FERMILAB-SLIDES-18-080-ND

Preliminary Analysis in MINERvA's Nuclear Targets for CCQE-like Events

2018-06-18

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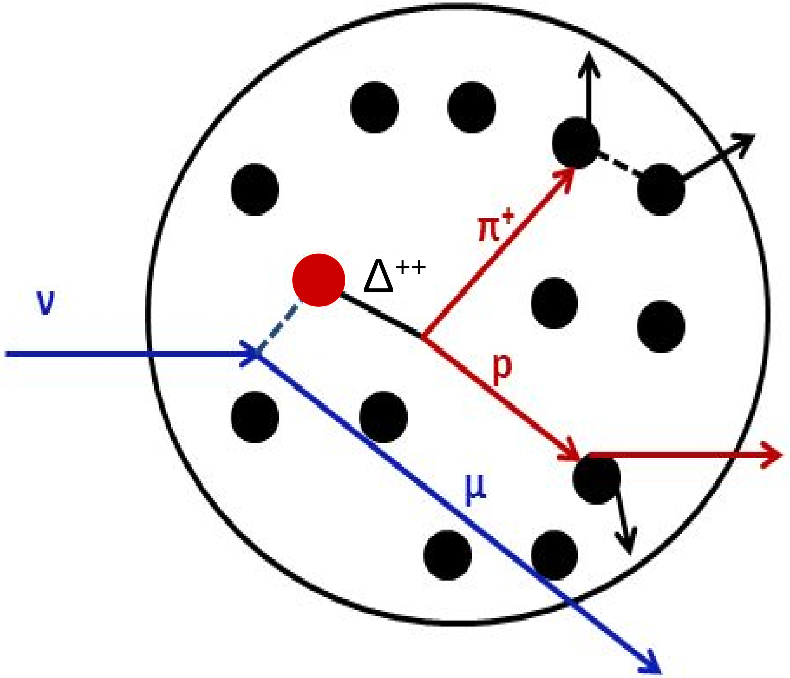
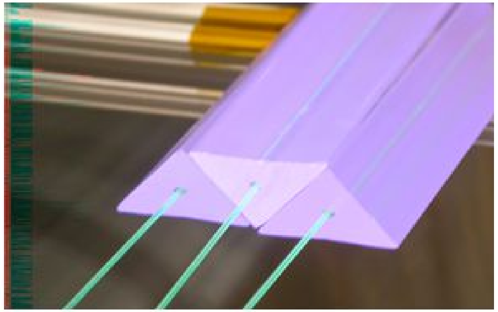
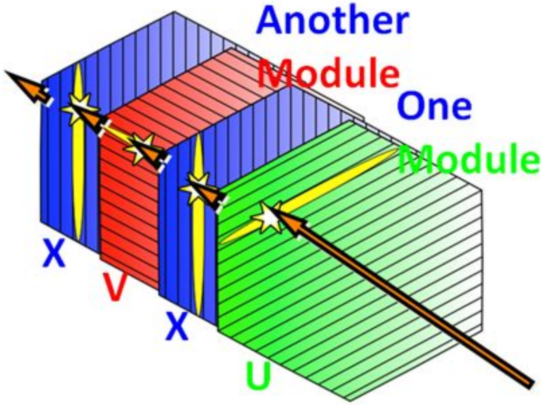
Motivation

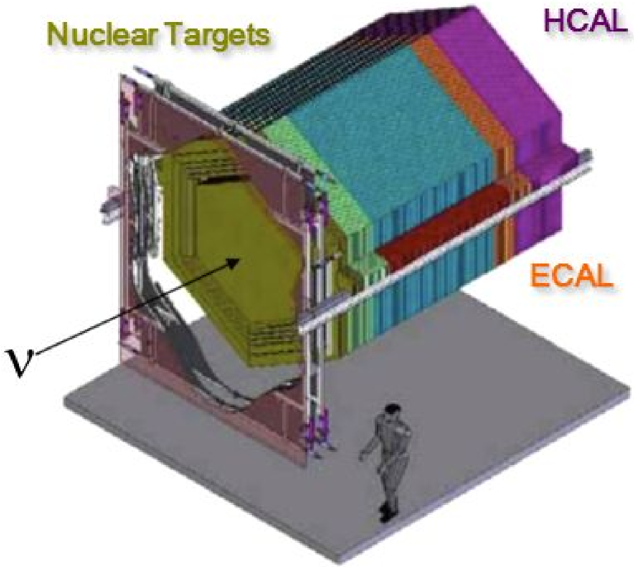
- Neutrino oscillation measurements need to know the neutrino energy to high precision
- Can't observe the neutrino directly
  - Reconstruct energy from outgoing particles
- Different interaction types
  ➔ different reconstructed E_ν
- Need precise measurement of neutrino-nucleus cross section
  - A dependence

