CERN and McGill University

Summer Student Project Report 2024

Development of ATLAS Liquid Argon Calorimeter Readout Tools for Phase-II Upgrade

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1 Introduction

The ATLAS detector is composed of many sub-detectors to help us study the collisions in the LHC. Notably, the electromagnetic and hadronic calorimeters are responsible for the detection and the energy measurement of electrons, photons and hadrons. The electromagnetic calorimeter is a liquid argon (LAr) calorimeter.

In a few years, the LHC is going into the third long shutdown. During this shutdown, it is going to be upgraded to the High Luminosity Large Hadron Collider (HL-LHC). This higher luminosity will allow more collisions in every bunch crossings. A bunch crossing is two packets of protons in the beam colliding together. In the LHC, they happen every 25ns.

As all the other detectors, ATLAS has to upgrade its components to survive the higher luminosity, and higher radiation. That means upgrading the electronics in the LAr calorimeter. The Liquid Argon calorimeter group is working on upgrading its readout system, and we need to test every part of this system to make sure it works properly and respects the specifications from the ATLAS Liquid Argon Calorimeter Phase-II Upgrade Technical Design Report [1]. A test-stand has been built at CERN to test the prototype electronics that will be eventually mounted on the upgraded detector.

The goal of this project is to develop some tools to help analyze the test-stand data coming from the front-end boards (FEB), on-detector electronics. This data goes through the off-detector electronics, and we get some output we can process. Off-detector electronics refers to the electronic boards that are not placed directly on the detector, but that receive data from it through the on-detector electronics. The difference between on-detector and off-detector electronics is important, especially in the context of the Phase-II upgrade because of the higher radiation previously mentioned. Radiation is harmful to electronics, so off-detector electronics are generally preferred.

In figure 1, the grey box on the left represents the output coming from the off-detector electronics (FELIX). Then, the big blue box in the middle is a decoder to transform the raw data into something more human-readable. It is divided in three parts which will be discussed later. On the far right, a small grey box represents the analysis done on the data, which will also be discussed later in this report.

2 First Tool : Decoder

The analog data coming from the calorimeter cells is transformed to digital data in the front-end boards (FEB) which are on-detector electronics. The analog-to-digital data (ADC) is then sent to off-detector electronics at 40MHz on two gains (high and low). The LASP (Liguid Argon Signal Processor) receives the data, but readouts only a subsample upon a trigger signal at a certain frequency, which can be changed. The output is a data file composed of blocks of hexadecimal words of 32-bits each. To make this file human readable and analyzable, we need to decode the output file. This decoding happens in two steps.

The first step is to construct the mapping between the output channels from the LASP and the input channels from the FEB. These input channels are direcly linked to the calorimeter cells. Then, the output channels from the FEBs are the input of the LASP, to finally have the output channels of the LASP. This process is not necessarily linear, so we need to know the mapping. In figure 1, this step is called "Pattern Decode". It constructs a file that we can then use in step two to write two other types of files : a HDF5 file and a ROOT file.

This project consisted in writing the script that allows us to build the HDF5 file. HDF5 stands for Hierarchical Data Format 5 and is a powerful tool to manage the formatting of data in a flexible way. The input for this mode of the decoder is a datafile coming from the front-end board when it is put into a calibration mode. Once the data is formatted the way we want it, it will be used for the FEB control (one

