Performance of ATLAS L1 Calorimeter trigger with data

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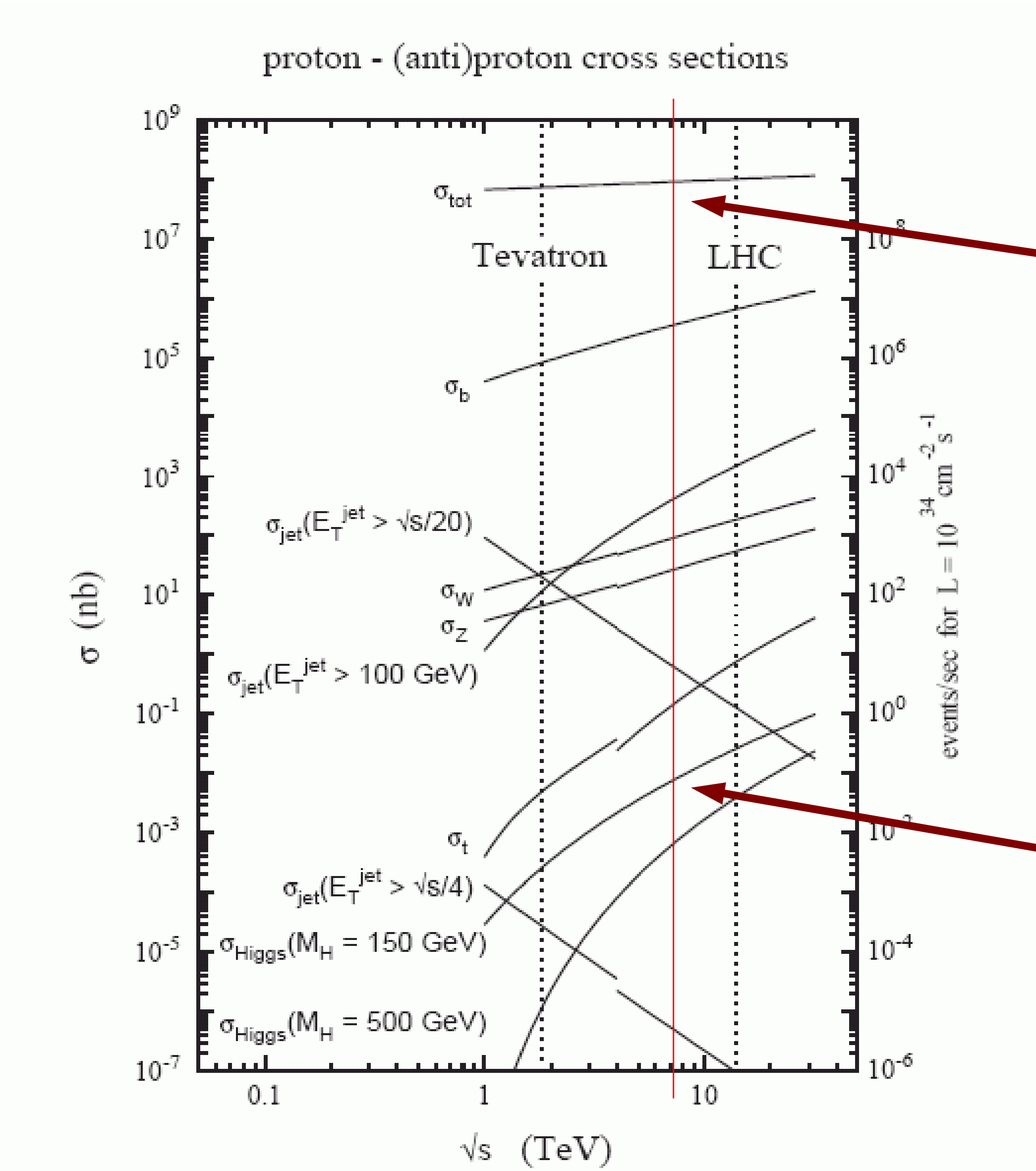
on behalf of the ATLAS Collaboration

TWEPP 2010, Aachen

- Introduction
- Calibration
- Experience from data taking
- Efficiency for physics objects

Life at hadronic colliders is not easy ...



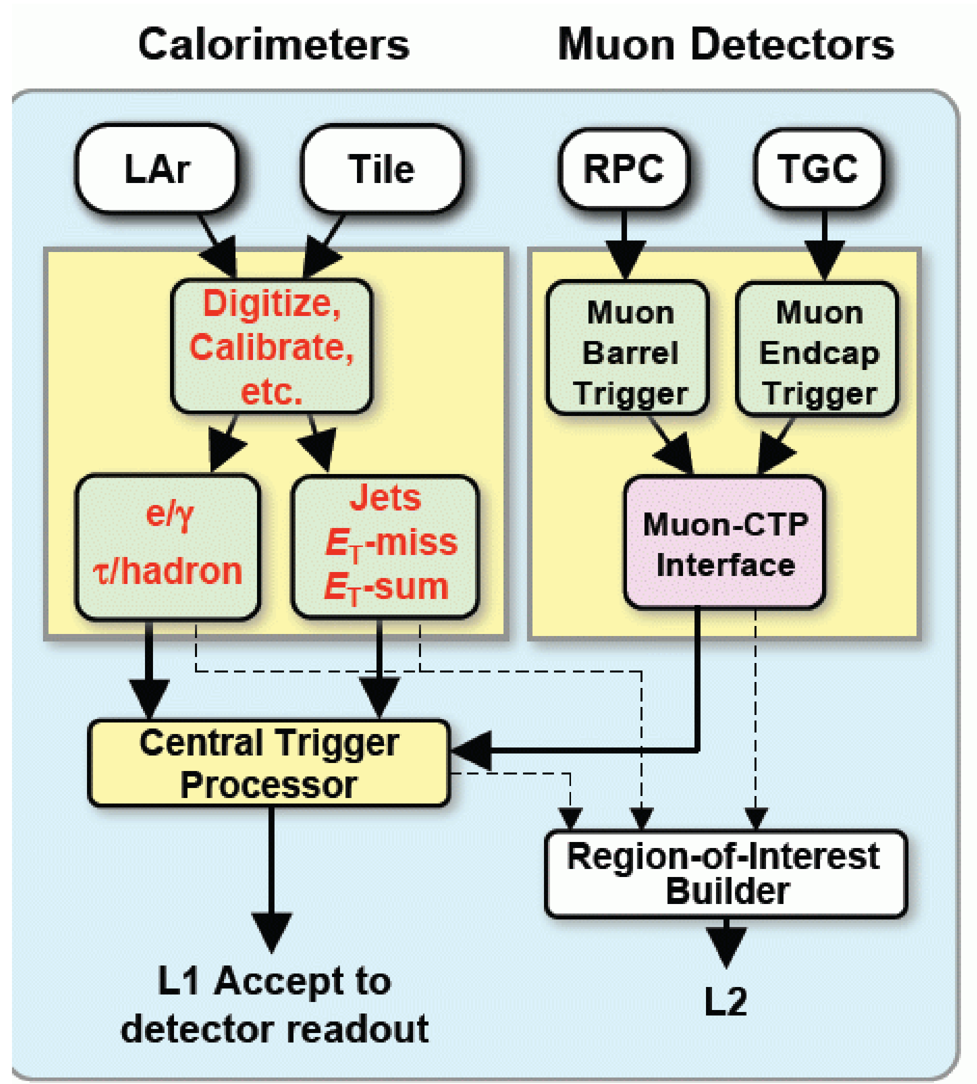
Most of the time this!

Here it gets really exciting!

L1Calo – a major part of ATLAS L1 trigger

- Level-1
  - Custom built HW (ASICS and FPGAs)
  - Fixed latency < 2.5 μs, L1A~75 kHz
- Level-2
  - CPU's
  - Full granularity for areas of activity marked by L1 – Regions of Interest (RoI)
  - Latency ~40 ms, L2A~2kHz
- Event Filter (Level-3)
  - CPU's
  - Offline algorithms on full event
  - Latency~1s, EFA~100Hz

- Level-1 trigger:
  - L1-Muons
  - L1-Calorimeters (L1Calo)



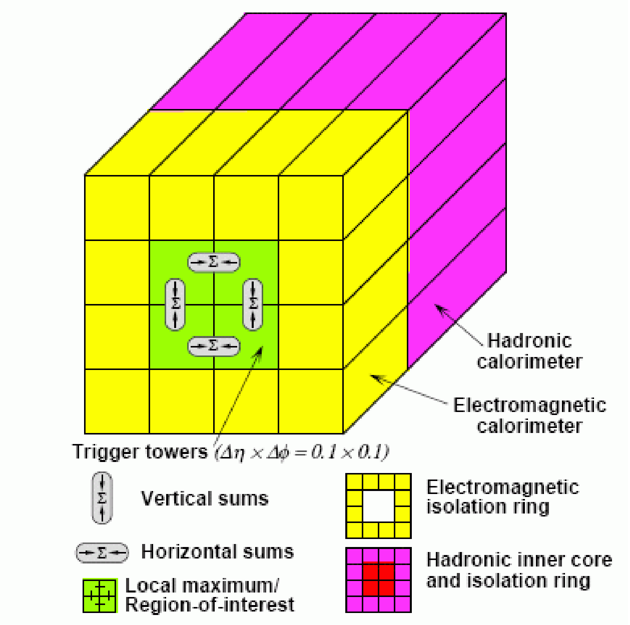
Selection of interesting events

Hard final state objects in an event:

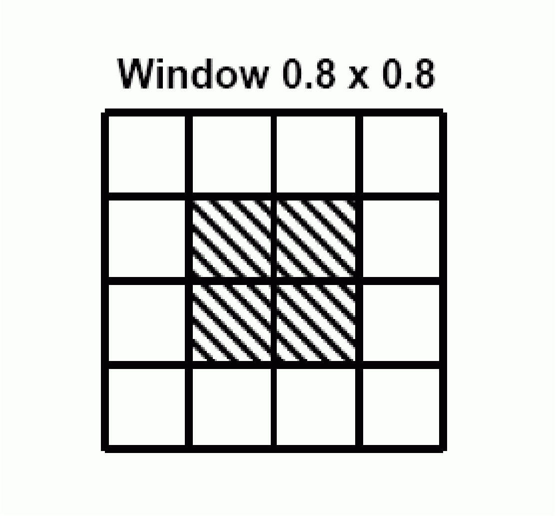
- e/γ and τ/h objects
- Jet candidates

Global event properties:

- E_T
- Missing E_T
- Jet sum E_T



- Sends to Central trigger:
  - Multiplicity of electrons/photons, τ's and jets passing 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 also for L2!