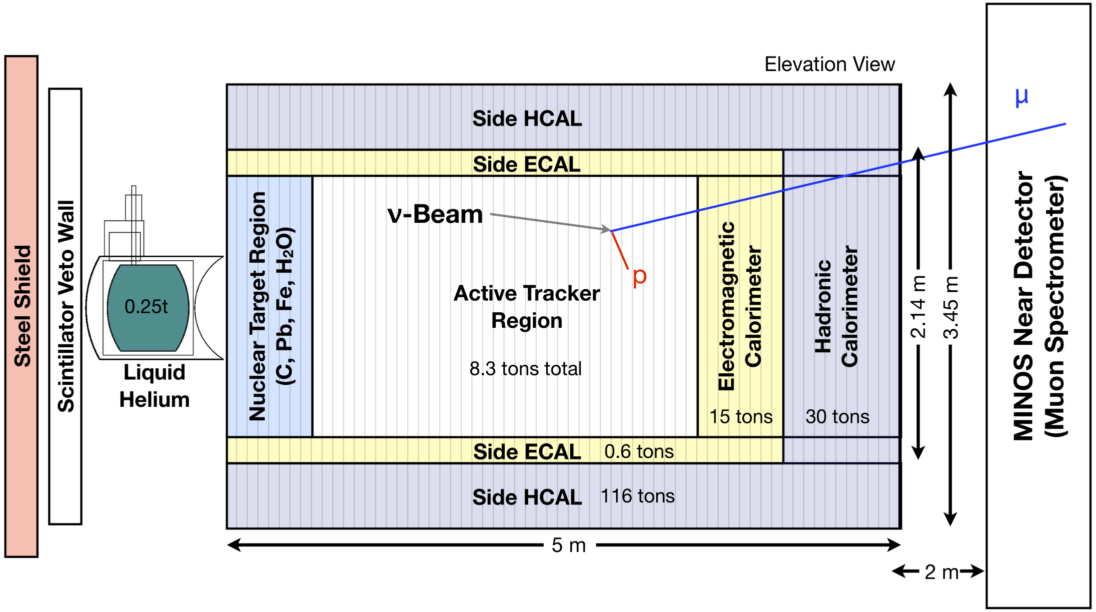


MINERvA Detector



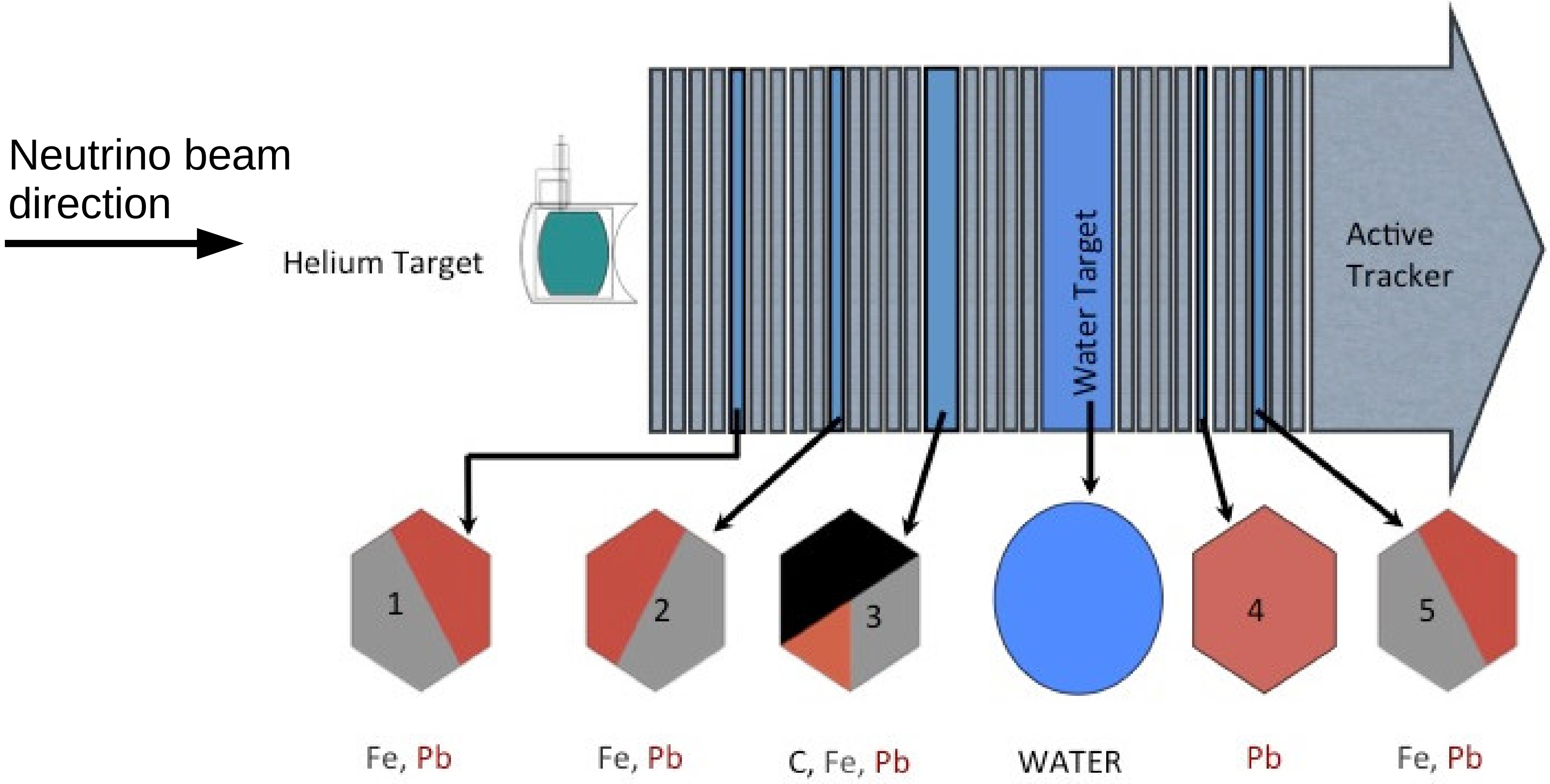




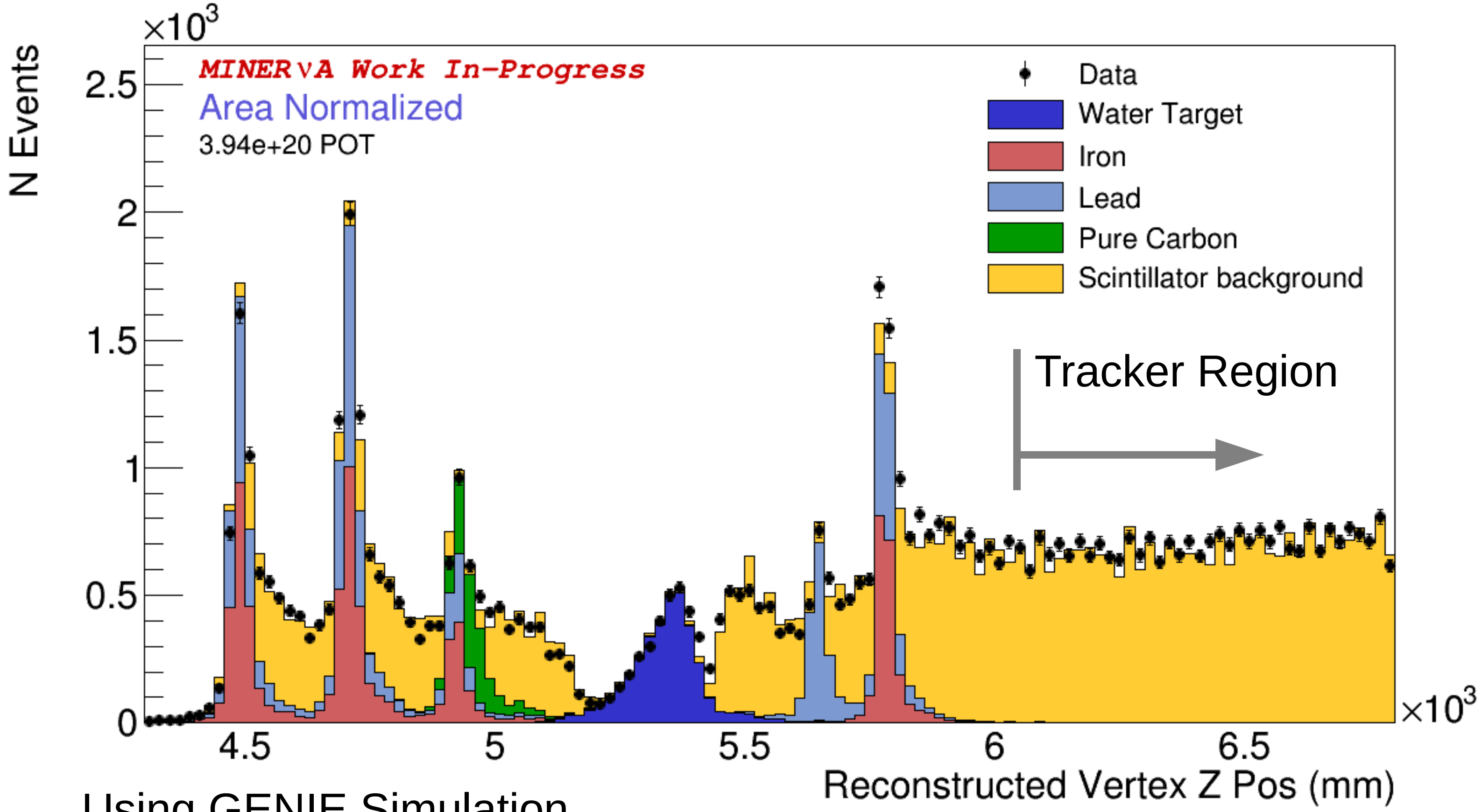


Nuclear Targets

Neutrino beam direction

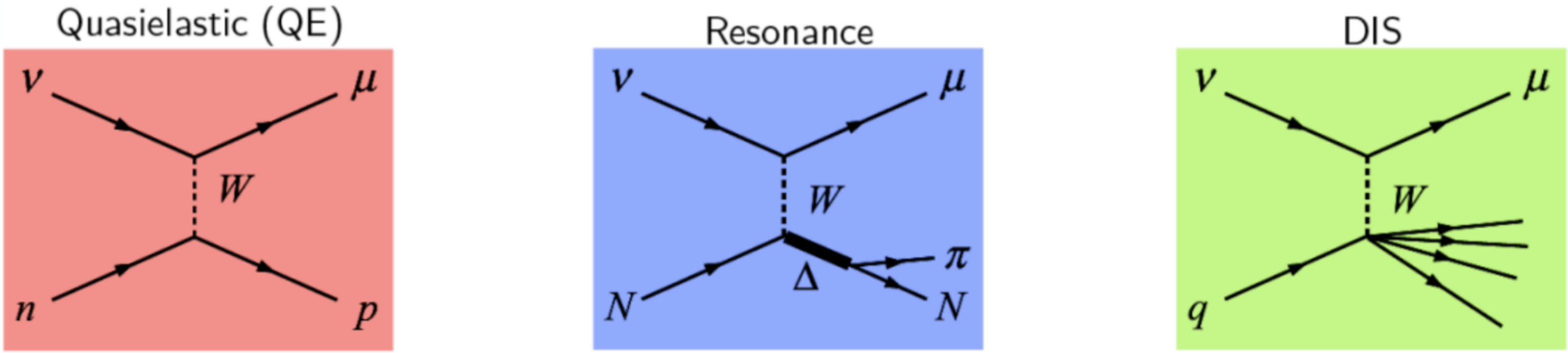


Reconstructed Interaction Vertex Position In Nuclear Target Region



Using GENIE Simulation

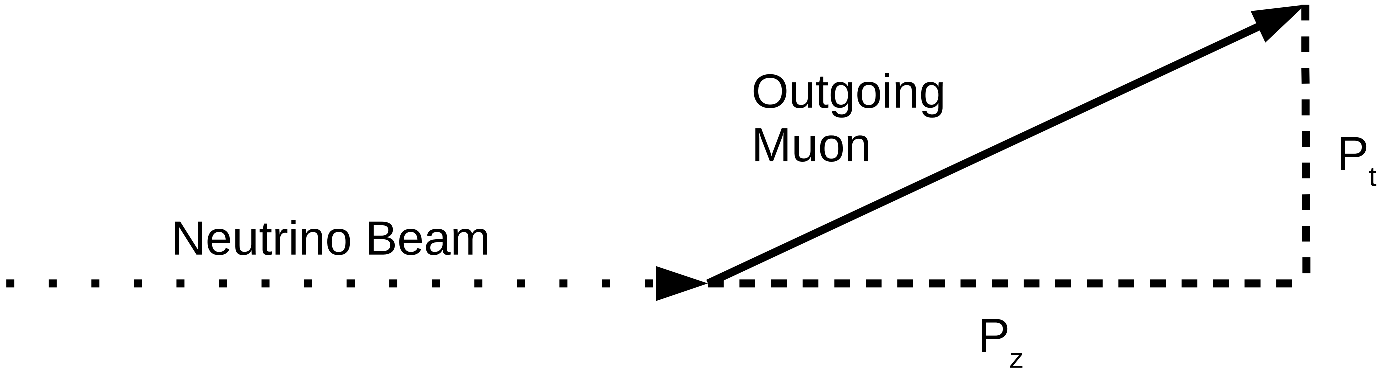
CCQE-like (CC0π)



- Pion can be absorbed by nucleus
  - Events with pions can look like QE
- Final state:
  1 Muon
  no mesons
  no gammas > 10 MeV (usually come from Pi0)
- More closely matches capabilities of proton-blind detectors

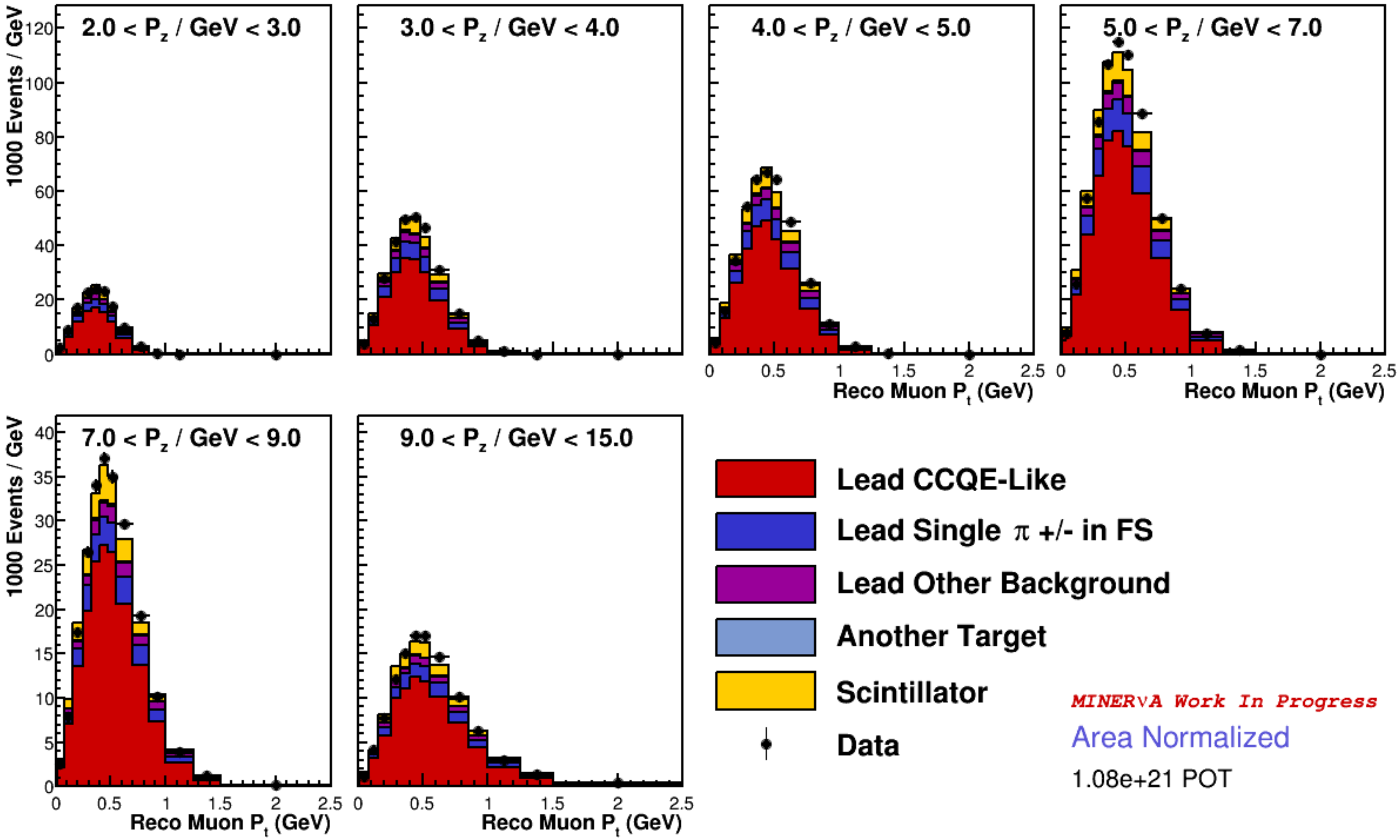
Muon Momentum

- Muon is largely unaffected by the nucleus
  - P_z = momentum along neutrino beam direction (z direction)
  - P_t = momentum along transverse direction (perpendicular to z)



*

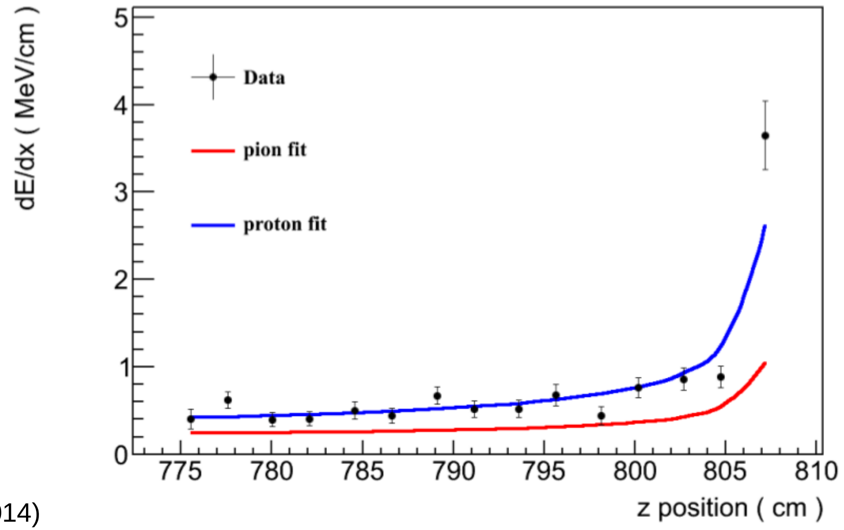
Lead Muon Momentum in Bins of P_z



Proton Kinetic Energy

- Proton Kinetic Energy (KE) found via dE/dX
- Only a portion of events have a reconstructed proton
  - Proton needs to create long enough track for reconstruction

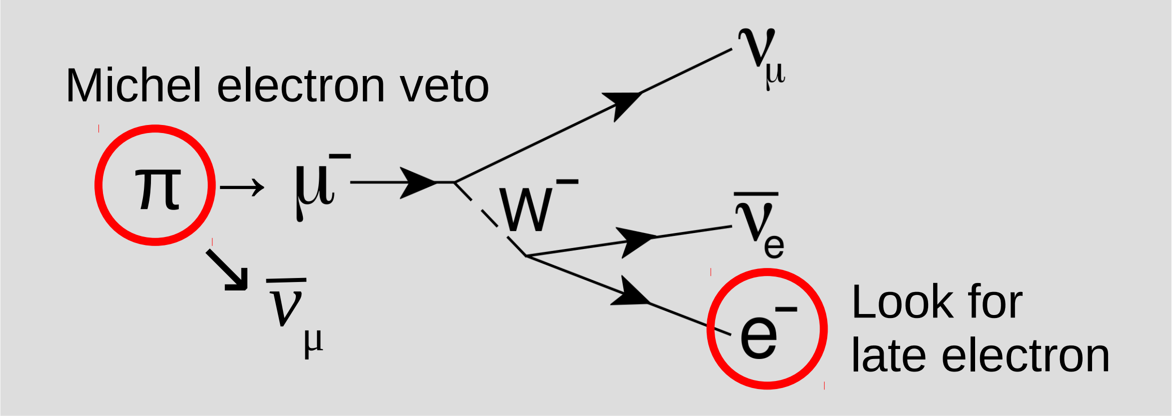
dE/dX profile comparison



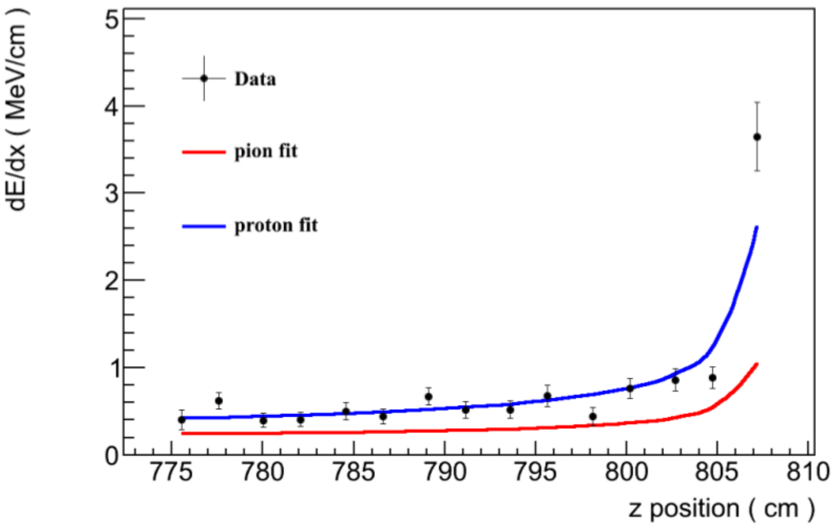
[1] L. Aliaga et al. (MINERvA Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **743**, 130 (2014)

Proton Kinetic Energy

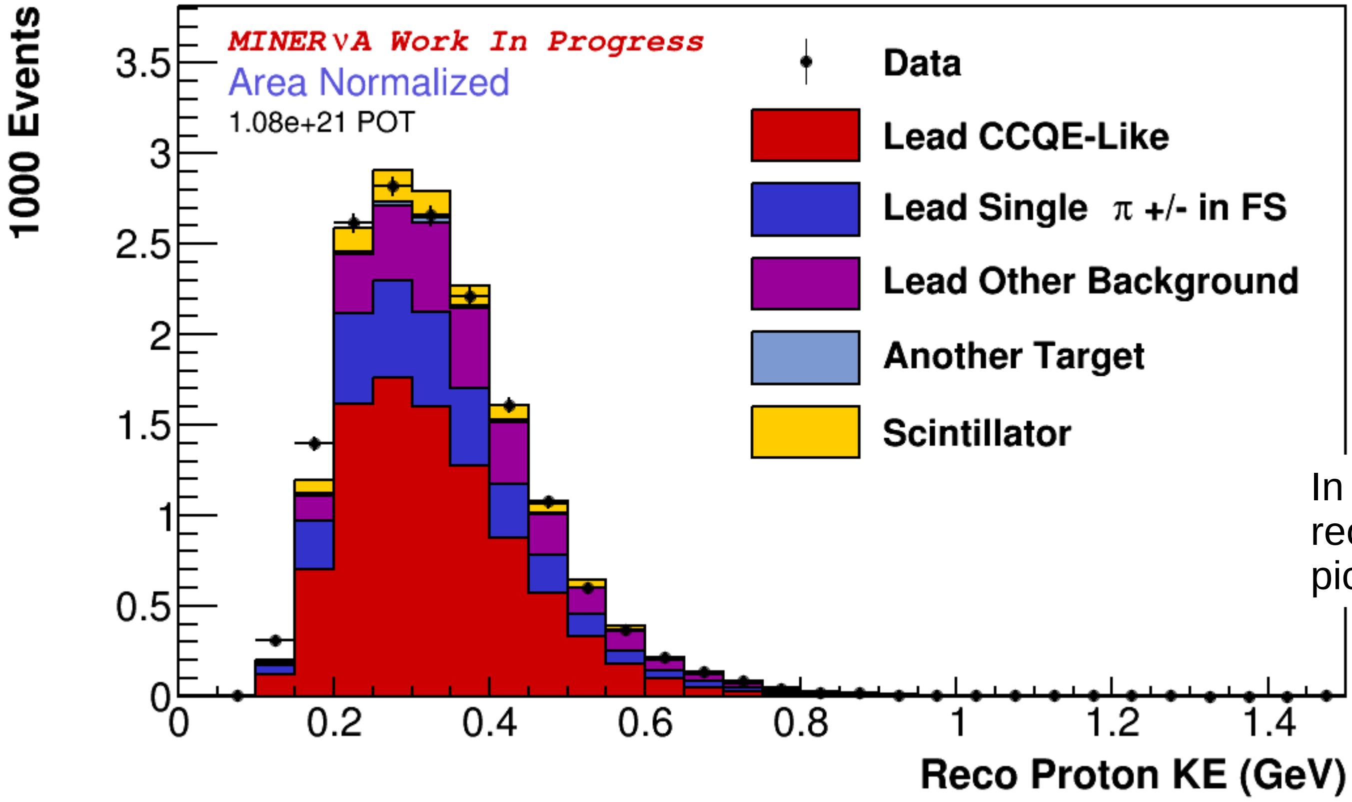
- Proton Kinetic Energy (KE) found via dE/dX
- Only a portion of events have a reconstructed proton
  - Proton needs to create long enough track for reconstruction
- Pions are rejected with two methods:



dE/dX profile comparison



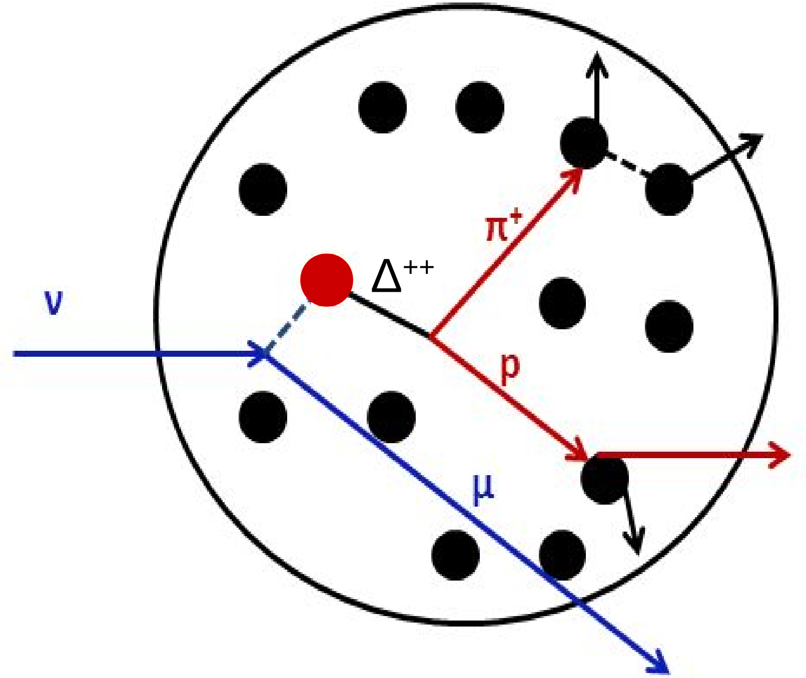
Reconstructed Proton Kinetic Energy in Lead



