Muon trigger assisted by calorimetry at the ATLAS experiment

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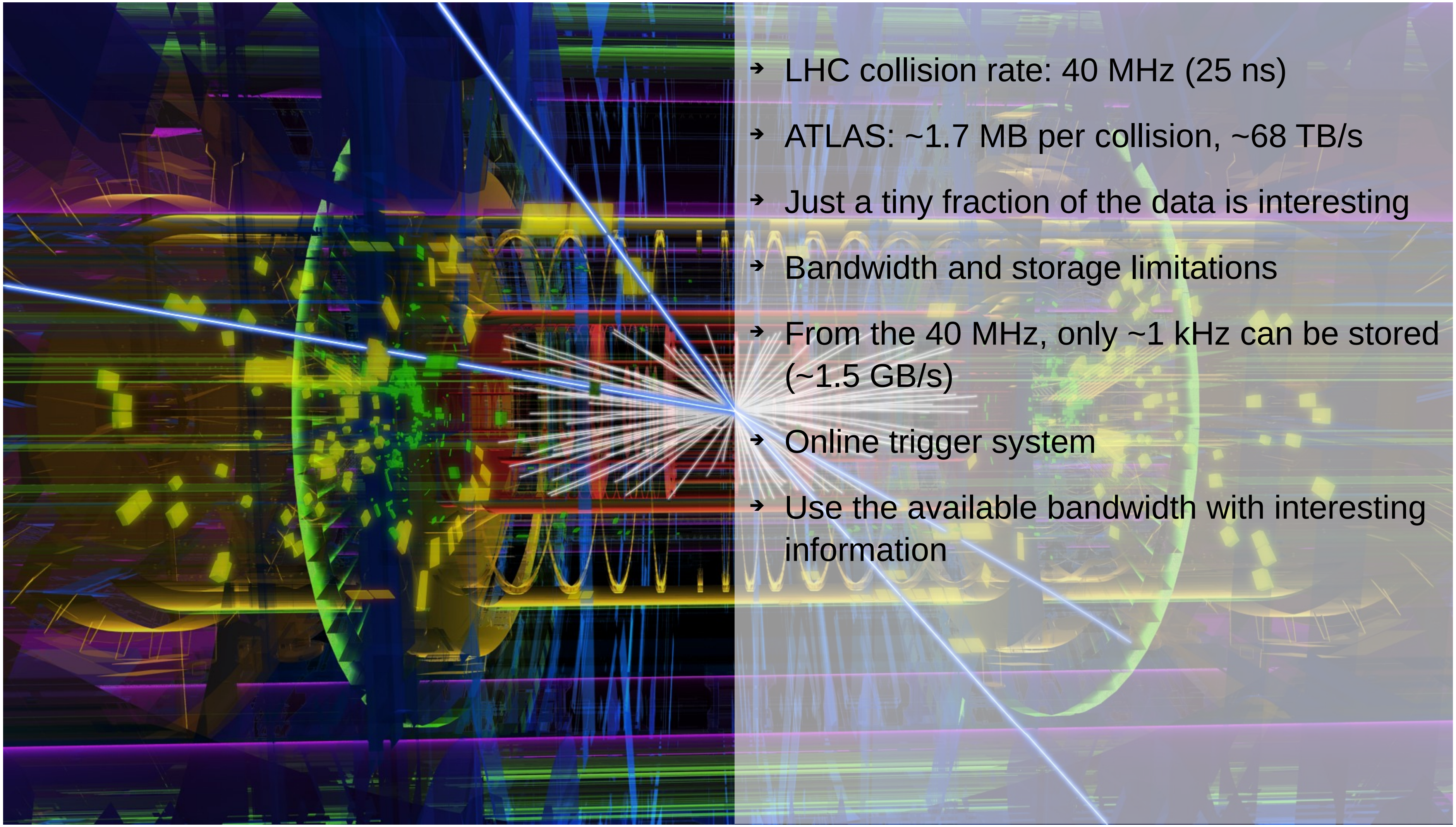
Overview

- Introduction
- Motivation
- The ATLAS experiment
- Muon trigger assisted by calorimetry: before the Phase-II upgrade
- Muon trigger assisted by calorimetry: after the Phase-II upgrade
- Summary / Current Status

Introduction

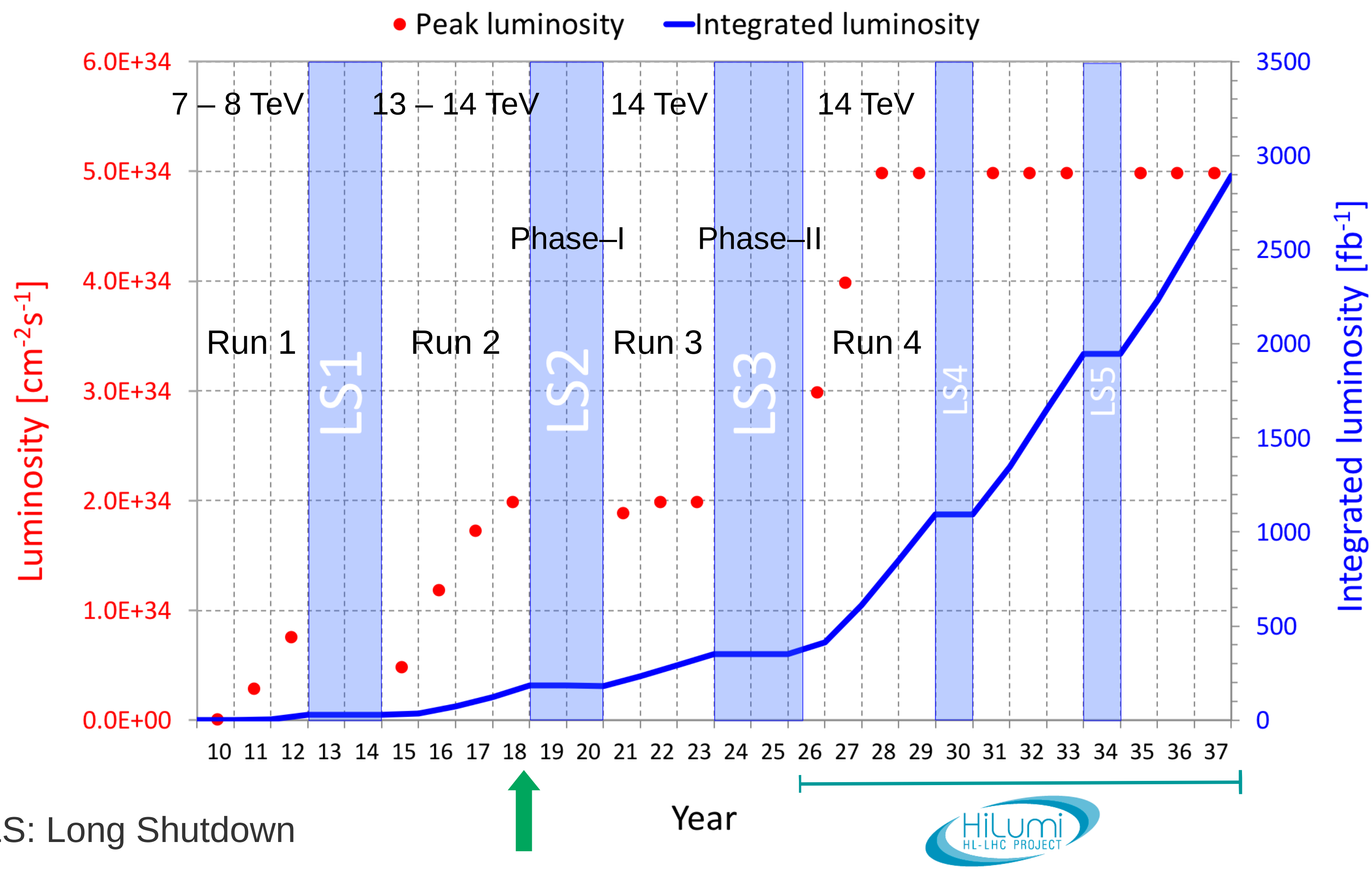
Online trigger system



- LHC collision rate: 40 MHz (25 ns)
- ATLAS: ~1.7 MB per collision, ~68 TB/s
- Just a tiny fraction of the data is interesting
- Bandwidth and storage limitations
- From the 40 MHz, only ~1 kHz can be stored (~1.5 GB/s)
- Online trigger system
- Use the available bandwidth with interesting information

Motivation

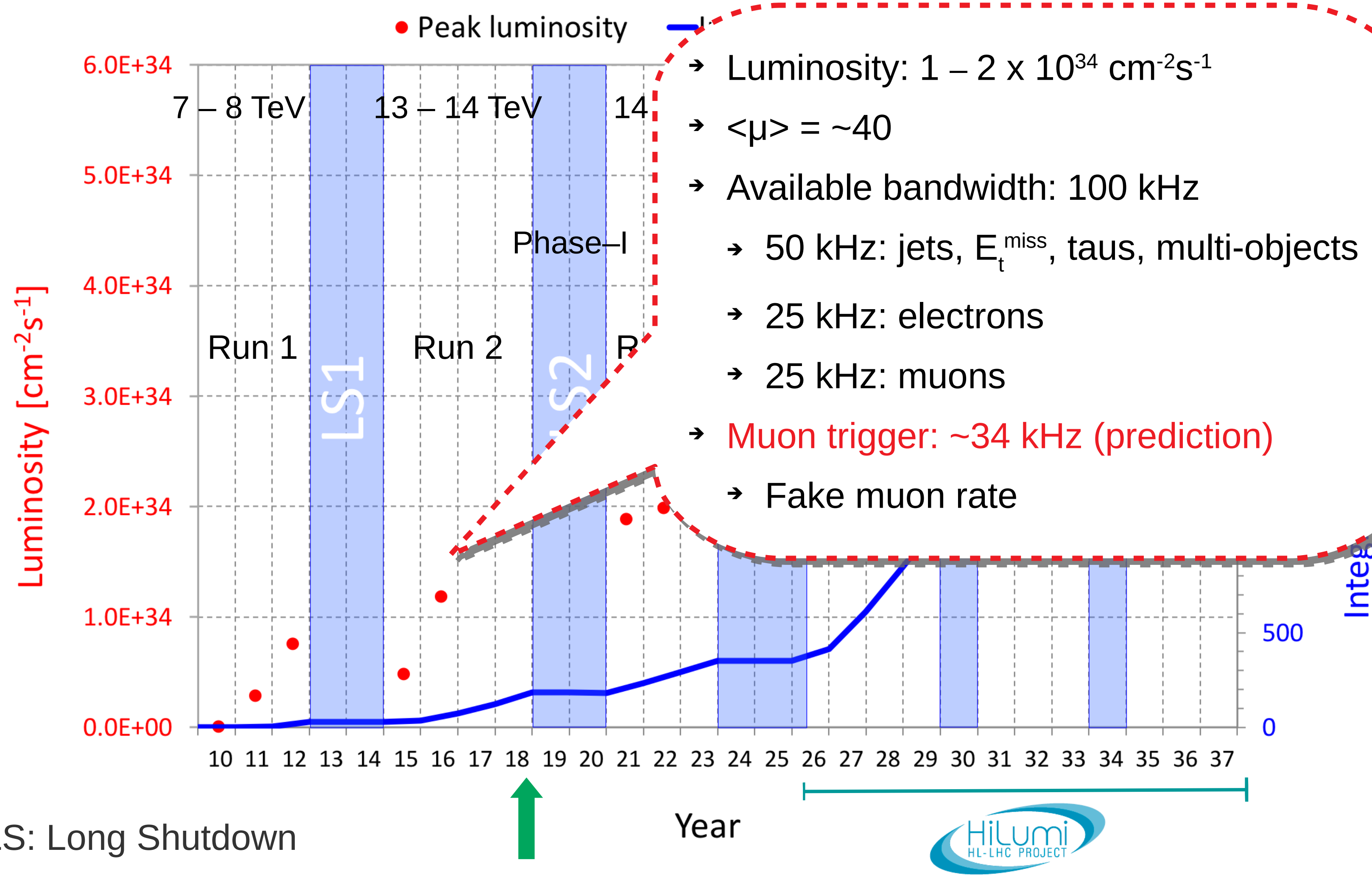
LHC/ATLAS Upgrades



LS: Long Shutdown

Motivation

Challenges and Solutions



- Luminosity: 1 – 2 x 10^{34} $cm^{-2}s^{-1}$
- <μ> = ~40
- Available bandwidth: 100 kHz
  - 50 kHz: jets, E_t^{miss}, taus, multi-objects
  - 25 kHz: electrons
  - 25 kHz: muons
- Muon trigger: ~34 kHz (prediction)
  - Fake muon rate

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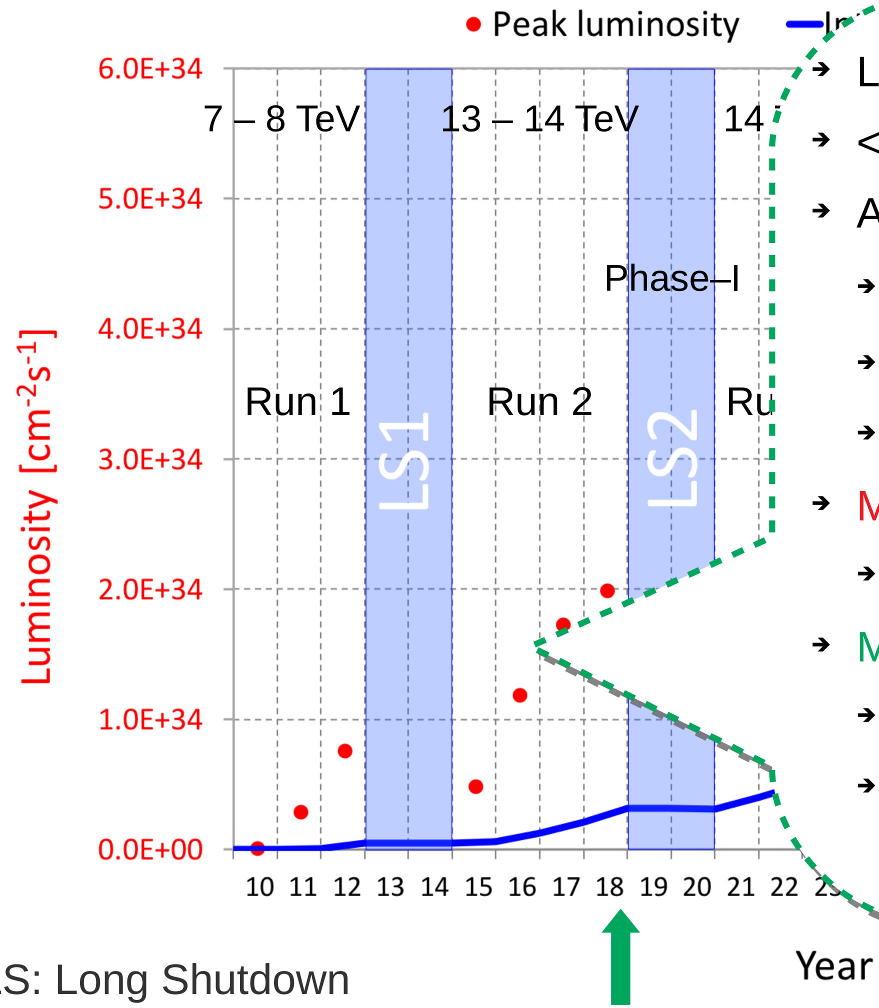

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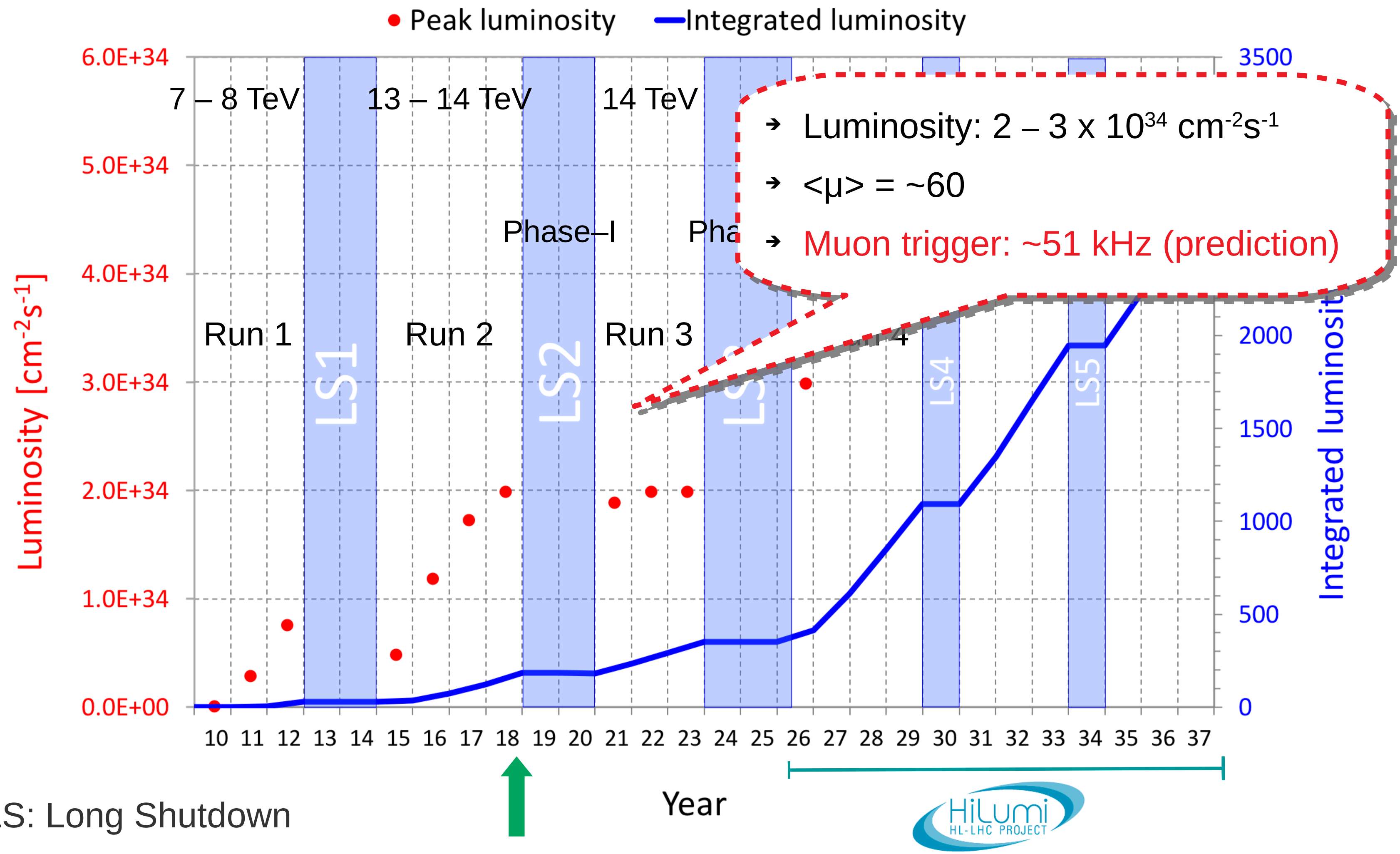
- Muon trigger: ~34 kHz (prediction)
  - Fake muon rate
- Muon trigger assisted by calorimetry
  - Tile-Muon trigger
  - New electronics system
    - Analog channels

LS: Long Shutdown

Challenges and Solutions



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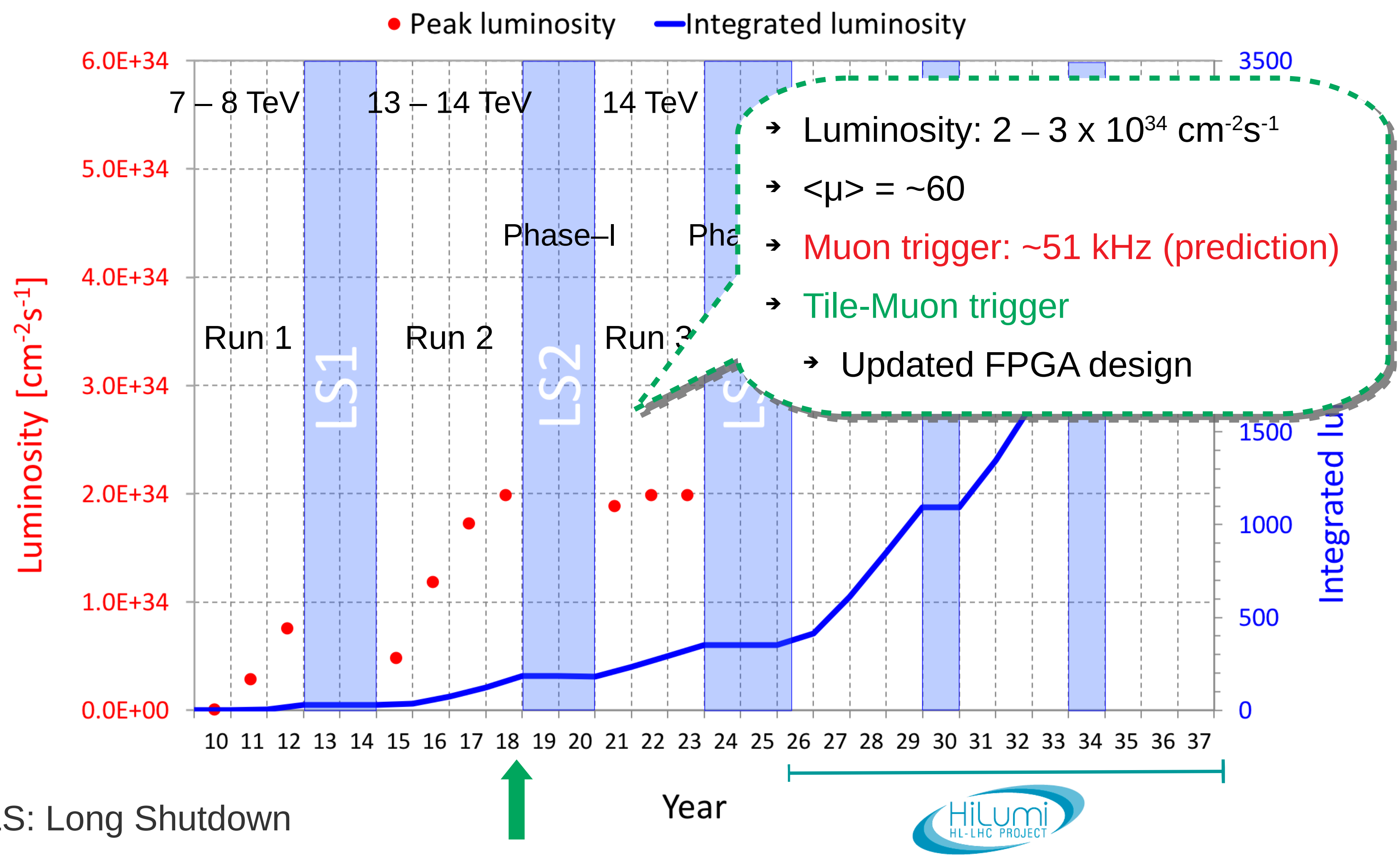
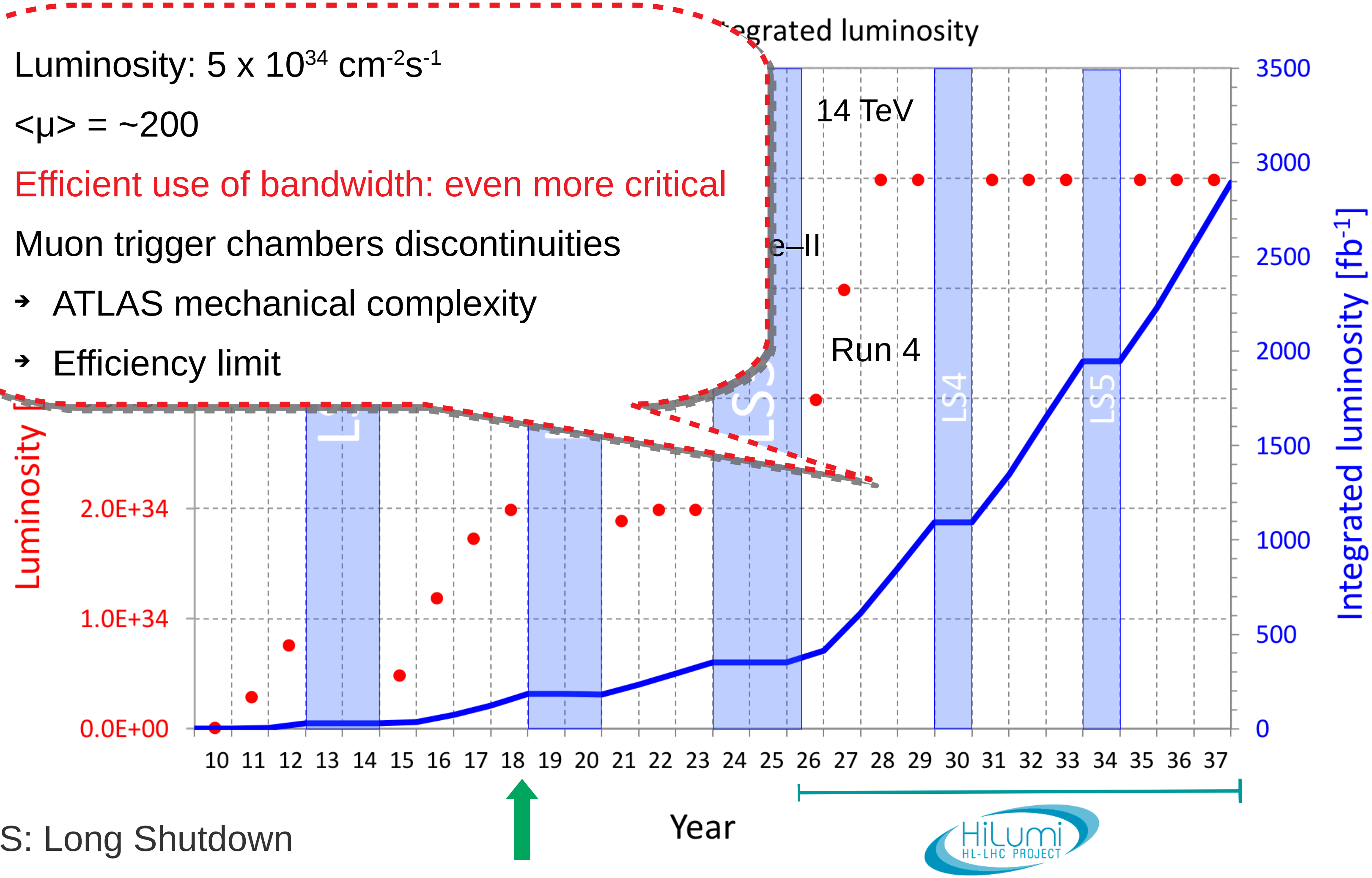


