Reconstruction in ALLEGRO

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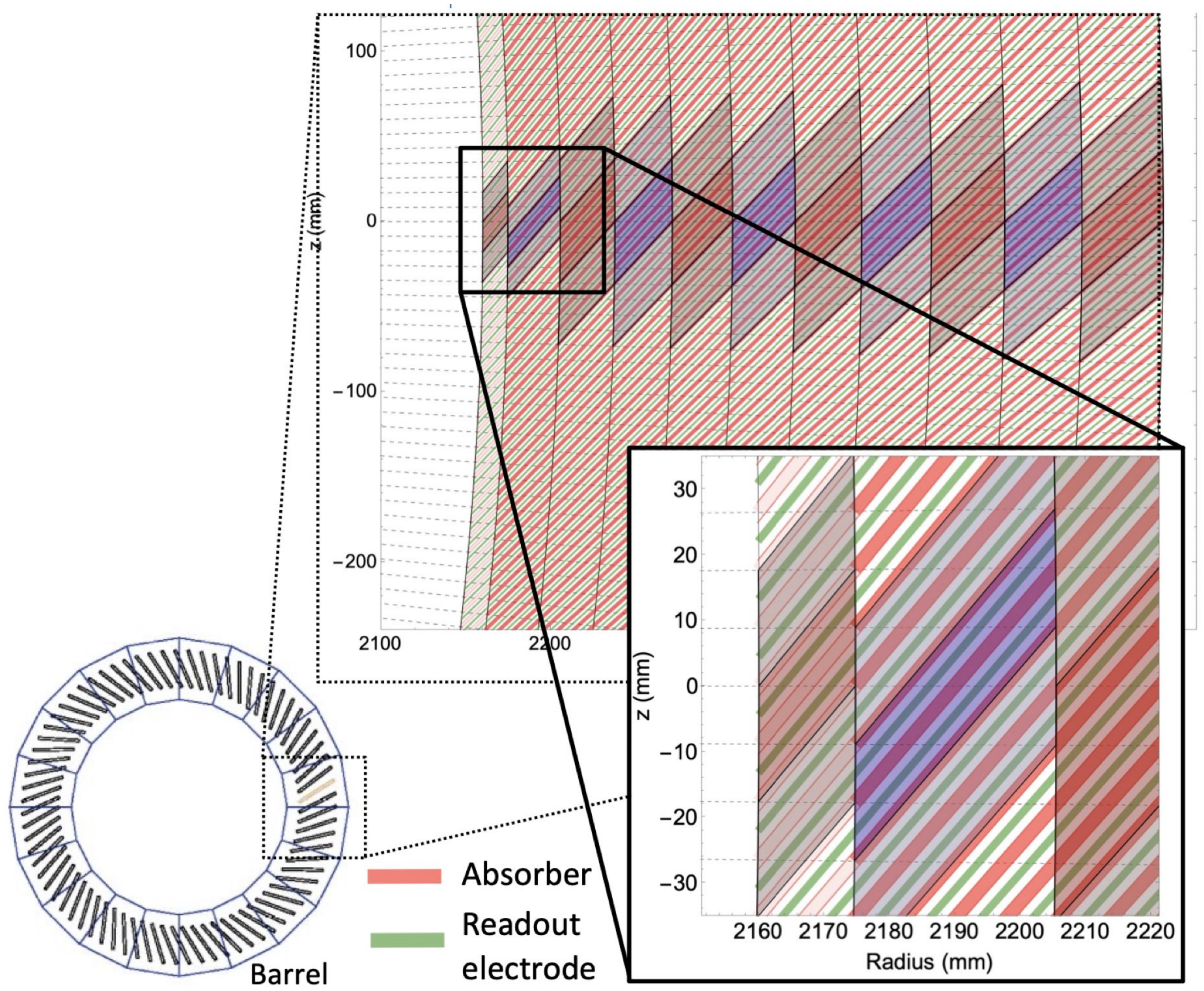
The ALLEGRO concept

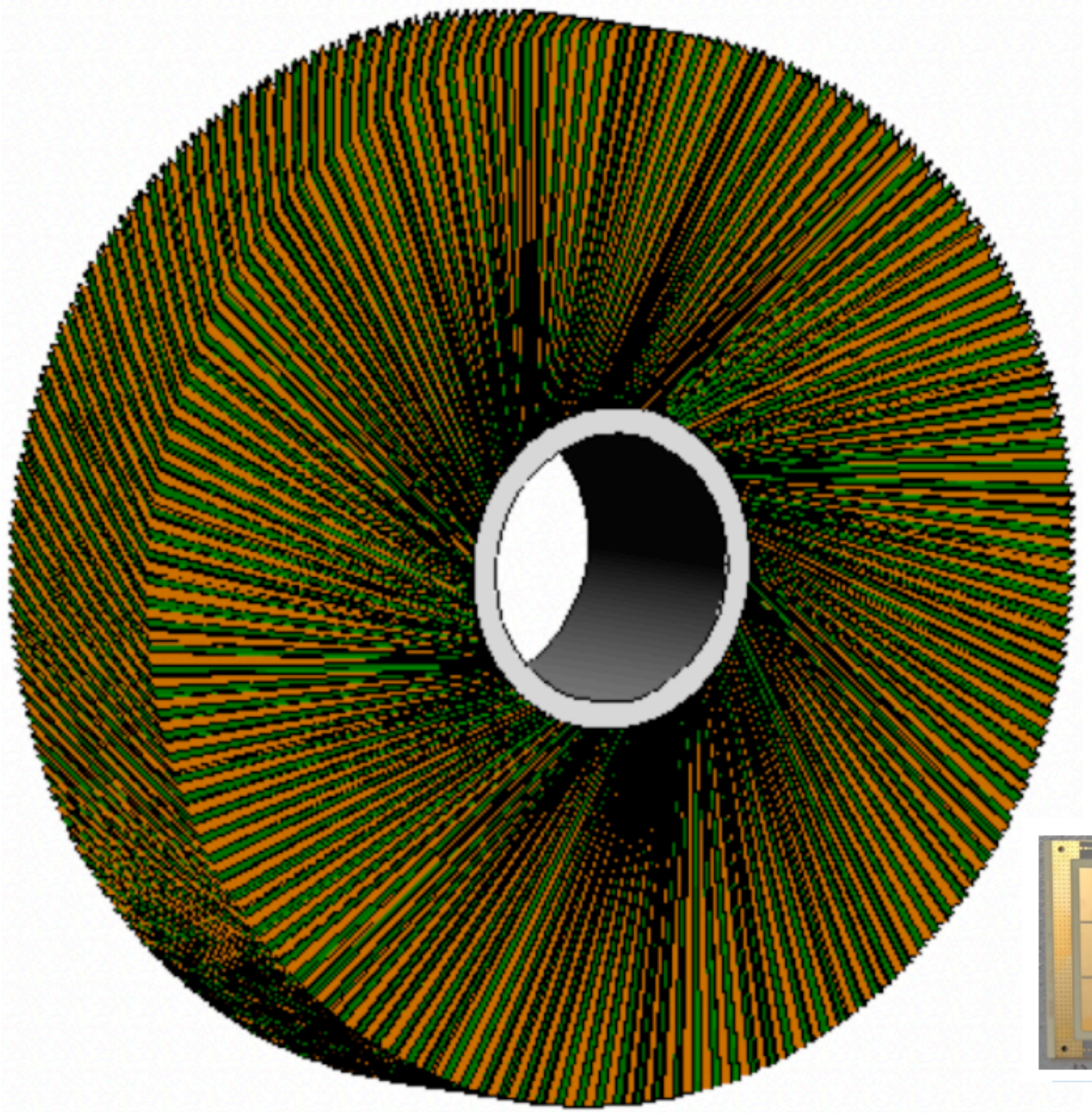
- **A** **L**epton-**L**epton collider **E**xperiment with **G**ranular **R**ead-Out
  - IDEA-like tracking system (VTX+DCH+Si wrapper), with possible replacement DCH->Straws
  - Highly granular noble-liquid ECAL inside solenoid
    - Pb/W+LAr (or denser W+LKr)
    - Coil inside same cryostat as LAr
  - CALICE-like or TileCal-like HCAL outside solenoid
  - Light coil (0.76 X_0) + low-material cryostat < $0.1X_0$
  - SiPMs directly on Scintillator or TileCal: WS fibres, SiPMs outside
- Detector design optimisation not complete yet - needs full simulation & reconstruction algorithms beforehand!
- Full detector implementation in DD4hep/key4hep recently completed (detailed vtx+wrapper, ECAL endcap)

