G4beamline target simulation for Fermilab muon g-2

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Summary

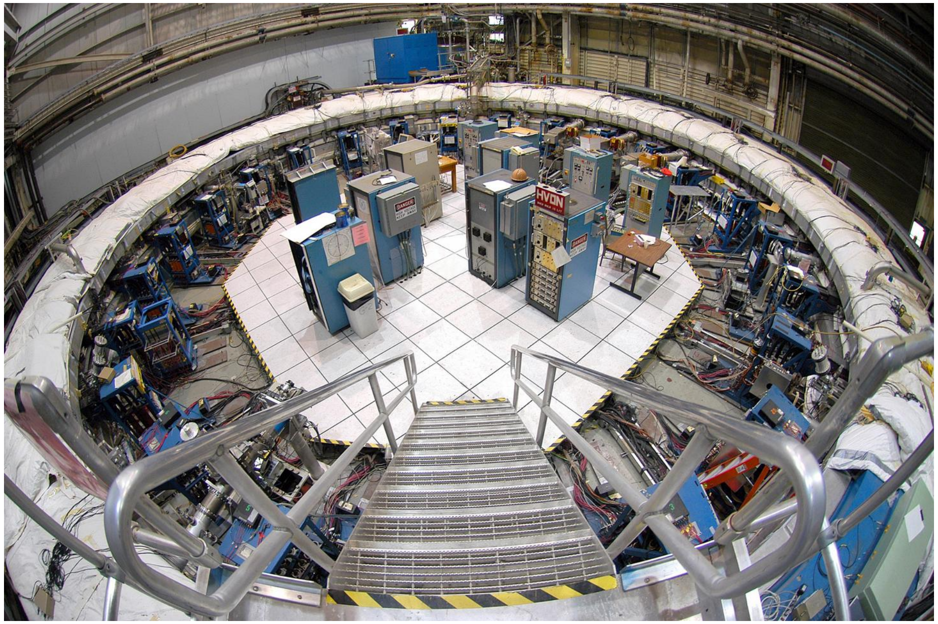
- The Muon g-2 Experiment, BNL and Fermilab
- Benchmarking G4beamline
- Target Station Simulation
- Future developments

Muon g-2 as a probe for new physics

- Anomalous magnetic moment of a particle is a contribution of quantum mechanics to the magnetic moment of that particle
- Sensitivity to this contribution increases with particle mass
- Muon is used because of its balance between high mass and long lifetime

E821 – BNL g-2

- Measured g-2 by circulating muons and antimuons in a magnetic storage ring
- Observed precession of muon spin due to magnetic field
- g-2 measured to precision of 540 ppb
- One of the most famous “cracks” in the Standard Model

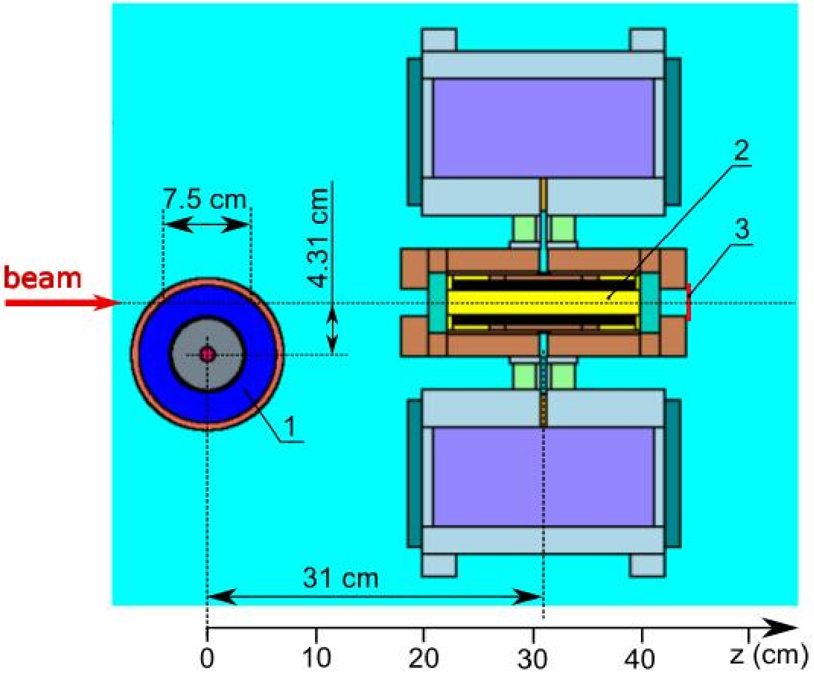


E989 – Fermilab g-2

- Will use storage ring from E989
- Planned fourfold increase in precision of g-2
- Higher precision from higher quality of pion source + other upgrades
- Ring moved in 2013, data taking to start in 2017

Current state of g-2 simulations

- Target station done in MARS
- Everything else (pion transport, debunching, etc.) done in GEANT4
- MARS was the best solution for pion production simulations



MARS code system

- Beamline simulation package written in Fortran
- Developed and maintained at Fermilab
- Rather difficult to use unless very experienced

G4beamline (G4BL)

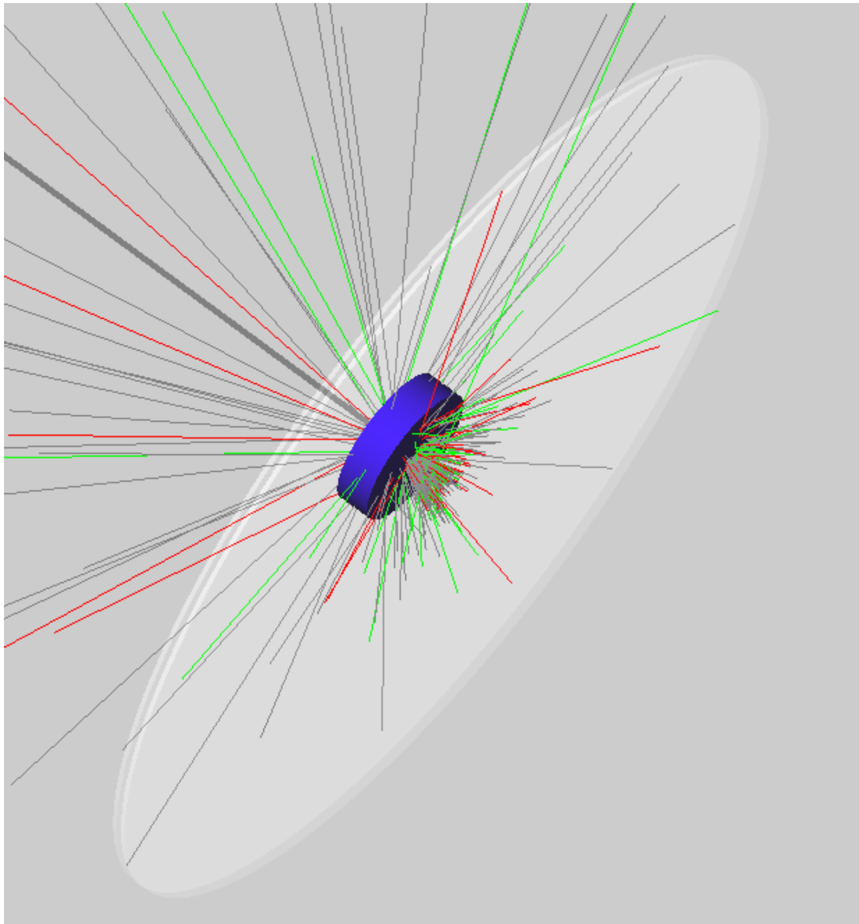
- Front end for GEANT4 with specialized primitives and commands to simplify accelerator design
- No C++ code required to make simulations
- Can directly call Geant4 functions if necessary

My Task(s)

- Compare G4BL to MARS
- Write and test simulation of Fermilab g-2 target station in G4BL

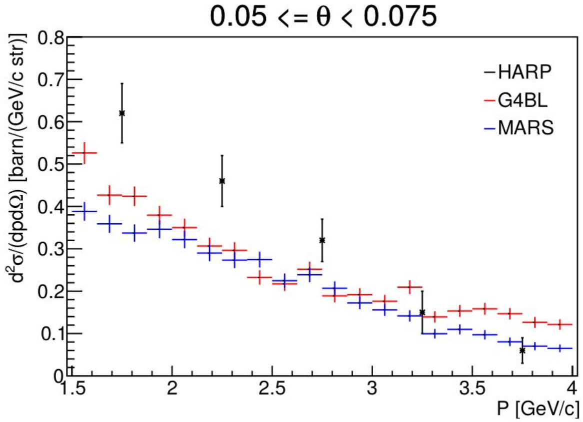
Benchmarking: G4BL vs. MARS

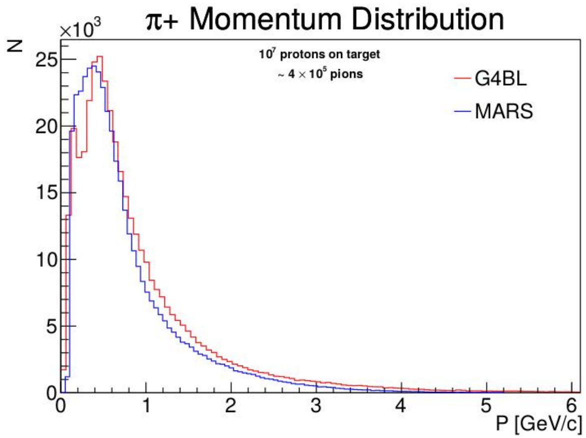
- Wrote a simple simulation of the geometry used in CERN's Hadron Production Experiment (HARP)
- Mentor simulated same geometry in MARS
- Compared pion production results of both simulations with real data from HARP
- Comparison done through double differential cross section, a measure of event probability within a certain momentum-angle bin



Benchmarking Results

- Data sets do not agree very well at low energies (<1.5 GeV/c)
- Agree reasonably well at energies of interest for g-2 (3-4 GeV/c)
- Agreement increases with energies
- G4BL uses physics libraries optimized for HEP, sot this is somewhat expected





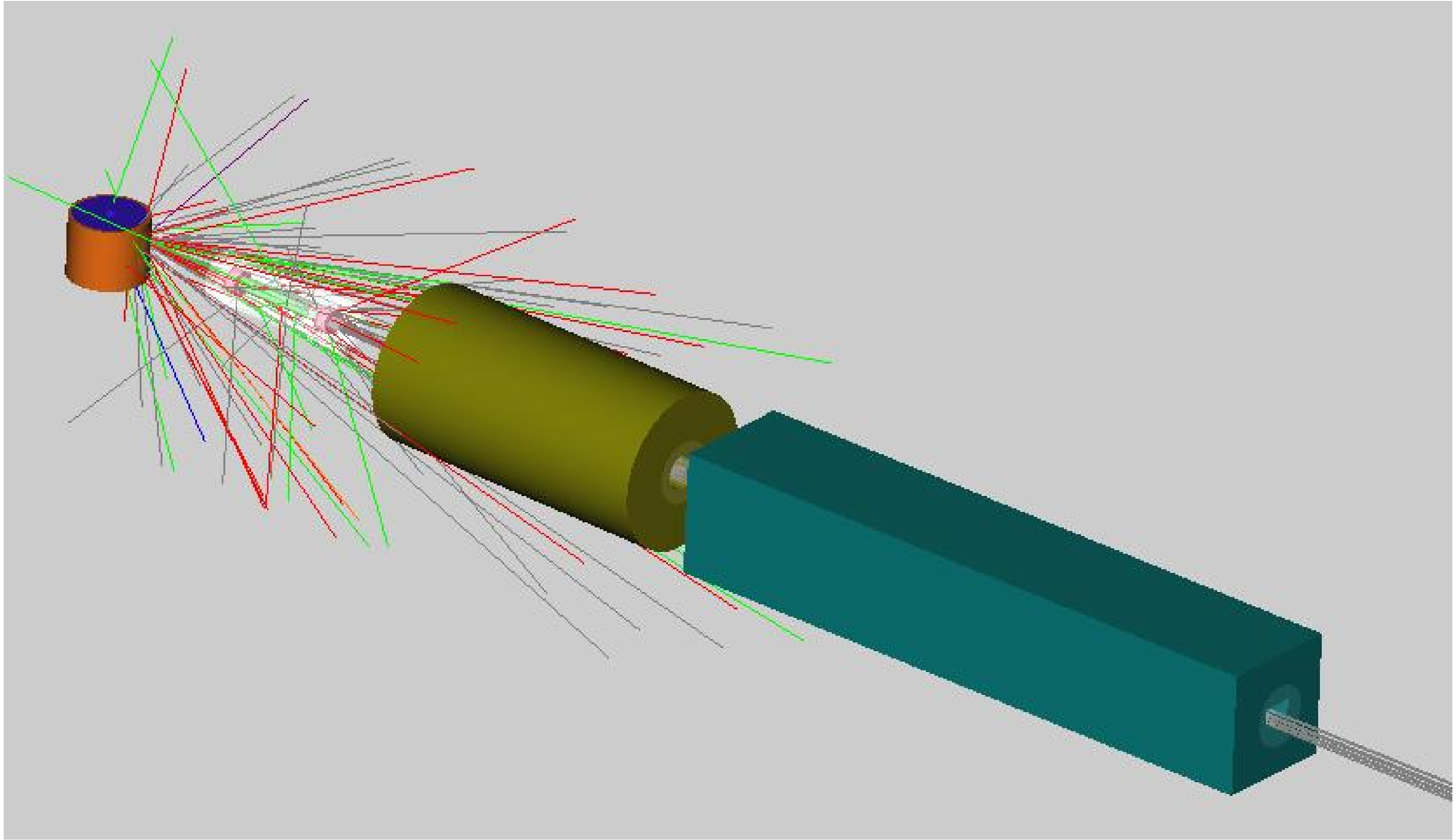
Fermilab Pbar Complex

- Source of muons for g-2 and other muon experiments
- Produces pions using proton beam, pions eventually decay to muons

Target Station Simulation

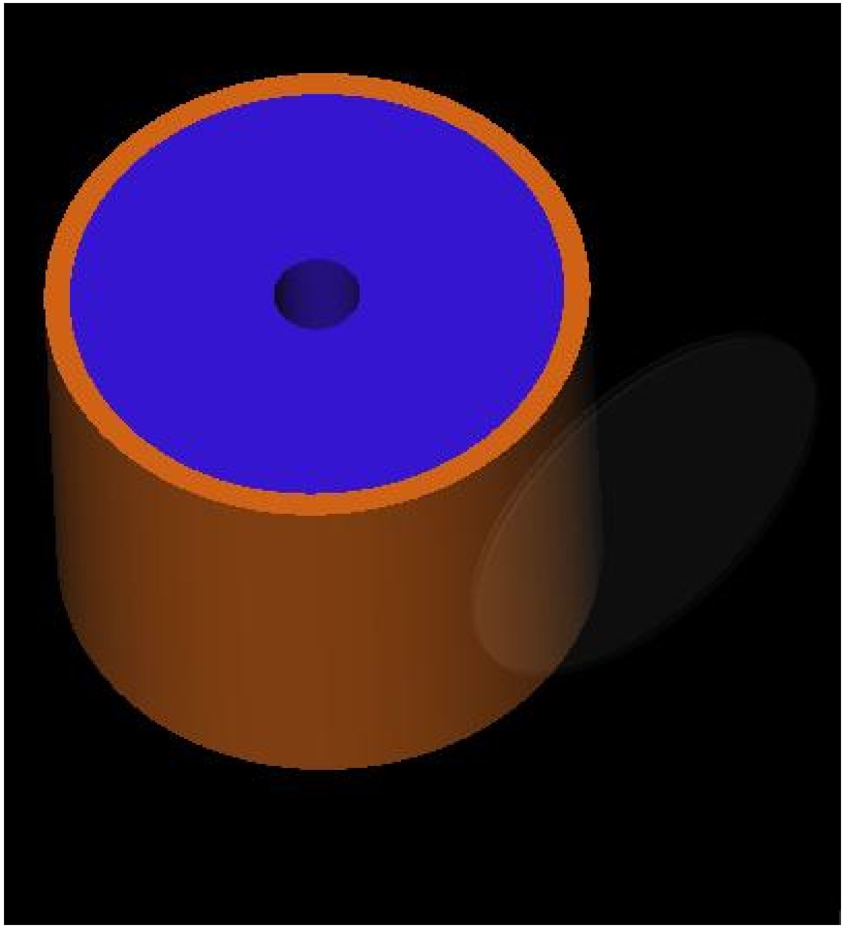
- Models four components: target, lithium lens, collimator and pulsed magnet
- Virtual detectors between components record particle data
- Runs ~1.1 million events/hour on typical desktop machine
- Focuses on particle production; no energy deposition data taken

Visual Overview



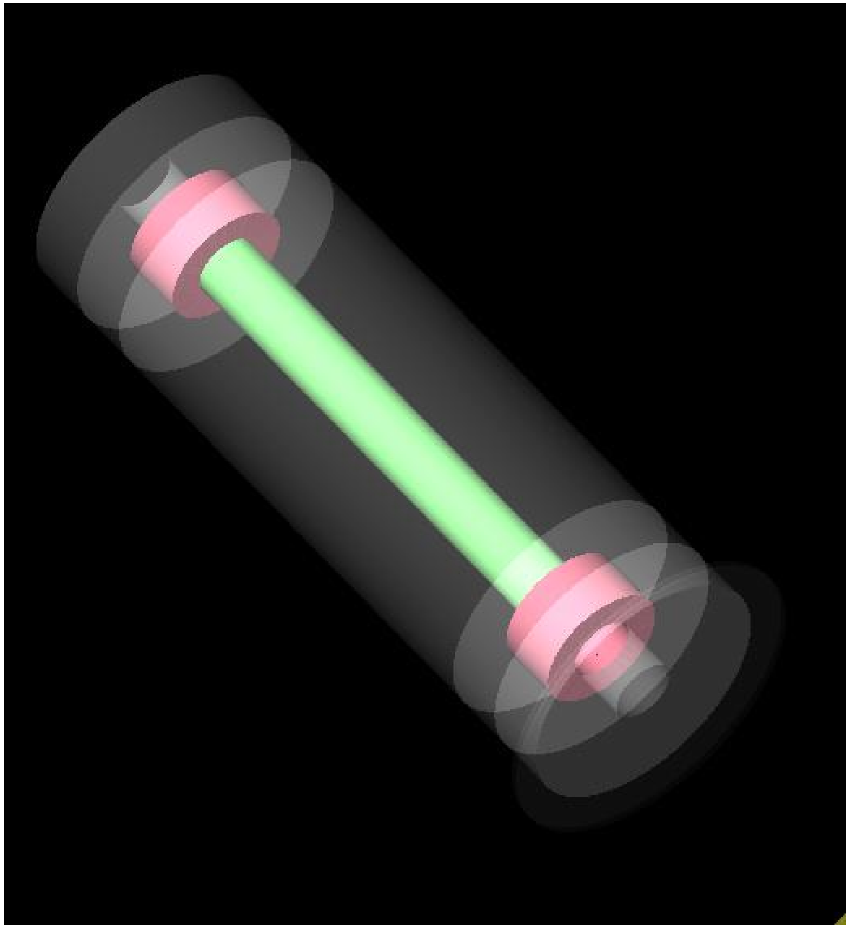
Target

- Inconel core (mostly nickel)
- 6 mm beryllium casing
- Takes 8 GeV proton beam and produces secondary particles



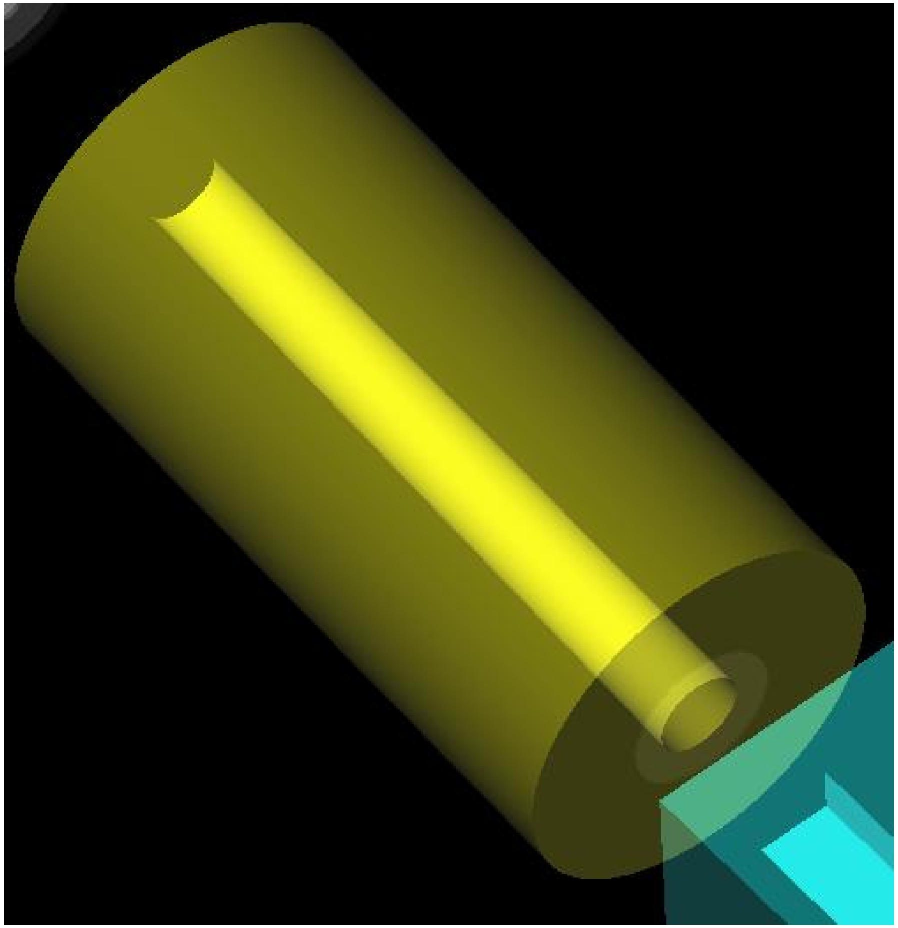
Lithium Lens

- Lithium rod with beryllium vacuum windows and titanium casing
- 116 kA current through lithium generates focusing magnetic field



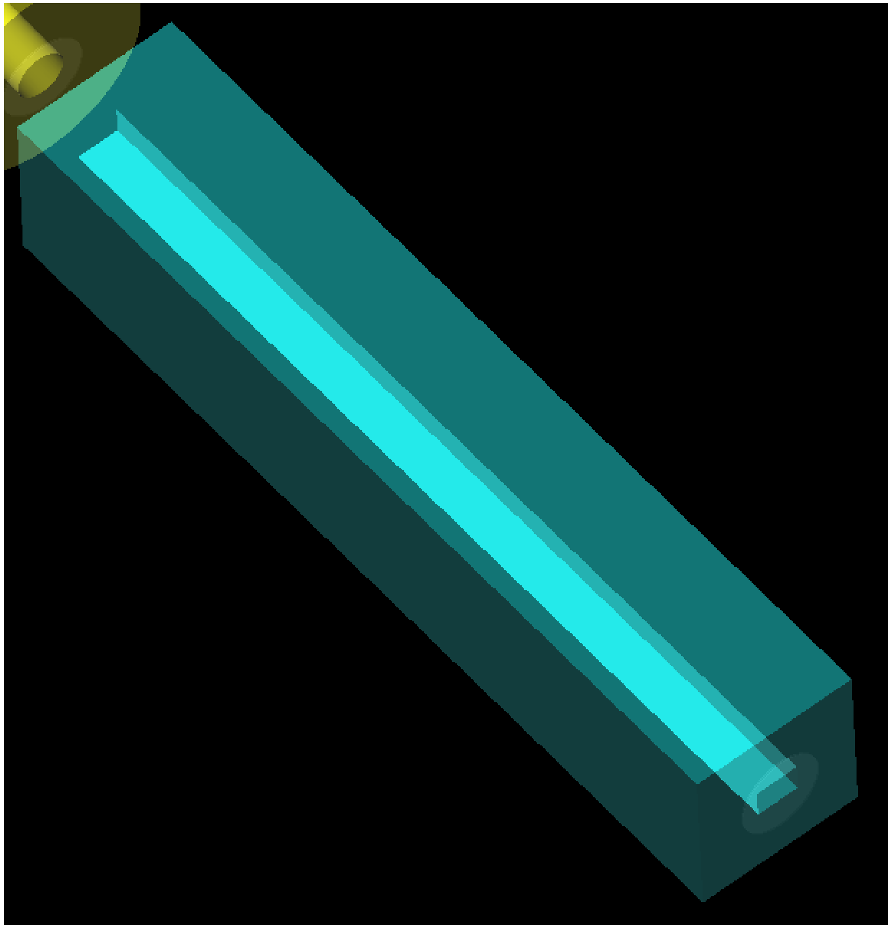
Collimator

- Solid cylinder of copper
- Shields magnet from excess energy deposition
- In simulation, kills particles on contact



Pulsed Magnet

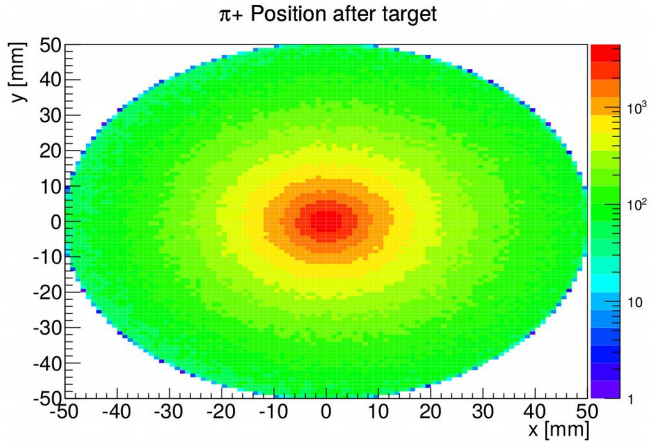
- 0.53 T vertical field bends particle paths
- Particles with momentum around 3.1 GeV/c continue to next part of beamline
- Unbent leftover protons sent to beam dump (not simulated)

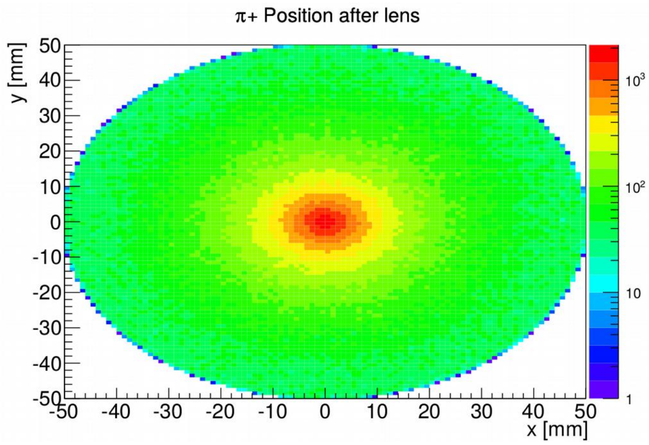


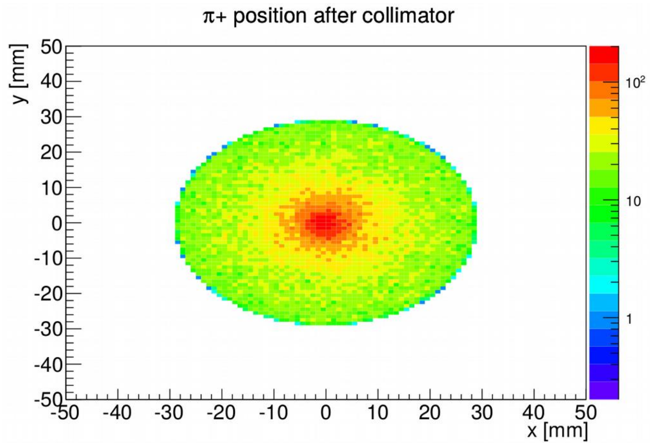
Pion Yields

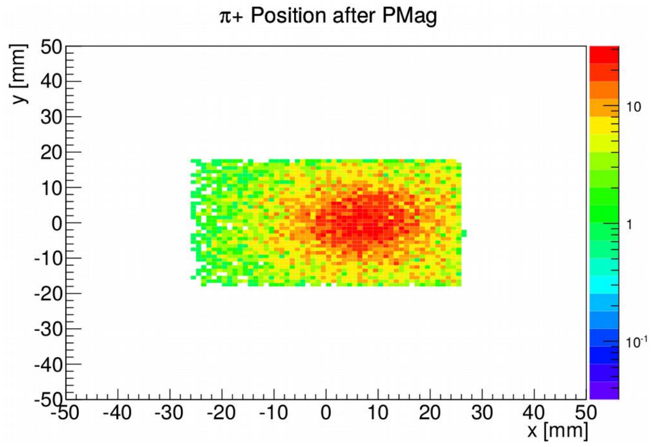
- Target – 0.2 pi+/POT
- Lens – 0.08 pi+/POT
- Collimator – 0.008 pi+/POT
- Dipole – 0.0014 pi+/POT
- About 6 x 10^{-6} pi+/POT within 2.5% of magic momentum after dipole

Pion Data - Position

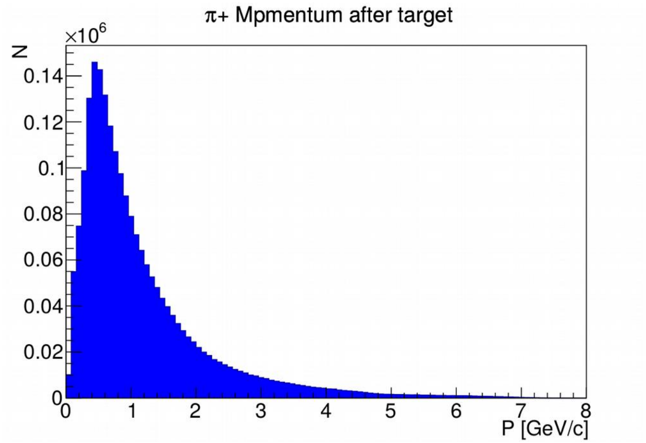


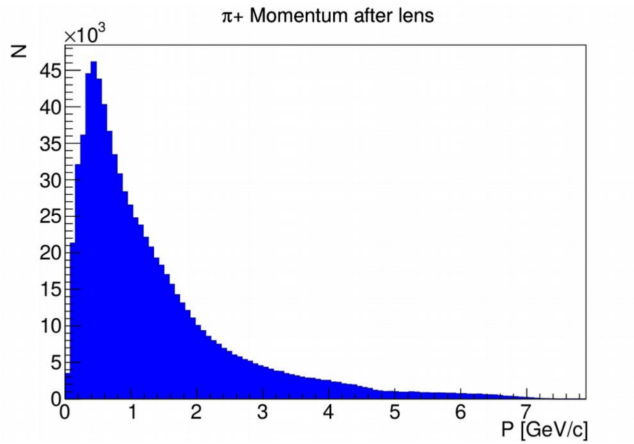


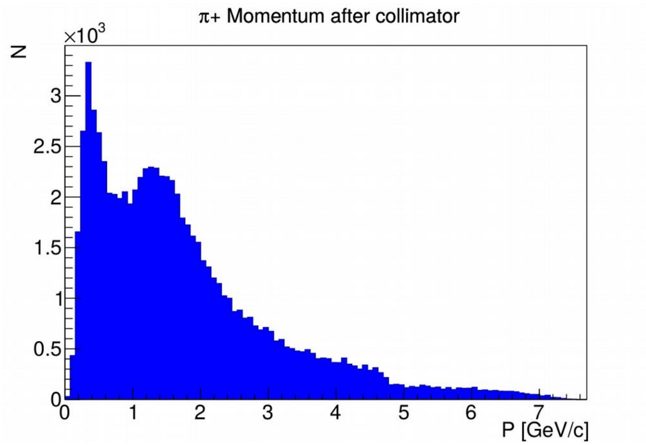


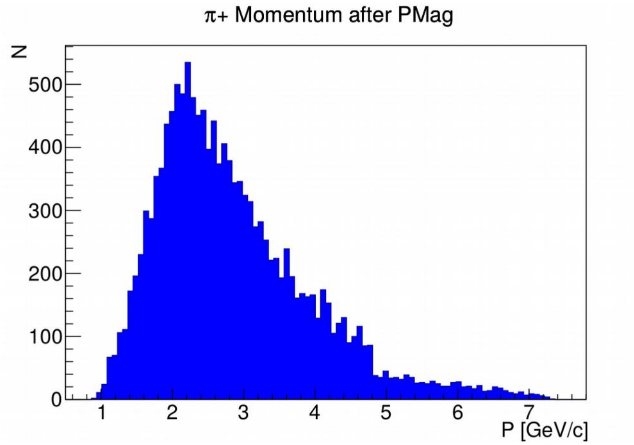


Pion Data - Momentum

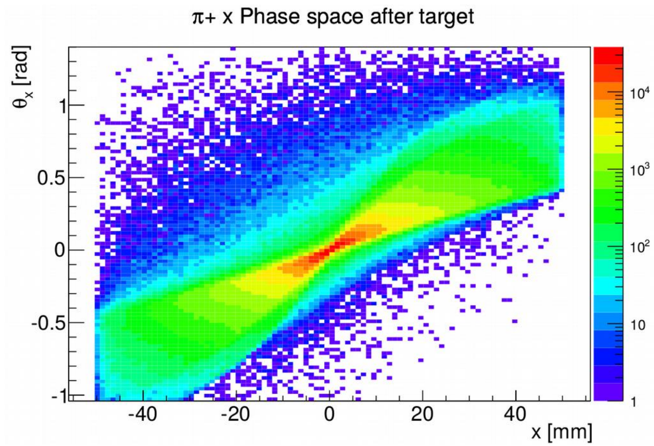


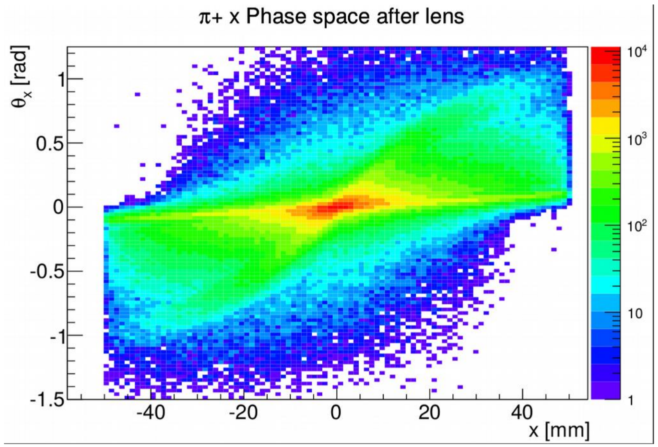


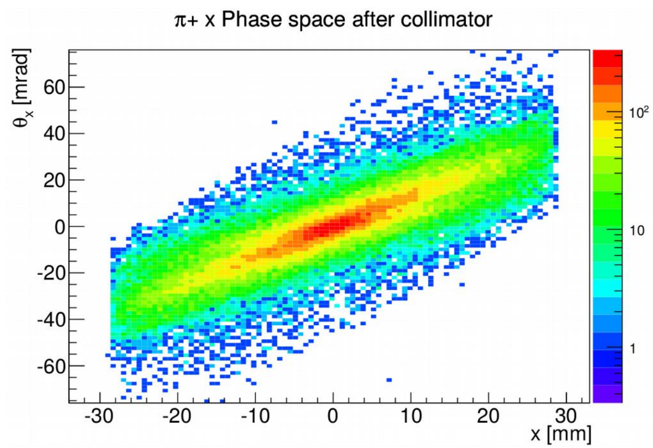


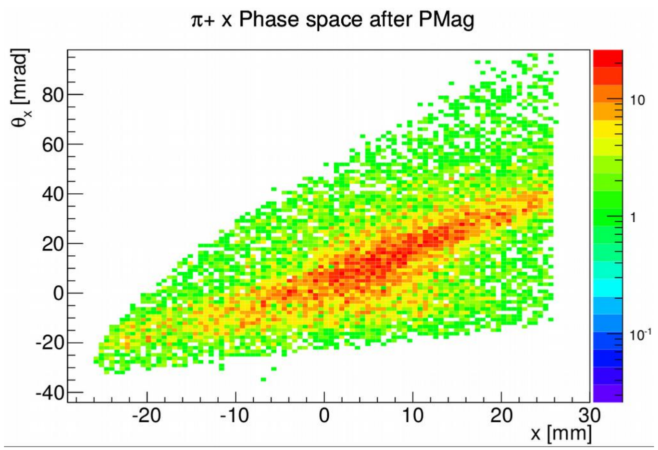


Pion Data – Phase Space

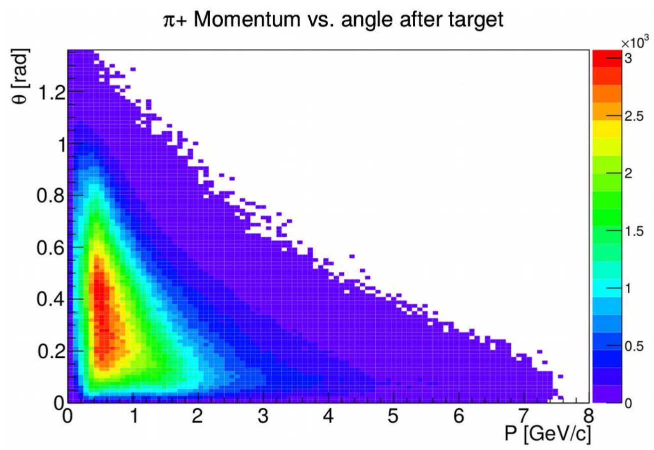


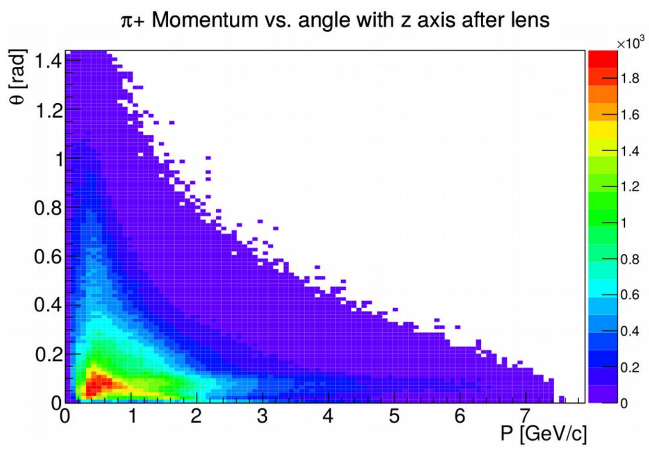


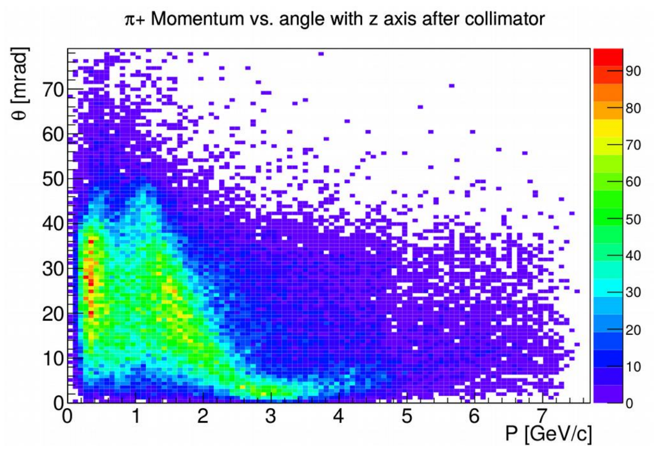


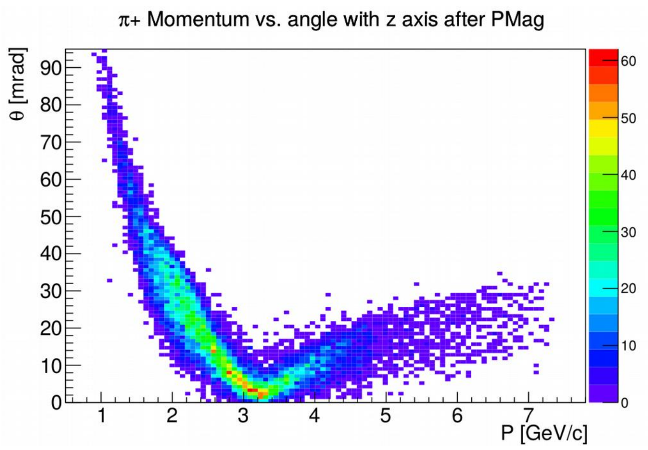


Pion Data – Momentum vs. Angle

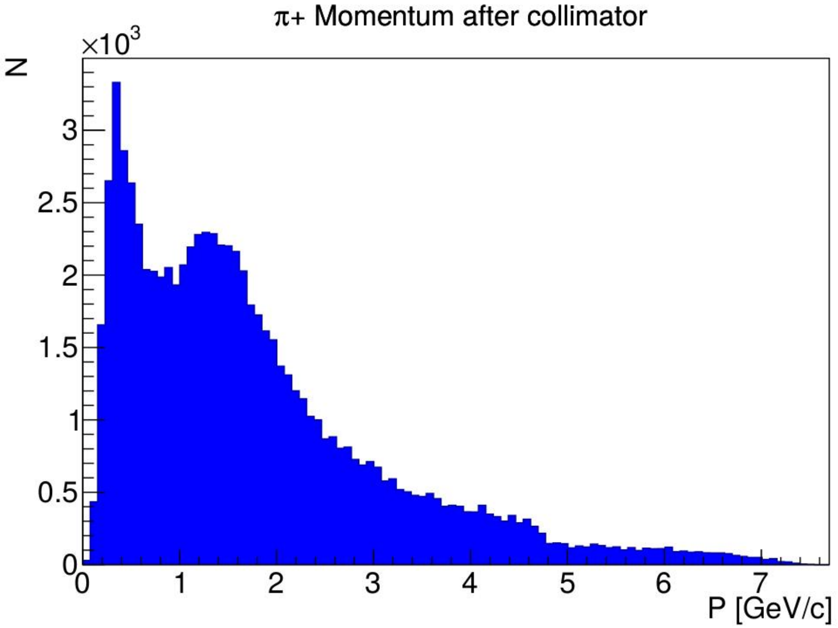


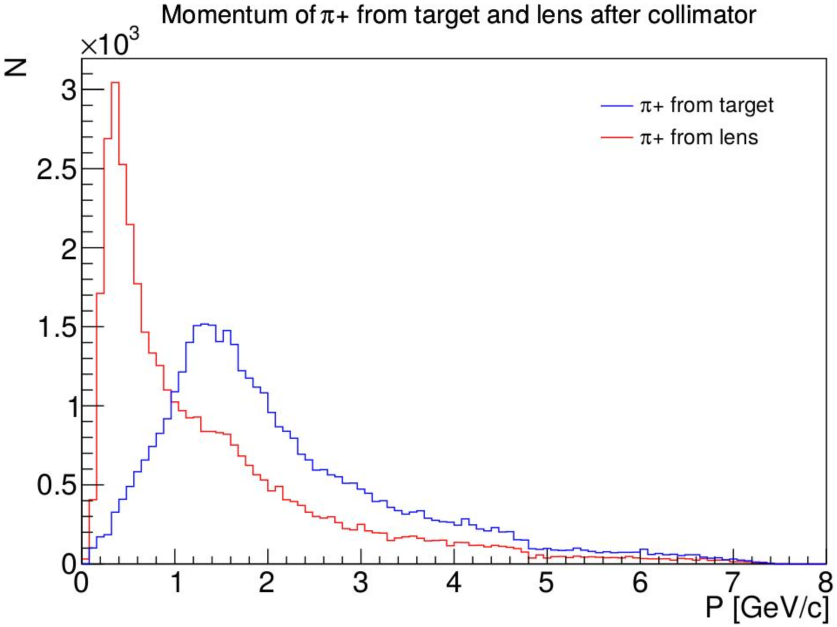




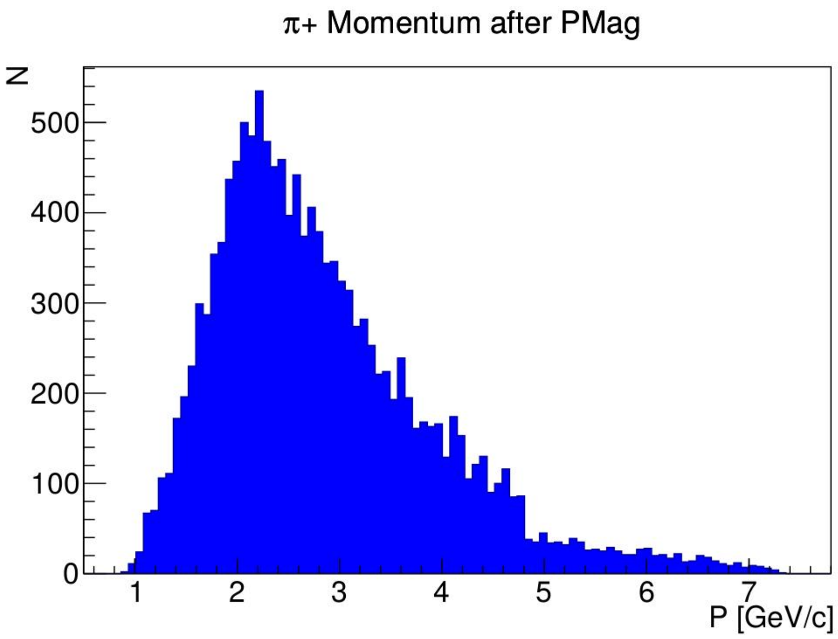


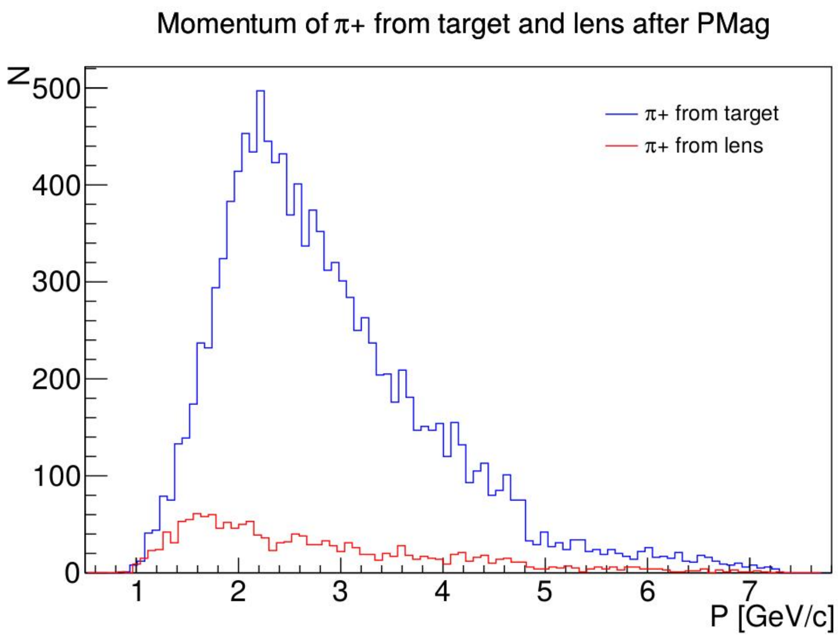
Bump in collimator data





Fate of lens pions





Results

- Pion production after lens and dipole roughly in line with previous simulations
- Lens and dipole magnet effects (focusing and momentum selection) clearly observable

Future

- Potential for optimization of component parameters using genetic algorithms
- Reconstruction of same target station geometry in MARS for direct comparison
- Streamlining of ROOT analysis scripts
- Implementation on RACF clusters for higher statistics