(Building Blocks)

ATLAS Muon and Calorimeter Trigger Primitives

(Hardware Triggers for HL-LHC)

v8

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on behalf of the ATLAS collaboration (2016.10.06)

ATLAS Calo. / µ Trigger Upgrade & HL-LHC plan

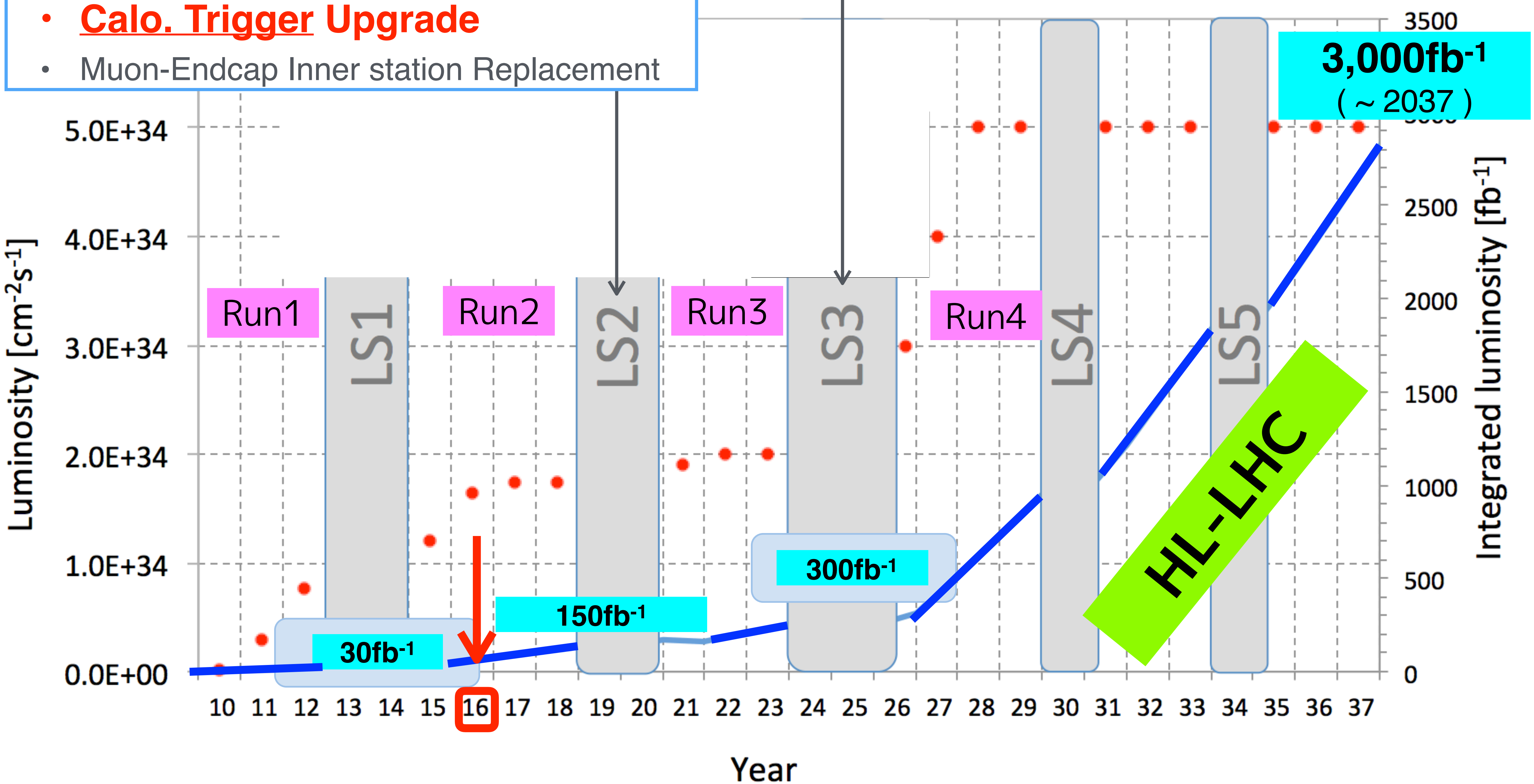
[LS3]

- **Muon Trigger Upgrade / additional Chamber Install (BI)**
- Calo. Trigger (higher granularity hadron R/O , forward electron)

big change on the Trigger Latency & Max. Rate

[LS2]

- **Calo. Trigger Upgrade**
- Muon-Endcap Inner station Replacement



Trigger Menu @ ATLAS (HL-LHC)

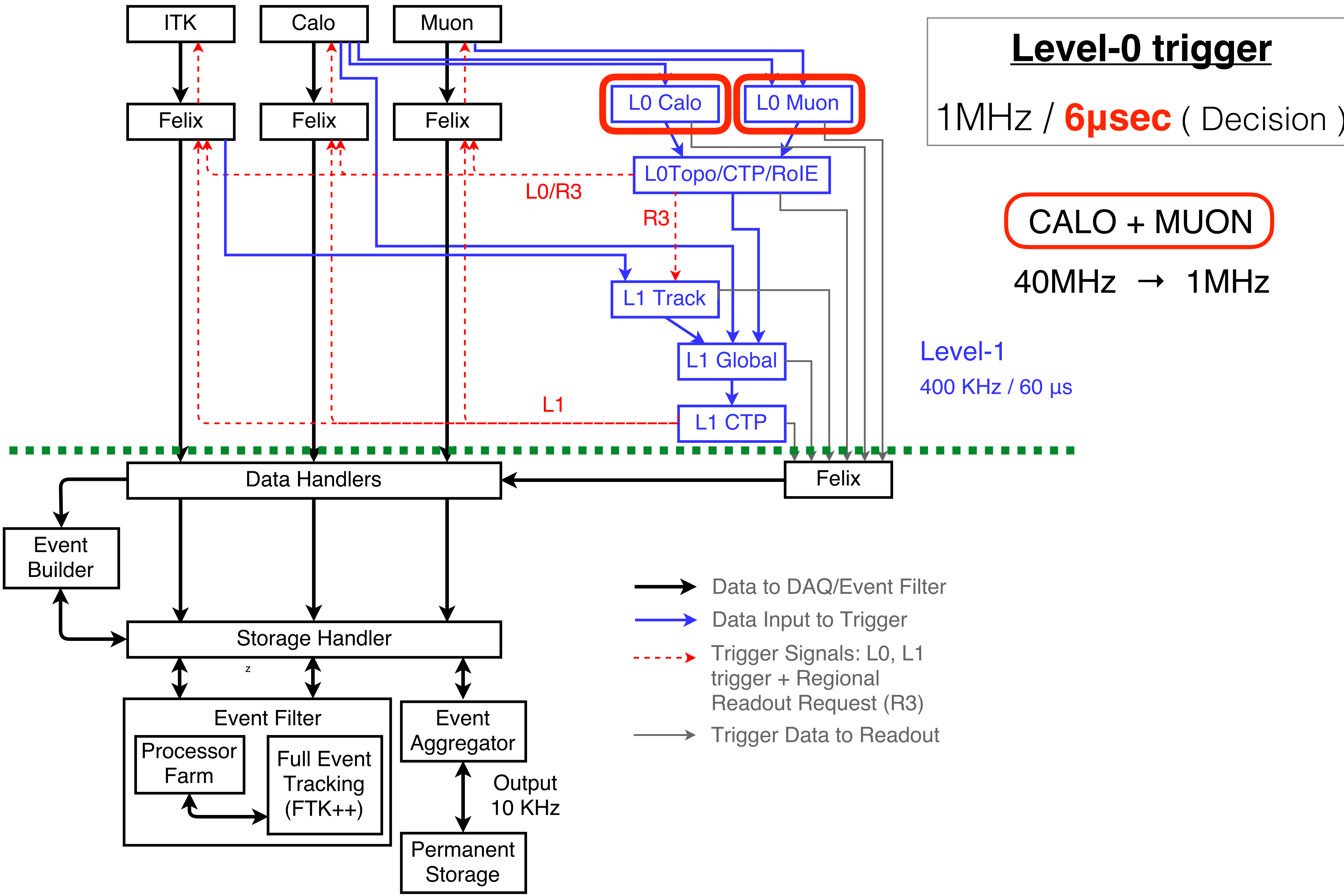
HL-LHC @ 7.5x10^{34}	Offline p_T Threshold [GeV]	Offline $\|\eta\|$	**L0** Rate [kHz]
isolated Single e	22	< 2.5	200
forward e	35	$2.4 - 4.0$	40
single γ	120	< 2.4	66
single μ	20	< 2.4	40
di-γ	25	< 2.4	8
di-e	15	< 2.5	90
di-μ	11	< 2.4	20
$e - \mu$	15	< 2.4	65
single τ	150	< 2.5	20
di-τ	40,30	< 2.5	200
single jet	180	< 3.2	60
fat jet	375	< 3.2	35
four-jet	75	< 3.2	50
H_T	500	< 3.2	60
E_T^{miss}	200	< 4.9	50
jet + E_T^{miss}	140,125	< 4.9	60
forward jet**	180	3.2 - 4.9	30
Total			**1MHz**

ex : single-lepton

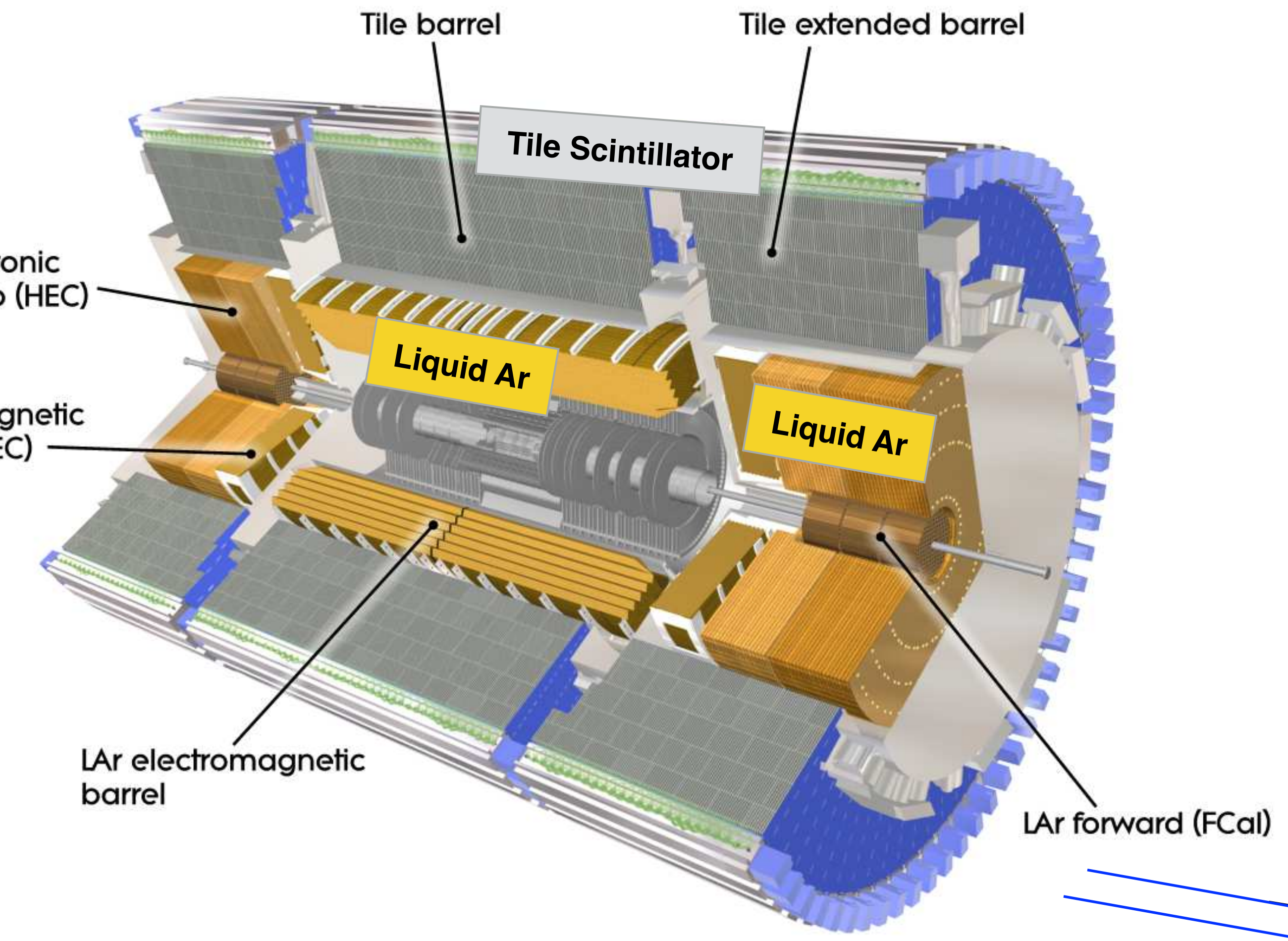
	Run-1	Run-2	**HL-LHC**
	0.8x10^{34}	2.0x10^{34}	**7.5x10^{34}**
1e	25 GeV	32	**22 GeV**
1μ	25 GeV	27	**20 GeV**

