Performance and Improvements of the ATLAS Level-1 Muon Trigger for Run 3

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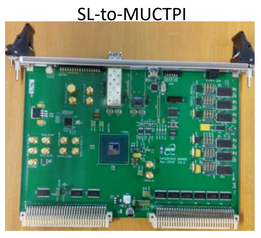
Yuichiro Hayashi(ICEPP, The University of Tokyo) on behalf of the ATLAS Collaboration
yuichiro.hayashi@cern.ch
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1MuonTriggerPublicResults

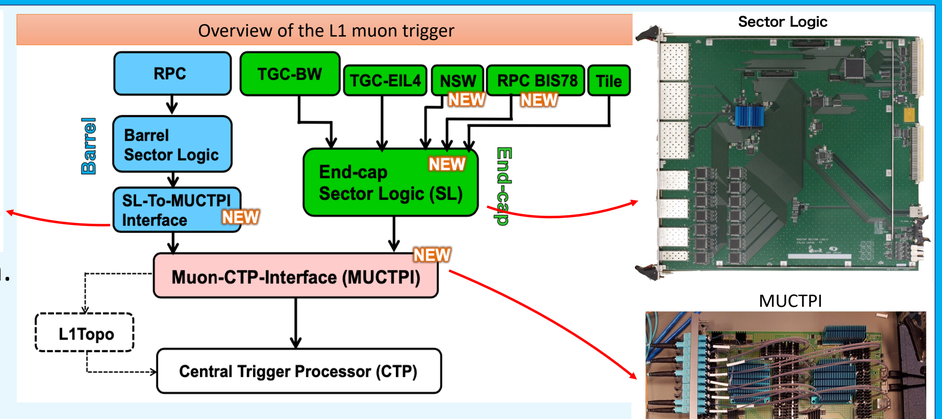
Abstract: The LHC is restarting the Run-3 operation for keeping longer time with an instantaneous luminosity of about 2×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ from this year to 2025. In order to cope with the high event rate, upgrades of the ATLAS Level-1 Muon trigger system were required. The new trigger system can enhance performance significantly by using finer track information from new muon detectors in the inner station NSW and RPC-BIS78. In order to handle data from both TGC and muon detectors in the inner station, a new trigger processor board known as Sector Logic (SL) and Muon-CTP-Interface (MUCTPI) has been developed. The commissioning status is shown as follows.

ATLAS Level1 Muon Trigger System for Run 3

- ATLAS Level-1 Muon Triger System
  - The trigger system of the ATLAS detector consists of the hardware-based **Level-1 Trigger (L1)** and a software-based High-Level Trigger (HLT).
  - The L1 trigger selection is based on the online reconstruction of muon objects by the **L1Muon Trigger system (L1Muon)** and calorimeter trigger objects by the L1 Calorimeter system.
  - The L1Muon system consists of **Endcap** ($1.05 \leq |\eta| \leq 2.4$) and **Barrel** ($|\eta| \leq 1.05$) triggers. The online muon reconstruction is performed by so-called **Sector Logic (SL)** processors. The **MUCTPI** receives the outputs **from the Endcap and Barrel SL** processors and sends them **to CTP and L1Topo**.
  - **Endcap** SL utilizes the **Thin Gap Chamber (TGC)** detectors with additional coincidence capability with tile hadronic calorimeter and the muon chambers in the inner station.
  - **Barrel** SL utilizes the **Resistive Plate Chamber (RPC)** detectors.

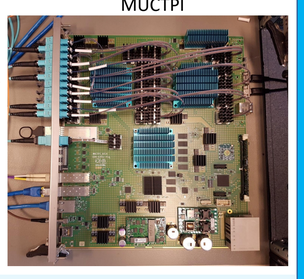
SL-to-MUCTPI



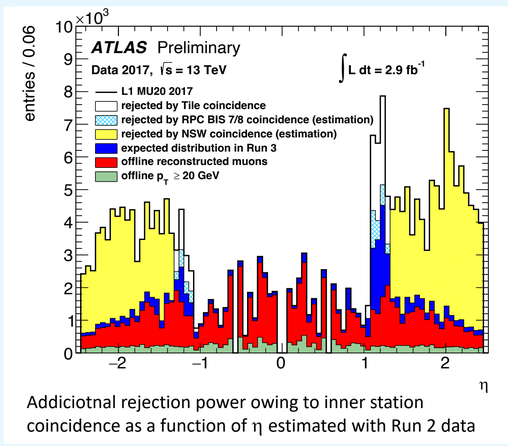


Sector Logic

MUCTPI

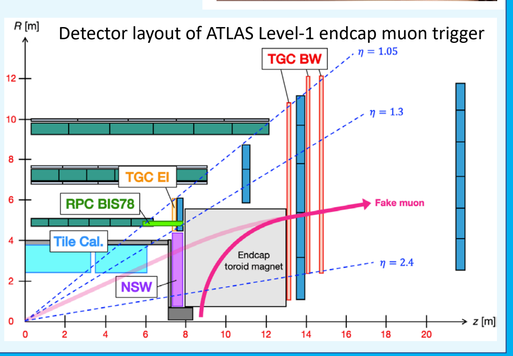


- L1Muon upgrade for the Run 3 (Phase-1 upgrade)
  - **A New SL processor** is introduced in the endcap system.
    - It extends the I/O and FPGA resources available for trigger logic implementation.
    - The upgrade allows us to have additional coincidence requirements with the track segments found in New Small Wheel (NSW) detectors for improved background rejection in the trigger level.
  - The **MUCTPI** has replaced the old system consisting of 18 VME boards with a new single board having high-speed optical I/O and a large-scale FPGA.
  - **SL-to-MUCTPI** is integrated for Barrel to cope with the upgraded interface for MUCTPI input.



Addiciotnal rejection power owing to inner station coincidence as a function of η estimated with Run 2 data

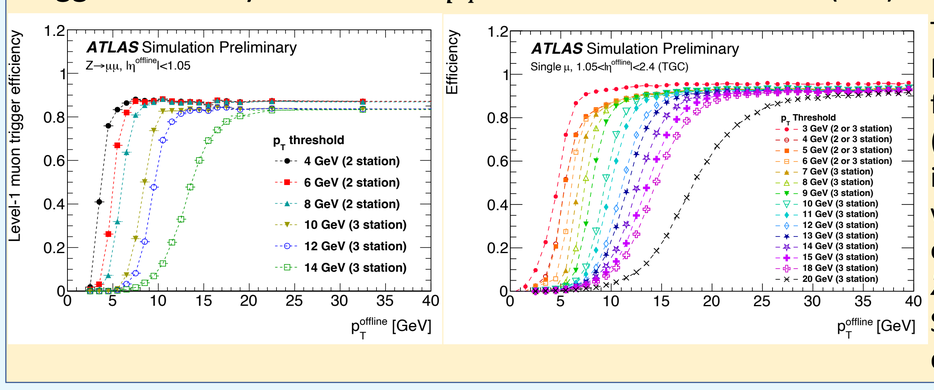
Detector layout of ATLAS Level-1 endcap muon trigger



New features of L1Muon Trigger in Run 3

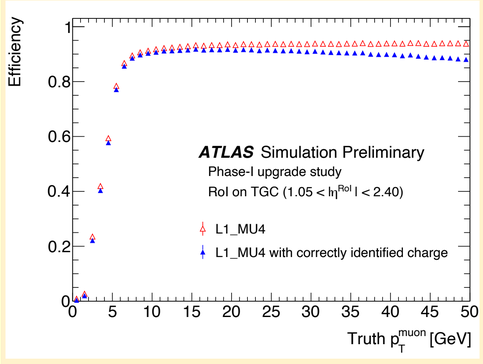
- **Additional information can be provided by Endcap and Barrel SL processors** with high-speed links between Sector Logic Boards and MUCTPI.
  - New finer granularity in the p_T thresholds in the Endcap region extends the capability of trigger rate control and improves the online event reconstruction in the L1Topo algorithm. The p_T thresholds in the Barrel regions have been coherently redefined.
  - Additional information is sent to MUCTPI to provide better selectivity.
    - Quality flags to specify candidates with worse momentum resolution (due to passing through a poor magnetic field region)
    - Charge information for L1Topo to perform event selections based on it (a new feature of Endcap SL)
    - A flag to specify that Barrel SL observes more than two candidates in a small area of RoI (Region of Interest), which improves efficiency for close-by dimuon events
- The major part of new algorithms in the Endcap Sector Logic have been implemented in the ATLAS trigger simulation framework. The new features for MUCTPI and L1Topo also have been implemented. The performance has been validated by MC simulation studies.

Trigger efficiency with various p_T thresholds in the Barrel (left) and Endcap (right) regions



The figures show the efficiency of the Run 3 Level-1 single muon triggers as a function of the transverse momentum (p_T) of the reconstructed offline muon in the Barrel and Endcap region for various p_T thresholds, respectively. The efficiency is estimated using simulated $Z \to \mu\mu$ events (left) and simulated Single μ events (right) with new definitions of p_T thresholds for Run 3.

