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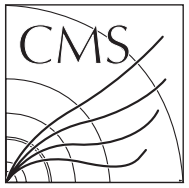

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Performance of CMS Level-1 Trigger Data Scouting during LHC Run 3

Sabrina Giorgetti for the CMS Collaboration

Abstract

The CMS Level-1 Trigger Data Scouting (L1DS) system represents an innovative approach within the CMS experiment, enabling the acquisition and processing of Level-1 Trigger (L1T) objects at the full LHC bunch-crossing (BX) rate of 40 MHz. The system will be fully deployed as part of the CMS Phase-2 Upgrade at the High-Luminosity LHC (HL-LHC), harnessing the improved Phase-2 L1T design, featuring tracker and high-granularity calorimeter data for the first time. This trigger-less infrastructure has the potential to enhance CMS's sensitivity to signatures that could be limited by the current search phase space, and that are generally challenging to detect with traditional systems, such as rare decays, light resonances, and exotic signatures. Since the start of LHC Run 3, the L1DS demonstrator has been actively collecting muons and calorimeter objects. Initial analyses of the L1DS data have focused on characterizing this novel dataset, offering significant insights into the system's performance. These results not only showcase the functionality of the L1DS infrastructure but also highlight its potential for further applications.

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PROCEEDINGS OF SCIENCE

Performance of CMS Level-1 Trigger Data Scouting during LHC Run 3

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The CMS Level-1 Trigger Data Scouting (L1DS) system represents an innovative approach within the CMS experiment, enabling the acquisition and processing of Level-1 Trigger (L1T) objects at the full LHC bunch-crossing (BX) rate of 40 MHz. The system will be fully deployed as part of the CMS Phase-2 Upgrade at the High-Luminosity LHC (HL-LHC), harnessing the improved Phase-2 L1T design, featuring tracker and high-granularity calorimeter data for the first time. This trigger-less infrastructure has the potential to enhance CMS's sensitivity to signatures that could be limited by the current search phase space, and that are generally challenging to detect with traditional systems, such as rare decays, light resonances, and exotic signatures. Since the start of LHC Run 3, the L1DS demonstrator has been actively collecting muons and calorimeter objects. Initial analyses of the L1DS data have focused on characterizing this novel dataset, offering significant insights into the system's performance. These results not only showcase the functionality of the L1DS infrastructure but also highlight its potential for further applications.

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1. The Level-1 Trigger Data Scouting demonstrator

The CMS experiment at the LHC employs a two-level trigger system to select events for physics analysis [1]. The Level-1 Trigger (L1T) filters out approximately 99.75% of events due to bandwidth, processing, and storage limitations. The Level-1 Trigger Data Scouting (L1DS) introduces a novel approach to reduce trigger bias by capturing L1T objects at the full 40 MHz bunch-crossing (BX) rate [2]. The L1DS demonstrator, operational since LHC Run 3, serves as a testbed for the future L1DS system, which will be fully integrated into the L1T as part of the CMS Phase-2 upgrade for the High-Luminosity LHC (HL-LHC) [3]. The infrastructure expands the coverage of phase space accessible for signature searches, while also providing unbiased data for trigger and detector diagnostics, as well as large data samples for luminosity studies. The L1DS demonstrator is processing L1T objects from three primary sources: up to 8 muons per BX from the Global Muon Trigger (GMT); up to 12 jets, e/γ and τ per BX, plus energy sums, from the Layer-2 Calorimeter Trigger; and muon stubs from the Barrel Muon Track Finder (BMTF). Details on the system's architecture can be found in Refs. [3, 4].

2. L1DS results with LHC Run 3 data

The LHC orbit, consisting of 3564 bunches that are either filled or unfilled depending on the filling scheme, represents the unit of L1DS data collection. The scouting ZeroBias (ZB) stream captures one orbit every N orbits, where N corresponds to the prescale factor. By storing all BXs, it provides valuable information on the rate and multiplicity of objects per BX, as well as the overall occupancy within an LHC orbit. Figure 1 shows the BX occupancy for e/γ objects, muon and jet multiplicity [5]. These results, derived from the ZB stream, illustrate the system's ability to monitor trigger object distributions across various bunch crossings.

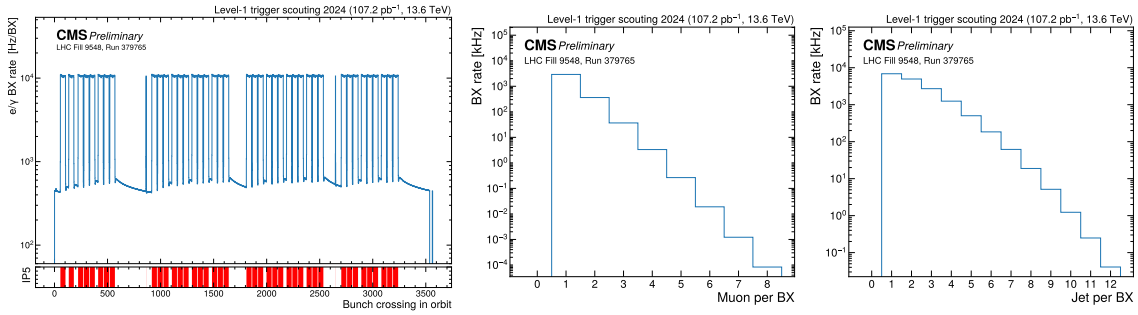

Figure 1: The distribution of the e/γ BX rate within an LHC orbit for fill 9548 (left). The bottom panel represents the filling scheme, where each bin indicates whether a bunch is filled (red) or unfilled (white). The rate multiplicity for muons (centre) and jets (right) is also shown for the same fill. The rate decreases as the number of objects per BX increases.

Standard Model candles are used as validation tools: the Z boson resonance is identified in both opposite-sign muon pairs and e/γ candidate pairs. In Figure 2, L1DS data are compared to L1 objects of Drell-Yan Monte Carlo (MC) simulated samples. The lower panel displays the ratio of the data to the fit performed, demonstrating a good agreement between the two [5].

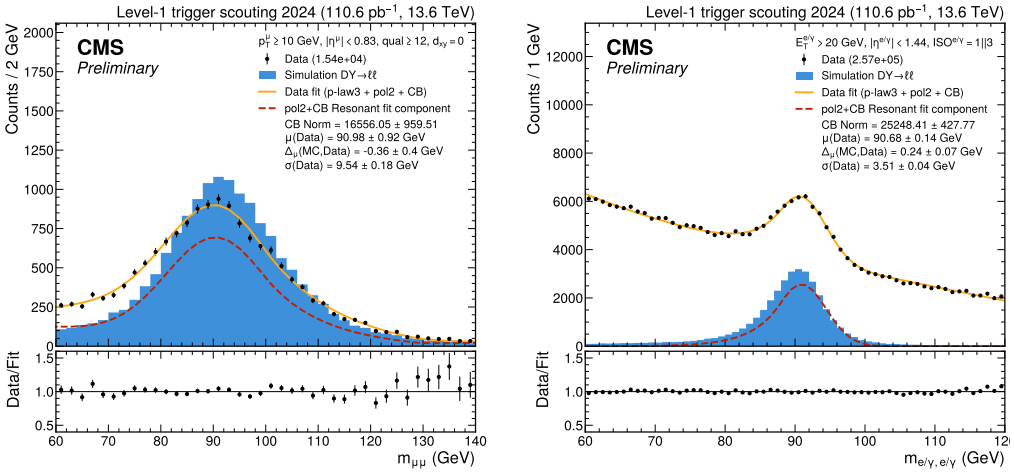

Figure 2: The invariant mass spectra for $\mu^+\mu^-$ pairs (left) and e/γ pairs (right), showing the Z boson resonance. The L1DS demonstrator data (black) are compared to DY MC simulations (blue). The fit to the data (orange) is performed using a combination of a power-law (p-law3), a second-order polynomial (pol2), and a Crystal Ball function (CB) for the resonant component. The fit to the resonance (red) is based on the pol2 and CB functions. The parameter Δ_μ accounts for any shift in the mean between the data and MC, reflecting L1T calibration effects.

The results of the L1DS analysis from Run 3 data confirm the system's functionality and provide insights into L1T objects and their resolution. The system successfully enables the collection and analysis of trigger objects at the full bunch-crossing rate, demonstrating the feasibility of 40 MHz data scouting.

Acknowledgments

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