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Fermilab U.S. DEPARTMENT OF ENERGY | Office of Science

Updating Hadron Models to Better Predict Neutrino Flux for DUNE

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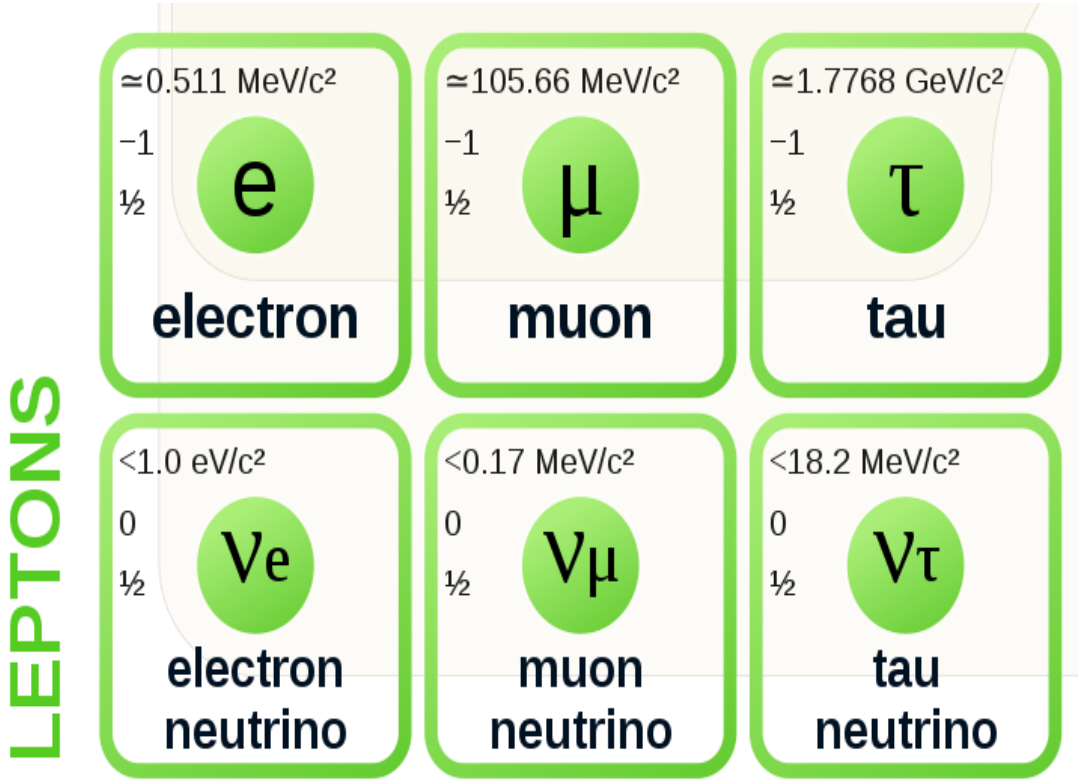
A Brief Review of Neutrino Physics

- There are 3 “flavors” of neutrinos
- Flavor is determined by associated charged lepton
- Massless in the Standard Model
- Rarely interacts
- Only interacts via the weak force and gravity

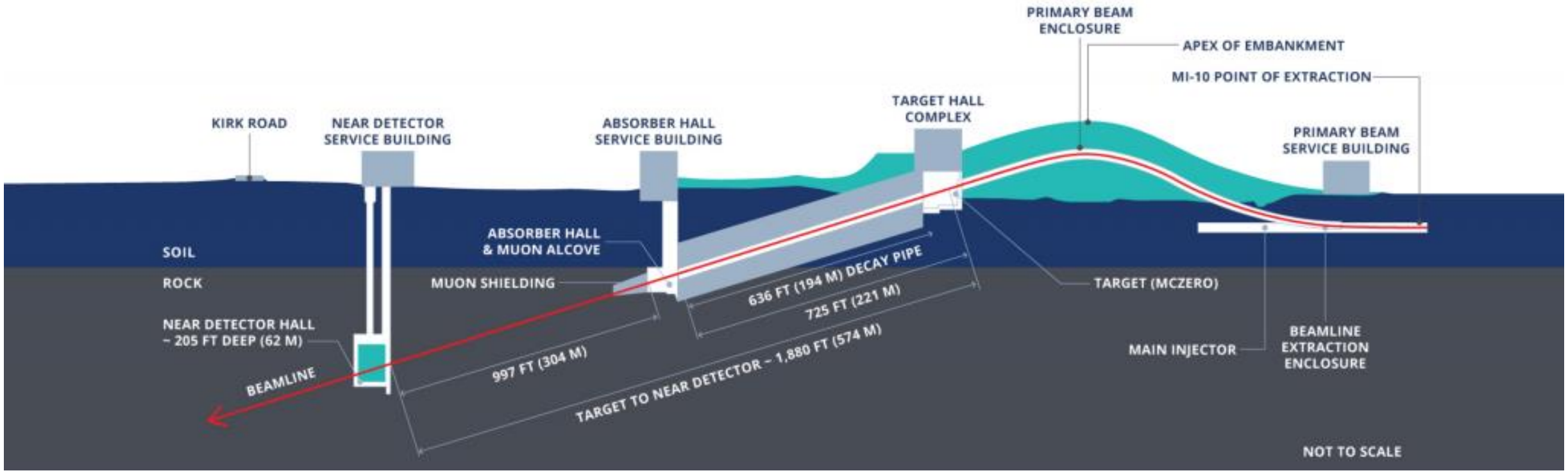


Why Do We Care?

