Error detection, handling and recovery at the High Level Trigger of the ATLAS experiment at the LHC

Real Time 2016
9 June
Padova

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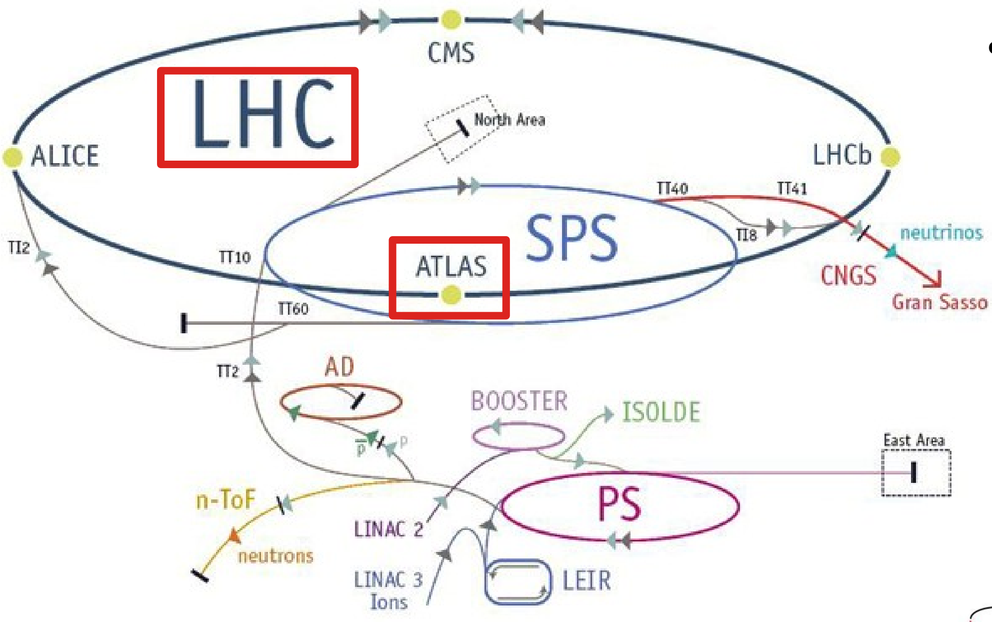
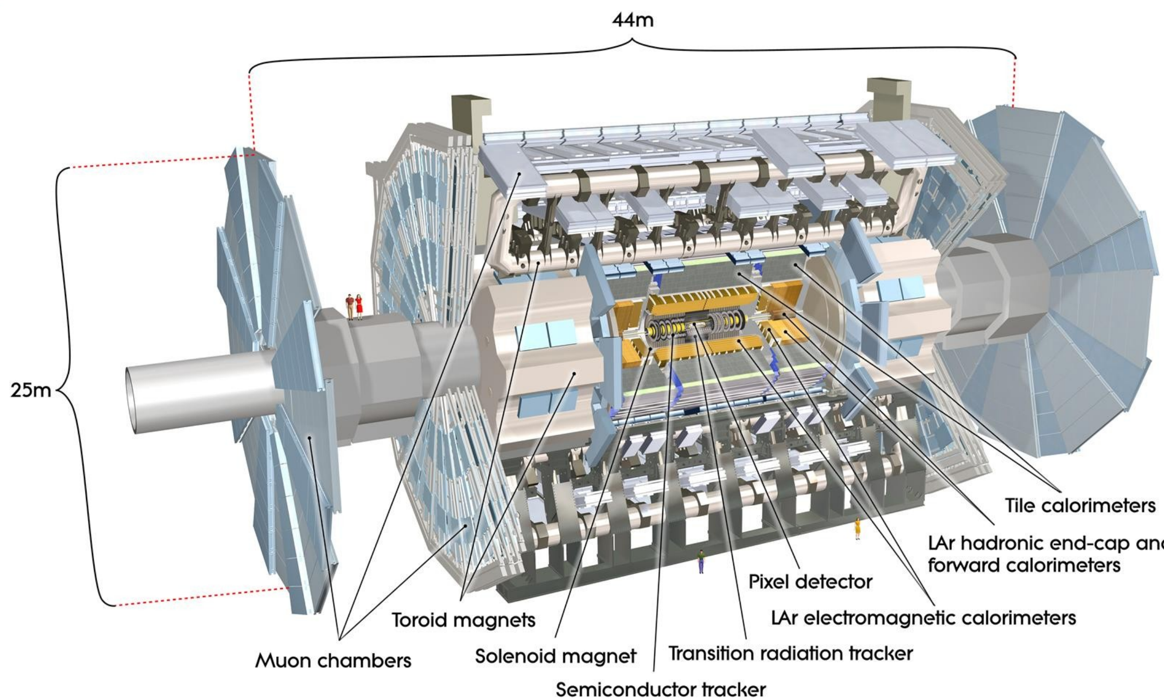
McGill University
on behalf of the ATLAS collaboration

Introduction



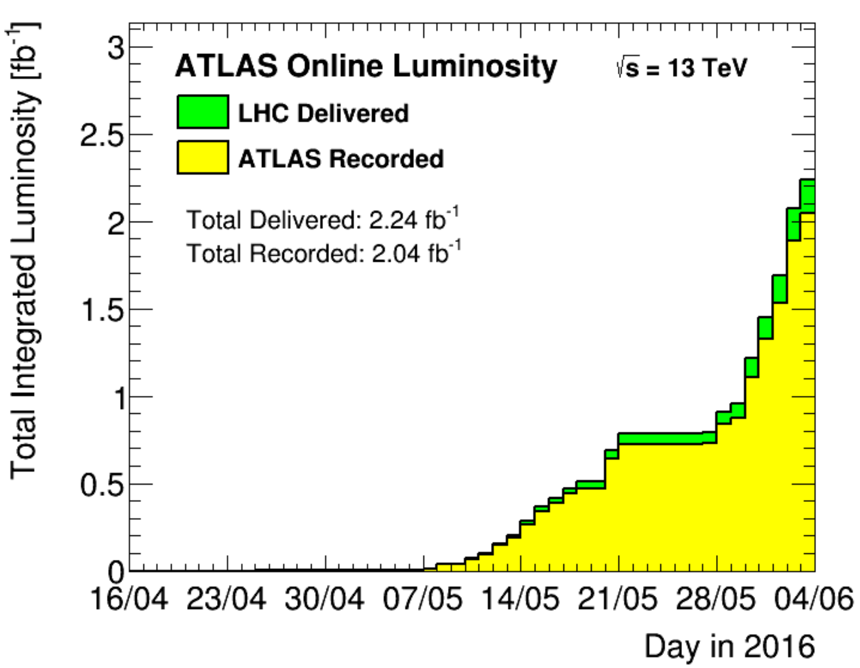
- Changes to the ATLAS trigger system for Run2
  - L1 (Level 1) detectors
  - FTK (Fast Tracker)
  - HLT (High Level Trigger)
  - Data streams

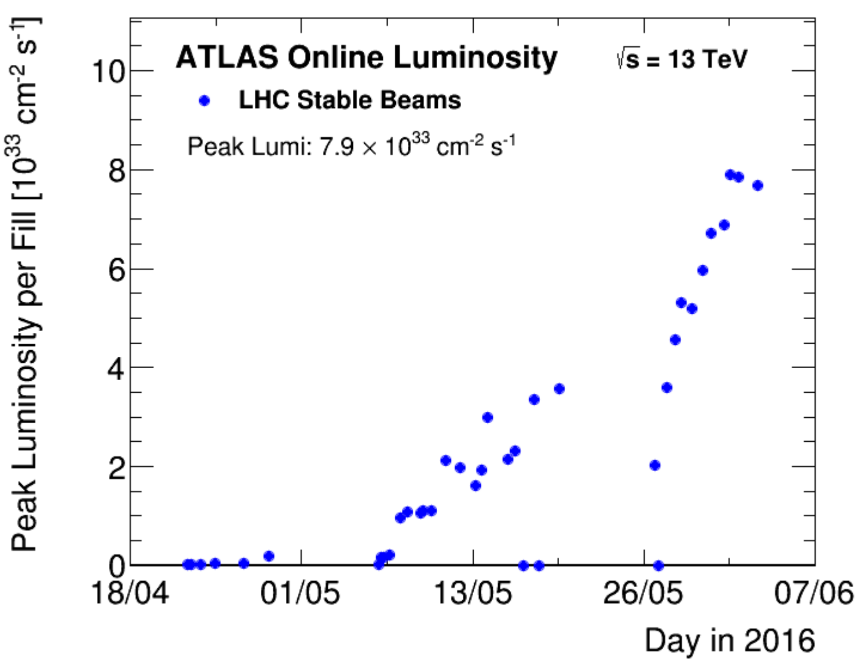
- Specific details
  - Debug streams
  - HLT errors
  - Live monitoring
  - Follow up
  - Recovery
  - Prevention/Testing



