The RPC Level-1 Muon Trigger of the ATLAS Experiment at the LHC

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Abstract—The three-levels ATLAS trigger system has been designed to reduce the initial LHC interactions rate from 1 GHz to ~ 100 Hz in order to allow permanent data storage. This result must be achieved preserving the less probable physics signals against a large background therefore providing a challenge task for the trigger and DAQ system. The Level-1 muon trigger in the barrel region of the Muon Spectrometer is provided by Resistive Plate Chambers (RPC) working in avalanche mode. More than 1000 RPC Units of different sizes will be installed covering a surface of about 3650 m^2 with a 350000 readout channels. A detailed simulation of the Level-1 has been developed in order to optimize the trigger logic design and to study his performances. A description of the Level-1 trigger in the barrel and preliminary results of his performances are presented.

I. INTRODUCTION

ATLAS [1] is one of the four experiments under construction at the Large Hadron Collider which is a $\sqrt{s}=14$ TeV proton-proton collider with a design luminosity of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ and a bunch crossing rate of 40 MHz. The detector design is optimized to fulfill the wide LHC physics program (discovery of the Higgs boson(s), new physics and precision measurement).

Starting from the interaction vertex, the main detector blocks are the central inner tracker located inside a 2T solenoid magnet, the Liquid Argon electromagnetic calorimeter and the hadronic calorimeter and outside the Muon Spectrometer.

The ATLAS trigger system is based on three levels of online physics selection aiming at reducing the interaction rate from 1 GHz to 100 Hz in order to allow permanent data storage.

The whole trigger system is splitted in two subsystems: the Level-1 trigger [2], a hardware system based on dedicated electronics accessing only a subset of data coming from the calorimeters and muon detectors, and the High-Level Trigger (HLT) [3], a software system accessing data coming from all the ATLAS subdetectors.

II. THE LEVEL-1 MUON TRIGGER IN THE BARREL

The Level-1 trigger selects events with experimental signature compatible with the presence of interesting physical objects like either high- p_T muons identified by the muon trigger chambers (RPCs in the barrel region and TGCs in the end-cap region) or high- p_T electrons and photons reconstructed by the

calorimeter trigger. The overall Level-1 accept/reject decision is taken by the Central Trigger Processor (CTP), see fig. 1.

Fig. 1. Atlas Level-1 Trigger scheme

The level-1 trigger must uniquely identify the bunch crossing of interest and also provide information on the position and p_T range of candidate objects (Region of Interest mechanism). These informations are sent to the Level-2 trigger which access only to the data in the Region of Interest (RoI) (usually a few per cent of the whole event data).

After the Level-1 the 1 GHz initial rate must be reduced to about 75 KHz with a maximum latency time of $2 \mu\text{s}$.

III. THE ATLAS RPC SYSTEM

The Level-1 muon trigger in the barrel region of the Muon Spectrometer is based on the use of RPCs as trigger detectors. The RPC chambers arranged in projective towers form three cylinders concentric with the beam axis and have a 16-fold segmentation in the azimuthal plane that follows the eightfold symmetry of the magnetic structure (fig. 2). The whole Muon Spectrometer barrel is divided in 32 physical sectors (16 within each half barrel).

Fig. 2. ATLAS barrel muon spectrometer view in the azimuthal plane. Three concentric RPC stations are located in the middle and in the outer stations of the Muon Spectrometer.

An ATLAS RPC chamber is composed of Units with two gas volume each one defined by two bakelite plates ($\rho \sim 10^{10} \Omega \text{ cm}$) which are separated by a grid of 2 mm thickness polycarbonate spacers. The gas mixture is composed of $\text{C}_2\text{H}_2\text{F}_4$ (94.7%), $\text{iso-C}_4\text{H}_{10}$ (5%) and SF_6 (0.3%) used as streamer suppressor. The rate capability foreseen is 100 Hz/cm^2 . The internal surface of the resistive plates are varnished with linseed oil and the external surfaces are coated with a thin layer of graphite paint connected to the high voltage system. Each gas volume is equipped with two orthogonal layers of readout strips allowing the measurement of the η and ϕ coordinates¹, the latter case being required also for the offline pattern recognition. This way each of the three RPC stations in a sector allow two η and two ϕ coordinate measurement.

IV. TRIGGER ALGORITHM

From the trigger point of view, each physical sector in the barrel is splitted in two parts leading to 64 trigger sectors.

