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The ATLAS Muon Trigger Performance in pp collisions

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Events with muons in the final state are an important signature for many physics topics at Large Hadron Collider (LHC), for instance, searches for Higgs boson production or new phenomena, measurements on the standard model processes like top-quark, W, Z production. Thus, efficient trigger on muons in data taking and understanding its performance are crucial to perform these physics studies. At LHC high rejection power against large backgrounds, while maintaining high efficiency for rare signal events, is required already at such online trigger stage. The ATLAS experiment employs a multi-level trigger architecture that selects the events in three sequential steps of increasing complexity and accuracy to cope with this challenging task.
This proceedings paper reports about efficiency and general performance of the ATLAS muon trigger in proton-proton collisions at $\sqrt{s}$ = 7 TeV in 2011 runs and also at $\sqrt{s}$ = 8 TeV in 2012 runs.

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1. Introduction

Muons in the final state are distinctive signatures of many physics studies performed in the ATLAS experiment at the LHC. The precise determination of the performance of the muon trigger system is essential for muon-related physics analyses. The ATLAS experiment has collected proton-proton (pp) collision data in 2011 at $\sqrt{s} = 7$ TeV, and 2012 at $\sqrt{s} = 8$ TeV with the peak instantaneous luminosity of 3.65×10^{33} in 2011 and 7.73×10^{33} in 2012 (as of 28 October, 2012). The more the instantaneous luminosity is, the harsher the pileup condition become, where pileup refers to multiple interactions occur at a same bunch crossing. The maximum number of the average interactions per bunch crossing has exceeded 30 in 2012. To keep the p_{T} threshold of the single muon trigger as low as possible, an algorithm which imposes an isolation cut in terms of tracking activities around the muon candidate at online stage introduced since 2012 runs.

This proceedings paper presents the performance evaluation of the ATLAS muon trigger system, mainly focusing on the high-p_{T} primary single muon triggers, in 2011 and 2012. The performance has been evaluated primarily using the tag-and-probe method with $Z \rightarrow \mu\mu$ samples.

2. ATLAS muon trigger system

ATLAS is a multi-purpose particle physics detector with a forward-backward symmetric cylindrical geometry and near 4π coverage in solid angle [1]. The ATLAS detector is designed to measure the properties of particles produced in proton-proton interactions. It consists of an inner tracking detector (ID) surrounded by a thin 2 T superconducting solenoid, electromagnetic and hadronic calorimeters, and a muon spectrometer (MS) incorporating three large superconducting toroid magnets.

The MS consists of separate trigger and high-precision tracking chambers operated in toroidal magnet field with an average strength of approximately 0.5 T. The deflections of muon trajectories are measured by the precision chambers which cover the region $|\eta| < 2.7$ with three layers of monitored drift tubes (MDT), complemented by cathode strip chambers (CSC) in the innermost layers of the forward region. The muon trigger system covers the range $|\eta| < 2.4$ with resistive plate chambers (RPC) in the barrel, and thin gap chambers (TGC) in the endcap regions. The barrel and the endcap region is divided at $|\eta| = 1.05$. Figure 1 shows a quarter-section of the muon system in a plane containing the beam axis.

A three-level trigger system is employed increasing complexity and accuracy. Each stage is named as Level 1 (L1), Level 2 (L2) and Event Filter (EF), respectively. The L2 and the EF are called higher level trigger (HLT) as a whole.