- Why Care About Neutrinos?
  - Neutrinos are everywhere
  - Now believe neutrinos have mass
  - Could explain why there is a matter-antimatter imbalance in the universe
- Why Care About DUNE?
  - Optimized to study Charge Parity symmetry violation
  - Study neutrino oscillation i.e. how neutrinos change flavor
  - Look for neutrinos coming from supernovas
  - Dark matter, proton decay, and more

DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

LBNF (Long Baseline Neutrino Facility)



- Primary proton beam 60-120 GeV
- Beam power of 1.2 MW, upgradable to 2.4 MW
- 2 m long graphite target
- 3 magnetic horns
- Near Detector is approx. 574 meters from target, located at Fermilab
- Far Detector is approx. 1300 kilometers from target, located at Sanford Underground Research Facility

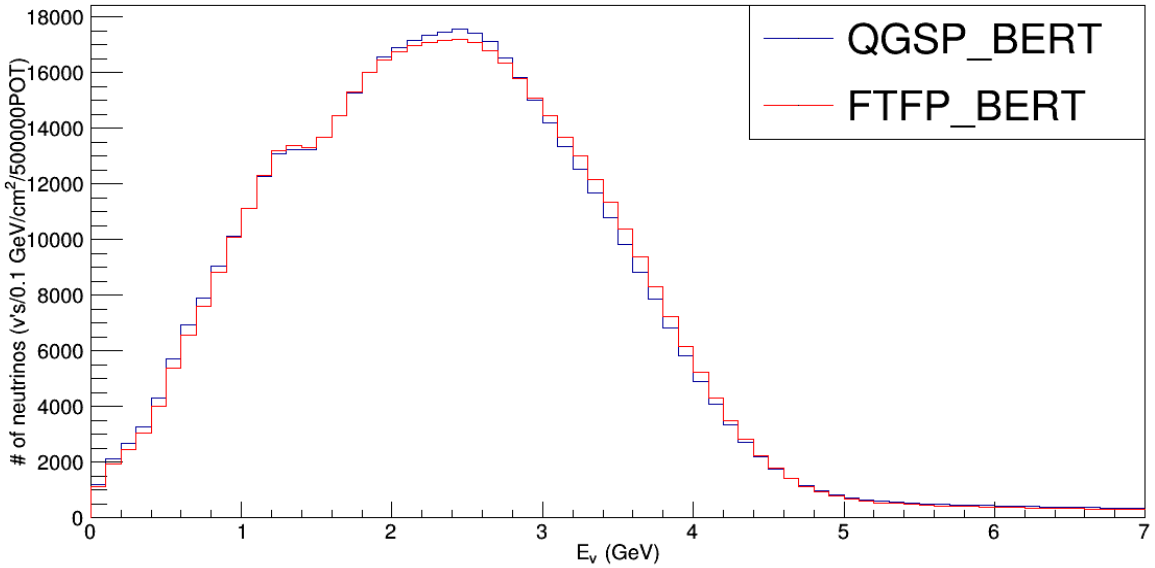
My Project

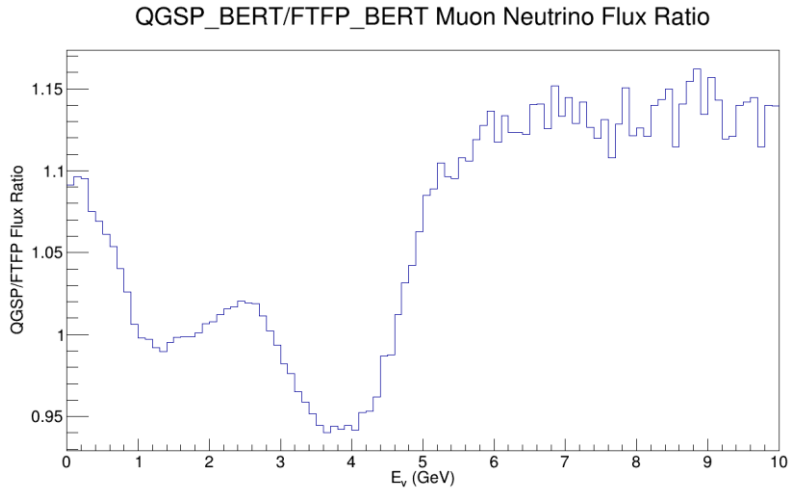
- Characterize the hadronic model interactions and then compare with experimental data from NA49.
- Then check the effect that correcting the models with the experimental data has on the flux prediction.
- It is important for DUNE that predictions of the neutrino flux are understood and have characterized uncertainties so measurement of neutrino oscillation can be made more reliably and accurately

My Progress

- Improved skills with Unix, C++,Root, Geant4, and learned how to use the grid
- Extracted simulated data on interactions, yields, and cross sections from Geant4
- Applied corrections to the QGSP_BERT model
- Corrections have been applied for proton on carbon creating pions and for the cumulative particles.

