Muon Beam Dynamics in HFOFO Cooling Channel

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USMCC

Recap

	Reference particle	Beam, no stochastics	Beam, with stochastics	Reference, with stochastic	Bethe-bloch
2.5 mm carbon absorber "tube" 200 MeV muon	3.24	3.24	3.27	To be implemented within G4beamline	3.29
2.5 mm carbon absorber "square" 200 MeV muon	3.24	3.24	3.27		3.29
LiH wedge absorber HFOFO 200 MeV muon	1.72	1.72	1.73		1.73

Today's focus

- Implementation in G4beamline
- Comparison of results using default and the modified versions [Col 1,2,3]

Implementation

- Reference particle states are extended to include *realistic-reference* and realistic-tune particles (stochastics enabled) with different eventIDs

```
printf("================= Prepare Realistic Tune Particle(s) with Stochastics turned ON=
    physics->setDoStochastics(FORCE_ON,0);
    runManager->Initialize();


printf("================= Begin Realistic Tune Particle(s) =============\n");
    state = REALISTICTUNE;
    setEventID(-4);
    beamIndex = 0;
    runManager->BeamOn(referenceVector.size());
    state = IDLE;

    // now track center particle
    printf("================= Begin Realistic Reference Particle(s) ==============\n")
    state = REALISTICREFERENCE;
    setEventID(-3);
beamIndex = 0;
    runManager->BeamOn(referenceVector.size());
    state = IDLE;
    beamIndex = 0;
```

Output trace file

```
# Event -2 Track 1
0 0 0 0 0 200 0 -13
```

Tune

```
# Event -1 Track 1
0 0 0 0 0 200 0 -13
```

Reference

```
# Event -4 Track 1
0 0 0 0 0 200 0 -13
```

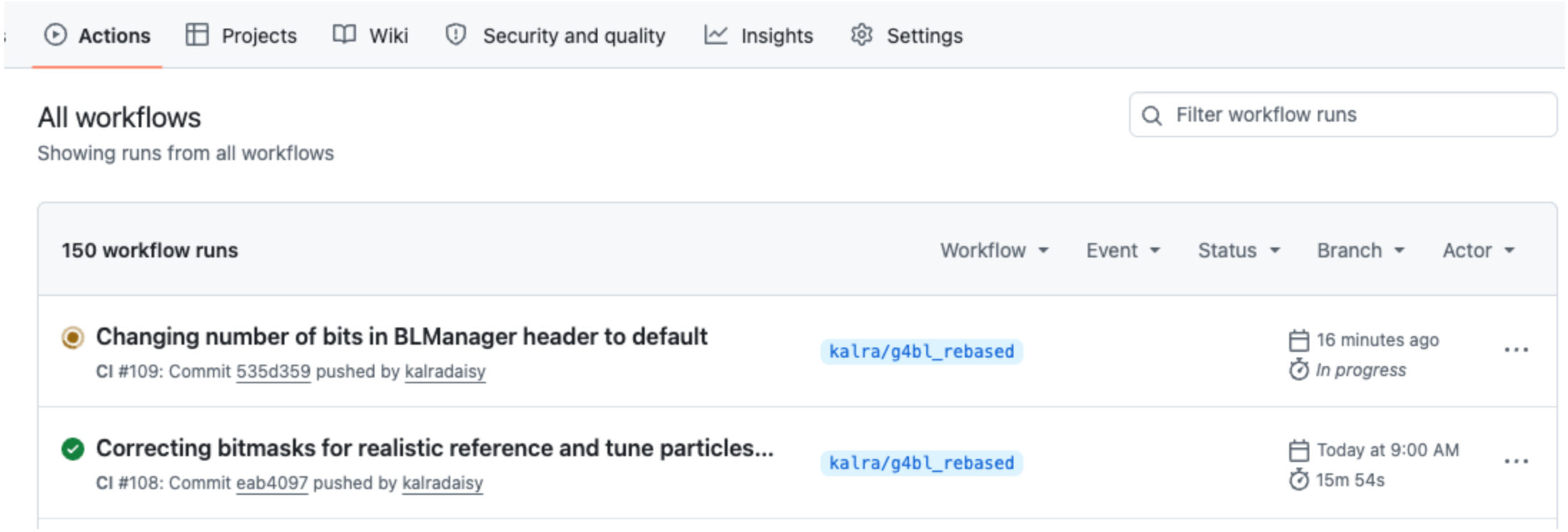
Tune with stochastics NO

```
# Event -3 Track 1
0 0 0 0 0 200 0 -13
```

