The Phase-II upgrade Demonstrator system for the ATLAS Hadronic Tile Calorimeter facing the High-Luminosity LHC era

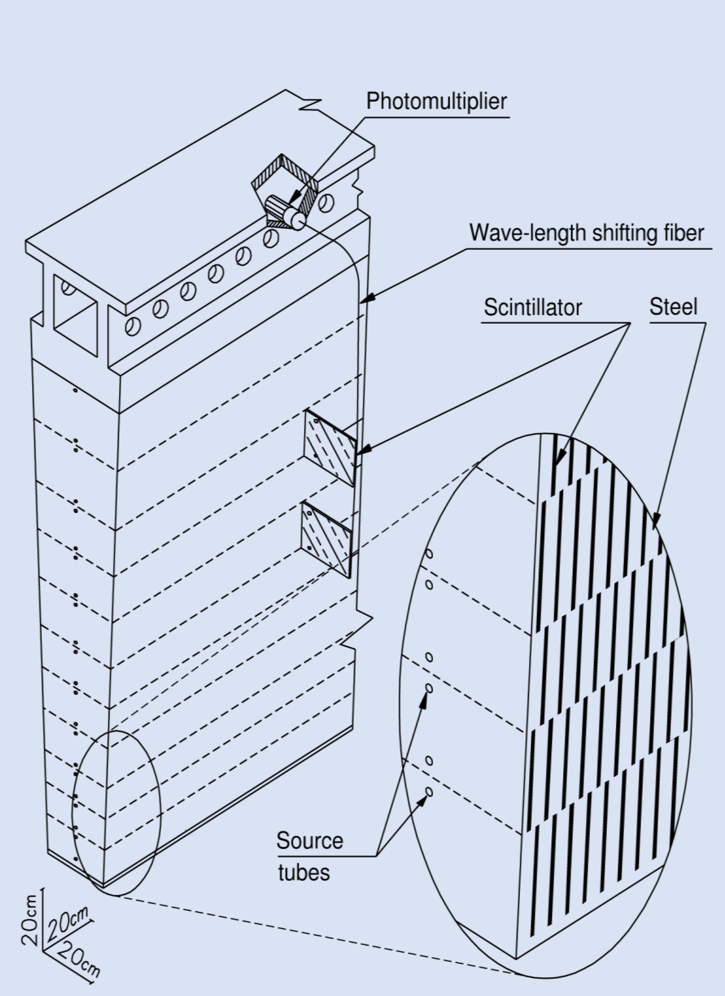

Figure 1 – Tile calorimeter structure

I. Introduction

The **Tile Calorimeter** (TileCal) is the central hadronic calorimeter within the ATLAS detector capturing the **jet-energy** in **proton-proton** (pp) **collisions** at the LHC. It is composed of **steel absorbers** and **scintillating tiles**, which re-emit part of the absorbed energy in the form of light (Fig. 1). The light from each tile cell is collected by **the wavelength shifting fibers** and guided to the core element of the detection, the **photomultiplier**, for converting the incoming photons into an electrical signal. The front-end electronics sums the PMT signals to form a fast analog trigger, digitizes the PMT signals and also integrates the continuous PMT current to measure low-light processes such as gamma rays and minimum bias events. Currently, TileCal records hadrons energies in proton-proton collisions with a luminosity of $10^{34}cm^{-2}s^{-1}$[1] with a large dynamic range, being able to identify single muons that deposit about 400 MeV in central cells and also to provide a precise measurements of jet energies up to several TeVs. The High-Luminosity LHC (HL-LHC) is a major upgrade of the Large Hadron Collider aiming to increase the instantaneous luminosity up to $7.5x10^{34}cm^{-2}s^{-1}$ and to measure jet energy at a center of mass of 14TeV. This leads to the Phase II Upgrade program for improving the TileCal performances according to the HL-LHC requirements. In order to cope with the increased luminosity, a completely new on-detector and off-detector electronics are being developed, aiming for increased trigger rates and high-performance data acquisition. A hybrid demonstrator prototype containing a new read-out system was inserted in the ATLAS detector for testing the Phase-II upgrade system during the long shutdown - LS2, as well as for using real conditions of pp collision during the Run-3.