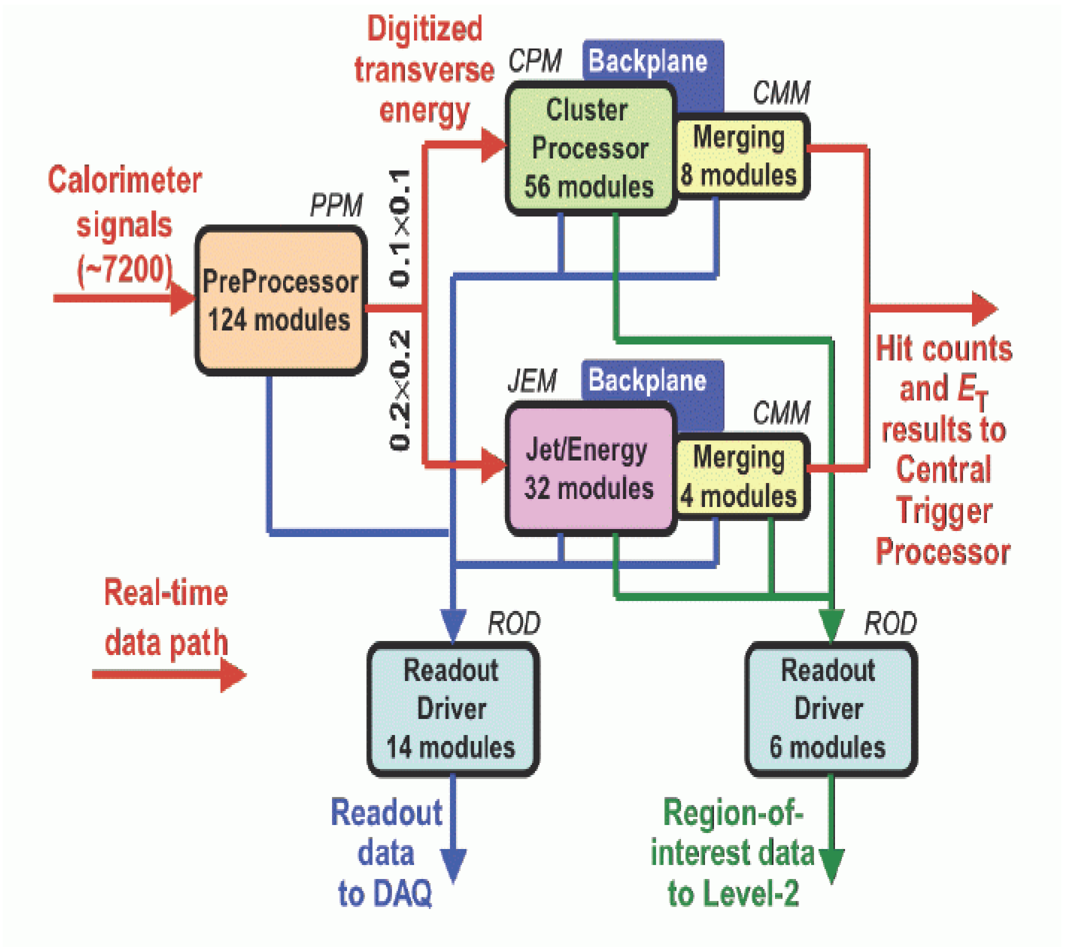


L1Calo - HW implementation

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

Main parts:

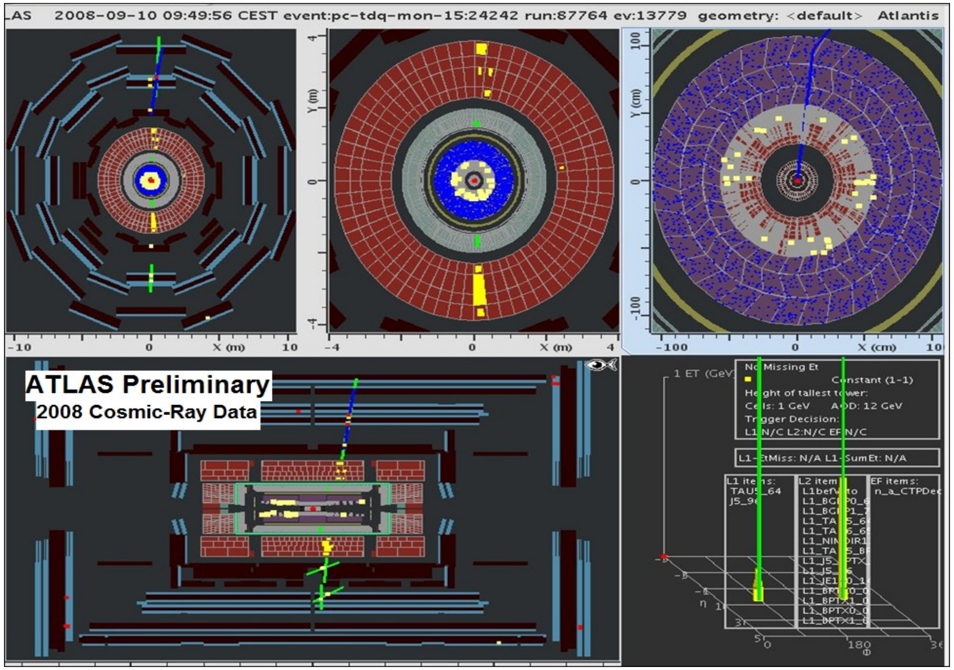
- Preprocessor:
  - Conditioning and calibration of analog signals, digitization, bunch cross identification
- Cluster processor:
  - Electrons/photons, taus
- Jet processor:
  - jets, E_T, Missing E_T



Full system installed in ATLAS cavern and running

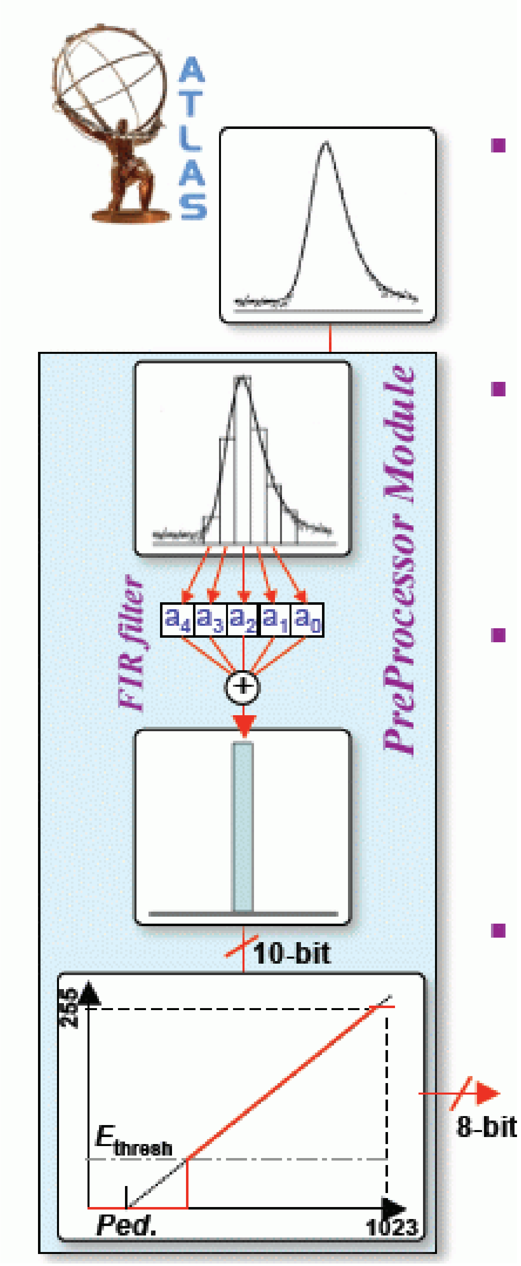
System installation and commissioning

- Most of the system installed end of 2007
- 2008, first part of 2009:
  - trigger commissioning with cosmics
    - fix digital links
    - repair faulty modules
  - First calibrations and timing with pulser
- Early data – end of 2009:
  - detailed checks of L1Calo performance
- Spring of 2010:
  - gradual increase in delivered luminosity
  - Stepwise updates of L1Calo calibrations
- Early July:
  - High Level Trigger rejects events (running in pass-through mode before)



Calibration of the trigger

Pulse conditioning and calibration



Analogue receivers:

- variable gain amplifier
- $E \rightarrow E_T$ conversion (where needed)
- first step in energy calibration ←

Digitization:

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

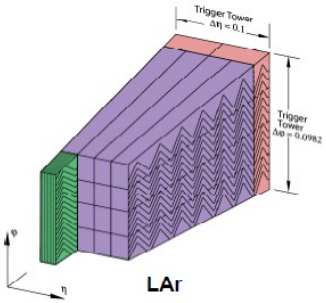
Bunch Crossing ID:

