PROCEEDINGS OF SCIENCE

The Muon Trigger of the ATLAS experiment: performance and improvements for Run 3

Andrea Ventura[a,*] **on behalf of the ATLAS Collaboration**

[a] *Università del Salento & Istituto Nazionale di Fisica Nucleare – Sezione di Lecce Via per Arnesano, Lecce, Italy*

E-mail: andrea.ventura@le.infn.it

Events with muons in the final state are fundamental to detecting a large variety of physics processes in the ATLAS detector, including both high precision Standard Model measurements and new physics searches. To this purpose, the ATLAS Muon Trigger has been designed and developed in two levels: a hardware based system (Level-1) and a software based reconstruction (High Level Trigger). They have been optimized to keep the trigger rate as low as possible while maintaining a high efficiency, despite the increased particle rates and pile-up conditions at the LHC. An overview of the muon triggering strategies will be provided, showing the performance on Run 2 data of both the Level 1 and High Level Trigger. The most recent improvements implemented for Run 3 will also be presented.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)654

1. Introduction

ATLAS [1] is a multi-purpose experiment running at the Large Hadron Collider (LHC) for high-precision Standard Model (SM) measurements and beyond SM searches. Its largest subdetector, the Muon Spectrometer (MS), aims at identifying and reconstructing muons with transverse momentum (p_T) up to 1 TeV. This is performed with a relative accuracy $\Delta p_T / p_T < 10\%$ over a range of $|\eta| < 2.7$, being η the pseudorapidity, defined as $\eta = -\ln[\tan \theta/2)]$ where θ is the polar angle with respect to the beam axis. In order to achieve a trigger decision based on fast readout, the MS uses Resistive Plate Chambers (RPC) and Thin Gap Chambers (TGC), arranged in three layers respectively in the barrel ($|\eta| < 1.05$) and in the endcap regions ($1.05 < |\eta| < 2.4$) [2]. High resolution tracking in the MS is performed with Monitored Drift Tubes (MDT) and Cathode Strip Chambers (CSC), in the barrel and endcap regions, respectively [3]. Further detector updates prepared and realized for the Run 3 are discussed in the following.

2. The ATLAS Muon Trigger system

The trigger system of the ATLAS experiment is based on two primary components, as described in the left part of Figure 1 [4]: a hardware-based Level-1 (L1) trigger and a software-based High-Level Trigger (HLT). The initial 40 MHz rate of proton-proton collisions produced by the LHC is first reduced down to 100 kHz by the L1, collecting trigger information on various objects from the calorimeters and from the MS. A further reduction is obtained through the HLT down to ~1 kHz, an optimal rate for the subsequent data storage.

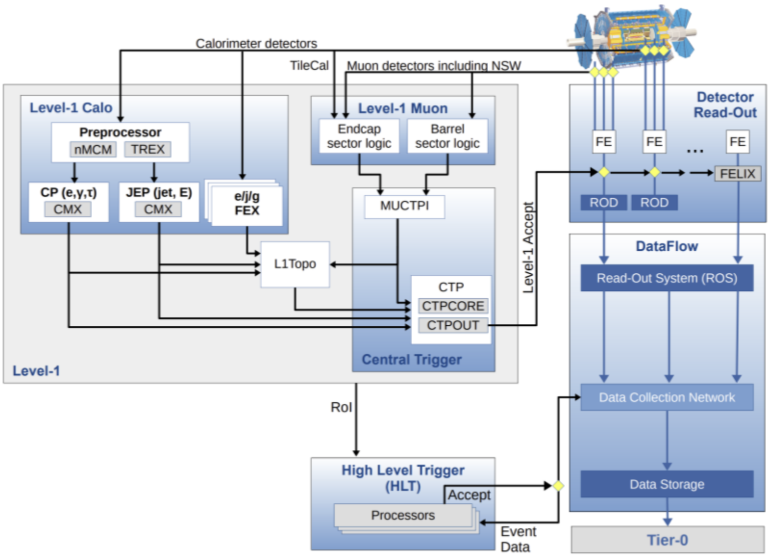

Figure 1: Block diagram of the ATLAS Trigger and DAQ system for Run 3 [4]. The Trigger is composed of Level-1 and High Level Trigger (blocks on the left), selecting data for collection and storage by the DAQ system (blocks on the right).

