CERN summer student work project report: Analysis of two of the detectors that will be used in CMS upgrade

Jean Ogier du Terrail
supervisor: Jeremie Merlin

(Dated: August 29, 2014)

This report will focus on two projects that I have been asigned this summer. The commissionning of the new PMTs and scintillators and the study of the gain of a GEM detector.

INTRODUCTION

When I saw for the first time the content of my project I felt lost I had no idea how to start or even what to do. If I could do what I did, it is thanks to many people that helped me throughout this project to better understand my job and the language and softwares I used. This is a non exhaustive list of the ones who helped me the most. Jeremie Merlin for his insight on the GEM detectors, his patience and his passion for research. He made me spend a week reading about GEMs and wire chambers so that I could understand his work and he gave me an attack plan the conjonction of which allowed me to begin the project with serenity.
Brian Dorney for his humour and his patience. The beginnings of my work on the cosmic stand were not great but he always kept on encouraging me so that I could improve. Siddhart Segghal for his great help on the cosmic stand. Marco Meyer for his outstanding understanding of C++ and ROOT.

My main project was to help Jeremie analize the huge quantity of data that he got by observing a GEM for more than one year. The idea was to see if the GEM chamber was ageing that is to say if its gain dropped or changed after it was used continuously for a long time. For a moment I also worked on the cosmic stand with Brian to measure the efficiency of 12 PMTs coupled with scintillators. This work required a lot of energy and time because I needed to change the place of the PMTs constantly so that the DUT (device under study) was in the middle of the stand and also to take a data point every 40seconds. I will begin with my work on scintillators.

COMIC STAND

Set-up and Methodology

We studied how PMTs reacted to the shower of muons coming from the sun or supernovas versus the voltage applied on them. In order to do that we took them 4 by 4, and aligned them at a centimeter precision. The purpose of this set up was that normal muons were supposed to pass through the 4 of them in a very short time window so that we could trigger the set up to count the number of muons detected by 4 of them at nearly the same time or only 3 of them (minus the DUT). So we could measure the efficiency of the 4th assuming that the 3 others were operating at 100 percent efficiency. The exact set up included logical gate and CFD thresholds in order to get rid of the noise induced by dark current. It is described in this picture.

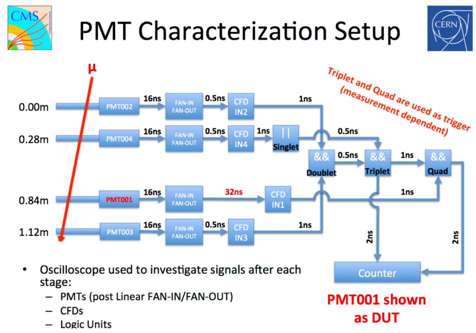

Figure 1. The cosmic stand set up

After doing the branching correctly : the DUT on the quad the others on the triplet (with the PMT from the inner part not under study self-oring) we had to make sure everything was ready for the measurements. First we had to check that the taping of the scintillators and PMTs were right so that the only photons multiplied by the PMTs are those created by the muons impact. In order to do that we set all the currents to 500mA and we use flashlights on the taped part. If we see an increase in the electron current that means the taping is badely done (photons are getting through the taping and therefore are accelerated). Once we have finished this part we have to check the alignement of the scintillators, which is tricky because it cannot be done with a very good precision. Only when this is done we can finally increase the voltage from 900V to around 1600V and calculate the efficiency by taking the ratio :

$$e = \frac{Q}{T} \tag{1}$$

If every step of the methodology is respected we get a nice sigmoïd. We also studied the influence of the thresholds of the DUT by setting it with a screwdriver and a voltmeter to 50, 40, 30 and 20mV.

Results

So we get for each PMT 4 curbs, and we have 12 PMTs so we presented 48 curbs. Here is some exemple for PMT 009:

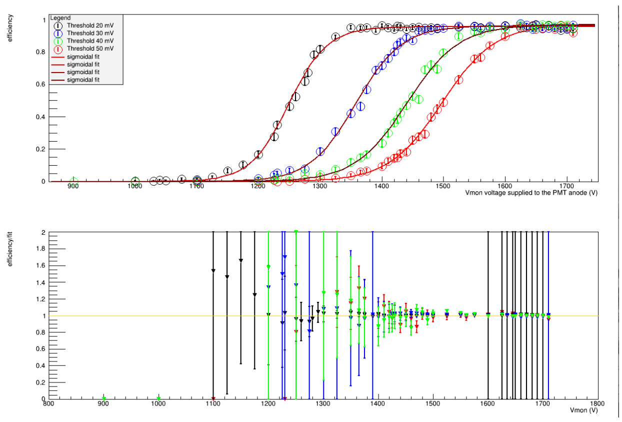

Figure 2. Efficiency curbs of PMT009

You can see the shift of the curbs to the left when the threshold is lowered. This was not finished because we had to make sure every count we got was from an actual muon and not a mistag due to the noise. So Sid was charged to do another set up totally where only three PMTs were aligned and triggered by others. This way we could actually know if our efficiency curbs were right.

With this we could also begin a 3D map of the efficiency histogramm vs the HV and the threshold for each PMT. We wanted to fit these curbs with a saddle aftewards so we can predict future behaviours. However this was not yet done when I left. Here are the curbs with the mistags :

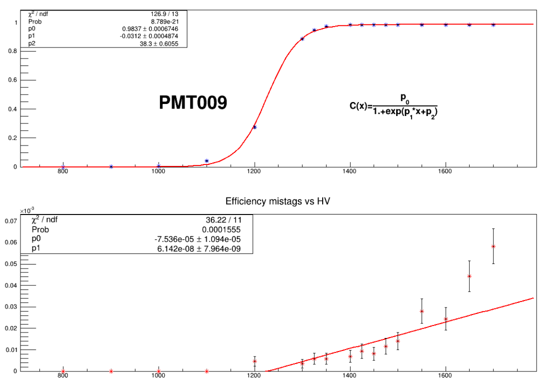

Figure 3. **Efficiency curb and mistags for PMT009**

Problems encountereds and the previously mentioned 3D plot

On the first curbs we observed, the efficiency only rose to values like 0.5. Fortunately it was just an error of timing. We forgot that the signal from the DUT goes to less logical operations than the others it arrives sooner so most of the times it doesn't trigger a count. So we used a longer cable for this one to compensate for its avance on the others. With this little trick we obtained much better looking curbs with efficiency close to 1. Also for some thresholds we needed more time to count the muons because the efficiency was low.

For the errors we took the binomial approximation: $error = \sqrt{\frac{((1-e)e)}{Q}}$ We sometimes had to do the measurements twice or thrice it took a lot of time but at the end we were happy to present our results in a videoconference. Here is the 3D plot with HV and CFD thresholds in the x and y axis and efficiency as the bin content:

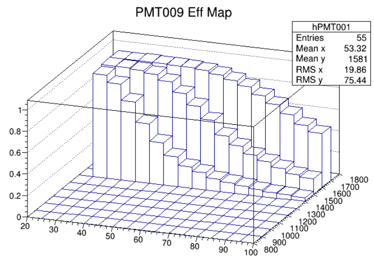

Figure 4. **3D histogram of PMT009**

AGEING OF GEMS

Beginnings

Jeremie gave me text files he got from the detectors he set up on the GEM. On these text files you could see the current monitored on the read out electrode the pressure the temperature and the humidity of the room and the dates of these measurements. My first job was to convert them to actually usable data in the most compressed format. That is why I had to use C++ and ROOT. The first thing was to get rid of the symbol that cannot be read from a C++ stream like (/ and :), to stream the file and to convert the dates into absolute dates counted from january the first 2013 at 00h00 in minutes. Then I could store them in a TTree a formidable structure offered by ROOT. Then followed a serie of surgical operations on these root files. The most important was the fusion of the two different files. I had to write an efficient and fast working algorithm to combine the measurements taken at the exact same dates. After doing two of this fusion I had to suture them together so I could get enough data to start the analysis. A lot more steps were required before the actual analysis, like suppressing every measurement containing a null current (when Jeremie had to shut down the machine), or normalising the current and counting the accumulated charge on the read out electrode. Then we had the possibility to see the fluctuations of the gain.

Analysis

The gain can be obtained directly from the current of the electrode by a proportionnality relation. So I first tried to sudy the current versus the time. However the fluctuations of the current are so strong that we cannot see anything. We have to find a kind of mean value of this fluctuations (the baseline) not directly time related and to see if it dropped or stayed constant. In order to do that I used M. Capeans's thesis and her empirical formula for the gain function of the pressure and the temperature.

$$G = G_0 \left(\frac{< P >}{P} \right)^{f_0} \left(\frac{< T >}{T} \right)^{g_0} \qquad (2)$$

So if we know f and g we can access the value of the gain deprived of the temperature and pressure fluctuations that is exactly what we want. To find f and g that is gonna be the main problem. That is where ROOT enters the game.I invented 3 kinds of algorithm based on different approaches. The first one was to follow exactly this expression and to find f_0 and g_0 by fiting the curbs. The second one use an exponential approximation and the third one a polynomial approximation which can be seen as the beginning of the Taylor serie of the exponential. In all three of them you can apply this algorithm an infinite amount of time depending on the precision you want however this does not seem to converge towards a straight line there are still some fluctuations from noise. I ploted the final corrected intensity versus the time (or the charge) in the same graph as the old ones the variations are less visible. So you can access the actual gain.

Limits of this approach

The quality of the fit depends on the data you input. On long period f and g have a tendancy to change a little so it is best to cut the graph into small parts and to apply the algorithm to each and everyone of these parts. I created algorithms to do a cut in time or in intensity if you want to get rid of some values that the user deems not physical and also an algorithm which does a mean on a number of points with the error. So you can reduce the statistical fluctuations again. I tried taking into account humidity too and it worked a bit. Here is a detail of the final curb that I obtained :

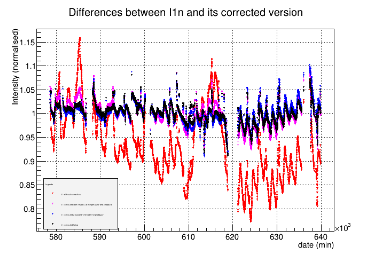

Figure 5. Correction of the normalised gain versus the time

The final curb is in black the first one is the red one the other colors are intermediary corrections. The segmentation analysis was full of surprise because the law of intensity as a function of temperature and pressure changed often especially in the beginning where Jeremy applied some filters. Like the first cut which corresponds of the beginning of the experiment could be fitted with extraordinary precision with an order two polynom and not with any of my method.

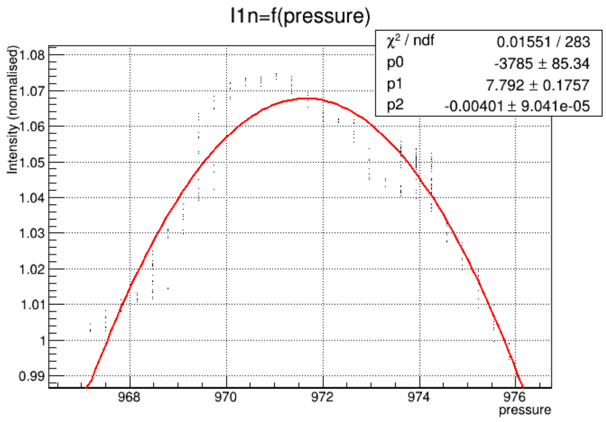

Figure 6. **First correction : curious fit**

This fit is very akward as most of the other cuts presented curbs like this :

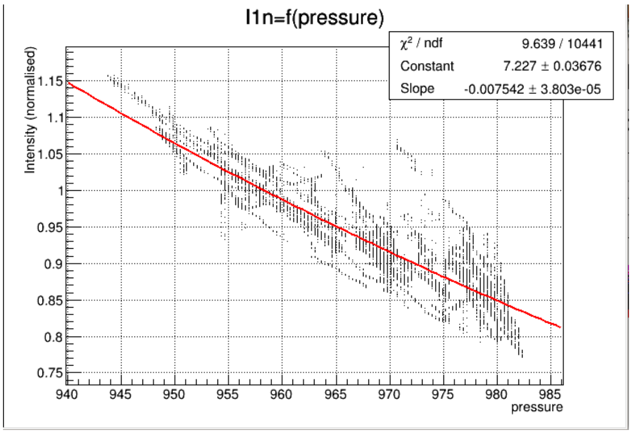

Figure 7. **First correction : normal fit**

Here are two corrections of the first cut one with my old algorithm and one with the polynom you can clearly see the polynom is splendidly working whereas the old correction is a failure.

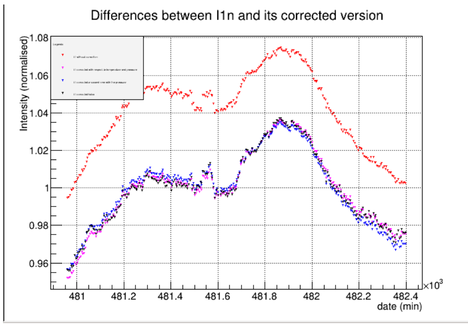

Figure 8. Old correction

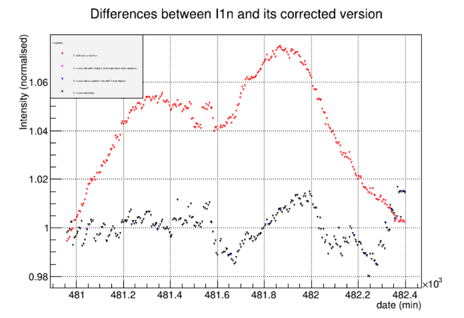

Figure 9. New correction with an order two polynom

A lot of work still needs to be done on the analysis but I developped the tools necessary for it so it is just a metter of time before we can see the actual gain. One of the thing we could do is to implement Fourier discrete transformation to access the baseline of the gain corrected and to cut all the high frequency components of the signal, which corresponds only to statistical fluctuations however we have to set ourselves some boundaries if we want to have results that still mean something.

CONCLUSION

I had only access to 4 currents corresponding to 4 electrodes if I could have had all the read out I could have mapped the gain to see if it was uniform fortunately Jeremie did that and the plot looks nice. This internship has been a great experience for me because it allowed me to perform some efficient data analysis using powerful tools that I will surely use again in the future.