ALLEGRO ECAL

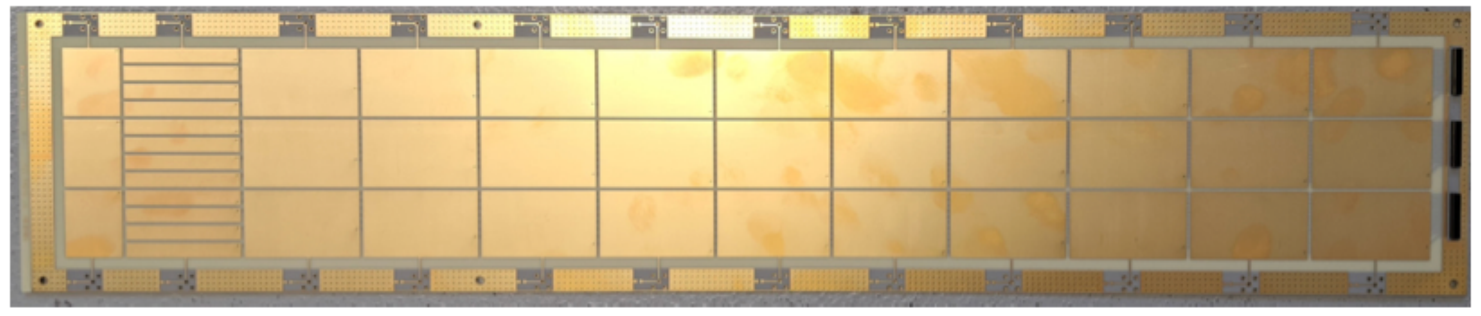
- highly granular calorimeter with absorbers planes inclined in r-phi (barrel) / arranged in turbine-like structure (endcap)
- readout by multi-layer segmented PCB planes alternated to Pb absorbers, gaps in between filled with LAr
- Some dimensions for the barrel: 11 longitudinal layers, $\Delta\theta$ ~ 10 (2.5) mrad for regular (L1 strip) cells, $\Delta\phi$ ~ 8 mrad
- Options: LKr vs LAr as active medium; W vs Pb absorbers; Al vs carbon fibre cryostat; trapezoidal vs planar absorbers