The Muon L1 produces transverse momentum estimates, which are obtained for each muon candidate as the degree of deviation from the hit pattern of infinite-p_T tracks with hits in RPCs and TGCs. Regions of Interest (RoIs) are defined in terms of spatial coordinates and p_T thresholds, which are then passed to the HLT for a more precise software reconstruction, based on information from both the MS and the Inner Detector (ID). The Muon HLT event selection is performed in two stages, both using information from the MS only and then combined with the ID. A fast reconstruction is first performed inside muon RoIs (which usually runs in few ms) and then more precise measurements of track parameters are realized using full reconstruction tools (typically running in a few hundreds of ms).

2.1 L1 Muon trigger

In Figure 2 a quarter-section longitudinal view of the MS setup for the Run 3 is shown. The upgrades of the detector with respect to Run 2 are highlighted: sMDT chambers and thin-gap RPCs in the region $1.0 < |\eta| < 1.3$, innermost muon chamber layers replaced with higher-granularity sTGCs and MicroMegas in New Small Wheels (NSW) in $1.3 < |\eta| < 2.7$ [5]. A new sector logic has been implemented in the TGC Big Wheel to cope with the higher rates expected in Run 3 [6].

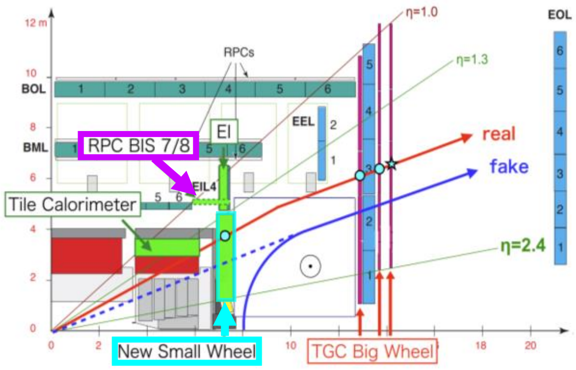

Figure 2: Schematic view of a quarter section of the muon spectrometer in a plane containing the beam axis [2].

Position and angle matching requirements between NSW hits and TGC Big Wheel hits (Figure 3) are expected to improve the quality of track reconstruction in Run 3 with respect to Run 2. Moreover, taking into account the effects due to multiple scattering with the detector material, the rate of fake muon triggers coming from low-p_T charged particles not originating at the interaction point is expected to be significantly reduced [6].

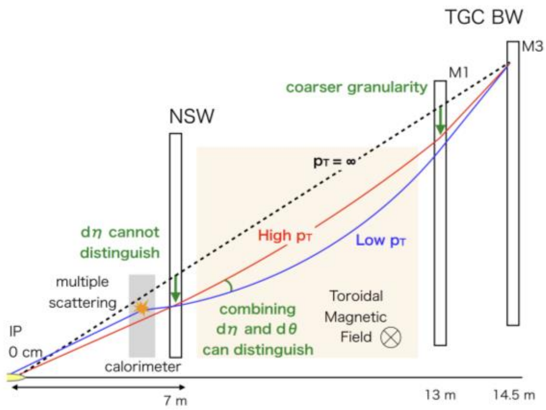

Figure 3: Schematic diagram of the angular matching algorithm performed between the TGC Big Wheel (BW) and the New Small Wheel (NSW) [6].

2.2 Muon HLT rates

At the instantaneous luminosity planned for Run 3 *pp* collisions (L=2.0×10^{34} cm^{-2}s^{-1}), muon trigger rates are expected to be very similar to those observed during Run 2. In Table 1, the lowest unprescaled triggers corresponding to a few muon signatures of interest are compared in terms of L1 and HLT rates between Run 2 observations and Run 3 expectations.

Muon trigger category	**Run 2** (L=1.7×10^{34} cm^{-2}s^{-1})			**Run 3** (L=2.0×10^{34} cm^{-2}s^{-1})		
	HLT p_T threshold [GeV]	L1 rate [kHz]	HLT rate [Hz]	HLT p_T threshold [GeV]	L1 rate [kHz]	HLT rate [Hz]
1 isolated μ	26	15	180	24	16	220
1 μ	50	15	60	50	16	40
2 μ	14, 14	1.8	26	14, 14	2.2	25

Table 1: Transverse momentum threshold, L1 rate and HLT rate for the luminosity reached during Run 2 (1.7×10^{34} cm^{-2} s^{-1}) and for the luminosity expected in Run 3 (2.0×10^{34} cm^{-2} s^{-1}), concerning some representative muon trigger signatures [2].

