FUTURE CIRCULAR COLLIDER

cnrs dépasser les frontières IN2P3 Les deux infinis

APC

Simulation in LAr-based calorimeter at FCC

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with Gregorio Bernardi, Nicolas Morange

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23 Nov. 2023

Outline

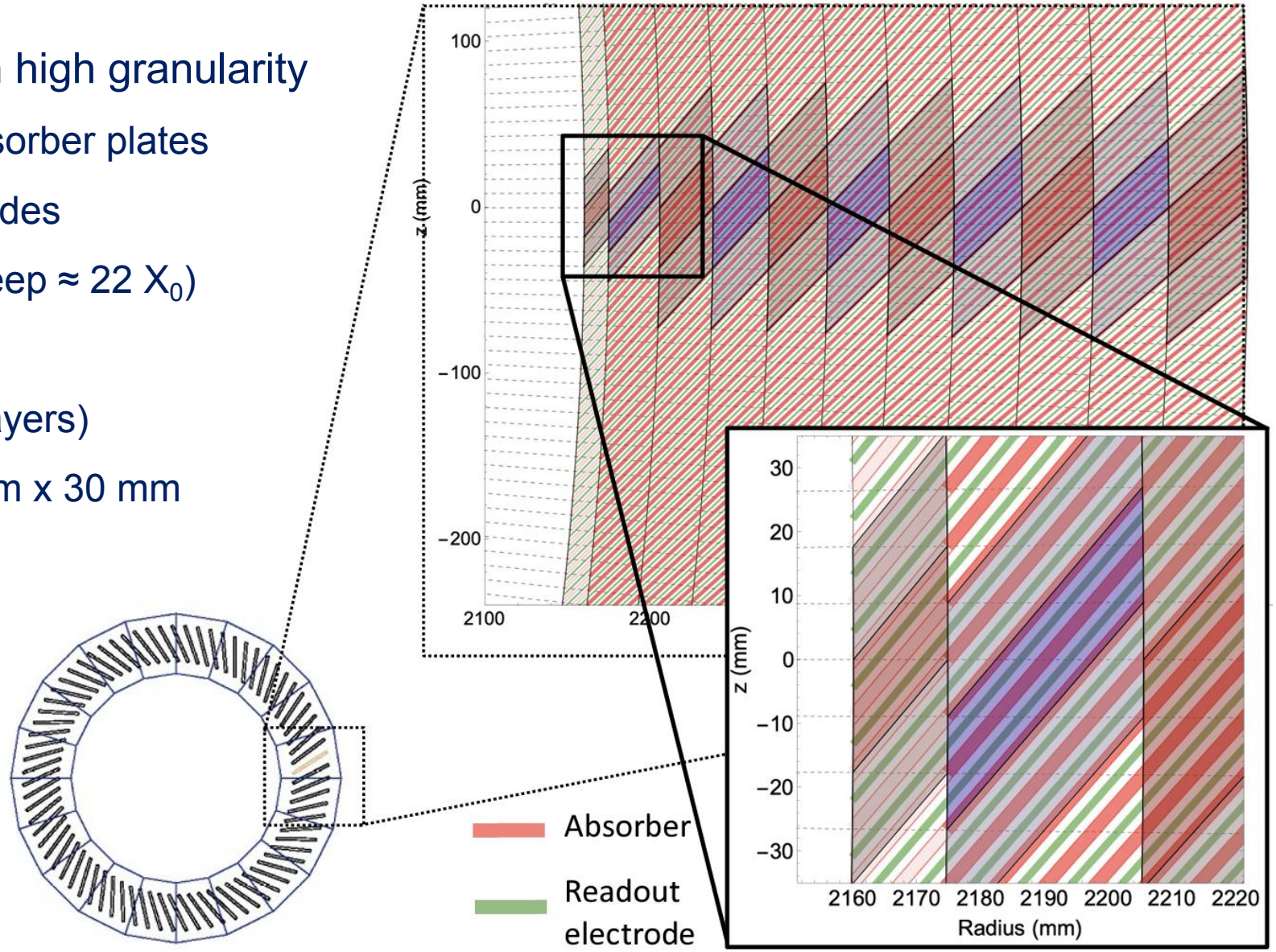
- Introduction
- Theta-Module Merged segmentation
- Topological Clustering
- Sliding-Window Clustering
- Summary

Related talks:
https://indico.cern.ch/event/1299615/#85-digitization-and-clustering
https://indico.cern.ch/event/1336505/#93-update-on-topo-clustering-w
https://indico.cern.ch/event/1319134/#21-a-root-based-event-display

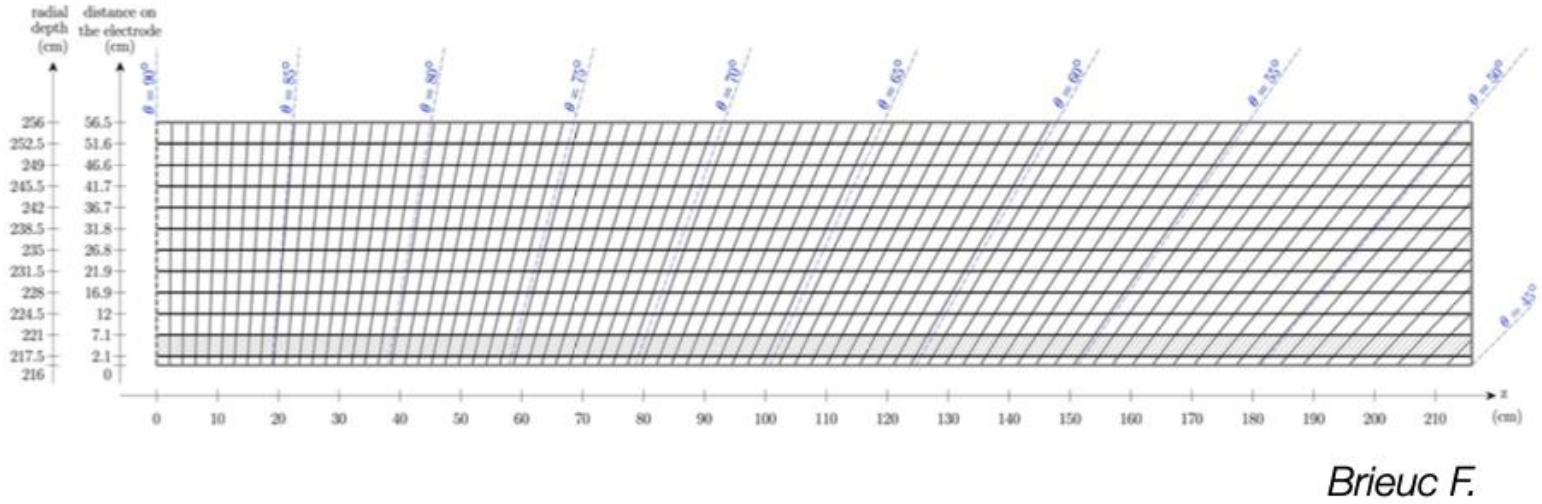
Introduction

Noble-Liquid (LAr) Calorimeter with high granularity

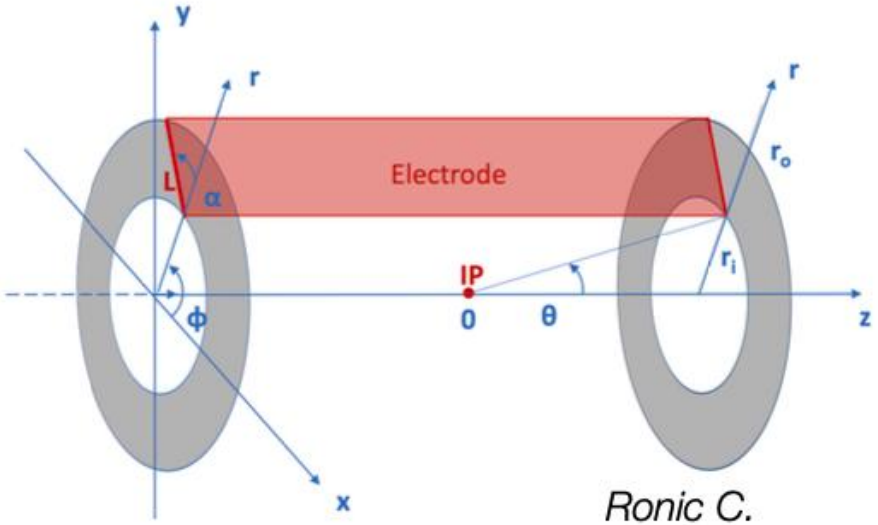
- 1536 straight inclined (50˚) Pb absorber plates
- Multi-layer PCBs as readout electrodes
- R_i = 216 cm, R_o = 256 cm (40 cm deep ≈ 22 X_0)
- 1.2 - 2.4 mm LAr gaps
- 11 longitudinal compartments (12 layers)
- Cell size in strips: 5.4 mm x 17.8 mm x 30 mm



Theta-Module Merged segmentation



Brieuc F.

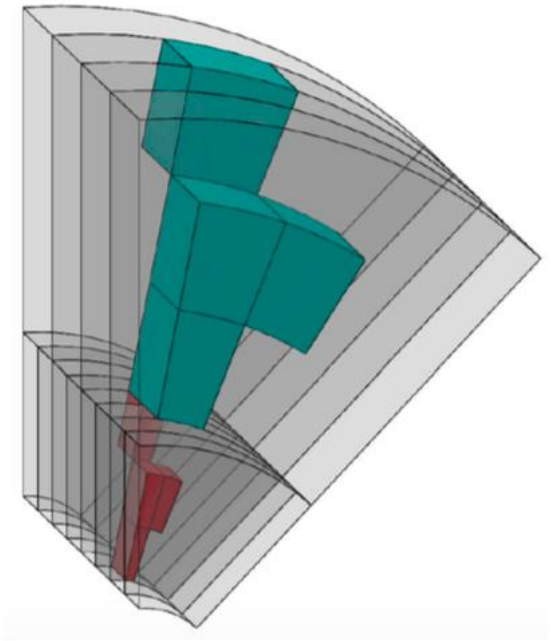


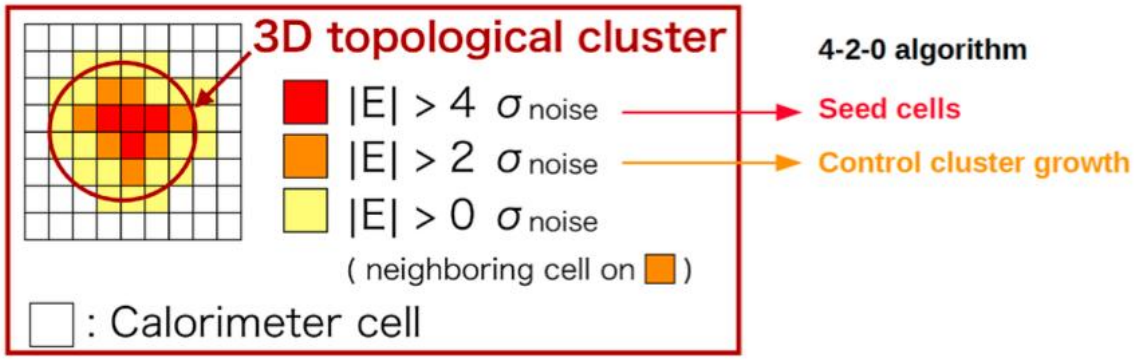
Ronic C.

- The geometry is with non-projective modules inclined in R-phi and logical grouping of cells along theta/module direction that can differ among the 12 radial layers
- Per-layer theta and module merging:
  - x 4 in theta in all layers but layer1, x 2 in module in all layers

Topological clustering

- Topo-cluster is a set of topologically connected cells with a significant signal above the noise
  - Usually used for reconstruction of jets
- Cells can be neighbours along theta, module (phi) or radial layer direction
- Using the Theta-Module Merged readout with cells merged along theta/module
  - Create the neighbour and noise maps





$$\varsigma_{\text{cell}}^{\text{EM}} = \frac{E_{\text{cell}}^{\text{EM}}}{\sigma_{\text{noise,cell}}^{\text{EM}}}$$

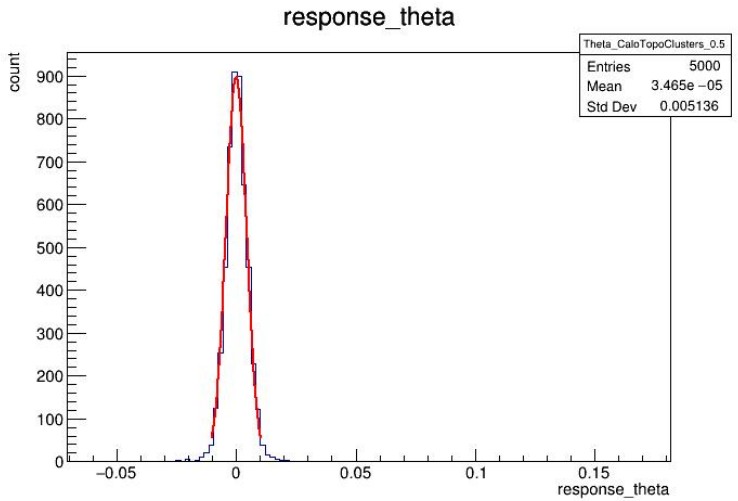
arxiv1603.02934

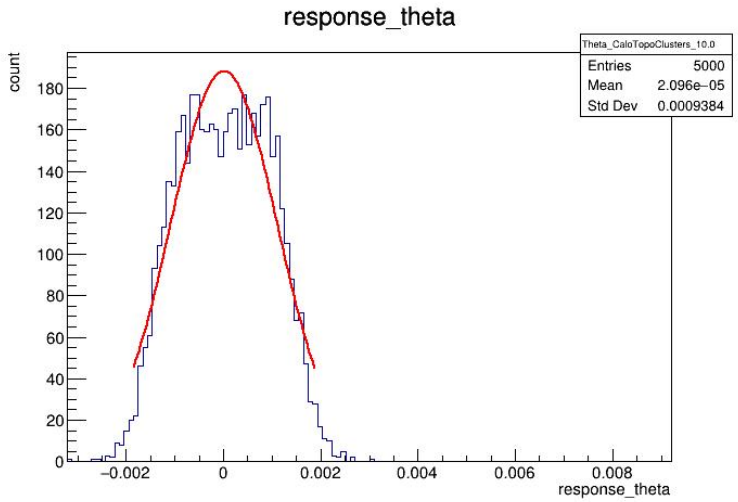
Topological clustering: Theta and Phi response

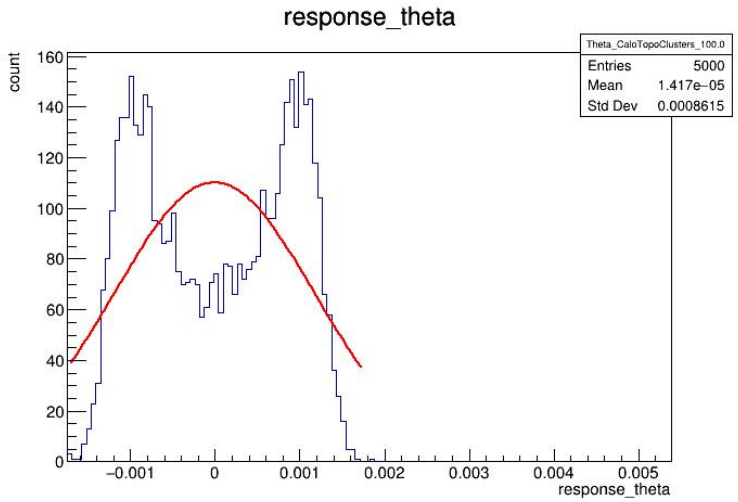
- From left to right: 0.5 GeV, 10 GeV, 100 GeV electron

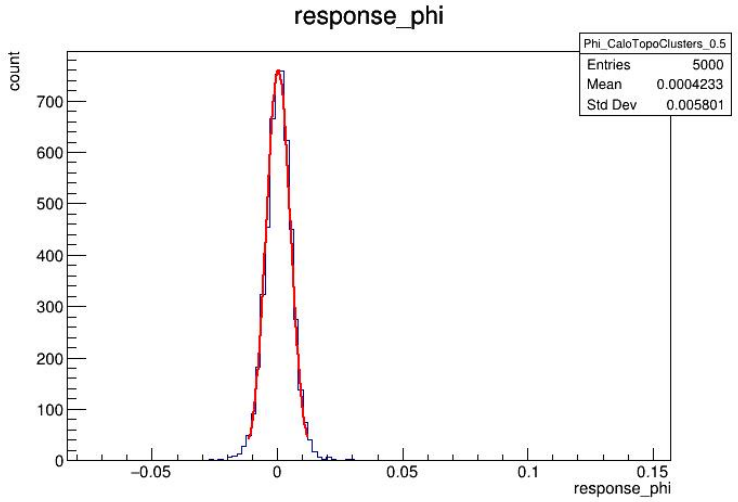
Top: Theta

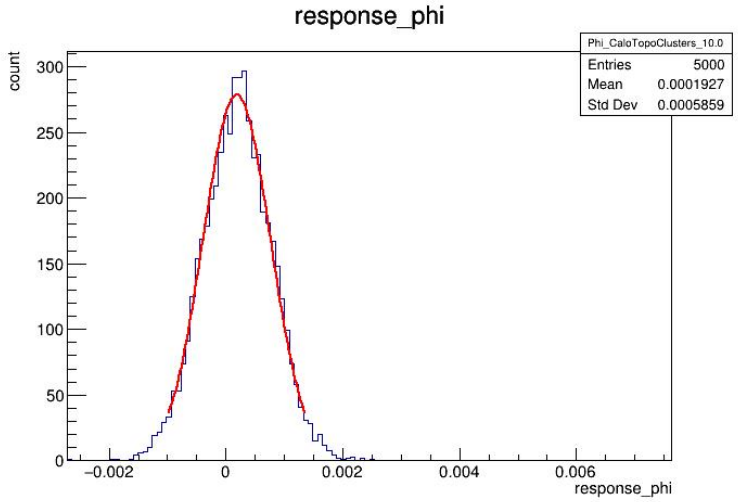
Bottom: Phi

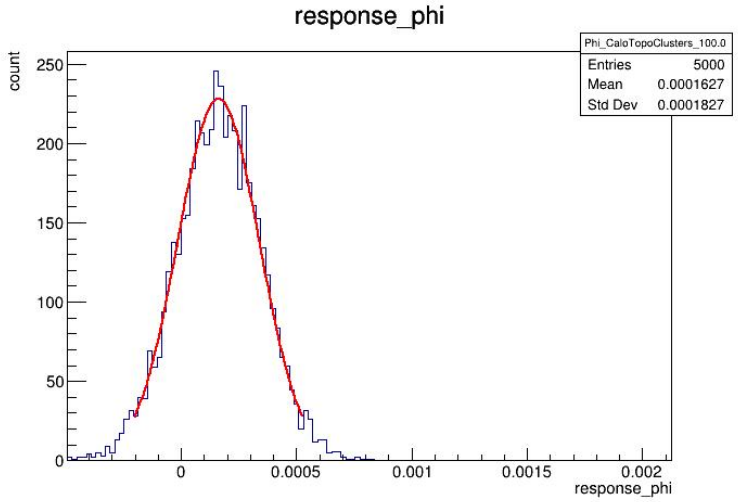












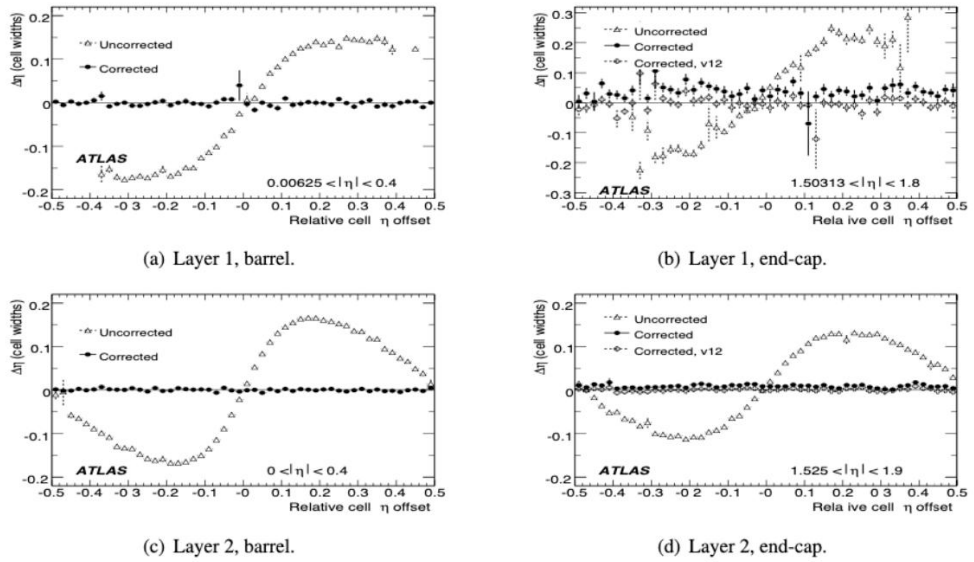
Topological clustering: Theta response

- Two-horn structure arises from well-known “S-curve” effect, due to theta projectivity and finite theta size of cells leading to dependence of returned cluster theta on particle delta_theta w.r.t. the center of cell

ATLAS CSC Note

2.1 η position correction (S-shape)

The cluster η position is first calculated in each layer as the energy-weighted barycenter of the cluster cells in that layer. (In layer 1, only the three strips around the cluster center are used, regardless of the specified cluster size.) Due to the finite granularity of the readout cells, these measurements are biased towards the centers of the cells. For examples, see Fig. 6. This figure plots the difference in η between the incident particle and the reconstructed cluster ($\Delta\eta = \eta_{\text{true}} - \eta_{\text{reco}}$) as a function of ν, the relative η offset of the cluster within the cell, which varies from $-1/2 \ldots 1/2$ across the cell. (The sign of $\Delta\eta$ is inverted for negative η, and in plots it is usually shown as a fraction of the cell η width.) The general functional form shown in this figure is often referred to as “S-shape”.

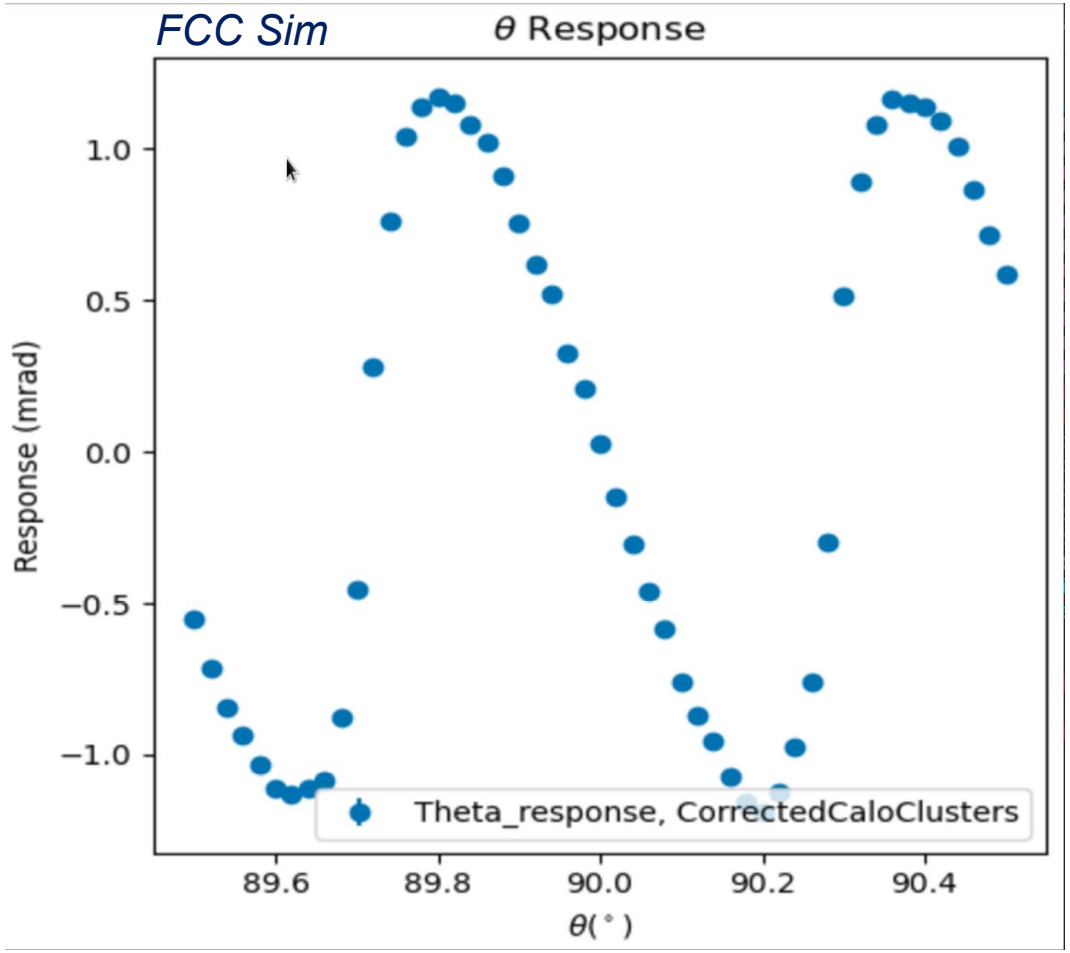


(a) Layer 1, barrel. (b) Layer 1, end-cap.

(c) Layer 2, barrel. (d) Layer 2, end-cap.

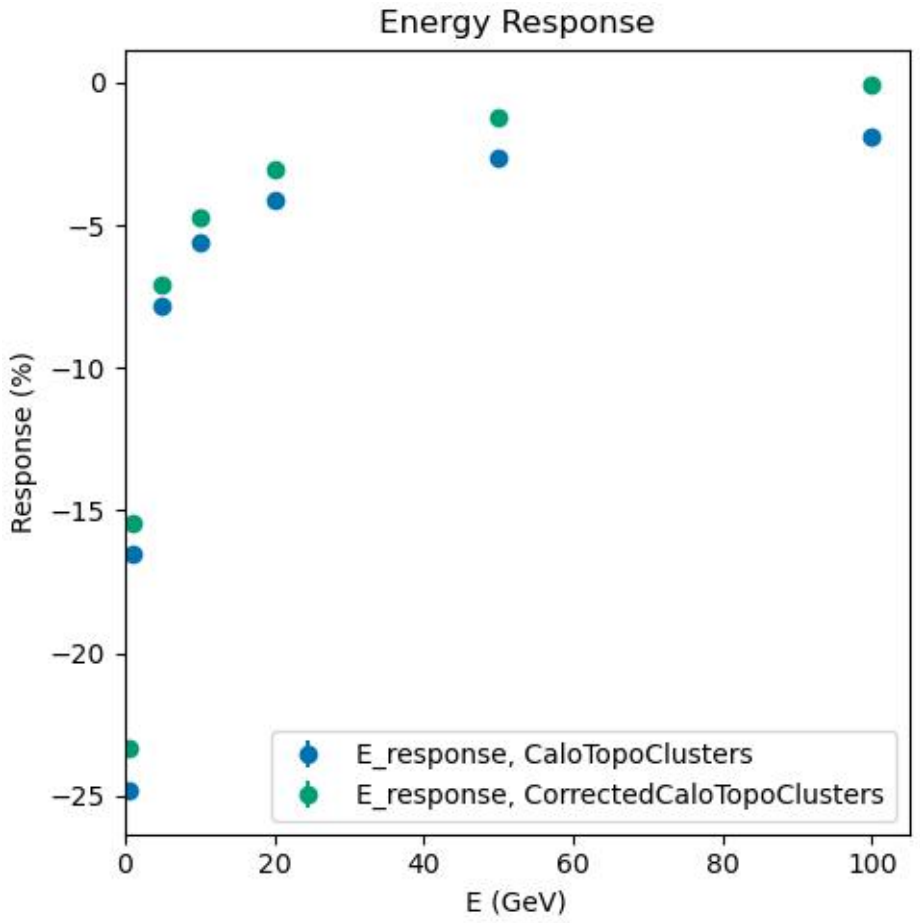
Figure 6: $\Delta\eta$ versus ν before and after correction for different regions and for 100 GeV electrons. Note the small systematic offset in the end-cap due to a change in the end-cap geometry since the corrections were derived. For comparison, the “v12” points show results reconstructed using the same geometry as that used to derive the corrections.

