ATLAS Trigger and Data Acquisition Upgrades for the High Luminosity LHC
High Luminosity LHC

- **Trigger & data acquisition challenge**
  - Luminosity: $2 \mapsto 7.5 \cdot 10^{34} \text{cm}^{-2}\text{s}^{-1}$
  - Pileup: $60 \mapsto 200$
    - more time consuming

- **ATLAS detector upgrade**
  - new Tracker, new Timing Detector,
    additional muon chambers, new Tile electronics, …

<table>
<thead>
<tr>
<th>Year</th>
<th>Run 3</th>
<th>Long Shutdown 3 (LS3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2022</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2023</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2024</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2025</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2026</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2027</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2028</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
<tr>
<td>2029</td>
<td>JFMAM</td>
<td>JASOND</td>
</tr>
</tbody>
</table>
Trigger DAQ upgrades

- Hardware based L0 trigger
  - Data reduction: 40 MHz → 1 MHz
    - 100 kHz in Run 3
  - Latency: 10 μs
    - 2.5 μs in Run 3

- Software based Event Filter
  - Data reduction: 1 MHz → 10 kHz
    - ~ 3 kHz in Run 3
Level-0 Trigger

- Data from calorimeters and muon detectors processed by dedicated trigger systems
  - L0Calo and L0Muon
- Global trigger runs full granularity offline-like reconstruction
  - @ 40 MHz
- Outputs sent to Central Trigger Processor to make L0 decision
  - Accepted events sent to Event Filter
Level-0 Calo

● **Feature EXtractors**
  ○ FPGA-based trigger boards optimized to trigger on different physics objects

● **Feature EXtractors from Run 3**
  ○ e(lectron)FEX, j(et)FEX, g(lobal)FEX
  ○ Hardware retained with upgraded firmware
  ○ Needed modifications currently being evaluated

● **New forward Feature EXtractor (fFEX)**
  ○ EM triggers for $|\eta| > 2.5$
  ○ Jet triggers for $|\eta| > 3.3$
  ○ Preliminary design being studied
Level-0 Muon

- **Sector Logic**
  - FPGA-based off-detector trigger logic

- **Common hardware platform for Barrel and End-Cap**
  - 1st prototype tested → integration with on-detector board, from trigger chambers to Sector Logic
  - 2nd prototype design started
Level-0 Muon

- Trigger Processors
  - receive data from precision muon chambers and new small wheel muon chambers
  - interact with sector logic

- ATCA blades based on a common open source platform (Apollo*), that simplifies custom ATCA blade design
  - Service module for common services
  - Command module containing application specific elements

* https://doi.org/10.48550/arXiv.1911.06452
Level-0 Muon

- **Trigger Processors**
  - receive data from precision muon chambers and new small wheel muon chambers
  - interact with sector logic

- **Barrel: MDT precision chambers**
  - v1 Command Module prototype under test

- **End-Cap: New Small Wheel**
  - schedule completely overhauled based on Run 3 experience
Level-0 Global Trigger

- Low-level analogue to Event Filter (EF)
  - HLT-like object-level and event-level reconstruction and analysis at 40 MHz
  - It will replace Run 3 topological processor
  - Input: 50 Tb/s

- Algorithms organized as trigger signatures in parallel with EF
  - Calo, muon, topological cluster, e/γ, τ, jets, $E^\text{miss}_T$ and other topological quantities
  - Initial trigger menu will start from Run 3 signatures
  - Additional triggers will be added during commissioning
L0 Global Trigger

- Farm of processing units
- Collect all data from a single event onto one FPGA
  - data aggregation and time multiplexing (MUX)
  - each Global Event Processors (GEP) process one event
  - demultiplexing step to collect GEP outputs and feed the Central Trigger Processor
L0 Global Trigger

- All modules based on common hardware ATCA platform
  - different functions implemented in firmware

- Prototypes
  - v2b available & tested
    - Based on Xilinx Virtex UltraScale+ 13P
  - v3 schematic review under way
    - w/ Versal Premium Xilinx VP1802
Central Trigger

● Central Trigger Processor
  ○ Final decision, prescales, vetos
  ○ Number of L0 triggers: 512 → 1024
  ○ Passed specification review

● CTP drives the Trigger, Timing and Control (TTC) system network
  ○ TTC distributed via the Local Trigger Interface (LTI) modules
    ■ Test Setup available

● Muon-CTP Interface (MUCTPI)
  ○ Re-use Run 3 HW with new FW
High Level Trigger

- Full event building at 1 MHz
  - 40 Tbps (5 TB/s)
- Heterogeneous commodity computing system
  - Offline-like algorithms
  - Under evaluation the possibility to use accelerators (GPUs or FPGAs)
- New DAQ infrastructure:
  - readout, dataflow, network, online software
Readout

- **Front-End LInk eXchange**
  - PC-based gateway
  - hosting FPGA-based PCIe I/O cards
- **FELIX interfaces**
  - custom optical links to/from front-end
  - to/from commodity switched network
- Partially deployed in Run 3
  - for new or already upgraded detectors
- To be upgraded for Run 4
  - FLX-182 prototype
Readout

- FLX-182 prototype (FPGA/SoC)¹
  - Xilinx XCVM1802, PCIe gen4
  - 24 links up to 25 Gb/s + TTC interface
- Functionality tests successful
  - Hardware and firmware functions
  - Optical links and PCIe transmission
  - Integration w/ ATLAS Global Trigger

¹ More details in Joaquin Hoya presentation, Thursday 2:45 pm [link]
Dataflow and networking

- Dataflow provides full events (from readout) to EF and storage
- Completing a SW prototype
  - Based on Run 3 Dataflow
  - w/ new features and optimizations
  - Supporting expected rate: 12 kHz per rack (Assuming SW only architecture)
- Networking studies ongoing¹
  - Investigating deep-buffer switches
  - Simulation Models

¹ More details in Eukeni Pozo Astigarraga presentation, Tuesday 4:45 pm [link]
Dataflow and networking

- **Persistent-storage buffer system**
  - Complementary dataflow option w.r.t. Run 3 application-based design
  - Developed using DAOS
    - an open-source high-performance distributed storage system
  - Using Intel’s high-end NVMes and persistent memories

- **Prototype being tested**
  - Viability depends on the evolution of storage technology
Online Software

- Responsible of configuring, controlling and monitoring the whole DAQ system
- Prototype EF farm orchestrator based on Kubernetes
  - Open-source orchestrator platform that automates deploying, managing and scaling containerized applications
  - Tests performed on Run 3 farm
- Started integration into the Run Control Software framework
Event Filter

- Commodity hardware:
  - CPU (7.8/11.4 MHS06 for Run 4/5)
  - Possibly w/ accelerators: GPU, FPGA
- Preliminary feasibility studies*
  - CPU showed x8 speed-up
  - Use of GPU/FPGA looked promising
- First demonstrators started
  - tracking, muon, calorimeter
- Technology decision about the use of accelerators in 2025

* For Technical Design Report Amendment (2021)
Event Filter

- Commodity hardware:
  - CPU (7.8/11.4 MHS06 for Run 4/5)
  - Possibly w/ accelerators: GPU, FPGA

- Preliminary feasibility studies*
  - CPU showed x8 speed-up
  - Use of GPU/FPGA looked promising

- First demonstrators started
  - tracking, muon, calorimeter

- Technology decision about the use of accelerators in 2025

* For Technical Design Report Amendment (2021)
**EF tracking**

- Many ongoing FPGA & GPU studies
  - for track seeding, pattern recognition, track fitting, ambiguity removal
- Exploring use of High Level Synthesis
  - Hough transforms with FPGAs\(^1\) and Graph Neural Network\(^2\)
- Plan to use Acts Common Tracking Software
  - Experiment independent toolkit for track reconstruction
  - Support for accelerators and heterogeneous options

---

\(^1\) More details in Abraham Kahn poster [link]

\(^2\) More details in Sebastian Dittmeier presentation, Tuesday 2:30 pm [link]
EF Calo and PPES

- EF Calo: demonstrated topological Cell Clustering w/ GPUs
  - speed-up w.r.t CPU (1st version)
    - ~3.5 for di-jets $<\mu> \sim 20$
    - ~5.5 for tt at $<\mu> \sim 80$
  - exploring FPGAs alternatives

- Physics, Performance & Event Selection group coordinates
  - simulation, performance and trigger menu development for Level-0 and EF algorithms
Conclusion

● Upgrades based on a mix of commodity and custom solutions
  ○ Most projects already passed many reviews
  ○ Prototypes available for many projects

● Level-0 trigger
  ○ focus on integration with the many interfaces

● Readout, Dataflow, Network, online SW
  ○ testing prototypes: 1st FELIX prototype, dataflow prototypes, container-based prototype farm orchestration

● Event Filter
  ○ investigating accelerator options, technology decision in 2025
Backup
L0 Muon: MTD trigger processor

- Use MDT hits to improve the muon track candidate parameters, coming from the RPC and TGC Sector Logic (SL) boards.
  - Refined candidates are then sent back for the final trigger decision
Level 0
Single particles (muons/pions), barrel region, no pile-up,
Event Filter

- Regional tracking in Regions of Interest identified at Level-0
  - to verify the presence of high-pT tracks in single lepton triggers
  - to associate objects to a common vertex

- Run full-scan tracking at reduced rate
  - after regional tracking for jets & $E_T^{\text{miss}}$

- Large radius tracking for exotics
  - focuses on tracks with high impact parameters like those resulting from the decays of Long Lived Particles