Triggering on Muons, Electrons, Photons, Tau Leptons, Jets, and Energy Sums during the Run-3 of the LHC with the CMS Level-1 Trigger

Panos Katsoulis[1] on behalf of the CMS Collaboration

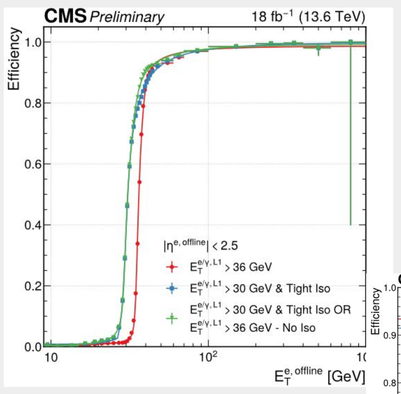
The Compact Muon Solenoid (CMS) uses a two-level Trigger, the Level-1 that runs on custom hardware, and the software-based High Level Trigger. The current system, upgraded with respect to Run-1 with better performance, maintains high standards in challenging Run-3 conditions with instantaneous luminosity up to 2.5e34 $cm^{-2}\,s^{-1}$ and intensive Pile-Up (65).

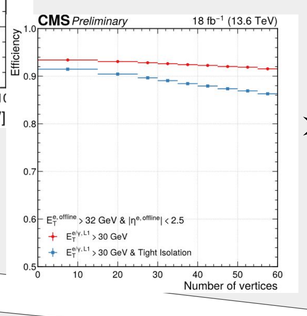
The Calorimeter Trigger, exploiting the enhanced granularity of the calorimeters, plays a central role in achieving the physics program of Run-3. The Muon Trigger uses new algorithms to target unconventional signatures from new physics (eg. displaced tracks from Long-Lived Particles).

The latest (2023) Run-3 performance of the Level-1 triggering objects, used for selecting events for benchmark analyses, is presented comparing to the offline reconstruction of the CMS experiment.

Electrons & Photons[3]

Reconstructed from energy deposits into the calorimeters, clustered together around one "seed" deposit that surpasses threshold amounts

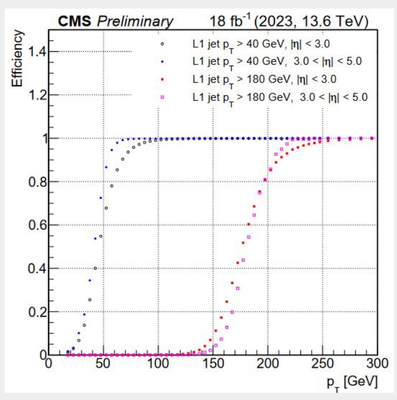




- Sharp turn-on, less than 5 GeV resolution for e/γ objects of 35 GeV momenta (15% w.r.t. offline) with and w/o isolation condition
- Greater than 90% (85%) efficiency for e/γ objects of high momenta with (w/o) isolation even for high Pile-Up

Jets[2]

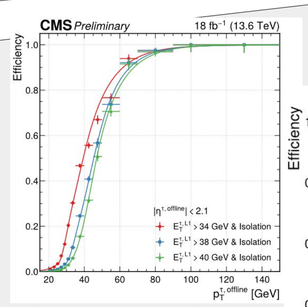
Like for e/γ, calorimeter energy deposits are used also for the jets, from 9x9 closeby deposits. Once reconstructed, the jets are calibrated to account for extra energy due to pile-up

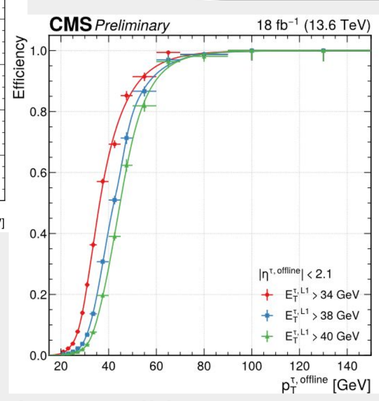


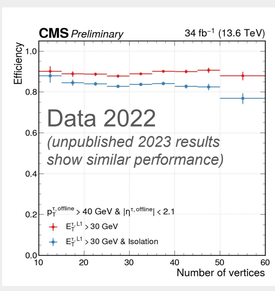
- Fully efficient reconstruction with slower turn-on comparing to e/γ and tau leptons (tenths of GeV)
- Faster turn-on for the forward jet objects, the current calibration overestimates the Level-1 jets' momenta