In the case of the triggers involving isolated muons [3], the lowest unprescaled HLT p_T threshold has been reduced from Run 2 (26 GeV) to Run 3 (24 GeV), allowing to significantly extend the physics potential and to improve statistics for all analyses characterized by low p_T muons, while keeping a reasonable trigger rate. In the case of non-isolated muon and symmetric di-muon triggers, the lowest unprescaled thresholds (50 GeV and 14 GeV, respectively) have been confirmed in Run 3, while expecting a moderate total trigger rate reduction with respect to Run 2.

3. Muon trigger performance in Run 2

Muon trigger efficiencies are measured directly on data by means of the «Tag-and-Probe method» [2], based on di-muon events (such as $Z\to\mu\mu$ and $J/\Psi\to\mu\mu$). The efficiencies corresponding to the lowest unprescaled L1 and HLT single muon triggers for Run 2 are shown in Figures 4 and 5, respectively, as a function of the offline muon p_T [2], separately for the barrel (left) and for the endcap (right) regions. The values obtained for different years of data taking are superimposed. The L1_MU20 trigger corresponds to a p_T threshold of 20 GeV.

PoS(ICHEP2022)654

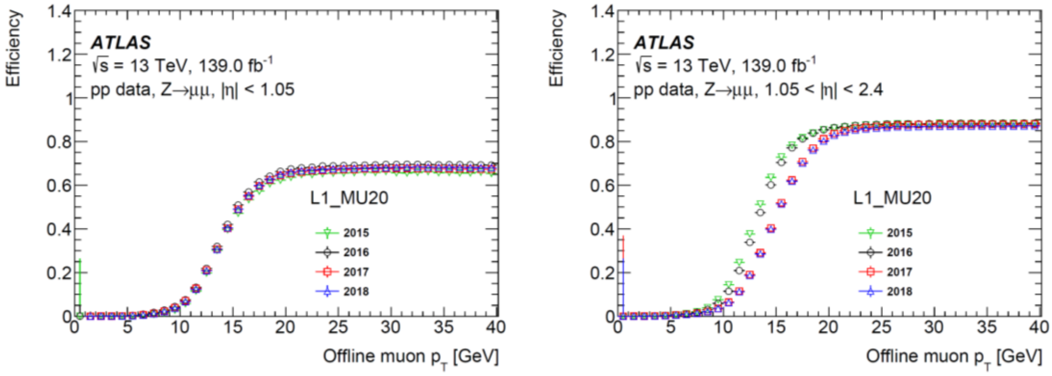

Figure 4: Efficiency of the L1_MU20 trigger as a function of the offline-reconstructed muon p_T in barrel (left) and in endcap (right) MS regions [2].

The considered efficiencies at HLT are computed for the OR of HLT_mu26_ivarmedium and of HLT_mu50, which correspond to the lowest unprescaled triggers, respectively, of isolated muons (p_T > 26 GeV) and of non-isolated muons (p_T > 50 GeV). The plateau values observed for the efficiencies are ≈68% (≈85%) in the barrel (endcap) regions, and are mostly due to L1 criteria, while the HLT efficiency relative to L1 is close to unity. The lower efficiency in the barrel region is essentially due to reduced geometrical coverage.

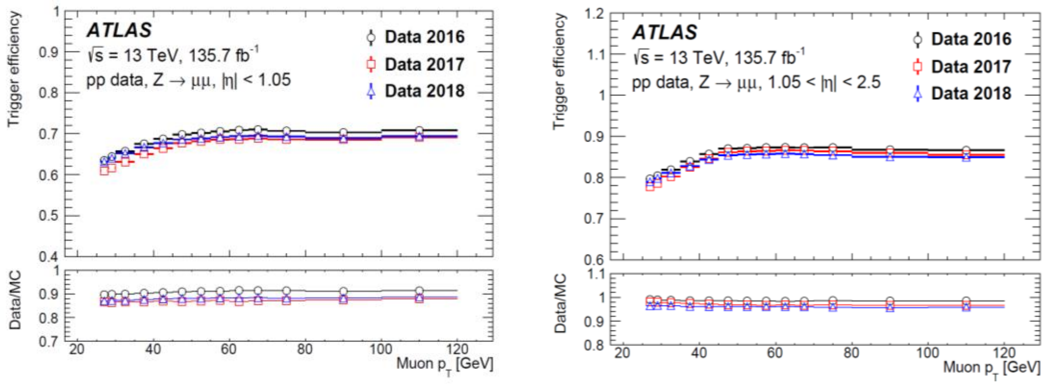

Figure 5: Efficiency of passing either HLT_mu26_ivarmedium or HLT_mu50 trigger as a function of the offline-reconstructed muon p_T in barrel (left) and endcap (right) MS regions [2].