Aim : similar threshold as Run-1 & Larger Geom. acceptance

ATLAS Trigger & Data Readout



ATLAS Calorimeter

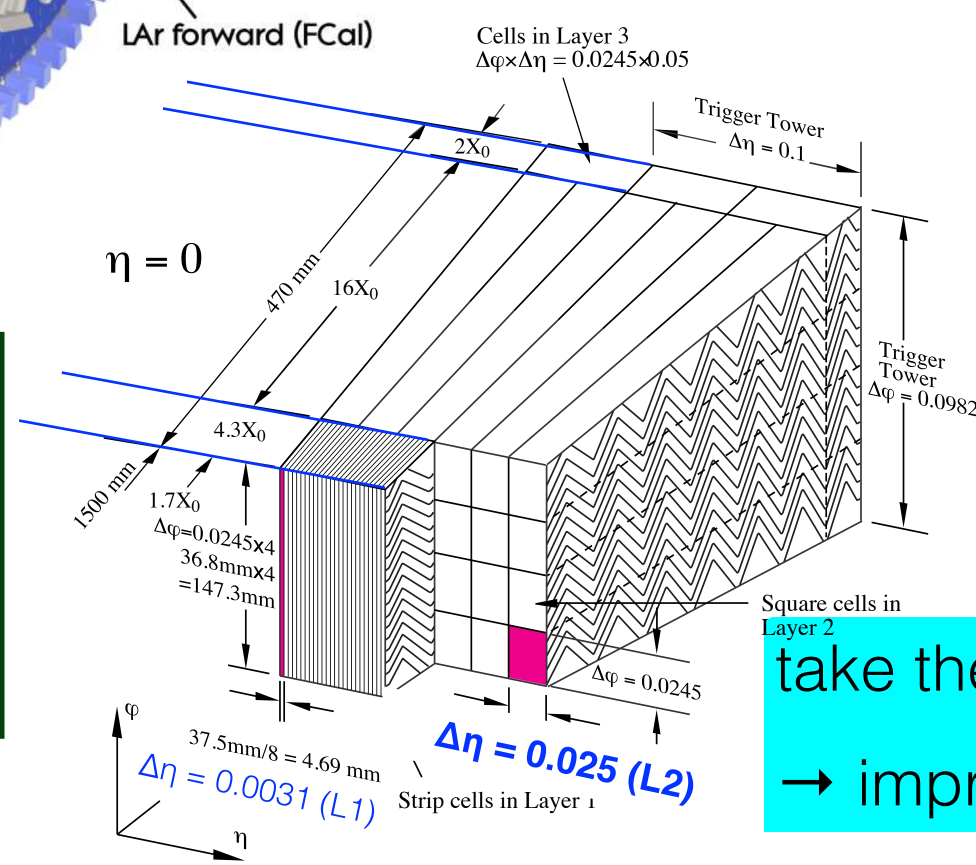


Sampling type Calorimeter

- EM Calo : LAr
- Hadronic Cal :
  - Barrel : Scintillator
  - Endcap : LAr

Characteristics

- Fine granularity in **η**-direction (EM)
- Segmented in depth (4 in EM , 3 in Tile)



e, γ, τ, jet, Missing-E_T

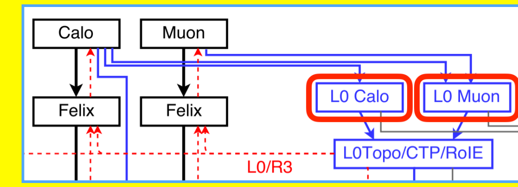
Offline : identify / measure

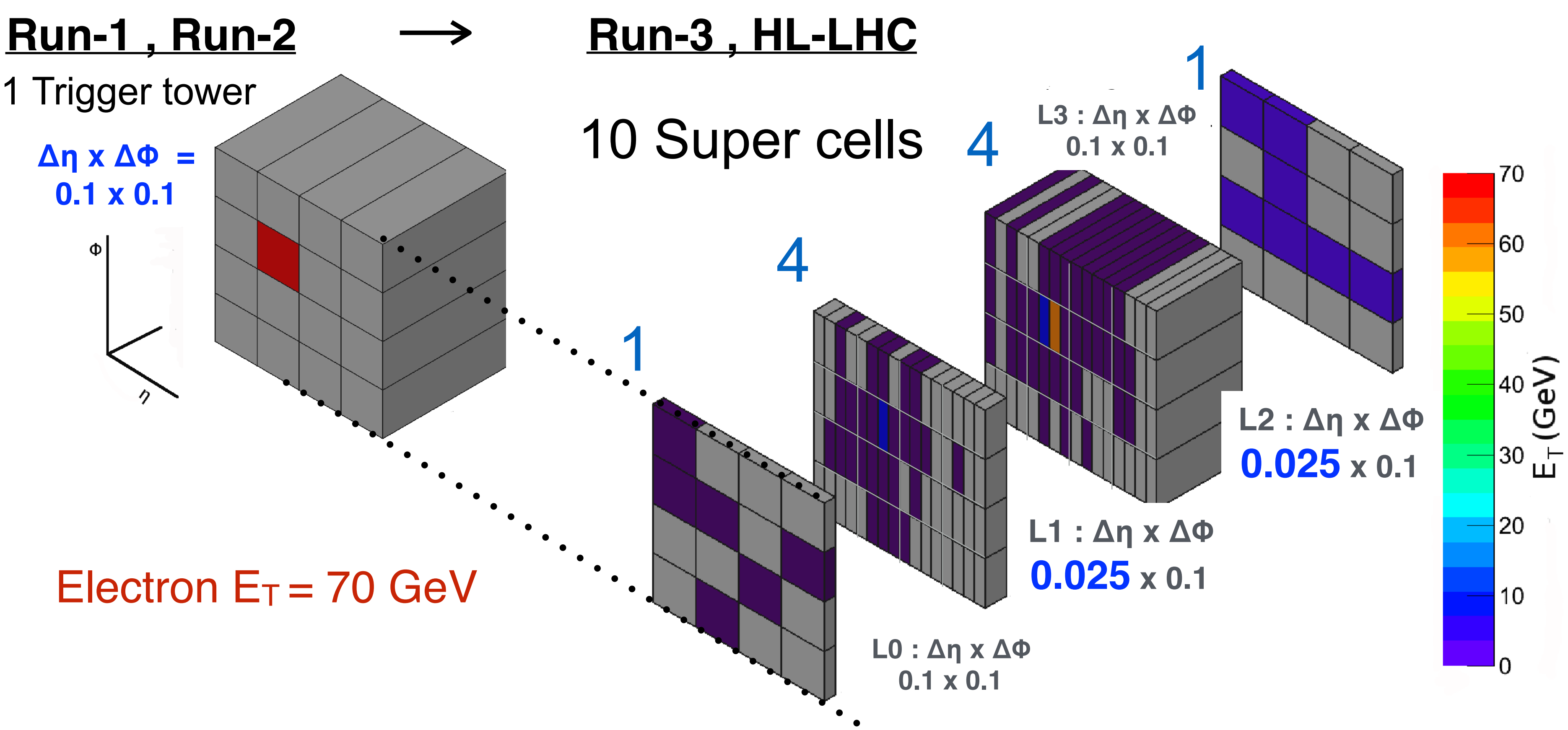
Trigger : provides inputs for their first level triggers

take the advantage, **"granularity"**

→ improve Trigger performance

Calorimeter Trigger



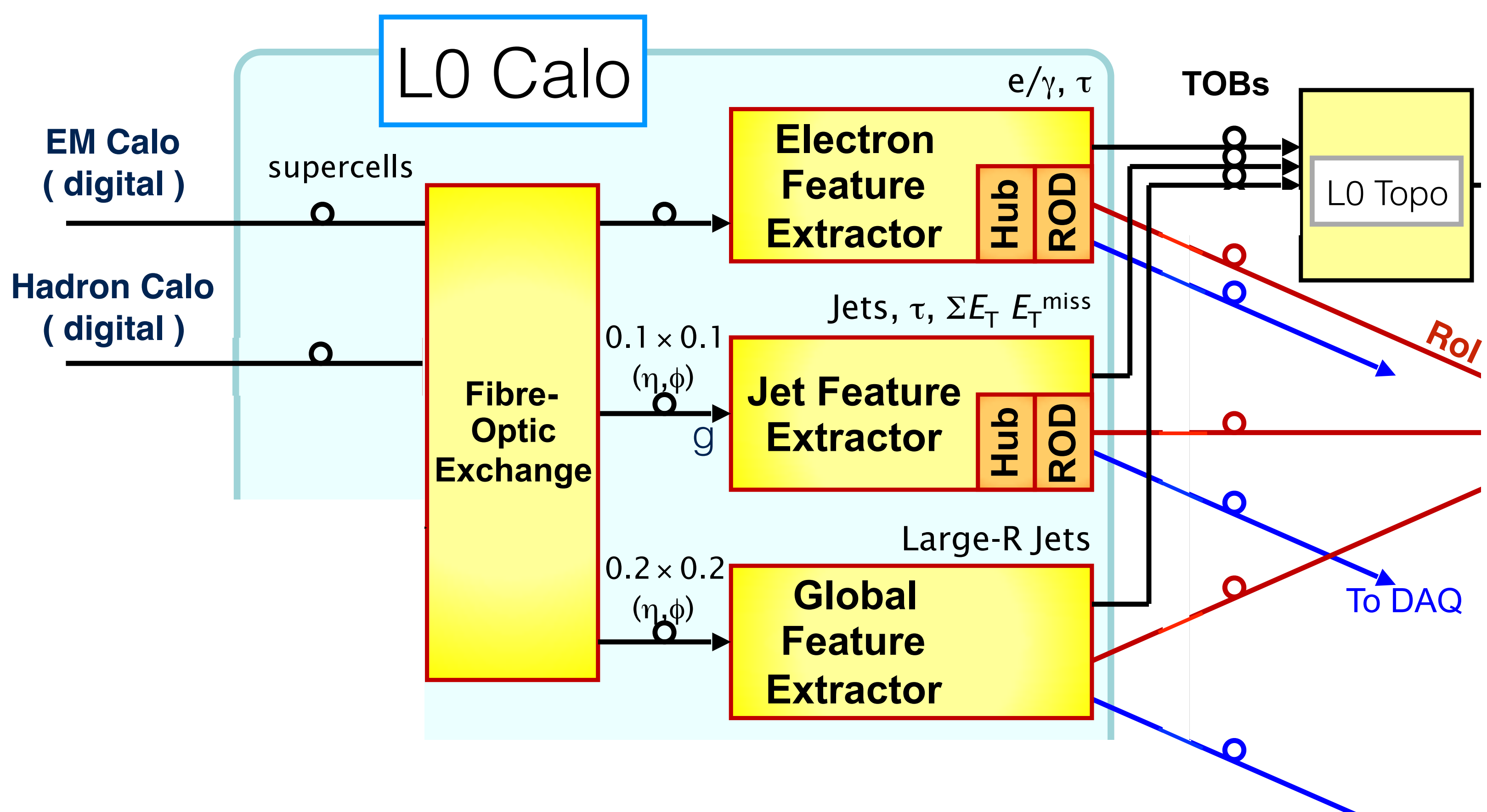


higher granularity

shower shape

- **4 times** finer unit : **η** (L1, L2)
- 1 → 4 units in **depth**

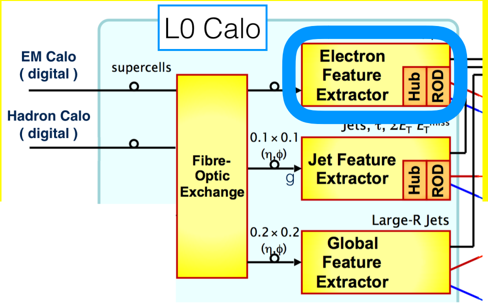
→ better **e / jet separation**



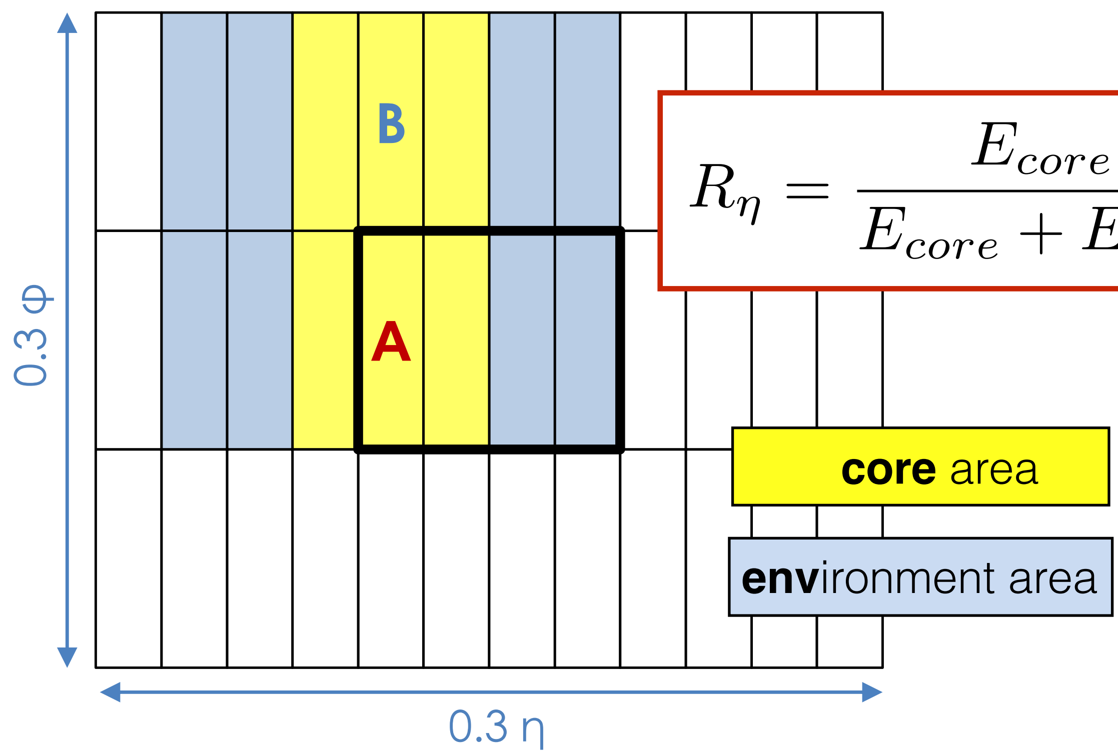
3 Feature Extractors

- **eFEX** : e / γ / τ
- **jFEX** : jet , τ , sumE_T , MET
- **gFEX** : large-R jet

