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**

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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

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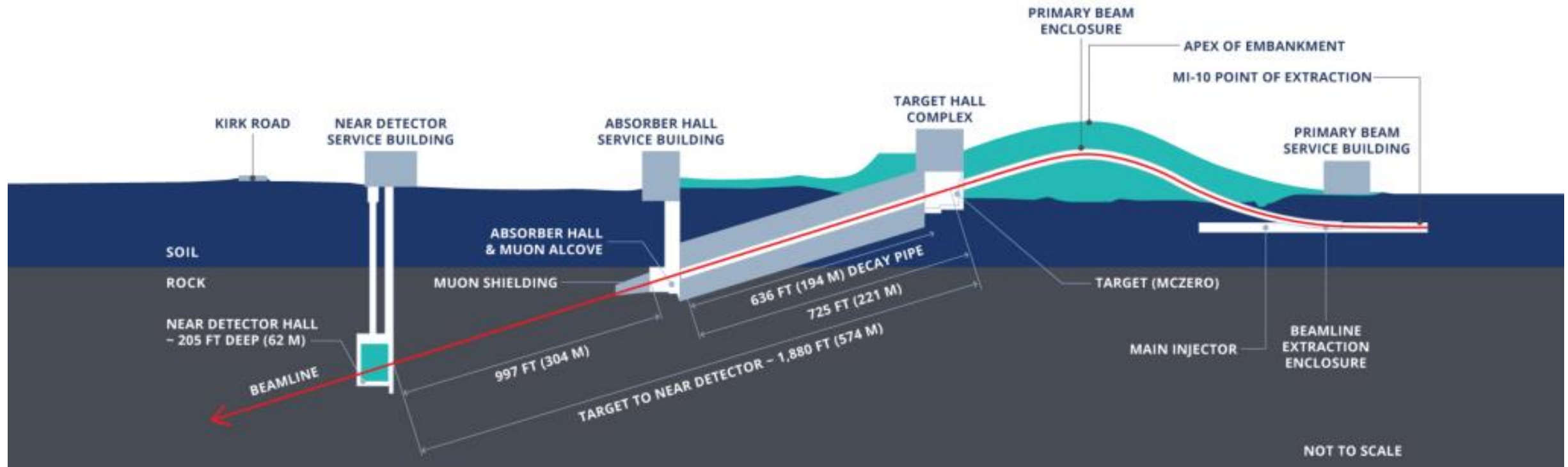
- **Primary proton beam 60-120 GeV**
- **Beam power of 1.2 MW, upgradable to 2.4 MW**
- **2 m long graphite target**
- **3 magnetic horns**
- **Near Detector is approx. 574 meters from target, located at Fermilab**
- **Far Detector is approx. 1300 kilometers from target, located at Sanford Underground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

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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

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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

- Geant4 version v4_10_3_p03b, G4LBNE v3r5p7

- Corrections have been applied for proton on carbon creating pions and for the cumulative particles. Done using a modified PPFX.
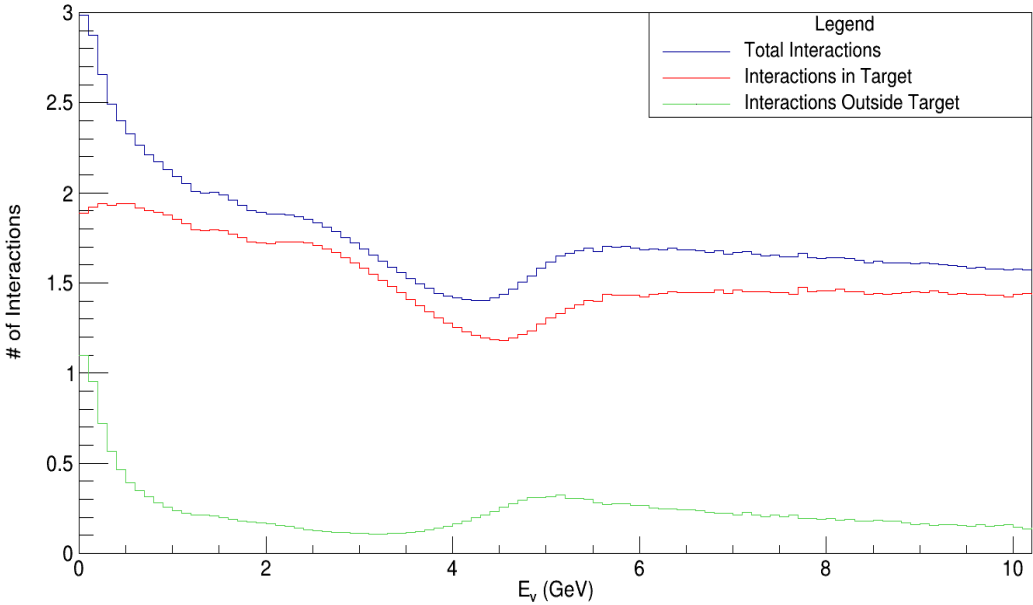
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Muon Neutrino Flux at the Near Detector

