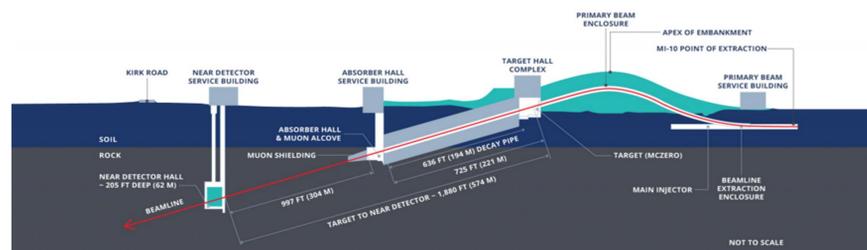


# Analysis of Hadron Models to Better Predict Neutrino Flux for DUNE

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## Introduction

My project was to characterize the interactions of the QGSP\_BERT and FTFP\_BERT hadron production models and compare them with experimental data. The experimental data used was NA49, which was an experiment conducted at CERN. NA49 tested the particle production of various proton interactions on targets of different materials. QGSP\_BERT is being used to simulate the LBNF beamline, so it is important for DUNE that the QGSP\_BERT model is characterized. Because then predictions of the neutrino flux are better understood and can have more accurate uncertainties so measurements of neutrino oscillation can be made more reliably and accurately.

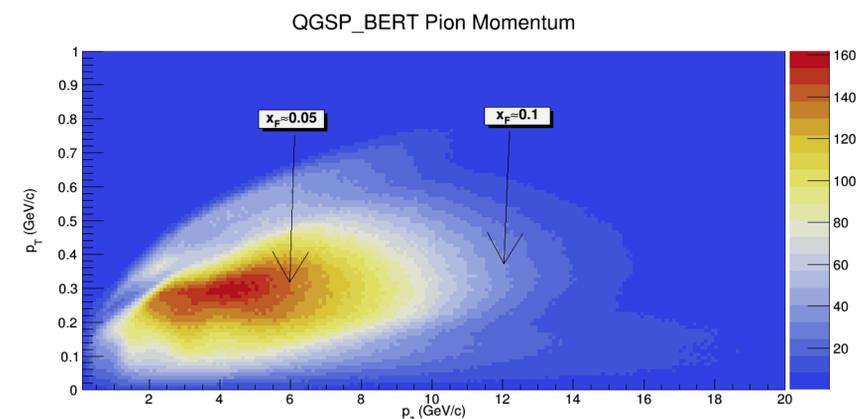


## Methods

The data was generated using two Geant4 programs one called G4LBNF, which simulates the LBNF beamline. The other program is called G4HP. G4HP is used to simulate the particle interactions and it works by:

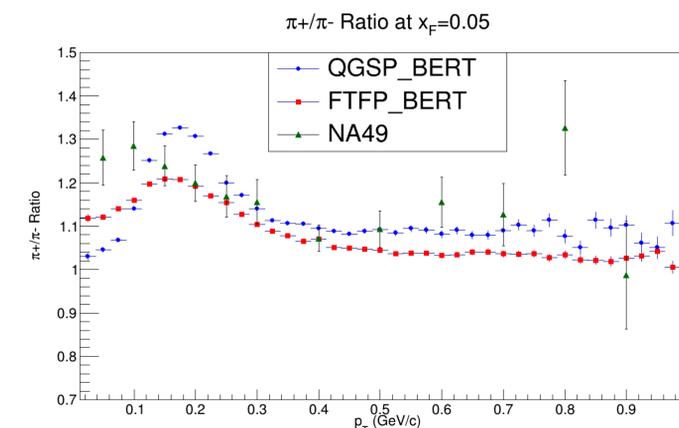
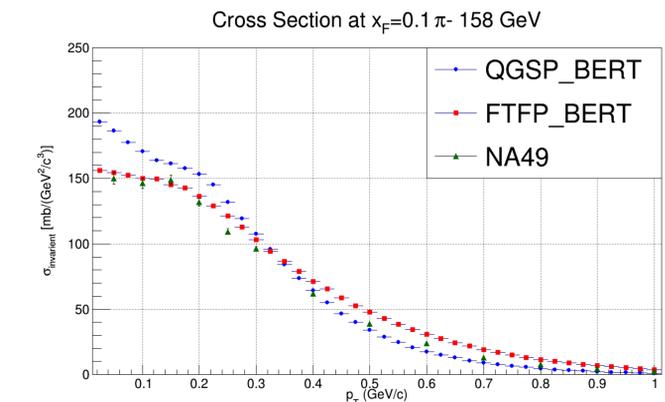
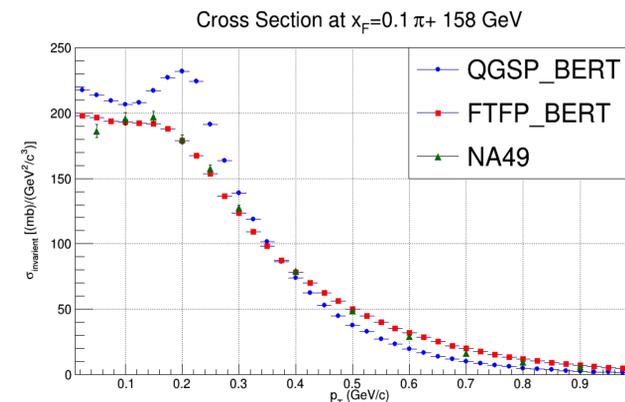
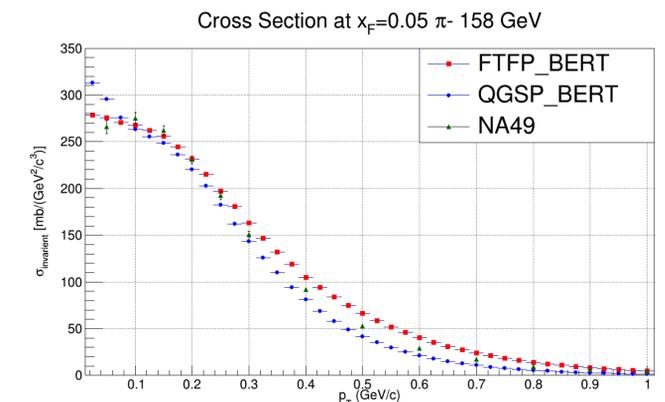
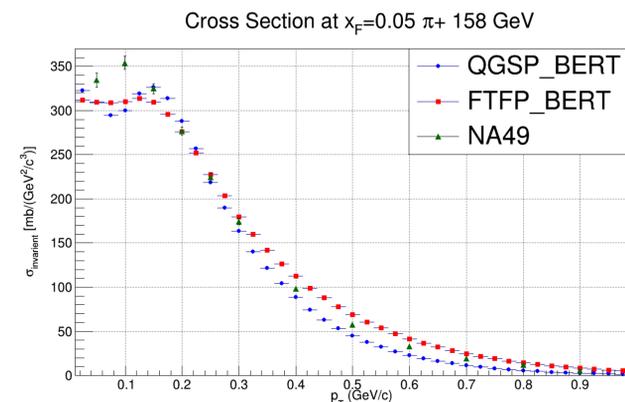
1. Setting the hadron model to use to either QGSP\_BERT or FTFP\_BERT.
2. Then the geometry and composition of the target are simulated.
3. Next protons at a given energy are fired at the target.
4. The data from the proton on target interaction is stored in a ROOT TTree.

The material used in the target for DUNE is carbon, so the interactions analyzed for my project were proton on carbon. These interactions create particles such as pions and kaons. To get the cross section data from the simulate a program called CreateYields is used to get the production yields of the secondary particles. Then the output from the CreateYields program is used in another program called CreateInvXS to create histograms of the invariant cross section of the interaction for a particular particle e.g. positively charged pions. The reason we use this method is because the data for the cross section is not directly available.



## Results and Discussion

The results of the simulation show that for both positive and negative pions at low transverse momentum QGSP\_BERT has a larger cross section compared to NA49. QGSP\_BERT's cross section also generally decreases as the transverse momentum increases until the cross section for QGSP\_BERT is smaller than the cross section for NA49. On the other hand FTFP\_BERT usually starts close to the NA49 data when transverse momentum is low and at higher transverse momentum it overproduces compared to NA49. Also of note is that the cross section of positive pions is greater than the cross section for negative pions. Important to know because the LBNF has magnets that can focus charged particles we want, and defocus charged particle we don't want. However, there will still be some background of the particles we don't want that get past the magnets into the beamline.



## Conclusion

FTFP\_BERT on average does a better job of more closely following the NA49 data than QGSP\_BERT. FTFP\_BERT could possibly be used to simulate proton on carbon interactions that we have no experimental data for comparison. However, there is still more work that needs to be done. The next step with this data should be to apply corrections to the models using the NA49 data and see what effects there are on the neutrino flux predictions.

## Acknowledgements

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