ATLAS Level-1 Calorimeter Trigger: Status and Development

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on behalf of the ATLAS Collaboration

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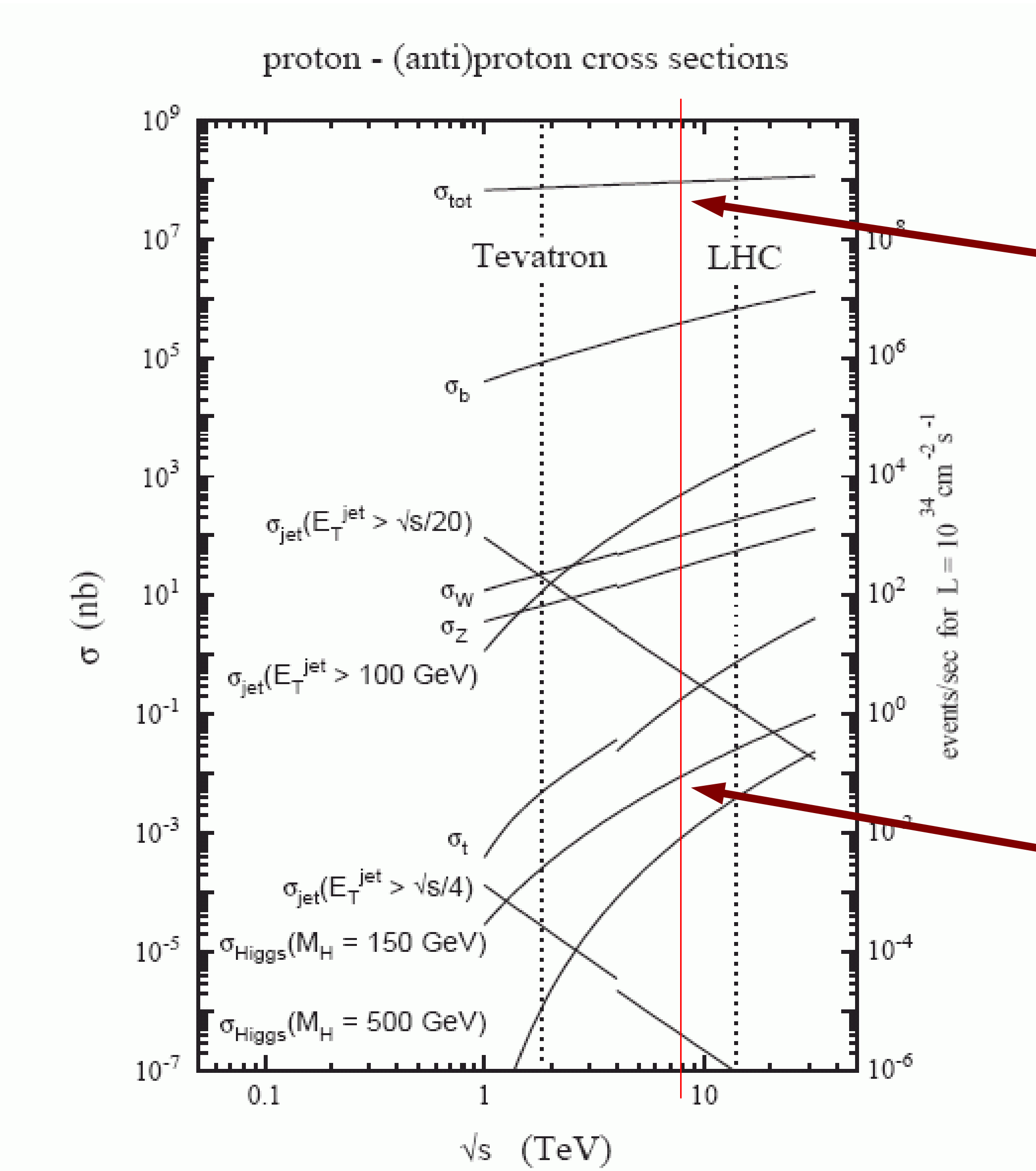
- ATLAS Level 1 Calorimeter Trigger (L1Calo)
- Calibration and operations
- Upgrade plans

Introduction ATLAS Level-1 Calorimeter trigger

Life at hadronic colliders is not easy ...

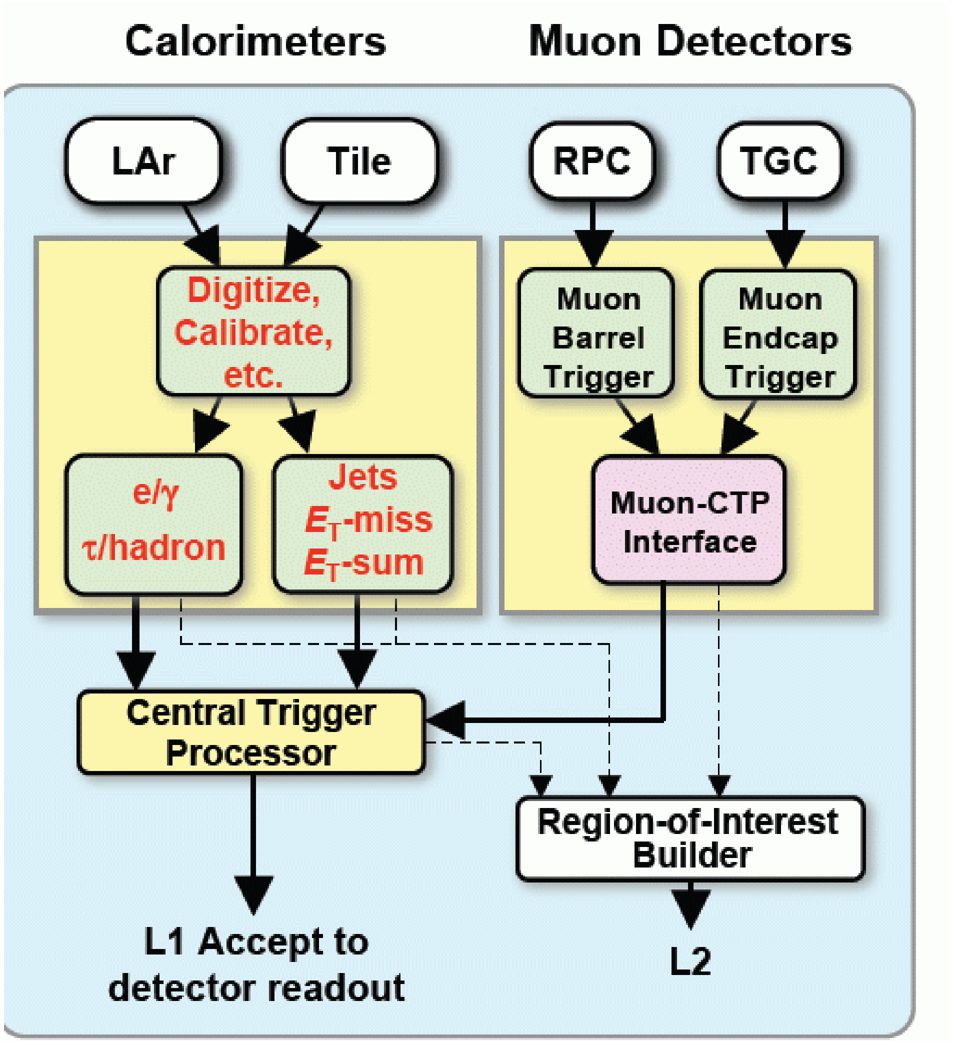


Most of time this!

From time to time this:

L1Calo – a part of ATLAS L1 trigger

- Level-1
  - Custom built HW (ASICS and FPGAs)
  - Fixed latency <2.5 μs, Accept rate ~75 kHz
  - Reduced granularity input
- Level-2
  - CPU's
  - Full granularity for areas of activity marked by L1 – Regions of Interest (RoI)
  - Latency ~40 ms, Accept rate~8kHz
- Event Filter (Level-3)
  - CPU's
  - Offline algorithms on full event
  - Latency~1s, Accept rate ~800 Hz



- Level-1 trigger:
  - L1-Muons
  - <u>L1-Calorimeters (L1Calo)</u> ←
  - L1-Central Trigger
  - ...

