First Data with the ATLAS Level-1 Calorimeter Trigger

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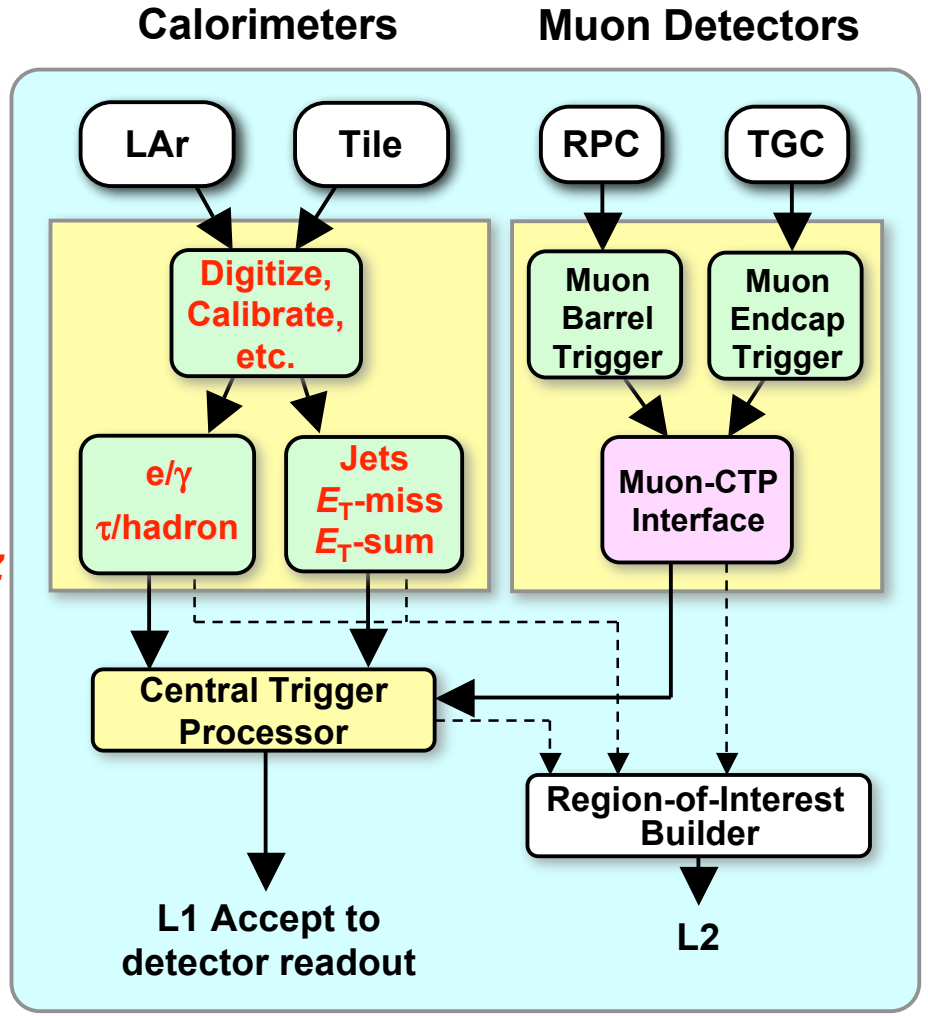
ATLAS Level-1 Trigger

Level-1

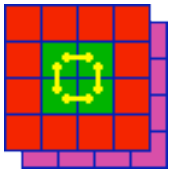
- Custom electronics
  - *ASICs and FPGAs*
- Calorimeters and Muon Detectors
  - *reduced granularity*
- Total latency < 2.5 μs
  - *including transmission delays*
- *Rate reduction:*
  40 MHz bunch-crossings → 75(100) kHz

Level-2 and Event Filter (L3)

- CPU farms
- All detectors
- Full granularity
- Regions of Interest
- *Rate reduction:*
  75(100) kHz → 200 Hz

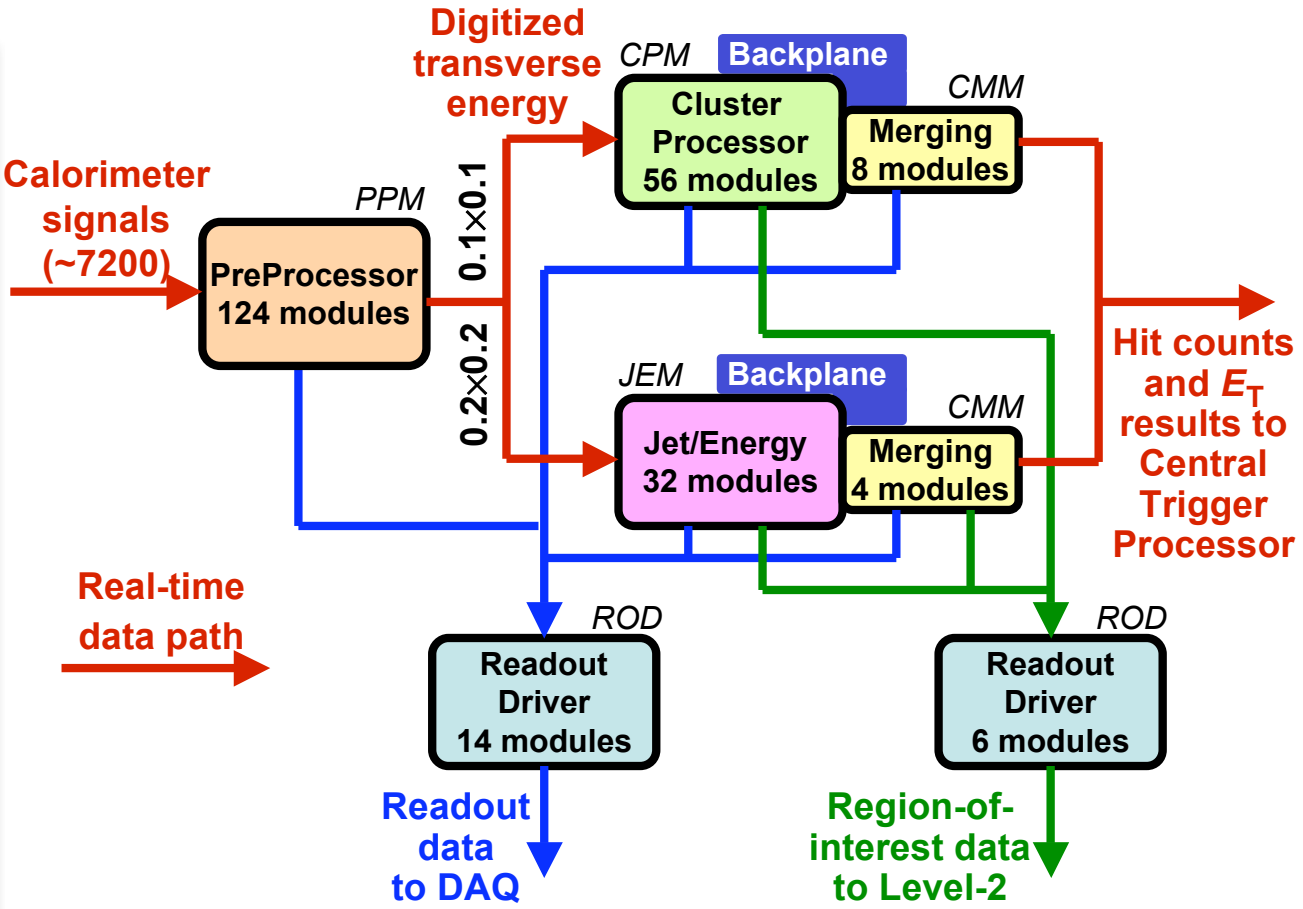


Level-1 Calorimeter Trigger ("L1Calo")



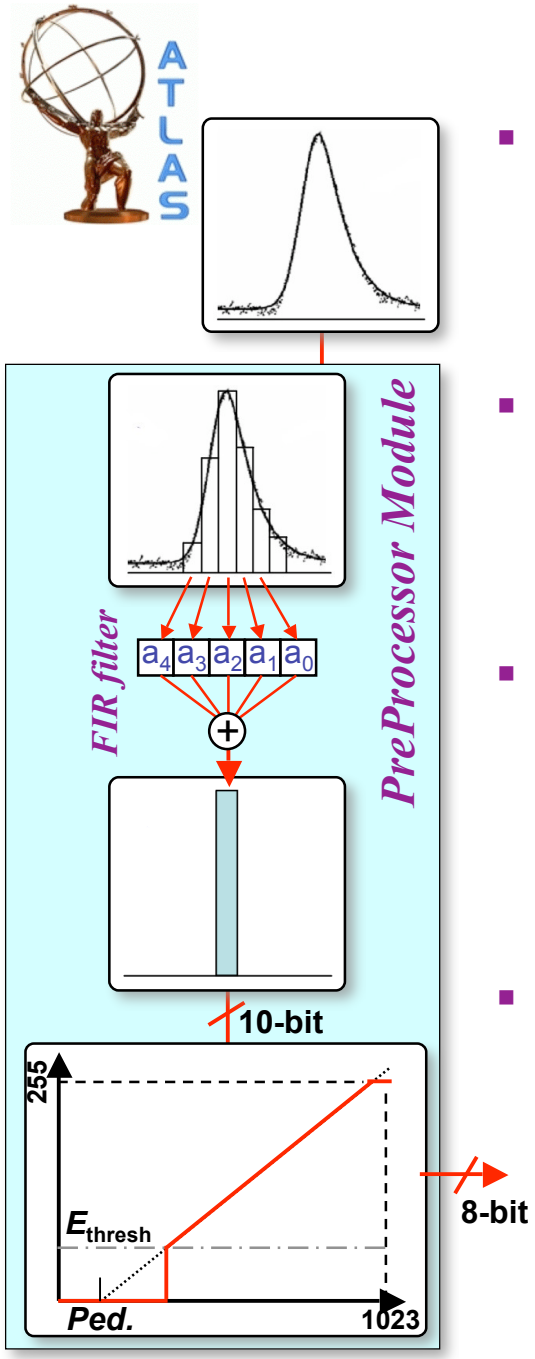
Features

- ~1 μs fixed latency
- Pipeline processing
- Massive parallelism
  ~300 Gbyte/s input
- FPGA-based
  only one L1Calo-specific ASIC type
- Complex connectivity
  overlapping sliding-window algorithms
- Multi-purpose modules
  CMM, ROD, backplane

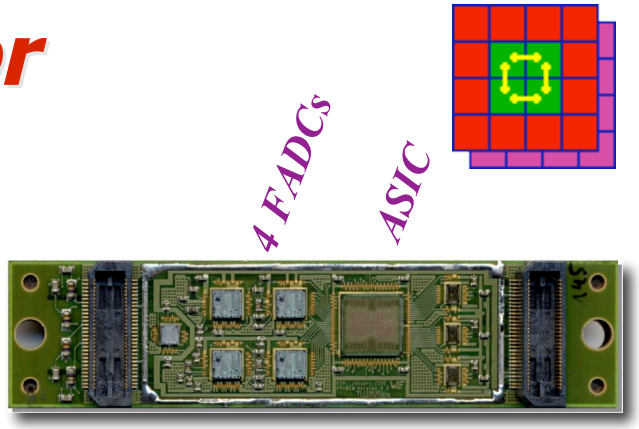


Five main types of custom 9U VME modules: PPM | CPM | JEM | CMM | ROD

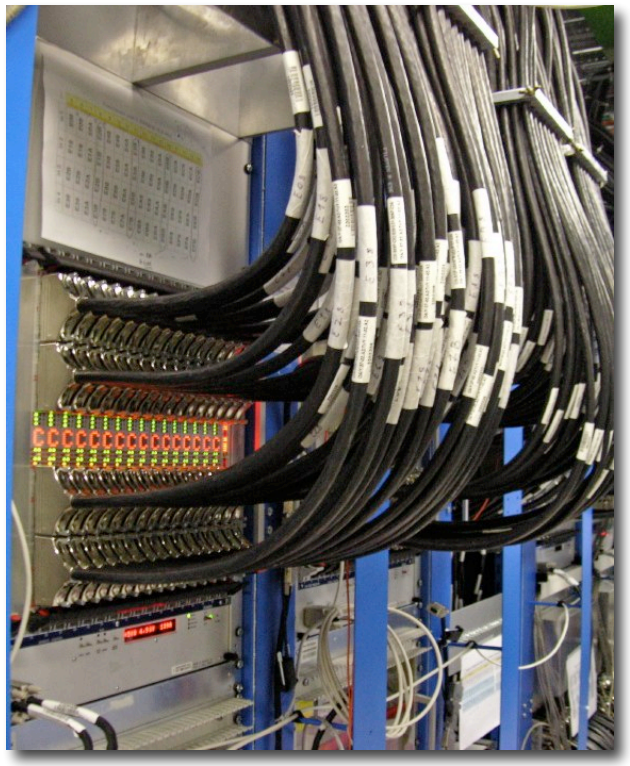
PreProcessor



- **Analogue Receivers**
  - Variable-gain amplifier
  - $E \rightarrow E_T$ conversion
  - Main energy calibration
- **Digitization**
  - 40 MHz, 10-bit flash-ADC
  - 0.25 GeV/count
  - Timing at nanosecond level
- **Bunch-crossing ID**
  - Assign to correct bunch-crossing *(including saturated)*
  - Finite-impulse-response filter
  - Peak finder
- **Look-up Table**
  - Pedestal subtraction
  - Noise suppression
  - Final energy calibration
  - 8-bit output for algorithms
  - *Deal with saturated pulses*
  - *Turn off bad channels*

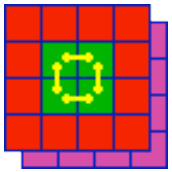


4-channel Multi-Chip Module (16 per PreProcessor Module)



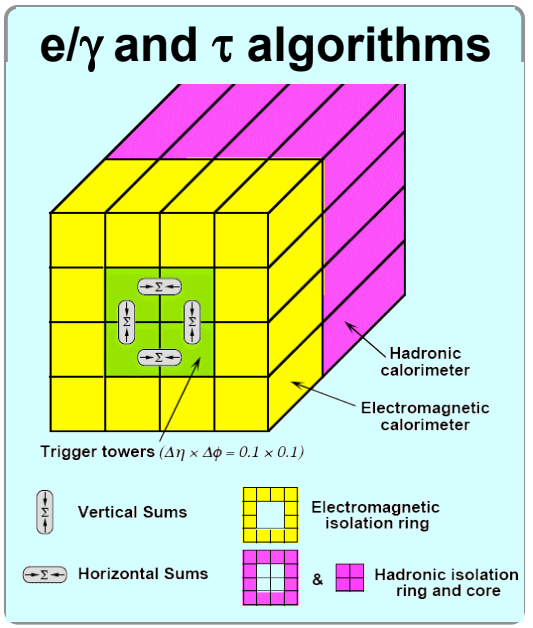
1 of 8 PreProcessor crates

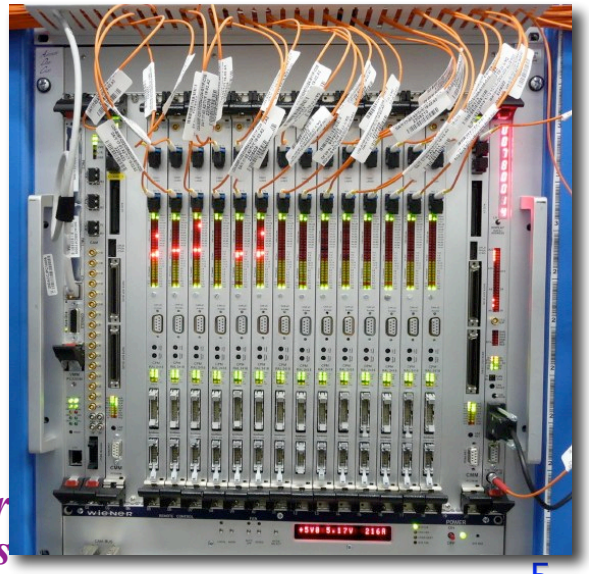
Cluster Processor (CP)



- 4 crates, 14 Cluster Processor Modules per crate
- Algorithm windows slide and overlap
- 8 e/γ and 8 τ (or e/γ) threshold sets, each consisting of:
  - core E_T cluster threshold
  - electromagnetic isolation E_T threshold
  - hadronic isolation E_T threshold(s)
- Defines Regions-of-Interest for Level-2
- Multiplicities for the 16 threshold sets summed by two Common Merger Modules per crate
- Data exchange handled by custom backplane:
  - fan-in/fan-out between neighbouring modules
  - 'hit' multiplicities to Common Merger Modules

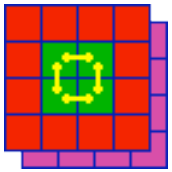
Trigger towers
0.1×0.1 in η–ϕ





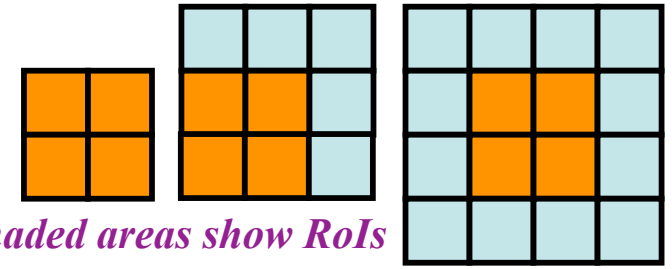
1 of 4 Cluster Processor crates

Jet/Energy-sum Processor (JEP)

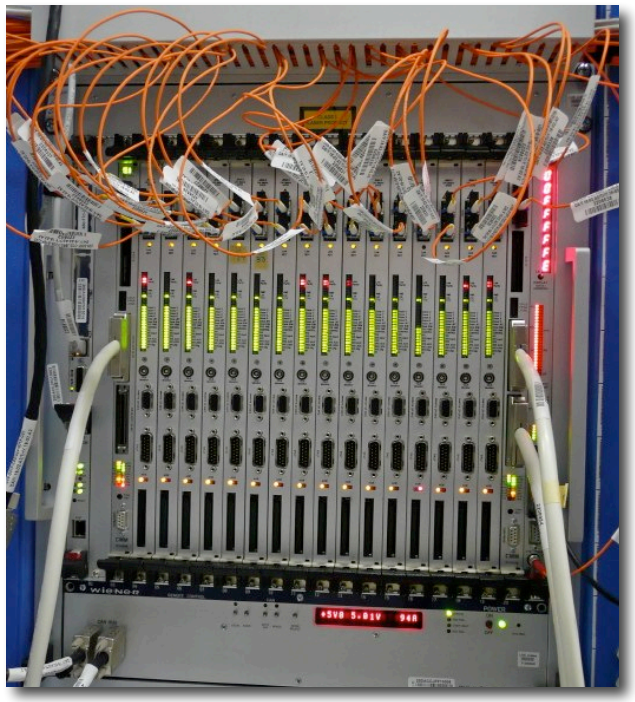


- 2 crates, 16 Jet/Energy Modules per crate
- Algorithm windows slide and overlap
- 8 jet threshold sets, each consisting of:
  - jet E_T threshold
  - jet window size
  - *can also set 4 thresholds for forward jets*
- Defines Regions-of-Interest (RoIs) for Level-2
- Multiplicities for the 8 jet thresholds summed by one Common Merger Module per crate
- Other CMM handles transverse-energy sums:
  - 8 missing-E_T thresholds
  - 4 total-E_T thresholds
  - 4 total-jet-E_T thresholds
- Data exchanges via custom backplane:
  - fan-in/fan-out between neighbouring modules
  - multiplicities & sums to Common Merger Modules

Jet elements 0.2 × 0.2 in η–φ
Window sizes:
0.4 × 0.4 0.6 × 0.6 0.8 × 0.8

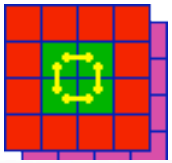


Shaded areas show RoIs

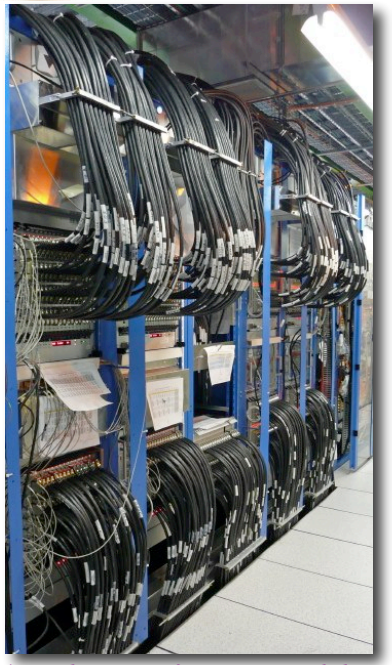


1 of 2 Jet/Energy-sum Processor crates

Analogue and Digital Links

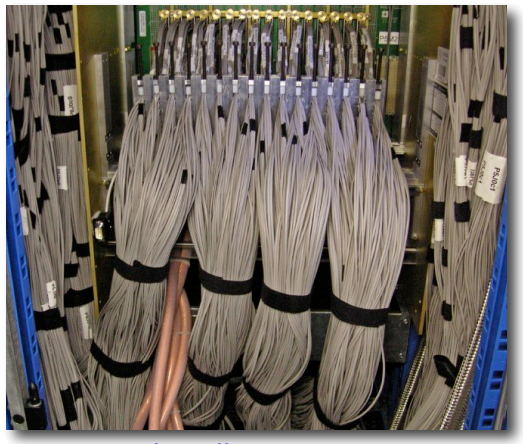


- Analogue input calorimeter signals
  - 16-way twisted-pair cables – stiff and difficult to work with
- Digital links from PreProcessor to Processors (LVDS)
  - ~1900 4-channel 400 Mbit/s cables
- In-crate Processor signals
  - High-density custom backplane
  - Used for both CP and JEP
  - ~1150 pins per slot, ~22,000 per crate
  - Initial problems with bent pins – now fixed, *but requires careful module and cable insertion*
- Readout to data acquisition system
  - 800 Mbit/s optical fibres
- *Overall, few errors after installation, and now a tiny number (<< 1%)*

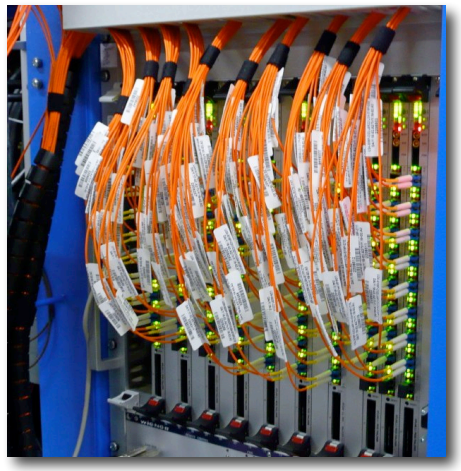


Analogue input cables

CP and JEP high-density custom backplane

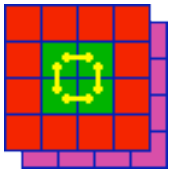


LVDS link cables



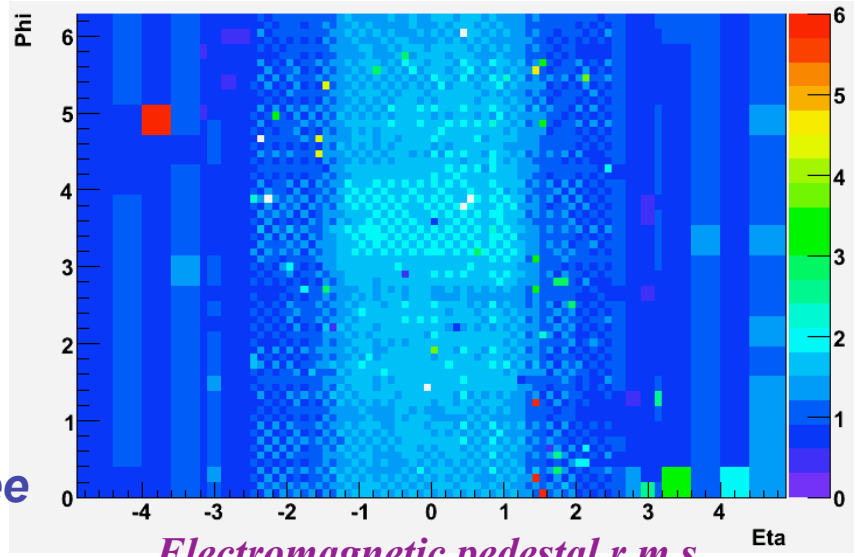
1 of 2 Readout Driver crates, with fibre inputs

Pedestals and Noise

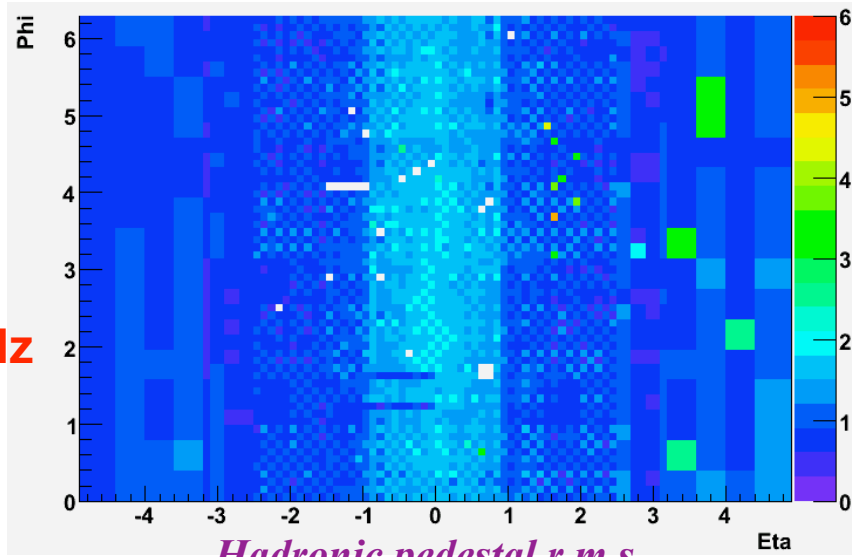


- **FADC pedestal values**
  - Set to nominal 40 counts by DAC
- **Noise**

  (FADC is 0.25 GeV E_T per count)
  - Expected trigger-tower r.m.s. noise E ~ 0.4–0.5 GeV – *that is what we see*
  - > 99% of channels behave correctly
  - Currently have noise thresholds of ~1 GeV E_T in look-up table
  - This produces trigger rates *(mostly cosmics, not noise)* of:
    - e/γ, 3 GeV threshold: 1 Hz
    - τ and jet, 5 GeV thresholds: 4 Hz
  - *These thresholds are much lower than those used for physics*



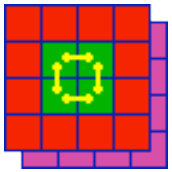
Electromagnetic pedestal r.m.s.



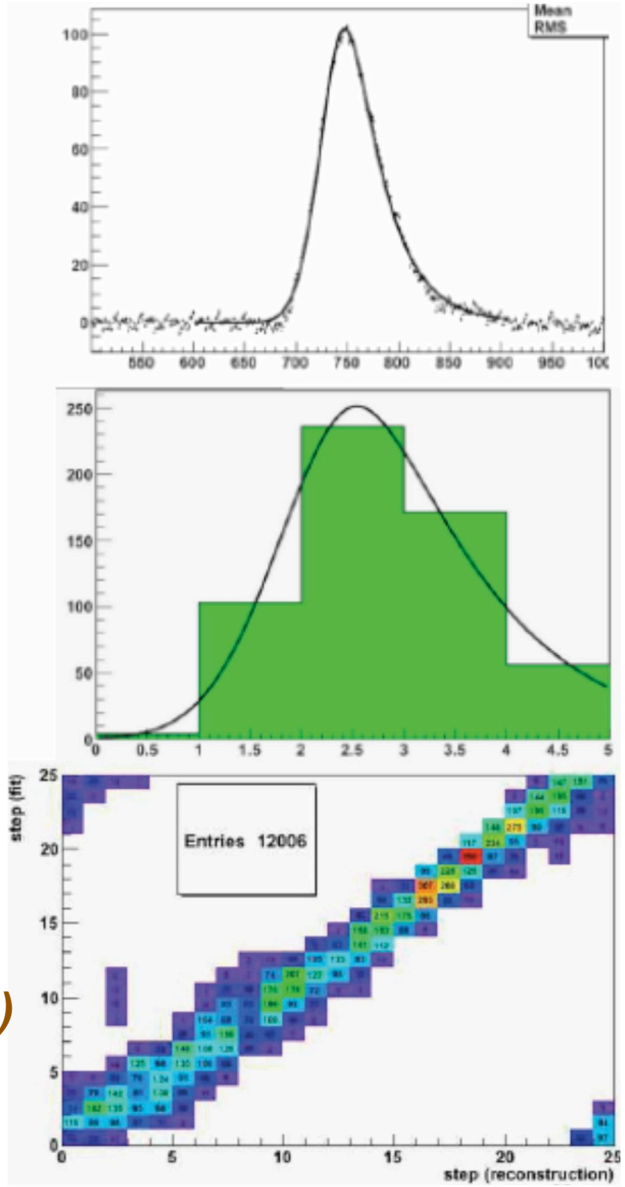
Hadronic pedestal r.m.s.

Colour shows FADC counts

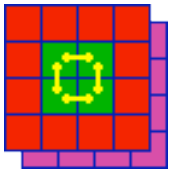
Timing: Analogue and Digital



- **Coarse timing at bunch-crossing level (40 MHz)**
  - Calorimeter input signals
    - must compensate for cable lengths, etc.
  - Internal digital signals
    - 40 MHz, but many backplane signals 80 or 160 MHz
  - Readout pointers to FIFOs
  - *Can set up all of these using calorimeter pulsers, but input signals must be iterated with beam*
- **Fine timing, at nanosecond level**
  - FADC strobe adjustable in 1 ns steps
  - Need timing to ~ few ns, for accurate energy and bunch-crossing assignment
  - Can do 1 ns fine scans with pulsers *(top)*
  - For beam, timing alters and pulses are different sizes – fit Gauss/Landau to single events *(middle)*
  - Works well – compare the two methods *(bottom)*
  - *Need beam for 1–2 days to get final settings*



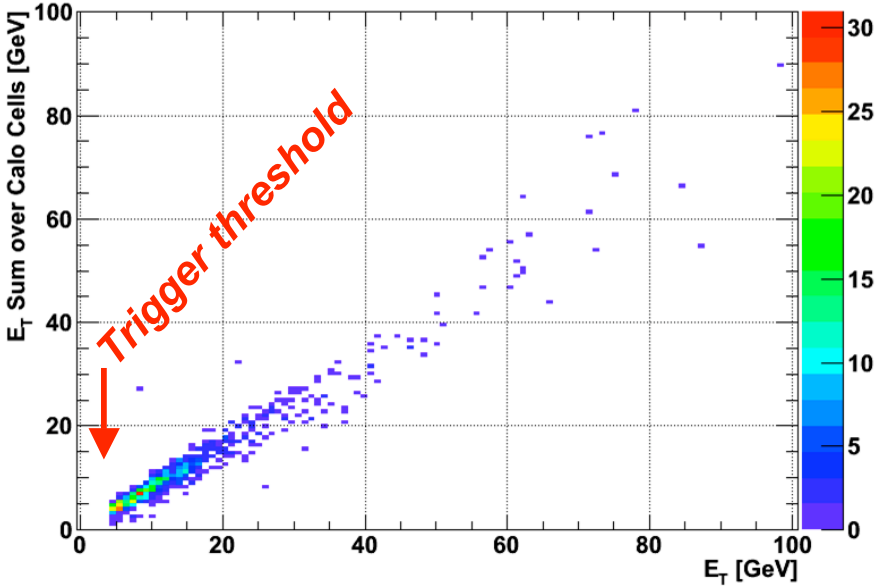
Energy Calibration

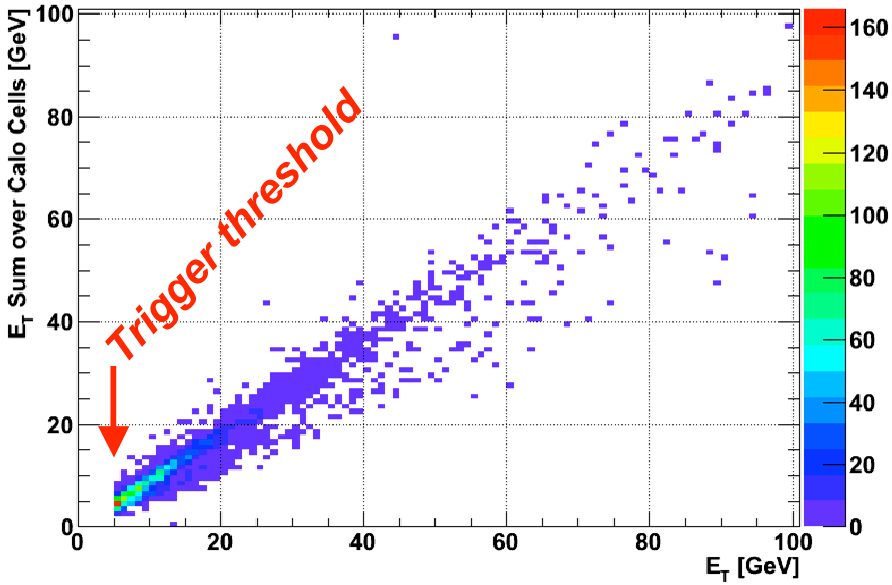


Electromagnetic E_T

Hadronic E_T

Calorimeter cell readout

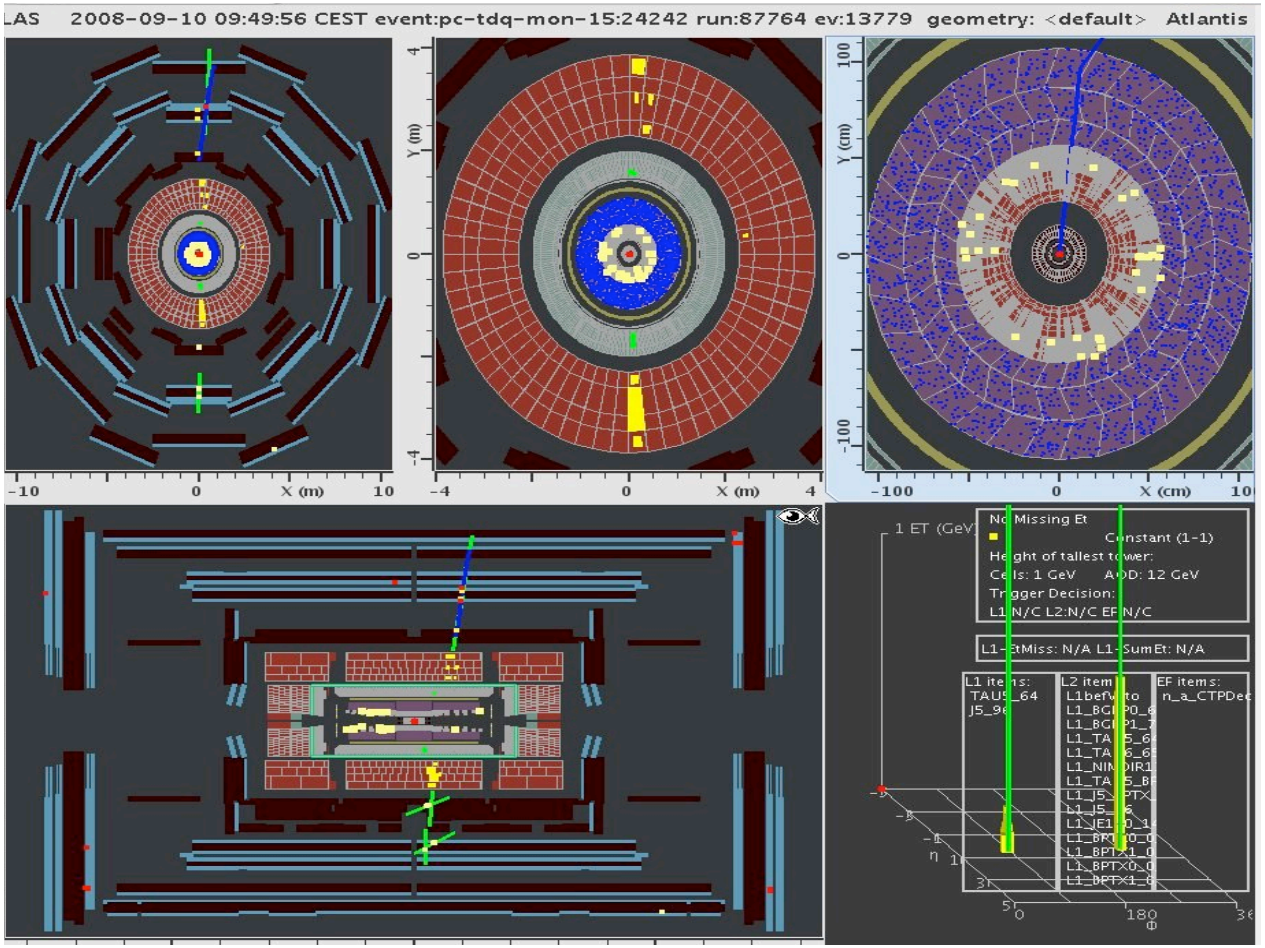




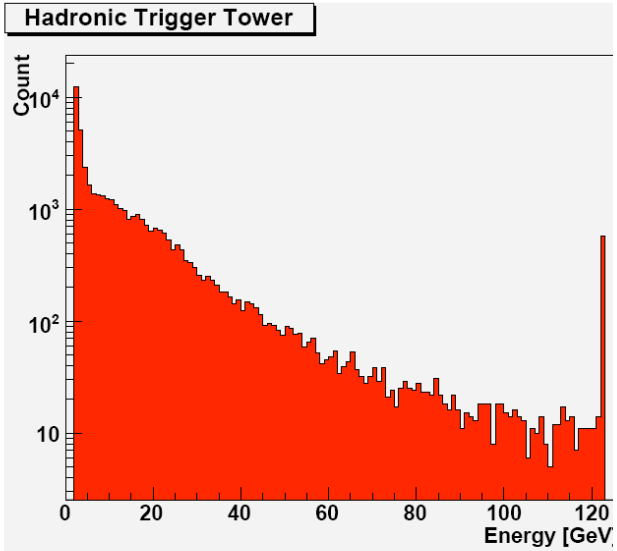
Trigger tower readout

- Calibration done using calorimeter charge-injection systems
- Plots show full calorimeter readout vs. L1Calo readout, for cosmic muons
  - Cosmics not synchronous with LHC clock, so energy resolution not ideal
- *Calibration work continues*

Cosmic Data



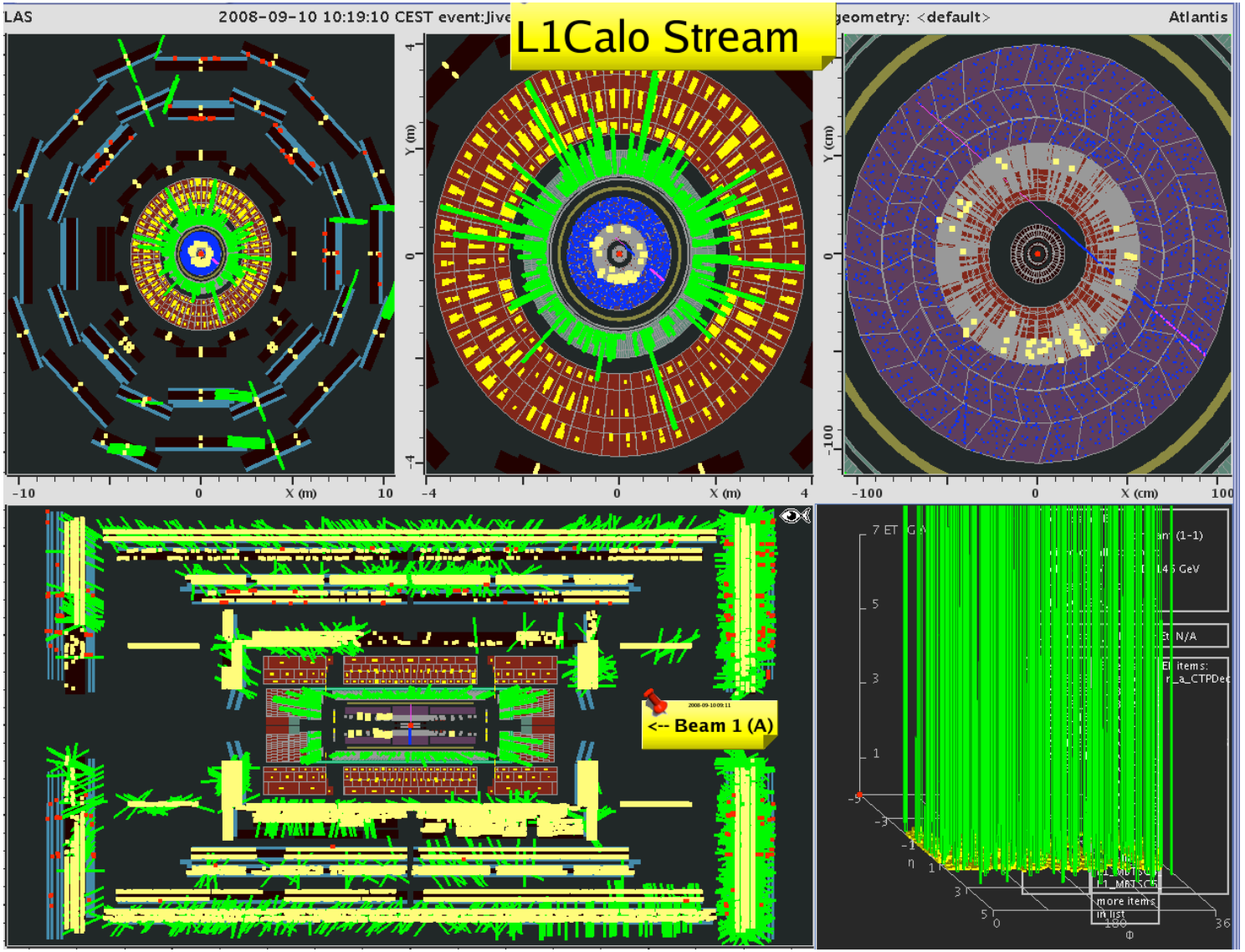
Cosmic event triggered by jet and tau triggers



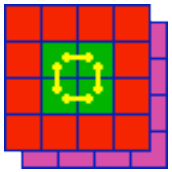
Hadronic trigger-tower energy spectrum

First Beams in LHC

First ATLAS event with circulating beam in LHC – triggered by L1Calo!



Summary



- **L1Calo is installed, and is working well and reliably**
  - **Integrated with calorimeters and data acquisition**
  - **Extensively used to provide cosmic triggers for setting up other parts of ATLAS**
  - ***Number of problems very small***
- **Timing and energy calibration progressing well**
  - **Using pulsers and cosmics**
  - ***Final tuning needs beam data***
- ***Waiting for first collisions …***

For more details: **R. Achenbach et al., The ATLAS Level-1 Calorimeter Trigger, 2008_JINST_3_P03001.**