ATLAS Run 3 Boosted Object Trigger Development

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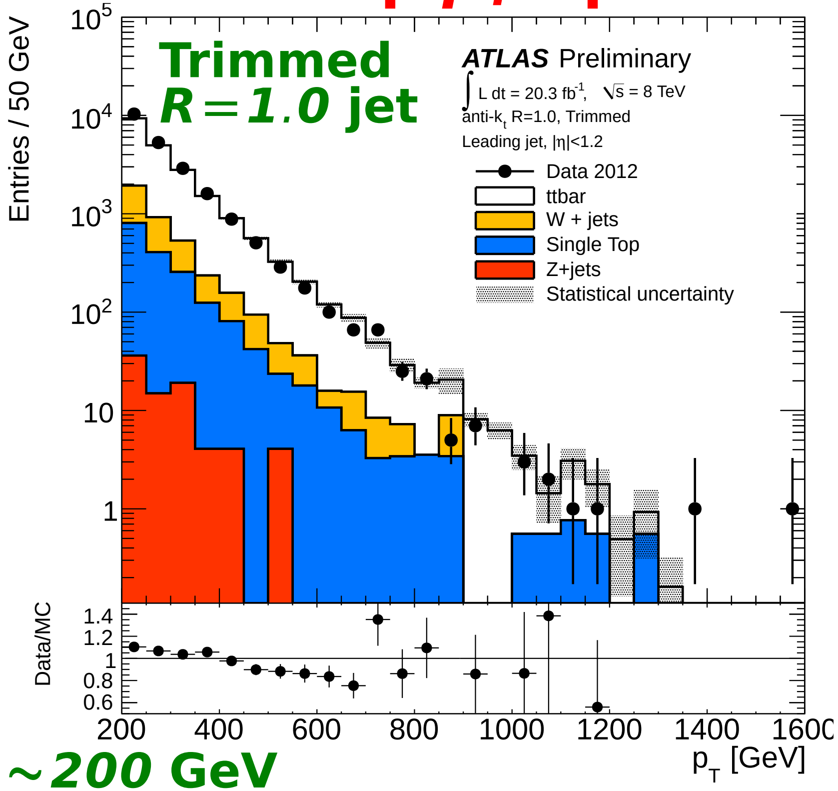
August 13, 2015

Triggering on Large-R Jets

- ***The study of hadronic decays of high-p_T bosons and fermions is a crucial and vital part of the ATLAS physics program***
  - W, Z, & Higgs bosons, top quarks, and exotic particles

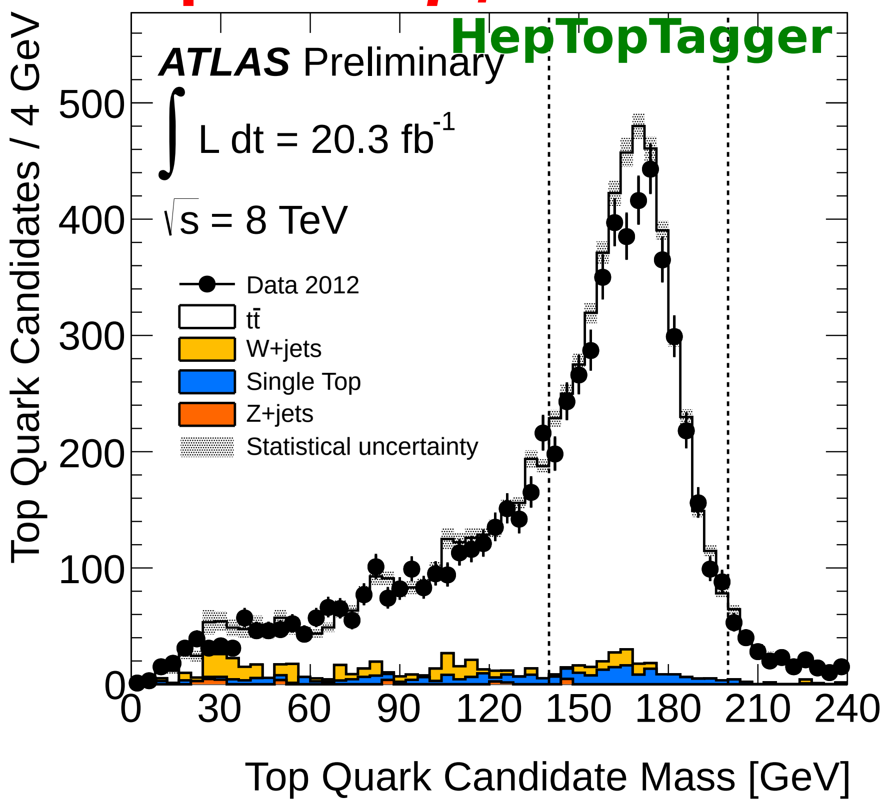
- ***Analyses use large-R jets with $R = 1.0$ or larger***
  - isolated lepton triggers inefficient ⇒ **requires jet triggers!**
  - target acceptance: $p_T \gtrsim 200$ GeV for top quarks; $\gtrsim 2 \times M_W$ for bosons

Boosted Top p_T Spectrum

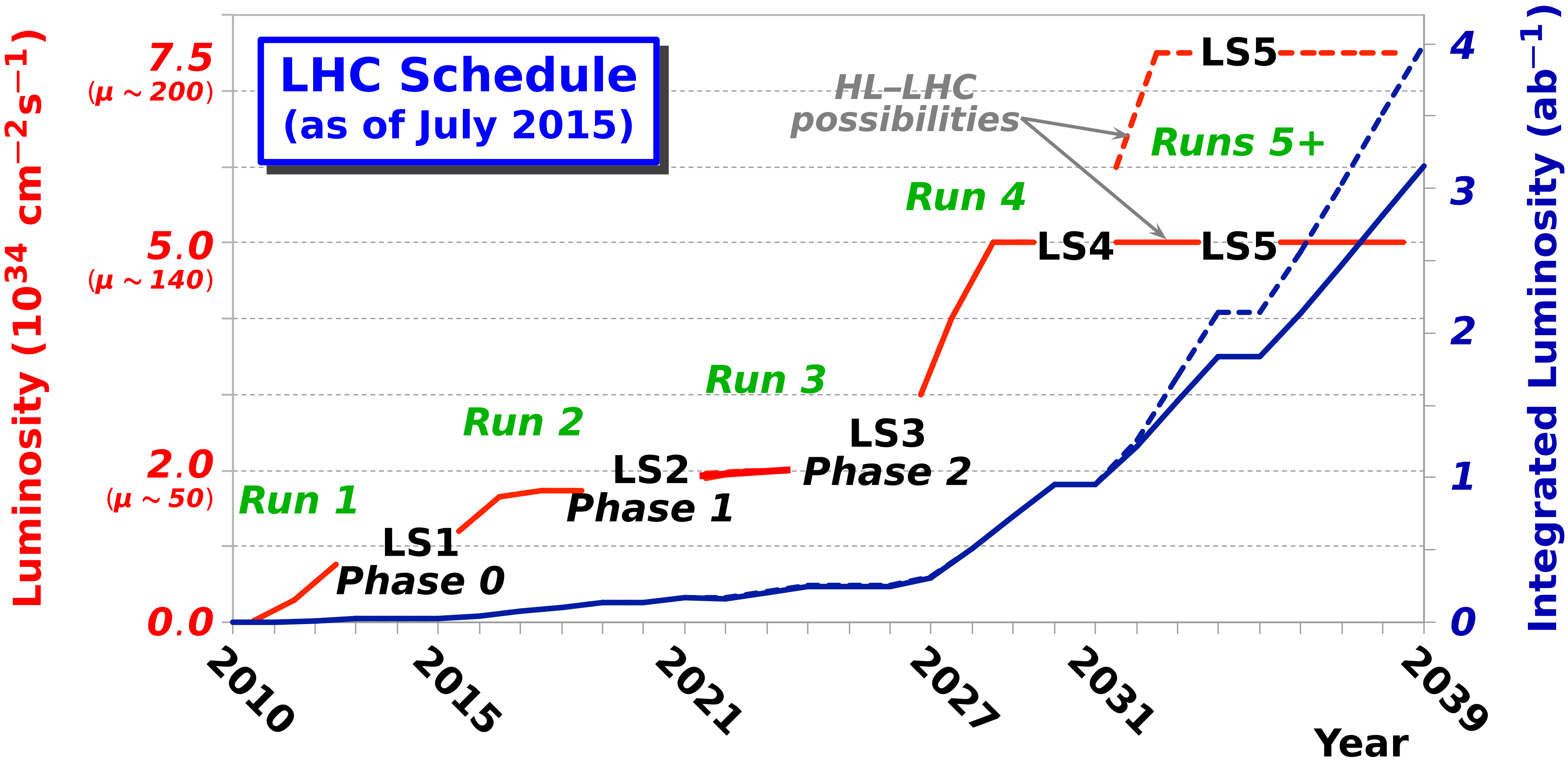


$p_T \sim 200$ GeV

Top Mass $p_T > 200$ GeV



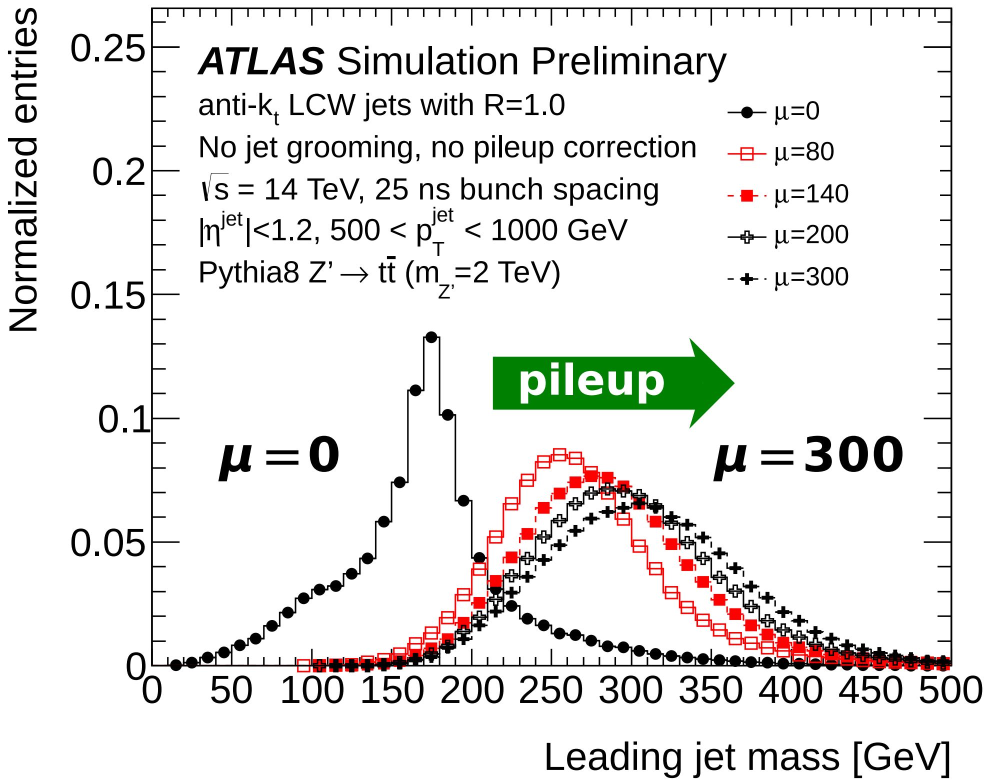
LHC Roadmap

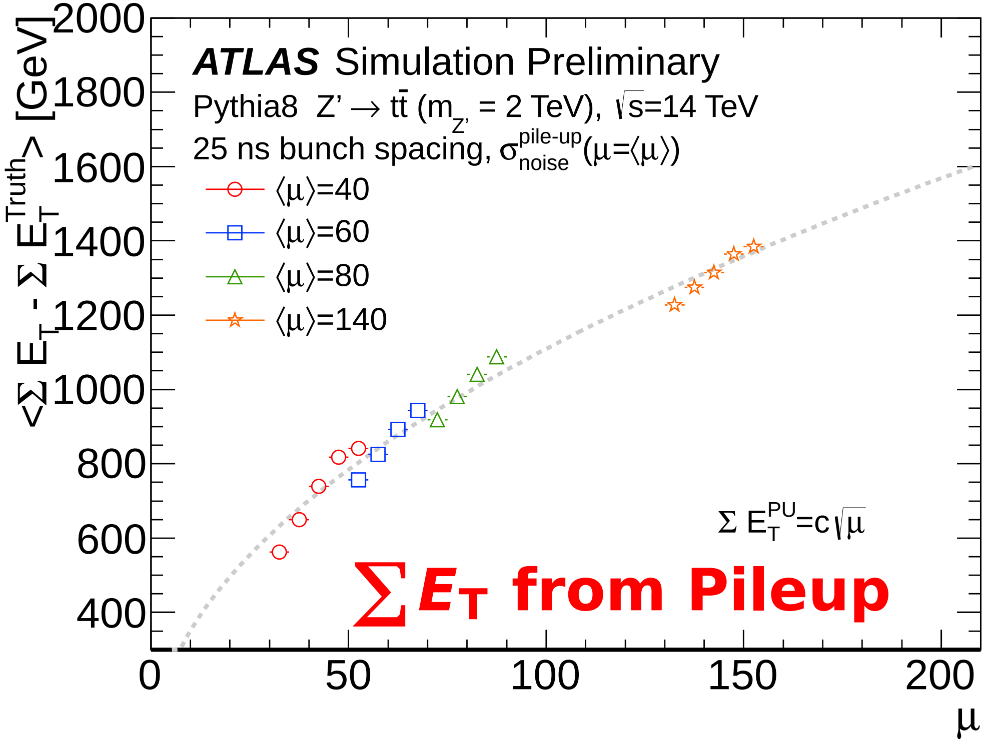

LHC Schedule
(as of July 2015)
Luminosity (10^{34} cm^{-2}s^{-1})
7.5 ($\mu \sim 200$)
5.0 ($\mu \sim 140$)
2.0 ($\mu \sim 50$)
0.0
Integrated Luminosity (ab^{-1})
0
1
2
3
4
Run 1
LS1
Phase 0
Run 2
LS2
Phase 1
Run 3
LS3
Phase 2
Run 4
LS4
LS5
HL–LHC possibilities
Runs 5+
LS5
2010
2015
2021
2027
2031
2039
Year