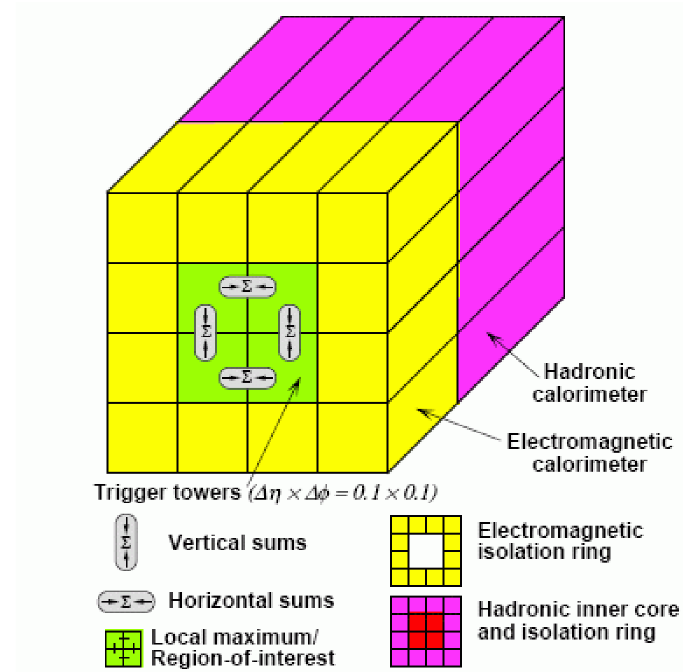
L1Calo- Event selection

Hard final state objects in an event:

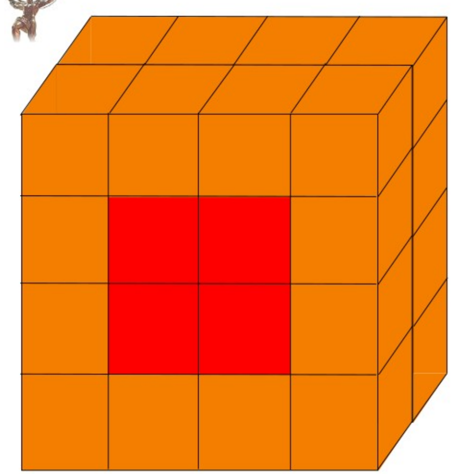
- e/γ and τ/h objects
- Jet candidates

Global event properties:

- Scalar E_T sum
- Missing E_T
- Jet sum E_T
- …

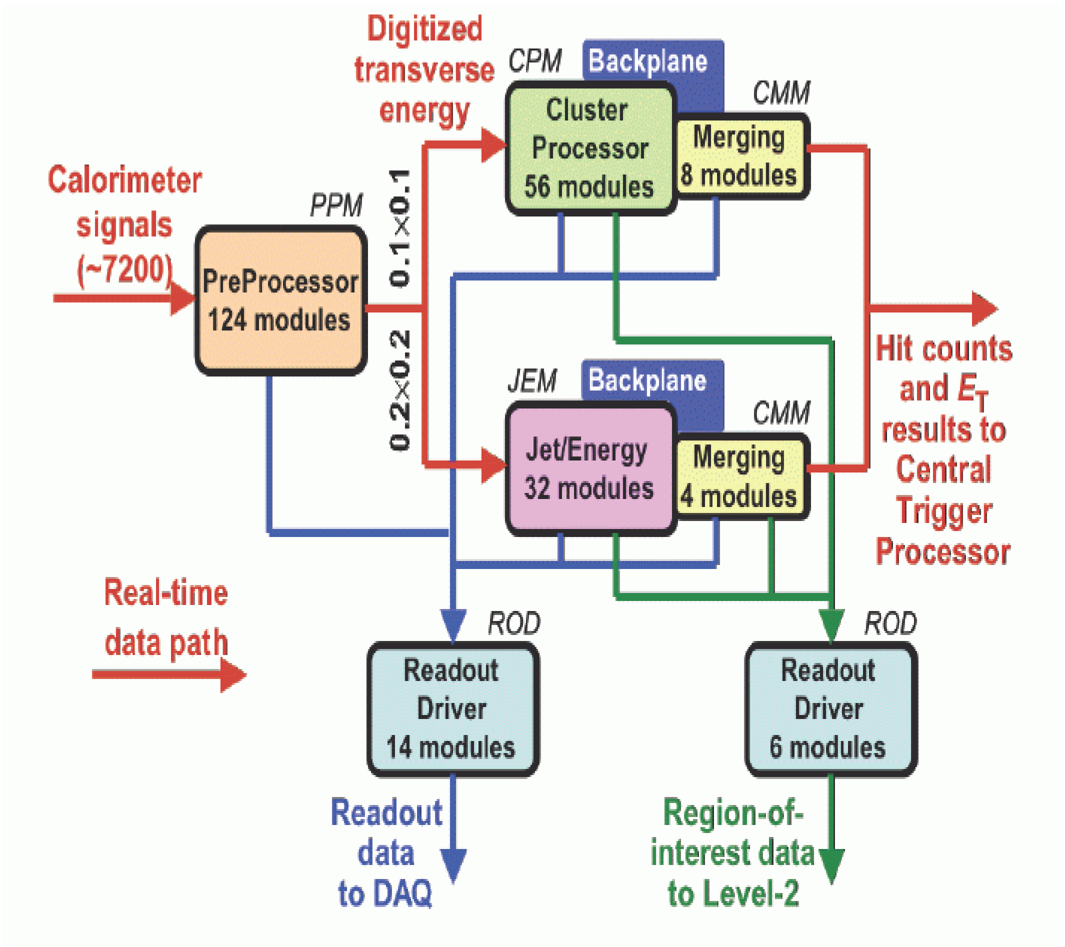


- Sends to Central trigger:
  - Multiplicity of electrons/photons, τ's and jets passing E_T (and isolation) thresholds
  - Thresholds passed by Total and Missing E_T
- Sends to Level 2 trigger:
  - position of RoIs ⇒ if L1 misses an object, it is lost twice !!



L1Calo - HW implementation

- Pipelined, synchronous system with fixed latency
- Several processing stages
- Highly parallel, mainly FPGA based
- Mostly custom electronics:
  - ~300 VME modules of 10 types housed in 17 crates



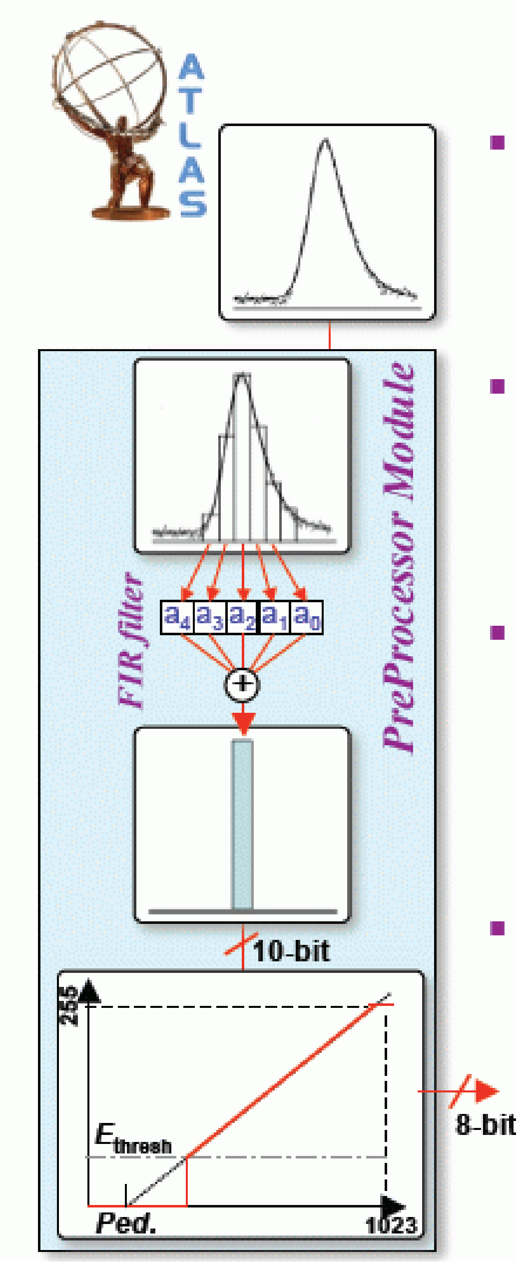
Main parts:

- Preprocessor:
  - Conditioning and calibration of analog signals, digitization, bunch crossing identification
- Cluster processor:
  - Electrons/photons, taus
- Jet processor:
  - jets, Scalar E_T sum, Missing E_T

Proud part of ATLAS trigger system ...

Calibration and operations

Pulse conditioning and calibration



Analogue receivers:

- variable gain amplifier
- $E \rightarrow E_T$ conversion (where needed)
- E_T calibration

Digitization:

- 40 MHz, 10-bit FADCs
- timing at ns level
- Resolution ~0.25 GeV/count

Bunch Crossing ID:

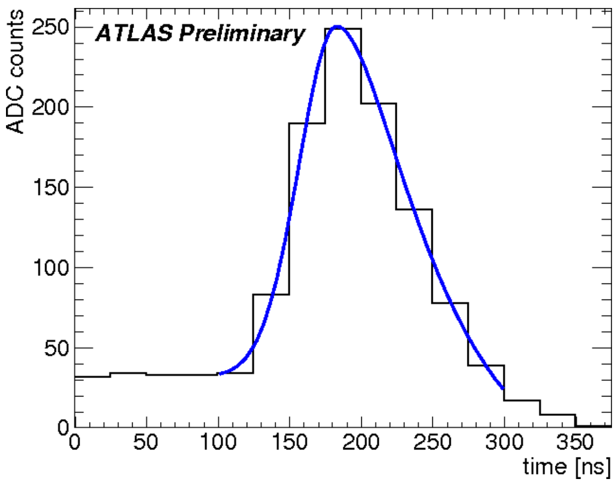
- assign signal to correct bunch crossing
- Linear digital filter
- special treatment of saturated pulses

Look-up table (LUT):

