Muon reconstruction and selection at the last trigger level of the ATLAS experiment

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The three-level Trigger and DAQ system of ATLAS is designed to be very selective while preserving the full physics potential of the experiment; out of the ∼1 GHz of p-p interactions provided by the LHC at nominal operating conditions, ∼200 events/sec are retained. This paper focuses on the muon reconstruction and selection algorithms employed at the last trigger level. One implements an "outside-in" approach; it starts from a reconstruction in the Muon Spectrometer (MS) and performs a backward extrapolation to the interaction point and track combination in the Inner Detector (ID). The other implements an "inside-out" strategy; it starts muon reconstruction from the ID and extrapolates tracks to MS. Algorithm implementations and results on data from real cosmic rays and simulated collisions are described.

Keywords: ATLAS; Trigger; Muon Event Filter

1. Introduction

The Large Hadron Collider (LHC) at CERN is expected to start its operation at the end of 2009. ATLAS[1] (A Toroidal LHC ApparatuS) is one of the four LHC experiments currently waiting to record the first collision data. Its main purposes are the search for the Higgs Boson and the discovery of new physics at the TeV energy scale, like Supersymmetry or Extra-Dimensions. At a design luminosity of 10^{34} cm^{-2}s^{-1} and at a centre of mass energy of 14 TeV an average of 25 interactions per bunch crossing is expected. The events have to be processed by the trigger system with the bunch crossing rate of 40 MHz. The trigger system reduces the initial rate to 200 Hz, given by the resources to store and post process events. The key objective is to be highly selective and at the same time efficient in retaining events with potentially interesting physics signatures. To accomplish this, the trigger system is structured in three subsequent levels of increasing precision, progressively reducing the rate. The first level, Level-1[2] , uses custom built electronics and has to bring the initial rate down to ∼75 kHz while the maximum latency to take a decision at Level-1 is 2.5 μs. The so-called High Level Trigger[3] (HLT) is made up of two software-based levels, Level-2 and the third level (Event Filter, or EF), whose aim is to reduce the total event rate to ∼3 kHz first and then to ∼200 Hz, with average processing times, per node, of ∼40 ms and ∼4 s, respectively.

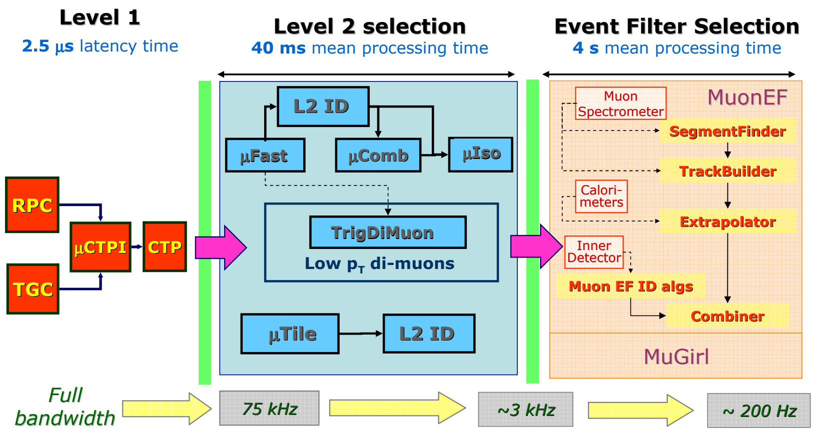

Fig. 1. Block diagram of the three-level ATLAS Muon Trigger.

2. The ATLAS muon trigger

The ATLAS Level-1 muon trigger is provided by Resistive Plate Chambers (RPCs) and Thin Gap Chambers (TGCs), placed respectively in the barrel ($|\eta| < 1.05$) and endcap ($1.05 < |\eta| < 2.4$) regions. It selects, in a high background environment, high p_T muons and associates them to the bunch-crossing of interest.

The Level-1 selects candidate muons and gives a coarse estimate of their position in azimuthal angle φ and pseudorapidity η in terms of Regions of Interest (RoI), restricted detector regions where physics activity has been detected.

The Level-2 trigger accesses the full muon detector granularity inside the RoI provided by Level-1. In particular muon position and p_T estimate are improved by executing fast specialized algorithms, which evaluate p_T by means of Monitored Drift Tubes (MDT) precision measurements and information from all subdetectors inside the Level-1 RoI.

The EF can access the full event and the latest alignment and calibration data. Figure 1 shows a block diagram of the ATLAS Muon Trigger.

3. The Muon Event Filter Implementation

In the Muon EF two packages have been implemented as "wrappers" of muon offline reconstruction tools: *TrigMuonEF* and *TrigMuGirl*. They follow complementary approaches: the former starts reconstruction from the Muon Spectrometer (MS) and extrapolates back to the IP, while the latter begins from the inner detector (ID) and carries on muon identification outerwards. *TrigMuonEF* can run both in a "full scan" (as in offline muon reconstruction) and in a "seeded" strategy, i.e. the access to the MS data is driven by the previous stage of the trigger chain, which provides the information from a specific RoI. It consists of a chain of four sequential feature extraction (FEX) and the corresponding hypothesis (HYPO) algorithms, allowing or not to produce the final trigger decision: SegmentFinder, TrackBuilder (TB), Extrapolator (SA), Combiner (CB). "Muon Object Oriented REconstruction" (MOORE) and "Muon Identification" (Muid[4]) are the offline packages which the four *TrigMuonEF* FEXs are based on. The MOORE package reconstructs muon tracks inside the MS taking advantage of its high precision tracking system and provides a precise measurement of the track parameters outside the calorimeter. Muid package performs a backward track extrapolation to the interaction region through the calorimeters, taking into account the magnetic field and corrections for energy loss and multiple scattering effects through all the crossed materials. In order to improve momentum resolution, extrapolated tracks are then combined with the corresponding matching tracks, if they exist, in the ID, using a global fit of all the hits collected in both MS and ID.

