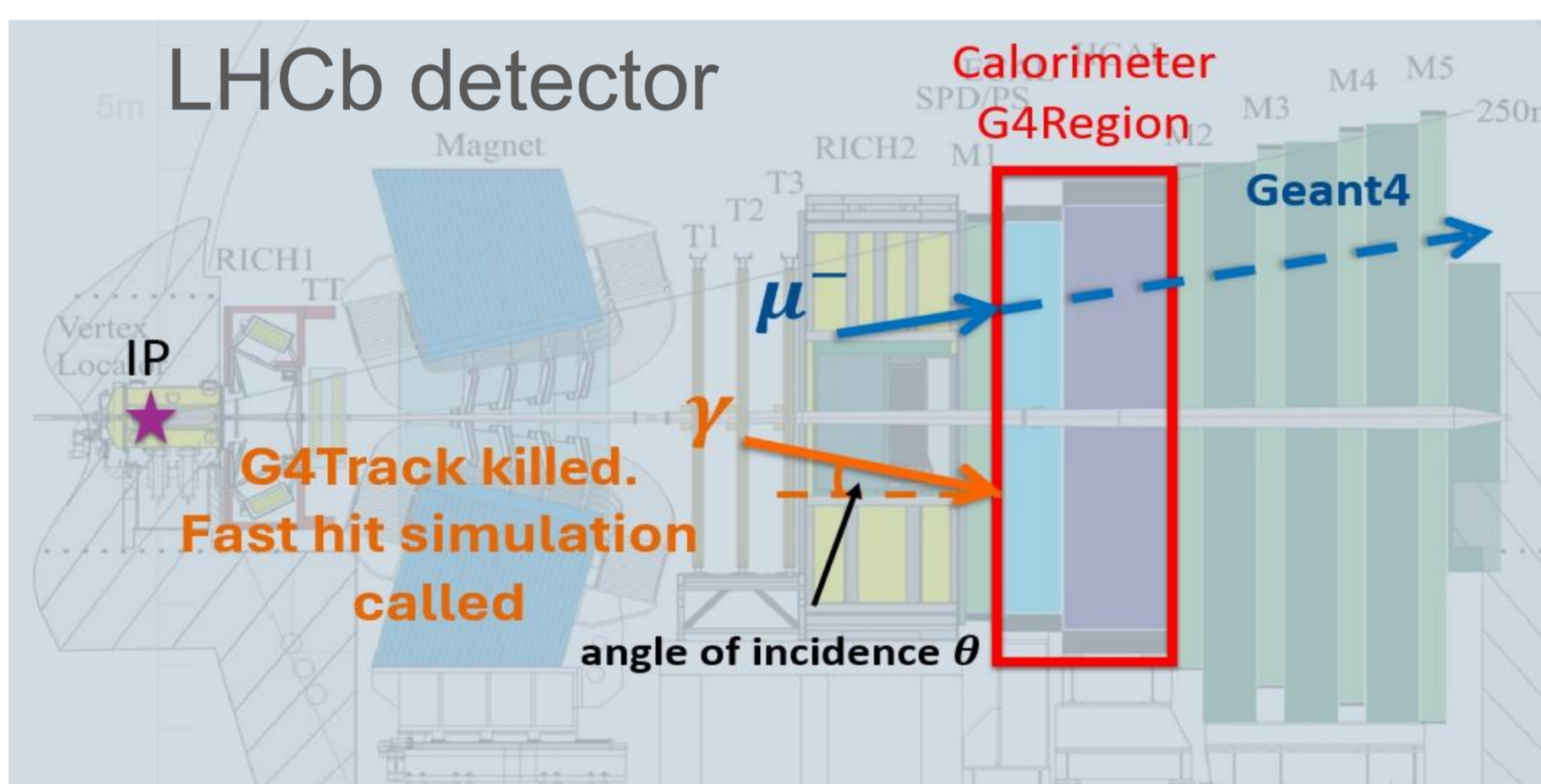
