The CMS Level-1 jet and energy sum triggers for the LHC Run II

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The CMS experiment implements a sophisticated two-level triggering system composed of the Level-1, instrumented by custom-design hardware boards, and a software High Level Trigger. A new Level-1 trigger architecture with improved performance is now being used to maintain high physics efficiency for the more challenging conditions experienced during Run II. We present the performance of the upgraded Level-1 jet, energy sum, and missing transverse energy (MET) triggers. The upgraded trigger benefits from an enhanced granularity at calorimeter level to optimally reconstruct hadronic objects. Dedicated pileup mitigation techniques are implemented for both jets and MET to maintain performance in the intense running conditions of the LHC. The performance of the new trigger system is presented, based on proton-proton collision data collected in 2016 and 2017 at a centre of mass energy of 13 TeV and pileup that reached 55. The selection techniques used to trigger efficiently on benchmark analyses are presented, along with the strategies employed to guarantee efficient triggering for new physics.

[1] The CMS Collaboration. "Level-1 jets and energy sums trigger performance with full 2017 dataset", report number: CERN-CMS-DP-2018-004 (2018).

[2] The CMS Collaboration. "Search for natural and split supersymmetry in proton-proton collisions at $\sqrt{s} = 13$ TeV in final states with jets and missing transverse momentum", *JHEP* (2018).

Introduction

The Level-1 (L1) Trigger in the CMS experiment is composed of hardware boards with firmware-implemented algorithms to select events that may prove interesting to physics analyses, while rejecting the majority of events that are not. High speed optical links allow event information from the calorimeters and muon detectors to be sent to the trigger system. Here, they undergo selections and reduce the recorded event rate from 40 MHz to 100kHz. The selected events are then sent to the software-based High Level Trigger for further processing.

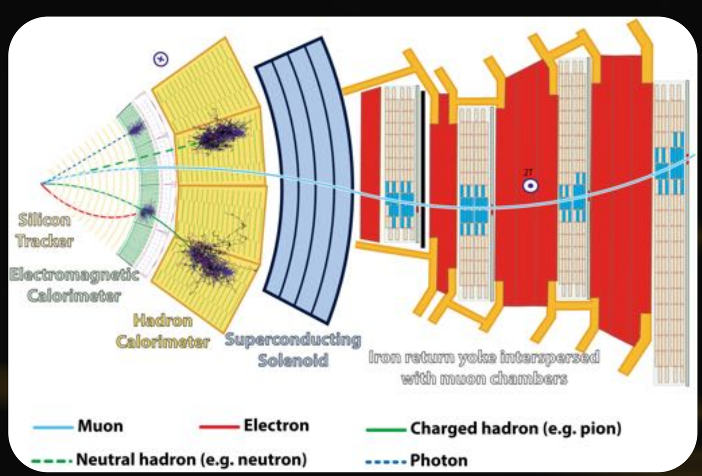


Fig. 1: An illustration of the CMS detector including the tracker, calorimeters and muon chamber.

In the L1 calorimeter triggers, objects are identified and energy calibrations applied to ensure uniformity of the detector response. Event level quantities, such as energy sums and pileup estimation, are also calculated. Time multiplexing allows full granularity data from the entire calorimeter to be processed by a single board. This also gives algorithms access to the global calorimeter view for better performance.

Whilst many objects have dedicated triggers at Level-1, this poster focuses on the following: jets; H_T, the scalar sum of the transverse momentum (p_T) of the jets; and missing transverse energy (MET), the magnitude of the negative vector sum of the transverse momenta of all calorimeter energy deposits.

Algorithms

Several algorithms are in place to optimise the reconstruction of jets and perform pileup subtraction, and to mitigate the pileup contribution to MET calculations.

The number of pileup jets are reduced by applying the following algorithm: a 9x9 trigger tower (TT) "sliding window" is centred on a tower with the local maximum E_T, labelled the seed (see Fig. 2). An inequality mask avoids self-vetoes and double counting of energy deposits, and an E_T threshold is applied to the seed to exclude pileup jets.

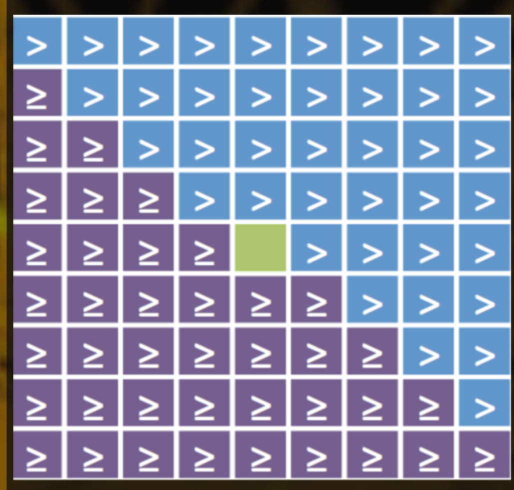


Fig. 2: Sliding window constructed around the jet seed (green). The masks signify vetoing candidates if tower E_T > seed E_T (blue), or if tower E_T ≥ seed E_T (purple).

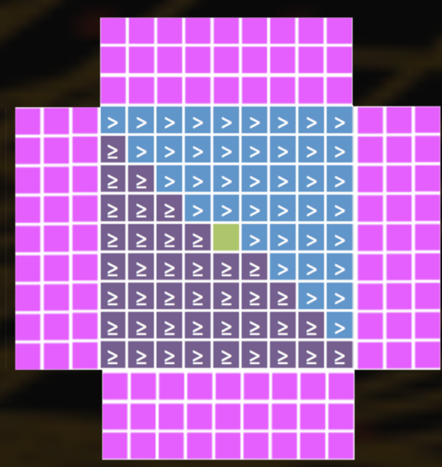


Fig. 3: Energy deposits in strips of 3x9 trigger towers (pink) around the jet are used to estimate the pileup energy density.

The pileup energy contribution to a jet is estimated by using "chunky doughnuts" (see Fig. 3). Strips of size 3x9 TT are positioned each side of the jet and the sum of the energy deposits in the three lowest-energy strips are subtracted from the jet energy.

Since 2017, pileup mitigation has been performed for MET. Dynamic tower E_T thresholds prevent towers with small energy deposits (indicative of pileup) from being included in the MET calculation. These are pseudorapidity η- and tower size-dependent since higher pileup is observed in the forward direction and for wider towers. An estimate of the pileup is obtained by counting the TT hits within $|\eta| < 0.348$, since the dependence is approximately linear.

Performance

Figure 4 showcases the performance of the jet and H_T triggers with the full 2017 dataset of 41.5 fb^{-1} [1]. Figure 5 demonstrates the effect of MET pileup mitigation deployed in 2017. These turn-on curves indicate the efficiency of the object trigger as a function of offline object E_T for a given L1 threshold. They are obtained from events selected by an independent muon trigger. Illustratively, the performance is better if the efficiency curve rises more steeply and above the threshold it is enforcing. Projections also extend to 2000 GeV, plateauing at an efficiency of 1 from the upper limit of these plots to that value.

Figure 6 highlights the difference between the online object energy compared to the offline matched object (or calculation in the case of MET) with 2016 data. These resolution plots peaking close to zero and appearing approximately symmetrical indicate that the algorithms, using only calorimeter information, do a remarkable job in matching online to offline objects.

Overall, performance has been excellent, despite the more challenging conditions in 2017 with high luminosity and pileup. This is, in part, due to better hardware, and more powerful and diverse algorithms that have adequately coped with the challenges Run II has presented. Sustaining the performance has been vital to the wide range of analyses these triggers are used in, such as supersymmetry searches [2].

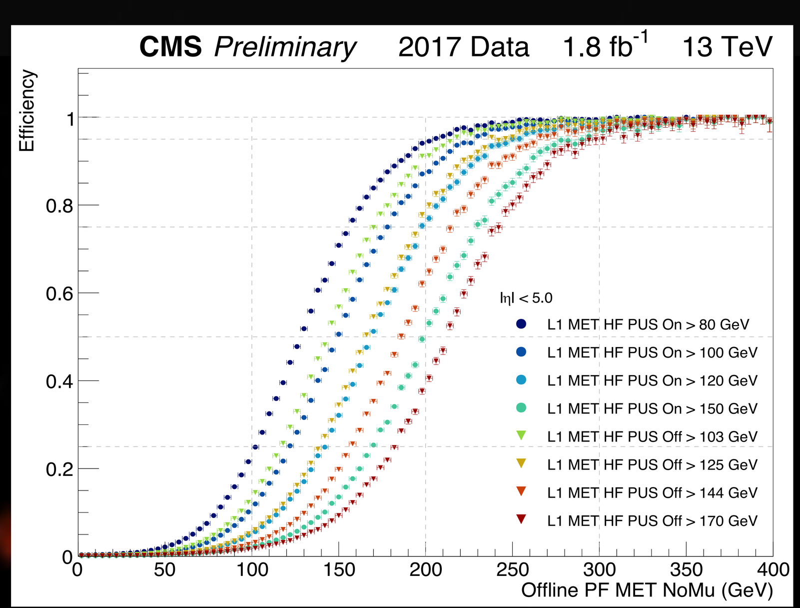
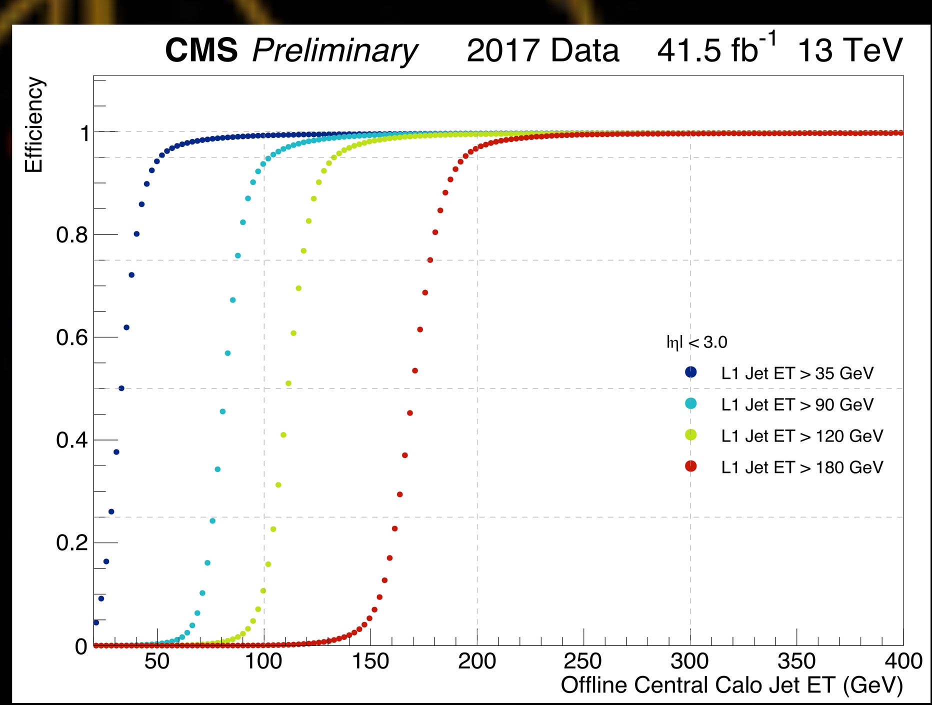
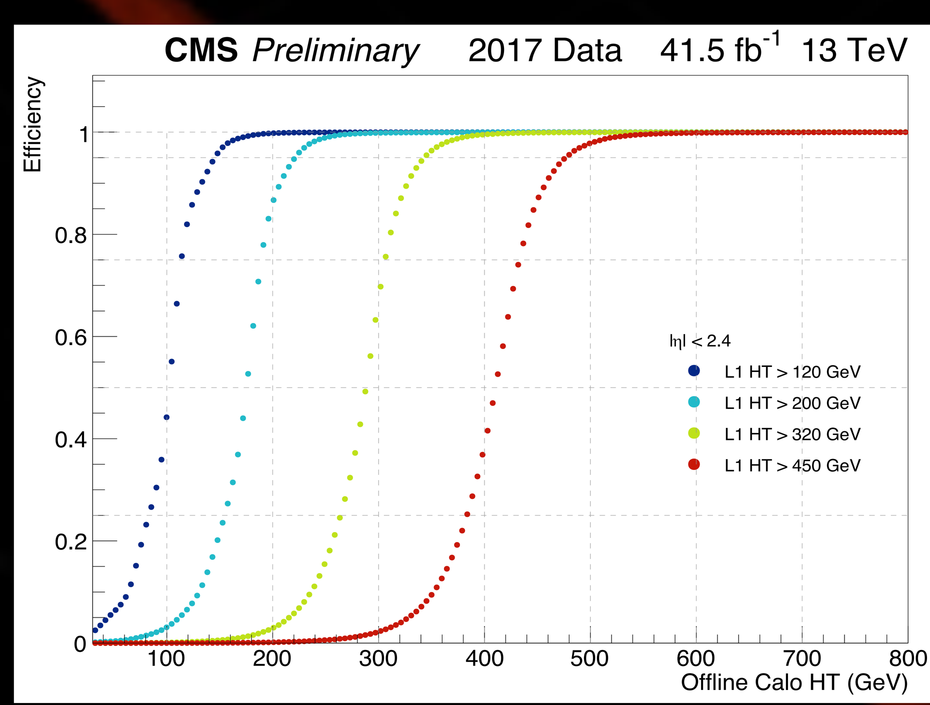


Fig. 5: Efficiencies for MET with and without pileup subtraction (PUS) using part of the 2017 dataset. These curves are compared for trigger thresholds that give the same Level-1 rate.

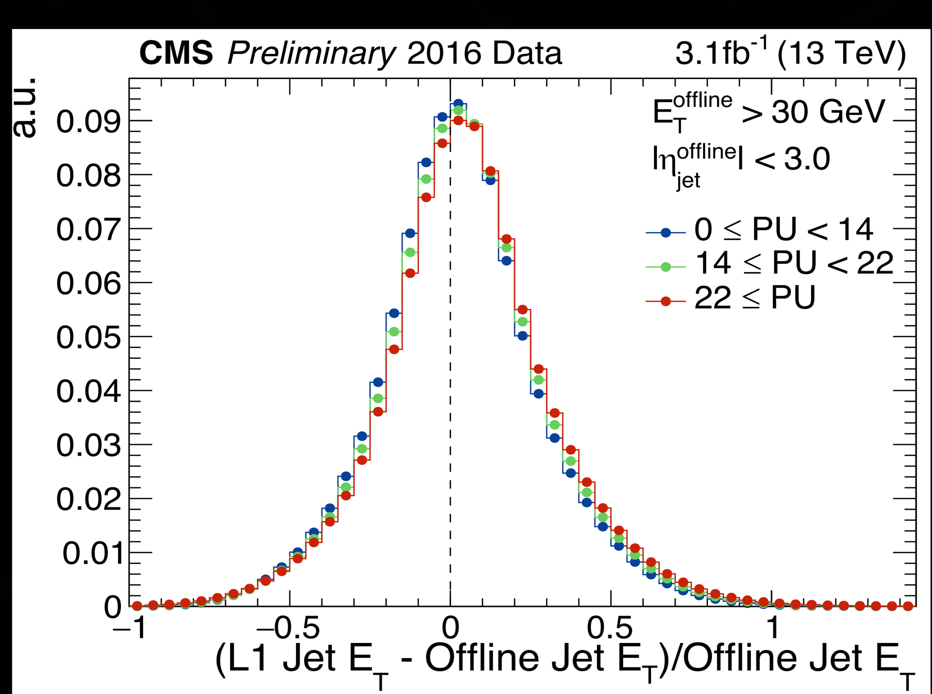


(a) Central Jets

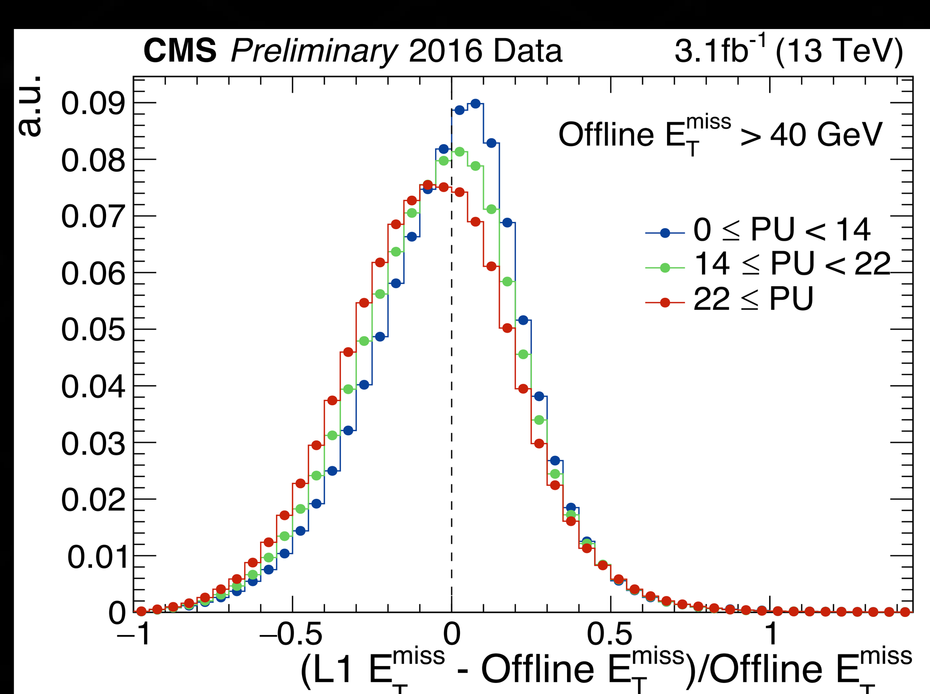


(b) H_T

Figure 4: Turn-on curves for hadronic object triggers at various energy thresholds using the full 2017 dataset. They showcase the efficiency of the trigger as a function of the energy of the offline object used for matching. The offline jets are clustered according to anti-k_t 0.4, have a p_T > 20 GeV (> 30 GeV for H_T), and are matched to L1 jets with ΔR < 0.4.



(a) Central Jets



(b) E_T^{miss}

Figure 6: Resolution plots for jets and MET using 2016 data, showcasing the fractional difference in E_T between the Level-1 and corresponding offline object. The online jets are matched to reference jets, and the offline MET is calculated with higher granularity and calibrations applied as much more information is available than at Level-1.