TrigMuGirl is based on "MuGirl" offline package which performs the association of muon hits and segments to an ID track in order to flag the track as muon. *TrigMuGirl* starts from track candidates inside a Level-2 RoI that can be provided by Level-2 or EF ID algorithms. Tracks are then extrapolated to MS chambers and if hits are found around the extrapolated ID track direction they are used to construct segments. Their corresponding hits, collected in the MS technologies, allow *TrigMuGirl* to improve extrapolation and then to identify muon-like candidates. A global fit, including the initial ID track and the MS hits, is then applied to the tracks belonging to identified muons for a further improvement of the momentum estimate. Moreover, when segment reconstruction is imperfect, *TrigMuGirl* can be run in a dedicated mode in order to select and trigger possible events containing slow massive particles (for instance low-β R-hadrons[5]) by properly estimating β from MDT and RPC and then correcting MDT hit/segment finding by taking into account this β to reconstruct the mass of the particle.

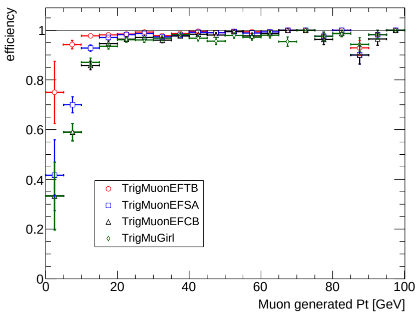

Fig. 2. Efficiencies versus the transverse momentum of the Muon EF with respect to Level-2.

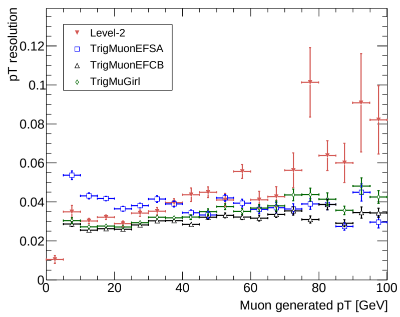

Fig. 3. Muon EF transverse momentum resolutions versus transverse momentum.

4. Muon Event Filter performance and results on 2008 cosmics data

Concerning Muon EF performance, results on a simulated $t\bar{t}$ sample are shown in Figures 2 and 3: Figure 2 shows the efficiency, with respect to Level-2, of the *TrigMuonEF* steps TB, SA, CB and *TrigMuGirl* as a function of p_T. No p_T thresholds have been applied for *TrigMuonEF*, while the requirement of a 10 GeV p_T muon in the event was applied for *TrigMuGirl*. The p_T resolution as a function of transverse momentum is shown in Figure 3 for SA and CB algorithms, compared to Level-2. It can be observed that p_T resolution is improved at each trigger level and, most of all, passing from MS-only tracks to MS+ID combined tracks. As can be observed in the two figures, *TrigMuonEF* CB and *TrigMuGirl* algorithms have very similar tracking performance.

The muon trigger has been tested and validated during 2008 cosmic run with the HLT running online. Figures 4 and 5 have been obtained with both solenoidal and toroidal fields on and compare the spatial position of the *TrigMuonEF* tracks with the ones obtained by the offline MS reconstruction tool, in terms of η and φ, respectively[6] . Standard deviations from the fit to a Gauss function of the differences in η and φ are about 0.007 in η and 17 mrad in φ, respectively. Some non-gaussian tails can be observed: these effects can be attributed to residual differences in (η, φ) estimates between the online and offline environments, such as the use of different calibration constants and other minor effects coming from the implemented RoI-based

TrigMuonEF seeding strategy instead of the standard offline full-scan.

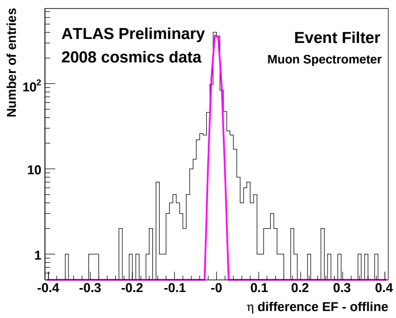

Fig. 4. Comparison in the pseudorapidity between *TrigMuonEF* and the corresponding offline tracks.

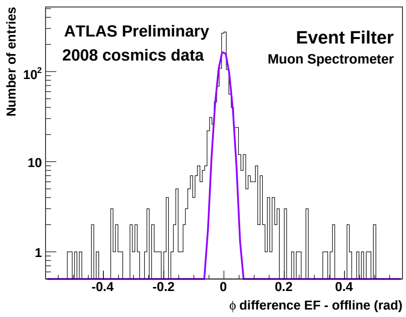

Fig. 5. Comparison in the azimuthal angle between *TrigMuonEF* and the corresponding offline tracks.

5. Conclusions

The Muon Event Filter has been designed and implemented to cope with the demanding requirements of the ATLAS trigger system in the high luminosity and background environment at the LHC. *TrigMuonEF* and *TrigMuGirl* have been successfully integrated in the Muon EF and are constantly tested and validated on suitable simulated samples, on which they show quite good and similar performance. At the startup, muon selection will take advantage of both algorithms running.

References

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