Muon Beam Dynamics in HFOFO Cooling Channel

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May 08, 2026

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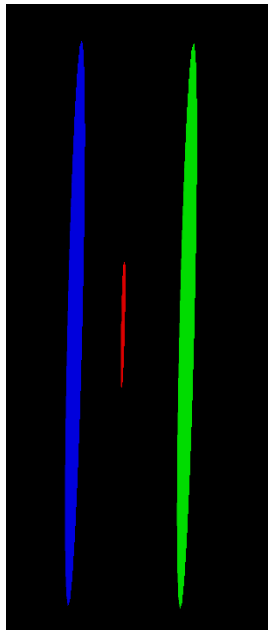
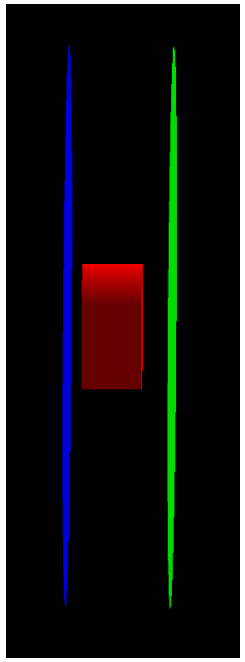
USMCC

Understanding energy loss from G4beamline

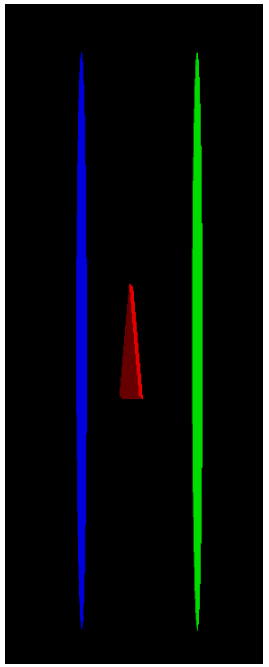
- **Simple test setups –** Simulate muons by passing them through different shaped absorbers with different materials (carbon and LiH) and recording particle properties with virtual detectors (placed before and after the absorber) https://github.com/kalradaisy/HFOFO/blob/main/EnergyLoss.in
  - Beam, no stochastics and with stochastics
  - Reference particle
  - Bethe-bloch



Thin "tube" shaped absorber



Thick "tube" shaped absorber



Wedge shaped absorber

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$$\frac{dE}{dx} = \rho K \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \left(\frac{2m_e \beta^2 \gamma^2 T_{\max}}{I^2} \right) - \beta^2 \right]$$

$$\beta = \frac{p}{\sqrt{p^2 + m^2}}, \qquad T_{\max} = \frac{2m_e \beta^2 \gamma^2}{1 + \frac{2\gamma m_e}{m} + \left(\frac{m_e}{m}\right)^2}$$

$$\gamma = \frac{\sqrt{p^2 + m^2}}{m}$$

For carbon, (Z,A) = (6,12). I = 81 eV

For LiH https://pdg.lbl.gov/2025/AtomicNuclearProperties/HTML/lithium_hydride_LiH.html

$(Z,A)_{Li}$ = (3,6.94)
I_{Li} = 40 eV

$(Z,A)_{H}$ = (1,1)
I_{H} = 19.2 eV

$$M_{\mathrm{LiH}} = A_{\mathrm{Li}} + A_{\mathrm{H}}$$

$$w_{\mathrm{Li}} = \frac{A_{\mathrm{Li}}}{A_{\mathrm{Li}} + A_{\mathrm{H}}}, \quad w_{\mathrm{H}} = \frac{A_{\mathrm{H}}}{A_{\mathrm{Li}} + A_{\mathrm{H}}}$$

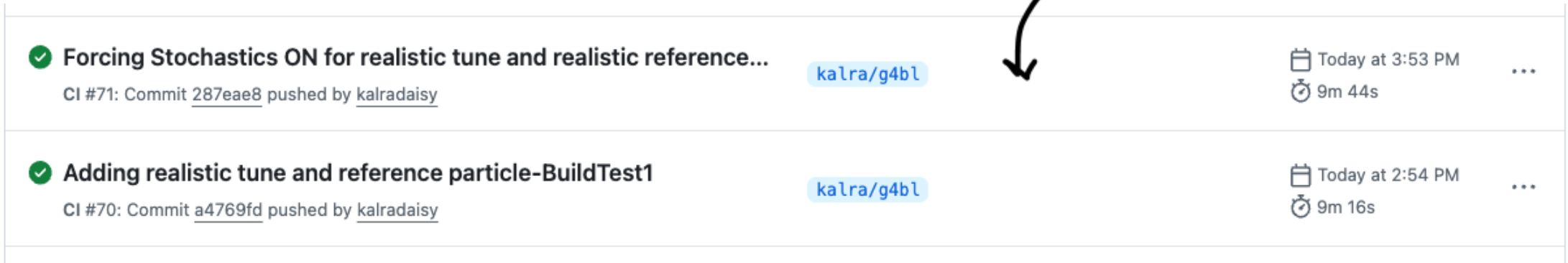
$$\left\langle \frac{Z}{A} \right\rangle = w_{\mathrm{Li}} \left(\frac{Z_{\mathrm{Li}}}{A_{\mathrm{Li}}} \right) + w_{\mathrm{H}} \left(\frac{Z_{\mathrm{H}}}{A_{\mathrm{H}}} \right)$$

$$\ln I_{\mathrm{mix}} = \frac{w_{\mathrm{Li}} \left(\frac{Z_{\mathrm{Li}}}{A_{\mathrm{Li}}} \right) \ln I_{\mathrm{Li}} + w_{\mathrm{H}} \left(\frac{Z_{\mathrm{H}}}{A_{\mathrm{H}}} \right) \ln I_{\mathrm{H}}}{\left\langle \frac{Z}{A} \right\rangle}$$

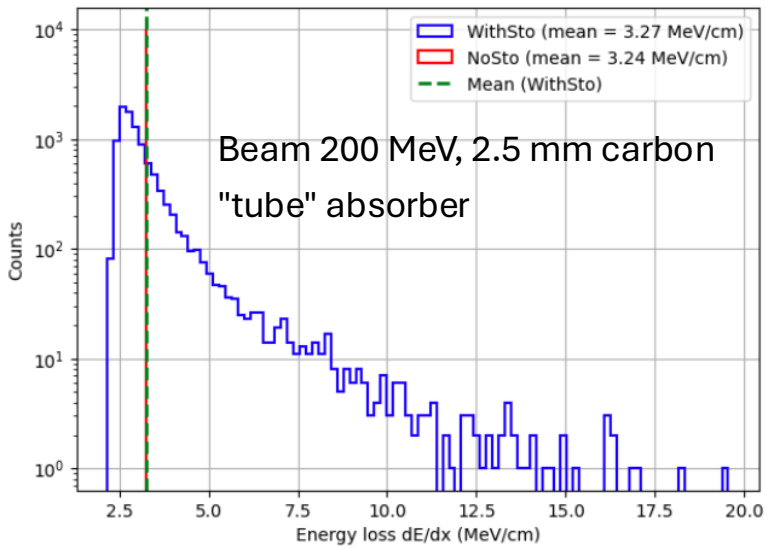
$$I_{\mathrm{mix}} = \exp(\ln I_{\mathrm{mix}})$$

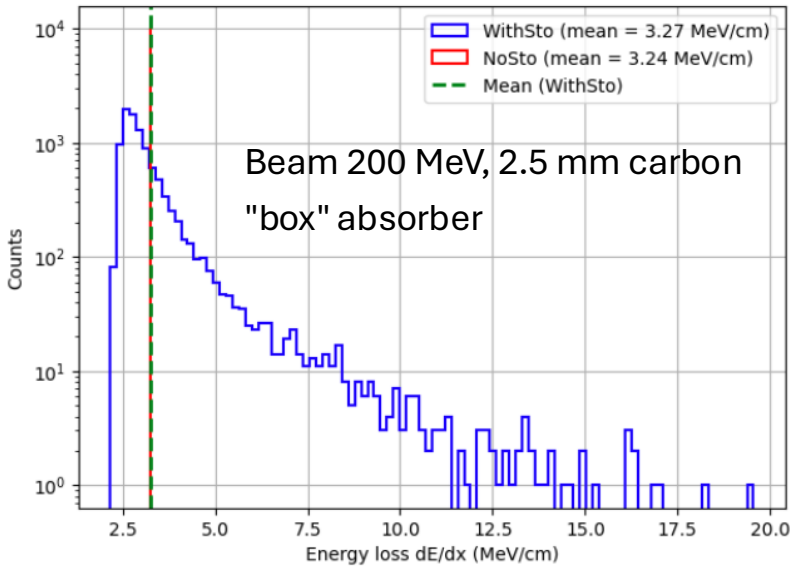
Average energy loss dE/dx

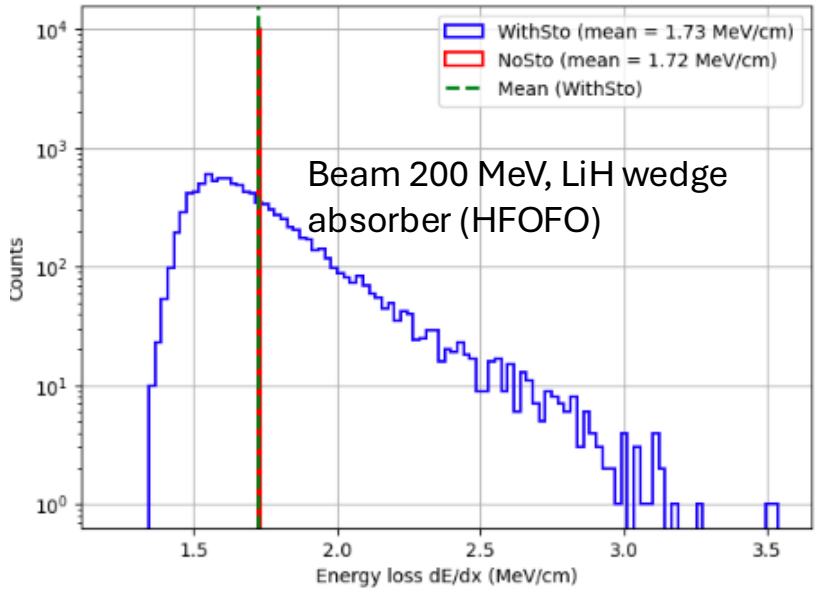
	Reference particle	Beam, no stochastics	Beam, with stochastics	Reference, with stochastic	Bethe-bloch
2.5 mm carbon absorber "tube" 200 MeV muon	3.24	3.24	3.27	In Progress (Implemented in g4beamline source code, testing TBD)	3.29
2.5 mm carbon absorber "square" 200 MeV muon	3.24	3.24	3.27		3.29
LiH wedge absorber HFOFO 200 MeV muon	1.72	1.72	1.73		1.73



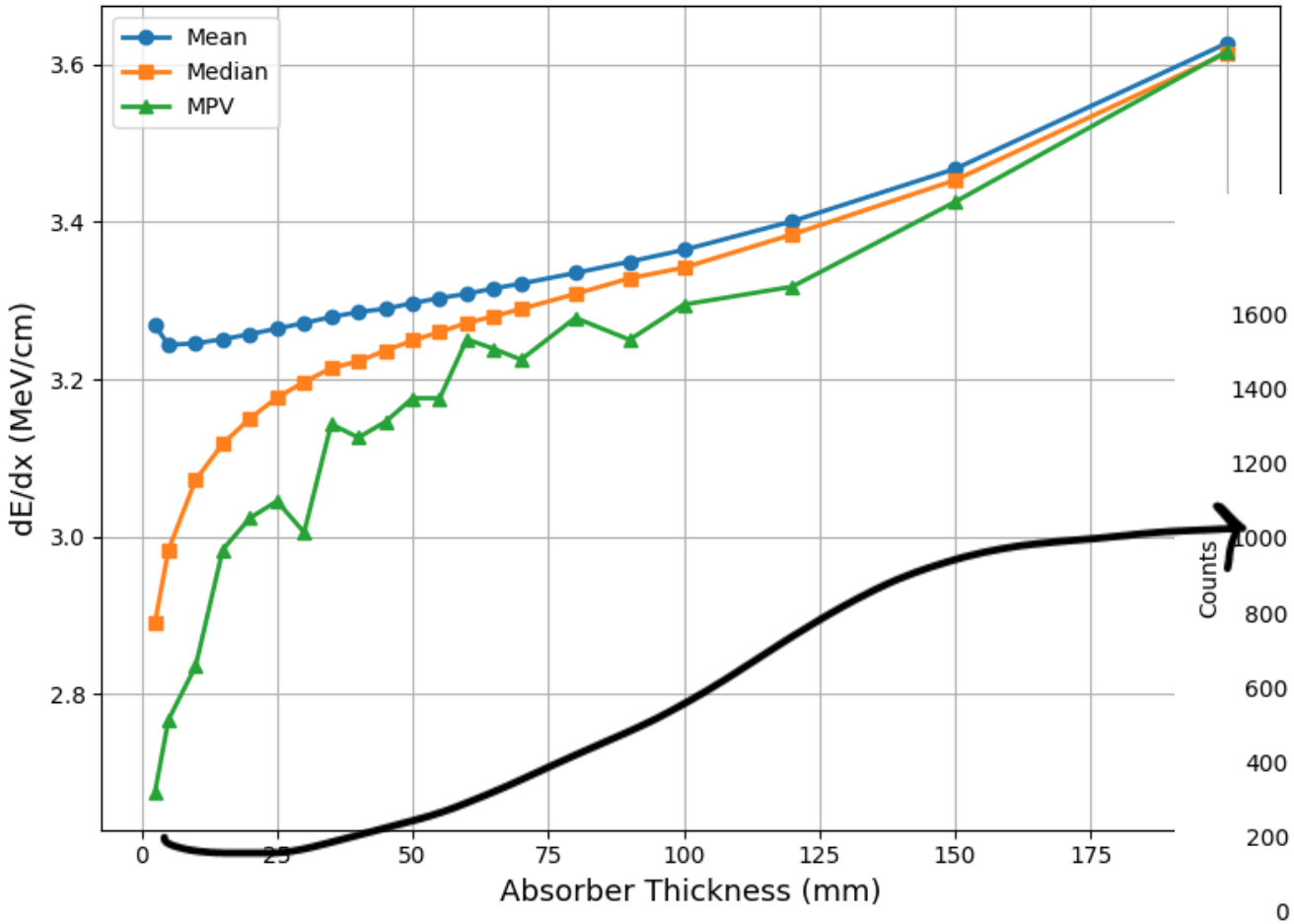
Energy loss distributions

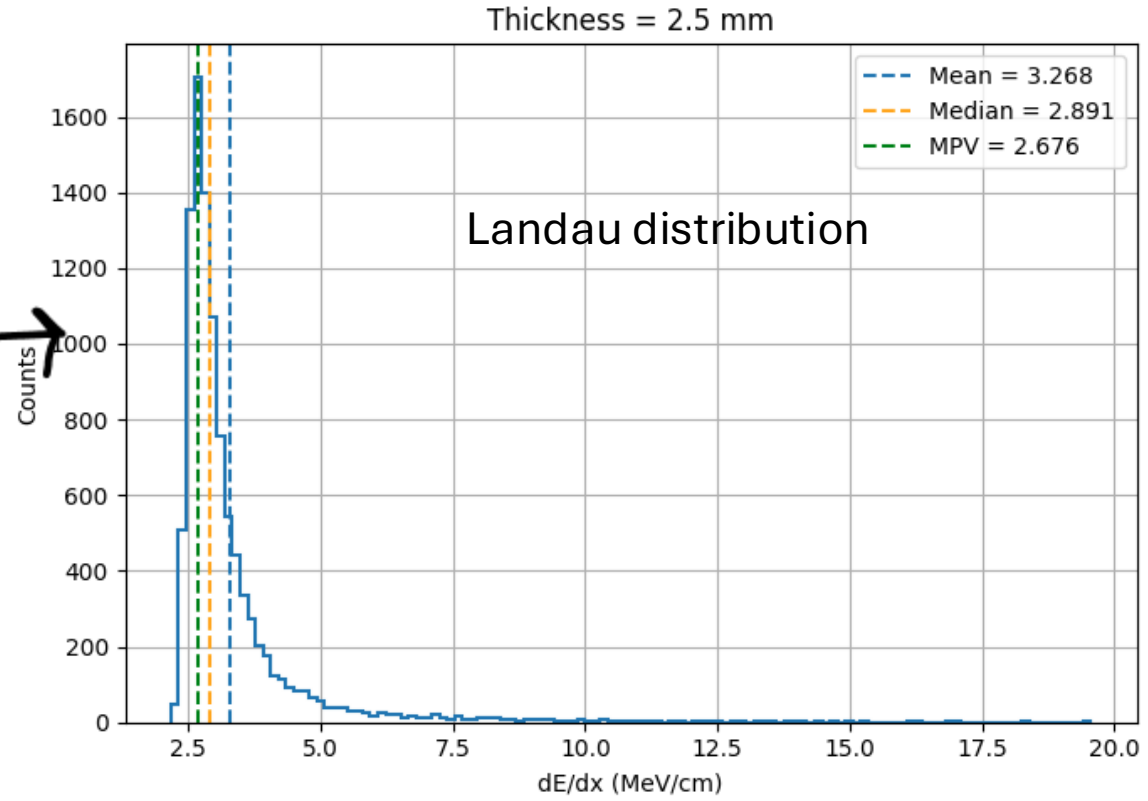






dE/dx with varied thickness absorbers





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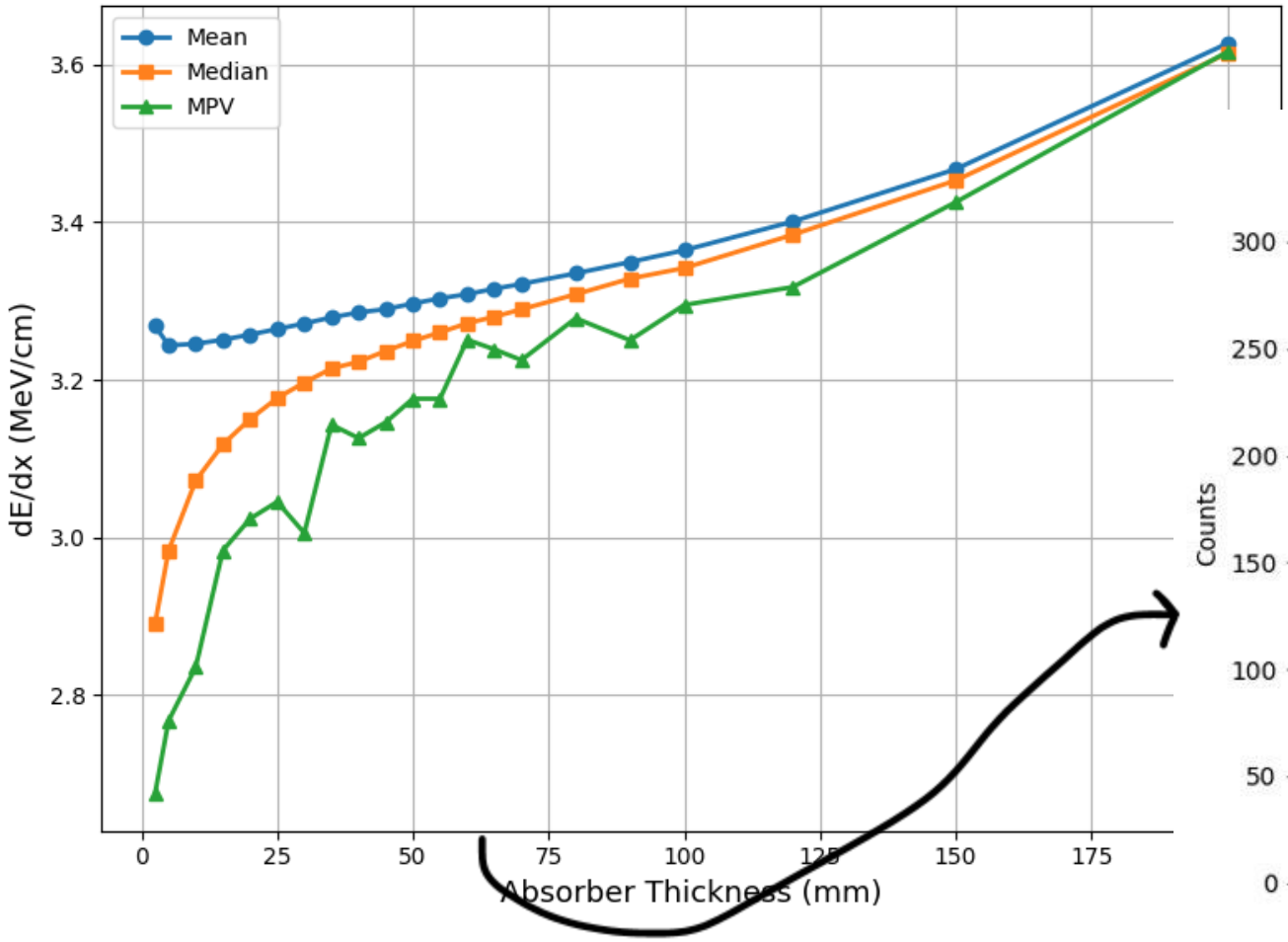
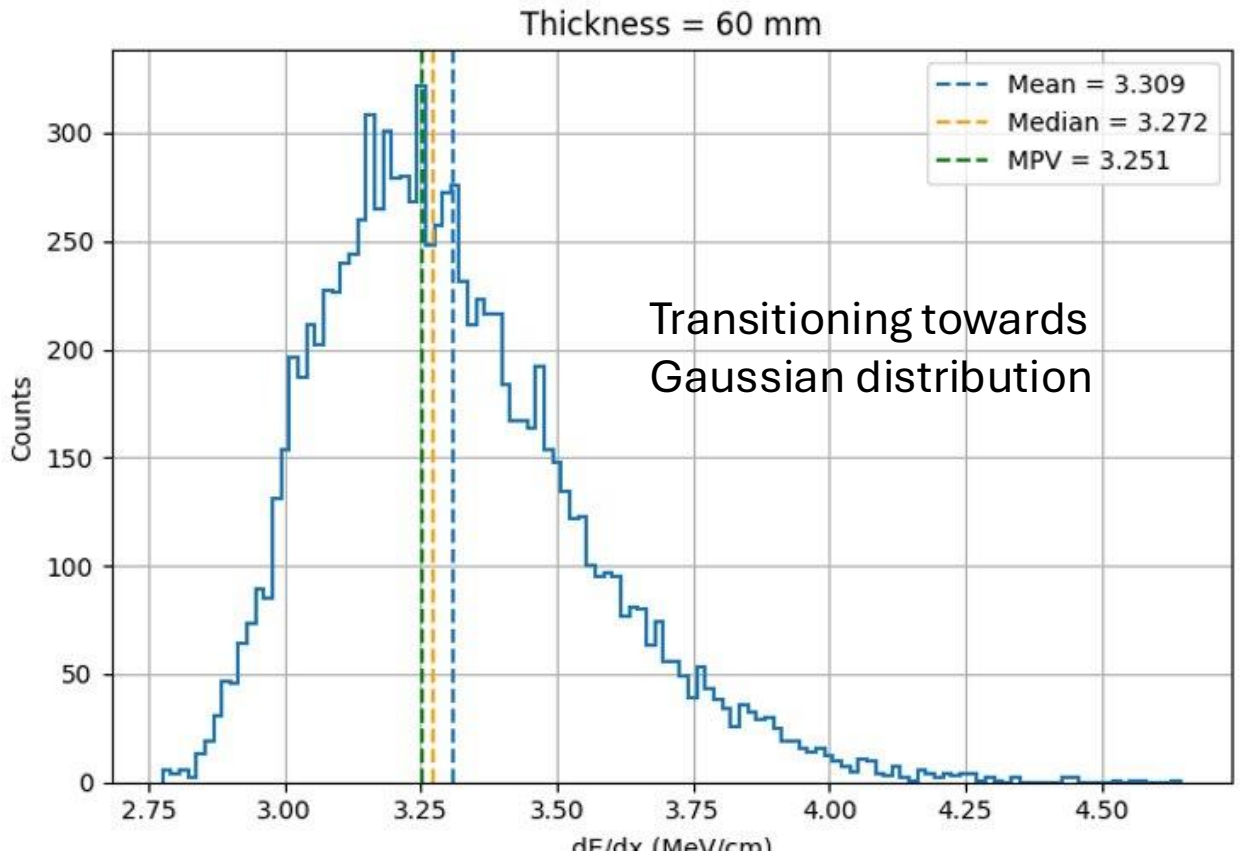
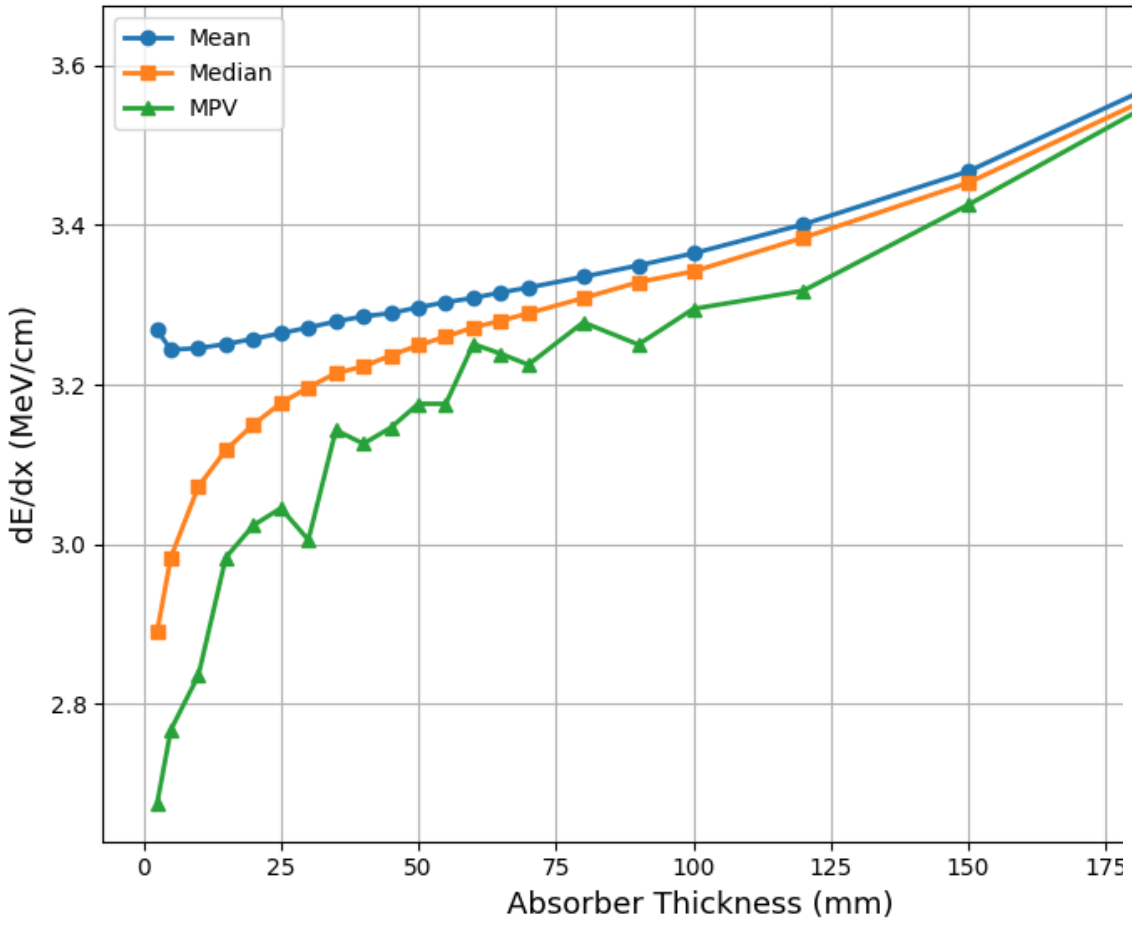
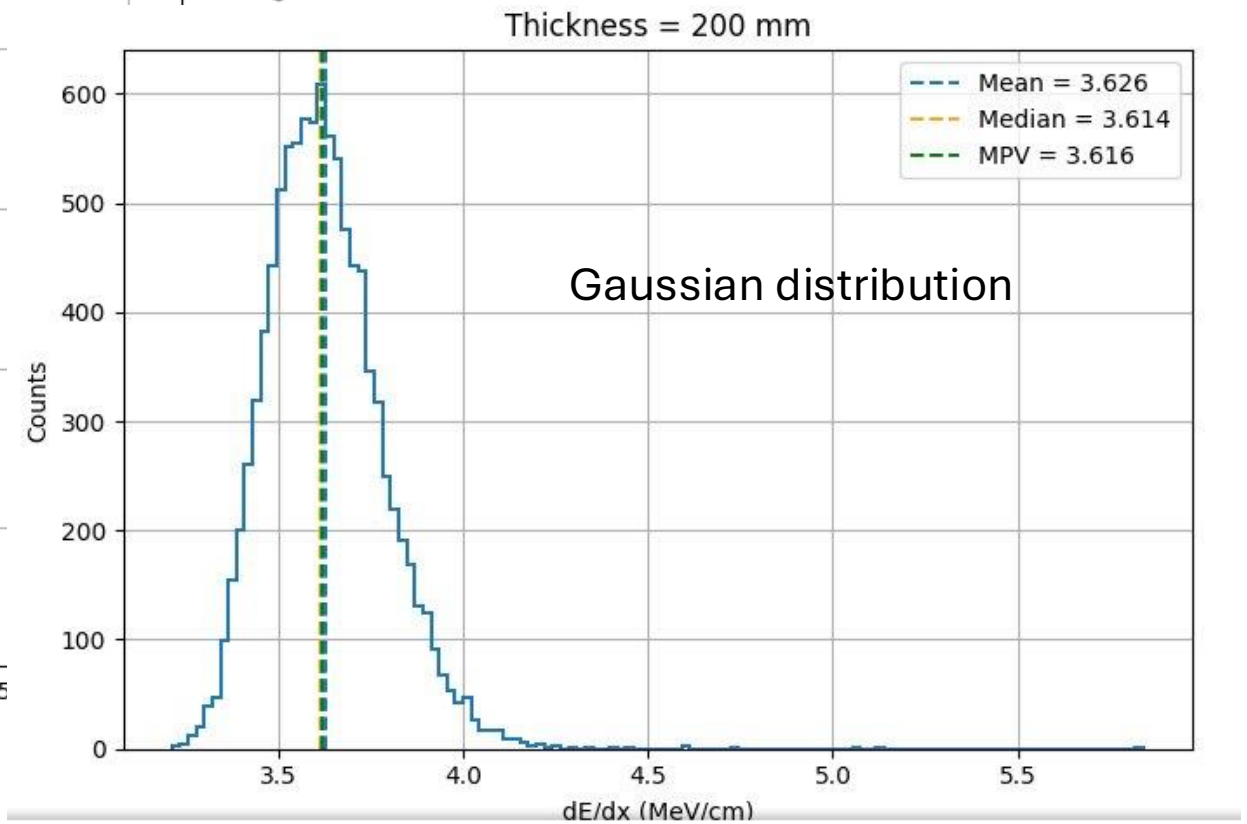




Transitioning towards Gaussian distribution

dE/dx with varied thickness absorbers





Next step

- Finish testing realistic reference and realistic tune particles.
- Fill the numbers

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