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Work Experience Report

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Analysis of the autotrigger of the read out chip of the front-end electronics for the HCAL of the ILC.

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Abstract

The purpose of my work was to analyse the autotrigger of the read out chip of the front-end electronics for the HCAL of the ILC. This future International Linear Collider and its detectors are still in a developement phase, so each technological part has to be tested. I have tested the autotrigger mode of the chip which will be included in the hadronic calorimeter. For that I have used different facilities of DESY such as an electronics laboratory and an electron beam. We have compared the behavior of the autotrigger to the results with the external trigger which is well known. The result is that the autotrigger of the SPIROC 2 chip is working, but that we still have to investigate some issues.

Résumé

Le but de mon travail a été l'analyse de l'autotrigger de la puce de lecture de l'électronique frontale pour le HCAL de l'ILC. Ce futur collisionneur linéaire et ces détecteurs sont encore dans une phase de développement, donc nous avons besoin de tester chaque partie de l'accélérateur. J'ai testé le mode autotrigger de la puce qui sera inclue dans le calorimètre à hadrons. Pour cela j'ai pu profité de différentes installations de DESY, comme le laboratoire d'électronique ou un faisceau d'électrons. Nous avons comparé le comportement de l'autotrigger avec les résultats obtenus avec le trigger externe qui est bien connu. Le résultat est que l'autotrigger de SPIROC 2 fonctionne, mais que nous avons encore à répondre à certaines questions.

Acknowledgments

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I especially want to thank my supervisor Dr. Mark TERWORT for all the time he spent with me and for his help.

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1 Introduction

1.1 DESY

DESY (Deutsches Elektronen Synchrotron) is one of the most important centers in the world for particle physics research. DESYs main site is in Hamburg in Germany but there is also a second site in Zeuthen near Berlin. DESY mainly works on particle physics and on photon science, for that DESY built several particle accelerators since its creation in 1959 like HERA or the future project European XFEL. The 2000 scientists working at DESY can use one of these facilities for their work but also work on international projects like ATLAS or the ILC.

Since the end of the e-p collider HERA there is no more particle physics experiment at DESY, but the facilities are now used for synchrotron radiation experiments. With the new XFEL under construction DESY will become the main center in the world for photon science and will be able to give access to a large spectrum of light sources to scientists from everywhere in the world. [1]

1.2 The International Linear Collider

The ILC (International Linear Collider) is an international project for an e^+e^- linear collider with up to 1 TeV center of mass energy. This facility is for the moment in a conception phase. The ILC should be a complement to the LHC (Large Hadron Collider) of CERN in Geneva. Indeed, unlike the LHC where the collisions are between protons, which are composite particles, the electrons and positrons are pointlike particles. This has many advantages, as the knowledge of the initial state. In the case of the proton, the energy is shared between its different components whereas in the case of the electron the energy is the one chosen by the operator.

One of the important reactions of the ILC is $e^+e^- \rightarrow HZ^0$, where one Z^0 boson is created in association to a Higgs boson, could help to define the mass of the Higgs boson, if it really exists. The expected mass of the Higgs boson (114 - 150 GeV) is on the scale of the ILC where the energy should reach 500 Gev to 1 TeV.

The ILC should also permit to study the top quark, the dark matter and SUSY particles if they will be discovered at the LHC. [2]

1.3 The chip SPIROC 2

Such a machine needs high technology in every field (detectors, production of positrons, data analysis, ...). My studies focused in particular on the front-end electronics for the hadronic calorimeter. The SPIROC (Silicon Photomultiplier Integrated Read Out Chip) is part of this electronics,

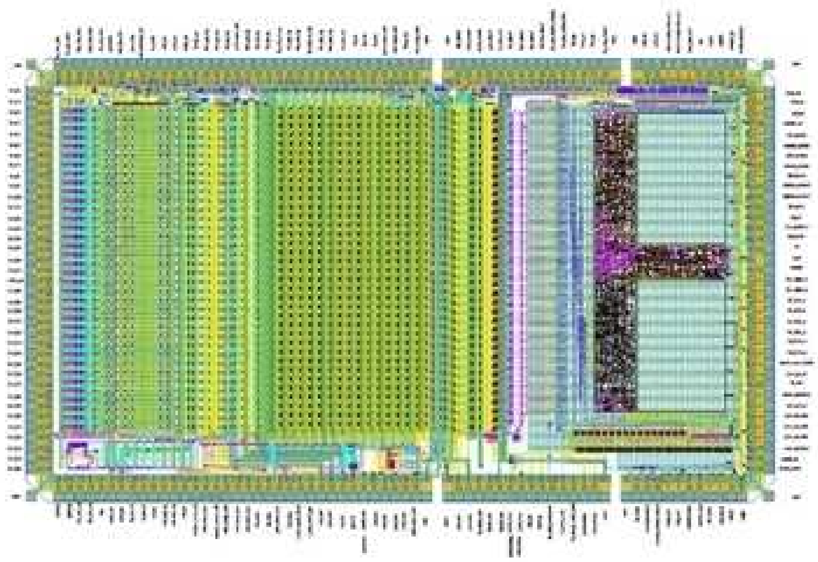

Figure 1: SPIROC 2 layout.

and is developed by the microelectronics group of the LAL (Laboratoire de l'accélérateur linéaire) at Orsay.

Unlike the detectors at the LHC, the electronics of the ILC will be placed directly in the calorimeter and not outside of it. This requires developments concerning the size of the circuit and the heat released by the chip. SPIROC has been designed in order to have a weak power consumption and a large dynamic range which goes from a few keV to hundreds of GeV.

SPIROC is a chip with 36 channels which allows to measure on each channel the charge from 1 to 2000 photoelectrons and the time. For each channel an analog memory array with a depth of 16 is used to store the time information and the amplitude measurement. An ADC is used to digitize the analog memory contents. The data are then stored in an internal RAM before being transfered and definitely stored. [3]

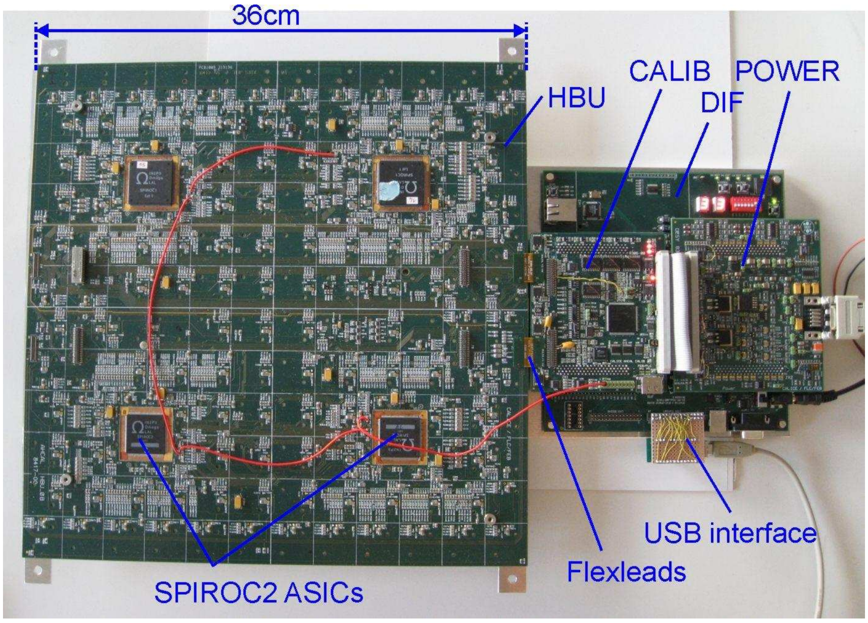

Figure 2: Top view of the module.

2 Purpose of my work

2.1 Modules, Testbeam

I have worked with two modules (Figure 2) with two SPIROC 2 chips on each one. These modules or HBUs (HCAL Base Unit) are part of the layer which will be included in the HCAL (Hadronic Calorimeter). On each HBU the two SPIROC 2 chips have their 36 channels linked to 36 scintillator tiles. We can use these modules for testbeam or LED measurements. The SPIROC chip is programmed by a Labview interface. The Labview slow control file is sent to the DIF (Detector Interface) which then programs the ASIC, such that we can choose the configuration of the chip that we want depending on which measurement we want to process. The data file is then sent to the computer and can be analysed. [4]

With the LED system the light is sent to the SiPM of each tile. We can also use direct charge injection to make a measurement. In this case we directly inject the signal in one channel with a pulse generator. This is a more precise measurement because the amount of charge injected in the channel by the pulse generator is well defined. Finally, thanks to DESY facilities, we also have access to a testbeam area where we can test our setup with a real 2 GeV electron beam. In this case we have a stage to move the module and to place the beam on a particular tile.

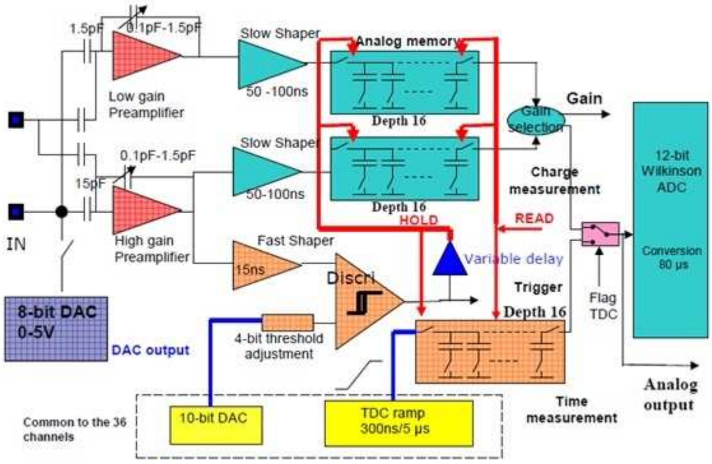

Figure 3: SPIROC analog scheme for one channel.

2.2 The autotrigger mode

The goal of my work is to test the SPIROC 2 chip in autotrigger mode, this means without any trigger coming from the outside. SPIROC 2 has been designed to be an autotriggered chip. The chip will decide by itself if there is an event or not, it doesn't need an external trigger indicating the occurence of the event.

For that we have to give to the chip a threshold value, that it knows which event it should keep. We give this value to the chip by choosing a DAC value in the slow control file. Then a discriminator compares this DAC value to the signal amplitude and if this amplitude is above the threshold the chip triggers. If the chip triggers, it puts the bit *Hit_Bit* to one in the read out file. The autotrigger is still working in external trigger mode so this Hit_Bit gives information about the autotrigger when we are using the external trigger. So this autotrigger mode gives us the possiblity to choose above which signal amplitude we want to trigger on.

On Figure 3 we have the analog part of SPIROC 2. We see the autotrigger part (with orange background) where the fast shaper signal is compared in the discriminator to the threshold.

This autotrigger mode has not been tested before. For the previous measurement we were using an external trigger for the chip. So I had to compare results with autotrigger with the results with the external trigger which we know that it works well. Then I also had to see if we really can choose the threshold value by changing the DAC value in Labview. During these investigations several other questions came up, which are described below.

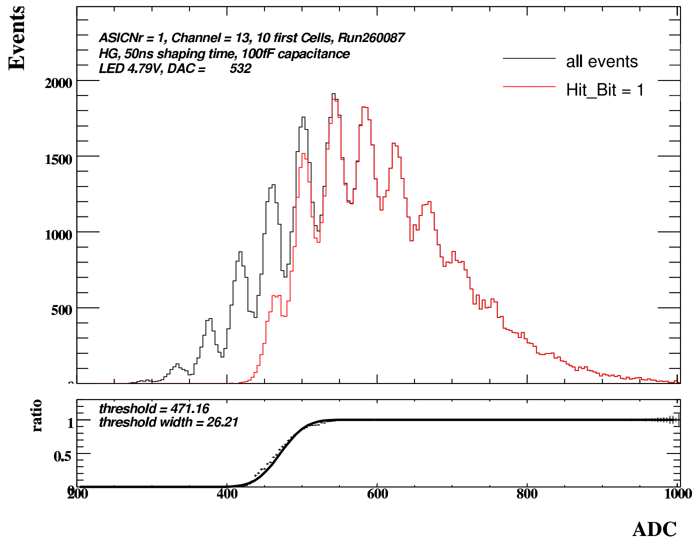

Figure 4: Comparison between external trigger and autotrigger for LEDs.

3 LED system

3.1 MIP-like LED signal

The first thing I have done to see if the autotrigger is working is comparing a MIP-like LED signal produced with LED light with the external trigger to the same signal but by looking only at the $Hit\_Bit = 1$ events, where the autotrigger fired (Figure 4).

On Figure 4 we see that above the threshold both triggers give the same result. This shows that the autotrigger really sees all the events and doesn't miss some. On this figure we also clearly see the threshold of the autotrigger.

3.2 DAC vs Threshold

I have repeated this measurement for several DAC values. Then by calculating the ratio of the two plots I was able to plot the curve of the DAC value versus the threshold in ADC counts (Figure 5). I have fitted this ratio with the function $0.5 * (Erf([0] * (x - [1])) + 1$ where Erf is the error function and [0] and [1] the two parameters of the fit. [0] and [1] give respectively the threshold width and the threshold.

This curve (Figure 5) tells us where we will cut the signal with the chosen DAC value. This curve is important because the goal of the autotrigger is to have a tunable threshold, so we really need to know which threshold belongs

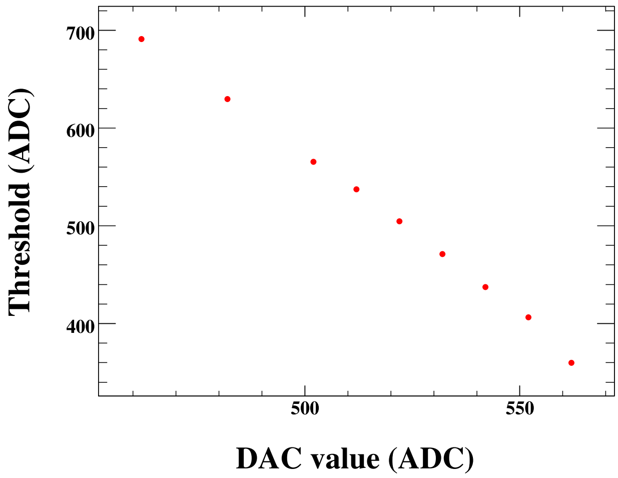

Figure 5: DAC value versus Threshold for LED signals.

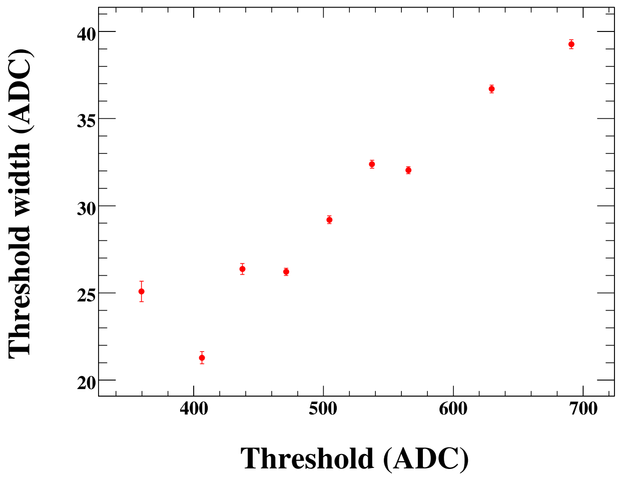

Figure 6: Threshold width versus Threshold for LED signals.

to the DAC value that I choose in Labview. On Figure 6 we can see that the width of the threshold is higher when the threshold is higher.

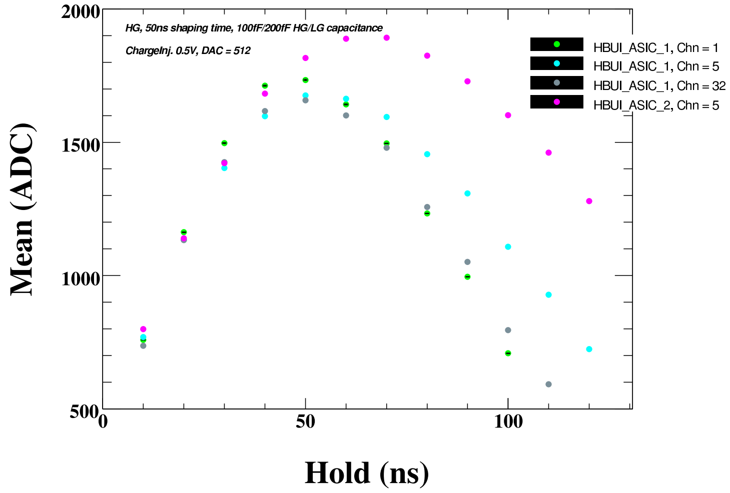

Figure 7: Holdscan for some channels of two ASICs.

4 Charge injection

4.1 Holdscan

The first thing to do to study the autotrigger is to find out at which time relative to the trigger signal the amplitude of the signal should be hold. For that we can choose, in Labview, the value of the hold time. This value, in ns, tells the ASIC where to select the value of the amplitude on the shaper signal. So we should find the hold value which gives the highest amplitude value for the signal. For that a holdscan has to be performed (Figure 7), where we scan a certain range of hold values and look at the mean of the signal to find the best value. We see on Figure 7 that the best hold value is almost the same for all the channels of one chip, but that this value can change from one chip to another (50 ns for asic0 and 65 ns for asic1). We didn't investigate all the 36 channels for both chips because of the time that this measurement takes.

Since we now know which hold value to choose for both chips we can look more precisely to the autotrigger by checking its linearity and its efficiency as a function of the injected charge.

4.2 Linearity and S-Curves

After finding the best hold value I have checked that the output signal amplitude using the autotrigger has a linear behaviour when we change the

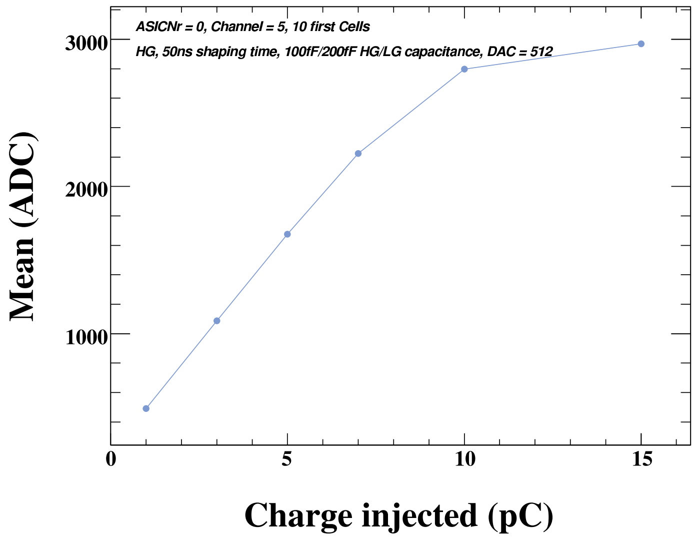

Figure 8: Linearity of the autotrigger as a function of the injected charge.

amount of injected charge (Figure 8). The curve is well linear up to 7 pC and then starts to saturate. 7 pC is much more than one MIP (1.6 pC) so the autotrigger is well linear in the range of interest.

Then I have investigated the efficiency of the autotrigger. The efficiency means how many events the autotrigger sees with respect to the number of events that we expected. We can do this efficiency measurement only with the charge injection because we exactly know how the signal that we sent to the asic looks. With the test beam for example we can't control how many photons are produced in the tile and how many pixels fire.

In order to make these S-curves, I injected a certain amount of charge into the chip and then take several measurements with changing DAC values in the slow control settings to see where the threshold for this amount of charge is (Figure 9).

The first information of these plots is that the threshold is well defined and narrow for a specific value of the charge. We need only one or two DAC values to go from zero to one. The second information is that the efficiency of the auto trigger is around 100% above the threshold. We now know that the autotrigger really triggers on all the events above the threshold.

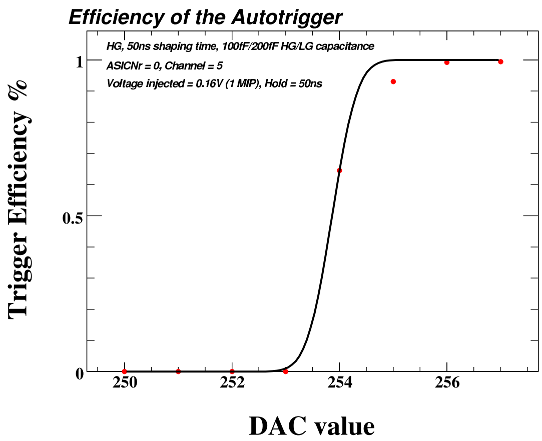

Figure 9: Example of S-curve.

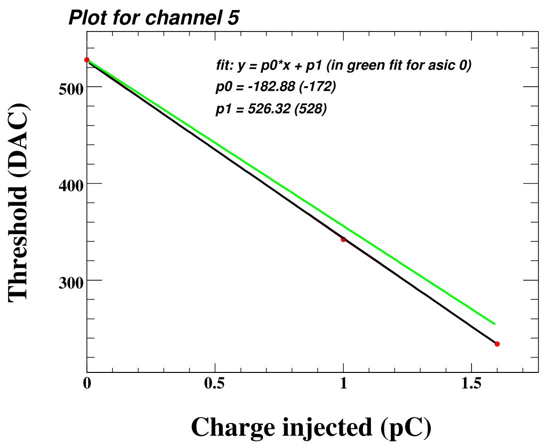

Figure 10: DAC value versus injected charge for both ASICs.

4.3 Charge vs DAC threshold

With all these different S-curves I have now the information about which DAC value corresponds to which signal amplitude. So I am now able to plot this information for both chips in order to compare them (Figure 10). We can see that the functions are similar for both ASICs.

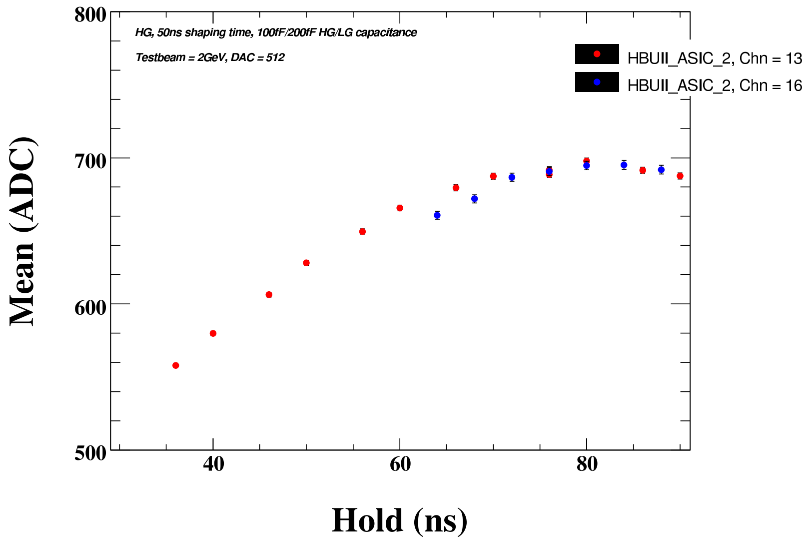

Figure 11: Holdscan with the beam for both ASICs.

