Pileup Mitigation in Hadron Forward Calorimeter for the Level-1 CMS Trigger at the HL-LHC

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on behalf of

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Abstract

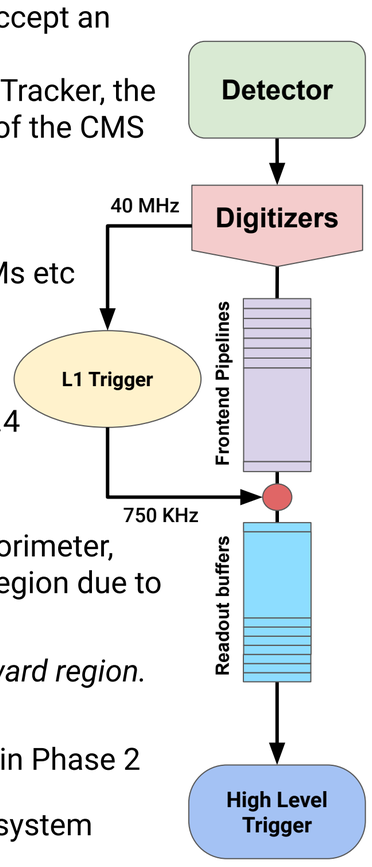
The high luminosity operation of the LHC will deliver collisions with a luminosity about 10 times the current design value. This poses a big challenge for trigger and data acquisition due to nearly 200 overlapping collisions per bunch crossing, called pile up, within the same bunch crossing. Disentanglement of the pileup particles from those of interesting physics processes is achieved by implementing the Pile-Up Per Particle (PUPPI) algorithm. We present the strategy for implementation of PUPPI at Level-1 trigger, focusing on the Hadron Forward (HF) Calorimeter subsystem of the CMS detector.

Introduction

- Anticipate upto 200 inelastic p-p collisions within a single bunch crossing
- A single, interesting scattering information gets recorded in the detector along with these less-energetic, unwanted, secondary collisions: **pile up (PU)**
- Extensive upgrade of the experiments for the HL-LHC operation essential for maximising the physics potential and sensitivity → **Phase 2 upgrade**
- The HL-LHC environment challenges event selection in real time: maximal mitigation of **PU** contribution for **efficient trigger** decision essential.
- Hadron Forward (HF) calorimeter covers the pseudorapidity (|η|) range between 3.0 and 5.2. It is critical for measurement of jets produced in forward-backward directions., eg. vector boson scattering (VBS), vector boson fusion (VBF) production of the Higgs boson etc.

Level 1 Trigger at the HL-LHC

- CMS Trigger structure: a two-tier system to reject or accept an event in real time for further scrutiny at a later stage.
- Uses information from the backend electronics of the Tracker, the Calorimeter and the Muon spectrometer subsystems of the CMS detector.
- Bunch crossing to Trigger rate: 40 MHz → 750 kHz.
- Custom-designed hardware with high-end FPGAs, SoMs etc
  - Processing latency **12.5 μs** .
- **Subsystems used for L1 trigger information:**



Tracker: Utilises track stubs for p_T> 2 GeV and |η| < 2.4
  - Provides vertexing capability
  - Helps to identify charged particles from PU

Calorimeter: More granular readouts for the barrel calorimeter, enhanced sensitivity in the mid-rapidity region due to high-granularity calorimeter.

Additional coverage of the forward-backward region.

Muon: Charged track in the outermost subsystem,
  - Single hit information available for the trigger in Phase 2

Correlator Layer: Collects information from each subsystem and builds global event description.
  - Links tracks to calorimeter clusters
  - Implements Particle Flow reconstruction
  - Applies the **Pile-Up Per Particle Identification (PUPPI)** algorithm to mitigate pile-up effects

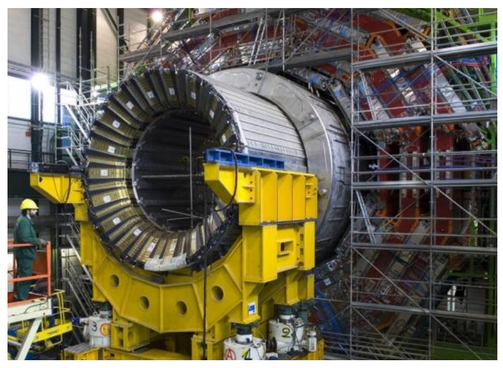
High Level Trigger (HLT): CPUs + GPUs with rate reduction 750 kHz → 7.5 kHz

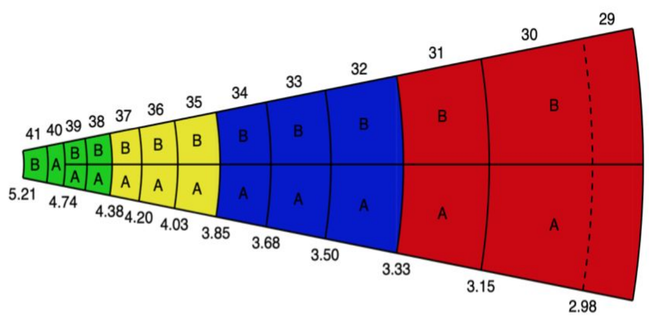
Schematic overview of CMS L1 Trigger at the HL-LHC

The Correlator layer collects and links the processed information form each subsystem to make a global description of each detected particles. The Tracker and HGCAL subsystems are new addition to the inputs of Level 1 Trigger of CMS at the HL-LHC.