barrel



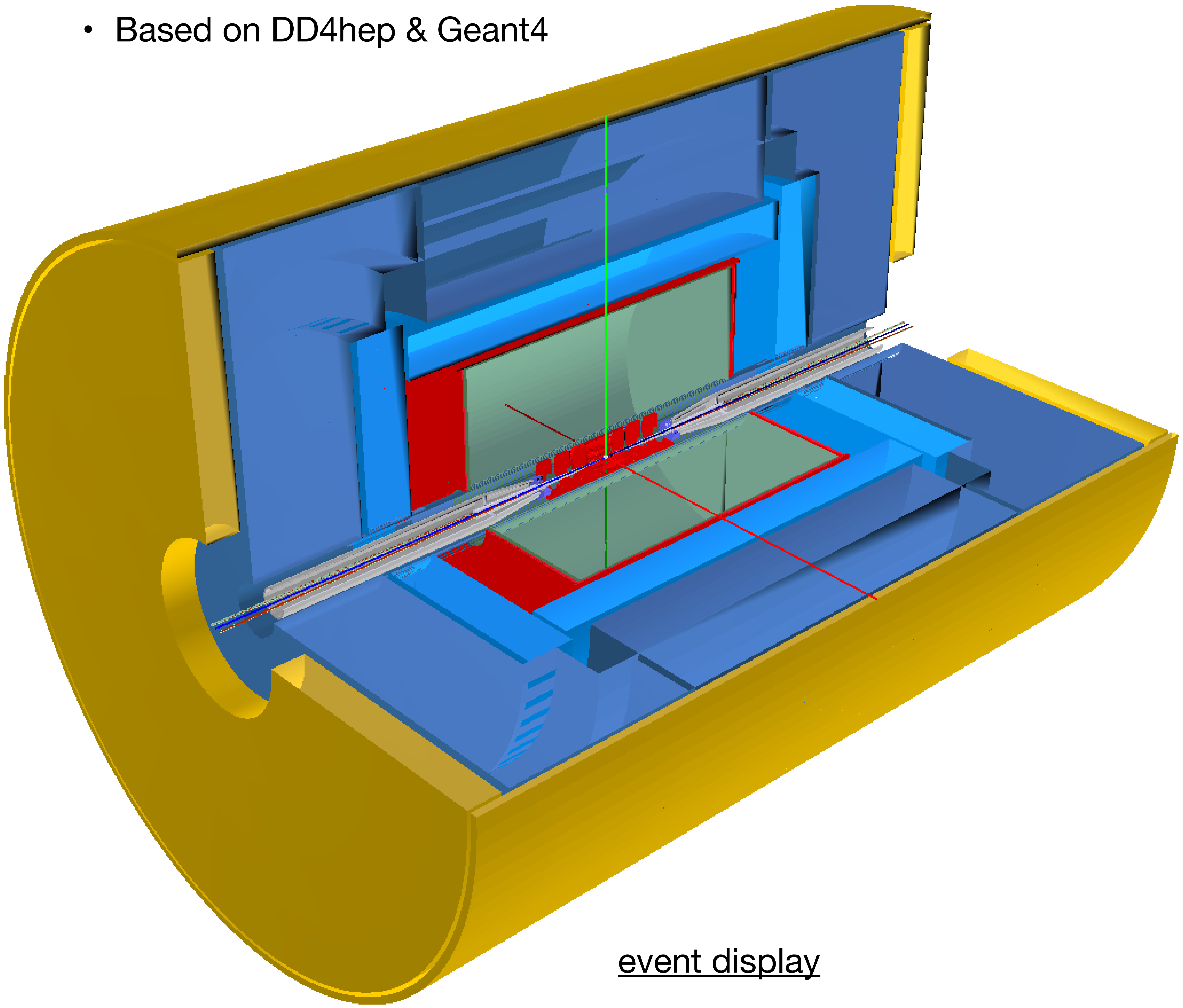
endcap

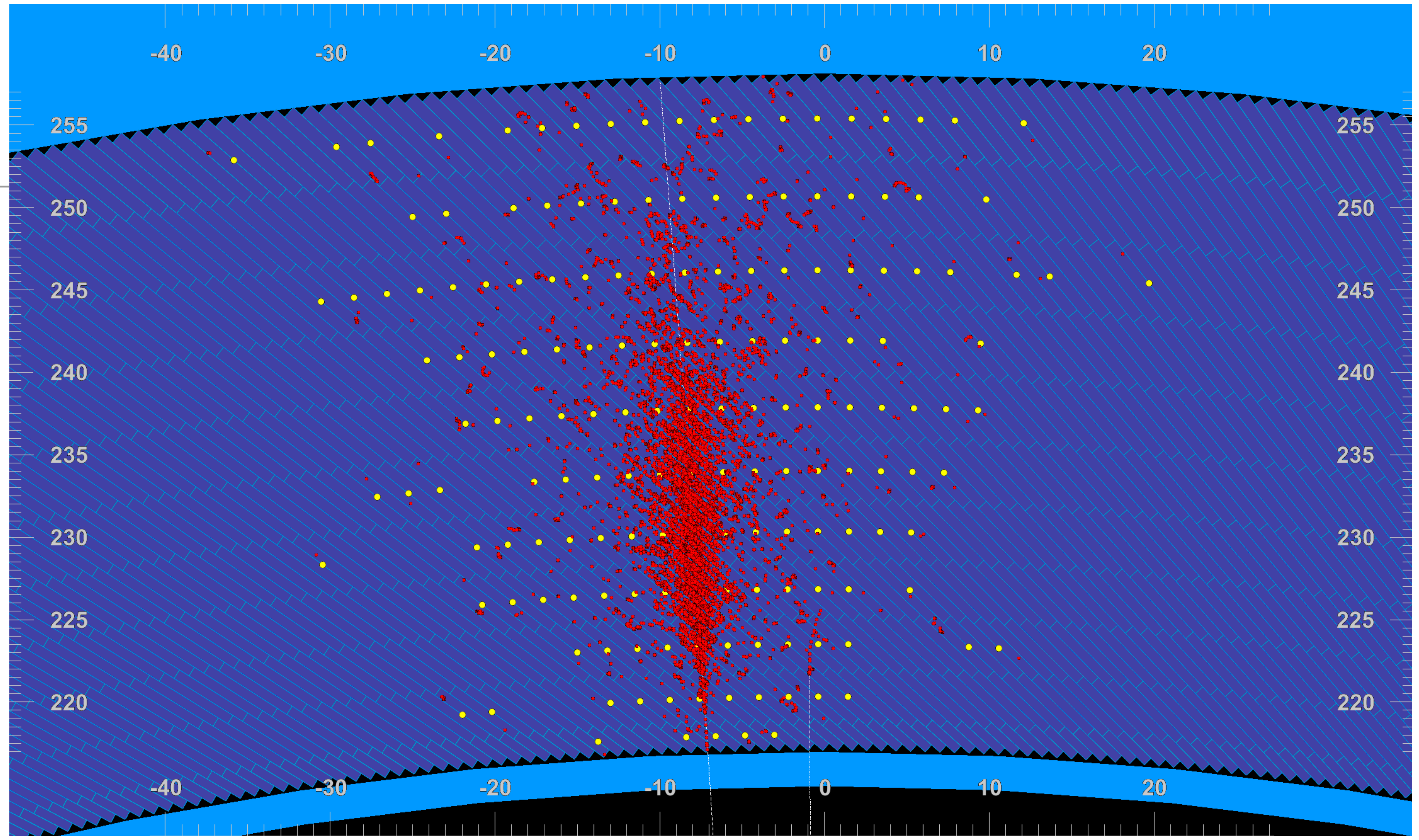


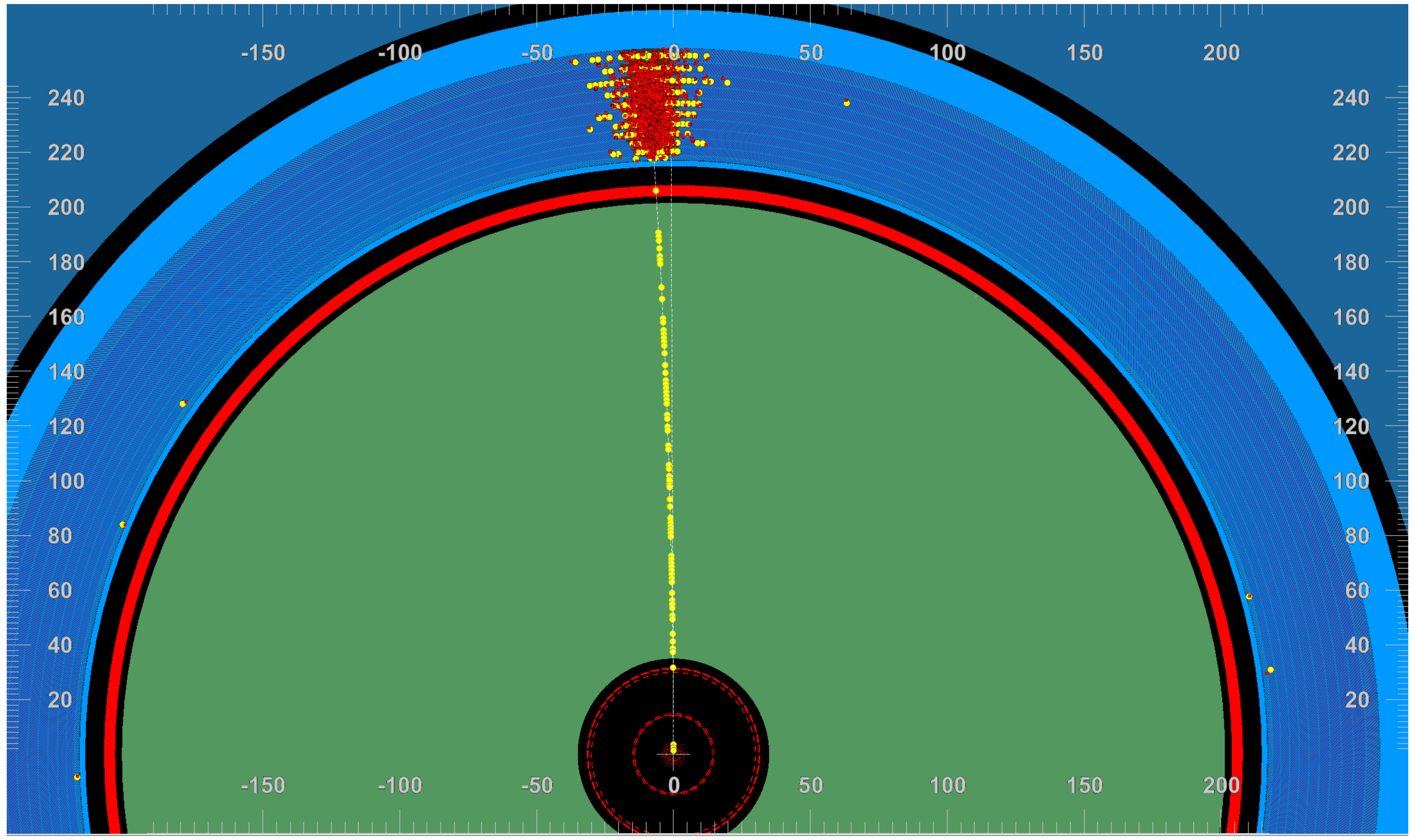
PCB (readout)

The ALLEGRO simulation

- Based on DD4hep & Geant4



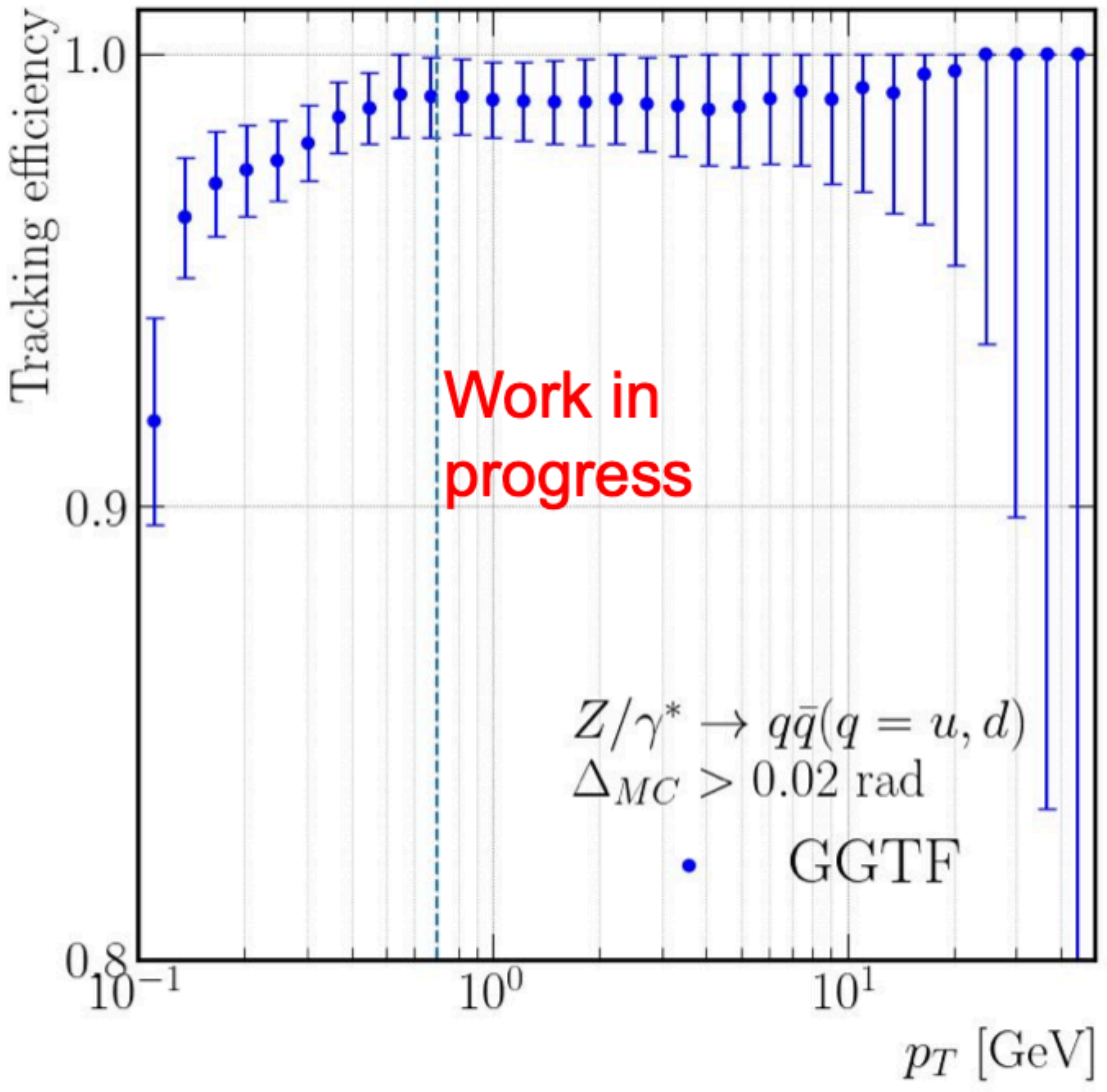




event display

ALLEGRO reconstruction: tracking

- Tracking in current ALLEGRO simulations is not yet ready
  - Hits are available, produced by applying Gaussian smearing to truth-level hits in trackers
  - Track reconstruction from hits not yet implemented
    - Significant work ongoing on ML-based tracking for IDEA (see talk by Andrea), could be ported with little effort to ALLEGRO once finalised

