PROCEEDINGS OF SCIENCE

ATLAS Level-1 Endcap Muon Trigger from Run 2 to Run 3

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In the Run-3 operation of the LHC from 2021, the center-of-mass energy is planned to be increased to 14 TeV, and the instantaneous luminosity is maintained at about 2.0×10^{34} cm^{-2} s^{-1}. In anticipation of a further increase of the luminosity in the future, an upgrade of the ATLAS trigger system is ongoing during the shutdown between Run 2 and Run 3. The level-1 endcap muon trigger system identifies high-p_{T} muons based on a coincidence of the signals from fast muon trigger detectors, Thin Gap Chamber (TGC), and the tile calorimeter (TileCal). From Run 3, in addition to them, new muon detectors, New Small Wheel (NSW) and RPC-BIS78, will be installed to provide better means for fake rejection and momentum resolution of the muon trigger. A combination of signals from TGC, TileCal, NSW, and RPC-BIS78 and wider η coverage of NSW can improve the performance of the level-1 endcap muon trigger significantly. A trigger processor, Sector Logic (SL) board, will be fully upgraded, which collects the signals from the four different detectors, performs a fast reconstruction of the muon candidates and passes the results to an interface board between muon trigger systems and the central trigger processor (CTP), called MUCTPI. An increased number of logic gates and the new high-speed optical interface make it possible to send much more information to MUCTPI, for example, p_{T} measured in 15 steps from 4 GeV to 20 GeV, muon charge information, and some trigger condition flags. The expected efficiency is about 97% for muons with $p_{\mathrm{T}} > 20$ GeV compared to the Run 2 performance, while the trigger rate is reduced down to 8–13 kHz depending on the configuration of NSW. The installation of the new SL boards has been completed, and the on-site commissioning is in progress.

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1. Introduction

In the Run-3 operation of the Large Hadron Collider (LHC) from 2021, the center-of-mass energy is planned to be increased to 14 TeV, and the peak luminosity at the ATLAS detector is maintained at about 2.0×10^{34} cm^{-2} s^{-1}. In anticipation of a further increase of the luminosity in the future, an upgrade of the ATLAS trigger system is ongoing during the long shutdown between Run 2 and Run 3. From Run 3, new muon detectors, New Small Wheel (NSW), and RPC-BIS78, will be installed as shown in Figure 1, to provide wider η coverage and a better angular resolution of the muon trajectory at the inner station for the endcap muon trigger. This article presents the upgrade of the ATLAS level-1 endcap muon trigger system to integrate the new detectors and provide more detailed information of the muon candidates to an interface board between the muon trigger system and the central trigger processor (CTP), called MUCTPI, for the central level-1 trigger decision.

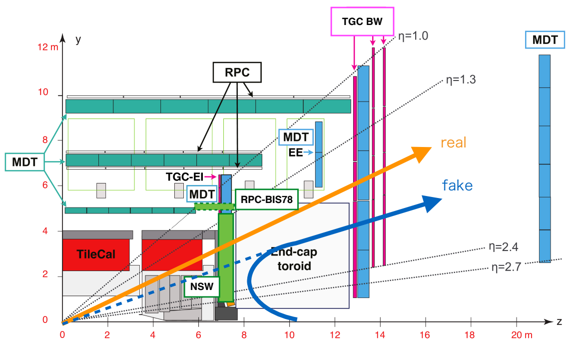

Figure 1: A schematic picture showing a quarter-section of the muon system in a plane containing the beam axis [1]. In addition to 3-station coincidence at TGC Big Wheel (BW), TGC-EI, tile calorimeter (TileCal), RPC-BIS78 and NSW will be used in the endcap muon trigger system in Run 3. Requiring the hit at the inner detector can reduce the background coming from soft particles (fake) misidentified as the high-p_T real muon, as shown by the blue dashed line. MDT is a detector for the measurement at HLT and offline algorithms.

2. Upgrade of the level-1 endcap muon trigger system

The ATLAS trigger system consists of two steps: the level-1 trigger roughly selects events containing interesting physics objects, such as high-p_T muons, using custom-made hardware and reduces the event rate to about 100 kHz; the software-based high-level trigger (HLT) applies more sophisticated selection, and events are recorded at about 1 kHz. Various "trigger chains" are defined depending on the instantaneous luminosity. The primary single muon trigger chain is optimized to keep high efficiency for events containing at least one muon with $p_T > 20$ GeV and no prescale depending on luminosity is applied for it. The level-1 bandwidth allocated to the primary single muon trigger is about 15 kHz.

In early Run 2, the level-1 endcap muon trigger system reconstructed muon candidates based on a coincidence of the three stations of the Thin Gap Chamber (TGC) Big Wheel (BW), assuming the interaction point, as shown by the orange line in Figure 1. Each station of TGC BW provided two-dimensional spacial point measurements (r, ϕ) of the muon candidate trajectories at the surface. Detector signals were collected by a trigger processor board, Sector Logic (SL) board, and the muon candidate's p_T was determined from a look-up table which described the pre-estimated relation between p_T and the hit patterns of TGC-BW stations, taking into account the magnetic field and the matter effect at the given detector position. The SL board sent p_T and spacial information of the muon candidates to MUCTPI. The muon p_T was classified in 6 groups, each of which aiming at selecting muons with $p_T > 4$ GeV (MU4), 6 GeV (MU6), 8 GeV (MU8), 10 GeV (MU10), 15 GeV (MU15) and 20 GeV (MU20). The primary single muon trigger chain required at least one muon candidate satisfying the MU20 requirement in the event, while primary di-muon and tri-muon chains required at least two and three muons with MU10 and MU4, respectively. MUCTPI passes the muon candidates' information not only to CTP but also to the level-1 topological trigger processor (L1Topo). It can apply cuts on event topologies, like di-muon mass and angular separation, with the allocated latency to the level-1 triggers in some chains.

Figure 2 shows the η distribution of the level-1 MU20 candidates taken in the early Run 2 period. Events containing real muon candidates reconstructed by the offline algorithm are shown by the red histogram. In the endcap region ($|\eta| > 1.05$), more than half of MU20 candidates were not matched to the offline muons, which are supposed to be "fake". Soft particles produced from nuclear interactions with the toroidal magnets and detector support materials, and a part of them, pointing to the interaction point, are misidentified as high-p_T muons, as illustrated by the blue dashed line in Figure 1. In order to reduce such fake muon backgrounds, hits at the inner station, TGC EI/FI chambers covering $1 < |\eta| < 1.8$ and tile calorimeter (TileCal) to compensate the inefficiency of TGC EI/FI in $1 < |\eta| < 1.3$, had been integrated into the coincidence logic [1]. As a result, the primary MU20 rate was about 15 kHz in the last year of Run 2, and the efficiency for muons with $p_T > 20$ GeV was about 88%.

From Run 3, NSW covers the wider η range $1.3 < |\eta| < 2.4$ than TGC FI used in Run 2. It provides a better angular resolution of the muon candidate trajectories at the inner station. In addition to the coincidence between NSW and TGC-BW hits, the polar angle measured by the NSW is required to be close to the angle measured by the NSW hit position and the interaction point. The resolution of the muon p_T at level-1 is improved, and low-p_T muons are removed effectively. RPC-BIS78 newly provides the inner-station hit in specific ϕ ranges in $1 < |\eta| < 1.3$, which has finer η granularity than TileCal. The SL board will be fully upgraded to integrate the new detectors and to improve the muon reconstruction performance [2]. MUCTPI will also be upgraded and be connected via a high-speed optical link with the SL boards. An increased number of logic gates in the SL board and the new optical links make it possible to send much more information, for example, p_T measured in 15 steps from 4 GeV to 20 GeV with an interval of 1 GeV, muon charge information, and some trigger condition flags. In addition, MUCTPI will be able to send the

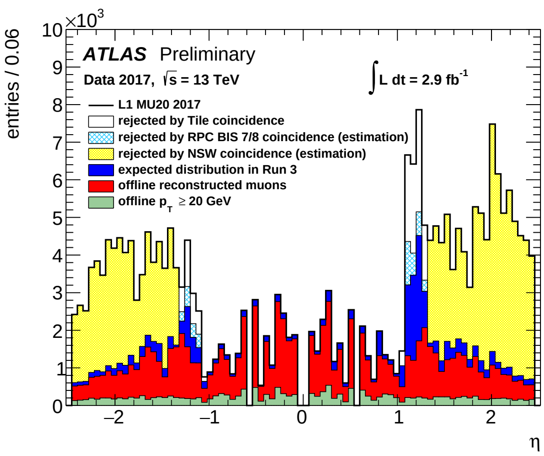

Figure 2: The η distribution of the level-1 MU20 candidates in 2017 data [3]. In Run 3, white, cyan and yellow contributions are rejected by tile calorimeter, RPS-BIS78, and NSW coincidences in the level-1 endcap muon system, respectively, and the expected distribution is shown by blue histogram. Signals at RPC-BIS78 and NSW are emulated by the MDT hits. Events containing at least one muon reconstructed by the offline algorithm and those with $p_T > 20$ GeV are estimated by the simulation and shown by red and green histograms, respectively.

muon (η, ϕ) information with finer granularity than Run 2, which leads to a better di-muon mass resolution in the L1Topo. The new SL board is already installed in the ATLAS counting-room, and the on-site commissioning is ongoing.

3. Expected performance

The performance of the Run 3 endcap muon trigger system is estimated by the simulation and the Run 2 data. The efficiency of the primary MU20 for muons with $p_T > 20$ GeV is estimated by the simulation and found to be 97% compared to the Run 2 system (the inefficiency of 3% comes from NSW track finding efficiency) [3]. The expected MU20 rate is estimated by the data, and it is found to be 8 kHz, as shown by the blue histogram in Figure 2. The signals from the new detectors are emulated by the MDT hits. In case NSW is installed only on one side of the detector ($\eta > 1$), it is expected to be 13 kHz, which can still meet the requirement of the experiment. The muon charge is measured at the TGC BW, and its accuracy is found to be greater than 98% at $p_T < 30$ GeV [3]. It is used for example to reconstruct opposite-sign muon pairs in the L1Topo processor. The measurement of p_T with 15 steps instead of 6 steps improves the muon p_T resolution in the L1Topo, which is about 30% at $p_T = 4$ GeV and about 15% at 20 GeV.

4. Summary

The upgrade of the ATLAS endcap muon trigger system for the LHC Run 3 has been presented. Newly introduced coincidence with inner detectors with the upgraded SL board achieves a significant fake muon reduction while keeping the efficiency as high for real muons. The expected trigger rate of the primary trigger, MU20, is 8 kHz, which meets the requirement of the experiment at 15 kHz. Additional information will be sent to the MUCTPI and the L1Topo processor. For example, muon p_T measured in 15 steps from 4 GeV to 20 GeV and muon charge measured with about 98% accuracy at $p_T < 30$ GeV can be used in the L1Topo. The new SL board is installed in the ATLAS counting-room, and the on-site commissioning is ongoing.

References

[1] ATLAS Collaboration, Performance of the ATLAS muon triggers in Run 2, arXiv:2004.13447 (submitted to JINST), 2020.

[2] ATLAS Collaboration, Technical Design Report for the Phase-I Upgrade of the ATLAS TDAQ System, CERN-LHCC-2013-018, ATLAS-TDR-023, 2013. https://cds.cern.ch/record/1602235

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