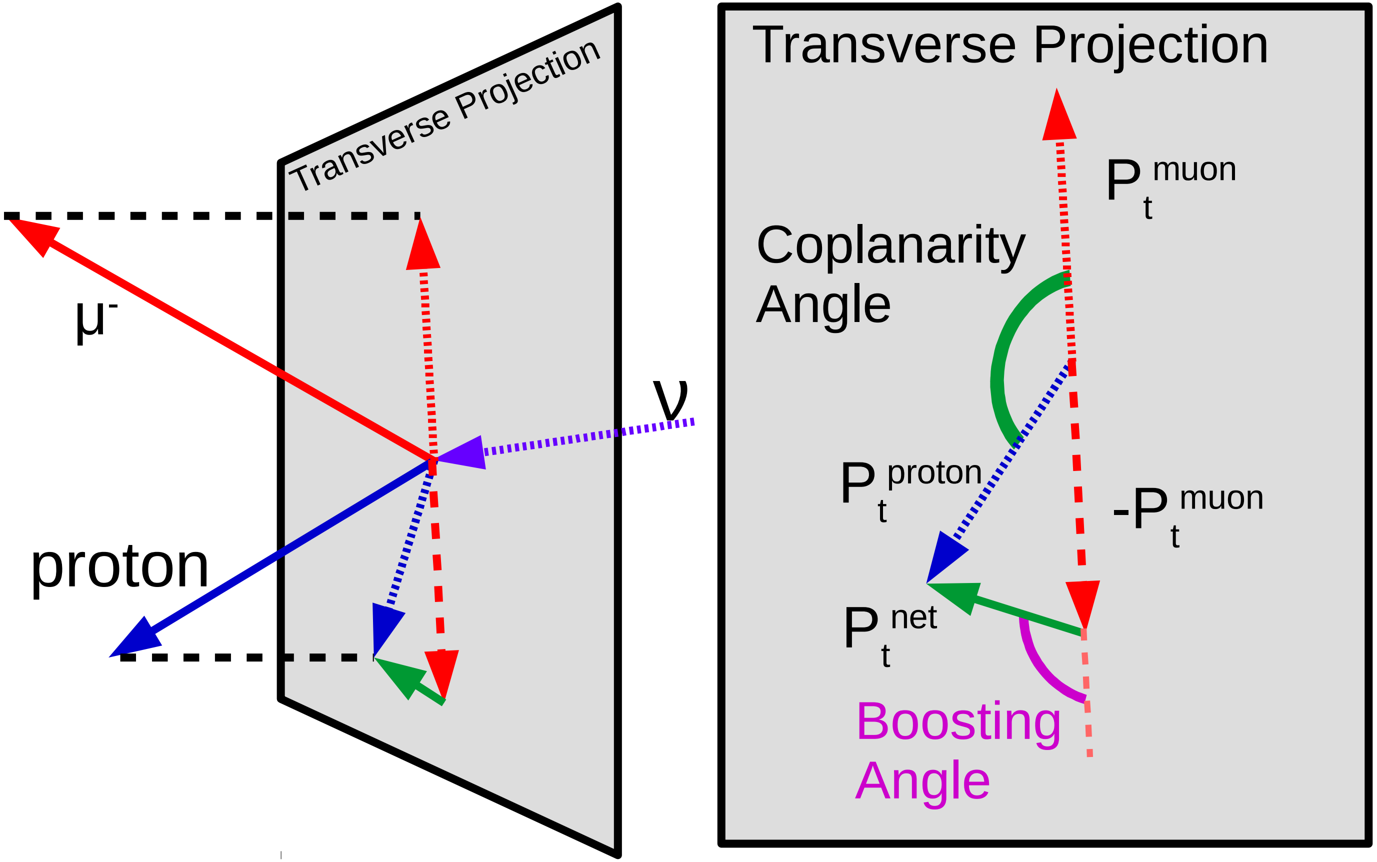
In case of two or more reconstructed protons, pick the highest energy

Inside the nucleus

- Fermi motion
  - Natural motion of protons and neutrons before interaction
  - Energy ~100s of MeVs
- Final State Interactions (FSI) can
  - Change proton momentum
  - Change particle charge
  - Absorb pions
  - Muon largely unaffected



Transverse Momentum Imbalance

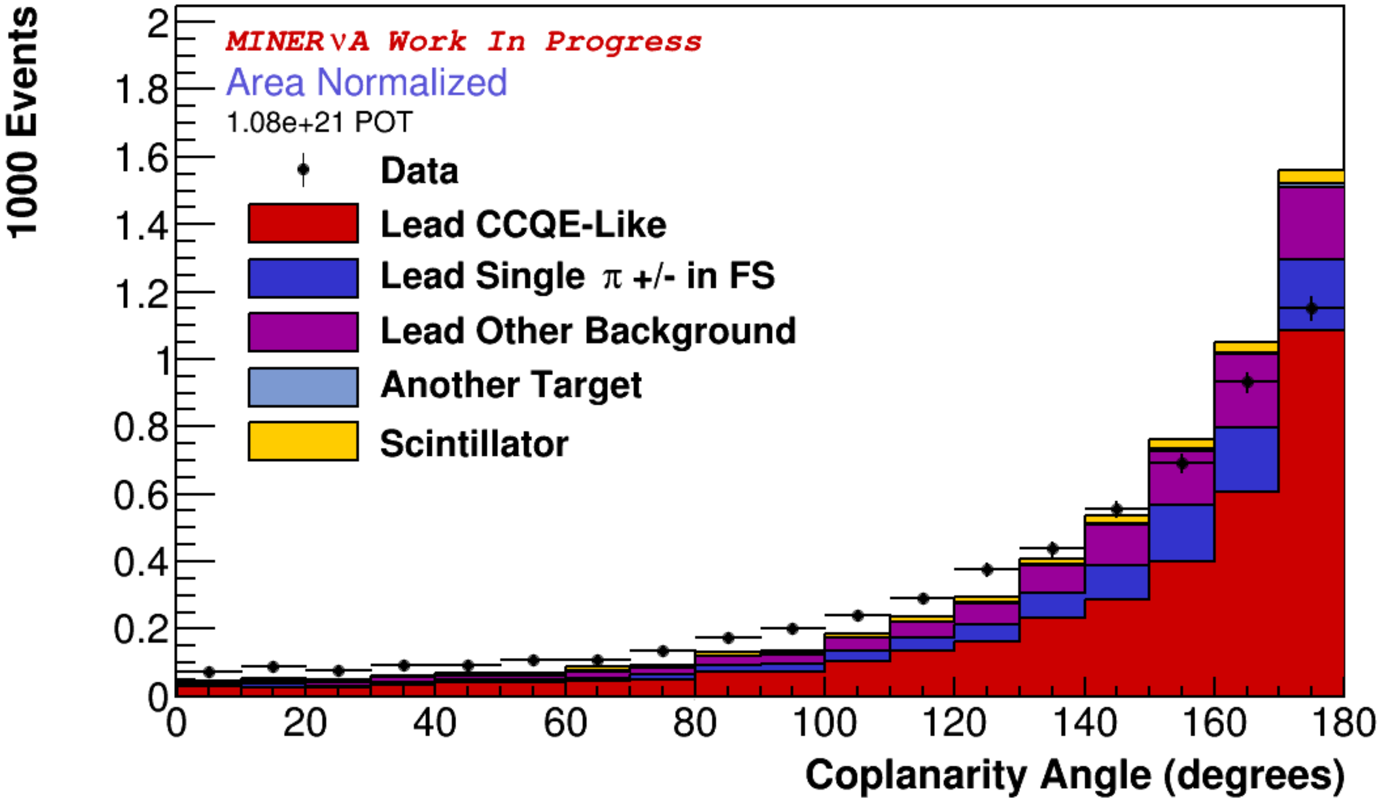


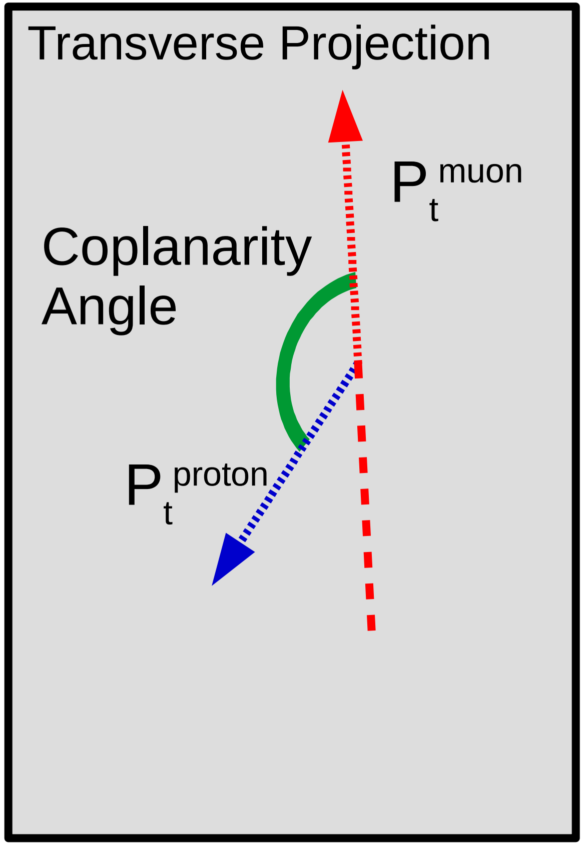
- With no interactions, proton transverse momentum would be opposite muon
- Muon-Proton momentum differences give insight into nucleus
- Coplanarity angle
  → proton deflection
- Boosting angle
  → other FSI effects

[2] A. P. Furmanski and J. T. Sobczyk, Phys. Rev. C **95**, 065501 (2017).
[3] X. Lu, et al. [MINERvA Collaboration], arXiv:1805.05486 [hep-ex]

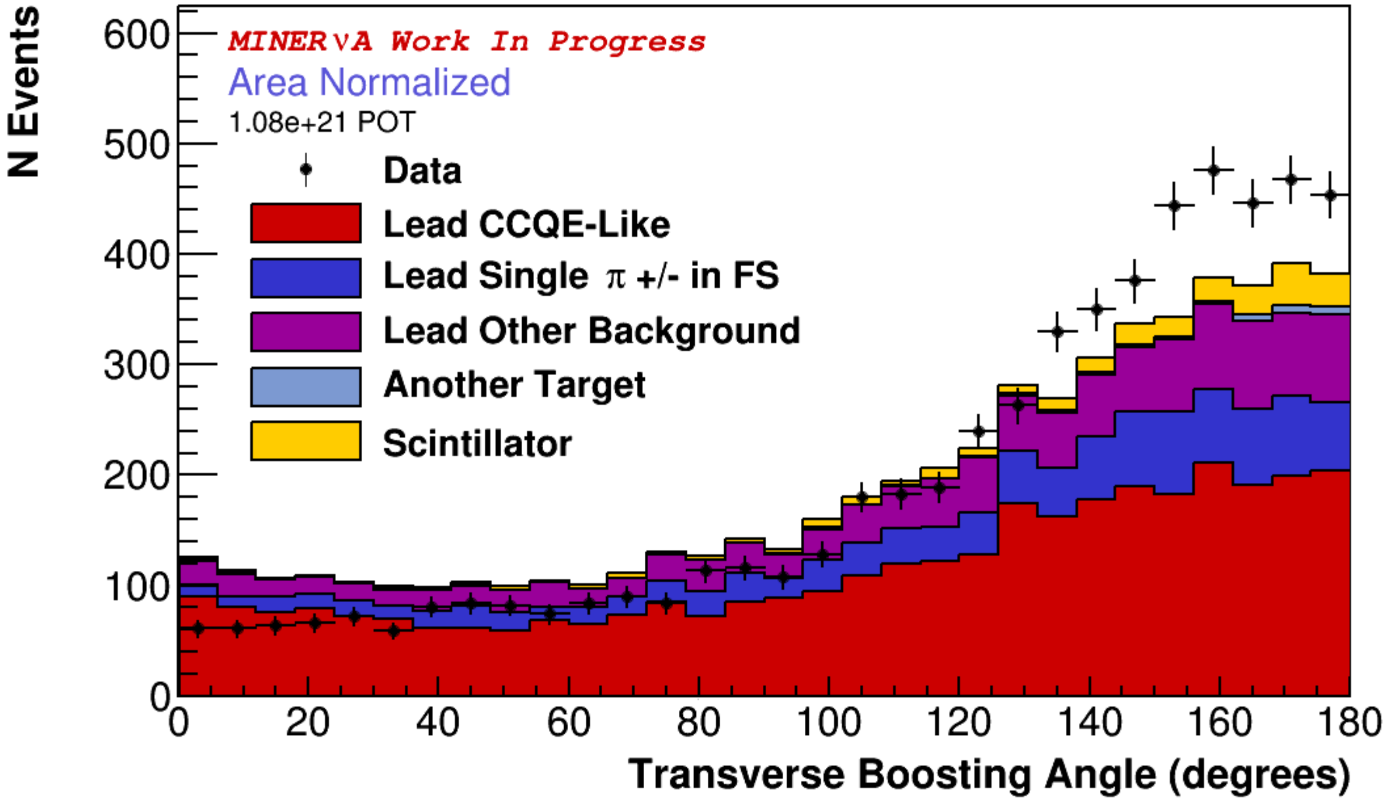
Coplanarity Angle in Lead

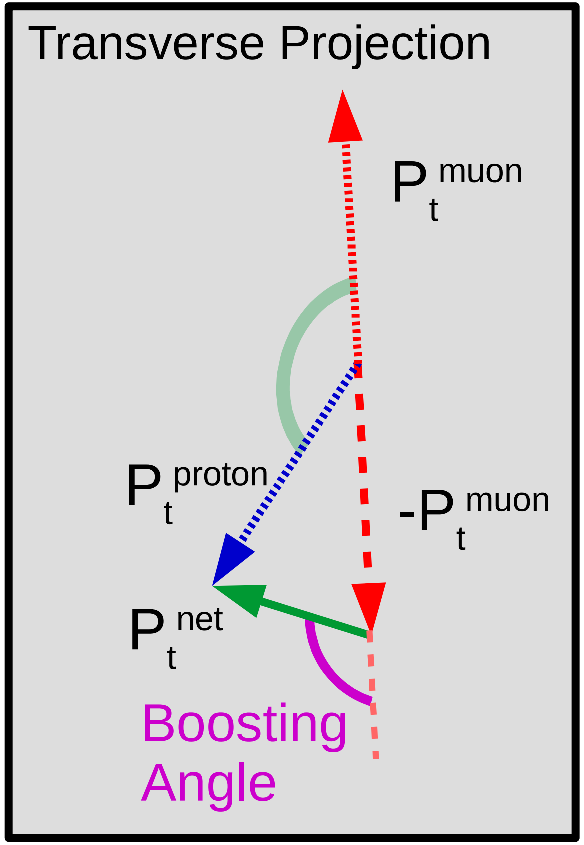
Measures Proton Deflection





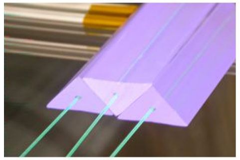
Transverse Boosting Angle in Lead

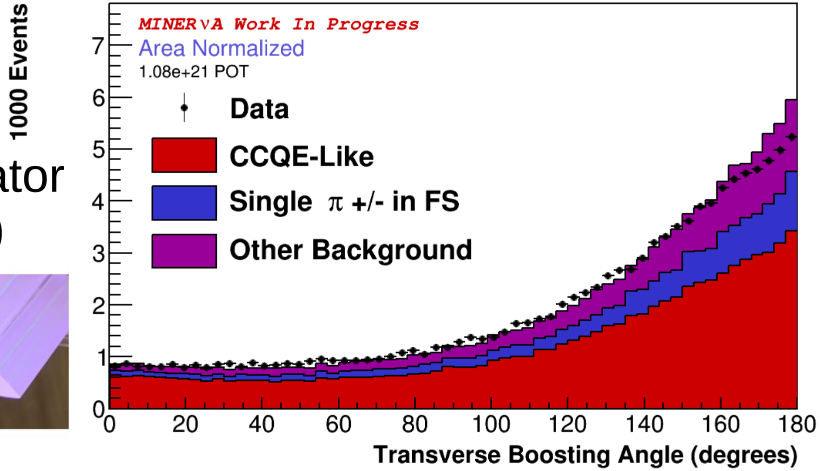


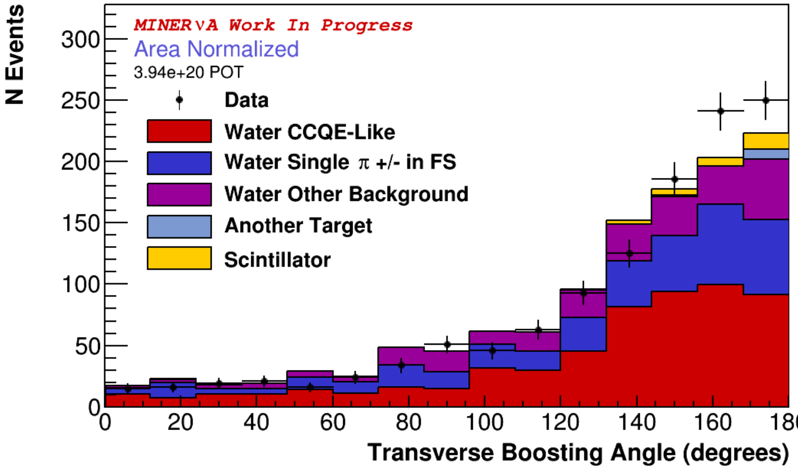


Comparison Between Materials

Scintillator (CH)

