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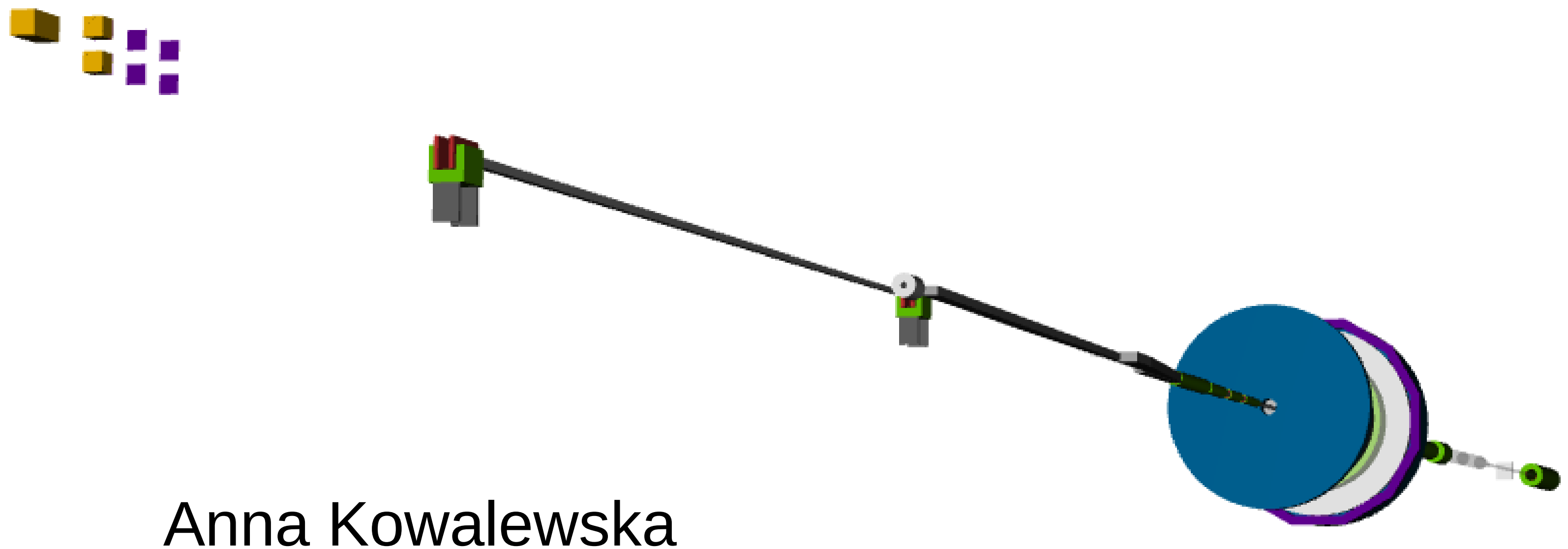
AGH UNIVERSITY OF SCIENCE
AND TECHNOLOGY

RESEARCH UNIVERSITY
EXCELLENCE INITIATIVE

Studies for bremsstrahlung energy deposits in PbW04 crystal lumi direct detector



Anna Kowalewska
AGH UST
HRC weekly meeting

08.05.2023

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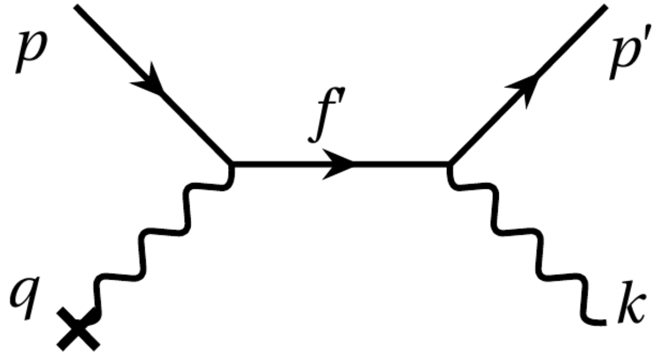
Tools for the bremsstrahlung event generation



* **Bremge:** *e-p as well as e-N and e-gas bremss events*

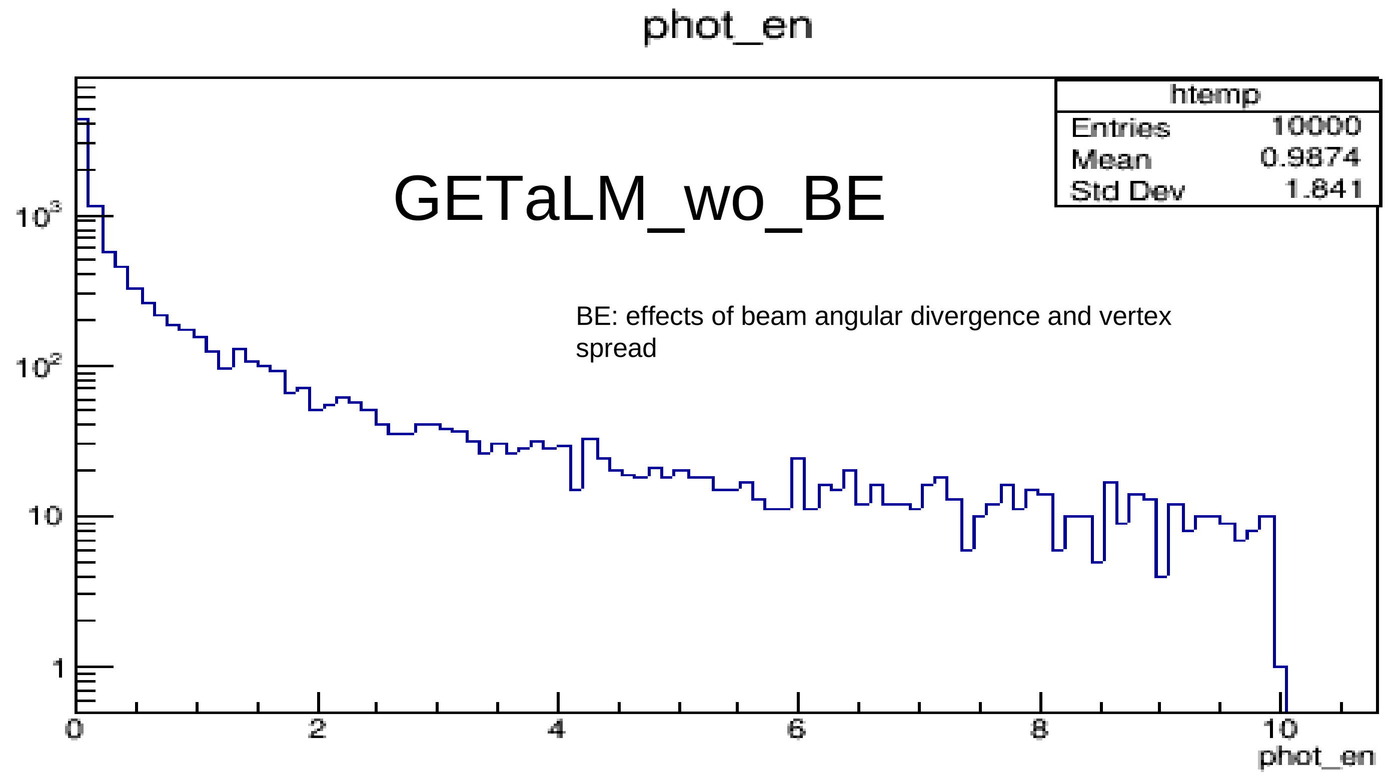
- hepMC3: two beam particles

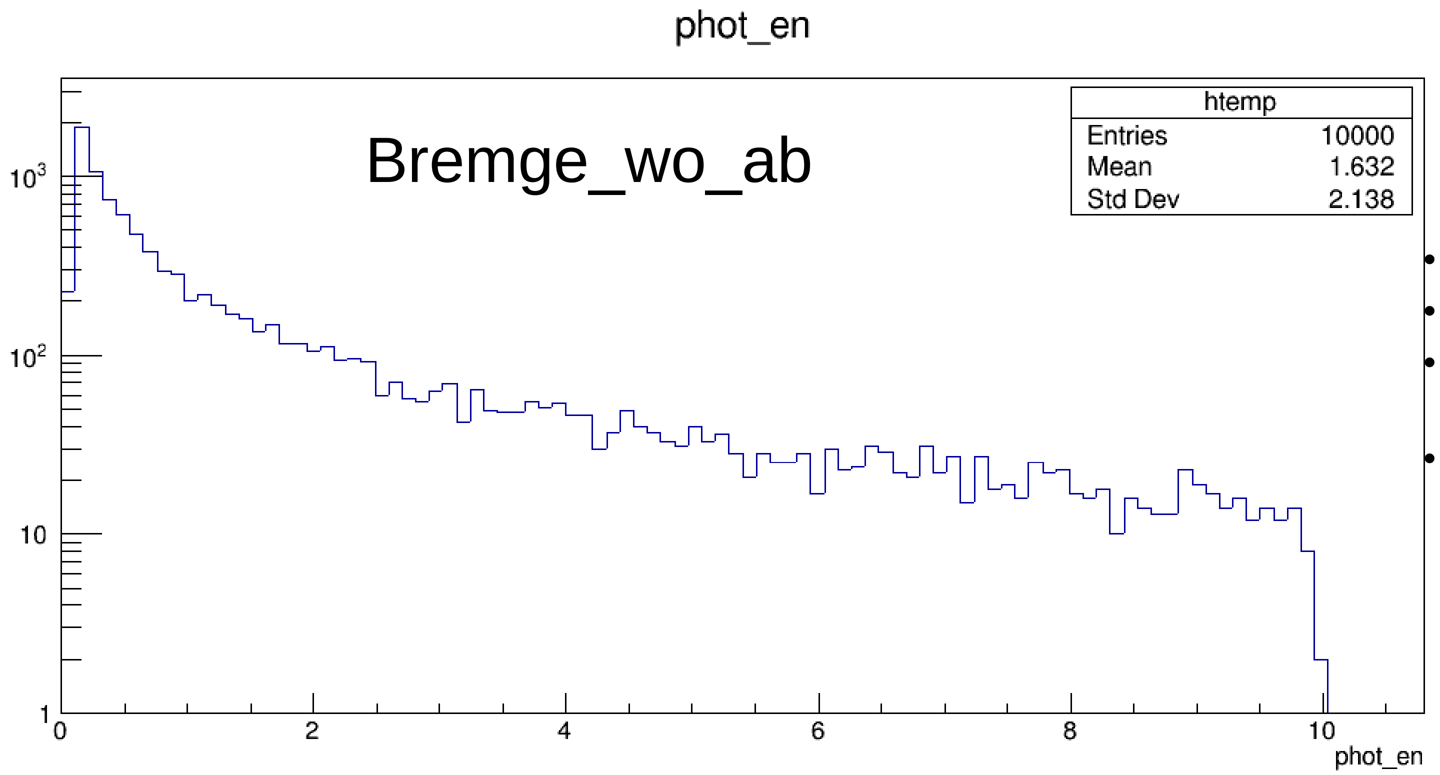
GETaLM: *set of event generators and related tools for simulations of luminosity monitor and electron tagger at the EIC.*

-hepMC3: one beam particles

Parameterizations of the bremsstrahlung cross section: Bethe-Heitler:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}E_\gamma} = 4\alpha r_e^2 \frac{E_e'}{E_\gamma E_e}\left(\frac{E_e}{E_e'} + \frac{E_e'}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4E_pE_eE_e'}{m_pm_eE_\gamma} - \frac{1}{2}\right)$$





ab==EIC MC afterburner:

