# Development of a Highly Selective Single Muon Trigger Exploiting Precision Muon Chamber Data for the ATLAS Experiment at the HL-LHC

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May 3, 2016

**Abstract**

The High-Luminosity LHC will provide the unique opportunity to explore the nature of physics beyond the Standard Model of strong and electroweak interactions. Highly selective first level triggers are essential for the physics programme of the ATLAS experiment at the HL-LHC where the instantaneous luminosity will exceed the LHC Run 1 instantaneous luminosity by almost an order of magnitude. The ATLAS first level muon trigger rate is dominated by low momentum muons, selected due to the moderate momentum resolution of the resistive plate and thin gap trigger chambers. This limitation can be overcome by including the data of the precision muon drift tube (MDT) chambers in the first level trigger decision. This requires the fast continuous transfer of the MDT hits to the off-detector trigger logic and a fast track reconstruction algorithm performed in the trigger logic.

We are presenting the reduction of the muon trigger rate that can be achieved by the proposed trigger scheme, a novel fast track reconstruction algorithm, and the demonstration of the scheme with test-beam data acquired at CERN's new Gamma Irradiation Facility.

## Summary

The trigger of the ATLAS experiment at the Large Hadron Collider uses a three-level trigger system. The first-level (L0) trigger for muons with high transverse momentum $p_T$ is based on chambers with excellent time resolution (better than 20 ns), able to identify muons coming from a particular beam crossing.

The trigger chambers also provide a fast muon $p_T$ measurement, however with limited accuracy due to their moderate spatial resolution along the deflecting direction of the magnetic field. The limited momentum resolution weakens the selectivity of the L0 trigger for high $p_T$ muons above a predefined threshold, like 20 GeV, accepting muons below the threshold.

The higher luminosity foreseen for the phase II of the LHC, the so-called "High-Luminosity LHC", puts stringent limits on the L0 trigger rates. A way to control these rates would be to improve the spatial resolution of the triggering system resulting in a drastically sharpened turn-on curve of the L0 trigger with respect to $p_T$. This is possible without the installation of new trigger chambers with higher spatial resolution by complementing the position measurements of the existing trigger chambers with the much more precise position measurements of the monitored drift-tube (MDT) chambers which are installed in the ATLAS detector to provide an accurate muon momentum measurement.

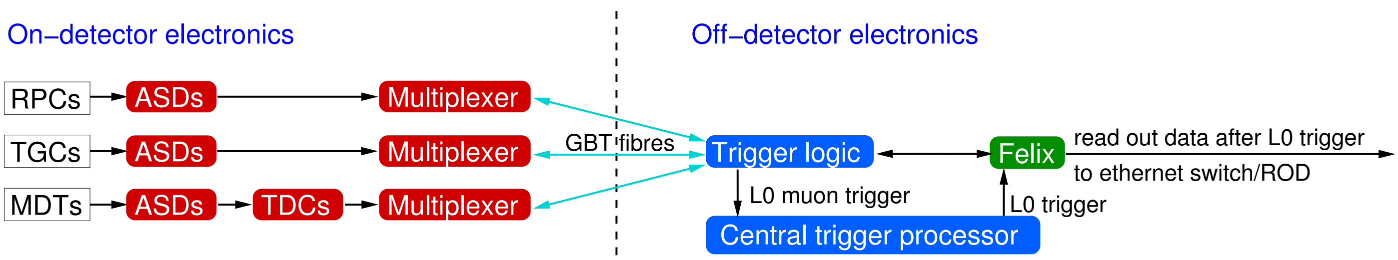


Figure 1: Schematic of the flow of muon chamber data in the ATLAS experiment. Trigger and precision muon chambers send off their data in a continuous stream to the trigger logic. The data are read out after an L0 via the so-called "Felix" module.

In this concept, as illustrated in Figure 1, the trigger chambers will be used to define regions of interest (RoI) inside which high $p_T$ muon candidates have been identified. MDT hits in the RoI(s) are passed to the trigger logic, where they are used for an accurate estimate of the track momentum, leading to an efficient suppression of sub-threshold muon triggers.

In order to collect the MDT hit coordinates early enough for use in the L0 trigger logic, the MDT hit data are streamed off the detector to the trigger logic in the counting room via an optical gigabit link. The trigger logic has to fullfil two tasks: (1) buffering of the data until a L0 trigger, (2) forming the L0 muon trigger.

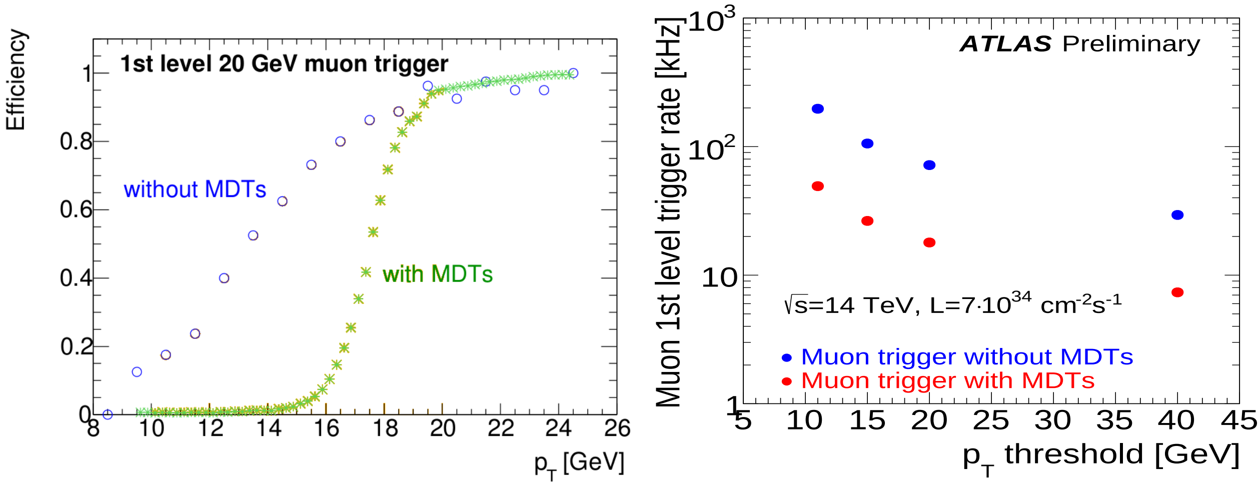


Figure 2: Left: Efficiency of the L0 muon trigger with and without the use of MDT chamber data. Right: Expected L0 single-muon trigger rate as a function of the $p_T$ threshold with and without the use of MDT data at the HL-LHC.

Studies with run-1 LHC and simulated data proved that the proposed MDT L0 trigger scheme can cope with these high background rates. Figure 2 shows the trigger turn-on curve for a 20 GeV muon trigger with and without the use of MDT chambers on the right and the expected trigger rates for the two configurations on the left. The used of MDT data significantly improves the selectivity of the trigger leading to a steeper turn-on curve and a rate reduction by a factor 5.

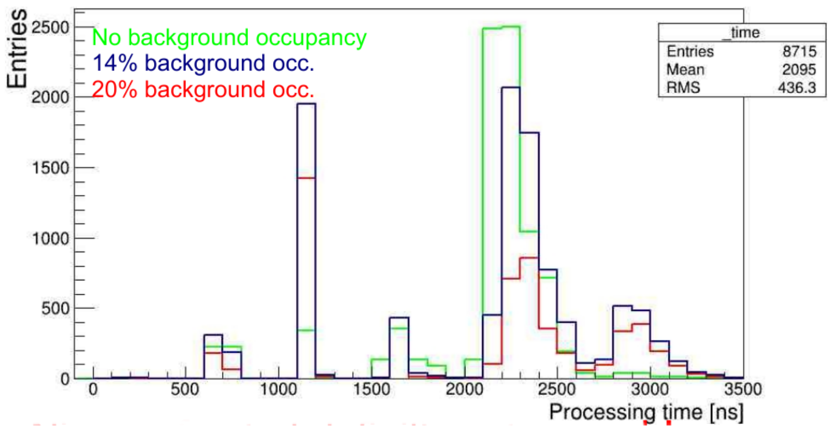


Figure 3: Processing time distribution for a fast track reconstruction algorithm for data acquired in CERN gamma irradation facitily.

A major difficulty in the ATLAS muon system is the presence of large background of thermal neutrons and $\gamma$ rays causing occupancies of up to 10% in the MDT chambers. A demonstatrator for the streamed MDT read-out using an FGPA for sending and receiving the hit data was successfully tested in CERN's gamma irradiation facility (GIF). No data were lost by the priority read-out chain. The data were passed to the embedded 1 GHz ARM Cortex-A9 CPU on the receiving end for track reconstruction. A novel fast track reconstruction algorithm coded in assembler making use of the ARM Neom SIMD engine was employed in this test. The distributions of the processing times of the tracks for different background levels are shown in Figure 3. The processing time was less than 3.5 $\mu$ which is within the latency of the ATLAS L0 trigger.