# MTA Pion Production Target Studies

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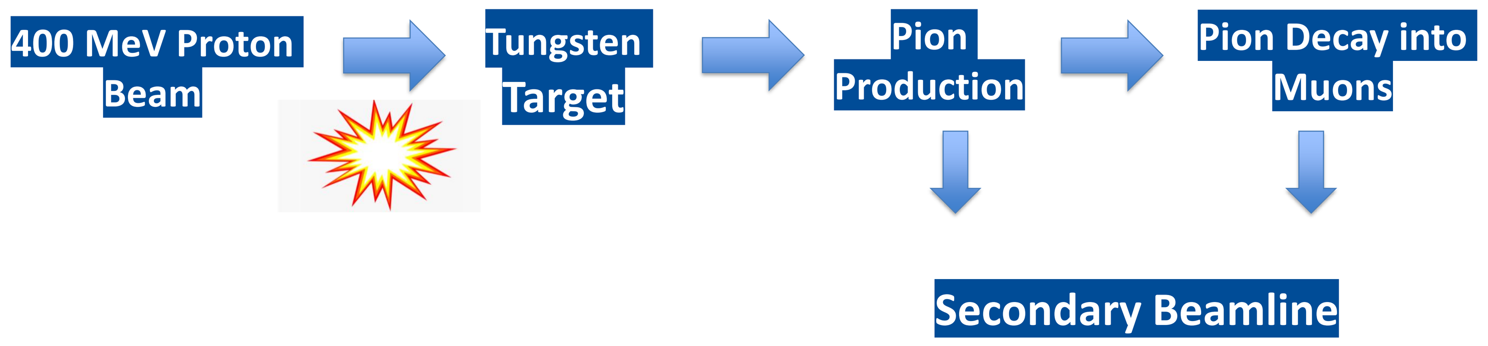
## Background

The muon is an elementary particle that can be produced using a particle accelerator, such as Fermilab's Linac 400 MeV proton beam, to collide high energy protons onto a fixed target, resulting in interactions that produce charged pions ($\pi^{\pm}$). The pion is unstable and will almost immediately decay into a charged muon ($\mu^{\pm}$) and a neutrino. The resulting muons would be collected and transported into a beam. The MuCOOL Test Area (MTA) Facility at Fermilab is currently hosting the Muon Catalyzed Nuclear Fusion experiment, one of many different experiments that will be able to utilize a low-energy, high-intensity muon source. The scientific community also has a wide interest in future low energy muon experiments, such as lepton flavor violation experiments, muon decay to 3 electrons experiments, etc.




## Purpose

The goal of the project is to maximize the muon yield for the purposes of the muon catalyzed fusion experiment, by optimizing the target geometry and the secondary beam-line added onto the 400 MeV linac. Extensive studies using Monte Carlo techniques will guide the optimization of both the target and the secondary beamline by using theoretical models to analyze the predictions of interactions between the 400 MeV proton beam and the tungsten (W) target.. Comparing and analyzing simulated data to real data will validate the theoretical models being used and will be an important source of information for theorists.

