

# Muon Beam Dynamics in HFQFO Cooling Channel

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# Recap

|   | Reference particle | Beam, no stochastics | Beam, with stochastics | Reference, with stochastic          | Bethe-bloch |
|---|--------------------|----------------------|------------------------|-------------------------------------|-------------|
| 2.5 mm carbon absorber "tube"<br>200 MeV muon   | 3.24               | 3.24                 | 3.27                   | To be implemented within G4beamline | 3.29        |
| 2.5 mm carbon absorber "square"<br>200 MeV muon | 3.24               | 3.24                 | 3.27                   |                                     | 3.29        |
| LiH wedge absorber HFOFO<br>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 = REALISTIC_TUNE;
setEventID(-4);
beamIndex = 0;
runManager->BeamOn(referenceVector.size());
state = IDLE;

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

## Output trace file

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

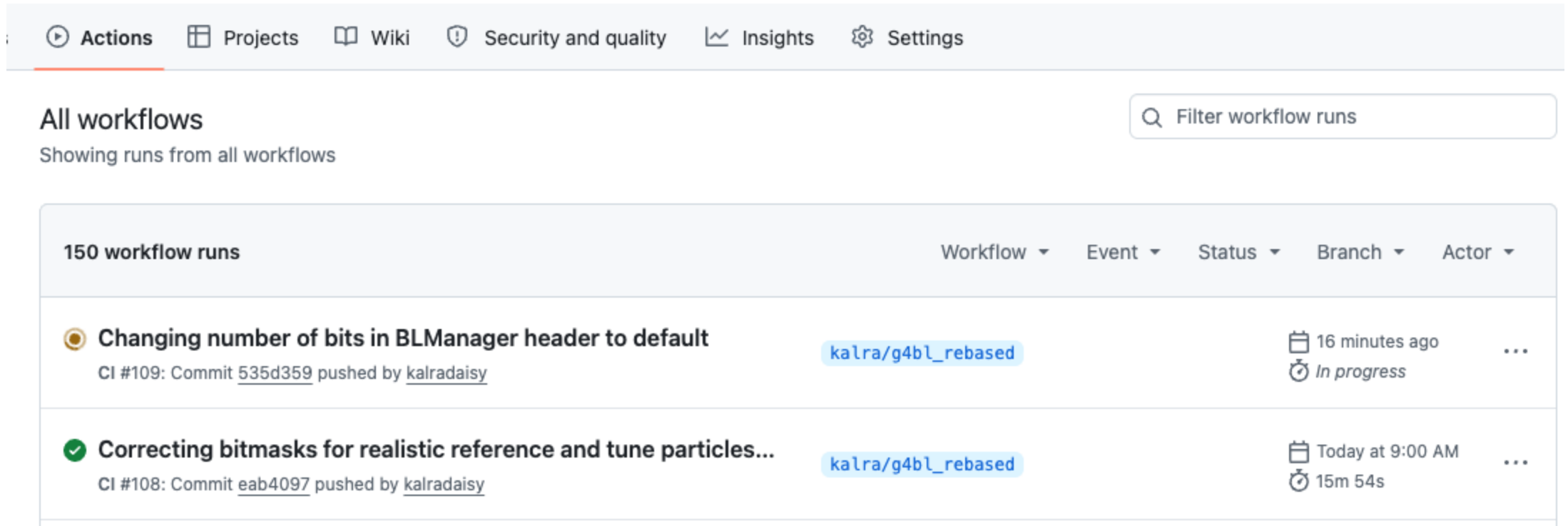
# Event -1 Track 1      Reference
0 0 0 0 0 200 0 -13 .

