NUISANCE-GENIE Validation and Sample Additions

Adrian Orea, FNAL SIST Intern

Supervisor: Minerba Betancourt

15 August 2017

Outline

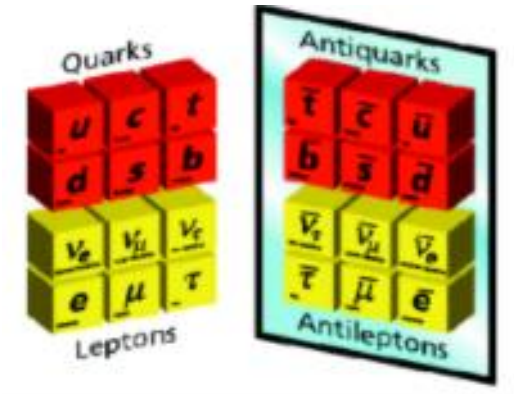
- Objective
  - Model and version validations
  - Sample additions to NUISANCE framework
- Background
  - NUISANCE and GENIE
  - Cross sections
  - MINERvA project
  - Neutrino interactions
  - Variables
- Validation and Model Comparisons
- Future work
- Conclusion

Objective

- The goal of the project came in two separate but related tasks
  - First, signal definitions in NUISANCE had to be validated
    - Also involved validating the functionality and validity of different versions of simulation software (GENIE)
  - Secondly, new samples were needed to be added into the NUISANCE framework to allow for future analysis with data and simulations (MC)
    - These samples were also added to validate papers in progress to be validated
  - Compare Different Models

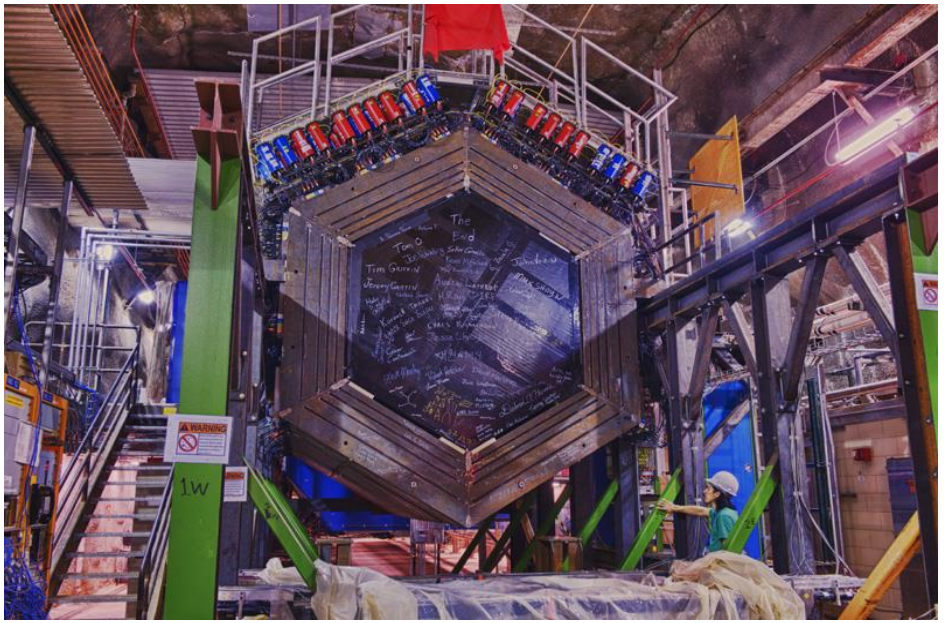
Neutrinos

- Neutral particles
  - Come in three “flavors”
  - We work with muon neutrinos (numu) and anti muon neutrinos (anti numu)
- Interact only via the weak force
  - Millions pass through us
  - ~1 light year of lead to interact
  - In order to get interactions in detectors, they need to be huge and have a high intensity beam



MINERvA Detector

- Large detector that uses the NuMI beam
- Unique detector
  - Unconventional hexagonal shape
  - Utilizes five nuclei to obtain data
    - Iron
    - Lead
    - Carbon
    - Water
    - Helium



[1]Photo Credit: Fermilab Photo Gallery (Reidar Hahn)

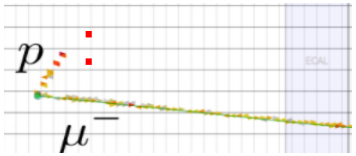
MINERvA

Fermilab

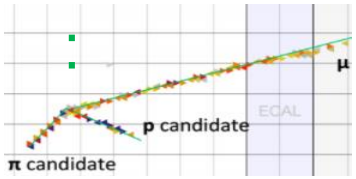
Interactions

- There are two categories in which an interaction can fall into
  - Charged current (CC)
    - The final state particles are charged and the flavor of neutrino can be determined
    - Fall in 1 of three categories
      - Quasi Elastic (QE)
      - Resonant Elastic (RES)
      - Deep Inelastic (DIS)
  - Neutral current (NC)
    - There are only neutral particles in the final state, no flavor can be determined

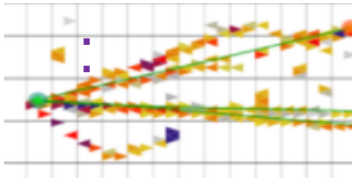
CCQE



CCRES

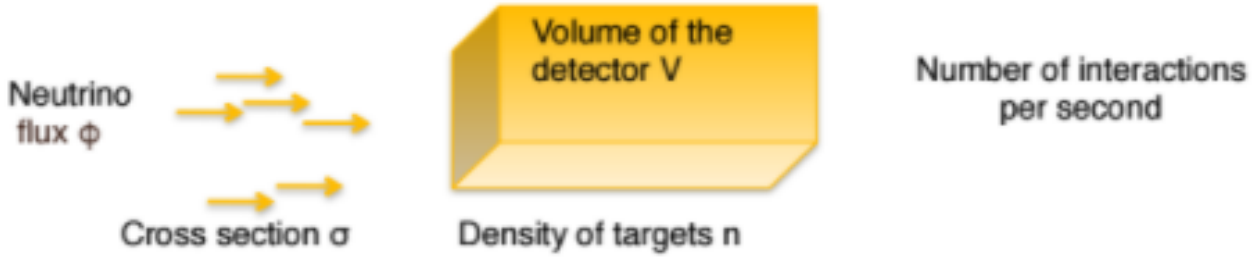


CCDIS



Cross Sections

- Measurement from detector that is proportional to the probability of the interaction occurring
  - Very small for neutrinos
- Differential cross section when related to a variable (angle)

