Usage of vertex detectors in the ATLAS trigger software

Vertex 2009 - Putten (NL) - September 18, 2009

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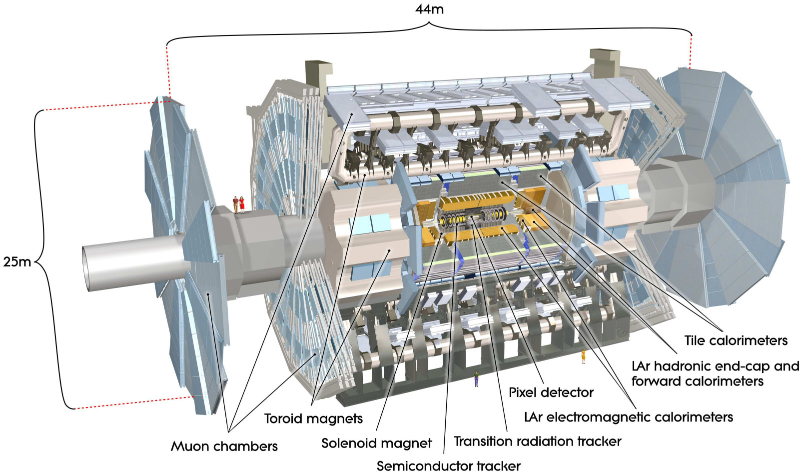
on behalf of the ATLAS collaboration

Outline

The ATLAS Apparatus



The ATLAS Tracking System

Inner Detector (ID)

The ATLAS experiment is equipped with the following tracking subsystems:

- Pixel detector:

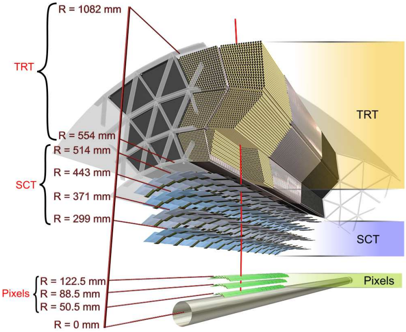
  3 layers and 3 disks of Si pixels;
  pixel size $50 \times 400\ \mu m^2$;
  maximum distance from beam: $\sim$ 12 cm.

- SemiConductor Tracker (SCT):

  4 layers and 9 disks of stereo Si strips;
  strip size 80 μm;
  maximum distance from beam: $\sim$ 50 cm.

- Transition Radiation Tracker (TRT):

  straw drift tubes with diameter 4 mm;
  30 μm sense wire;
  maximum distance from beam: $\sim$ 1 m.



The ATLAS Tracking System

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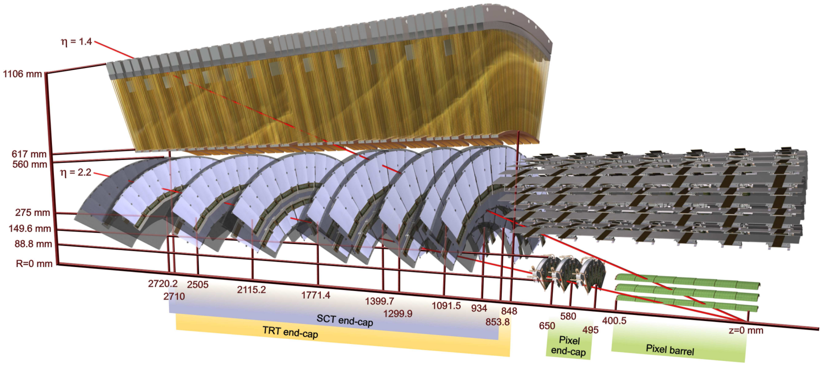
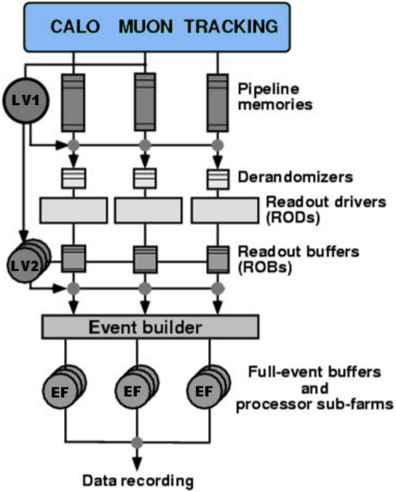


The ATLAS Trigger

Conceptual design

LHC interaction rate is reduced through three subsequent selection steps:



The ATLAS Trigger

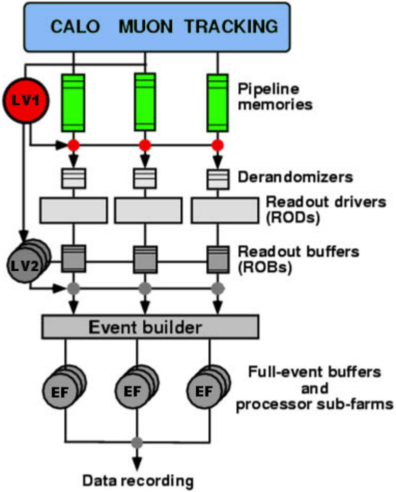
Conceptual design

LHC interaction rate is reduced through three subsequent selection steps:

Level1 Trigger (LVL1):

- hardware based;
- latency 2 μs;
- input/output rate: from 40 MHz to 75 KHz;
- coarse granularity calo and muon data.

- regions of interest (RoIs) are selected by LVL1 Trigger and passed to the following selection step in order to minimize processing time and network traffic.



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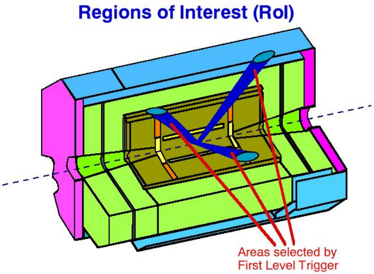


The ATLAS Trigger

Conceptual design

LHC interaction rate is reduced through three subsequent selection steps:

High Level Trigger (LVL2+EF):

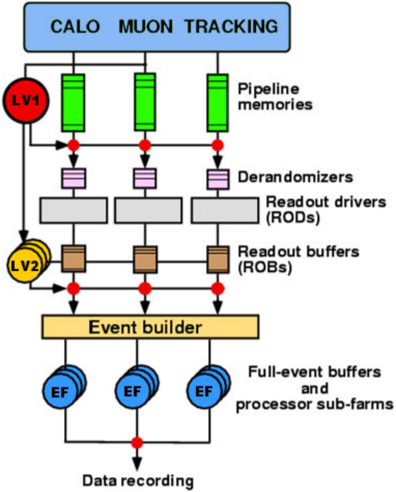
- software based;
- full granularity for all subdetectors

Level2 Trigger (LVL2):

- average execution time $\sim$ 40 ms
- input/output rate: from 75 KHz to 3 KHz;
- RoI driven from LVL1;

Event Filter (EF):

- average execution time $\sim$ 4 s
- input/output rate: from 3 KHz to $\sim$ 200 Hz
- off-line quality algorithms;
- data storage: $\sim$ 300 MB/s.



LVL2 Tracking Algorithms

Overview

In the trigger selection, LVL2 is the earliest stage where tracking information can be used.

The tight constraint on the mean execution time forces algorithm development to a very delicate balance between time consumption and performance.

LVL2 tracking is used for the definition of the following trigger items:

- selection of high-p_T electrons and muons: tracks reconstructed in the ID are used to match information from the calorimeters and the muon detectors;
- reconstruction of tracks from tau decays: tracks are used for both matching information from outer detectors and to apply cuts on track multiplicity;
- b-jet tagging: the impact parameters of the reconstructed tracks are used to evaluate the discriminant variables for identifying jet flavor;
- B physics: identifying specific B-physics decay channels by using decay vertex reconstruction, mass cuts etc.

LVL2 Tracking Algorithms

TRT Segment Finder

TRT Segment Finder is a TRT-only algorithm with separate implimentations for cosmic running and collisions. It is a wrapped version of the offline tracking and it has been extensively used during cosmic data-taking periods.

IDScan

IDScan is a silicon hit based algorithm that exploits a space point histogramming method.

The determination of the z position of the interaction point along the beam axis is the first mandatory step, needed to identify clusters of hits in η-ϕ space. Then, groups of hits from these clusters that are consistent in $1/p_T$-ϕ space are passed to the track fitter.

SiTrack

SiTrack is also a silicon hit based algorithm that implements a combinatorial approach to match space points in order to form full tracks.

It looks for seed pairs of hits in the inner layers consistent with beam-line constraints. Couples are then combined and extended with space points from outer layers, if matching cuts are opportunely satisfied. Groups of hits consistent with single tracks are merged and passed to the track fitter.

LVL2 Tracking Tools

Fit tools

Fitting is used to evaluate the parameters of the reconstructed track candidates. All the tools share a common interface and switching between them can be easily done via configuration.

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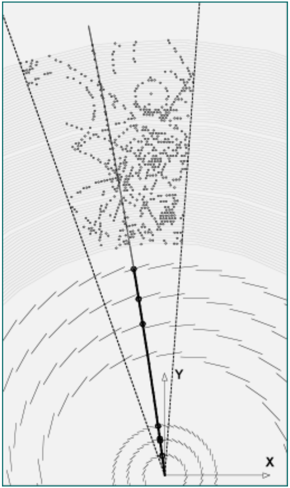
Extension tools

Tracks in the silicon detectors can be extrapolated into the TRT to provide improved p_T resolution. A TRT extension tool, designed to be particularly robust given the high occupancy of the detector (up to 50%), is available for operations:

- single-pass recursive algorithm with almost linear execution time;
- consists of two main blocks: hit association and track update.



EF Tracking Algorithms

Overview

The EF trigger selection software is based on the idea of reusing as much as possible the code developed for off-line reconstruction.

To cope with the limited time budget available at the trigger level, some adaptations are mandatory; among them:

- off-line code is executed within wrapper algorithms, which allow the algorithms to be run multiple times per event processing only the data in the RoIs. This is a major difference w.r.t. the off-line framework where reconstruction algorithms can access data from the entire event;
- some tuning of the algorithm parameters can be performed to reduce the number of iterations and consequent processing time.

HLT Vertexing

Overview

- vertexing tools are implemented in the HLT framework and available for operations.

Vertexing for b-tagging:

- primary vertex reconstruction improves the impact parameter resolution for the reconstructed tracks, consequently improving the discriminant power of the impact parameter based variables;
- reconstruction of secondary vertices enables to implement additional discriminant variables which are uncorrelated with the ones based on impact parameters (jet multiplicity, invariant mass and fraction of jet energy associated to the secondary vertex particles).

Vertexing for B-physics:

- secondary vertex reconstruction is used to reject fake combinations which don't correspond to a common vertex;
- refit of the tracks associated to a given vertex is used to refine the invariant mass constraints applied;

HLT b-tagging

Overview

Tracking and vertexing are the main ingredients for the online b-jet selection, used to improve the flexibility of the trigger scheme and extend its physics performance.
b-jet tagging can be used to lower the jet trigger thresholds for events containing more than one *b*-jet in their final states.

Different approaches studied and implemented to ensure trigger flexibility and robustness wrt different working conditions.

Selection strategies

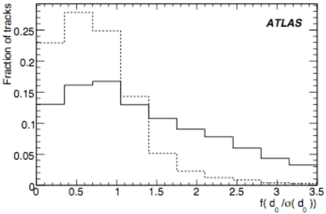
1. likelihood-ratio approach based on the impact paramter significances (powerful but it needs impact parameter distribution of a pure *b*-jet sample, not easily accessible from real data);
2. probability for a jet to originate from the primary vertex (more robust than the likelihood-based approach since it relies on the transverse impact parameter distribution of prompt tracks in multi-jet events);
3. other taggers based on secondary vertex reconstruction are being developed and studied.

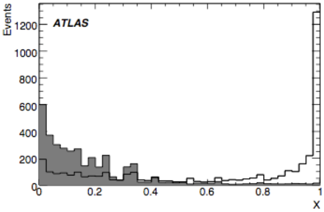
HLT b-tagging

Likelihood ratio method

Impact parameter distribution for tracks coming from *b*-jets (solid line) and u-jets (dashed line)

Likelihood-ratio variable distribution for *b*-jets and u-jets

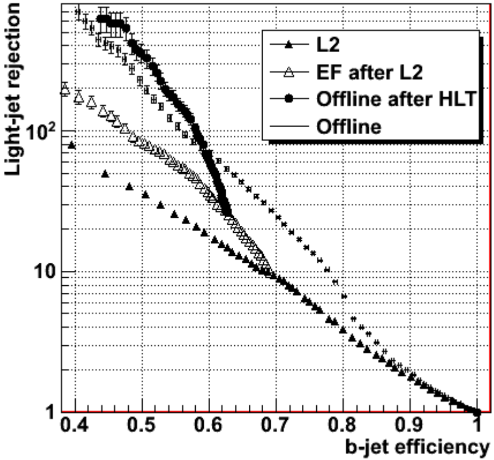




$$W = \prod_{i=1}^{N_{tracks}} \frac{P_b(S_i)}{P_u(S_i)} \rightarrow X = W/(W+1)$$

HLT b-tagging

Performance on $t\bar{t}$ MC sample



High-Level Trigger Commissioning

Overview

In order to be ready for collisions, the High-Level Trigger system needs to be commissioned (event steering, event streaming, monitoring framework, algorithm timing and performance in real conditions, ...).

ID Tracking algorithms commissioning:

- cosmic muons
  - real detector alignment, noise occupancy and data preparation;
  - different event topology wrt collisions.
- pass-through triggers to study algorithm efficiency:
  - LVL1 from muon and calorimeter detectors;
  - HLT without rejecting events;
  - HLT running algorithms and streaming events based on LVL1 and HLT informations.

Cosmics data-taking

Overview

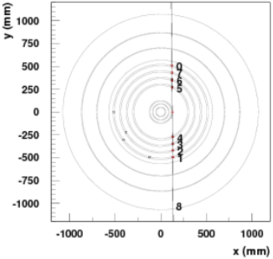
- $\sim$ 200 million cosmic events collected by ATLAS during combined running from September to December '08;
- another ATLAS combined cosmic data-taking in June '09;
- all LVL1 signatures with a confirmed reconstructed LVL2 track fed into a dedicated ID cosmic stream;
- possible to collect high momentum tracks passing through the ID and illuminating as much as possible the detector barrels (needed to align the ID).

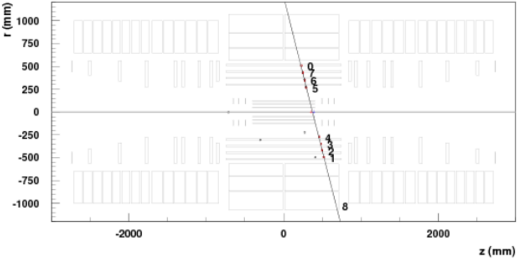
Cosmics data-taking

Silicon tracking algorithms configuration

Silicon tracking algorithms deal in a different way the typically large impact parameter of cosmic tracks.

- IDScan uses collision tuning with a preprocessing stage where space points are shifted as orginating from the origin of the ATLAS coordinate frame (tracking performance is biased by efficiency of the space-points shift);
- SiTrack runs without any ad-hoc shift and uses a dedicated tuning with relaxed track-pointing constraints (fake tracks are overestimated if compared to performance with collision mode).

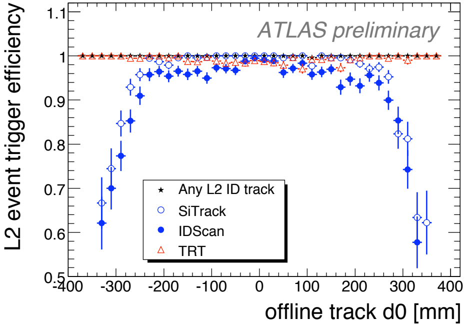




HLT Tracking performance on cosmics

LVL2 event reconstruction efficiency as a function of impact parameter d_0

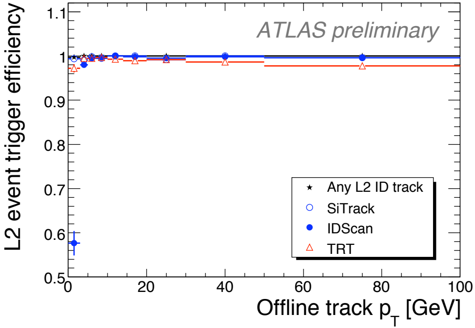
- efficiency is defined w.r.t. an event with an off-line track;
- off-line track is required to have at least 3 silicon space points in the upper and 3 in the lower part of the silicon barrel;
- TRT readout time window in $[-10, 25]$ ns is required.



HLT Tracking performance on cosmics

LVL2 event reconstruction efficiency as a function of track transverse momentum p_T

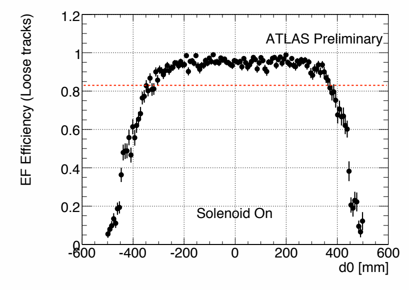
- efficiency is defined w.r.t. an event with an off-line track;
- off-line track is required to have at least 3 silicon space points in the upper and 3 in the lower part of the silicon barrel;
- TRT readout time window in $[-10, 25]$ ns is required;
- $|d_0| < 200$ mm is required;
- low efficiency for IDScan at the lowest-PT bin is due to the spacepoint shifter used before the pattern recognition which works with low efficiency for low momentum tracks.

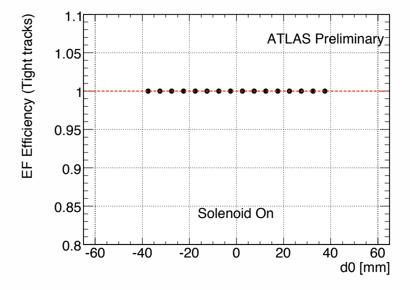


HLT Tracking performance on cosmics

EF track reconstruction efficiency as a function of impact parameter d_0

- efficiency is defined w.r.t. an event with an off-line track;
- loose (tight) selection: 18k (450) tracks, eff. 83.0% (100%).





Summary and outlook

- the ATLAS tracking and vertexing trigger is based on mature software which has been well studied and validated on simulated collisions data samples and in real cosmic data-taking;
- ID trigger has been actively operated during cosmic running and LVL2 tracking algorithms have been used to stream cosmic events;
- tracking efficiencies have been characterized wrt offline tracking on real cosmic data, showing very good performance;
- more detailed performance studies on cosmic data are still ongoing in the ATLAS community;
- application to HLT *b*-tagging has been showed, final commission will be possible only with real collisions;
- LHC operations will restart this autumn and first collisions are anticipated before the end of the year. ID trigger will be ready for first beam, emphasis will be on stable and safe running.