ND-GAr-Lite with SPY B-Field

Andrew Cudd
ND-GAr(-Lite) Meeting
2020/12/14

University of Colorado **Boulder**

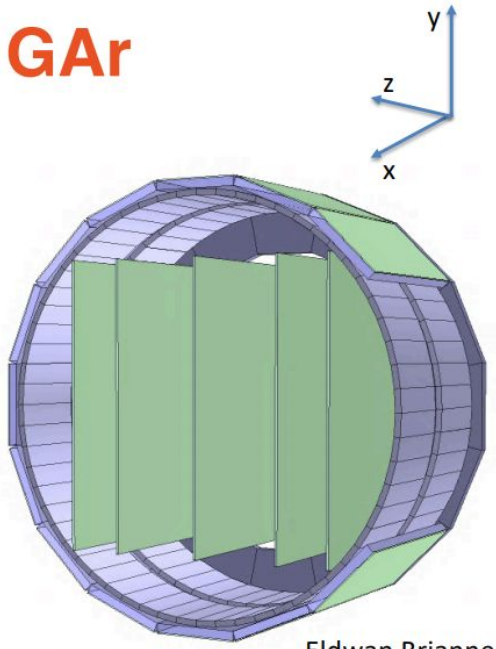
ND-GAr-Lite

ND-GAr without the GAr

The detector geometry.

SPY + Minerva-like Sc layers

- The temporary MPD (soon new name) is as the following
  - The magnet as the SPY
    - 10 cm Al solenoid
    - an iron return yoke about 30 cm thick, integrating a muon id system ➠ (3 layers 10 cm iron, 1.67 cm Sc)
    - an open window in front of the LAr
    - 7 m in diameter maximum
  - Inside, 5 scintillator layers (6 m x 5 m) of 4 cm thickness segmented Minerva-like (triangles)
    - ➠ distance between layers is to be optimised for better tracking



Almost exactly a 5x5 m^2 square in the (y,z) plane inside a 7 m diameter circle.

Eldwan Brianne

DESY. Eldwan Brianne | HPgTPC meeting | 15/06/2020

Not sure if information is still accurate.

Study Goals

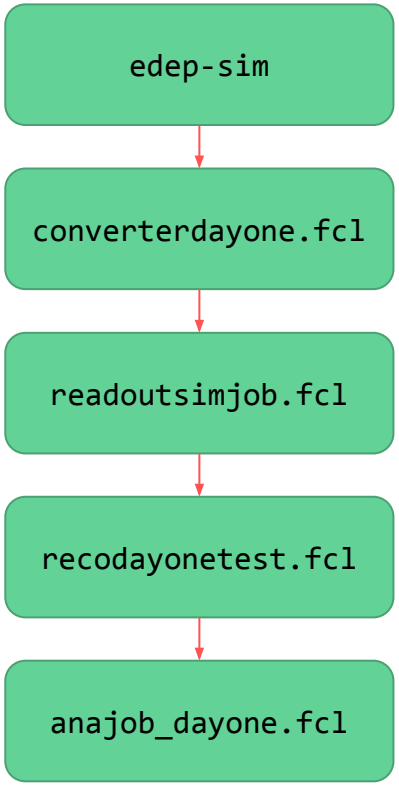
Benchmark the performance of the current ND-GAr-Lite configuration and reconstruction.

Specifically interested in the following for this presentation:

- momentum reconstruction
- charge/sign selection
- performance using a “realistic” magnetic field

Show that our five scintillator plane system is sufficient to perform as a muon spectrometer for ND-LAr.

Simulation Chain



Using a slightly customized version of edep-sim to generate events.

The resulting events are passed through the GArSoft simulation chain for ND-GAr-Lite.

Most of these .fcl files need slight tweaks to run to run with the B-field map and the ND-GAr-Lite configuration.

GArSoft also requires very slight modifications for this to run without throwing an exception (namely the anatree).

Simulation Parameters

Simulated negative muons placed just inside the cryostat before the first scintillator plane.

Initial position (where (0,0,0) is the “TPC” center):

- X = 0 +/- 20cm (uniform)
- Y = 0 +/- 20cm (uniform)
- Z = -350 +/- 0 cm

Initial direction: 30 degree cone centered on the z-axis (isotropic within cone)
Initial energy: 1000 MeV kinetic energy (1101 MeV momentum)
Geometry file: DayOne_SPY_v2_wMuID.gdml
Magnetic field: Uniform or SPY field map (with reduced grid points)

Magnetic Field

Several combinations of the magnetic field used to simulate events and the magnetic field used to reconstruct events are considered:

- Simulated uniform field, reconstructed uniform field
- Simulated SPY field, reconstructed uniform field
- Simulated SPY field, reconstructed SPY field

This gives useful metrics for a best-case scenario and something more realistic for detector performance.

It also show the importance of including the effects of the non-uniform magnetic field for the reconstruction.

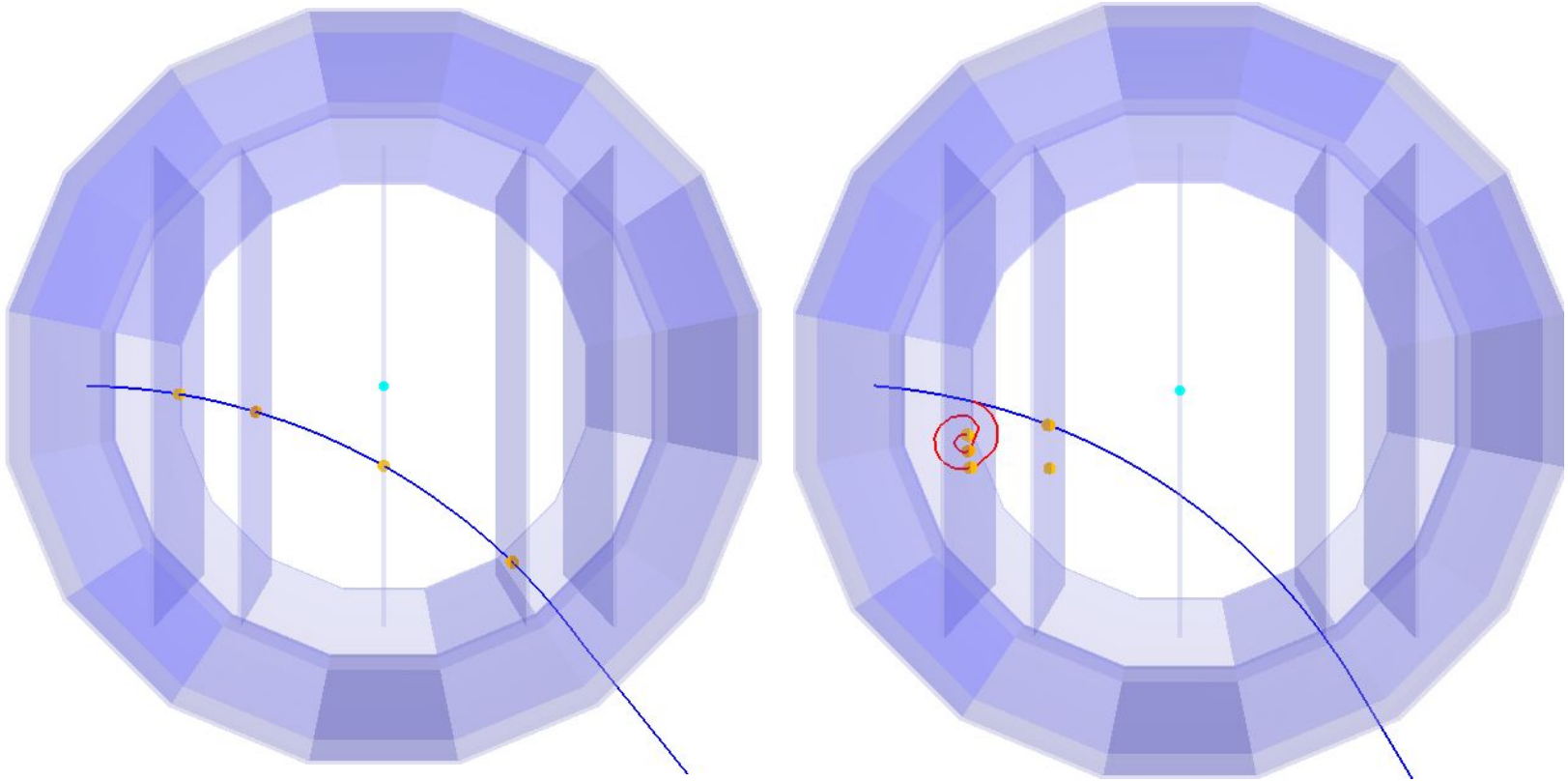
Reconstruction Refresher

- We need three hits to find a **circle** in the YZ plane.
- Find triplets of hits that have no more than one hit per station (10 cm distant in Z from other hits)
- For each triplet, make a candidate track and find all the hits that are within 5 cm of the track. Pick the closest hit to the track candidate in each plane (hits within Z of 0.5 cm of others are in the same plane)
- The triplet that has the most added hits is chosen as the best track.
- So far, only one track is found per event.

Copied from Tom Junk's slides Sept 24th, 2020 for the DUNE collaboration meeting. (Emphasis mine).

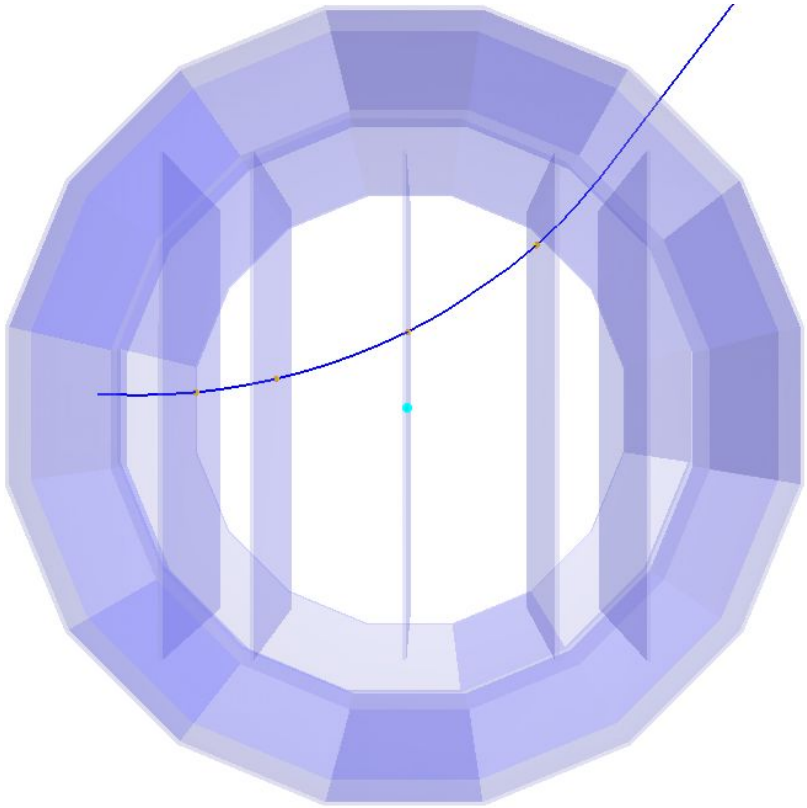
Event Displays!

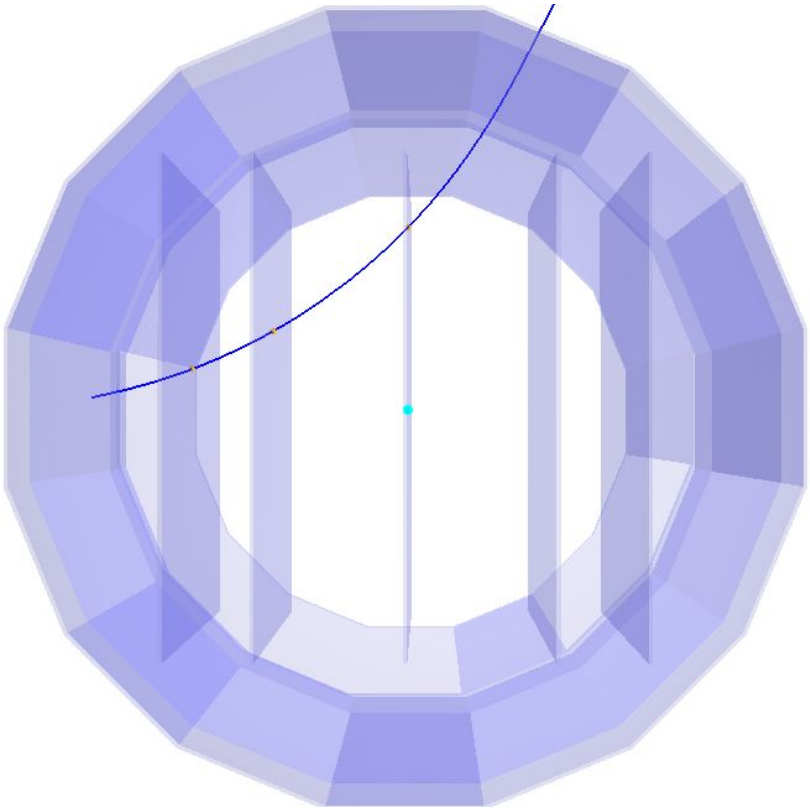
Simulated with uniform magnetic field. The right display shows an electron (red) spiraling through the scintillator.



Event Displays!

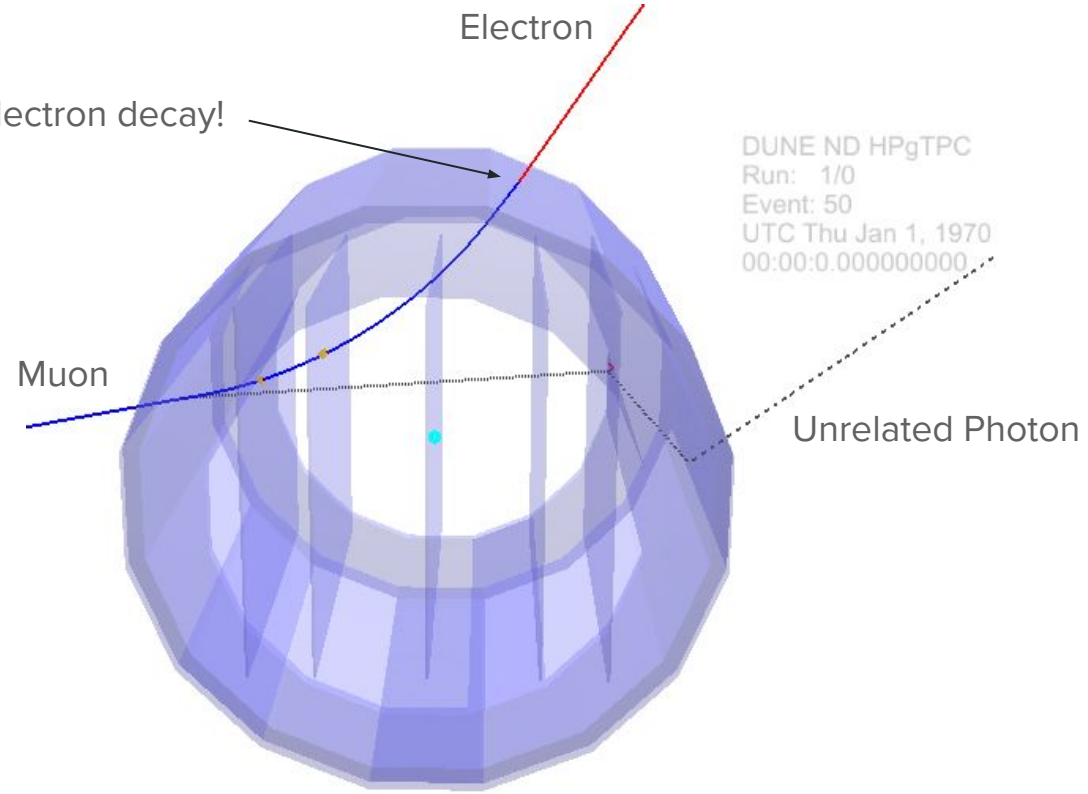
Simulated with SPY magnetic field map. Yes, these tracks now bend upward. The SPY field map is actually nominally -0.5 T in the X direction.





Fun Event Display

Event with muon to electron decay!
(or something else?)



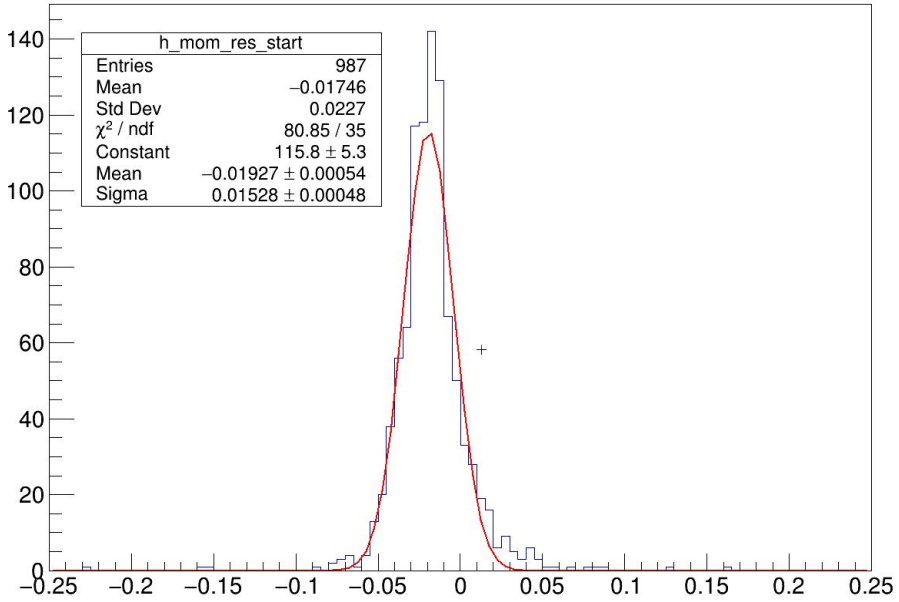
Uniform Sim & Reco

Plot on the right is Δp/p. Quoted values from Gaussian fit to distribution.

Average bias in momentum is -1.93% or about 21 MeV.

Width of the momentum distribution is 1.53%.

1000 mono-energetic events at 1.101 GeV momentum.



Δp/p = (p_reco - p_true) / p_true

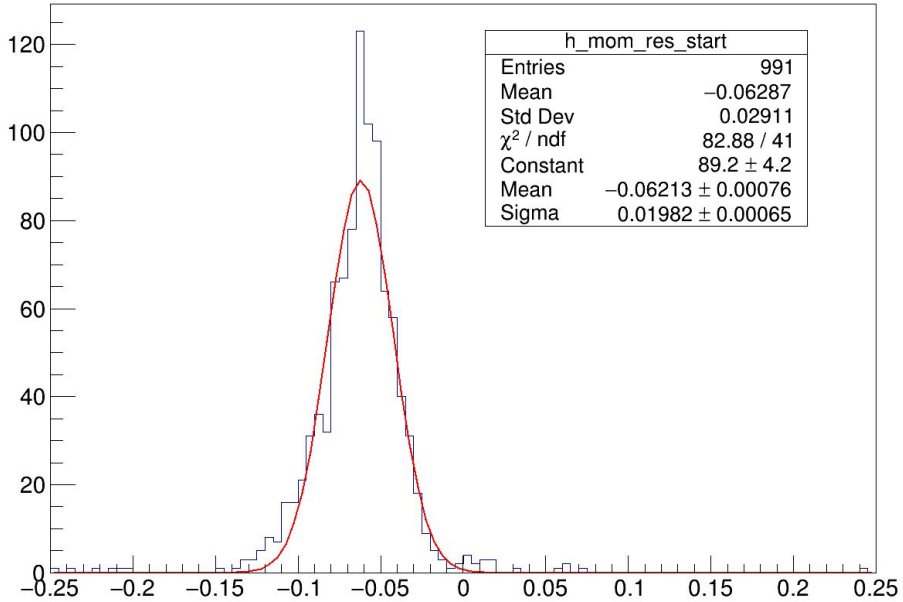
SPY Sim & Uniform Reco

Plot on the right is Δp/p. Quoted values from Gaussian fit to distribution.

Average bias in momentum is -6.21% or about 68 MeV.

Width of the momentum distribution is 1.98%.

1000 mono-energetic events at 1.101 GeV momentum.



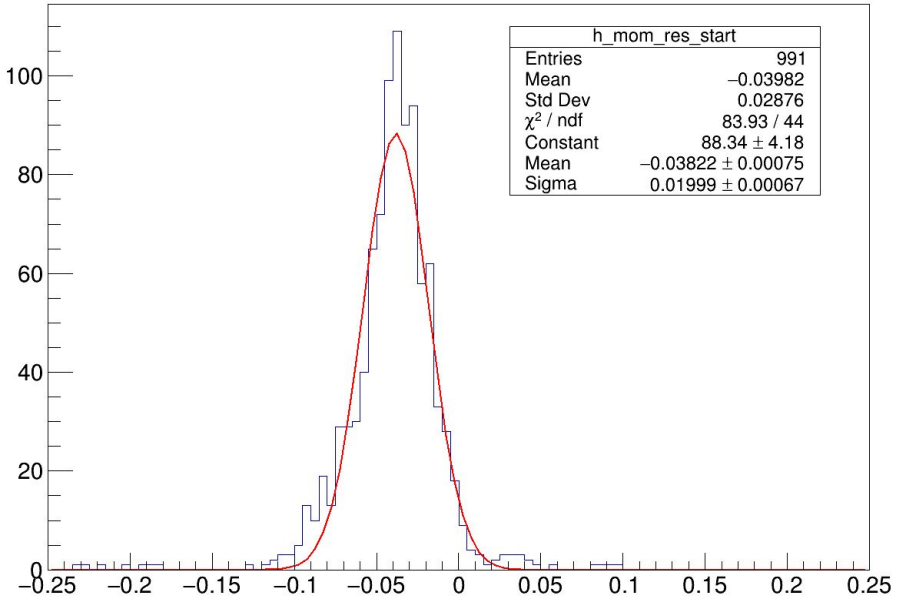
SPY Sim & Reco

Plot on the right is Δp/p. Quoted values from Gaussian fit to distribution.

Average bias in momentum is -3.82% or about 42 MeV.

Width of the momentum distribution is 2.00%.

1000 mono-energetic events at 1.101 GeV momentum.



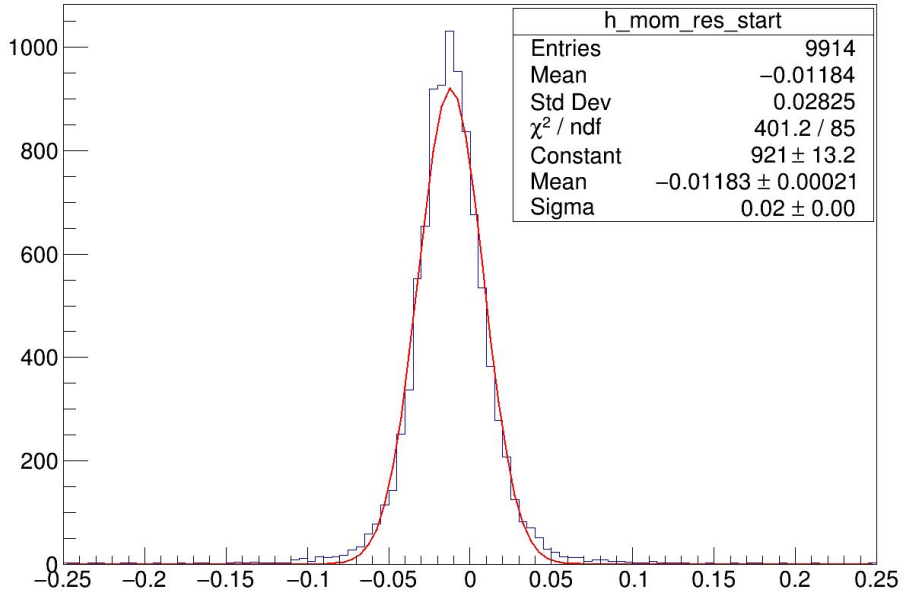
Uniform Sim & Reco

Plot on the right is Δp/p. Quoted values from Gaussian fit to distribution.

Average bias in momentum is -1.18%.

Width of the momentum distribution is 2.00%.

10000 events with a uniform distribution of 500 - 4000 MeV KE.



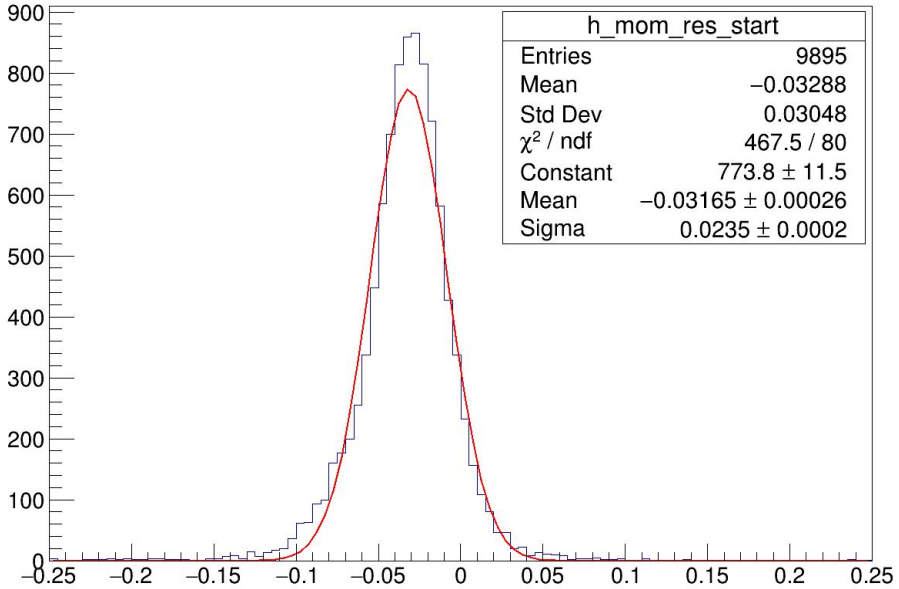
SPY Sim & Reco

Plot on the right is Δp/p. Quoted values from Gaussian fit to distribution.

Average bias in momentum is -3.17%.

Width of the momentum distribution is 2.35%. Visibly skewed / asymmetric distribution.

10000 events with a uniform distribution of 500 - 4000 MeV KE.



Muon Sign Selection

Using the sample of 10000 negative muons with KE of 500 to 4000 the sign selection purity is:

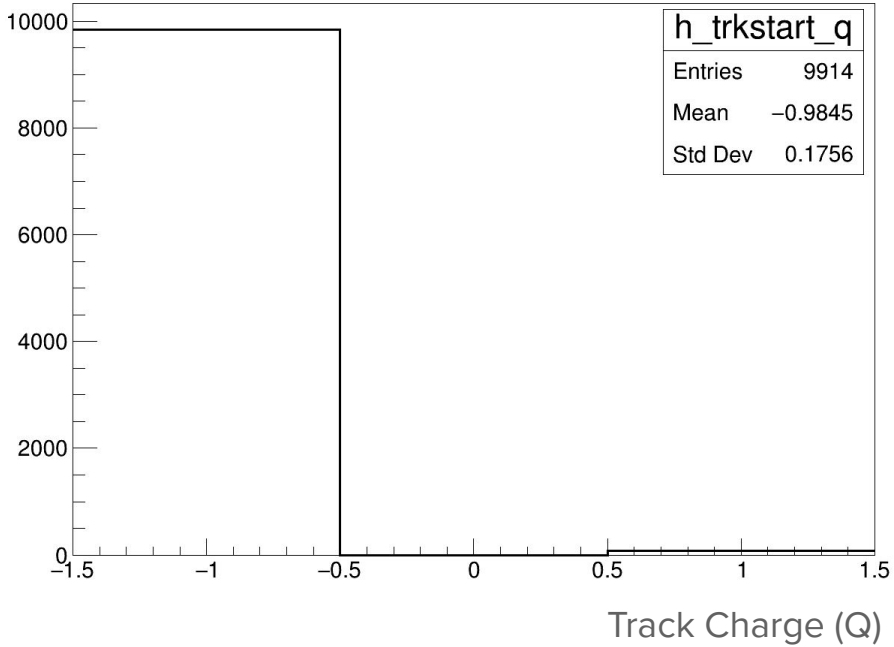
Uniform sim & reco:

- StartQ : 9837/9914 = 99.22%
- EndQ : 9804/9914 = 98.89%

SPY sim & reco:

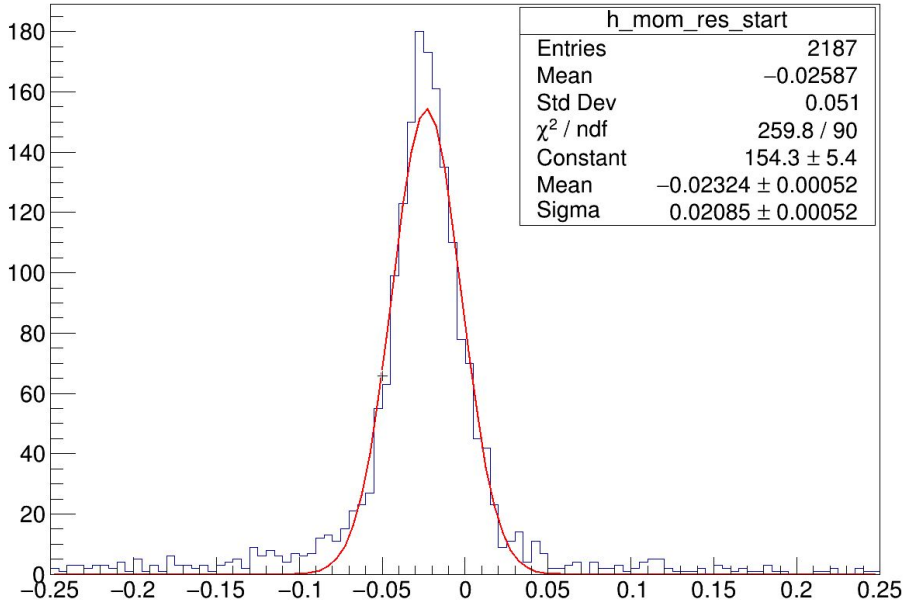
- StartQ : 9802/9895 = 99.06%
- EndQ : 9773/9895 = 98.77%

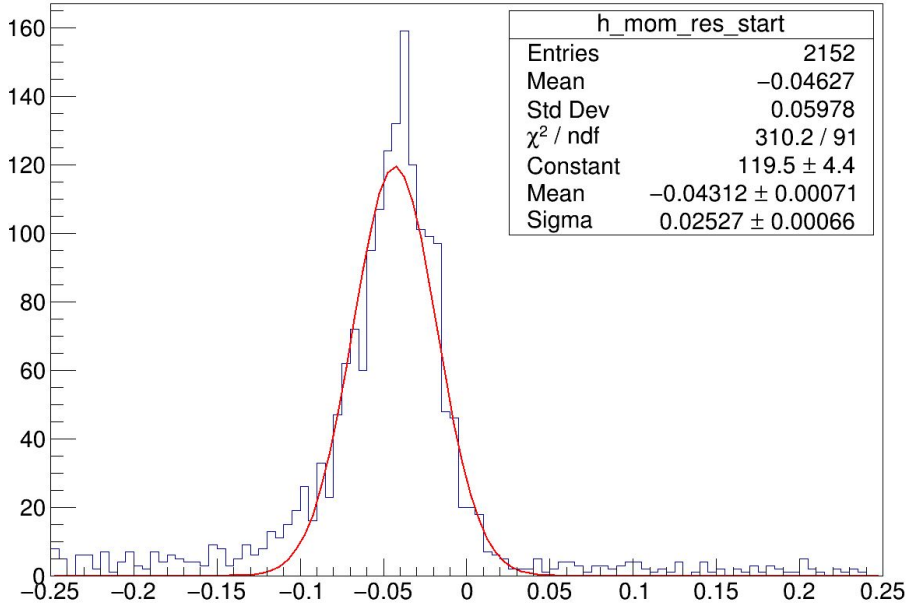
Uniform sim & reconstruction



Low Energy Sample

Δp/p = (p_reco - p_true) / p_true

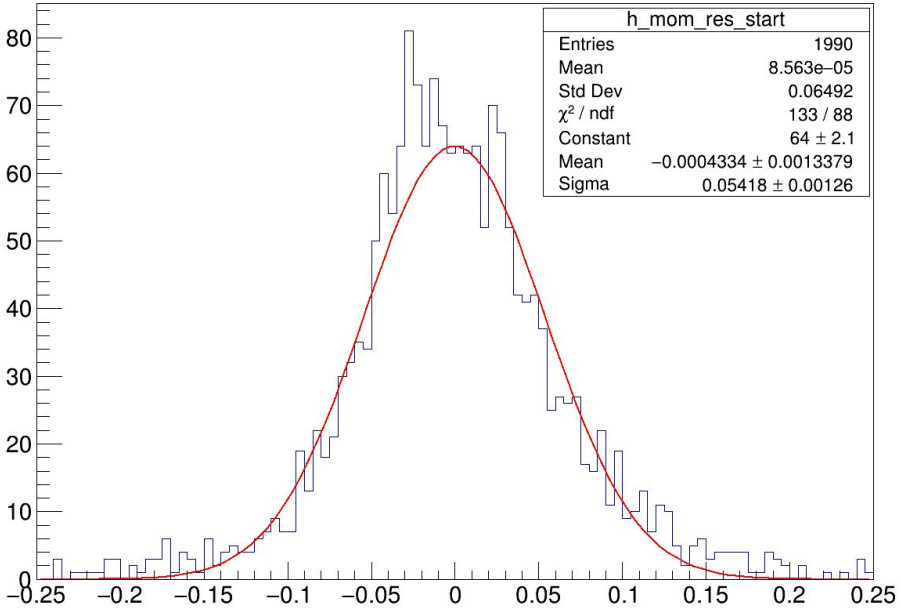


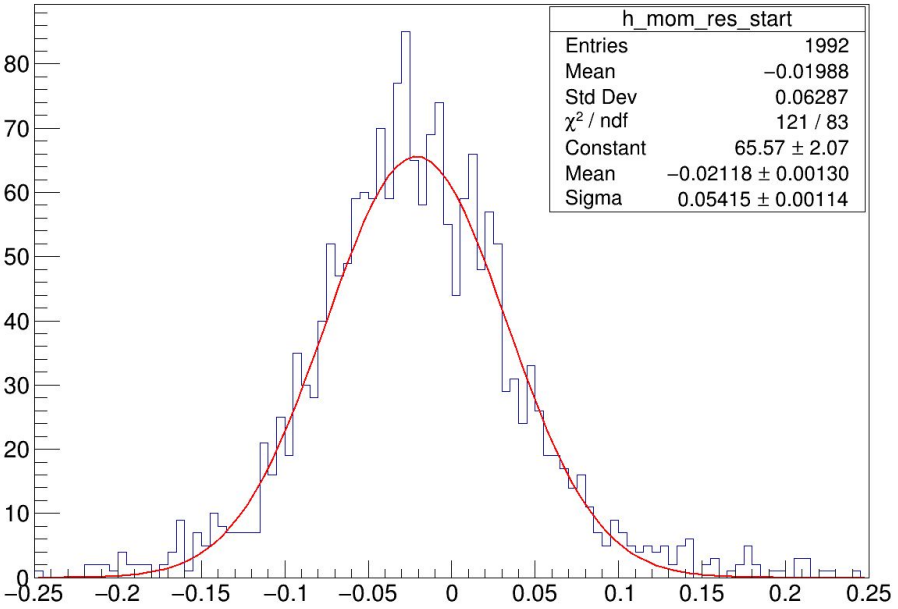


- Sample of 2500 negative muons with 200 - 1000 MeV KE (about 287 - 1101 MeV momentum).
- Uniform sim/reco on the left, SPY sim/reco on the right.
- Larger bias, similar or larger resolution, but sizable fraction of events in tails of distribution
- Efficiency starts to drop off (86%); sign selection also lower (96%)

High Energy Sample

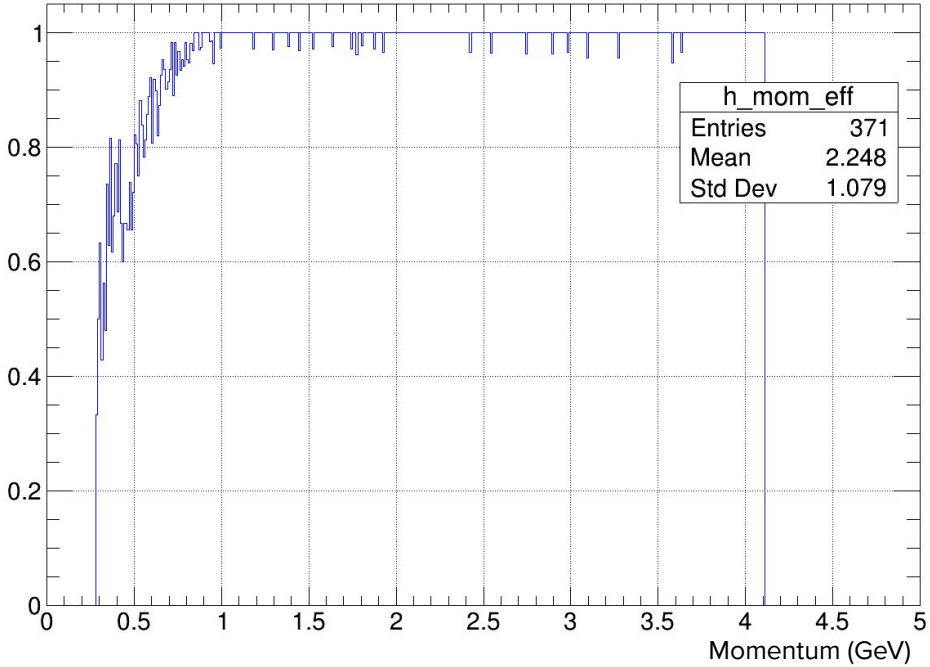
Δp/p = (p_reco - p_true) / p_true

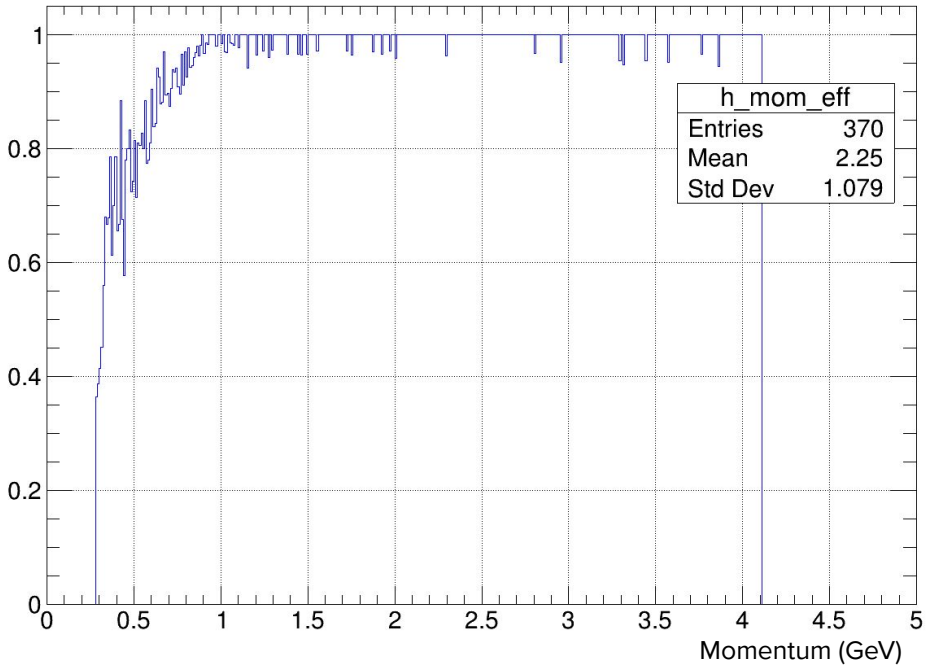




- Sample of 2000 mono-energetic negative muons with 10 GeV KE (about 10.1 GeV momentum).
- Uniform sim/reco on the left, SPY sim/reco on the right.
- Mean moves closer to zero bias, but the width is larger.
- Efficiency and sign selection are still around 98% or higher.

Efficiency vs. Momentum

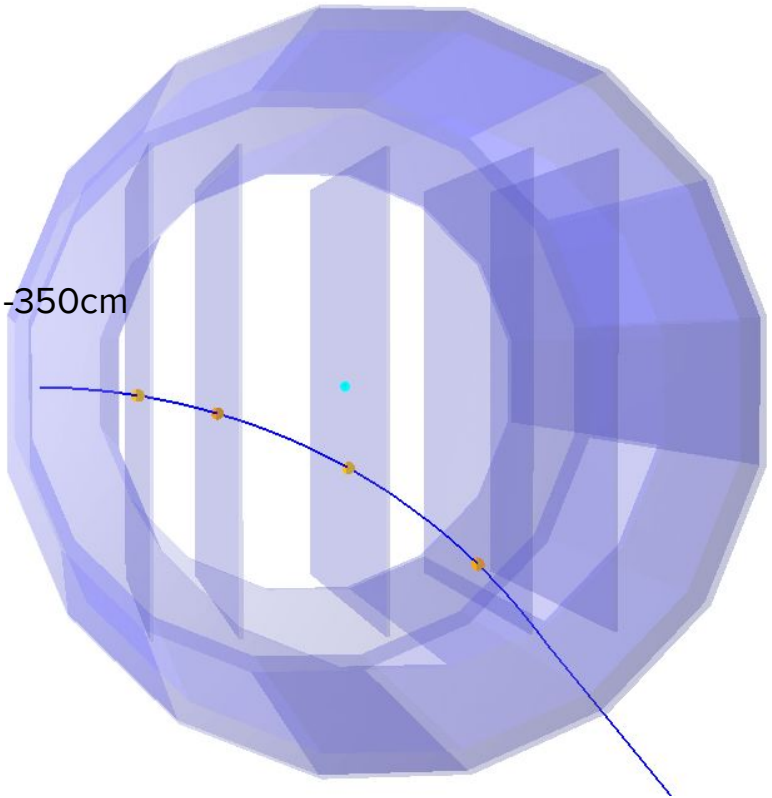




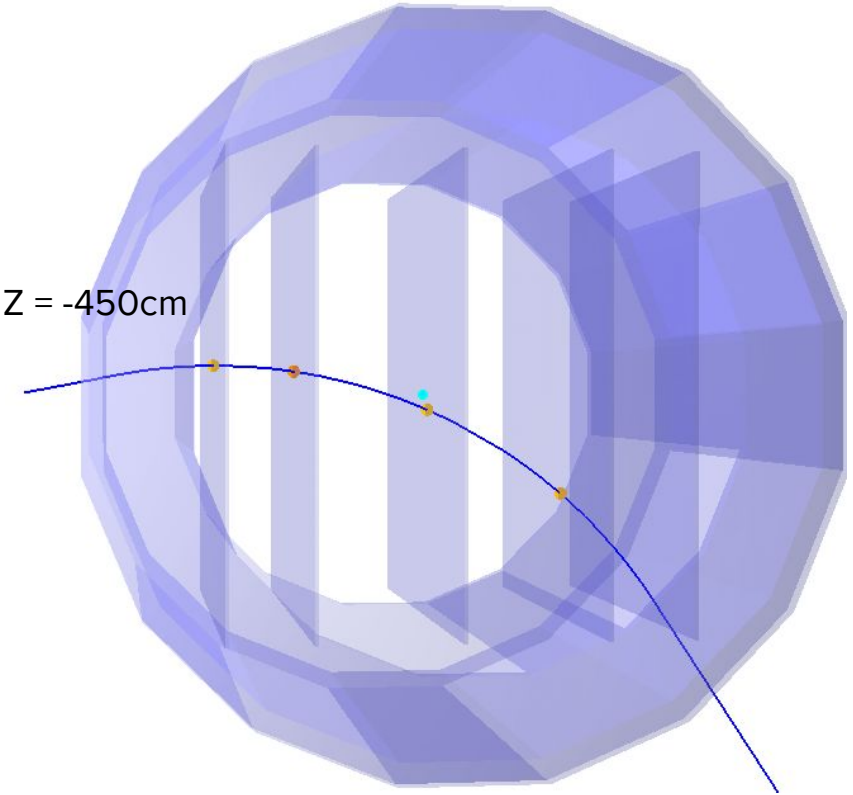
- 12500 negative muon events (mostly) uniform from 287 - 4100 MeV momentum (200 - 4000 MeV KE)
- Uniform sim/reco on the left, SPY sim/reco on the right.
- Efficiency starts to drop around 800 to 900 MeV in momentum

“Inside” vs “Outside” Muons

Z = -350cm



Z = -450cm



Outside Muons

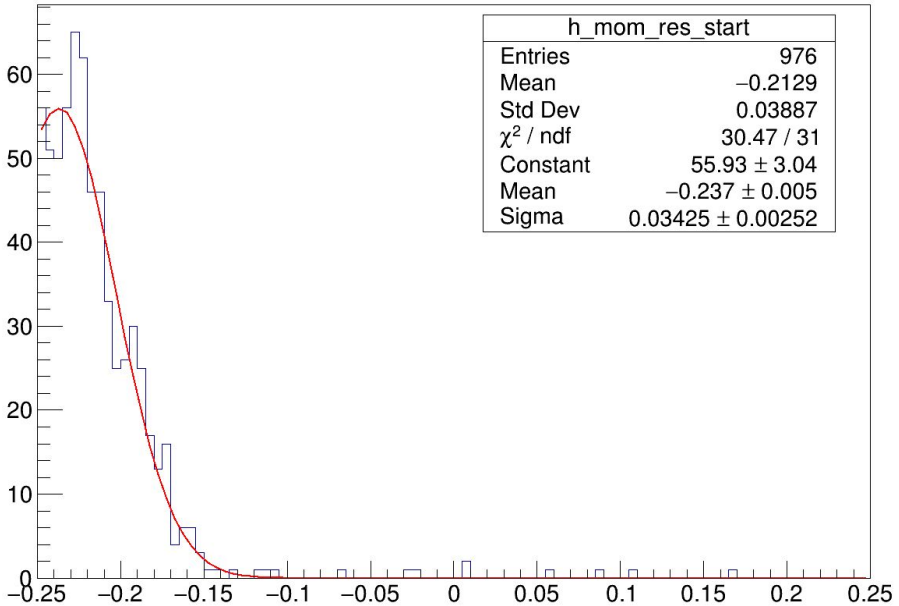
If muons are generated outside the cryostat (z = -450cm), a large momentum bias is seen.