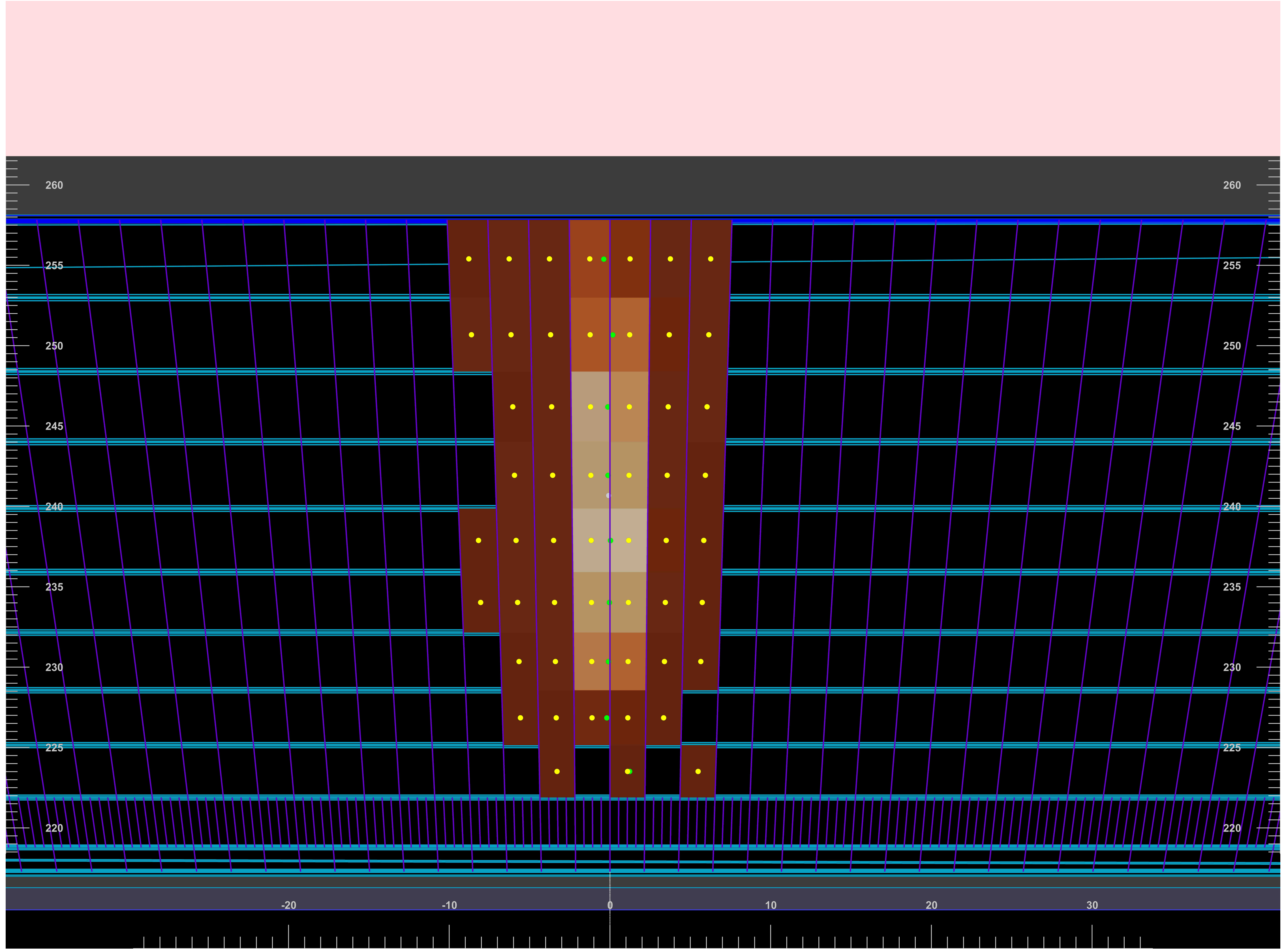


- As a proxy, for the time being, to enable starting p-flow reconstruction studies, reconstruction-level tracks are produced by cloning the generator-level tracks

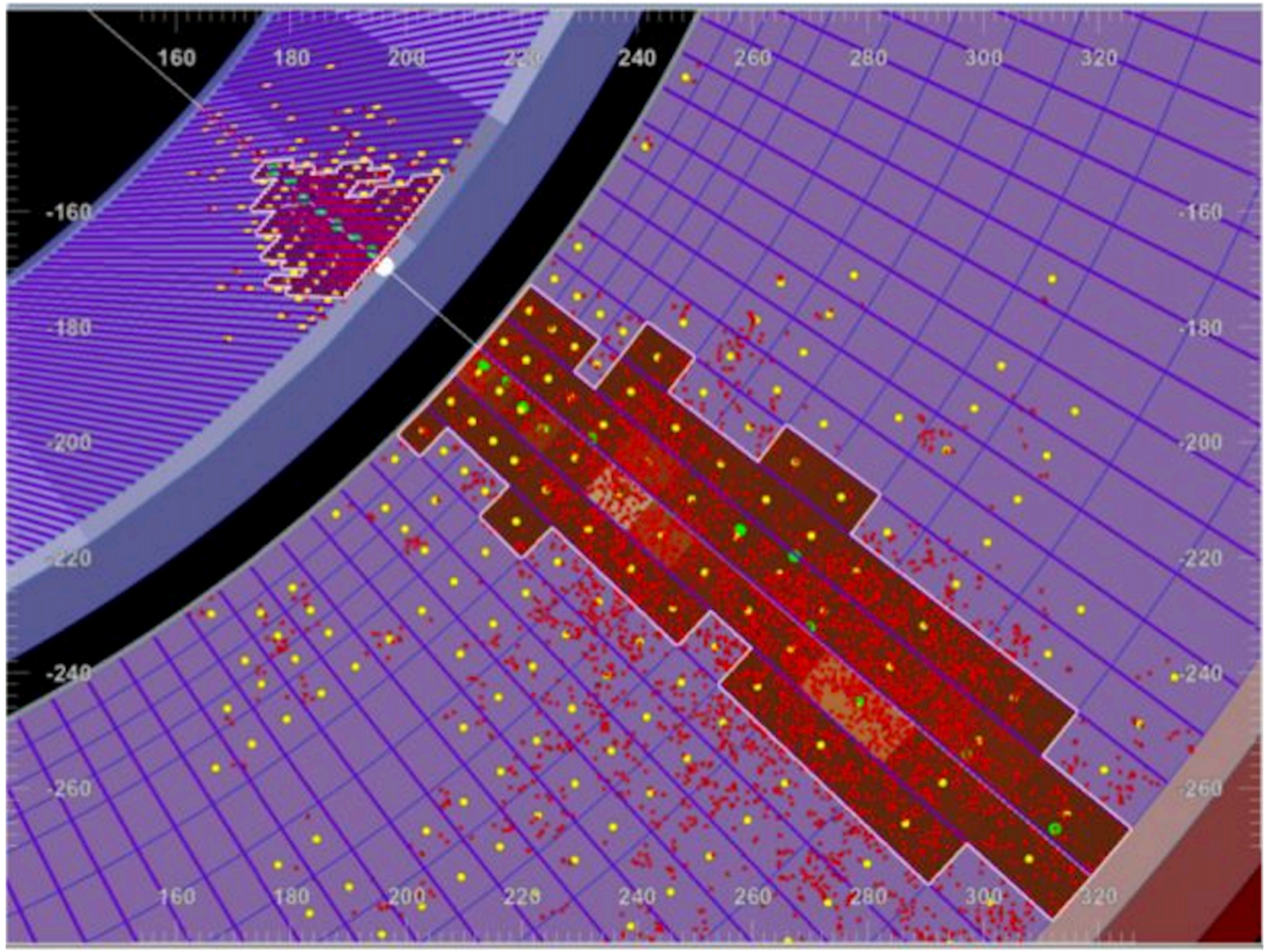
ALLEGRO reconstruction: calorimetry

- **Digitisation** is implemented by summing all G4 hits within a given readout cell, defined by the detector readout granularity, and applying a sampling fraction correction to the cell energy for an initial calibration
  - Implemented for all calorimeter sub detectors (ECAL and HCAL barrel and endcaps)
  - Recent addition of past months: emulation of noise and x-talk in ECAL barrel (to be followed soon by other sub detectors)
    - Noise: addition of random Gaussian-distributed noise energy per cell, starting from calculations of expected noise based on detector geometry and detailed electric field simulations of the cells
    - Crosstalk: see talk by Zhibo in parallel session yesterday
- **High-level reconstruction**: two clustering algorithms implemented so far, fixed-sized and topoclusters
  - Fixed-size: scan theta x phi space with sliding window of constant size to identify local maxima in energy deposition => build clusters of fixed size
  - Topological clusters: search for seed cells with S/N>T_seed, attach neighbouring cells with S/N > T_neighbours => build topologically connected clusters of variable size
  - Both algorithm can be configured to use cells from only one subsystem (e.g. ECAL-only “EM" clusters) or both (ECAL+HCAL => seeds for jet reconstruction)
    - SW implemented for all configurations; topoclustering working so far for ECAL/HCAL barrels; work ongoing on implementation for endcaps

