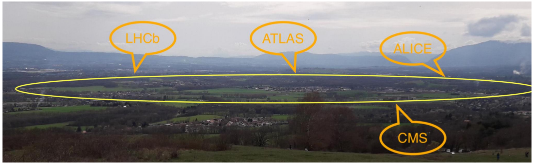


ATLAS Liquid Argon Calorimeters Performances in LHC Run-2

CALOR 2018, EUGENE, OR, USA

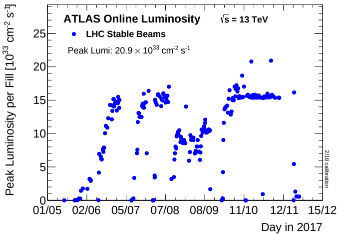
Clément Camincher
on behalf of the ATLAS
Liquid Argon Calorimeters group

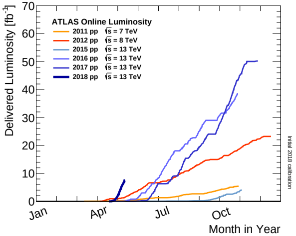
21/05/2018

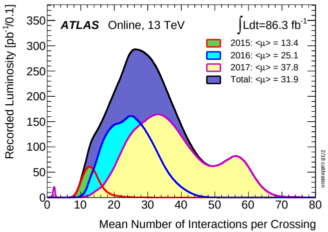
The LHC Run-2 data taking conditions

Records breaking: collisions of protons at $\sqrt{s} = 13\ \mathrm{TeV}$ + high instantaneous luminosity + high pile-up

- Max Inst. Luminosity up to $2.14 \times 10^{34}\ cm^{-2}s^{-1}$
- $\approx 100\ \mathrm{fb}^{-1}$ recorded so far by ATLAS
- High pile-up up to 80 interactions/bunch crossing (31.9 on average during Run-2)

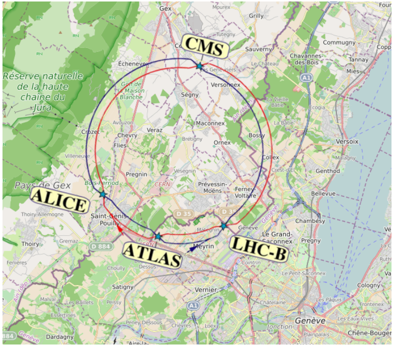


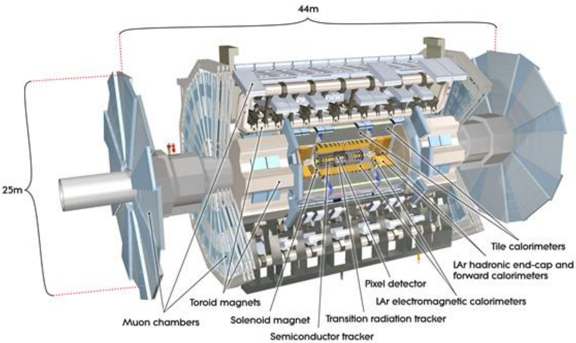




More challenging conditions in the years to come and at the HL-LHC

The ATLAS detector



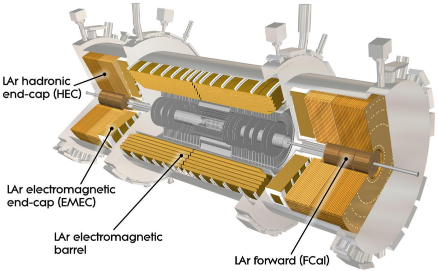


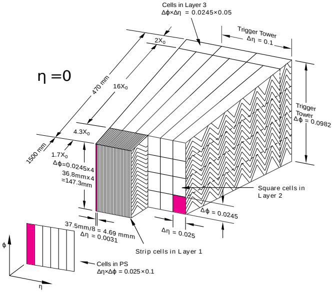
- ATLAS is a multi-purpose physics experiment at the LHC
- It is build of different detector layers:

  Tracker → electromagnetic calorimeters → Had. calorimeters → Muon spectrometer
- Designed to discover the Higgs boson and new physics
- Also dedicated to perform precise measurements of the Standard Model

The Electromagnetic Calorimeters (LAr Calorimeters part 1)

- The EM LAr Calorimeter is divided into a barrel and two end-caps sections
- Sampling calorimeter with lead as passive material and argon as active material





coverage

- **presampler**: $|\eta|<1.8$ (9K cells)
- **barrel**: $|\eta|<1.475$ (100k cells)
- **end-caps**: $1.375<|\eta|<3.2$ (62k cells)

- Accordion shape for the passive material

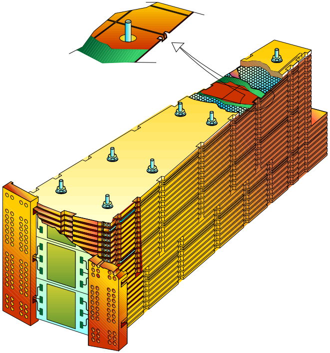
$\Rightarrow$ good homogeneity

- 1 presampler + 3 layers in depth (up to $|\eta| = 2.5$)

$\Rightarrow$ allows to determine shower shapes and photon pointing

The Hadronic and forward calorimeters (LAr Calorimeters part 2)

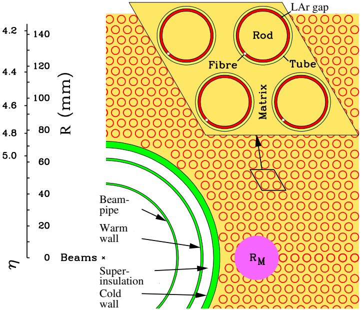
Hadronic end-caps



- **Coverage**: 1.5<$|\eta|$<3.2
- passive material: copper plates
- 5.6k cells

Forward calorimeter

- **Coverage**: 3.1<$|\eta|$<4.9
- Honeycomb holes in copper/tungsten matrix
- Small gap of argon to avoid space charge effects
- 3.5k cells

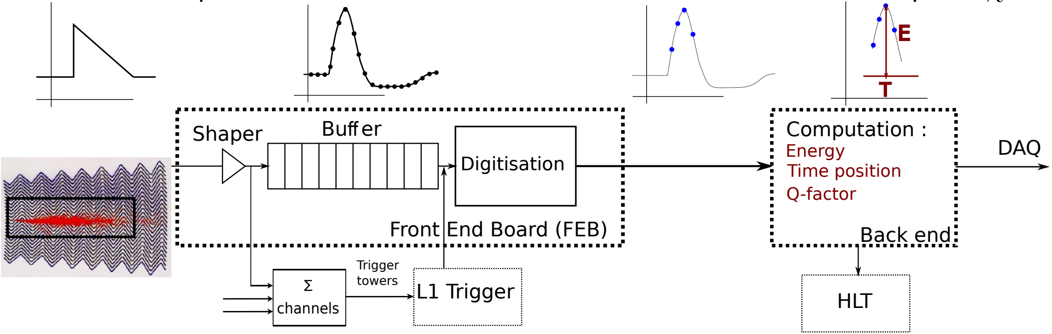


LAr Calorimeters simplified readout structure

Signal is amplified the shaped with 3 gains and sampled at 40MHz

4 samples are digitized

Optimal filtering method computes energy, time position and simplifed χ^2

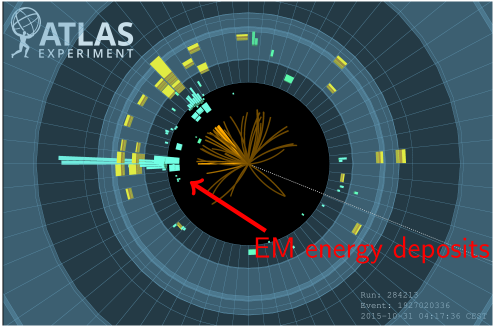


Channels are summed to create trigger towers

In barrel : 4(PS) + 32(L1) +16(L2) +8(L3)

LAr Calorimeters as a central system in ATLAS

- LAr Calorimeters enter in the reconstruction of electrons, photons, Jets and transverse missing energy
- Both discovery channels (di-photons and 4 leptons) of Higgs boson used EM particles
- Evidence of $H \rightarrow b\bar{b}$ in 2017 strongly relied on the b jets invariant mass



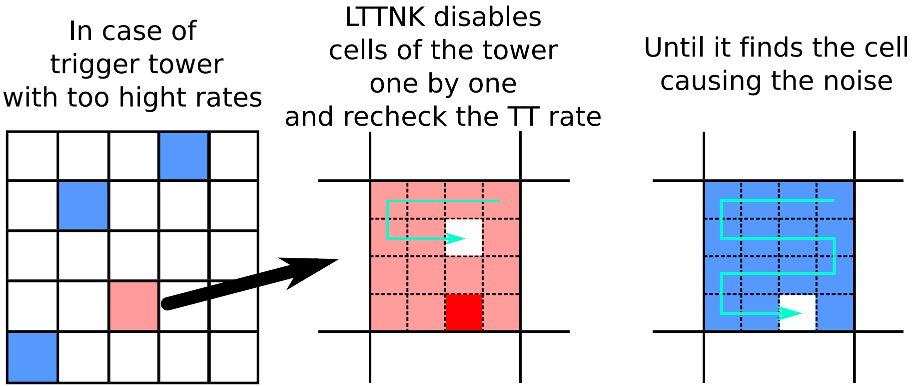
Required:

- Good reliability of the LAr Calorimeters
- High precision on energy measurement

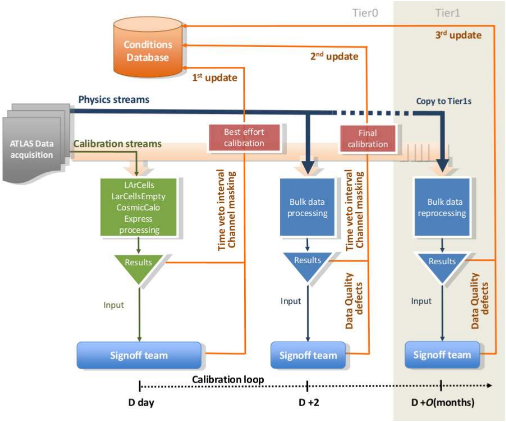
Automatic tools development

- Smooth running achieved due to daily efforts of keeping the software running stably
- Automation of recovery procedures:
  - LAr Trigger Tower Noise Killer (LTTNK)

⇒ Automatically finds noisy cells in a trigger tower and disables them.



Data quality procedure



- Assess data quality in a sample of reconstructed data (express processing)

⇒ Update condition database within 48h after data taking

- Full reconstruction start afterward.

In LAr Calorimeters: condition update used to

- Mask noisy cells

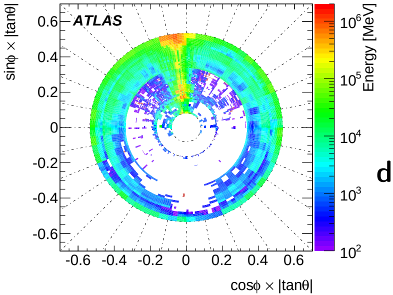
⇒ Energy computed by averaging the values from the neighbours cells

- Define veto periods due to noisy events or corrupted data

⇒ Vetoed events will not be used in analyses

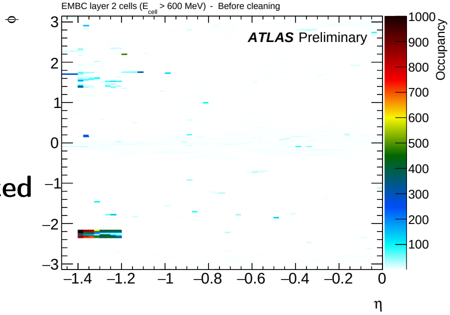
Two types of coherent noise

End-caps



No energy deposits expected

Barrel

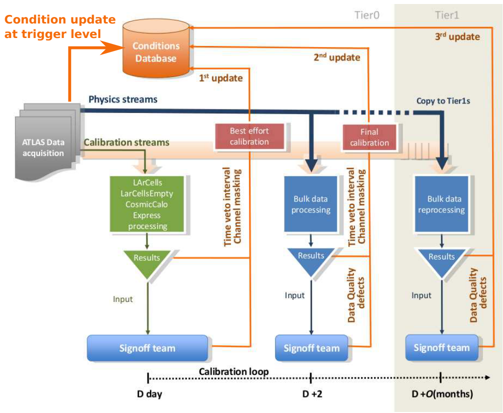


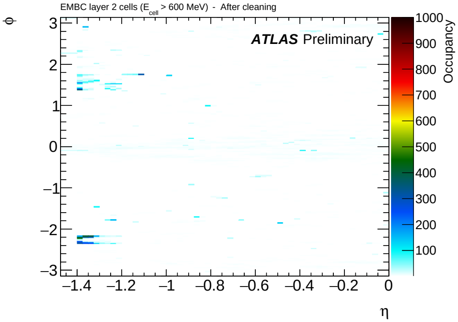
- Large scale noise with high value of energy measurement
- Burst of noisy events within few μs

- Localized noise $\mathcal{O}(10)$ channels
- Single or burst of noisy event appearing every minute

Coherent noise affects: the cell masking procedure the cluster energy and create fake missing energy

Treatment of noise bursts with event veto





Example of cleaning by event veto

- Events affected by coherent noise are time vetoed at the trigger level

⇒ Noisy event are already excluded from the express processing

⇒ Don't affect the cell masking anymore

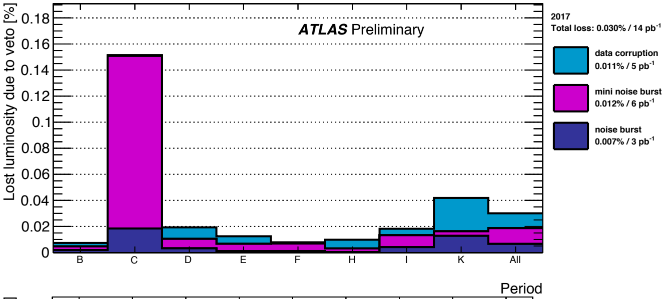
Data quality efficiency in 2017

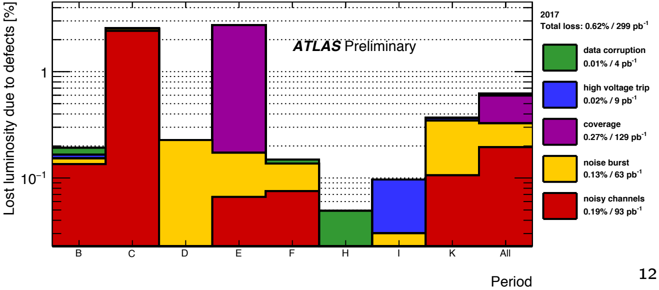
- Event vetoing allowed to reject only 0.03% of data
- For issues not treatable by event veto.

⇒ Minimum of 1 minute of data is rejected

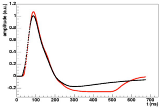
- Loss of data: 0.62% (300 pb^{-1})
- Over the years: efficiency above 99%

	2015	2016	2017
ATLAS	87.1%	93%	93.6%
LAr	99.4%	99.8%	99.5%





The computation of the energy uses several calibration constants and the predicted physics pulse shape



$$E_{\text{cell}} = F_{\mu\text{A}\to\text{MeV}} \cdot F_{DAC\to\mu\text{A}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \sum_{i=1}^{M_{\text{ramps}}} R_i \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]^i$$

Cell energy

Sampling fraction

Calibration board

ADC to DAC (Ramps)

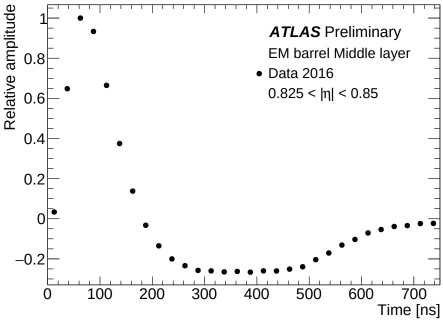
Pulse Samples

Optimal Filtering Coefficients

Pedestals

- Constants are routinely monitored
- We keep improving the measurement with specific studies

Pulse shape measurement



- Measuring precisely the physics pulse shape allow to :
  - Reduce our uncertainties on the shape correction
  - Compute drift time of electrons in the argon:
  - $\Rightarrow$ It allows to estimate the argon gap size
  - $\Rightarrow$ Will improve the homogeneity corrections
  - Improve the baseline corrections

- In 2016 4 sample recorded randomly around a single colliding bunch $\rightarrow$ probe the whole shape on average
- In 2017/18 events recorded with 32 digitized samples (instead of 4 in regular operation) separated by 25 ns
- Readout time was shifted in step of 3 ns to also measure the pulse between the usual sampling points

$\Rightarrow$ Now the pulse shape is measured in 256 time positions

Baseline corrections

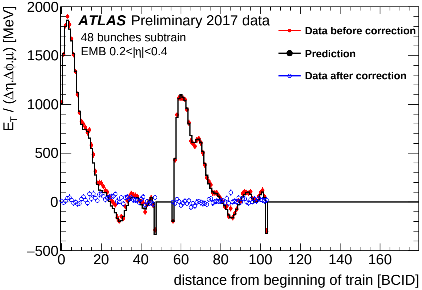
- With the bipolar shaping no average energy from pile-up is expected

⇒ Ideal situation only valid for infinite bunch trains

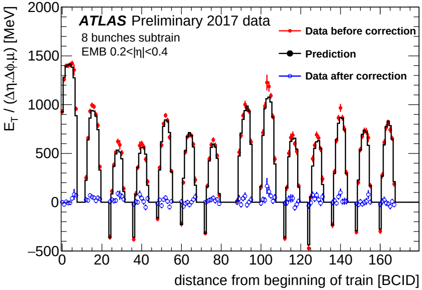
- Finite bunch trains length and bunch to bunch luminosity induce energy shifts

⇒ Corrected in the data processing

- Need also precise knowledge of the pulse shape to compute the corrections



Trains of 48 bunches



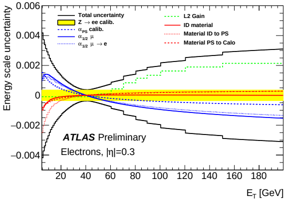
Trains of 8 bunches

Energy scale and resolution measurement

- Energy scale derived with in-situ corrections from the Z mass

$\Rightarrow$ corrections precise only for electrons with $p_T \approx 40\ GeV$: 0.1% uncertainty

- Need to propagate uncertainties to higher/lower energy using:
  - Layer inter-calibration
  - Difference between high and medium gain



Energy scale uncertainties

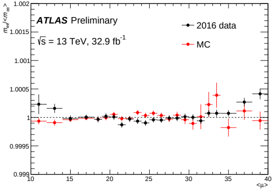
- Z invariant mass very stable with pile-up

$\Rightarrow$ Variation within 0.5 per mill

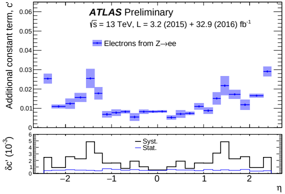
- Constant term of energy resolution computed

$\Rightarrow$ Smearing of the Z mass resonance

$\Rightarrow$ Values below 1% in most of the barrel (within the design value)



Stability vs pile-up



Constant term measurement

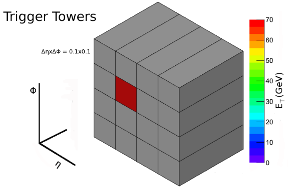
Toward the Run-3

- Between 2019 and 2020 the trigger system based on the LAr Calorimeters will be upgraded (Phase 1)
- One purpose is to keep low energy thresholds for L1 trigger with a 20kHz maximum rate under high pile-up conditions ($\mu = 80$)
- Solution: improve the EM particles - jet differentiation

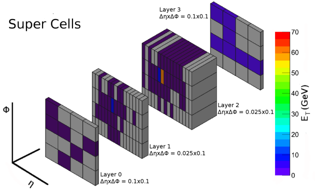
$\Rightarrow$ Increase the granularity on which the L1 trigger takes the decision (Trigger tower $\rightarrow$ Super Cells)

$\Rightarrow$ Super Cells signal is sampled and digitized at 40 MHz.

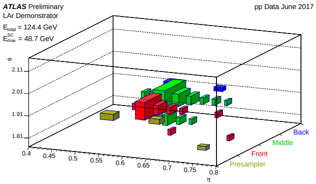
During the Run 2 a demonstrator using the upgraded system was and is still running on parallel with the current trigger



Trigger Tower



Super Cells

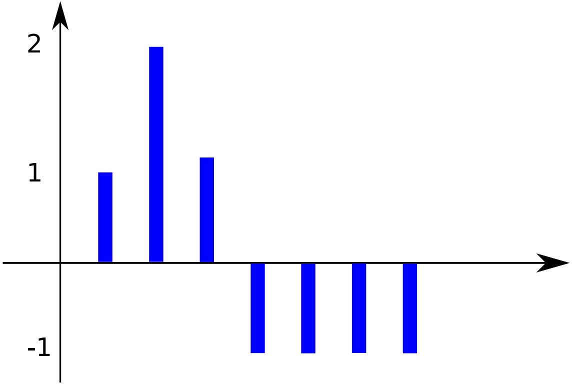


Event recorded with the demonstrator

Thank you

Questions ?

BACKUP



- For MET trigger the sum of energy should be 0 all the time in the detector
- Not the case in non infinite bunch train
- Pulse shape of energy deposit shaped to have 0 integral

BCID	sum of energy in all cells	total
1	1	1
2	1+2	3
3	1+2+1	4
4	1+2+1-1	3
5	1+2+1-1-1	2
6	1+2+1-1-1-1	1
7	1+2+1-1-1-1-1	0