

Physics and Event Selection Architecture for the ATLAS Experiment

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ABSTRACT: The extraction of tiny signals of interest at LHC from a huge number of events is an unprecedented challenge in data handling. The ATLAS on-line system, based on three levels of selection, will provide a large and accurate data reduction in order to ease the off-line physics analysis. After the first level trigger, a reduction factor of about 10^3 is to be provided by the High-Level Triggers (HLT) system, with two components: the second level trigger (LVL2) and the Event Filter (EF). LVL2 has to provide a fast decision with specially devised algorithms, acting only on a fraction of the full event, however with full granularity and combining different sub-detectors. The EF is capable of full event reconstruction: its algorithms are off-line inspired and use detailed calibration and alignment parameters. The Physics and Event Selection Architecture is presented, specifying the strategy for effectively selecting events and covering both the physics and the system performance.

1. Introduction

This contribution starts with a short overview of the LHC machine, its physics program and a description of the ATLAS detector. The next section contains the presentation of the ATLAS Trigger and DAQ system, which is followed by a discussion of the Physics and Event Selection Strategy. Before concluding, the selection performance is described in detail for two examples.

1.1 The LHC machine

The LHC will provide proton-proton collisions at $\sqrt{s} = 14$ TeV for a design luminosity of $\mathcal{L} = 10^{34}$ cm⁻² s⁻¹. Proton bunches will collide every 25 ns. Due to the large inelastic pp cross-section, each bunch crossing will contain at design luminosity about 23 inelastic interactions (“minimum bias events”).

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1.2 The LHC physics program

The main focus of the LHC physics is the understanding of the origin of the electroweak symmetry breaking and the search for new physics beyond the Standard Model. In addition, precision measurements of Standard Model processes (and also of new physics processes – if found) will be performed.

The LHC can discover a Standard Model Higgs boson over the full relevant mass range and determine several of its properties. In case of a minimal super-symmetric extension (MSSM) of the Standard Model, at least one of the five Higgs bosons will be observed over the full parameter space. Supersymmetric particles (esp. squarks and gluinos) can be seen up to masses of about 2.5 TeV, as well as new heavy gauge bosons such as $W'(Z')$ for masses less than 4.5(6) TeV. In addition, there will be several precision measurements of Standard Model parameters, such as the W boson mass to an accuracy of 15 MeV and the top quark mass to 1.5 GeV. A complete overview of the physics reach and the precision can be found in [1].

The LHC physics programme implies a huge range in the cross-sections for signal processes. This requires a very efficient on-line selection being able to also detect rare processes, whilst at the same time being able to reject background processes with larger cross-sections. The selection is going to be based mostly on high p_T objects (where $p_T = \mathcal{O}(10 \text{ GeV})$), such as charged leptons, photons, jets (with and without a b tag) and missing transverse energy.

1.3 The ATLAS detector

ATLAS[2] is one of the two general-purpose experiments at LHC. It consists of a set of tracking detectors (“Inner Detector”) located inside a 2 T solenoidal field. The interaction point is surrounded by silicon pixel layers, followed by silicon strip layers and a transition radiation tracker (TRT). Outside of the superconducting coil, a fine grained liquid Argon (LAr) electro-magnetic calorimeter is situated, followed by hadronic calorimetry: in the barrel region a scintillator-tile based and in the endcap/forward region a LAr based component. The detection and measurement of muons is performed by a stand-alone muon system based on air-core toroid magnets and precision chambers.

2. The ATLAS Trigger and DAQ system

In Fig.1 an overview of the ATLAS Trigger and DAQ system is given. It consists of three physical levels of on-line selection: the first level trigger (LVL1), the second level trigger (LVL2) and the event filter (EF). LVL1 has to reduce the interaction rate of 1 GHz to about 75(100) kHz. A further factor of about 1000 in rate reduction is to be provided by the High-Level Triggers (HLT), which comprise LVL2 and the EF.

During the LVL1 decision latency, the data are stored in front-end electronic pipeline memories. Upon a LVL1 accept, these data are transferred via readout drivers to readout buffers (ROB). Here they are kept until the LVL2 decision is made. Upon an accept, the event fragments are assembled from the large number (≈ 1700) of ROBs (“event building”)

and transferred to a processor of the EF farm, before being possibly accepted for mass storage.

2.1 The LVL1 Trigger

The decision of the LVL1 trigger[3] is based on calorimetry (in coarse granularity) and on dedicated muon trigger chambers. It recognises signatures such e.m. clusters (to select photons and electrons), tau hadrons, jets, missing (as well as summed) transverse energy and muons.

LVL1 operates within a maximum latency of $2.5 \mu\text{s}$ and is based on special purpose hardware, using custom designed chips (ASICs) and programmable logic arrays (FPGAs). It also provides guidance to the next stage (LVL2) about regions in the detector where high p_T objects are located (so called “Regions of Interest” (RoI)).

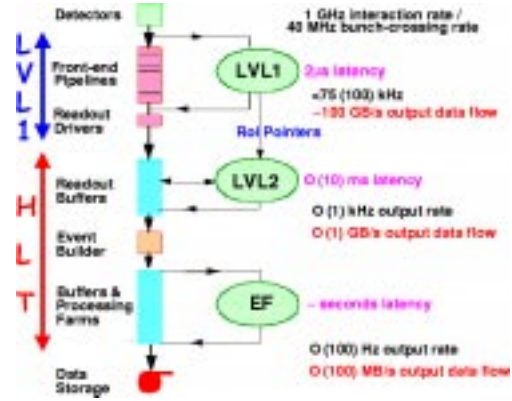


Figure 1: Overview of the ATLAS Trigger and DAQ system.

2.2 The HLT system

The LVL2 component of the HLT [4] will use mostly only a few percent of the full event data, thanks to the guidance obtained through the RoI information provided by LVL1. It has access to the full granularity information from all sub-detectors and thus can combine *e.g.* calorimeter and tracking information. LVL2 has to make its decision within a latency of about 10 ms.

After event building, the full event information is available for the EF processing, which will also have access to more detailed calibration and alignment information. The latency requirements are less strict than for LVL2: the average time for an event decision should be about 1 s.

Both components of the HLT will perform a selection based on algorithms implemented in software, thus providing a very flexible approach to cope with changes in conditions. For LVL2, the development of optimised code is foreseen, whereas at the EF off-line based code should be deployed.

3. Physics and Event Selection Strategy

The physics and event selection strategy has to be flexible, redundant and robust in order to cope with the unprecedented conditions at LHC. Four major elements define the selection strategy. These are:

Algorithms, which identify physics objects with associated properties and global features of the event (*e.g.* an electron candidate with its values of E_T , η and ϕ , as well as information on its isolation),

Sequence, which defines the order of the execution of algorithms (*e.g.* according to the complexity of the algorithms),

Selection, which performs the rejection of background events (by executing sequences of algorithms and verifying the physics objects obtained against a trigger menu),

Classification, which identify basic event topologies and tag events for later analysis (*e.g.* for a hot-line path to quickly analyse events of special interest), but will not reject any event.

The strategy has been derived based on the physics program of ATLAS, defining the physics objects and the criteria for selection, which are mostly using inclusive signatures to maximise the discovery potential. Many algorithms have then been implemented to perform this selection and the selection sequence has been optimised for the best system performance.

3.1 Selection criteria

A rather small set of inclusive physics signatures (*i.e.* requiring one or two high p_T physics objects) will cover most of the physics program of ATLAS. The selection uses (in case of low luminosity ($\mathcal{L} = 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) the following signatures¹: $e25i$, $2e15i$, $\gamma60i$, $2\gamma20i$, $\mu20i$, $j360$, $3j150$, $4j100$ and $j60 + xE60$. For low luminosity an additional selection is made to be able to do B -hadron physics (see below).

3.2 Selection software design

The software to perform the selection and control of the HLT system is being developed in a C++/OO approach, using a mature software development process. The requirements capture has been followed by a high-level design. Fig. 2 shows the domain decomposition obtained, highlighting the three major areas: the *Steering* controls the execution of the selection processes, the *HLT algorithms* extract the physics objects candidates with their properties from raw data and the *Event Data Model* defines the entities used in the processing and their relationship. These domains have several external interfaces to provide access to raw and meta data, to monitoring, to configuration and to other services. The proper definition of these interfaces will allow the major part of the software to be used simultaneously on-line as well as off-line (*e.g.* for testing and development).

The on-going steps involve the detailed design, the implementation and the testing of the package.

¹Here the first letter indicates the type of the object, the number gives the p_T threshold and i indicates an isolation criterium



Figure 2: Domain decomposition of the selection and control software.

4. Selection Performance

Two aspects of the performance can be distinguished: the physics performance (*e.g.* efficiency for signal processes and rejection against background processes, which should both be as large as possible) and the system performance, quantified *e.g.* by the execution time needed and the amount of data required to make the selection (both should be small, but at least within certain limits).

All these parameters influence the size and the cost of the HLT system, *e.g.* the product of rate and data size determines the bandwidth needed and the product of rate and execution time influences the number of CPU required. It is important to realize that physics and system performance cannot be optimised separately. They also influence the resources needed for the off-line computing, *e.g.* the size of the mass storage and of the processing farms for reconstruction and analysis.

4.1 Physics performance example 1: high p_T electron selection

The high p_T electron trigger selects a variety of physics processes, such as the production of W and Z bosons and Drell-Yan pairs, of top quarks and of Higgs bosons, as well as *e.g.* new heavy gauge bosons. The challenge here is the rejection of a large background due to jets faking an electron signature.

The selection starts with a detailed shower shape analysis using the information from the fine-grained ATLAS e.m. calorimetry. It is followed by a search for charged tracks, which are then matched to the calorimeter cluster. Further refinements include the use of transition radiation signals to identify electrons and the recovery of events which have undergone Bremsstrahlung.

Fig. 3 shows the rate (at design luminosity) for the electron trigger vs. the efficiency (wrt. LVL1) for various steps of various selection sequences (which differ in the sharing of the selection between LVL2 and EF). The initial LVL1 rate of 21.7 kHz is reduced by the HLT to 114 Hz, where the accepted sample consists of 40 % of electrons from W decays, 13 % of electrons from b and c quark decays and only 47 % from fake signatures or conversions.

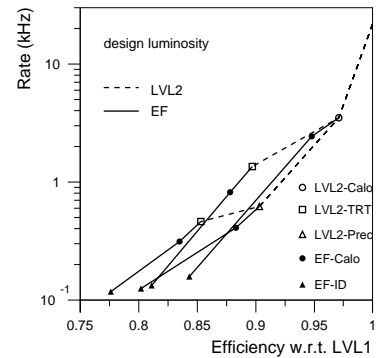


Figure 3: Rate vs. efficiency for the high p_T electron HLT selection at design luminosity for different selection sequences.

4.2 Physics performance example 2: B -physics selection

The selection of events for B -physics is used to make measurements of CP violation, B_s oscillations and rare B -decays. The major challenge is the need for a semi-exclusive decay reconstruction which involves low p_T ($\mathcal{O}(\text{GeV})$) particle, where LVL1 can not provide guidance. Thus an unguided search over the full tracking volume is required.

The B -physics selection is initiated at LVL1 using a low p_T muon signature (nominal threshold of 6 GeV), which yields at low luminosity ($\mathcal{L} = 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) a rate of 23 kHz. The muon selection is refined at LVL2 by using the information from the precision muon

e25i 2e15i	γ 60i 2 γ 20i	μ 20i	j360 3j150 4j100	j60+xE60	B-physics	total
~ 20 Hz	~ 20 Hz	~ 15 Hz	~ 25 Hz	~ 20 Hz	~ 60 Hz	~ 160 Hz

Table 1: Rates after HLT selection at low luminosity.

detectors and by matching to a track found in the Inner Detector. The resulting rate is 5 kHz. Next, an unguided search for low p_T tracks has to be performed in the Inner Detector to be able to do semi-exclusive decay reconstruction. Three decay modes are used to benchmark the performance: $B \rightarrow J/\Psi + X$ with $J/\Psi \rightarrow e^+e^- (\mu^+\mu^-)$, $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow D_s(\phi(K^+K^-)\pi) + X$. The rate obtained after this selection amounts to 60 Hz.

4.3 System performance

As mentioned above, especially LVL2 is subject to strong performance requirements (*e.g.* average latency of about 10 ms and access mostly to a few percent of the event data) in order to reduce the necessary resources needed to implement the system. A sequential selection will be used, where an event is rejected as early and as fast as possible, using algorithms with increasing complexity (and thus execution time).

Fig.4 shows a measurement of the LVL2 decision for a high p_T electron selection, including both the latency due to the algorithms and due to the data access, using an emulated system of about 100 nodes². Half of the events have the decision taken within 3.1 ms, and 99 % of the events are treated within 10.8 ms, which shows that for this selection the latency requirement is already fulfilled using today's technology.

4.4 Total rate

In table 1 an overview of the rates expected at $\mathcal{L} = 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ after the HLT selection is given. Not indicated are error estimates on these rates, which are due to statistical accuracy on one side (of up to 20 %) and due to uncertainties in the cross-sections for signal and background processes, which can be larger than the statistical accuracy in some cases.

Also it has to be noted that this compilation does not contain any pre-scaled triggers, to be used *e.g.* for extending cross-section measurements to smaller scales, to obtain monitor and calibration samples of physics events and to provide sets of data to understand backgrounds.

5. Conclusions

The on-line selection architecture for the ATLAS experiment at LHC has been presented,

²450 MHz dual Pentium II PC

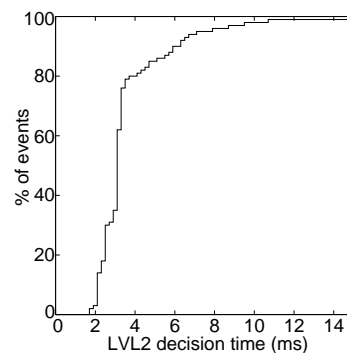


Figure 4: Integrated latency distribution for the electron selection at LVL2. The first selection step (calorimetry only) takes up to 3 ms, the first tracking step (TRT) up to about 5 ms and the second tracking step (SCT/pixel) up to about 9 ms.

which is capable of reducing a 1 GHz interaction rate to a value of $\mathcal{O}(100)$ Hz for mass storage. The selection architecture provides good efficiency for the broad spectrum of LHC physics signatures.

The on-line selection has strong relations, dependencies and influences on the off-line computing. On one side, the last stage (EF) of the on-line selection is to use off-line based algorithms, while on the other side the resources needed for off-line computing (CPU power, storage space) strongly depend on the quality of the on-line selection. An un-biased rejection of most events which are never going to be analysed off-line is mandatory in the LHC environment and should be achieved by mostly using simple, inclusive signatures. Tagging of events on-line (event classification) will ease the off-line analyses.

References

- [1] ATLAS collaboration, ATLAS Detector and Physics Performance Technical Design Report, CERN/LHCC 99-14 and 99-15 (1999).
- [2] ATLAS collaboration, ATLAS Technical Proposal, CERN/LHCC 94-43 (1994).
- [3] ATLAS collaboration, ATLAS First Level Trigger Technical Design Report, CERN/LHCC 1998-14 (1998).
- [4] ATLAS collaboration, ATLAS High-Level Triggers, DAQ and DCS Technical Proposal, CERN/LHCC 2000-17 (2000).