The phase-1 upgrade of the ATLAS level-1 calorimeter trigger

September 5th, 2023
Technology and Instrumentation in Particle Physics
Emily Smith on behalf of the ATLAS collaboration


THE UNIVERSITY OF CHICAGO

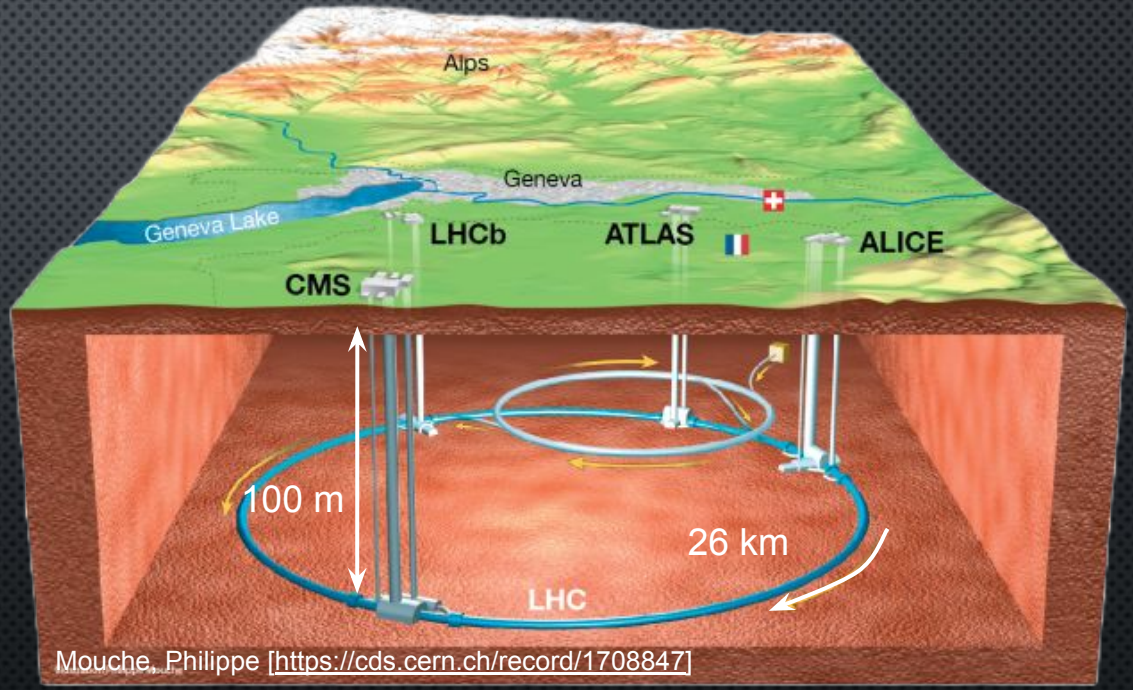
The Large Hadron Collider (LHC)

proton-proton collider

center of mass energy of 13.6 TeV

40 MHz interaction rate

most intense conditions result in **proton bunch collision, or "event" every 25 nanoseconds!**



Mouche, Philippe [https://cds.cern.ch/record/1708847]

