The Phase-1 Upgrade of the ATLAS Level-1 Calorimeter Trigger

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On behalf of the ATLAS Collaboration

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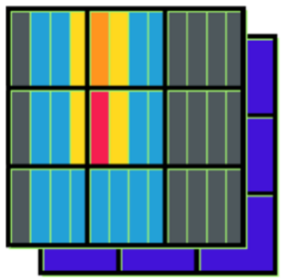
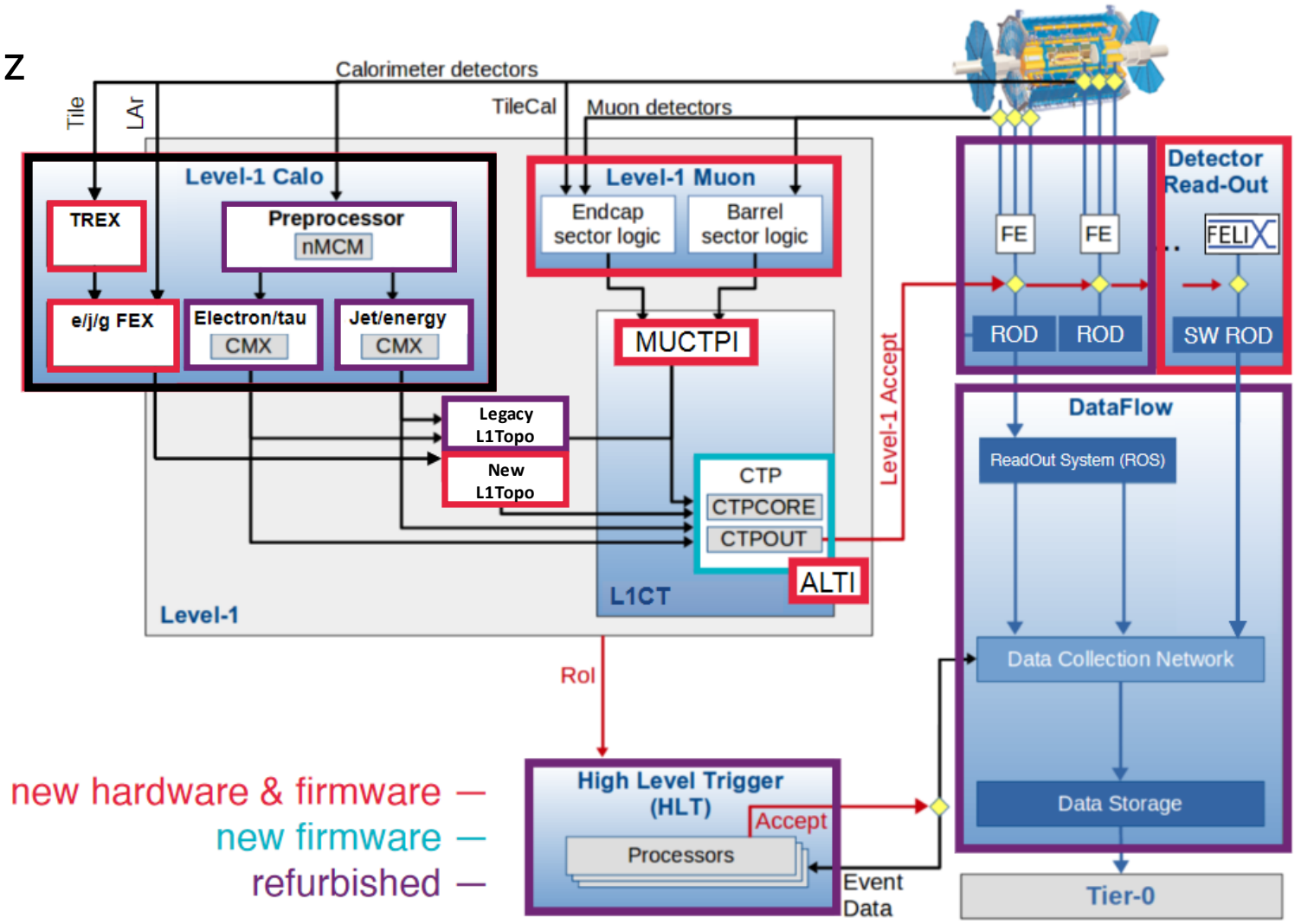


ATLAS Trigger and Data Acquisition

- Proton-proton collisions at 40 MHz
- Multi-level trigger system
- Level-1 Trigger
  - Custom Hardware
  - Accept rate of 100 kHz
- High-Level Trigger (HLT)
  - Software-based
  - Accept rate of 1.5 kHz
- Latency of max. 2.5us



