CPAD Instrumentation Frontier Workshop 2021

Global Trigger for the ATLAS Phase-II upgrade

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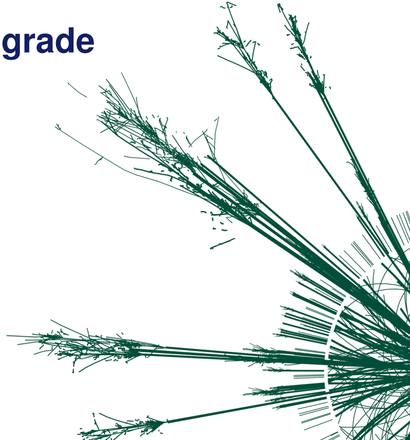
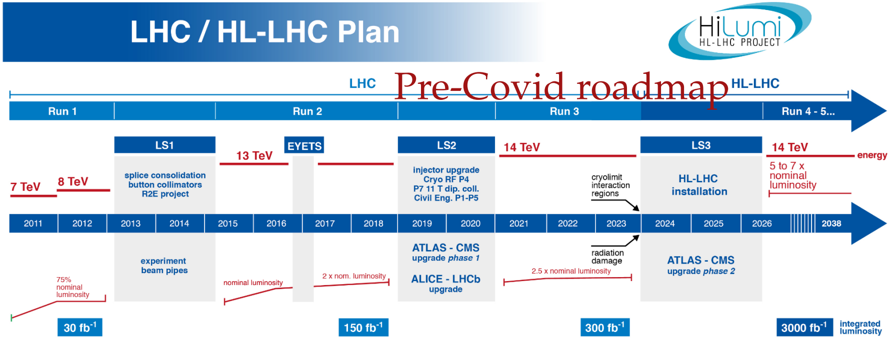


UNIVERSITY OF OREGON

ATLAS EXPERIMENT

Taking the LHC to high luminosity



2018	$\Rightarrow$	Run 4
50 fb^{-1}/year		**300** fb^{-1}/year
$\mathcal{L} = \mathbf{2} \times 10^{34}$ cm^{-2}s^{-1}		$\mathcal{L} > \mathbf{5} \times 10^{34}$ cm^{-2}s^{-1}
Pileup $\approx$ **20-60**		Pileup up to **200**!

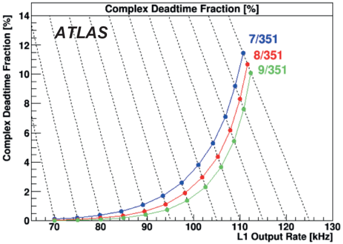
But want trigger thresholds to stay $\sim$constant!
Huge challenge for TDAQ

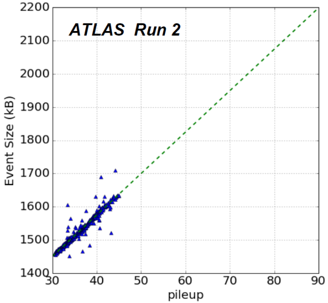
Limitations of the Run 3 TDAQ system

- Run 3 TDAQ system designed for $\mathcal{L} = 3.0 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $<\mu>= 80$
- The pileup conditions at HL-LHC design luminosity dictate a trigger rate increase by a factor of 10
- Level-1 rate cannot be increased beyond 100 kHz without an unacceptable increase in deadtime
- Latency (2.5 μs) too short for elaborate algorithms
- Readout and dataflow components cannot handle the increased (> factor 20) bandwidth due to larger event sizes and rates

$\Rightarrow$ Could raise requirements on physics objects, at the price of a degraded physics programme

↓ ATLAS-TDR-029





↑ ATLAS-TDR-029

The Phase-II TDAQ system

Driving principles

- Design Phase-II TDAQ not just to keep what we have, but to get even better
- Maintain legacy hardware where appropriate, accomodate new detectors and exploit full detector granularity where possible
- Learn from TDAQ-related physics limitations in Run 1-3 and avoid them (e.g. Long-lived particles)

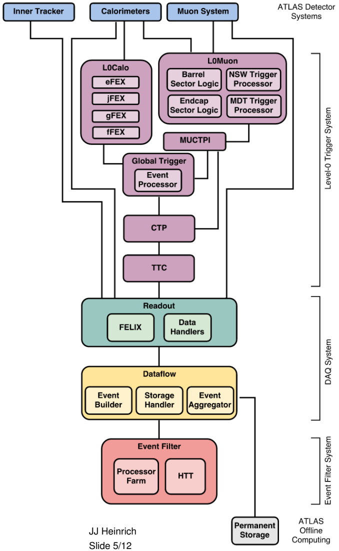
Constraints for Phase-II TDAQ

- Principle constraints on rate are set by the tracker and muon small wheel readout electronics
- Space and material in Pixel and Strip detector set limit on readout bandwidth

