PERFORMANCE OF CMS LEVEL-1 TRIGGER DATA SCOUTING DURING LHC RUN 3

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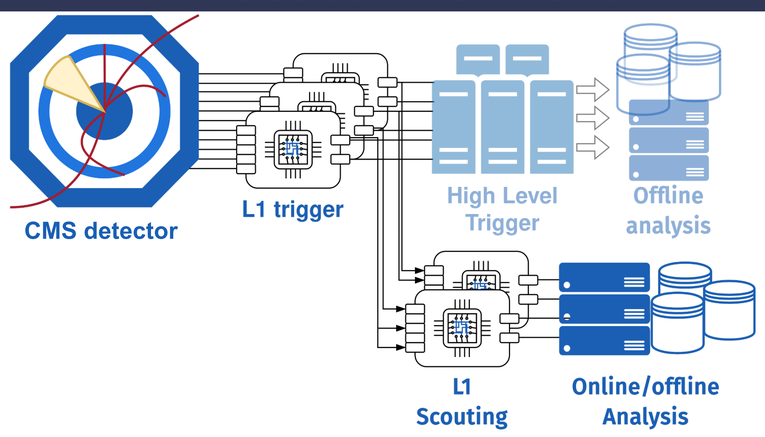
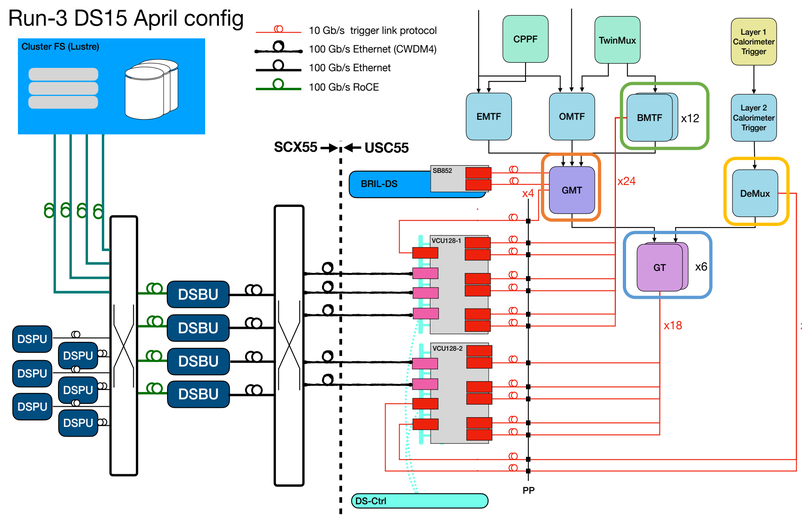
40MHZ SCOUTING AT CMS



The **CMS Level-1 Trigger Data Scouting (L1DS)** defines a new approach within the CMS Level-1 Trigger (L1T), capturing L1T objects at the **40 MHz bunch-crossing (BX) rate**, in contrast to the traditional CMS two-level trigger system. The L1DS will reach its full potential with the CMS Phase-2 Upgrade at the HL-LHC, leveraging the improved Phase-2 L1T design featuring tracker and high-granularity calorimeter data [1]. With a **trigger-less infrastructure**, the L1DS can **enhance the physics discovery potential** of the experiment by targeting rare decays, light resonances and signatures across multiple BXs, difficult to reach through standard triggering techniques [2].

THE LEVEL-1 TRIGGER DATA SCOUTING DEMONSTRATOR

As proof of concept, a L1DS demonstrator has been included in the L1T since LHC Run-3 (2022-). It collects objects reconstructed by the L1T from four sources at a 40 MHz rate. In early 2024 data-taking, only the readout from the Global Muon Trigger and Calorimeter Layer-2 systems has been in production.



Global Muon Trigger (GMT)
Up to 8 muons

Layer-2 Calorimeter Trigger
Up to 12 jets, e/γ, τ, missing transverse energy, energy sums

Barrel Muon Track Finder (BMTF)
Stub primitives

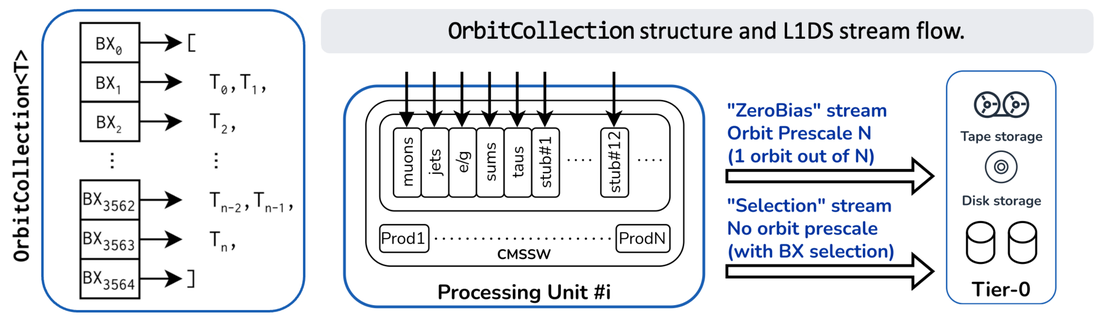
Global Trigger (GT)
GT algorithm decision bits