Data taking

- Run1:
  - 2009-2011 @ 7TeV
  - 2012 @8TeV: peak lumi 7.73x10^{33} cm^{-2}s^{-1} recorded 21fb^{-1}
- Run2:
  - 2015 @13TeV: peak lumi 5.02x10^{33} cm^{-2} s^{-1} recorded 4fb^{-1}
  - 2016 continue @13TeV
    - A slight pause due to the marten incident
    - Longer pause PS accelerator problems
    - LHC has progressed up to 2040 bunches
    - Set new record peak luminosity for the LHC





The ATLAS trigger system

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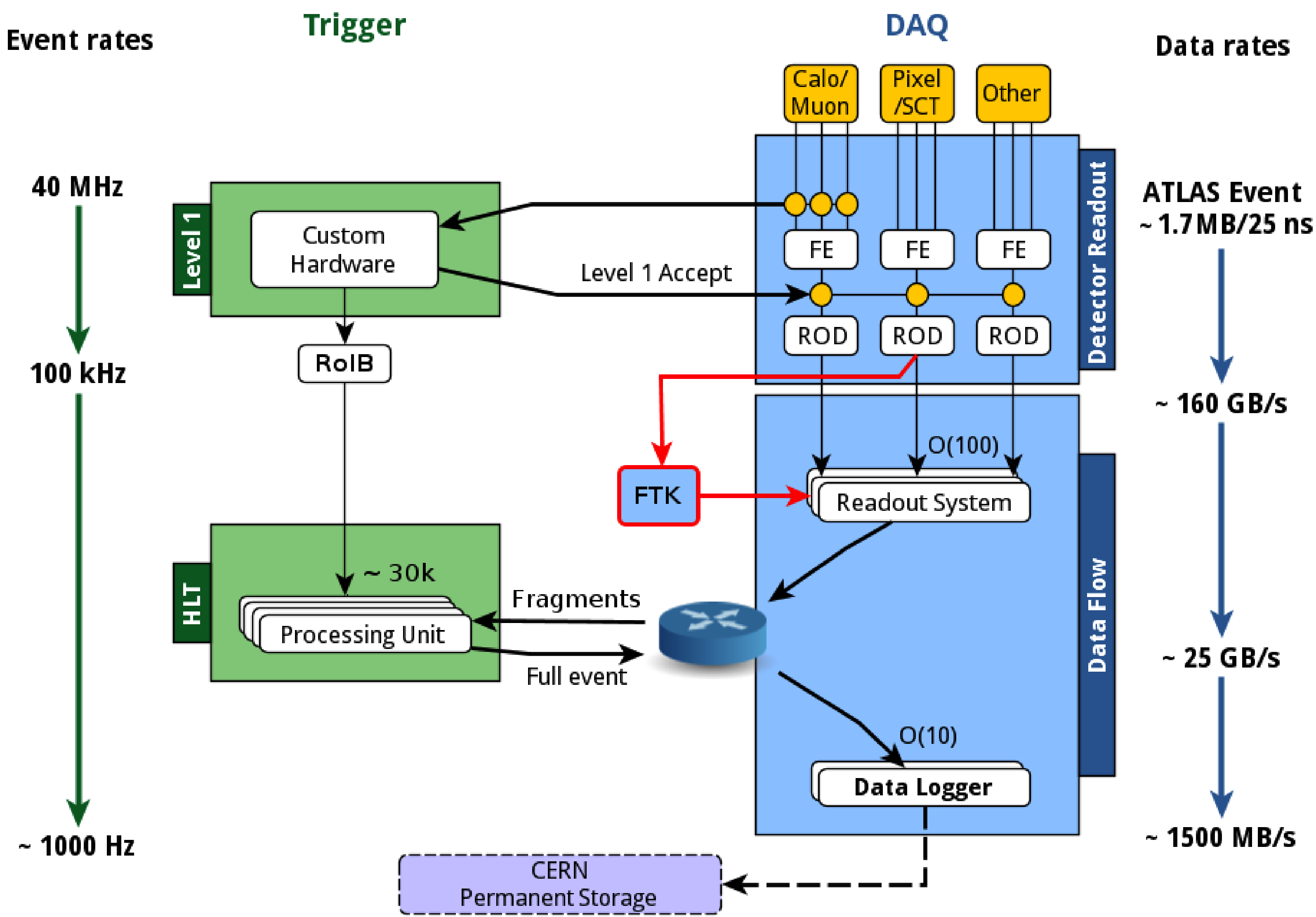
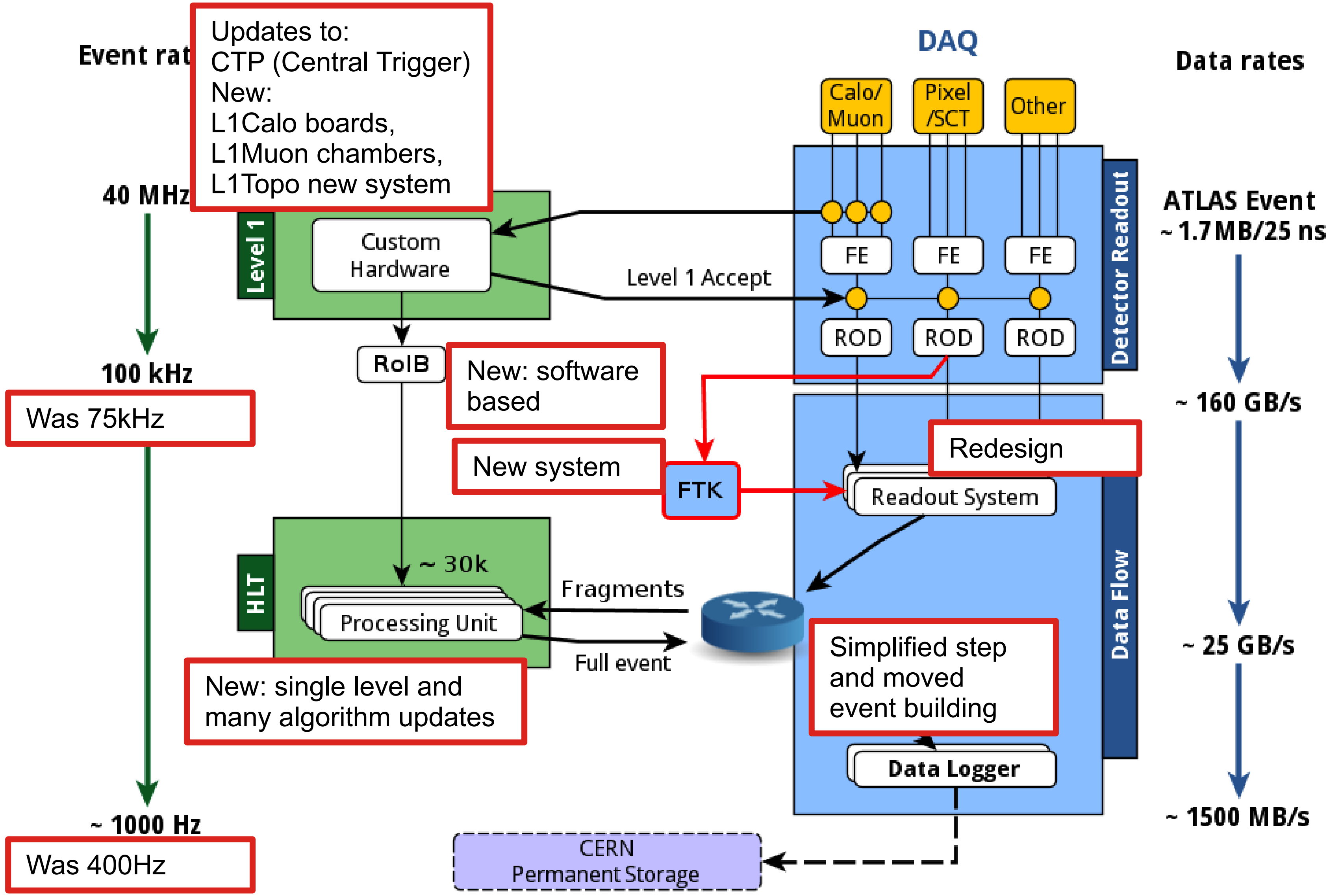


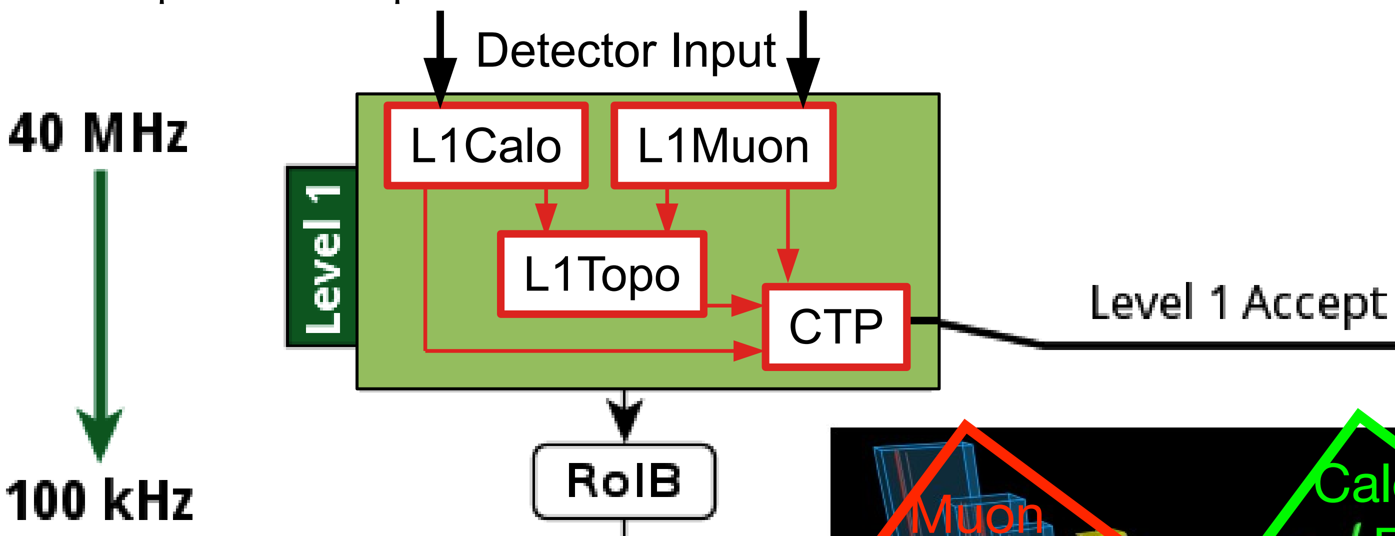
The ATLAS trigger system

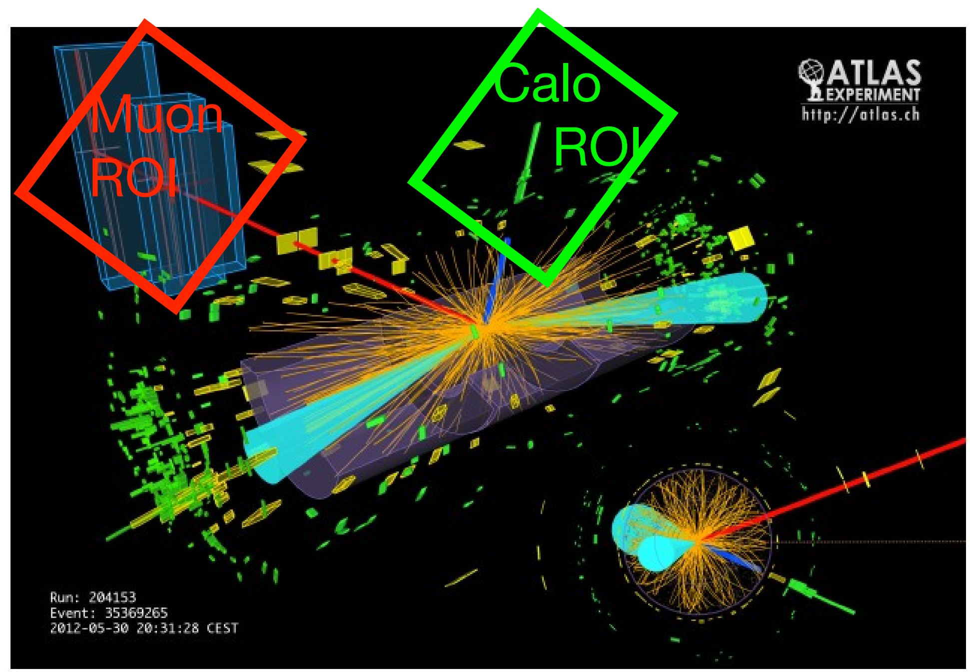
- New for Run2



Level 1 system

- Fast custom made electronics
  - Synchronous at 40 MHz with a fixed latency of 2.5 μs
  - Output rate up to 100kHz





- L1Calo
  - Uses both the LAr (EM) and Tile (Hadronic) calorimeters
  - Triggers on electrons/photons, jets, missing/total energy
- L1Muon
  - Uses the TGC and RPC fast muon trigger detectors
- Both find regions of interest (ROI)

Level 1 system

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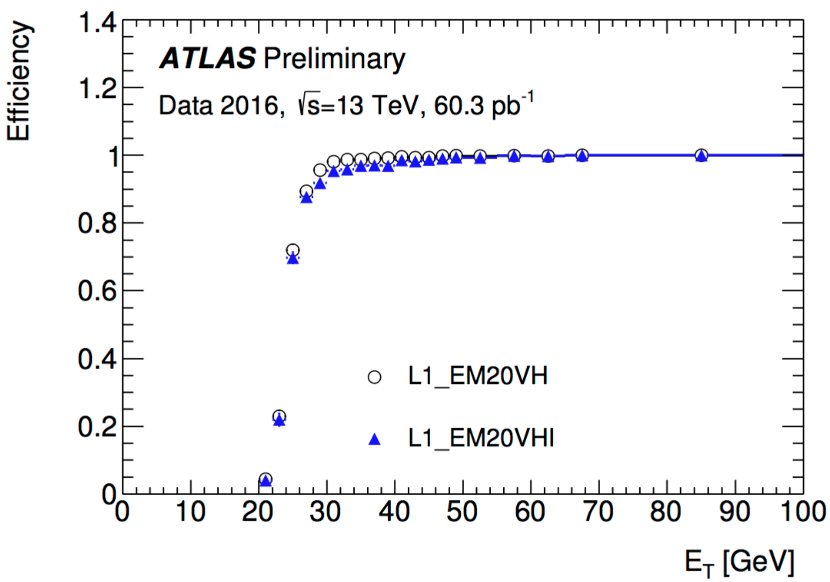
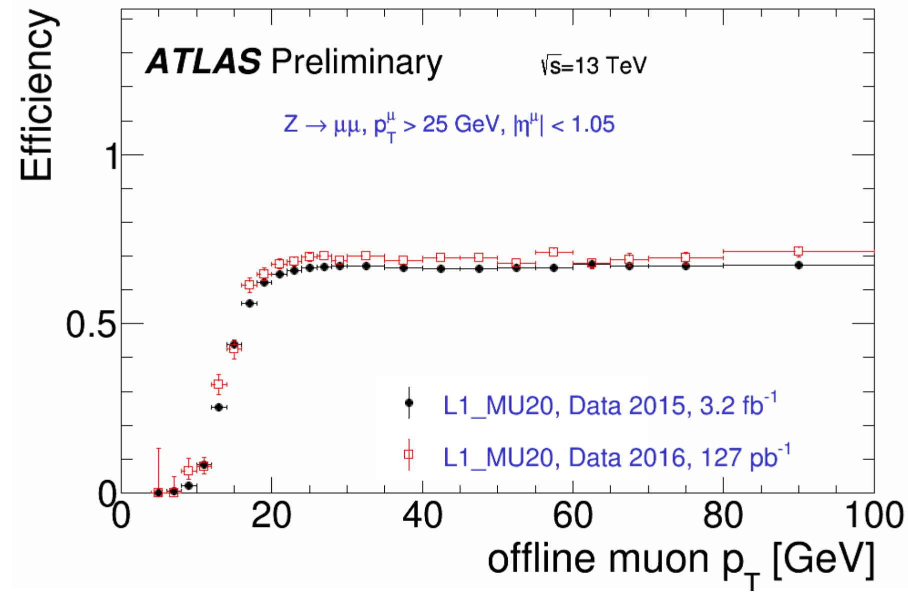




- L1Calo Run2 improvements:
  - Relative isolation and hadronic energy cuts
  - Improved granularity in eta dependence of Et thresholds
  - New hardware to improve the pileup suppression

- L1Muon Run2 improvements:
  - Additional feet chambers in barrel region and commissioning using Tile extended barrel region
  - Coincidence logic to reduce rate from low p_T particles (protons)

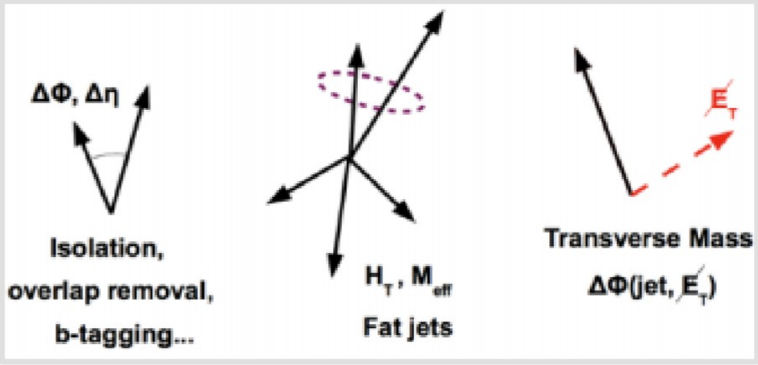
Level 1 system

- Fast custom made electronics
  - Synchronous at 40 MHz with a fixed latency of 2.5 μs
  - Output rate up to 100kHz

- L1Calo
- L1Muon

- L1Topo
  - Being deployed in Run2
    → Used to keep L1 thresholds low
  - Decisions on FPGA within L1 latency
  - Use a variety of topological event selections between L1 objects

  - For more info see talk by Marek Palka
    - The ATLAS Level-1 Topological Trigger Performance



Angular Requirements

$\Delta\eta, \Delta\varphi, \Delta R^2, \Delta\eta + \Delta\varphi$

Mass Requirements

$M^2 = 2E_T^1 E_T^2(\cosh\Delta\eta - \cos\Delta\varphi)$

$M_T^2 = 2E_T^1 E_T^{miss}(1 - \cos\Delta\varphi)$

$M_{CT}^2 = 2E_T^1 E_T^{miss}(1 + \cos\Delta\varphi)$

Event Requirements

$H_T = \sum p_T(jets)$

$H_{CT} = \sum p_T(central\ jets)$

$M_{eff} = H_T + MET$

L1Topo MET

Dedicated Algorithms

Calorimeter Ratio

Delayed Particles

- Also have L1 detectors for specific purposes:
  - Min-bias triggers
  - Beam conditions and luminosity
  - Forward detectors along the beam pipe

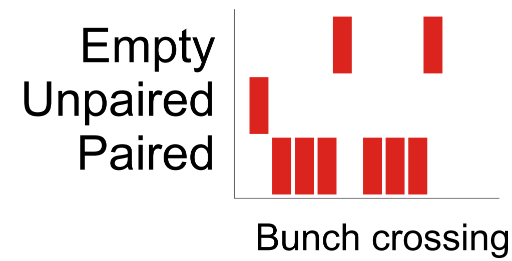
Level 1 system

- Fast custom made electronics
  - Synchronous at 40 MHz with a fixed latency of 2.5 μs
  - Output rate up to 100kHz

- L1Calo
- L1Muon

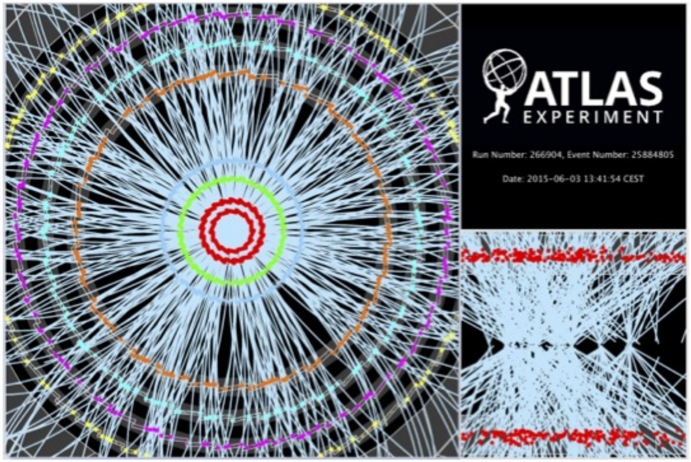
- L1Topo
- Other specific L1 detectors

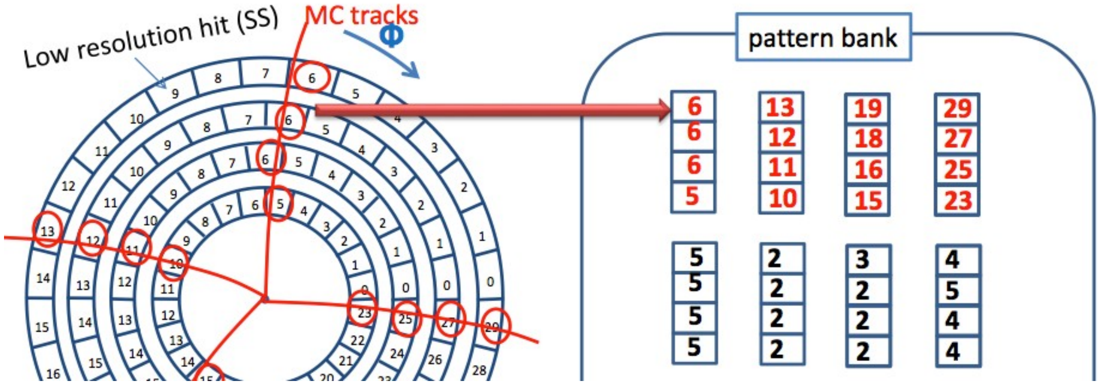
- CTP (Central Trigger Processor)
  - Applies prescales
    - Take 1 event for every X events
  - Applies bunchgroups
    - Used to categorise collisions on LHC filling scheme
  - Applies deadtime veto
    - Used to protect the detector readout
      - Simple - to protect from overlapping events in front end buffers
      - Complex - to protect from bursts of triggers
  - New for Run2: the single CTP can be used by 3 "partitions" at once
    - Will be used to simplify scheduling testing and calibration runs with the CTP



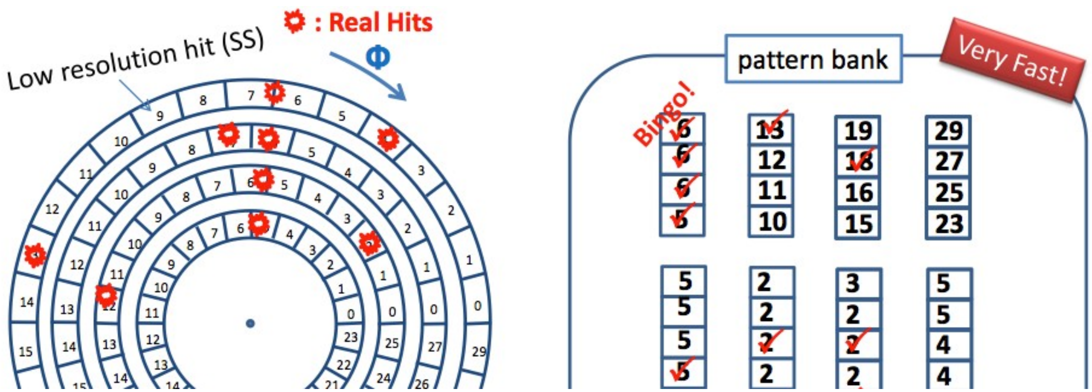
See poster by Ioannis Maznas: The Associative Memory System Infrastructure of the ATLAS Fast Tracker

- Hardware in commissioning during 2016
- Reconstruct all tracks at 100kHz by using pattern matching
- Input from tracking detectors (IBL, Pixels and SCT)





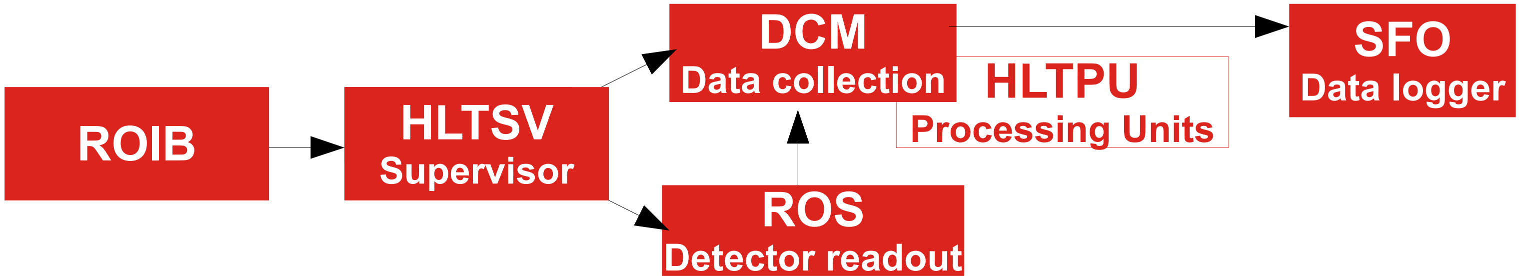
- Create a pattern bank from MC



- Then in data match hits to the patterns

- The matched pattern then has track parameters
- All this information is then passed on to the HLT for faster processing

HLT (High Level Trigger)



- ROIB - passing the L1 ROI's to the HLT
  - Upgraded to single PCI-Express (RobinNP) card meet the 100kHz

- The two levels of the HLT were merged in Run2:
  - Reduces complexity and duplicated data fetching
- HLTSV passes the L1 result and ROIs to the DCM
- DCM collects data fragments and passes to HLTPUs
- HLTPUs: execute HLT algorithms;
  - Tasks are forked to maximise memory sharing

- Algorithms mainly reconstruct in ROI, but can also do unseeded reconstruction for specific detectors
- The HLT algorithms are now closer to offline → reduces rates at an early stage
  - Example improvement in algorithms: Tracking pattern recognition and data preparation run only once (fast tracking) and later refined tracking (precision tracking)

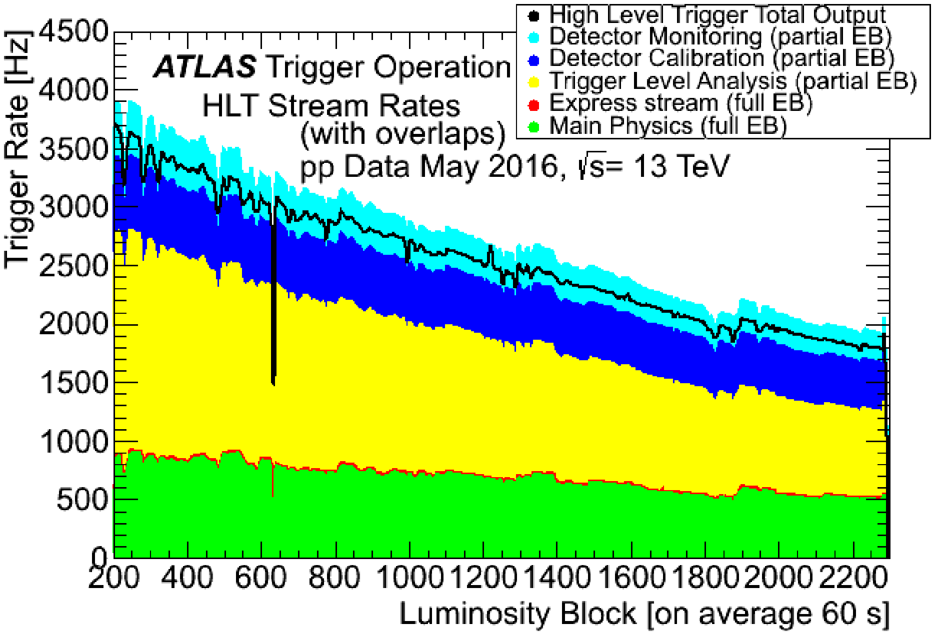
- Accepted events then sent by SFO to storage

Data streaming

- Stream: collection of events or event fragments within a dataset
  - Type decided by trigger result from the HLT
  - RAW data streams are generated at the SFO (data logger)

- All streams are inclusive in Run2, except for the debug stream

- Physics
  - Single stream (Main) used for most data analysis
  - Other small physics streams: for standby/cosmics/special runs…
- Express
  - Events for prompt reconstruction (part of calibration loop)
  - Subset (~2%) of physics_Main
- Calibration/Monitoring
  - Use partial event building (PEB)
  - Small event size allows high rate
- Datascouting
  - Events stored only at HLT level, i.e. store calo jets reconstructed by the HLT only
  - For Trigger Level Analysis (TLA) → greatly increases statistics
- Debug -
  - Focus of the next slides



HLT Errors

- The HLT is a complex system with improvements being added frequently
  - Also runs during ever changing detector and accelerator conditions
- With software validation we aim to not see errors online
  - But if we do miss something…

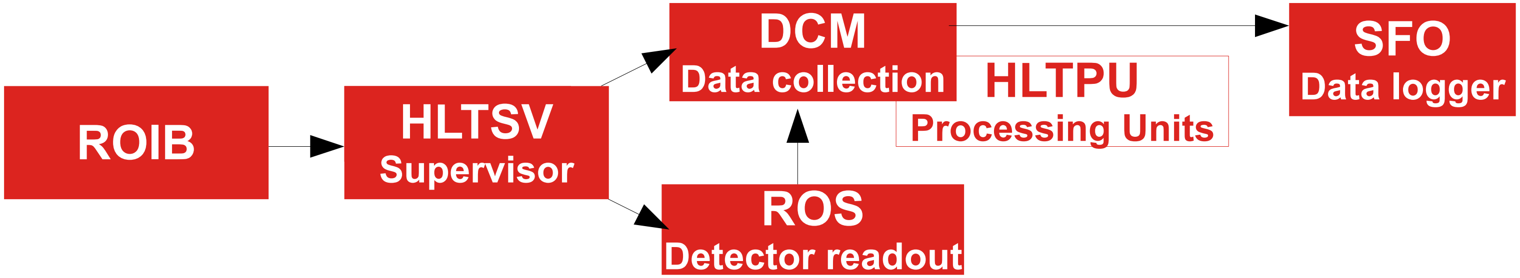
    → important to keep the problem events for debugging
    - Typically the debug stream is <0.01% of data taking

    → testing is then vital to make sure the issue is resolved

- The following slides will go through
  - How the debug stream is filled
  - How errors are reported online
  - How the follow up is carried out
  - How the events are recovered for physics analyses
  - How the software is validated

Debug streams

- Events without full trigger decision, due to an online failure
- Several streams grouped by failure type:
  - DAQ issues
    - Problems retrieving or receiving invalid data from a detector
    - ROIB: incomplete data fragment or inconsistent L1 identifier's in the ROIs
    - Late events which didn't arrive at SFO before closing a lumi-block of events
      - Lumi-block: 1 min time intervals of data taking
    - HLTPU crash - where the application/node has severe problems



Debug streams

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- Events without full trigger decision, due to an online failure
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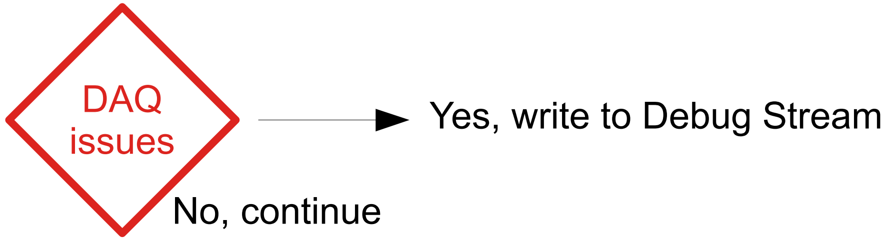
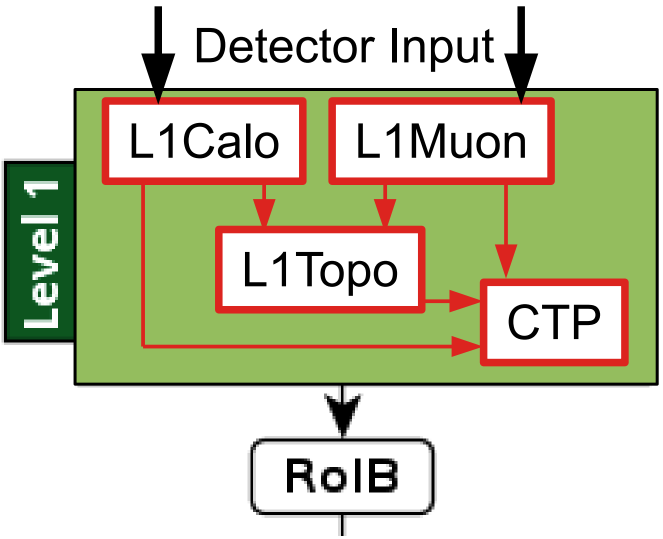


- HLT finds missing data/could not process the event
  - Level1 result fragment is empty
  - Inconsistencies in the CTP fragments
  - Problems recording the eventInfo data
  - Problems recording the HLT result (or checking it post writing)



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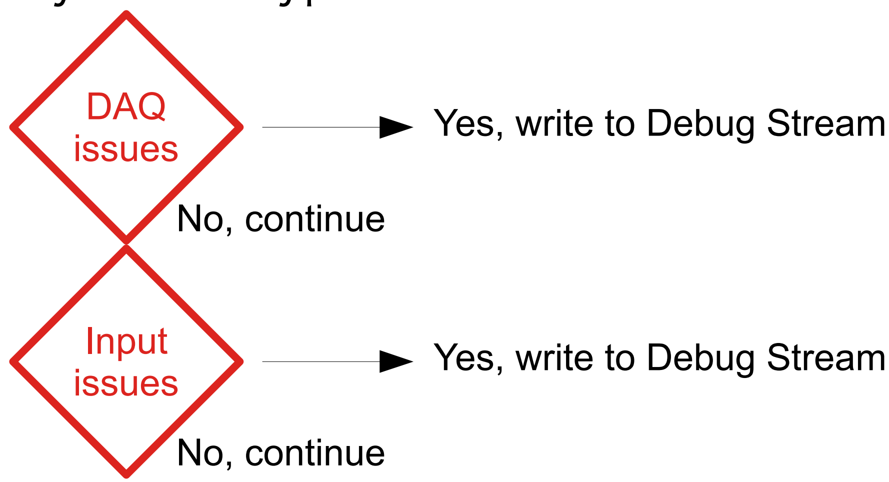

- HLT Error
  - A severe error which can cause an algorithm to abort the event processing
  - Will have a HLT result to identify the problem the particular algorithm had

HLT Error

- As an algorithm runs it passes error codes to the framework (steering) composed of three parts
- Desired action:
  - Continue - processing of algorithm went correctly; move to next
  - Abort Chain - algorithm needs to be exited from as it hit a problem
    - E.g. can't read an ROI
  - Abort Event - problem could affect subsequent algorithms
    - E.g. missing data
  - Abort Job - when problems suggest the algorithm is misconfigured
    - E.g. tool doesn't initialise
- Explanation:
  - Missing detector data
  - Corrupted detector data i.e. it can't be decoded
  - Missing feature - an object needed by the current algorithm is missing from a preceding algorithm
  - Timeout - processing time goes over the limit
  - Bad job setup - i.e. algorithm miss-configuration
  - Additional explanations are available for each algorithm
- Overall input from the framework:
  - To cover issues from the framework or general issues not particular to a single algorithm

Debug streams

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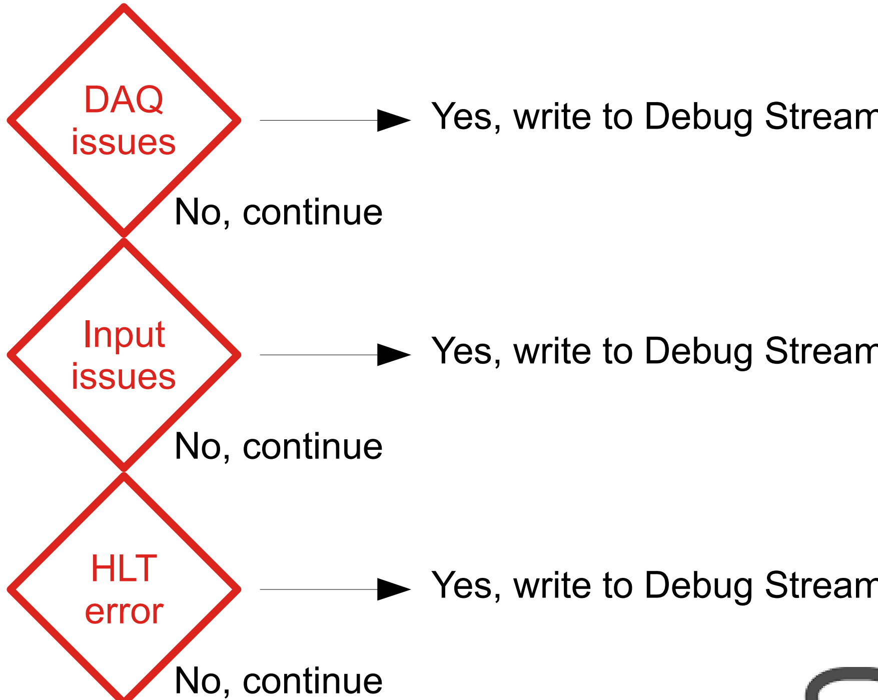
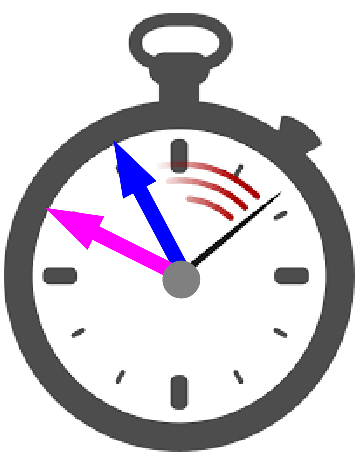
- Events without full trigger decision, due to an online failure
- Several streams grouped by failure type:



- Timeouts
  - Configurable limits are set on how long an event can be processed for
  - Soft timeout
    - Skip subsequent algorithms
    - Partial HLT result kept
  - Hard timeout
    - Skipping takes too long force timeout



Debug streams

- Events without full trigger decision, due to an online failure
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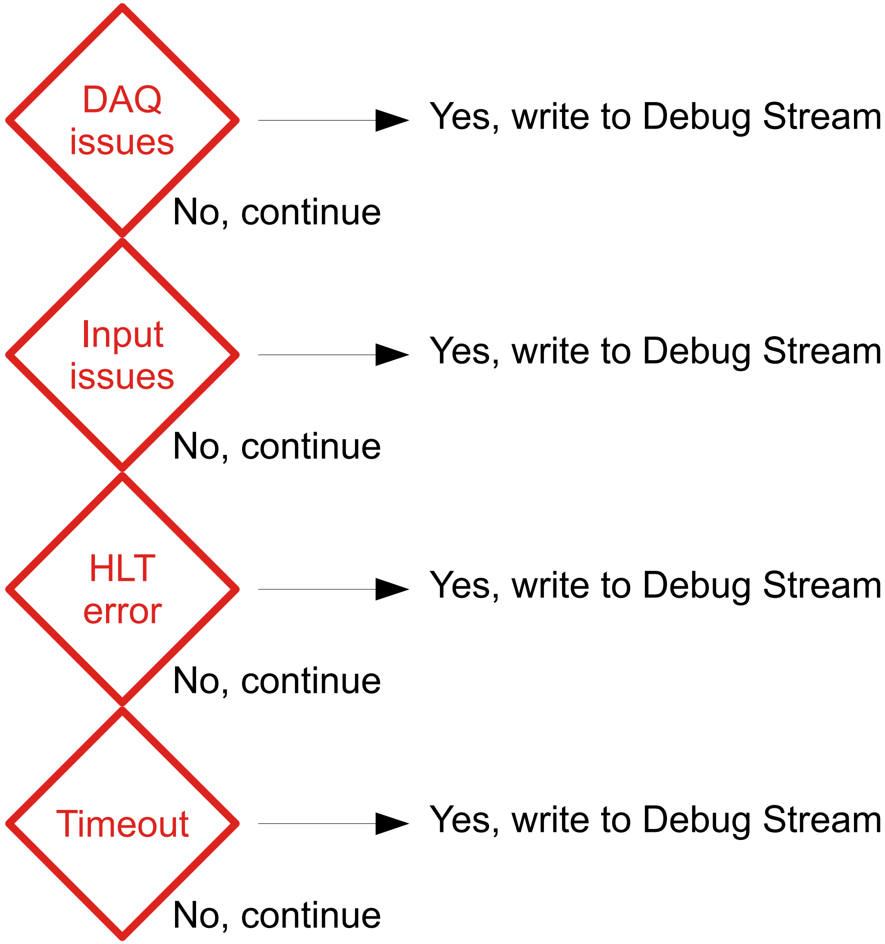
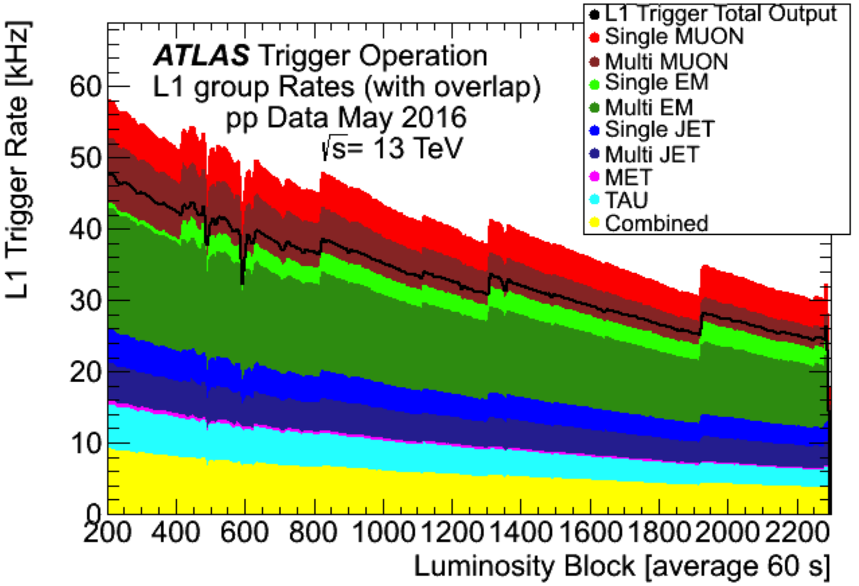


- HLTSV force accept
  - Catch all for any problems not covered by the above criteria
  - Event is re-assigned (by HLTSV) but the HLT algorithms are not run
    - Instead event automatically sent to debug stream

Live monitoring

- HLT errors monitored by 24/7 control room shift crew
  - Debugging process begins whilst we continue to take data
- Errors are communicated via the message transfer service (MTS)
  - Subscriber applications can then filter to the messages of interest

- Monitoring histograms
  - These store the error codes both per algorithm and for the framework
  - Tools are used to draw shifters attention by flagging potential problems
- Trigger rates
  - Rates of all items/streams are monitored live
  - Make sure that the rate to the debug stream is small
    - Again extra tools in place to draw shifter's attention to large deviations

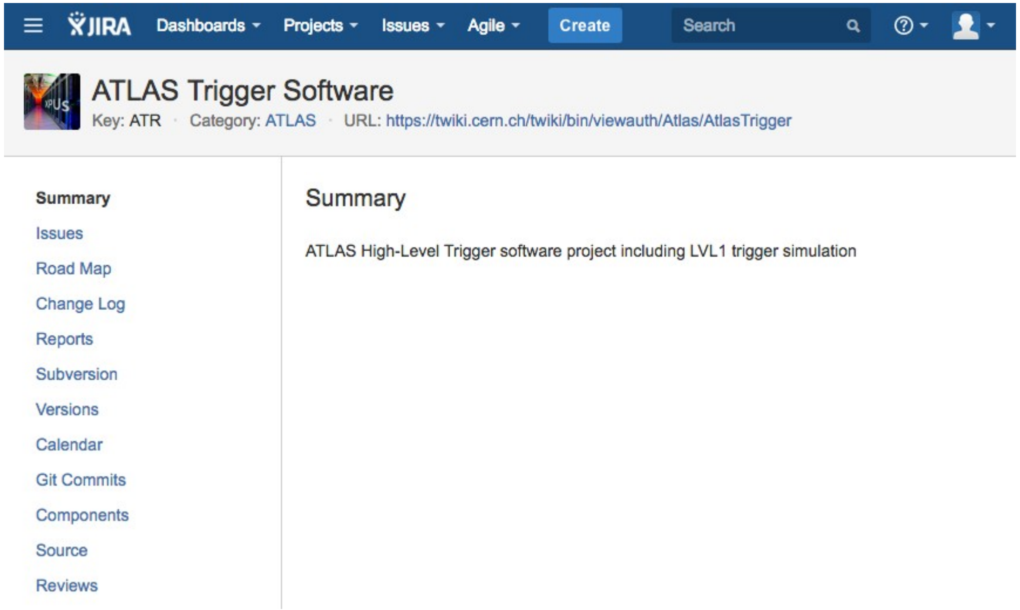


Follow up

- Many ways to analyse any problems offline
  - Shifters use an electronic logbook to record their observations
  - Daily emails produce a summary of:
    - Relevant HLT error messages from previous day
    - Amount of events written to debug streams
  - All the monitoring histograms and log messages/files can be viewed afterwards by applications or web-viewers

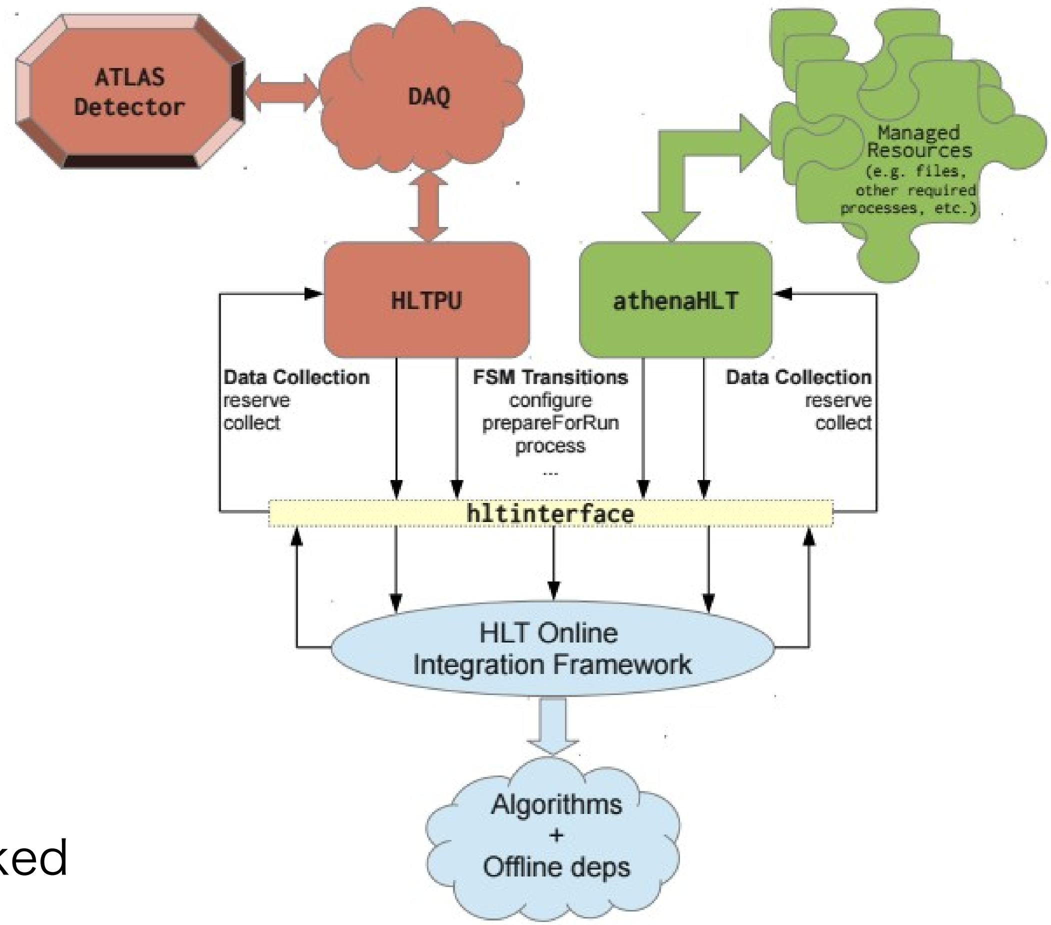
- Operational notes of known issues/procedures for the shift crew to be aware of are stored on Twiki

- Follow up with experts is then handled on JIRA
  - This issue-tracking software states per entry:
    - Type
      - e.g. bug, task, improvement
    - Severity
    - Components
      - e.g. relevant algorithm
    - Software release
      - Track both what software was affected and when it is resolved
    - Comments for discussion



Recovery

- Debug stream events can be recovered
  - Launched automatically
- Uses athenaHLT - emulator of the online system
  - Replicates DAQ communication and HLT processing
- Performed with the identical configuration as online but relaxed timeout limits
  - e.g. prescales reproduced due to reseeding pseudo random numbers generators
- >90% successful
  - Especially in cases not linked to detector problems
  - If we fail to do so the relevant lumi-blocks are excluded from analyses
- Recovered events are written to specific recovery streams
  - Then ready for use in physics analysis



Prevention/Testing

- Testing and validation is vital, both when following up issues seen online and also while developing new features

Nightly test

- Latest trigger software tested with series of tests
- Use athenaHLT to run common actions
- Run over data taken online
  - Example: have tests to swap the algorithm execution order → checks process of running over an event is fully reproducible

Reprocessing

- Build a candidate trigger release
- Run over recent data
- From RAW data → Rerun HLT → Full reconstruction
  - Includes "cost" monitoring to check resource usage
- Make sure no errors and that the results obtained are correct
  - Reprocessing signed off by physics signature experts
  - The combination removes mistakes almost fully

Hardware

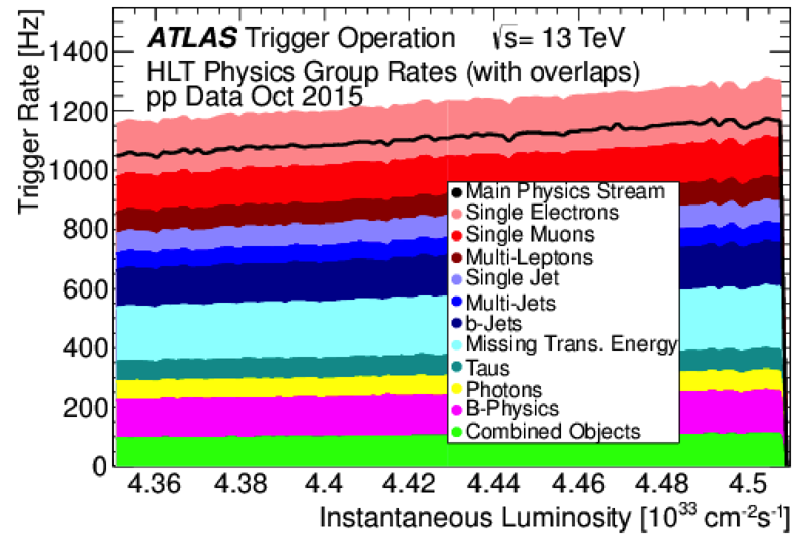
- Used to validate the new software or investigate problems
- Testbed
  - Partial replica of the HLT farm away from Point1
- Validation machines
  - At Point1 but not used for data taking
- HLT farm itself
  - Take/re-play data through the system

Summary

- ATLAS is successfully taking 13TeV data in 2016
  - Trigger operations are running well
  - Many upgrades operational (or in commissioning) to continue improving the performance despite the more challenging conditions in Run2
- Well established procedures for algorithm error reporting
  - Debug streams used to allow further analysis of the flagged events
  - Many monitoring and follow up procedures in place to limit problems
  - Automatic recovery successfully recovers most events
  - Preventative steps in place to validate the software well in advance of it being installed online
- Thank you for your attention

Backup

- Physics signature:
  - Defined as a group of closely related trigger chains:
    - Muons/B-physics
    - Electrons/photons
    - Jets/bJets/Met/taus
    - Minimum Bias



- Chain: one full L1 → HLT selection
  - Starting with a L1 item as seed each chain is organised in steps (Trigger Elements)
  - At any step it can be rejected
  - Each step executes a sequence of algorithms, typically Feature Extraction (FEX) and hypothesis testing (Hypo)
- If passes through all steps → event accepted

- ROIB - passing the L1 ROI's to the HLT
  - The custom VME based ROIB was replaced with a single PCI-Express (RobinNP) card
  - Needed as the Run1 system could not operate at the 100kHz rate in Run2