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

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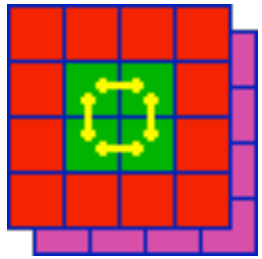


Outline

- Introduction
- Liquid Argon (LAr) calorimeter readout upgrades

- Level 1 Calorimeter trigger upgrades

- Conclusions

- Other ATLAS L1 Calorimeter (L1Calo) trigger-related talks:
  - L1 Calorimeter trigger in Run 2 (Marek Palka, Saturday)
  - FELIX system for readout (Andrea Borga, Thursday afternoon)

LHC upgrade timeline

$\sqrt{s}$ = 7-8 TeV, L~0.8 × 10^{34} $cm^{-2}s^{-1}$, BS=50ns

$\sqrt{s}$ = 13-14 TeV, L~1 × 10^{34} $cm^{-2}s^{-1}$, BS=25ns

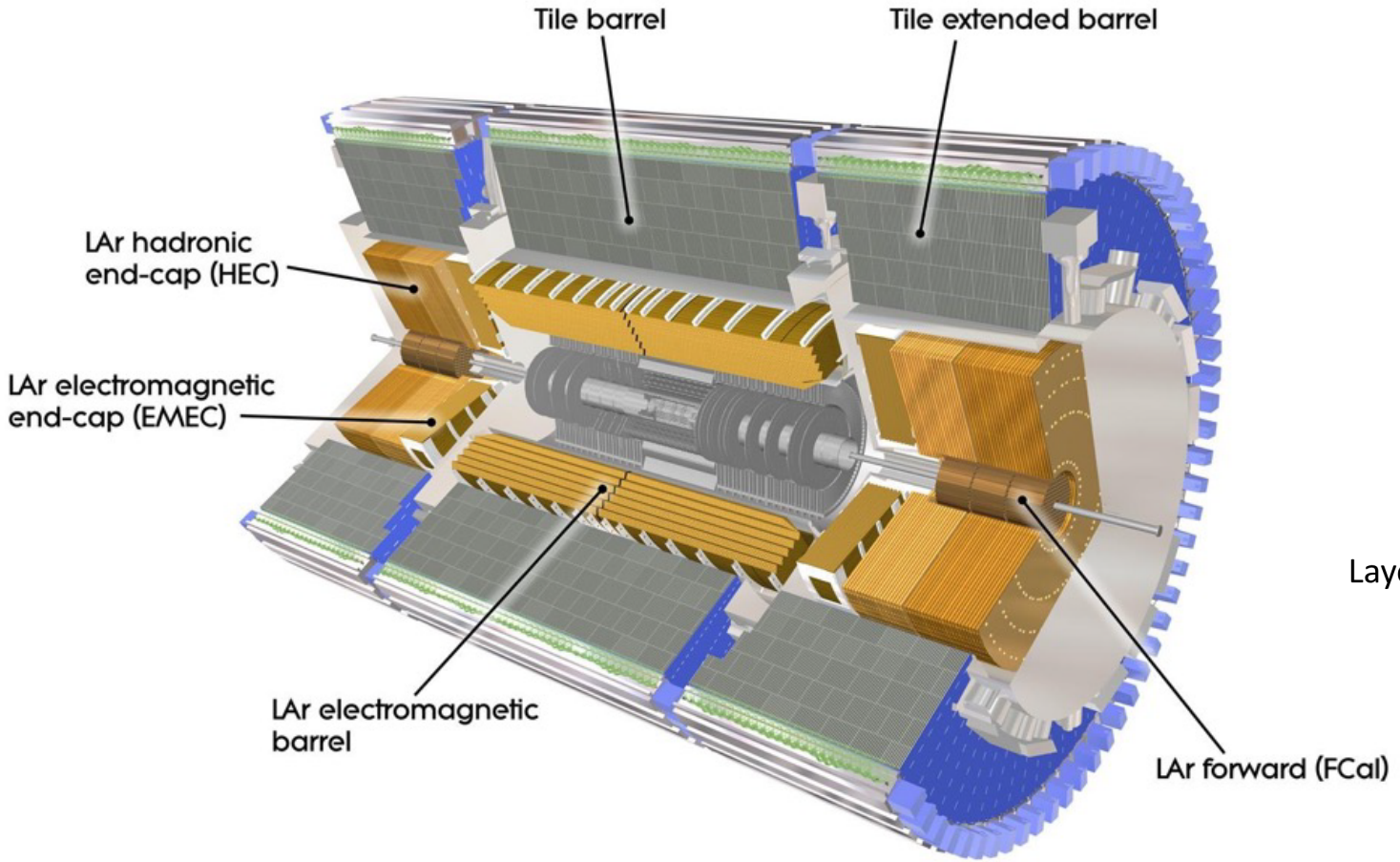
- Phase I upgrades ← Focus of this talk

$\sqrt{s}$ = 14 TeV, L~2 × 10^{34} $cm^{-2}s^{-1}$, BS=25ns

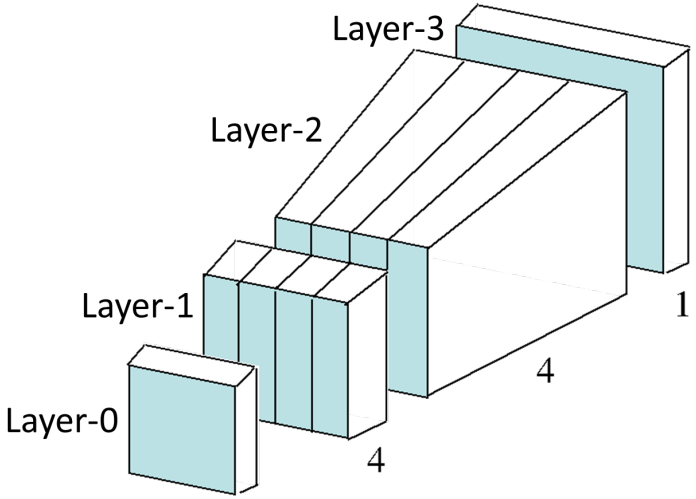
- Instantaneous luminosity increasing
  - Number of interactions per bunch crossing increases
- Pile-up effects significantly degrade calorimeter trigger performance

BS = Bunch Spacing

ATLAS calorimetry



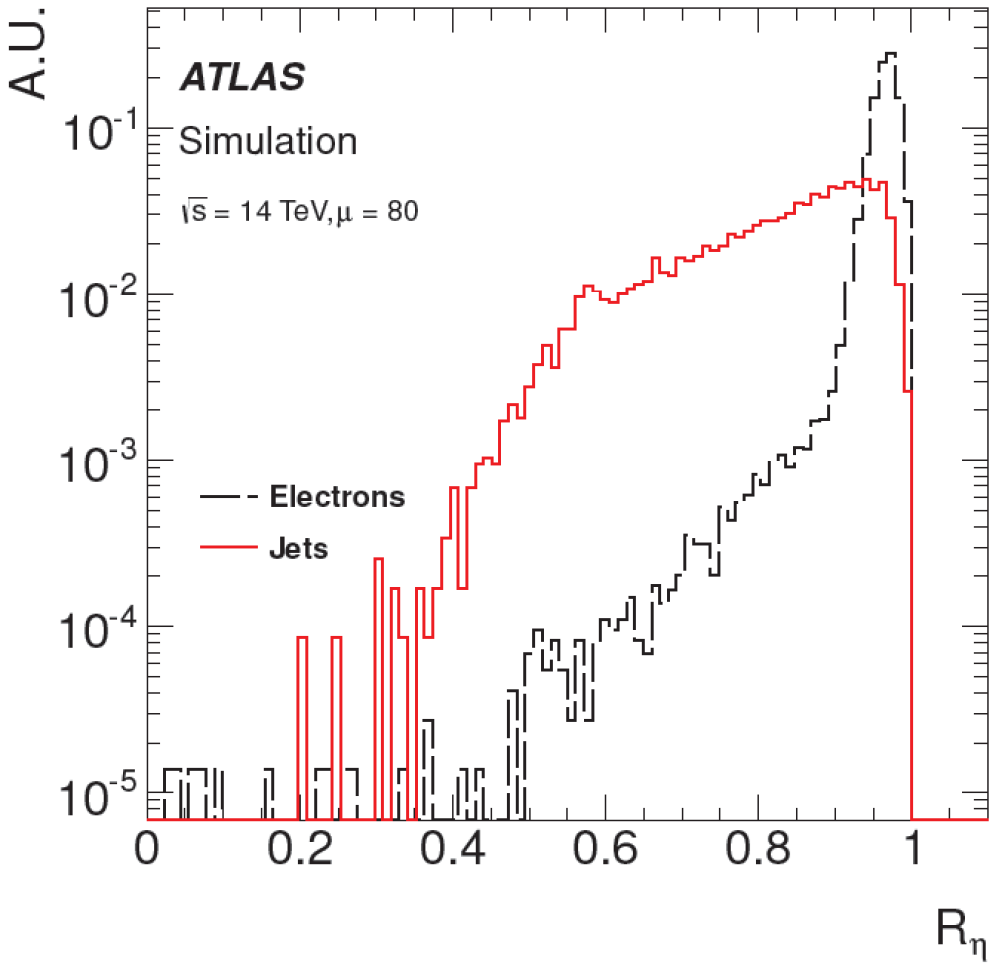
LAr: Pre-sampler
+ 3 EM layers

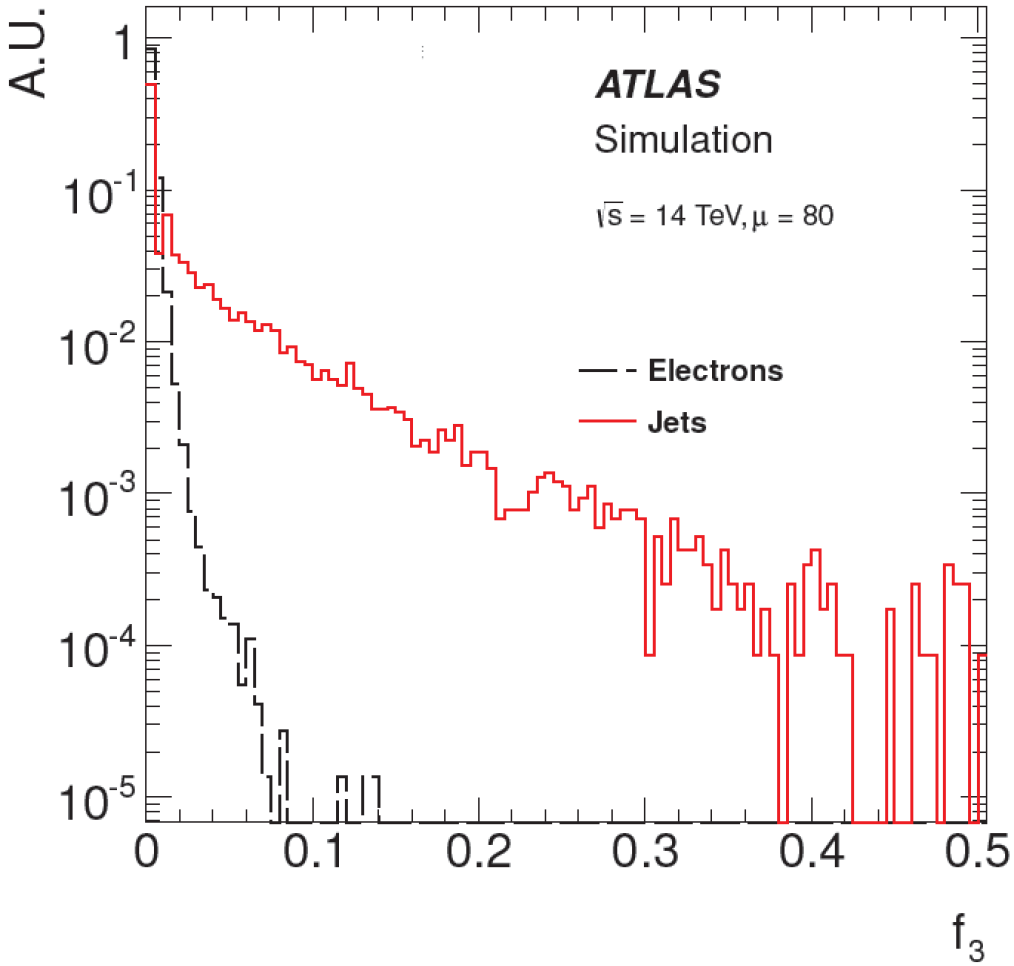


- Liquid Argon (LAr) electromagnetic calorimeter
  - Lead absorber, LAr as active material and copper/kapton electrode
  - Fine segmentation: 4 layers, ~200k readout channels in total
- Hadronic calorimeters : Tile (steel&scintillator), LAr endcap/forward
- Plays a major role in identifying/measuring e, γ, τ, jet and missing ET (offline) and provides inputs for their triggers at the hardware level (L1Calo triggers)

Phase 1 trigger improvements: e/jet separation

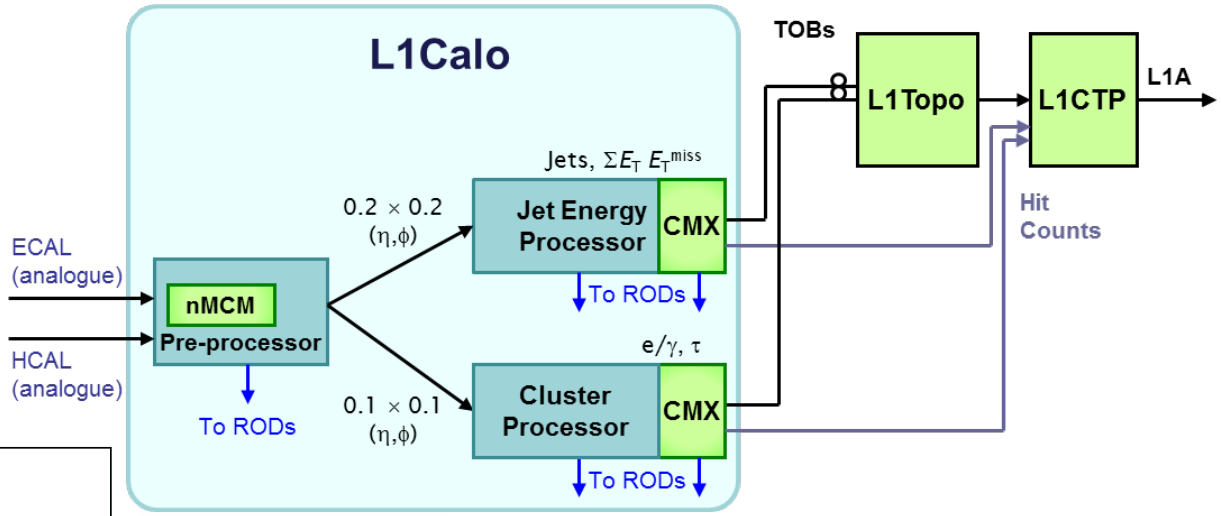
- Utilize more of the calorimeter shower shape information
  - Electron-jet separation
  - lateral R_η - relate energy in central core to immediate surroundings
  - depth f_3 - relate back sampling to whole cluster