LS: Long Shutdown

Motivation

Challenges and Solutions

- Luminosity: 5 x 10^{34} $cm^{-2}s^{-1}$
- <μ> = ~200
- Efficient use of bandwidth: even more critical
- Muon trigger chambers discontinuities
  - ATLAS mechanical complexity
  - Efficiency limit



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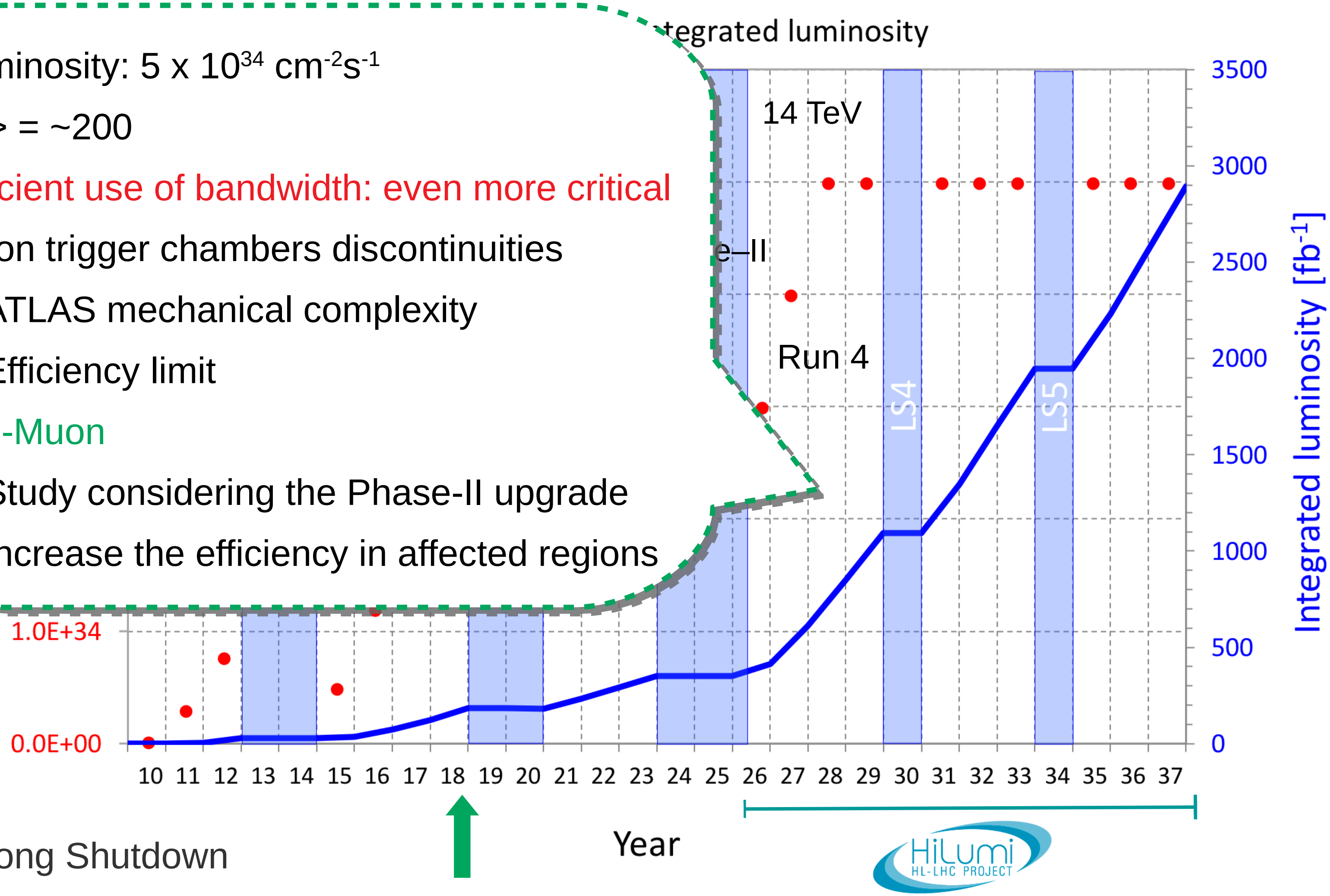
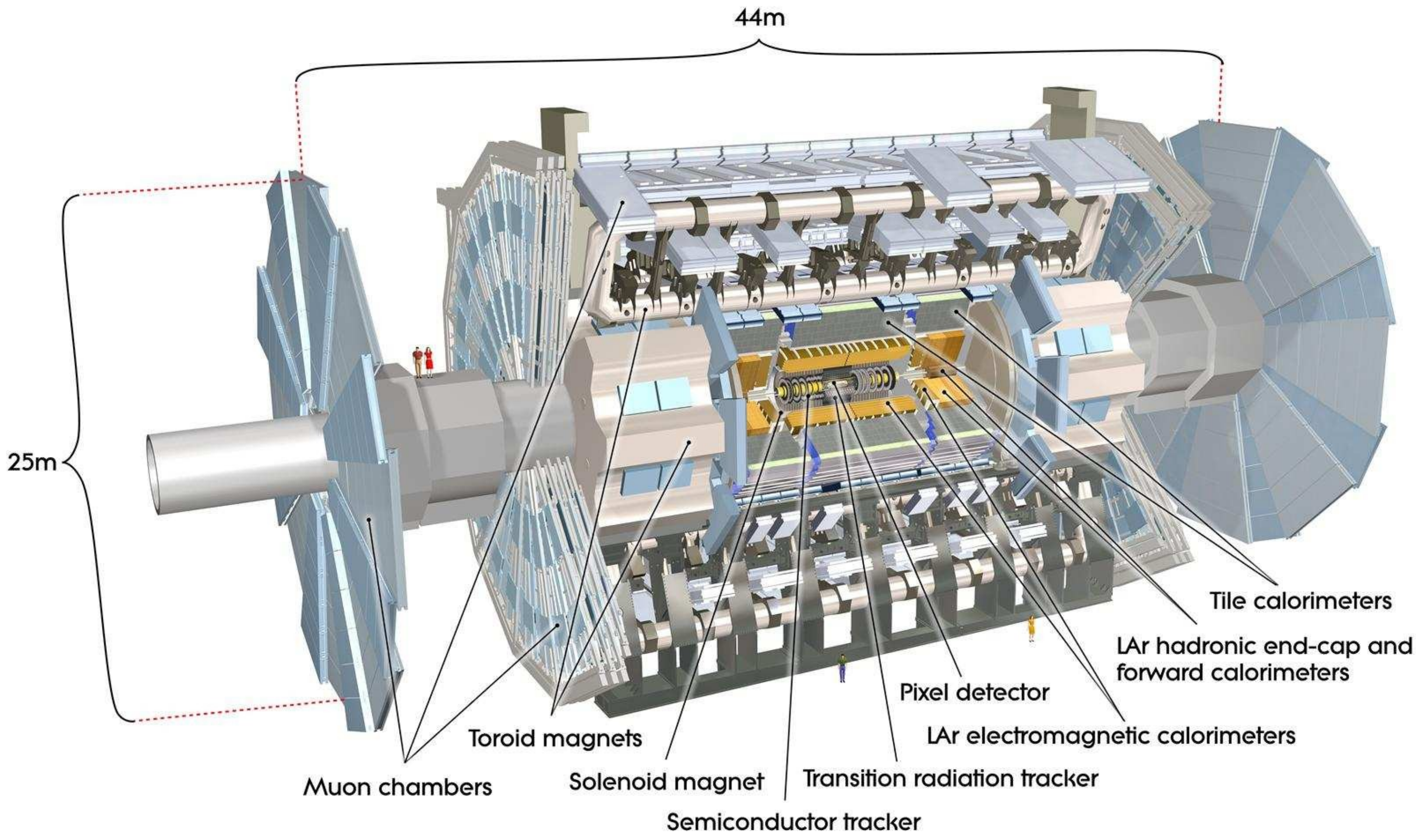
  - Efficiency limit
- Tile-Muon
  - Study considering the Phase-II upgrade
  - Increase the efficiency in affected regions



LS: Long Shutdown

The ATLAS experiment

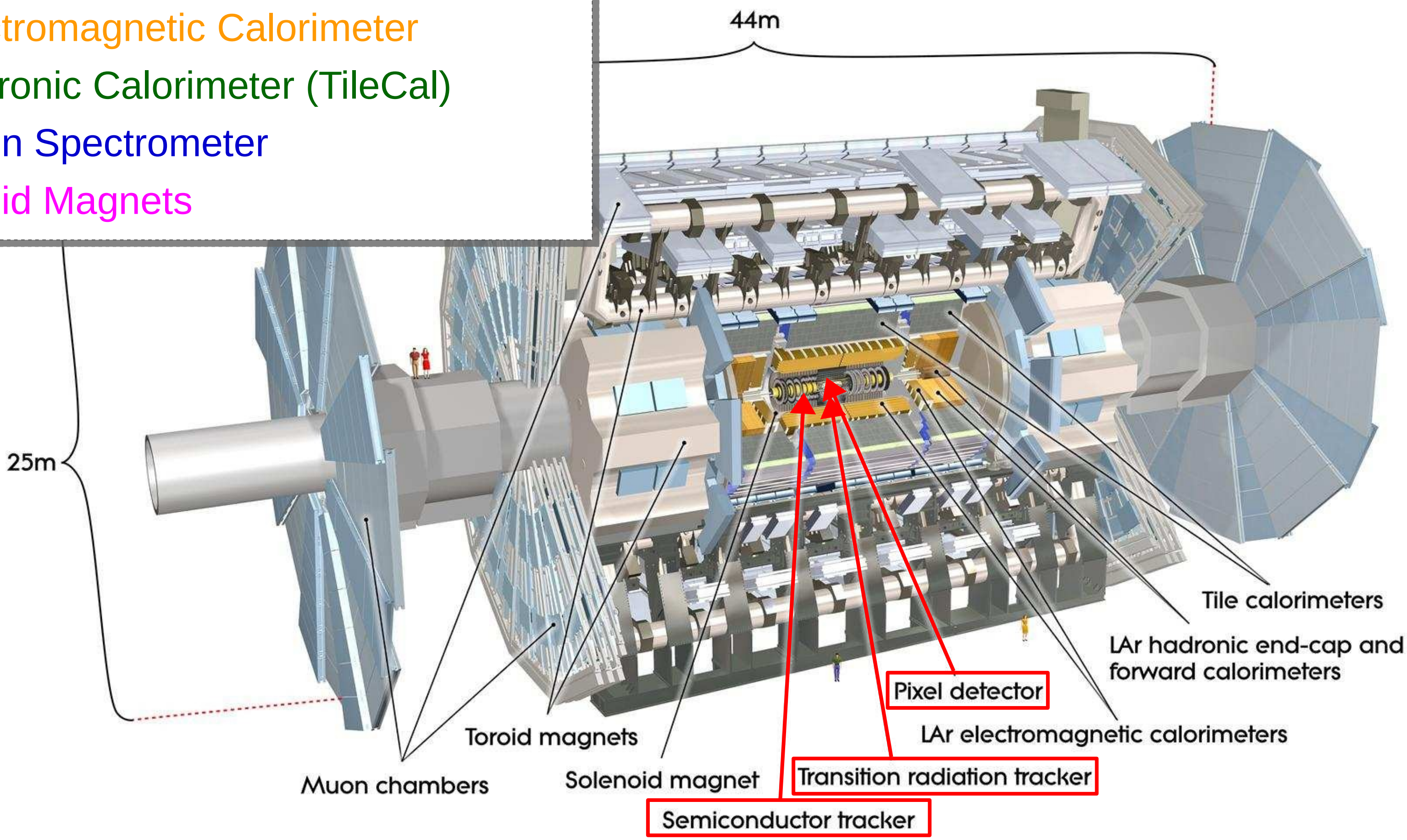
Detectors



The ATLAS experiment

Detectors

- Inner Detector
- Electromagnetic Calorimeter
- Hadronic Calorimeter (TileCal)
- Muon Spectrometer
- Toroid Magnets



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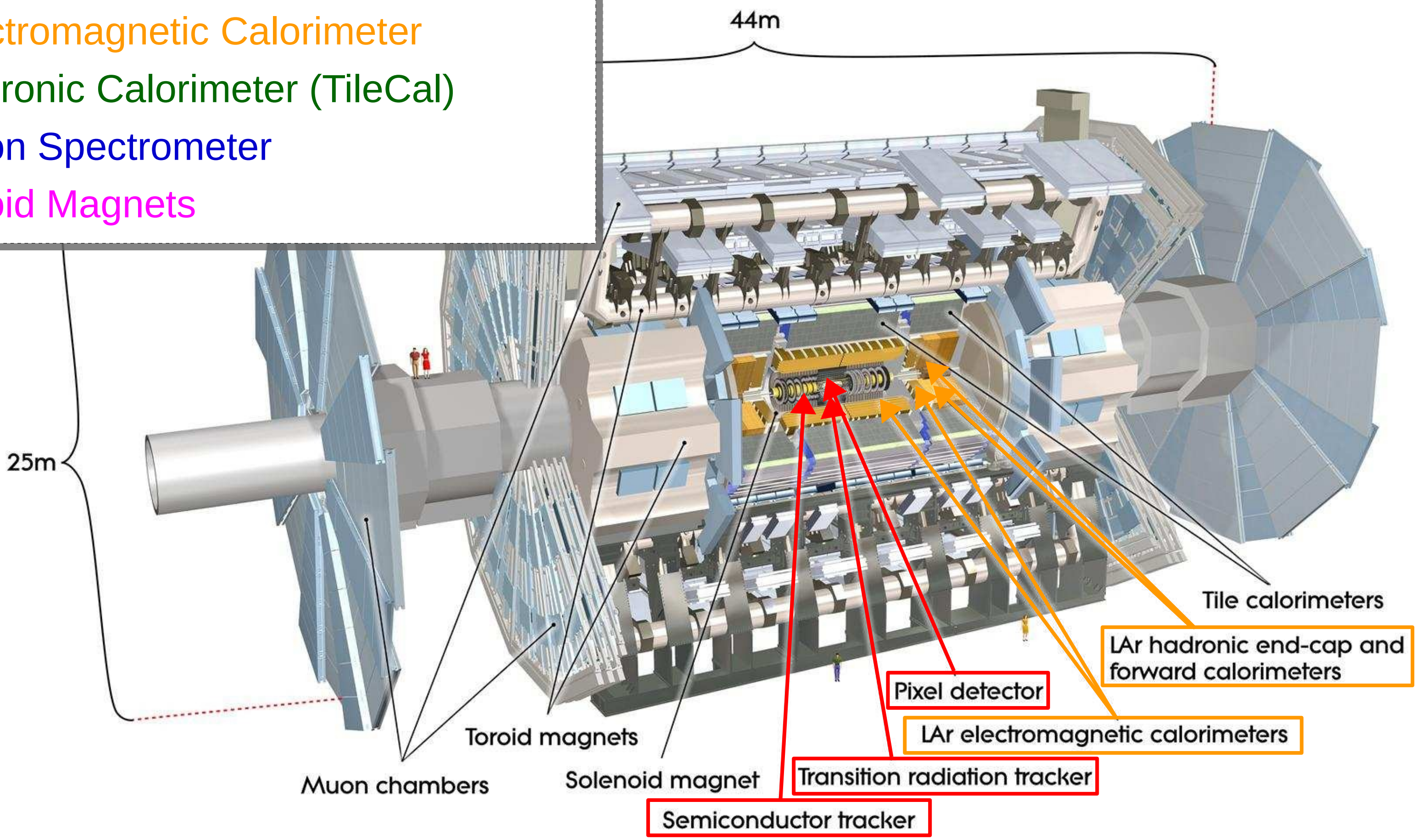

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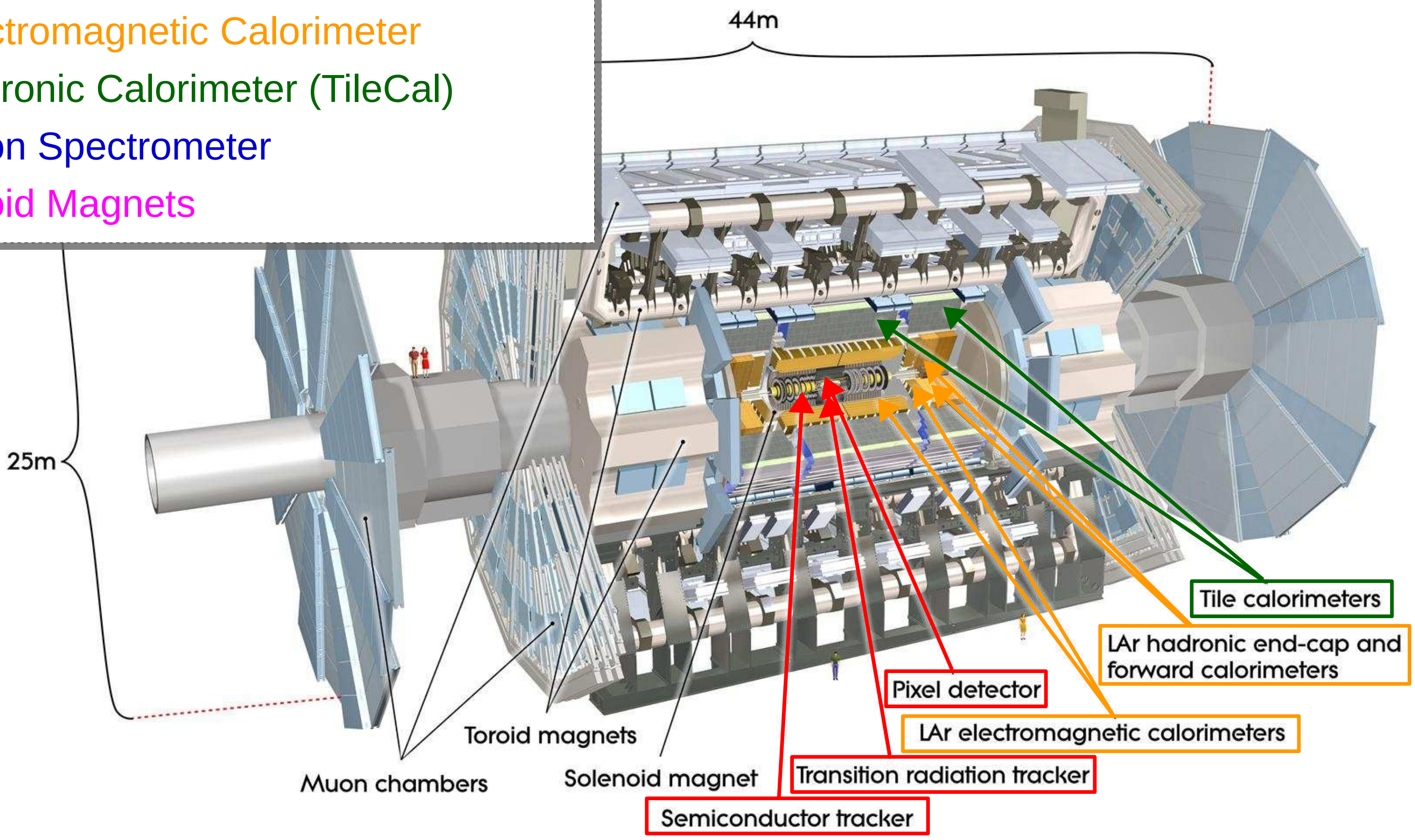

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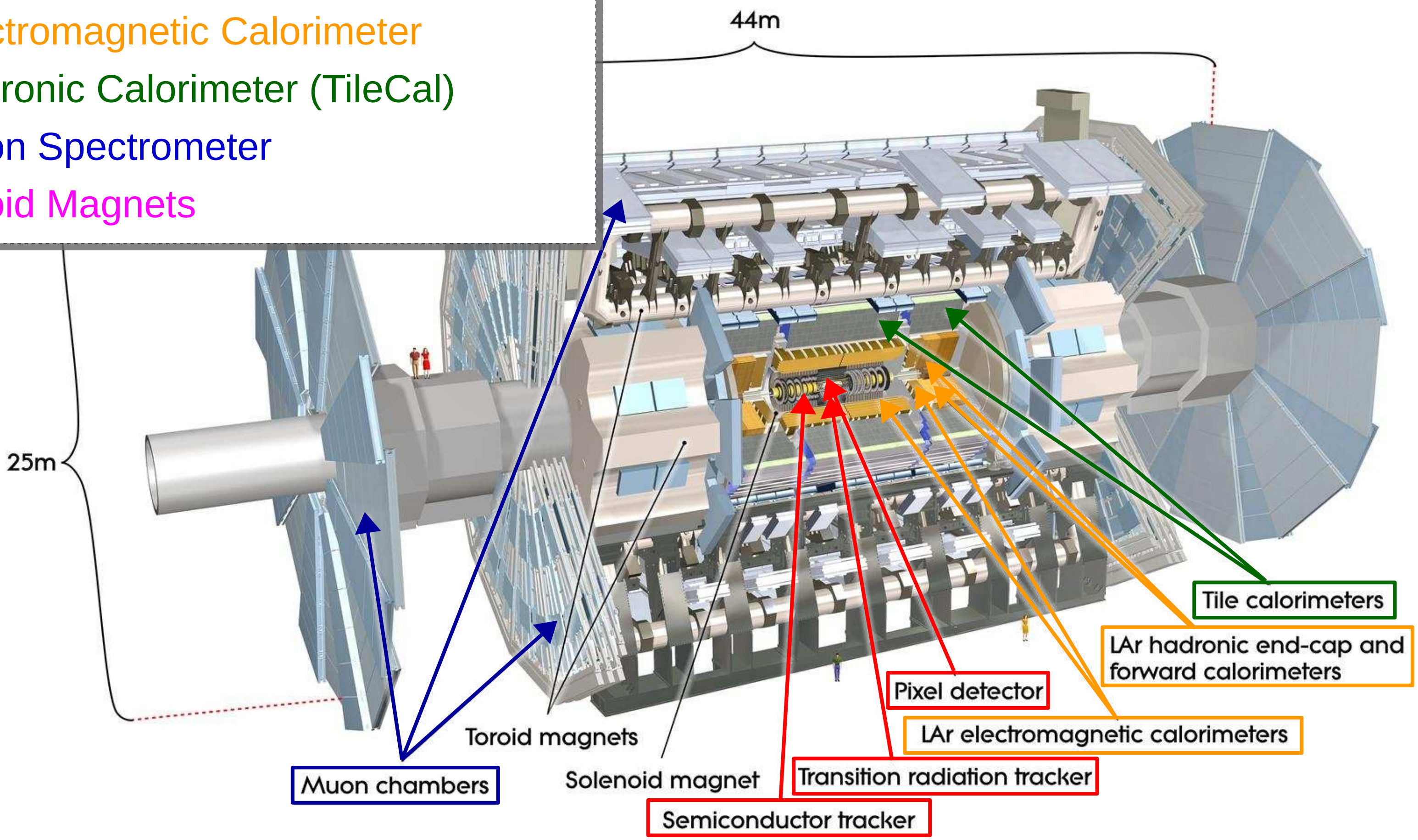

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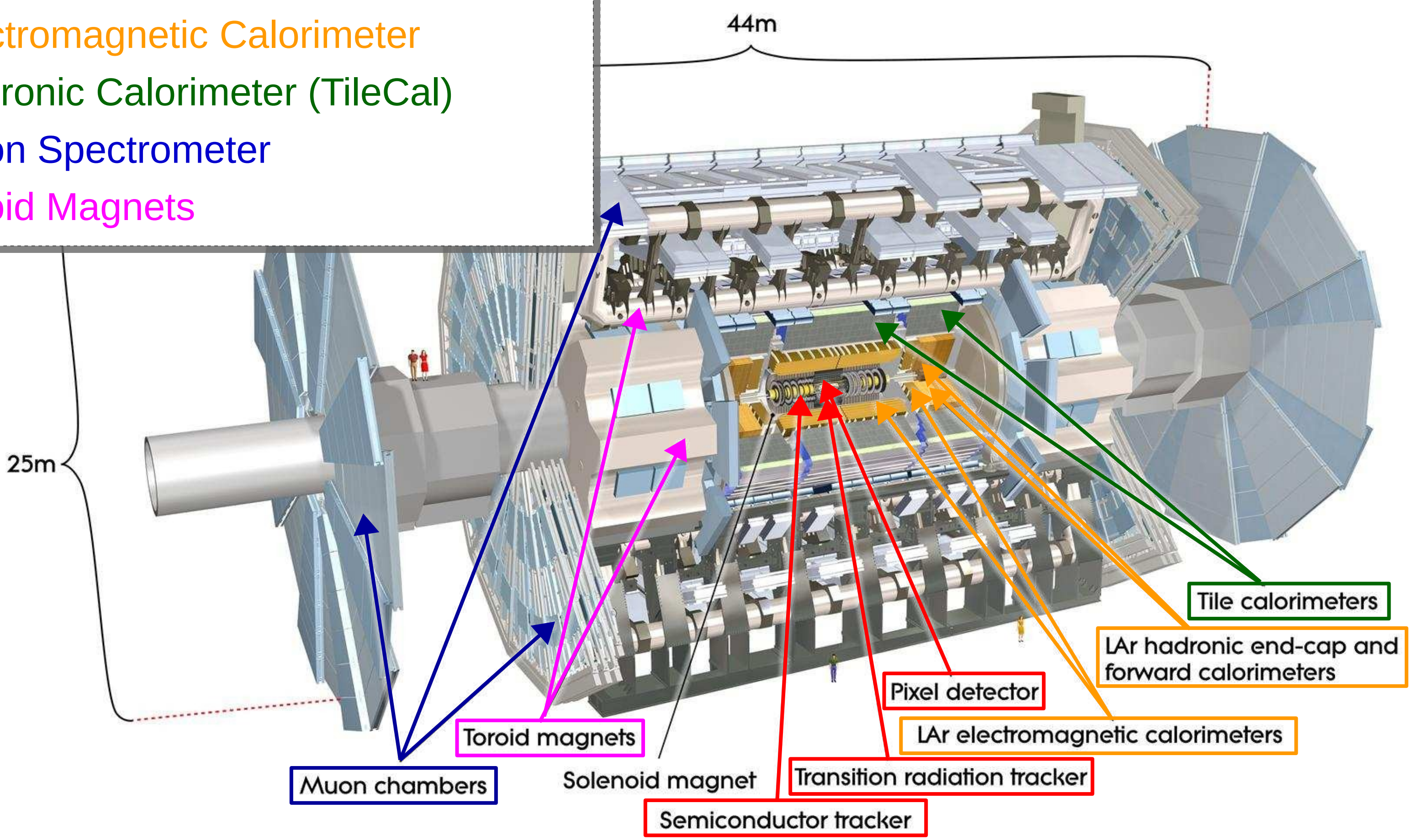
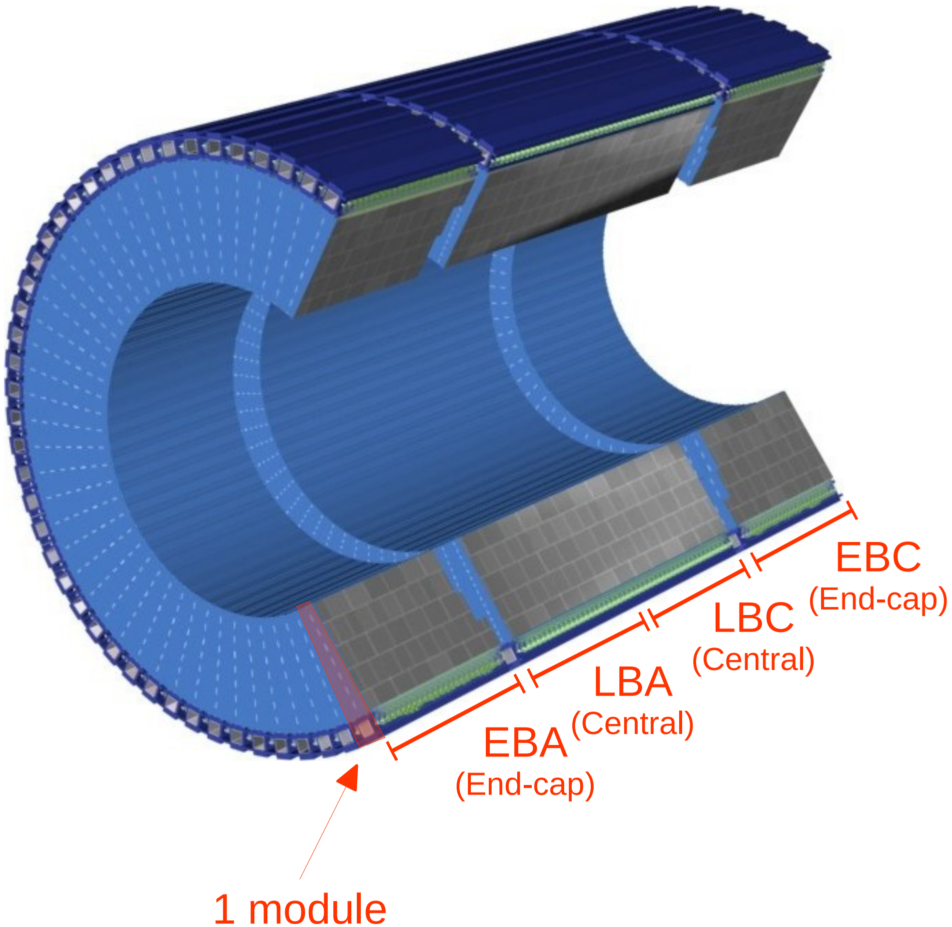


The ATLAS experiment

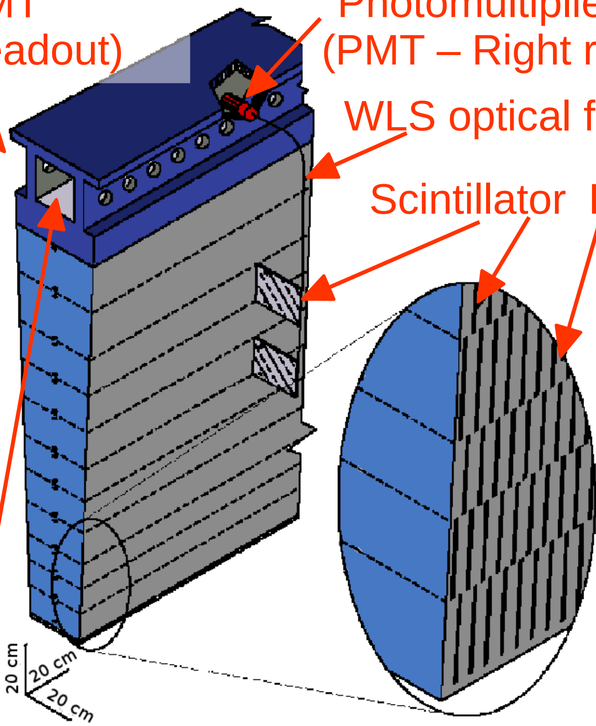
The Hadronic Calorimeter (TileCal)

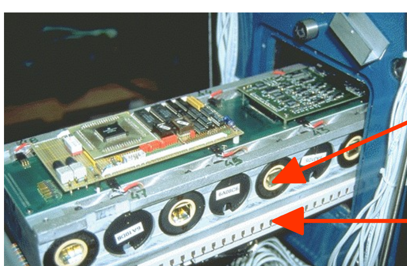


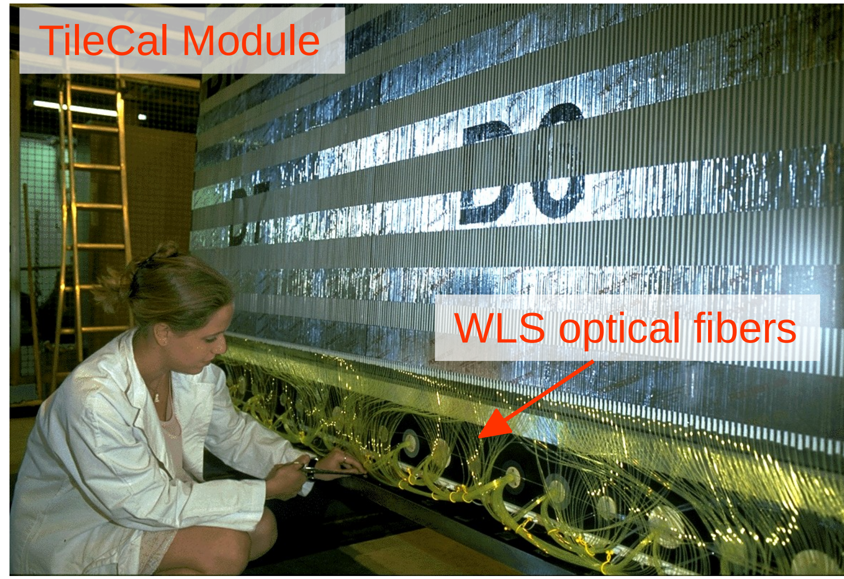
- Composed by 4 sections
  - Long Barrel (LB) – sides A and C
  - Extended Barrel (EB) – sides A and C
- 64 modules per section
- The modules are divided into cells
- The cells have double readout (left and right)
- ~10.000 readout channels
- Measuring hadronic particles

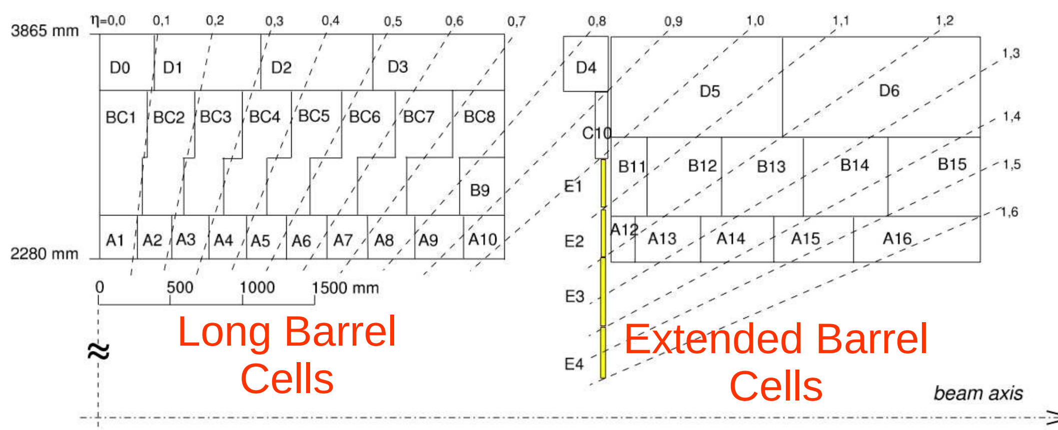
The ATLAS experiment

The Hadronic Calorimeter (TileCal)



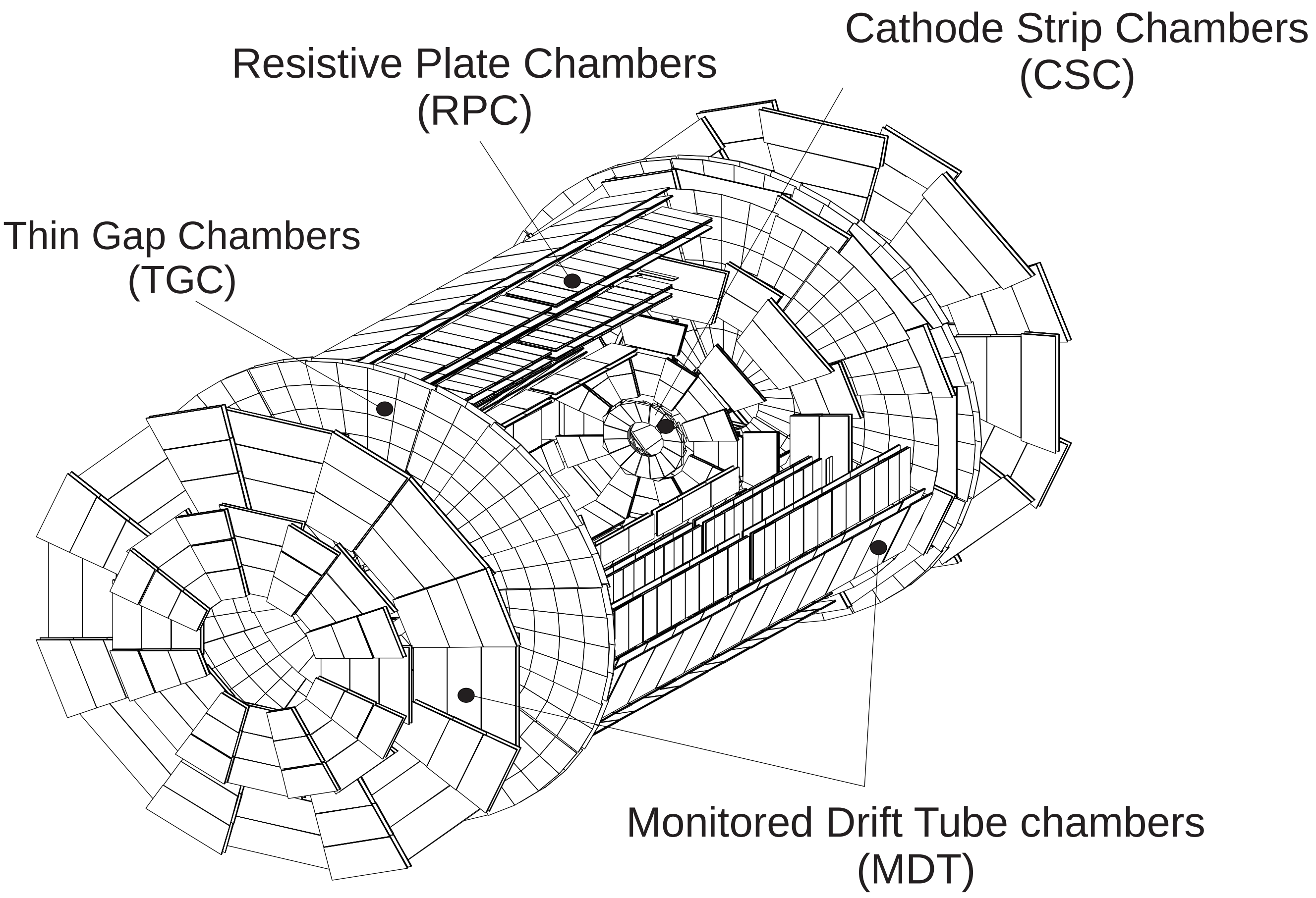






The ATLAS experiment

The Muon Spectrometer



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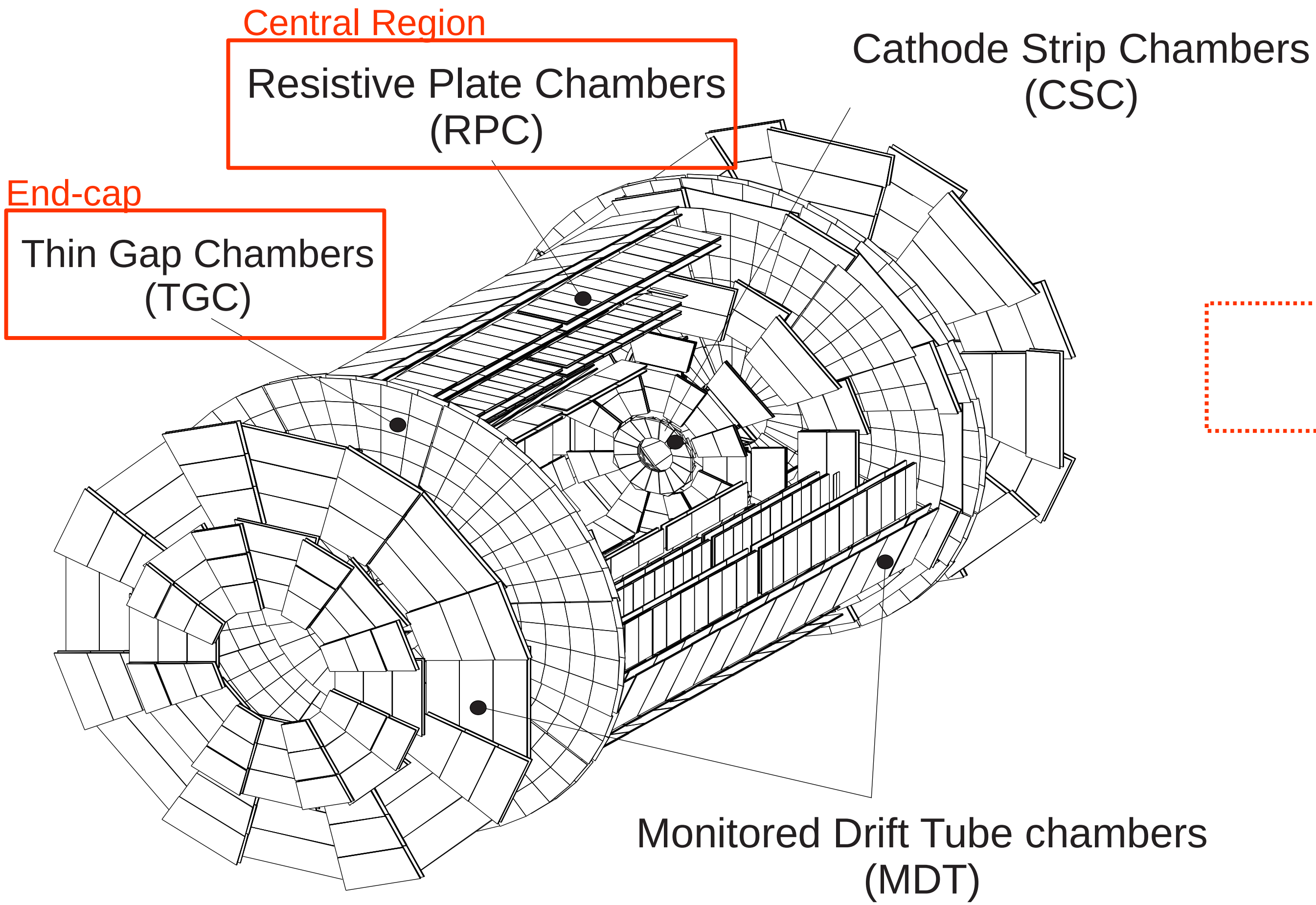
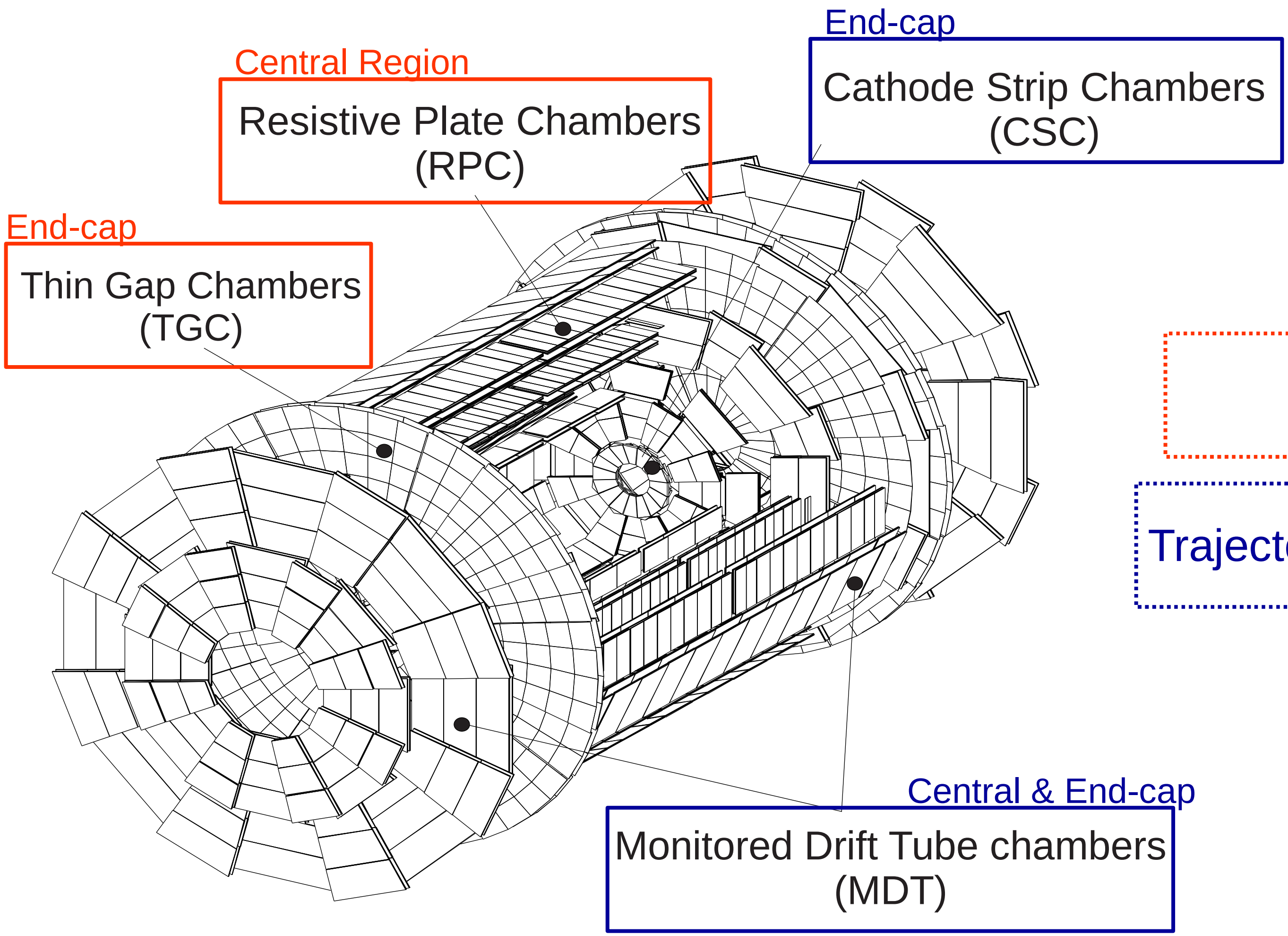


