The upgraded ATLAS Trigger and DAQ system for the second LHC run

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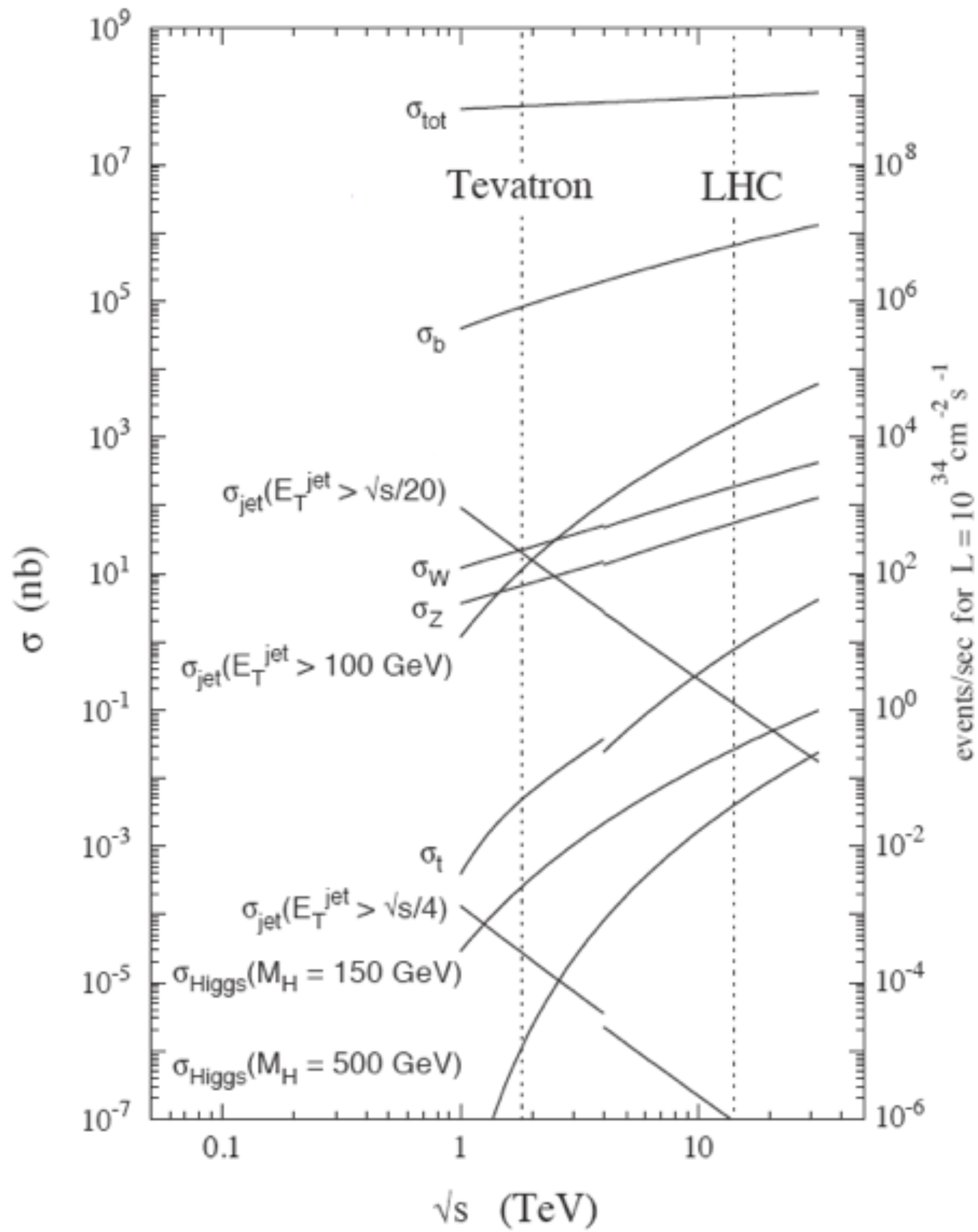
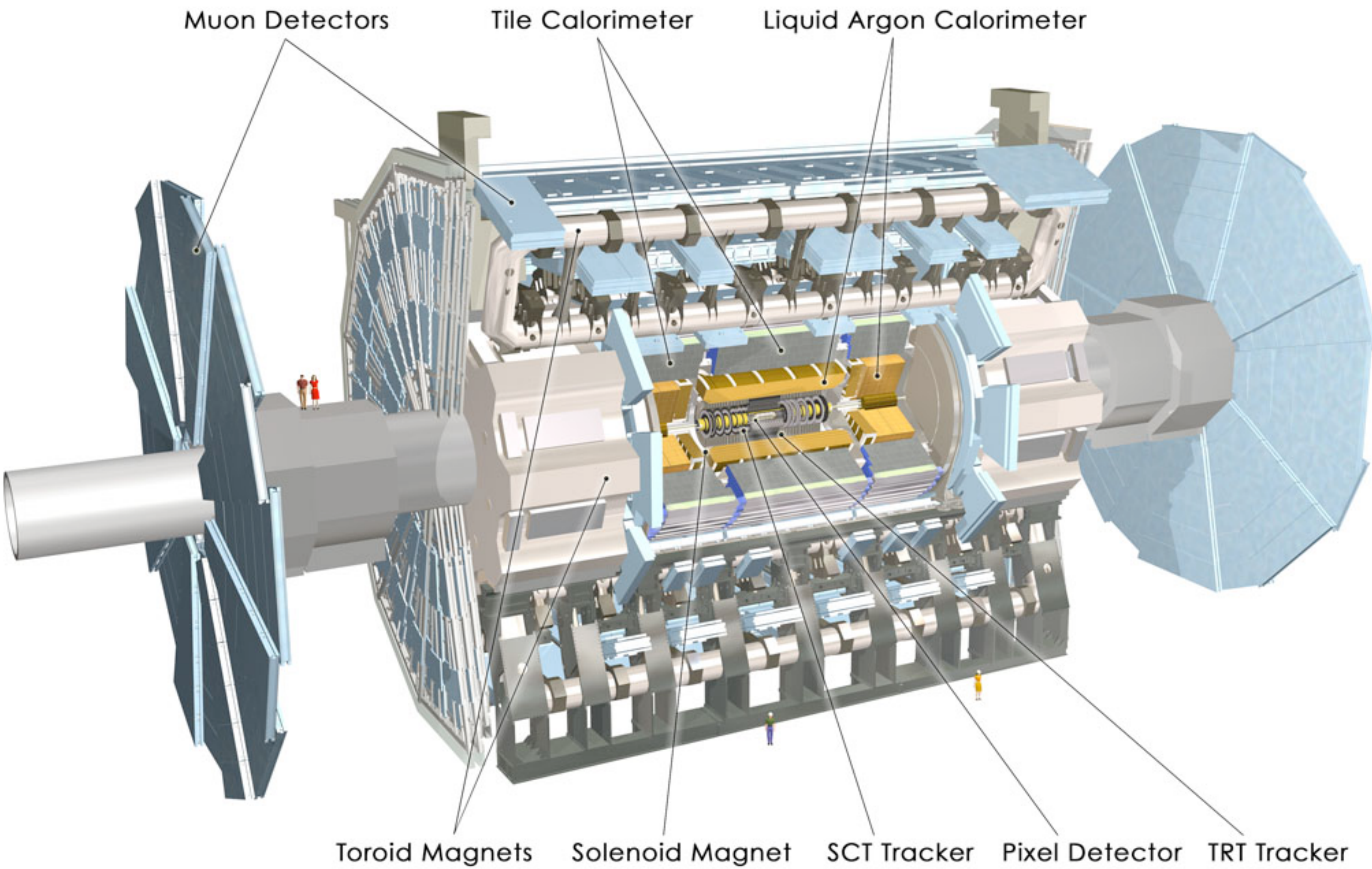
on behalf of the ATLAS collaboration

ATLAS Experiment

- ATLAS covers a huge breath of physics topics that consists of many different types of final state topologies
    - b-physics, W and Z, top quark, Higgs boson, SUSY and exotic searches
- Many orders of magnitude between total pp cross-section and physics of interest
- Must deal with additional pp interactions from the same bunch crossing (in time pile-up) and other bunch crossings (out of time pile-up)

