5th Detector Workshop on Detector Development
Helmholtz Alliance "Physics at the Terascale"
University of Bonn, Germany
March 14 – 16, 2012

ATLAS Level-1 Calorimeter Trigger

Martin Wessels

Kirchhoff Institute for Physics
University of Heidelberg, Germany

LHC and ATLAS Operations

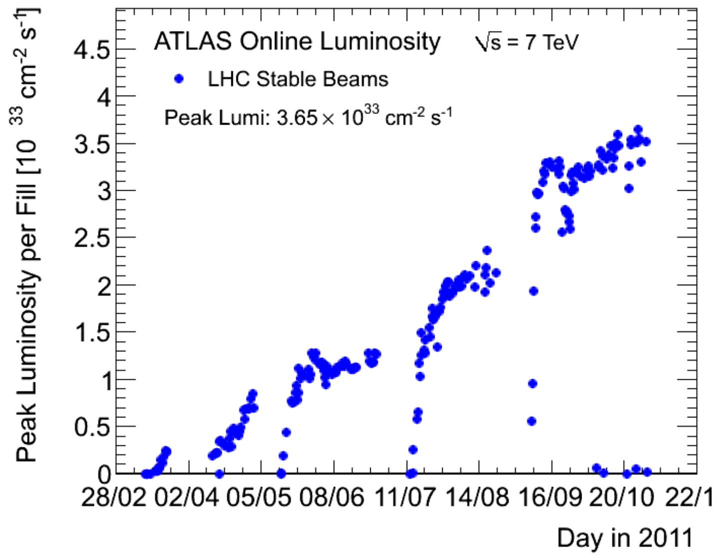
Proton-proton running at √s = 7 TeV

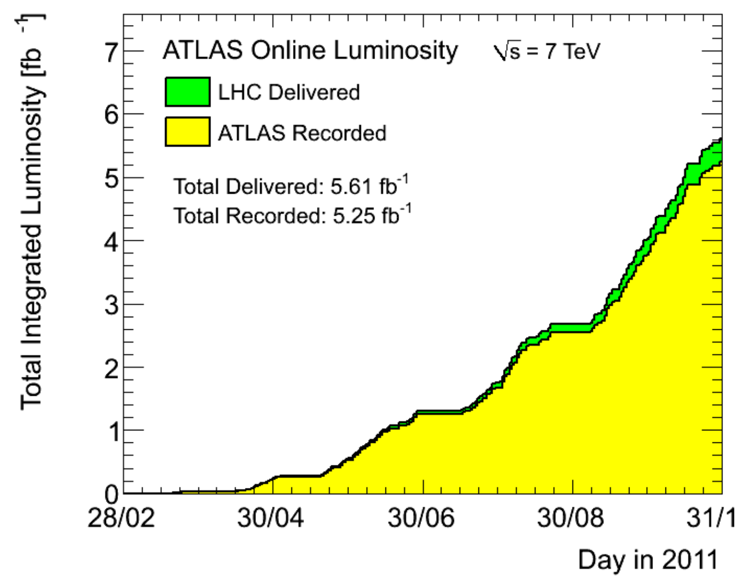
- Steadily increasing peak luminosities
- Stepwise increasing number of bunches and higher bunch charge
- Decrease of β^* from 1.5 to 1m in August 2011

	2010	2011
Peak luminosity ($cm^{-2}s^{-1}$)	$2.1 \cdot 10^{32}$	$3.65 \cdot 10^{33}$
ATLAS recorded integrated luminosity	45 pb^{-1}	5.25 fb^{-1}
Mean number of interactions per bunch crossing (pile-up)	~2	6.3 / 11.6

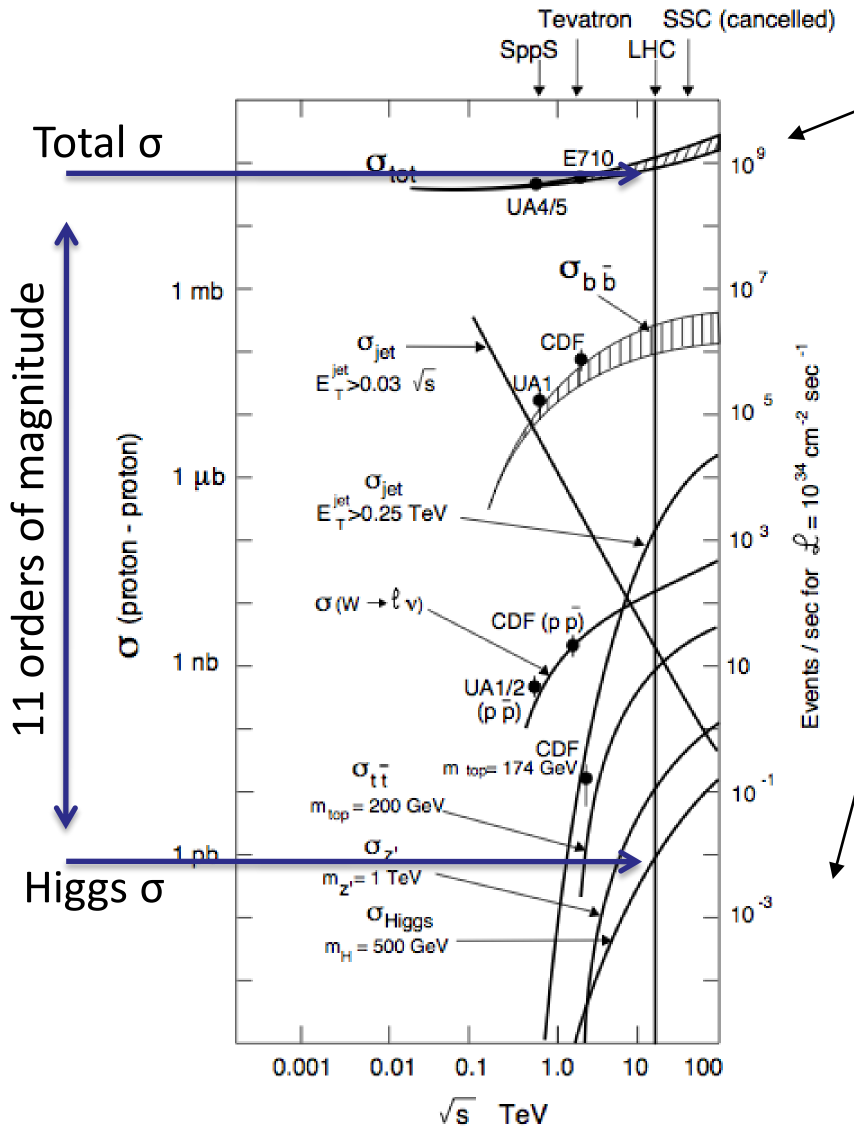
Heavy Ion running at $\sqrt{s_{NN}}$ = 2.76 TeV

- Pb-Pb collisions, 287 TeV on 287 TeV
- In total 158μb^{-1} recorded, 0.9 μb^{-1} in 2010





What Is Interesting?



Most of the time we are here

But here it gets really exciting!

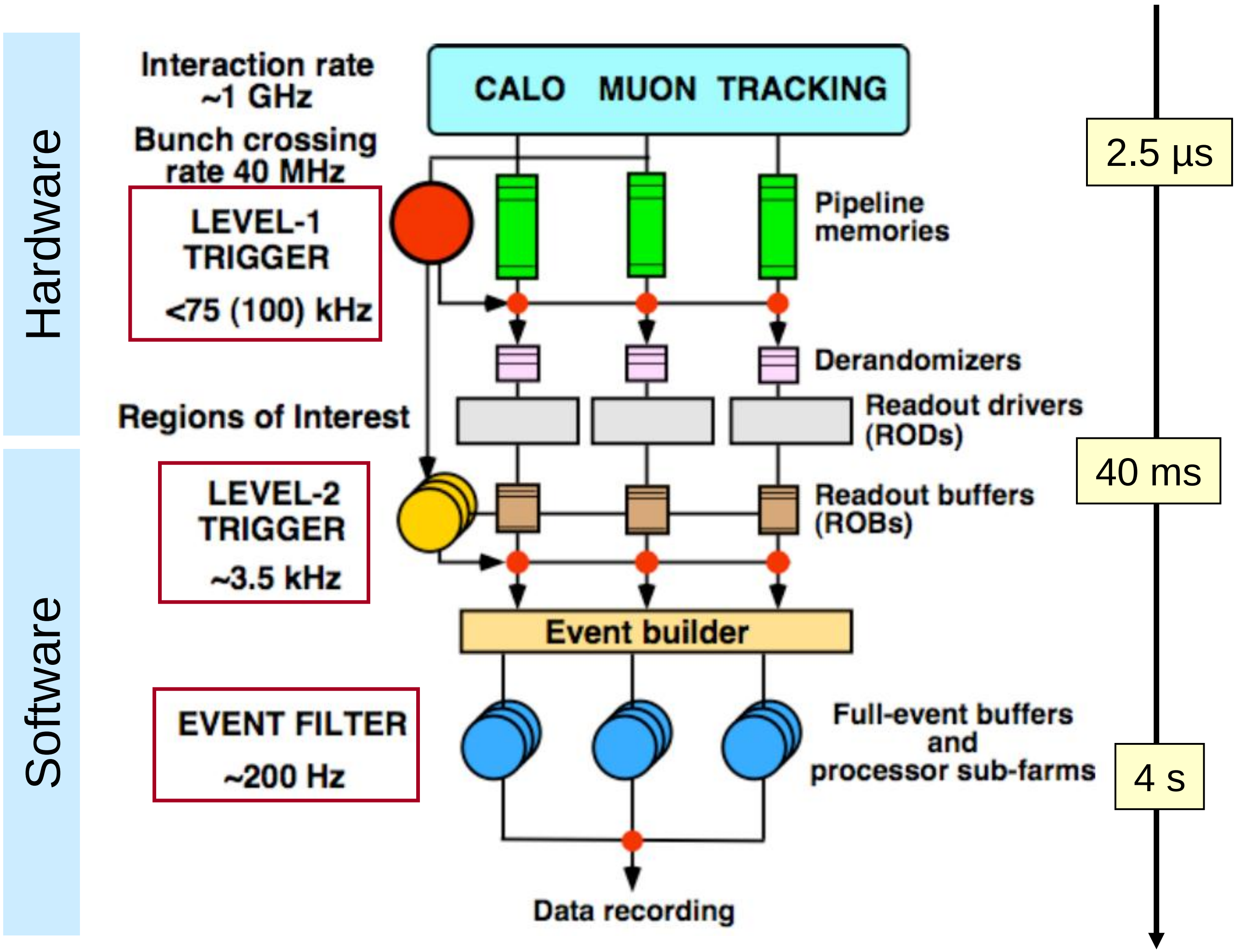
During one second at the LHC
(at design luminosity and energy)

