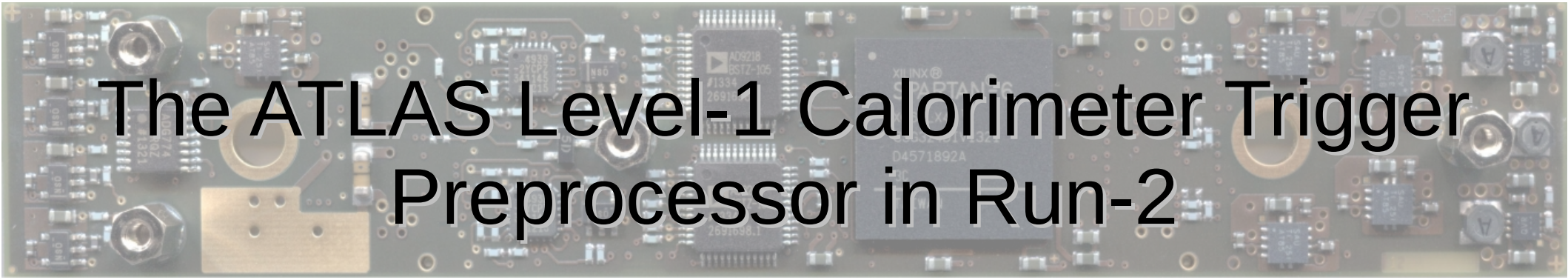


The ATLAS Level-1 Calorimeter Trigger Preprocessor in Run-2

Jan Jongmanns

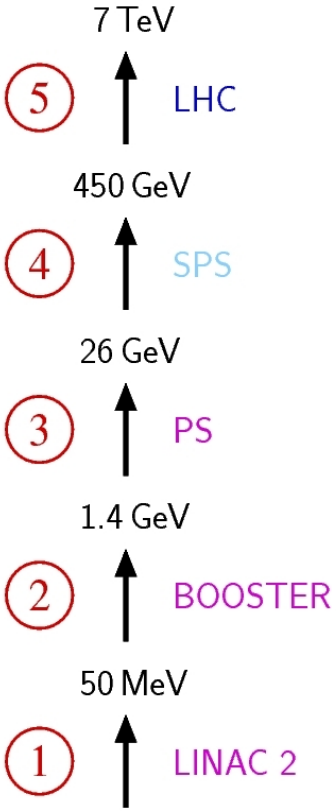
HighRR Seminar

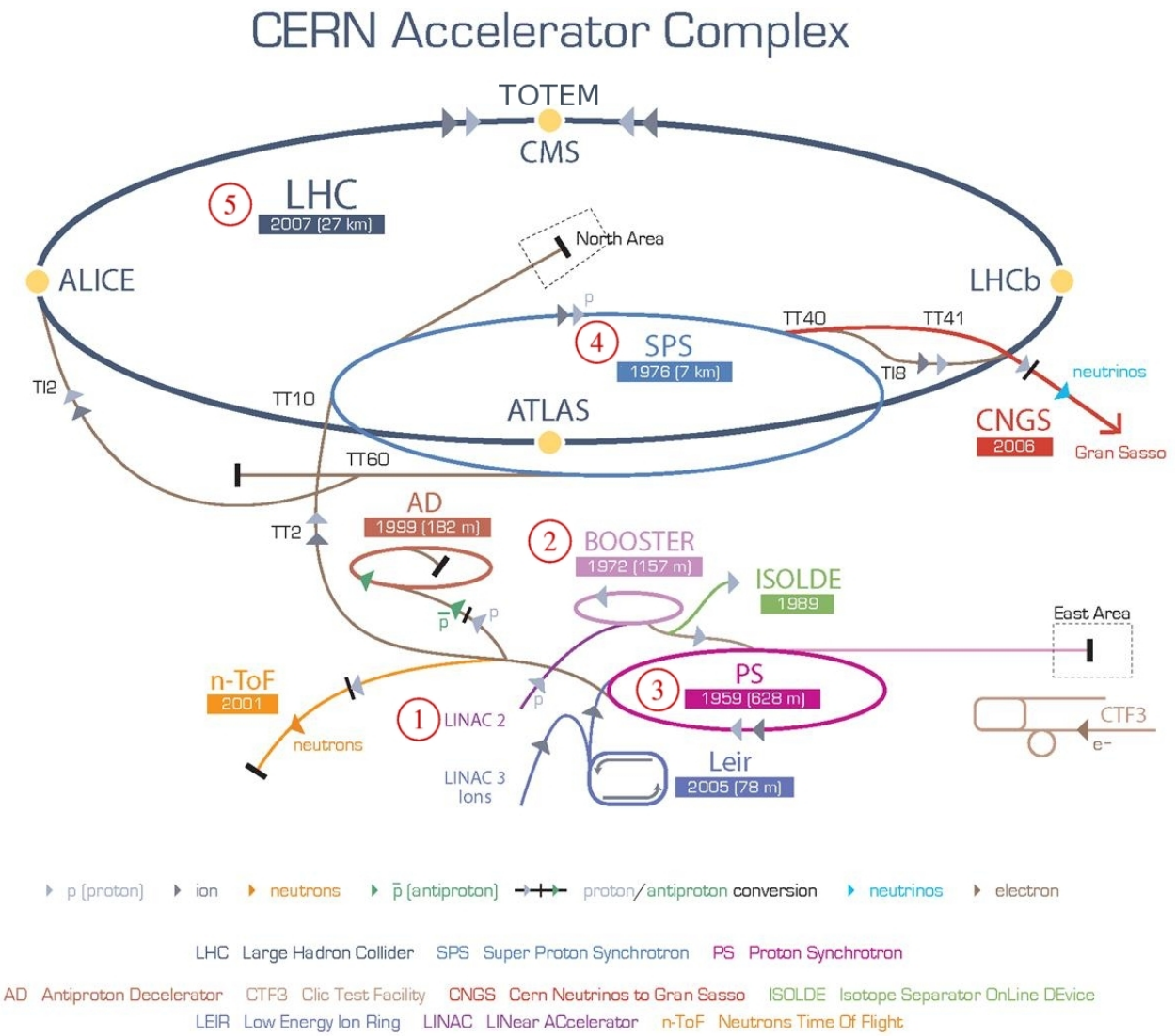
17.02.2016

-Outline-

- LHC & ATLAS
- ATLAS Trigger
- L1Calo Preprocessor
- New Run-2 Features
- Summary

-LHC & ATLAS-
The LHC Accelerator



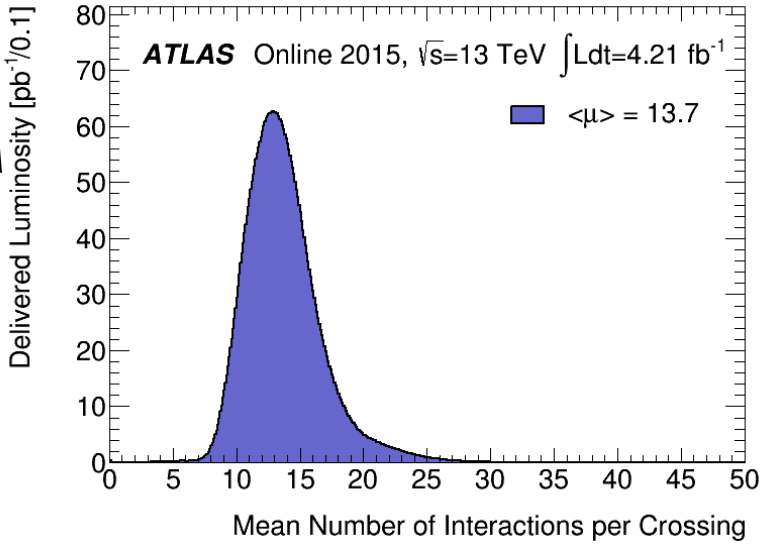


-LHC & ATLAS-
LHC Beam Setup

- LHC circulates protons in separated '**bunches**' of 10^{11} particles
  - 3564 possible bunch slots, >2000 'filled' in good runs
  - Bunches collide at up to 40.08 MHz (25 ns 'bunch spacing')

- Each 'bunch crossing' (BC) produces several pp collisions
  - Typically few 'interesting' events rest -> '**pile-up**'

1 $pb^{-1} \sim 10^{11}$ coll.



-LHC & ATLAS-
LHC Runs

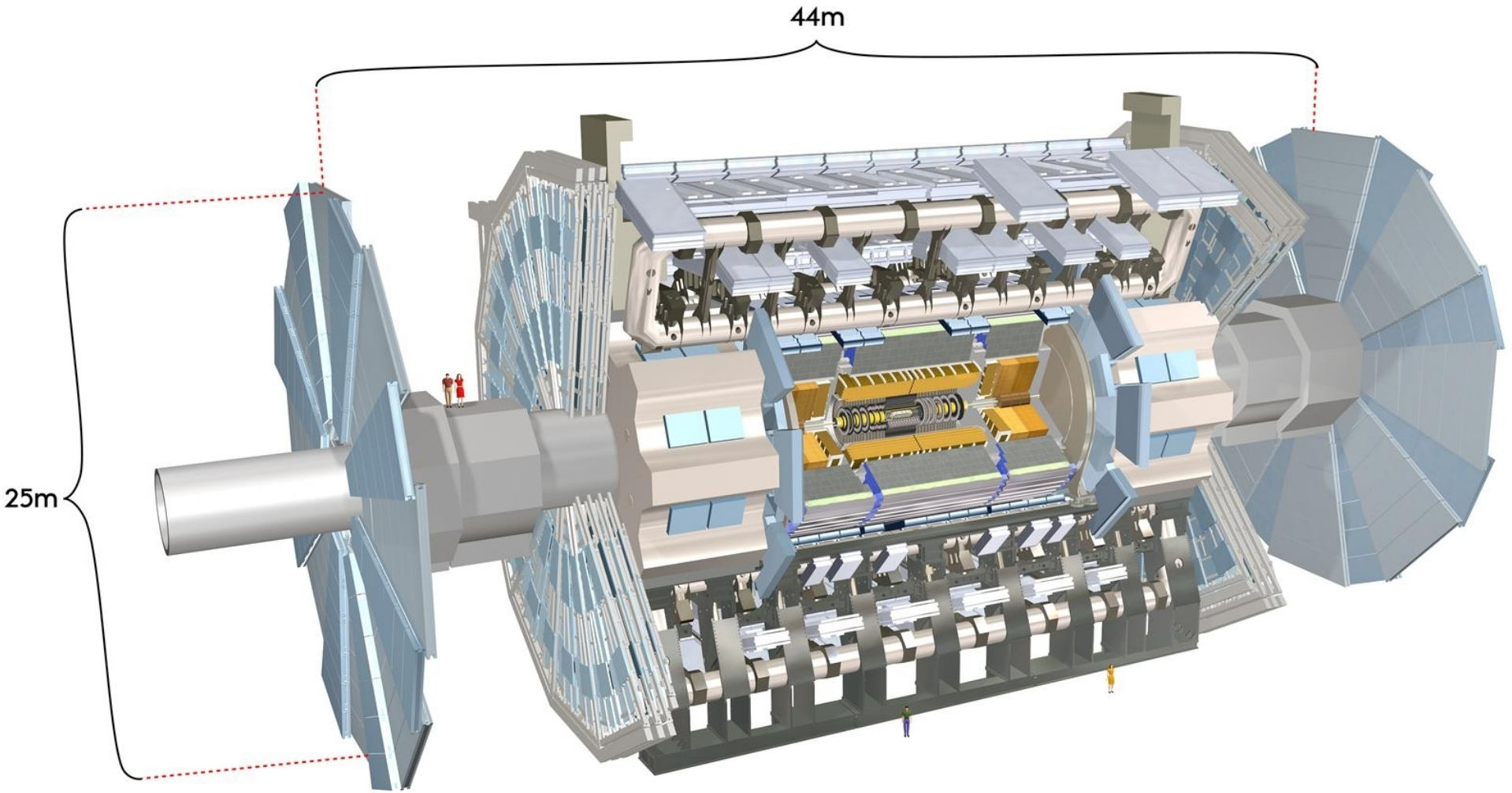
Run-1 (2009-2013)

- LHC parameters
  - $\sqrt{s}$ = 7~8 TeV
  - L = ~7 x 10^{33} $cm^{-2}s^{-1}$
  - Bunch spacing 50 ns
- Physics results
  - Higgs discovery
  - Quark gluon plasma
  - New baryons, pentaquarks
  - Limits, limits, limits …

Run-2 (2015-2018)

- LHC parameters
  - $\sqrt{s}$ = 13~14 TeV
  - L = ~10^{34} $cm^{-2}s^{-1}$
  - Bunch spacing 25 ns
- Physics goals
  - Higgs properties
  - Higher limits, …
  - ???

-LHC & ATLAS-
ATLAS Detector

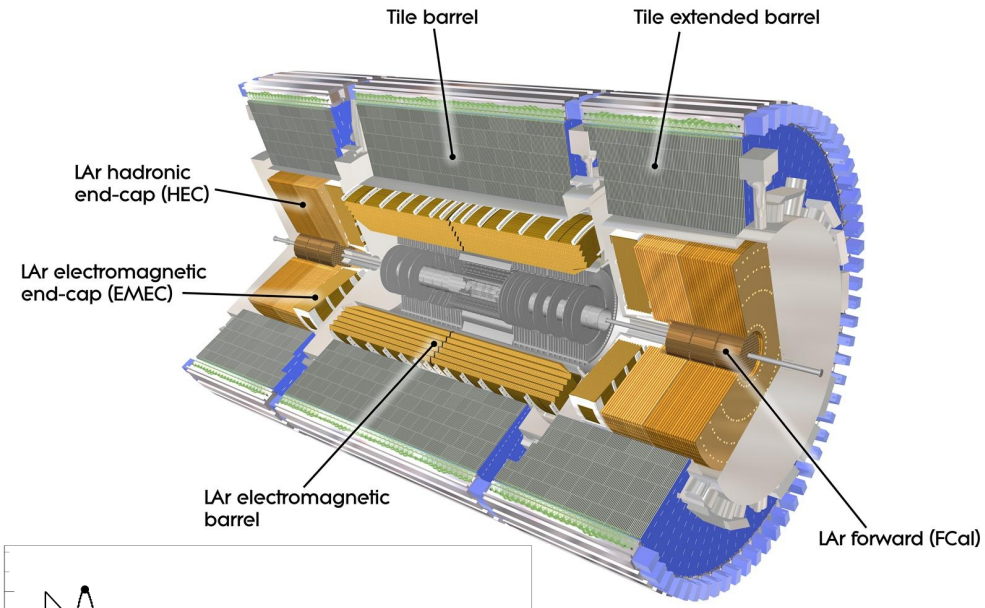


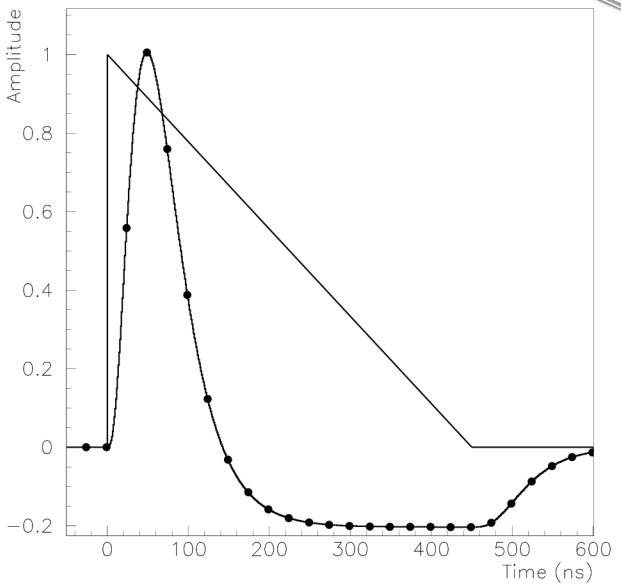
-LHC & ATLAS-
ATLAS Calorimeter

Sampling calorimeter

- Active medium
  - Liquid argon
  - Scintillating tiles
- Absorber
  - Lead (Central LAr)
  - Copper (Forward LAr)
  - Stainless Steel (Tile)

Front-end electronics
produce bipolar pulseshape



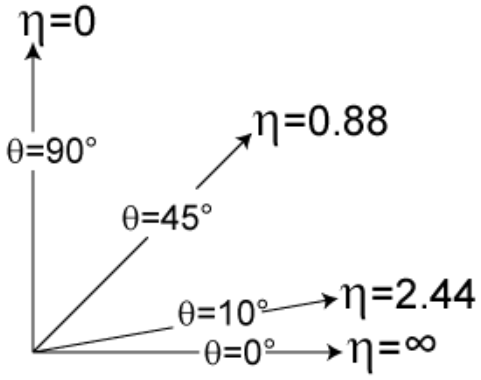


-LHC & ATLAS-
ATLAS Coordinates

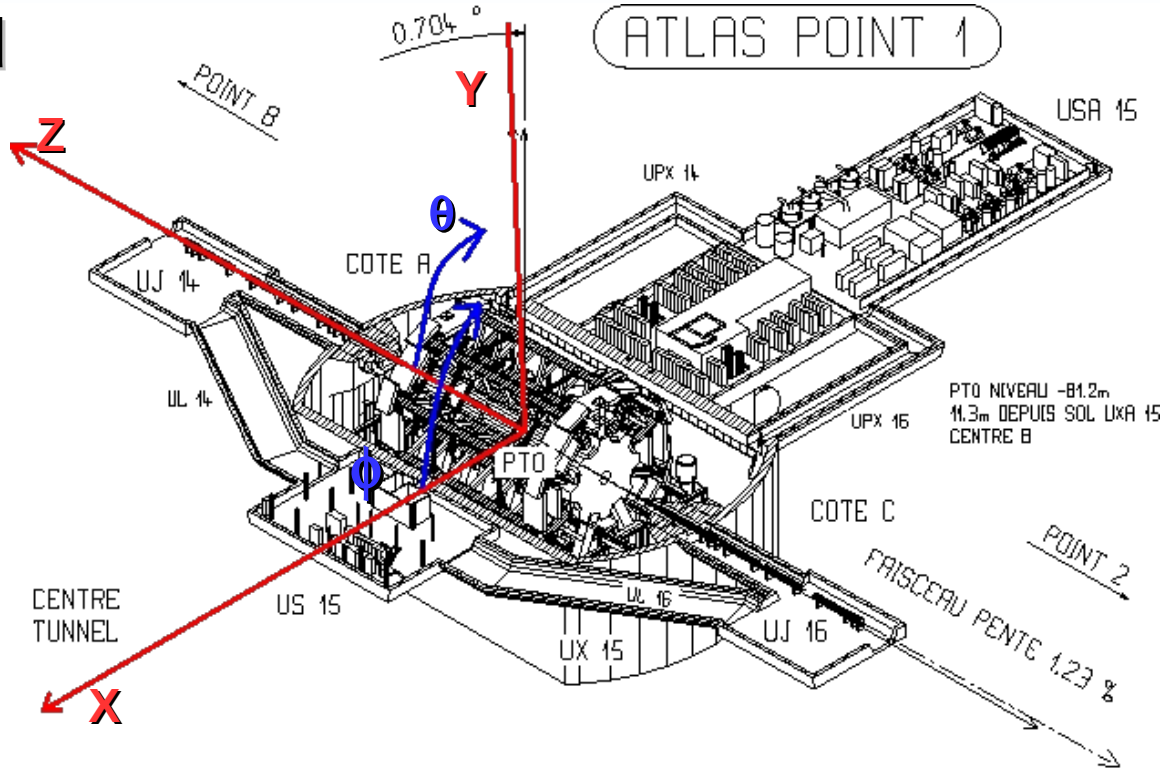
ATLAS uses **right-handed polar coordinate** system

- Instead of polar angle θ, use pseudorapidity η

$$\eta = - \ln(\tan(\theta/2))$$



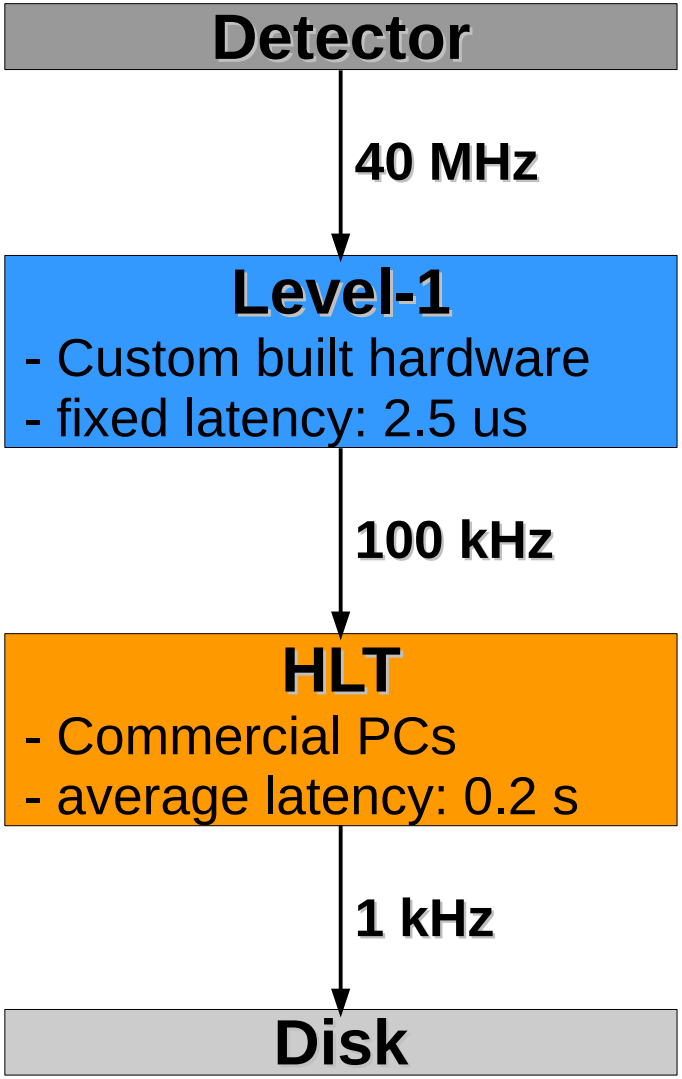
In relativistic limit, η = y



Rapidity $y = \frac{1}{2} \ln((E+p_L)/(E-p_L))$

- Δy invariant under Lorentz transformation
- Particle flow ~ constant in y

-ATLAS Trigger-
Overview



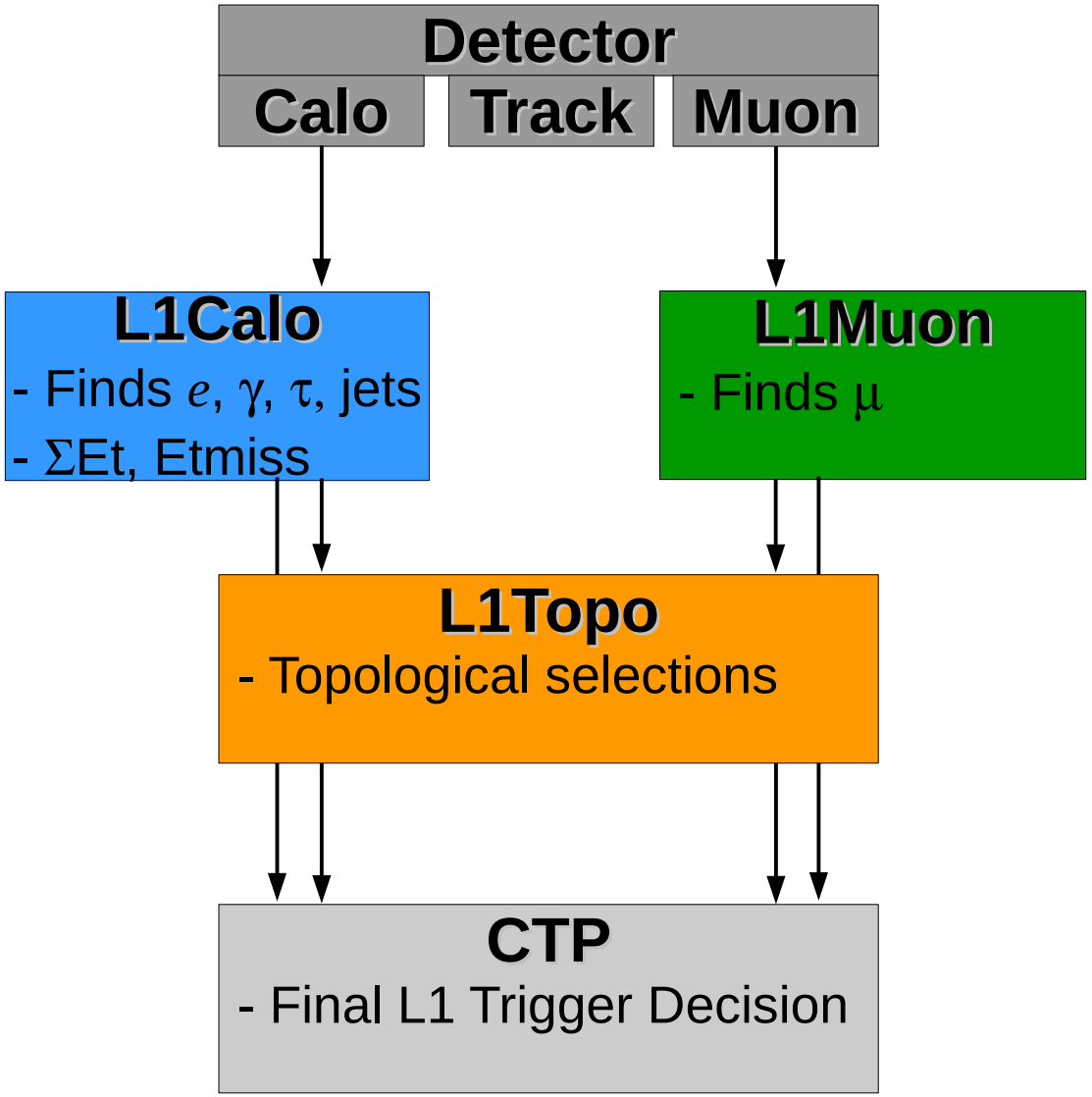
Level-1

- Reduced granularity
- Calorimeter & muon only
- Triggers on object multiplicity
- Reduction factor: 400

High-Level-Trigger

- Reconstructs full event
- Offline-like algorithms
- Reduction factor: 100

-ATLAS Trigger-
Level-1 Trigger



L1 Trigger systems

- find object candidates (e.g. e > 10 GeV)

Topological Processor

- sophisticated selections (e.g. m_{jj} > 50 GeV)

Central Trigger Processor

- Trigger based on object multiplicities (e.g. at least 2 μ > 30 GeV)

-ATLAS Trigger-
Level-1 Calorimeter Trigger

Calorimeter

7200 analogue 'Trigger Towers'

Preprocessor
- Digitisation & Energy calib.
- Synchronisation

Digitized energies

Cluster Processor
- e, γ, τ candidates
- Sliding window algorithm

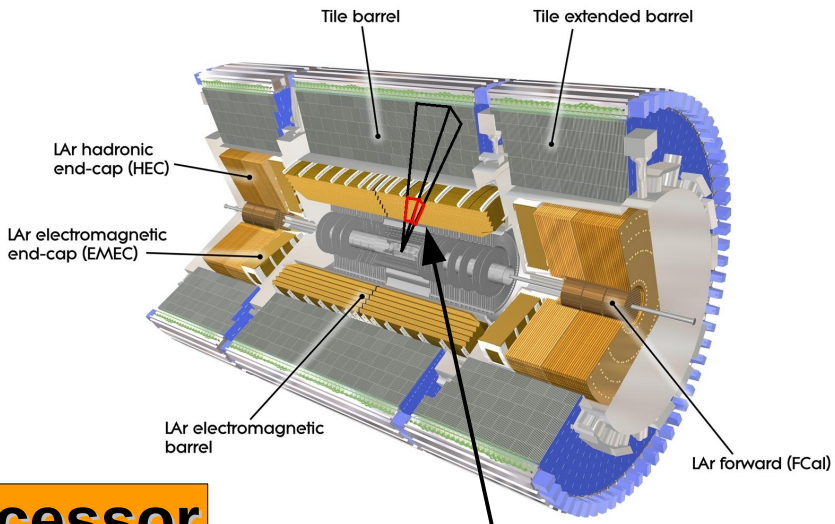
Jet/Energy Processor
- Sliding window jet finder
- Total and missing Et

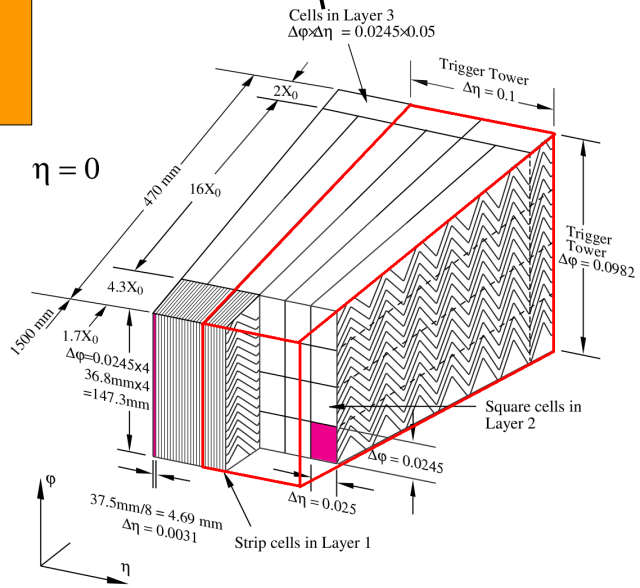
Object candidates

L1Topo

Object multiplicities

CTP

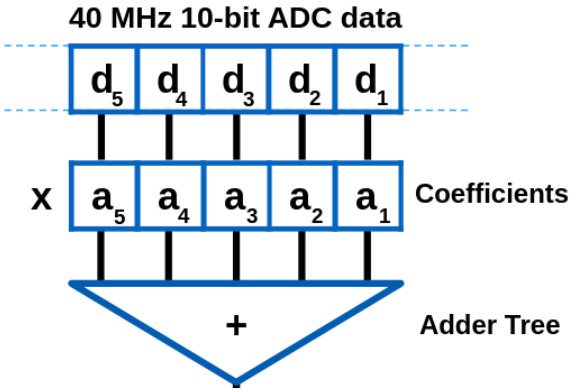


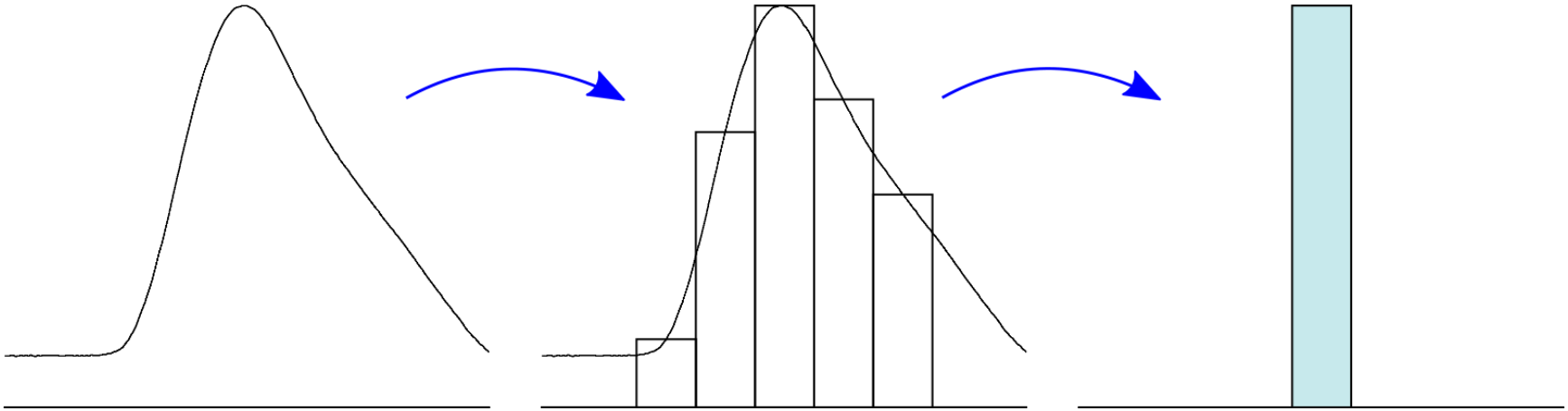


-L1Calo Preprocessor-
Functionality

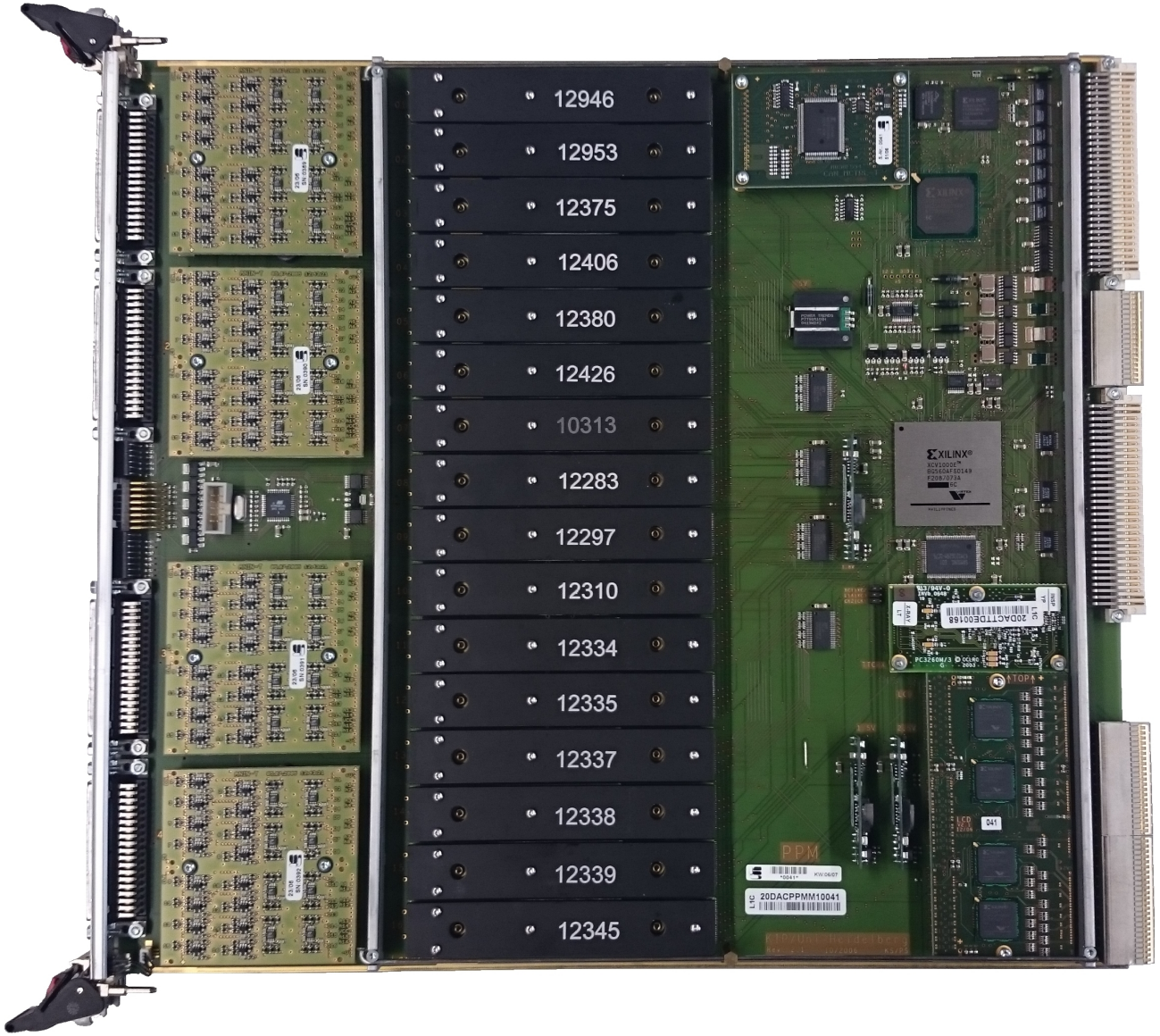
Preprocessor prepares calorimeter signals for object finding

- Digitization of analogue calorimeter signals
- Synchronization of digital signals
- Digital filter to reduce noise
- Peak-Finding to identify energy deposition
- Calibration of signal amplitudes to GeV scale energies





-L1Calo Preprocessor-
Hardware Implementation



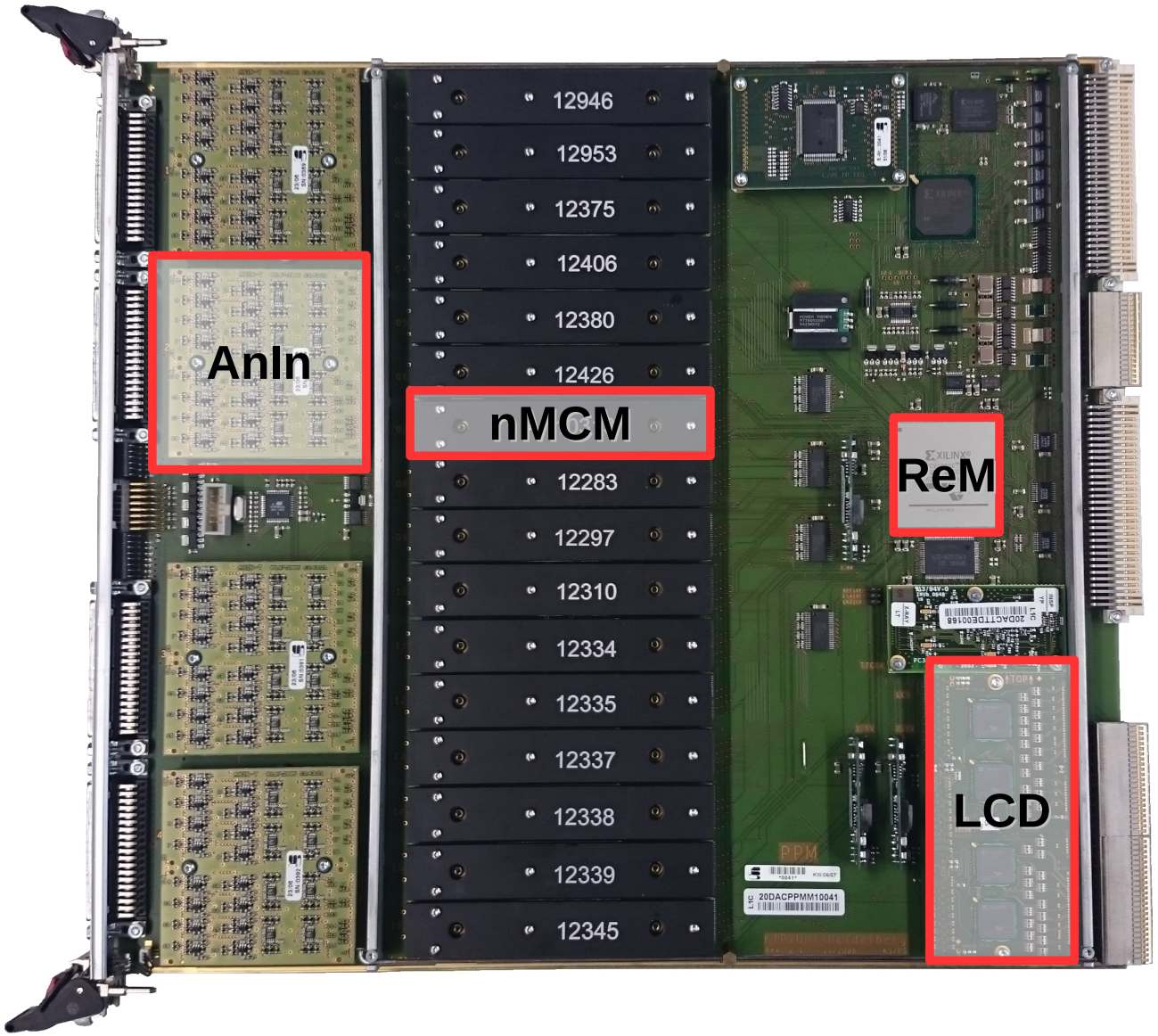
To handle 7200 channels

- Highly **parallel** …
- … **modular** system

Preprocessor Module

- 128 Modules total
- 64 channels each

-L1Calo Preprocessor-
Preprocessor Module



Analogue Input Board

- Signal Shaping

(new) Multichip Module

- Main Processing Unit

Readout Merger

- Readout & Config.

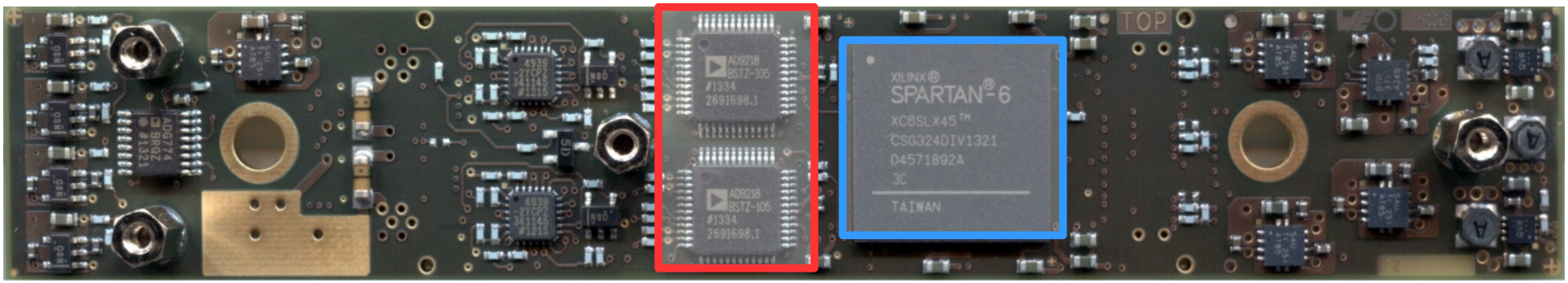
LVDS Cable Driver

- Data to Processors

-L1Calo Preprocessor-
The new Multichip Module

16 nMCM / PPM (2048 total) - 4 channel / MCM

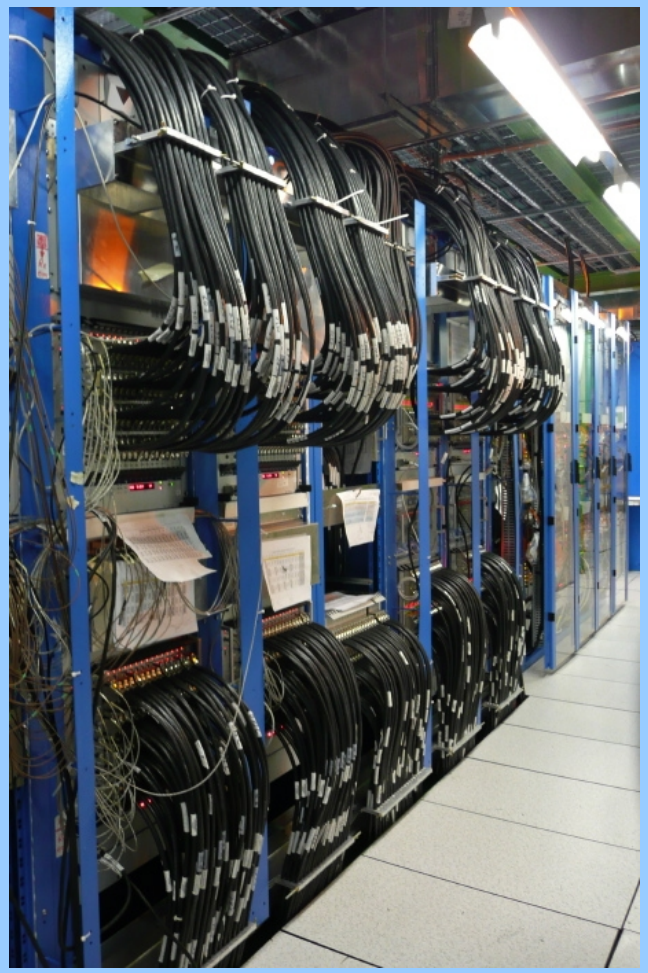
2x dual-channel FADC
- 80 MHz, 10-bit



'Calippr' FPGA (CALorimeter Information PrePRocessor)

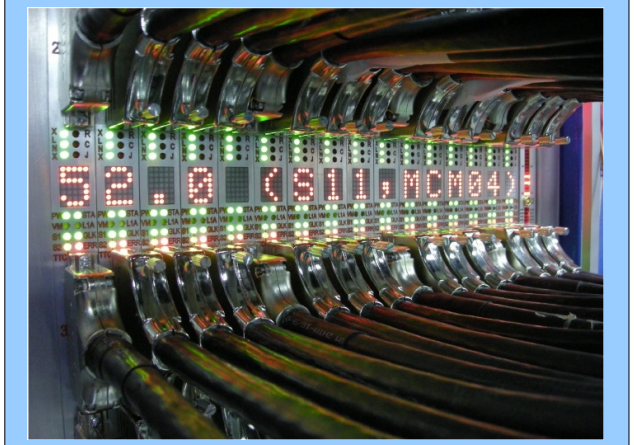
- Synchronization FIFOs for input signals
- Digital Filter to reduce thermal & pile-up noise
- Identification and measurement of energy deposition
- Stronger chip than Run-1, allows more advanced algorithms

-L1Calo Preprocessor-
Impressions from the Cavern



Cables from calorimeter into Receivers and Preprocessor

LVDS cables to Processors on backside of Preprocessor

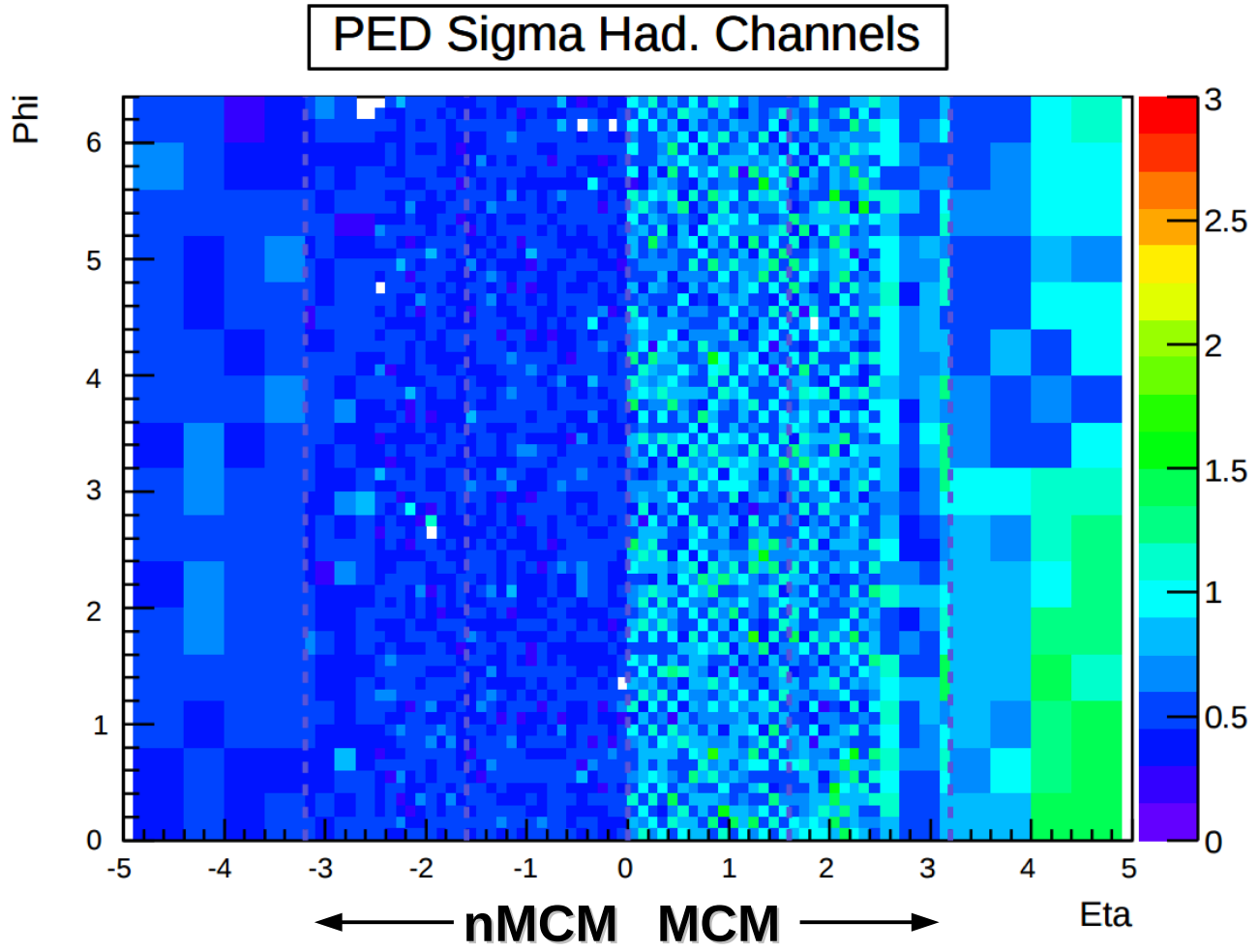


Preprocessor display shows temperature & position of hottest MCM

-L1Calo Preprocessor-
Run-2 Hardware Performance

Run-2 system outperforms Run-1 Hardware in many ways

- **Noise smaller & more homogeneous**, less fine timing effect on ADC, …



-L1Calo Preprocessor-
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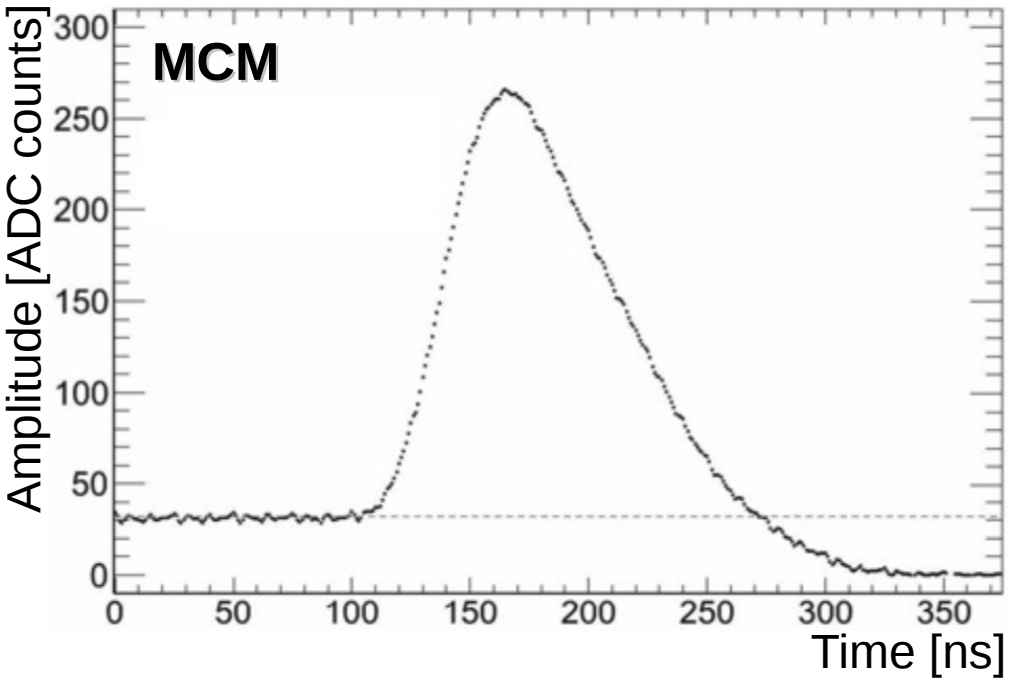
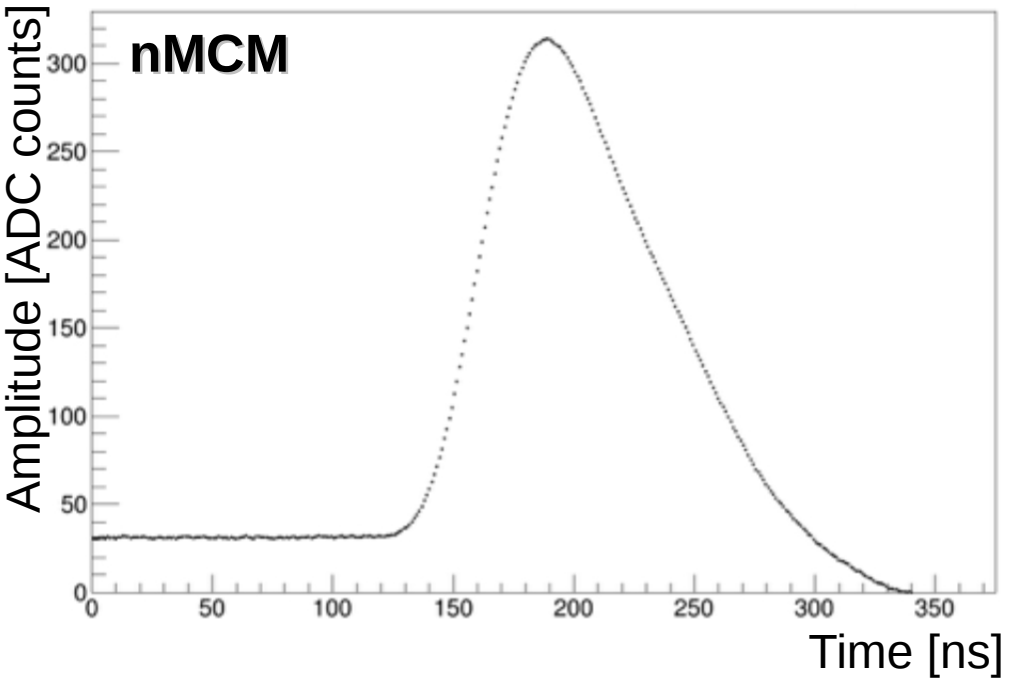
Reconstructed pulse shapes by scanning ADC strobe in 1 ns steps

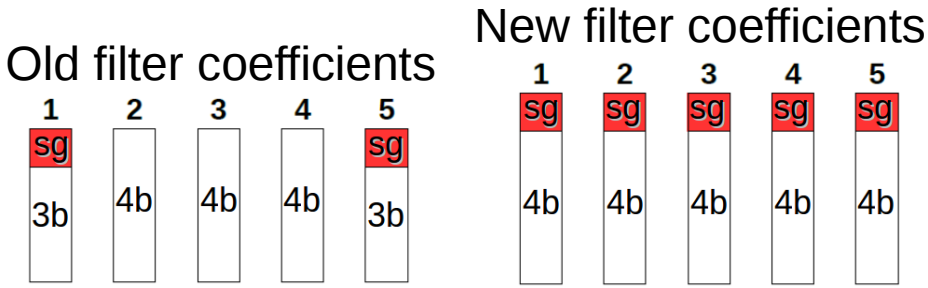


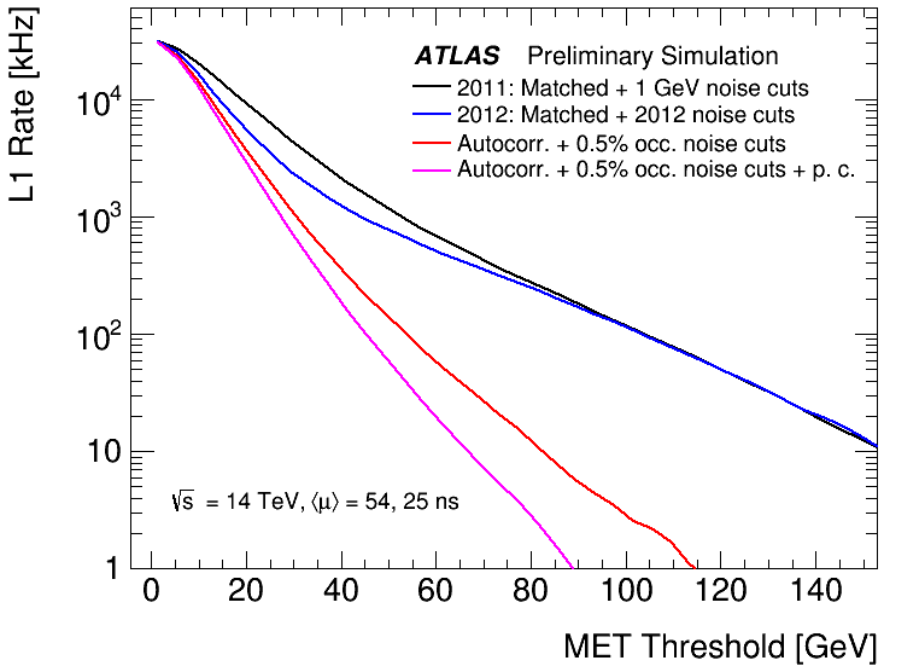


-New Run-2 Features- Overview

New MCM allows for many new & enhanced algorithms

- **More flexible digital filters allow better pile-up noise treatment**
- Use 80 MHz digitisation to enhance processing of saturated signals
- Separate energy calibrations for CP and JEP systems
- Dynamic correction for pile-up induced fluctuations of baseline





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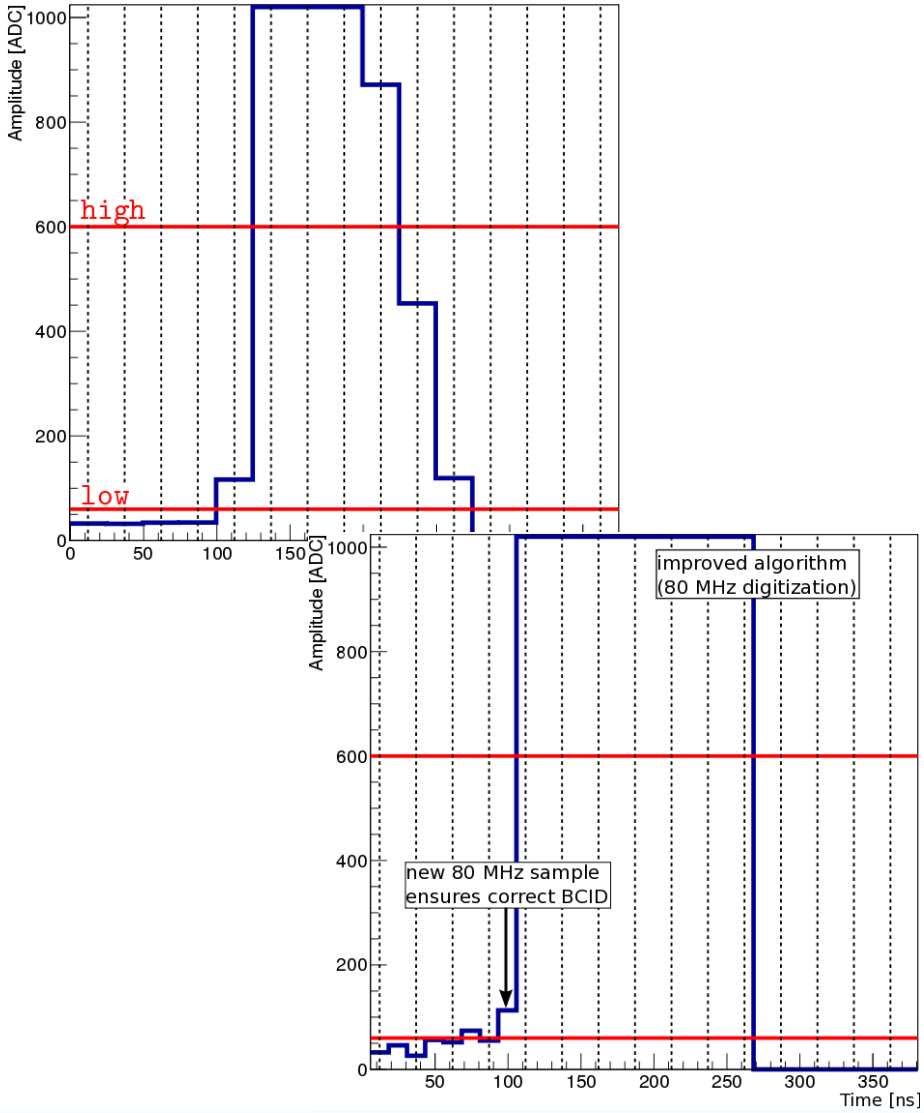

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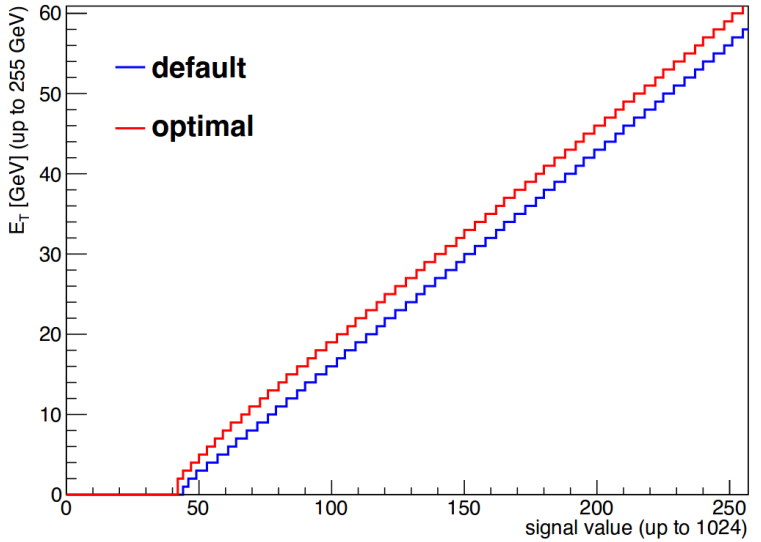
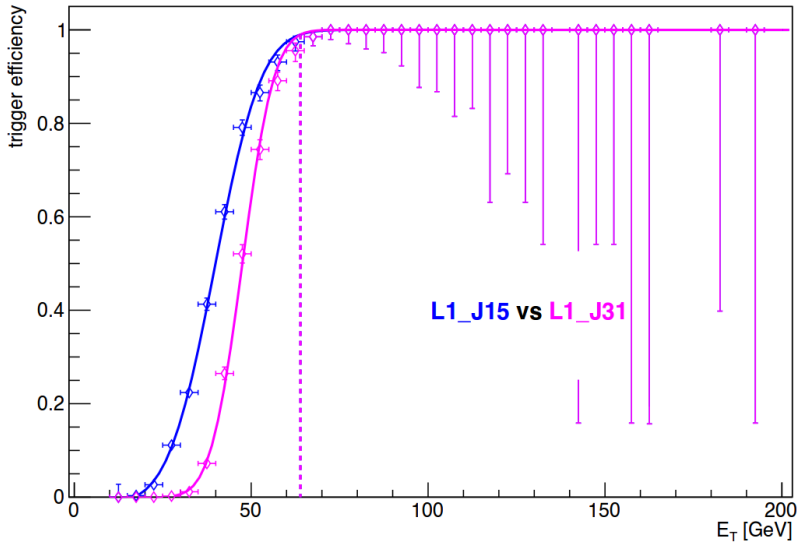
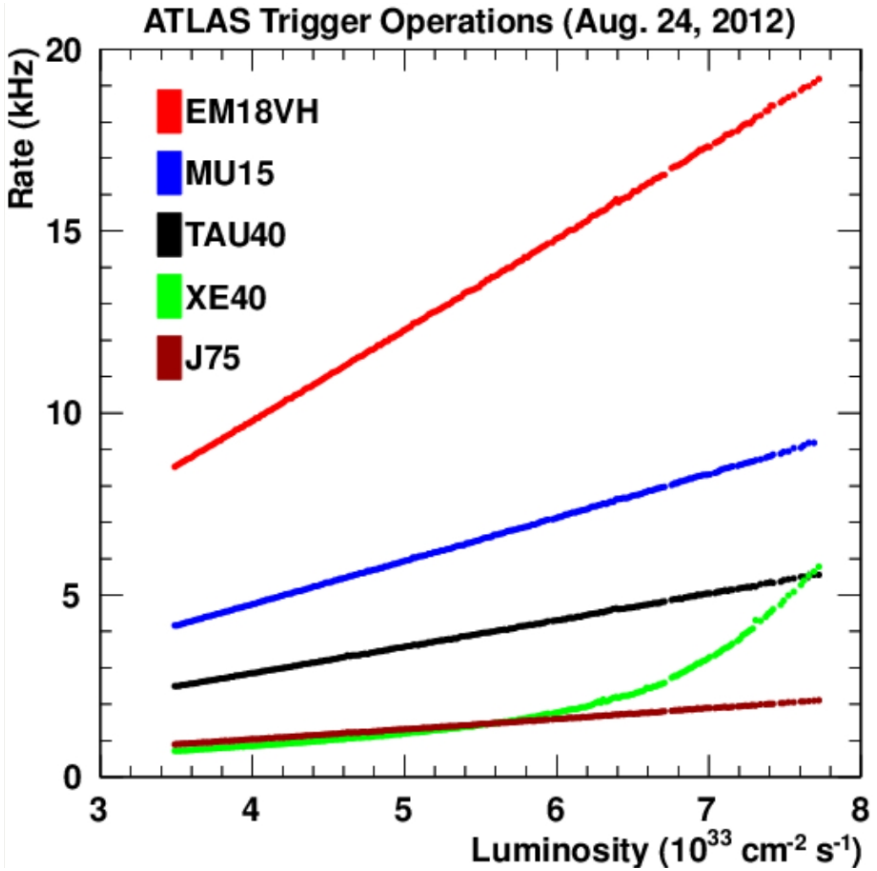


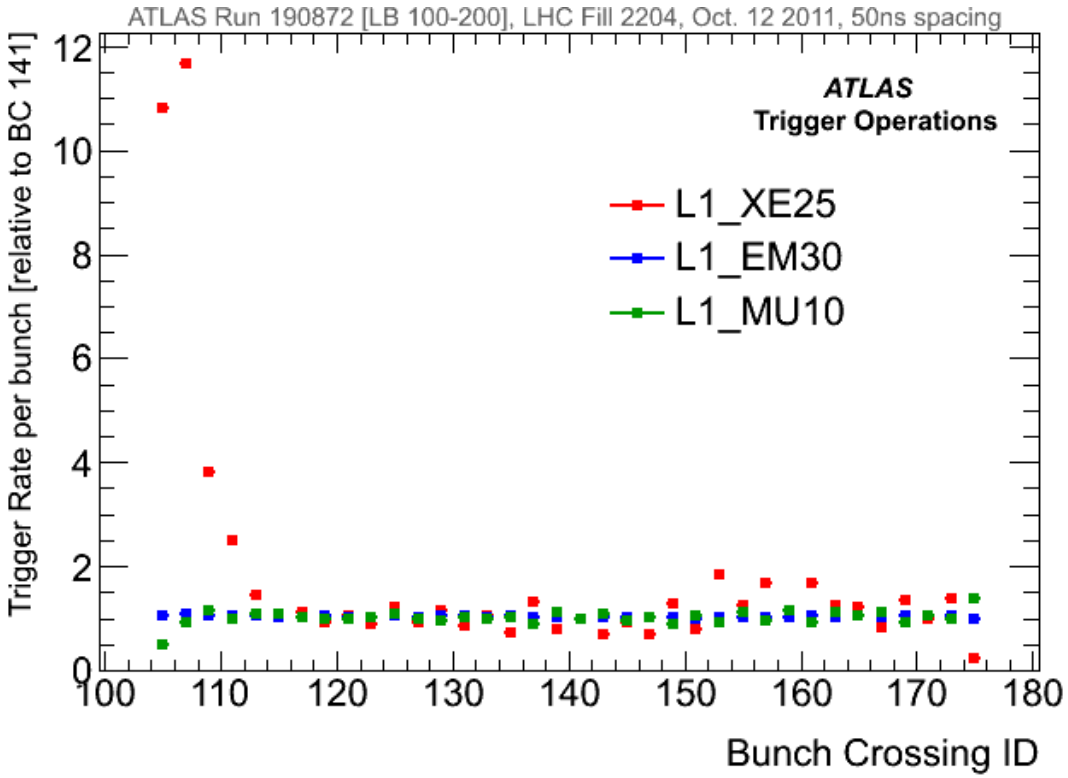


-New Run-2 Features-
Non-Linear Trigger Rates in Run-1

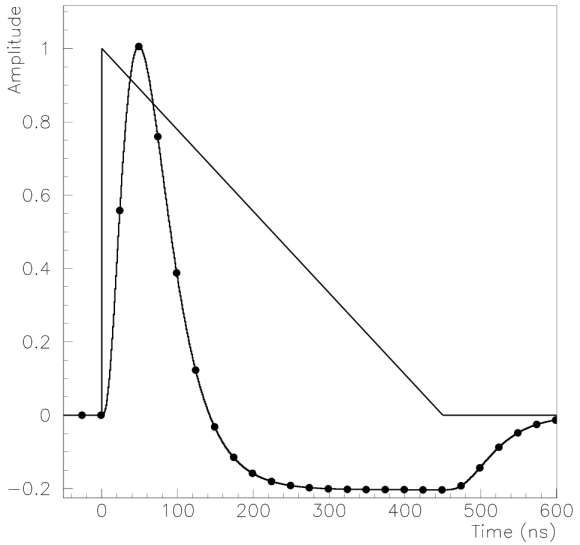
Trigger rates scale linearly with luminosity (N = L x σ)

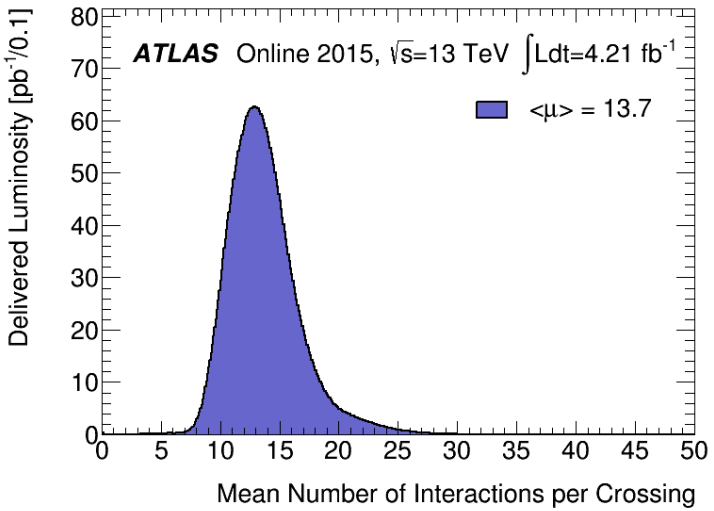
- In Run-1, multi-object triggers and Etmiss clearly non-linear
- Run-2 luminosity is higher -> unphysical events fill bandwidth

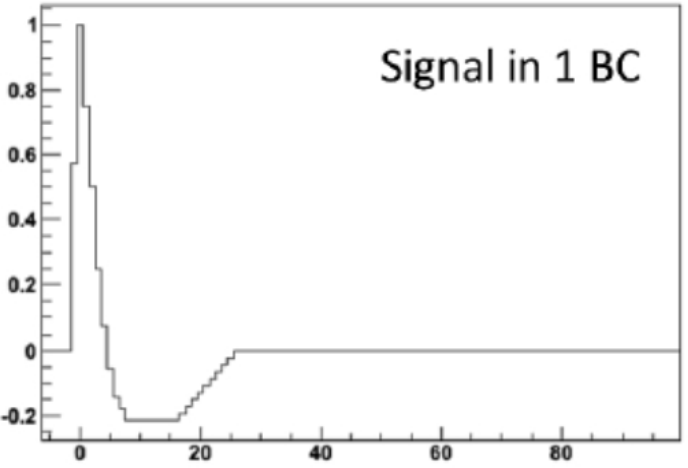
- 

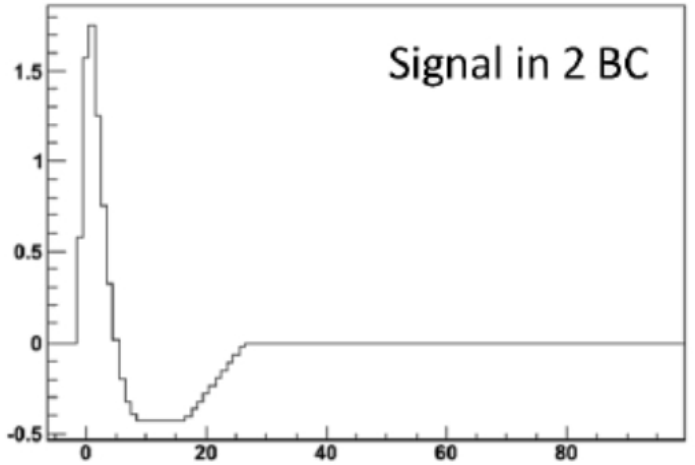


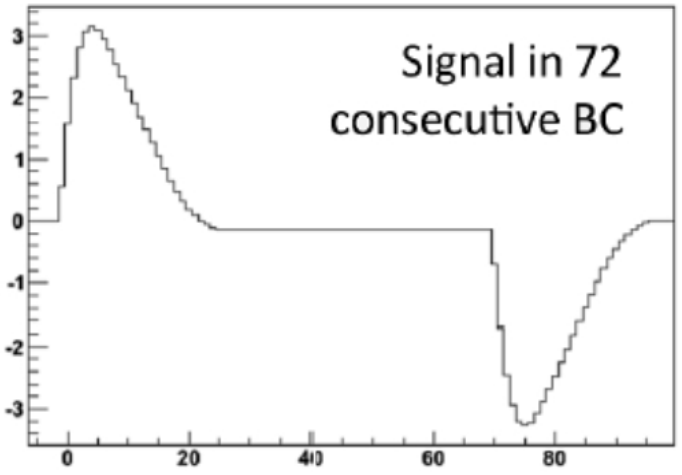
-New Run-2 Features-
Pedestal Fluctuations











-New Run-2 Features-
Pedestal Fluctuations

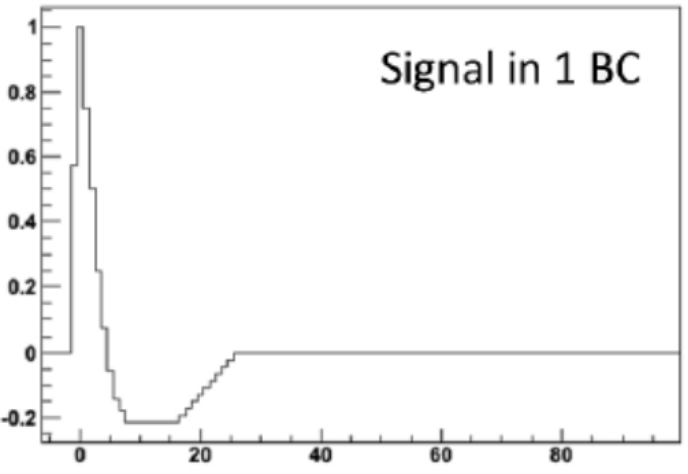
Baseline increase **at beginning of each bunch-train**

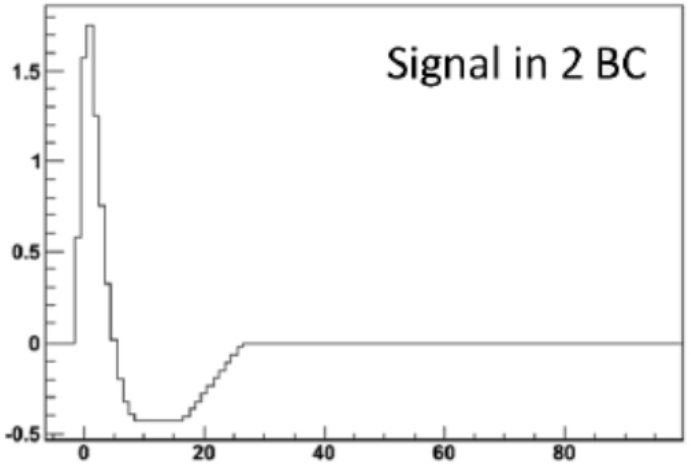
- Effect **in all L1Calo input channels** at same time

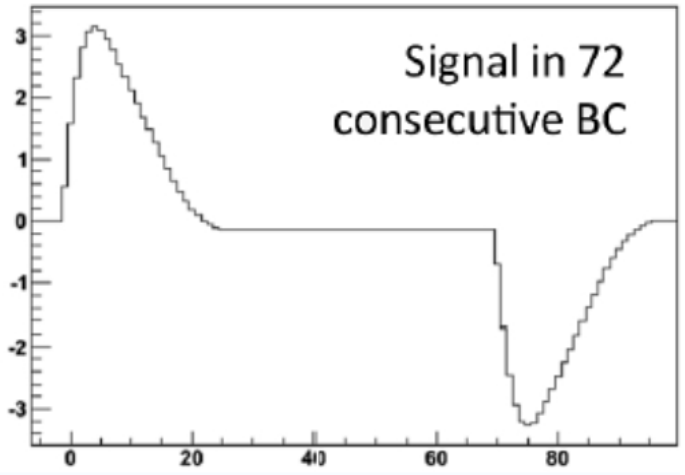
-> Triggers which sum many channels strongly affected

Correct for this effect by **correcting the baseline**

- Independently **for each channel**
- Independently **for each BCID** (position along LHC orbit)







-New Run-2 Features-
Pedestal Correction

Static vs Dynamic implementation

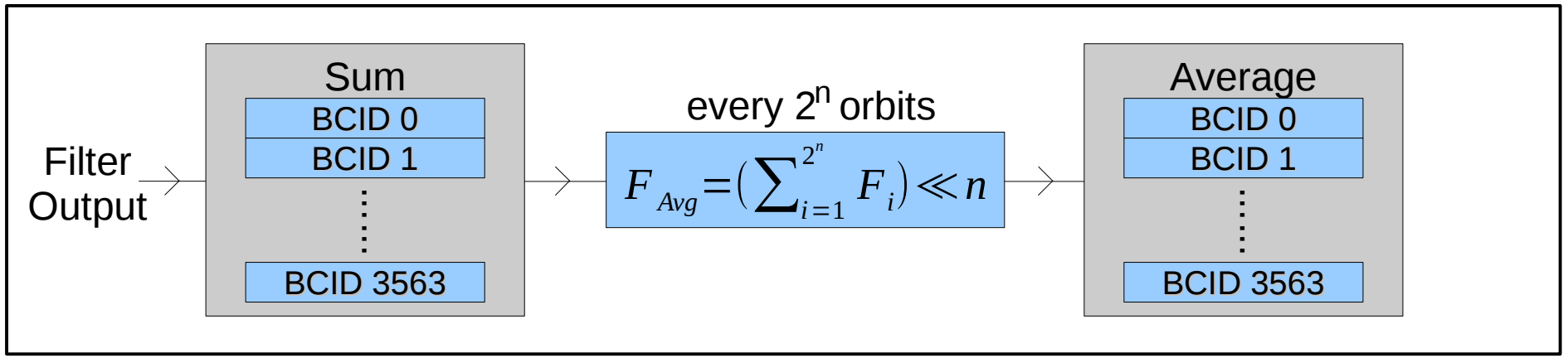
- **Static**: Load 3564 defined values during configuration
  - Change in LHC setup requires update
  - Luminosity falls during data-taking runs, affecting baseline shift
- **Dynamic**: Calculate values on-the-fly during the run
  - More complicated and resource intensive FW implementation

Dynamic solution preferred due to ease of operation & flexibility

- Update frequently enough to follow luminosity trend
- Ability to recover from 'bad states' (e.g. bad calo signals)
- Stability of output under stable operating conditions

-New Run-2 Features-
Dynamic Pedestal Correction

- Calculate **average** of filter values **per BCID for each channel**
  - Each LHC orbit add one value to each BCIDs sum
  - Repeat for configured number of orbits (2^n, n configured)
  - Calculate averages by dividing sum by number of orbits (>> n)



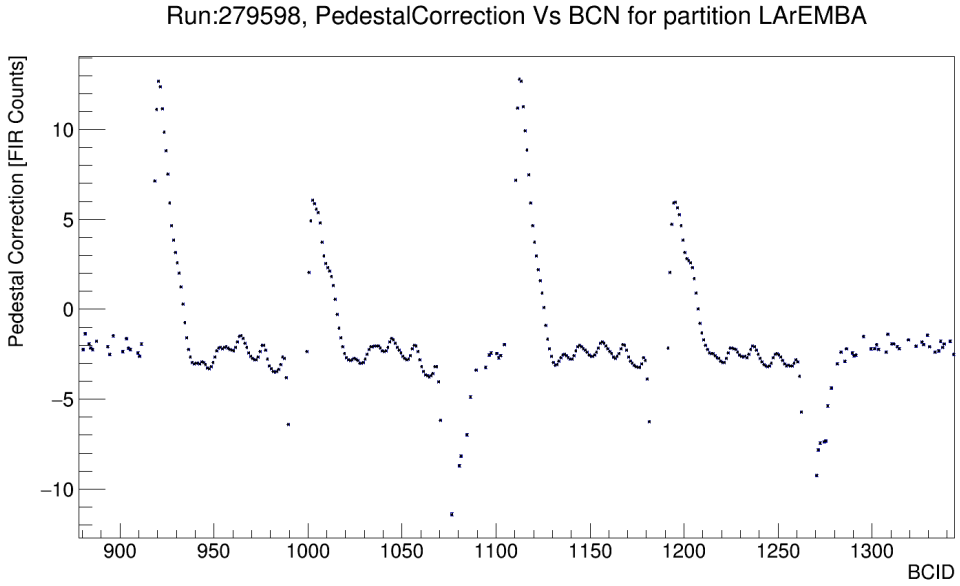
- Correct to configurable pedestal value by subtraction

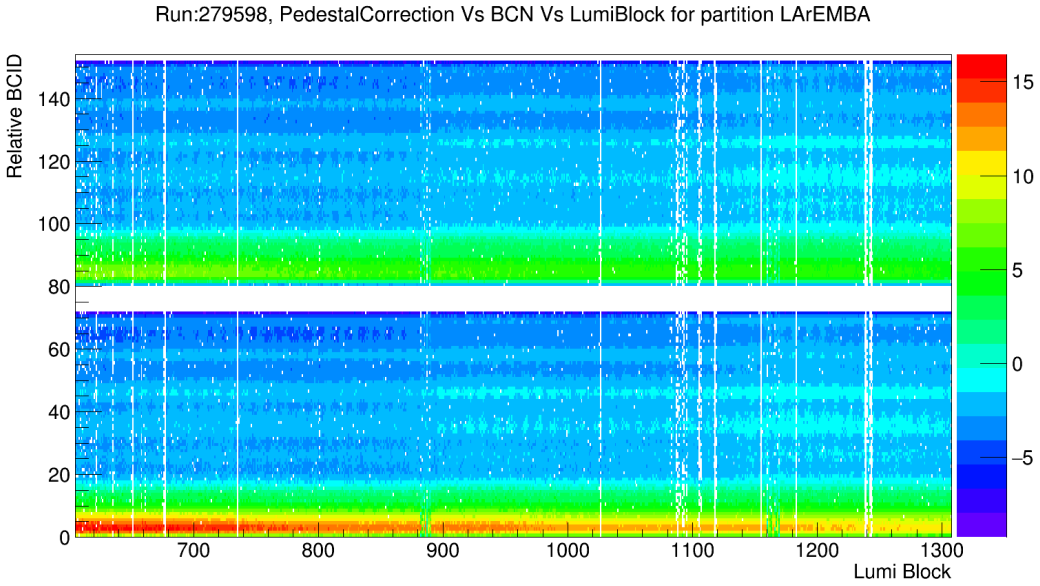
$$F_{corr} = F - \left(F_{Avg} - Ped_{Cfg}\right)$$

-New Run-2 Features-
Pedestal Correction Performance

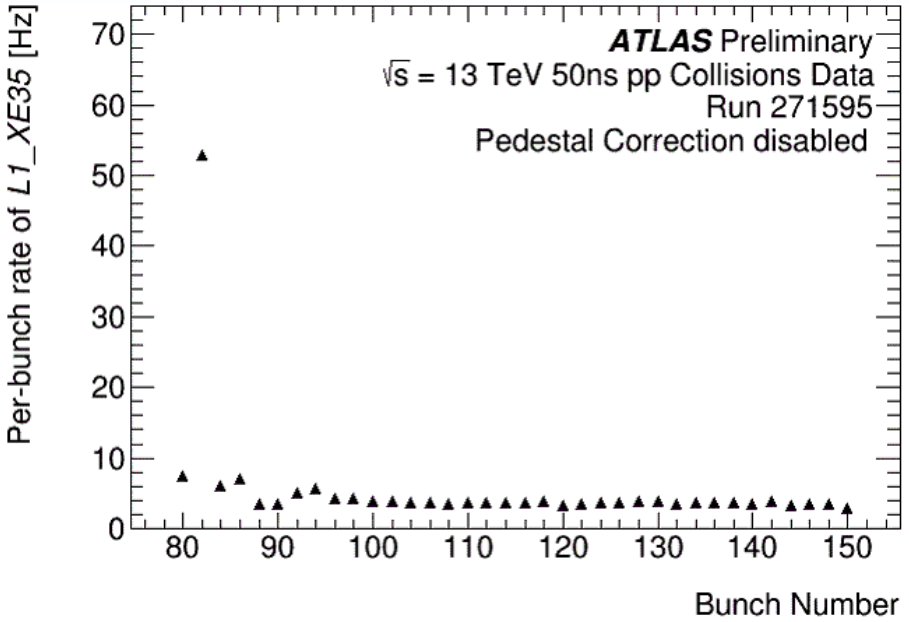
Correction values are read out during operation for monitoring

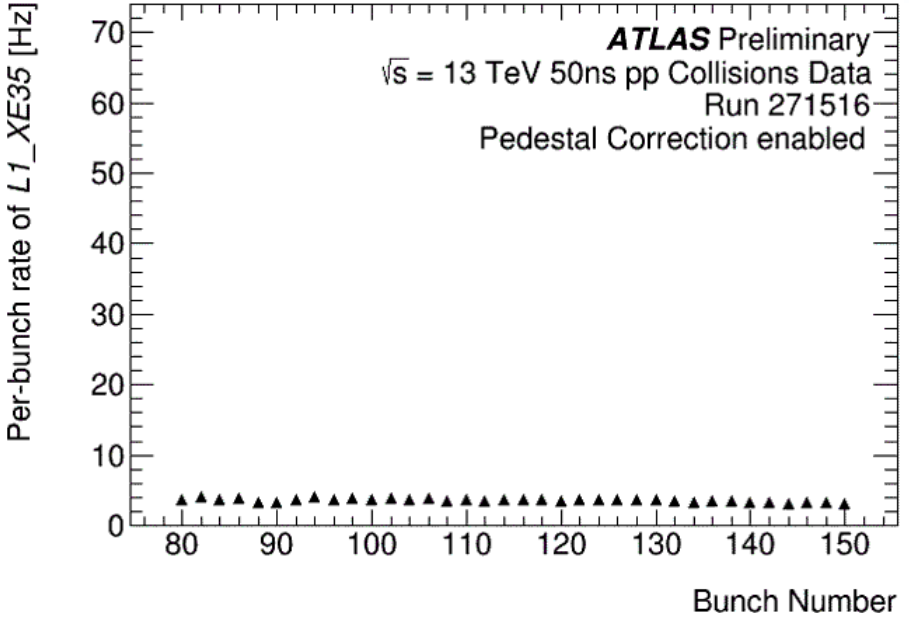
- To ensure operational stability
- Also allows study of performance

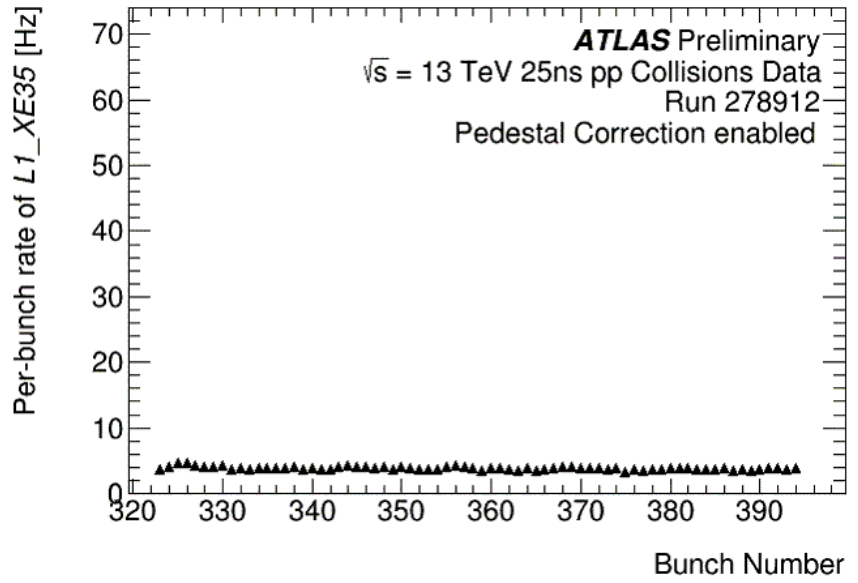


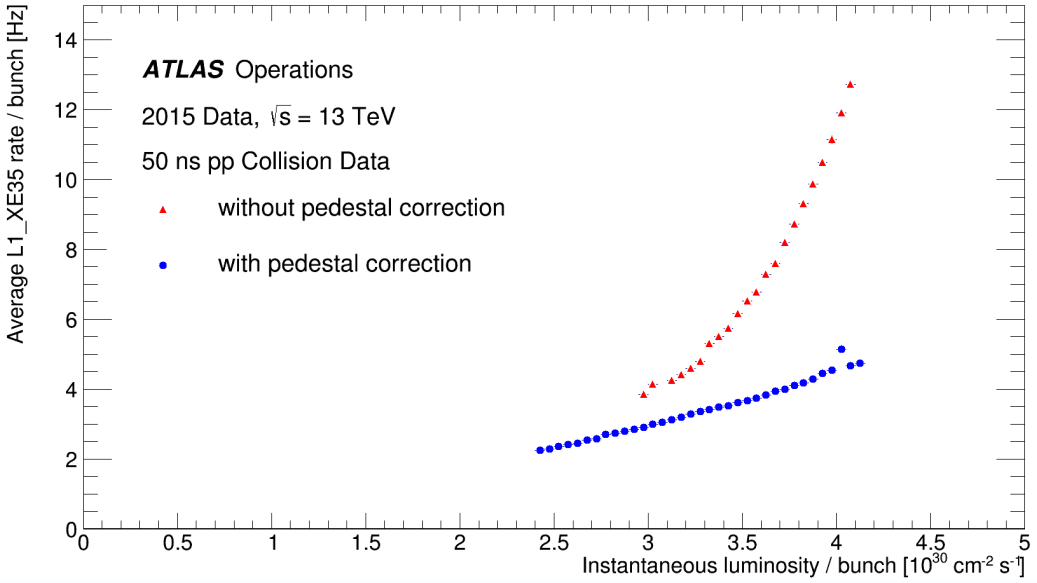


-New Run-2 Features-
Pedestal Correction Performance









-Summary-

- LHC Run-2 provides higher energy and luminosity

  -> More potential for physics, harsher environment for detector

- L1Calo Preprocessor upgraded to improve performance

  - Better digitisation performance from modern ADC

  - More possibilities in signal processing from modern FPGA

- Dynamic Pedestal Correction for pile-up induced fluctuations

  - Calculates on-the-fly correction for each channel, for each BC

  - Large reduction in fake Etmiss rates

  - Solid performance over many months of running in 2015