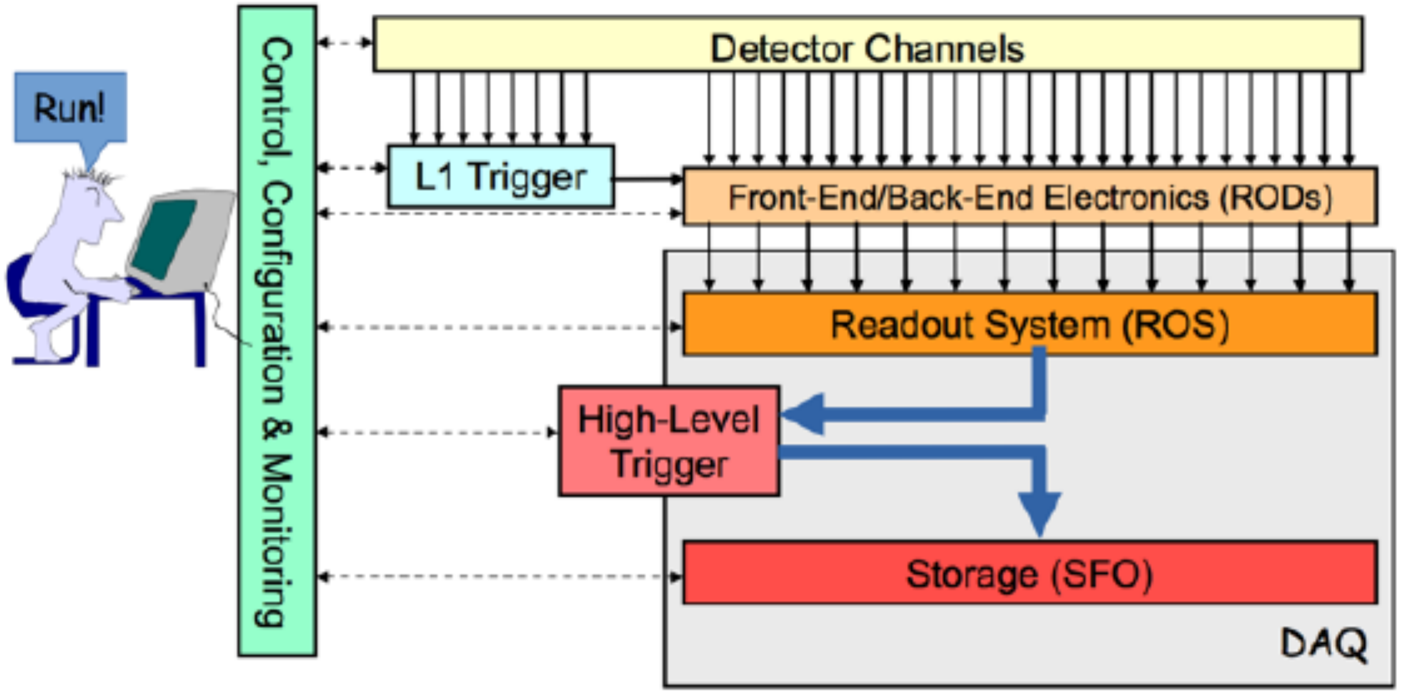


ATLAS Detector



Trigger and DAQ

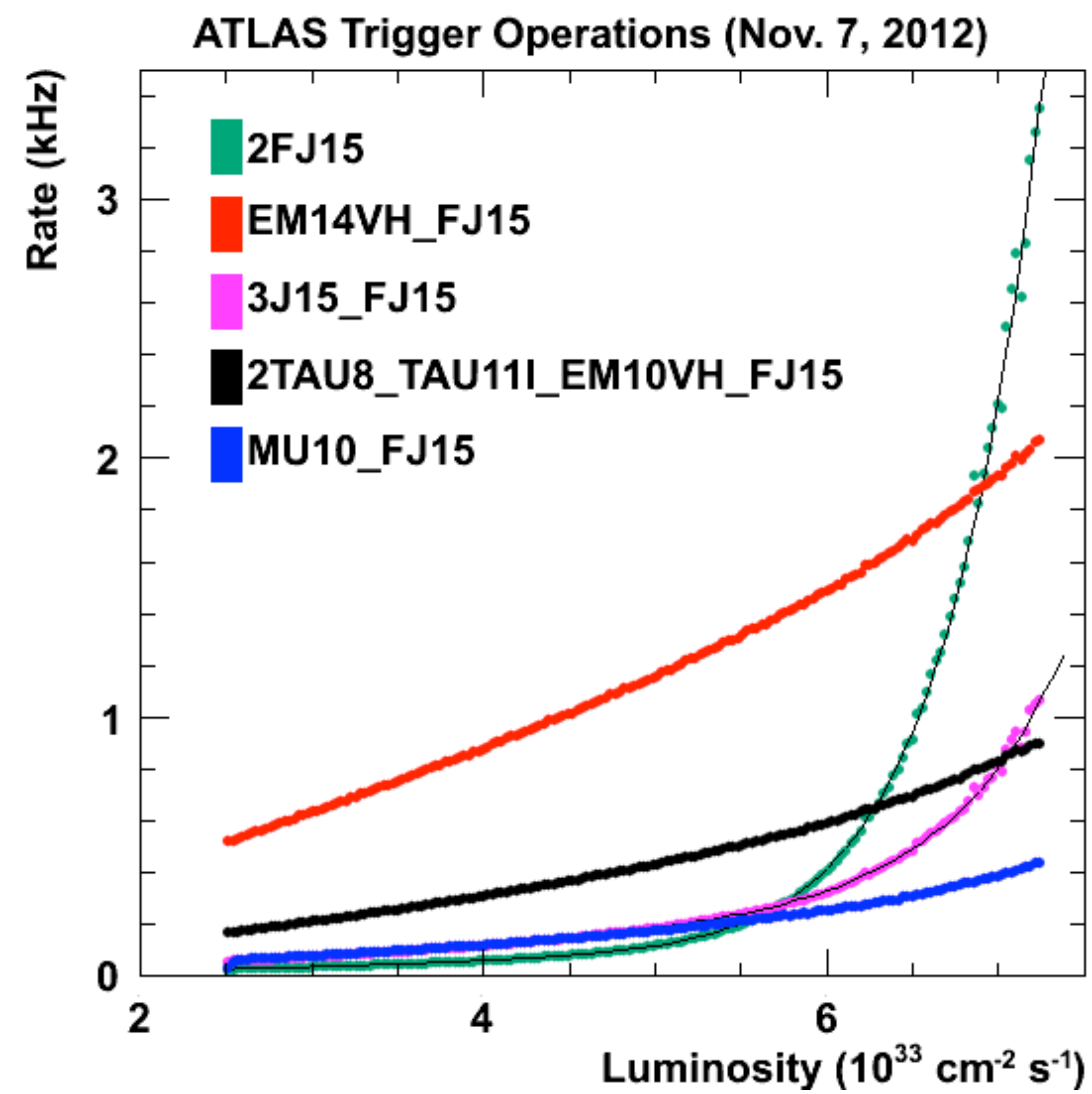
- Data Acquisition System (DAQ)
  - gather the data information from the front end electronics from the detector
  - puts the data from all the different detectors together and builds individual events
  - Stores the data to be sent to permanent storage
  - provides control, configuration and control
- Trigger
  - Multi-tiered system that decides which events to record



Environment Changes

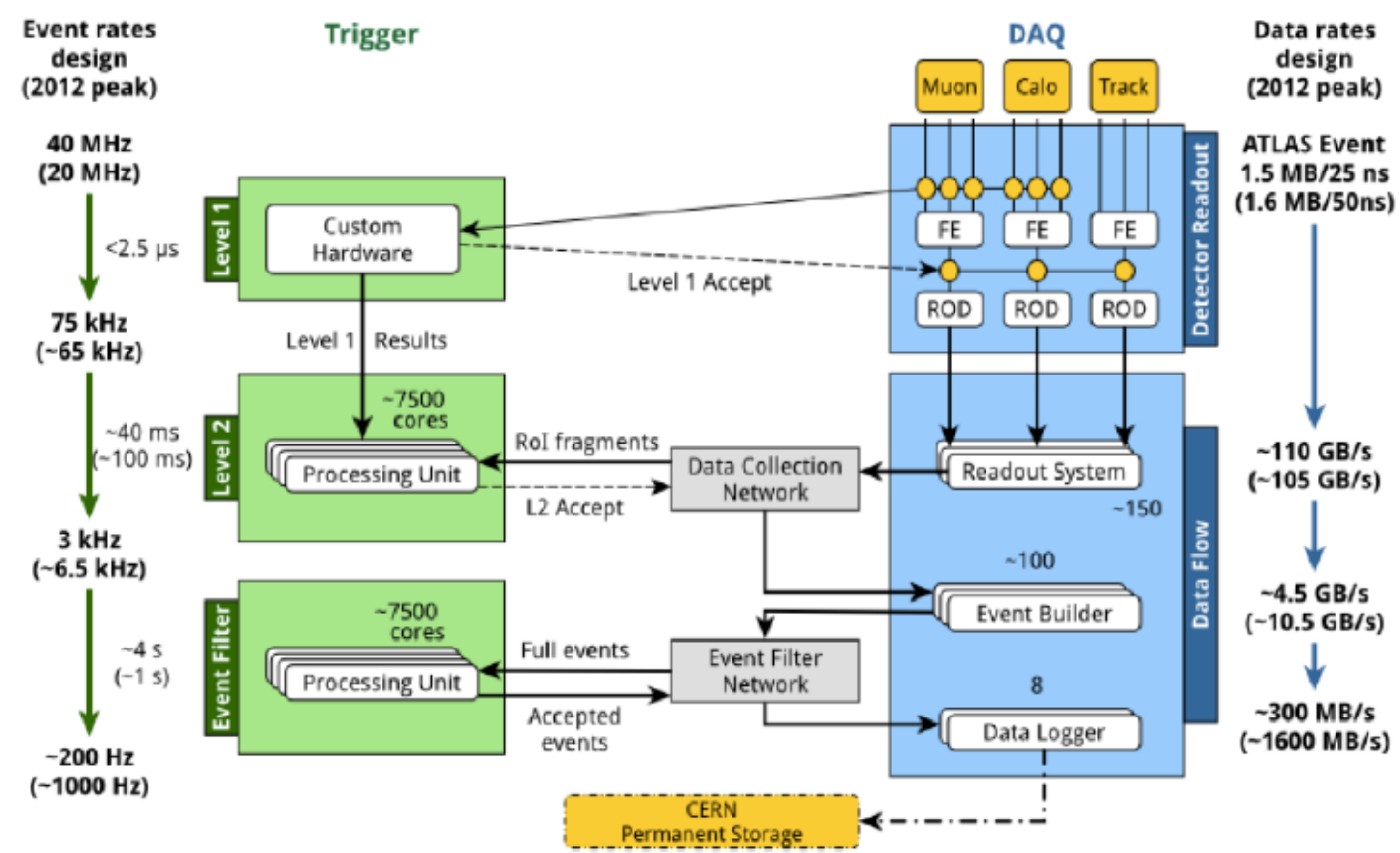
Period: year	Bunch-spacing	√s	Luminosity	Pileup μ_{peak}
Run-1: 2012	50 ns	8 TeV	~8e33	40
Run-2: 2015-2018	25 ns	13 TeV	**1.7e34**	50

- Rate increases by ~5
  - ~x 2 for increase in energy
  - ~x 2-3 for increase in luminosity
- Additional pp interactions from the same bunch crossing (in time pile-up) and other bunch crossings (out of time pile-up)



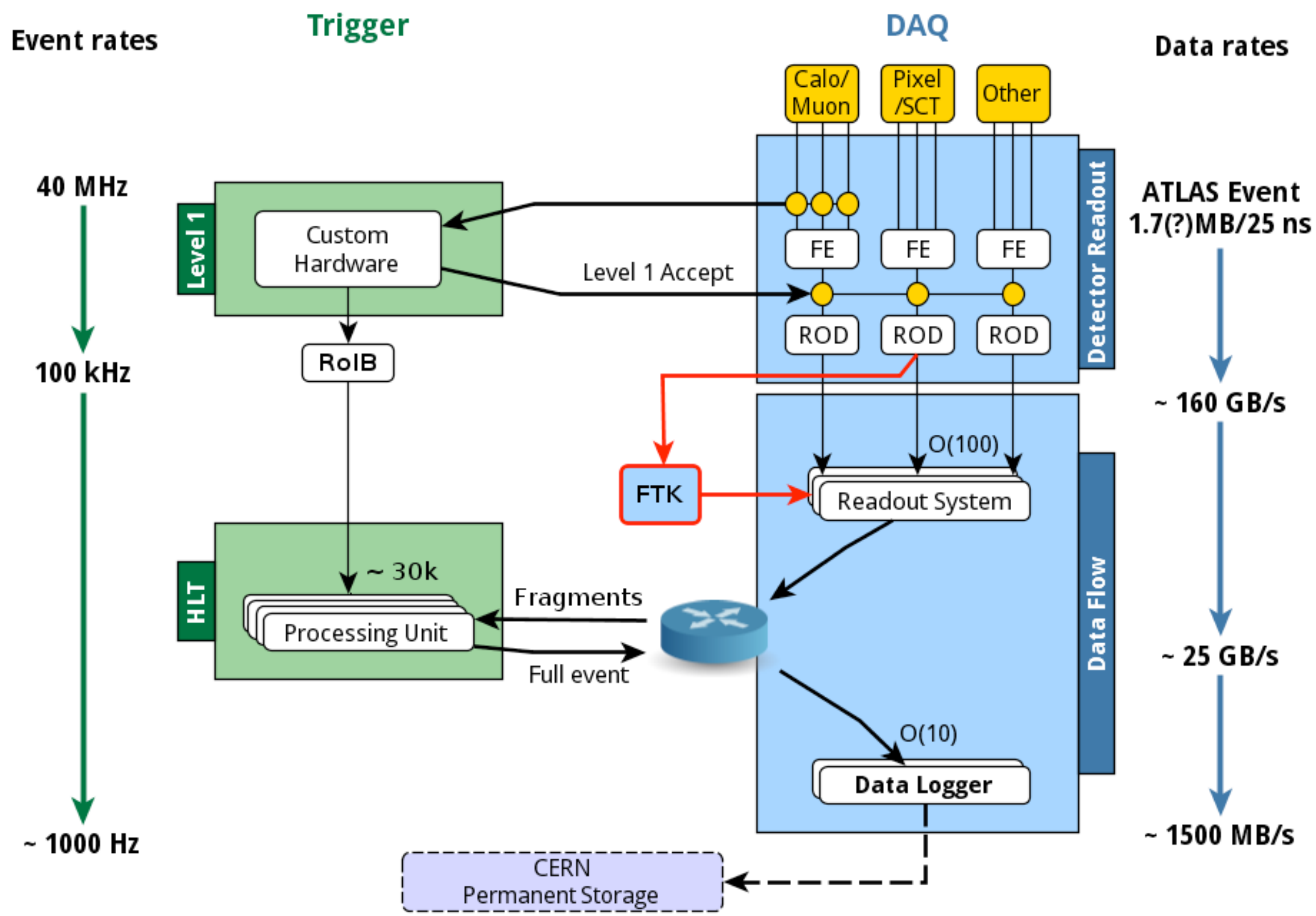
DAQ and Trigger Evolution

- Run 1 - Three level system
  - Level 1- Custom Hardware utilizing calorimeter and muon spectrometer data looking for ‘regions of interest’ (ROI) to base L1 decision and examine in more detail
  - Level 2- fast software processing data in ROI (projective tower in η and ϕ)
  - Event Filter (EF) - close to offline reconstruction driven by ROI but with possibility of examining the full event



DAQ and Trigger Evolution

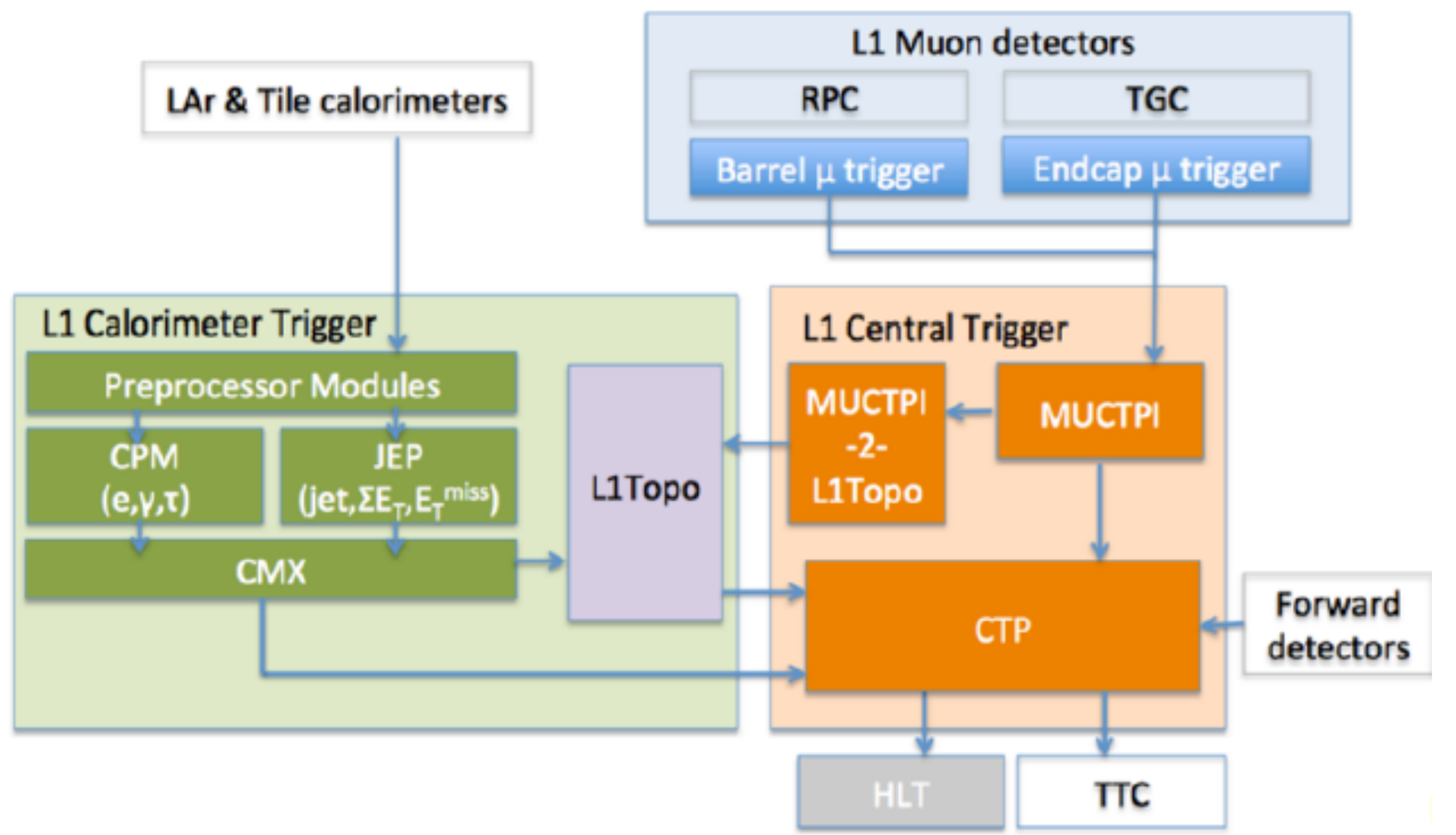
- Run 2- Two level system
  - Level 1- Similar to Run 1 but with many upgrades
  - Merged L2/EF in single CPU farm to take advantage of common tools and results from L2 in final stage



Stage	Functionalities	Components	Latency	Rate reduction
Level-1 (L1)	Fast custom-made electronics finds regions of interests using Calorimeter/ Muon data with coarse info	L1Calo, L1Muon, L1Topo, Central Trigger Processor	$< 2.5\ \mu s$	40 MHz → 100 kHz
High-Level Trigger (HLT)	Fast algorithms in RoI, or offline-like ones with full-event info on PC farm	(FTK,) HLT farm	~0.2 s (average)	→ 1 kHz (average)

Level 1 Trigger

- Level 1
  - Central Trigger processor issues L1 trigger decision based on inputs from L1 calorimeter trigger, L1 muon central trigger processor, forward detectors, and (run 2) the L1 topological trigger
  - MuCPTI sends muon candidates (6 P_T thresholds) from the endcap and barrel on detector trigger electronics
  - Calorimeter Trigger finds electron, photon, tau, jets, as well as sum E_T and missing E_T passing candidates to the central trigger processor

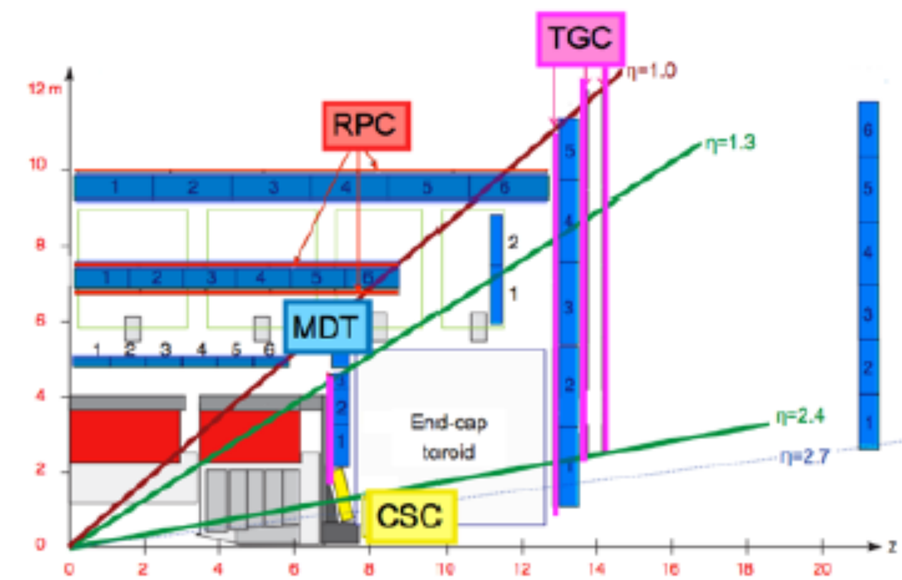


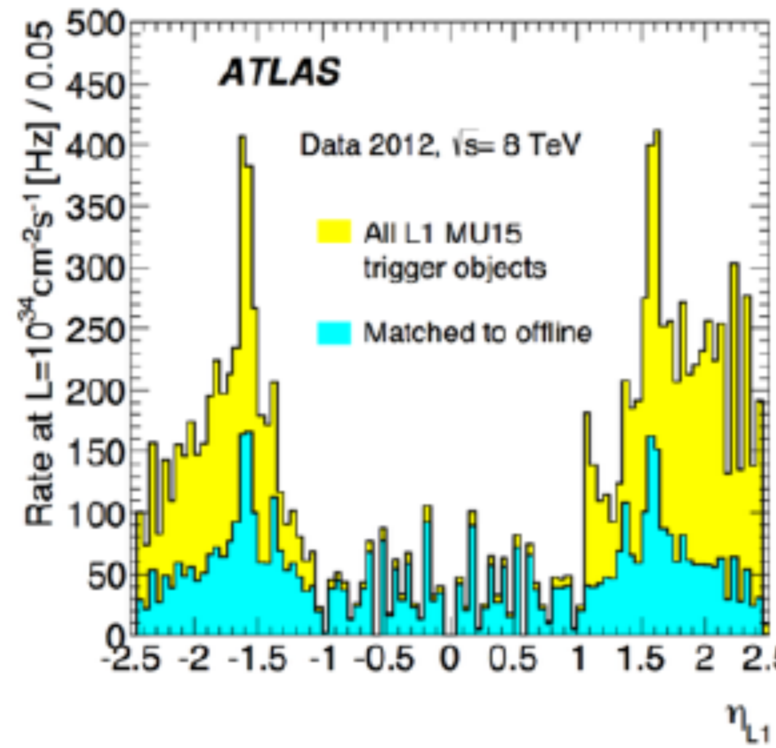
L1 Muon Improvements

- L1 trigger formulated by Resistive Plate Chambers (RPC) in barrel , and Thin Gap Chambers (TGC) in endcaps

- L1 rates were dominated by low P_T particles produced in the end-cap toroid or cryostat from particles not associated with hard scattering from proton-proton collision of interest

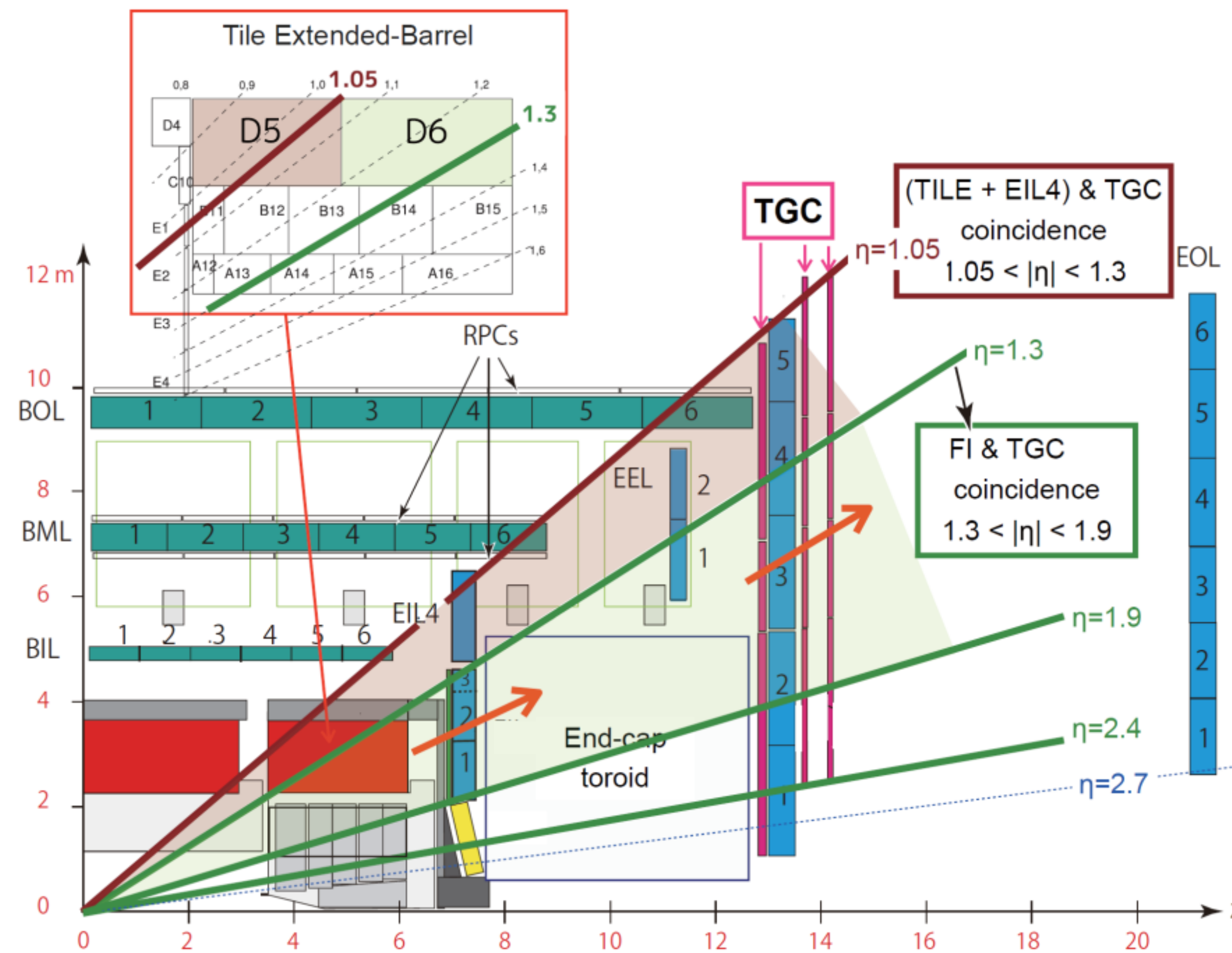
- Run 2 has several improvements to reduce the endcap rates





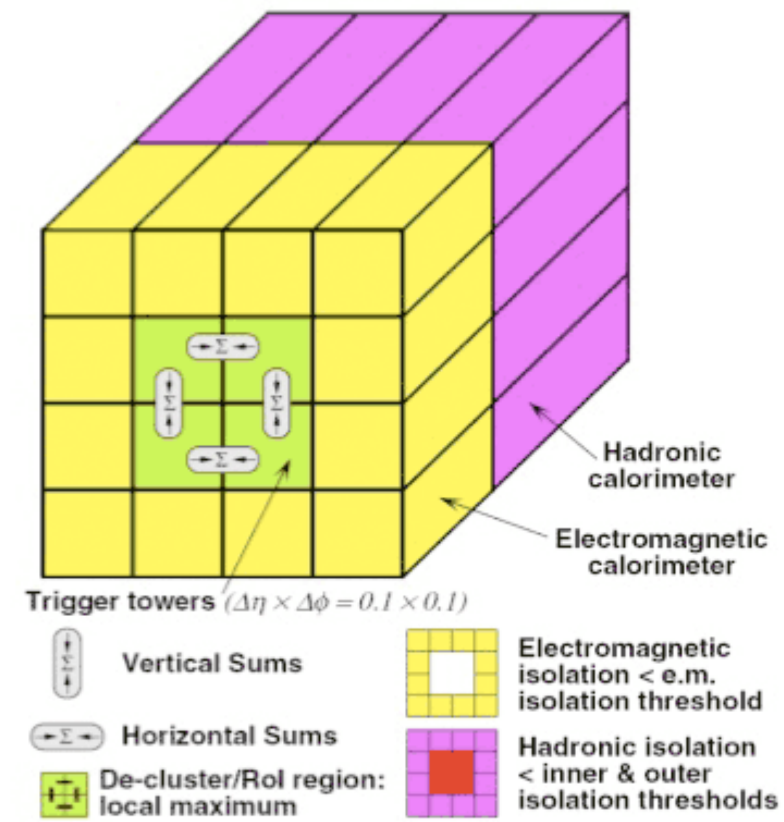
L1 Muon Improvements

- Options to reduce rates for Run 2
    - Reduce rate in endcaps by requiring coincidence with tile-calorimeter and additional coincidence with inner wheel TGC
    - exclude zero-field region (reduction of < 5% acceptance)
- Increased acceptance in barrel (~4%) by additional RPC chambers in feet region (being commissioned)

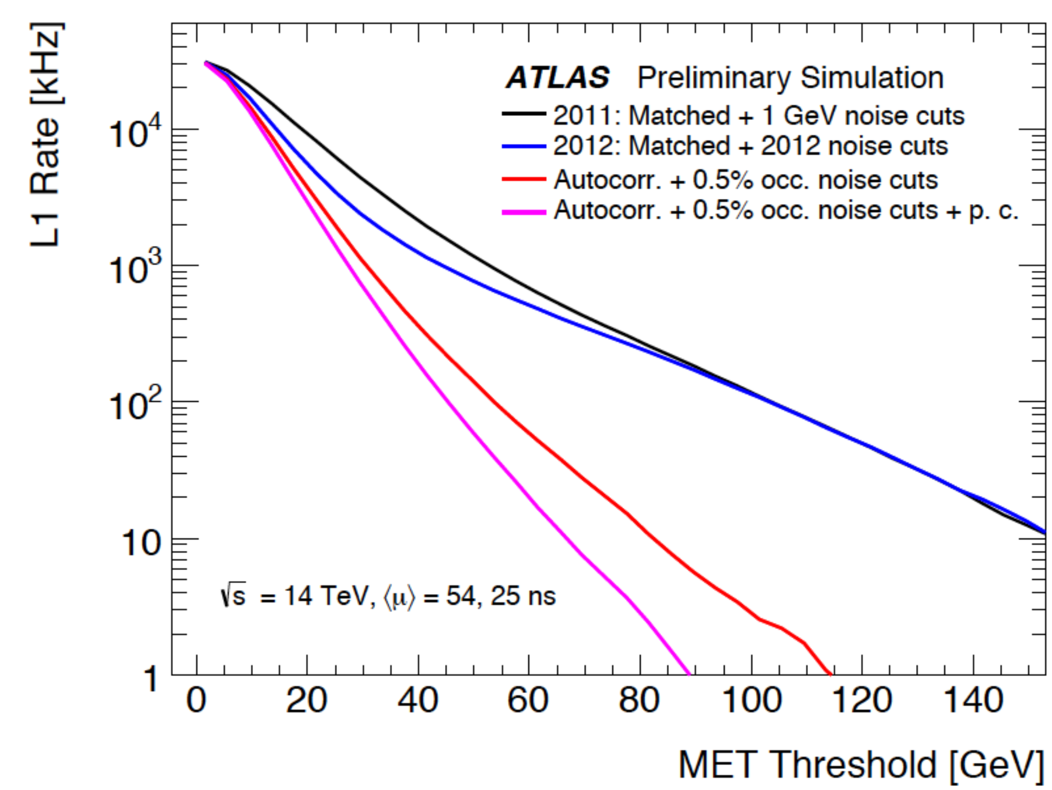


L1 Calorimeter

- 3 main components
  - Pre-processor that digitizes analogue inputs, identifies bunch crossing, and channel by channel calibration
  - Cluster processor - sliding window algorithm for electron, photon, and tau candidates
  - Jet processor - selection of jet candidates, calculation of energy sums, missing energy calculation

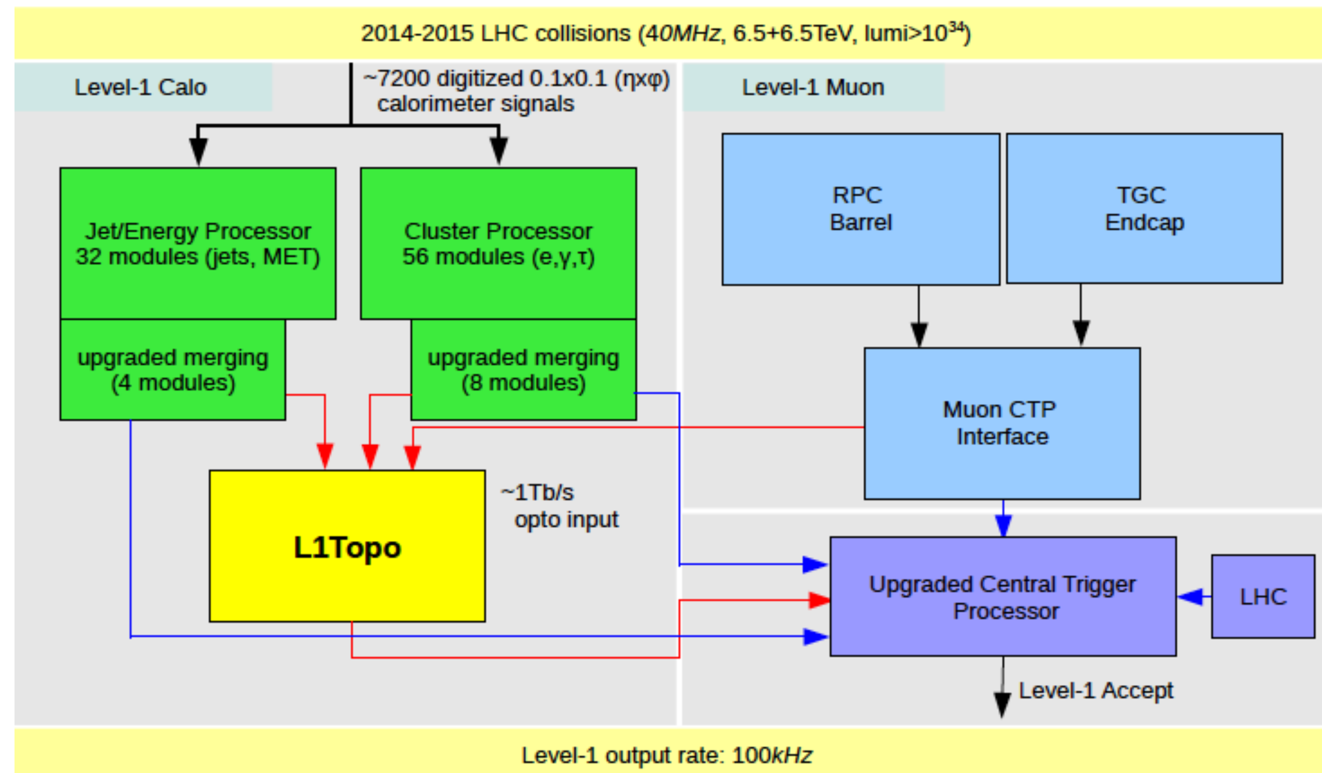


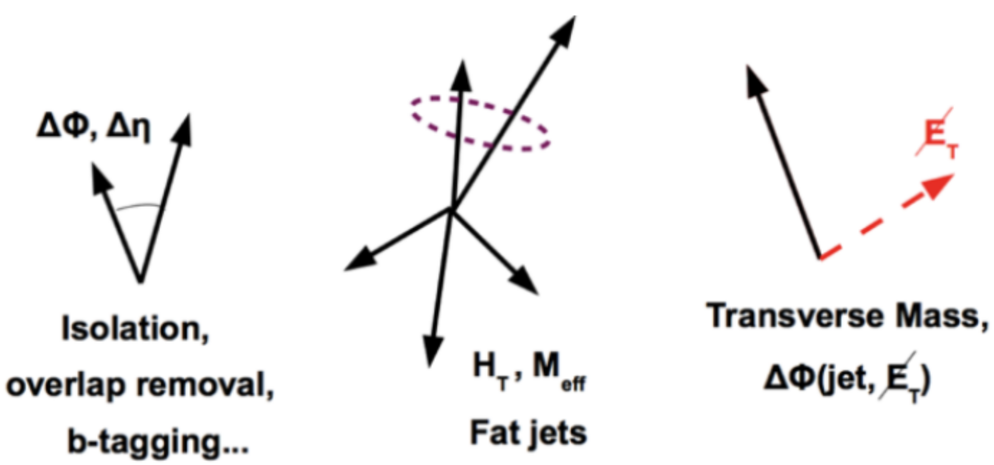
- new Multi Chip Module in preprocessor
  - dynamic pedestal subtraction for pileup (huge reduction in missing transverse energy trigger rates rates)
  - improved jet energy resolution



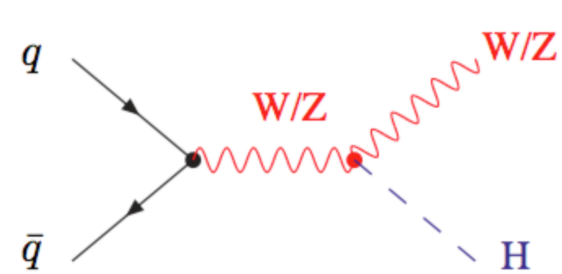
L1 Topological Trigger

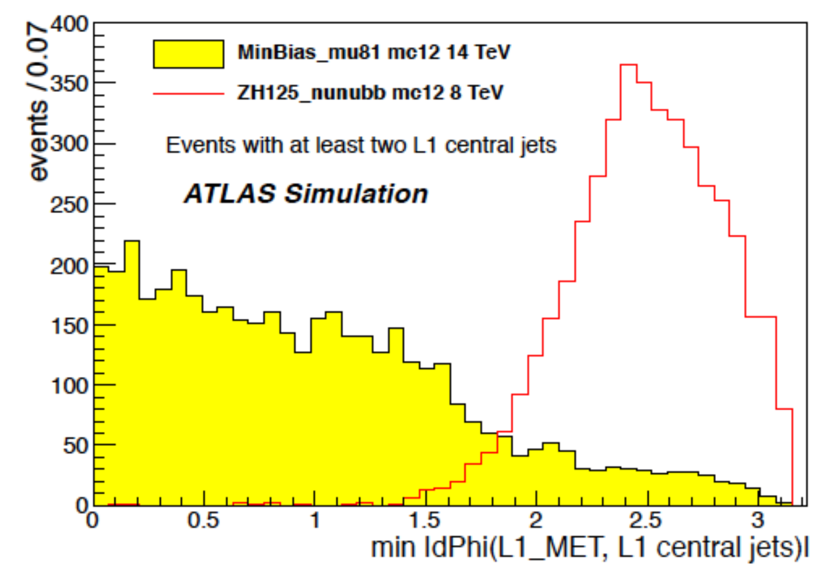
- In Run 1 , L1 triggers could be single item or logical AND of two items but could not use detailed properties to combined items
- In Run 2, a topological processor has been introduced. This allows topological properties of the event to be calculated from Calorimeter and Muon processor.





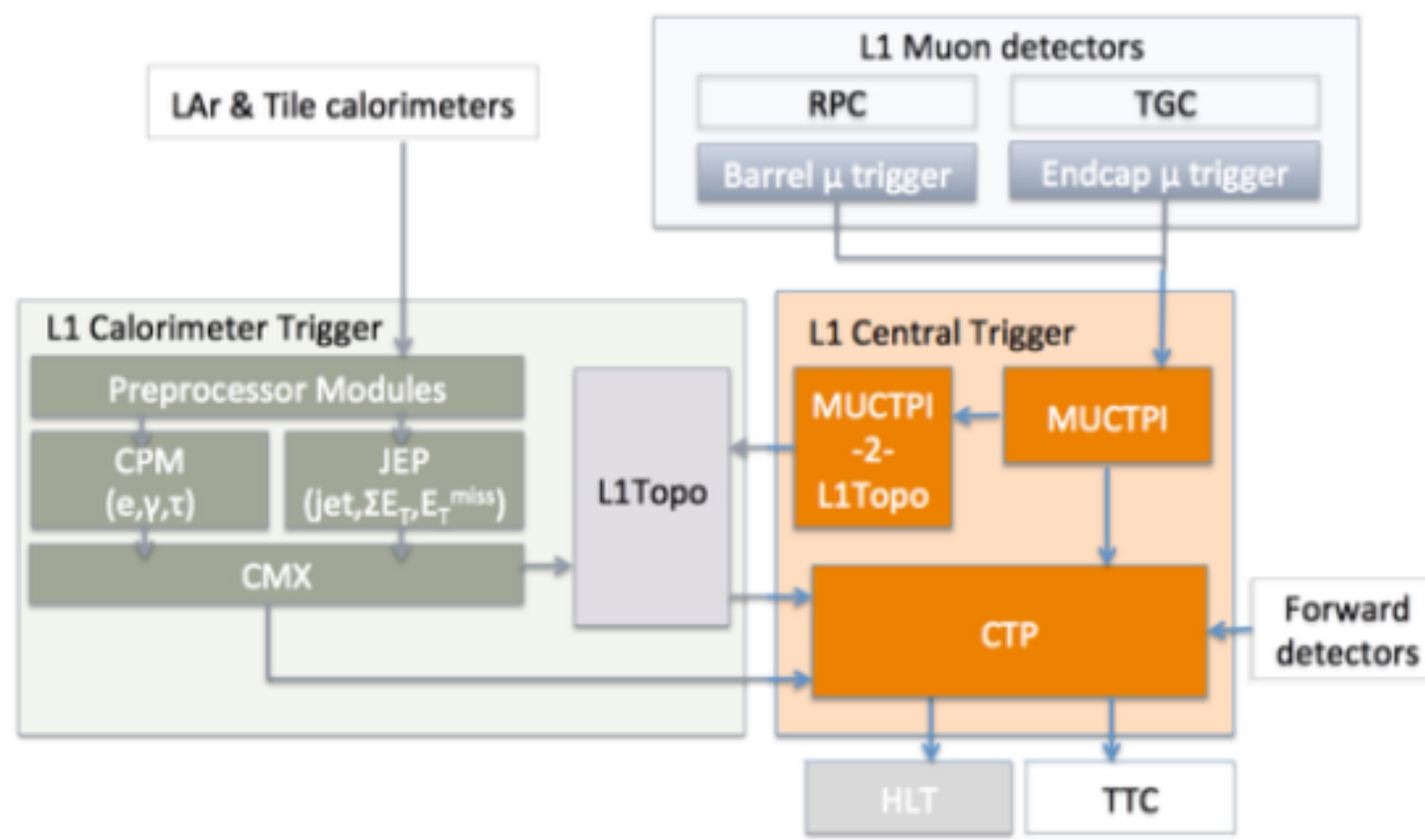
L1 Item	ZH Eff wrt offline (2012)	Rate (kHz)
L1_XE70	79%	5.6
L1_XE40_J75	50%	5.5
L1_J100	26%	4.6
L1_XE50	96%	42
L1_XE50_J40_dPhi1	92%	5





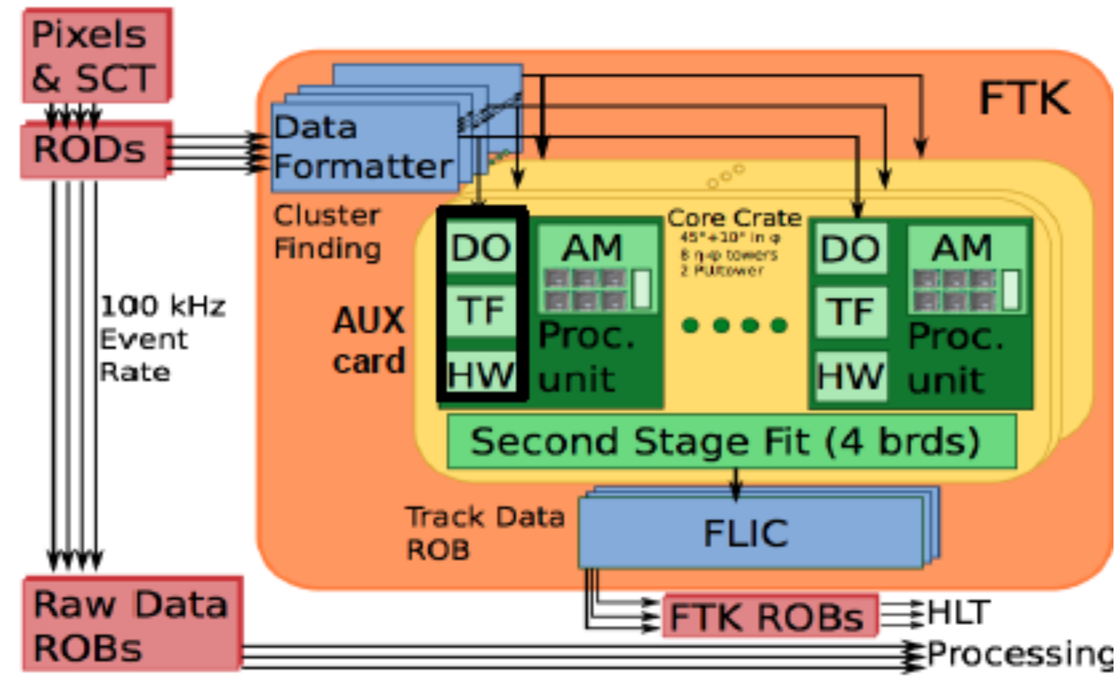
Central Trigger Processor Improvements

- Increase in inputs (160 ->320) inputs + 192 for L1 Topological trigger and forward detectors
- 256->512 trigger items at L1
- Increased Latency from addition of L1 topological trigger saved by direct input into CTP core processing
- Improved monitoring and web based configuration

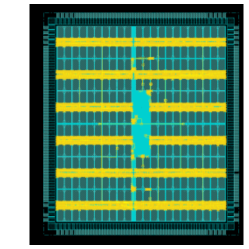


FTK

- L1 does not use inner detector (huge number of channels and time consuming tracking)
  - Run 1 - tracking done at L2 software driven by region of interest found by L1 calorimeter or muon trigger
  - Run 2 - dedicated hardware to prepare tracks for HLT for full detector
    - saves most time consuming part of Run 1 CPU consumption at L2
    - tracks of P_T > 1 GeV for full detector

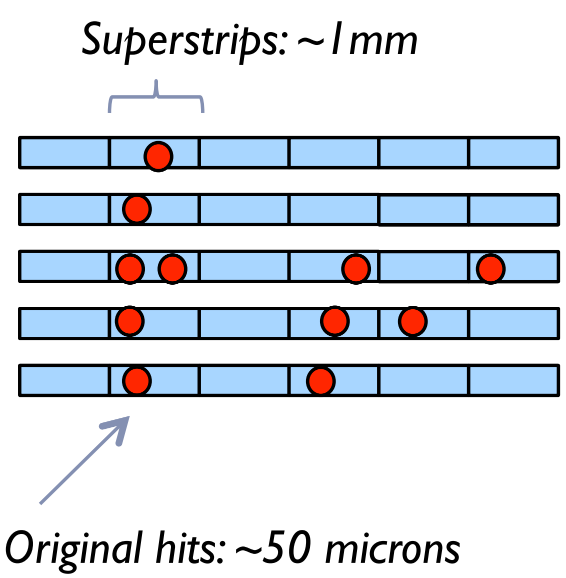


First Slice Integrated in the Fall 2015 - full detector Fall 2016

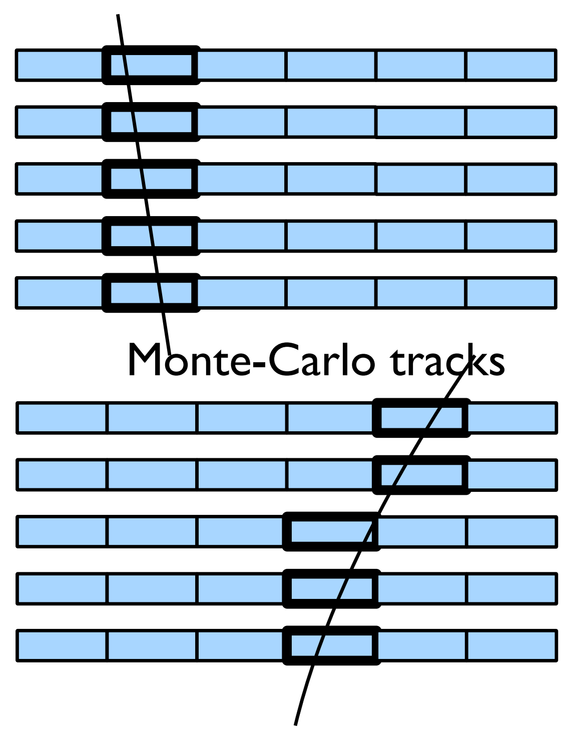


FTK approach: pattern recognition

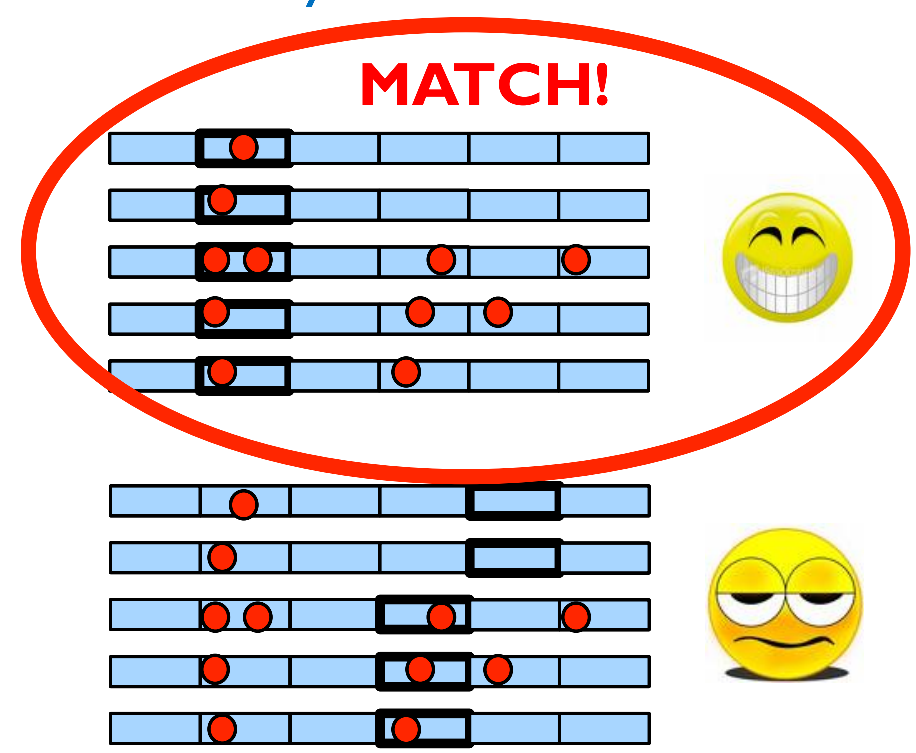
1. Given a collection of hits in an event, we gang them together to form coarse "superstrips" – about 1 mm wide.



2. Build a pre-calculated lookup table of all coarse paths ("patterns") that a charged track might take through the tracking layers. For full ATLAS detector, we expect about 1 billion such patterns

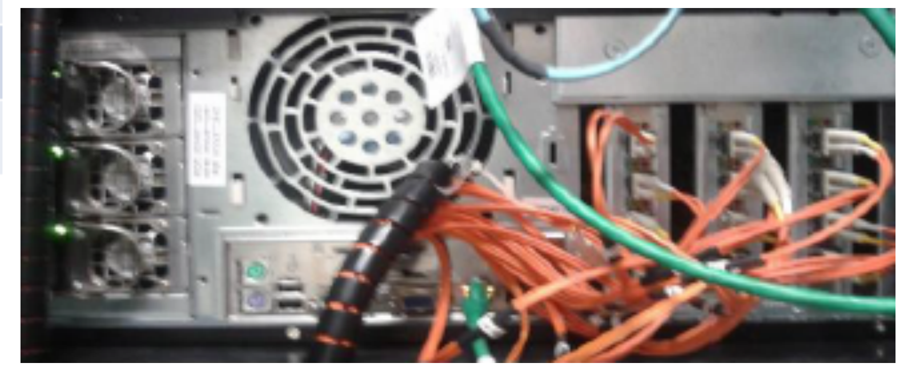


3. Load these patterns into specialized hardware – Associative Memories – that can **simultaneously** compare the event with ALL stored patterns and quickly return only those that match.

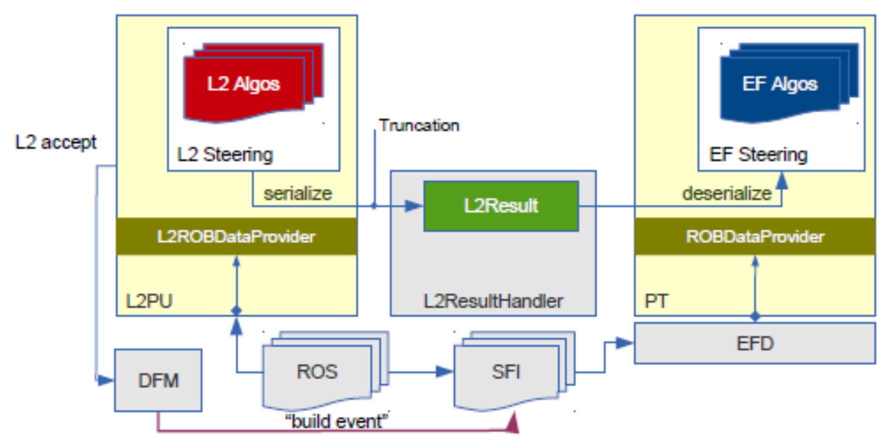


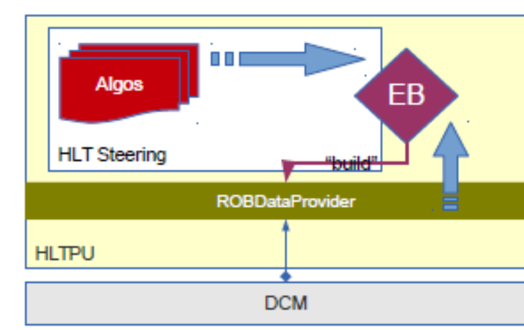
DAQ Upgrade

Links	3	12
Memory per link (MB)	64	682
Output Bandwidth (MB/s)	266	1600 (3200 possible)
Max Input Bandwidth (MB/s)	480	2400



- New Read Out System (ROS) with new CPU and readout cards
- 4 times great link density from front end to CPU farm
- 40 GbE data connection to each PC
- In Run 1 - two data flow networks for L2/EF merged to one data flow network for merged HLT

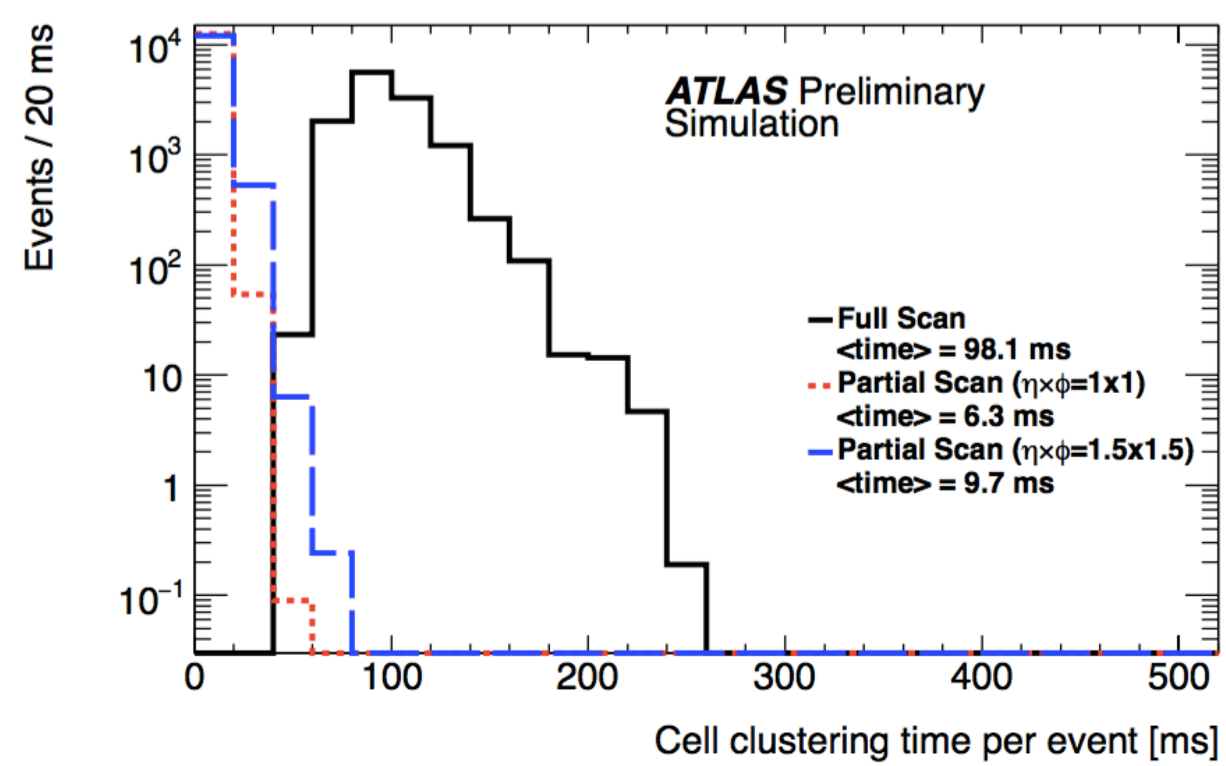




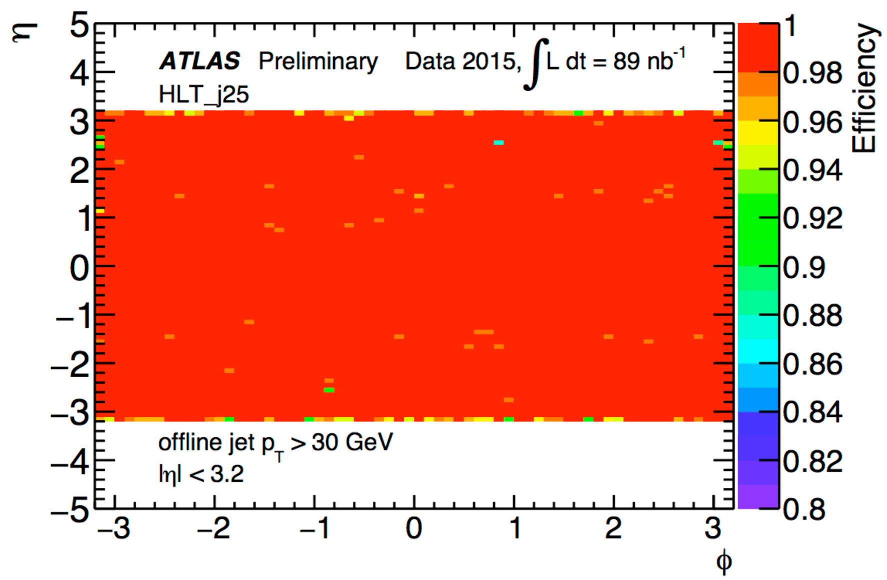
Improvements at HLT

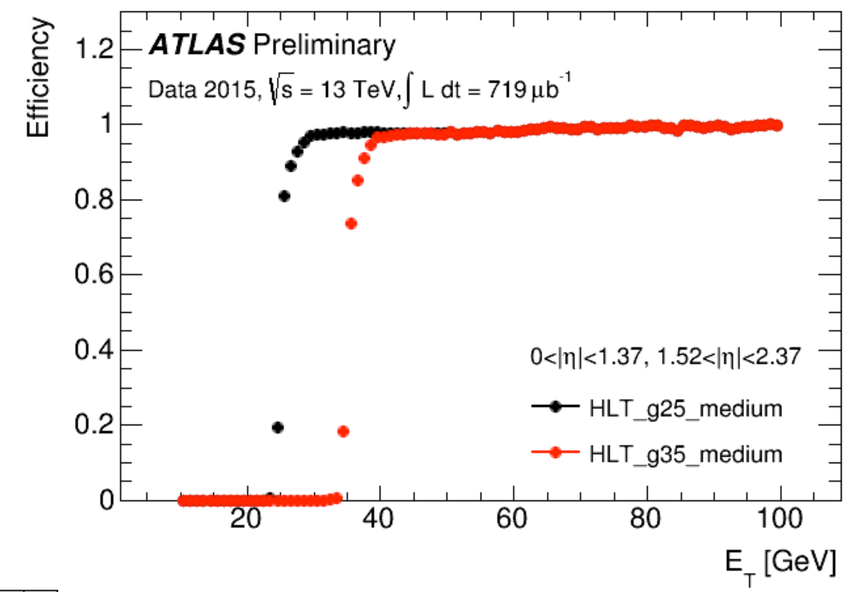
- Merger of HLT CPU means dynamic resource sharing
  - Still have algorithmically different stages can share common software and results between L2+EF (i.e. skip combinatorial tracking and refine tracks at EF stage)
  - where possible HLT code utilizes offline code to improve performance and minimize duplication
  - See Ben Sowden's talk for details of tracking code improvement

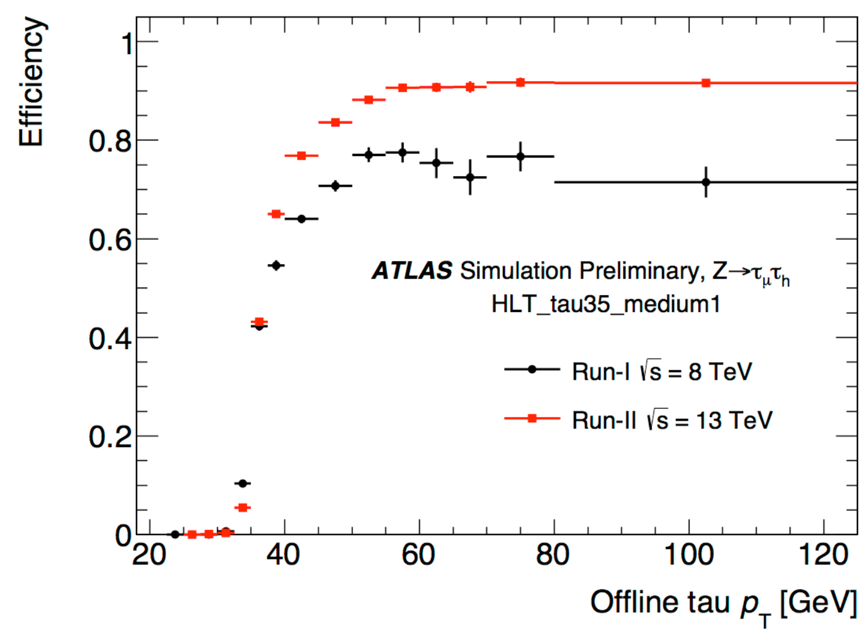
Signature	HLT Reconstruction methods
Tracking	FastTracking + offline tracking
E/gamma	FastTracking + offline tracking + LH/cut-based ID
Muon	Fast muon reco (L2MuonSA) + offline reco (3rd chain)
Jets	Topo-clusters, AntiKt
MET	Topo-clusters (no track correction)
Taus	Calo-based preselection, tracking, BDT ID
b-jets	offline b-tagging

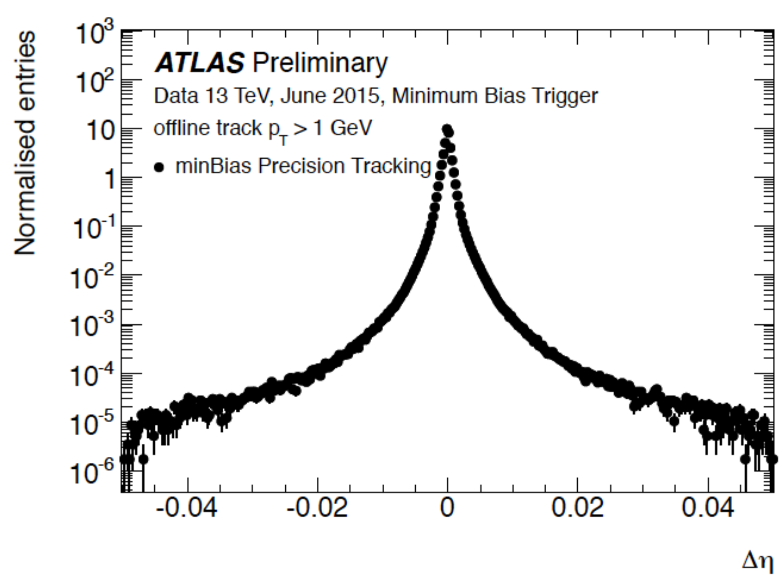


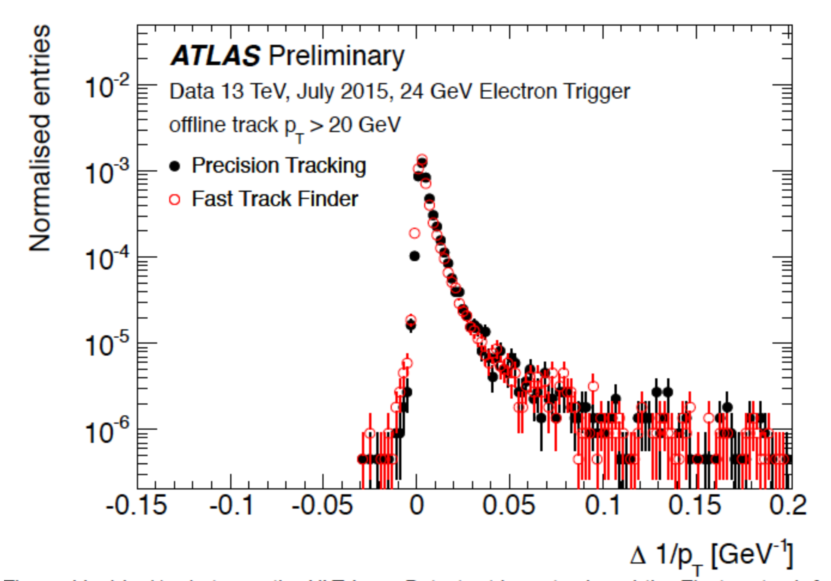
First Results









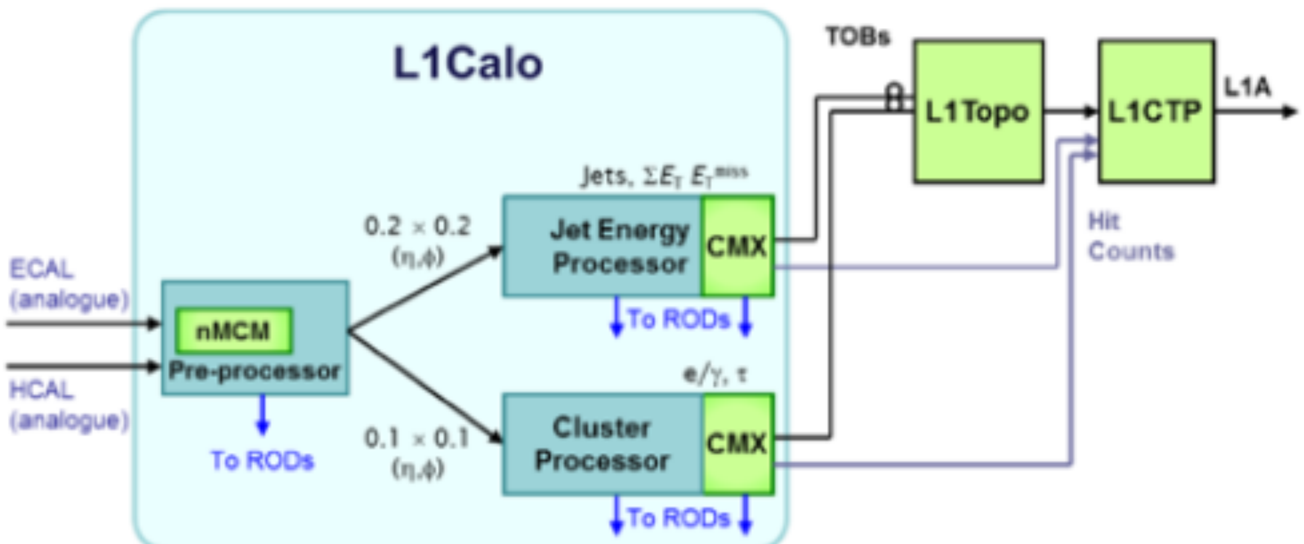


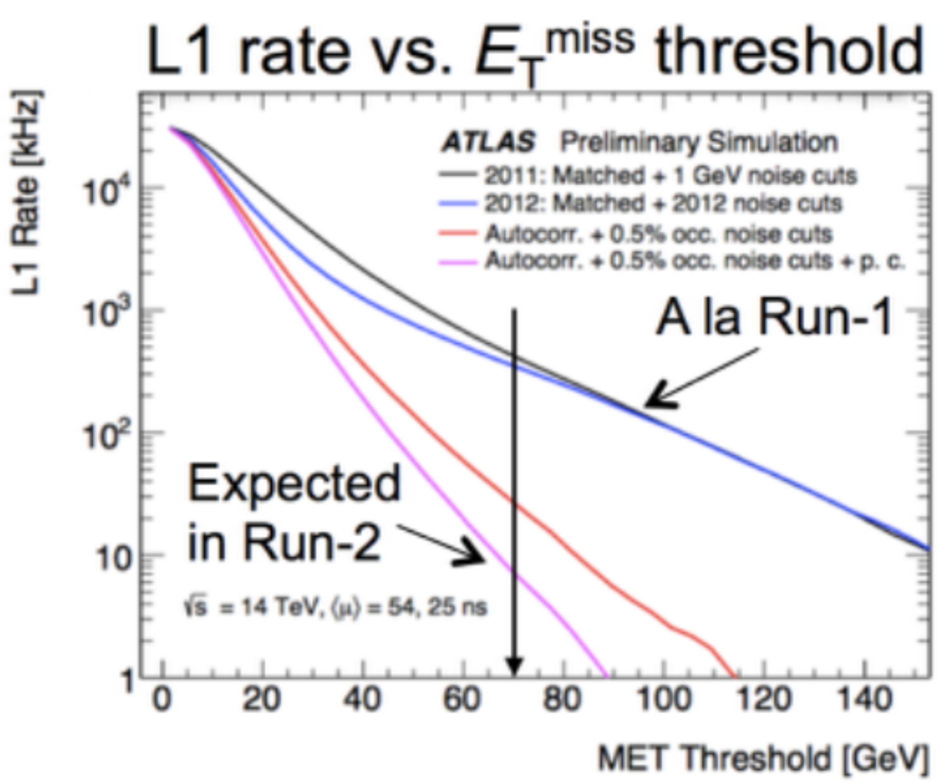
Summary

- Many new additions to ATLAS TDAQ as well as merged HLT
- Critical improvements have been added to keep bandwidth under control with increased rejection and use of topological information
- Taking data successfully and ready for increased luminosity
- Run 1 had a long commissioning time - Run 2 is starting fast with high instantaneous luminosity expecting soon at 13 TeV

Backup

L1 Calorimeter Improvements

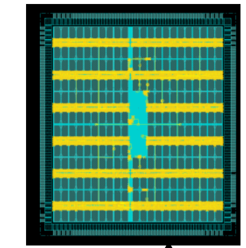




new Multi Chip Module in preprocessor

- dynamic pedestal subtraction for pileup (huge reduction in MET rates)
- improved jet energy resolution

- New Merger Module
  - input to L1 topological trigger
  - increase # of thresholds by x2

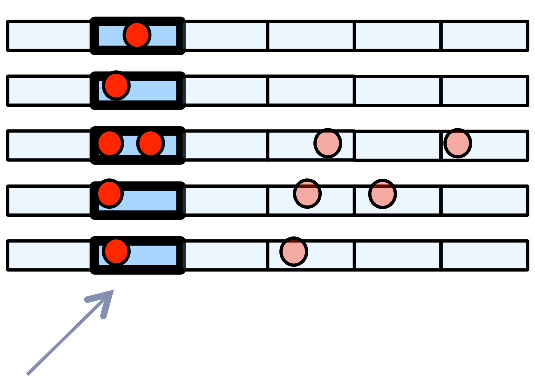


FTK approach: track fitting

4. Restore full-resolution hits inside each matched pattern.

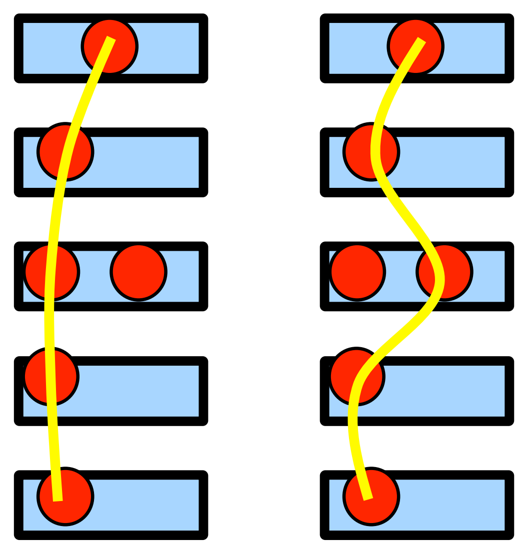
Ultimately, we need to create a list of tracks with:

- χ^2 (track quality)
- Curvature (~ $1/p_T$)
- Phi
- Impact parameter, etc



5. Because our patterns are narrow, we have very few hits inside of them.
The remaining combinatorial problem can be solved via the brute-force method – i.e., trying out every combination.

This pattern has two combinations:



6. For each combination, perform a linearized fit to arrive at final track parameters.
Since these fits involve only scalar products, they can be performed VERY quickly in modern FPGA chips: **1 fit / ns**

track parameters and χ^2 components

hit coordinates

$$p_i = \sum_j c_{ij} \cdot x_j + q_i$$

Pre-computed constants

Finally, we apply a χ^2 cut to remove bad tracks, perform duplicate removal, and send all final tracks to LVL2 trigger.