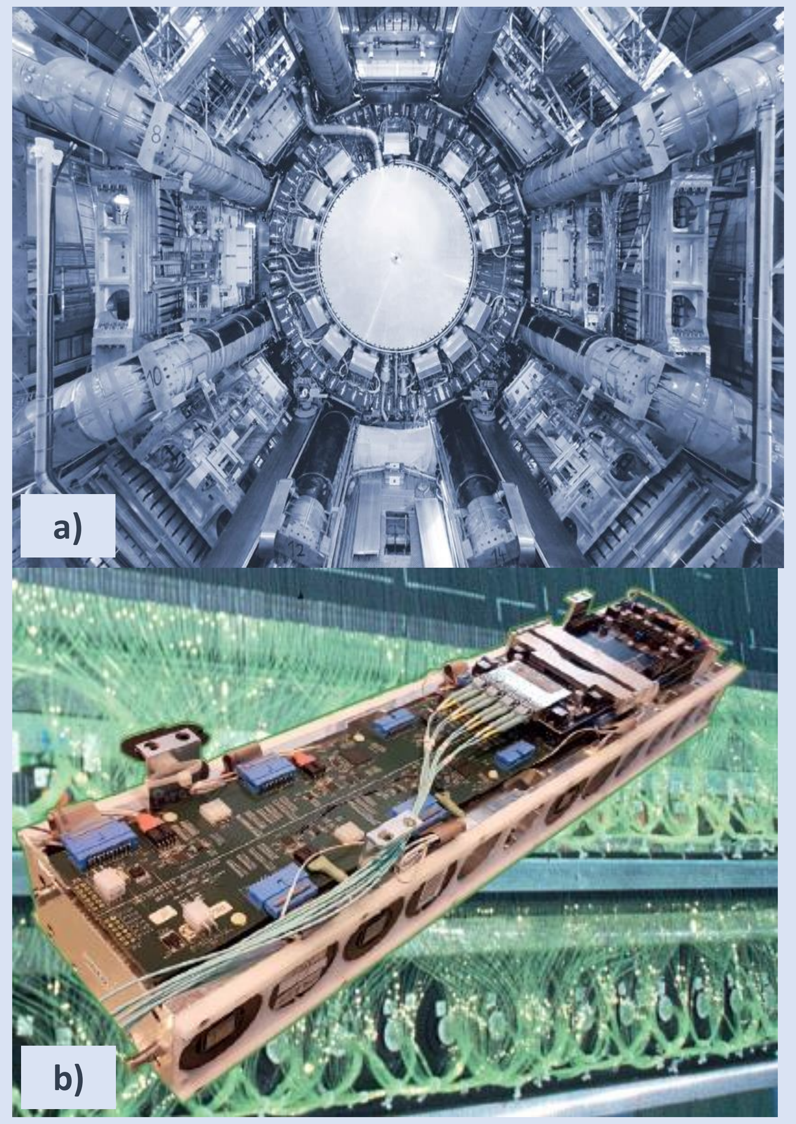

Figure 2 – a) ATLAS detector, b) the mini-drawer concept for the front-end electronics

II. Tile Calorimeter Phase-II Upgrade for the HL-LHC

The objective of the High-Luminosity Large Hadron Collider (HL-LHC) project is to increase the luminosity by a factor of 10 beyond the LHC's design value. This leads to an instantaneous luminosity of $7.5x10^{34}cm^{-2}s^{-1}$, corresponding to an average of 200 simultaneous pp interactions per bunch crossing. For handling the increased flux of particles passing through tiles, **new read-out strategies** and more **radiation hard on-detector electronics** are needed. Thus, calorimeter samples corresponding to each cell are simultaneously sent to the off detector electronics at 40 GHz, using the new read-out architecture through the optical links (Fig. 3). Off-detector, the preprocessor system stores data in the pipeline buffers waiting for a trigger decision and, in parallel, provides the reconstructed data to the trigger system. The reconstructed information includes calibrated energy per cell or group of cells. After the trigger decision, the selected data events are transferred to the central ATLAS DAQ, data acquisition system. In order to achieve this performance, 1024 downlinks at 4.8 Gbps and 2048 uplinks at 9.6 Gbps will re-place the legacy 256 down-links and 256 up-links at 80 MHz and 800 MHz respectively. Moreover, the read-out architecture involves both **replacing the most degraded PMTs** and **increasing the radiation hardness** for handling a maximum total integrated radiation dose-TID of 244 Gy, estimated over 10 years of operation. Considering front-end electronics power supplies, the Phase-II upgrade involves both a remote high-voltage regulation system and more radiation tolerant low-voltage power supplies with increased redundancy. In terms of mechanical structure, the Phase-2 design includes the **mini-drawer concept** (Fig.2) assuring easy accessibility for the electronic maintenance during technical stops.

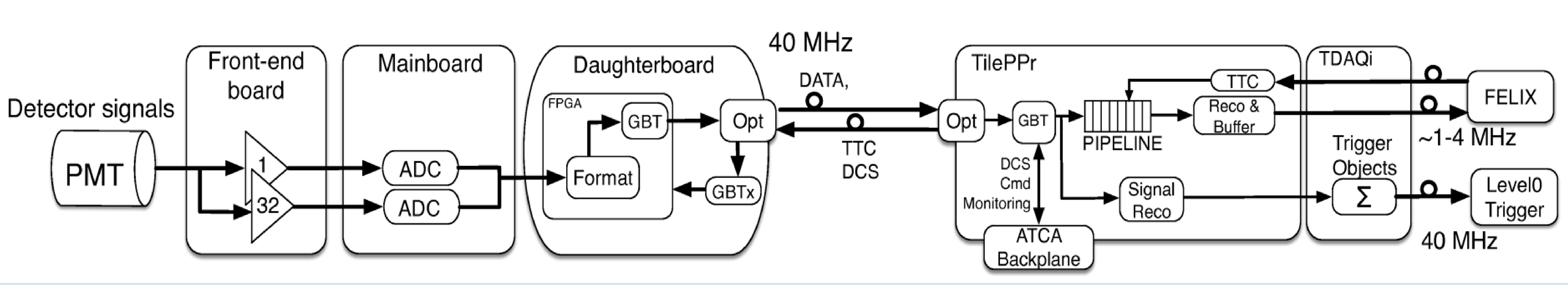

Figure 3 - The new readout architecture: a) on-detector electronics b) off-detector electronics

III. The Demonstrator System

The Demonstrator represents a fully functional Phase-II read-out prototype compatible with the current system (i.e. legacy system), providing hadronic energy measurements for every calorimeter cell and also the analog trigger sums that are sent to the current Level-1 trigger. This allows the Demonstrator to be integrated in the current system for the detector Run-3, offering the possibility to compare the performances of the full digital readout system with the one of the legacy system. The demonstrator is composed of four mini-drawers (Fig. 2.b), each of them including up to 12 PMTs, together with their corresponding front-end electronics (Fig. 3.a). It was successfully tested during multiple test-beam campaigns [2]. Thus, Fig. 4.a shows the muon signal reconstructed when 150GeV muons are hitting Demonstrator at -90 °, whereas Fig. 4.b shoes the distribution of the measured energy for 30 GeV kaons (the low energy peak is due to muons). The Demonstrator was inserted inside the ATLAS detector in June 2019. Laser calibration pulse in empty bunches and cosmic events were successfully recorded.

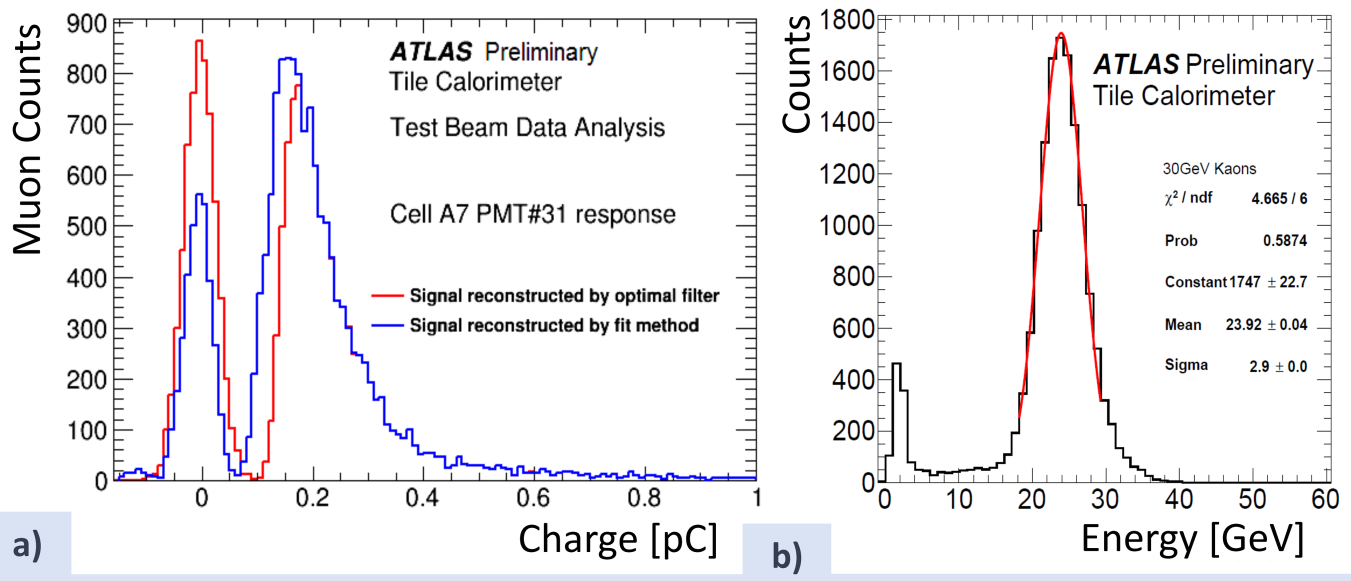

Figure 4 – Demonstrator performance exemplification during test-beam campaigns; a) reconstructed muon signals, b) measured energy for 30 GeV kaons.

❖ Calibration and data quality runs

For accurate cell energy reconstruction, the Demonstrator was used together with the entire TileCal for taking calibration and data quality runs. The main objectives for Demonstrator data analysis are: (i) pedestal stability over long periods, (ii) stability of the noise, (iii) stability of the timing in Laser runs and (iv) PMT Response variation. Further on we will focus on the pedestal stability analysis. The pedestal value is estimated in special calibration runs and it is subtracted from the received digital samples. Digitized ADC samples for each channel *i* can be expressed as $y_i=ped_i+Ag(t_i+T)+n_i$, where ped is the signal pedestal, A is the true amplitude, g(t) is the normalized reference pulse shape at time t, *T* corresponds to the phase between the expected and measured times, and n_i is the background noise [3]. Correlations for pedestal measurements in-between all 12 channels within mini-drawers MD1, MD2, MD3 and MD4 were performed. Reduced correlation coefficients show that no linear association exists between pedestal measurements for mini-drawer channels sharing the same electronics. Also, the pedestal averages and noise for the Demonstrator channels together with the ones for the legacy super-drawer LBA15 channels are illustrated in Fig. 7.a and 7.b.

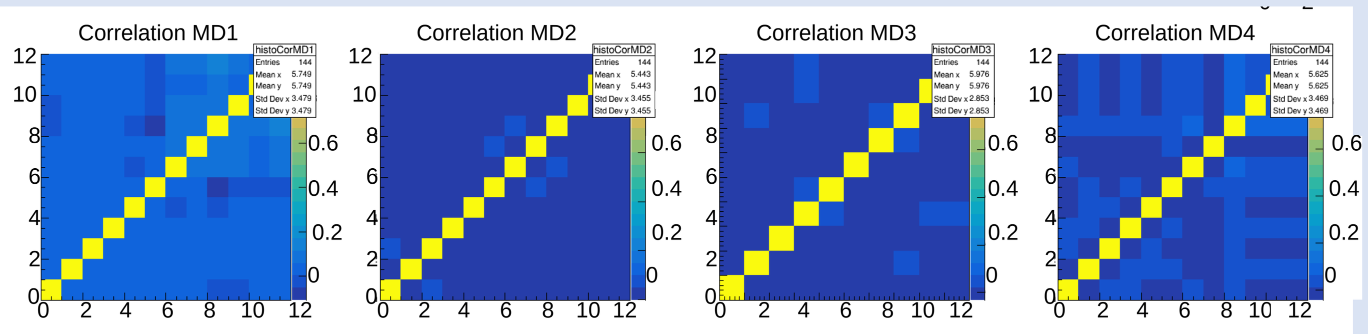

Figure 5 – Correlation analysis for the Demonstrator pedestal distributions

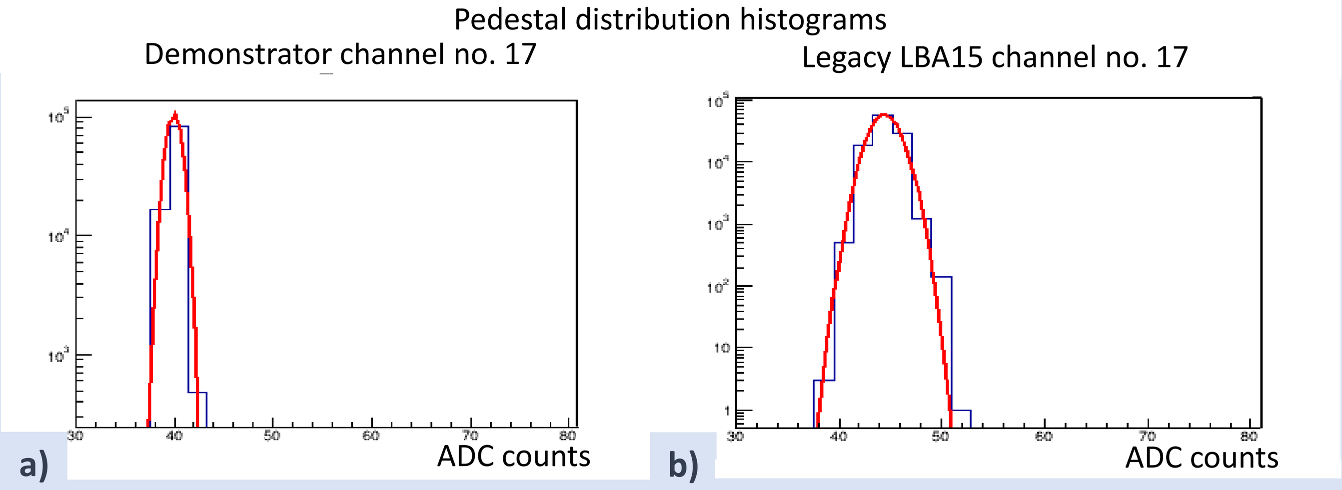

Figure 6 – Channel 17 pedestal distributions for a) the Demonstrator and b) the Legacy system LBA15; the Gaussian function fit performed on the pedestal measurements is shown using the red line.

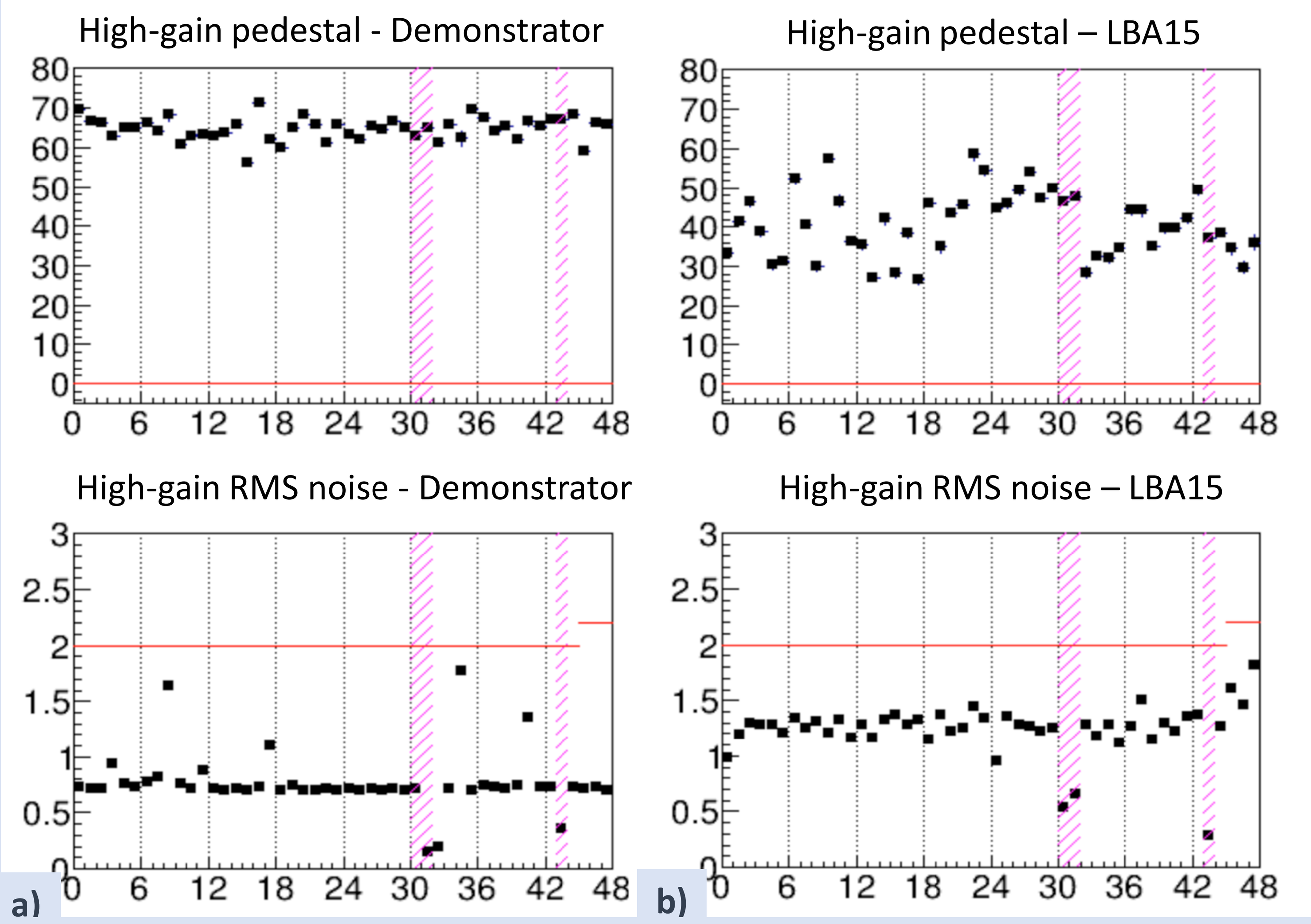

Figure 7 – Average pedestal and pedestal noise for the a) Demonstrator and b) LBA15

IV. Summary

- ❖The Phase II Upgrade assures the detector functionality considering the increase of instantaneous luminosity of the HL-LHC.
- ❖TileCal on- and off-detector electronics will be replaced by 2027 during Phase II upgrade; initial tests show good performance.
- ❖One Demonstrator super drawer with new electronics was inserted in the ATLAS detector and its performance is being evaluated; the pedestal analysis showed better performances compared with the legacy system.

Bibliography: [1] ATLAS collaboration. Technical Design Report for the Phase-II Upgrade of the ATLAS Tile Calorimeter. CERN-LHCC-234 2017-019, TDR028, 2018.

[2] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileTestBeamResults

[3] The TileCal Energy Reconstruction for LHC Run2 and Future Perspectives J. M. de Seixas, on behalf of the ATLAS Collaboration, arXiv:1510.01690 [physics.ins-det]

Bogdan Belean, on behalf of Tile Calorimeter System.

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