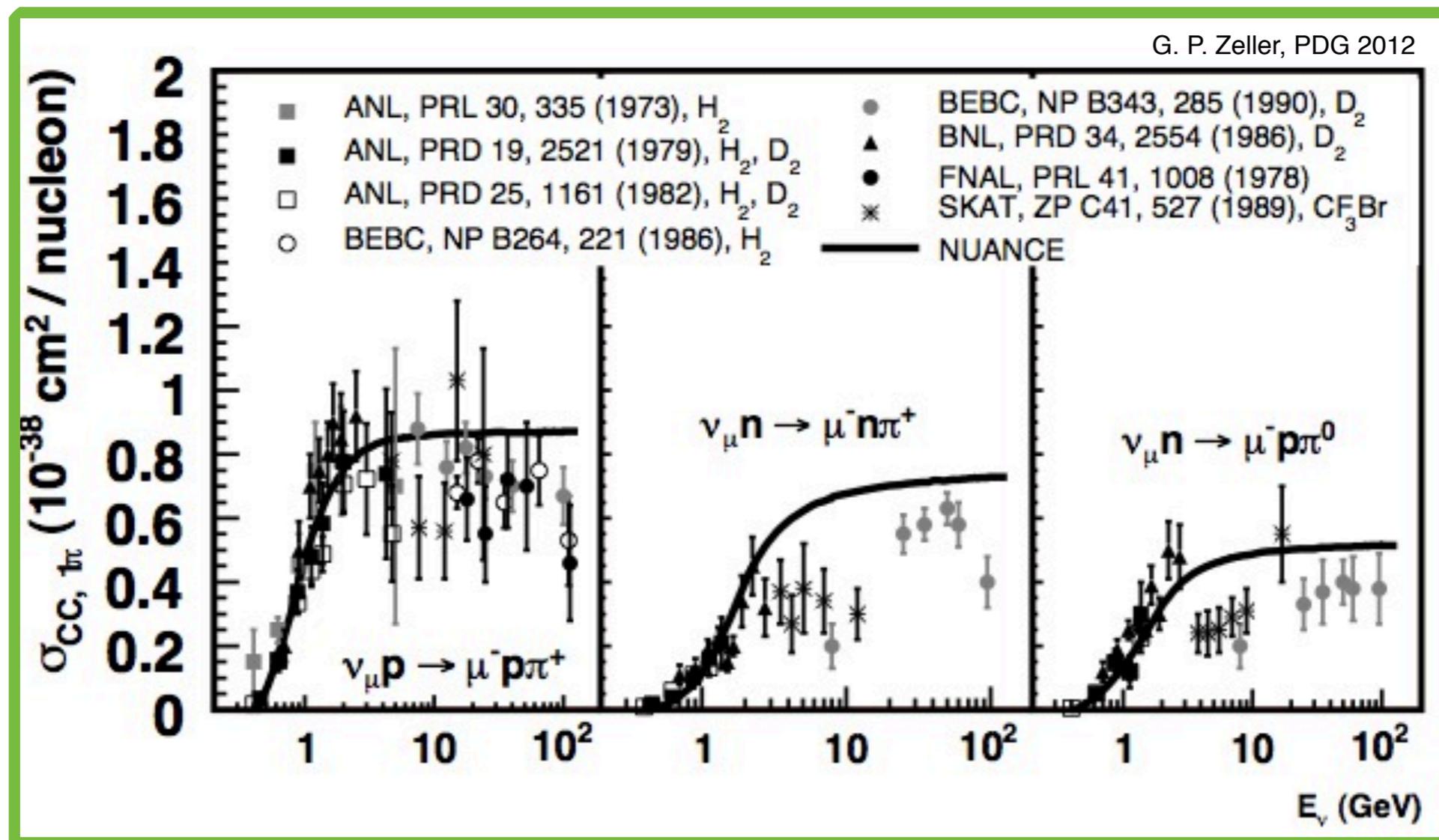


Evidence of Electron Neutrino Appearance in a Muon Neutrino T2K arXiv:1304.0841

Parameter	Input Value	Uncertainty
M_A^{QE} (GeV)	1.21	0.43
x_1^{QE}	1.00	0.11
x_2^{QE}	1.00	0.30
x_3^{QE}	1.00	0.30
x_{SF}	0.0	1.0
$p_F(^{12}\text{C})$ (MeV/c)	217	30
$p_F(^{16}\text{O})$ (MeV/c)	225	30
M_A^{RES} (GeV)	1.16	0.11
$x_1^{CC1\pi}$	1.63	0.43
$x_2^{CC1\pi}$	1.00	0.40
$x^{NC1\pi^0}$	1.19	0.43
$x_{1\pi E_\nu}$	off	on
W_{eff}	1.0	0.51
$x_{\pi\text{-less}}$	0.2	0.2
$x^{CC\text{coh.}}$	1.0	1.0
$x^{NC\text{coh.}}$	1.0	0.3
$x^{NC\text{other}}$	1.0	0.3
$x_{CC\text{other}}$ (GeV)	0.0	0.4
x_{ν_e/ν_μ}	1.0	0.03

Model Parameter	Uncertainty
CC Resonance Norm.	20%
Resonance M_A	20%
Non-resonances π production	50%

Neutrinos Induced Pion Production

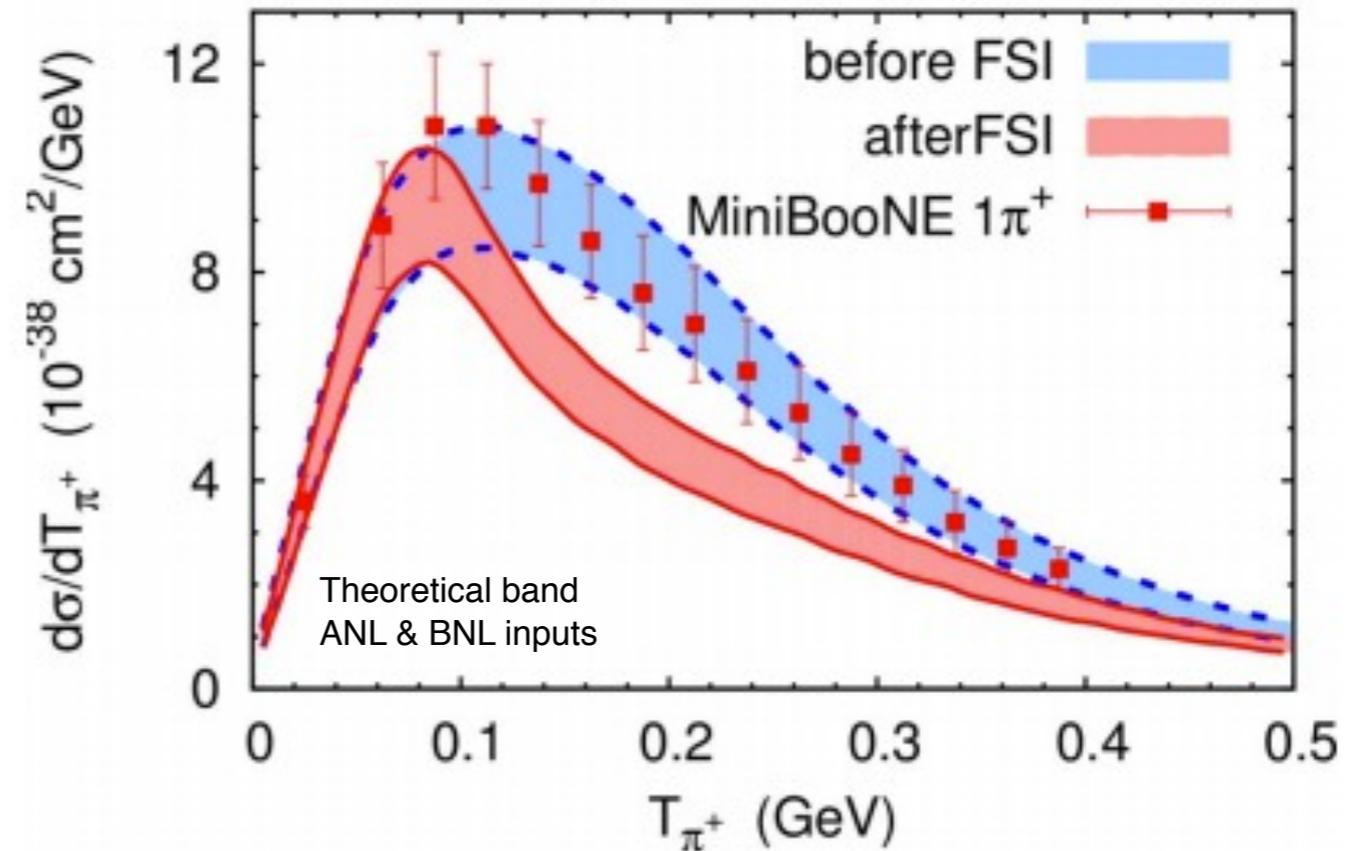
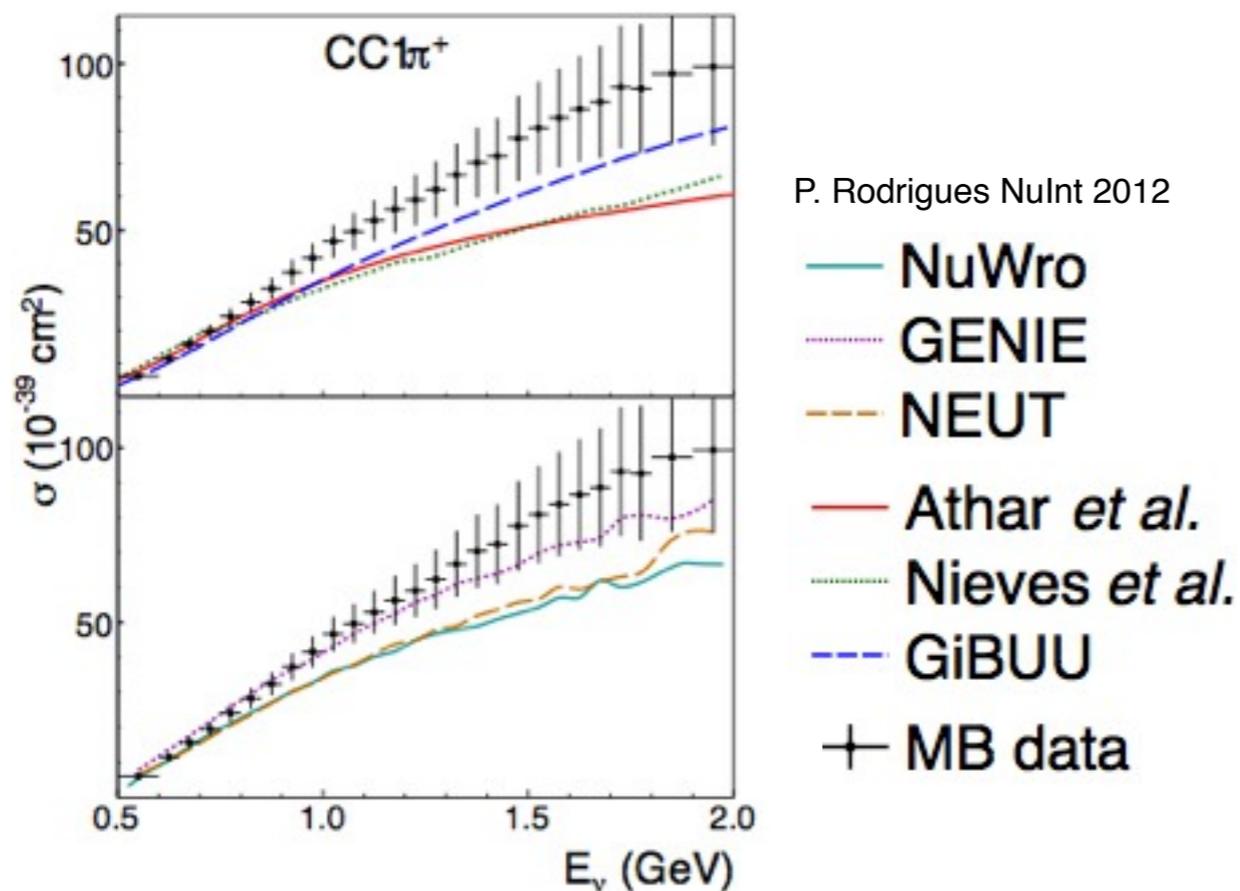


- Early experiments measured exclusive final states on H and D₂ bubble chambers
- Neutrino hits a nucleon
- Low statistics
- Uncertain flux determination

Neutrinos Induced Pion Production

S. Dytman NuInt 2012, GIBUU

- More recently measurements by MiniBooNE of CC $1\pi^+$ on CH_2
- High statistics
- Neutrino hits a nucleon within a nucleus
- Final State Interaction FSI

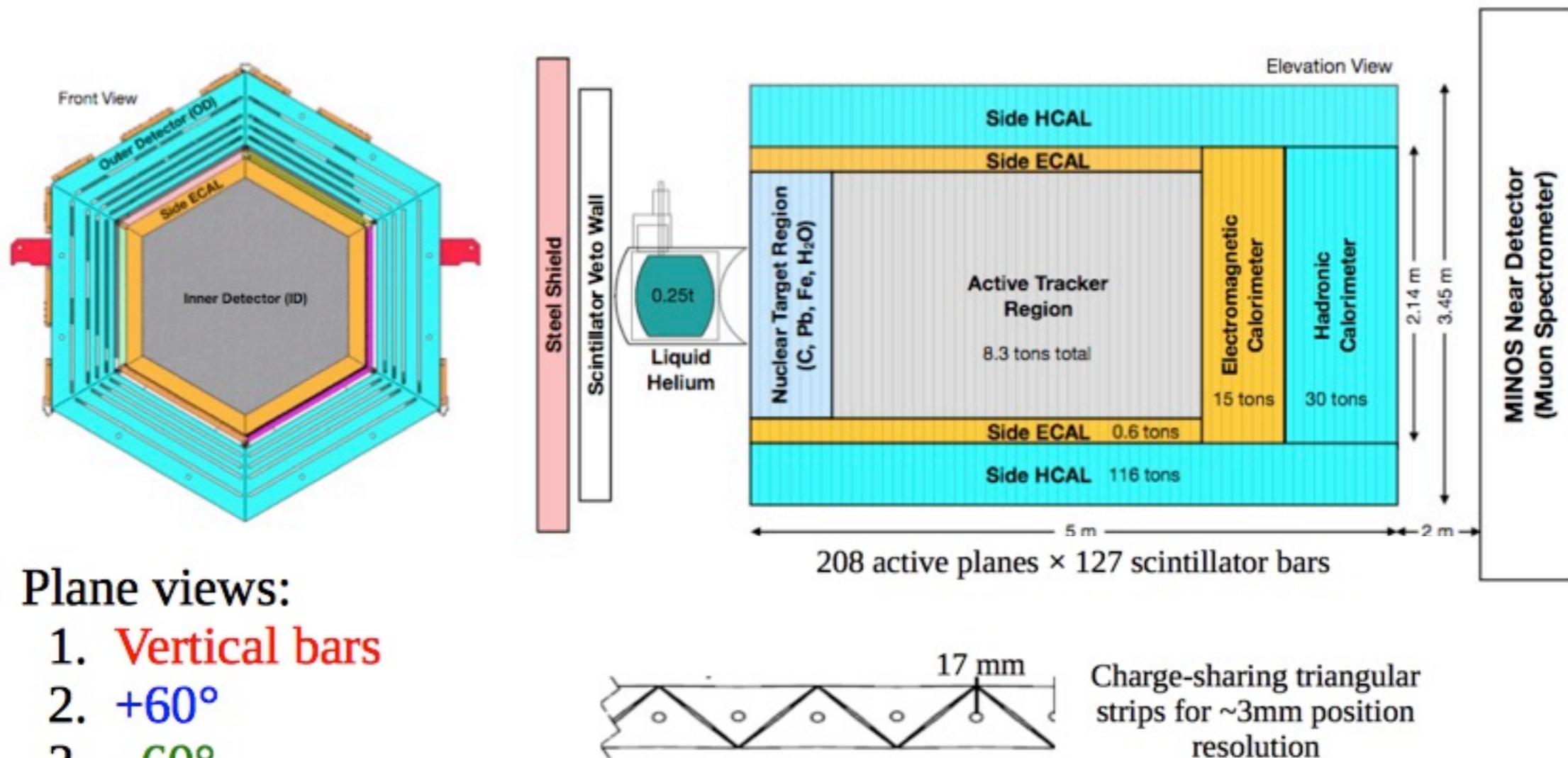


- Disagreement between MiniBooNE and H, D_2 data?
- Problem with FSI model?
- “Tension” between nucleon and nucleus data?

MINERvA

MINERvA is a neutrino scattering experiment in the NuMI beamline at Fermilab.

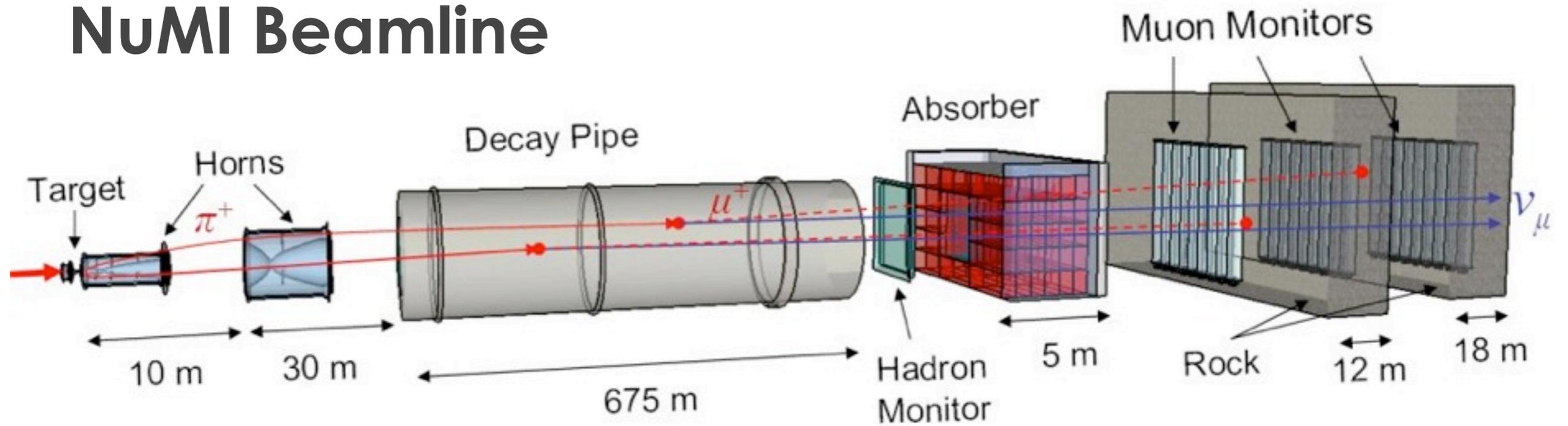
Designed to measure neutrino cross sections, final states, nuclear effects and A-dependence on a variety of targets in the few-GeV region.



Plane views:

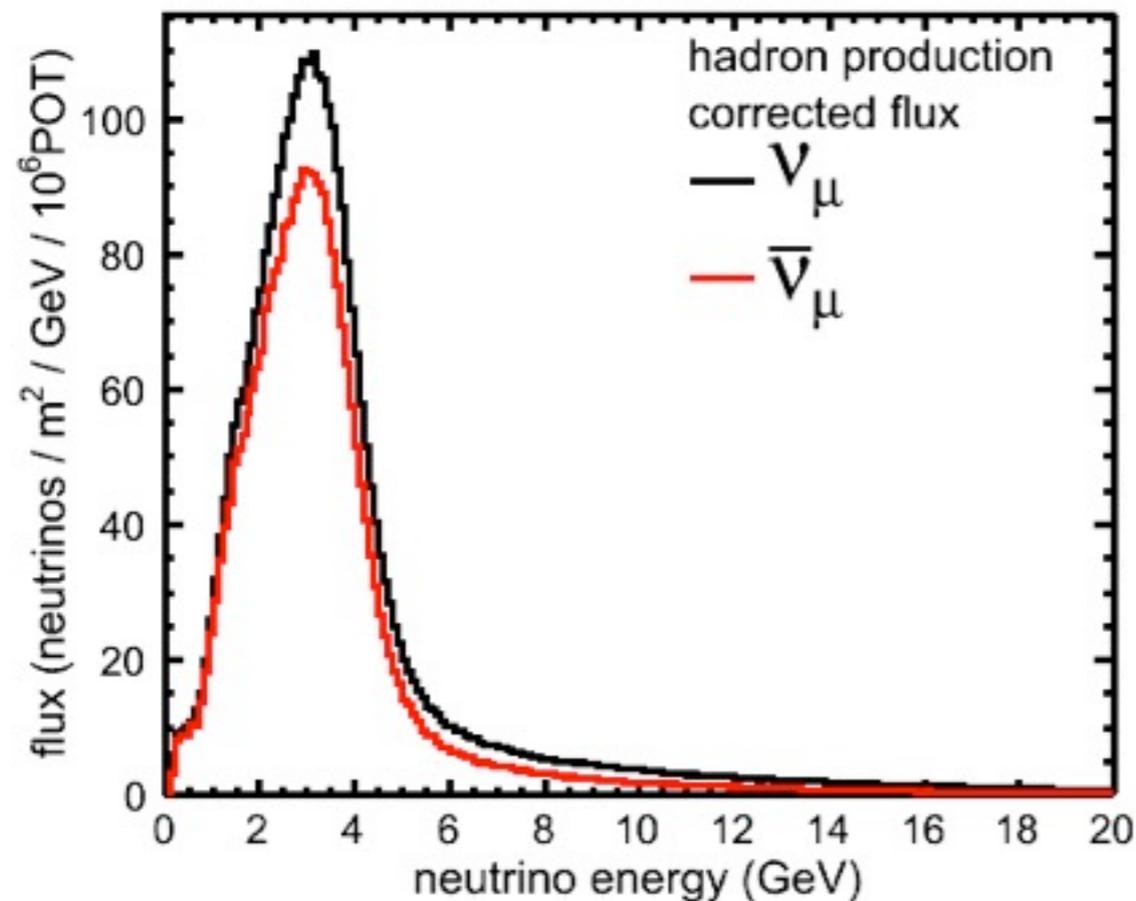
1. **Vertical bars**
2. **+60°**
3. **-60°**

NuMI Beamline



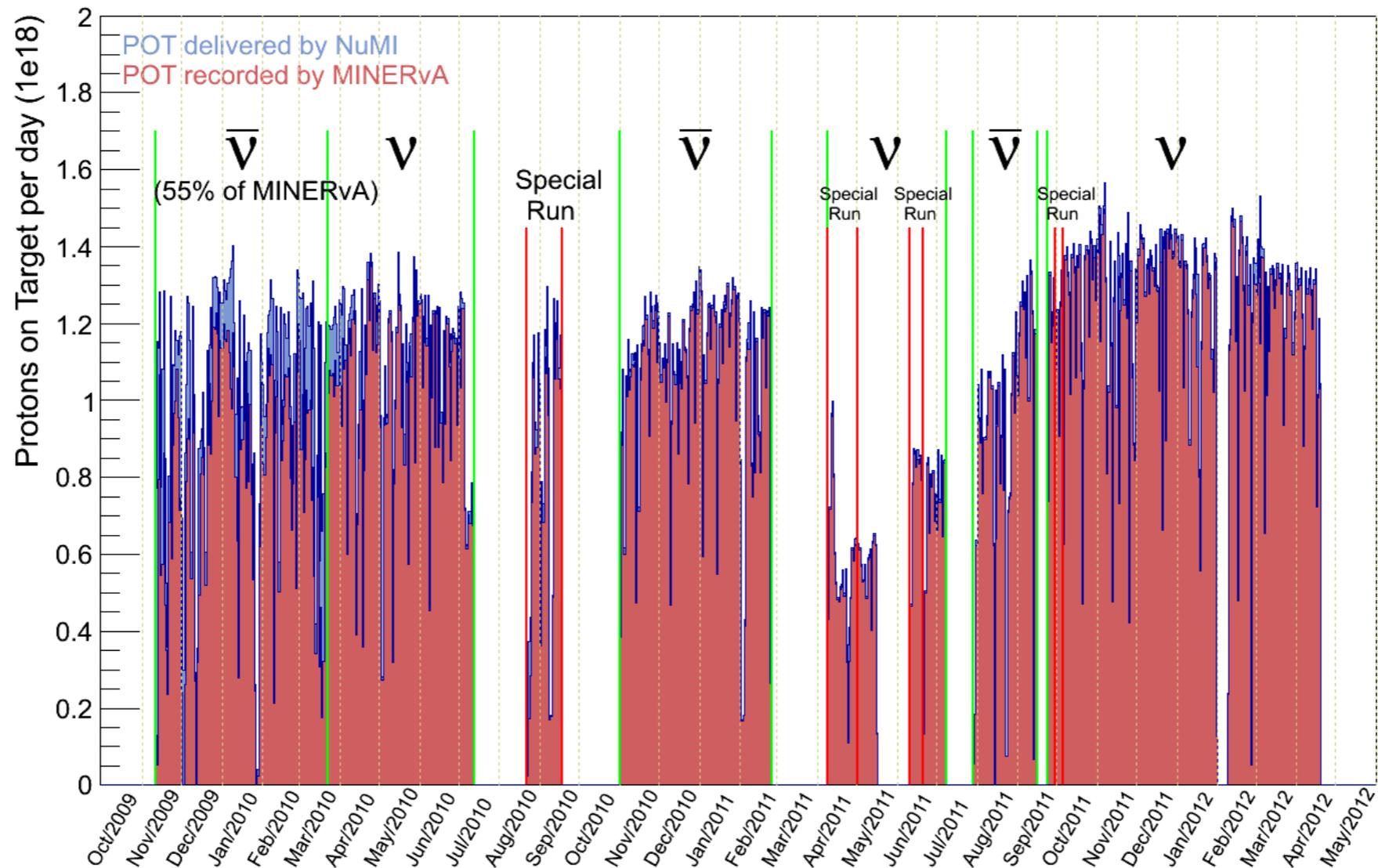
NuMI Low Energy Beam

figure courtesy Z. Pavlović



- 120 GeV/c protons from MI
- Graphite target
- Tunable spectrum
- Neutrino and Anti-Neutrinos

MINERvA Data Set (LE run)



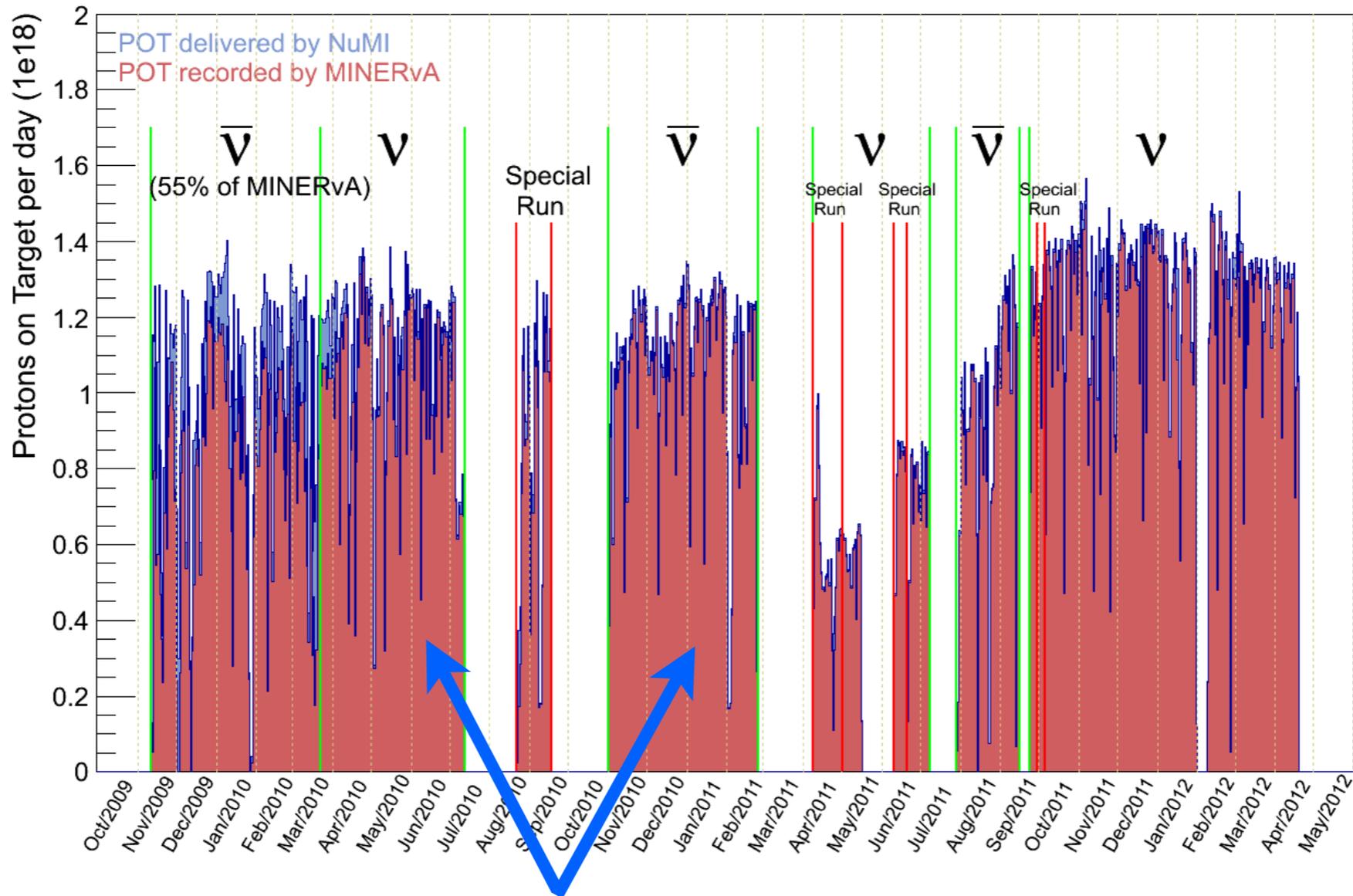
Physics data set:

3.98×10^{20} P.O.T LE Neutrino mode

1.7×10^{20} P.O.T LE Anti-Neutrino mode

Detector live time > 97.0%

MINERvA Data Set (LE run)

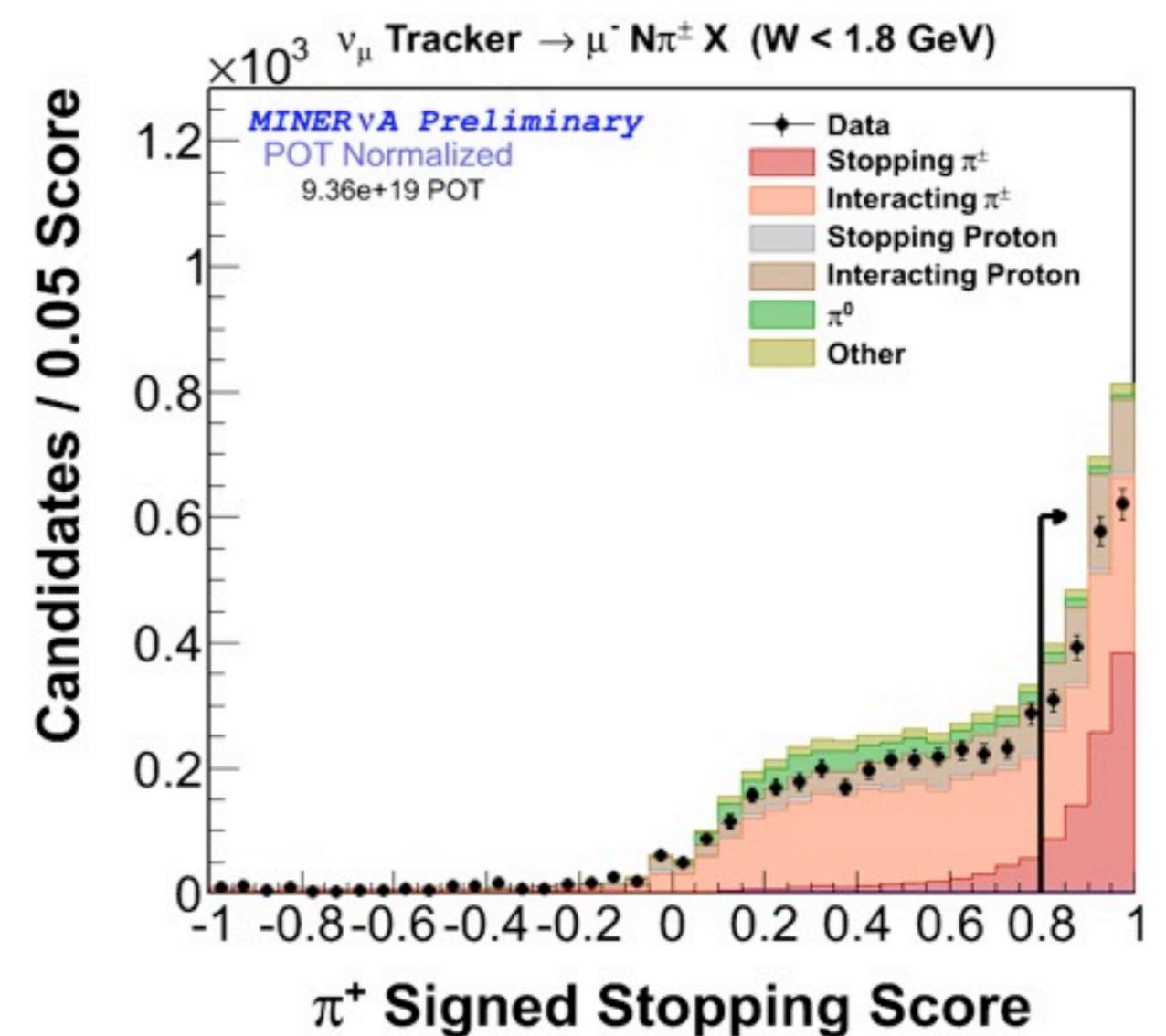
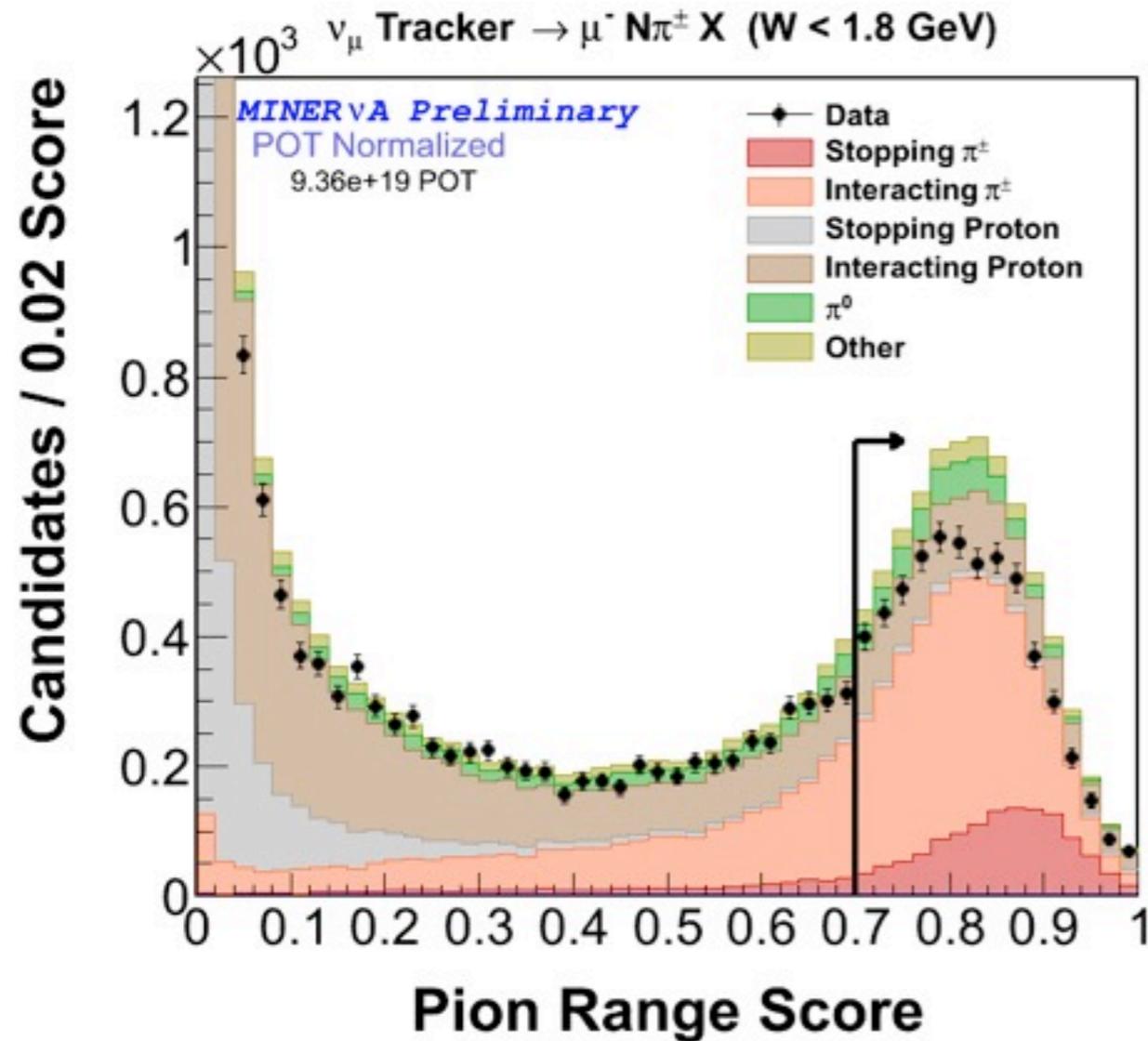


