High Rate Calorimeter Simulations

Yasir Ali

Research Fellow AGH UST
Krakow Poland

Supervisor: Professor
Krzystof Piotrzkowski

Plan of the presentation

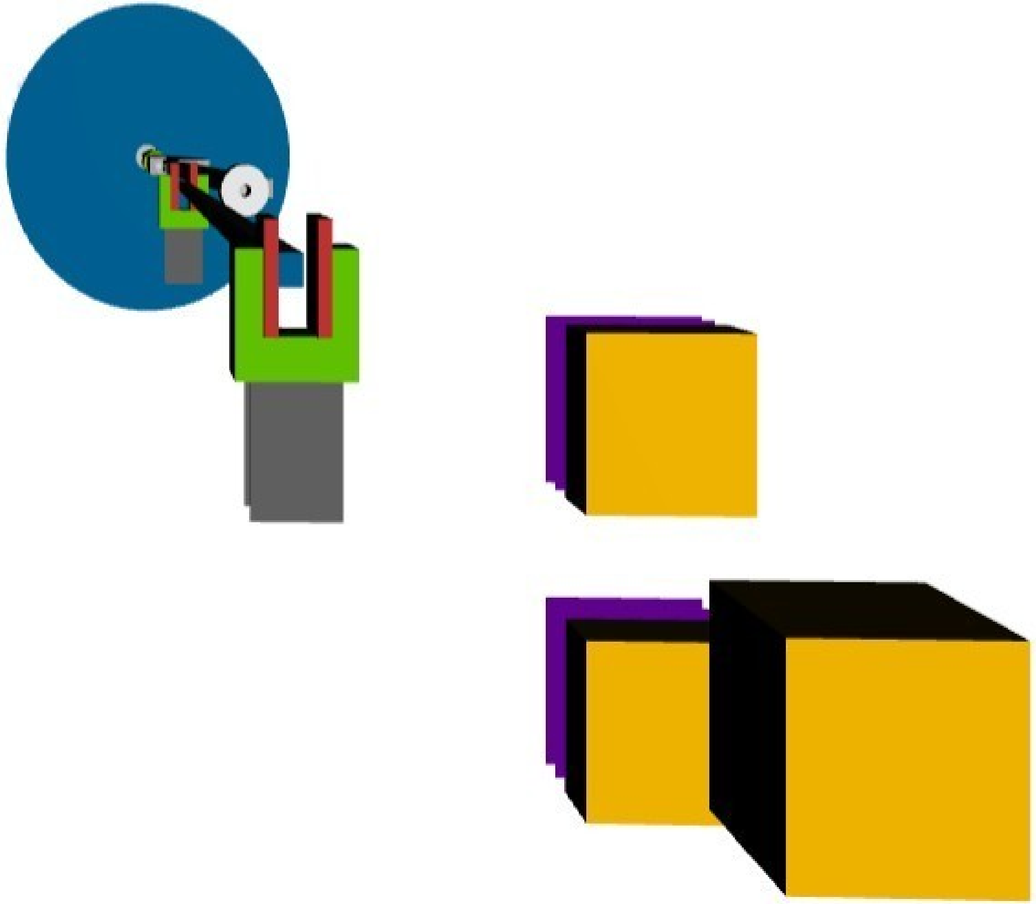
- Need of High Rate Calorimeter - Direct Photon detection (an
- Introduction) Brief overview of epic software framework
- Bremge input for Simulation
- Test HRC design based on PbWO4 crystals using dd4hep tools
- Simulation Parameters and Energy deposition (Hottest cell +
- Neighbours) Design of HRC using Base-Line Detector Technologies
- Study of Energy Deposition with new design of Sampling Calorimeter
- Summary and Future Outlook Back Up Slides

Direct Photon Detection: Introduction

In principle, measurements of direct bremsstrahlung photons should provide very simple and precise luminosity measurements at the EIC, as photon (geometrical) acceptance is almost 100% and one has to simply account for photon energy cutoff, which can be well calibrated.

However, using this simple method of photon counting is only possible at low luminosities. For the nominal $L = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ about 23 hard photons on average will be emitted for each bunch crossing, forcing measurements of energy flow instead, which are more difficult. ⇒

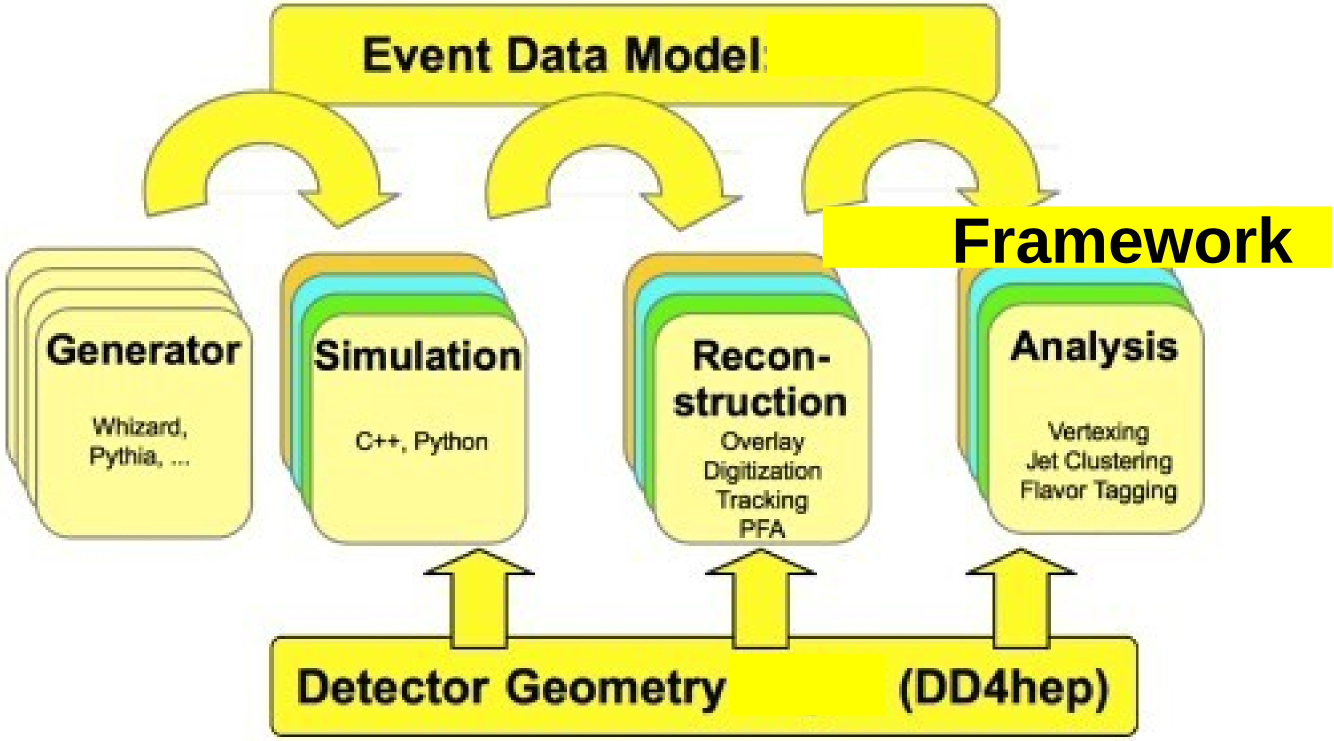
Therefore, **two** separate direct photon calorimeters are proposed: one with an **excellent energy resolution** to be used only for the special luminosity calibration runs at low L, and one which is capable of withstanding > 1 GHz event rates and be used for a robust luminosity monitoring during the nominal ePIC running.



Reference: Slide adopted from Professor Krzystof Piotrzkowski Presentation for Far Farward/Backward Cutt-off Meeting

EPIC software framework

- Design and simulation of High Rate Calorimeter is based on the software stack using DD4hep and DDsim plugins:
- EIC environment: dd4hep, ddsim, eicrecon, etc *run physics simulations with ddsim and geant4



https://eic.github.io/tutorial-setting-up-environment/
https://eic.github.io/tutorial-simulations-using-ddsim-and-geant4/

Overview of Simulation

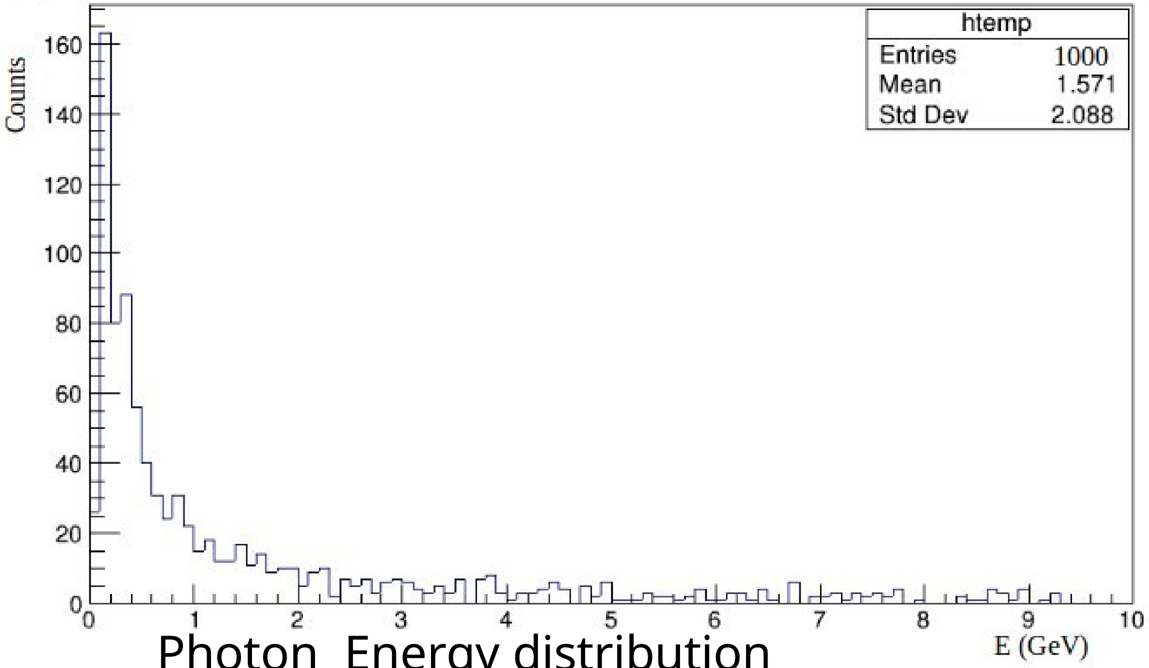
- High Rate Calorimeters are being studied using DD4hep/epic and DDsim tools
- For this study 1K Bremsstrahlung events are used with lateral hit position
- smearing PbWO4 crystal calorimeter is simulated for reference
- Energy depositions are calculated for its 10cm x 10cm x20cm size Simulations
- of Tungsten-SciFi/Quartz fiber calorimeters are being studied Calculations of
- energy depositions in fibers is in progress

Bremge input for Simulation

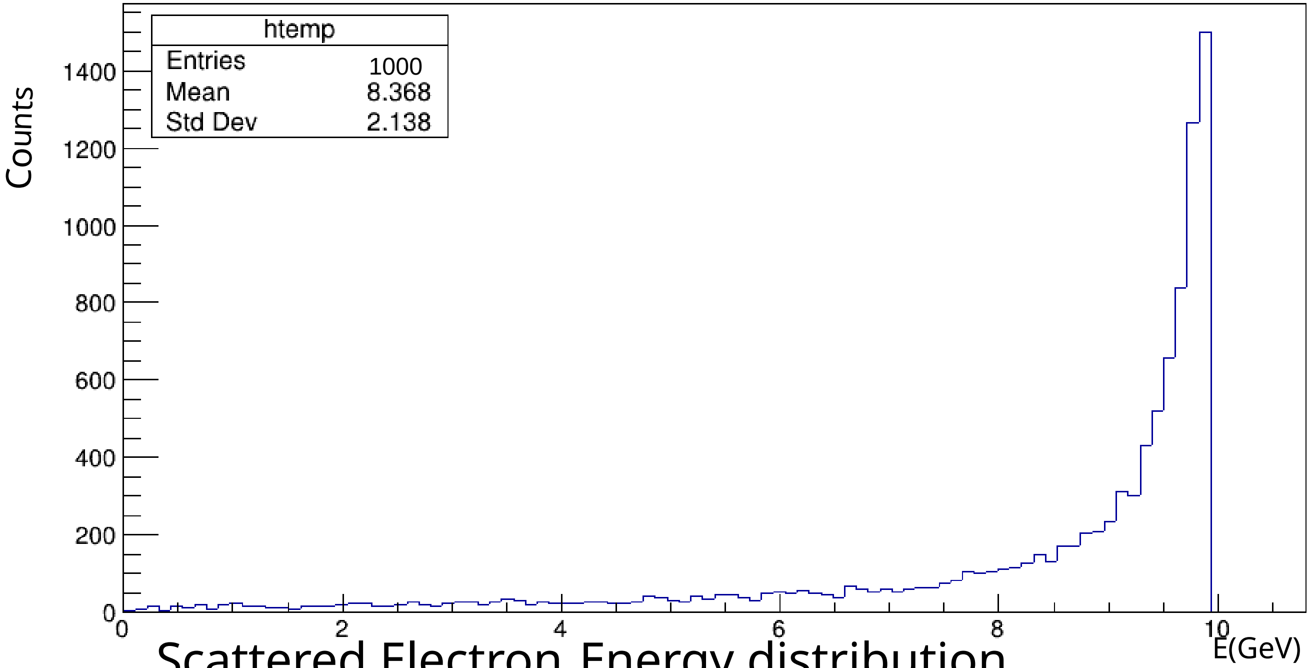
Bremge uses:

- mt19937 pseudo-random number generator.
- Monte Carlo methods to generate electron-proton (e-p) and electron-nucleus (e-A) bremsstrahlung events based on the initial generator parameters.

- Incoming Bremsstrahlung Energy Distributions 10 GeV electrons,
- Minimal Photon energy of 100 MeV

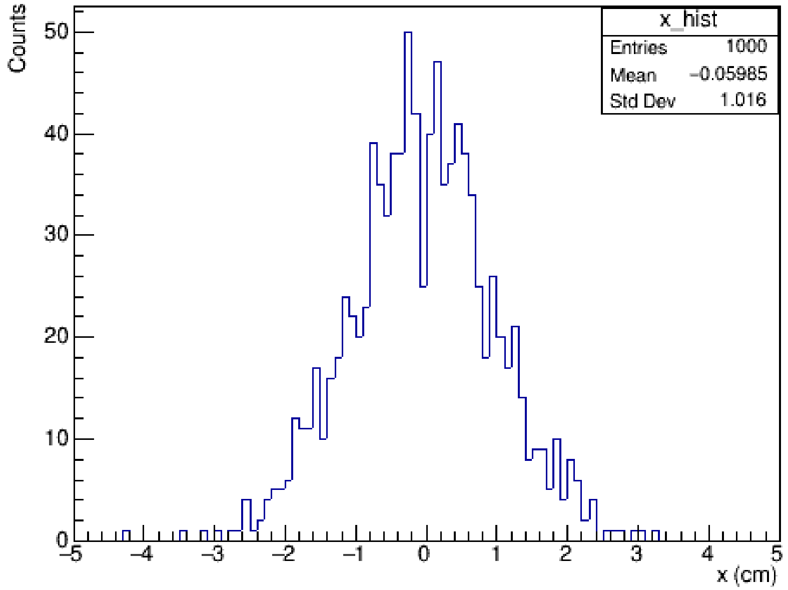


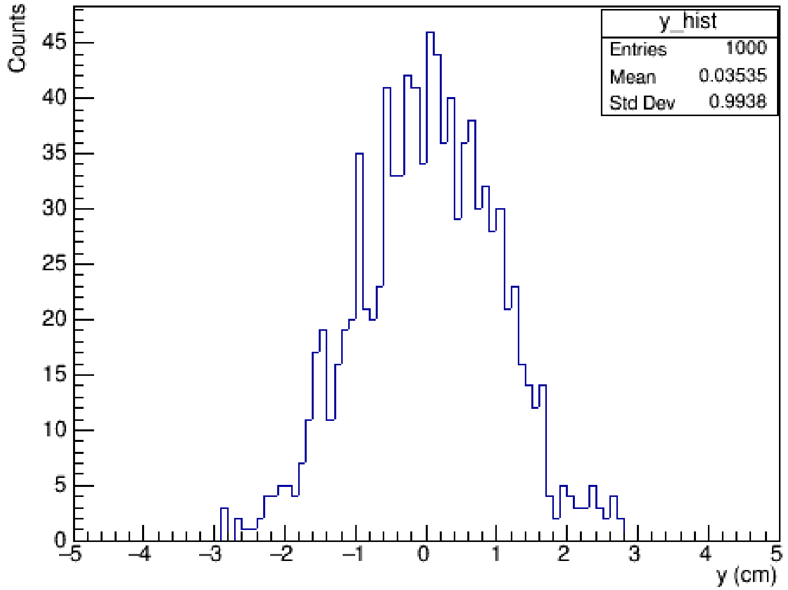
Photon Energy distribution

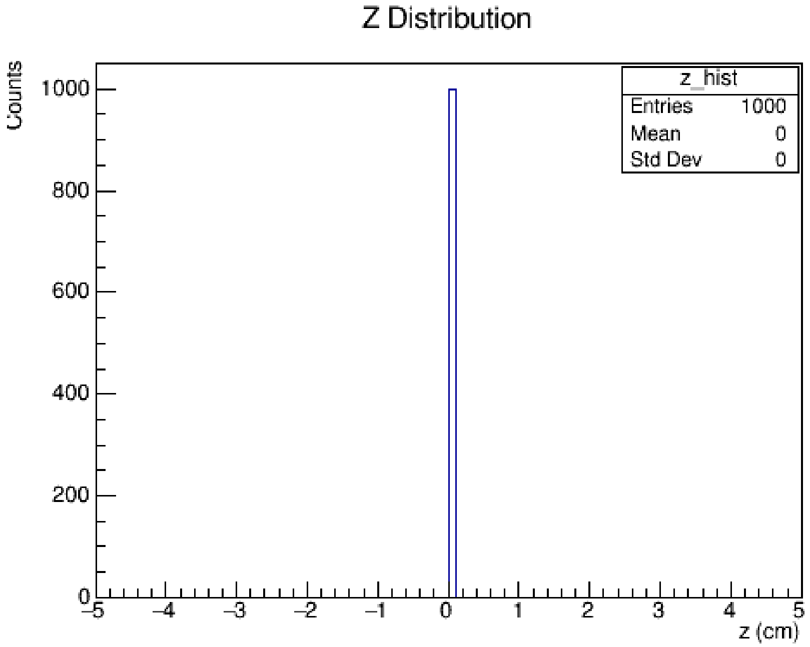


Scattered Electron Energy distribution

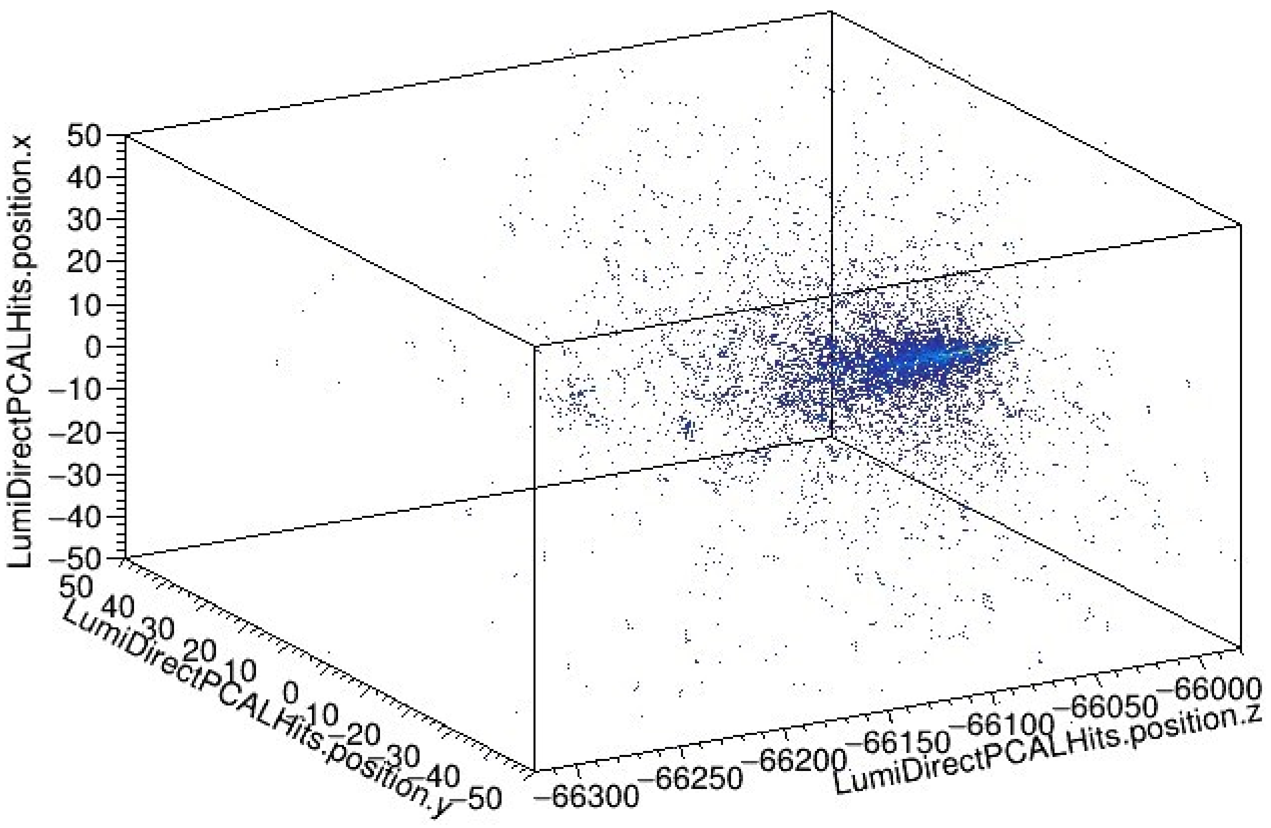
x y Distributions of the Incoming Bremsstrahlung Photons (with and without smearing) and Z (without Smearing) with Minimal energy - 100 MeV

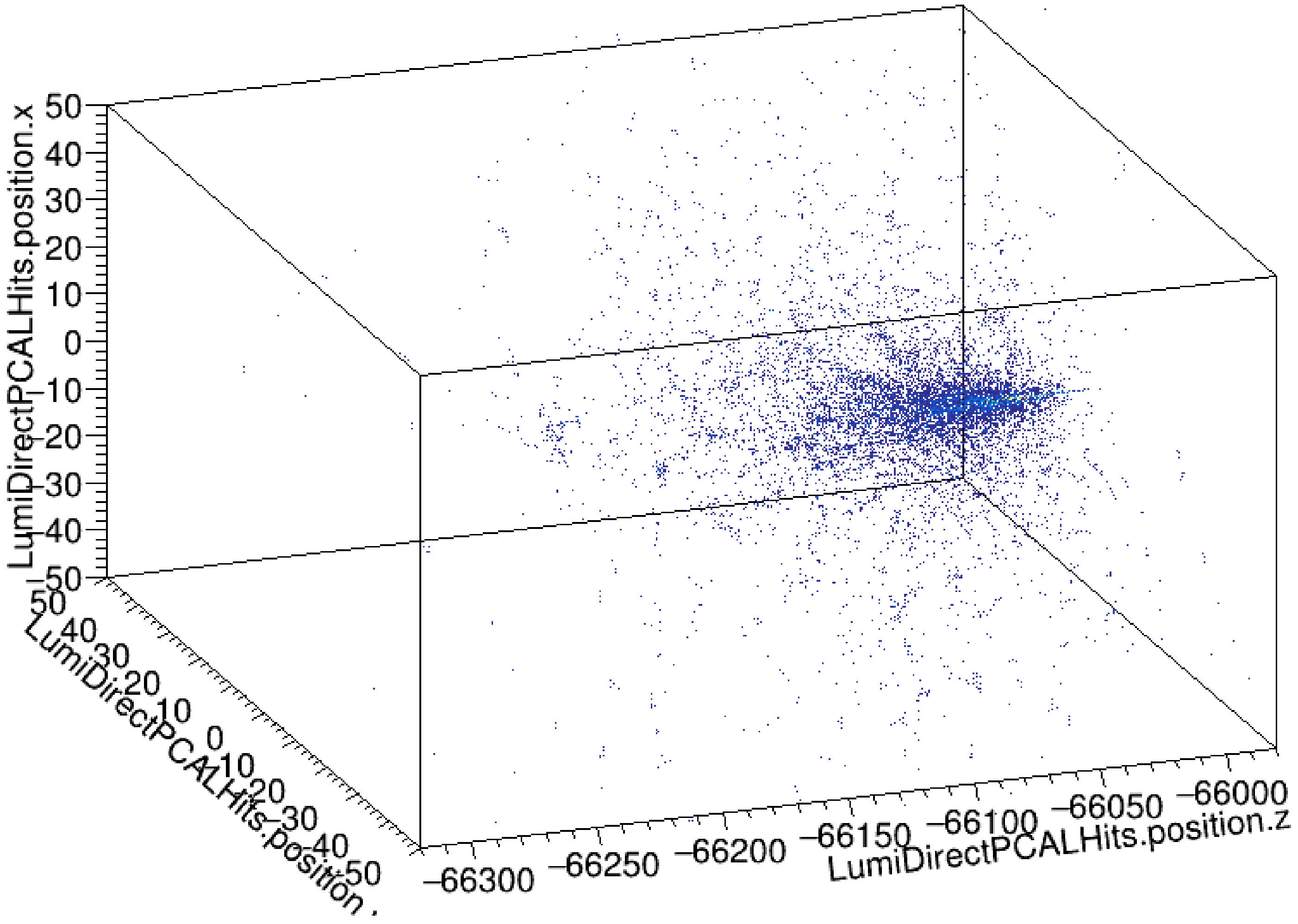






Visualization of 2 single events – 100 MeV Photons (Particle Gun)