LEVEL-1 SCOUTING DEMONSTRATOR DATA ANALYSIS: RESULTS FROM RUN 3 DATA

The results presented characterize the first data collected by the L1DS demonstrator and assess its performance [CMS-DP-2024-056]. The LHC orbit, which contains 3564 BXs, is the unit of L1DS data. The scouting **`OrbitCollection`** stores object information for all BXs within the orbit, enabling the study of bunch-to-bunch correlation in addition to the object parameters. In 2024, the L1DS demonstrator produces two main data streams to fit within the allocated bandwidth of 200 MB/s of repacked scouting data.

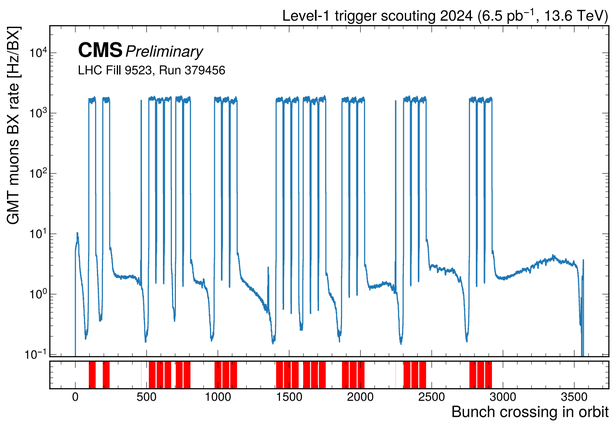
ZeroBias stream
- Orbit prescale stream in which 1 orbit every N (prescale factor) is stored.

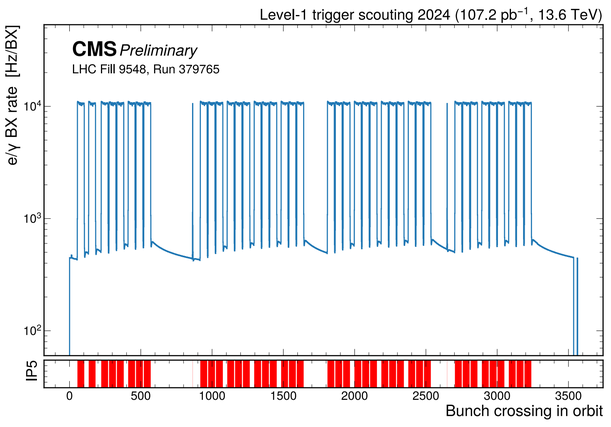
ScoutingSelection stream
- It stores all objects for the BXs which contain a targeted signature, no prescale applied.
- It's a prototype for future online analysis at the full BX rate.
- Several selection streams: di-jet, high-multiplicity jets, a muon inside a jet cone, single GMT barrel muon and high-quality double muons.

