# Recent Results From MINERvA


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Rencontres de Moriond EW 2016

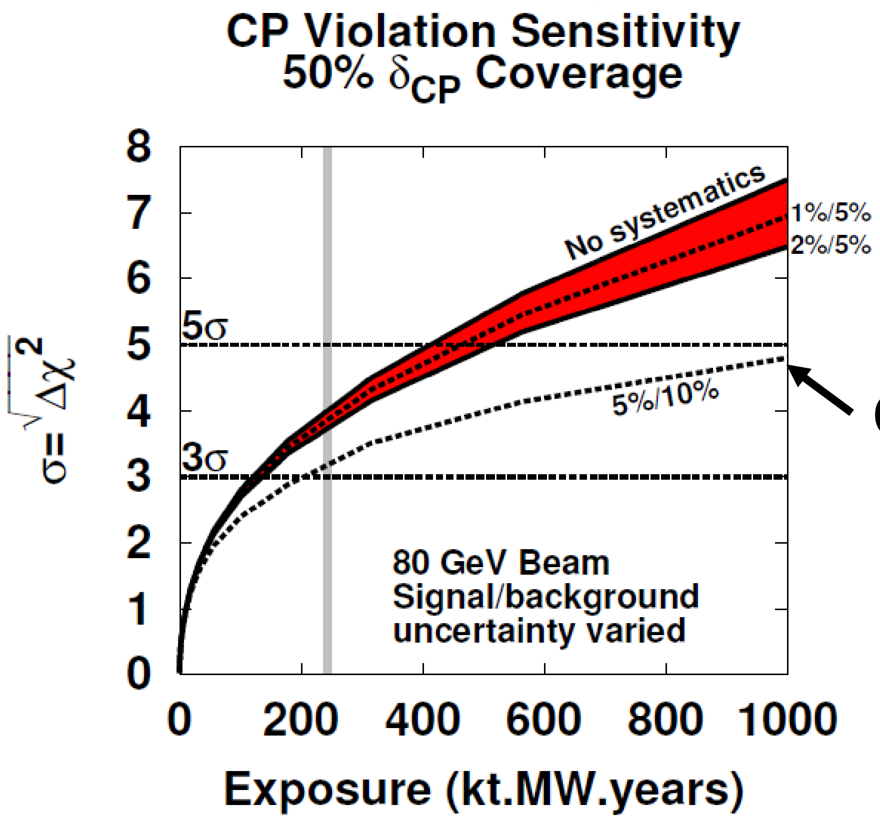
March 14th, 2016

# The MINERvA Experiment

- Study neutrino-nucleus scattering at a few GeV
  - Measure the effects of the nuclear environment on neutrino scattering
  - Improve understanding of neutrino-nucleus cross section model by working with generators
  - Benefits current and future neutrino oscillation experiments

# Neutrinos Are Interesting!

- Neutrinos oscillate, but do they violate CP?
  - A big question with big detector(s) to measure it
    - DUNE, Hyper-Kamiokande, …

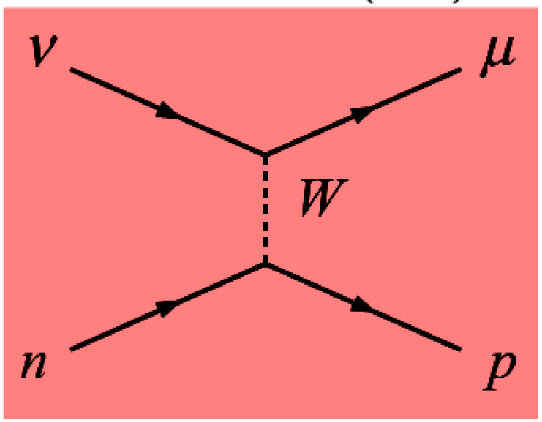



Want to be here: 1% signal and 5% background unc.

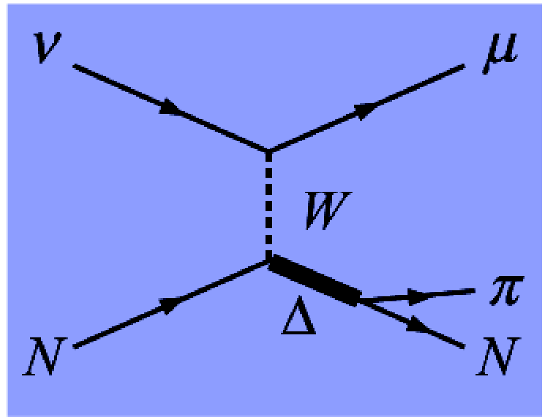
Currently here with 5-10% unc.

# Neutrino Cross Sections

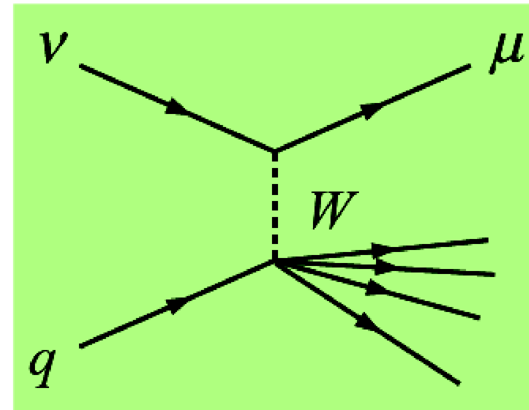
Quasielastic (QE)



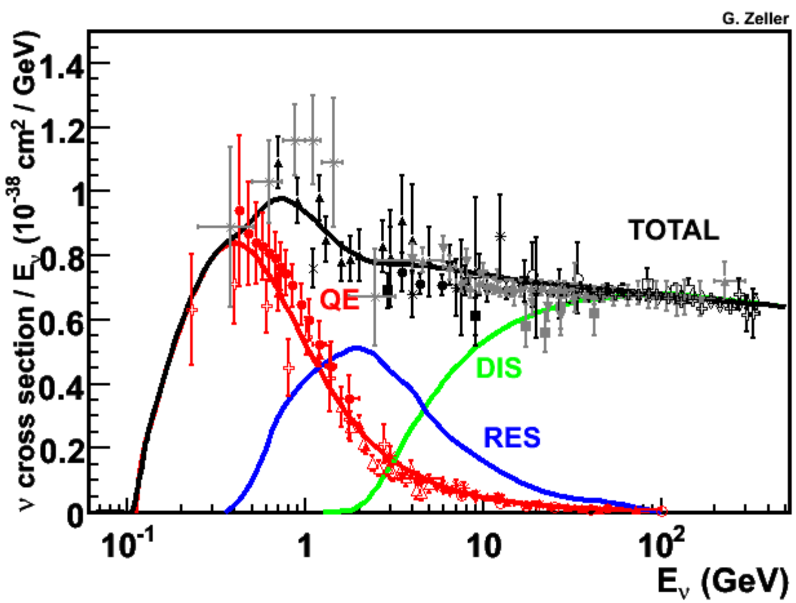

Resonance

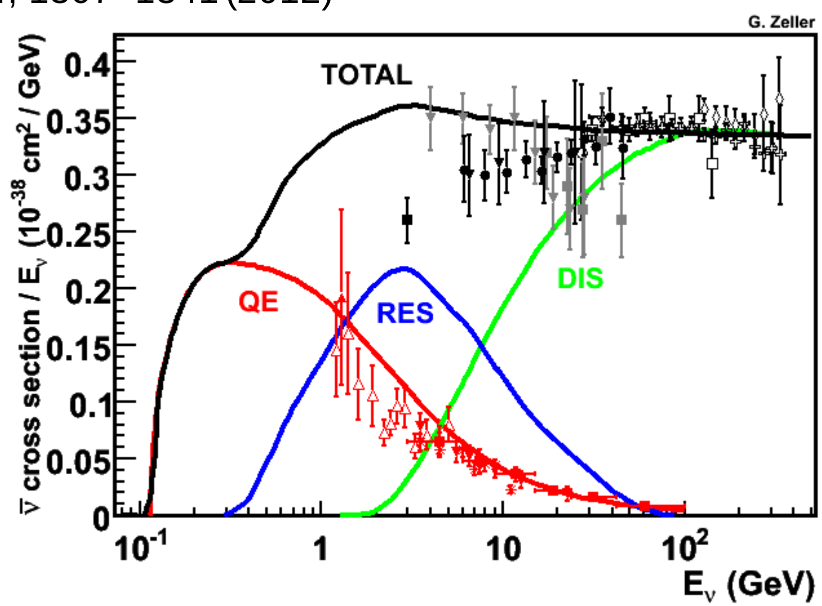



DIS




Rev. Mod. Phys. 84, 1307–1341 (2012)

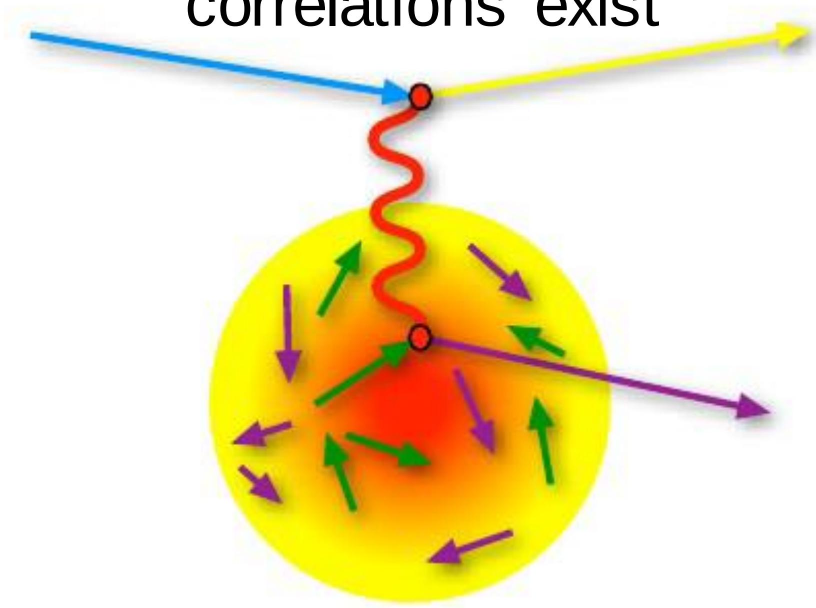


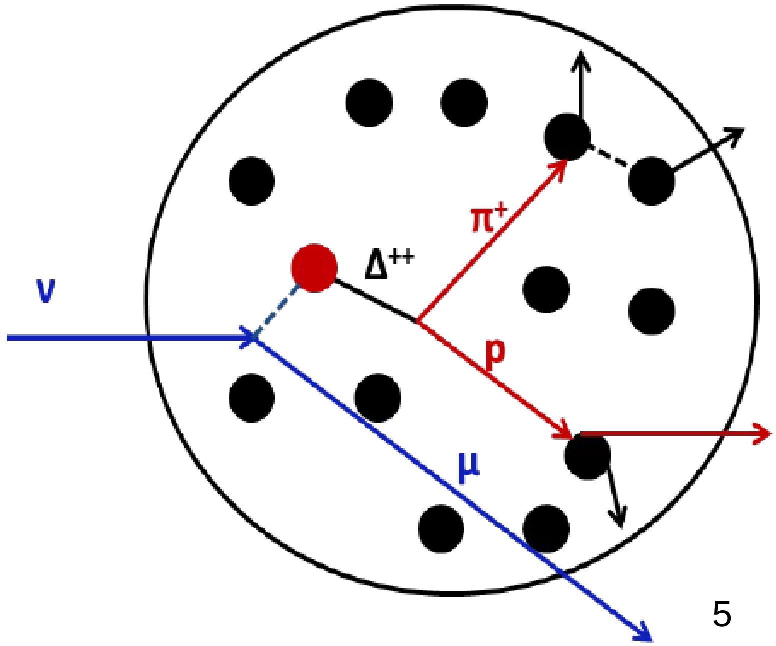
# Nuclear Targets: A double-edged sword

- Detectors built with heavy nuclei for a higher interaction rate but introduces complications!

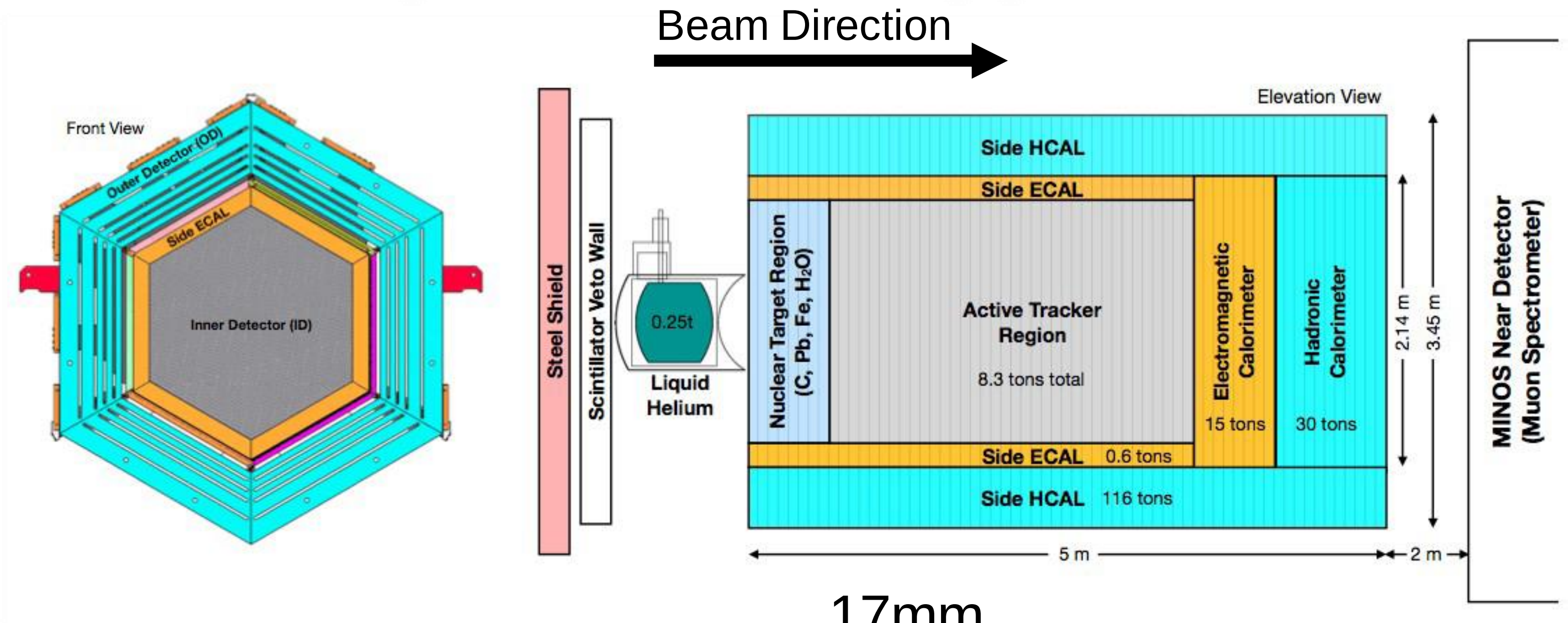
Struck nucleon is not isolated short and long range correlations exist



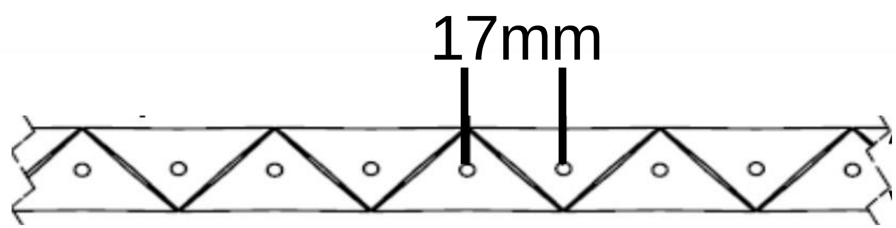
Particles created have to propagate out of the nucleus. So called final state interactions (FSI)



# Experimental Apparatus



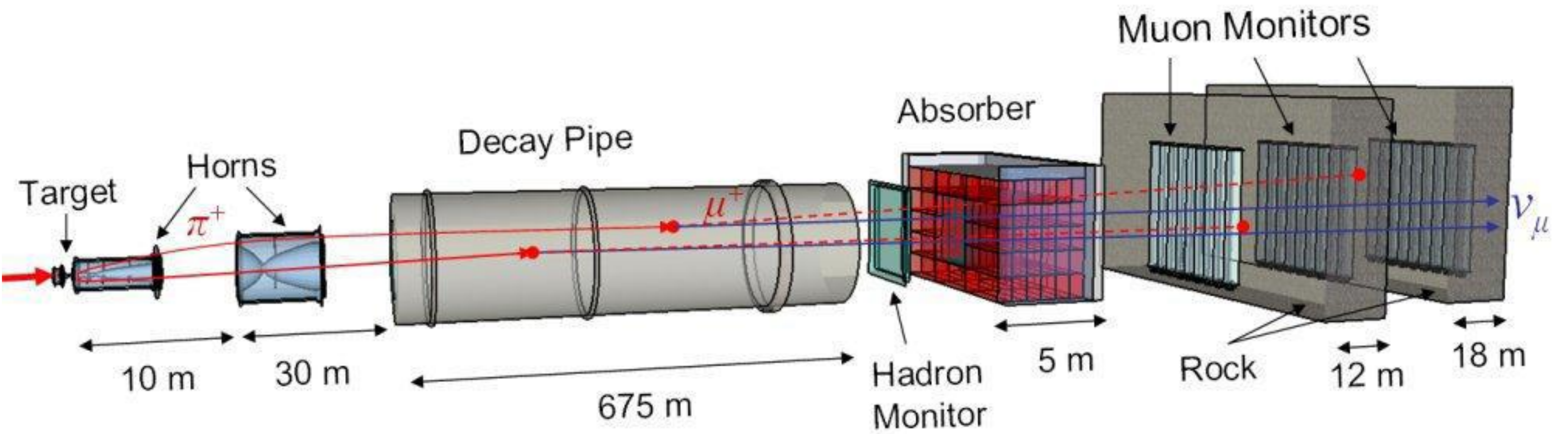

Three views:
X: Vertical
U,V: ±60



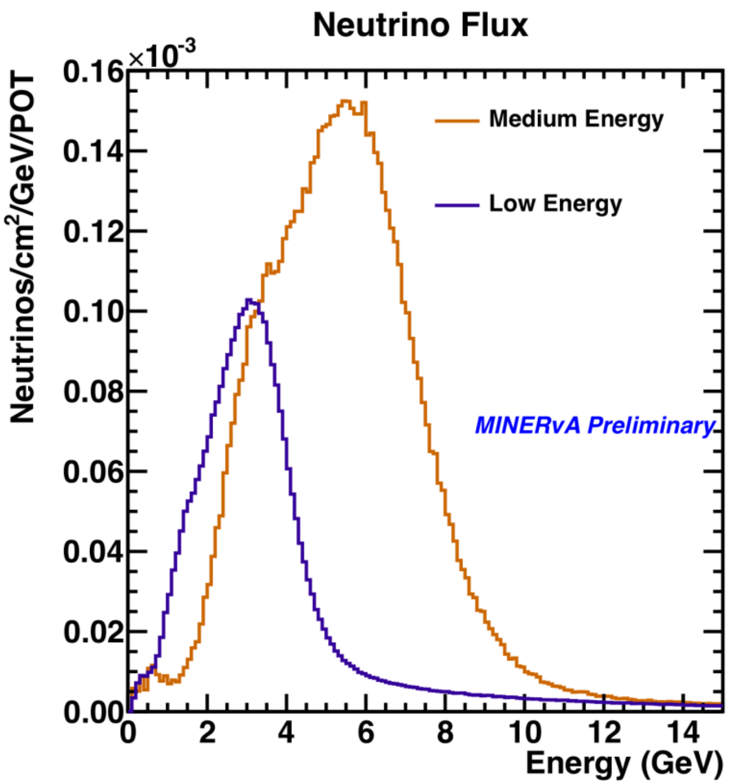

Spatial resolution ~3mm
Timing resolution ~3ns

Nucl. Inst. and Meth. A743 (2014) 130
arXiv:1305.5199

# The NUMI beam




Towards MINERvA/MINOS

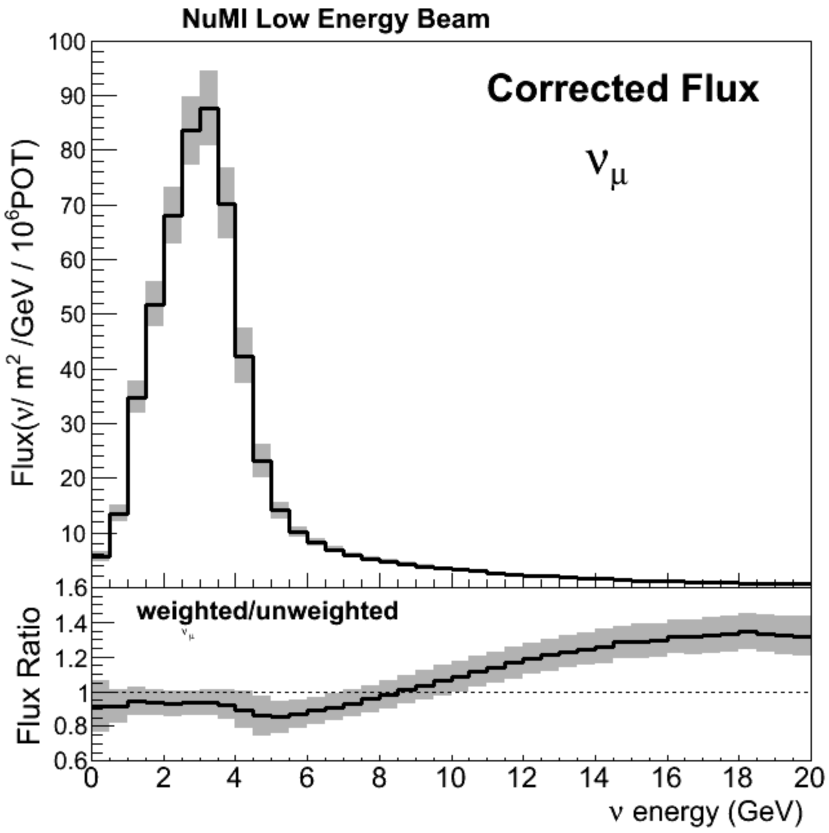


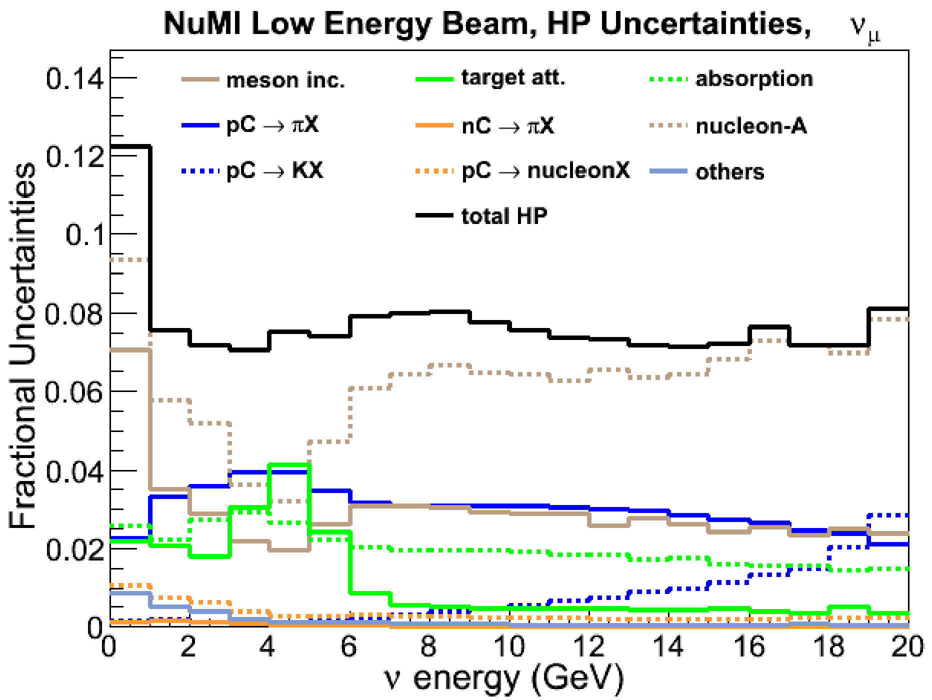

Results shown today use the low energy flux.

Currently taking data with the medium energy flux.

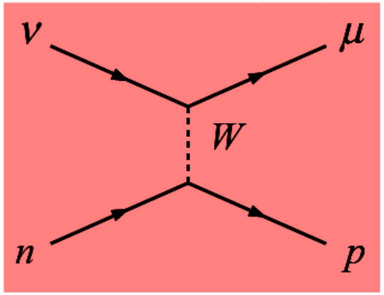
# Improved Flux Prediction

- Updated central value and improved uncertainties using external hadron production data



Quasielastic (QE)



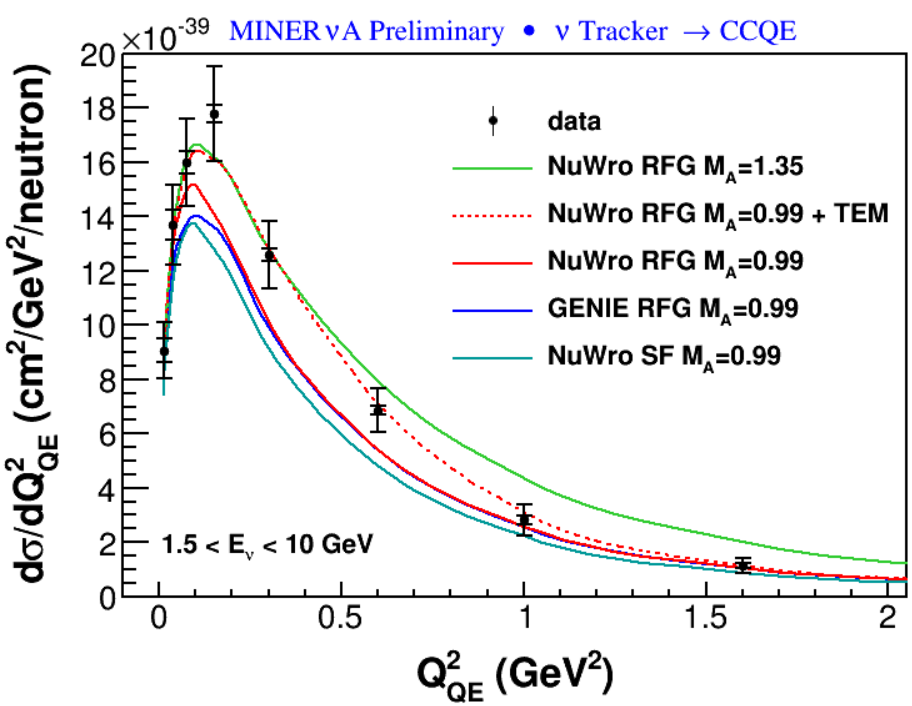

# Updated CCQE Results

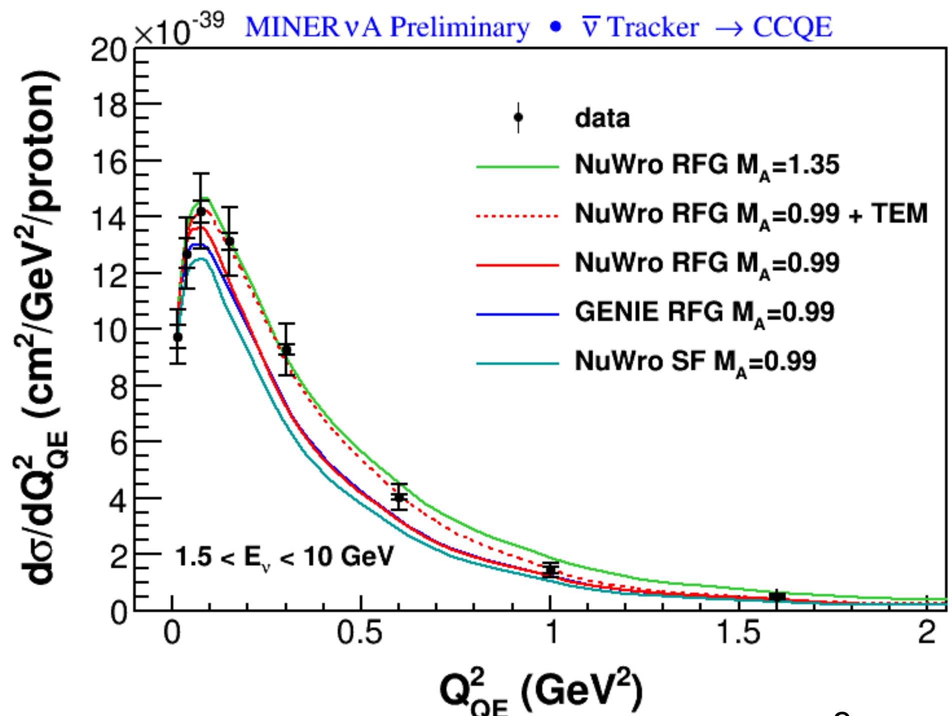
$$Q^2_{QE} = -m_l^2 + 2E_\nu^{QE}(E_l - \sqrt{E_l^2 - m_l^2}cos\theta_l)$$

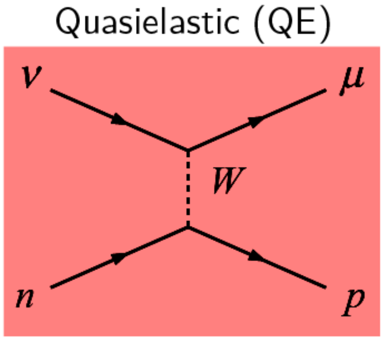
- Previous cross section updated with new flux prediction:

Phys. Rev. Lett. 111, 022501 (2013)

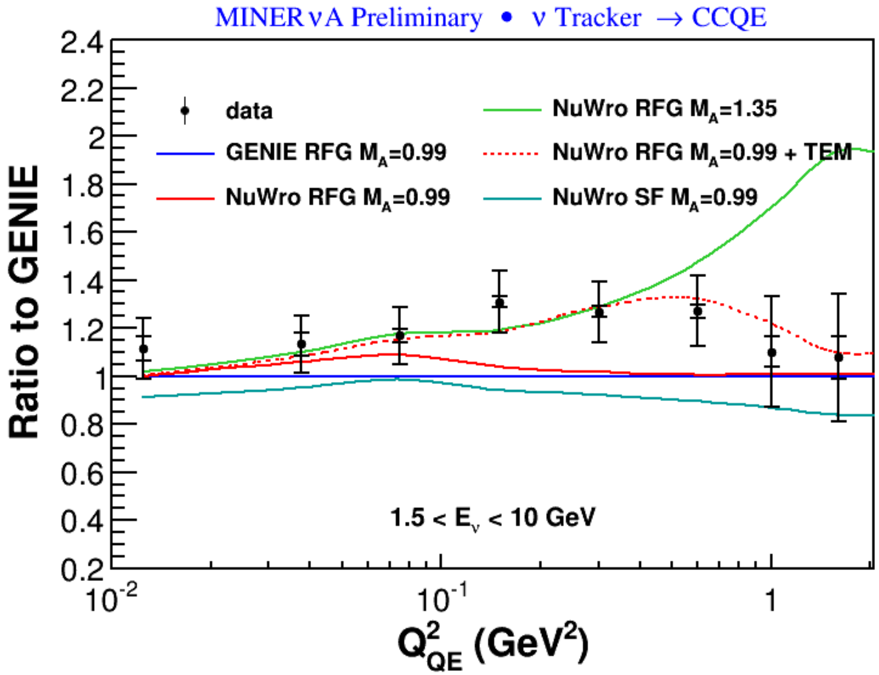
Phys. Rev. Lett. 111, 022502 (2013)

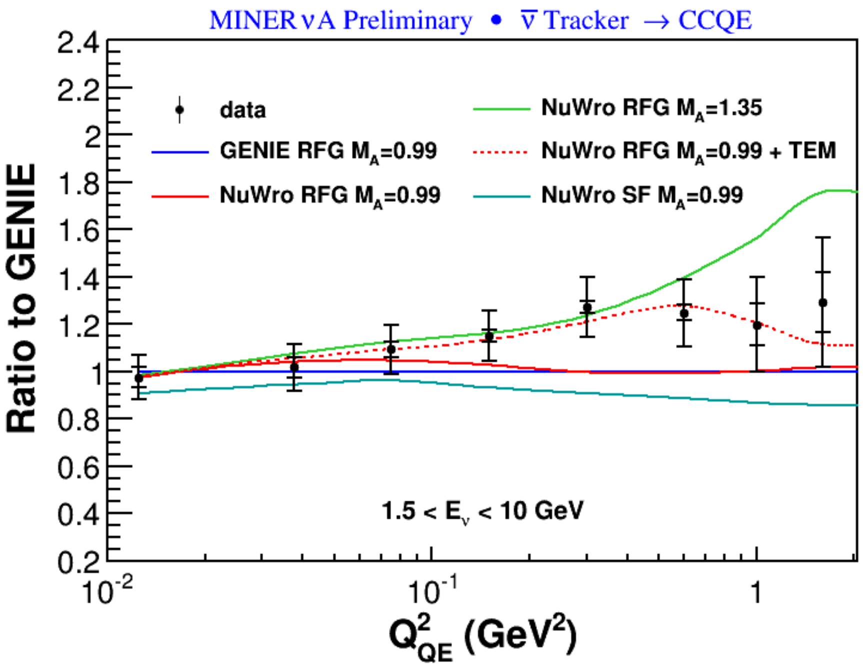





# Updated CCQE Results



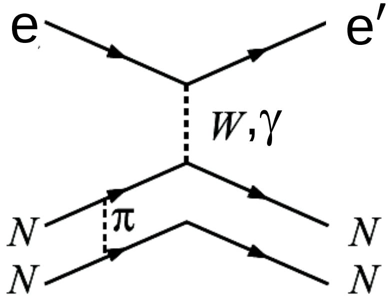




$M_A = 1.35$: Fit to the MiniBooNE CCQE data

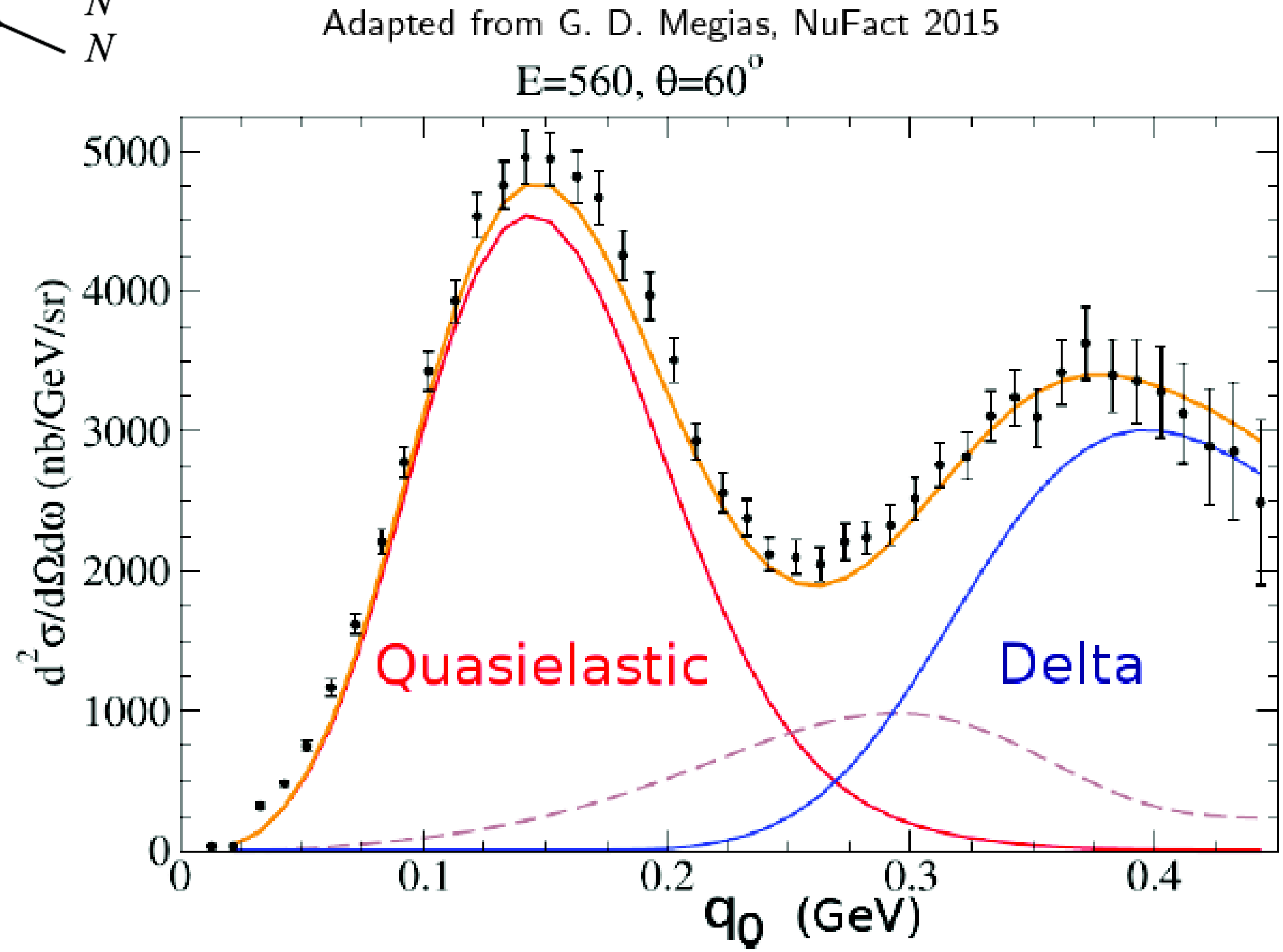
TEM: Transverse Enhancement Model – empirical model based on electron scattering

GENIE: Uncorrelated nucleons in a mean field

SF: Spectral function providing a more realistic nucleon momentum-energy relationship



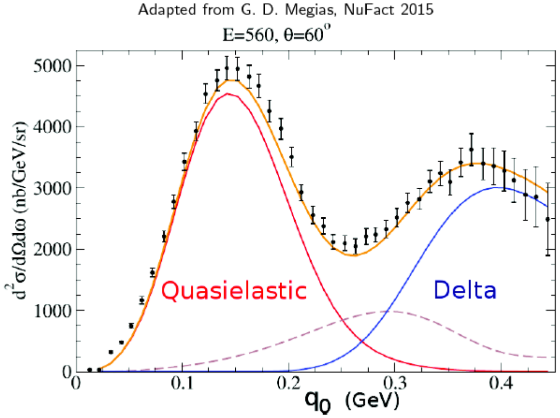

# Electron Scattering




$$q_0 = E_e - E_{e'}$$

# Inclusive Charge Current cross section

Adapted from G. D. Megias, NuFact 2015

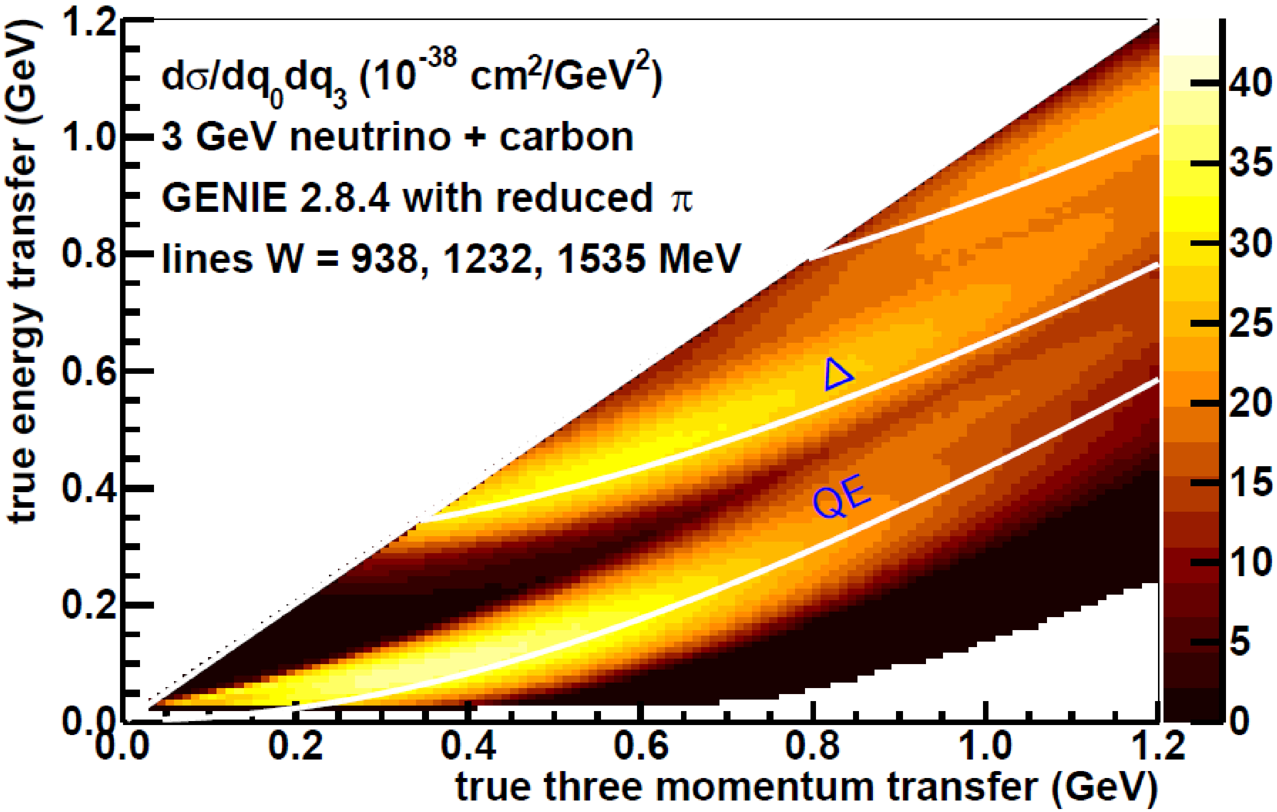



$q_0 = E_e - E_{e'}$

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

$$E_\nu = E_\mu + q_0$$

$$q_3 = \sqrt{Q^2 + q_0^2}$$

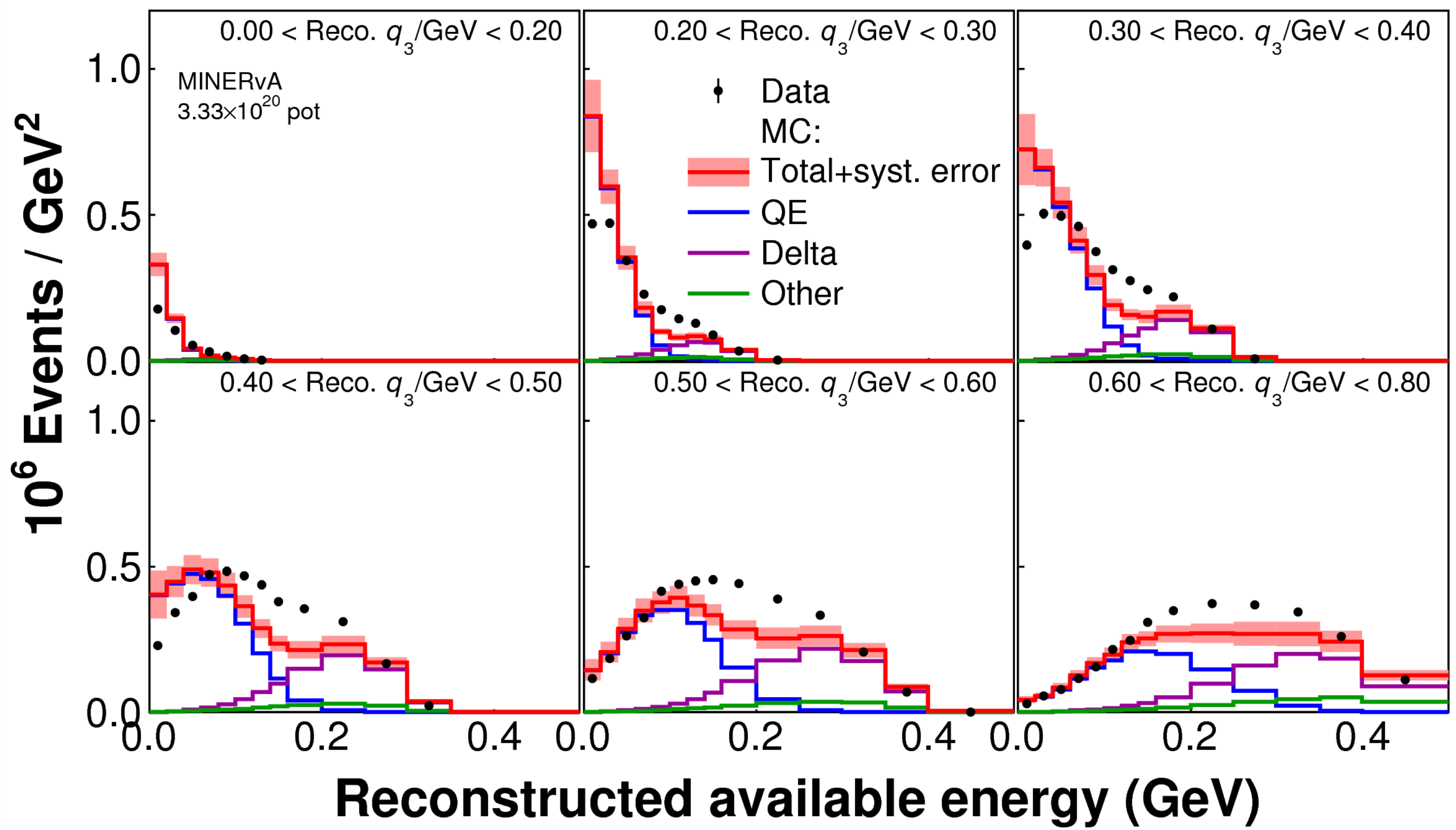



MINERvA can make a similar measurement using the hadronic system and the outgoing lepton

# GENIE Model

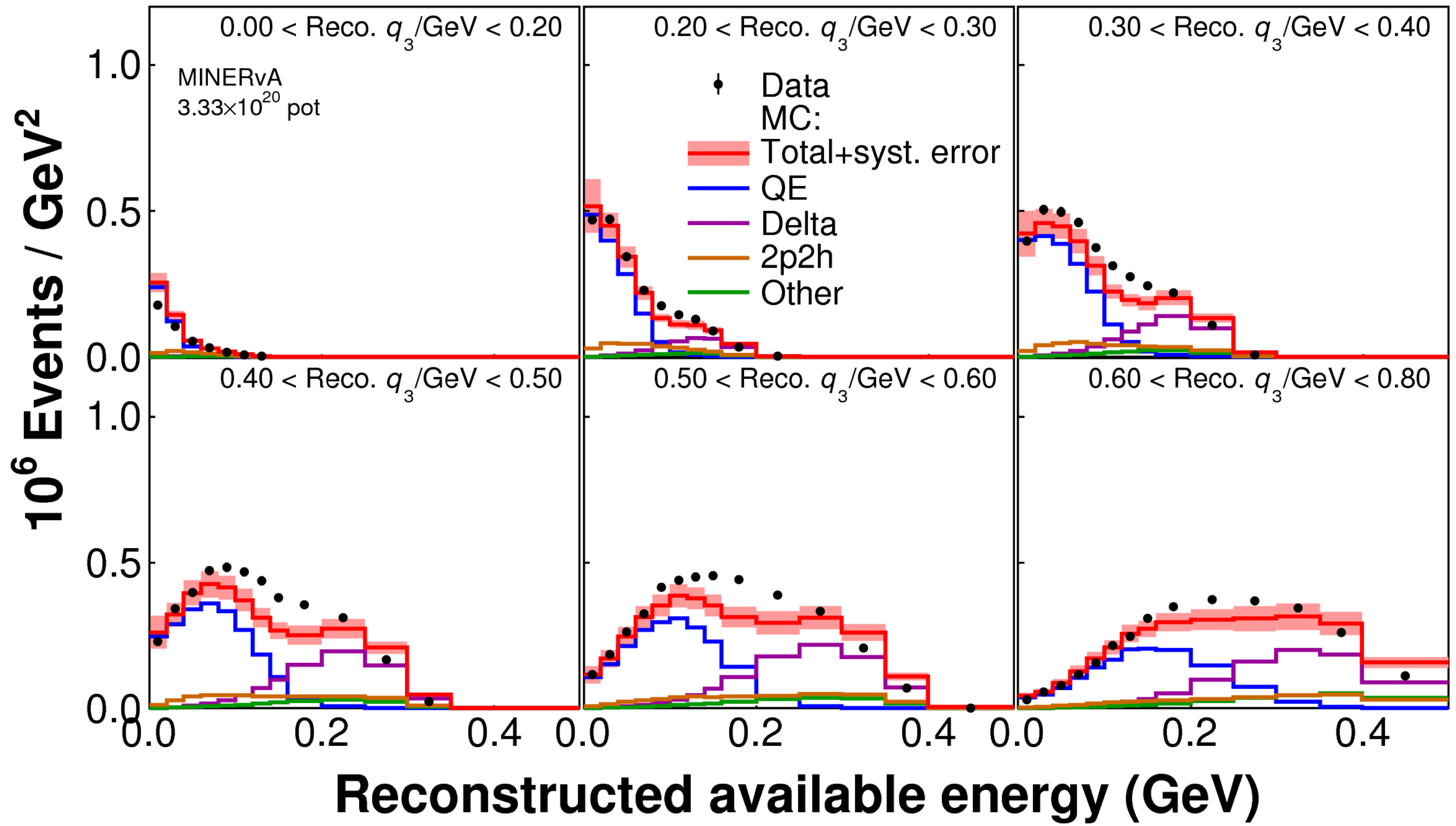
## with modified pion production cross section

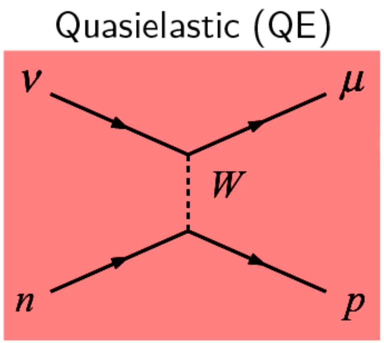
Phys. Rev. Lett. 116, 071802 (2016)



# Add long range correlations (RPA) and 2 particle 2 holes (2p2h)

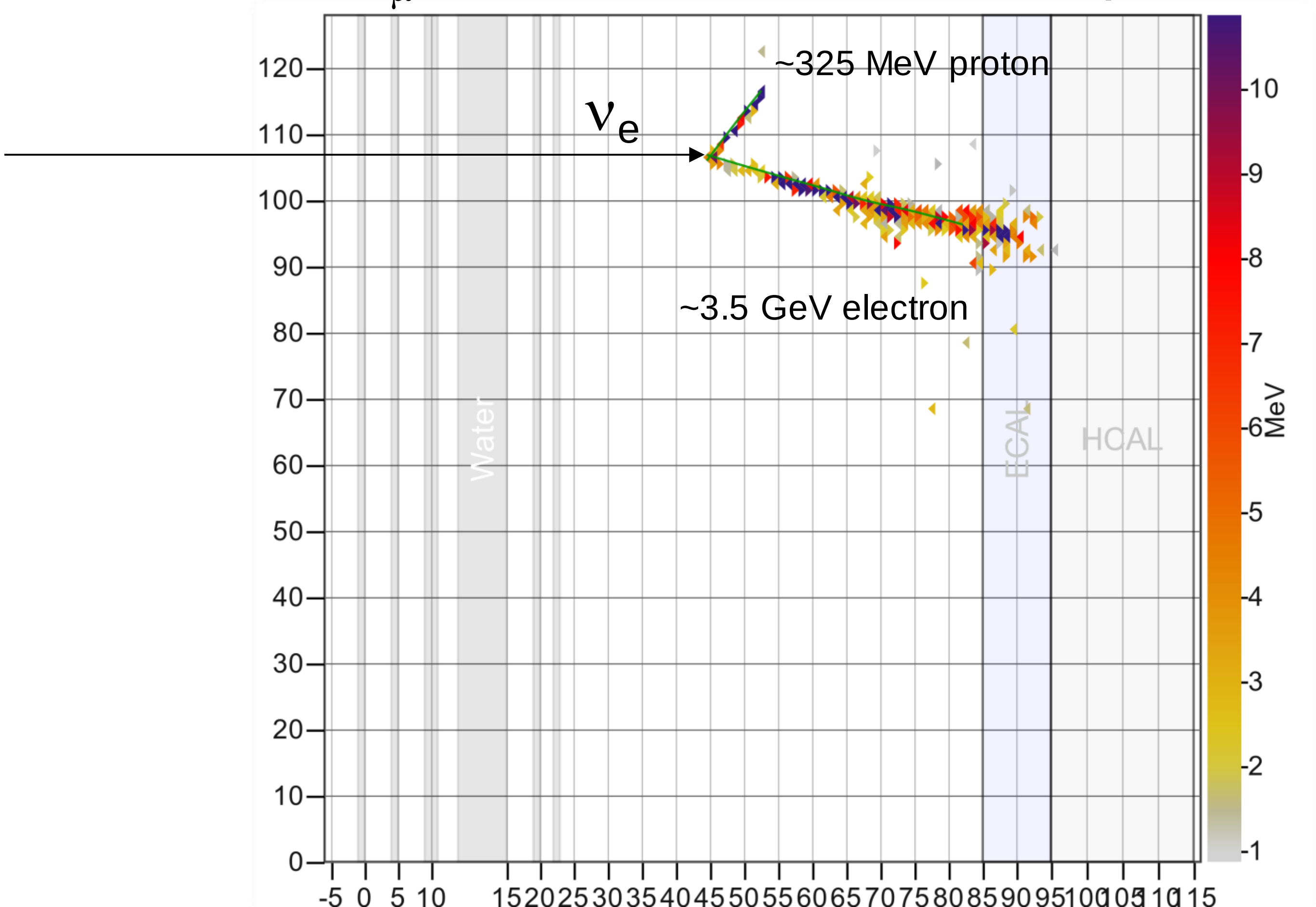
Phys. Rev. Lett. 116, 071802 (2016)





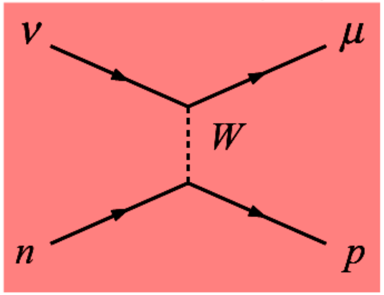

# CCQE via $\nu_e$–nucleus scattering

- Dominant neutrino oscillation $\nu_e$-appearance signal process.
- Modelled as $\nu_\mu$-CCQE with a modified lepton mass.

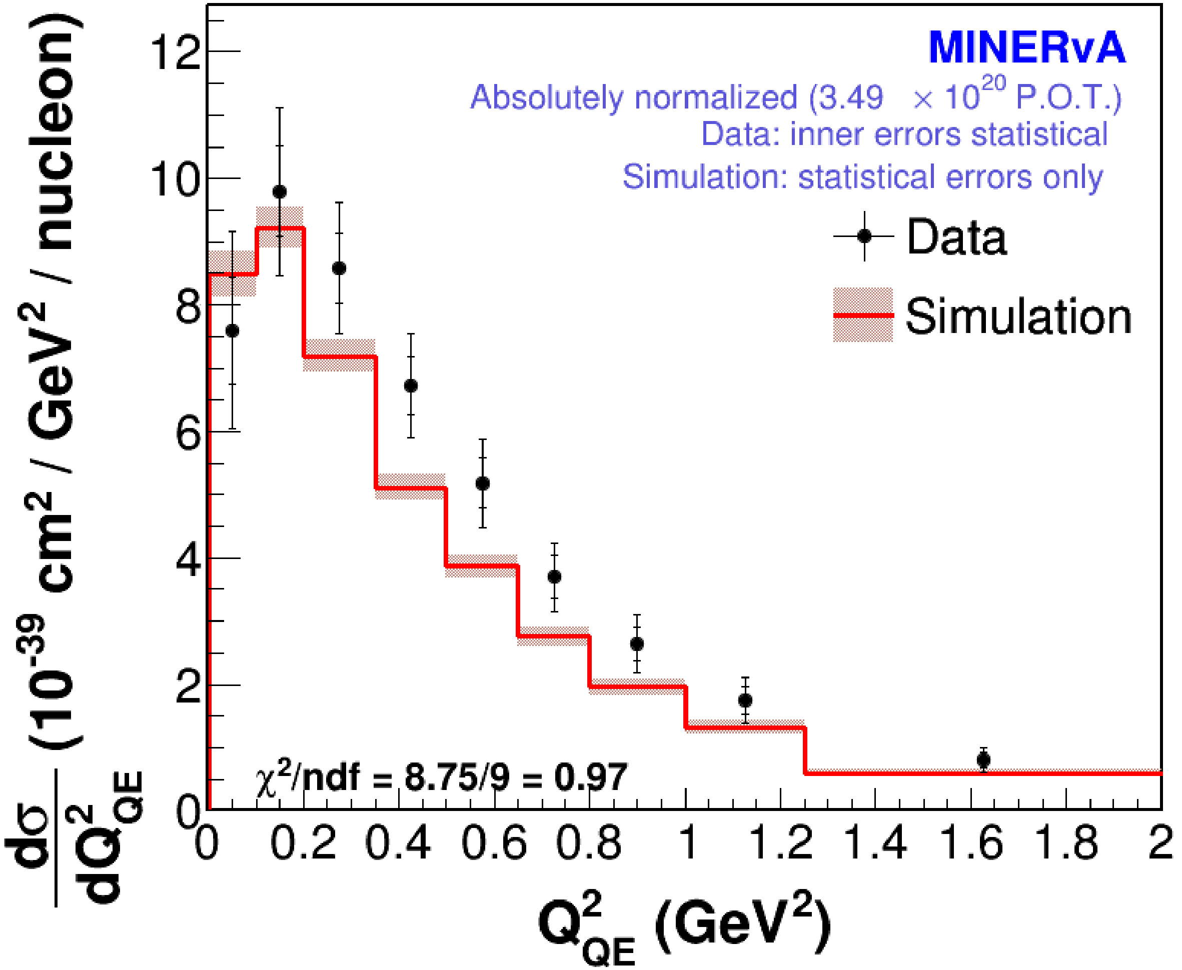


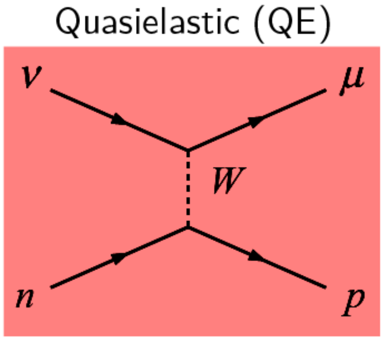
# $\nu_e$ CCQE differential cross section

Quasielastic (QE)




hep-ex: arXiv:1509.05729

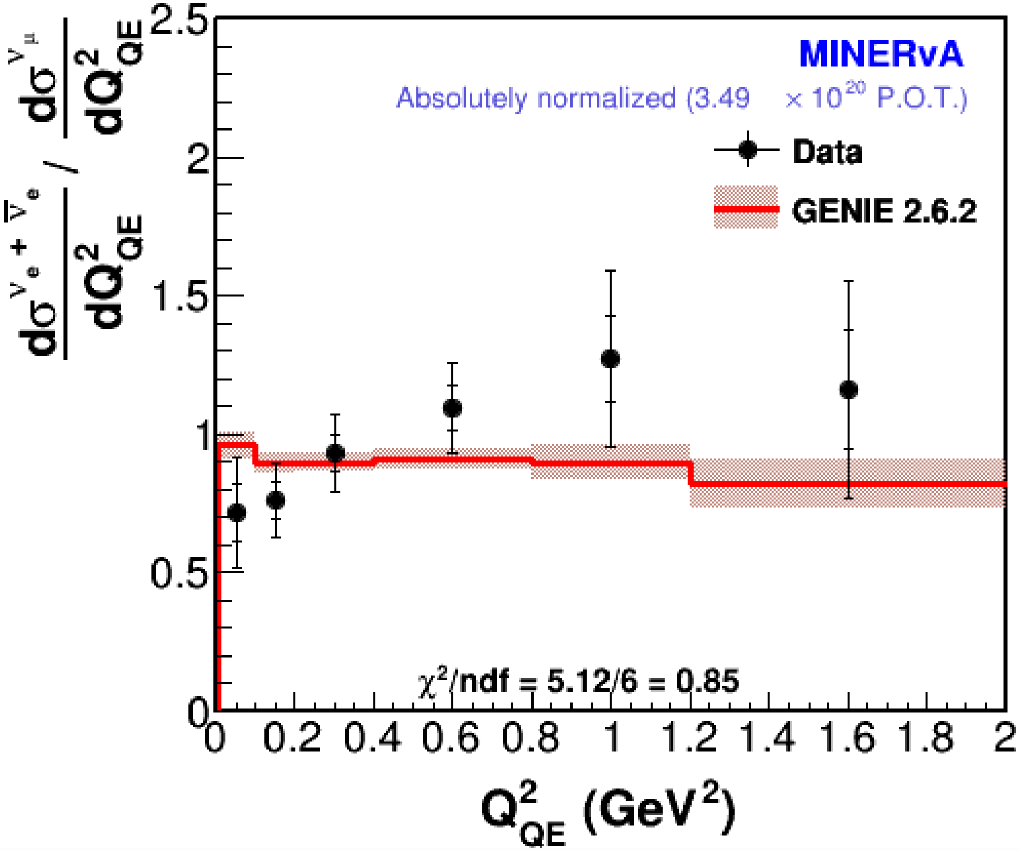


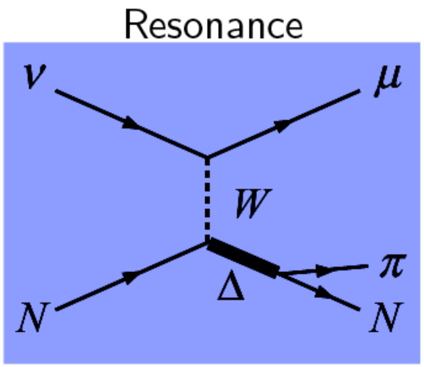



# $\nu_e$ to $\nu_\mu$ differential cross section ratio

- Ratio is consistent with 1.0
- Shape is not significant
  - Large correlated errors

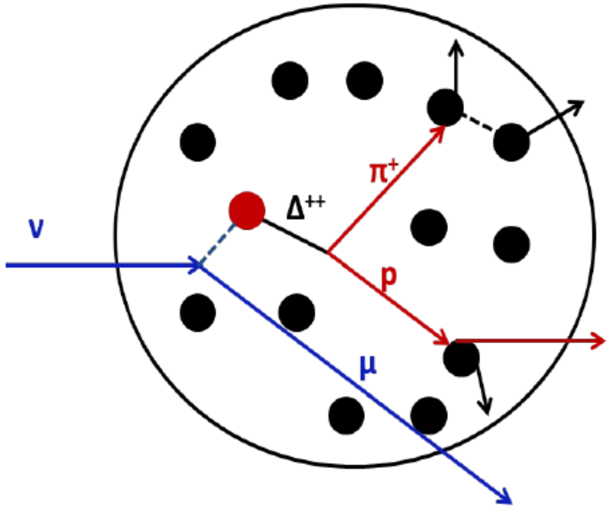
hep-ex: arXiv:1509.05729





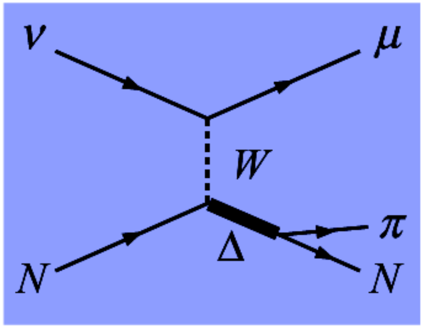

# Charged and neutral pion production

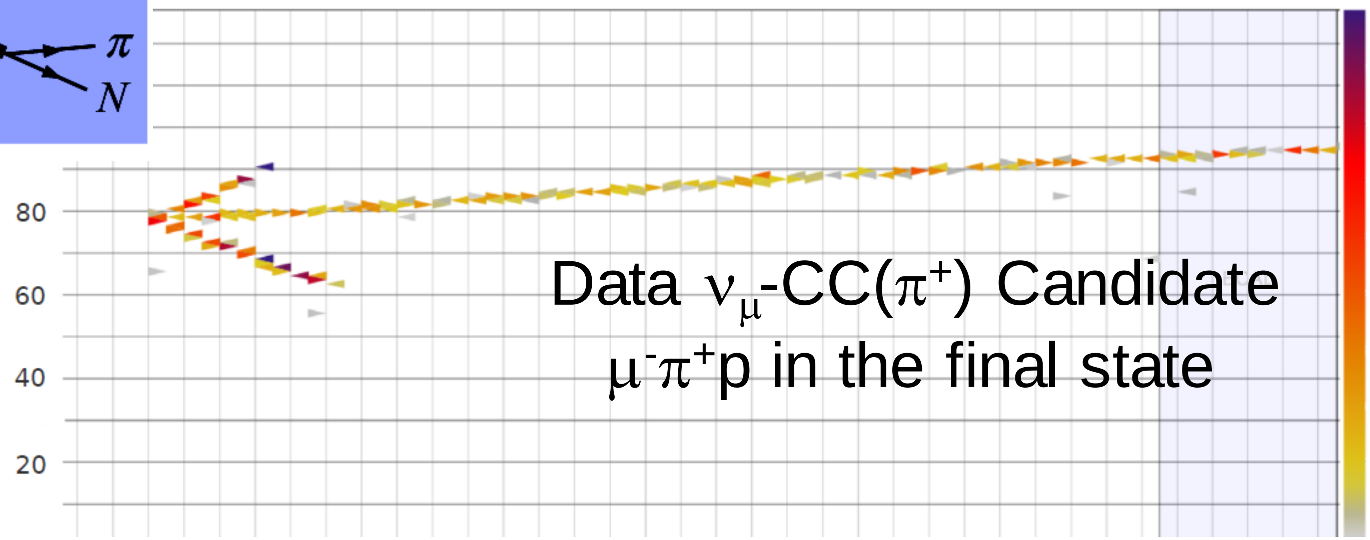
- Can investigate final state interactions by measuring the pion spectra
- Can investigate nuclear modifications by measuring $Q^2$ which is insensitive to pion FSI since you measure via the outgoing lepton

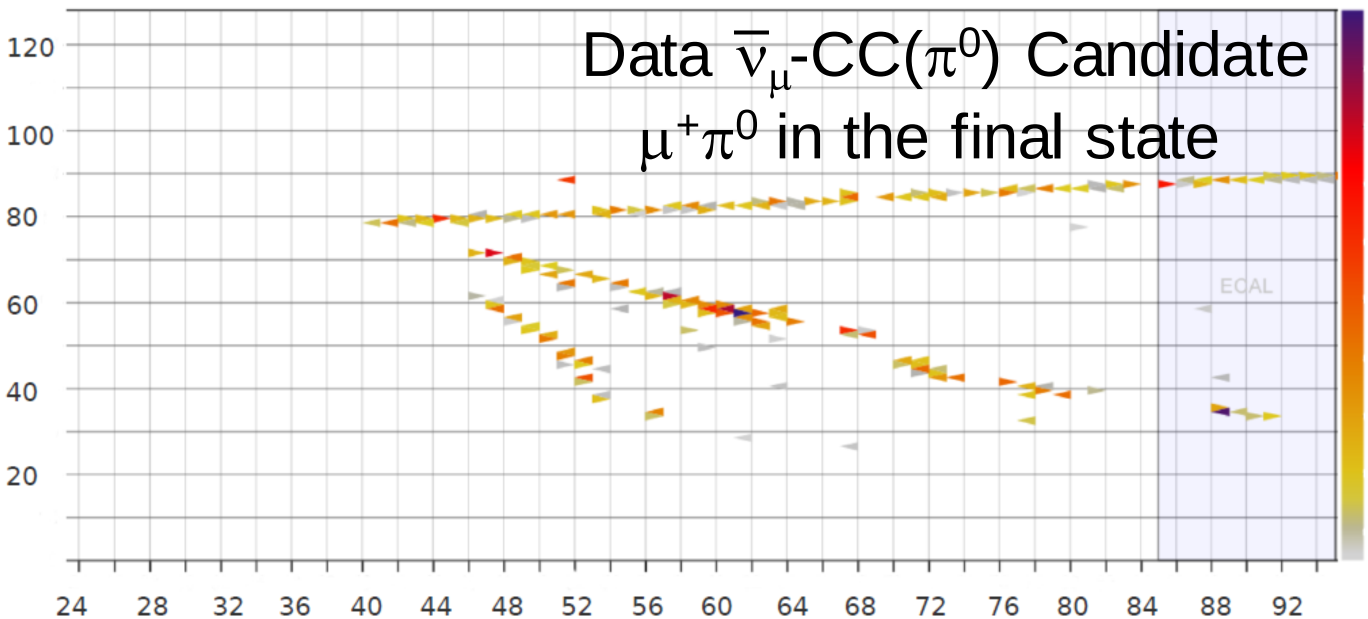


# Pion production

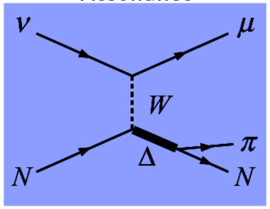
Resonance



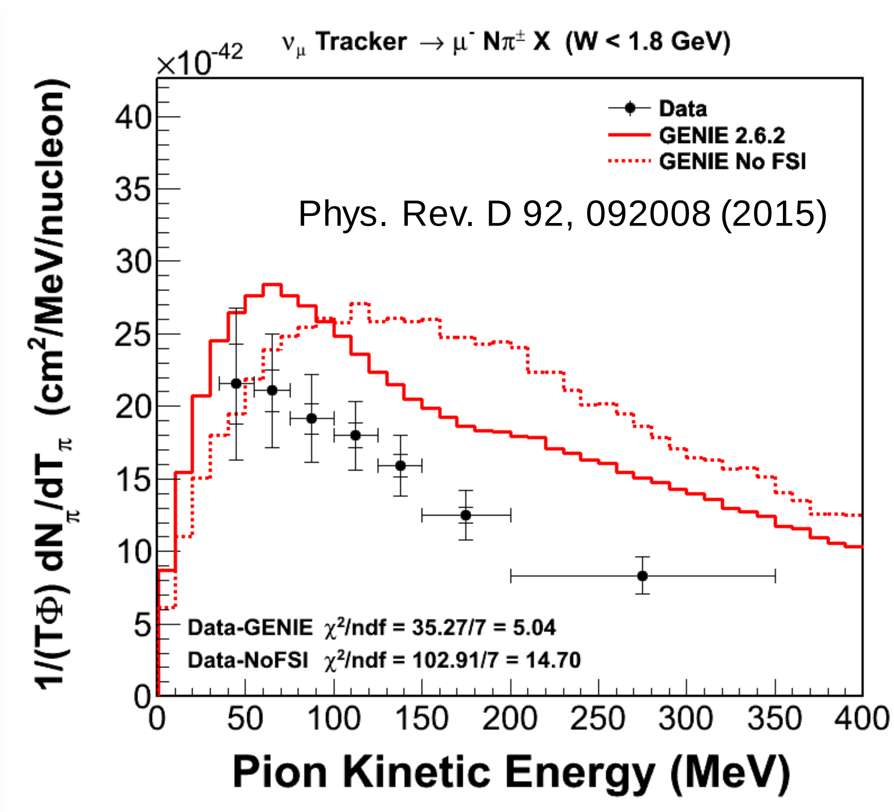



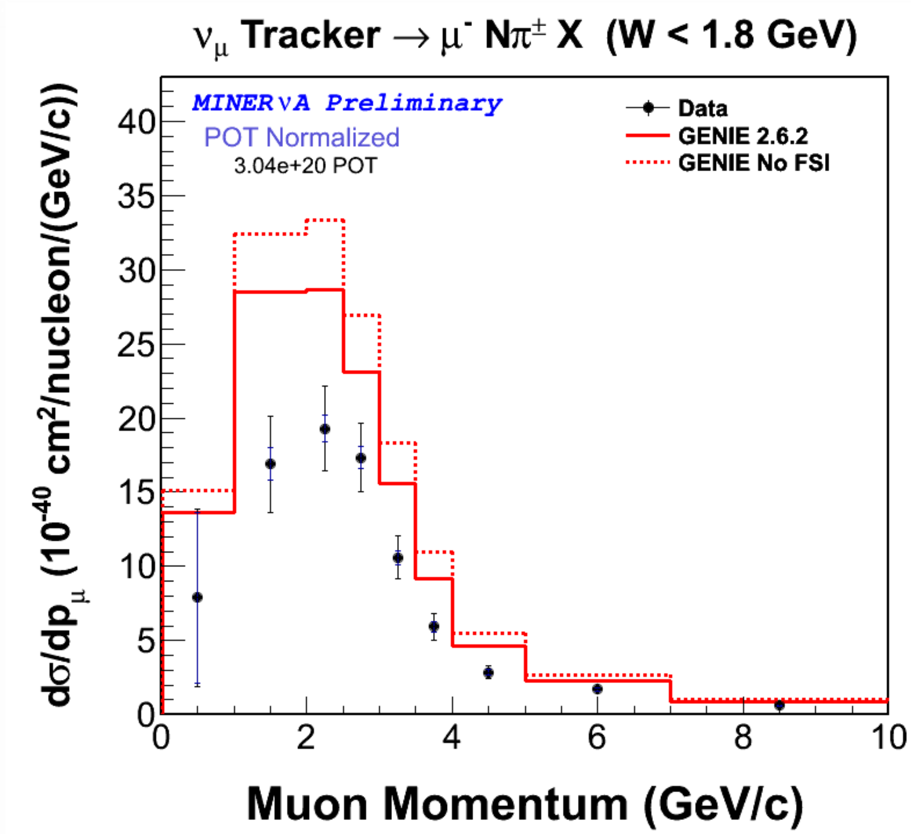



Resonance

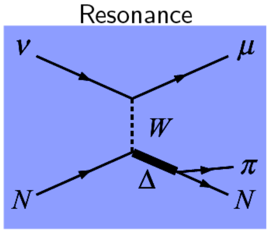



# Charged Pion Results

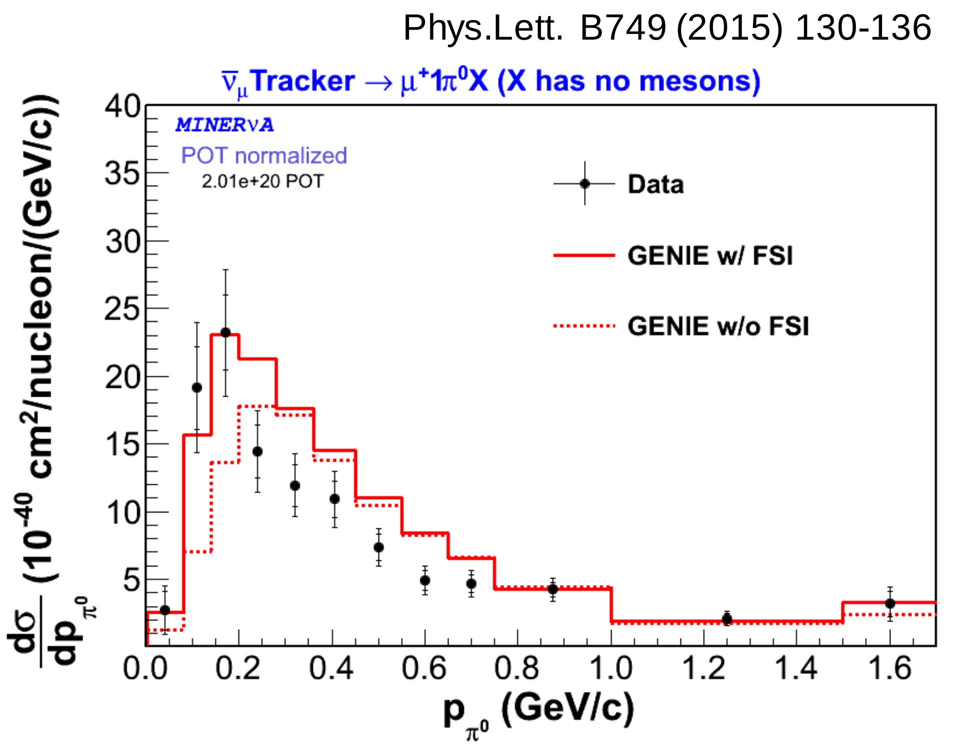


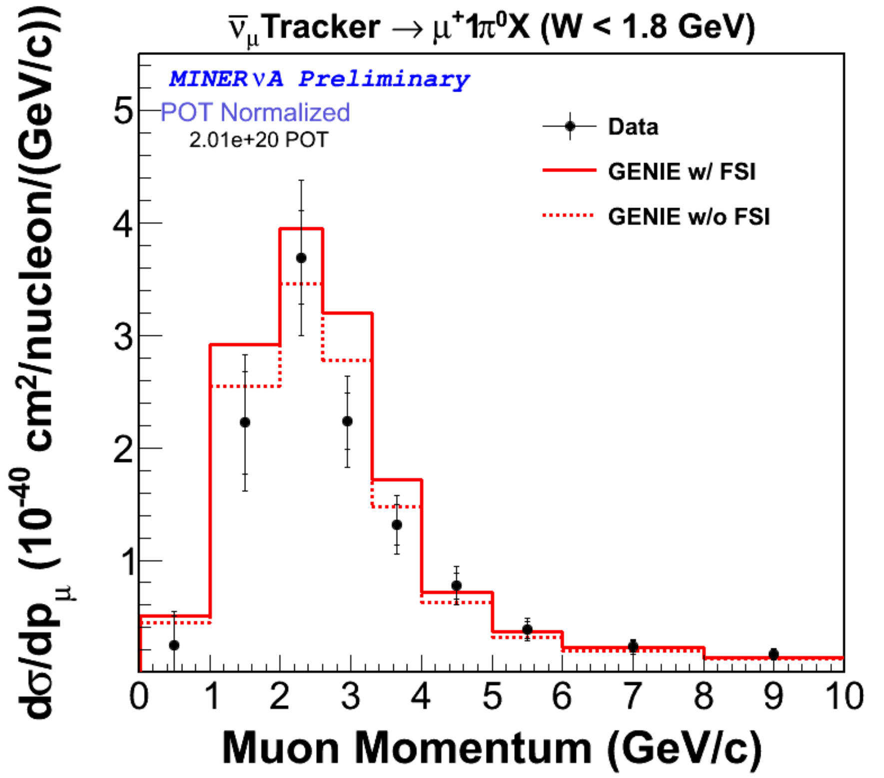




- Shape agrees, but cross section is over predicted
- FSI reduces the cross section due to pion absorption




# Neutral Pion Results




- Shape agrees
- FSI increases the cross section due to charge exchange

# Conclusions

- MINERvA measures neutrino scattering and the associated nuclear effects due to the use of heavy nuclei in our detectors
- All results today come from the low energy beam configuration
  - More results from this configuration are to come
  - Taking data in a higher-energy configuration with more exposure
    - nearly 3x the low-energy data set and growing!

# Thank You

The MINERvA collaboration in Duluth, Minnesota, 2014

# Backups