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

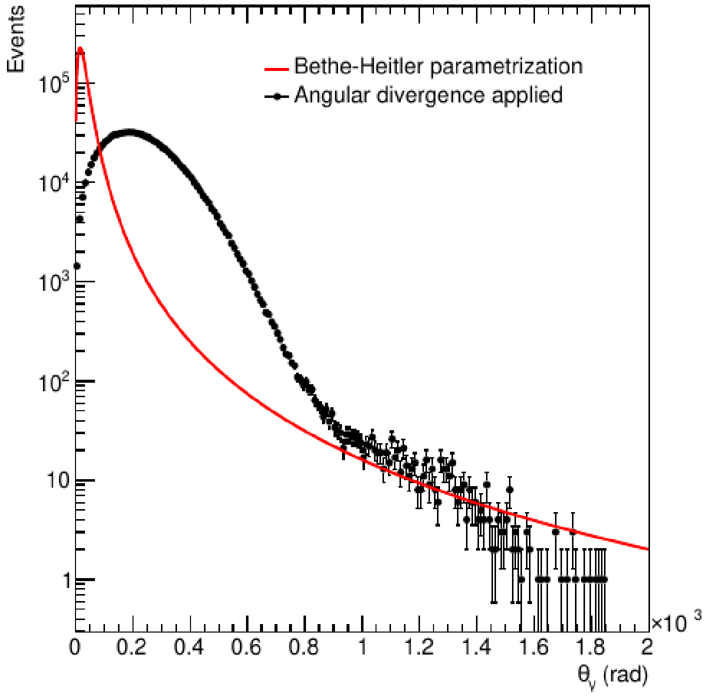
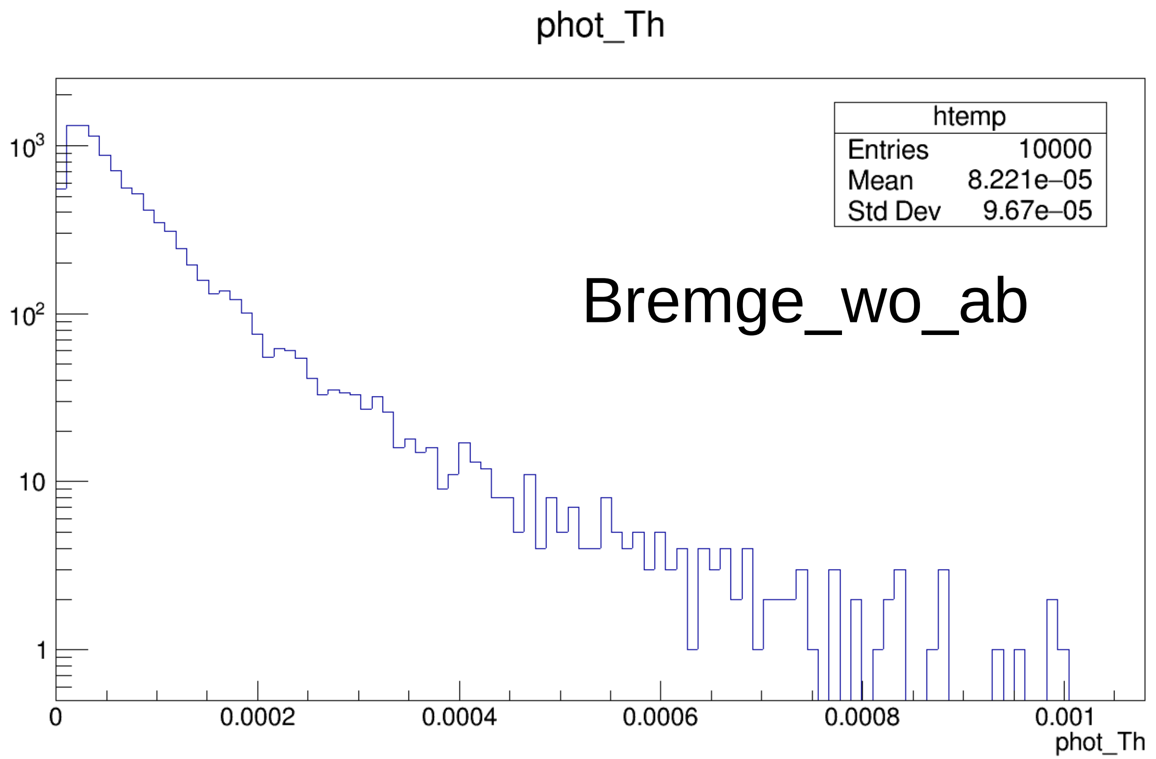
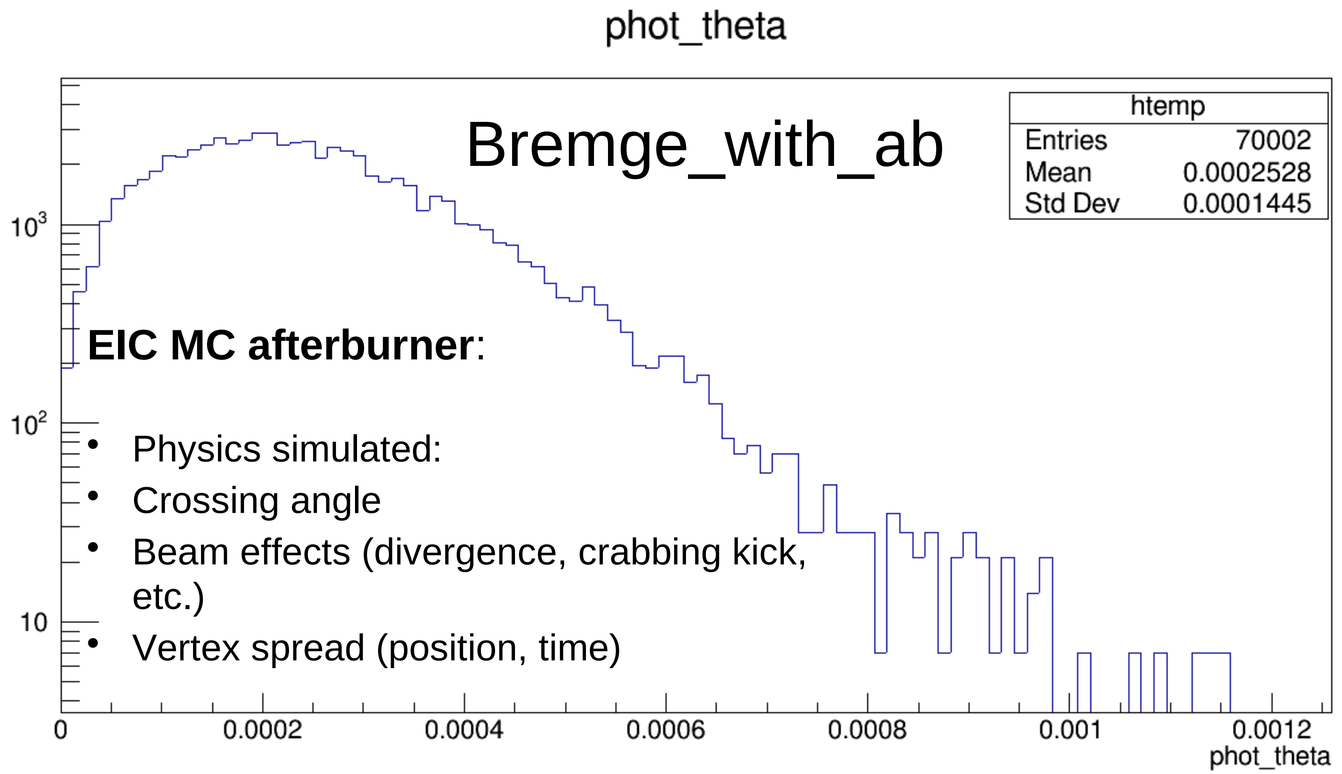


Figure 11.111: Angular dependence of bremsstrahlung cross section. The effect of beam angular divergence is shown.





EIC MC afterburner:

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

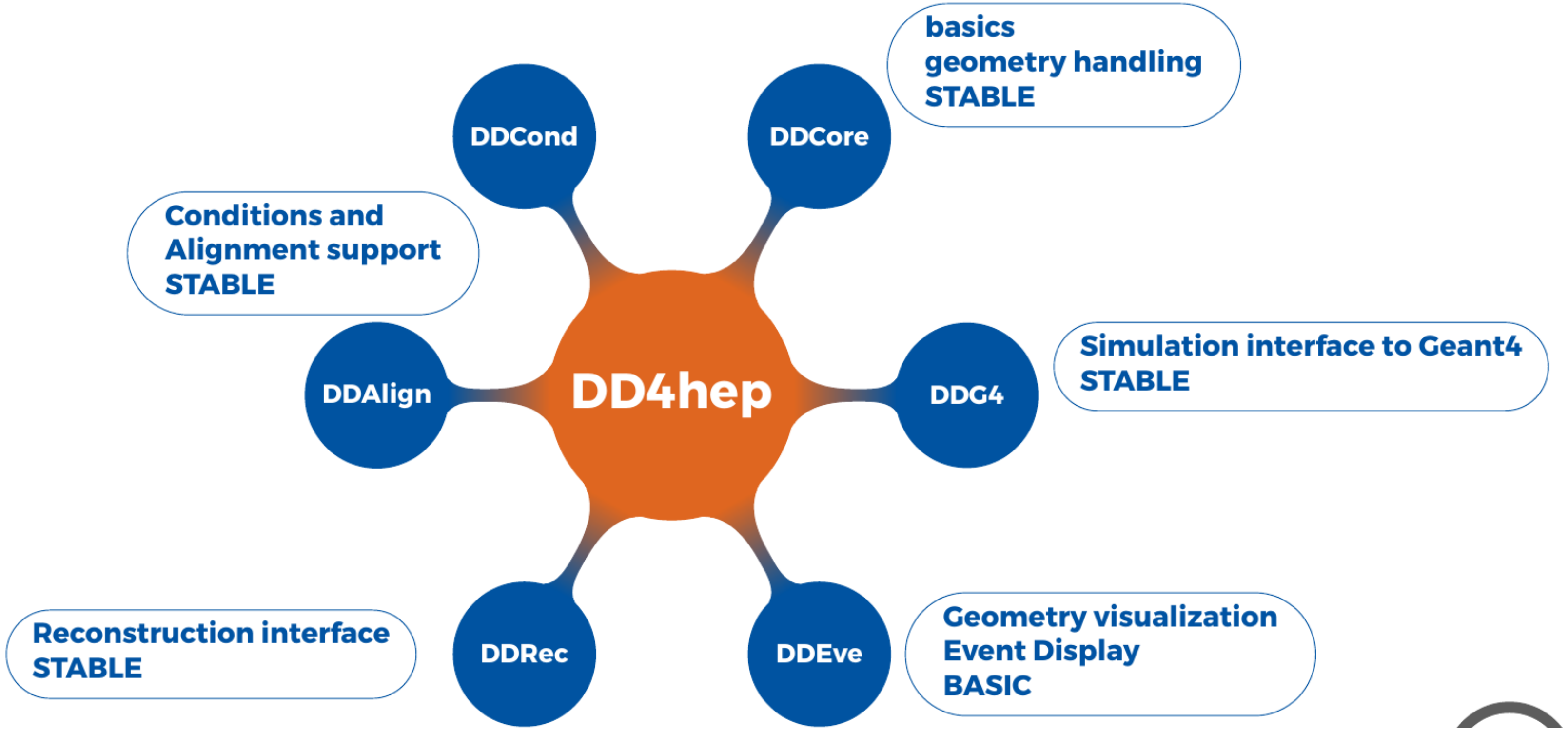
The angle θγ is the angle of the 3-momentum component of the outgoing photon k relative to the 3-momentum component of the incoming electron p.

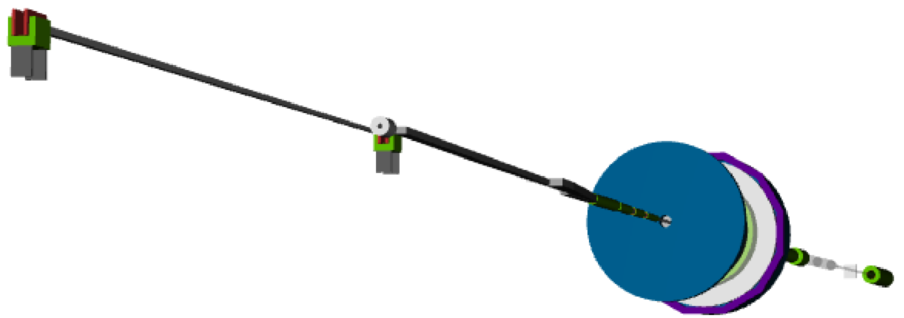
Structure and packages

EIC environment:

dd4hep, ddsim, eicrecon, etc

**run physics simulations with ddsim and geant4*





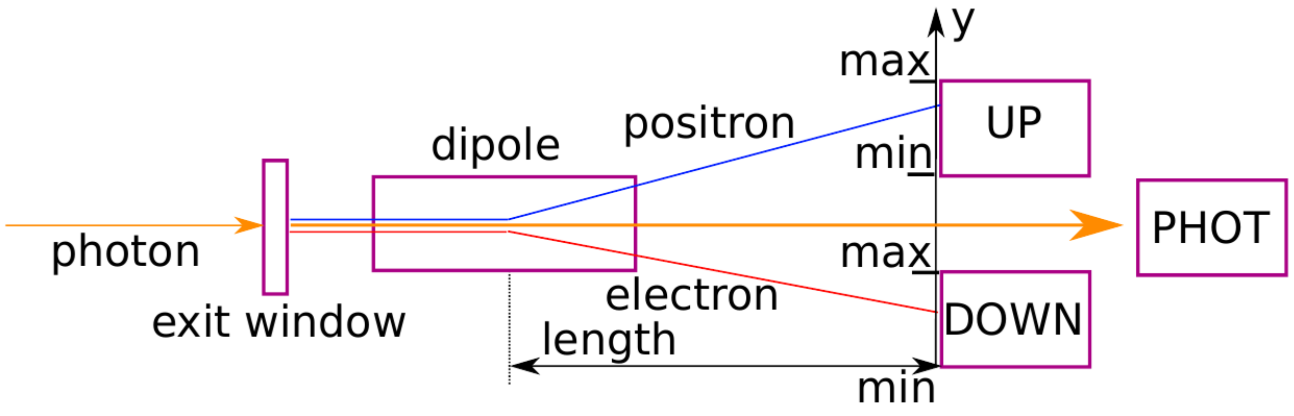


Figure 11.112: Principle of the luminosity measurement. Bremsstrahlung photons are incident on an aluminum exit window. Converted electron-positron pairs are split in the spectrometer dipole magnet and detected in the UP and DOWN detectors. Non-converted photons reach the photon calorimeter PHOT.

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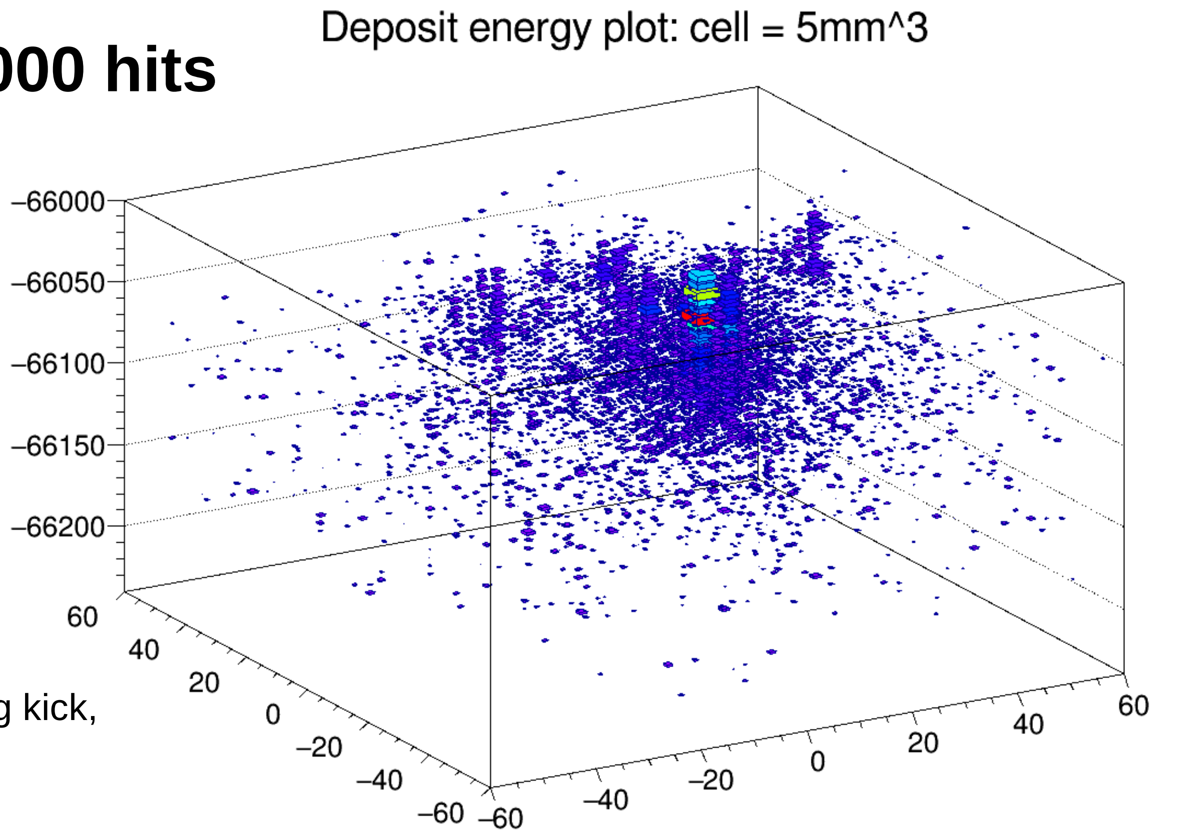
illustrative drawing:5000 hits



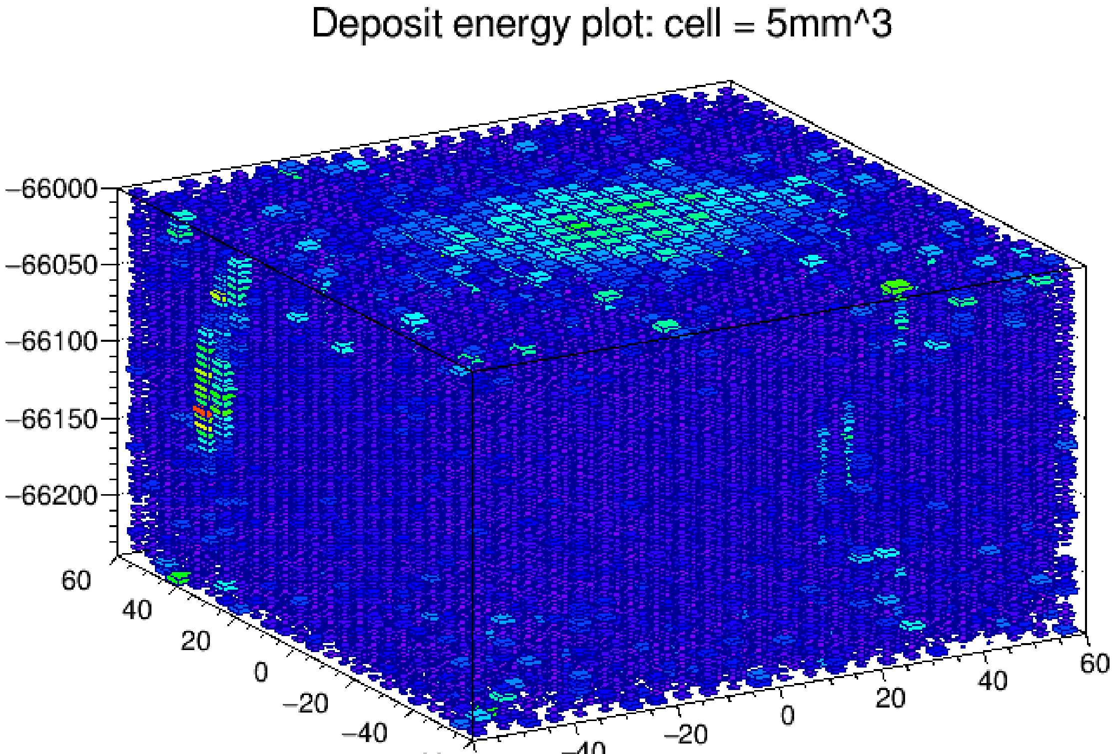
Bremge: with validated crossing angle and beam effects: EIC MC afterburner.

hits: 5260765

Emax 0.563382 GeV

x 0 y 0 z -66035 mm

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

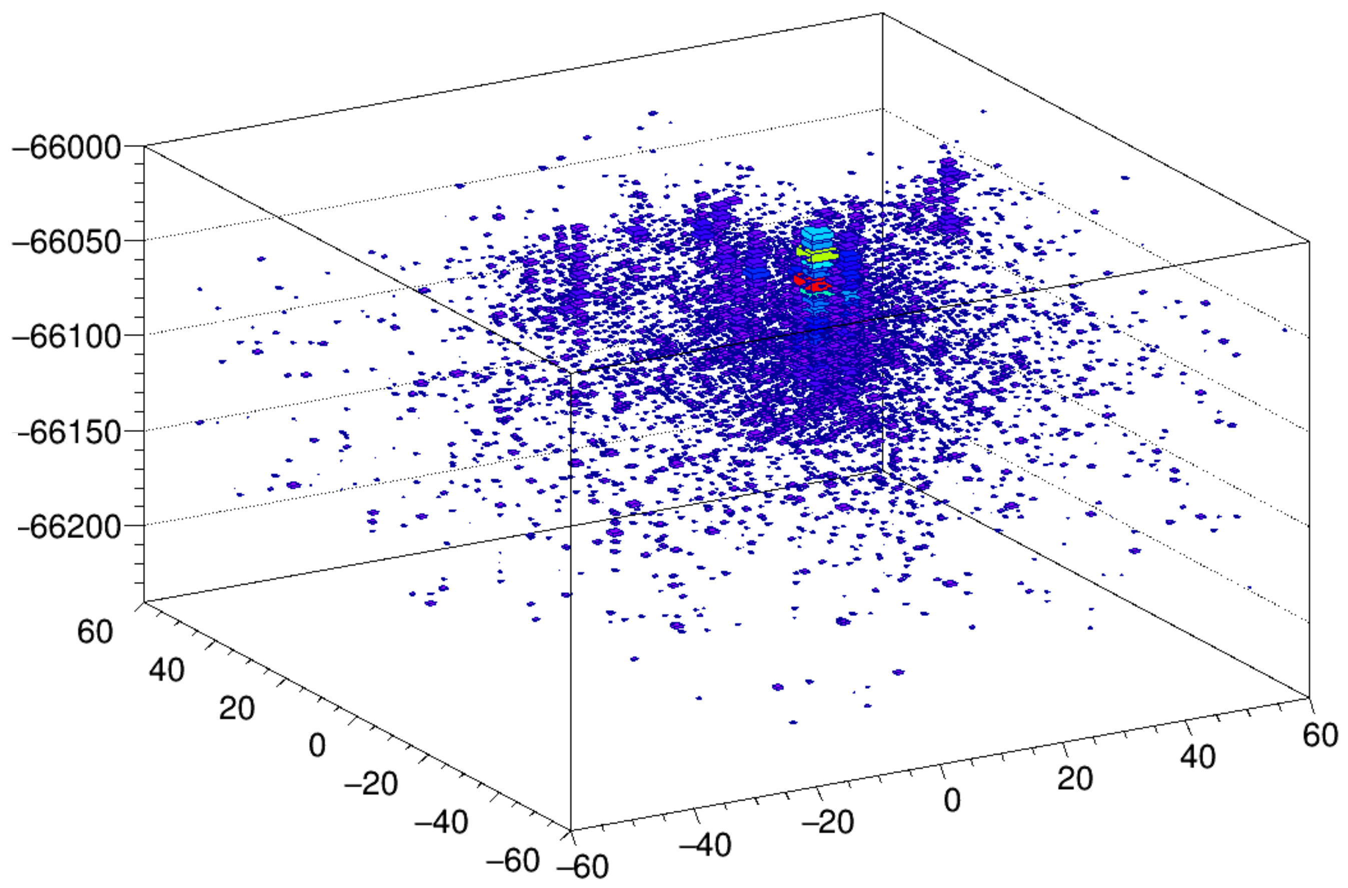


- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

EIC MC afterburner:

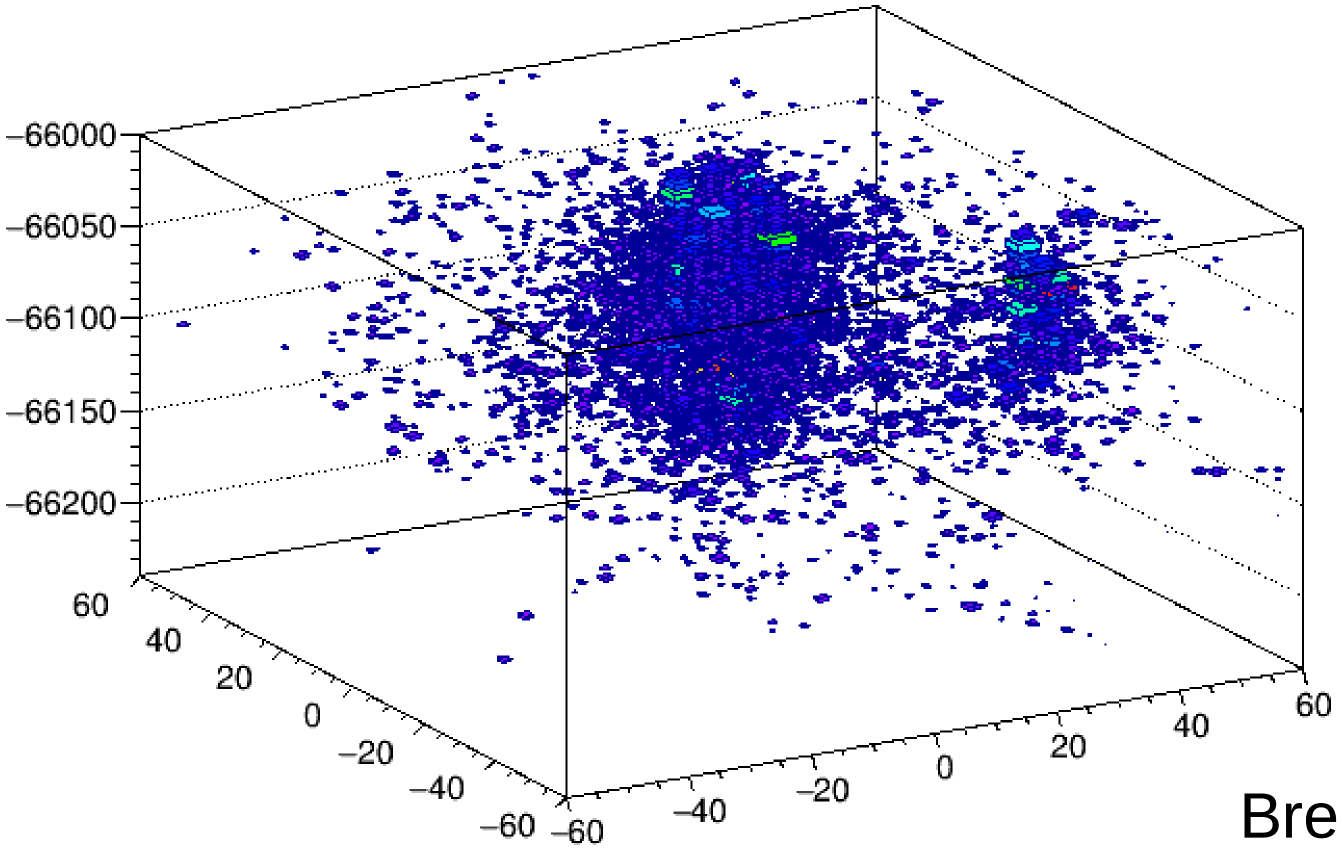
- Physics simulated:
- Crossing angle
- Beam effects (divergence, crabbing kick, etc.)
- Vertex spread (position, time)

Deposit energy plot: cell = 5mm^3



Bremge_with_ab

Deposit energy plot: cell = 5mm^3



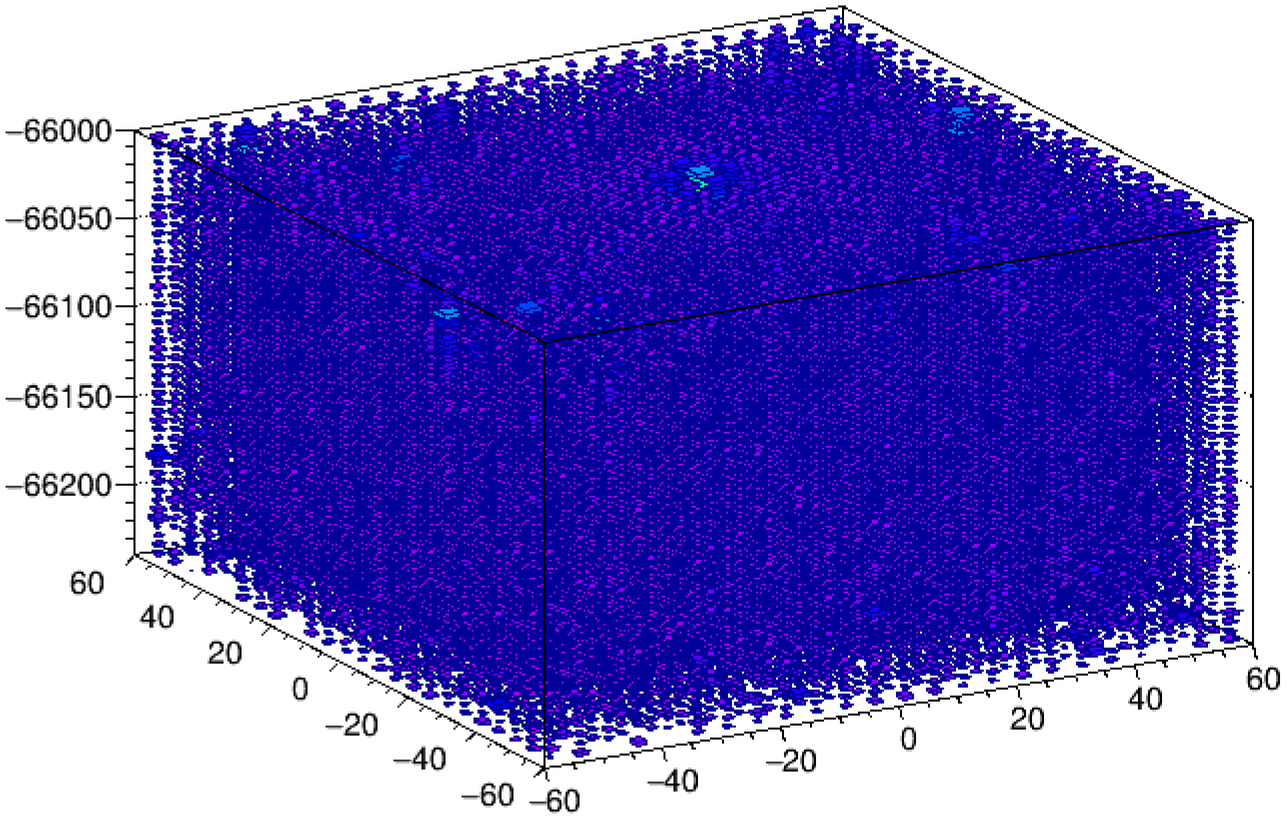
Bremge_wo_ab

EIC MC afterburner:

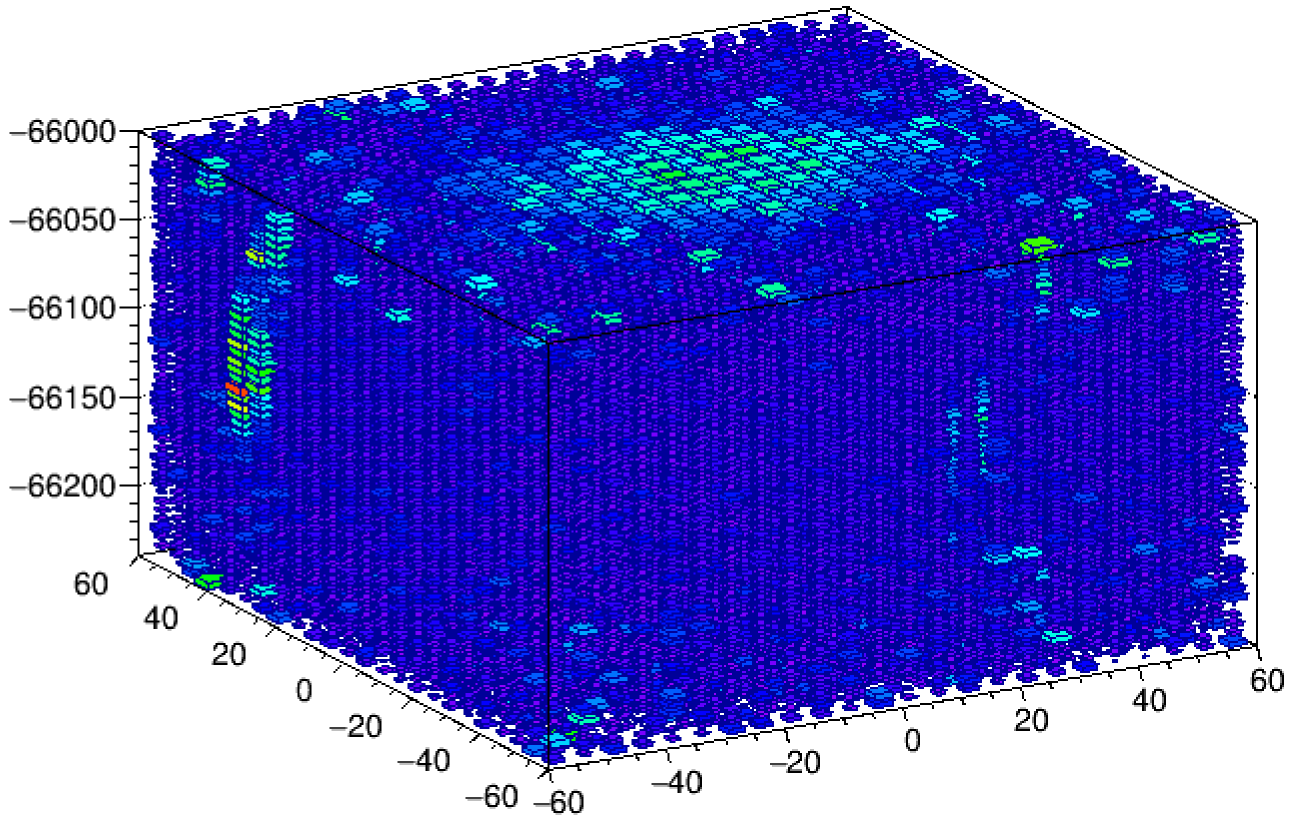
- Physics simulated:
- Crossing angle
- Beam effects (divergence, crabbing kick, etc.)
- Vertex spread (position, time)

Bremge_wo_ab

Deposit energy plot: cell = 5mm^3



Deposit energy plot: cell = 5mm^3



Bremge_with_ab

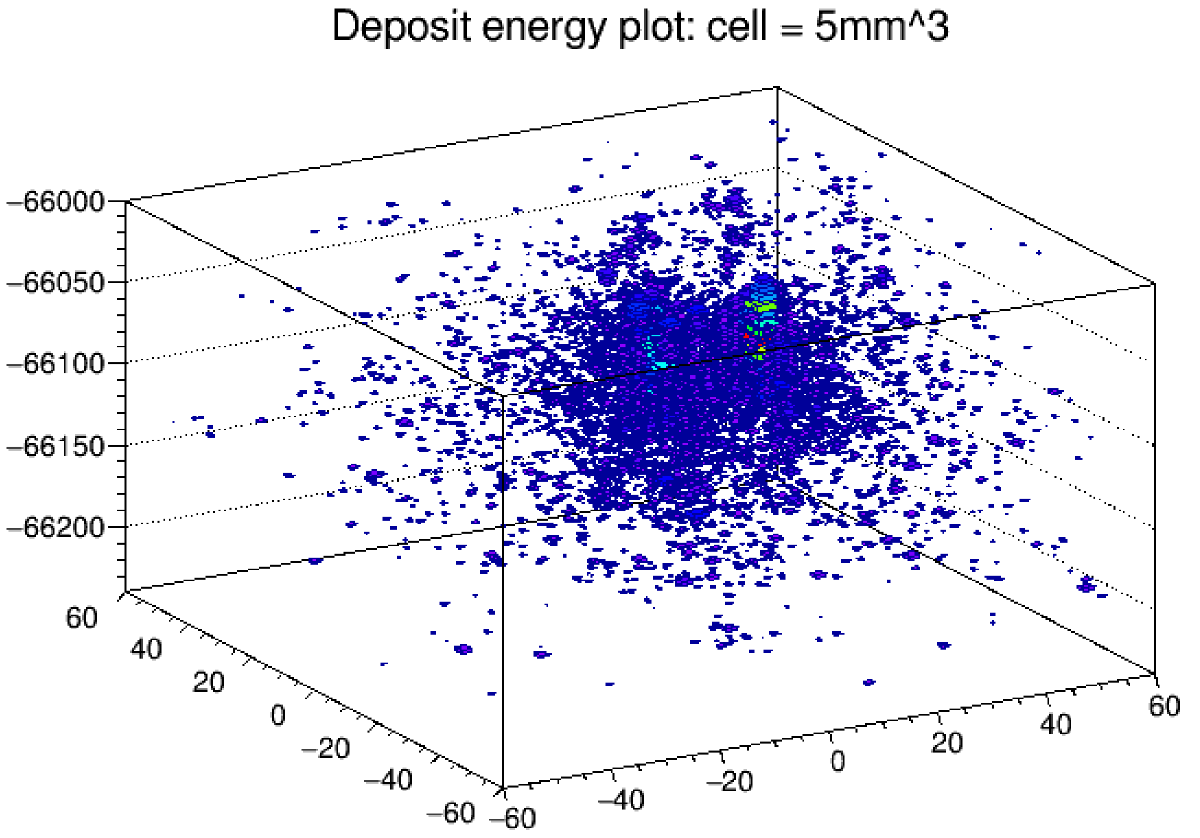
illustrative drawing:5000 hits

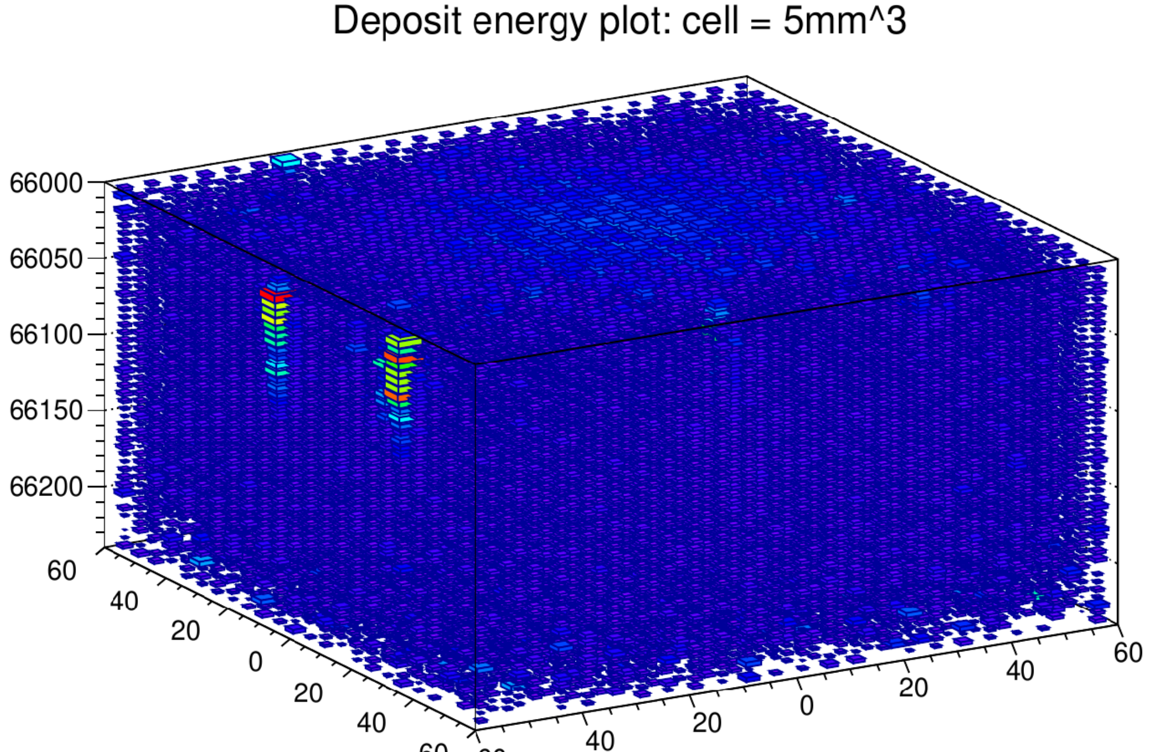
GETaLM: with effects of beam angular divergence and vertex spread

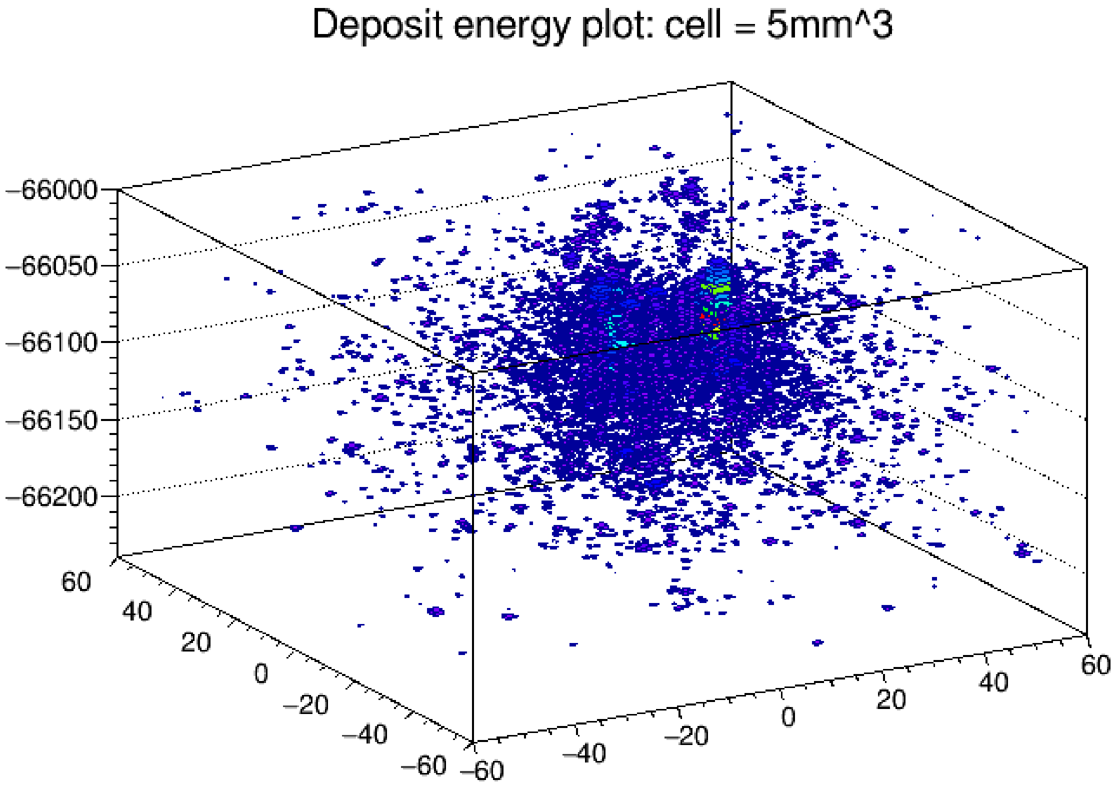
- **hits: 3298949**
- **Emax 0.496139 GeV**

