Evaluation of Muon Trigger Efficiencies and Scale Factors on 2016 ATLAS data

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1. Introduction

For its rich physics program the ATLAS experiment [1] at the Large Hadron Collider (LHC) [2] during Run-II in 2016 collected about 36.3 fb^{-1} of proton-proton collision data at the centre-of-mass energy of 13 TeV with 25 ns spacing between bunch crossings.

The ATLAS trigger system is designed to select the most interesting for physics events already at the early stage of data taking by identifying muons, electrons, taus, photons, jets and B hadron candidates, as well as using event-based signatures, such as missing transverse energy or other topological strategies.

To cope with almost 5 times increase of expected trigger rates in *Run-II* compared to *Run-I* (a factor of ∼2 due to higher energy and a factor of 2-3 due to the luminosity increase), the trigger structure has been redesigned from a three-level scheme in *Run-I* [3] to a two-level scheme for *Run-II*.

At the first level, called L1, custom made hardware identifies Regions-of-Interest (RoI) in the muon spectrometer and/or in the calorimeter with coarse resolution and reduces the rates from 40 MHz to ∼100 kHz within less than 2.5 μs, rejecting most backgrounds.

At the second stage, called high level trigger (HLT), which incorporates both, Level-2 (L2) and Event Filter (EF), trigger levels in *Run-I*, custom fast software handles the complexity of events accessing the full event information of all the detectors and performs a reconstruction close to the offline level reducing the event rates from ∼100 kHz to ∼1 kHz.

During the data taking period of 2016, aiming needs of different physics analyses, a few unprescaled muon trigger chains were used. The lowest unprescaled muon trigger chain continuosly used for the whole 2016 data taking year is $HLT\_mu26\_ivarmedium$, which is seeded by the L1 trigger $L1MU20$ (corresponding to a 3-station coincidence in the Muon Spectrometer).

The ATLAS trigger system is reflected in a Monte Carlo (MC) simulation of the experiment and the differences in the trigger performance in the experiment and MC are corrected by comparing the MC trigger efficiencies with the ones obtained from data. With this goal muon trigger scale factors have been deduced by taking ratio of muon trigger efficiencies obtained from real data to the efficiencies obtained from the MC simulations. The efficiencies have been computed using the "Tag & Probe" method applied to events in which a Z boson decays into $\mu\mu$ final state as described in the following.

2. Event selection

The $Z \to \mu\mu$ candidate events are triggered by a requirement of the presence of at least one muon with a minimum transverse momentum of 28 GeV. For the offline analysis combined (CB) muons [1] are used following the recommendations from the Muon Combined Performance group [4]. The following set of cuts summarizes the selections used in the analysis.

To select "Tag & Probe" muon pair candidates, events with two opposite charge muons with a di-muon invariant mass, $m_{\mu\mu}$, in the interval from 81 to 101 GeV are selected. The tag muon is defined as the one passing HLT chain $HLT\_mu26\_ivarmedium$ with the p_T higher than the nominal trigger threshold by ∼5%, i.e. 28 GeV in the current analysis.

The probe muon is specified by the selection cuts:

- number of PIXEL hits ≥ 1, and at least 1 hit in the b-layer, number of SCT hits > 5 and

[1]For the combined muons track reconstruction is performed independently in the inner detector (ID) and in the muon spectrometer (MS) and a combined track is formed with a global refit that uses the hits from both the ID and MS subdetectors

no more than 2 holes of the track [2] in PIXEL and SCT detectors, (for $0.1 < |\eta| < 1.9$ the total number of hits has to be > 5 and the fraction of outlier hits to total hits < 0.9, for $|\eta| < 0.1$ or $|\eta| > 1.9$, if total hits are > 5, then the fraction of outlier hits to total hits is required to be < 0.9);

- $|z - z_{vtx}| < 10$ mm, where z_{vtx} is the z coordinate of the primary vertex in the event, and the significance of the transverse impact parameter d_0 has to satisfy $\frac{|d_0|}{\sigma(d_0)} < 3$;
- for an adequate request on isolation, sum of p_T of tracks in a $\Delta R = 0.20$ cone [3] around the muon has to be < 1.8 GeV.

The probe muon is considered to be triggered if a trigger object within $\Delta R < 0.20$ from the probe muon is found.

Each of the two muons from the di-muon pair has been interchangeably used first as the tag and then as the probe in order to avoid systematics retailed with the choice of a muon and to maximize the available statistics.

3. Muon Trigger Scale Factors

Fig. 1 shows the efficiencies and the scale factors for *HLT_mu26_ivarmedium* trigger chain seeded by the *L1MU20* L1 trigger as a function of muon transverse momentum for the barrel ($|\eta| < 1.05$) and endcap ($1.05 < |\eta| < 2.4$) detectors regions (top and bottom plots, respectively) computed for *medium* muons with the *IsoGradient* muon isolation criterion for data taken during the a specific period (called period G) in 2016. The trigger efficiency scale factors show no major dependence on muon p_T for both detector regions, while some differences for trigger efficiencies are seen for barrel and endcaps. The efficiencies in the barrel, after a short turn-on within a few GeV p_T range, show practically no essential p_T dependence, but instead show some ∼10% discrepancy between the data and MC. On the contrary in the endcap regions the discrepancy between the data and MC is only a few %, but some p_T dependence is observed for some data-sets. This dependence is taken into account by adding an additional systematic uncertainty. However, the efficiency discrepancy between data and MC for barrel has improved with respect to the data taken during 2015, reducing it from ∼20% to the current ∼10%.

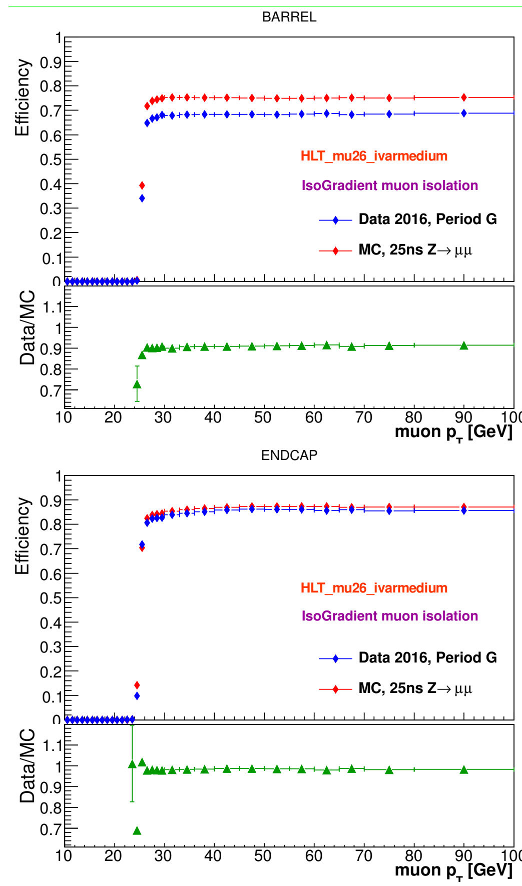

Figure 1. Muon trigger efficiency and scale factor for *HLT_mu26_ivarmedium* HLT chain seeded by the *L1MU20* L1 trigger as a function of muon p_T for the barrel (top) and endcap (bottom) detector regions for data taking during the period G in 2016. Muons are selected to satisfy *medium* quality requirements and have *IsoGradient* isolation.

To account for inefficiencies of different detector regions, the scale factors for physics analysis are provided as a function of φ and η. Fig. 2 shows the trigger scale factors as a two-dimensional function of η and φ taken for muons with p_T >27 GeV, where the muon trigger is on its efficiency plateau region.

In general, the large difference in the efficiency plateau values between barrel and endcaps for data is mostly due to the different L1 trigger acceptance of the Muon Spectrometer. For example in the barrel around $\varphi \simeq -\pi/2$ the presence of the feet of

[2] A hole is defined as an unassigned measurement which was expected to belong to a given track trajectory.

[3] In ATLAS the distance between two objects ΔR is defined as $\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$, where $\Delta\eta$ and $\Delta\varphi$ are the differences in η and in azimuthal angle φ, respectively.

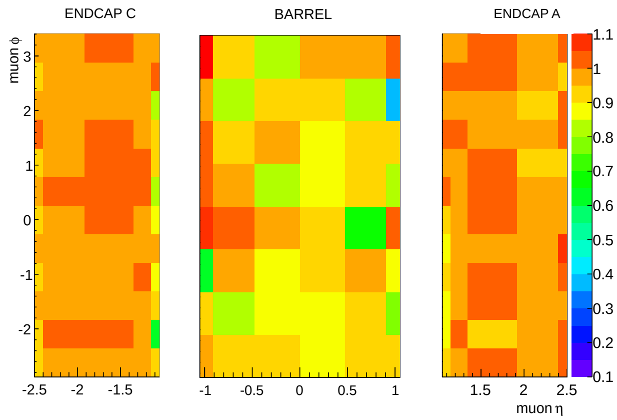

Figure 2. Muon trigger scale factors for $HLT\_mu26\_ivarmedium$ HLT chain as a function of muon η and φ for the barrel (middle) and the endcap (left and right) regions for muon p_T efficiency plateau region for data taken during the period G in 2016.

the Muon Spectrometer leads to lower barrel L1 efficiency. The discrepancy in data and MC efficiencies for barrel part is due to misconfiguration of the simulation setup, which is still under revision to improve for the data taking period in 2017.

A more detailed survey on the muon trigger scale factors for the data taking periods of 2015 and 2016 including all HLT chains used for ATLAS triggering can be found in [6].

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