2nd International Conference on
Technology and Instrumentation in Particle Physics
TIPP 2011

Chicago, Illinois, USA

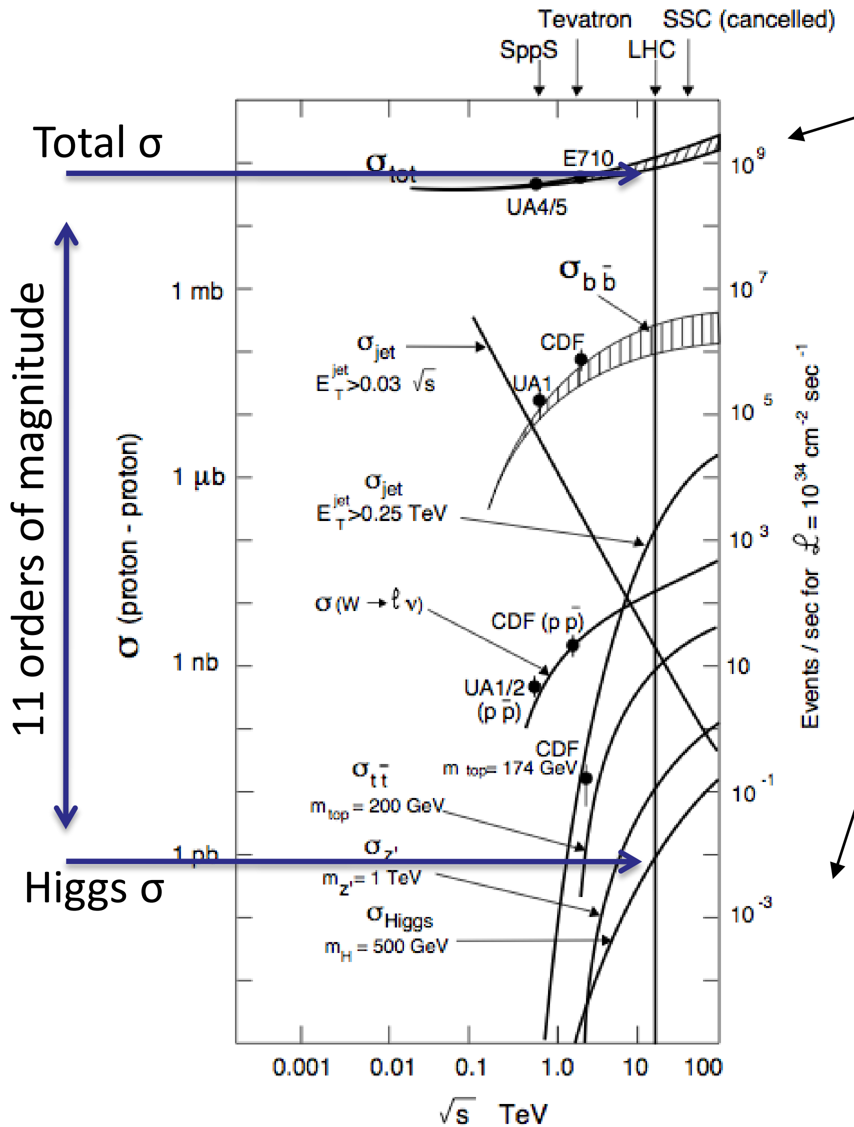
June 9 – 14, 2011

# Calibration and Performance of the ATLAS Level-1 Calorimeter Trigger

Martin Wessels
on behalf of the ATLAS Collaboration

Kirchhoff Institute for Physics
University of Heidelberg, Germany

# 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)

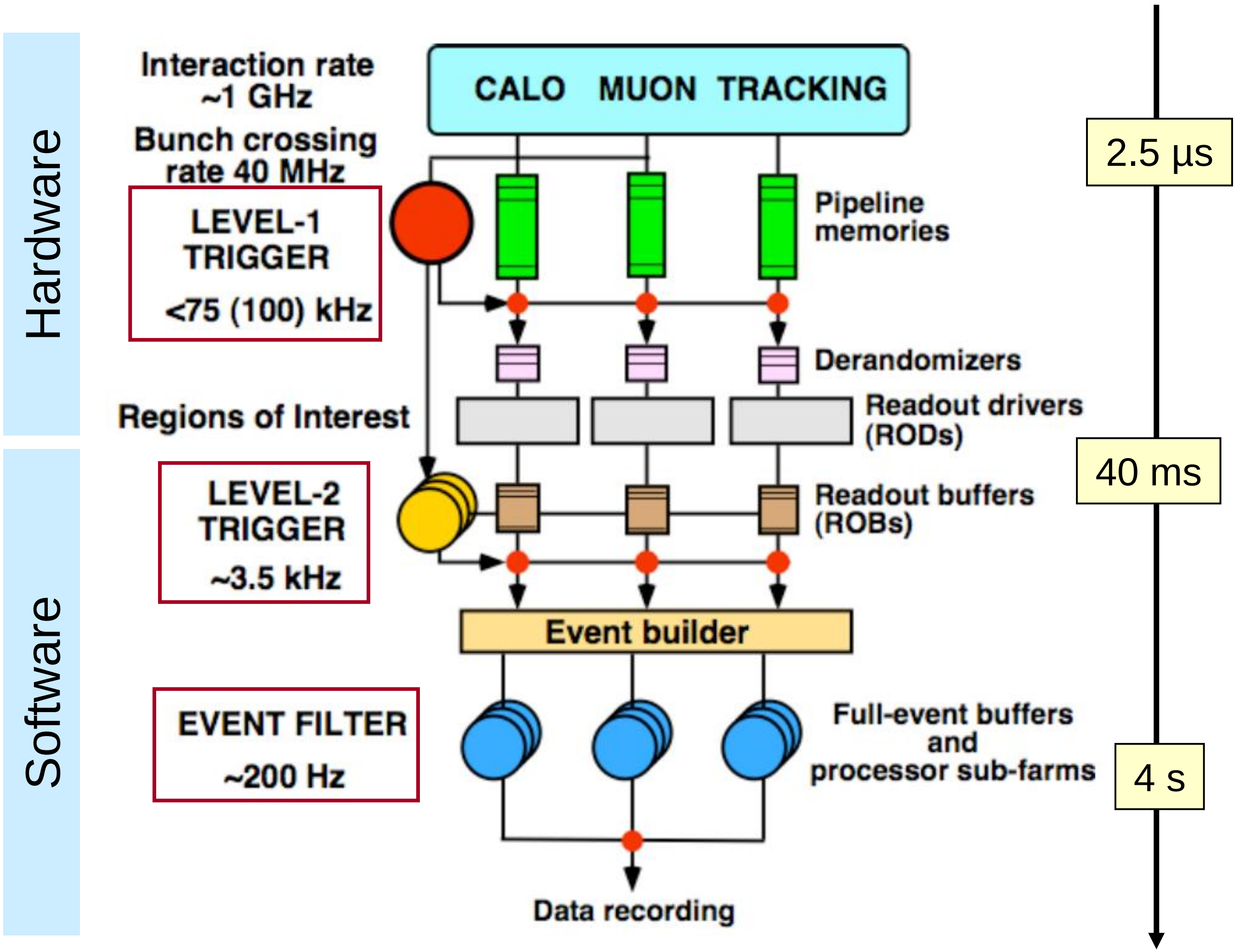
- ~$10^9$ pp interactions
- ~$10^3$ W events
- ~500 Z events
- ~10 top events
- ~9 SUSY events (?)
- ~0.1 Higgs events (?)

→ But only ~200 can be recorded

→ Powerful trigger needed

# ATLAS Trigger Overview

Three trigger layers

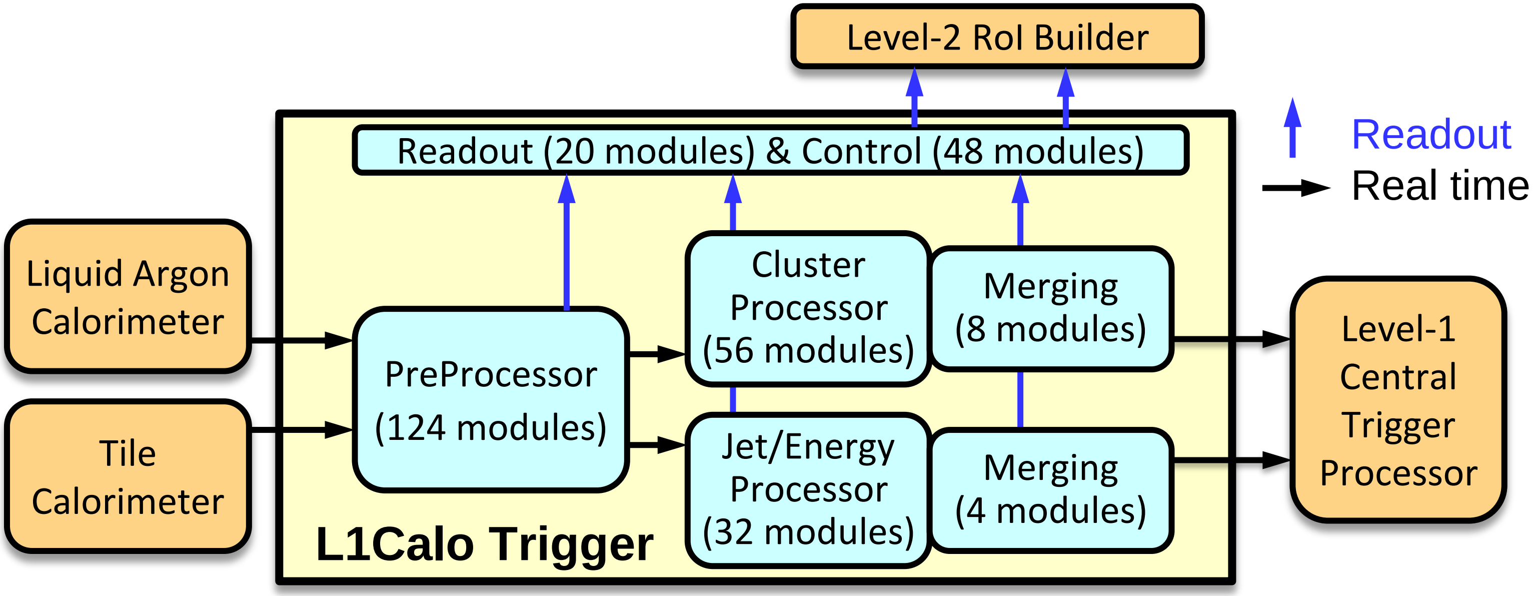



**LVL1:** Mainly calorimeter and muon data with reduced granularity

**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

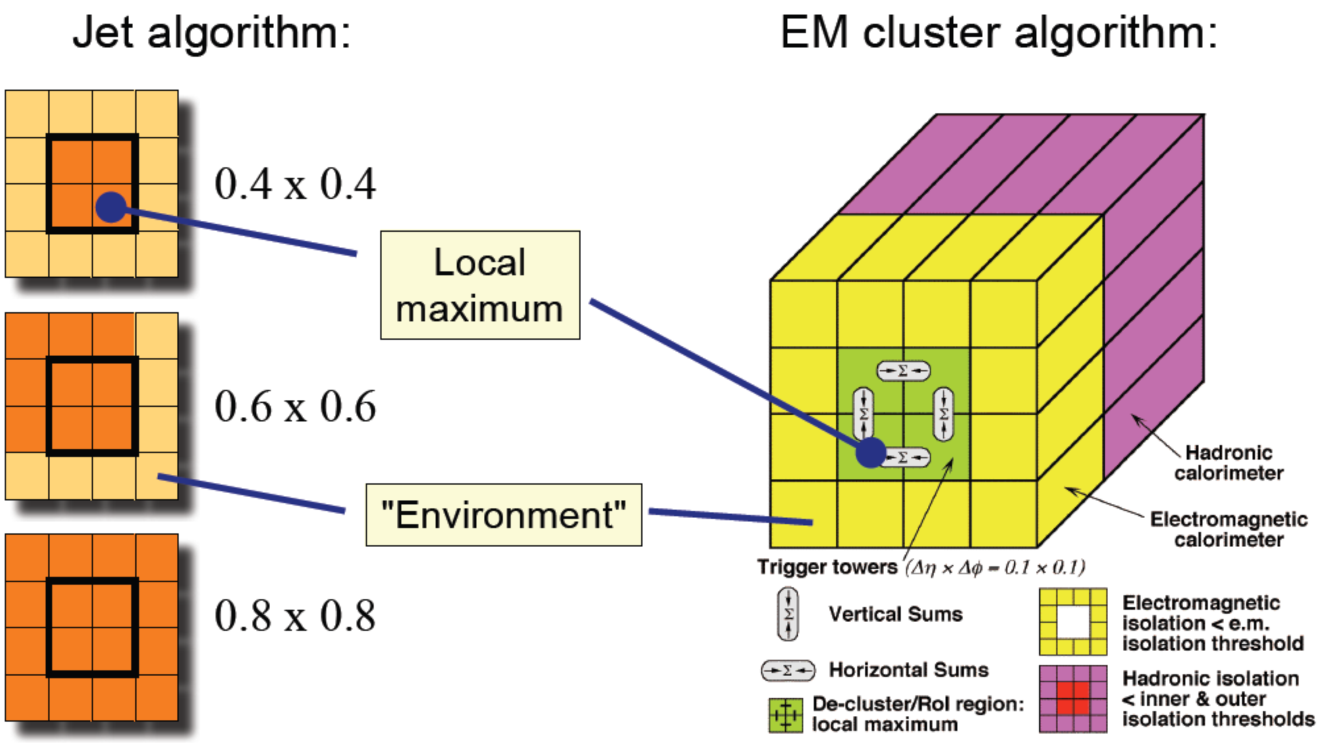
Entirely located off the detector in the ATLAS electronics cavern

**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




- 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

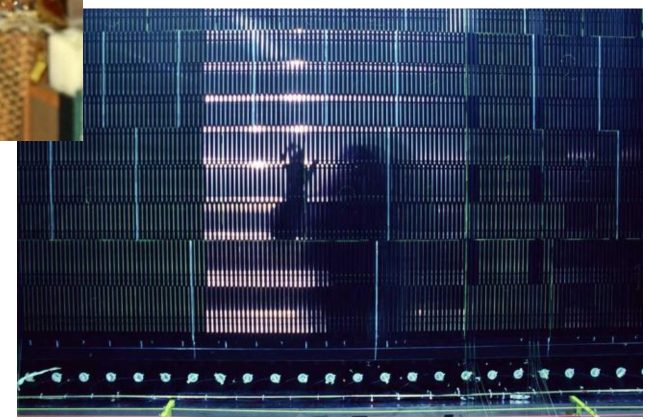
→ Multiplicities of objects (e.g. electrons, photons, jets) above settable $E_T$ thresholds transferred to central trigger

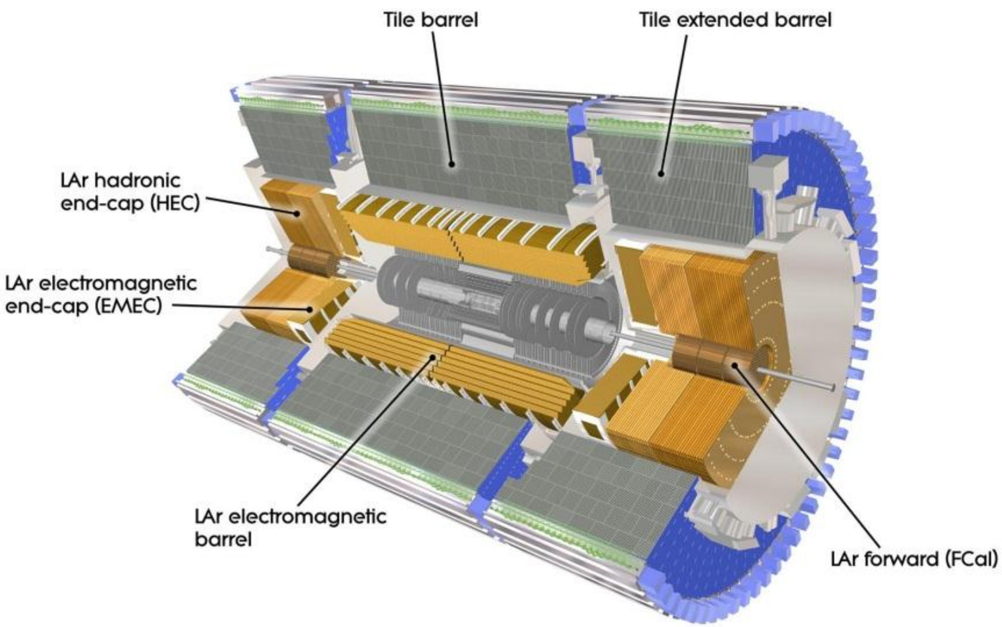
→ RoIs giving details of object candidates read out by RODs and sent to L2 RoI Builder

# ATLAS Calorimeters

**Liquid Argon Calorimeter (LArg)**

- Mainly accordion-shaped Kapton electrodes and lead/copper absorber plates
- Three sampling layers.
  Barrel segmentation:
  $\Delta\eta x \Delta\varphi = 0.025x0.025$



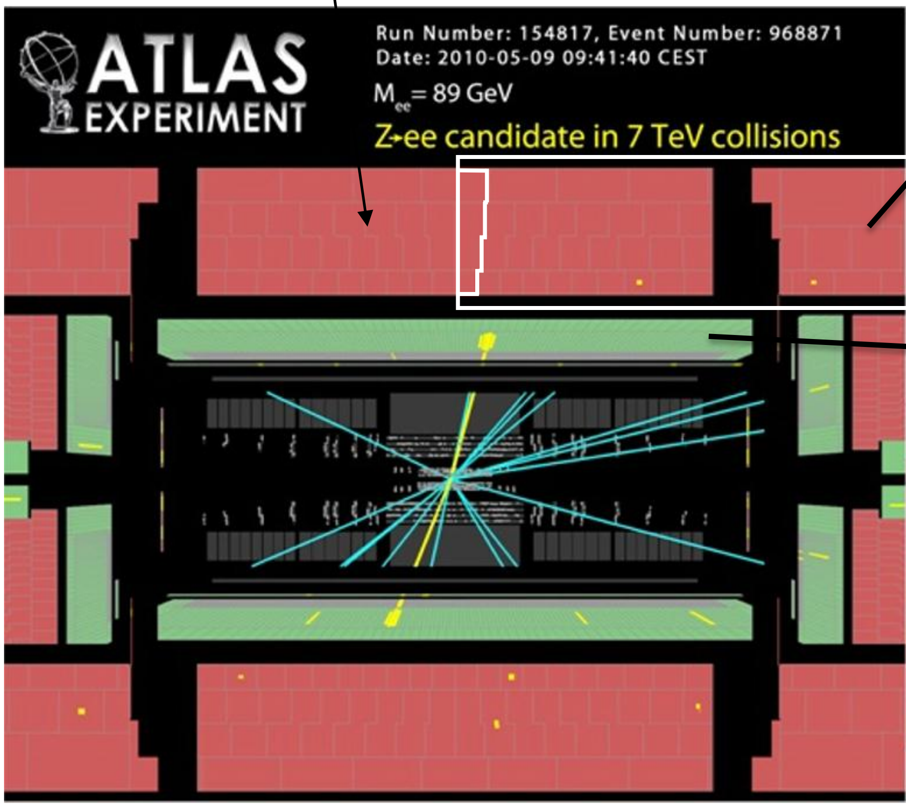


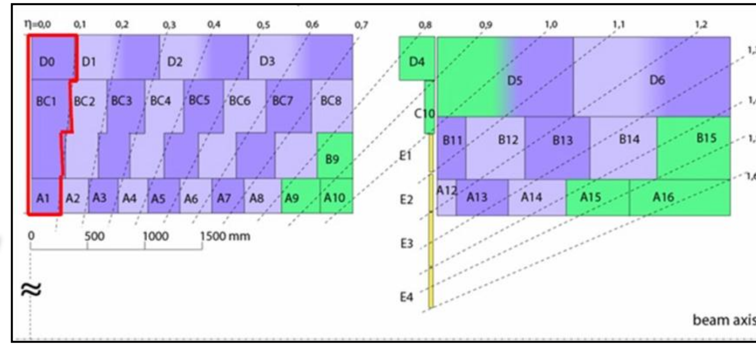

**Hadronic Tile Calorimeter**

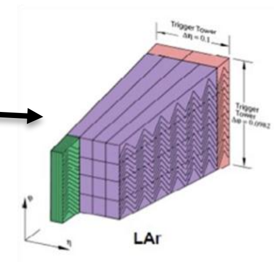
- Uses scintillating tiles with steel absorbers (total thickness is 9.7 interaction lengths)
- Three sampling layers.
  Segmentation: $\Delta\eta x \Delta\varphi = 0.1x0.1$

# L1Calo Input: Trigger Towers

Outer hadronic Tile Calorimeter




~7200 projective trigger towers

Inner electromagnetic / hadronic LArg Calorimeter

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

Granularity 0.1×0.1 in eta/phi

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

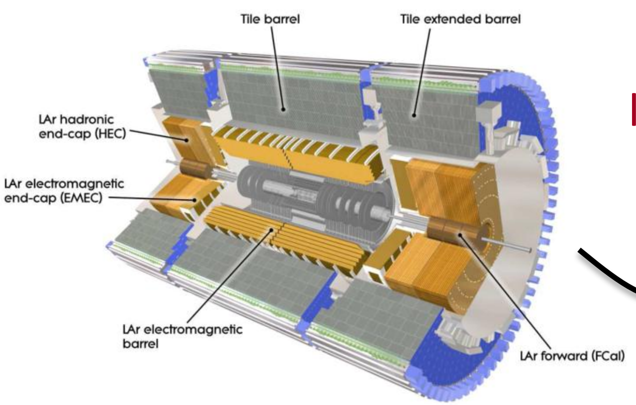
# ATLAS L1Calo Hardware

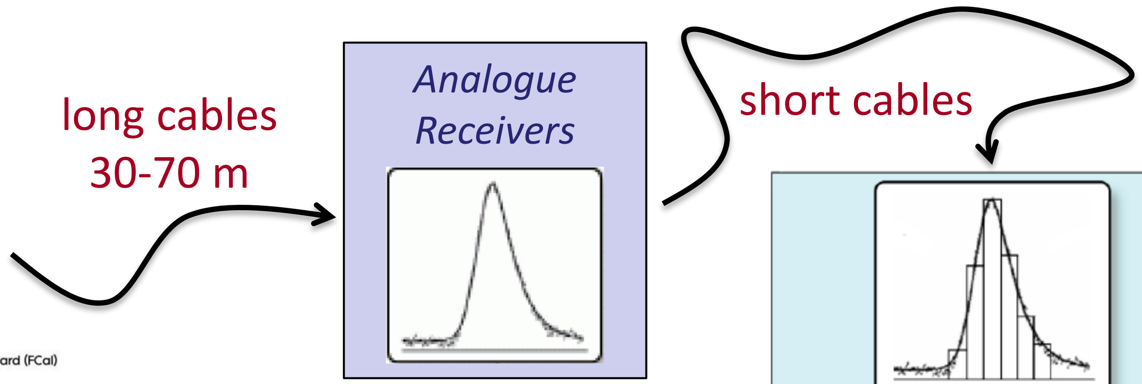
(Half of) Receivers and PreProcessors

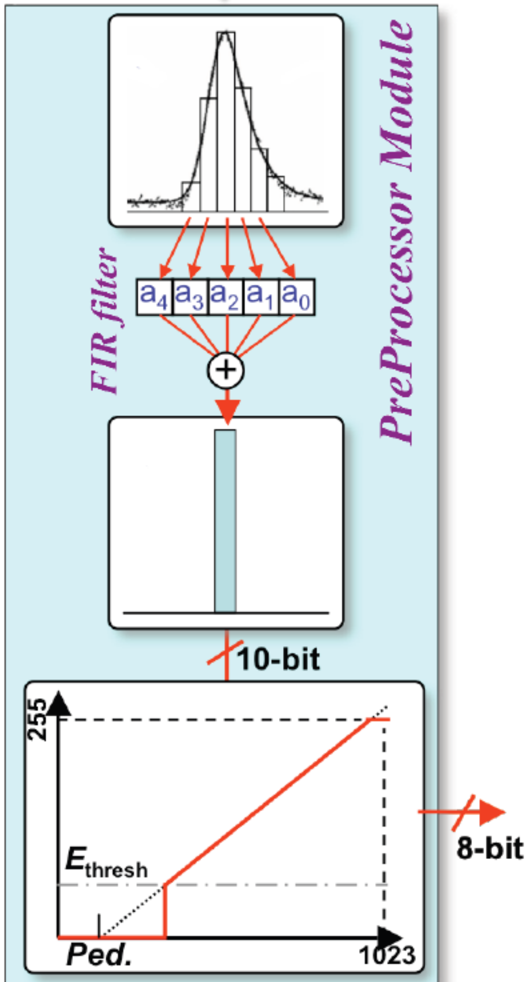
Processors

Readout Drivers

# Analogue Signal Path




**Analogue receiver system**

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

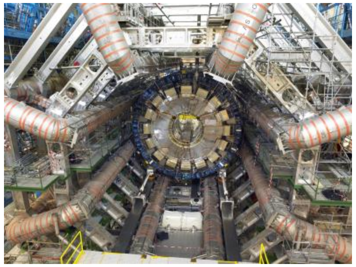
**L1Calo PreProcessor system**

- 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

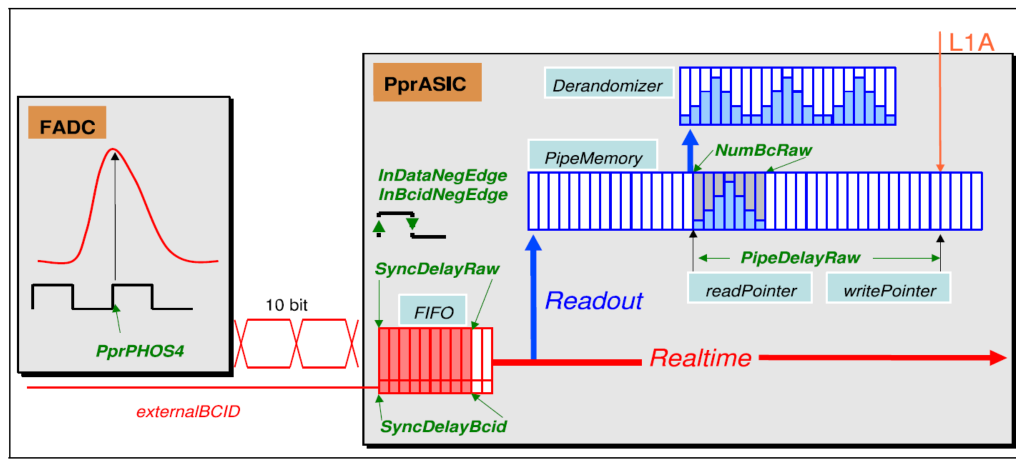
- Initial timing derived from analysis of first LHC splash events (Nov 2009)
- Improved timing delays applied early after first 7 TeV collisions (July 2010)
- Since then small updates and corrections, timing achieved better than ±2ns

**Coarse timing (to 1BC)**

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

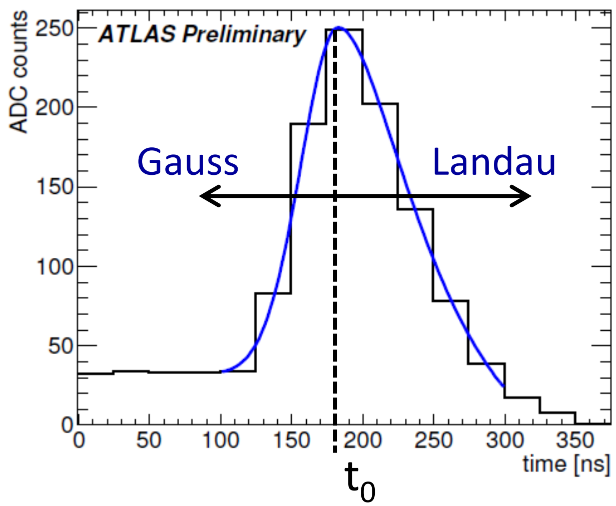
**Fine timing (to 1ns)**

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

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

**Fitting parameters:**

A: free normalisation

$t_0$: free timing offset

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

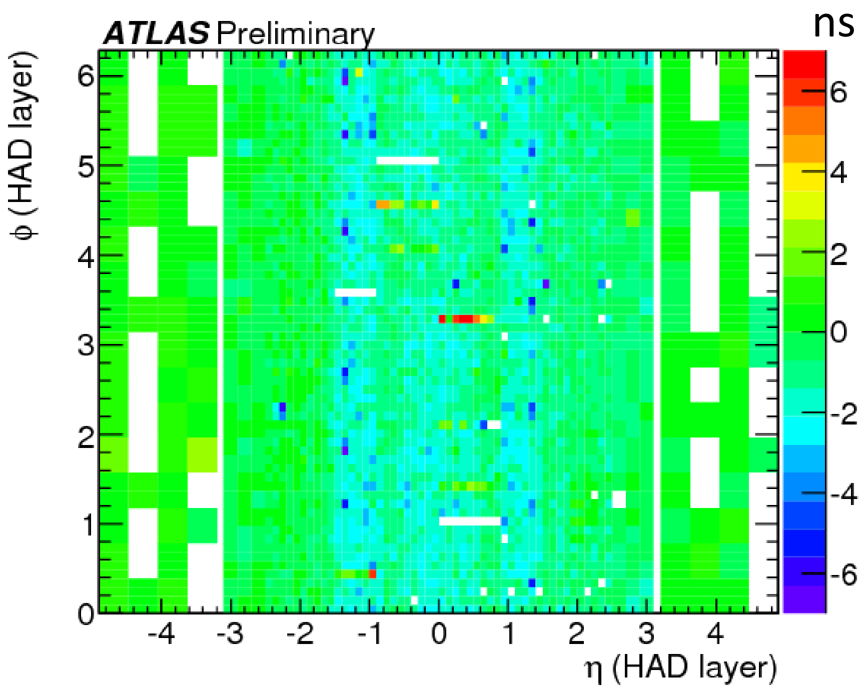
C: fixed pedestal

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

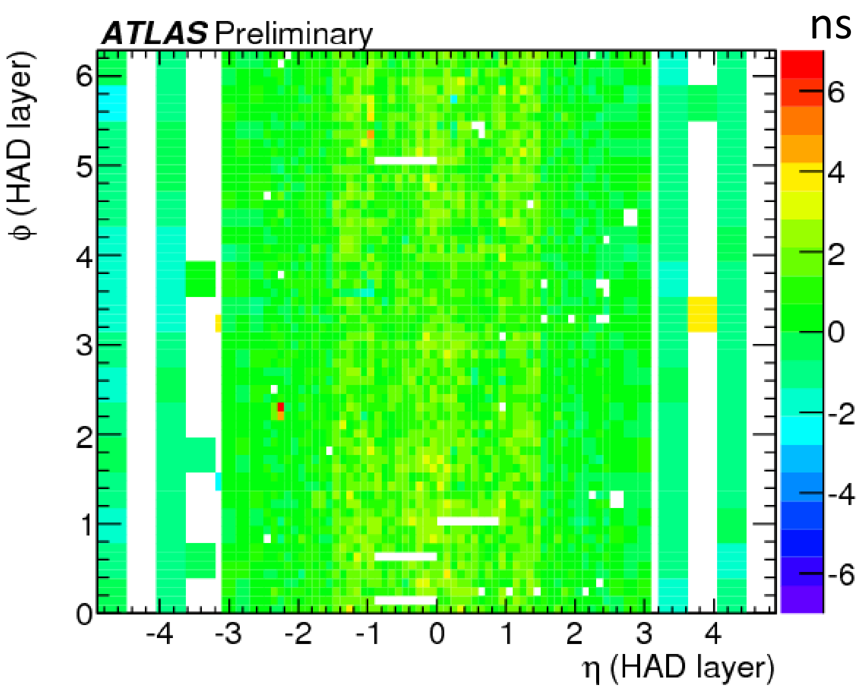
# Timing Status in 2011

- 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



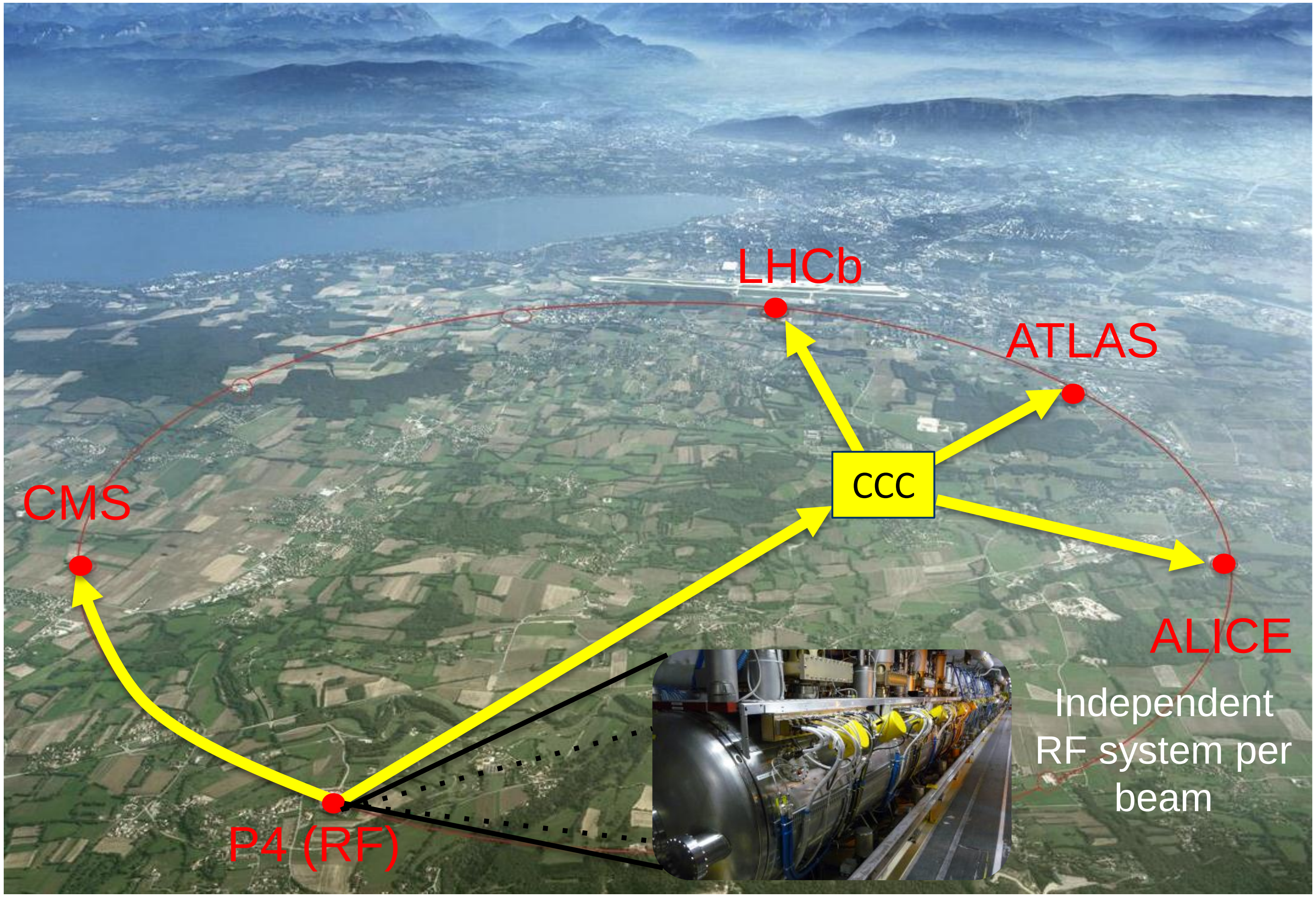

Timing within ±2ns at the beginning of the 2011 running period (March)

Largest offsets for electronics repaired during winter shutdown



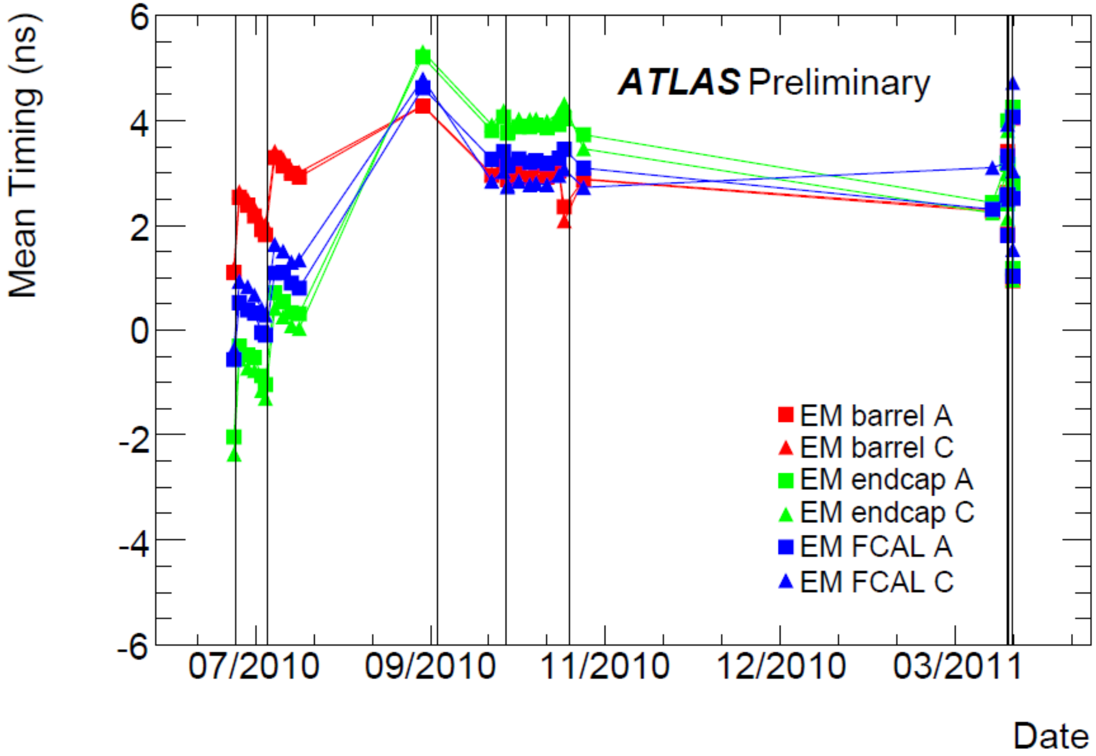

Timing offsets in April after applying corrections

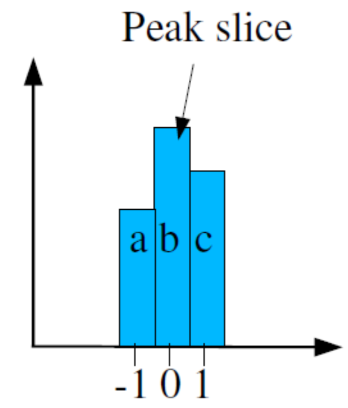
# Timing Signals from LHC




- 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

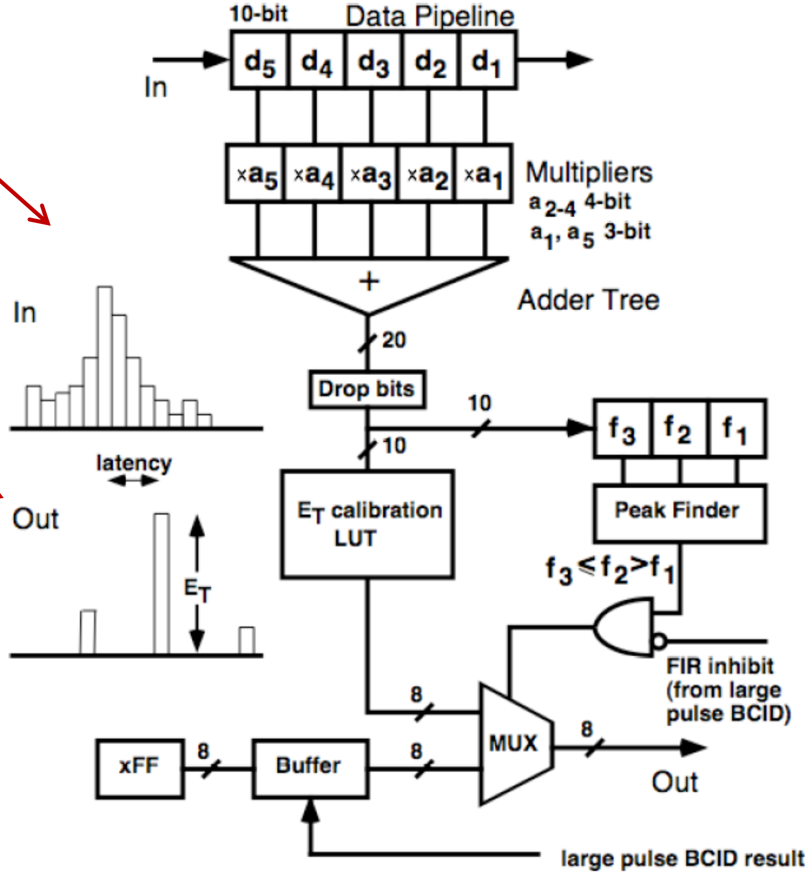
# FIR Filter and LUT Calibration

- 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

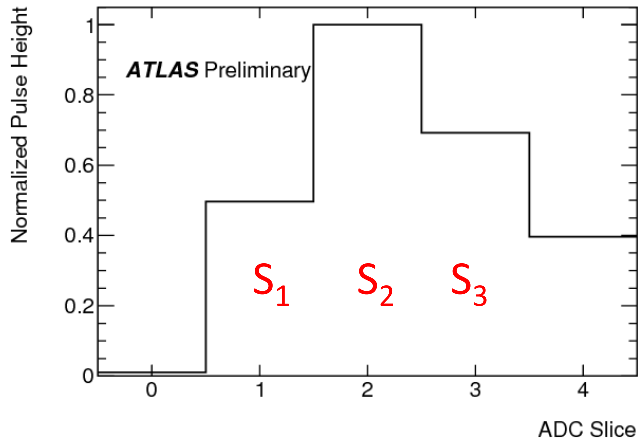
→ Best performance expected for filters adjusted to signal shape

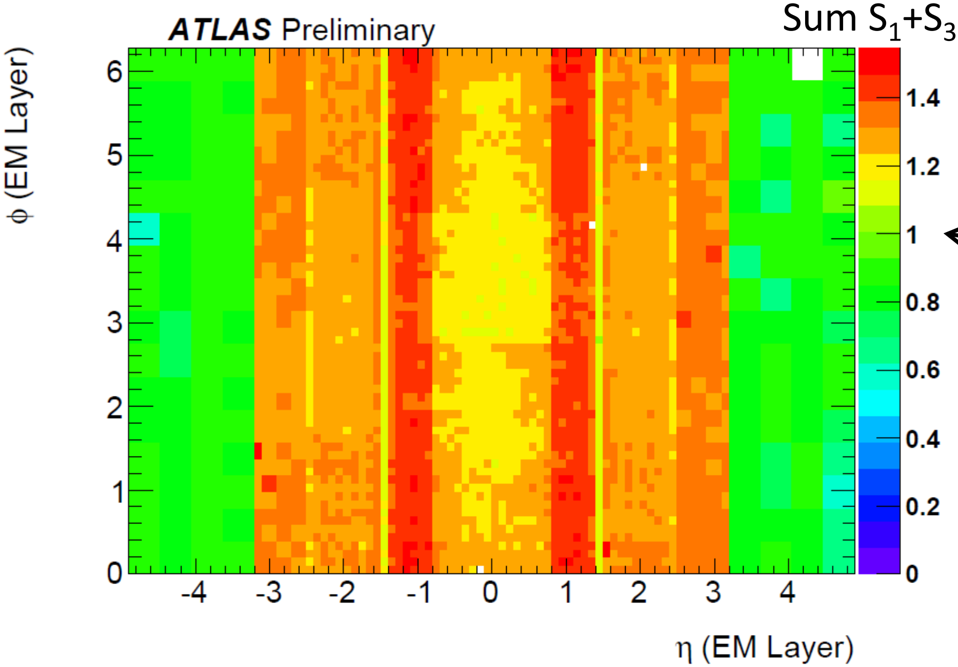
→ Optimisation using LHC collision data



# 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

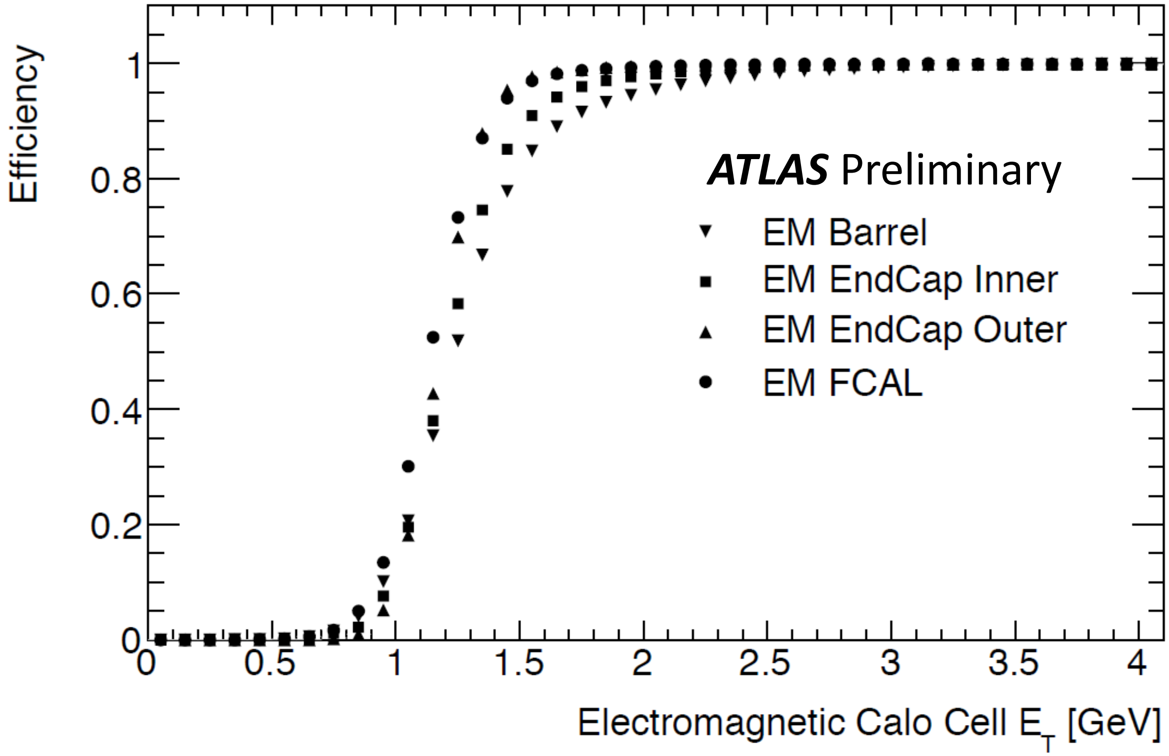



Identified regions with similar pulse shape for EM layer:
|η| = [0, 0.8] , [0.8, 1.4] , [1.4, 1.5] , [1.5, 3.2] , [3.2, 4.8]

- 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

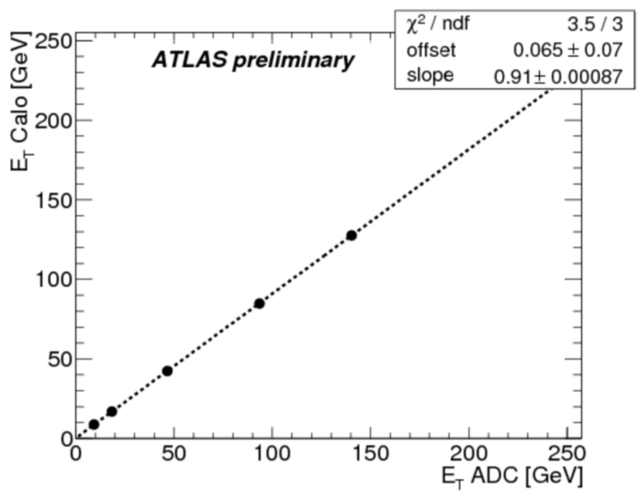
# BCID Identification Efficiency



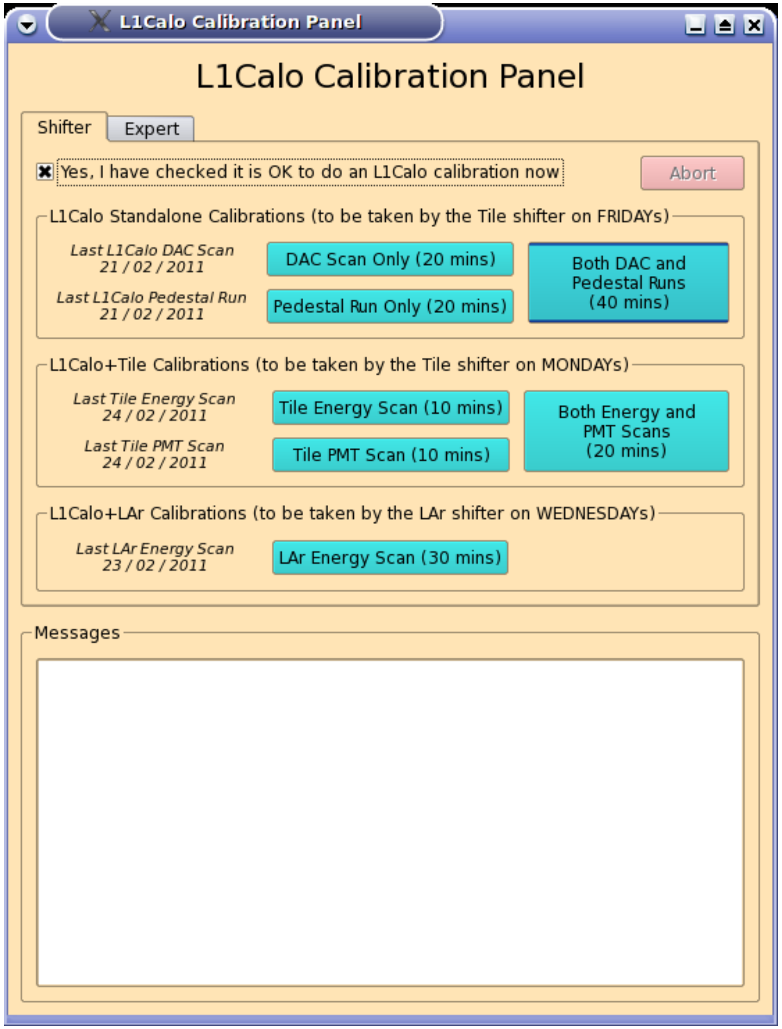

- Good indication of the success of timing and BCID logic is the efficiency of associating small energy deposits to the correct bunch crossing
- The turn-on at around 1.2 GeV is a result of the LUT noise cut and in line with the optimal performance expected from simulation

# Energy Calibration Procedure

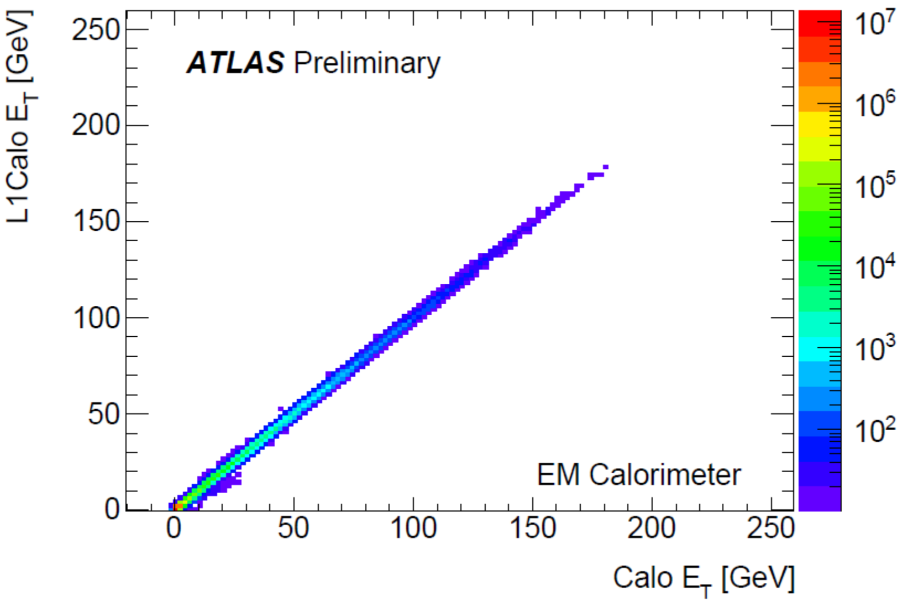
- Energy calibration (ADC to $E_T$) implemented in analogue receiver gains (and LUT slope)
- Use dedicated calorimeter pulser runs taken in between LHC luminosity fills

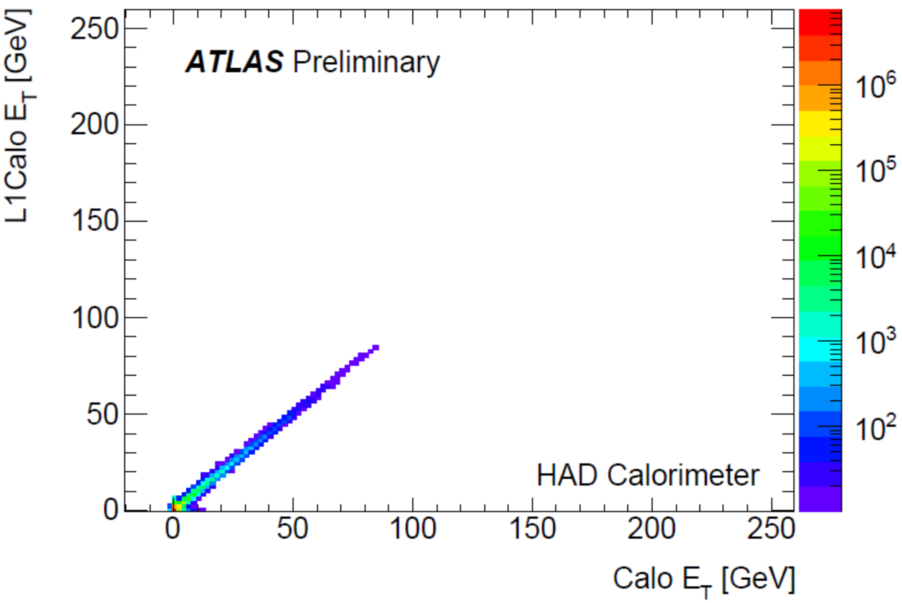



- Calibrate with respect to the (more precise) energy as measured by the calorimeter
- In offline analysis derive receiver gain from slope of linear fit to energy points in the calibration run



# Energy Calibration Results

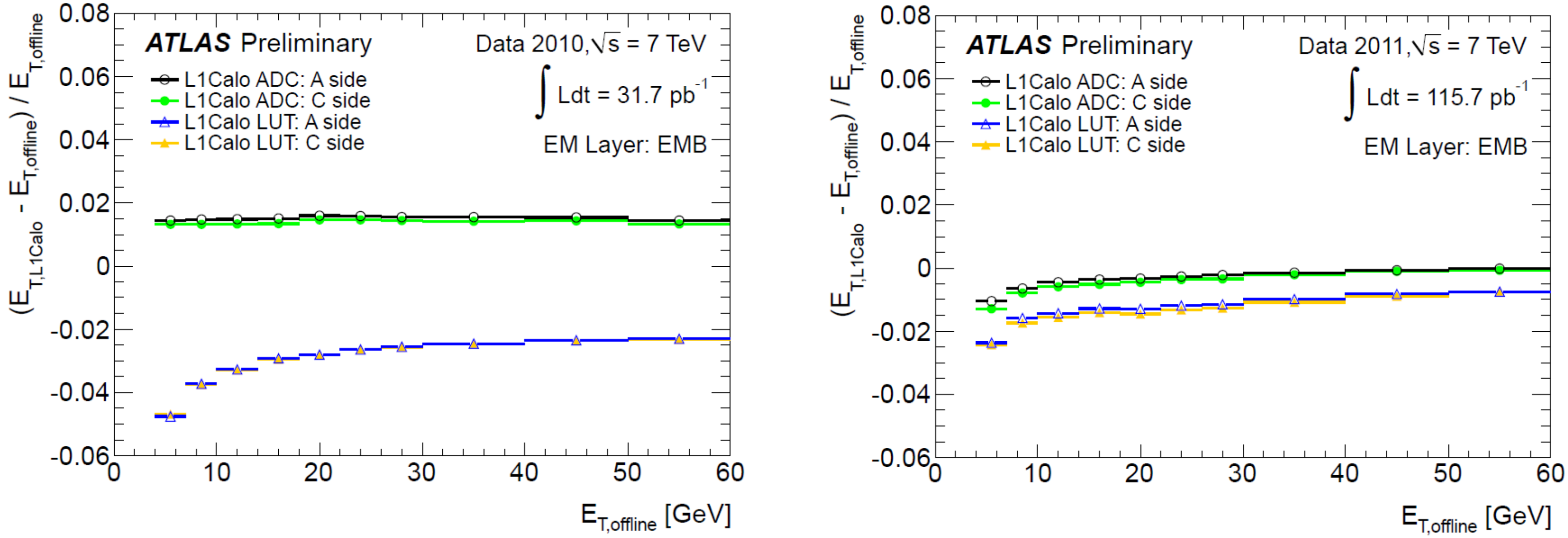


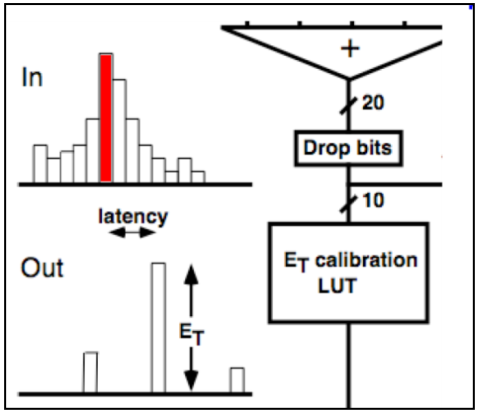

- Energy correlations for the electromagnetic and hadronic layer derived from initial 2011 collision data

→ Very good agreement between the L1Calo and calorimeter measured energies

# Optimisation of LUT Performance

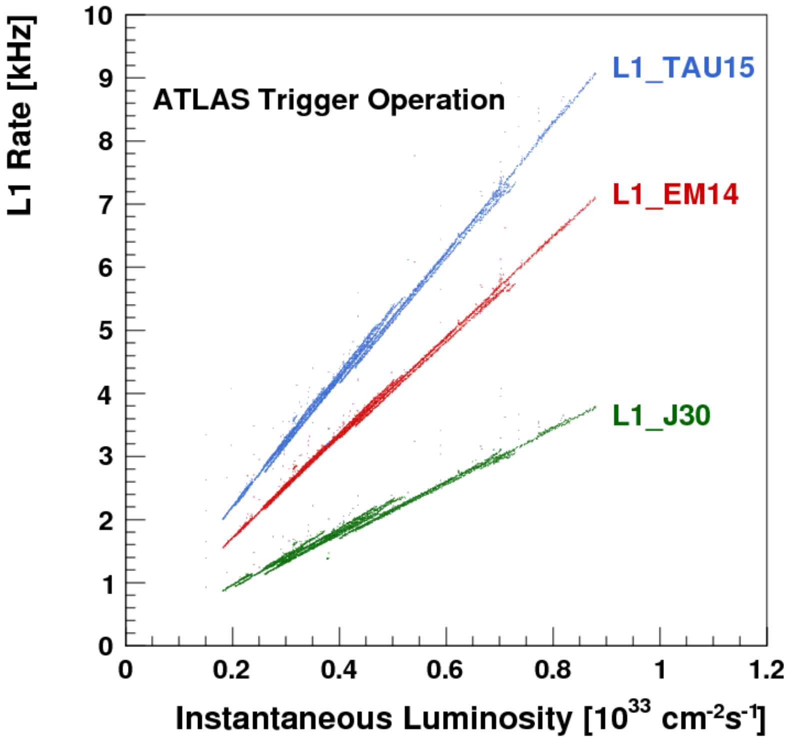



- Fractional difference of L1Calo and calorimeter $E_T$ in comparison for 2010 and 2011 collision data
- The L1Calo $E_T$ is calculated using two different methods:
  - The ADC peak position: **black**/**green**
  - The final LUT result: **blue**/**yellow**

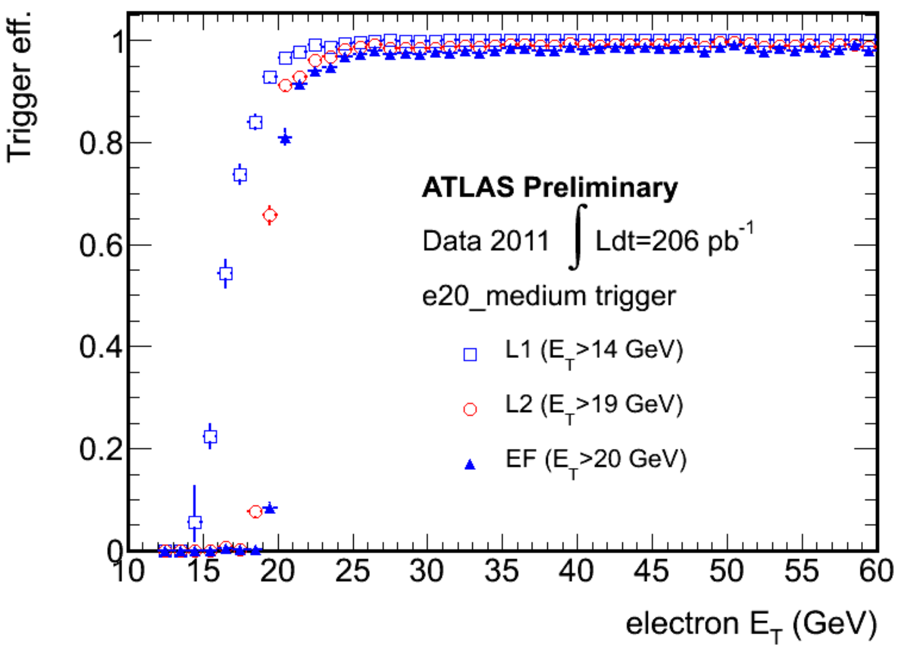



→ 2010 calibration revealed small LUT deviation at low energies due to rounding bias which was corrected for 2011 running period

# Trigger Rates and Efficiencies




L1Calo trigger rates and efficiencies for 2011 look good!

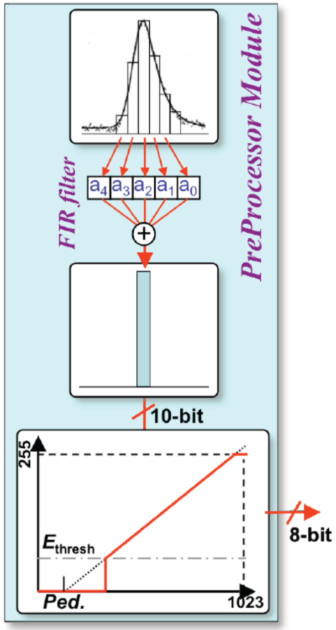


# Conclusions

- 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:

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

- 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