The ATLAS Detector

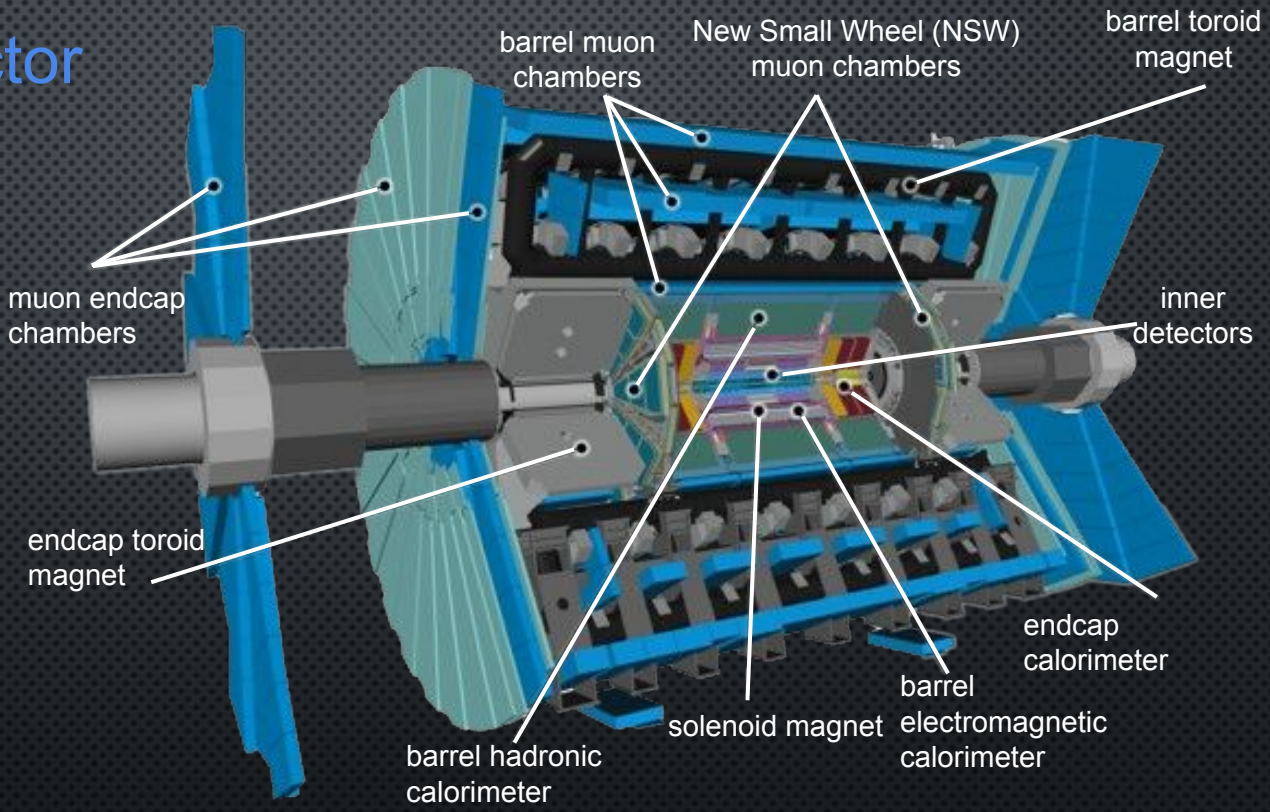
general purpose detector at the LHC

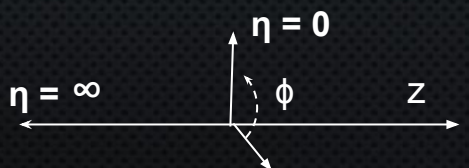
several upgrades installed in preparation for Run 3 which started in July 2022

p_T - momentum in the transverse plane

E_T^{miss} - missing transverse momentum, calculated from momentum conservation

ATLAS Run 3 [arXiv:2305.16623]





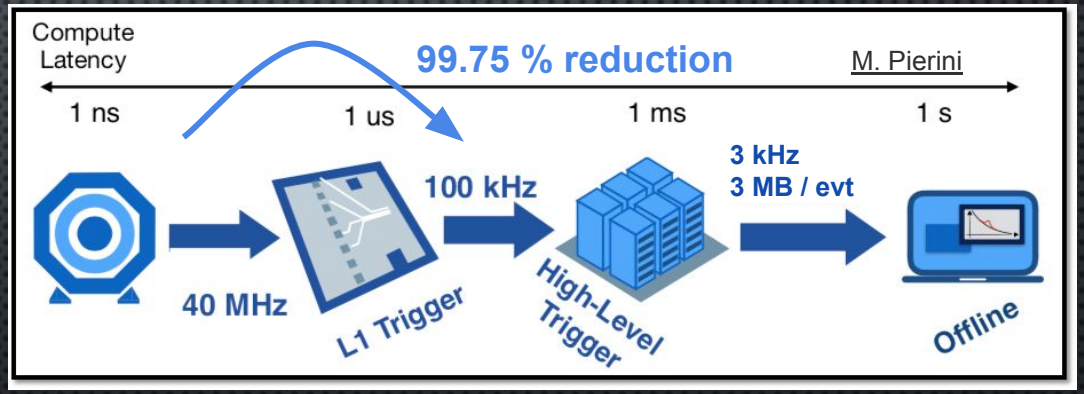
ATLAS Trigger and Data Acquisition

25 nanoseconds / event

140 million data channels

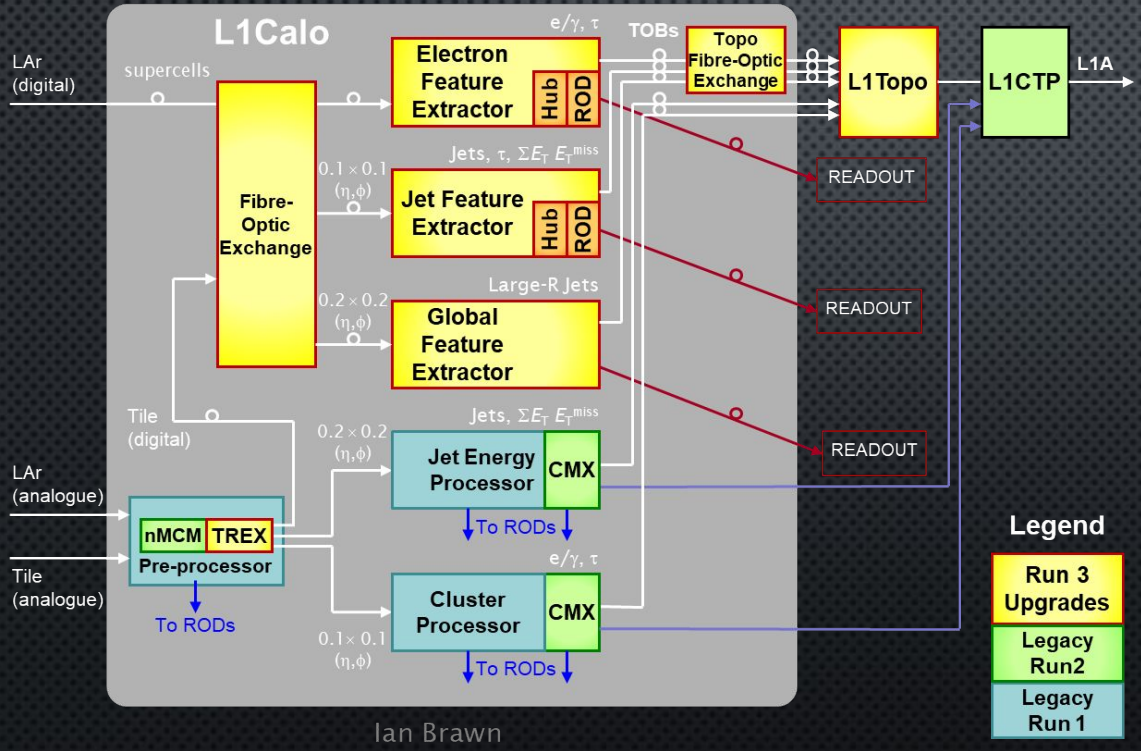
3 MB of data / event

~ a petabyte (10^{15}) of data / second



Level-1 hardware trigger system
- Custom hardware
- 100 kHz event accept rate
- 2.5 μs latency

Level-1 Calorimeter Trigger System



Ian Brawn

hardware based fixed-latency system

processes energy deposits from calorimeters

Calculates Trigger Objects (TOBs):

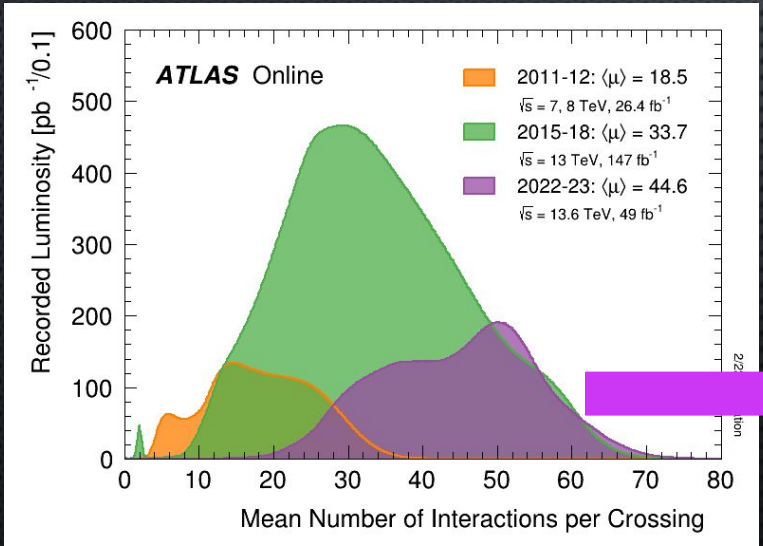
- electrons, photons, taus
- large radius jets, small radius jets
- missing E_T & ΣE_T

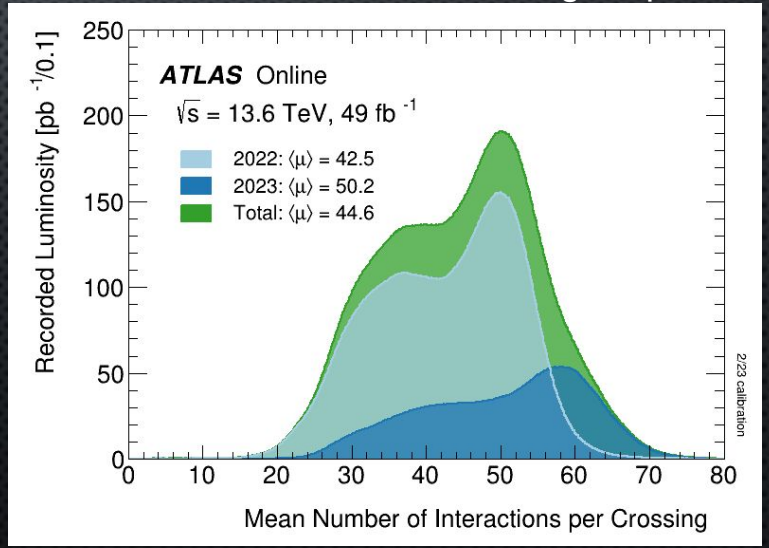
New **Feature Extractors** (FEXs) for upgraded algorithms and performance!

Run 3 L1Calo Upgrade Motivation

1) More extreme conditions in Run 3 with much higher pile-up

more recent collisions ⇒higher μ



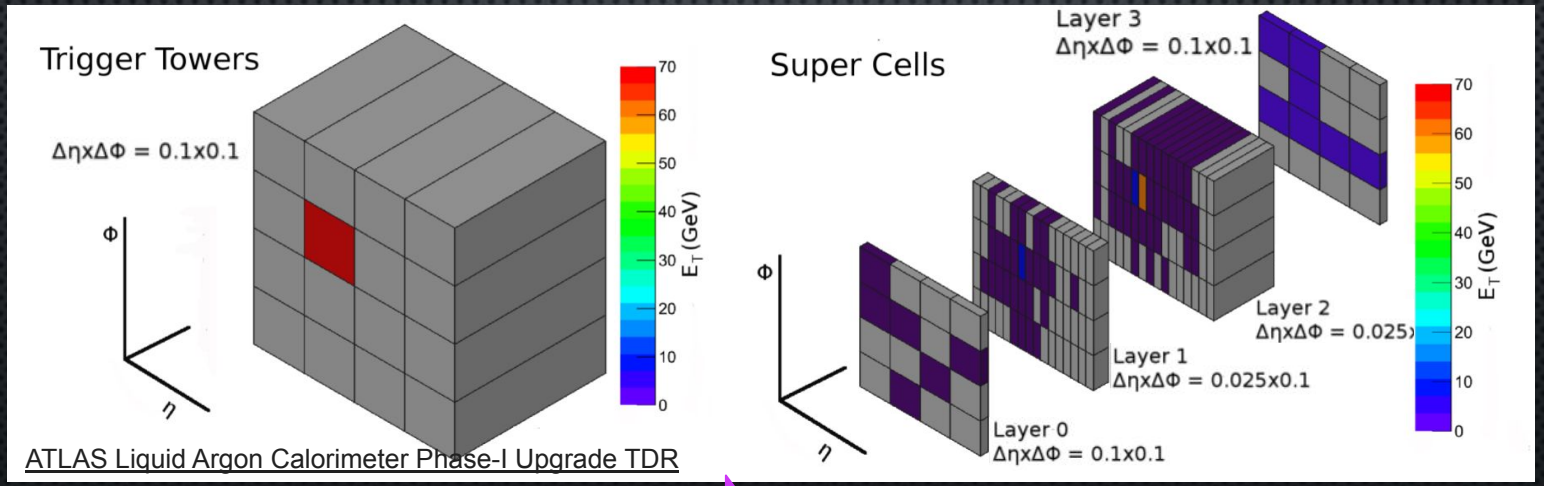


ATLAS Public Luminosity Results

Run 3 L1Calo Upgrade Motivation

1) More extreme conditions in Run 3 with much higher pile-up

2) Increased resolution and digital signal processing in the calorimeters



ATLAS Liquid Argon Calorimeter Phase-I Upgrade TDR

Run 2 → **Run 3**

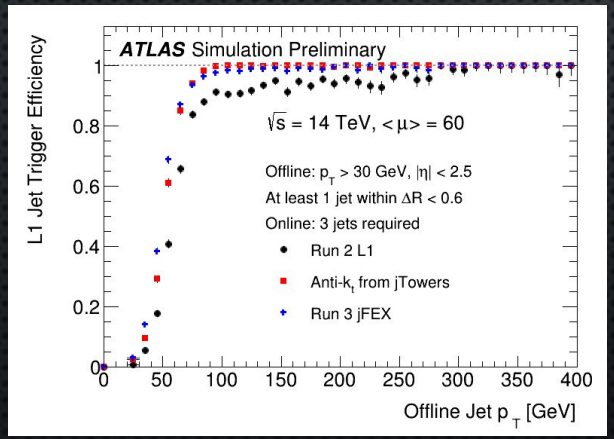
Run 3 L1Calo Upgrade Motivation

1) More extreme conditions in Run 3 with much higher pile-up

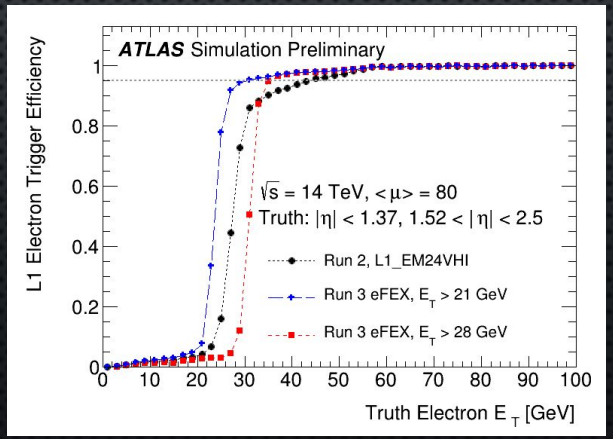
2) Increased resolution and digital signal processing in the calorimeters

3) More sophisticated hardware and algorithms that result in better expected performance!

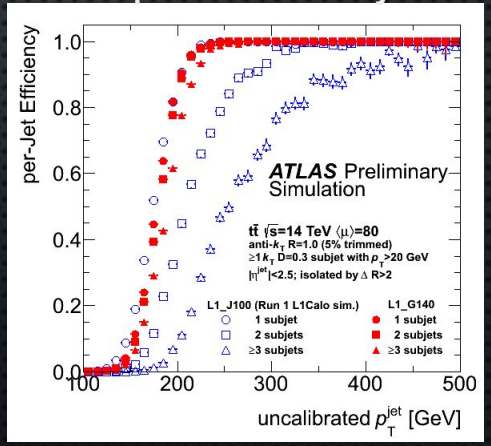
jFEX 3 jet events expected efficiency



eFEX electron events expected efficiency

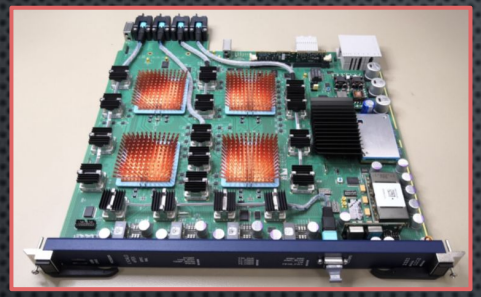


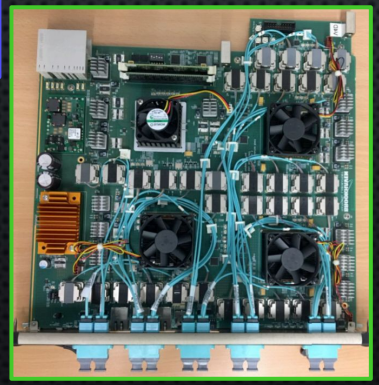
gFEX large radius jet events expected efficiency



ATLAS Public L1Calo Trigger Results

Custom L1Calo Hardware





electron Feature Extractor (eFEX)

- 24 ATCA modules
  - 4 Xilinx Virtex 7 processor FPGAs, 1 Xilinx Virtex 7 control FPGA
- Utilizes full calorimeter granularity to identify electron, photon, and tau objects

jet Feature Extractor (jFEX)

- 6 ATCA modules
  - 4 Xilinx Virtex Ultrascale+ FPGAs, 1 Zynq Ultrascale+ control FPGA
- Small radius jets, large radius jets, taus, missing E_T, and ΣE_T

global Feature Extractor (gFEX)

- 1 ATCA module
  - 3 Xilinx Virtex Ultrascale+ FPGAs, 1 Zynq Ultrascale+ SoC
- Entire calorimeter on one board, large radius jets, small radius jets, missing E_T, and ΣE_T

Custom L1Calo Hardware

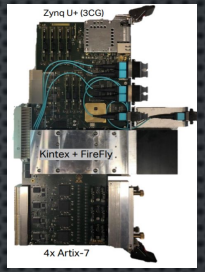
Fiber Optic Link Exchange (FOX)

- 6 boxes map ~7.5k fibers from LAr and Tile calorimeters to FEXs
- Topo-FOX maps ~1.5k fibers from L1Calo & L1Muon to L1Topo

All hardware fully installed and integrated with the calorimeter inputs and the ATLAS readout systems!

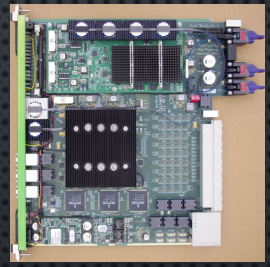
Tile Rear Extension (TREX)

- 32 modules
- Processes all Tile trigger towers
- Extension of the Run 2 module
- Bridge legacy and Run 3 systems



Hub & Readout Driver (ROD)

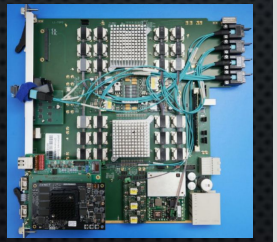
- 7 ATCA modules
- Sends clock and other signals, and collates and buffers data for one shelf of eFEX/jFEX modules



Level-1 Topological Trigger (L1Topo)

- 3 ATCA modules
  - 2 Xilinx Virtex Ultrascale+ FPGAs
  - 1 Zynq Ultrascale+ control FPGA
- Topological algorithms with FEX and L1Muon trigger object inputs

Details in L1Topo talk at 12:20 on Friday!



Integration and Commissioning

Intense process that started as early as 2019 in the Surface Test Facility at CERN

Surface Test Facility holds a full set of source modules, FEXs, and the destination L1Topo module, and provides a testing infrastructure not available at any one institution.

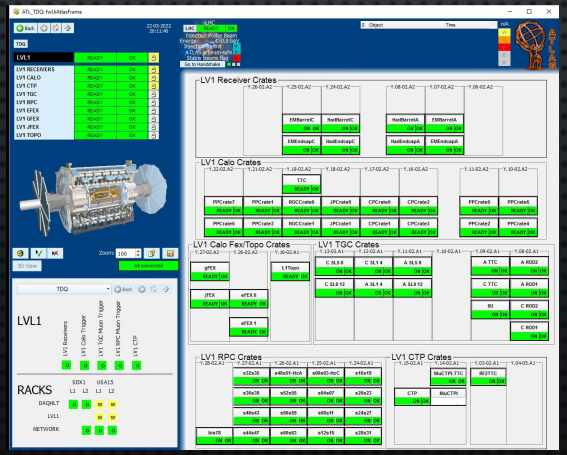
Installation in ATLAS

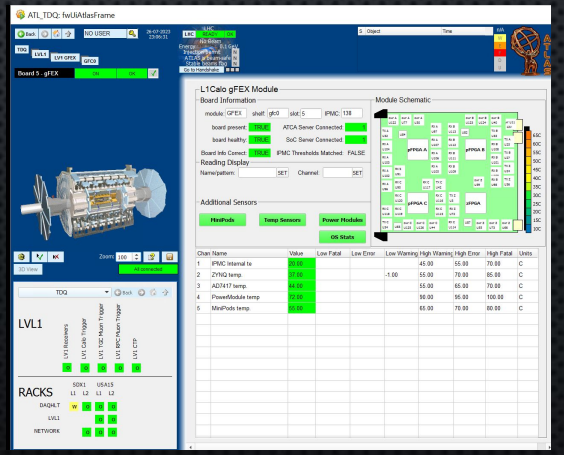
System fully installed in the ATLAS electronic cavern!

Full mapping has been validated all the way from the calorimeters through the FEXs and to L1Topo

Full monitoring of all systems through Detector Control Systems in the ATLAS Control Room

All systems operating within planned power and thermal parameters



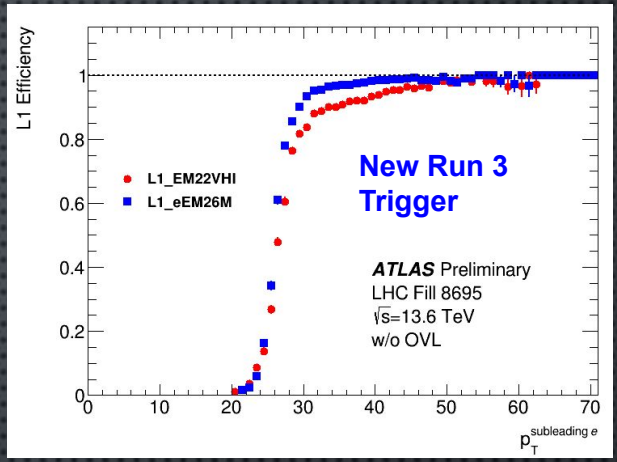


electron Feature Extractor (eFEX)

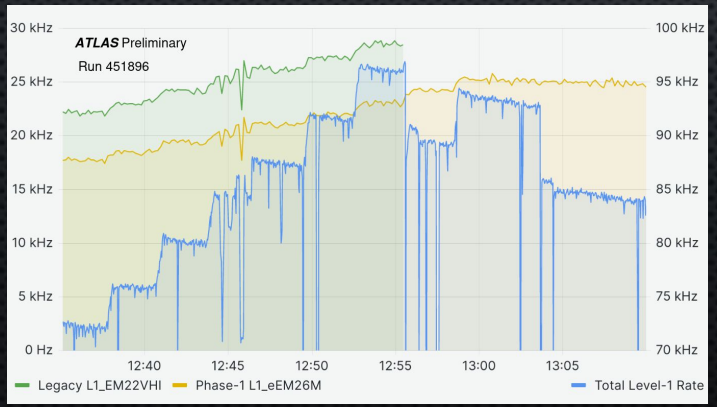
Electron, photon and tau triggers regularly used in ATLAS.

Reduces rate by ~5kHz while increasing efficiency!

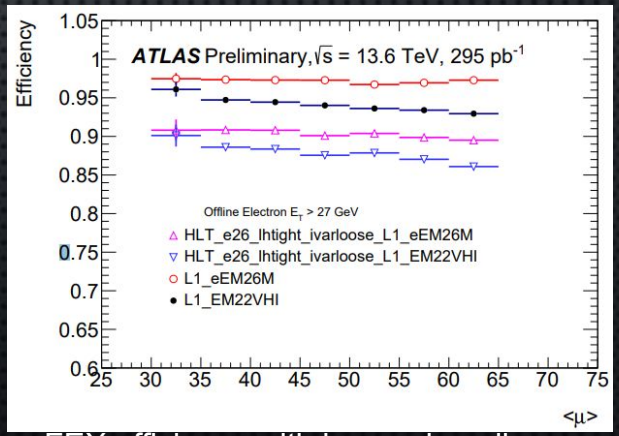
Legacy triggers disabled in May 2023!



Single electron trigger efficiencies in data
[L1CaloPublicResults]



Rate reduction with new Run 3 triggers
[L1CaloPublicResults]



eFEX efficiency with increasing pile-up
[Electron trigger performance]

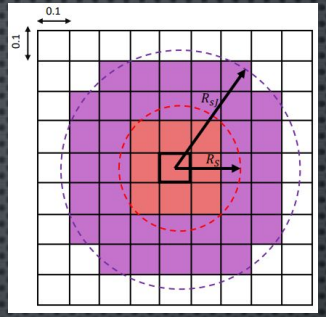
jet Feature Extractor (jFEX)

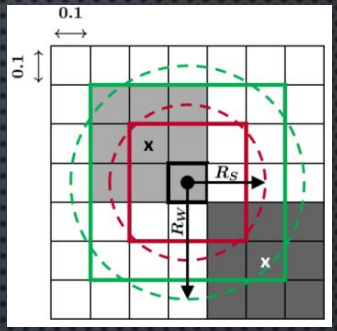
Takes advantage of increased calorimeter granularity and provides increased scope for calibration

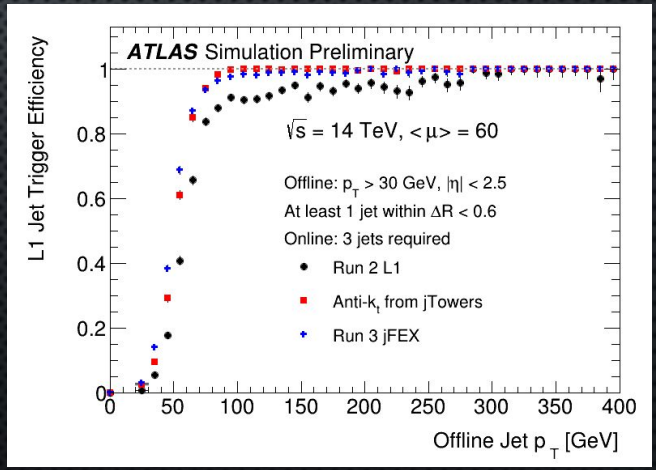
Algorithmically complete, parameters being tuned

E_T^{miss} triggers under commissioning

Small-radius jet triggers enabled in July 2023 alongside legacy jet triggers!







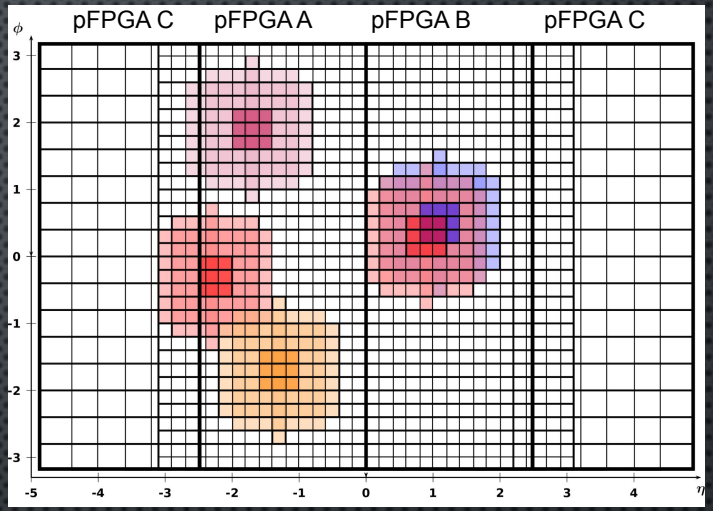
Simulated jFEX 3-jet efficiencies [L1CaloPublicResults]

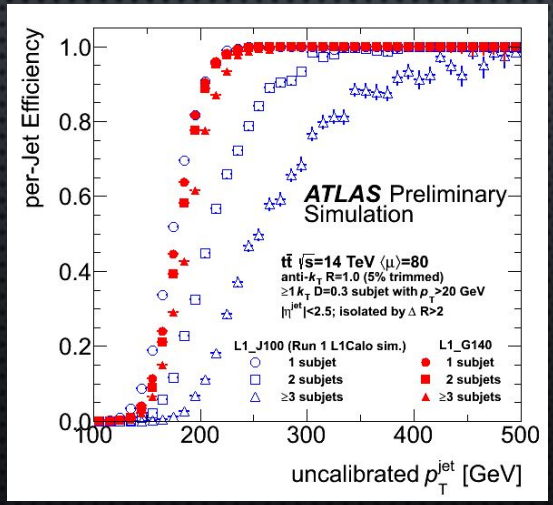
global Feature Extractor (gFEX)

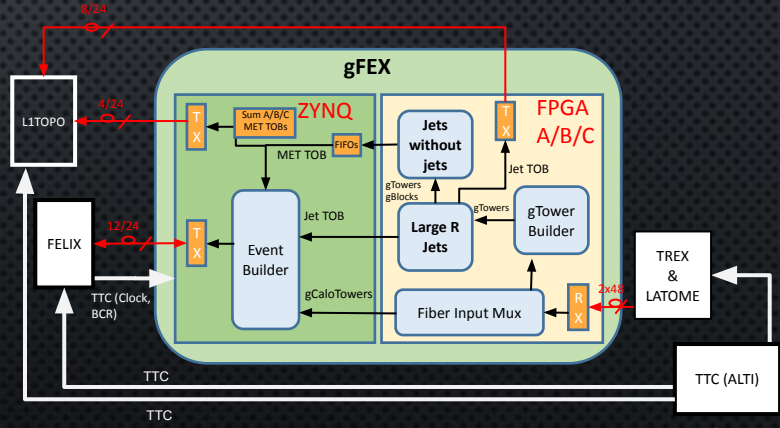
Large-radius jet, small radius jet and baseline E_T^{miss} trigger algorithms fully implemented, and parameters are being tuned

Utilizes a System on Chip and custom OS

Small-radius jet triggers enabled July 2023 alongside legacy jet triggers!







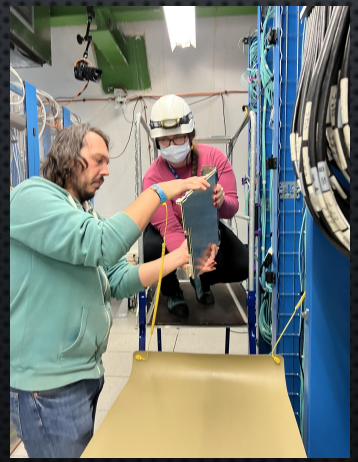
Simulated gFEX large radius jet efficiencies [L1CaloPublicResults]

Summary

15 institutions worldwide with experts at home institutions and at CERN!

Several years of work to commission and install the currently running system!

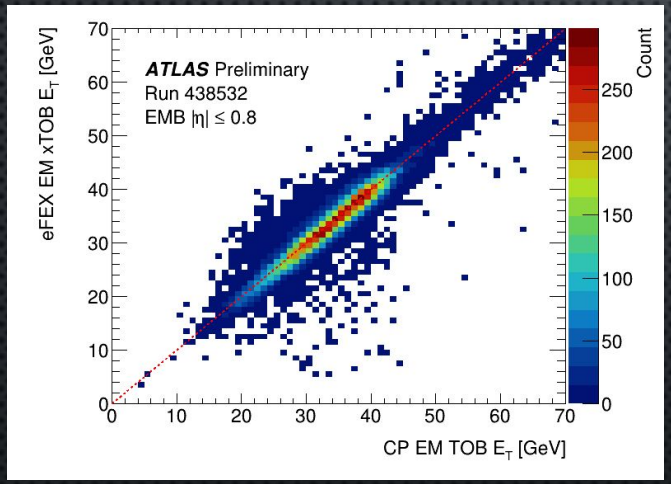
Plans to continue commissioning of the remaining new Run 3 triggers, hope to be fully enabled in 2024!



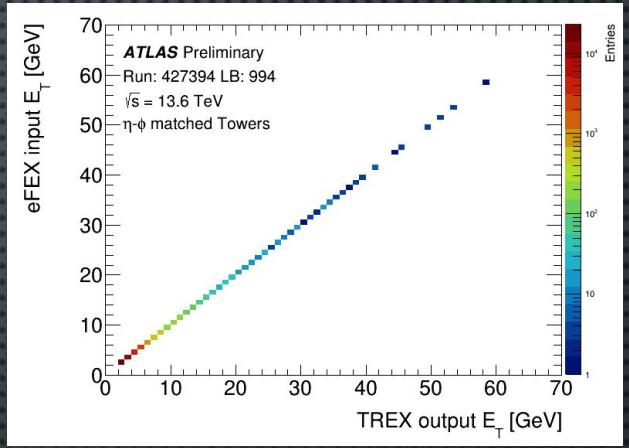
Backup

Validation with Legacy System

eFEX vs legacy TOB energy



TREX readout vs eFEX inputs



Legacy module with legacy readout compared to legacy module with felix readout