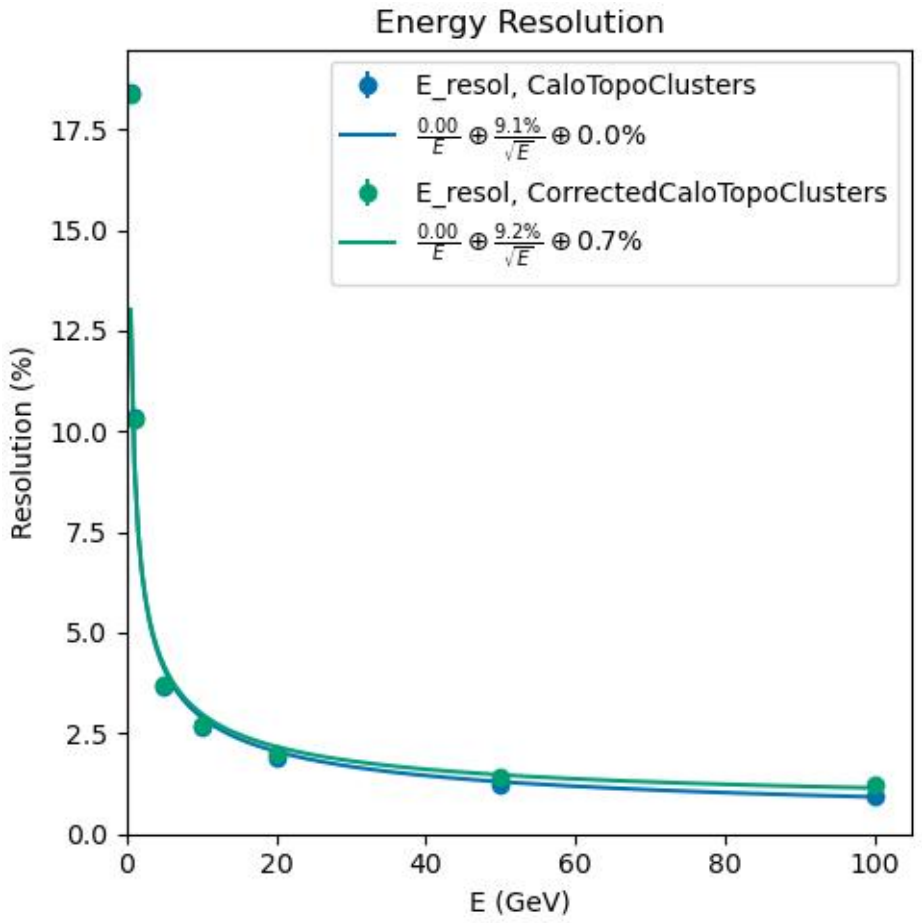
FCC Sim



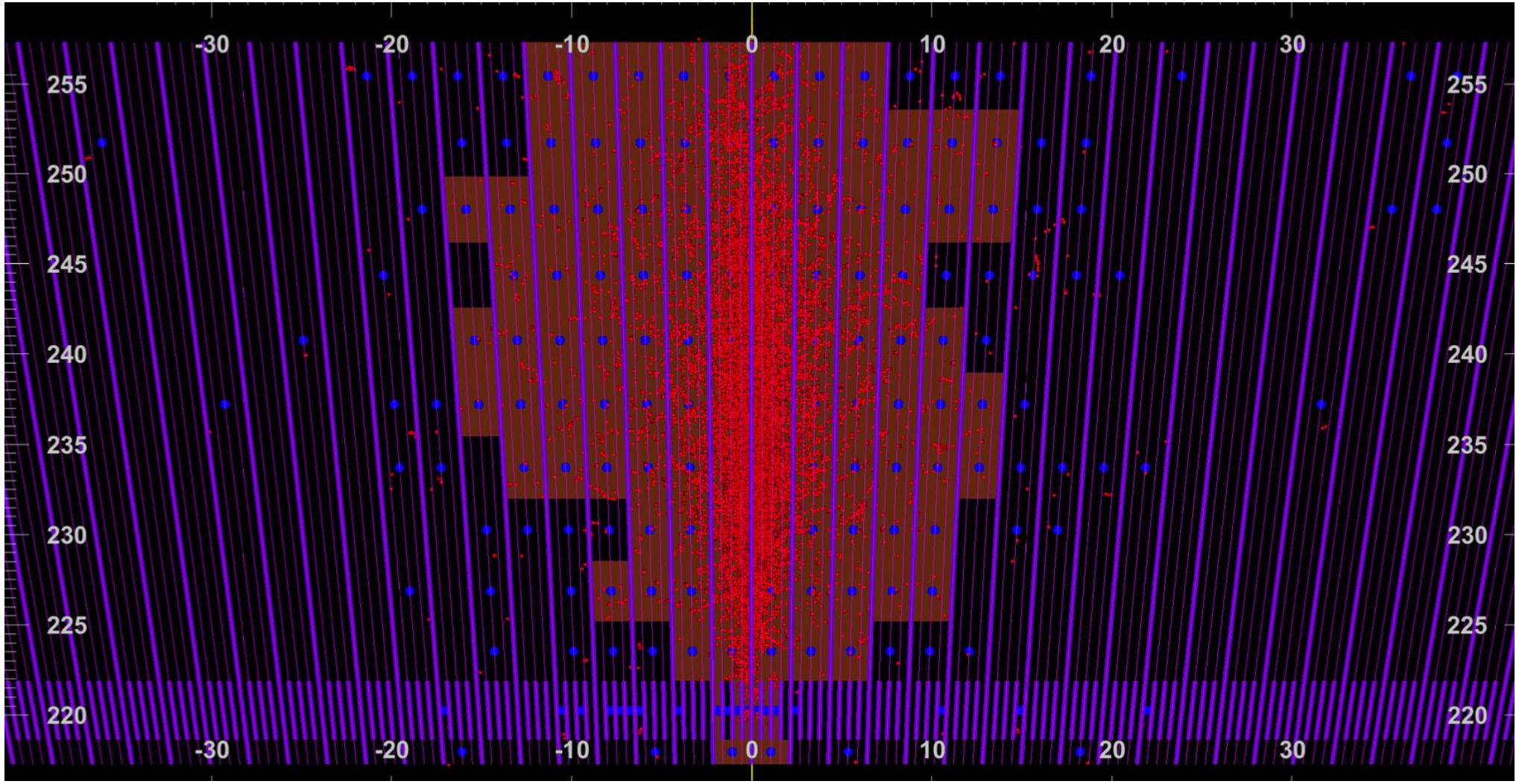
Topological clustering: energy response and resolution

- Energy response and resolution for topo-clusters and corrected topo-clusters
  - “Corrected” means applying up/downstream corrections





Topological clustering: event display (50 GeV electron)

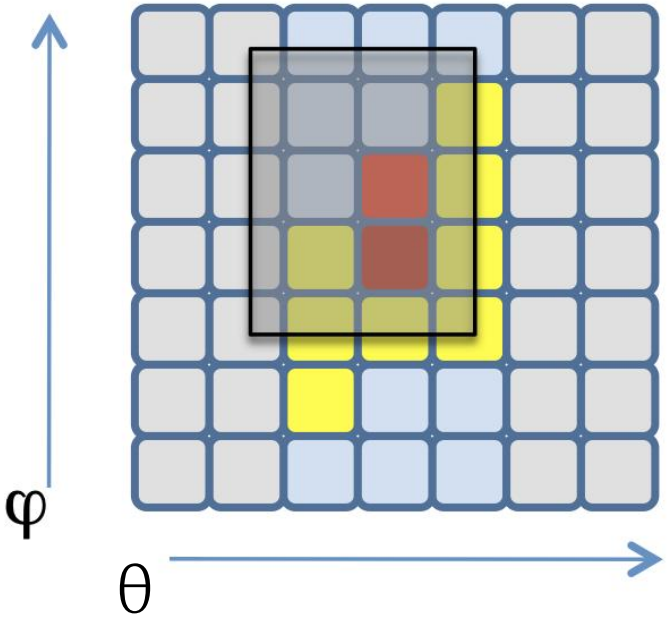


CaloDisplay Tool

Sliding-Window clustering

- Creating calorimeter clusters from cells with fixed-size in Theta-Phi
  - Performs well for electron/gamma reconstruction

1. Create calorimeter towers in Δtheta × Δphi.
2. Find local maxima using sliding-window.
3. Remove duplicates.
4. Build final clusters.



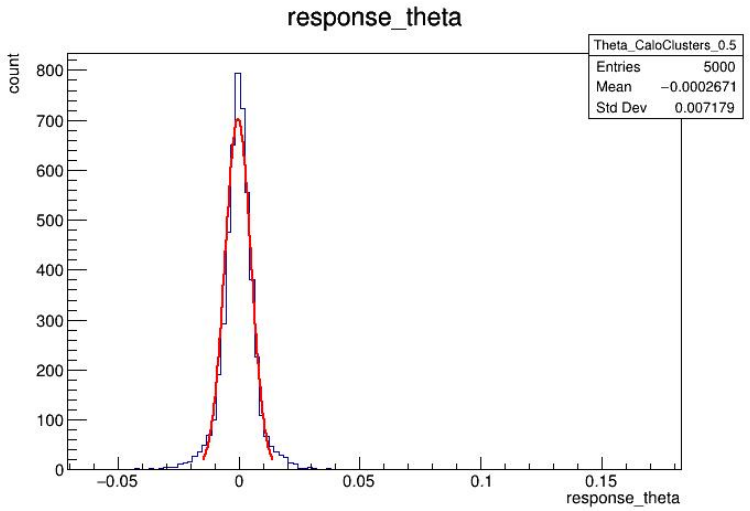
- Calo-tower size:
  - 4 × strips in Theta
  - 2 modules in Phi

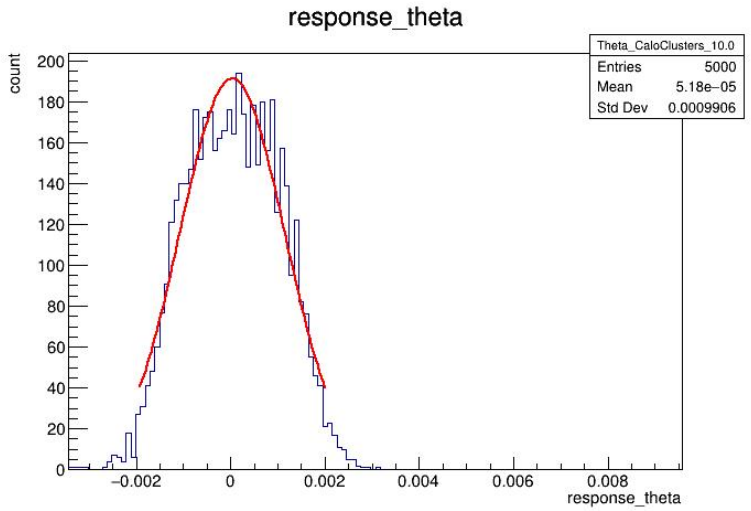
Sliding-Window clustering: Theta and Phi response

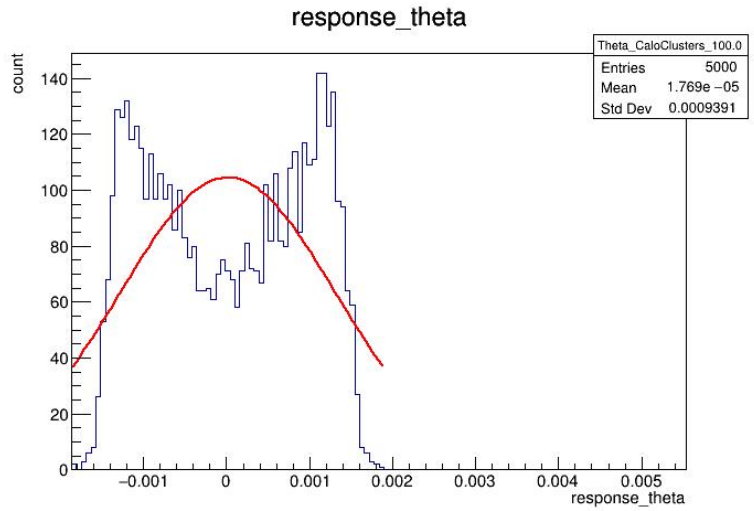
- From left to right: 0.5 GeV, 10 GeV, 100 GeV electron

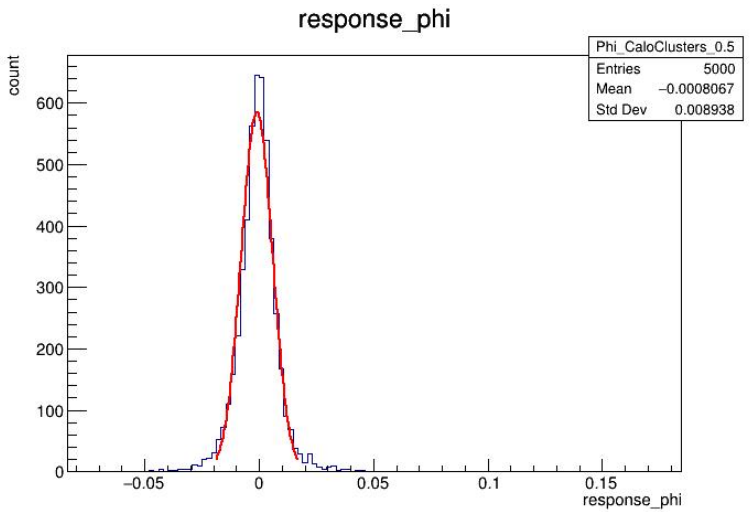
Top: Theta

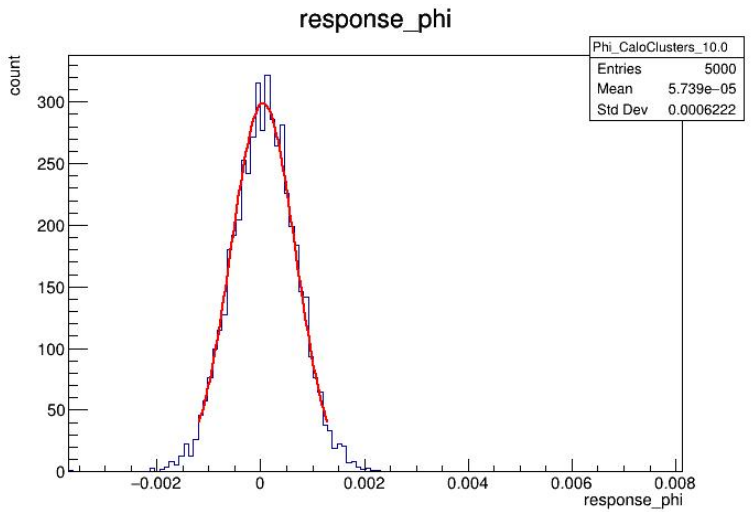
Bottom: Phi

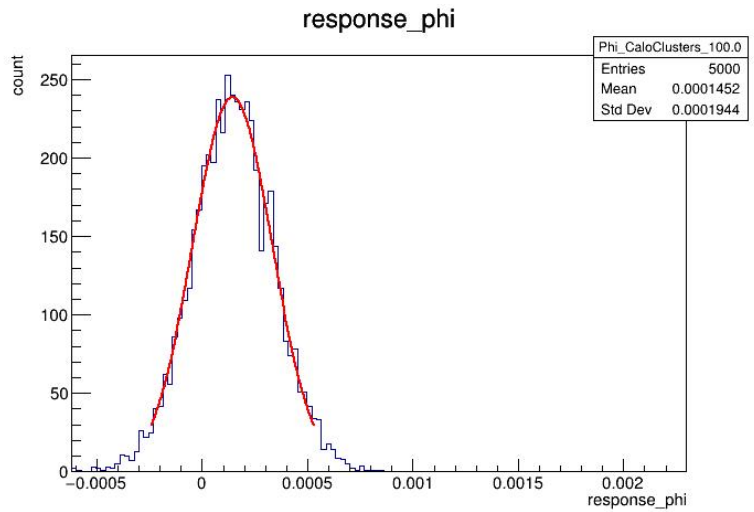






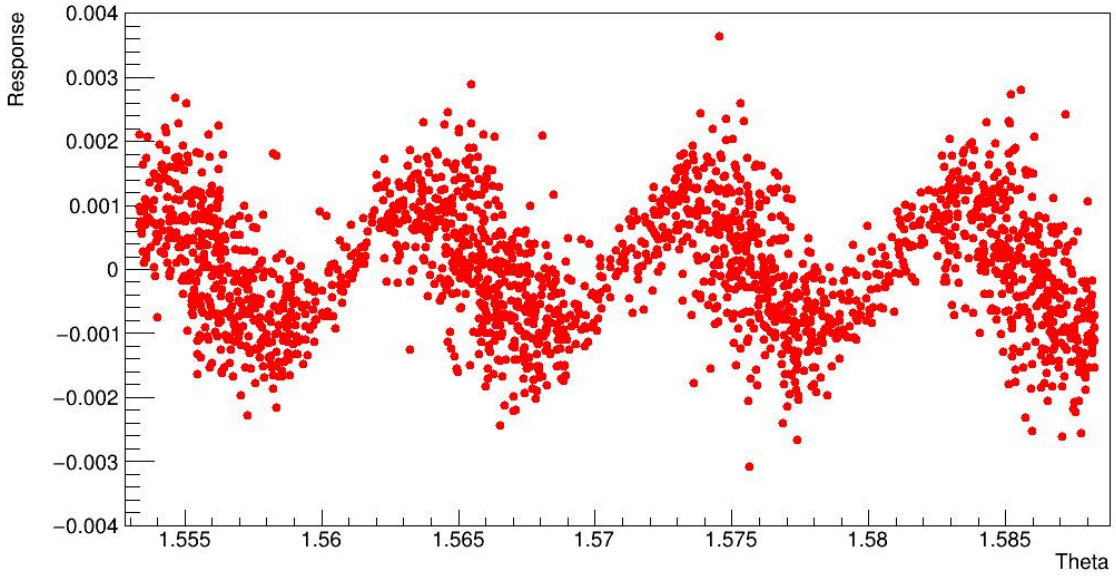




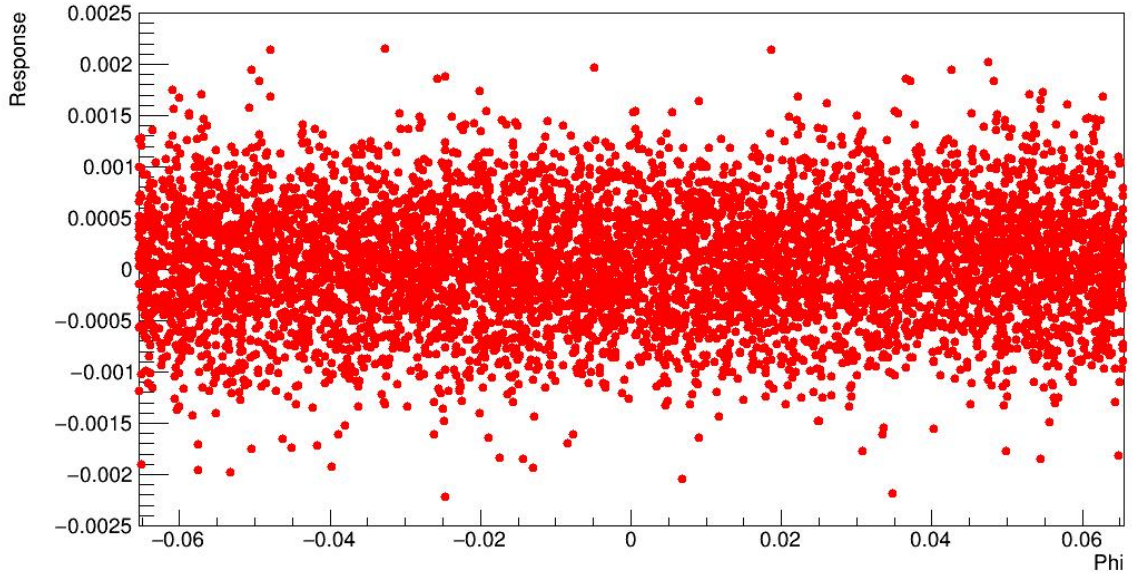


Sliding-Window clustering: Theta and Phi response

- Theta/Phi response as a function of Theta/Phi
  - Scan over several cells to see the dependence
  - S-curve effect observed in Theta response



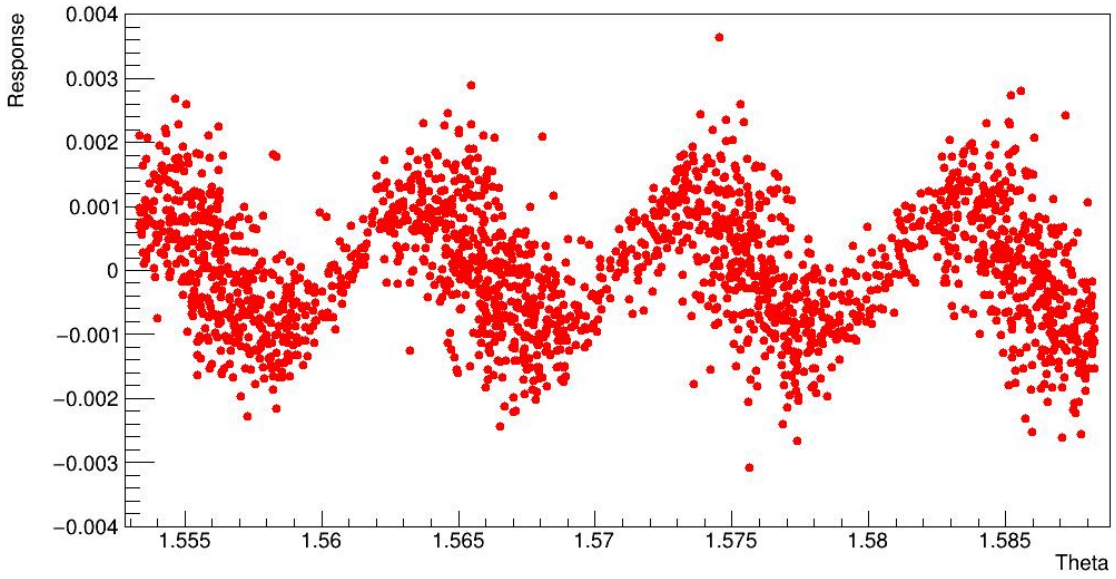
Theta



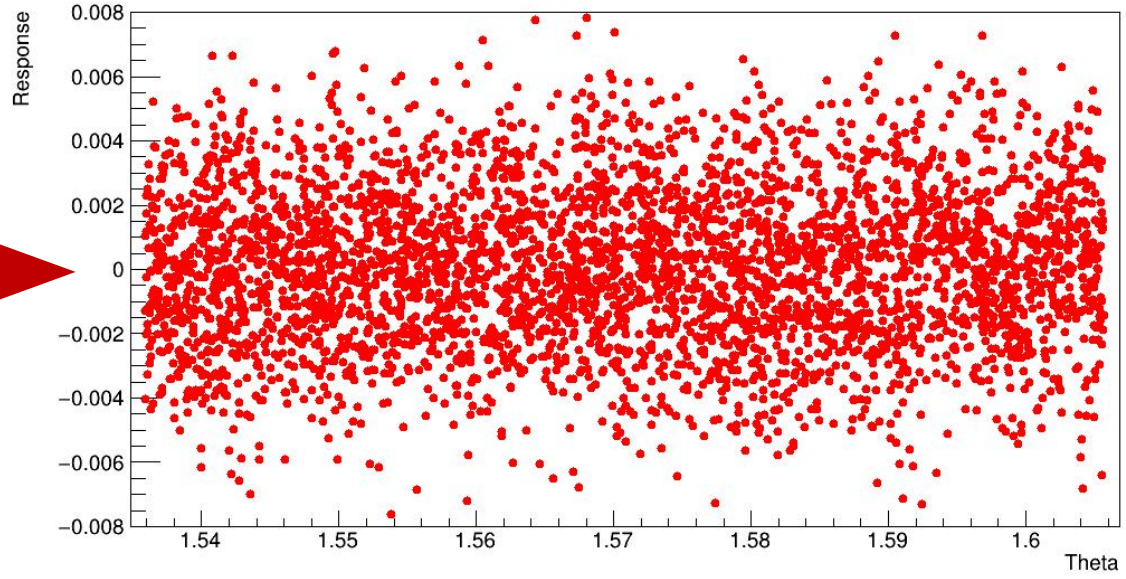
Phi

Sliding-Window clustering: Theta response correction

- S-curve effect observed in Theta response
  - Re-calculate the cluster barycenter using $\ln(E_{cell})$ as weight



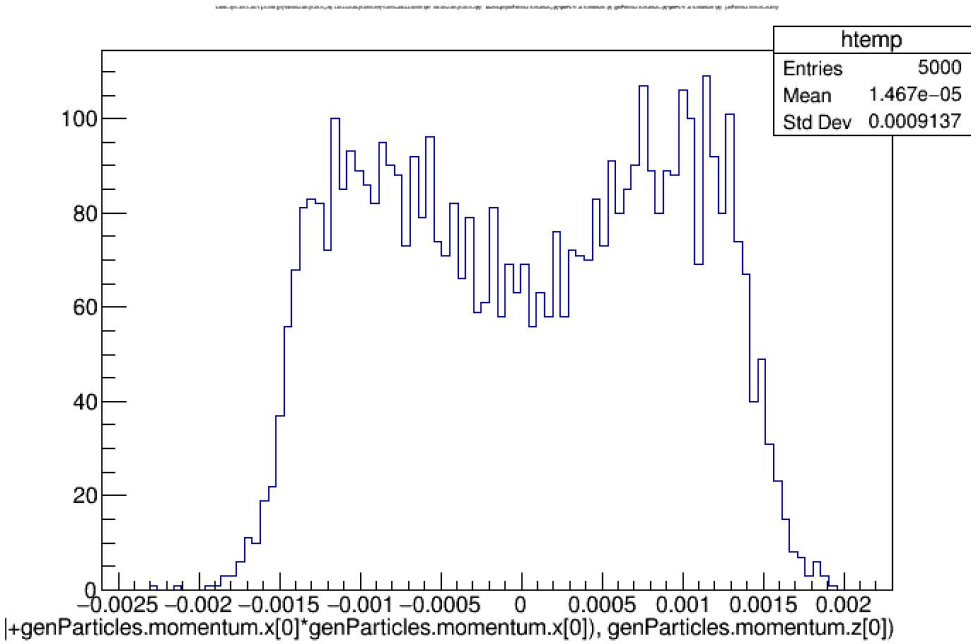
before correction



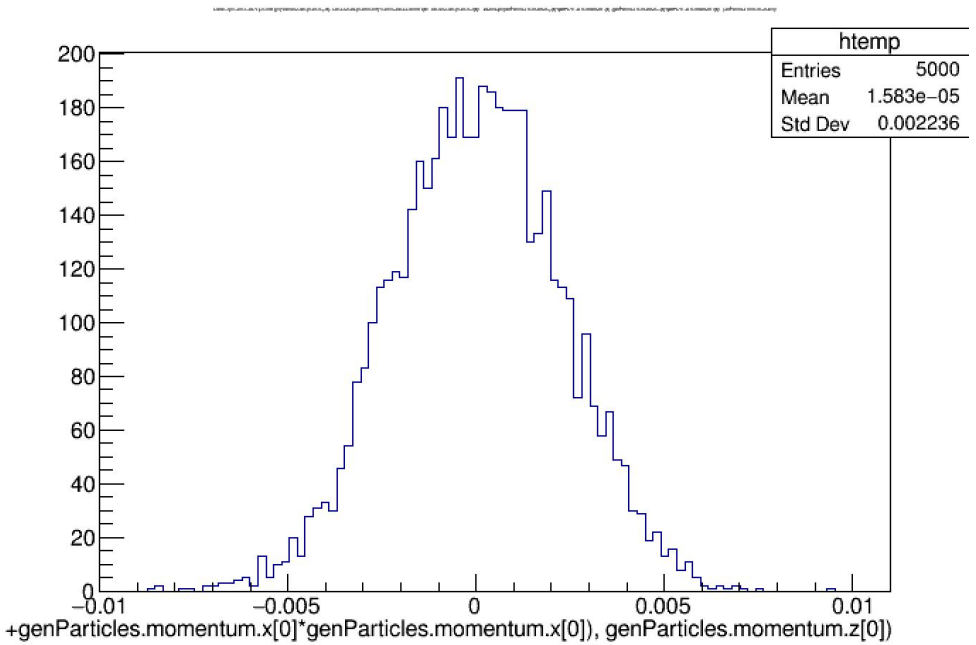
after correction

Sliding-Window clustering: Theta response correction

- S-curve effect observed in Theta response
  - Re-calculate the cluster barycenter using $\ln(E_{cell})$ as weight



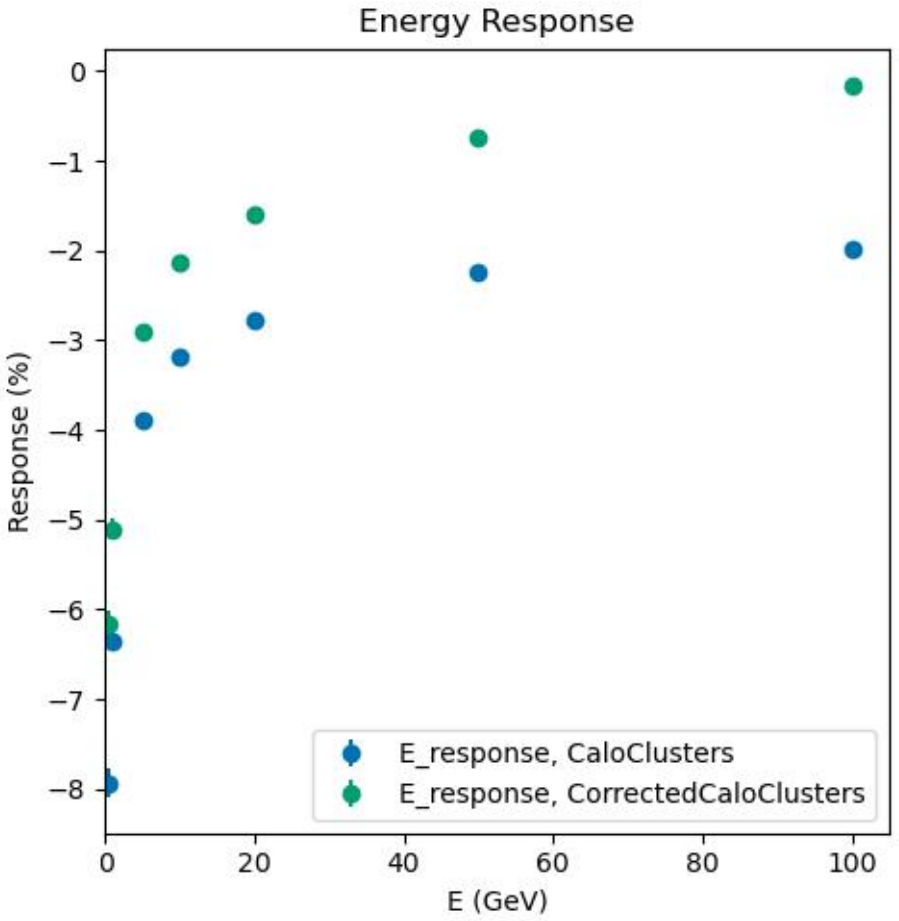
before correction

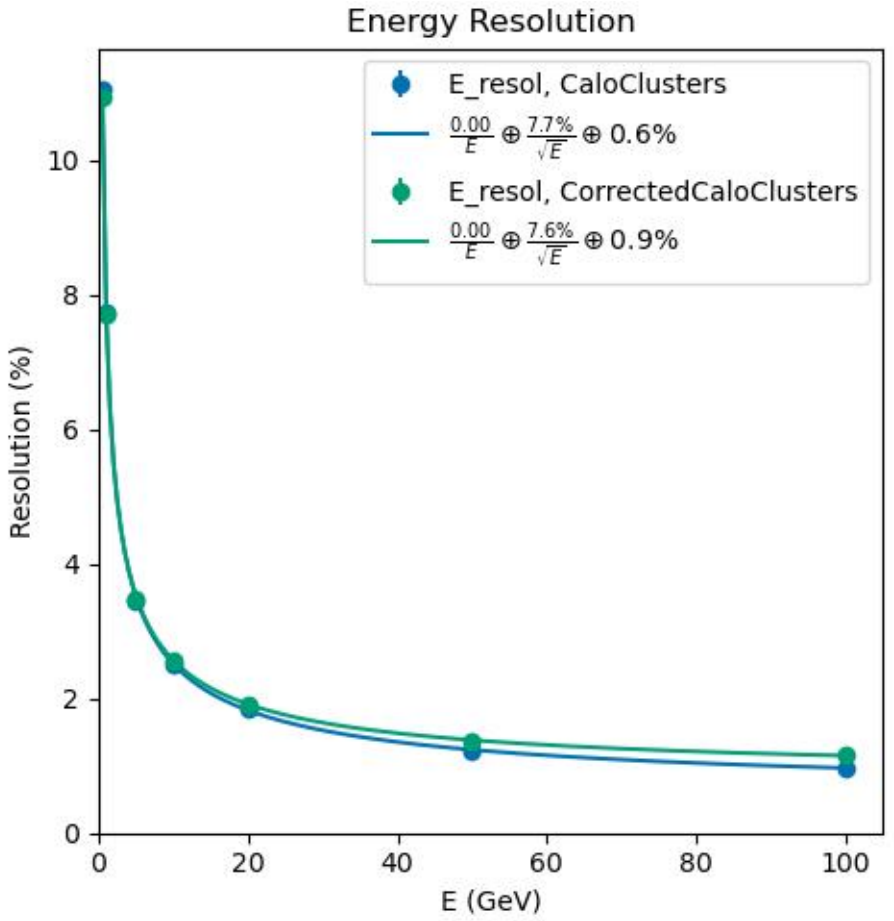


after correction

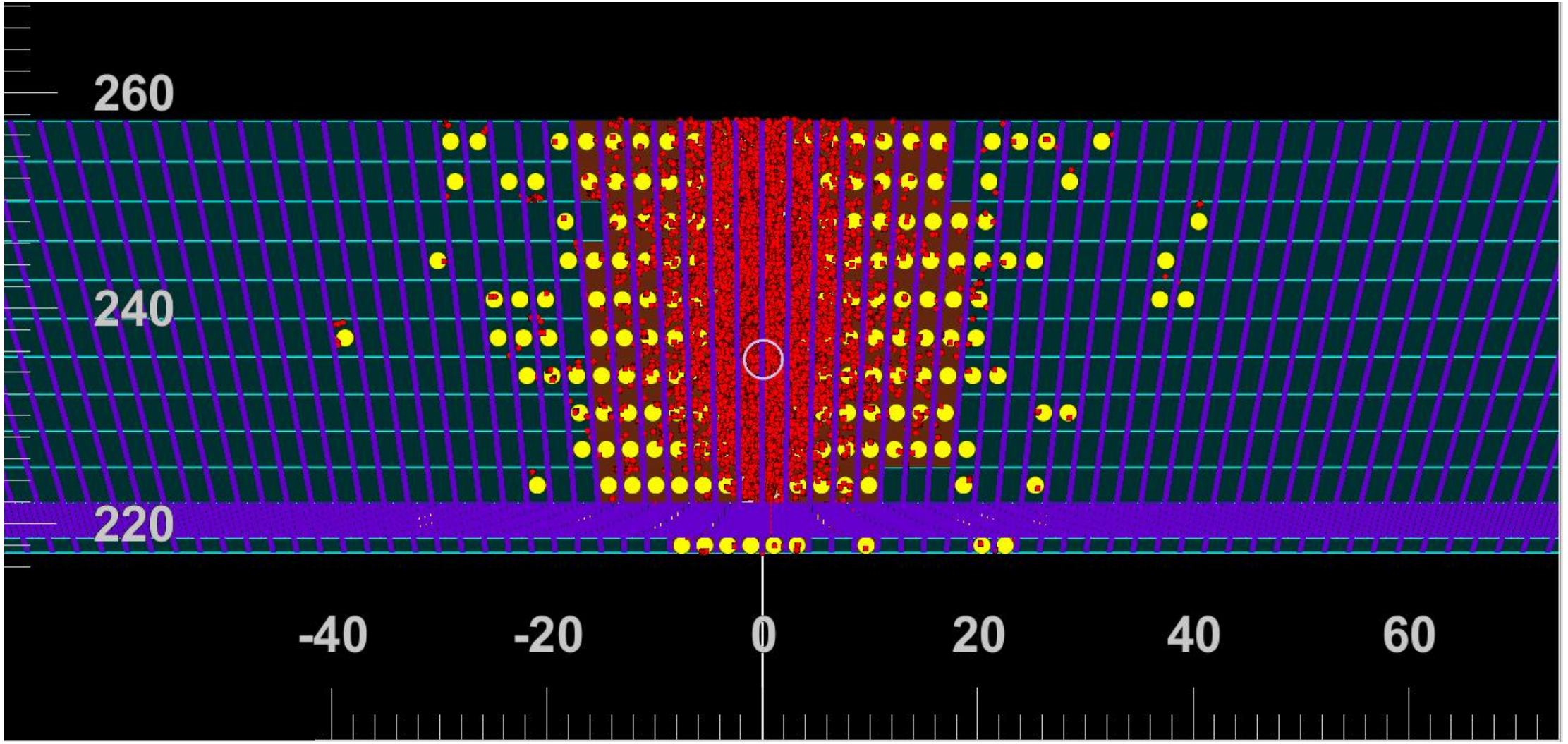
Sliding-Window clustering: energy response and resolution

- Energy response and resolution for calo-clusters and corrected calo-clusters
  - “Corrected” means applying up/downstream corrections





Sliding-Window clustering: event display (50 GeV electron)



CaloDisplay Tool

Summary

- Theta-Module Merged readouts are implemented in ECal Barrel of LAr calorimeter
- Topological and Sliding-Window clustering performances are shown
  - Theta/Phi and energy response/resolution
  - Correction of the “s-curve” effect
  - Event display

➢ Training the MVA to calibrate clusters

➢ Working on the HCal-ECal connection

  ➢ To run clustering in the whole calorimeter

- Related Pull-Requests:

➢ Theta-Module Merged segmentation (merged):

https://github.com/HEP-FCC/FCCDetectors/pull/56

https://github.com/HEP-FCC/k4RecCalorimeter/pull/48

https://github.com/HEP-FCC/k4SimGeant4/pull/46

➢ Topological clustering (merged):

https://github.com/HEP-FCC/FCCDetectors/pull/63

https://github.com/HEP-FCC/k4RecCalorimeter/pull/51

https://github.com/BrieucF/LAr_scripts/pull/13

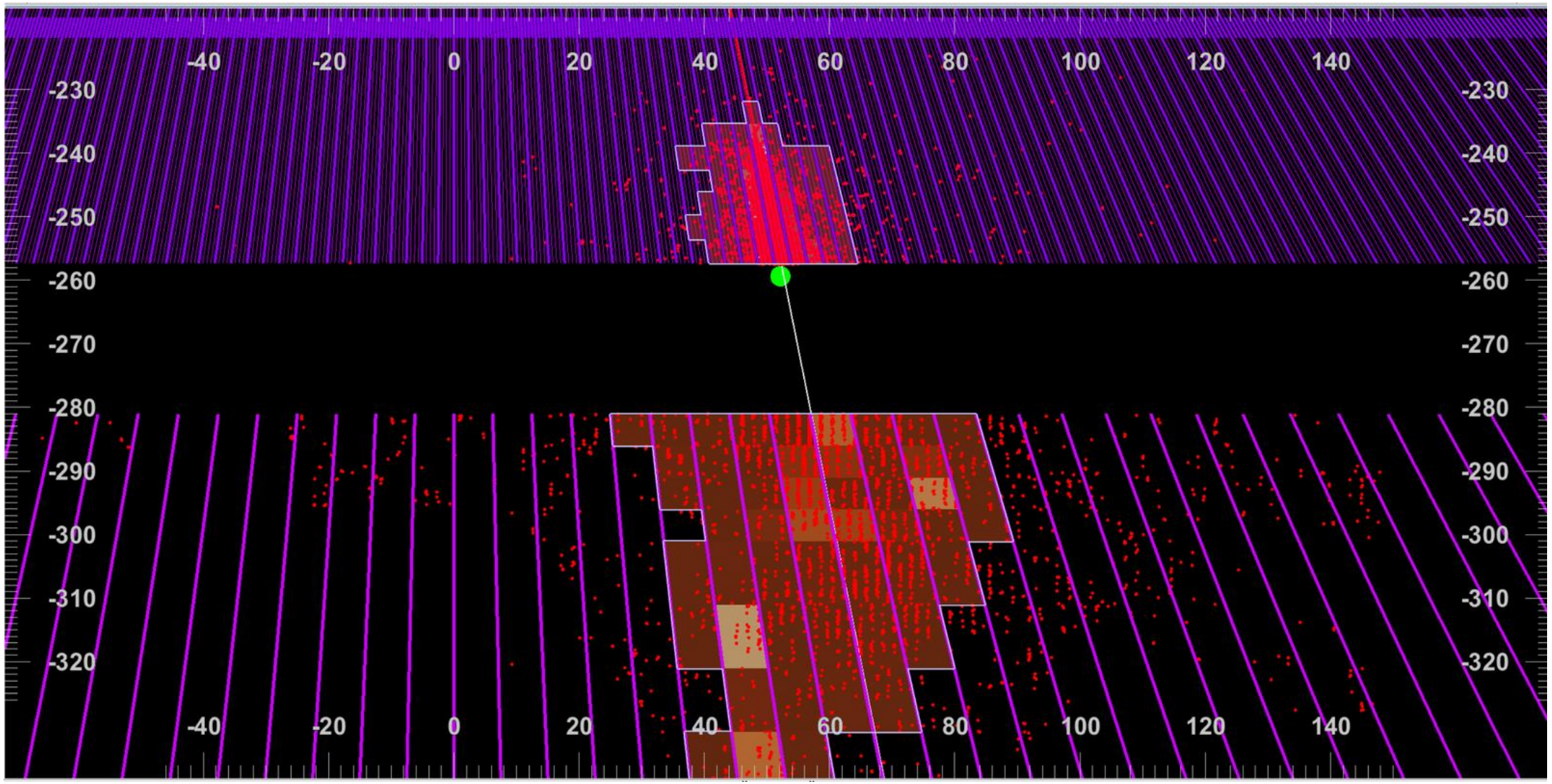
➢ Sliding-Window clustering (Open):

https://github.com/key4hep/k4FWCore/pull/158

https://github.com/HEP-FCC/k4RecCalorimeter/pull/58

https://github.com/BrieucF/LAr_scripts/pull/16

HCal + ECal topo-clutering: event display



[CaloDisplay Tool]

Giovanni M.

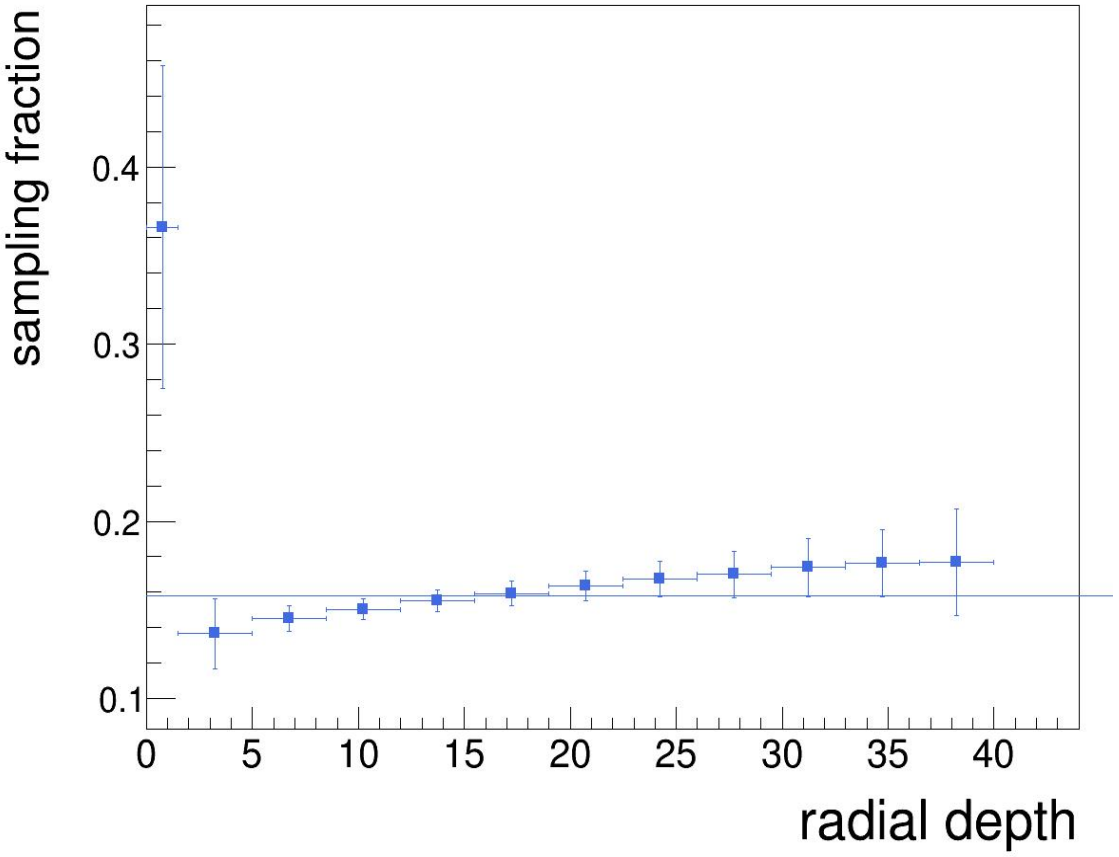
Back Up

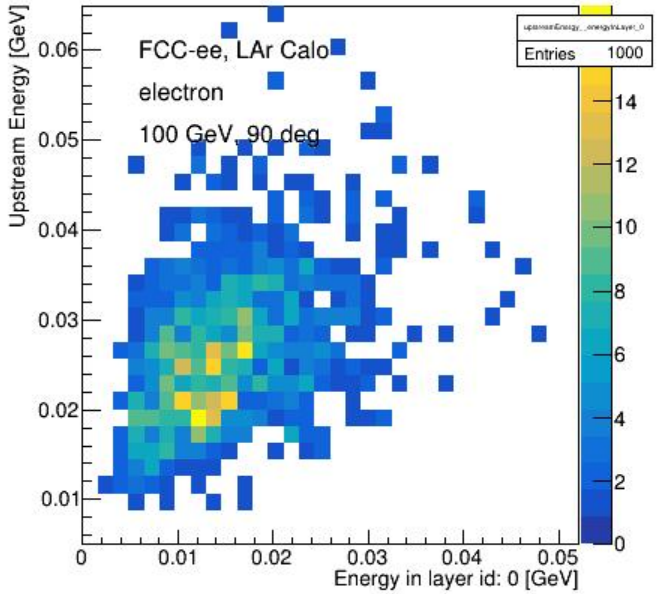
Theta-Module Merged readouts

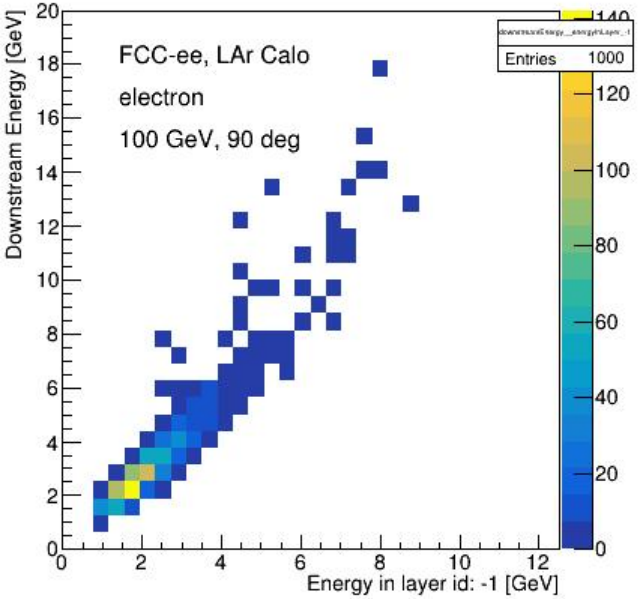
- Number of merged cells in Theta and Module (Phi) are defined in the .xml file
- One can add a new readout from here

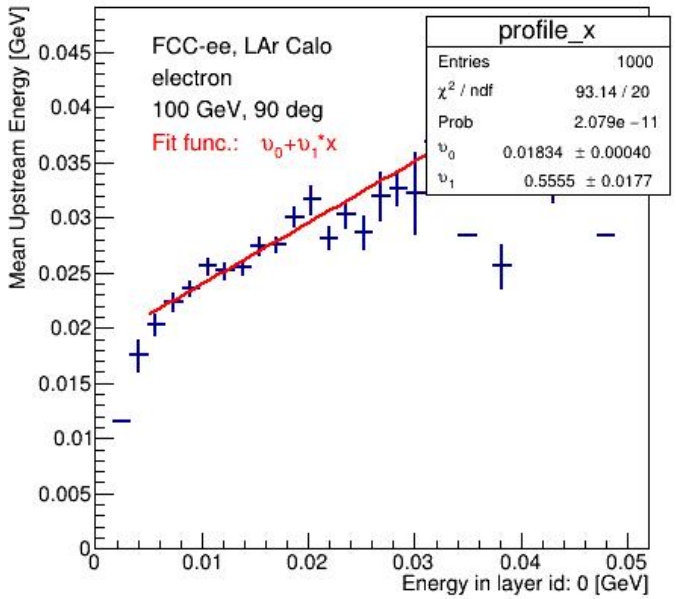
```
  <readouts>
    <!-- readout for the simulation, with the baseline merging: 2x along the module direction in each layer; 4x al
ong theta in each layer except layer 1 -->
    <!-- the lists mergedCells_Theta and mergedModules define the number of cells to group together in the theta a
nd module direction as a function of the layer -->
    <readout name="ECalBarrelModuleThetaMerged">
      <segmentation type="FCCSWGridModuleThetaMerged" nModules="1536" mergedCells_Theta="4 1 4 4 4 4 4 4 4 4 4 4"
mergedModules="2 2 2 2 2 2 2 2 2 2 2 2" grid_size_theta="0.009817477/4" offset_theta="0.5902785"/>
        <id>system:4,cryo:1,type:3,subtype:3,layer:8,module:11,theta:10</id>
    </readout>

    <!-- example of adding a second readout for the reconstruction, to compare the two -->
    <readout name="ECalBarrelModuleThetaMerged2">
      <segmentation type="FCCSWGridModuleThetaMerged" nModules="1536" mergedCells_Theta="2 4 2 1 2 1 2 2 1 1 1 2"
mergedModules="2 1 1 2 2 1 1 1 2 2 1 1" grid_size_theta="0.009817477/4" offset_theta="0.5902785"/>
        <id>system:4,cryo:1,type:3,subtype:3,layer:8,module:11,theta:10</id>
    </readout>
  </readouts>
```

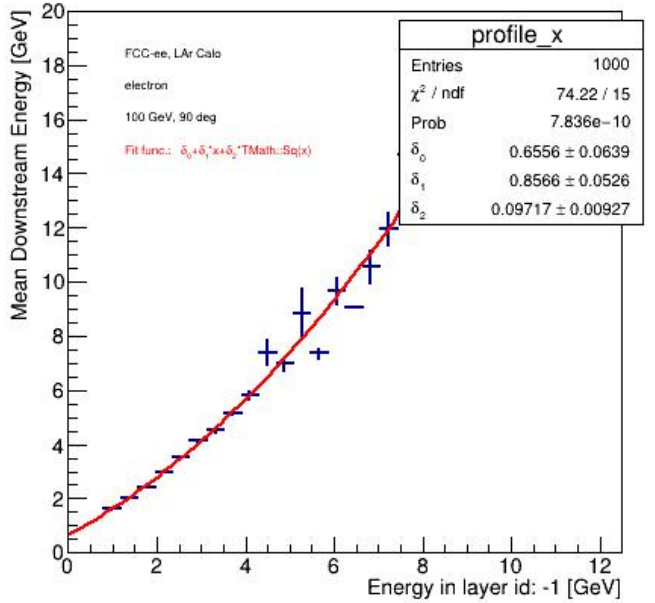
Sampling fraction and up/downstream correction