QGSP_BERT/FTFP_BERT Muon Neutrino Flux Ratio
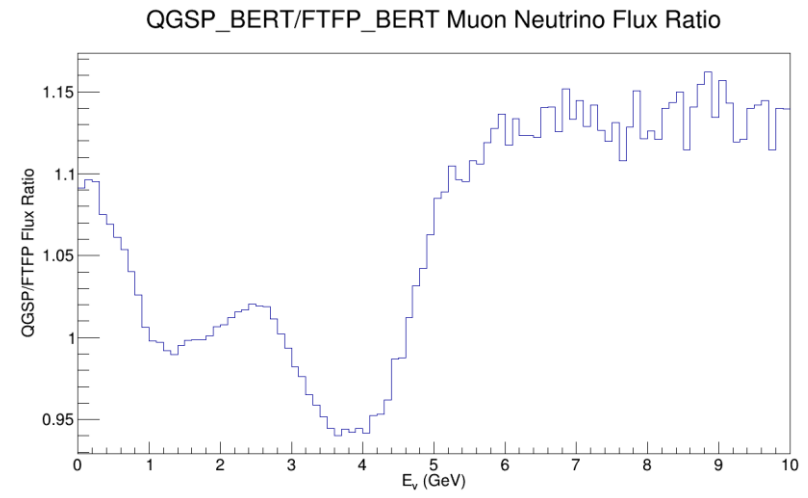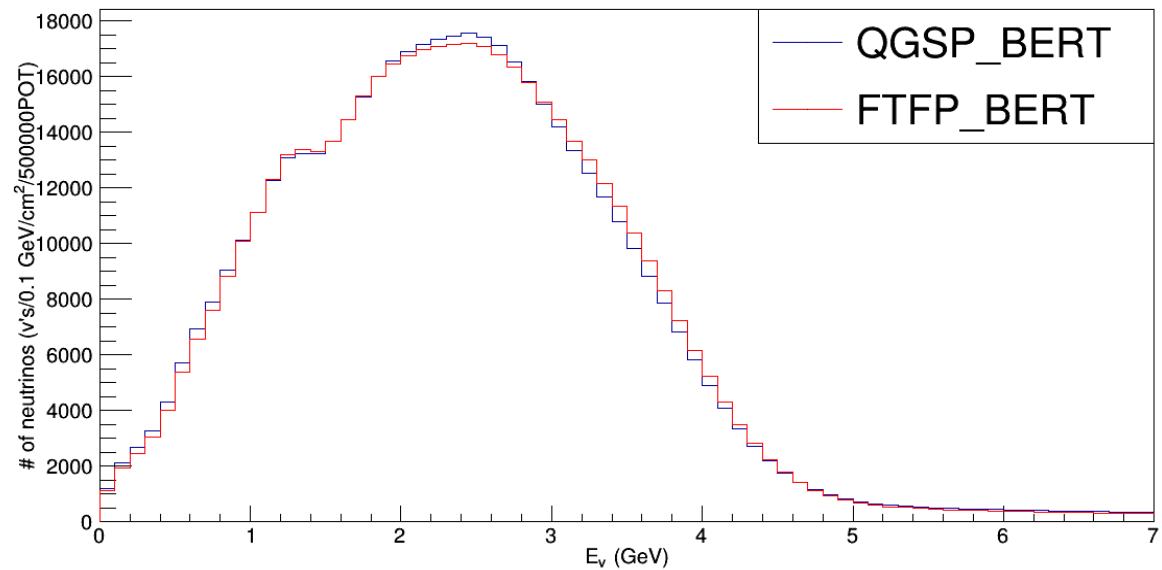
Total Interactions

