Design of the CMS High Granularity Calorimeter Trigger Primitive Generator System

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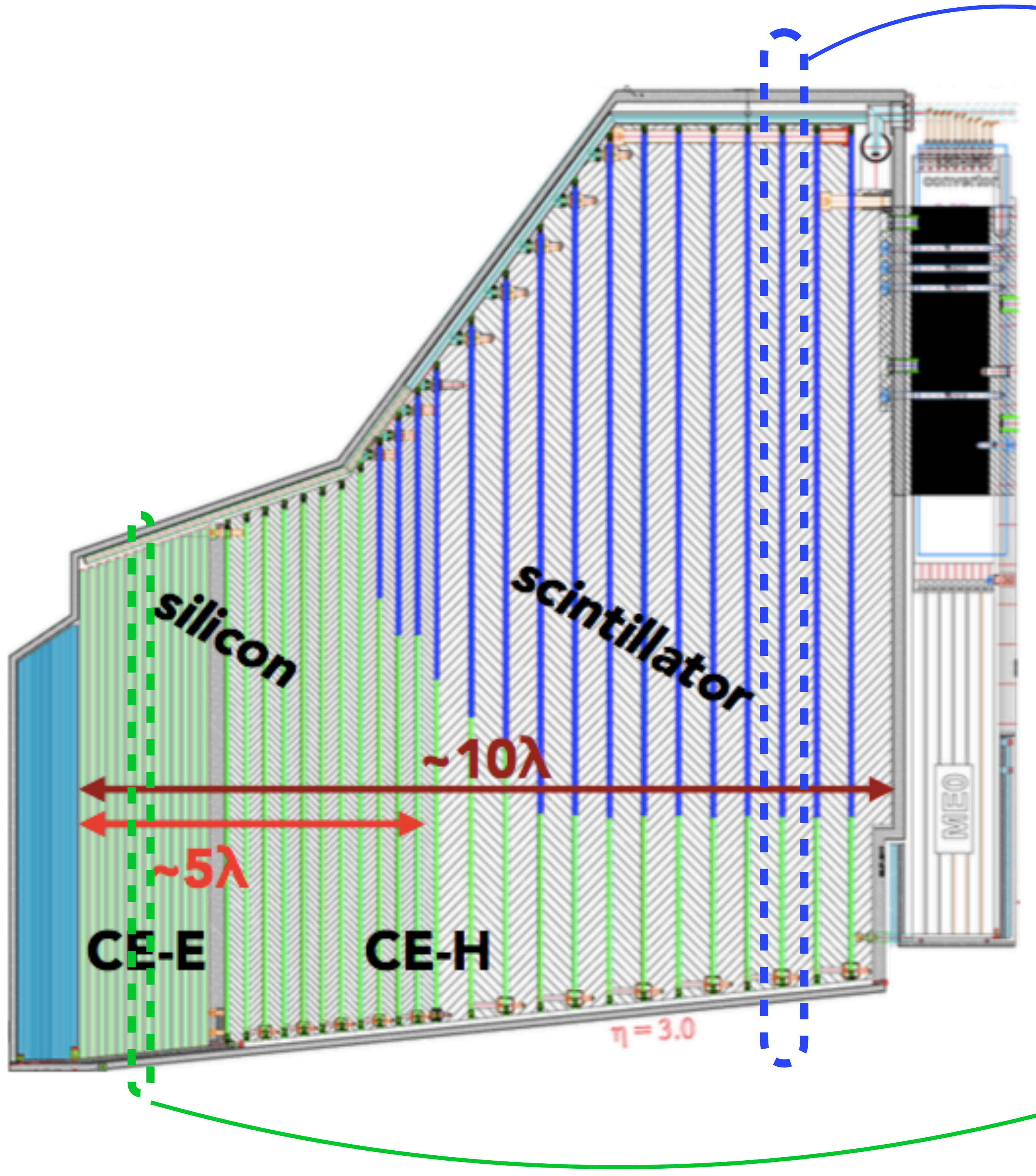
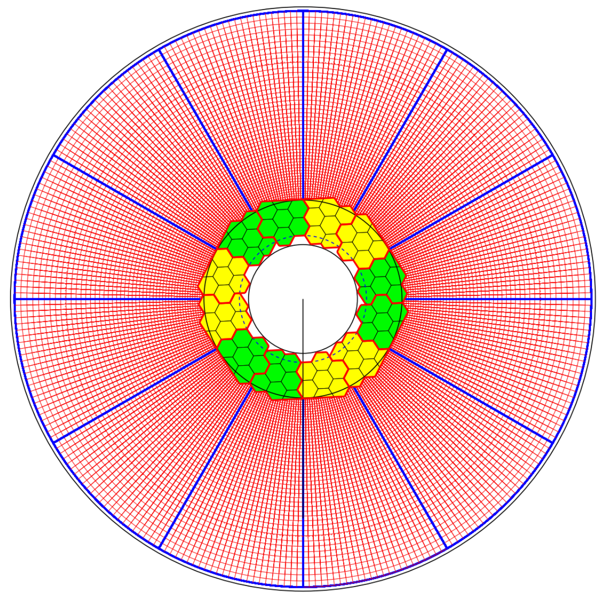
- Alves, B. Clustering in the Heterogeneous Reconstruction Chain of the CMS HGCAL Detector, *J. Phys : Conf. Ser. 2438 (2023) 012015*
- Portales, L. L1 Triggering on HGCAL information at the HL-LHC, *Instruments 6 (2022) 71*
- CMS Collaboration. The Phase-2 Upgrade of the CMS Endocarp Calorimeter, *Technical design report, 10.17181/CERN.IV8M.1JY2*