Trigger

The ATLAS experiment

The Muon Spectrometer

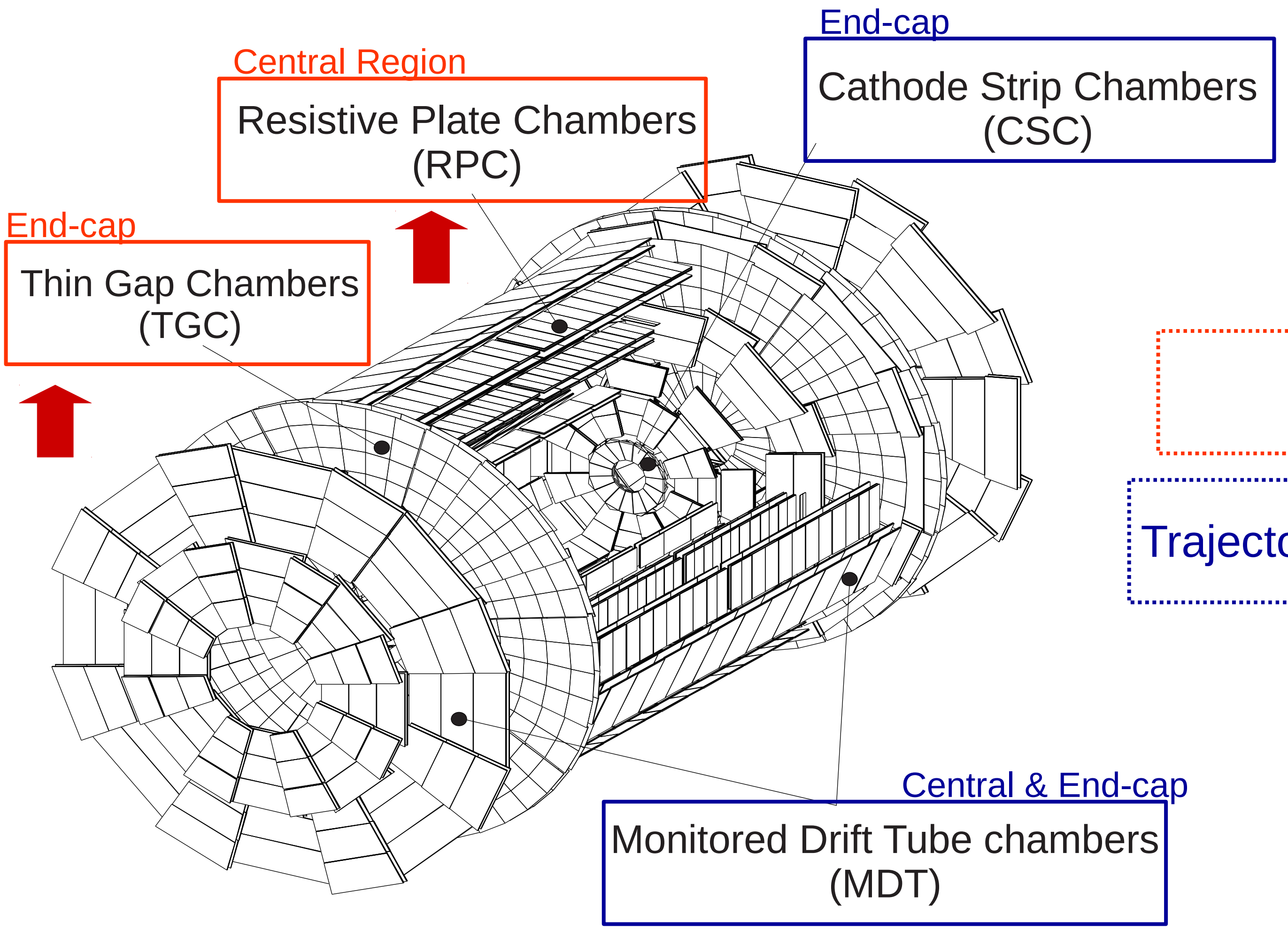


Trigger

Trajectory and Momentum

The ATLAS experiment

The Muon Spectrometer

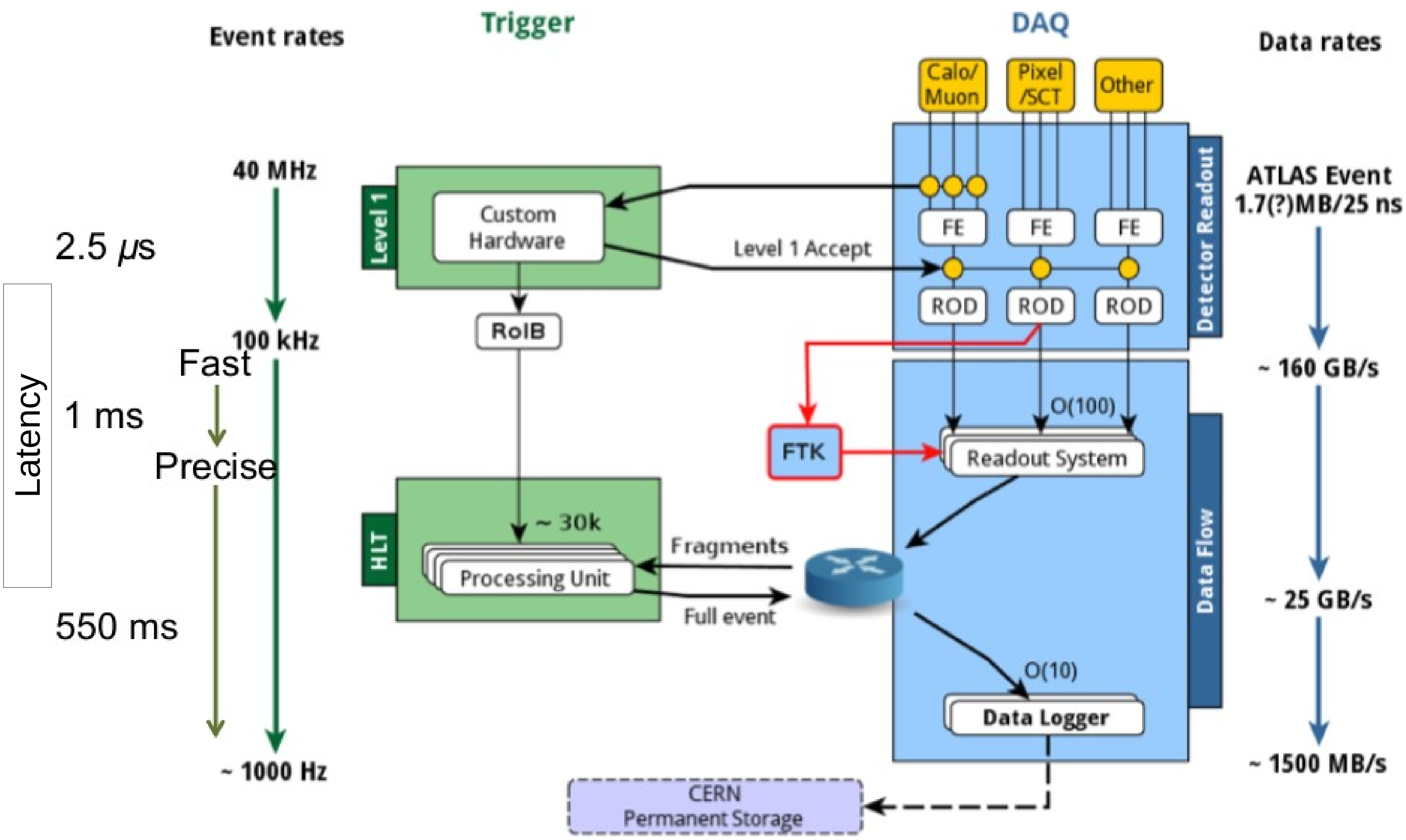


Trigger

Trajectory and Momentum

The ATLAS experiment

The ATLAS online trigger system



The ATLAS experiment

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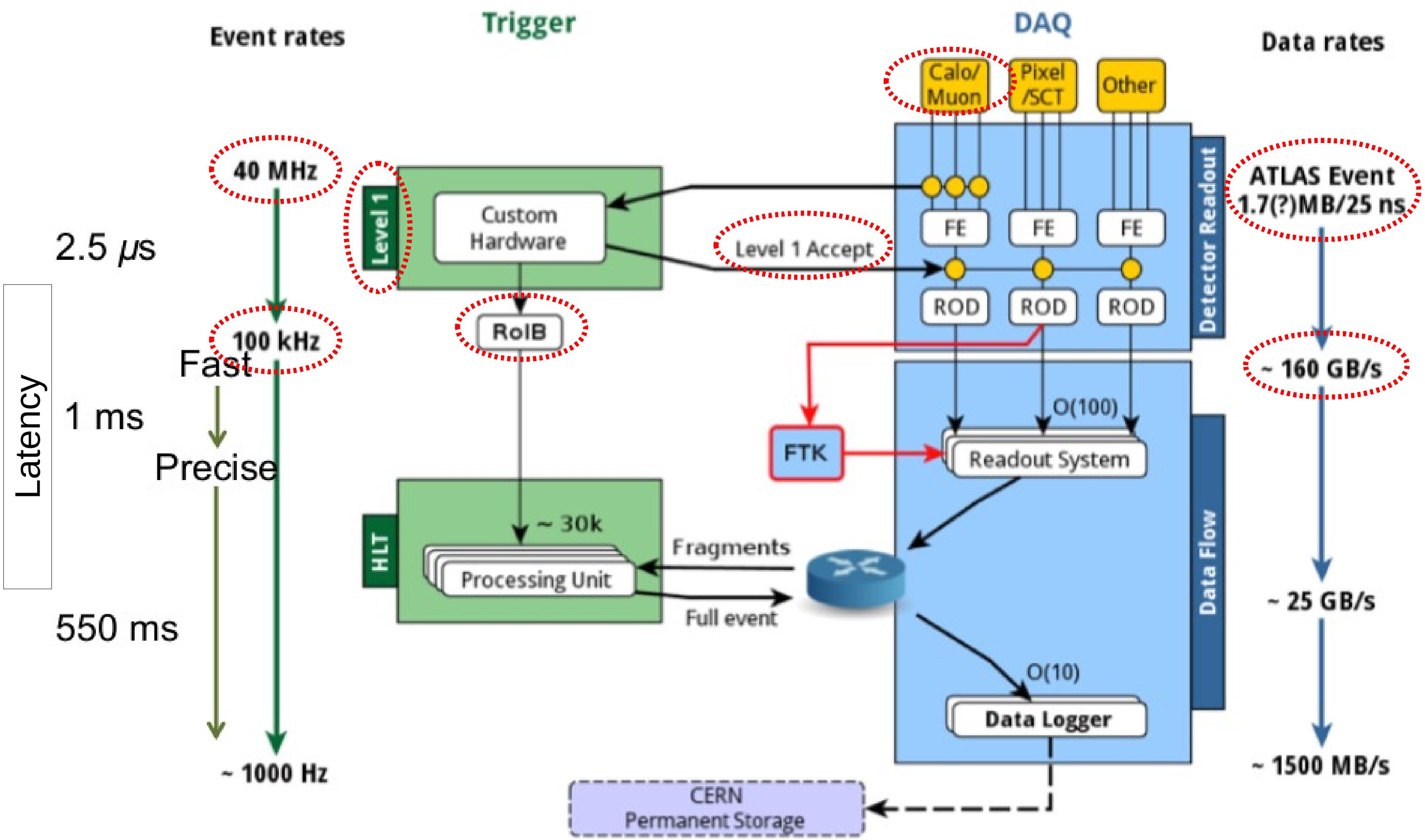

The ATLAS experiment

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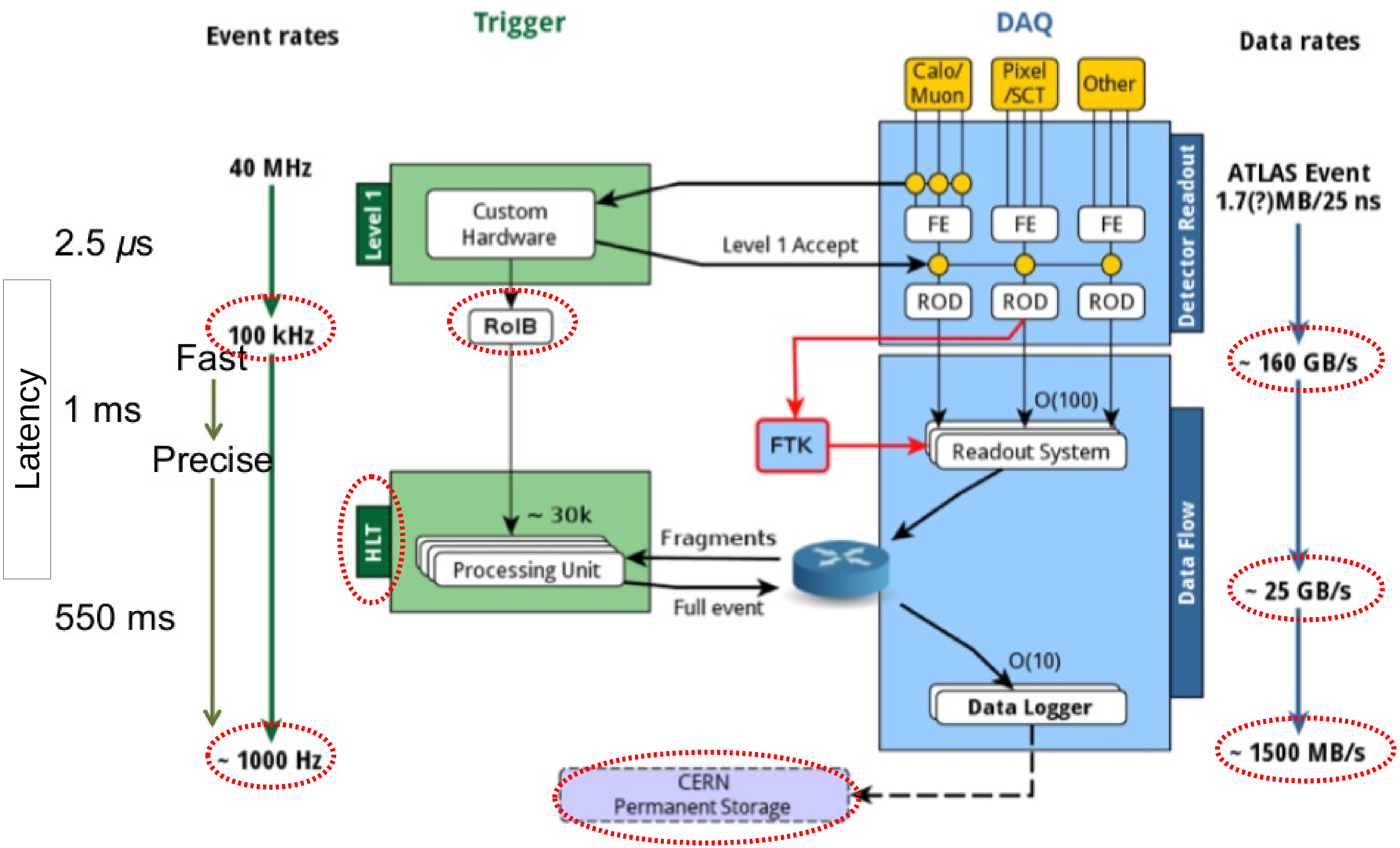
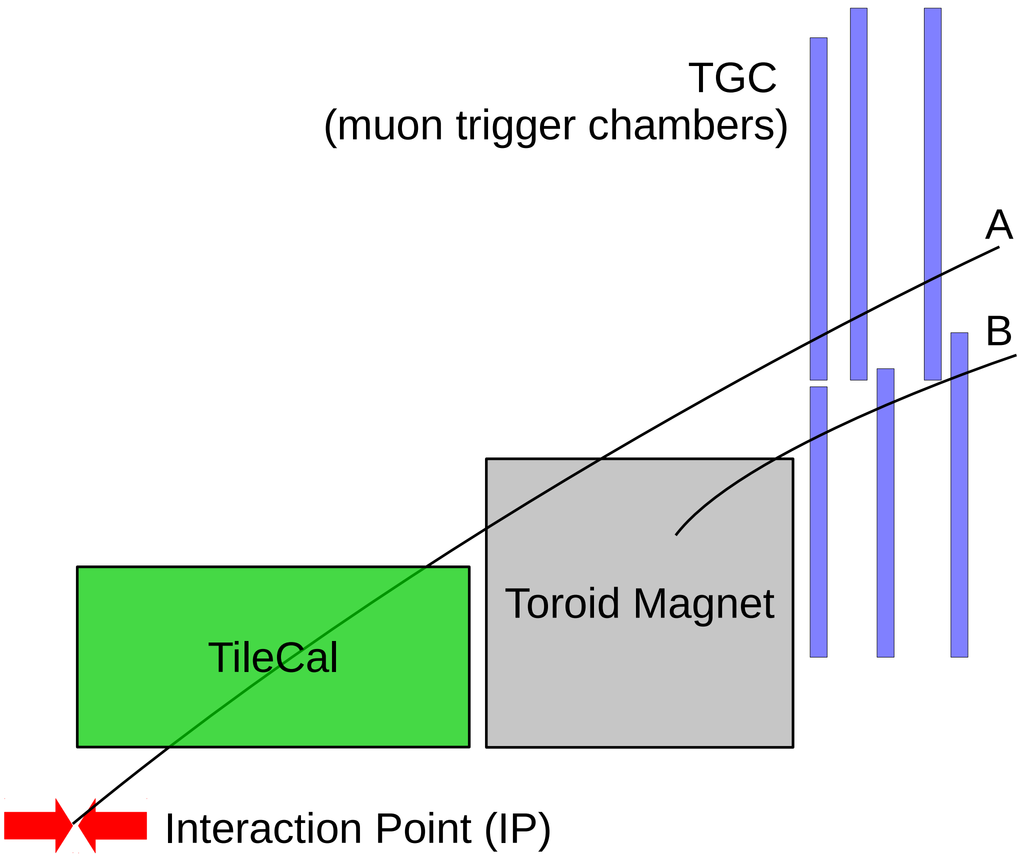


Muon trigger assisted by calorimetry: before the Phase-II upgrade

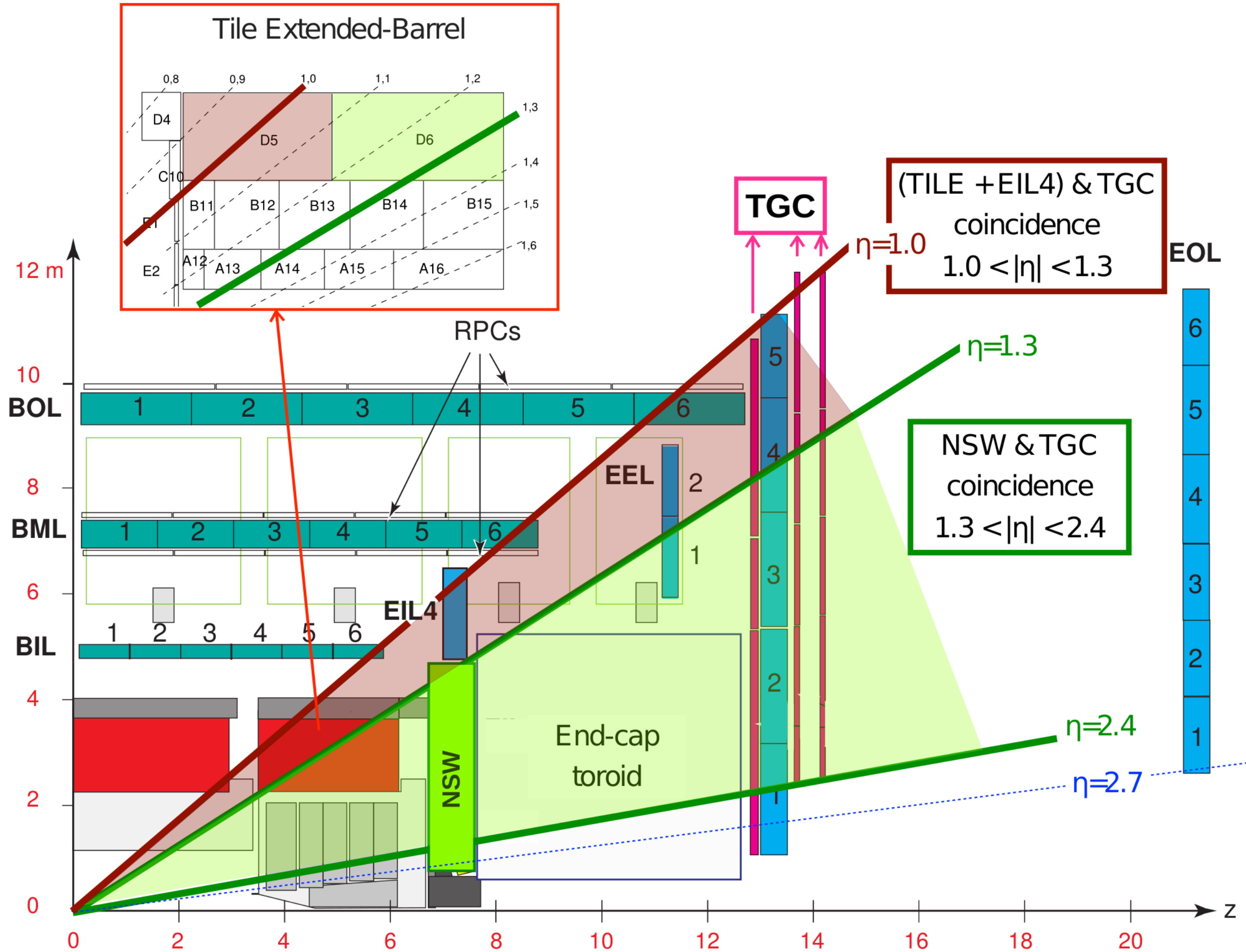
Information fusion to attenuate the false alarm rate



- L1Muon: would exceed its bandwidth
- Protons (low p_T) in the end-cap region
- A: Collision muon
- B: Low energy proton
- Information fusion
  - Tile Extended Barrel
  - TGC
- Confirmation through TileCal
  - Rejecting the fake muons

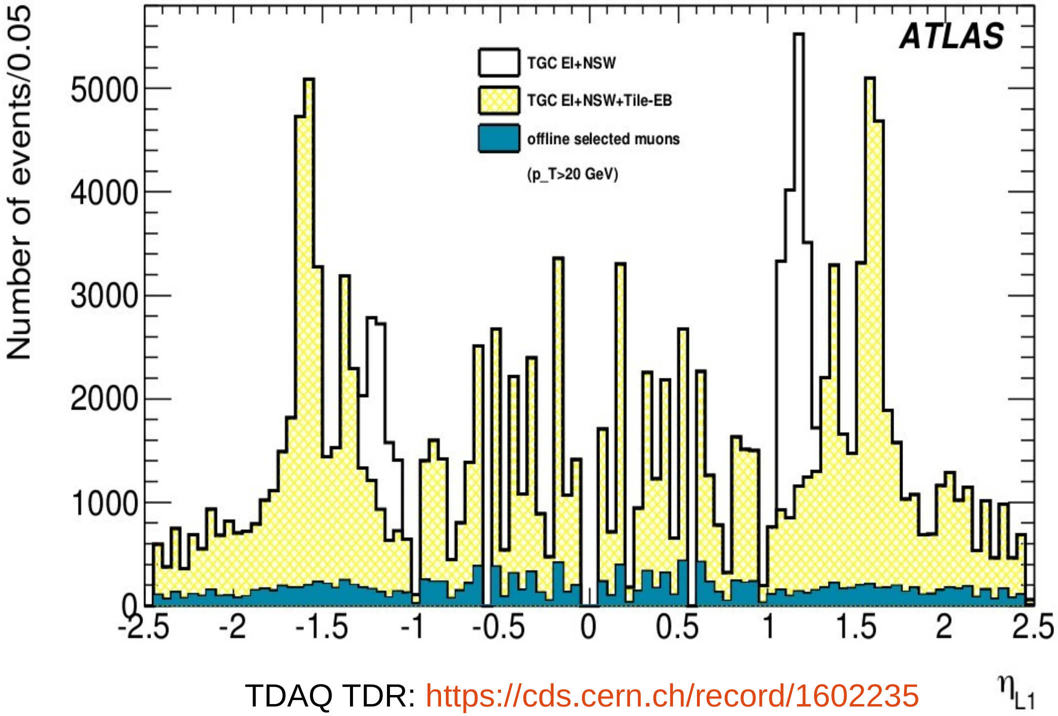
Muon trigger assisted by calorimetry: before the Phase-II upgrade

Coincidence between Tile Extended Barrel and TGC



Muon trigger assisted by calorimetry: before the Phase-II upgrade

Muon candidates and offline muons



TDAQ TDR: https://cds.cern.ch/record/1602235

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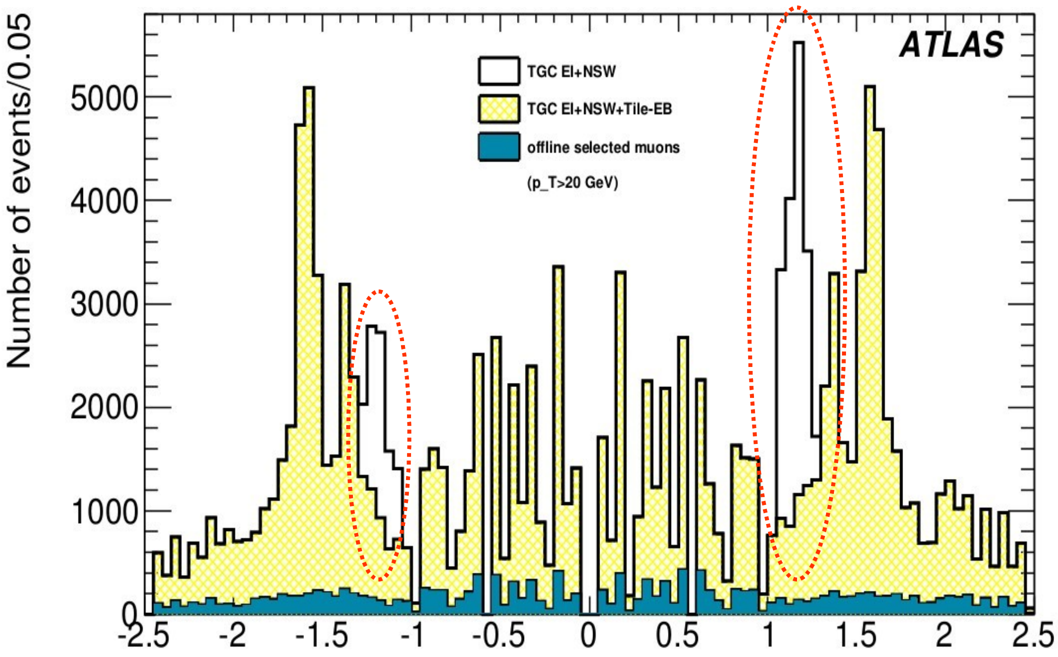


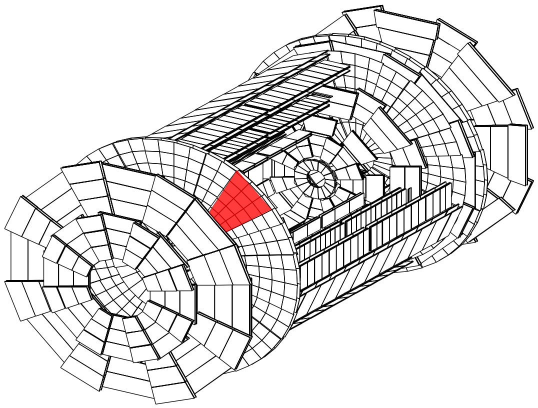
TDAQ TDR: https://cds.cern.ch/record/1602235 η_{L1}

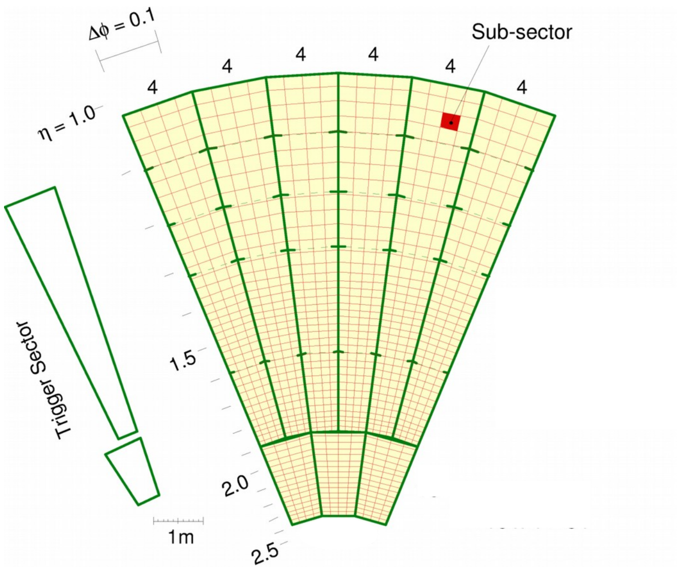
TileCal (D5+D6) & TGCs eliminates the peaks in $1,0 < |\eta| < 1,3$

Muon trigger assisted by calorimetry: before the Phase-II upgrade

Geometry Matching

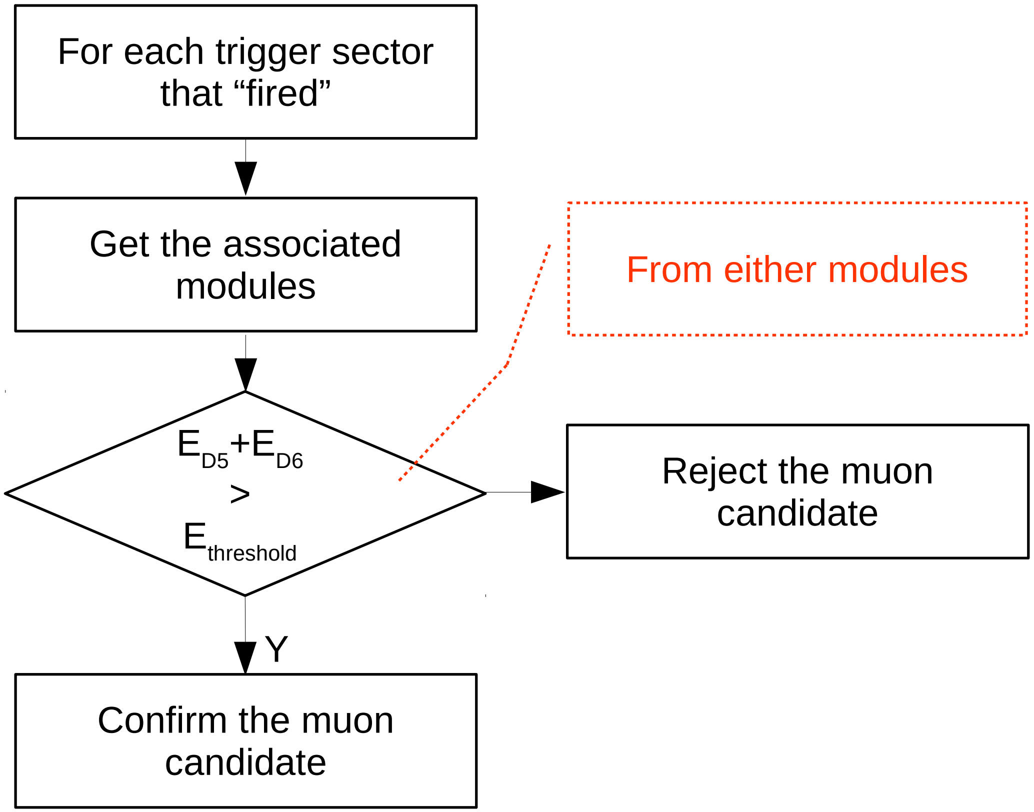
- How the information is combined?
- L1Muon (end-cap region) is fed by the TGC
- The information is mapped into trigger sectors
  - TGC: divided into 48 regions in Φ (for each side)
- TileCal: divided into 64 modules in Φ (for each side)
- Geometry matching in Φ
  - 1 trigger sector ← 2 TileCal modules





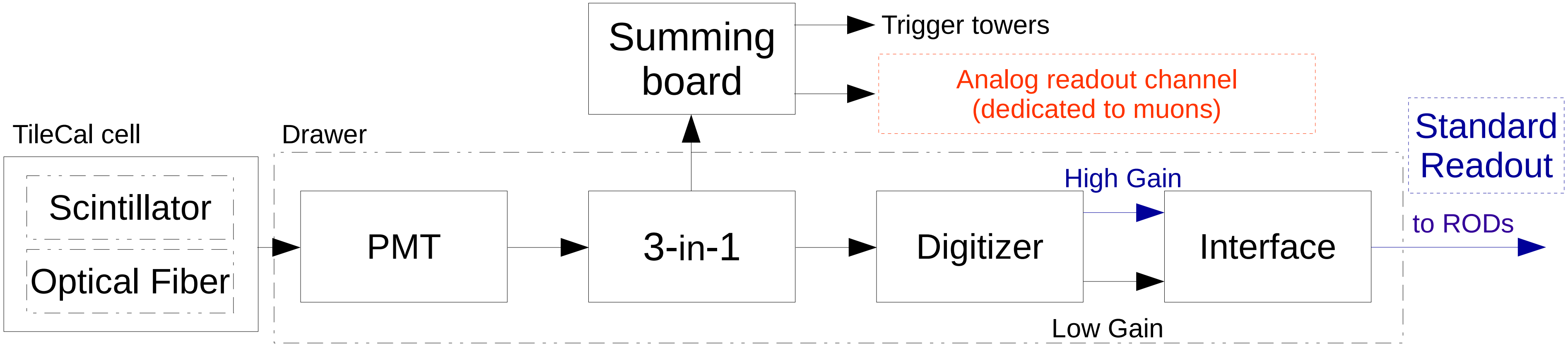
Muon trigger assisted by calorimetry: before the Phase-II upgrade

Hit confirmation algorithm



Muon trigger assisted by calorimetry: before the Phase-II upgrade

TileCal Signal Chain



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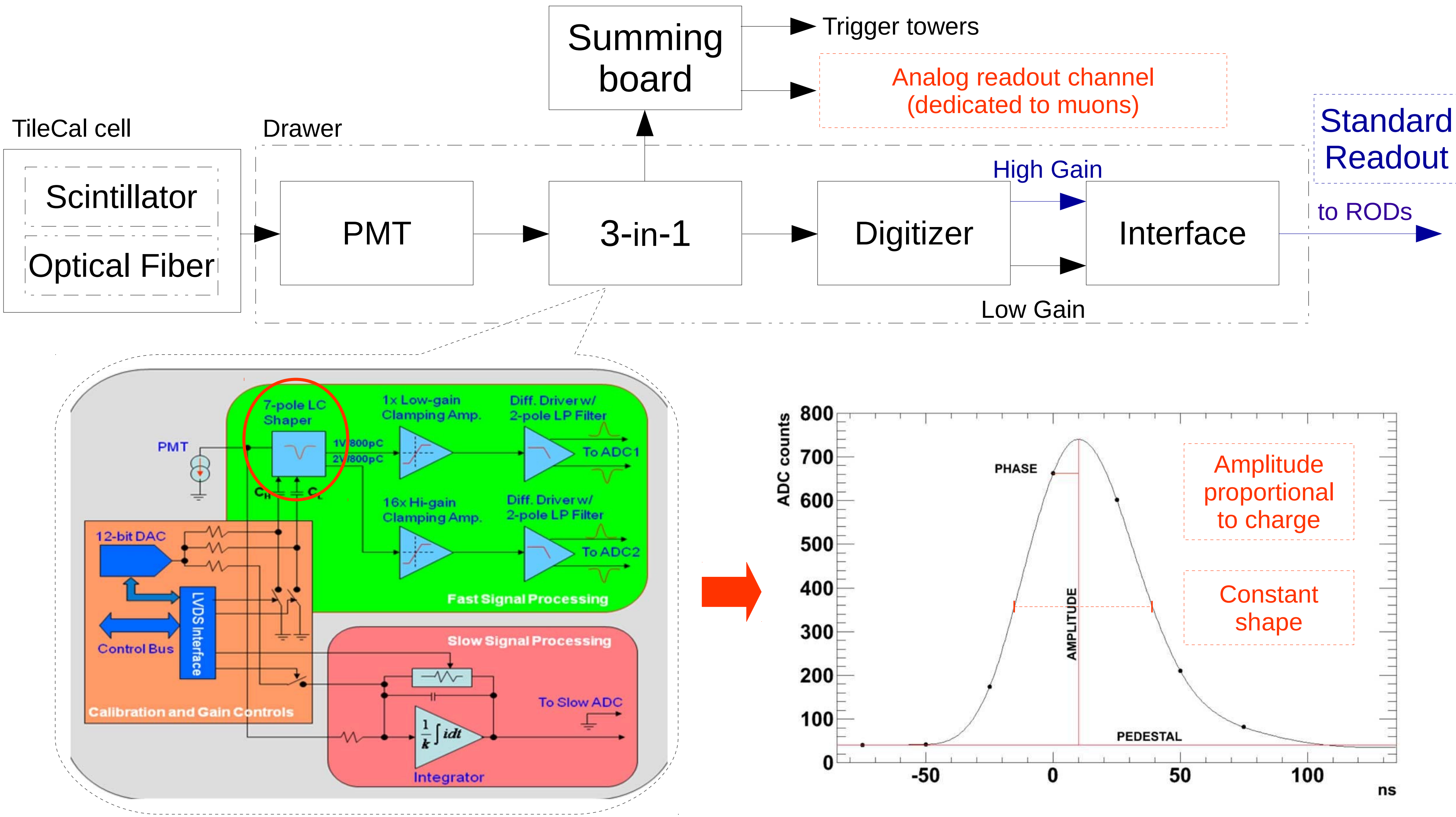

Muon trigger assisted by calorimetry: before the Phase-II upgrade

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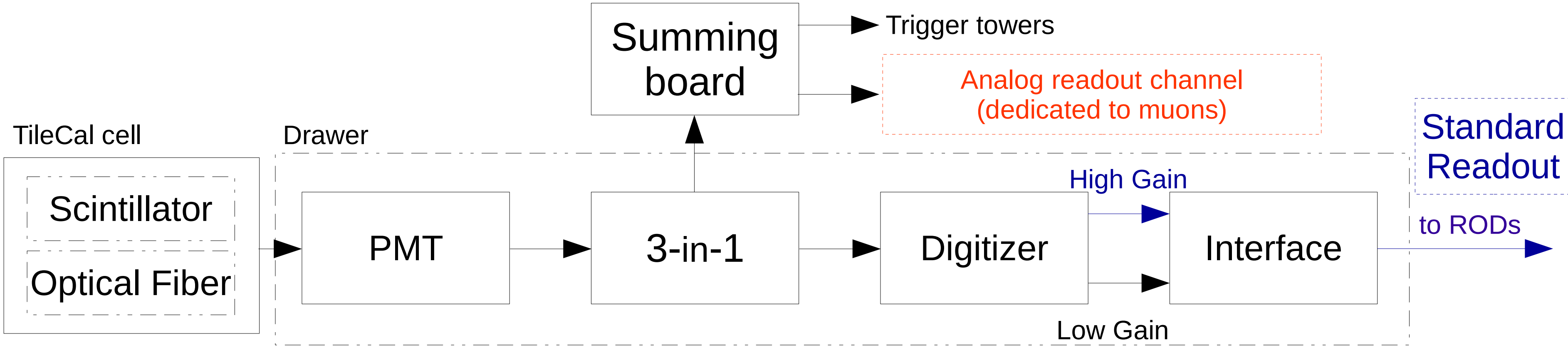
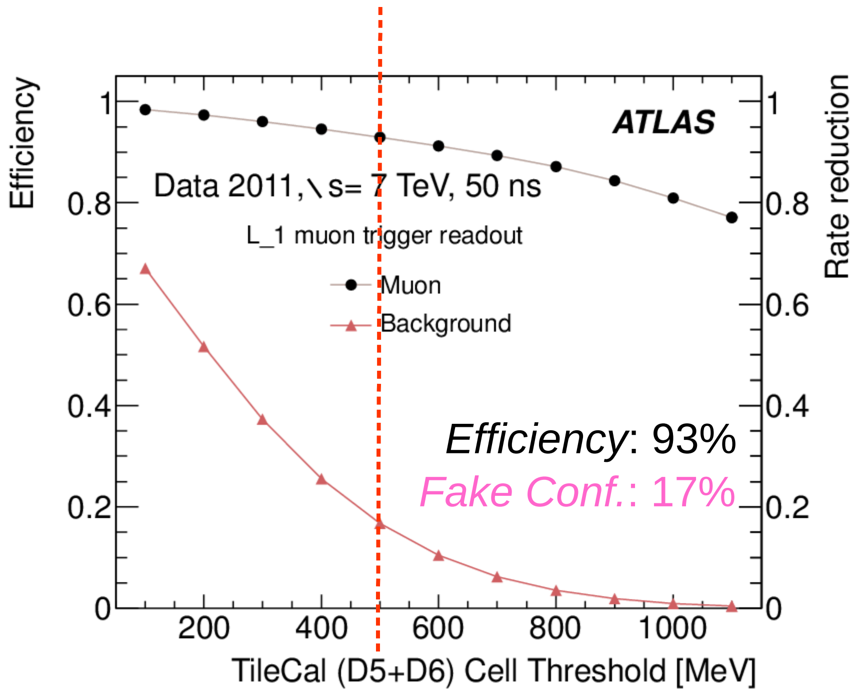


- Analog readout channel dedicated to muons
  - Developed during TileCal conception
  - D-layer only readout
    - Cell area
    - Particles absorbed by the previous calorimeters layers
  - Never have been used
  - Except in...

Muon trigger assisted by calorimetry: before the Phase-II upgrade

Preliminary Performance

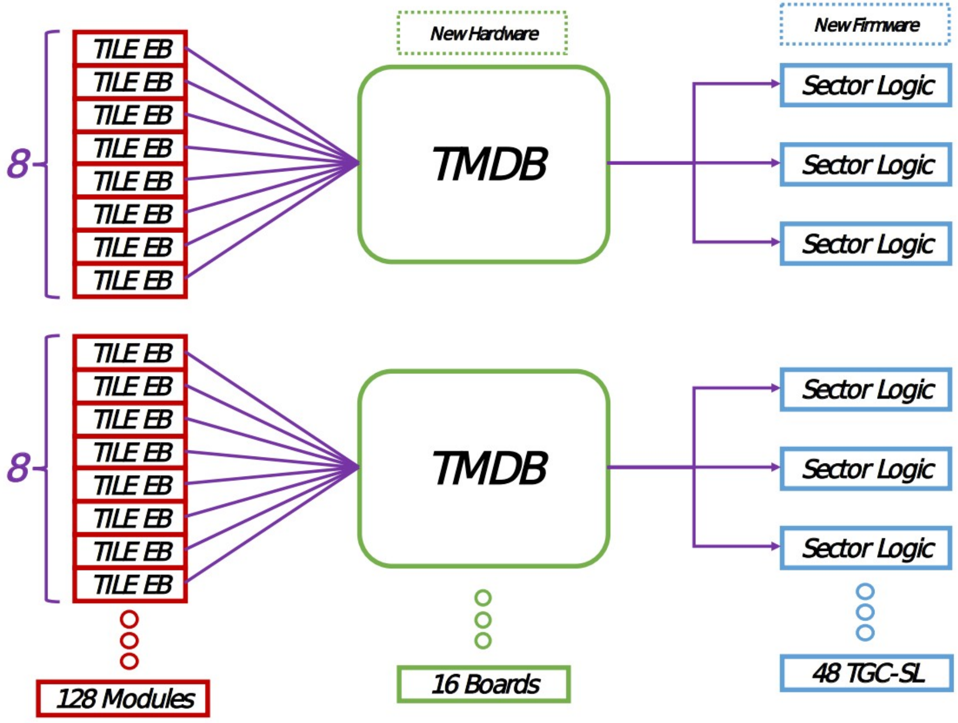


TDAQ TDR: https://cds.cern.ch/record/1602235

- 2011: for an octant of the modules, the muon readout channels were instrumentalised
- Spare digitizer boards
- Efficiency: 93% (confirmed real muons)
- Fake confirmation: 17%
- By losing 7% of real muons
- Reduce 83% of fake muons
- Threshold is adjustable to trigger demands
- New electronics system to fully digitize/process the muon readout

Muon trigger assisted by calorimetry: before the Phase-II upgrade

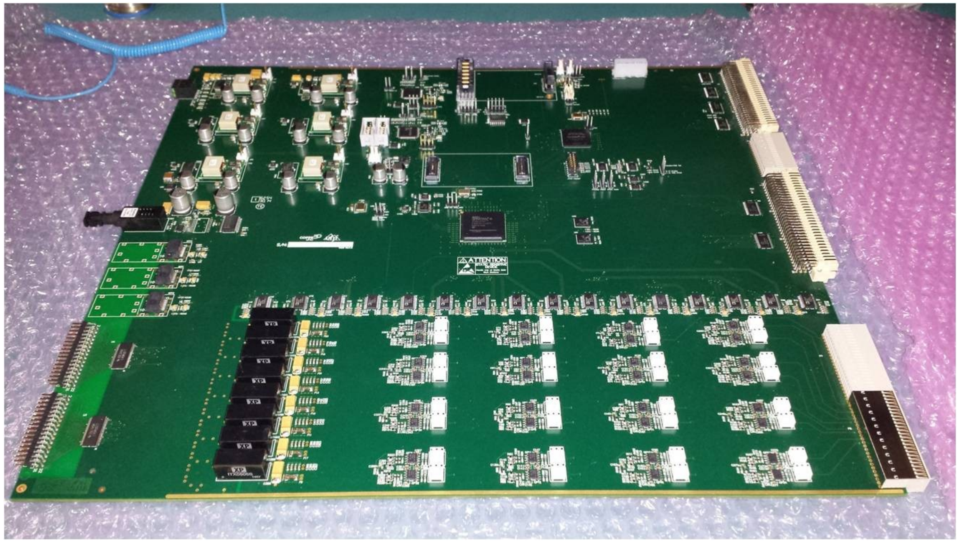
Overview of the electronic system



- TileCal Extended Barrel: 64 modules for each side – 128 modules
- For each module: D5(L & R) e D6(L & R)
- 512 channels
- L1Muon electronics: TGC-Sector Logic
- 48 TGC-Sector Logic
  - New FPGA RTL coding
- TMDB (Tile-Muon Digitizer Board)
  - 32 channels (matched filtering & detection)
  - 16 TMDB boards

Muon trigger assisted by calorimetry: before the Phase-II upgrade

The TMDB (Tile Muon Digitizer Board)

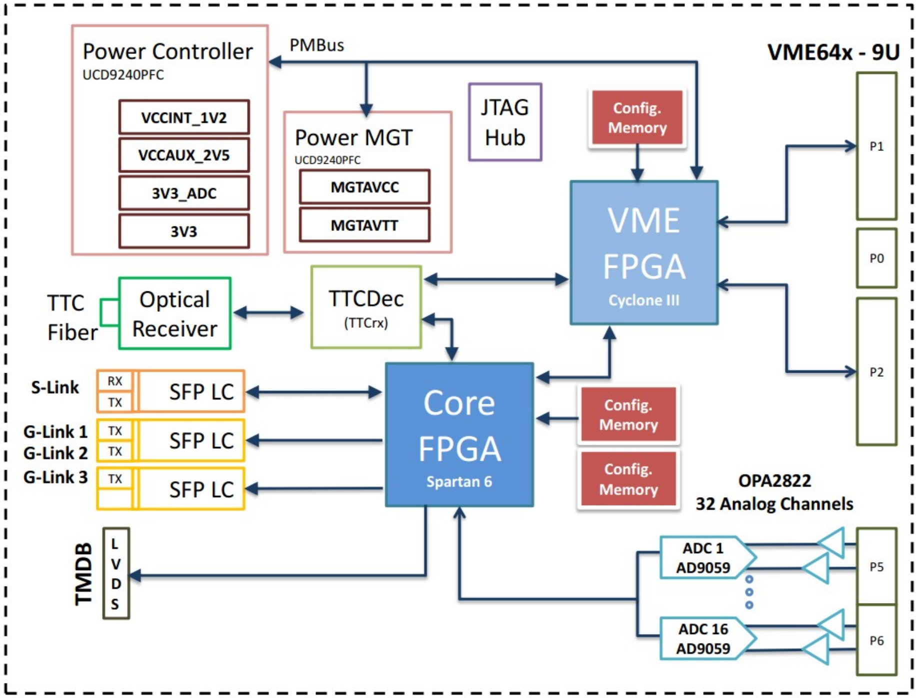


- VME64x, 9U standard
- FPGA based (core processing, VME interface)
- G-Link (x3): 800 Mbps each (TGC-SL)
- S-Link: 2,0 Gbps (ROS)
- Optical receiver and decoder for the TTC
- PCB: 16 layers (density and signal integrity)
- Designed and assembled in Brazil
  - UFRJ
  - UFJF
  - Private companies (PCB manufact. & assembly)

Muon trigger assisted by calorimetry: before the Phase-II upgrade

ATLAS EXPERIMENT

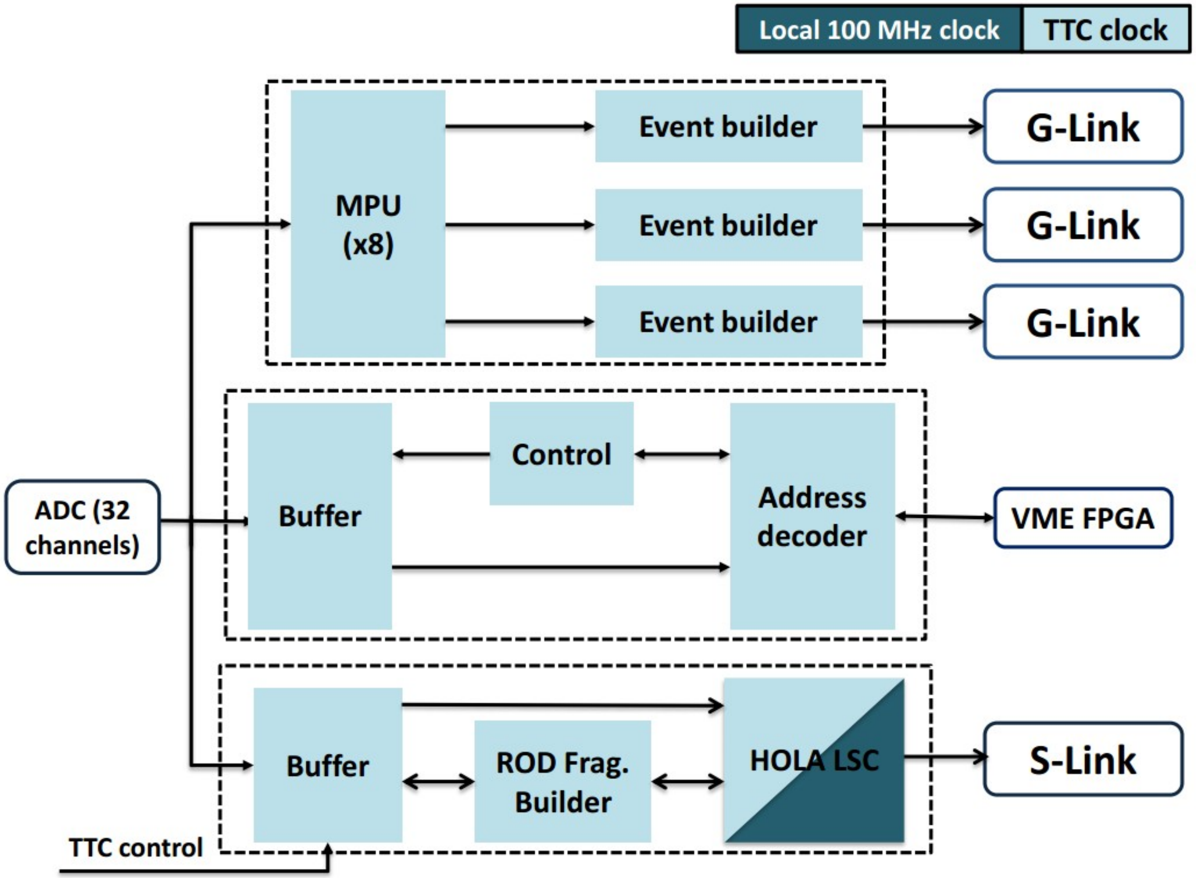
The TMDB (Tile Muon Digitizer Board)



- A/D conversion channels (x32)
  - 3 stages
    - Transformer coupled buffer
    - RC passive filter – f_{-3dB} = 20 MHz
    - Attenuator (ADC dynamic range)
- Core FPGA
  - Processing
    - Matched filtering
    - Detection
  - GTP Transceivers
    - G-Link (TGC-Sector Logic)
    - S-Link (ATLAS ROS)
- VME FPGA
  - VME bus interface
  - Registers configuration
  - FPGA programming through VME

Muon trigger assisted by calorimetry: before the Phase-II upgrade

Digital circuits synthesized in the Core FPGA



Muon trigger assisted by calorimetry: before the Phase-II upgrade

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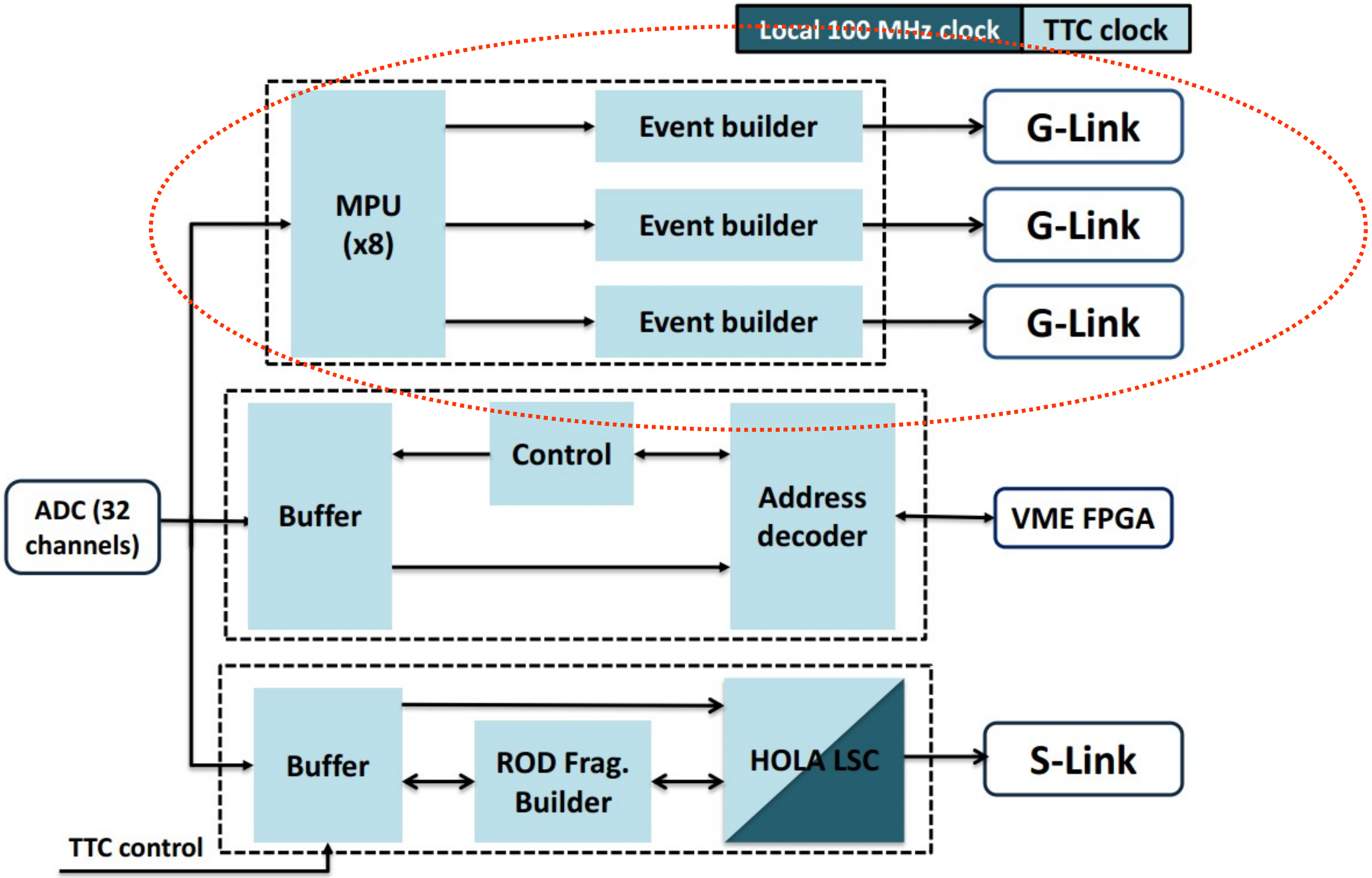

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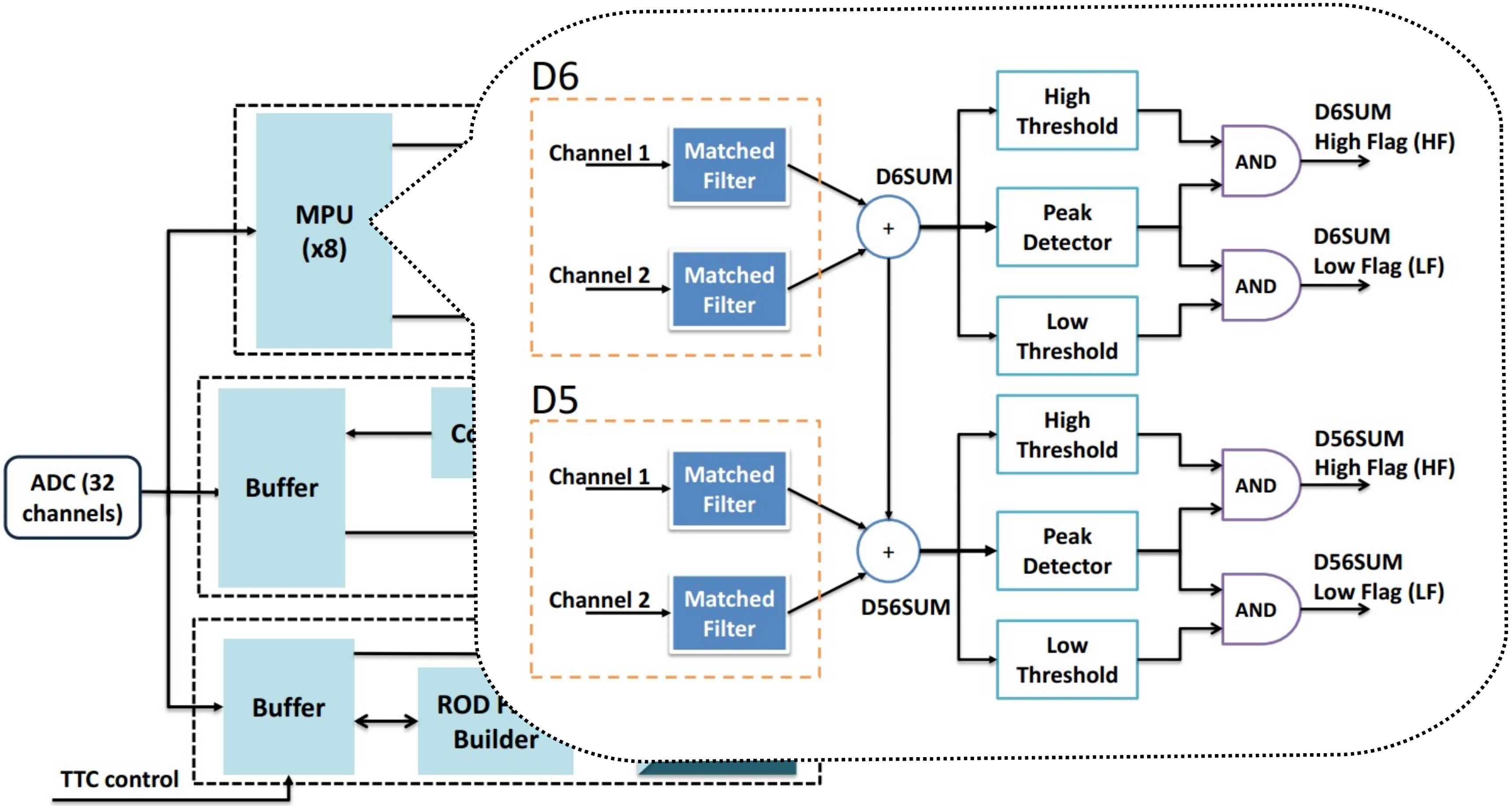

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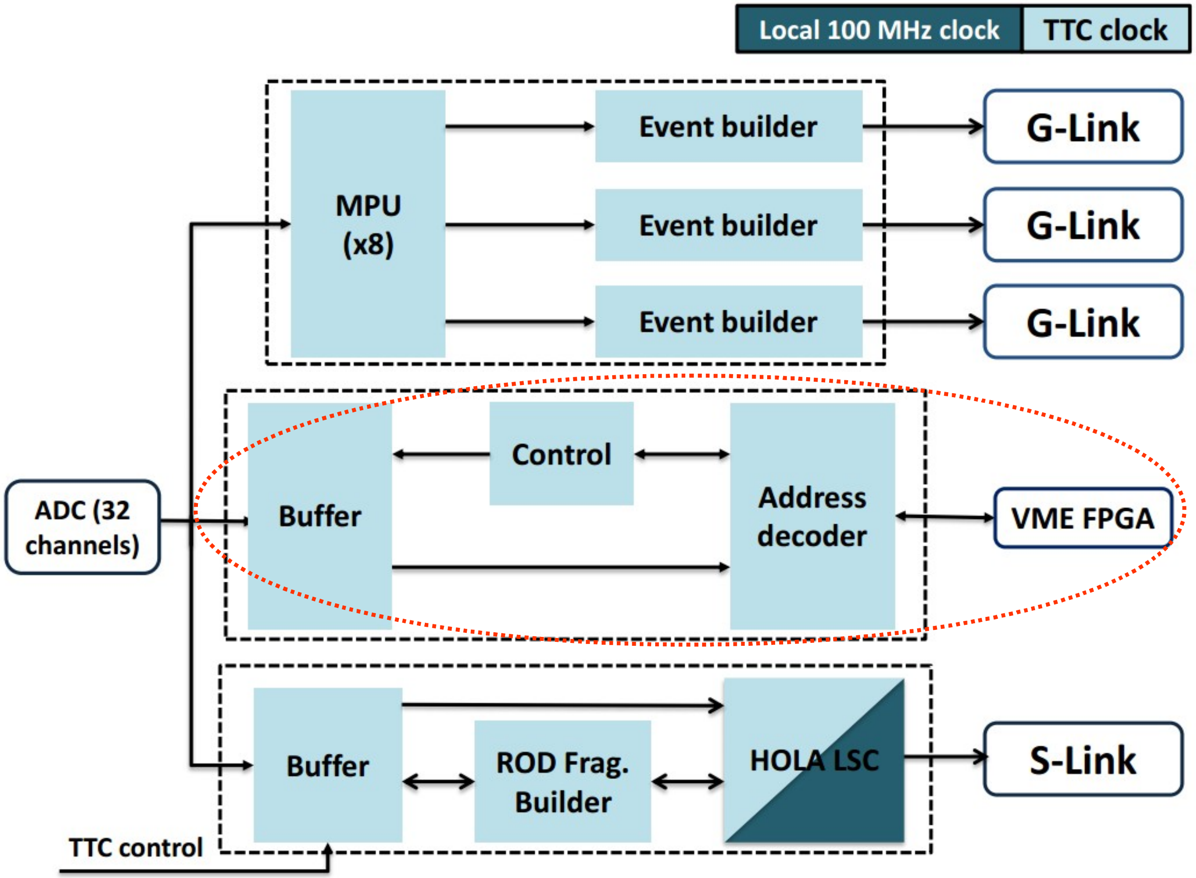

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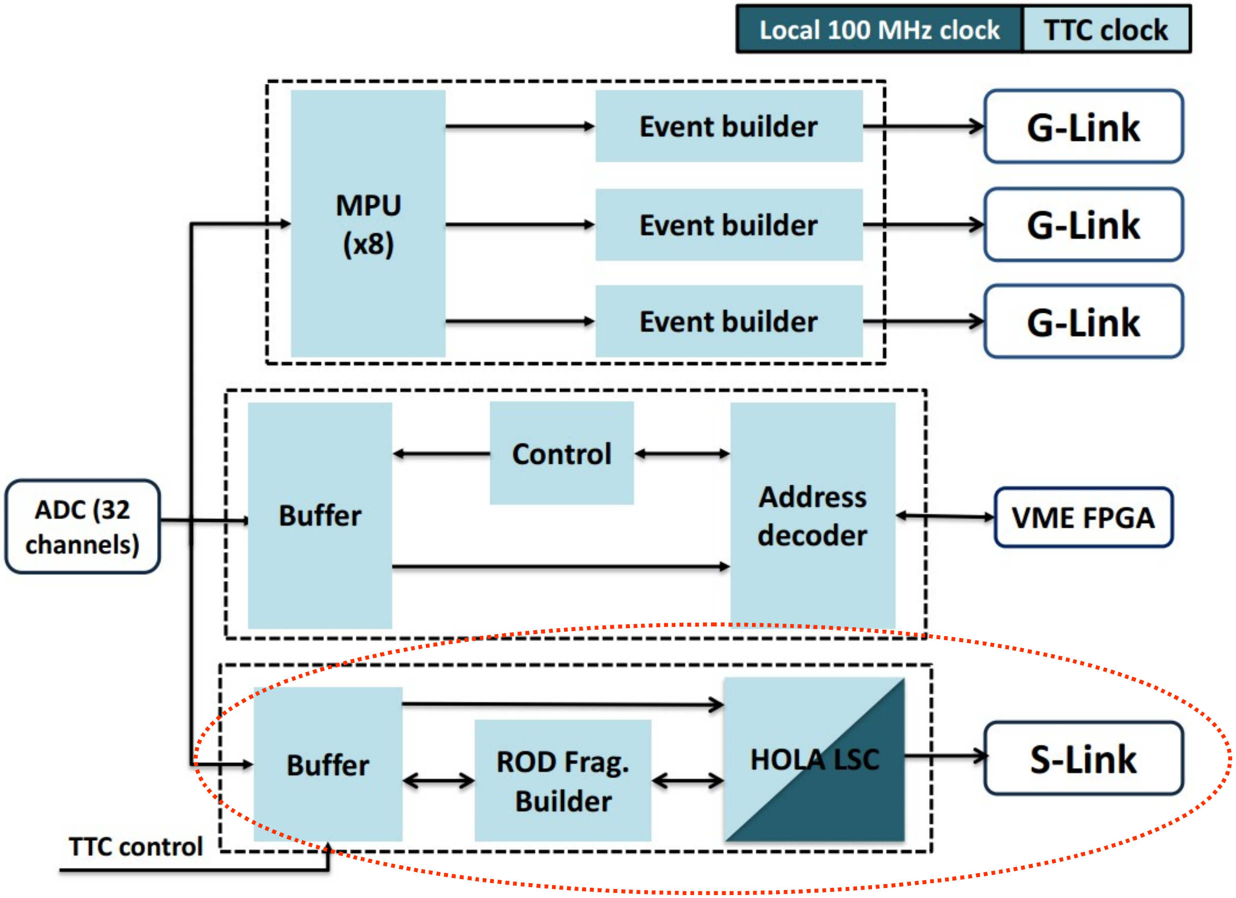
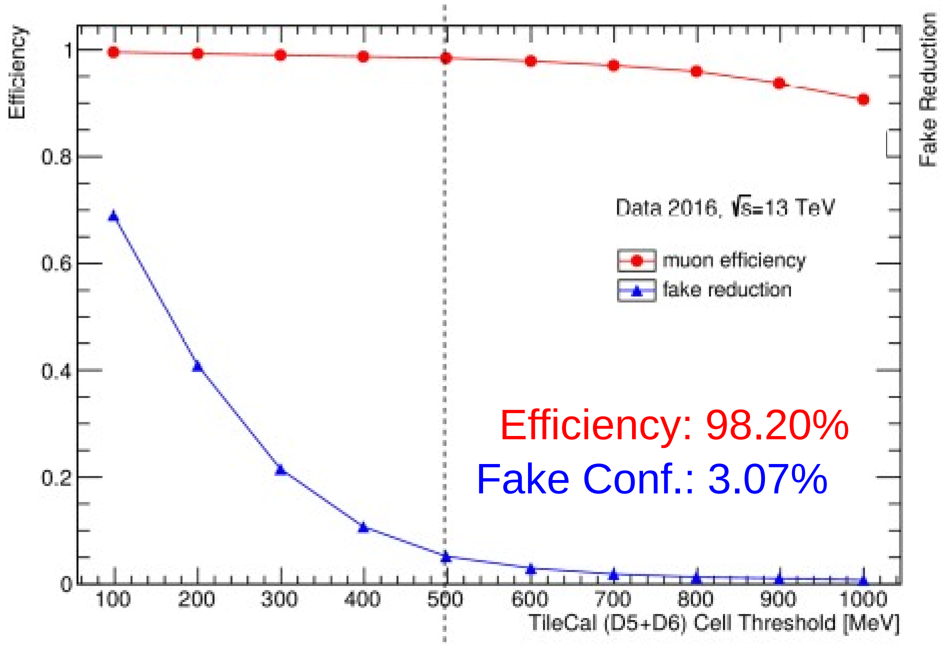


Muon trigger assisted by calorimetry: before the Phase-II upgrade

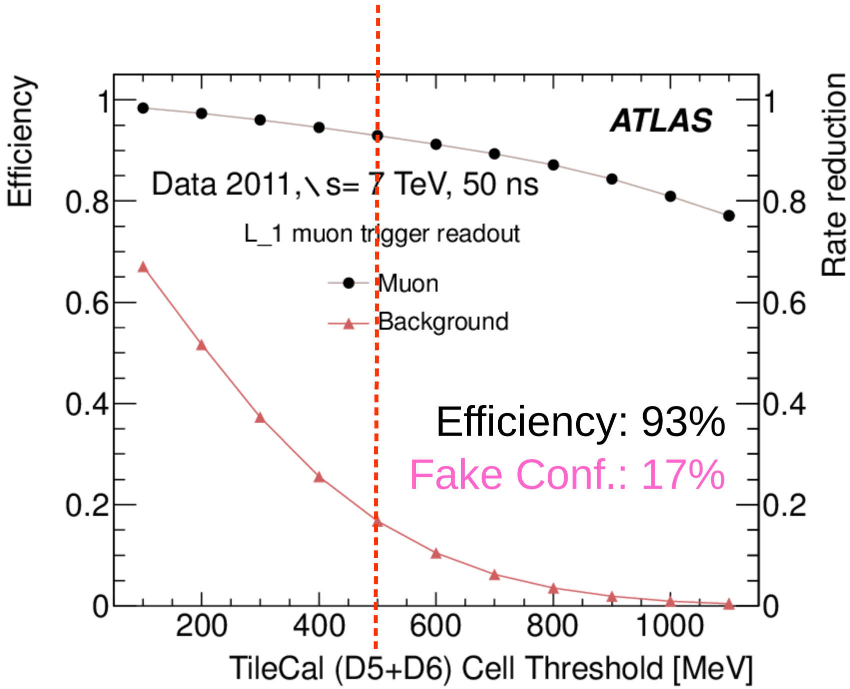
Commissioning performance

Commissioning



D. O. Gonçalves

Preliminary Result (2011 data)



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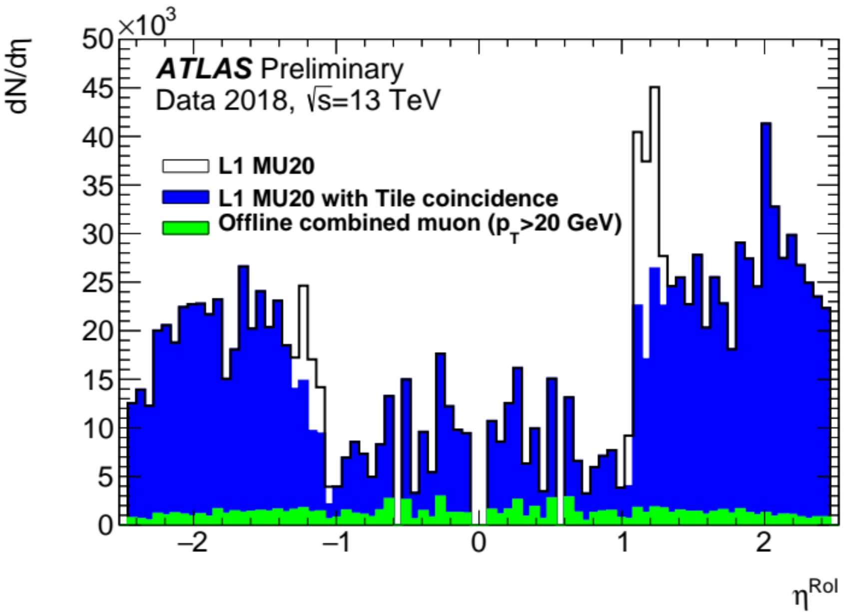
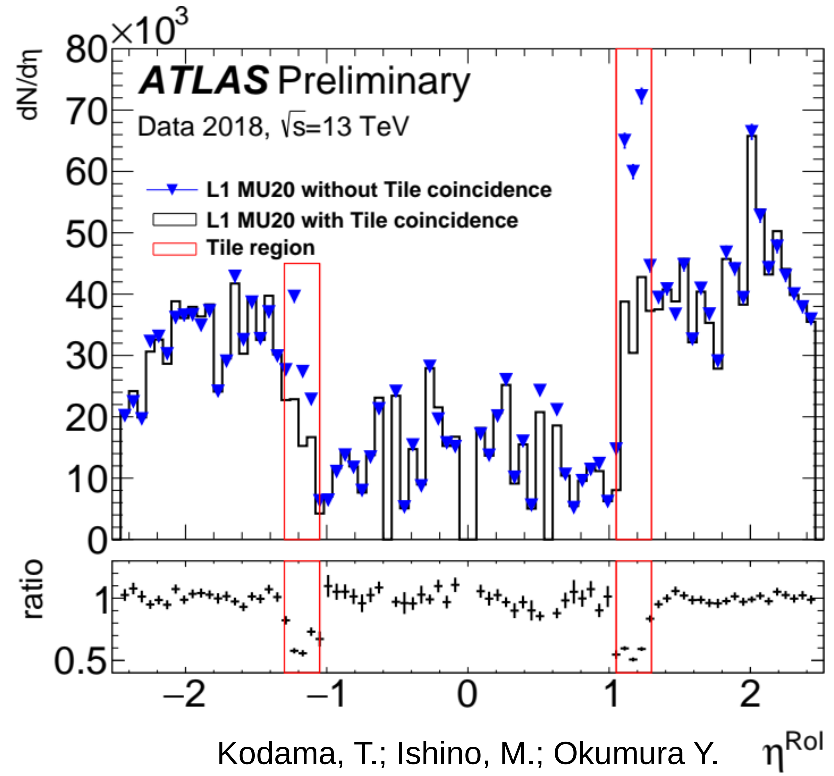
Muon trigger assisted by calorimetry: before the Phase-II upgrade

Run 2 performance



Kodama, T.; Ishino, M.; Okumura Y.
(The University of Tokyo)



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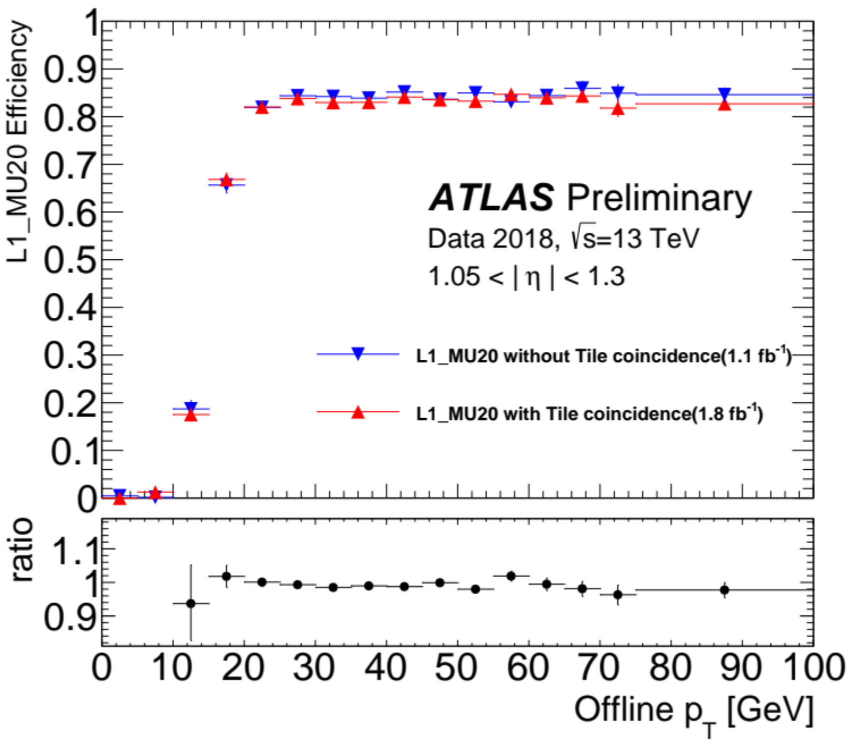

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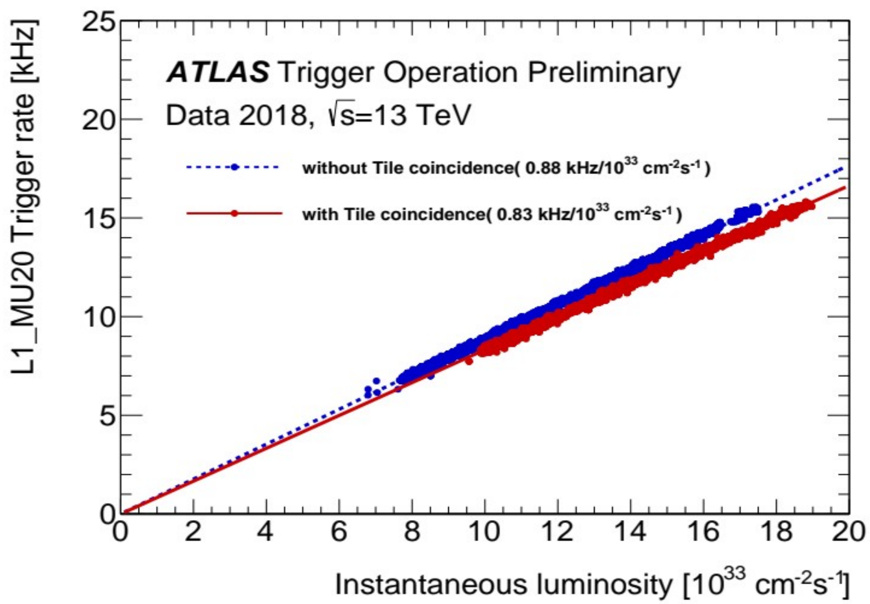

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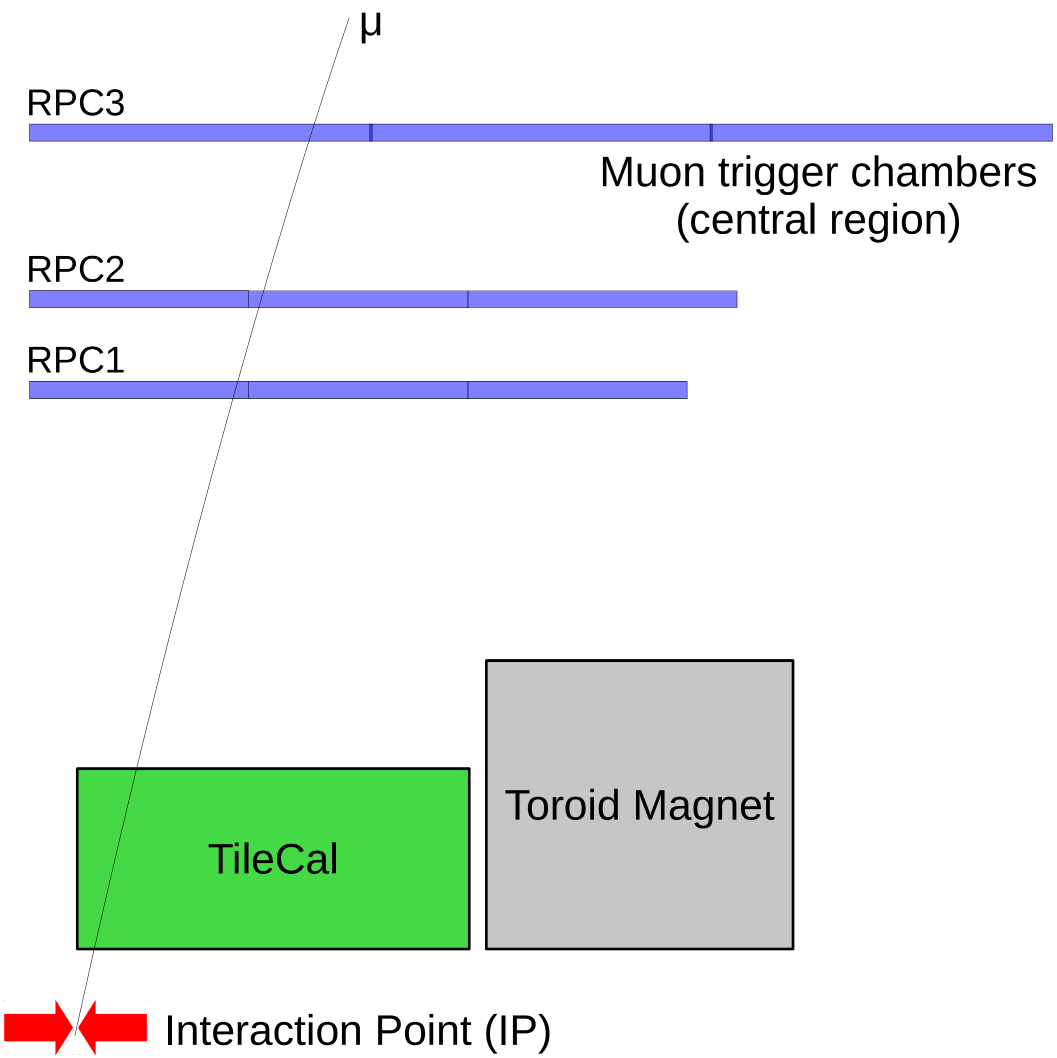
Muon trigger assisted by calorimetry: after the Phase-II upgrade

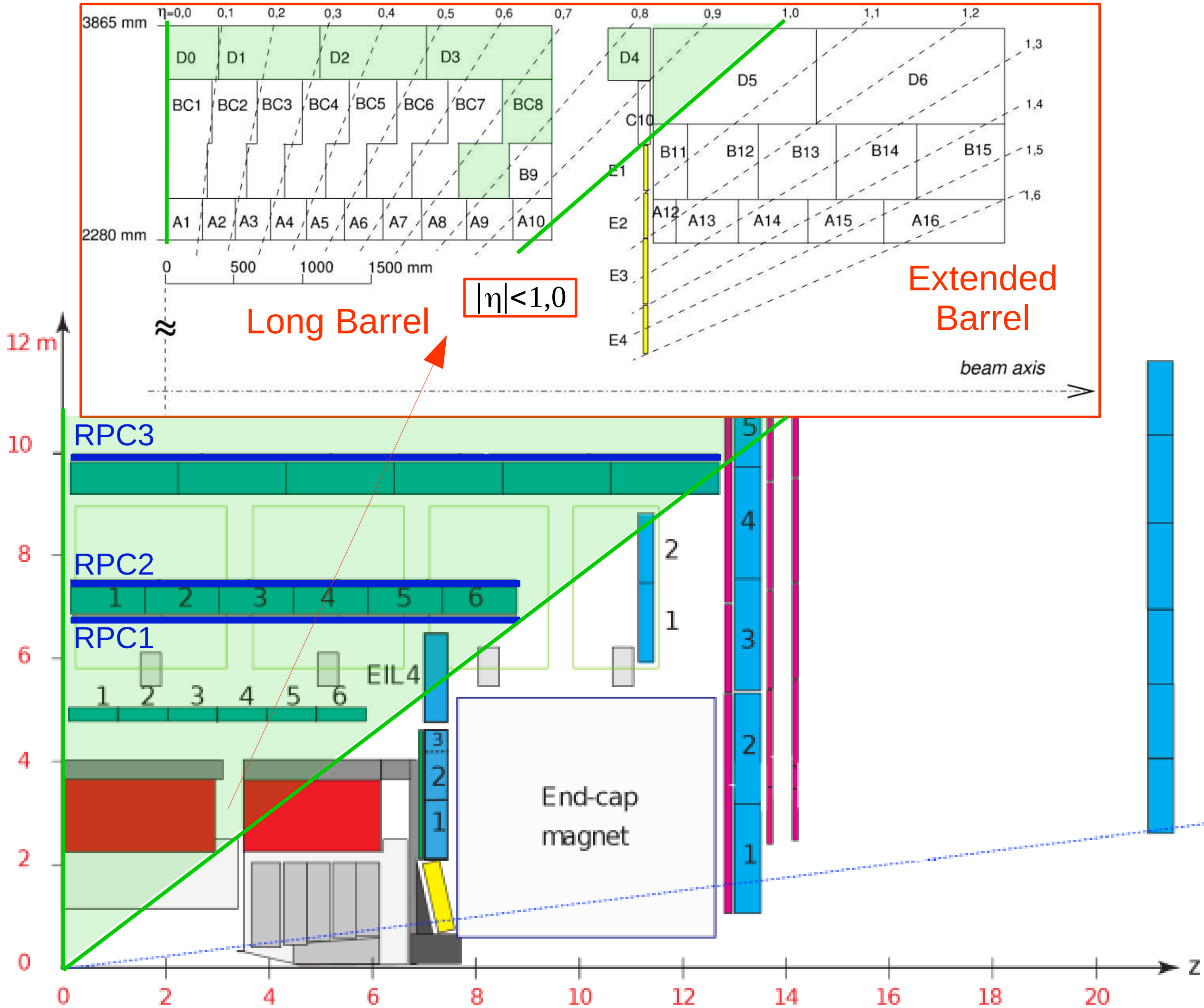
Increase the muon detection efficiency in the central region



- Discontinuities on the muon trigger chambers of the central region
  - Efficiency limit
- L1Muon requires a muon hit coincidence on 3 layers of chambers
- Most of the mechanical discontinuities: RPC1 and RPC2
- Combine the information
  - RPC3 chambers
  - TileCal D cells
- Detect muons on both TileCal LB and EB (small part)

Muon trigger assisted by calorimetry: after the Phase-II upgrade

Detecting muons in the TileCal for the ATLAS central region



Muon trigger assisted by calorimetry: after the Phase-II upgrade

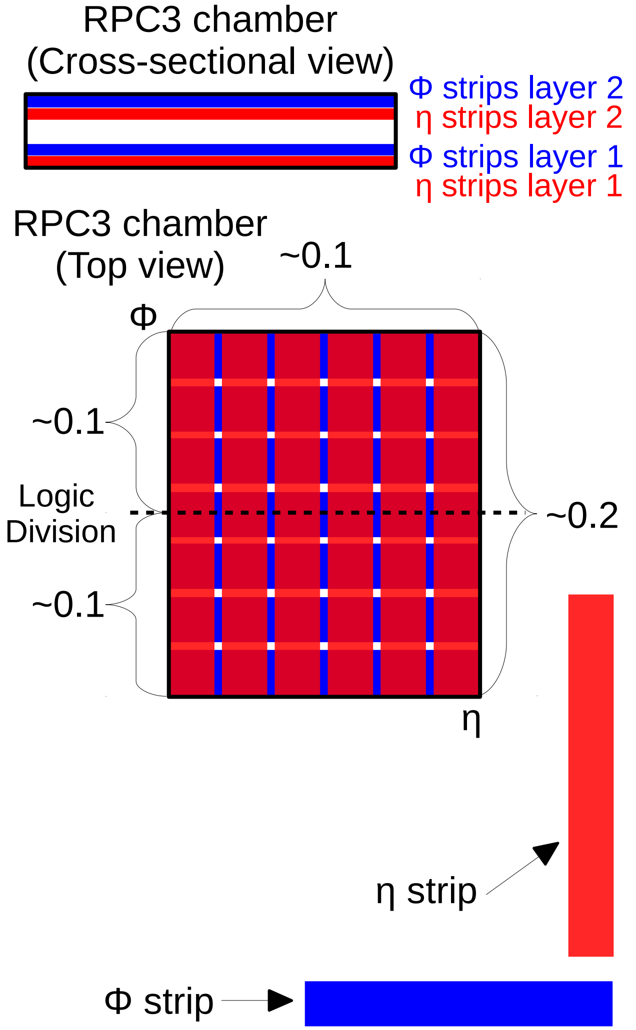
TileCal readout electronics after the phase-II upgrade

- Phase-II upgrade: New TileCal electronics
  - Digital channel dedicated to the trigger system
    - Electronic noise for the digital channel (RMS): ~20 MeV (or better)
    - Electronic noise for the current muon analog channel (RMS): 200 MeV
    - Previous study: muon detection in very difficult in the LB with the analog channel
- The current TileCal default readout has an electronic noise of ~20 MeV
  - Enabling the analysis that is going to be presented

Muon trigger assisted by calorimetry: after the Phase-II upgrade

Detecting muons using only the RPC3 (RPC3 trigger)

- Goal: exclude RPC1 and RPC2 participation
- Based on the muon hit coincidence for different layers within a RPC3 chamber
- Vertical strips (red): measure the η coordinate
- Horizontal strips (blue): measure Φ the coordinate
- Strips superposition: enables the measurement of the muon and coordinates
- RPC3 chamber dimensions: ~0.1 x ~0.2 [η x Φ]
- L1Muon resolution: ~0.1 x ~0.1 [η x Φ]
- Logic division for the Φ direction
  - To get the same L1Muon resolution
    - We consider an RPC3 chamber as 2 Logic Regions of ~0.1 x ~0.1 [η x Φ]



Muon trigger assisted by calorimetry: after the Phase-II upgrade

ATLAS EXPERIMENT

RPC3 trigger: coincidence methods

➔ Loose

Hit on η layer 1 OR
hit on η layer 2
AND
hit on Φ layer 1 OR
hit on Φ layer 2

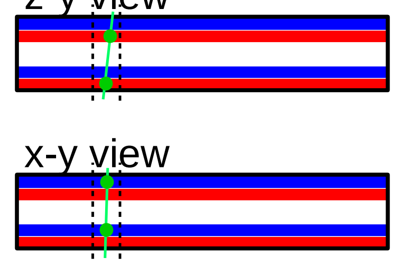
The time difference between hits must be within a window of 1 BC

➔ Medium

Hit on η layer 1
AND
hit on Φ layer 1

The time difference between hits must be within a window of 1 BC

➔ Tight

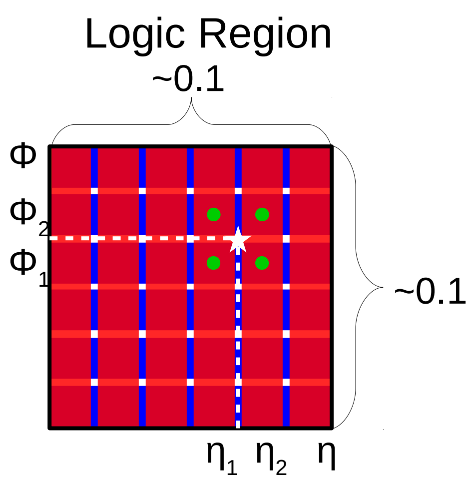


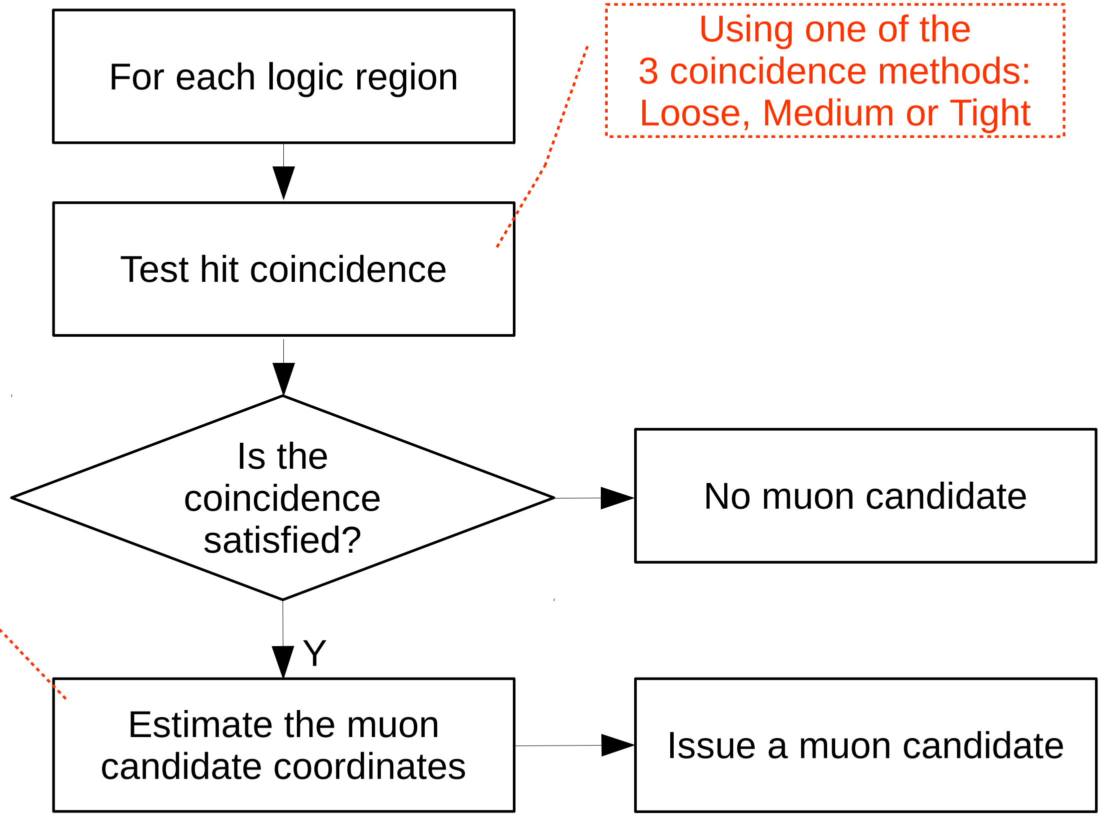
Hit on η layer 1 AND
hit on η layer 2
AND
hit on Φ layer 1 AND
hit on Φ layer 2

The time difference between hits must be within a window of 1 BC

Muon trigger assisted by calorimetry: after the Phase-II upgrade

RPC3 trigger: algorithm





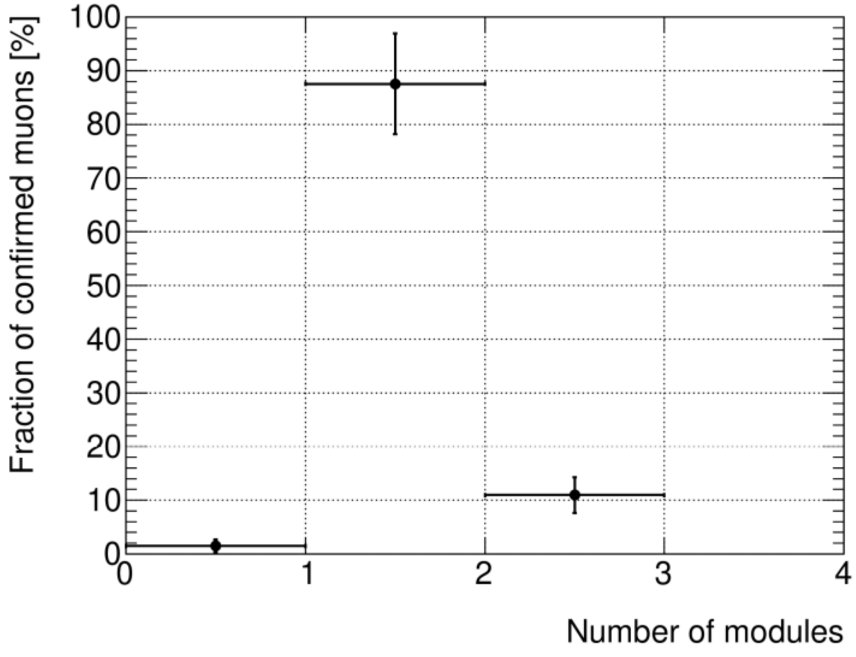
$$\eta = \frac{1}{N} \sum_{i=1}^{N} \eta_i$$

$$\phi = \frac{1}{M} \sum_{j=1}^{M} \phi_i$$

Muon trigger assisted by calorimetry: after the Phase-II upgrade

Geometry matching

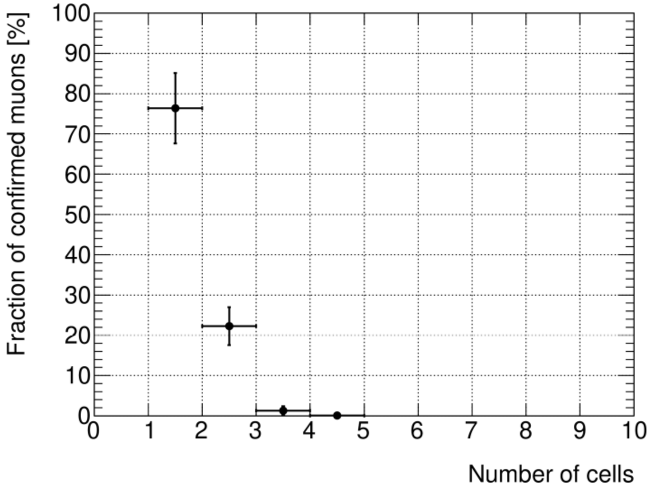
- Where in the TileCal does a muon candidate pass through?
- Different geometries
- There is no direct relation between modules/cells and chambers
- For the Φ direction
  - Simulated muons (p_T > 15 GeV)
    - ~88% hit 1 modules
    - ~11% hit 2 modules
    - ~1% hit a disabled module in the simulation
- Region of up to 2 modules

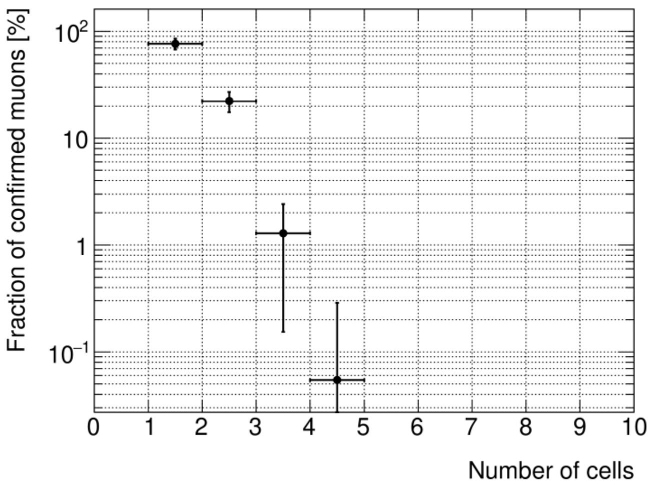


Muon trigger assisted by calorimetry: after the Phase-II upgrade

Geometry matching

- For the η direction
  - There is no direct relation: cells/chambers
  - Toroid magnetic field
  - Simulated muons (p_T > 15 GeV)
    - ~76% hit 1 cell per module
    - ~22% hit 2 cells per module
    - ~1,95% hit 3 cells per module
    - ~0,05% hit 4 cells per module
  - Region of up to 2 cells

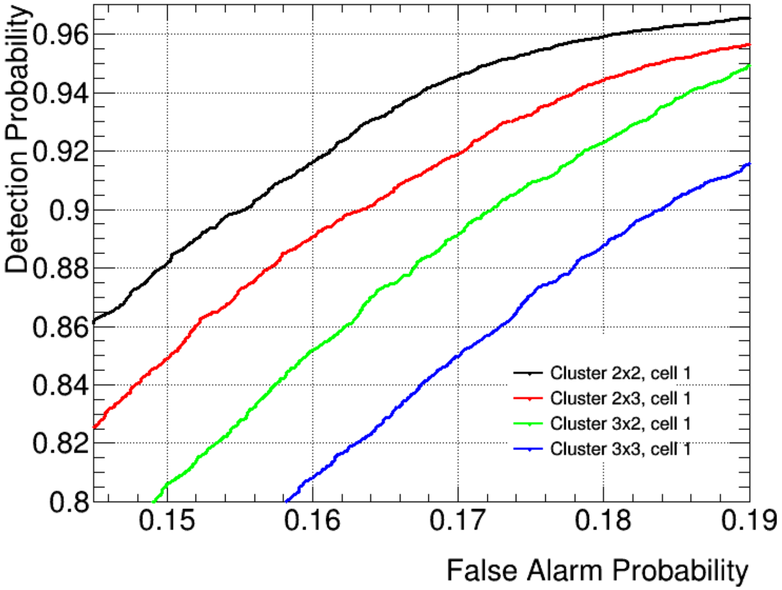




Muon trigger assisted by calorimetry: after the Phase-II upgrade

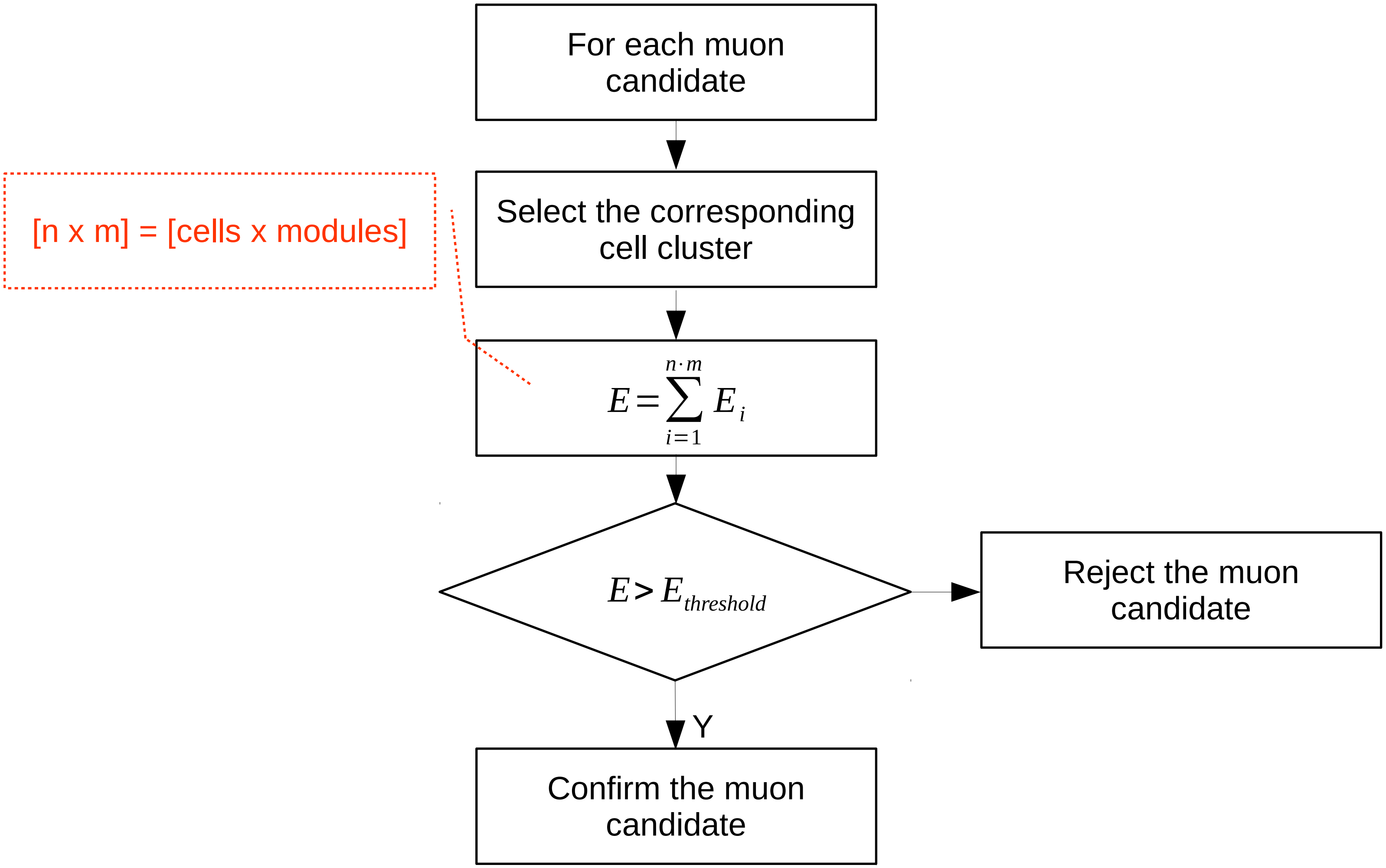
Geometry matching

- Muon candidate: hits up to 2 x 2 [cells x modules]
- Solenoid magnetic field influence in Φ
- Toroid magnetic field influence in η
- We tested the following regions (clusters)
  - 2 x 2 [cells x modules]
  - 2 x 3 [cells x modules]
  - 3 x 2 [cells x modules]
  - 3 x 3 [cells x modules]
- Best performance: with the 2 x 2 cluster



Muon trigger assisted by calorimetry: after the Phase-II upgrade

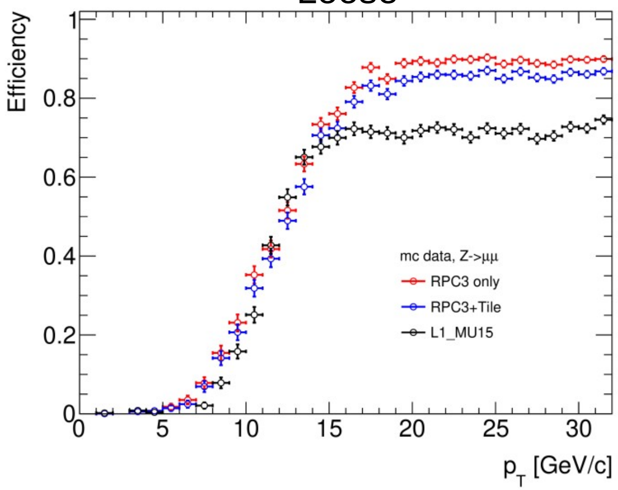
Muon candidate confirmation with TileCal: RPC3+Tile trigger



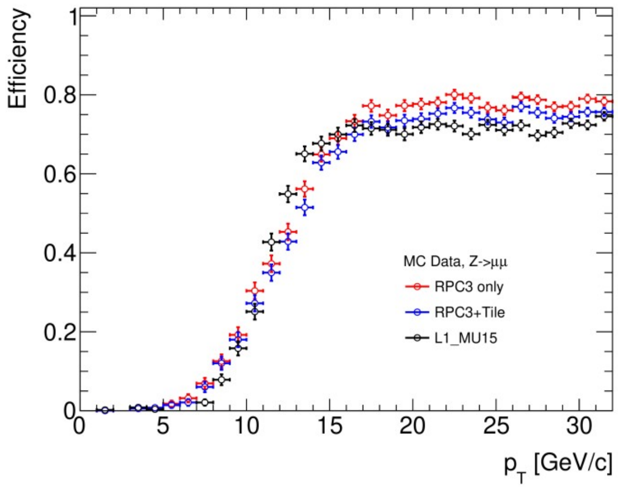
Muon trigger assisted by calorimetry: after the Phase-II upgrade

Performance: Turn-on curves

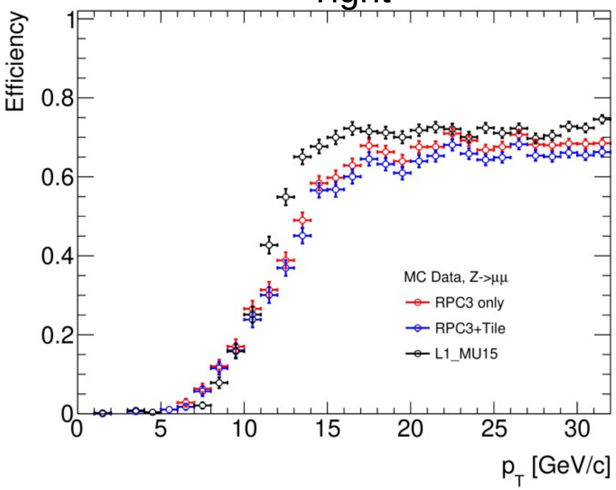
Loose



Medium

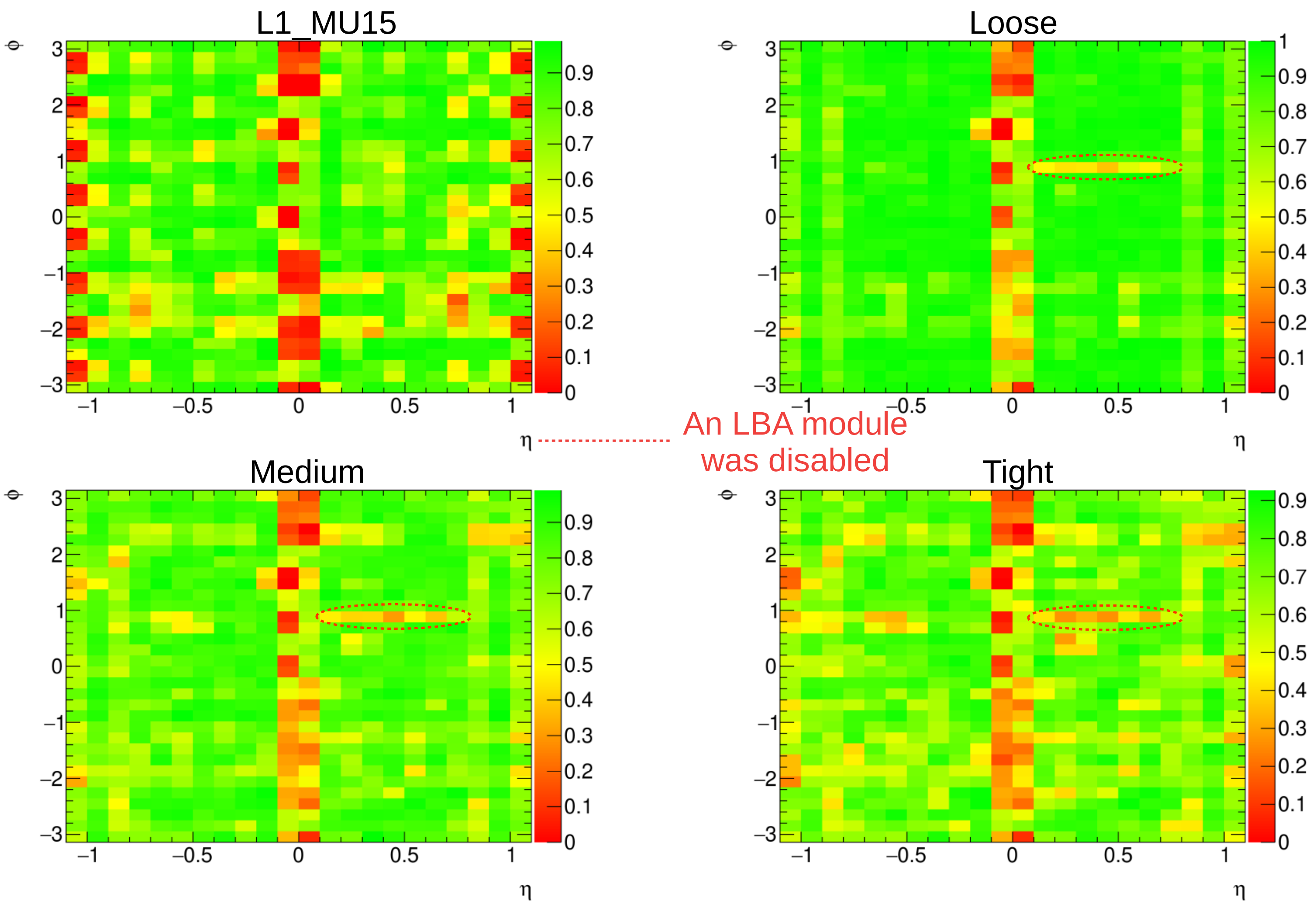


Tight



Muon trigger assisted by calorimetry: after the Phase-II upgrade

Efficiency Map



Muon trigger assisted by calorimetry: after the Phase-II upgrade

RPC3+Tile Performance

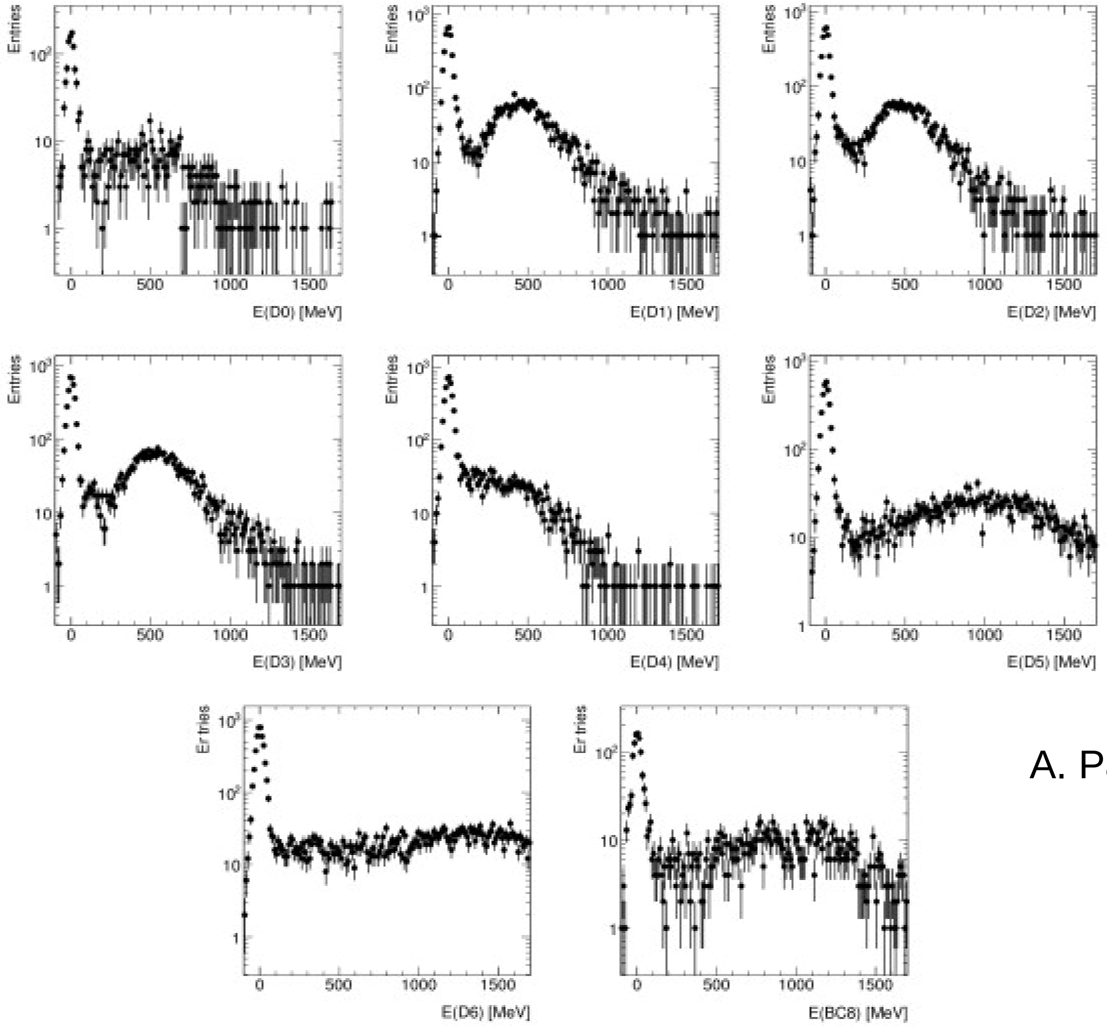
Trigger	Det. Rate [%]	False Rate [%]
RPC3+Tile loose	90,91	6,68
RPC3+Tile medium	83,16	4,97
RPC3+Tile tight	73,59	2,73
L1_MU15	77,90	2,93

Conclusion & Outlook

- Increase of the LHC luminosity
  - Big challenge to ATLAS
  - Trigger system
- Muon trigger assisted by calorimetry before the Phase-II upgrade
  - Current results (Run 2, 2018): Tile-Muon behaves as expected
    - Reduces the fake muon rate with a minor efficiency impact
  - Preparation for Run 3
    - Muon trigger electronics: New TGC-Sector Logic board
    - TMDB: G-Link @ 800 Mbps → Aurora based (8b/10b) @ 1.6 Gbps
- Muon trigger assisted by calorimetry after the Phase-II upgrade
  - RPC3+Tile trigger: increase efficiency for the central region
  - Continue the study: more suitable dataset (characteristics after the Phase-II upgrade)
    - Student from UFRJ working on this

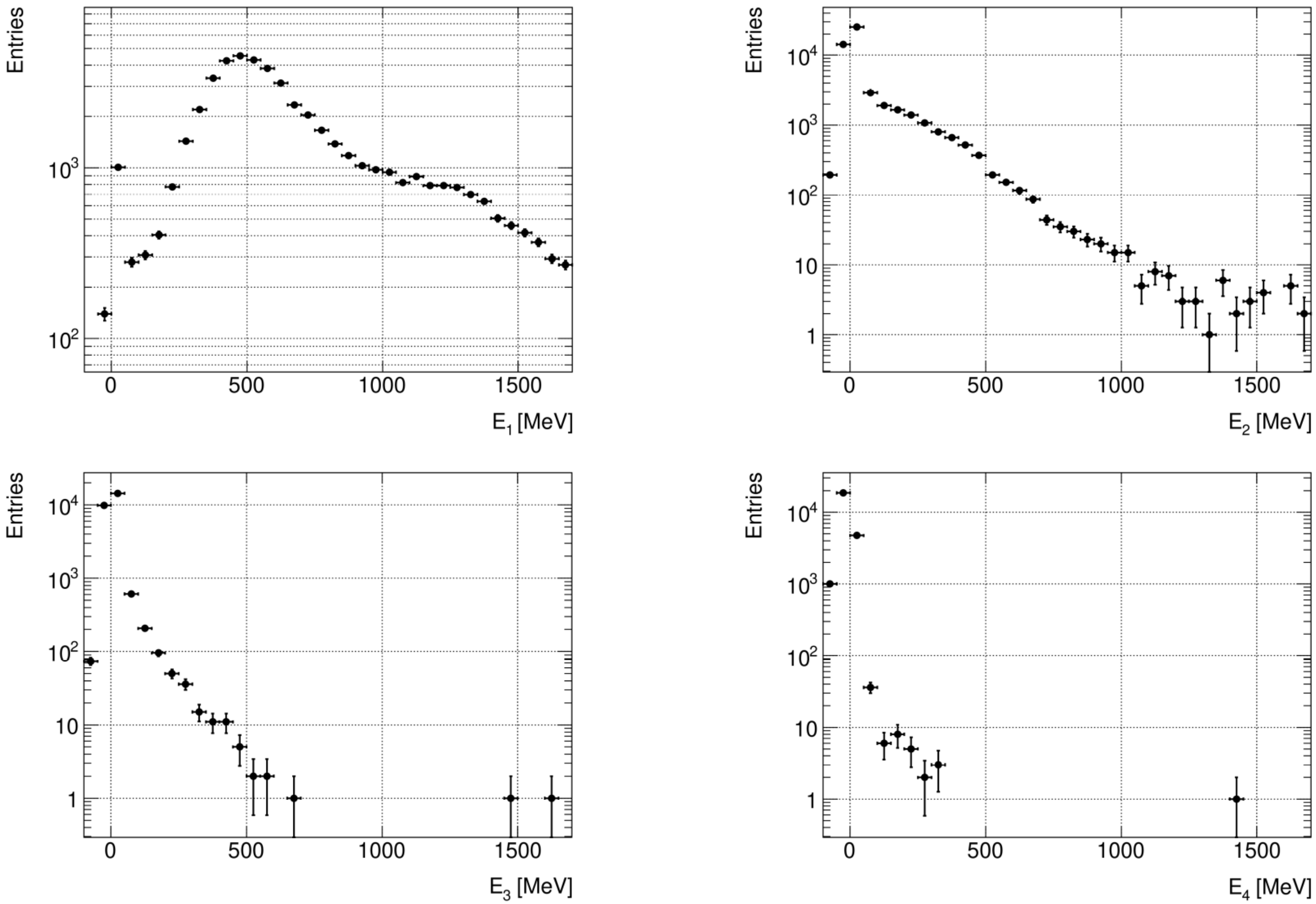
BACKUP

TileCal cell muon energy deposition profile (p_T > 15 GeV)



A. Paramonov

TileCal cluster muon energy deposition profile



RPC3 only vs RPC3+Tile Performance

Trigger	*DP* [%]	*FP* [%]	*SP* [%]
RPC3 *loose*	95,00	37,50	77,90
RPC3+Tile *loose*	90,91	6,68	92,10
RPC3 *medium*	86,90	27,90	79,30
RPC3+Tile *medium*	83,16	4,97	89,00
RPC3 *tight*	76,90	15,30	80,80
RPC3+Tile *tight*	73,59	2,73	85,00
L1_MU15	77,90	2,93	87,20