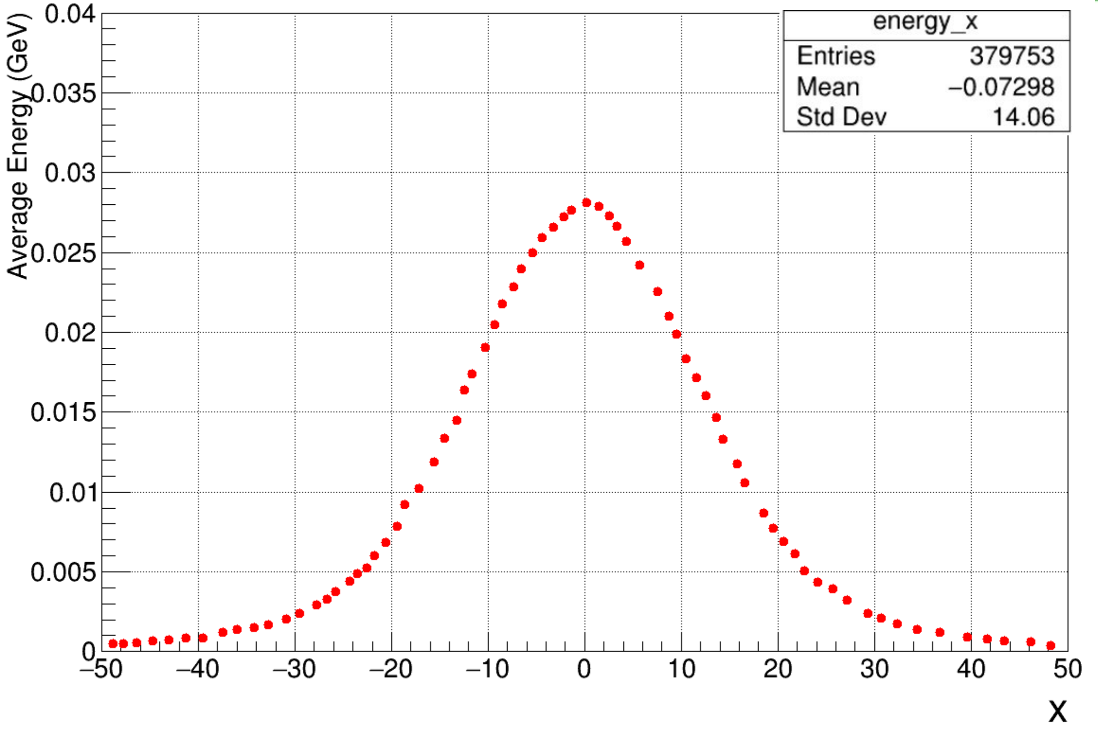


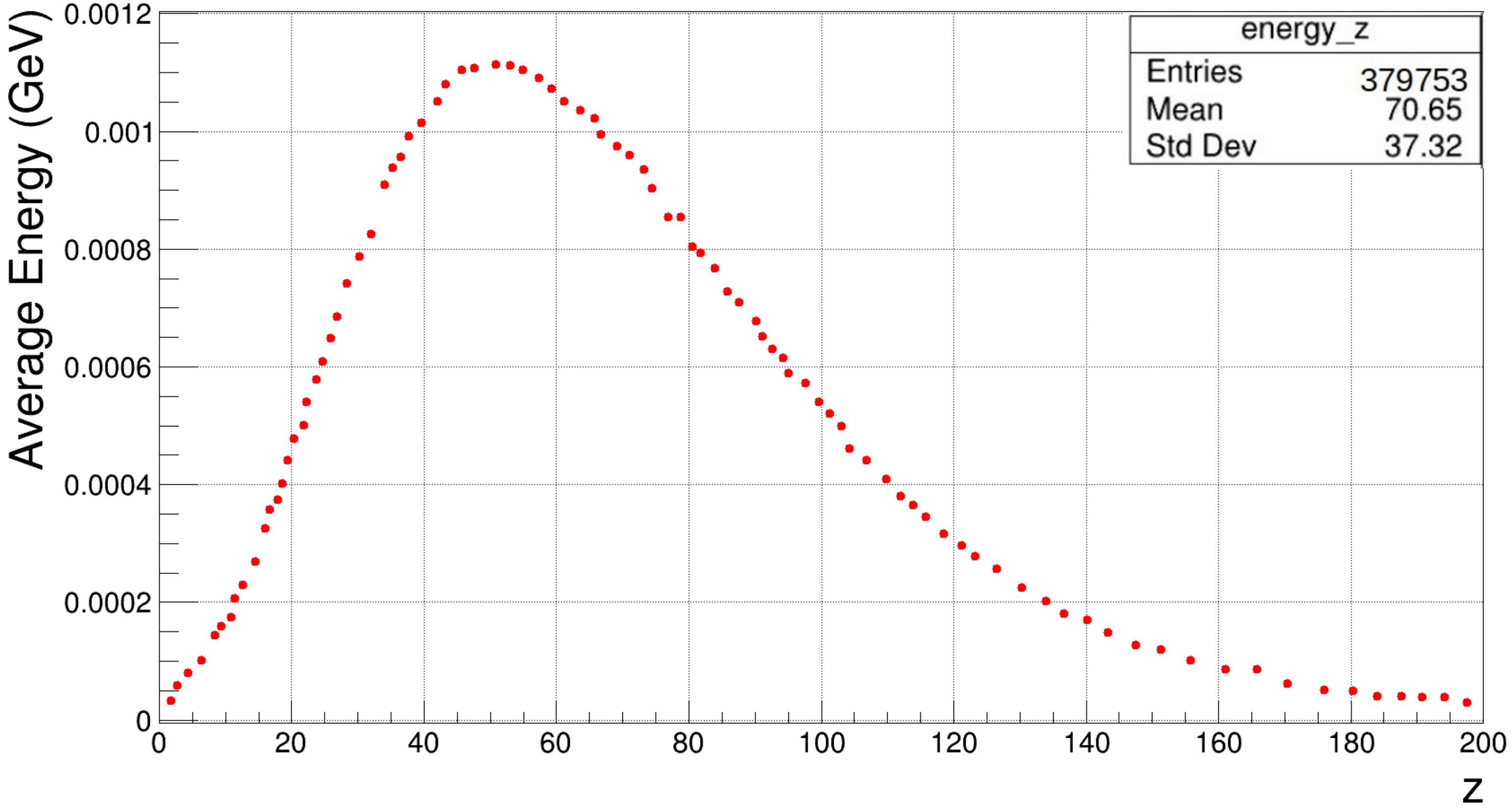
(All Dimensions in mm)

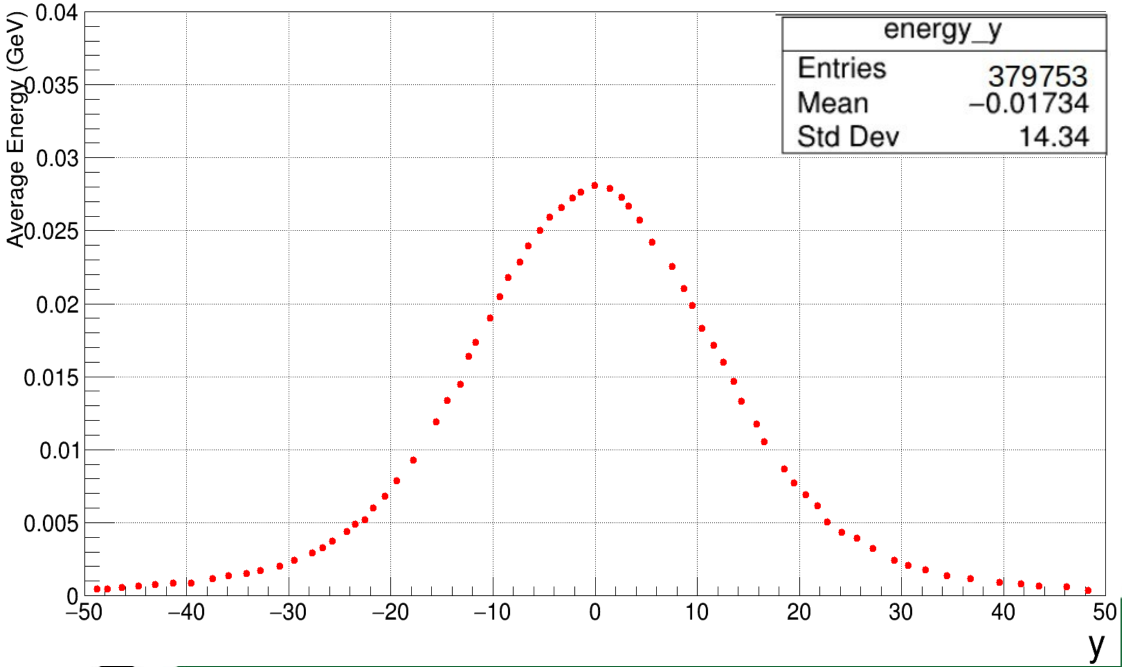
Results Presented in the upcoming Slides considered two cases:

1) With Smearing of 1cm (Smearing refer to Slide 7)
2) Without Smearing

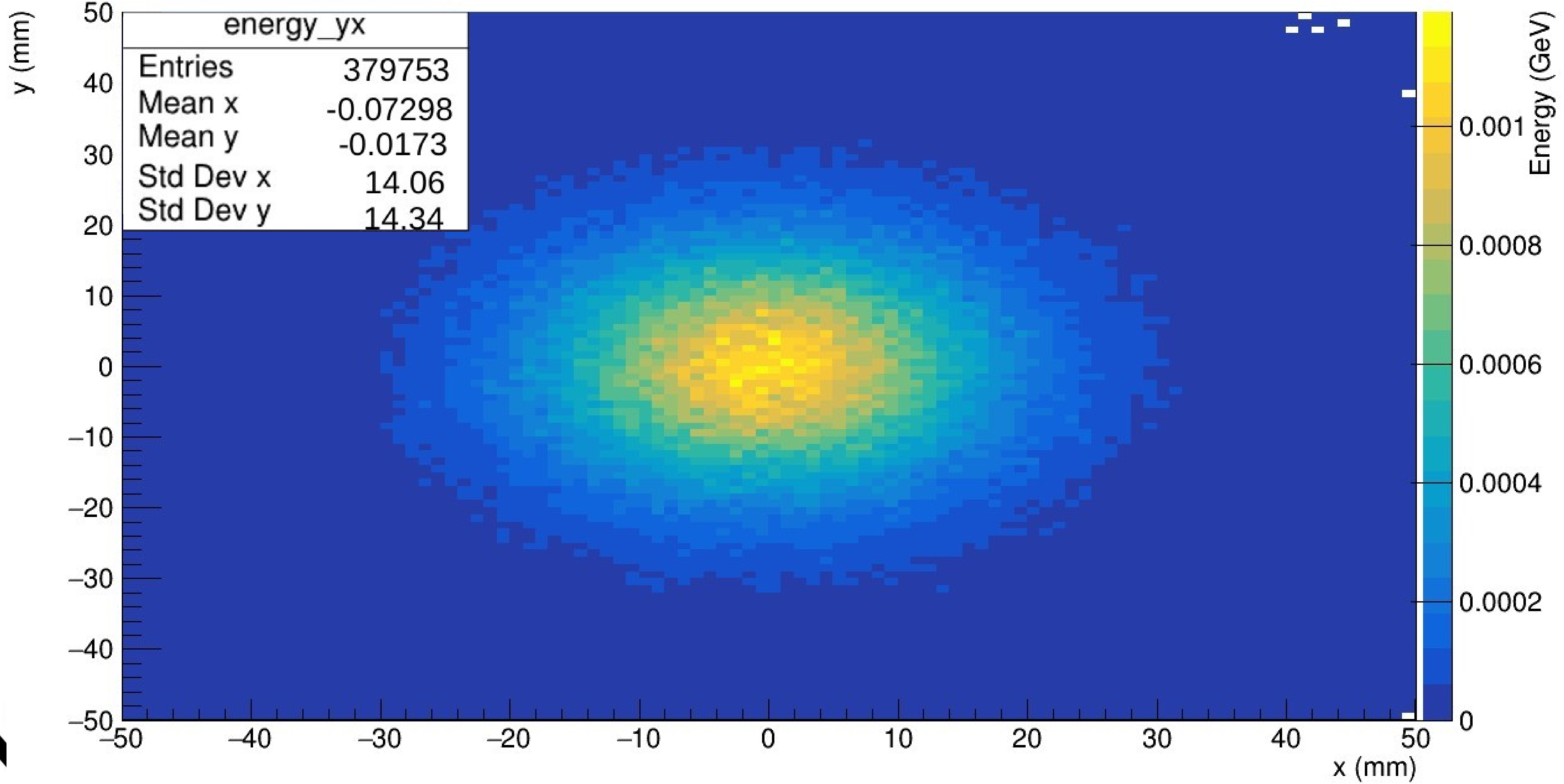
- 1D – distributions (With Smearing x, y) for PbWO4 Crystal
- Calorimeter 1000 Events







- Sum of Energy Deposits in PbWO4 Crystal Calorimeter
- 1000 Events - 10cm x 10cm x 20cm size of Calorimeter - With 1cm Gaussian smearing



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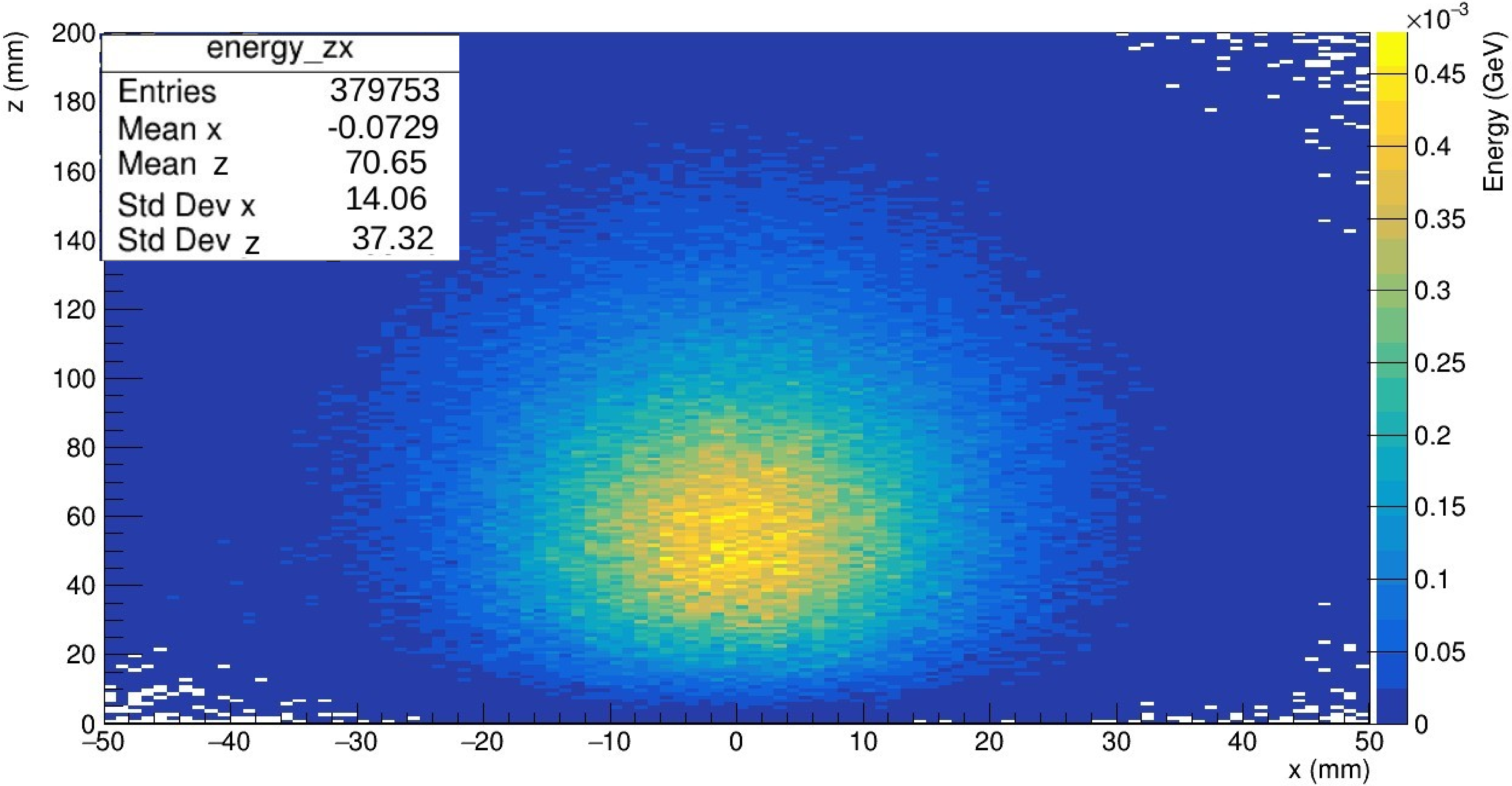

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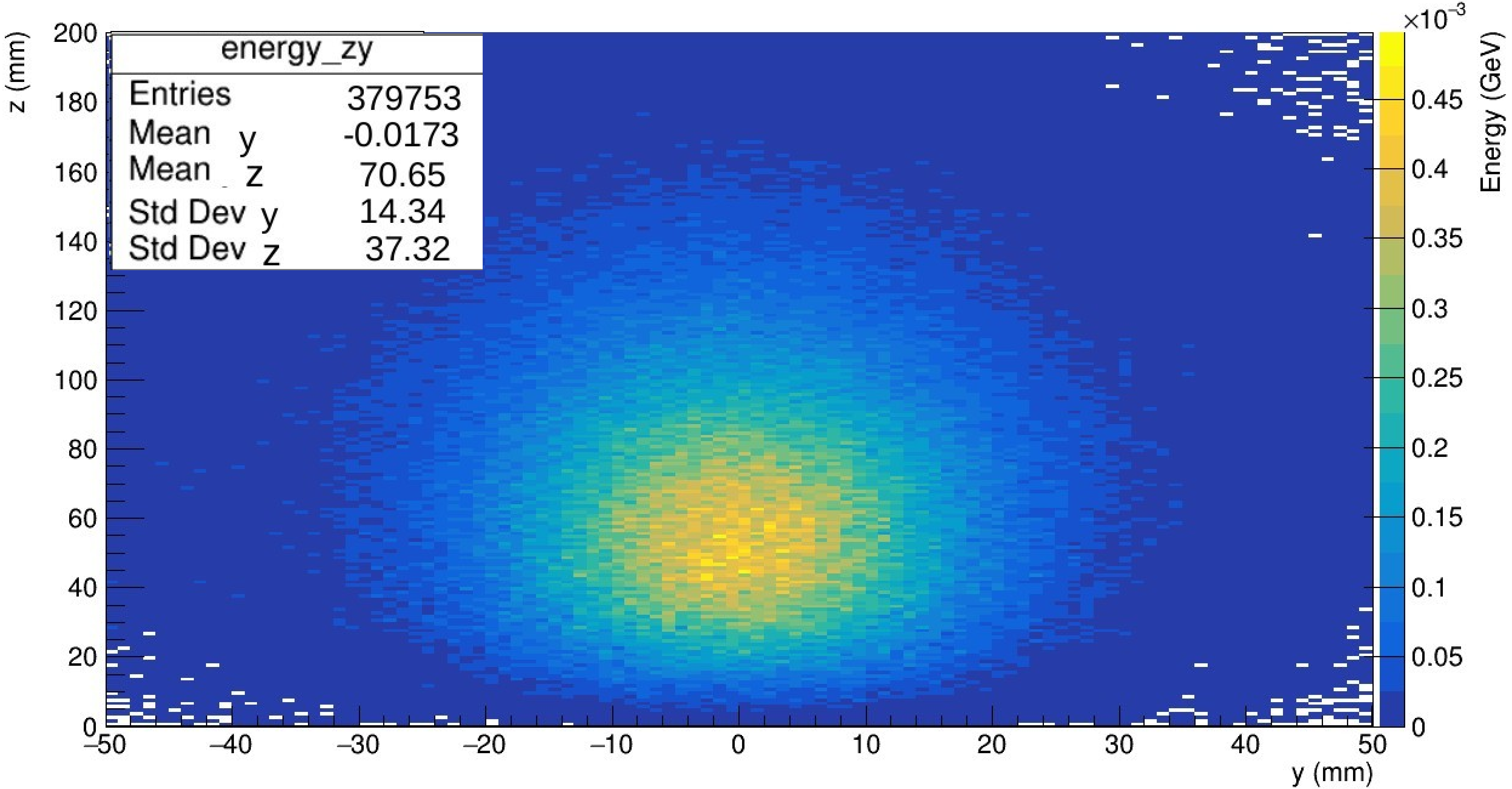
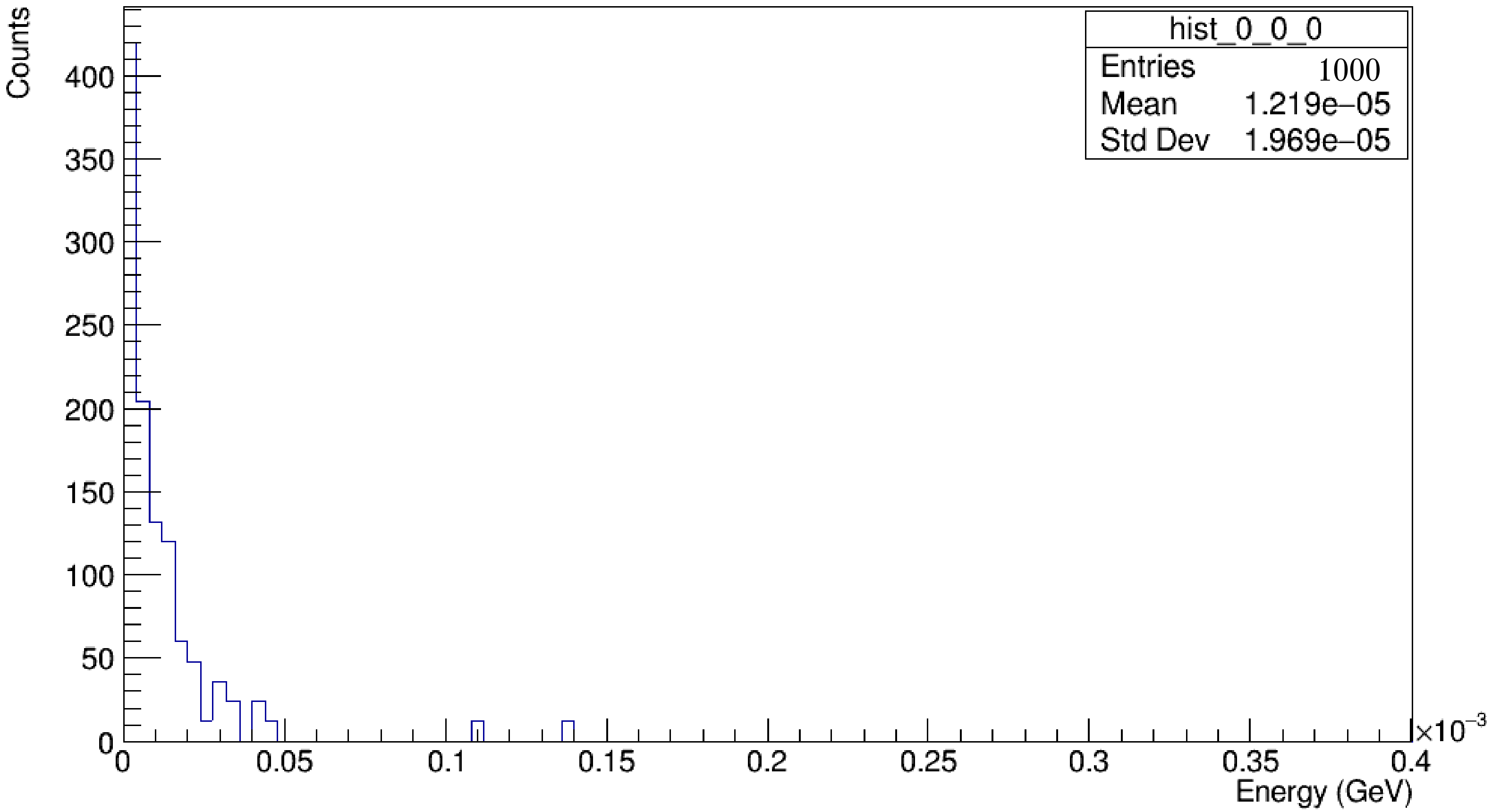


With Smearing

Hottest Cell(Crystal Case)
Highest average Cell Energy
= 0.0121 MeV

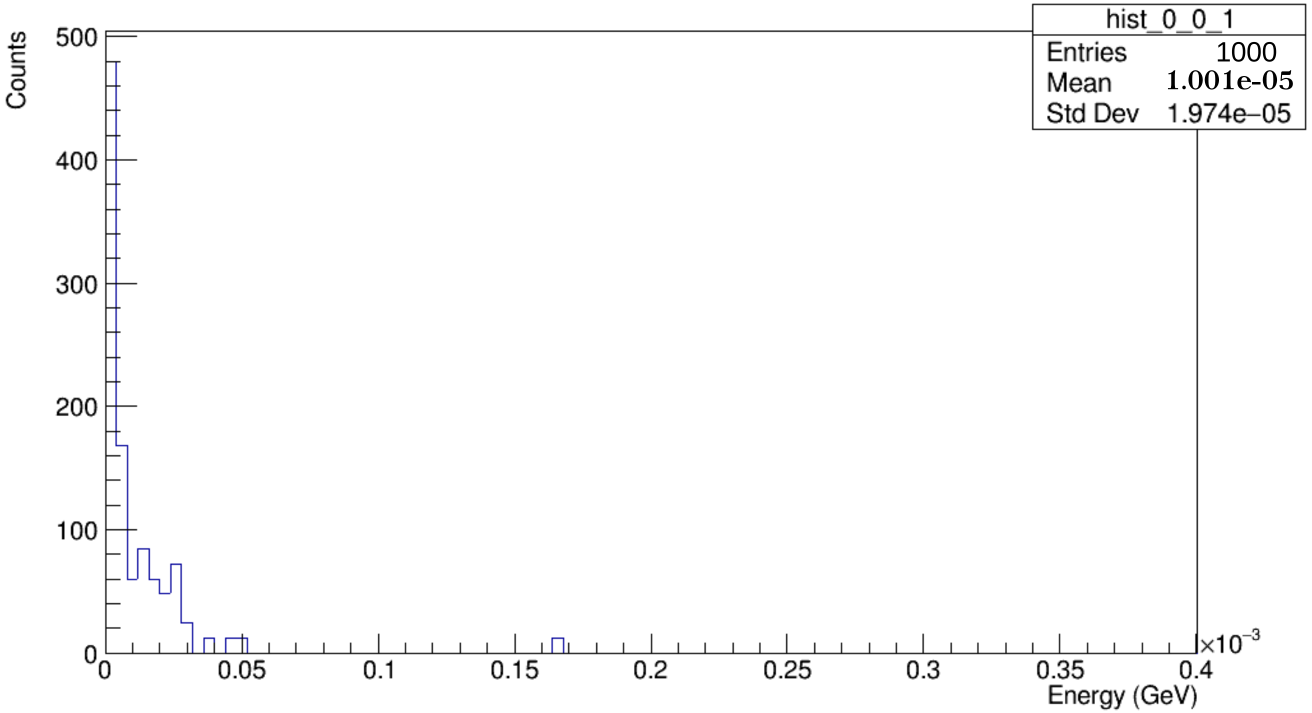
- 1000 Events
- 10cm x 10cm x 20cm
- Cell size = $1mm^3$



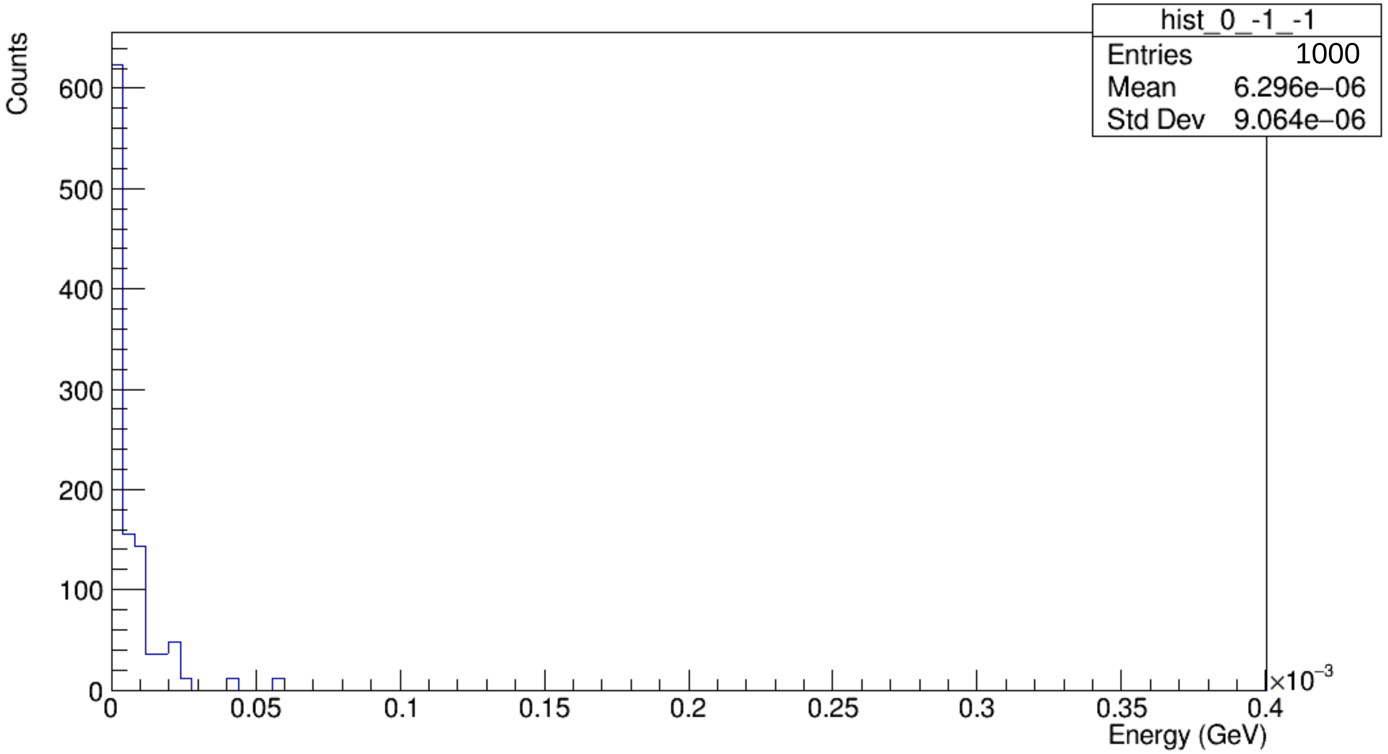
Coordinates x y z (0,0,51)

