Pre-Production Validation of the ATLAS Level-1 Calorimeter Trigger System

ATLAS Level-1 Calorimeter Trigger Collaboration:

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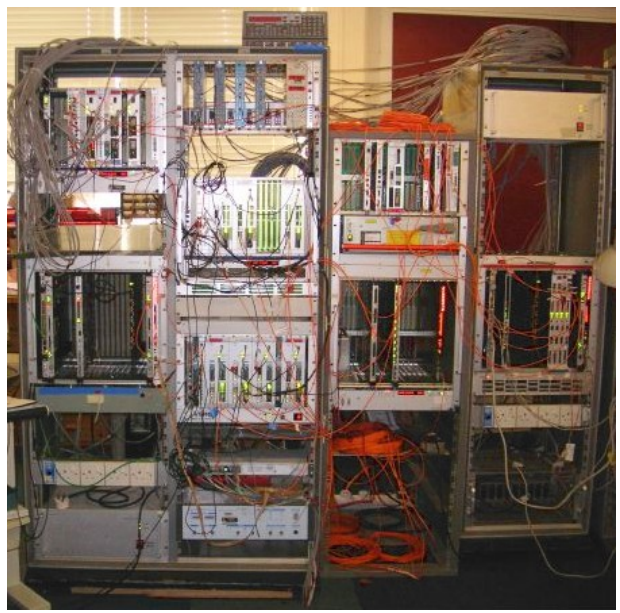

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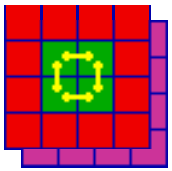
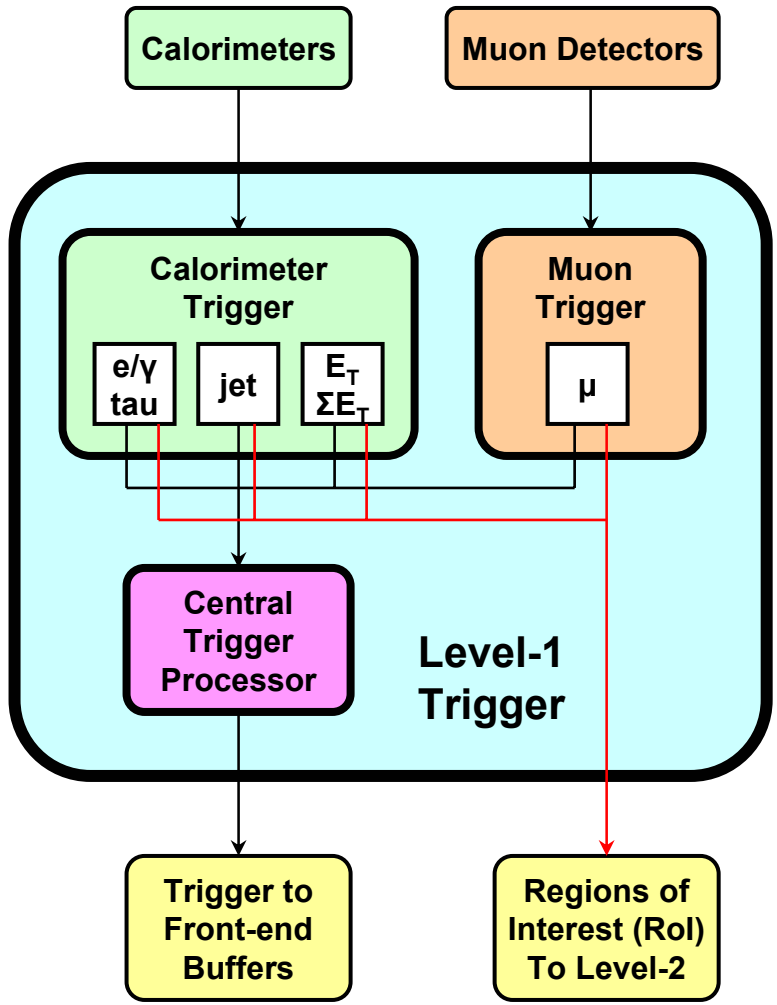


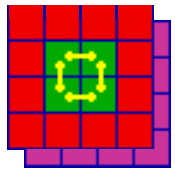
- Trigger Architecture
- Module Design and Challenges
- Testing Methodologies:
  - Software data verification
  - Real-time link stability measurements
  - Test-beam performance

Level-1 triggering in ATLAS

- All data buffered at bunch-crossing rate of 40 MHz for 2.5 μs
- Three-stage triggering system
  - Level-1: custom built hardware, fixed latency – target rate 75 kHz
  - Level-2: software, RoI based selection – target rate 1000 Hz
  - Event Filter: software, full detector – target rate 200 Hz
- Level-1 has three sub-systems:
  - Calorimeter Trigger
  - Muon Trigger
  - Central Trigger (CTP)



Calorimeter Trigger Requirements



< 1μs

~2000 Tile Calorimeter Trigger Towers

300 Gbyte/s

~5000 Liquid Argon Calorimeter Trigger Towers

Calorimeter Trigger

~100 bits (0.5 Gbyte/s)

Central Trigger

Real time (40 MHz)

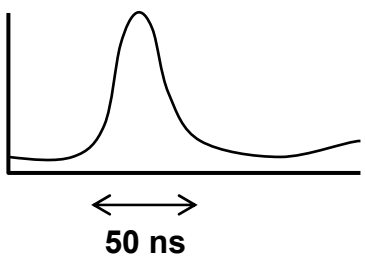
Triggered read out (75 kHz)

