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Deployment of the ATLAS High Level Trigger

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***Abstract*— The ATLAS combined test beam in the second half of 2004 saw the first deployment of the ATLAS High-Level Triggers (HLT). The next steps are deployment on the pre-series farms in the experimental area during 2005, commissioning and cosmics tests in 2006 and collisions in 2007. This paper reviews the experience gained in the test beam, describes the current status and discusses the further enhancements to be made. We address issues related to the dataflow, selection algorithms, testing, software distribution, installation and improvements.**

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I. INTRODUCTION

The ATLAS experiment [1] at CERN will use a 3-level trigger system to help identifying new physics phenomena generated by LHC proton-proton interactions. The program includes a search for the Higgs boson, super-symmetry and other new phenomena. The ATLAS detector is composed of specialized sub-detectors to register the properties of the decaying particles: an inner detector inside a magnetic field of 2 T measuring trajectories, a Calorimeter to measure energy and finally a muon spectrometer.

The First-Level Trigger (LVL1) is directly connected to the detector front-end electronics of the calorimeter and muon detectors. Fast algorithms and energy adders implemented in custom hardware are used for LVL1 event selection. This trigger level also defines Regions of Interest (RoIs) in the detector where interesting physics signatures were found. Event data of accepted events are sent out into the Data Acquisition system (DAQ) via read-out drives (RODs) and are made available to the High-Level Triggers (HLT) through ∼1,600 read-out buffers (ROBs). The LVL1 trigger has to cope with the high input bandwidth of the experiment (40 MHz), being design to have a maximum output rate of 75 kHz, upgradeable to 100 kHz.

The RoIs found by LVL1 are used as seeds for the Second-Level Trigger (LVL2). The RoI information is transmitted to the LVL2 by means of a custom hardware component known as RoI Builder. This component collects information from different LVL1 modules, concatenates and sends it to the LVL2 Supervisor. The later receives the LVL1 result and fans it out to one of the LVL2 Processing Units (L2PUs). L2PUs contain the event selection framework and perform event filtering.

By only looking at data in LVL1 RoIs, it is possible to reduce the amount of data transferred the LVL2 processors to

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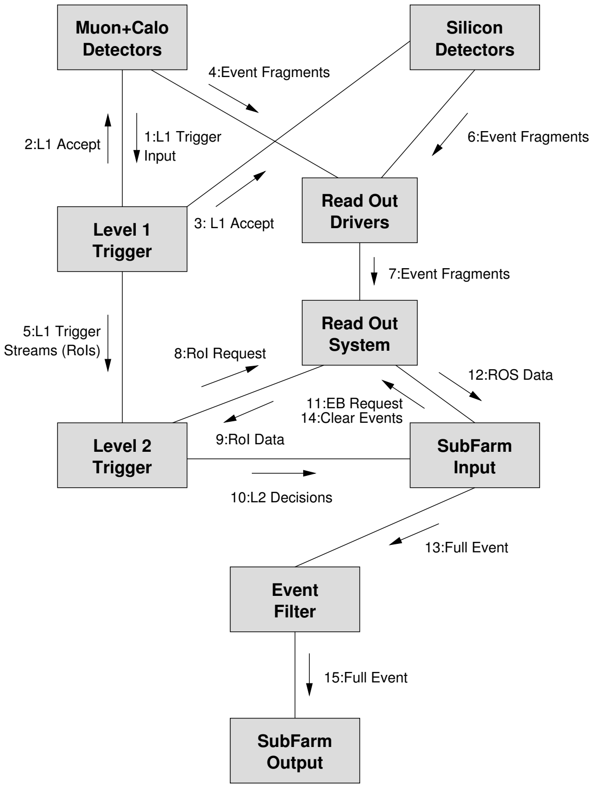

Fig. 1. Principal components of the Data Flow and HLT systems.

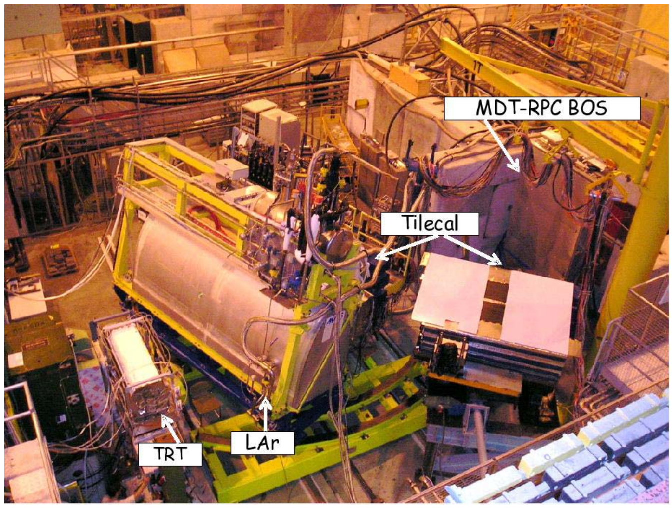

Fig. 2. Photograph of ATLAS 2004's Combined Testbeam setup.

less than 2% of the total event data (∼1.3 MB) and achieve further background rejection. LVL2 selection algorithms request data from variable numbers of RoIs, typically 1 or 2. A RoI spans on average 18 ROBs when located in the calorimeter section, but only a maximum of 3 ROBs if LVL1 triggered on muon candidates. If an event is accepted by LVL2, a detailed summary of the processing, the LVL2 Result, is appended to the event stream and used by the Event Filter to proceed with the analysis.

The last trigger level is the Event Filter (EF). After a LVL2 accept, the full event data is assembled by special computing nodes (Subfarm Inputs, or SFIs) and redirected to specialized processing farms, where more elaborate filtering and monitoring algorithms are used. This level still reduces the output rate to ∼200 Hz. If the event is accepted, it is recorded to permanent storage, via Sub-Farm Output nodes (SFOs) for later offline analysis. The final event stream will also contain a summary of the processing executed at this trigger level. The flow of data is depicted in Fig. 1.

A. *Time and hardware requirements*

At LVL2, the total average processing time per event is expected to be ∼10 ms [2]. Considering the LVL1 output rate, LVL2 will require a processing farm with a capacity equivalent to 1,000 CPUs at 4 GHz. In this configuration, each node should deliver a trigger decision rate of ∼100 Hz, requiring an input bandwidth of 2.6 MB/s.

The total expected average processing time per event in the EF is abount 1 s. Considering the LVL2 output rate, the EF will require a processing farm of 3,200 CPUs at 4 GHz. The input bandwidth of every processing node in this configuration will be 1.3 MB/s.

B. *The ATLAS High-Level Trigger Event Processing framework*

Both the LVL2 and EF use offline software components for doing event selection. A thin interface, the Steering Controller (SC) [3], binds the offline ATHENA/GAUDI [4] software environment to the HLT framework. Slightly different implementations of the SC are available for LVL2 and EF. Event selection happens in LVL2 in multiple, concurrent threads of execution, while the EF is process based.

In both cases, multiple algorithms are scheduled on a per-event basis by a common steering software. It manages the execution order of algorithms based on the seed received, i.e., in LVL2, it uses the LVL1 result, while in EF, the LVL2 Result.

II. Functional Description of the Trigger at 2004's Combined Testbeam

An experimental detector setup (shown in Fig. 2 and Fig. 3) to verify the functionality of the different hardware components was put in place at CERN, starting early in June 2004. The setup was composed of different detector prototypes in final or almost final version and computing infrastructure running up-to-date Trigger and DAQ software to analyze and monitor data produced by beams from CERN's Super Proton Synchrotron (SPS).

The order in which outcoming particles will interact in the final ATLAS detector was preserved during the tests, although the setup resembles that of a fixed target experiment. The beams produced by SPS would pass by a magnet housing prototypes of the Pixel and SCT detectors, followed by a Transition Radiation Tracker (TRT) module. After the Inner Detector modules, a Liquid Argon (LArg) and Scintillating

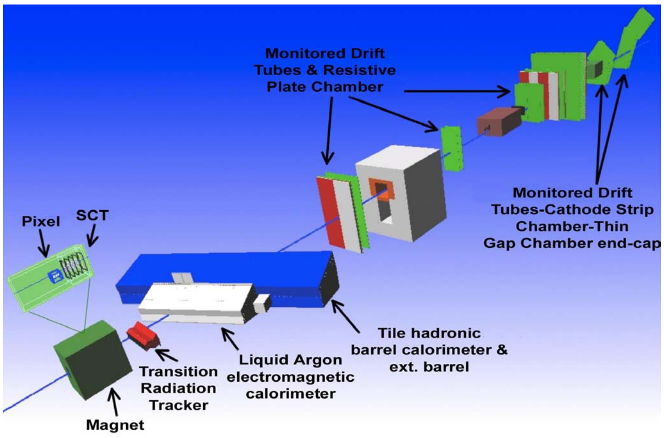

Fig. 3. Comprehensible schema of ATLAS 2004's Combined Testbeam setup.

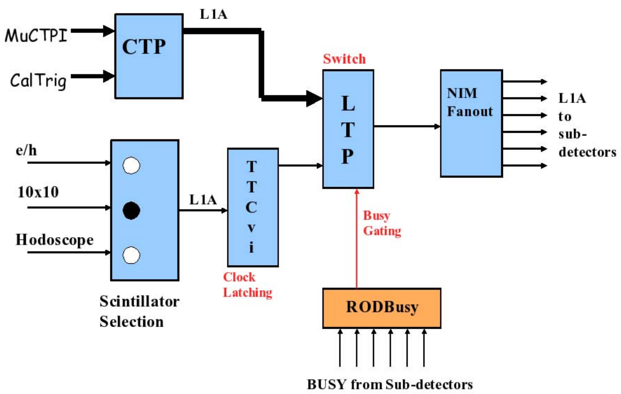

Fig. 4. LVL1 Trigger connection schematics for 2004's Combined Test Beam.

Tiles (hadronic) calorimeter prototypes were placed and finally, at the end of the setup, components of the Muon Detector.

The LVL1 Trigger hardware was connected to the detector RODs and was triggered either by:

- coincidence scintillators (hodoscope), for muons;
- interesting objects in the calorimeters or muon chambers, using the normal trigger logic;
- signals coming from the SPS infrastructure, via the LVL1 Timing, Trigger and Controls module (TTC);

The trigger precedence could be configured via hardware switches and summaries were always available both to the RoIB and the LVL1 Readout Crate Data Acquisition, as trigger sources. The triggering signals were also propagated to the detector Read-out Drivers (RODs), as depicted in Fig. 4. These adjustments allowed the system to run with very few modifications and to maximize original functionality testing.

A. HLT operation during ATLAS's Testbeam

Although primarily intended for hardware tests, the HLT team was able to test its software components together with

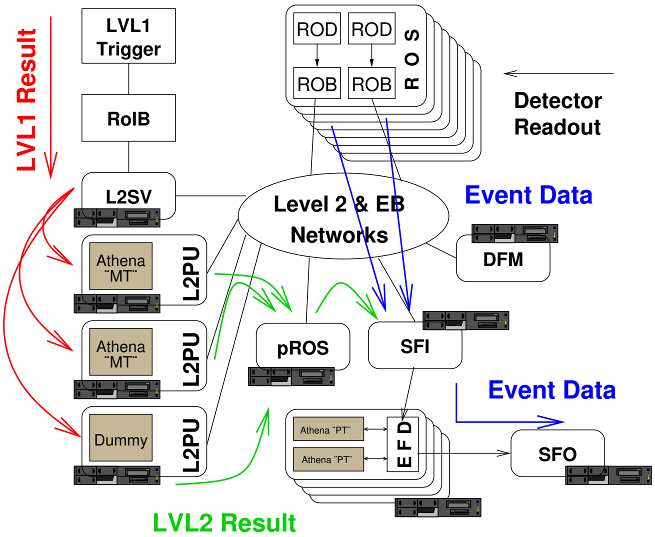

Fig. 5. Deployment of the HLT at the combined testbeam in 2004.

the combined setup at this last opportunity before ATLAS commissioning.

The LVL2 farm for the testbeam was composed of a RoIB prototype and 4 single processor Intel Xeons running at 2.4 GHz and equipped with 1 Gb of memory each. This farm housed one L2SV, up to three L2PUs and a dataflow application used to transmit the LVL2 to the EF, the so called pseudo-ROS (pROS). This unit has the responsibility of buffering the LVL2 result and act like a normal detector read-out system as seen from the event building side of the system. The *in situ* EF farm was composed of 4 nodes in the same configuration as for LVL2. Other external EF farms were deployed through out the testbeam (see [5]) and will not be covered in this text. Every local EF node was running one Event Filter Dataflow Manager (EFD) and up to two processing tasks.

The dataflow inside HLT was not changed for the testbeam exercise. The decision returned by the L2PUs was forwarded to the Data Flow Manager (DFM) which initiated event building in the Sub-Farm Input processor (SFI). The SFI then sent the complete event to one out of the four EFDs.

All the events were accepted by default at the L2PU and Processing Task levels because in this way detectors groups could keep all data for later analysis of hardware problems. To assure continuous data taking, in case of problems with the selection software, one of the L2PUs was equipped with a dummy version of the HLT event selection framework, that did not load any data from the detector readout or executed any calculations. The LVL2 result information from the other two L2PUs contained relevant output that was used by the EF algorithms and monitoring tools. The events recorded by the Sub-Farm Output processor (SFO) also contained the detailed EF result. The events were finally stored on the CERN mass storage facility. This setup is shown in Fig. 5.

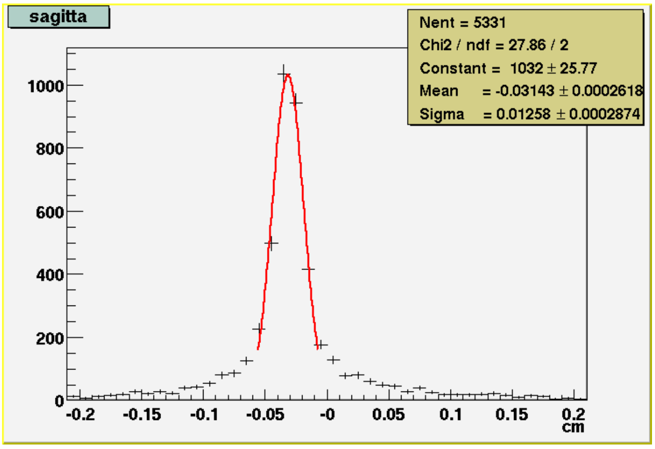

Fig. 6. Distribution of track sagitta values obtained at LVL2 from muFast.

B. Algorithms running in the HLT framework

The L2PU in the test beam was configured to run track fitting algorithms for the Pixel, SCT, TRT and muon detectors. The algorithms were scheduled by the HLT steering framework [6] using many software components from the ATLAS offline detector description, Event Data Model and infrastructure software.

Because of the nature of the tests executed in the CTB, many different parts of the LVL1 hardware were being tested, switched on, off or simply re-configured. The LVL1 Result contents therefore, could not be used as a seeder in LVL2. In absence of RoI information for all detectors, a software simulation of the RoI data was used to initiate the event selection process. In an initial phase the raw data decoding software of a LVL2 muon selection algorithm was commissioned with beam data and cosmic data. The raw data decoding software was in a second phase complemented with the full muon track fitting algorithm "muFast" [7], using alignment and calibration data. The obtained event/track features were encoded in the LVL2 result record, which was send together with the LVL2 decision to the EF farm.

At EF, the event selection was further refined with the "TrigMoore" [5] selection algorithm. TrigMoore's event reconstruction was "seeded" with the LVL2 result information. For both, LVL2 and EF, histograms allowed to monitor the selection process. The histograms were sent from the processing units to a histogram collection facility from where display programs could retrieve them for graphical presentation. Fig. 6 shows e.g. the distribution of track sagitta values obtained at LVL2.

Before installation at the test beam the software was extensively tested in LVL2 and EF emulators as well as combined LVL2 and EF multi-node testbeds, as devised in the development strategy adopted by HLT (see also [3]).

III. Experiences

The setup described was part of the Trigger and DAQ chain of the 2004's ATLAS Combined Testbeam (CTB) in several occasions, including extended data taking periods lasting several hours with good results. Millions of events have passed through LVL2 and EF components. The LVL1 Result trigger path into the LVL2 system, composed by the RoIB and the L2SV worked without problems during the whole period. The data was transmitted accuratly from the LVL1 subsystem into the single L2SV and then distributed to one of the three L2PUs successfuly. The L2PUs carrying HLT algorithms worked reliably and similarly the EF nodes.

The algorithms running at the L2PUs, seeded by the L2SV, were able to take data from the ROB's, transform it into higher-level objects and apply algorithmic work. The LVL2 decision and processing log were reused at the EF level to monitor and confirm LVL2 analysis. The result transmission path, via the pROS, was extensively tested and proved to work. The data were recorded reliably by the SFO and made available for offline studies.

A. Data quality

Occasional data corruption was one source of difficulties during the test period. It cause crashes in the data conversion process. At these moments, the L2SV and EFD systems were timing-out and letting the event be recorded on disk. The data sets which contained corrupted events where imported into off-site testbeds and the problems were analyzed. The necessary protections were added to the data conversion modules. The system was running smoothly after these changes. Data samples taken during this period were of extreme importance to debug the detector readout and the HLT system.

B. Configuration and Software installation

Because of the fast condition changes of the testbeam, the HLT team was forced to change HLT-algorithmic run configuration quite frequently. The text-based configuration system inherited from the Athena offline environment was not flexible enough in this operation mode. Parameter changes still required specialist intervention.

The software installation was normally carried out by system adminstrators and, because of the fast change of conditions, the HLT team was obliged to frequently patch the installed software release. This proved to be flexible enough for development, but rather inconvinient for larger scale setups reproduction and should be avoided on future setups.

IV. Next major milestone: The ATLAS Trigger and DAQ preseries

Starting in July 2005 ATLAS intends to install a representative prototype system of the final trigger system in the ATLAS experimental area. This setup will be used for studying system management issues of large processor farms, evaluating hardware architecture options and software deployment issues. All design choices shall be confirmed within this system, before HLT commissioning, starting in 2006.

The prototype system, also known as the *Preseries* will be composed of up-to-date computer hardware both in the underground experimental areas and in the surface. This farm will be composed of:

- 12 ROS computers equipped with 4 ROBs each;
- 1 RoIB;

These equipments will be located in the underground area, nearby the detector hall. Connected to the readout system and to the RoIB, the following computing power will be available on the surface:

- 30 PC's, as L2PUs;
- 3 PC's, as L2SVs;
- 10 Event Building PC's (6 SFIs, 2 SFOs and 2 DFMs);
- 8 PC's for farm control and fileserving.

These computer nodes will be connected by dedicated control and data gigabit-ethernet networks. The next steps after HLT commissioning are cosmics tests in 2006 and collisions in 2007.

V. Outlook

The issues found during the combined testbeam are already addressed in new development efforts.

A. Configuration

A new HLT configurations ystem should allow users and operators to setup, query and monitor software configurations for the different HLT components. The HLT software configuration will be integrated in the overall Trigger configuration system [8]. The system will use a database backend to distribute the configuration information to several thousand computing nodes. Organization of configuration information, integration in the overall system and scalability issues are presently being addressed.

B. Software Management and Installation

Software management has proven to be an important aspect during the testbeam. Easier methods for software installation, installation monitoring and patching are desirable. Tests with different package management systems, e.g. pacman, will be done on large testbeds. The installation procedures are also strongly influenced by the overall system organization, like, for example, the use of cluster-wide filesystems or the user of computing nodes with a local software installation.

C. Stability and Robustness

For validation purposes, selection chains of HLT software need to be tested against larger, realistic, data samples before the HLT commissioning in 2006. This will assure the needed robustness and stability off-site before the commissioning and deployment of the trigger software. Monte Carlo simulations can still be used to verify the physics and timing performances of the software.

VI. Conclusions

The deployment of the ATLAS High-Level Triggers software in the 2004 combined testbeam was presented. Millions of events flowed through the system without major problems. The HLT development model based on the re-use of offline software components and extensive off-site testing worked as expected. The transmission of the LVL2 result as seed to EF algorithms has also been demonstrated.

A few issues that need further development have been identified. They mainly concern the reproduction of setups, configuration logging, monitoring and error handling.

VII. Acknowledgments

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