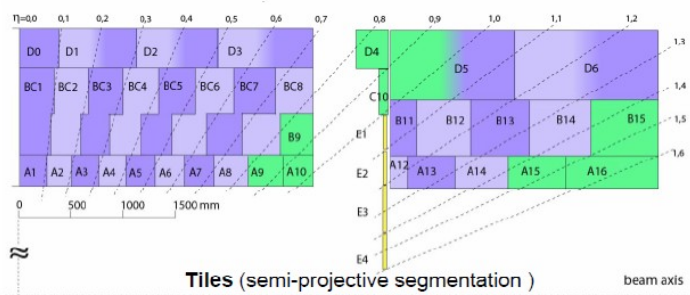
- assign signal to correct bunch crossing
- Linear digital filter ←
- special treatment of saturated pulses

Look-up table (LUT):

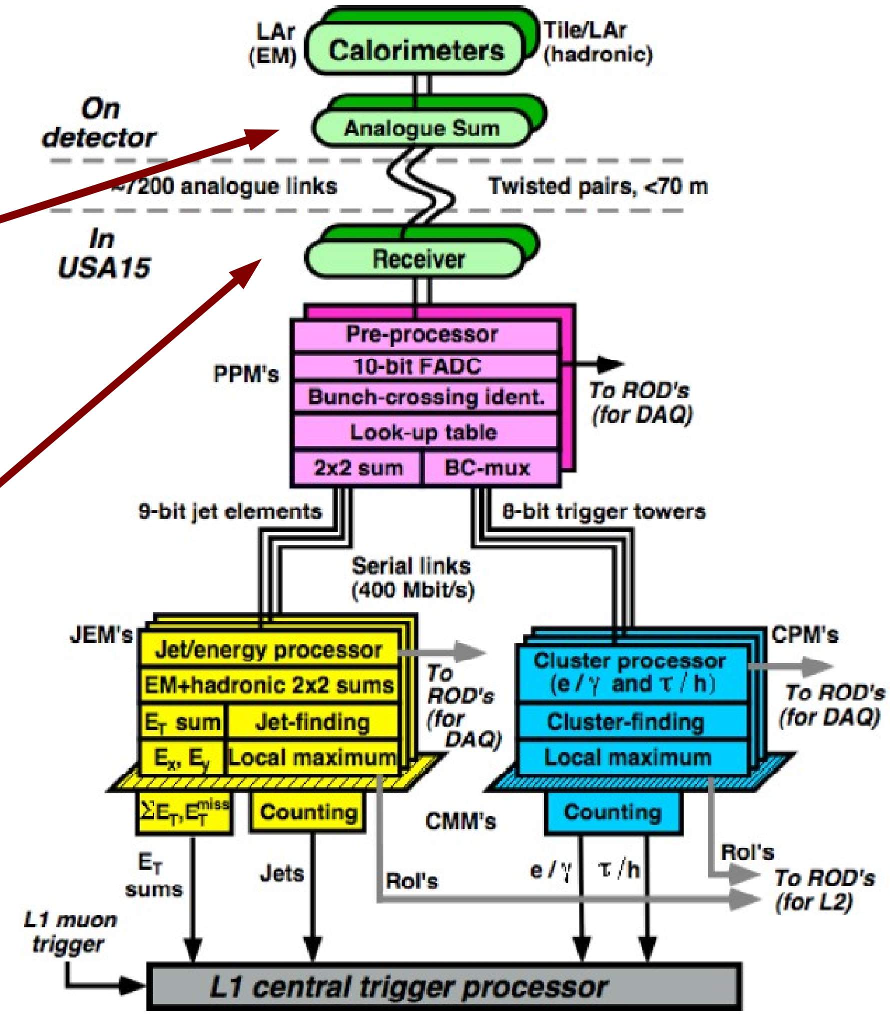
- pedestal subtraction
- noise suppression
- killing of noisy channels
- final energy calibration
- 8-bit output for algorithms

Timing - Introduction





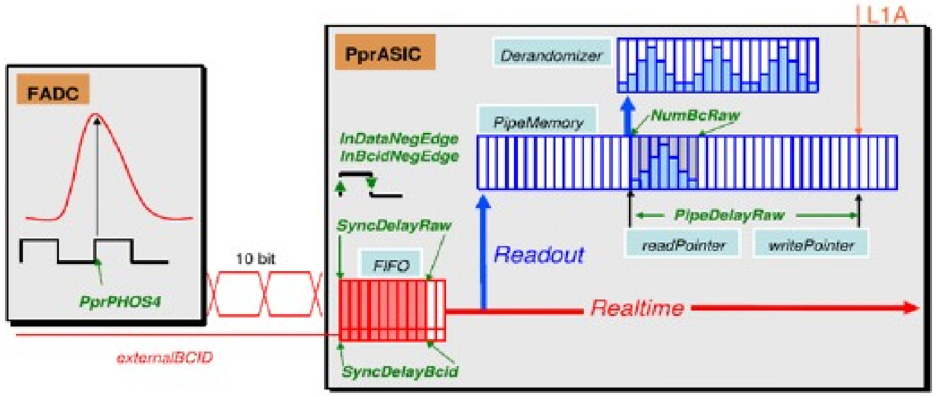
- Signals from individual calorimeter cells summed on detector into projective Trigger Towers
- Analogue signals routed using 30-70 m long twisted pair cables (4.76 ns/m)
- Signals at input of L1Calo need to be aligned in time
- Compensate for:
  - Different cable lengths
  - Individual channel variations
- If mistiming large, event lost
- Smaller mistiming means wrong energy measurement



Timing with pulser

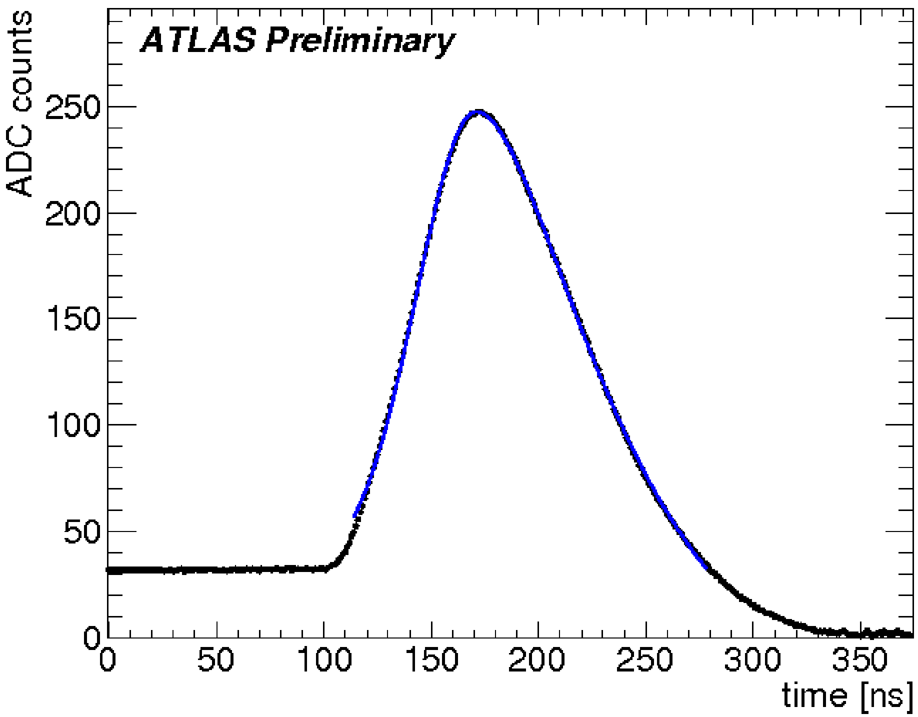
Several parameters available to adjust timing:

- Fine timing (PHOS4 chip) – 1 ns step
- Input delays (in input FIFO) – step of 1 BC
- Readout pointer – 1 BC step, used for the data readout of triggered events

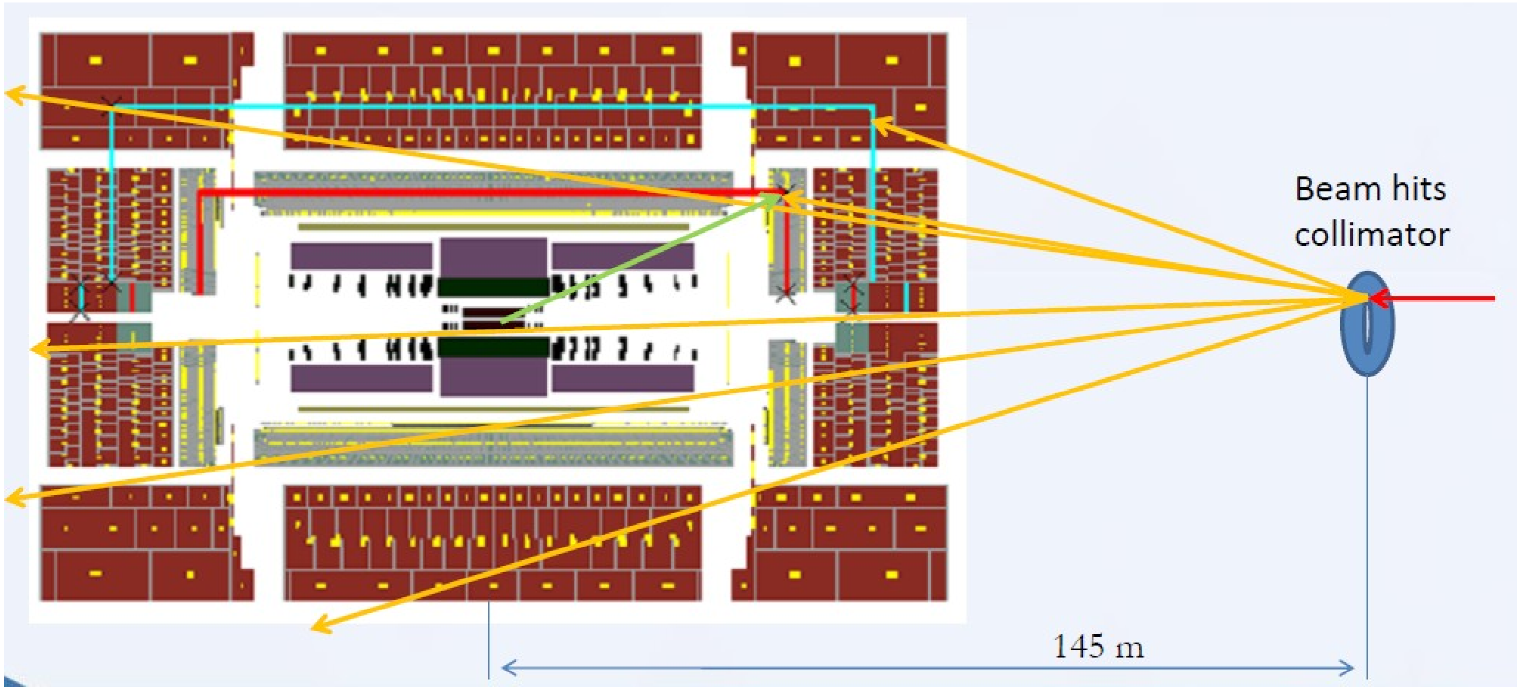


First approximation done in dedicated runs with pulser (setup to mimic collisions):

- Adjust readout pointer such that signals are visible
- Align signals with BC precision using input timing
- Adjust fine timing to strobe at pulse maximum



Timing with splashes I

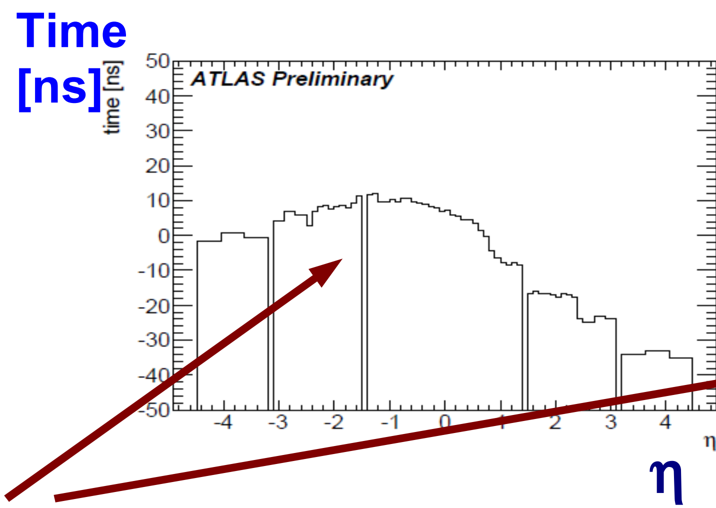


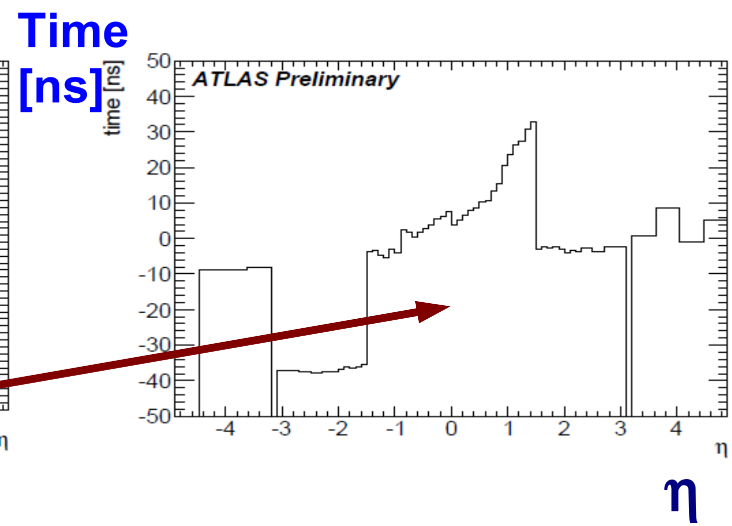
Splash events occur when beam is hitting collimator:

- Large signals in all towers
- Geometry of splashes different to collisions, need to correct for different time-of-flight effects:
  - ToF from collimator to Trigger Tower
  - ToF from beam vertex to Trigger Tower

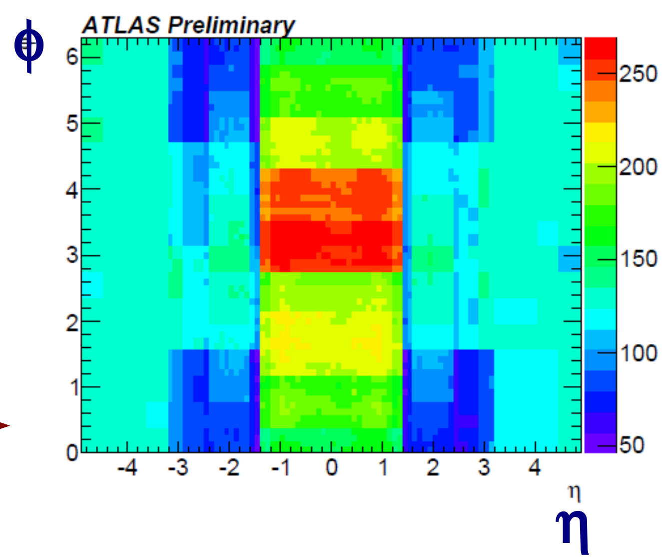
Timing with splashes II

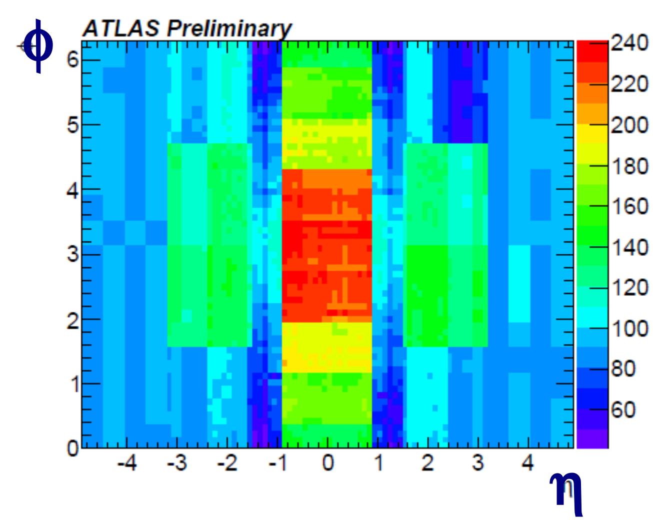
- Signals from splashes fitted by a function describing expected pulse shape
- Determine position of signal peak in time
- See time of flight for splashes nicely



