ATLAS Muon Trigger Performance

Andrea Ventura, on behalf of the ATLAS Collaboration ‡
Università del Salento and INFN Lecce, Via per Arnesano - Lecce - Italy
E-mail: `andrea.ventura@le.infn.it`

December 2019

Abstract. Events containing muons in the final state are an important signature for many analyses being carried out at the Large Hadron Collider (LHC), including both Standard Model measurements and searches for new physics. To be able to study such events, it is required to have an efficient and well-understood muon trigger. The ATLAS muon trigger consists of a hardware-based system (Level-1), as well as a software-based reconstruction (High-Level Trigger). Due to the high luminosity in Run 2, several improvements have been implemented to keep the trigger rate low, while still maintaining high efficiency. Some examples of recent improvements include requiring a coincidence of hits in the muon spectrometer and the calorimeter and optimised muon isolation. We will present an overview of how we trigger on muons, recent improvements, the performance of the muon trigger in Run 2 data and an outlook for the improvements planned for Run 3.

Keywords: LHC; trigger; muons.

1. Introduction

The muon trigger in the ATLAS experiment [1] covers the phase space of muons corresponding to a wide range in terms of transverse momentum (p_{T}). This allows the study of many interesting physics processes from the production of Higgs bosons to processes involving B-hadrons. The ATLAS detector is characterized by two components for reconstruction of muons: a Muon Spectrometer with a toroid magnet system of $1-1.5$ T and an Inner Detector (ID) with a 2 T solenoid magnet.

The hardware-based Level-1 (L1) muon trigger uses Thin Gap Chambers (TGCs) and Resistive Plate Chambers (RPCs) in order to select events by means of coarse p_{T} estimates. A dedicated trigger logic is implemented on the custom-made hardware to achieve a high-speed selection (40 MHz input rate, 2.5 μs latency). The L1 trigger also defines Regions of Interest (RoIs) which are regions of the detector defined in terms of pseudorapidity (η) and azimuthal angle (φ), considered in a second step by the software-based High-Level Trigger (HLT).

Table 1. Transverse momentum threshold and peak rate at a luminosity of 2.0×10^{34} cm^{-2} s^{-1} for some representative muon triggers during Run 2 [2].

Representative trigger	**p_{T} threshold (GeV)**		**Peak rate** $L = 2.0 \times 10^{34}$ cm^{-2} s^{-1}	
	L1	**HLT**	**L1**	**HLT**
One isolated μ	20	26	16 kHz	218 Hz
Two μ	10, 10	14, 14	2.2 kHz	30 Hz
	20	22, 8	16 kHz	47 Hz

The muon HLT employs dedicated software to reconstruct muons in the RoIs defined by L1 using information from precision trackers, Monitored Drift Tubes (MDTs), Cathode Strip Chambers (CSCs) and ID. The HLT is divided into two stages of reconstruction algorithm: the first stage is based on simple algorithms which provide fast selection, while the following stage takes advantage of the full detector information using algorithms which are very similar to those implemented in the offline reconstruction. In addition to precise p_{T} measurements, for some triggers, isolation criteria are also applied to reject non-prompt muons. The lowest p_{T} threshold of the isolated single-muon trigger is 26 GeV. Triggers with lower thresholds are also available, with rates suppressed by requiring multiple muons from the decays of B-hadrons or more objects, corresponding to other types of event signatures. In Table 1, the lowest p_{T} muon and di-muon thresholds are reported for both L1 and HLT, together with the corresponding peak rates reached during Run 2 [2]. The asymmetric di-muon trigger with 22 GeV and 8 GeV muon p_{T} thresholds is a full-scan trigger in which the leading-p_{T} muon is reconstructed at the HLT in an RoI seeded by L1 with a threshold of 20 GeV, while the other muon is reconstructed at the HLT without any seeds, in order to recover inefficiency from the L1.

2. Muon Trigger performance in Run 2

The most exploited method to study the performance of the muon trigger is the "tag-and-probe". This method uses $Z \rightarrow \mu\mu$ events, with one of the two muons considered as a *tag* by requiring to match the single-muon trigger, and the other acting as a *probe* to measure trigger efficiency. Also, $J/\Psi \rightarrow \mu\mu$ events are used to study lower p_{T} muons.

In Figure 1 the absolute efficiencies with respect to the offline muon p_{T} are represented for muons in the barrel ($|\eta| < 1.05$) and in the endcap ($1.05 < |\eta| < 2.4$) regions [4], corresponding to the L1 20 GeV p_{T} threshold, L1_MU20, (in black) and to the HLT for the OR of the 26 GeV p_{T} threshold with the isolation requirement mu26_ivarmedium and of the 50 GeV p_{T} threshold mu50 (in red). Also, the relative efficiency of the HLT with respect to the L1 is superimposed in the plots (in blue).

While the L1 trigger efficiency reaches plateau values of about 90% in the endcaps,

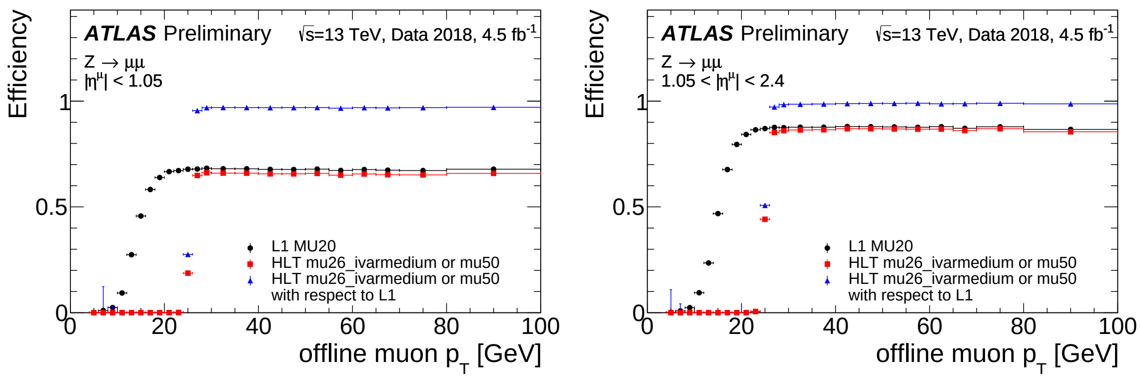

Figure 1. Absolute efficiency of L1_MU20 trigger and absolute and relative efficiencies of the OR of mu26_ivarmedium with mu50 HLT, represented as a function of the $p_{\rm T}$ of offline muon candidates in the barrel (left) and in the endcap (right) detector regions [4].

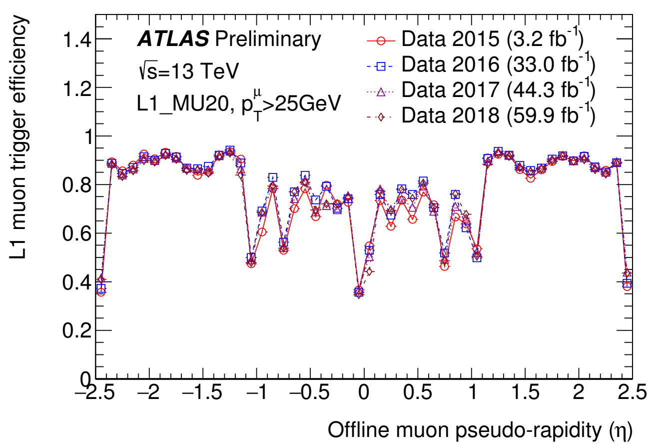

Figure 2. Trigger plateau (for offline muon $p_{\rm T} > 25$ GeV) efficiencies of L1 single-muon triggers for L1_MU20 as a function of the η of the reconstructed muon for different years in Run 2 [3].

it is lower than 70% in the barrel. Such efficiency loss in the barrel is essentially due to uncovered detector regions, caused by the presence of the support structures and of gaps needed to provide space for services of the ID and of the calorimeters. The HLT efficiency with respect to L1 is characterized by a very sharp turn-on shape, which helps to maximize the rejection of muons below the threshold and by a plateau value which is very close to 100% , allowing to keep the final efficiency as high as possible.

The ATLAS muon trigger performance has been stable during Run 2. This is evident in Figure 2, where the trigger plateau efficiency (for offline muon $p_{\rm T}$ greater than 25 GeV) is shown for L1_MU20 as a function of η [3]. Efficiencies are represented with different symbols and colours for each of the four years of Run 2 data taking from 2015 to 2018.

The L1 trigger decision in the barrel region is based on the coincidence of hits from

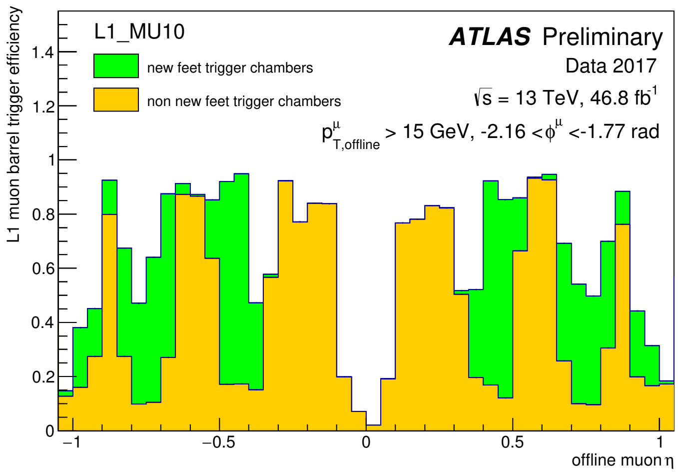

Figure 3. Efficiency of L1_MU10 trigger in 2017 including (in green) or excluding (in light brown) the newly commissioned trigger chambers in the support structure barrel region of the ATLAS muon spectrometer [3].

three (two) concentric RPC stations for the three high- (low-)p_{T} thresholds. During the shutdown of the LHC in 2013−2014, an additional layer of RPC chambers was added in the detector *feet* regions † (for $-2.16 < \varphi < -1.77$ and for $-1.37 < \varphi < -0.98$) to recover holes in the geometrical acceptance. These RPC chambers were already installed at the time of the construction of the ATLAS detector, but they were not yet equipped with trigger electronics. In Figure 3 their impact on the trigger efficiency (for a trigger threshold of 10 GeV at L1, L1_MU10) in one of the two φ regions is shown (in green), as an evident improvement with respect to the previous situation (in light brown) [3].

In order to reach optimal performance for the ATLAS trigger, an effective rejection of fake muon triggers ‡ in the region $1.05 < |\varphi| < 1.3$ during Run 2 has been possible by exploiting a coincidence between the TGC chambers and the tile hadronic calorimeter (TileCal). This coincidence mitigates the effect of the inner muon detector's poor φ coverage ($\sim$ 50%) due to the toroidal magnets. In Figure 4 the pseudo-rapidity distribution of the single muon triggering L1_MU20 is shown for the case without (blue triangles) and with (solid line histogram) the new TileCal coincidence [3].

In order to verify the performance of the muon trigger in different pile-up conditions, the efficiency has been tested as a function of the number of reconstructed vertices. The considered trigger in Figure 5 is for the OR of the 26 GeV p_{T} threshold and of the isolation requirement, and for the 50 GeV p_{T} threshold. Efficiencies of L1, HLT and the total efficiency are shown for offline muons reconstructed in the barrel region with a p_{T} larger than 27 GeV [4].

† The *feet* regions correspond to the support structures of the ATLAS muon spectrometer.
‡ Fake muons can be due to particles not originating from the interaction point or from badly reconstructed tracks than can cause the muon trigger to fire.

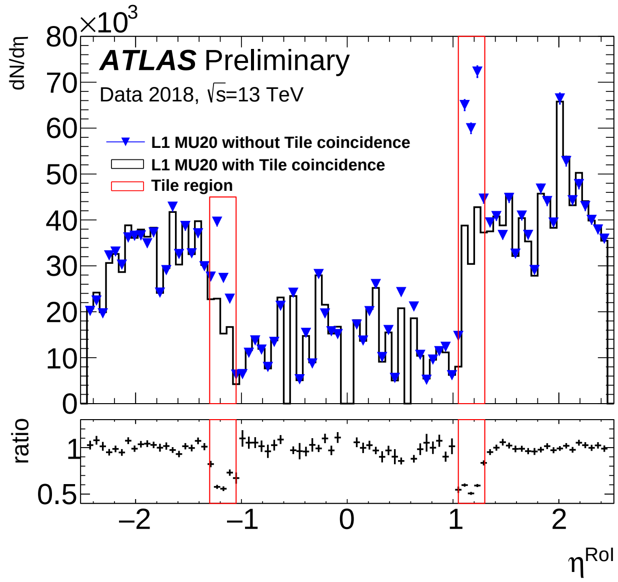

Figure 4. Pseudorapidity distribution of the Level 1 RoIs which fulfill the L1_MU20 requirement after the deployment of the new TileCal coincidence in the Level-1 trigger decisions [3].

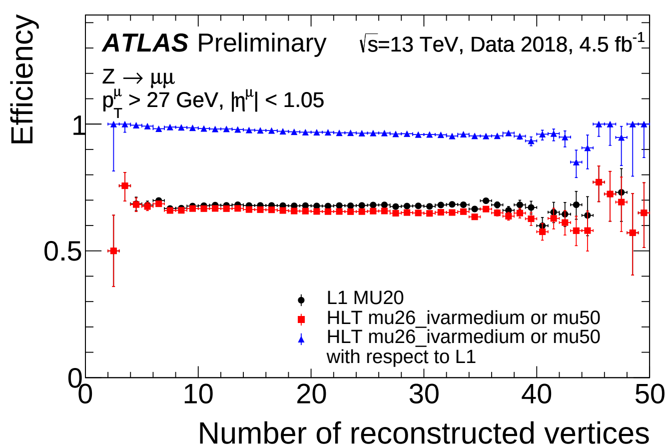

Figure 5. Muon trigger efficiency in the barrel region as a function of the number of reconstructed vertices [4].

3. Expected performance during Run 3

The performance of the ATLAS muon trigger has been studied considering the expected conditions for Run 3, for which an integrated luminosity of 300 fb^{-1} will be collected. As an example, in Figure 6 the rate reduction of L1_MU20 is shown, as estimated by using data collected during Run 2 and using the results of single muon simulation studies with a center-of-mass energy of 13 TeV and a bunch-crossing interval of 25 ns. Here rates are estimated from MDT and CSC muon segment information when enabling coincidences of New Small Wheels (NSW) [5] and RPCs in the small sectors of the barrel inner layer (BIS) 7 and 8 [6, 7]. As a result, more than 90% of the fake muon triggers are expected

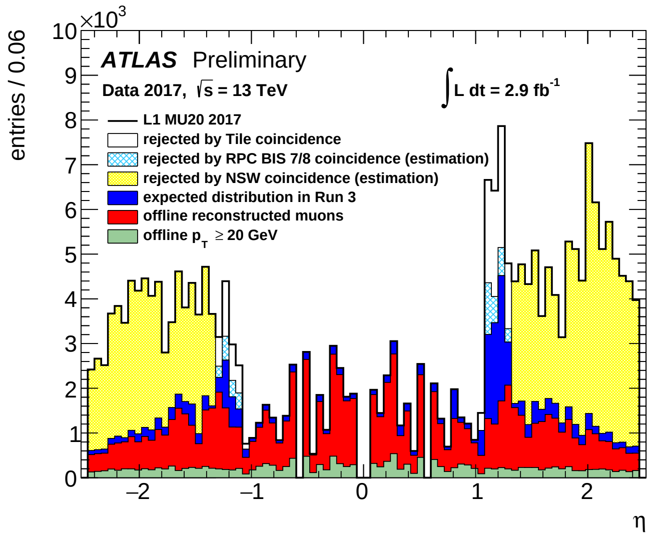

Figure 6. Pseudorapidity distributions of the L1_MU20 candidates collected in Run 2 with a center-of mass energy of 13 TeV and a bunch-crossing interval of 25 ns [3].

to be rejected, with a final rate reduction of the order of 45%.

Relative trigger efficiencies compared to the Run 2 L1 trigger for a single muon with transverse momentum above 20 GeV are illustrated in Figure 7, for RoIs in the region $1.3 < |\eta| < 2.4$. The efficiencies are computed with respect to offline reconstructed muons, and are represented as a function of the p_{T}. Efficiencies with new coincidence requirements applied to L1_MU20 are shown by coloured markers. The open circle markers show the efficiency with NSW coincidence logic using a $\mathrm{d}\eta - \mathrm{d}\theta$ coincidence window, while the open triangle markers show the efficiency with NSW coincidence logic using both a $\mathrm{d}\eta - \mathrm{d}\varphi$ and a $\mathrm{d}\eta - \mathrm{d}\theta$ coincidence window derived from the simulation study [3].

4. Conclusions and outlook

The ATLAS muon trigger has shown stable performance over the entire LHC Run 2 data taking period. Significant detector upgrades are moving from design to production and commissioning in order to improve trigger performance towards Run 3. Even more performing features are expected for the High-Luminosity LHC, whose operations are expected to start in 2026, to cope with higher luminosity/energy and more difficult pile-up conditions. The final goal is to maximize the impact on new physics searches and high-precision Standard Model processes, improving signal acceptance and reducing background rates.

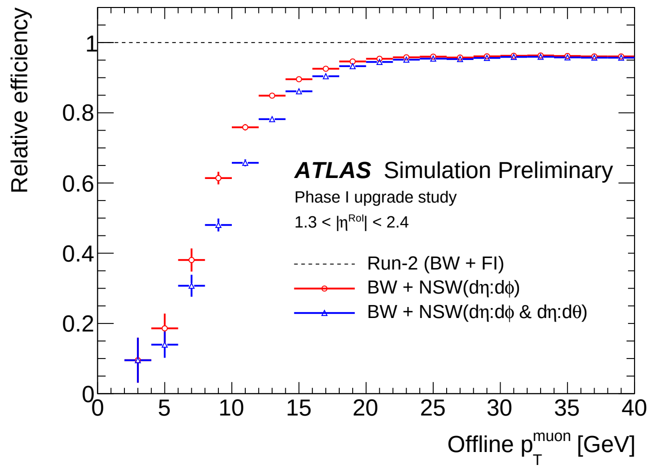

Figure 7. Relative trigger efficiencies compared to Run 2 L1_MU20, at $1.3 < |\eta| < 2.4$ [3].

References

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

[2] ATLAS Collaboration, Trigger menu in 2018, *http://cdsweb.cern.ch/record/2693402/*.

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

[4] ATLAS Muon Trigger Public Results, *http://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonTriggerPublicResults*

[5] ATLAS Collaboration, New Small Wheel Technical Design Report, *http://cds.cern.ch/record/1552862/*.

[6] ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer, *http://cds.cern.ch/record/2285580/*.

[7] ATLAS Collaboration, Proposal of upgrade of the ATLAS muon trigger in the barrel-endcap transition region with RPCs, *http://pos.sissa.it/213/117*.