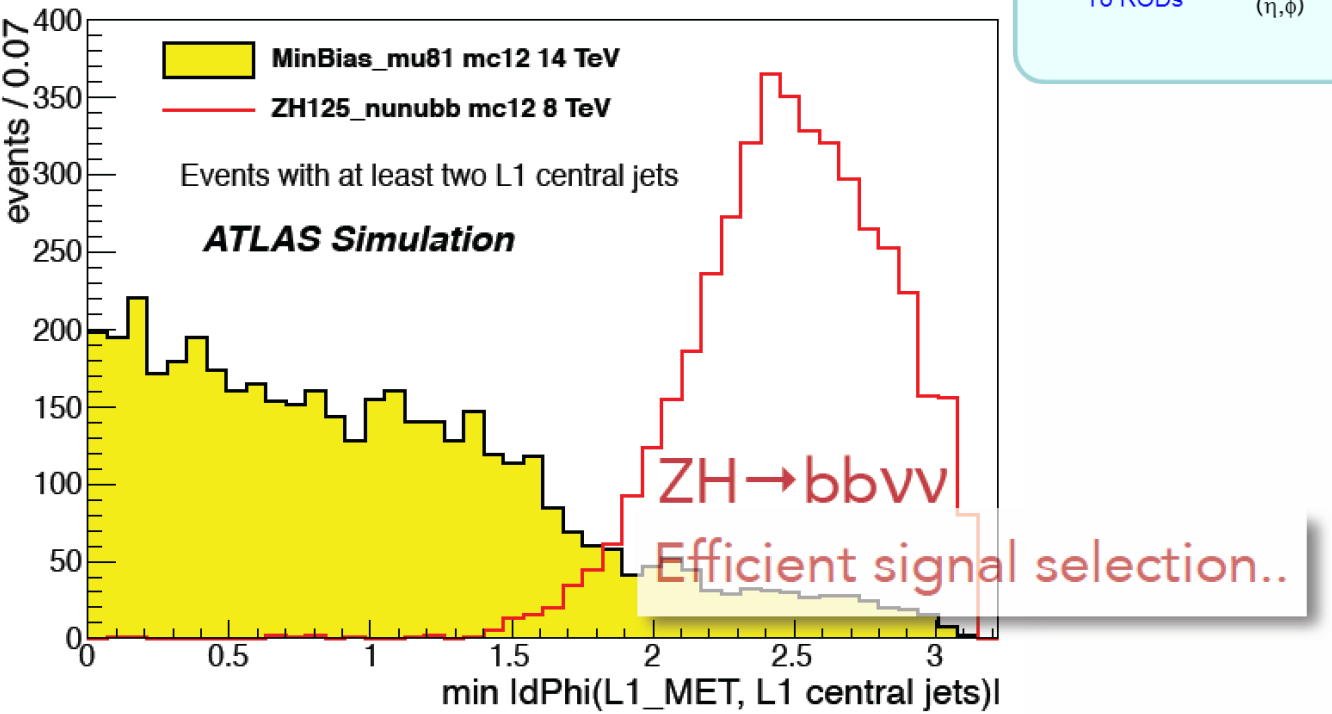




Trigger improvements: Topological processor

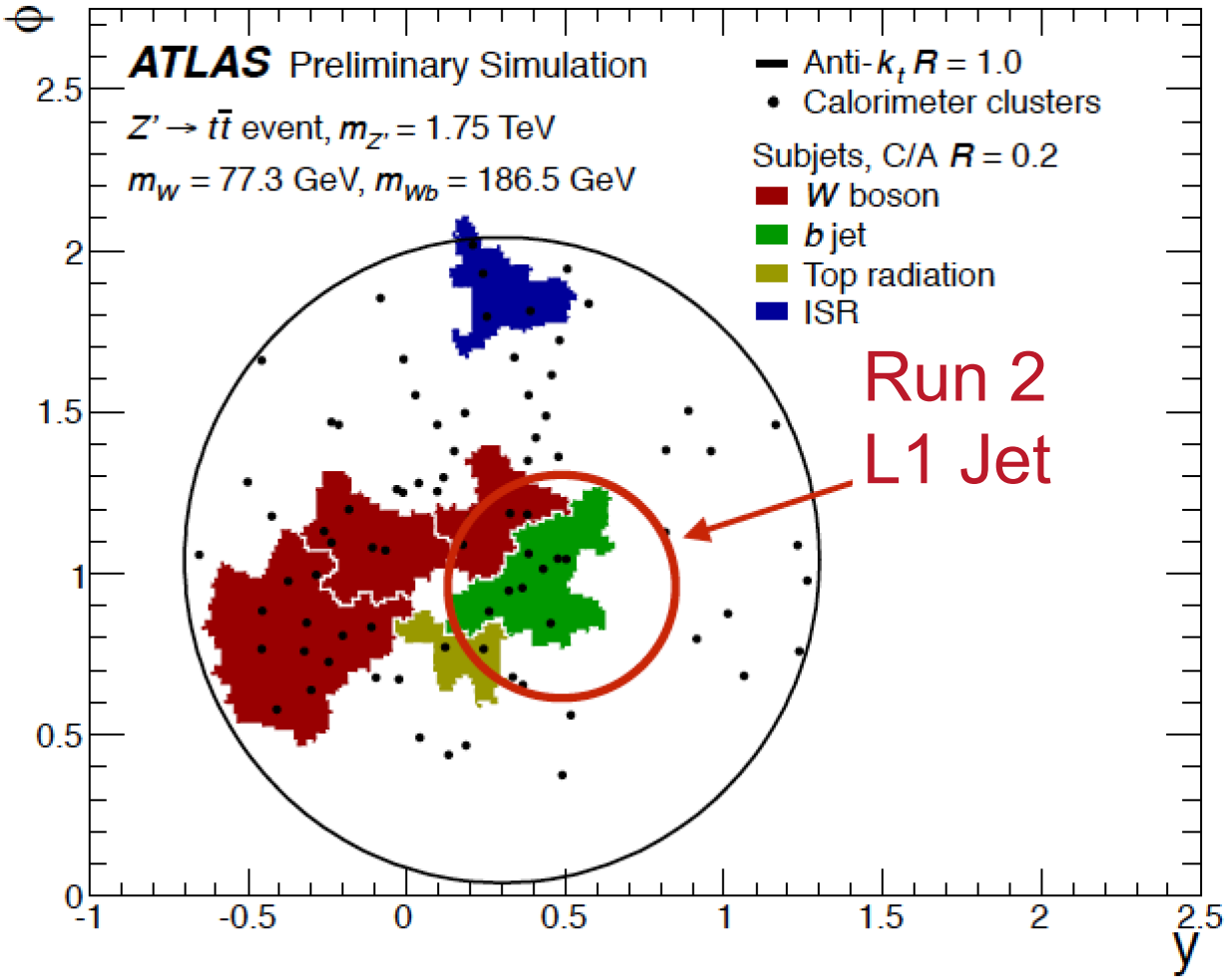
- Use more of the event-wide calorimeter information
  - Topological processor, already partially implemented for Run 2
    - See Marek's talk on L1 Calorimeter trigger in Run 2 on Saturday
  - Add muon information in Phase 1 upgrade
  - Can apply selection with topological variables as $\Delta\varphi$, $\Delta\eta$, ΔR, H_T





Trigger improvements for Phase 1: boosted jets

- High p_T bosons and fermions are a key component of ATLAS physics
  - W,Z and H bosons, top quarks and exotic particles
- Boosted objects at the trigger level



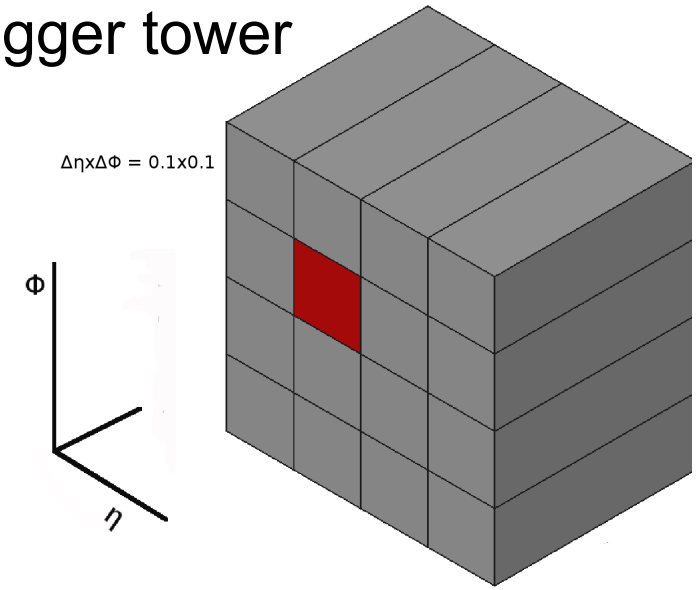
General upgrade concepts

- To achieve these trigger features, develop new hardware for trigger readout and processing
- LAr calorimeter trigger signals
  - Fully digitized readout with finer granularity & digital filtering for out-of-time pile-up correction and bunch-crossing identification
- L1Calo trigger processing
  - Pile-up subtraction
  - Employ selection fully based on object features and event topology information
- Readout through FELIX system
  - See Andrea's FELIX talk on Thursday
- Challenges:
  - Highly dense electrical & optical circuit boards
  - High-speed optical links (up to ~10 Gb/s)
  - Signal mapping and data duplication among readout modules
  - Trigger algorithms in FPGA firmware
    - Complexity
    - Short latency