Challenges at High Luminosity

- ***Pileup is major challenge***
  - extra energy (offset)
  - increased confusion
  - degraded jet and E_T^{miss} resolution (event-by-event and local fluctuations)
  - additional jets

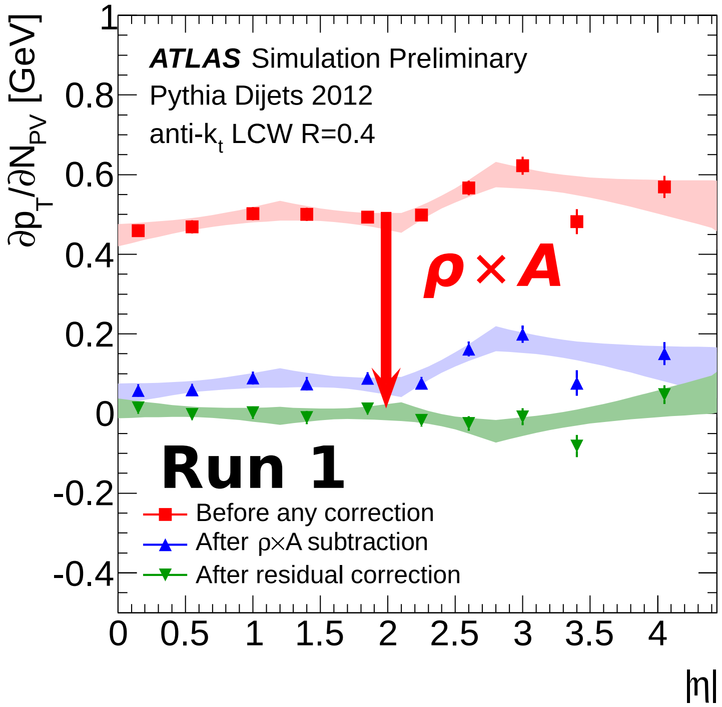
Boosted Top Jet Mass



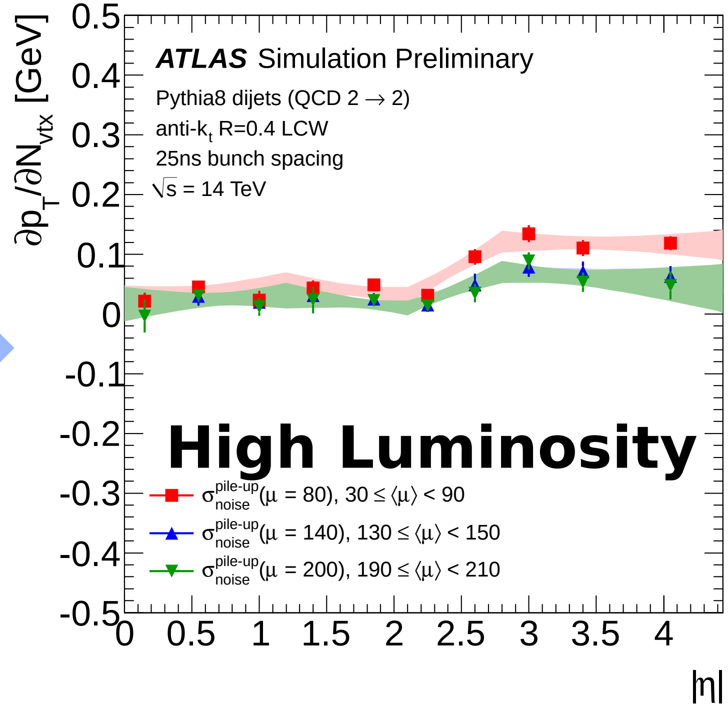


- ***Sophisticated techniques available to identify jet substructure and remove unwanted contributions from jets***
  - performance extensively studied by ATLAS, CMS, and the theory community
  - used in precision measurements and in searches for new physical phenomena
  - ***see, for example, most of the talks this week***

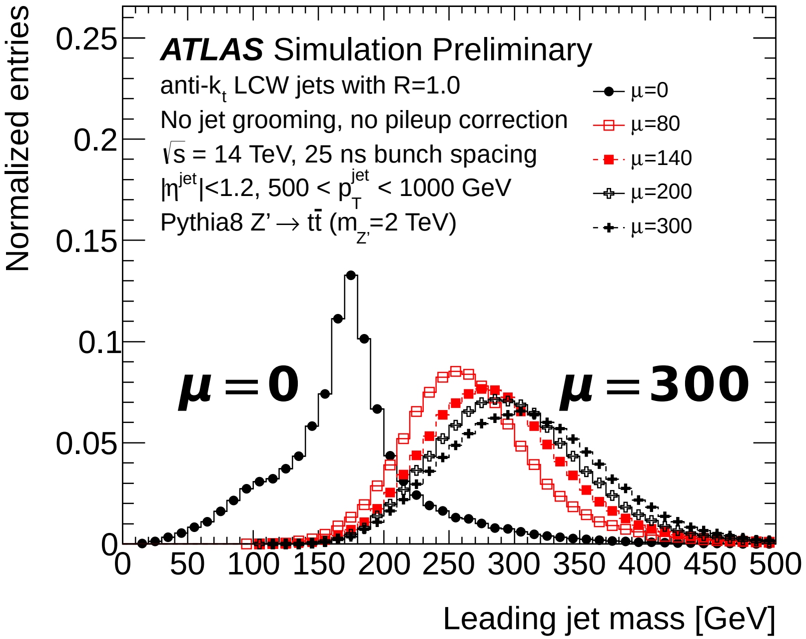
- ***Many techniques work well at high luminosity***



large μ

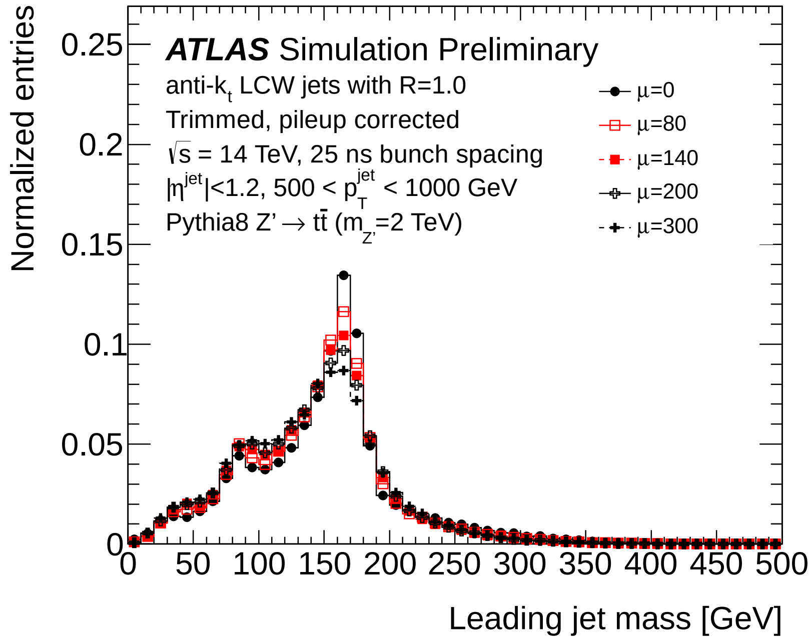


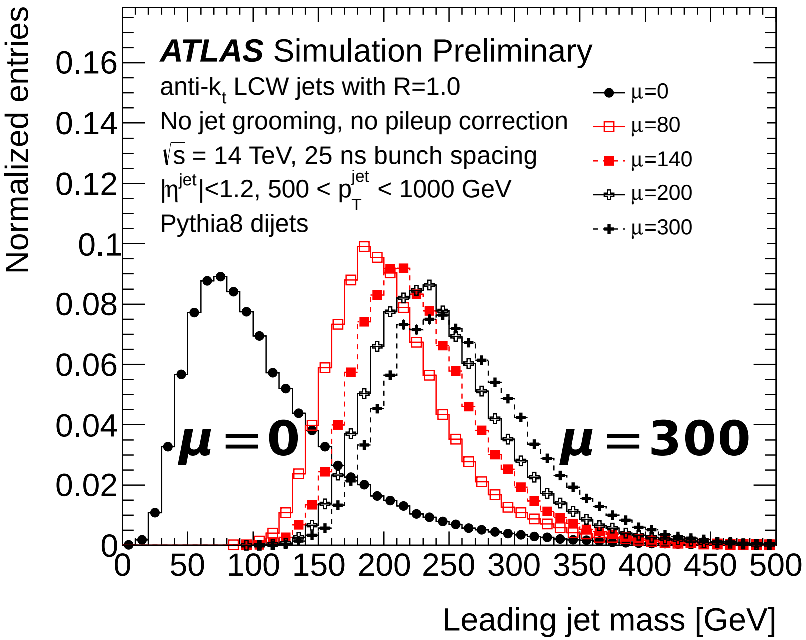
Run 1 optimization and calorimeter



Signal

trimming pileup subt.

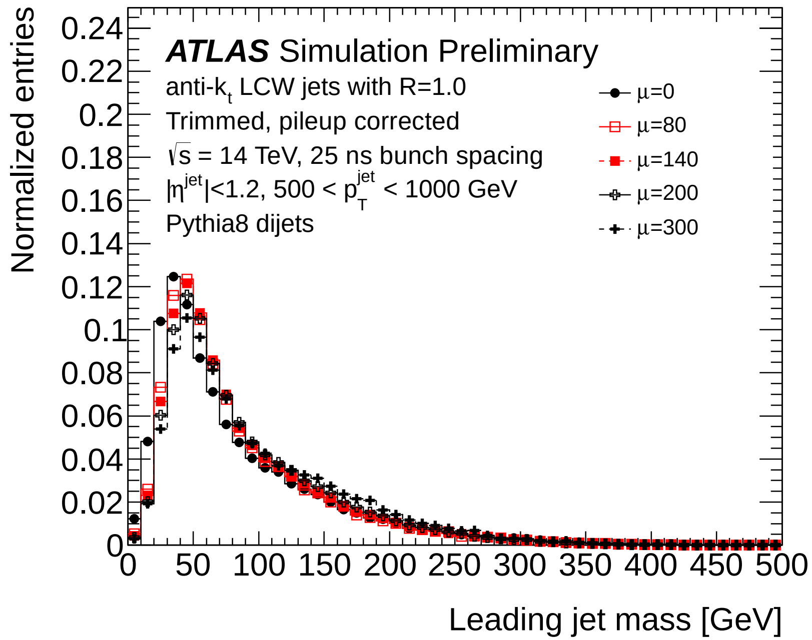




Background

trimming pileup subt.