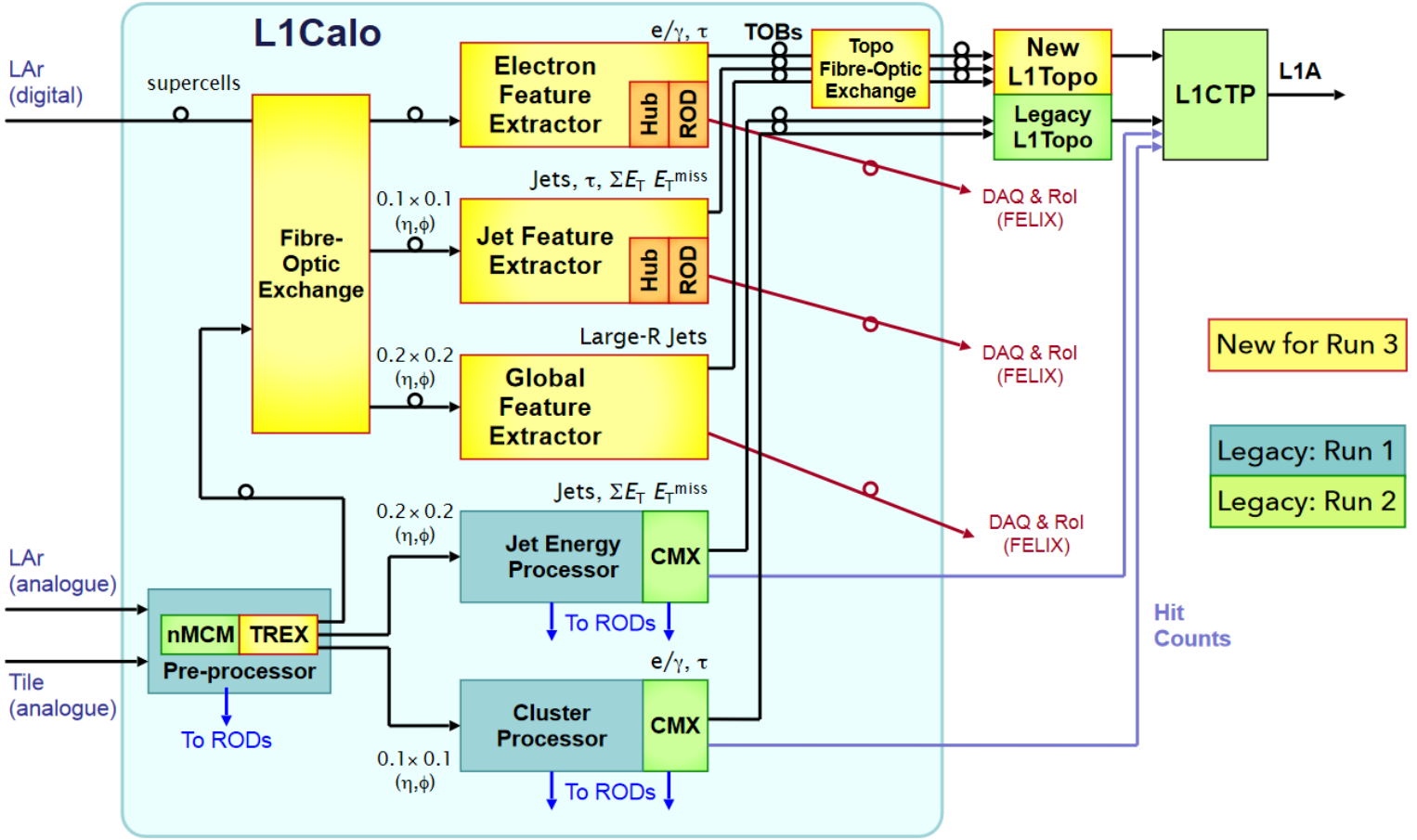
Overview of the ATLAS Trigger and Data Acquisition

Overview of L1Calo

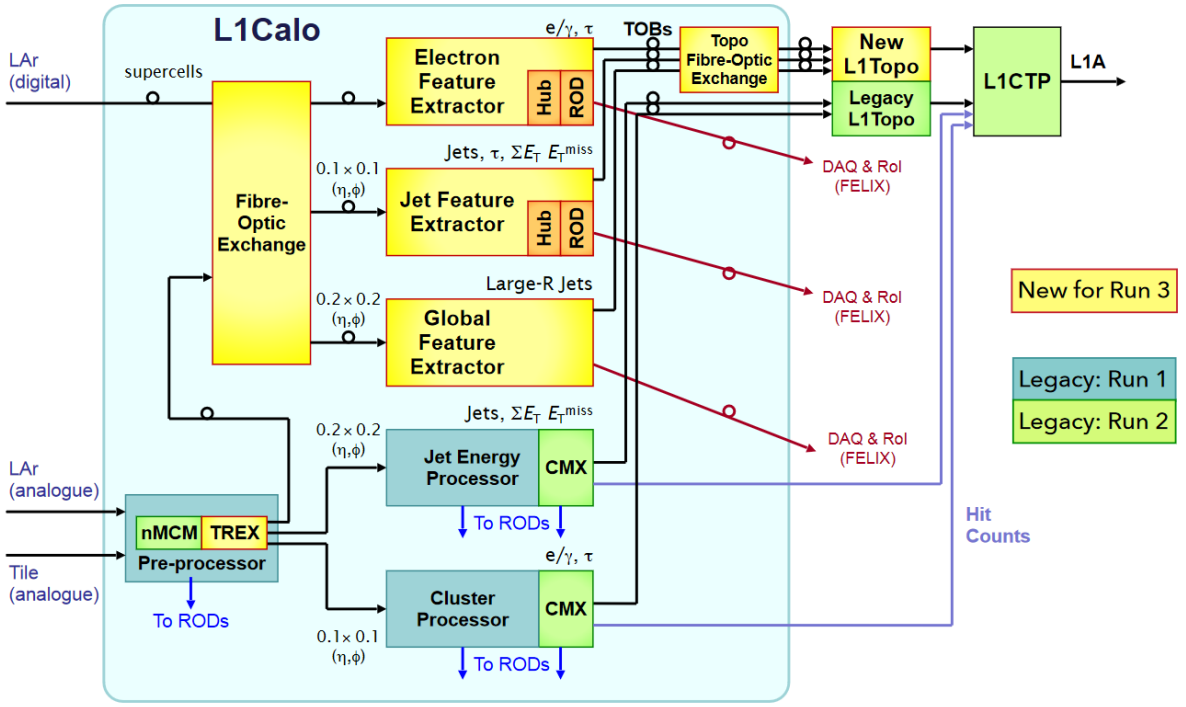
- Hardware-based, pipelined system
- Processing signals from the ATLAS Liquid Argon (LAr) and Tile calorimeters
- Identifies e, γ, τ candidates
- Small and large-R jet candidates
- Missing E_T and Σ E_T

- Upgrade:
  - New Feature Extractor (FEX) processors
  - Upgraded Level-1 Topological (L1Topo) processor
  - New Tile Rear Extension (TREX)
  - New readout system: Front-End Link eXchange (FELIX)

- The L1Calo Upgrade and legacy systems will run in parallel during commissioning

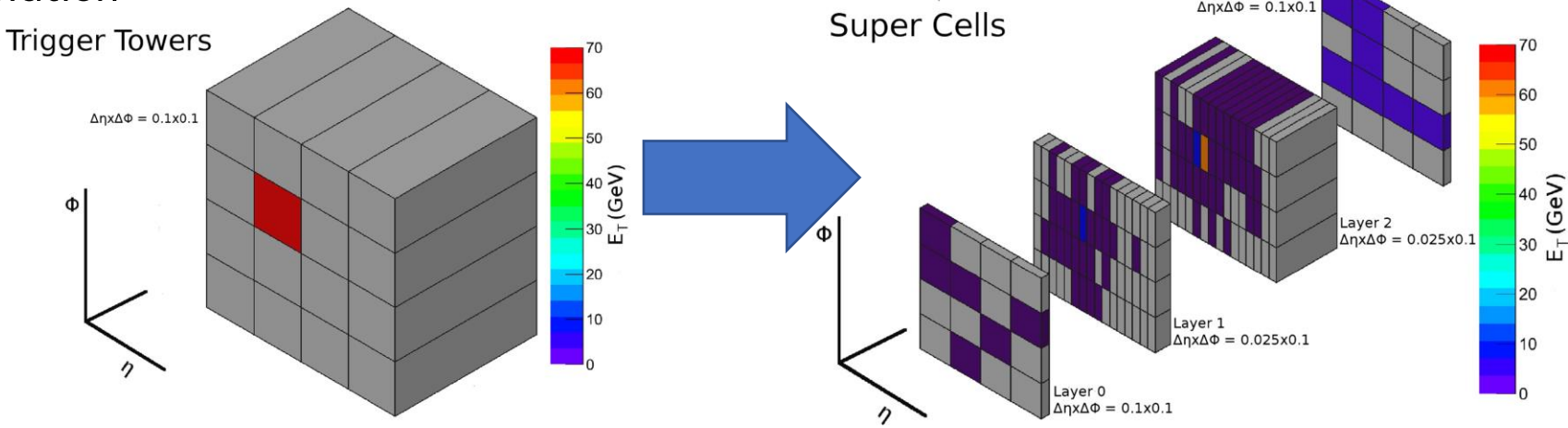


Why upgrade?



- Challenging high-pileup environment

- New calorimeter trigger electronics from LAr
  - Run 2 used lower granularity Trigger Tower ($\Delta\eta\times\Delta\varphi = 0.1\times0.1$) information
  - 10x granularity increase with Super Cells ($\Delta\eta\times\Delta\varphi = 0.025\times0.1$)
  - Higher resolution and shower information

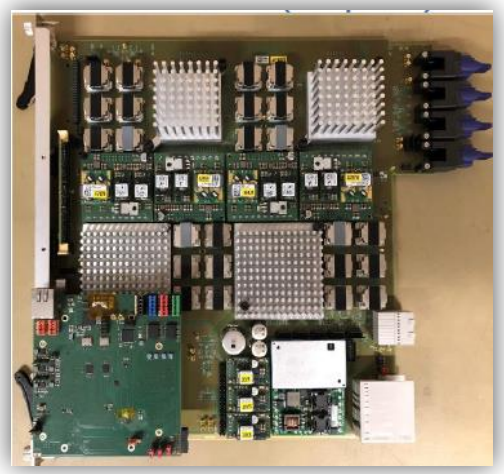


- More sophisticated algorithms
  - Better performance

- Reduce Level-1 rate while maintaining low selection thresholds

Hardware overview

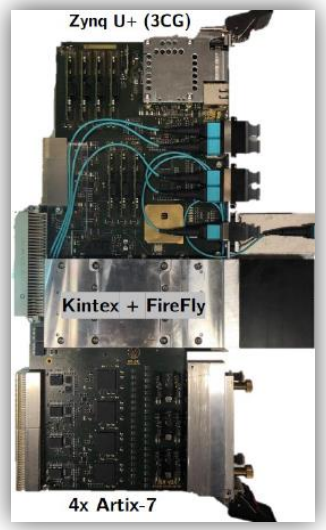
- Electron Feature Extractor (eFEX)
  - 24 modules in 2 ATCA shelves
  - Takes advantage of the new higher granularity of the EM calorimeter
  - e, γ, τ identification

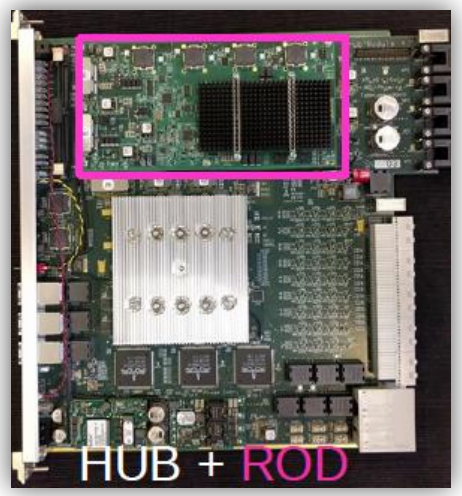


- Jet Feature Extractor (jFEX)
  - 6 ATCA modules
  - Taus, Large- and small-R jets
  - Missing E_T and Σ E_T

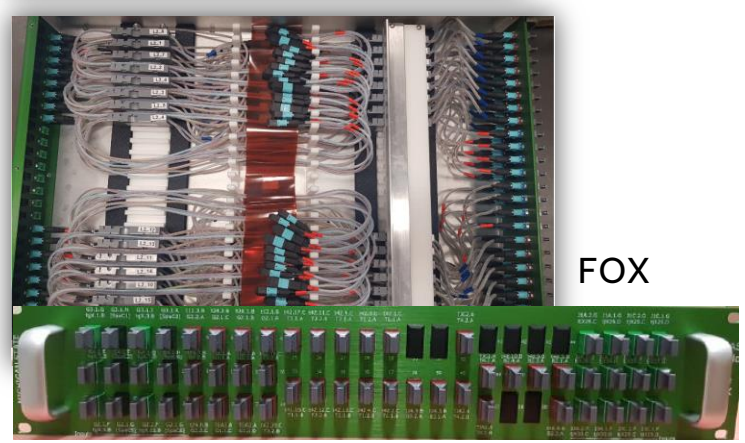
- Global Feature Extractor (gFEX)
  - 1 ATCA module
  - Large-R jets
  - Missing E_T and Σ E_T
  - Receives inputs from the entire calorimeter systems

Hardware overview





Topo-FOX

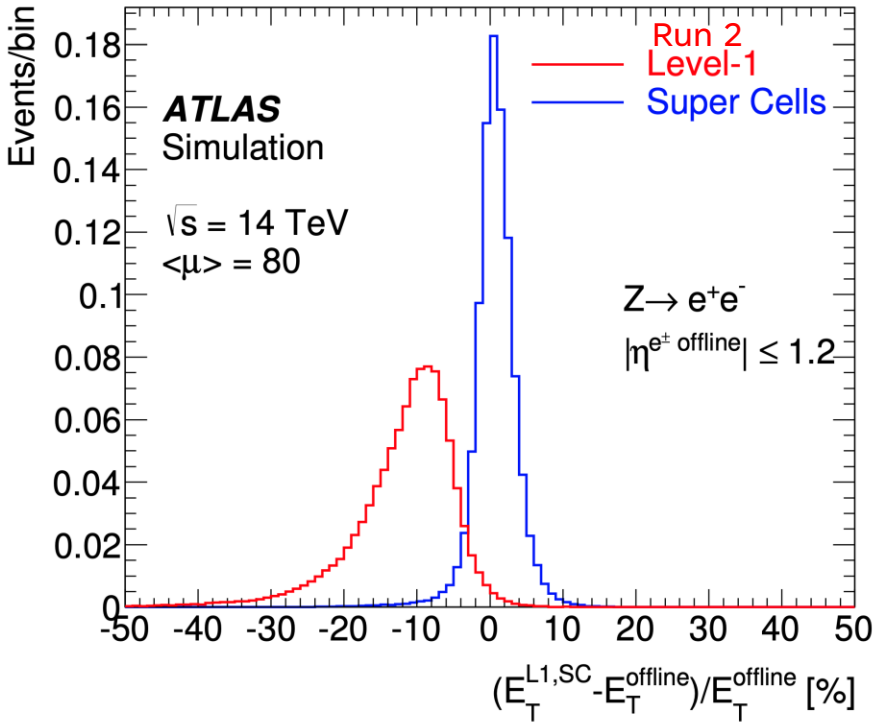


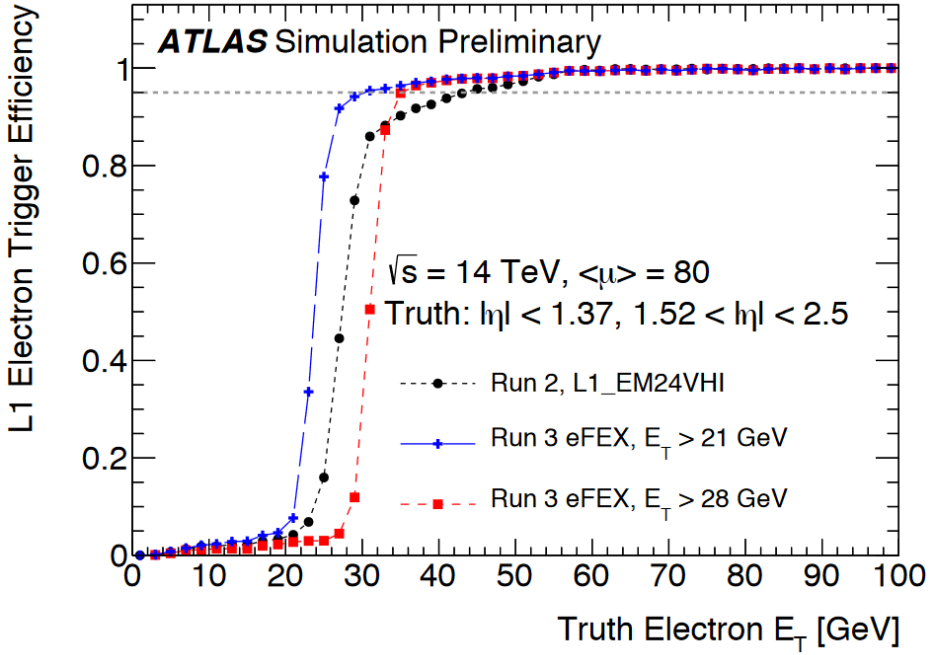
FOX

- Level-1 Topological Trigger (L1Topo)
  - 3 ATCA modules
  - Receives inputs from the FEXes + L1 Muon
  - Performs topological algorithms and multiplicity trigger
- Tile Rear Extension (TREX)
  - 32 VME-RTM modules
  - Physical extension of the Legacy PreProcessor
  - Provides digitized hadronic inputs from TileCal to the FEXes (optical) and the Legacy system (electrical)
- Hub+Readout Driver (ROD)
  - 7 ATCA modules
    - 2x2 in eFEX, 2x in jFEX 1x in L1Topp shelves
  - Distributes timing and trigger information to eFEX/jFEX/L1Topo
  - Buffers and sends readout data to the DAQ
- Fiber-Optic Exchange(FOX)
  - 6 boxes
  - Map calorimeter inputs to FEXes
  - ~7500 fibers
  - FEX-L1Topo box (Topo-FOX)
    - ~1500 fibers

Expected Performance

- Significant improvement to the energy resolution w.r.t existing L1 E_T
- Improved efficiency and sharper turn-on curves
- eFEX performance
  - Using full detector resolution
  - Z → ee simulation comparing the upgrade with the existing system
  - Thresholds chosen to match the Run2 rate

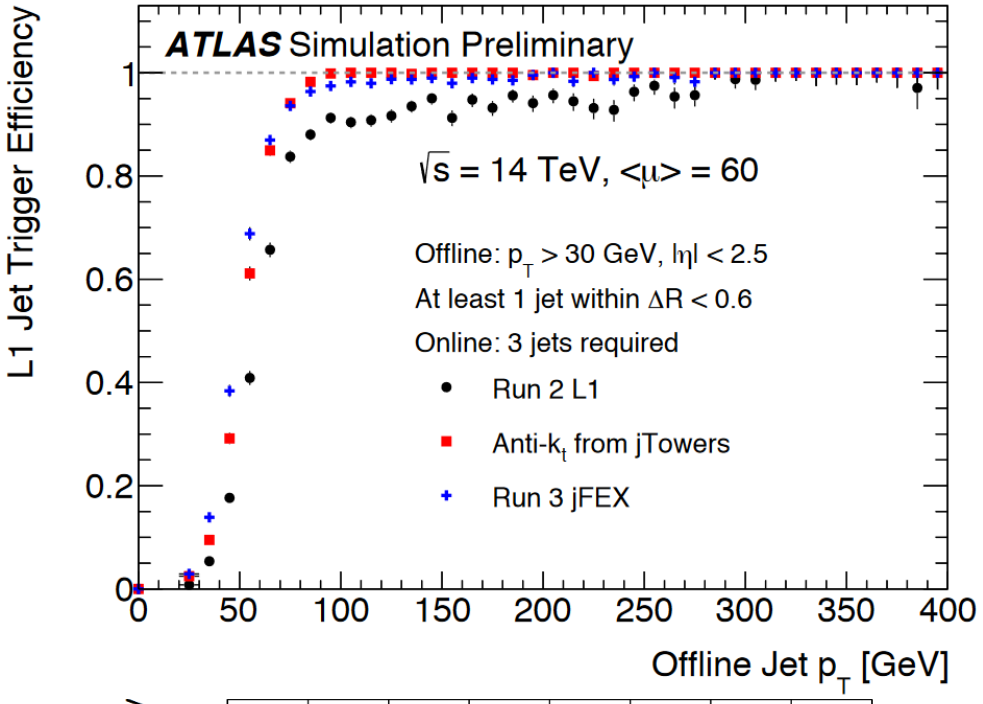


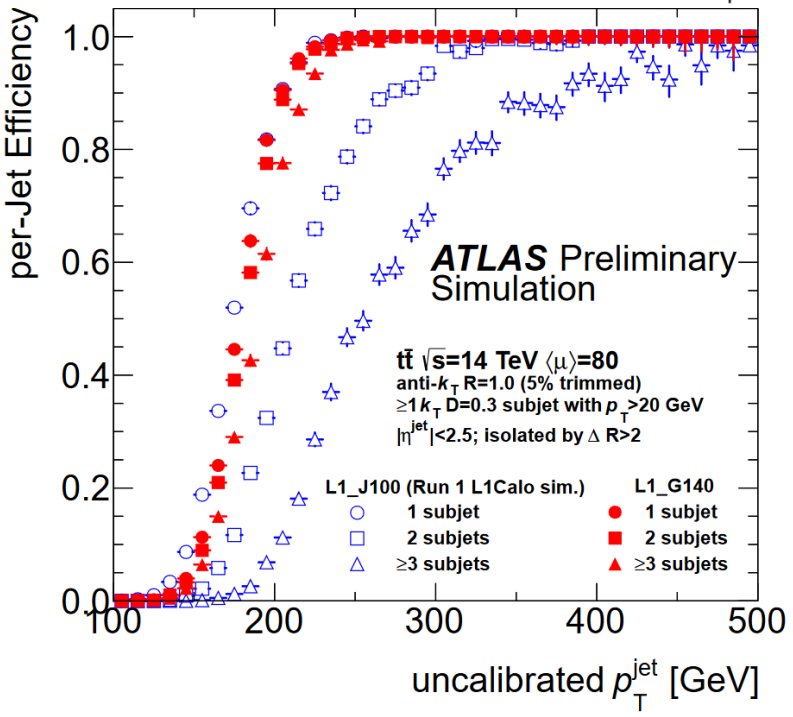


Expected Performance

- jFEX performance:
  - Per-jet efficiencies using HH→ bb(bb) simulation
  - New circular 0.9 x 0.9 sliding window
  - Comparison with offline Anti-kt and Run 2 L1
  - Thresholds of the methods tuned to have matching trigger rates

- gFEX performance:
  - Per-jet efficiencies using pair-produced top quark simulation with a pileup level of <mu> = 80
  - Seeded cone algorithm with a nominal jet radius of R = 1.0





Installation in ATLAS

- All racks and ATCA shelves installed
  - 3x racks
  - 2x eFEX, 1x jFEX, 1x gFEX, 1x L1Topo shelves
- Control and monitoring PCs installed
  - 4x PCs for the Detector Control System
  - 2x PCs Monitoring/ControlHub
  - 2x PCs for JTAG connectivity
- Optical fibers and network cabling routed between the modules
  - ~ 6000 fibers
- Modules undergo validation at home institutes and CERN at the Surface-Test-Facility (STF) before installation

eFEX with Hub+ROD

gFEX testing

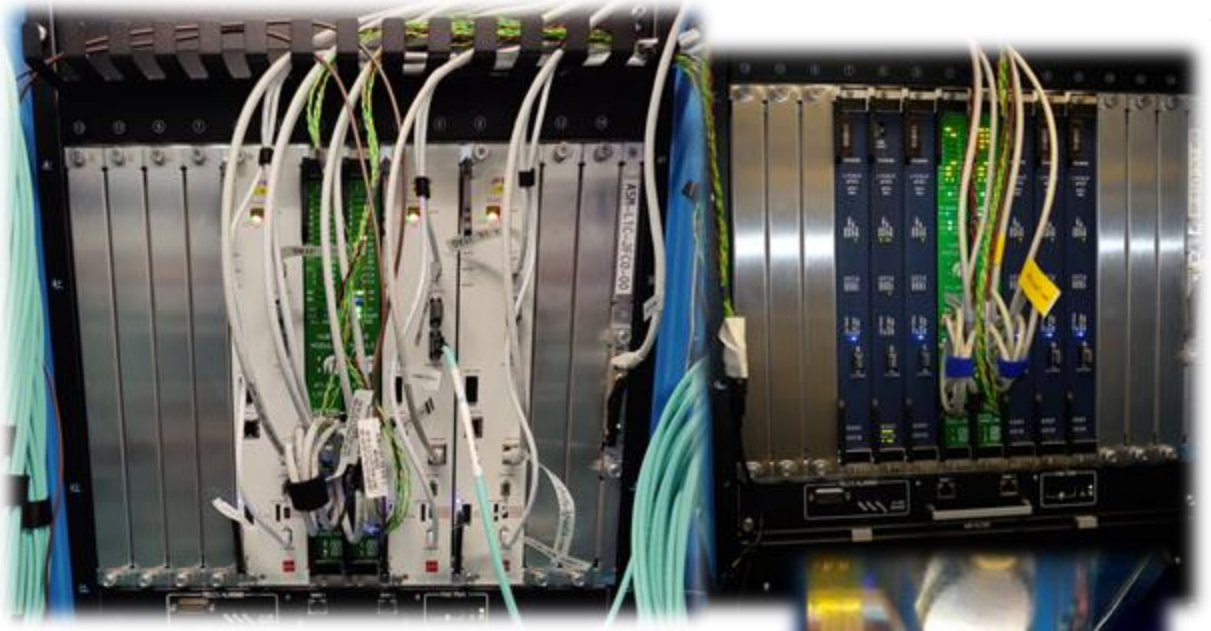
Installed gFEX module

Topo-FOX installation

Installation in ATLAS

- gFEX (1/1) and TREX (32/32) fully installed!

- eFEX
  - 6 module installed (out of 24)
  - 18 to be installed in 2022
- jFEX
  - 3 module installed (out of 6)
  - 2 further modules to be installed soon
- L1Topo
  - 1 module to be installed by the end of the year
- Hub + ROD
  - 4 modules installed
  - Rest of the modules at CERN and ready to be installed
- FOX + TopoFOX
  - 6 Boxes
  - FOX fully installed and connected
  - TopoFOX installed and soon to be connected



e/jFEX shelves with Hub+RODS

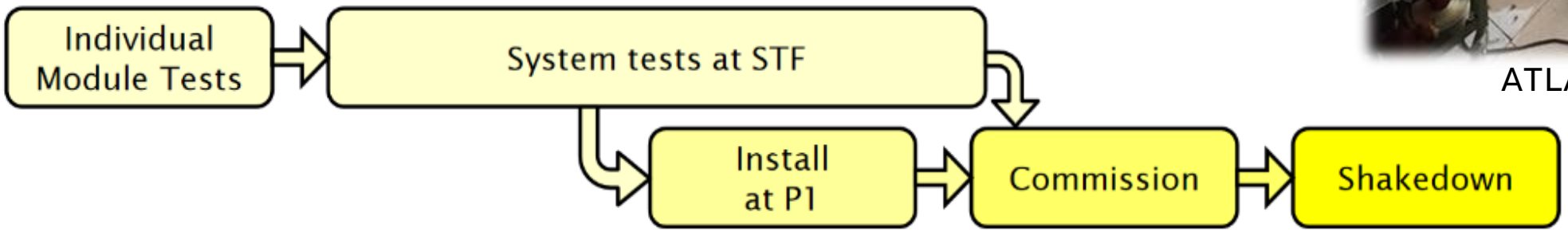
Fully equipped TREX crate

Commissioning

- Surface Test Facility (STF)
  - Test-rig for single modules
  - Full vertical slice of L1Calo modules
  - Full DAQ infrastructure available
- Dedicated for firmware and software integration
- Achieved combined slice with all modules!
  - Synchronous readout and event building
  - Successful transmission tests

STF

ATLAS P1



We are here for most of the modules

Commissioning in ATLAS

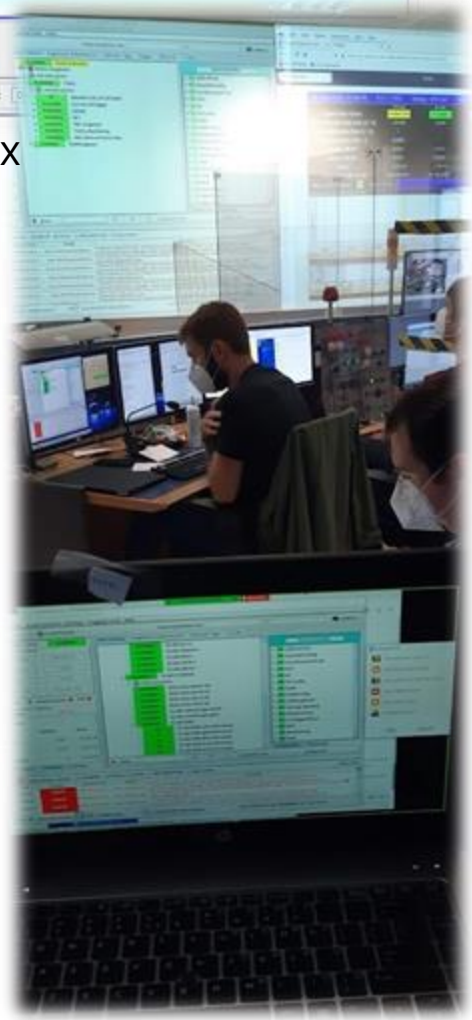
- ATLAS – P1
  - Integration into ATLAS run control software
  - Fiber mapping and connectivity debugging
  - Bit-Error Rate Testing of the high-speed transmission links
  - Integration with the Calorimeters
  - Timing-in the full Trigger system

- Module control integrated in the ATLAS software

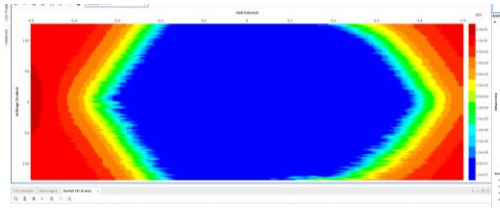
- TREX running in ATLAS with 100 kHz readout
- Installed FEX modules successfully integrated in ATLAS

- Preparing for first LHC Pilot Beams!

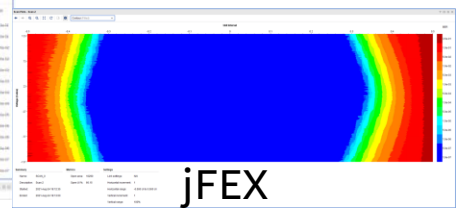
High-rate readout including TREX



ATLAS Control Room during L1Calo Tests

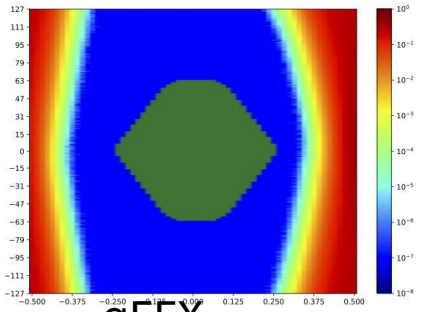


eFEX



jFEX

BER results



gFEX

Summary

- Huge effort from experts all around the world!
  - 15 institutes from USA and Europe
  - Experts working at CERN and remotely
- Installation and commissioning activities ramping up in ATLAS
  - Transmission tests and mapping validation ongoing
- Firmware development of all modules in good shape and close to completion
- Ready to test with LHC pilot beams