The accuracy of identification of charge



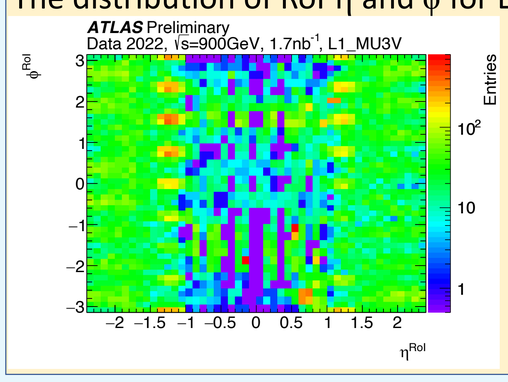
The figure shows the efficiency of the Level-1 endcap muon trigger with the p_T threshold of 4 GeV (L1_MU4) expected in Run 3 and the additional requirements for assigning the correct charge (blue), respectively. The efficiency was estimated by using a single-muon simulation with a flat distribution of η and ϕ. The accuracy of muon charge identification deteriorates in the high-p_T region.

L1 Muon Commissioning status

- Tools to ensure stable operation from the beginning of Run 3 data taking have been developed.
  - **The monitoring tools have been implemented** and fully tested in the combined tests.
  - **A system diagnostic tool has been implemented**.
    - Especially, for the commissioning of the new endcap SL system, we exploited the test pulse functionality of the TGC system. It allows us to tune the timing parameters without muons from collisions. Also, with the dedicated readout test, we spotted malfunctioned electronics and optical links and cleaned them up.
- Validation of L1Muon Trigger system with actual data taken in cosmic runs and early 900 GeV collisions.
  - **Timing parameters**, which are tuned in the test pulse runs, **have been fully validated** by the cosmic runs and LHC 900 GeV collisions.
  - All Endcap and Barrel trigger processors participated in the commissioning runs. **It is confirmed that all processors are functional** with respect to the observed η-ϕ distribution in the commissioning runs.

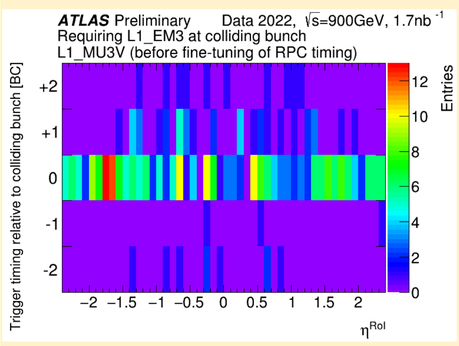
Early performance study with early 900 GeV collisions

The distribution of RoI η and ϕ for L1MU3V



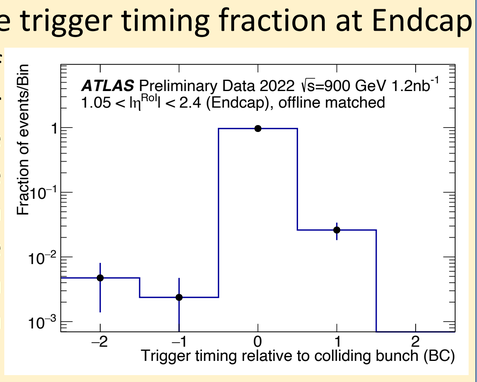
The figure shows the distribution of RoI η and ϕ for the Level-1 item L1_MU3V. The L1_MU3V is a level-1 muon trigger requiring thresholds at 3 GeV in the endcap region and 4 GeV in the Barrel region.

The trigger timing as a function of η



The left figure shows the trigger timing distribution of the L1Muon RoIs as a function of eta of RoIs region for the L1_MU3V Level-1 item. The right figure shows the trigger timing in only Endcap, where cosmic muons are not major contributions, for a more detailed study with offline muon matching required. The used events were recorded by other Level-1 items from muon in a colliding bunch so that the L1Muon trigger selection does not bias the timing distribution.

The trigger timing fraction at Endcap



Summary

- The Level-1 muon trigger is upgraded with new detectors and electronics for Run 3.
- The tools for diagnosing the system and monitoring have developed.
- Validation of L1Muon Trigger system with actual data taken in cosmic runs and early 900 GeV collisions.
  - Analysis of 900 GeV collisions run shows expected behaviors of the L1muon trigger.