The ATLAS Trigger Muon ”Vertical Slice”*

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Abstract

The *vertical slice* of the muon trigger is a key component of the Trigger/DAQ system for the ATLAS experiment. To cope with the high collision rate of the LHC collider a three-level trigger has been designed and *on-line* muon selection will be crucial for the ATLAS physics program.

In this paper we will present the whole trigger chain that identifies muons *on-line*.

INTRODUCTION

ATLAS is one of the four LHC (Large Hadron Collider) experiments at CERN; it is a general purpose experiment that analyzes proton-proton collisions at $\sqrt{s} = 14$ TeV. ATLAS has faced several technological challenges. In particular the data acquisition system has to cope an extremely high interaction rate of collisions and reduce the the 40 MHz bunch-crossing frequency, corresponding to an interaction rate of 1GHz at the design instantaneous luminosity ($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$), to about ~ 200 Hz allowed by the permanent storage system.

Final states with muons represent a key signature for many physics measurements and discoveries: b-physics, top physics, W and Z bosons final states (electroweak physics, Higgs boson searches and measurements,...), physics beyond Standard Model (SUSY, Extra Dimensions,...).

The capability to select events with muons at an early stage of the trigger system is therefore crucial to cope with the expected rates and to perform the various physics measurements of the ATLAS physics program.

The *Trigger Vertical Muon Slice* is the full integrated chain of Trigger/DAQ running from the ATLAS Muon Spectrometer data and is composed by three trigger levels: an hardware implemented Level1 (LVL1) and a software implemented High Level Trigger (HLT) composed by Level2 (LVL2) and Event Filter (EF). A schema of the whole ATLAS Trigger is shown in Fig.1.

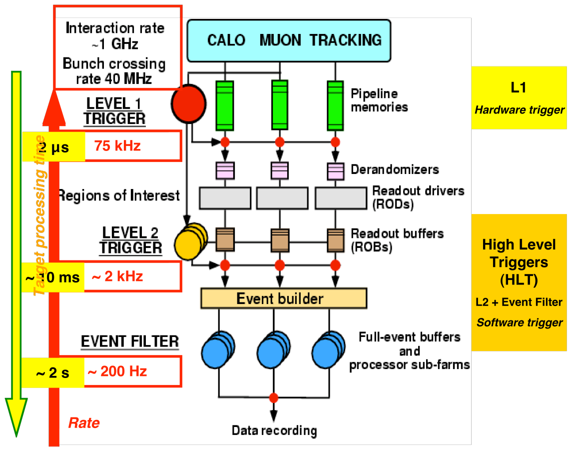

Figure 1: ATLAS Trigger overall schema.

This paper is devoted to the presentation of the whole trigger and data acquisition of the muon system. We will show the algorithms and the performances that compose the three muon trigger level and their integration (Fig.2).

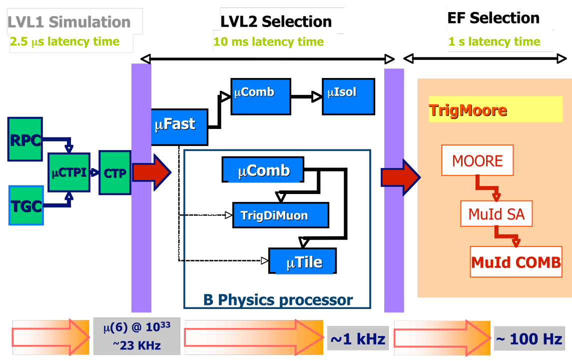

Figure 2: Algorithm flows composing the muon slice.

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LEVEL I

The ATLAS Muon Spectrometer (MS) surrounds the other ATLAS sub-detectors and is composed by four different detector types: Resistive Plate Chambers (RPC) , Monitored Drift Tubes (MDT), Thin Gap Chambers (TGC), Cathode Strip Chambers (CSC).

The first level of the muon trigger (LVL1) is a synchronous process with a fixed latency of 2.5 μs. Using the full granularity of the RPC detectors located at the two external stations of the MS it selects muons with transverse momentum above six programmable thresholds with a coarse evaluation of the pseudorapidity and azimuthal angle (respectively η and ϕ) coordinate and associates the trigger candidate with the correct LHC bunch crossing (Fig.3).

The system provides both trigger and RPC readout information. The algorithm looks for hit coincidences within different RPC detector layers inside the programmed geometrical roads which define the transverse momentum cut. The coincidence is performed on both eta and phi projections. The LVL1 event-decision part is implemented in the Central Trigger Processor (CTP) that is in common to other LVL1 triggers coming from other sub-detectors; it also resolves possible double counting of muons that traverse more than one detector region.

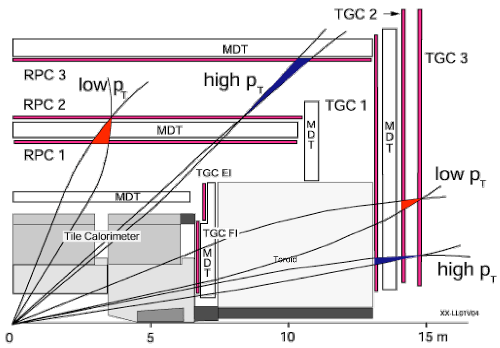

Figure 3: Muon LVL1 algorithm

LVL1 is also responsible to select the Regions of Interest (RoI) with a size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ that contain hits of the MS that will be further analyzed by the HLT. The output rate is reduced to the allowed input rate of the HLT ($\sim$75-100 kHz).

During data-taking the LVL1 trigger algorithm and the readout of the RPC detector on the bending and non-bending planes will use a Coincidence Matrix ASICs [1]. In the vertical muon slice presented here, the LVL1 is implemented using a software simulation reproducing with great detail the hardware implementation.

LEVEL 2

The second trigger level (LVL2) is implemented in the HLT Event Selection Software (HLTSSW) that runs on dedicated farms and is common also to the Event Filter trigger level. The HLTSSW is composed by four components: the Steering, the Data Manager, the Event Data Model, and the HLT Algorithms(Fig.4). The steering [2] controls the order in which the various algorithms are executed, given the results at each processing step such to refine the muon selection in successive steps and eventually reject the event as soon as possible. The Data Manager handles the event and trigger-related data during processing, in particular it is responsible for managing the RoI. The total latency time is 10ms and the rate is reduced from $\sim$75kHz to 1kHz.

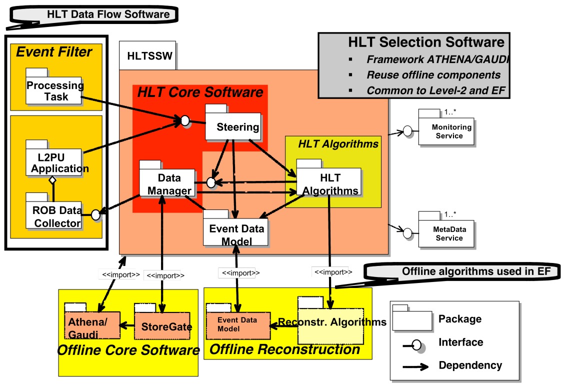

Figure 4: HLT Event Selection Software (HLTSSW) implemented for HLT framework.

Algorithms run on full granularity data on RoI selected by LVL1 Trigger. Data analyzed by LVL2 are therefore $\sim 1-2\%$ of the full event size. The Algorithms fill-up a *feature* data object containing muon measured quantities in the Event Data model that will be retrieved to perform the trigger decision.

The key idea in the development of LVL2 algorithms is to avoid lengthy calculations such as non-linear fits and time-consuming service accesses (alignment, geometry, calibration, magnetic field map,...) using as most as possible linear approximations and LVL2 specific services.

muFast

muFast is the first algorithm to run at LVL2[3]. After a LVL1 emulation in order to reconstruct the RPC pattern that fired the LVL1 trigger, it selects MDT hits within roads seeded by the guessed muon trajectory from RPC hits. In each MDT station a local linear fit is performed using MDT hits to get the intersection of the muon trajectory with the station itself and its slope. From these points the radius of the muon trajectory is measured. The transverse muon momentum is determined as an output of a Look Up Table (LUT) whose entries are radius, ϕ and η at the entrance of the MS. muFast, as well as the other algorithms, has been tested on various simulated event samples. To measure efficiencies and momentum resolution Monte Carlo simulated single muons events with different P_T have been used. Expected trigger rates have been evaluated with muons from in-flight decay of π and K, $c\bar{c} \rightarrow \mu X$, $b\bar{b} \rightarrow \mu X$ and $W \rightarrow \mu\nu$. Robustness against cavern background (mainly photons and neutrons) have been tested using single muon events with pileup superimposed. Momentum resolution are shown in Fig.5. Expected rates for different physical sources are shown in Tab. 1. Timing performances have been measured on a Xeon @ 2.4 GHz and are reported in Fig.6

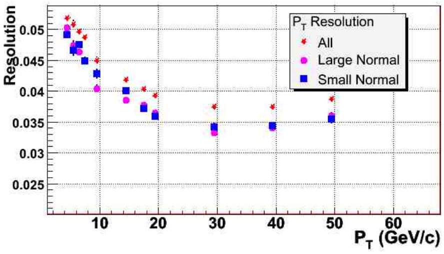

Figure 5: muFast momentum resolution.

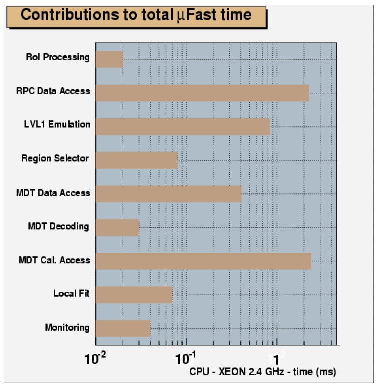

Figure 6: Measured timing performances of muFast sub-components (Xeon @ 2.4 GHz).

muComb

The next algorithm to run at LVL2 is muComb. This algorithm combines the Inner Detector (ID) tracking measurements with the MS measurements. The transverse momentum, azimuthal angle and pseudorapidity matching between the two trajectories is performed using windows determined analytically. In a similar way of muFast, no lengthy fit procedures are involved. The main goal of muComb is to reduce rates from low P_T muons coming from in-flight decays of π/K decays. Expected rates are shown in Tab.1.

muTile

A specific algorithm for identifying low momentum muons has been developed: muTile[4]. This algorithm exploits the full segmentation of the ATLAS Tile Calorimeter[5]. The algorithm starts with a search for a candidate muon in all the outer radial layer cells. A candidate muon is defined when the energy deposition in one cell is compatible with a muon. Individual thresholds for each cell are determined using single muon events. When a candidate is found the search is continued in the central and innermost layer cells following a pattern from the candidate cell toward the interaction region, evaluating at each step the compatibility of the cell energy with the energy deposition of a muon. The ϕ and η coordinates of the found track are calculated as the average coordinates of the crossed cells in the three layers. The average efficiency, in the range $|\eta| \leq 1.4$ is about 60% down to $P_T = 2$ GeV.

Table 1: Trigger Rates for Level 2.

	Low P_T (6 GeV)		
	L1 rate (kHz)	L2 rate muFast (kHz)	L2 rate muComb (kHz)
π/K	7.60	3.18	1.1
b decays	1.50	0.91	0.68
c decays	0.90	0.41	0.35
Fake	1.0	< 0.001	< 0.001
W decays	-	-	-
Total	11.0	4.5	2.13

	High P_T (20 GeV)	
	L1 rate (kHz)	L2 rate muFast (kHz)
π/K	1.11	0.07
b decays	0.73	0.10
c decays	0.32	0.04
Fake	< 0.001	< 0.001
W decays	0.03	0.03
Total	2.19	0.24

TrigJPsi

J/Ψ are important signatures for many b-physics measurements (*e.g.* $B_0 \rightarrow J/\Psi K_s$ and many other channels). The expected dimuon rates are several orders of magnitude less than single muon rates. To enhance the ATLAS B-Physics potential it is therefore essential to select dimuons from J/Ψ as soon as possible in the trigger chain with the highest efficiency. TrigJPsi is a specific trigger implemented for this purpose. It runs after muFast and selects dimuons with $M(\mu,\mu) > 2.8$ GeV/c^2. The expected rates and efficiencies are shown in Fig.7.

EVENT FILTER

A third trigger level, called Event Filter (EF) accesses and reconstructs the full event. Within a latency time of $\sim$ 1-2 s it will reduce the rate to $\sim$ 200 Hz. Different algorithms have been implemented for event reconstruction inside the MS and combining the measurements of all ATLAS sub-detectors in order to provide the best estimate of their momentum at the production vertex.

Two offline packages have been adapted to work in the HLT framework: MOORE ("Muon Object Oriented RE-

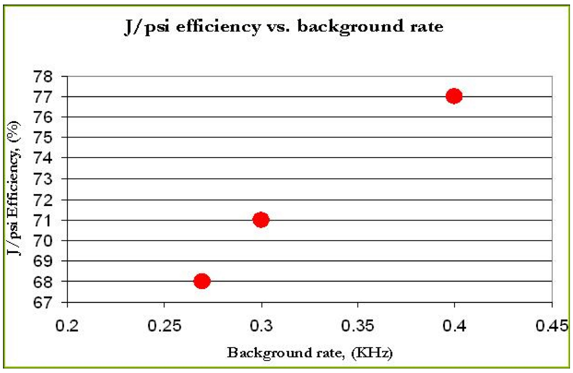

Figure 7: Expected rates and efficiencies for LVL2 TrigJPsi

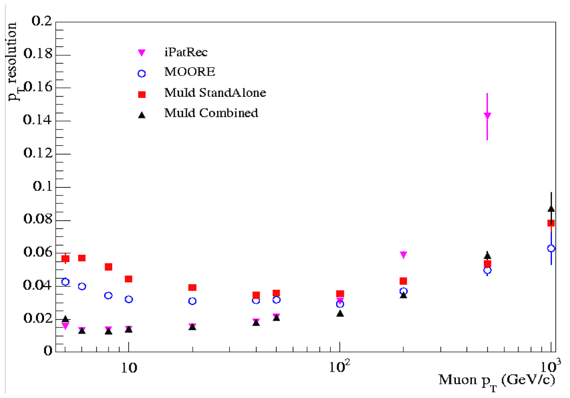

Figure 8: P_T resolution from TrigMOORE

construction") and MuId ("Muon Identification"). The former performs track reconstruction in the Muon Spectrometer while the latter extrapolates the track to the interaction point (MuId Standalone) and combines the muon and Inner Detector track segments (MuId Combined) [6]. It is possible to run the two algorithms with two modes: the *full-scan* or the *seeded* mode. The former allows to run the whole offline reconstruction chain from the online environment, reconstructing the event by accessing all the Muon Spectrometer data while in the latter, that is necessary for running in an on-line framework, the reconstruction process accesses only those subdetectors that are of interest for the RoIs selected at previous trigger levels. In order to run in the HLT framework, explicit dependencies from the offline package have been avoided merging the code in a specific on-line package: TrigMOORE.

The full chain has been tested on various simulated event samples. Expected resolution and trigger rates from different physics sources are shown respectively in Fig.8 and Tab.2.

Table 2: Trigger Rates at Event Filter output. *Note: No selection applied on LVL2 muComb*

	MuID MS only (kHz)	
Muon sources	6 GeV Threshold $L = 10^{33} cm^{-2} s^{-1}$	20 GeV Threshold $L = 10^{34} cm^{-2} s^{-1}$
π/K	2.8	0.056
b	0.82	0.080
c	0.43	0.031
W	0.003	0.036
Total	4.0	0.20
	MuId Combined (kHz)	
Muon sources	6 GeV Threshold $L = 10^{33} cm^{-2} s^{-1}$	20 GeV Threshold $L = 10^{34} cm^{-2} s^{-1}$
π/K	2.0	0.054
b	0.64	0.077
c	0.33	0.030
W	0.003	0.022
Total	3.0	0.18

CONCLUSION

We have presented the status of the ATLAS *Muon Trigger Vertical Slice*. Performances, rates and timing are under control. The whole trigger chain should be ready and implemented in a form close for the integrated cosmic data taking in the last months of 2006.

ACKNOWLEDGMENTS

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REFERENCES

[1] R. Cardarelli *et al.* "The Implementation of the ATLAS Level-1 Muon Trigger in the Barrel Region", CHEP95, Rio de Janeiro, September 1995 and http://atlas.web.cern.ch/Atlas/GROUPS/MUON/TDR/Web/TDR.html.

[2] G. Comune *these proceedings*.

[3] A. Di Mattia *et. al.* "A Level-2 trigger algorithm for the identification of muons in the ATLAS Muon Spectrometer" ATL-DAQ-CONF-2005-005, presented at CHEP04, Interlaken, Switzerland, 2004.

[4] G. Usai, Nucl. Instr. Methods **A 518** (2004), 36 presented at *Frontier Detectors for Frontier Physics* La Biodola, Isola dElba, 2003.

[5] ATLAS/Tile Collaboration, Tile Calorimeter Technical Design Report CERN/LHCC/9642.

[6] M. Biglietti *et al.* "Muon Event Filter Software for the ATLAS experiment at LHC" ATL-DAQ-CONF-2005-008. presented at CHEP04, Interlaken, Switzerland, 2004 and A. Ventura *et al.* "Muon Reconstruction and Identification for the Event Filter of the ATLAS experiment" ATL-COM-DAQ-2005-035 presented at *9th International Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physical Applications*, Como, Italy, 2005.