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Pileup Mitigation at CMS Level-1 Trigger for the HL-LHC

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The high luminosity operation of the LHC will deliver collisions with a flux of about 10 times higher than the original design value of the instantaneous luminosity planned during early 1990s. This poses a big challenge for trigger and data acquisition in real-time due to the very high rate of interesting collisions and to the high number of (~200) overlapping collisions, called pileup. The CMS experiment will revamp its trigger structure as part of the required upgrade, to have the tracking information and more granular calorimeter data available for the first layer (Level 1, L1) of the trigger deployed in custom hardware including high-end FPGAs, SoM (System on Module), etc. The correlator units at L1 will further process the information from each sub-detector to make a global event description through the particle-flow (PF) approach. Disentanglement of the contributions from the pileup particles from those of interesting physics processes is achieved by implementing the Pile-Up Per Particle Identification (PUPPI) algorithm at L1. We present the strategy for implementation of PUPPI and PF at the L1, focusing on the Hadron Forward Calorimeter detector of CMS.

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1. Introduction

The Phase 2 upgrade of the CMS detector[1] and data acquisition system has been planned to utilize the 7.5 times higher instantaneous luminosity delivered by the High-Lumi LHC (HL-LHC). The CMS experiment uses a two-tier trigger system for selecting the events in real time and to be stored for in-depth analysis offline. The first layer is the Level 1 Trigger (L1) implemented in custom electronics boards. The second tier is a CPU (Central Processing Unit)+GPU (Graphics Processing Unit) farm running a faster version of the full reconstruction scheme and implementing more refined selections based on physics.

2. The Level 1 Trigger upgrade

The Phase 2 L1 trigger of CMS [3] uses granular information from the calorimeter, the muon spectrometer and the tracker subsystems. The L1 trigger has a fixed latency of 12.5 μs and selects 750 kHz of events using custom algorithms running on high-end FPGAs. Tracker subsystem in trigger reconstructs the track stubs with transverse momentum > 2 GeV and $|\eta|$ < 2.4. These stubs are processed by the *track finder* to produce tracks that are used further to obtain the vertices in the event. The barrel calorimeter upgrade brings in the full granularity readouts in Phase 2. The region covering $1.5 < |\eta| < 3.0$ has the high granularity calorimeter (HGCAL) which is a silicone based sampling calorimeter. The muon systems are also updated with increased coverage up to $|\eta| < 2.8$ and provide track matched muon chamber hits along with the standalone muons reconstructed from the subsystem.

The information from each of these subsystems are then fed into the *correlator* layer of L1 trigger which makes a *particle-flow* (PF) based event description linking the tracks to the energy deposits in the calorimeter. The PF candidates are then processed by the Pile-Up Per Particle Identification (PUPPI) algorithm to identify the particles coming from the pileup vertices.

3. The PUPPI Algorithm

This algorithm [4] utilizes the global (vertex association) and local information available in the event description. It assigns a weight for each PF candidates in the event based on the likelihood of it being coming from the primary vertex, PV (the reconstructed p-p interaction vertex with the highest associated track momentum) or from other vertices of scattering at a lower energy scale. In the barrel region ($|\eta| < 2.4$) where the tracker information is available, the charged tracks not originating from the PV are assigned a null weight and are discarded from further calculations in the algorithm. The neutral particles are then assigned a weight depending on the density and the transverse momenta of the neighbouring particles in the η-ϕ plane. In the forward region of the CMS detector, $|\eta|$ > 2.5, the tracking information is not available; hence a version of the algorithm, independent of the tracker information, is used for assigning the PUPPI weights.

The particle candidates, after getting assigned PUPPI weights, are then clustered into jets. The variables like the missing transverse energy (MET) and the jet p_T scalar sum are calculated as weighted sums with the PUPPI weights taken into account. This approach provides a better suppression of unwanted candidates from the pileup interactions, in turn providing better kinematic resolution to the reconstructed particle candidates. The parameters for the algorithm have been optimized as a function of the $|\eta|$, since particle multiplicity grows with rapidity.

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4. Pileup Mitigation for the Hadron Forward Calorimeter

The hadron forward calorimeter in the CMS detector, provides a fiducial acceptance of $3.0 < |\eta| < 5.2$. It consists of 18 wedges each spanning 20 degrees in the azimuthal direction (ϕ). Since the PUPPI algorithm in forward regions does not require inputs from any other subsystem, it is implemented alongside other calorimeter based trigger algorithms that make Calorimeter Jets and MET. For implementation of the algorithm that can accept inputs at the bunch crossing frequency of 40 MHz, using the minimal resources of the available FPGAs, we resort to a regionized approach (see 1). We implement two copies of the PUPPI algorithm to meet the throughput requirement. Information from three wedges are combined as a sector and processed by a PUPPI block. Every 25 ns, each PUPPI block accepts three such sectors. The algorithm is successfully implemented in firmware and will be integrated to the full trigger system in the near future. The outputs of the PUPPI algorithm are sent to the correlator units for further processing.

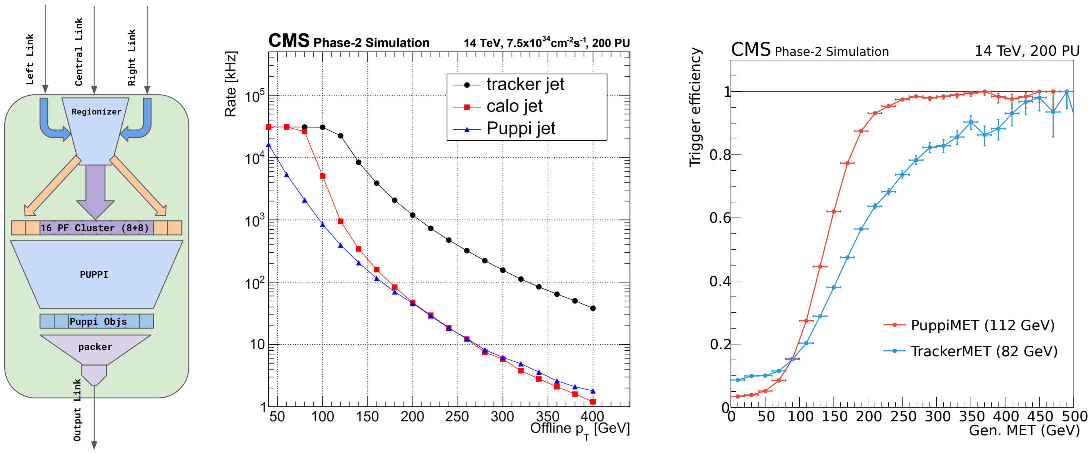

Figure 1: (left) Block diagram showing the regionized approach for PUPPI implementation for HF. (middle) Acceptance rate of different jet algorithms as a function of the p_T threshold. (right) Performance of the MET trigger at a fixed bandwidth [3].

5. Performance of the PUPPI algorithm

Figure 1 presents the performance of PUPPI algorithm implemented at L1 trigger. The middle plot compares the performance of single jet triggers at implemented with three different approaches, one using only tracker information, one using only calorimeter information, and one using the PF-PUPPI candidates. The rightmost plot compares the performance of the trigger with MET calculated using only tracker information and MET calculated from the PF-PUPPI candidates. The PF-PUPPI candidates are able to achieve lower selection thresholds for each of these algorithms enhancing the event acceptance for the physics studies at a fixed background rate. As a consequence, the CMS experiment is able to cope with the very high instantaneous luminosity delivered at the HL-LHC, keeping the trigger rates at the sustainable values without compromising on the physics.

References

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