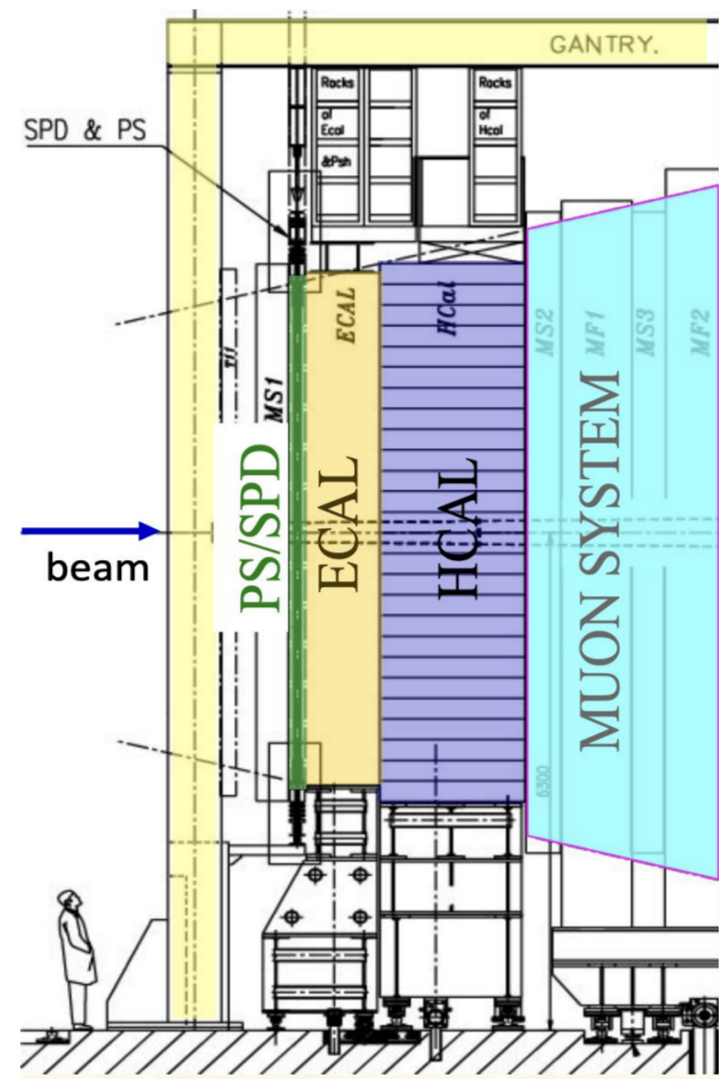


## 1 CPU time in LHCb detector simulation

- The LHCb experiment at CERN specializes in the study of  $b$  and  $c$  quark decays produced in  $pp$  collisions
  - Though event simulation dominates CPU usage (>95%), more simulated events are needed to reduce systematic uncertainties.
  - Calorimeter simulation with Geant4 is the dominant contributor to CPU consumption ( $\geq 50\%$ )
- ⇒ **Speeding up the simulation of the calorimeter response is highly desirable**

## 2 LHCb calorimeter simulation

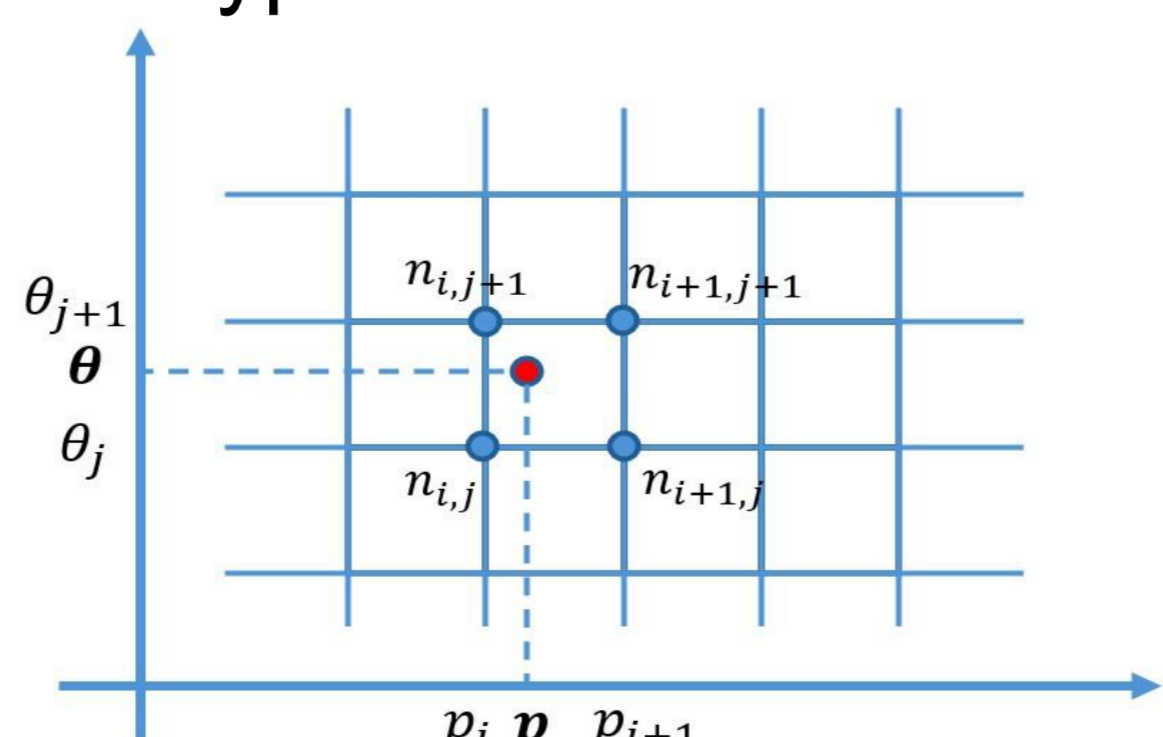
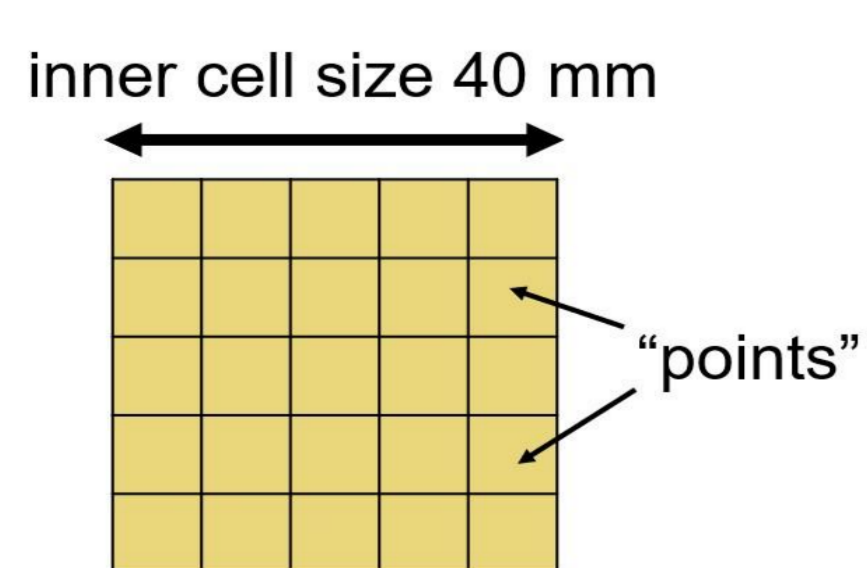
- LHCb CALO comprises 2 sub-detectors:
  - ECAL: Electromagnetic sampling calorimeter (Shashlik: layers of Sc+Pb)
  - HCAL: Hadronic calorimeter (layers of scintillator interlayered with Fe)
- In Run 1 and 2, 2 additional scintillating hodoscopes placed in front of them
- When the fast simulation is switched ON, the simulation of hits by Geant4 is replaced with the generation of hits from a fast simulation model [1]



Here we present the development of a fast simulation engine based on a library of calorimeter hits

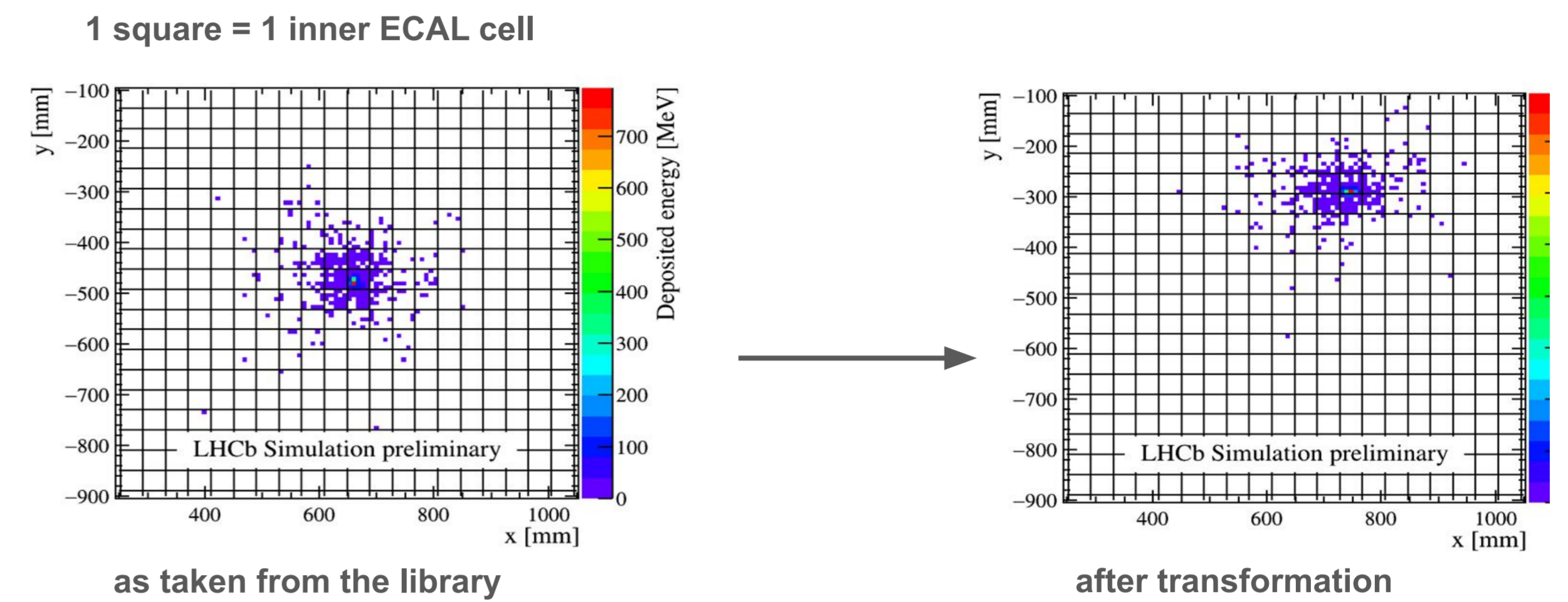
## 3 The point library

- The library is a collection of energies deposited in regions much smaller than the cell size ⇒ **point** library [2]
- The energy deposits are pre-simulated with Geant4
- They are stored for a discrete set of the particle's  $p, \theta$  (nodes)
  - 80  $p$  nodes from 1 MeV to 100 GeV
  - 13  $\theta$  nodes from 0 to 35 deg
  - 100 hit collections per node
- For a given  $p, \theta$  of the incident particle, one collection of hits is randomly picked from the closest node
- **Hits from all sub detectors are included**
- Library size: ~100 MB per particle type