- ~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



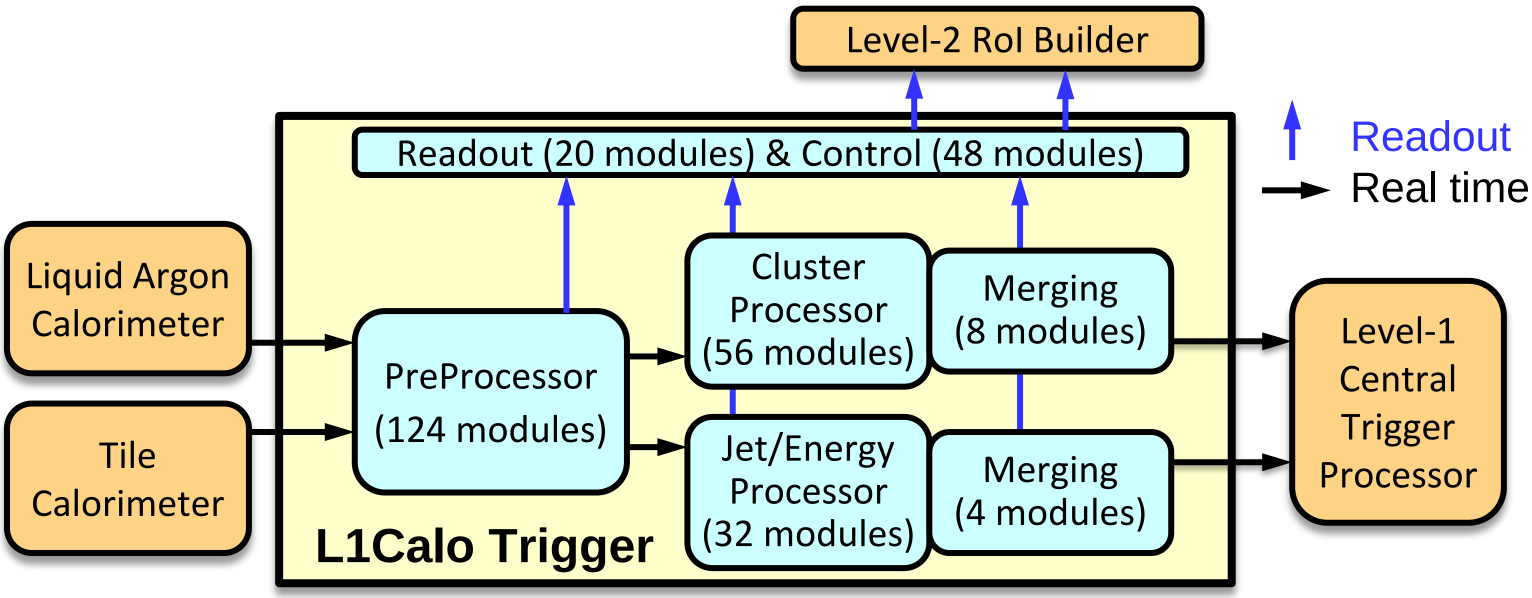
Three trigger layers

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

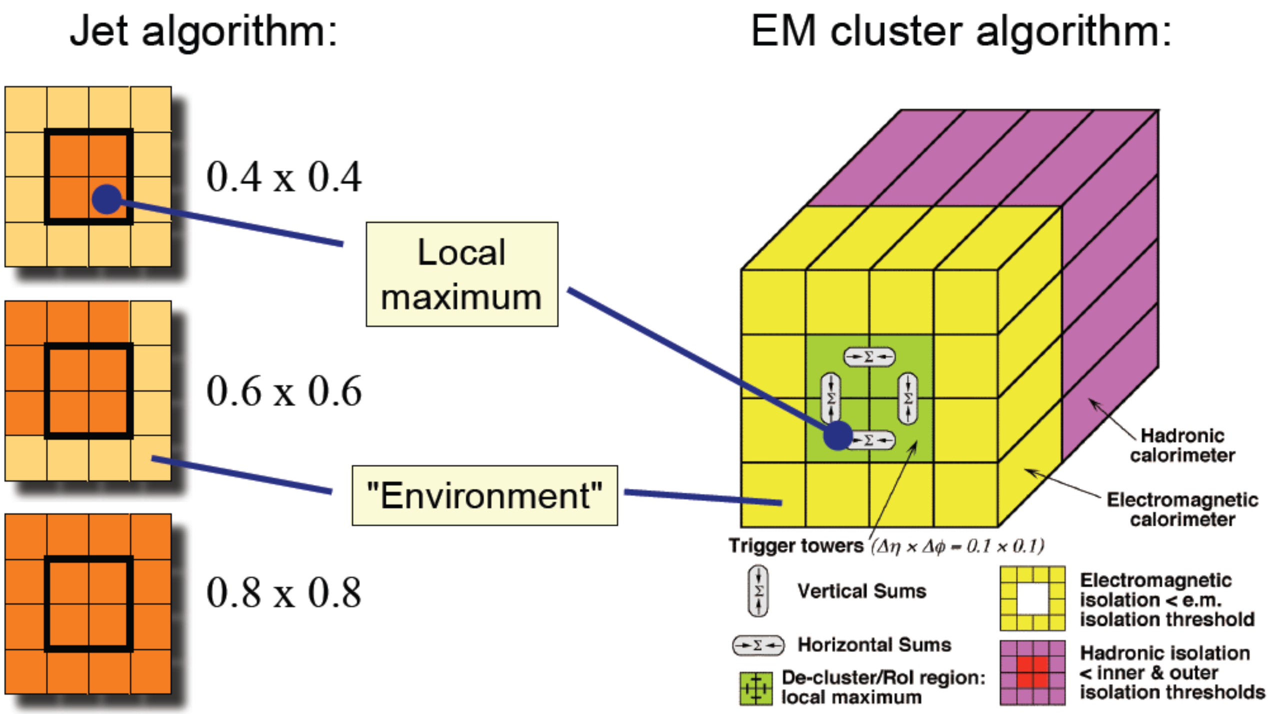
Entirely located off the detector in the ATLAS electronics cavern

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



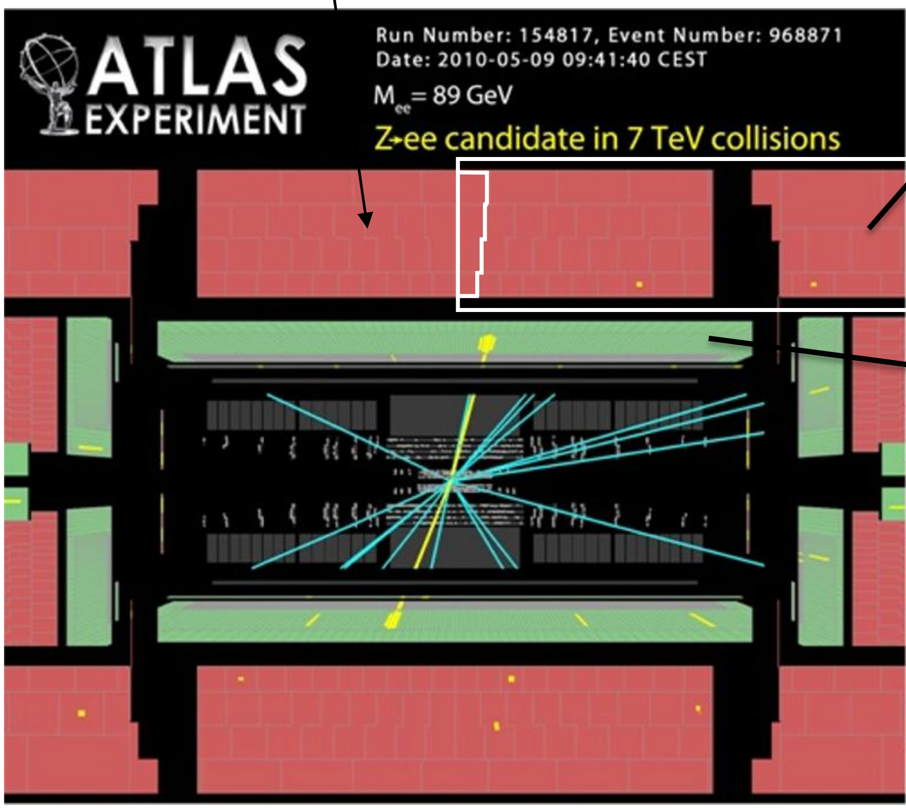
- Two independent processor subsystems (CP/JEP) using common architecture
- Processor input is matrix of digitized trigger tower energies from PPr system
- Search for local (isolated) maxima using overlapping, sliding windows

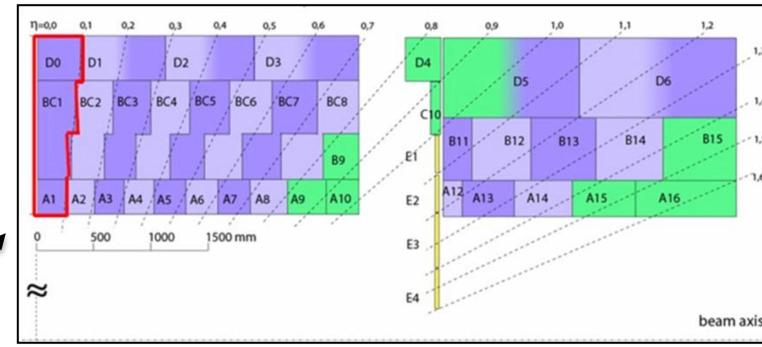
→ Multiplicities of objects (e.g. electrons, photons, jets) above programmable E_T thresholds transferred to central trigger

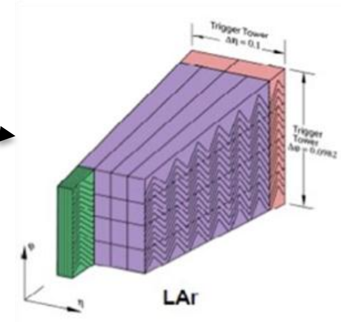
→ RoIs with details of object candidates read out by RODs and sent to L2 RoI Builder

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

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

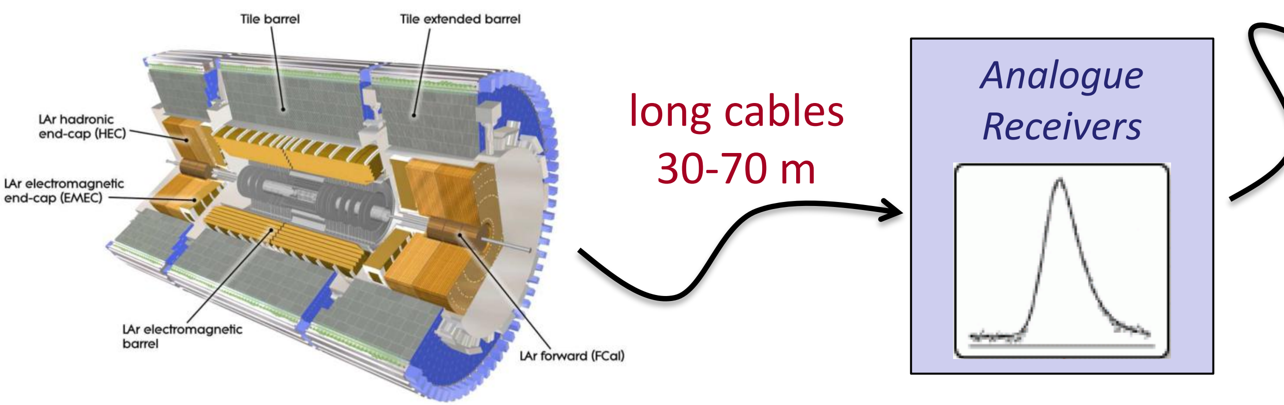
ATLAS L1Calo Hardware

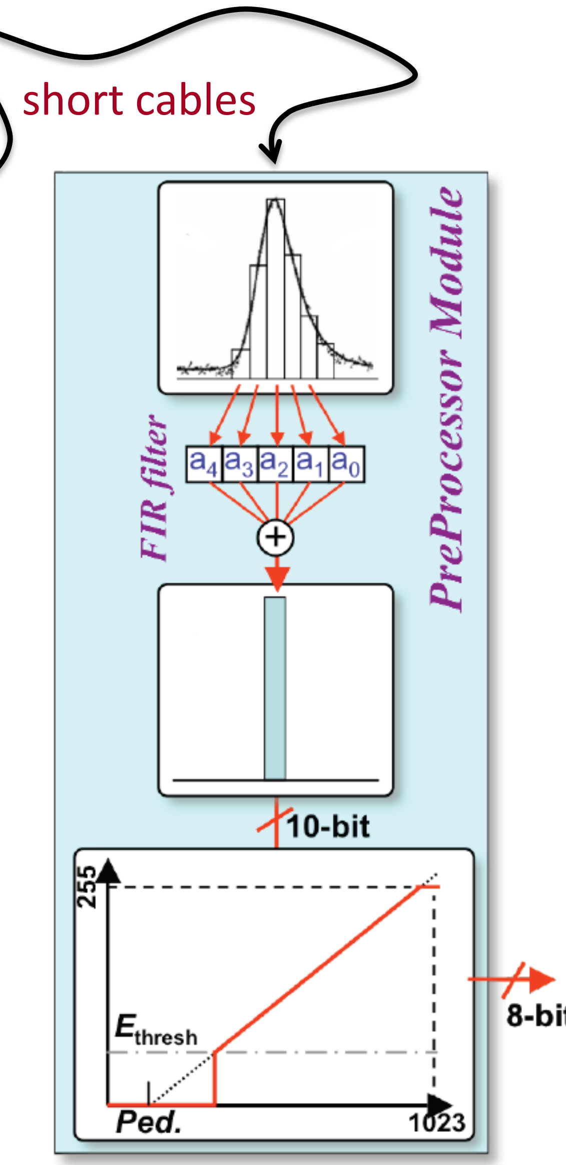
(Half of) Receivers and PreProcessors

Processors

Readout Drivers

L1Calo Analogue Signal Path





Analogue receiver system

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

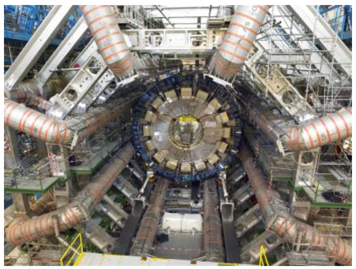
L1Calo PreProcessor system

- 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), including noise suppression and disabling of towers

→ 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 energy resolution (~2%)
- Direct impact on trigger efficiency turn-on curves

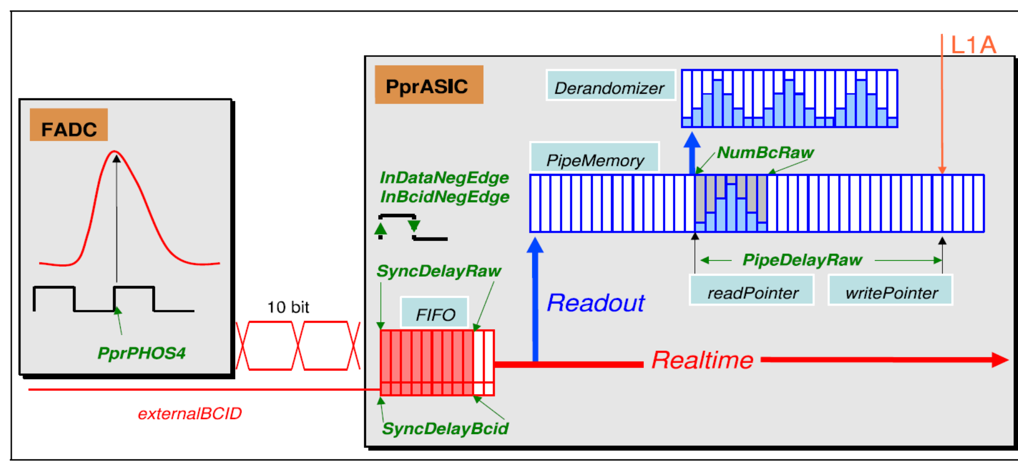
- Initial timing derived from analysis of first LHC splash events (Nov 2009)
- Improved timing delays applied early after first 7 TeV collisions (July 2010)

Coarse timing (to 1BC)

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

Fine timing (to 1ns)

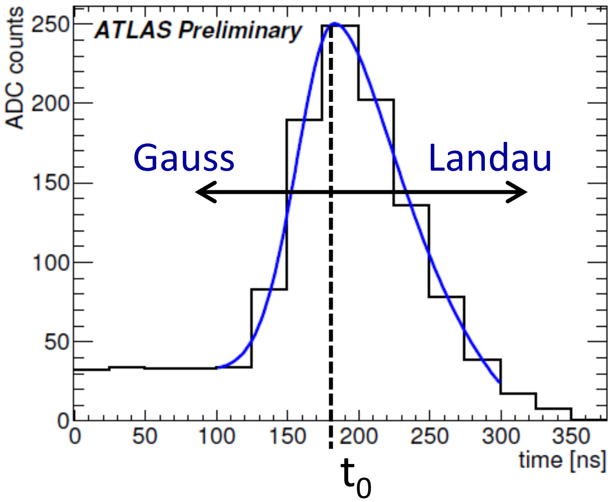
- for precise energy determination and BC identification
- by using the PHOS4 delay chip



- Since then only small updates and corrections, timing achieved better than ±2ns

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

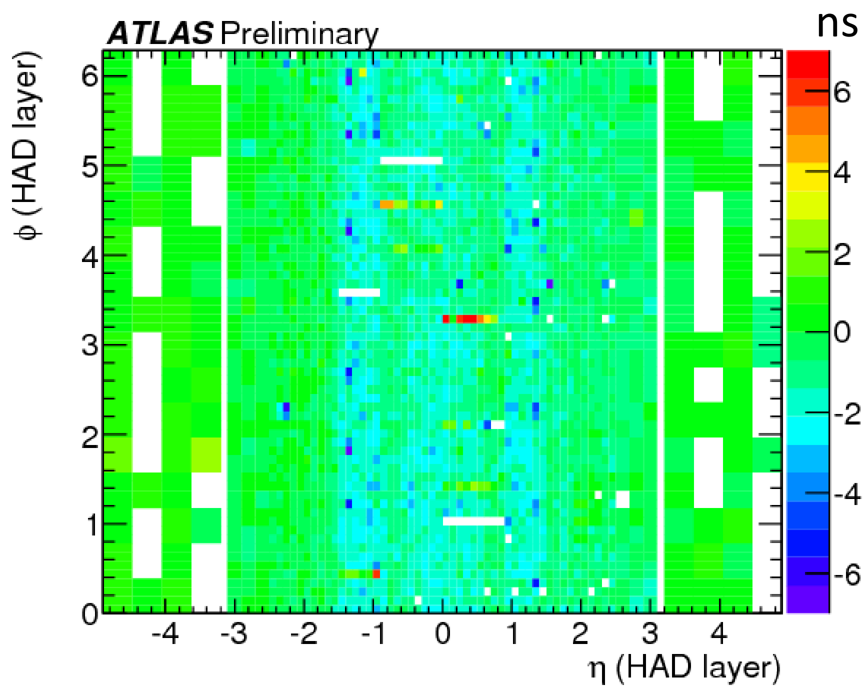
C: fixed pedestal

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

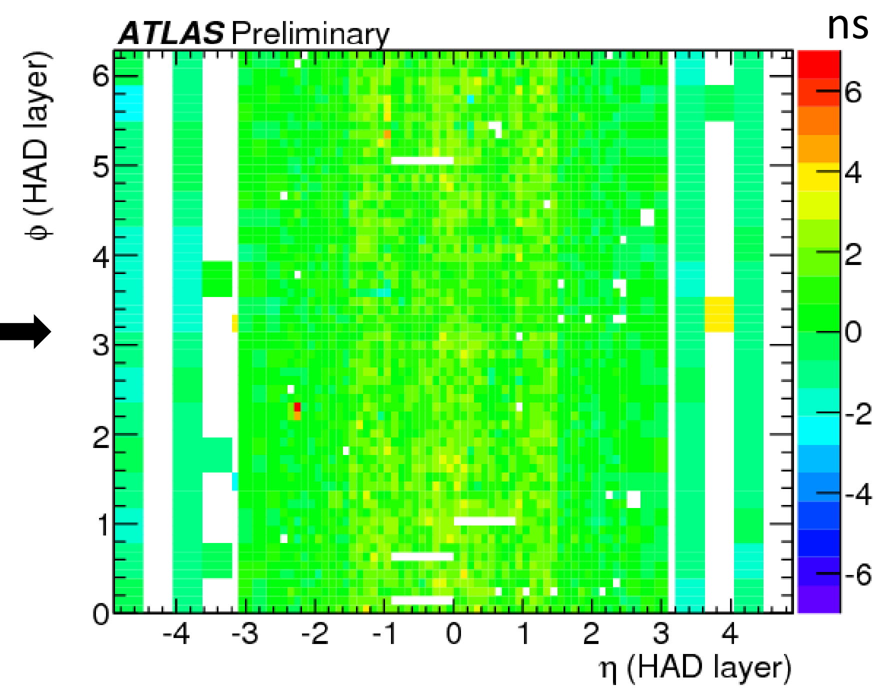
Timing Status in 2011

- 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 2011 after applying corrections

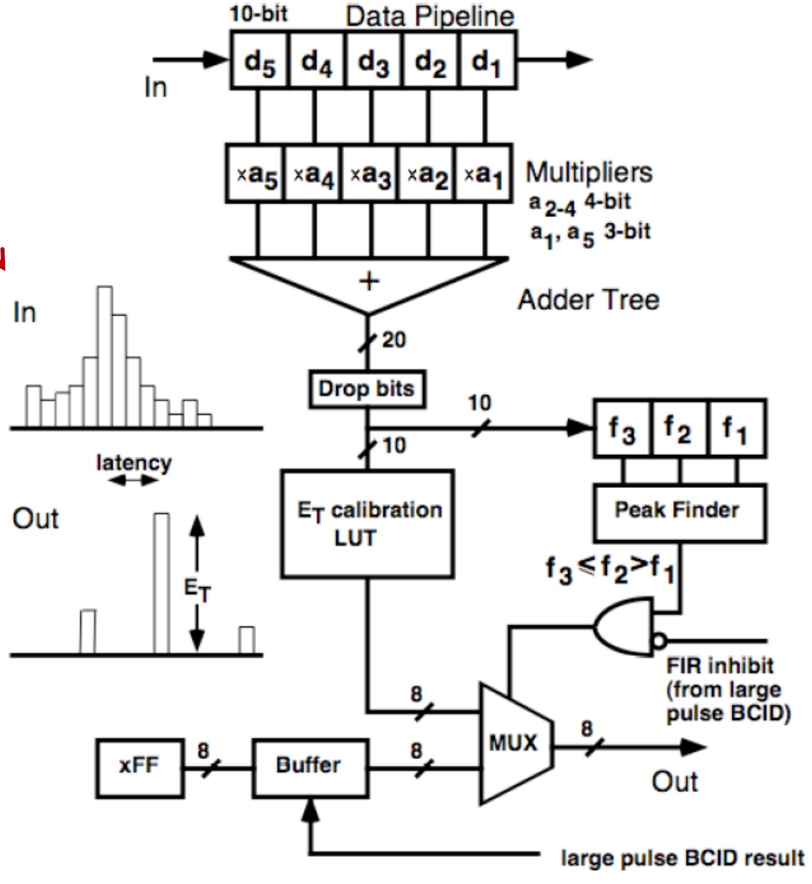
FIR Filter and LUT Calibration

- 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

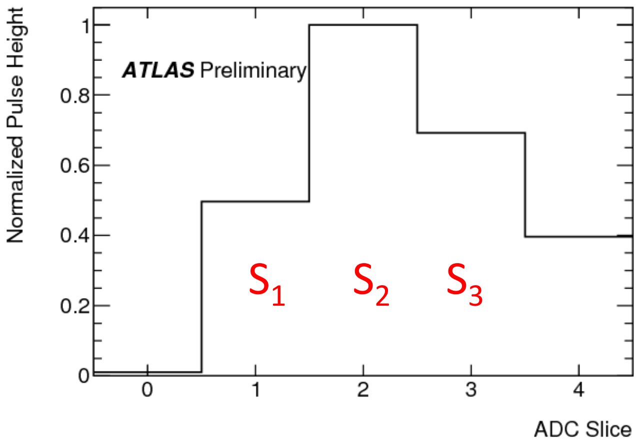
→ Best performance expected for filters adjusted to signal shape

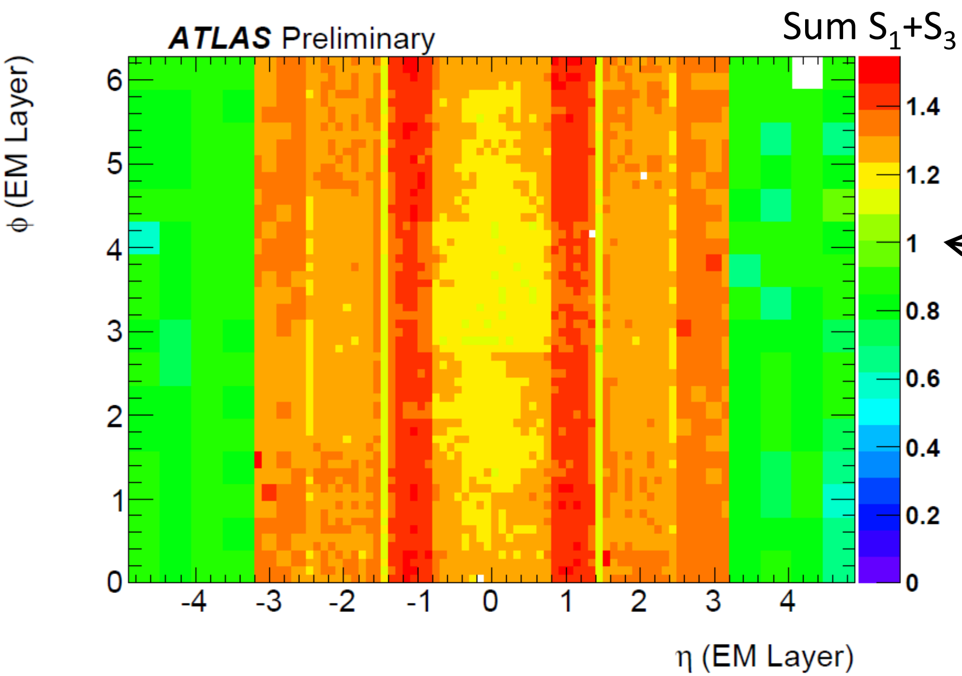
→ Optimisation using LHC collision data



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

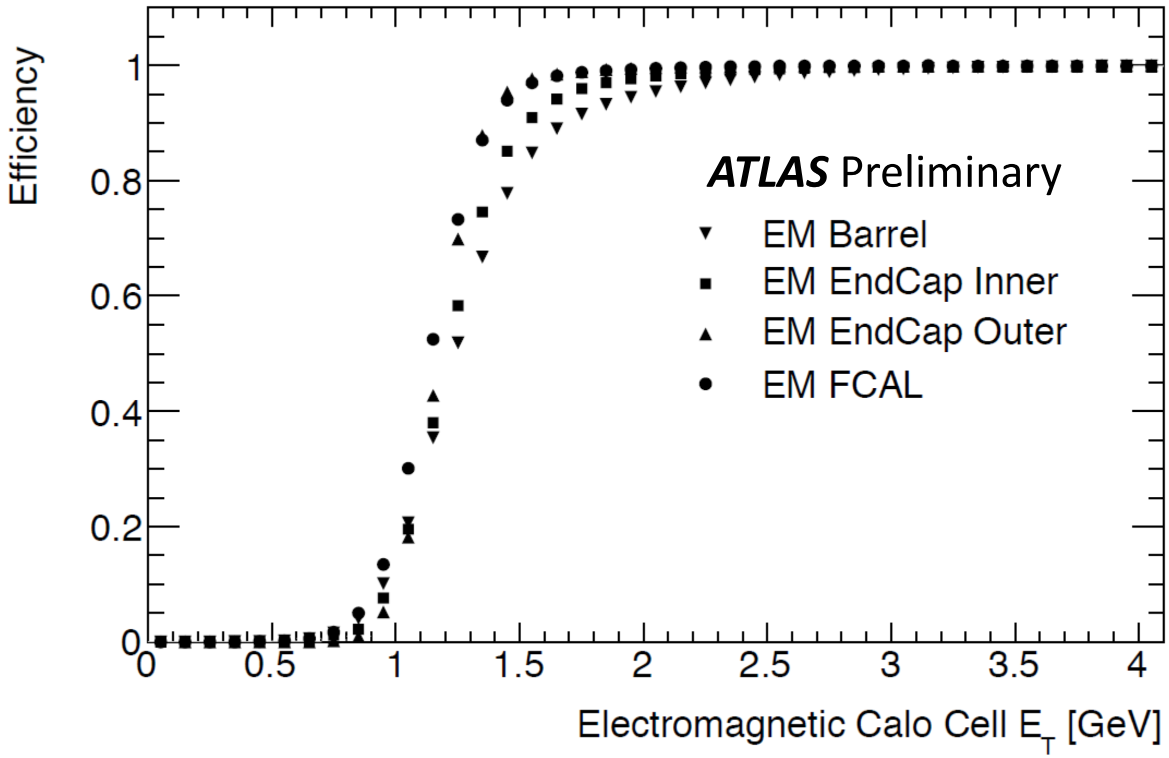




Identified regions with similar pulse shape for EM layer:
|η| = [0, 0.8] , [0.8, 1.4] , [1.4, 1.5] , [1.5, 3.2] , [3.2, 4.8]

- 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

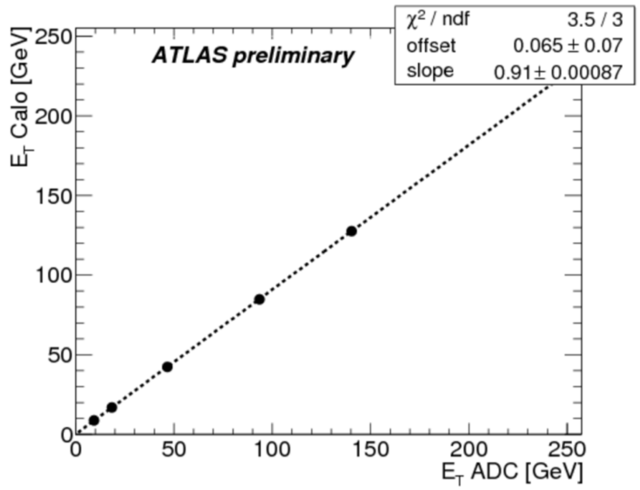
BCID Identification Efficiency



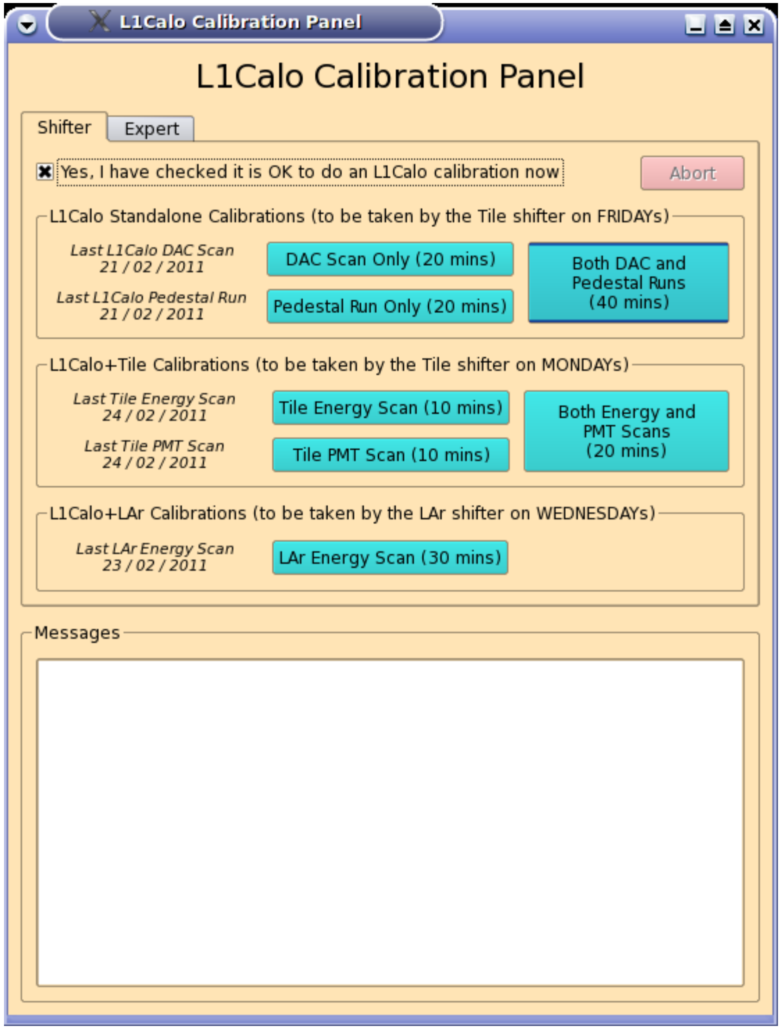
- Good indication of the success of timing and BCID logic is the efficiency of associating small energy deposits to the correct bunch crossing
- The turn-on at around 1.2 GeV is a result of the LUT noise cut and in line with the optimal performance expected from simulation

Energy Calibration Procedure

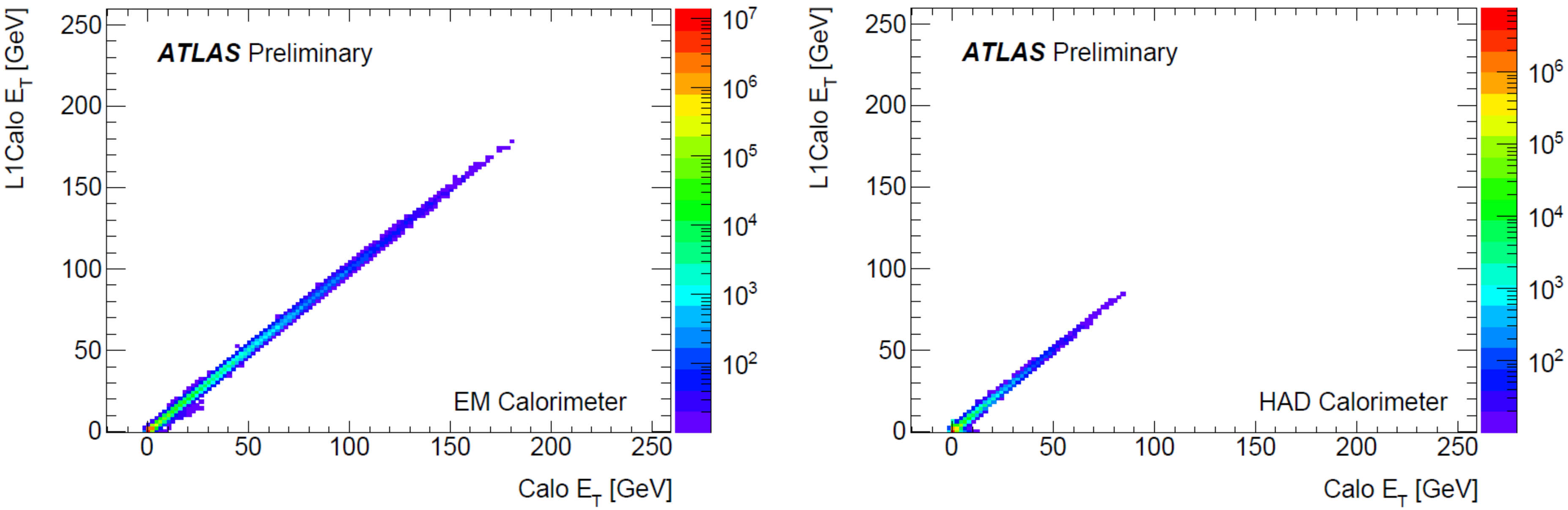
- Energy calibration (ADC to E_T) implemented in analogue receiver gains (and LUT slope)
- Use dedicated calorimeter pulser runs taken in between LHC luminosity fills



- 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



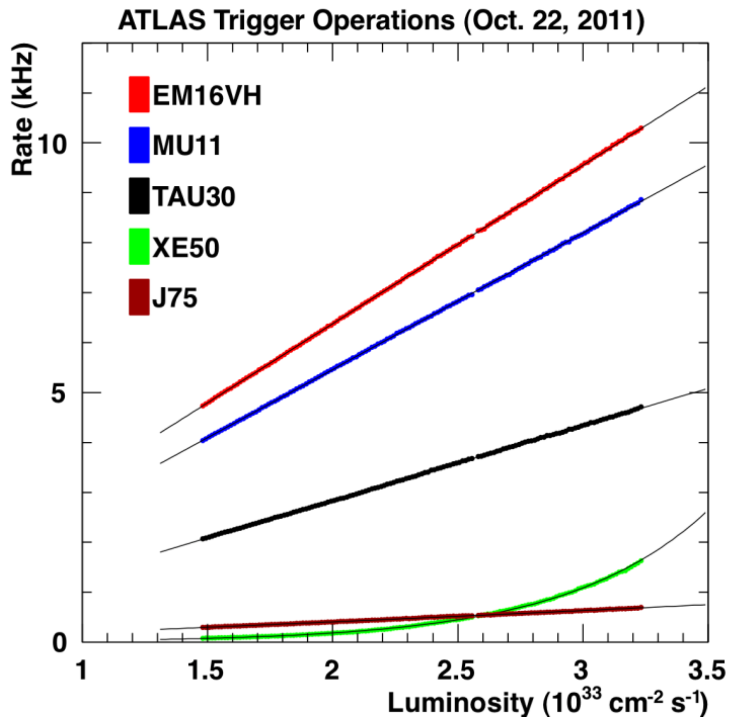
Energy Calibration Results



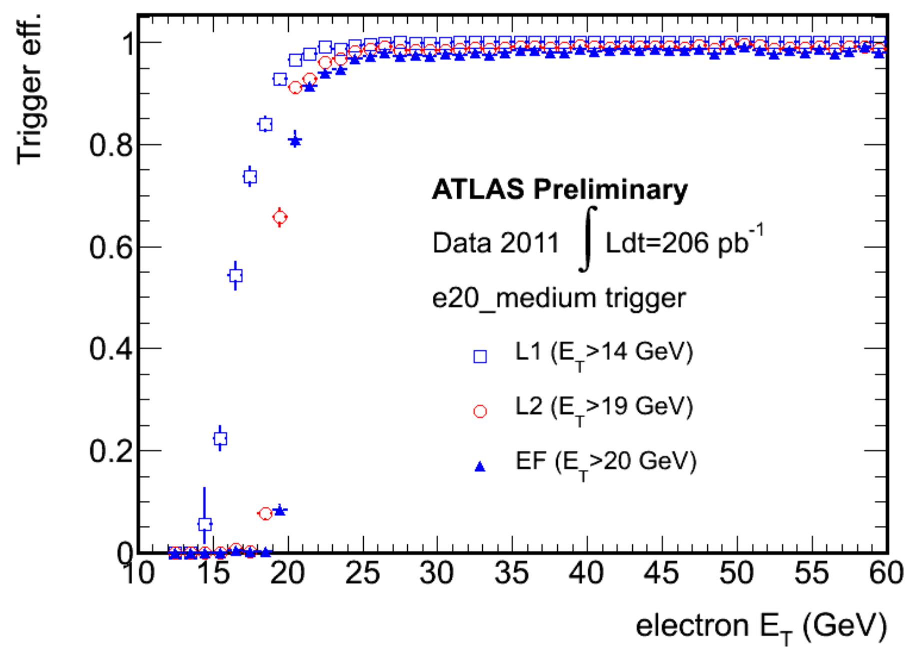
- Energy correlations for the electromagnetic and hadronic layer derived from initial 2011 collision data

→ Very good agreement between the L1Calo and calorimeter measured energies

Trigger Rates and Efficiencies

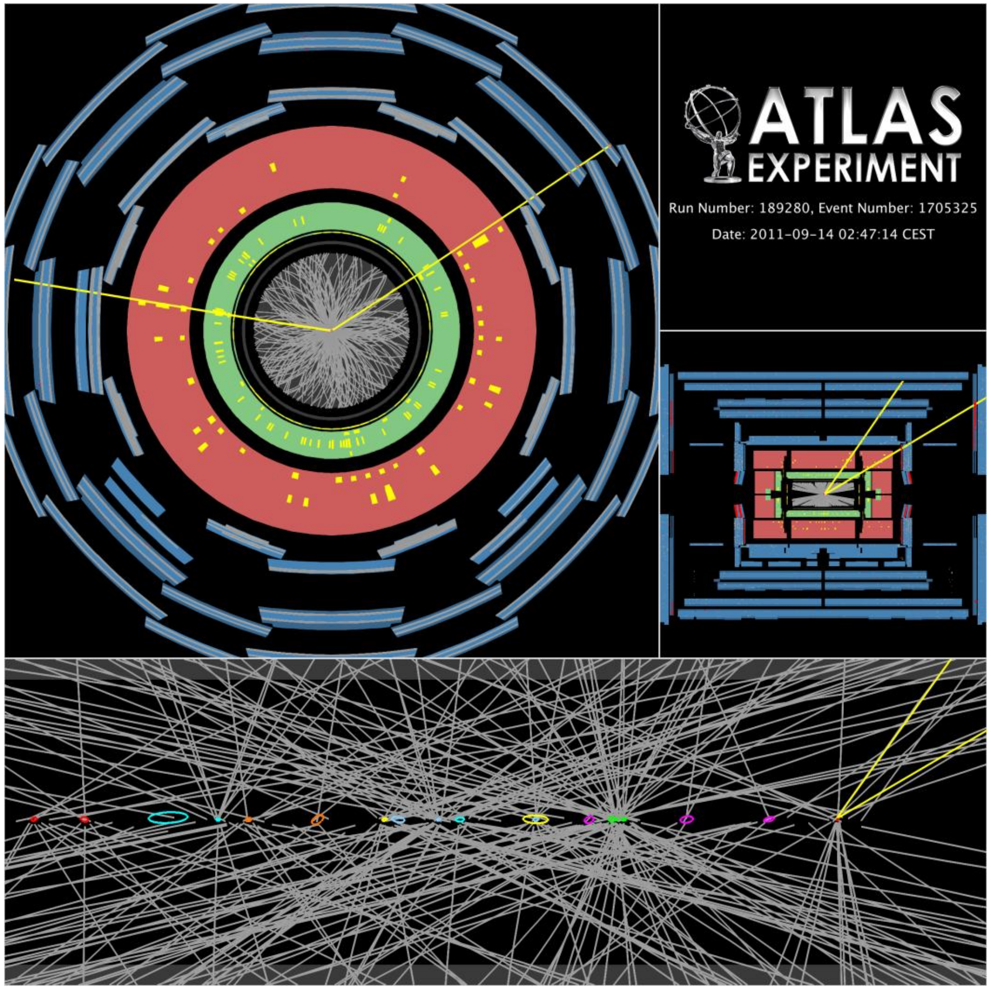


L1Calo trigger rates and efficiencies for 2011 overall look good!

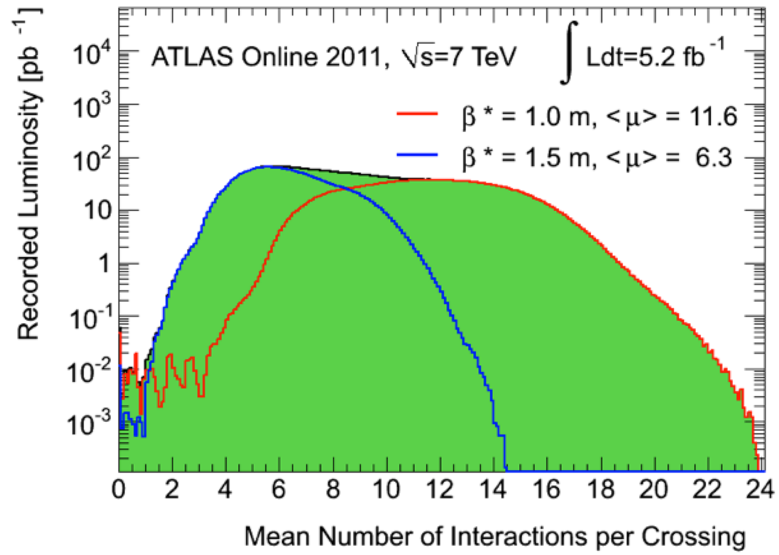


As expected, pile-up mainly affects missing and total E_T as well as trigger items based on forward calorimetry

Pile-up: The Challenge for 2011 and 2012



Z→ μμ candidate with 20 reconstructed vertices



- Up to 20 pile-up interactions, comparable to design luminosity

→ Up to 34 expected for 2012

In-time pile-up: Several interactions in same bunch crossing (BC)

Out-of-time pile-up: Effects due to interactions in neighbouring BCs

Trigger Cross Sections

Any process rate: R = L * σ

(L = inst. luminosity, σ = cross section)

For physics σ independent of L

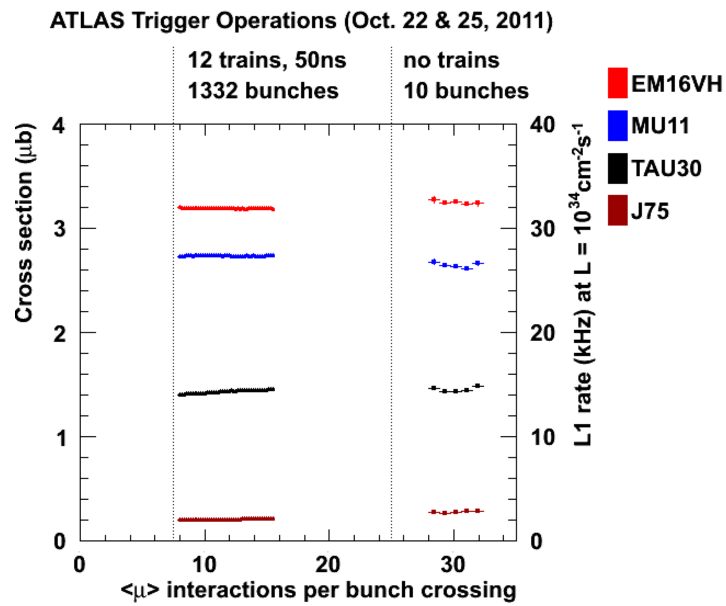
"Trigger cross sections"

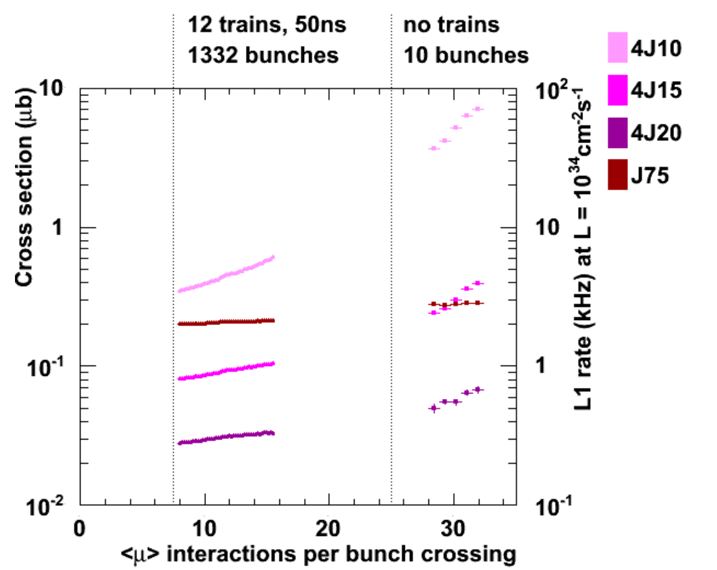
$$\sigma_{trig} = A/L + B + C\,L + D\,L^2$$

constant rate (e.g.cosmics) → A/L

constant σ → B

grow terms → C L + D L²



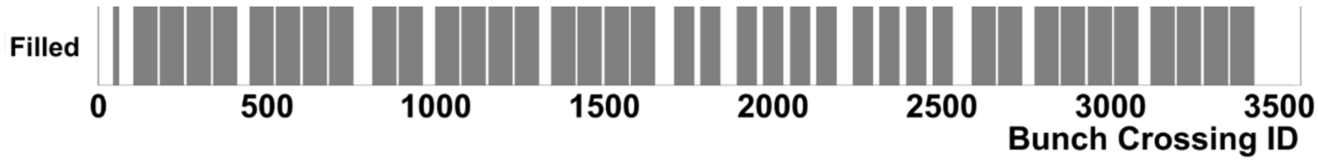


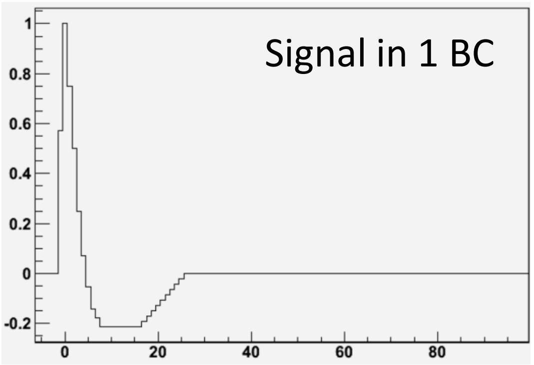
Extra powers of L can be caused by

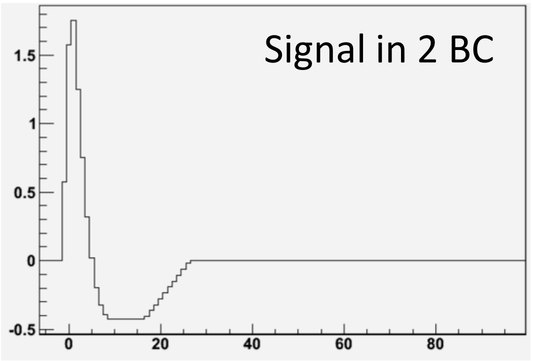
- overlapping objects from different interactions (pile-up)
- luminosity dependent fakes

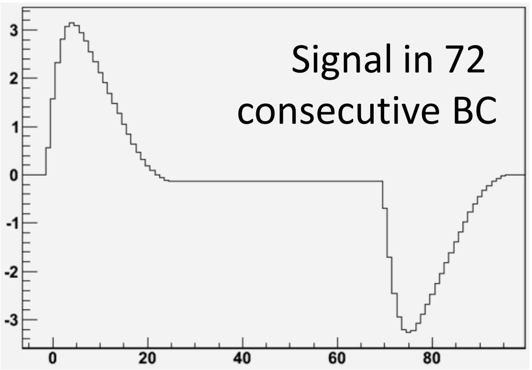
Pile-up Effects in L1Calo

LHC 50ns filling scheme:
1318 filled bunches









Bunch Crossing ID

LAr signal shape, Collard et al, ATLAS-LARG-PUB-2007-010

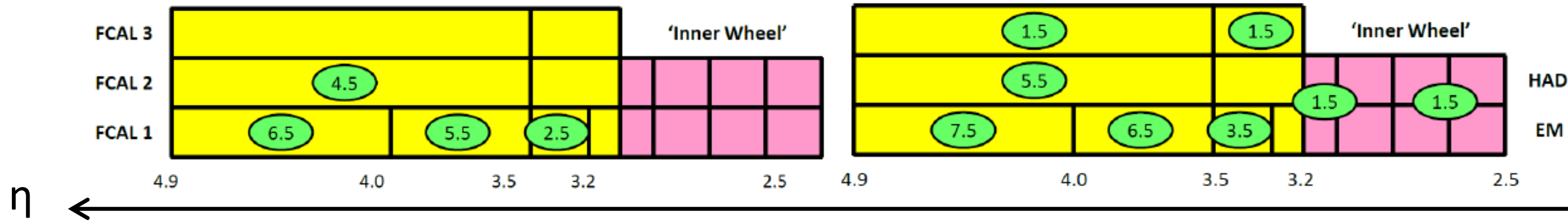
- Time between two filled bunches (50ns) is smaller than typical calorimeter signal lengths

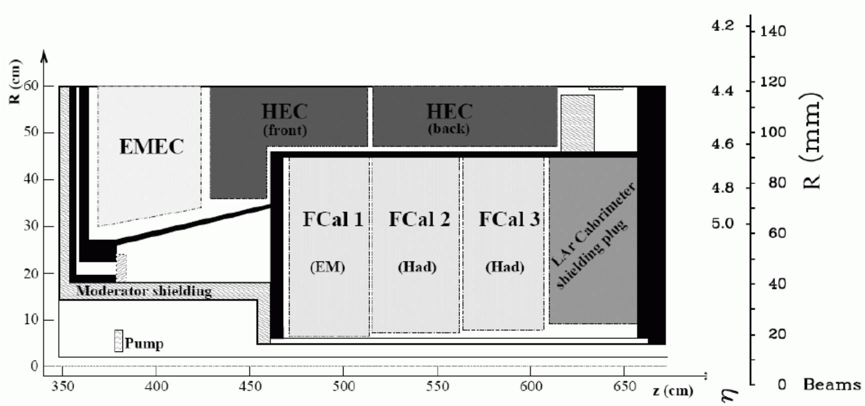
→ L1Calo experiences pedestal shifts due to unbalanced overlaying LArg analogue signals which in particular affected the forward calorimeter (FCAL) trigger towers

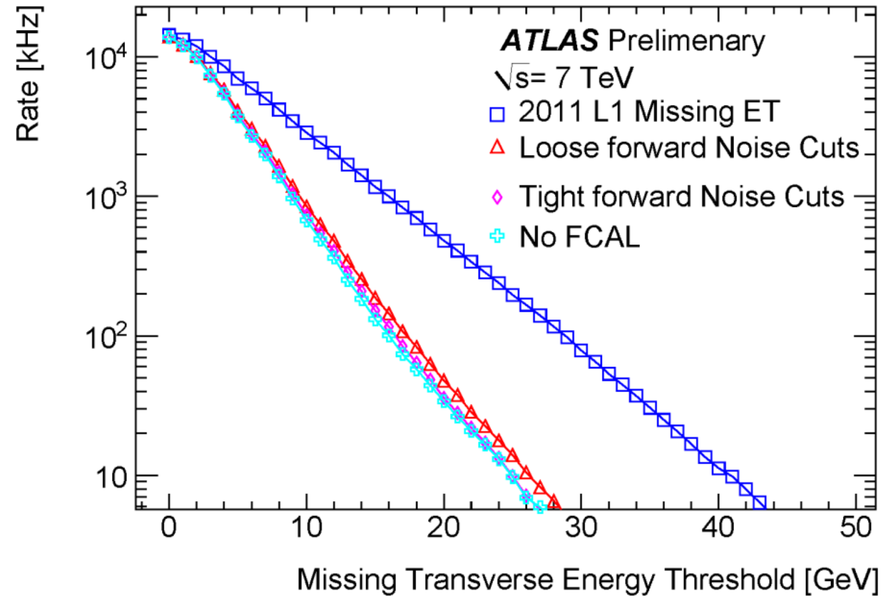
Pile-up Noise Cuts

Loose Cuts

Tight Cuts







- Recalculate L1Calo missing E_T rate as a function of threshold for different noise cuts using pure background/pile-up events

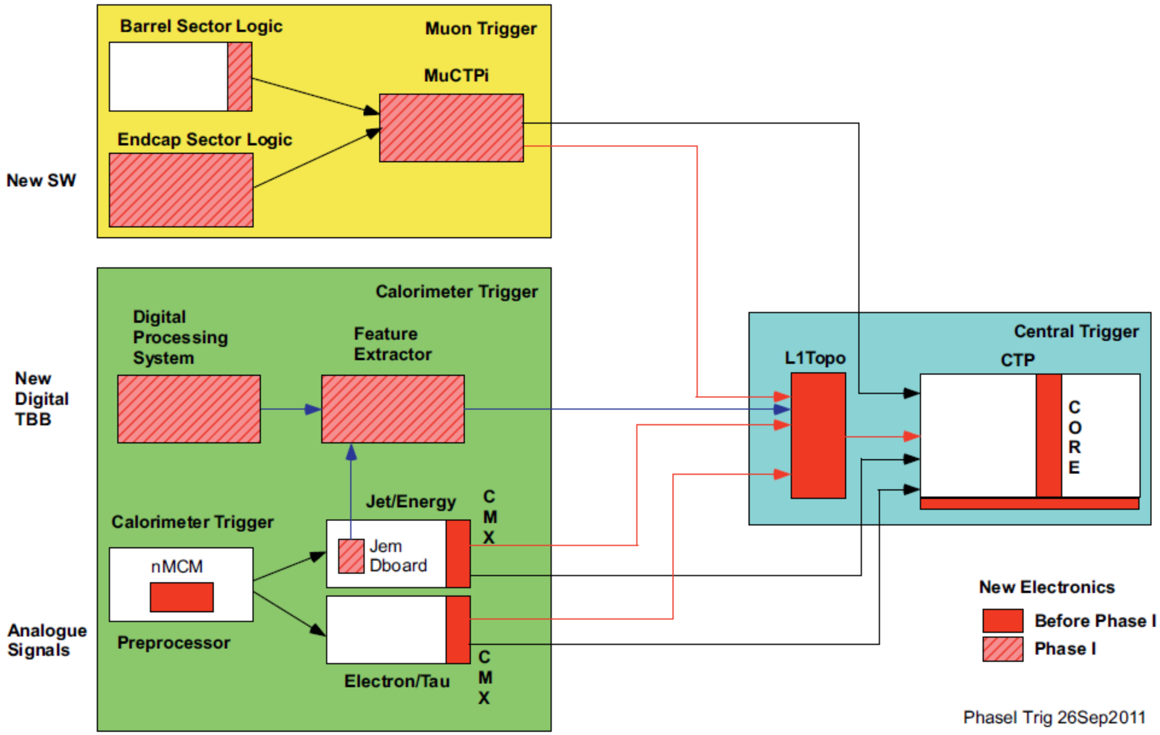
→ Optimised cuts derived in preparation for upcoming 2012 data taking period

L1Calo Upgrades in a Nutshell

Pre-Phase I

nMCM

- Talk P. Hanke: FPGA vs. ASIC
- Replace current ASIC based MCM with FPGA based
- Faster digitization with low noise
- Flexibility to improve FIR and BCID algorithms



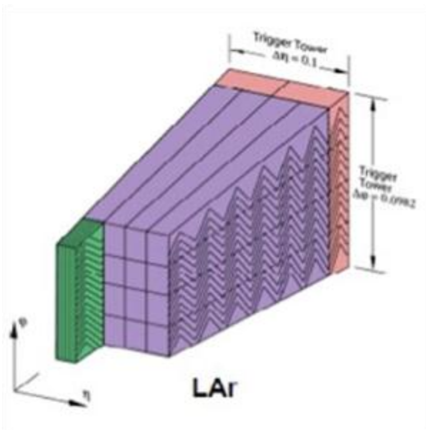
CMX

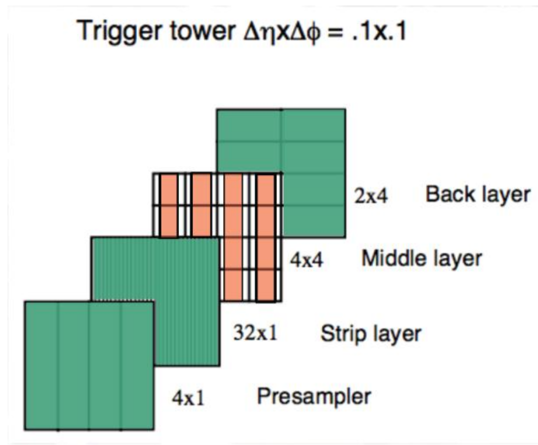
- Current CMMs to be replaced by eXtended Common Merger modules
- High speed links to new Topological Processor L1Topo

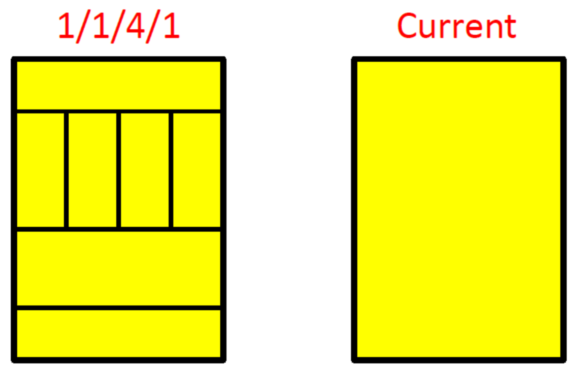
Phase-I

- Higher-granularity calorimeter data to be available to L1Calo
- Improve performance at higher pile-up and provide increased flexibility
- Has to use current max. latency of ~2.5 μs

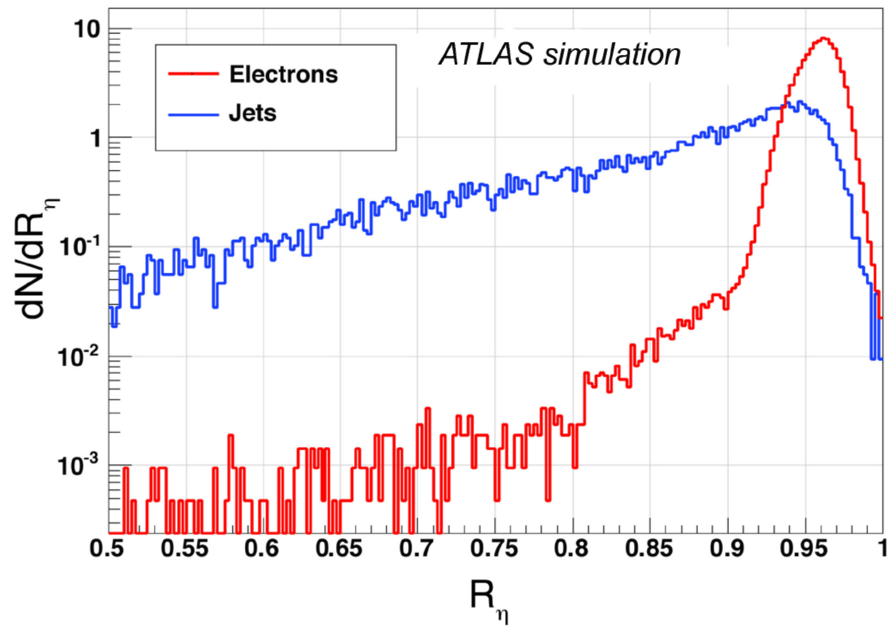
High Granularity Trigger Towers







- High granularity trigger tower (digitized on detector) provided by LArg sTBB
- Processed through new real-time data path: the Digital Processor System (DPS) and Feature Extractor (FEX)
- Middle layer granularity in particular important for low EM thresholds
- Shower shape algorithms based on “Supercells” achieve a background rejection similar to current L2 system



R_η = Ratio of energy in 3x2 over 7x2 cluster

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
- Precise L1Calo calibration essential for sharp trigger turn-ons and good efficiencies
- Performance was good for 2010 running and has been optimised further for the 2011 data taking period
- Improved pile-up noise suppression in preparation for 2012 running period