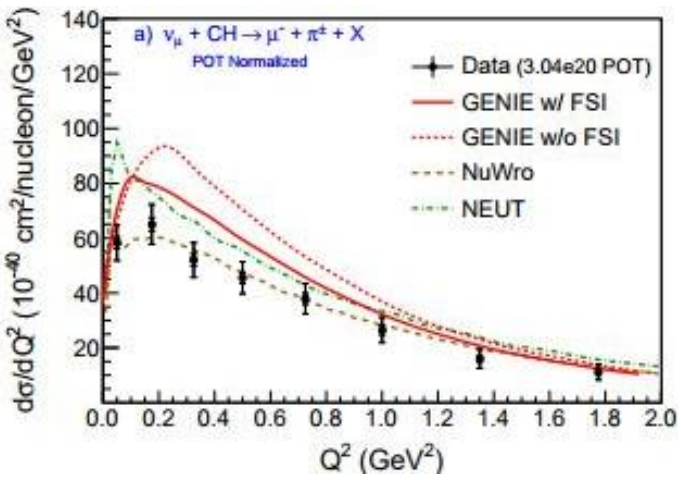


$$\sigma = \frac{N}{\Phi T}$$

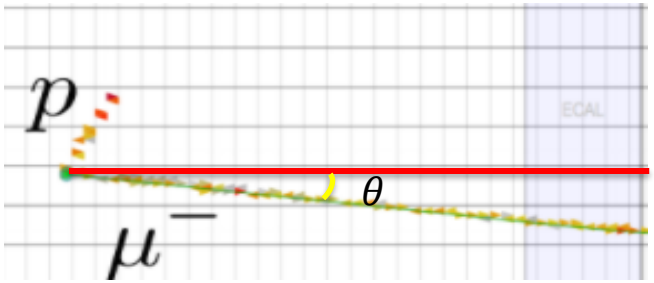
$$\sigma(\nu N) \sim 10^{-38} cm^2$$

Variables

- Disagreement with MC data
  - Work with variables to focus on certain parameters
  - Needs tuning



- Can be calculated from detector data or taken directly



Fermilab

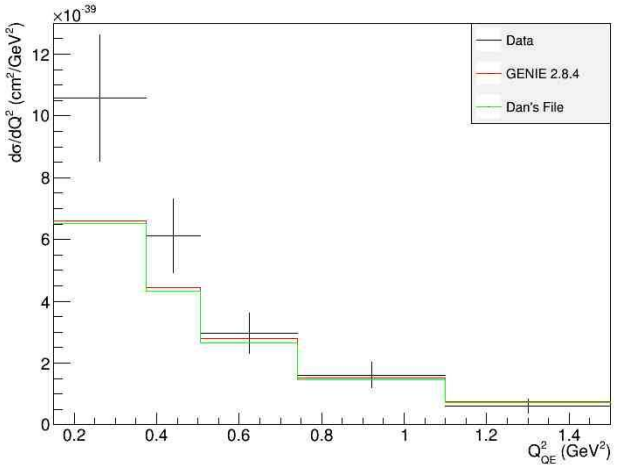
GENIE

- Used by the majority of Neutrino experiments at Fermilab
- Flexible MC neutrino event generator
  - Different targets
  - Wide energy range
  - Different neutrino flavors
- ROOT based
  - Written with ~120,000 lines of C++
- Able to be modified for needs of future detectors
  - Higher energy range
  - New target
- In the process of being tuned to MINERvA data

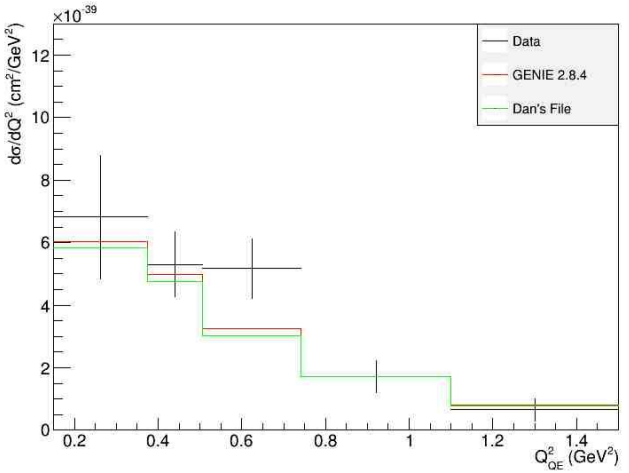
NUISANCE

- Comparison framework used for analysis
  - Read in data and MC data
  - Performs any cuts in signal definition
  - Makes any calculations needed for variables
- Able to read in MC data from different generators
  - GENIE, NuWro, GIBUU…
- Very useful for model tuning
- New for use in Neutrino experiments at Fermilab, hence the validations