## 4 Point spatial transformations

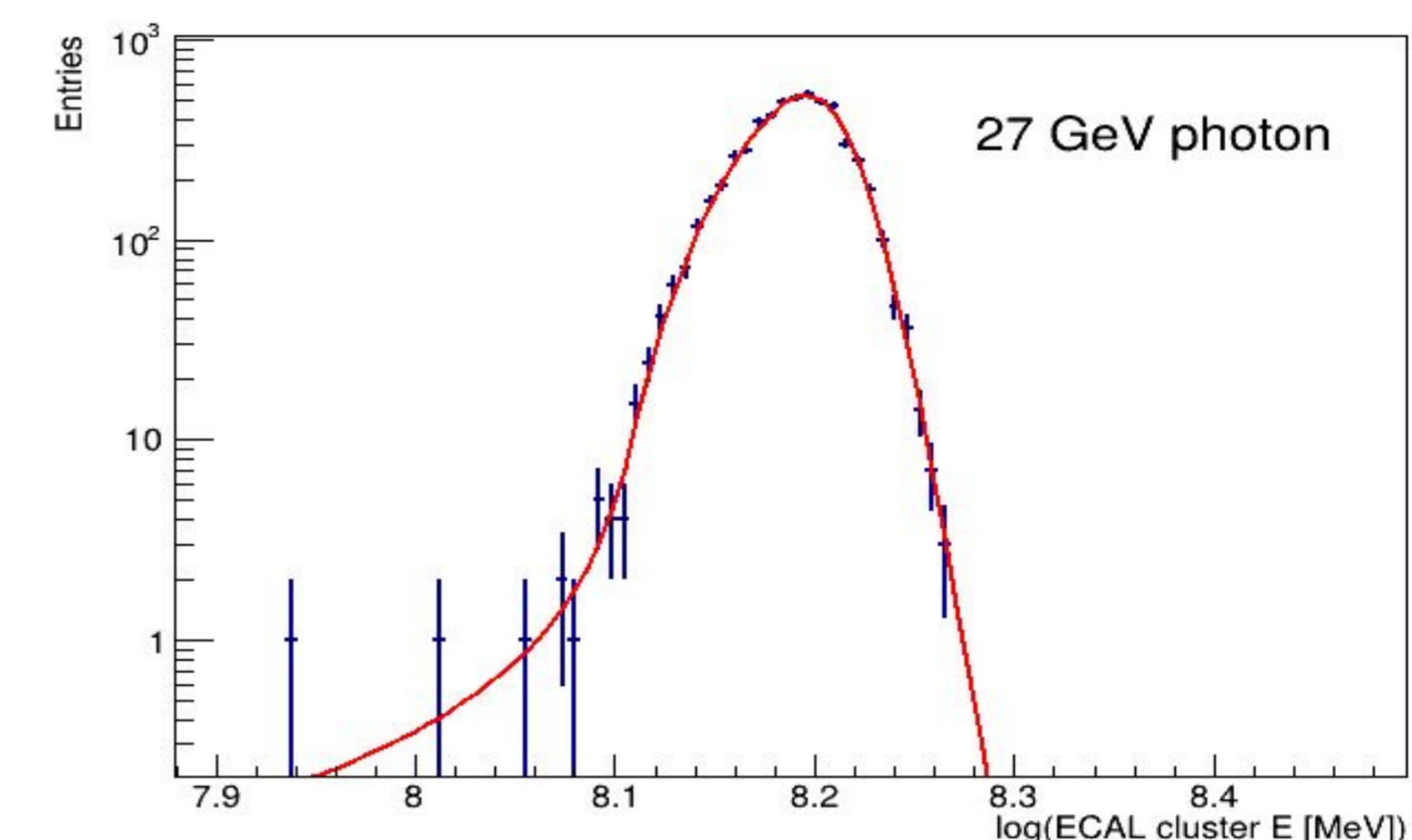
- The extracted point collection is transformed (stretched, rotated, translated) depending on the exact  $p, \theta, \phi, x, y$  of the incident particle



- This way the library depends only on the particles'  $p$  and  $\theta$ , with runtime **memory usage kept below a few hundred MB**

## 5 Overcoming limited statistics

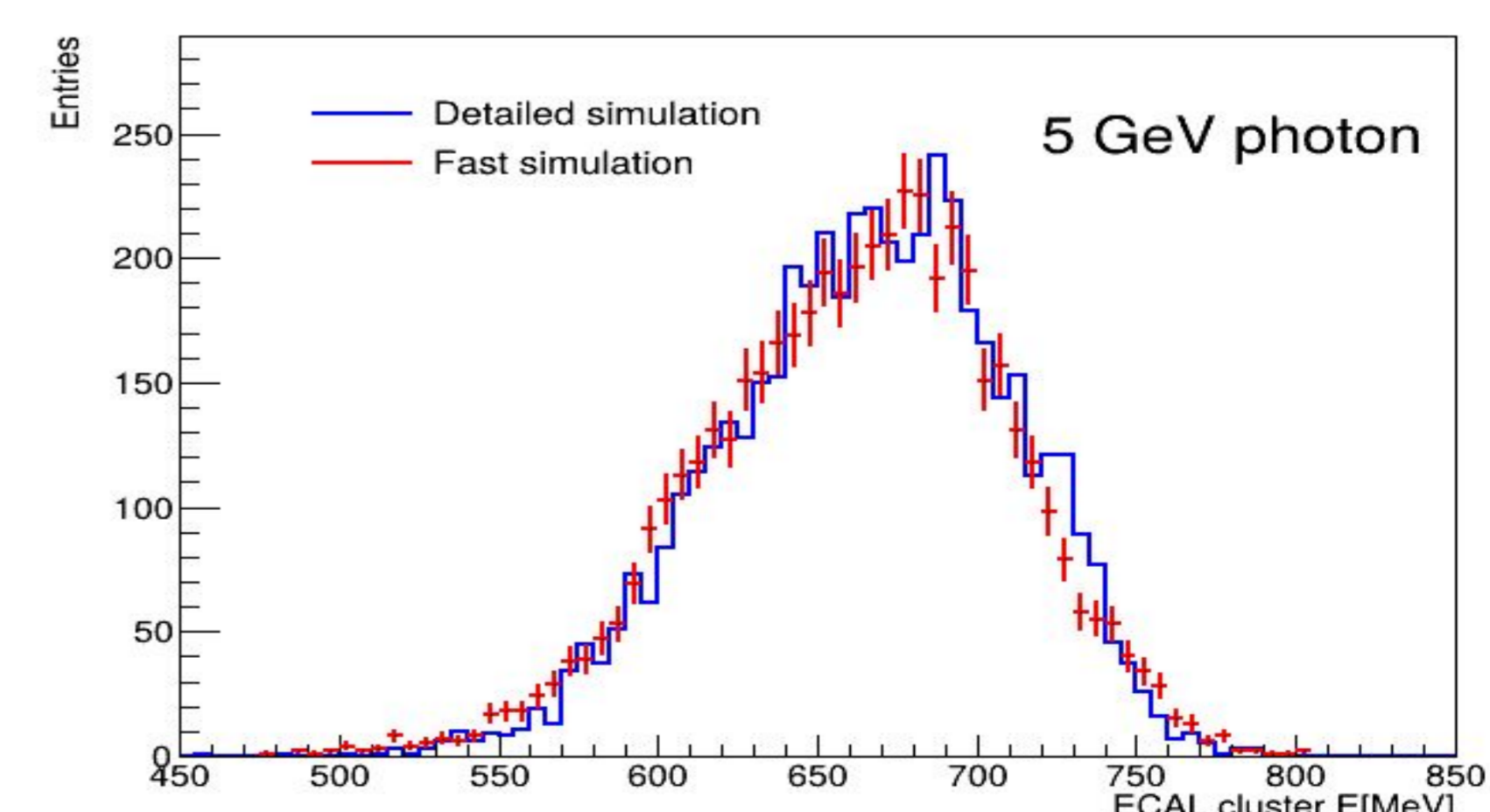
- The limited number of collections in the library ( $O(100)$ ) restricts the statistical variation of the generated samples
  - Especially important for the ECAL cluster energy
- Solution:
  - For each  $p, \theta$  node, fit high-stat cluster E distribution
  - Store fit parameters in library and use them to **generate continuous total energy of the cluster**



- A  $p, \theta$  internode correction is applied on the hit energies

## 6 Performance

- Example of ECAL cluster energy comparison between point library and Geant4 simulation



- **Calorimeter simulation time can be reduced to negligible level (~400 faster) compared to the rest of the detector**

## Summary

- Fast simulation based on point library covering all calorimeter systems (SPD, PS, ECAL, HCAL)
- Good accuracy with negligible CPU time per event
- Implemented for photons and  $e^\pm$
- Dedicated library for particles entering from the beam pipe region also developed

[1] M. Mazurek *et al*, [https://doi.org/10.31577/cai\\_2021\\_4\\_815](https://doi.org/10.31577/cai_2021_4_815)

[2] M. Rama, <https://indico.cern.ch/event/868940/contributions/3814342/>