Online Muon Reconstruction in the ATLAS Level-2 Trigger System

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***Abstract*—To cope with the 40 MHz event production rate of LHC, the trigger of the ATLAS experiment selects events in three sequential steps of increasing complexity and accuracy whose final results are close to the offline reconstruction. The Level-1, implemented with custom hardware, identifies physics objects within Regions of Interests and operates with a first reduction of the event rate to 75 kHz. The higher trigger levels, Level-2 and Level-3, provide a software based event selection which further reduces the event rate to about 100 Hz. This paper presents the algorithm (μFast) employed at Level-2 to confirm the muon candidates flagged by the Level-1. μFast identifies hits of muon tracks inside the barrel region of the Muon Spectrometer and provides a precise measurement of the muon momentum at the production vertex. The algorithm must process the Level-1 muon output rate ($\sim$20 kHz), thus particular care has been taken for its optimization. The result is a very fast track reconstruction algorithm with good physics performance which, in some cases, approaches that of the offline reconstruction: it finds muon tracks with an efficiency of about 95% and computes p_T of prompt muons with a resolution of 5.5% at 6 GeV and 4.0% at 20 GeV. The algorithm requires an overall execution time of $\sim$1 ms on a 100 SpecInt95 machine and has been tested in the online environment of the Atlas detector test beam.**

***Index Terms*—ATLAS Level-2, online, trigger.**

I. Introduction

THE ATLAS experiment [1] at the Large Hadron Collider (LHC) has been proposed to explore the high-energy physics frontier at the 1 TeV energy scale. It is designed to exploit the full discovery potential of the LHC machine, in particular for the Higgs search. The trigger system will be one of the major challenges of the experiment because it has to reduce the global event rate by a factor of about 10^7 (at maximum luminosity, a bunch crossing produces 20 collisions) and identify the interesting events with high efficiency in spite of a background with several orders of magnitude higher rate. Among the different trigger subsystems, the one based on muon identification and reconstruction will be particularly important because it allows the selection of the cleanest channel for the Higgs discovery ($H \rightarrow ZZ^{(*)} \rightarrow 4\mu$).

II. The ATLAS Muon Spectrometer

The main feature of the ATLAS experiment is the design of the muon spectrometer [2] which uses a toroidal magnetic field of 0.5 T. The field is provided by three air core toroidal magnets (one for the barrel, two for the endcaps) and covers the rapidity range up to $\eta = 2.7$. The muon trajectory inside the magnetic volume is measured by planes of tracking chambers and planes of trigger chambers (Fig. 1) arranged in 16 physics sectors in the transverse view. The tracking chambers [monitored drift tubes (MDTs) [2]] measure the coordinate in the bending projection (r, z) with a resolution of about 80 μm on each point, whilst the trigger chambers [resistive plate chambers (RPCs) [3], for the barrel and thin gap chambers (TGCs) [4], for the endcaps] provide the identification of muons and measure the second coordinate (ϕ) with a resolution of 1 cm. In the very forward region, where the particle flux and the background conditions are extreme, the MDTs are replaced by the cathode strip chambers (CSCs) [2]. The ATLAS Muon System allows a standalone high precision measurement of the muon momentum with constant performance up to $\eta = 2.7$.

III. The ATLAS Level-2 Muon Trigger

In ATLAS the event selection is performed in three sequential levels of increasing complexity. The Level-1 [5] is implemented with custom hardware and uses low granularity data from a subset of the trigger detectors to identify physics objects within Regions of Interests (RoIs). It reduces the input rate of 40 MHz to 75 kHz. The higher trigger levels (HLT) [6] provide a software based event selection which further reduces the event rate to about 100 Hz. The Level-2 uses the full granularity data, but examines only the RoIs to confirm the physics objects flagged by the Level-1 and to perform a first event selection via physics menus. After the Level-2 selection, which is expected to reduced the rate by a factor of about 100, the Event Filter (Level-3) takes the final decision using the full event data.

In the Level-2 architecture [6], the trigger components are implemented by means of software programs, based on the

Manuscript received May 22, 2006; revised May 29, 2006.
Please see the Acknowledgment section for author affiliations.
Digital Object Identifier 10.1109/TNS.2006.872630

