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A muon trigger upgrade with high transverse momentum resolution for the ATLAS detector at the High-Luminosity LHC

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ABSTRACT: The Level-1 trigger for muons of the ATLAS experiment is based on trigger chambers with excellent timing resolution which identify muons coming from a particular beam crossing. To cope with the stringent constraint on the trigger rates expected during phase II of the LHC, the so-called High-Luminosity LHC, it is proposed to include precision tracking chambers in the Level-1 muon trigger for improving the transverse momentum resolution. The rate of a single muon trigger with a transverse momentum threshold of 20 GeV is estimated to be reduced by about a factor of two over the entire pseudorapidity region by introducing the proposed upgrade. An architecture of the electronics includes an additional priority readout chain, which is independent of the standard and asynchronous readout. A demonstrator of the frontend electronics has been developed and an initial test based on cosmic muons shows position resolution measurements consistent with the simulation.

KEYWORDS: Muon spectrometers; Trigger algorithms; Trigger detectors



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1 Introduction

The trigger of the ATLAS experiment at the Large Hadron Collider (LHC) is based on a three-level system [1]. The Level-1 trigger for muons is provided by resistive-plate chambers and thin-gap chambers (“trigger chambers”) with excellent timing resolution which identify the muons coming from a particular beam crossing. Due to the limited momentum resolution of the trigger chambers, muon candidates with momenta below the threshold cause “fake” triggers, mostly corresponding to event signatures without physics interest.

2 Concept of a muon trigger upgrade

The phase II of the LHC, the so-called High-Luminosity LHC, is planned to start in 2025 with a leveled instantaneous luminosity of $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$. The event rate is increased proportionally to the luminosity, while the accept rate of the Level-1 trigger should remain at a manageable level from a point of view of the bandwidth for the data transfer of the accepted events. In order to retain the acceptance for various physics processes, the trigger threshold on the transverse momentum (p_T) has to be kept at a relatively low level. This requires an upgrade to the Level-1 trigger system to control the associated Level-1 accept rate.

It is proposed to upgrade the Level-1 muon trigger system by complementing the position measurements of the existing trigger chambers with more precise position measurements of the monitored drift-tube (MDT) chambers [2]. Figure 1 shows a cross-sectional view of the ATLAS detector. Track segments of the muon candidates are reconstructed at two or more locations. The deflection angle between the track segments, corresponding to the track curvature in the magnetic fields, is used for evaluating p_T .

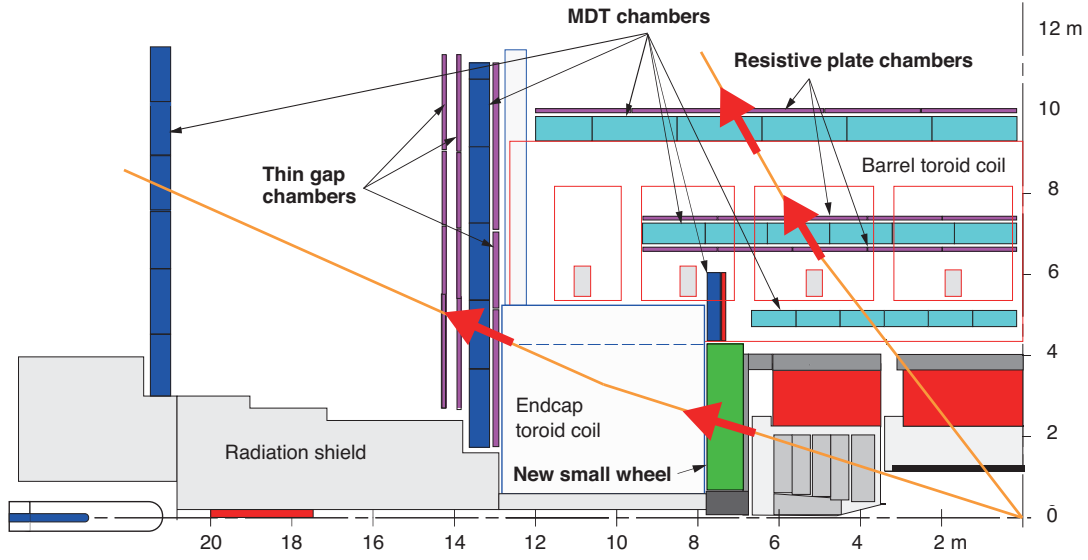


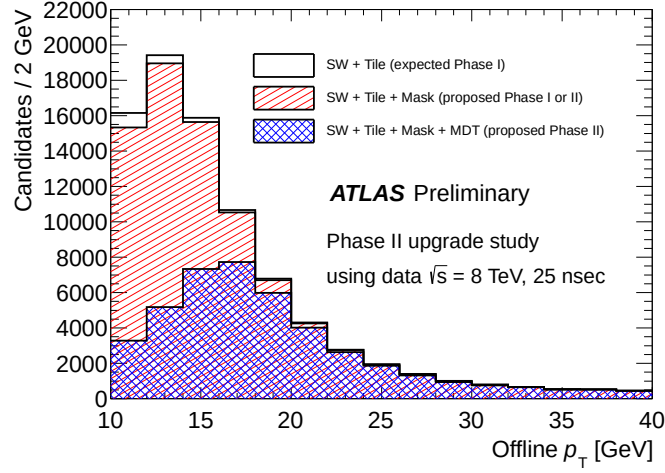
Figure 1. Concept of a muon trigger upgrade based on precise position measurements provided by the MDT chambers. Deflection angle between the track segments reconstructed at two or more locations is used for evaluating the transverse momentum p_T . Smaller angle corresponds to higher p_T .

3 Estimation of a trigger rate reduction

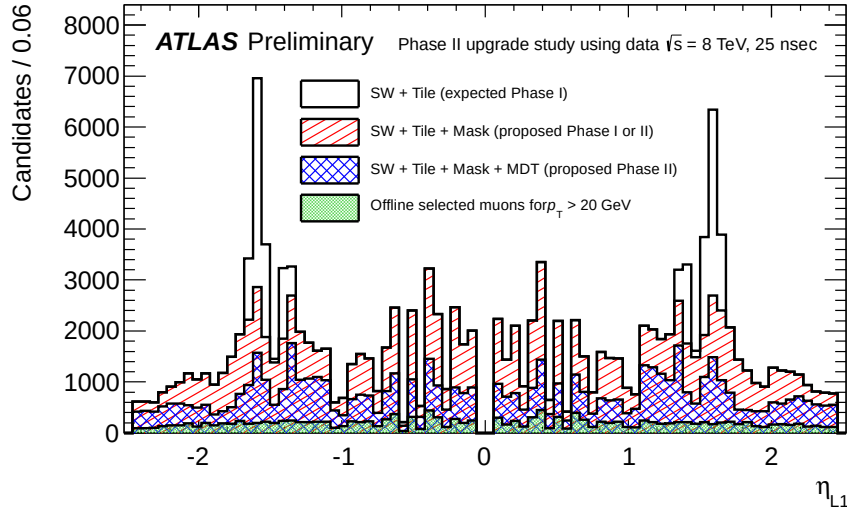
Experimental data recorded by the ATLAS experiment in 2012 are used to evaluate the trigger rate reduction by introducing the proposed upgrade [3]. The data sample corresponds to proton-proton collisions with a center-of-mass energy of 8 TeV and a bunch-crossing interval of 25 nsec. Events are selected by requiring the Level-1 muon trigger with a p_T threshold of 20 GeV. The improvements expected to be included before the start of the High-Luminosity LHC are applied to the events [4].

A mask is applied for the areas in which the magnetic field is relatively small and hence the p_T resolution is poor. The areas are located in a pseudorapidity (η) region of $1.3 < |\eta| < 1.7$, around a boundary between the barrel toroid magnets and the endcap toroid magnets. After areas are masked, a requirement on the deflection angle evaluated from the track segments reconstructed by the MDT chambers is applied. The requirement is set depending on η and the azimuthal angle of the Level-1 muon candidates. By introducing the requirement based on the MDT chambers, the accept rate for a Level-1 single muon trigger with a p_T threshold of 20 GeV is estimated to be reduced by about a factor of two.

Figure 2 (a) shows the p_T distributions of the Level-1 muon candidates matched with a track reconstructed by the offline analysis. The Level-1 muon candidates with $p_T < 20$ GeV are well rejected by the requirements corresponding to the proposed upgrade, while most of the Level-1 muon candidates with $p_T > 20$ GeV are retained. Figure 2 (b) shows the η distributions of the Level-1 muon candidates. The rejection of the entries is provided in an entire η region covered by the muon spectrometers.