Muon Neutrino Flux at the Near Detector





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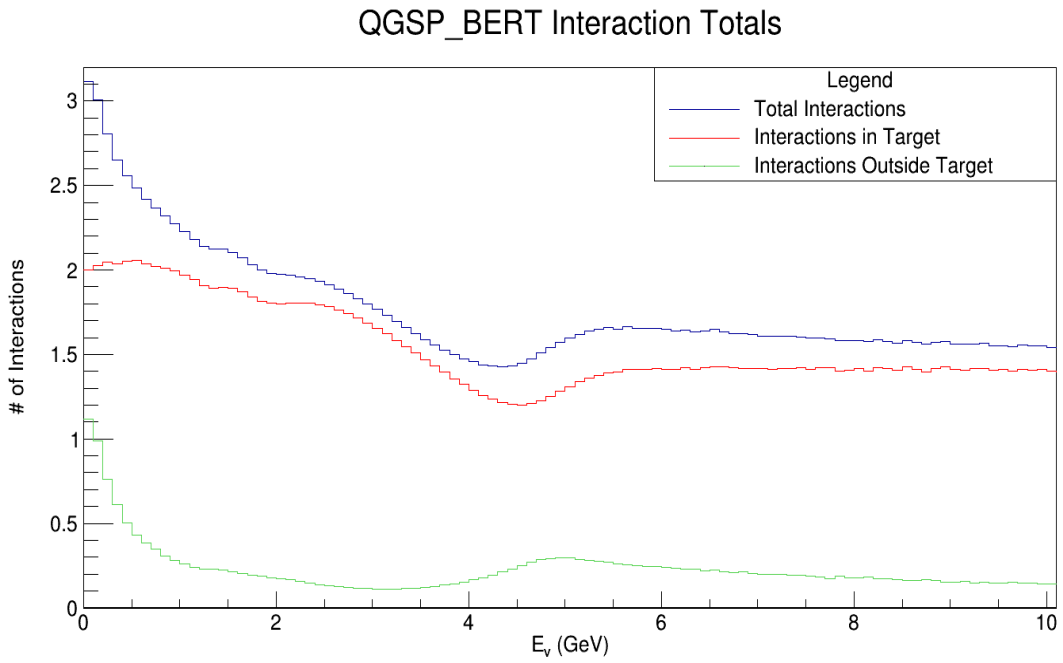
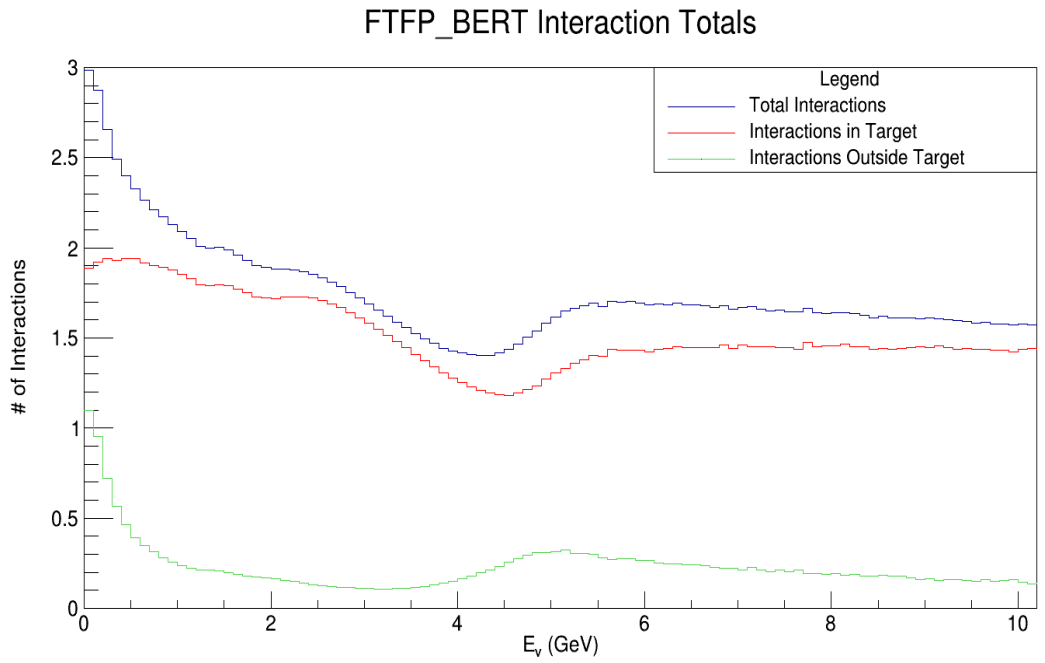
Total Interactions