The basic physical principle underlying the implementation of the trigger logic relies on the selection of events with muons coming from the interaction vertex having a large transverse momentum (p_T). This idea is translated in *trigger language* requiring the identification of the candidate muon tracks with a p_T greater than a given threshold. The ATLAS physics benchmark [4] has suggested two threshold regimes for muon triggers: the high- p_T regime (20 and 40 GeV thresholds) for heavy objects searches and a low- p_T trigger (6, 8, 10 GeV) specialized for b-physics studies. The algorithm is performed both in η and ϕ projections.

The low- p_T trigger analyzes data coming only from the first two RPC planes. The algorithm is steered by signals on the *pivot plane* (RPC2). If a hit is found on the RPC2 a search for hits is made in the first plane (RPC1) within a road (Coincidence windows) whose centre is defined by the line of conjunction of the hit in the RPC2 and the interaction vertex.

¹ η is defined as $-\log(\tan(\frac{\theta}{2}))$ where θ is the polar angle and ϕ is the azimuthal angle in the transverse plane with respect to the beam axis

Fig. 3. Schematic view of the trigger algorithm in the η projection.

Due to the action of the magnetic field, the muon distance from the centre of such cone is a function of the p_T . The higher the muon momentum is the smaller the distance. If a hit is found in the RPC1 within the Coincidence Windows the muon is accepted. This way the algorithm select only muons with a p_T greater than a certain value (see fig. 3).

The System is designed so that three p_T thresholds in each projection can be applied simultaneously. In addition, to cope with background from low-energy particles in the cavern, a 3/4, 4/4 majority coincidence of the four hits of the two doublets can be required.

The high- p_T trigger algorithm operates (only in presence of a low- p_T trigger) in a very similar way requiring the coincidence with the RPC3 station.

V. SYSTEM SLICE DESCRIPTION

The basic module in the trigger logic electronics is the PAD. Signals coming from the first two RPC stations are sent to the low- p_T PAD boards. Almost all the relevant functions needed for the barrel trigger algorithm and also RPC strips readout are performed by dedicated processors contained in the PAD boxes: the Coincidence Matrix ASIC (CMA) [5].

The low- p_T CMAs receive $(32 \times 2) \times (64 \times 2)$ input signals from the four detector layers (two from the pivot plane and two from the RPC1 plane) concerning the signals coming from the η strips (η -CMA) or the ϕ strips (ϕ -CMA). The CMA boards align in time the RPC input signals, perform preprocessing logic (declustering algorithm, majority logic) and apply the geometric coincidence logic.

The CMAs output is a bit pattern containing hits which generated the valid trigger and the highest activated trigger threshold. Data coming from four CMAs (two η -CMA and two ϕ -CMA) are collected in a single PAD board which performs the RoI logic defining the associated ROI as the overlap of the η and ϕ activated CMAs (fig. 4).

Fig. 4. Trigger segmentation: Each Trigger sector is composed by six or seven PAD regions. Each PAD comprises four CMAs.

Fig. 5. Trigger system slice: Front-end RPC signals go to the PAD boards (each one hosting four CMA). Trigger results and readout data are sent to the off-detector electronics via optical link for readout and trigger data processing.

These information are transferred, synchronously at 40 MHz, to the corresponding high- p_T PAD boards which performs the high- p_T algorithm using the low- p_T trigger results and the signals coming from RPC3 station. The overall results are sent to the off-detector electronics via an optical link transmitter.

The trigger results coming from all the PAD belonging to one trigger sector (up to 8 PADs) are sent to one Sector Logic board located in the USA15 counting room. Each Sector Logic board count the number of muon candidates in a trigger sector and encode the trigger results. The processed trigger data are finally sent to the Muon Interface to the Central Trigger Processor (MUCTPI).

VI. SIMULATION

In order to optimize the Level-1 trigger logic design and to understand his performances, a C++ code with very detailed simulation of the logic and hardware system components has been developed. RPC positions and structure are derived from an ASCII database (AMDB [6]) which includes also detailed information on inactive volumes. Detector response has been

modelled according to the behavior of RPCs measured in laboratory test using GEANT3 package. The widths of the Coincidence Windows inside each Coincidence Matrix have been defined using an automatic procedure [7] (~ 10000 foreseen Coincidence Matrix). For each trigger threshold, the width is defined as the one for which more than 90% of muons of both charges having p_T equal to the threshold are within the geometrical road.

Fig. 6. Results for a single low- p_T CMA from Coincidence Windows calculation procedure. The allowed coincidence regions become smaller with increasing p_T threshold.

A large sample (10^6) of single muon events with a wide p_T range ($3 \div 50$ GeV) has been tracked in the simulated ATLAS detector, processed using the simulation code and applying the predefined Coincidence Windows. The efficiency curves as a function of the muons p_T have been determined both for the low- p_T and the high- p_T system and are shown in fig 7. The curves reach the plateau at about 82% of efficiency for the low- p_T and 78% for the high- p_T trigger. This inefficiency is mainly due to the reduced geometrical acceptance of some sectors of the barrel spectrometer.

In particular, as shown in fig. 8, a lot of the acceptance is lost in two sectors (Feet Chamber Sector) because of the presence of the feet structure supporting the magnetic system. The contribution to the inefficiency due to the presence of the *feet sectors* is of about 5%.

The Level-1 trigger rates have been calculated by the convolution of the inclusive muon cross sections for the main decay mode that give rise to muons in the detector [8] with the trigger

Fig. 7. Level-1 Muon Trigger Efficiency curves for low- p_T and high- p_T system.

efficiency curves. The inclusive muon cross-sections at LHC for the decays of b and c hadrons, top quark and W/Z boson decays have been calculated using the MonteCarlo program Pythia 5.7 [9] while the in-flight decays of π/K mesons have been calculated using the DPMJET MonteCarlo program [10]. The cross sections, integrated in the kinematic region ($|\eta| < 2.7$, $p_T > 3$ GeV), as a function of p_T are shown in fig. 9.

At lower p_T the π/K decays are the dominant source of muons and even if the low- p_T trigger efficiencies are very small in this p_T range the overall effect is to produce a very large increase of the trigger rates. For $p_T > 8$ GeV the cross sections are dominated by the semileptonic decays of b and c hadrons which represent major sources for the high- p_T trigger rates. The estimated rates are shown in the tab. I for the standard low- p_T (6 GeV, $\mathcal{L}=10^{33}$ cm $^{-2}$ s $^{-1}$) and high- p_T (20 GeV, $\mathcal{L}=10^{34}$

Fig. 8. Level-1 Barrel efficiency map. The major sources of inefficiency (black) corresponds to muon spectrometer regions not covered by RPC trigger chambers.

Fig. 9. Inclusive muon cross section as a function of p_T .

cm $^{-2}$ s $^{-1}$) thresholds. Uncertainties on trigger rates arise from several sources. The most important are significant uncertainties in the prompt-muon cross sections estimated by Pythia mainly in the lower p_T range ($p_T < 6$ GeV) and uncertainties in the modelled muon rate from π/K decays. Other minor sources such as statistical uncertainties on the trigger efficiency curves and convolution numerical method are well understood and the effect on the final trigger rate is low.

The high background level expected in the ATLAS experimental hall can contribute to the muon trigger rate by accidental coincidences of hits produced by background particles in the

μ sources	Low- p_T (Hz)	High- p_T (Hz)
π/K	7100	680
b	1400	500
c	800	210
W	3	26
t	~ 0	~ 0
Total	~ 9300	~ 1400

TABLE I

TRIGGER RATES FOR DIFFERENT MUON SOURCES AT LHC

trigger counters [11]. In order to evaluate the impact of the fake muon trigger rate on the level-1 trigger performances preliminary studies have been carried out using a sample of simulated single muons with a p_T of 100 GeV/c merged with different levels of background activity. The muon trigger system appears robust against the accidental coincidences even for a background level 5 times higher than that is expected from detailed MonteCarlo simulation programs (see tab. II).

Background level	6 GeV	8 GeV	10 GeV	20 GeV	40 GeV
No Background	82.0	81.9	81.9	78.2	78.0
Nominal (X1)	83.7	83.5	83.2	78.7	78.4
High (X5)	86.0	85.2	84.8	79.3	78.7

TABLE II

LEVEL-1 SELECTION EFFICIENCY (100 GeV/c SINGLE MUONS EVENTS)
FOR DIFFERENT THRESHOLDS AS A FUNCTION OF BACKGROUND ACTIVITY.

VII. CONCLUSIONS

Resistive Plate Chambers will be used in the ATLAS detector as dedicated trigger detectors in the barrel region of the Muon Spectrometer. Data coming from the RPCs will be used to discriminate the muon transverse momentum in order to allow the Level-1 trigger system to perform a coarse tracking and a fast selection of the candidates *muon* events, to associate them the corresponding bunch crossing, to determine delimited geometrical ROI in the detector and to measure the second coordinate in the non-bending projection. A brief description of the ATLAS Level-1 muon trigger system in the barrel Muon Spectrometer and the RPC detectors has been given. Results on trigger simulation concerning the system performances (efficiency curves and trigger rates and robustness) are also given.

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