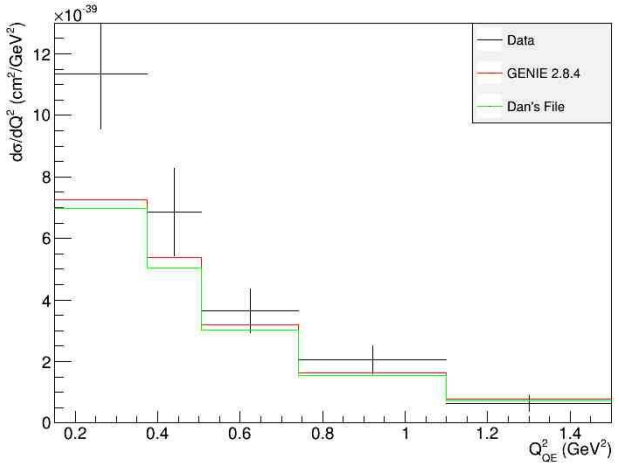
Validation



CC0pi Four momentum transfer, Lead



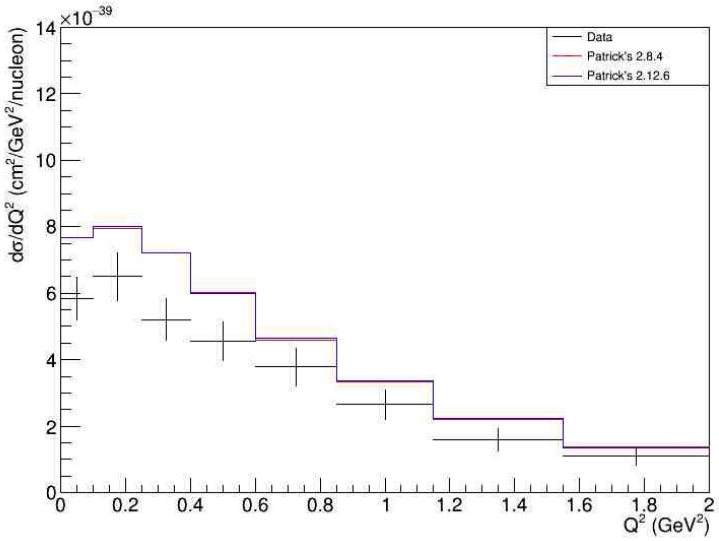
CC0pi Four momentum transfer, Carbon

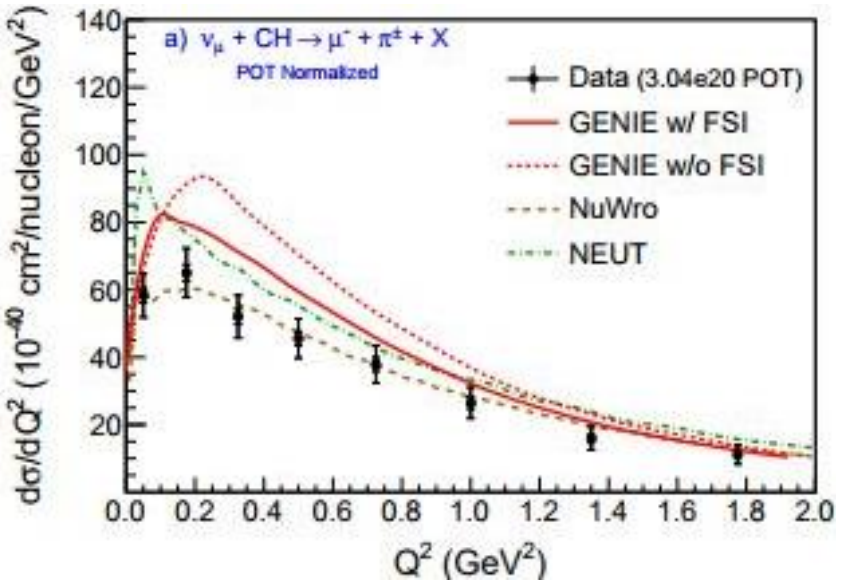


CC0pi Four momentum transfer, Iron

Fermilab

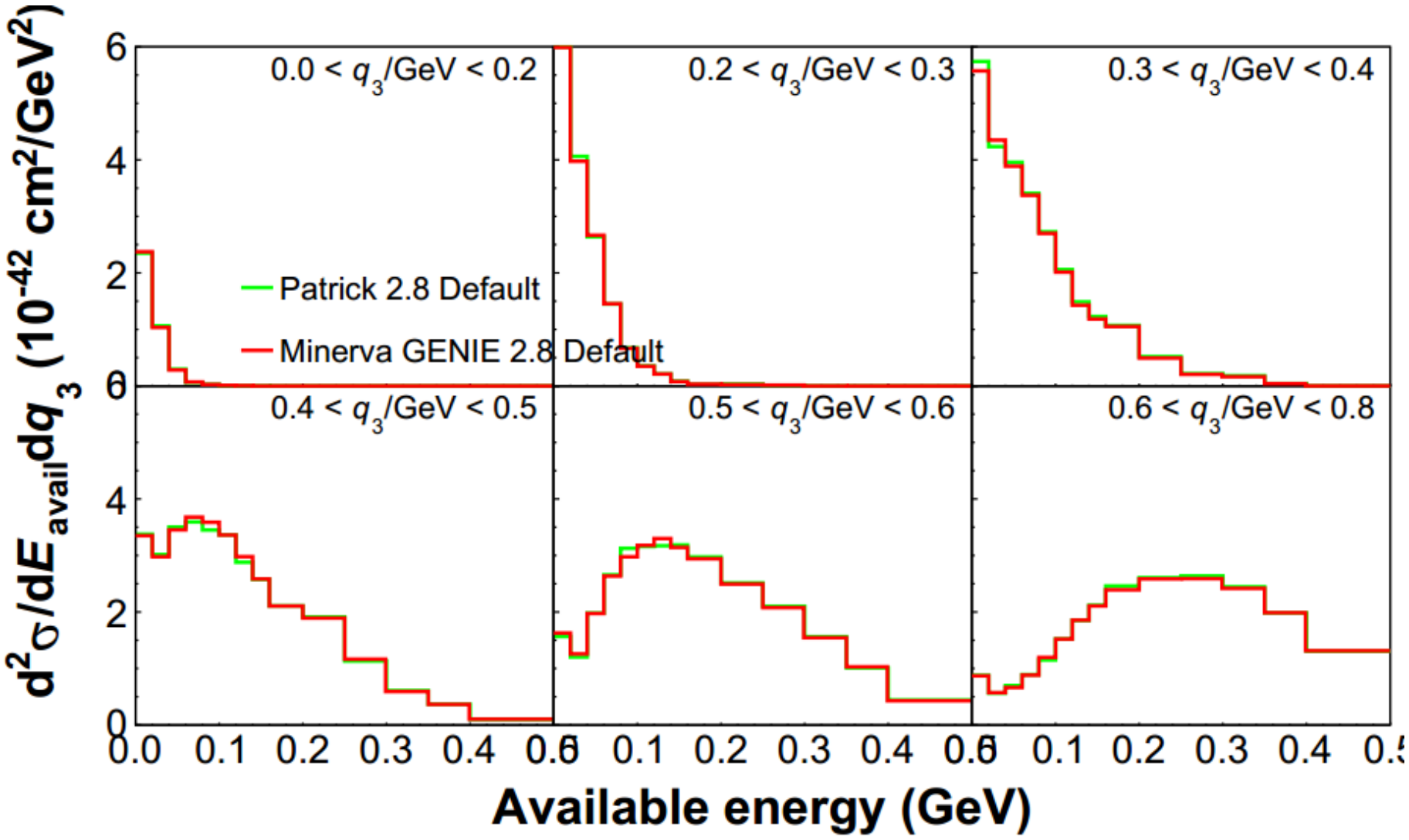
Validation cont.





- CCNpip Four momentum transfer, validating GENIE 2.8.4 and 2.12.6

Validation cont

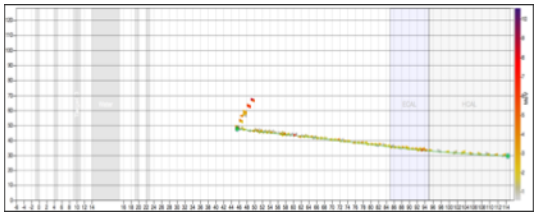


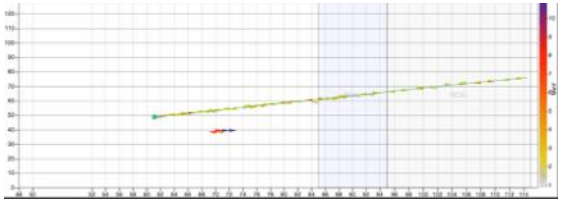
Comparison of Nuisance output to GENIE extractor

