# gFEX Calorimeter Trigger Algorithm Validation and Early Performance in the ATLAS Detector

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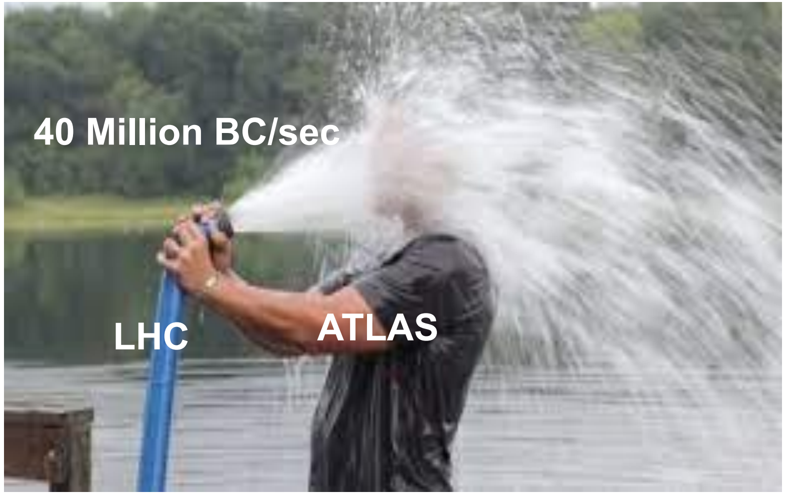
DPF-Pheno Parallel Talk

# Overview

- ATLAS at LHC - The  need for a trigger system
- L1Calo trigger system
- gFEX Motivation and Hardware
- Description of gFEX Algorithms
- Validation work
- Run 3 so far - FW testing
- Conclusions

# Experiments at the LHC - Why do we need a trigger?

- In Run 3 of the LHC, bunch crossings occur at a rate of 40 MHz
    - If we were to try to save all this data, we would need storage for many terabytes per second
- Majority of events are “boring”
    - Simple quark or gluon scattering, how do we find the good stuff?
- We need to throw out some events, but how do we choose??
    - Answer: We implement a trigger system!



# ATLAS Detector Hardware Trigger System - L1Calo

- The Level 1 Calorimeter Trigger System is the hardware trigger for ATLAS
- Responsible for reducing the acceptance rate from 40 MHz down to ~100 kHz before passing events to the High Level Trigger (HLT)
- Primary features for Phase I upgrades (Run 3) are the feature extractors, or FEXes

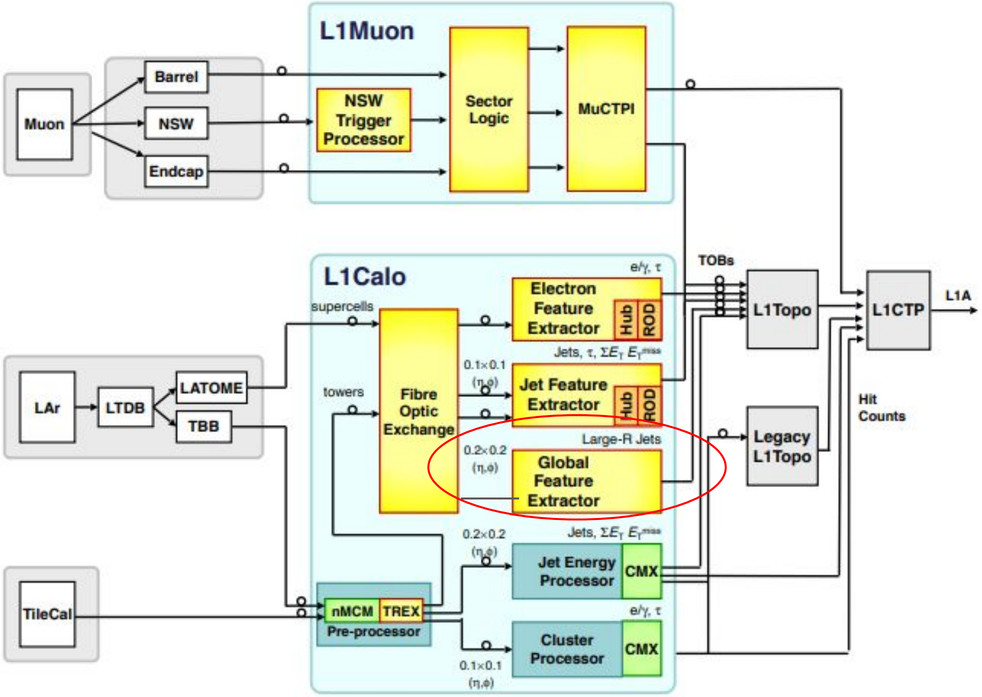
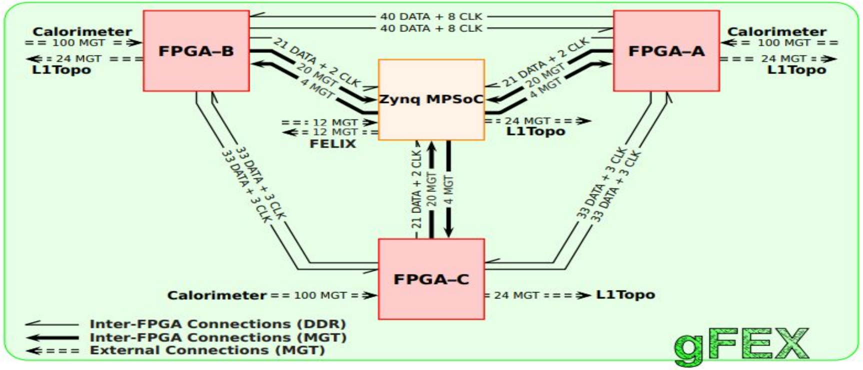


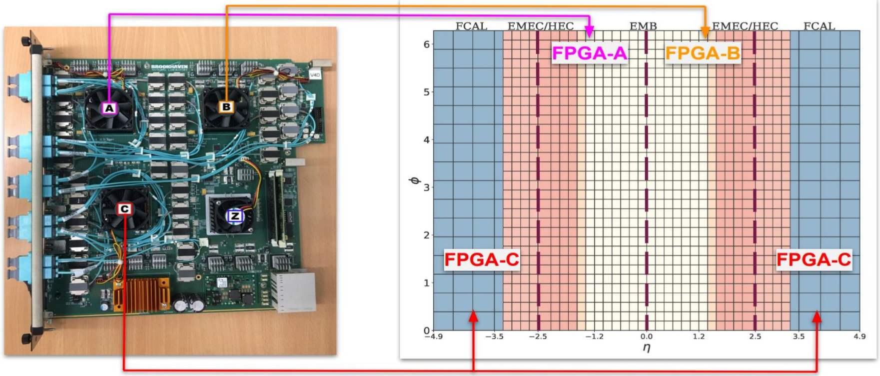

Figure from [1]

# Motivation for the Global Feature Extractor (gFEX)

- Primary purpose of gFEX is to enhance L1 sensitivity to key physics channels to aid in Beyond Standard Model (BSM searches)
- Main triggers: Large Radius Jets (R~1.0) and Missing Transverse Energy (MET)
  - Large R Jets can be indicative of boosted objects, which occur both in SM and BSM processes
  - MET is a signature in several BSM searches
- Additional items/perks
  - Event by event pile up correction (PUC) for Large R Jets
  - Small R Jets (gives some jet substructure info)
  - Total Energy (TE) possible via the MET algorithm
  - Alternative MET algorithms (Pitt group!)