Intermediate data

Region of Interest data

Readout System

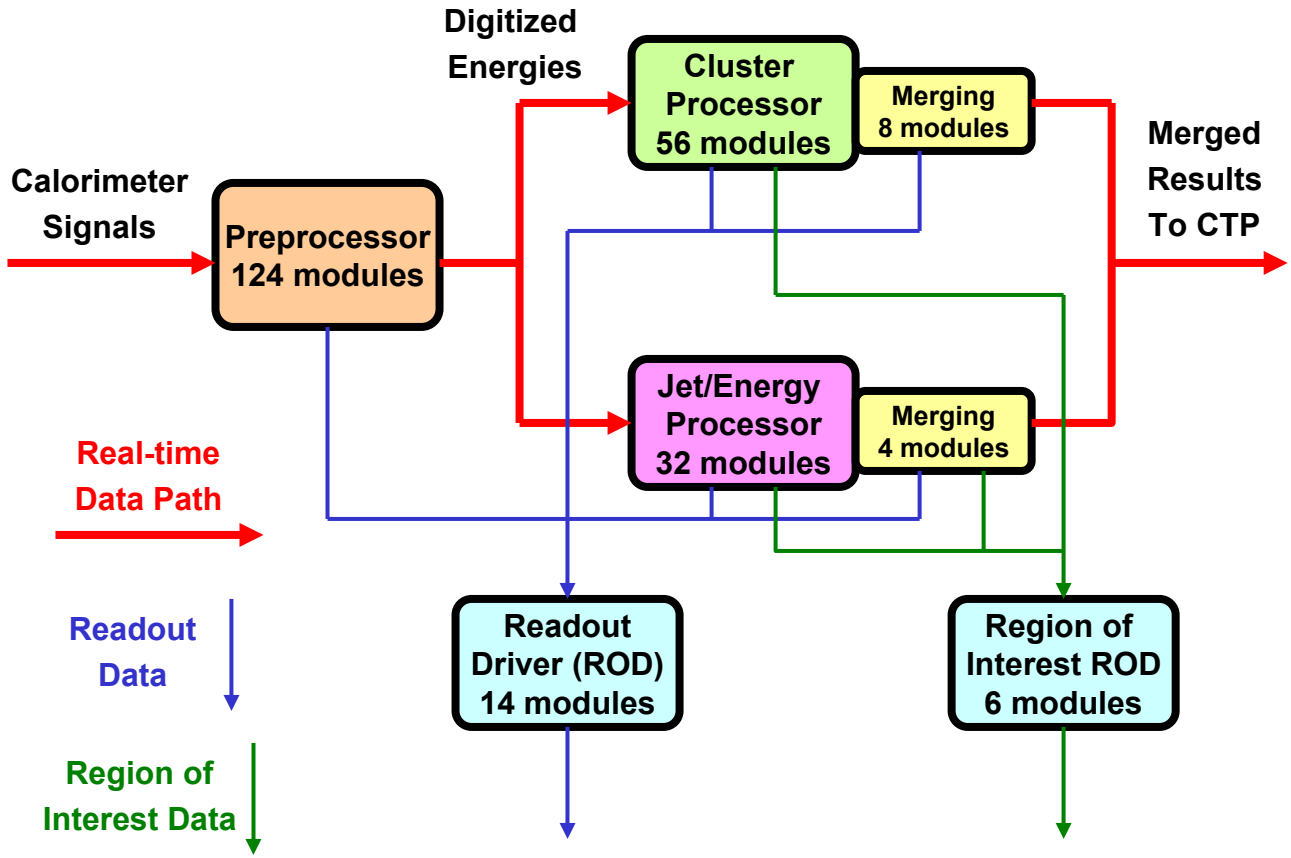
Level-2 Trigger



Calorimeter Trigger Architecture

Features:

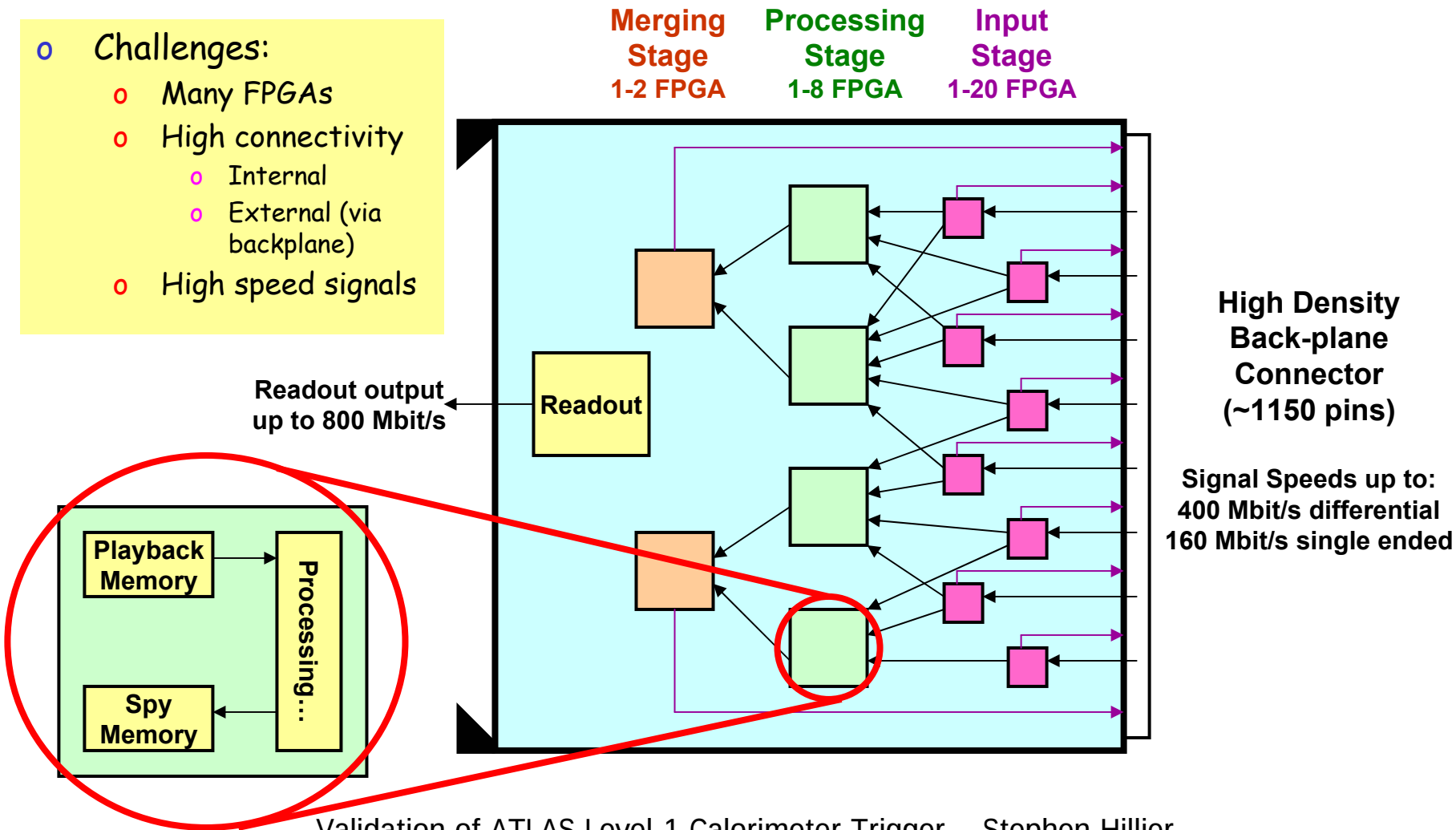
- Realtime Path: Fixed Latency Pipelined
- Many stage processing
- Massive parallelism
- Dual purpose modules
- Heavily FPGA based