The HL-LHC and the HGCAL

The High Luminosity LHC (HL-LHC):

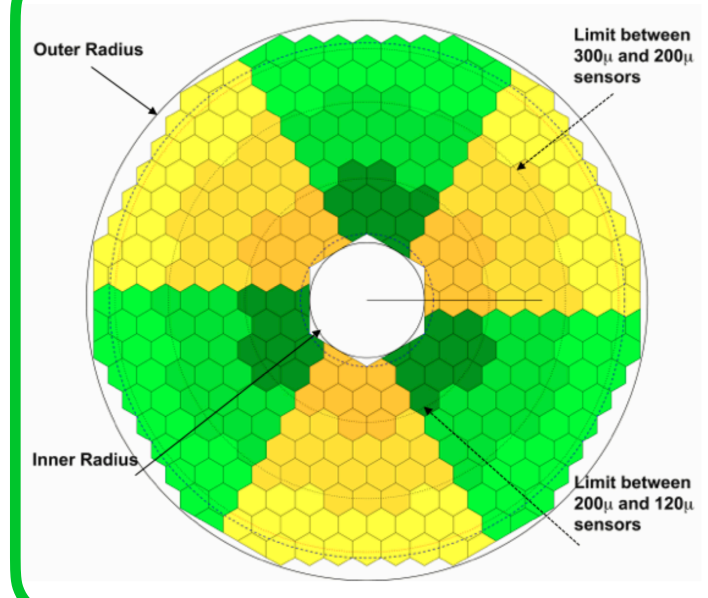
- Luminosity:
  $L = 10^{34}\ cm^{-2}s^{-1} \rightarrow 4 \times L_{LHC}$
- Integrated Luminosity:
  $L_{Int} \approx 3000\ fb^{-1}$ (nominal),
  $4000\ fb^{-1}$ (ultimate) $\rightarrow 10 \times L^{LHC}_{Int}$
- Pileup: ~ 140 (nominal) , ~ 200 (ultimate) $\rightarrow 3.5 \times PU_{LHC}$





Hadronic Section (CE-H):