  $\Rightarrow$ Maximal readout rate of 1 MHz
- Available memory in muon small wheel micromega sector constraints latency

  $\Rightarrow$ Maximal latency of 10 μs

The Phase-II TDAQ architecture



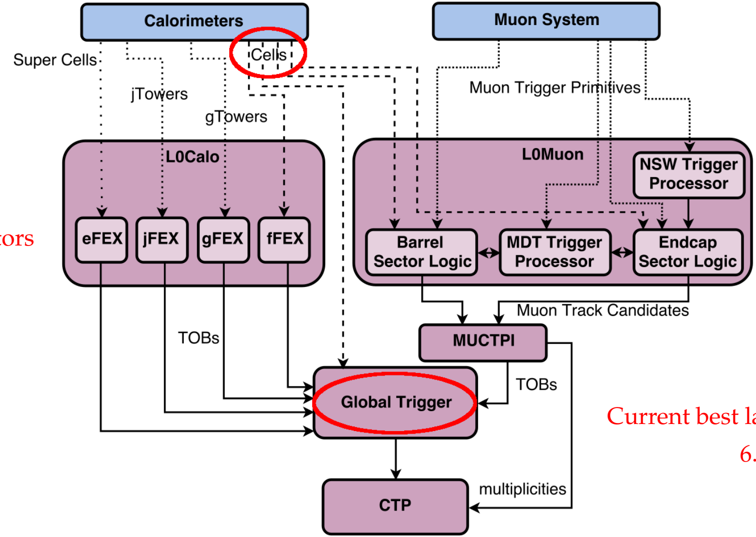
- The baseline TDAQ design contains a single-level hardware trigger: Level-0
- Level-0 receives inputs from the calorimeter (L0Calo) and the muon system (L0Muon)
- Target detector readout rate is 1 MHz with a maximum latency of 10 μs
- A new Global Trigger is introduced to perform offline-like algorithms
- The evolution into a dual-level hardware trigger system is possible and under study
- The Event Filter (EF) is based on a commodity CPU farm and a custom HTT co-processor
- Target output rate to permanent storage is 10 kHz

↑ ATLAS-TDR-029

The ATLAS Phase-II Level-0 trigger

↓ ATLAS TDAQ Phase-II TDR

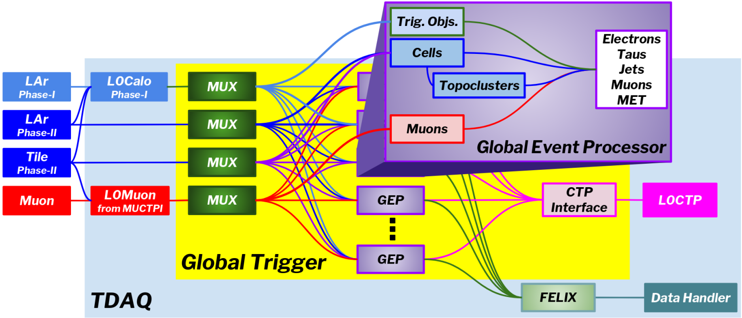
Feature EXtractors (Phase-I)



Current best latency estimate: 6.9 μs

The Global Trigger

↓ ATLAS TDAQ Phase-II TDR

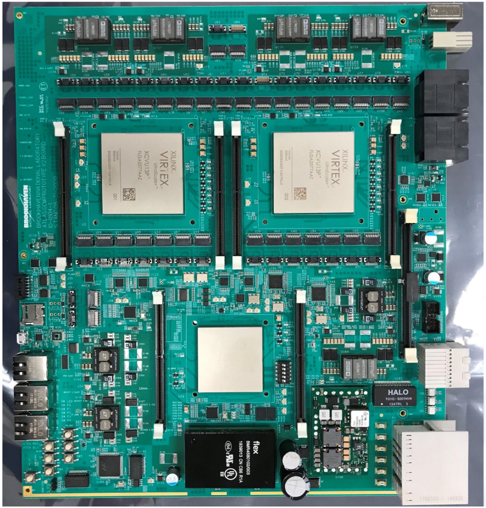


- GCM: Global Common Module
- MUX: GCM Node for data aggregation and time multiplexing
- GEP: Global Event Processor, GCM node for event processing and trigger algorithms
- CTP Interface: GCM node for interfacing with the Central Trigger Processor

- Global Trigger aggregates full event data onto single FPGA at 40 MHz $\Rightarrow \approx 60$ Tb/s
- Data is time multiplexed for maximal flexibility and performance:
  - Removes limitation on number of input trigger objects
  - Decoupling from LHC bunch-crossing rate allows asynchronous and complex algorithms (topo-clustering, jet finding)

Global Common Module

Slide adapted from Shaochun Tang (BNL)



- Different functions and algorithms implemented in firmware rather than hardware
- Global Trigger is mainly a firmware project that uses common hardware design for each component

  $\Rightarrow$ Global Common Module (GCM)

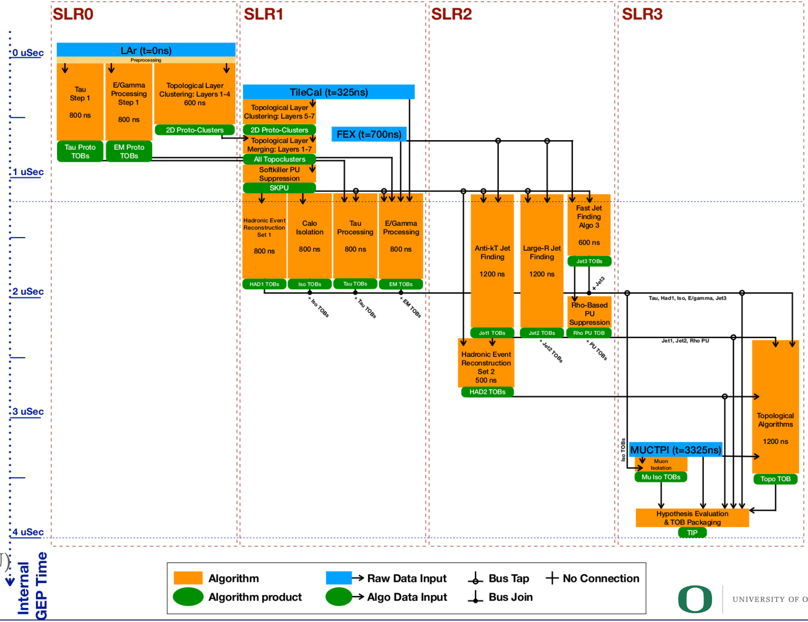
- Board design conceptually similar to gFEX (ATLAS Phase-I upgrade)
- ATCA-based board with 2 FPGAs (e.g. Xilinx Ultrascale + VU13P), Zynq
- 48 GCMs in baseline design
- Prototype v2 currently being tested

GEP data flow

- Very preliminary concept
- Initial assumptions about which algorithms, inputs and outputs are required

- With 48 GCMs pipline depth is 48 BC = 1.2 μs

  ⇒ Ideally limit all algorithms to 1.2 μs to allow for efficient pipeline of data



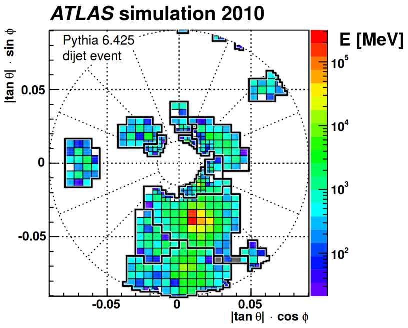
Slide adapted from Wade Fisher (MSU)

Example of challenges: TopoClustering

Current offline clustering:

- Clustering algorithm is controlled by three parameters for seeding, growing, and bounding

  ⇒ Currently used: 4-2-0
- Algorithm is recursive, fully 3D and has very few restrictions, all cells can be clustered
- A cluster splitter seeks to split large clusters into smaller ones
- Several calibration steps for all clusters



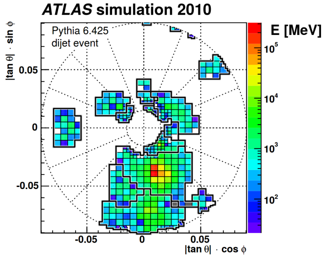
↑ Eur. Phys. J. C77 (2017) 490

Global Trigger clustering:

- Impossible to run recursive, 3-dimensional algorithms in hardware
- Only sent cells with $> 2\sigma$ energy content to GEP ⇒ 4-2-0 clustering reduces to 4-2 clustering
- No cluster splitting or calibrations

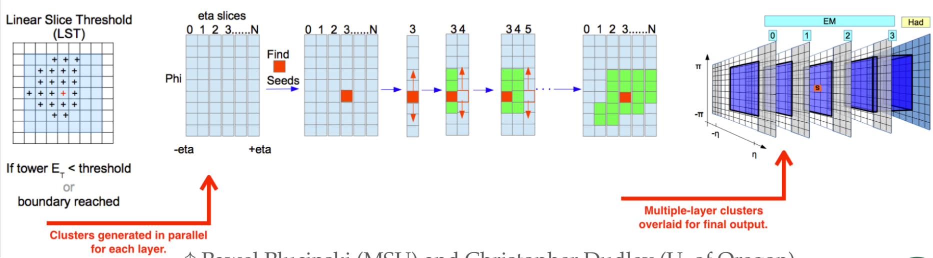
Example of challenges: TopoClustering

↓ Eur. Phys. J. C77 (2017) 490



- Need to be very clever to make clustering efficient
- Start processing data while still arriving

  ⇒ Order of data matters!
- Breaking 3D algorithm down to several 2D algorithms
- Stop execution of clustering after a fixed number of clustering steps



↑ Pawel Plucinski (MSU) and Christopher Dudley (U. of Oregon)

Summary

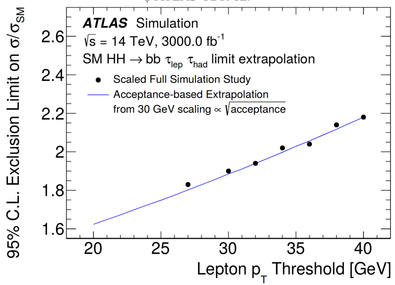
- ATLAS TDAQ system will undergo a major upgrade for High-Luminosity LHC
- New single-layer hardware trigger will allow rate increase from 100 kHz to 1 MHz with latency 10 μs
- A new Global Trigger for topological algorithms is added
- Global Trigger has access to full-granularity calorimeter information time-multiplexed on single node
- Hardware prototype has been built, firmware in development

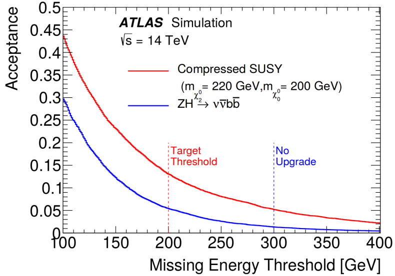
BACKUP MATERIAL

Physics drivers for Run 4+5

- Precision measurements of the properties of the Higgs boson
  E.g. Coupling to fermions, coupling to W/Z, diff. xsections, Self-coupling, Higgs + invisible
- Precision Standard Model measurements
  E.g. Forward/backward asymmetry, Vector-boson scattering, Precision top mass and xsection
- Searches for BSM signatures E.g. Searches for new vector bosons, electroweak SUSY, Dark Matter, new resonances, long-lived particles
- Flavour Physics E.g. Lepton flavour violation, FCNC in top decays, rare B-meson decays
- Heavy-Ion Physics
  E.g. Light-by-light scattering, Quarkonia production

↓ ATLAS-TDR-029





↑ ATLAS-TDR-029

The Athena TopoClusterMaker

- The Athena offline TopoClusterMaker can be found here: CaloTopoClusterMaker.h
- Documentation of the clustering is given in this document
- Algorithm is controlled by three parameters {S, N, P} for seeding, growing, and bounding; currently used: 4-2-0

- Step 0: Create list of all cells including eta, phi, energy and signal over noise ζ_{cell}

$$\zeta_{\text{cell}} = |E_{\text{cell}}| / \sigma_{\text{cell,noise}}$$

- Step 1: Find seed cells with energy $> S$ (in allowed samplings) and order them according to largest ζ_{cell}, all seeds form proto-clusters
- Step 2: Grow the proto-cluster by checking all neighbouring cell energies and make sure each cell is only used once
  Neighbour: two directly adjacent cells in same sampling, or cell in adjacent layer if some overlap in (η, ϕ) plane, multiple subsystems allowed

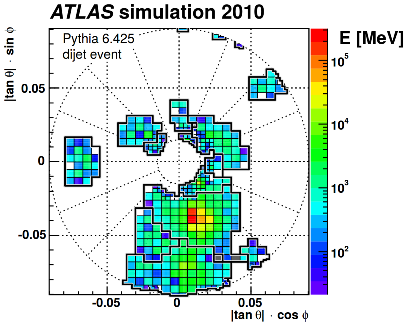
The Athena TopoClusterMaker

Depending on energy different actions are taken:

- $E_{\text{neighbour}} > S$: Merge proto-clusters
- $S > E_{\text{neighbour}} > N$: Add cell to proto-cluster and consider its neighbours in next iteration
- $N > E_{\text{neighbour}} > P$: Add cell to proto-cluster
- $E_{\text{neighbour}} < P$: No action

If a neighbouring cell is attached to two different proto-clusters the clusters are merged

- Step 3: Perform step 2 iteratively until no more neighbouring cells with energy $> N$ are found
- Step 4: Order clusters in energy



- Algorithm is recursive, fully 3D and has very few restrictions, all cells can be clustered
- Only absolutes are considered, negative energy clusters possible
- A cluster splitter seeks to split large clusters into smaller ones