At the L1, hits pattern along the muon trajectory in the layers of trigger chambers is analyzed by custom made hardware to estimate its p_{T}. The p_{T} information is carried to the HLT along with region of interest (RoI) information, position information of the detector regions where the muon candidate is found. At the L2, the candidate from L1 is refined by using the precision data from the MDTs in the RoI. At this stage, combined muon is already reconstructed from a track identified in the ID and a track identified in the MS. At the EF, combined muon is reconstructed using algorithms which rely on offline muon reconstruction software, accessing entire event information. A combination method which starts with the ID track and extrapolates its trajectory to the MS is

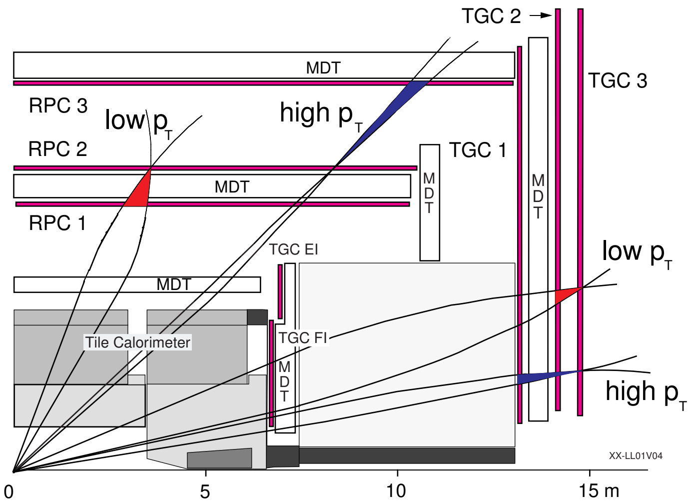


Figure 1: Quarter-section of the muon system in a plane containing the beam axis. CSC detectors are not shown but located at around z = 7 m covering η region beyond the MDT acceptance [2].

called as inside-out approach. Another complementary method which starts with MS track is called as outside-in approach. Both methods are used in the data taking through 2011 and 2012.

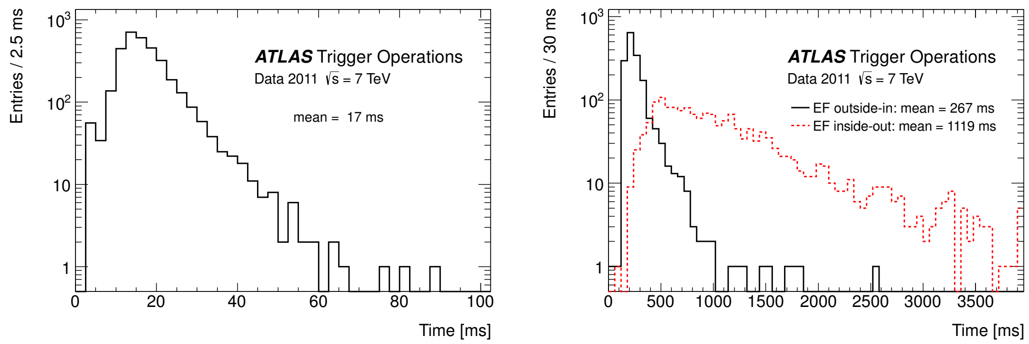
3. The performance in 2011

In the 2011 data taking, the p_T threshold of the primary single muon triggers were kept at 18 GeV. The L1 trigger seeding the triggers was the L1_MU10, a L1 single muon trigger with a p_T threshold of 10 GeV, until the beginning of August 2011. After that, the L1_MU11 was used while the luminosity exceeds 1.9×10^{33} cm^{-2}s^{-1}. The p_T threshold of L1_MU11 is 10 GeV as L1_MU10. However, L1_MU11 is sorely composed of three station coincidence while L1_MU10 deploys a two (three) station coincidence in the barrel (endcap) region.

The processing times of the HLT algorithms have been determined on computers equipped with Intel ® Core^{TM} 2 Duo CPU E8400 with clock speed of 3.00 GHz running on raw data from the events selected by jet, tau or E_T^{miss} triggers at a luminosity of about 3.1×10^{33} cm^{-2}s^{-1}. The processing time for the L2 combined muon trigger is shown in Figure 2(a). The mean processing time was 17 ms. Figure 2(b) shows the processing times for the EF outside-in and inside-out algorithms. The average processing times were about 270 ms and 1120 ms for outside-in and inside-out algorithms, respectively. The processing times of the HLT chains were well within the time restrictions allowing a stable trigger operation at luminosity of 3.0×10^{33} cm^{-2}s^{-1}.

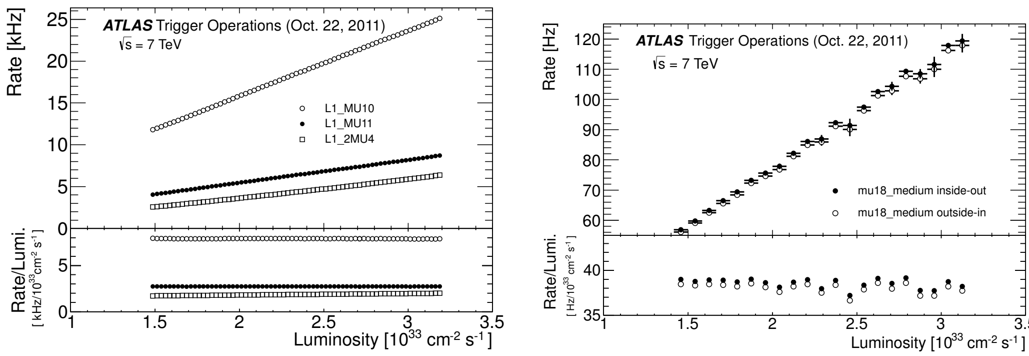
Trigger rates have been measured during a run with a fill of 1332 proton bunches in 12 trains with 50 ns bunch spacing. Figure 3(a) shows the L1 trigger rates before prescale as a function of the instantaneous luminosity. Figure 3(b) shows rates of the EF algorithms for the primary single muon triggers with a p_T threshold of 18 GeV. The EF rates were about 110 Hz at 3.0×10^{33} cm^{-2}s^{-1}.

The efficiency of the primary single muon triggers and seeding L1 triggers, namely L1_MU11 and L1_MU10, have been evaluated using the tag-and-probe method with $Z \to \mu\mu$ samples. Figure 4(a) and 4(b) show the L1 trigger efficiencies as a function of p_T with respect to isolated offline



(a) (b)

Figure 2: Execution times of the HLT algorithms per RoI. (a) is for the L2 combined reconstruction chain. (b) is for the EF algorithms for the primary single muon triggers in 2011 [2].



(a) (b)

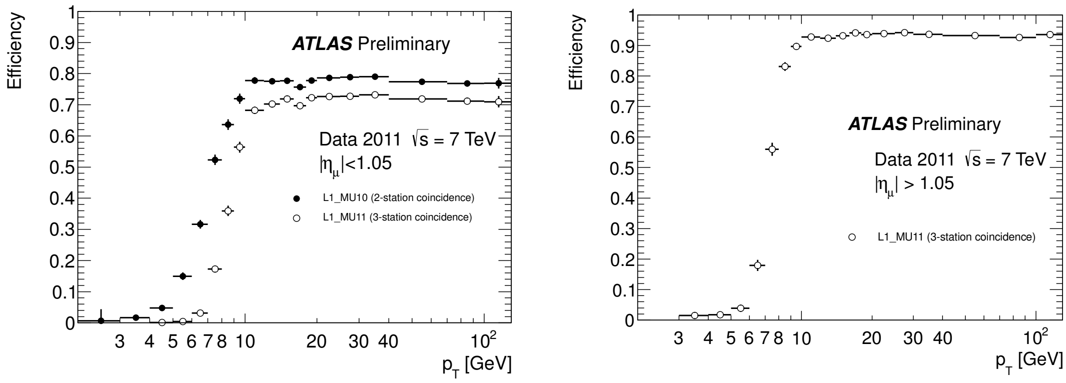
Figure 3: Trigger rates for (a) the L1 triggers before prescale and (b) the EF algorithms for the primary single muon triggers operating at a p_{T} threshold of 18 GeV in 2011 [2].

muons for the RPC and the TGC, respectively. For the TGC, L1_MU11 and L1_MU10 are identical. The L1_MU11 efficiencies on plateau, which include geometrical acceptance losses, were about 70 % for the RPC and about 90 % for the TGC. As the efficiencies of the L2 and EF algorithms are close to unity, the efficiencies for the primary single muon triggers were almost the same as the L1 efficiencies above the p_{T} threshold of 18 GeV.

4. The performance of the primary trigger in 2012

In the 2012 data taking, two major changes have been introduced.

- **Merged EF algorithm:** The EF inside-out and outside-in approaches have been merged into a single algorithm resulting in a more efficient trigger. The inside-out algorithm is executed only if the outside-in algorithm couldn't find a muon candidate in the merged algorithm.
- **Isolation requirement:** An isolation requirement at the EF is firstly applied for the primary single muon trigger. The isolation working point has been set at $\sum p_{\mathrm{T}}/p_{\mathrm{T}}^{\mu} < 0.12$, where

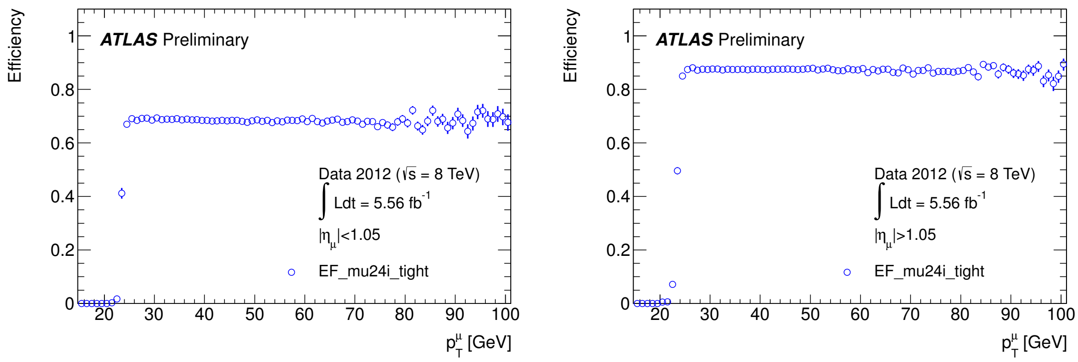


(a) (b)

Figure 4: L1 trigger efficiencies for (a) the RPC and (b) the TGC with respect to isolated offline muons [2].

$\sum p_{\mathrm{T}}$ is the sum of p_{T} of the tracks surrounding the muon candidate in the cone of $\Delta R < 0.2$ and p_{T}^{μ} is the p_{T} of the muon candidate. p_{T} of the tracks should be greater than 1 GeV and $|z_0(\mathrm{track}) - z_0(\mathrm{muon})| < 6$ mm.

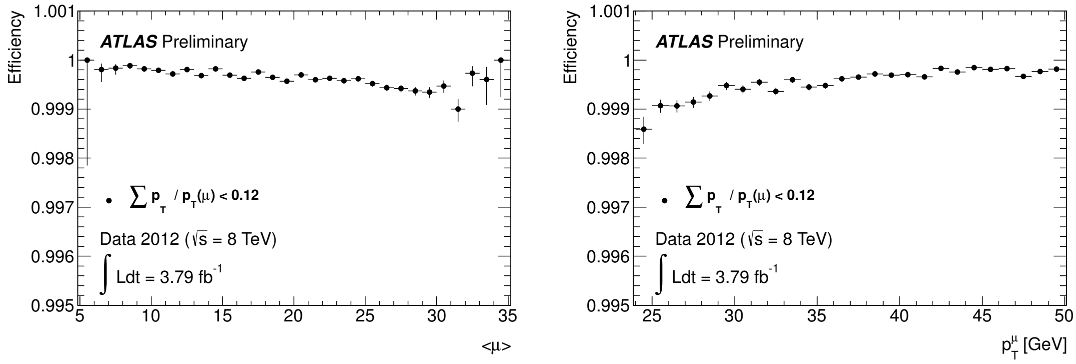
The primary single muon trigger in 2012, named as mu24i_tight, has deployed the above two major changes operating at a p_{T} threshold of 24 GeV, with the p_{T} threshold of a seeding L1 trigger raised to 15 GeV. Figure 5(a) and Figure 5(b) show the efficiencies for the mu24i_tight for the barrel and the endcap, respectively. The efficiencies have been evaluated using the tag-and-probe method with $Z \to \mu\mu$ samples with respect to offline muons which satisfy an offline isolation requirement of $\sum p_{\mathrm{T}}/p_{\mathrm{T}}^{\mu} < 0.10$. In the offline reconstruction, the isolation variable is calculated requiring the ID tracks to be associated with the same primary vertex for the muon candidate instead of requiring a cut on $|z_0(\mathrm{track}) - z_0(\mathrm{muon})|$. The amount of data used in the evaluation corresponds to 5.56 fb^{-1}. The efficiencies on plateau is about 70 % for the barrel and 90 % for the endcap.



(a) (b)

Figure 5: Efficiencies of the mu24i_tight as a function of p_{T} for (a) the barrel region and (b) the endcap region with respect to offline muons which satisfy an offline isolation requirement of $\sum p_{\mathrm{T}}/p_{\mathrm{T}}^{\mu} < 0.10$. [3].

Figure 6 shows the efficiency for the isolation cut used in the mu24i_tight at the EF with respect to an offline isolation cut of $\sum p_{\mathrm{T}}/p_{\mathrm{T}}^{\mu} < 0.10$ as a function of (a) the average number of interactions per bunch crossing $<\mu>$ and (b) p_{T} of the muon candidate. The stability seen in the figures shows a good robustness of the mu24i_tight against pileup events over a wide p_{T} range of the muon candidates.



(a) (b)

Figure 6: Efficiency of the isolation cut used in the mu24i_tight at the EF with respect to an offline isolation cut of $\sum p_{\mathrm{T}}/p_{\mathrm{T}}^{\mu} < 0.10$ as a function of (a) $<\mu>$ and (b) p_{T} [3].

5. Conclusion

The performance of the ATLAS muon trigger system has been evaluated with proton-proton collision data collected in 2011 at $\sqrt{s} = 7$ TeV and in 2012 at $\sqrt{s} = 8$ TeV.

In the 2011 data taking, the p_{T} threshold of the primary single muon triggers was kept at 18 GeV at the EF. The processing times of the HLT chains are well within a requirement which allows a stable trigger operation at a luminosity of 3.0×10^{33} cm^{-2}s^{-1} along with 110 Hz of the output rate. The efficiency on the plateau of the L1_MU11 trigger, which seeded the primary single muon trigger in the later period in 2011, was determined as about 70 % for the barrel and 90 % for the endcap using the tag-and-probe method with $Z \to \mu\mu$ samples.

In the 2012 data taking, an additional requirement of isolation in terms of the tracking activities around the muon candidates have been imposed on the primary single muon trigger as well as the introduction of a merged algorithm of the outside-in and the inside-out approaches at the EF. The trigger has been keeping a p_{T} threshold at 24 GeV with the efficiencies on plateau of about 70 % for the barrel and 90 % for the endcap. A study shows a stability of the trigger efficiency against the pileup events up to the average number of interactions per bunch crossing of 35 over a wide p_{T} range. The trigger has been actively used in many physics analyses.

References

[1] ATLAS Collaboration, 2008 *JINST* **3** S08003

[2] ATLAS Collaboration, ATLAS-CONF-2012-099, http://cdsweb.cern.ch/record/1462601

[3] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonTriggerPublicResults