Evaluation of Muon Trigger Scale Factors on 2015 ATLAS data

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1. Introduction

The ATLAS experiment [1] at the Large Hadron Collider (LHC) [2] collected about 3.3 fb^{-1} of proton-proton collision data at the centre-of-mass energy of 13 TeV with 25 ns spacing between bunch crossings during the 2015 data taking period.

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 $\sim$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 $\sim$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 $\sim$100 kHz to $\sim$1 kHz.

During the data taking period of 2015, aiming needs of different physics analyses, a few unprescaled muon trigger chains have been used. The lowest unprescaled muon trigger chain used is $HLT\_mu20\_iloose\_L1MU15$, which is seeded by the L1 trigger $L1MU15$ (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 too. Since it is impossible to account for all subtle details of the real experiment in the simulation, which in the end has an effect on the simulated trigger efficiency, one has to correct the efficiency obtained in the MC simulation by comparing it with the efficiency extracted from real experimental data.

To correct muon trigger efficiencies in MC simulation in use in all ATLAS physics analyses containing muons in the final state, muon trigger scale factors have been deduced by taking ratio of muon trigger efficiencies obtained from real data to efficiencies obtained from the MC simulations. The efficiencies in the pseudorapidity range of $|\eta| <2.5$ 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 20 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 muon with a di-muon invariant mass, $m_{\mu\mu}$, in the range $|m_{\mu\mu} - m_Z| < 10$ GeV are selected.

The tag muon is defined as the one passing HLT chain $HLT\_mu20\_iloose\_L1MU15$ with the p_T higher than the nominal trigger threshold by 5%, i.e. $20 \cdot 1.05 = 21$ GeV.

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 $\frac{|d_0|}{\sigma(d_0)} < 3$;
- together with an adequate request on isolation (sum of p_T of tracks in a $\Delta R = 0.20$ cone [3] around the muon) < 1.8 GeV.

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

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 the barrel ($|\eta| < 1.05$) and endcap ($1.05 < |\eta| < 2.4$) regions of the muon spectrometer for $HLT\_mu20\_iloose\_L1MU15$ trigger chain computed for medium muons and IsoTight [5] isolation working point using data from the period E of *Run-II* taken during the autumn 2015. While the trigger efficiency scale factors show no major p_T dependence for both barrel and endcap regions, the trigger efficiencies for data and MC show different behavior for these two detector regions. In the endcap regions rather good agreement between data and MC efficiencies is seen, yielding the scale factors close to 1, while in the barrel region there is a large discrepancy between the data and MC trigger efficiencies, reaching up to 20%. This discrepancy in the efficiencies is seen better in the two-dimensional plots of muon η and φ, as shown in the Fig. 2 taken for the efficiency plateau region in p_T.

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 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 under improvement for the coming data taking period in 2016.

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

[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.

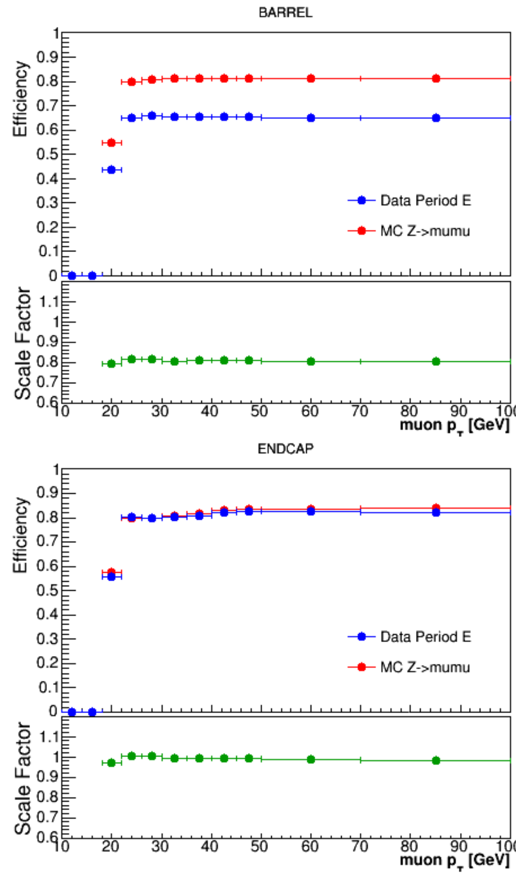

Figure 1. Muon trigger efficiency and scale factor for $HLT\_mu20\_iloose\_L1MU15$ HLT chain as a function of p_T for the barrel (top) and endcap (bottom) regions for 2015 data taken during the period E.

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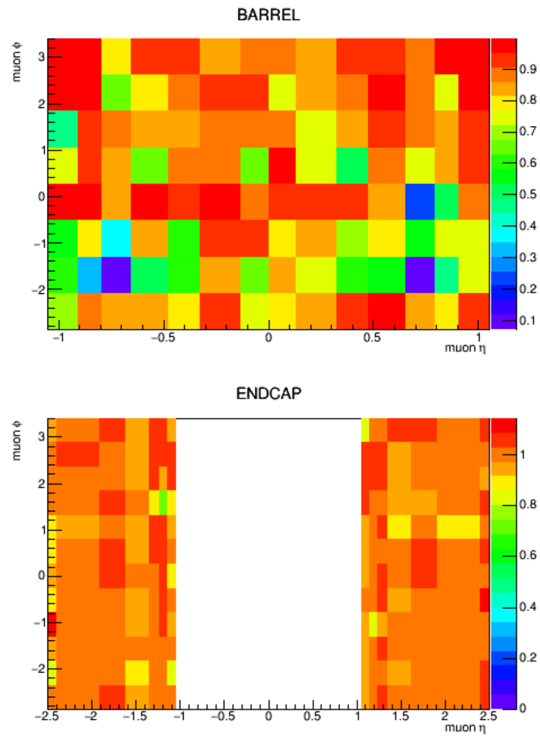

Figure 2. Muon trigger scale factors for $HLT\_mu20\_iloose\_L1MU15$ HLT chain as a function of η and φ for the barrel (top) and the endcap (bottom) regions for muon p_T efficiency plateau region for 2015 data taken during the period E.

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