Phase-1 ATLAS Level-1 Trigger in Run-3

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on behalf of the ATLAS Collaboration

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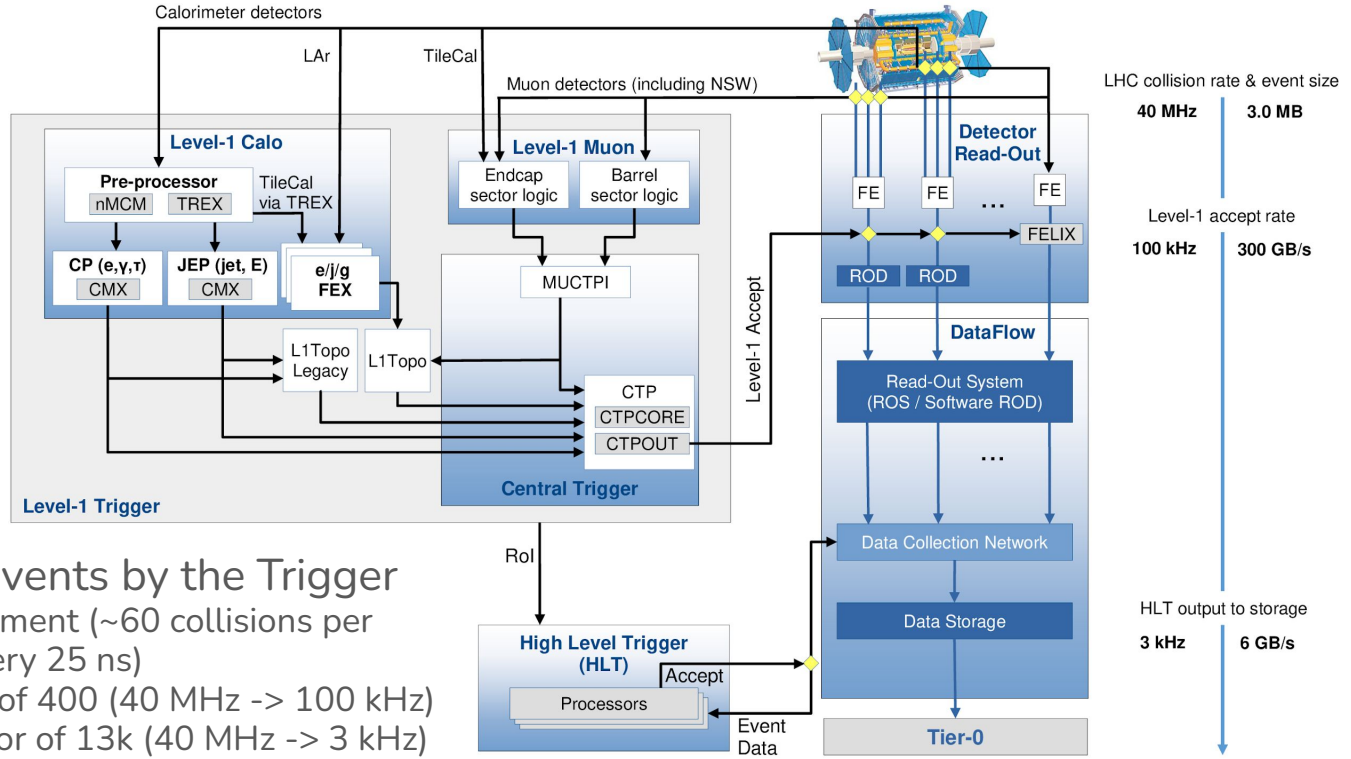
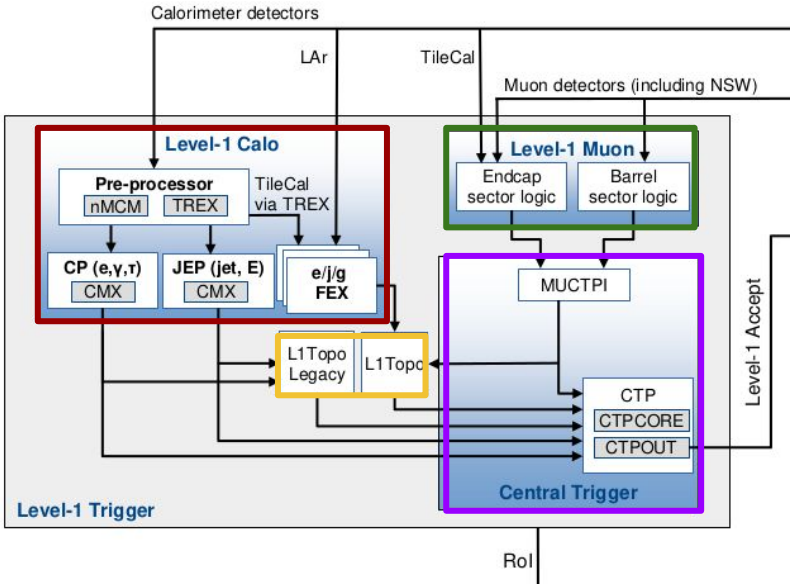
ATLAS Trigger in Run 3

- Level-1 (L1) Trigger
  - Hardware
  - Fast sub-detector signal
- High-Level Trigger
  - Software, multi-tasking/processing
  - Region of Interest
- Data Acquisition
  - Detector Readout
  - Buffering
  - Data Flow