Si + Scintillator tiles
21 layers, 8.5 λ
Absorber: Cu, steel

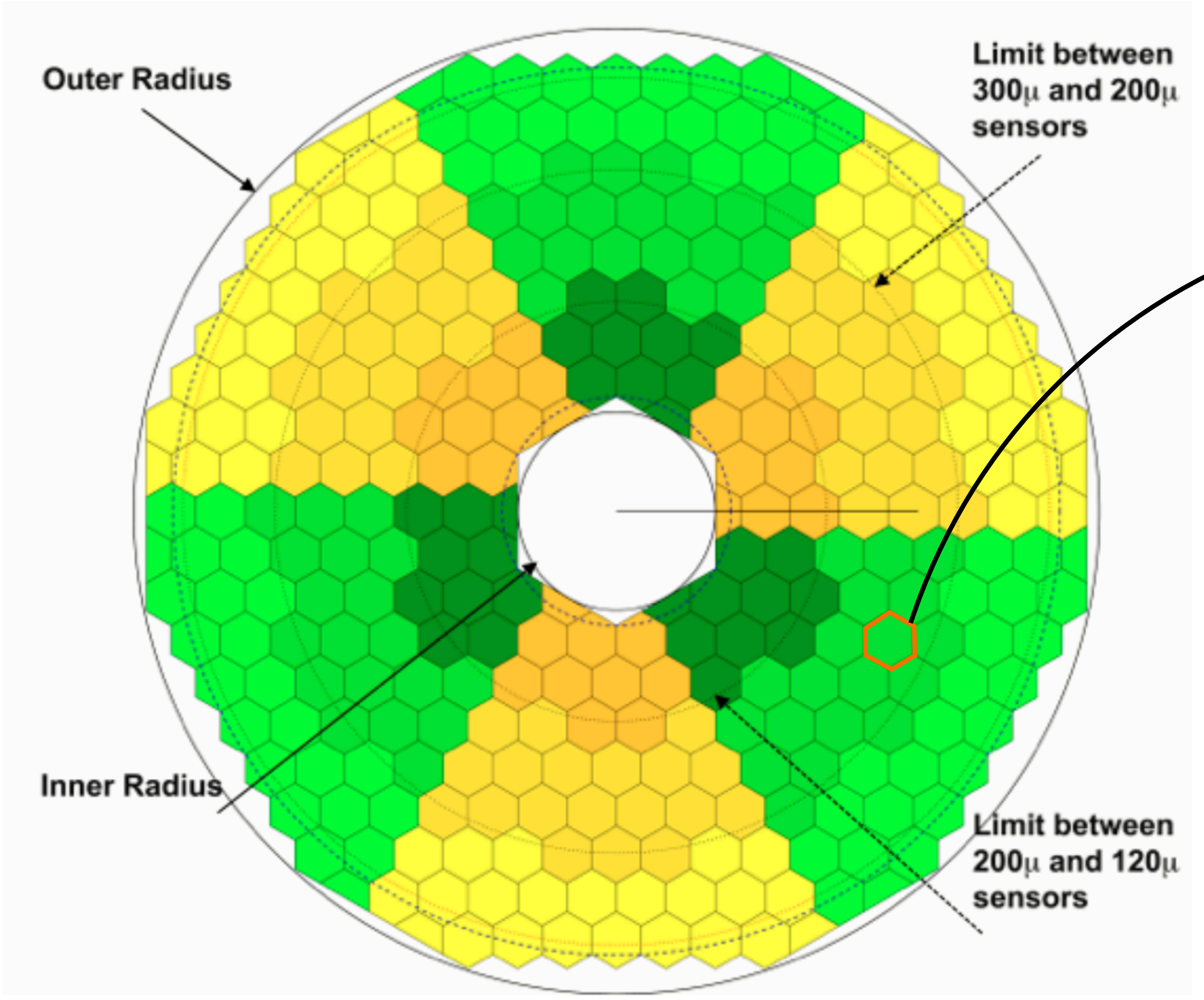


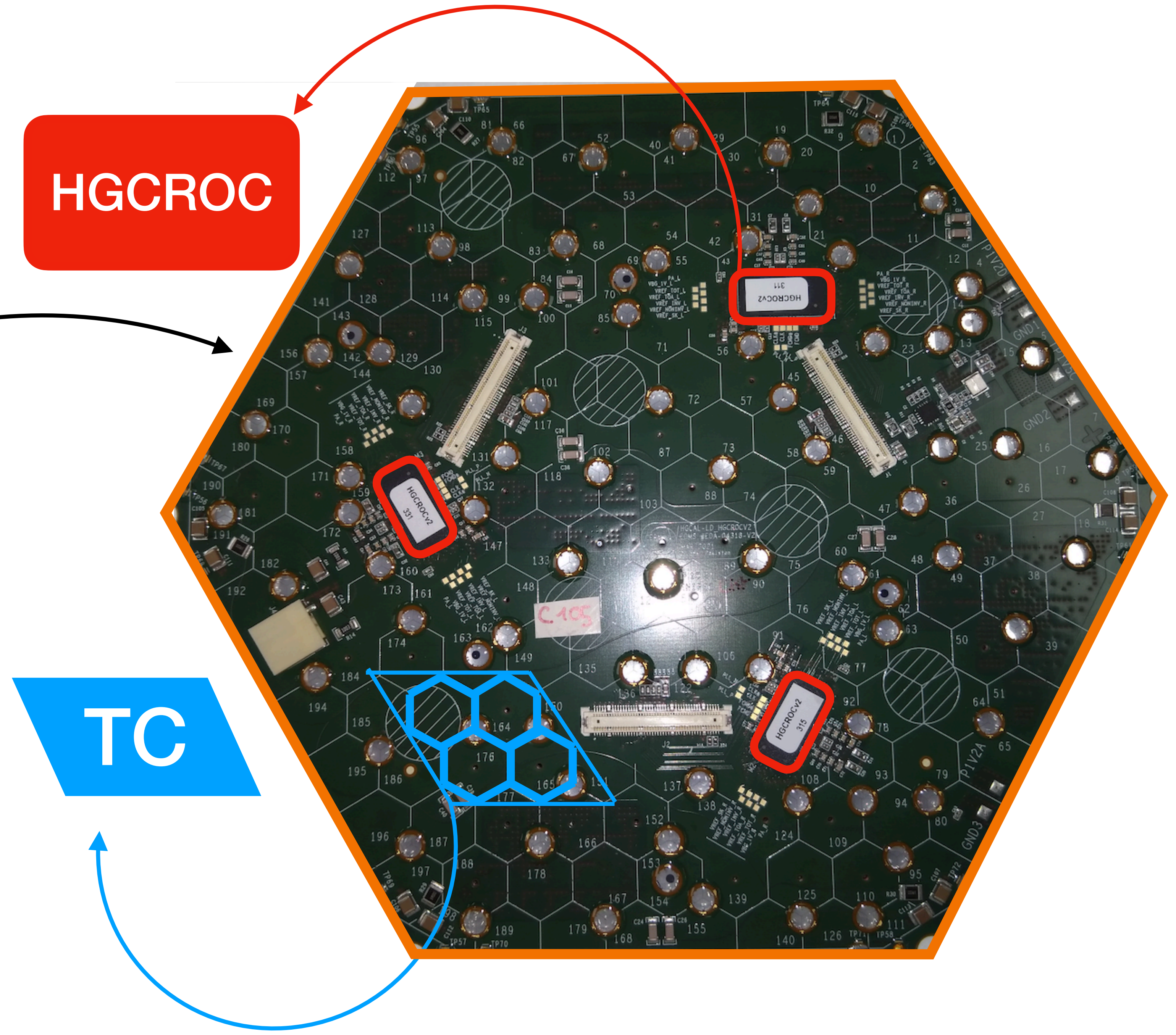
EM Section (CE-E):

