Design of the CMS High Granularity Calorimeter trigger primitive generator system

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The High-Luminosity LHC Phase

In the High-Luminosity phase, the Large Hadron Collider (LHC) will undergo enhancements and upgrades to broaden the possibilities for **Beyond the Standard Model** (BSM) and **precision physics**:

- $L = 7.5 \cdot 10^{-34} cm^{-2} s^{-1}$, 4 times more than the LHC;
- $L_{integrated} = 3000 fb^{-1}$, 10 times more than the LHC;
- Up to 200 collisions per bunch crossing.

The High-Granularity Calorimeter (HGCAL)

The CMS detector must be upgraded:

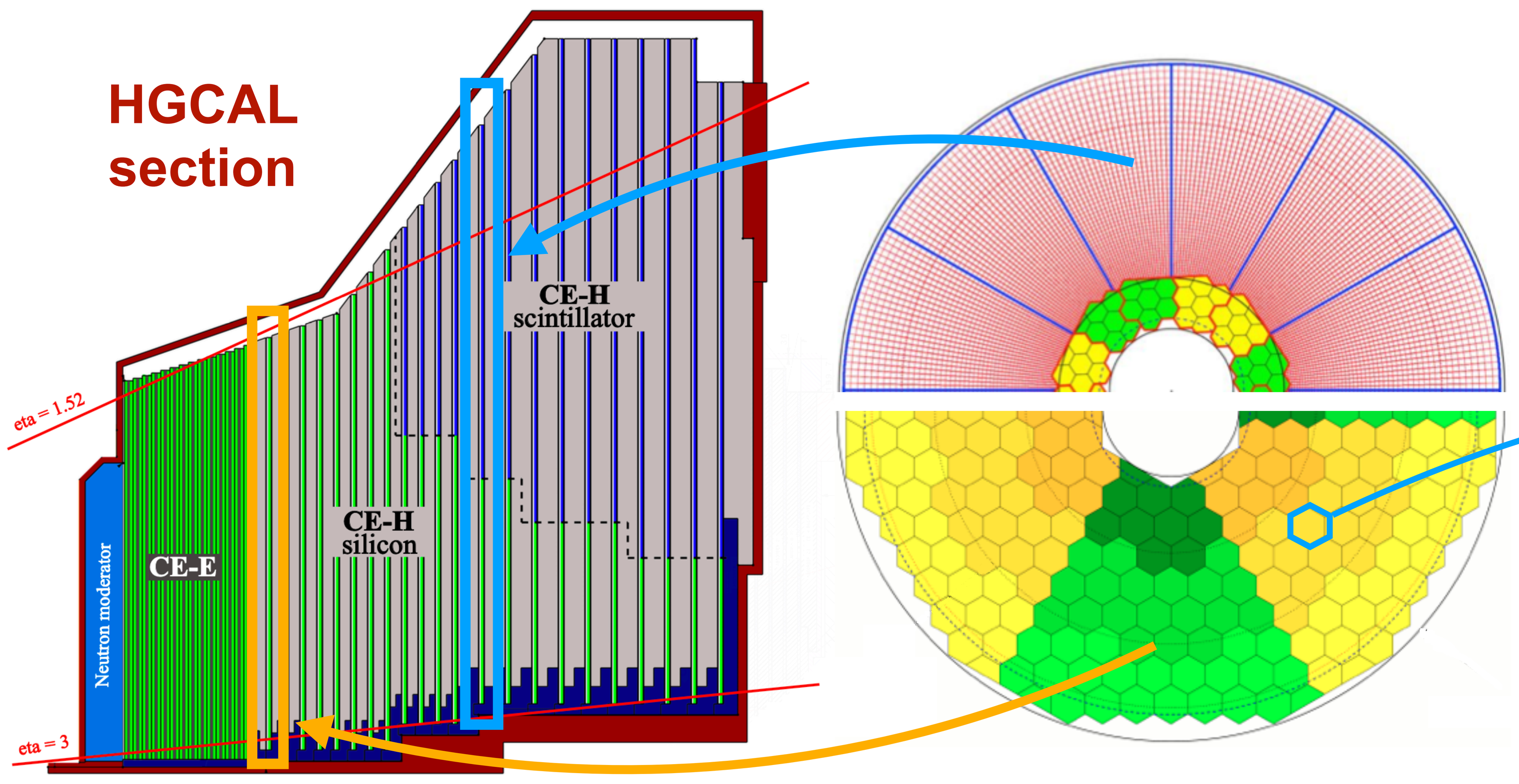
- **Increasing the granularity** for particle flow (PF) reconstruction;
- Mitigating the effects of pile-up (PU) events;
- Endcap calorimeters will be exposed to unprecedented levels of radiation.

The High Granularity Calorimeter (HGCAL) will meet these requirements:

- 5D measurements detector: **position**, **energy** and **timing**;
- Replacing the current ECAL endcap, HCAL endcap and ES.

The HGCAL trigger primitives generation (TPG)

Front-end electronics (FE)

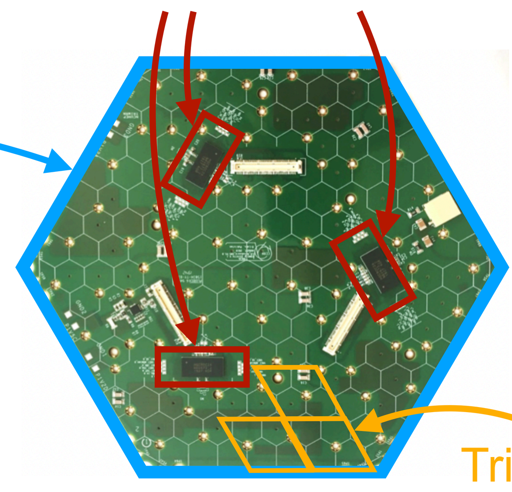


Hadronic section:
Si + Scintillator tiles
21 layers, 8.5 X_0
Absorber: Cu, steel

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

HGCROC

- Groups cells into TCs
- Compresses to 7-bit floating point



Module

Trigger cell (TC): 2x2 or 3x3 cells

ECON-T:

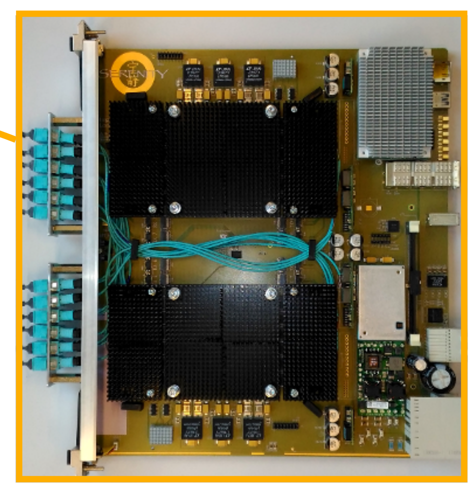
- Selects or compresses TCs:
  - TCs above a threshold
  - or N most energetic TCs
  - or TCs aggregation (STCs)
- Computes **module sums** w/o any threshold

Max 120 links @ 10Gbit/s per FPGA

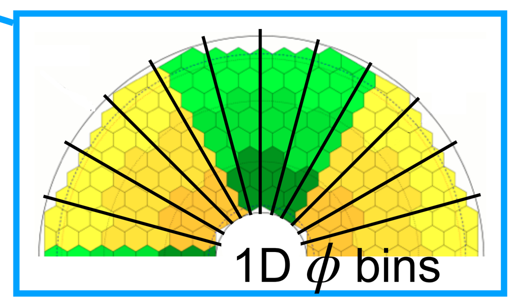
Back-end electronics (BE)

Stage 1 FPGAs

Serenity board equipped with VU13P FPGAs



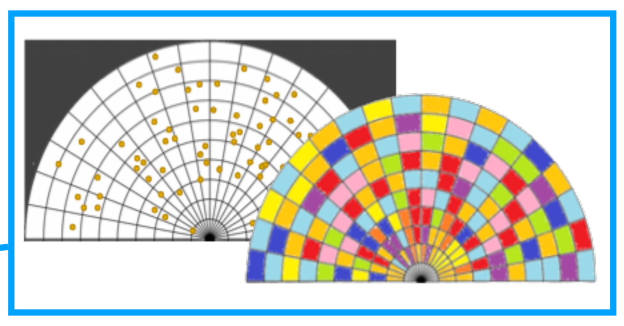
- Data aligner and **unpacker**
- TCs recalibration
- **Sort** TCs into ϕ bins
- Group **module sums** into partial towers (pTT)
- Data **formatter**: Data-stream creation, time-multiplex



6x18 links @ 16Gbit/s per FPGA

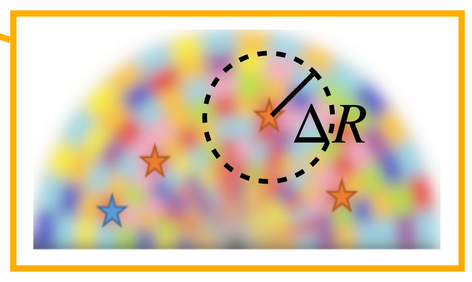
Stage 2 FPGAs

- Data unpacker
- $(r/z, \phi)$ energy **histograms**



- Identify local energy maxima, **seeding**

- Build **clusters**: $d(\text{seed}, TCs) < \Delta R$



- Group pTT into (η, ϕ) **trigger tower**
- Data packer: Clusters' position, energy, shapes

L1 Trigger

Trigger primitives (TPs)

Global Calorimeter Trigger

- TPs from calorimeters barrel and endcaps are grouped

Correlator Trigger

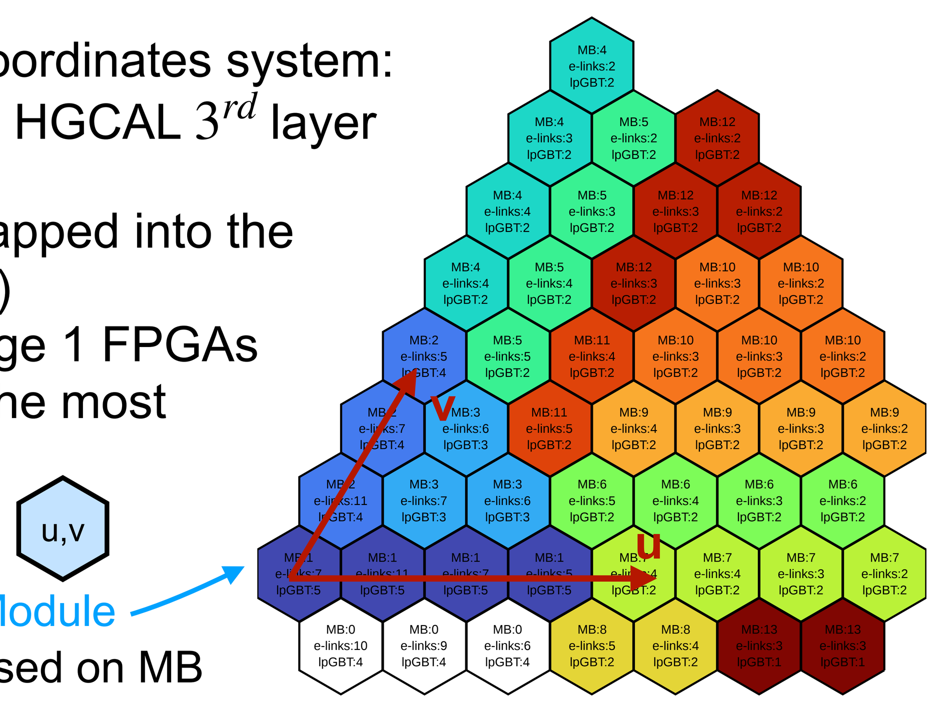
- The HGCAL, the muon and the tracker TPs are combined for the purpose of particle flow reconstruction.

Module and motherboard geometry

- FE data follows **module** and motherboard (MB) **geometry**:
  - Each MB collects e-links from several modules and forwards the collected data to the BE electronics;
- BE produces TPs using **projective coordinates** $(r/z, \phi)$ to create 2D energy histograms;
- **Non-trivial dataflow** in the BE and FE interface:
  - Event-by-event dataflow is variable within the same $(r/z, \phi)$ bin and requires special techniques to handle it.
  - FE and BE constraints must be taken into account;

Detector non-orthogonal coordinates system: the internal structure of the HGCAL 3^{rd} layer

- Several modules are mapped into the same motherboard (MB)
- MBs are mapped in Stage 1 FPGAs
- Currently investigating the most suitable configuration



Colour-coded modules based on MB

Investigating clustering improvements

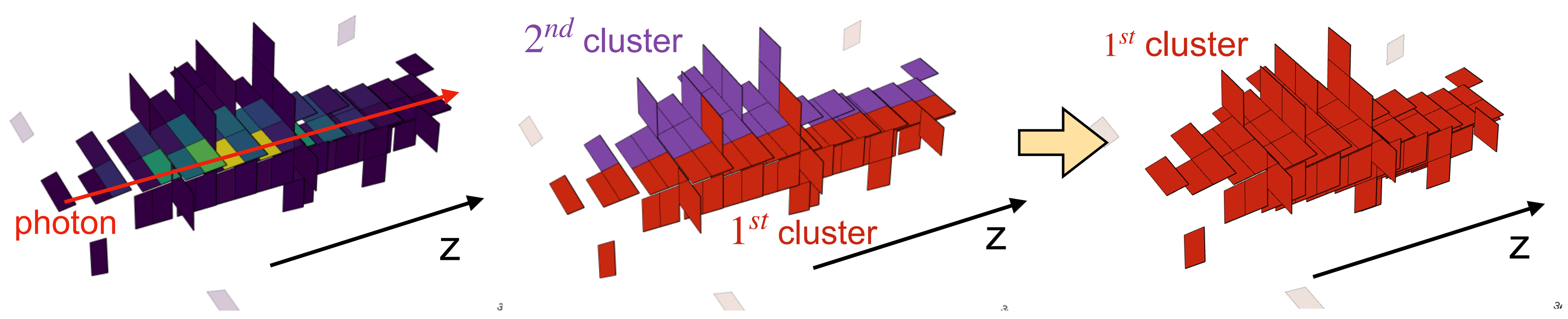
In $(r/z, \phi)$ histograms the distribution of TCs into bins is non-homogeneous:

- Bins size smaller than TCs at high η: nonphysical **cluster splitting** observed;
- Large bin at low η: difficult to separate nearby showers.

Various methods are being explored to mitigate cluster splitting:

- **Reducing the variance** of the number of TCs/bin along ϕ:
  - Artificial TC shifts are applied within bin triplets;
- Extending along ϕ the detector region where to find local maxima, i.e. seeds;
- Modifying the smoothing kernel along ϕ before seeding;
- Using **detector coordinates** (u, v) instead of r/z and ϕ in the BE FPGAs.

Example of a cluster splitting removal process for simulated 0PU photon in the HGCAL:



Colour-coded TCs based on deposited energy

Colour-coded TCs based on seed index.

- B. Alves, Cluster reconstruction in the HGCAL @ Level 1 Trigger, CHEP 2023
- L. Portales, L1 triggering on High-Granularity information at the HL-LHC, CALOR 2022
- N.Strobbe, Readout electronics for the CMS Phase II Encap Calorimeter, TWEPP 2021