Five Types of Custom 9U Modules: **PPM** **CPM** **JEM** **CMM** **ROD**

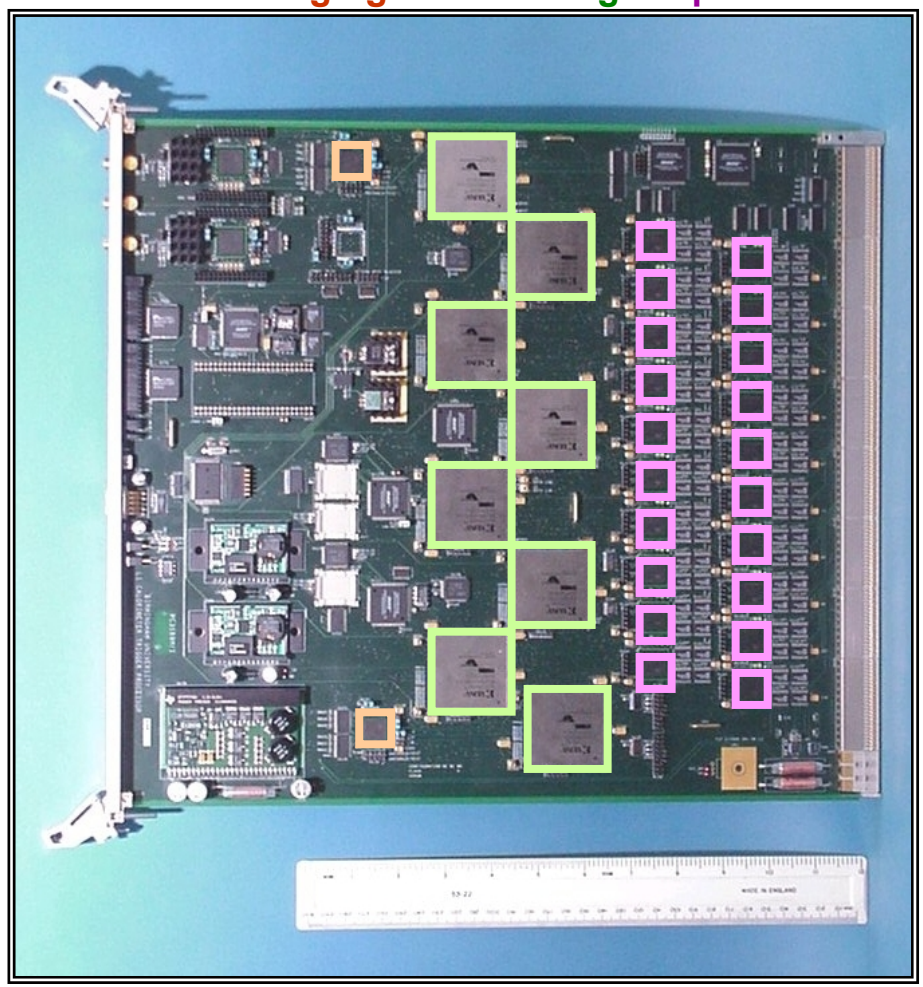
Generic Module Design

- Challenges:
  - Many FPGAs
  - High connectivity
    - Internal
    - External (via backplane)
  - High speed signals

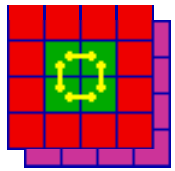


A real example: the Cluster Processing Module

- Backplane Connector i/o
  - Input: ~58 Gbit/s
  - Output: ~28 Gbit/s
- Input Stage:
  - 20 FPGAs
- Processing Stage:
  - 8 FPGAs
- Merging Stage:
  - 2 FPGAs
- Modules Needed: 56



Module Testing Goals and Tools



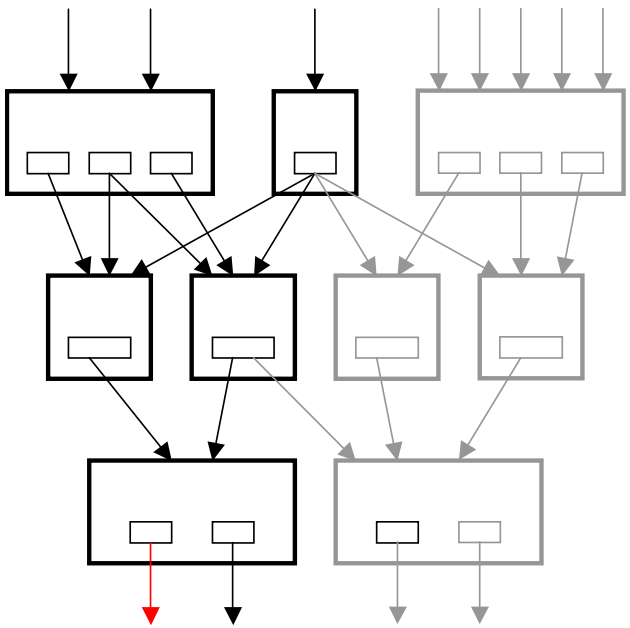
- High speed link stability and performance
  - Use data integrity to establish good timing windows
  - High statistics mode measurements in real-time
    - Parity error counting
    - Dedicated firmware loads
- Algorithm correctness
  - Use specially designed test-vectors, eg:
    - Physics-like
    - Boundary conditions
- Data formatting
  - Read-out must conform to external expectations
- System Integration
  - Does the complete chain work as a trigger?

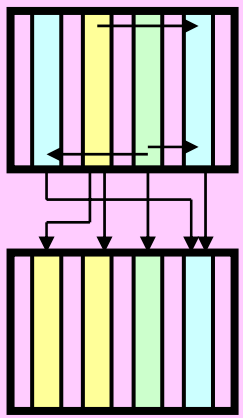
Detailed Module Simulation
- Runs in parallel with hardware
- Predicts output data at any stage
- Requires generation of synchronised trigger patterns

Test-beam operation
- Analogue inputs vs Calorimeter data
- Digital processing integrity

Simulation architecture and usage

- Generic C++ framework
- VHDL inspired
  - Processes, Ports, Links
- Hierarchical, Scalable
- Output 'Driven'





Online Database:
- Modules present
- Cabling
- Configuration
- Test Vectors
- Trigger Pattern

Configure hardware
(data in playback memories)

Run hardware

Read hardware
(spy memories, readout)

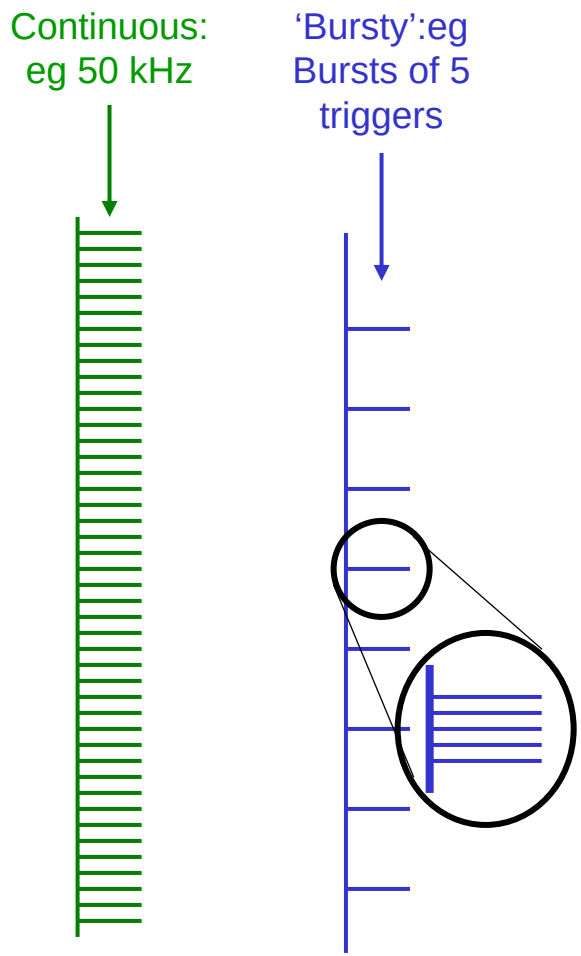
Run simulation

Simulation Results

Compare

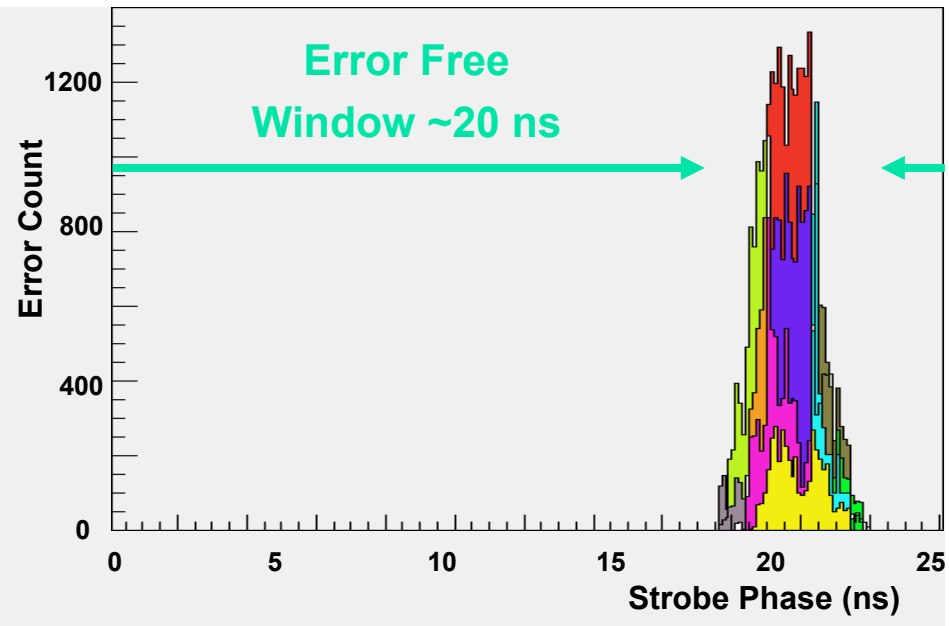
Artificial trigger generation

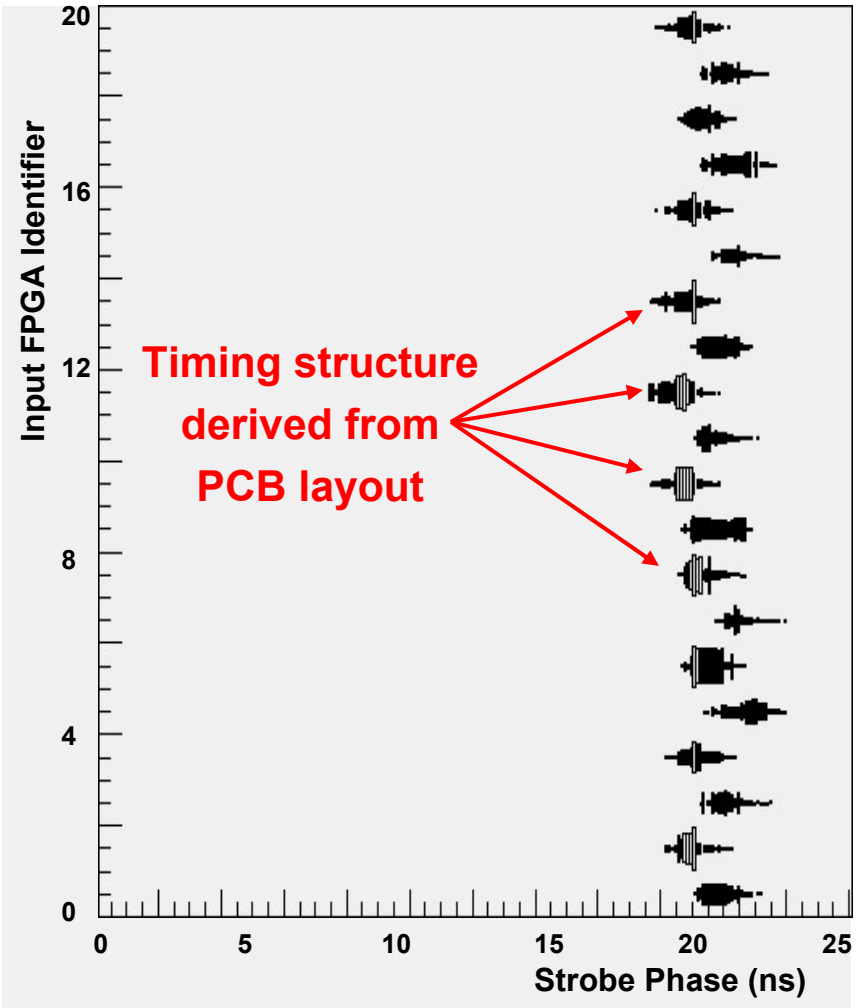
- To predict readout data need to control trigger generation
- Also need to test hardware with high rate and 'difficult' trigger patterns
- Done via a custom module plus trigger pattern generation (under user control)
- Triggers synchronised to playback memories
- Simulation also knows about trigger pattern
- Many types of pattern possible



CPM input LVDS timing windows

- Input FPGAs receive 40 Mbit/s signals
- Input strobing requires timing
- Timing window: 20ns over whole module
- Once optimised, check with firmware
  - No error in 10 minutes in whole module
    = bit error rate < 1 in 10^{13}

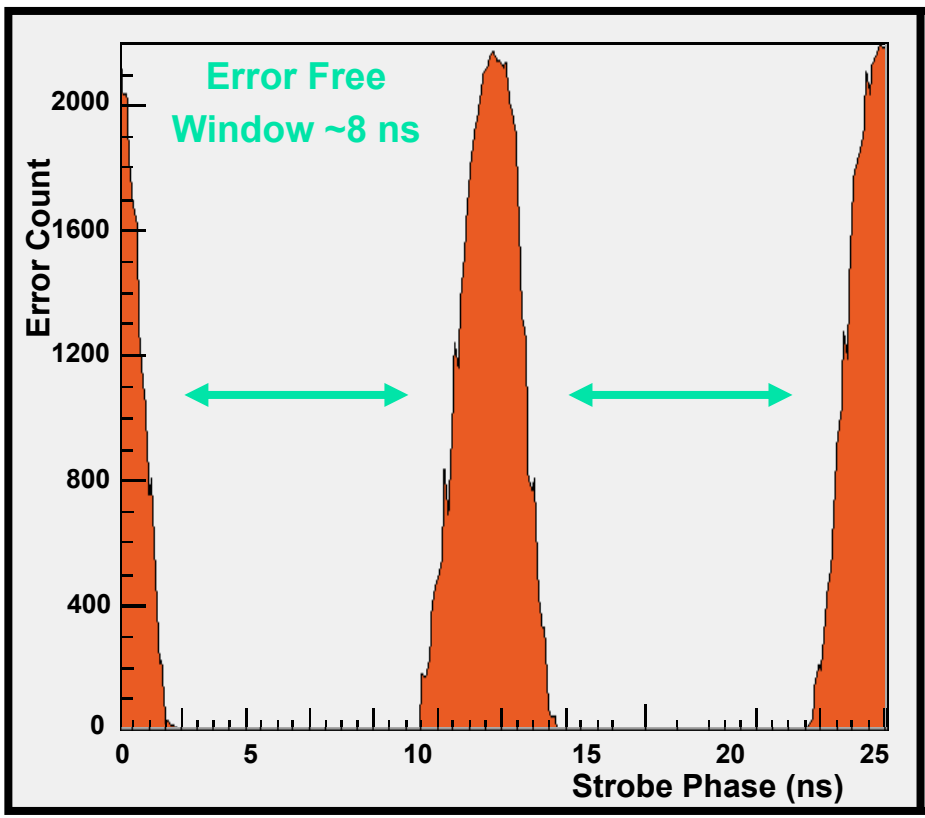


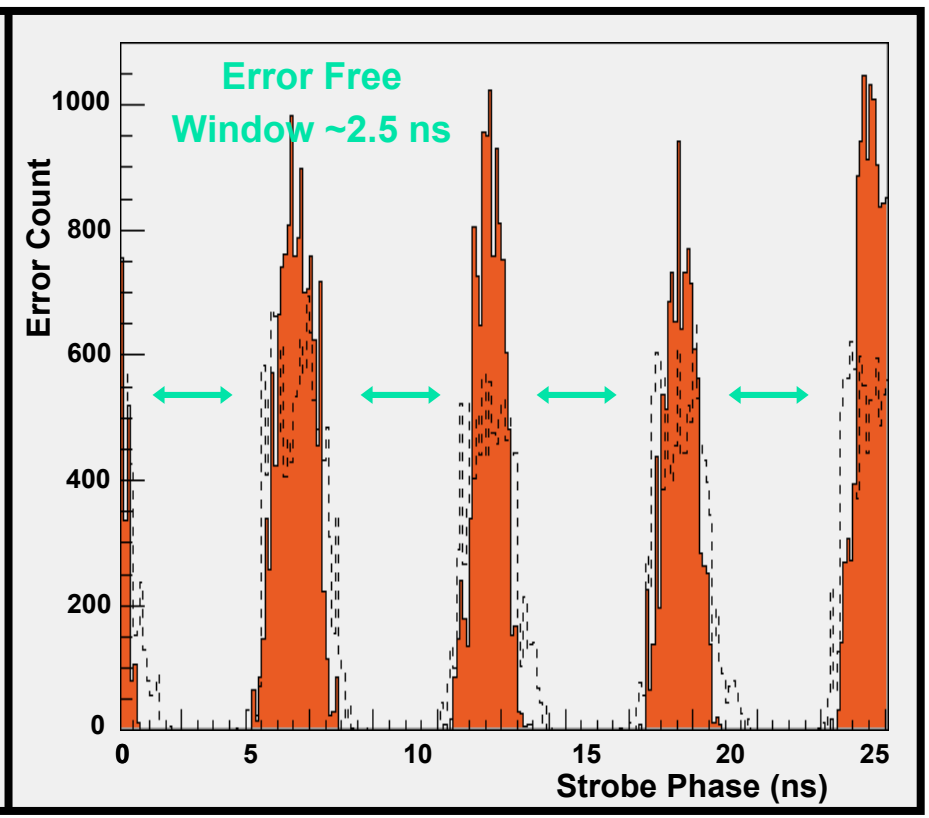


Processor FPGA timing windows

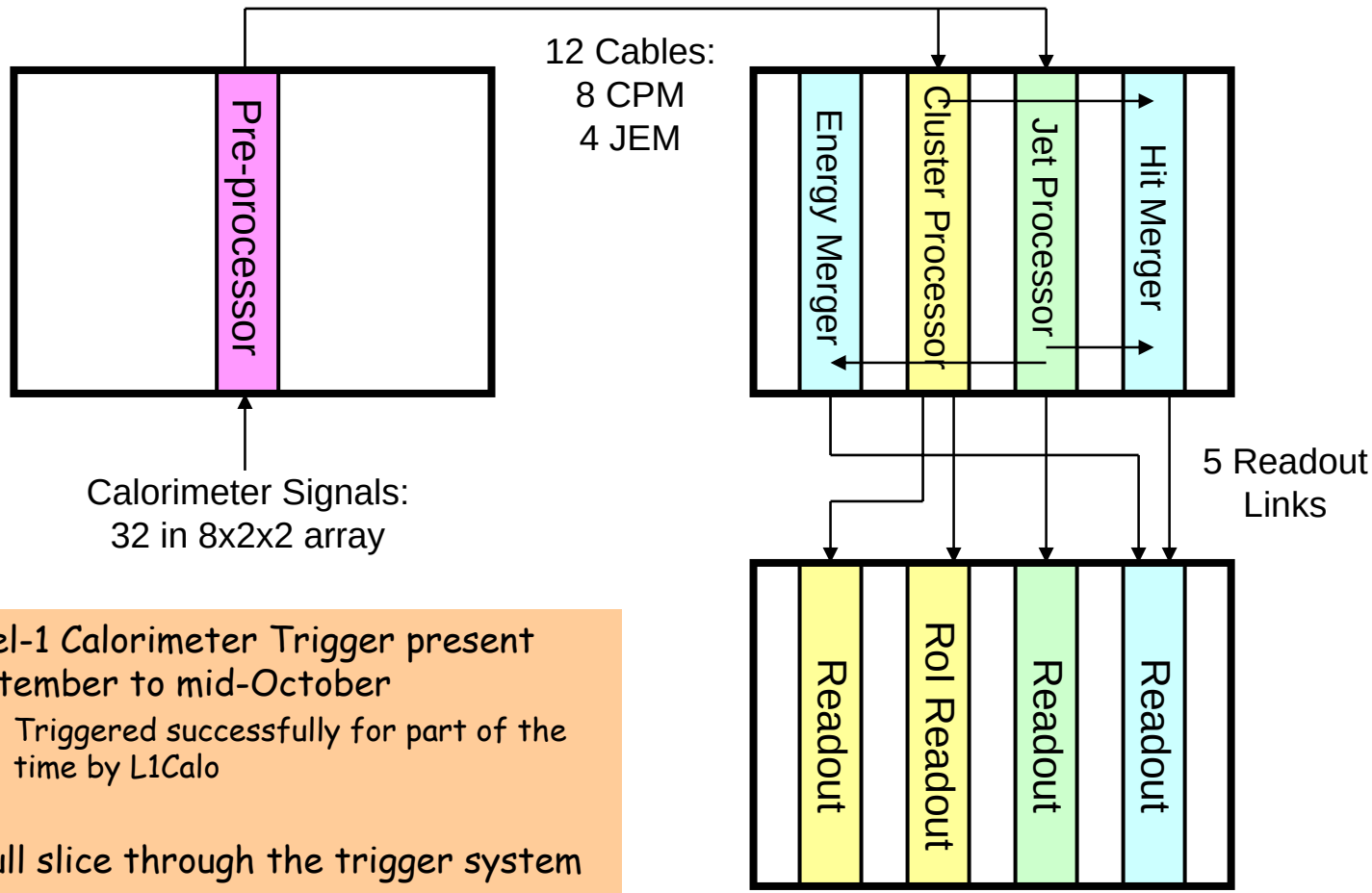
- Jet/Energy Processor FPGAs:
  385 inputs at 80 MHz
  210 on-board, 165 from backplane

- Cluster Processor FPGAs:
  108 inputs at 160 MHz
  60 on-board, 48 from backplane



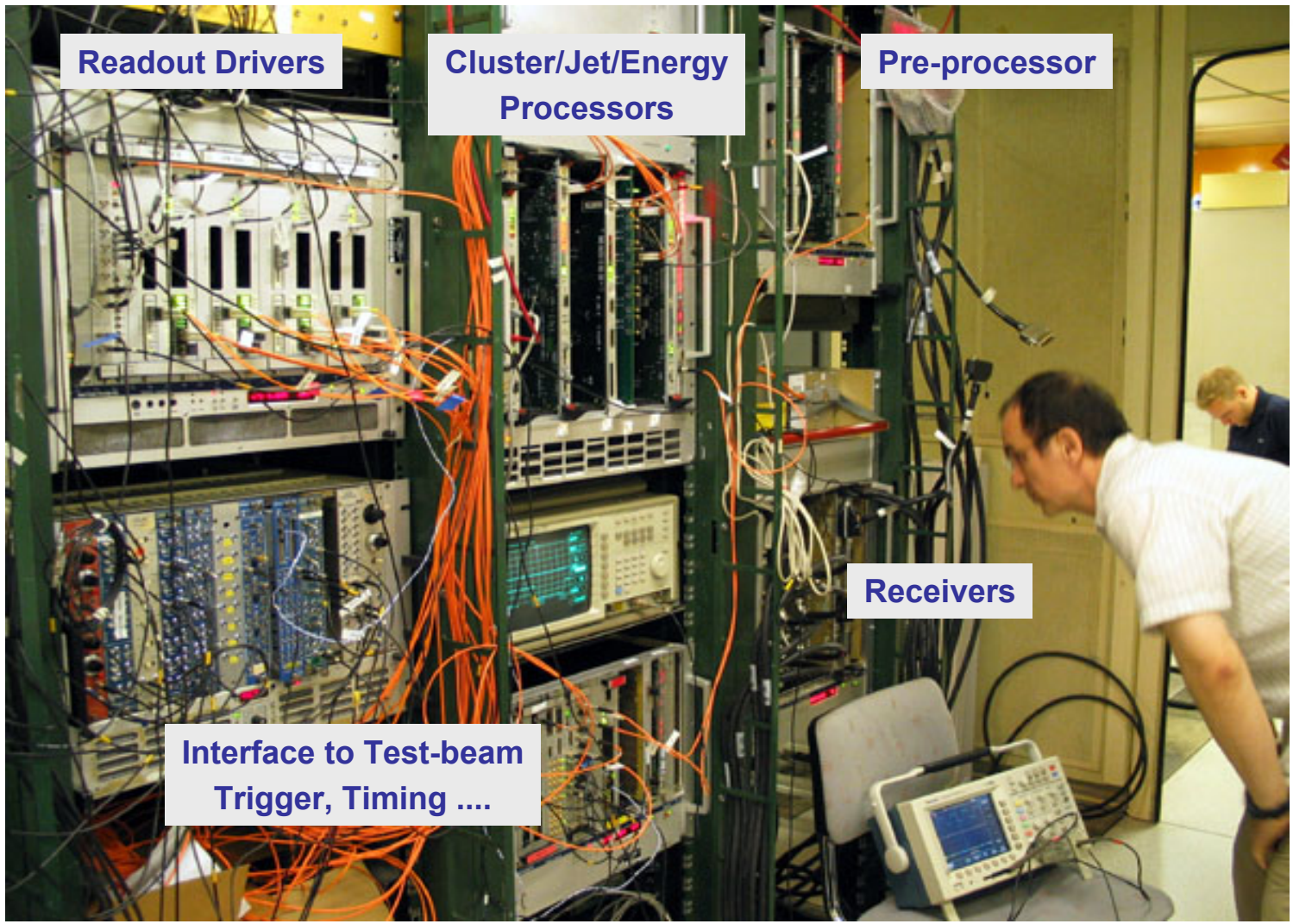


ATLAS Combined Test-beam 2004

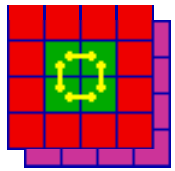


- Level-1 Calorimeter Trigger present September to mid-October
  - Triggered successfully for part of the time by L1Calo
- A full slice through the trigger system
  - ~1% of final capacity

The Reality

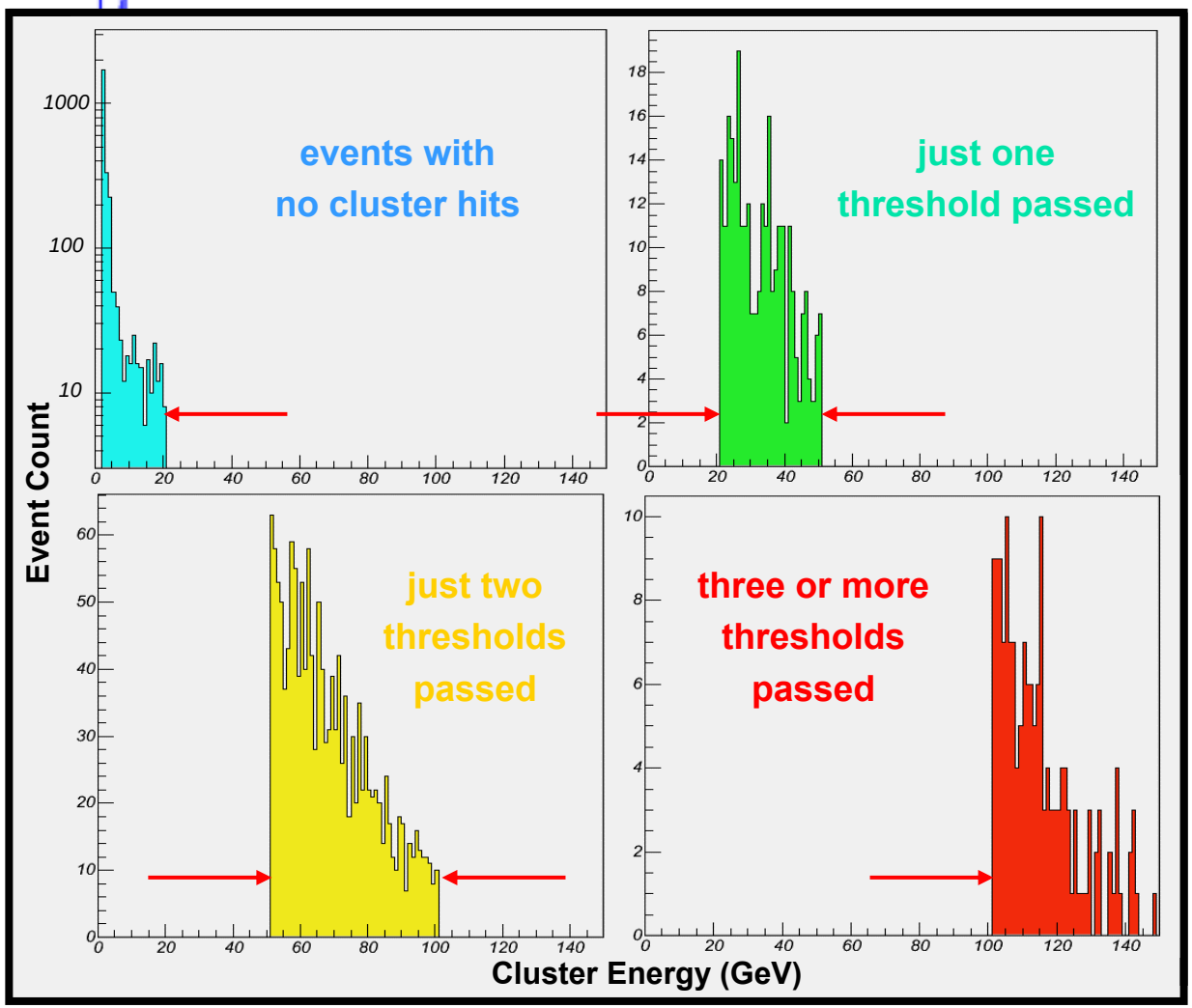

Readout Drivers
Cluster/Jet/Energy Processors
Pre-processor
Receivers
Interface to Test-beam Trigger, Timing ....

Checks on Test Beam data



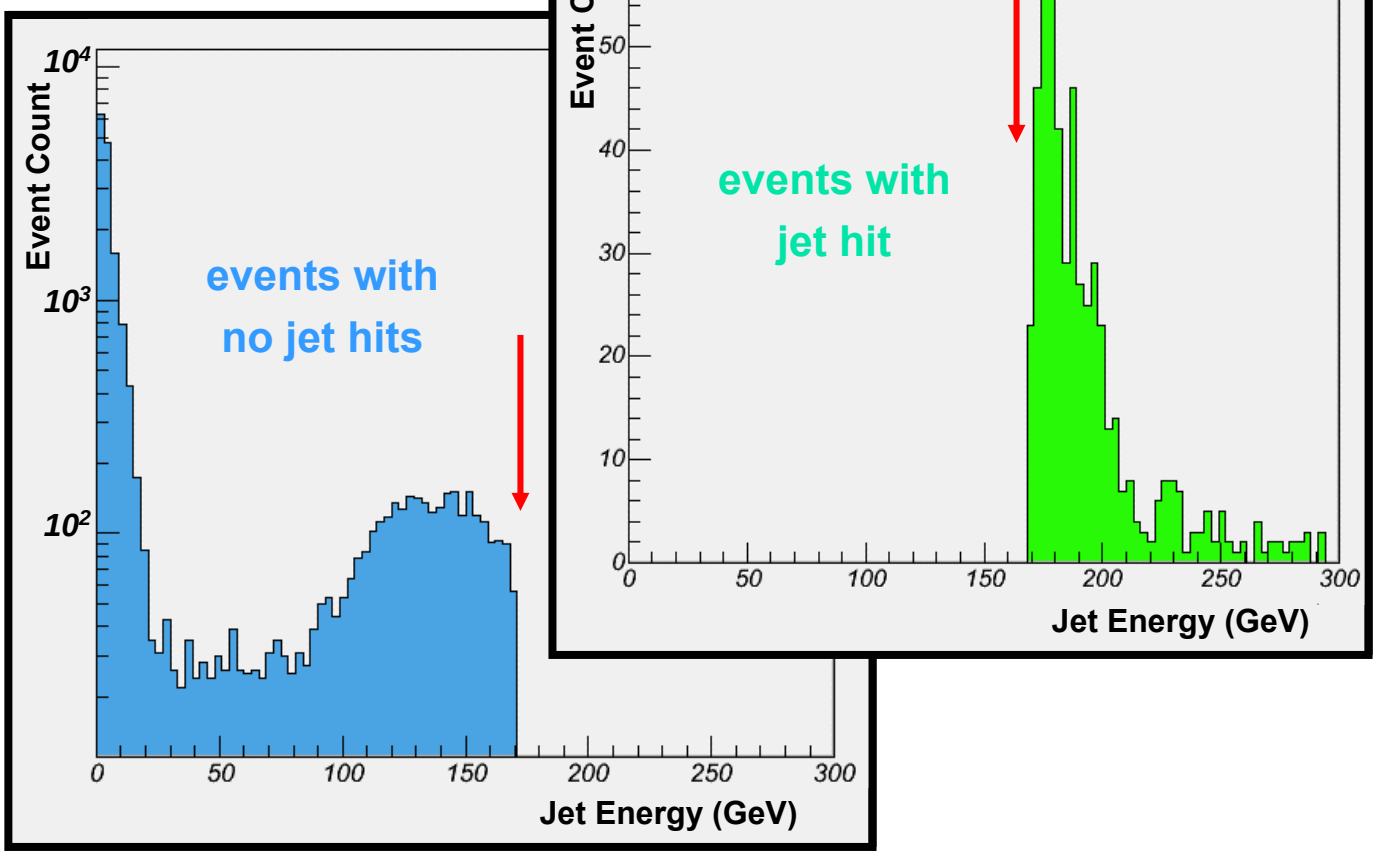
- Internal Consistency checks
  - Assume full granularity input data is correct
  - Are all other data (energies, hits etc) consistent?
  - Performed in ~500,000 events
    - Only minor problems, identified as firmware features
    - No evidence of data integrity problems
- Comparisons with Calorimeters
  - Good correlation was seen
    - With some problems – overlapping pulses?
  - Triggers generated on genuine physics events

Cluster processor hit results



- Four thresholds
  - 20, 50, 100, 200 GeV
- Hit results are as expected
- RoIs also checked
- Positions, hits all formed correctly

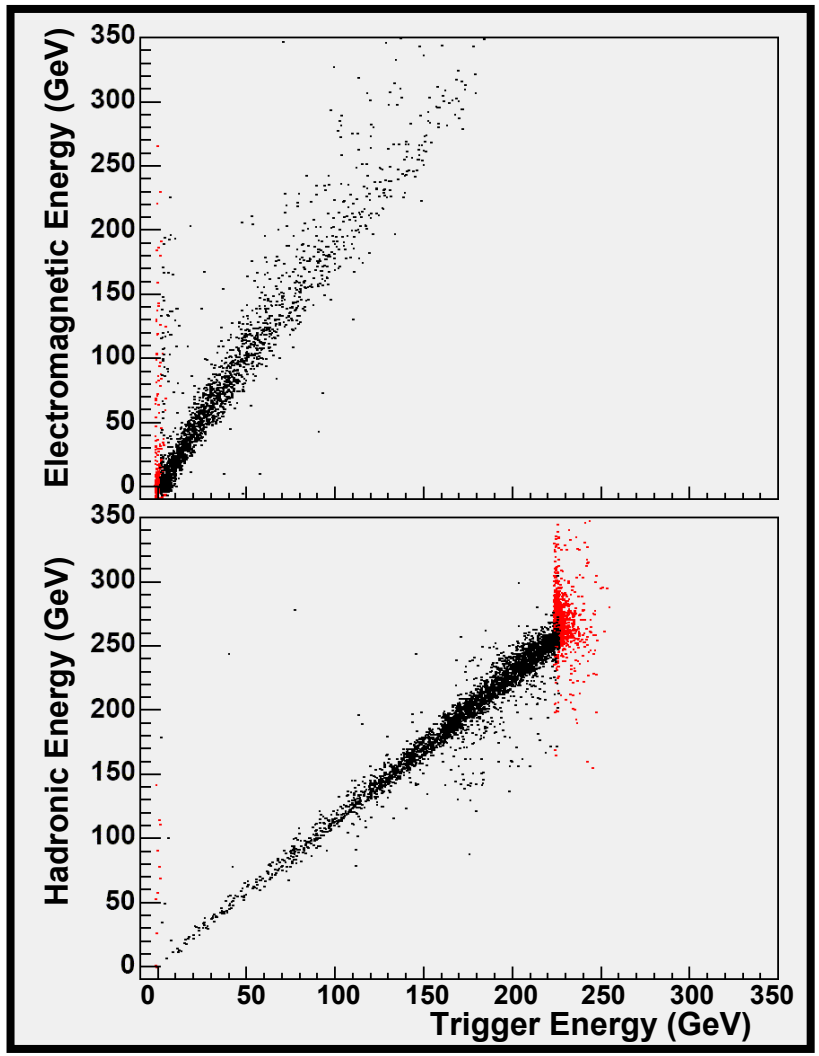
Jet/energy algorithm results



- Only one threshold used
  - 170 GeV
- No errors seen in hits
- No errors seen in energy sums

Correlation with calorimeters

- Liquid Argon comparison:
  - ~factor 2 scaling (ET)
  - Lose energy in some events: overlapping events? bunch-crossing identification problem?
- Tile comparison:
  - Very encouraging
  - Saturation at ~225 GeV understood



Did the Trigger Work?

- Run with Cluster Threshold of 20 GeV as CTP trigger
- Clear cut-off in Electromagnetic Energy as Measured by Liquid Argon Detector