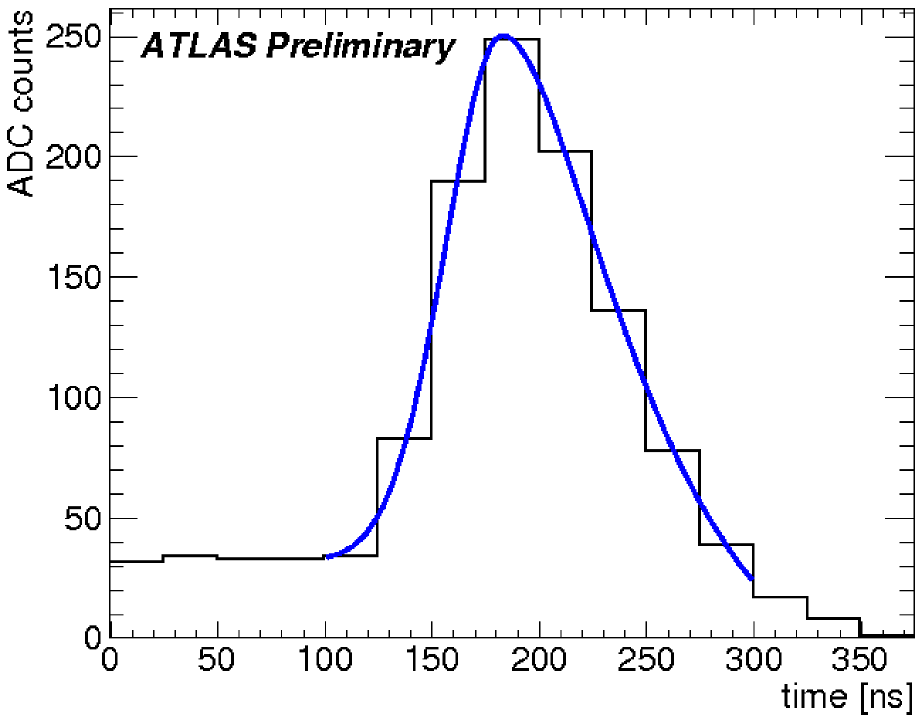


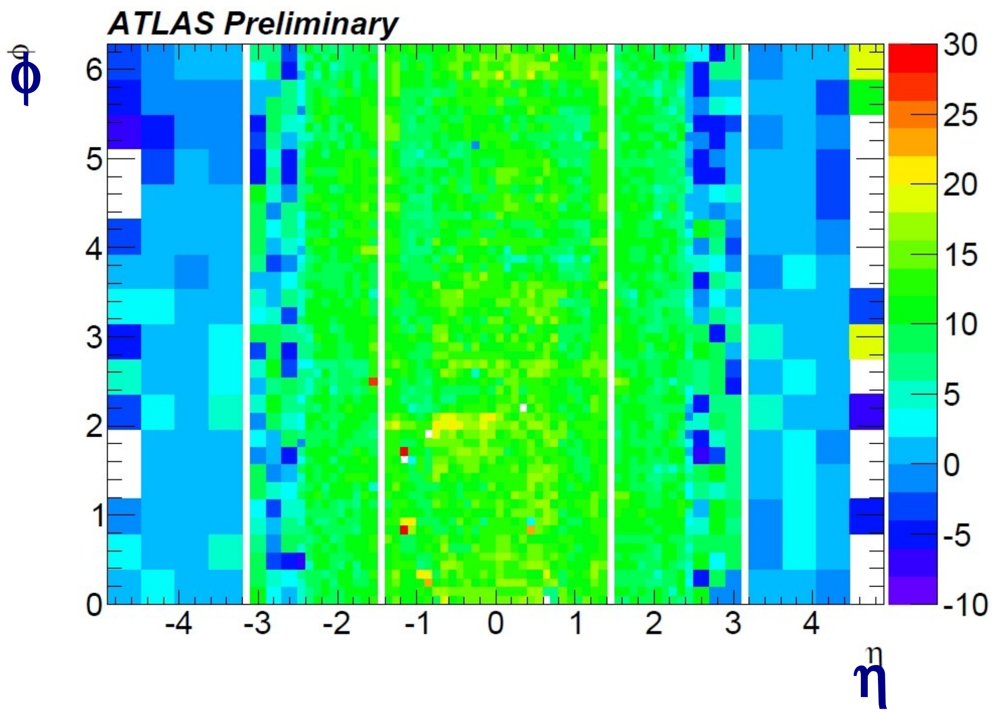
- Correct for differences in time of flight between splashes and collisions
- timing delays as used for early data!





Timing with collisions





Final corrections are extracted from collision data:

- Good signals are selected
  - No hardware problems or noise
  - Coming from collisions
- Fit 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

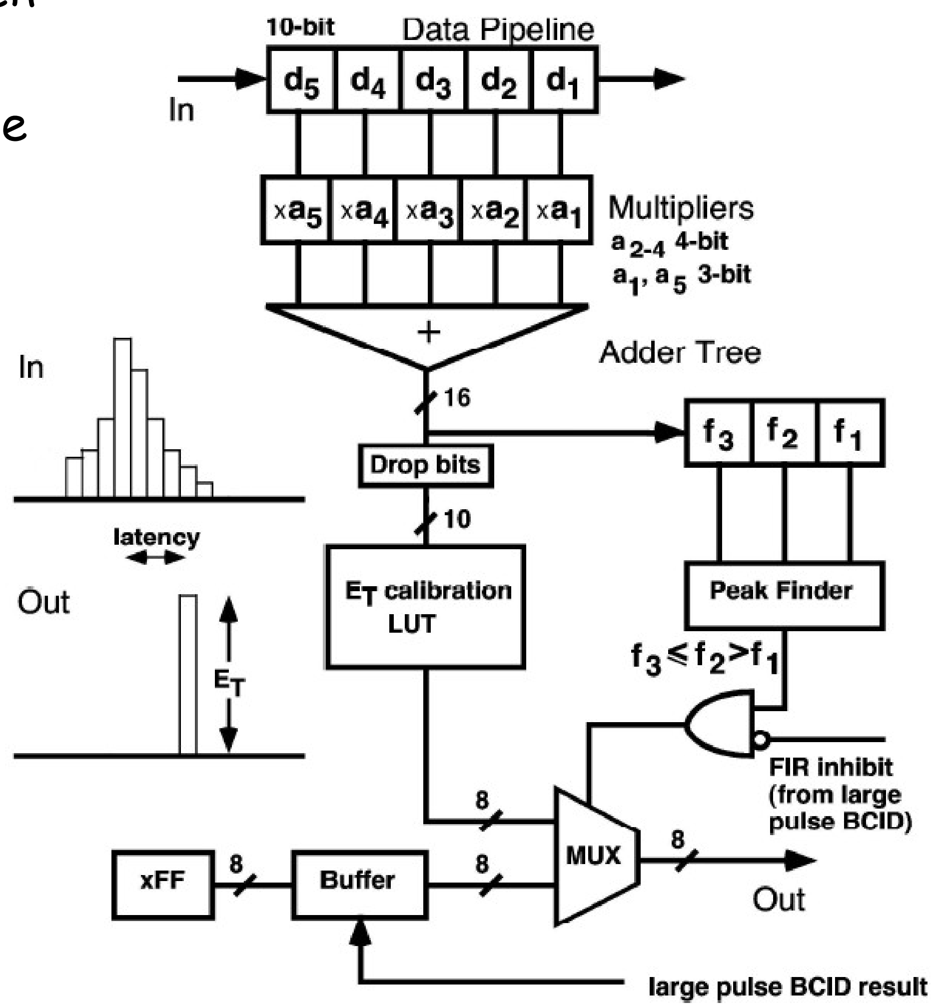
FIR filter I

- pulses are several bunch crossings wide
- Need to associate them with a single bunch crossing
- A 5-sample digital Finite Impulse Response (FIR) filter is applied:

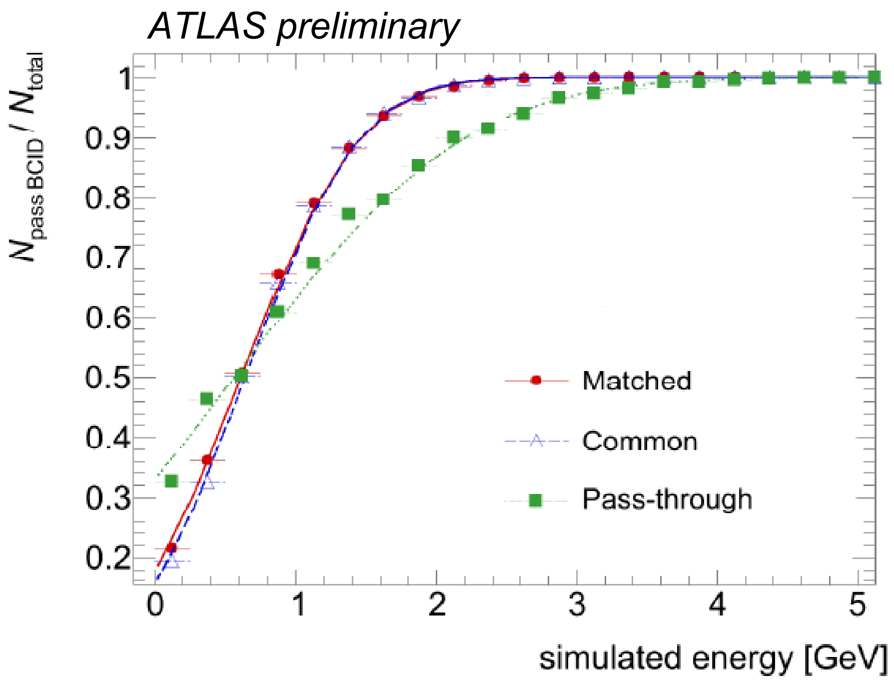
$$S = \sum_{BC's} c_i \, FADC_i$$

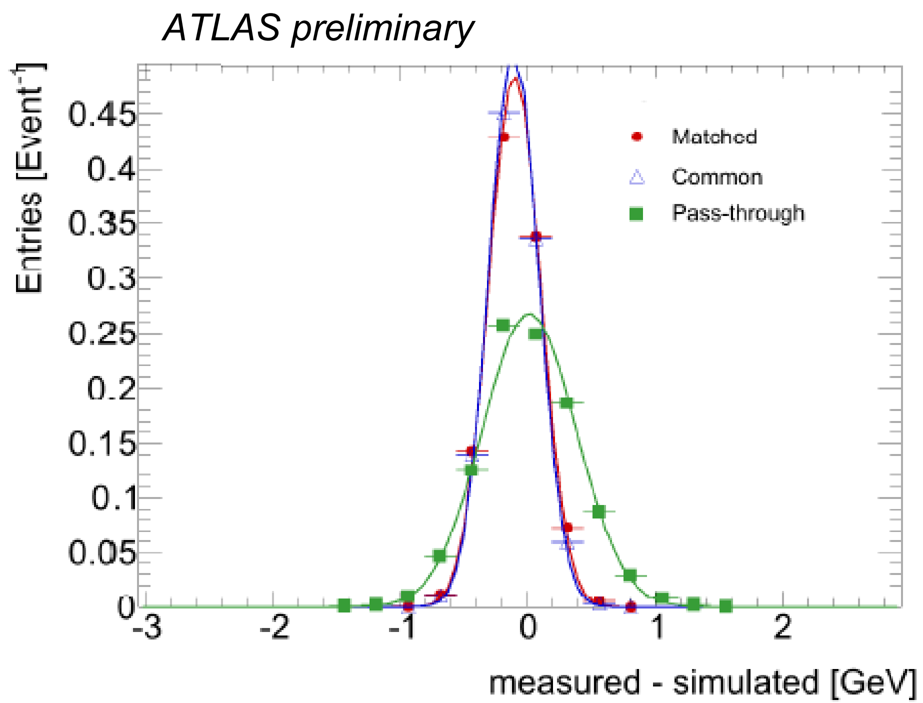
- Maximum of filter output defines bunch crossing
- Value of filter output is input to LUT, output from LUT gives E_T

- Best performance expected for filter adjusted to the shape of pulse in each tower
- Studied using calibration pulses superimposed on realistic noise



FIR filter II

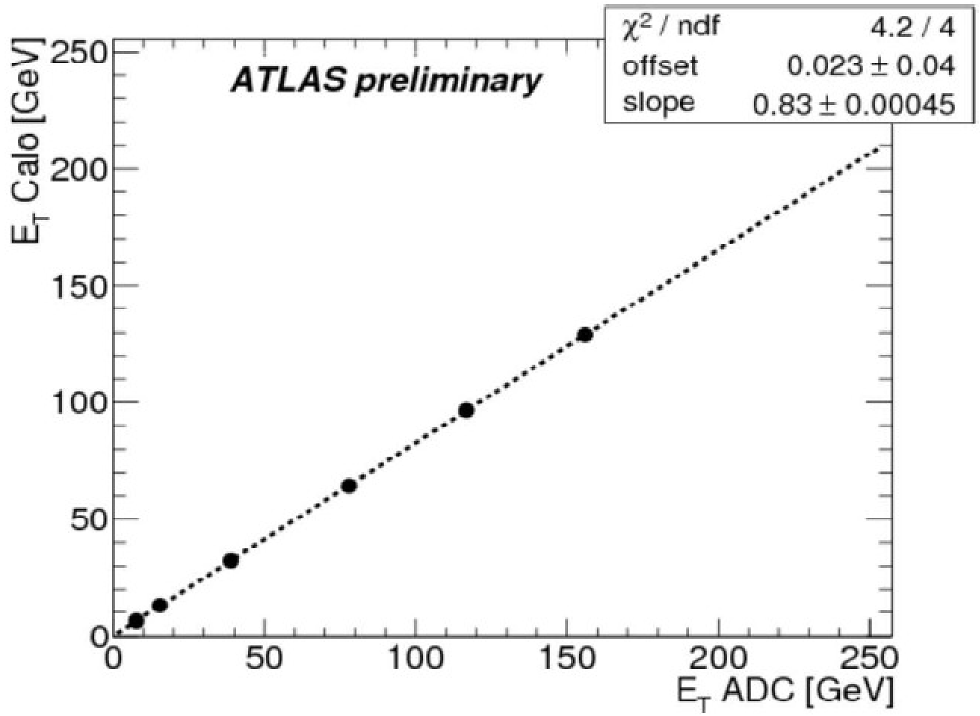




- Three sets of coefficients:
  - Matched to each tower
  - Common (one for EM layer, one for HAD, one in forward region)
  - Pass-through (only central sample in time is used)
- FIR filter clearly helps for:
  - Efficiency for small pulses
  - Noise rejection
  - Energy resolution
- Only marginal difference between matched and common
- Running with common filters now
- Next step- take into account differences between calibration and physics pulse shapes

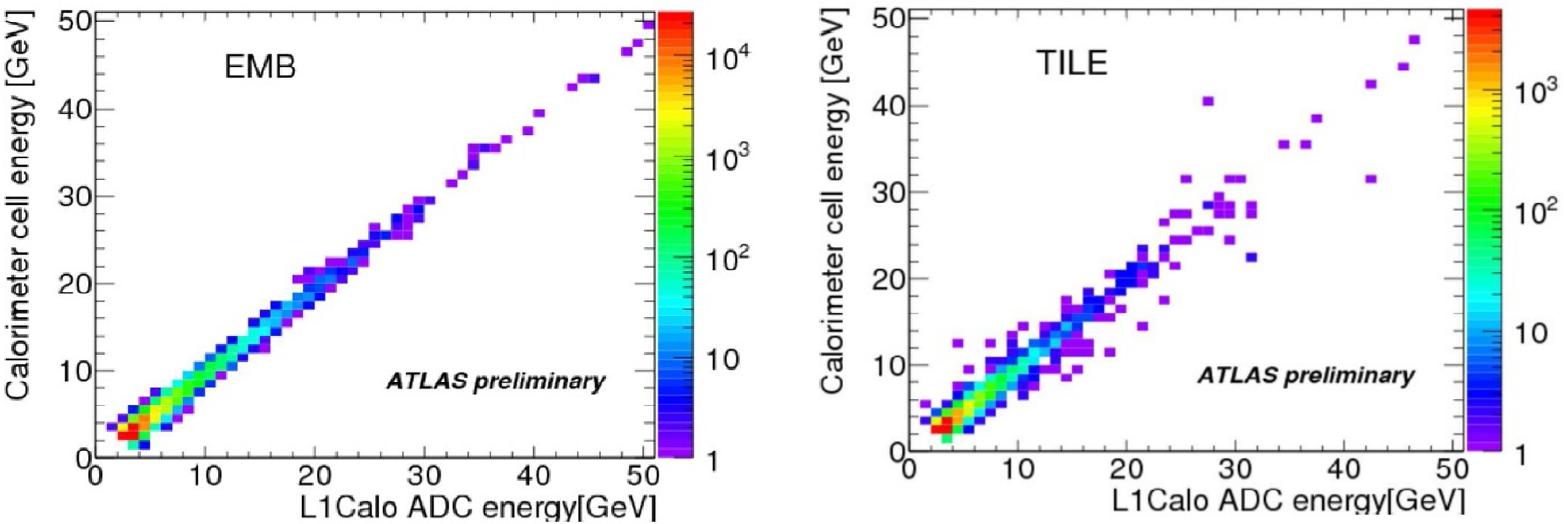
Energy calibration with pulser I

- Number of ADC counts does not immediately translate to energy in GeV (1 FADC count ≈ 0.250 GeV)
- need (energy) calibration
  - Implemented in receiver gains (and LUT slope)
- 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



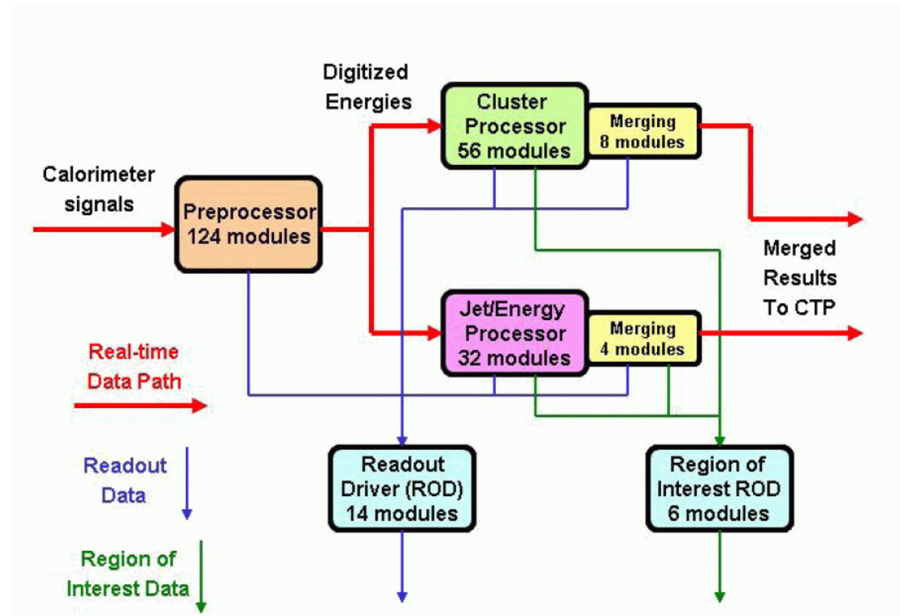
- Checks of the calibration done with collision data
- Compare E_T of large energy deposits seen in L1Calo readout with E_T seen in corresponding areas in calorimeters
- Correlation looks reasonable
- Next steps:
  - understand/fix problematic electronic channels
  - Use physical objects

Experience from datataking

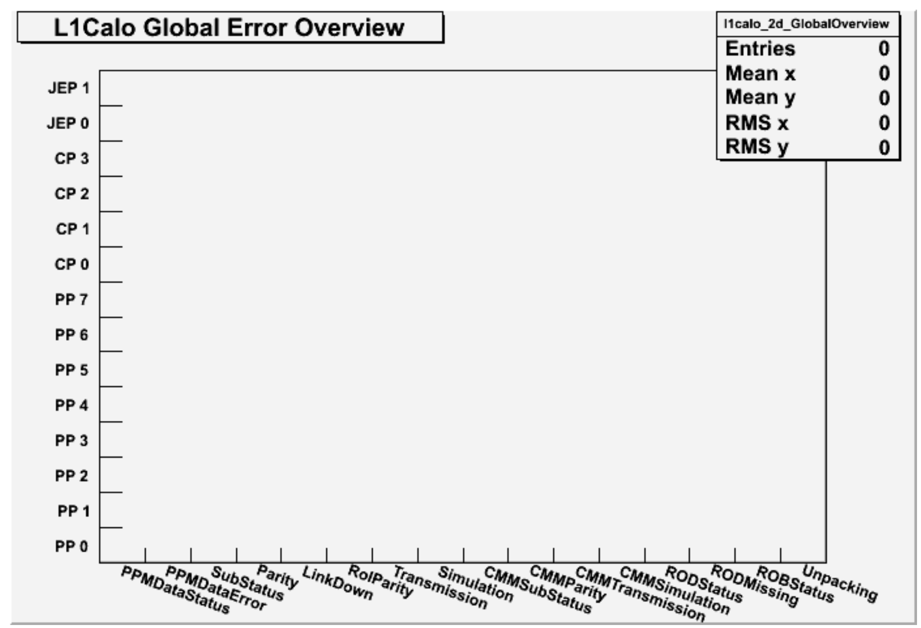
Datataking performance I

Digital consistency:

- duplicated readout from several places in the system
  - Good system in place to ensure that there are no digital inconsistencies!
- Trigger readout compared to bit-by-bit trigger simulation
  - Starting from FADC counts
  - Simulating (recalculating) response of the electronics