Si sensors
26 layers, 28 X_0
Absorber: CuW, Pb

Front-end Electronics (FE): HGCROC

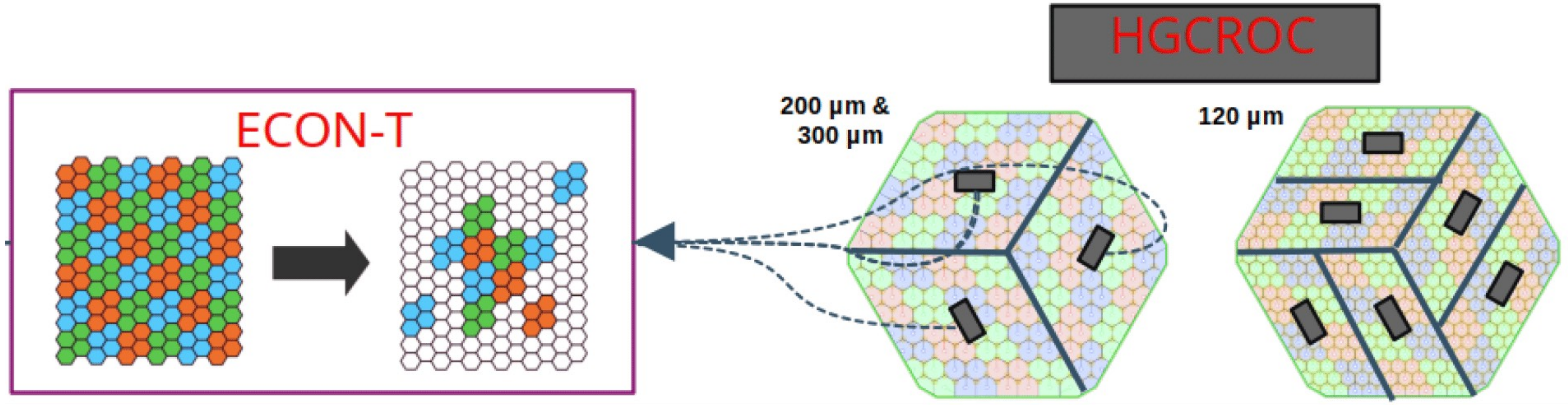
- **Measures individual cell charges at** $40\ MHz$
- **Groups individual sensors into Trigger Cells (TCs).**
  - **3x3 in high-density regions**
  - **2x2 in low-density regions**
- **Compresses resulting sums into 7-bit floating point**