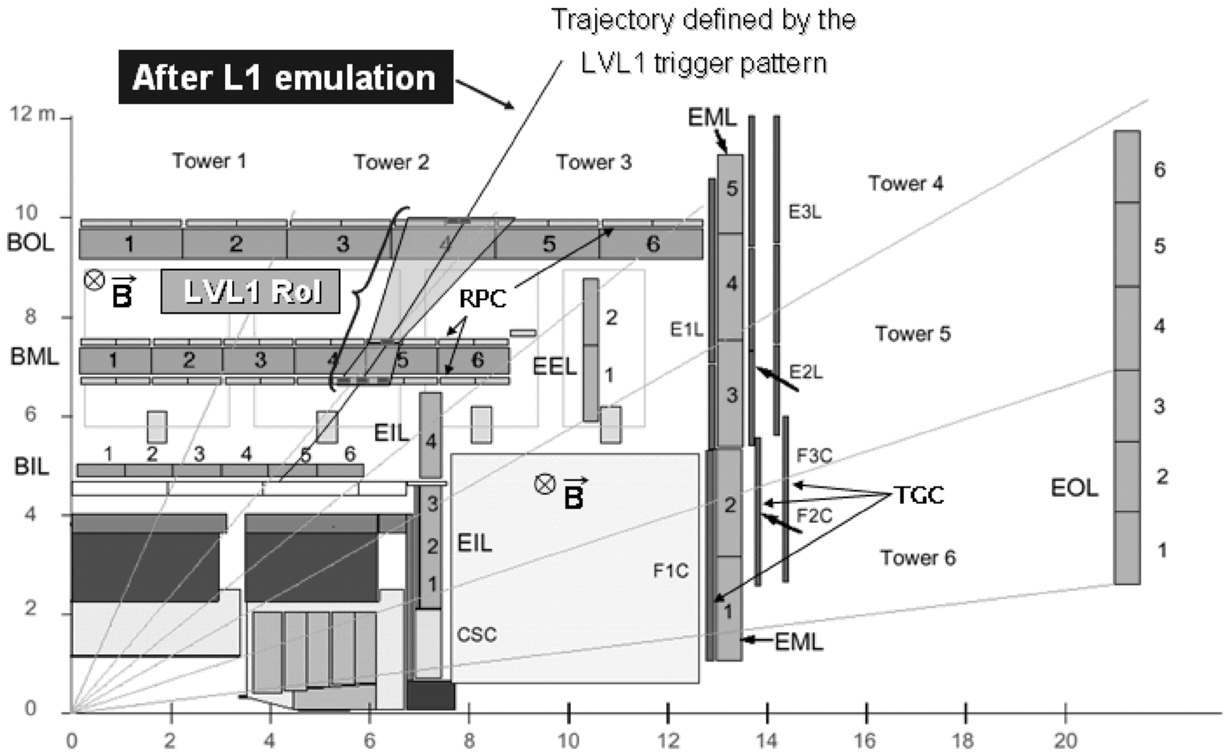

Fig. 1. Longitudinal view of the ATLAS muon spectrometer showing the MDT stations (BIL, BML, BOL for the barrel, and EIL, EML, EOL for the endcap), the trigger chambers (RPCs for the barrel and TGCs for the endcap) and the CSCs in the very forward region. The Level-1 RoI for a muon track is also shown together with the trigger chamber hits and the approximated trajectory reconstructed from RPC data.

ATLAS dataflow framework. These applications run on commodity PCs, interconnected by a network to exchange event data. The Level-1 accepted events flow from detector read out drivers (RODs) to the read out systems (ROSs) made of several read out buffers (ROBs). The Level-2 processing units (L2PUs) of the Level-2 farm request data fragments from selected ROBs corresponding to the RoI to be processed. This information, produced by the Level-1 trigger, is sent to the L2PU via the Level-2 Supervisor (L2SV). This component steers the Level-2 tasks and, in particular, assigns the event to a L2PU. For the accepted events, the Level-2 result is sent back to the L2SV and also to a *pseudo* ROS (pROS) to be used as a seed by the event filter. The described architecture is shown in Fig. 2.

The Level-2 muon trigger task is to confirm muons found at Level-1 by means of a more precise muon momentum measurement (*muon feature extraction*) and to reject fake Level-1 triggers induced by physics background. The better quality of momentum measurement allows for a sharper p_T threshold, but the trigger system is required to exploit the full potential of the ATLAS muon spectrometer within ~10 ms imposed by the overall latency of the Level-2 trigger system. Thus, not only a fast feature extraction algorithm has to be employed, but also a fast access to the data is needed since the data to be processed come from different parts of the muon spectrometer. The latter is achieved by organizing the data flow in such a way as to minimize the traffic towards the trigger processors and using an appropriate format which allows a fast data decoding. To minimize the traffic through the network, the detector is subdivided in six eta regions called trigger towers, as illustrated in Figure 1. A

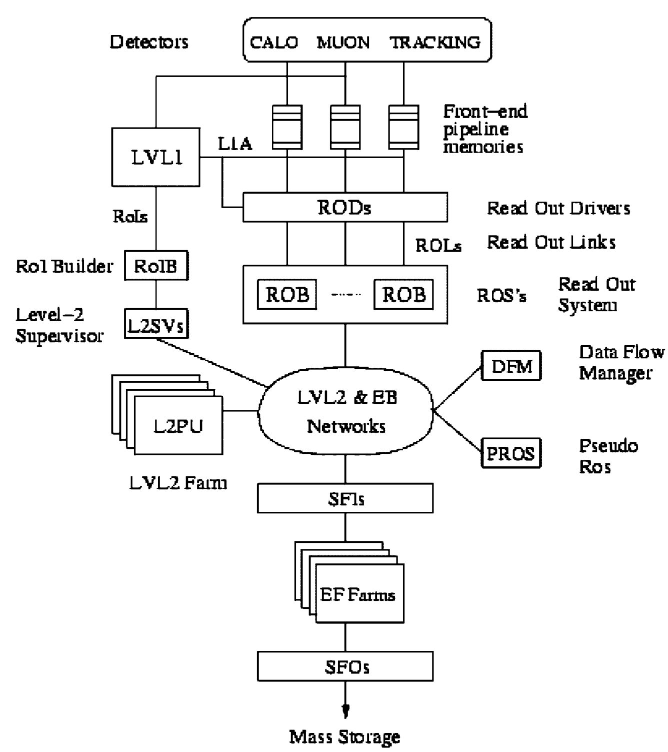

Fig. 2. Principal components of the dataflow and HLT system.