Reference with stochastics ON

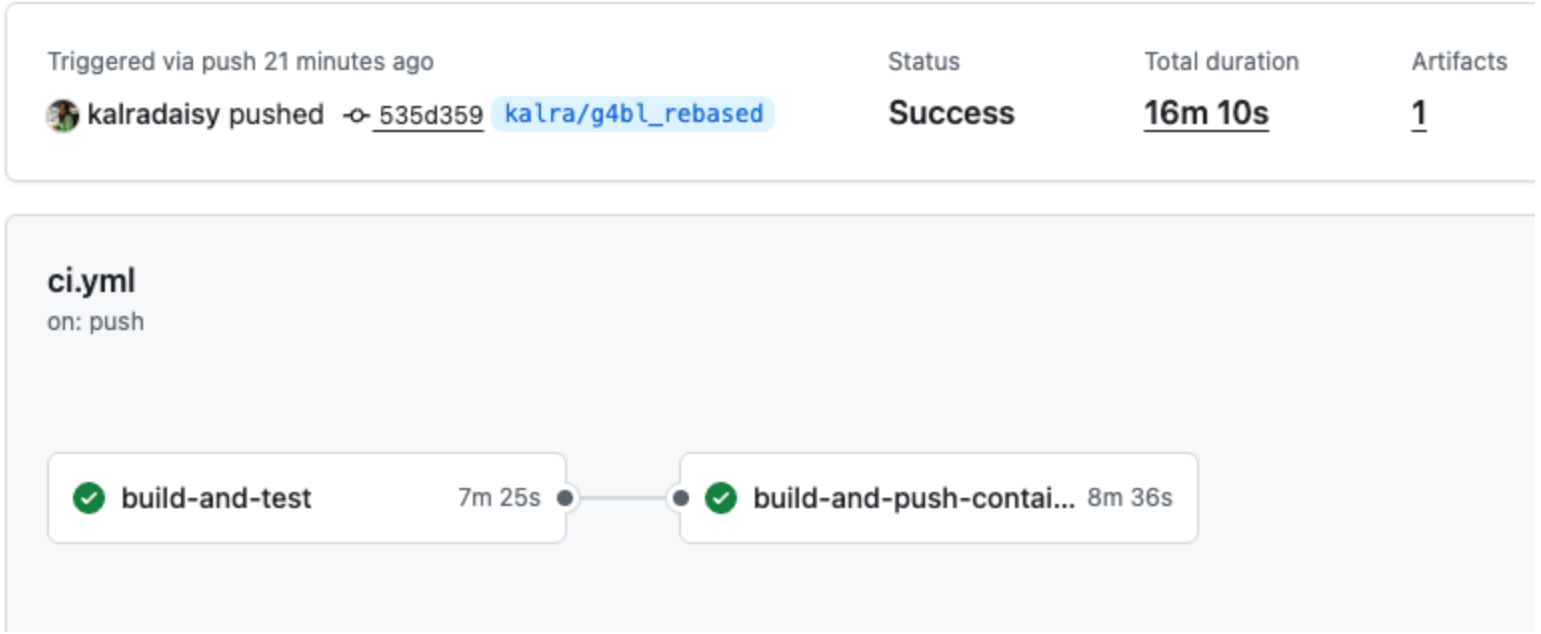
Implementation

- GitHub https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl_rebased
- Make changes locally, push it to Git, trigger build workflow, docker image (Credit: Larry Lee)