Fermilab

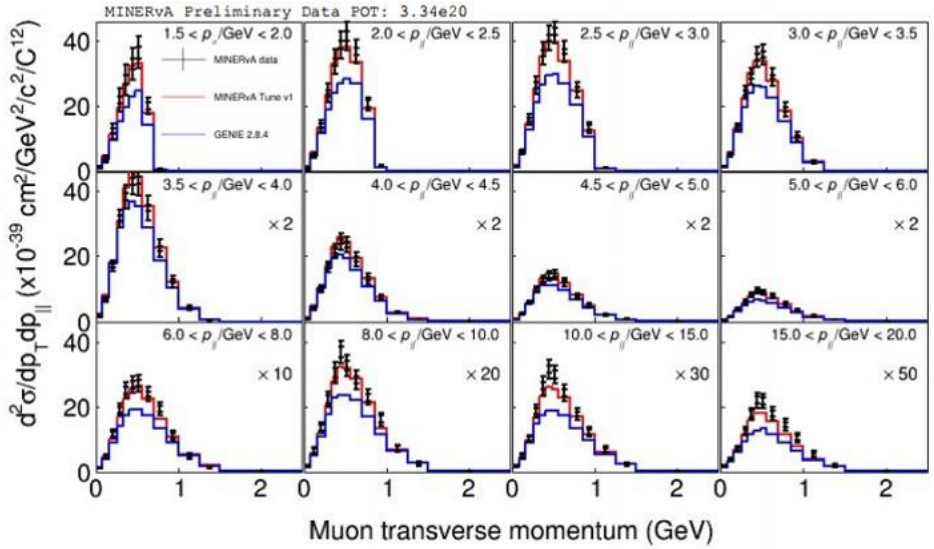
Signal Definitions

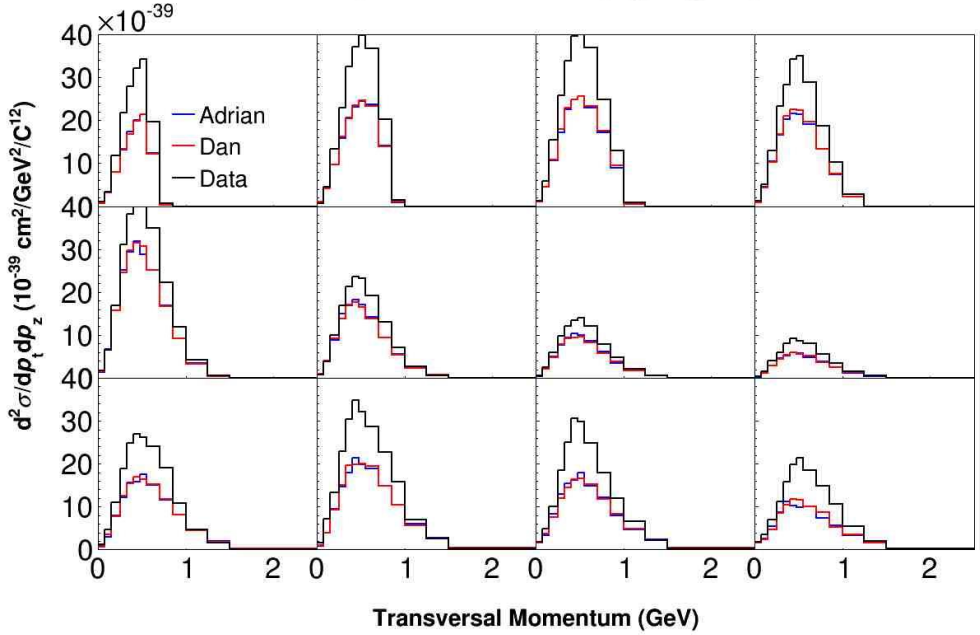
- Added these cuts to compare with measurements
  - Neutrinos
    - Muon and any # of nucleons of any momentum
    - No mesons
    - No heavy baryons
    - No gammas > 10MeV
  - Anti-Neutrinos
    - Same as Neutrinos
    - No protons about 120 MeV
- Later normalized per Carbon (NuInt Slides)





Sample Additions cont.



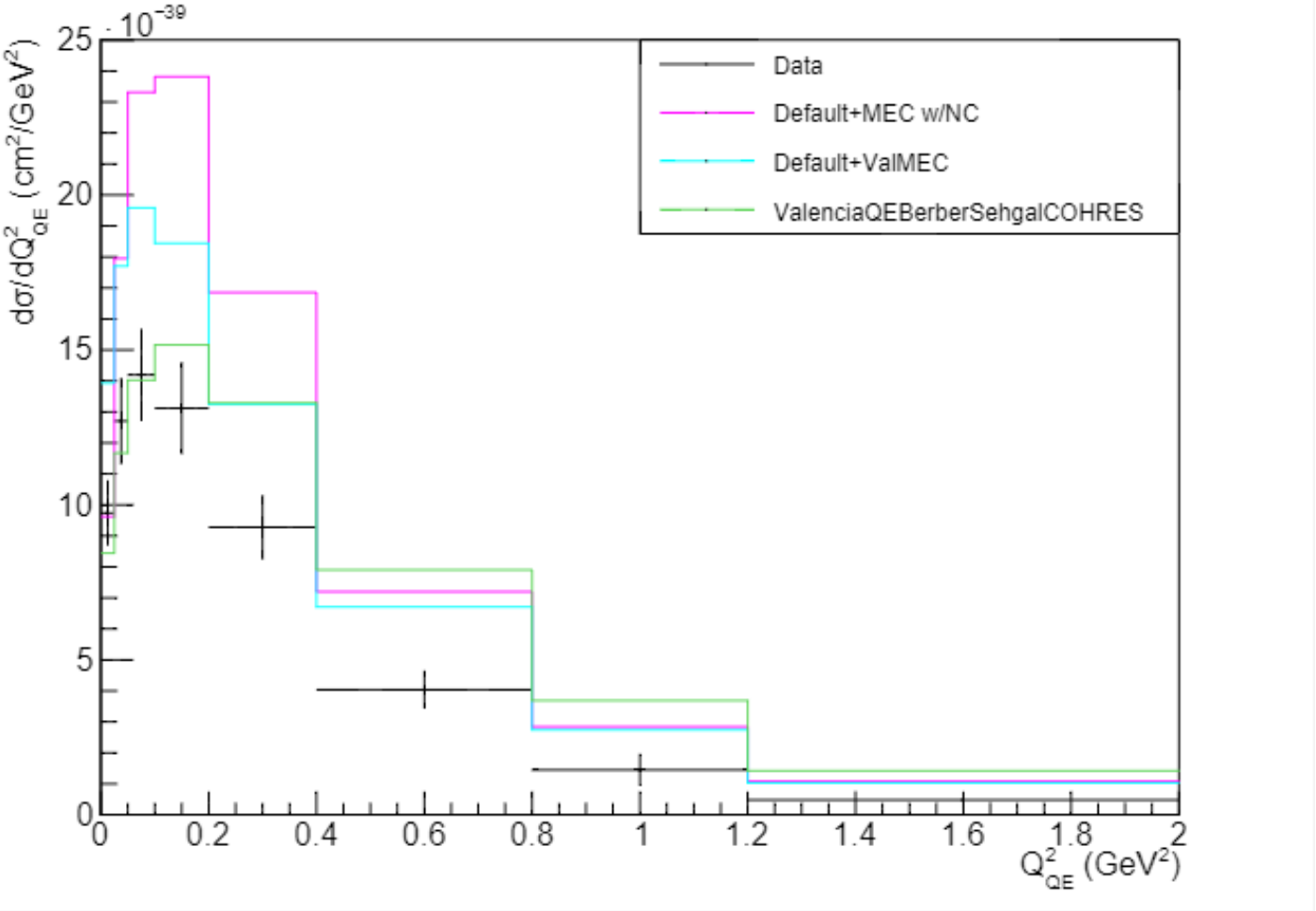


Fermilab

Models

- Very different ways of predicting interaction events
- Ones used for this analysis
  - Default
    - Smith-Moniz QE, with Relativistic Fermi Gas (IS)
  - DefaultPlusMECWithNC
    - Includes empirical model for multiple nucleons (MiniBooNE)
  - DefaultPlusValenciaMEC
    - Theoretical 2p2h model (Valencia) Only for outgoing Muon
  - EffSFTEM
    - Replaces QE model with spectral function model (TEM)
  - ValenciaQEBergerSehgalCOHRES
    - Local Fermi Gas model (Best “theory” in GENIE)

Models cont.



Valencia seems to agree at low four momentum transfer, but tuning is needed to agree at the entire range

Fermilab

Future Work

- More Sample Additions
  - Neutrino and Anti-Neutrino Ratio for CCinc
- Continue to validate more publications
  - GENIE 2.8.4-GENIE 2.12.6
- More comparisons between models
- Tune the models
  - Direct continuation from my project

Conclusion

- Plots were validated!
  - 2016 Article
  - 2017 Presentation
- Sample has been added!
  - Need to run tests to validate
- Models were compared
  - Will lead to tuning

Acknowledgments

- I would like to thank the following people for their patience and help as they were always available to answer my many questions. Without them, I would have not accomplished anything
  - Minerba Betancourt, Kevin Ewart, Patrick Stowell, Gabriel Perdue, Aaron Bercellie, and Sarah Henry

- Finally, I would also like to thank Fermilab, the coordinators of SIST, and North Central College for such an amazing summer experience

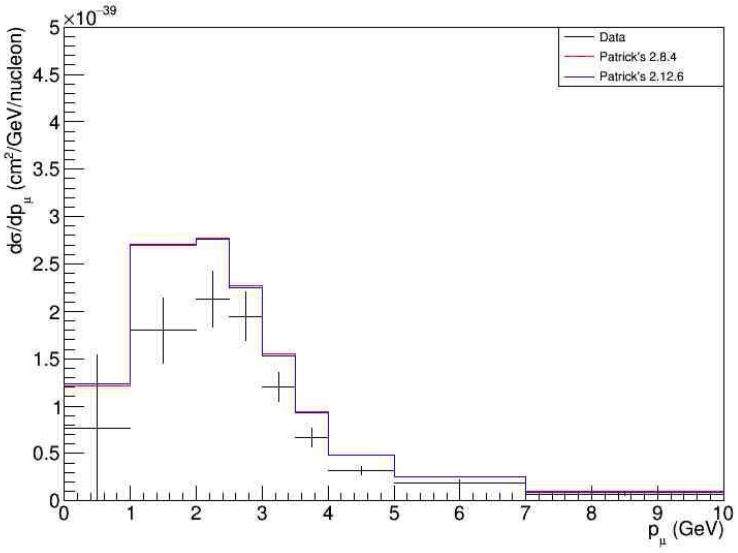
References

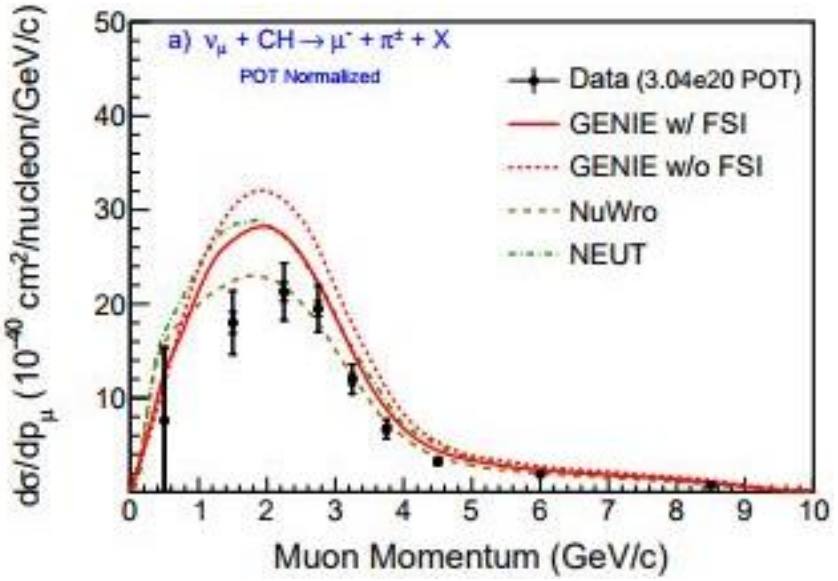
- McGivern, C.L., et al. “Cross Sections for Nμ and ν¯μ Induced Pion Production on Hydrocarbon in the Few-GeV Region Using MINERvA.” 19 Aug. 2016, pp. 1–17., arxiv.org/pdf/1606.07127.pdf.
- Ruterbories, Daniel. “MINERvA CC0pi Results.” NuInt . NuInt, 29 June 2016, Guanajuato, MX.
- Betancourt, Minerba. “Neutrino Experiments at Fermilab.” TARGET. 6 July 2017, Batavia.
- C.Andreopoulos, C.Barry, S.Dytman, H.Gallagher, T.Golan, R.Hatcher, G.Perdue and J.Yarba
  The GENIE Neutrino Monte Carlo Generator: Physics and User Manual
  e-Print: arXiv:1510.05494[hep-ph]

References cont.

- C.Andreopoulos, A.Bell, D.Bhattacharya, F.Cavanna, J.Dobson, S.Dytman, H.Gallagher, P.Guzowski, R.Hatcher, P.Kehayias, A.Meregaglia, D.Naples, G.Pearce, A.Rubbia, M.Whalley and T.Yang The GENIE Neutrino Monte Carlo Generator
  Published in Nucl.Instrum.Meth.A614 (2010) 87-104
- NUISANCE: a neutrino cross-section generator tuning and comparison framework.
  P. Stowell, C. Wret, C. Wilkinson, L. Pickering, et. al., 2017 JINST 12 P01016, arXiv:1612.07393

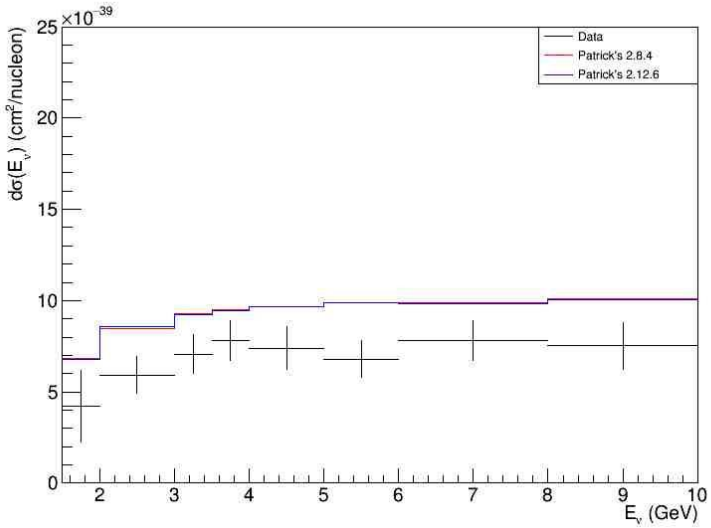
Validation cont

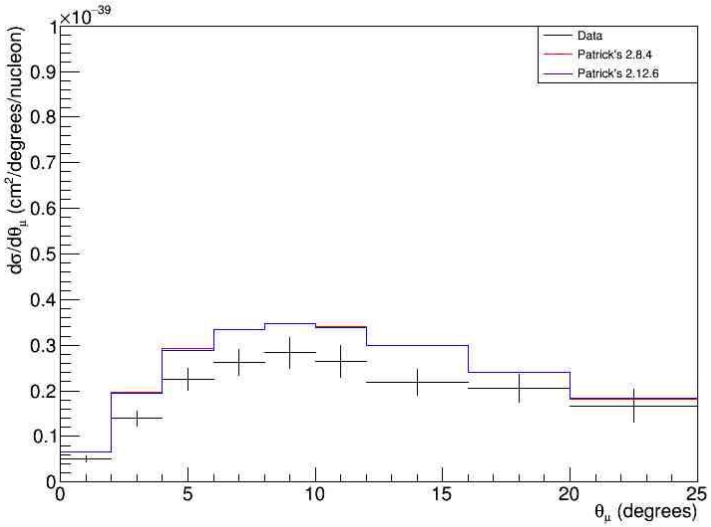


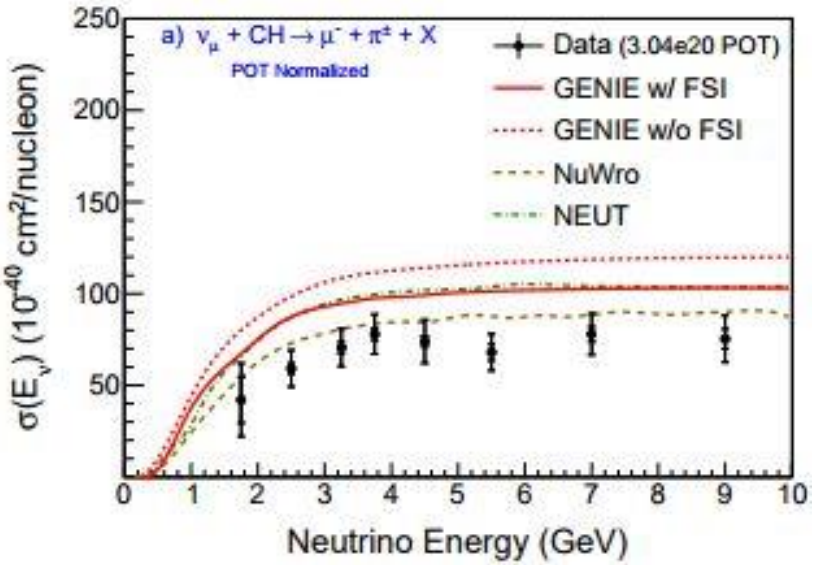


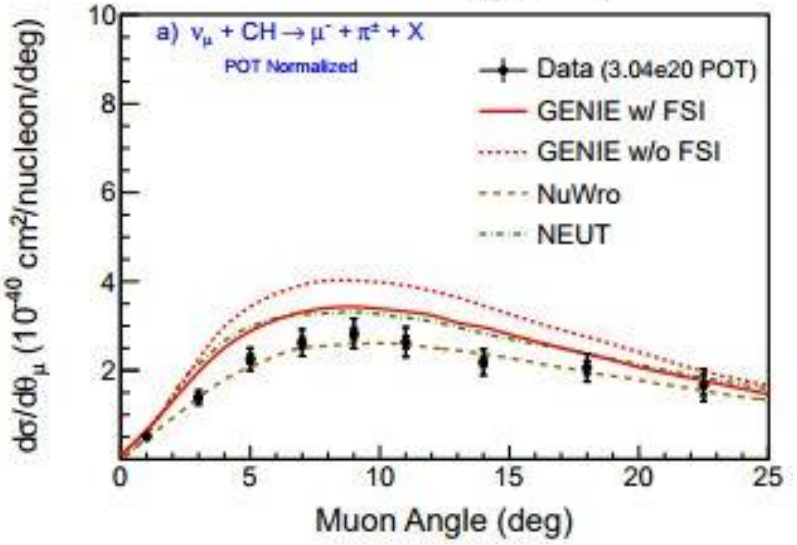
Fermilab

Validation cont



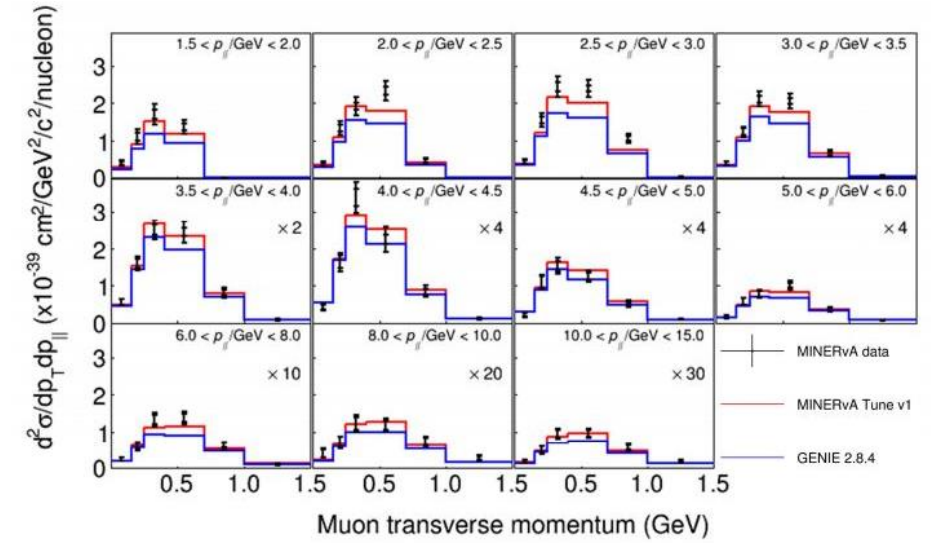


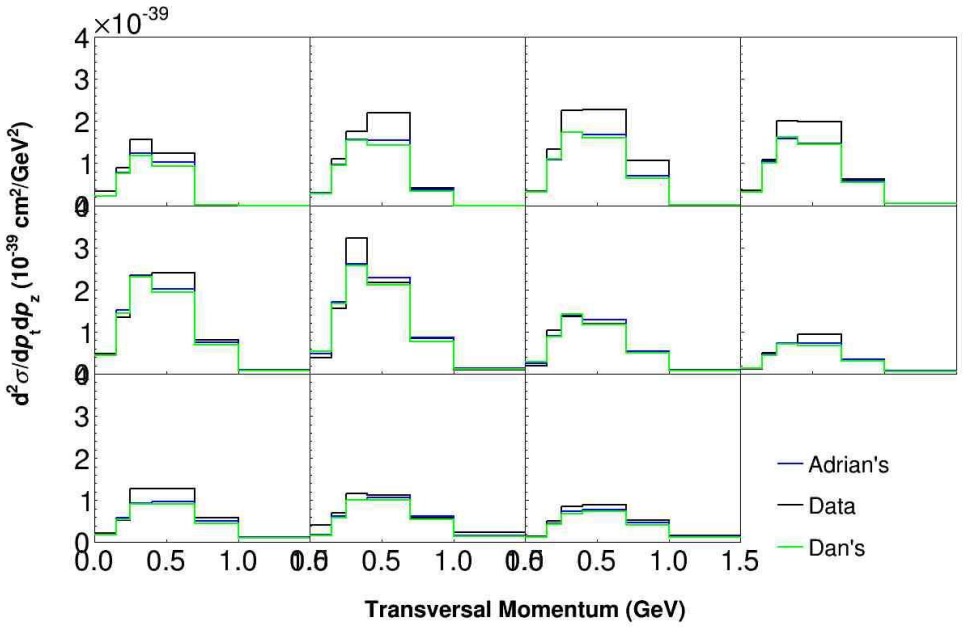




Fermilab

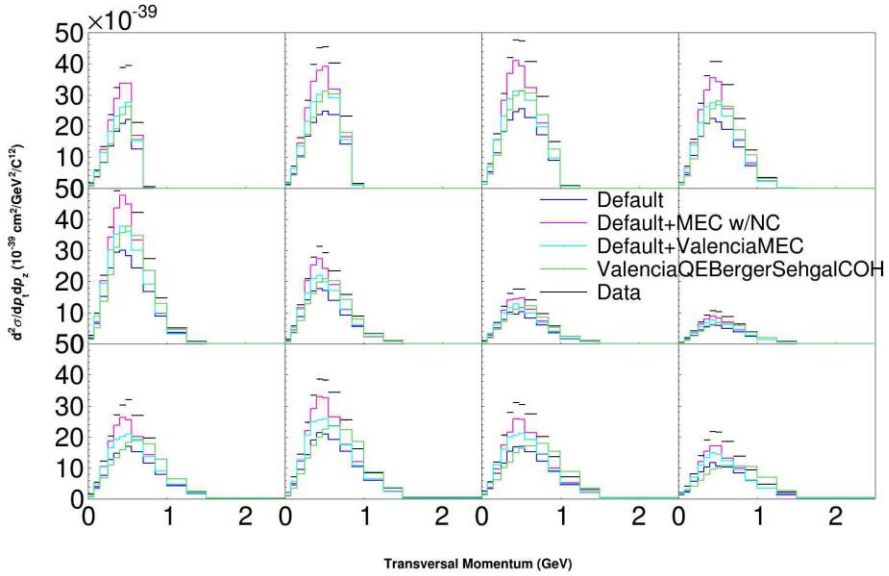
Sample Additions cont.

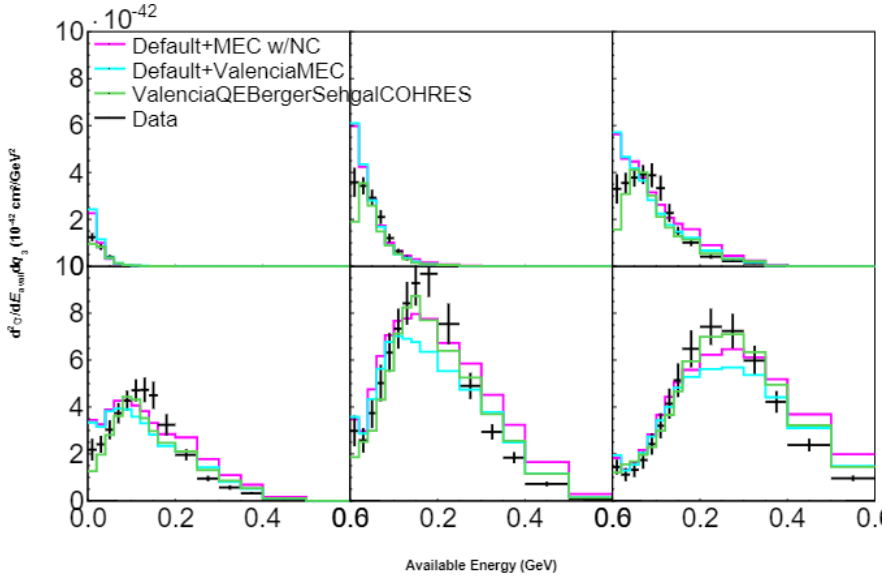


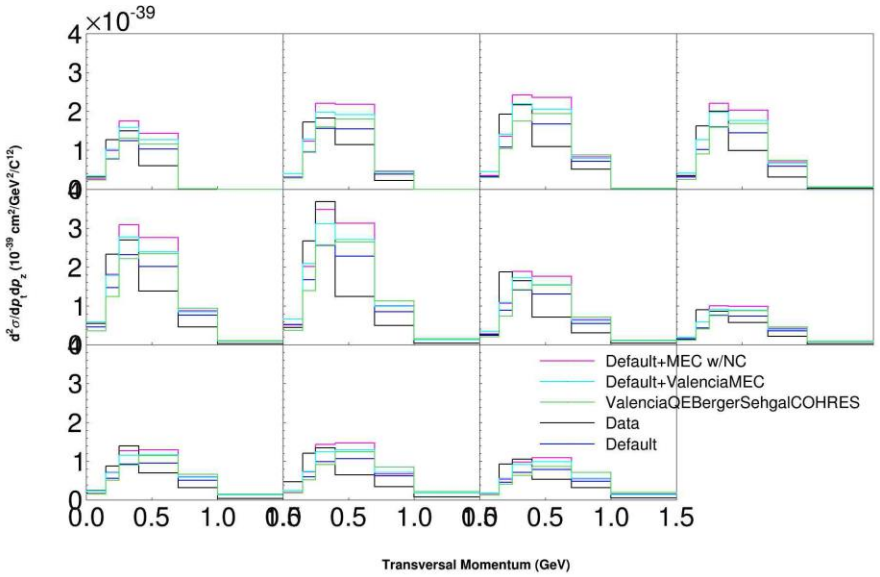


Fermilab

Models cont.

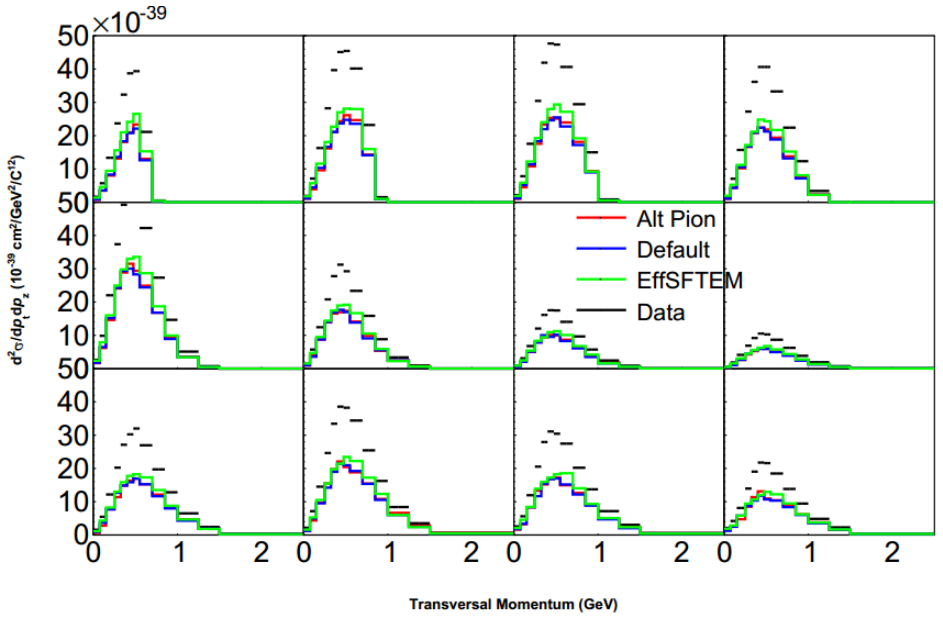


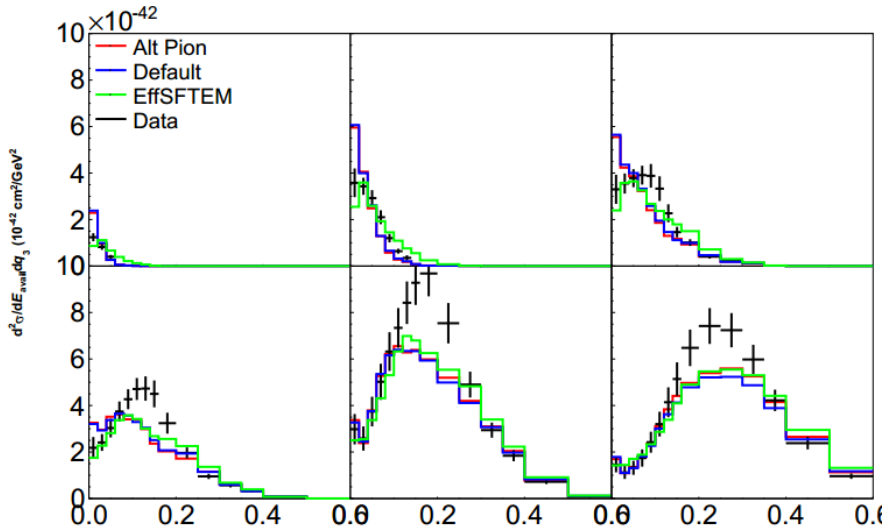


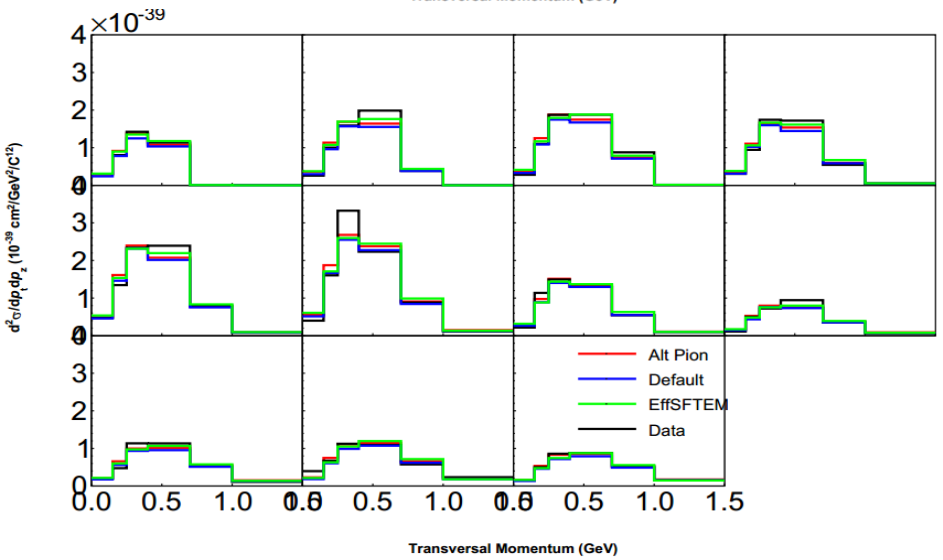


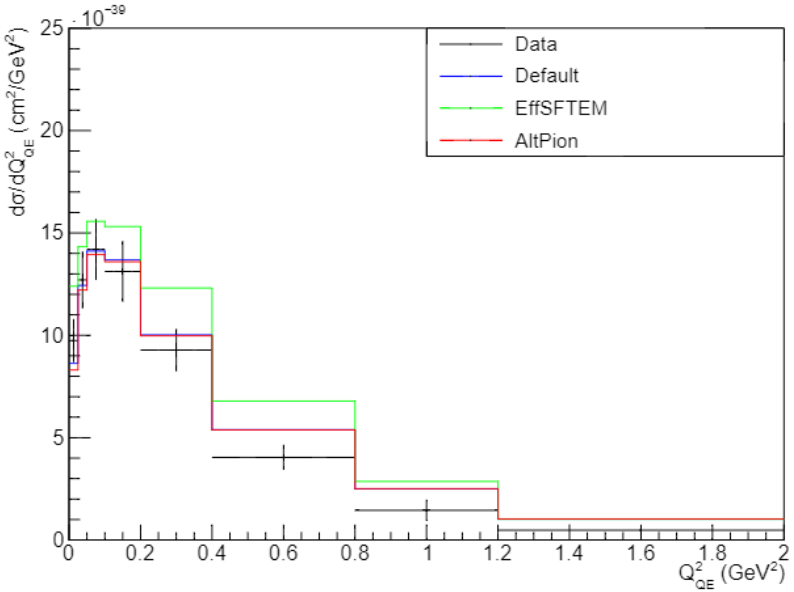
Fermilab

Models cont.









Fermilab