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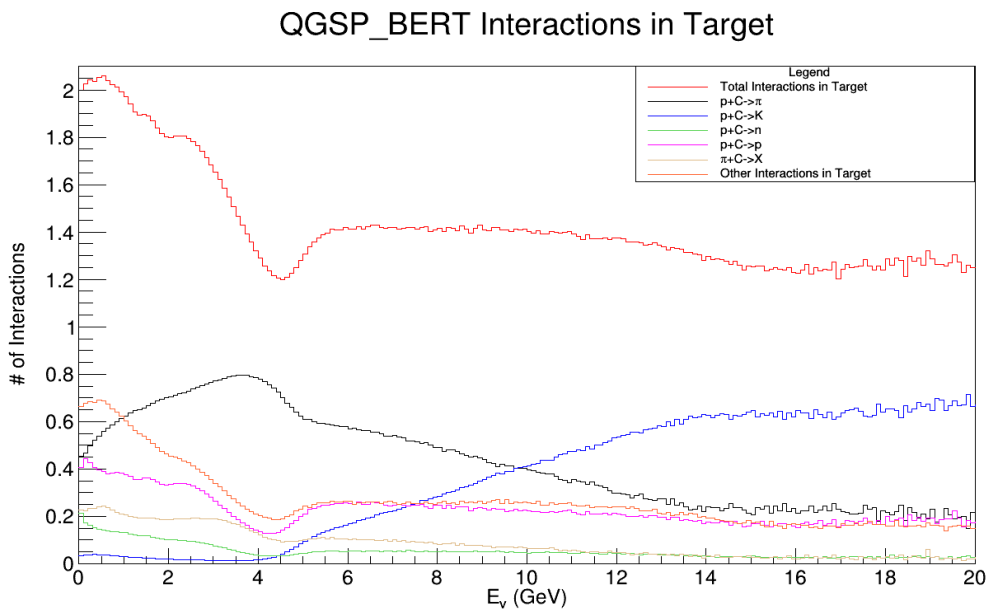
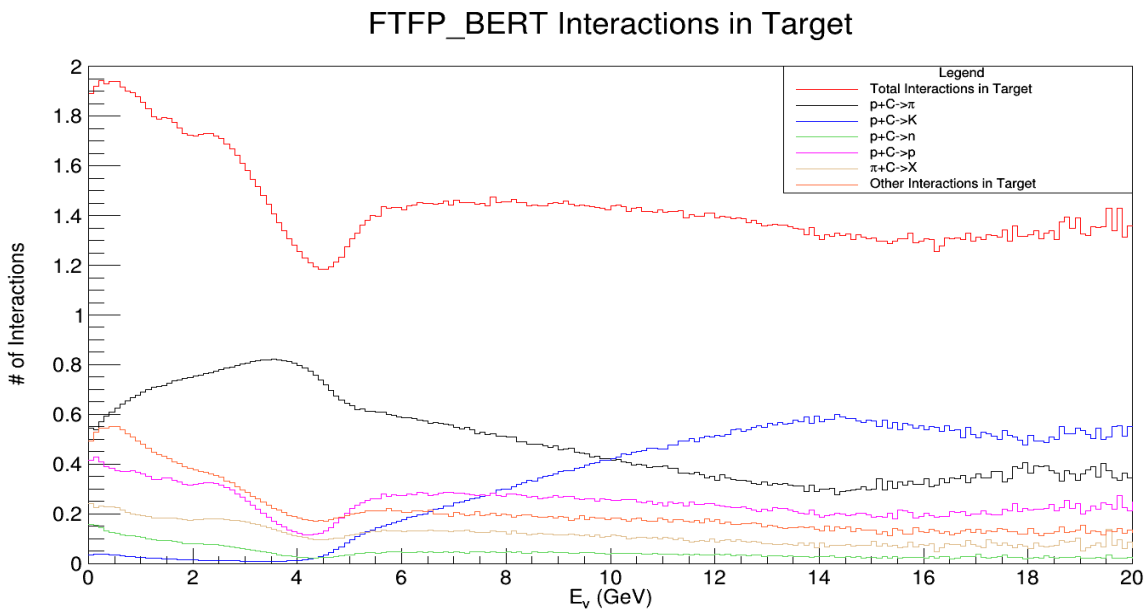
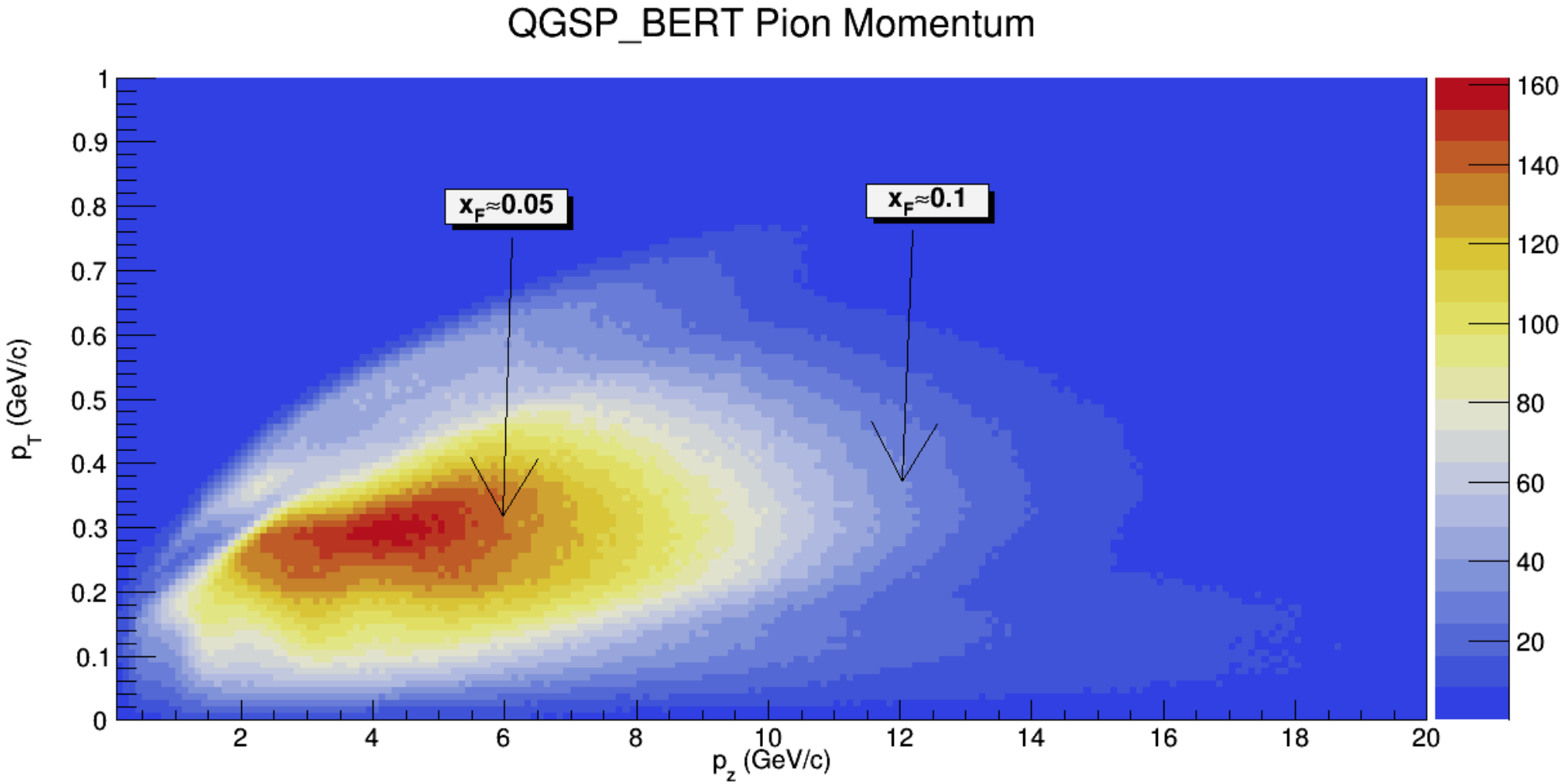
Interactions in Target





