Concepts and design of the CMS High Granularity Calorimeter Level-1 Trigger

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CALOR 2016 – Daegu – 18/05/2016

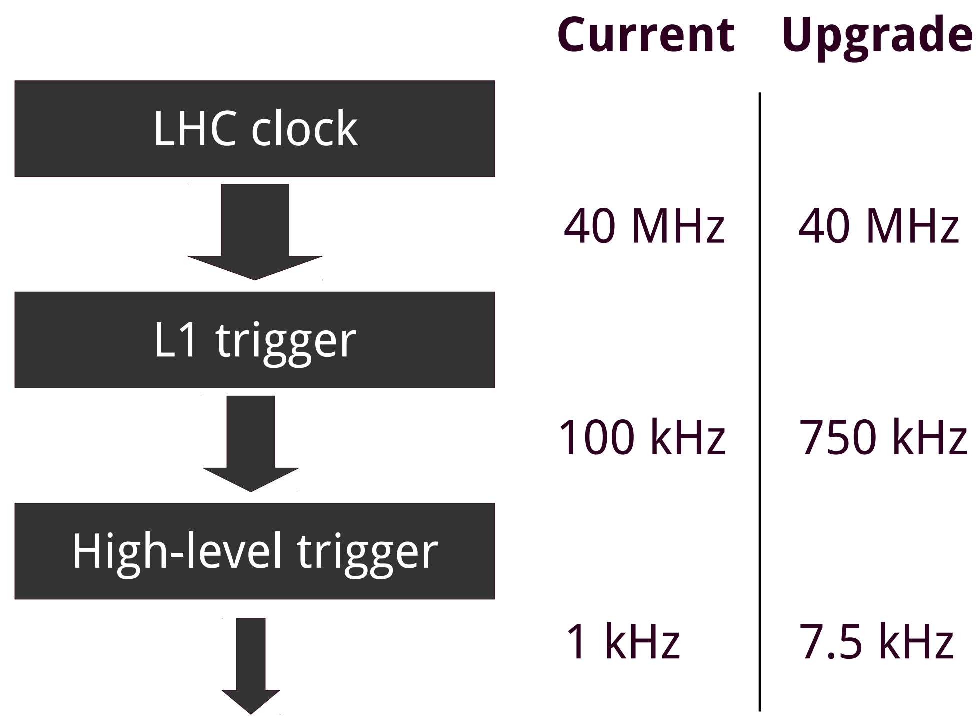
See C. Ochando's talk for an overview of the HGCAL

HL-LHC: challenges for the L1 trigger

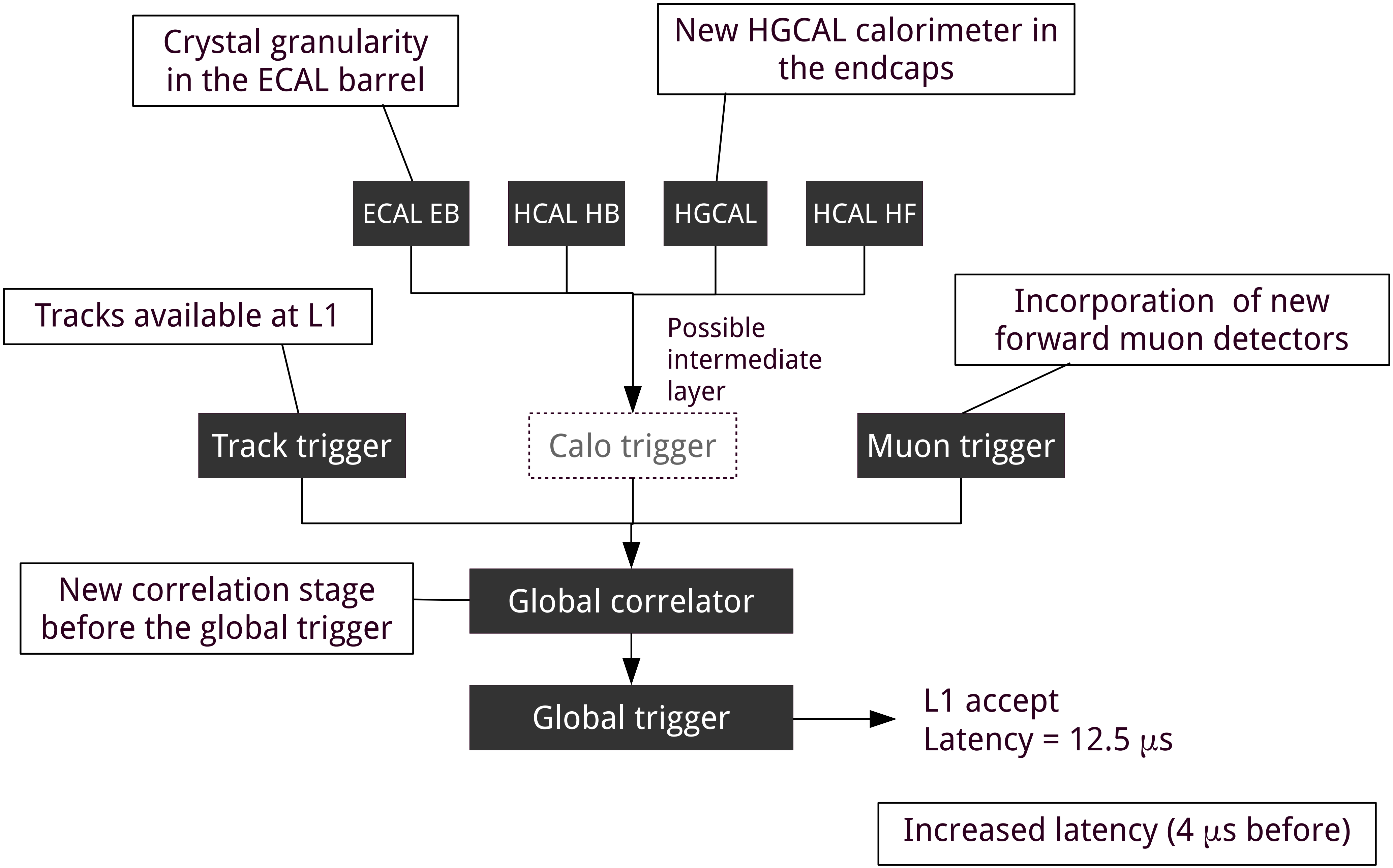
- We will want to continue exploring the electroweak scale at the HL-LHC
- Trigger thresholds should remain comparable to what they are now
  - With an instantaneous luminosity 3-4 times larger than Phase-1
  - With many more interactions (“pile-up”) per bunch crossing (up to 200)
- This is a challenge for the L1 trigger
  - Higher rates in general
  - In particular, hadronic trigger rates blow up with the increasing pile-up
- For the desired thresholds, the current trigger system would give a L1 rate much higher than the available bandwidth
  - At least 1500 kHz, with 100 kHz available

Overview of the CMS trigger system

- CMS trigger organized in two stages
  - Level 1 trigger
    - Coarse data from sub-detectors
    - Custom made hardware
  - High-level trigger
    - Partial reconstruction of the event with full readout
    - Farm of computers
- The Phase-2 upgrade will increase the data rate of the system
  - By a factor 5-10 at each of the two trigger levels

