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Design and Performance of the ATLAS Muon Trigger System

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The ATLAS muon trigger system is used to identify LHC proton collision events of interest to both Standard Model measurements and searches for new physics. Composed of both hardware (Level-1) and software (High-Level Trigger) components, the trigger system was successfully optimized during Run 2 to provide high efficiencies while maintaining sufficiently low trigger rates. These proceedings provide a brief description of the design performance of the ATLAS muon trigger system during Run 2. Several improvements which have been developed for Run 3 are also summarized.

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1. Introduction

The ATLAS experiment [1] employs a trigger system designed to manage the rate of proton collision data by flagging only a subset of events for further analysis. In particular, many Standard Model measurements and new physics searches are of processes involving muons in the final state, and so it is critical to store events containing prompt muons, i.e. muons originating from the primary vertex. A muon trigger menu is curated to cover the available phase-space within the allotted data bandwidth as efficiently as possible. Brief descriptions of the ATLAS trigger system, the performance of the muon trigger system during Run 2, and the improvements developed for Run 3 are provided below. For more information on the trigger system and its performance during Run 2, please refer to [2] and [3].

2. Trigger System

The two primary components of the ATLAS trigger system are the hardware-based Level-1 (L1) trigger and the software-based High-Level Trigger (HLT) [2]. The L1 trigger uses coarse-grained calorimeter and muon spectrometer information to reduce the event rate from the 40 MHz bunch-crossing rate to 100 kHz. The L1 topological processor (L1Topo), commissioned during Run 2 in 2016, performs additional selections using kinematic information from multiple calorimeter and muon trigger objects; these selections are particularly beneficial in reducing the trigger rate of low-p_T muon triggers (Figure 1). The HLT then further reduces the event rate to ~1 kHz using full-granularity detector information, and events passing the HLT triggers are stored for further analysis.

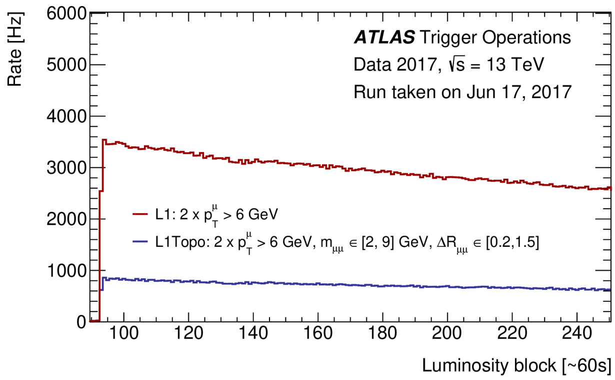


Figure 1: L1 trigger rate, as measured during a 2017 run, without (red) and with (blue) the L1Topo requirement. The rate is reduced by approximately a factor of 4 at the cost of a 12% reduction in the HLT efficiency with respect to offline reconstruction [3].

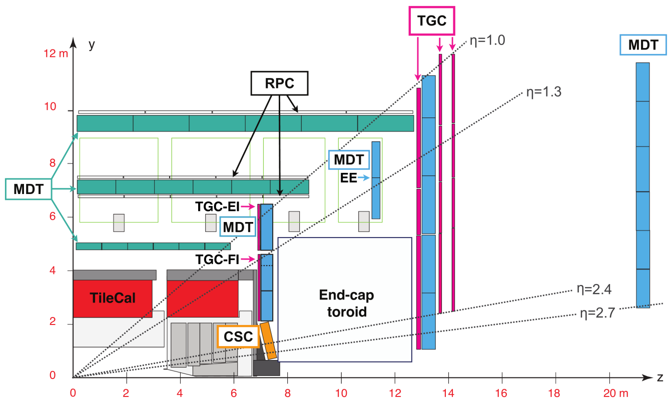


Figure 2: A quarter-section view of the Muon Spectrometer in a plane containing the beam axis [3].

3. Muon Spectrometer

The ATLAS muon trigger system uses information from the Inner Detector (ID) and the Muon Spectrometer (MS) of the ATLAS detector; the latter is shown in Figure 2. L1 triggering is provided by Resistive Plate Chambers (RPCs) in the barrel region (pseudorapidity $|\eta| < 1.05$) and by Thin Gap Chambers (TGCs) in the endcap regions ($1.05 < |\eta| < 2.4$), which provide position resolution on the order of mm. The HLT uses more precise (on the order of 100

μm) position information obtained by Monitored Drift Tubes (MDTs) and Cathode Strip Chambers (CSCs) in the barrel and endcap regions, respectively. The MS has been upgraded to cope with the increased luminosity of Run 3, as described in Section 6.

4. Trigger Efficiency Studies

The efficiencies of the various muon triggers are measured using a tag-and-probe method, which is performed on pairs of offline-reconstructed muons produced through Z or J/ψ decays. A muon with $p_T > 28$ GeV and satisfying suitable isolation requirements is identified as a "tag" muon if it is within $\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.1$ of the object which fired the lowest unprescaled trigger. The other muon in the decay pair is then treated as the "probe" and is used to measure the efficiency of the trigger at the identification working point of interest. If both muons satisfy the tag selections, the probe muon is then considered a tag candidate in turn. This, along with the use of the lowest unprescaled trigger to select the tag muons, ensures that the sample of probe muons is unbiased.

5. Run 2 Performance

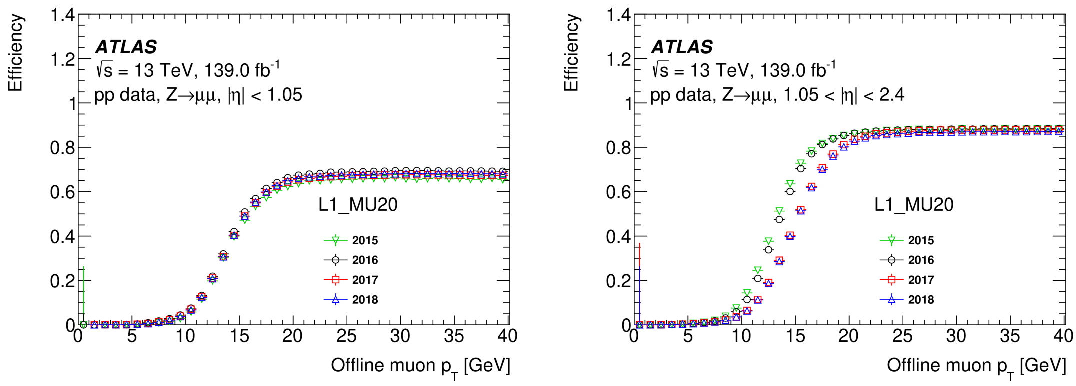


Figure 3: Efficiency of the L1_MU20 trigger as a function of the offline-reconstructed muon p_T in the barrel (left) and endcap (right) regions [3].

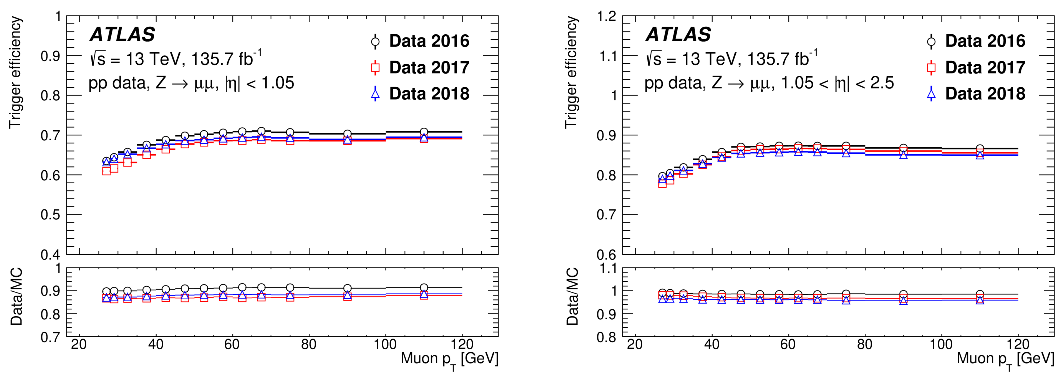


Figure 4: Efficiency of passing either the HLT_MU26_ivarmedium or the HLT_mu50 trigger as a function of the offline-reconstructed muon p_T in the barrel (left) and endcap (right) regions [3].

Figures 3 and 4 show the efficiencies in Run 2 of the lowest unprescaled L1 and HLT single-muon triggers, respectively, in the barrel (left) and endcap (right) regions; the L1 and HLT triggers whose efficiencies are illustrated are in the same trigger chain, and so the L1 efficiencies translate directly to the HLT efficiencies. The efficiencies level off at ≈68% (≈85%) in the barrel (endcap) regions; the lower efficiency in the barrel region is due to reduced geometrical coverage. The HLT efficiency scale factors, shown in the lower panels of Figure 4, are used to correct the muon trigger efficiency in simulations. Overall, the performance of both the L1 and HLT trigger menus was consistent throughout Run 2.

6. Upgrades for Run 3

Several upgrades have been made to the MS and to the muon trigger system to handle the 50% increase in luminosity expected for Run 3. The most significant detector upgrade is the replacement of the innermost muon chamber layers at $1.3 < |\eta| < 2.7$ with the New Small Wheels (NSWs). The increased granularity of the NSWs should significantly decrease the L1 trigger rate (Figure 5). Position and angle matching requirements between the NSW and the TGC Big Wheel (BW) are expected to reduce the number of fake muon triggers and low-p_T muons (Figure 6). The MS has also been upgraded at $1.0 < |\eta| < 1.3$ with new RPC chambers, which help to reject fake muons. Meanwhile, the muon trigger software has been upgraded by migrating the HLT system to a multi-threaded CPU platform in order to minimize CPU and memory usage. Thanks to these upgrades, and the continued maintenance of the Run 3 trigger menu, the muon trigger is fully ready to help ATLAS complete its physics program.

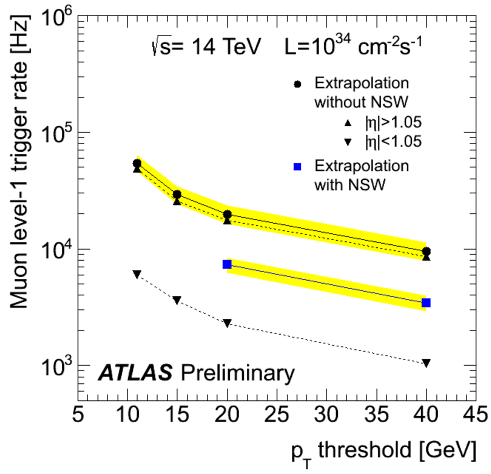
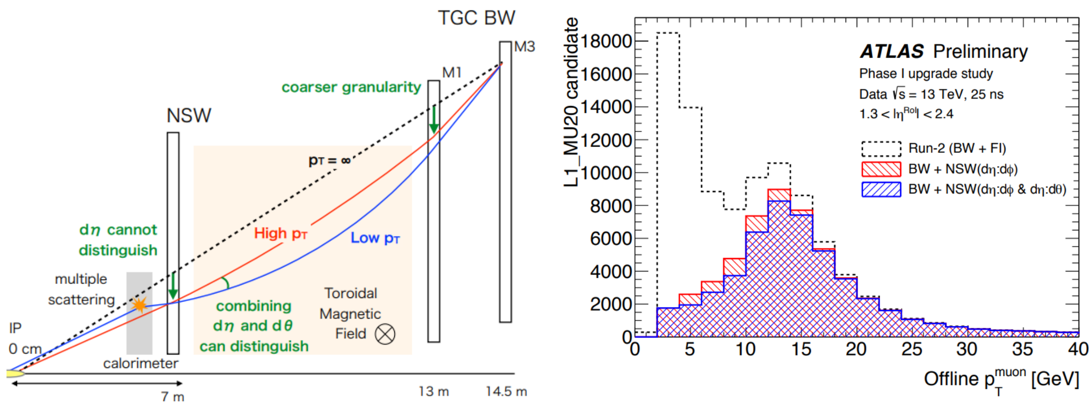


Figure 5: Estimation of the Run 3 L1 trigger rates, extrapolated for pp collisions at $\sqrt{s} = 14$ TeV, as a function of the p_T threshold [5].



(a) **(b)**

Figure 6: (a) Schematic diagram of the angular matching algorithm performed between the TGC Big Wheel (BW) and New Small Wheel (NSW) [4]. (b) Distribution in p_T of muons passing the L1 primary trigger, which illustrates the suppression of low-p_T candidates by the TGC BW-NSW coincidence requirements [5].

References

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

[2] Arantxa Ruiz Martínez, on behalf of the ATLAS Collaboration, *The Run-2 ATLAS Trigger System*, J. Phys.: Conf. Ser. **762** (2016) 012003.

[3] ATLAS Collaboration, *Performance of the ATLAS muon triggers in Run 2*, JINST **15** (2020) P09015, arXiv:2004.13447 [physics.ins-det].

[4] Shunichi Akatsuka, on behalf of ATLAS Collaboration, *The Phase-1 Upgrade of the ATLAS Level-1 Endcap Muon Trigger*, arXiv:1806.09234 [physics.ins-det].

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