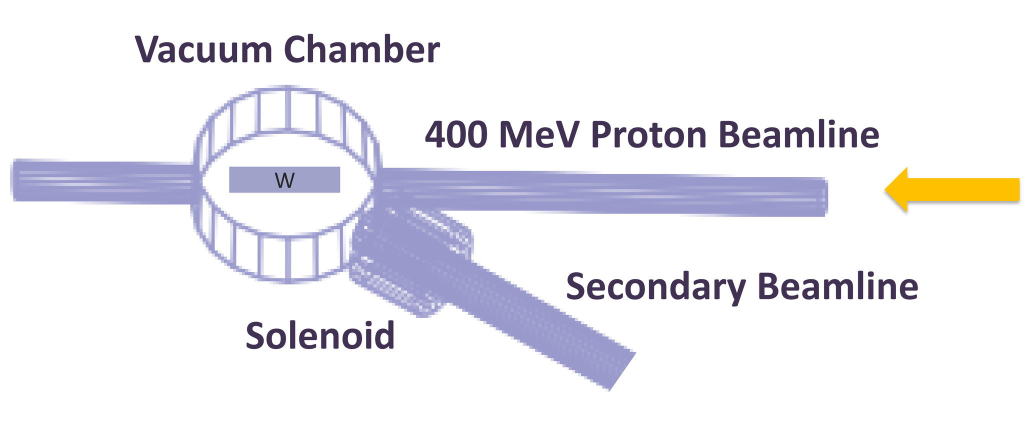



Image simulated using the ROOT framework

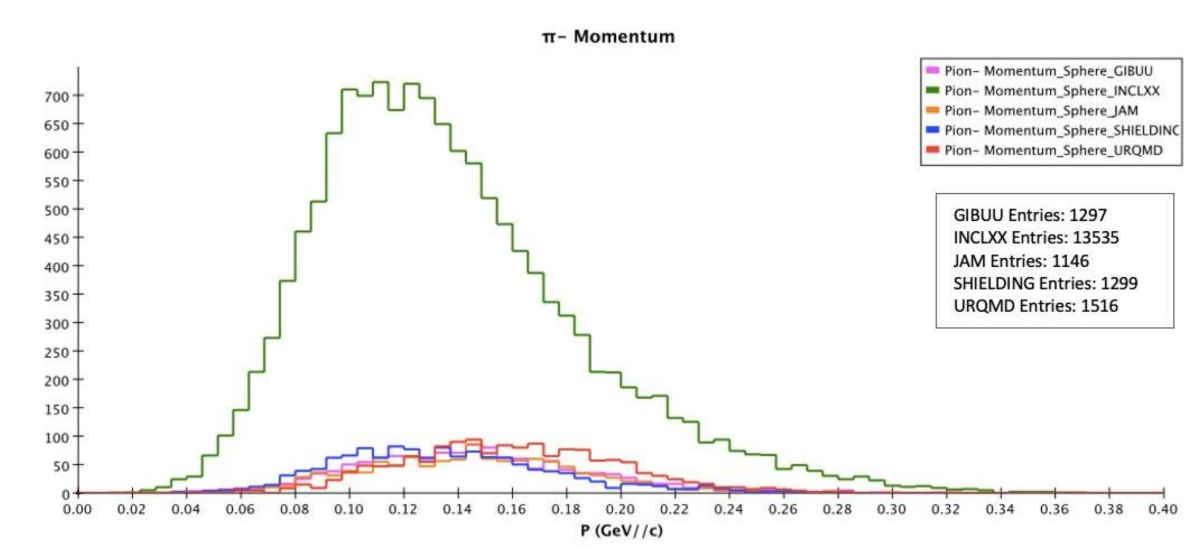
## Studies

Primary hadronic interactions are simulated using different nuclear interaction models, including GiBUU, INCL++, JAM, and UrQMD, and are compared with GEANT4 using Shielding and INCL++ physics lists. Secondary particles are tracked using the GEANT4 toolkit, in order to study the momentum distribution of pions and muons and to track the pion origin and yield at the entrance to the secondary beamline. Data analysis is performed on Jas3, an AIDA (Abstract Interfaces for Data Analysis) compliant framework, and a Java-based macro was developed in order to plot relevant graphs and collect necessary data.

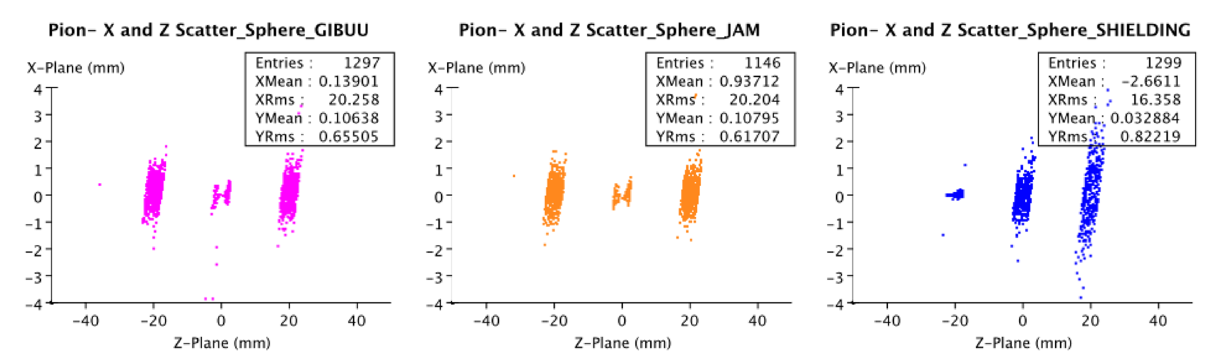
## Simulations

The geometry description of the primary and secondary beamlines, the production chamber, and the target are all an essential part of the simulation studies. GDML (an XML-based geometry description language) has been chosen because it is compatible both with ROOT and GEANT4.

Preliminary studies used three thin tungsten target slices (3.3mm) to develop the analysis macro and to among different hadronic models. The momentum distribution and the origin was collected for protons, neutrons, gammas, pions, and muons, both on the walls of the vacuum chamber and at the entrance to the secondary beamline.

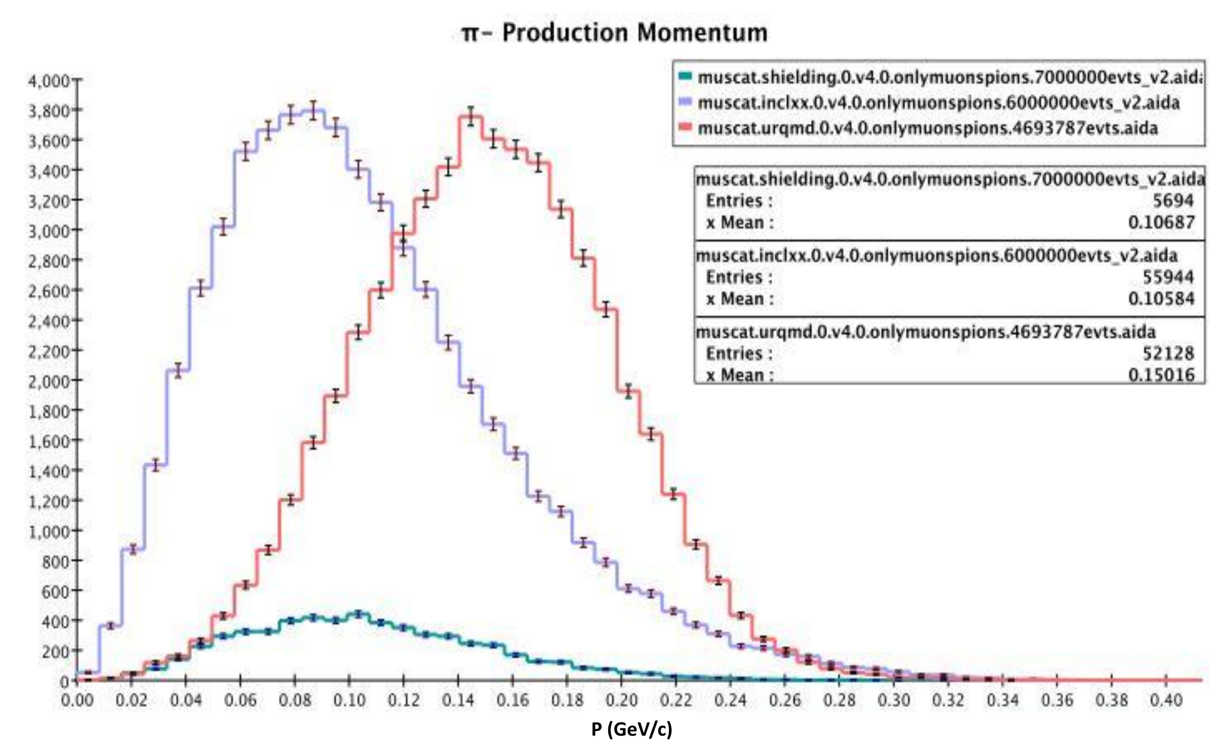



**Momentum distribution of produced π- scored on the wall of the vacuum cham for five different models during preliminary studies. GEANT4 [SHIELDING] π- are produced from 4,690,630 POT, INCL++ π- are produced from 23,264,237 POT, UrQMD π- are produced from 15,623,779 POT, GIBUU π- are produced from 2,830,990 POT, and JAM π- are produced from 4,557,292 POT. Numbers not normalized.**

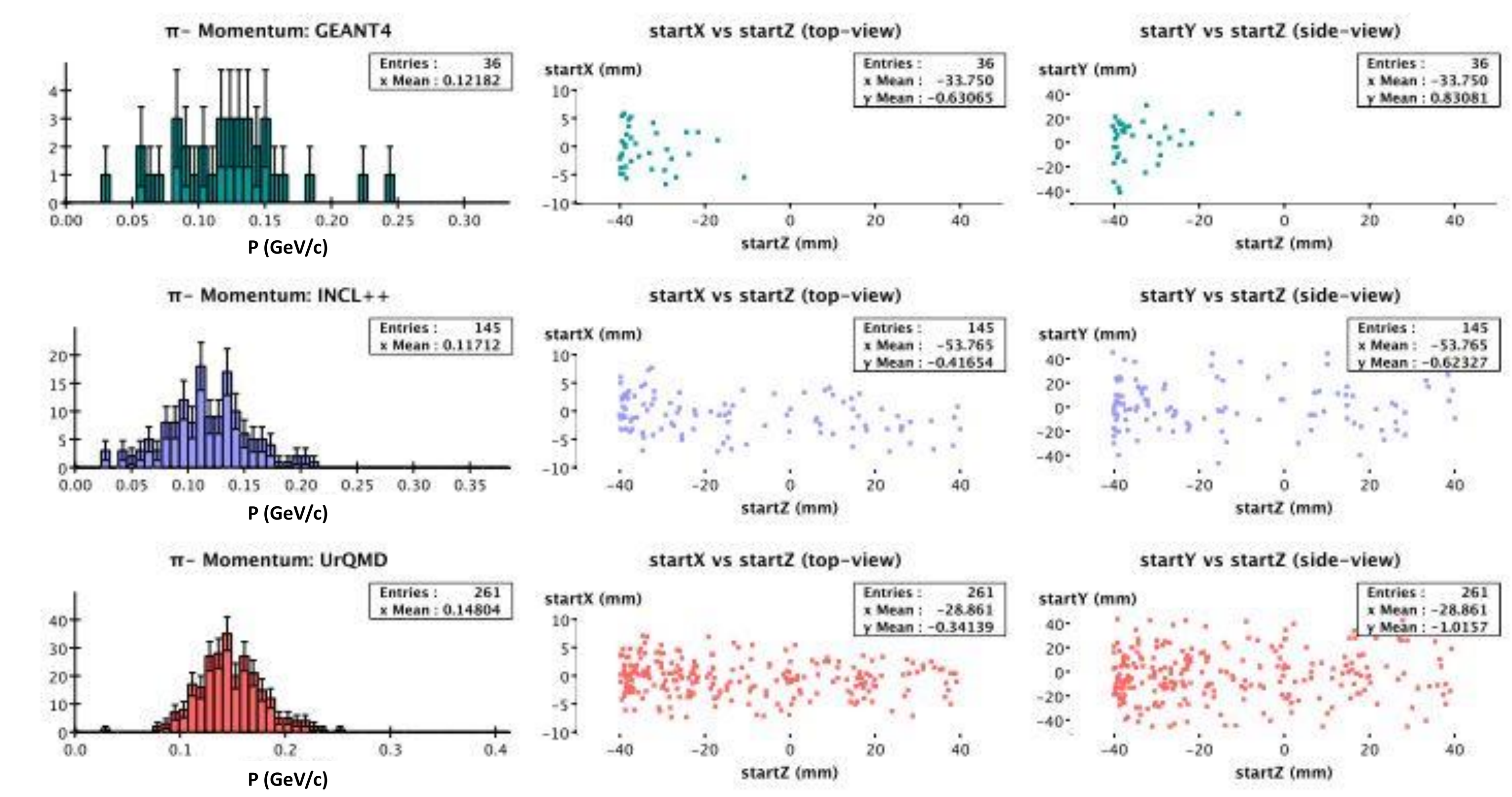



**Origin (top-view) of produced π- for three different models during preliminary studies. Numbers not normalized.**

## Results




**Momentum distribution and origin of produced π- for three different models. GEANT4 π- are produced from 7,000,000 POT, INCL++ π- are produced from 8,128,044 POT, and UrQMD π- are produced from 6,358,551 POT. Histograms not Normalized.**




## Conclusion

The studies done in this project will help guide the decision regarding the best target for optimized pion production and muon beamline in the MTA facility. This work will initially be used by the muon catalyst fusion experiment.

Current studies show that the full picture of the pion production and their transport can be reliably obtained by comparing the different hadronic interaction models.

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