# gFEX Architecture




- 1 Advanced Telecommunications Computing Architecture (ATCA) board covers the entirety of the detector (up to |η| < 4.9)
  - Unique for gFEX, other FEXes have many boards
- 3 Xilinx Virtex Ultrascale+ processor Field Programmable Gate Arrays (FPGAs), labeled A,B,C
- 1 Zynq Ultrascale+ FPGA for control and global calculations

Figures from [1]

# Starting point for gFEX Algorithms - Tower Builder

- The basis for all gFEX algorithms are the 0.2x0.2 gTower cells
- Inputs to gFEX (gCaloTowers), contain $E_T$ from both calorimeters, which are summed together appropriately via complicated mapping
- gBlocks are 3x3 squares of gTowers, which are identified as small radius jets (Note: R=0.3 for gFEX small R jets)

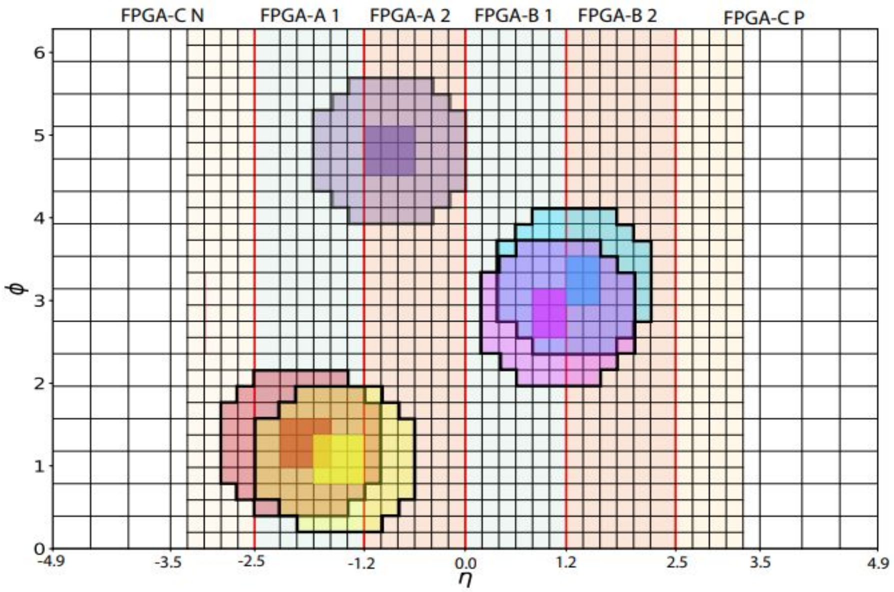
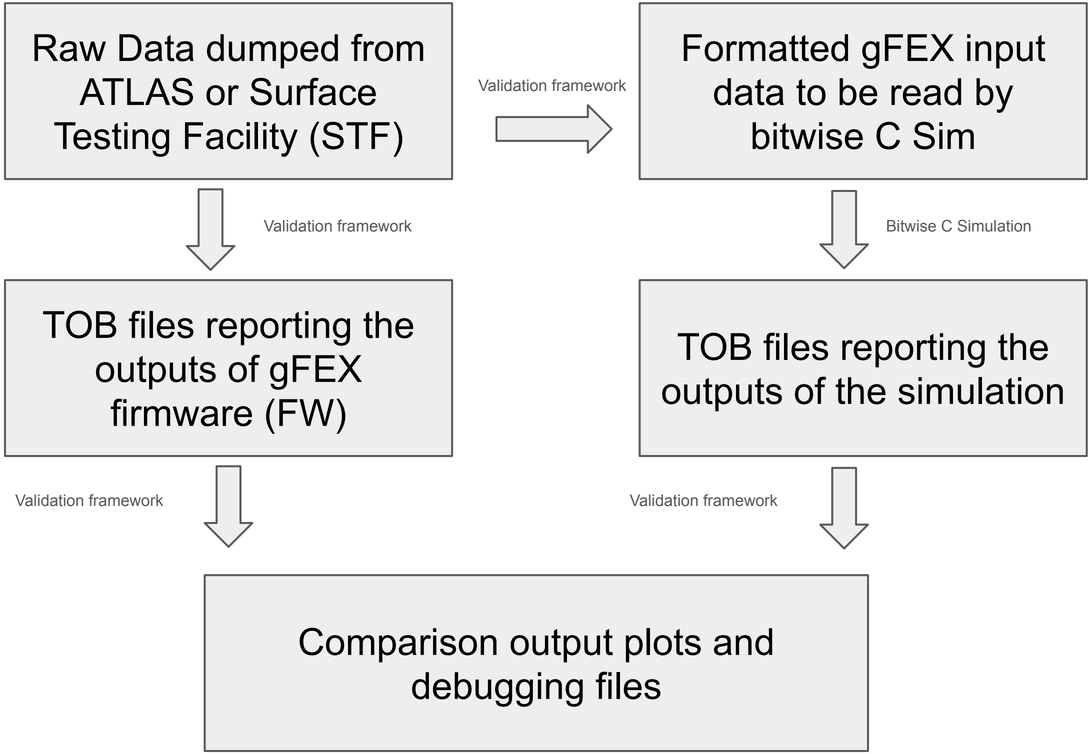