Pion Kinematics



$$x_F \approx \frac{p_L}{\sqrt{s}/2}, in\ the\ center\ of\ mass\ frame$$

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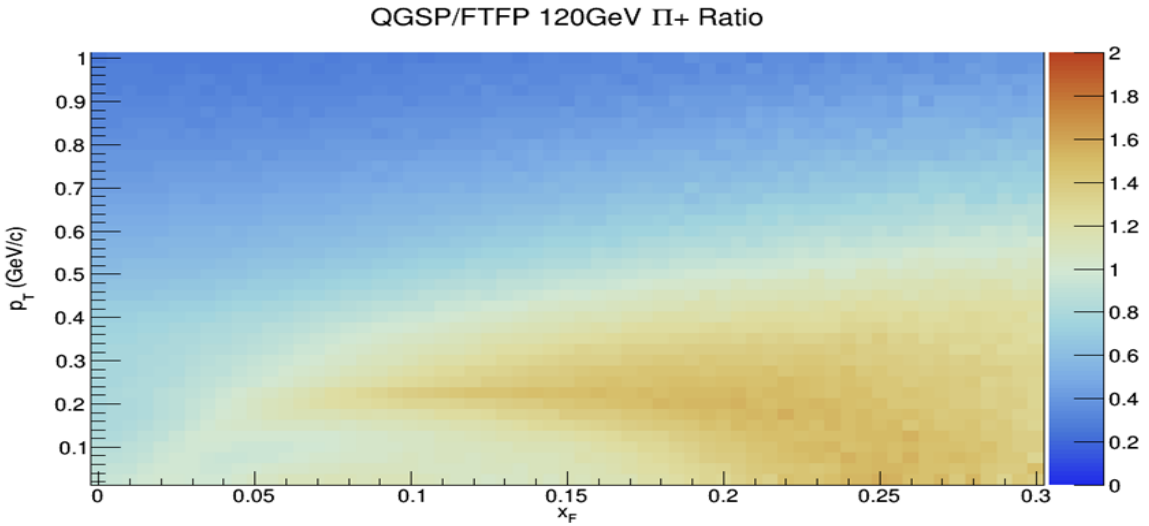
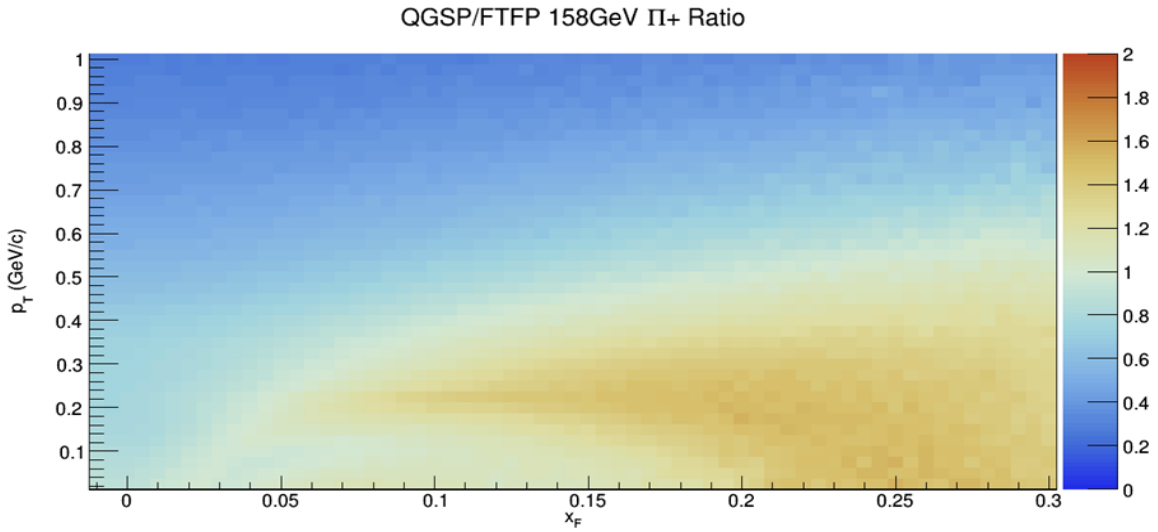
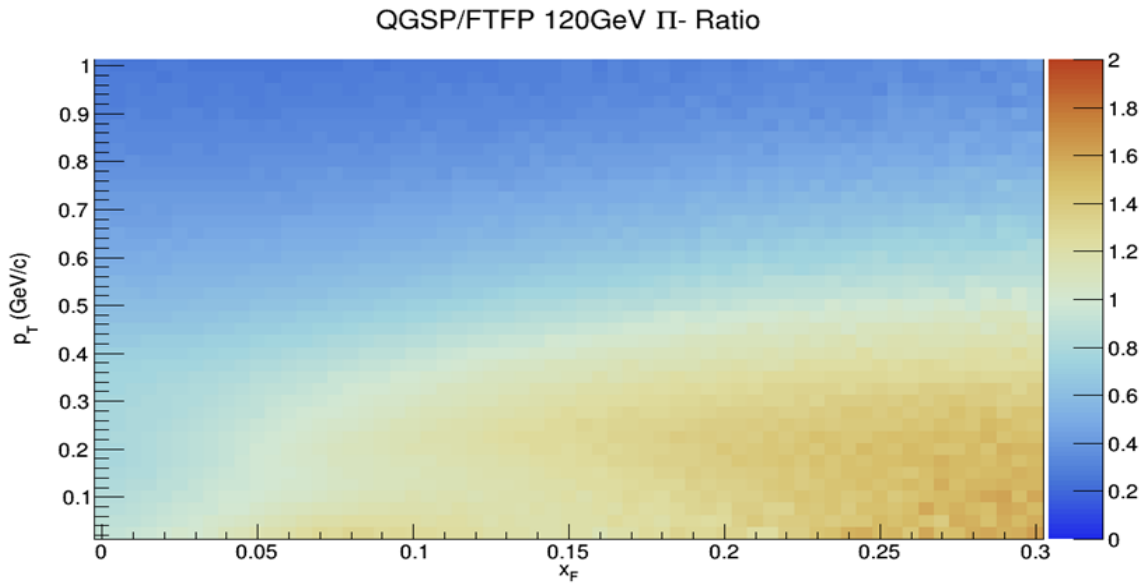
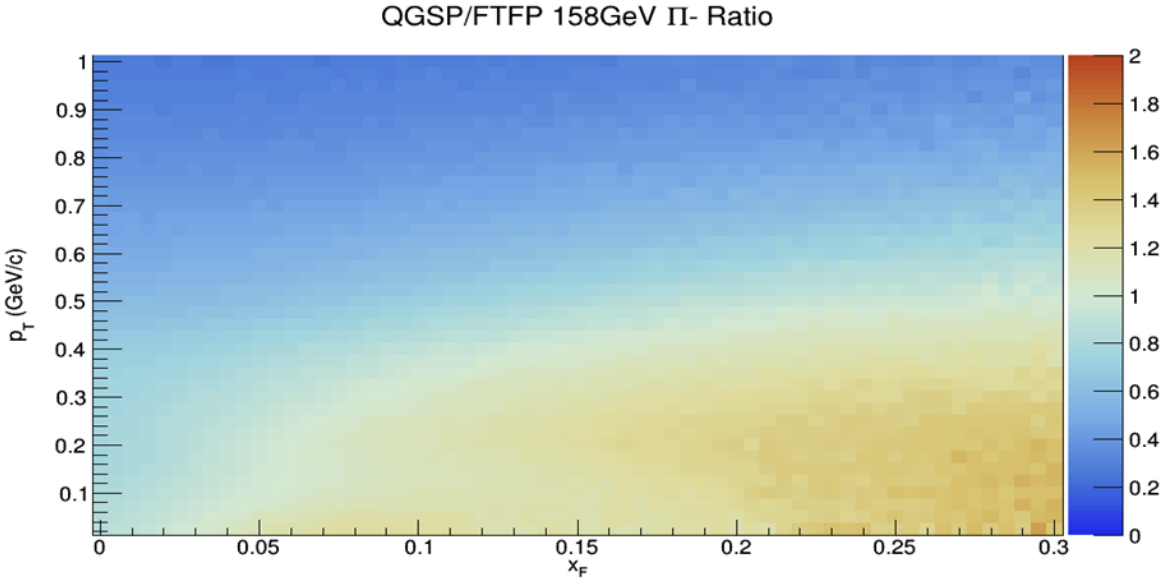
QGSP/FTFP Cross-Section Ratios









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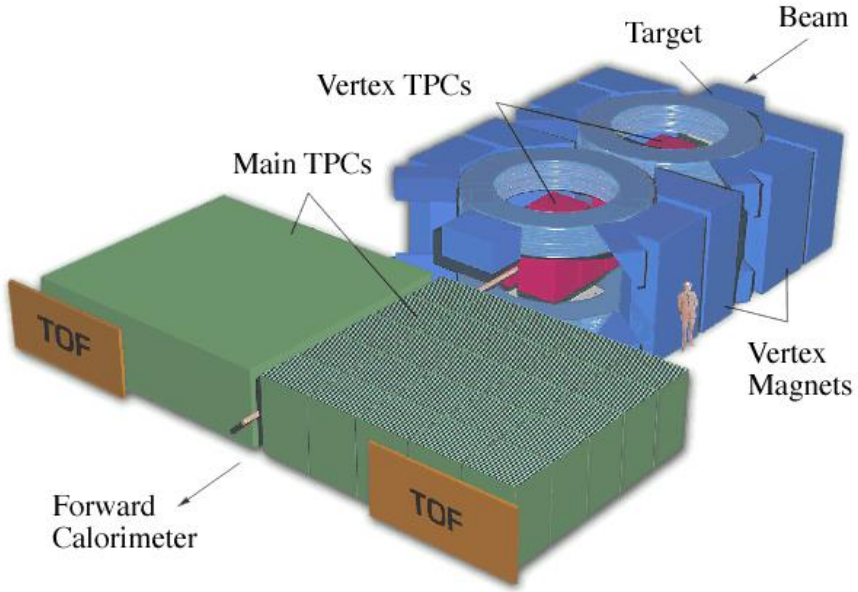
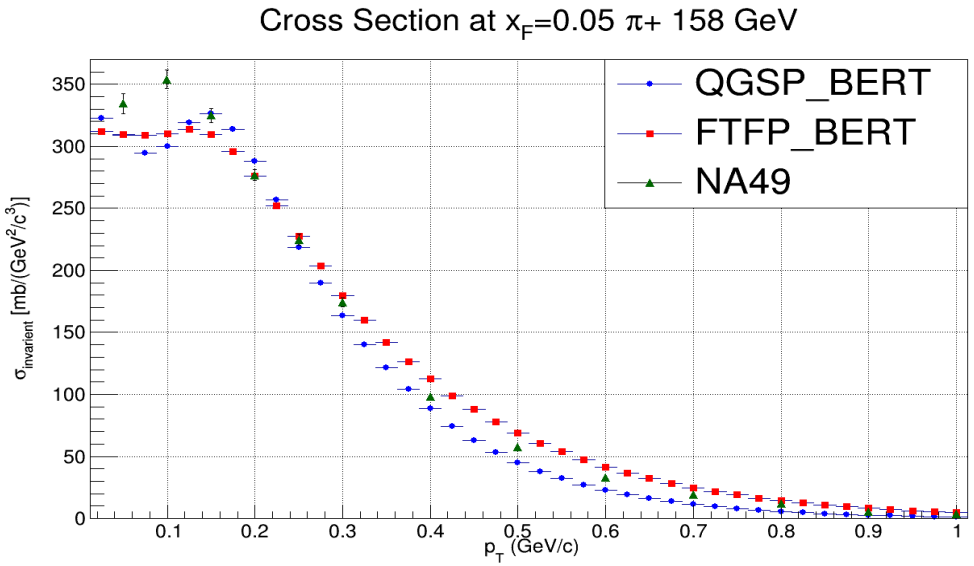
NA49

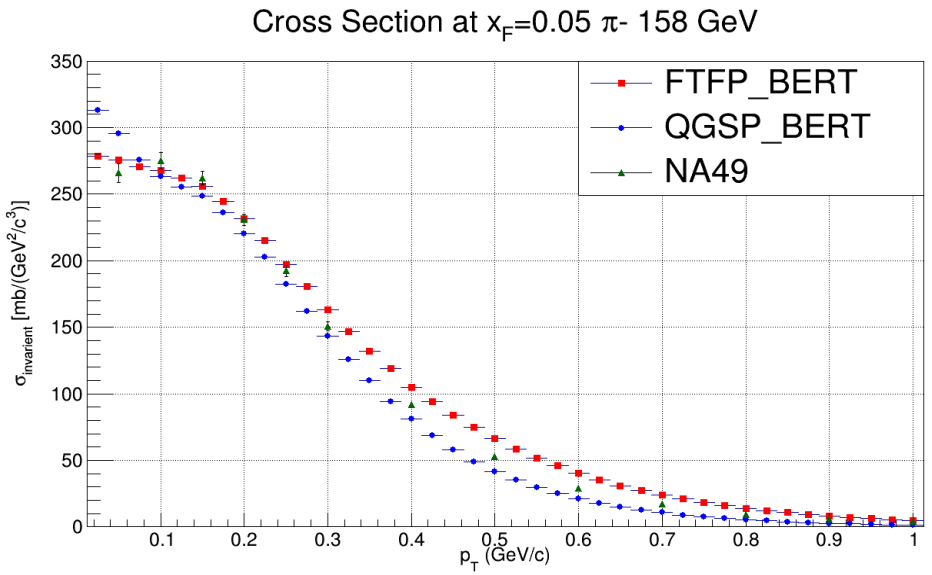
- Experiment conducted at CERN on hadron production
  - Started Sept. 1991 and completed Oct. 2002
  - Studied various proton interaction