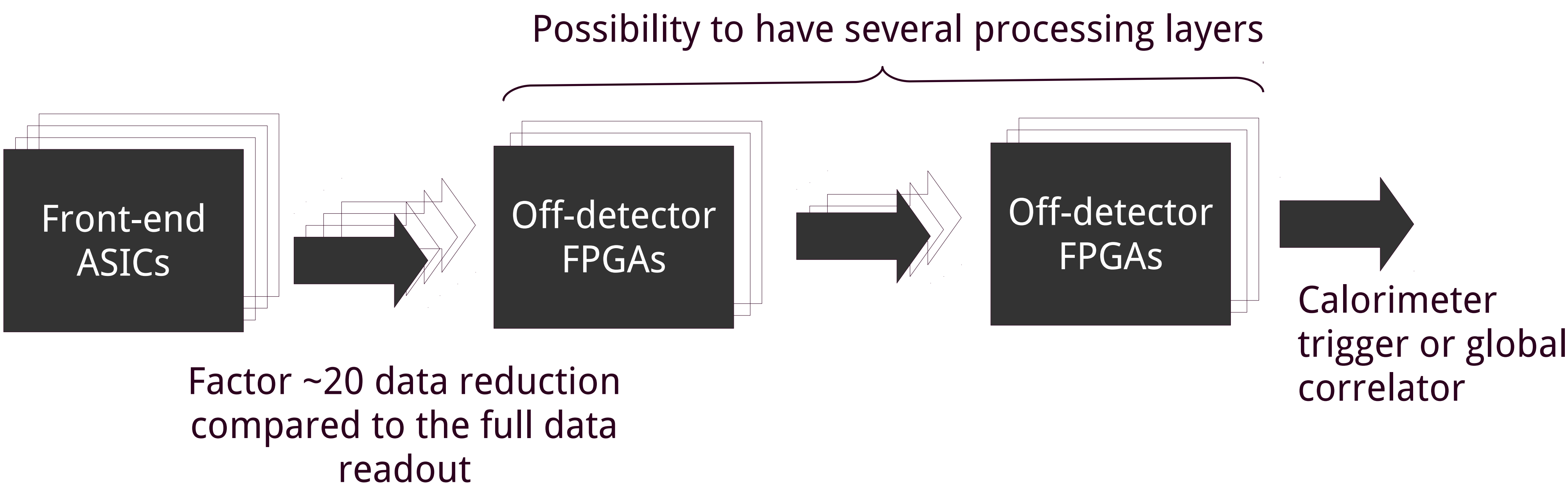


L1 trigger upgrade



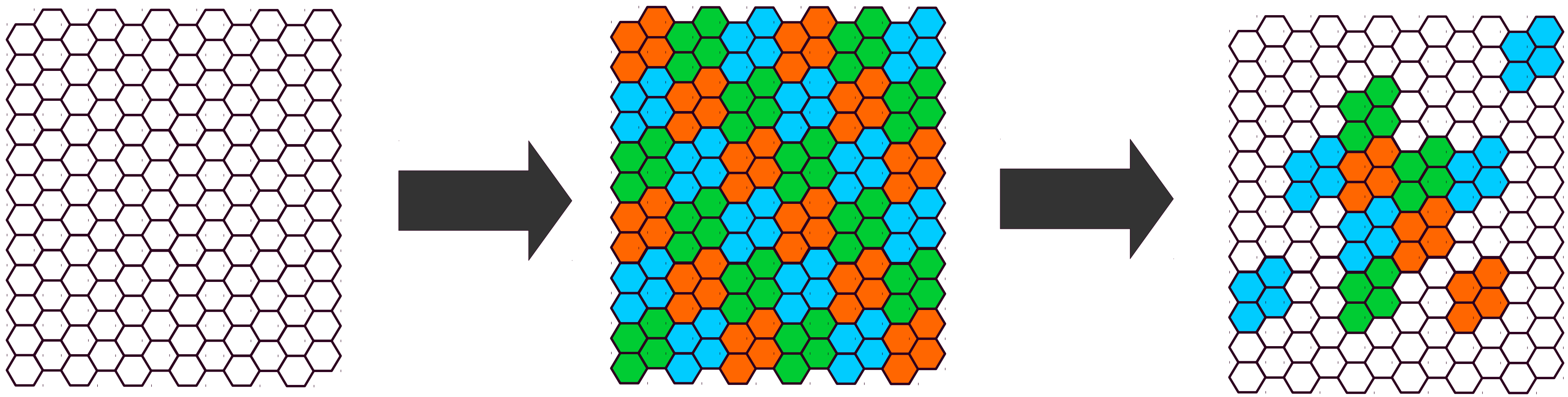
The HGCAL trigger

- The HGCAL trigger processing will be done both on-detector and off-detector
- The HGCAL data need to be reduced in order to be sent off-detector at 40 MHz
  - First step of processing inside the ASICs of the front-end
  - Need to be as simple as possible to minimize power consumption
- The remaining processing will be done off-detector in FPGAs
  - Clustering, pile-up estimation, etc.
  - Possibility to have one or several processing stages there



Data reduction in the front-end

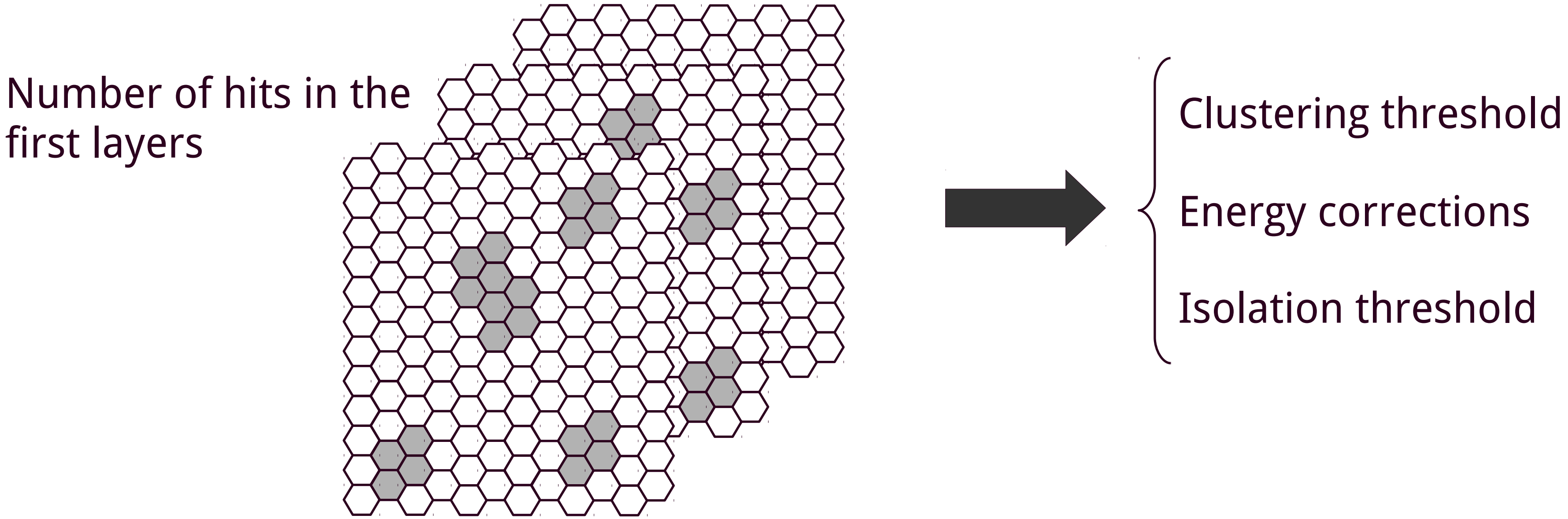
- The data reduction in the front-end can be done in several ways
  - The dynamic range and resolution of the measured energy are reduced
  - Timing information is discarded
  - Cells are grouped into (larger) trigger cells
  - Only the most energetic trigger cells are selected and sent off-detector



- This reduced information is sent via a mixture of optical and electrical links
  - Optical links @10Gbps in the low pseudo-rapidity region
  - Electrical links @5Gbps in the high pseudo-rapidity region, with electrical to optical conversion possibly behind the calorimeter

Back-end processing: Pile-up mitigation

- The most important challenge is to reduce the sensitivity of the trigger to pile-up
- We need an estimate of the level of pile-up, event-by-event
  - The simplest way is to count the number of cells above a given threshold
  - This can be done regionally (to reduce FPGA resources and latency)
  - The longitudinal segmentation allows for an efficient estimate using only the first layers, dominated by pile-up energy

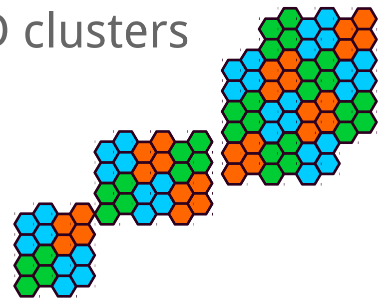


- Timing information, if propagated, could eventually provide an additional handle to mitigate pile-up

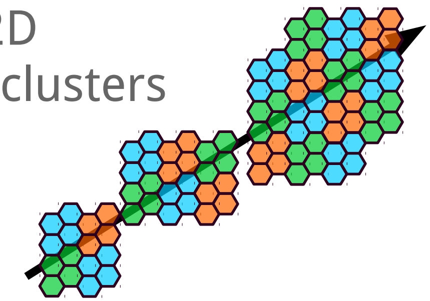
Back-end processing: Clustering

- The energy clustering can first be done in 2D

1) Formation of 2D clusters in each layer

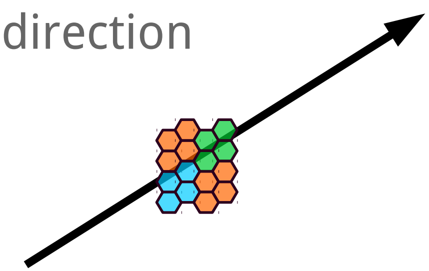


2) Linking of these 2D clusters to form 3D clusters

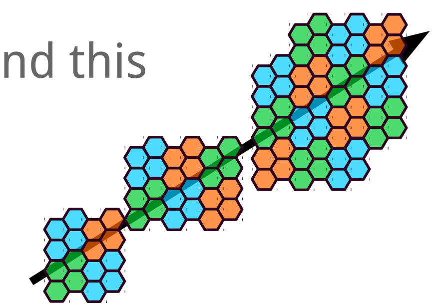


- It can also be done directly in 3D

1) Seeding and direction finding



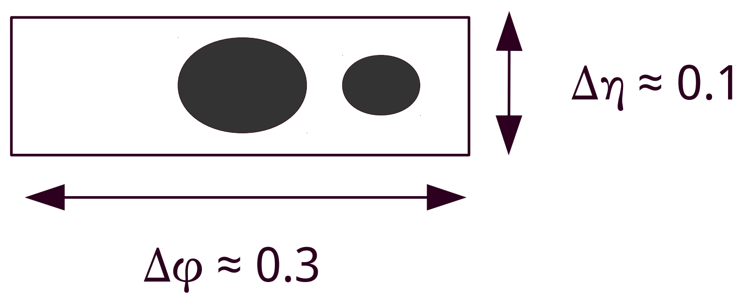
2) Clustering around this direction



- The architecture of the system is highly dependent on the algorithm
  - Number of consecutive processing layers
  - Detector coverage of each processing board in the system
- Only the performance of an algorithm based on the 2nd option has been studied so far

Electrons and photons

- 3D clusters will be sent to the global correlator (or to an intermediate calorimeter trigger)
  - Energy and position
  - Information on the shape and quality of the cluster
  - The longitudinal shape helps discriminating between electromagnetic and hadronic showers
- Electrons and photons can then be built from close-by clusters compatible with electromagnetic showers
  - Recovers energy from bremsstrahlung and conversions



- The clusters can finally be matched to tracks in the global correlator
  - Separation electrons / photons

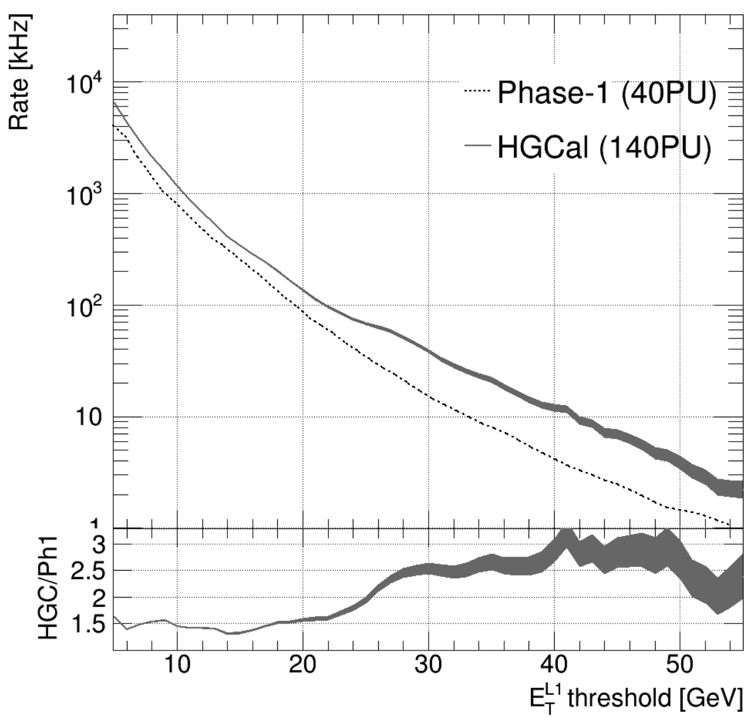
Jets

- Projective trigger towers with a coarse granularity will also be sent to the calorimeter trigger
  - They provide a full coverage of the detector, useful for global quantities and jets
- Given their large size, jets are highly sensitive to pile-up energy
- Jets can be seeded by high-density clusters
  - In order to limit the number of reconstructed pile-up jets
  - And built from projective trigger towers around these seeds
- Keeping the jet cone as small as possible (typically $\Delta R = 0.2$) helps mitigating the effects of pile-up
  - Such that the sum of pile-up and non-containment fluctuations are minimized
  - Missing out-of-cone energy can then be corrected

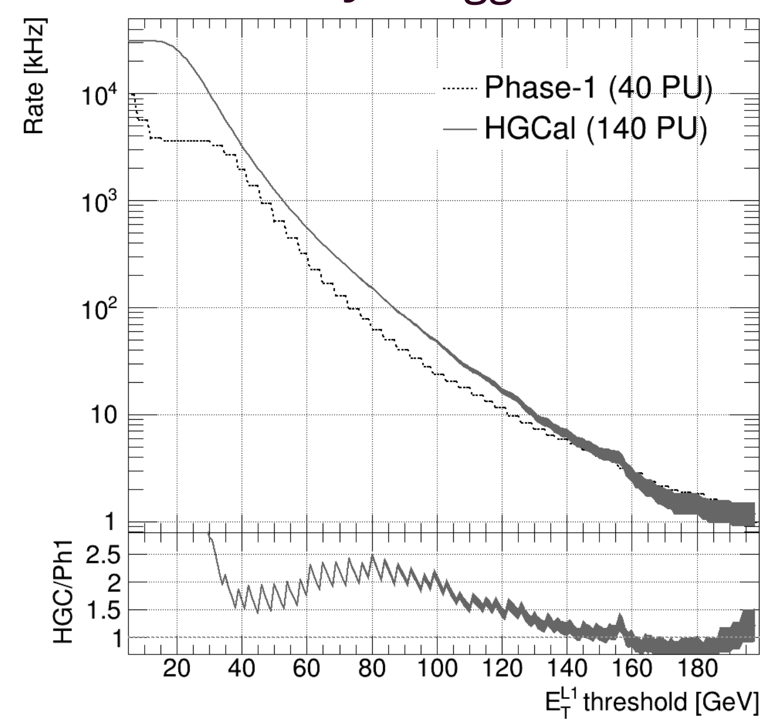
Trigger performance (Standalone HGCAL)

- The longitudinal information allows for efficient pile-up mitigation techniques and cluster identification
- The background rate is increased by less than a factor 2.5 – 3
  - For an increase of the luminosity by a factor 3.5
- With similar signal efficiencies (close to 100%)

Electron and photon trigger



Jet trigger



(CMS Phase-2 Technical Proposal: CERN-LHCC-2015-10)

Conclusion

- Preliminary concepts and design of the HGCAL L1 trigger have been developed and evaluated
- Challenges in terms of data handling and processing
  - Both in the front-end ASICs and in the back-end electronics
- Simple techniques can provide an effective data reduction in the front-end ASICs
- Efficient pile-up mitigation and rate reduction can be obtained using the 3-dimensional information of the energy deposits in the back-end electronics
- The fine granularity will also be of great help for correlations with the other sub-detectors
  - In particular with the tracks from the track trigger