The Phase-I Upgrade of the ATLAS level-1 calorimeter trigger

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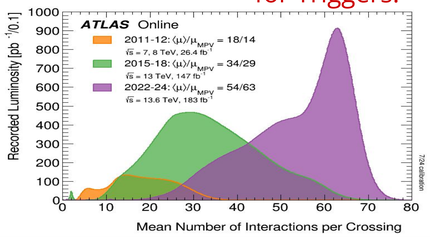
LHC Run 3 Conditions

- 13.6 TeV center-of-mass energy
- Increased interactions per bunch crossing (pileup)
- More signal events Good!
- More background, increased event complexity Challenging for Triggers!



ATLAS TDAQ: Collisions to Recorded Data

Bunches of protons collide at a rate of 40 MHz

Level-1

100 kHz Level-1 Accepts (L1As) with a latency ≲ 2.5 μs

HLT

~3 kHz recorded data with a latency O(1s)

Inputs from the ATLAS Calorimeters

Liquid Argon Calorimeter

Electromagnetic and hadronic (|η| ≳ 1.6) calorimeter Run 3: on Detector digitization of signal to pass to L1Calo

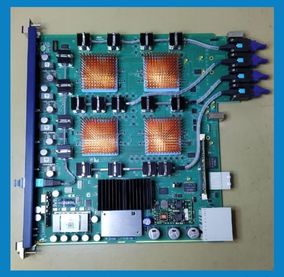
Tile Calorimeter

Hadronic Calorimeter Analog output signal, fed via PreProcessor into L1Calo's **T**ile **R**ear **EX**tension (TREX)

Fiber Optic Exchange (FOX)

Data is passed through FOX and sent via complex cable mapping of ~7500 fibers to the Phase-I Feature Extractors (FEXes)

The Level-1 Calorimeter Trigger Feature Extractors



Production eFEX module

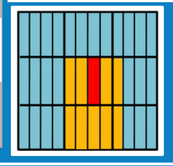
Electron Feature Extractor (eFEX)

Δη x Δφ	0.025 x 0.1
max |η|	2.5
processor FPGA	Virtex 7
control FPGA	Virtex 7
# pFPGA per board	4
# boards	24

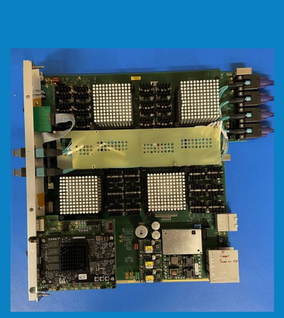
Algorithms

e/γ: identify energy deposits characteristic of isolated e/γ in a 0.3 x 0.3 window. Improvement from legacy: finer resolution and isolation capability

τ: similar algorithm to e/γ, with Boosted Decision Tree implemented for isolation working points



eFEX seed finder algo (right) and an eFEX tau cluster in the first two EM layers (left)



Production jFEX module

Jet Feature Extractor (jFEX)

Δη x Δφ	0.1 x 0.1
max |η|	4.9
processor FPGA	Virtex Ultrascale+
control FPGA	Zynq MPSoC
# pFPGA per board	4
# boards	6

Algorithms

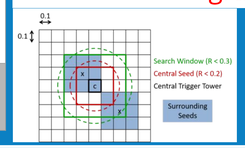
Jets: R=0.4 jets identified by a sliding window algorithm

$E_T^{Miss}/\Sigma E_T$: Summed by φ/η slice

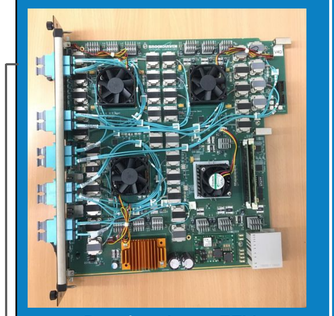
τ_{had}: seeds identified as for jets

e: electron triggers outside of eFEX range

Improvement from legacy: more dynamic algorithms, pileup correction, finer granularity



The jFEX seeding process, used to find local maxima in the jFEX jet algorithm



Production gFEX module

Global Feature Extractor (gFEX)

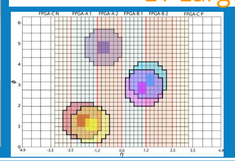
Δη x Δφ	0.2 x 0.2
max |η|	4.9
processor FPGA	Virtex Ultrascale+
control FPGA	Zynq MPSoC
# pFPGA per board	3
# boards	1

Algorithms

Jet Finder: Using a R=0.3 small jet as a seed, identifies a R = 0.9 large jet, including pileup subtraction

$E_T^{Miss}/\Sigma E_T$: Novel Jets without Jets algorithm. Split into hard and soft terms of missing/total energy in xy plane

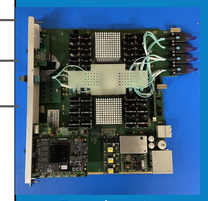
Improvement from legacy: Entirely new subsystem, no legacy equivalent. Providing L1 Large R Jet Triggers



Large R (R=0.9) jets from gFEX Jet Finder Algorithm. Darker regions in the middle of each jet show the small R jet used as a seed

Trigger Objects (TOBs)

L1 Topological Processor (L1Topo)



Production L1Topo module

Inputs	FEXes and L1Muon
processor FPGA	Virtex Ultrascale+
control FPGA	Zynq MPSoC
# pFPGA per board	2
# boards	3

Algorithms

Sort/select/no sort: reformat TOBs, sort or select based on p_T/E_T

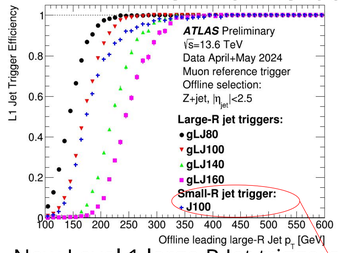
Decision: calculations based on multiple objects from different FEXes/Muon to check if condition is met

Multiplicity: count # objects passing threshold in region

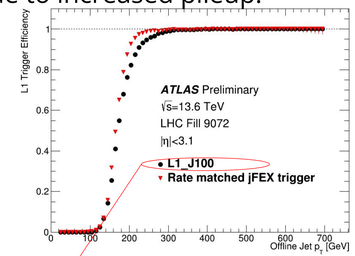
Onward to Central Trigger Processor (CTP)!

L1Calo Performance in Run 3

Turn on curves have gotten sharper, all while maintaining the same or better rate in an increasingly difficult trigger environment due to increased pileup.

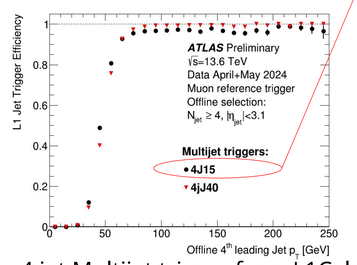


New Level 1 large R Jet triggers from gFEX compared to legacy small R Jet

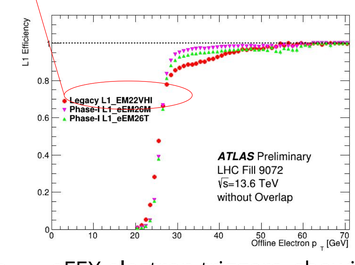


jFEX small R Jet trigger rate matched to legacy, showing sharper turn on

Legacy



4 jet Multijet trigger from L1Calo compared to equivalent legacy trigger



eFEX electron triggers showing a better turn and providing 6 kHz of rate saving compared to legacy

References

ATLAS Collaboration. "The ATLAS experiment at the CERN Large Hadron Collider: a description of the detector configuration for Run 3". *JINST*, **Vol 19**. P05063. DOI: 10.1088/1748-0221/19/05/P05063

ATLAS Collaboration Luminosity Public Results, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3

ATLAS Collaboration L1CaloTrigger Public Results, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

ATLAS Collaboration Jet Trigger Public Results, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetTriggerPublicResults