ATLAS Trigger Overview

Triggering Discoveries in High Energy Physics

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Introduction

Contents:

1. LHC and ATLAS
2. Schematic of ATLAS Trigger
3. Level 1
   - Bias towards Level 1 Calorimeter Trigger
4. Level 2 and Event Filter

Warning

This talk has a heavy bias towards the Level 1 Calorimeter Trigger as the Birmingham group has played a major role in its construction and operation

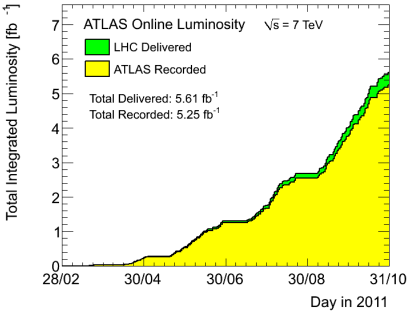
This talk will not discuss the operation or performance of the trigger. Please Richard Mudd's talk after lunch.

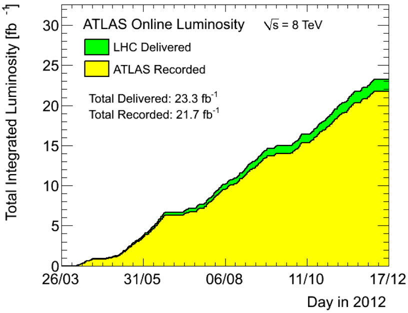
LHC


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

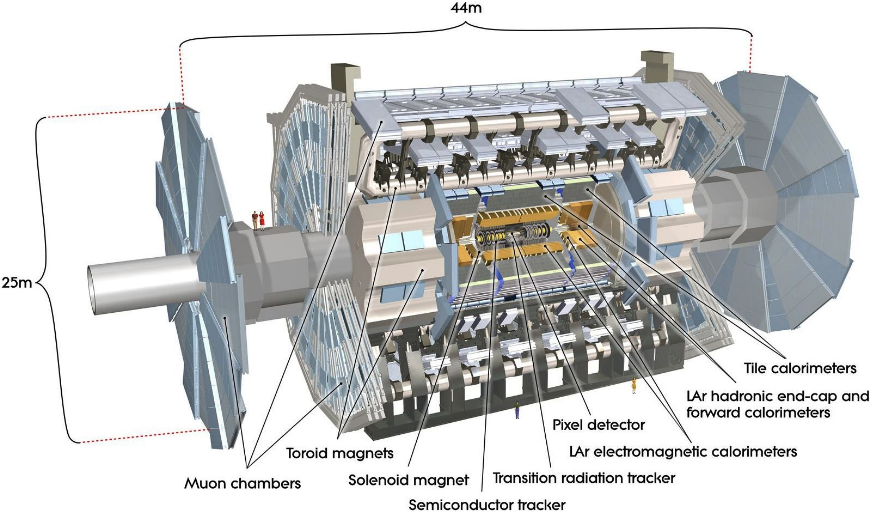
LHC

- Design Energy 14 TeV, 2011: 7 TeV, 2012: 8 TeV
- Design Luminosity $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, for Run I operated below this
- ATLAS takes full luminosity available from LHC
- Bunch crossing period of 25ns
- Huge quanities of data recorded by ATLAS: 5.25 fb^{-1} in 2011, 21.7 fb^{-1} in 2012



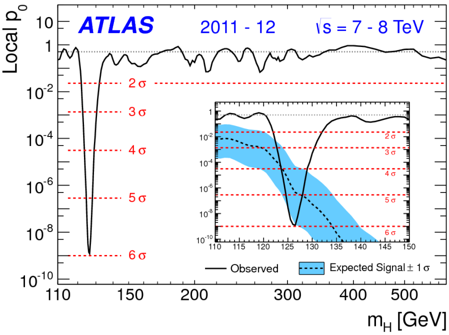


The ATLAS Detector



Why do we need a Trigger?

- ATLAS is a general purpose experiment with wide but focussed physics goals.
- ATLAS and its trigger must be able to detect and record a very large variety of objects and topologies
- Events containing final state electrons, muons, photons and jets as well as high $E_{\mathrm{T}}^{\mathrm{miss}}$ are used in analyses making precision Standard Model meausurements as well as searches for the Higgs Boson and extensions to the Standard Model.

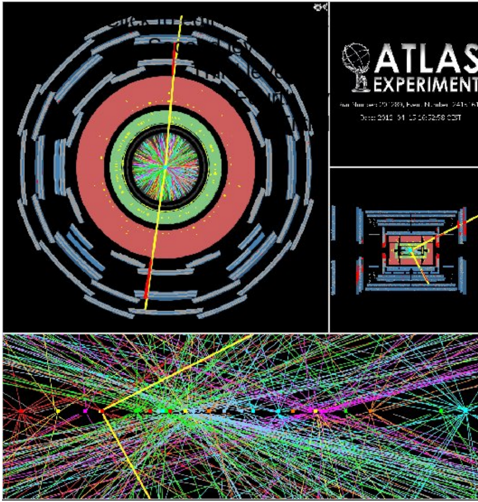


- Higgs discovery and broad search strategy would not be possible without highly performant trigger

Why do we need a Trigger?

- To give us maximum events in search channel we would like to be able to record everything.
- But luminosity delivered to ATLAS is huge: frequent bunch crossings plus multiple collisions per crossing
- Event/Data rate becomes unfeasible both for readout technology and reconstruction
- 40 MHz clock (25ns bunch spacing) gives a raw data rate of ≈ 1 Peta Byte per second.
- After full trigger selection ATLAS records 200-400Hz : only 0.001%

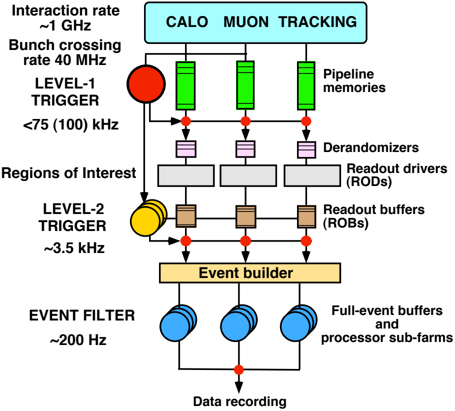
$Z \to \mu\mu$ with 25 primary vertices



- Trigger is also useful mechanism for recording calibration data

ATLAS Trigger Schematic

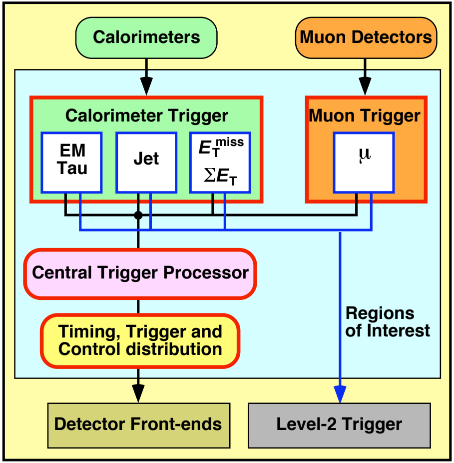
- ATLAS uses 3 level trigger
- High interaction rate prevents Level from being implemented in software
- Level 1 uses fast custom electronics
- Main tracking too slow to be used in Level 1
- Level 2 and Event Filter: high performance computing farms



  - Level 1 works synchronously
  - Level 2 and EF may work asynchronously $\rightarrow$ try different algorithms in order
  - Latencies of L1: 2.5μs, L2: 40ms, EF: 4s

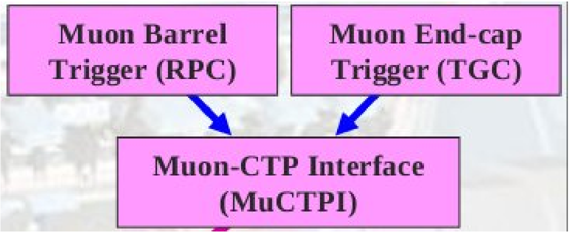
Level 1

- Custom built electronics: mostly ASICs & FPGAs
- Coarse granularity allows faster calculations
- Level 1 consists of 3 sub-systems
- Level 1 Calorimeter (L1Calo) and Level 1 Muon (L1Mu) identify trigger objects passing preset thresholds
- Level 1 Central Trigger Processor checks these multiplicities against trigger menu
- Only events with at least required multiplicities accepted and passed along chain



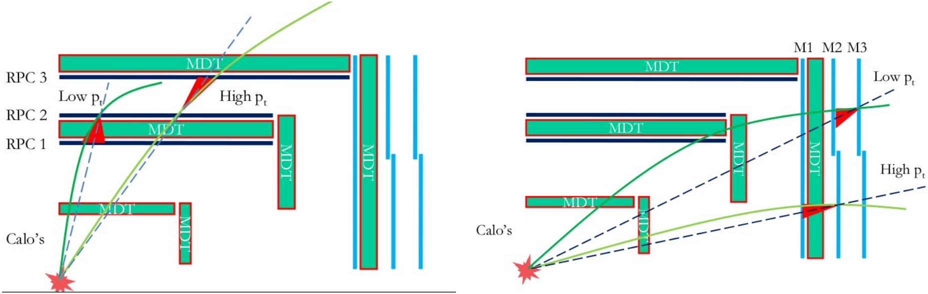
Level 1 Muon Trigger

- ATLAS muon detectors are extremely accurate in spatial dimensions but very slow to readout
- Sandwhich with fast readout technology for triggering
- Different technology used in barrel and forward region
- Within $|\eta| < 1.0$: Resistive Plate Chambers (RPC)
- For $1.0 < |\eta| < 2.4$ Thin Gap Chambers (TGC)
- Two systems combined by Muon-CTP Interface (muCTPI)



Level 1 Muon Trigger

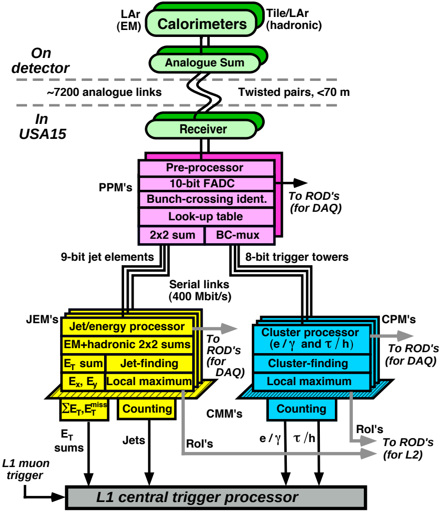
- Look for coincidences in chamber layers
- Hits formed into track using ASICs
- Low p_{T} algorithm uses only inner 2 layers
- High p_{T} combines this information with outer layers



- Positions of muons passing 6 different p_{T} thresholds output from L1Mu

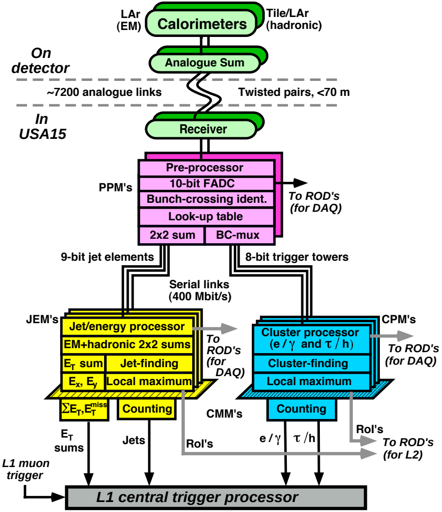
L1Calo

- Huge quanitity of data produced by ATLAS Calorimeters
- At LV1, too many events to look at all Calo information
- Calorimeter cells divided into approx 7200 towers (half EM, half Had)
- Towers of size $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$
- All Calorimeter layers within EM summed up to give single value for tower, same for Had



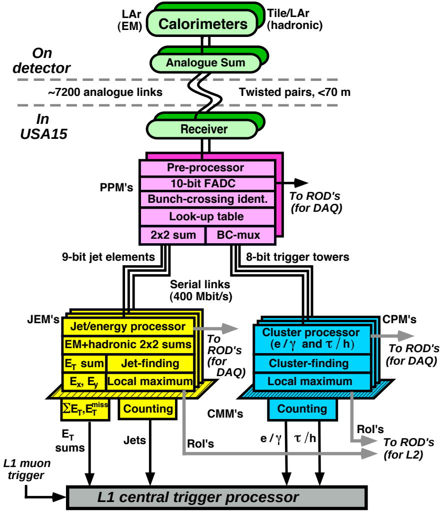
L1Calo

- Custom Hardware made up of ASICs and FPGAs
- FPGAs for algorithms give speed of fixed chip but flexibility to modify setup
- Not radiation hard so kept in USA15 cavern, protected from high radiation environment but thick rock
- 3 main module types
- Seek to first extra the energy deposited in each tower in each event
- Algorithms used to determine objects that left these deposits



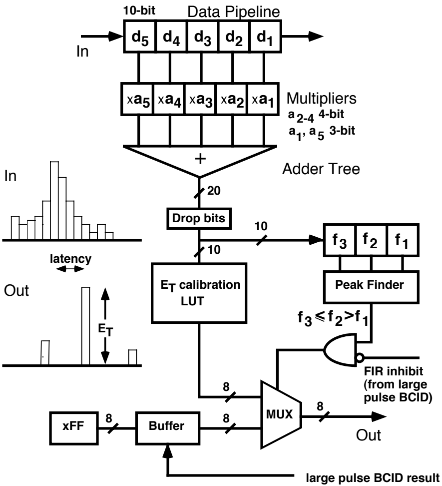
PreProcessor Module

- PreProcessor Module (PPM) resposnible for transforming pulses from calorimeters into a calibrated E_{T}value for object identification
- Analogue Trigger Tower sums converted to digital using 10 bit Flash Analogue to Digital Converters (FADCs).
- Sampling every 25ns (LHC bunch period)
- Fine timing correction 1-25ns
- Then use digital pulse shapes to perform Bunch Crossing Identification



Bunch Crossing Identification in L1Calo

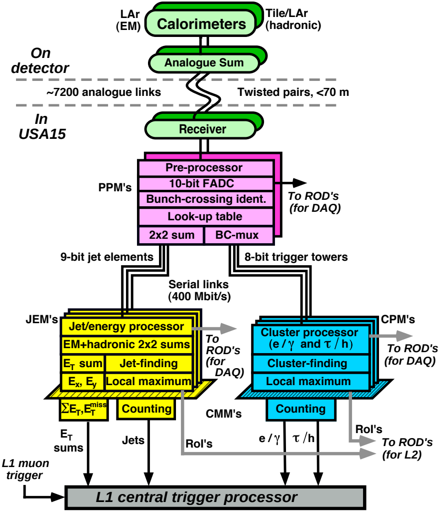
- Trigger Tower pulses are several bunch crossings wide
- BCID system associates Calo pules with a single bunch crossing
- Saturated pulses above $255\mathrm{GeV}(2^8 - 1)$: Shape of leading edge of pulse
- Non Saturated $<255\mathrm{GeV}$: Finite Impulse Response (FIR) Filter
- "Common" filter: coefficients fitted to general shape of pulses in regions
- "Matched" filter: coefficients set for each tower
- Peak finder selects bunch crossing where $f_2 > f_1$ & $f_2 \geq f_3$



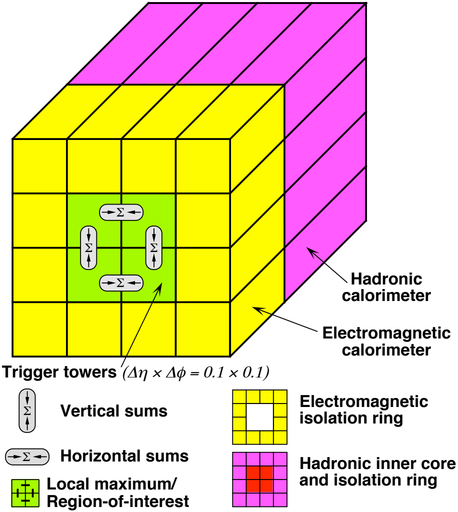
$$f_{output} = \sum_{i=1}^{5} a_i d_i$$

PreProcessor Module

- Output from BCID process is a single non-zero time slice
- Height of central slice calibrated to E_T using Look Up Table (LUT)
- η position also used
- First take off baseline pedastal present in particular region
- Noise cut applied to take account of Calo cell noise RMS
- LUT then converts remaining to 8-bit E_T value
- Can be used to zero badly behaving towers
    - Tower information passed onto Cluster Processor Modules and Jet/Energy Processor Modules

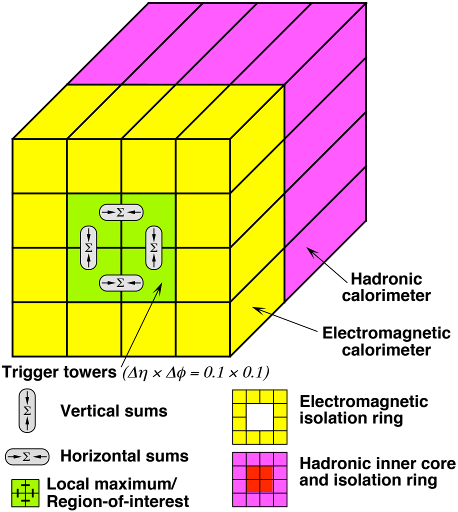


- Cluster Processor Module (CPM) designed to identify electrons, photon and hadronically decaying taus
- Used in region $|\eta| < 2.5$, towers become too large at higher eta for precision
- Objects selected by CPM are expected to form narrower clusters with little activity nearby
- Algorithms designed to select large E_{T} deposits in pairs of towers and veto large activity nearby



Cluster Processor Module

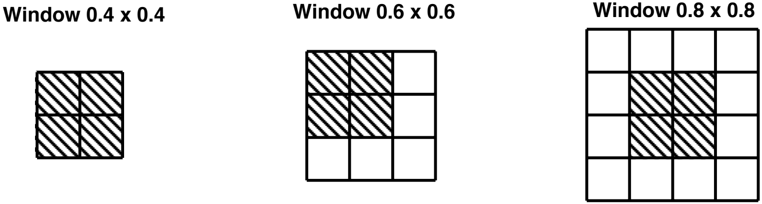
- Electron/photon
  - Select 2×2 EM using Sliding window algorithm
  - Sliding window selects local E_{T} maximum
  - One of 4 poss horizontal/vertical sums must be above threshold
  - Can then apply isolation based on Had core, Had ring or EM ring
- Tau
  - Same basic algorithm as Electron/Photon
  - Sum is over both EM and Had layers
  - Therefore cannot veto on Had core.



- Current construction of algorithms means that by definition all those passing EM will pass Tau

Jet/Energy Processor Module

- Jet/Energy Processor Module(JEM) identifies jets as well as calculating Total E_{T} $E_{\mathrm{T}}^{\mathrm{miss}}$ and $E_{\mathrm{T}}^{\mathrm{miss}}$ signifficance
- Jet algorithm works on jet elements - 2×2 trigger towers
- E_{T} sums within 2×2,3×3 and 4×4 jet elements calculated with a different threshold for each size
- Window must be local maximum and fully surround the 2×2 which is maximum
- Two jet regions: normal in $|\eta| < 3.2$, forward jet in $3.2 < |\eta| < 4.9$ (less reliable)
- Total E_{T} $E_{\mathrm{T}}^{\mathrm{miss}}$summed over all towers out to $|\eta| - 4.9$

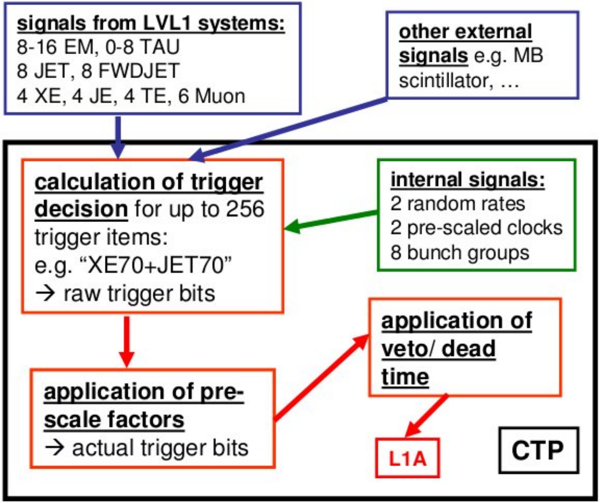


Level 1 Central Trigger Processor

- The Level 1 Central Trigger Processor (CTP) checks L1 Object multiplicities
- L1Calo and L1Mu pass multiplicities of objects passing various thresholds to the CTP
- CTP compares input to the Trigger menu containing up to 256 items
- L1Mu inputs multiplicites of 6 muon p_{T}thresholds
- L1Calo inputs multiplicites of 8 thresholds for jet and forward jet, 16 between electron/photon and tau as well total E_{T} and $E_{\mathrm{T}}^{\mathrm{miss}}$
- CTP responsible for applying deadtime

9U VME64x crate, FPGA based

CTP



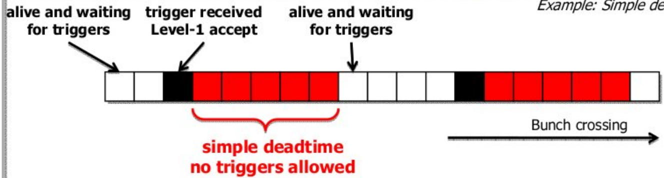
- If event passes $\geq$ one item then CTP sends L1 Accept signal
- This causes Regions of Interest (RoI) to be passed to Level 2 and prompts pipelined data to be read out

Deadtime

- Trigger and DAQ cannot readout events too close together
- When processing data deadtime occurs to prevent further data
- ATLAS uses both simple and complex deadtime

Simple Deadtime | Prevent overlapping samples in detector front-ends

Example: Simple dead-time = 5 (BC)



Complex Deadtime | Protect readout buffers from trigger bursts

Example: Complex dead-time = 4/570

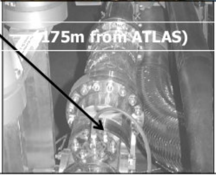
leaky bucket algorithm:

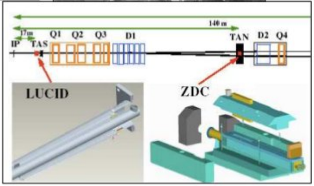
- bucket is filled with L1A tokens at constant rate up to bucket size
  (e.g. 1 token every 570 BC until 4 tokens in bucket)
- every L1A takes one token out of the bucket
- if bucket is empty (no L1A tokens left), deadtime is applied

Other L1 Triggers

- Several other triggers not from L1Calo or L1Mu exist at Level1

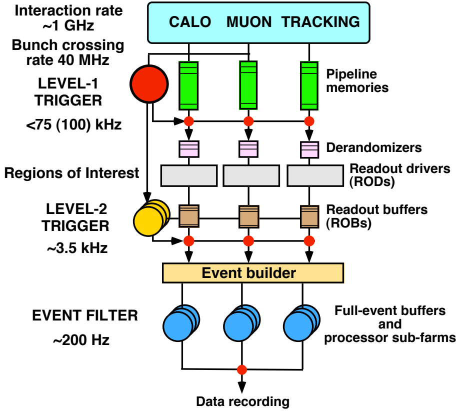
- L1_MBTS: → Minimum Bias Trigger Scintillators
- L1_BPTX: → Beam Pickup Timing Experiment
- L1_BCM: → Beam Condition Monitors
- L1_LUCID: → Luminosity Measurement with Cherenkov Integrated Detector
- L1_ZDC: → Zero Degree Calorimeter
- L1_TRT:
  Cosmic Track Trigger
- L1_CALREQ:
  Calo Calibration Triggers
- L1_RD0/L1_RD1 (random)



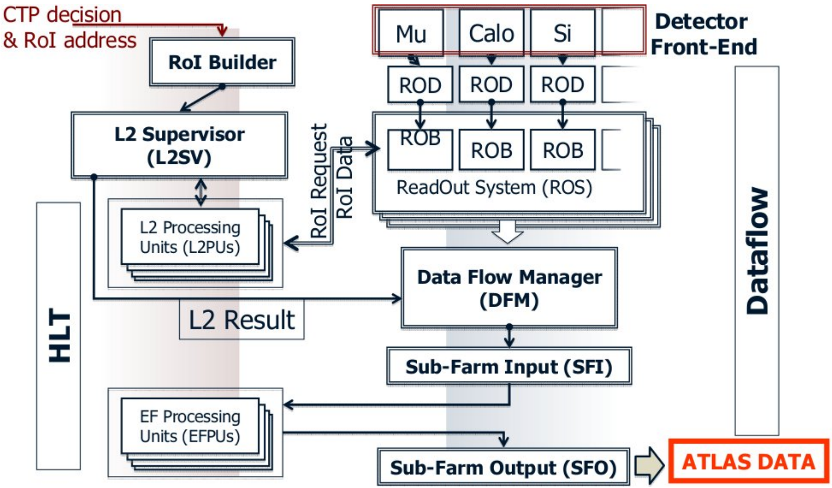


High Level Trigger

- Level 2 and the Event Filter (EF) are jointly referred to as the High Level Trigger (HLT)
- HLT consists of standard high performance computing farms
- Level 2 refines the object selection made by Level 1
- EF looks at the whole event picture
- HLT can act asynchronously, many event processed simultaneously and overlapping
  - Simpler, quicker algorithms first and then up complexity



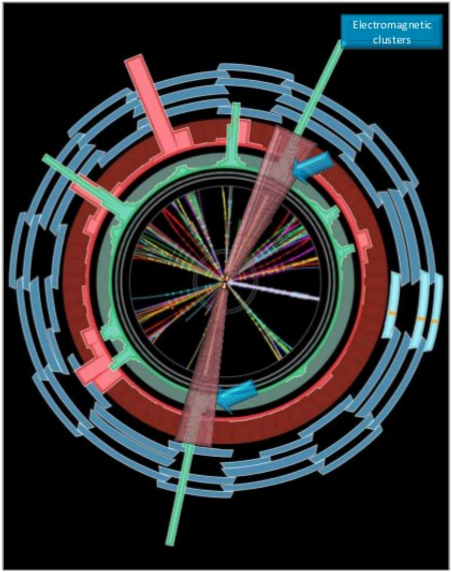
High Level Trigger - Level 2



High Level Trigger

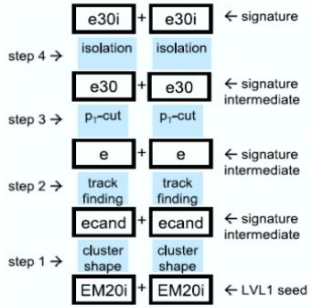
- When an L1 Accept signal is produced by L1 CTP, increased granularity information read out from detector
- L1Mu and L1Calo send event RoIs to L2 system
- L2 loads data from cone around RoI as and when needed
- Around 2% of event data associated with each RoI
- L2 reduces rate by approximately a factor 15 in 40ms per event
- Refined objects checked against trigger menu in similar way to L1CTP but this time in software

Example of EM RoI



Level 2 Example

- Level 2 sequence used for searching for hight p_{T} di-electron events based on L1Calo RoIs



example: di-electron trigger

ATLAS trigger terminology:
- **Trigger chain**: whole decision sequence
- **Trigger signature**: intermediate result
- **Trigger element**: trigger object

LVL1-items are the start for HLT activity:

step-wise processing and decision
fast algorithms first
increasing complexity of algorithms

seeded reconstruction
algorithms use results from previous steps
initial seeds for LVL2 are LVL1 RoIs Chains
can be split at beginning of new level

LVL2 confirms & refines LVL1
EF confirms & refines LVL2
Event read-out and building after LVL2
EF accept events according to physics selection

early reject
as soon a signature fails, all following connected chains at all levels are switched off

High Level Trigger - Event Filter

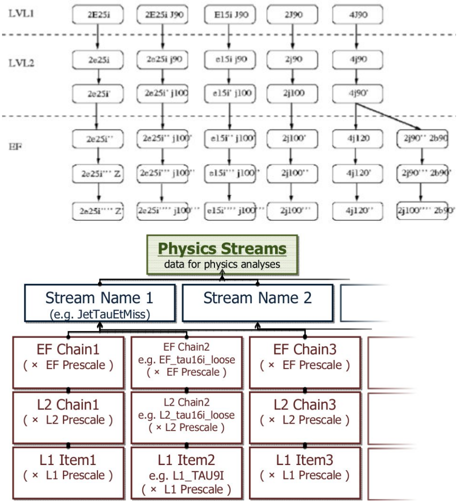
- The Event Filter (EF) takes only events passing L2 object selection
- EF performs a partial reconstruction of the whole event and takes ∼4s
- Algorithms quite similar to offline algorithms used in physics analyses

CPU racks used in HLT

- Much greater use of Topological quantities: e.g. di-object mass cut, angular, b-tagging
- Multiple trigger signatures for single event can be checked simultaneously → Event lost once all fail
- Balance of signatures requested, between e,g, electron or muon, determined by needs of physics analysis groups

Recording Data from trigger

- Algorithms and thresholds at different levels joined in chains
- Check algorithm at level if event passed corresponding trigger at previousl level
- Depending on the type of trigger event passes, e.g. electron or jet, the event will be written out to a different file for physics analysis, known as a Stream
- Streams may overlap e.g. elec and jet trigger in same event



- Some event signatures are desirable but too common so we cannot record them all $\rightarrow$ prescale the trigger whereby we take only a random proportion of events passing

Summary

- The design and implementation of the ATLAS Trigger has been presented
- The 3 level trigger is well designed to cope with the high luminosity and high pileup conditions of the LHC
- A combination of software and hardware allows a high rejection rate while also applying sophisticated algorithms for object and topology identification
- The 3 levels refine and expand on the decisions made previously
- ATLAS can trigger on a wide variety of objects, allowing data to be recorded for a wide range of analyses

Please see talk by Richard Mudd after lunch for information on the operation and performance of the ATLAS trigger.