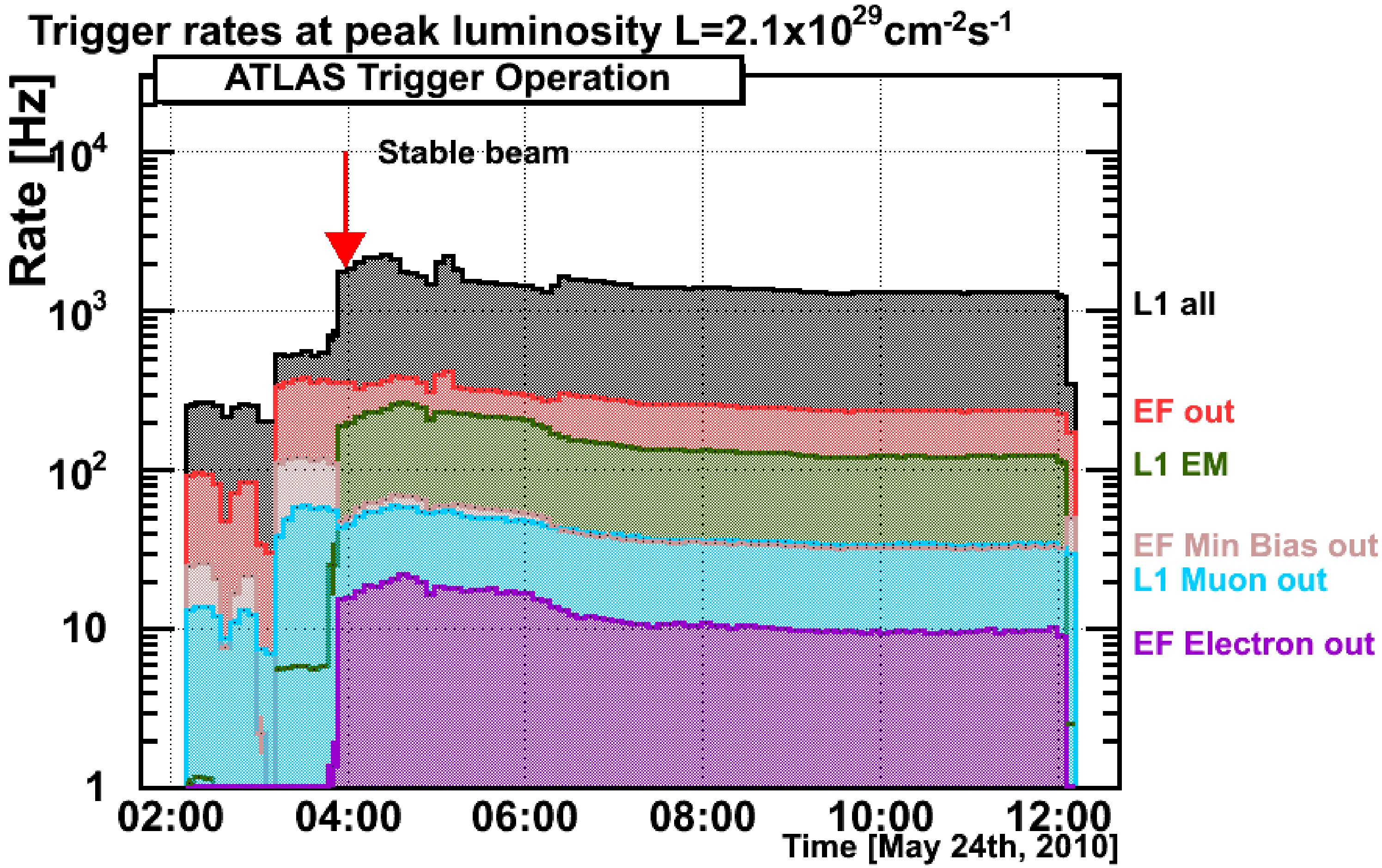


Zero tolerance to digital errors!



- Checked for each run
- Online (during data taking) for part of events
- Offline (when the data are reconstructed) for all events

Datataking performance II

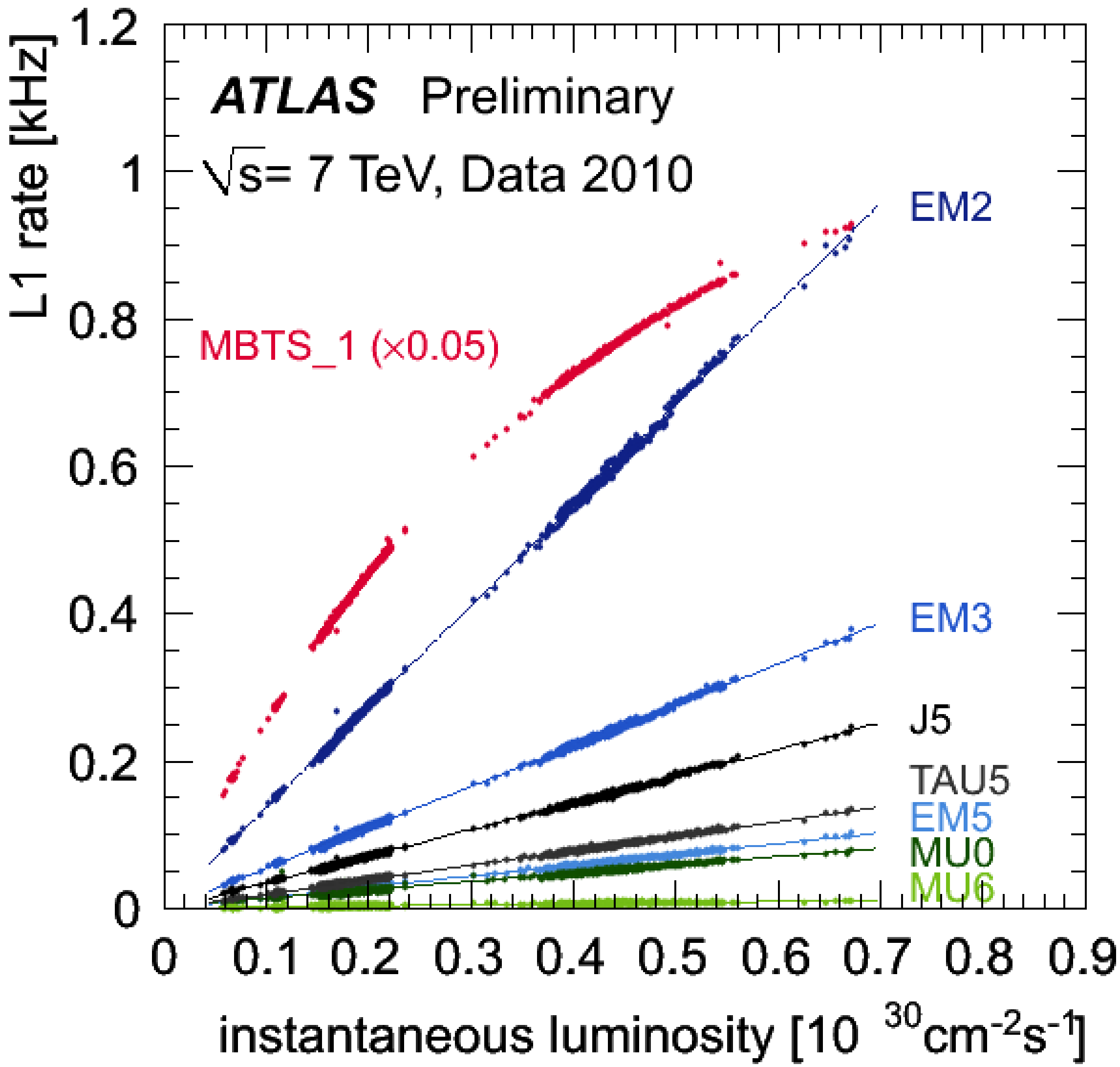


Typical LHC fill:

- Smooth data taking, rate excursions are very rare!
- Rates of L1 electromagnetic triggers follow nicely luminosity profile of the fill
- High level trigger improves event selection, reducing rate to acceptable level

Datataking performance III

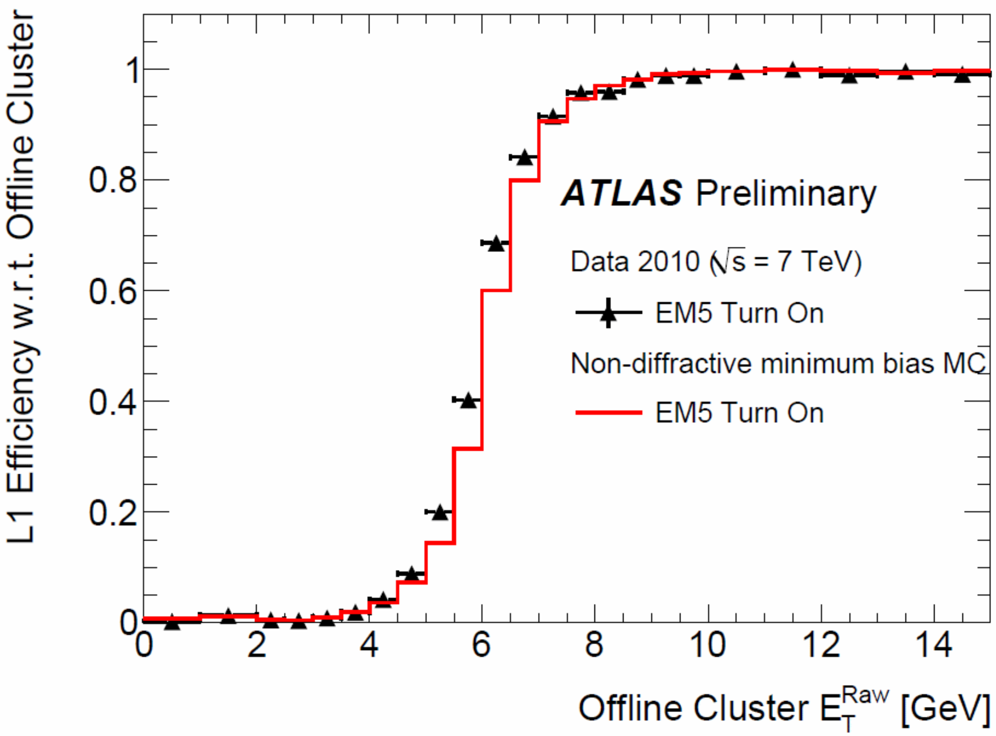
- Raw L1 rates as a function of instantaneous luminosity
- June 2010 (two colliding bunches)
- Nice linear dependence of L1Calo rates on luminosity
- Contribution of noise negligible, mainly QCD background
- Rate of Minimum Bias Trigger Scintillators (MBTS), used to trigger bulk of inelastic cross section saturates at high rates



Efficiency for triggering of physical objects

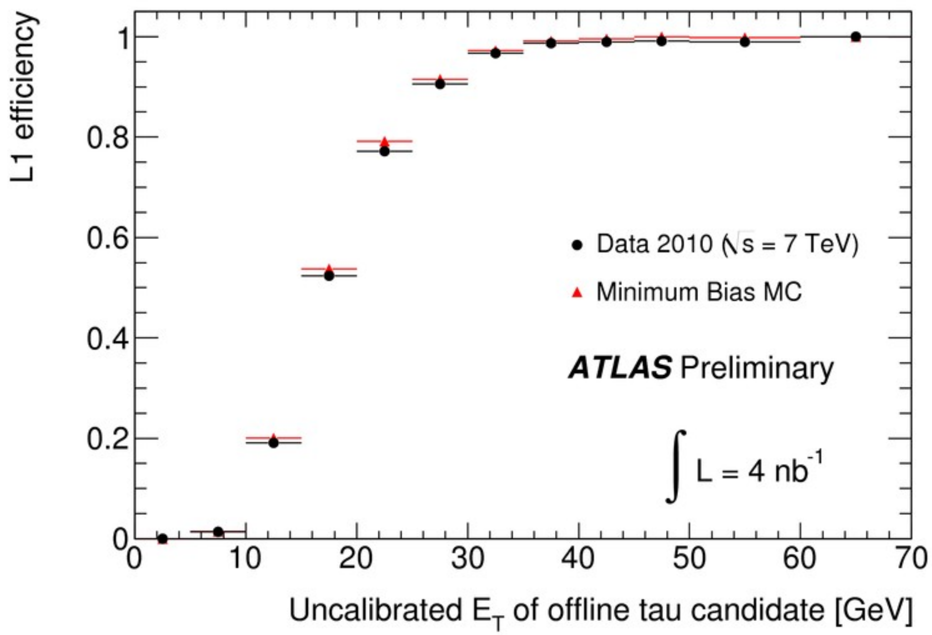
Efficiency for physics objects – EM clusters

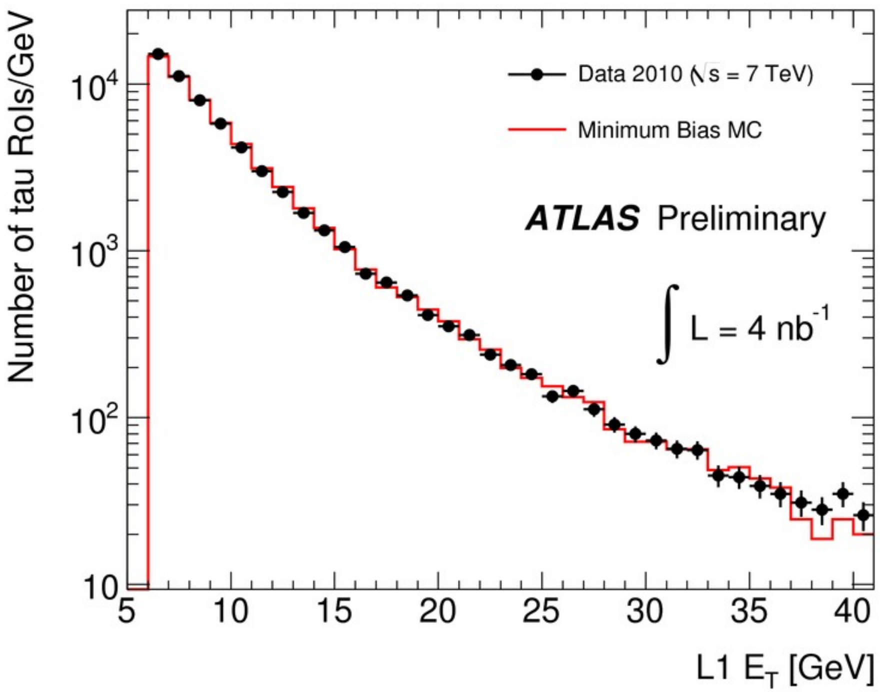
- Data taken using independent trigger (MBTS) - checking efficiency (#triggered/#all) of electromagnetic L1Calo trigger for reconstructed offline clusters
- L1 threshold EM5:
  - Energy of cluster as seen by L1 should be larger then 5 counts (output of LUT)
  - roughly equivalent to 5 GeV
  - that is where efficiency curve starts to rise (trigger uses E_T>threshold condition)
  - Full efficiency reached at 8 GeV



- Good agreement between data and MC !

Efficiency for physics objects – hadronic τ

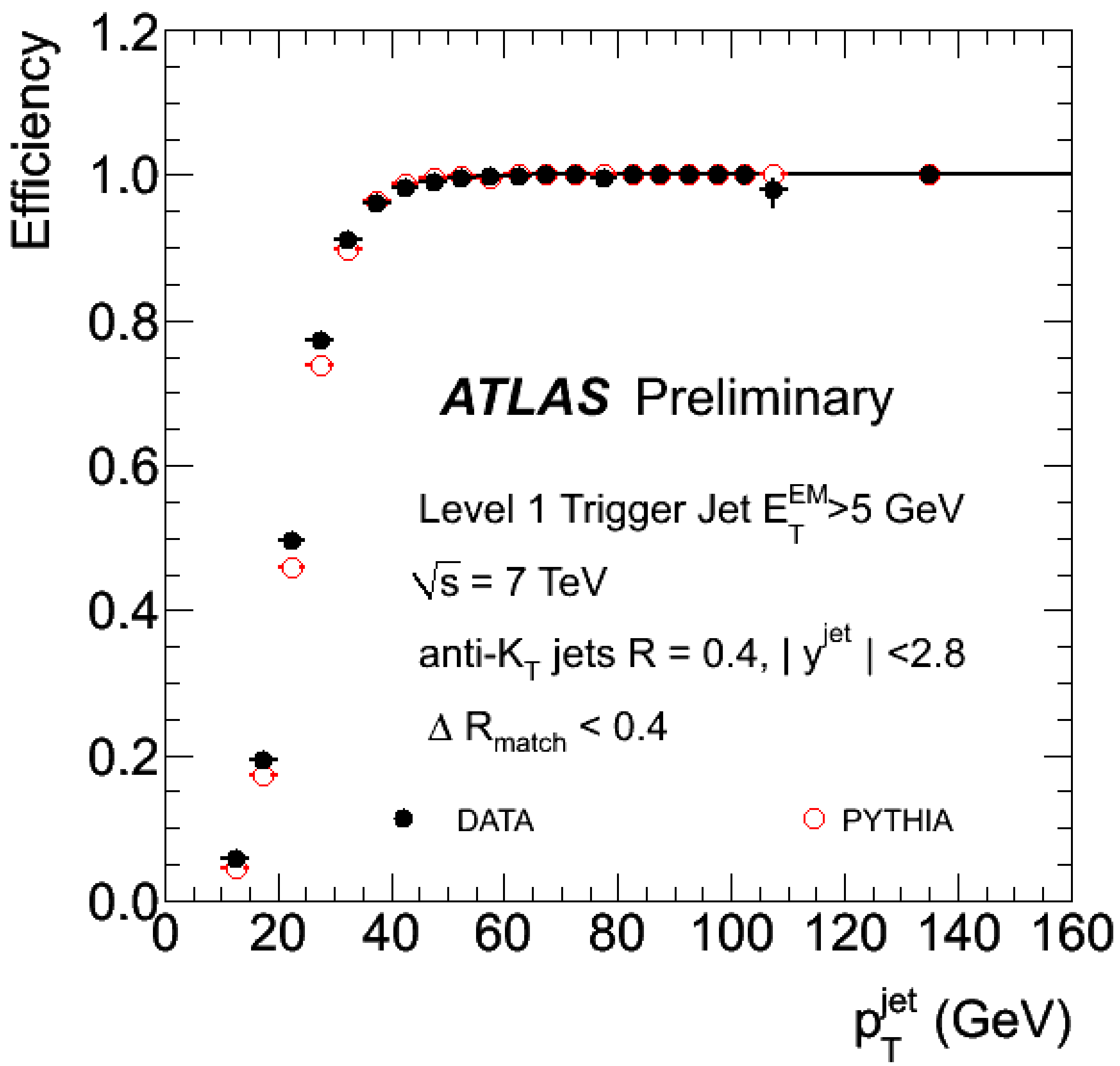




- Trigger efficiency for reconstructed offline τ
- L1 threshold set to 5 (LUT) counts (~ 5 GeV)
- Efficiency rises up to 100% at τ E_T of 30 GeV
  - L1 uses "raw" EM energy scale without dead material corrections
  - Part of τ energy may not be contained in L1 τ cluster
  - Noise cuts at L1 are harder than offline
- Both efficiency and E_T distribution of L1 τ candidates are well described by Monte Carlo !

Efficiency for physics objects - jets

- efficiency (#triggered/#all) for reconstructed offline jets
- L1 threshold set to 5 (LUT) counts (~ 5 GeV)
- Efficiency rises up to 100% at offline jet E_T of 40 GeV
  - L1 uses "raw" EM energy scale without dead material corrections
  - Often not whole offline jet energy gets collected into L1 object
  - Noise cuts at L1 are harder than offline
- Turn-on curve is well described by Monte Carlo !



Conclusions and plans

L1 Calorimeter trigger is an essential part of ATLAS trigger

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

To run it efficiently is a challenge ...
(but getting there!)

Looking forward to wealth of LHC data !!!