HF region

Data from each HF (3< |η| <5.2) read out in 20^0 azimuthal angle (ϕ) wedges by PMTs





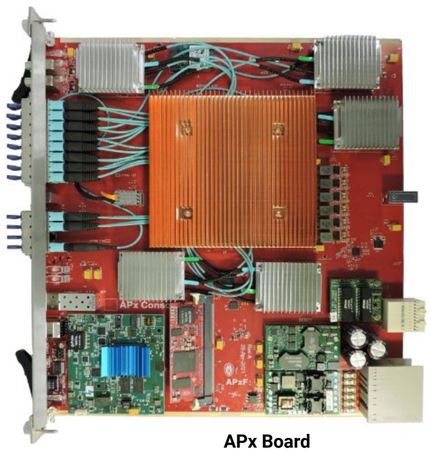
PUPPI Algorithm

- Utilizes collision information and charged particle vertexing to reduce pile up effect
- Each particle (charged and neutral) is assigned a weight, dependent on the density and p_T of other particles in its neighbourhood (distance in η-ϕ space $\Delta R < 0.3$)
- Contribution of a neighbouring particle of transverse momentum p_T to the weight is roughly proportional to $p_T^2/(\Delta R)^2$
- Parameters for the PUPPI algorithm are also optimized as a function of η

Challenges during the firmware implementation of the PUPPI *for* HF

Design details:

- Custom-designed *APx* boards:
  - Xilinx-VU13P FPGA based, running at 360 MHz on Global Calorimeter Trigger (*GCT*) boards
  - Processes events at 40 MHz throughput
- 48 clusters from either of HF+ or HF- passed through 6 links for further processing
- PUPPI algorithm implemented in absence of the tracking information



APx Board

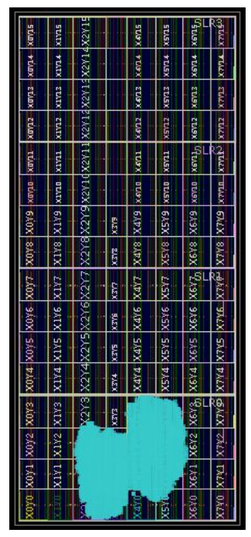
Challenges tackled:

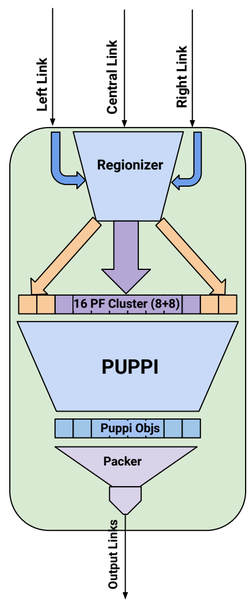
- Limited resources available on the FPGA after handling information from the barrel region of the calorimeter
- Regionized approach with reduced complexity
- Divides each HF into 6 sectors along ϕ direction
- Implements 2 copies of PUPPI firmware to achieve a reduced latency of 255 ns and fitting in 1 Super Logic Region (SLR) of the FPGA
- Initiation Interval (II) of 9 is achieved

Integration with the other calorimeter algorithms is ongoing

Latency (cycles)		Latency (absolute)		Interval (cycles)		Type
min	max	min	max	min	max	
92	92	0.255 us	0.255 us	9	9	yes

	DSP	FF	LUT
Total	12288	3456000	1728000
SLR Available	3072	864000	432000
SLR %	25.00%	25.00%	25.00%
C synthesis	544	625496	168222
Total %	4.43%	18.10%	9.74%
SLR %	17.71%	72.40%	38.94%
RTL synthesis	544	93630	86114
Total %	4.43%	2.71%	4.98%
SLR %	17.71%	10.84%	19.93%
Implementation	544	94949	82630
Total %	4.43%	2.75%	4.78%
SLR %	17.71%	10.99%	19.13%





Firmware resource usage

Conclusion

- ***Particle Flow-based event description and PUPPI algorithm for pile up mitigation has been implemented to process the information from Hadron Forward Calorimeter for Level 1 Trigger information.***
- ***PUPPI-based physics objects, e.g., p_T of the reconstructed jet, missing transverse energy lead to reduced trigger rates and better efficiencies.***
- ***Calorimeter based trigger decision can now use reliable information from the HF+ and HF- regions of the detector and enhance the physics scope of CMS at HL-LHC.***

References:

1. The Phase-2 Upgrade of the CMS Level-1 Trigger, *CERN 2020, CERN-LHCC-2020-004*
2. Pileup per particle identification, *Bertolini, D., Harris, P., Low, M., & Tran, N. (2014).JHEP, 2014(10)*
3. *CMS picture:* https://cms.cern/book/export/html/1202