Figure from [1]

# gFEX Algorithms in a Nutshell

- Jet Finder Algorithm - runs in each half FPGA
  - Take each gTower and calculate the sum of energy around it (69 cells R~1)
  - gTower with largest energy sum is the large R Jet candidate
  - Pile up correction is applied by subtracting an event energy density from Jet energy (energy density is also listed in readout for checking)
  - Since jets are so big, required FPGAs to communicate with each other for energy sums (interFPGA communication)
- JWJ MET Algorithm - runs in each FPGA
  - Based on paper [2]
  - Works by separating gTower ET into hard and soft terms.
  - Sums are vector decomposed using sin/cos look up tables, then a weighted sum is performed
  - $MET_{x,y} = a*MST_{x,y} + b*MHT_{x,y} + c$
  - a,b,c are coefficients we can set in the trigger menu after optimization

# Algorithm Validation Framework



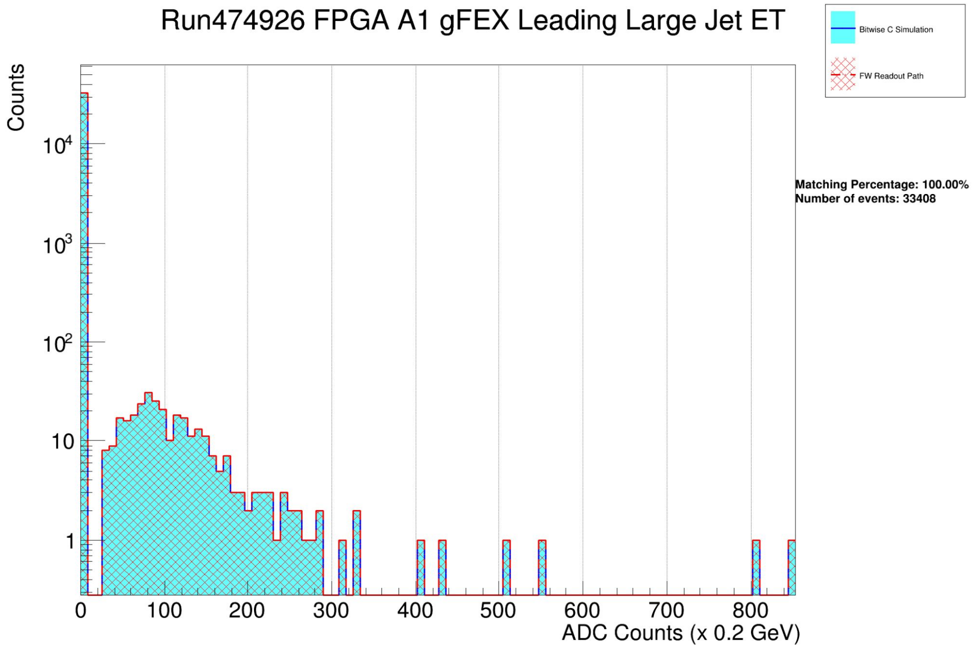

Workflow for validating the gFEX algorithms.