Implementation

- GitHub https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl_rebased
- Make changes locally, push it to Git, trigger build workflow, docker image (Credit: Larry Lee)



Implementation

- GitHub https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl_rebased
- Make changes locally, push it to Git, trigger build workflow, docker image (Credit: Larry Lee)
- ***docker pull ghcr.io/lawrenceleejr/g4beamline:kalra-g4bl_rebased***
- ***docker run –it –em –env-file EnvFile –v $(pwd):/work ghcr.io/lawrenceleejr/g4beamline:kalra-g4bl_rebased bash***
- ***/opt/g4beamline/build/bin/g4bl EnergyLoss.in***

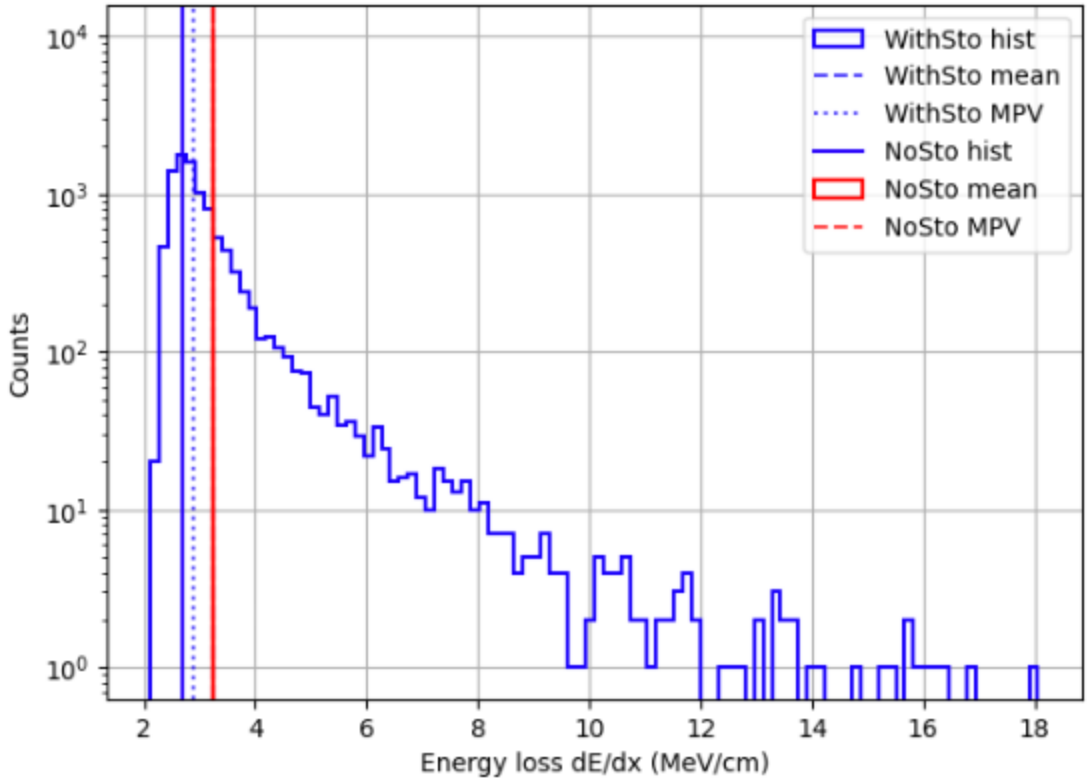
Comparison

- Compare the energy loss for beam and reference particles (no stochastics) using different absorbers with default G4beamline and modified G4beamline

Comparison – beam particle – carbon absorber

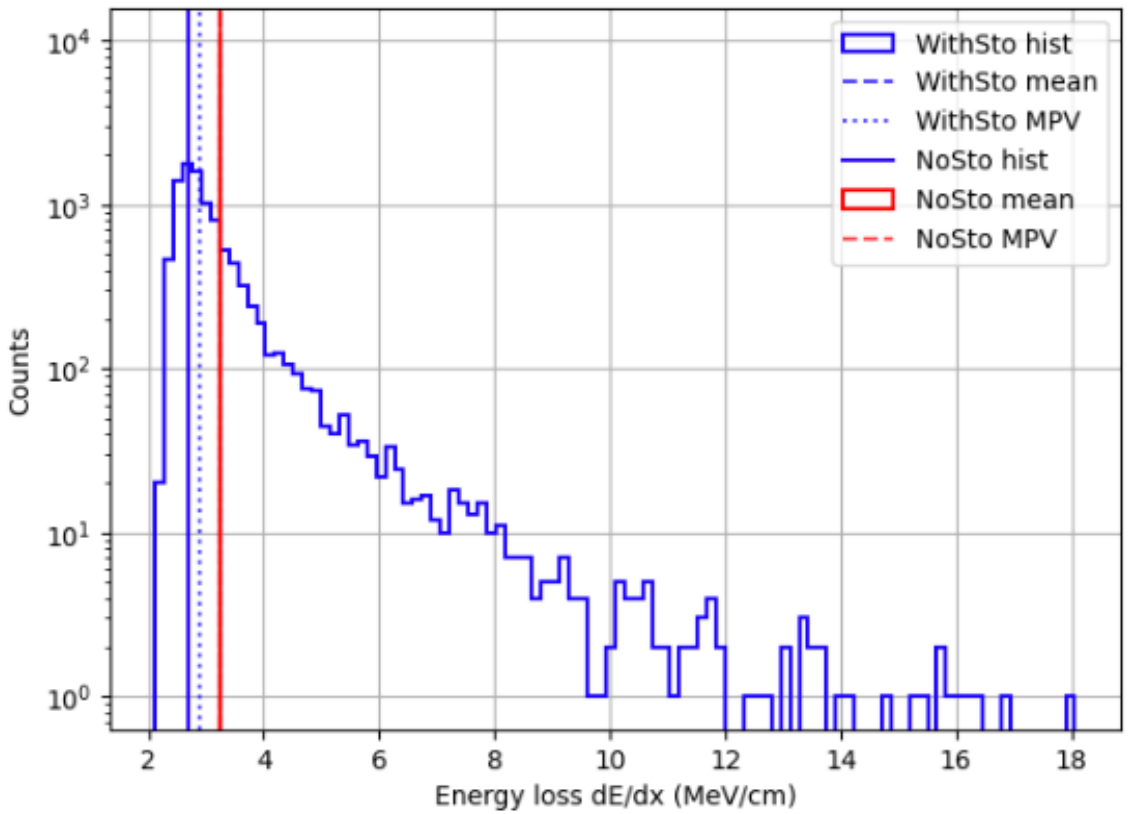
default

```
===== WithSto =====
Entries: 9994
Mean dE/dx    = 3.249 MeV/cm
Median dE/dx = 2.887 MeV/cm
MPV dE/dx     = 2.680 MeV/cm

===== NoSto =====
Entries: 10000
Mean dE/dx    = 3.242 MeV/cm
Median dE/dx = 3.242 MeV/cm
MPV dE/dx     = 3.247 MeV/cm
```