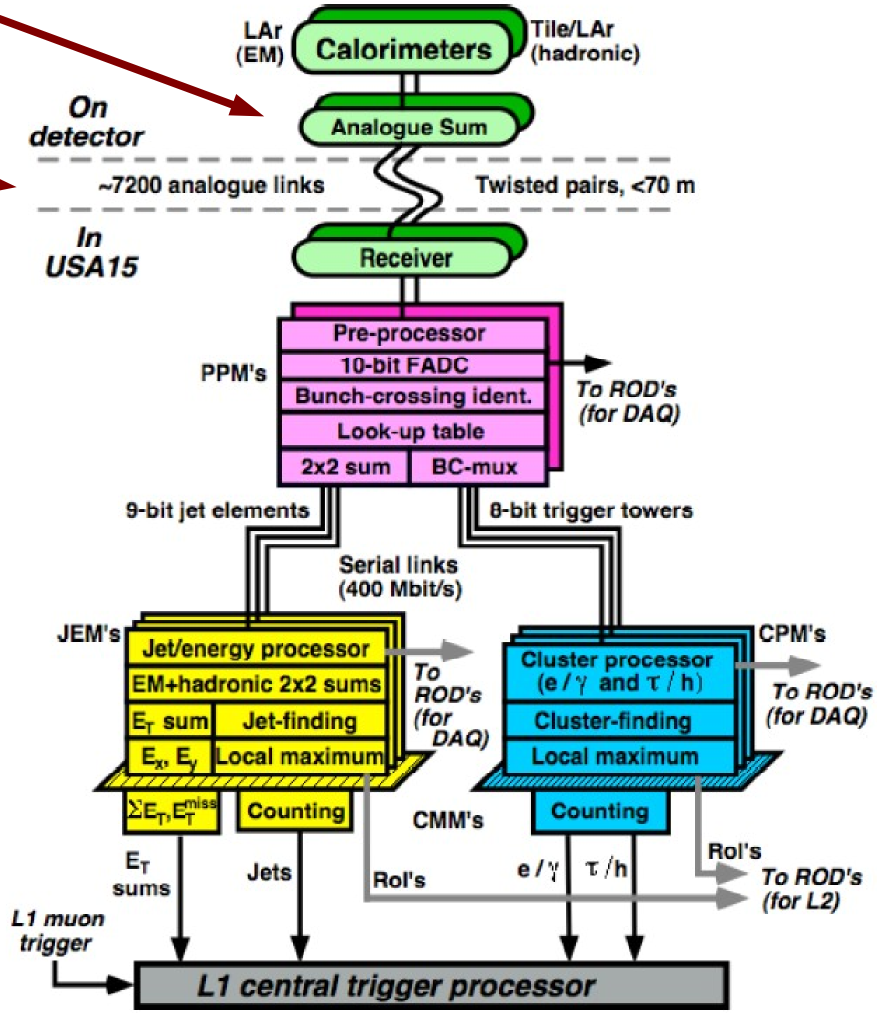
- pedestal subtraction
- noise suppression
- killing of noisy channels
- 8-bit output for algorithmic processors

Timing - Introduction

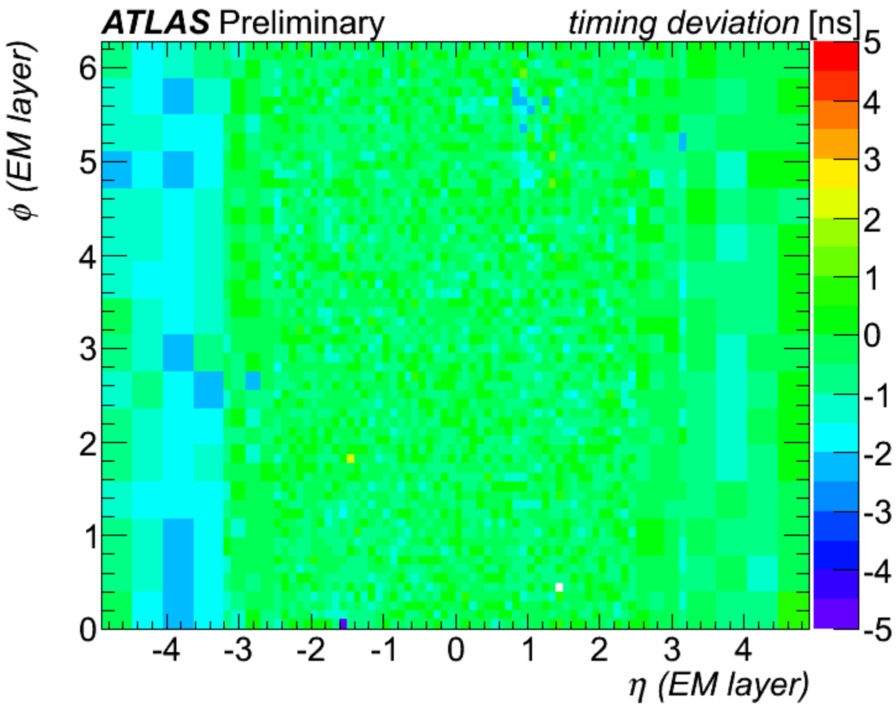
- Signals from individual calorimeter cells summed on detector into projective Trigger Towers
- Analogue signals routed using 30-70 m long twisted pair cables (4.76 ns/m)
- Signals at input of L1Calo need to be aligned in time and sampled at pulse maximum:

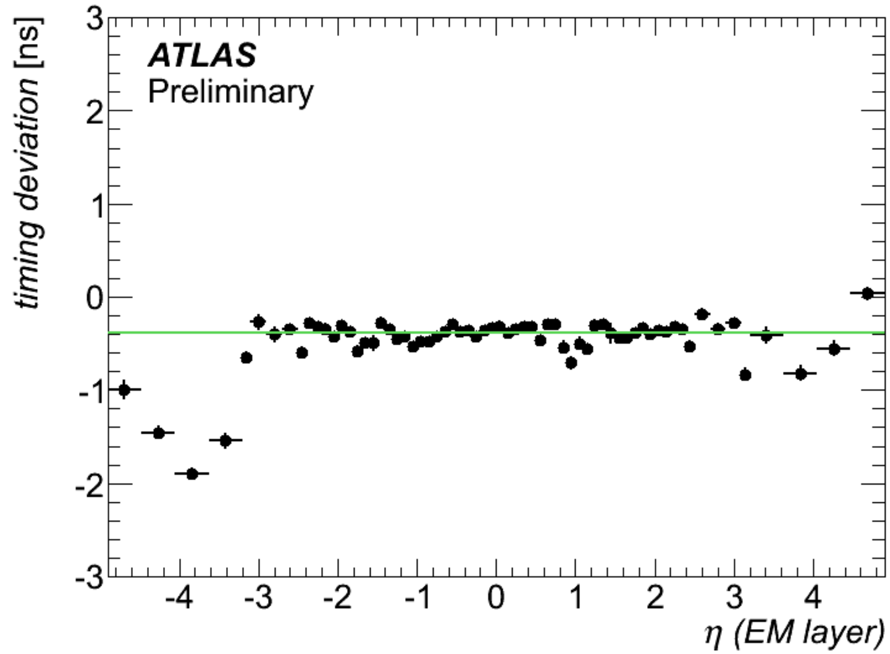


- Variations due to:
  - Different cable lengths
  - Individual channel variations
- If mistiming large, signal (event?) lost
- Smaller mistiming may mean wrong energy measurement



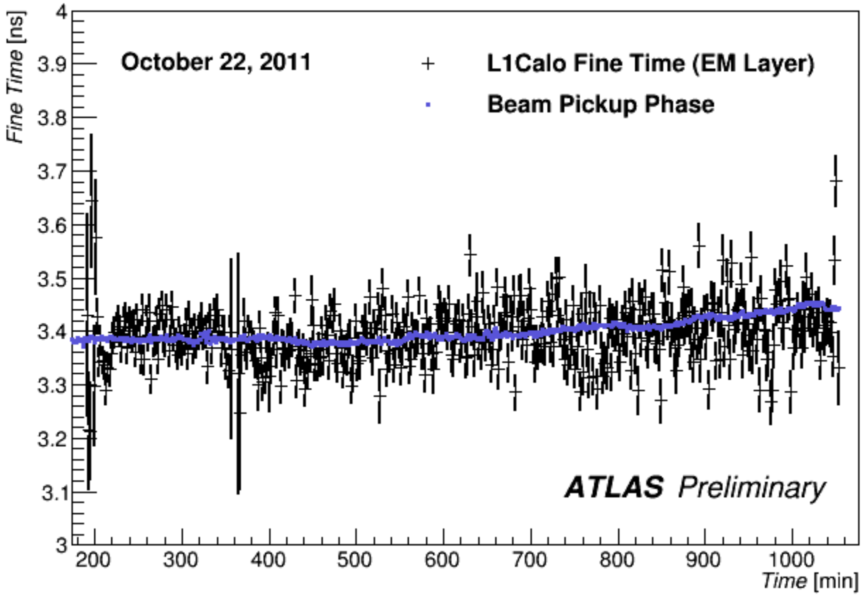
Timing adjustment

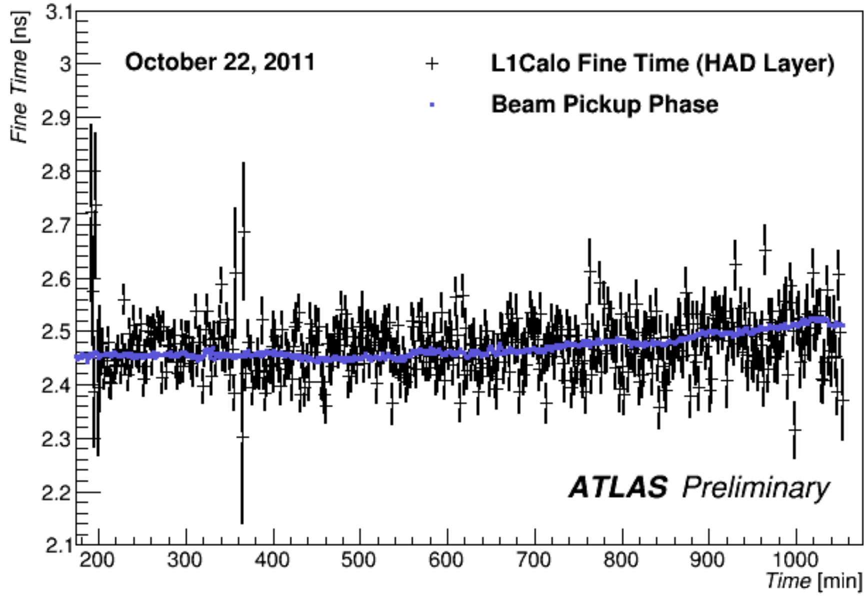




- Full timing corrections on the level of 10 BC's
- Timing done in several steps:
  - Calibration (pulser) runs
  - Beam splashes
- Final corrections are extracted from collision data:
  - Fit signals with function describing expected pulse shape
  - Determine timing corrections for individual Trigger Towers
  - After this correction timing known (for most towers) at the level of ±2 ns

Timing stability monitoring

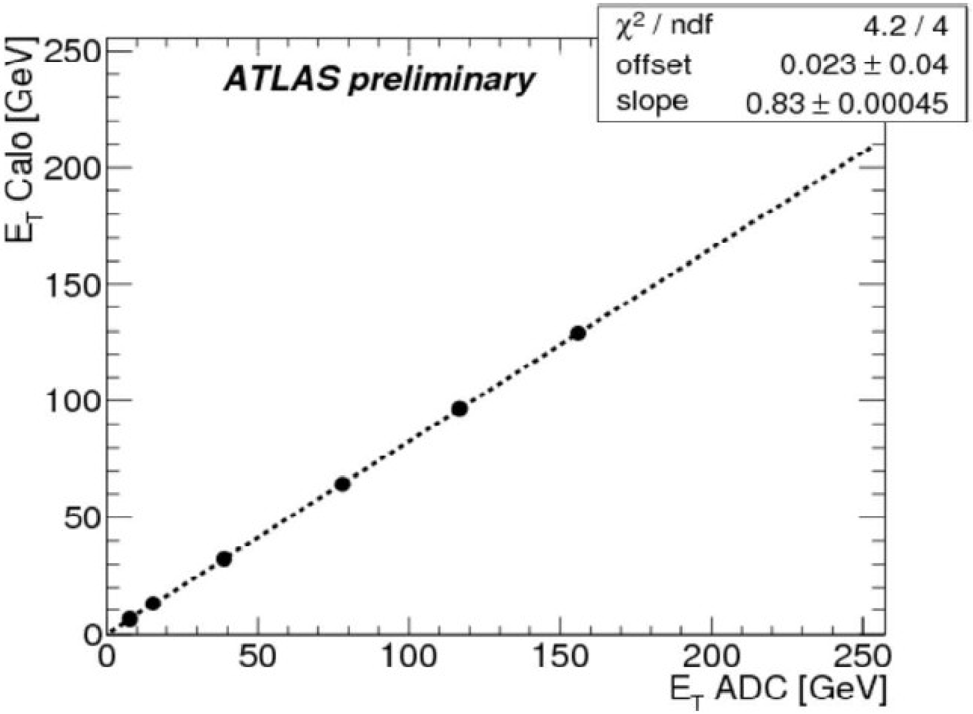




- Regularly checked on several levels:
  - On-line monitoring
  - Off-line monitoring
  - Dedicated offline analysis
- Very stable during 2012/13 data taking, visible shifts in global timing between runs corrected for whole of ATLAS by Central Trigger

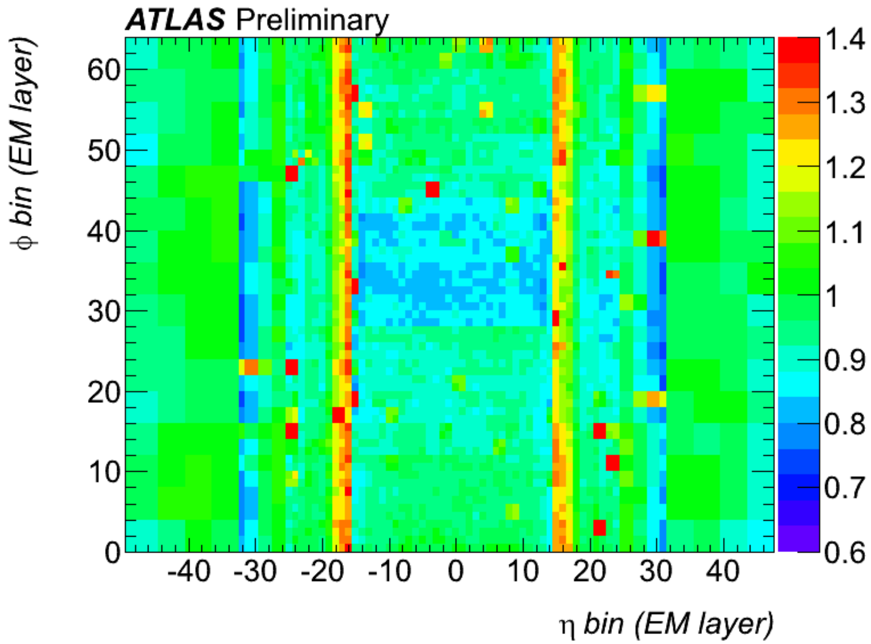
Energy calibration with pulser I

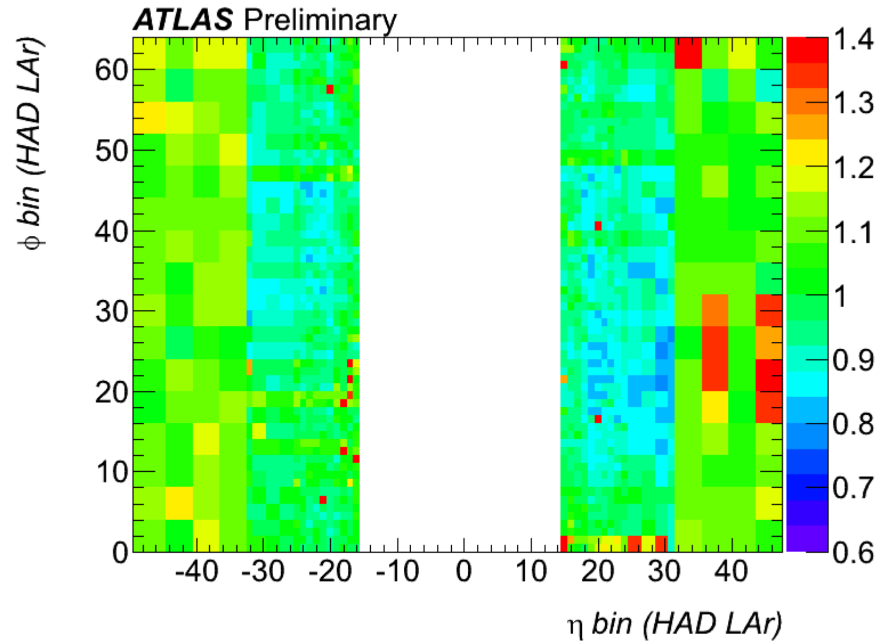
- Number of ADC counts does not immediately translate to energy in GeV (1 FADC count ≈ 0.250 GeV)
- E_T used to get to energy scale
  - Implemented in receiver gains
- Use dedicated pulser runs
- Calibrate with respect to energy measured in calorimeter readout (more precise than trigger readout)
  - Several energy (pulse amplitude) steps
  - Compare energy seen in calo readout and in L1Calo Trigger Towers
  - Calibration factors determined in offline analysis



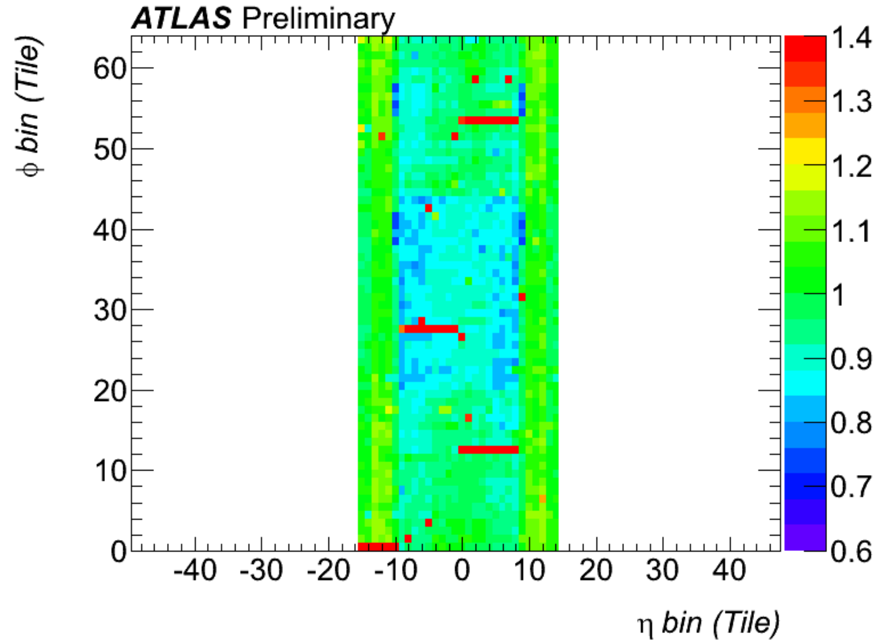
L1Calo readout

Energy calibration with pulser II



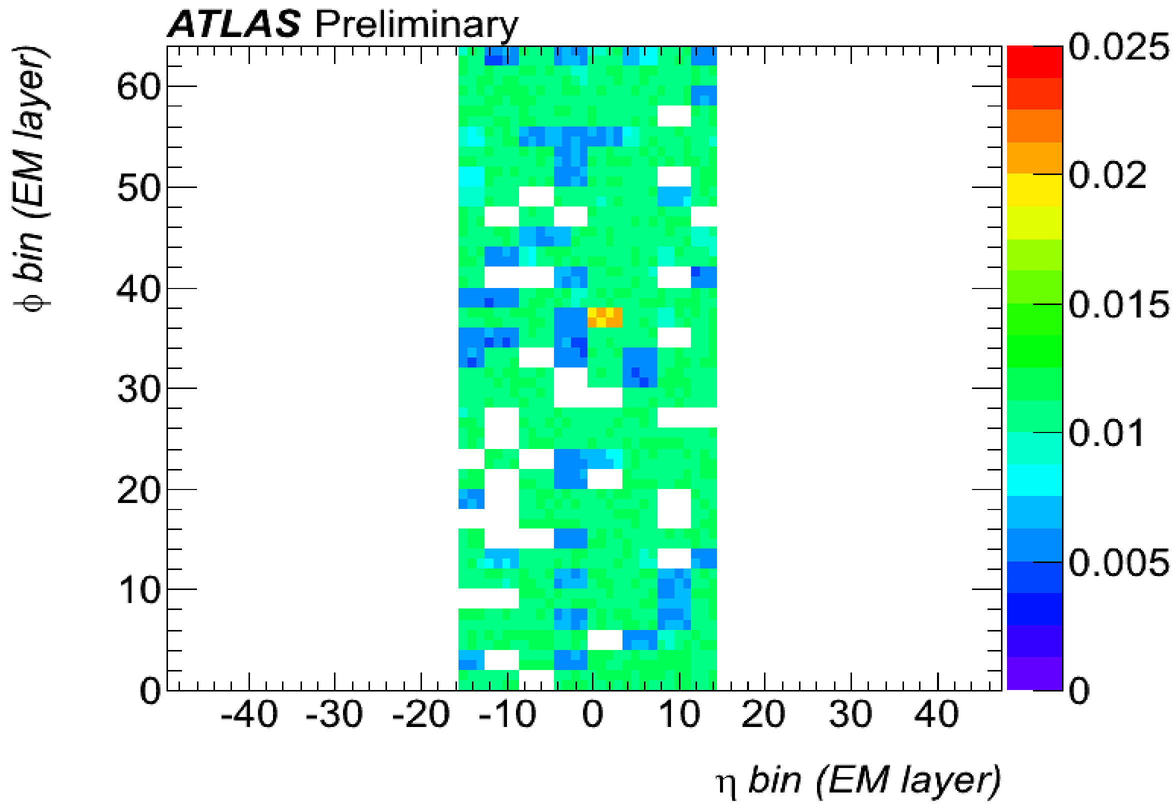


- Calibration (pulser) runs taken weekly
- Analysed automatically on CAF
- Using receiver gains to:
  - Obtain stability of response in time
  - Correct for non-optimally performing hardware



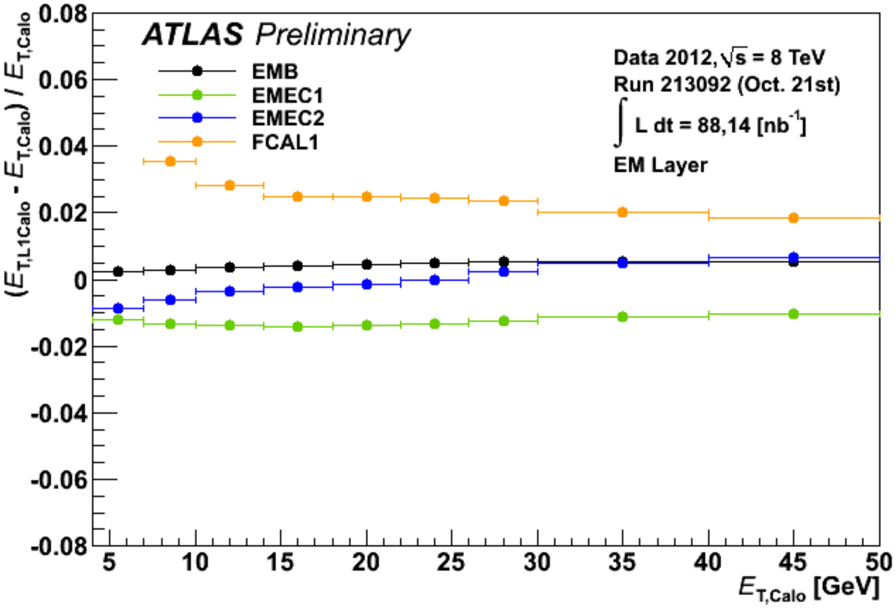
Energy calibration with pulser III

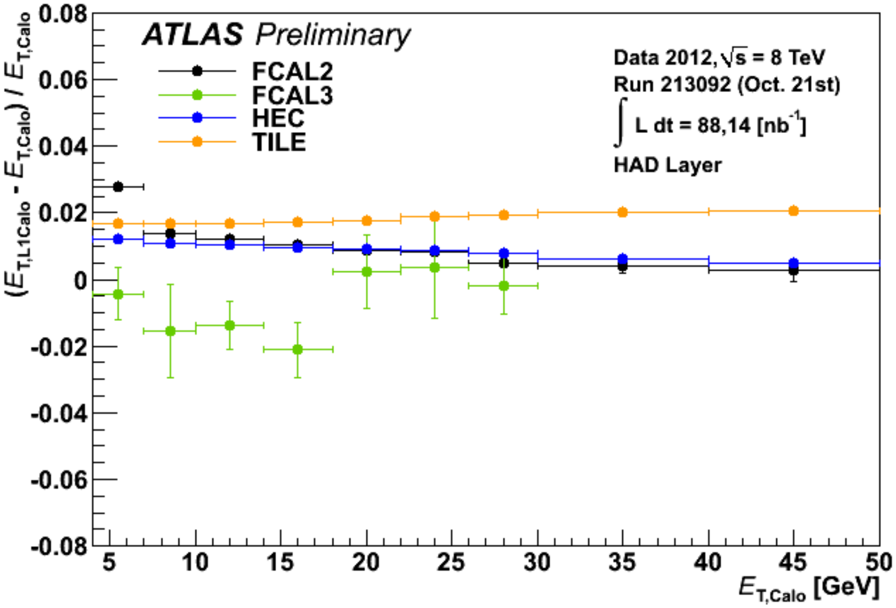
- Using pulser runs to correct for most of hardware effects:
  - Dead/noisy cells
  - Reduced HV in Lar
  - Tile modules with reduced response
  - ...
- Picking up corrections used by calorimeters in reconstruction of calibration runs
- Typical cycle of weekly calibration updates (if needed)



- Occasionally aiming at higher precision or faster turn-around:
  - LAr HV corrections calculated using dedicated set of scripts

