Concepts and Design of the CMS High Granularity Calorimeter Level 1 Trigger

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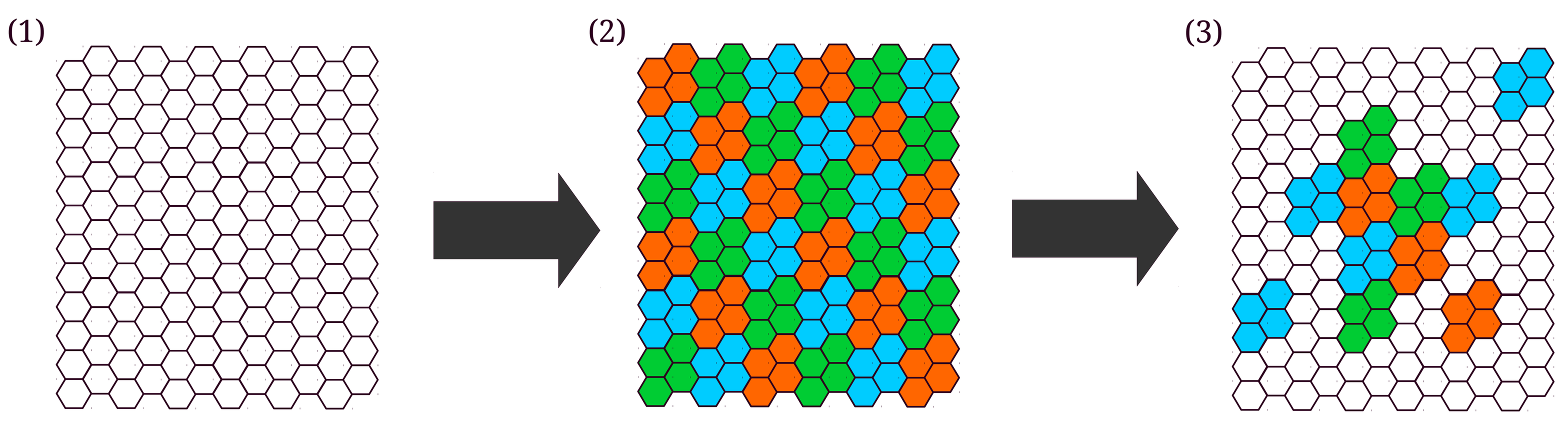
The Challenge of the High Luminosity-LHC

Triggering on physics objects in the High-Luminosity LHC (HL-LHC), where the average number of events per crossing (pile-up) will be 140-200, will be a major engineering and computational challenge for the upgraded CMS detector, and in particular the planned High Granularity Calorimeter (HGCal). The HL-LHC will begin running in the mid 2020s with an expected instantaneous luminosity of $1 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, five to ten times the present LHC. The HGCal is a silicon and scintillator fine-grained sampling calorimeter with 52 layers and 6 million cells. The cells in the silicon layers are 0.5–1cm^2, smaller than the typical width of an EM shower. Compounding the fine granularity of the device, the increased instantaneous luminosity during the HL-LHC poses an enormous data processing challenge for the HGCal in the context of offline/online reconstruction, and hardware-based triggering. Attaining the physics goals of the CMS upgrade while addressing these challenges requires enormous data throughput and careful evaluation of the trigger architecture to maintain and improve the performance of triggering on leptons, photons, and vector-boson fusion (VBF) jets. We discuss a hardware-based first level (L1) trigger system for the CMS HGCal, and demonstrate the algorithms being implemented towards these goals.

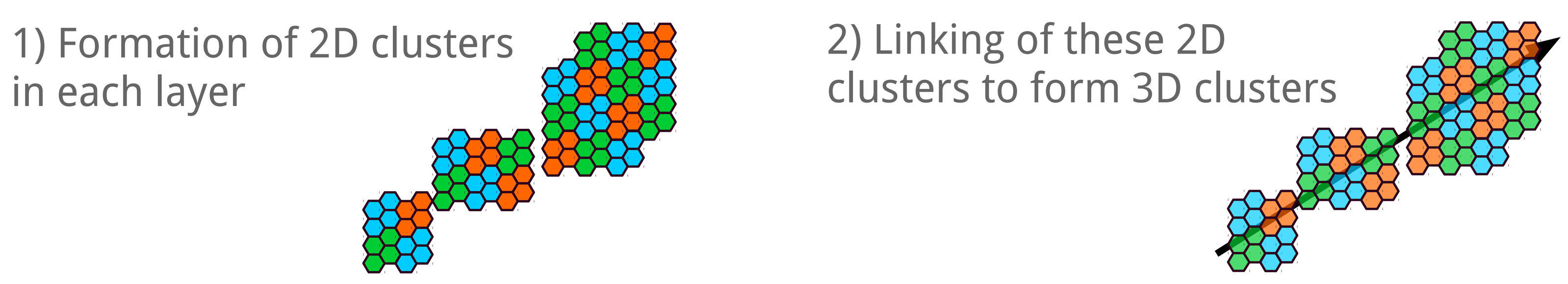
Front-end Data Reduction

The first level data reduction in the trigger stream is performed in a front-end ASIC. The uniform distribution of HGCal hexagonal cells (1) give digitised values which are calibrated and summed 4-to-1 to give an array of "trigger cells" (2). The most energetic of these are selected (3) and transmitted off-detector for back-end processing.

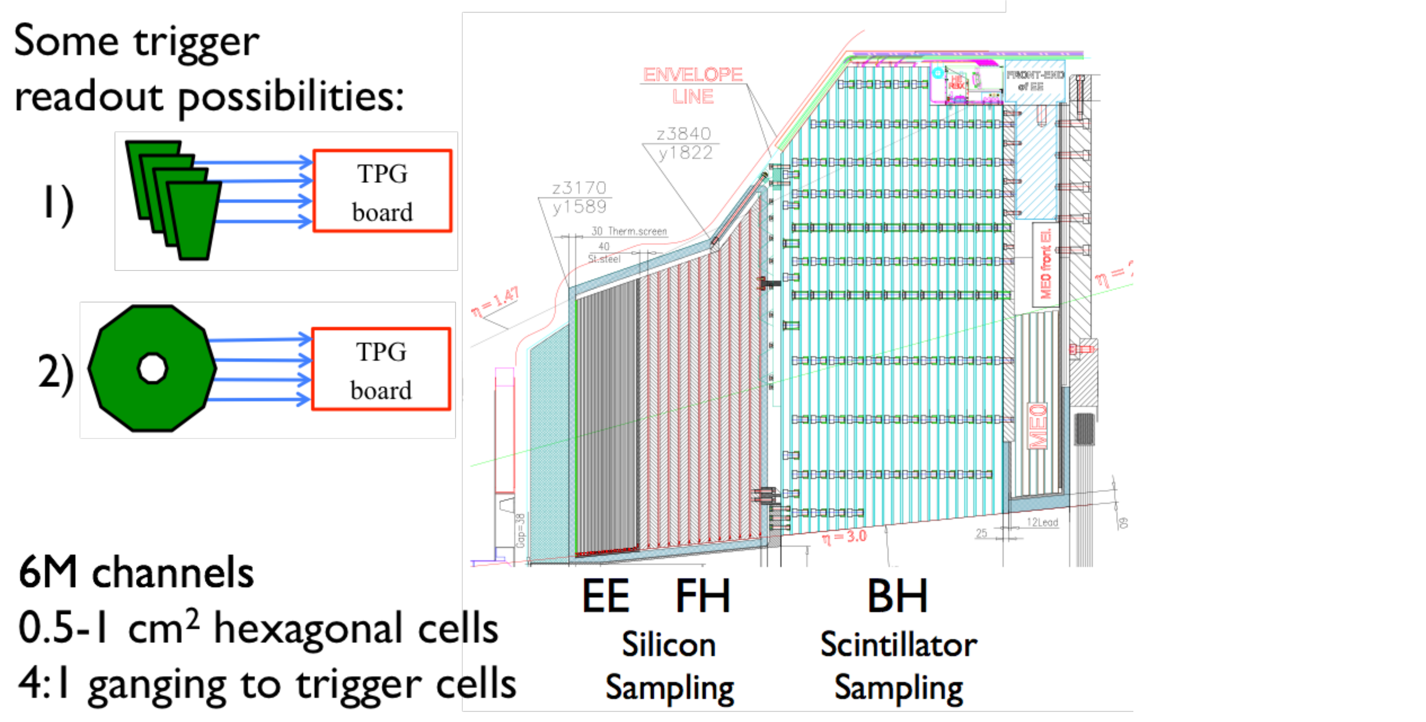


Back-end Processing

Following step (3) above, the selected trigger cells are clustered together within each layer. These 2D clusters are used to calculate centroid position and energy information per layer. Using the derived centroid information, clusters are associated in 3D across layers resulting in development of a shower axis and full "imaging" of the shower. With full 3D shower information in hand, the 3D clusters can be classified as EM or hadronic and clustered as isolated electromagnetic candidates or jet constituents.



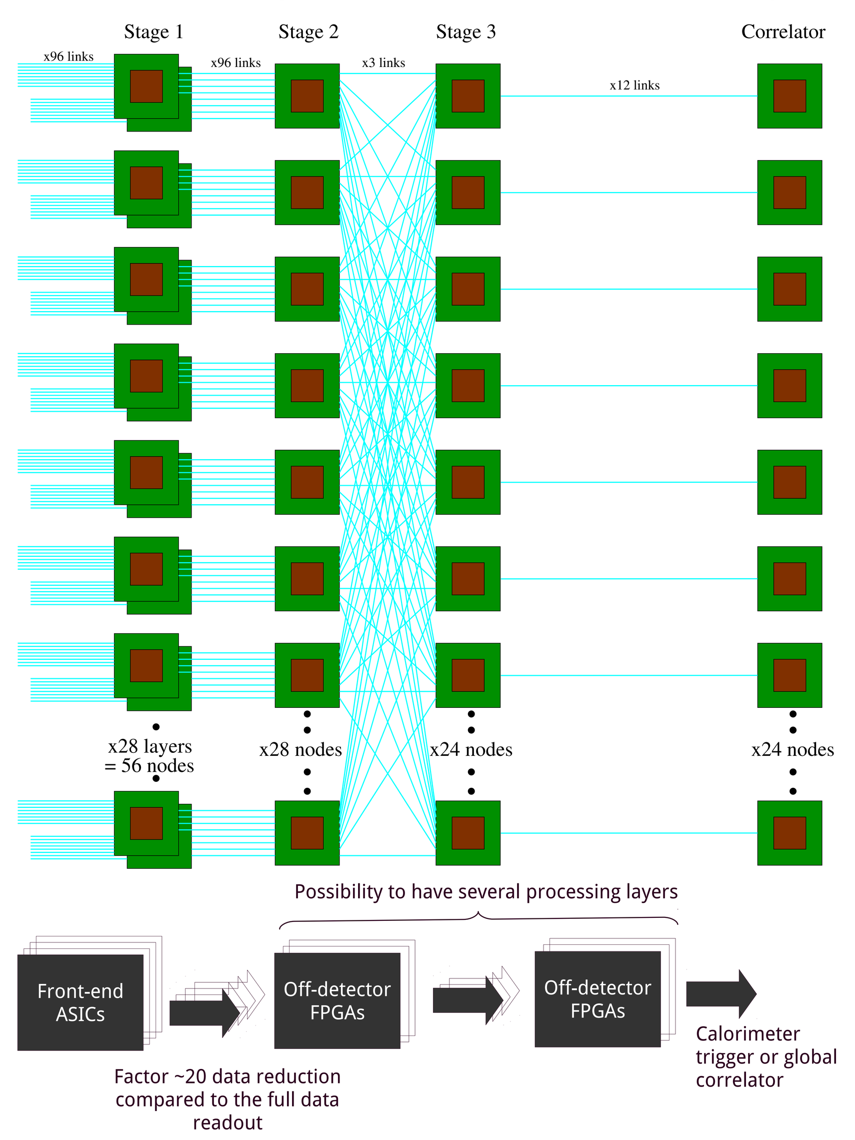
The CMS HGCal



- Electromagnetic section (EE): W/Cu absorber 28 Si layers, 26χ_0, 1λ_0.
- Front Hadronic section (FH): Stainless Steel (SS) 12 Si layers, 3.5λ_0.
- Back Hadronic section (BH): SS, 11 scintillator layers, total of 10.5 λ_0
- Can read out to trigger primitive generators (TPG) in ϕ sectors or whole layers.

The HGCal Level-One Trigger

A possible architecture assuming 24x time multiplexing, 40 Tbps per endcap.

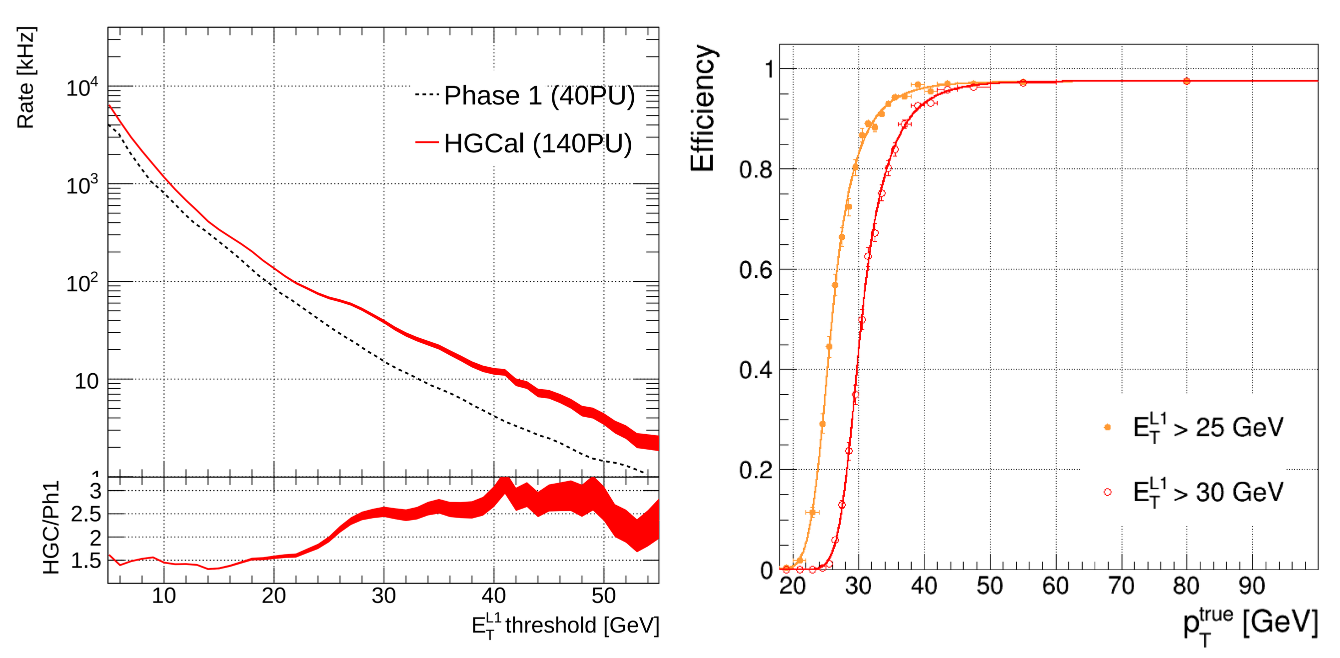


The trigger architecture is composed of three stages:

- Stage 1 performs 2D clustering on half of each layer.
- Stage 2 merges layers and multiplexes the 2D cluster output.
- Stage 3 forms 3D clusters and transmits to rest of the CMS L1 Trigger.

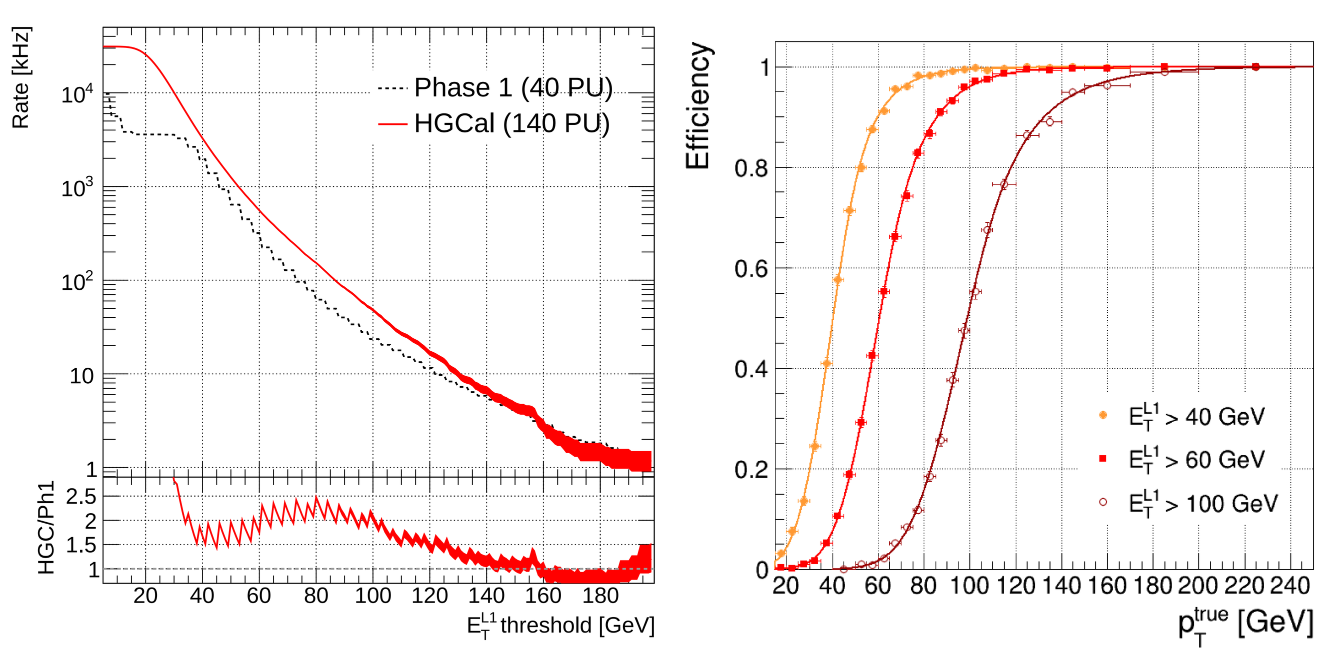
The underlying hardware of the HGCal trigger is based upon generic hardware employing high-bandwidth links and large FPGAs. Using this processing fabric facilitates testing of many algorithms and readout schemes while leaving open alternative architectures as the system is fully engineered.

Electron Performance



Single electron and photon L1 trigger rates (left) and efficiencies (right) in the HGCal, as a function of the true electron p_T, for L1 thresholds of 25 and 30 GeV using Z→ee events in 140PU CMS simulation. The L1 trigger rates are compared to the present (Phase 1) CMS detector, demonstrating slower scaling of trigger rate than the luminosity. A flat efficiency working point is used here, but relaxed working points at larger transverse energies can also be used in order to recover 100% efficiency at high p_T, while limiting the impact on the fake rate.

Forward Jet Performance



Single jet L1 trigger rates and efficiencies in the HGCal as a function of the p_T of the true jet, reconstructed with the anti-kt algorithm with a cone of 0.4, with efficiencies given for L1 thresholds of 40, 60 and 100 GeV. As with electrons, the rate scaling is considerably better than the luminosity from jet $p_T > 40$ GeV and typically within 50% of the rate in the endcaps for the current CMS trigger. The quark jets used here are from VBF H→ $\tau\tau$ events generated with 140 pile-up, and passed through the full CMS simulation.