Today's Results

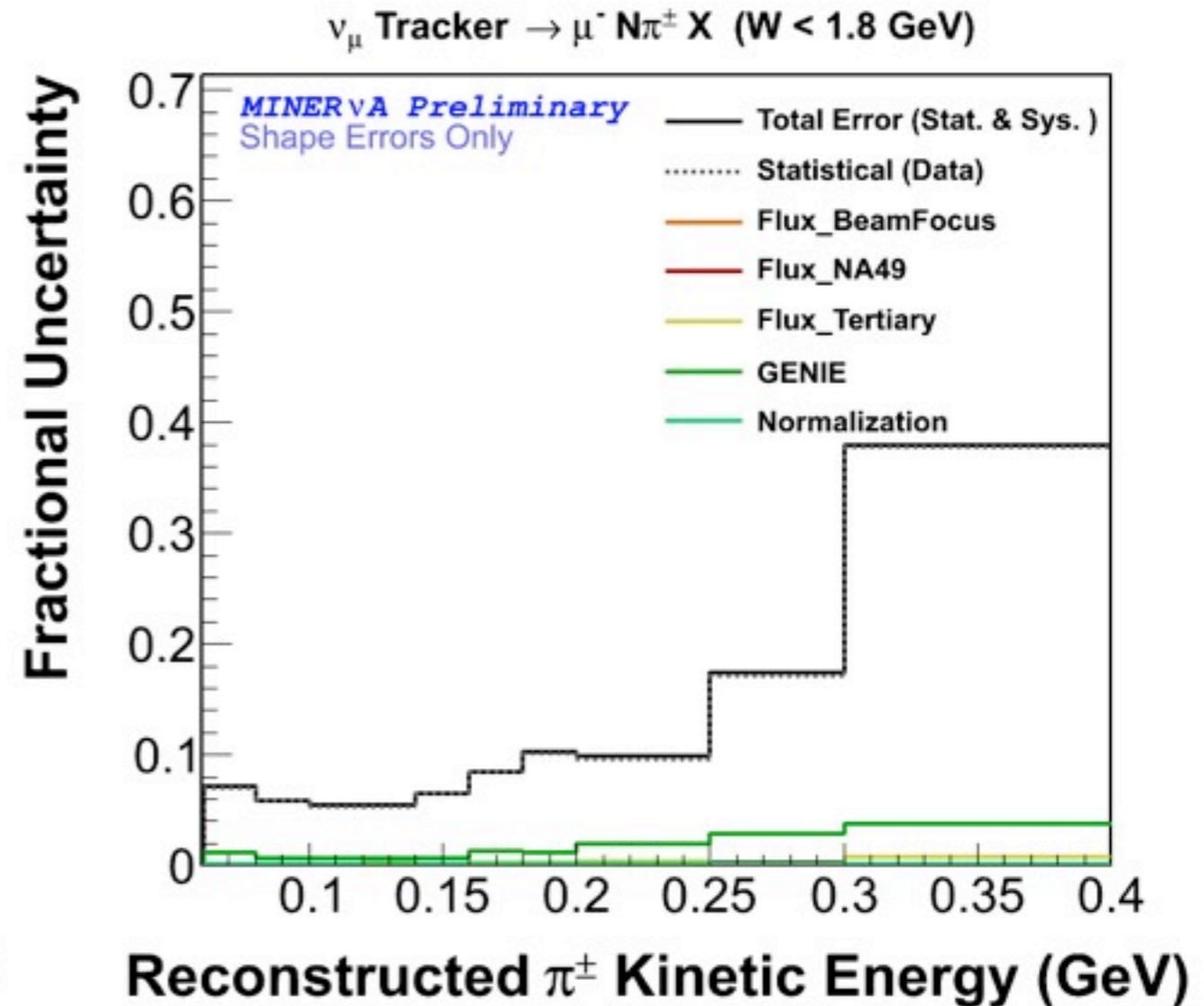
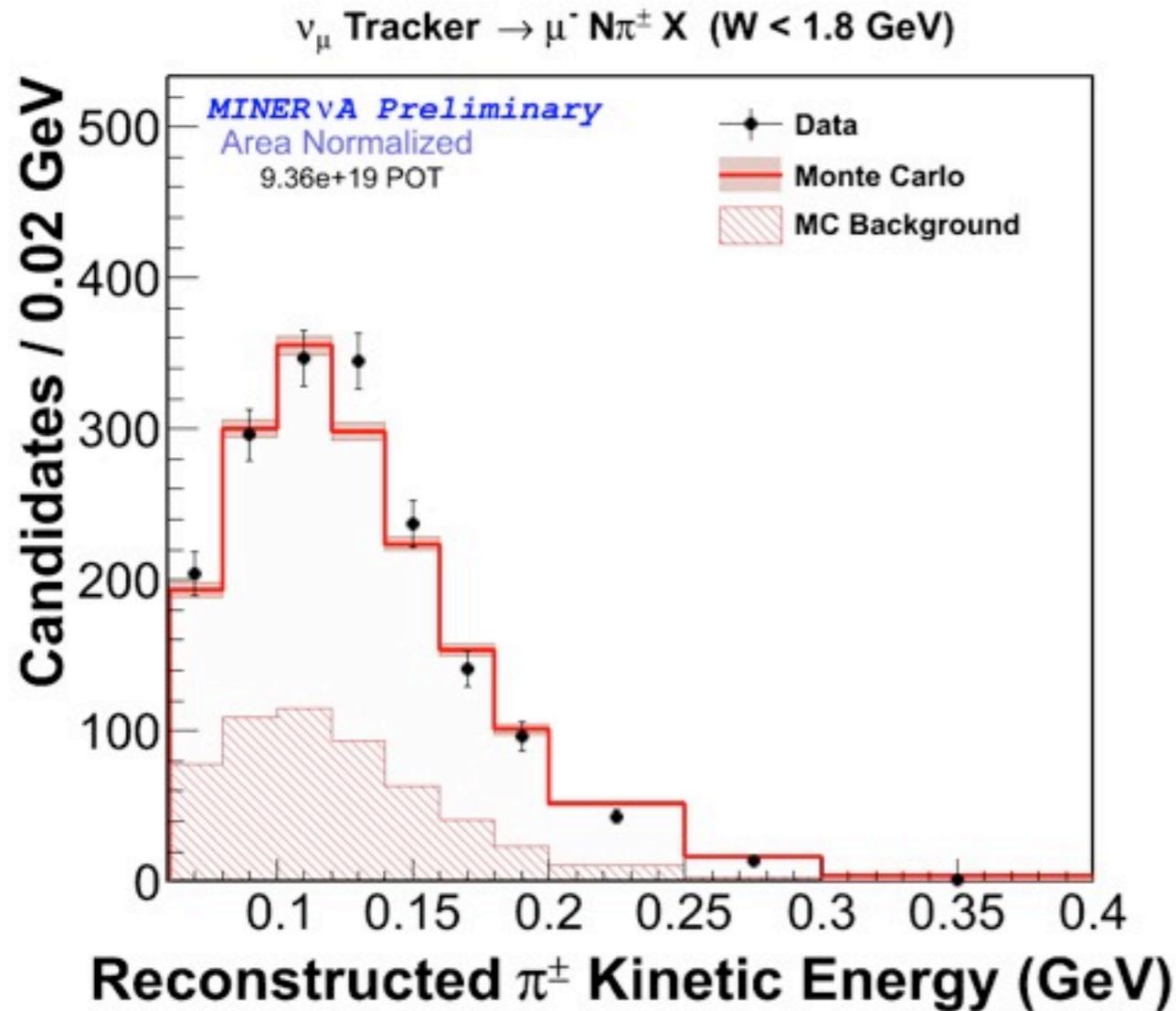
CC Inclusive Pion Production by Neutrinos

- Signal definition
 - FV tracker CH
 - μ^- MINOS-matched track
 - At least $1\pi^\pm$ in the final state

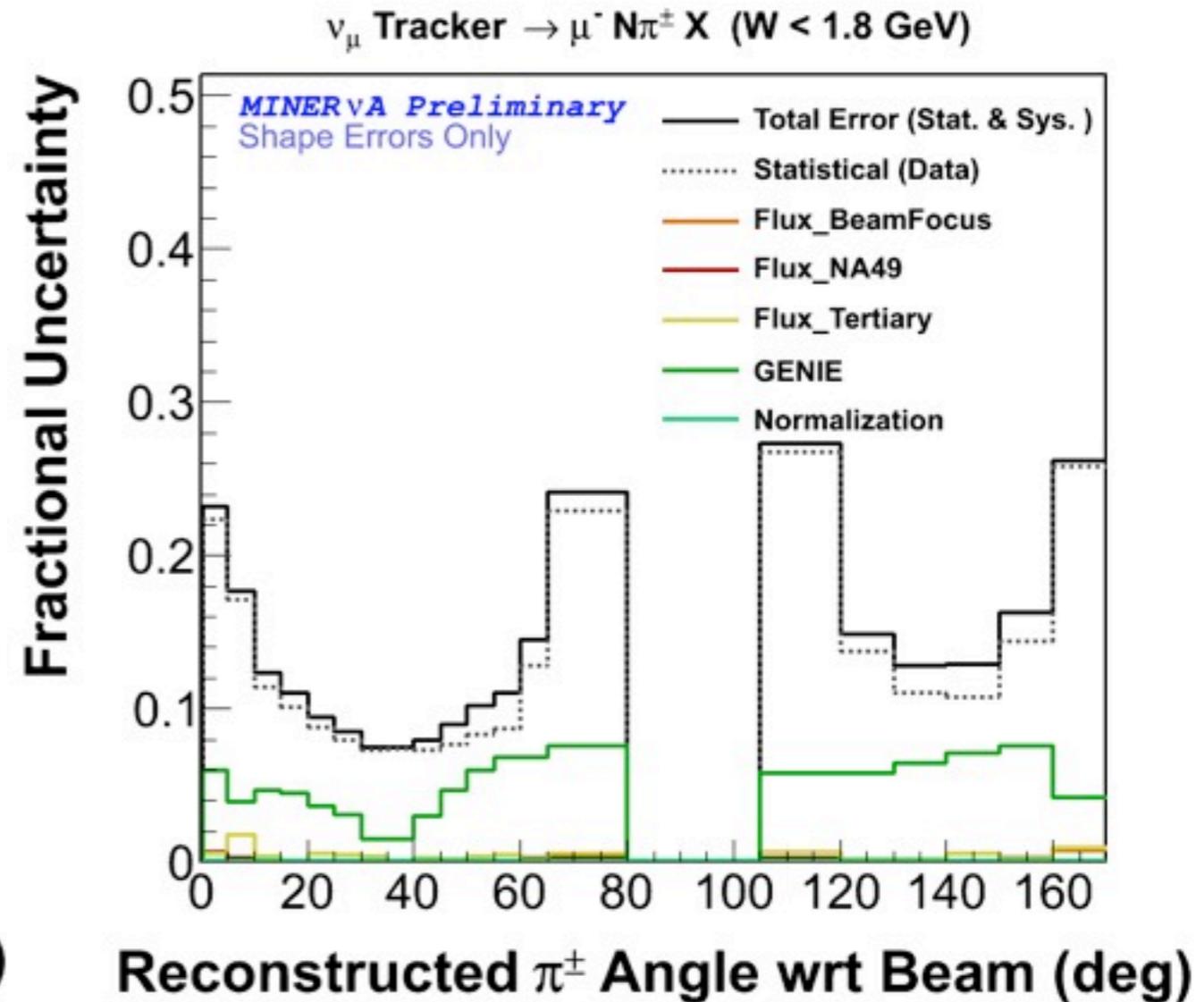
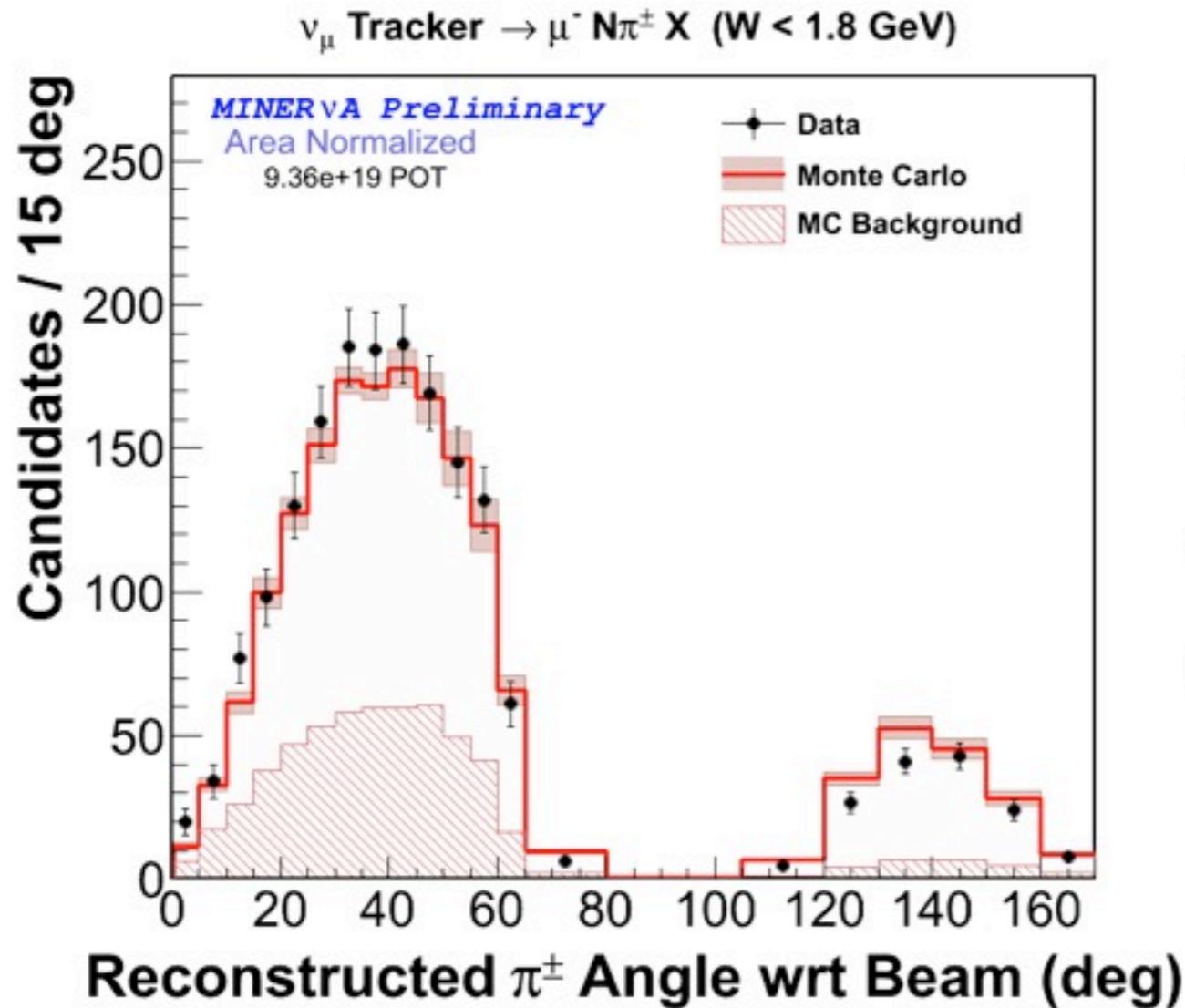
- 41.7 % efficiency
- 80.3 % purity



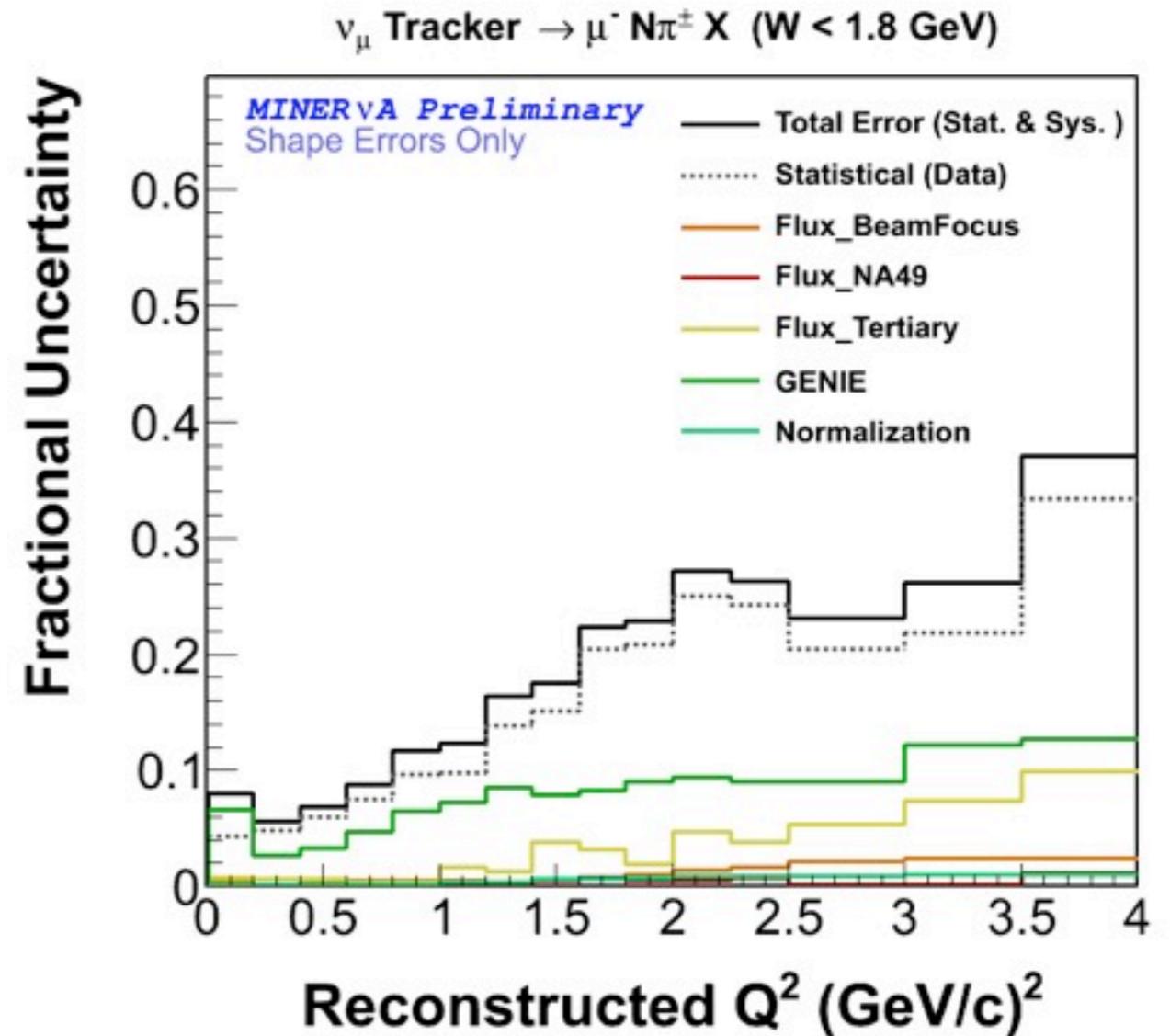
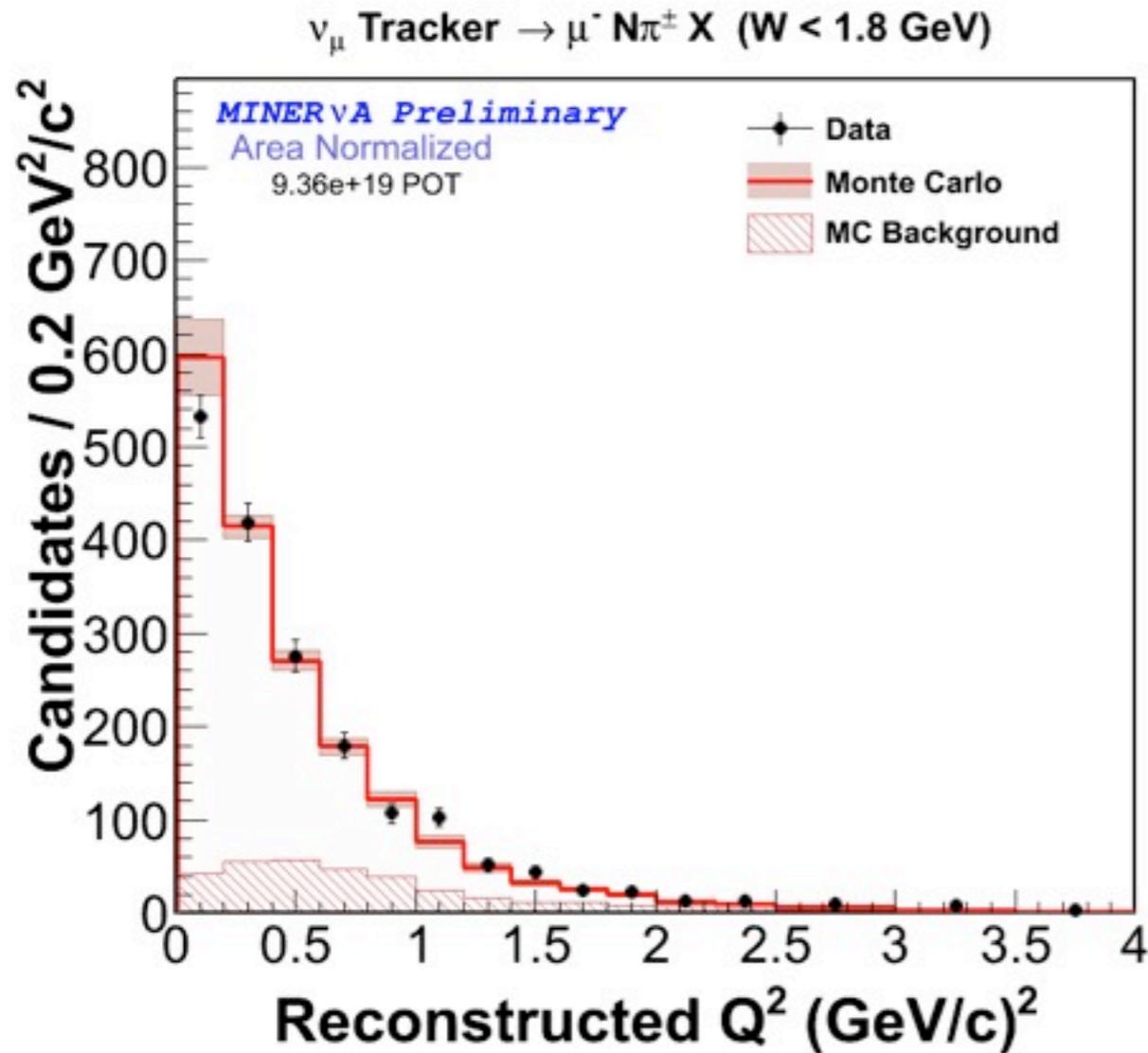
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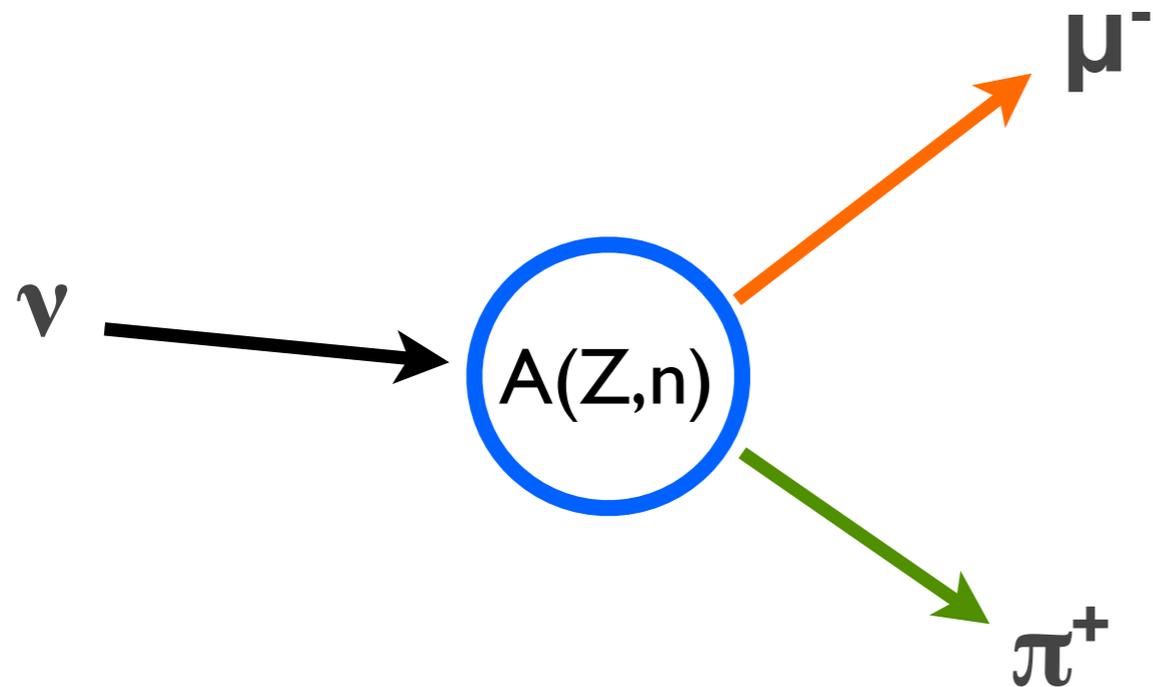
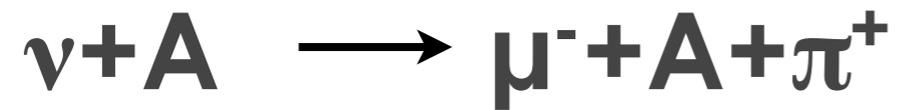
CC Inclusive Pion Production by Neutrinos



CC Inclusive Pion Production by Neutrinos



CC Coherent Pion Production



- Two final states particles $\mu^- + \pi^+$
- Small Q^2
- Nucleus remains in its ground state
- Small $t = (q - p_\pi)^2$

PCAC Models

The reaction is generally modeled by combining the PCAC with a specific description of the pion-nucleus scattering.