ALLEGRO reconstruction: calorimetry



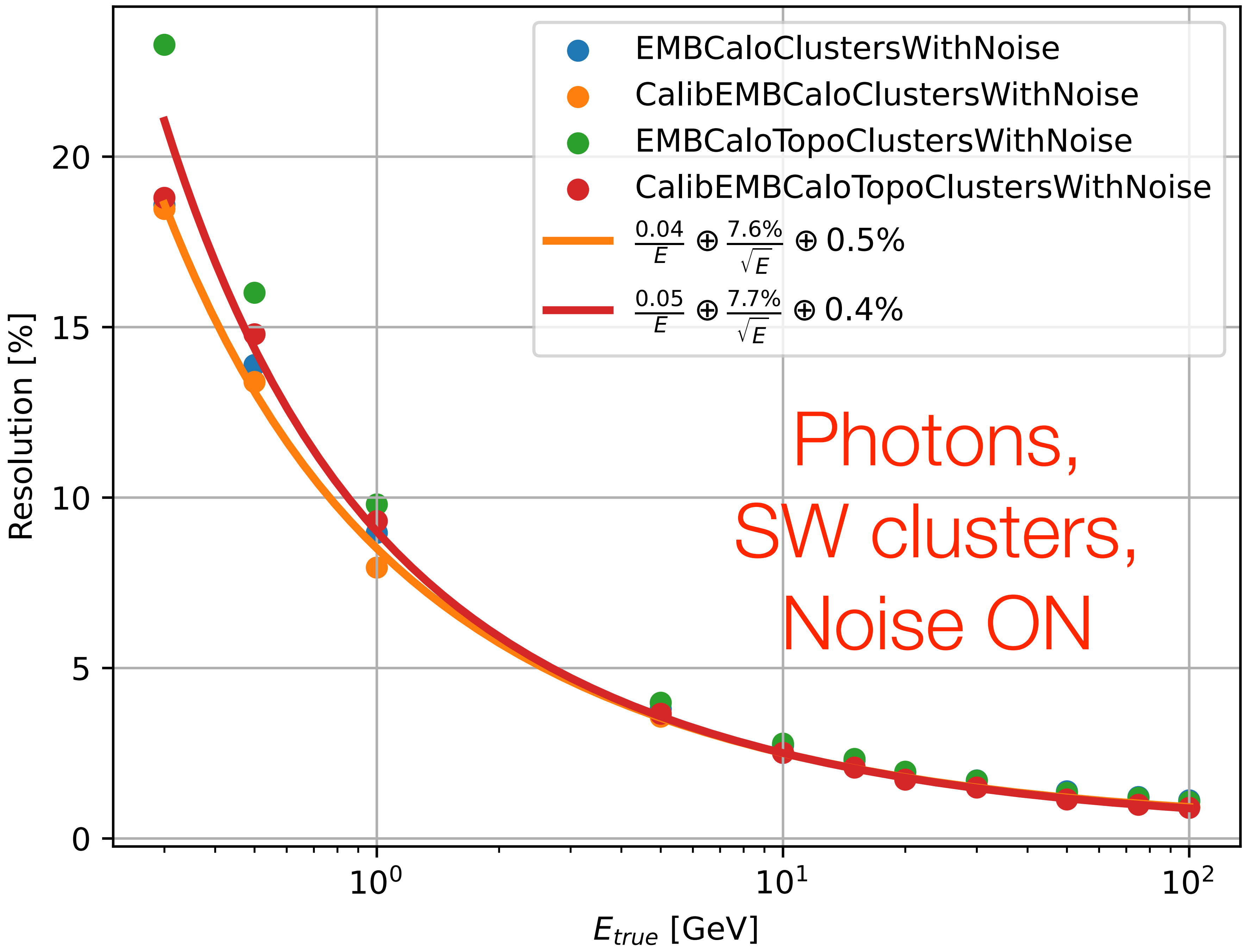
ECAL-only SW cluster (photon)

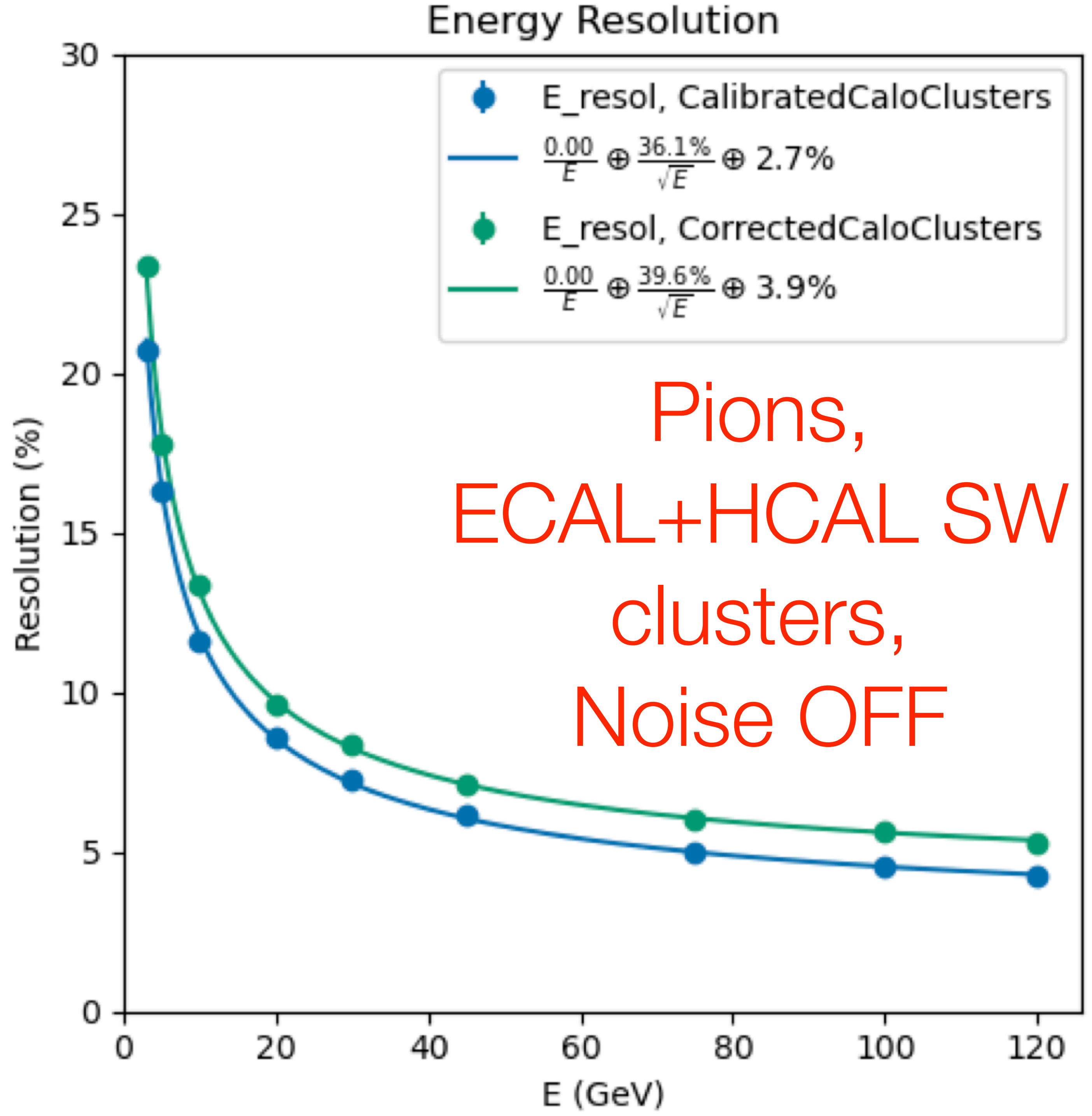


Joint ECAL+HCAL topocluster (pion)