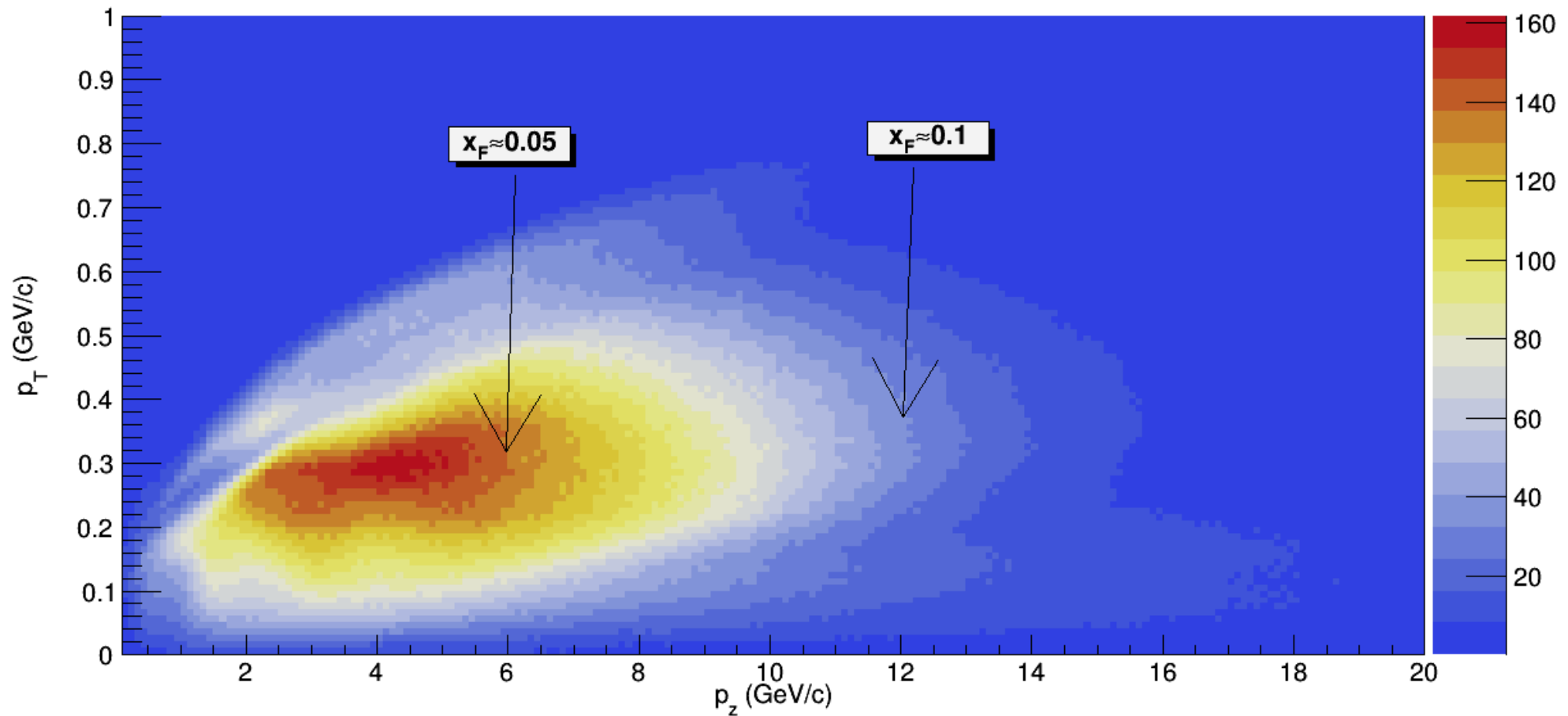QGSP_BERT Interaction Totals
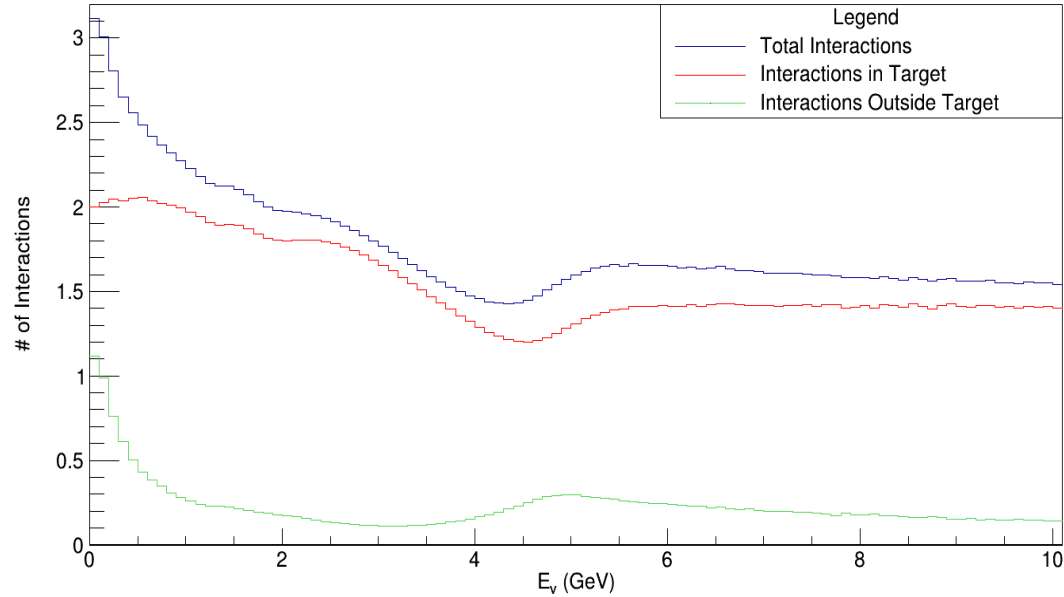
FTFP_BERT Interaction Totals