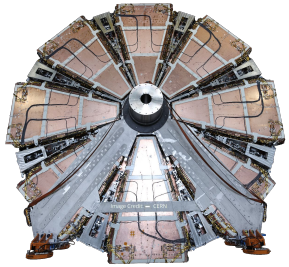
- Selection of signal events by the Trigger
  - High pileup environment (~60 collisions per bunch-crossing, every 25 ns)
  - L1 reduction factor of 400 (40 MHz -> 100 kHz)
  - Total reduction factor of 13k (40 MHz -> 3 kHz)
  - Jet with pT > 100 GeV in every 10k event, W-boson in every 10M event

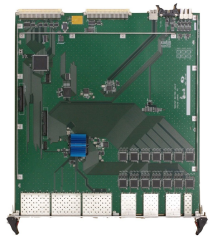
ATLAS Level-1 Trigger

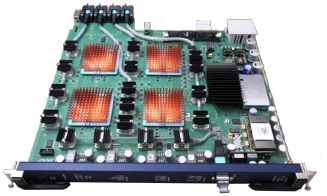


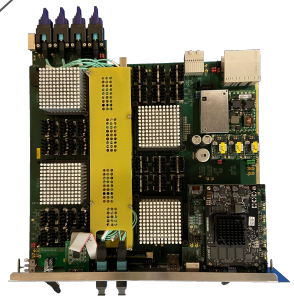
- Level-1 Muon •
  - Fast muon detector input + calorimeter coincidence
  - Barrel: resistive plate chambers (RPC) technology
  - End-cap: thin-gap chambers (TGC), small-strip TGC (sTGC) and micro-mesh gaseous structure (MicroMegas) technologies
- Level-1 Calorimeter •
  - Reduced granularity calorimeter inputs
  - Physics object identification by their footprint, particle shower
  - Electromagnetic and Hadronic calorimeter
    - Liquid Argon (LAr)
    - Solid scintillator (Tile)
- Level-1 Topological Procesor •
  - Calculation of angular features and mass of higher-level objects (di-lepton, di-jet, etc.)
- Central Trigger •
  - Aggregation of L1 Trigger inputs in the Central Trigger Processor (CTP)
  - L1 Trigger accept decision
  - Timing and control signals distribution

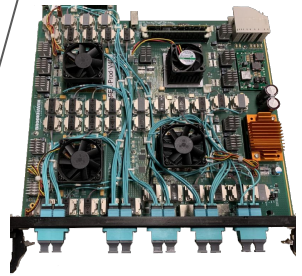
Phase-1 Upgrade

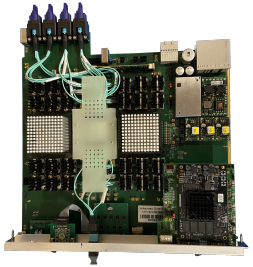


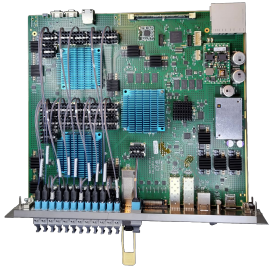












- New Small Wheel (NSW)
  - New **muon sub-detector** for ATLAS end-cap
    - High granularity detectors, two types of technology
  - Coincidence with the current sub-detectors
- Level-1 Muon
  - New muon sector logic boards with optical links
- Level-1 Calorimeter (L1Calo)
  - Increased calorimeter granularity (new LAr digital trigger)
  - Modular approach for physics object identification, three **feature extractor** modules (FEX)
    - Electron FEX (eFEX) for **electron/gamma/tau** objects
    - Jet FEX (jFEX) for **jet/tau/(missing)ET/forward electron** objects
    - Extra module for global features (gFEX) for **large-jets and (missing)ET**
- Level-1 Topological processor (L1Topo)
  - Low latency multi-board to handle all FEX modules and L1 Muon inputs
- Central Trigger
  - New **Muon-to-CTP Interface** (MUCTPI) with optical links
  - CTP adapted to handle the optical inputs
  - New timing, trigger, and control distribution boards

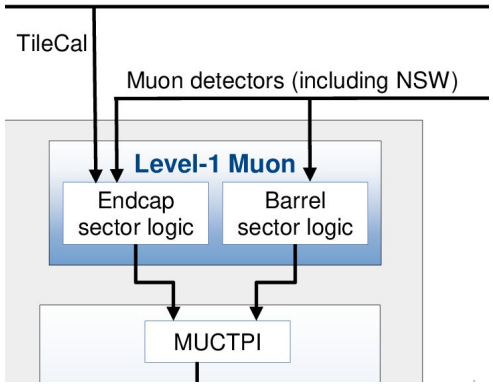
Level-1 Muon Phase-1

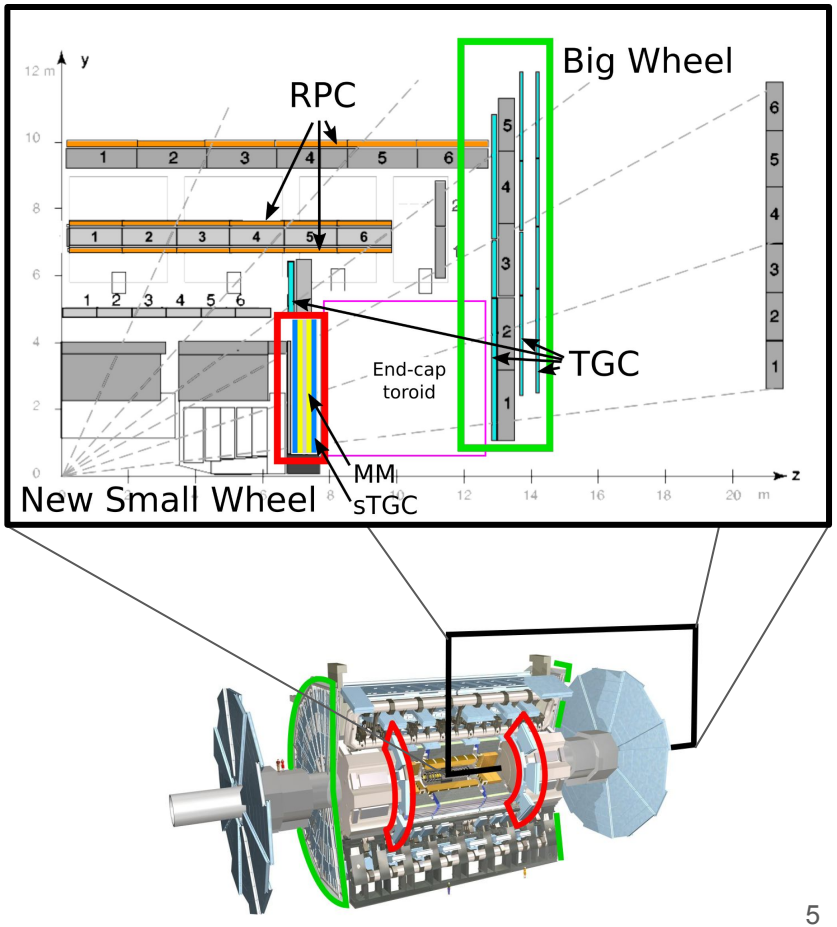
Gathering of signals from the muon detectors

- RPC and TGC layers in the barrel and end-cap
- Generation of the feature tags (charge, coincidence, magnetic field)

Phase-1 upgrade

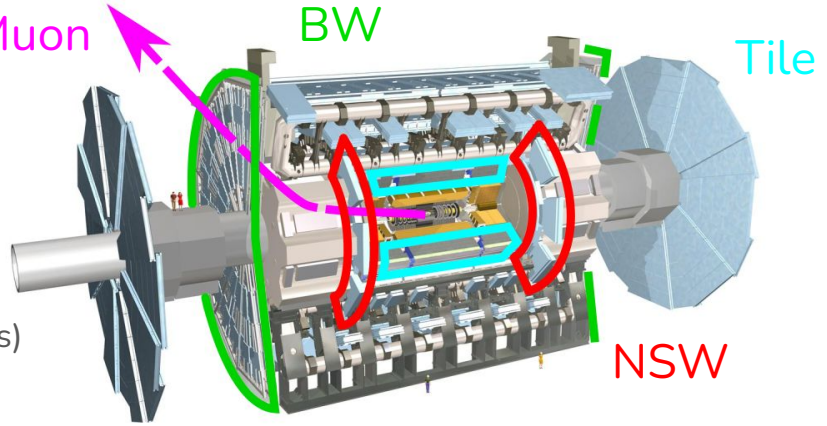
- Optical muon sector logic boards connected to MUCTPI
- New Small Wheel, end-cap muon detector
  - All sTGC and MM sectors included in the L1 trigger
  - Stability and efficiency studies of individual channels

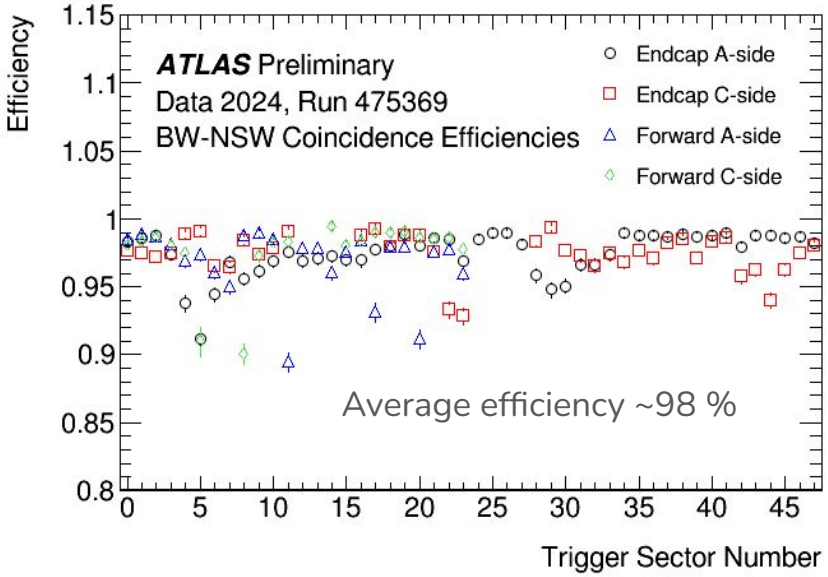


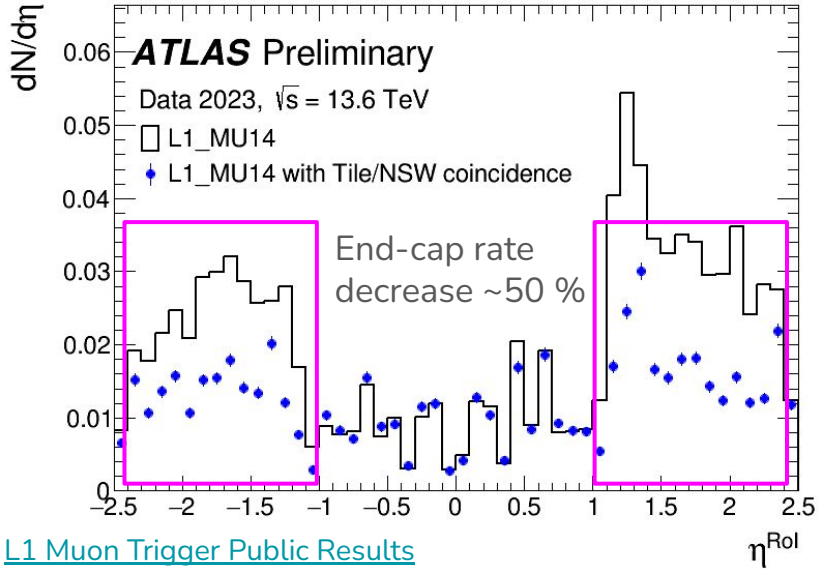


Trigger Coincidence

Big Wheel (BW) - New Small Wheel (NSW) -
- Tile calorimeter detector aggregation
  - End-cap toroid between BW and NSW
  - Fake muon rejection (beam-induced background particles)
  - Tile calo (1.03 - 1.3 η), NSW (1.3 - 2.4 η)





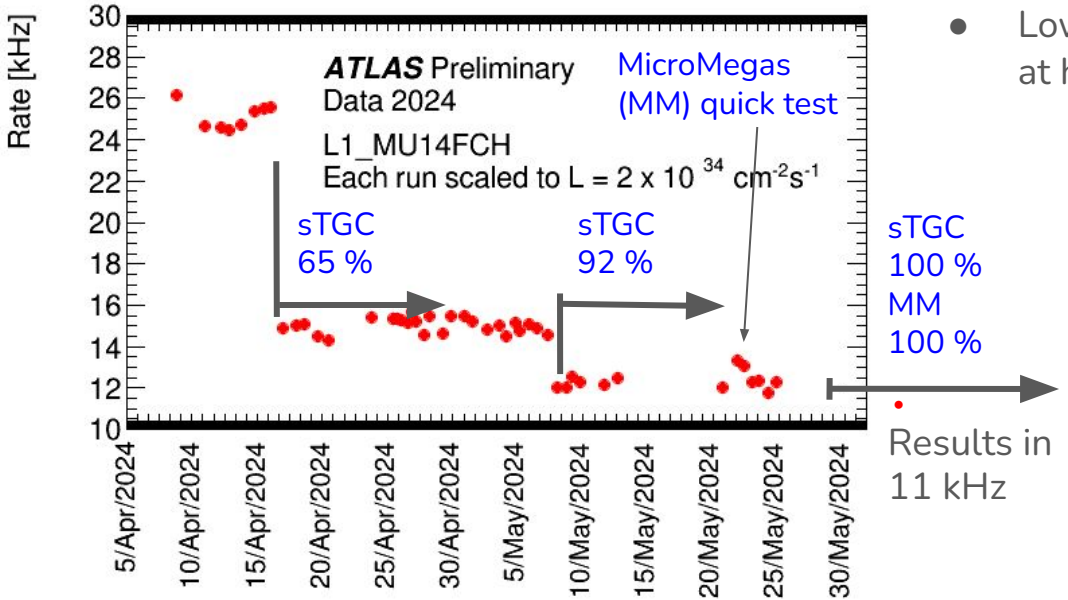


[L1 Muon Trigger Public Results]

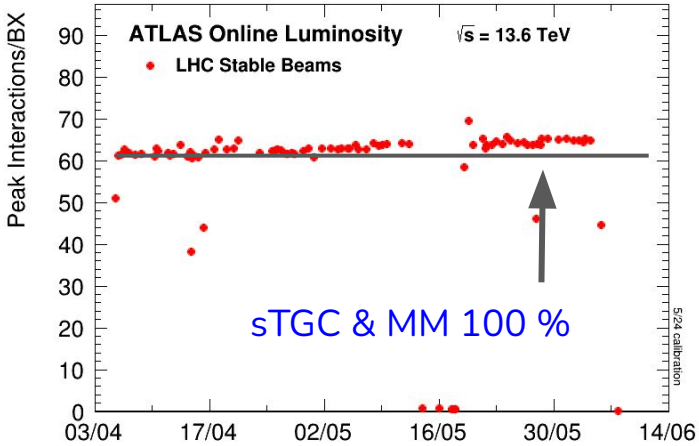
Level-1 Muon Performance

Muon L1 trigger

- Progressive inclusion of the NSW coincidence rapidly decreases the trigger rate.



- NSW muon sectors were added sequentially to the L1 trigger
  - sTGC: 65 -> 92 -> 100 % of sector logics
  - MicroMegas: 100 % since May 28
- Turn-on curve as sharp as in Run 2
- Trigger efficiency decreased by ~4 %
  - Trade-off for the urgent decrease of the trigger rate
  - This will be improved by tuning the NSW detectors
- Lower L1 muon rate allows ATLAS to operate at higher p-p collision pile-up



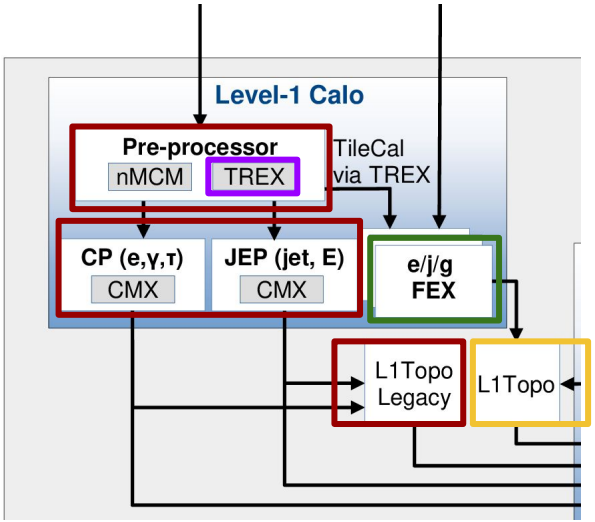
[L1 Muon Trigger Public Results]

[Luminosity Public Results]

L1Calo Architecture

Dual architecture for commissioning

- Updated architecture of Run 2
  - Updated modules, legacy L1Topo
- New Phase-1 architecture
  - FEXes, new advanced L1Topo



Run 2 architecture ●

- Pre-processor
  - Signal processing, Bunch-Crossing association
- Cluster and Jet/Energy Processor (CP and JEP)
  - Legacy identification of the physics objects
  - CP: electron, photon, and tau particles
  - JEP: jet, missing energy
- Transition upgrade
  - Improved signal processing (nMCM)
  - Optical modules
    - Trigger signals for the Central Trigger (CMX)

Phase-1 architecture

- L1 Topological Procesor ●
  - The only connection to the Central Trigger now
- Modular Feature Extractors
  - eFEX, jFEX, and gFEX ●
    - Multiple boards for each extractor
    - Extendable for other physics objects
  - Tile calorimeter data to FEXes module (TREX) ●

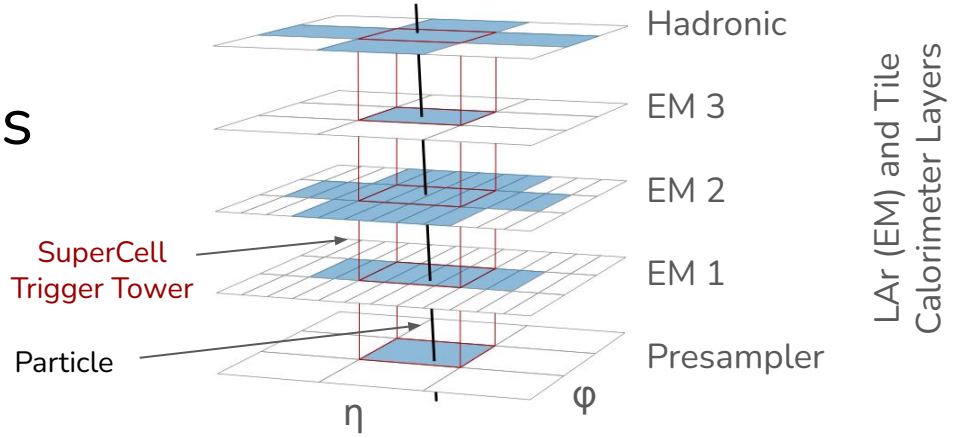
L1Calo Phase-1 Algorithms

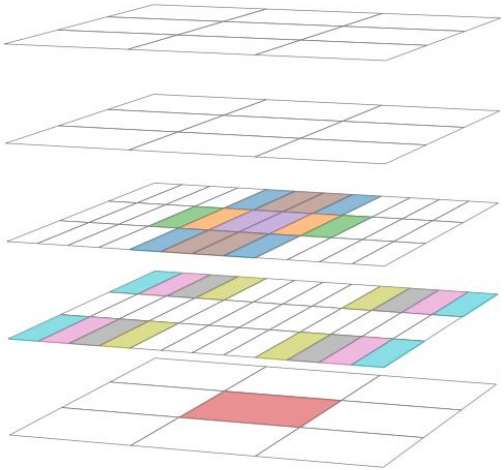
Physics object identification

- Fine granularity for electron/photon
  - New **LAr digital trigger** provides 4-fold higher granularity in layers one and two
- Isolation by the ratio between the surrounding and seed cells (most energetic)
- Veto by layers (elmag/hadronic)

Phase-1 FEX algorithms

- New fast electronics
- Variable threshold for surrounding cells
- Application of **machine learning methods**
  - Boosted Decision Trees (BDT) discrimination for the tau L1 trigger
  - Being tested with various variables across the layers

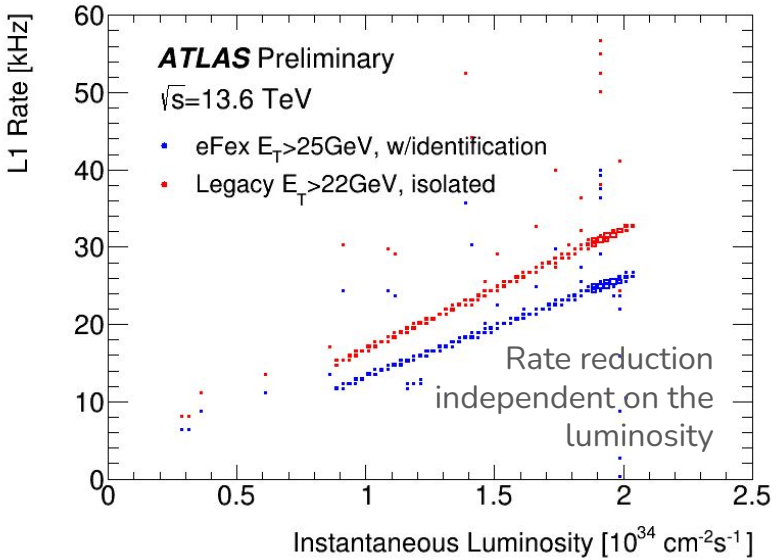




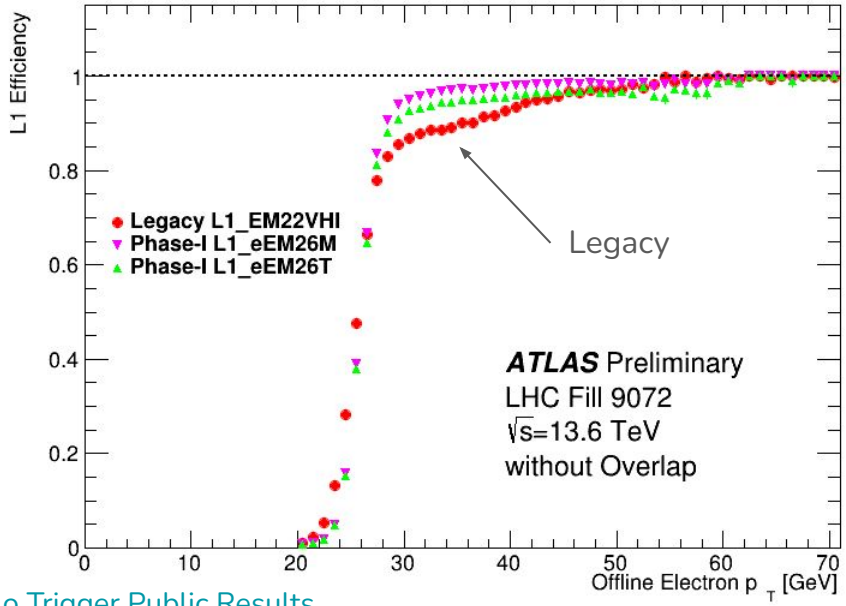
Summation of the cells with the same color serves as input variables to the BDT as well as the summation of the whole SuperCell in the upper picture.

L1Calo eFEX Performance

Phase-1 electron L1 trigger
- Trigger rate reduced by 20%
- Fully commissioned in 2023



- Sharper turn-on curve of the equivalent trigger item
- Higher efficiency in the lower energies
- **Improved purity**



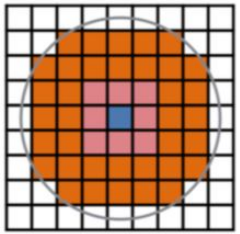
[L1Calo Trigger Public Results]

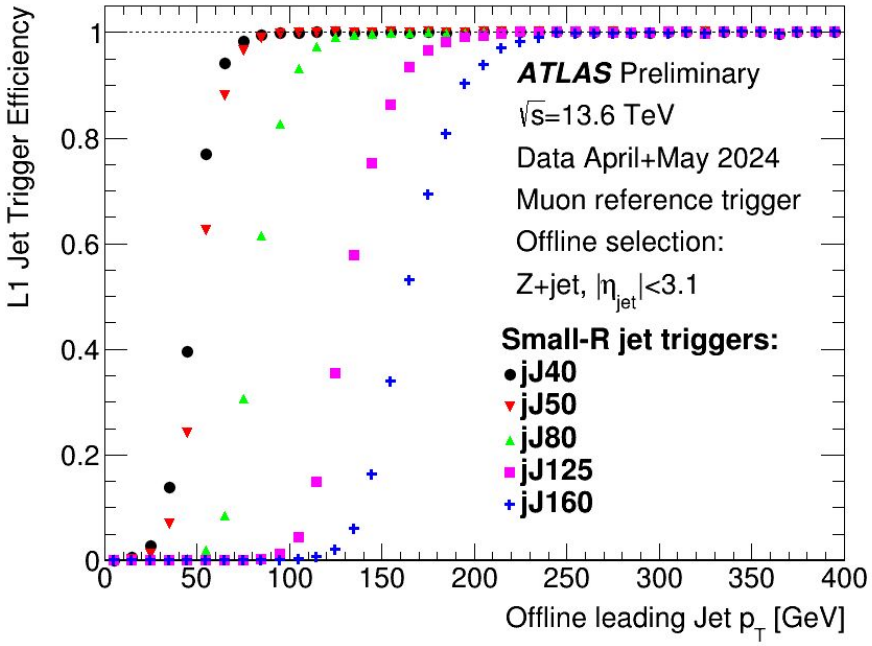
L1Calo jFEX Performance

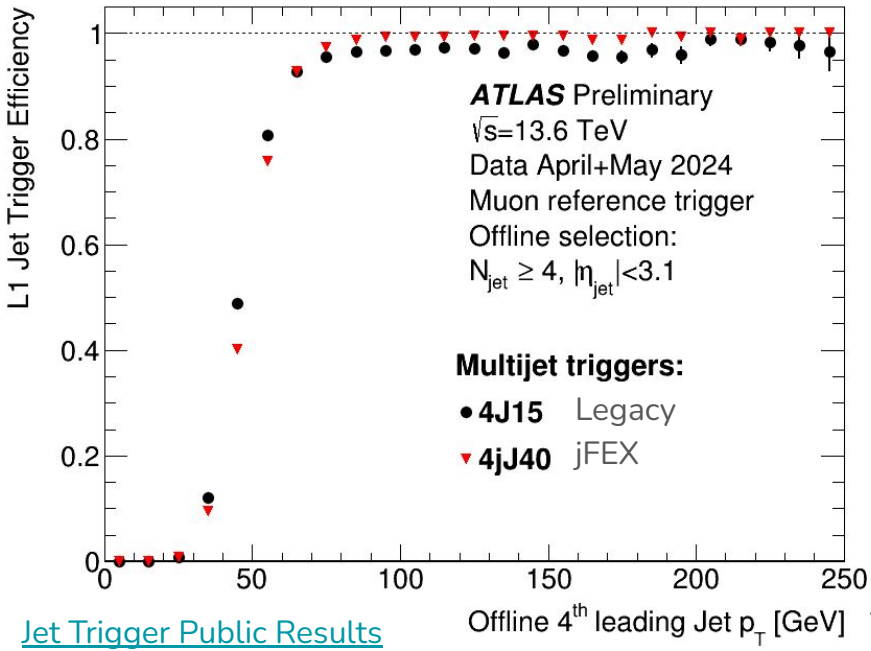
Phase-1 single and multi-jet L1 triggers
- Sharp turn-on curves of all jet triggers
- Higher granularity and improved algorithms allow **better resolution of close-by jets**

Run 2 —> Run 3

Cells:
Tower: 2×2 —> 1×1
Seed: 4×4 —> 3×3
Isolation: 8×8 —> 9×9



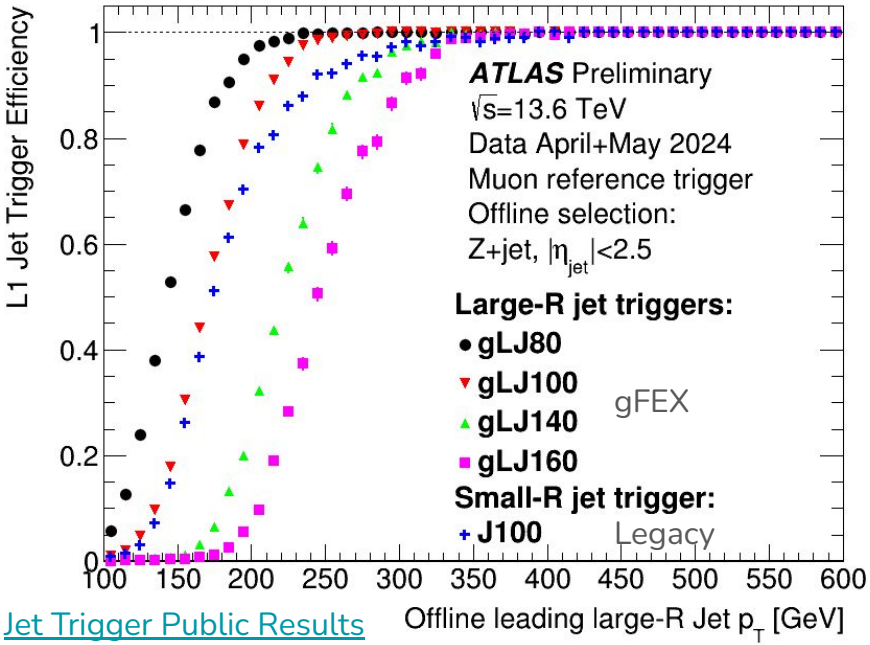




Jet Trigger Public Results

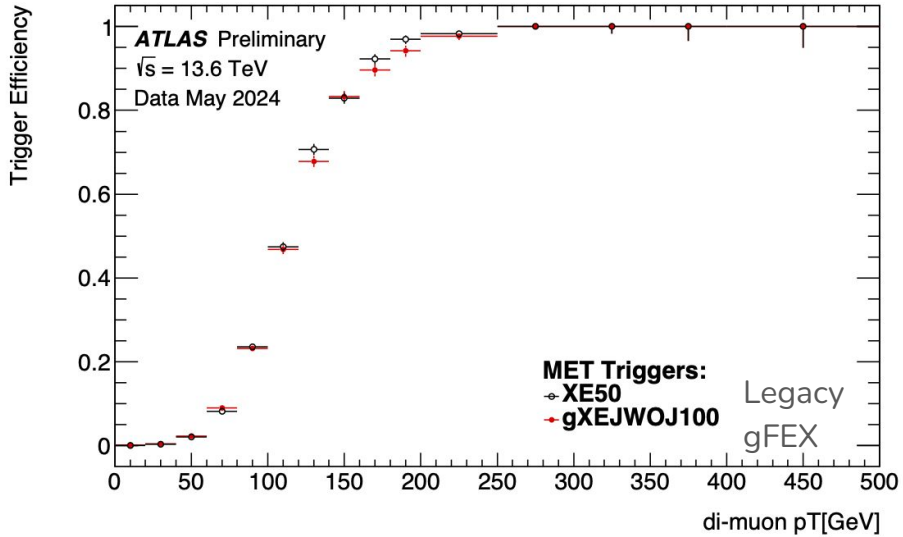
L1Calo gFEX Performance

- Large-R jet L1 triggers
  - Good turn-on curves in comparison with legacy small-R jets



Jet Trigger Public Results

- Missing transverse energy L1 trigger
  - Primary trigger is still coming from the jFEX
  - Commissioning the gFEX trigger in 2024
    - Similar efficiency
    - New calibration decreases the trigger rate

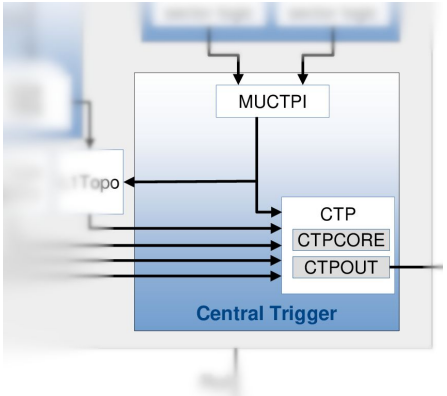


L1Calo Trigger Public Results

Level-1 Central Trigger

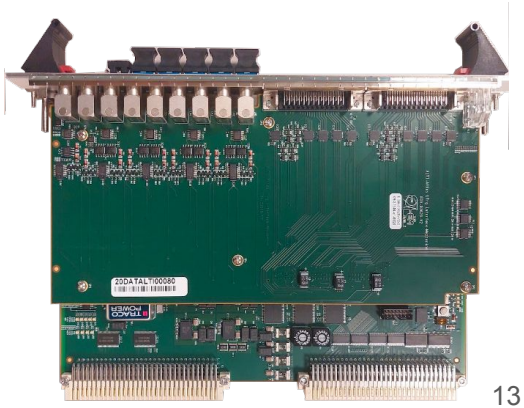
Calculation of the L1 Accept decision

- Central Trigger Processor (CTP) gathers inputs from the L1Muon, L1Calo, L1Topo, and forward detectors
  - New optical inputs and switch matrix
- Redesigned MUCTPI board
- New board for Trigger, Timing, and Control signals distribution (TTC)
  - ATLAS Local Trigger Interface (ALTI)



ALTI is a piece of the Central Trigger for each sub-system

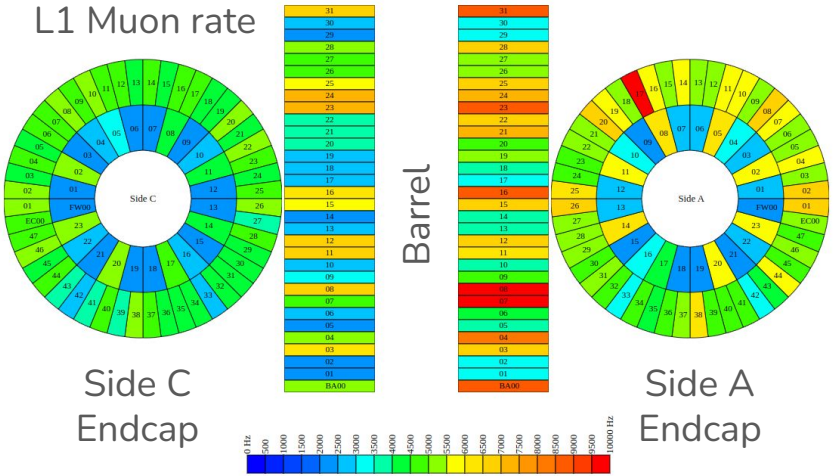
- Synchronization of most of the sub-detectors in ATLAS
- Aggregates three legacy boards in one
- Mini CTP functionality
  - Enables sub-systems to do tests with L1 trigger in their environment
  - Provides locally programmable:
    - trigger items, random triggers,
    - prescaling, deadtime,
    - pattern generator, etc.

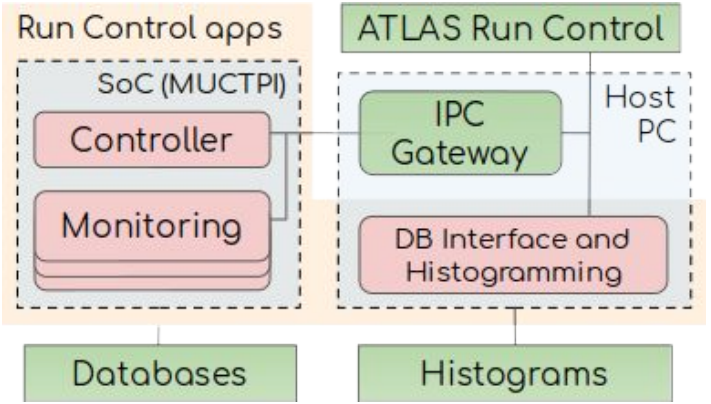


Phase-1 MUCTPI

Muon-to-CTP Interface upgrade

- Complete redesign
  - Single board replaces 18 legacy boards
  - Advanced electronic housing (VME -> ACTA)
  - Optical connections
- Capability to process up to four Muon candidates per sector in the end-cap TGC (two in legacy)
- Overlap removal between muon sectors
- Full muon trigger information for L1Topo
- Network isolated System-on-Chip (SoC) on the board
  - ATLAS Run Control software is running directly on SoC (unique in ATLAS)
  - Advanced monitoring
  - Low-level software is designed according to the high-level description of the firmware
  - XML description of the firmware registers
  - Linux operating system
  - Dedicated host computer (Host PC) acts as a gateway to the ATLAS technical network





Summary

Phase-1 ATLAS upgrade commissioning is advancing well

- Wide usage of new technologies
  - State-of-the-art processors and electronics (FPGAs)
  - Optical connections
- Redesigned electronics to exploit the finer granularity of the calorimeters
  - LAr digital trigger provides a fast and finer readout of the calorimeter
- Modular approach of the Feature Extractors of L1 Calo
  - Electron triggers commissioned in 2023
  - Feature extractors providing other primary triggers commissioned in 2024
- Integration of finer muon detectors in L1 trigger
  - All New Small Wheel sectors included
- Pioneering ways how to control and monitor electronic board operation
  - System on Chip on the MUCTPI, gFEX, and TREX boards
- High trigger efficiency while improving/maintaining turn-on curves and purity
- Majority of the hardware is designed to be easily adaptable or directly reused in the Phase-2 upgrade