PROCEEDINGS OF SCIENCE

The ATLAS Muon Trigger Design and Performance

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Muon triggers are essential for the studies of various physics processes at the ATLAS experiment, including Standard Model measurements and searches for new physics. The ATLAS muon trigger system consists of hardware based and software based subsystems. Both subsystems have been optimised during Run 2 to suppress the trigger rate while keeping the efficiency for high momentum muons. The performance of the muon triggers in Run 3 is expected to be improved by installing new detectors and exploiting multithreading technology. We present the improvements and the performance at Run 2 and the improvements and the readiness for Run 3.

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1. The ATLAS Muon Spectrometer

In the ATLAS experiment [1], the Muon Spectrometer consists of four types of subdetectors (Fig. 1). Resistive Plate Chambers (RPC) and Thin Gap Chambers (TGC) cover the barrel and endcap regions, respectively. Their fast response is exploited for the initial event selection at the muon trigger. Monitored Drift Tubes (MDT) and Cathode Strip Chambers (CSC) have higher position resolution. They are used for precise tracking at a later stage of the muon trigger and in the offline analysis.

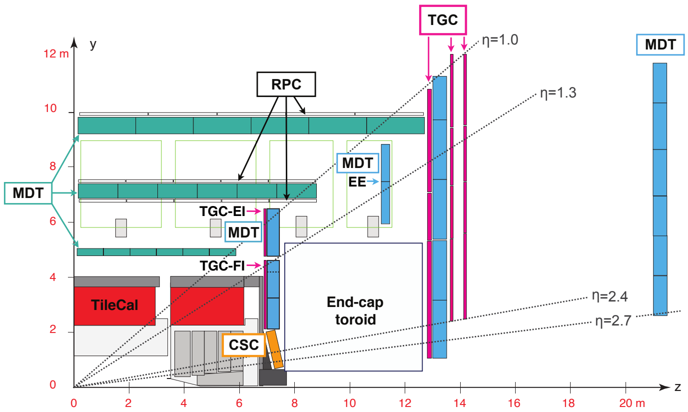


Figure 1: Schematic view of a quarter section of the muon spectrometer in a plane containing the beam axis [2]. The z-axis is taken as the beam axis, while the y-axis is perpendicular to the beam axis.

2. The Muon Trigger System

The ATLAS muon trigger has two stages. The first stage is based on hardware and called Level-1 (L1) trigger. In this stage, the coincidence of hits in RPCs and TGCs is required and the transverse momentum (p_T) of muon is estimated by comparison to expected muon track with infinite p_T. The L1 trigger outputs Regions of Interest (RoIs) that represent the location of the muon with a latency of 2.5 μs. The second stage is based on software and called High-Level Trigger (HLT). In this stage, fast tracking based on RoIs and precise tracking using offline reconstruction software are performed with an average latency of 0.2 s.

3. Improvement on Single-muon Triggers at HLT Level for Run 2

The muon trigger has been improved during Run 2 to cope with the high-pileup environment. Triggers requiring muons isolated from other physics objects are crucial for various physics analyses at the ATLAS experiment. In isolated muon triggers, a p_T-dependent isolation cone is defined around the muon candidate. The isolation criterion is defined as the p_T sum of the tracks in the cone over the muon p_T (Fig. 2). Tracks are selected if the distance between their impact parameter and the muon track in the beam axis ($|\Delta z|$) is within a defined value. The requirement on $|\Delta z|$ was originally set to 6 mm. The fraction was found to be higher in the high-pileup environment of the data-taking in 2017. The $|\Delta z|$ requirement was optimised to 2 mm, which mitigated the inefficiency of the isolated muon trigger in the high-pileup environment in the data collected in 2018.

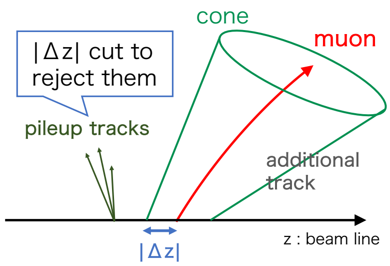


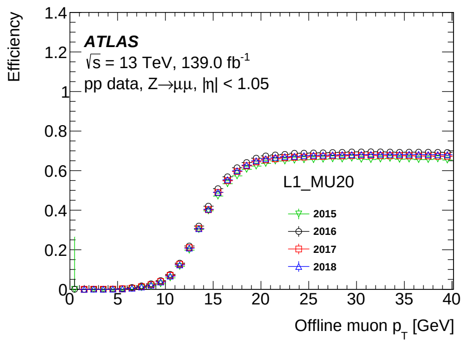
Figure 2: Illustration of the muon, the isolation cone, and the tracks originating from pileup. The tracks with |Δz| within a defined value are used for the isolation requirement.

Table 1: Trigger rates at 2×10^{34} cm^{-2}s^{-1} and efficiencies for two pileup values for the isolated single-muon trigger with p_T threshold of 26 GeV. The values are shown for three |Δz| requirements. The requirement used in 2018 was |Δz| < 2 mm [3].

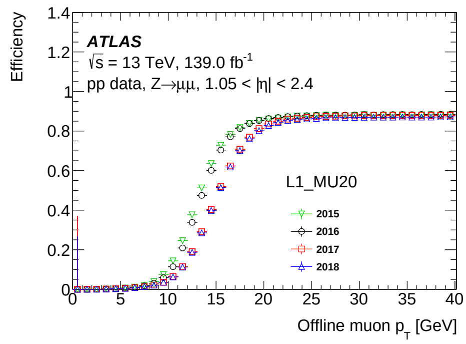
Requirement on |Δz|	Rate [Hz]	Efficiency at pileup = 60	Efficiency at pileup = 80
|Δz| < 6 mm	223	96%	91%
|Δz| < 2 mm	239	99%	97%

4. Performance of the Muon Trigger in Run 2

Fig. 3 shows the efficiencies of a L1 single-muon trigger with a p_T threshold of 20 GeV, and Fig. 4 shows the efficiencies of a single-muon trigger including L1 and HLT with a p_T threshold of 26 GeV in the barrel and endcap regions. The inefficiencies arise mainly from the limited geometrical coverage of the muon detectors. Similar efficiencies in the plateau region in Fig. 3 and 4 indicate that the muon trigger at HLT level is almost 100% efficient.



(a) Barrel region

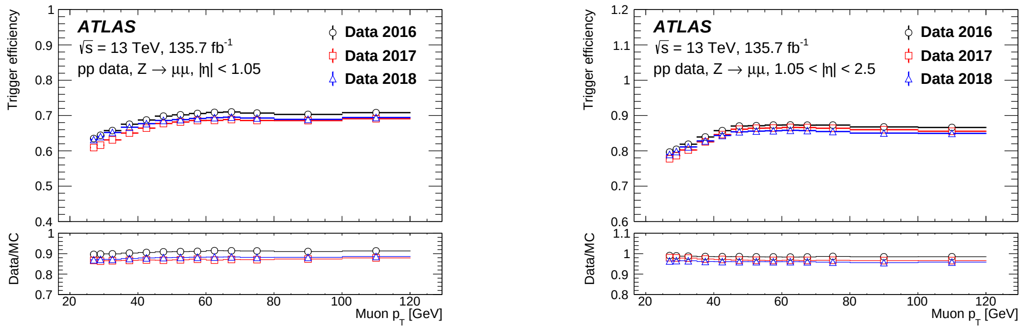


(b) Endcap region

Figure 3: Efficiencies of the L1 single-muon trigger with a p_T threshold of 20 GeV in the barrel (a) and endcap (b) regions, as a function of the reconstructed offline muon p_T in different years in Run 2 [2].

5. Improvements and Readiness for Run 3

The new muon detectors, which will be installed before the start of the Run 3 data taking, will be exploited to improve the trigger performance. A new RPC detector will be installed in the transition region between the barrel and endcap to increase coverage. The muon detectors inside



(a) Barrel region

(b) Endcap region

Figure 4: Efficiencies of single-muon trigger including L1 and HLT with a p_T threshold of 26 GeV in the barrel (a) and endcap (b) regions, as a function of the reconstructed offline muon p_T in different years in Run 2 [2].

the endcap toroidal magnet in $1.3 < |\eta| < 2.7$ will be replaced by the New Small Wheel (NSW) [4]. The NSW improves the precision of the coincidence between inner and outer stations of the muon detectors in the endcap region. As a result, misidentified and low p_T muons are suppressed as shown in Fig. 5.

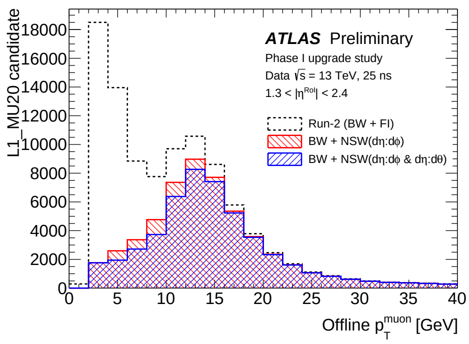


Figure 5: Distributions of p_T of offline reconstructed muons matched to muon candidates reconstructed in L1 trigger with a p_T threshold of 20 GeV in $1.3 < |\eta| < 2.4$ [5]. Requirements of the coincidence with NSW are applied for the colored distributions.

The multithreading approach is being introduced to the HLT software for optimised memory usage per CPU. The migration is completed, and the validation and the performance evaluation are in progress. The monitoring system has also been updated in response to the HLT software renewal. The number of the histograms to be monitored is reduced and the histograms are sorted out for simpler operation and maintenance at Run 3.

6. Summary

The ATLAS muon trigger system was successfully adapted to the challenging data-taking environment at the LHC. Stable and highly-efficient data taking was achieved in Run 2 (2015–2018). The upgrade of the muon trigger system is underway for the coming Run 3 period (2022–) both at the L1 and HLT levels.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[2] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*, *JINST* **15** (2020) P09015.

[3] ATLAS Collaboration, *Trigger menu in 2018*, ATL-DAQ-PUB-2019-001.

[4] ATLAS Collaboration, *New Small Wheel Technical Design Report*, ATLAS-TDR-020.

[5] ATLAS Collaboration, *L1 Muon Trigger Public Results*, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1MuonTriggerPublicResults.