# Event -4 Track 1      Tune with
0 0 0 0 0 200 0 -13 .      stochastics NO







# Event -3 Track 1      Reference with
0 0 0 0 0 200 0 -13      stochastics ON
```

# Implementation

- GitHub [https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl\\_rebased](https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl_rebased)
- Make changes locally, push it to Git, trigger build workflow, docker image (Credit: Larry Lee)



The screenshot shows the GitHub Actions interface for the repository 'lawrenceleejr/g4beamline'. The 'Actions' tab is selected, displaying a list of workflow runs. The page title is 'All workflows' with a search bar for 'Filter workflow runs'. Below the title, it says 'Showing runs from all workflows'. The main content area shows a table of workflow runs with columns for 'Workflow', 'Event', 'Status', 'Branch', and 'Actor'. Two runs are visible: one in progress and one completed.

| 150 workflow runs   |  | Workflow ▾                         | Event ▾ | Status ▾   | Branch ▾ | Actor ▾ |
|---|--|------------------------------------|---------|--|----------|---------|
|  | <b>Changing number of bits in BLManager header to default</b><br>CI #109: Commit <a href="#">535d359</a> pushed by <a href="#">kalradaisy</a>            | <a href="#">kalra/g4bl_rebased</a> |         |  16 minutes ago<br> <i>In progress</i> |          | ...     |
|  | <b>Correcting bitmasks for realistic reference and tune particles...</b><br>CI #108: Commit <a href="#">eab4097</a> pushed by <a href="#">kalradaisy</a> | <a href="#">kalra/g4bl_rebased</a> |         |  Today at 9:00 AM<br> 15m 54s          |          | ...     |

# Implementation

- GitHub [https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl\\_rebased](https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl_rebased)
- Make changes locally, push it to Git, trigger build workflow, docker image (Credit: Larry Lee)

Triggered via push 21 minutes ago

|   | Status         | Total duration        | Artifacts       |
|---|----------------|-----------------------|-----------------|
| kalradaisy pushed <a href="#">535d359</a> <code>kalra/g4bl_rebased</code> | <b>Success</b> | <b><u>16m 10s</u></b> | <b><u>1</u></b> |

**ci.yml**  
on: push

```
graph LR; A[✓ build-and-test 7m 25s] --> B[✓ build-and-push-contai... 8m 36s]
```

The screenshot displays a successful GitHub Actions workflow run. The top section shows the trigger event: a push by user 'kalradaisy' to the 'kalra/g4bl\_rebased' branch, with commit hash '535d359'. The workflow status is 'Success', with a total duration of 16m 10s and one artifact generated. Below this, the workflow configuration is shown as 'ci.yml' triggered on a push. The workflow consists of two steps: 'build-and-test' (7m 25s) and 'build-and-push-contai...' (8m 36s), both of which completed successfully, as indicated by green checkmarks.

# Implementation

- GitHub [https://github.com/lawrenceleejr/g4beamline/tree/kalra/g4bl\\_rebased](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

==== WithSto =====

Entries: 9994

Mean dE/dx = 3.249 MeV/cm

Median dE/dx = 2.887 MeV/cm

MPV dE/dx = 2.680 MeV/cm

**default**

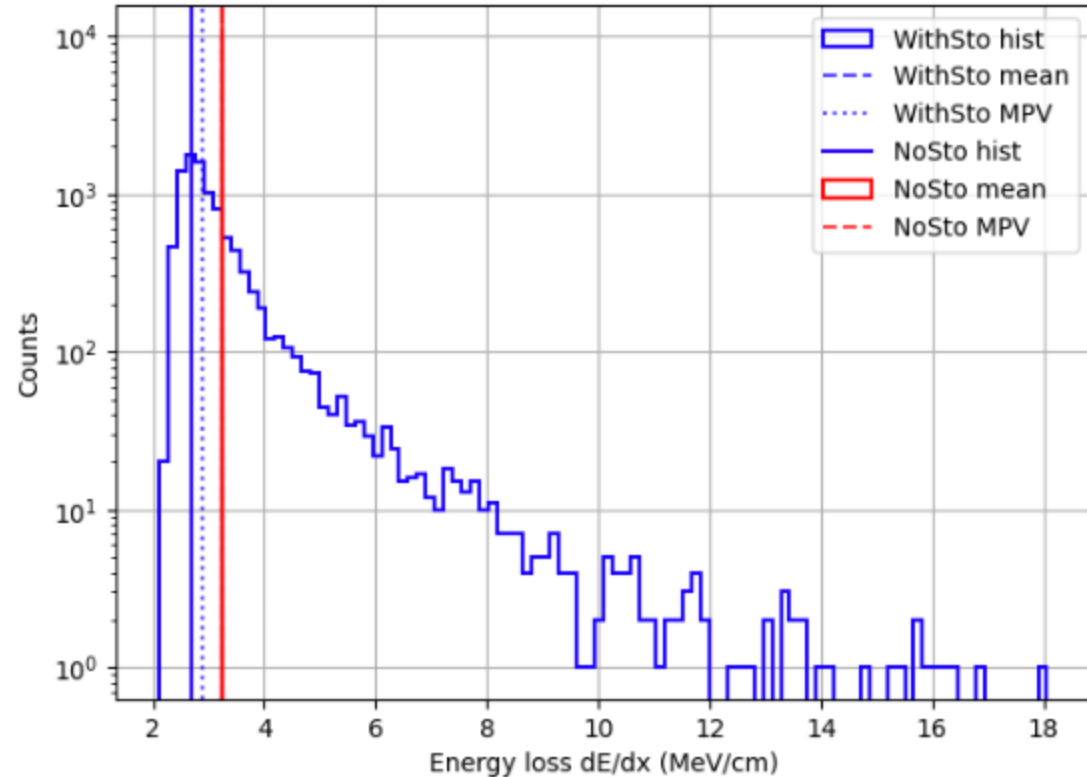
==== NoSto =====

Entries: 10000

Mean dE/dx = 3.242 MeV/cm

Median dE/dx = 3.242 MeV/cm

MPV dE/dx = 3.247 MeV/cm



==== WithSto =====

Entries: 9994

Mean dE/dx = 3.249 MeV/cm

Median dE/dx = 2.887 MeV/cm

MPV dE/dx = 2.680 MeV/cm

**modified**

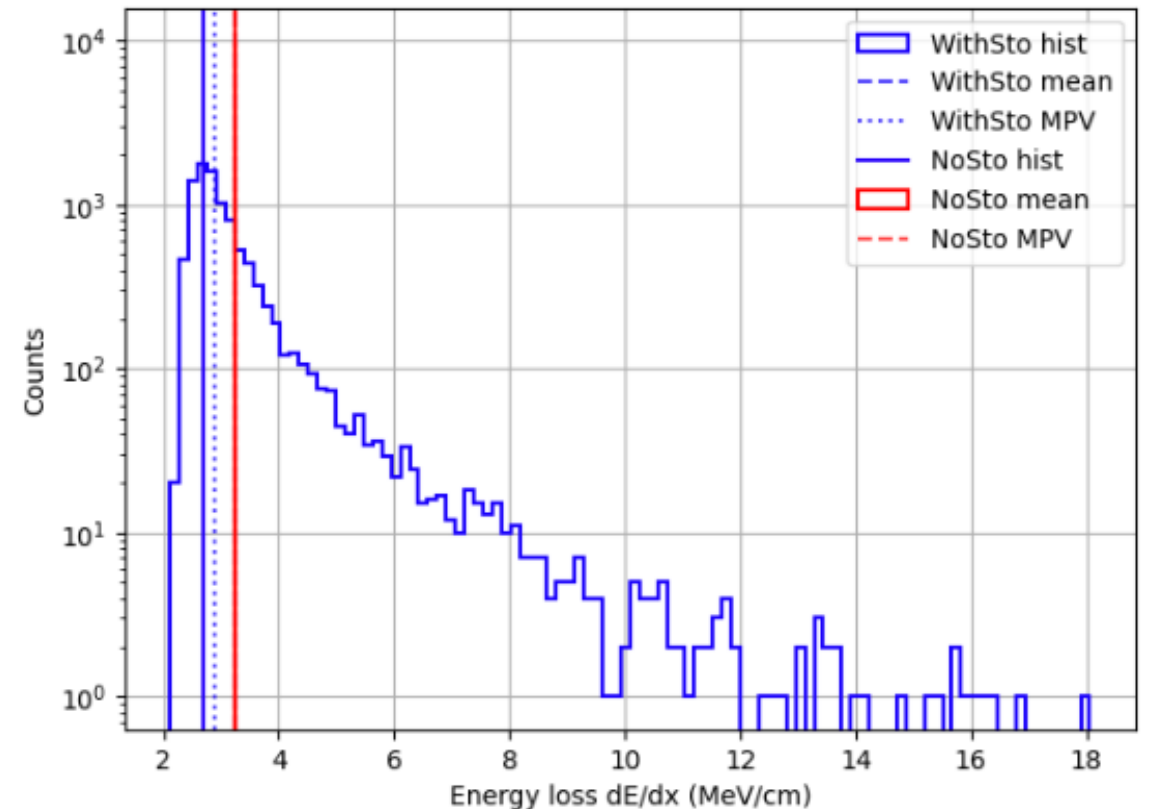
==== NoSto =====

Entries: 10000

Mean dE/dx = 3.242 MeV/cm

Median dE/dx = 3.242 MeV/cm

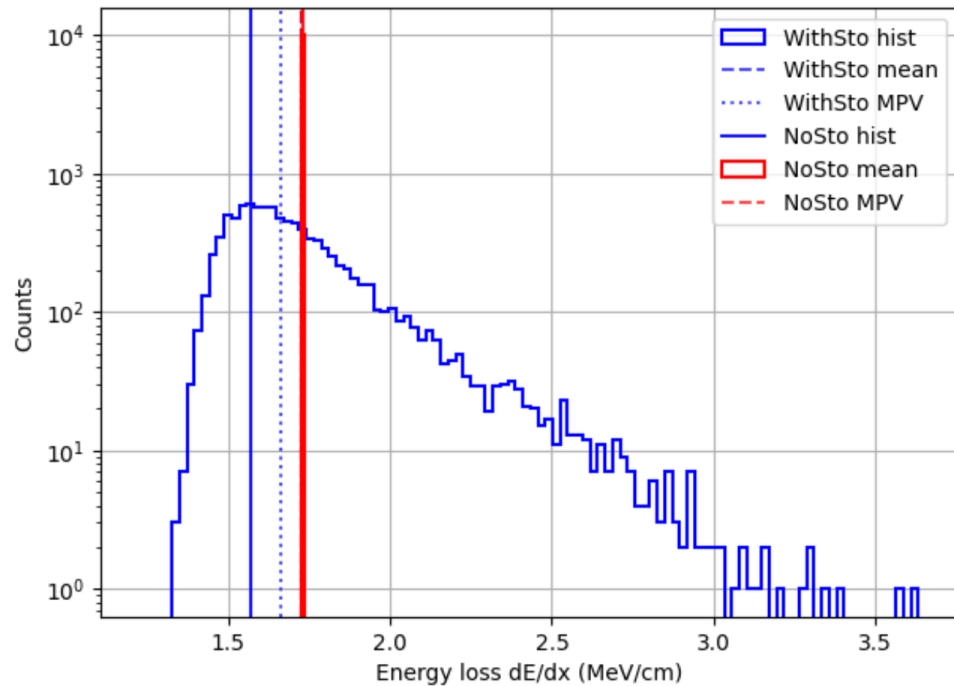
MPV dE/dx = 3.247 MeV/cm



# Comparison – beam particle – LiH absorber

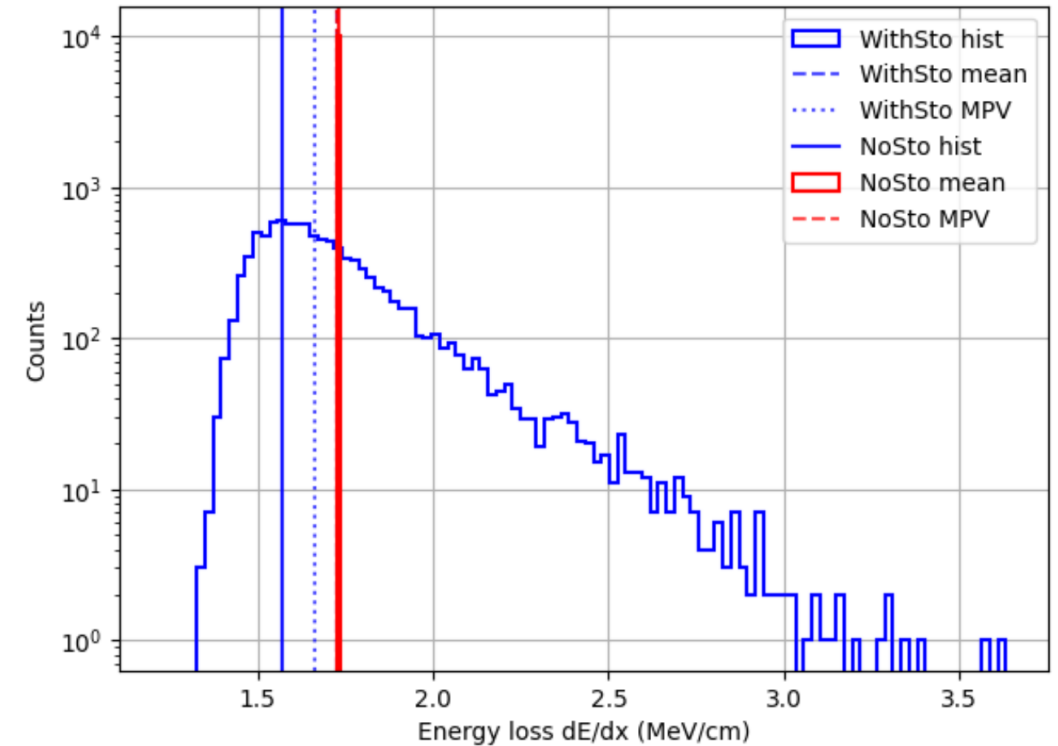
default

