Performance and validation of the muon Event Filter of the ATLAS experiment

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1. Introduction

The ATLAS experiment (A Toroidal LHC ApparatuS) [2] is a multi-purpose experiment to run at the LHC (Large Hadron Collider), CERN, Geneva. At its design luminosity (10^{34} $cm^{-2}s^{-1}$), the LHC will be able provide about 23 inelastic proton-proton collisions for each bunch crossing every 25 ns at a center of mass energy of 14 TeV.

The Trigger and Data Acquisition (TDAQ) system of the experiment has therefore to deal with an unprecedented rate of 10^9 interactions per second and to reduce this to a final event rate of the order of ∼200 Hz (as imposed by the limited storage data flow). This implies the need of a compromise between selecting rare physics events and rejecting the huge amount of background expected at the LHC. The ATLAS TDAQ system is structured in three levels [3, 4], each one with the aim to refine the hypotheses formed previously.

2. The Muon Event Filter

After a first level trigger (LVL1) implemented in a custom hardware that uses measurements from the trigger chambers of the Muon Spectrometer (MS) to select muons with high transverse momentum in defined Regions of Interest (RoIs), and a second level (LVL2) in which fast algorithms run on an online software architecture, there is a third-level trigger (called Event Filter, EF) which is designed and implemented to use offline-like algorithms and to access the full event, providing the best possible muon reconstruction/identification.

The Muon Event Filter consists of four algorithms: SegmentFinder, TrackBuilder, Extrapolator and Combiner, organized in a package called *TrigMuonEF*. These algorithms are wrappers for the reconstruction tools which are used in the ATLAS offline framework.

EF processing normally starts with a *seed* from LVL2 but, for debug purposes, it can start from LVL1 RoI directly. Inside such RoI segments are made first, using Monitored Drift Chamber (MDT) precision hits. Tracks are made from segments by the TrackBuilder, using information from the MS only. The extrapolation to the interaction point is performed by the Extrapolator and uses a parametrization of the energy loss in calorimeters, for faster computation. As final step of the chain, the Combiner adds information from the Inner Detector (ID) EF algorithms to make combined tracks by means of a global refitting procedure.

3. Performance studies

The performance of *TrigMuonEF* algorithms is checked on dedicated Monte Carlo samples every time that new versions of the official ATLAS reconstruction software (ATHENA) are released or new simulated samples are produced.

Studies are first of all devoted to ensure a high efficiency of all algorithms with respect to previous levels, in particular LVL2. Efficiency is defined here as the fraction of reconstructed EF tracks normalized to the number of seeds provided by LVL2 in proximity of generated muons, i.e. with spatial distance ΔR below a given value[1] from the generated muon. Maximum values of ΔR are defined for each algorithm at every trigger level according to the corresponding η and φ resolutions. Multiple RoIs seeding the EF in the same event are separately considered, provided that they are enough distant among each other.

In Fig. 1 the efficiencies for the TrackBuilder, the Extrapolator and the Combiner algorithms are shown as functions of the generated muon transverse momentum on simulated $t\bar{t}$ events with at least one of the two W's produced by (anti)top decaying leptonically. The MS standalone recon-

[1]Spatial distance between two directions in ATLAS detector is defined as $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$, where $\Delta\eta$ and $\Delta\varphi$ are the corresponding differences in pseudorapidity η and in azimuthal angle φ, respectively.

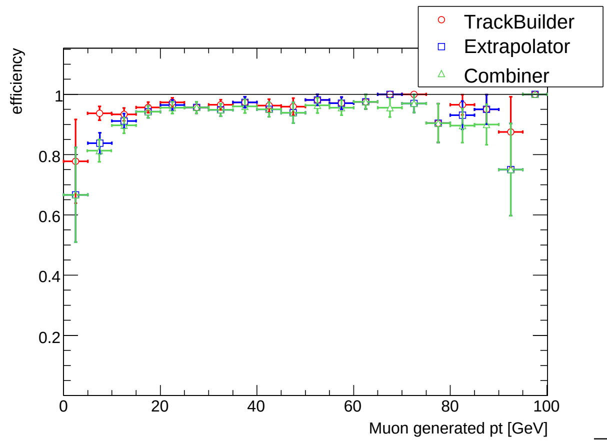

Figure 1. Efficiency of *TrigMuonEF* algorithms with respect to LVL2 as a function of muon p_T.

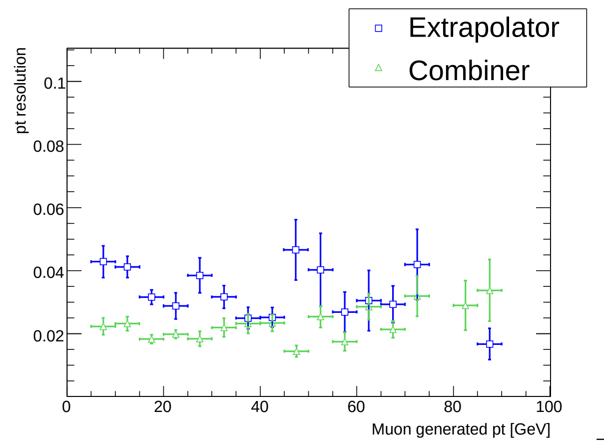

Figure 2. Resolution on transverse momentum for Extrapolator and Combiner algorithms as a function of muon p_T. Track parameters are evaluated at the interaction point.

struction by TrackBuilder has in average more than 95% efficiency, while the extrapolation to vertex has some inefficiency at low p_T owing to systematic uncertainties coming from multiple scattering and energy loss in the calorimeters. The final combination step shows also a decrease in efficiency at very high p_T owing to problems in track matching while muon showers can be formed.

In events with successfully reconstructed tracks, spatial and transverse momentum resolutions are obtained as standard deviations of gaussian fits performed on the $\Delta\eta$, $\Delta\varphi$ and $\Delta(1/p_T)$ distributions obtained as differences between reconstructed and generated muons. In Fig. 2 the transverse momentum resolution at the vertex is reported for the Extrapolator and for the Combiner algorithms, with average values of about 2% and 4%, respectively.

The robustness of the Muon Event Filter can be tested in different detector conditions, including addition of pileup and cavern background [5], sub-detector misalignments, geometrical deformations, presence of noisy channels, vertex displacements and so on. Results show that, in such realistic scenarios, the degradation of performance is reasonably kept down, with fake track probabilities at the level of percent and generally negligible increases of the total EF rate.

4. Muon Event Filter validation

Besides a periodical study of its performance, the Muon Event Filter software needs to be continuosly tested against possible problems raising from changes in the code developed for the algorithms as well as for any software tool or package on which they can depend. This crucial task is carried out in the context of the ATLAS Trigger Validation [6] together with a number of actions needed for the best possible functionality of the muon trigger software, and in particular of the *TrigMuonEF* package.

Each night, the ATLAS software is built for different platforms and different branches. A validation build provides a buffer to test new code before adding it to the more stable development build. The nightly builds are automatically controlled by the NIghtly COntrol System (NICOS), which includes a web interface to display all the results of the package compilation. The output of jobs is subsequently checked by the ATLAS Testing Nightly (ATN) infra-structure with small statistics reconstruction jobs. Larger statistics jobs are also run within the Run Time Tester (RTT) infra-structure, from which it is possible to control plots, tables and log files for a quick and efficient identification of inconsistencies.

The outputs produced by all the tests involving the Muon Event Filter are systematically compared to reference log and histogram files, which need to be constantly updated every time that significant developments take place inside the code. While ATN jobs run only a small statistics with the purpose to validate the basic functionality of the code, RTT jobs take longer and can therefore provide also reasonable estimates of the physics performance of the *TrigMuonEF* package. The final goal of validation is to promptly spot and address solutions to bugs, error messages, memory leaks, efficiency losses and any other kind of criticality which can affect the Muon Event Filter functionality and performance.

REFERENCES

1. ATLAS Collaboration is made of about 2500 Physicists coming from 167 Institutions of the following countries: Argentina, Armenia, Australia, Austria, Azerbaijan, Belarus, Brazil, Canada, Chile, China, Colombia, Czech Republic, Denmark, France, Georgia, Germany, Greece, Israel, Italy, Japan, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan, Turkey, UK, USA, CERN, JINR.
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