With Smearing Neighbouring Cells (Crystal Case)

1000 Events cell size = $(1mm)^3$



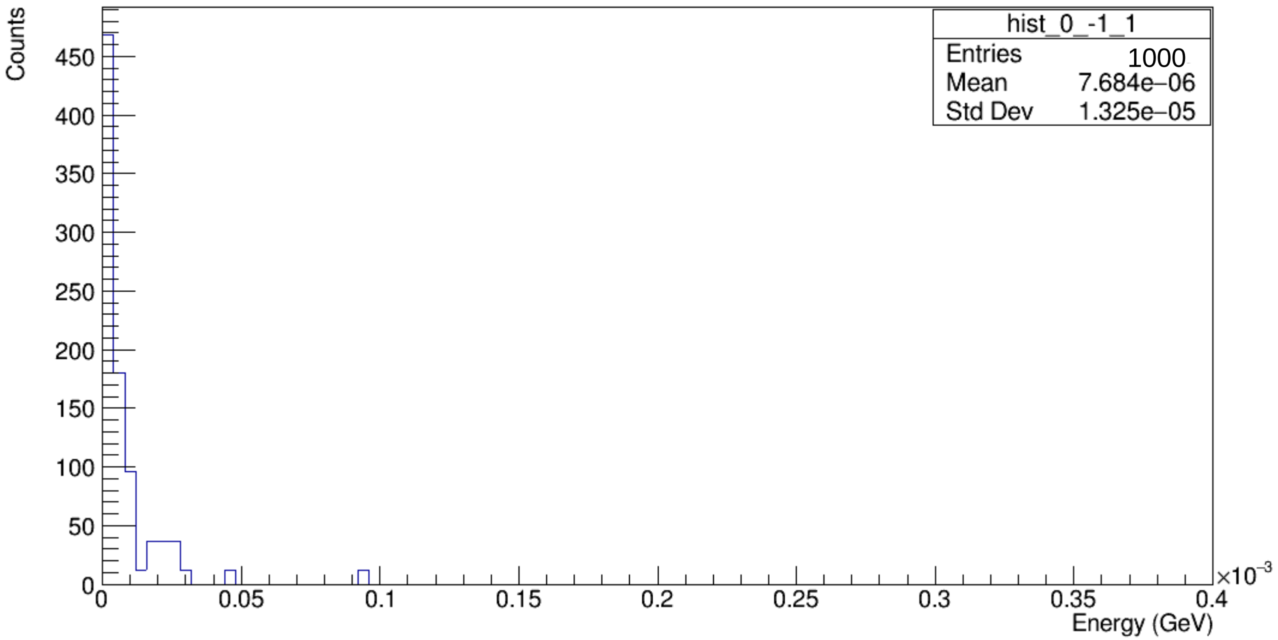
Coordinates x y z (0,-1,50)

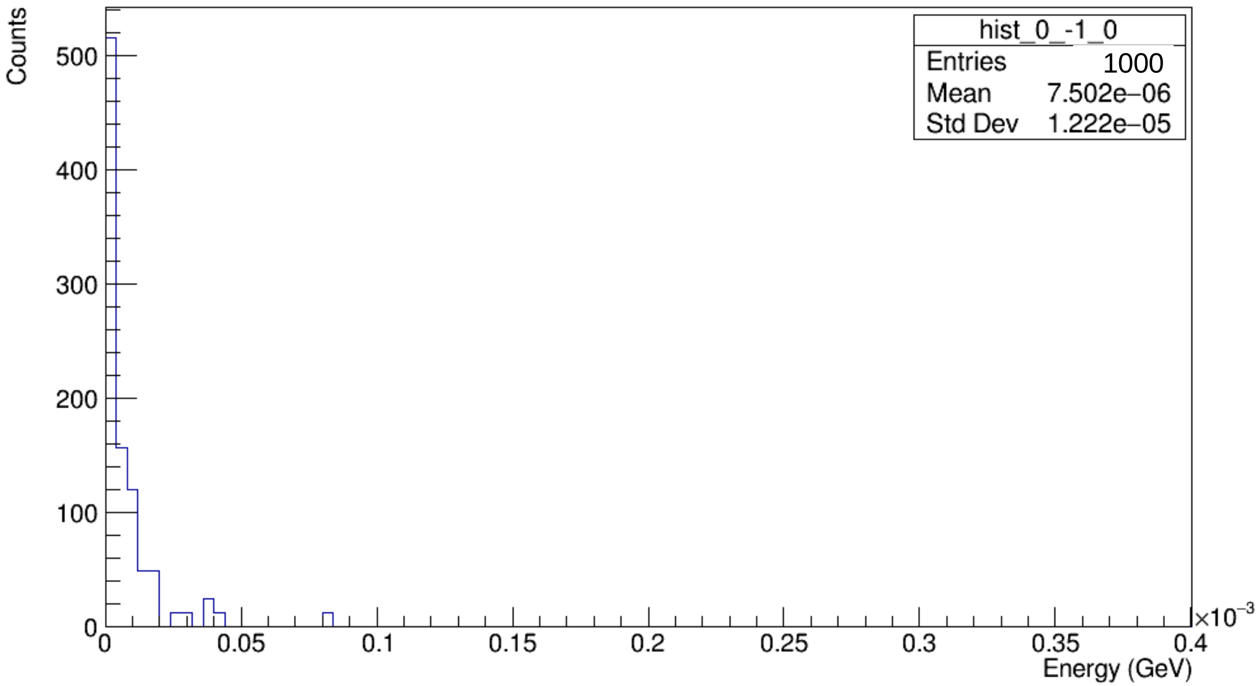


Coordinates x y z (0,1,49)

With Smearing Neighbouring Cells (Crystal Case)

1000 Events cell size = $(1mm)^3$

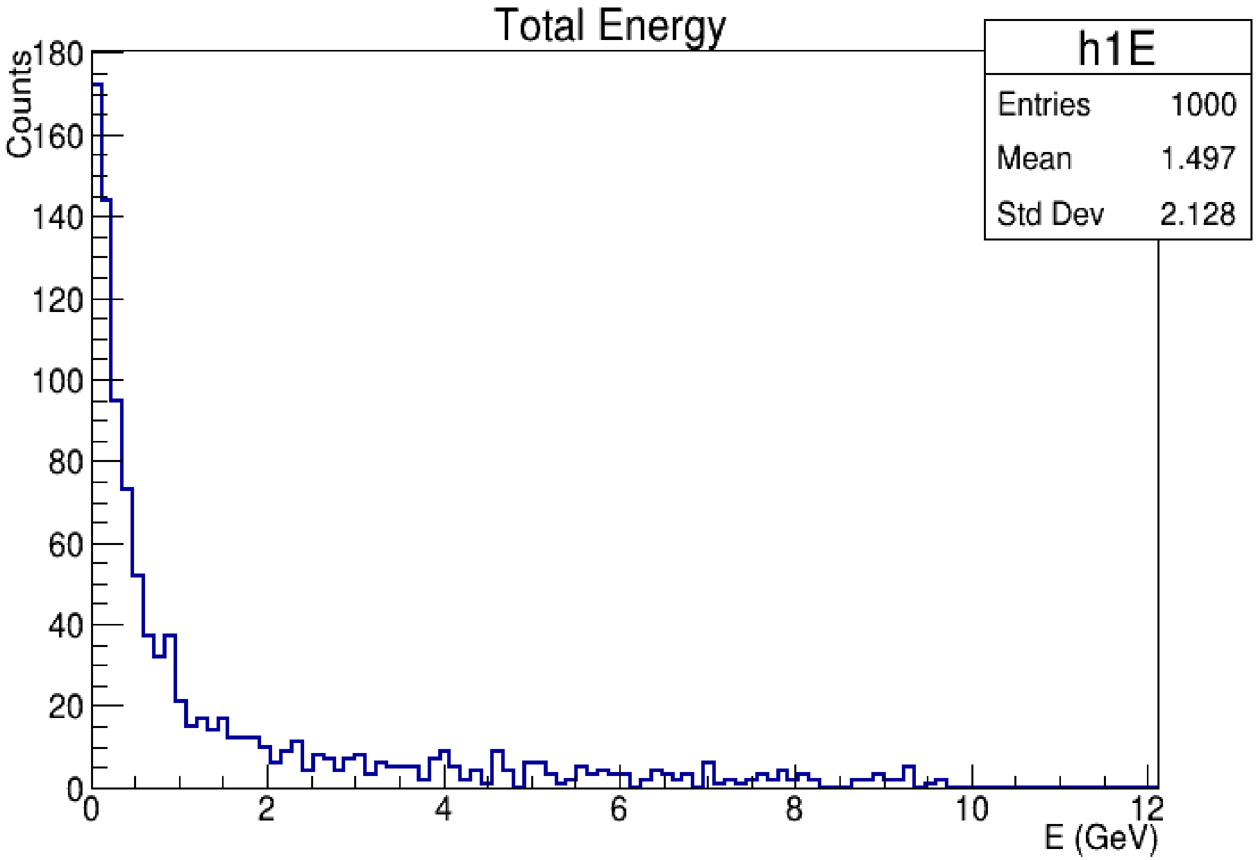


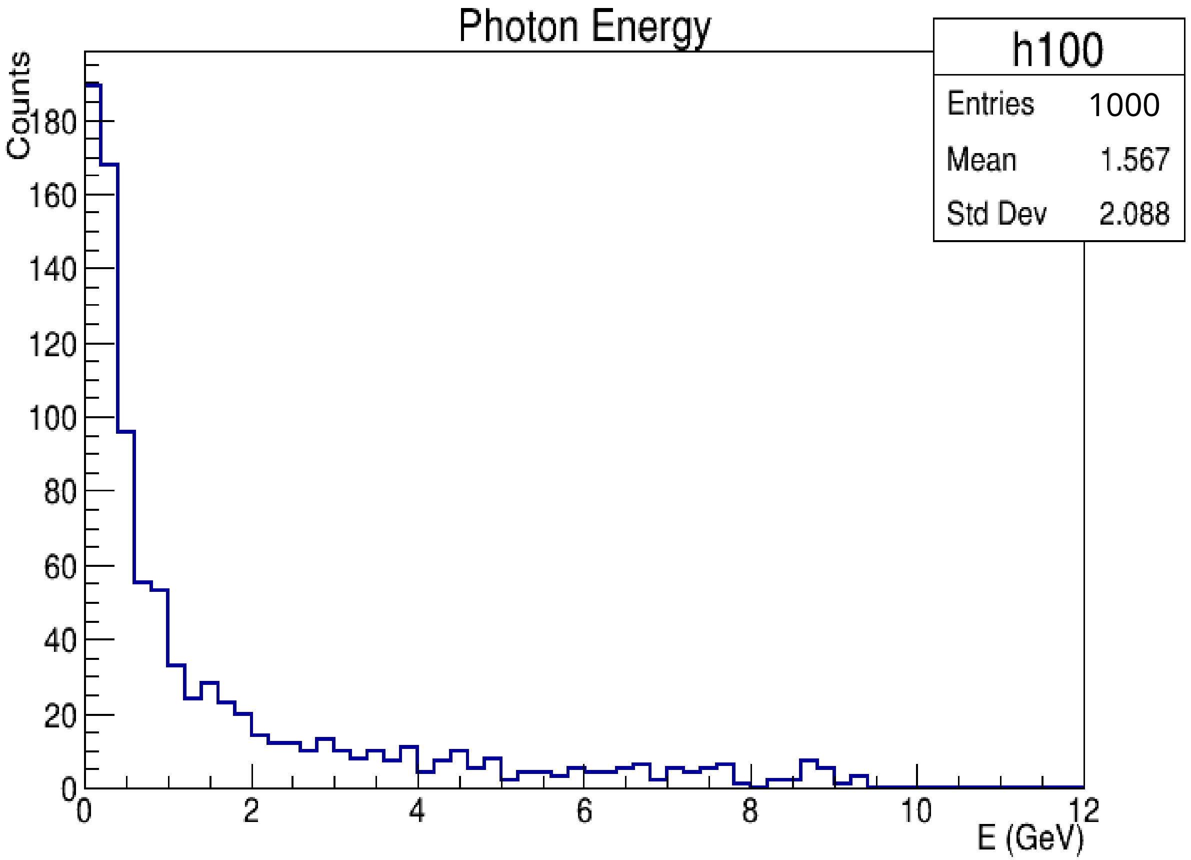


Coordinates x y z (0,-1,50)

Coordinates x y z (0,1,52)

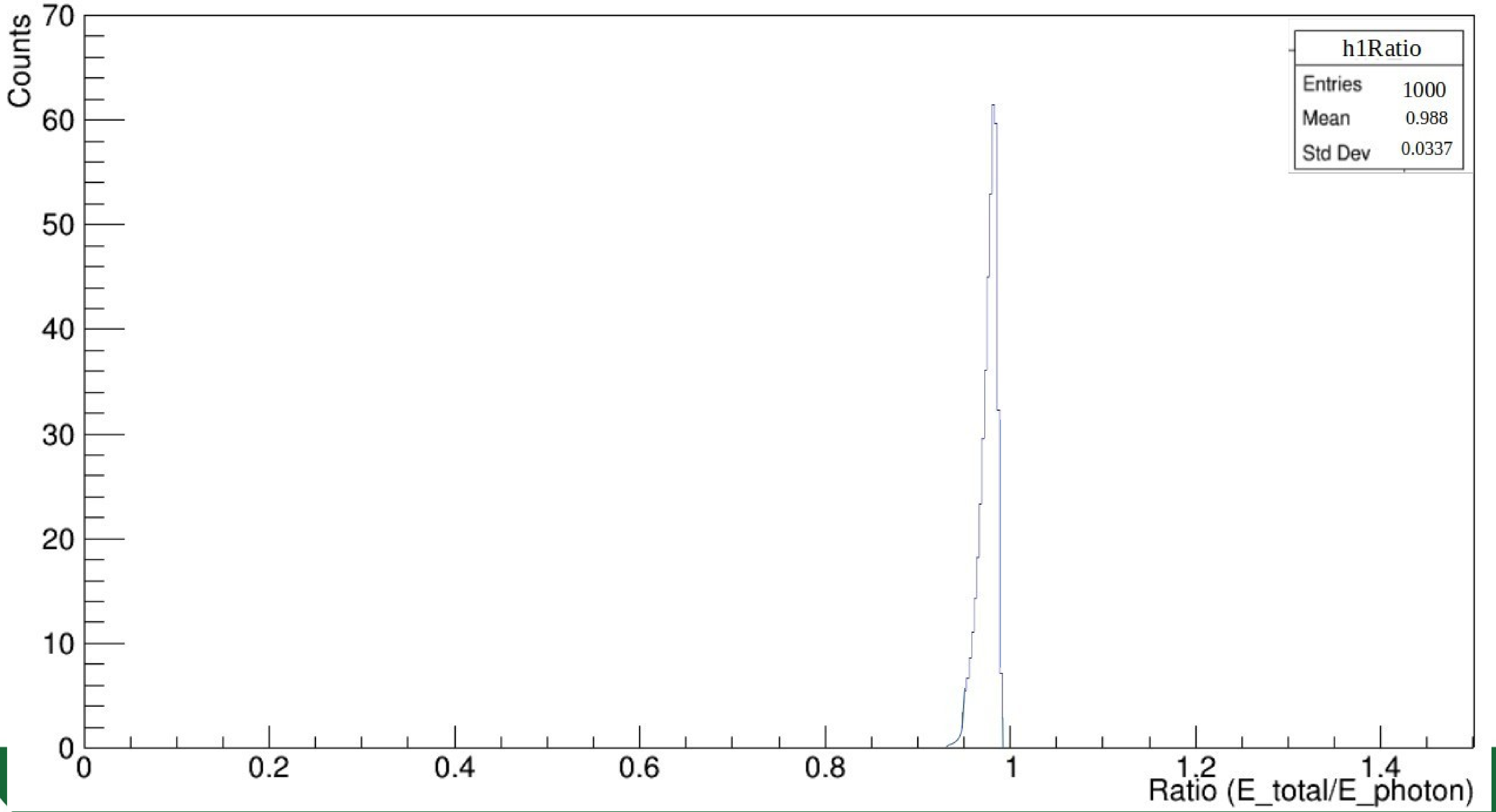
Total Energy Deposit in Crystal and incoming Photon Energy distributions





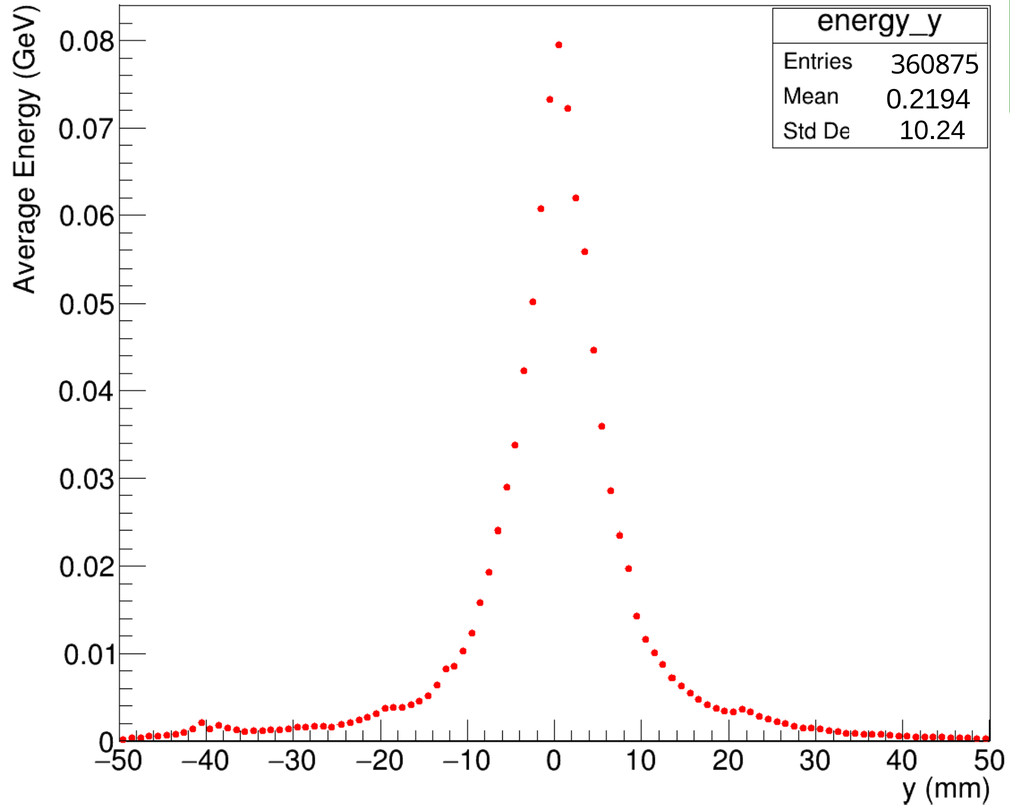
Same Photon Energy Distribution as on slide 7

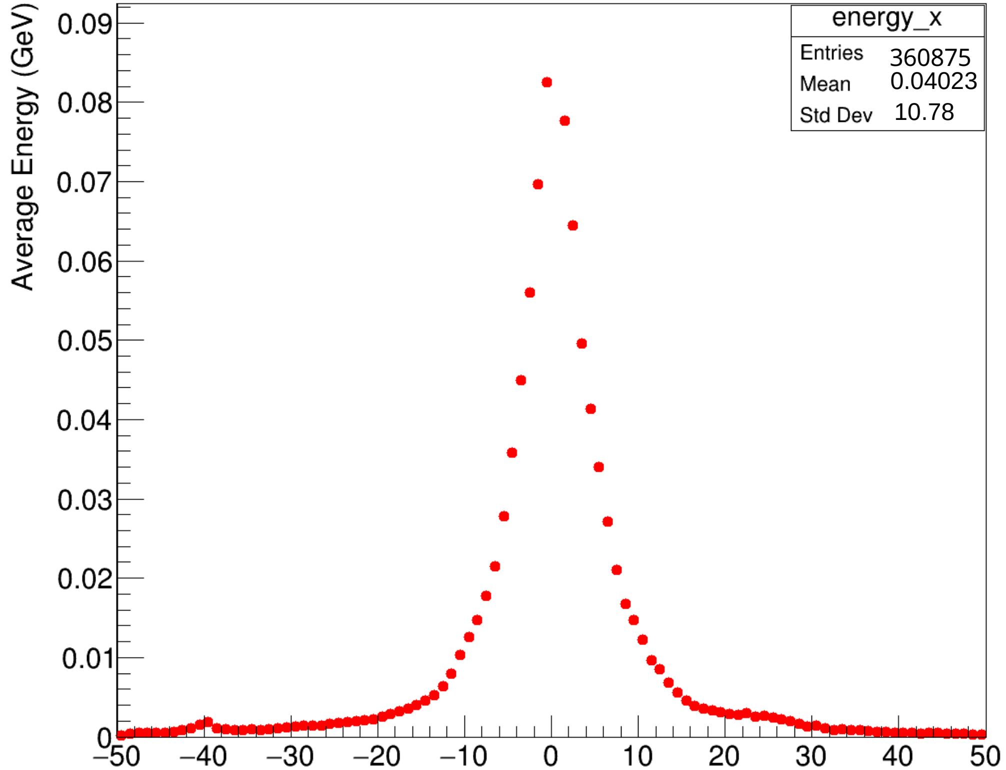
Ratio of Total Energy Deposit in Crystal and incoming Photon Energy distributions

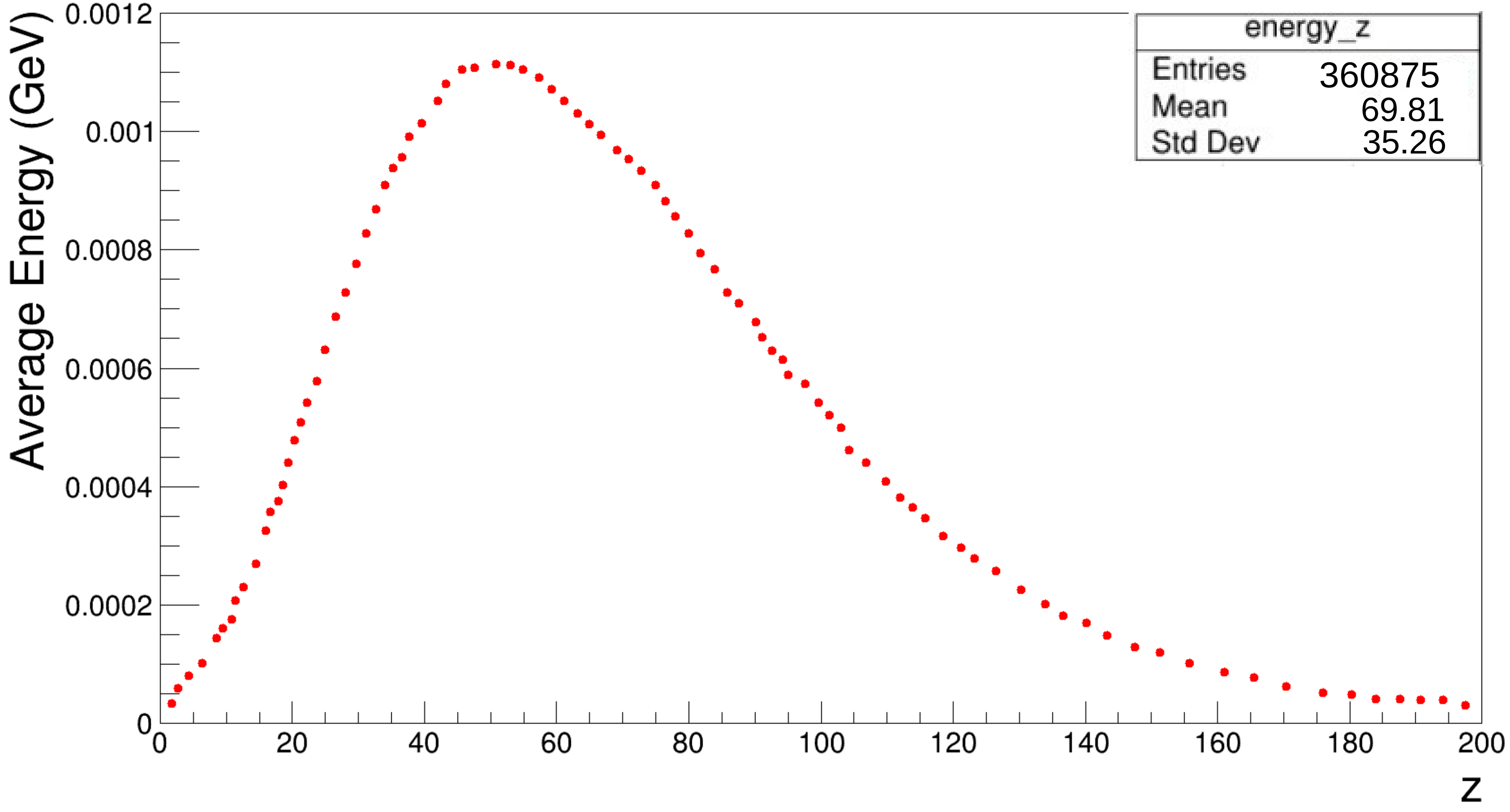


2) Without Smearing

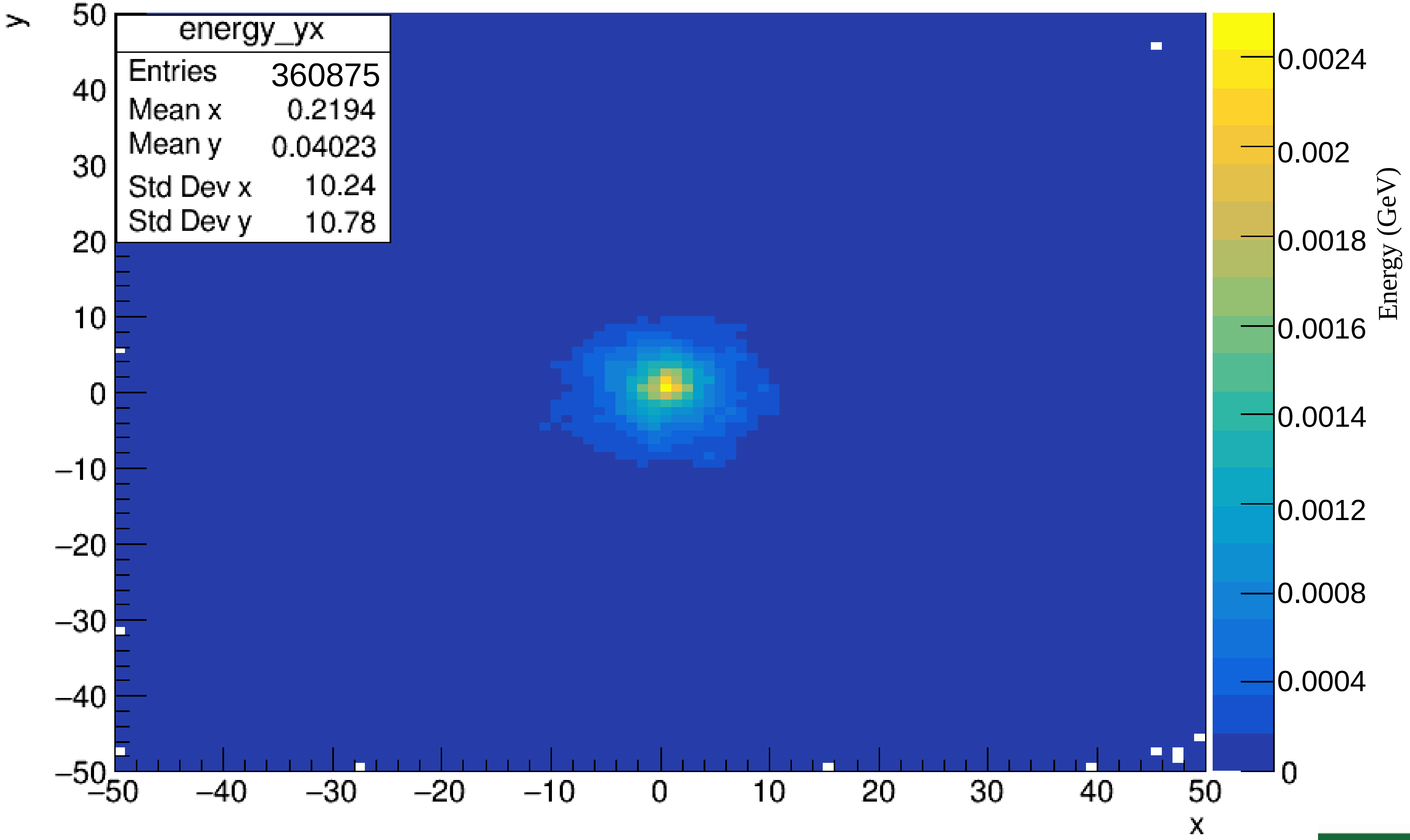
- 1D – distributions (With out Smearing x, y) for PbWO4 Crystal
- Calorimeter 1000 Events