eFEX : e / γ / τ

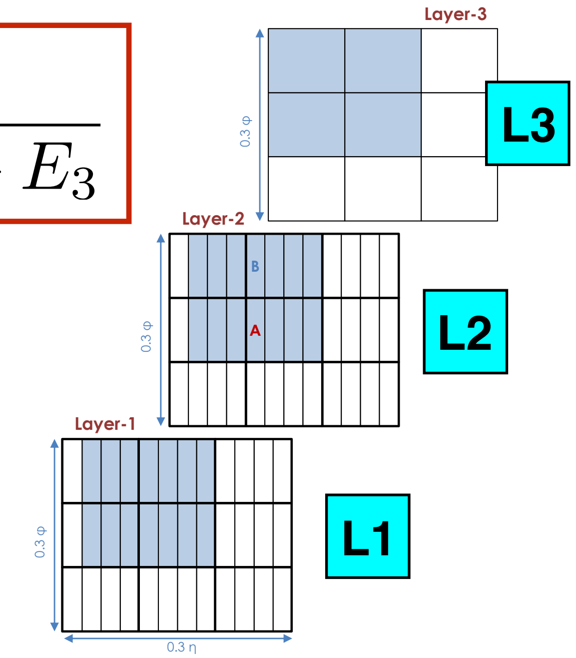


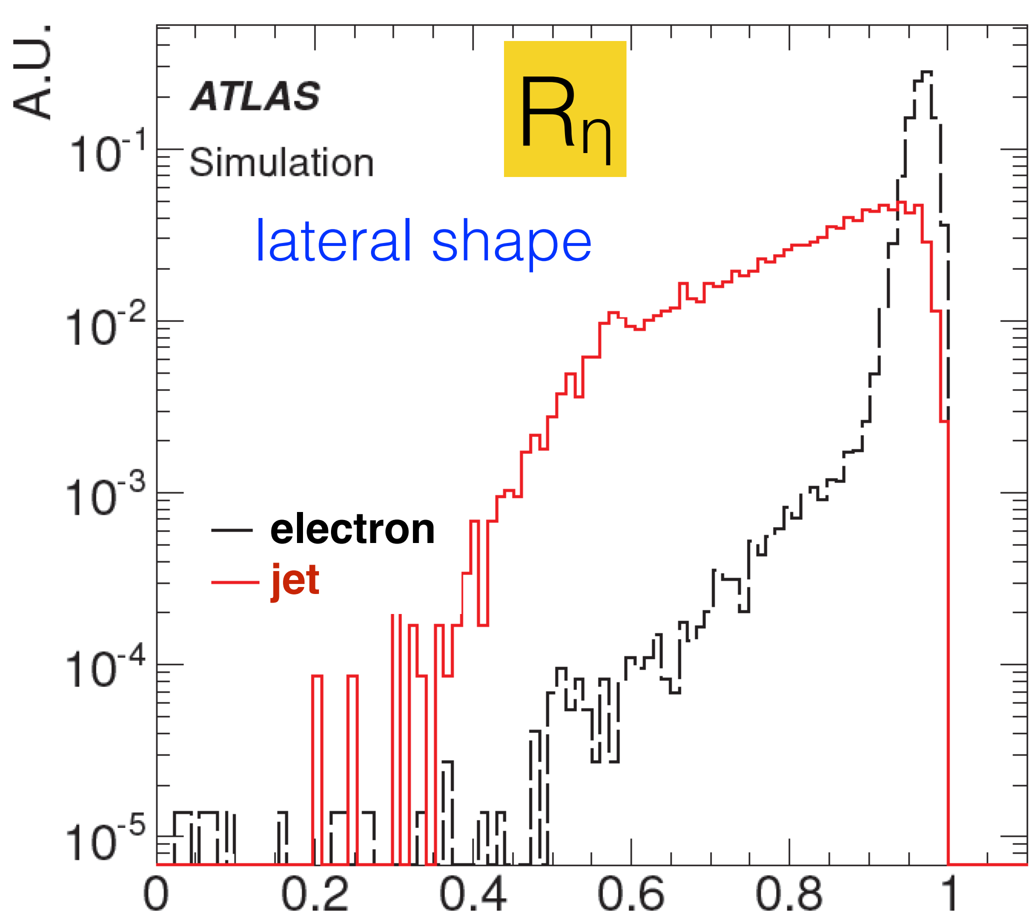
Layer-2

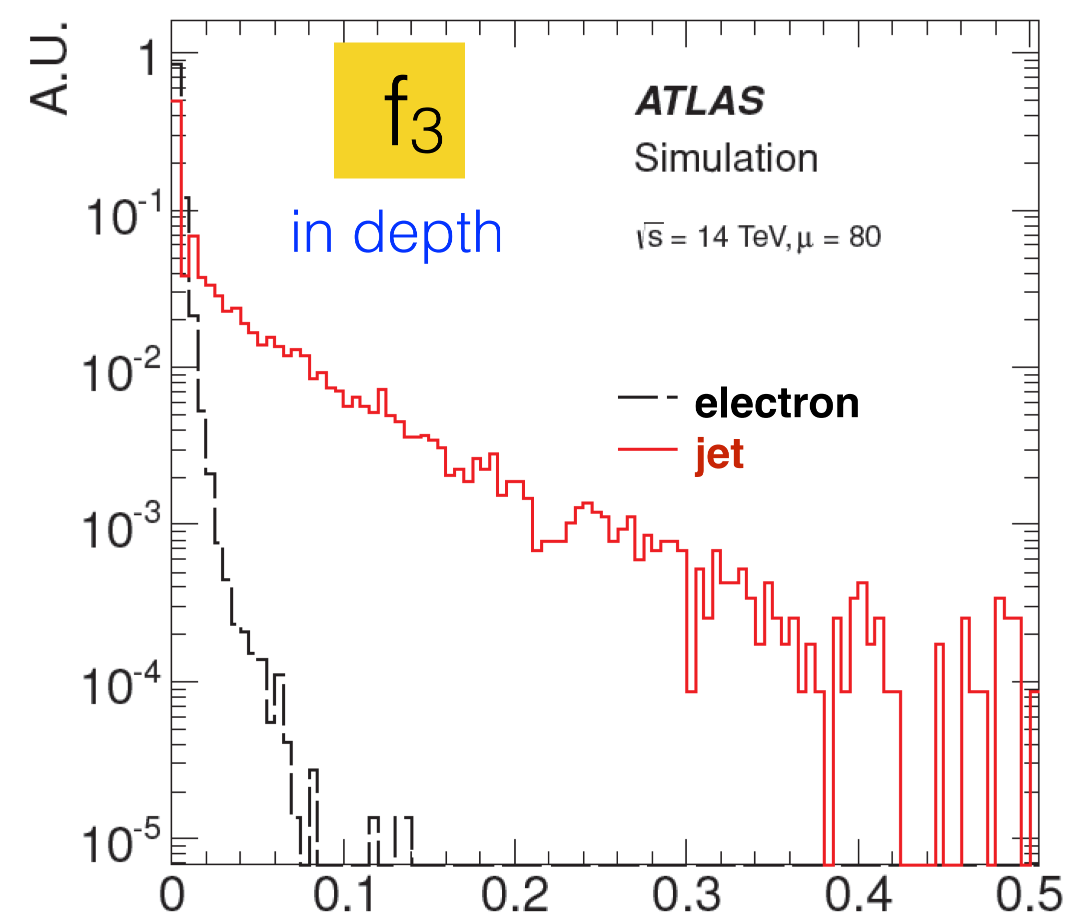


$$R_\eta = \frac{E_{core}}{E_{core} + E_{env.}}$$

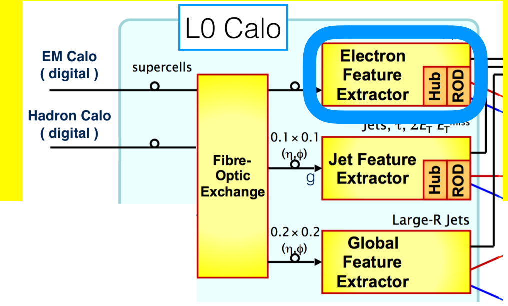
$$f_3 = \frac{E_3}{E_1 + E_2 + E_3}$$

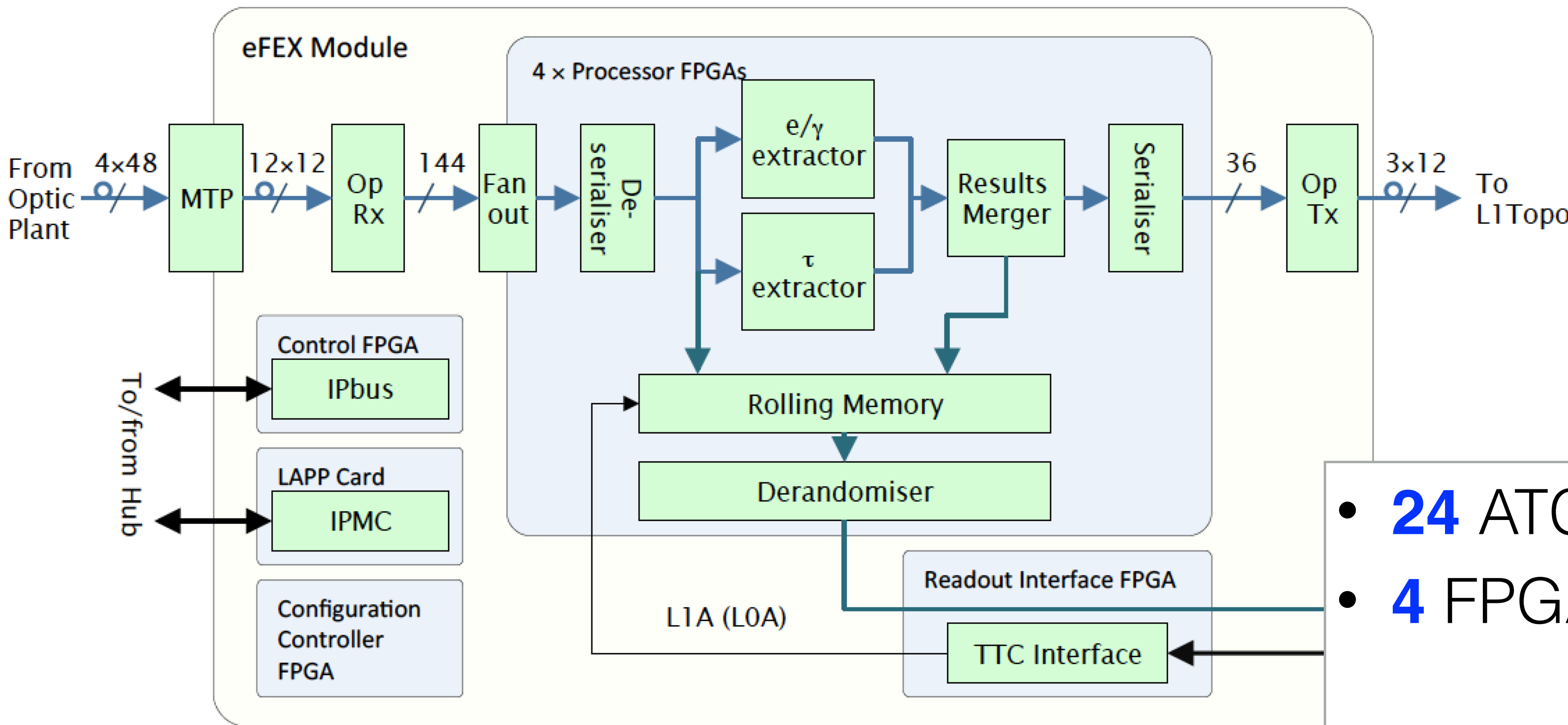






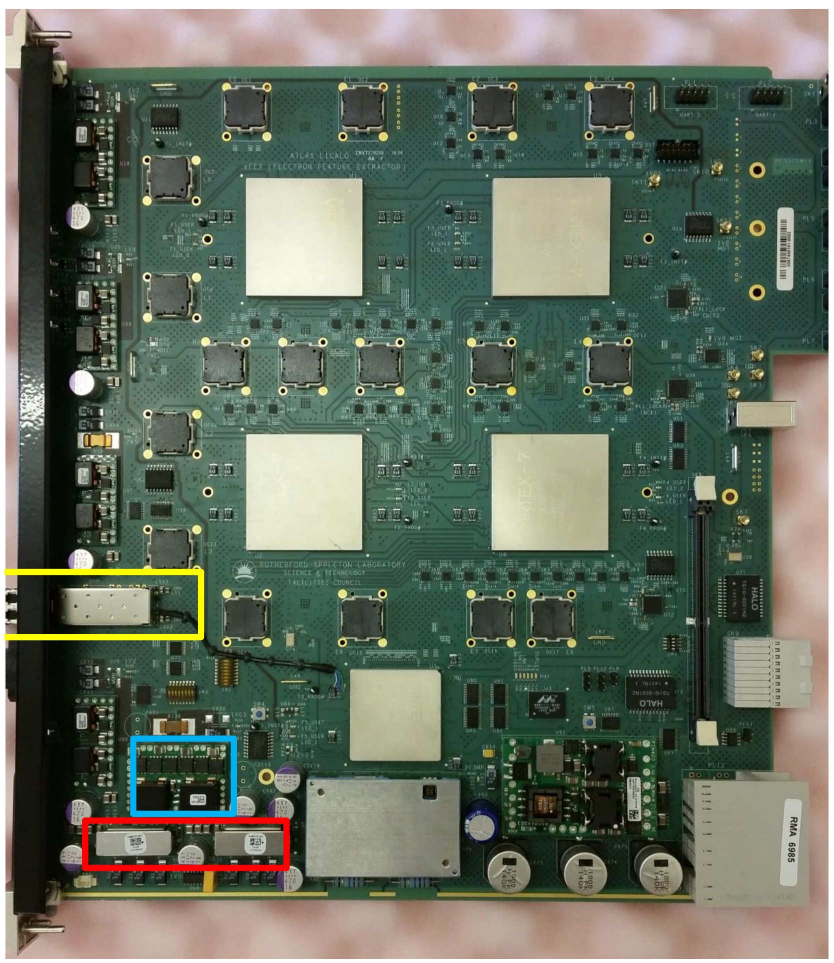
eFEX : specification / prototype



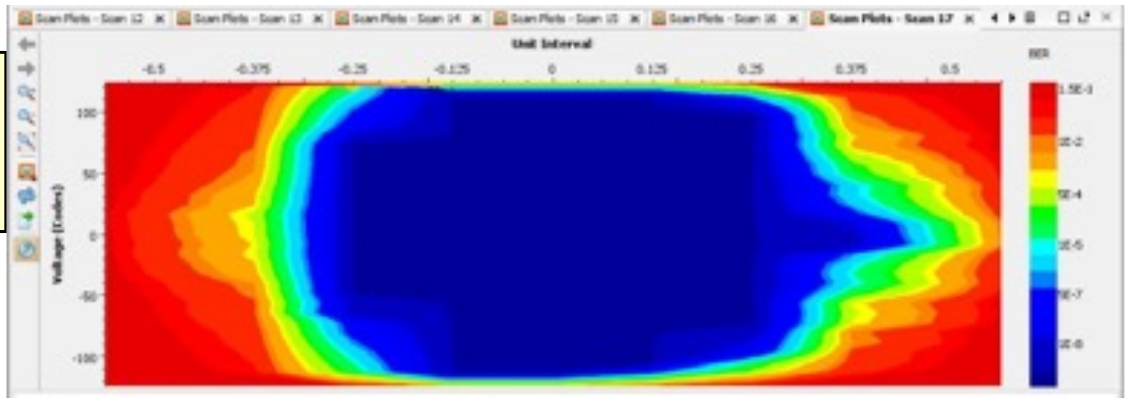


- **24** ATCA modules in 2 shelves
- **4** FPGAs per module

- Multi-Gbps links (11.2Gbps)
  - all FPGA-FPGA links tested
    - **BER < 10^{-14}**
    - track length < 30cm

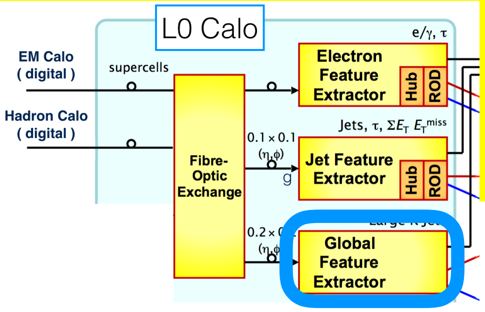


eFEX Eye Diagram at 11.2 Gb/s

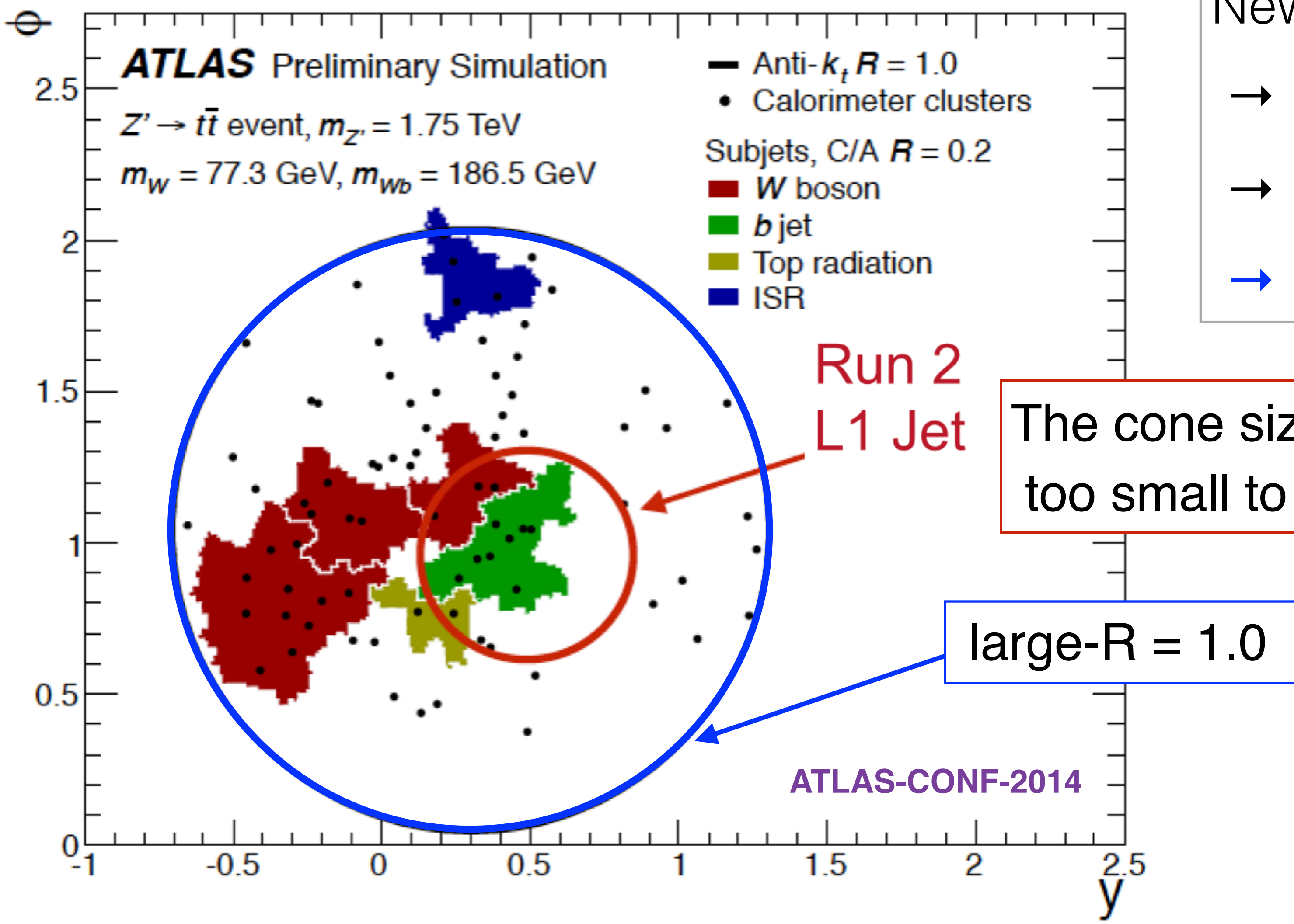


very good eye opening

gFEX : large-R jet



large-R jet from top (Z' → tt , $m_{Z'}$=1.75 TeV)



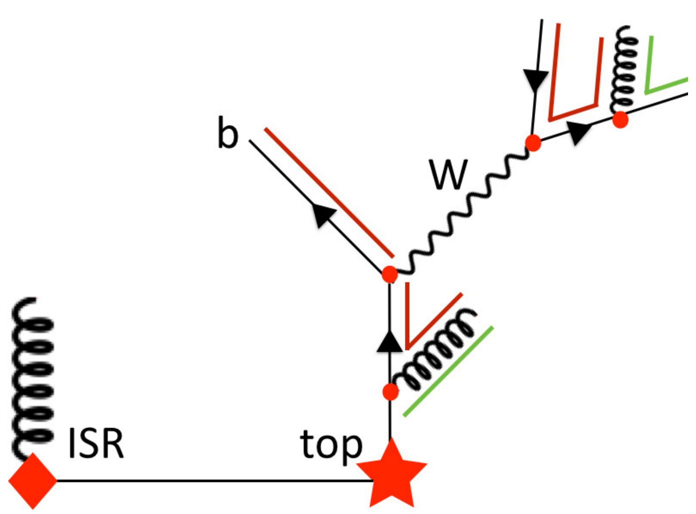
New **Heavy** Particle Search (e.g. Z')

→ **boosted** W , Z , top , Higgs (w/ ISR)

→ hadronic decay , jets are close each other

→ **large-Radius jets to be triggered !**

The cone size of Run-2 Calo. Trigger is too small to cover top quark decay products

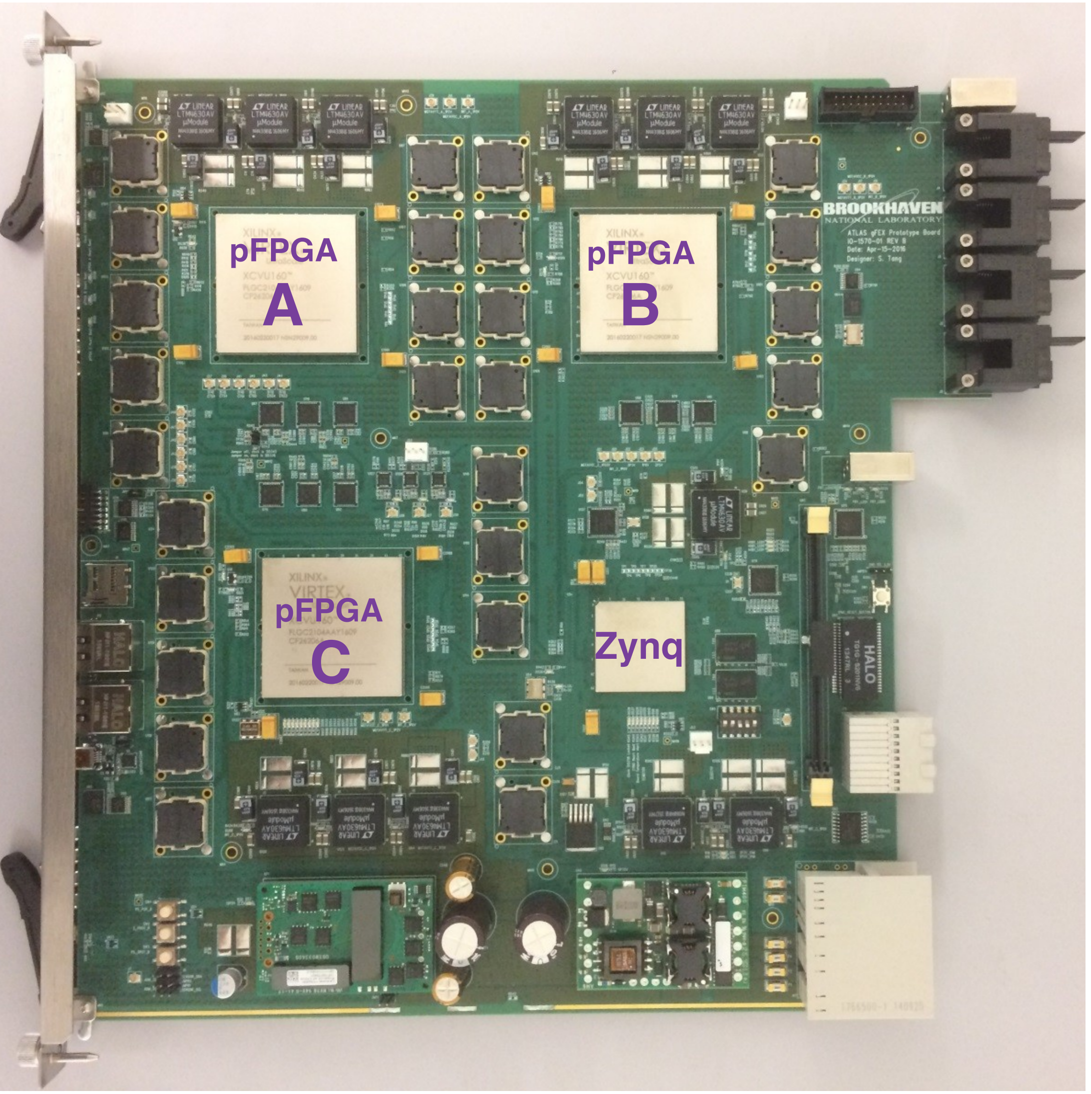


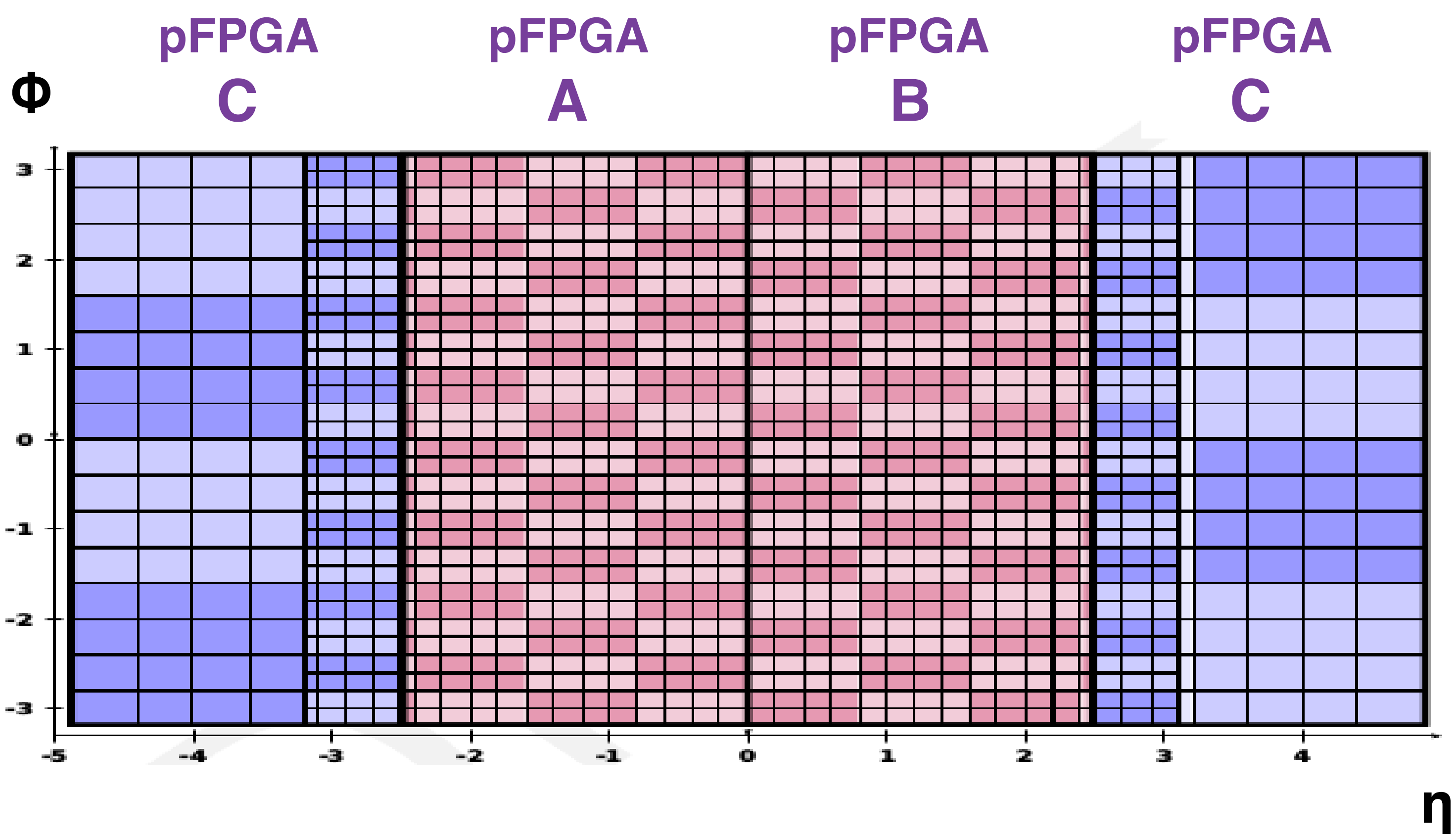
The gFEX receives the **entire calorimeter data in a single module** in a ATCA shelf

→ full-scan algorithms

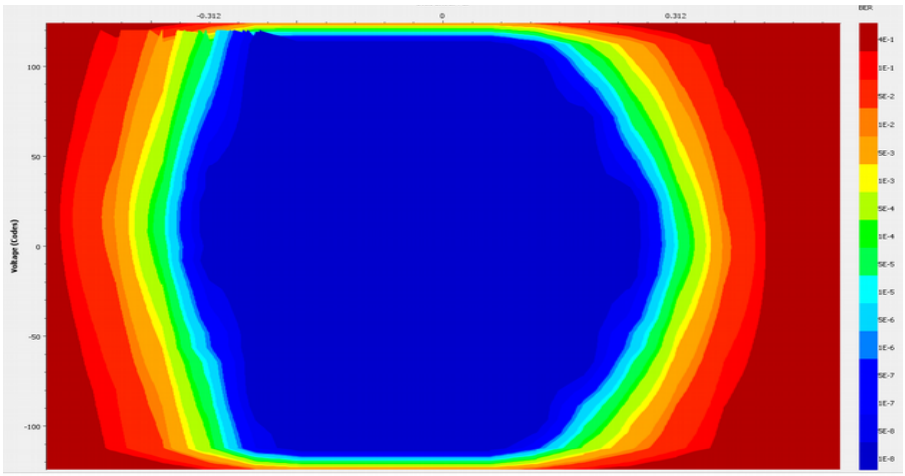
→ large-R jets as well as MET , Energy Sum , …

gFEX : specification / prototype





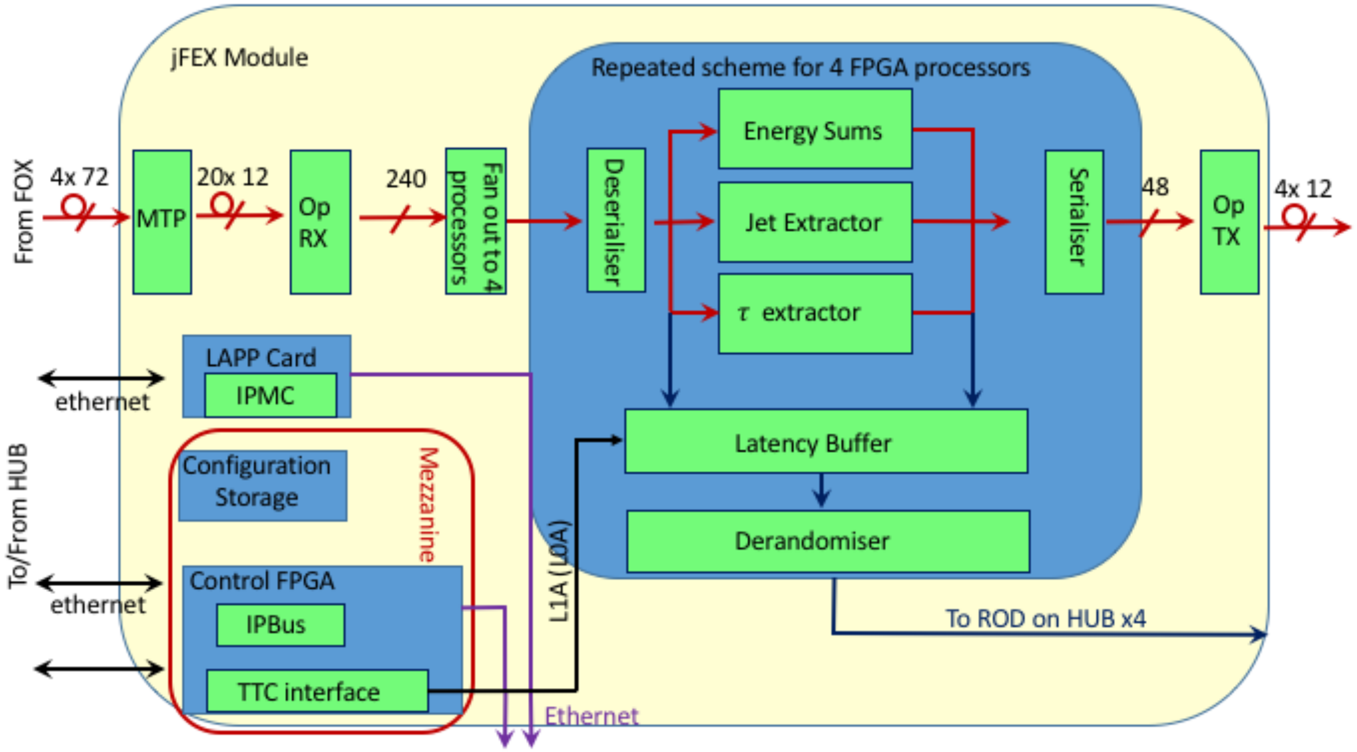
pFPGA - pFPGA @ 12.8Gbps

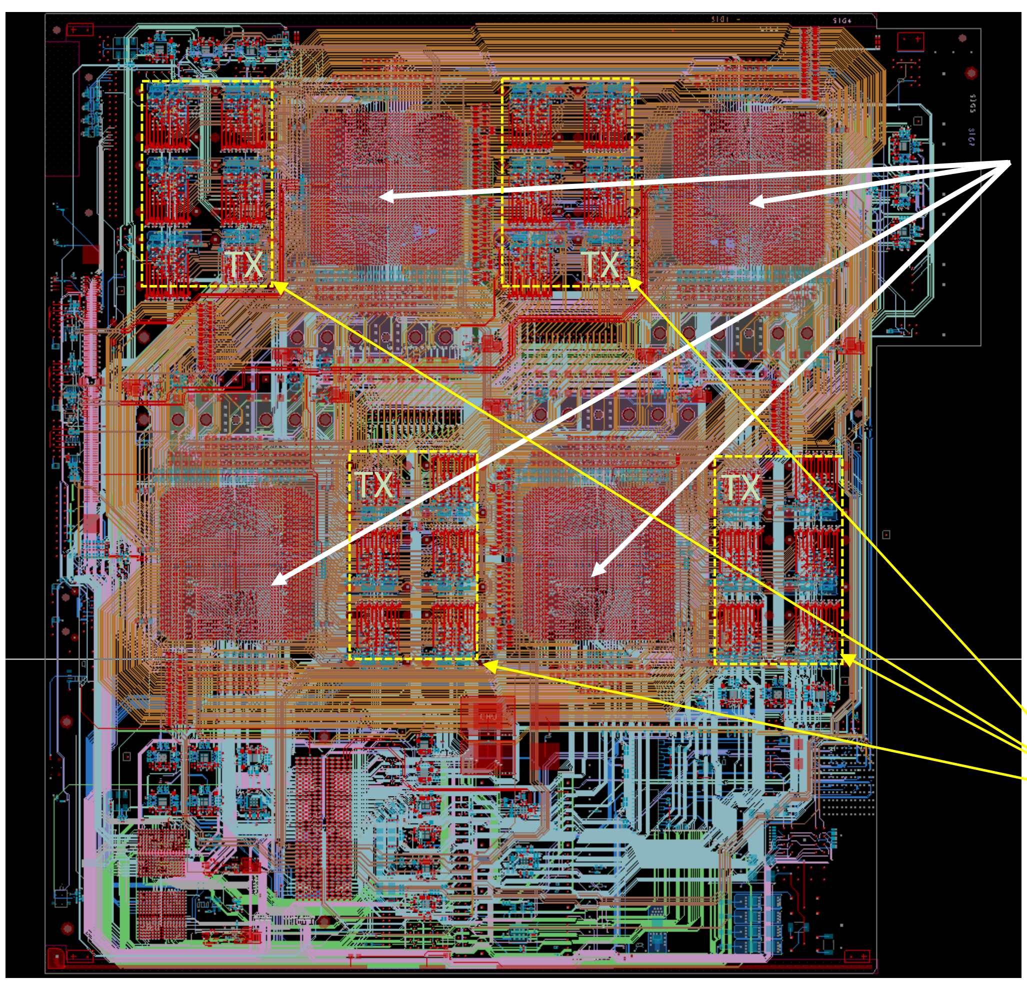


good eye opening

- **single** ATCA module
  - coarser granularity input : 0.2x0.2
- Architecture
  - 3 processing FPGAs (pFPGA)
    - running algorithms (large-R , E_T^{miss} , …)
  - 1 Zynq FPGA
    - control , Monitoring, …

jFEX : specification / prototype





4x

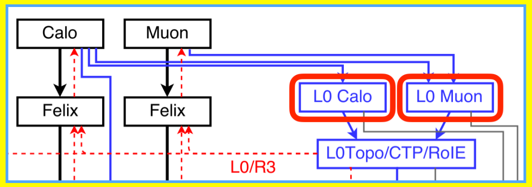
24 (20RX and 4TX)
miniPOD
(http://www.avagotech.com/)

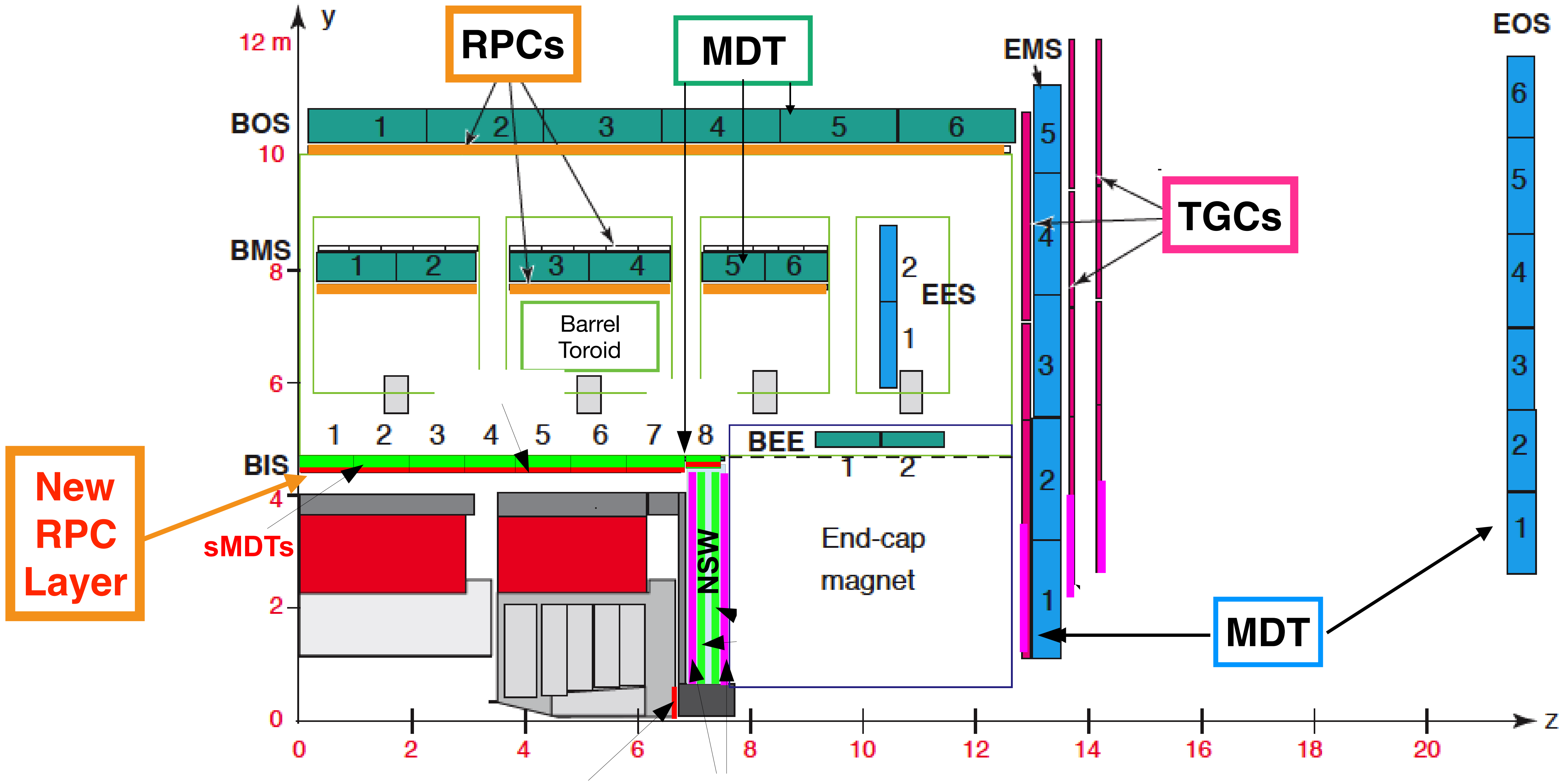
- **jet , sumE_T , E_T^{miss}**

- **System Overview**
  - 7 ATCA modules in One Shelf
  - 4 FPGA / module (Ultrascale)
  - max. 3.6Tbps input

- **Specific points** : improvements
  - dynamic range : increased
  - granularity x 4
  - **jet definition algorithm**
    - Gaussian fitter
    - non-square
    - …

ATLAS Muon Spectrometer

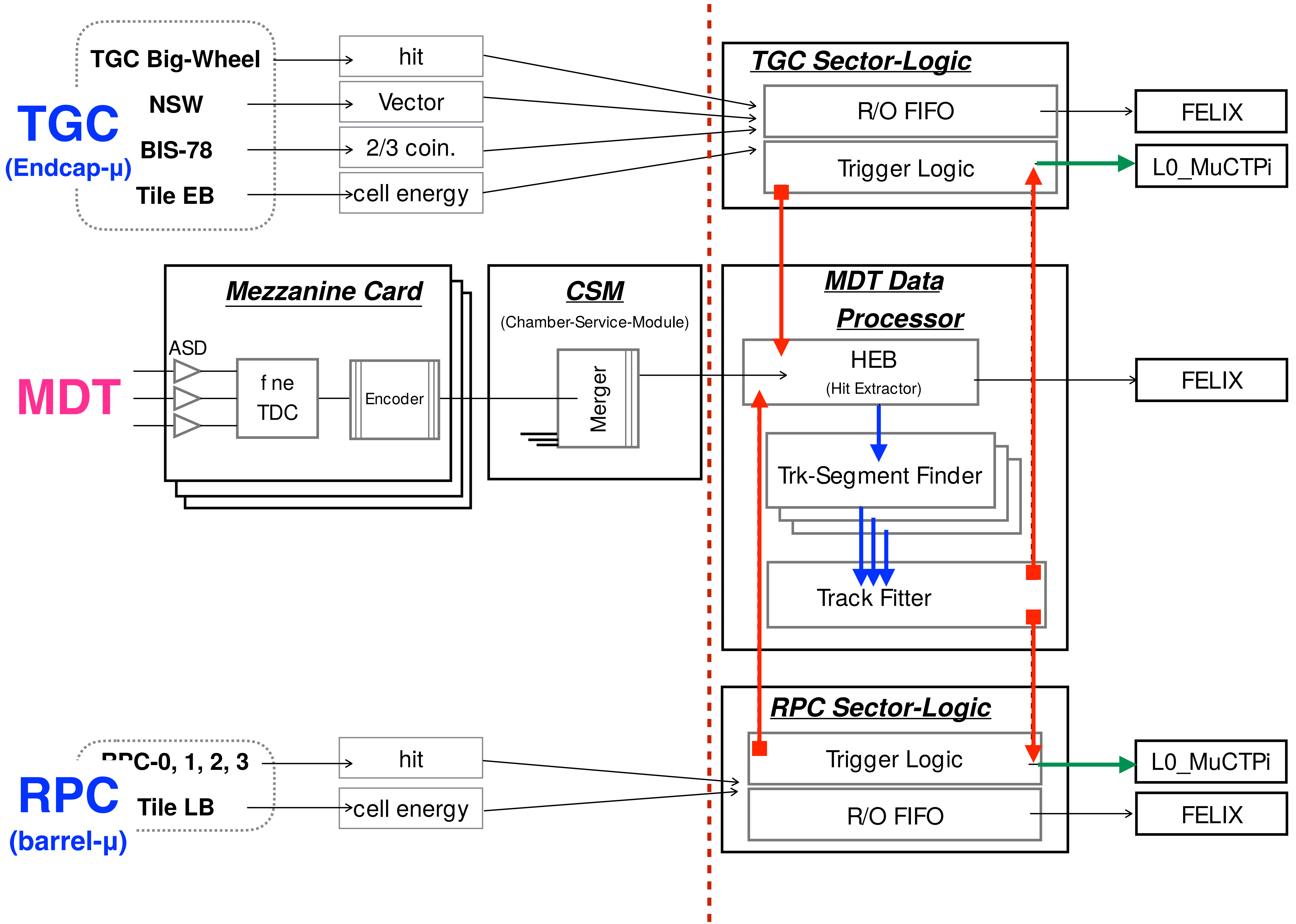




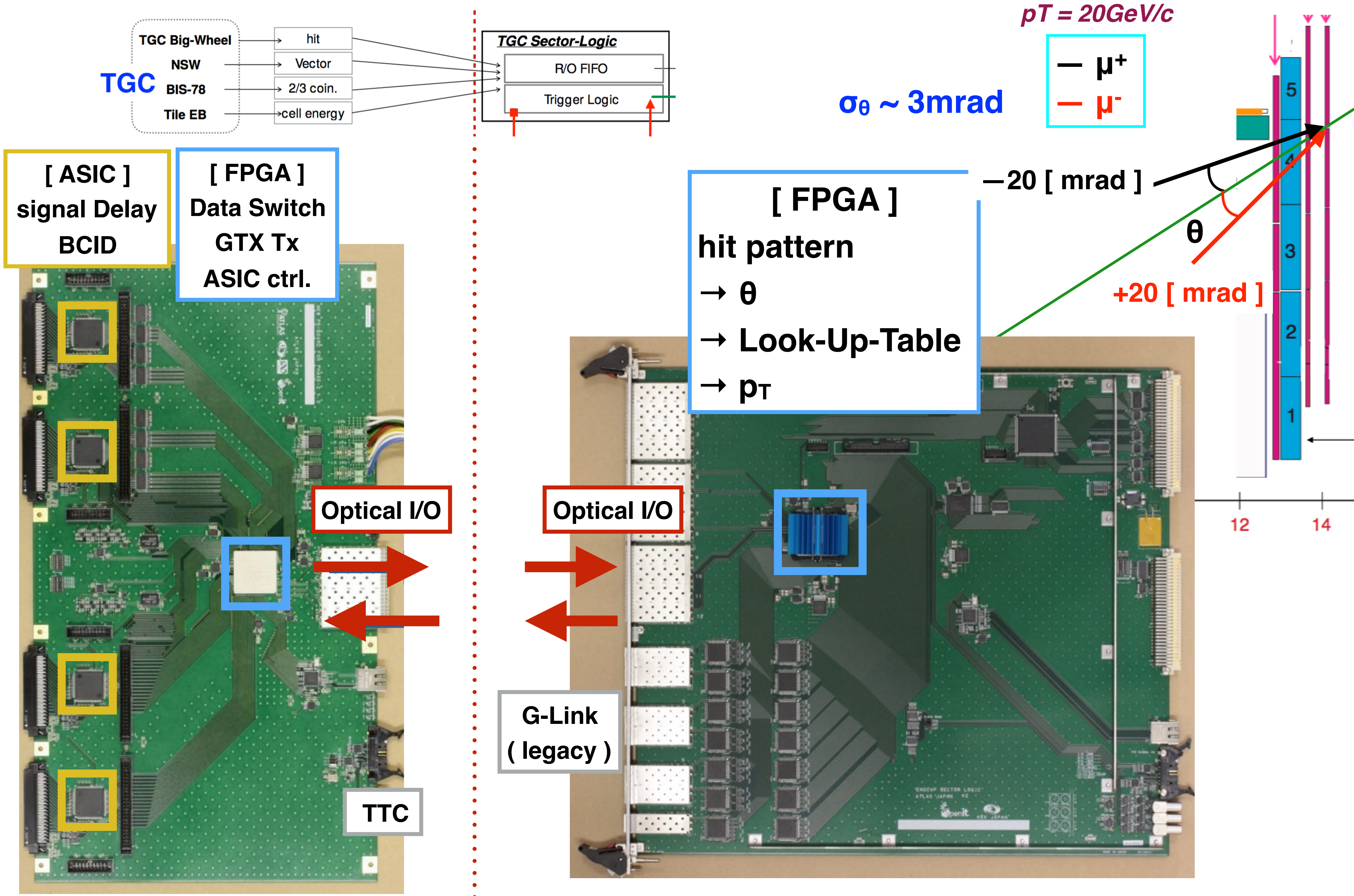
- A complex of **Trigger** chamber (RPC / TGC + NSW) and Precision **tracker** (MDT, NSW)
- To cope with longer latency & higher trigger rate, **all the electronics to be replaced**

- **MDT** (max. Drift-Time ~ 700ns) to be a part of **Hardware μ-Trigger**
- **ALL the hit** (40MHz) of TGC/RPC/MDT sent to off-detector → process Trigger

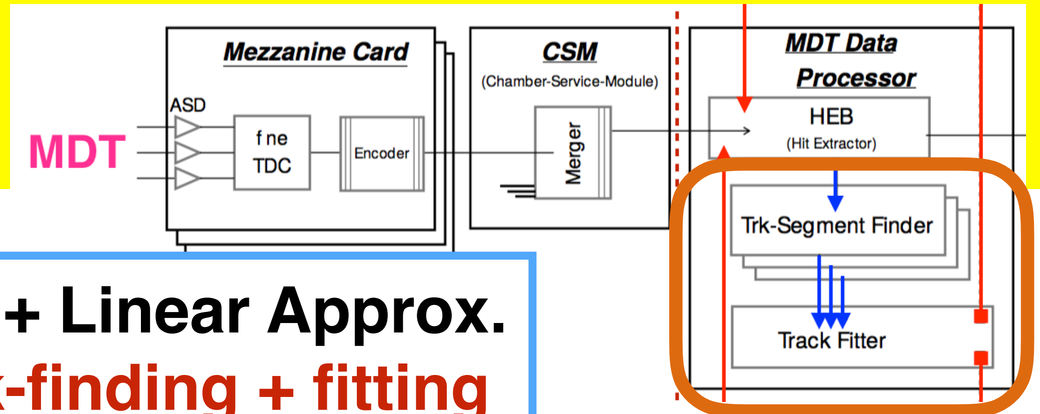
HL-LHC : L0 Muon Trigger



L0 TGC Trigger



L0 MDT Trigger



Micro processor on FPGA for track-finding / fitting

Xilinx kit ZC706

Irradiate γ-ray @ GIF

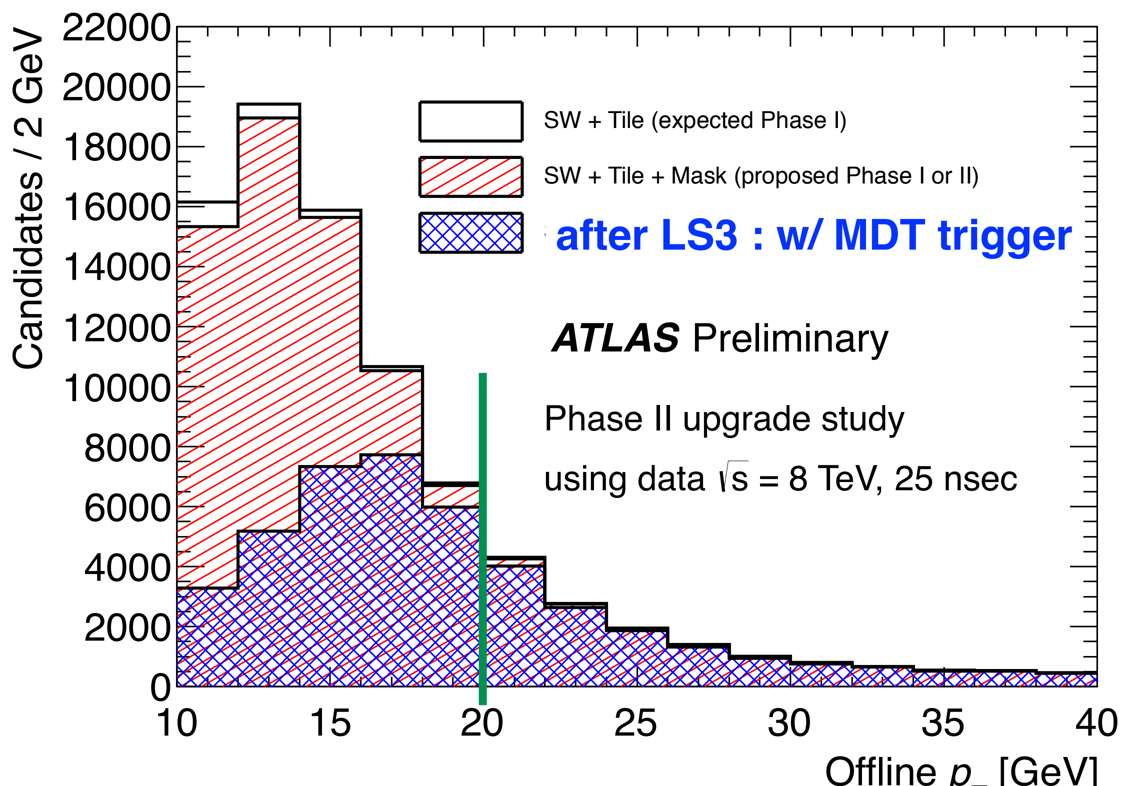
~ 20% occupancy : higher than HL-LHC

processing time < 3.5 μs

- **fit to the total L0-latency of 6μs**

(and still large room to speed-up , multi-core processor, algo.)

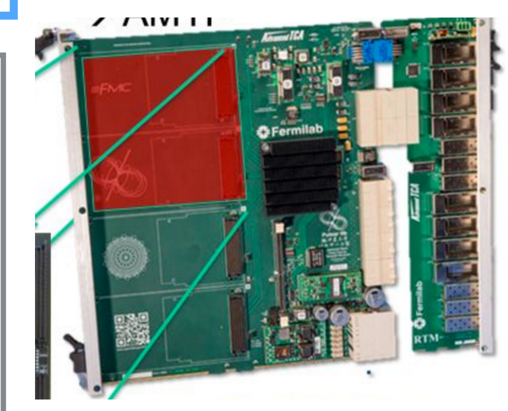
- **comparable to the offline performance**

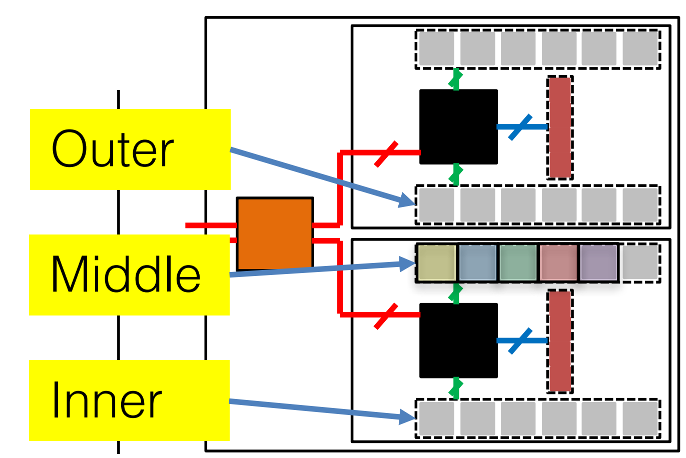


AM-chip + Linear Approx. for track-finding + fitting

apply **ATLAS-FTK Board**
(Pulsar-2)

64 ATCA Boards (8 shelves) to cover all the MDT system



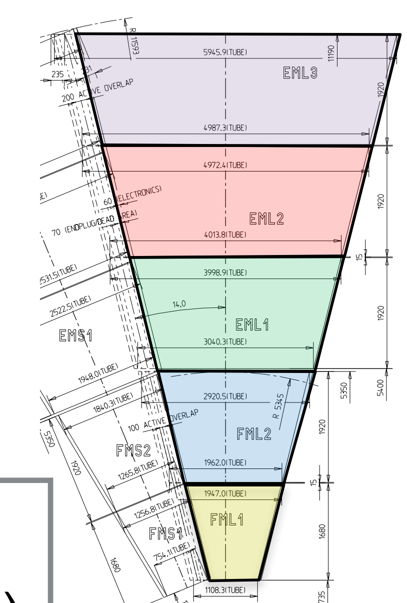


To Do

Hit-Pattern < AM capacity

Performance studies

- efficiency
- p_T resolution



processing time ~ 1.3 μs
(+ 0.3μs : reserver queuing)

Summary

Calorimeter & μ-Trigger upgrades towards HL-LHC

- production of prototypes , final modules, tests ,
- firmware , software developments are on-going ! (depends on the timing to deploy)

Calorimeter :

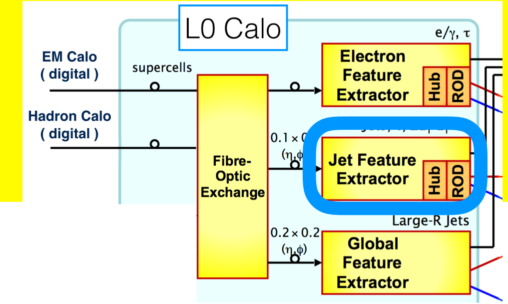
- eFEX , jFEX : higher granularity (lateral , depth) , e , γ , τ / jet
- unique feature of gFEX to catch, large-R jet , (MET , sumE_T)
- aiming to deploy the upgrade system **after LS2**

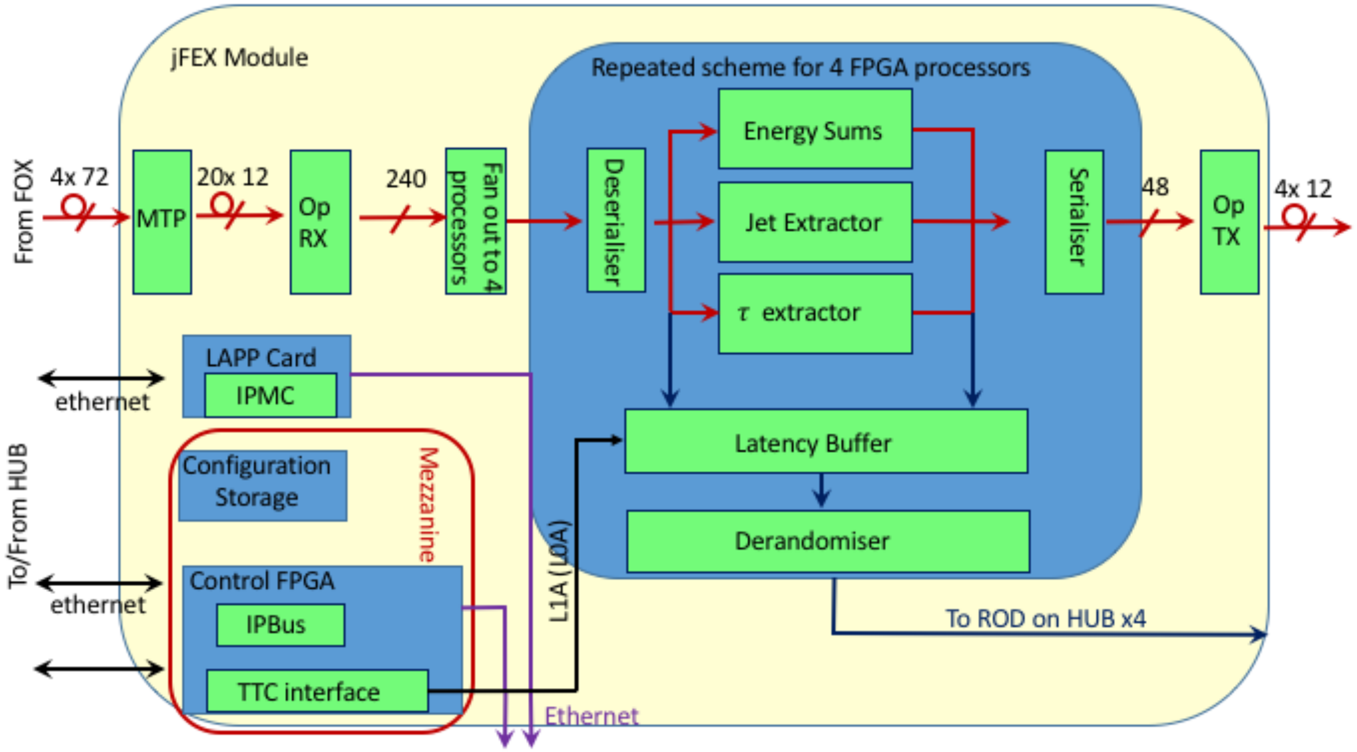
Muon :

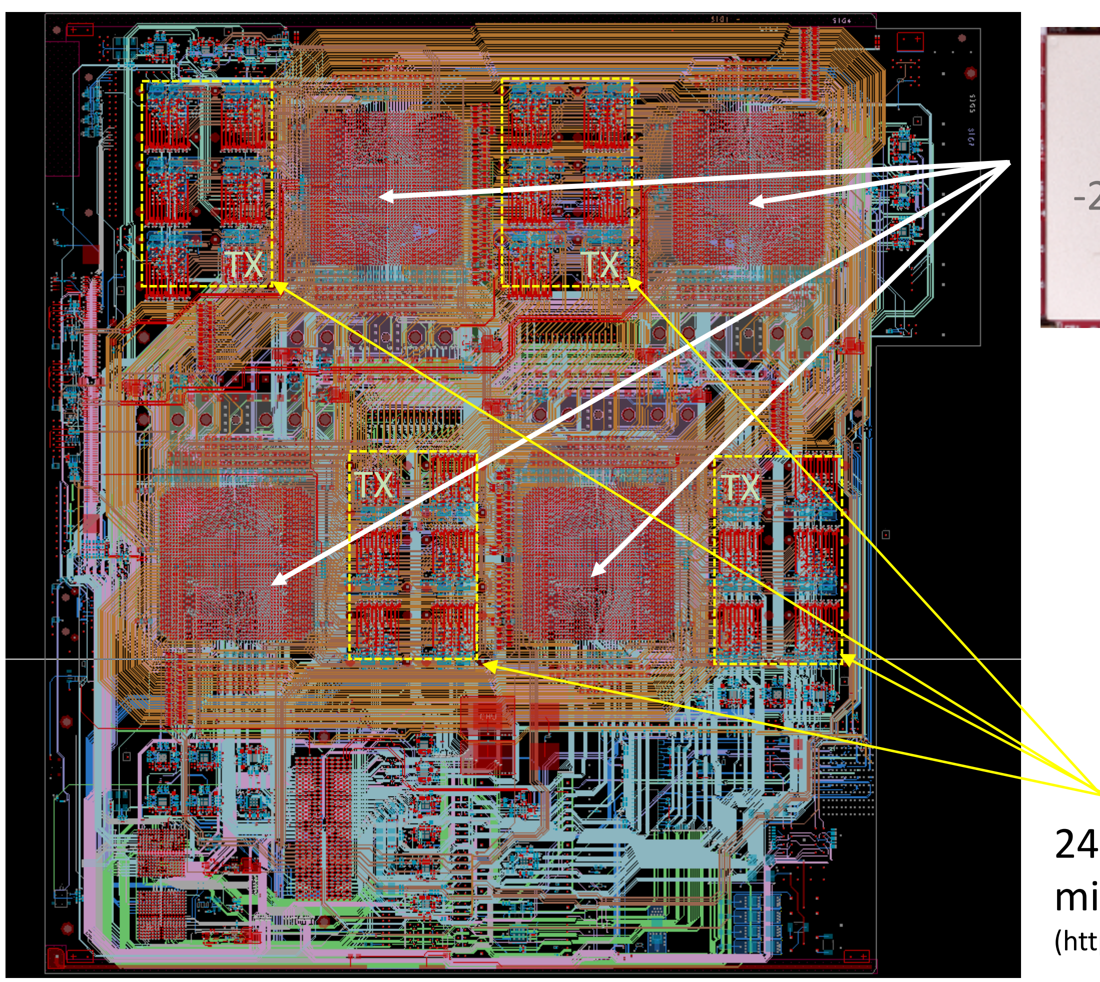
- all the hit information is sent to off-detector → to retrieve full potential
- precision tracker (MDT) participates to the trigger system
- as a complex system, gain geometrical acceptance & keep low p_T threshold

Backup

jFEX : specification / prototype







4x

24 (20RX and 4TX) miniPOD
(http://www.avagotech.com/)

Physics tasks:

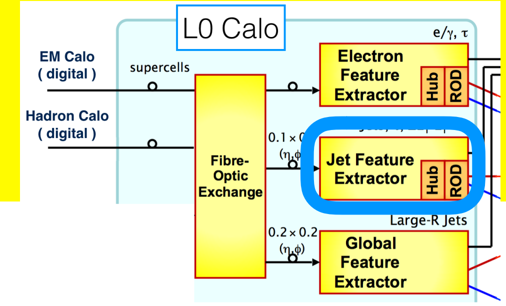
- jFEX identifies jet candidates and calculates ΣE_T and E_T^{miss} for each BC

Features:

- Data received by the central and forward calorimeters: |η|< 4.9 with different granularities
- jFEX is an ATCA board
- 4 Xilinx Ultrascale FPGAs per module
- 24 MiniPOD: 20 RX + 4 TX
- Up to 120 MGTs x 4 per module
- Up to 3.6 Tbps in input
- 2 types of MGTs: GTH and GTY
- Data duplication via PMA loop-back (Φ ring coverage per module)

- 7 (+spares) modules to be built

jFEX : specification / prototype



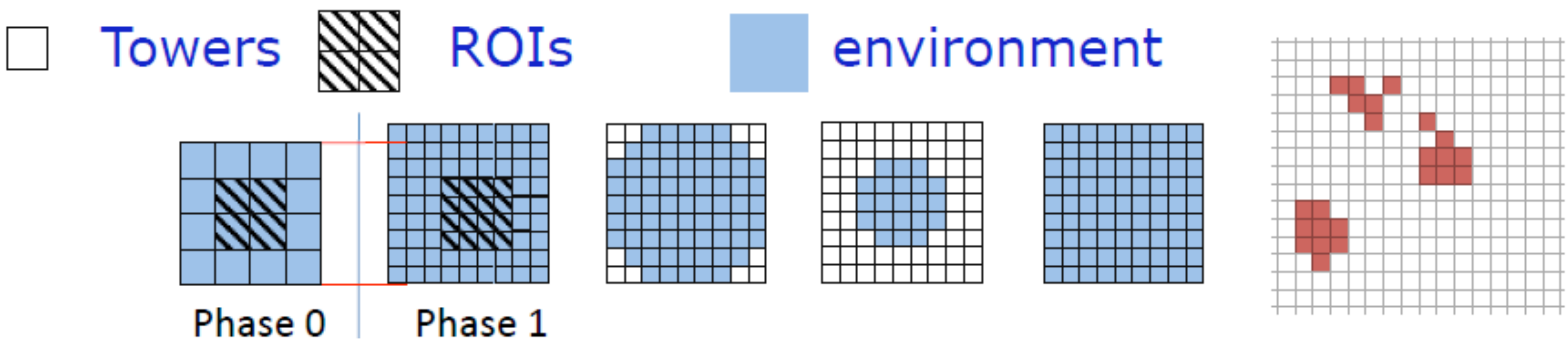
Compared to current JEP system

- increased dynamic range
- granularity × 4
- allows flexibility in jet definition (non-square, Gaussian filter, …)

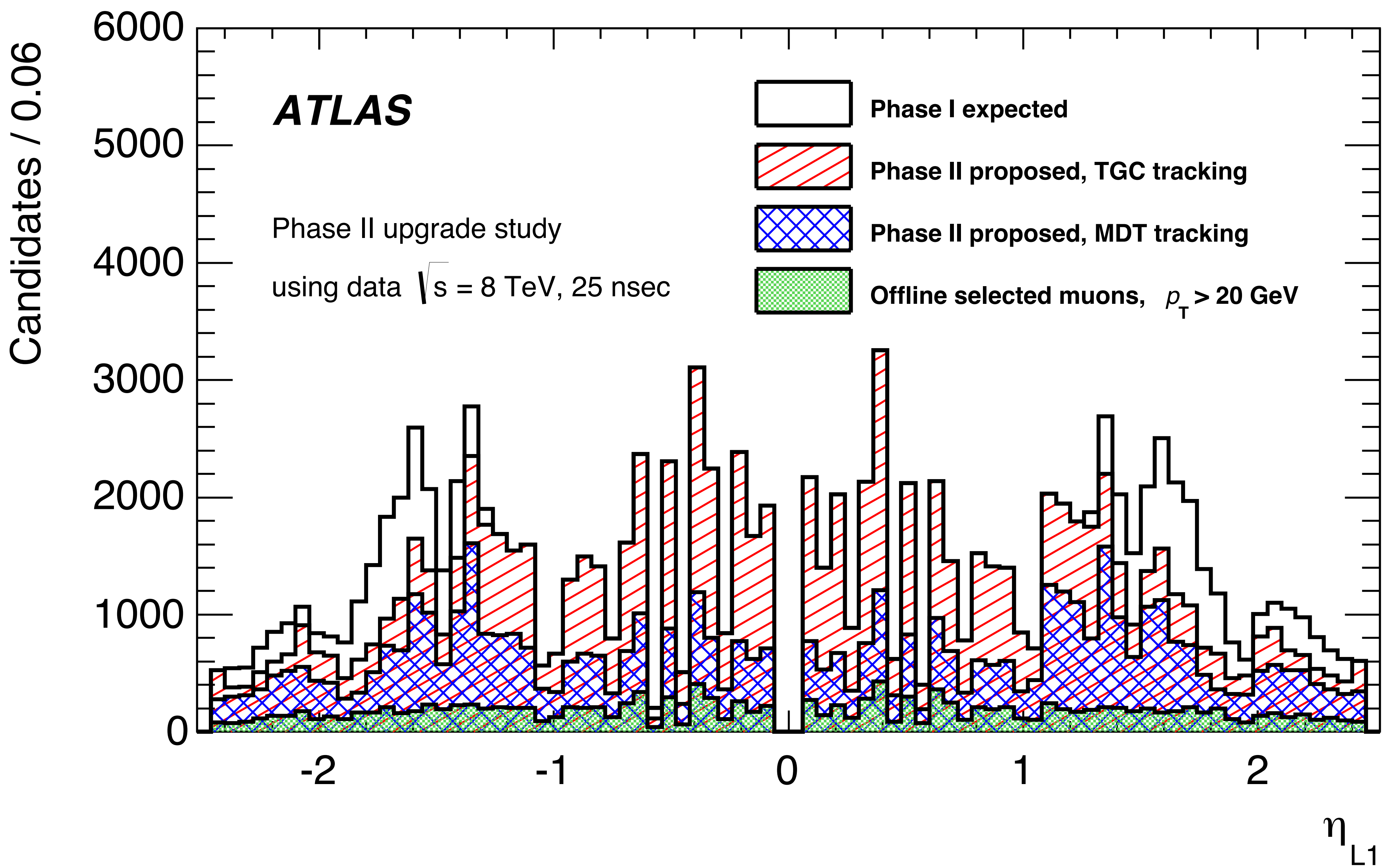
Increased jet environment

$\leq 0.9 \times 0.9$ ($\eta \times \phi$)

- increases with higher bandwidth or pre-clustering in jFEX, large jets at L1Topo



Level-0 Muon trigger

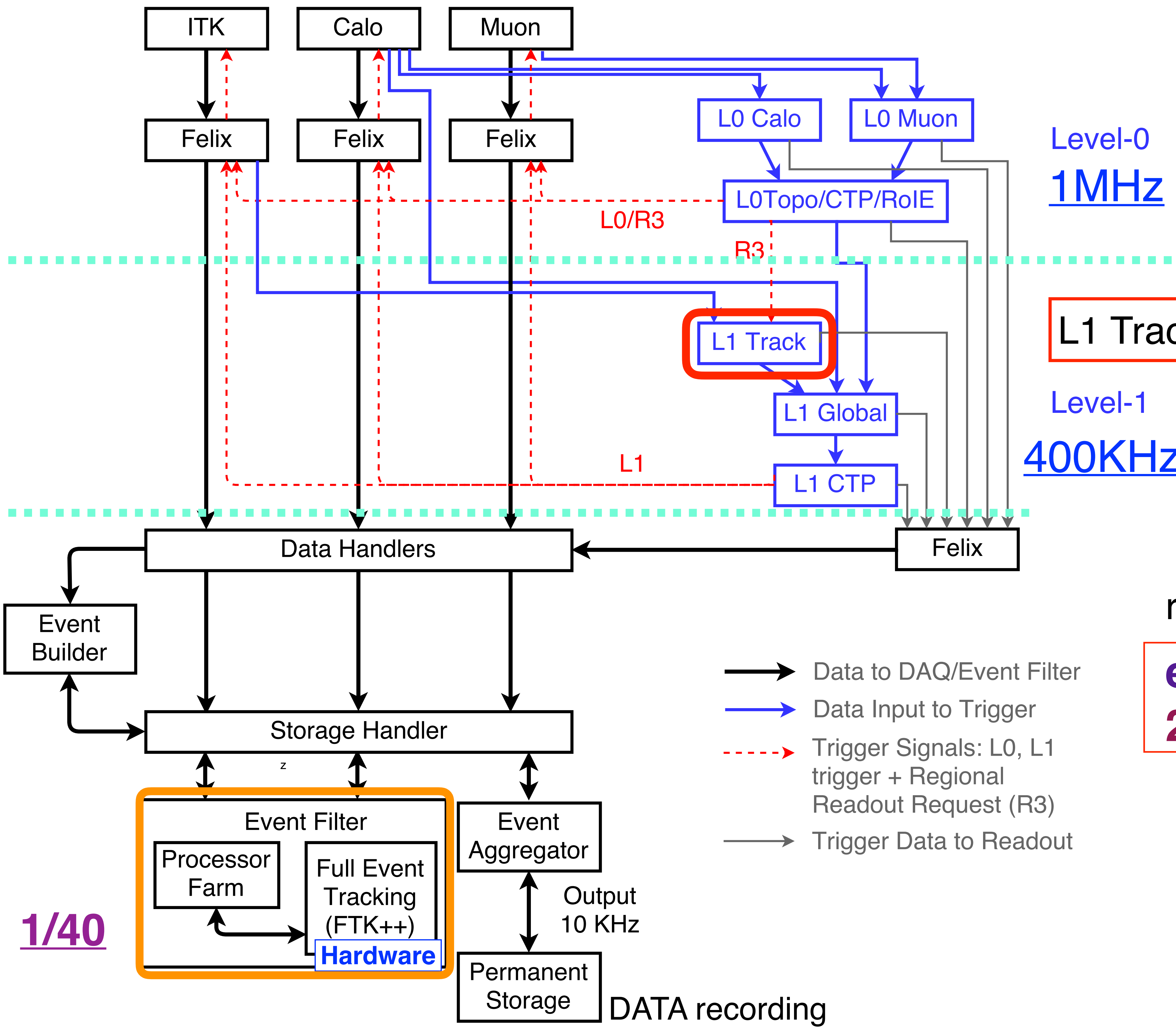


TGC tracking trigger (1.0 < |η| < 2.4) — **25%**

MDT tracking trigger (1.0 < |η| < 2.4) another — **35%** or more

higher position resolution → sharper turn-on

TWO level trigger scheme : L0→L1



DATA recording

L0 : CALO + MUON
40MHz → 1MHz

L1 Track ; p_T > 4GeV/c @ RoI

Comb. w/ TRK

rate reduction : L0 → L1

e , (2e) : **1/5** , (1/10)
2τ : **1/6**