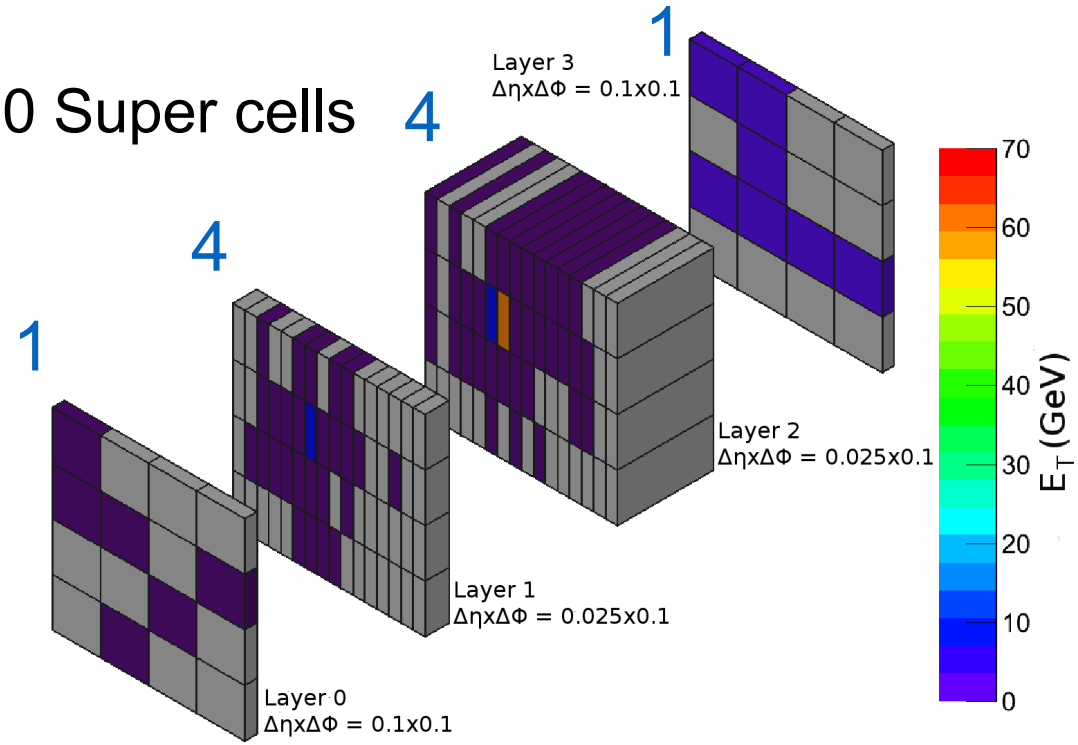
New LAr calorimeter trigger granularity

Electron with E_T=70 GeV as seen by Run 1/2 and Run 3 systems

1 Trigger tower



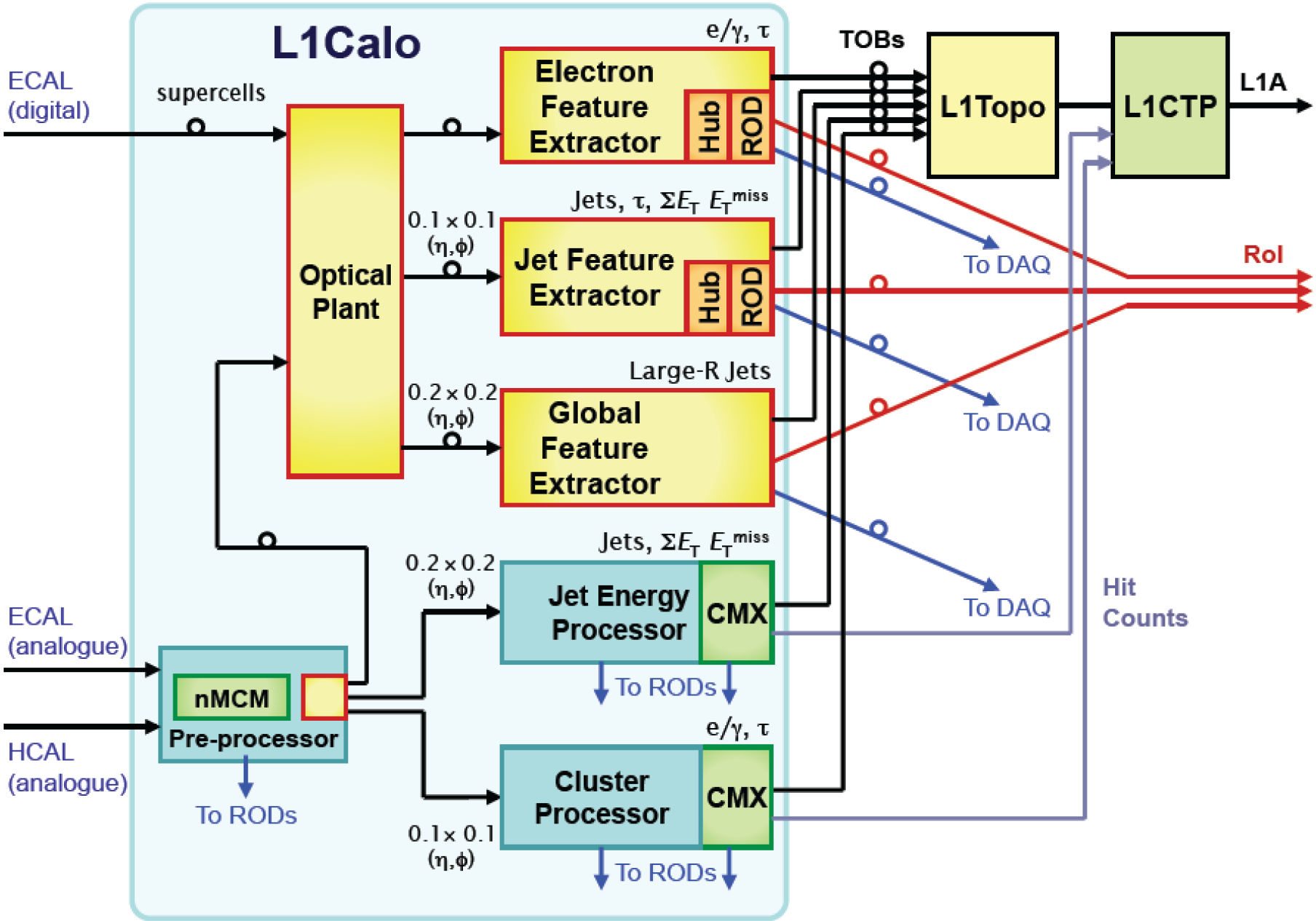
10 Super cells



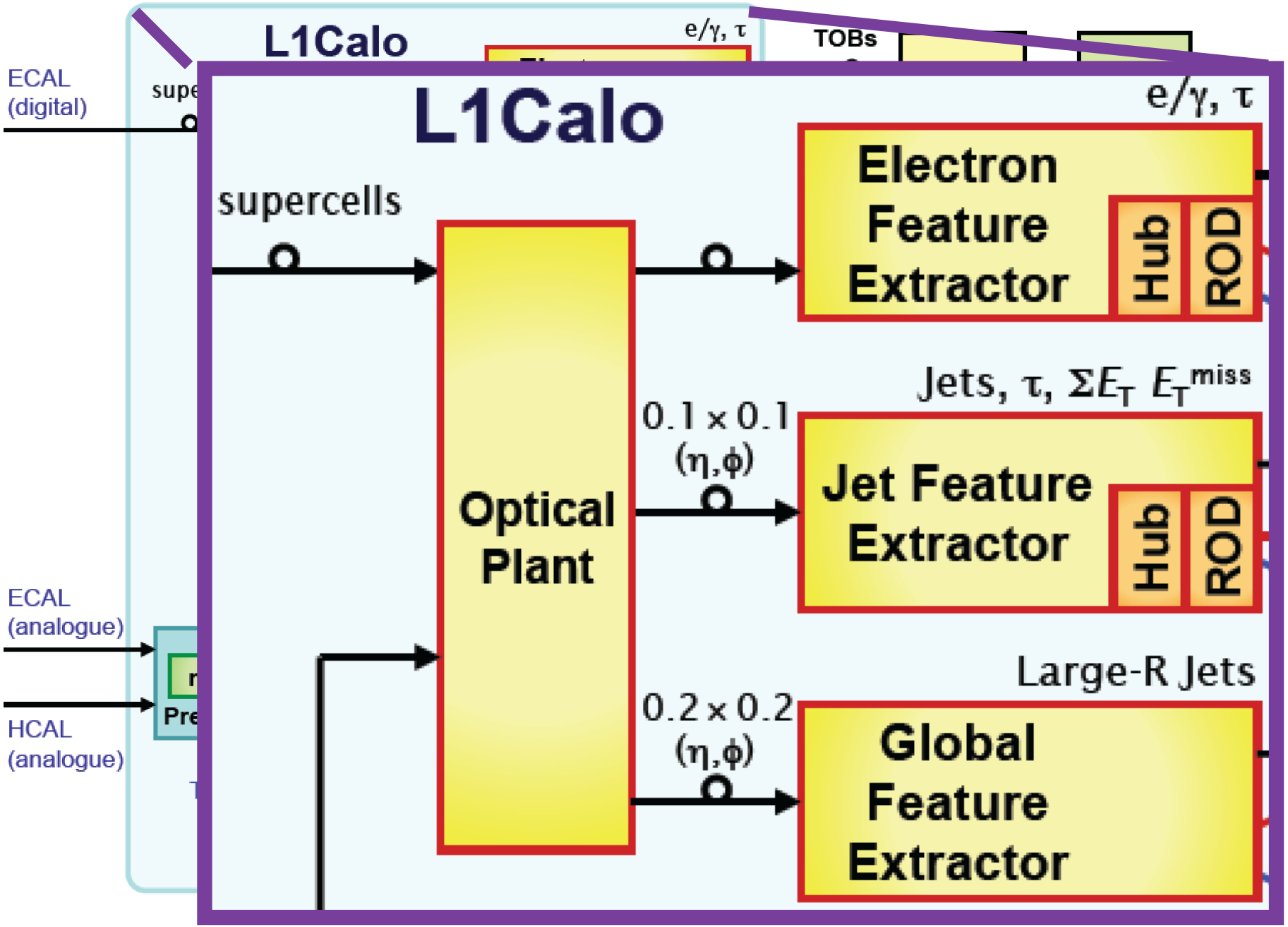
- Trigger towers
  Δη x ΔΦ = 0.1 x 0.1
- Separate of electrons, taus, jets limited by granularity

