ATL-DAQ-CONF-2007-006
12 April 2007

Implementation and performance of the ATLAS Trigger Muon "Vertical Slice"

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The ATLAS (A Toroidal LHC ApparatuS) trigger system is designed to keep high effiency for interesting events while achieving a rejection of low transverse momentum (p_T) physics of about 10^7, thus reaching the ~200 Hz data storage capability of the Data Aquisition system. A three levels structure has been implemented for this purpose, as described in this work for the case of the muon trigger system. After describing the implementation, some performance results are presented in terms of final trigger rates, resolutions, efficiencies, background rejection and algorithm latency.

1. Introduction

High p_T muons are important for many known processes, that can be used for monitoring and calibration ($Z \to \mu\mu$), and for several new phenomena (Higgs, SUSY), predicted at the energy of the Large Hadron Collider (LHC). Therefore the muon trigger system is of primary importance. The detector dedicated to the identification of muons is the Muon Spectrometer (MS). It consists of resistive plate and thin gap trigger chambers (RPC and TGC) and precision detectors consisting of monitored drift tubes (MDT) and cathode strip chambers (CSC).

The Muon Trigger "Vertical Slice" consists of three main trigger steps, one hardware, level 1 (LVL1) and two software, level 2 (LVL2) and event filter (EF), referred as High Level Trigger (HLT). Decision on each event is based on reduced-granularity detector data for interesting regions at LVL1, full-granularity and precision, but only for same LVL1 regions, at LVL2, and

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full event data, as in offline, at EF.

2. Level 1 trigger

LVL1 selects active detector regions (Region of Interest, RoI) in the event, using RPC for $|\eta| < 1$ and TGC for $1 < |\eta| < 2.4$ (Fig.1). Six programmable thresholds are applied with two kinds of majority logic: a low p_T scheme (for 6, 8, 10 GeV/c) and a high p_T (11, 20, 40 GeV/c) level triggers. Overall LVL1 acceptance is 83% for low p_T, and 79% for high p_T particles. The rates depend on the machine luminosity: at the low luminosity of 10^{33}cm^{-2}s^{-1} with the low p_T threshold, the expected rate is about 11 kHz, while at the high luminosity of 10^{34}cm^{-2}s^{-1} with the high p_T threshold, the expected rate is about 2 kHz.

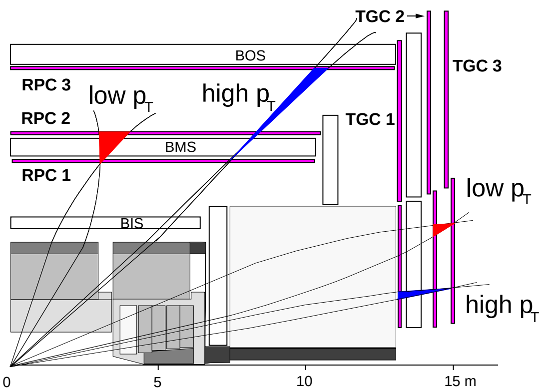

Figure 1. RPC $|\eta| < 1$ and TGC $1 < |\eta| < 2.4$ used in LVL1 trigger.

3. Level 2 trigger

Many different software algorithms compose the LVL2 trigger. The names are chosen to explain their role in the trigger chain. The core algorithm is *muFast*, that confirms/rejects LVL1 result and refine muon p_T evaluation, using MDT precision measurements. The following steps are executed within a 10 ms latency time: "global pattern recognition", involving trigger chambers and positions of MDT tubes (without using drift times); "local segment reconstruction" involving drift time measurements for each station; fast "p_T estimate" via a look-up-table. To refine the muFast p_T, *muComb* combines information from Inner Detector (ID) data, allowing to sharpen the threshold at low p_T. Efficiencies for LVL2, with respect to LVL1, is above 80% for muons with p_T at the selection edge and well above 90% for muons with higher p_T.

3.1. A LVL2 trigger for B-Physics

J/ψ particles are widely produced in B decays. A specific J/ψ selection is done by *TrigDiMuon* requiring one muon with a $p_T > 6$ GeV/c to be triggered by muFast; in the ID must be two opposite sign tracks, one pointing to the LVL1 RoI, the other successfully extrapolated to the MS. The invariant mass for the di-muon must be $m(\mu\mu) > 2.8$ GeV/c^2. The efficiency for this kind of events is about 66%–78% at LVL2, with output rate of about 260–380 Hz.

4. Event Filter

The Muon Event Filter consists of three algorithms: *MOORE*, *MuId StandAlone* and *MuId Combined*. They are offline packages fully integrated in the ATLAS software framework: *ATHENA*. Imported in the trigger environment, they became *TrigMOORE*. TrigMOORE can work in two different modes: wrapped, scanning full detector data, and seeded, starting from RoI seeded by LVL2 (full trigger chain) or alternatively by LVL1 (for trigger studies).

The role of MuId StandAlone is to extrapolate MS tracks to the production point. Muon momenta are measured with a resolution $\Delta p_T/p_T <$ 10% up to 1 TeV. Tracks are reconstructed also in the ID by one dedicated software (iPatRec). MuId Combined uses these informations, thus enhancing momentum resolution to about $< 3\%$ for p_T up to 50 GeV/c. In Tab.1 are reported, for all trigger level, the rates for single muons.

4.1. Background studies

The radiation generated by p-p collisions interacts with the detector and the collider activating their material. Particles released by the materials, mainly neutrons, produce secondary time-uncorrelated photons that subsequently produce electrons, diffusing in the apparatus like a gas. This cavern background causes counting rates expected at design luminosity of the order of 10–100 Hz/cm^2 in the barrel and $\sim$ 1 kHz/cm^2 in the endcaps, slightly depending on pseudorapidity. Outer stations are less affected. To be conservative simulations are done with background levels multiplied by safety factors. The effects on the resolutions are small.

4.2. A trigger chain example

Trigger software works with objects called *Trigger Elements* (TE). *Feature Extraction Algorithms* (FEX) are activated by input TE produced by previous trigger levels. FEX access the detector data and compute physical quantities, Features, that are then associated to the output TE. Selection is done in *Hypothesis Algorithms*, that validate or reject TE according to trigger menu requirements.

In-flight decays of pions and kaons are the main source of LVL1 trigger rate at low p_T (see Tab.1). One goal of the muon HLT is to reject such fake muons while having high selection efficiency on prompt muons up to p_T of 6 GeV/c. Trigger sequences like the one on Fig. 2 can be used for this purpose.

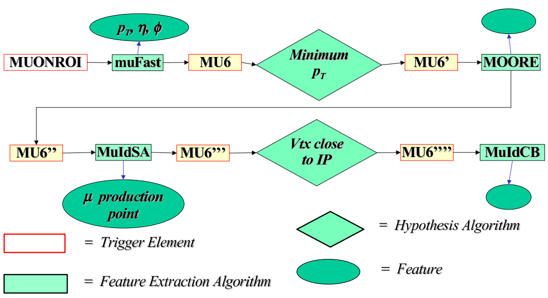

Figure 2. A trigger sequence example.

Table 1
Single muon rates for all trigger levels in the barrel. Further rate reduction is expected when cuts dedicated to K/π rejection, will be applied.

	Rates (kHz) Low p_T (6 GeV/c) L=10^{33}cm^{-2}s^{-1}		
decays	LVL1	LVL2	EF
$K\pi$	7.60	3.18	2.0
b	1.50	0.91	0.64
c	0.90	0.41	0.33
W	–	–	0.003
Total	11.0	4.5	3.0
	Rates (kHz) High p_T (20 GeV/c) L=10^{34}cm^{-2}s^{-1}		
decays	LVL1	LVL2	EF
$K\pi$	1.11	0.07	0.054
b	0.73	0.10	0.077
c	0.32	0.04	0.030
W	0.03	0.03	0.022
Total	2.19	0.24	0.18

5. Conclusions

ATLAS and LHC are under completition and first collisions are expected by the end of 2007. A big effort will be required to the trigger, to reach the required performances of background suppression and high efficiency for events signal of new physics. The Muon Trigger Vertical Slice, designed with the three level system, should be able to cover such difficult role, remaining within the tiny window allowed by data access and latency time.

REFERENCES

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