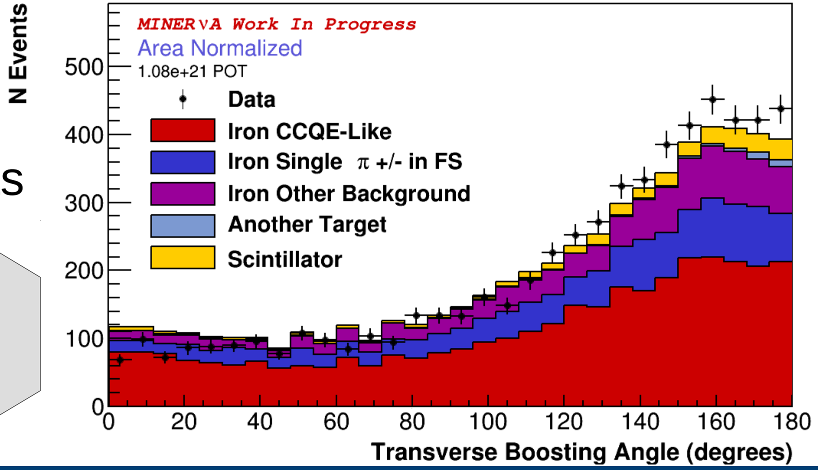


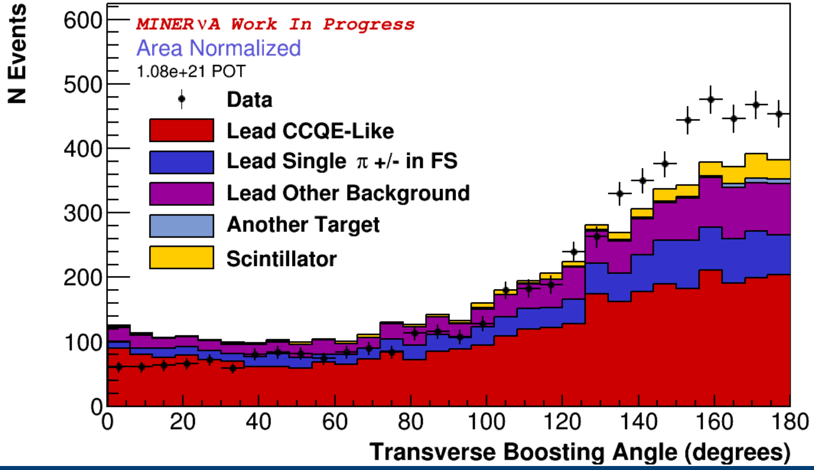




Water Target

Iron Targets





Lead Targets

Conclusion

- NuMI beam's medium energy run provides high statistics
- Mature analysis technique to isolate events in nuclear targets
- Statistically significant differences between data and simulation
  - See trend as function of nucleus size
- Double differential cross section
- Results coming soon

Thank You

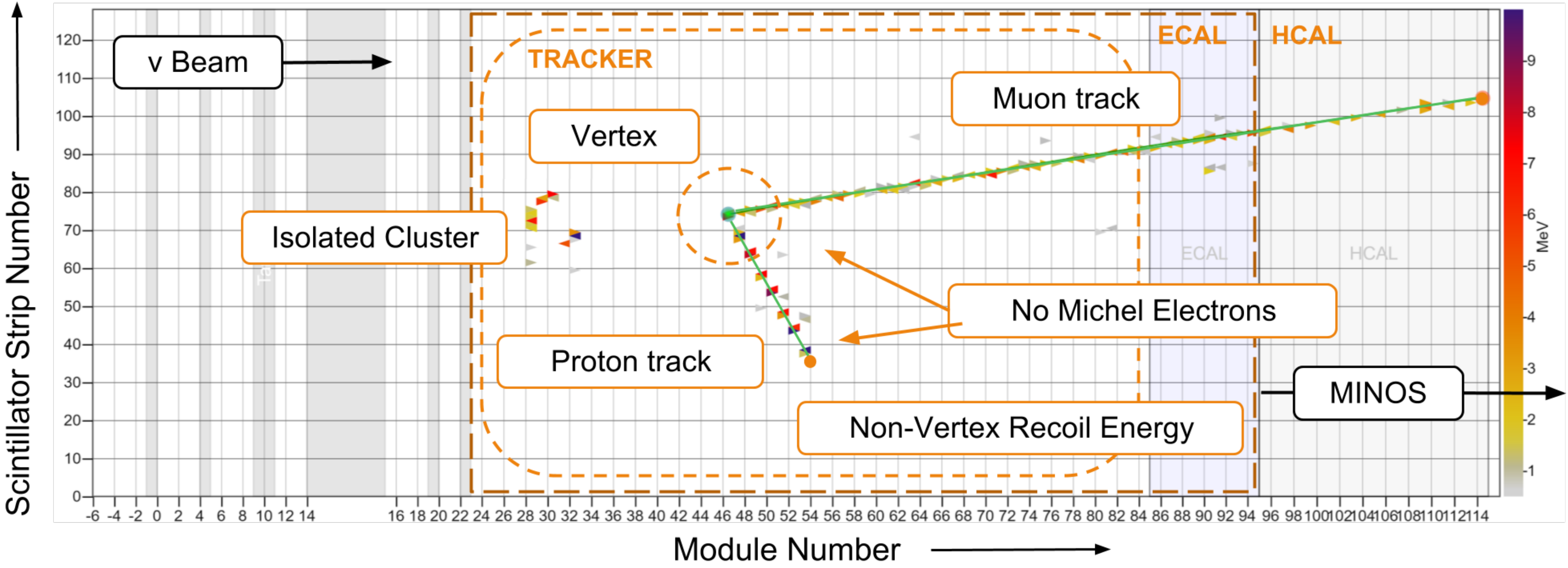
Backup

Simulation Info

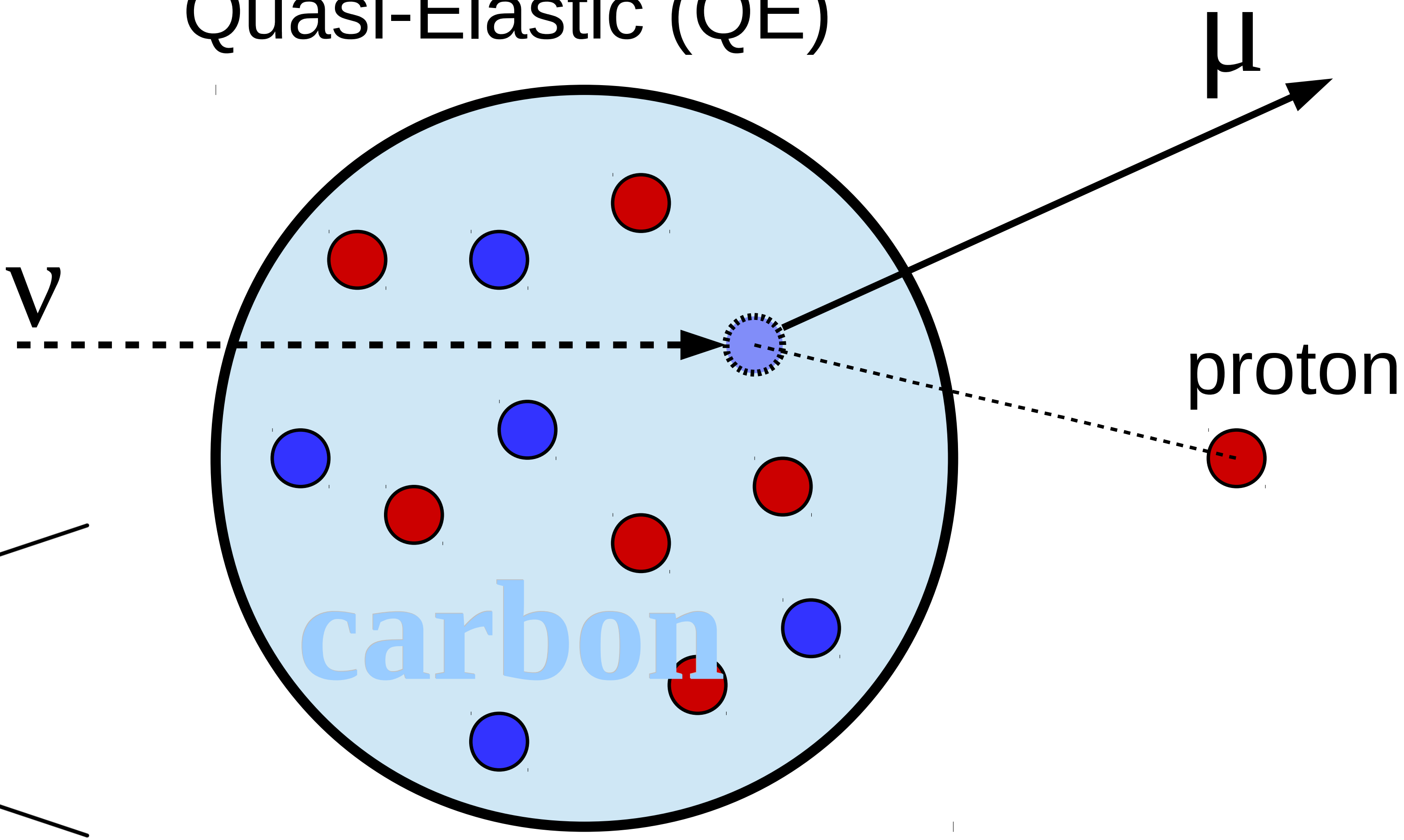
- Using MnvGENIE-v1 simulation with various changes including
  - Reduced pion production
  - Random Phase Approximation (RPA) correction
  - Valencia 2p2h with tune using MINERvA inclusive scattering data
    - No pion prediction
  - See [1-6]

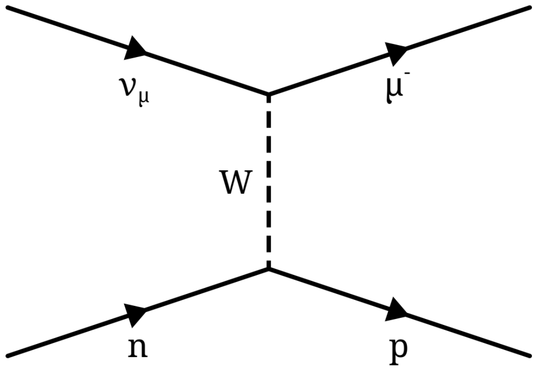
[1] C. Andreopoulos et al., Nucl. Instrum. Meth. A 614, 87 (2010), Program version 2.8.4, with private modifications, used here.
[2] A. Higuera et al. (MINERvA Collaboration), Phys. Rev. Lett. 113, 261802 (2014), arXiv:1409.3835 [hep-ex] .
C. Wilkinson et al., Phys. Rev. D 90, 112017 (2014), arXiv:1411.4482 [hep-ex] .
C. Wilkinson et al., In preparation 90 (2015), 10.1103/PhysRevD.90.112017, arXiv:15xx.xxxxx [hep-ex] .
[3] J. Nieves, J. E. Amaro, and M. Valverde, Phys. Rev. C 70, 055503 (2004), arXiv:nucl-th/0408005 [nucl-th].
[4] J. Nieves, I. Ruiz Simo, and M. Vicente Vacas, Phys. Rev. C 83, 045501 (2011), arXiv:1102.2777 [hepph] .
[5] R. Gran, J. Nieves, F. Sanchez, and M. Vicente Vacas, Phys. Rev. D 88, 113007 (2013), arXiv:1307.8105 [hep-ph] .
[6] P. A. Rodrigues et al. [MINERvA Collabtoration], Phys Rev. Lett. 116, 071802 (2016)

Event Selection

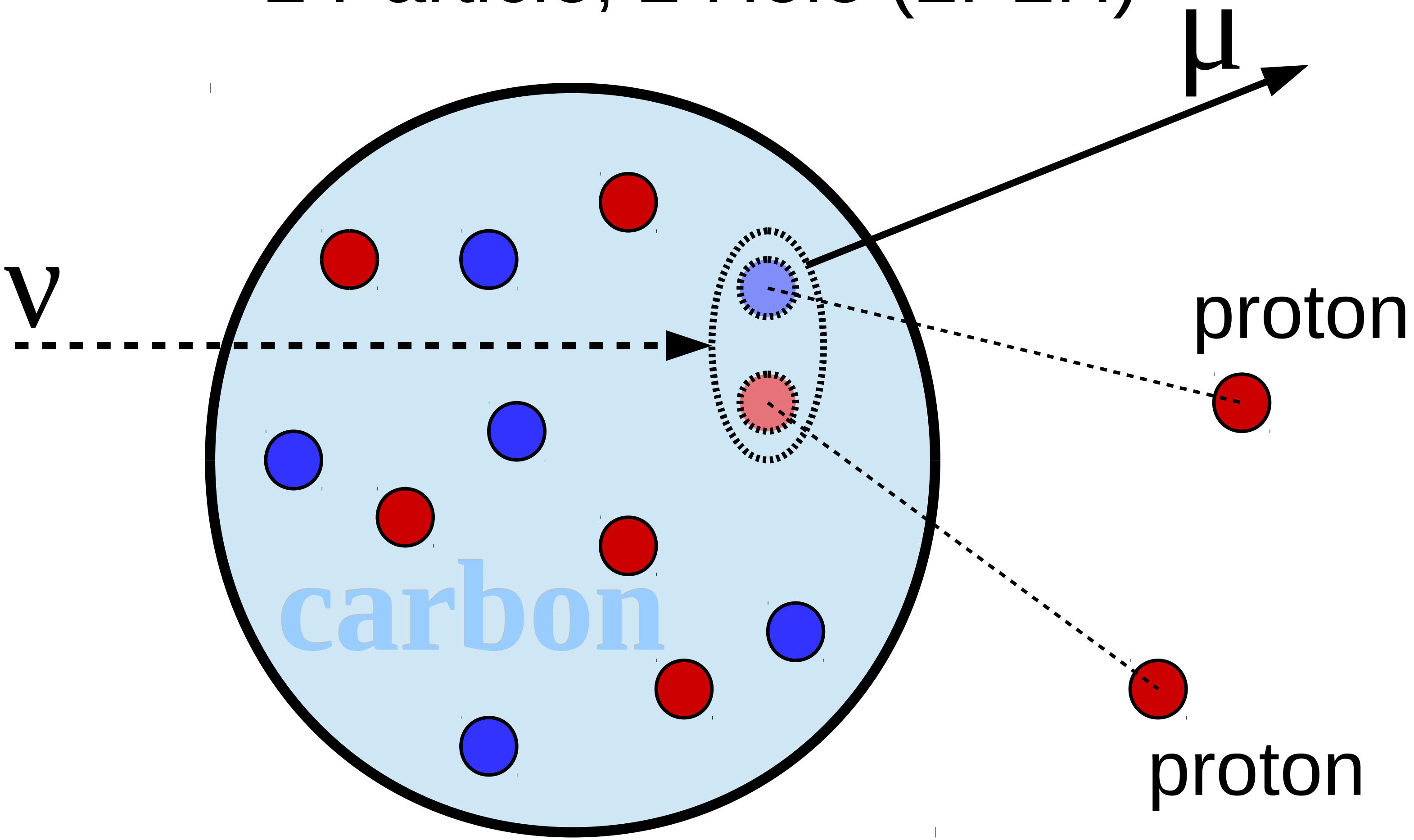


Quasi-Elastic (QE)

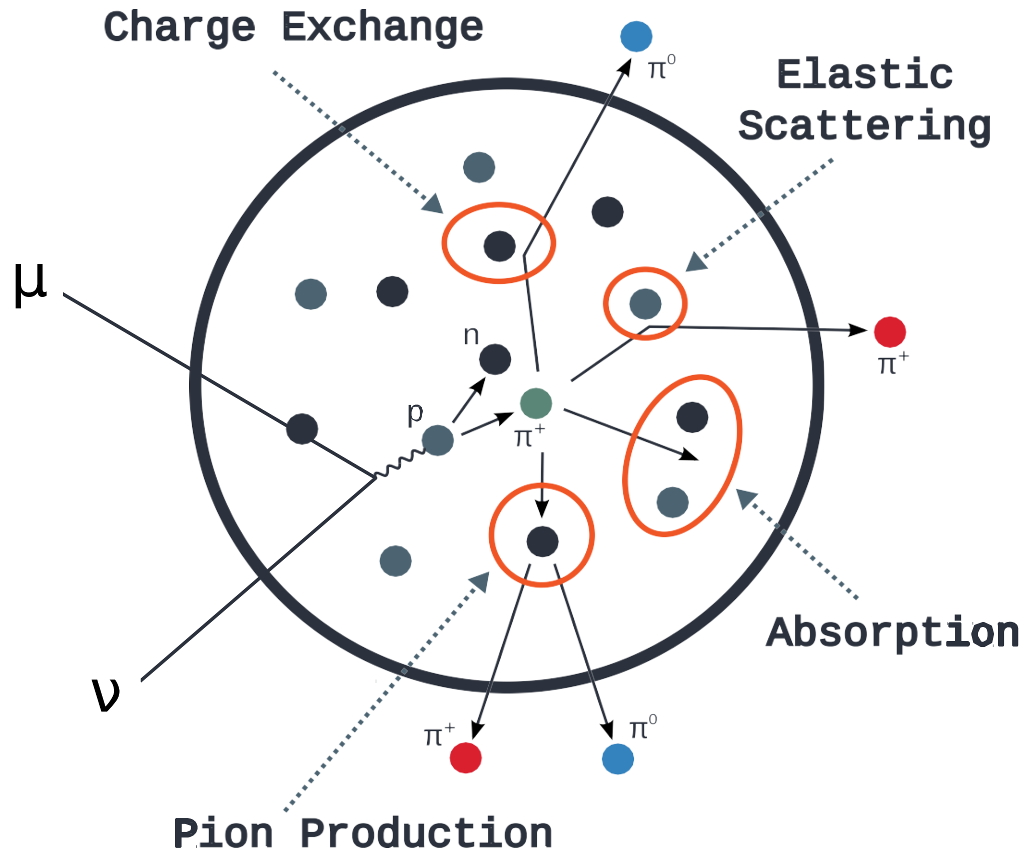




2 Particle, 2 Hole (2P2H)



Final State Interaction



- Initial hadron shower interact within the nucleus changing
  - apparent final state configuration
  - detected energy.
- An initial pion can charge exchange or be absorbed on a pair of nucleons. The final state observed is μ + p that makes this a fine candidate for QE production
- We've probably also lost measurable energy