Conceptual design of a highly selective first level muon trigger based on ATLAS MDT chambers for the HL-LHC

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Abstract

A highly selective first level single muon trigger is essential to exploit the full physics potential of the ATLAS experiment at the HL-LHC where the instantaneous luminosity will exceed the LHC design luminosity by almost an order of magnitude. The ATLAS experiment plans to increase the rate of the first trigger level to 1 MHz at 6 μs latency. This requires new muon trigger electronics and the replacement of the read-out electronics of the muon trigger and precision MDT chambers. The renewal of the electronics and the latency of 6 μs will make it possible to include the MDT data in the first level trigger decision to maximize the momentum resolution at trigger level and therefore increase the selectivity of the first level muon trigger. We use run-I LHC data to study different options how to use the MDT data and show that a substantial reduction of the first-level muon trigger rate to about 10 kHz at transverse momentum threshold of 20 GeV is achievable.

Summary

The trigger of the ATLAS experiment at the Large Hadron Collider uses a three-level trigger system. It is planned to preserve a multilevel trigger system at the "high-luminosity (HL) LHC' though with increased rates and latencis to cope with the increased luminosity of the HL-LHC. The first-level will operated at a rate of up to 1 MHz at a latency of 6 μs. Yet keeping the rates within these limits requires the improvement of the selectivity of the trigger.

The level-1 (L1) trigger for muons with high transverse momentum p_T is based on chambers with excellent time resolution (better than 20 ns), able to assign muons to the beam crossing in which they were created. 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 L1 trigger for high p_T muons above a predefined threshold, like 20 GeV, allowing muons below threshold to cause "fake" triggers, mostly corresponding to event signatures that are of no physics interest.

A way to reduce the muon trigger rates would be to improve the spatial resolution of the triggering system resulting in a drastically sharpened turn-on curve of the L1 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.

In this concept, 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 L1 trigger logic, the relevant hits are read out through a priority read-out chain.

A major difficulty in the ATLAS muon system is the presence of large background of thermal neutrons and γ rays causing occupancies of up to 10% in the MDT chambers. An algorithm for the fast reconstruction of track segments in the MDT chambers which can cope with high background rates has been developed and tested with simulated and data recorded in CERN's gamma irradiation facility. As illustrated in Figure 1 the algorithm has a high reconstruction efficiency of $\gtrsim 95\%$ up to background occupancies of 30% at a fake rate of the order of a per-cent. At the occupancy of 10% as expected for the HL-LHC and efficiency $> 99\%$ at 1% fake rate is achieved.

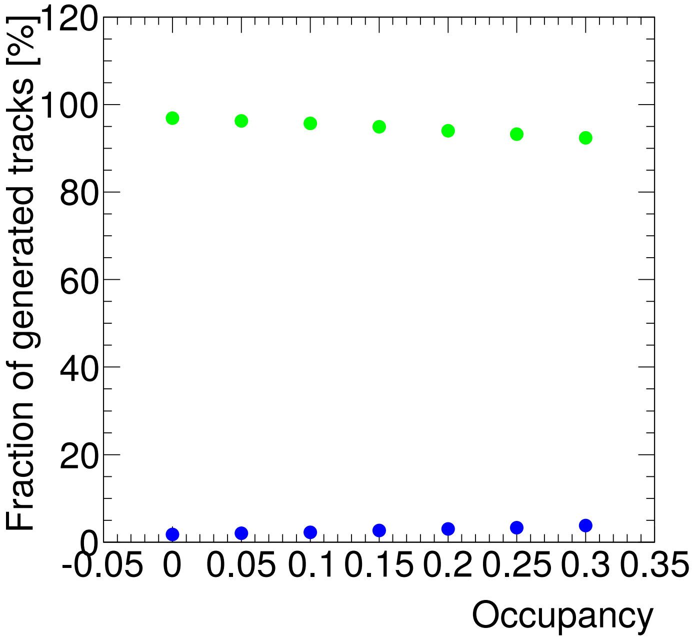

Figure 1: Study of the performance of a fast track reconstruction algorithm with simulated data. Green: Track reconstruction efficiency. Blue: Probability of reconstructing a false track (”fake rate”).

The algorithm was also applied to LHC run-I data in order to determine the selectivity of the muon trigger. Two approaches were compared: In the first approach the muon momentum is determined from the angle between the track segments of two MDT chambers along the muon trajectory in the RoI; in the second approach, the positions of the track segments in three consecutive chambers in the RoI are used. Figure 2 shows the muon trigger efficiency after the application of both methods. Both method increase the selectivity of the muon trigger substantially: the 2-point method reduces the trigger rate to about 50% of the initial value, the 3-point method to about 20% of the initial value. The 3-point measurement provides a higher selectivity because one can achieve a better momentum resoluton with the 3-point measurement than the deflection angle measurement.

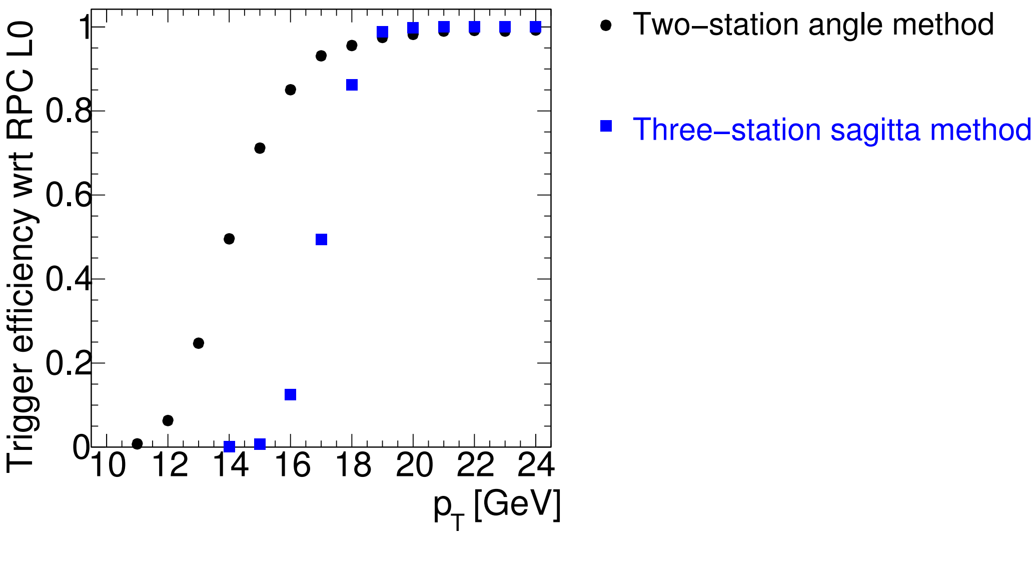

Figure 2: Trigger efficiency as a function of the transverse muon momentum p_{T} for two MDT trigger approaches. The dashed line shows the trigger efficiency without the MDT trigger, the red and blue points the efficiencies of the two methods for the MDT trigger.