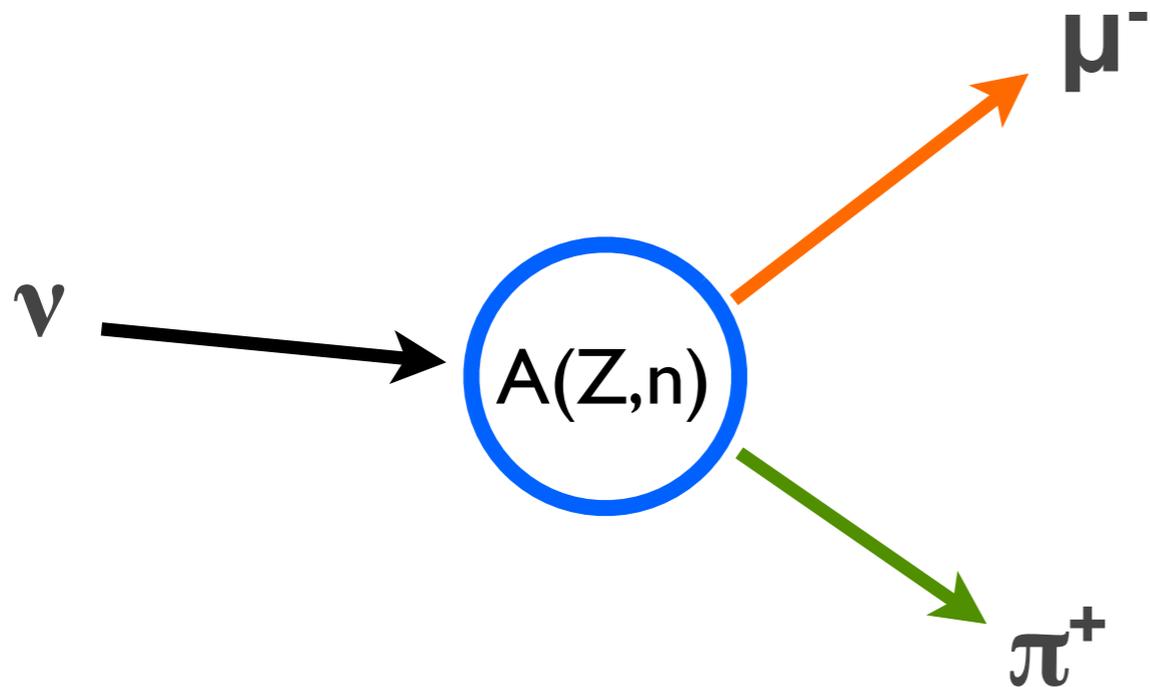
Rein-Sehgal, *Nuclear Phys B*223, 29-44 (1983).

Berger-Sehgal, *Phys. Rev. D*79, 053003 (2009).

Paschos-Schalla, *Phys. Rev. D*80, 033005 (2009).

CC Coherent Pion Production

$$\nu + A \longrightarrow \mu^- + A + \pi^+$$



- Two final states particles $\mu^- + \pi^+$
- Small Q^2
- Nucleus remains in its ground state
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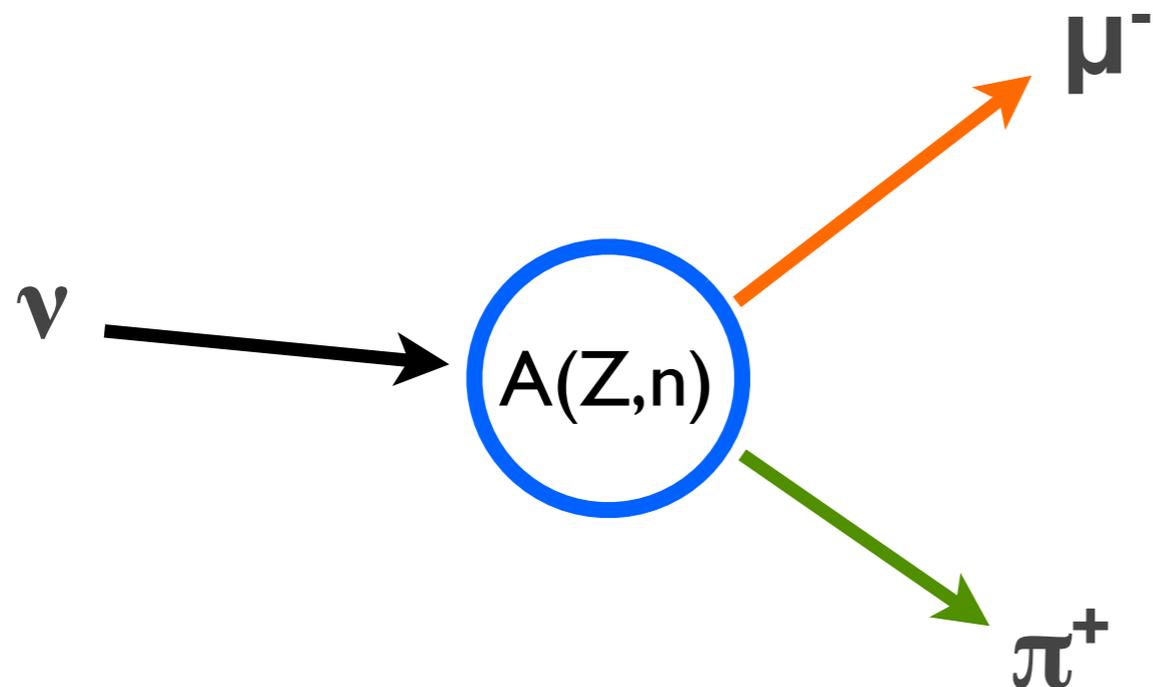
Microscopic Models

They have neutrino-nucleon pion production via resonance production (typically, Δ resonance). Distortion of the pion wave function is taken into account with a realistic optical potential.

Alvarez-Ruso et al. *Phys. Rev. C* 75, 055501 (2007).

Hernandez, Nieves et al. *Phys. Rev. D* 76, 033005 (2007).

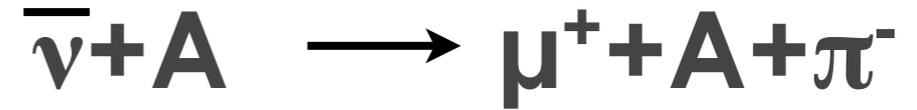
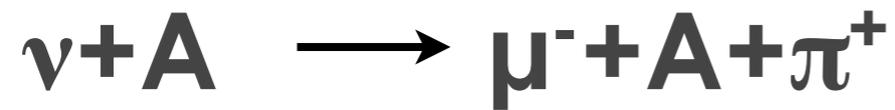
CC Coherent Pion Production



- Two final states particles $\mu^- + \pi^+$
- Small Q^2
- Nucleus remains in its ground state
- Small $t = (q - p_\pi)^2$

- Existing data from bubble chambers
- Low statistics
- Recent measurements could not find evidence at very low neutrino energies K2K (Phys. Rev. Lett 95) & SciBooNE (Phys. Rev. D78)
- Applications
 - NC case is one of the key background for ν_e appearance
 - Coherent pion production can be used to determine the divergence of neutrino beams

CC Coherent Pion Production

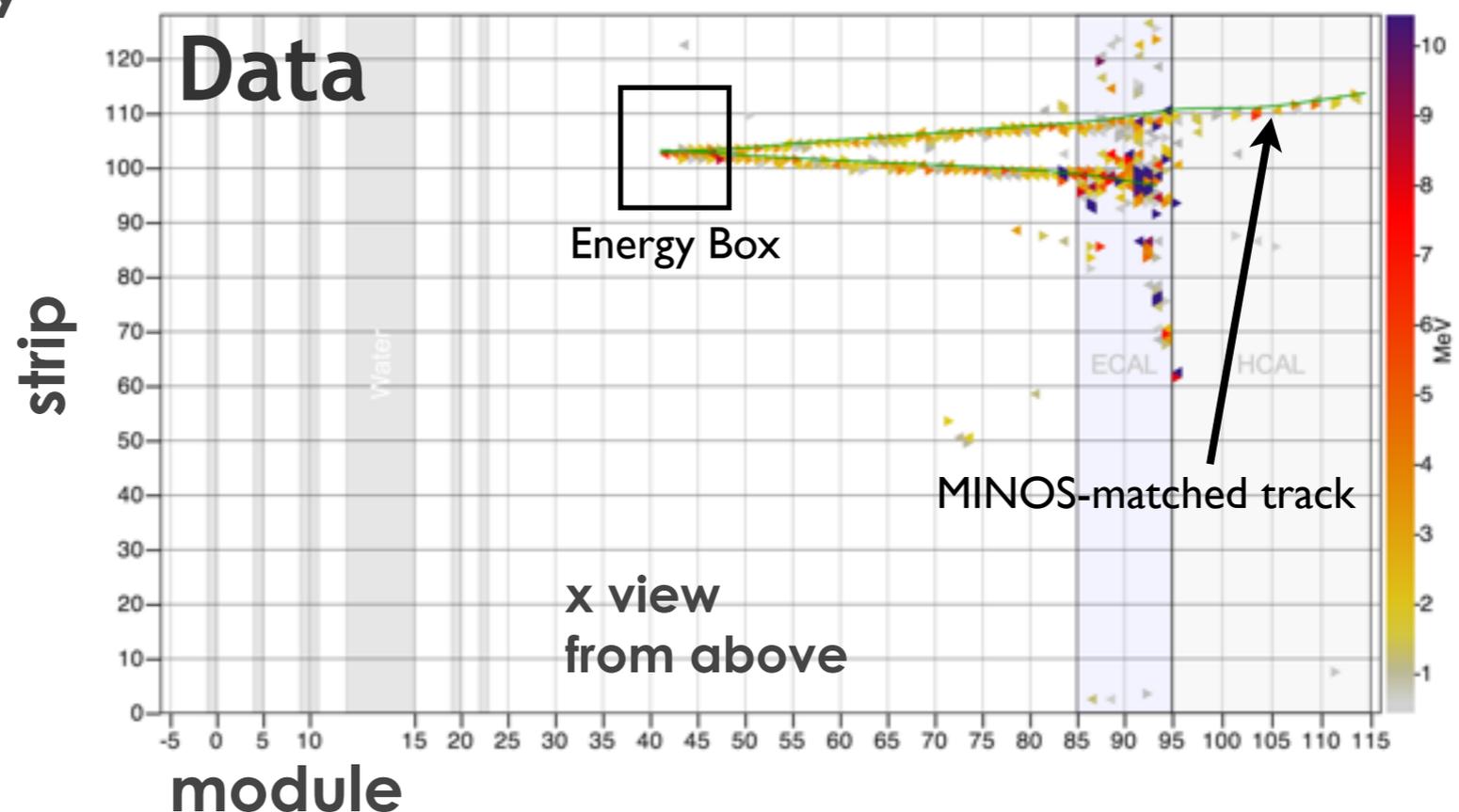


- Signal definition

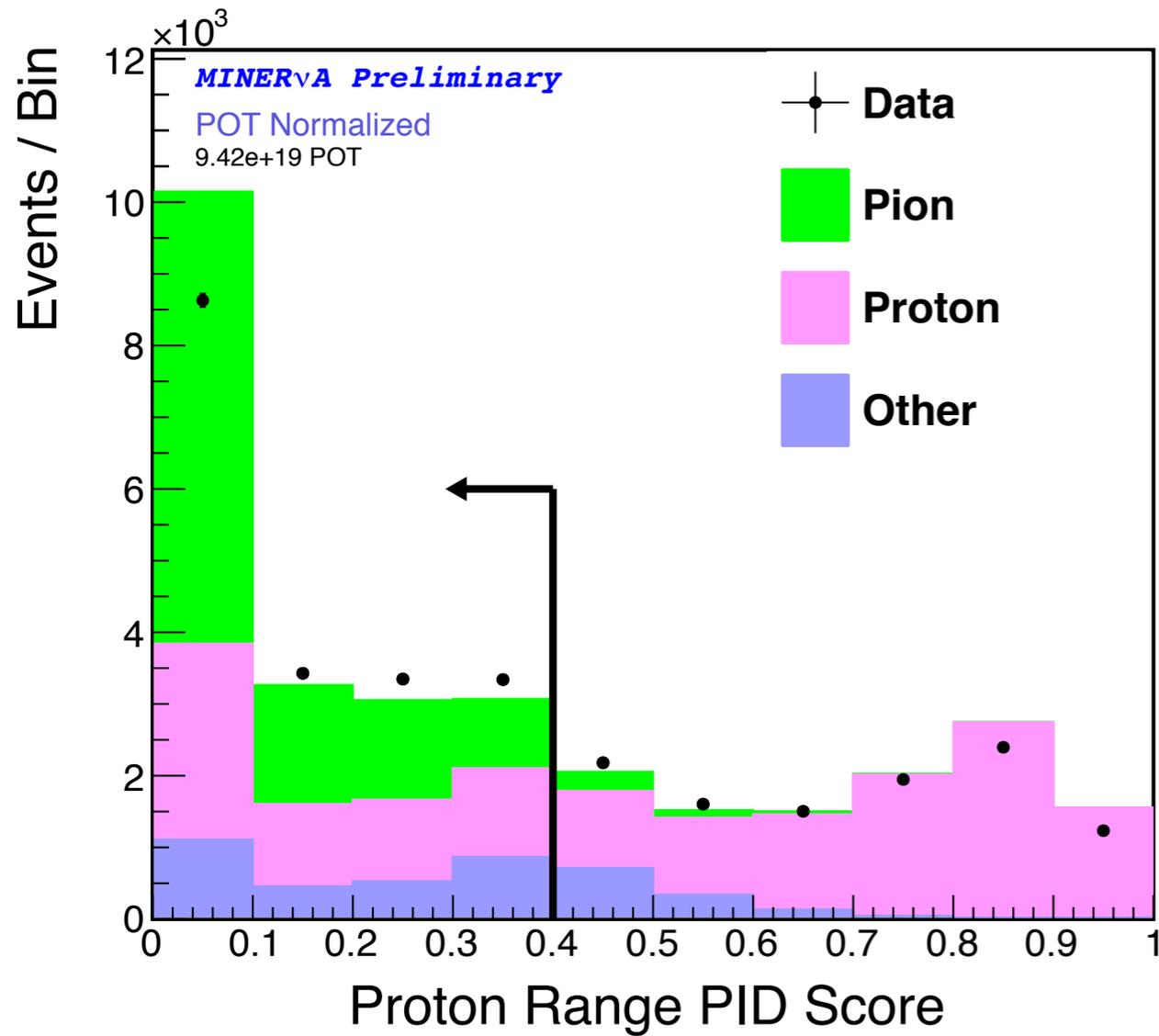
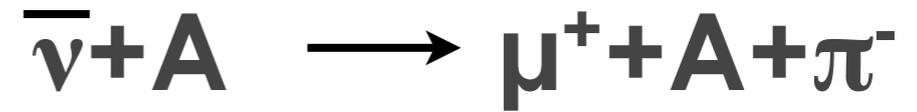
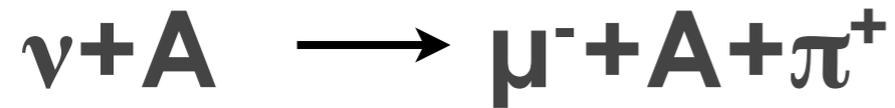
- FV tracker CH
- μ^- MINOS-matched track
- No proton
- Low Q^2
- No vertex energy
- Low $t = (q - p_\pi)^2$

- Signal definition

- FV tracker CH
- μ^+ MINOS-matched track
- No vertex energy
- Low $t = (q - p_\pi)^2$