modified

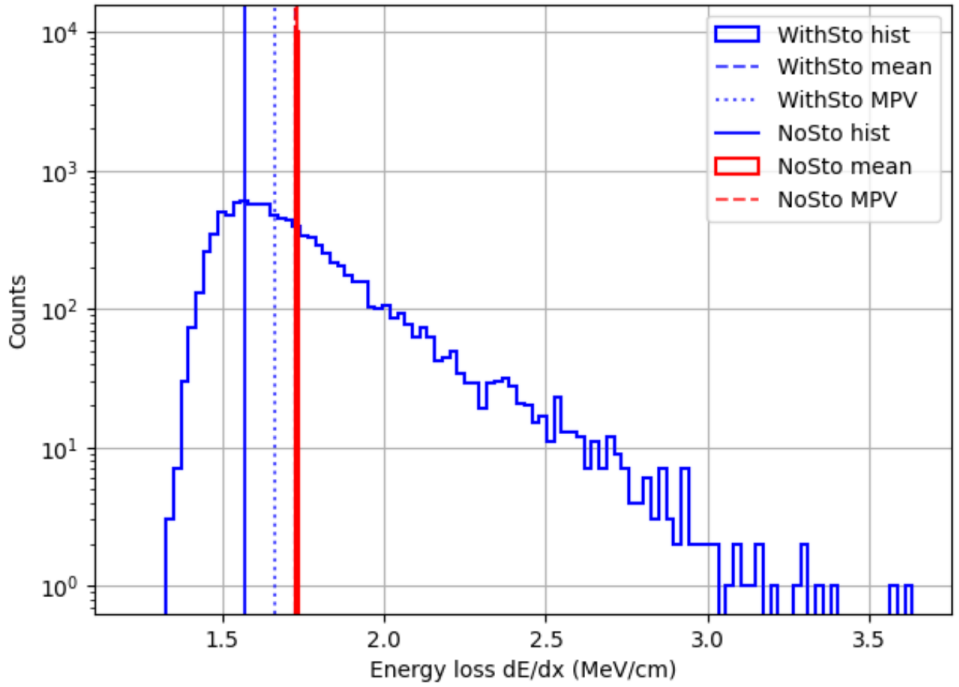
```
===== WithSto =====
Entries: 9994
Mean dE/dx    = 3.249 MeV/cm
Median dE/dx = 2.887 MeV/cm
MPV dE/dx     = 2.680 MeV/cm

===== NoSto =====
Entries: 10000
Mean dE/dx    = 3.242 MeV/cm
Median dE/dx = 3.242 MeV/cm
MPV dE/dx     = 3.247 MeV/cm
```



Comparison – beam particle – LiH absorber

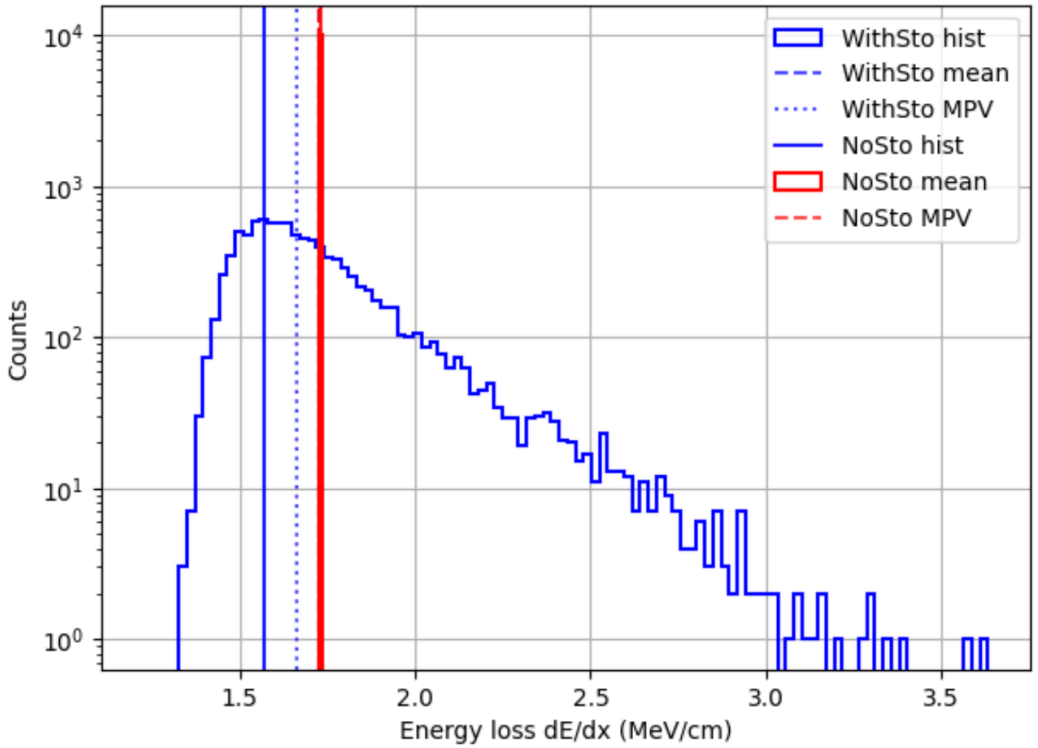
default

```
===== WithSto =====
Entries: 9991
Mean dE/dx   = 1.726 MeV/cm
Median dE/dx = 1.663 MeV/cm
MPV dE/dx    = 1.568 MeV/cm

===== NoSto =====
Entries: 10000
Mean dE/dx   = 1.724 MeV/cm
Median dE/dx = 1.724 MeV/cm
MPV dE/dx    = 1.729 MeV/cm
```