Cluster properties and performance: energy calibration

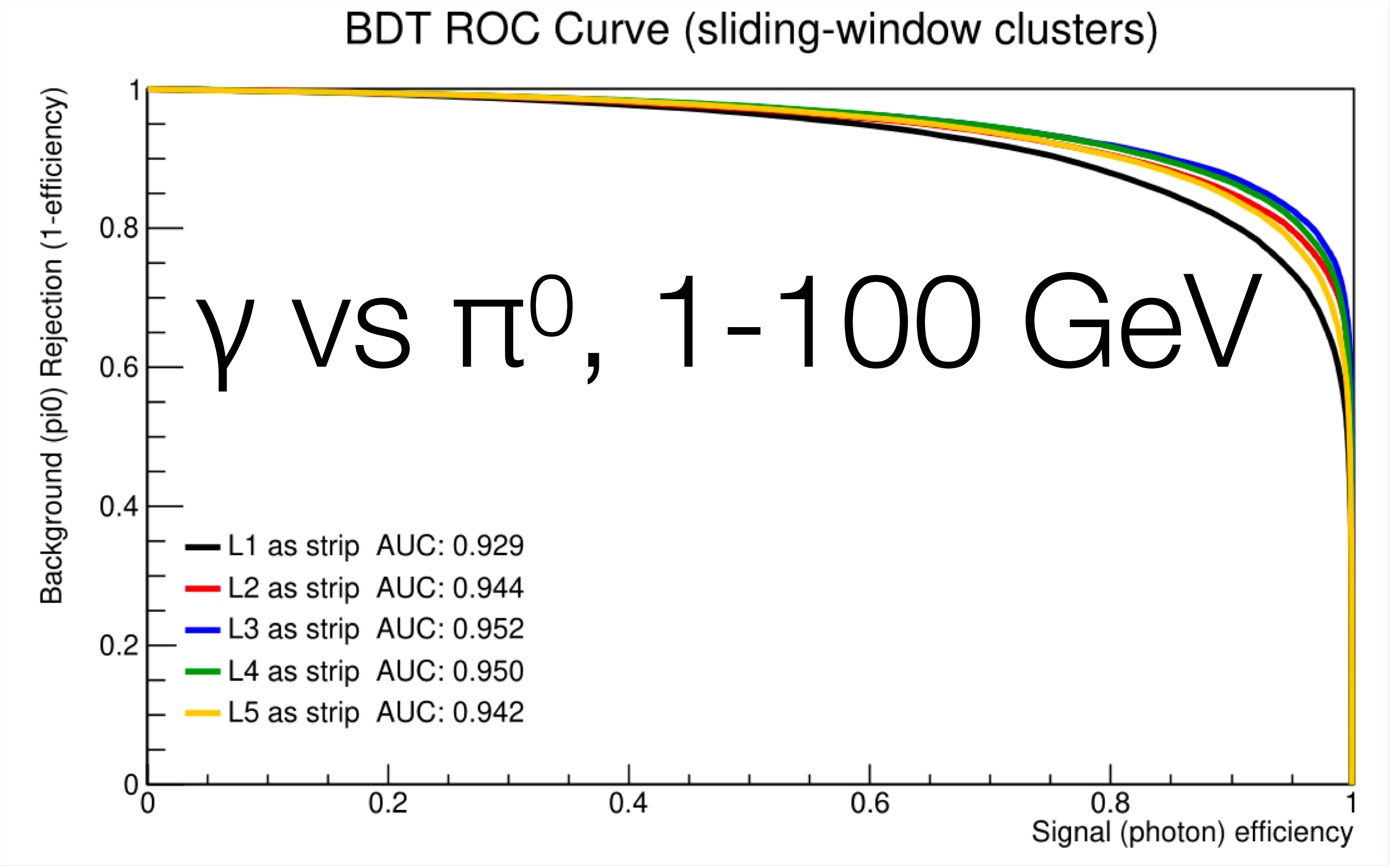
- BDT-regression-based calibration implemented
  - Inputs: energy fraction in each layer, total energy, cluster barycentre theta-phi
  - Target: E_cluster/E_particle
  - Energy fractions are calculated by Gaudi algorithm and saved as cluster decorations (shapeParameters in EDM4hep), so that one does not need to persist cell-level info
  - BDT trained with external tool, output saved to portable ONNX format, that can be read out in Gaudi
  - Calibration can be applied by another Gaudi algorithm in all subsequent simulations and saved as cluster decoration