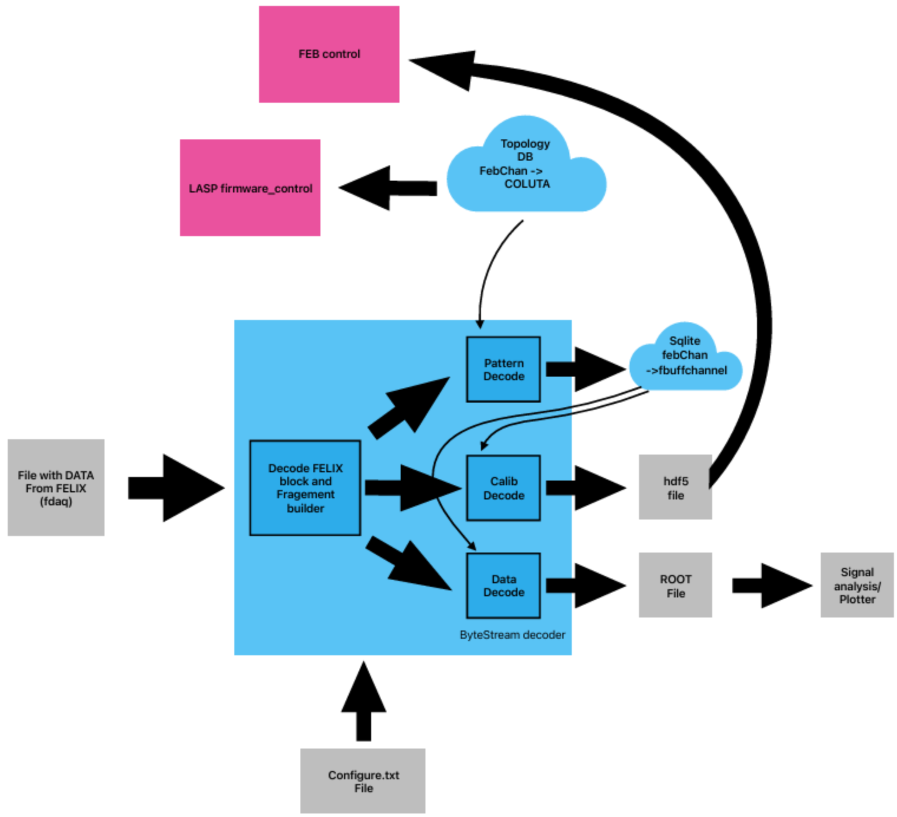


FIGURE 1 – Schematic of the decoder.

of the pink boxes in figure 1). In figure 2, we can see the different groups used to organize the data. With the name of the input file, we can get the measurement number, a number between 0 and 31 as there are 32 calibration measurements needed. Then, every front-end board has 128 channels so there should be 128 groups for channels. Here, we only write active channels into the file so we don't always see all of them as the boards are not currently fully functional. Each channel has the possibility of having high gain ADC values (hi) or low gain ADC values (lo). In these groups, we have all the data corresponding to the FEB channel.

Writing the second type of file, the ROOT file, was not part of this project. Nevertheless, the ROOT output is useful to the other part of this project.

3 Second Tool : Noise Analysis

With the ROOT output, we want to analyze the noise coming from the front-end boards to see if it respects the specifications from the ATLAS Liquid Argon Phase-II Upgrade Technical Design Report (TDR) and if there are no disturbing features. To do this, we want to create different types of plots to extract useful information.

Before showing any plots, figure 3 helps to better understand the type of data we can access. What are called "events" in this report are the bigger ticks with numbers on this timeline. They correspond to a trigger in the electronics, between which samples are taken (the smaller ticks, called "bunch crossings").

The first thing we can plot is the raw data in multiple forms. For example, we can look at the first bunch crossing of every event in the dataset, like shown in figure 4. There is also the option of looking at

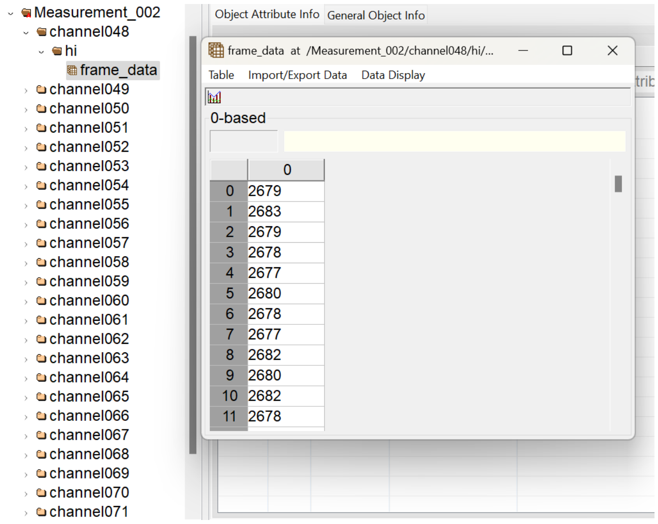


FIGURE 2 – Example of a HDF5 file.

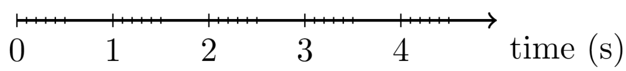


FIGURE 3 – Representation of the data taking. The numbers represent the trigger, and between each number there is the sampling, or the bunch crossings.

other bunch crossings, and this can be modified in the software. We can also look at the data from only one event, like in figure 5, where we have an example of an event with 24 bunch crossings, and another with 200 bunch crossings.

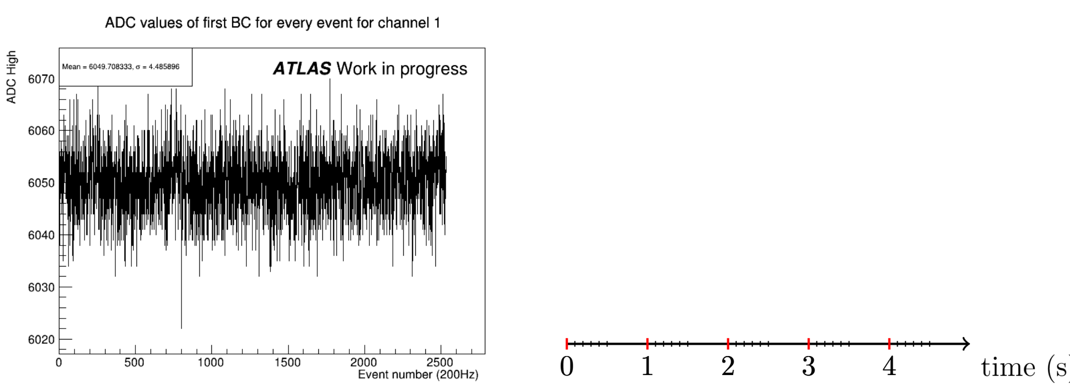
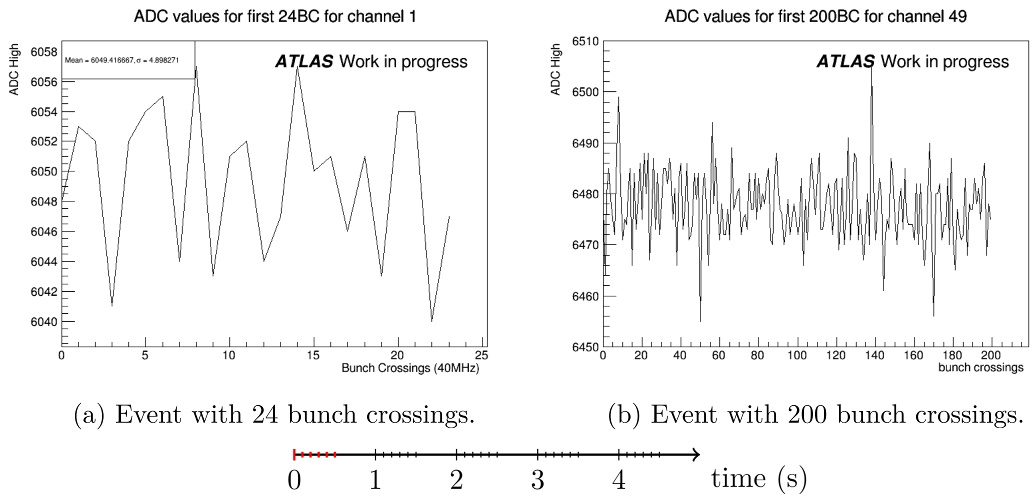


FIGURE 4 – First bunch crossing of every event. Represented by the red ticks on the left figure.

Another interesting thing we can do without computing the data is to project the values of all of the ADCs into the y-axis, and look at the resulting distribution. It should be pretty close to a Gaussian distribution as we can see in figure 6. We can compute the mean and the standard deviation with a fit or with the raw data and compare the values we obtain. These values are compared to the specifications from the ATLAS TDR and used for the calibration of the FEBs.

We can then manipulate the data to make other histograms, such as the sum of the centered distributions of ADC values for all of the channels (figure 7a), or the histogram of the mean ADC values for



(a) Event with 24 bunch crossings. (b) Event with 200 bunch crossings.

FIGURE 5 – Example figures of the ADC values for the first event for two different datasets. Represented by the red ticks on the bottom figure.

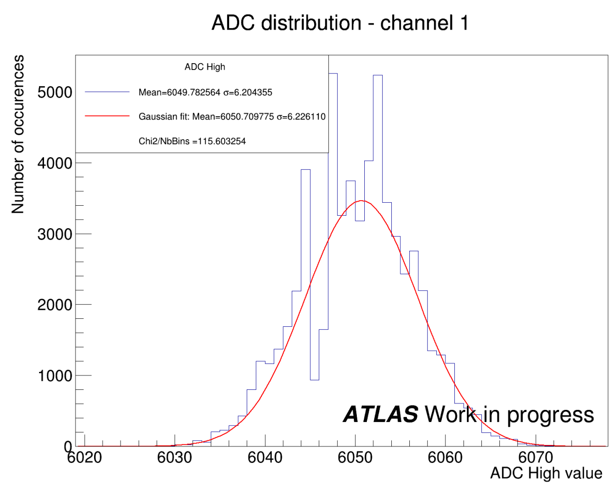


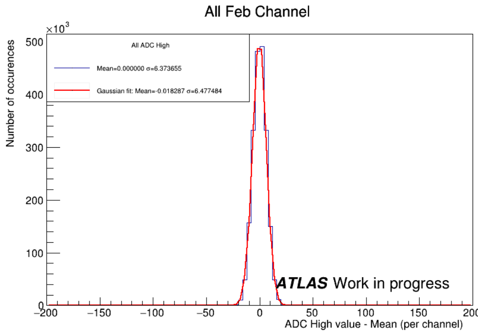
FIGURE 6 – All of the ADC values for one channel projected on the y-axis to build an histogram.

all the channels (figure 7b), or the same thing with the standard deviation(figure 7c).

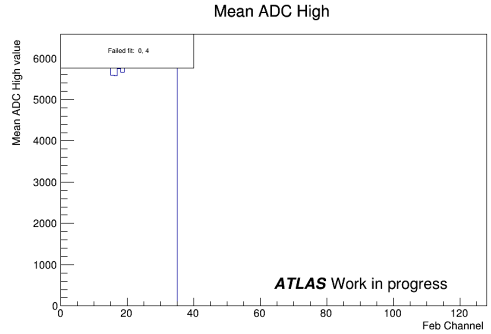
A little similar to the previous plots, we can look at the mean or standard deviation of the ADC values, but for every events separately, figure 8a and 8b respectively. This is useful to check the stability of the system over time.

To see the influence of every channels on each other, we can compute the Pearson correlation coefficient (PCC) of the ADC values for every channels. The PCC is the covariance of the ADC values of two channels divided by the product of standard deviation for the two channels. In figure 9, we can see these coefficients represented in a 2D histogram. With the colour gradient, we can easily see the auto-correlation diagonal and the channels that are more correlated to each other. We can see squares around the diagonal because of how the channels are organized and linked together. At the moment these plots were made, we only had 36 channels active, but eventually, the figure 9b should be full.

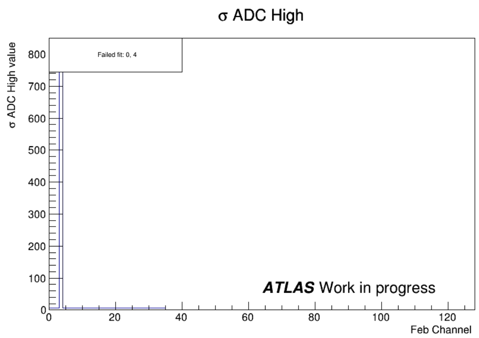
Finally, we can compute the Fourier transforms of the different datasets with a fast Fourier transform (FFT) algorithm. Computing the FFT helps us look if we don't have parasite noise in the FEB's hardware



(a) Sum of the centered distributions for all the channels.

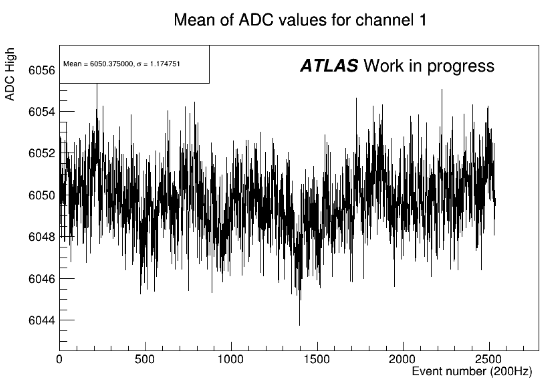


(b) Mean ADC values for all the channels.

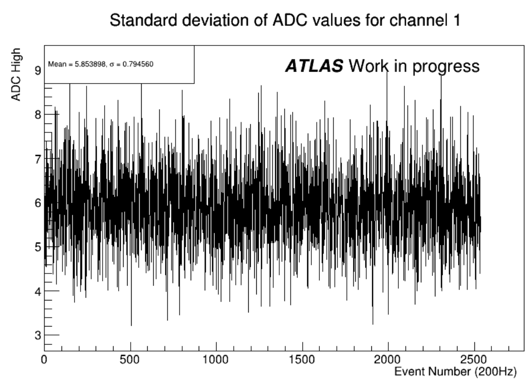


(c) Standard deviation of the ADC values for all the channels.

Figure 7 – Other distributions.



(a) Mean of ADC values for every event.

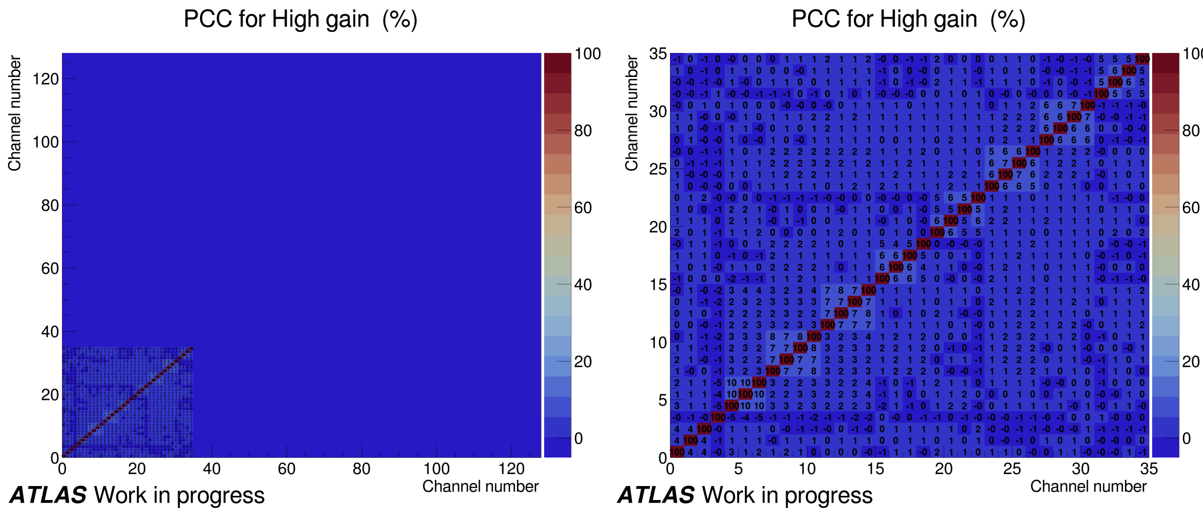


(b) Standard deviation of ADC values for every event.

Figure 8

at certain frequencies. We take the data in the time domain, and we transform it so it is in the frequency domain. We can then look if there are particularities at certain frequencies. We have access to different ranges of frequencies because we can either choose to look at all of the events, or only one of them. In the dataset used for the example figures of this report, the trigger rate was 200 Hz, and the sampling rate was 40 MHz. However, the frequency ranges are only half of those frequencies because the other half of the frequency range would be symmetric. Hence, all of the information is contained in half of the total frequency.

In figure 10, we can see the Fourier transform on the first bunch crossing of every event (figure 4).

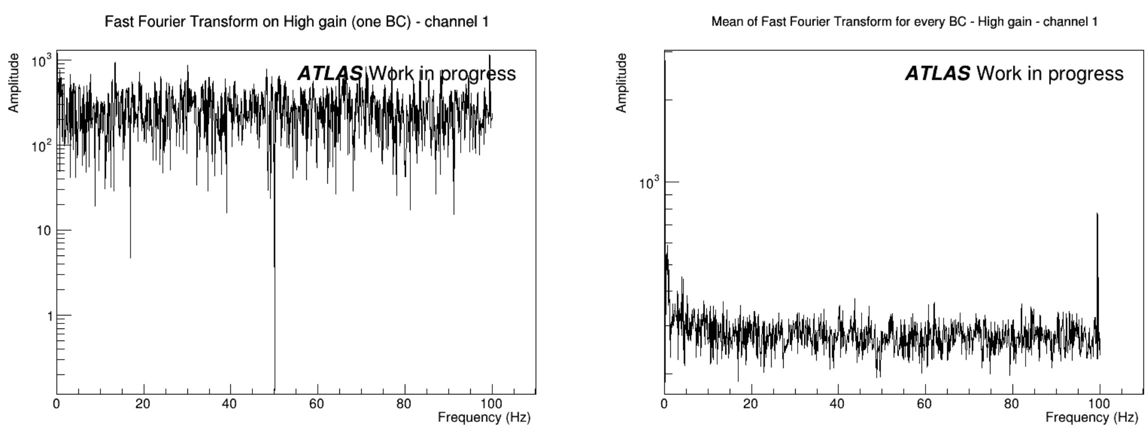


(a) Pearson Correlation Coefficient of ADC values for all the channels.

(b) Zoom on active channels.

FIGURE 9

The frequency range is from 0 Hz to 100 Hz because the trigger rate is of 200 Hz for this dataset. On the left of this figure, we can see the mean of the fast Fourier transform on all the bunch crossings - so for this dataset, it is the sum of 24 fast Fourier transforms divided by 24.



(a) Fast Fourier transform on the first bunch crossing of every event. Trigger rate at 200Hz.

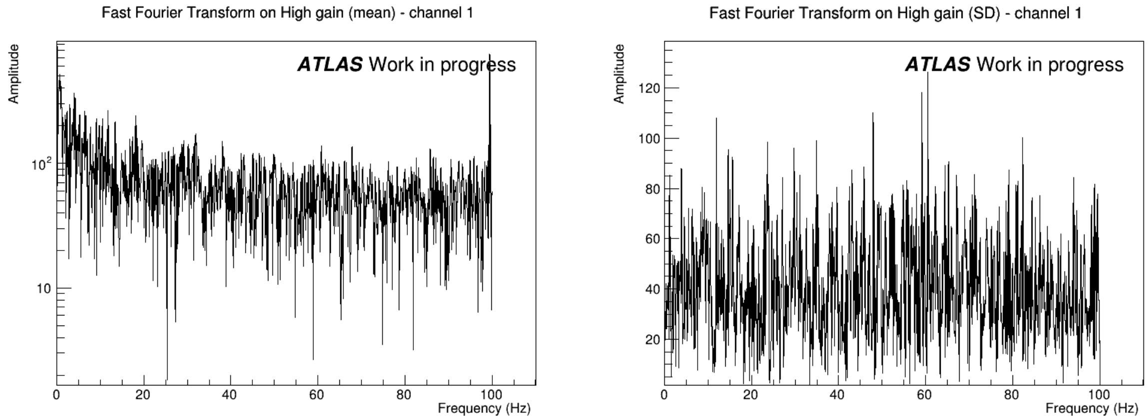
(b) Mean of all the bunch crossings.

FIGURE 10

In the same frequency range, as seen in the figure 11, we can compute the fast Fourier transform on the mean or standard deviation of the ADC values for all of the events (figures 8a and 8b).

In figure 12, we can see the same computation but with all the bunch crossings for only one event. The dataset used in this report only has 24 bunch crossings per event, so to give a good example, we look at a different dataset where 200 bunch crossings were recorded. The sampling rate is 40 MHz, so the range of frequency on these figures goes from 0 Hz to 20 MHz.

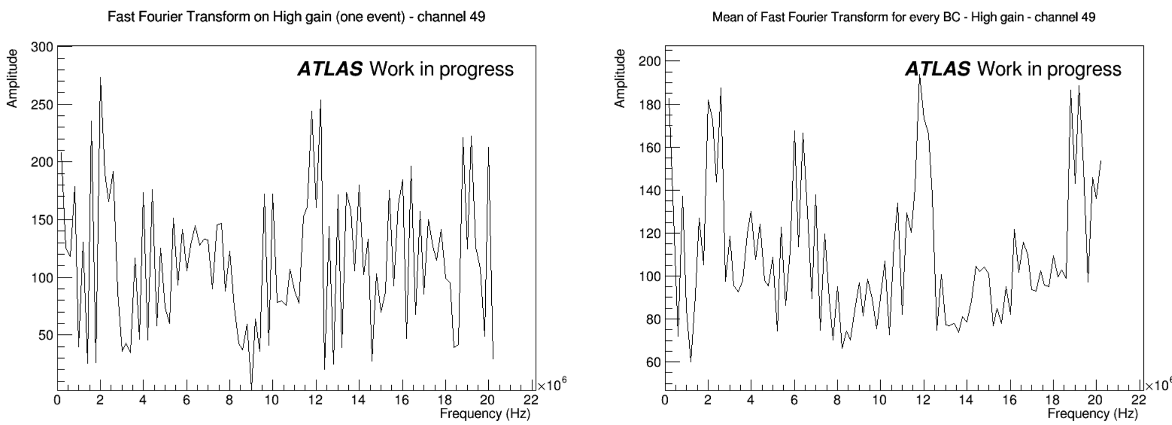
Something interesting with the FFTs and the upgraded FEBs is that we have access to two different ranges of frequencies, which was not possible before. Although we have a larger range of frequencies, we still miss the range from 100Hz to about 1MHz. New readout solutions should be explored.



(a) Fast Fourier transform on the mean of the ADC values for every events.

(b) Fast Fourier transform on the standard deviation of the ADC values for every events.

Figure 11



(a) Fast Fourier transform on the ADC values of the first event with 200 bunch crossings. Sampling rate at 40 MHz.

(b) Mean of all the events.

Figure 12

4 Conclusion

In conclusion, the HDF5 files will help update the calibration values of the ADC chips on the front-end boards by formatting the data in an easily reusable format. The noise analysis software will allow the evaluation of the proper functioning of the FEB and of the readout chain by making sure that we dont' have noise that appears in specific frequencies. These two tools are necessary in the context of the tests leading to the Phase-II upgrade of the ATLAS detector.

References

[1] The ATLAS Collaboration. (2018). *ATLAS Liquid Argon Calorimeter Phase-II Upgrade Technical Design Report.* CERN-LHCC-2017-018 ATLAS-TDR-027 https://cds.cern.ch/record/2285582/files/ATLAS-TDR-027.pdf?version=2