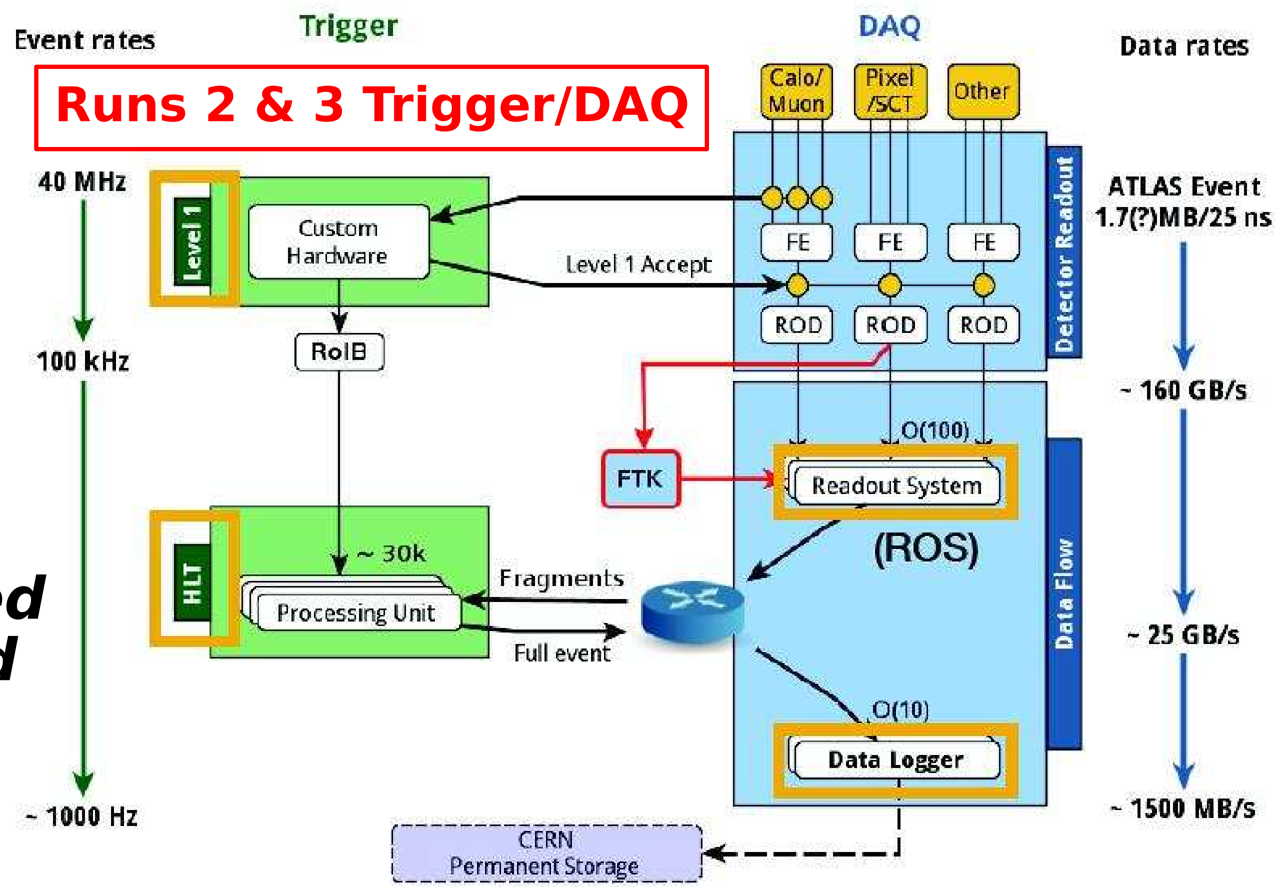
Run 1 optimization and calorimeter



Trigger at High Luminosity

High Luminosity ⇒ High Trigger Rates ⇒ High Trigger Thresholds

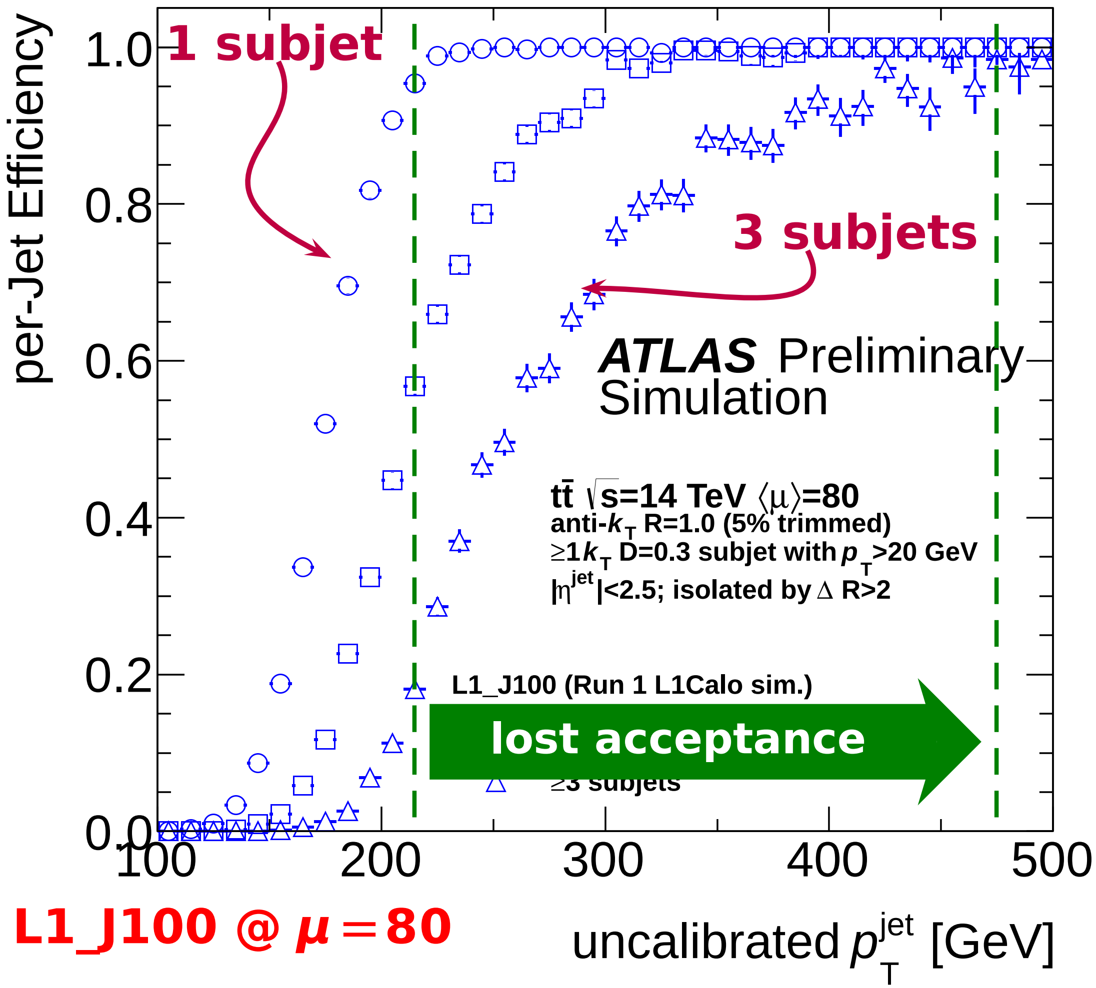
- ***Many techniques to suppress contributions due pileup and identify substructure in jets are implementable in the ATLAS High-Level Trigger (HLT)***
  - computer farms running offline-like software & algorithms
    - calorimeter cell-based topological clusters, (limited) tracking & vertex identification
    - FastJet
  - **anti-k_T $R = 1.0$ jets included in Runs 1 & 2 HLT Trigger**
    - substructure observables being integrated into Run 2 HLT for detailed evaluation
  - trigger bias is a concern
    - overly specialized techniques unnecessarily limit advanced technology in analyses
- ***Adding new capabilities to the Level-1 hardware-based trigger more...complicated***



Level 1 Jet Trigger Acceptance

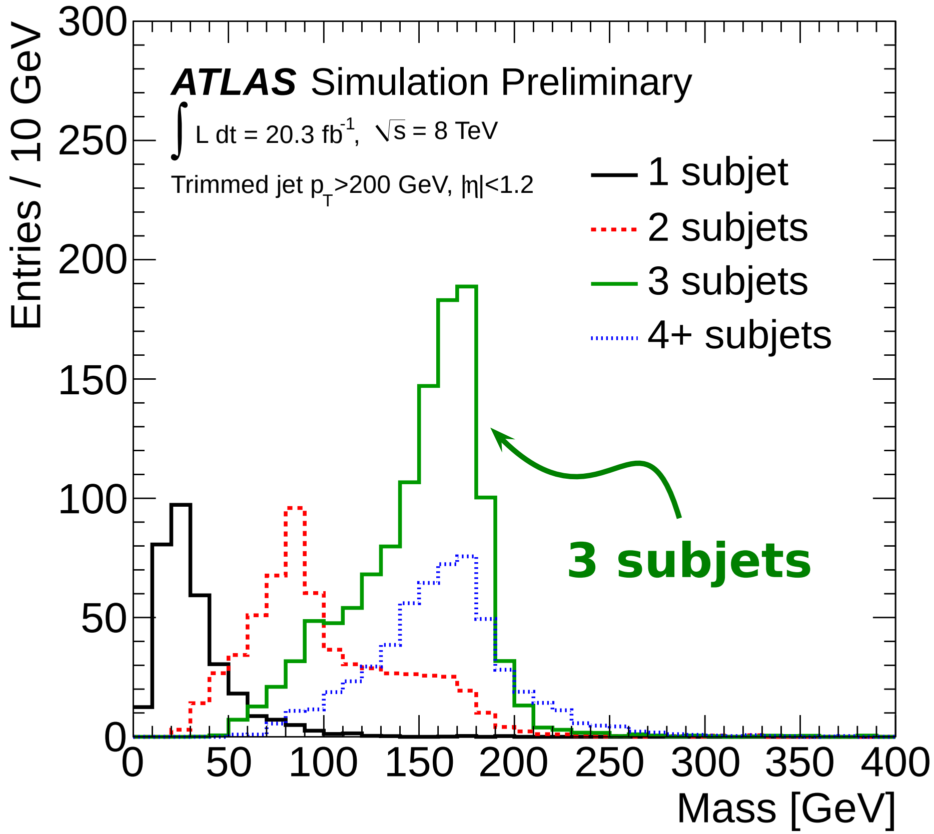
- ***Level 1 Trigger designed for narrow jets ($R = 0.4$) in Runs 1 & 2***
  - large-R jet acceptance in HLT circumscribed by L1 requirements
  - multijet and H_T triggers also ineffecient for these events
  - ***trigger efficiency depends strongly on jet substructure!***

Trimmed $R = 1.0$ Boosted Top



L1_J100 @ $\mu = 80$

Boosted Top with $p_T > 200$ GeV



Level 1 Jet Trigger Acceptance

- ***Standard L1 jet trigger is narrow Region-of-Interest (RoI)***

  $\Delta\eta \times \Delta\phi$:
  - 0.8×0.8 in Runs 1 & 2
  - 0.9×0.9 in Runs 3 & 4

- ***Need significantly larger RoI to avoid biasing against boosted objects***

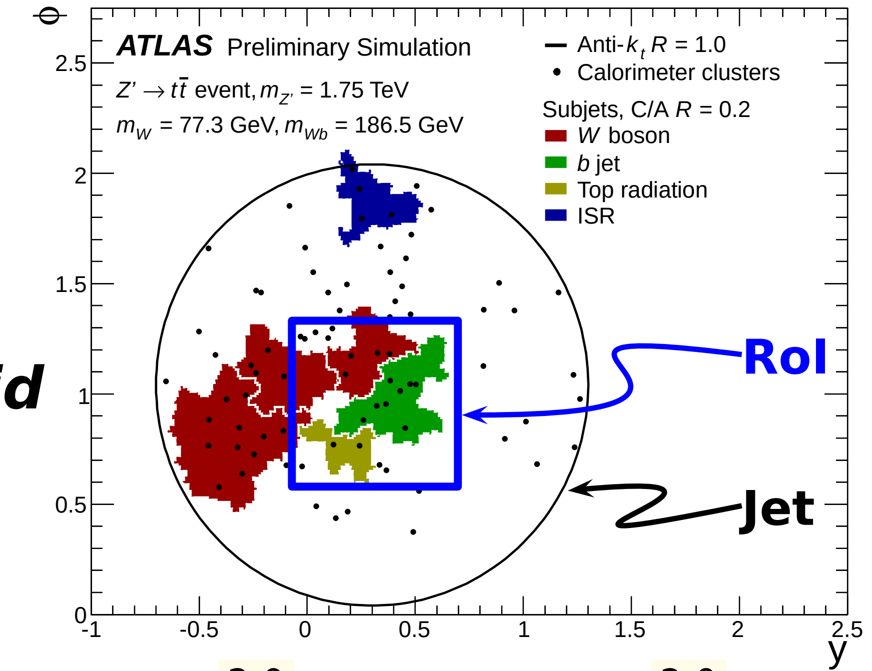
Consider two jets with equal p_T:

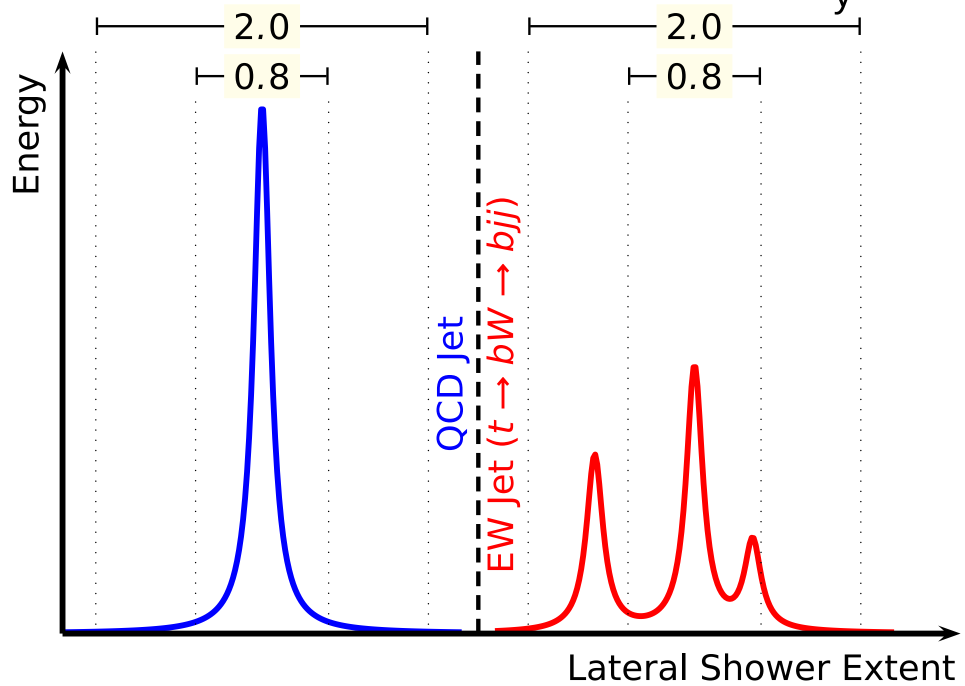
A 0.8×0.8 RoI contains
- most of QCD jet
- fraction of EW jet

A 0.8×0.8 threshold efficient for QCD jets will miss EW jets.

