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Calibration and Performance of the ATLAS Level-1 Calorimeter Trigger

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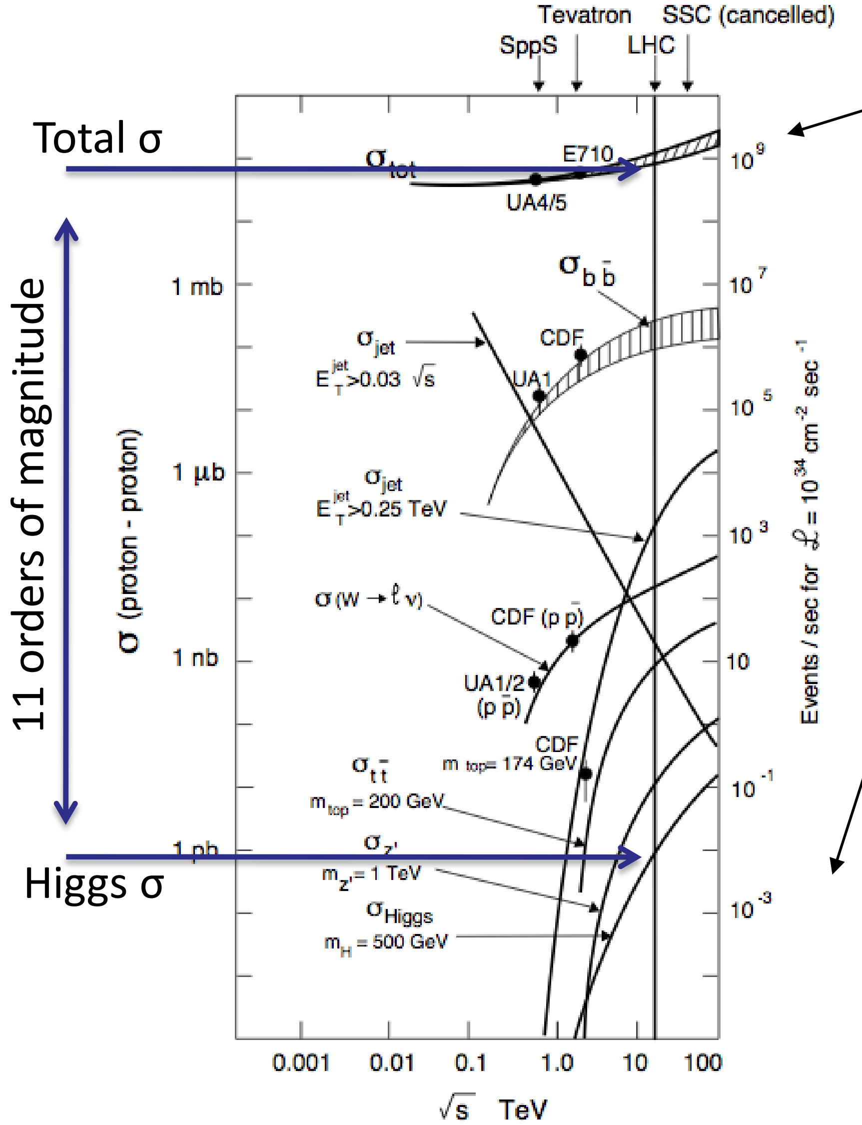
What Is Interesting?



Most of the time we are here

But here it gets really exciting!

During one LHC second

(at design luminosity and energy)

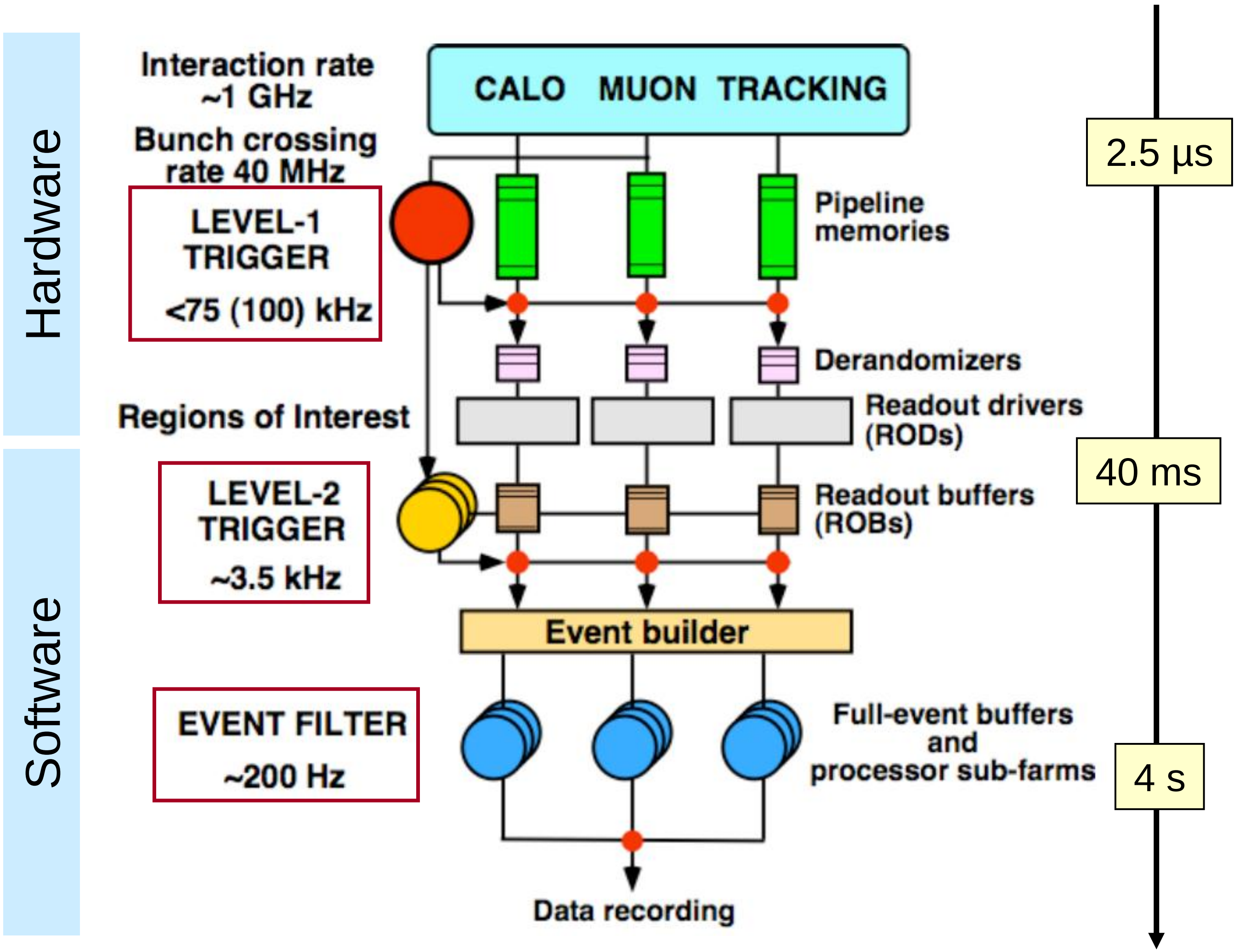
- ~10^9 pp interactions
- ~10^3 W events
- ~500 Z events
- ~10 top events
- ~9 SUSY events (?)
- ~0.1 Higgs events (?)

→ But only ~200 can be recorded

→ Powerful trigger needed

ATLAS Trigger Overview

Three trigger layers

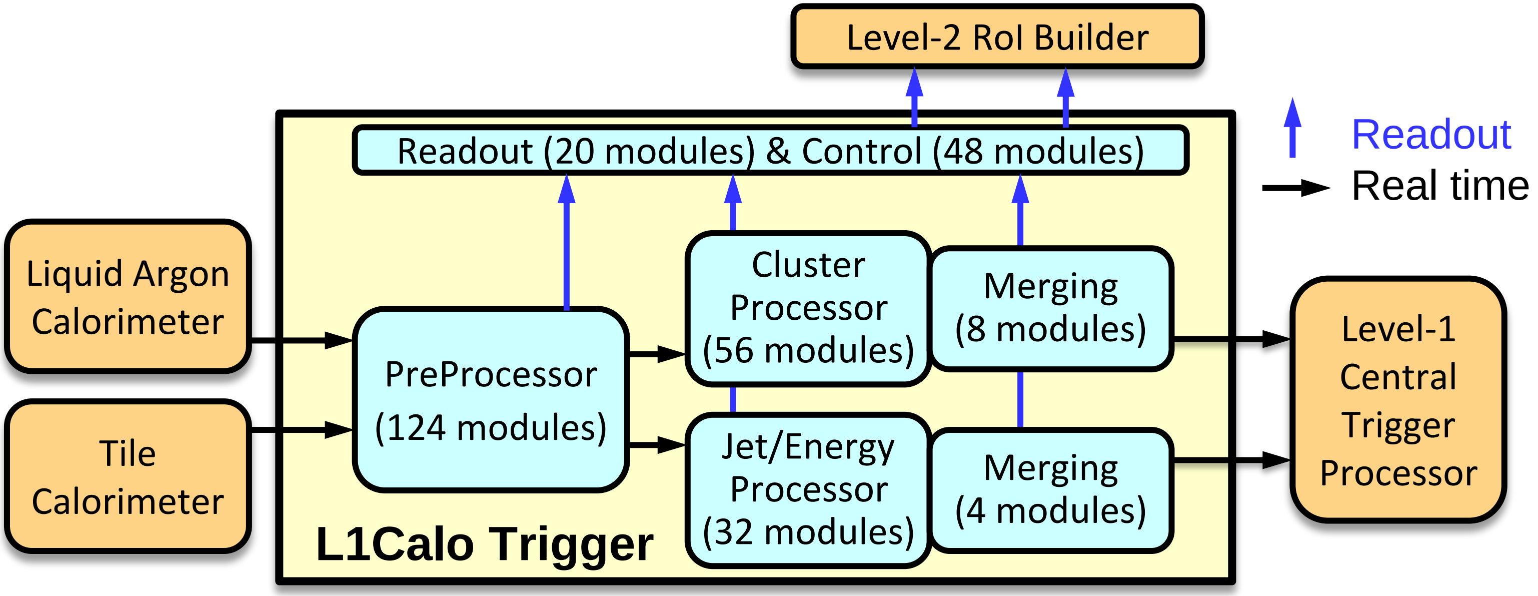


LVL1: Mainly calorimeter and muon data with reduced granularity

LVL2: "Regions of Interest" RoI data with full granularity from selected sub-detectors

EF: Refined selection based on full event readout

ATLAS Level-1 Calorimeter Trigger



Fixed latency, pipe-lined, hardware based system using custom electronics

Nearly 300 VME modules of about 10 different types housed in 17 crates

Mixed-signal system

Entirely located off the detector in the ATLAS electronics cavern

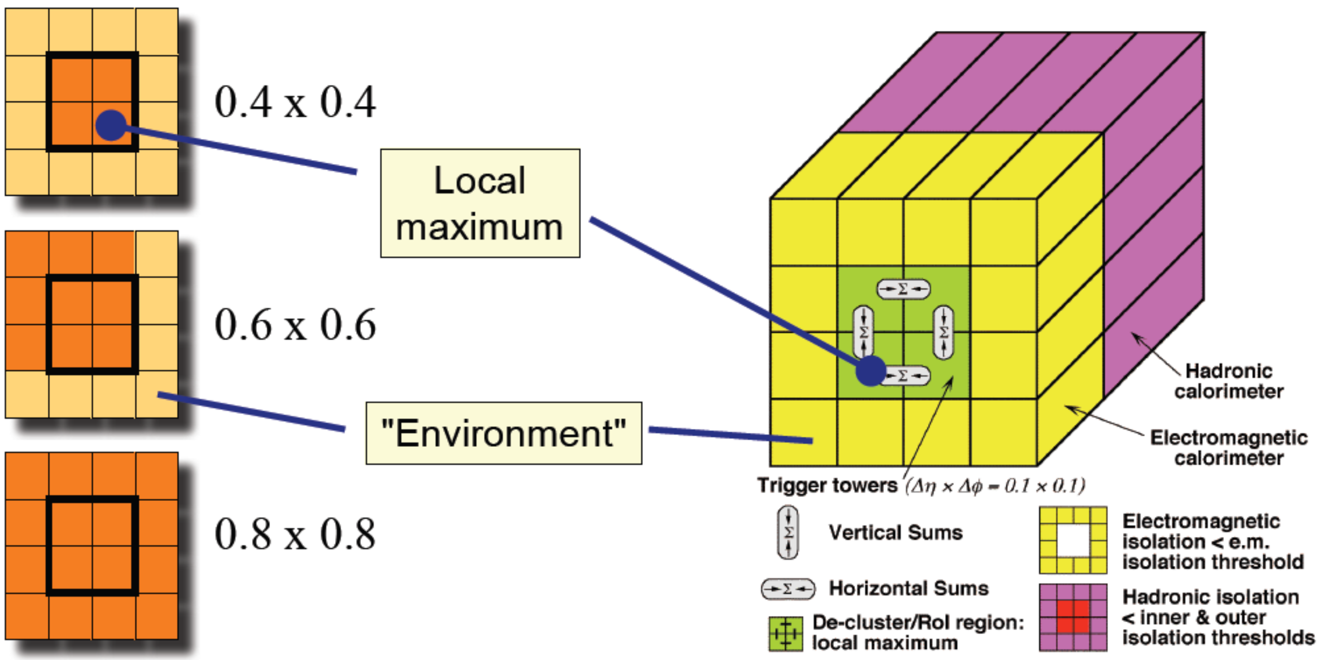
PreProcessor PPr: Digitisation and bunch crossing identification

Cluster Processor CP: Identifies electrons, photons and hadrons

Jet/Energy Processor JEP: Jet finding and energy sums

L1Calo Algorithms

Jet algorithm: EM cluster algorithm:

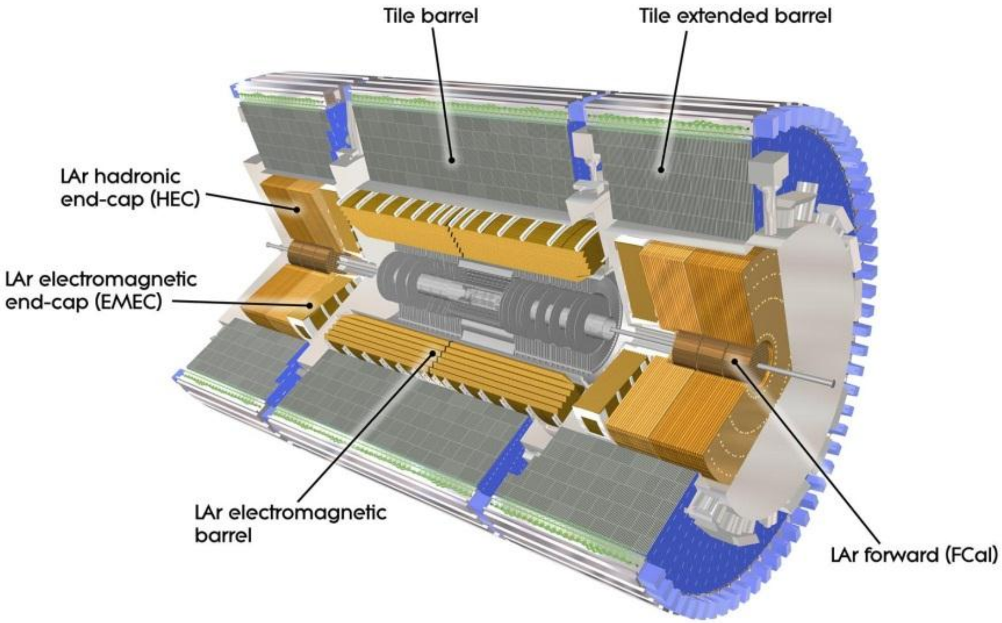


- Two independent processor subsystems (CP/JEP) using common architecture
- Processor input is matrix of digitized trigger tower energies from PPr system
- Search for local (isolated) maxima using overlapping, sliding windows
- → Multiplicities of objects (e.g. electrons, photons, jets) above settable E_T thresholds transferred to central trigger
- → RoIs giving details of object candidates read out by RODs and sent to L2 RoI Builder

ATLAS Calorimeters

Liquid Argon Calorimeter (LArg)

- Mainly accordion-shaped Kapton electrodes and lead/copper absorber plates
- Three sampling layers. Barrel segmentation: $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$

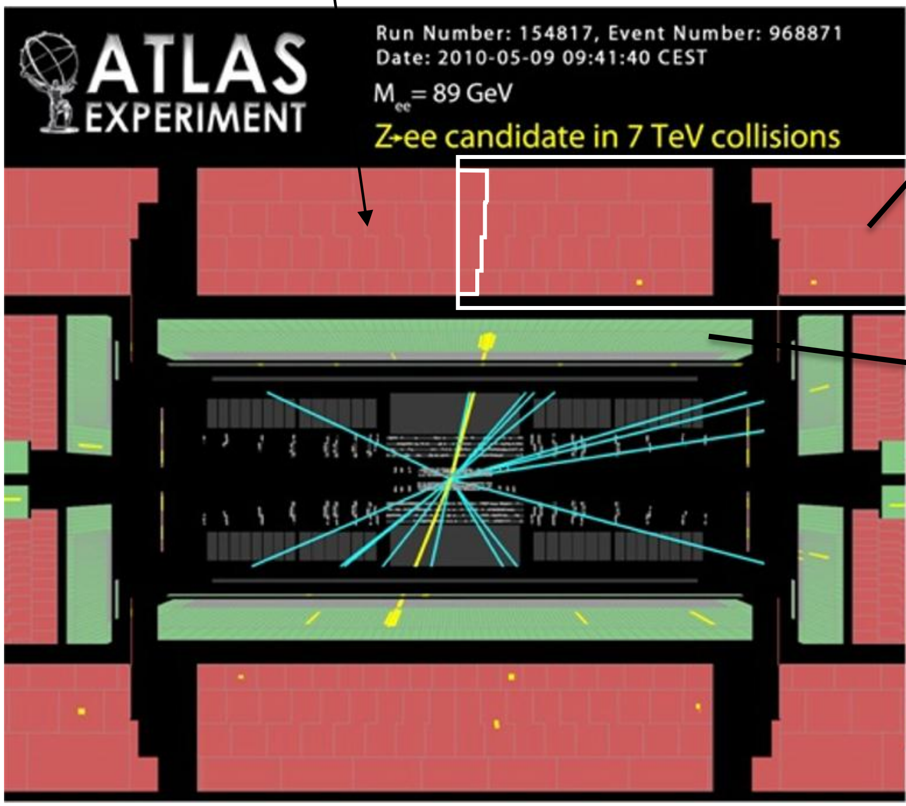


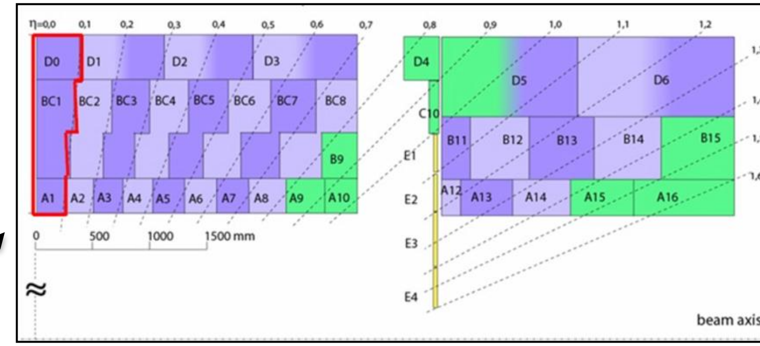
Hadronic Tile Calorimeter

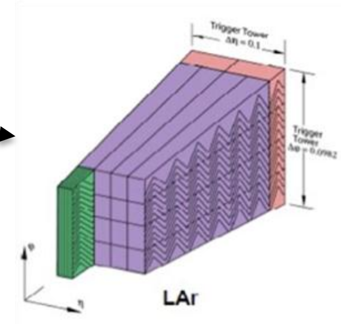
- Uses scintillating tiles with steel absorbers (total thickness is 9.7 interaction lengths)
- Three sampling layers. Segmentation: $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

L1Calo Input: Trigger Towers

Outer hadronic Tile Calorimeter







~7200 projective trigger towers

~250k calorimeter cells summed on detector to 7168 trigger towers

Granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

Analogue signals routed to L1Calo system using up to 70m long cables

Inner electromagnetic / hadronic LArg Calorimeter

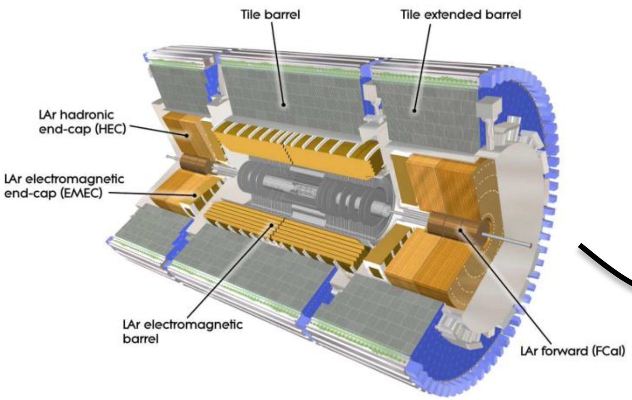
ATLAS L1Calo Hardware

(Half of) Receivers and PreProcessors

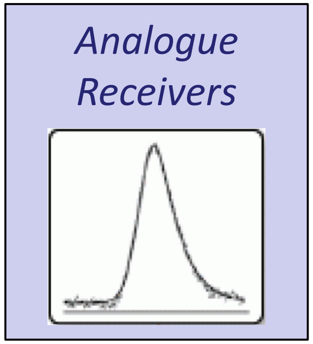
Processors

Readout Drivers

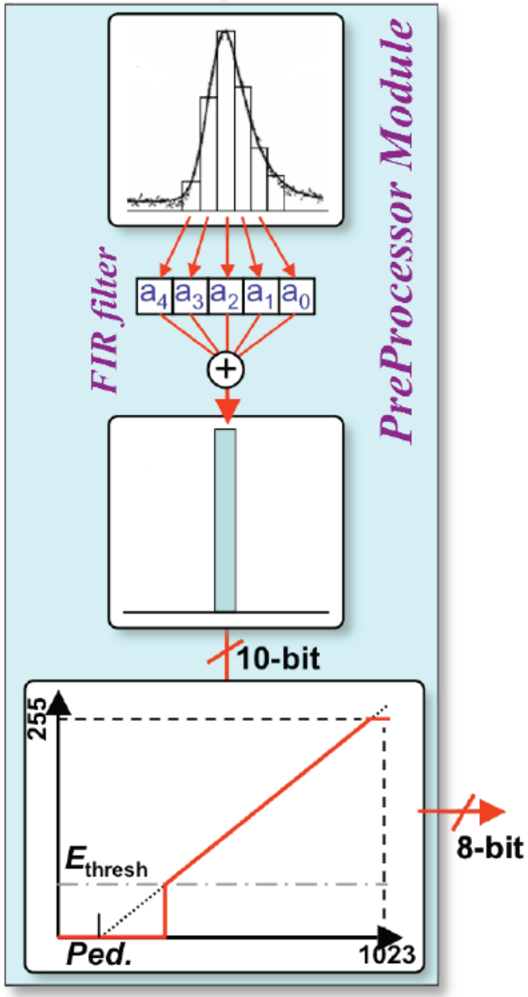
Analogue Signal Path



long cables 30-70 m



short cables



Analogue receiver system

- Variable gain amplifier (1st stage of energy calibration)
- Signal adjustment proportional to sin(θ) (where needed)

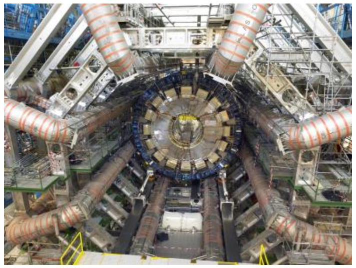
L1Calo PreProcessor system

- Fine timing adjustment at ns level
- Digitisation at 40 MHz, 10 bit ADC, ~0.25 GeV/count
- Bunch crossing identification (BCID) using digital filter
- Final energy calibration in look-up-table (LUT)

→ Calibrated 8-bit trigger tower E_T sent to L1Calo processors

Timing Calibration

30-70m long cables



Analogue signals need to be precisely aligned in time at L1Calo input:

- → Need ±5ns precision for accurate BCID and ~2% energy resolution
- → Direct impact on trigger efficiency turn-on curves

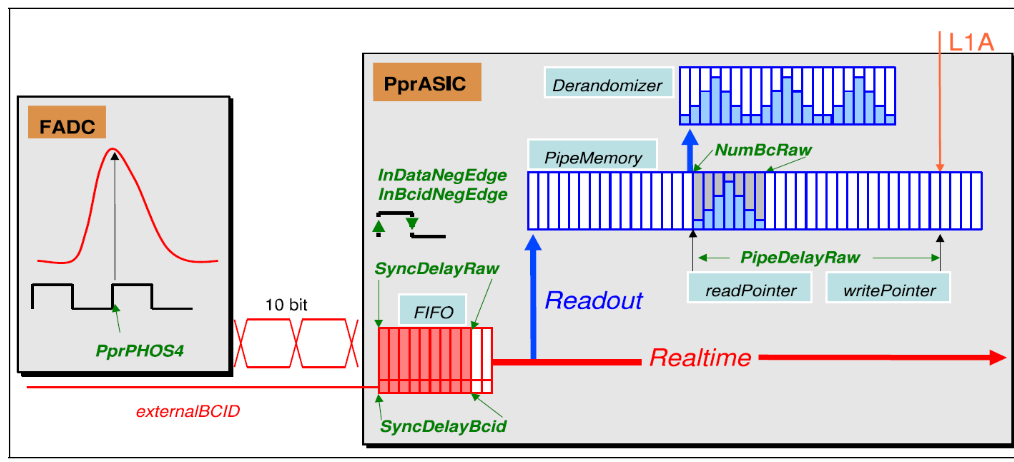
- Initial timing derived from analysis of first LHC splash events (Nov 2009)
- Improved timing delays applied early after first 7 TeV collisions (July 2010)
- Since then small updates and corrections, timing achieved better than ±2ns

Coarse timing (to 1BC)

- to compensate for different cable lengths
- adjustment of readout pointer

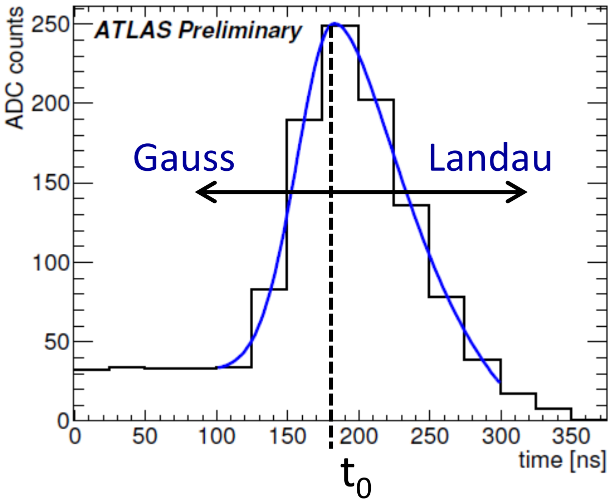
Fine timing (to 1ns)

- for precise energy determination and BC identification
- by using the PHOS4 delay chip



Fitting Method

- Use Gauss-Landau or Landau-Landau function (depending on calorimeter position) to fit trigger tower signals using LHC collision data



Gauss: $$f(t \leq t_0) = A \cdot exp\left[-\frac{(t-t_0)^2}{2\sigma^2_{gaussian}} - \frac{1}{2}\right] + C$$

Landau: $$f(t > t_0) = \left(A + D \cdot exp\left(\frac{1}{2}\right)\right) \cdot exp\left[-\frac{1}{2}\left(\frac{t-t_0}{\sigma_{landau}} + exp\left(-\frac{t-t_0}{\sigma_{landau}}\right)\right)\right] + C - D$$

Fit parameters:

A: free normalisation

t_0: free timing offset

$\sigma_{Gauss/Landau}$: fixed widths

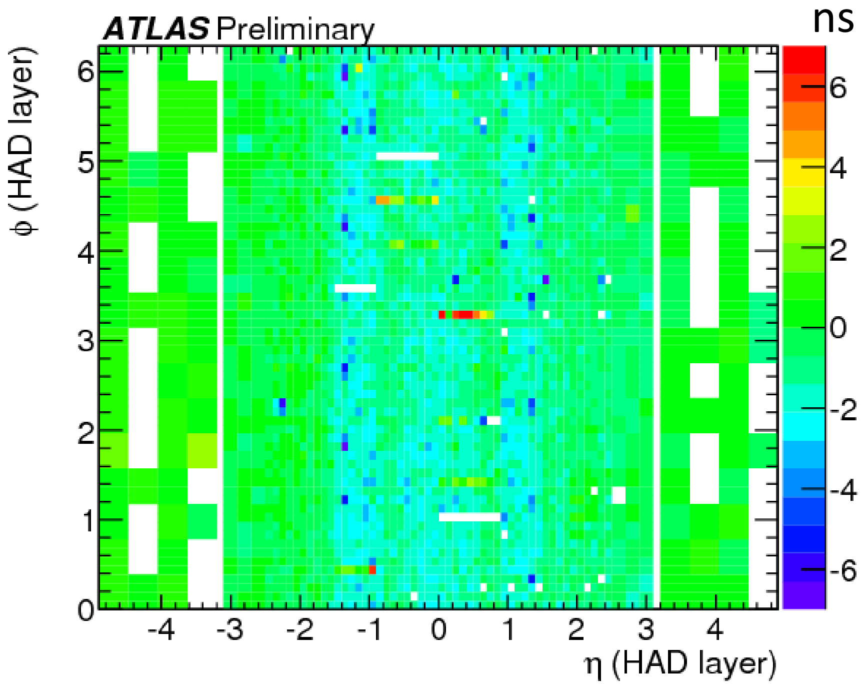
C: fixed pedestal

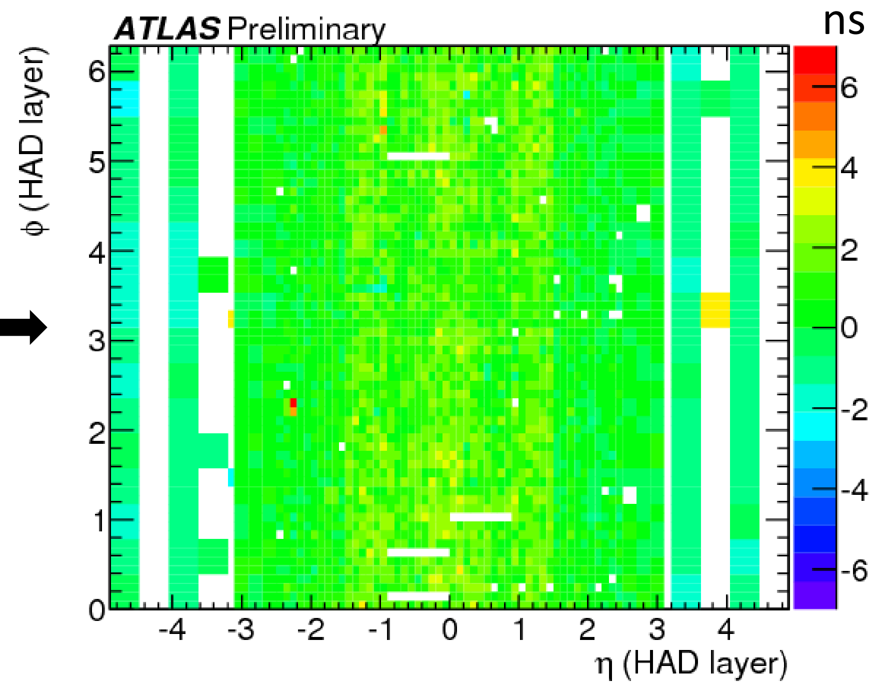
D: partially fixed

- Some parameters derived from pulser calibration runs (timing scans) and fixed for collision pulse fits
- Pulses in calibration runs broader than in physics runs, need to understand impact on fit method and timing results

Timing Status in 2011

- The offset to the ideal timing (in ns) as derived from collision data is given by the mean difference between the fitted maximum position t_0 and the middle of the central bin



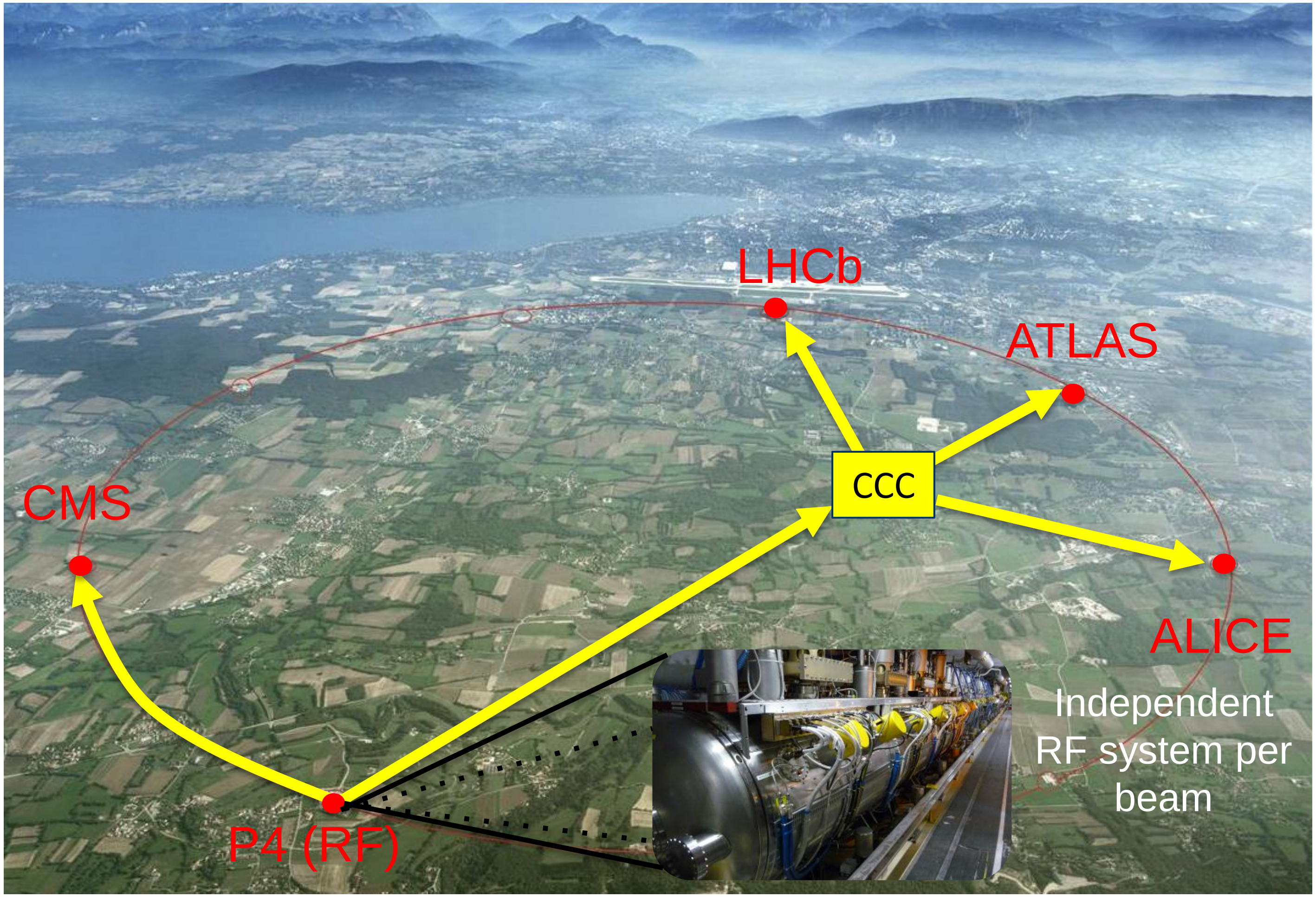


Timing within ±2ns at the beginning of the 2011 running period (March)

Largest offsets for electronics repaired during winter shutdown

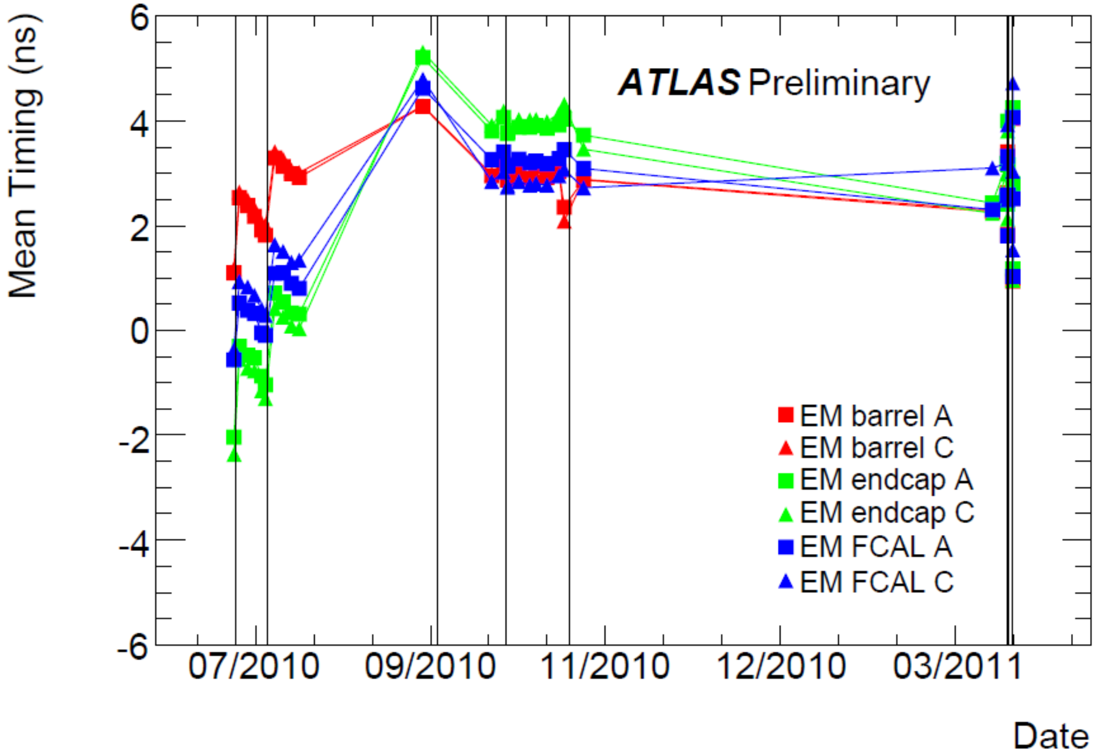
Timing offsets in April after applying corrections

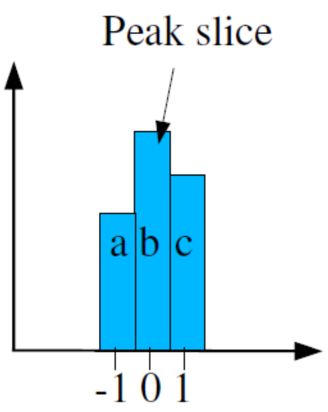
Timing Signals from LHC



- LHC clock distribution to ATLAS sensitive to environmental effects
- Regular readjustment of ATLAS clock phase needed

Monitoring the Timing





$$fine\ time = \frac{c - a}{2\,(2b - c - a)}$$

- Monitor the timing using a simplified fit method which determines the "fine time" per trigger tower
- Simplified method cannot be used to measure the absolute timing but very good for monitoring relative changes
- Timing monitoring accurate enough to measure changes of LHC clock

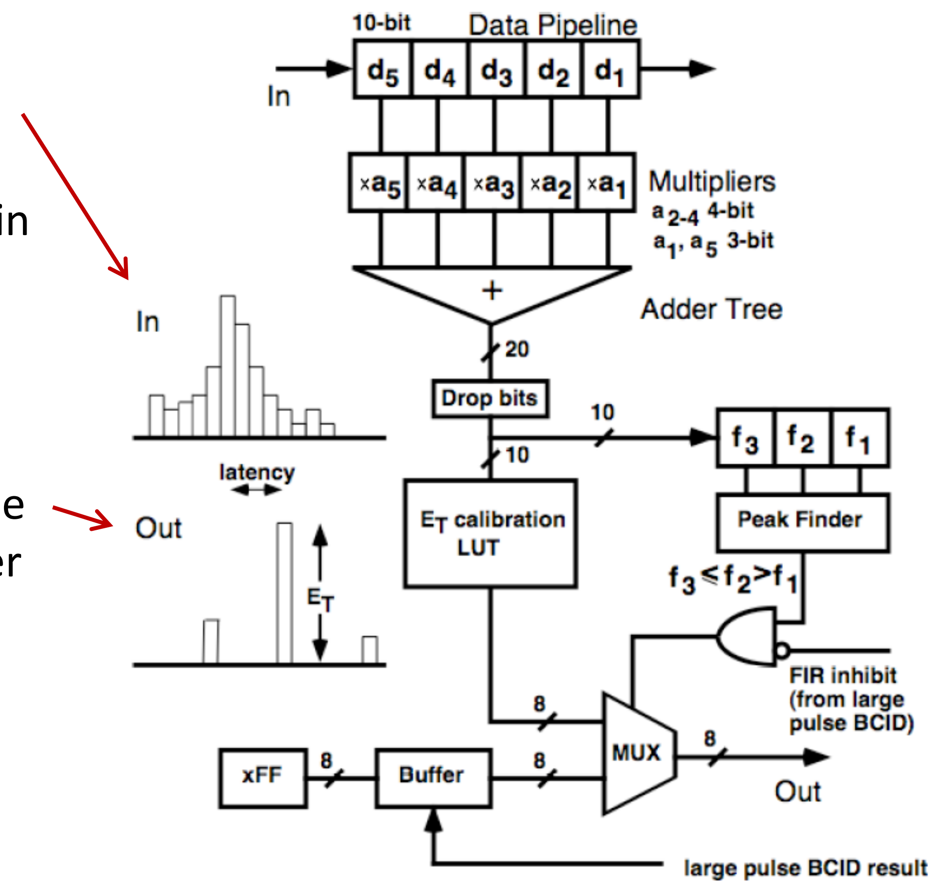
FIR Filter and LUT Calibration

- Need to identify the correct LHC bunch crossing down to lowest energies
- Main method for unsaturated pulses is Finite-Impulse-Response (FIR) filter which "sharpens" the pulse before putting it through a peak finder

1. Pulses are sampled with 40 MHz and several bunch crossings (25ns) wide
2. Weighted sum of several samples made in digital pipeline to sharpen pulse
3. 20-bit sum is adjusted to 10 bit range (in "drop bits")
4. "Drop bits" output is fed to Look Up Table (LUT) for E_T conversion and to peak finder to associate with correct bunch crossing

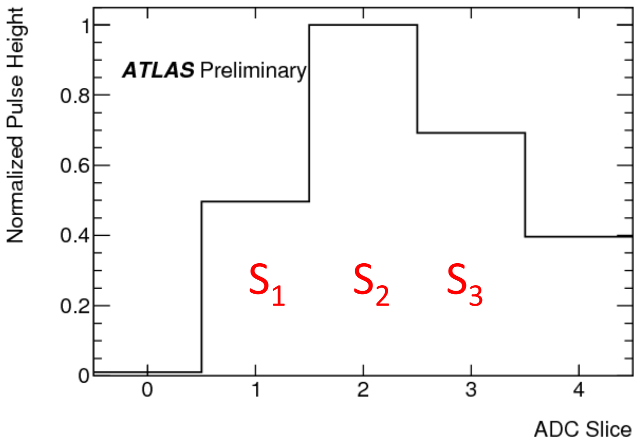
→ Best performance expected for filters adjusted to signal shape

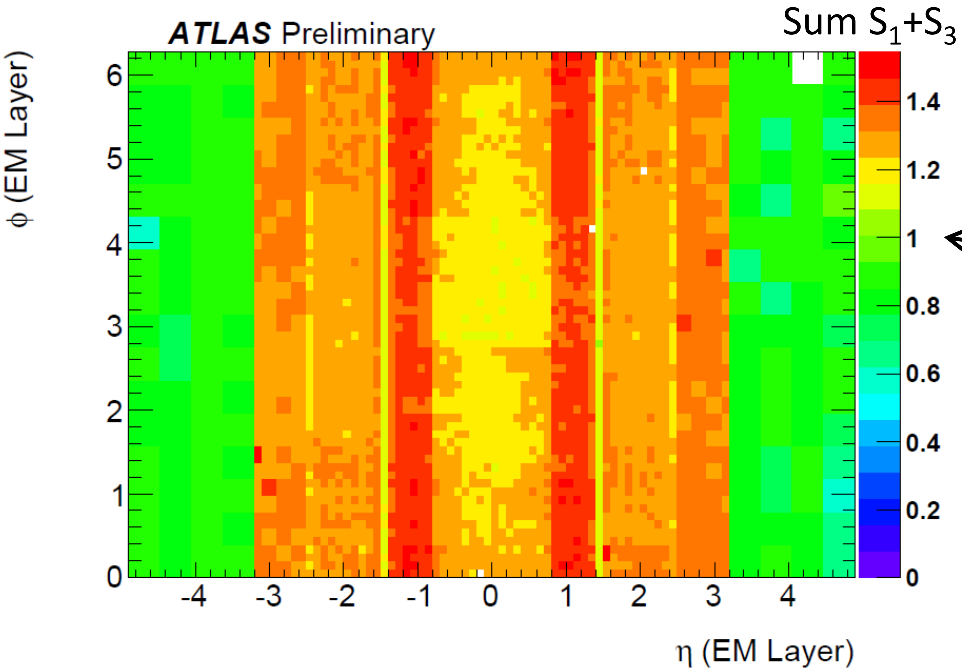
→ Optimisation using LHC collision data



FIR Filter Calibration

- Initial FIR filters derived from calibration pulses but pulse shapes slightly different for real particles from collisions
- For each trigger tower determine the normalised pulse shape from LHC collision data

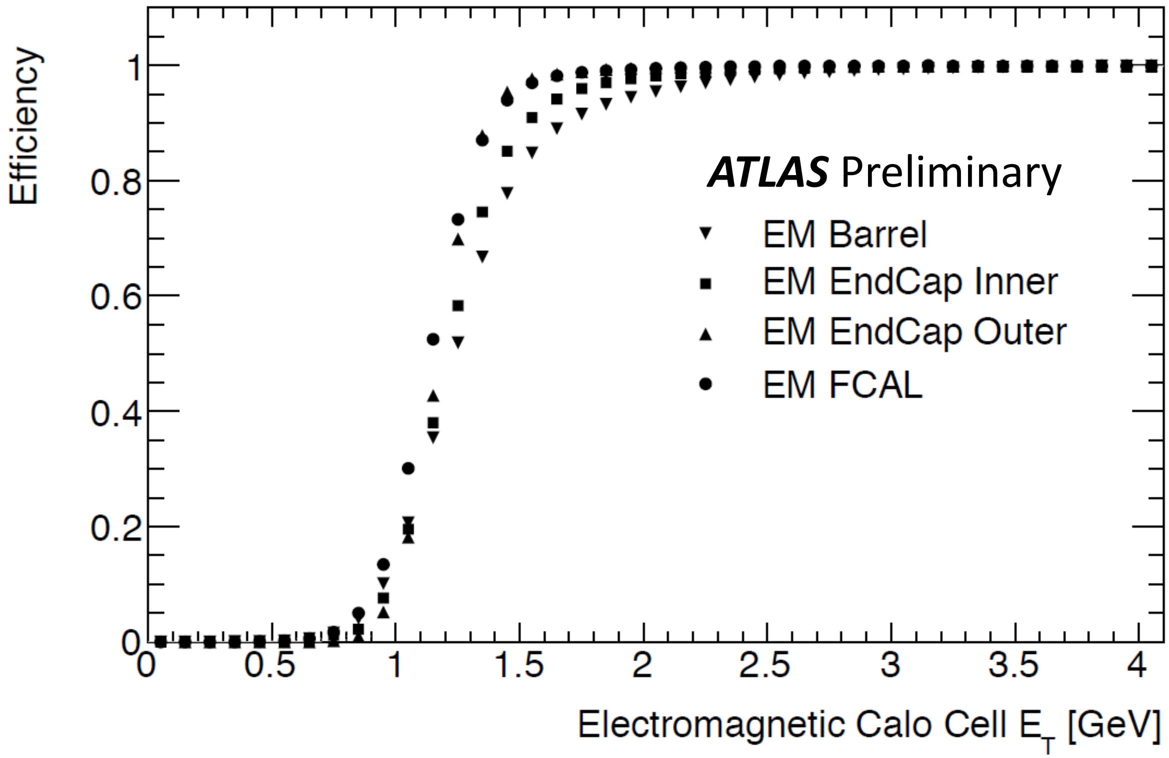




Identified regions with similar pulse shape for EM layer:
|η| = [0, 0.8] , [0.8, 1.4] , [1.4, 1.5] , [1.5, 3.2] , [3.2, 4.8]

- Identify regions (in eta) with similar pulse shape by using the sum (S_1+S_3) where S_i is the normalised peak height of the i-th ADC sample
- Derive averaged pulse shape for each identified region
- Use these shapes to derive FIR coefficients for each region
- Choose normalisation and drop-bits range such that 8-bit LUT coverage is maximised

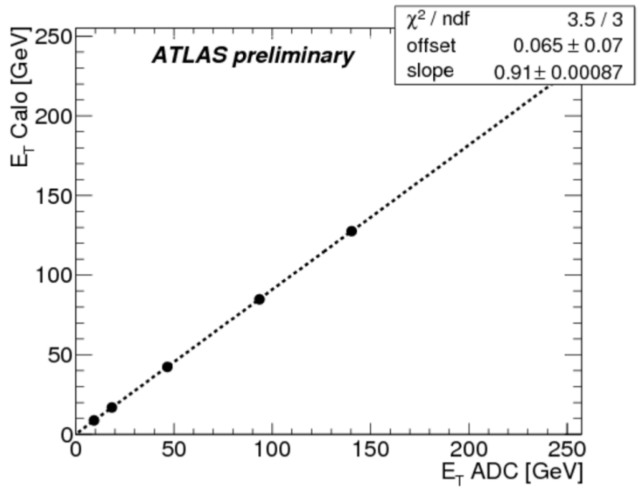
BCID Identification Efficiency

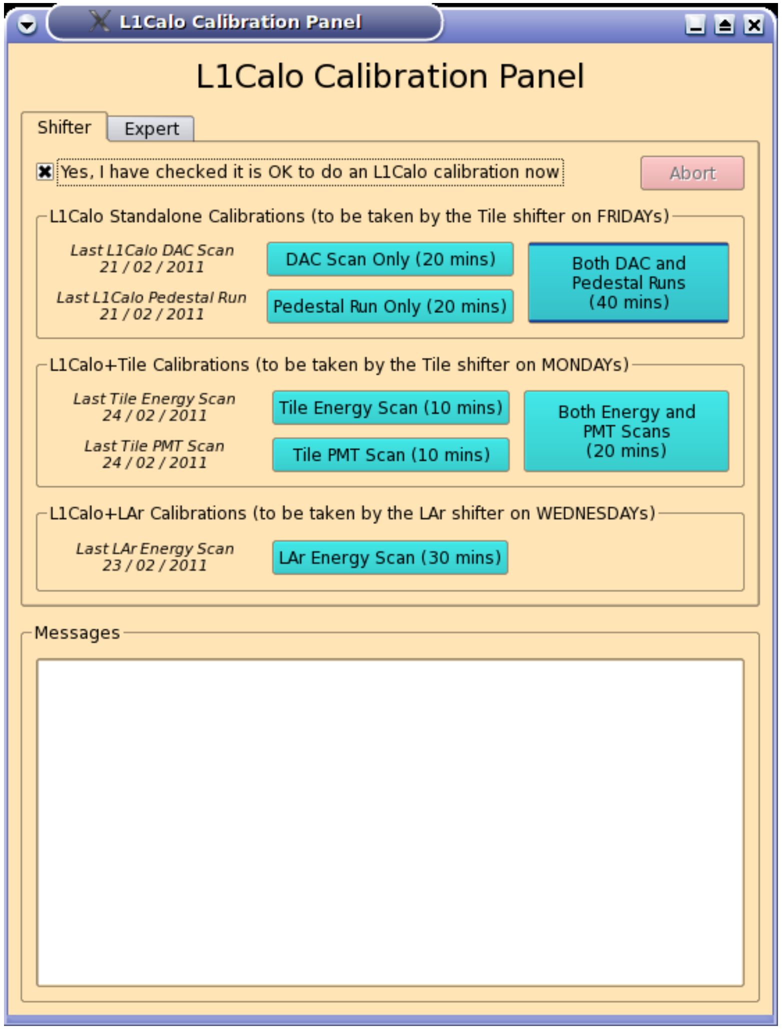


- Good indication of the success of timing and BCID logic is the efficiency of associating small energy deposits to the correct bunch crossing
- The turn-on at around 1.2 GeV is a result of the LUT noise cut and in line with the optimal performance expected from simulation

Energy Calibration Procedure

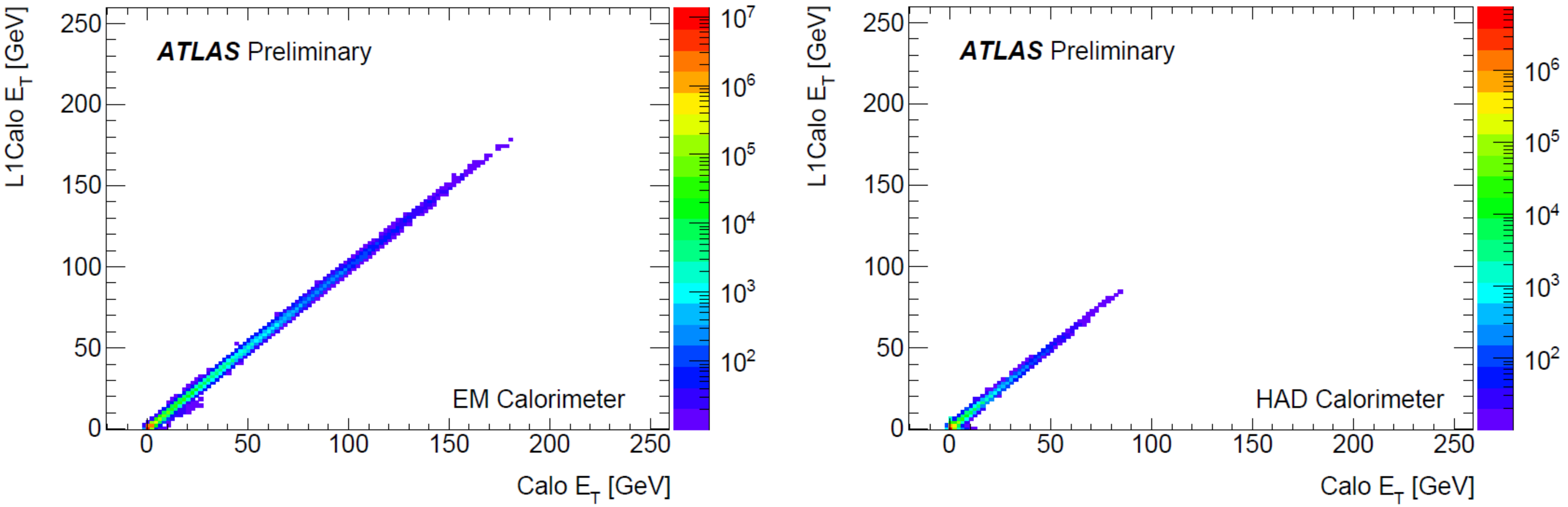
- Energy calibration (ADC to E_T) implemented in analogue receiver gains (and LUT slope)
- Use dedicated calorimeter pulser runs taken in between LHC luminosity fills





- Calibrate with respect to the (more precise) energy as measured by the calorimeter
- In offline analysis derive receiver gain from slope of linear fit to energy points in the calibration run

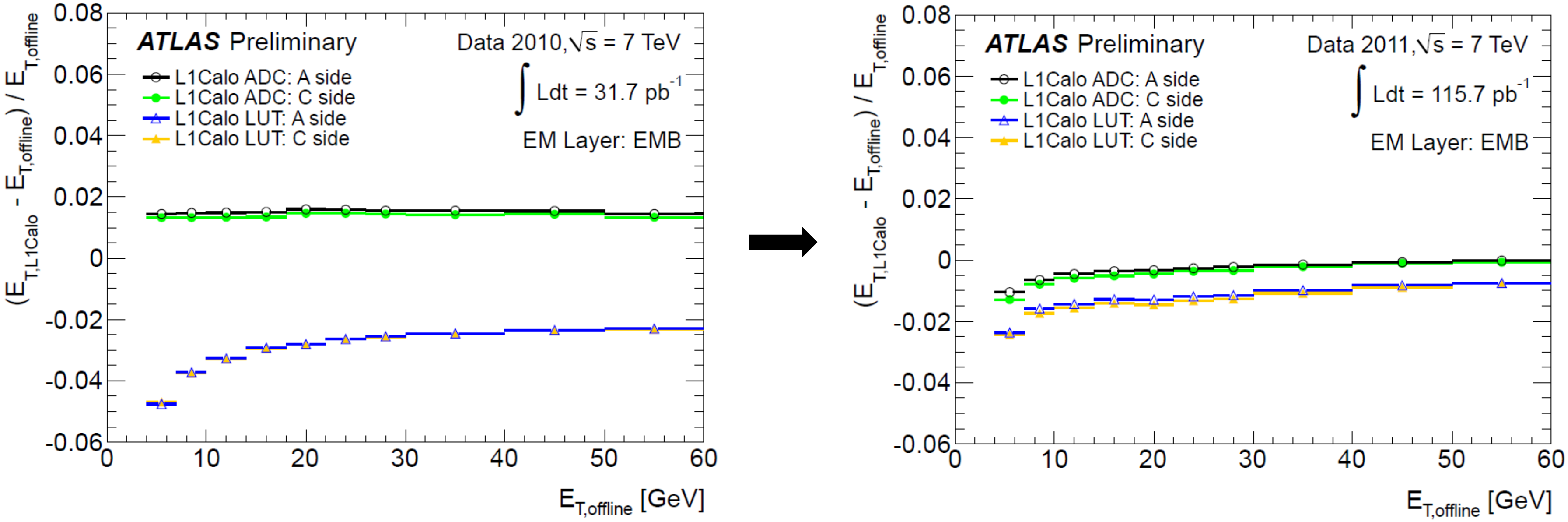
Energy Calibration Results



- Energy correlations for the electromagnetic and hadronic layer derived from initial 2011 collision data

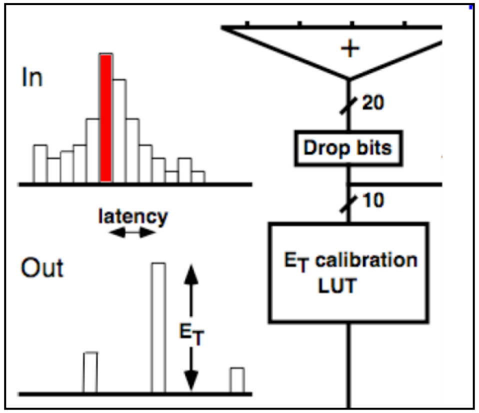
→ Very good agreement between the L1Calo and calorimeter measured energies

Optimisation of LUT Performance

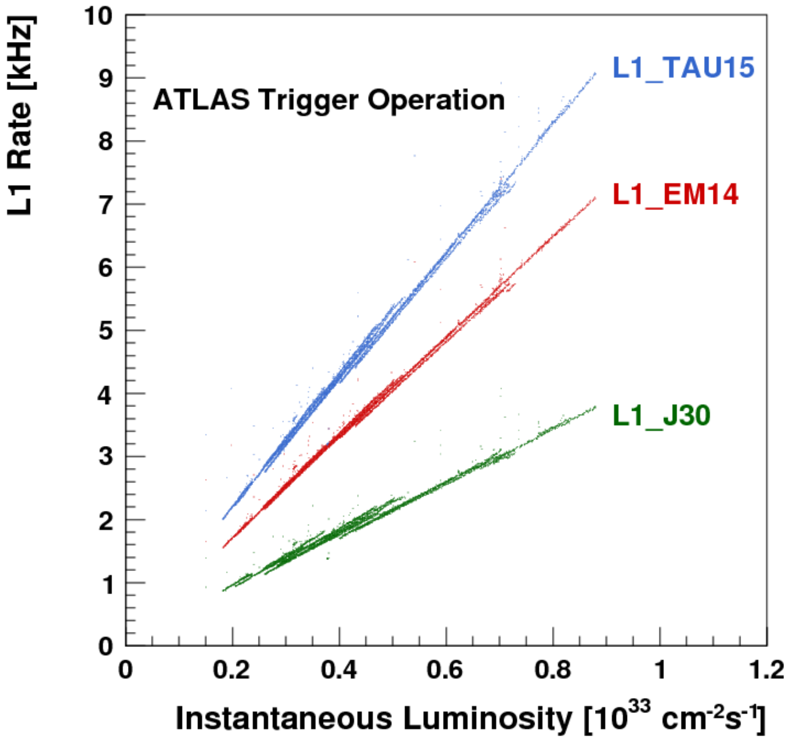


- Fractional difference of L1Calo and calorimeter E_T in comparison for 2010 and 2011 collision data
- The L1Calo E_T is calculated using two different methods:
  - The ADC peak position: **black**/**green**
  - The final LUT result: **blue**/**yellow**

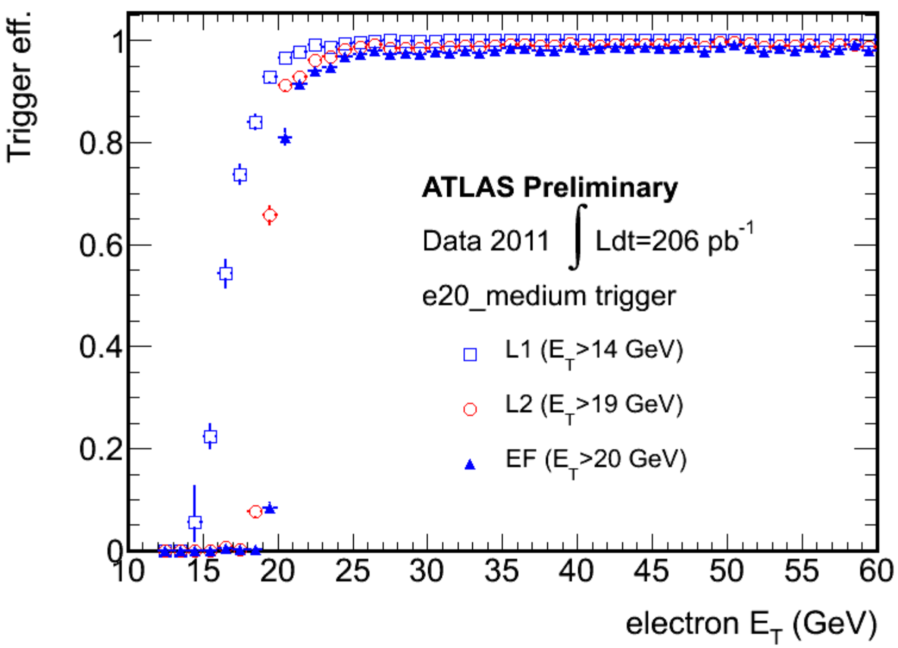
→ 2010 calibration revealed small LUT deviation at low energies due to rounding bias which was corrected for 2011 running period



Trigger Rates and Efficiencies



L1Calo trigger rates and efficiencies for 2011 look good!

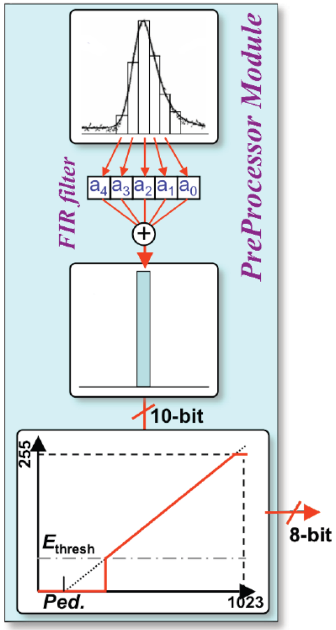


Conclusions

- L1Calo is a fixed latency, pipe-lined, hardware based system using custom electronics with ~7200 trigger towers
- Central part of the ATLAS L1 trigger system, identifying calorimeter based particles and jets within 2.5µs
- Timing calibration and BC identification were good for 2010 running and have been optimised further for the 2011 data taking period
- Regular energy calibration runs in between LHC fills; very good correlation between L1Calo and calorimeter energies archived
- Precise L1Calo calibration essential for sharp trigger turn-ons and good efficiencies

Backup Slides

LUT Slope Calibration



- Perform tower by tower LUT slope calibration using collision data
- To optimise LUT coverage fit FIR output (before drop-bits) as a linear function of peak ADC:

$$LUT_{\text{Slope}} = \frac{2^{drop\ bits} \times 1024}{gradient}$$

- In order to remove fake triggers due to small energy deposits the LUT also contains a noise cut to the output energy
- Distribution of the fitted gradient reflects the eta regions as given by the FIR coefficients chosen previously