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Overview of the High-Level Trigger Electron and Photon Selection for the ATLAS Experiment at the LHC

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***Abstract*— The ATLAS experiment at the Large Hadron Collider (LHC) will face the challenge of efficiently selecting interesting candidate events in pp collisions at 14 TeV center-of-mass energy, whilst rejecting the enormous number of background events. The High-Level Trigger (HLT = second level trigger and Event Filter), which is a software based trigger will need to reduce the level-1 output rate of ≈ 75 kHz to ≈ 200 Hz written out to mass storage. In this talk an overview of the current physics and system performance of the HLT selection for electrons and photons is given. The performance has been evaluated using Monte Carlo simulations and has been partly demonstrated in the ATLAS testbeam in 2004. The efficiency for the signal channels, the rate expected for the selection, the global data preparation and execution times will be highlighted. Furthermore, some physics examples will be discussed to demonstrate that the triggers are well adapted for the physics programme envisaged at the LHC.**

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I. Introduction

The ATLAS (A Toroidal LHC ApparatuS) detector [1] is one of the two mayor multi-purpose detectors currently under construction at the Large Hadron Collider (LHC). It consists of a series of detecting devices. Its inner elements are tracking detectors enclosed in a solenoidal magnet of around 2T in the central part. From the inside to the outside, it consists of pixel detectors, scilicon strip detectors (SCT) and transition radiation detectors (TRT).

The tracking detectors are surrounded by a electro-magnetic calorimeter based on liquid Argon technology and a hadronic calorimeter based on LAr in the end-caps and a sampling calorimeter with an active part of scintillators (Tile) in the barrel. The global detector dimensions (diameter 22 m, length 42 m) are defined by a large air-core muon spectrometer.

The physics program envisaged ranges from the search for the Higgs boson, which is the last missing particle within the Standard Model (SM), searches for physics beyond the SM such as supersymmetric particles, new additional W and Z bosons, etc., precision SM studies, like measurements of the t

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quark and W boson masses, and detecting possible unexpected signals from unpredicted physics scenarios.

At LHC, protons will collide at a center of mass energy of 14 TeV, with a design luminosity of $10^{34} cm^{-2} s^{-1}$. The corresponding 40 MHz bunch crossing rate (with an average of ≈ 23 superimposed events) and the huge amount of read-out channel ($\approx 10^8$) outline the challenge of the ATLAS Trigger and Data Acquisition (TDAQ) system.

II. The ATLAS TDAQ System Overview

The ATLAS Trigger and Data Acquisition (TDAQ) system must be able to select and store events at a bunch crossing rate of 40 MHz. The required data reduction factor, equivalent to a rejection factor of about six orders of magnitude, is achieved on-line via a data acquisition system organized in three different trigger levels (LVL1, LVL2 and Event Filter), as depictured in Figure 1.

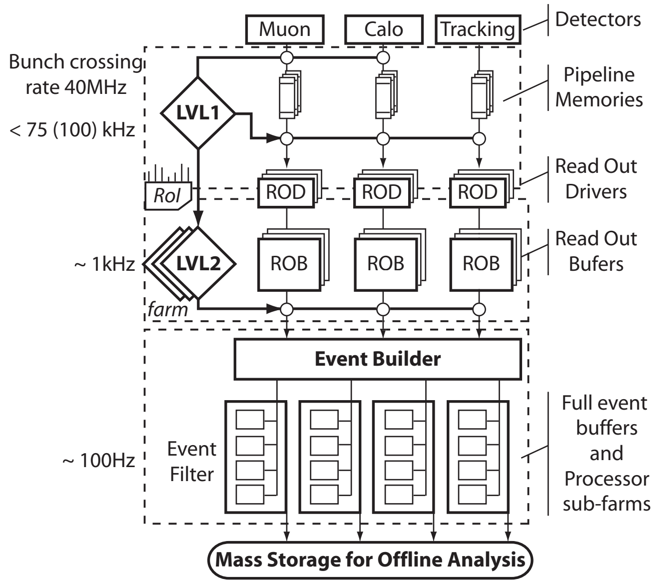

Fig. 1. Block diagram of the ATLAS Trigger/DAQ system.

Each level refines the decisions made at the previous one and, where necessary, applies additional selection criteria. The time available for event processing increases in each level. This allow the use of an increasing amount of information to either accept or reject the event. The hardware-based First Level Trigger (LVL1) performs a preliminary rejection using only reduced granularity data coming from the calorimeters and the muon detectors. It operates within a 2 μs latency, producing a maximum output rate of 75 kHz, upgradable to 100 kHz.

The High Level Triggers (LVL2 and Event Filter) [7], implemented on two different commodity component farms, provide a further reduction factor of about 10^3. Reconstruction at LVL2, seeded by information collected at LVL1, can exploit the full granularity information from all ATLAS subdetectors. LVL2 reconstruction is performed by a parallel data processing of one or more geometrical regions identified at LVL1. These regions, also called Regions of Interest (RoI), correspond to around 2% of the total event size. Event selection is designed to provide an average an output rate of 1 kHz. The LVL2 decision must be taken with a mean processing time of 10 ms. This execution time is one of the major contraints of the LVL2 reconstruction algorithms, which have to be optimized for timing performance.

III. The Electron and Photon Selection Goal

Events with electrons and photons in the final state are important signatures for many physics analysis envisaged at the LHC, as electrons and photons are easy to identify and trigger on. For example, $H \rightarrow 4e$ of $H \rightarrow \gamma\gamma$ lead to a final state containing isolated electrons and/or photons, which provide very clean signatures.

Electron and photon reconstruction mainly exploits data coming from the Electromagnetic calorimeter and the Inner Detector (ID) tracking systems. As described in detail in the next section [8], electrons can be identified in the calorimeter by looking at the transverse shower shapes and the leakage into the hadronic calorimeters. For electrons a track is searched for in front of the calorimeter, in case of photons converted photons can be searched for. As will be shown, this will results in the required rejection of 10^3 in th HLT while selecting around 80% of electrons and photons.

A. Implementation at the HLT

The LVL2 e/γ trigger is the starting point for the formation of LVL2 electron and photon trigger objects. The e/γ trigger procedure at the HLT is guided by the Region of Interest mechanism. In particular, LVL2 reconstruction uses information on the transverse energy and the direction of the electromagnetic clusters selected by the LVL1 trigger. The LVL2 trigger refines the LVL1 information using full-granularity information from the calorimeters. The LVL2 trigger also profits from improved though not final calibrations and thresholds.

First, the energy and position measurements obtained at LVL1 are refined. The measurement of E_T at LVL2 results in sharper thresholds and allows tighter E_T cuts. Then, the leakage into the hadronic calorimeter is evaluated and variables related to the transverse shower shape in the electromagnetic calorimeter are used to perform preliminary particle identification. If a candidate is found to be consistent with an electron, track reconstruction is performed in the ID. In the next step, cluster to track association is done using (η, ϕ) matching criteria, achieving further rejection against fake candidates. In case the matching was successful, the E_T/p_T ratio between the transverse energy measured in the EM calorimeter and the transverse momentum of the corresponding ID track is evaluated for particle identification as well as the match in $\Delta\eta$ and $\Delta\phi$ between the calorimeter cluster and the extrapolated track. Figure 2 shows a simplified block diagram of e/γ trigger steps described.

In the case of photon candidates, reconstructed EM clusters undergo tighter shower shape cuts. After each step in the selection a hypothesis algorithms is called and the event

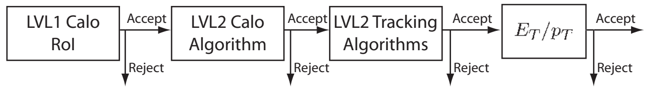

Fig. 2. Trigger event selection diagram. Step-based execution of sequences of seeded algorithms.

processing is only continued if the e/γ candidate is still compatible with an electron or photon. If the objects under analysis fulfill the required signatures the event and its LVL2 result are passed to the Event Filter (EF). In the EF information on the complete event is available, along with more precise calibrations and alignment constants. As at LVL2 electrons and photon selection can be seeded by the improved direction as found at LVL2. Even if selection at the EF follows the same scheme described for LVL2 operation, the looser timing constraints enable to employ more sophisticated reconstruction algorithms such as bremsstrahlung recovery for electrons and conversion reconstruction for photons.

IV. LVL2 Algorithms

The challenging ATLAS on-line environment imposes strong requirements on the design of the LVL2 system [9]. In the following, the present view of the algorithms needed to implement LVL2 selection is given. It is worth while noticing that several options for using detector information in the best possible way are taken into account, hence more than one algorithm is available to accomplish a defined task. This will allow the implementation of a robust, flexible and redundant selection scheme, which will be studied with present and future simulations.