Sum of Energy Deposits in PbWO4 Crystal Calorimeter
1000 Events - 10cm x 10cm x 20cm size of Calorimeter - No Gaussian smearing



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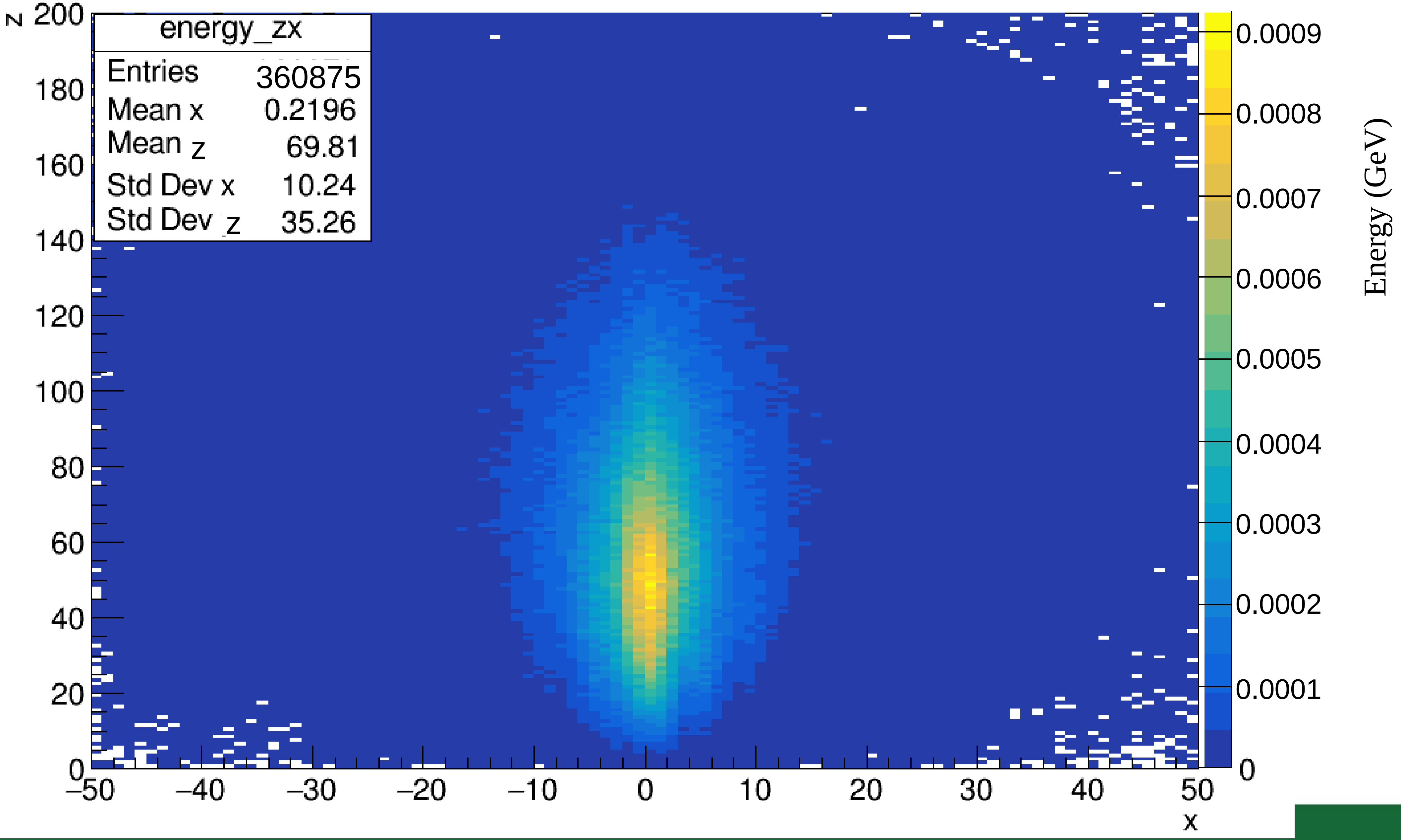

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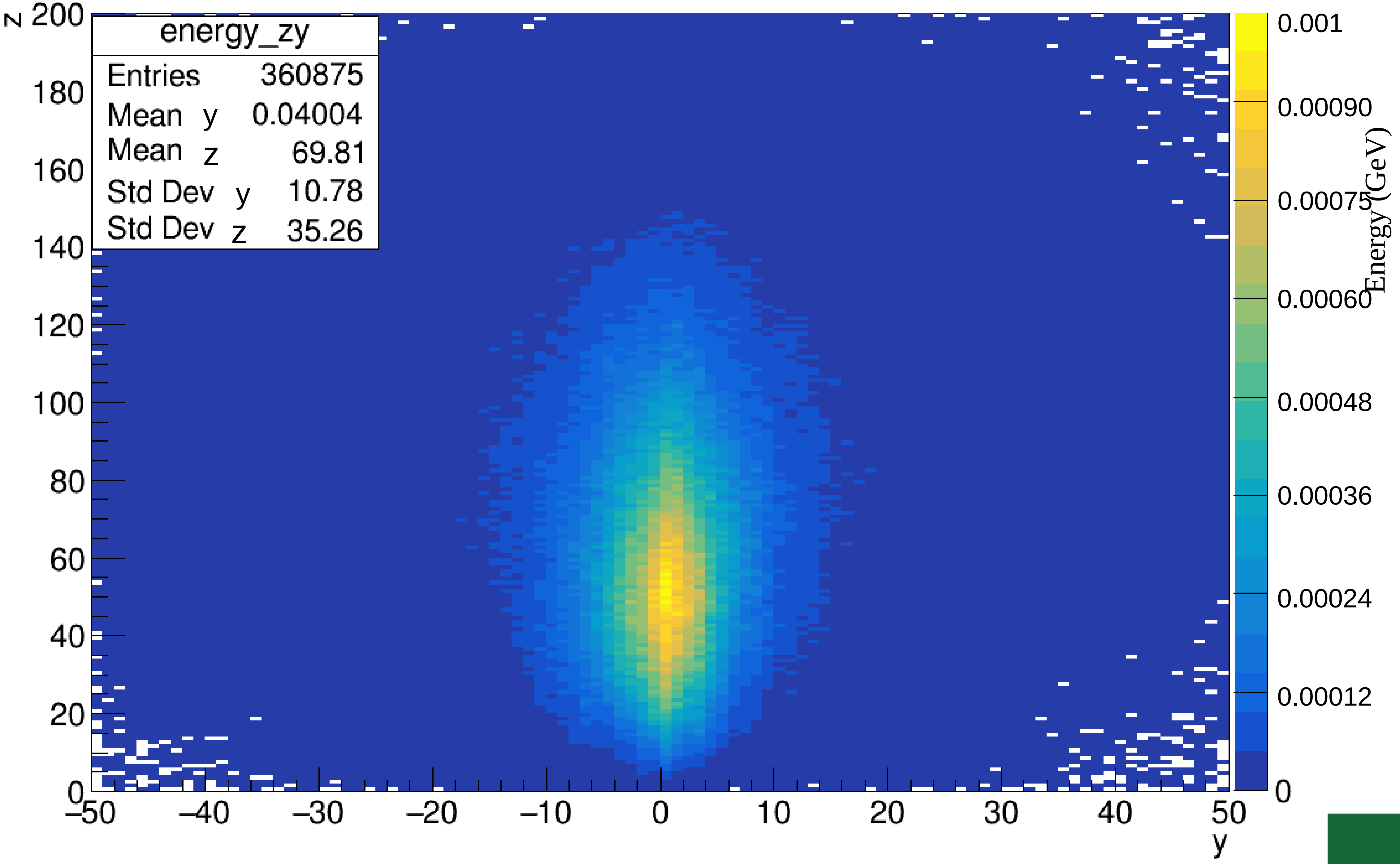
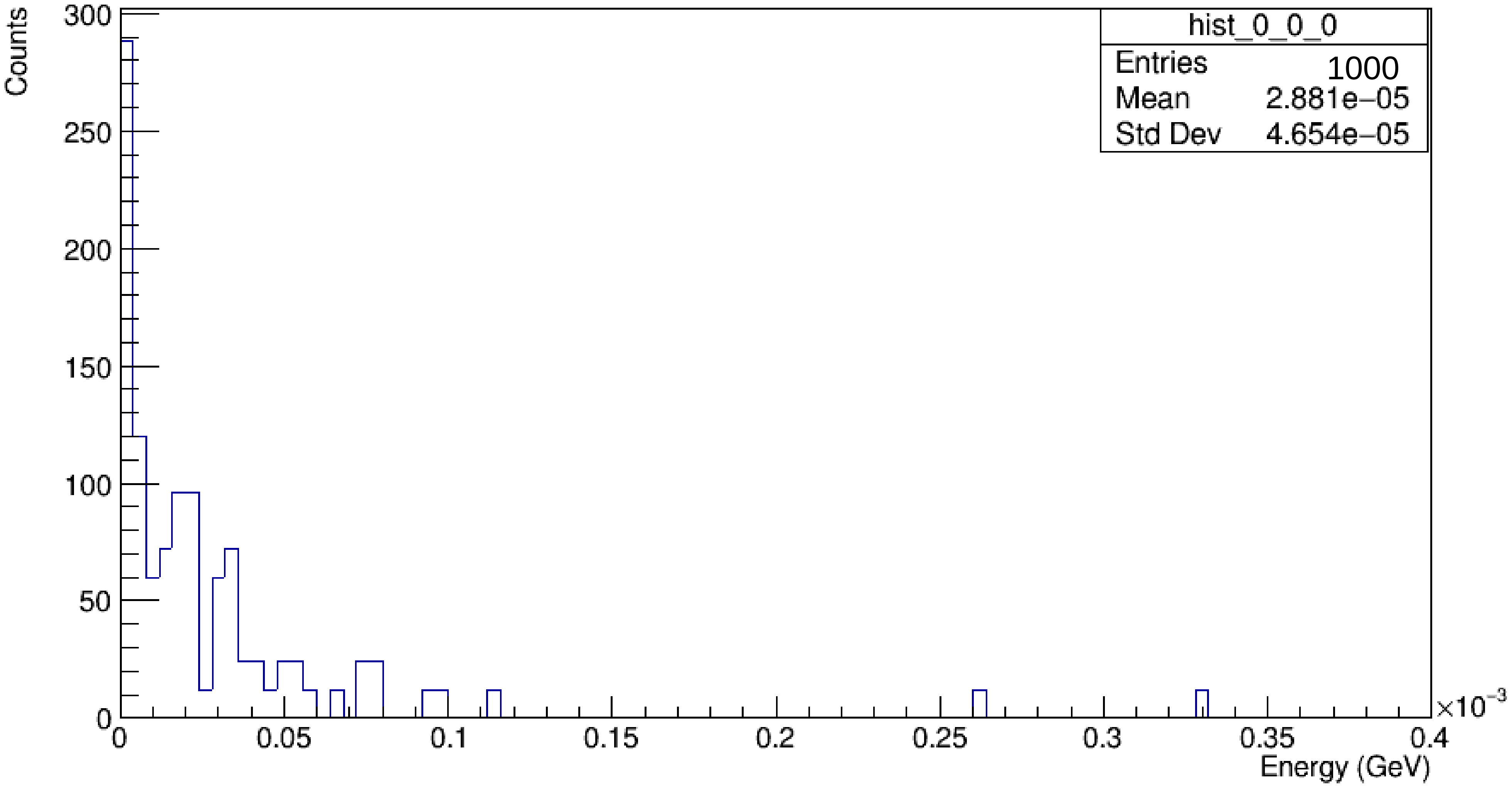


With-out Smearing

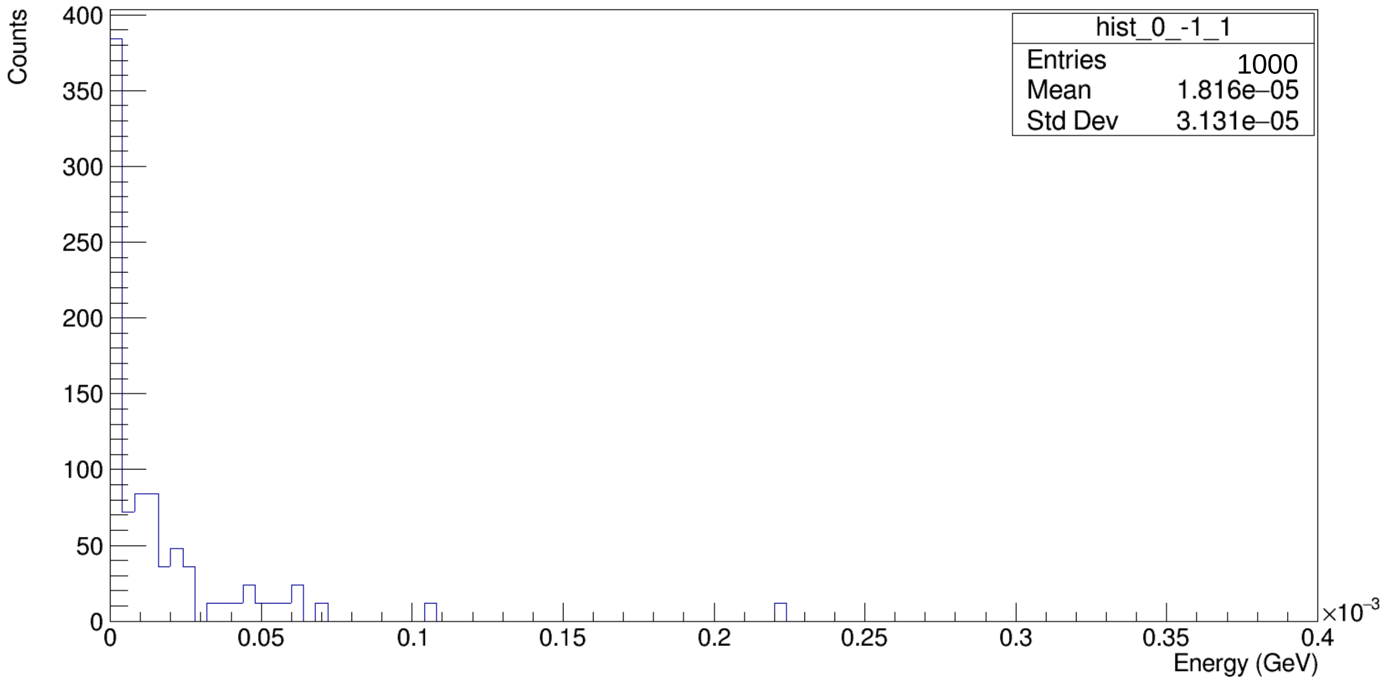
Hottest Cell(Crystal Case)

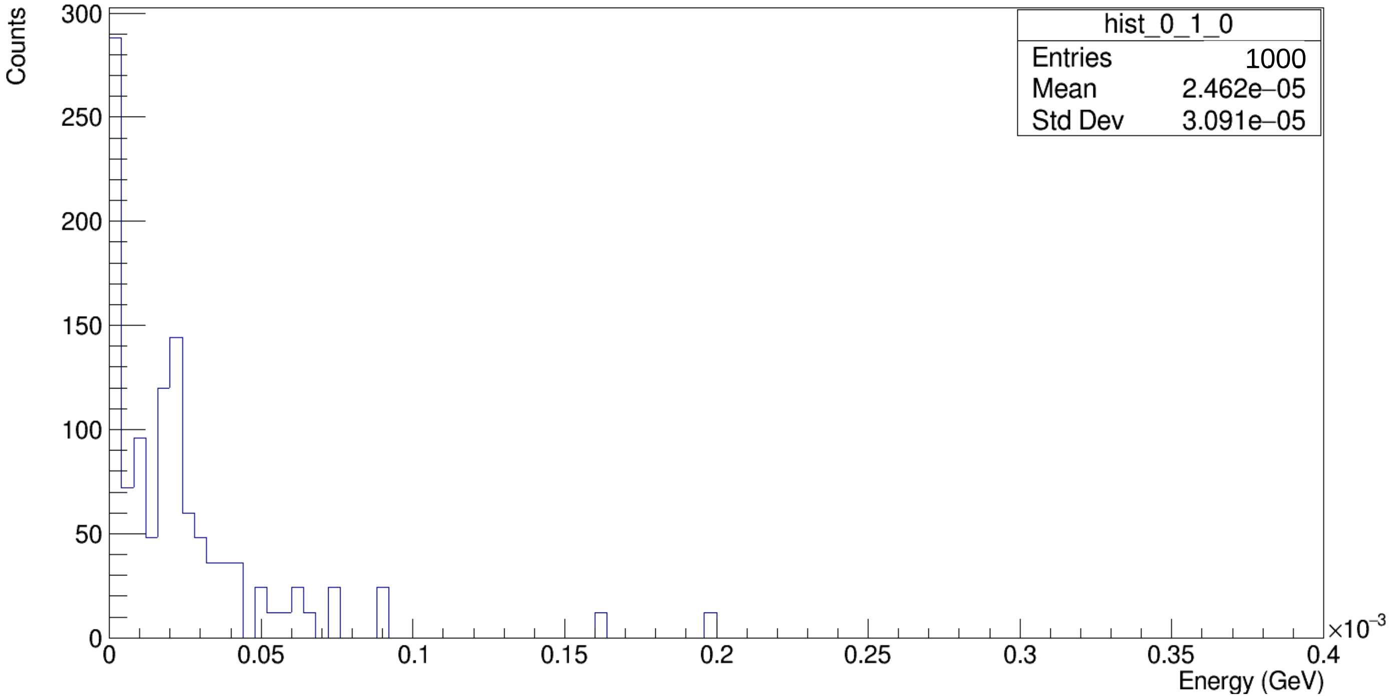
Highest average Cell Energy = 0.0288 MeV

1000 Events
10cm x 10cm x 20cm
Cell size = 1mm^3



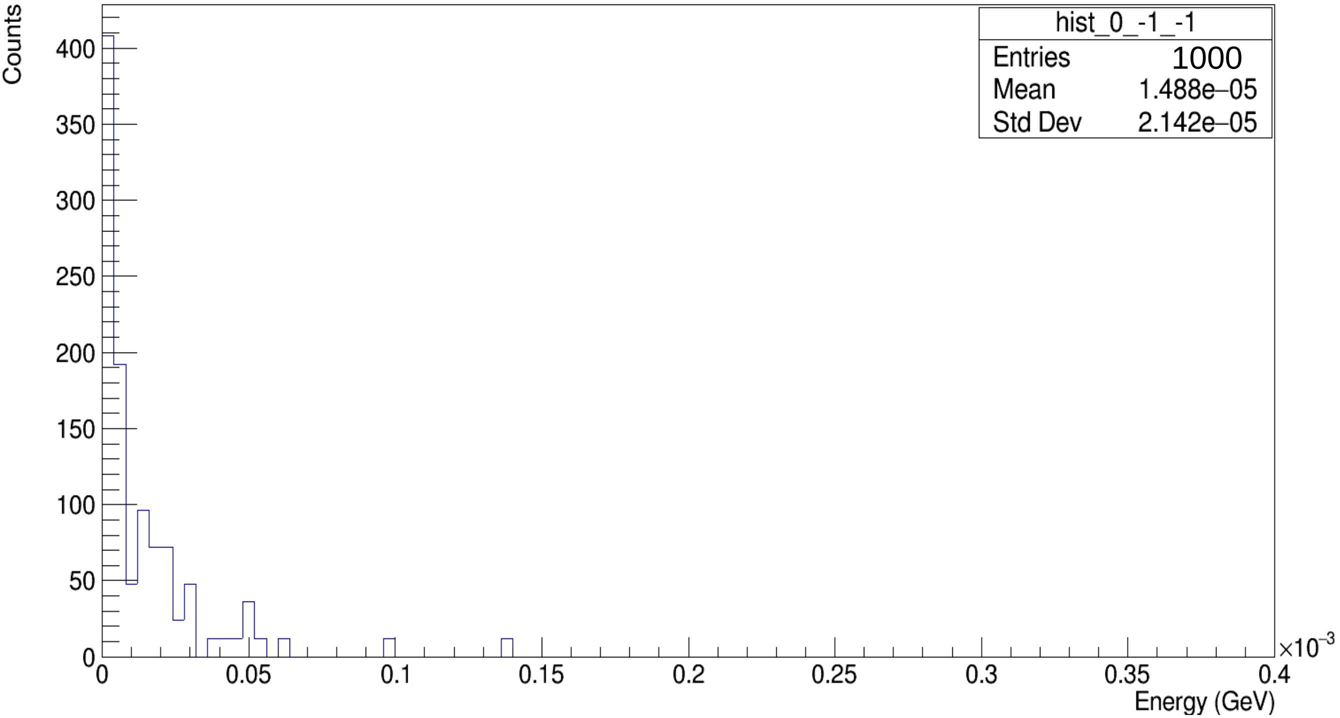
Coordinates x y z (0,0,50)



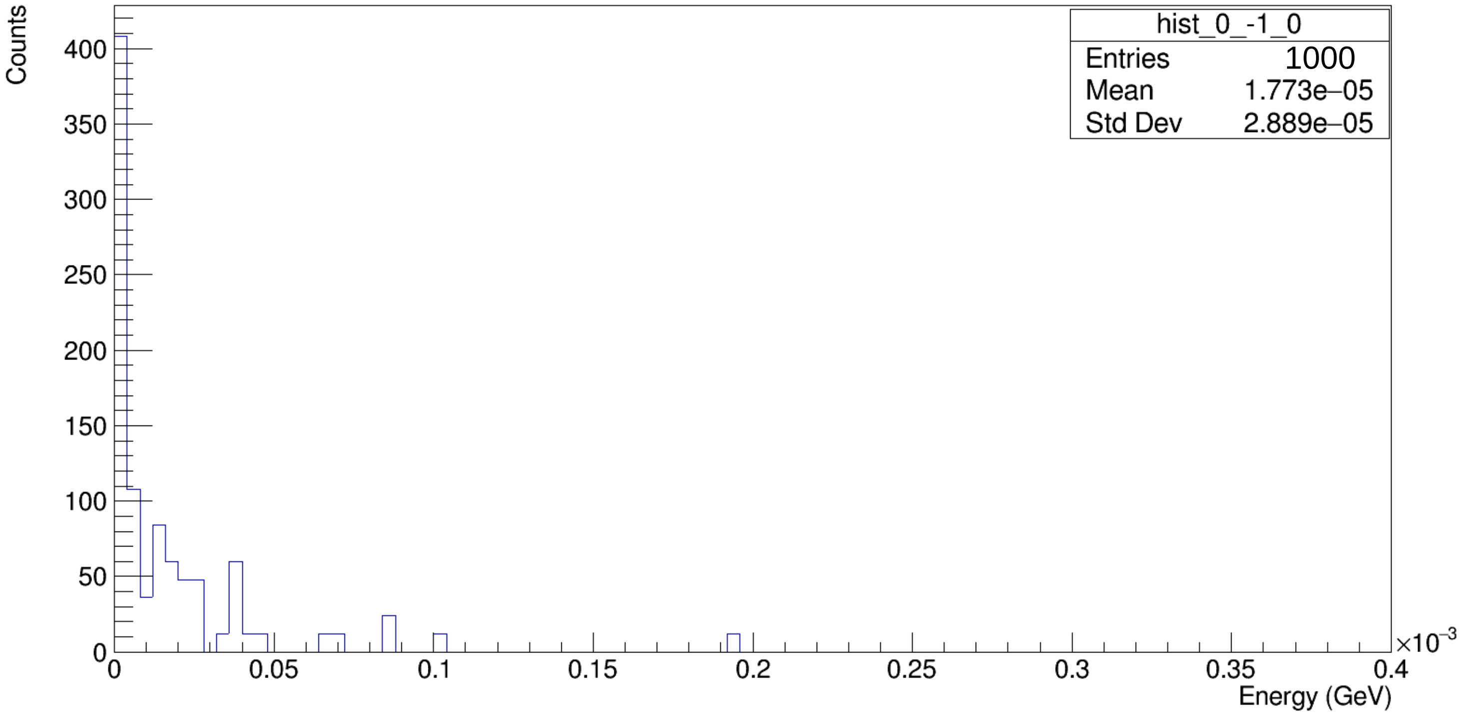


Coordinates x y z (1,0,49)

Coordinates x y z (0,-1,51)



Coordinates x y z (0,1,49)



Coordinates x y z (-1,0,50)

DD4hep based PbWO4 Crystal Calorimeter Geometry

Limitations of PbWO4 crystals:

1) Radiation damage

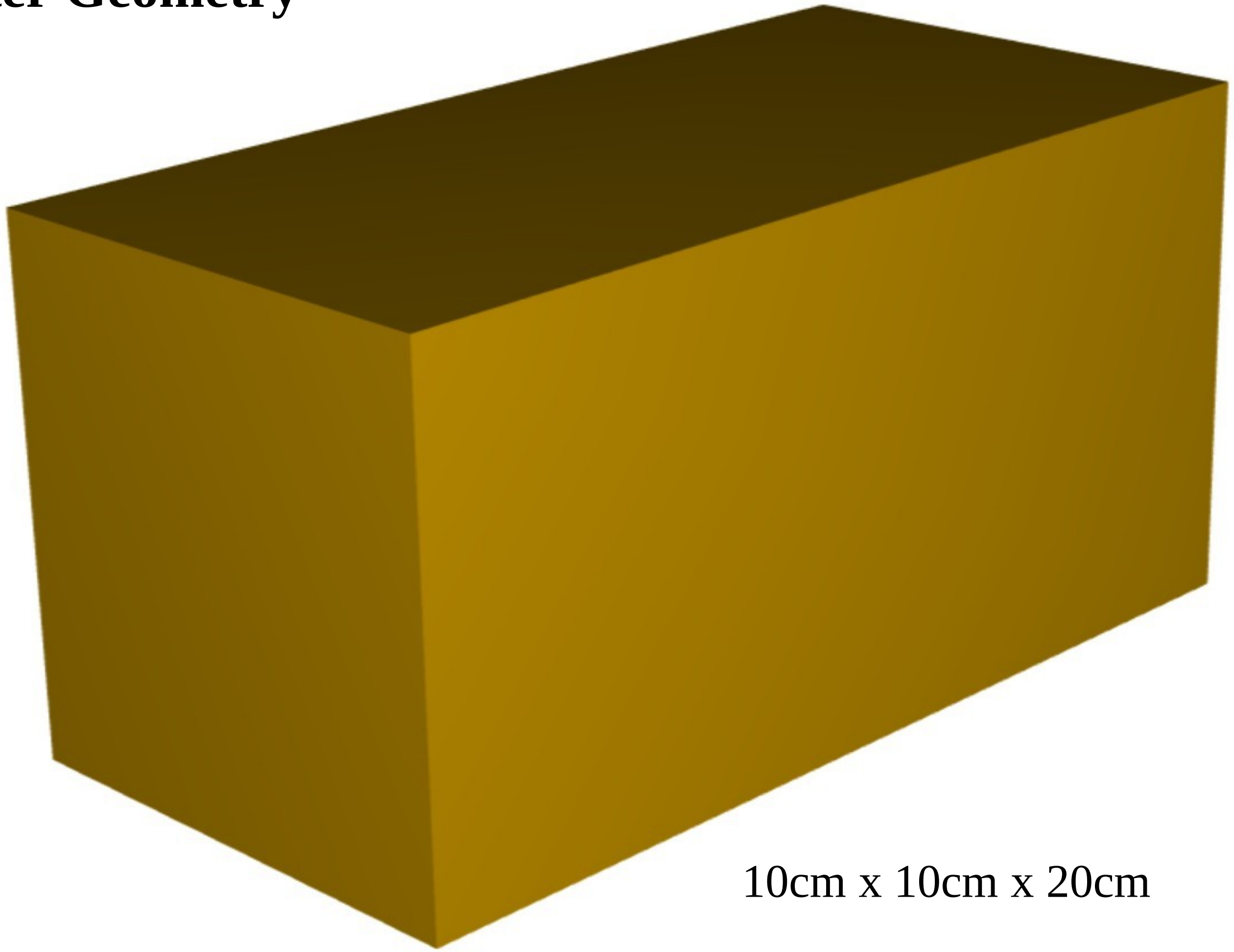
2) Temperature sensitivity
3) Slow scintillation decay time
4) Hygroscopic nature
5) Limited light yield

- Advantages of SciFi (Scintillating Fiber) in Calorimeters:

High Resolution, Fast Response Time, Radiation Hardness

- Quartz Fibers in Calorimeters:

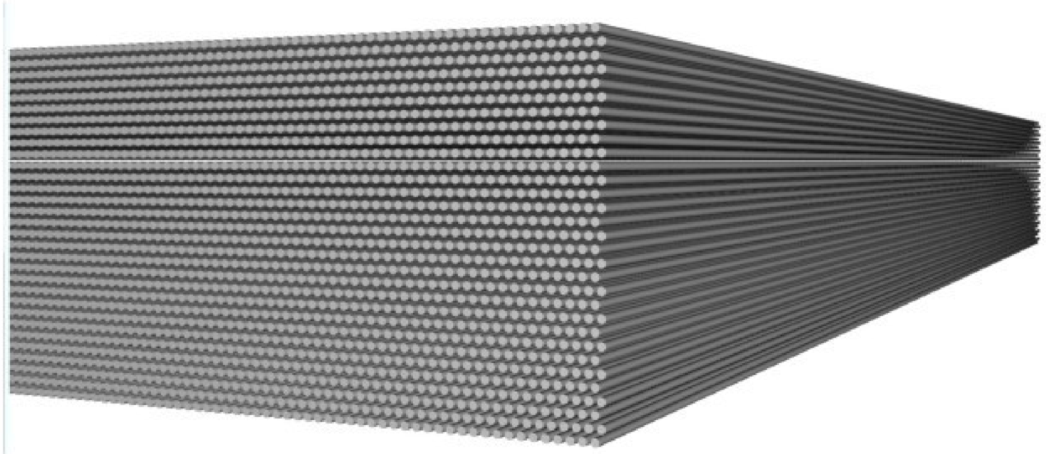
High Transparency, High Temperature Stability, Radiation Tolerance, Low Background Noise:

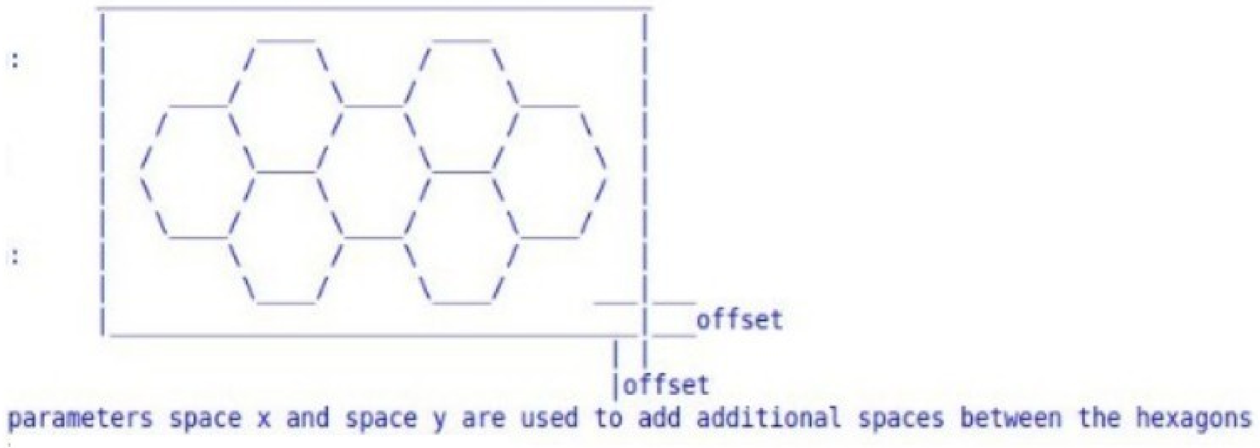


10cm x 10cm x 20cm

Base-Line Detector Technologies:

- Quartz fiber/tungsten spaghetti calorimeter for energy flow – maximal radiation hardness.
- Sci fiber/tungsten spaghetti calorimeter for single photon measurements – maximal energy resolution
- Active Layer: Fiber (Size: 1mm) - Absorber: Tungsten
- Fibers are placed in a honeycomb and each fiber is fully contained in a regular hexagon
- Calorimeter is tilted at 5°/10° to avoid anomalous events when bremsstrahlung photons can directly hit a fiber





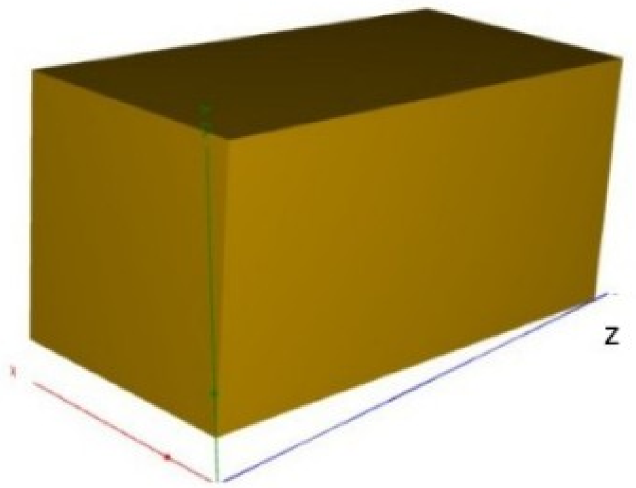
Fibers placed in a honeycomb with the radius = sqrt(3)/2. * hexagon side length

- Design/Parameters reference code adopted from Wouter Deconinck, Jihee Kim, and Whitney Armstrong
- https://github.com/yasirali12345/LumiDetector_WSciFi_Code_testing

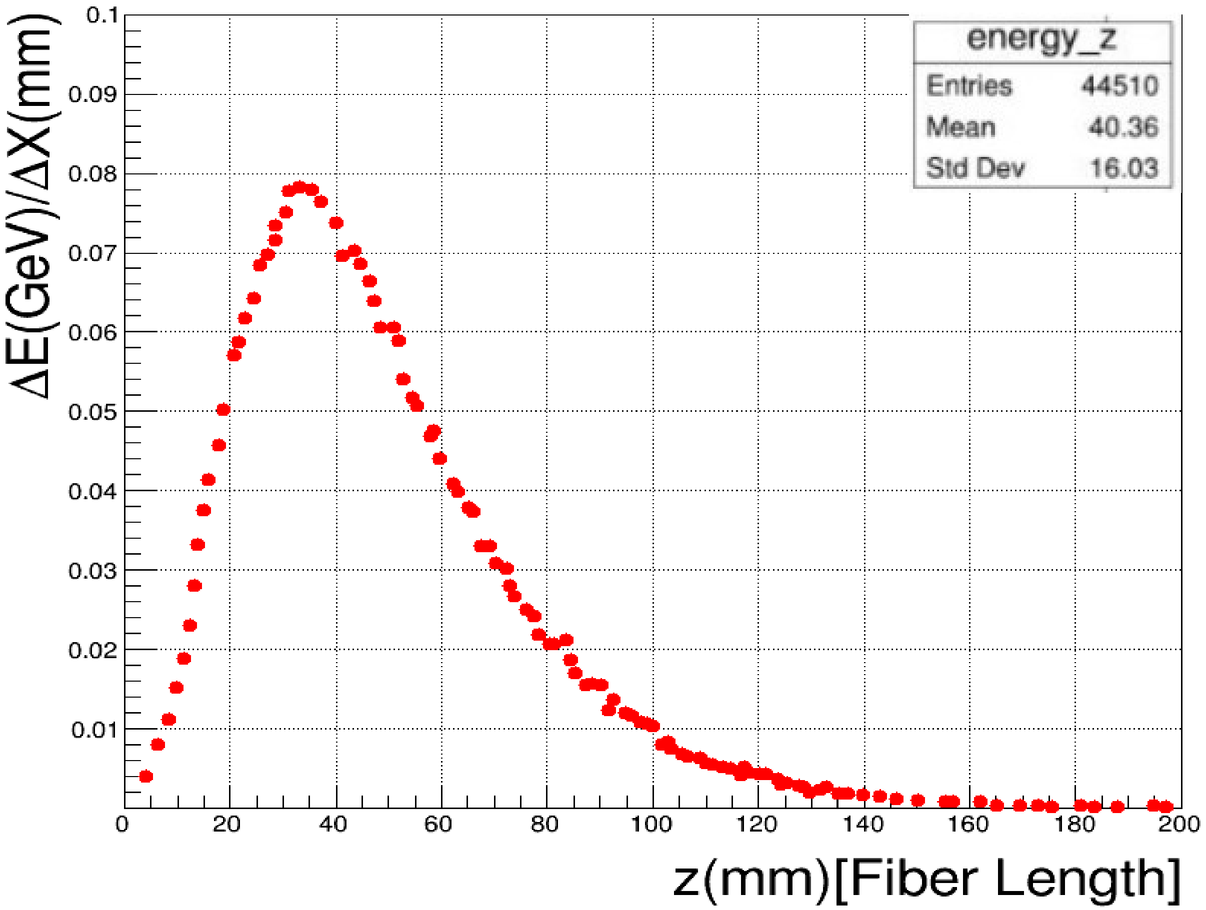
Result of Energy Distributions for Fibers are with Smeared Photons

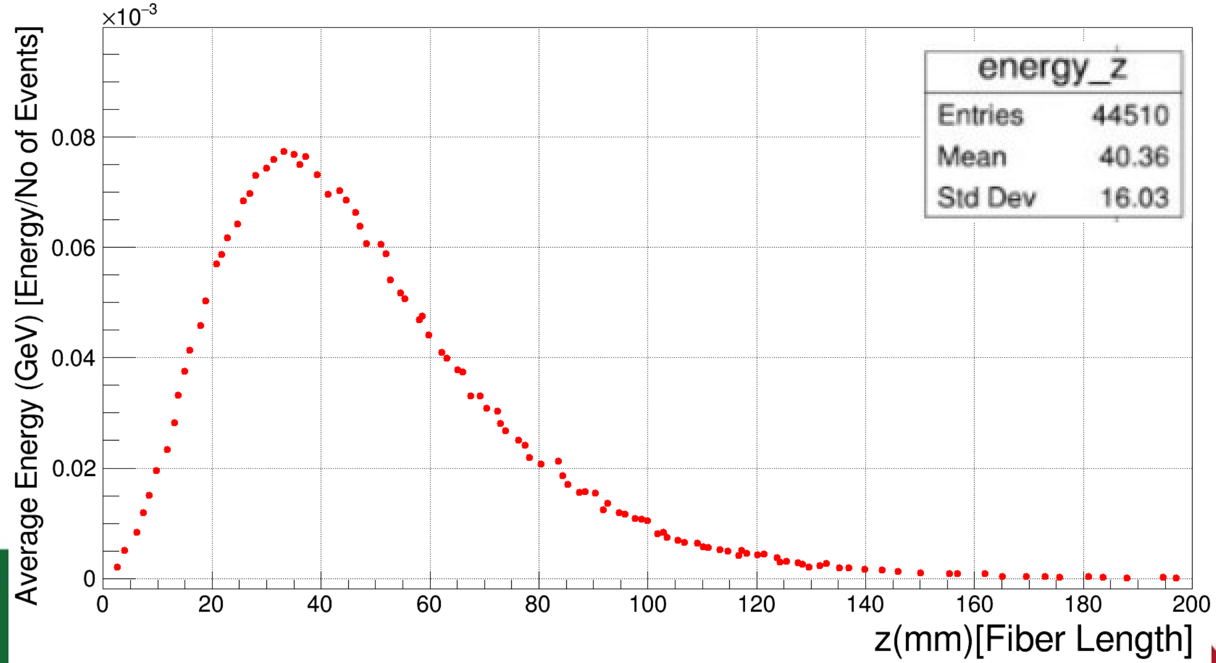
Energy Distribution for Quartz Calorimeter with Rotation

5 degree



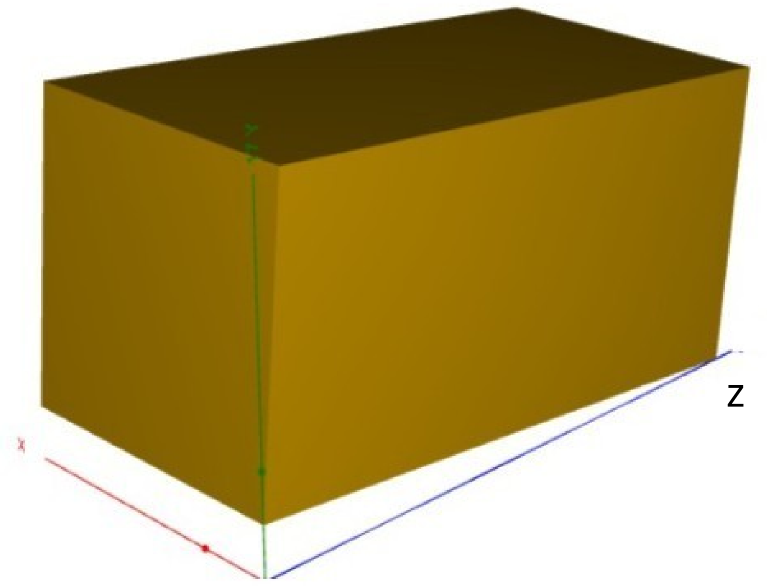
Coordinates (x,y,z) 0 , 0, 49)



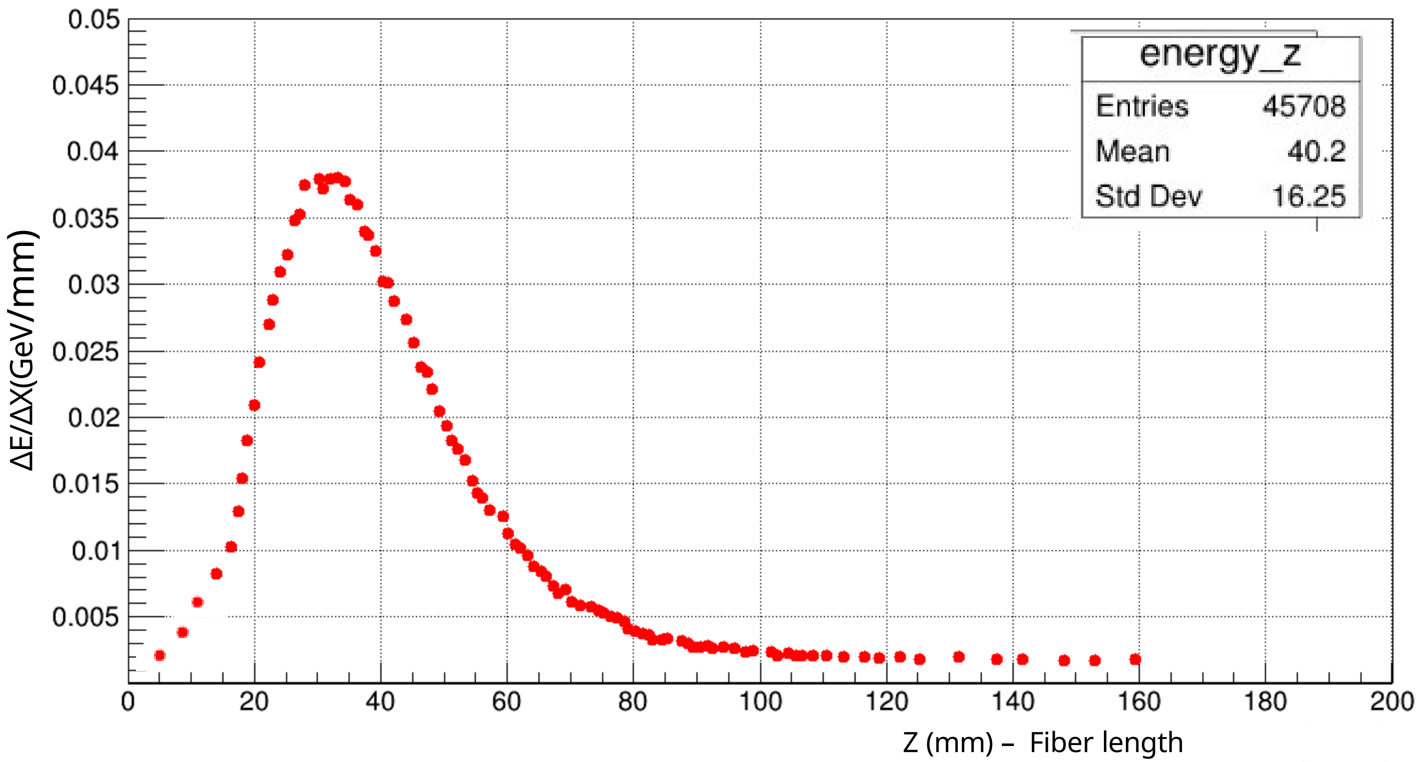


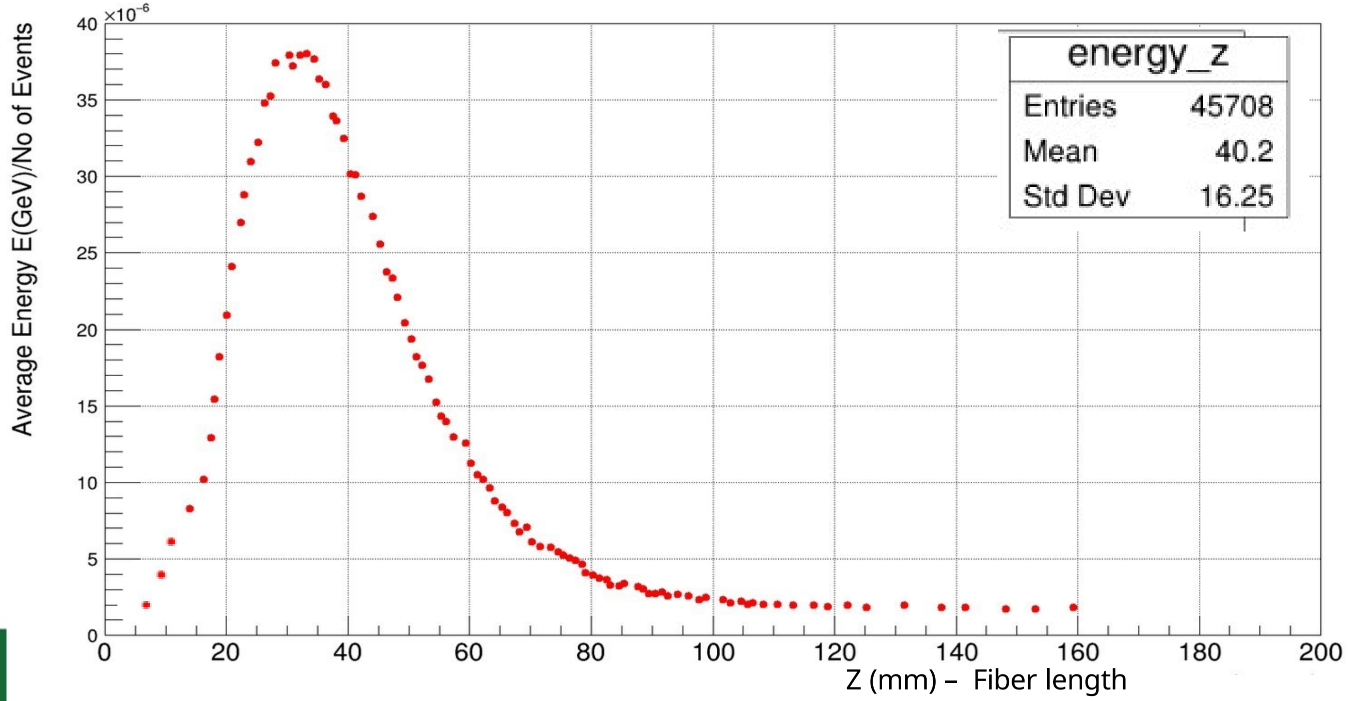
Energy Distributions for SciFi Calorimeter (with Rotation)

5 degree



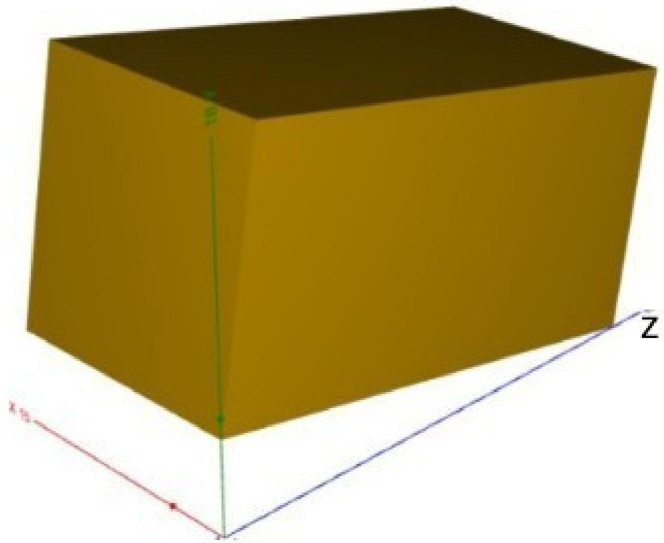
Coordinates (x,y,z) 0 , 0, 48)



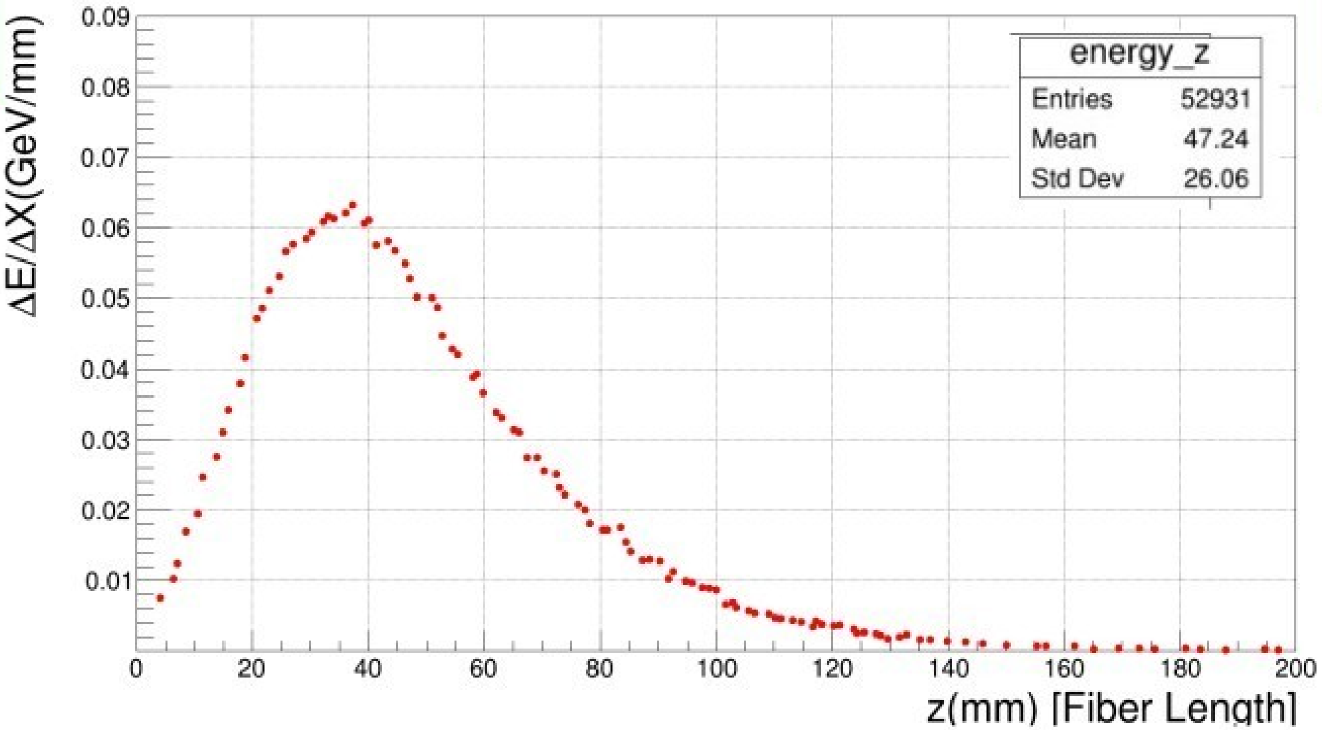


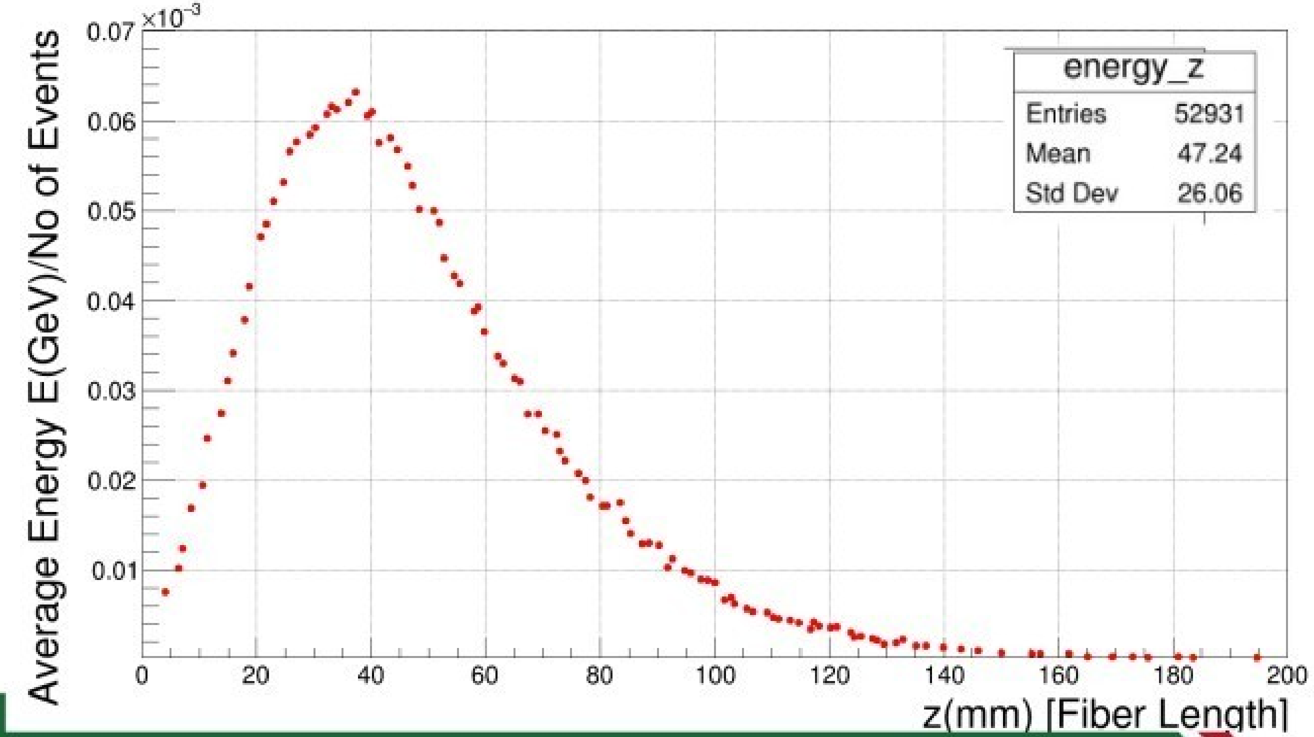
Energy Distributions for Quartz Calorimeter (with Rotation)