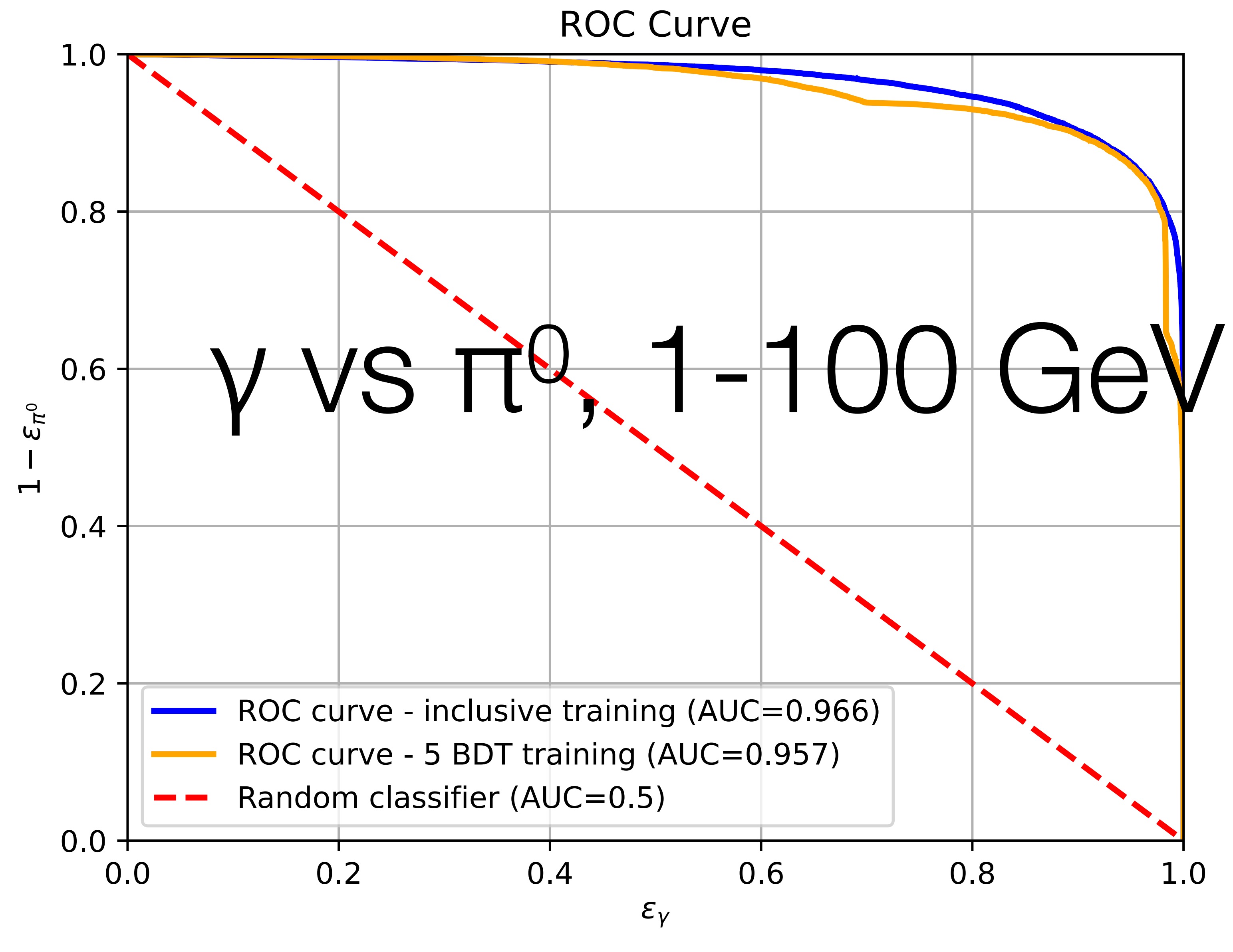


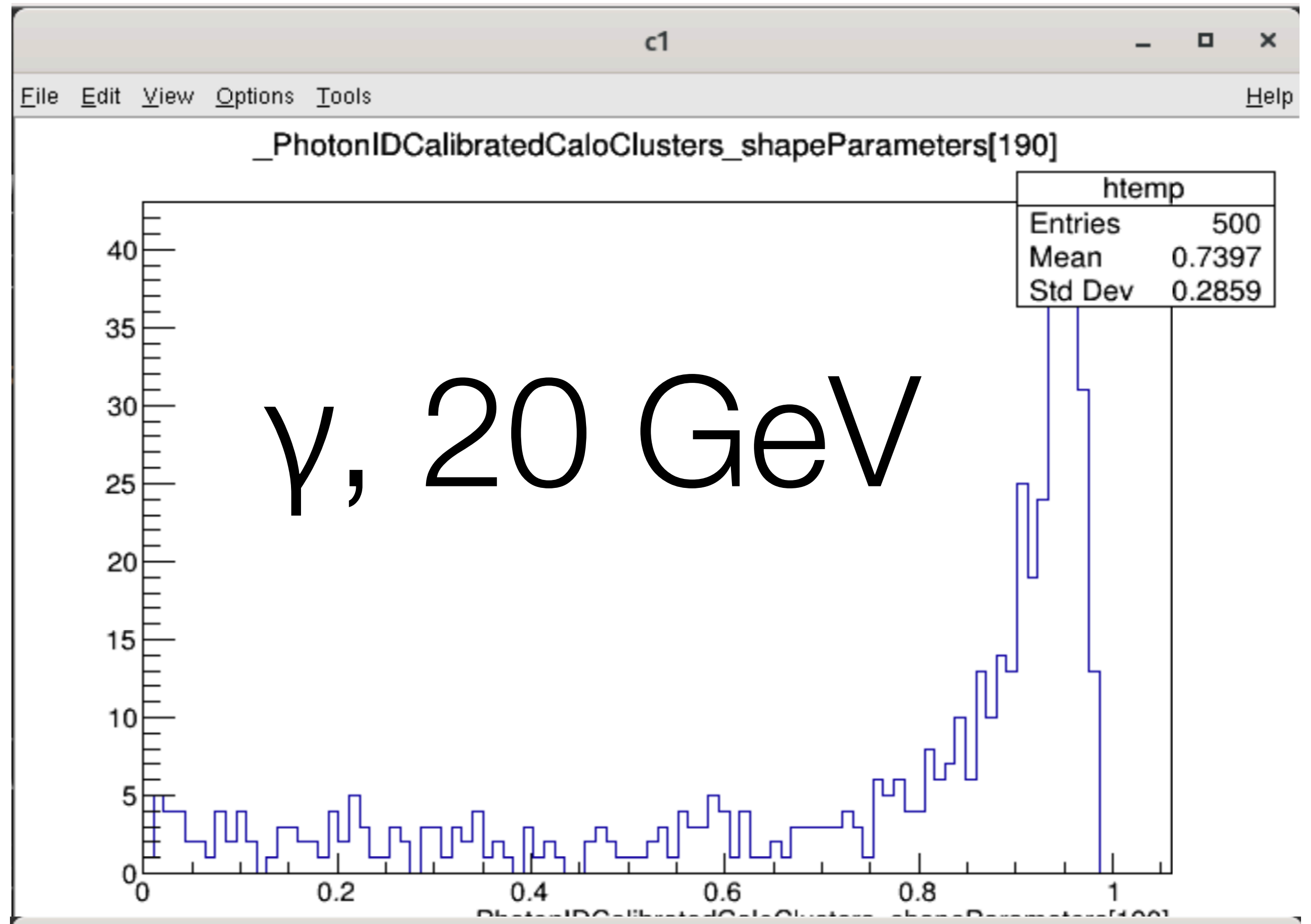


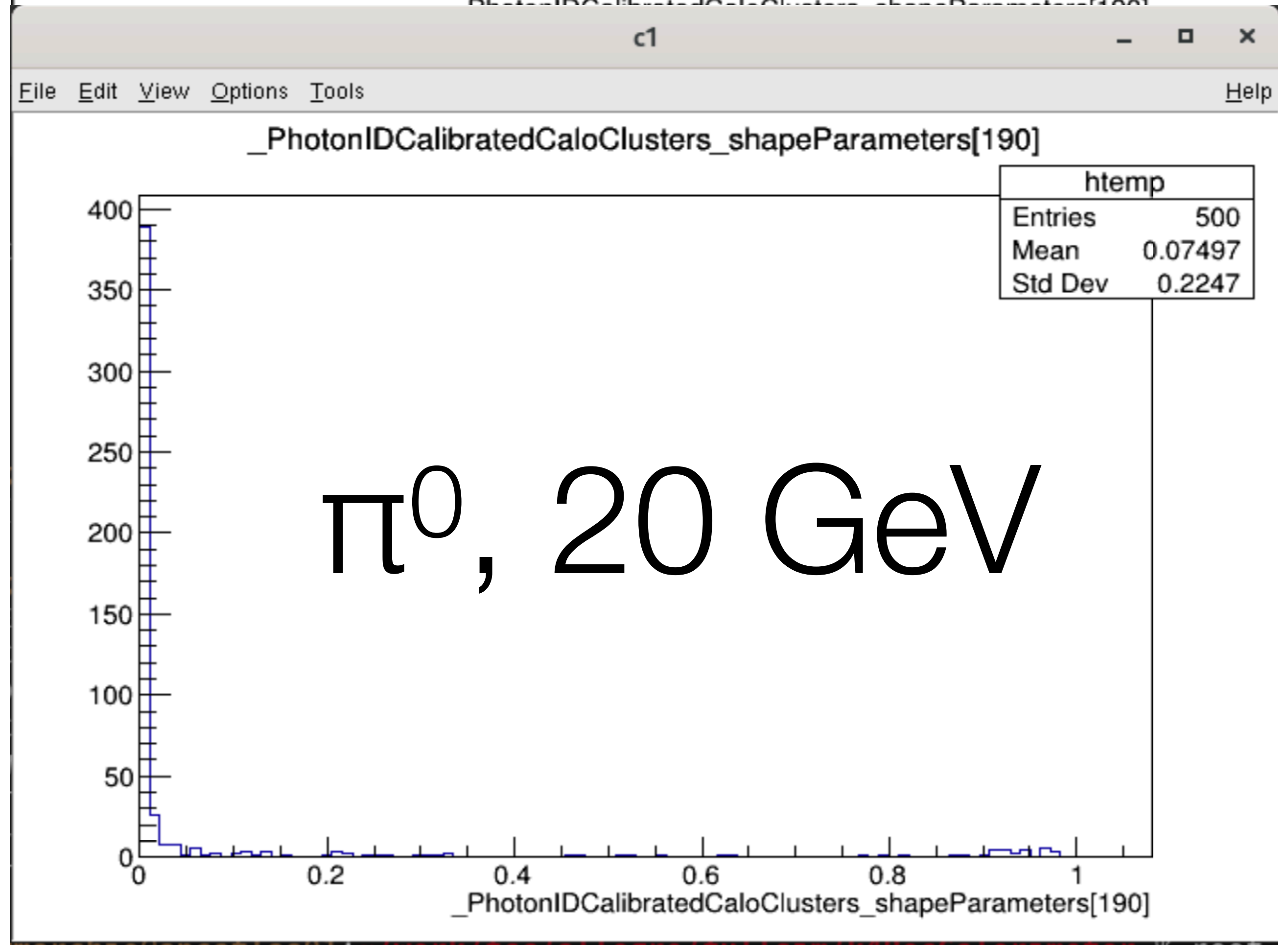
Cluster properties and performance: photon identification

- BDT-based photon ID algorithm implemented
  - Inputs: longitudinal/lateral shower shapes from cell energies, calculated/saved as shape parameters by Gaudi algorithm
  - Target: binary classification with maximum area under curve
  - BDT trained with external tool, output saved to portable ONNX format, that can be read out in Gaudi
  - Inference can be applied by another Gaudi algorithm in subsequent simulations and BDT score saved in output
  - Model trained for photons vs pi0s with 1<p<100 GeV, used to compare alternative detector
  - Starting to assess impact of x-talk (==> Zhibo) & noise