A. T2Calo

T2Calo is a clustering algorithm for electromagnetic(EM) showers. It is seeded by Level-1 EM trigger RoI positions. This algorithm takes calibrated calorimeter `cells` as input and provides discriminating variables to separate isolated EM objects from jets using shower-shape quantities and the leakage into the hadronic calorimeter. The improved measurement of the electron/photon candidate allows results in a sharper thresholds and helps to select efficiently candidates above a certain energy threshold defined by the trigger menu item. The first step of T2Calo is the refinement of the Level-1 position. The highest energetic cell is searched for in the second layer of the EM calorimeter (typically more than 70% of the cluster energy is deposited in this sampling). The electron/photon cluster is then build around this seed cell in a window of $\Delta\eta \times \Delta\phi = 0.075 \times 0.125$. Subsequently the cluster energy will be corrected to account for the leakage ouside the window. The position (η_1, ϕ_1) of the highest energy `cell` is calculated using the energy weighted CaloCluster position in this in the second sampling.

B. IDSCAN

IDSCAN[10], [11] is a track-reconstruction package for LVL2. It takes as input Space Points found in the Pixel and SCT Detectors. A series of sub-algorithms (Z-Finder, Hit Filter, Group Cleaner, Track Fitter) then process these inputs and output Tracks and the Space Points associated with them.

C. SiTrack

SiTrack[12] is a track-reconstruction package for LVL2 which takes Pixel and SCT Space Points as input. The output are fitted reconstructed Tracks. Each tracks stores the pointers to the Space Points used to build it. SiTrack is implemented as a single main algorithm executes a user-defined list of subalgorithms.

D. TRT-LUT

TRT-LUT is a LVL2 algorithm for track reconstruction in the TRT[13], [14]. The algorithm takes as input Hits in the TRT. The algorithmic processing consists of Initial Track Finding, Local-Maximum Finding, Track Splitting, Track Fitting and Final Selection. It outputs the Hits used and Tracks with their parameters, which are ϕ, p_T, electric charge Q and the track curvature C.

E. TRTxKalman

The TRTxKalman[15] utilizes only the information from the TRT part of Inner Detector. The core of the algorithm is a set of utilities from the offline reconstruction package xKalman[6] for reconstructing tracks in the TRT detector. It is based on the Hough-transform (histogramming) method. At the initialization step of the algorithm, a set of trajectories in the $\phi - R(Z)$ space is calculated for the barrel and endcap parts of the TRT. The real value of the magnetic field is taken into account at each hit in the straw along the track when calculating the track trajectories.

V. LVL2 e/γ trigger efficiency

The performance of the e/γ trigger menus has been evaluated on Monte Carlo simulated samples for which the detector response has been simulated in detail by GEANT. Results are given in terms of the efficiency for the real electron and photon signals and of the expected output rates, directly related to the rejection power for fake candidates.

As an example Table I shows the efficiency and rejection rate for the trigger menu selecting single isolated electrons with a transverse energy (E_T) exceeding 25 GeV (e25i) at initial luminosity ($L = 2 \times 10^{33} cm^{-2} s^{-1}$). Errors, as also in the following, only take into account the statistical uncertainty contribution. It should be noted that the uncertainties in the QCD dijet cross-sections at the LHC are of the order of 2-3. Results have been evaluated on a simulated single electrons with p_T = 25 GeV with a flat distribution over the full tracking rapidity range $|\eta| < 2.5$. The efficiencies and rates are evaluated, after each HLT selection step, with respect to a LVL1 output efficiency of ≈95% and a LVL1 EM cluster rate of 12 kHz.

The preliminary HLT e/γ results on timing are shown in Table II. Data access and preparation, referred to as unpacking, corresponds to a critical timing consuming step for LVL2 algorithms. The timing results for QCD jet events events at $L = 2 \times 10^{33} cm^{-2} s^{-1}$, were measured per RoI and scaled to a 8GHz machine.

TABLE I

RATES AND EFFICIENCIES FOR THE SINGLE ELECTRON TRIGGER SELECTING EFFICINETLY ELECTRONS WITH A $p_T > 25$ GEV.

	Eff (%)	Rate
LVL2 Calo	97.3	1.9 kHz
LVL2 ID	93.1	395 Hz
LVL2 IDCalo	91.0	170 Hz
EF Calo	90.0	125 Hz
EF ID	84.9	75 Hz
EF IDCalo	79.8	40 Hz

TABLE II

TIMING PERFORMANCE OF THE e/γ SLICE

	Time (ms/8GHz CPU RoI)
T2Calo	4.0
IDSCAN	7.4
Total	6.0

The total timing performance presented in Table II were calculated taking into account the rejection power after each selection step (see Table I). Around 90% of the time is currently spent in the unpacking of the data. In order to improve unpacking timing measurements, a new data access approach will be tested. It is expected that the time will decrease significantly in the future.

VI. EXPERIENCE WITH COMBINED TEST BEAM DATA

In 2004, components from all ATLAS sub-detectors were aligned along a beam line to test the overall sub-detector performance as well as the combined performance for electrons, photons jets and muons[17], as depictured in Figure 3.

During the test beam period part of the trigger system was as well tested. To validate the LVL2 algorithms and the electron selection strategy the recorded CTB data is being analysed and e/π separation has been studied.

Preliminary results of LVL2 Calorimeter (L2Calo) electron selection algorithm for 50 GeV electrons and pions, are shown in Figure 4. Electron efficiency and pion fake rate calculation using L2 trigger calorimeter are presented in Table III. The electron and pion beams contain (depending on energy) a certain fraction of pion, muon and electrons. Using the beam instrumentation and the information of the TRT the electron and pion beam was cleaned up.

TABLE III

EFFICIENCY AND FAKE RATE RESULTS OF LVL2 CALORIMETER TRIGGER AY 50 GEV.

	Electron efficiency	Pion fake rate
LVL2 calorimeter cuts	98.82 ± 0.18	1.13 ± 0.14
Electron purity = 97%		
Pion purity = 100%		

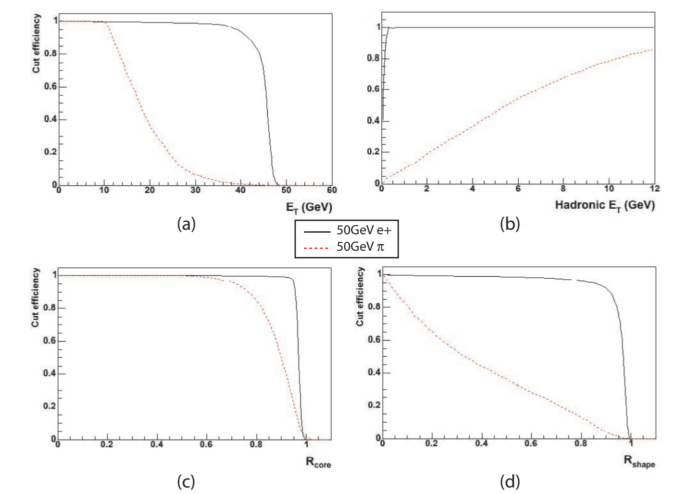

Fig. 4. Study e/π separation with 2004 CTB data using the LVL2 calorimeter and tracking algorithms. (a) Cut efficiency at the first step of T2Calo algorithm. (b) Cut efficiency at the second step of T2Calo. (c) Cut efficiency at the third step of T2Calo. (d) Cut efficiency at the last step of T2Calo.

VII. CONCLUSION

This paper we made an overview of the HLT e/γ selection for the ATLAS Experiment at the LHC. The electron selection efficiency for single-e with pile-up for LVL2, at 25 GeV with a luminosity of $2 \times 10^{33} cm^{-2} s^{-1}$, was ≈97% with a rate of 1.9 kHz for LVL2 Calo and ≈91% for LVL2 ID-Calo with 170 Hz of rate. Estimates of time and rates meet the requirements at start-up, i.e., consumes ≈5% of LVL2 CPU power.The performance study with real data from the CTB 2004 at 50GeV was 98.8±0.2% and a pion fake rate of 1.13±0.14%. Electron efficiency and pion fake rate calculation used LVL2 trigger calorimeter after Beam detector particle filtering. Efficiency and fake rate results are consistent with previous LAr studies using 2002 Test beam data. This has been an important step to validate the selection architecture chosen in a real on-line environment.

ACKNOWLEDGMENT

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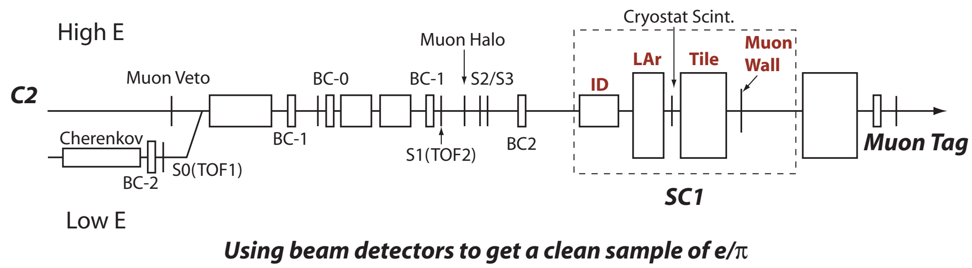

Fig. 3. Block diagram of the e/π separation study with 2004 CTB data using the LVL2 calorimeter and tracking algorithms.

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