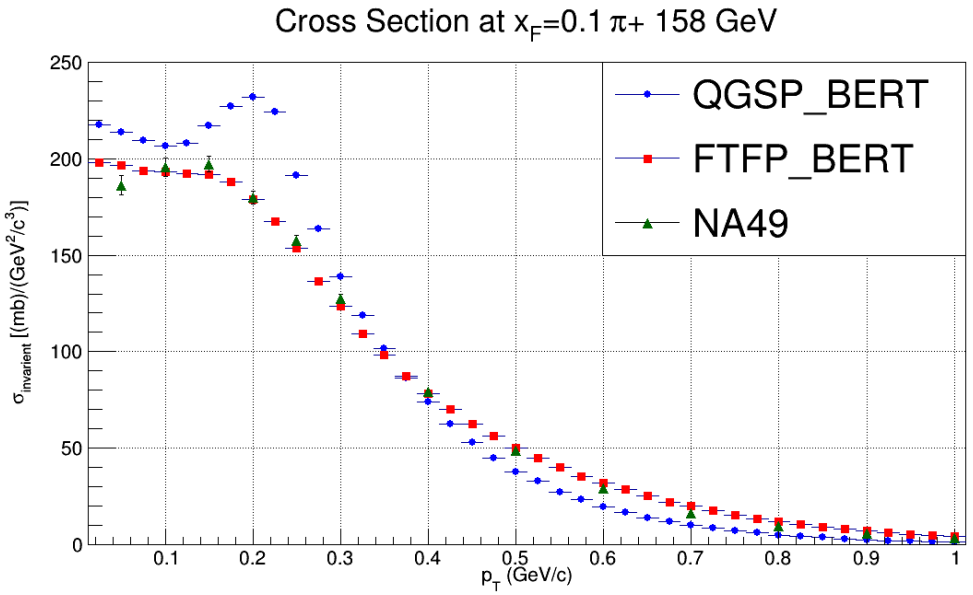
- Studied proton on carbon interactions at 158 GeV
  - Has Cross section data for Pions

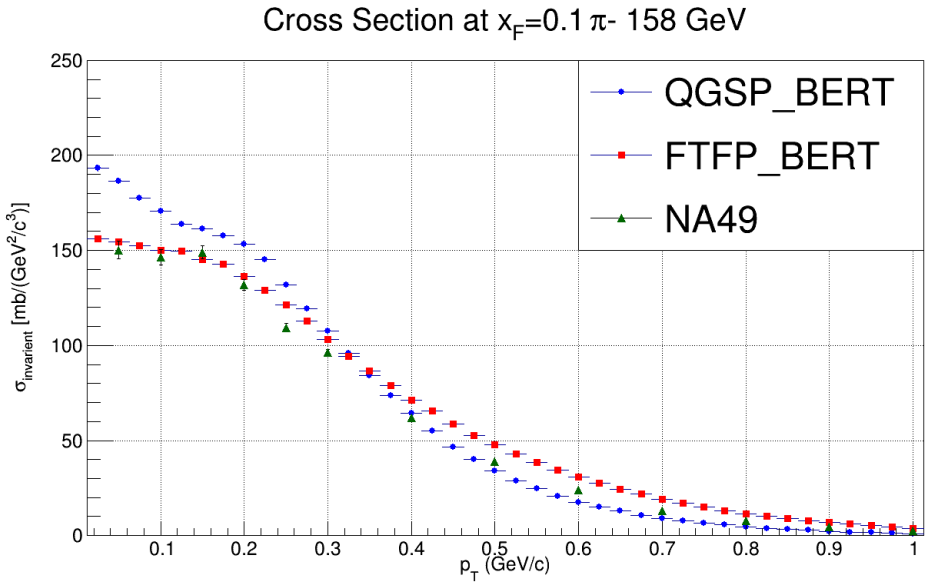


Invariant Cross Section









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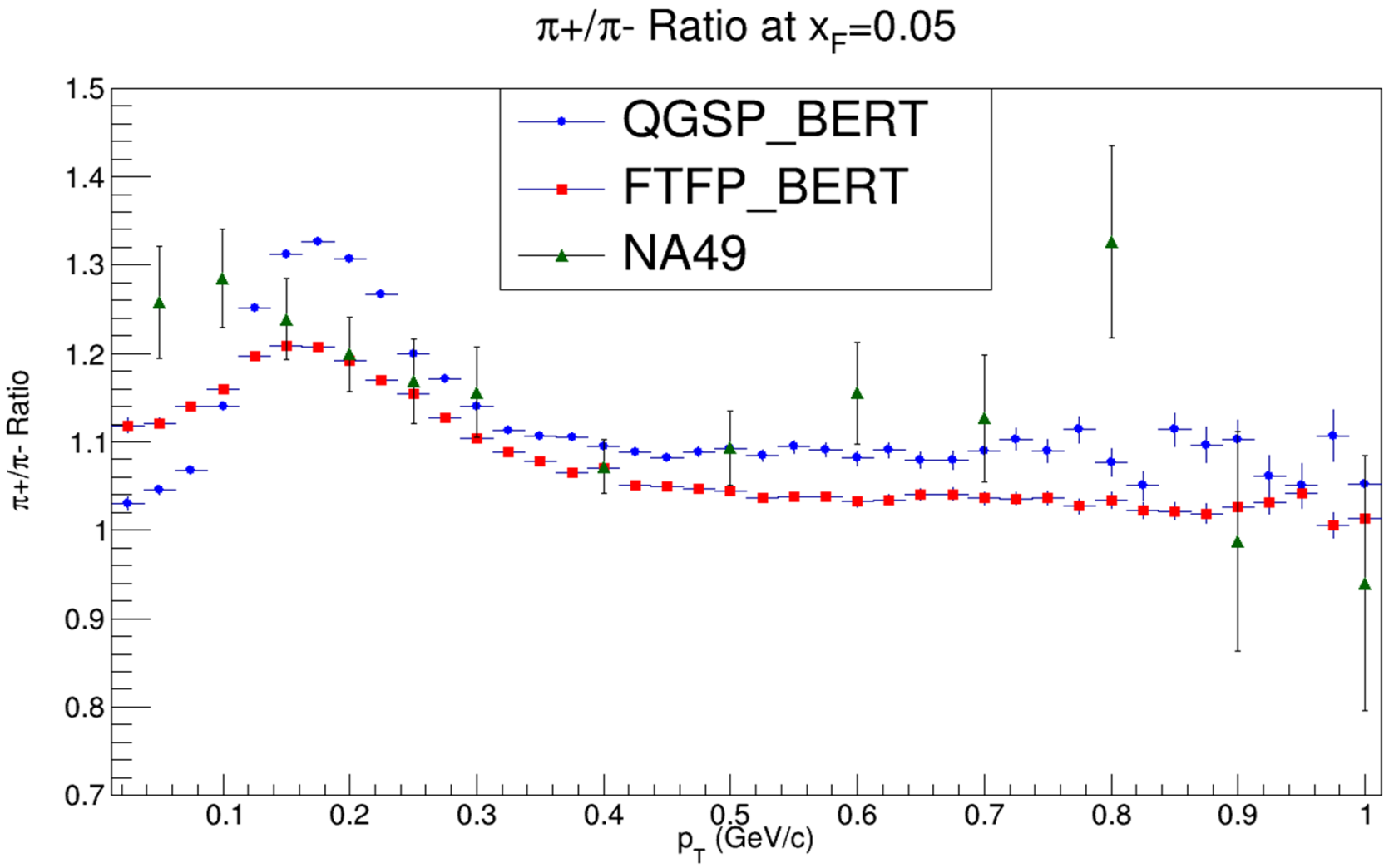
Pion Production Ratio 158 GeV



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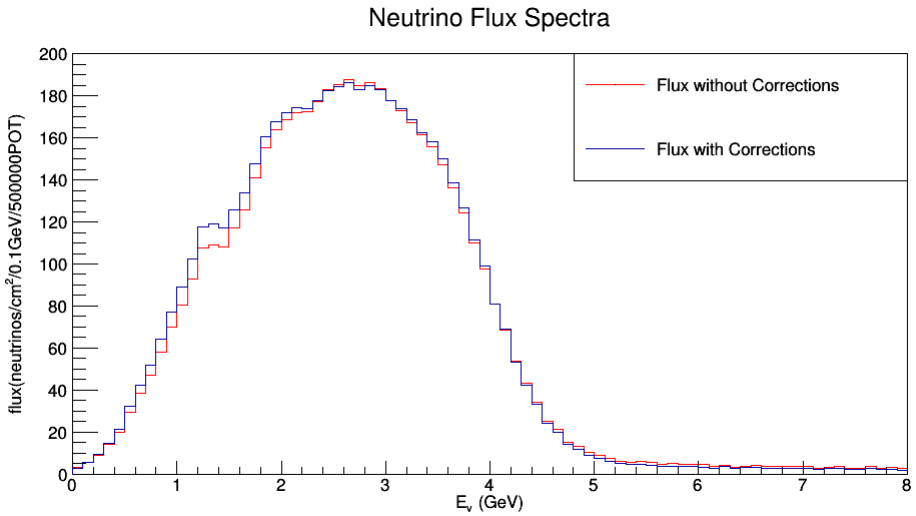
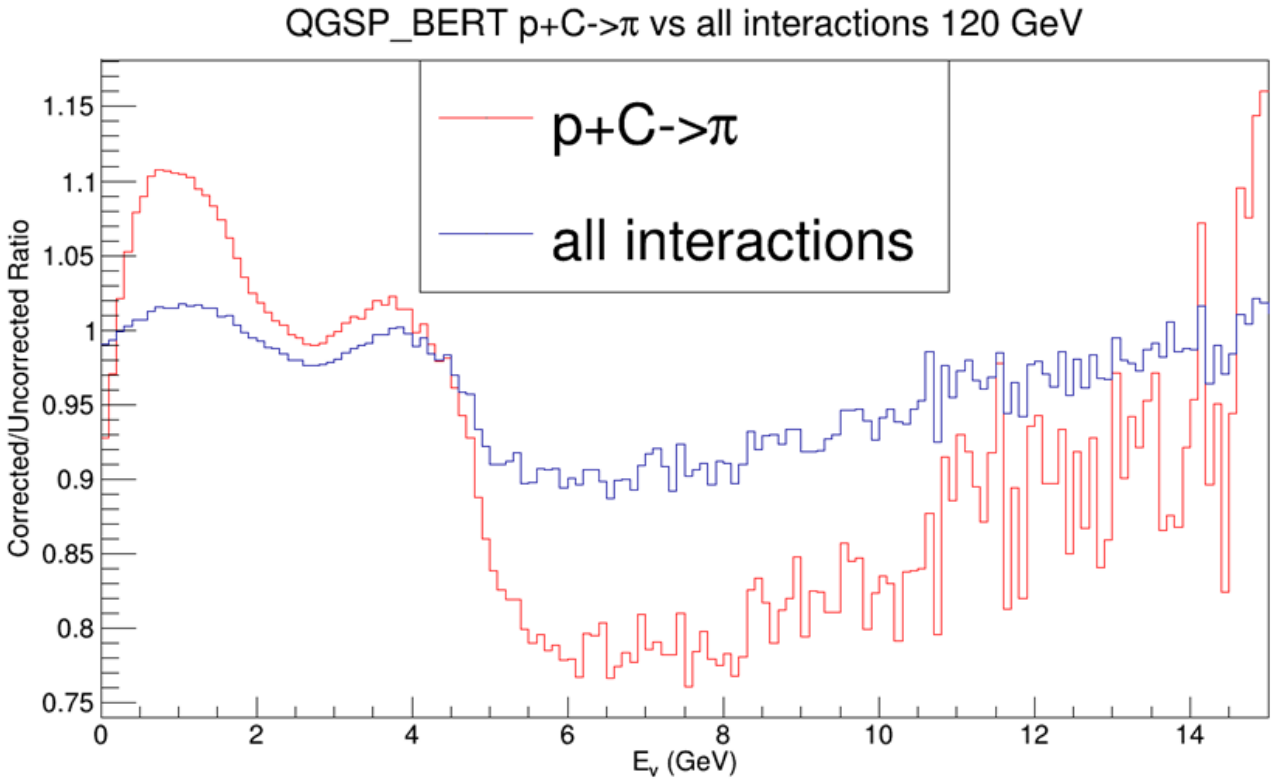
Results





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Conclusions

- When there are no corrections FTFP_BERT on average does a better job of more closely following the NA49 data than QGSP_BERT
- My project can be used as a template to correct for other particles, e.g. kaons.
- Next step should be to apply corrections beyond primary proton i.e. particles that reinteract in the target.

Acknowledgements

- Thank you
  - Supervisor: Leo Aliaga
  - Mentors: Arden Warner and Charlie Orozco
  - The SIST committee for transitioning this experience online