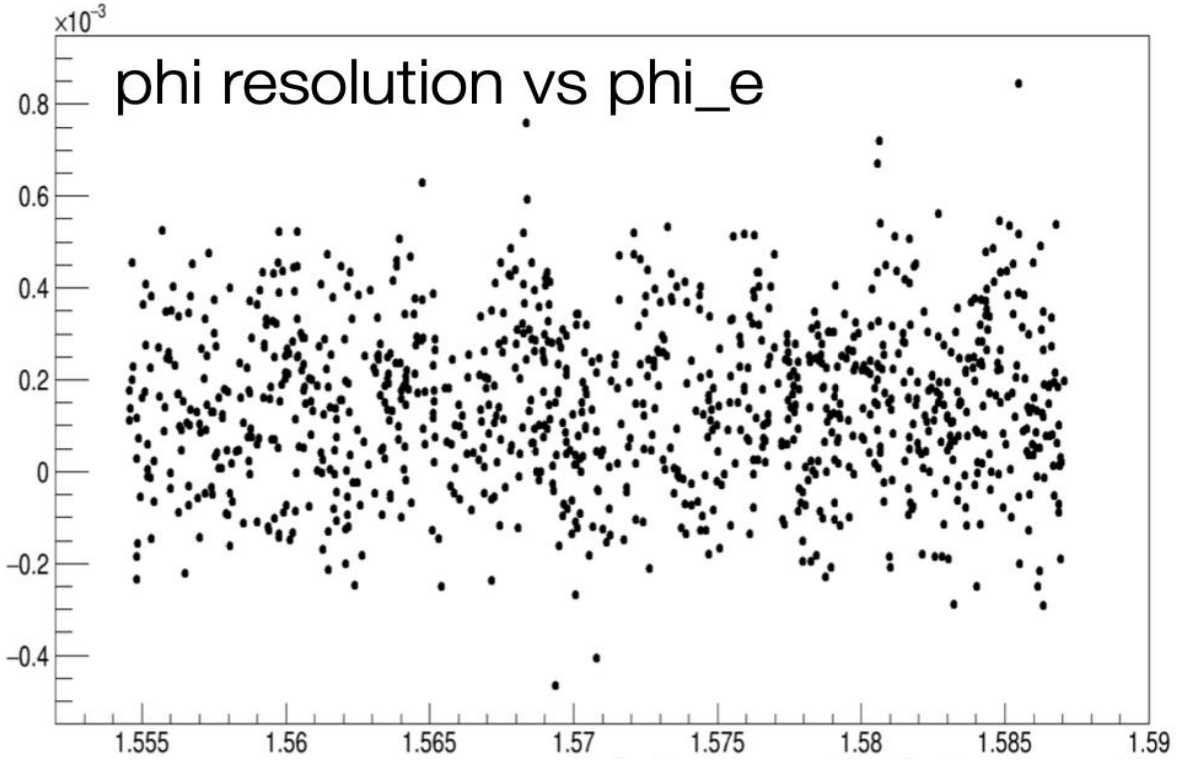


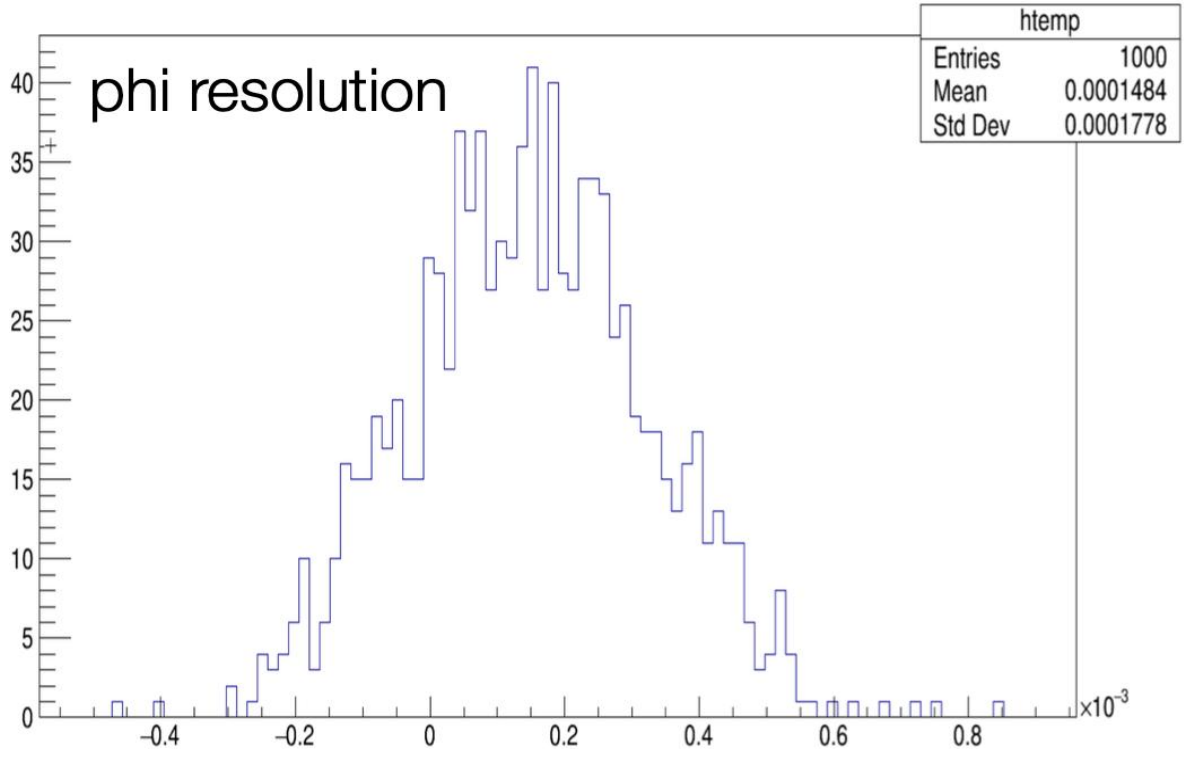


Topological clustering: Theta and Phi resolution

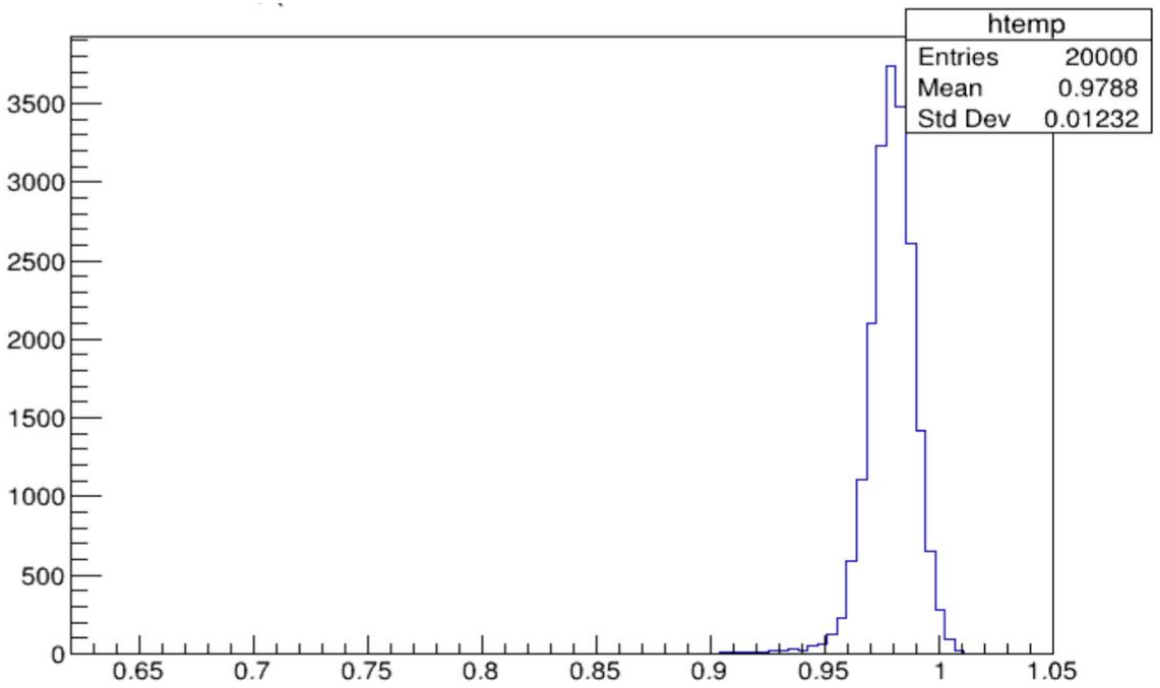
- Tried to check if phi asymmetric/biased curve also arises from some similar effect (dependence of resolution/response on impact position within cell)

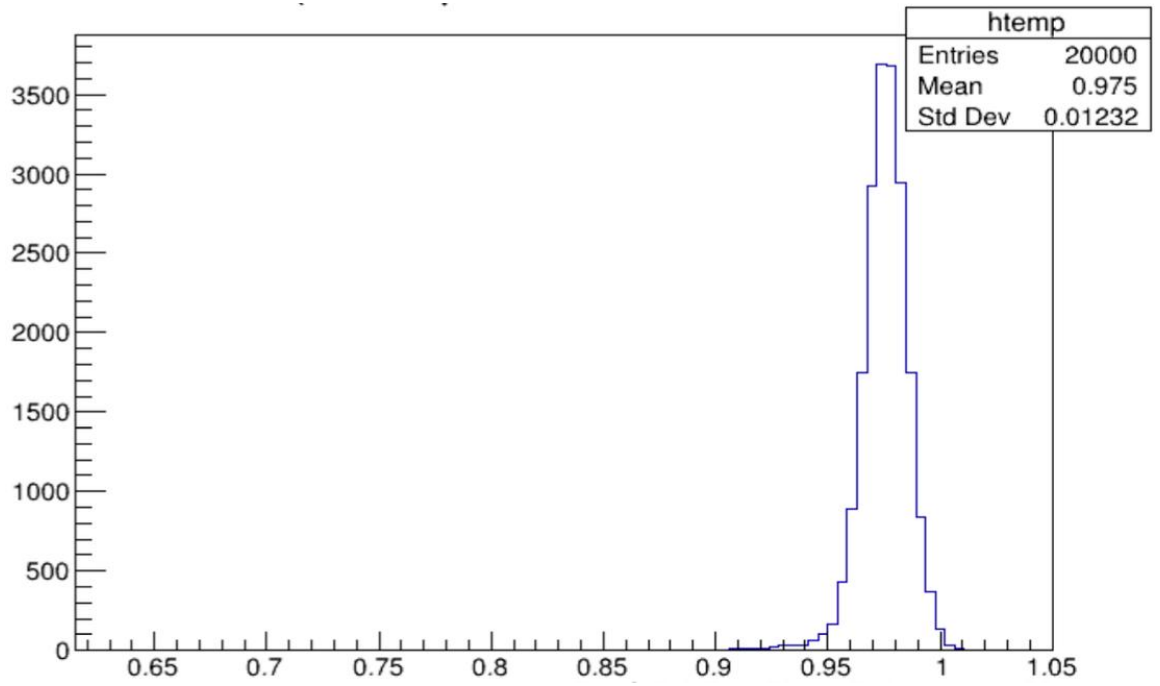
  → didn't find obvious effect for phi spanning +/-2 modules around phi_e = 90 degrees





Topo-clustering – cell and cluster energy





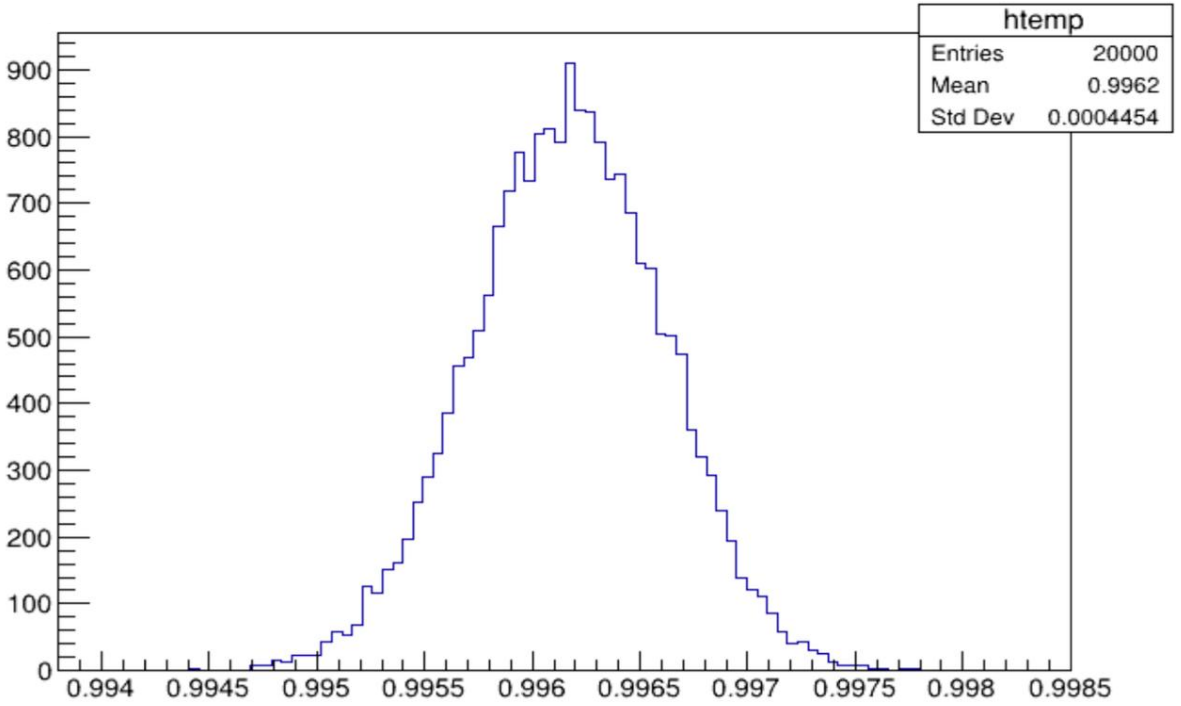
- LEFT: energy of all cells (at EM scale) / energy of incident electron (100GeV)

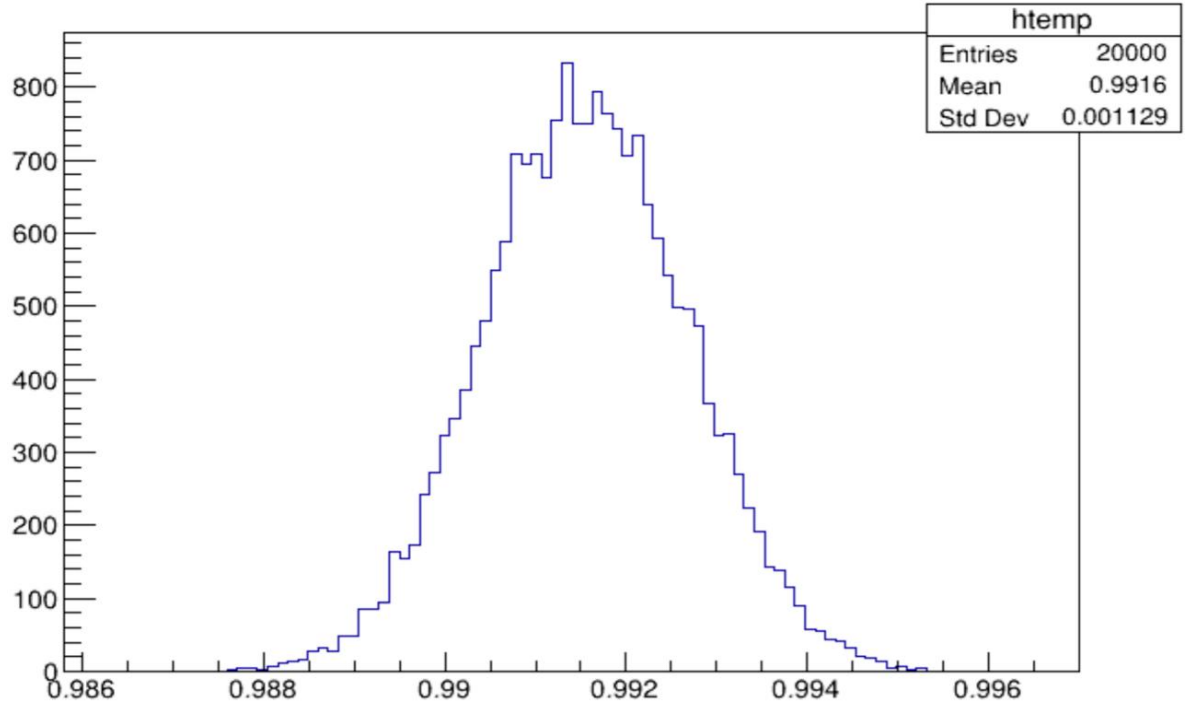
→ -2.1% (up/downstream losses)

- RIGHT: energy of clustered cells / energy of incident electron (100GeV)

→ -2.5% (small extra drop due to unclustered cells)