Allows for checks of bitwise agreement between the FW and Simulation

Bitwise C Simulation is our gold standard, is the basis for the offline Athena and online gFEX simulations

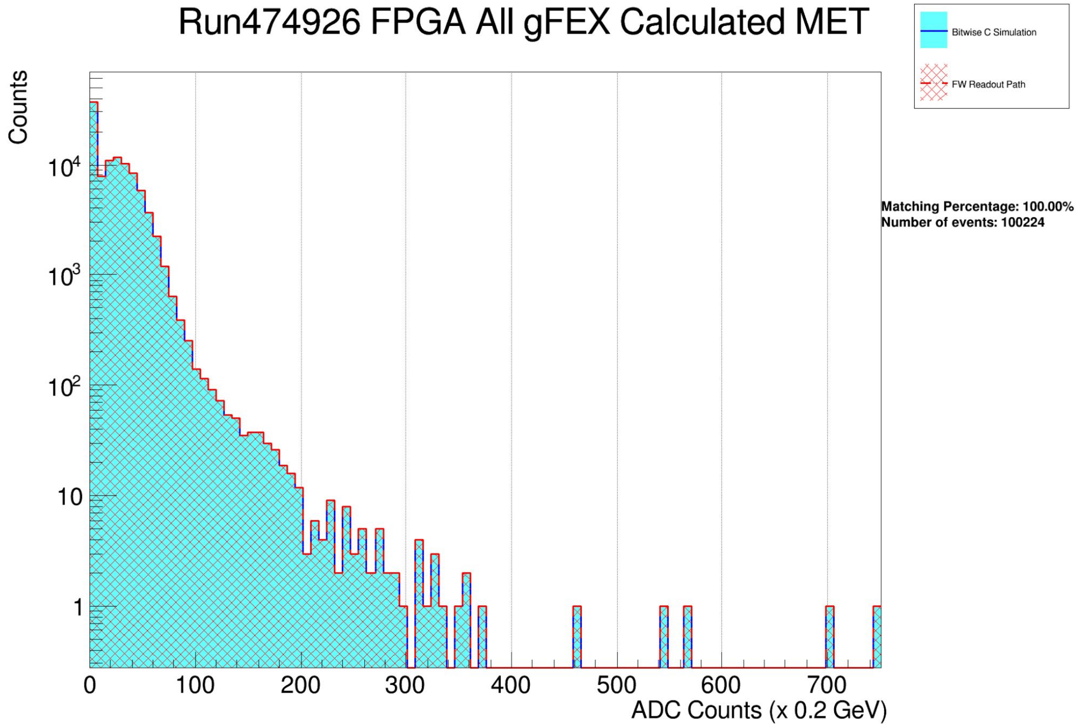
# Comparison Results - Jet TOBs

- Comparison here taken from the ZeroBias stream of a physics run taken around May 2 - 3, 2024 (overnight run)
- Overlayed distributions allow us to see how the data looks overall as well as agreement between the FW and simulation
- As of 2023 and in 2024, gFEX Jet and MET TOBs are showing perfect agreement with C Simulation



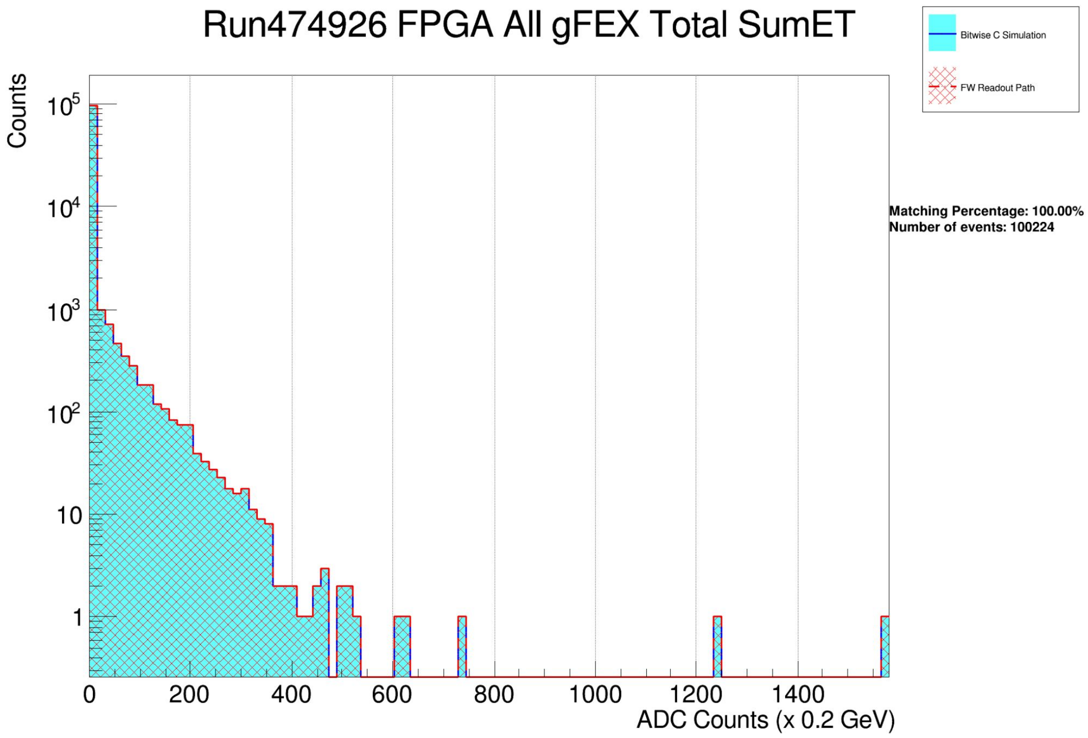
# Comparison Results - MET TOBs

- Same events as previous slide (Run 474926 ZeroBias)
- MET has been calculated from it's x and y vector components
- Comparison Results show values from all 3 FPGAs



# Active Work on FW - Testing SumET

- FW has recently developed another addition, calculating the total energy (internally referred to as SumET)
  - Calculated in a similar weighted sum as JWJ
- Initial testing is done, now working in ATLAS
- SumET for all 3 FPGAs for the ZeroBias Run 474926 data shown to the left



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# Conclusions

- The gFEX board in L1Calo is designed to heighten sensitivity to global values such as MET and Large Radius Jets
- The main algorithms for gFEX have been validated and are implemented in ATLAS
- While there is still work to do including tracking down small bugs/edge cases, this framework has been instrumental in getting gFEX ready for data taking
- The validation framework continues to be a useful tool for fast tests and debugging FW development, even as we have built up our more formal offline simulation

# Thank You for Your Attention!

Any Comments or Questions are welcome!

Special thanks to the gFEX and L1Calo groups at ATLAS!

# References

[1] The ATLAS Collaboration. The atlas experiment at the cern large hadron collider: A description of the detector configuration for run 3. Journal of Instrumentation, 2023.

URL: https://doi.org/10.48550/arXiv.2305.16623

[2] Daniele Bertolini, Tucker Chan, and Jesse Thaler. Jet observables without jet algorithms. *Journal of High Energy Physics*, 2014(4), apr 2014.

URL: https://doi.org/10.1007/JHEP04%282014%29013

# Backup



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# Unpacking TOBs for Comparison

ATOB1_dat 0
0 00000000
1 28a31281
2 30a2e483
3 28c1da85
4 00000000
5 00000000
6 000000bc

ATOB2_dat 0
0 00000000
1 **58f1b282**
2 30f1ae84
3 28e1b786
4 00000000
5 00000000
6 000000bc

TOBs are unpacked from hexadecimal and their components are saved for comparisons

58f1b282

0101 1000 1111 0001 1010 0010 1000 0010

0 10110 001111 000110100010 1 00 00010