10 degree



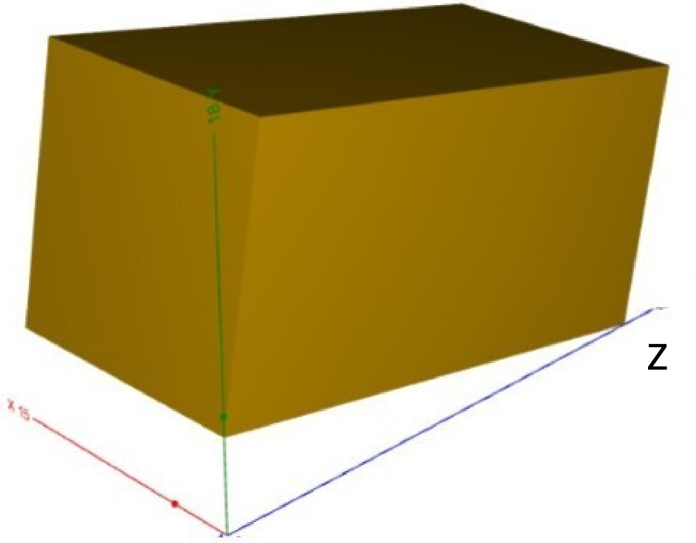
Coordinates (x,y,z) 0 , 0, 50)



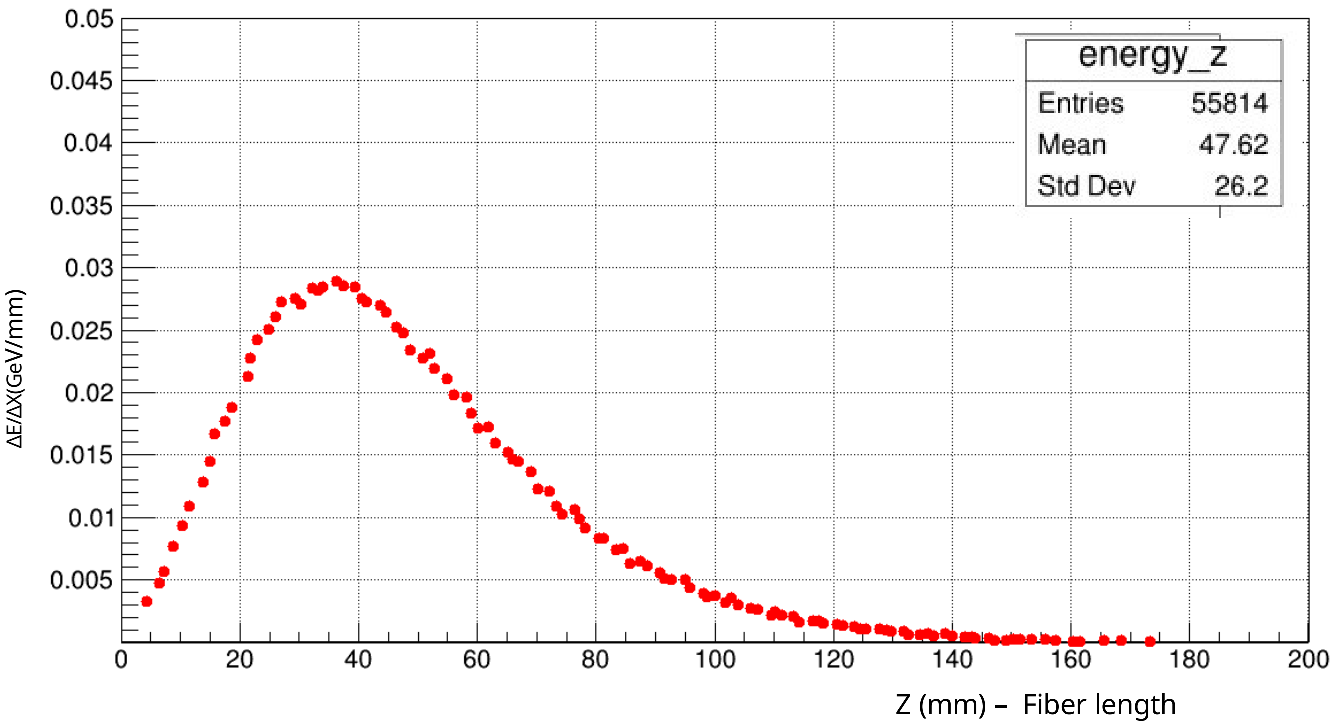


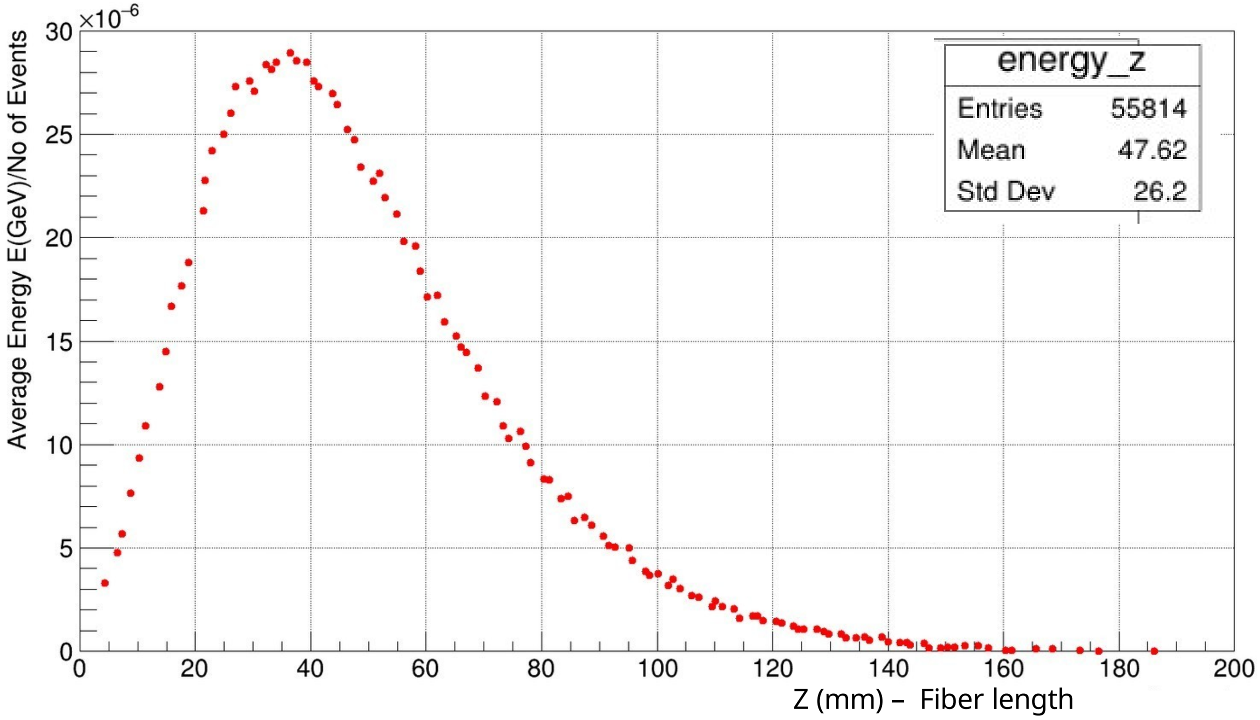
Energy Distributions for SciFi Calorimeter (with Rotation)

10 degree



Coordinates (x,y,z) 0 , 0, 52)





Energy Deposition in Fiber Case:

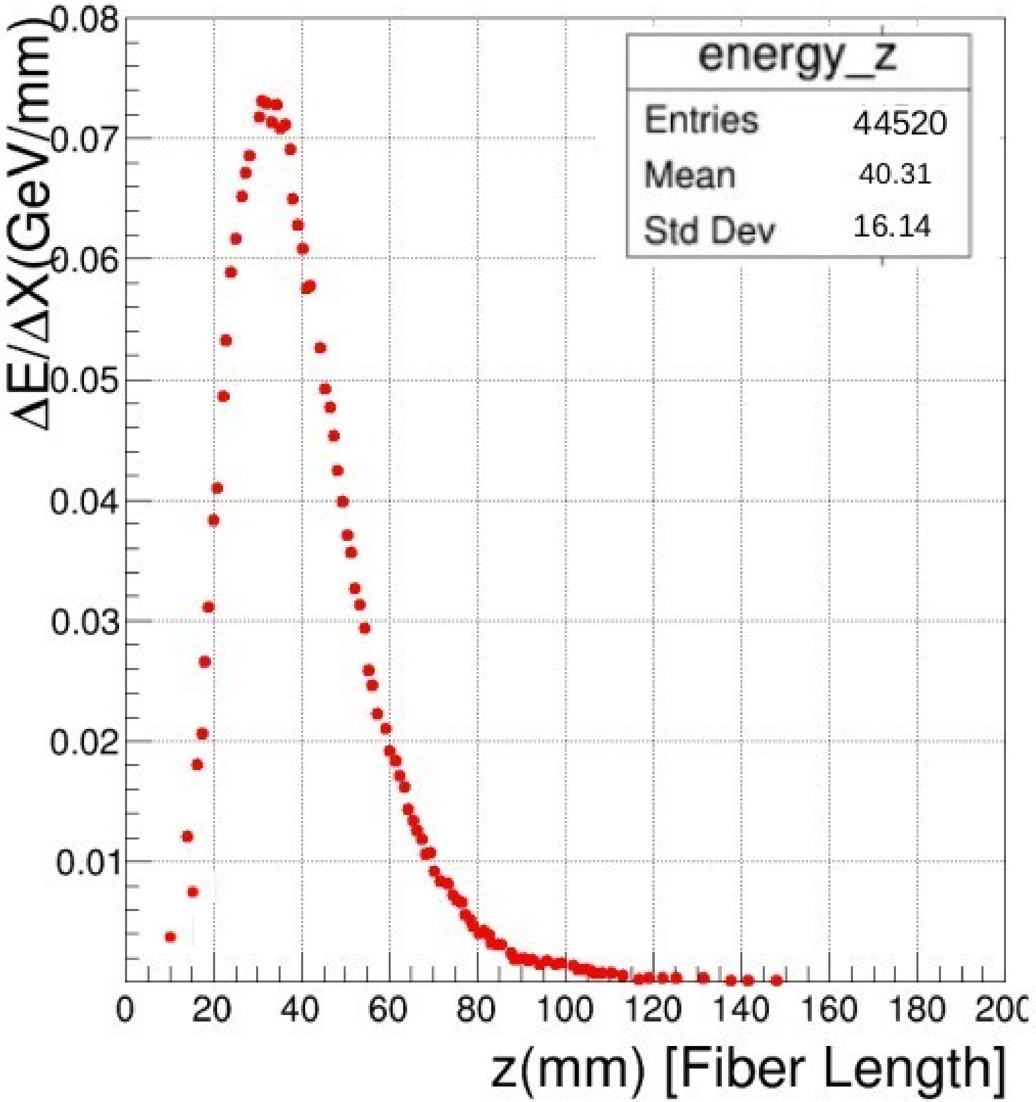
Fiber Type	5 Degree (Rotation Angle) ΔE/ΔX(GeV/mm)	10 Degree (Rotation Angle) ΔE/ΔX(GeV/mm)
Quartz	0.08	0.062
SciFi	0.04	0.03

Summary and Future Outlook

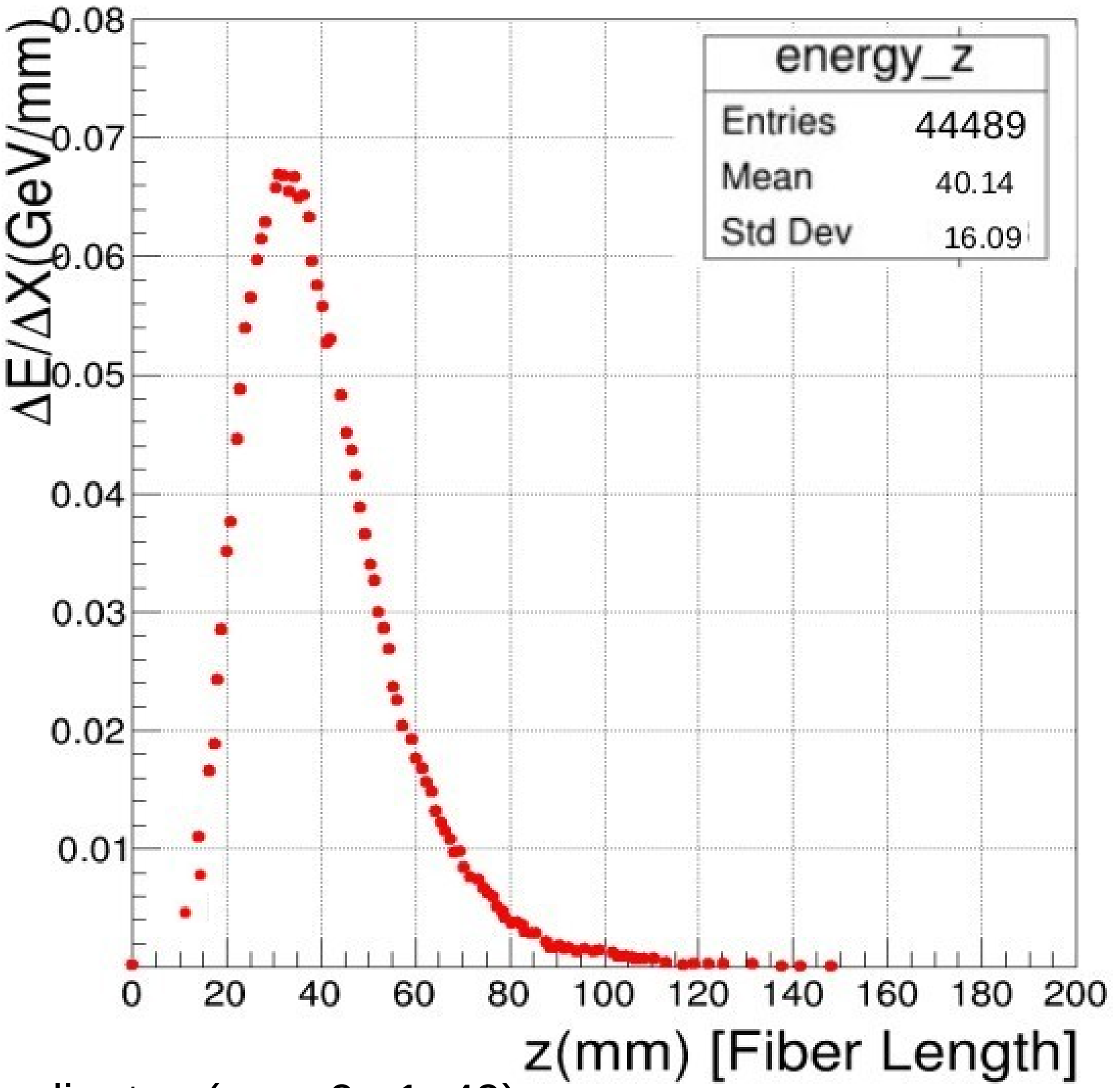
- High Rate Calorimeter Simulations have been performed using dedicated eic/epic tools like dd4hep and ddsim.
- Simulations have been performed using Bremsstrahlung 10 GeV electrons, - Minimum Photon energy of 100 MeV.
- For Test case $PbWO_4$ Crystal Calorimeter of size 10cm x 10cm x20cm was considered for this study.
- For Non Smeared Case Highest average Cell Energy = 0.012 MeV While for smeared case highest average cell energy = 0.028 MeV
- For baseline Quartz/Tungsten and SciFi/Tungsten Calorimeters of sizes 10cm x 10cm x20cm with fiber size of 1mm are designed and studied.
- Almost Double Energy is deposited in Quartz Fibers as Compared to SciFi. (higher density of Quartz)
- Next Steps would include to involve EIC-Recon step to see the light output of the fiber.

Thank You

Energy Distributions for Quartz Fiber (Neighbours) Calorimeter (with Rotation)

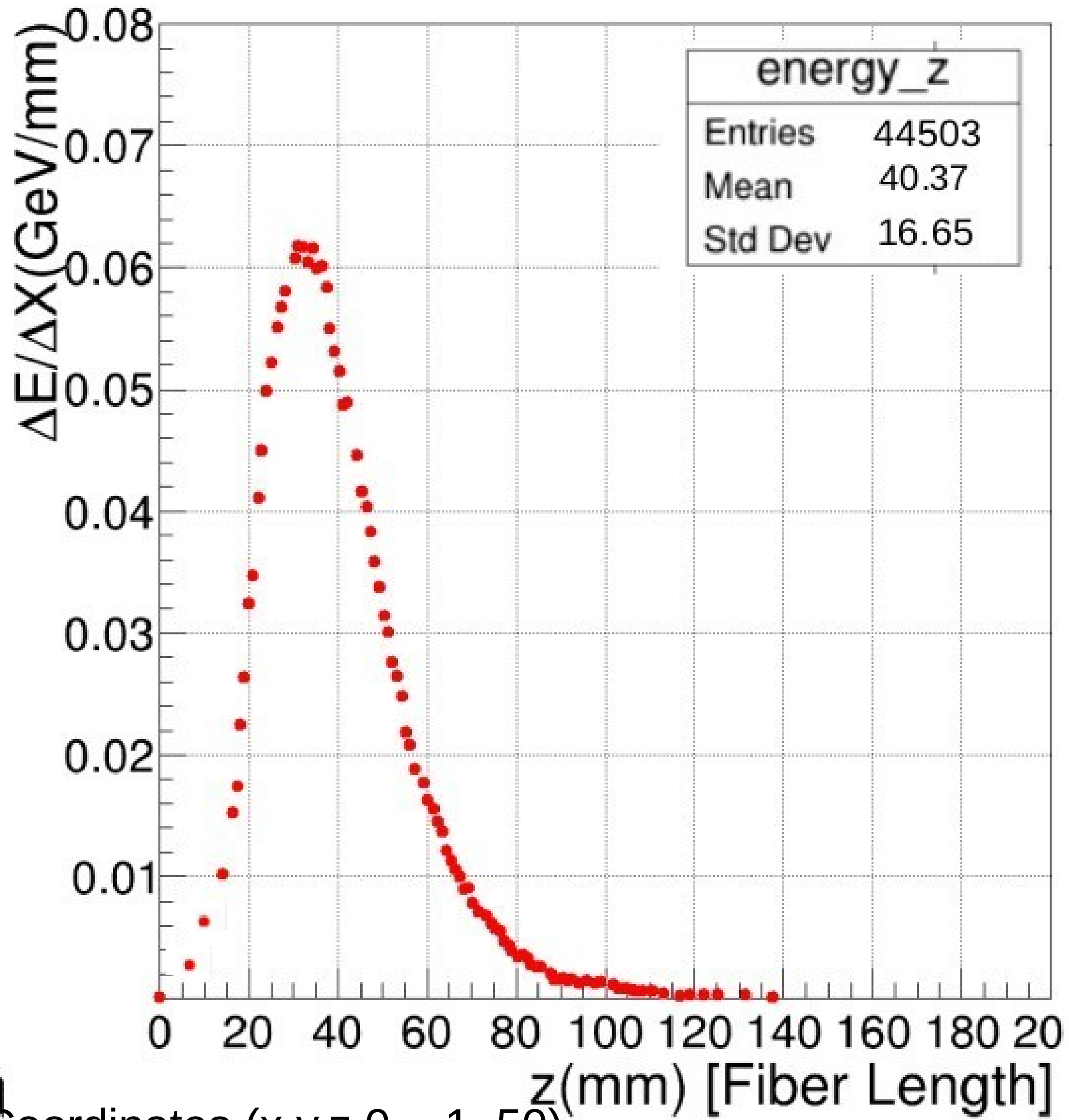


Coordinates (x,y,z -1 , 0, 49)

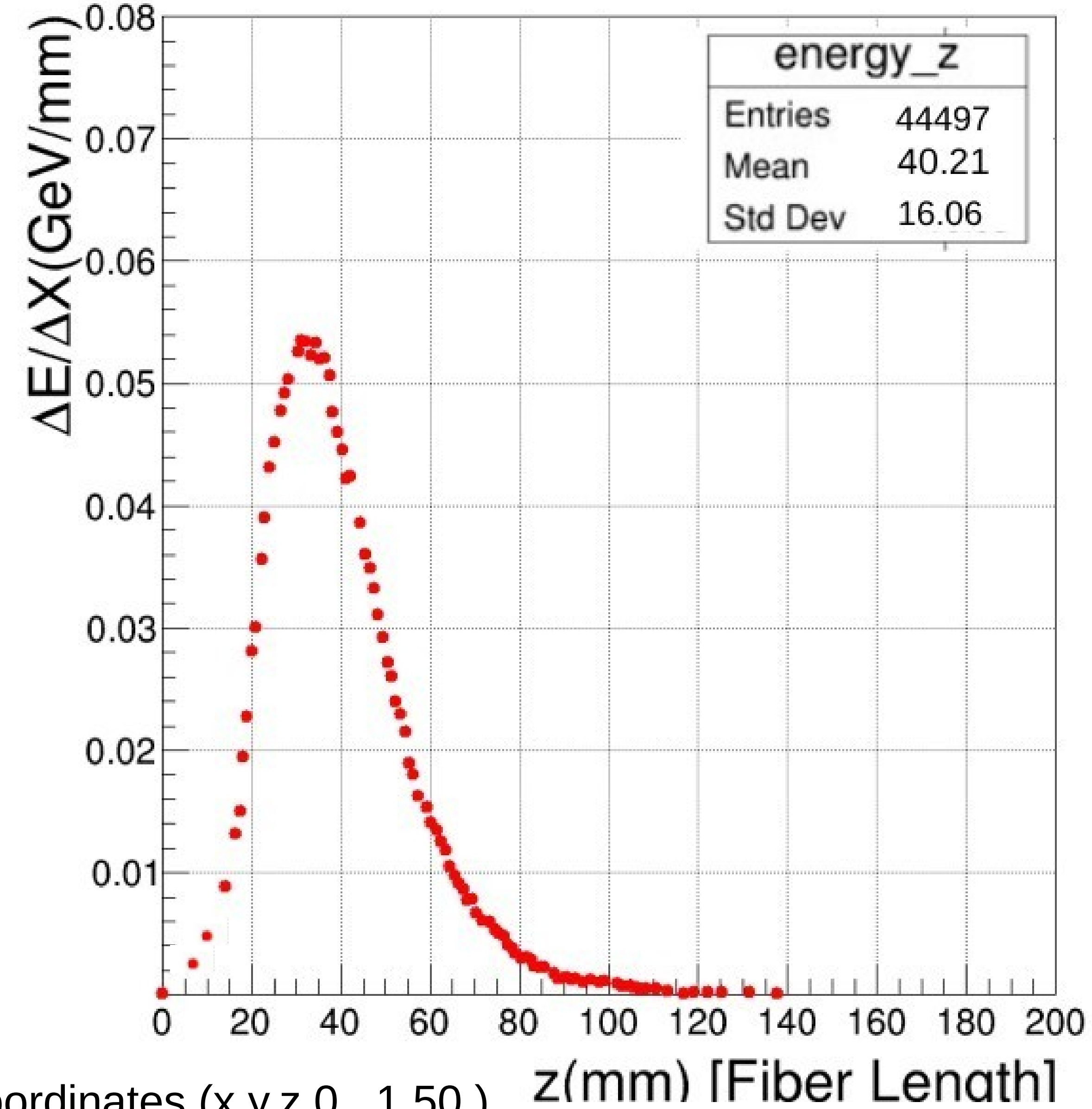


Coordinates (x,y,z 0 , 1, 49)

Energy Distributions for Quartz Fiber (Neighbours) Calorimeter (with Rotation)

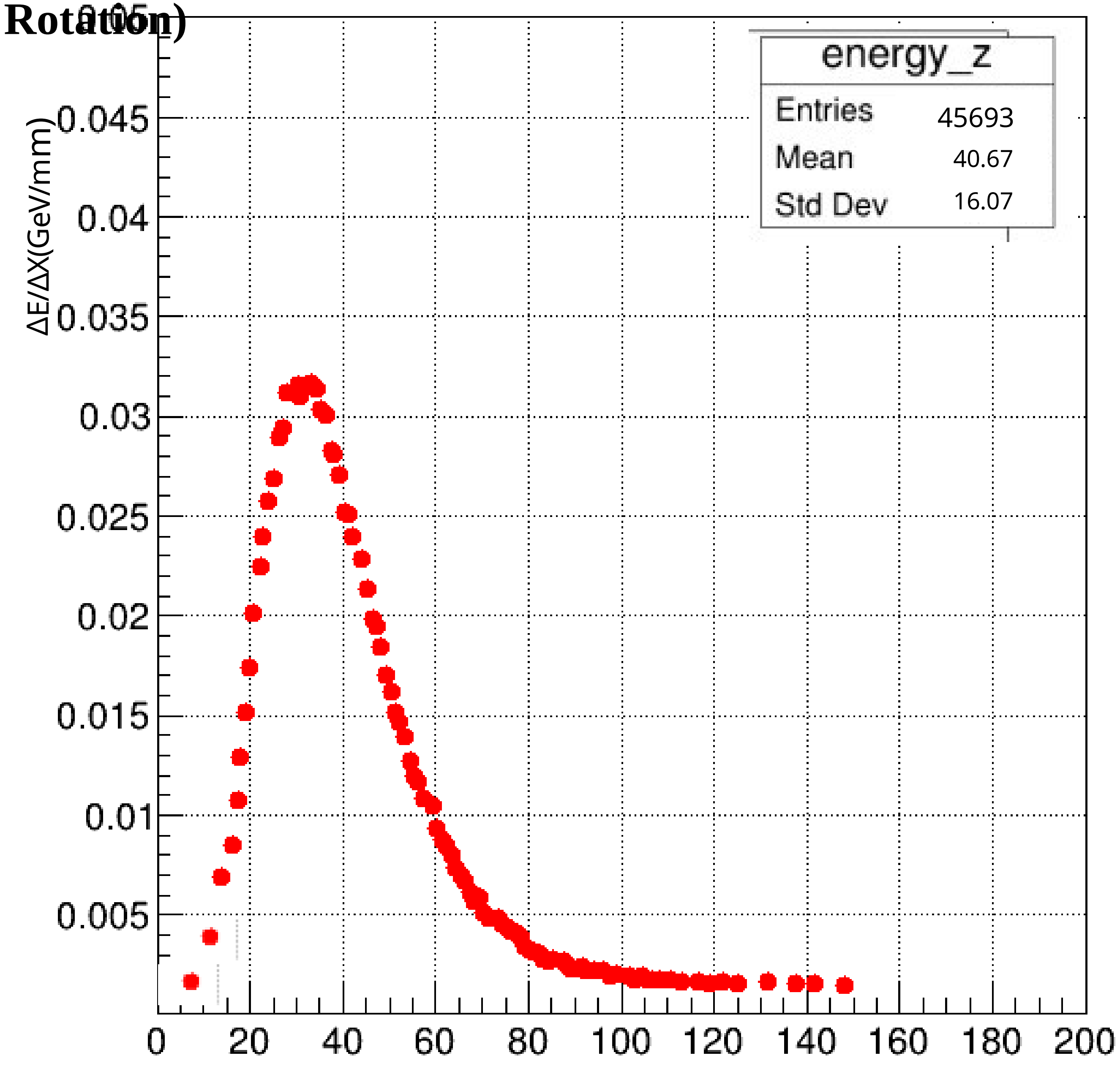


Coordinates (x,y,z 0 , -1, 50)



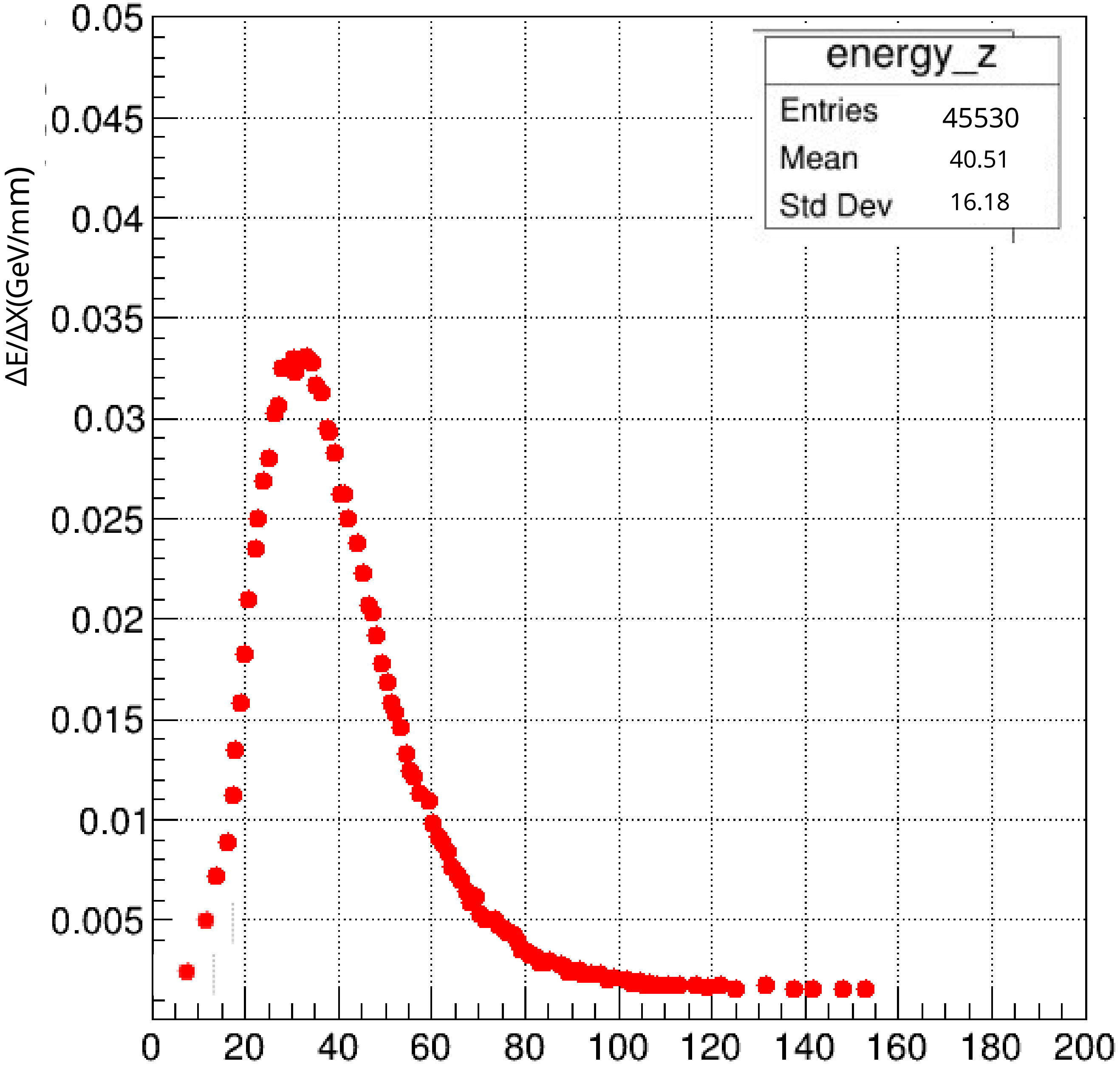
Coordinates (x,y,z 0 , 1,50)

Energy Distributions for SciFi (Neighbours) Calorimeter (with Rotation)



Coordinates (x,y,z) 0 , -1, 48))

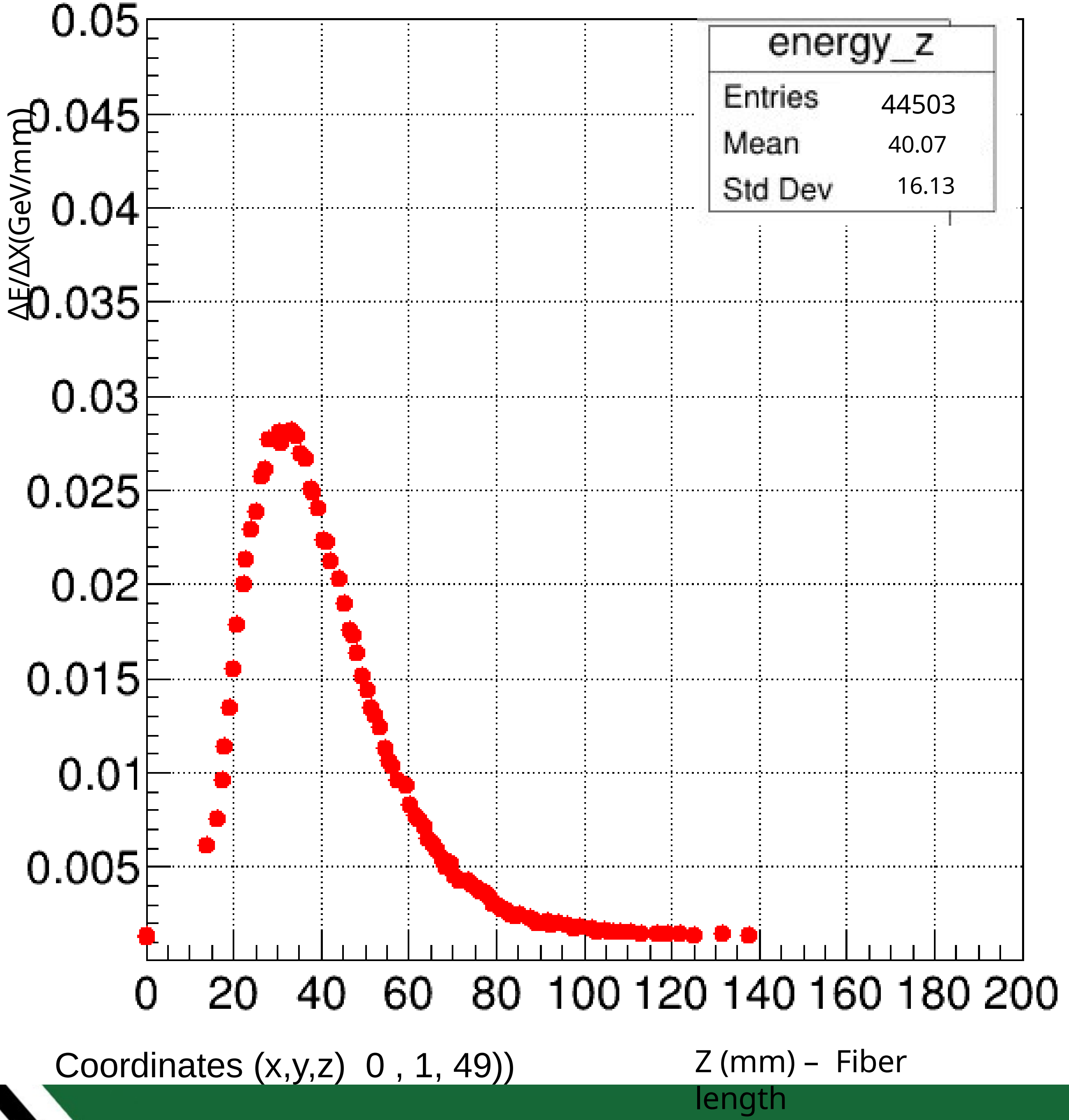
Z (mm) – Fiber length



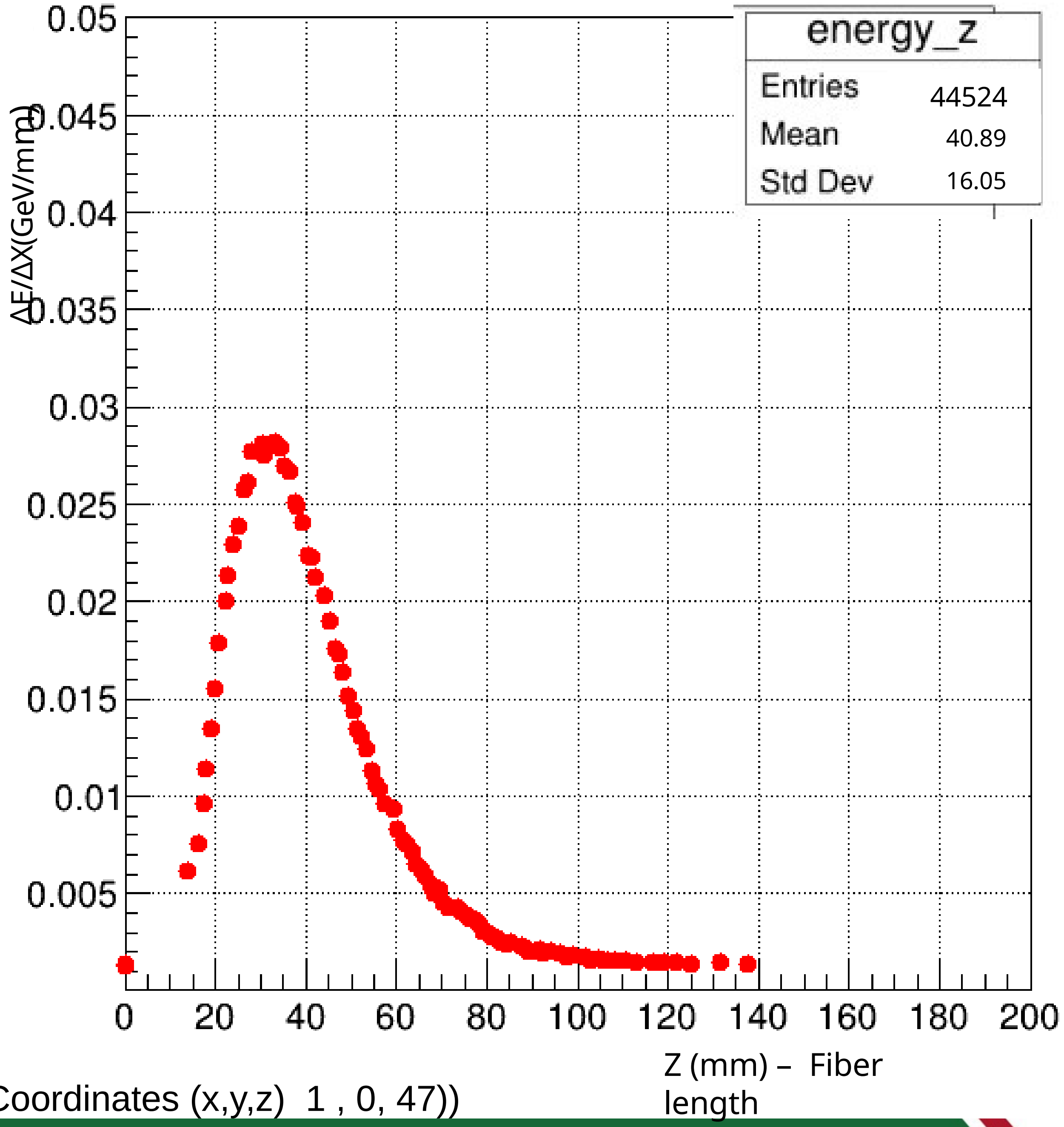
Coordinates (x,y,z) 1 , 0, 48))

Z (mm) – Fiber length

Energy Distributions for SciFi (Neighbours) Calorimeter (with Rotation)

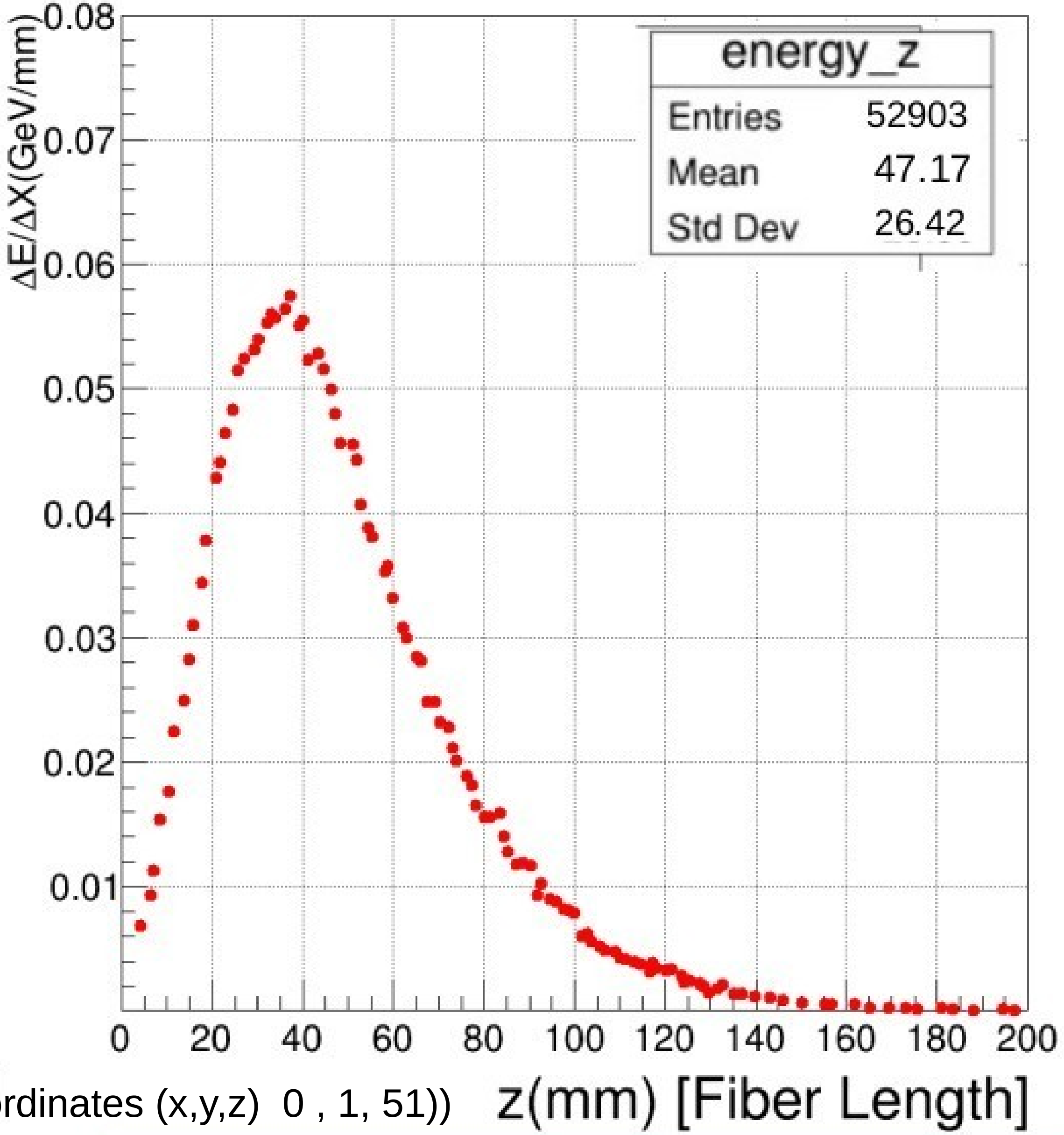


Coordinates (x,y,z) 0 , 1, 49))

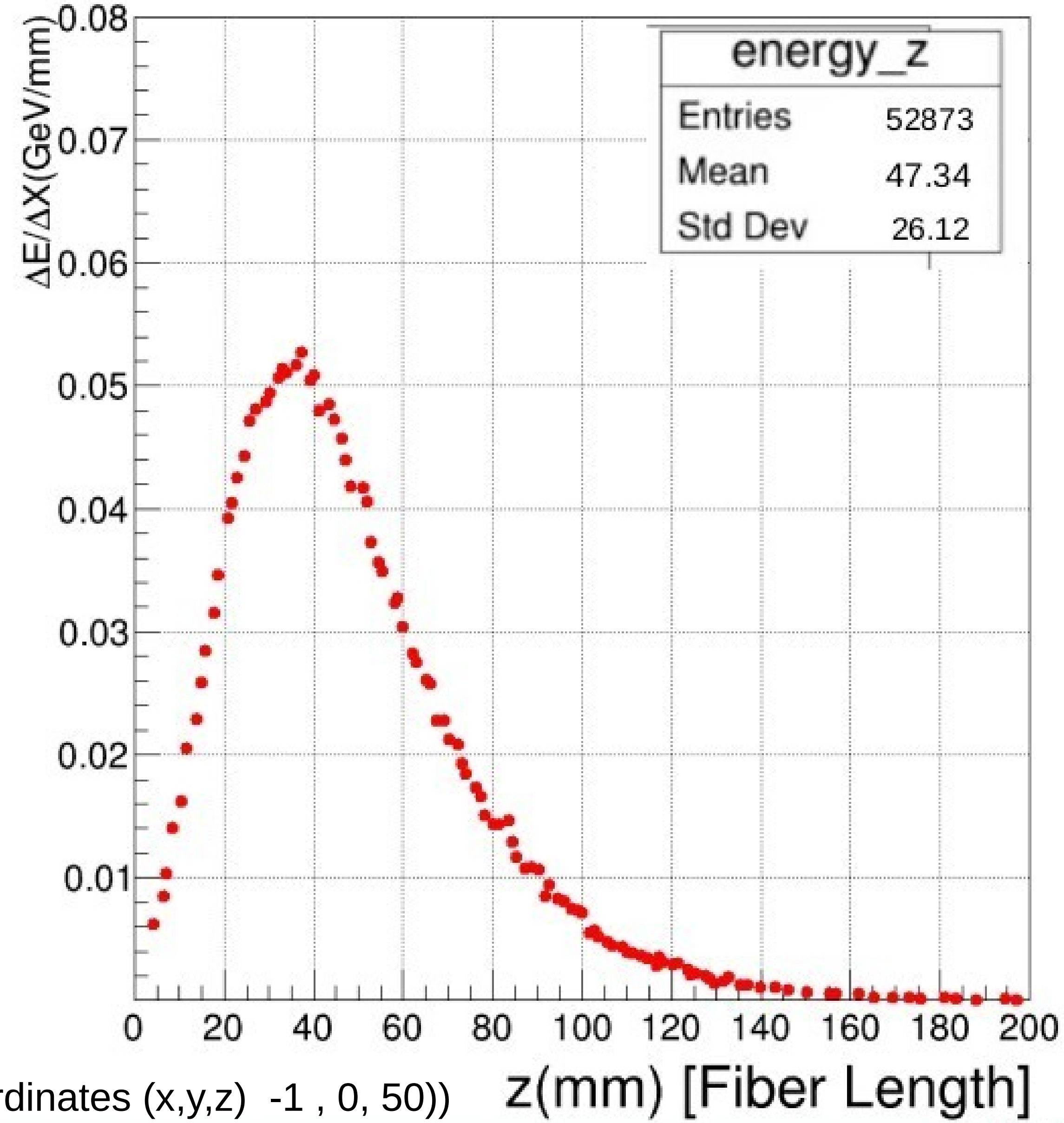


Coordinates (x,y,z) 1 , 0, 47))

Energy Distributions for Quartz Fiber (Neighbours) Calorimeter (with Rotation)

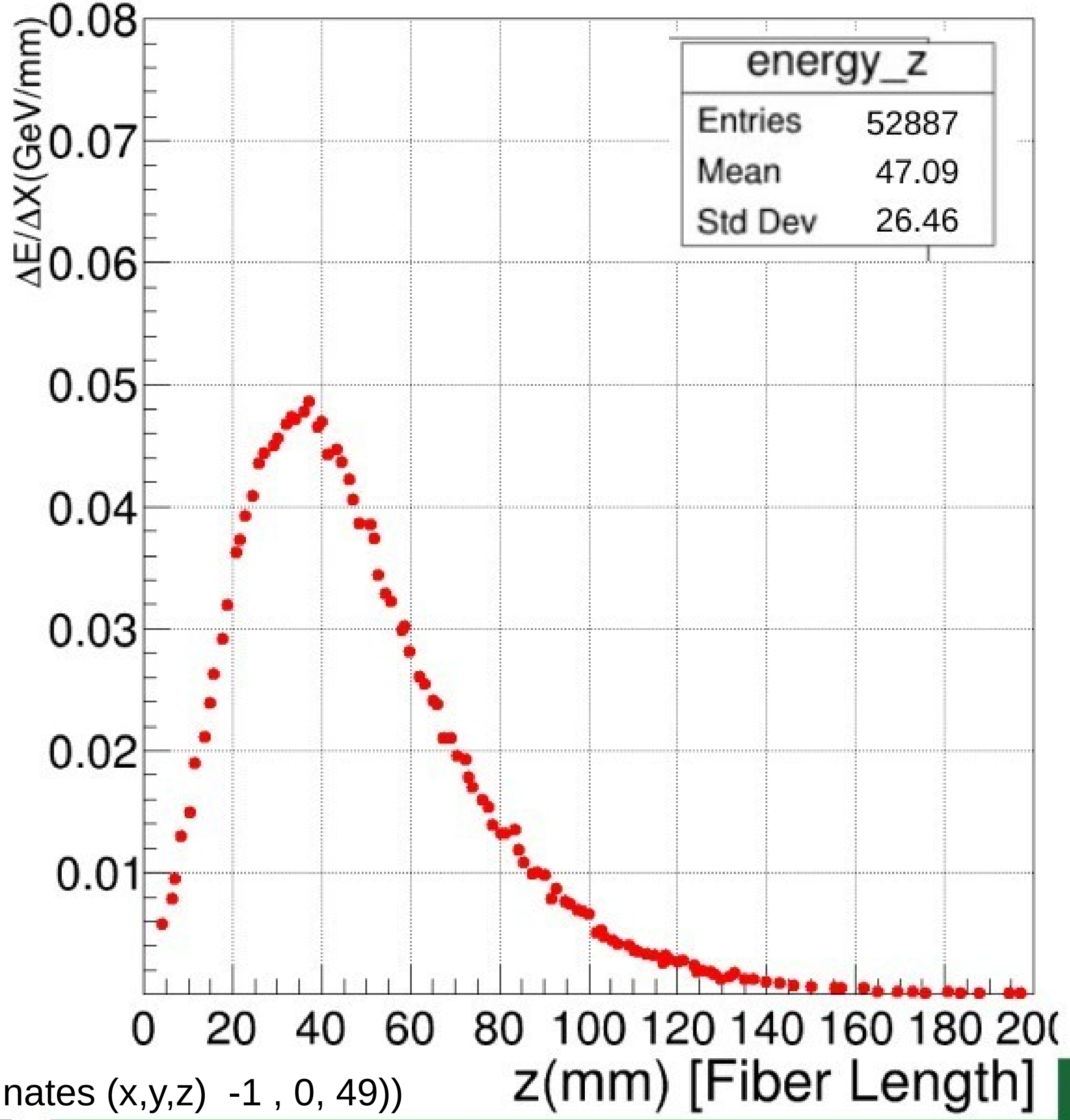


Coordinates (x,y,z) 0 , 1, 51))

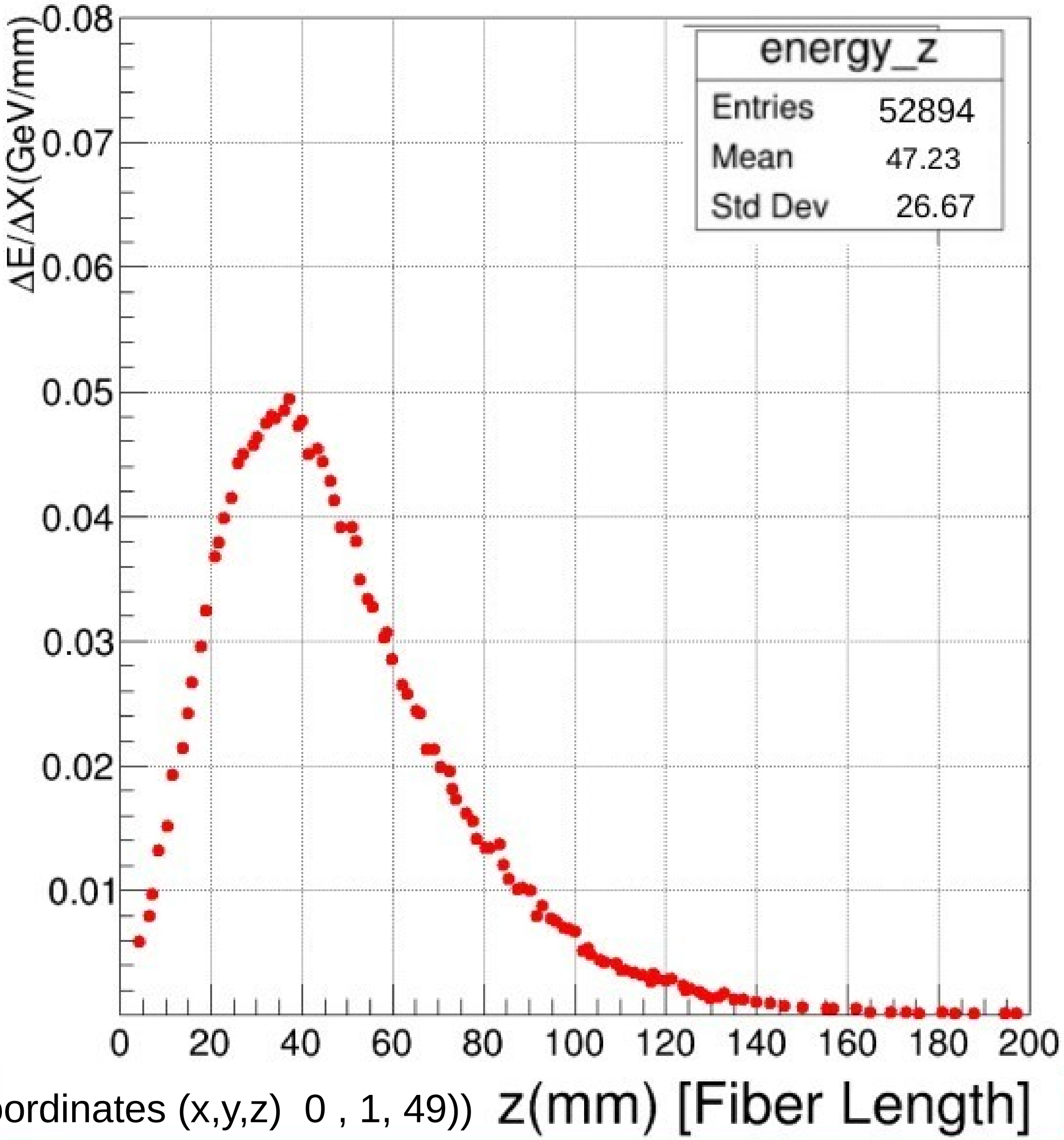


Coordinates (x,y,z) -1 , 0, 50))

Energy Distributions for Quartz Fiber (Neighbours) Calorimeter (with Rotation)

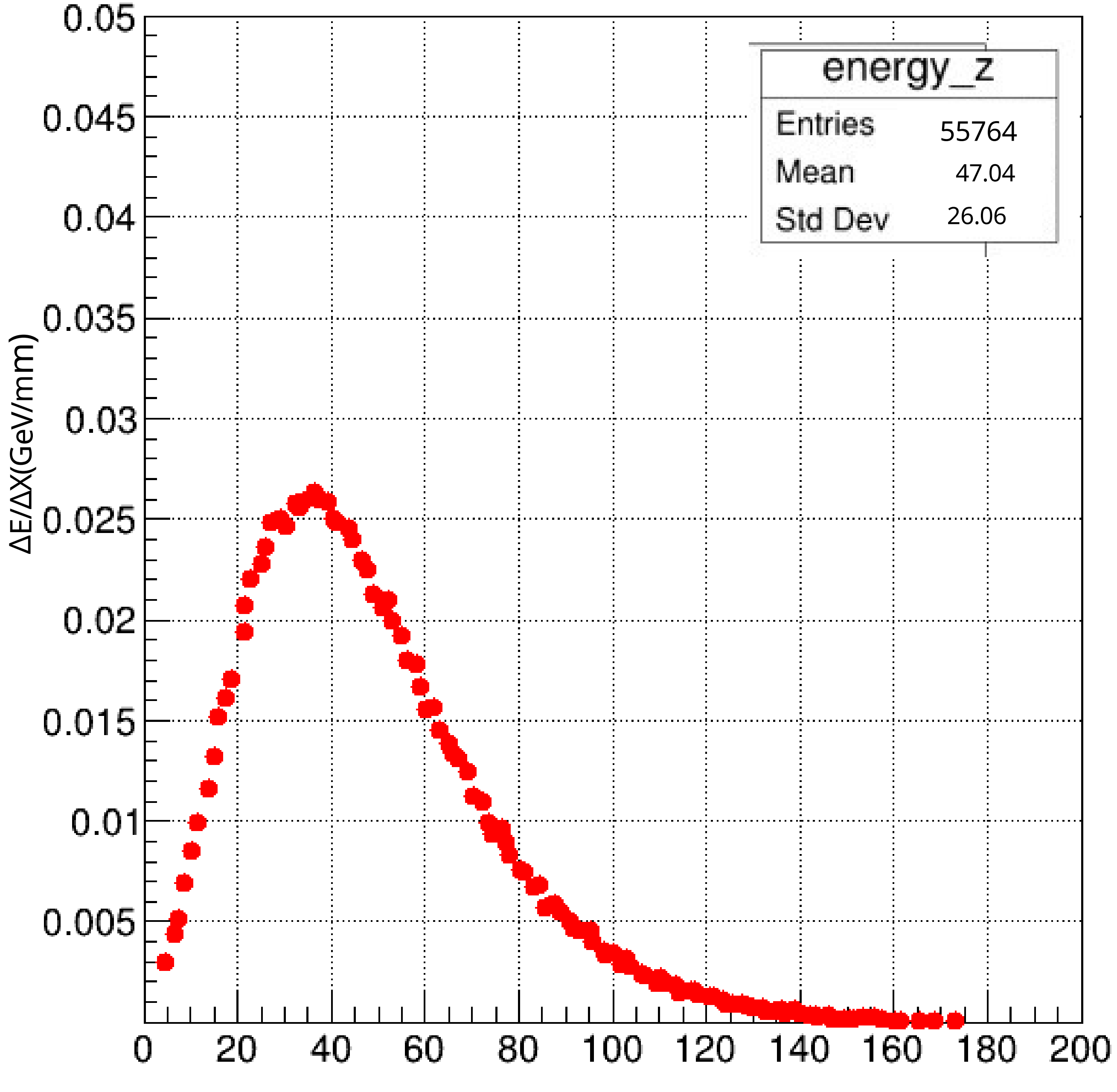


Coordinates (x,y,z) -1 , 0, 49))

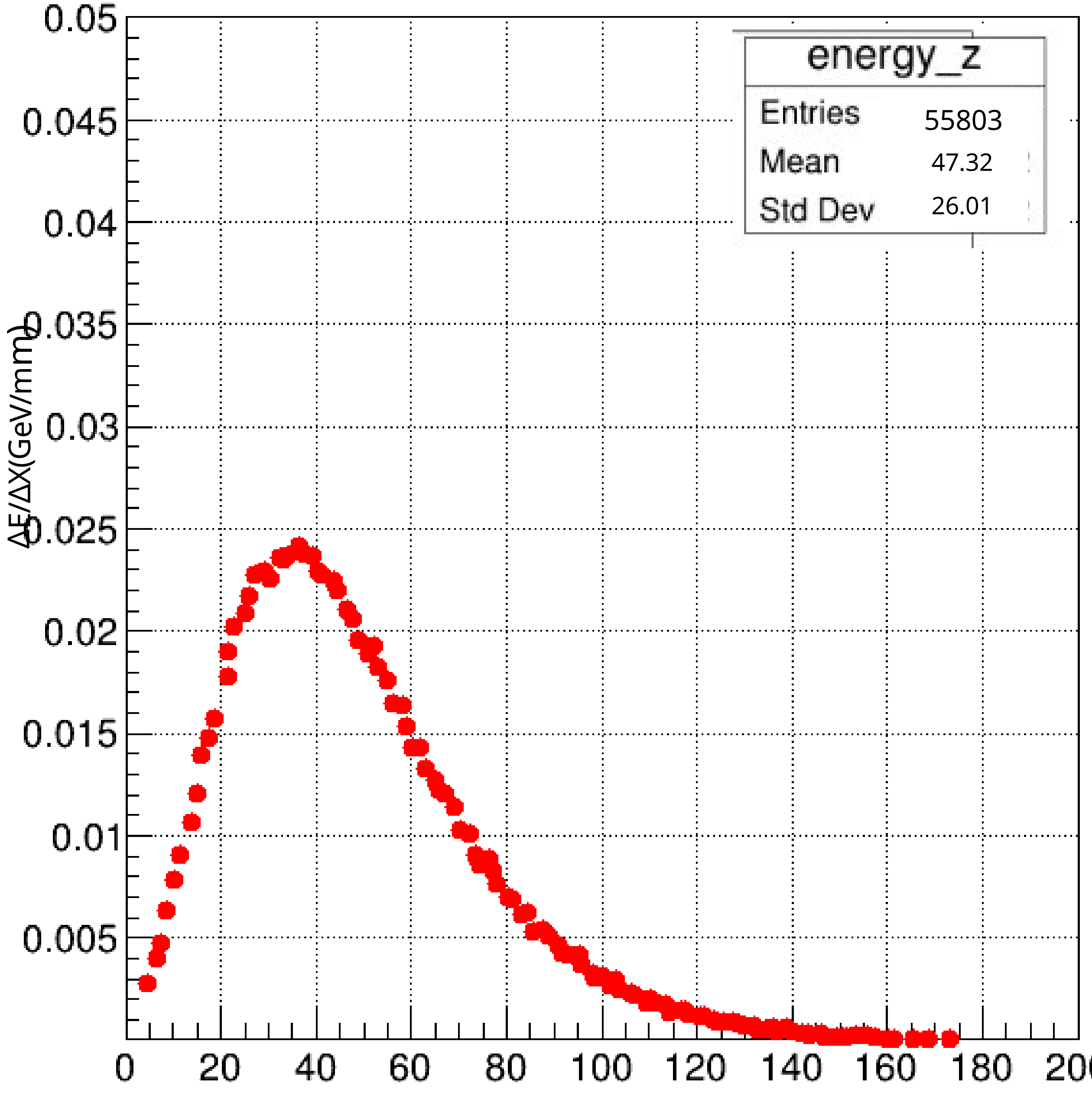


Coordinates (x,y,z) 0 , 1, 49))

Energy Distributions for SciFi (Neighbours) Calorimeter (with Rotation)

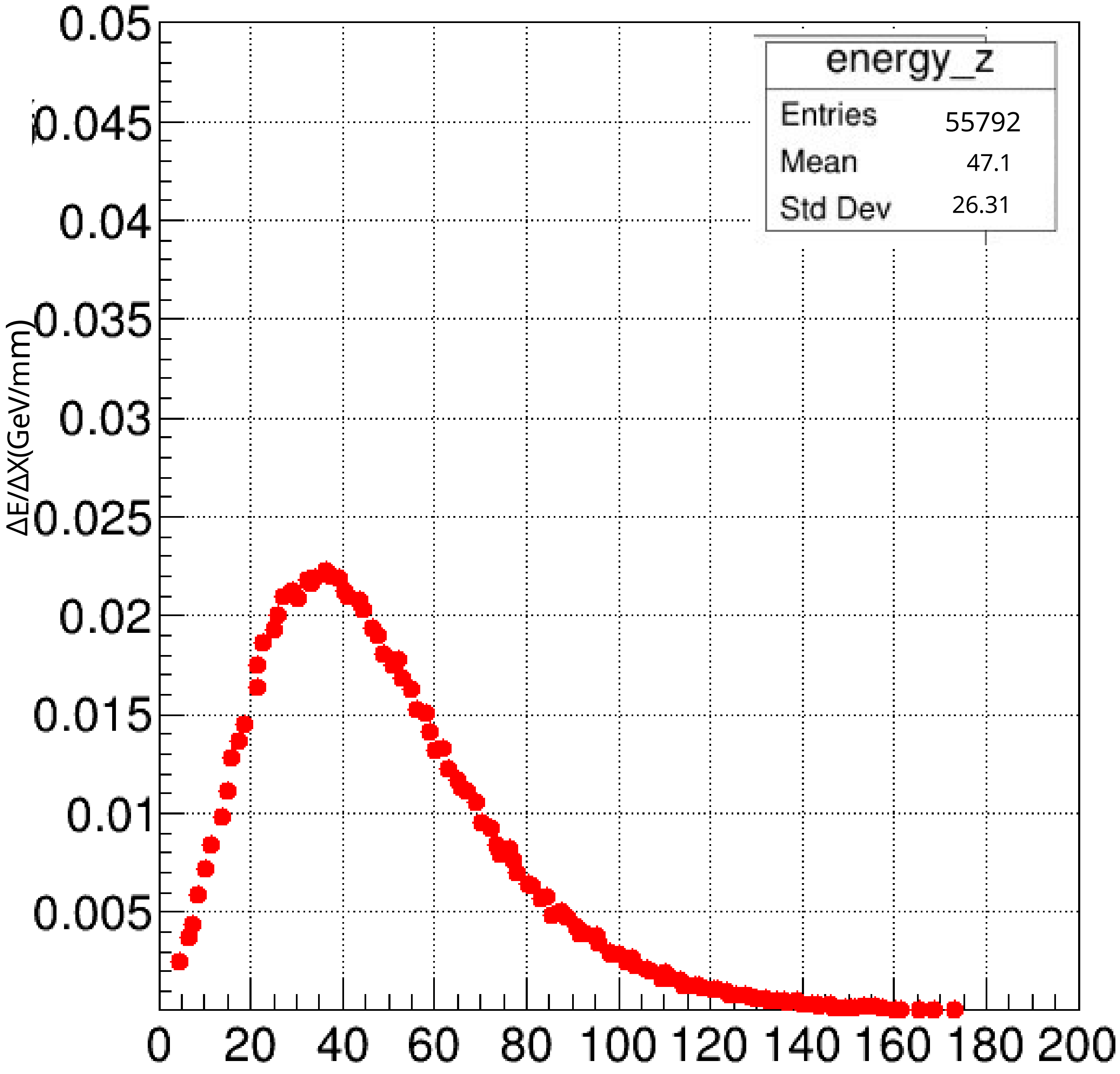


Coordinates (x,y,z) 0 , -1, 51)) Z (mm) – Fiber length

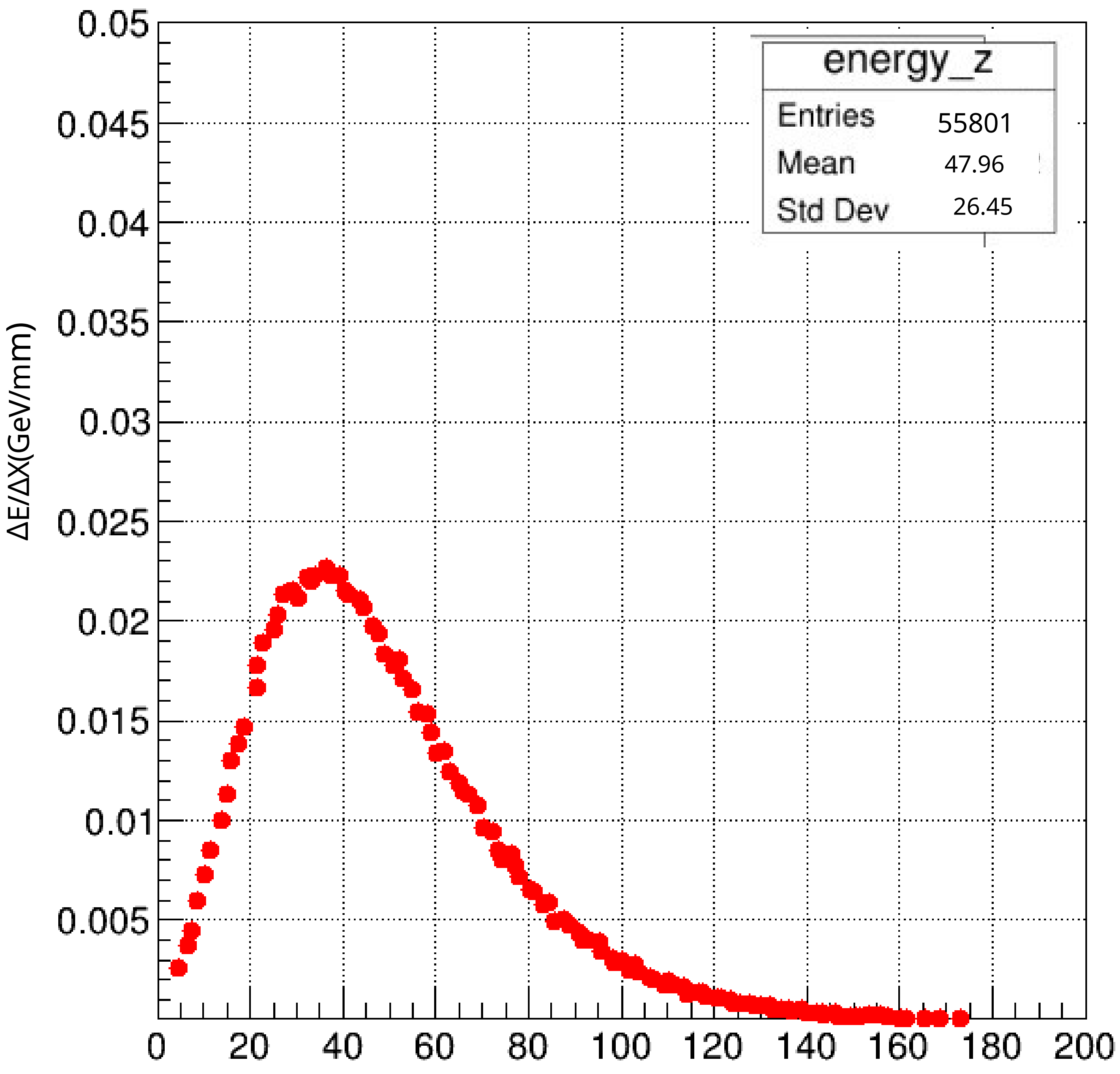


Coordinates (x,y,z) 1 , 0, 51)) Z (mm) – Fiber length

Energy Distributions for SciFi Fiber (Neighbours) Calorimeter (with Rotation)

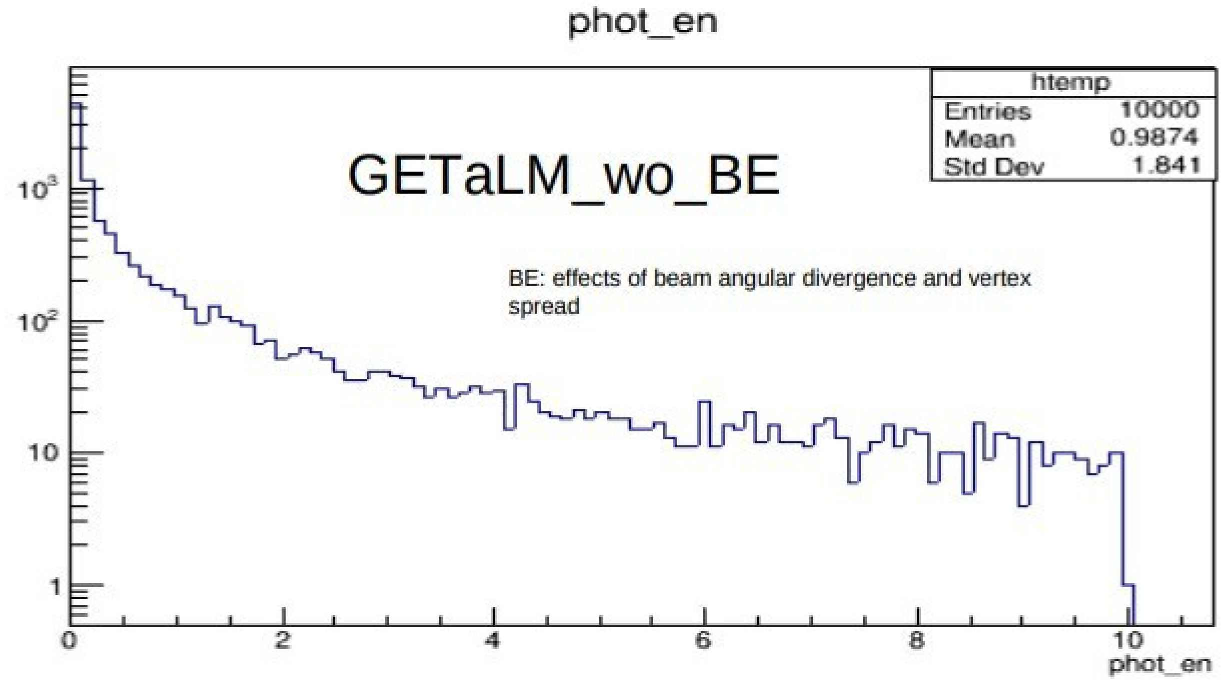


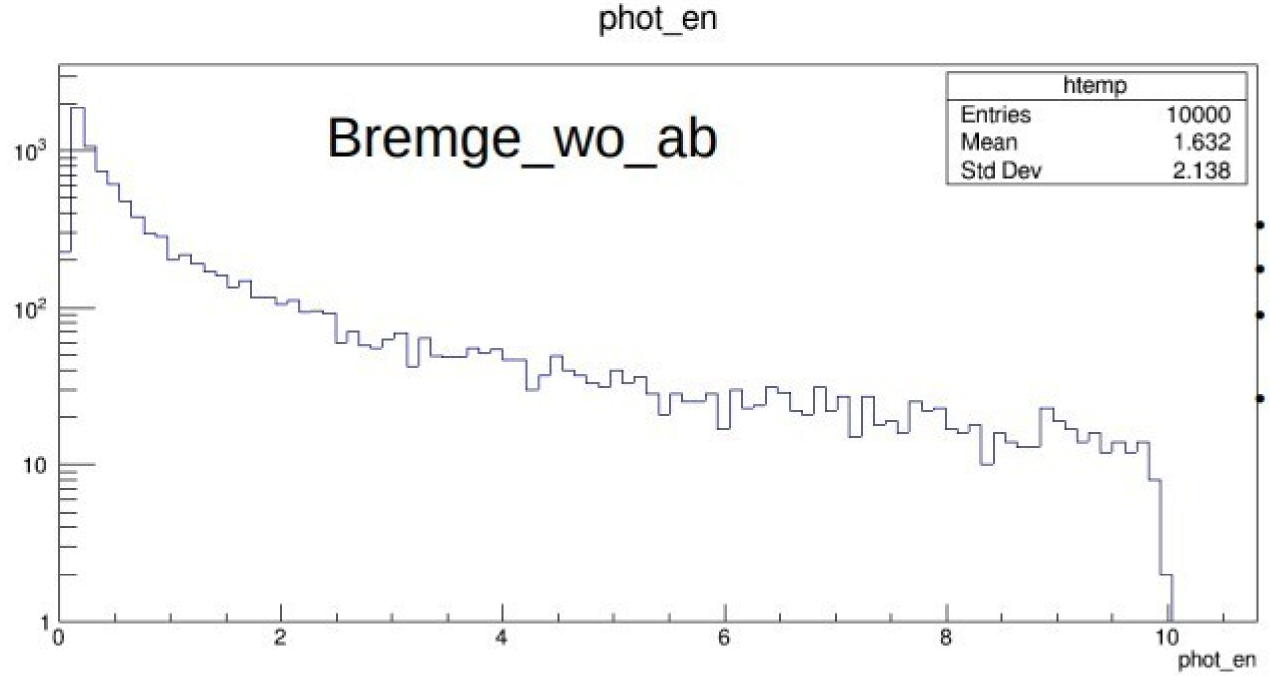
Coordinates (x,y,z) 1 , 0, 53)) Z (mm) – Fiber length



Coordinates (x,y,z) 0 , 0, 53)) Z (mm) – Fiber length

BACKUP SLIDE

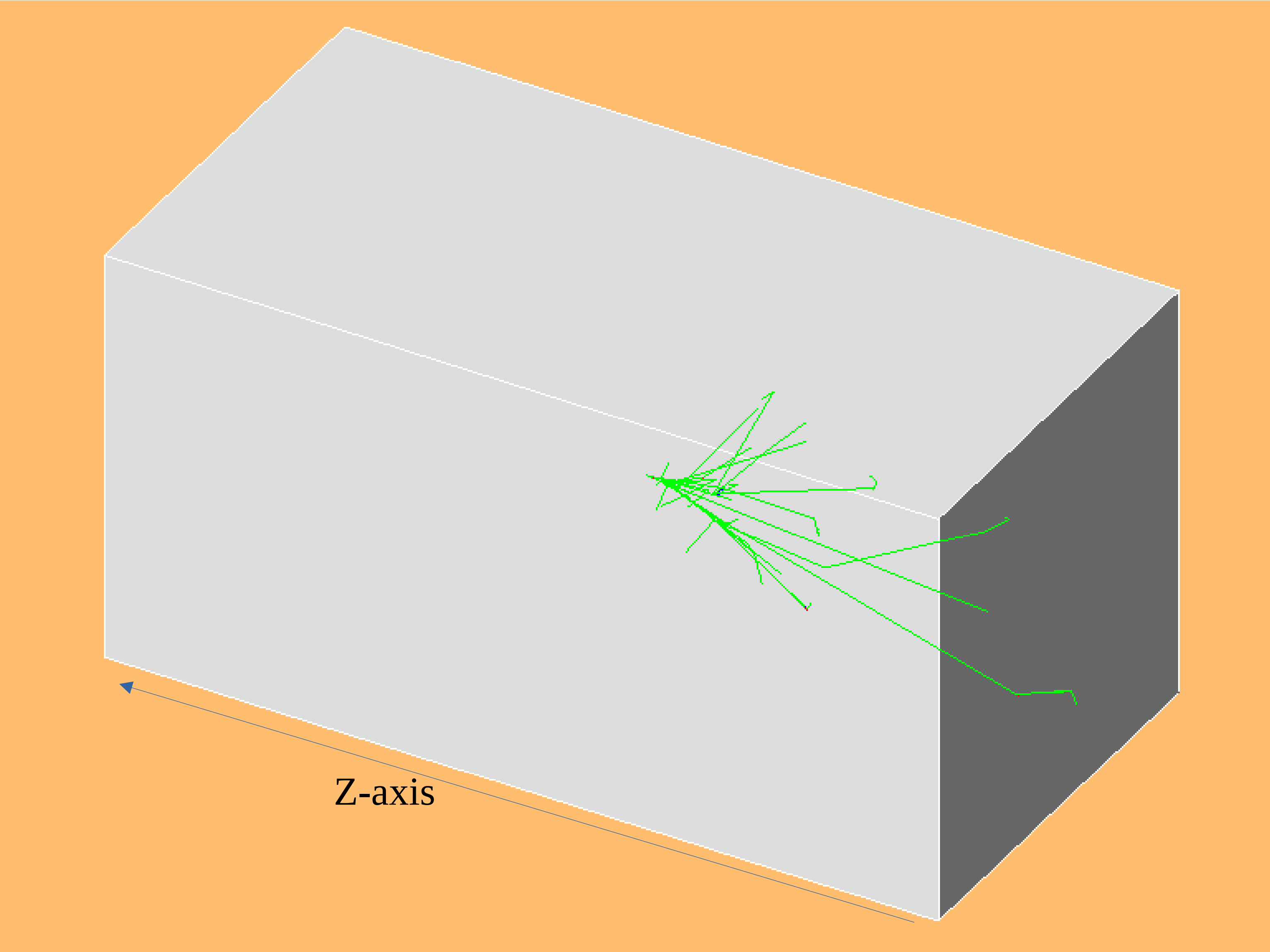




ab==EIC MC afterburner:

- Physics simulated:
- Crossing angle
- Beam effects (divergence, crabbing kick, etc.)
- Vertex spread (position, time)

GEANT4 Simulated 1 event
E_photon = 100 MeV
Box Dimensions: 10cm x 10cm x 20cm



30