A 2.0×2.0 RoI would have comparable efficiency for both.
- *but with much higher trigger rate!*

Acceptance for boosted objects limited by RoI size

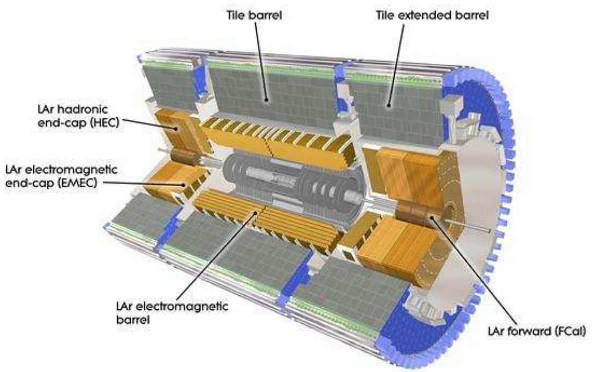




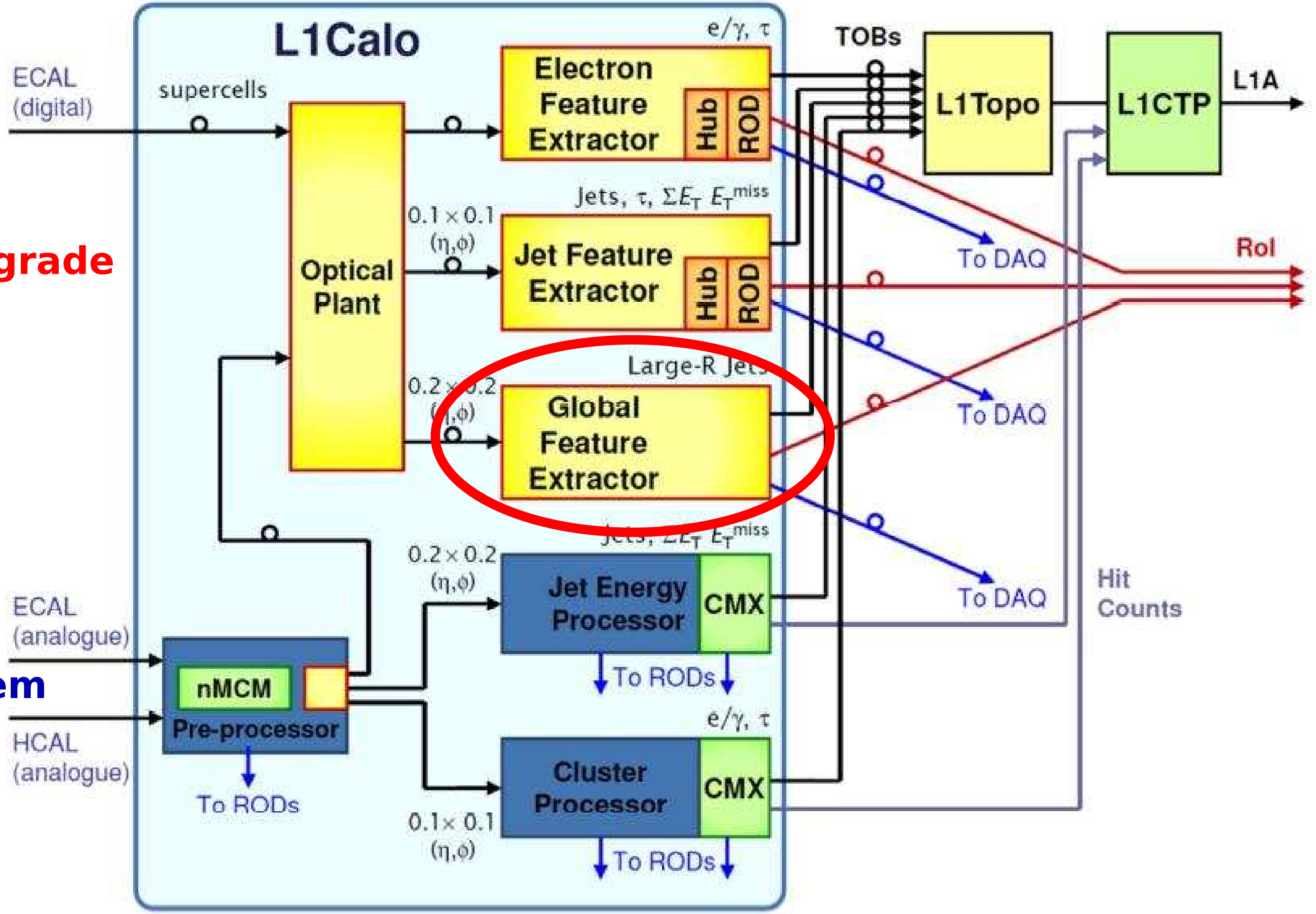
Phase-1 L1 Calorimeter Upgrade

- ***Level 1 Calorimeter during Run 3***
  - new LAr calorimeter trigger electronics (Tile electronics are Phase-2 upgrade)
  - new *Feature Extractors* for electons/taus, jets, and “large” objects (boosted jets)
- ***System remains in Runs 4, 5, . . . as Level 0 Trigger***

Phase-1 Upgrade

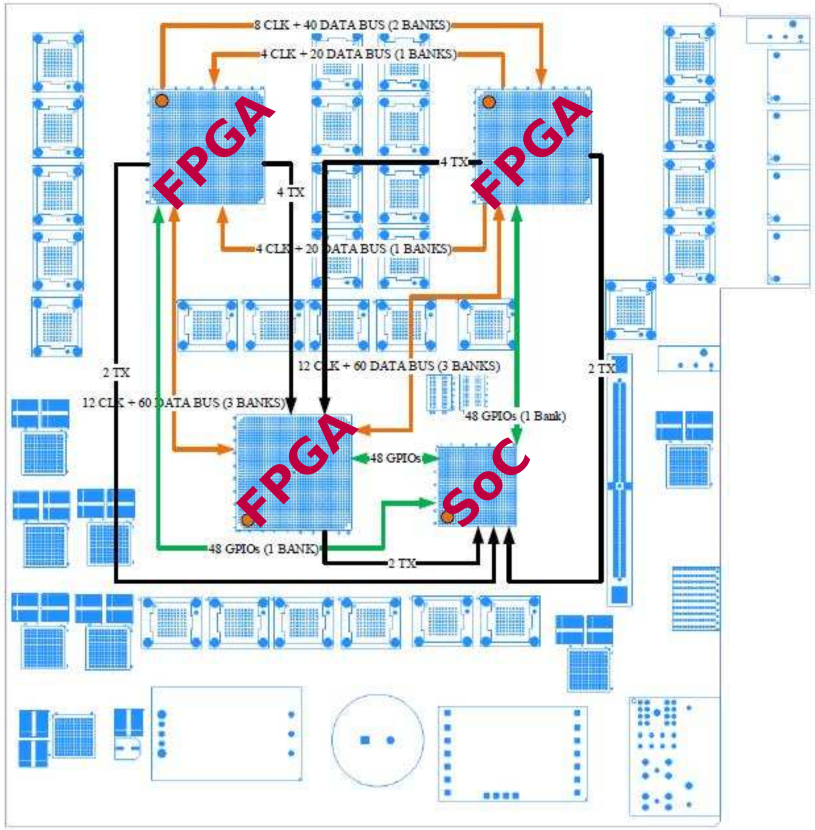


Run 2 Legacy System



Global Feature Extractor (gFEX)

- ***Entire calorimeter on a single board!***
  - *unique ATLAS Level-1 Trigger facility*
  - 0.2×0.2 tower granularity (nominal)



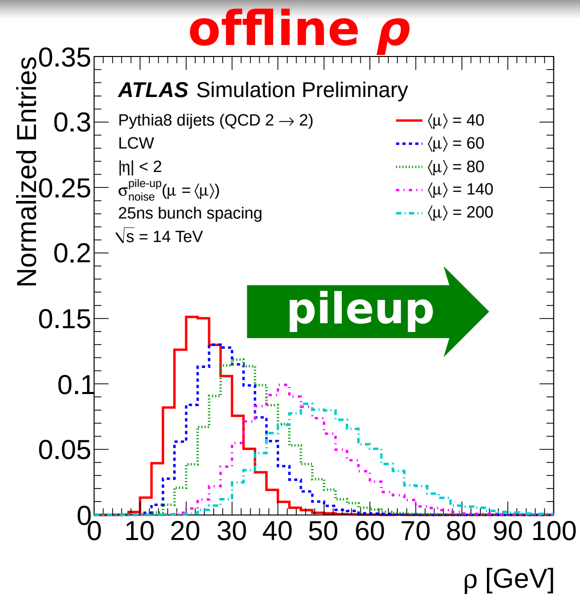
- ***Identifies events with large-R jets***
  - **improves trigger acceptance for events with Lorentz-boosted W, Z, Higgs bosons, top quarks, and exotica**
  - jet-level pile-up subtraction
  - can reject QCD jets compared to EW jets
    - subjet multiplicity
    - substructure variables

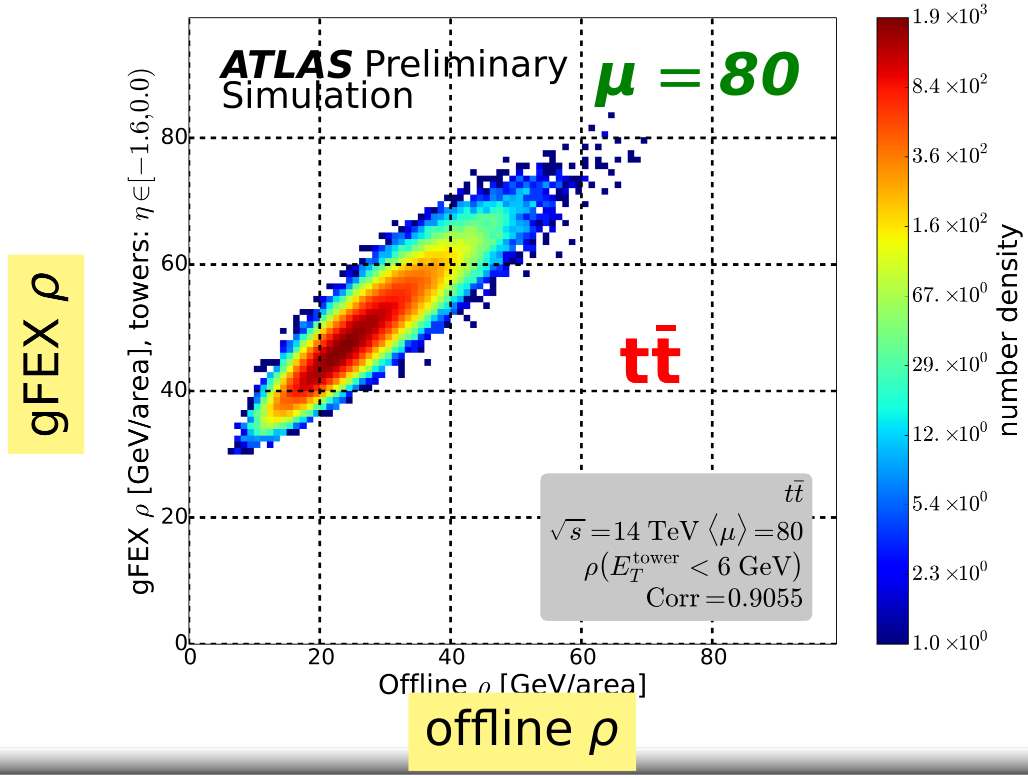
- ***Calculates global event variables***
  - E_T^{miss}, centrality, etc
  - “jets without jets” observables (Bertolini, Chan, Thaler, arXiv:1310.7584 [hep-ph])

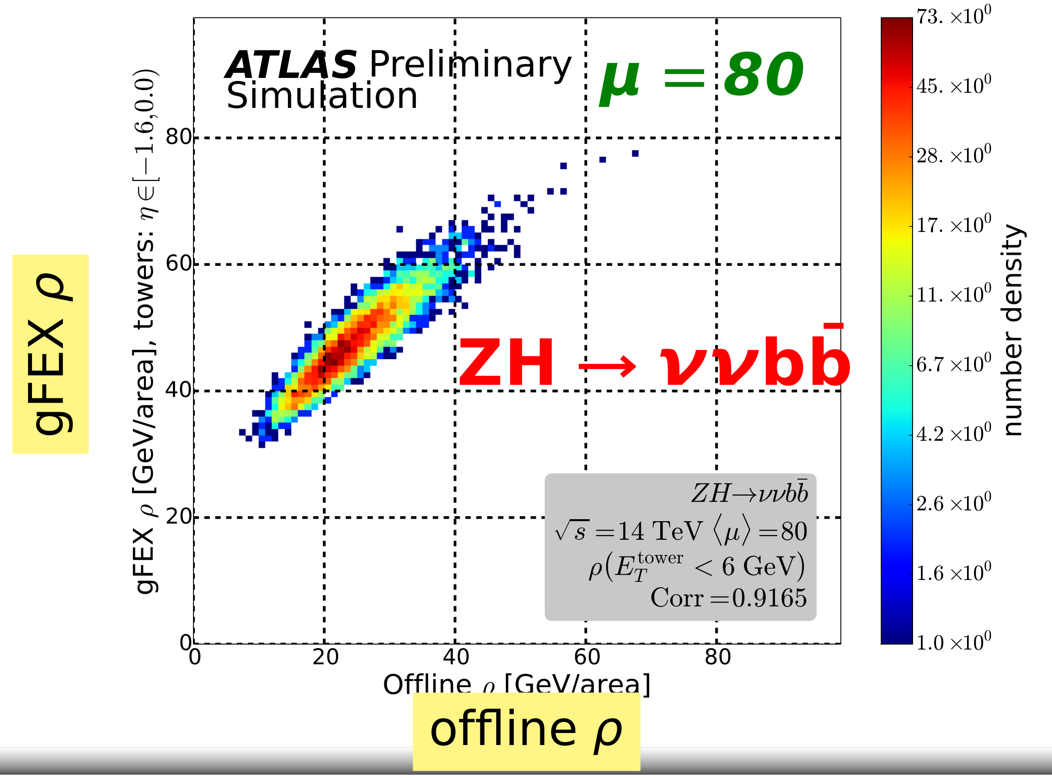
- ***L1 Calorimeter specification is 125 ns for physics algorithms***
  - jet finding and pileup suppression *must* fit within this latency
  - implemented in highly parallelized architecture (FPGA)
    - 3 large Xilinx Ultrascale FPGA & Zynq System-on-Chip (SoC)
  - only non-iterative algorithms have reasonable time profile

Area-Based Pileup Subtraction

- ***Advanced pileup suppression techniques difficult to implement in Level 1 trigger***
  - only coarse calorimeter information available; no tracks!
- ***ρ proportional to pileup activity... but standard calculations impractical***
  - building the median too expensive on FPGA
  - **measure truncated mean (towers with E_T < 6 GeV) separately on each FPGA**

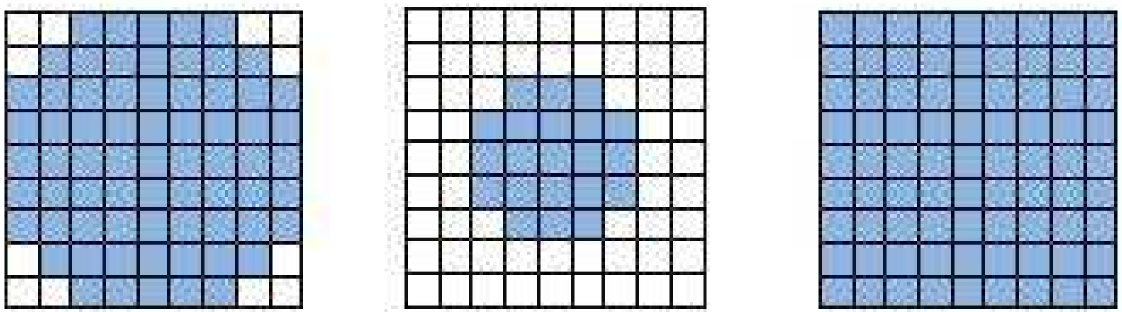






Level 1 Jet Finding

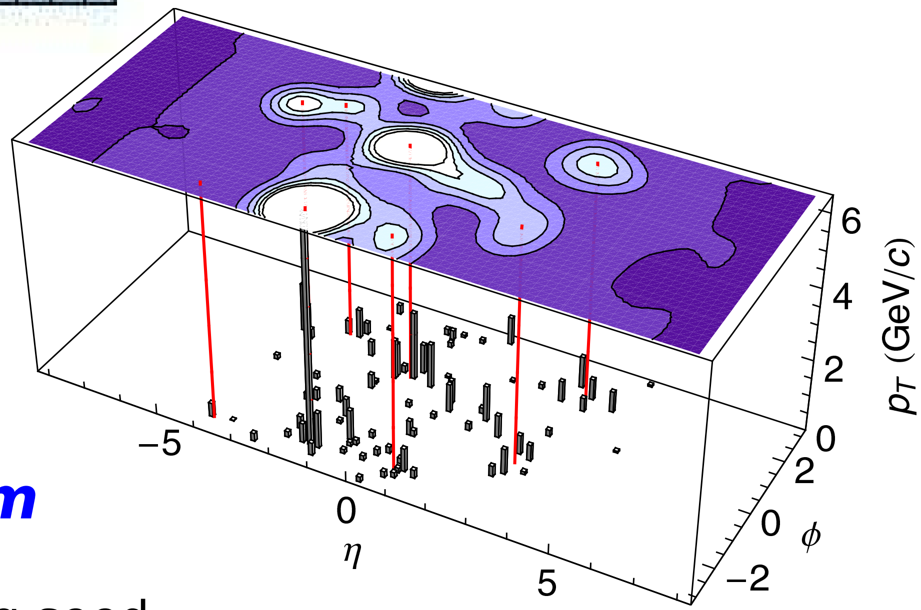
- ***Sliding Window algorithm***
  - identifies local maxima
  - window can have any reasonable shape



125 ns available for data preparation, ρ, and jet finding

$\langle t \rangle \sim 1$ ms for FastJet anti-k_T (CPU)

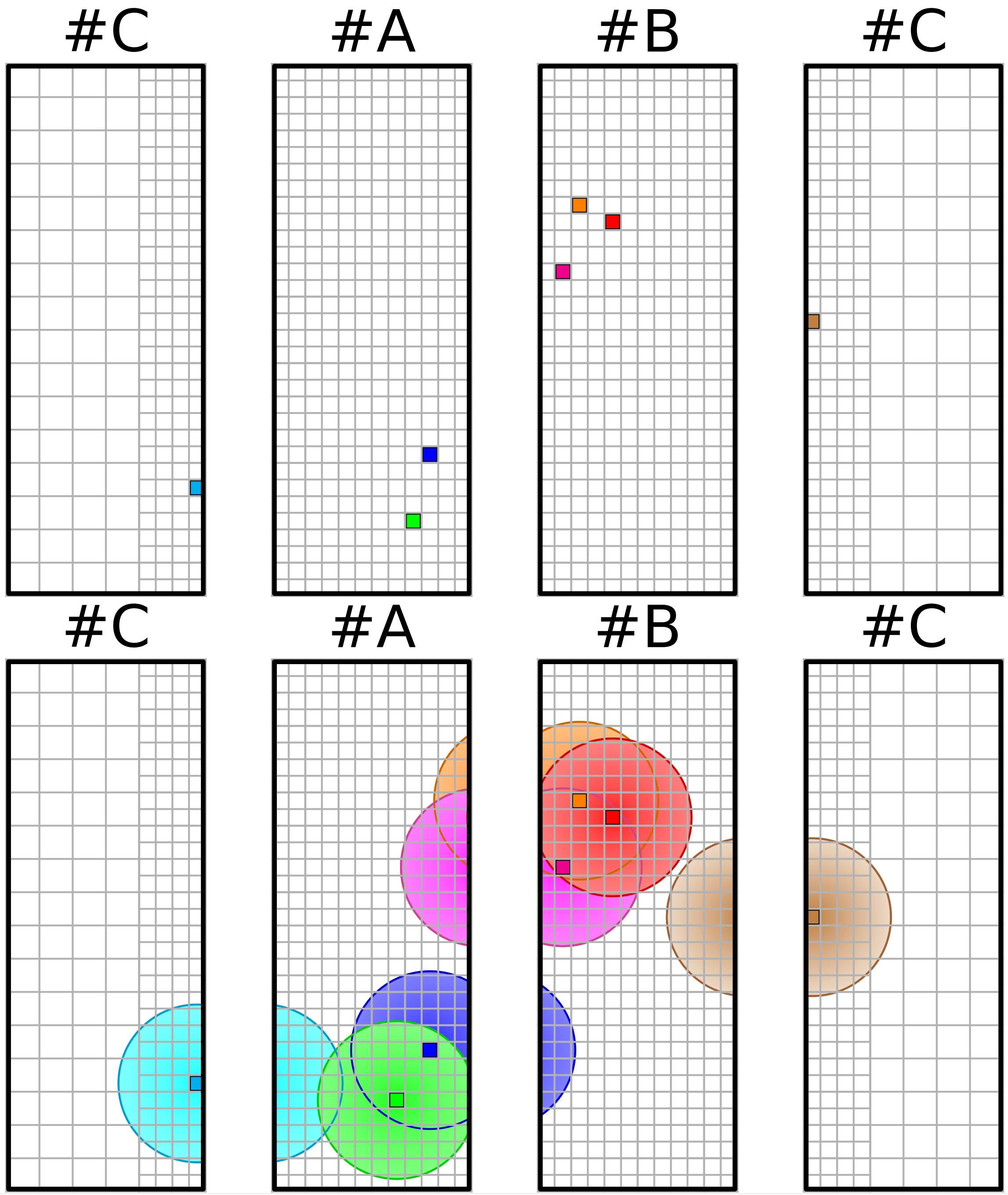
- ***Gaussian Filtered jet algorithm***
  - unseeded algorithm using Fast Fourier Transform with Gaussian kernel
  - easily implemented in FPGA but too slow
  - *Lai & Cole, nucl-ex/0806.1499*



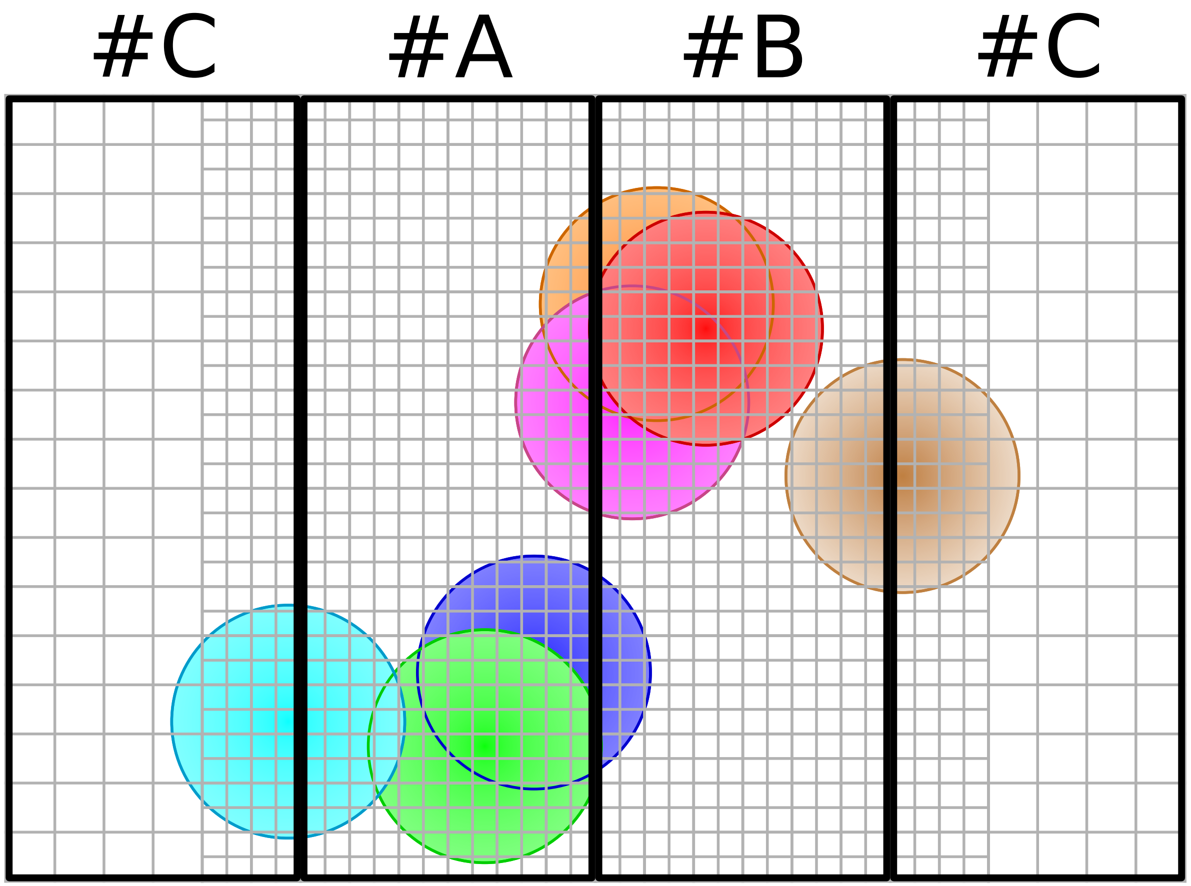
- ***Seeded Simple Cone jet algorithm***
  - identify towers over threshold
  - sum energies in circular region surrounding seed
  - towers can be weighted during sum (e.g., Gaussian or Bessel function)

Seeded Simple Cone Jet Finding

- ***Choose seeds with E_T over threshold***
  - 0.2 × 0.2 towers or 0.6 × 0.6 blocks
- ***Pass "overlapping" seeds to each neighboring FPGA***
  - no local maximum requirement
  - **defines FPGA interconnections**
- ***Sum towers around seeds***
  - radius~1.0
  - include seeds from neighbors
  - **jets allowed to overlap to maximize efficiency**
- ***Transfer "partial" sums to neighboring FPGA***
  - no overlap between FPGA
- ***Subtract pileup per jet***

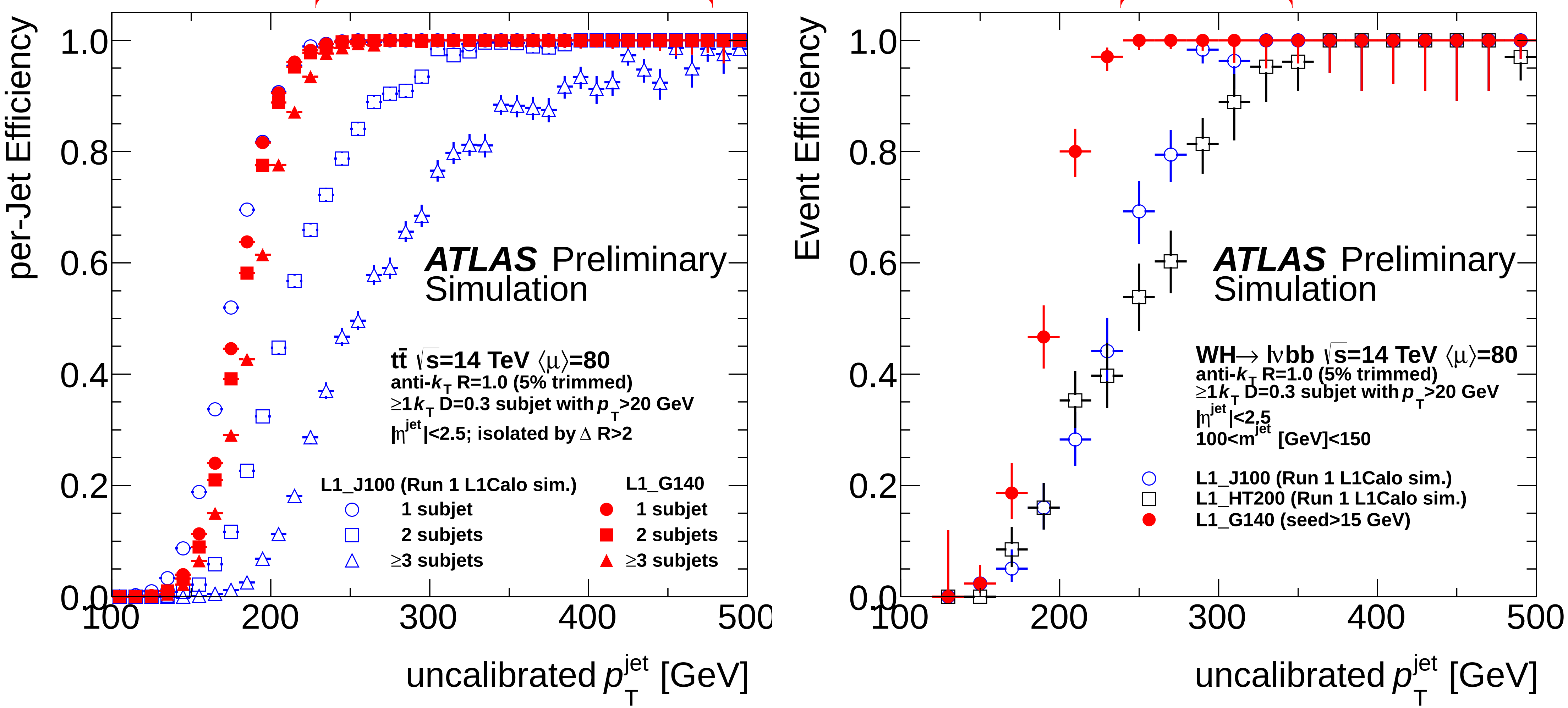


- ***Prototype algorithms consume ∼ 90 ns out of 125 ns budget***
  - ρ for pileup calculations
  - all pileup-subtracted $R = 1.0$ jets
  - jets-without-jets observables: multiplicity, $E_{\mathrm{T}}^{\mathrm{miss}}$, $H_{\mathrm{T}}^{\mathrm{miss}}$
  - $E_{\mathrm{T}}^{\mathrm{miss}}$
- ***Substructure variables to reduce rate (as needed)***



acceptance gain for boosted top

(unoptimized) acceptance gain for $H \rightarrow b\bar{b}$



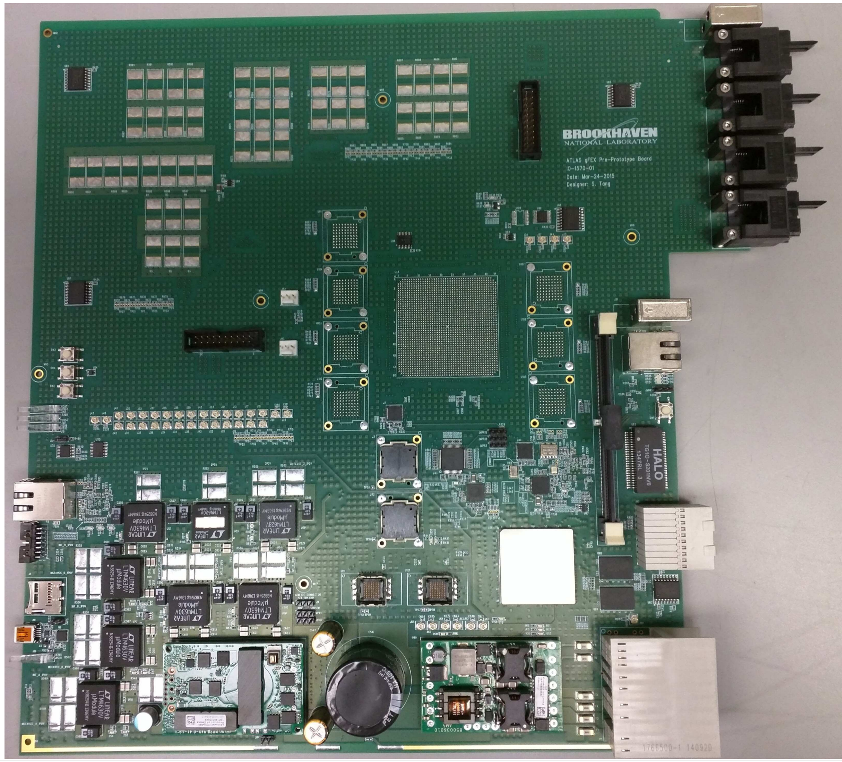
Summary

- ***The study of hadronic decays of high-p_T bosons and fermions is a critical and vital part of the ATLAS physics program***
  - many results, publications, and workshops

- ***The high luminosity expected from the LHC (2019→2039) necessitates increased trigger rejection to preserve acceptance***

- ***The gFEX adds capability and flexibility to the ATLAS L1 Trigger***
  - efficient large-*R* jet finding
  - pileup suppression
  - "jets without jets" and other event shapes
  - centrality-dependent Heavy-Ion triggers
  - many possibilities for improved rejection using jet substructure
    - jet grooming
    - simplified substructure observables (nsubjettiness → seed multiplicity)
    - calorimeter timing information

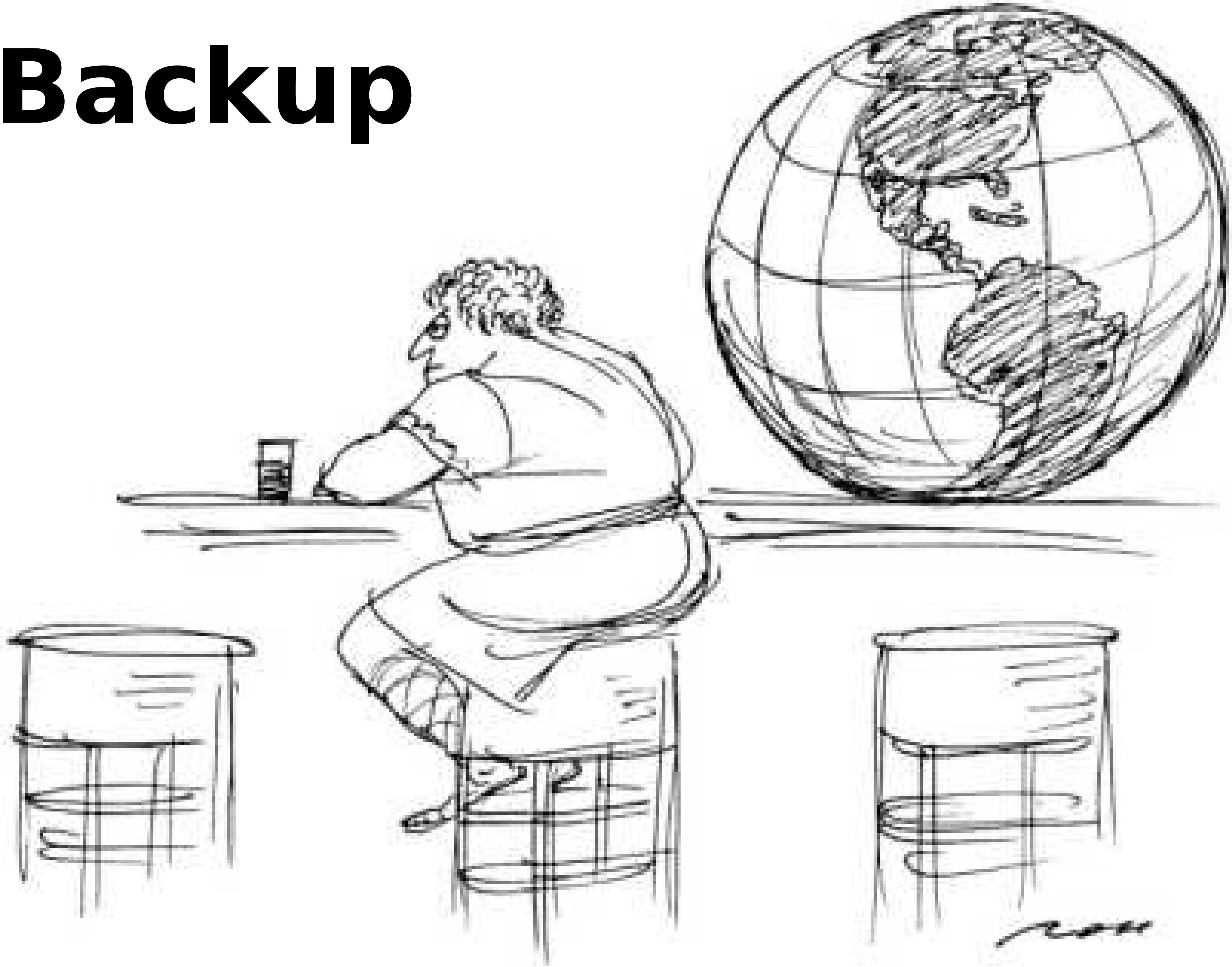
- ***Initial prototype gFEX is currently being commissioned!***



Trigger

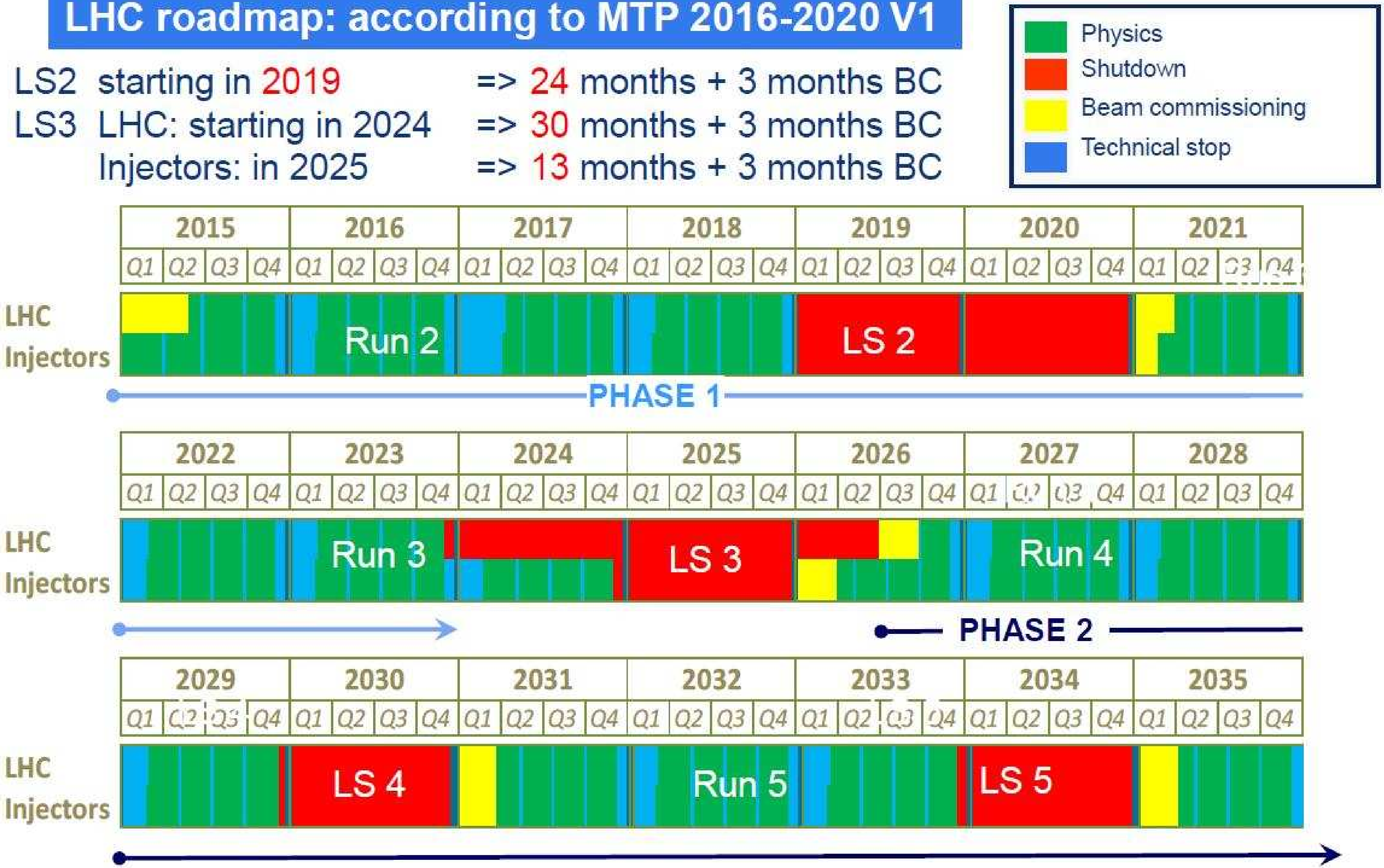
Don't miss the unexpected!

Backup

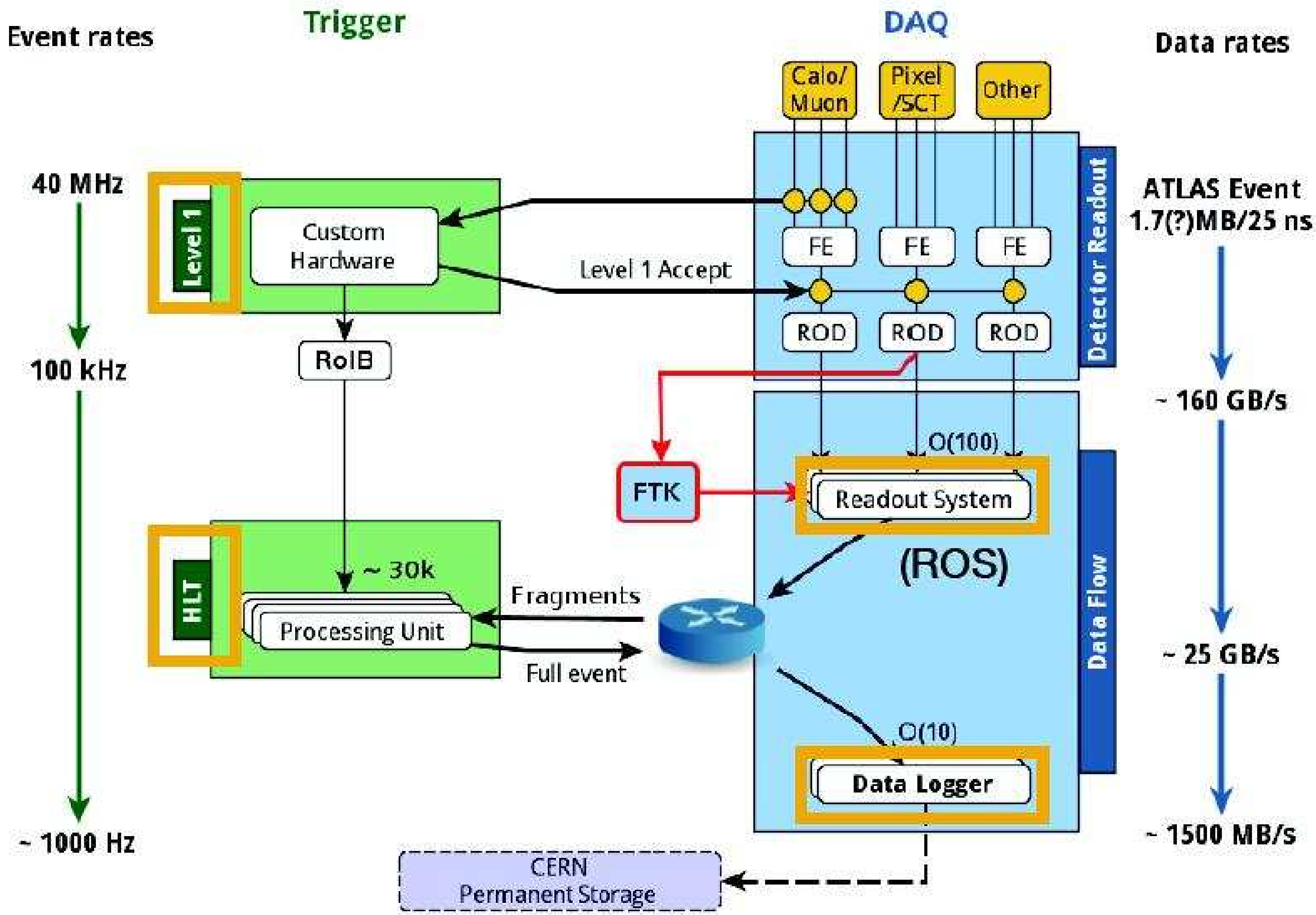


LHC roadmap: according to MTP 2016-2020 V1

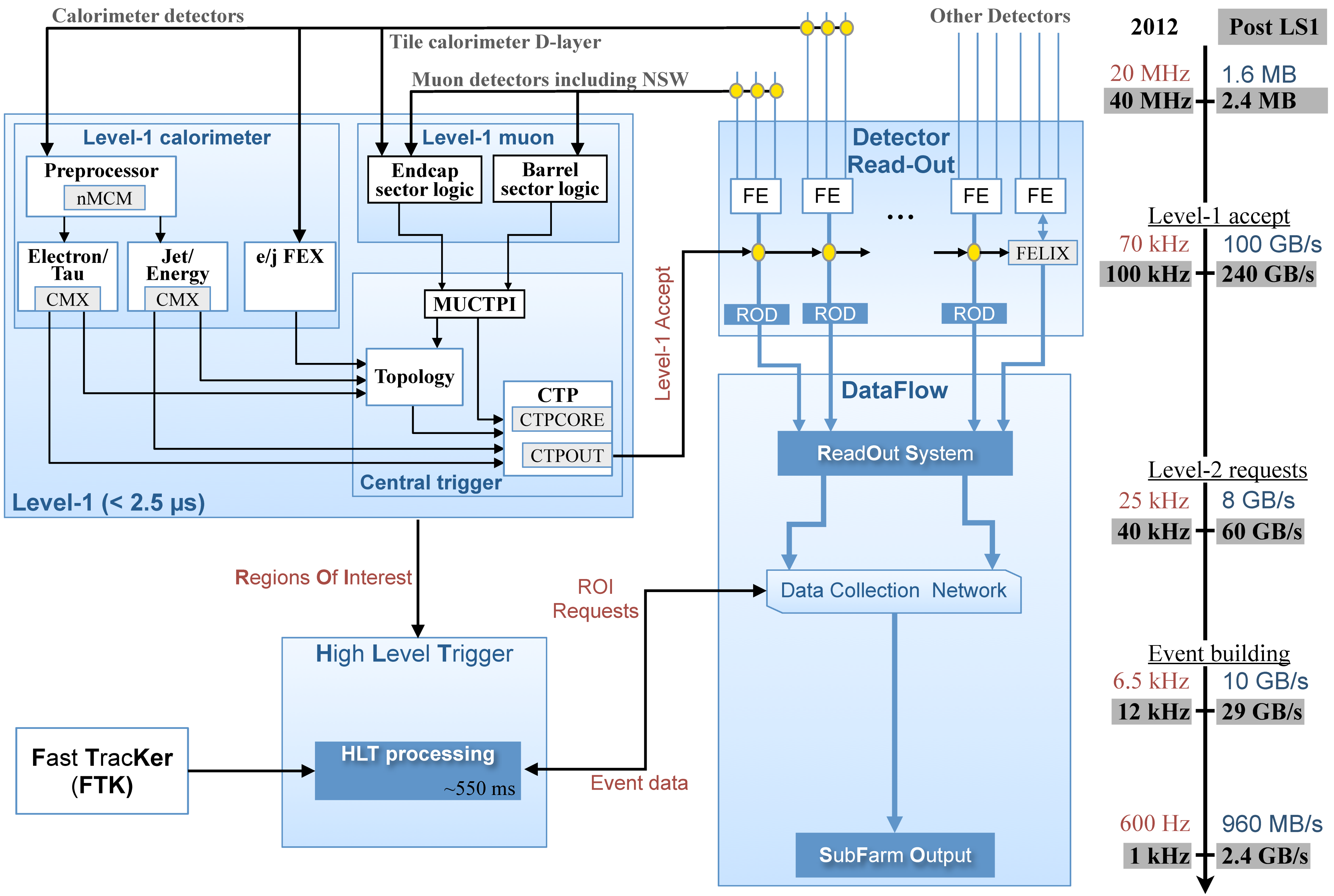
LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC



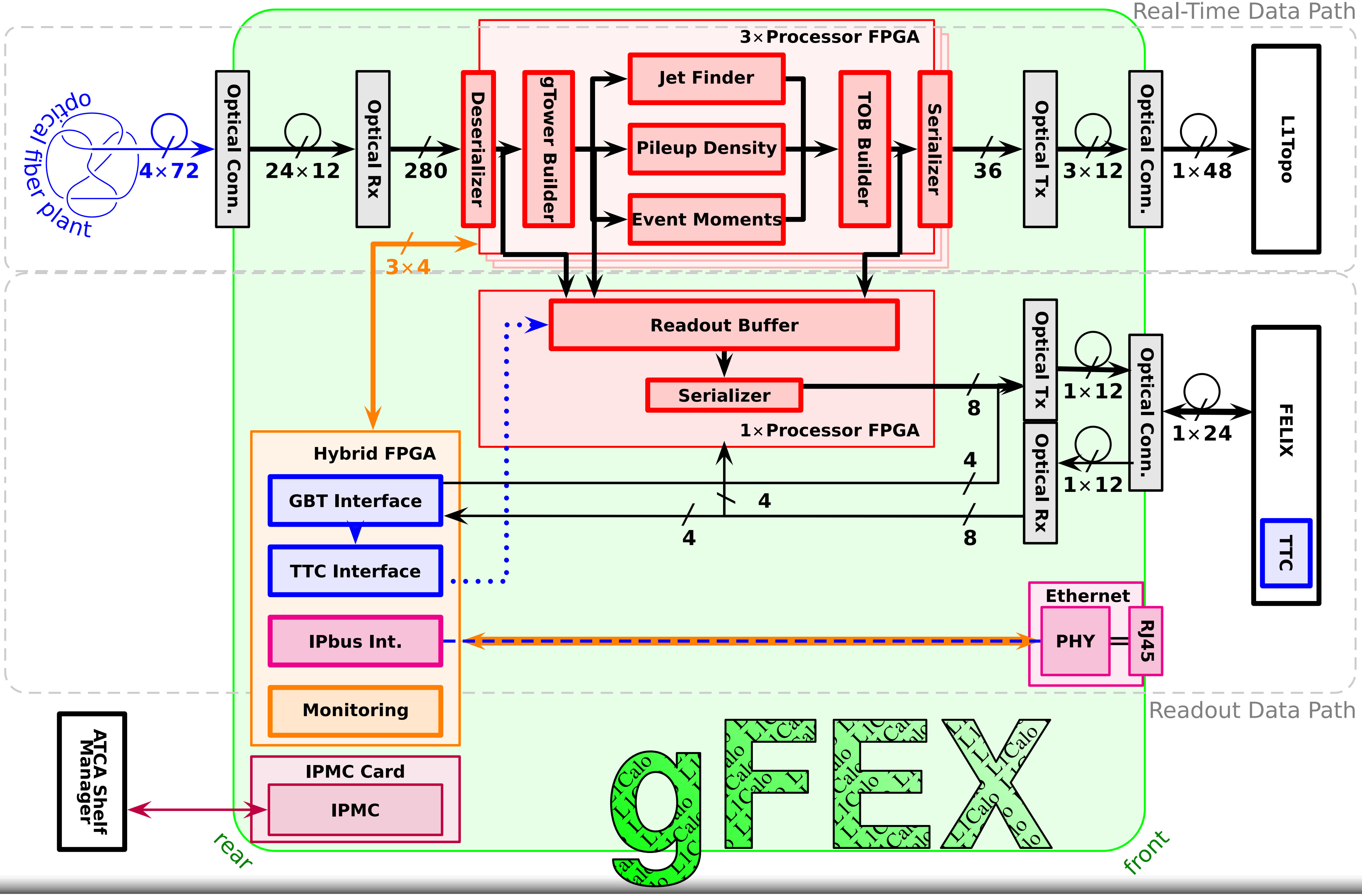
Run 2 Trigger & DAQ



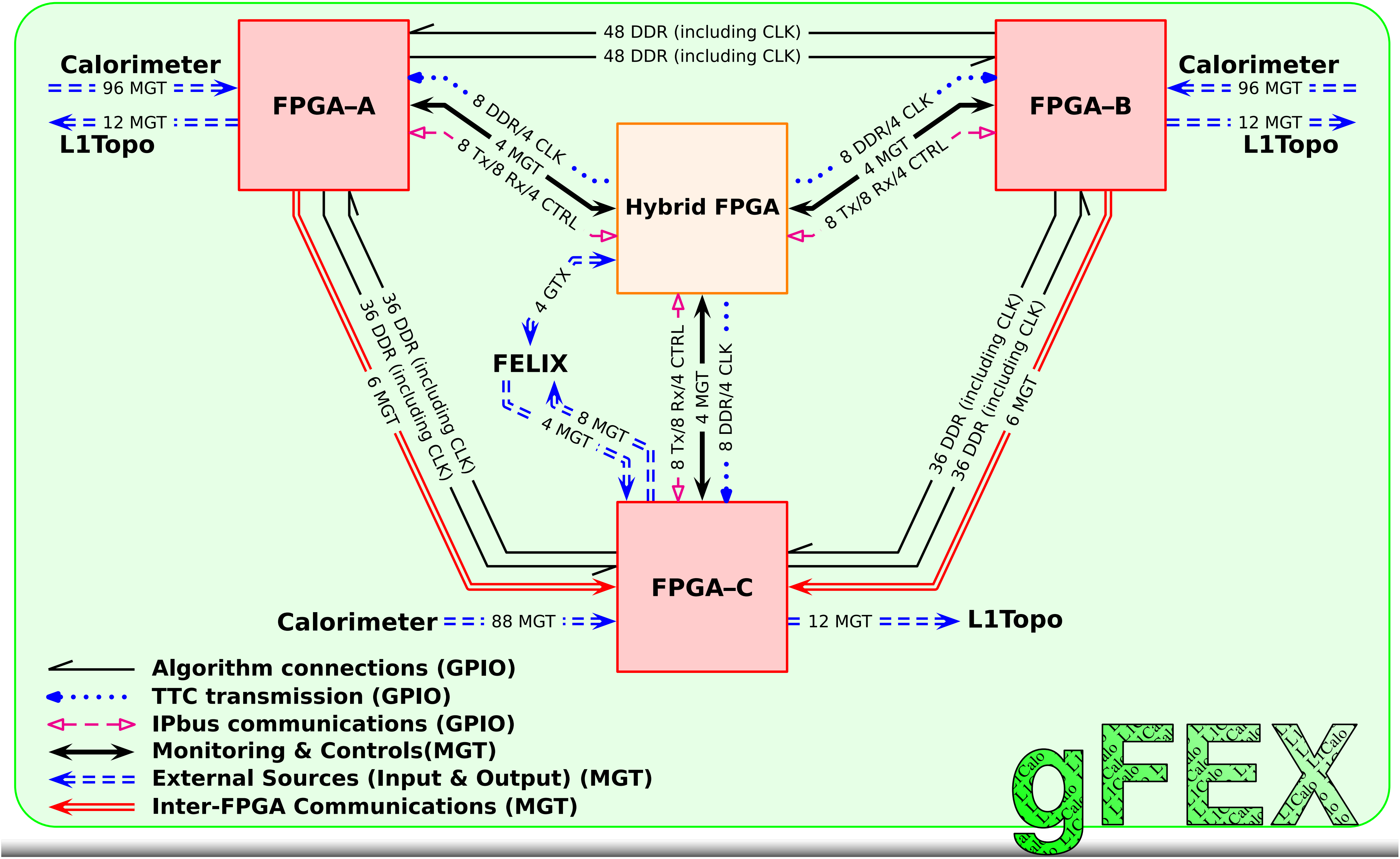
Run 3 Trigger & DAQ

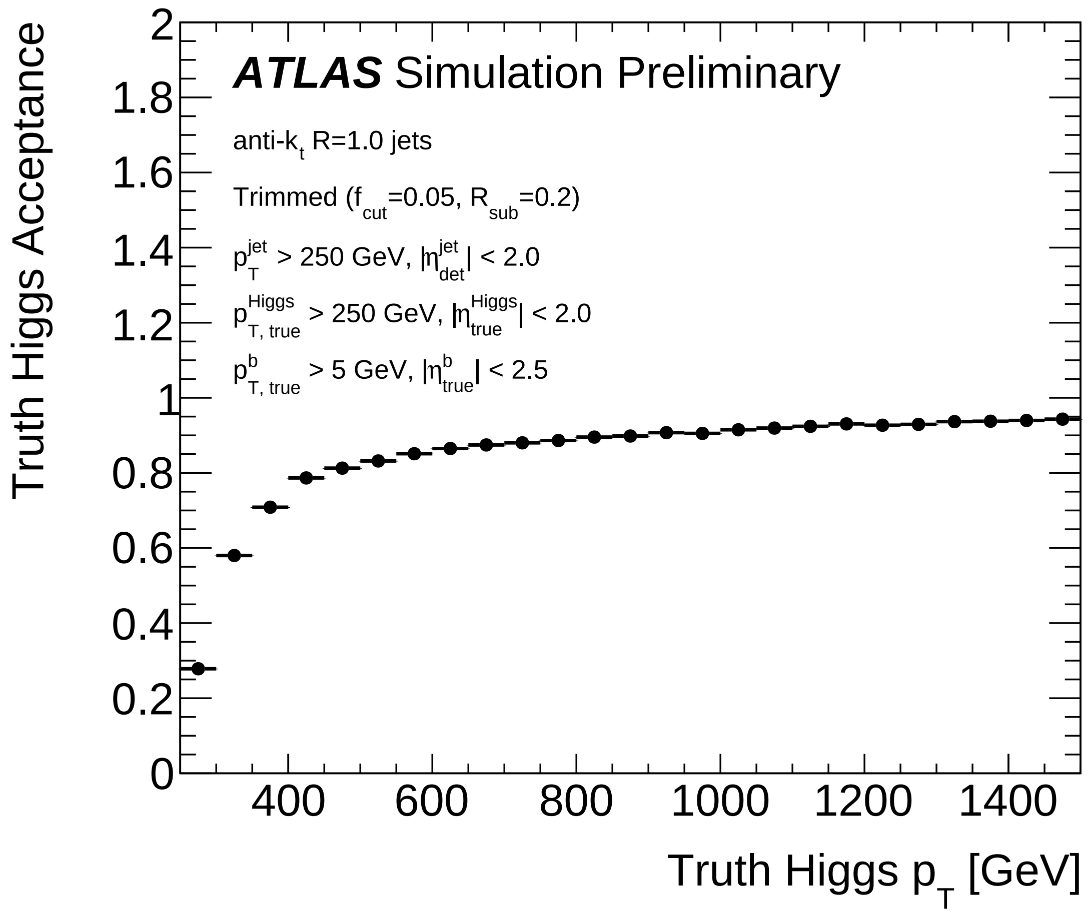


gFEX Functional Diagram

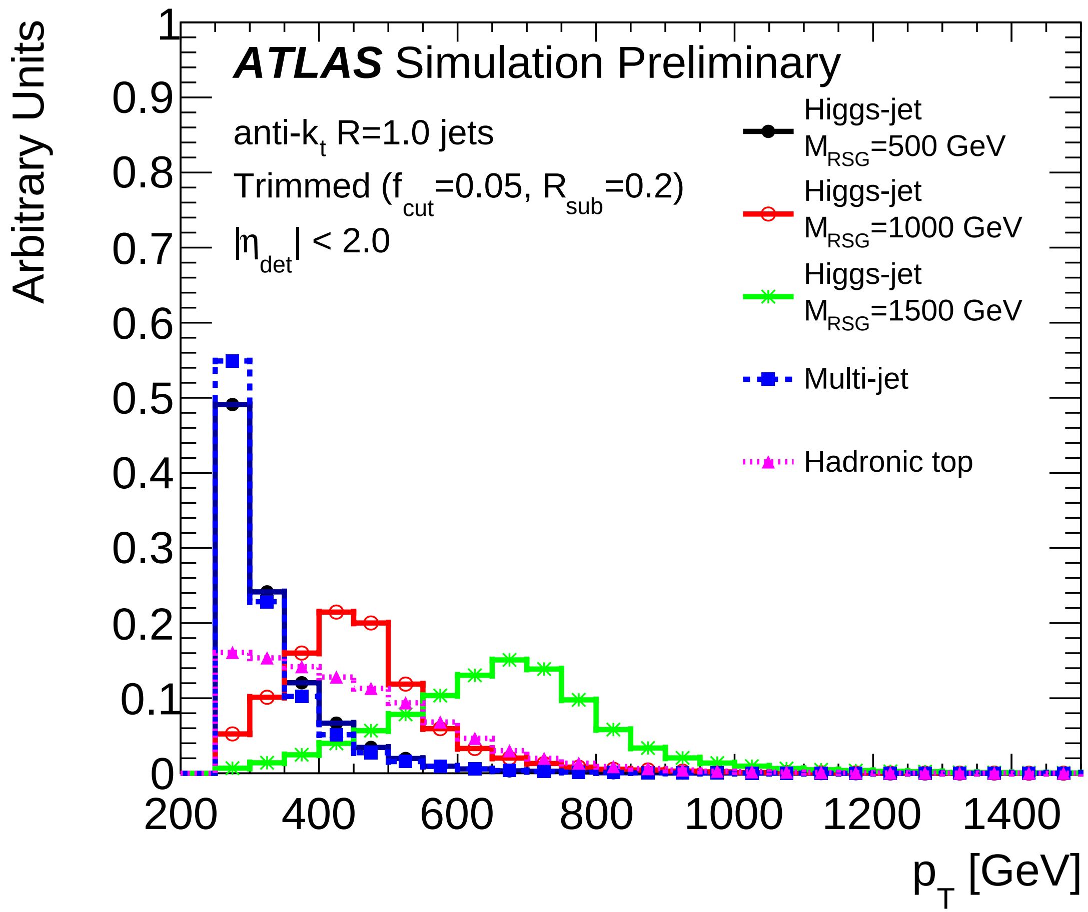


gFEX FPGA Connections





ATLAS Simulation Preliminary
anti-k_t R=1.0 jets
Trimmed (f_{cut}=0.05, R_{sub}=0.2)
p_T^{jet} > 250 GeV, $|\eta_{det}^{jet}|$ < 2.0
$p_{T, true}^{Higgs}$ > 250 GeV, $|\eta_{true}^{Higgs}|$ < 2.0
$p_{T, true}^{b}$ > 5 GeV, $|\eta_{true}^{b}|$ < 2.5
Truth Higgs Acceptance
Truth Higgs p_T [GeV]



ATLAS Simulation Preliminary
anti-k_t R=1.0 jets
Trimmed (f_{cut}=0.05, R_{sub}=0.2)
$|\eta_{det}|$ < 2.0
Higgs-jet M_{RSG}=500 GeV
Higgs-jet M_{RSG}=1000 GeV
Higgs-jet M_{RSG}=1500 GeV
Multi-jet
Hadronic top
Arbitrary Units
p_T [GeV]