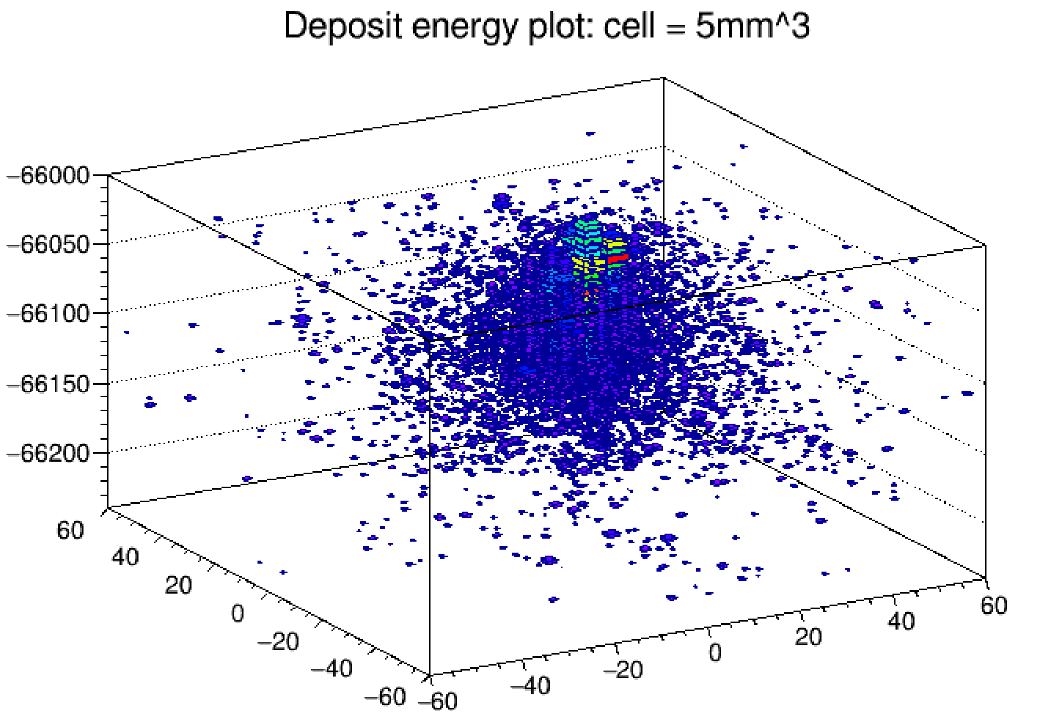
x 5 y -5 z -66050

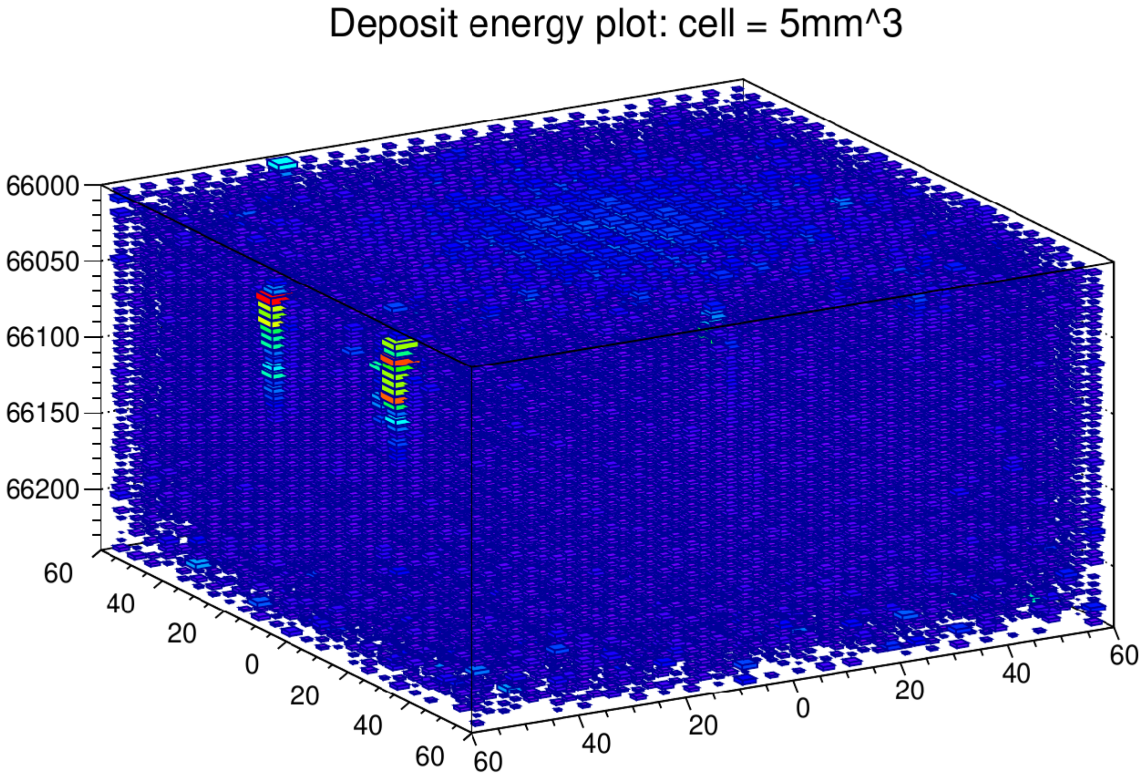
- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

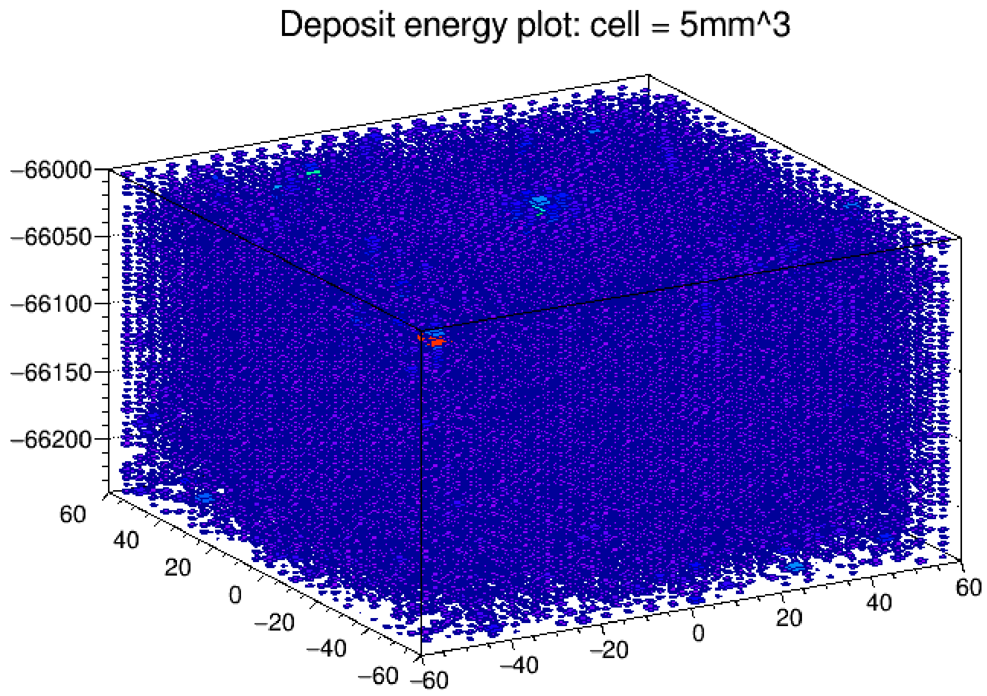





Deposit energy plot: cell = 5mm^3
−66000
−66050
−66100
−66150
−66200
60 40 20 0 −20 −40 −60
−60 −40 −20 0 20 40 60

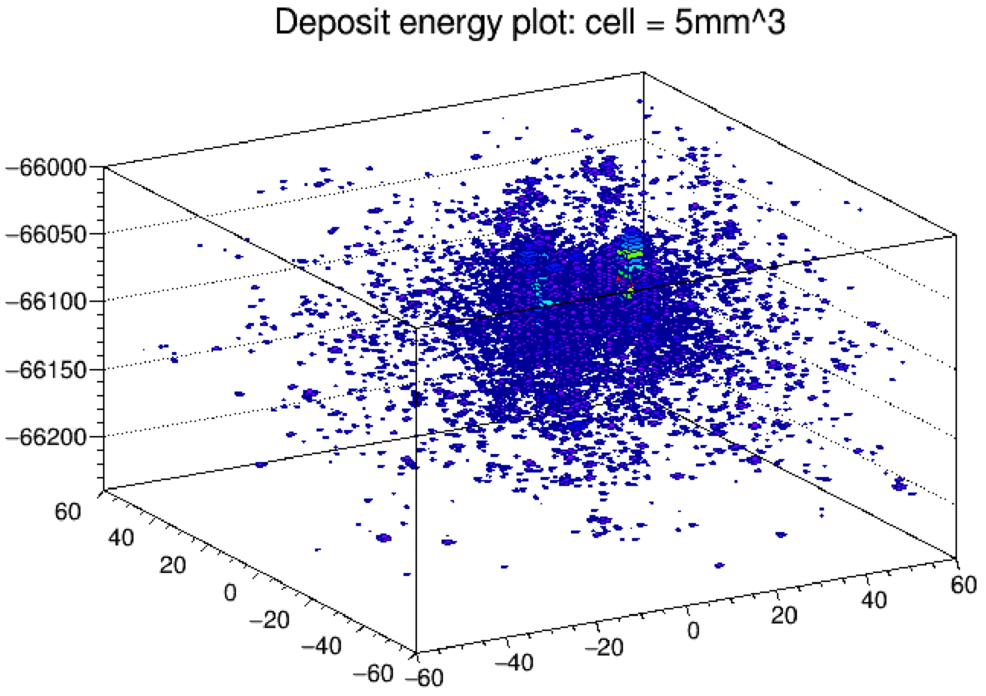

Deposit energy plot: cell = 5mm^3
−66000
−66050
−66100
−66150
−66200
60 40 20 0 −20 −40 −60
−60 −40 −20 0 20 40 60

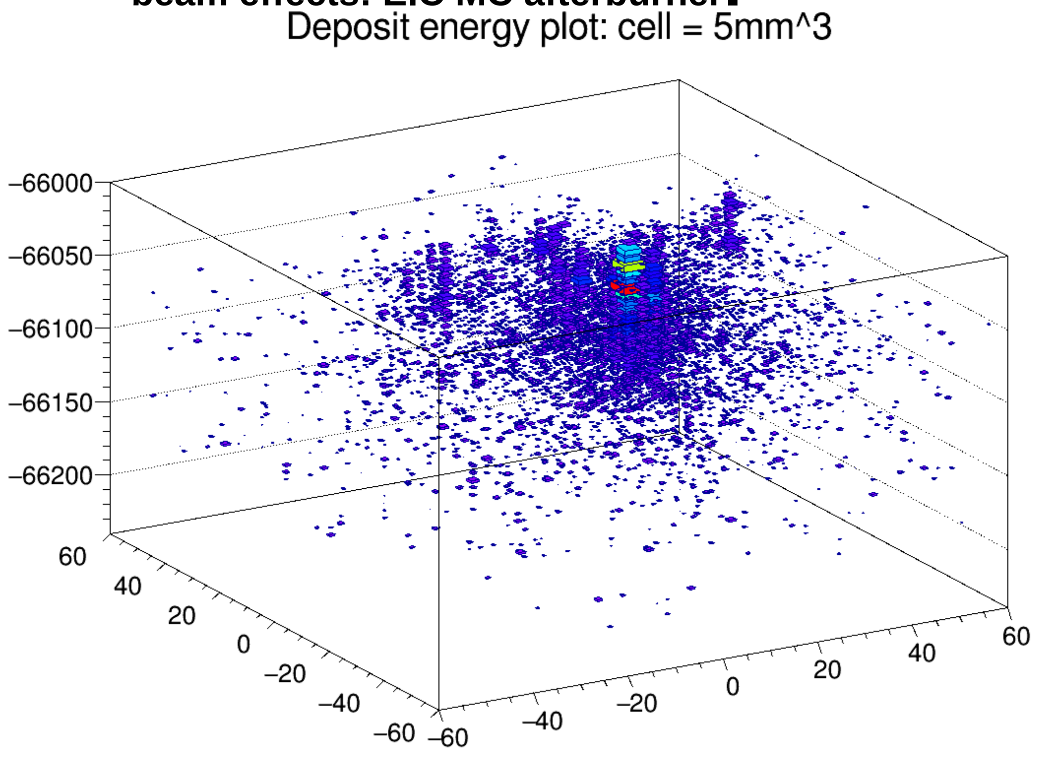

Deposit energy plot: cell = 5mm^3
66000
66050
66100
66150
66200
60 40 20 0 20 40 60
60 40 20 0 20 40 60

