CERN Summer Student Report

Performance study of LAr calorimeter trigger system after Phase-I upgrade

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Abstract

During the last long shutdown of LHC, the Phase-I upgrade of ATLAS liquid argon calorimeter has been completed. This upgrade improves the trigger system in order to prepare it for high-luminosity LHC. A commissioning process is now ongoing to make sure that the trigger system is operational. This report will give an overview of my project as a summer student, analyzing data of the digital trigger of liquid argon calorimeter to study the performance of the system.

Contents

1 Introduction

Located at the border between France and Switzerland, close to Geneva, CERN (European organization for nuclear research) is an international laboratory where physicists and engineers from all around the globe work. CERN is holding the largest particle accelerator in the world, the Large hadron collider (LHC), where the Higgs boson was discovered in 2012. ATLAS is one of the four detectors of the LHC (Large Hadron Collider) at CERN. Like CMS, the detector is designed for general purpose, with the aim of pushing the frontiers of knowledge and understanding better the universe and its elementary components. [1] With 45m long and a diameter of 25m, ATLAS is the largest detector ever built for a particle collider. The ATLAS collaboration is composed of more than 5500 members located all around the world.

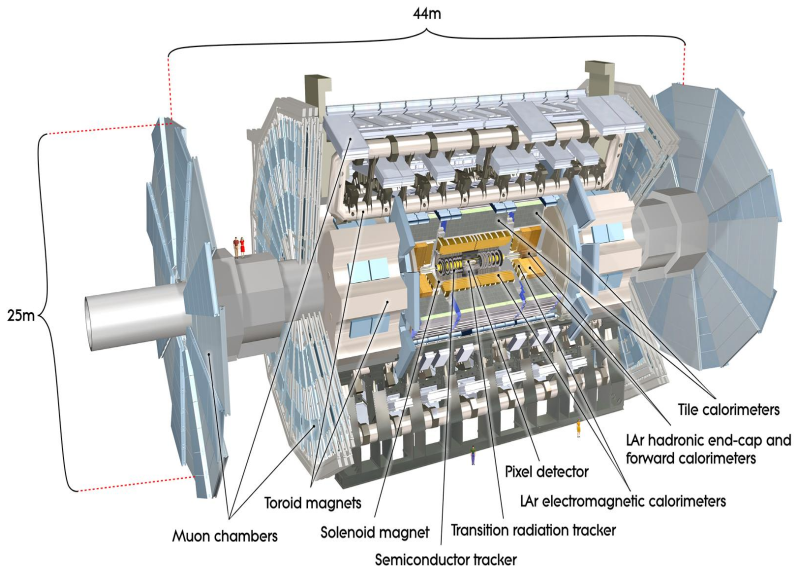


Figure 2: Representation of ATLAS detector [1]

The liquid argon (LAr) calorimeter is an essential part of ATLAS detector's trigger system, that is the online event selection process. Indeed, too many events happen at the collision point and we need to decide which ones would be interesting for physics studies. The calorimeter measures the energy of the particles, allowing us to choose which events we are recording. The LAr calorimeter is composed of four parts : the electromagnetic barrel (EMB), the electromagnetic end-cap (EMEC), the hadronic end-cap (HEC) and the forward calorimeter (FCal). The electromagnetic calorimeter measures the energy of photons and electrons while the hadronic calorimeter measures the energy of jets. Each part is divided into 2 sides (A and C) and in different layers, up to 4. The direction of the beam defines the z-axis, the interaction point being the center of the coordinates. A-side is defined as the side with positive z and C-side with negative z.

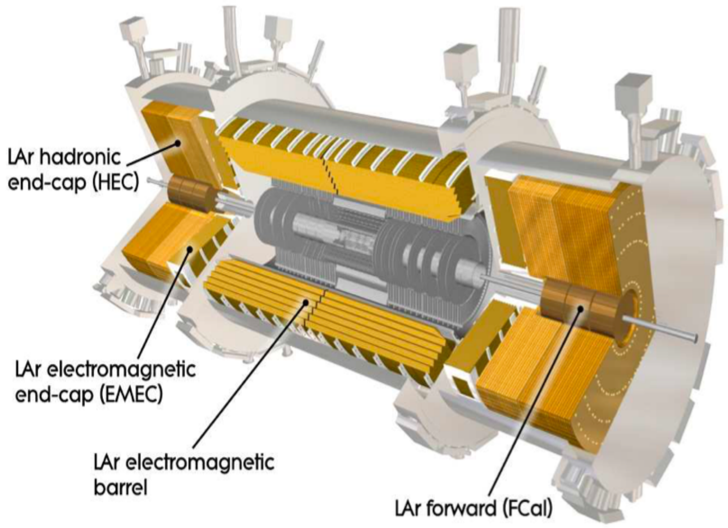


Figure 3: Representation of ATLAS liquid argon calorimeter [2]

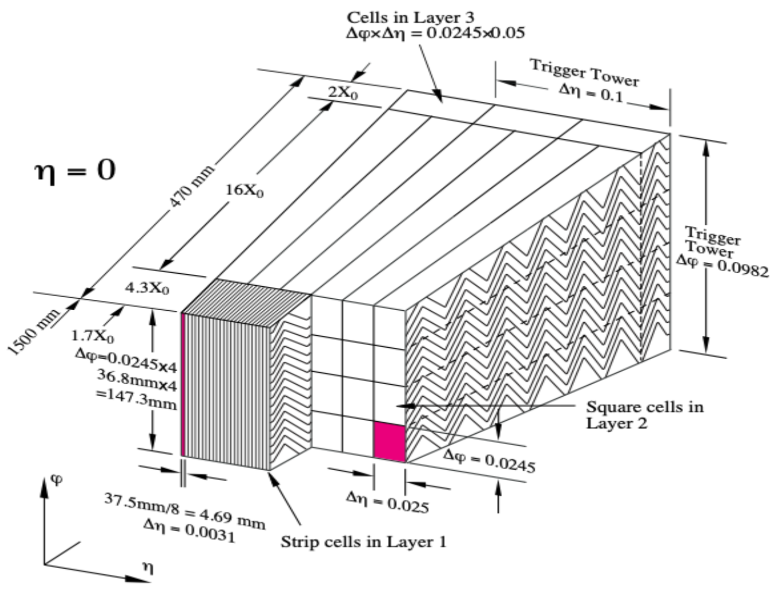


Figure 4: Sketch of a barrel module with the different layers [1]

All these subdetectors use liquid argon as a detection medium for its linear behaviour, stability over time and resistance against radiation. [1] The signal detected is generated by the ionization electrons moving into an electrical field created by the high voltage inside the liquid argon gap, between the readout electrode and the absorber. This signal is deposited into the cells, then amplified by a pre-amplifier, shaped in 3 different gains (low, medium and high), stored and finally digitized and transmitted to the back end electronics. [3]

The increasing luminosity of LHC for Run 3 and High-Luminosity LHC makes the selection more challenging and implies an upgrade of the trigger system to improve the rapidity and efficiency of the triggering process. The readout electronics producing the trigger information has recently undergone a Phase-I upgrade to achieve that goal. [4]

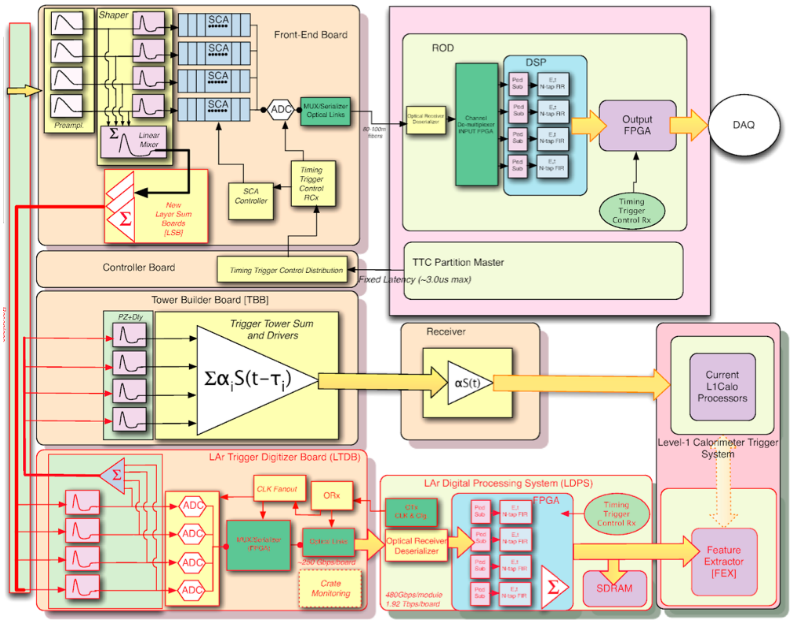


Figure 5: Schematic of the Phase-I upgrade architecture. New components are indicated by the red outlines [5]

Before the upgrade, the calorimeter was combining energy deposits from subdivisions of the detector called "trigger towers", containing different cells. These trigger towers have been replaced with a finer granularity scheme called "super cells".

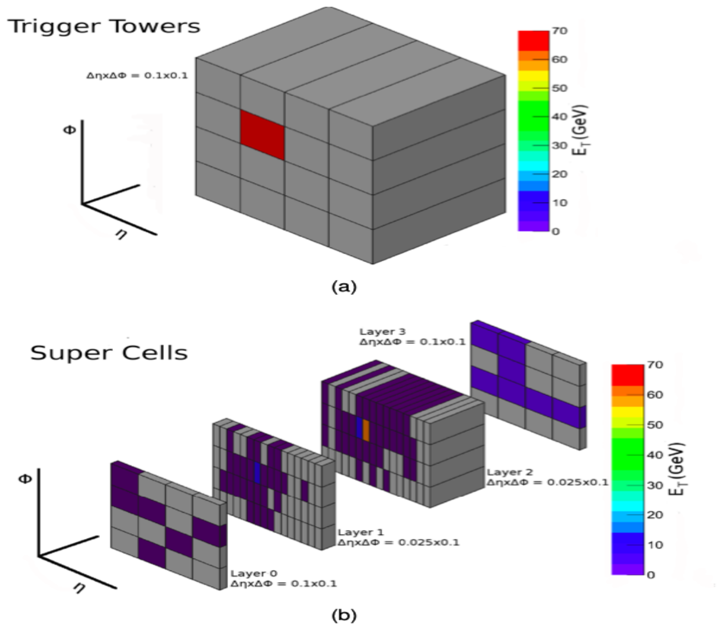


Figure 6: Trigger tower and super cells [6]

However, since the trigger system is a crucial part of the detector, physicists decided to keep the legacy trigger system operational while the new trigger system is being tested and will eventually move to the digital trigger if the commissioning is successful. Therefore, it is now important to analyze the data coming from the new electronics to ensure the hardware is working as it should. [5] As a summer student, my project was to analyze data from the digital trigger of the liquid argon calorimeter and compare it to data from the legacy system in order to illustrate the performance of the detector after the upgrade.

2 Study of Cosmic Calo runs

I started by studying data of CosmicCalo (run 454322) to get more familiar with ROOT [7] and LAr calorimeter. CosmicCalo is a calibration stream used for data quality assessment that contains events with no collision. Indeed, even if the two beams of the LHC collide every 25ns, the proton beams are made of bunches, so there are gaps between collisions. That allow us to select events where we know that there are only noise and cosmic muons.

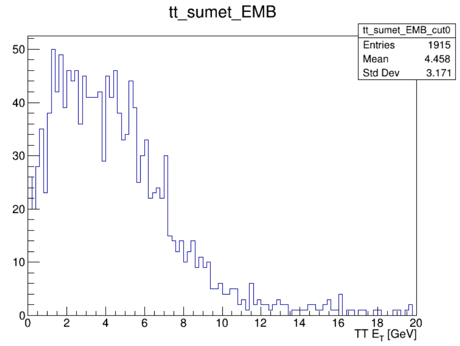
2.1 Method

I used LArPromptAnalysis to create a ROOT file with the energies and position of the events in the calorimeter, looking at one run. LArPromptAnalysis is a data analysis framework used by LAr team to produce ntuples and plots in order to study the performance of LAr calorimeter. It creates files in ROOT, which is a data analysis framework developed at CERN by physicists for physicists. It is mainly used in high energy physics and allows to process an important amount of data. After creating the files, I plotted in a ROOT Tcanvas the energy of the trigger towers, from the legacy system. I also plotted 2D histograms with eta and phi [1], determining the position of the super cell inside the detector, this time for the new trigger. I made one plot for each subdetector of the LAr calorimeter : EMB, EMEC, HEC and FCAL. For the Phi vs Eta histograms, I also made different plots for each layer.

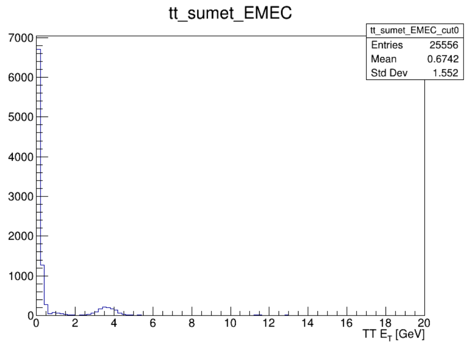
2.2 Results

We can see that the energy is close to zero, which is what we expect given that we have no collision in these runs. For EMB (figure a) the numbers of events seem to be higher but the reason is that the scale of the y-axis is much lower than for the other plots.

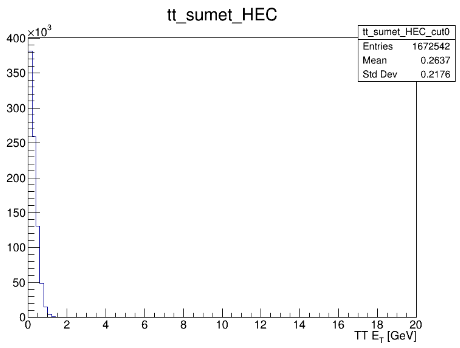
[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Polar coordinates (r, φ) are used in the transverse plane, φ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Angular distance is measured in units of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$



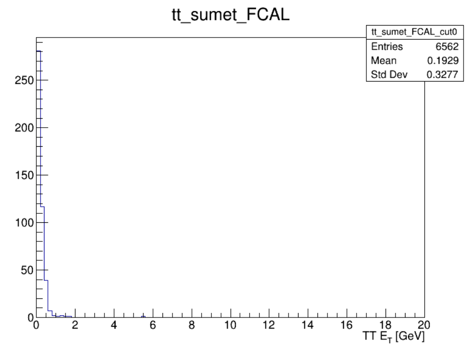
(a) EMB



(b) EMEC



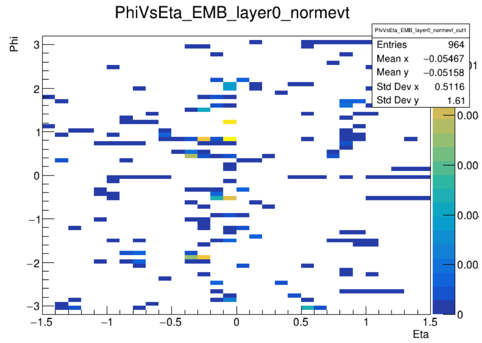
(c) HEC



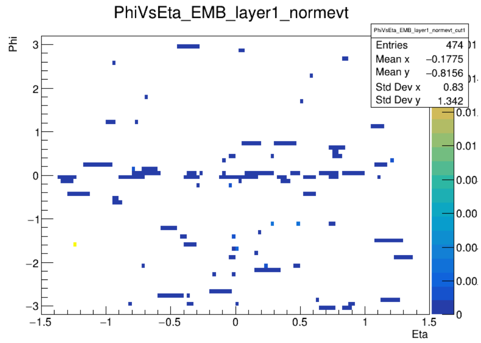
(d) FCAL

Figure 7: Energy distribution of the trigger towers for run 454322

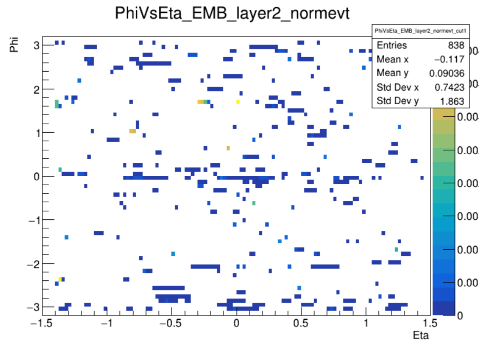
Similarly, the 2D histograms with eta and phi show a small amount of events in the super cells. The events we witness can be attributed to noise or cosmic rays.



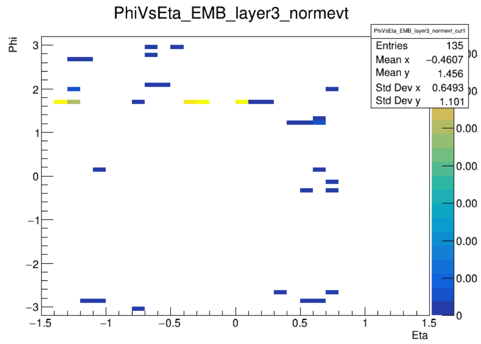
(a) layer 0



(b) layer 1

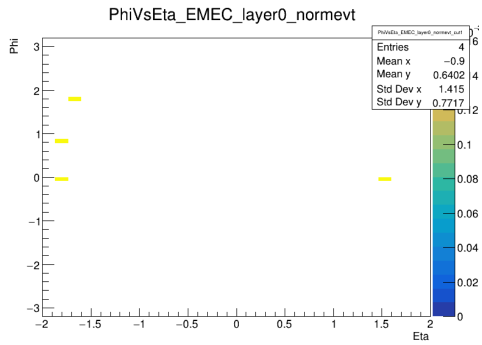


(c) layer 2

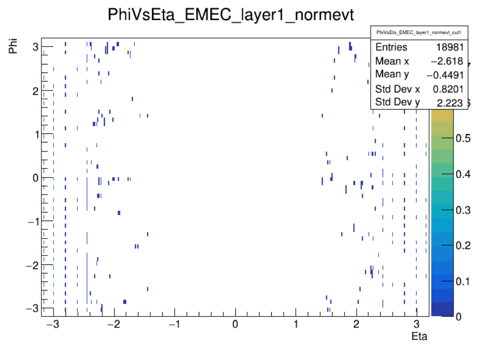


(d) layer 3

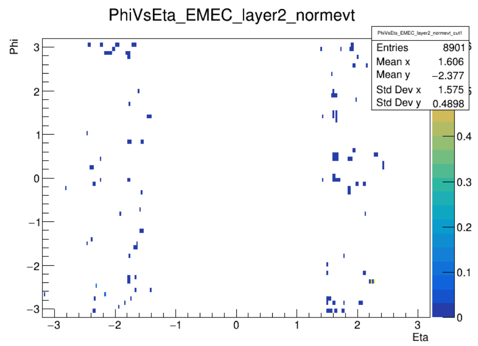
Figure 8: Location of the events in EMB for run 454322



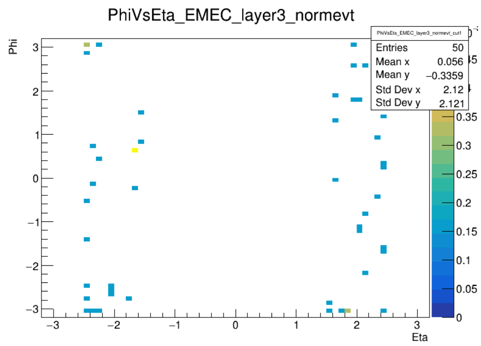
(a) layer 0



(b) layer 1



(c) layer 2



(d) layer 3

Figure 9: Location of the events in EMEC for run 454322

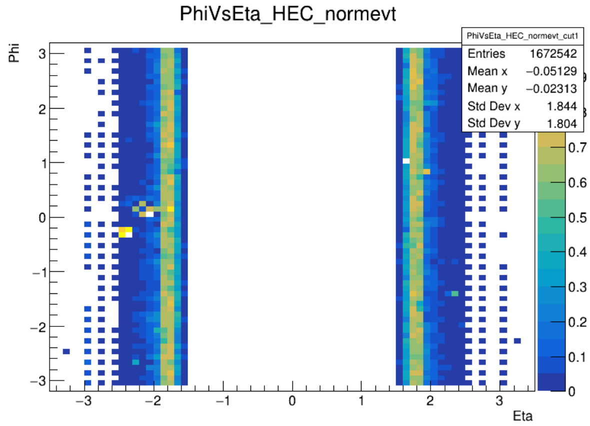
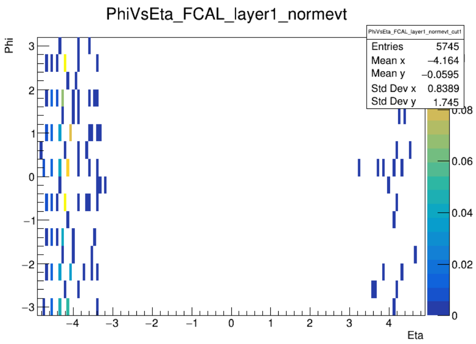
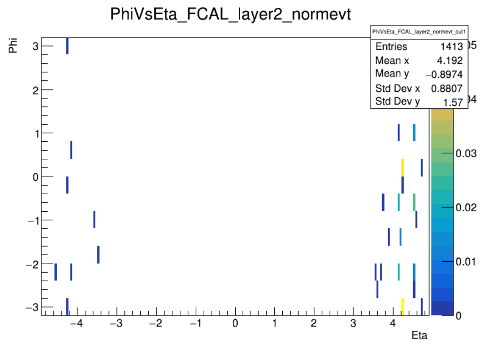


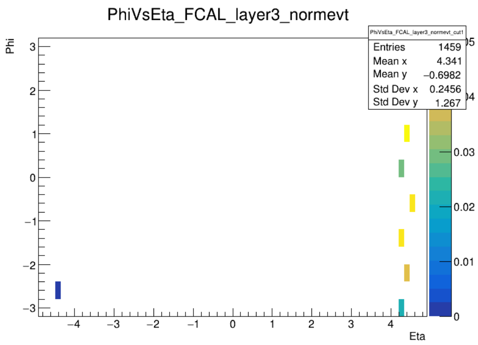
Figure 10: Location of the events in HEC for run 454322



(a) layer 1



(b) layer 2



(c) layer 3

Figure 11: Location of the events in FCAL for run 454322

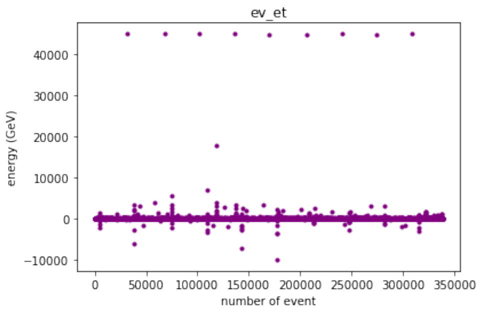
3 Comparison between offline and online energies

3.1 Method

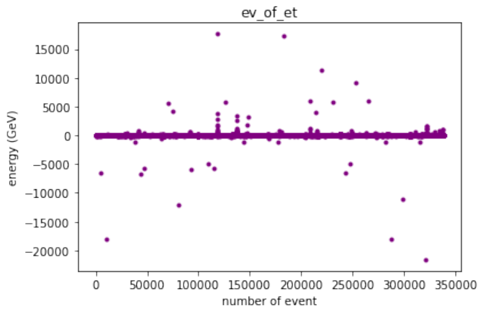
I used the scripts of LArPromptAnalysis to create ntuples with the energy (online and offline), the subdetector and the layer of the events in trigger towers and supercells, with a configuration I wrote. Indeed, to process a file with LArPromptAnalysis, it is necessary to input a file with the data to process, specify a configuration which tells the script which ntuples or histograms should be created, and an output file where the histograms and ntuples will be stored. I ran the script on files from different luminosity blocks in an Express run (run 452573) and merged them to have more data. A luminosity block corresponds to the data taken during a period of one minute in a run. Express is a calibration stream that contains runs with collisions, unlike Cosmic Calo. The file contained an important amount of luminosity blocks and I had to choose which ones to use. I had to remove the first and last luminosity blocks since the data is being registered before the start of the run, to be sure that we don't miss any. There is a website called ATLAS Run Query that shows which luminosity blocks are good for physics for a given run, which I used to select the 10 luminosity blocks I would merge.

3.2 Results

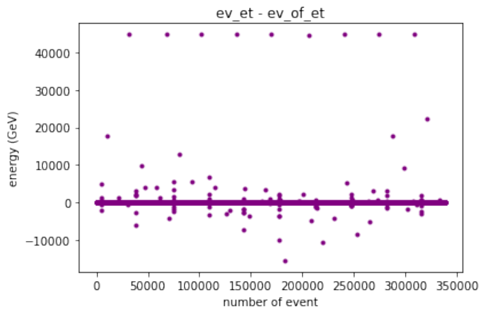
We expect the online energy and the energy calculated offline to be more or less the same.



(a) Online energy



(b) Offline energy



(c) Difference between online and offline energy

Figure 12: Online energy, offline energy, and difference between both

We can see on the y-axis the energy in GeV and on the x-axis the number of the event. The difference between online and offline energies is close to 0 in most cases. The values over 40000 are a default value for non valid signals, and therefore shouldn't be taken into account. The negative energies seem non physical but are possible in the calorimeter as a result of pileup and electronic noise.

I didn't spend much time on this task since I was given a more important task soon after, and would need to go back to it to better exploit the results. It would be interesting to make these plots with a cut on the bad events to only take into account valid signals.

4 Comparison of mphysovermcal for digital trigger and legacy readout

4.1 Method

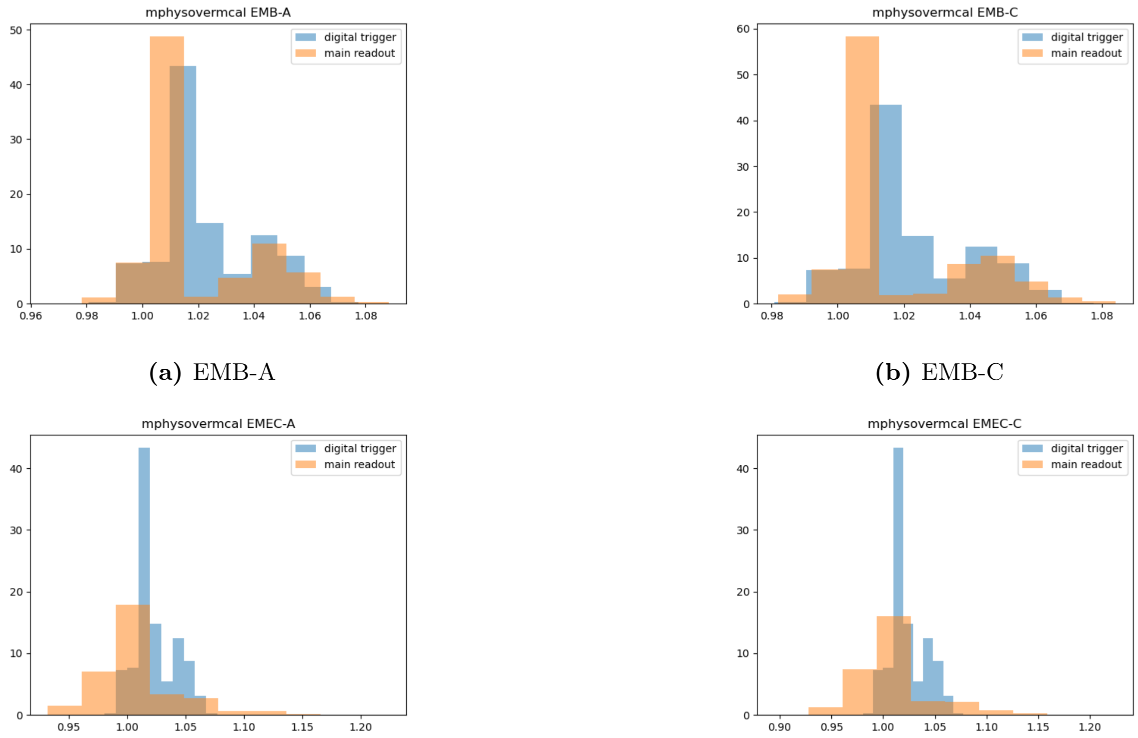
I then worked with ROOT files filled with data from both super cells and trigger towers from different runs. I compared the variable mphysovermcal for the trigger towers (legacy system) and the digital trigger. Mphysovermcal is a variable that quantifies the difference between the calibration pulse and the expected physics pulse for the same initial current : $\frac{M_{phys}}{M_{cal}}$. I extracted the values for each subdetector, side and layer. Mphysovermcal is a value between 0 and 1. However, 'bad channels' are given a default value of mphysovermcal=-999. This happens when some super cells are not fully pulsed in a run and therefore the data cannot be considered. Therefore I selected only the events for which mphysovermcal was between -10 and 10 to get rid of the bad channels (it can be slightly below 0 or over 1 since experimental data is not perfect). In order to do that, I used *uproot* to convert the ROOT ntuples to a *pandas* dataframe and did my selection on this dataframe. I then created *numpy* arrays with the selected data that I plotted with *matplotlib.pyplot*. I also selected the events with gain=0, that is a high gain.

The performance needs of the subdetector FCAL being less important, there is no prediction of the ionization pulse and FCAL uses only the calibration pulse. Therefore, mphysovermcal=1 for FCAL and there is no need to plot it. The hadronic end-cap (HEC) has fewer layers and the super cells sum all of them so I summed the layers of the cells (from the main readout) in order to compare them. If the file for the main readout (legacy system) contained the information on the layers, the file with the digital trigger did not so I applied a cut on the channel numbers using a pedestal file that links the channel numbers to the layer associated. Moreover, the events from HEC were clearly labelled for the main readout but not for the digital trigger. To select the events from HEC in the digital trigger, I used cuts on the feedthrough and slot number. The feedthrough is the front end crate the super cells read out to, and the slot number corresponds to the front end board inside the crate.

4.2 Results

The x-axis represents $\frac{M_{phys}}{M_{cal}}$ and the y-axis is the number of occurences of the mphysovermcal value. The histogram is drawn as a probability density since there are 5 times more cells in the standard readout than super cells in the digital trigger.

We are interested in the position of the peak of mphysovermcal for both systems in order to compare them. Both average values are expected to be more or less the same, but we noticed that it was slightly higher for the super cells in EMB, which motivated this study. In the following plots, we can see that the average mphysovermcal is indeed higher for the digital trigger in the electromagnetic barrel. This is something to be understood.

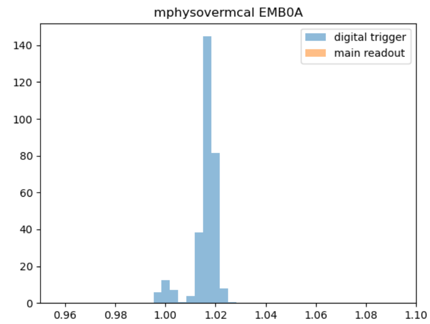


(a) EMB-A **(b)** EMB-C

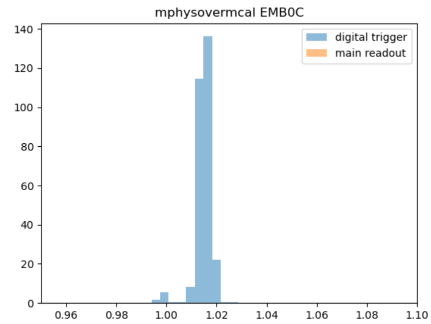
(c) EMEC-A **(d)** EMEC-C

Figure 13: mphysovermcal for EMB and EMEC

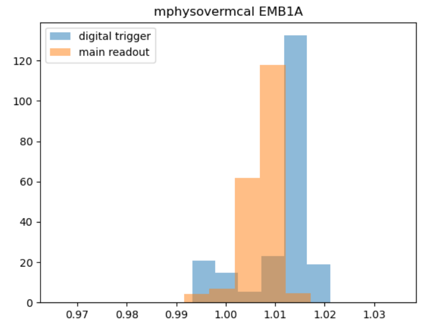
The absence of entries for the main readout for the layer 0 (figures a and b) is unexpected.



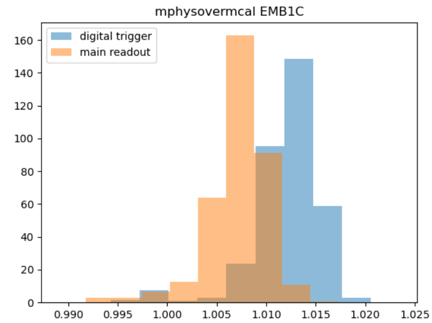
(a) EMB-A layer 0



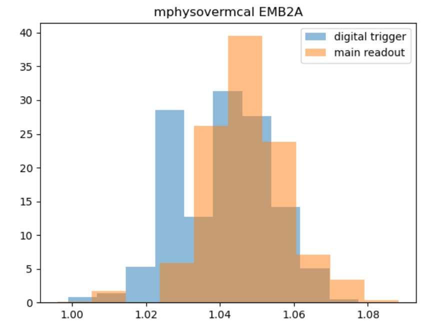
(b) EMB-C layer 0



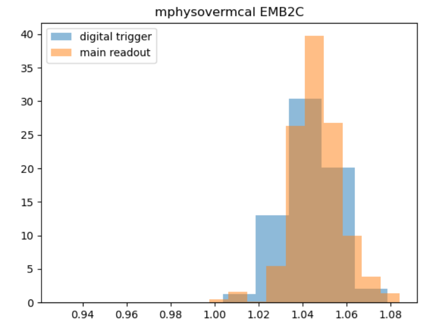
(c) EMB-A layer 1



(d) EMB-C layer 1

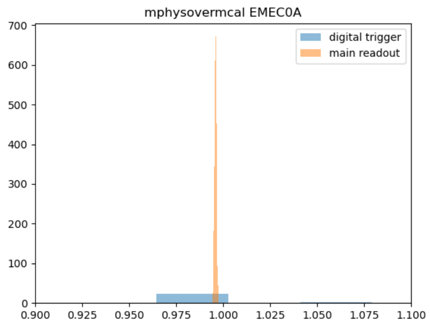


(e) EMB-A layer 2

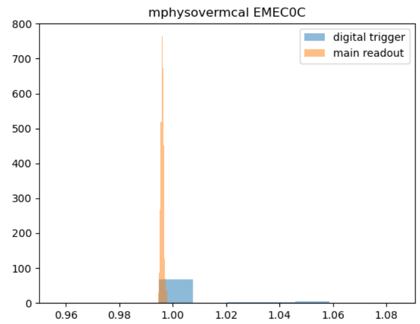


(f) EMB-C layer 2

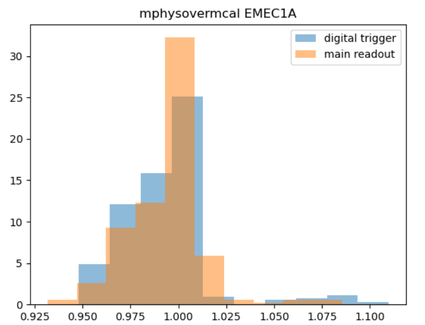
Figure 14: mphysovermcal for EMB per layer



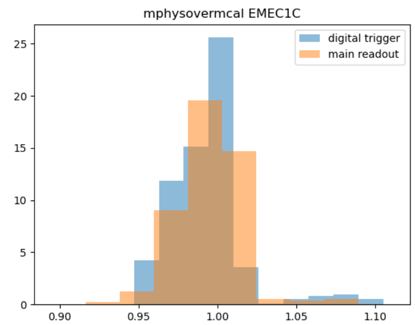
(a) EMEC-A layer 0



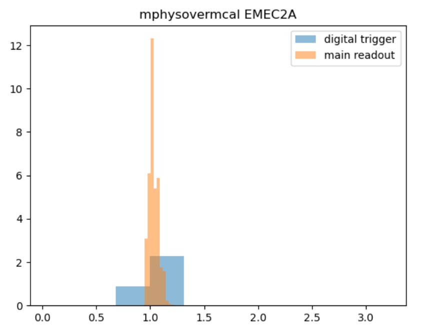
(b) EMEC-C layer 0



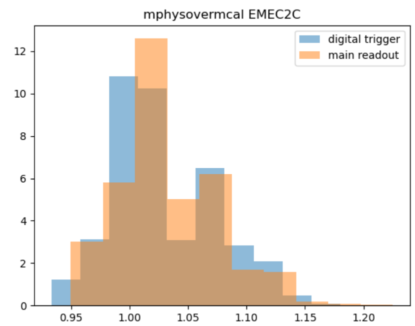
(c) EMEC-A layer 1



(d) EMEC-C layer 1



(e) EMEC-A layer 2



(f) EMEC-C layer 2

Figure 15: mphysovermcal for EMEC per layer

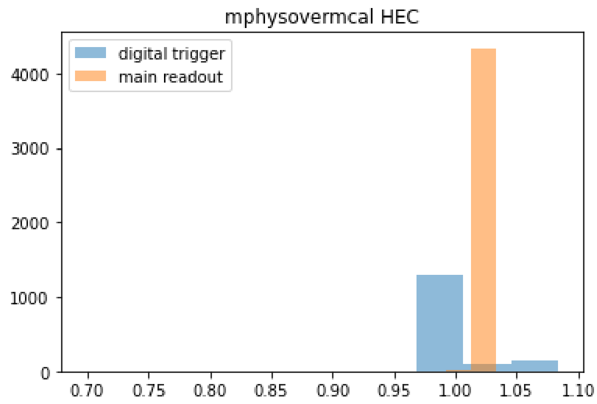


Figure 16: mphysovermcal for HEC

The average mphysovermcal for HEC seems higher for the main readout than for the digital trigger, but as for FCAL we are less interested in the value of mphysovermcal for HEC and might set it at 1.

5 Noisy cells

It was reported that the super cells noise seems to be larger than the cells noise. I was therefore asked to investigate this, plotting the noise for both cells and super cells. The noise is given by the variable RMS (root mean squared) multiplied by the LSB, a factor of conversion between the analog-digital convertor and energy in MeV.

5.1 Method

In order to compare the noise between super cells and main readout, I needed to sum the noise of the super cells from one trigger tower and compare it to the noise in the same trigger tower according to the main readout. I could then plot the ratio for all trigger towers and see how far it is to 1.

To know which trigger tower the super cells are from, I used a database called LArIdtranslator, opening it in a SQL browser. I then used the package *sqlite3* in order to connect the database to my python script. It allowed me to select the columns I was interested to, that is the index of the trigger towers and the super cells, and convert them into a *pandas* dataframe.

I used the data from the file with merged lumi blocks that I used for comparing online and offline energies before.

I began comparing the online energies of the trigger towers and super cells since I didn't have the file with the noise of the trigger towers and had to wait for someone to create it. For that, I did a loop on the trigger towers index and filled an array with the energy of the trigger towers, and another array summing the energies of the super cells in the same trigger tower. I then tried to plot the ratio between both. The ratio was not close to one as it should be but it was probably due to a problem of conversion factors that I didn't have time to investigate. I also filled an array with the sum of the noise from the super cells in one trigger tower for each trigger tower, but would need the noise of the trigger towers to do a comparison of both.

Unfortunately, I did not have time to finish this study, but colleagues of my team will probably pursue this work.

6 Work apart from my project

6.1 Shadow shift

As a member of the Liquid Argon team, I had the opportunity to shadow a shift in ATLAS Control room (that means assisting at a shift without operating as a shifter) at the Calorimeter desk (usually shortened to calo). The task of the Calo shifter consists in looking at screens with the status of the different parts of the calorimeter and intervening or contacting the appropriate person if an error appears. The shifts are usually 8 hours, but I did only 4 hours since it was only to see what the shifter's work was like and not training to become an actual shifter. The shifter has a big responsability since every second of lost data is an important amount of lost physics events and money. It is therefore essential to react quickly, either as a shifter or as an expert on call. Indeed, each week, members from the team are experts on call and have to be called in case a fatal error appears on the screens or if the shifter doesn't know what to do. The experts on call have to remain available 24/7 and can be contacted in the middle of the night or during the weekend since LHC doesn't sleep. Working in the detector operations team is a job that requires dedication, but the members of the team are really bonded and passionate about their work.

6.2 CERN summer student programme

6.2.1 Lectures and visits

Being part of the CERN summer student programme, I followed lectures covering various topics of particle physics. The lectures took place every morning during one month and covered different fields important for CERN such as detector physics, accelerator physics, theoretical physics, flavour physics, experimental physics at colliders and so on.

We also had visits of different facilities of CERN : the first synchrocyclotron (which is not used anymore and became a museum), ATLAS Control Room, the Data Center, the Antimatter factory and its antiproton decelerator ELENA and ISOLDE (Ion Separator OnLine DEvice). As a member of LAr team, I was shown the electronics caverns of ATLAS and thanks to technical shutdowns, I was also able to visit ATLAS and LHCb caverns, which remains a memorable experience.

6.2.2 Workshops

Moreover, we could sign up for different workshops (limited spots were available, so we had to choose the ones we were most interested in). I took part in a ROOT workshop and a MadGraph workshop. The purpose of the ROOT workshop was to give us basic knowledge about ROOT since it is used very often in high energy physics. As for MadGraph, it is a tool to draw and calculate Feynman diagrams. You can generate a process (for instance two protons producing a pair tau and anti-tau) and MadGraph will produce the different Feynman diagrams at leading order and next leading order. You can specify constraints (only QED/QCD for instance) and ask for the cross-sections of the different diagrams produced.

I am also going to participate in a workshop about gaseous detectors, with a focus on Micro Pattern Gas Detectors (MGPDs). MGPDs are used in several particle detectors, like ATLAS, ALICE or CMS. The Gas Detector Development team which organizes the workshop was created by Georges Charpak who won the Physics Nobel prize in 1992 for the Multiwire proportional chamber, a type of particle detector using gas. In their labs, we will operate on MGPDs prototypes used for R&D purposes.

6.2.3 Hackathon

I also had the opportunity to participate in Webfest, the CERN hackathon. This year's theme was 'Education, Science, Research' and we had 48h to produce a website or an app answering to a problematic related to the theme. With my team, we created a web game about subatomic physics with an educational purpose, titled 'What are we made of?' [8]. The game aims at middle school or high school students, to pique their curiosity and show them that science doesn't have to be complicated and can be actually pretty fun. In this game, the player goes through a labyrinth of CERN tunnels and meets a scientist who will teach them about what we are made of, from atoms to quarks and gluons, and finally the Higgs boson as a bonus level. After each level, the player has to answer a question to go to the next level. We tried to emphasize the fact that science is for everyone, and young girls or minorities in general shouldn't censor themselves if they like sciences.

7 Conclusion and acknowledgements

During my project, I analyzed different data from both the legacy system and the new digital trigger to see how it is performing since the Phase-I upgrade. I used runs with and without collisions, and looked mostly at energies and mphysovermcal to compare the behavior of the trigger towers and super cells. Although, there is a lot of work remaining to do in order to validate the performance of the new trigger system.

I probably won't have time to do much more, but it would be useful to compare the noise between the trigger towers and the super cells once having the data about the noise in the trigger towers. Furthermore, I mostly did my plots using Python, and should try doing it in ROOT since it is much more used at CERN.

First, I would like to thank my supervisor Ellis Kay for her guidance through this internship and her kindness, along with her supervisor Guillaume Unal for both allowing me to be part of the CERN summer student program. Working at CERN this summer was a really great experience, and I would also like to thank the coordinators of this program for giving students the opportunity to come to this place so connected to history of physics, and meet wonderful people from all around the world. I enjoyed visiting the state of the art facilities as well as seeing parts of old experiments, or memorial plates where the web was created or where Niels Bohr inaugurated the Proton Synchrotron for instance. I was also glad to learn more about particle physics and data analysis since this is the carreer I want to pursue, and I want to thank the LAr team for welcoming me into the team and teaching me about their work. Finally, I would like to thank the friends I met here for making this summer an unforgettable experience. I liked every day spent here and I hope I can come back to work here as a physicist.

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8 Appendix

```
Selections:
  - name: preSelect
    type: PreSelection
    #cuts: Selections/PreSelection_ofc.cuts
    hist: Histos/PreSelection.histos
    save:
IEvent,BCID,channelId,sc_eta,sc_phi,sc_det,sc_layer,sum_main,s_com,of_et,of_ettau,of_cali_et,of_cali_ettau,ev_et,ev_of_et,ev_of_et
tau,of_ettau,sid_max_et,sid_max_of_et,sid_min_of_ettau,samples_ADC_BAS,sc_ped,sc_ped_rms,sc_hvcorr,sc_mpmc,sc_lsb,bcidVec_ADC_BAS,
bcidVec,energyVec_ET_ID,bcidVec_ET_ID,sc_badword_UPD1,sc_badword_UPD4

  - name: events
    type: Selection
    #cuts: Selections/PreSelection_ofc.cuts
    save: IEvent, tt_sumet_GeV,tt_det

include: include/cern.config
```

Figure 17: config used to process files with LArPromptAnalysis