tower is made by two adjacent MDT chambers in each station and by the corresponding trigger chambers. Data from a single

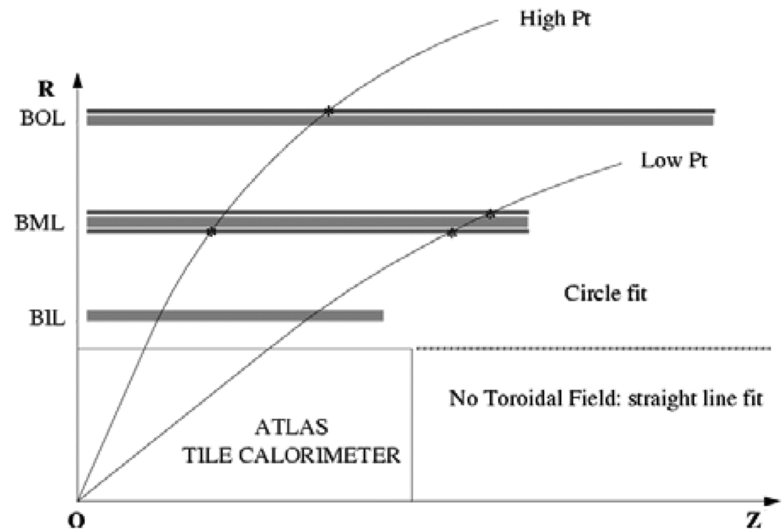

Fig. 3. To find the muon trajectory, RPC hits and LVL1 output are used. In the nonbending projection, the trajectory is the line through two points, while in the bending projection it is a circle plus its tangent line pointing to the interaction vertex.

tower of the barrel region will flow within two ROBs (one for the MDT and one for the RPC) thus increasing the probability to find the muon track within a few buffers.

The method employed for feature extraction has to be as simple as possible to save processing time. It is the result of an optimization between the CPU usage and the physics performance needed to trigger interesting events: high selection efficiency for high-p_T muons and high rejection of low-p_T muons.

IV. The μFast Algorithm

The Level-2 feature extraction algorithm, μFast, performs the muon track reconstruction in the barrel Spectrometer ($|\eta| < 1$) and measures the transverse momentum of the muon at the interaction vertex. It is steered by the level-1 RoI data consisting of the p_T threshold fired at Level-1 and the $\eta - \phi$ position of the RoI. The algorithm requests two ROBs for each RoI, corresponding to the trigger towers containing the Level-1 RoI and the closest one with respect to the exact RoI position. This allows the processing of muons passing through two trigger towers.

μFast processes the data in three sequential steps: a *pattern recognition* involving trigger chamber hits and the position of the MDT hit tubes, a *track fit* performed on each MDT chamber, and a p_T *estimate* using look up tables (LUTs) in order to avoid time consuming fitting methods. The track position at the entrance of the Spectrometer, the direction of flight and the p_T at the interaction vertex are the computed muon features. At this stage, the interaction vertex is defined by the average position of the interactions provided by offline measurements.

A. Pattern Recognition

The pattern recognition is designed to select clusters of MDT tubes belonging to a muon track without using the drift time measurement. Being seeded by the RPC trigger data, *muon roads* are opened in each MDT chamber and hit tubes are collected according to the position of the sensitive wire. No track fit is performed at this stage, because solving the pattern ambiguities through combination of different hits would lead to a too high CPU load.

In the barrel, the Level-1 trigger data consist of 16-bit patterns of RPC strips. They are the input to the "coincidence matrices" of the Level-1 trigger processor [7]. To extract the RPC strips firing the trigger (trigger hits), the data patterns need to be processed by an algorithm that emulates the trigger processor logic. This constitutes the first step of the μFast pattern recognition.

The trigger hits are used to compute the initial muon trajectory according to the model shown in Fig. 3. The interaction vertex is used for defining the trajectory of both low-p_T and high-p_T candidates because it increases the accuracy of the muon path extrapolation over the innermost station (BIL, see Fig. 1), where RPC hits are not available.

Subsequently, the MDT hit finding procedure is started opening muon roads around the resulting Level-1 trajectory. For each hit tube the residual from the initial trajectory is computed and the tube position is stored if its residual is inside the road (Fig. 4).

The road width is tuned to collect 96% of muon hits; it is computed for both low-p_T and high-p_T candidates and for each muon sector (large, small and special). This allows to optimize the road cut for different muon paths and magnetic field values. Typical sizes of the roads are 20 cm in case of large sectors, and 40 cm in case of small sectors.

Finally a contiguity algorithm is applied on the selected hits in order to remove the background. This is a recursive procedure in which the mean direction of the hit cluster is computed and the hit tube having the highest deviation from the mean is removed. The contiguity algorithm terminates only when at most a single hit tube on each MDT layer is left.

Altogether the muon hit selection has 96% of efficiency with a background contamination of 3%.

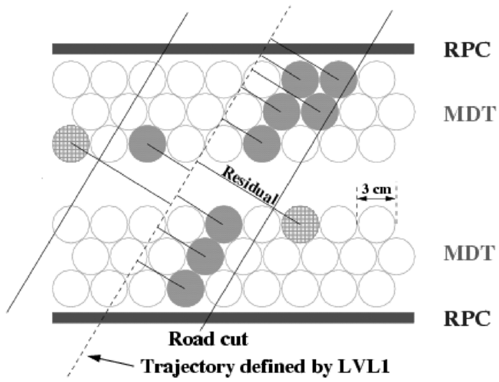

Fig. 4. The application of the muon road in the BML station. Inside the MDT chamber the Level-1 trajectory is defined as the chord of the arc formed by the intersection of the muon path with the chamber envelope. The residuals are defined as the distance of the center of the hit tube to the Level-1 trajectory. The width of the drift tubes is 3 cm.

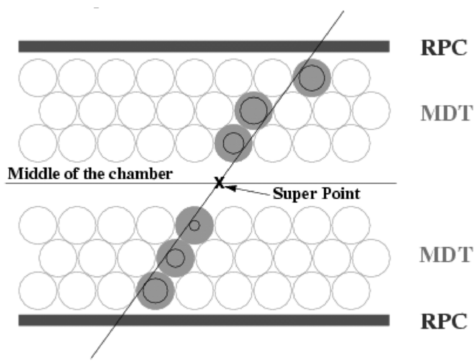

Fig. 5. The track fit uses the drift time measurements (represented as a circle inside the tubes) to fit the best straight line crossing all the hit tubes. The fit output is the track super point.

B. Track Fit

The track reconstruction approximates the muon track with straight segments obtained separately on each MDT chamber. The advantage of this approach is that, whilst a complete helix fit through the spectrometer would require a time consuming minimization procedure, a linear fit has an analytic solution and doesn't need the magnetic field map. Nevertheless the momentum reconstruction is not significantly degraded by this approximation: the sagitta of a 6 GeV p_T muon within a chamber is typically 500 μm, whilst it spans from 20 cm to 30 cm within the spectrometer.

Using the drift time measurement, a track segment is built if at least four MDT hits (two per MDT multilayer) can be used for the fit (Fig. 5). The left–right ambiguity with respect to the sensitive wire is solved by fitting all the possible straight segments through the drift circles and choosing the one with the best χ^2. The fitted segment provides a precision measurement (*super point*) of the muon track to measure the bending of the muon in the spectrometer. Fakes from Level-1 are rejected by requiring at least two super points in the event. No cut is applied on the quality of the fit because this would introduces an inefficiency in the selection: due to the straight line approximation, the fit quality is not good even in the case of a real muon track.

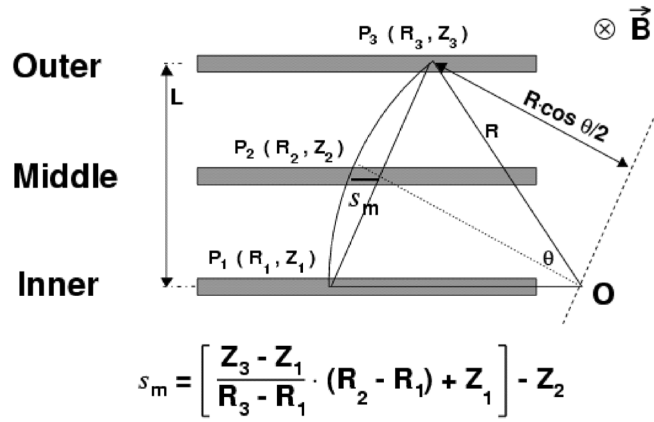

Fig. 6. The track bending (p_T estimate) is computed with a sagitta (s_m) method. Three points are required to compute s_m : P_1, P_2 and P_3 as illustrated in the figure.

To achieve good physics performance, the effective time-distance relationship of the MDT tubes is employed. Thus the MDT calibration constants are accessed at runtime for converting the drift time into a space measurement and for subtracting the time-of-flight and the propagation time along the sensitive wire. The latter requires the measurement of the muon track in the r-ϕ view which is provided by the RPC data.

C. p_T Estimate

In the present implementation of the algorithm the track bending is measured through the sagitta (s_m), that is computed from three super points as shown in Fig. 6. An estimate of the muon p_T is then found using the inverse linear relationship between the sagitta and the p_T

$$\frac{1}{s_m} = A_0 \cdot p_T + A_1$$

This formula is valid for tracks originating at the interaction vertex. The A_0 parameter is related to the setup of the spectrometer (magnetic field, lever arm) while the A_1 parameter takes into account the energy loss in the calorimeter. This function has been mapped into an LUT by dividing the detector region in which the algorithm operates into η and ϕ bins and computing the A_0 and A_1 parameters for each bin. This allows a very fast estimate of the muon p_T from the track sagitta anywhere in the region of the LUT calculation. The muon track is assigned to a given $\eta - \phi$ cell according to its position at the entrance of the spectrometer.

The multiple scattering at the external surface of the calorimeter, the energy loss fluctuations and the non uniformity of the magnetic field are the main sources of the uncertainty on the p_T estimate and depend on the muon path through the apparatus. Thus the LUT binning has to be optimized to minimize these contributions; a binning of 30 cells in ϕ and 60 cells in η has been seen to be adequate to calibrate the muon reconstruction inside a physics sector of the spectrometer. The effect of the finite size of the LUT is rendered less important through the use of an interpolation procedure.

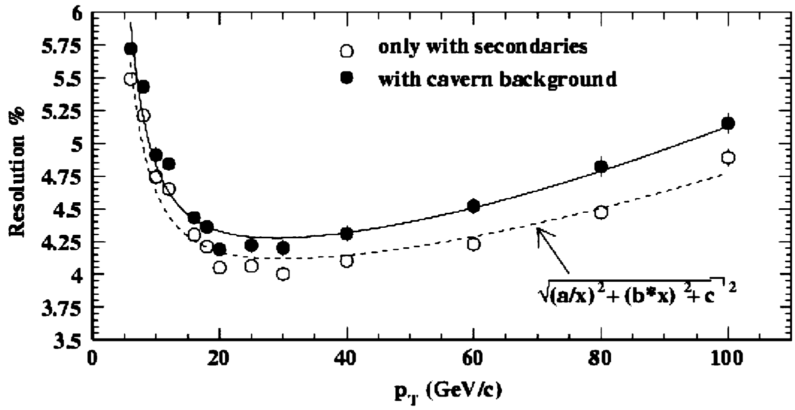

Fig. 7. The p_T resolution of μFast as a function of the muon p_T in the region $|\eta| \leq 1$. The cavern background is simulated at the maximum luminosity. To fit the p_T resolution a function with the following parameters has been used; "a" for the measurement fluctuation, "b" for the energy loss fluctuation in calo; and "c" for the multiple scattering fluctuations, with $x = 1/pT$.

V. The ATLAS Monte Carlo

The detector behavior is reproduced using GEANT3 [6], which simulates the passage of particles inside the matter (down to 10 KeV for electromagnetic interactions, down to 10 MeV for hadronic interactions) taking into account also the bending of the magnetic field. In this framework, the inertial material of the apparatus, the geometry of the sensitive detectors, and their readout electronics responses (including clustering and dead time) have been described in great detail to have the highest accuracy of the simulation. The magnetic field is provided by a 3-D map.

In addition to the GEANT3 simulation, FLUKA [9] is employed to simulate the hadronic interactions and the transport of the neutral particles down to neutron thermal energy. Low energy neutrons and photons, coming from neutron capture, are the components of the so called "cavern background" which constitutes the main source of background for the muon spectrometer. They are the relics of hard hadrons scattering happened in the forward machine elements and in the beam pipe shielding. The fluences of these particles through the muon system are estimated by using FLUKA and their effects on the sensitive detectors are taken into account in the full simulation.

VI. The Performance of μFast

The physics performance presented here has been obtained with Monte Carlo studies where the simulated space-time relationship of the MDT tubes was known in advance. But in normal running conditions, the algorithm will access MDT calibration constants computed using previous runs, thus providing a non-perfect knowledge of the actual space-time relationship. To account for this effect, the reconstruction of the space drift does not correct the spatial shift due to the Lorentz effect (simulated on the data). This yields an error of about hundreds of micrometers on the knowledge of the space-time relationship, the same order of that expected when using precomputed calibrations.

The μFast algorithm measures the p_T of prompt muons with a resolution of 5.5% at 6 GeV, and 4% at 20 GeV. These values are only a factor of two worse than the resolution achieved by the offline muon reconstruction programs which use sophisticated fitting procedures. For other p_T values, the corresponding resolution, with or without cavern background, is shown in Fig. 7. The efficiency, relative to the output of the Level-1, with which the muon track is identified is $\sim$90% at the required trigger threshold and reaches 97% for high-p_T muons.

TABLE I
Total Output Rates of the Level-1 and Level-2 Muon Trigger for the Barrel Region ($|\eta| \leqslant 1$). As Far as the Error Are Concerned; See Text

Processes	6 GeV 10^{33} cm^{-2} s^{-1}		20 GeV 10^{34} cm^{-2} s^{-1}	
	Level-1 (KHz)	µFast (KHz)	Level-1 (KHz)	µFast (KHz)
beauty	1.4	0.75	0.50	0.06
charm	0.80	0.40	0.21	0.02
$W \to \nu\, \mu$	0.003	0.003	0.03	0.02
π/k decays	7.1	2.70	0.68	0.04
fakes	1.0	< 0.003	< 0.003	< 0.003
Total	10.3	3.9	1.42	0.15

The performance on muon momentum resolution allows to reduce the Level-1 muon output rate from 10.3 kHz to 3.9 kHz at low-p_T and from 1.42 kHz to 0.15 kHz at high-p_T (values referred only to the barrel part). The sample composition of the Level-1 trigger rate and the relative reduction factor applied by μFast are shown in Table I.