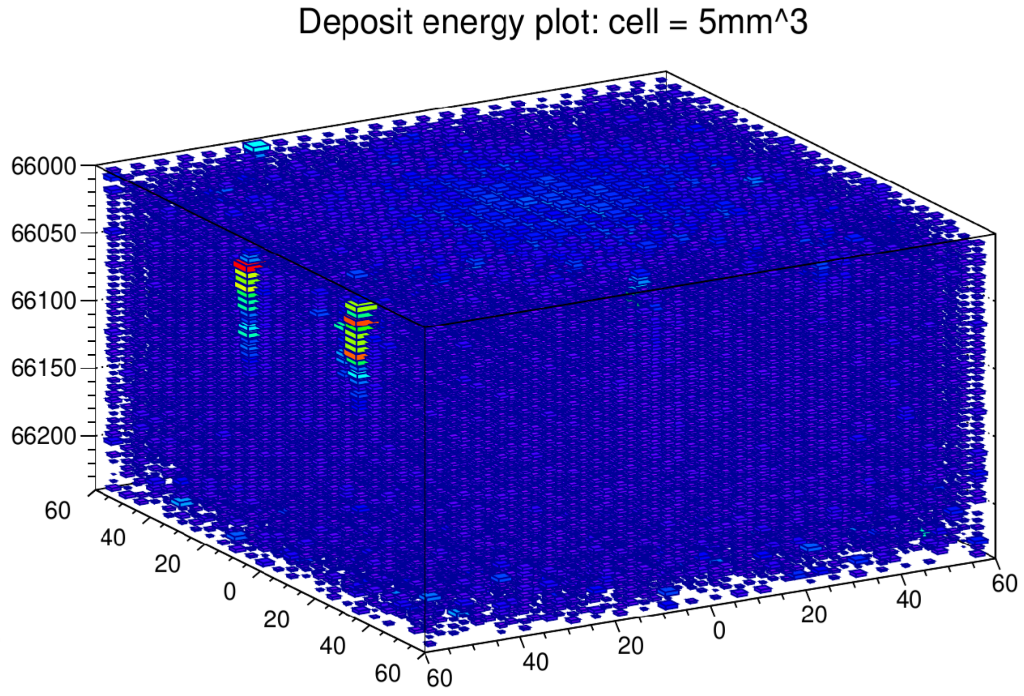

Deposit energy plot: cell = 5mm^3
−66000
−66050
−66100
−66150
−66200
60 40 20 0 −20 −40 −60
−60 −40 −20 0 20 40 60

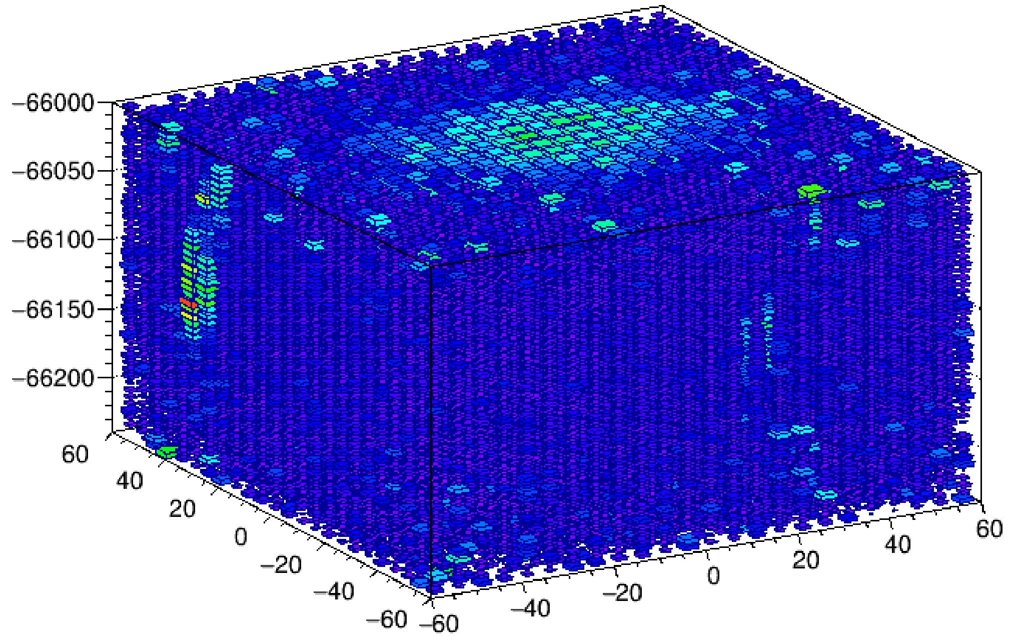
GETaLM:with effects of beam angular divergence and vertex spread

Bremge: with validated crossing angle and beam effects: EIC MC afterburner.









backup

illustrative drawing:5000 hits

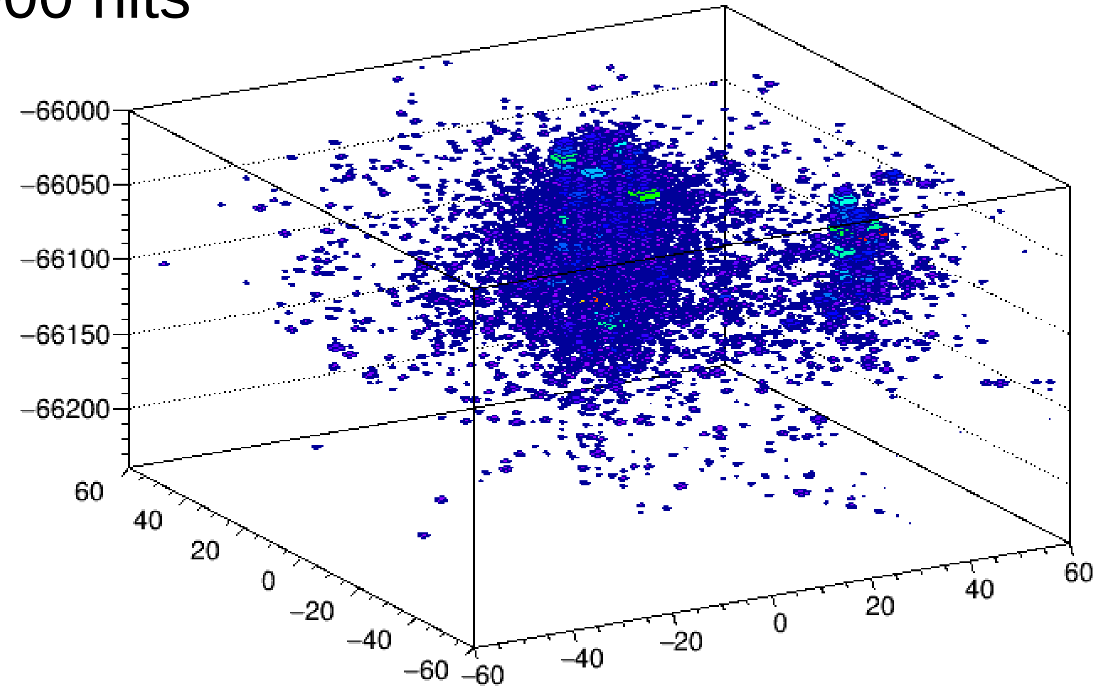
Bremge: without validated crossing angle and beam effects:

- **hits: 5243428**
- **Emax 0.5327 GeV**

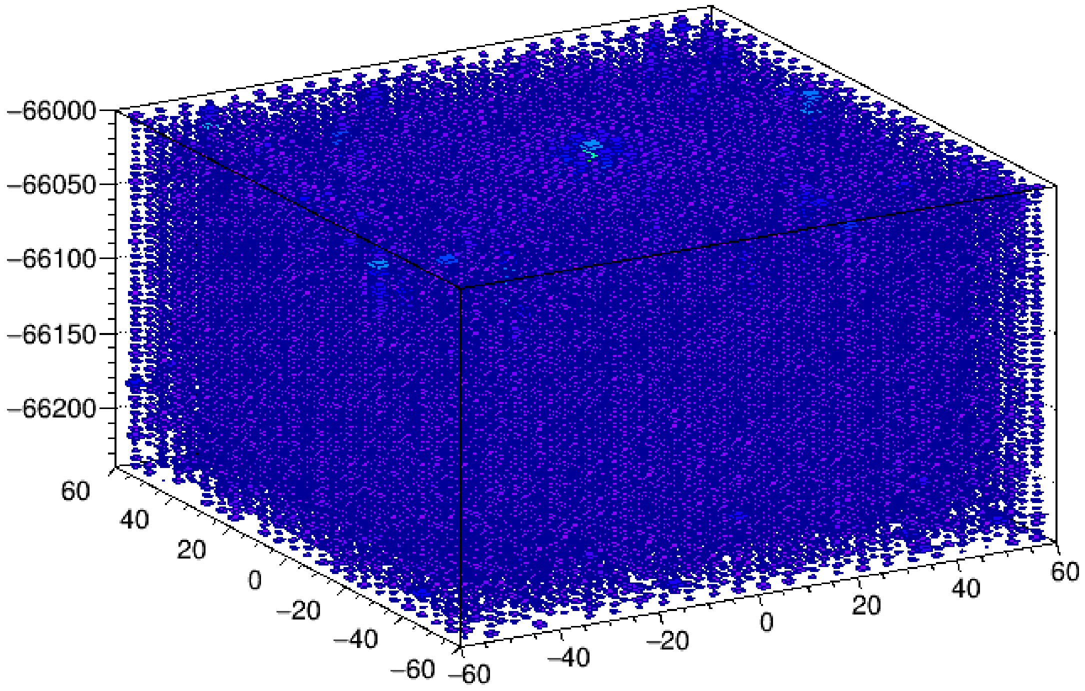
x 5 y 0 z -66045 mm

- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

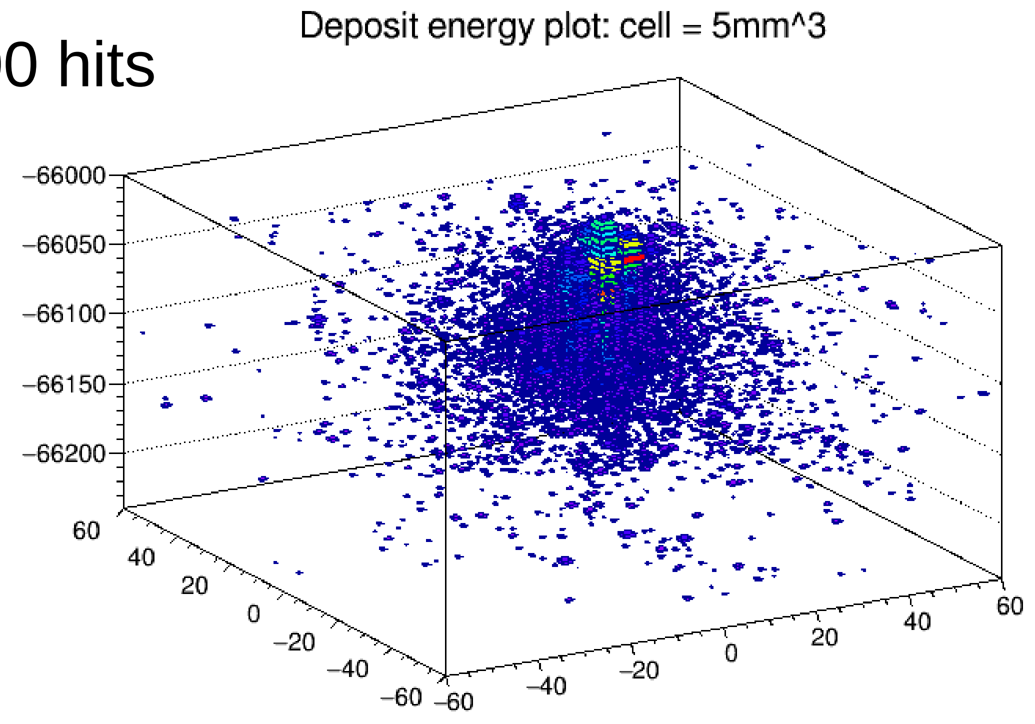
Deposit energy plot: cell = 5mm^3



Deposit energy plot: cell = 5mm^3



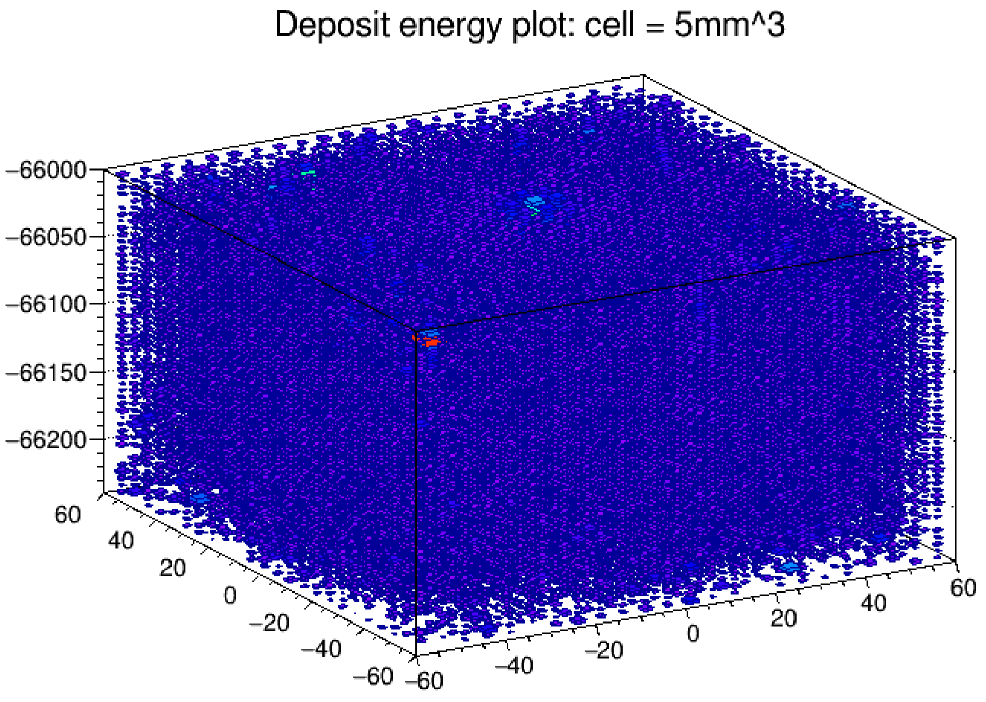
illustrative drawing:5000 hits



GETaLM: wo beam effects

- **hits: 3246520**
- **Emax 0.505228 GeV**

x -5 y 0 z -66060



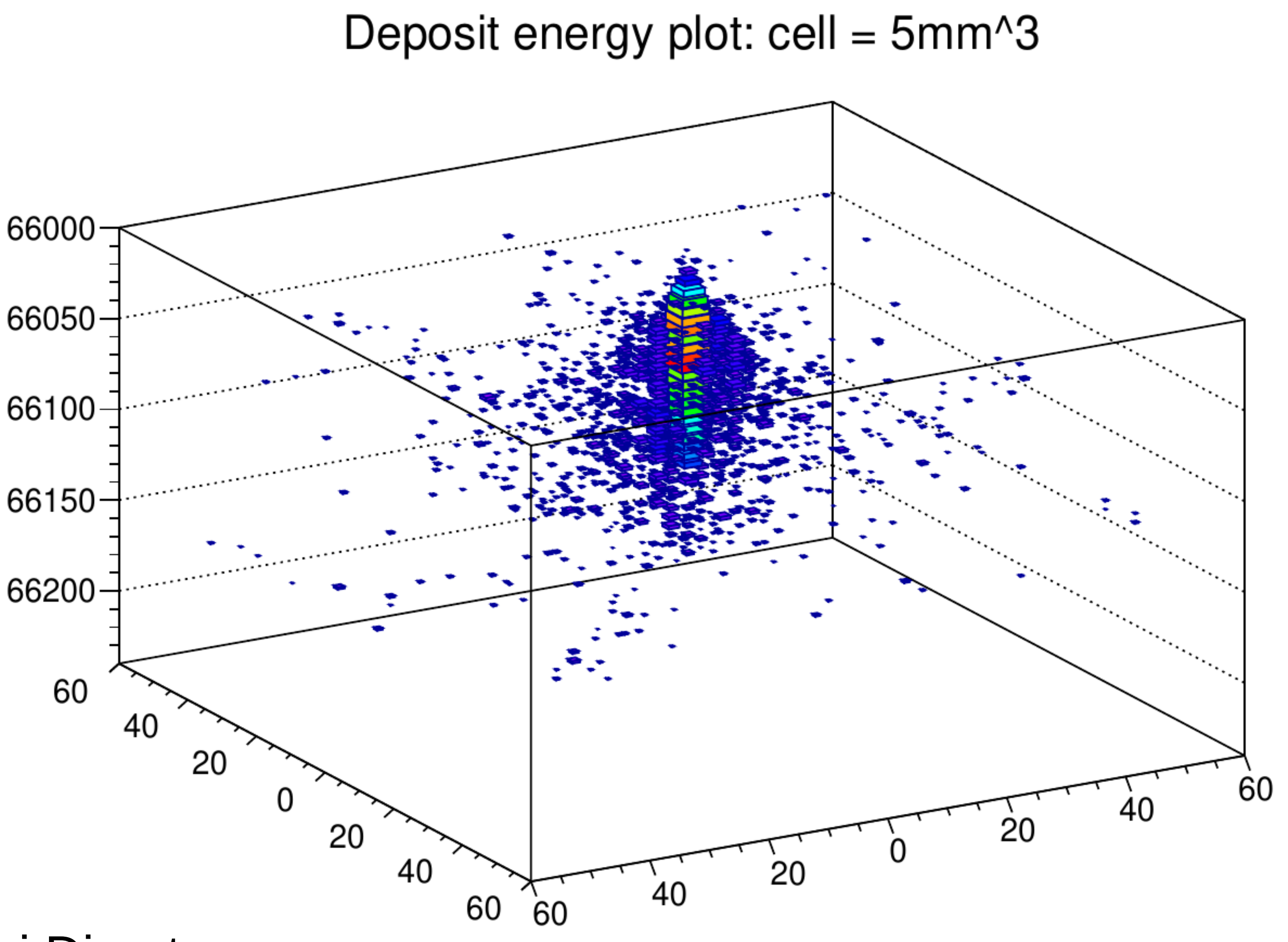
- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

Particle Gun:

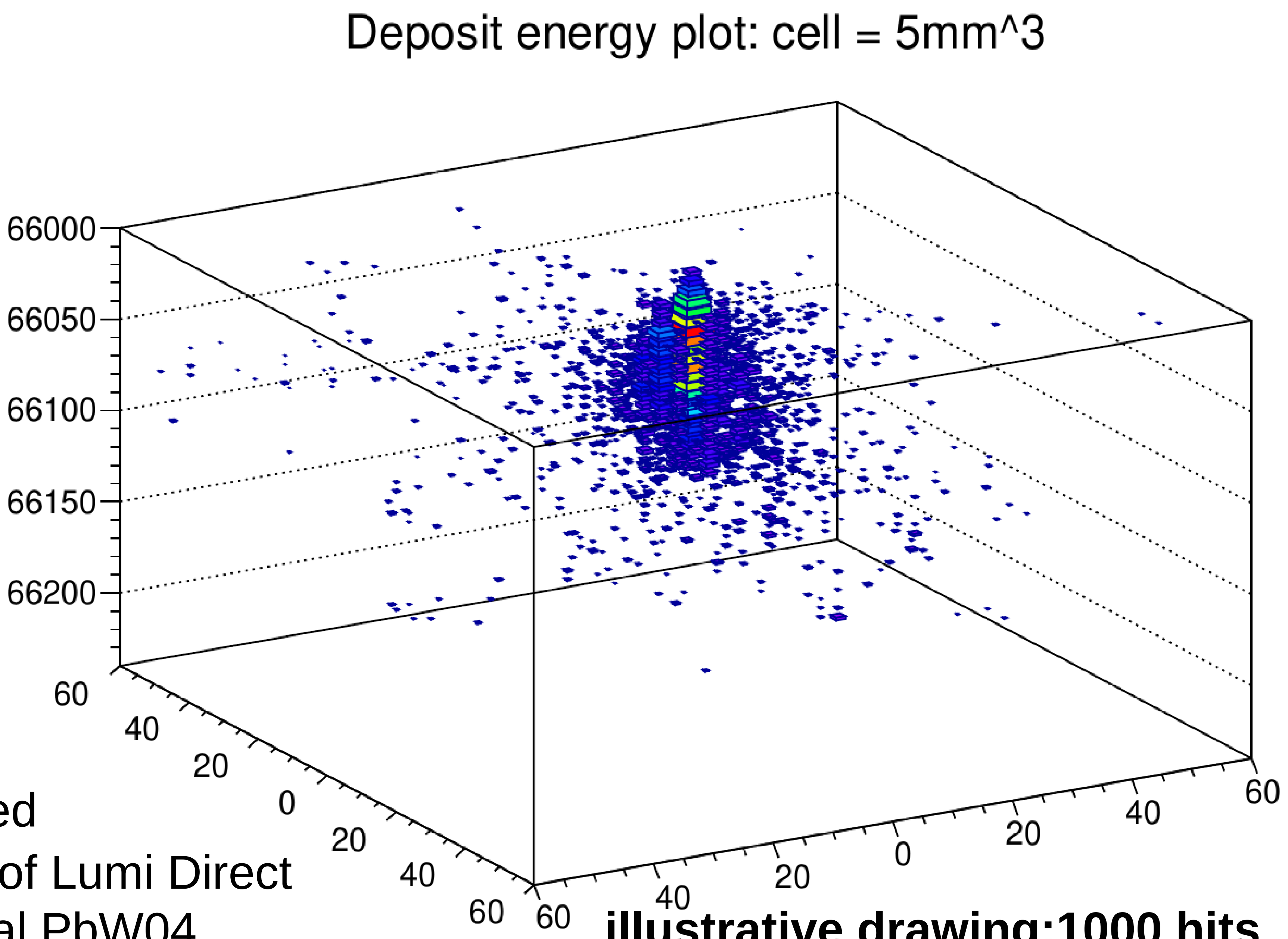
- z=surface of LDdetector
  - **hits: 21413781**
  - **Emax 0.686002 GeV**

x 0 y 0 z -66045

- Egamma: 10 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell



illustrative drawing:1000 hits



Particle Gun:

- ip
  - **hits: 24495417**
  - **Emax 0.678314 GeV**

x 0 y 0 z -66045

- Egamma: 10 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

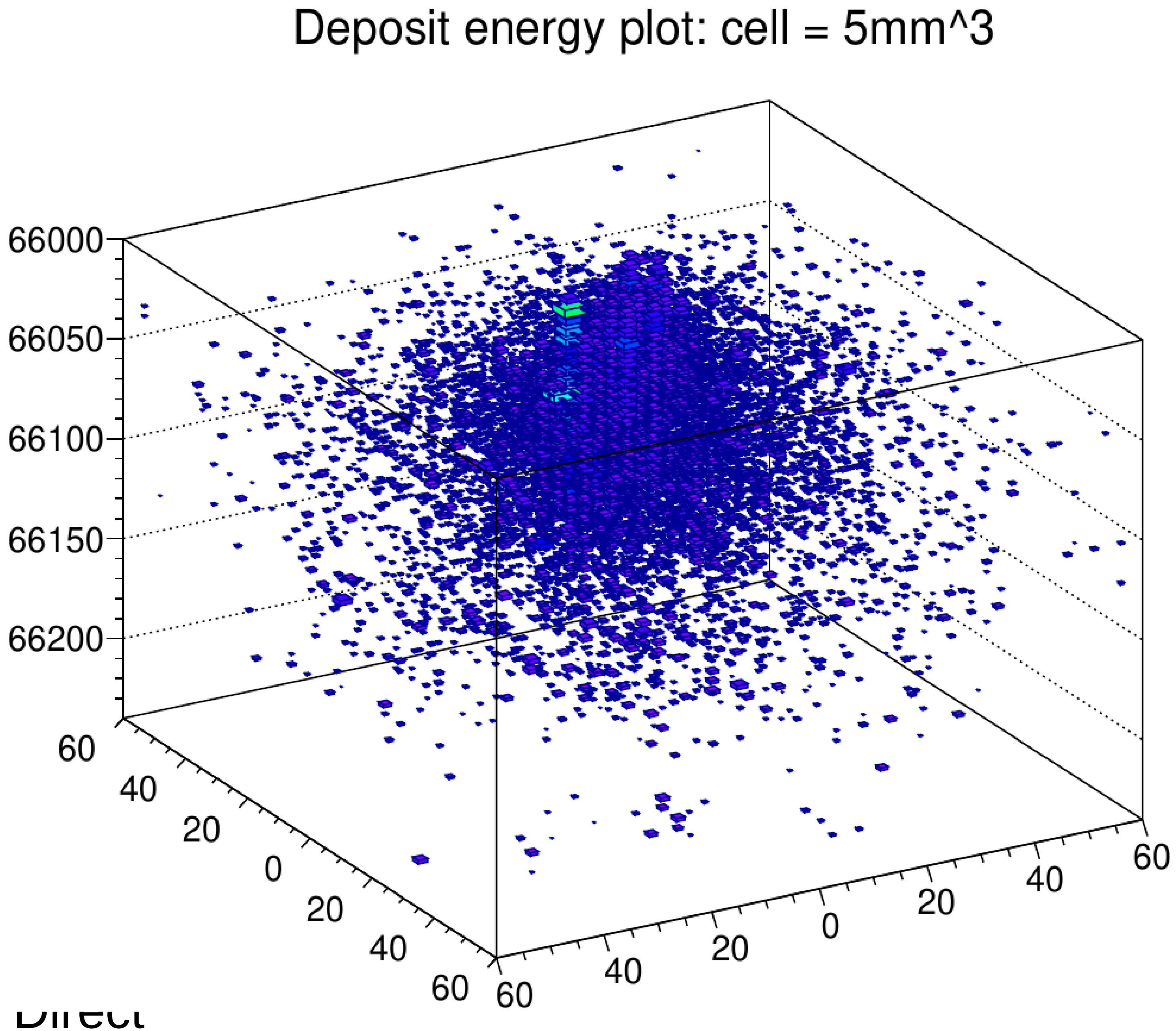
illustrative drawing:1000 hits

Bremge: wo beam effects

- **hits: 5216665**
- **Emax 0.477702 GeV**

x 0 y 0 z -66055

- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell



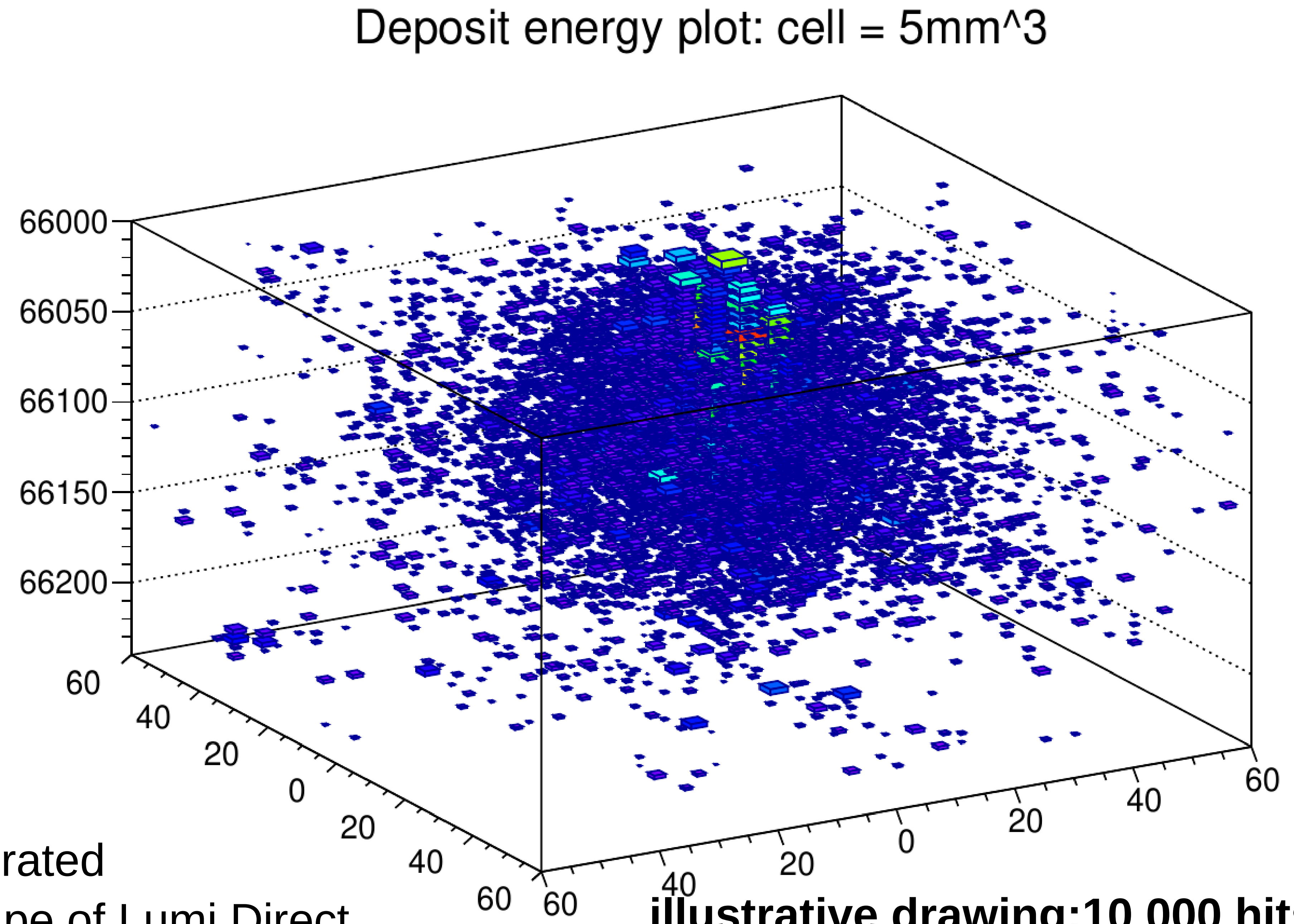
illustrative drawing:10 000 hits

GETaLM: wo beam effects

- **hits: 3246520**
- **Emax 0.505228 GeV**

x -5 y 0 z -66060

- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

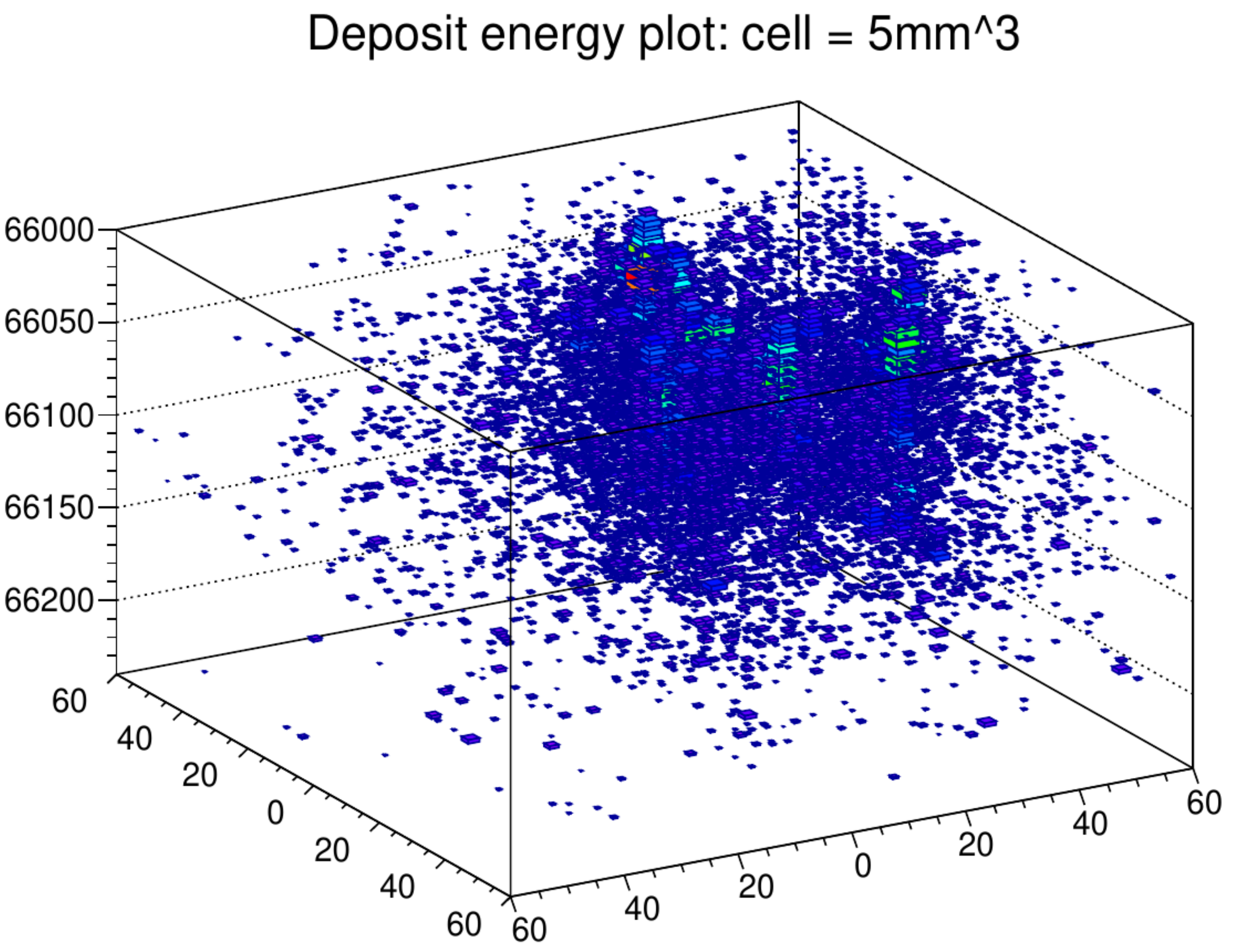


illustrative drawing:10 000 hits

GETaLM: with beam effects

- **hits: 3298949**
- **Emax 0.496139 GeV**

x 5 y -5 z -66050



illustrative drawing:10 000 hits

- Ee: 10 GeV
- Ep: 275 GeV
- 10 000 events generated
- 12x12x24 cubic shape of Lumi Direct Detector, made of cristal PbW04
- 5mm each cell

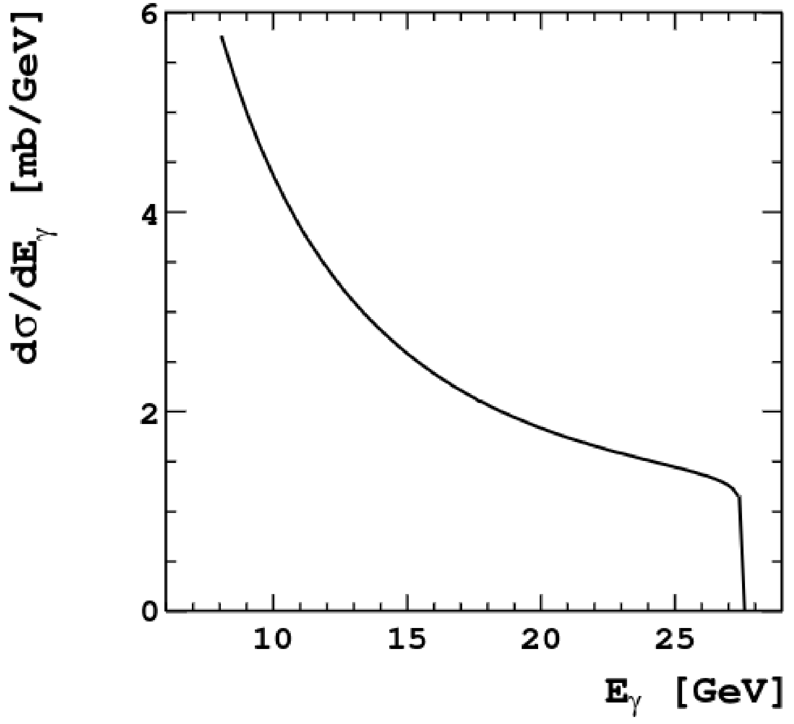


Figure 1: The energy spectrum of bremsstrahlung photons obtained from Eqn.(2).

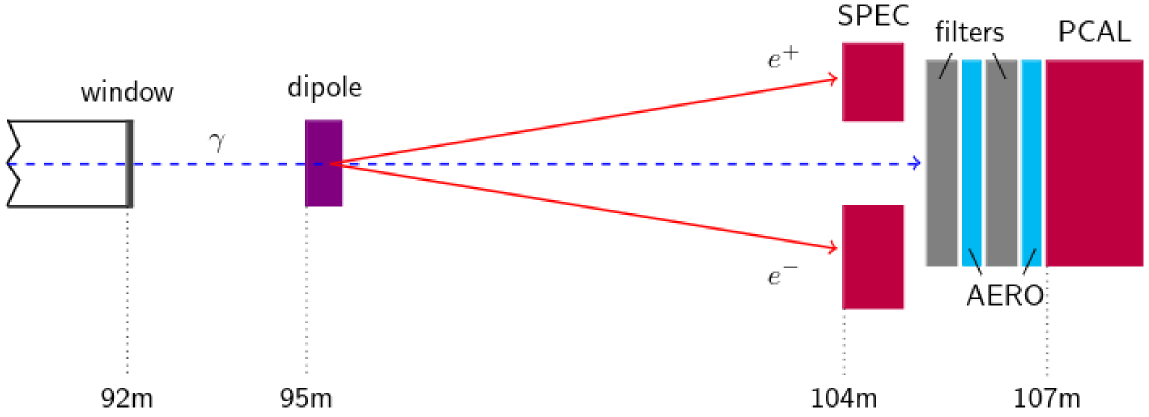


Figure 2: The layout of the luminometers in the ZEUS experiment. The IP is on the left side in the ZEUS detector. A dipole magnet just downstream of the beam-exit window deflected electrons originating from converted photons to the two electromagnetic calorimeters of the spectrometer SPEC. PCAL denotes the photon calorimeter and filters the carbon absorber blocks. AERO are Cerenkov counters not used for the luminosity measurement.

Taking the event rates recorded for each of the energy thresholds and the electron pilot bunches, the rate of bremsstrahlung events, R_γ, corrected for interactions of the beam with residual gas, was obtained as

$$R_\gamma = R_{tot} - R_{pilot} \cdot \frac{I_e^{tot}}{I_e^{pil}}, \tag{5}$$

where R_{tot} and R_{pilot} were the total photon rate and the rate from the pilot

At high photon rates more than one photon from a single bunch crossing may have hit the calorimeter. The average number of photons per bunch crossing, $\bar{n}_\gamma$, was estimated to be

$$\bar{n}_\gamma = \frac{R_\gamma \cdot \sigma_b}{\sigma(E_\gamma > E_{tres.}) \cdot f_r \cdot N_{cb}}, \tag{6}$$

where σ_b and $\sigma(E_\gamma > E_{tres.})$ are the total bremsstrahlung cross section[3] and the bremsstrahlung cross section above an energy threshold $E_{tres.}$, f_r is the HERA orbit frequency and N_{cb} the number of colliding bunches. The bremsstrahlung rate corrected for multiple photons per bunch crossing was then

$$R'_\gamma = R_\gamma \cdot (1 + P(E_{tres.}, \bar{n}_\gamma)), \tag{7}$$

where the correction term $P(E_{tres.}, \bar{n}_\gamma)$ was determined from Monte Carlo simulations.

5.1. Photon Calorimeter Simulation

Photons with an energy larger than $E_{min} = 0.1$ GeV not converted in the beam exit window or air were transported to the photon calorimeter and a shower was simulated. The energy deposited in the scintillators and scintillator fingers was recorded for shower energy and position reconstruction. The light collection and the impact of the readout electronics was parametrised using test-beam data.

A detector response function $F(E_{cal})$ was calculated as a function of the photon energy E_γ,

$$F(E_{cal}) = 1/\sigma_b \times \int_{E_{min}}^{E_e - m_e} \frac{d\sigma}{dE_\gamma} P(E_\gamma, E_{cal}) dE_\gamma, \quad (8)$$

with $P(E_\gamma, E_{cal})$ being the probability that for an incident photon with an energy E_γ the energy E_{cal} was measured in the calorimeter and σ_b the bremsstrahlung cross section integrated from E_{min} to the upper kinematic limit. Using the detector response function the cross section, σ_{thr}, for photons with a measured energy above a threshold, E_{thr}, is obtained,

$$\sigma_{thr}(E_{thr}) = \sigma_b \int_{E_{thr}}^{\infty} F(E_{cal}) dE_{cal}. \quad (9)$$

The acceptance A is the number of events above a given energy threshold, N_{thr}, divided by the generated number of events, N_{gen},

$$A = \frac{N_{thr}}{N_{gen}} = \int_{E_{thr}}^{\infty} F(E_{cal}) dE_{cal}. \quad (10)$$