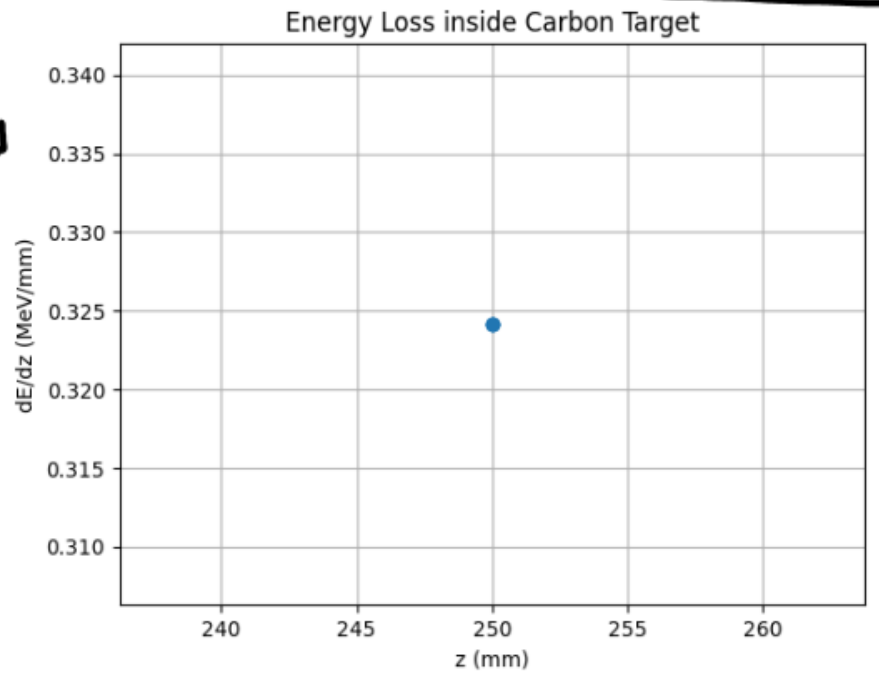
modified

```
===== WithSto =====
Entries: 9991
Mean dE/dx   = 1.726 MeV/cm
Median dE/dx = 1.663 MeV/cm
MPV dE/dx    = 1.568 MeV/cm

===== NoSto =====
Entries: 10000
Mean dE/dx   = 1.724 MeV/cm
Median dE/dx = 1.724 MeV/cm
MPV dE/dx    = 1.729 MeV/cm
```