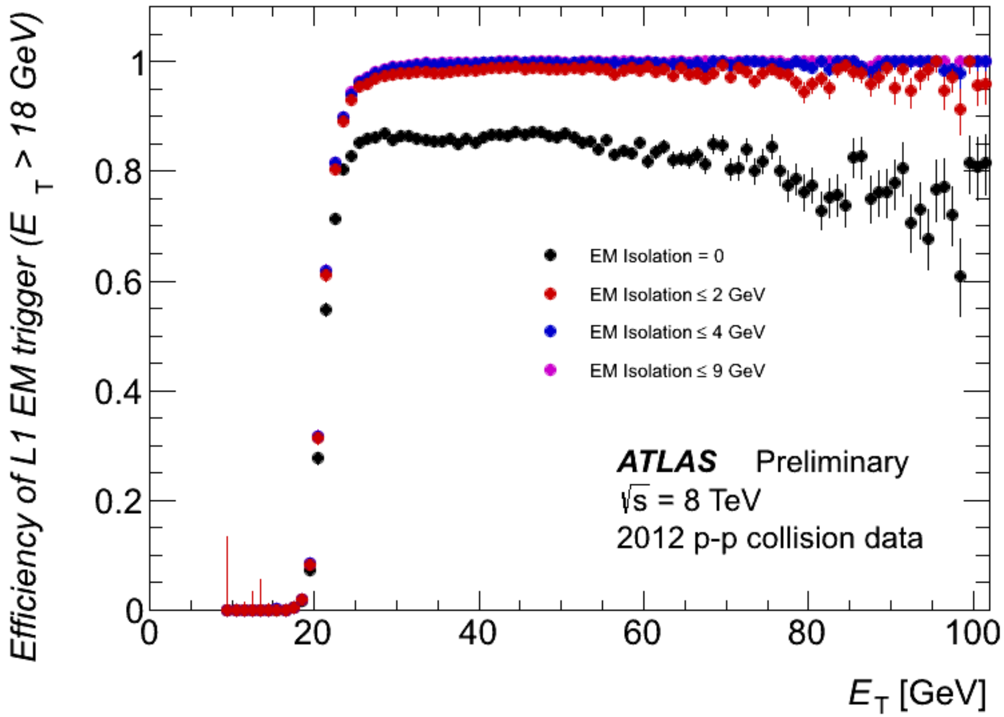
Quality of energy calibration

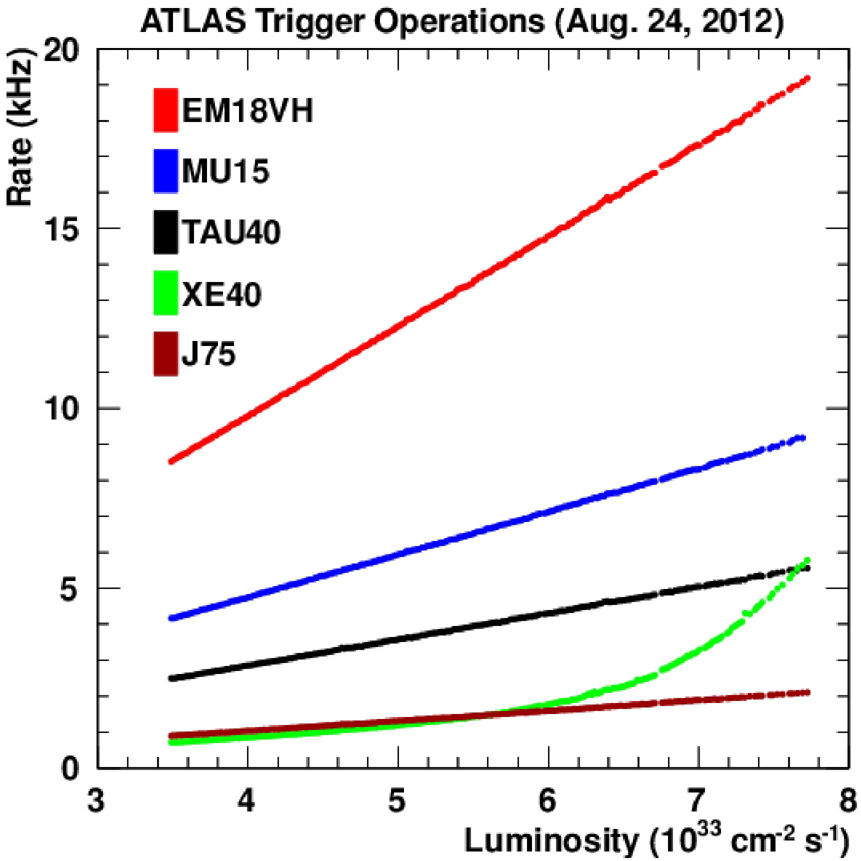




- Final E_T scale obtained using final set of pulser-to-physics corrections
  - Correcting for difference between pulser and physics data
  - Determined in offline data analysis
  - O(1%)
- Updated typically once for running period
- Quality of calibration is checked regularly in monitoring and offline analysis
- Everywhere better than ~2%

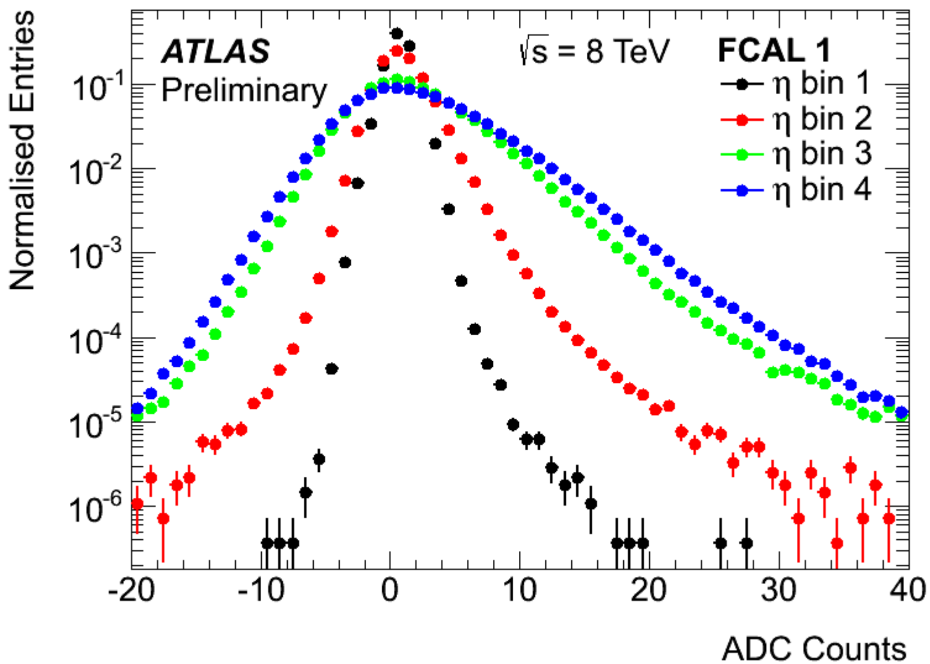
Trigger performance

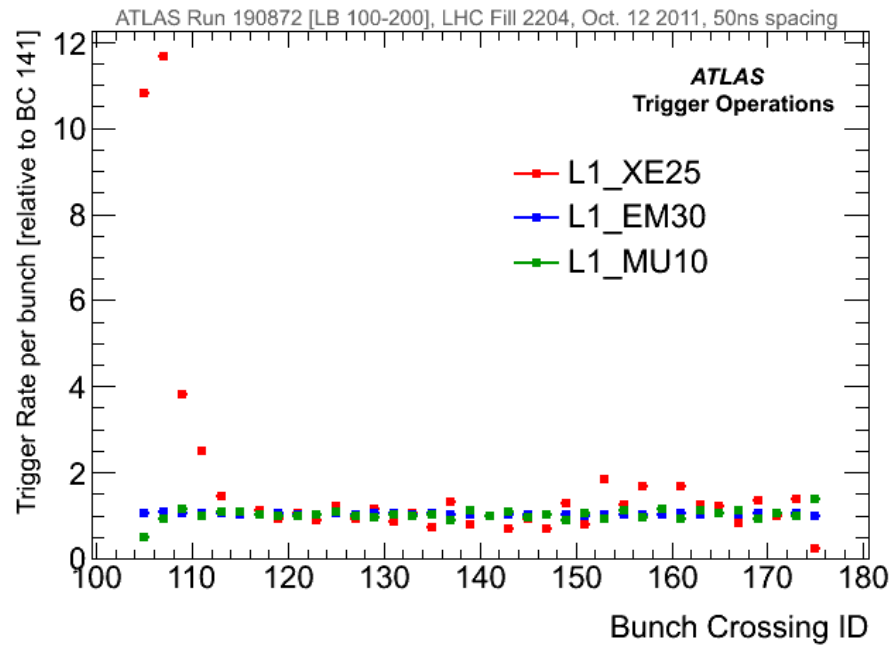




- Good energy scale uniformity, sharp turn-on
- Rates of local triggers (e/gamma, tau, jets) directly proportional to luminosity
- For global trigger (like missing E_T) see strong pile-up dependence

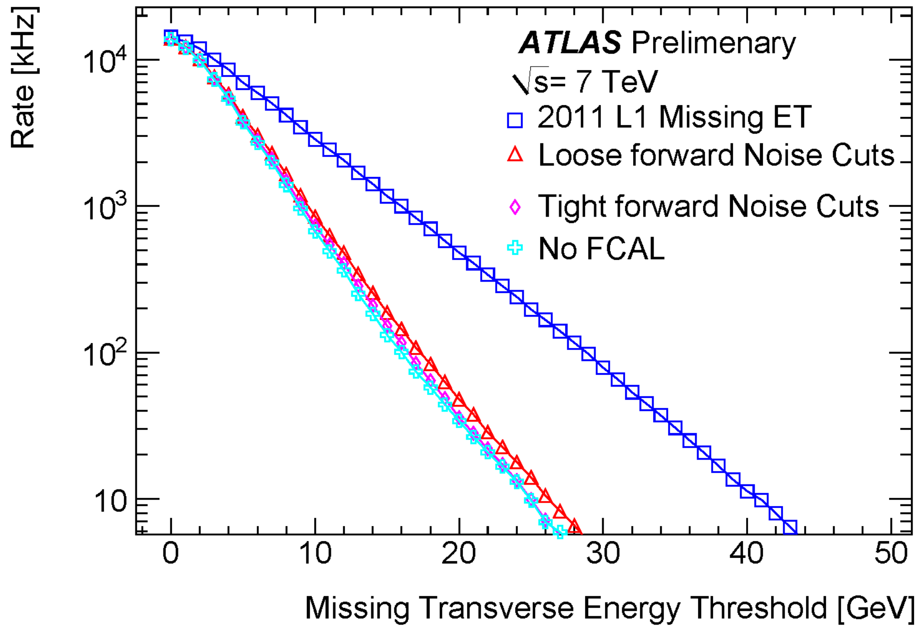
Pile-up effects I

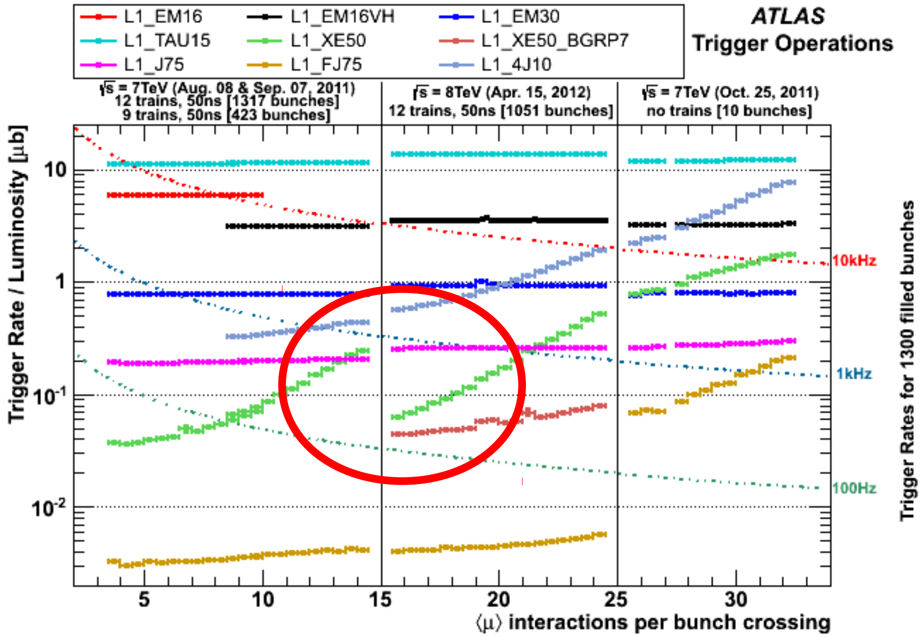




- Pile-up effect strongest at:
  - High η (forward calorimeters, η bin 4 closest to beam-pipe):
    - large occupancy
    - Large tower size
  - Beginning of bunch trains:
    - baseline shifts due to out-of-time pile-up
    - (Later in the train positive an negative parts of calorimeter pulse compensate each other)

Pile-up effects II





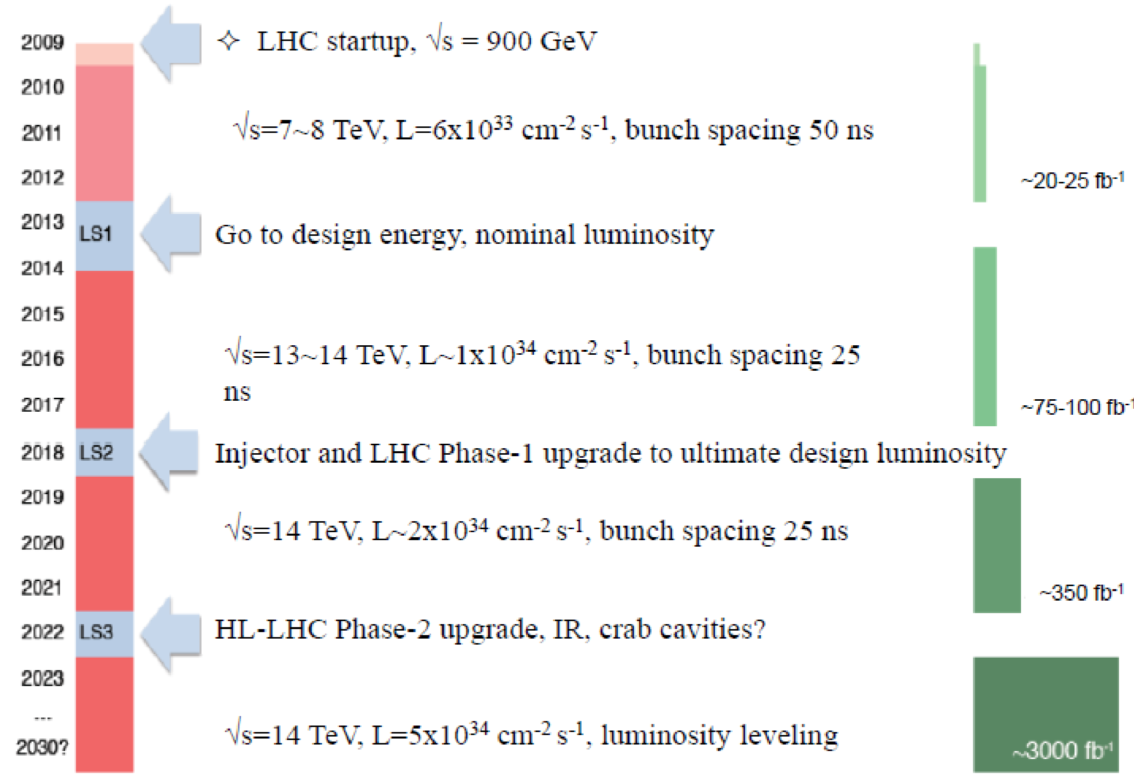
- Rates of missing E_T very sensitive to noise cuts in forward regions
  - Currently main tool to keep rates under control
  - Increased couple of times during 2012
  - Optimized for beginning of bunch trains
- After LS1 plan to use in addition pile-up optimized filters

Upgrade plans

Time-scales and boundary consitions

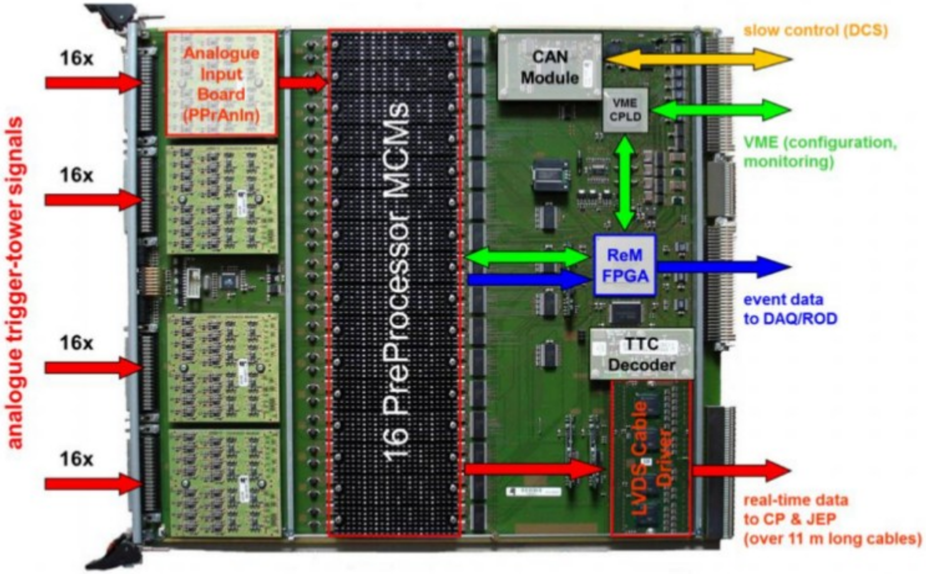
- Two windows for major changes to calo/trigger electronics:
  - LS2 (~2018)
  - LS3 (~2022)
- Ultimate goal - digital trigger with full signal granularity from all calos (LS3)
- Partial upgrades possible in LS1 and LS2
- Time for system development and commissioning very short, need to do it in parallel with running working system

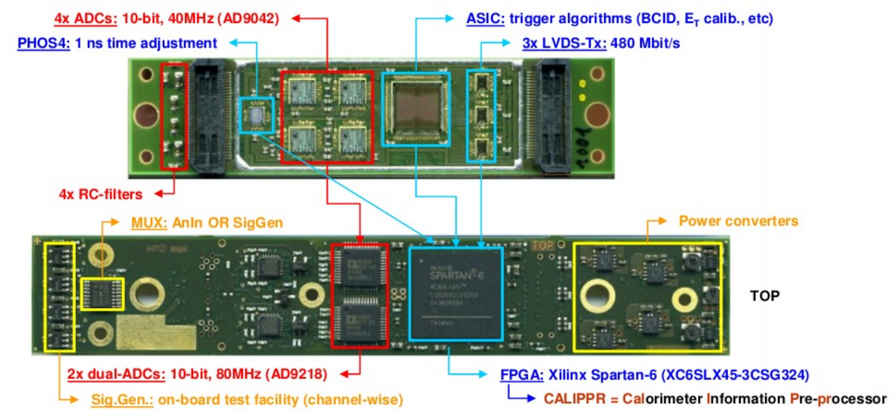
The LHC Timeline



Will concentrate on upgrades happening now (LS1)

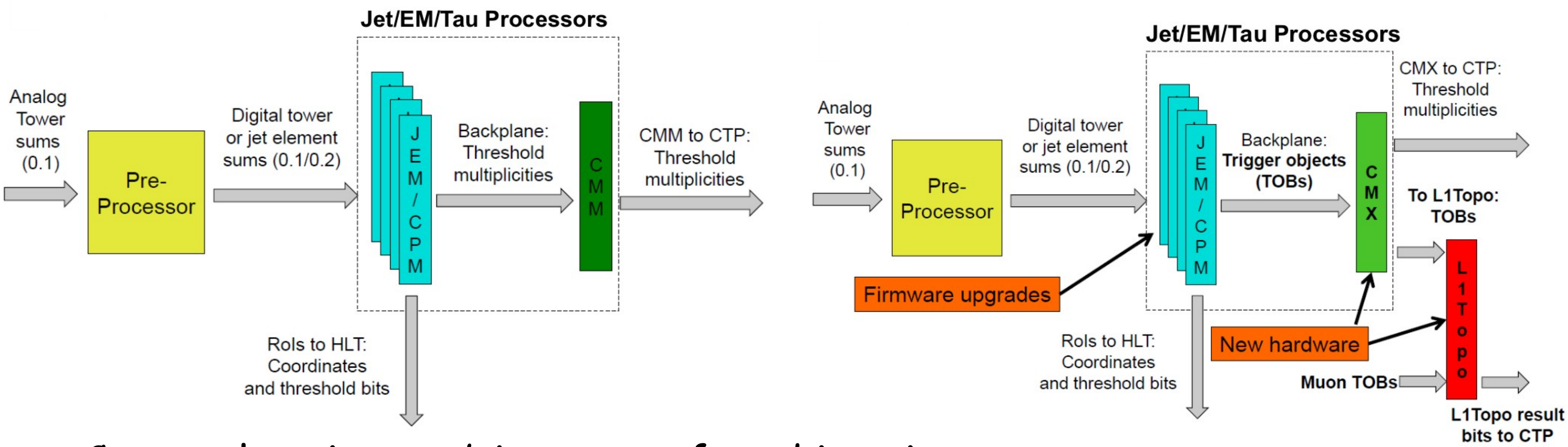
Quality of input signals - nMCM





- Input signal conditioning, digitization and filtering done in PreProcessor daughterboards – Multi-chip-modules (MCMs)
- All being replaced by new FPGA oriented design (nMCM):
  - Better signal conditioning
  - Better pile-up filtering
  - Better BC identification for saturated pulses
  - Possibility of FADC sampling at 80 MHz
  - More flexibility

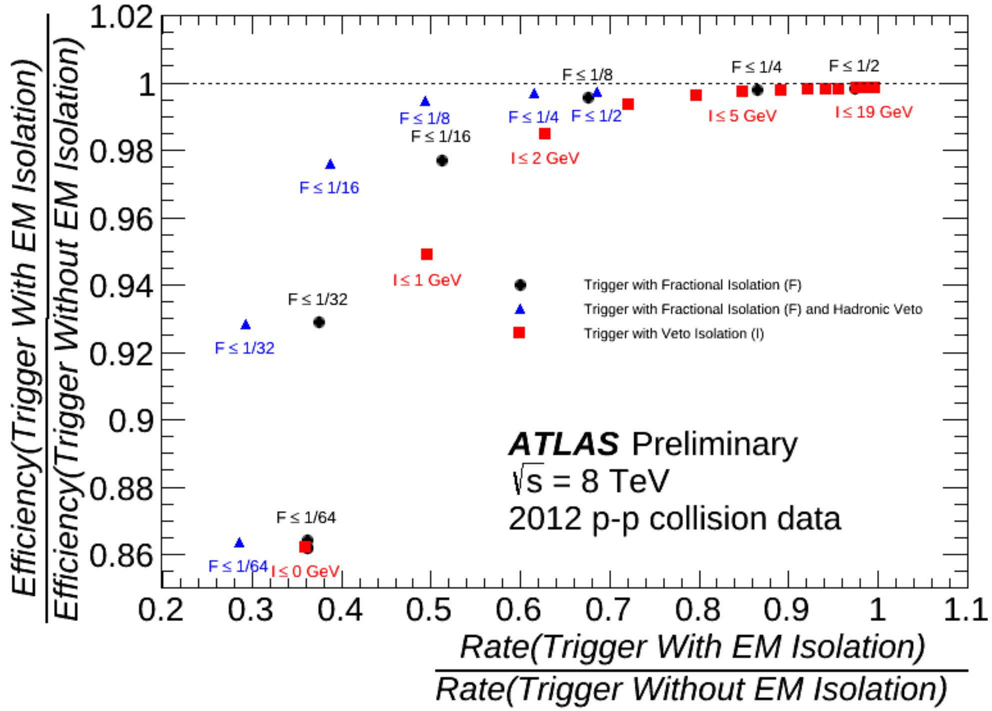
Changes to trigger object treatment I

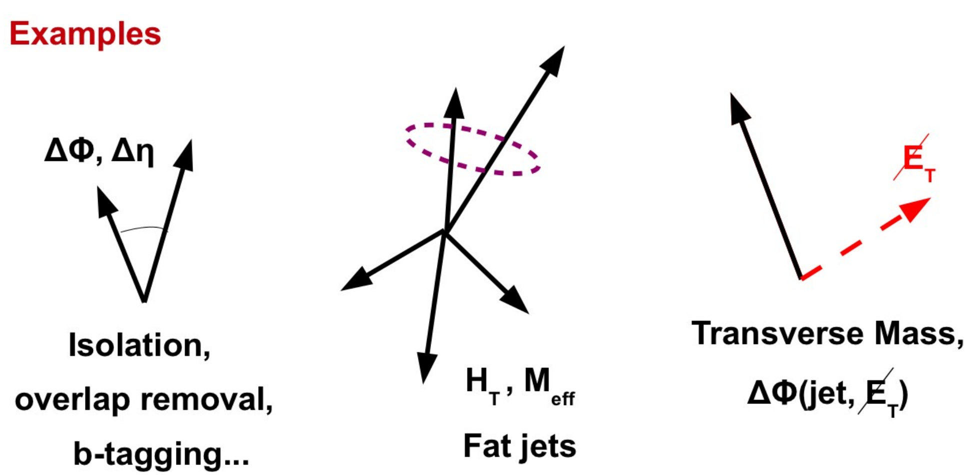


- Currently trigger objects are found in trigger processors:
  - Multiplicity of each threshold used in L1 decision
  - Details (E_T and position) used by L2
- Plan to make energy and position available for L1 decision:
  - Increased bandwidth over processor crate backplanes (new firmware)
  - New summing modules (CMXs)
  - New topology trigger (L1Topo): one crate with few custom boards
  - Using muon objects in addition

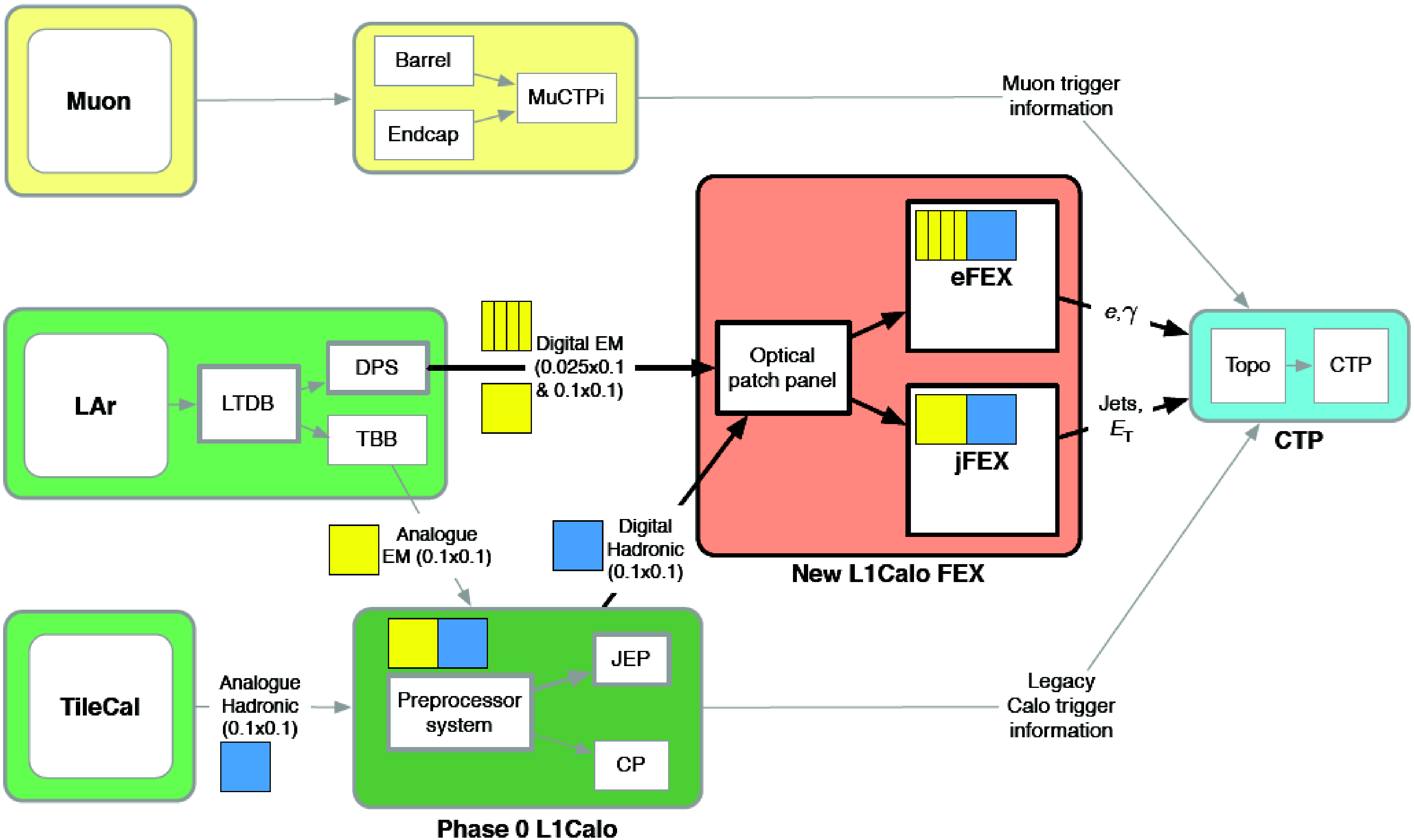
Changes to trigger object treatment II

- Improvements to inclusive EM and tau triggers:
  - Fine threshold granularity in eta (thresholds adjustable with step of 0.1)
  - Better treatment of EM and TAU isolation (LUT instead of fixed-value cut)
- Use of topological triggers on Level1:
  - Delta phi, eta triggers
  - Trigger on transverse mass
  - Overlap removal
  - Topological jet combinations
  - Topological combinations of jets and EM/TAU/μ objects
  - ...





L1Calo after LS2



A possible architecture of new, digital trigger to be installed during LS2 ...

Conclusions and outlook

L1 Calorimeter trigger is an essential part of ATLAS trigger

- Based on custom hardware
- Optimized for speed
- As much parallel processing as possible

A lot of effort went into ensuring its efficient operation and good calibration...

Rich upgrade programme