```
===== 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
```



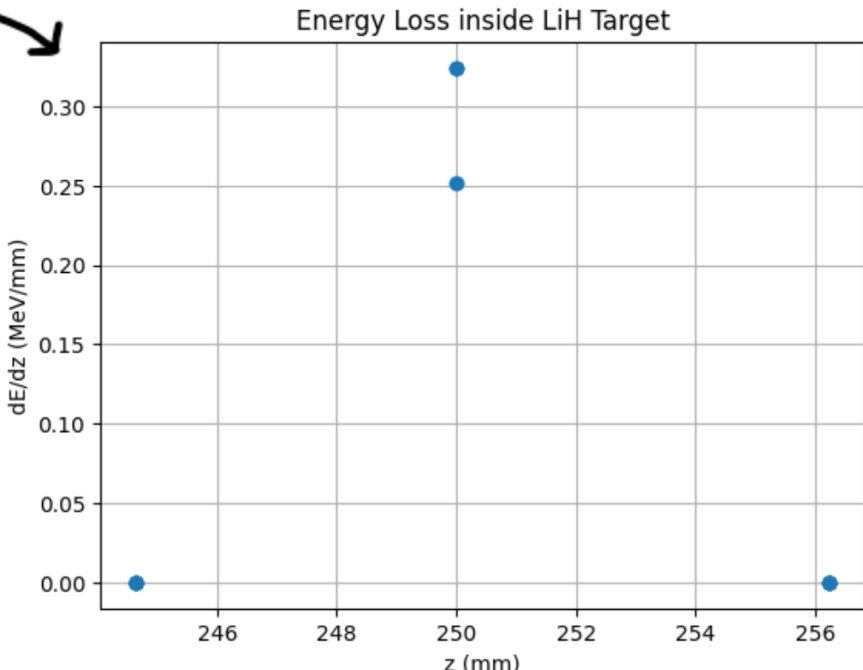
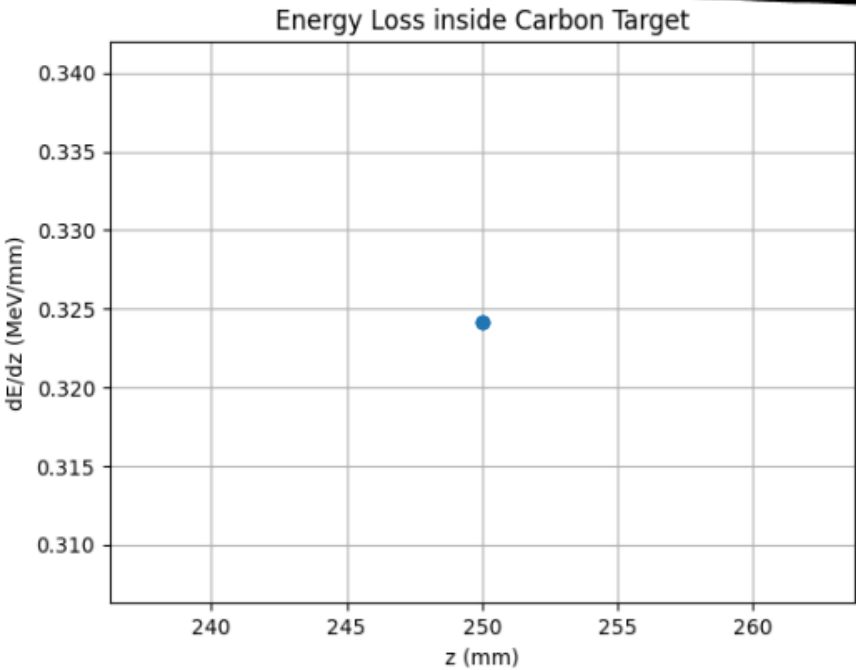
modified

```
===== 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

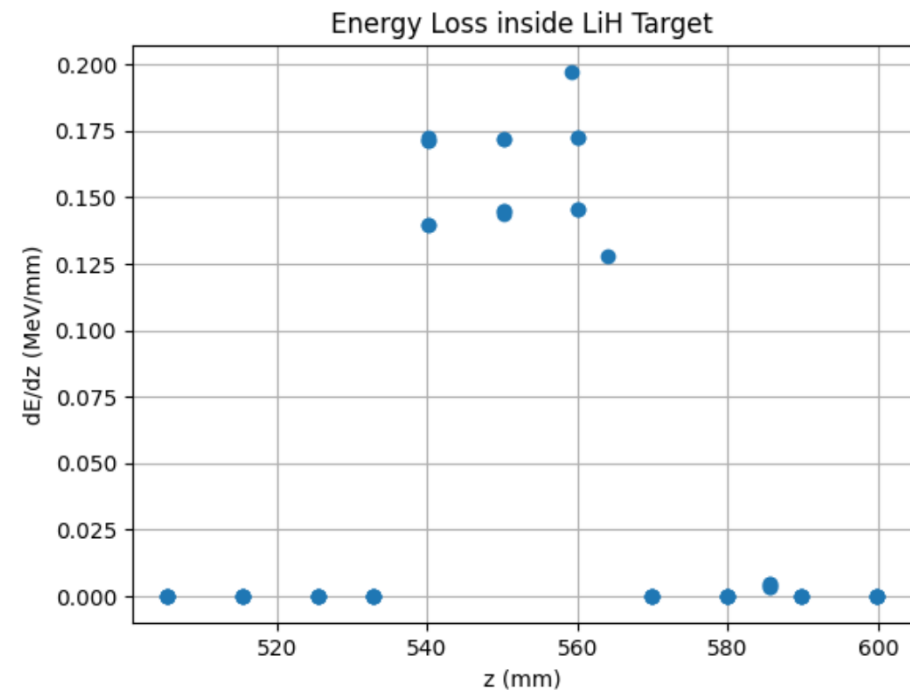
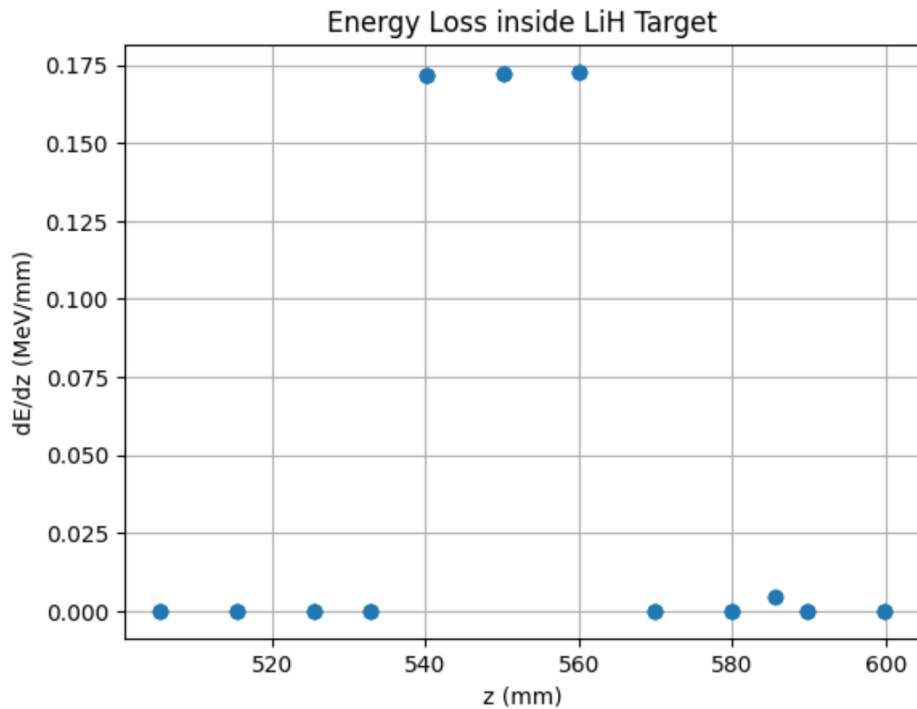
|          | Mean dE/dx (MeV/cm)<br>Reference, no stochastics,<br>eventID == -1<br>Carbon absorber | Mean dE/dx (MeV/cm)<br>Reference, no stochastics,<br>eventID == -1<br>LiH absorber |
|----------|---|--|
| Default  | 3.24  |  |
| Modified | 2.95  |  |



Mean dE/dz in target = 0.3241609119019131 MeV/mm

# Comparison – reference particle

|          | Mean dE/dx (MeV/cm)<br>Reference, no stochastics,<br>eventID == -1<br>Carbon absorber | Mean dE/dx (MeV/cm)<br>Reference, no stochastics,<br>eventID == -1<br>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 ( $\mu^+$ ) traversing different absorber geometries and materials using `G4beamline`. The primary objective is to characterize the energy loss distributions and compare their statistical properties using: