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ATLAS Level-0 Endcap Muon Trigger for HL-LHC

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High-Luminosity LHC (HL-LHC) is an upgrade of LHC to achieve higher luminosities, enabling experiments to reach better physics sensitivity. Operation of HL-LHC is scheduled to start in 2026 with an instantaneous luminosity of $7.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In order to cope with the luminosity, the trigger and readout systems are planned to be upgraded. The new Level-0 endcap muon trigger system is required to reconstruct muon candidates with an improved momentum resolution to suppress trigger rate while keeping efficiency. That can be achieved by combining signals from thin gap chambers and various subdetectors. Design for the Level-0 endcap muon trigger of the ATLAS experiment at HL-LHC and status of the development are presented.

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1. Introduction

The ATLAS detector [1] is a general-purpose detector at the Large Hadron Collider (LHC), investigating a wide range of physics. HL-LHC is expected to start operations in 2026 with an instantaneous luminosity of $7.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, resulting in a total integrated luminosity of 3000 fb^{-1} after its ten years of operation. As the instantaneous luminosity is increased to its ultimate configuration, the experiment needs to cope with about 200 proton-proton collisions per bunch crossing. In order to handle this high luminosity, the trigger and readout systems are planned to be upgraded. This paper describes design and development status of the Level-0 endcap muon trigger of the ATLAS experiment at HL-LHC.

2. Level-0 endcap muon trigger scheme for HL-LHC

In the original scheme for the first level of the muon trigger, muon track candidates are identified by simple coincidence logic in on-detector boards and the transverse momentum (p_T) is evaluated by look-up tables in off-detector trigger logic boards.

In the new Level-0 endcap muon trigger for HL-LHC, all hit information is transferred from the on-detector boards to the new off-detector boards. Muon track "segments" are reconstructed in the Thin Gap Chamber on the Big Wheel (TGC BW) due to the availability of the individual hits. TGC is a multi-wire proportional chamber which measures two-dimensional position using signals from wires and strips orthogonal to the wires. TGC BW consists of three stations: Station M1, M2 and M3 have three, two and two layers, respectively, as shown in Fig. 1a .

The main source of background in the muon endcap trigger system is low-momentum charged particles emerging from the endcap toroid magnets ("fake muons"). Triggers by the fake muons are suppressed by combining signals from various subdetectors: TGC in the endcap inner station (TGC EI), Resistive Plate Chambers in the barrel inner station (RPC BIS78), New Small Wheel (NSW), and Tile hadronic calorimeter (TileCal) as shown in Fig. 1a and Fig. 1b.

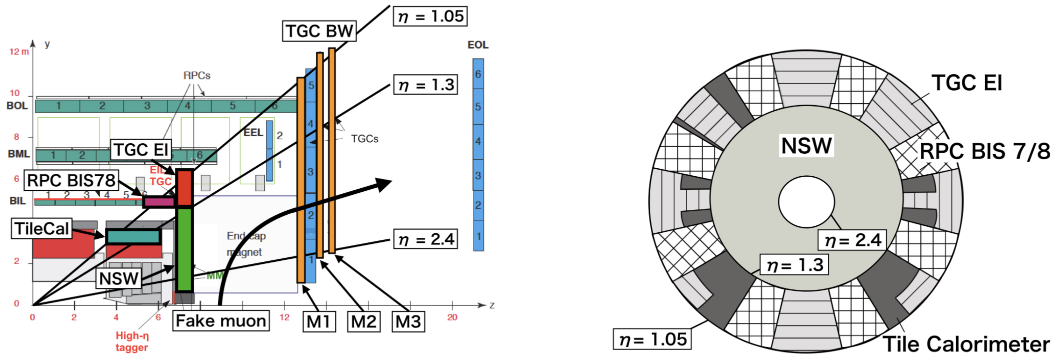
After the muon track candidates are provided by TGC BW and the subdetectors, the Monitored Drift Tube (MDT) is used to improve the p_T resolution at the Level-0 muon trigger.

The trigger logic is provided for each sector defined by the boundaries of combinations of RPC and TGC chambers and implemented on an FPGA in Sector Logic (SL). SLs receive information from the subdetectors as inputs for the trigger logic. The Virtex UltraScale(+) FPGAs provided by Xilinx are assumed for the FPGA on SL.

3. TGC track segment reconstruction

The track segments are reconstructed in TGC with a pattern matching algorithm that compares the TGC hits with predefined hit lists for high-p_T muons. Each predefined hit pattern has angle and position associated to a track segment. Average angular resolution is about 4 mrad as shown in Fig. 2.

In the trigger scheme by Run-3, at least two (one) hits in the inner three (two) layers and at least three hits in the outer four layers for wires (strips) are required for the high-p_T muons. In the endcap SL for HL-LHC, a looser coincidence with at least five (four) hits in the seven (six) layers for wires (strips) is required to improve the efficiency.



(a) R-Z view (b) X-Y view

Figure 1: Layout of the ATLAS muon spectrometer. [2]

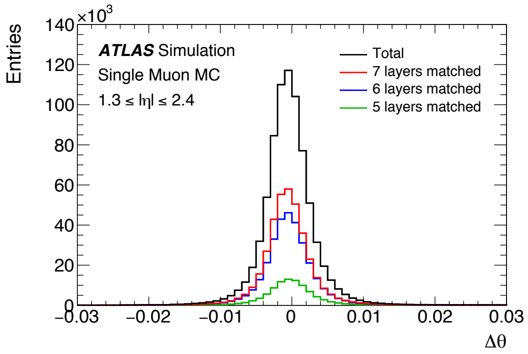


Figure 2: Distributions of difference of the polar angle ($\Delta\theta$) between the TGC track segments and track segments reconstructed in MDT. Red, blue and green histograms are for the TGC track segments reconstructed with seven, six and five hits respectively. The black histogram is the sum of the three histograms.[3]

4. Trigger scheme using inner detectors

Muon candidates in the trigger system are provided by combining the TGC track segments reconstructed in TGC BW and the information from the subdetectors.

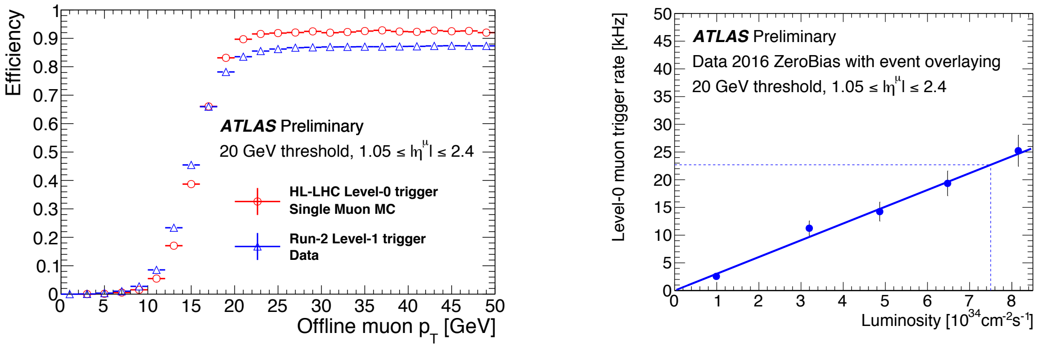
In $1.05 < |\eta| < 1.3$, the p_T is determined with a combination of the position and the angle of the TGC BW track segments and the positions of the hits in TGC EI, RPC BIS78 and TileCal.

In $1.3 < |\eta| < 2.4$, the p_T is determined with the polar angle difference between the TGC BW track segments and the tracks reconstructed in NSW.

5. Improvement of trigger performance

Trigger performance of the Level-0 endcap muon trigger (not including the more precise p_T measurement in MDT) is evaluated here. Figure 3a shows expected efficiency to offline muons of the new trigger algorithm obtained with a single muon Monte Carlo simulation sample. Compared to the trigger scheme in Run-2, higher efficiency in the plateau region and better rejection for the low p_{T} muons are obtained thanks to the looser coincidence and the good angular resolution, respectively.

Figure 3b shows expected trigger rates; the lowest luminosity point is taken from Run-2 data using random trigger and the higher luminosity points from overlaying the Run-2 events. The obtained trigger rate for 20 GeV threshold is about 23 kHz at the luminosity of $7.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is the nominal value of HL-LHC. Further rate reduction by $\sim 50\%$ in the next step with MDT is expected.



(a) (b)

Figure 3: (a) Expected efficiency for the Level-0 muon trigger with the HL-LHC scheme (red) and with the Run-2 scheme (blue) . (b) Estimated rate of the Level-0 single muon trigger at HL-LHC based on TGC, TileCal, and NSW for a pseudorapidity range $1.05 < |\eta| < 2.4$ and a p_{T} threshold of 20 GeV.[4]

6. Summary

The performance of the Level-0 muon trigger for HL-LHC is evaluated and it showed higher efficiency and better rejection for the low p_{T} muons, compared to the current system. The rate for 20 GeV threshold is about 23 kHz.

References

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

[2] ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer, CERN-LHCC-2017-017. `https://cds.cern.ch/record/2285580`

[3] ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS TDAQ system, CERN-LHCC-2017-020. `https://cds.cern.ch/record/2285584`

[4] ATLAS Collaboration, Level-0 TGC trigger performance of trigger algorithms in software and firmware implementations, `https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L0MuonTriggerPublicReults`