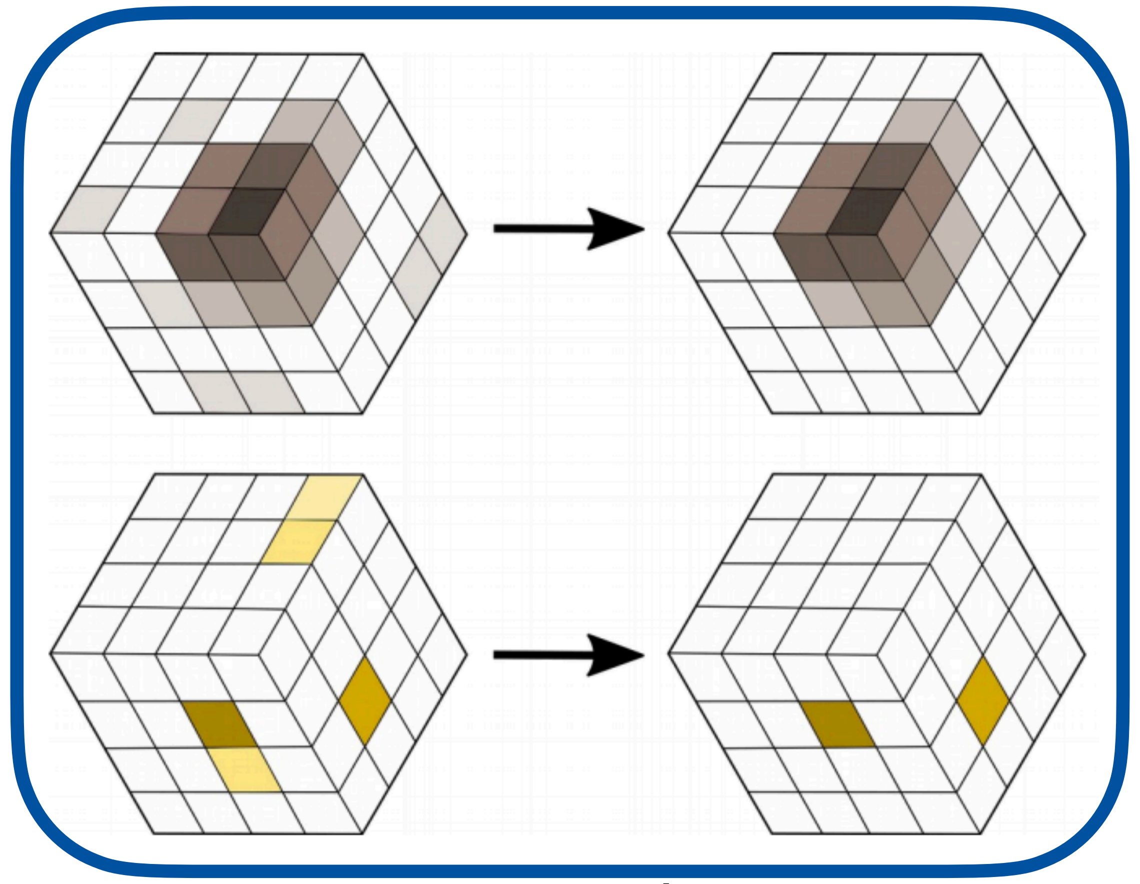


Front-end Electronics (FE): ECON-T

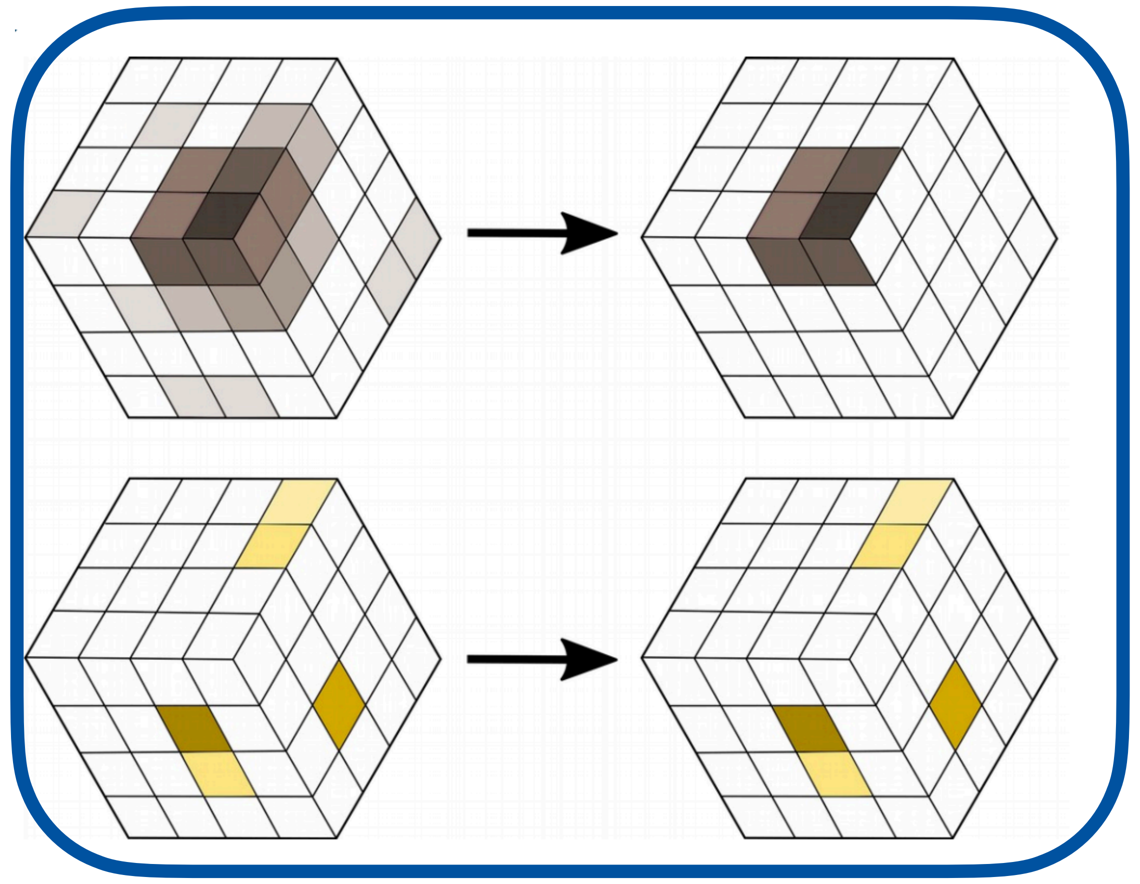
- Receives TC data from HGCROC and reduces the data stream via:
    - Energy thresholds or
    - N most energetic TCs (best choice) or
    - TC aggregation into super trigger cells (STCs)
- Performs energy sums of the whole module without applying any threshold



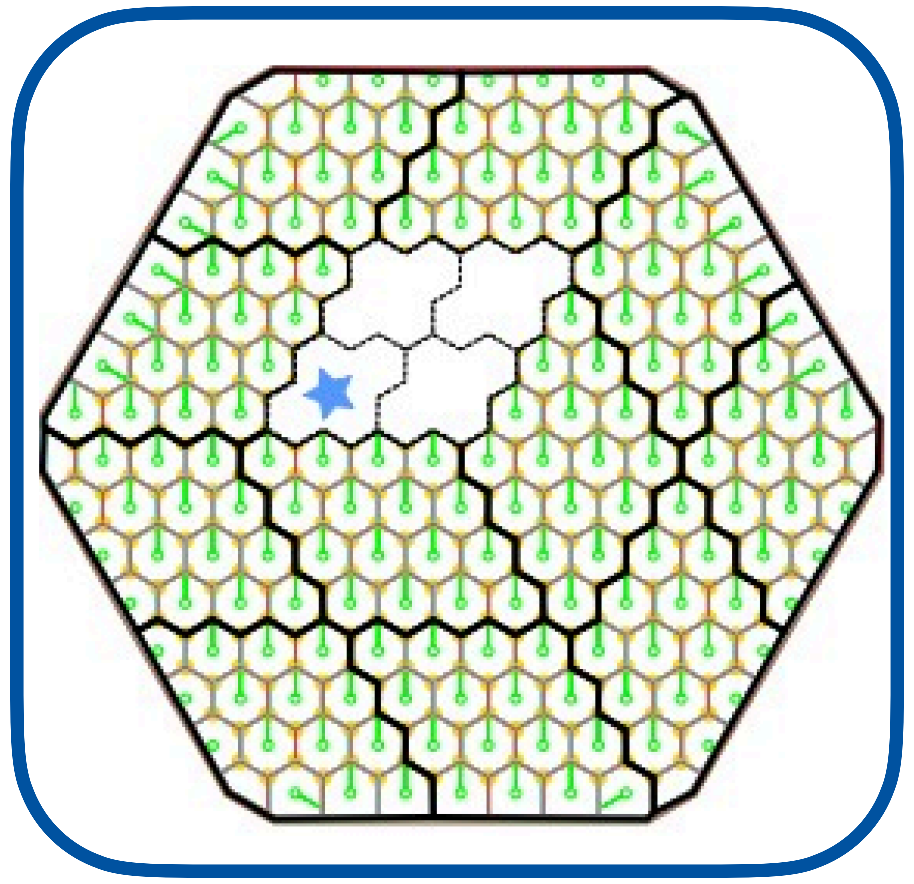
Threshold



Best Choice



STCs



Back-end Electronics (BE): Stage 1

Data Unpacker and Aligner:
Groups data sent from FE per bunch crossing

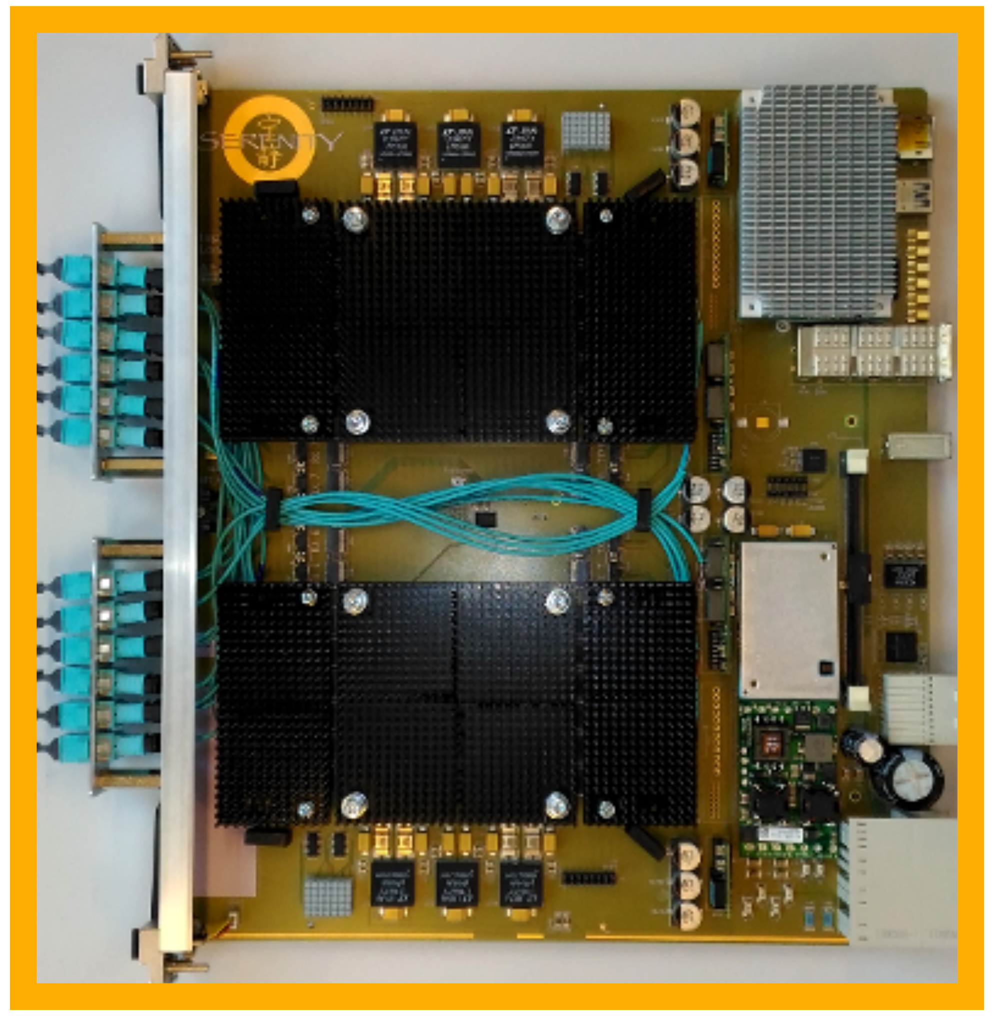
Group Module Sums into partial Trigger Towers (pTTs)

Relabel/recalibrate TCs

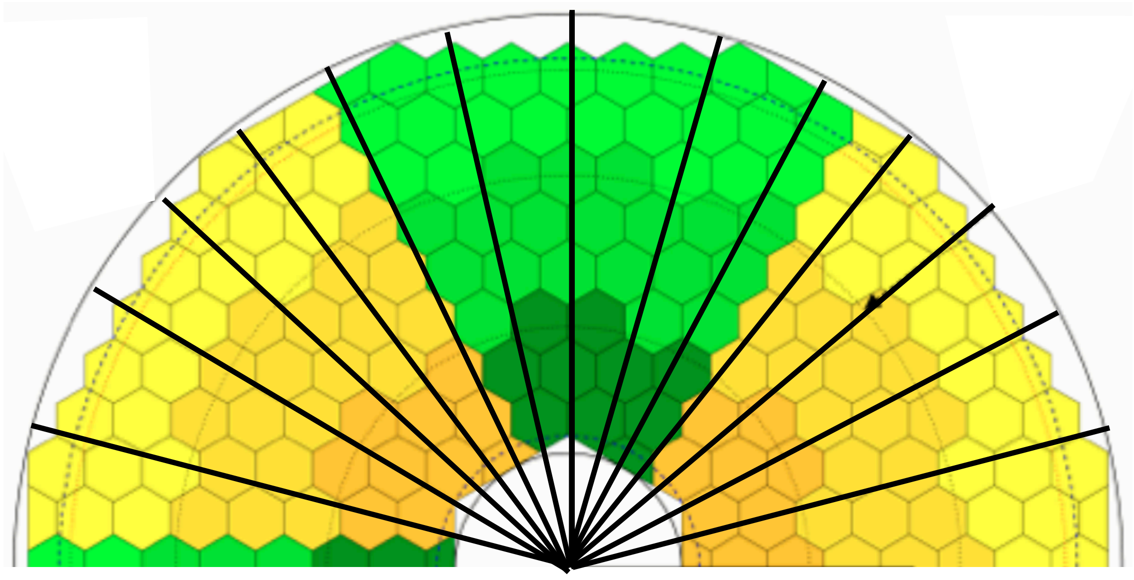
Sort TCs in 1D ϕ bins

Format Data:
Create data-stream and time-multiplex

Serenity Board equipped with Xilinx VU13P FPGAs



ϕ bins in 1 CE-E layer



Back-end Electronics (BE): Stage 2

Unpack Stage 1 Data

Group pTTs into (η, ϕ) Trigger Towers (TTs)

Histogram TCs in $(r/z, \phi)$ bins $\rightarrow$ smooth across $(r/z, \phi)$

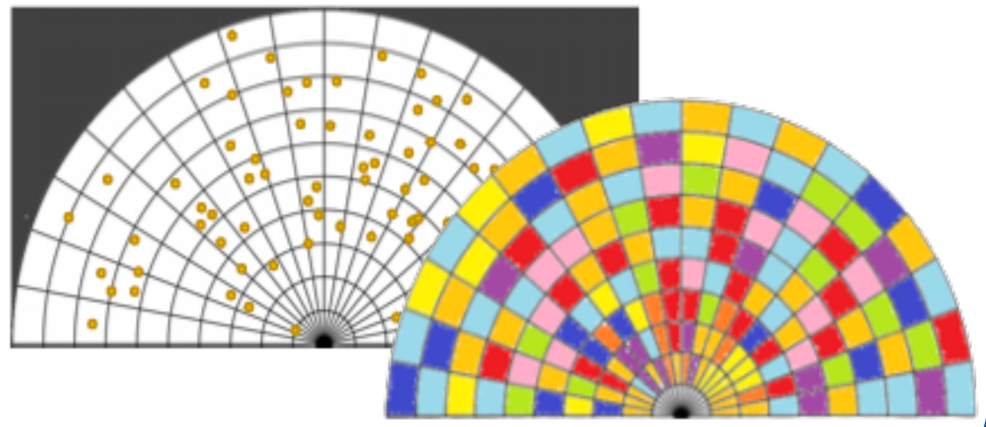
Cluster Seeds defined as local E_{max}

3D Clusters:

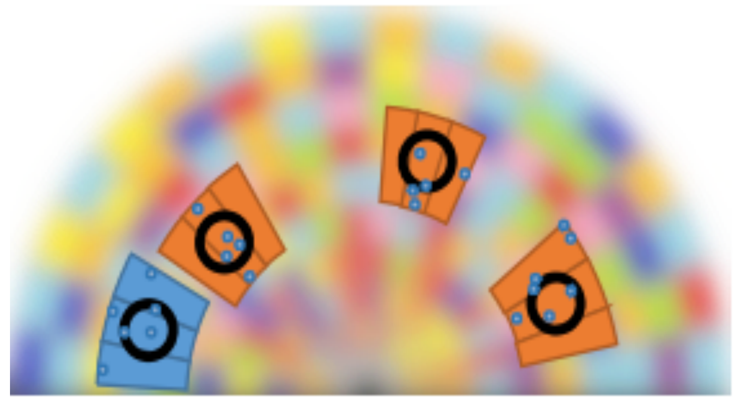
$$\Delta R(seed, TC) = \sqrt{\Delta(x/z)^2 + \Delta(y/z)^2} \leq r^{Cl}$$

Data Packer:
Trigger Towers and 3D Clusters (energy, position, shape)

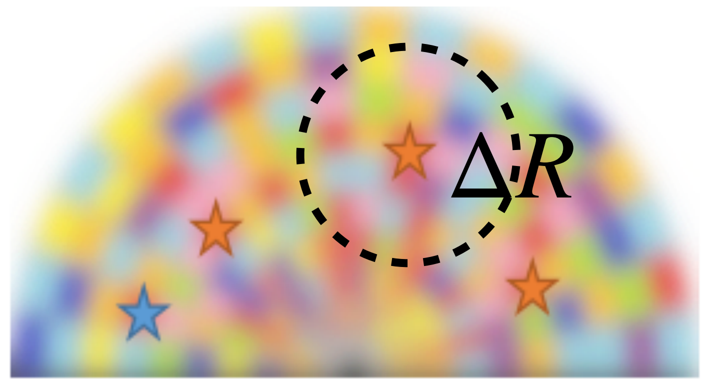
Histogramming



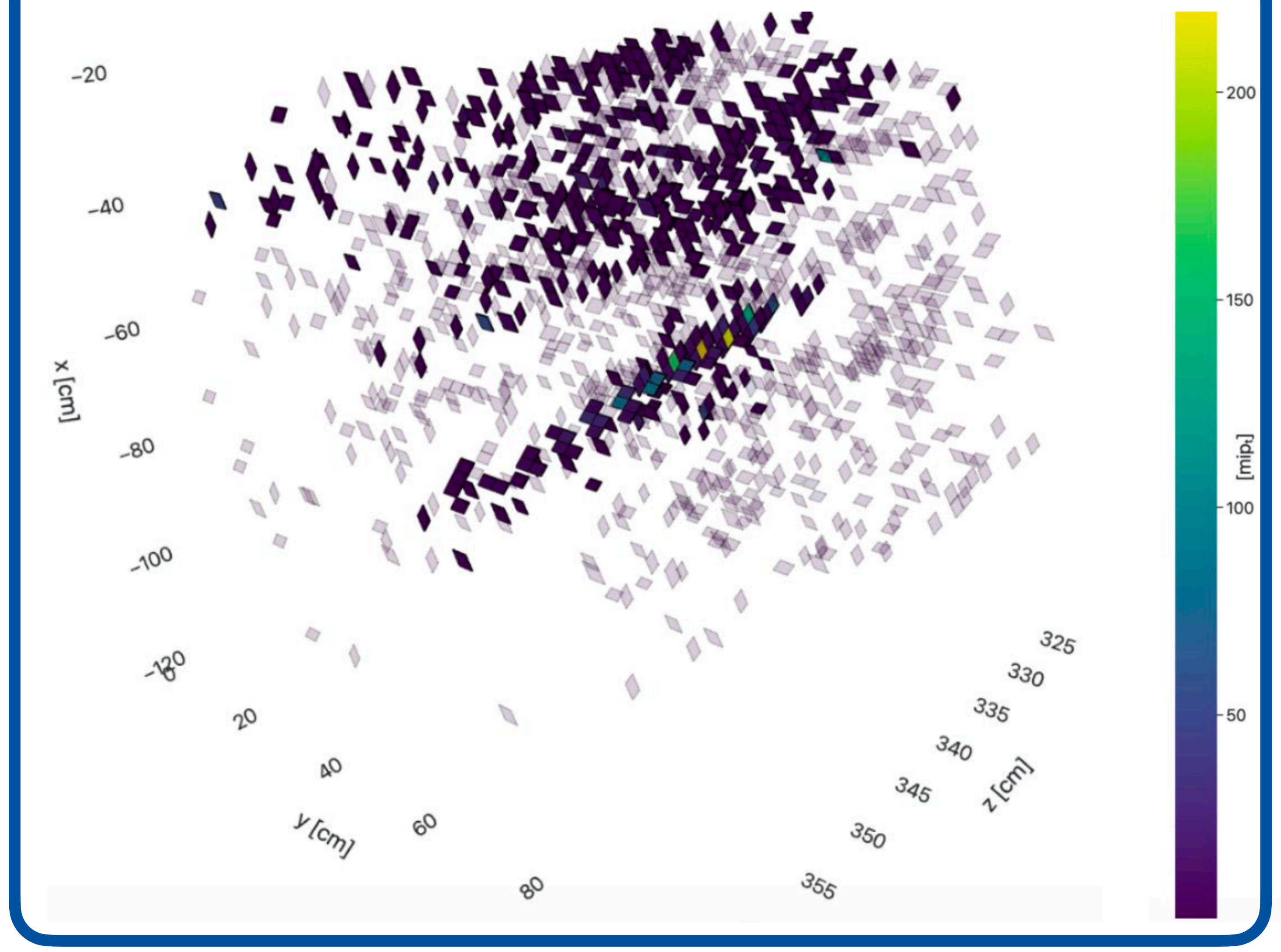
Seeding



Clustering



Event Display of γ-shower



Ongoing Developments

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1. Many optimization studies are in progress. One such study varies the maximum clustering radius, r^{Cl}, to achieve the best TPG response and resolution.

   - A constant r^{Cl} is well optimized for EM and charged hadron showers.
   - Performance can be improved by optimizing r^{Cl} independently in each HGCAL layer.

2. Implementation of the Stage 1 and Stage 2 firmware is happening in parallel with optimization studies.

TPG Resolution of $\gamma/e/\pi$ showers