Topo-clustering – cell and cluster energy





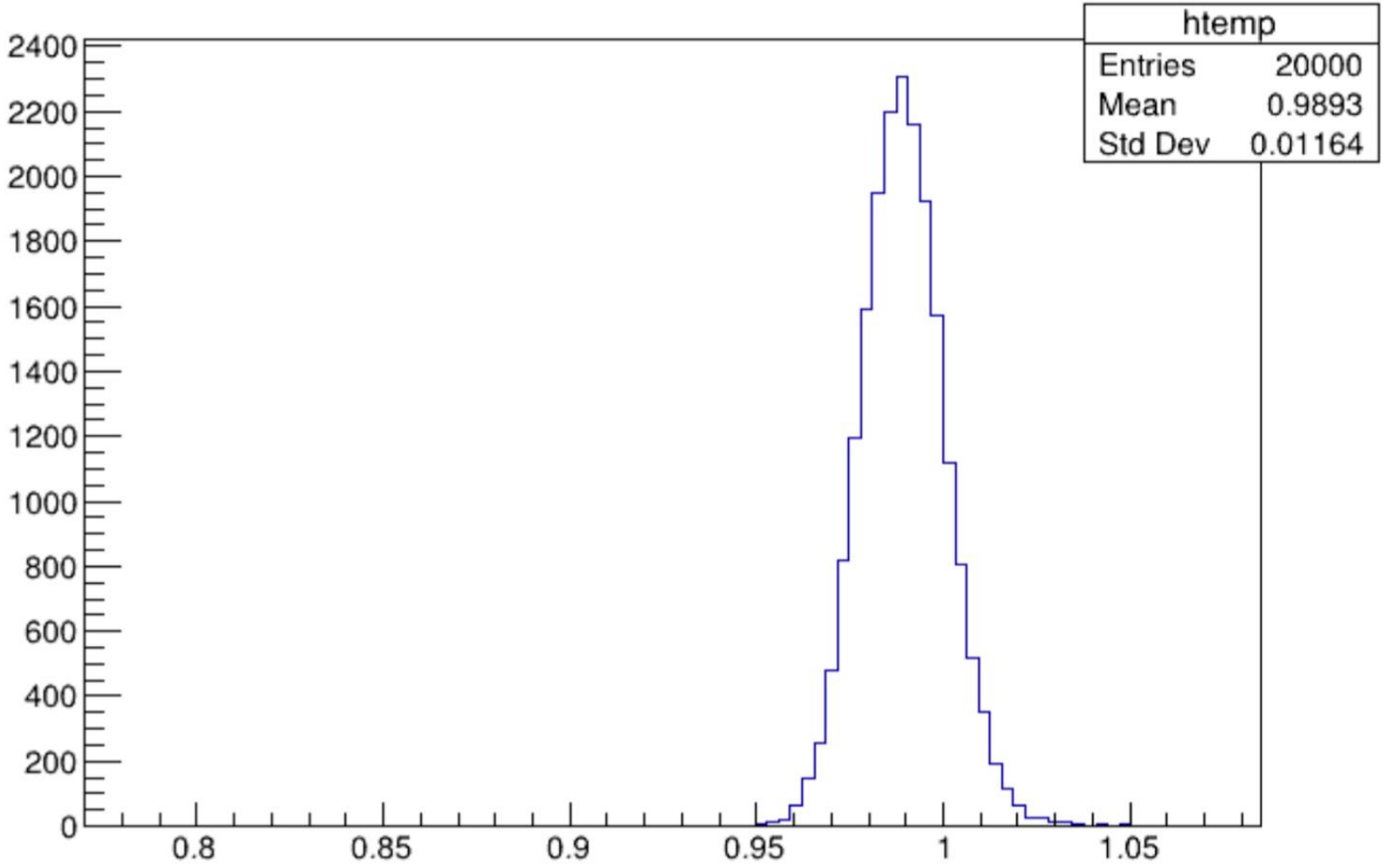
- LEFT: Energy of all clusters / Energy of all cells

→ Same 0.4% deficit seen in previous slide (slide 7)

- RIGHT: When rejecting low-energy clusters (< 2GeV)

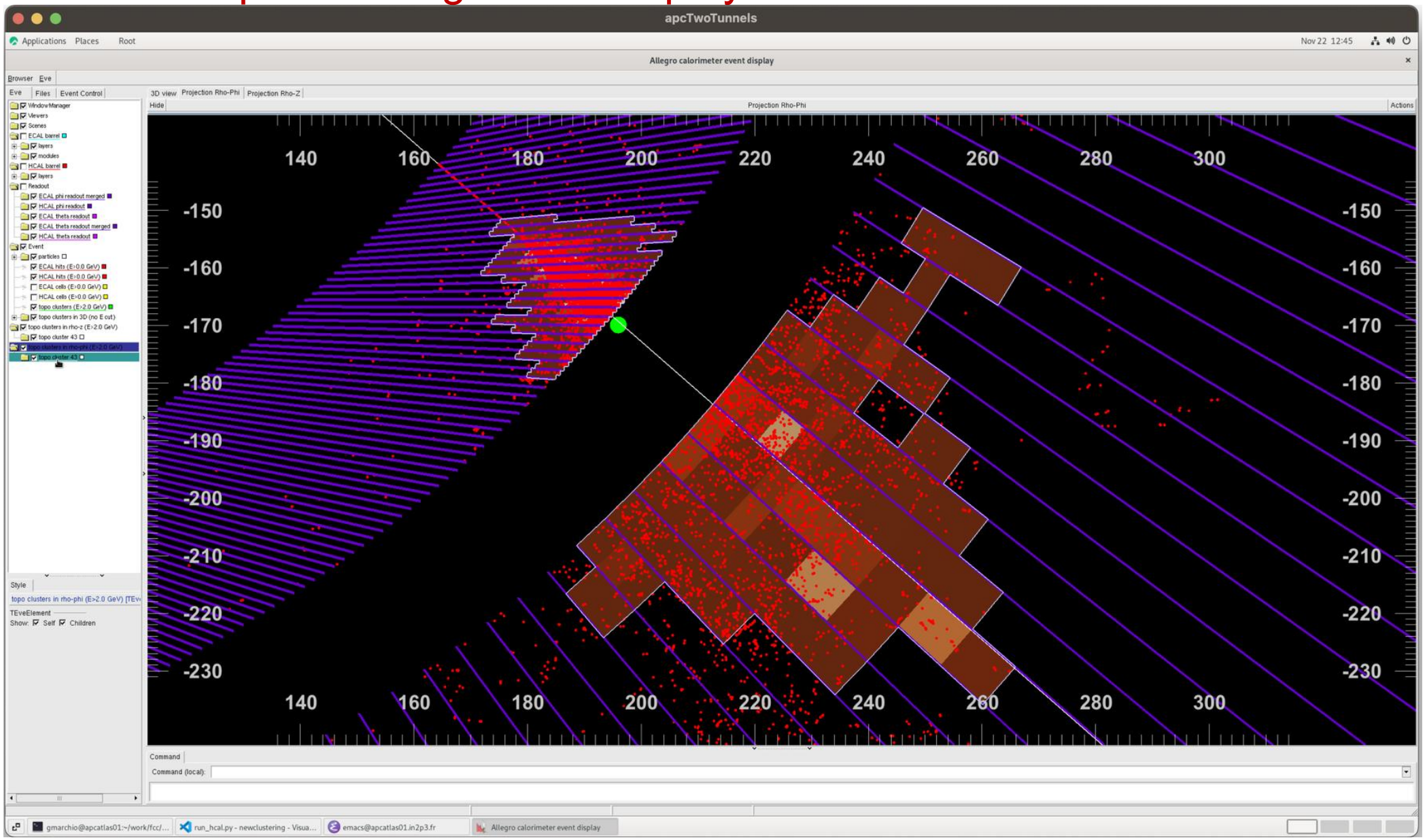
→ 1 cluster/event is left, containing ~99.2% of the energy of all cells

Topo-clustering – up/downstream correction



- After up/downstream corrections, topo-cluster energy is ~99% that of incident 100GeV electron
  - Can correct for it with the MVA calibration
  - Could also try to recover more of it with superclusters (adding satellite clusters)

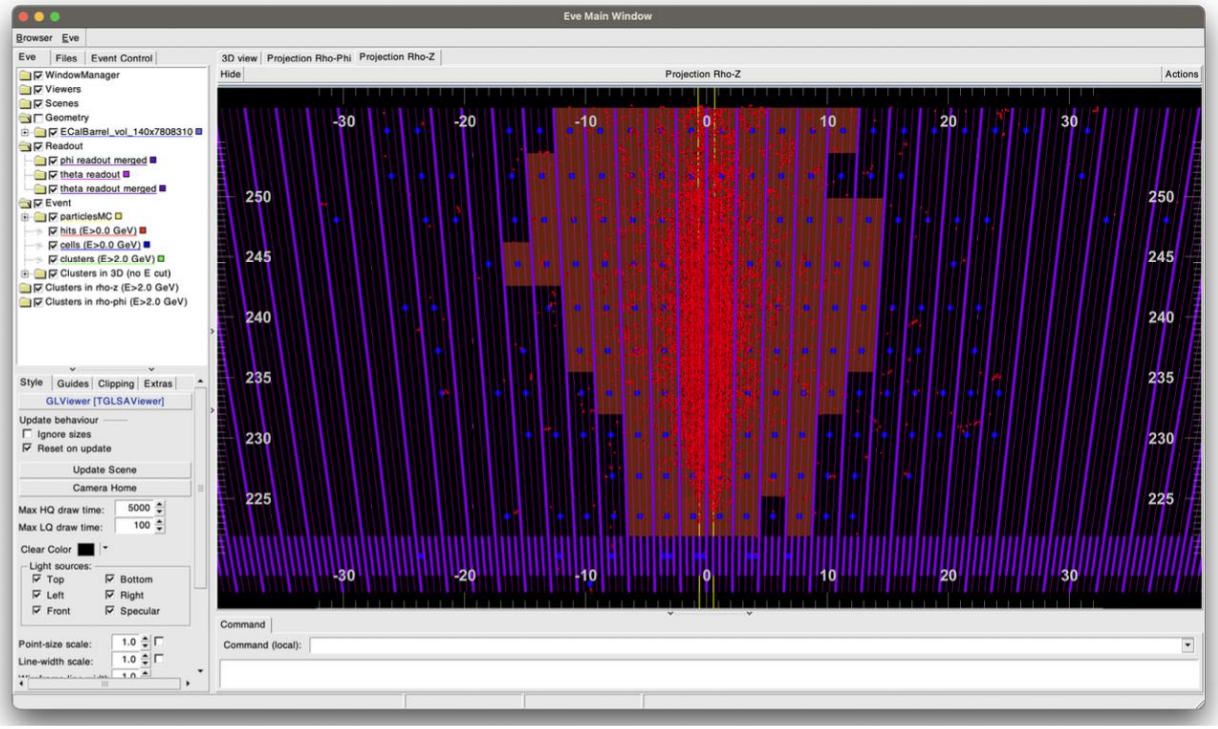
HCal + ECal topo-clutering: event display



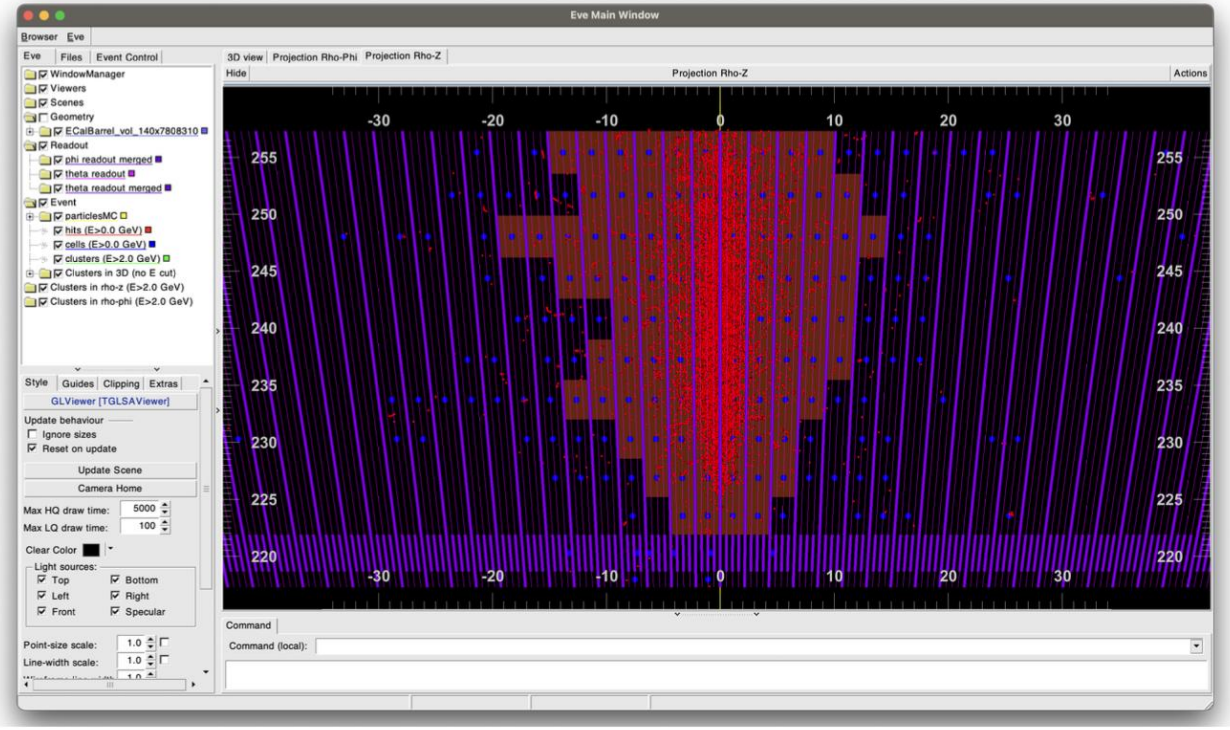
[CaloDisplay Tool]

Giovanni M.

Topological clustering: event display



pi0 50 GeV



photon 50 GeV

[CaloDisplay Tool]