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

Jean-Baptiste Sauvan
On behalf of the CMS Collaboration

CERN

CALOR 2016 – Daegu – 18/05/2016

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

<table>
<thead>
<tr>
<th>Current</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC clock</td>
<td>40 MHz</td>
</tr>
<tr>
<td>L1 trigger</td>
<td>100 kHz</td>
</tr>
<tr>
<td>High-level trigger</td>
<td>1 kHz</td>
</tr>
</tbody>
</table>
L1 trigger upgrade

- Crystal granularity in the ECAL barrel
- New HGCAL calorimeter in the endcaps
- Tracks available at L1
- Track trigger
- Calo trigger
- New correlation stage before the global trigger
- Global correlator
- Global trigger
- L1 accept Latency = 12.5 μs
- Incorporation of new forward muon detectors
- Possible intermediate layer
- Muon trigger
- Increased latency (4 μs before)
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.

Factor ~20 data reduction compared to the full data readout.

Possibility to have several processing layers.
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
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.
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 2\textsuperscript{nd} 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

\[ \Delta \phi \approx 0.3 \]
\[ \Delta \eta \approx 0.1 \]
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
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%)
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.