- Finer granularity
  - Longitudinal and transverse
- Finer energy quantization

Upgraded L1Calo trigger

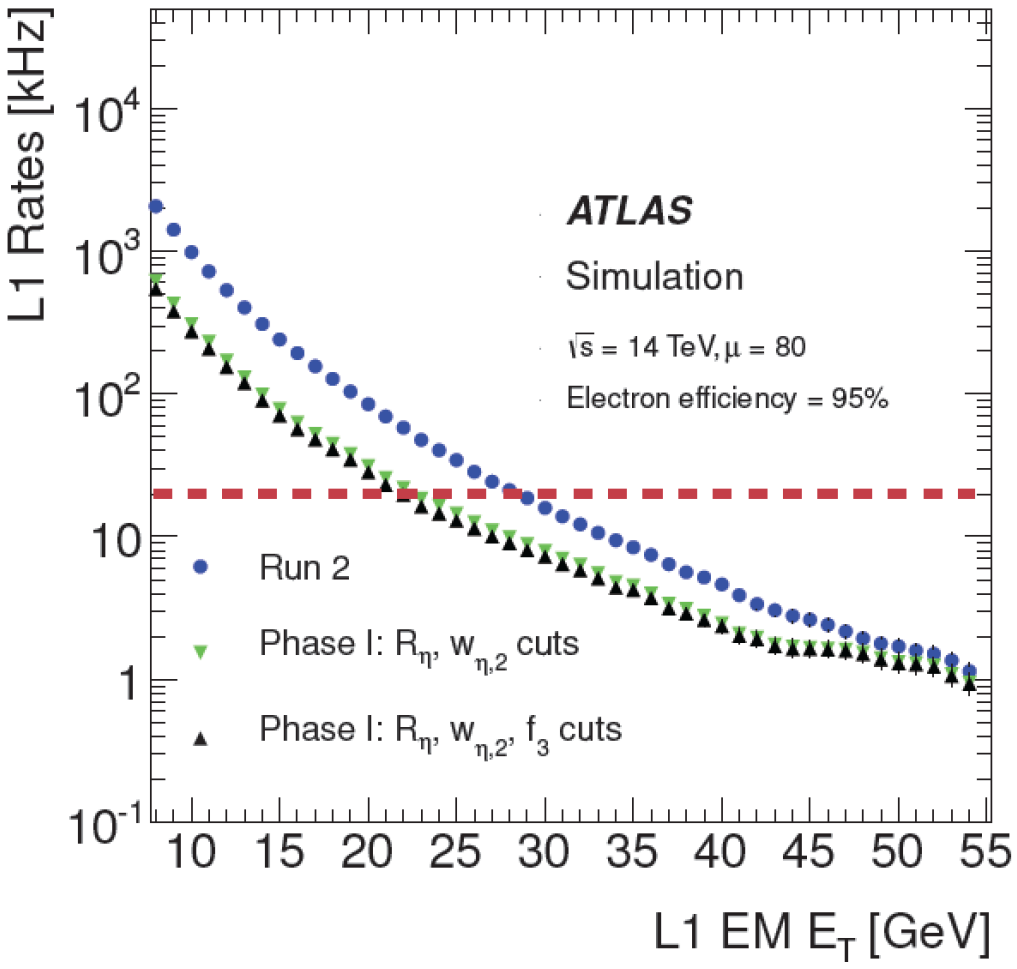


Updated L1Calo trigger



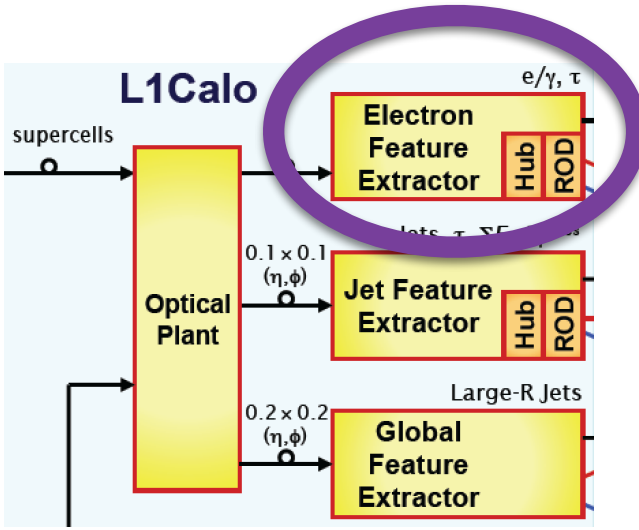
L1Calo Feature Extraction: eFEX

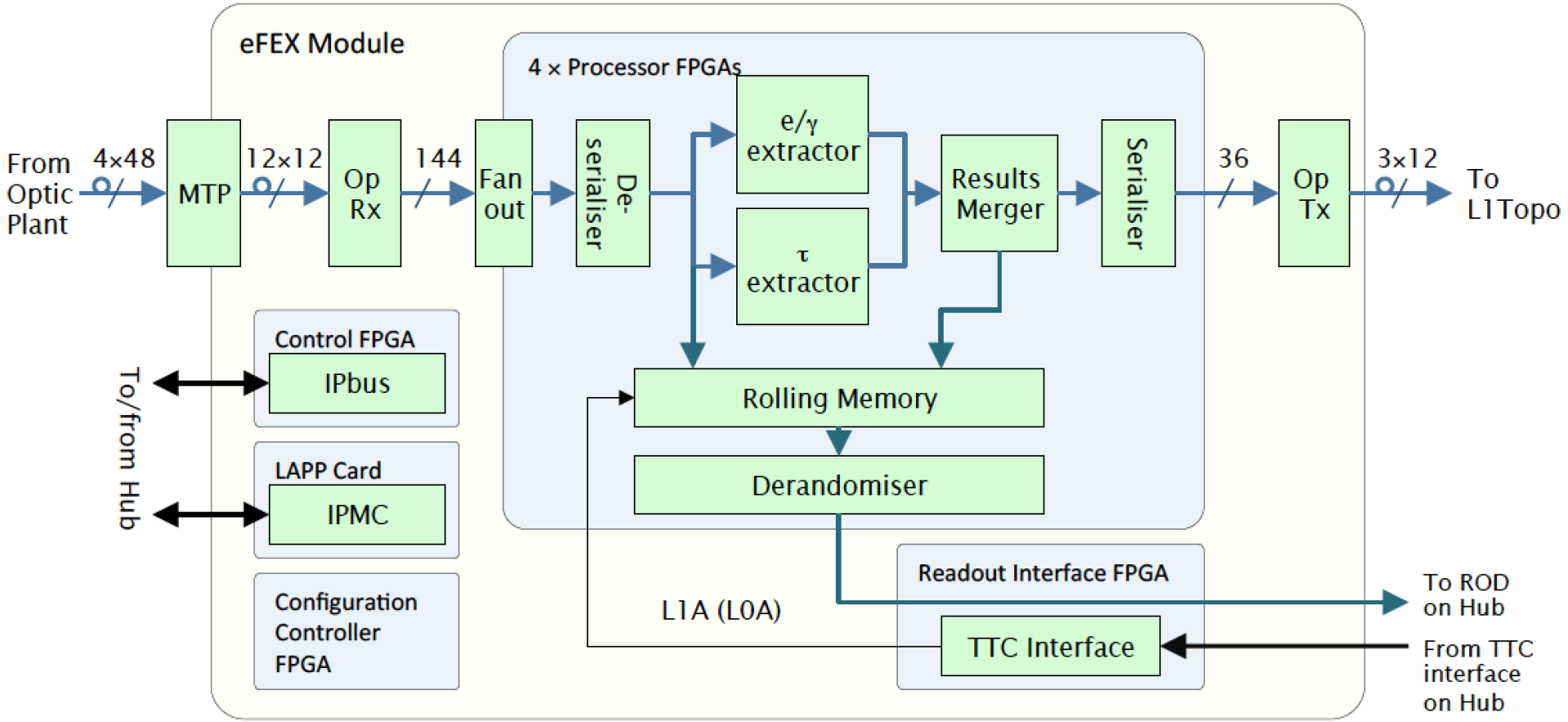
- Cluster and identify e/γ/τ using isolation and cluster shape variables
- Flexible rejection algorithms
- EM trigger rate:
  - Adopting jet rejection using shape variables, the threshold can be lowered by 7 GeV
    - Compared at reference points of 20kHz (Run 2 rate budget) and 95% efficiency
    - Can maintain high photon efficiency (>96%)
    - Reduce rate by factor ~3



eFEX

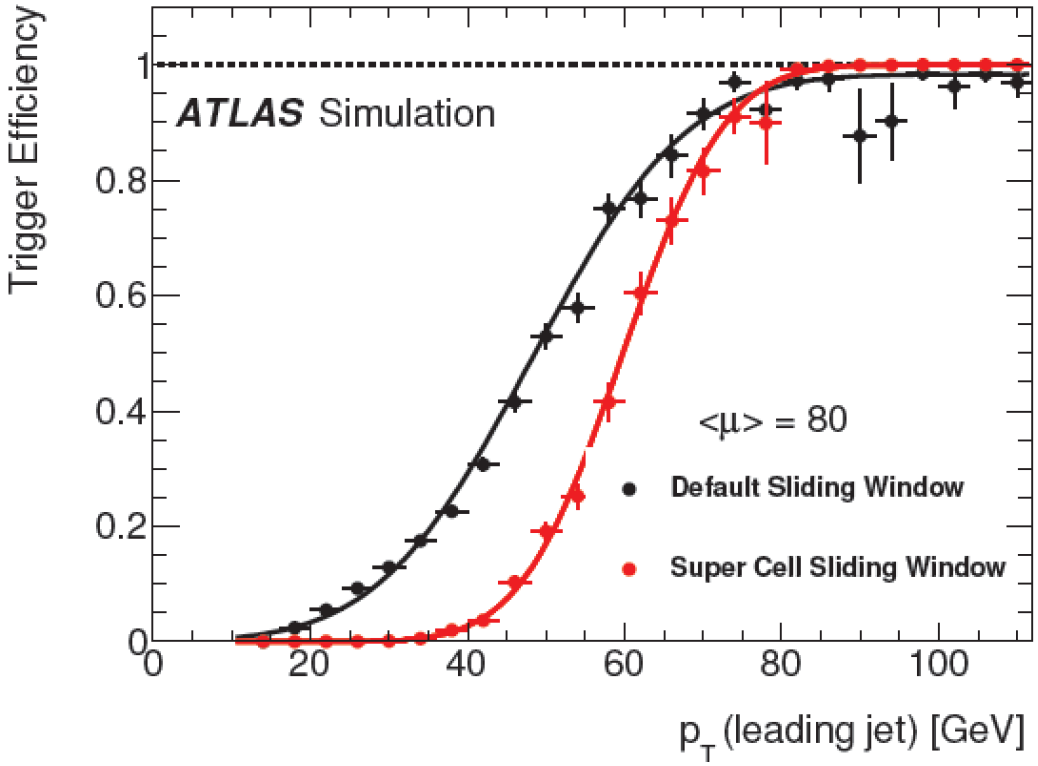
- 24 ATCA modules (2 shelves)
- 4 FPGAs per board
- Some input data sharing
  - Between boards
  - Between FPGAs

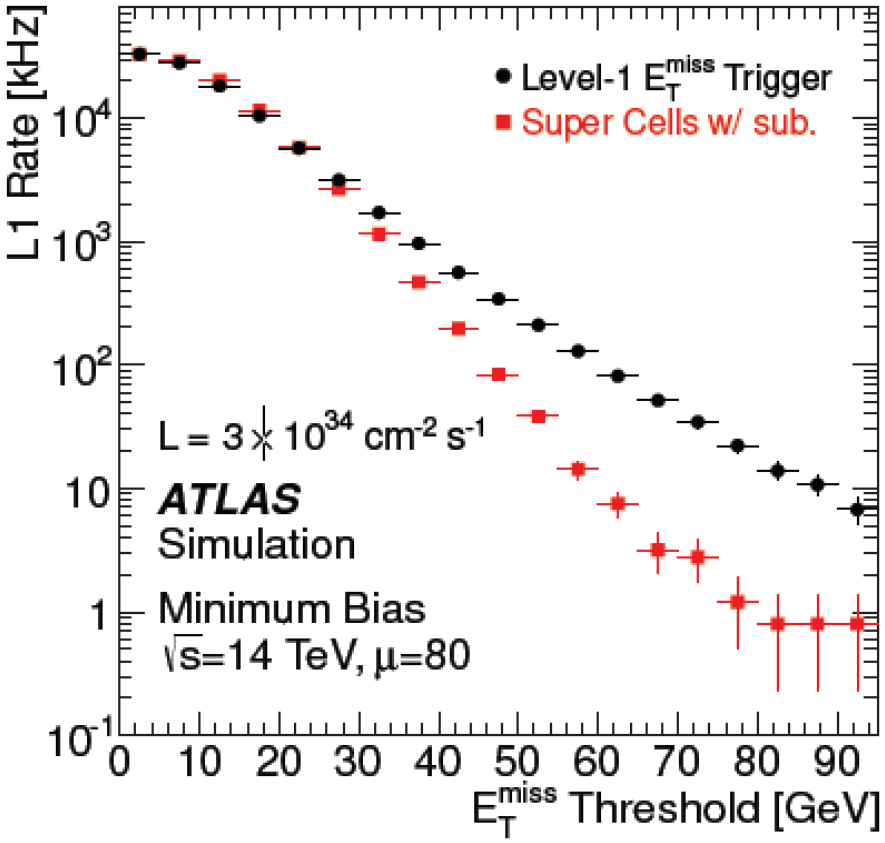




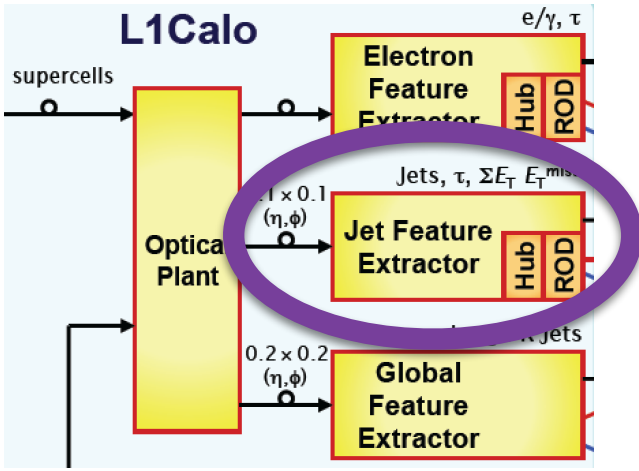
L1Calo Feature Extraction: jFEX

- Cluster and identify jets/τ and calculate MET and H_T
- Enables pile-up suppression using event energy density
- Better trigger turn-on for jet and missing E_T triggers
  - Pileup suppression, improved jet reconstruction

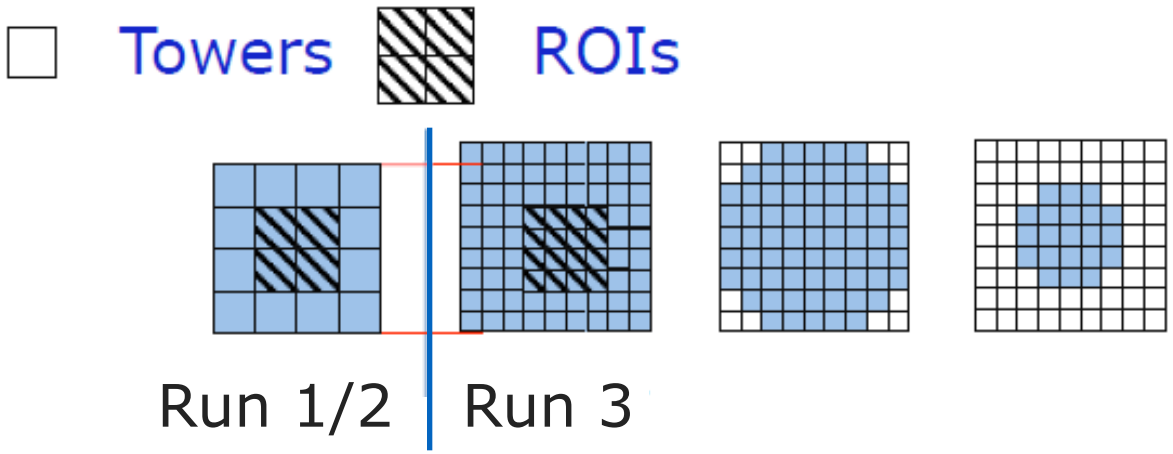




jFEX

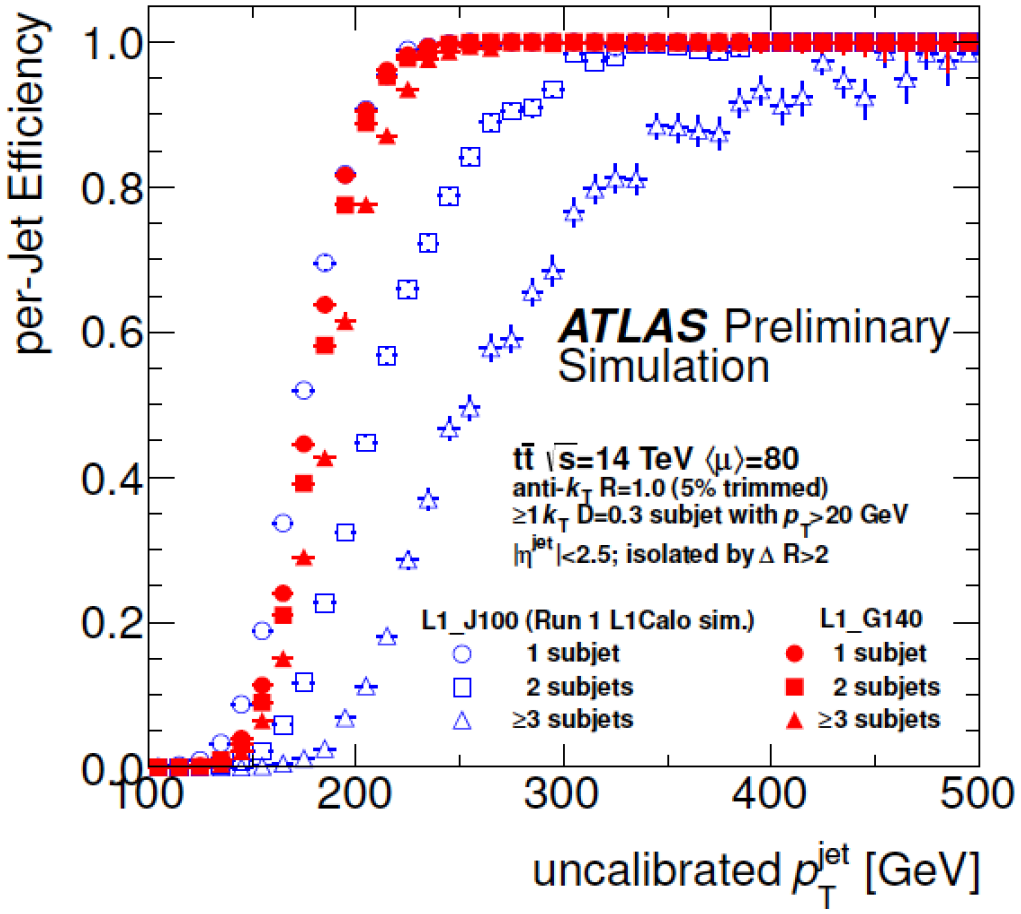


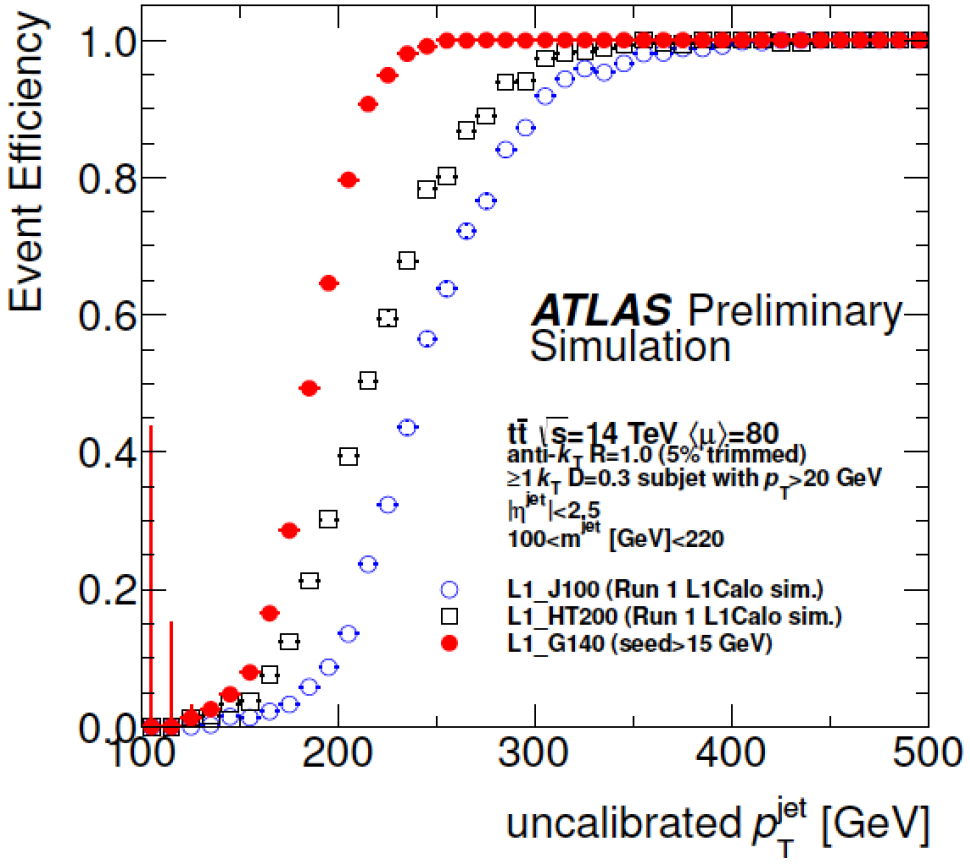
- 7 ATCA modules (1 shelf)
- 4 large FPGAs per board
- Large jet environment
  - ≤ 0.9x0.9 (ηxφ)
- Increased dynamic range compared to Run 1/2
- Increased granularity (x4) compared to Run 1/2
  - allows flexibility in jet definition (non-square, Gaussian filter, …)



L1Calo Feature Extraction: gFEX

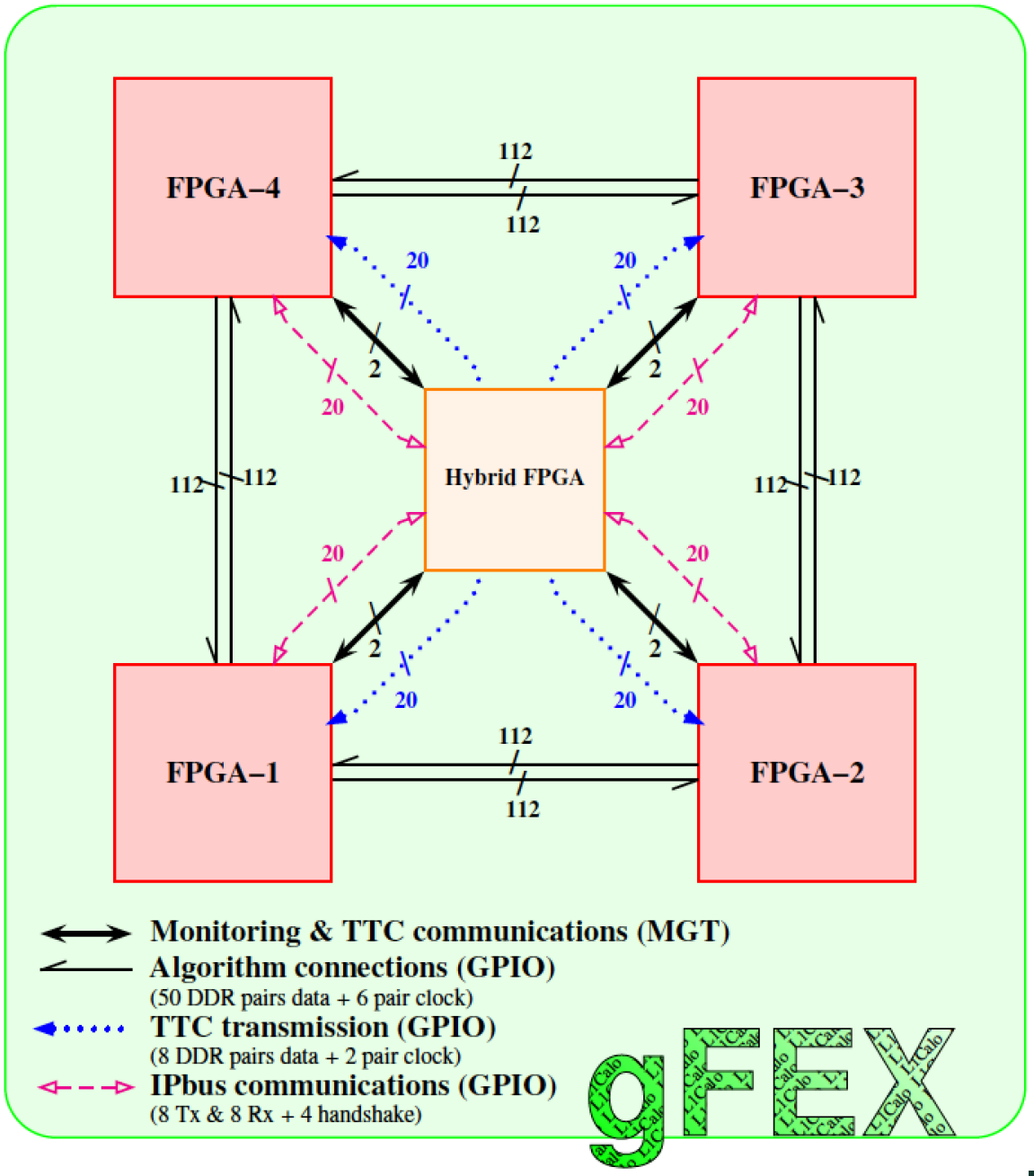
- Global event processing
- Large-area jets for dedicated physics cases
- Larger trigger acceptance for boosted heavy objects
  - Sharper turn-on-curve behavior