(a) Distributions of the transverse momentum p_T of the Level-1 muon candidates matched with the tracks reconstructed by an offline analysis.



(b) Distributions of the pseudorapidity η_{L1} of the Level-1 muon candidates.

Figure 2. Distributions of the Level-1 muon candidates obtained from a data sample of proton-proton collisions at a center-of-mass energy of 8 TeV and a bunch-crossing interval of 25 nsec. The white (unshaded) distribution is obtained by applying the requirements expected to be included before the start of the High-Luminosity LHC, based on the precision tracking chambers in the inner station of the endcap (SW) and the extended-barrel tile calorimeter. The red (parallel-hatched) distribution is obtained by further applying a mask in the transition region of the barrel and endcap toroid magnets. The blue (cross-hatched) distribution is obtained by further applying a requirement based on the MDT chambers. The green (shaded) distribution, shown only for (b), is obtained by further applying a requirement on the transverse momentum p_T reconstructed by an offline analysis to satisfy $p_T > 20$ GeV. The distributions are overlaid.

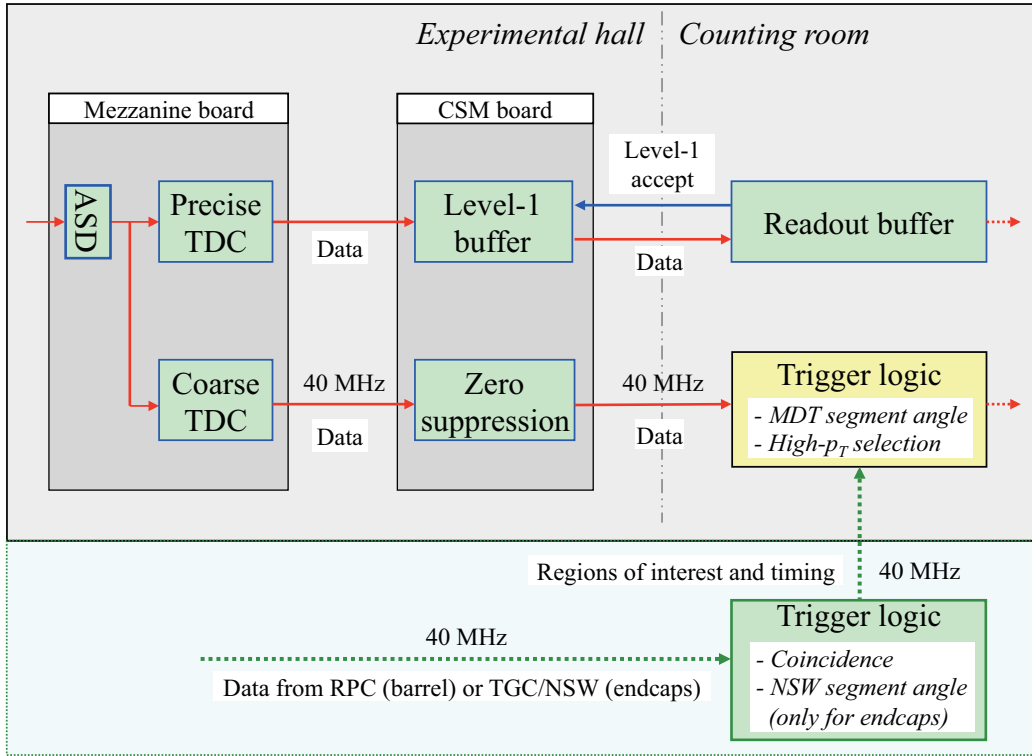


Figure 3. A simplified block diagram for a proposed electronics of the MDT-based muon trigger. A priority readout chain based on coarse TDCs is added to the standard and asynchronous readout. Track segment reconstruction is performed in the regions of interest provided by the trigger chambers. The time origin of the drift time measurements is obtained from the bunch crossing identification provided by the trigger chambers. The trigger decision is based on the deflection angle of the track segments.

4 Technical implementation

Figure 3 shows a simplified block diagram for the proposed electronics of the MDT-based muon trigger [5]. In order to collect the MDT hit coordinates early enough for use in the Level-1 trigger logic, the relevant hits are read out through a priority readout chain, independent of the standard and asynchronous readout. The priority readout chain is based on time-to-digital converters (TDCs) with a foreseen clock frequency of 80 MHz. The hit data are transferred from the experimental hall to the counting room by optical fibers after substantial reduction of the data size for the drift tubes with zero hit signals.

The hit signals transferred to the counting room are used for reconstructing the track segments. The track segment reconstruction is performed in the regions of interest obtained by the trigger chambers, which will reduce the resources needed for the reconstruction. The bunch crossing identification provided by the trigger chambers plays an essential role for determining the time origin of the drift time measurements of the MDT chambers. The reconstructed track segments are used for evaluating the deflection angle of the muon candidates. The deflection angle is used for the trigger decision.

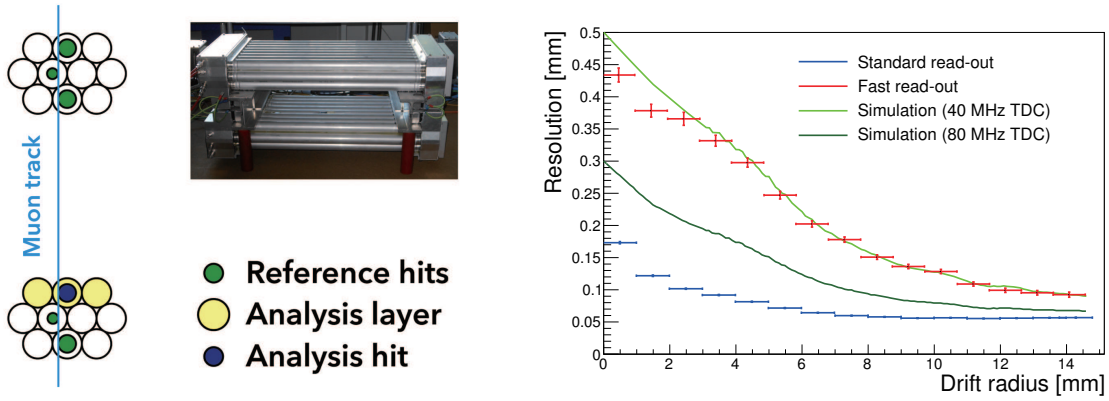


Figure 4. A schematic view and a picture of a test setup with the demonstrator, and a preliminary result on the position resolution for single drift tube as well as a simulation assuming TDCs with clock frequencies of 40 MHz and 80 MHz.

5 Hardware demonstrator and a preliminary test result

To test the feasibility of the technical concept, a demonstrator of the frontend electronics has been developed by adding a fast readout path to the already existing standard MDT readout [6]. The TDCs of the fast readout path are implemented in a field-programable gate array. A clock frequency of 40 MHz, which is a half of the frequency foreseen for the final implementation, is employed. The functions of a reduction of the data size for the drift tubes with zero hit signals and of a track segment reconstruction are under development.

Figure 4 on the left shows a schematic view and a picture of a test setup with the demonstrator. The setup includes the drift tubes which has specifications similar to the ones installed in the ATLAS detector, except for their shorter length of about 50 cm. The drift tubes constitute 3×2 layers. Five layers are used to reconstruct the tracks for reference. The remaining one layer is used to estimate the detection efficiency and the position resolution for single drift tube. Cosmic muon data has been taken with the standard and fast readout paths triggered by scintillator signals. The time measurements are sent to the storage disk without further functions applied. The recorded data are used in an offline analysis.

The detection efficiency for single drift tube is obtained to be $> 99\%$ in most of the region of the drift tube for both standard and fast readout paths. Figure 4 on the right shows a preliminary result on the position resolution for single drift tube for each of the standard and fast readout paths. The position resolution for single drift tube is obtained to be 0.05–0.2 mm (0.1–0.5 mm) for the standard (fast) readout path depending on the drift radius. The result for the fast readout path is in a good agreement with a simulation based on MDT’s drift velocity. The position resolution for single drift tube based on a clock frequency of 80 MHz is expected to be < 0.3 mm.

6 Conclusion

We present a new muon trigger algorithm for the ATLAS experiment based on precision tracking chambers proposed for High-Luminosity LHC. The proposed upgrade is estimated to reduce the

accept rate of a single muon trigger with a transverse momentum threshold of 20 GeV by about a factor of two over the entire pseudorapidity region. A designed electronics includes an additional priority readout chain, which is independent of the standard and asynchronous readout. A demonstrator of the frontend electronics has been developed and an initial test using cosmic muons shows a resolution of position measurements consistent with a simulation. Further studies using the demonstrator are ongoing to test the feasibility of the technical concept of the new muon trigger.

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