Tau Leptons[3]

Similar reconstruction to e/γ from calorimeter energy deposits, for tau objects the closeby clustered deposits may merge to account for decay products



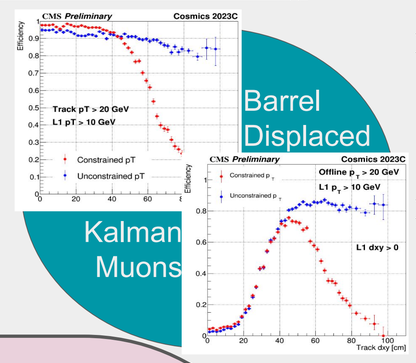




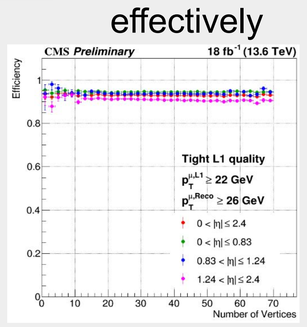
- About 7 GeV turn-on resolution for 35 GeV tau objects (20% w.r.t. offline) with or w/o the isolation condition
- Stable performance for low and high Pile-Up, similar to the Electrons & Photons. Efficiency above 90% (85%) with (w/o) isolation for tau objects with high momenta.

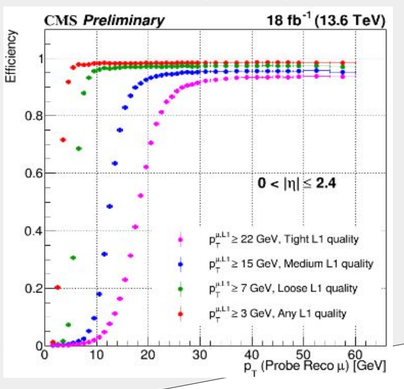
Prompt & Displaced Muons[4],[5]

Reconstruction using information from 3 types of muon detectors. Track reconstruction and momenta assignment using techniques like Kalman Filter, Pattern Classifier, and Boosted Decision Tree

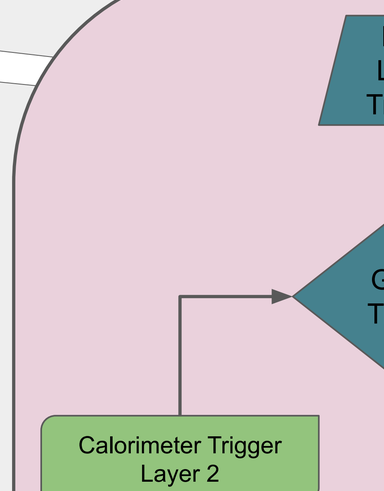


- High efficiency (greater than 90% w.r.t. offline) both for high and low momenta prompt muons
- The Kalman Filter (in Barrel) reconstructs tracks from secondary decays efficiently (80% up to 1m displacement), with clear turn-on that allows to discard prompt tracks effectively





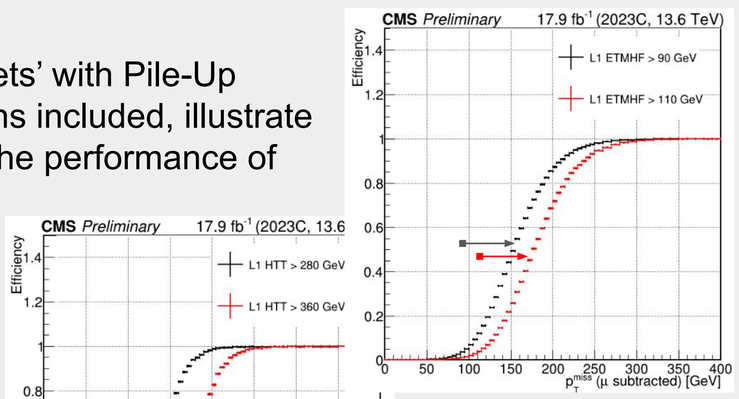
- Good prompt efficiency even for high Pile-Up, above 90%