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Interactions in Target
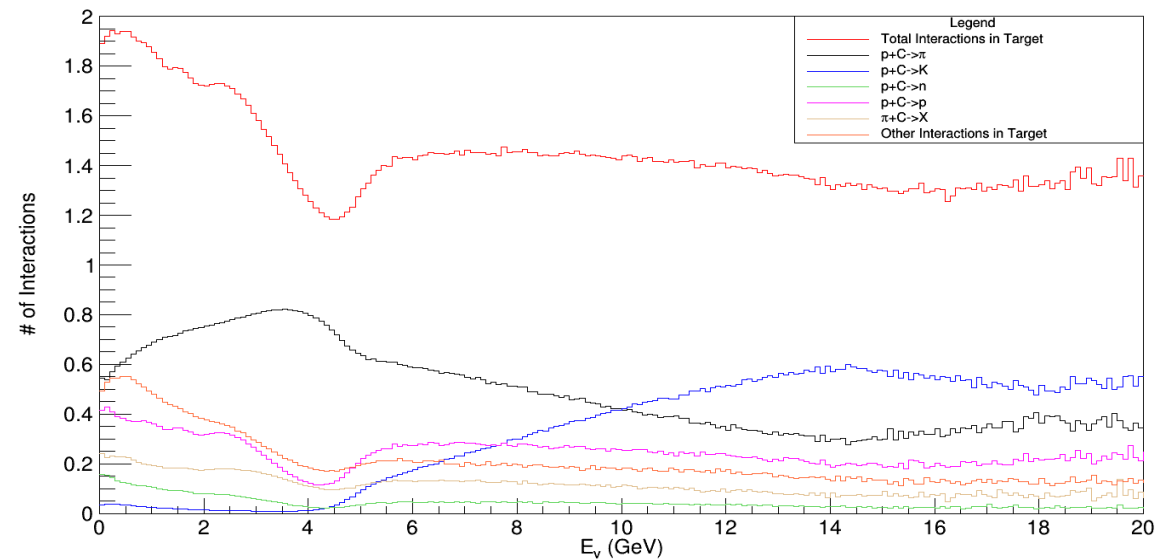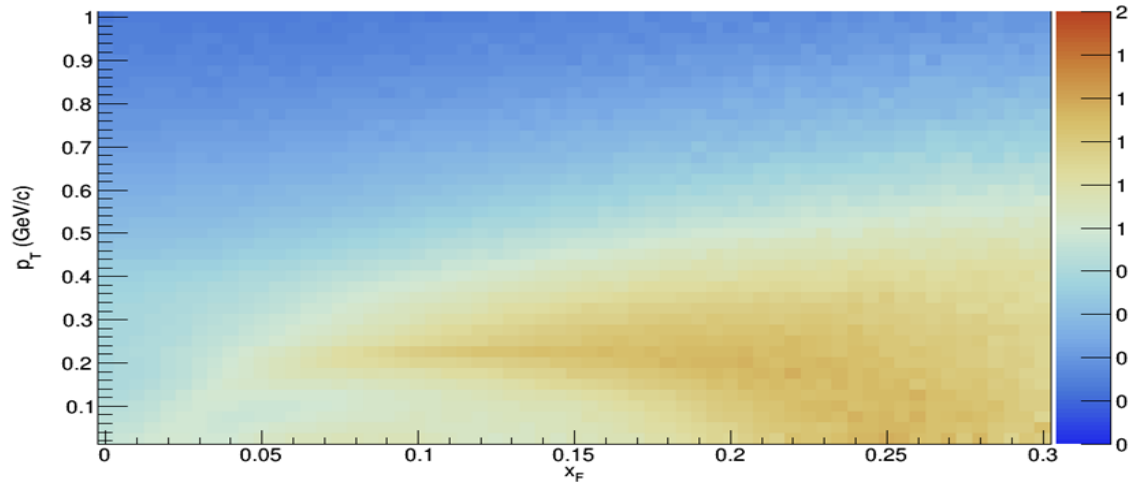
Pion Kinematics