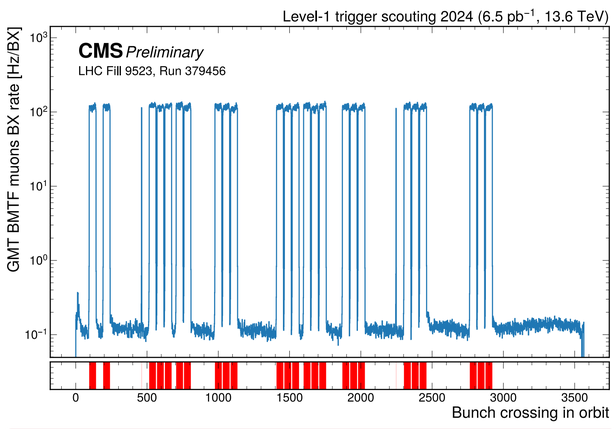


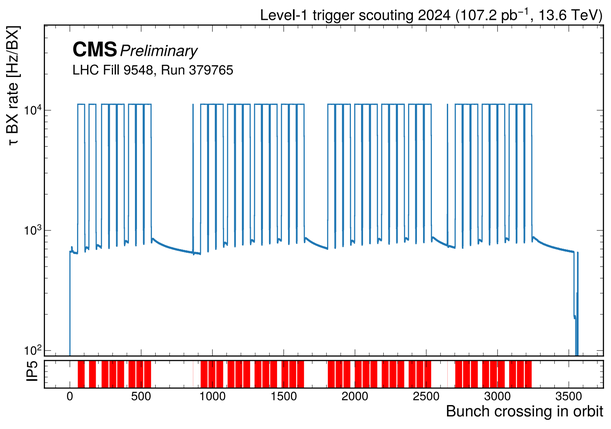
ZeroBias STREAM

The scouting **ZeroBias** stream stores all BXs, making it of interest to examine **occupancy per BX** and object **multiplicities**. The objects' BX rate within an LHC orbit shows their distribution in colliding and non-colliding bunches, also revealing contributions from cosmic muons, beam halo, and machine-induced backgrounds in the latter.





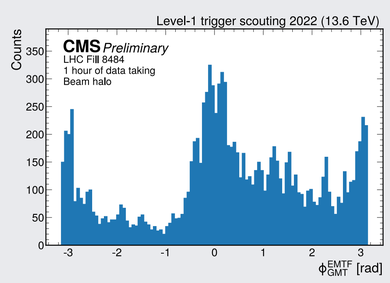


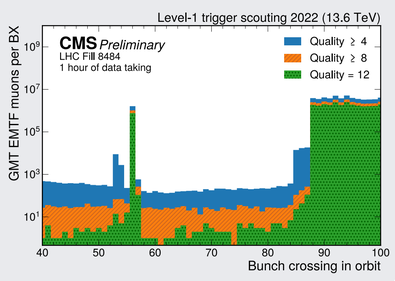


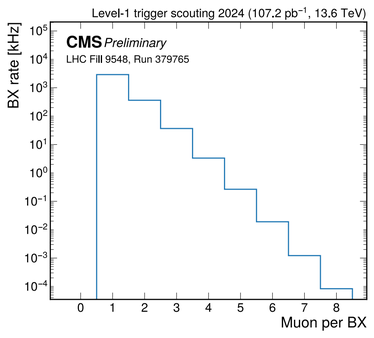
Occupancy of GMT muons (top) and GMT barrel muons (bottom) for a fill with 1199 colliding BXs (red).

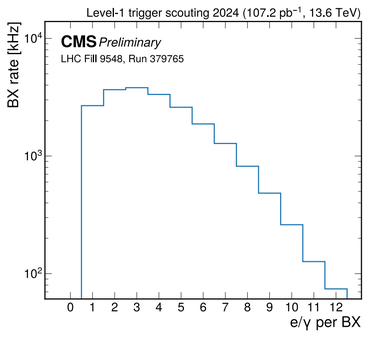
Occupancy of e/γ (top) and τ (bottom) for a fill with 1970 colliding BXs (red).

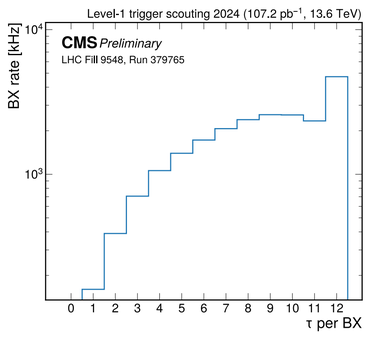
The **beam halo effect** is mostly visible 2-3 bunches before colliding BXs and for muons reconstructed by the Endcap Muon Track Finder (EMTF). Halo muons are mainly produced on the beam pipe plane, with higher occupancy for $\phi \sim 0$ and $\phi \sim |\pi|$. However, they have lower quality, and their rate drops as muon quality improves ($Q = 12$) [CMS-DP-2023-025].







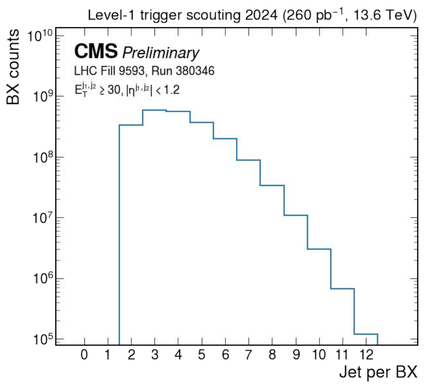




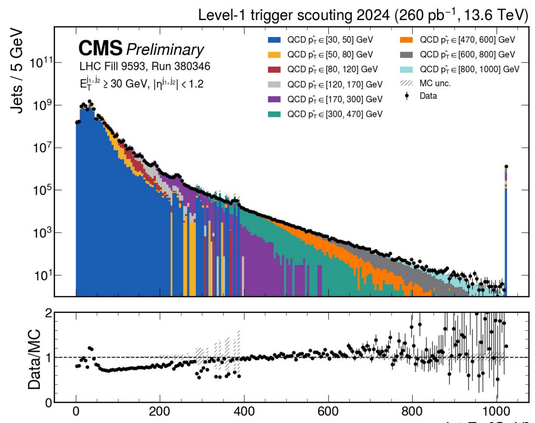
Multiplicity of muons (left), e/γ (centre), τ (right) in colliding bunch crossing only.

ScoutingSelection STREAM

The scouting **DiJet30** stream requires at least two jets per BX with transverse energy $E_T > 30$ GeV and pseudorapidity $|\eta| < 1.2$. It is of interest for low-energy di-jet resonance searches.

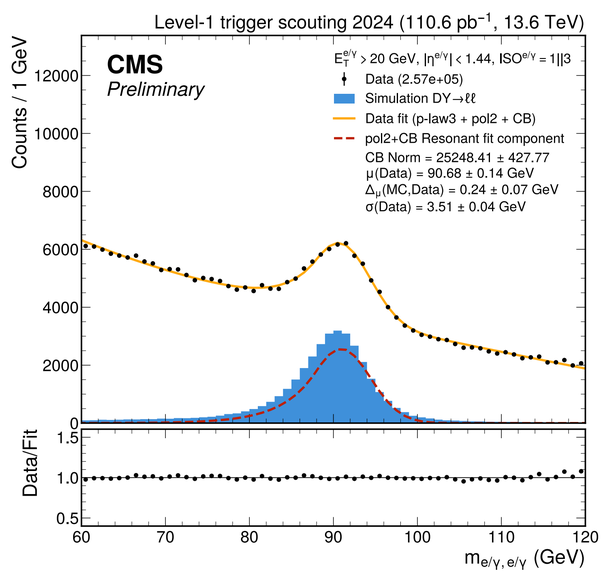


Multiplicity of DiJet30 stream jets.



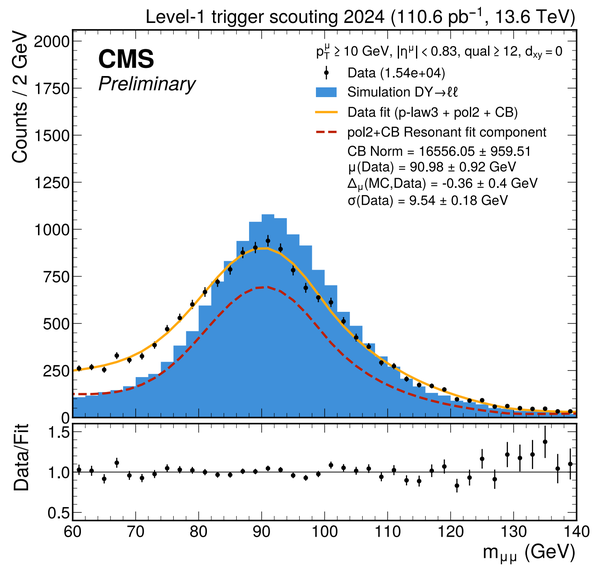
Spectra of E_T for jets of the DiJet30 stream. The L1 jets (black) are compared to QCD MC samples. The peak at the high end of the E_T spectrum is due to the saturated towers. Some calibration artifacts are visible as bumps in the distribution in the low-energy region.

STANDARD MODEL CANDLES WITH L1 TRIGGER OBJECTS



The invariant mass distribution of e/γ pairs, showing the resonance from the $Z \to e/\gamma\ e/\gamma$ decay.

Standard Model (SM) candles provide valuable insights into the resolution of L1T objects and serve as a validation tool. The decay of the Z boson to leptons and photons is considered by reconstructing the invariant mass for pairs of μ and e/γ. The L1DS demonstrator data are then compared to L1 objects of Monte Carlo (MC) simulated samples.



The invariant mass spectra for events with only two GMT muons in the barrel region, showing the resonance from the $Z \to \mu\mu$ decay.

The current L1T system uses coarse primitives' information (the tracker information cannot be included). The resolution achieved allows the peak in the invariant mass distribution to be observed to an acceptable precision, that could be improved through machine learning (ML) algorithms on FPGAs. This method is explored for muon recalibration [CMS-DP-2022-066].

[1] CMS Collaboration. (2020). *The Phase-2 Upgrade of the CMS Level-1 Trigger*. https://cds.cern.ch/record/2714892.
[2] E. Meschi, *The CMS Level-1 Trigger Data Scouting System for the HL-LHC Upgrade*. *Talk* presented at ICHEP 2024.