4. Expected muon trigger performance in Run 3

The muon trigger performance has been studied considering the new muon detectors and the improved conditions for Run 3, for an expected integrated luminosity of 300 fb^{-1}. As an example, the installation of the NSW is expected to improve the precision of the coincidence between inner and outer stations of the muon detectors in the endcap region [7]. As shown in Figure 6 (left), the misidentification of low-p_T tracks as muons is expected to be strongly suppressed, allowing a ≈45% rate reduction below the 20 GeV threshold in Run 3 with respect to Run 2, with a negligible efficiency loss. Figure 6 (right) also shows the η distributions of L1 muon candidates with p_T > 20 GeV, including both measurements obtained in Run 2 and estimates for

PoS(ICHEP2022)654

Run 3: large part of the rate reduction is expected as a consequence of the coincidences involving the NSW and the RPCs in the transition region $1.0 < |\eta| < 1.3$ [7].

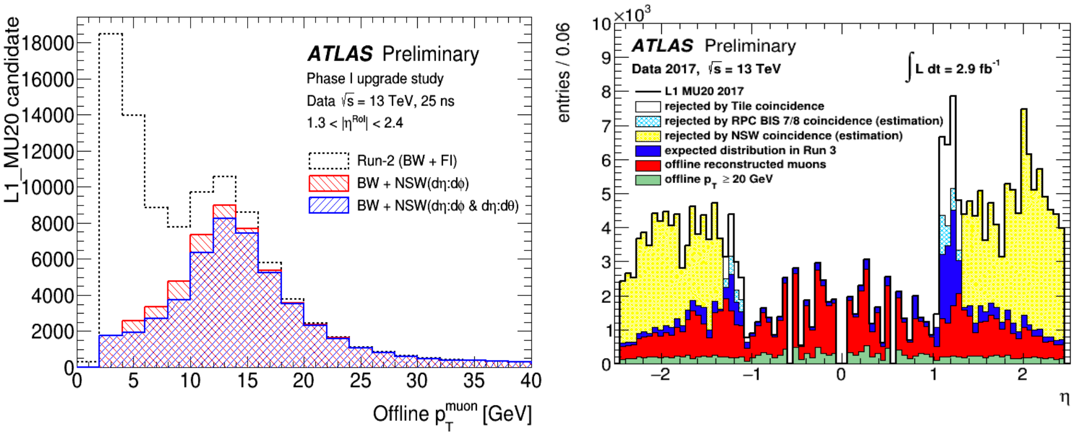

Figure 6: Distribution in p_T of muons passing the L1 primary trigger, showing the suppression of low-p_T candidates by the TGC BW-NSW coincidence requirements [7] (left). Pseudorapidity distributions of the L1 muon candidates with $p_T > 20$ GeV collected in Run 2 with a center-of-mass energy of 13 TeV and a bunch-crossing interval of 25 ns [7] (right).

Another important upgrade for the muon trigger software in Run 3 concerns the full migration of the HLT system to a multi-threaded platform which will allow to minimize CPU and memory usage.

5. Conclusions

The ATLAS Muon Trigger system has shown excellent performance during the Run 2 of the LHC (2015-18), successfully fulfilling all physics program requirements. Stable performance and high efficiencies have been achieved in the Muon Trigger, both at L1 and at HLT. Various upgrades have been realized toward Run 3 (2022-24) to handle higher luminosity at the LHC, while ensuring no efficiency losses with respect to Run 2.

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, *Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at √s = 13 TeV*, Eur. Phys. J. C **81** (2021) 578.

[4] ATLAS DAQ public plots, *https://twiki.cern.ch/twiki/pub/AtlasPublic/ApprovedPlotsDAQ/tdaq-run3-schematic-withoutFTK.pdf*.

[5] ATLAS Collaboration, *New Small Wheel Technical Design Report*, CERN-LHCC-2013-006, ATLAS-TDR-020.

[6] S. Akatsuka on behalf of ATLAS Collaboration, *The Phase-1 Upgrade of the ATLAS Level-1 Endcap Muon Trigger*, [arXiv:1806.09234].

[7] ATLAS L1 Muon Trigger Public Results, http://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1MuonTriggerPublicResults.