Trigger rates are computed by convolving the relevant efficiencies with cross sections extracted from Monte Carlo calculations. The errors of the quoted numbers are on the last digit and account for the computing approximations and for a non-precise setting of the Level-1 trigger threshold. The uncertainties coming from the Monte Carlo are not taken into account. Such uncertainties are unpredictable and can raise the production rates of π/k and beauty by a factor of about 2. Anyway the reduction factor applied by μFast should stay unchanged.

The robustness of μFast has been checked by studies of background in the muon spectrometer. As shown in Fig. 7, the p_T resolution is not spoiled in presence of high levels of background such that expected at the LHC. Therefore the background effect on the trigger efficiency (hence on the trigger rates) is negligible. Moreover the algorithm schema has been tested against

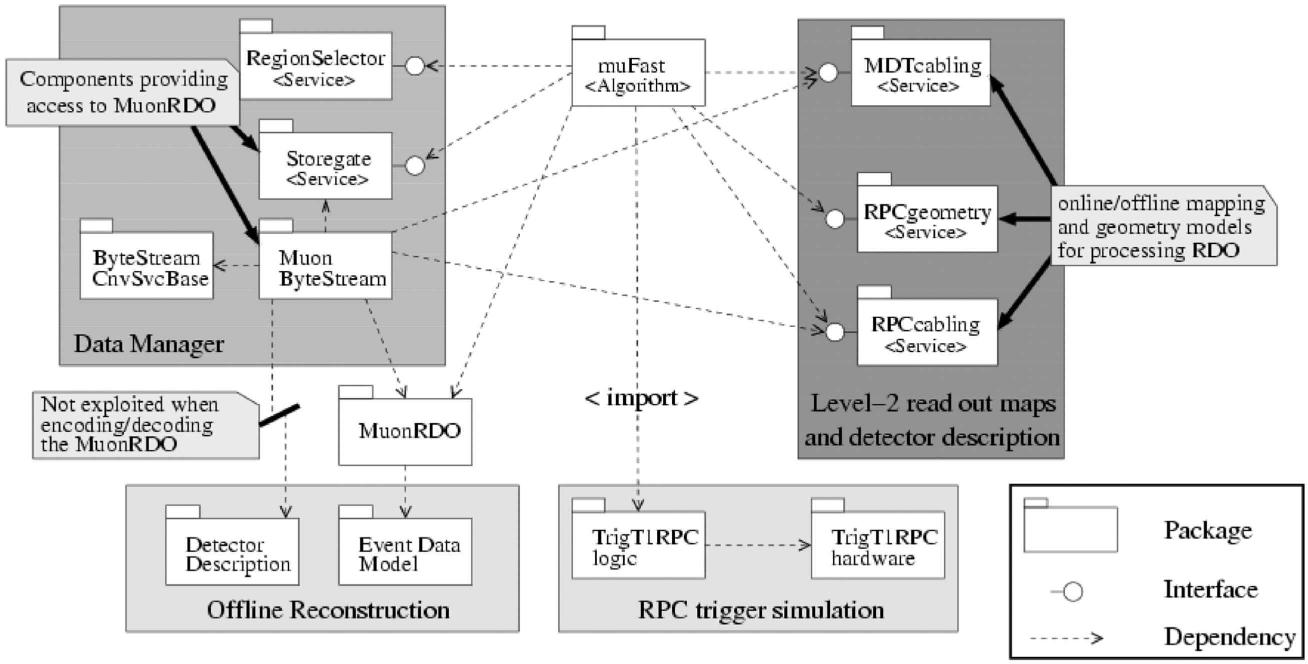

Fig. 8. μFast dependencies. The muon raw bytestream is modeled by the muon RDO classes. The Data Manager provides a standard conversion mechanism for these classes which are requested by μFast throught the Sotegate interface.

fake Level-1 triggers arising from cavern background. The estimated rejection factor on such events is $< 10^{-3}$ for a rate of the cavern background corresponding to the nominal luminosity (10^{34} cm^{-2}s^{-1}). Such estimate increases up to 10^{-1} if the rate of the cavern background is multiplied by a safety factor of 10. This latter takes into account the uncertainties on the prediction of the cavern background rate and allows for a more robust test of the algorithm.

VII. Algorithm Implementation in The Online Environment

The μFast code is a piece of the ATLAS Event Selection Software (ESS) [11] and runs in the software environment provided by the L2PU [12]. Such framework [13] reuses some of the offline software components in order to ease the development of the algorithms. It is made of three packages: the Steering, which controls the processing of the HLT algorithms, the Event Data Model, which describes all the data entities and their relationships, and the Data Manager, which manages the data access. μFast needs to be interfaced properly to these packages and, in particular, it has to use the Level-2 infrastructure to request the RoI data from the ROSs. At the same time, it has to comply with the requirements of the online environment, such as thread safety and timing performance.

In μFast the commonalities between the offline and the online software architectures are exploited to implement the access to the detector data. Anyway the offline processing schema, based on the data retrieving on demand, has been modified to better match the online requirements. In particular, the components providing access to the run condition data has been substituted with Level-2 specific services. Such services implement a processing model where a single read-only copy of the meta data exist in memory to serve the event processing threads. The complete schema of the software components used by μFast is shown in Fig. 8. Being an algorithm tuned only for Level-2 reconstruction, μFast does not use components from the offline event data model and from the offline reconstruction.

The architecture of the ESS and of μFast is very modular which makes easier the adaptation of the software to the expected evolution of the requirements and allows for a better long term maintainability. Moreover the main parameters steering the algorithm, such as trigger thresholds, read out cabling maps, and LUTs, are stored in a configuration data base. This also facilitates the changes of the trigger configuration and its selection power to adapt to new experimental conditions.

A prototype of the Level-2 system has been implemented in a testbed for studying the system performance. All the trigger components are the ones to be used in the final system except for the ROSs where a modified version is employed to allow the emulation of the detector read out and the preloading of the detector data. The testbed has been particularly useful to finalize the trigger software before testing it in the real environment provided by the ATLAS test beam at the CERN SPS.

A. Code Optimization

Besides μFast, the reconstruction of muon tracks is also performed in the inner detector and in the calorimeters to refine the muon object properties. Thus, assuming a total Level-2 processing time of 10 ms on average, the time for μFast reconstruction is O (1 ms).

Because of the time constraint, μFast avoids CPU intensive techniques, like dynamic memory allocation or data organization through STL (Standard Template Library) containers. Moreover, all the tasks described in the previous section operate on data structures especially organized to minimize the exchange of data modelled through complex classes and to speed up the access to the processed data.

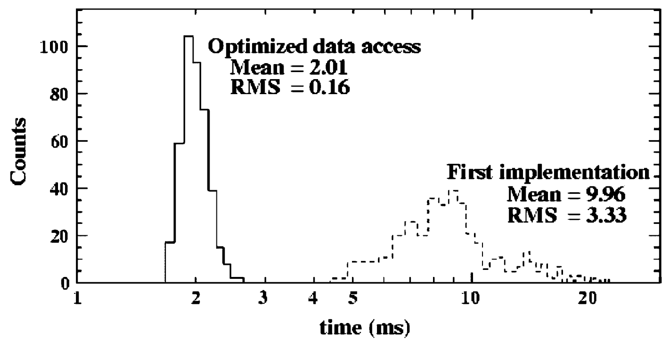

Fig. 9. Execution time of the Level-2 muon reconstruction (data access time + μFast time) on a 2.4 GHz XEON processor. The μFast time is $\sim$1 ms.

To further reduce the processing time, the definition of the trajectory reconstructed from RPC data using the position of the interaction vertex is tuned to reduce the road size without affecting the muon hit selection efficiency. A small road size removes most of the MDT hits due to the background in the ATLAS cavern, and therefore simplifies the pattern recognition and increases the algorithm robustness against background.

The procedure for requesting and receiving the event data has also been improved: online software infrastructure is implemented using offline software components that are not optimized for speed. Thus, without specific tuning for the muon case, data access time dominates the overall processing time. This is shown in Fig. 9, where the pure algorithmic part takes $\sim$1 ms.

In particular, accessing all RoI data of the MDT chambers is not efficient: typically a muon ROI spans over seven MDT chambers, while the muon track data are always contained in only three of them. Actually the muon road, that selects a thin slice of the spectrometer around the muon track without losing critical information, is the best candidate for issuing the MDT data request because it eliminates the time overhead due to the conversion of useless data.

Further optimization in this area is obtained by choosing a data model that eases the decoding task and preparing only the data used for the fit (i.e., associating space points to detector hits, performing calibrations etc.). This task is carried out in the algorithm by a specific code that provides fast access to the detector geometry.

The overall effect of the optimization work is shown in Fig. 9, where the execution time of the previous μFast implementation is compared with the new one. The optimized version is now fully compliant with the Level-2 latency.

VIII. Test Beam Results

The integration of the Level-2 trigger in a real environment is a very important test which has a twofold purpose: perform a functionality test of all the trigger components, hardware and software, thus verifying their interfacing to the external systems (Level-1 trigger, ROSs, EF); check the data access mechanism, the data decoding and most steps of the μFast algorithm. Of course, with the experimental setup and the running conditions being different from the ATLAS ones, only part of the full trigger task could be tested. Nevertheless, what could be achieved is meaningful enough to give confidence in the system robustness and its performance.

Therefore the Level-2 trigger has been integrated into the DAQ system of the ATLAS test beam at the CERN SPS H8 beam line. In this experimental environment, pieces of ATLAS detectors have been exposed to beams of different particles and energies, and μFast has been used to process the muon detector data online. The setup of the muon chambers consists of three barrel stations and three endcap stations positioned along the beam line, with each station being made of two neighboring MDT chambers equipped with the corresponding trigger chambers.

Two scintillator systems, positioned before the first barrel station, provide the trigger for the muon tracks. One system covers a wide area and triggers the full beam profile, while the other selects a very thin slice of the beam. The signal from the scintillators measures the time shift between the machine clock and the passage of muon and is delivered to the central trigger processor of Level-1 to start the data acquisition. The Level-1 electronics, mounted on the trigger chambers, can also provide the muon trigger together with the bunch identification. This option has been used only during the 25 ns run to emulate the LHC conditions.

In order to process the test beam data, the cabling and the detector description employed by the Level-2 data converters have been adapted to describe the test beam setup. Operated online, μFast identifies muon tracks and reconstructs the muon sagitta, which is delivered to the event filter program to be used as a seed. This has constituted a powerful test of the functionalities of a complete trigger slice, from Level-1 to event filter.

The reconstructed muon sagitta is shown in Fig. 10. Its resolution is worse by a factor of about two with respect to that obtained with the offline reconstruction program. In fact, μFast does not correct the chamber positions measured by the alignment system. The effect of such an approximation is seen on the mean value of the resolution peak which is shifted by about 300 μm with respect to nominal zero position. Compared to the approximations made by the fit method, this error is negligible.

Although the plot of the reconstructed sagitta demonstrates that the full algorithm sequence works well, several other checks have been performed on the various steps of the track reconstruction. Data access and decoding have been verified by matching the distributions of RPC hit strips and MDT hit tubes with the beam profile expected on the chambers. Moreover a correlation between the MDT and the RPC hits has been found which shows a Gaussian distribution with σ1 cm. As expected, such value is very little with respect to the muon road size, which is optimized to select tracks curved by the ATLAS toroidal field. This proved that the pattern recognition works well.

Operating the algorithm on real data has improved our understanding on fault tolerance. Procedures have been set up in the data converters and in μFast to recover the processing of those events with a partial failure of the read out electronics.

IX. Conclusion

The μFast algorithm presented here has been developed to reconstruct muon tracks in the Level-2 trigger of the ATLAS experiment. Its physics performance appears adequate to select a clean sample of muon events for the LHC physics program. The algorithm has been successfully implemented in the online environment, both in a testbed and at the test beam where its integration has constituted the first demonstration of a full HLT

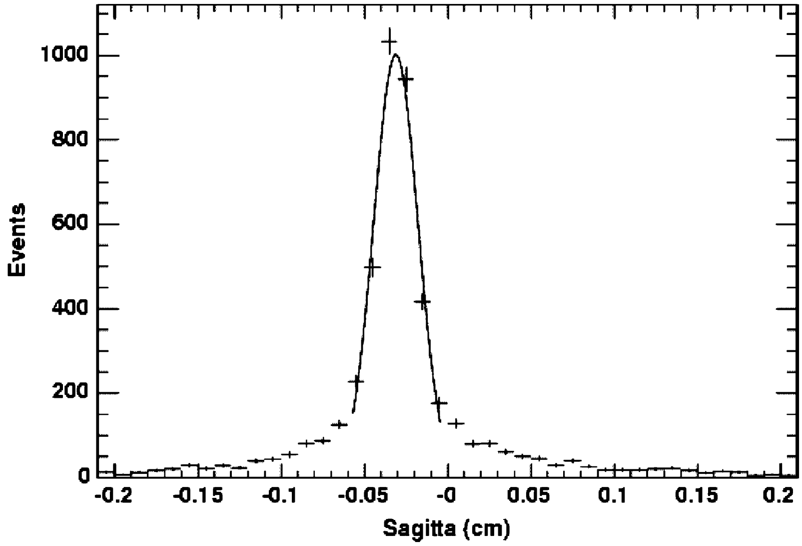

Fig. 10. Muon sagitta reconstructed by μFast processing data from a straight muon beam of 250 GeV. The resolution is about 120 micrometer, a factor of two worse than the resolution achieved by the offline reconstruction program. The sagitta peak is shifted by about 300 micrometer from the zero position, because the reconstruction of mFast does not make use of the alignment constants of the chambers.

slice. For the time being μFast is implemented only for the barrel region and will be extended soon to cover the full rapidity range of the ATLAS muon spectrometer.

Acknowledgment

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J. T. M. Baines, D. Emeliyanov, and F. J. Wickens are with the Rutherford Appleton Laboratory, Chilton, Didcot, U.K.

C. P. Bee, C. Meessen, Z. Qian, and F. Touchard are with the Centre de Physique des Particules de Marseille, IN2P3-CNRS-Univesité d'Aix-Marseille 2, France.

M. Biglietti is with the University of Michigan, Ann Arbor, MI USA.

J. A. Bogaerts, V. Boisvert, P. Conde Muino, N. Ellis, M. Grothe, T. Maeno, C. Padilla, P. Pinto, S. Rosati, C. Santamarina, and P. Werner are with the CERN, Geneva, Switzerland.

M. Bosman, P. Casado, M. Dosil, G. Merino, C. Sanchez, E. Segura, and S. Sushkov are with the Institut de Física d'Altes Energies (IFAE), Universidad Autónoma de Barcelona, Barcelona, Spain.

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