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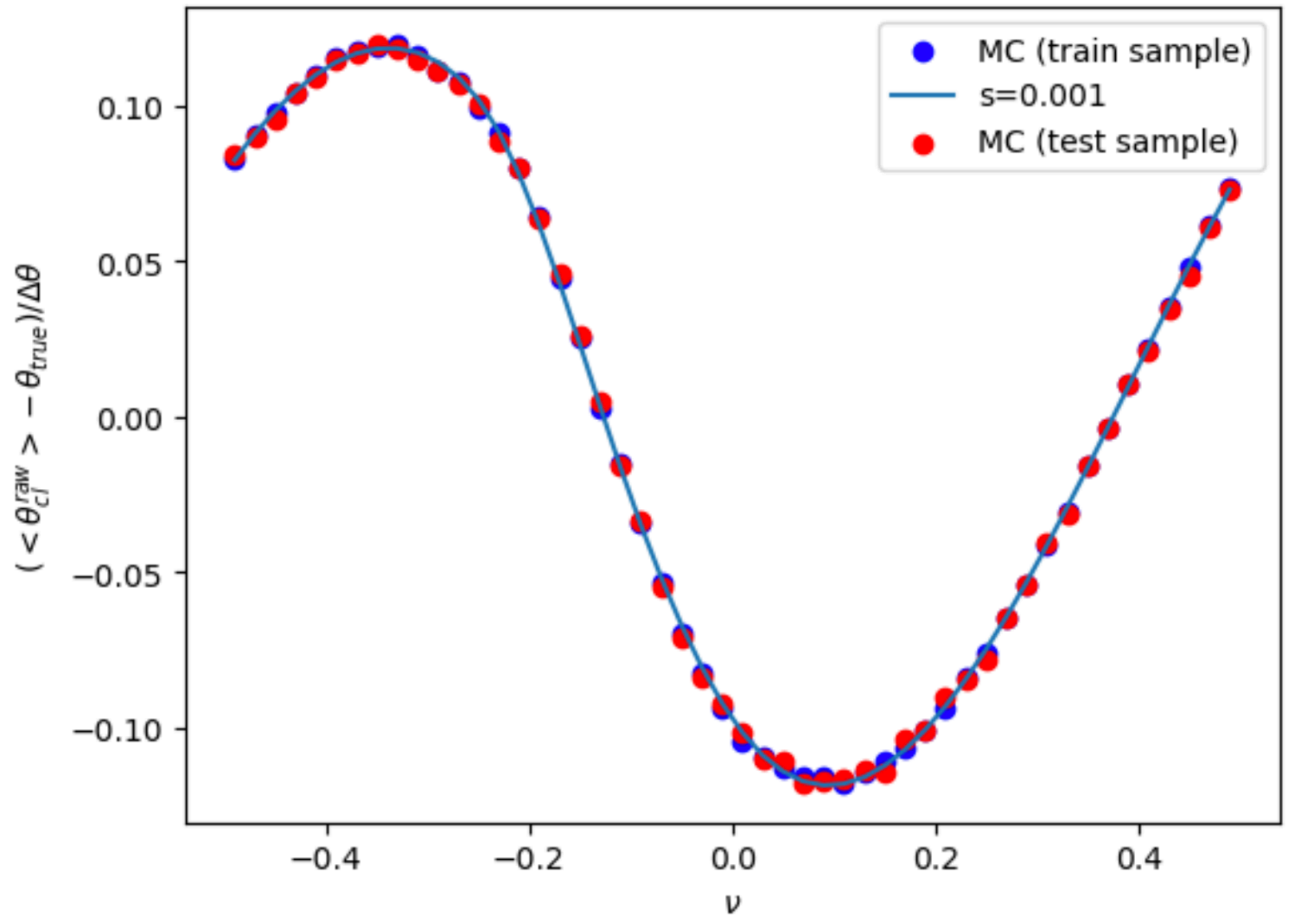
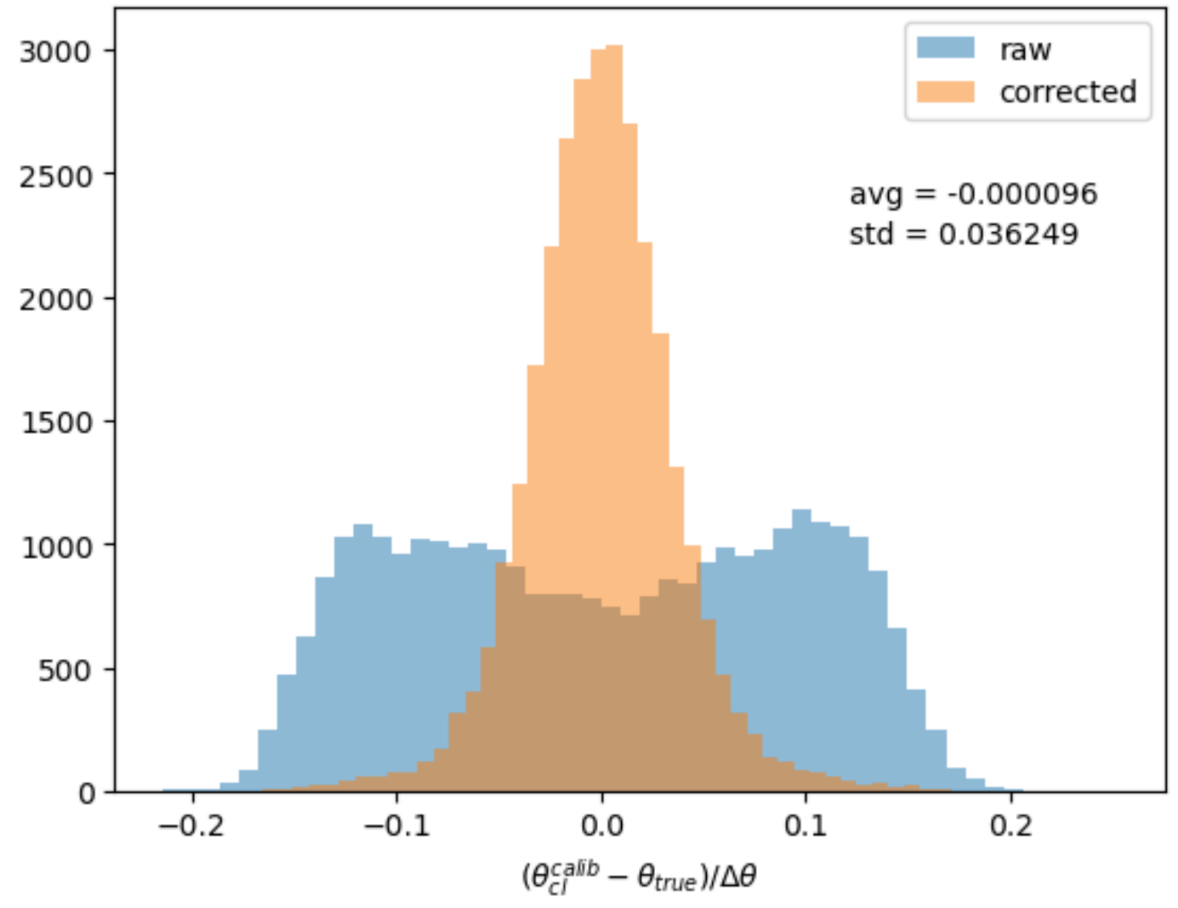
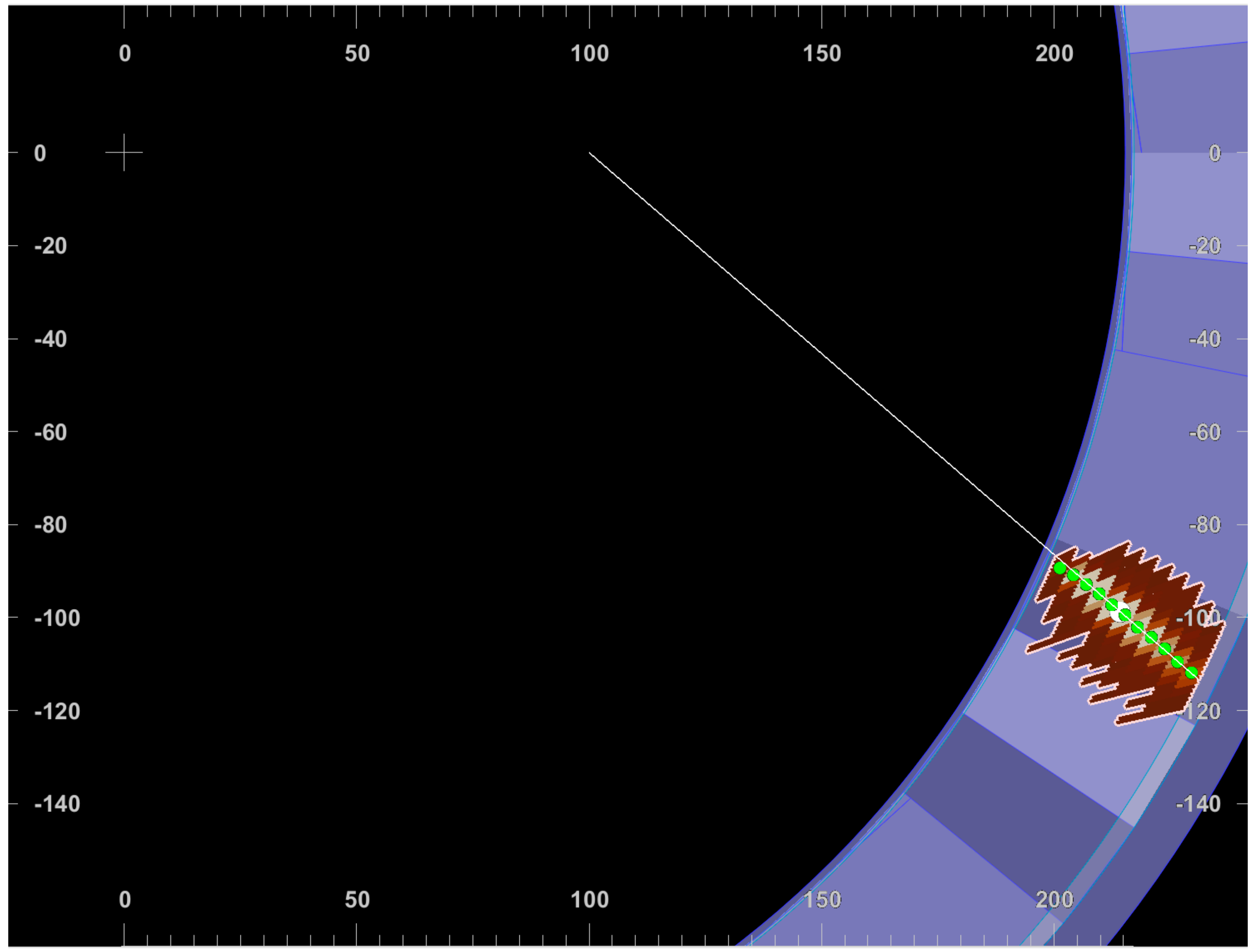
Cluster properties and performance: position and direction

- Position (overall and vs layer): response in theta from cell energy barycentre with linear weights (E_cell) show clear dependence on impact position, as also seen in ATLAS, due to finite cell granularity







  - Offline study performed shows that this can be corrected e.g. with ad-hoc correction/regression
  - Alternatively, similar performance has been observed using max(log(E_cell/E_layer), w0) weights
- Layer-by-layer barycenters are now calculated by Gaudi algorithm with sets of w0s that optimise resolution and saved as cluster shapeParameters
- Next-step: determine theta, phi energy resolutions vs layer and use layer barycenters and resolutions to reconstruct particle direction (e.g. non-pointing photons)

Conclusion

- Basic algorithms for cluster reconstruction, calibration and identification in calorimeter implemented
  - But not for all sub detectors (missing topoclusters for ECAL/HCAL barrels)
- Now that full detector model is in place, we can hopefully start to spend less time on software itself and more on physics, and have more stable results in the coming months
- Impact of noise and x-talk on the performance of these basic algorithms starts to be assessed
- Correction for cluster barycentre position (overall and layer-by-layer) also in place
  - Next: reconstruct cluster direction from layer barycentres without assuming projectivity from IP
- Beyond all this: more holistic approach to reconstruction and identification planned
  - Particle-flow
  - Machine learning techniques