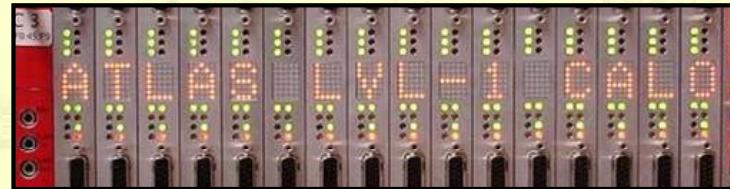


Analysis of initial performance of the ATLAS Level-1 Calorimeter Trigger

Damien Prieur

STFC Rutherford Appleton Laboratory



On behalf of the Level-1 Calorimeter Trigger collaboration

School of Physics and Astronomy, **University of Birmingham**, Birmingham, UK

Kirchhoff-Institut für Physik, **University of Heidelberg**, Heidelberg, Germany

Institut für Physik, **University of Mainz**, Mainz, Germany

Physics department, **Queen Mary, University of London**, London, UK

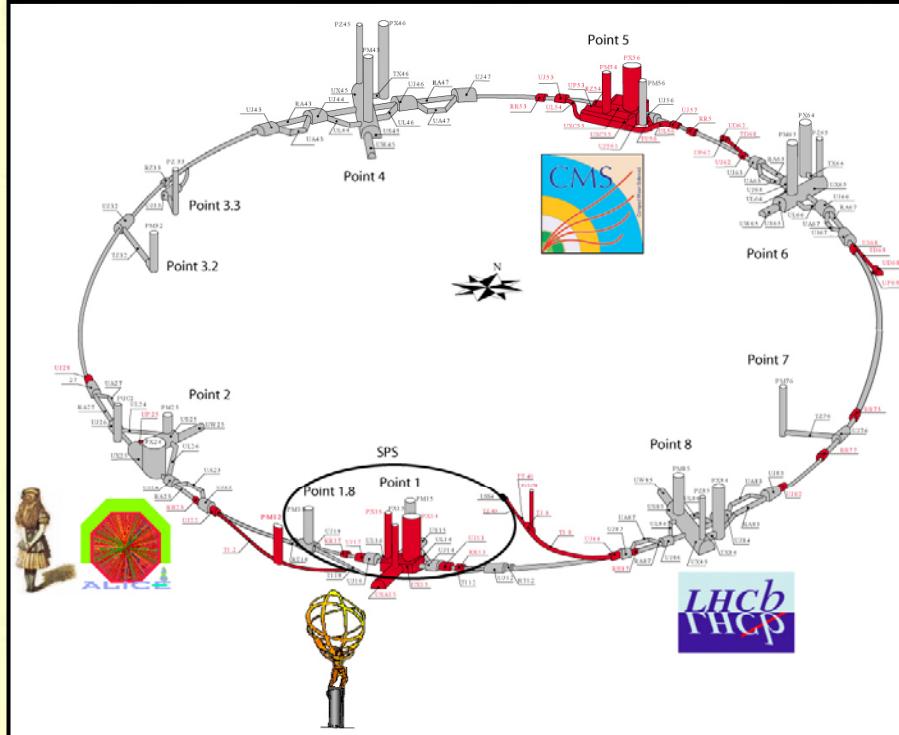
STFC Rutherford Appleton Laboratory, Oxon, UK

Fysikum, **Stockholm University**, Stockholm, Sweden

Outline

- LHC & the ATLAS detector
- Trigger system
- Level-1 calorimeter trigger
- Commissioning & Cosmic rays

The Large Hadron Collider - LHC



- pp collisions at $\sqrt{s} = 14 \text{ TeV}$
- Bunch crossing: 25 ns
- 10^{11} protons per bunch
- Initial luminosity : $L_0 = 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
($L = 50 \text{ pb}^{-1}/\text{year}$)
- Low luminosity : $L_0 = 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
($L = 10 \text{ fb}^{-1}/\text{year}$)
- Nominal luminosity: $L_0 = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
($L = 100 \text{ fb}^{-1}/\text{year}$)
- First collisions: Very soon....

- 4 Detectors:

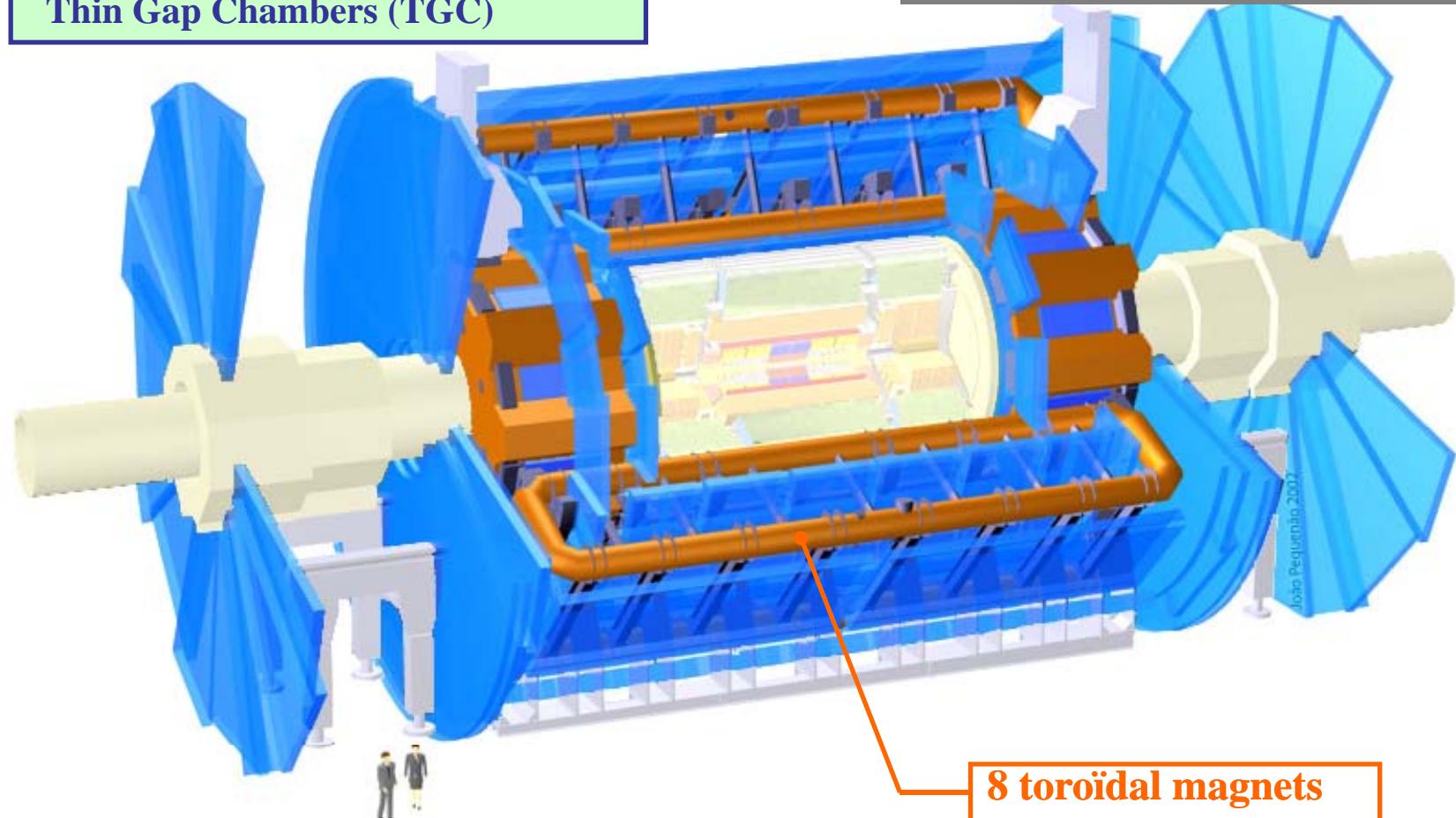
- ATLAS & CMS: p-p collisions, Standard Model and beyond
- LHCb: p-p collisions, B physics, CP violation
- ALICE: ion-ion/p-ion collisions, quark-gluon plasma

The ATLAS detector

Muon spectrometers

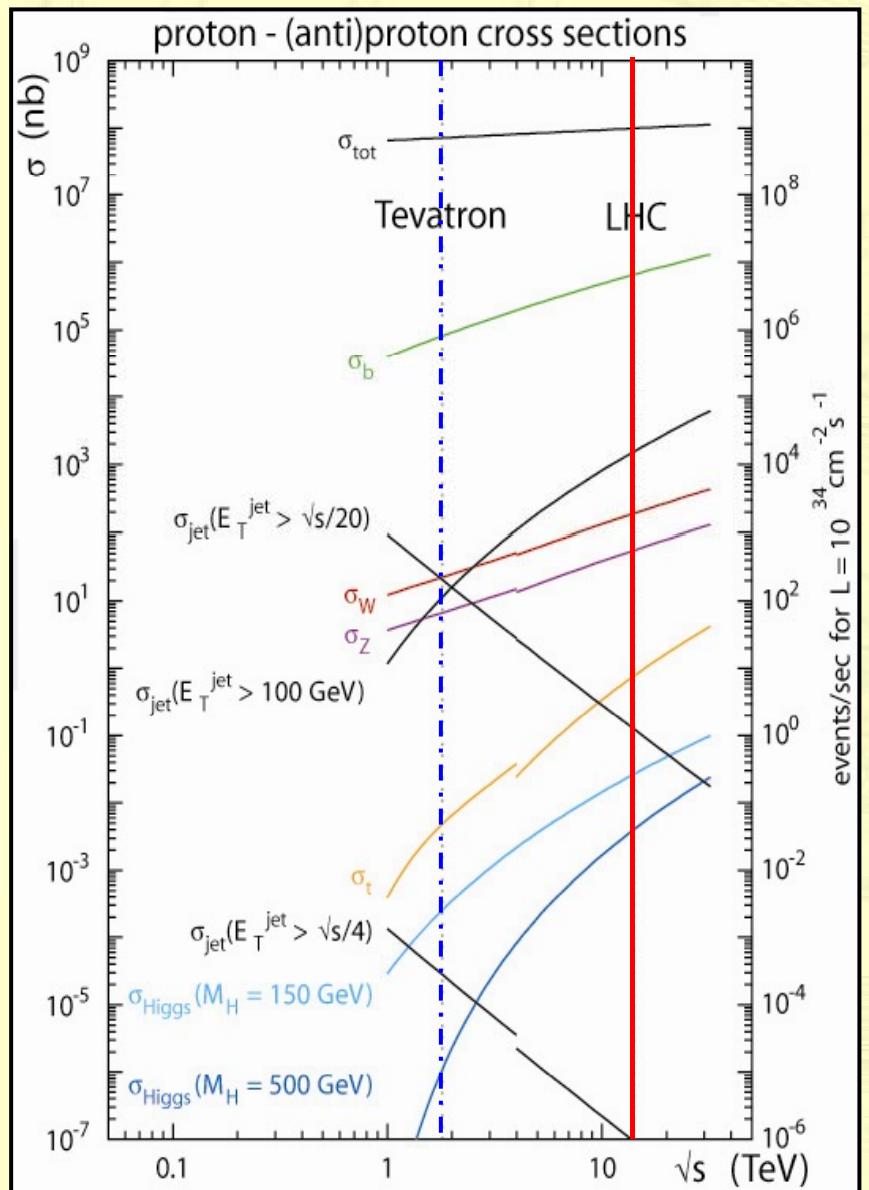
- Monitored Drift Tubes (MDT)
- Cathode Strip Chambers (CSC)
- Resistive Plate Chambers (RPC)
- Thin Gap Chambers (TGC)

Detector component	resolution	η coverage
Tracking	$\sigma_{p_T}/p_T = 0.05\% p_T \oplus 1\%$	$ \eta < 2.5$
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	$ \eta < 3.2$
Hadronic calorimetry (jets)		
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	$ \eta < 3.2$
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \eta < 4.9$
Muon spectrometer	$\sigma_{p_T}/p_T = 10\%/p_T @ p_T=1 \text{ TeV}$	$ \eta < 2.7$



8 toroidal magnets

Cross sections & rates



- p-p inelastic cross section: **70 mb**
- **23** collisions / bunch crossing ($10^{34} \text{ cm}^{-2}\text{s}^{-1}$)
⇒ pile-up
→ **10^9 interactions/s** (high luminosity)
- Need stringent selections to keep only interesting events:
 - Search for processes with small cross-sections
 - Rejection power 10^{12} ($H \rightarrow \gamma\gamma$ 120 GeV)
 - Looking for a needle in a haystack...
- Technological constraints:
 - Event size: 1.5 Mb
 - To tape: 300Mb/s

⇒ Have to reduce the acquisition rate from **40 Mhz** to **200 Hz**

Trigger strategy

L1

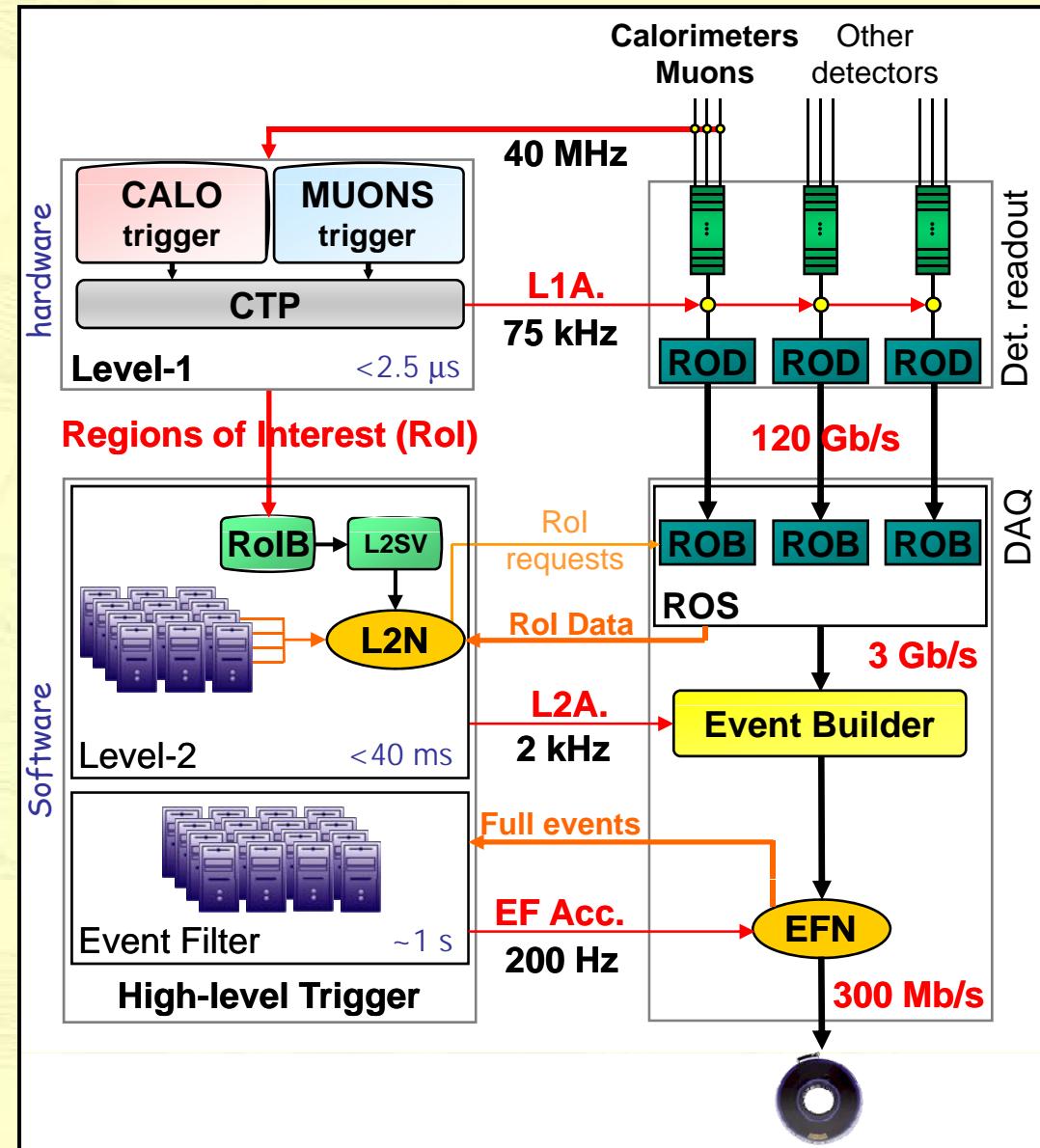
- Dedicated hardware (ASICs & FPGAs)
- Calorimeters & muons
- Latency $< 2.5 \mu\text{s}$
- L1A 75 kHz

L2

- ~500 dual CPUs
- Full granularity
- Regions of Interest (~2%)
- Latency ~40 ms
- L2A 2kHz

Event Filter (L3)

- ~1600 dual CPUs
- Access to full event & calibration constants
- More detailed reconstruction
- Use Offline algorithms
- Latency ~1s
- 200Hz



Level-1 trigger system (L1)