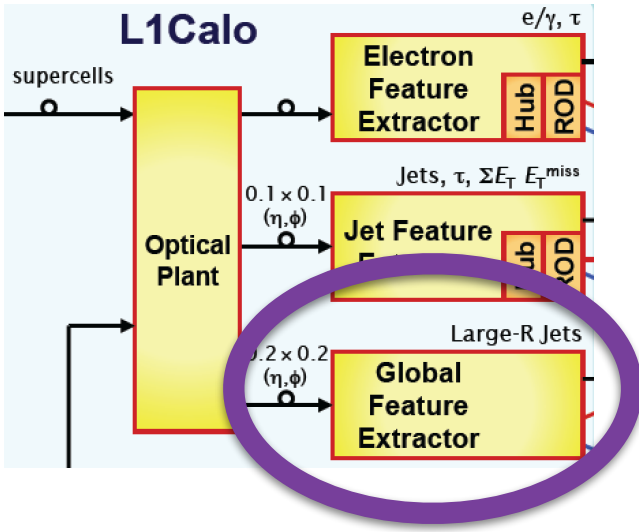




gFEX

- 1 ATCA module

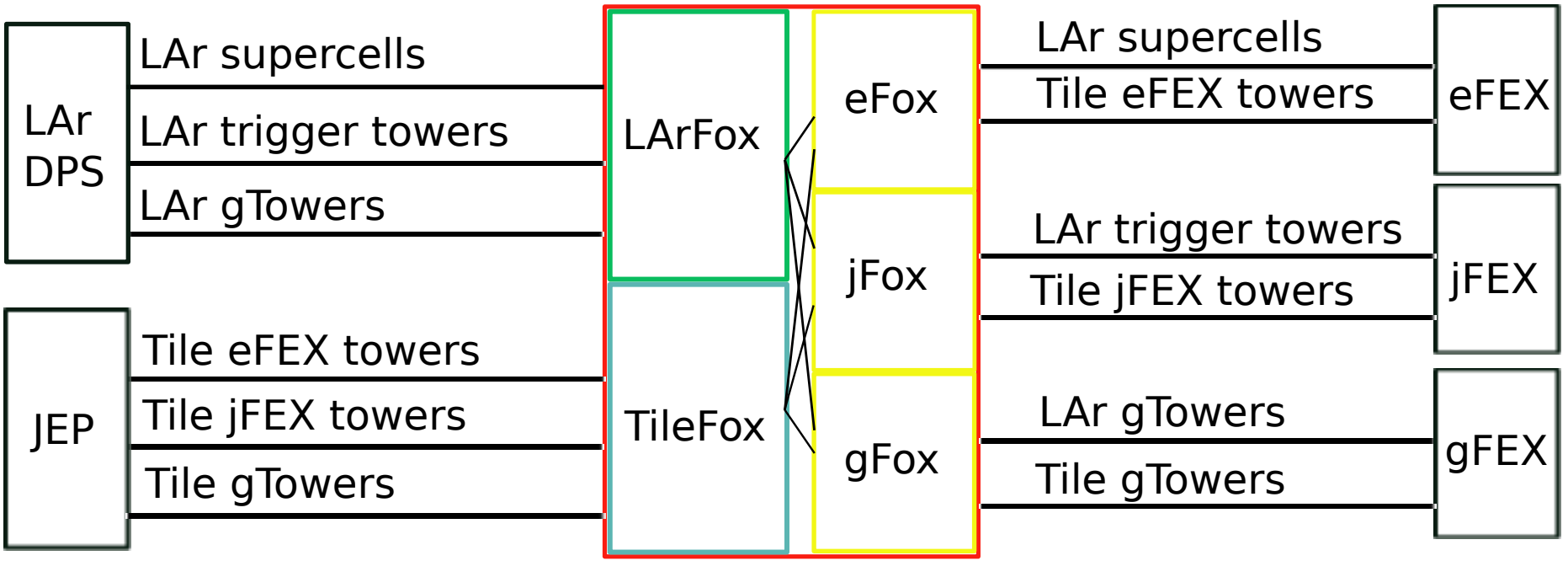




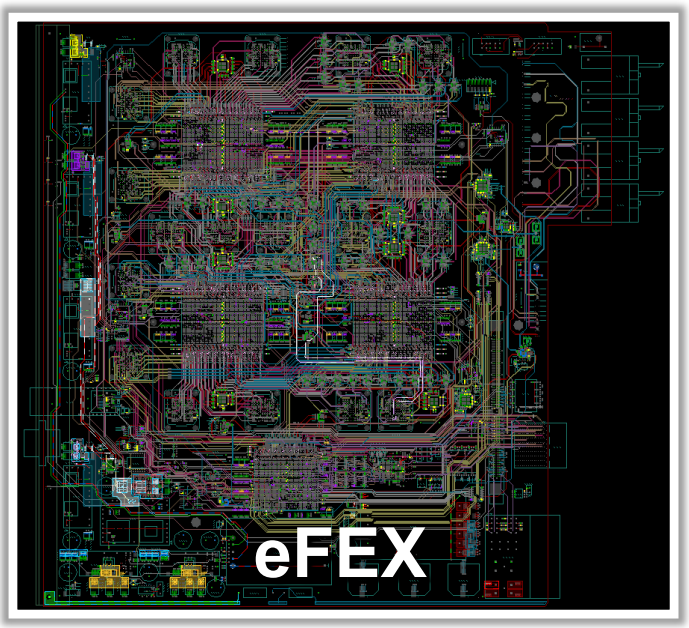
- Coarse granularity data ($\Delta\eta$x$\Delta\varphi$=0.2x0.2) from calorimeters
- Large-radius jet finding in 13 bunch crossings (325 ns)

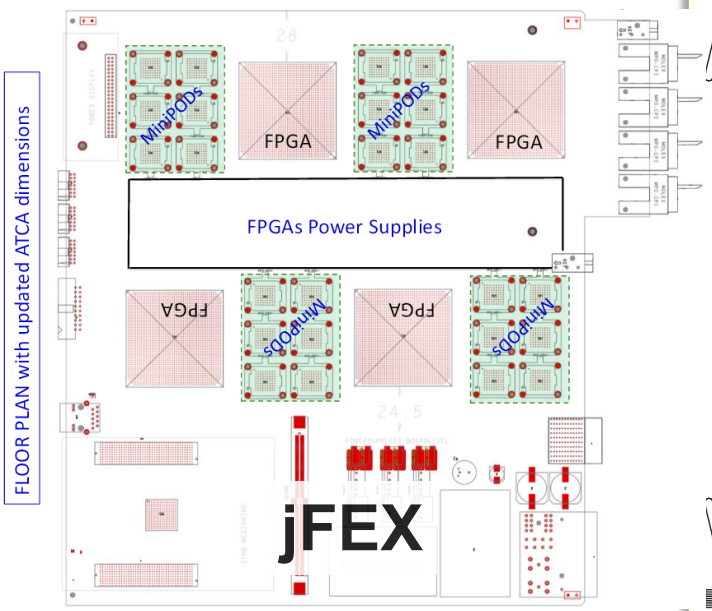
Mapping and duplication of inputs: FOX

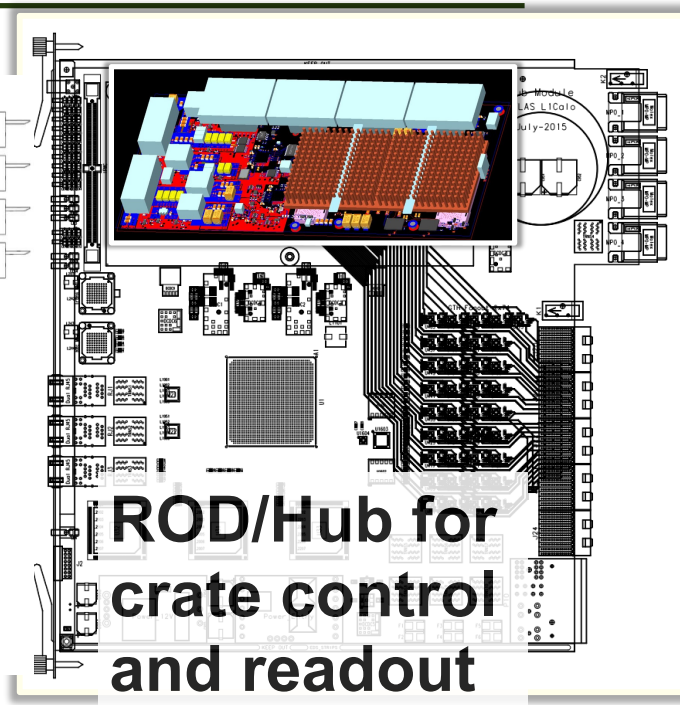
- Fiber-Optic eXtractor (FOX)
- Calo → FEXes signal mapping
  - ~7500 optical fibers
- Signal duplication
  - Provide passive splitting for fraction of fibers if necessary
- Requirements
  - Minimal loss, transmission time
  - Signal integrity, stability

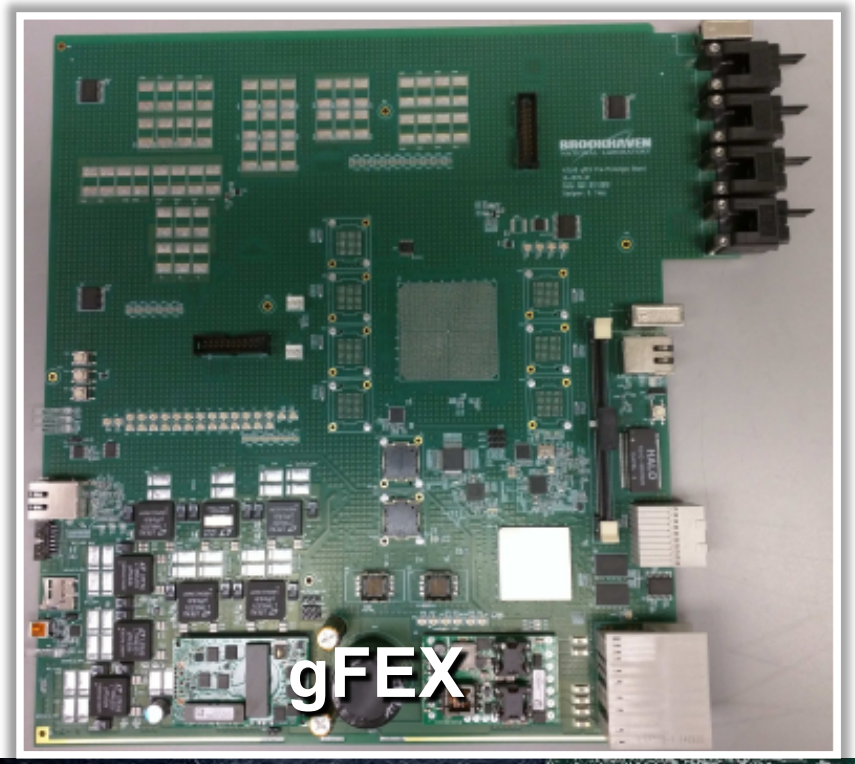


Prototype module design and construction









Conclusions

- Upgrade activities ongoing in order to explore full physics of the high-luminosity LHC
- ATLAS is developing new electronics for calorimeter triggering
- Expect improved trigger performances with the upgraded system even in severe pile-up conditions.
- Challenges
  - FEX boards have many-layer with many high-speed traces
  - Optical and electronic signals at up to 10 Gb/s
  - Signal mapping, data duplication
- R&D, design and production progressing well toward installation in 2019-2020
  - Prototypes are now being built