Average bias is -23.7% or 261 MeV for 1.101 GeV momentum muons.

Width of momentum distribution is 3.43%.

Should the cryostat cause this much energy loss?

Uniform sim & reconstruction



Δp/p for 1.101 GeV mono-energetic muons

Outside Muons -- High Energy Version

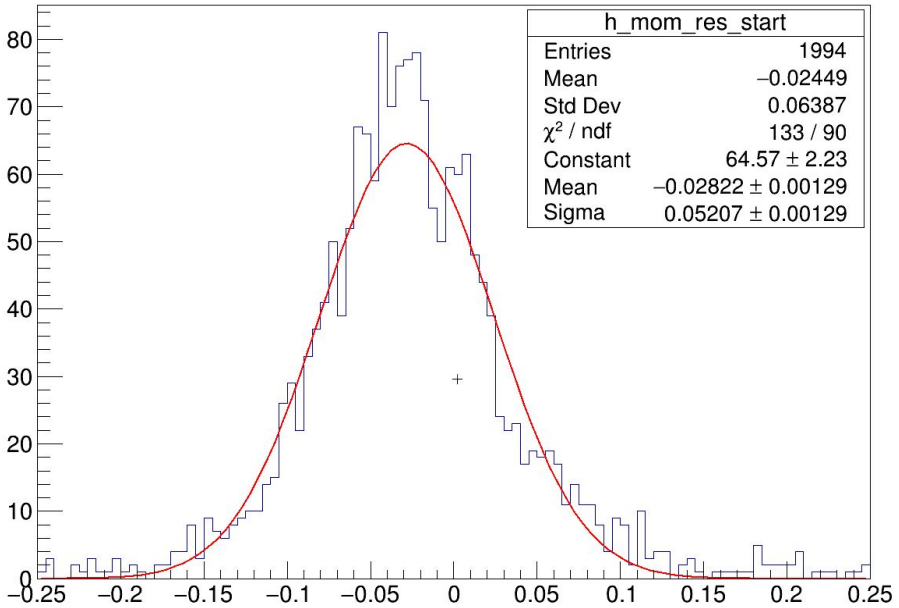
If muons are generated outside the cryostat (z = -450cm), a large momentum bias is seen.

Average bias is -2.8% or 285 MeV for 10.101 GeV momentum muons.

Width of momentum distribution is 5.21%.

Should the cryostat cause this much energy loss?

Uniform sim & reconstruction



Δp/p for 10.101 GeV mono-energetic muons

Summary

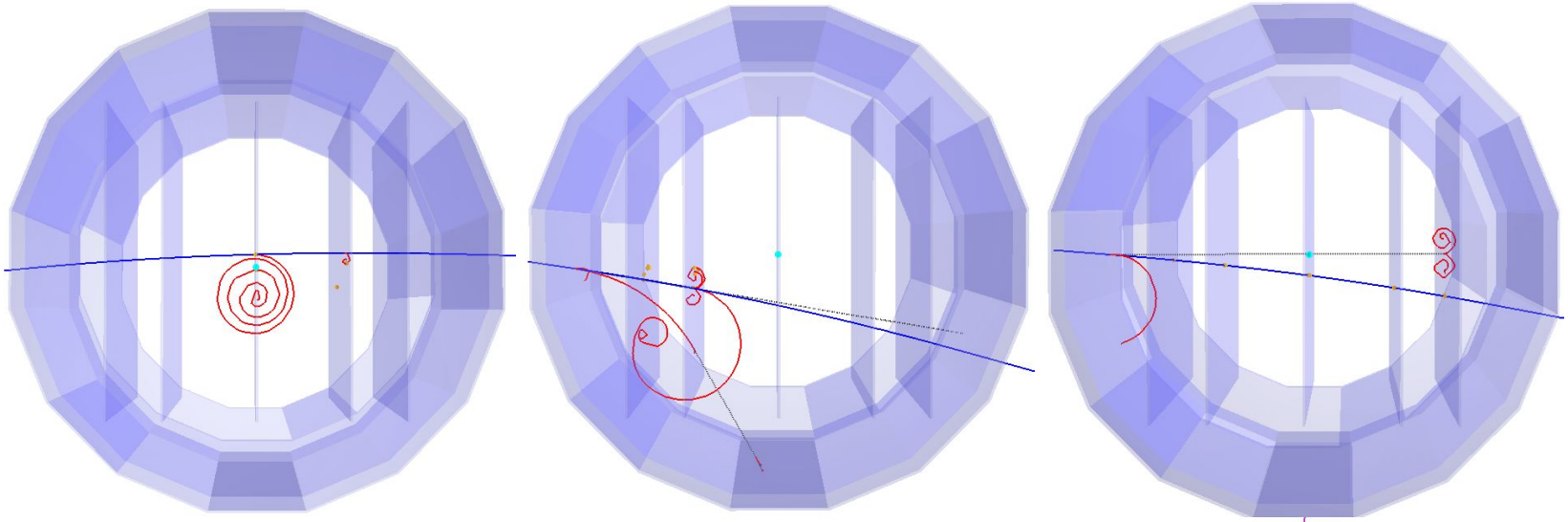
Noticeable effect of using the SPY field map versus the uniform magnetic field.

More or less as expected the momentum reconstruction is slightly worse with the non-uniform field.

Very high efficiency for finding tracks and purity of sign selection, 98+% in most cases. Low energy muons (less than 0.8 GeV) start to drop off in efficiency.

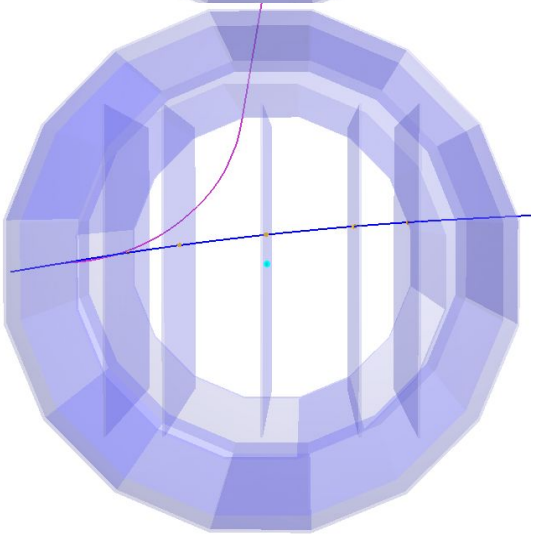
However these numbers represent a very optimistic case for the reconstruction. Need to try with a more realistic muon sample (particularly the incoming direction).

Overall the current state of the ND-GAr-Lite design and simulation is performing quite well.



Trajectories:

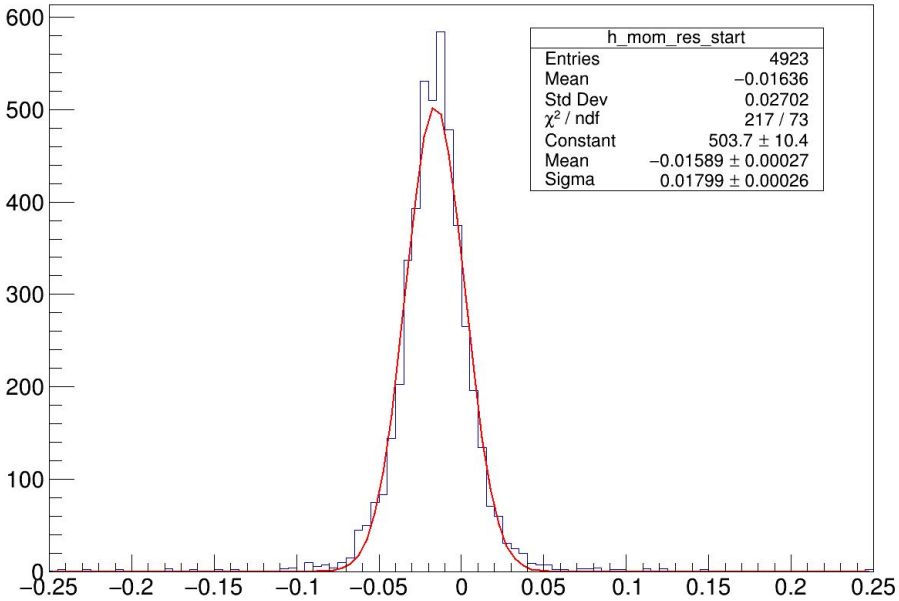
- Blue: muon
- Red: electron
- Purple: pion
- Black/Dashed: photon

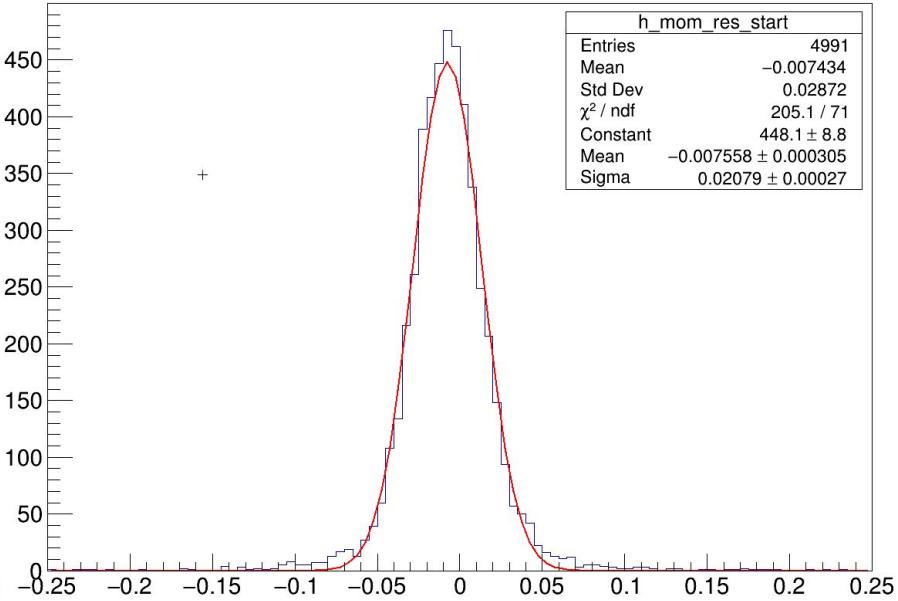


Bonus Displays! 10 GeV KE muons.

Backup Slides

Uniform Sim & Reco



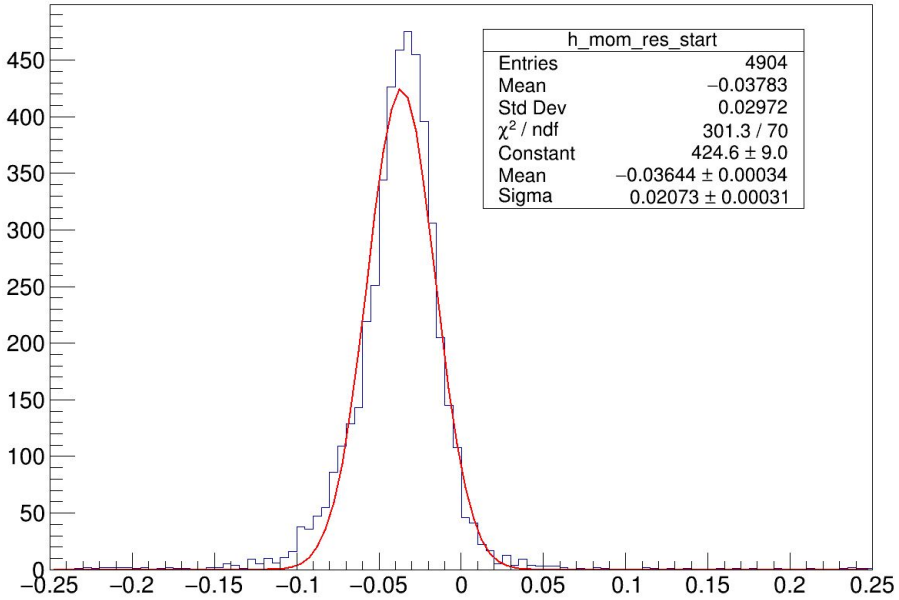


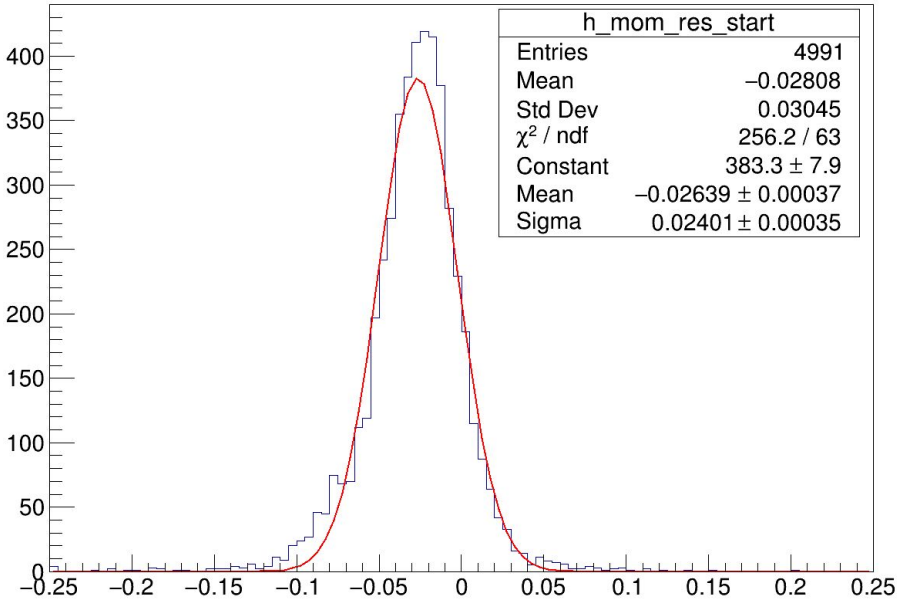
Plots are momentum resolution on the x-axis: Δp/p.

Left plot: 5000 negative muons with 500 - 2000 MeV KE, uniformly distributed

Right plot: 5000 negative muons with 2000 - 4000 MeV KE, uniformly distributed

SPY Sim & Reco





Plots are momentum resolution on the x-axis: Δp/p.

Left plot: 5000 negative muons with 500 - 2000 MeV KE, uniformly distributed

Right plot: 5000 negative muons with 2000 - 4000 MeV KE, uniformly distributed