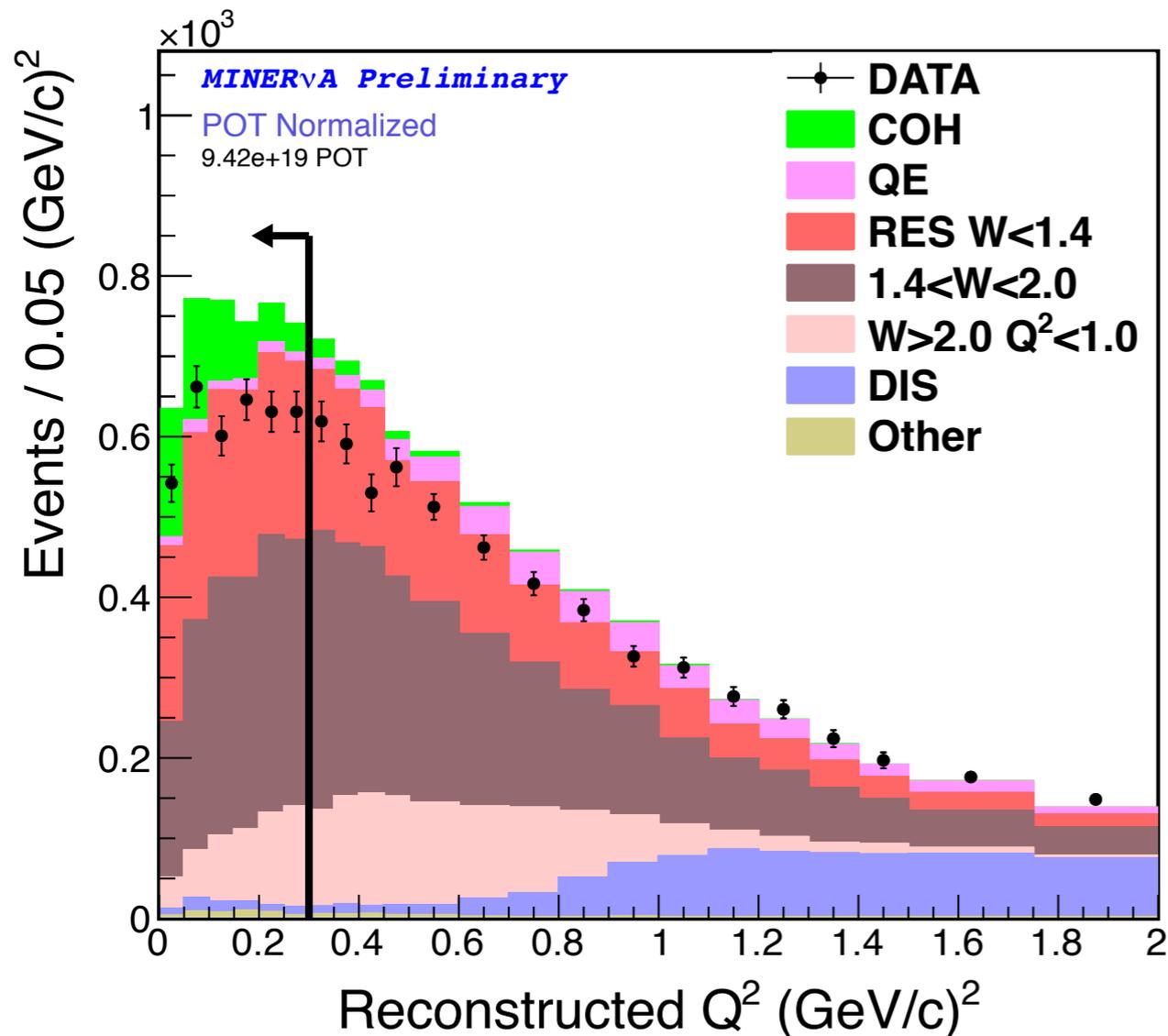
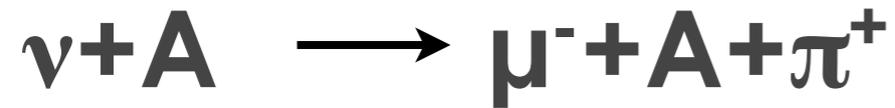


CC Exclusive Pion Production (Coherent)



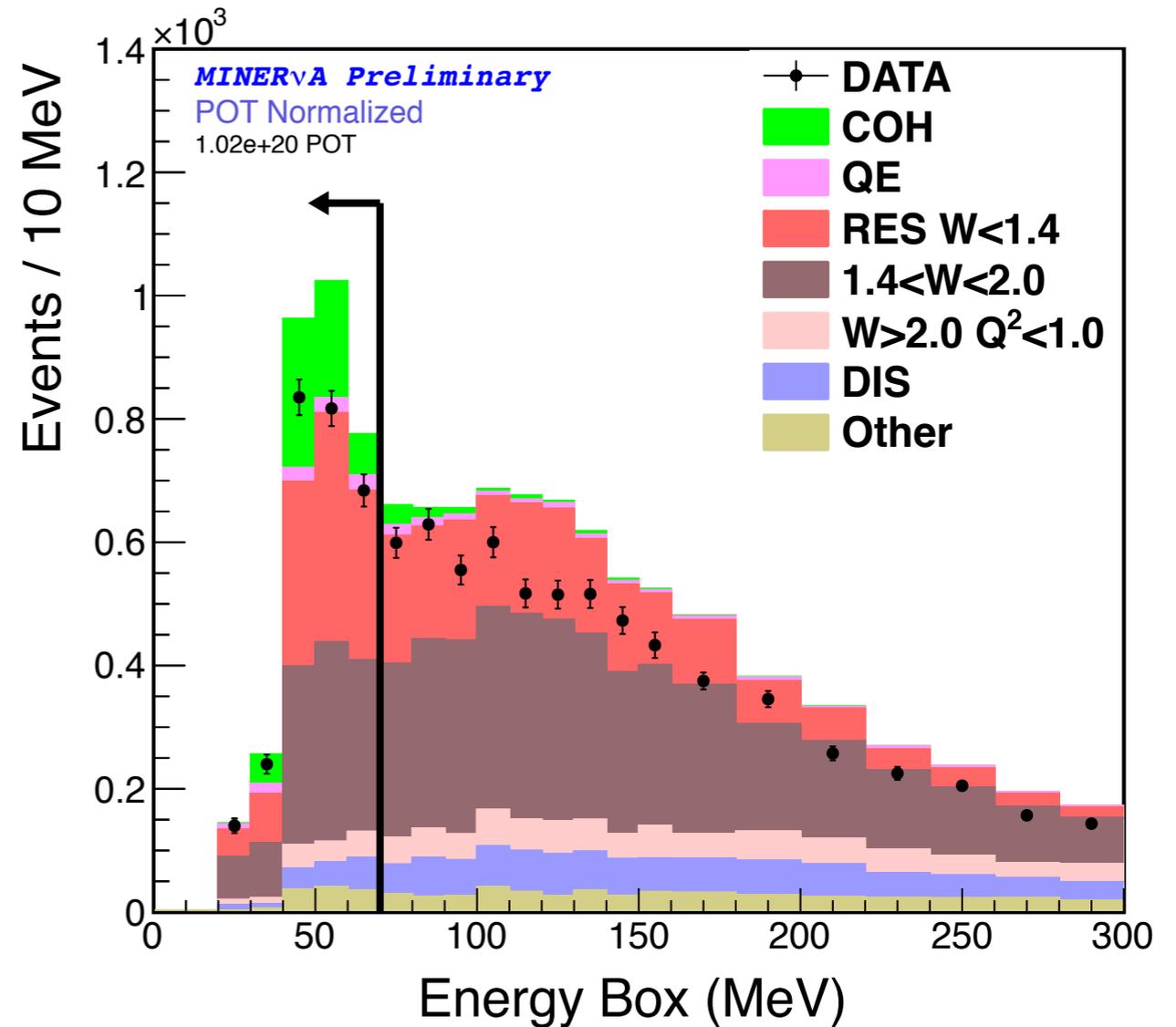
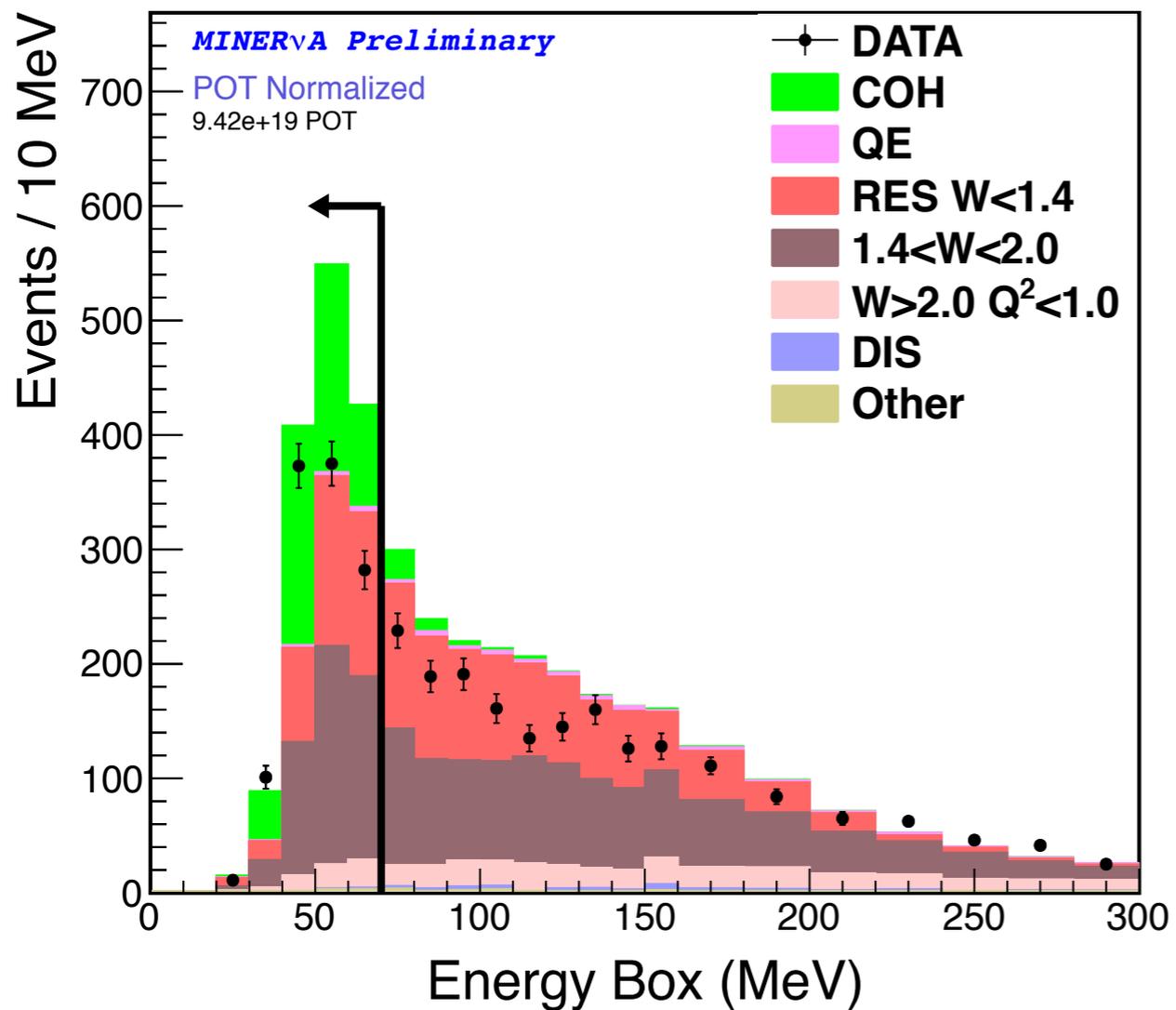
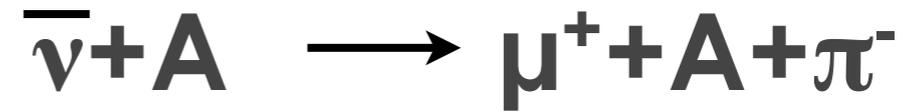
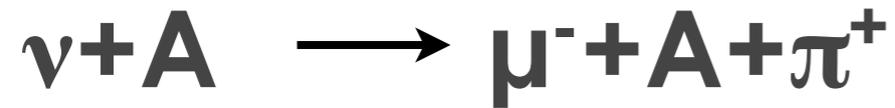
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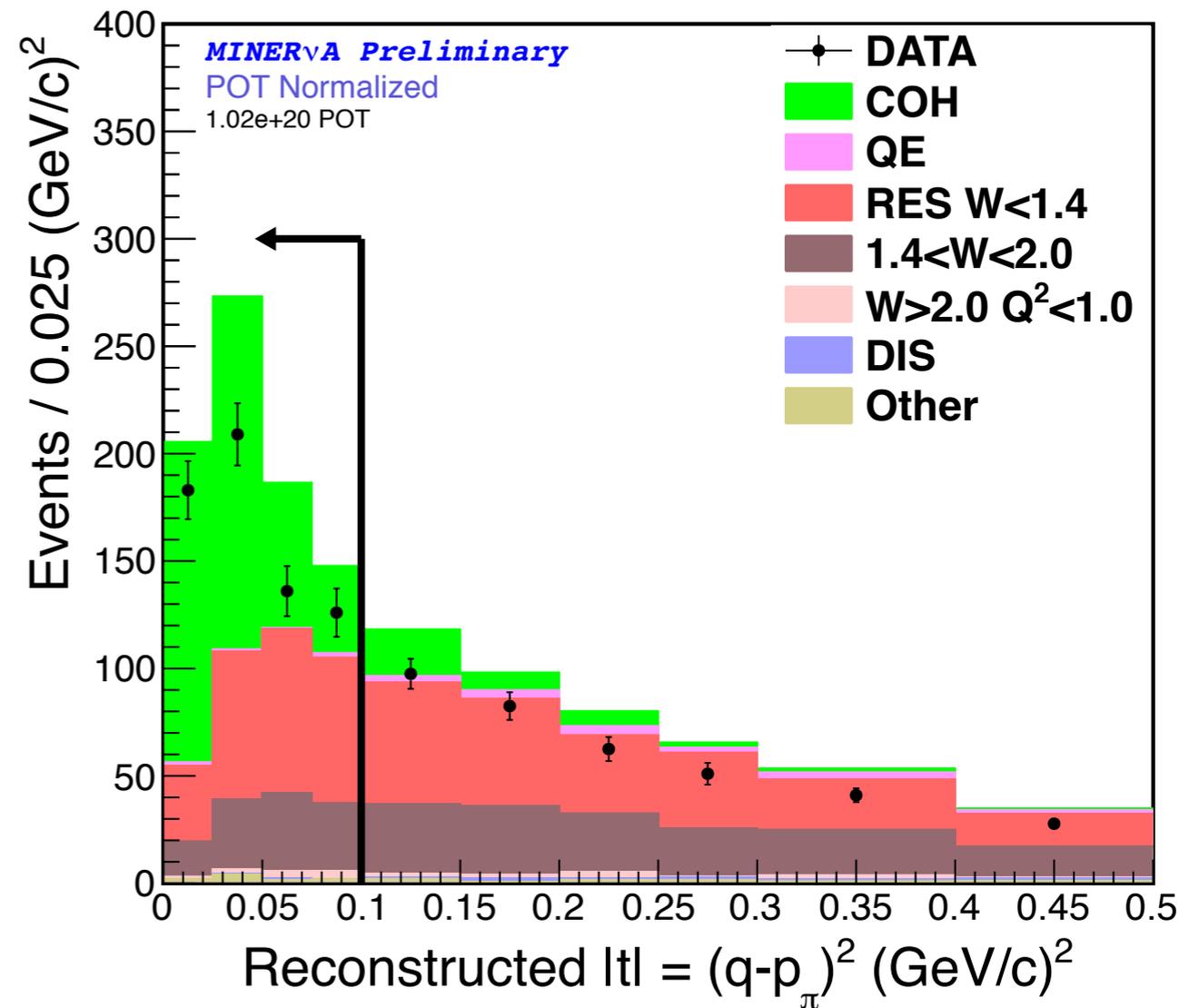
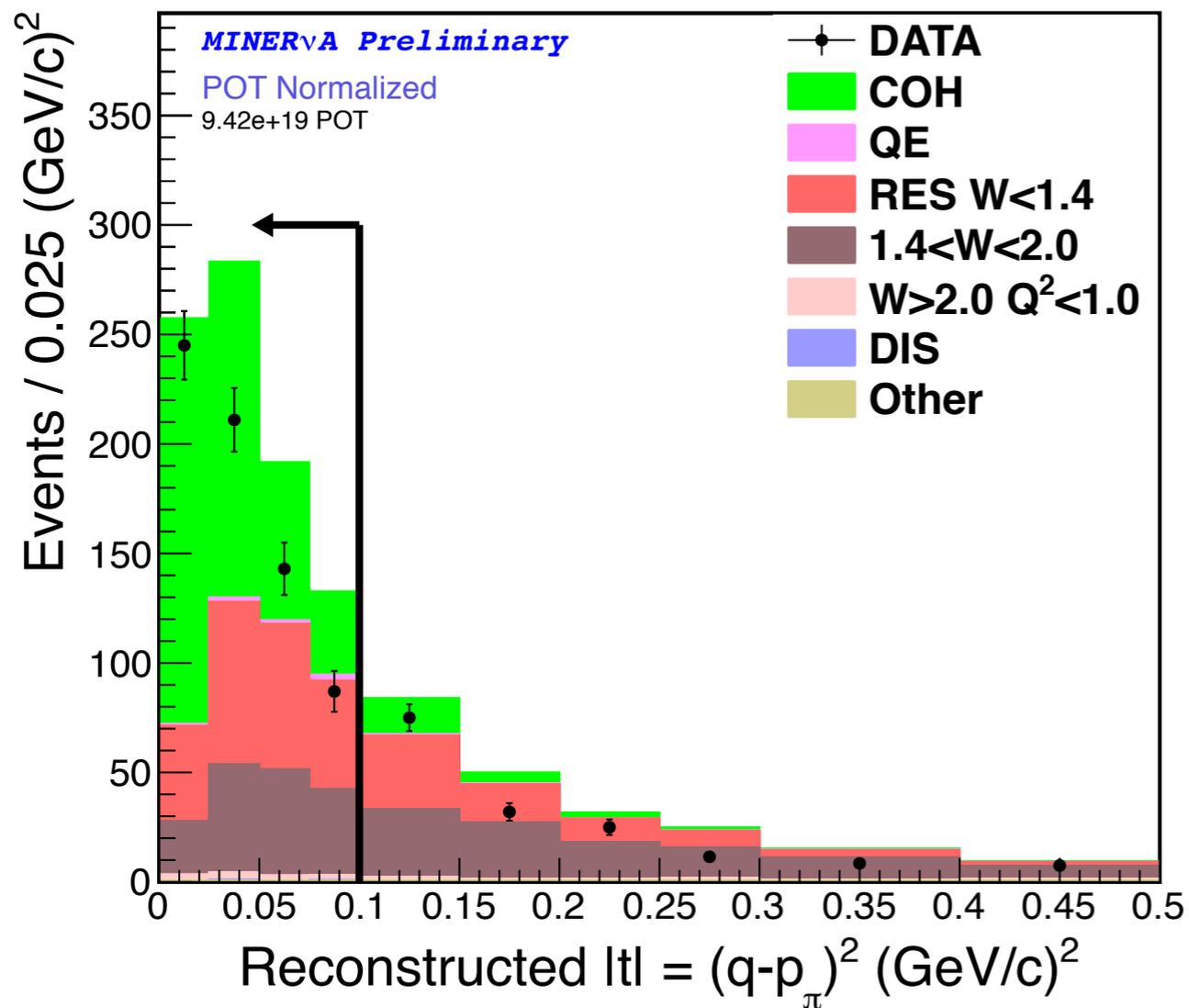
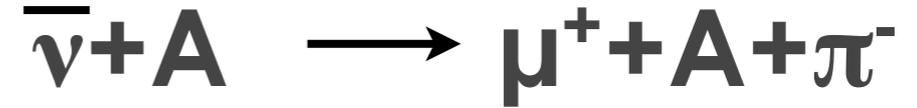
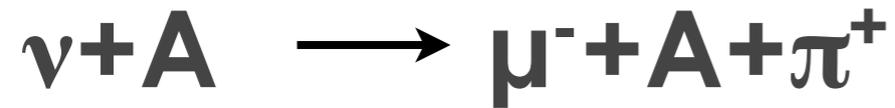


- Signal definition
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 - Low $t = (q - p_\pi)^2$

CC Exclusive Pion Production (Coherent)



CC Exclusive Pion Production (Coherent)



Summary



- **MINERvA has the capability of studying inclusive, exclusive and coherent pion production by neutrinos and anti-neutrinos**
- **MINERvA will provide high statistics results**
- **Need to investigate A-dependence of inclusive and exclusive pion production using one single detector**
- **First evaluation of systematic errors**
- **Δ -rich sub sample could be used to measure resonance form factor parameters**
- ***Stay tuned for results soon!!!***

The MINERvA Collaboration



University of Athens, Athens, Greece
Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
UC Irvine, Irvine, CA
University of Chicago, Chicago, IL
Fermi National Accelerator Laboratory, Batavia, IL
University of Florida, Gainesville, FL
Université de Genève, Genève, Switzerland
Universidad de Guanajuato, Guanajuato, Mexico
Hampton University, Hampton, VA
Inst. Nucl. Reas. Moscow, Russia
Mass. Col. Lib. Arts, North Adams, MA
University of Minnesota-Duluth, Duluth, MN
Northwestern University, Evanston, IL
Otterbein College, Westerville, OH
University of Pittsburgh, Pittsburgh, PA
Pontificia Universidad Católica del Perú, Lima, Peru
University of Rochester, Rochester, NY
Rutgers University, Piscataway, NJ
Universidad Técnica Federico Santa María, Valparaíso, Chile
University of Texas, Austin, TX
Tufts University, Medford, MA
Universidad Nacional de Ingeniería, Lima, Peru
College of William & Mary, Williamsburg, VA



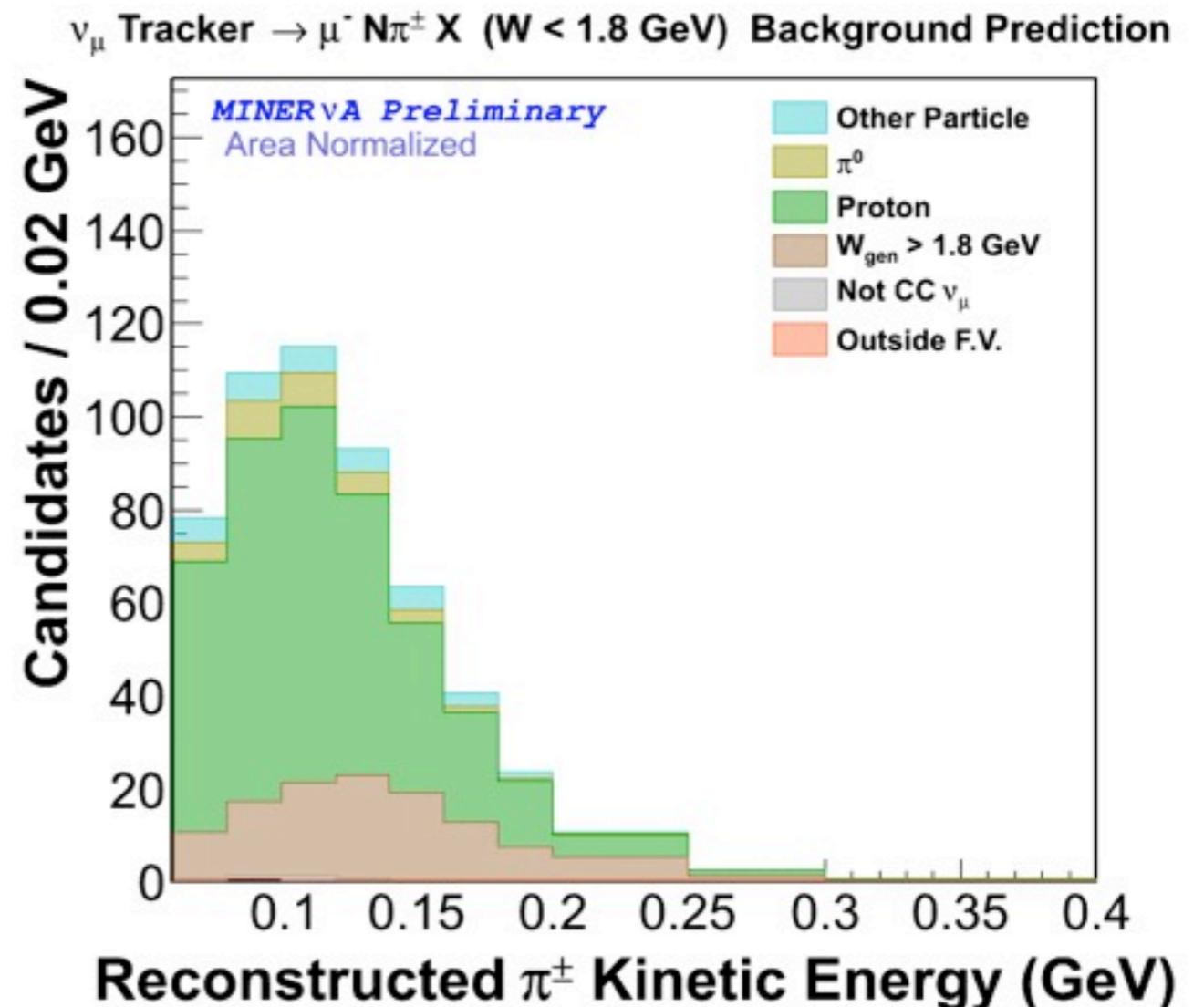
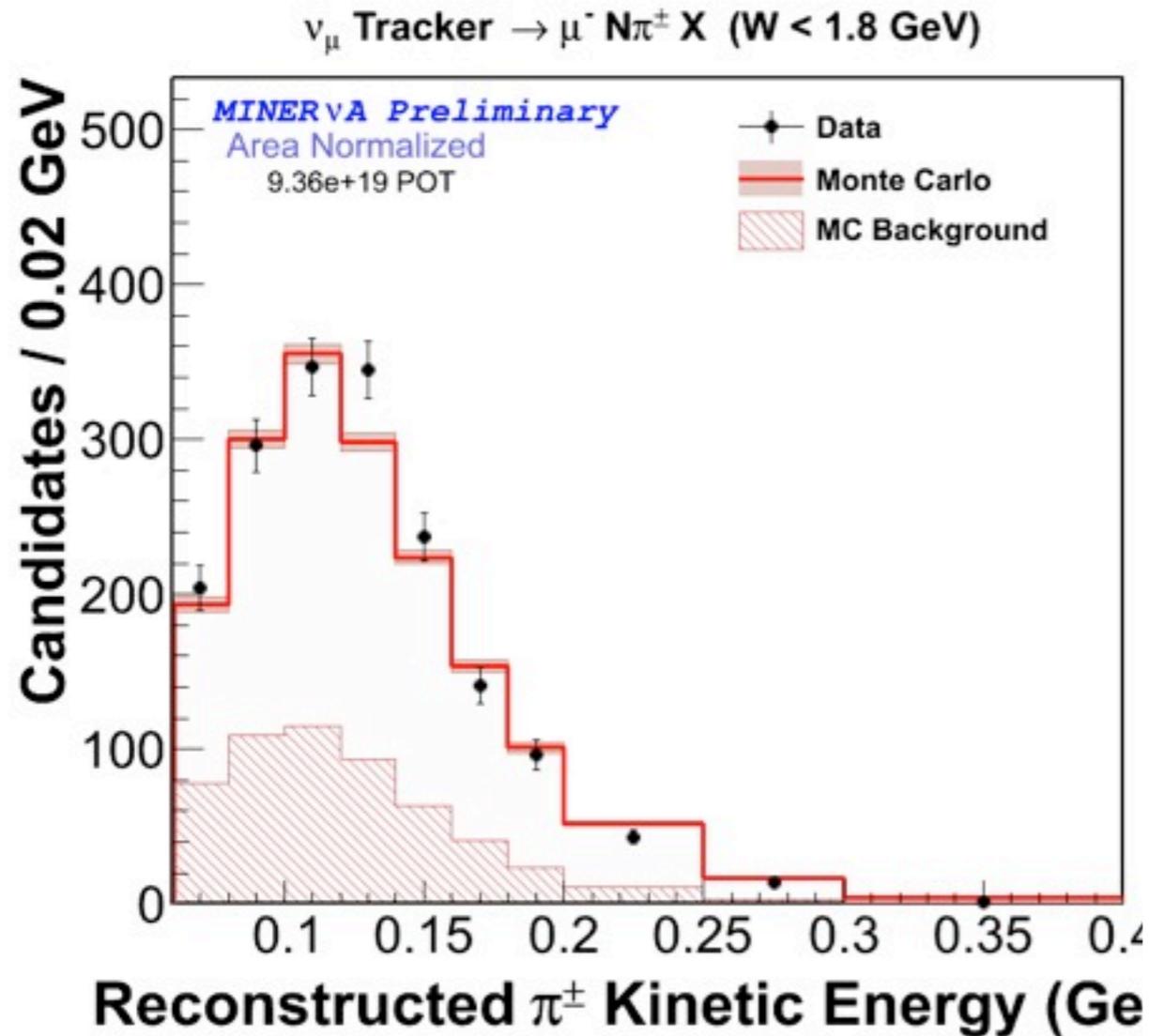
Thank you for listening

Back-up Slides

CC Inclusive Pion Production by Neutrinos

- Signal definition
 - FV tracker CH
 - μ^- MINOS-matched track
 - At least $1\pi^\pm$ in the final state

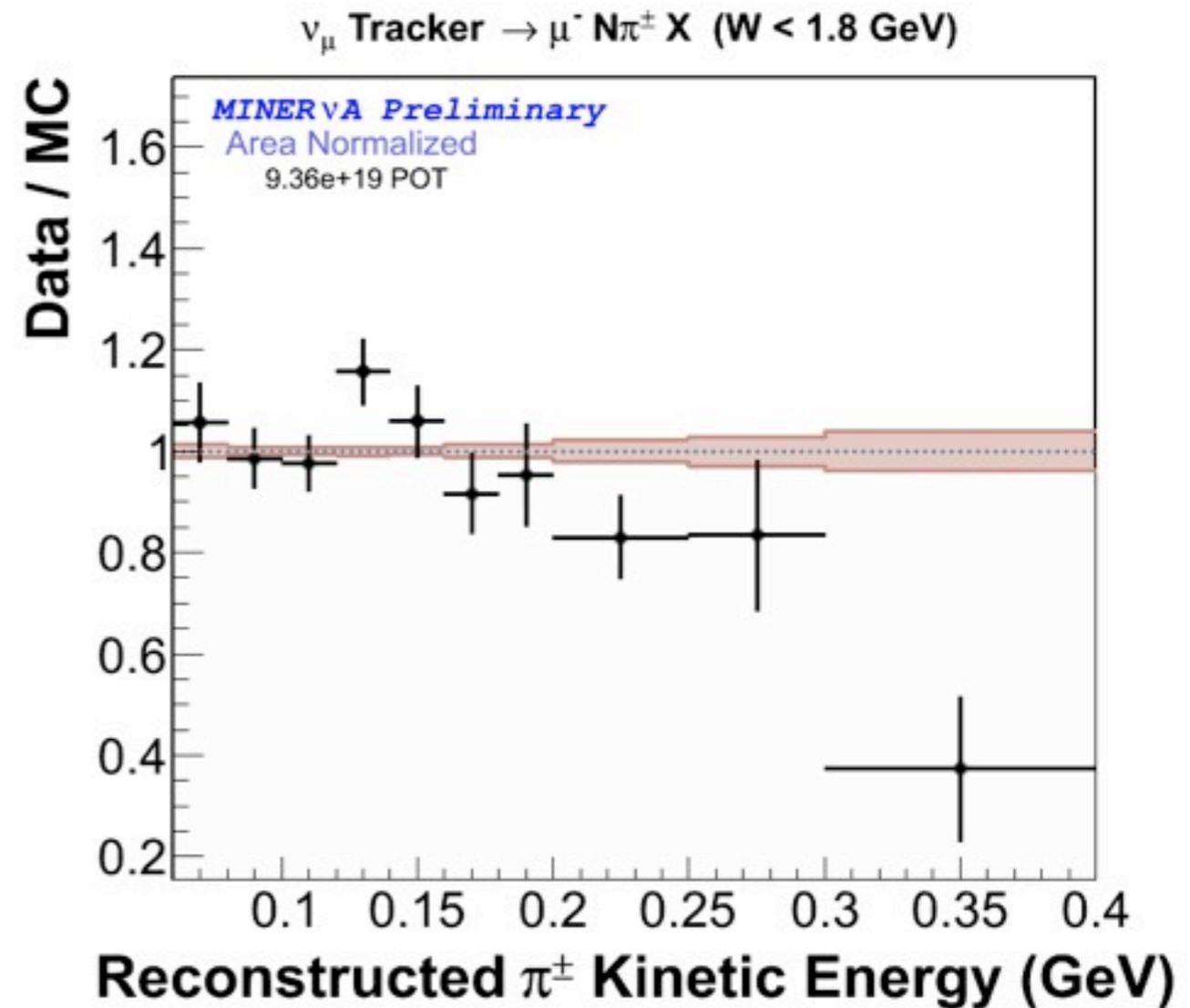
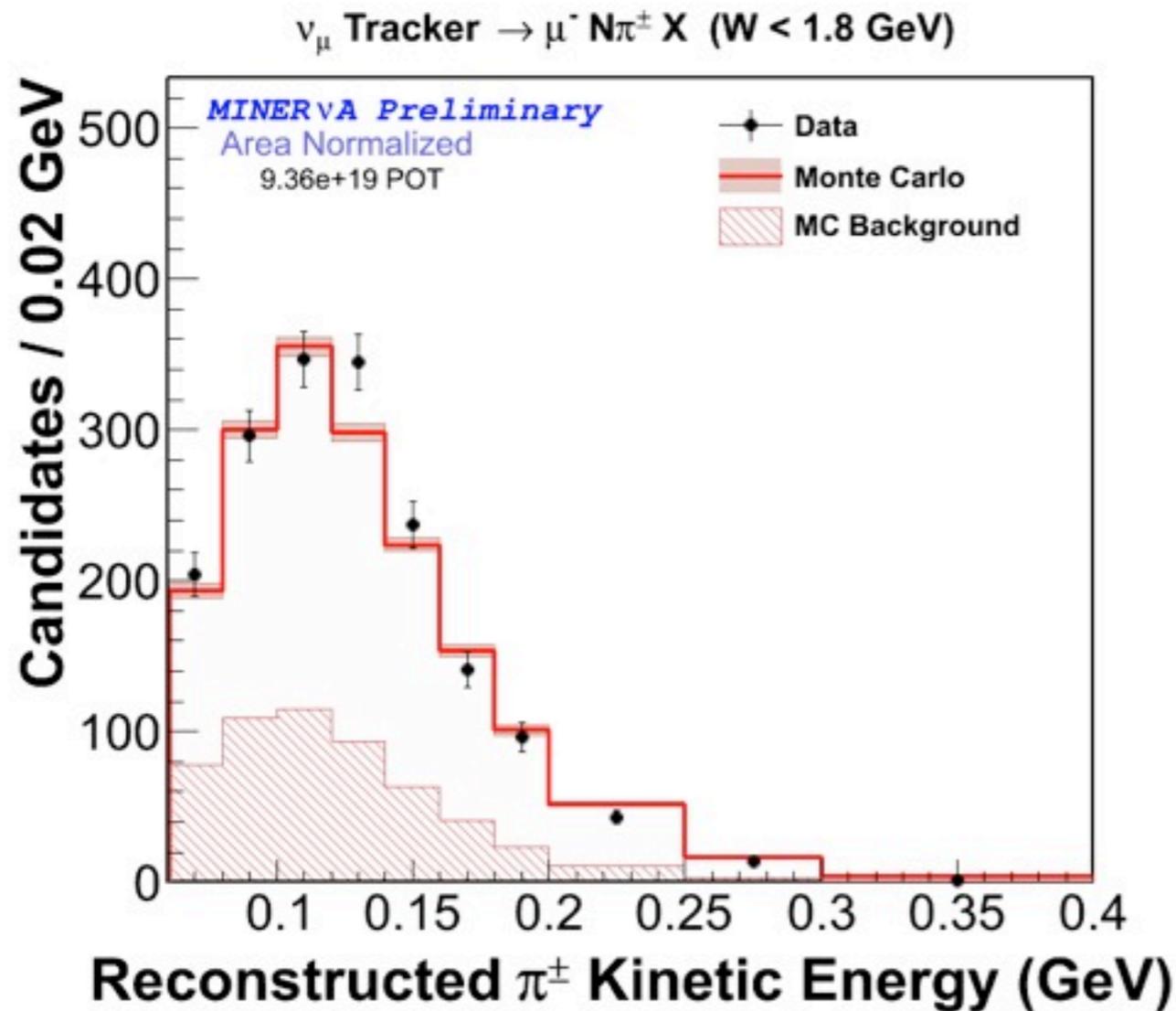
- 41.7 % efficiency
- 80.3 % purity



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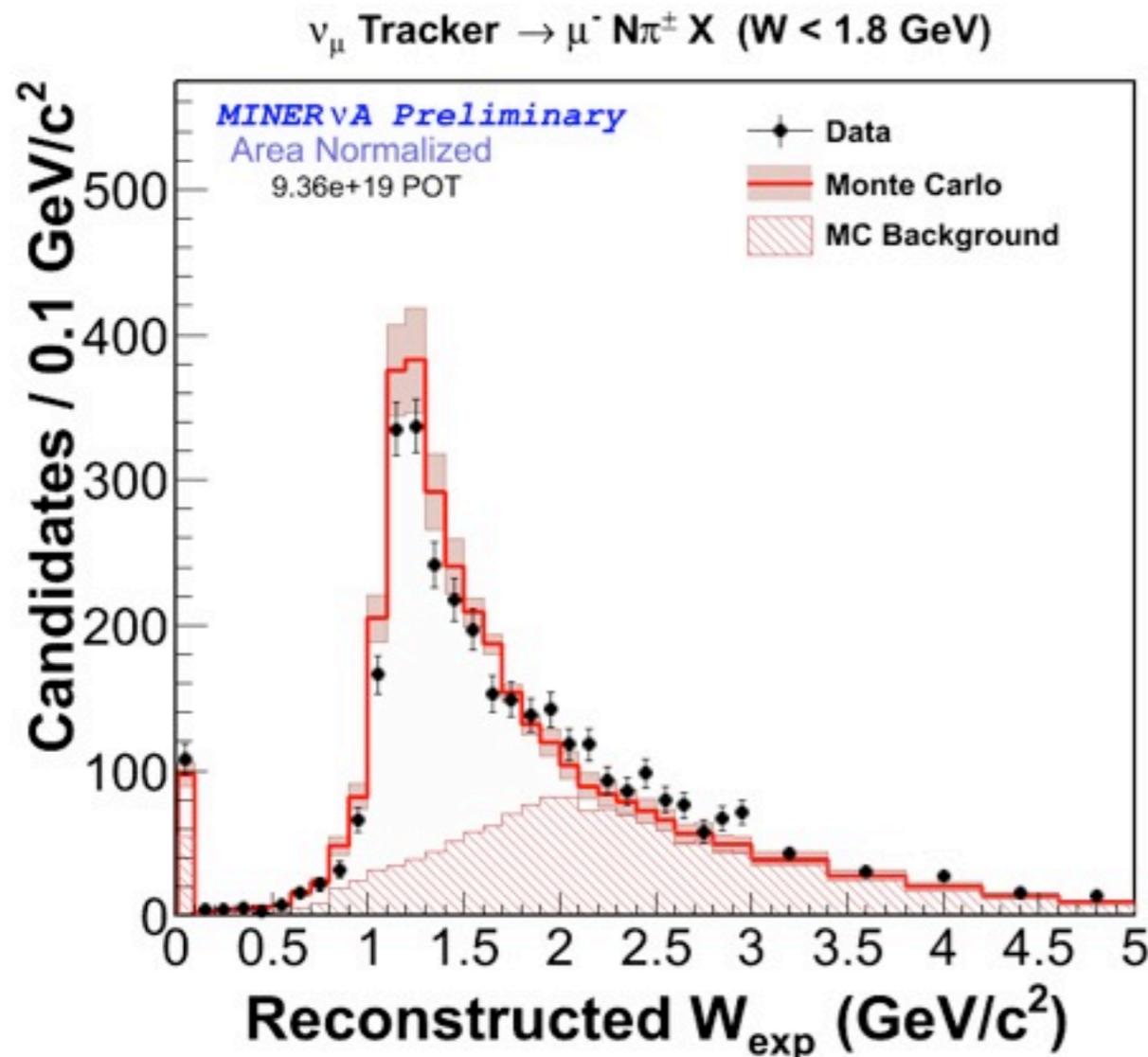
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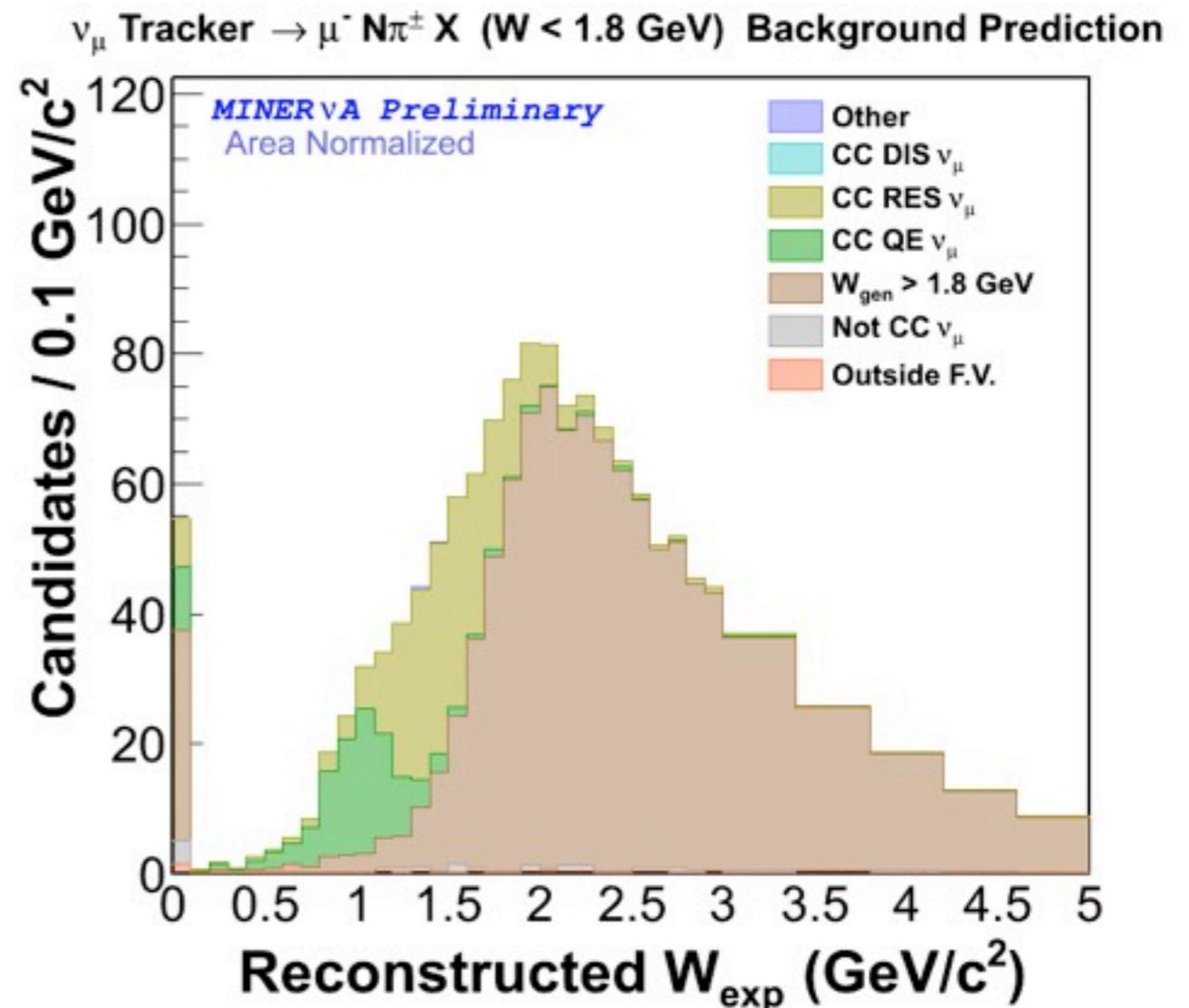
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$$Q^2 = 2E_\nu(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2$$

$$W^2 = m_n^2 - Q^2 + 2 m_n E_H$$



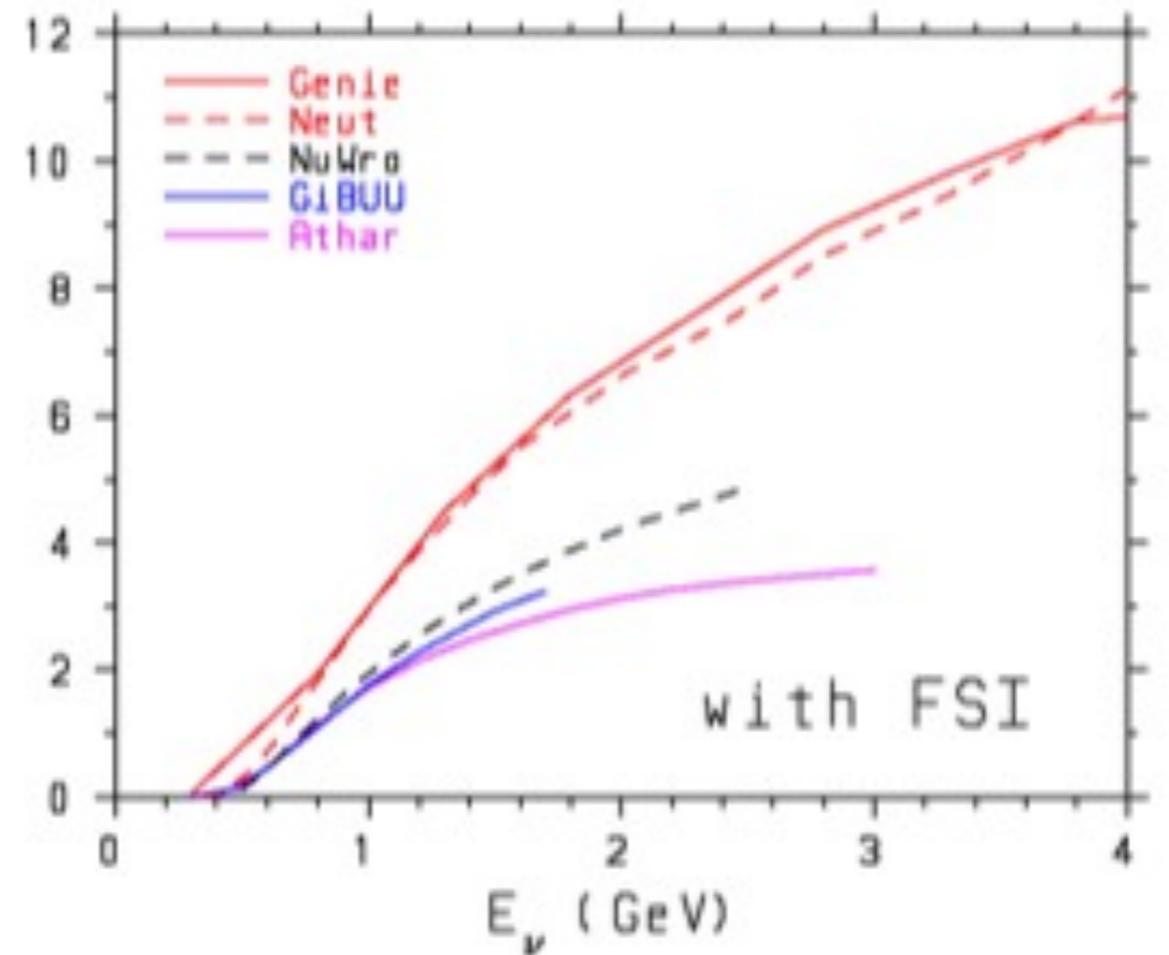
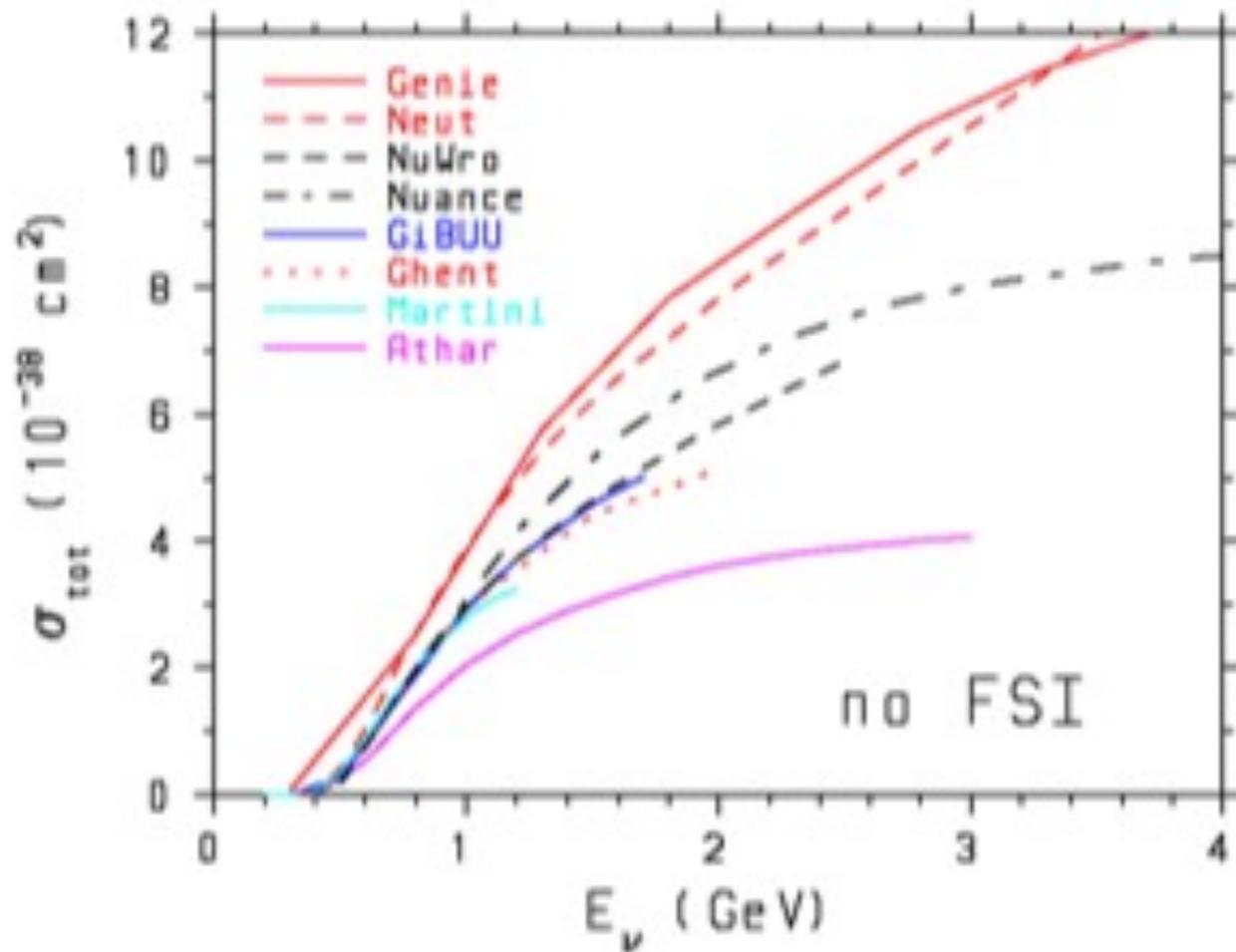
NuFact 2013, Beijing, China



Aaron Higuera, Universidad de Guanajuato

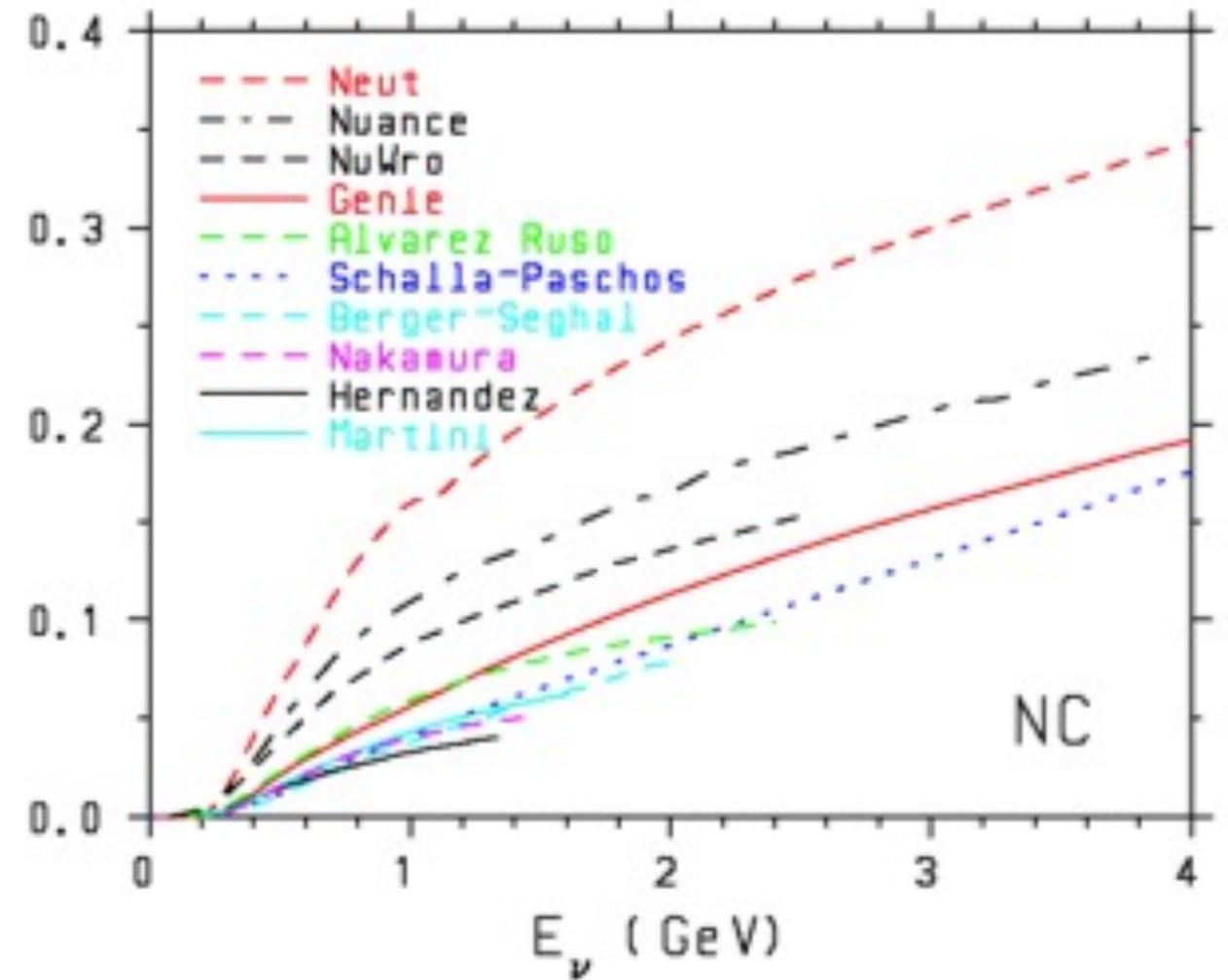
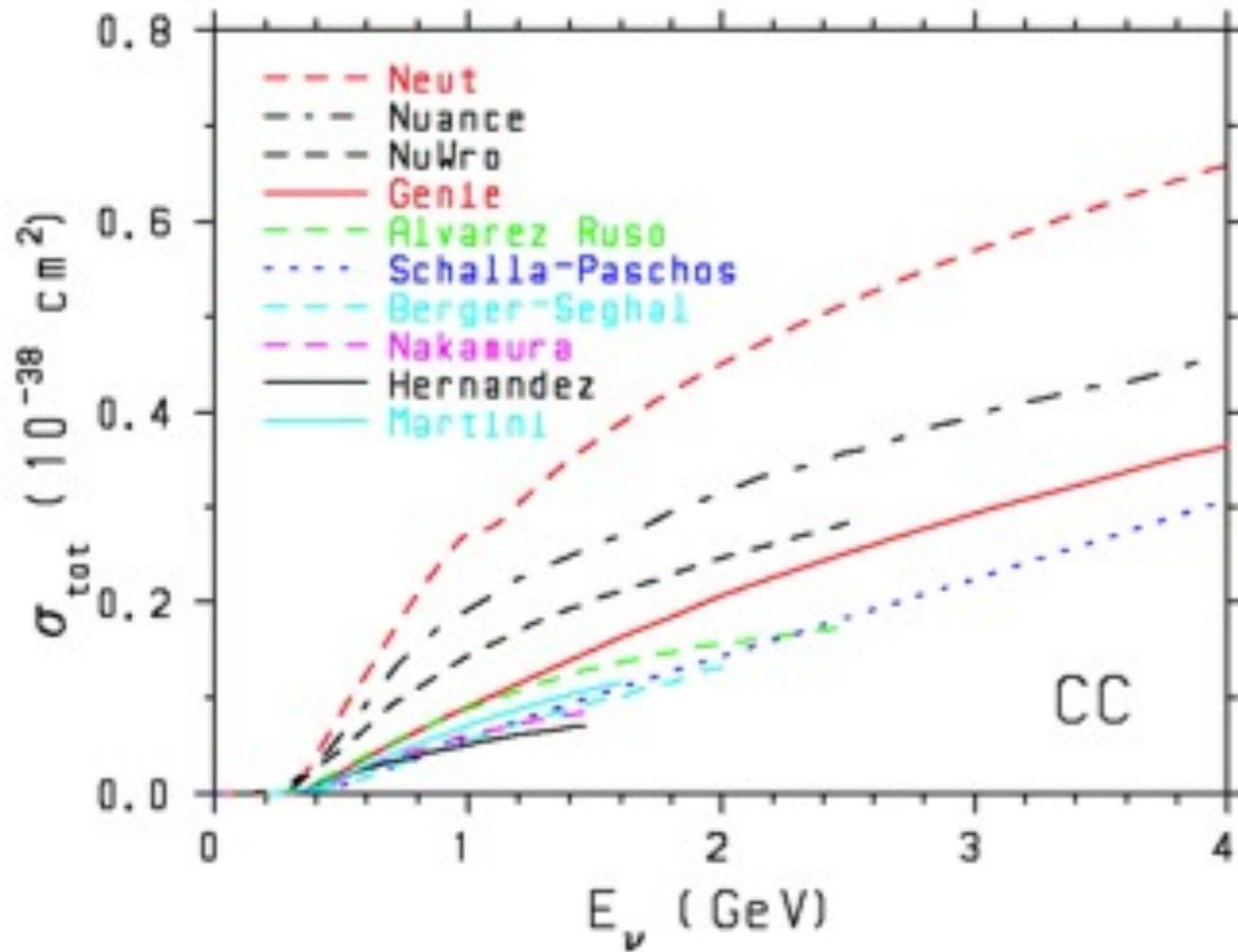
Single π^+ Production on C_{12} Cross Section

S. Dytman NuInt 2009



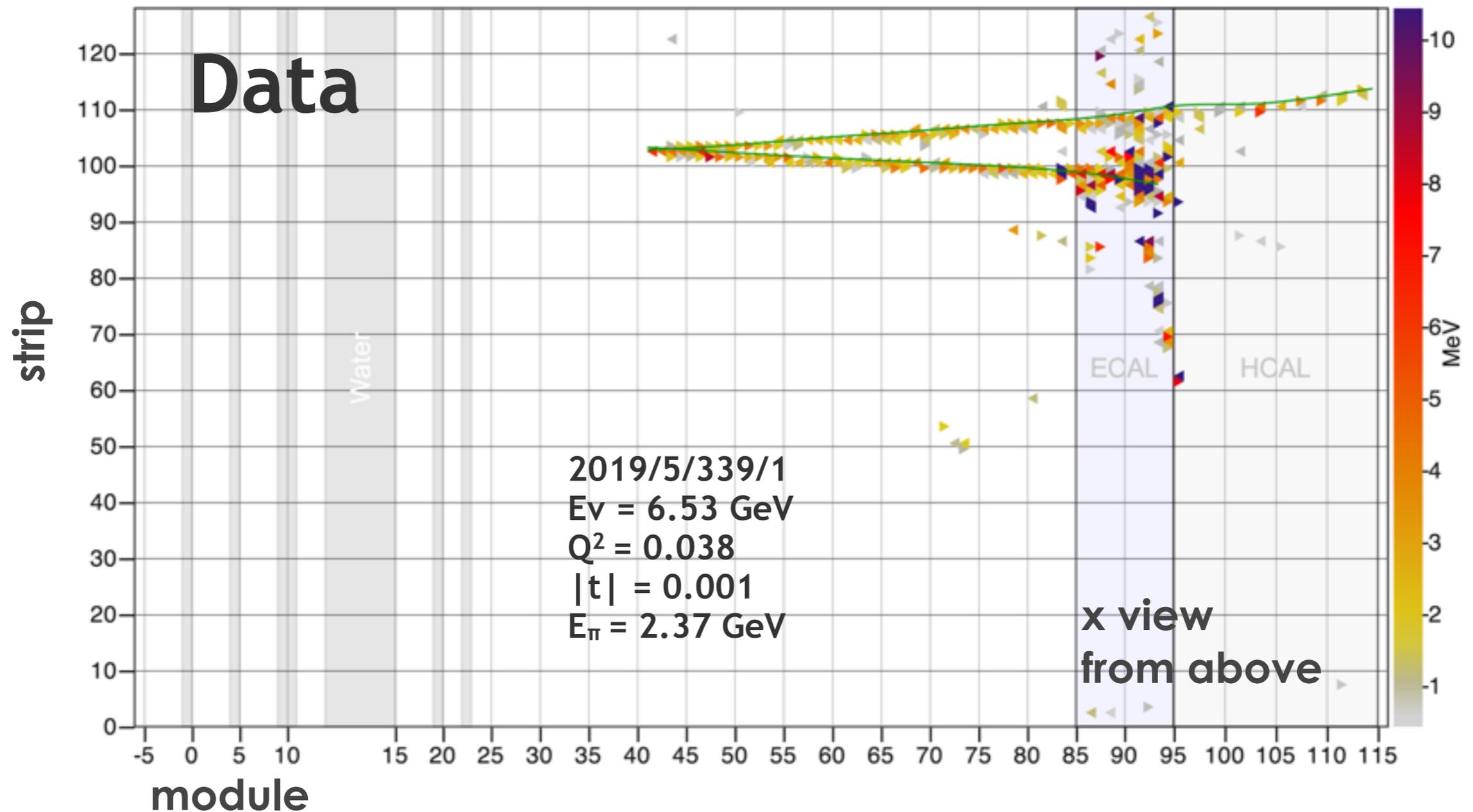
Coherent Cross Section

S. Dytman NuInt 2009



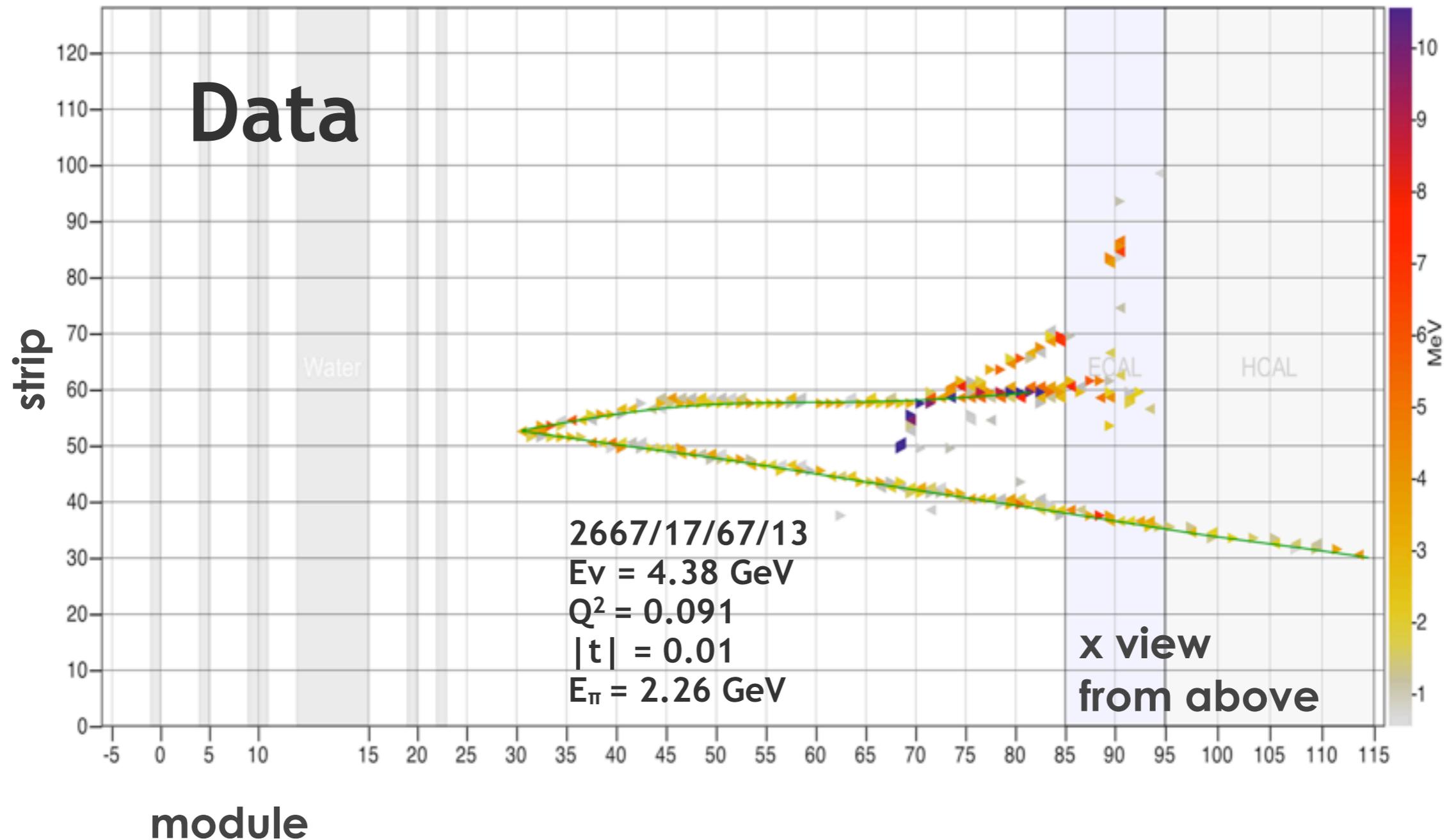
CC Coherent Candidate

Neutrino

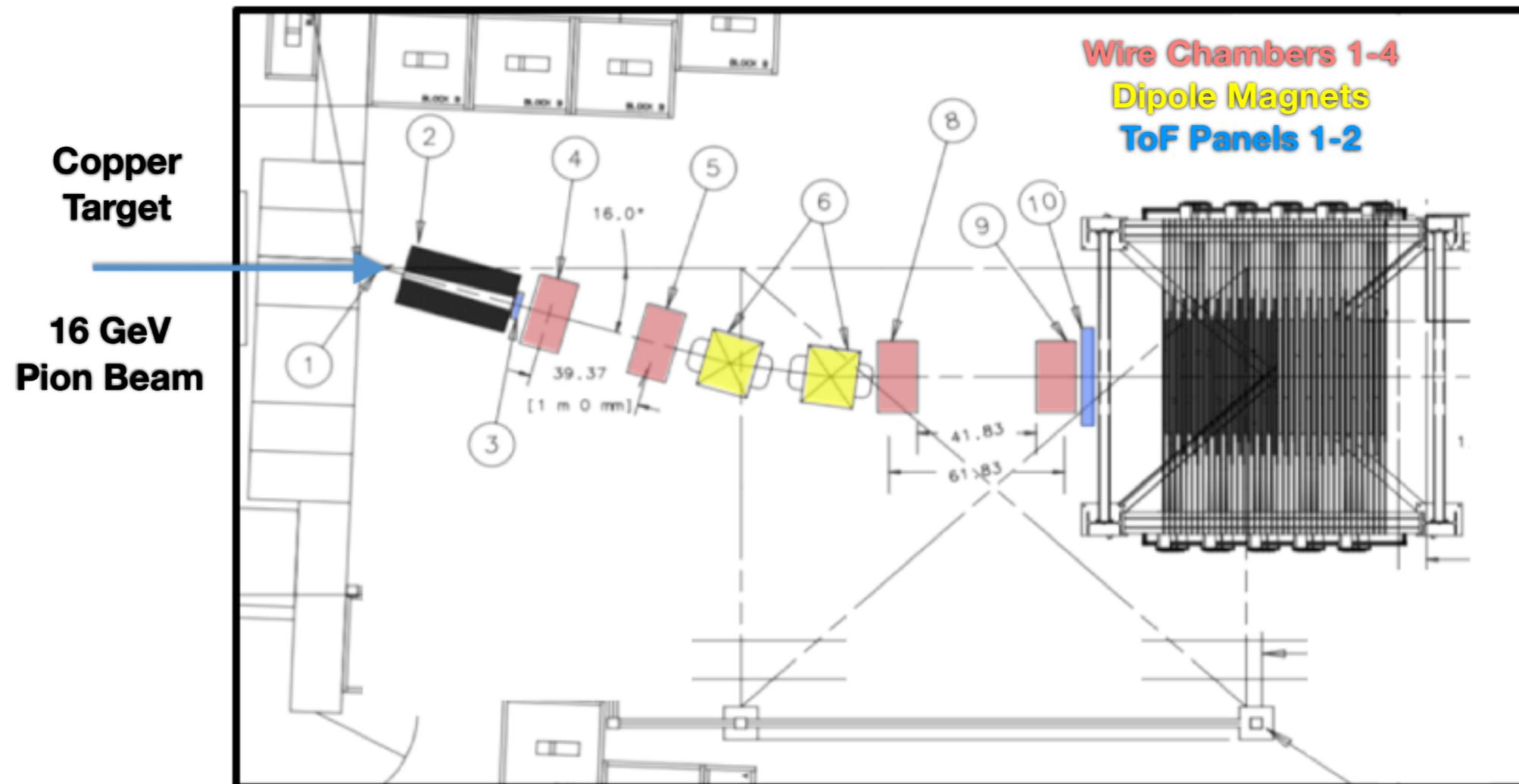


CC Coherent Candidate

Anti-Neutrino



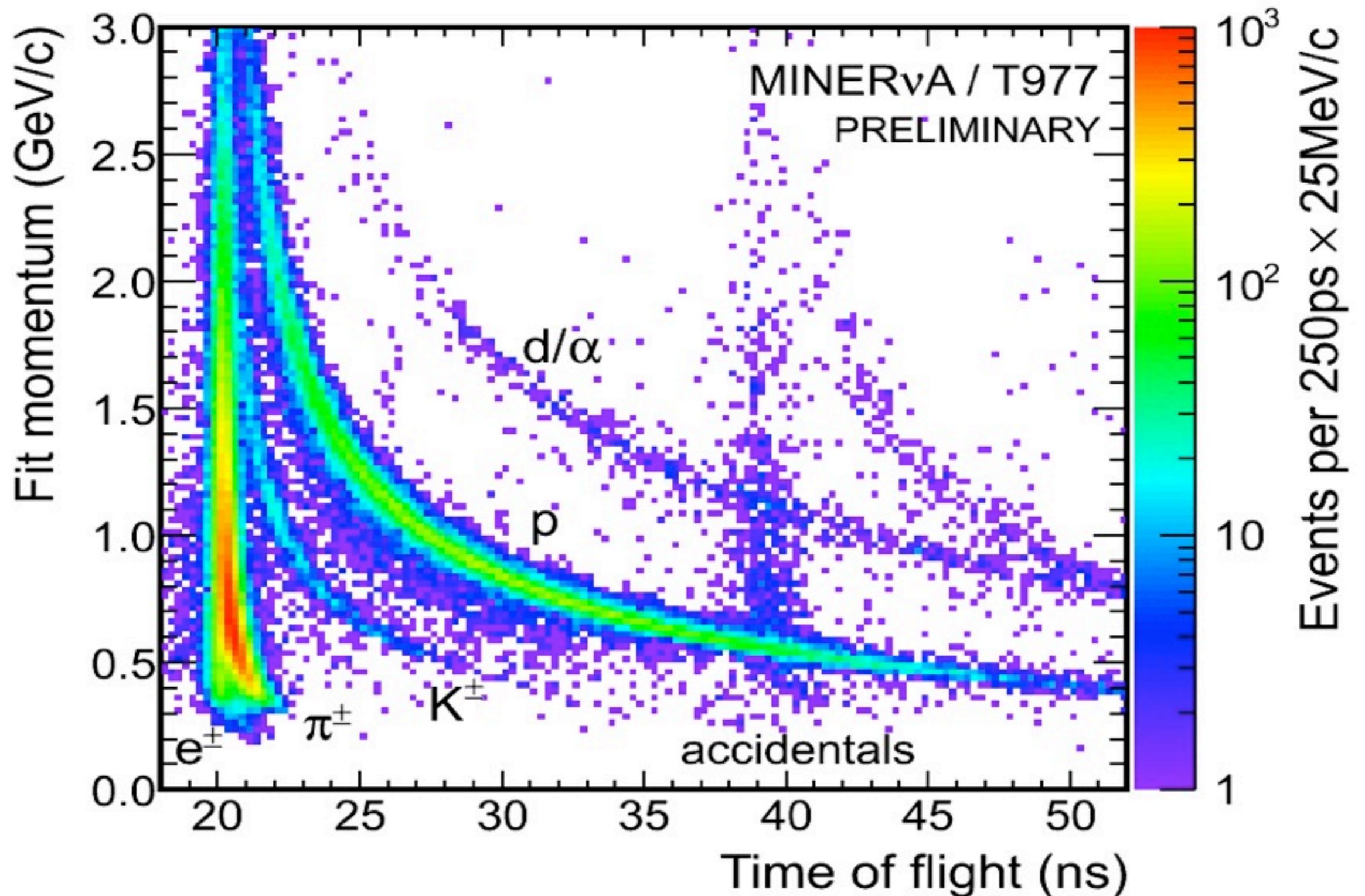
MINERvA Test Beam Experiment T-977



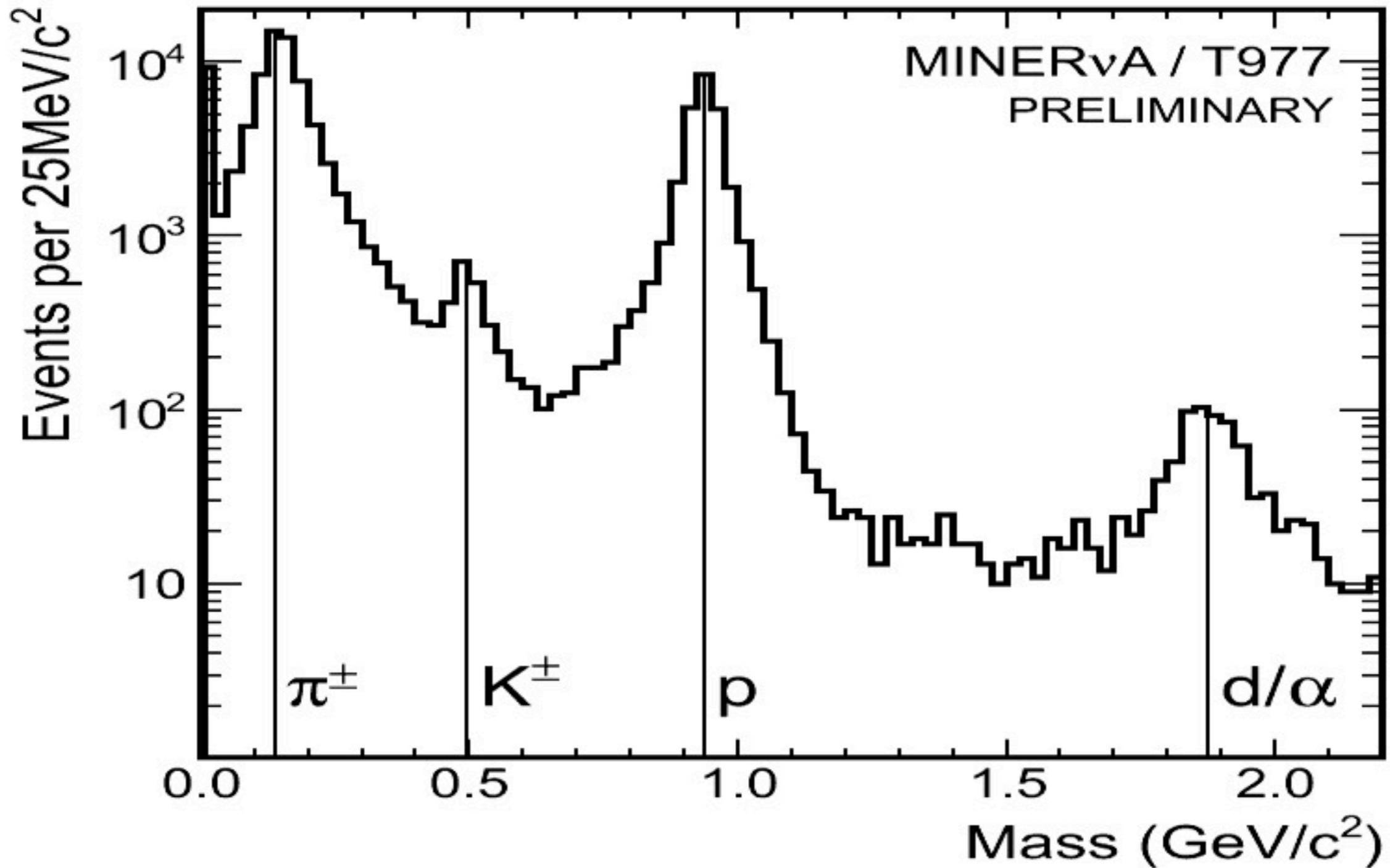
- Target (1).
- Collimator (2).
- Time of Flight System (3,10).
- Spectrometer (4,5,6,8,9).
- Test Beam Detector.

**Tertiary beam
400-2000 MeV/c**

Tertiary Beam Component

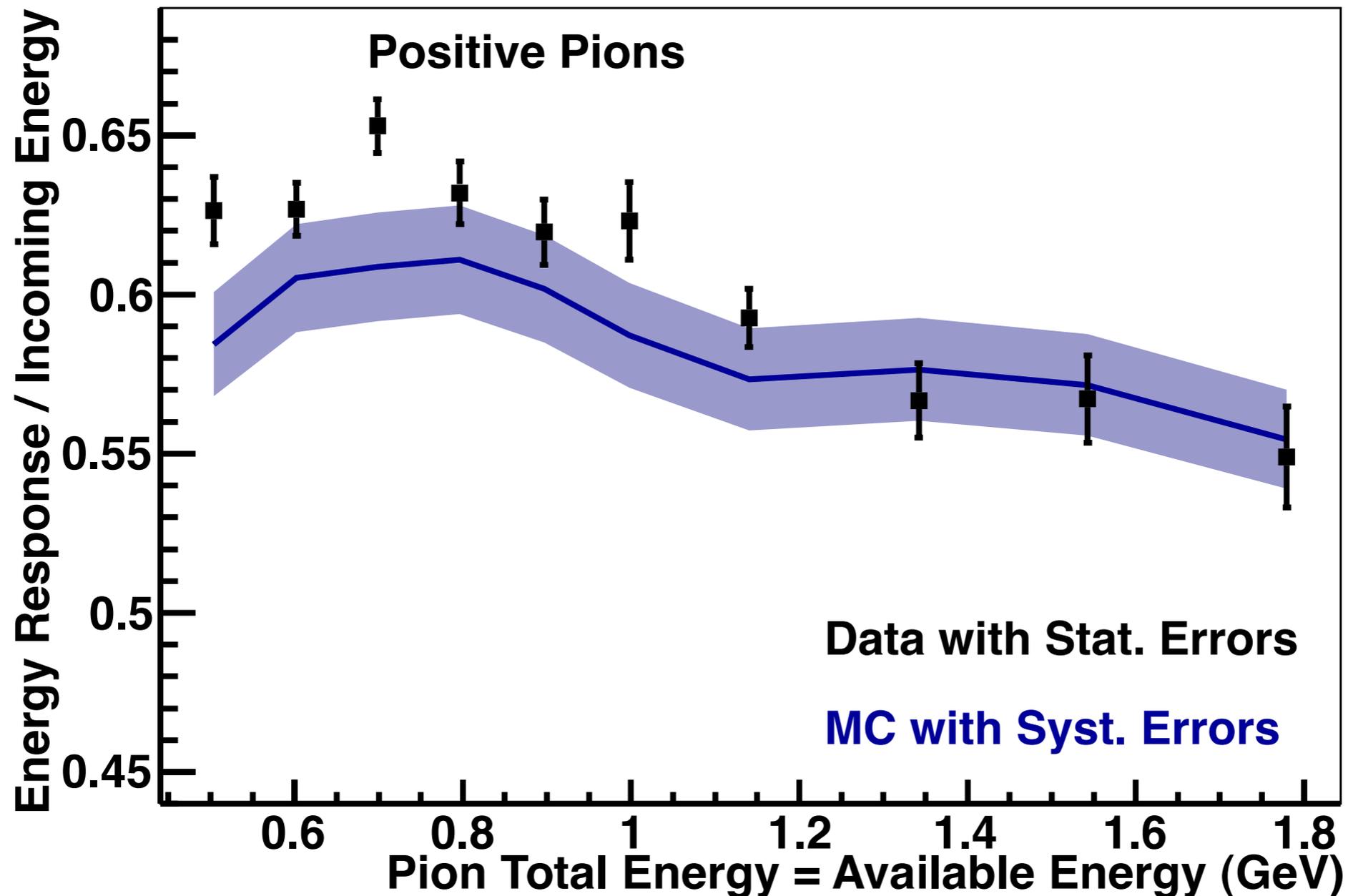


Tertiary Beam Component



Current Analysis (Calorimetry)

T977 + MINERvA Preliminary



- 20 ECal + 20 HCal config.
- The energy response is corrected for the passive material.