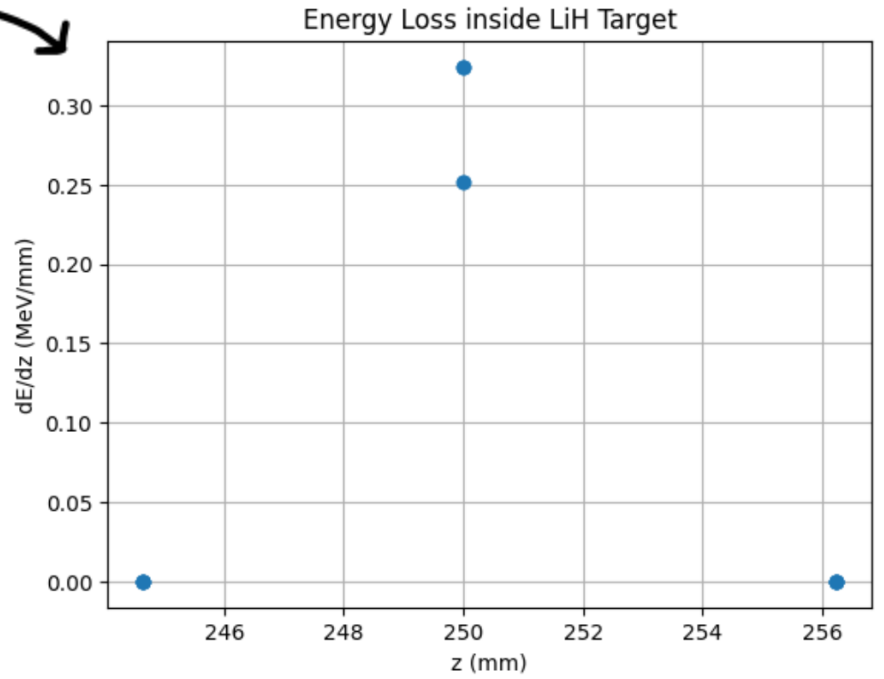


Comparison – reference particle

	Mean dE/dx (MeV/cm) Reference, no stochastics, eventID == -1 Carbon absorber	Mean dE/dx (MeV/cm) Reference, no stochastics, eventID == -1 LiH absorber
Default	3.24	
Modified	2.95	

