The ATLAS High-Level Calorimeter Trigger in Run-2

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On behalf of the ATLAS Experiment

CALOR 2018

UNIVERSITY OF
COPENHAGEN

ATLAS
EXPERIMENT

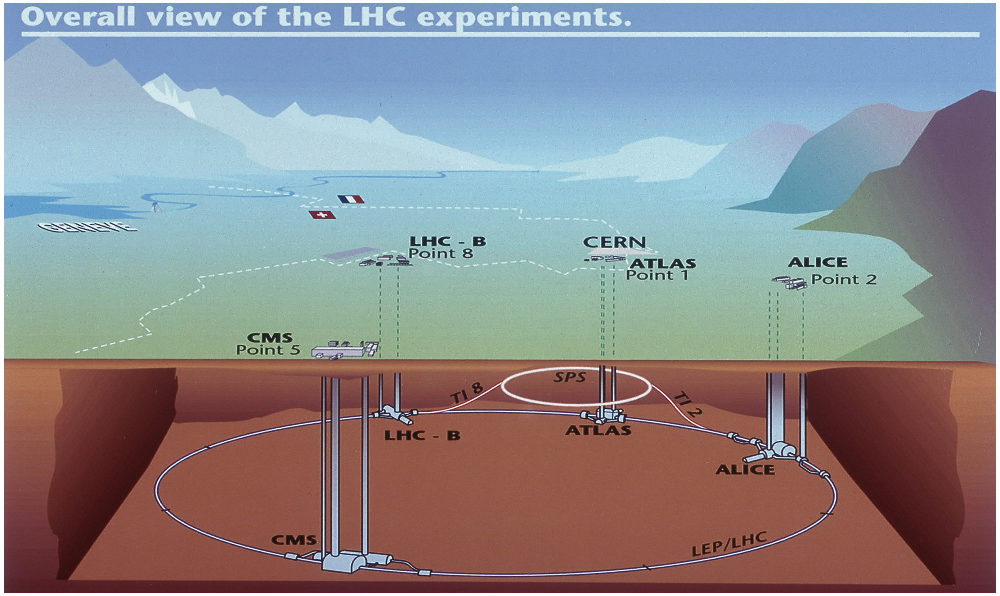
The LHC and The ATLAS Experiment

- The LHC and ATLAS are performing impressively!
- Run-2 (@13 TeV) ends this year
- Peak luminosity of **21.4 x 10^{33} cm^{-2}s^{-1}**

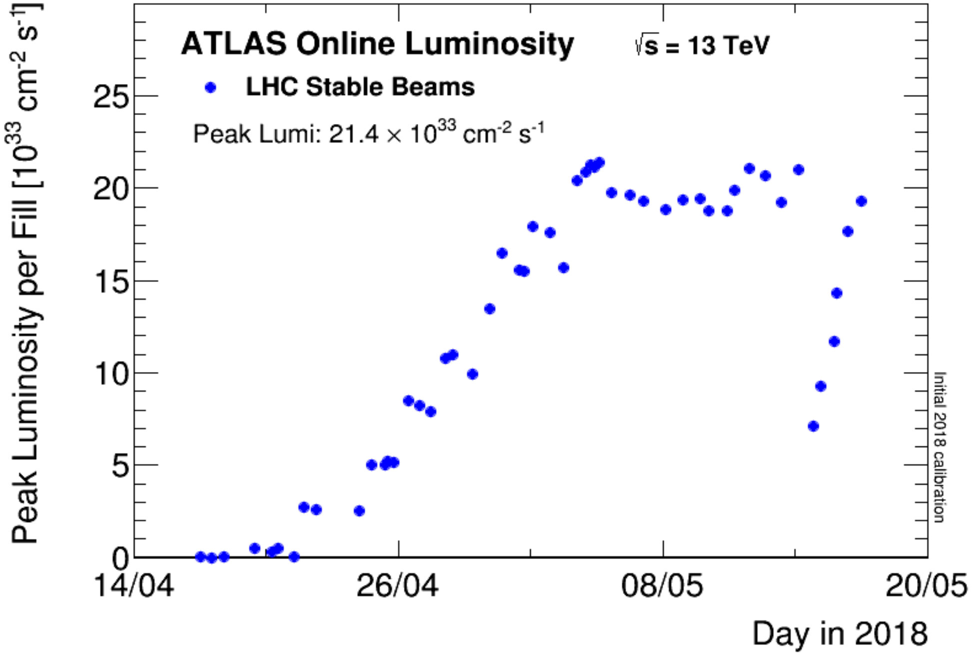
  *> **x2** design luminosity of the LHC!*

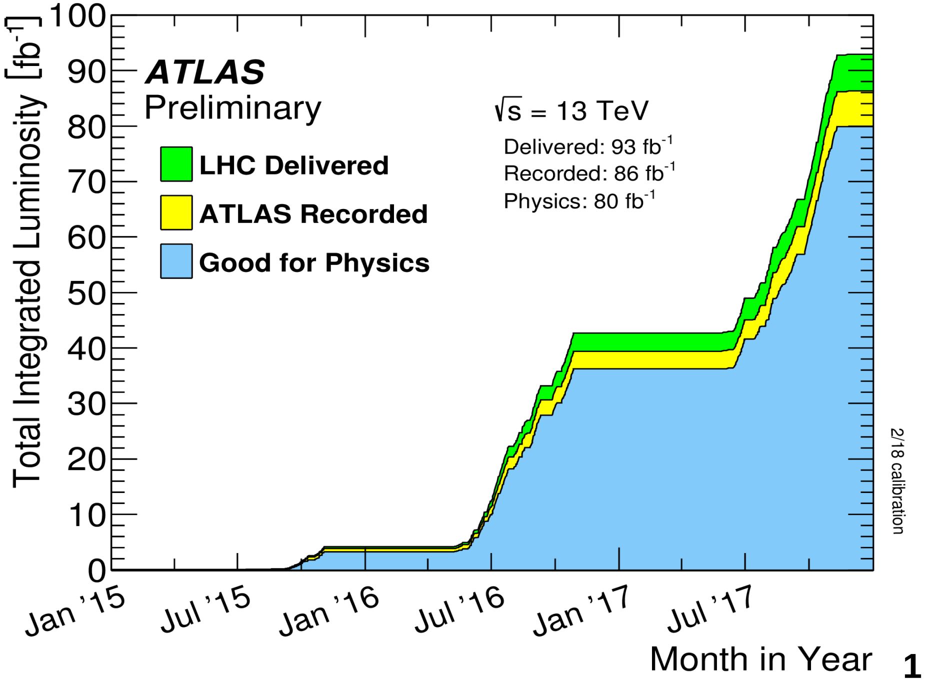
- ATLAS Run-2 physics dataset **~80 fb^{-1}**

  *Targeting **~120 fb^{-1}** by end of Run-2 (2015 - 2018)*

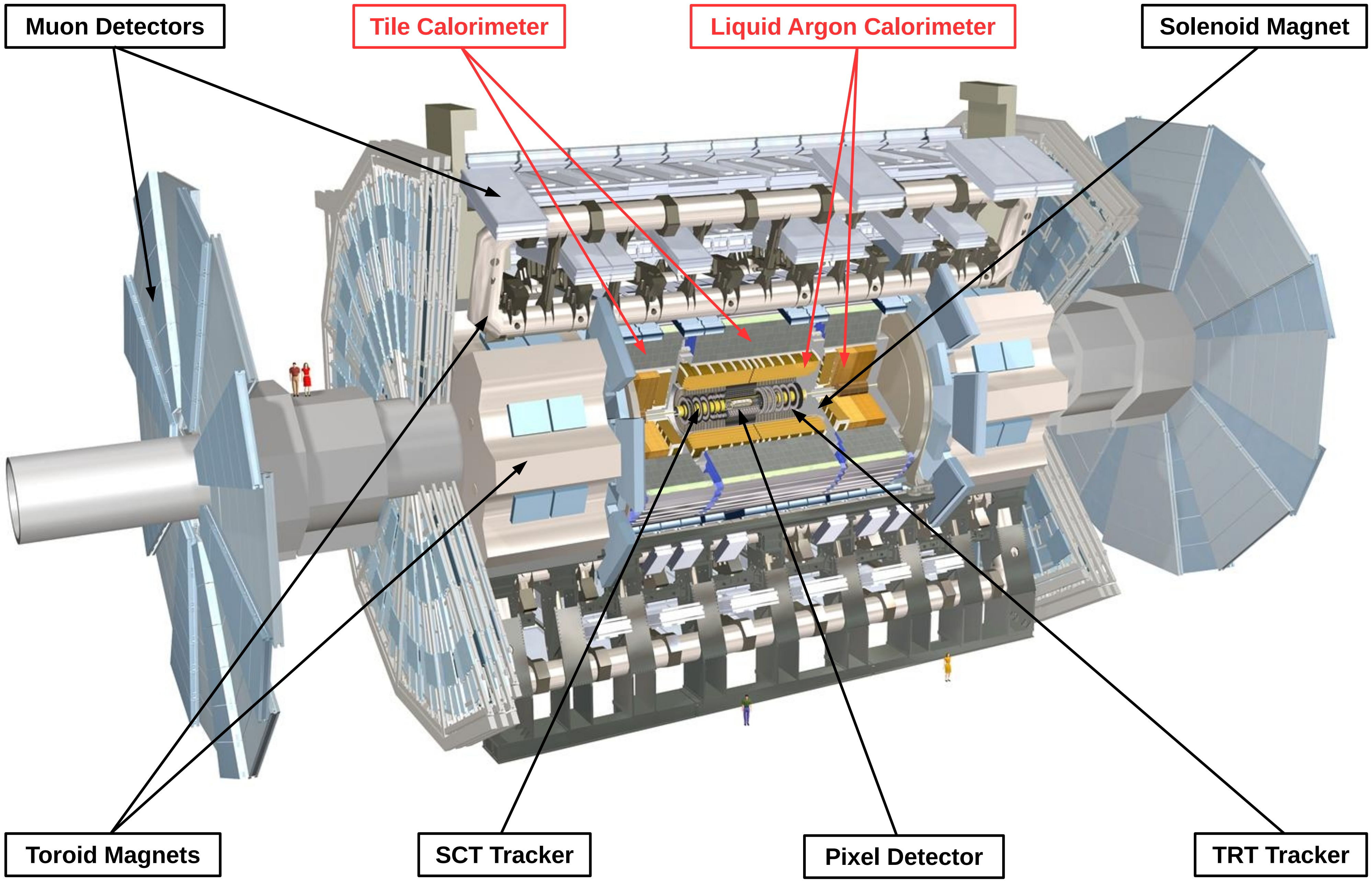


[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2]





The ATLAS Detector



Muon Detectors

Tile Calorimeter

Liquid Argon Calorimeter

Solenoid Magnet

Toroid Magnets

SCT Tracker

Pixel Detector

TRT Tracker

The ATLAS Calorimeters

Electromagnetic (EM) Calorimeter

- Liquid Argon / Lead
- $|\eta| < 3.2$
- 3 Layers (except certain η regions)
- $\Delta\eta \times \Delta\phi \geq 0.025 \times 0.025$

Tile Calorimeter (TileCal)

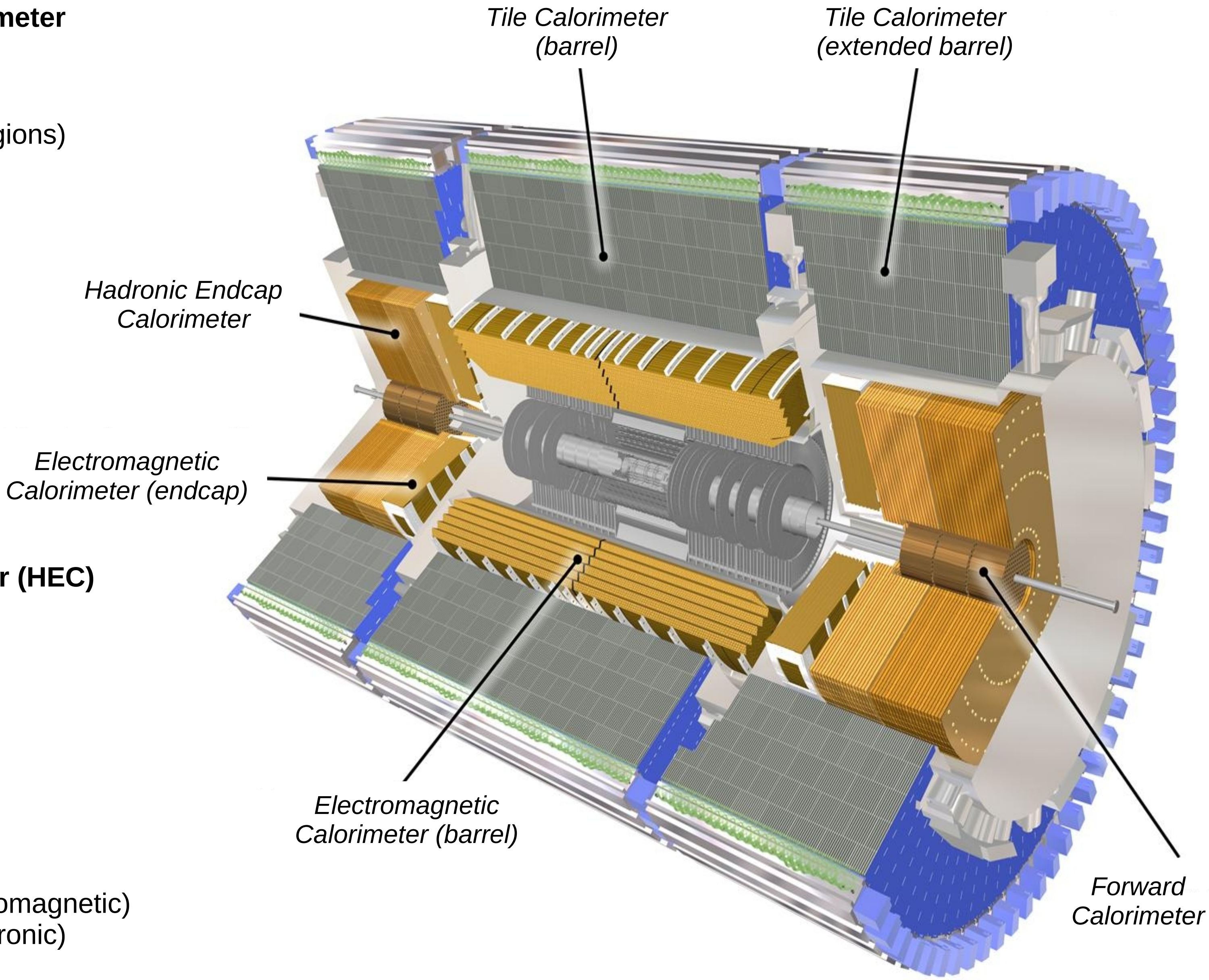
- Plastic Scintillator / Steel
- $|\eta| < 1.8$
- 3 layers
- $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

Hadronic Endcap Calorimeter (HEC)

- Liquid Argon / Copper
- $1.5 < |\eta| < 3.2$
- 4 Layers
- $\Delta\eta \times \Delta\phi \geq 0.1 \times 0.1$

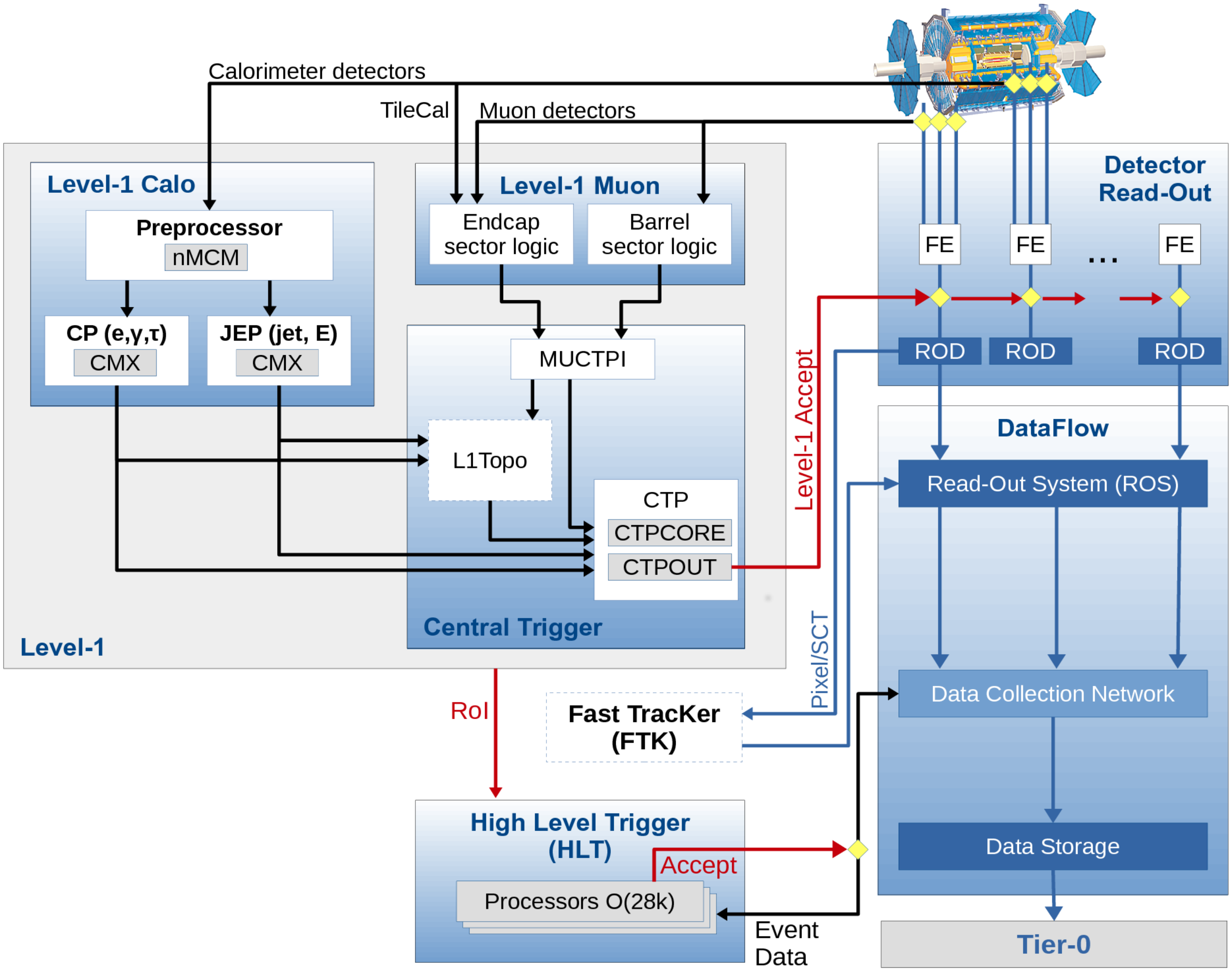
Forward Calorimeter (FCal)

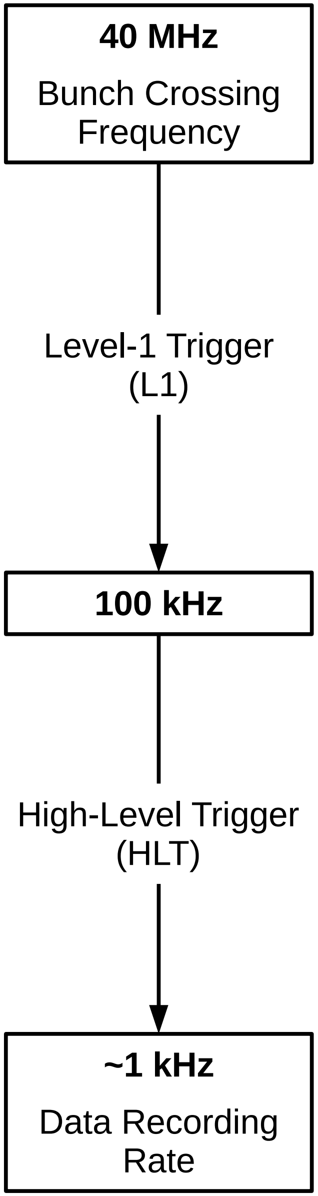
- Liquid Argon / Copper (Electromagnetic)
  Liquid Argon / Tungsten (Hadronic)
- $3.1 < |\eta| < 4.9$
- 3 Layers



The ATLAS Trigger

The ATLAS Trigger is responsible for the online selection of events to be written to disk





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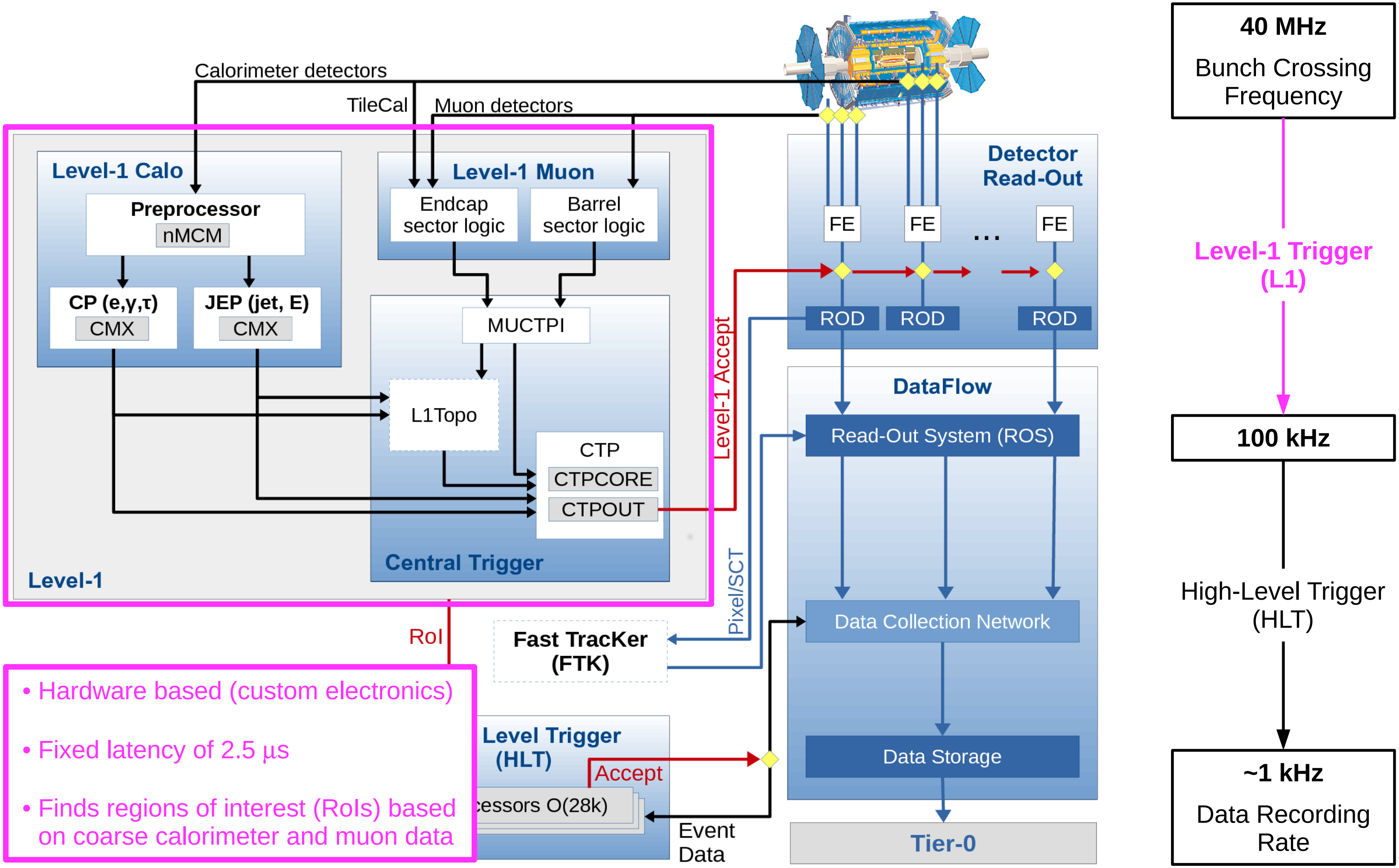

- Hardware based (custom electronics)
- Fixed latency of 2.5 µs
- Finds regions of interest (RoIs) based on coarse calorimeter and muon data

The ATLAS Trigger

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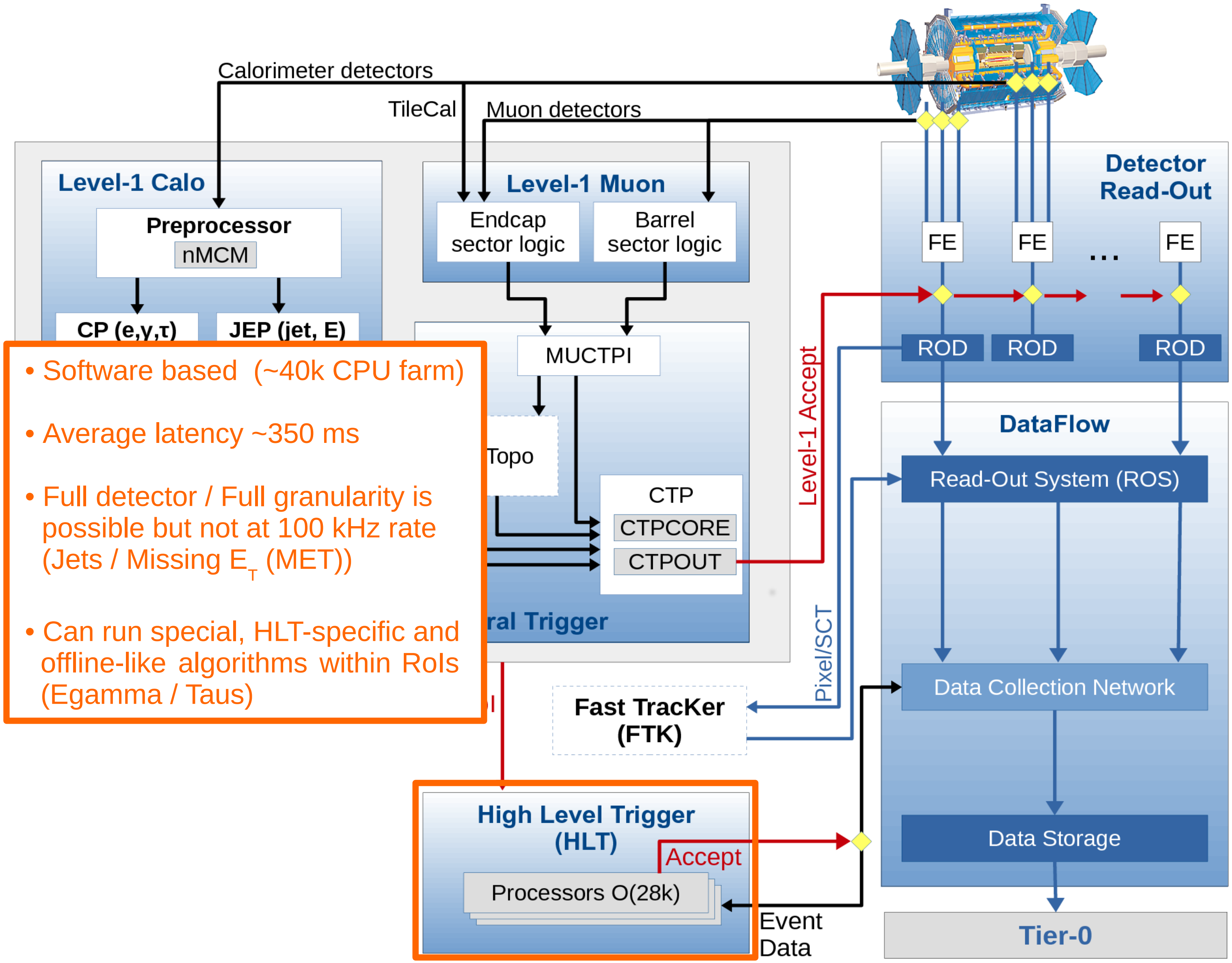
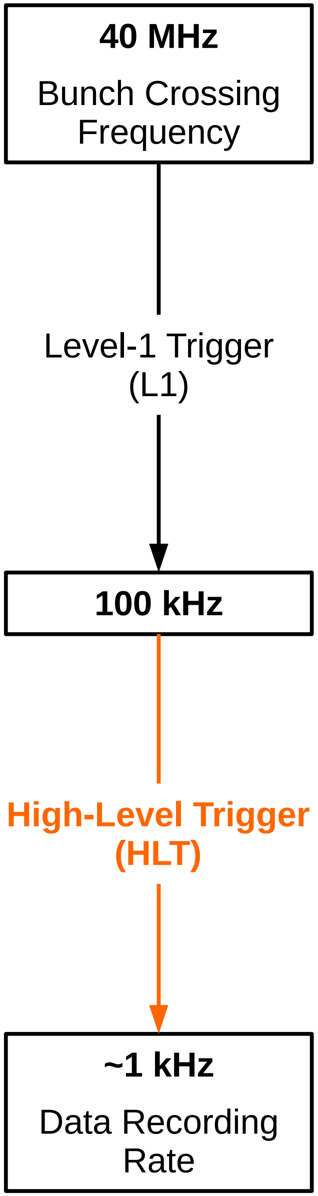


- Software based (~40k CPU farm)
- Average latency ~350 ms
- Full detector / Full granularity is possible but not at 100 kHz rate (Jets / Missing E_T (MET))
- Can run special, HLT-specific and offline-like algorithms within RoIs (Egamma / Taus)



The Challenges for the HLT in Run 2

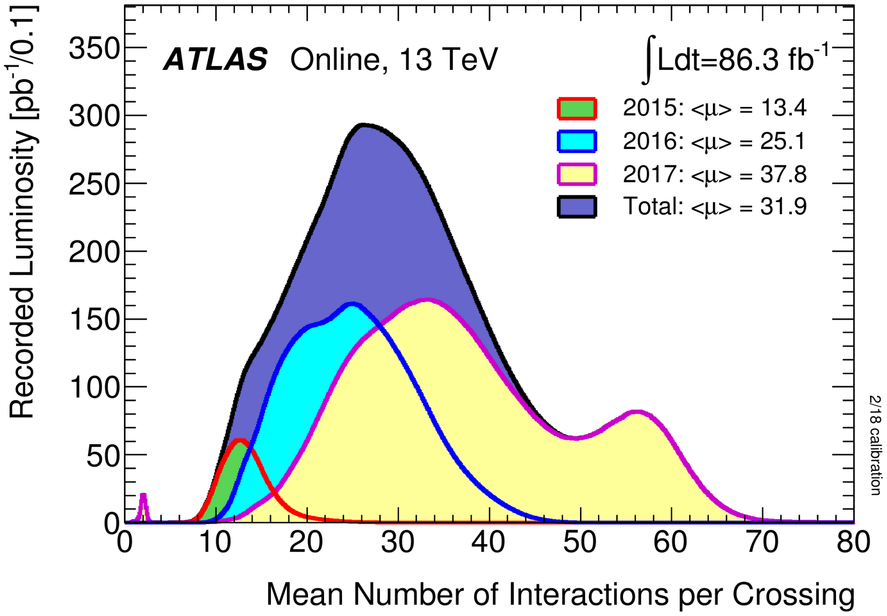
Centre-of-mass energy and luminosity increased in Run-2

→ both leading to increased ***pile-up***

	√s [TeV]	***Bunch Spacing [ns]***	***Peak Luminosity [cm^{-2}s^{-1}]***	***Peak μ***
Run 1	*8*	*50*	*7.7 x 10^{33}*	*37*
Run 2	*13*	*25*	*20.9 x 10^{33}*	*80*

μ *= number of interactions per bunch crossing*

[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2]

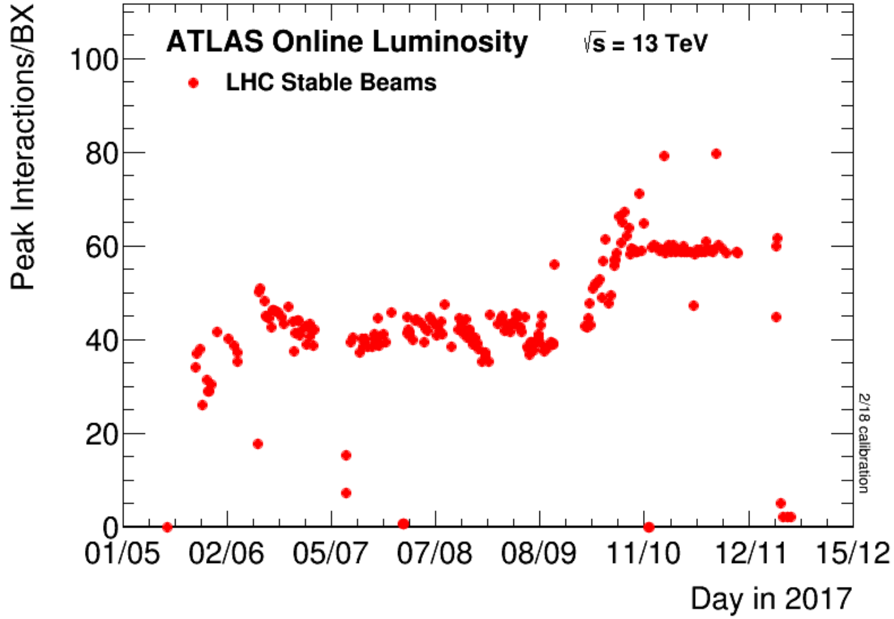


(In-Time) Pile-Up

The effect of multiple pp interactions within the bunch crossing

Out-of-Time Pile-Up

The effect of multiple pp interactions within *(up to 20) previous bunch crossings*



Pile-up increases trigger rates - need to control rates whilst maintaining efficiency for the interesting physics

The High-Level Calorimeter Trigger

High-Level Calorimeter Trigger refers to calorimeter-based software for online reconstruction of calo-based objects

- Unpacks raw byte-stream data to build cell objects
- Runs clustering algorithms to build clusters of cells **

- Optimised tools to perform RoI or Full-Scan unpacking
- Memory re-usage to avoid on-the-fly memory allocation

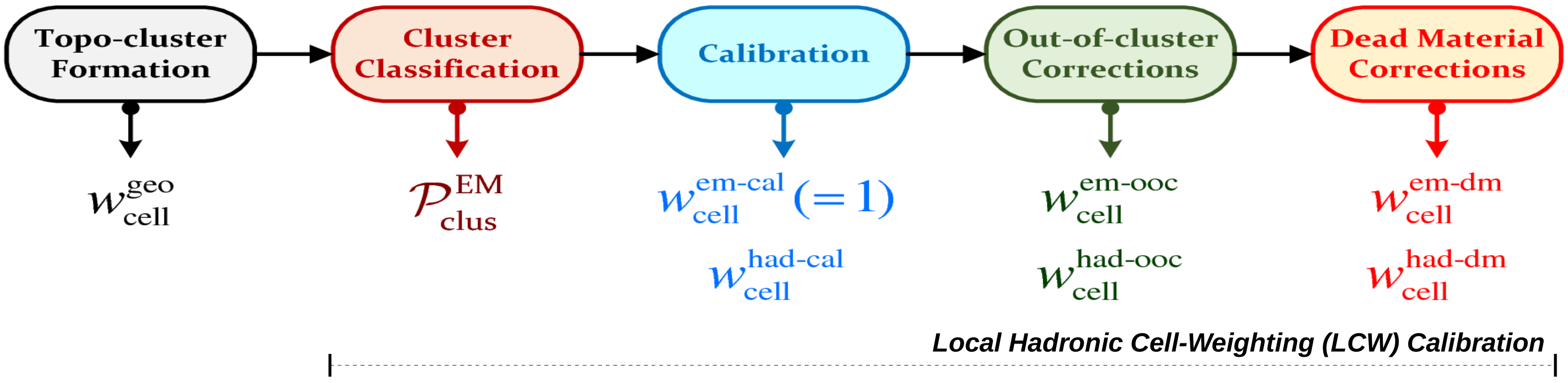
Sliding Window (SLW) Clustering Algorithm

- Operates over a grid of projective towers of cells
- Scans the grid to find window with a local E_T max
- Cluster formed if E_T > threshold
- Sums the cells within a fixed rectangular window
- *Barrel:* $\Delta\eta \times \Delta\phi = 0.075 \times 0.175$
  Endcap: $\Delta\eta \times \Delta\phi = 0.125 \times 0.125$

Topo-Clustering Algorithm

- Based on *cell significance (S)* where $S = \frac{|E_{cell}^{EM}|}{\sigma_{cell\ noise}^{EM}}$
- Identifies seed cells with: *S > 4*
- Iteratively adds the neighbouring cells with: *S > 2*
- Includes the directly neighbouring cells with: *S > 0*
- Topo-clusters have no predefined shape
- Are available at both the EM scale and LCW scale

[Eur. Phys. J. C (2017) 77: 490]



*** Also includes Egamma-specific shower shape and ringer algorithms.... See the following talk by Joao!*

The High-Level Calorimeter Trigger

In topo-clustering the noise for each cell is estimated by:

$$\sigma^{EM}_{cell\,noise} = \sqrt{(\sigma_{electronic\ noise})^2 + (\sigma_{pile-up\ noise})^2}$$

Note: In Run 2 $\sigma_{pile-up\ noise} > \sigma_{electronic\ noise}$

$$\sigma_{pile-up\ noise} \propto \sqrt{N_{MB}} * \sigma_{MB}$$

σ_{MB} = RMS of the energy dist. per cell for 1 MinBias event

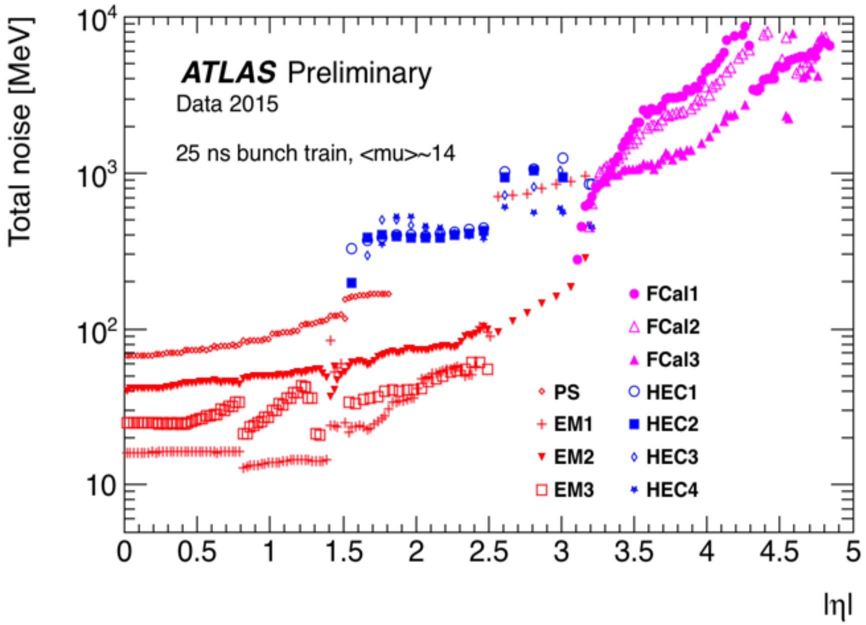
N_{MB} = The estimated average number of MinBias events per bunch crossing *

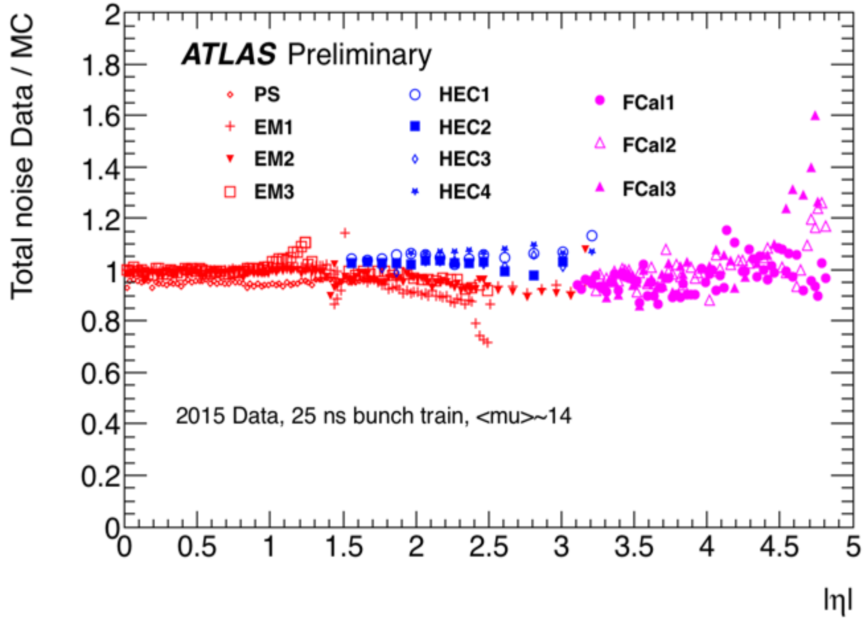
** Fixed value – typically set at the start of a running period*

$\mu < N_{MB}$ pile-up noise overestimated → *fewer clusters*

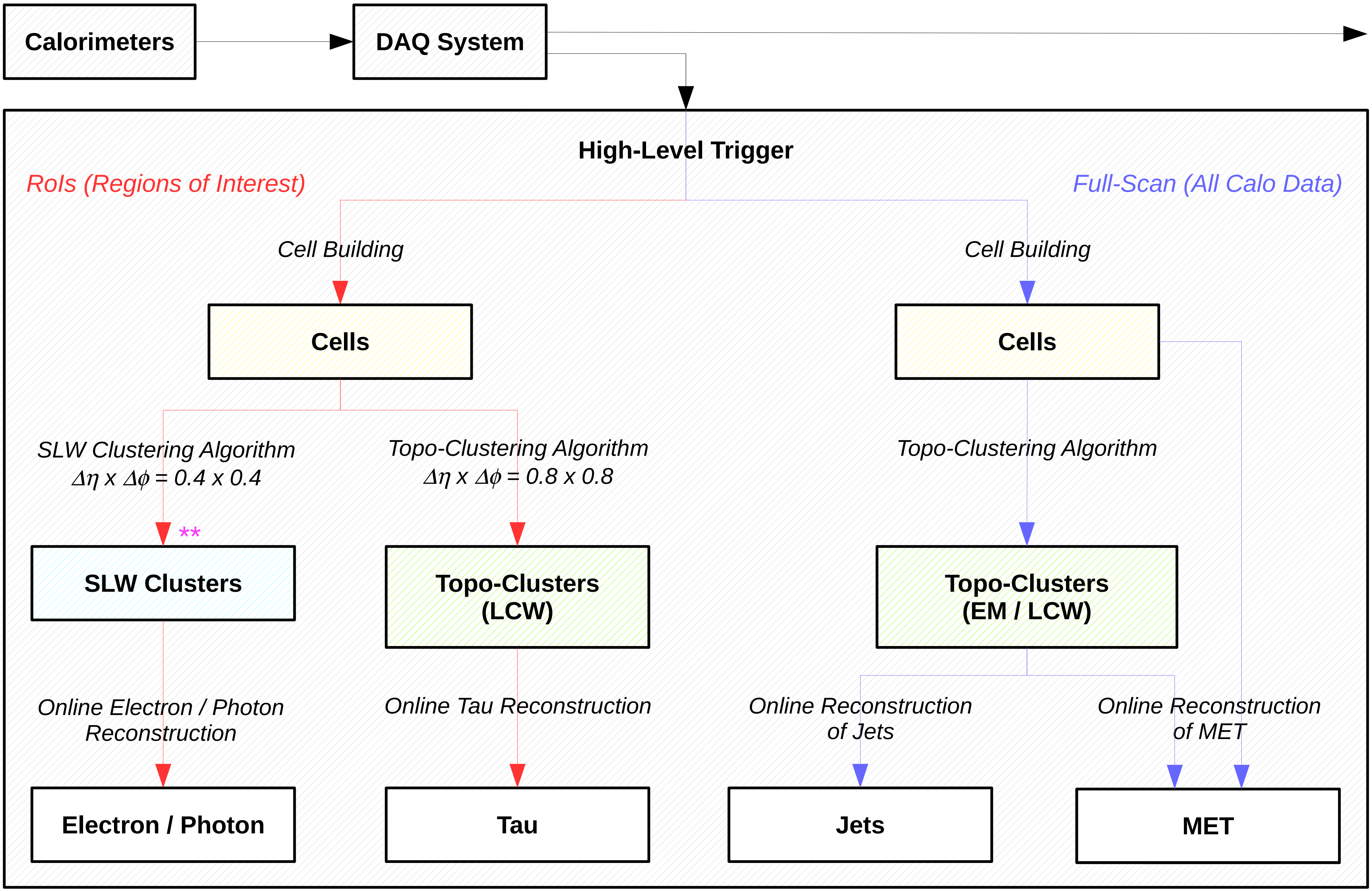
$\mu > N_{MB}$ pile-up noise underestimated → *more clusters*

[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LArCaloPublicResultsDetStatus]





The High-Level Calorimeter Trigger



Calorimeters

DAQ System

High-Level Trigger

RoIs (Regions of Interest)

Full-Scan (All Calo Data)

Cell Building

Cell Building

Cells

Cells

SLW Clustering Algorithm
$\Delta\eta$ x $\Delta\phi$ = 0.4 x 0.4

Topo-Clustering Algorithm
$\Delta\eta$ x $\Delta\phi$ = 0.8 x 0.8

Topo-Clustering Algorithm

**

SLW Clusters

Topo-Clusters (LCW)

Topo-Clusters (EM / LCW)

Online Electron / Photon Reconstruction

Online Tau Reconstruction

Online Reconstruction of Jets

Online Reconstruction of MET

Electron / Photon

Tau

Jets

MET

** *Also includes Egamma-specific shower shape and ringer algorithms*

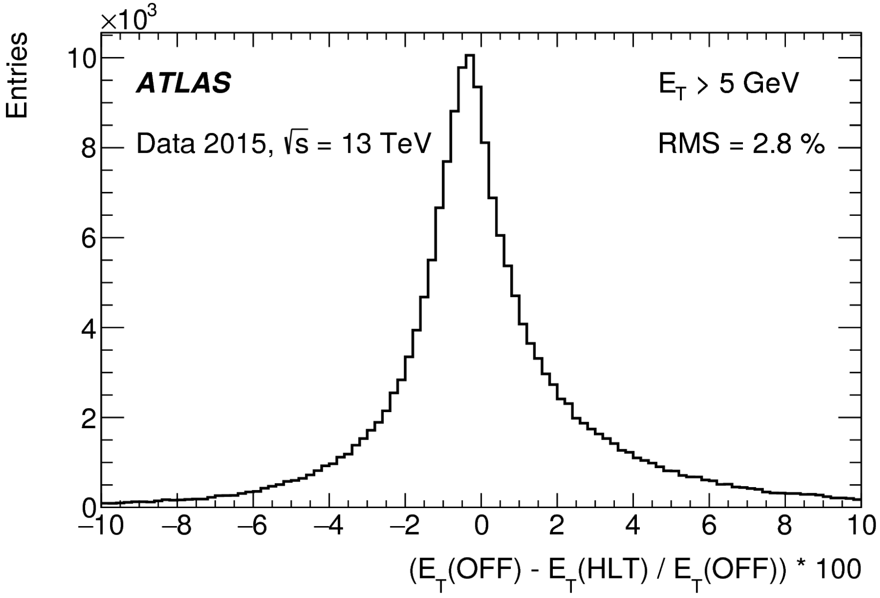
Clustering Algorithm Performance

Run-2 cluster energy resolution in the HLT with respect to offline clusters:

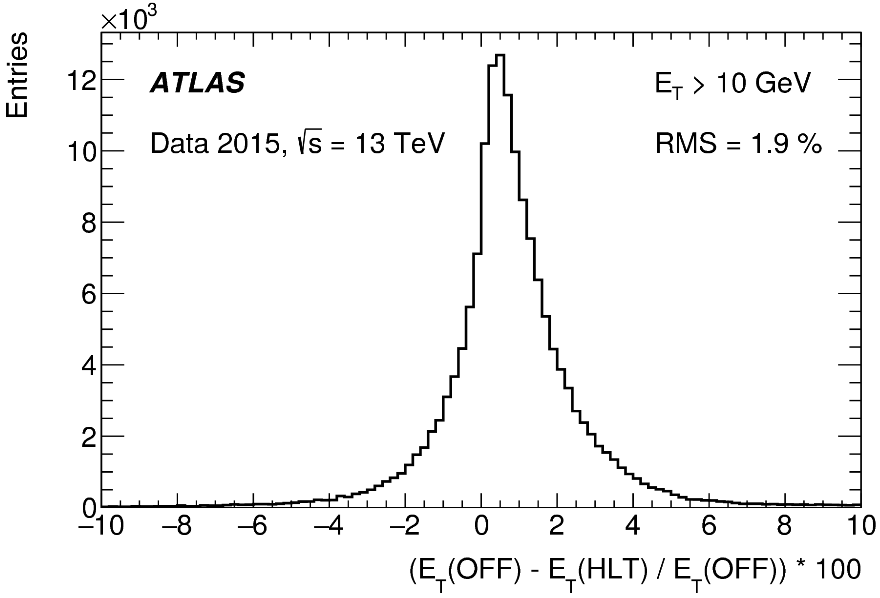
3% for SLW clusters (> 5 GeV)

2% for Topo-clusters (> 10 GeV)

[Eur. Phys. J. C (2017) 77: 317]



Sliding Widow Clusters



Topo-Clusters

Note:

- In 2015 out-of-time pile-up effects were corrected offline but not online. (See later).
- There was a mismatch between hadronic calibration constants used online / offline.

Algorithms and CPU Limitations

Plan for Run-2 was to run full-scan topo-clustering at earlier stage in HLT – **to improve harmony with offline**

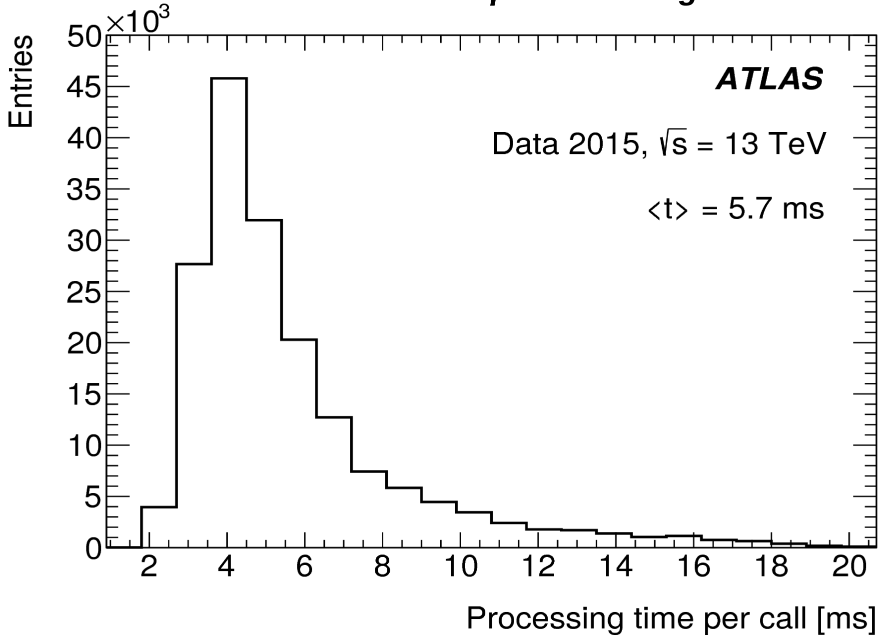
But... topo-clustering was already one of the most CPU intensive algorithms in Run-1

Required CPU resources ~ (algorithm execution time x rate of calls to algorithm)

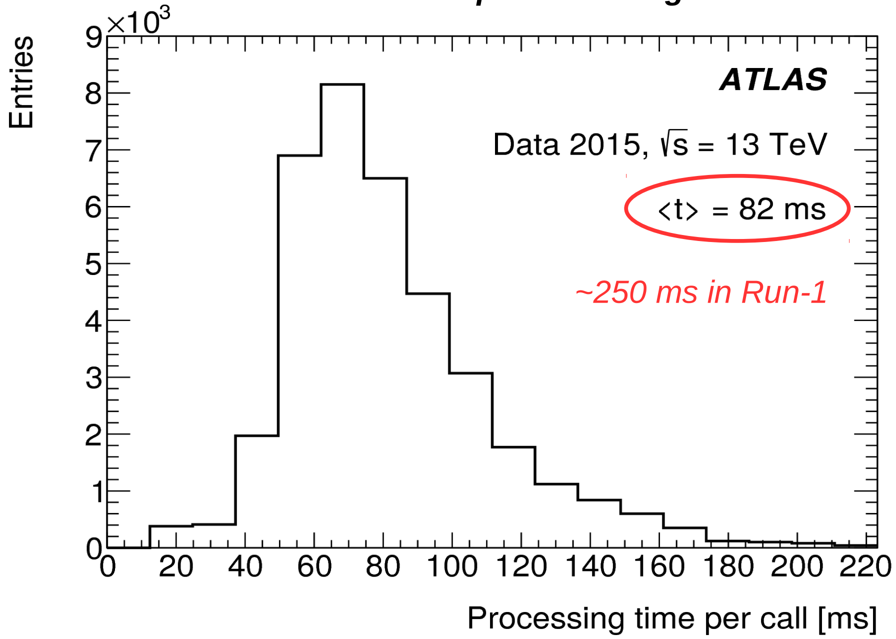
Optimisation of the topo-clustering (and cell building) algorithms allowed us to run full scan topo-clustering as first step in the HLT – *uses about 10% of the CPUs*

[Eur. Phys. J. C (2017) 77: 317]

RoI-Based Topo-Clustering



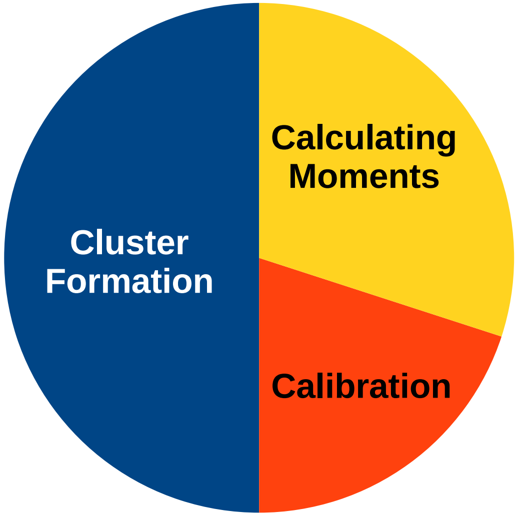
Full-Scan Topo-Clustering



~250 ms in Run-1

Algorithms and CPU Limitations

Time spent in topo-clustering:



Areas where speed improvements were made:

- Few minor improvements in software quality
- More in-lining of software
- Avoiding unnecessary calls to expensive functions
- Implementing more instances of data pre-fetching

[Eur. Phys. J. C (2017) 77: 317]

Average algorithm execution times in Run-2:

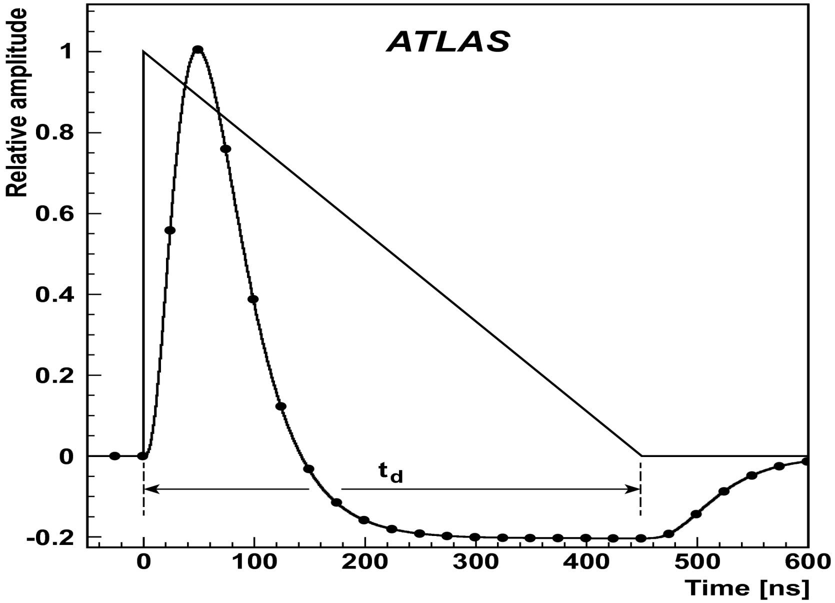
	Execution Time [ms]	
	Per RoI	**Full Scan**
Cell Building	2	20
Topo-Clustering Algorithm	6	82
SLW Clustering Algorithm	< 2.5	x

Out-of-Time Pile-up Effects

Out-of-time pile-up results in so called **“bunch train effects**”

→ increased energy (and rates) seen at start of bunch trains

→ comes from the long LAr pulse shapes

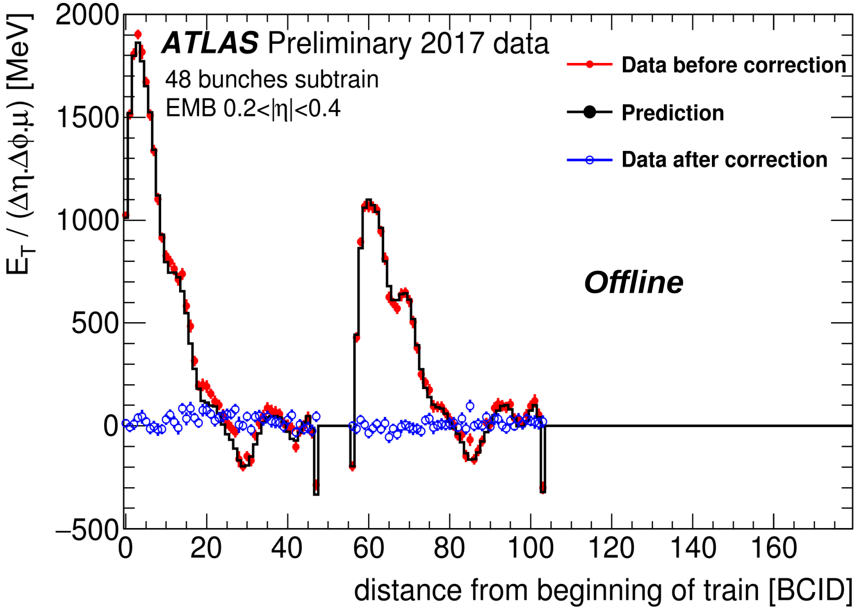


[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LArCaloPublicResults2015]

Cell-level energy corrections are estimated from:

- Average energy deposition (per cell, per BCID)
- BCID
- Luminosity
- LAr pulse shape

… size of the corrections vary from MeV to GeV



At start of Run-2 corrections applied offline but ***not online***

→ lead to increased trigger rates at start of bunch trains

→ *Effects are particularly significant in multi-jets and MET*

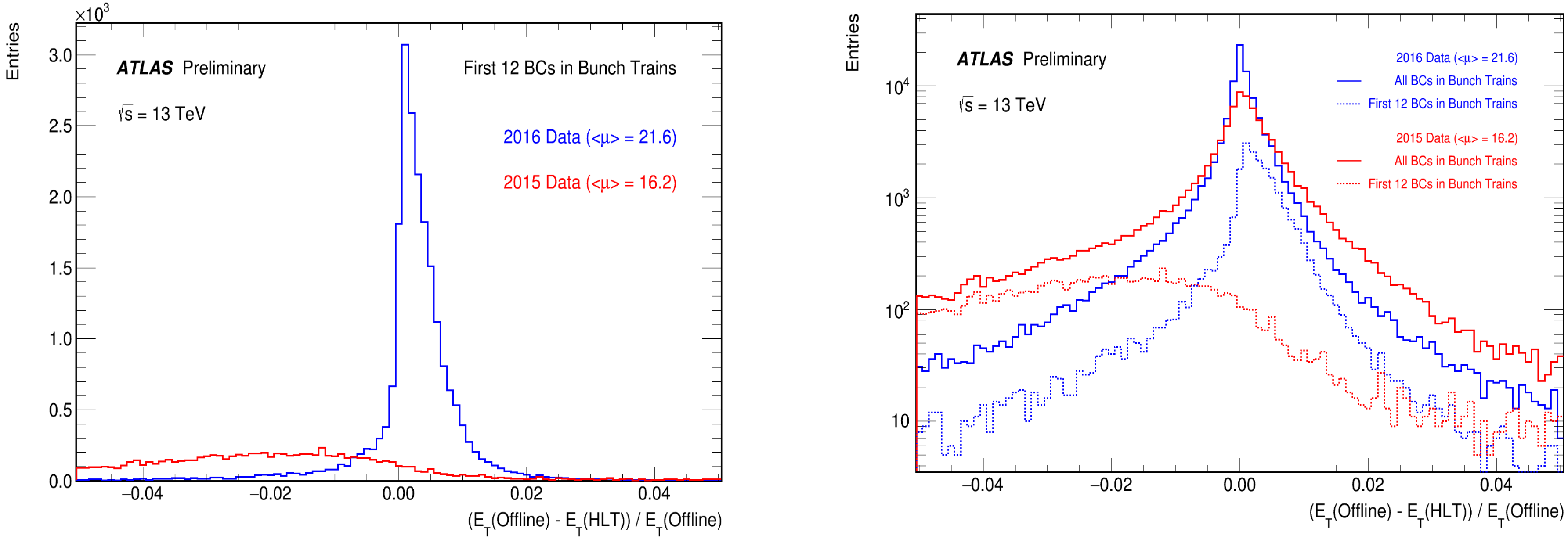
Out-of-Time Pile-up Effects

The corrections were introduced in the HLT in mid-2016 and had significant impact:

→ improved energy resolution (with respect to offline)

→ reduced trigger rates (little/no impact on efficiency)

[ATL-DAQ-PUB-2017-001]



Note:

- Offline corrections make use of event-by-event luminosity information
- HLT only has periodic access to online luminosity (known within < 5%)

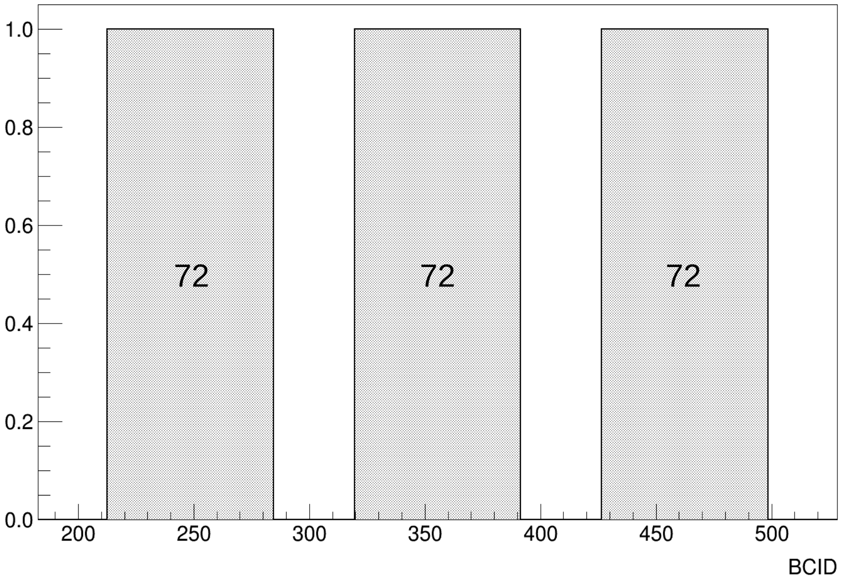
Impact of the LHC Filling Scheme

Out-of-time pile-up became more relevant when LHC proposed the **8b4e** filling scheme

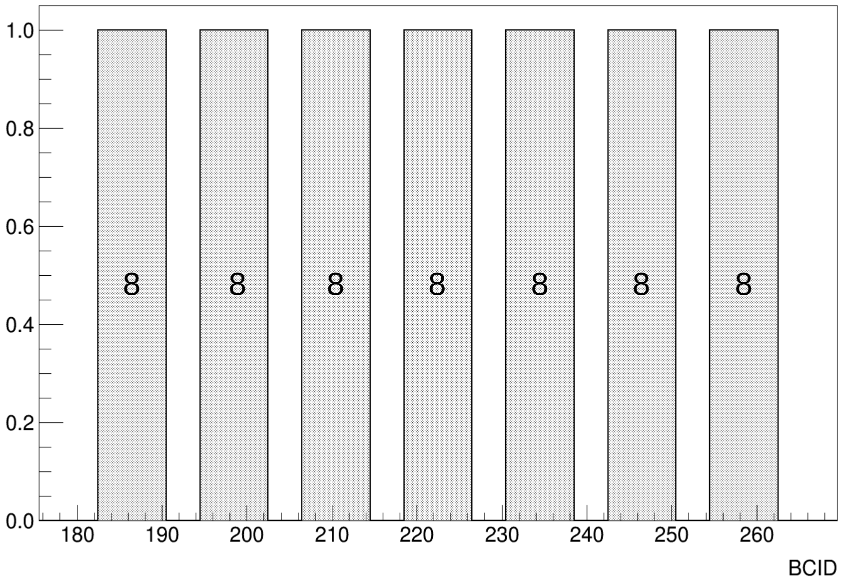
→ **8 filled bunches** followed by **4 empty**

→ suppresses formation of electron clouds

Typical filling scheme (2016)



8b4e filling scheme (2017)



In 8b4e scheme ***every event*** experiences bunch train effects

→ *essentially every event looks like the start of a bunch train*

Out-of-time pile-up corrections are now an essential part of the High-Level Calorimeter Trigger

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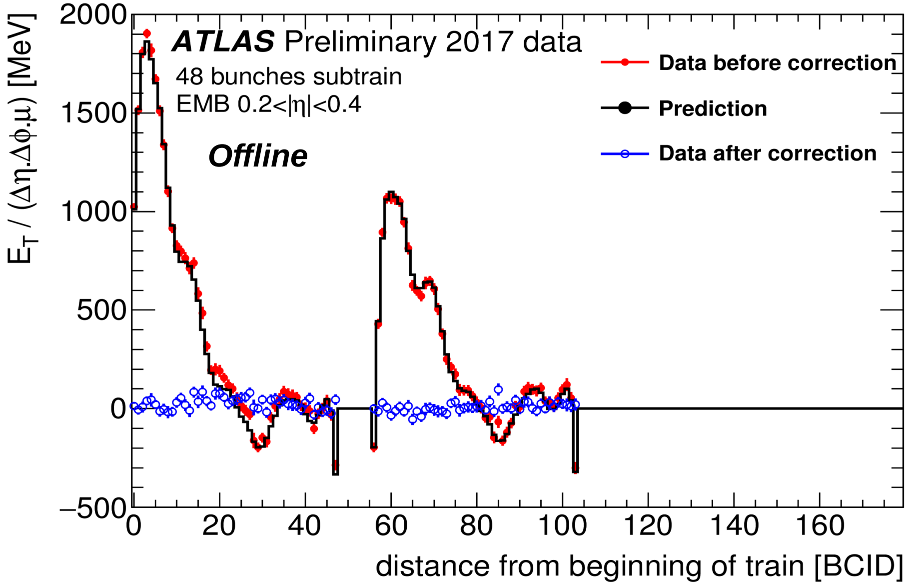
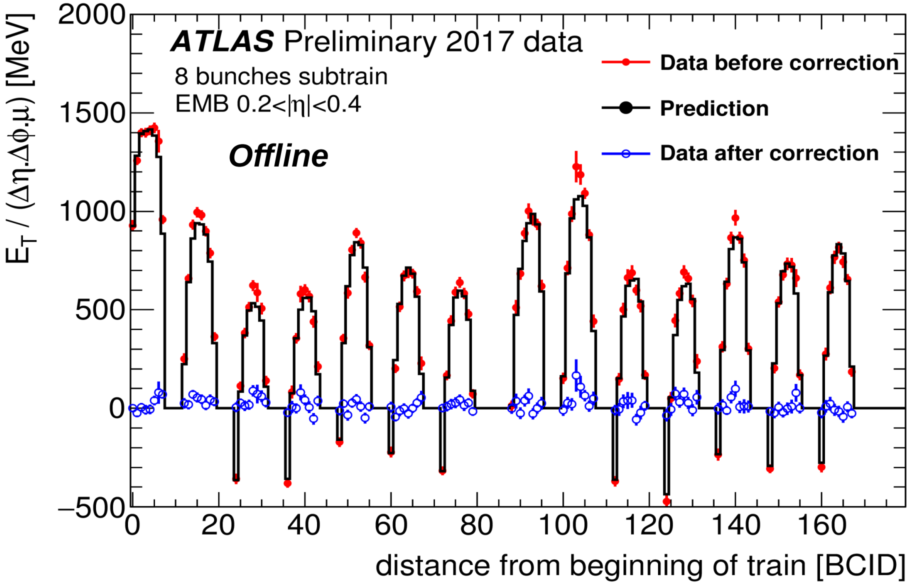

Filling Scheme With 48 Filled Bunches (2017)


8b4e filling scheme (2017)

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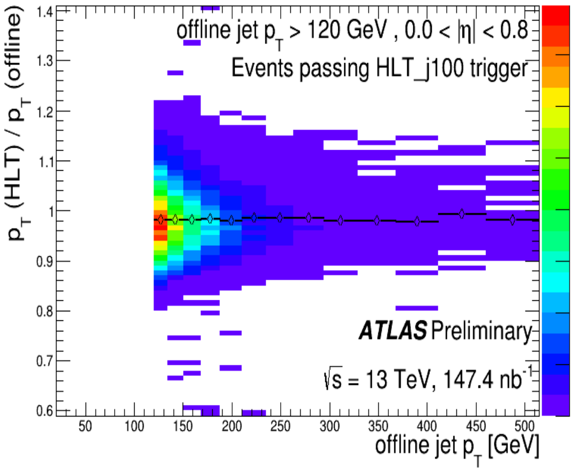
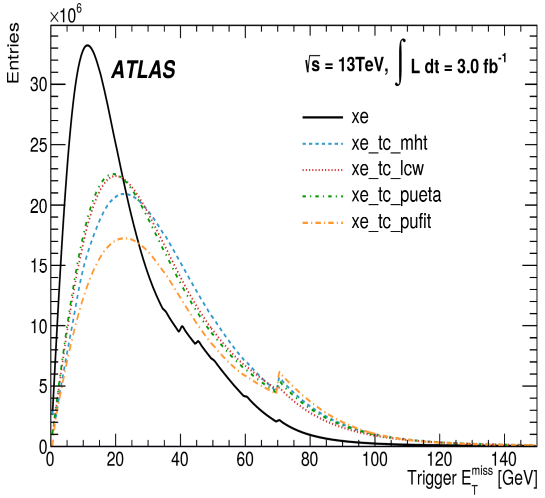
HLT Performance in Run-2

Jets



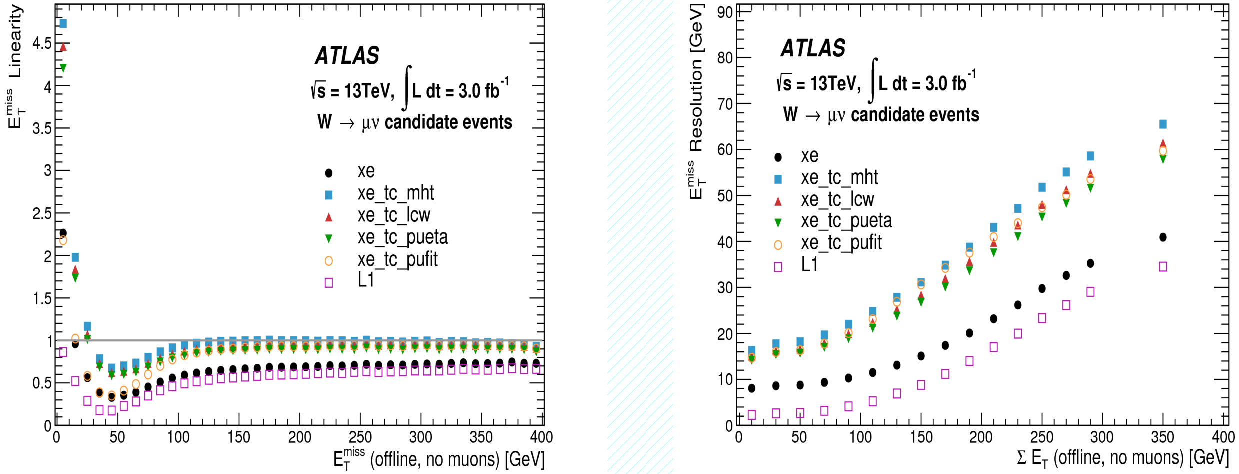
[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetTriggerPublicResults]

MET



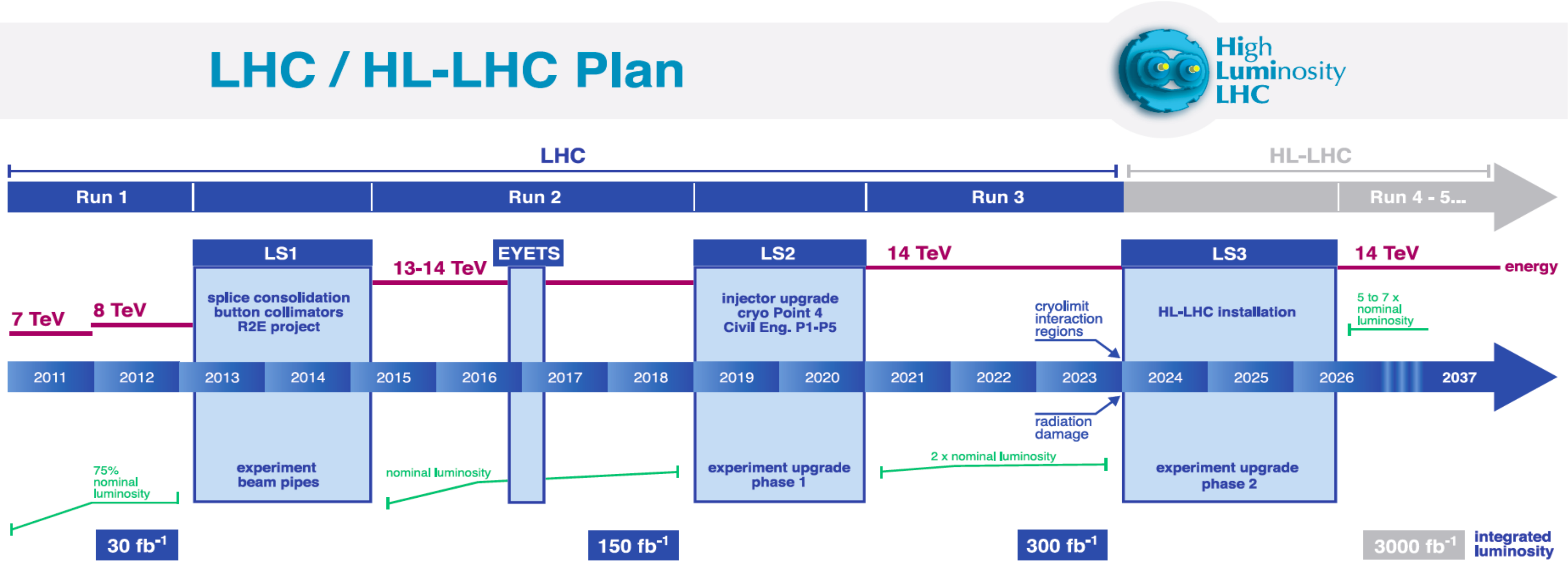
MET

[Eur. Phys. J. C (2017) 77: 317]



Summary

- The ATLAS High-Level Calorimeter Trigger performing well in Run-2
- More harmonisation between online and offline (compared to Run-1)
- Introduction of out-of-time pile-up corrections improved performance
- Generally operating in very stable / consistent manner
- Now looking towards preparations for Run-3 (and beyond – HL-LHC **)



See the talks... Development of the ATLAS Liquid Argon Calorimeter Readout Electronics for the HL-LHC – Timothy Robert Andeen

Upgrade of the ATLAS Tile Calorimeter for the High luminosity LHC – Fabrizio Scuri