ATLAS muon trigger performance

Andrea Ventura and on behalf of the ATLAS Collaboration

Università del Salento and INFN Lecce, Via per Arnesano—Lecce, Italy
E-mail: andrea.ventura@le.infn.it

Received 7 February 2020, revised 30 March 2020
Accepted for publication 17 April 2020
Published 1 May 2020

Abstract
Muons in the final state represent an important signature for many physics studies performed at the Large Hadron Collider (LHC), involving analyses on Standard Model measurements and on new physics searches. An optimized selection of such events requires an efficient and deeply understood muon trigger system. The present work describes the ATLAS muon trigger, consisting of a hardware-based system (Level-1) followed by a software-based reconstruction (High-Level Trigger). To handle the increase of luminosity in Run 2, several upgrades have been implemented to reduce the trigger rate, while still maintaining high values for the efficiency. Such improvements include the request of a coincidence of hits in the muon spectrometer and the hadronic tile calorimeter, an optimised muon isolation and a better estimation of transverse momentum. An overview will be presented on the most recent improvements of the ATLAS muon trigger and on its performance during Run 2. Finally an outlook for the most relevant upgrades planned for Run 3 will be reported.

Keywords: LHC, ATLAS, trigger, muons

(Some figures may appear in colour only in the online journal)

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 (MS) with a toroid magnet system of 1 −1.5 T and an Inner Detector (ID) with a 2 T solenoid magnet. In figure 1 a quarter-section view of the MS is represented.

For muon track precision measurements, Monitored Drift Tubes (MDTs) are used in the region \( |\eta| < 2 \), located in three concentric cylindrical shells around the beam axis, while in the region \( 2.0 < |\eta| < 2.7 \), two layers of MDTs are used in combination with one layer of Cathode Strip Chambers (CSCs).

The hardware-based Level-1 (L1) muon trigger is provided by Resistive Plate Chambers (RPCs) and Thin Gap Chambers (TGCs), which are arranged in three layers (called stations), respectively in the barrel (\( |\eta| < 1.05 \)) and in the endcap regions (\( 1.05 < |\eta| < 2.4 \)), 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 (\( \eta \)) and azimuthal angle (\( \phi \)), considered in a second step by the software-based High-Level Trigger (HLT).

The muon HLT employs dedicated software to reconstruct muons in the RoIs defined by L1 using information from precision trackers: MDTs, 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 physics 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 [3].

1 https://atlas.cern/discover/collaboration - Copyright 2019 CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.
The asymmetric di-muon trigger with 22 GeV and 8 GeV muon \( p_T \) thresholds is a full-scan trigger, spanning over the entire MS coverage by using offline-based reconstruction algorithms, 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 2 the efficiencies with respect to the offline muon \( p_T \) are represented for muons in the barrel and in the endcap regions [4]. In particular, the absolute efficiencies corresponding to the L1 20 GeV \( p_T \) threshold L1_MU20 are represented (in black), together with the relative efficiencies corresponding to the OR of the 26 GeV \( p_T \) threshold with the isolation requirement, mu26_ivarmedium, and of the 50 GeV \( p_T \) threshold without isolation, 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, 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 3, where the trigger plateau efficiency (for offline muon \( p_T \) greater than 25 GeV) is shown for L1_MU20 as a function of \( \eta \) [5]. 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 three (two) concentric RPC stations for the 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\(^2\) (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 4 their impact on the trigger efficiency (for a trigger threshold of 10 GeV at L1, L1_MU10) is shown in one of the two \( \varphi \) regions (in green) by analyzing an inclusive sample selected using all non-muon L1 triggers in 13 TeV data from 2017 with a bunch-crossing

\(^2\) The feet regions correspond to the support structures of the ATLAS MS.
interval of 25 ns. This study demonstrates an evident improvement on the trigger efficiency with respect to the previous situation [5].

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 TGCs and the tile hadronic calorimeter (TileCal). In figure 5 the pseudo-rapidity distribution of the single muon triggering L1_MU20 is shown for the case with the new TileCal coincidence (solid line histogram), superimposed to the same distribution without (blue triangles), as obtained on 2018 data with a center-of-mass energy of 13 TeV and a 25 ns LHC bunch spacing [5]. It is evident that this coincidence has allowed to achieve a ∼50% rate reduction in the η range uncovered by the innermost TGCs. The asymmetry between positive and negative η regions is explained by the particular acceptance of the low-momentum particles

3 Fake muons can be due to particles not originating from the interaction point or to badly reconstructed tracks than can cause the muon trigger to fire.

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 7 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) [6] and RPCs in the small sectors of the barrel inner layer (BIS) 7 and 8 [7, 8]. As a result, more than 90% of the fake muon triggers are expected 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 8, 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 $d\eta$—$d\phi$ coincidence window, while the open triangle markers show the efficiency with NSW coincidence logic using both a $d\eta$—$d\phi$ and a $d\eta$—$d\phi$ coincidence window derived from the simulation study [5].

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. Further performance enhancements 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 measurements of Standard Model processes, improving signal acceptance and reducing background rates.

ORCID iDs

Andrea Ventura © https://orcid.org/0000-0002-3368-3413

References

[1] ATLAS Collaboration 2008 The ATLAS experiment at the CERN large hadron collider JINST 3 S08003
[2] ATLAS Collaboration 2015 Performance of the ATLAS muon trigger in pp collisions at \( \sqrt{s} = 8 \) TeV Eur. Phys. J. C 75 120
[3] ATLAS Collaboration 2018 Trigger menu in 2018 CERN Document Server ATLAS Note ATL-DAQ-PUB-2019-001 (http://cdsweb.cern.ch/record/2693402/)
[4] ATLAS Muon Trigger Public Results, (http://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonTriggerPublicResults)
[5] ATLAS L1 Muon Trigger Public Results, (http://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1MuonTriggerPublicResults)
[6] ATLAS Collaboration 2013 New small wheel technical design report CERN Document Server ATLAS Note ATLAS-TDR-020 (http://cds.cern.ch/record/1552862)
[7] ATLAS Collaboration 2017 Technical design report for the Phase-II upgrade of the ATLAS muon spectrometer CERN Document Server ATLAS Note ATLAS-TDR-026 (http://cds.cern.ch/record/2285580/)
[8] Massa L and for the ATLAS Collaboration 2014 Proposal of upgrade of the ATLAS muon trigger in the barrel-endcap transition region with RPCs Proceedings of Science TIPP2014 213 117 (http://pos.sissa.it/213/117), (https://ui.adsabs.harvard.edu/abs/2014tipp.confE.117M)