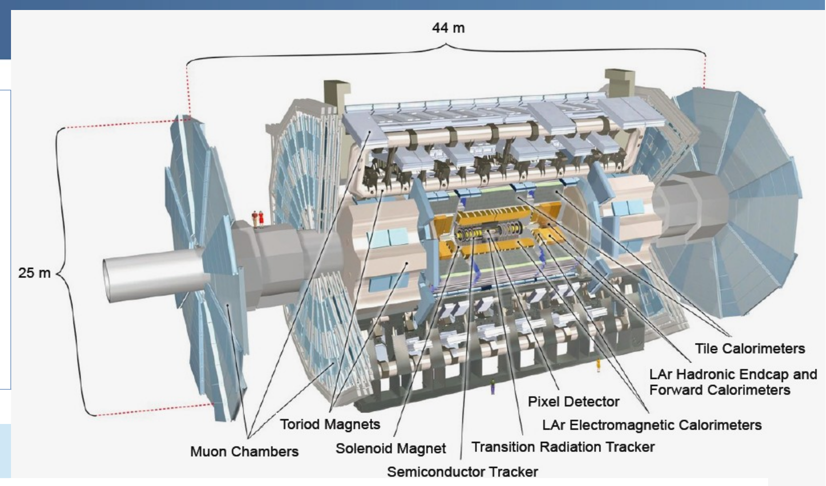
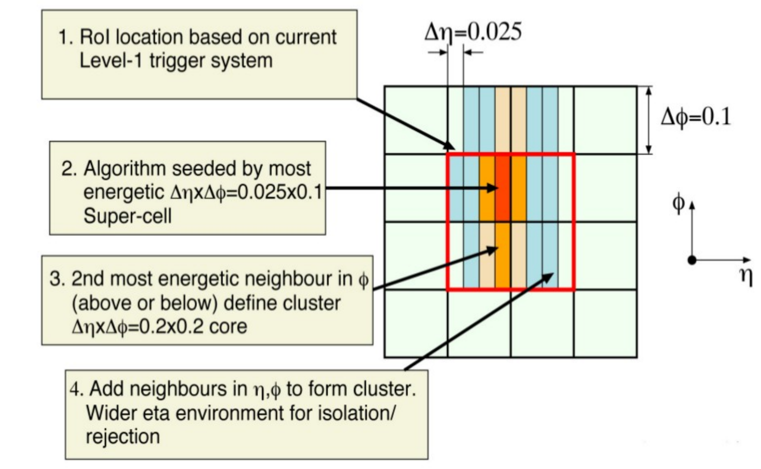
Demonstrator for the ATLAS LAr calorimeter Phase-I Trigger Readout Upgrade

From 2019 – 2021, during Run 3, the LHC will achieve luminosities of about $\mathcal{L} \sim 2.2\times10^{34}$ cm^{-2} s^{-1} and an integrated luminosity of ~ 300 fb^{-1} is expected. In order to exploit the higher luminosity while keeping the same first level trigger bandwidth of 100 KHz, higher transverse granularity and depth information for the ATLAS Liquid Argon (LAr) Calorimeter Trigger is required.

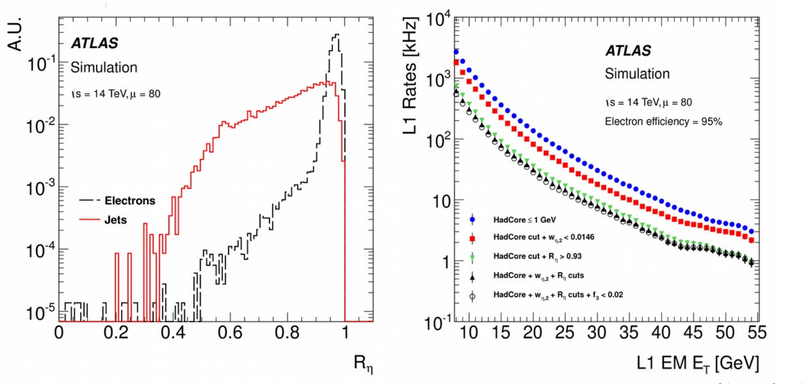


Why is the upgrade needed?

- The upgrade will provide higher-granularity, higher-resolution and longitudinal shower shape information from the calorimeter to the Level-1 trigger processors
- The upgrade will improve the trigger energy resolution and efficiency for selecting electrons, photons, τ leptons, jets and missing transverse momentum, while enhancing discrimination against pile-up



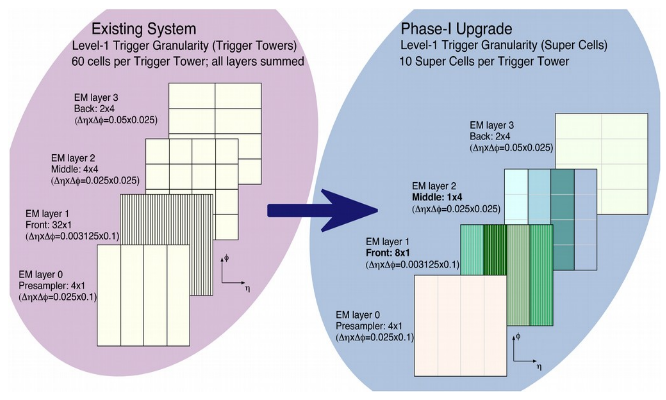
The variable R_η is computed by calculating the energy in a 3×2 cluster around the most energetic cell divided by the energy in a 7×2 cluster. f_3 is the ratio of the transverse energy in Δη × Δφ = 0.2 × 0.2 in the back EM layer to that deposited in the front, middle and back layer. The energies in the front and middle layer are reconstructed in the area Δη ×Δφ = 0.075 × 0.2. w_η is the spread of the shower in the middle EM layer in a 3×2 Super Cell region.



Distributions of R_η allowing to distinguish between electrons and jets with pT> 20 GeV and with the upgraded Level-1 trigger. Each distribution is normalized to unit area.

Trigger rates for $\mathcal{L} \sim 3\times10^{34}$ cm^{-2} s^{-1} as a function of E_T thresholds with optimized requirements on hadronic core energy, R_η, w_η and f_3.

- Existing calorimeter trigger information is based on the sum of the energy deposition across the longitudinal layers of the calorimeter in units as big as Δη × ΔΦ = 0.1 × 0.1 ("Trigger Towers")
- New finer granularity scheme is based on "Super Cells", which provide information for each layer of the calorimeter and finer segmentation (Δη × ΔΦ = 0.025 × 0.1) in the front and middle layer of the EM barrel and endcap

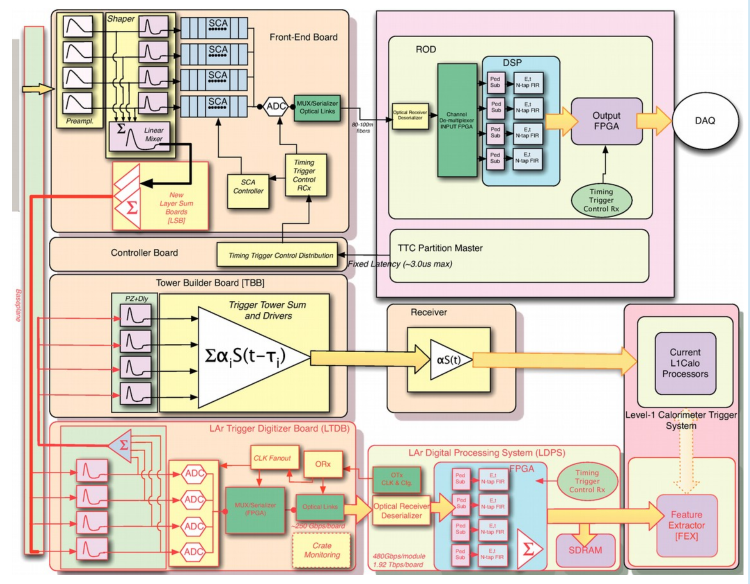


Here the geometry of a Trigger Tower is shown. Each square represents an area of size Δη × ΔΦ = 0.1 × 0.1. In the old sytem (left) the transverse energies of all layers are summed, in the new system (right) they are retained in addition to the finer granularity in front and middle layer.

Architecture of the upgrade electronics

New LAr Trigger Digitizer Boards (LTDB) will:

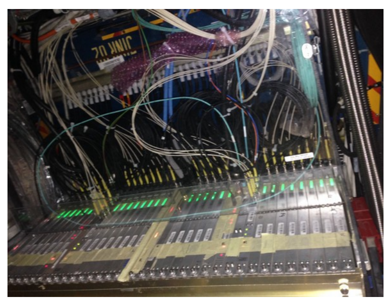
- Digitize the higher-granularity information
- Recreate the analog sums for the Trigger Towers and feed them back to the Tower Builder Board (TBB) to maintain the legacy L1 trigger system operational
- Digitized signals will be converted to calibrated energies and passed on to the trigger processors



Phase 1 upgrade LAr trigger readout architecture:
The new components are indicated by the red outlines and arrows.

Installation of the in-situ demonstrator

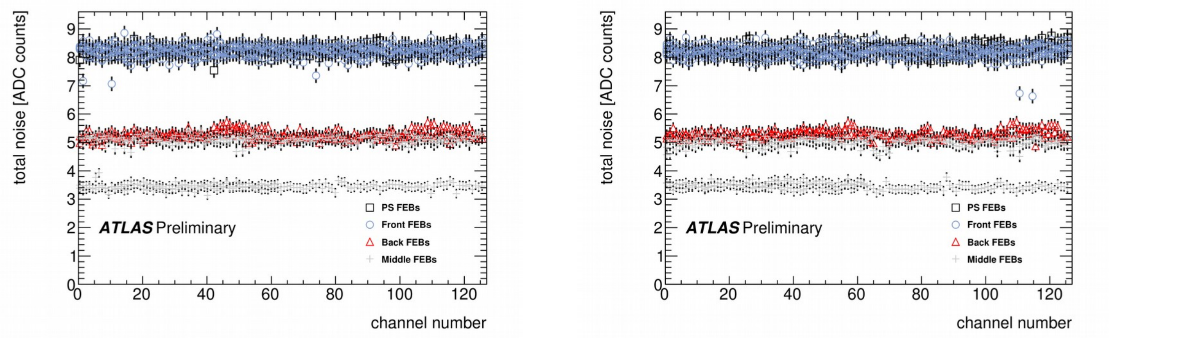
- Demonstrator was installed in ATLAS in the I06 crate of the EM barrel in summer 2014



In the picture the demonstrator crate with all FEBs, two TBBs, two Calibration and Control boards and the two new LTDBs can be seen. The green lights of all FEBs are on, which means that they are properly configured. The two blue cables are the fibres going from one LTDB to the ATLAS electronic cavern.

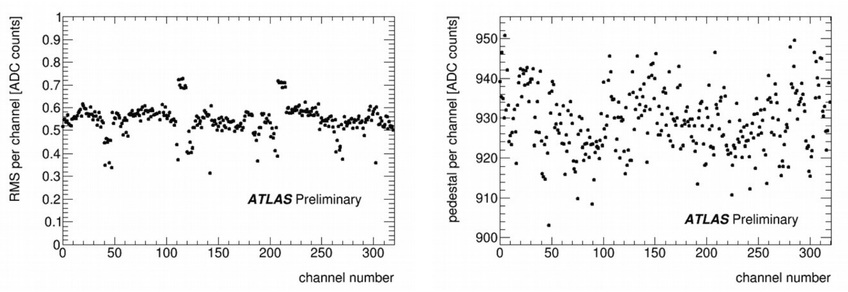
- In order to verify the proper installation of the demonstrator, calibration data was taken both via the standard readout and with the LTDB.
- As in EMF, the noise, coherent noise, connectivity and additionally, the amplitude shapes were checked. All values were compared to neighbouring crates to exclude that the demonstrator crate behaves differently.

- Total noise on Front End Boards



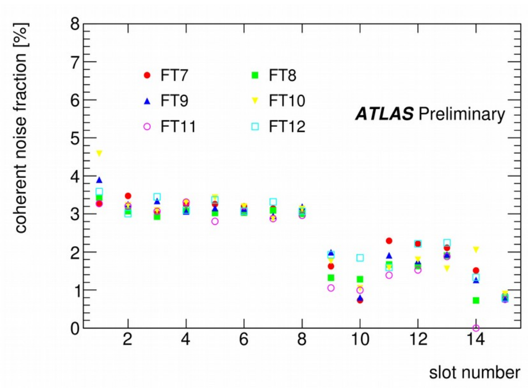
On the left side the RMS for all channels of the FEBs of the demonstrator crate can be seen, on the right side the same for the neighbouring crate I05 is shown. The noise levels are expected to be the same since the FEBs in both crates read out regions of the calorimeter which are close to each other. When comparing the plots it can be seen that the noise levels are the same and there was no additional noise introduced by the demonstrator crate.

- LTDB noise and pedestal



Here, the pedestal values and noise levels of the 12-bit ADC of the 320 channels of the LTDB demonstrator are shown.
One ADC count corresponds to roughly 125 MeV.

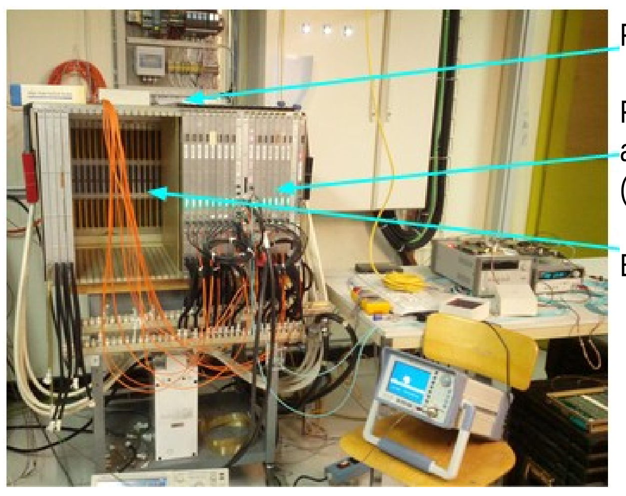
- Coherent noise fraction (CNF)



Here, the noise which is coherent is shown as fraction of the total noise per readout channel. The CNF for feedthroughs (FT) 7-12 on the detector has been computed, of which FT 9 and 10 belong to the demonstrator crate I06, FT 7 and 8 to I05 and FT 11 and 12 to I07.
The last entry is the CNF of the whole half-crate.

Tests at the LAr Electronic Maintenance Facility (EMF)

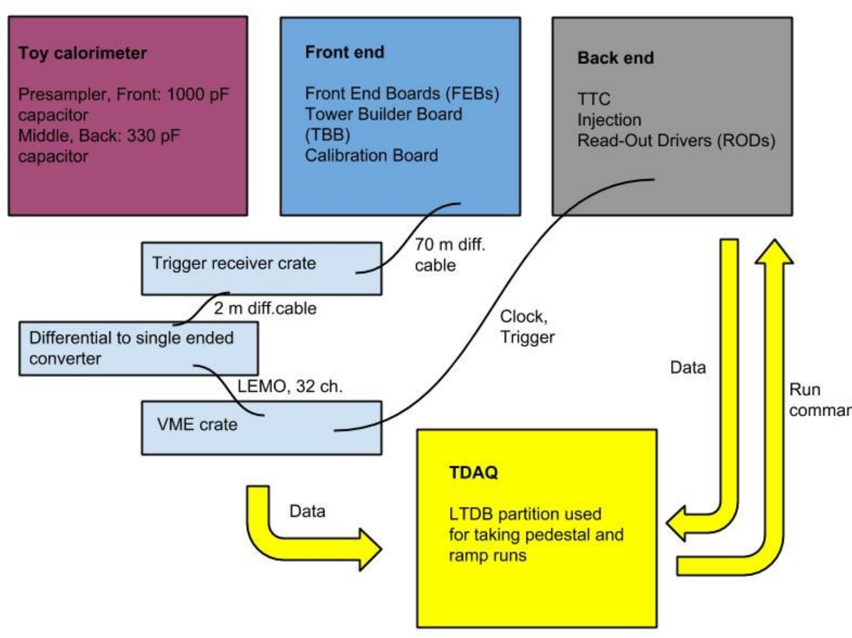
- Test setup: half Front End Crate (FEC) equipped with boards and a readout system equivalent to the one operating in ATLAS (see picture on the right)
- Calorimeter cells simulated by a load which was plugged at the back of the baseplane; calibration system used for injecting signals into the Front End Boards (FEB)
- Validated new baseplane and the demonstrator LTDB



Setup at the EMF

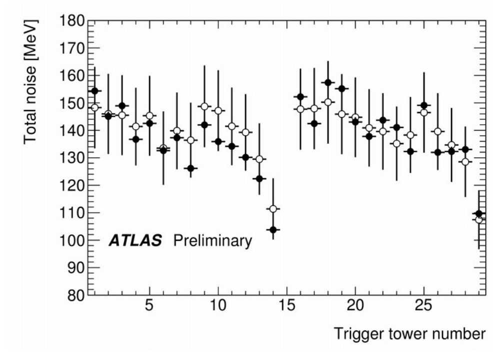
Validating the demonstrator system and testing the upgraded system

- Setup close to original setup in ATLAS established as benchmark (see figure right)
- Levels of the following properties were measured and compared to ATLAS:
  - total and coherent noise of the trigger path and main readout
  - cross-talk between the Trigger Towers
  - autocorrelation between time samples in one trigger readout channel
  - connectivity for all channels
- Baseplane and the Layer Sum Boards (LSB) on the FEBs were exchanged and demonstrator LTDB introduced into the system
- Noise, cross-talk and connectivity measurements were again performed



A set of FEBs, a Calibration and a Controller board and a Tower Builder Board were installed into the FEC. The output of the TBB was transmitted via a 70 m long cable to the receiver boards and digitized by a set of Flash ADCs at 40 MHz. The standard readout containing the full TDAQ chain as in ATLAS was also used.

Total noise on FADCs



Here, the RMS measured on the trigger readout path is shown.
The values represented by the full circles were measured with a spectrum analyzer, the values shown in open circles were measured with Flash ADCs.

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