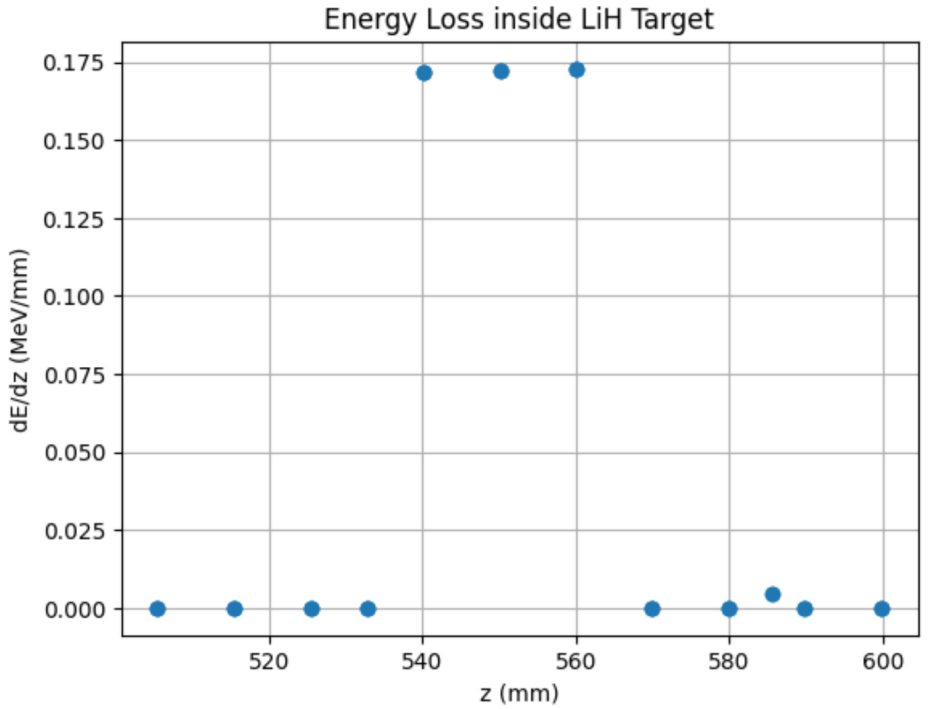


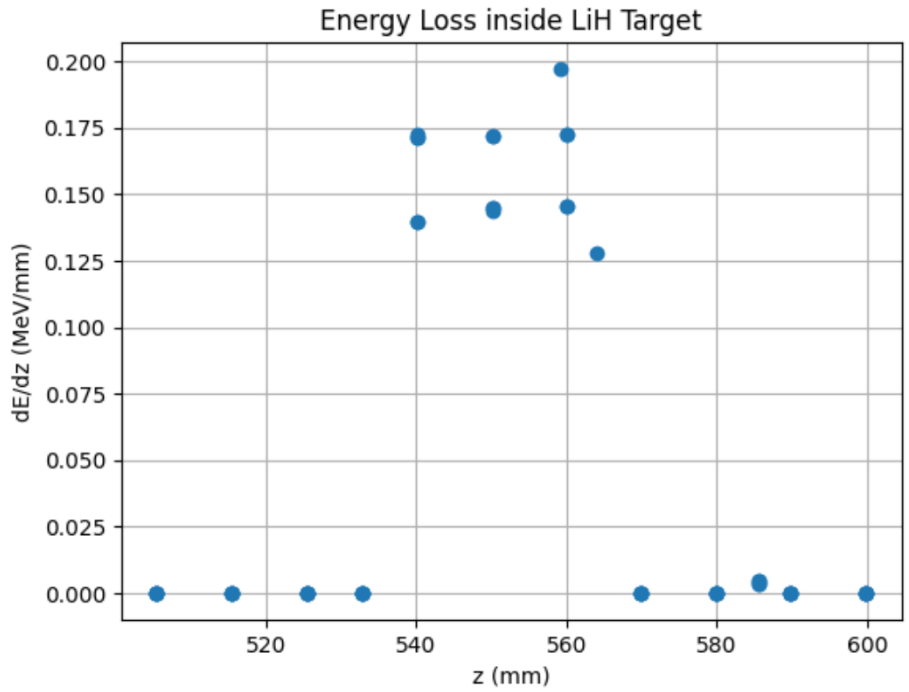
Mean dE/dz in target = 0.3241609119019131 MeV/mm



Comparison – reference particle

	Mean dE/dx (MeV/cm) Reference, no stochastics, eventID == -1 Carbon absorber	Mean dE/dx (MeV/cm) Reference, no stochastics, eventID == -1 LiH absorber
Default	3.24	1.72
Modified	2.95	1.58





Conclusion and next steps

- It seems as there are more than one callback at a particular z-position because of the new added states.
- Debug…

Energy Loss Characterization within G4beamline

Daisy Kalra, UTK Group, ...

May 12, 2026

1 Introduction

Understanding the energy loss behavior of charged particles in matter is essential for the design and optimization of accelerator and detector systems. In particular, muon cooling channels for future Muon Collider concepts rely heavily on precise modeling of ionization energy loss in low-Z absorber materials. Accurate characterization of both the average energy loss and its stochastic fluctuations is therefore important for validating simulation tools and understanding beam dynamics.

This study investigates the energy loss behavior of positive muons (μ^+) traversing different absorber geometries and materials using `G4beamline`. The primary objective is to characterize the energy loss distributions and compare their statistical properties using: