9 Muon trigger overview and requirements

9.1 Muon trigger overview

The level-1 muon trigger is based on dedicated, fast and finely segmented muon detectors. The layout of these so-called trigger chambers, Resistive Plate Chamber (RPC) detectors in the barrel and Thin Gap Chamber (TGC) detectors in the end-caps, has been documented elsewhere [9-1]. Very briefly, the RPC-based system covers the pseudorapidity range $|\eta| < 1.05$, while the TGC-based system covers $1.05 < |\eta| < 2.4$. More details on the layout, and in particular on changes compared to the layout in [9-1], are given in Chapter 10.

The RPCs are wireless strip detectors with time resolution σ_t = 1.5ns. The TGCs are multi-wire detectors with both wire and induced strip read-out having a finer segmentation albeit a larger timing-resolution. As discussed in following chapters, the timing resolution of both kinds of detectors is sufficient to provide unambiguous identification of the bunch crossing containing a high-p_T muon candidate.

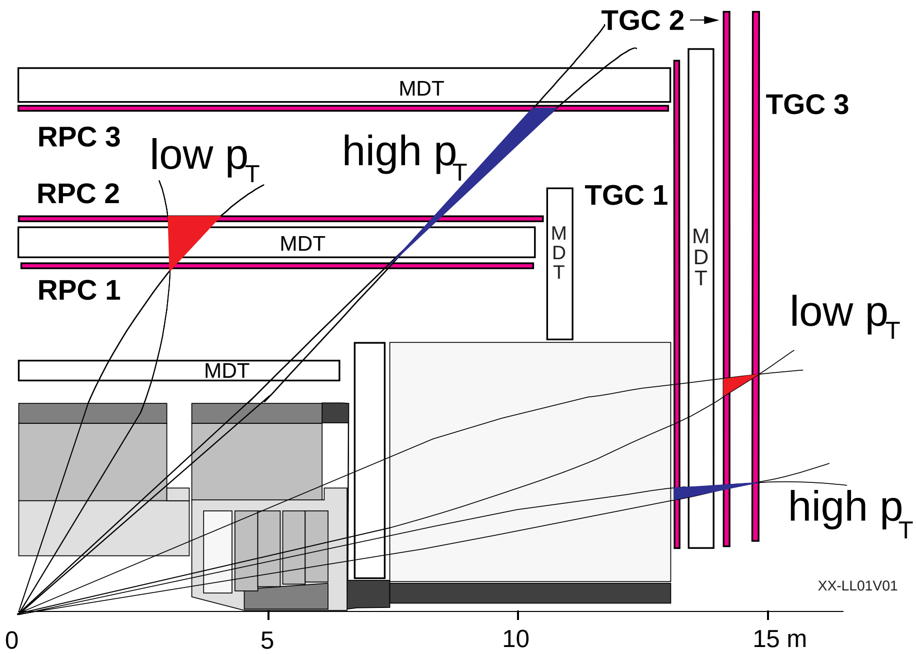

Figure 9-1 Longitudinal view of the end-cap and barrel muon trigger systems.

As illustrated in Figure 9-1, the LVL1 trigger is based on three trigger stations. Two stations are used for low-p_T muon triggers (threshold range approximately 6–10GeV), while the third station is used in addition for high-p_T triggers (threshold range approximately 8–35GeV). Each station is composed of two detector planes (with the exception of the innermost TGC station that has three planes). Each detector plane is read out in two orthogonal projections, η and φ, that will be referred to as the bending and non-bending projections, even though in the 'non-bending projection' there is some bending in the barrel and substantial bending in the end-cap. (Note that in the innermost TGC triplet, only two of the three planes are read out in the non-bending projection.)

The sharpness of the p_T cut applied by the trigger is mainly given by the information read out from the detectors in the bending projection. However, the information in the non-bending view helps to reduce the background trigger rate from noise hits in the chambers produced by low-energy photons, neutrons and charged particles, as well as localizing the track candidates in space as required for the LVL2 trigger. In addition, the trigger chamber information in the non-bending view provides the second coordinate measurement for offline reconstruction of muons (the precision chambers give information only in the bending projection).

As indicated in Figure 9-1, the basic principle of the algorithm is to require a coincidence of hits in the different chamber layers within a road. The width of the road is related to the p_T threshold to be applied. Space coincidences are required in both views, with a time gate close to the bunch-crossing period (25 ns). The coincidence requirement allows for missing layers due to detector inefficiencies, dead regions, etc. For the low-p_T trigger, hits are required within the road in at least three of the four layers, in each of the two projections. For the high-p_T trigger, an additional requirement is made, demanding hits in at least one of the two layers in each of the two projections of the third station. (In the case of the third station for the TGCs, there are three active detector layers in the bending plane, and a two-out-of-three requirement is made.)

As discussed below, a system of programmable coincidence logic allows concurrent operation with a total of six thresholds, three associated with the low-p_T trigger and three associated with the high-p_T trigger. Each of the six thresholds is independently programmable.

9.2 Requirements analysis

A detailed study has been made of the requirements for the LVL1 muon trigger (L1MT). In this section we give a summary of the main requirements; details can be found in [9-2]. Here we discuss what the L1MT has to do, without discussing how it should do it. Subsequent chapters address algorithm and implementation issues.

A context diagram for the L1MT is shown in Figure 9-2, showing its connections to external systems.

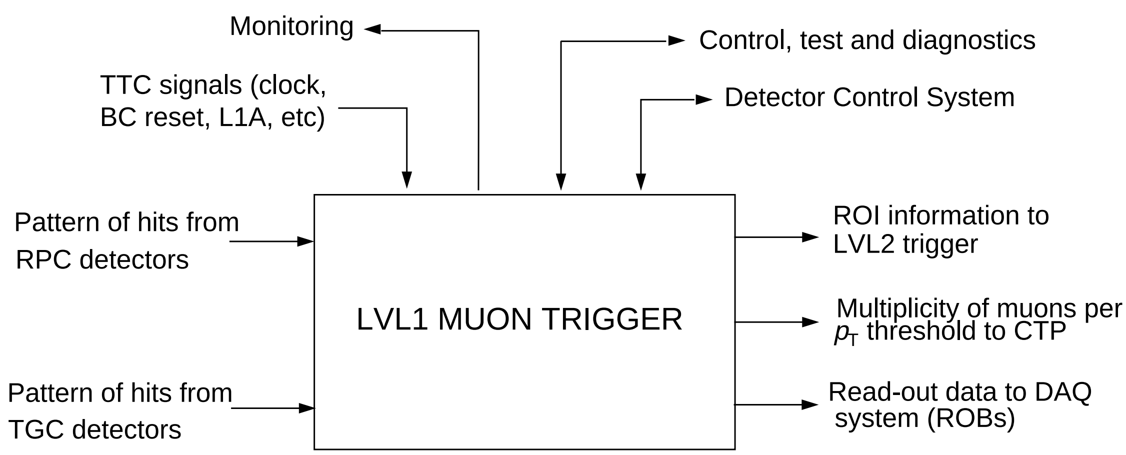

Figure 9-2 Context diagram for the level-1 muon trigger.

The L1MT has to process hit information from the so-called Trigger chambers, RPCs in the barrel region and TGCs in the end-caps [9-1], identifying candidate muon tracks. The hit signals are provided by Amplifier-Shaper-Discriminator (ASD) circuits that are part of the RPC and TGC front-end electronic systems. The muon track candidates must be assigned to a unique bunch crossing. The trigger must provide six independently-programmable p_T thresholds; a p_T range has to be indicated for each track candidate.

The L1MT has to provide data to a number of systems: the LVL1 central trigger processor (CTP), the LVL2 trigger and the DAQ. The data to be sent to the CTP are the muon-candidate multiplicity values for each of the six p_T thresholds. Data to be sent to the LVL2 trigger and the DAQ include the multiplicity values and information about each of the candidate tracks (p_T range; position in η, ϕ). The pattern of hit strips and wire-groups also has to be sent to the DAQ. The data sent to the CTP, which are used to make the overall LVL1 trigger decision, must be provided with the smallest possible latency. A specific requirement is that the information from the L1MT must arrive at the CTP within 51 bunch-crossings following the collision that produces the muon(s); this figure includes cable propagation delays.

9.2.1 Requirements on trigger performance

There are a number of requirements on the performance of the L1MT which are summarized in this subsection. As discussed later in Chapter 14, simulations have been performed to demonstrate that the proposed trigger design meets the requirements.

The trigger has to be able to operate with p_T thresholds in the range 6–35 GeV. The threshold value is defined such that muons with transverse momentum greater than the quoted value shall be triggered with > 90% efficiency if they fall within the acceptance of the trigger.

An average acceptance of at least 90% is required for muons in the pseudorapidity range $|\eta| < 2.4$. Note that the p_T-dependent trigger efficiency and the acceptance have to be combined when evaluating the overall probability that a muon a of given p_T will be identified by the trigger.

The trigger has to make a reasonably sharp cut on the p_T of muon candidates. It is required that, for a variety of threshold settings, there should be at least a specified fraction of muons with true p_T above the threshold p_T value. For example, for a trigger threshold setting of 20 GeV, at least 25% of the muons selected by the trigger should have true p_T greater than 20 GeV. These requirements take into account real muons from a number of sources: decays of bottom and charm quarks, decays of W and Z particles and decays in flight of charged pions and kaons.

The step size by which the trigger thresholds can be adjusted has to be reasonably small. Quantitatively, it is required that the increase in rate for the inclusive muon trigger, due to decreasing the threshold by one step, shall not be more than a factor of 1.5 within the p_T range 6–20 GeV (factor 2 within the p_T range 20–35 GeV).

The rate of triggers due to background sources has to be kept as small as possible. It is required that the rate of fake triggers, due to correlated and/or uncorrelated noise hits in the trigger chambers, shall be much less than the rate from real muons. It is also required that the trigger rates due to cosmic rays, beam-halo particles and due to hadronic shower leakage into the trigger chambers shall be small.

The L1MT has to provide to the CTP the multiplicity of muon candidates for each of the six p_T thresholds. This is important so that, for example, a low-p_T dimuon trigger can be maintained at high luminosity. It is foreseen that the threshold on the dimuon trigger will be kept at about 6 GeV per muon for $L = 10^{34}$ cm^{-2} s^{-1}, while the threshold for the single-muon trigger will have to be about 20 GeV for an acceptable trigger rate. Given the steeply falling muon p_T distribution, it is important that muons should only very rarely be double counted (e.g. in areas of overlapping chambers), giving fake dimuon triggers from single-muon events. It is required that at most 10% of the dimuon triggers shall be due to doubly-counted single muons.

The trigger system may not be able to resolve pairs of muons that are not well separated in the detector. It is required that the fraction of events that are lost will be small for a number of representative physics processes.

It should be possible to use the L1MT to provide a cosmic-ray and beam-halo trigger for the experiment, for use in calibration and alignment studies. In the cosmic-ray mode, the system would be driven by a free-running 40 MHz clock.

9.2.2 Other requirements

The detailed requirements for the data to be sent, for LVL1-accepted events, to the LVL2 trigger and to the DAQ can be found in Ref. [9-2]. Very briefly, the required data (pattern of hit strips and wire groups, information on each muon candidate and the multiplicities for the various thresholds) have to be retained in pipeline memories during the latency of the LVL1 trigger. When an event is accepted by the LVL1 trigger, the corresponding data have to be sent to the DAQ system using the ATLAS standard read-out link / read-out buffer chain. A subset of the data, including the information on each of the muon candidates, has to be sent via a separate path to the region-of-interest builder of the LVL2 trigger. The data that are sent to the DAQ will be used for monitoring the performance of the trigger, and also for calculation of trigger efficiencies and acceptances. The data that are sent to the LVL2 trigger will be used to guide the LVL2 processing by defining roads in which to search for muon-track candidates.

The L1MT is a data source that, from the point of view of the DAQ, resembles a front-end system. It must therefore conform to the ATLAS requirements for the interface between front-end systems and the DAQ [9-3]. Similarly, it must take into account the needs of the LVL2 trigger [9-4].

There are numerous other requirements concerning the ability to control, test, and monitor the L1MT system, and also on error handling and fault tolerance, and maintenance. These are documented in [9-2].

An important issue for all parts of the LVL1 trigger (and also for detector front-end systems) is the need for a strategy for setting up the timing for various modes of operation: beam–beam collisions, cosmic-ray and beam-halo triggers, test and calibration running. The system contains numerous programmable delay and phase-adjustment circuits, and a means has to be worked out for determining the appropriate values of all the parameters of these components. The procedure for setting up the timing should not rely on physical access to the electronic systems, some of which are in any case on the detector and therefore inaccessible when there is beam in the machine.

9.3 System implementation overview

The electronics implementation of the level-1 muon trigger is shown in Figure 9-3 below. The detector and front-end electronics are described in the Muon Spectrometer TDR [9-1]. Summary and update information can be found in Chapter 10. Despite the problems of radiation, magnetic fields, power distribution and cooling, a large fraction of the system is mounted on the detectors in order to enable the accurate timing of detector signals into the coincidence logic and to reduce cabling – the on-detector coincidence logic reduces about 800,000 channels to about 1000 optical links to the off-detector trigger electronics located outside the ATLAS cavern in underground area USA15. In both the barrel and end-cap systems track candidates found independently in η an ϕ are subsequently combined. The η-ϕ area is divided into sectors, 64 for the barrel and 144 for the end-cap. Each sector provides track candidates to the Muon to Central Trigger Interface (MUCTPI). In addition to providing trigger signals, the system reads out all hits in the muon trigger chambers for all ATLAS level-1 triggers. The MUCTPI counts muon candidates for six thresholds, removing doubly counted tracks in overlap regions, and generates the Region-of-Interest (RoI) list for the level-2 trigger system. A RoI is generated for each candidate.

Differences between the barrel and end-cap region requirements result in different capabilities and different implementations. These are summarized in Section 2.4.2.

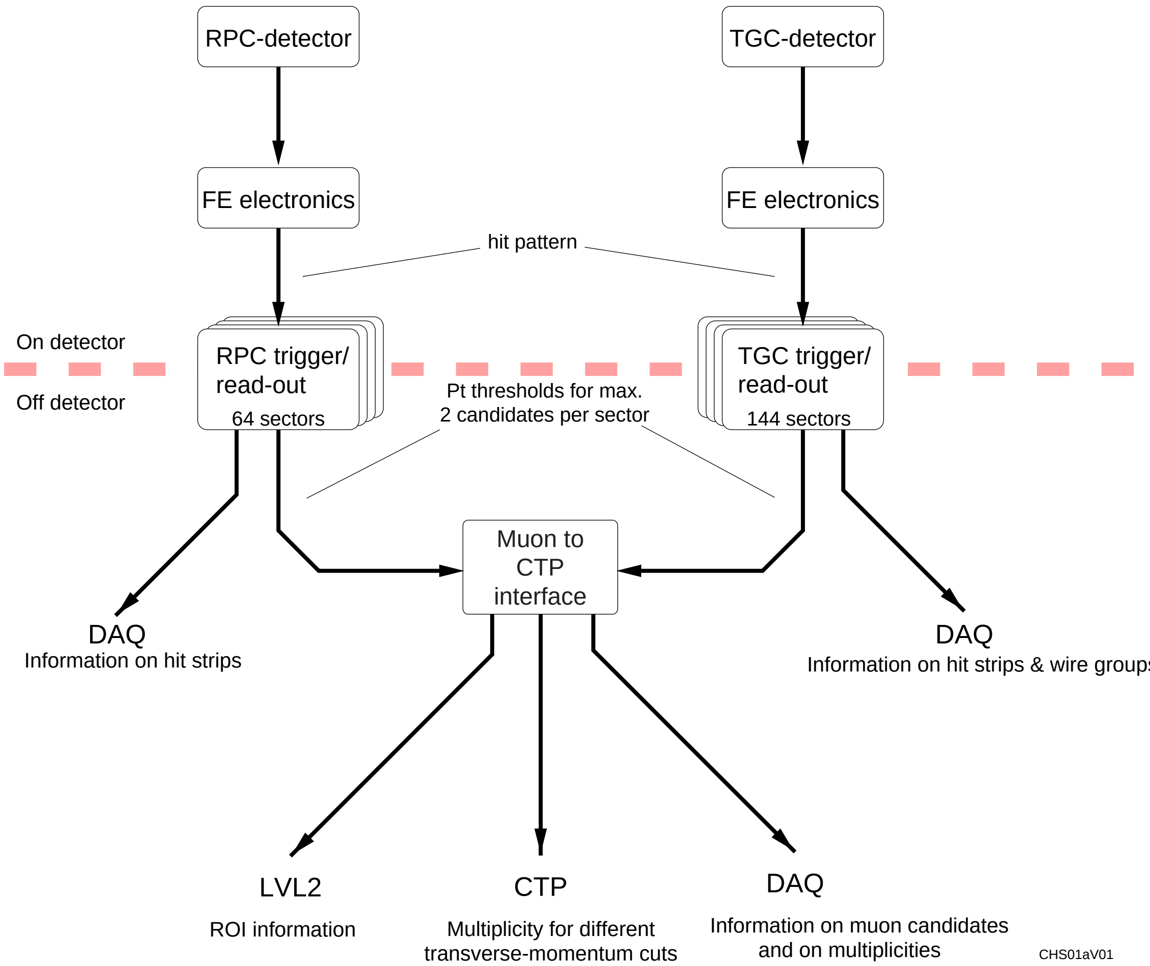

Figure 9-3 Block diagram of the level-1 muon trigger system.

9.4 References

9-1 *ATLAS Muon Spectrometer Technical Design Report*, CERN / LHCC / 97–22, May 1997.

9-2 *LVL1 Muon Trigger User Requirements Document (Draft Version 1.4)*, ATLAS working document, ATL–DA–ES–0002, March 1998.
http://atlasinfo.cern.ch/Atlas/GROUPS/DAQTRIG/LEVEL1/muons/L1MT980309.ps

9-3 *Trigger and DAQ Interfaces with Front-End Systems: Requirement Document (version 2.0)*, ATLAS note DAQ–NO–103, June 1998.
http://www.cern.ch/Atlas/GROUPS/FRONTEND/FEreq980310.ps

9-4 *ATLAS Level-2 Trigger User Requirements Document*, ATLAS note DAQ–NO–079, November 1997.