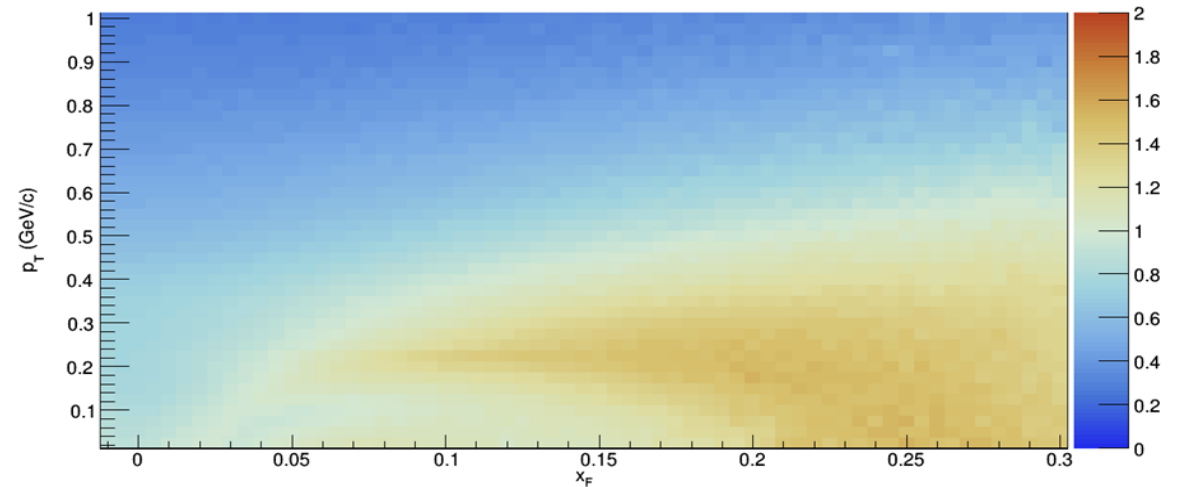QGSP_BERT Pion Momentum

$$x_F \approx \frac{p_L}{\sqrt{s}/2}, in\ the\ center\ of\ mass\ frame$$
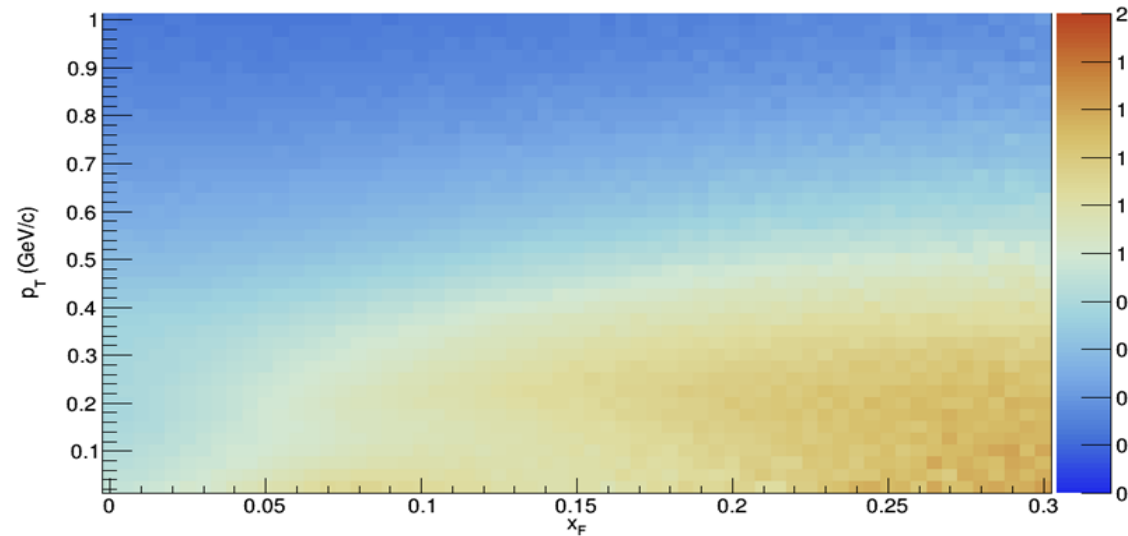
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QGSP/FTFP Cross-Section Ratios
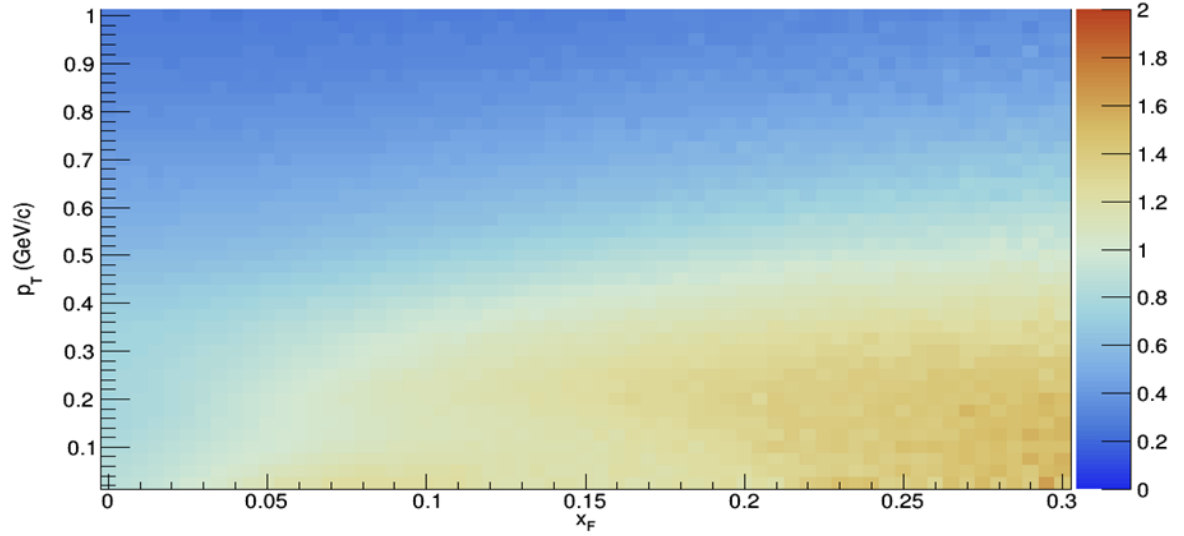

QGSP/FTFP 120GeV Π+ Ratio

QGSP/FTFP 158GeV Π+ Ratio
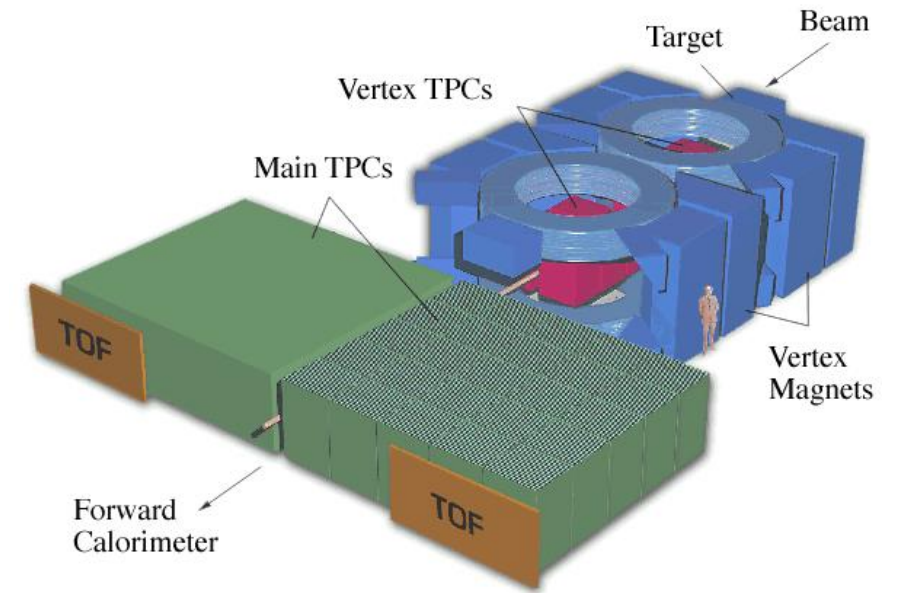
QGSP/FTFP 120GeV Π- Ratio

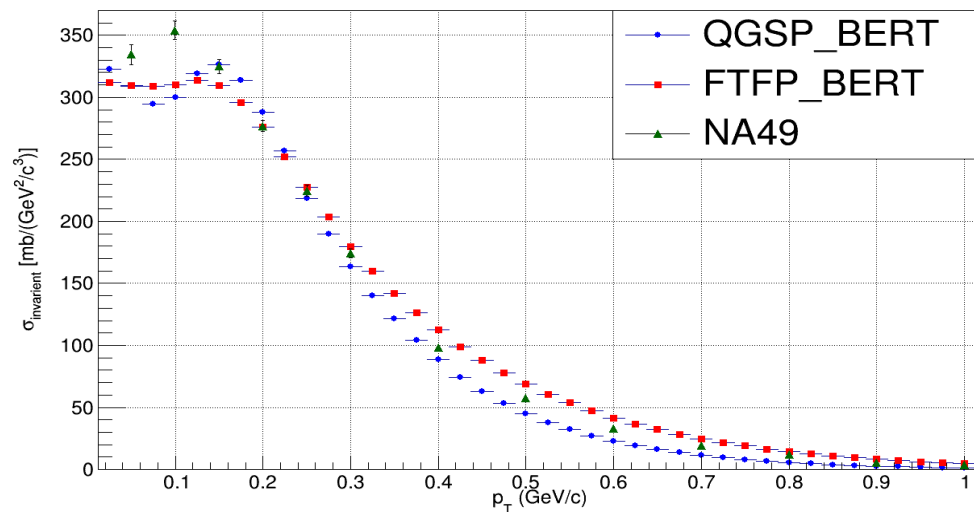QGSP/FTFP 158GeV Π- Ratio

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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
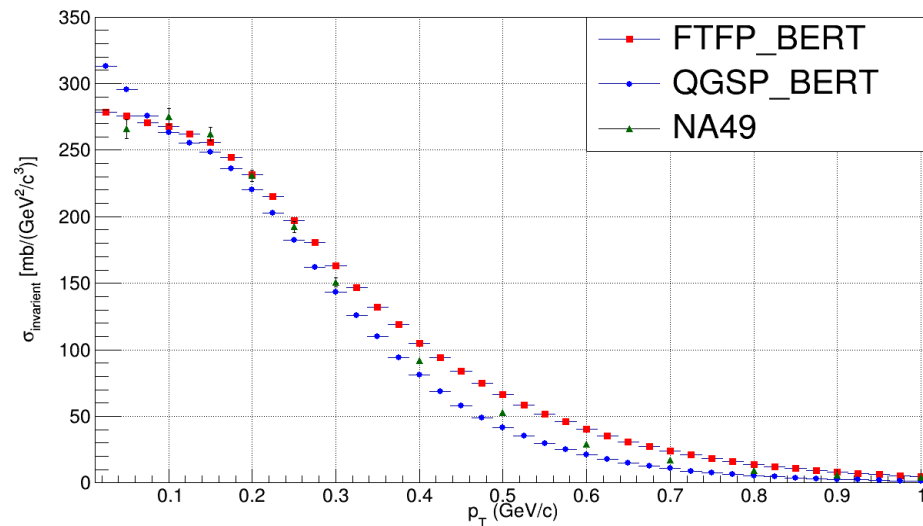 - Has Cross section data for Pions

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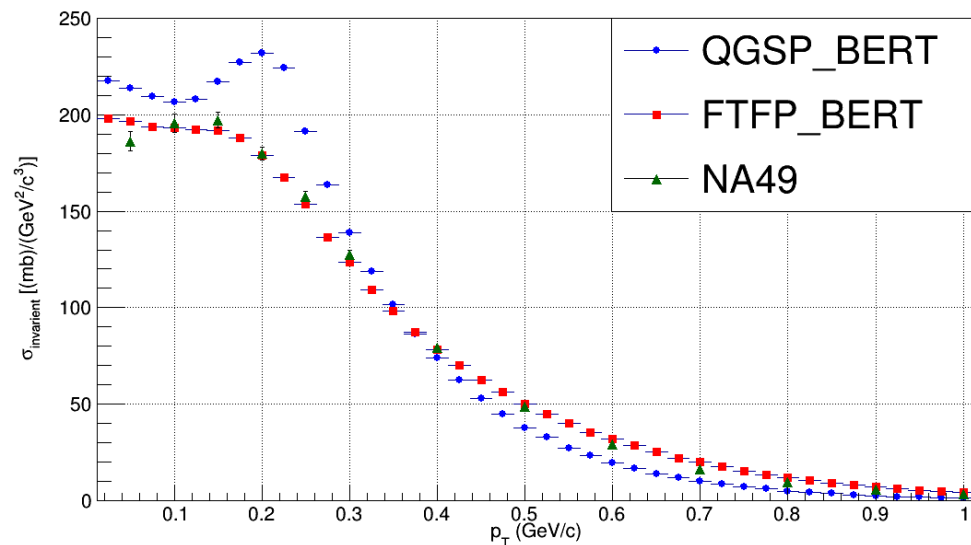
Invariant Cross Section

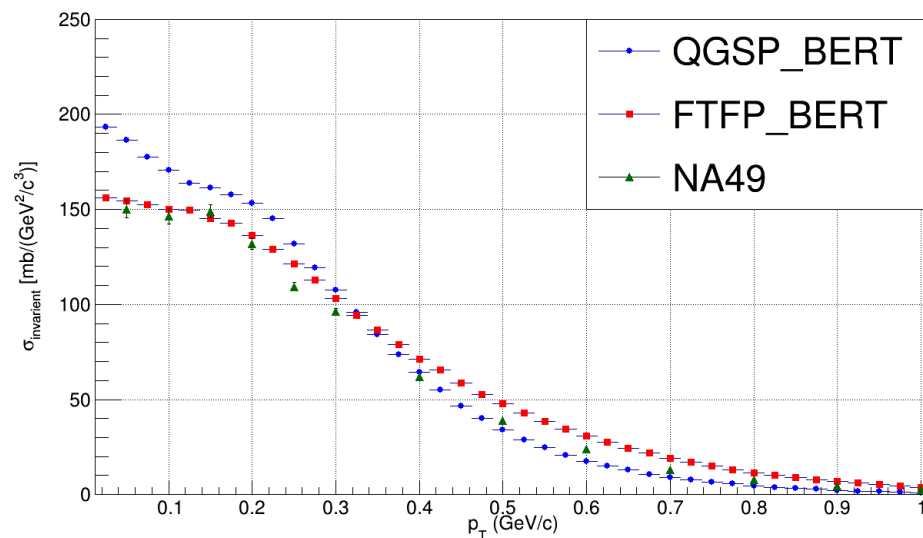
Cross Section at $x_F=0.05$ $\pi+$ 158 GeV

Cross Section at $x_F=0.05$ $\pi-$ 158 GeV

Cross Section at $x_F=0.1$ $\pi+$ 158 GeV

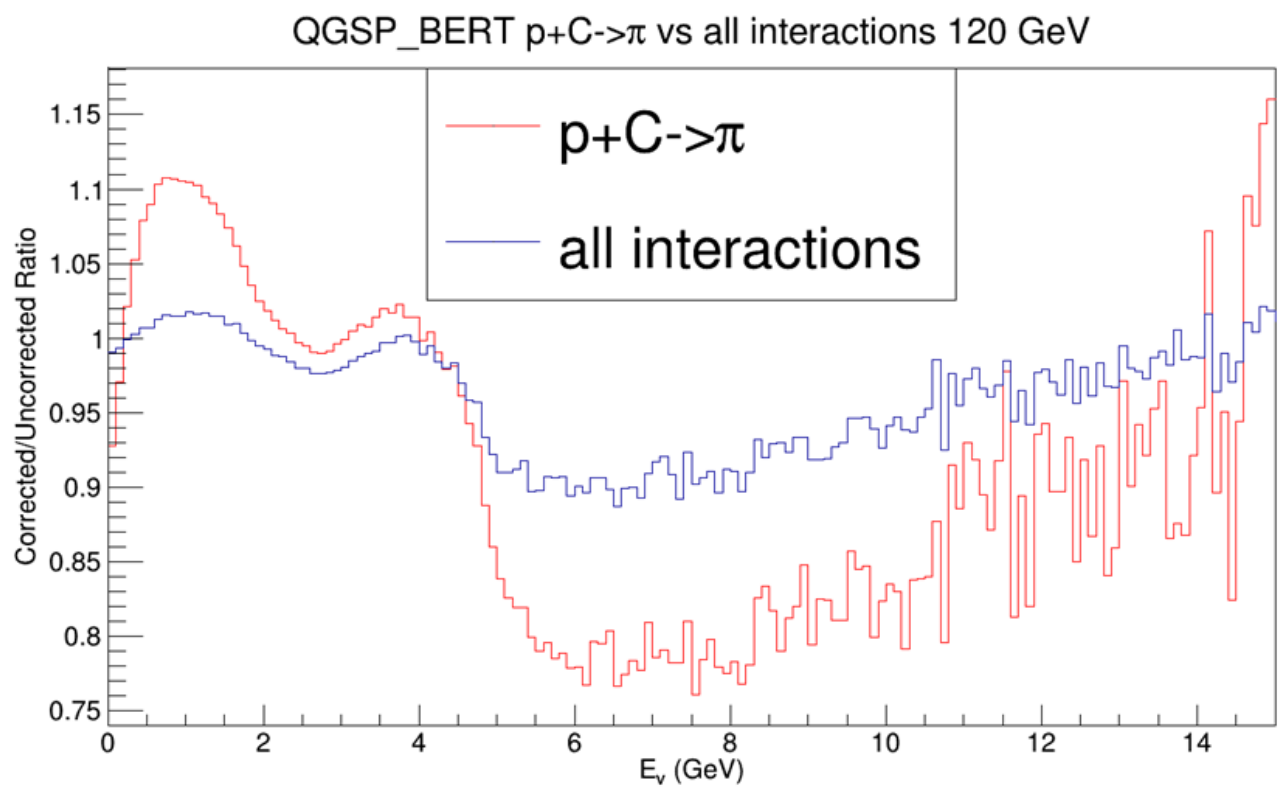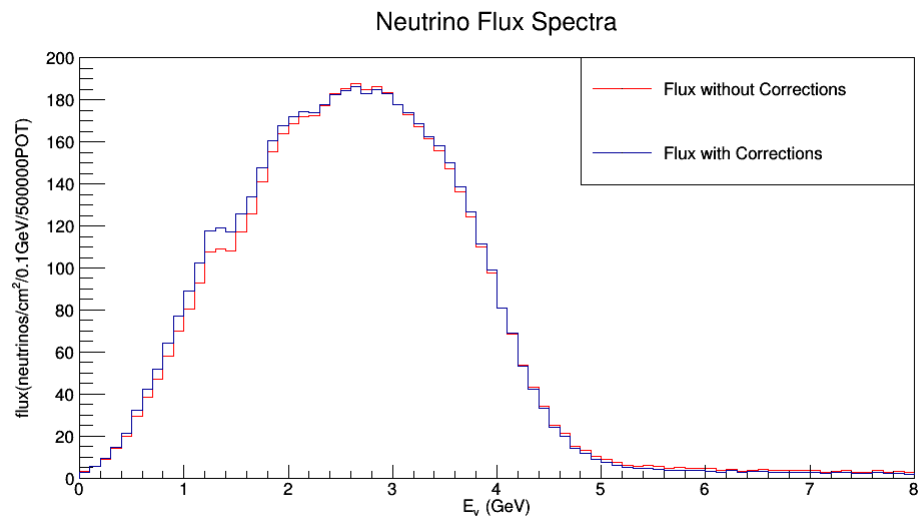Cross Section at $x_F=0.1$ $\pi-$ 158 GeV

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Pion Production Ratio 158 GeV

π+/π- Ratio at x_F=0.05

Correction Results

Neutrino Flux Spectra

QGSP_BERT p+C->π vs all interactions 120 GeV
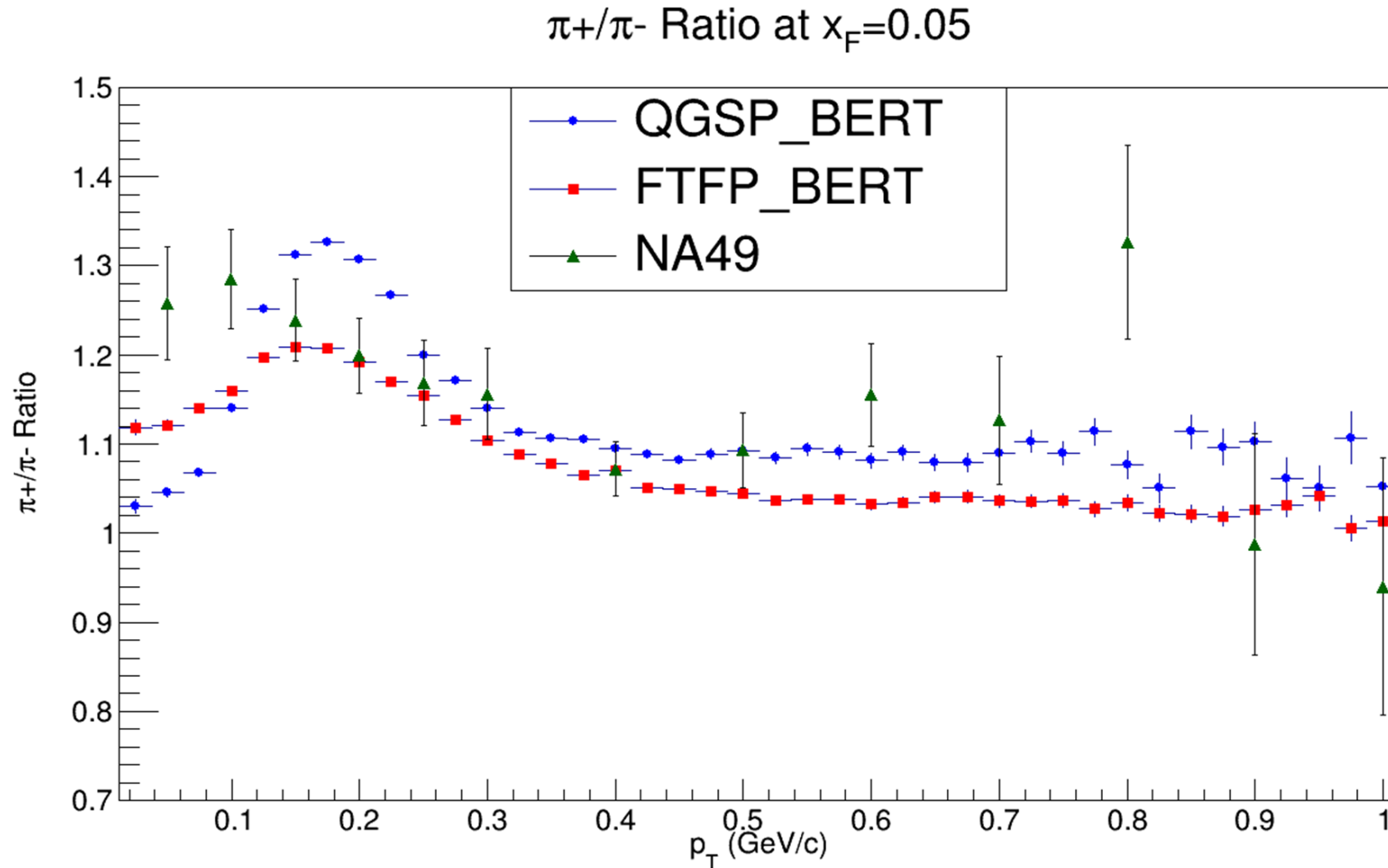
Conclusions

- 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.

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Acknowledgements

- Thank you

  – Supervisor: Leo Aliaga

  – Mentors: Arden Warner and Charlie Orozco

  – The SIST committee for transitioning this experience online

References

- NA49: Eur.Phys.J.C49:897-917,2007

- Aliaga Soplin, Leonidas. Neutrino Flux Prediction for the NuMI Beamline. United States: N. p., 2016. Web. doi:10.2172/1250884.