3 sub-systems

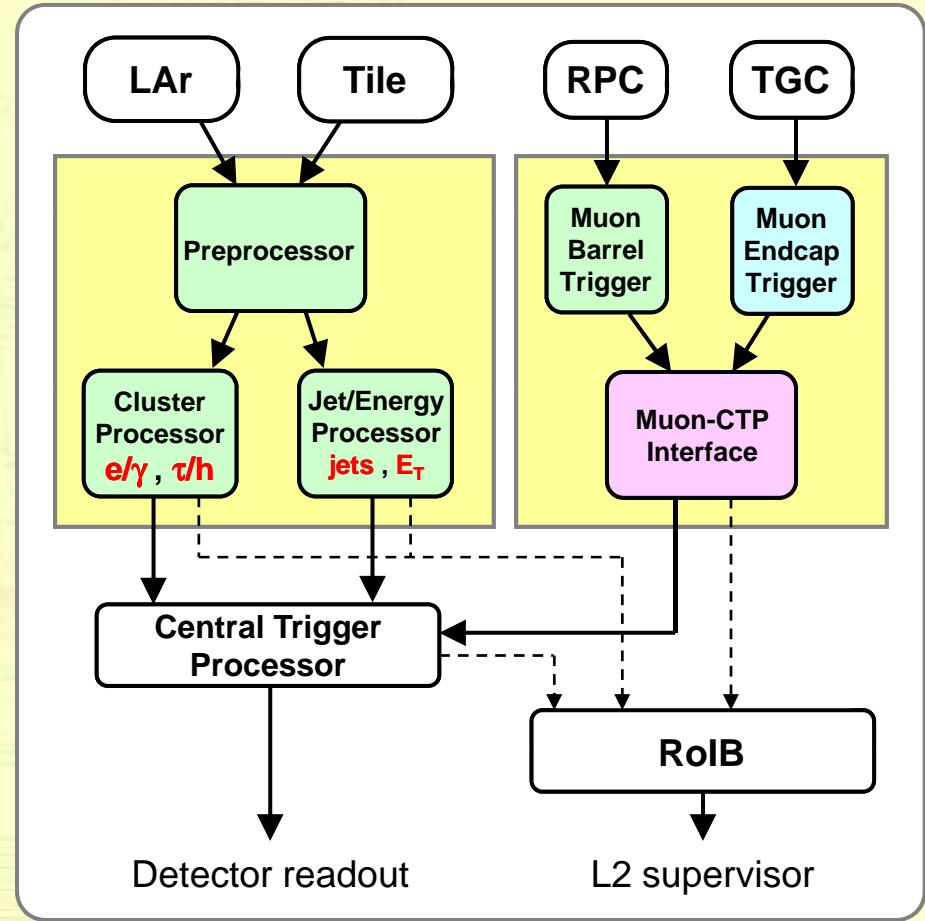
- L1 - Calorimeters (L1Calo)
- L1 - Muons
- Central Trigger Processor (**CTP**)

Signature identification

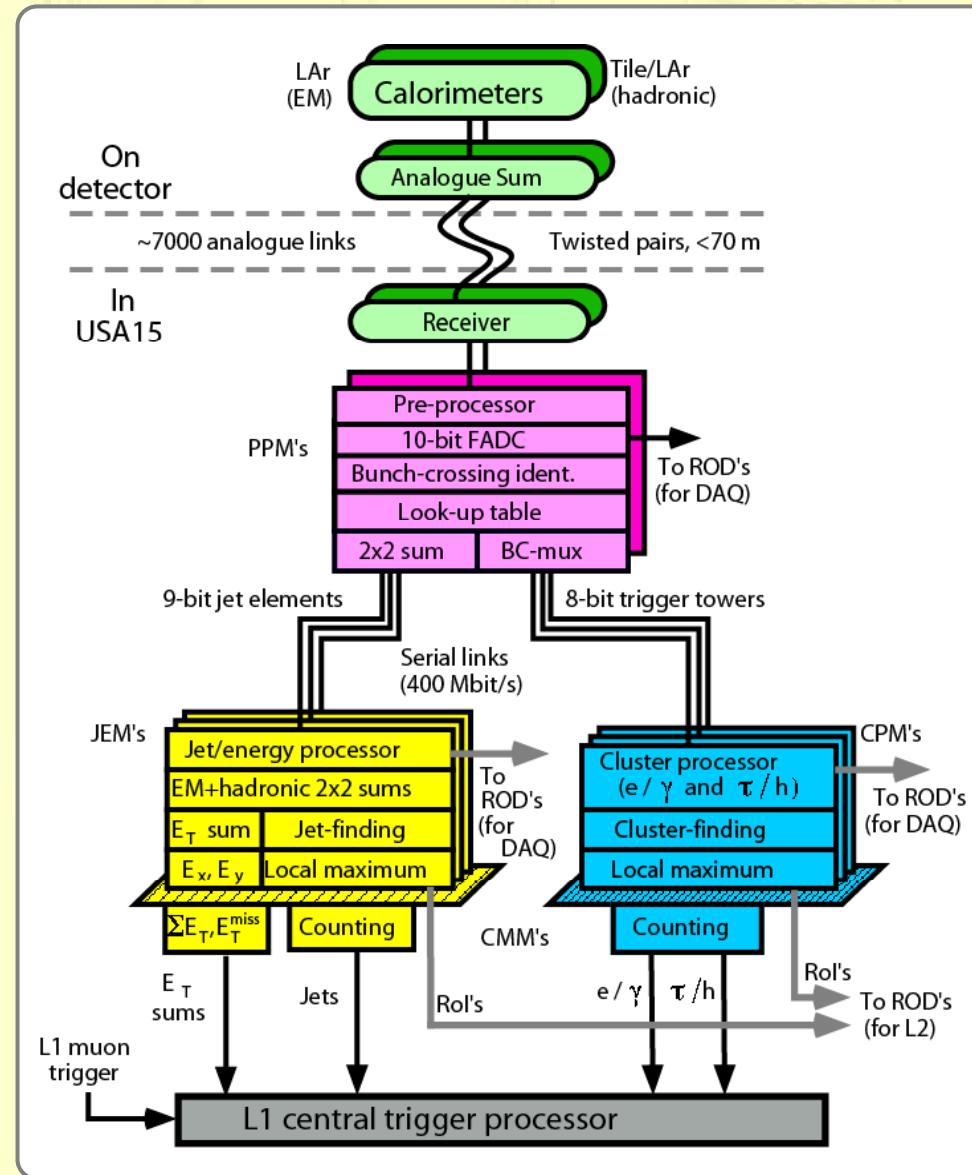
- $e/\gamma, \tau/h, \text{jets}, \mu$
- Multiplicities per p_T threshold
- Isolation criterion
- Missing E_T , total E_T , jet E_T

CTP

- Receive & synchronize trigger information
- Generate level-1 trigger decision (L1A)
- Deliver L1A to other sub-detectors



L1 Calorimeter - Architecture



- L1Calo partitioned into 3 sub-systems

Pre-Processor (PPr)

- Receive & sample signal from calorimeters
- Coarser granularity (**Trigger Towers**)
- Noise filter
- Bunch crossing identification (BCID)
- Determine final E_T value

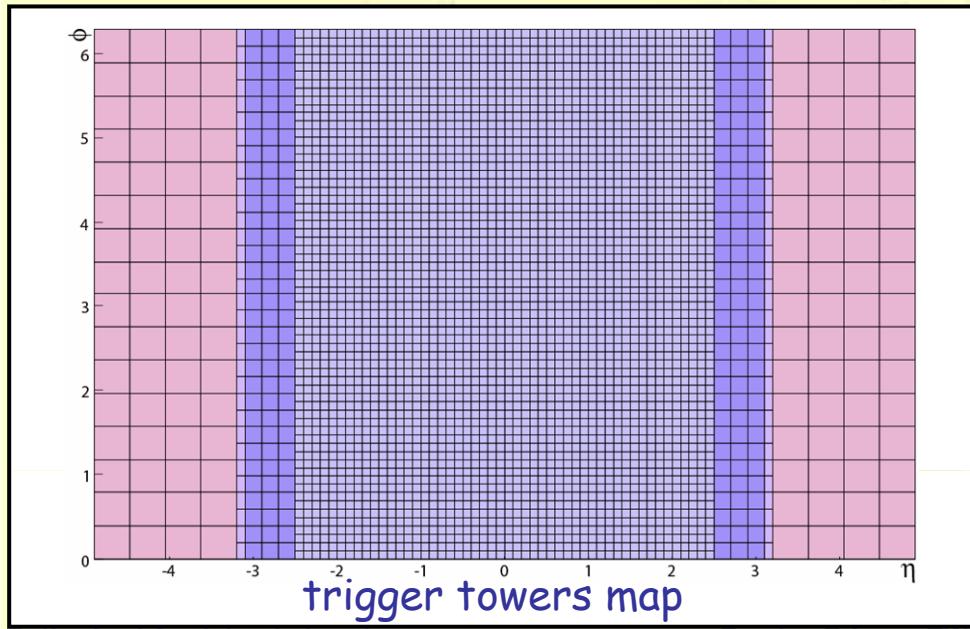
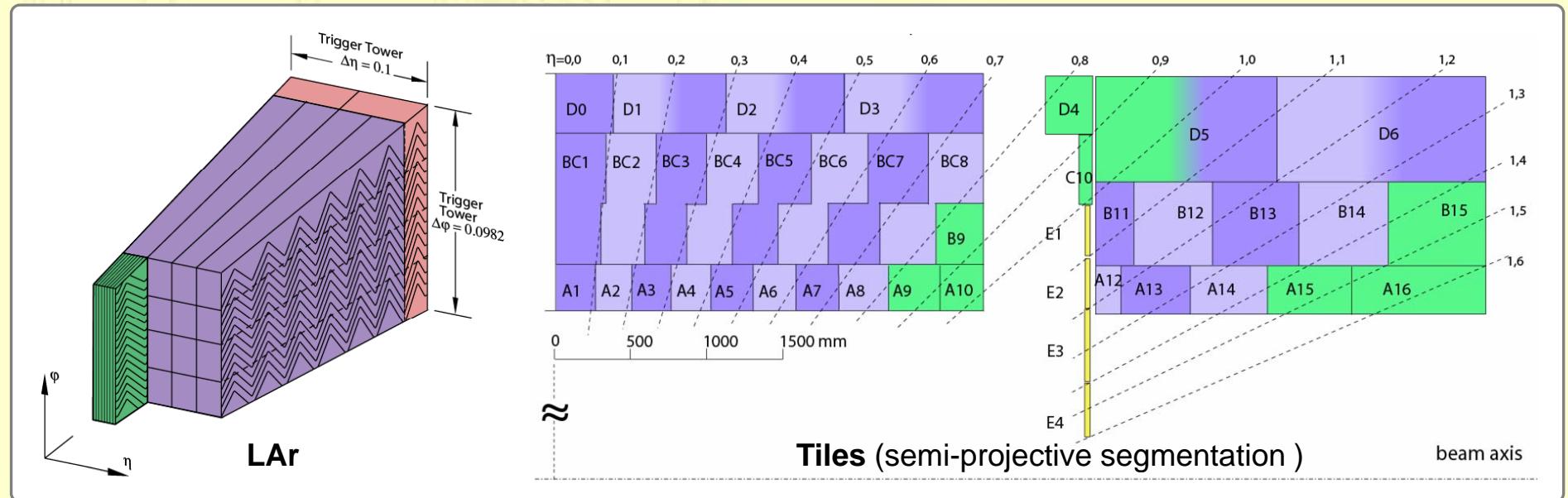
Processors JEP & CP

- Physics algorithms
- Search for and identify:
 - isolated leptons, taus
 - jets
- Compute E_T total, missing,...

⇒ Real time transmission to CTP

⇒ DAQ + RoIs at each L1A (75kHz)

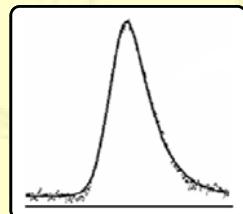
Trigger towers (TT)



- Analogue summation of calorimeter cells
- 3584×2 (EM+HAD) trigger towers

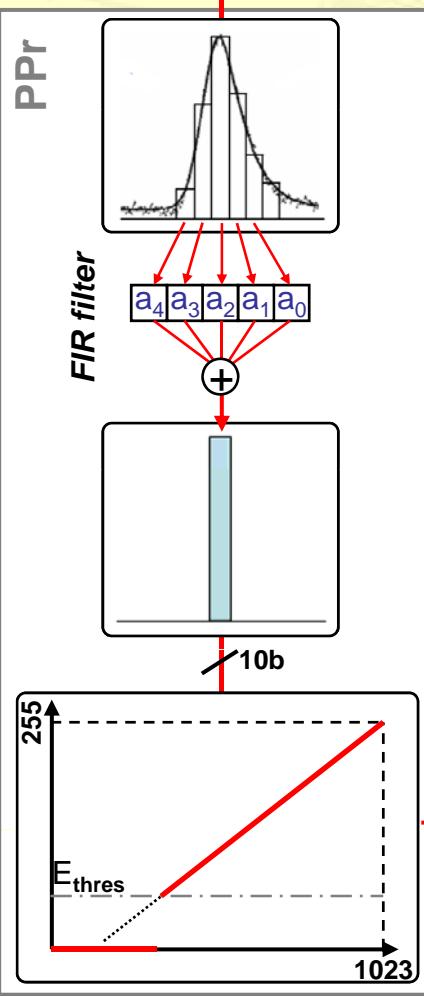
Position	$\Delta\eta \times \Delta\phi$
$ \eta < 2.5$	0.1x0.1
$2.5 < \eta < 3.1$	0.2x0.2
$3.1 < \eta < 3.2$	0.1x0.2
$3.2 < \eta < 4.9$	0.4x0.4125

Pre-Processors - Energy reconstruction



■ Receivers (Rx)

- Input signal conditioning to L1 ($2.5\text{V} \rightarrow 250\text{GeV}$)
- Variable gain amplifier (VGA)
- $E \rightarrow E_T$ Conversion (Hadronic layers only)
- Local signal monitoring



■ Sampling

- 40 Mhz, Flash-ADC 10 bits
- 1 ADC = 250 MeV
- Pedestal 40 ADC

■ Bunch crossing identification (BCID)

- Finite impulse response filter (FIR)
- Peak finder (linear/saturated)
- Assign E_T to the 'correct' bunch crossing

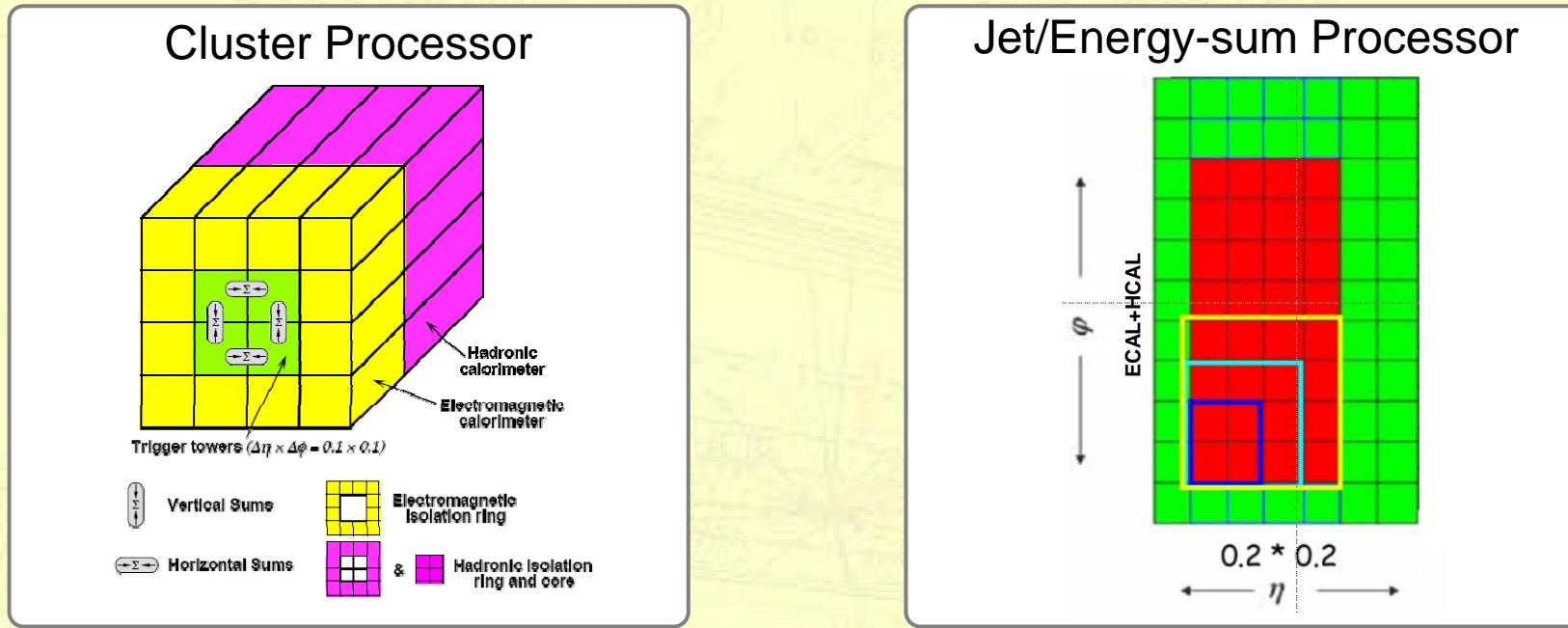
■ E_T calibration

- Look-Up Table (LUT)
- Pedestal subtraction, noise suppression
- $\text{ADC (10b)} \rightarrow \text{GeV (8b)}$ conversion

■ Transmission to processors & DAQ

Regions of Interest (RoI)

- Processors input is a matrix of tower energies
- Algorithms look for physics signatures (sliding window)
- RoI's sent to Level-2 trigger



- Criteria for e/γ or τ/h candidate:
 - EM or Had. cluster $> E_{\text{threshold}}$
 - Total E_T in EM Isolation Ring \leq EM isolation thresh.
 - Total E_T in Had. Isolation Ring \leq Had. isolation thresh.
 - Local E_T Maximum compared to neighbor windows.
- e/γ only:
 - Had. core \leq core isolation threshold

- Jet candidate
 - Coarser granularity 0.2×0.2 (jet element)
 - Digital summation EM + Had.
 - Sliding, overlapping windows (3 sizes)
- Missing energy

See next talk by Andrea Neusiedl

Installation & Commissioning

■ System fully installed since end of 2007

- Hardware production achieved
- Last modules installed
- Cabling finalized

■ Commissioning

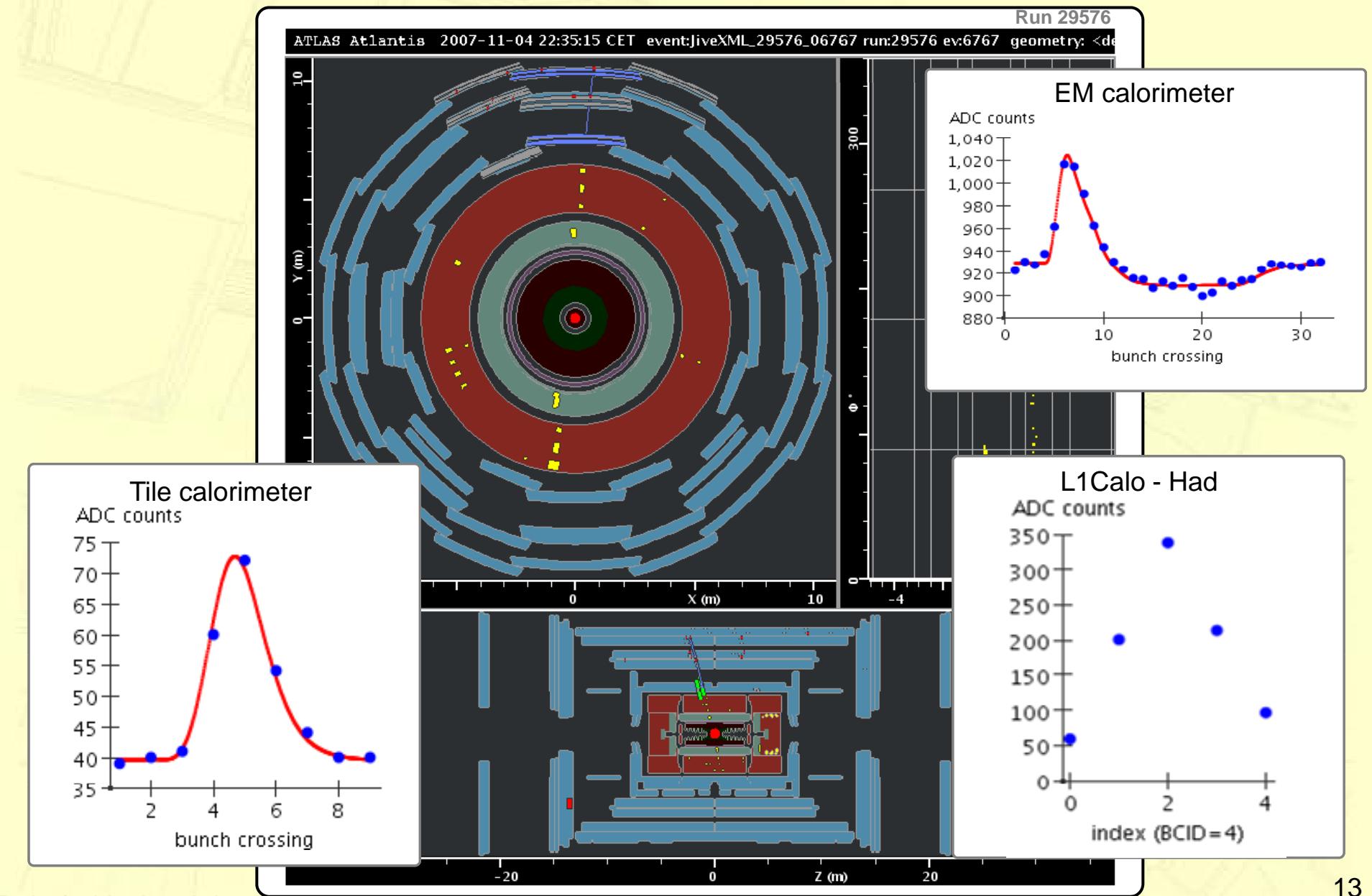
- Hardware/software testing
- Calibration procedures with calorimeters
- Several integration & data taking campaigns

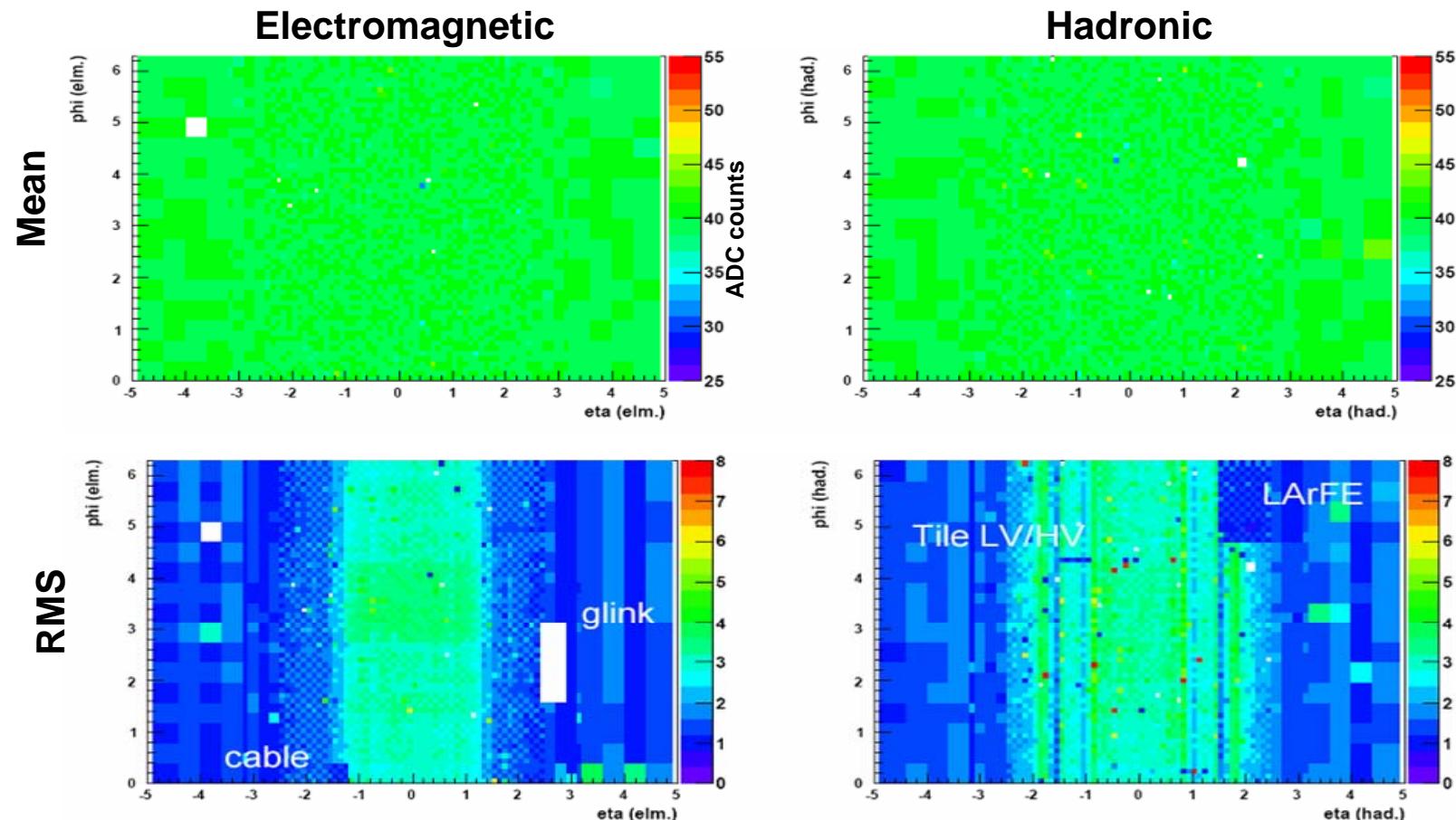
■ Cosmic muons

- Proved to be very useful
- Acquisition chain understanding
 - Analogue & digital parts
 - Calorimeters - L1Calo comparisons
- Assess system stability
- Triggering on muons
 - Proof that L1Calo is behaving correctly



Event display of a cosmic muon

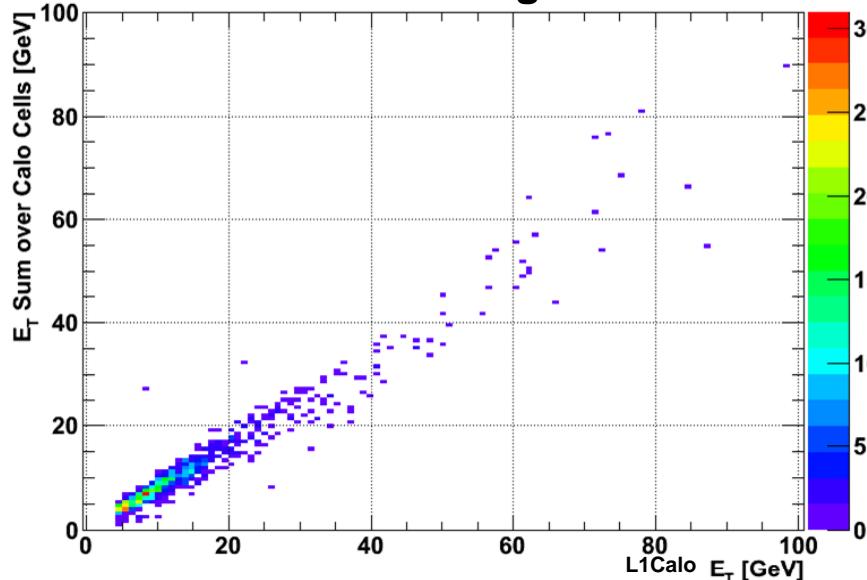




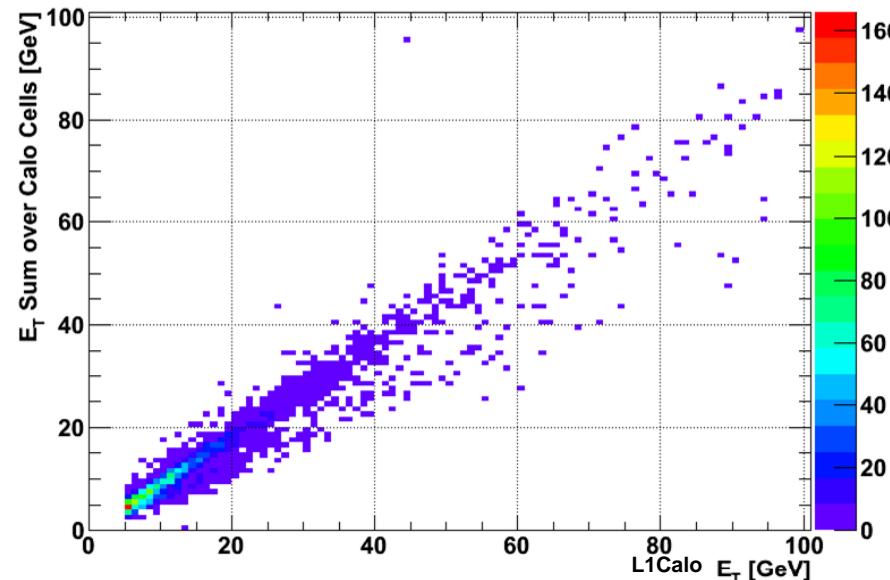
- Pedestals set to 40 ADC counts
- Sensible RMS ~ 400 MeV
- Nearly all channels behaving correctly (>99%)

Energy correlation with calorimeters

Electromagnetic

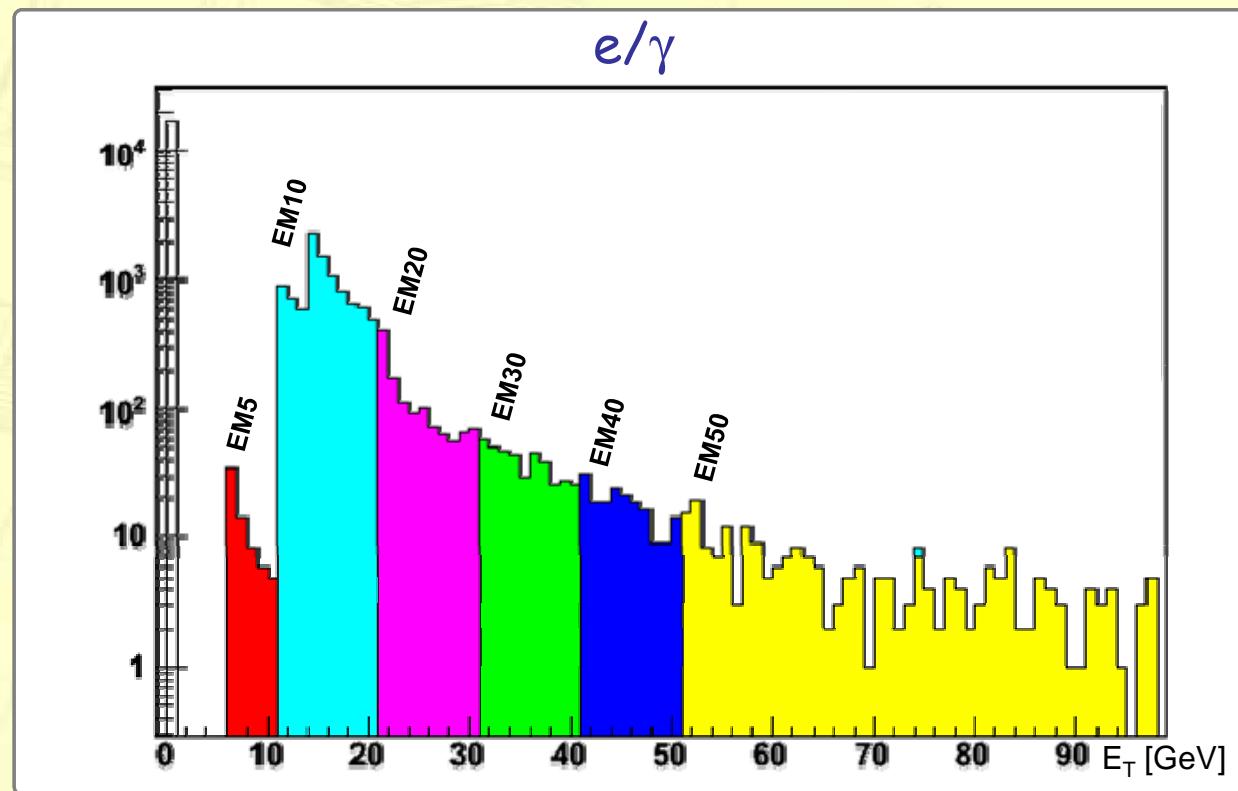


Hadronic



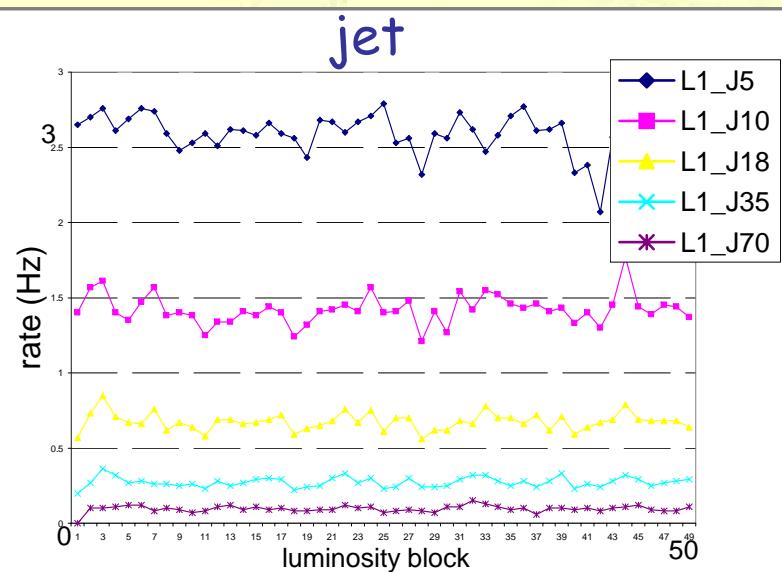
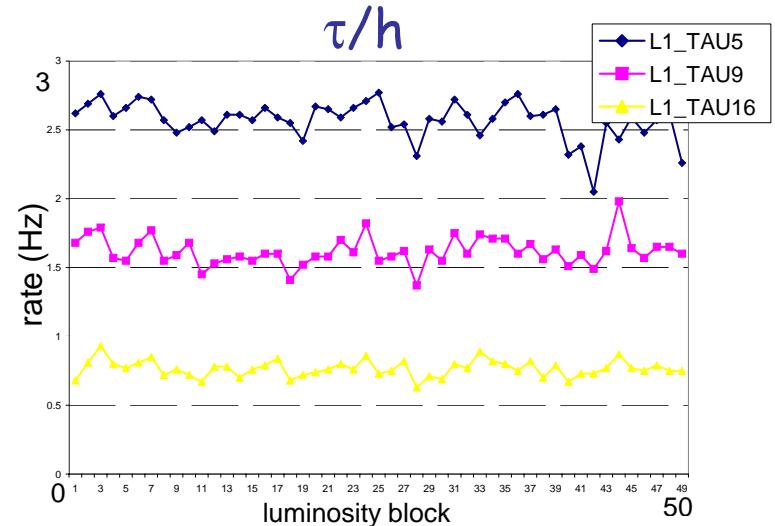
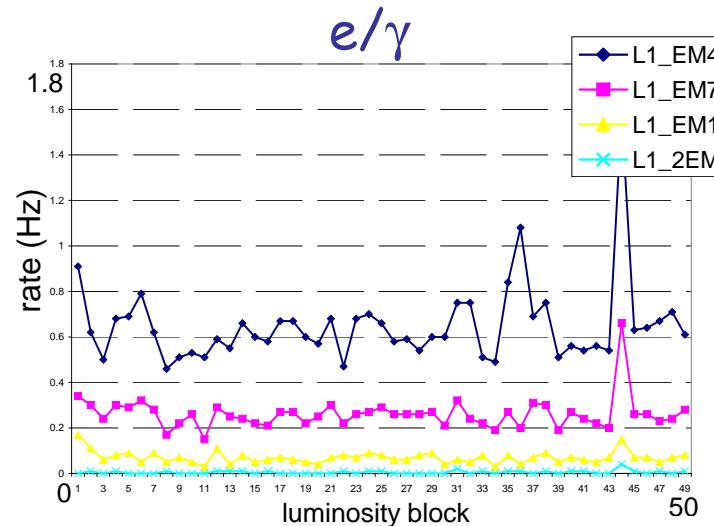
- L1Calo reconstructed E_T vs calorimeter precision readouts
- Cosmic muons
- Reasonable correlation achieved
- Very crude calibration applied, still room for improvement

EM & Hadronic cluster Energy



- E_T for Cluster Processor RoIs
- 8 E_T thresholds for e/γ & τ/h
- Show the thresholds are working
- Steps between thresholds correspond to
 - Different pre-scale settings
 - HLT algorithms at Level-2

Trigger rates



- Long overnight cosmic runs
 - 1 luminosity block = 5 minutes
- Stable trigger rate at level of few Hz
- Capability to separate good events from background
- Rate monitoring tools
 - Very useful to spot hot channels

Conclusions

System fully installed since end of 2007

- Cabling, Hardware & signal testing,...
- Technical & integration runs with other sub-detectors

Cosmic runs

- Providing trigger in all the last campaigns
- Very useful for debugging
- More control over the system (stability, rates...)
- Proved capability to trigger reliably

Toward the first collisions...

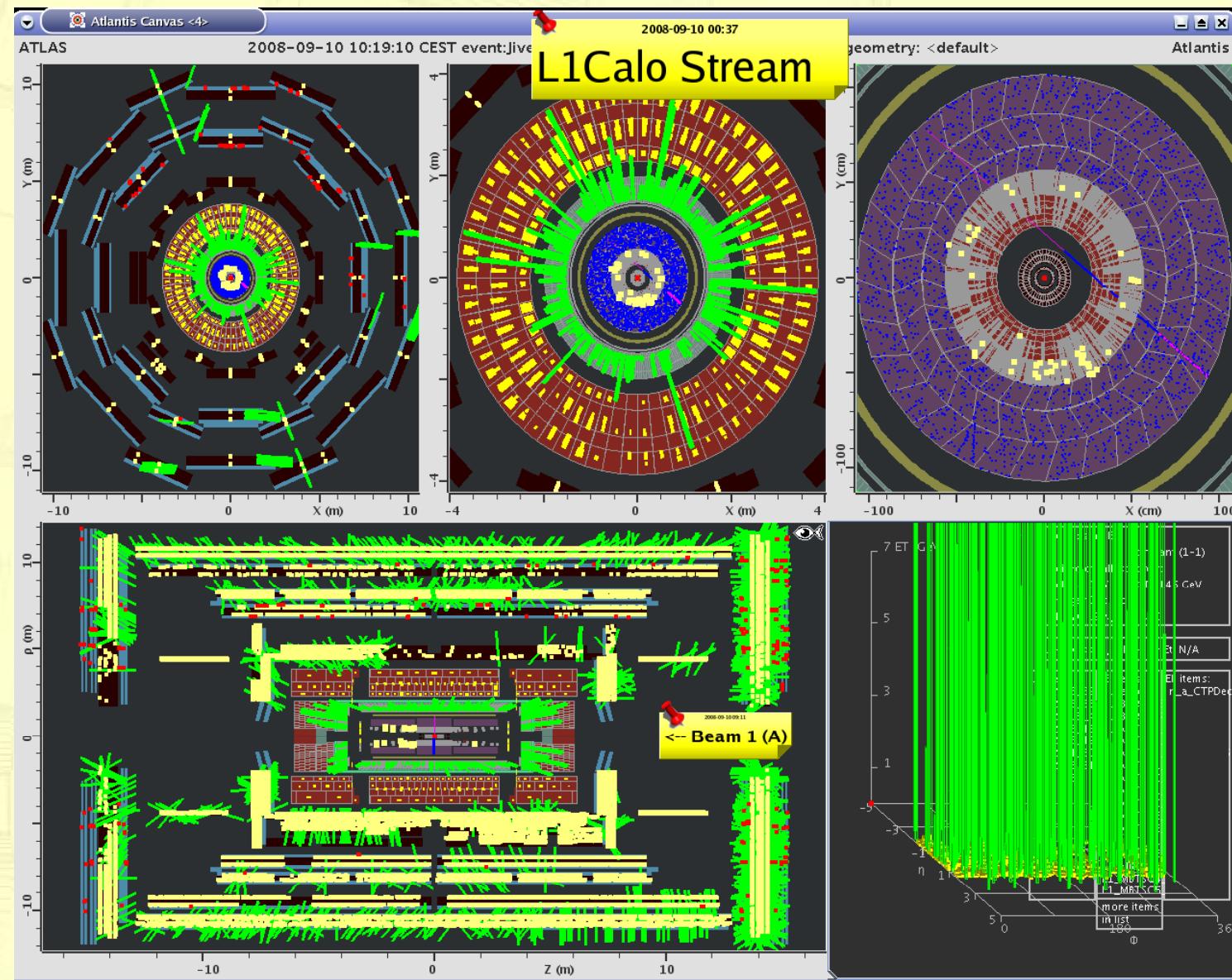
- Preparing for beam
- Fully operational L1Calo trigger
 - >99% working channels
 - Timing will be crucial
- Focusing on calibration procedures
 - See poster by Rainer Stamen
- Performance
 - Trigger efficiency
 - Correction for misbehaving channels



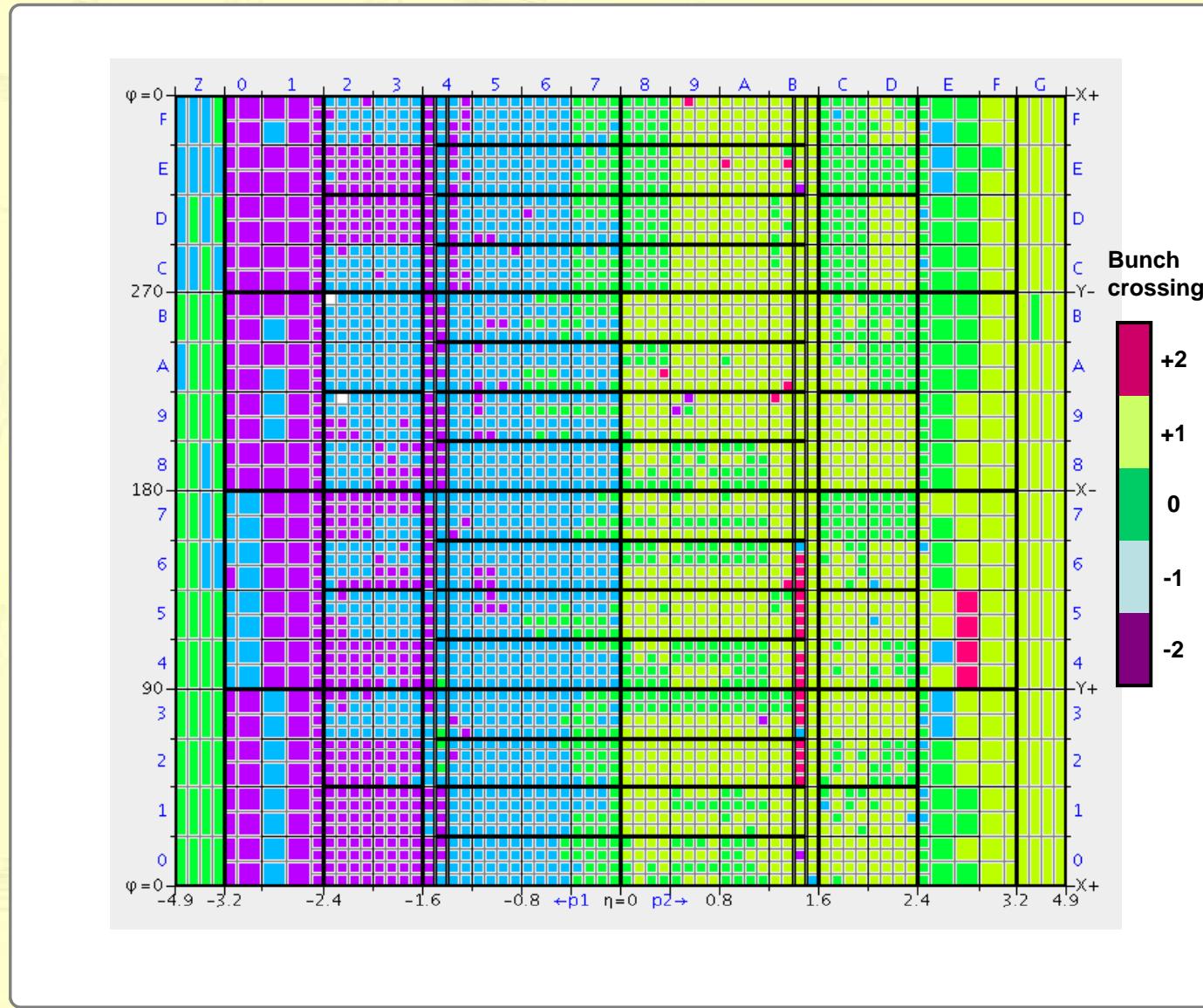
B A C K U P . . .



Beam splash

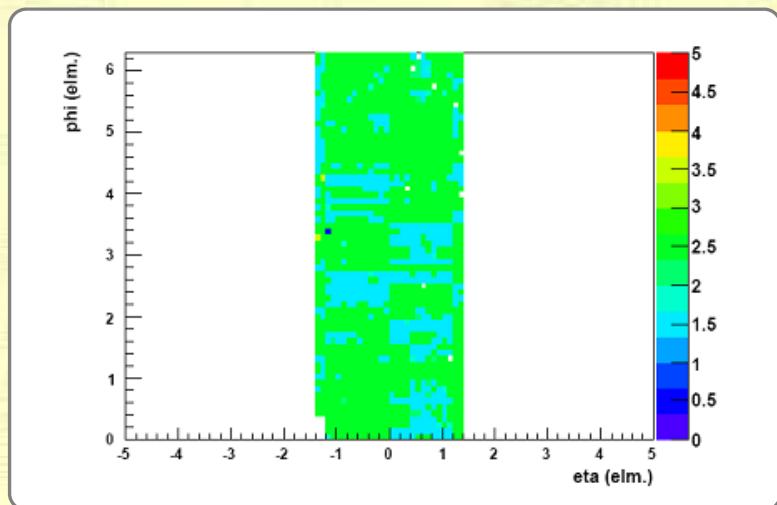
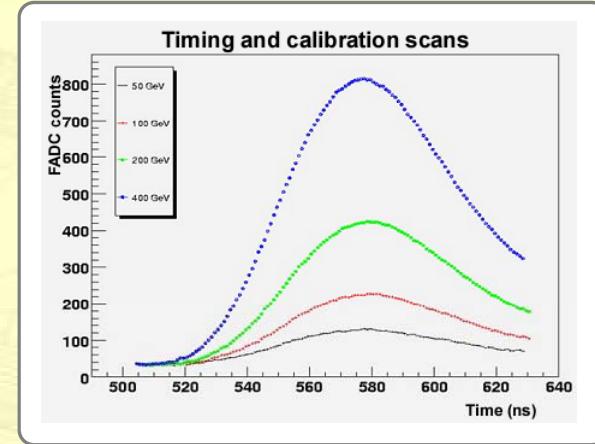


Average offset from L1A timing in EM layer

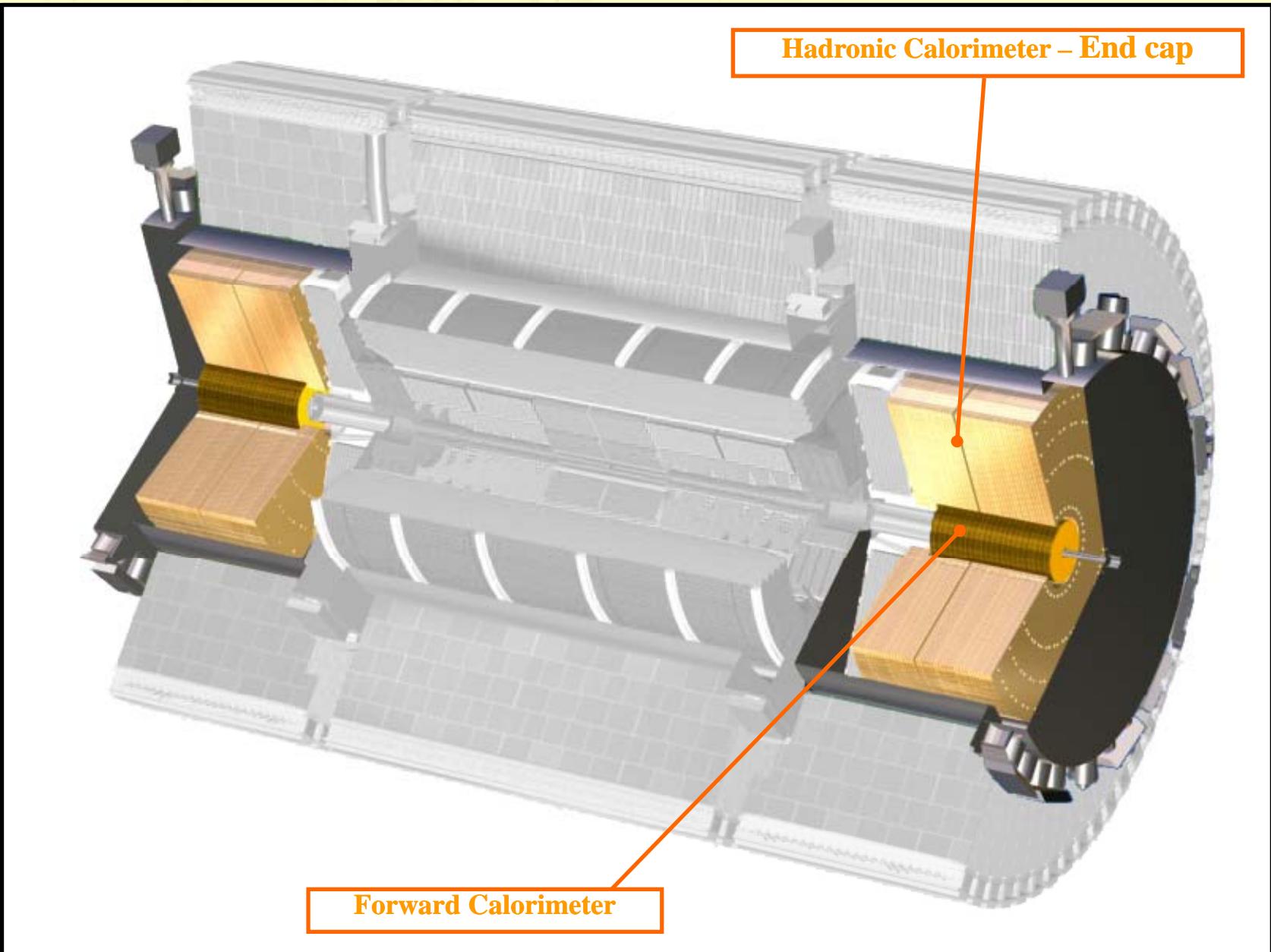


Timing calibration

- Internal timing of L1Calo trigger is achieved
- Input timing realized in pre-processors
- Not a trivial task
- Several strategies depending on signal origin:
 - calibration
 - cosmic rays
 - collisions
- Different setup & automatic procedures
 - Setup coarse/fine timing
 - Ensure signals are correctly sampled (3rd sample at maximum)
 - Signal shape with **1 ns** sampling step



- LAr EMB timing from pulser run
- Coarse timing ok
- Focusing on fine tuning



Central Trigger Processor (CTP)

- Receive, synchronize and align trigger information
- Other signals:
 - Random trigger
 - Calibration
 - Minimum bias events (MBTS)
- Generate the level-1 trigger decision (L1A)
 - Programmable trigger menu
 - Latency 100 ms (4BC)
- Deliver the L1A to the other sub-detectors

