Validation of the muon High Level Trigger of the ATLAS experiment

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1. Introduction

The ATLAS detector (A Toroidal LHC ApparatuS) [1] is presently taking proton-proton collision data at the LHC (Large Hadron Collider) of CERN, Geneva. Since the machine start-up at the end of year 2009, the centre-of-mass energy has been initially set to 900 GeV, then to 2.36 TeV and, for large part of year 2010, to 7 TeV, reaching a maximum luminosity of $2 \times 10^{32}\ cm^{-2}s^{-1}$.

The Trigger / Data Acquisition (TDAQ) system of the ATLAS experiment has the goal of selecting rare interesting events within the allocated bandwidth ($\sim$300 Hz) and rejecting the very large amount of background physics processes dominating the rate of recorded data. A three-level structure has been designed and implemented for the ATLAS TDAQ system, from a first hardware-based level (Level 1 [2]) to a second and third software-based level (Level 2 and Event Filter, also referred as to High Level Triggers, or HLT [3]): the goal of each level is to validate the hypotheses formed at the previous levels, improving the resolution of the relevant measured quantities and provides the best possible reconstruction and identification of interesting physics objects.

2. Trigger Validation

The ATLAS HLT is organized in a system of hundreds software packages belonging to a set of interdipendent projects, which are developed and maintained within the Collaboration. In this large and complex system, it is fundamental to check the quality of the software implementation and of the physics performance: this is done centrally by means of a dedicated infrastructure, called ATLAS Trigger Validation [4].

A significant benefit in the validation process of the trigger online environment comes from the possibility of reutilizing large part of the already developed tools implemented for the offline framework, therefore taking advantage of the ATLAS Offline development model. Every day the ATLAS software is built on different platforms and for different branches [1]. The *validation build* allows for possible tests of new code to be included, if successful, on the more stable *development build*. All tests are usually performed every night within the NIghtly COntrol System (NICOS, [5]), which provides build and test results via a web interface.

The goal of NICOS is to check the sanity of all packages, both at compilation and at run time: this is done by means of a set of customized reconstruction tests which can be run using ATN (ATLAS Testing Nightly) or RTT (Run Time Tester) infrastructures. Thanks to the output of these tests (flags, log files, ROOT [6] files), it is possible to promptly spot differences in the validation build and to solve possible problems and inconsistencies in it. While ATN jobs run on a small statistics with the purpose to validate the basic functionality of the code, RTT jobs take longer and can therefore give also rough estimates of the physics performance of the HLT packages.

3. Validation of Muon HLT

Similarly to the ATLAS Trigger itself, the Trigger Validation is structured in tests concerned to a number of specific physics signatures: one of the most relevant signatures, in which the ATLAS group in Lecce is deeply involved, is given by muons, since many physics processes of interest include muons in the final state and a significant rate of events is expected to come from them.

The Muon High Level Trigger is composed of a number of reconstruction/identification algorithms: *TrigMuFast*, *TrigMuComb* and *TrigMuIso* at the Level 2, and *TrigMuonEF* and *TrigMuGirl* at the Event Filter. While the first three algorithms have been explicitly designed and implemented for the trigger environment, the last two are actually wrappers for reconstruction tools which are used in the ATLAS offline framework. Level 2 algorithms are designed for fast execution times and provide a *seed* (a *Region of Interest*, or RoI) to Event Filter. Inside a RoI segments are made first, using hits from precision chambers. Tracks are then made from segments by the

[1]Software is often organized in branches whenever a modification in the code cannot be done coherently with the *main branch*, and for this reason needs to be developed separately. This occurs, for instance, when a relevant change is being done on data formats, geometry definition, database access.

TrackBuilder, using information from the Muon Spectrometer only. The extrapolation to the interaction point is performed by the Extrapolator and uses a parametrization of the energy loss in calorimeters. As final step of the full muon trigger chain, the Combiner adds information from the Inner Detector algorithms to make combined tracks by means of a global refitting procedure.

Besides the daily validation checks, each one of the muon HLT algorithms is tested against possible problems raising from changes in the code developed as well as for any software tool or package on which they can depend. This is done every time that a new version of the official ATLAS reconstruction software (ATHENA) is released or new simulated data samples are produced. The validation of muon HLT physics performance is based on a standard scheme which includes the evaluation of:

- trigger counts,
- efficiencies,
- resolution,
- fake probabilities,

which are studied, whenever possible, for several trigger chains of interest[2] on both real and simulated data. The knowledge of trigger counts is crucial to estimate the rates of existing triggers and to foresee the rates of new possible chains to be defined and optimized. Efficiencies are generally estimated with respect to an offline muon reference [3], therefore considering an overall behaviour of the muon trigger, but can be also normalized to the previous trigger level, especially for debug purposes. Results are usually provided as functions of η and φ, to check possible efficiency losses in some part of the detector, or as function of p_T, to verify the sharpness of the turn-on efficiency curve for each trigger hypothesis.

In events with successfully reconstructed offline tracks (used as reference), spatial and transverse momentum resolutions are obtained by computing the standard deviations of gaussian fits on the differences in pseudorapidity (η), azimuthal angle (φ) and $1/p_T$ distributions between reconstructed and trigger muons. In Fig. 1 the transverse momentum resolution at the vertex is reported for the relevant muon HLT algorithms: it can be observed that combined algorithms have, at Level 2, resolution from 2% up to 6% at increasing p_T, while at Event Filter resolution improves to 1%. For each given muon trigger signature, the fake trigger probability is defined as the fraction of events containing *features* of the corresponding trigger algorithms found at large ΔR values[4] from any offline reconstructed track, divided by the whole number of events satisfying the signature in question. The study of fake triggers is particularly important for the forthcoming 2011 data taking period, in which the luminosity will be furtherly increased and event rates will become higher: results are now concentrating especially on the Muon Spectrometer only single particle triggers, in which tracks without the request of combination to Inner Detector happen to provide fake signal with relatively high probability (of order of %).

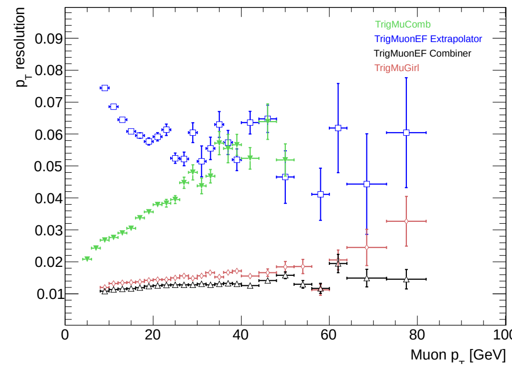

Figure 1. Resolution on transverse momentum for TrigMuComb at Level 2, for TrigMuonEF (Extrapolator and Combiner) and for TrigMuGirl algorithms as a function of muon p_T. Results are referred to parameters of offline muon tracks at the interaction point.

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[2] Trigger chains correspond to sequences of algorithms and hypotheses which produce an event-based trigger decision.

[3] On real data it is preferred to consider muons reconstructed by the offline tools as references for trigger studies; in the case of Monte Carlo simulated data, efficiencies can be also obtained with respect to the *truth* muons.

[4] ΔR is defined as $\sqrt{\Delta\eta^2 + \Delta\phi^2}$, and is chosen here to be lower than 0.5.