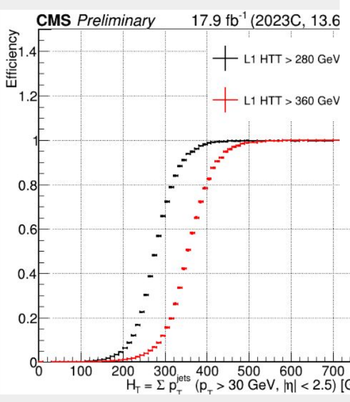


Energy Sums[2]

The Energy Sums are totals of calorimeter energy deposits. Precalculated threshold values of energy are selecting the deposits to account for Pile-Up energy.

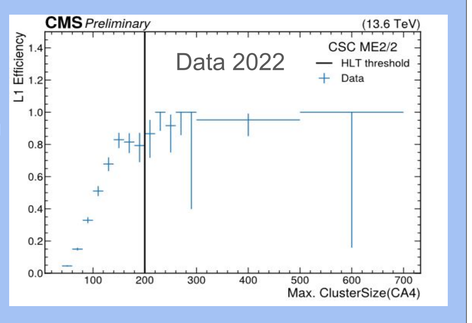
- HTT, the scalar sum of the Jets' with Pile-Up corrections and jet calibrations included, illustrate very similar performance to the performance of the Jet objects
- ETMHF, the vectorial sum of energy deposits incorporating Pile-Up corrections but without jet calibrations, illustrates significant shift on the turn-on w.r.t. targeted offline values





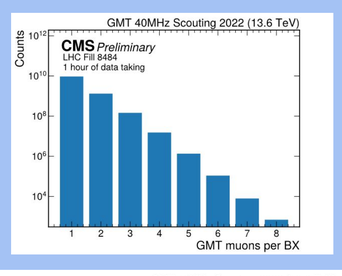
High Multiplicity Trigger[6] in the Level-1

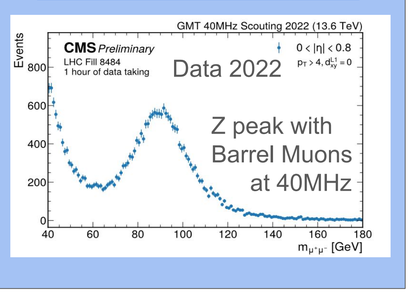
- Targets hadronic cascades in the Cathode Strip Chambers (CSC)
- Significant contribution for scenarios with long-lived particles that decay in the CSCs w.r.t using only standard triggers
- Part of a 2-Layer implementation (Level-1 & High Level Trigger), selects events with high multiplicity of CSC hits in a given chamber



40 MHz Scouting System[7] for the Level-1

- Demonstrated in 2018 and implemented for Run 3
- Incorporates inputs from the Barrel Muon, the Global Muon, and the Calorimeter Trigger Layer-2 systems
- Studies with this parasitic system target improvements of the current Level-1 performance and serve as "proof of concept" for the Phase-2 of the LHC





Ongoing Developments for the Level-1 Systems

- Neural-Network approach in the Endcap Muon System is developed/studied for reconstructing displaced tracks (online since June 2023)
- Modification of the Pattern Classifier algorithm in the Overlap Muon System is also prepared for providing displaced tracks
- Integration and feasibility studies for the Gas Electron Multiplier Detector (GEM) in the Endcap Muon System, extensive investigation about using effectively the GEM information during Run-3

(1) University of Ioannina, Greece

References:

(2) CMS Collaboration, Performances of L1 Jets and MET Trigger in early Run3, CMS DP-2023/054
(3) CMS Collaboration, Performance of Level-1 Trigger e/γ and τ in Run 3, CMS DP-2023/055
(4) CMS Collaboration, Level-1 Muon Trigger Performance with part of 2023 dataset, CMS DP-2023/057
(5) CMS Collaboration, Displaced BMTF Efficiency Using 2023 Data, CMS DP-2023/056
(6) CMS Collaboration, CSC High Multiplicity Trigger in Run 3, CMS-DP-2022-062
(7) CMS Collaboration, 40MHz Scouting Muon Studies, CMS-DP-2023-025