5 Testbeam

5.1 Holdscan

Like for the charge injection I have started my measurement with the beam by doing a holdscan for both ASICs (Figure 11). For the beam the holdscan has a completely different shape and also a different hold value. But this value is the same for both ASICs (80 ns), even if we didn't check that for all the 36 channels.

5.2 Spectra

The Figure 12 shows an example of what gives results with the beam. In case of the beam we can't have the same number of events for each measurement because of the stability of the beam. So we need to rescale the histogram to compare them and that's why they didn't perfectly fit like in the case of the LED. We see here a typical SiPM single-pixel spectrum (in red) with the pedestal peak (around 280 ADC count) and some pixels. We also see here the influence of the threshold on the autotrigger spectra which is cut well behind the pedestal in the present case.

On this plot we already can see some problems of the autotrigger with the beam. First of all the *Hit_Bit* seems not to work properly like we see on Figure 12 that the *Hit_Bit* curve doesn't fit at all with the autotrigger

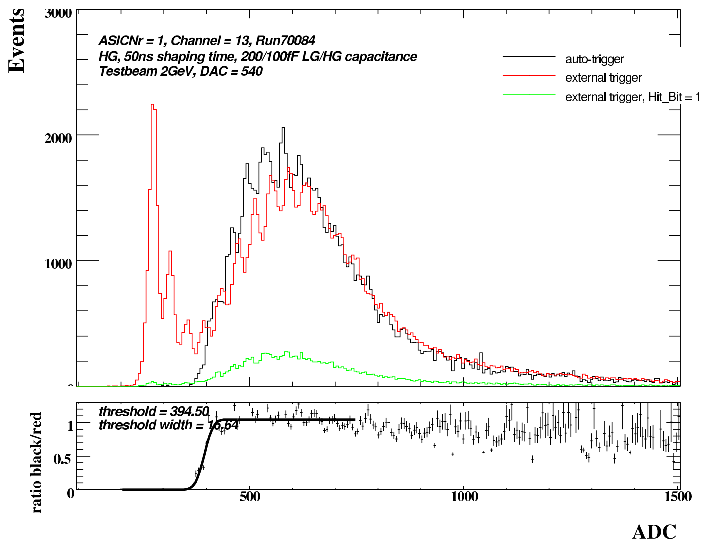

Figure 12: Example of plot with the beam.

curve. But this problem was expected from the people from LAL. The second problem is that the external curve and the autotrigger curve are shifted. I will discuss this second problem later.

5.3 Pedestal cut at 10^{-4}

We have seen that the threshold of the autotrigger is tunable, so we can choose where we want to cut the signal. We now need to define this value. We have two things to take into account:

- The MIP efficiency, so how many MIP events we still have after our cut.
- The noise trigger rate, so how many noise events we can accept in our results.

For the detector we define an acceptable noise trigger rate as a certain amount of noise hits per ILC event in the complete calorimeter. This can be converted into a ratio of the pedestal peak that we should cut. We define the acceptable ratio to be:

$$\frac{\int_{cut}^{\infty} \text{pedestal}}{\int_{0}^{\infty} \text{pedestal}} \leq 10^{-4}. \tag{1}$$

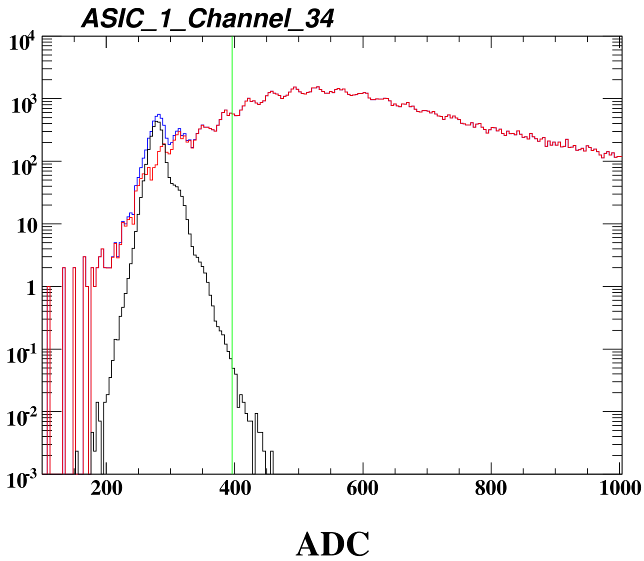

Figure 13: Pedestal histogram (in black) and the cut at 10^{-4} (in green).

To calculate this cut value we need a pedestal run with a very high statistics in order to see the tails of the pedestal and really be able to make a coherent ratio at 10^{-4}. We also remove the beam noise (the beam does not target to the module but some electrons still passed through the tiles) for this pedestal run by simulating it with a pulse generator for the coincidence trigger.

On Figure 13 we see the pedestal histogram (in black) on a log scale and in green the value in ADC counts where we should cut to have a ratio of 10^{-4}. We also see where this cut takes place on the MIP signal (in red).

I have done this study only for several channels for one of the ASICs. On Figure 14 we have the distribution of the value of the cut in ADC counts for all these channels.

After having found the value in ADC counts where we should cut the pedestal for each channel I am able to calculate the corresponding MIP efficiency. The MIP efficiency is defined like that:

$$\frac{\int_{cut}^{\infty} \text{MIP signal}}{\int_{0}^{\infty} \text{MIP signal}} = \text{MIP efficiency}. \tag{2}$$

This value tells us how many MIP events we loose if we want such a good noise ratio. If we loose too many events then the energy resolution of the calorimeter will become worse. In order to have the real MIP efficiency we need to have only MIP events in the histogram, for that we need to subtract

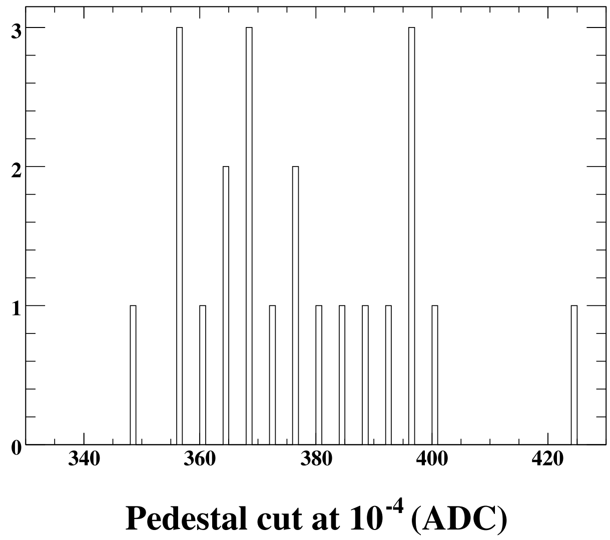

Figure 14: Distribution of the pedestal cut for several channels.

the pedestal events. I have subtracted the pedestal events by using the same pedestal histogram that I used to calculate the pedestal cut. I have rescaled this histogram to the scale of the MIP histogram. To find the scale factor I have estimated the amplitude of the pedestal in the MIP histogram by calculating the difference between the amplitude of the pedestal peak and the amplitude of the next minimum. I have then multiplied this difference by a factor corresponding to the part of the pedestal gaussian that is hidden under the MIP events. We can see the result of this subtraction on Figure 15 where we have the MIP histogram before (in blue) and after (in red) subtraction of the pedestal (in black).

On Figure 16 we have the distribution of the values of the MIP efficiencies for all these channels. For most of the channels the MIP efficiency is around 95%, which is a good result.

Finally we have to choose where we want to put the threshold, if we want a high MIP efficiency or a low noise trigger rate. We also should take into account that we only can choose one DAC value for all the 36 channels, so the results can't be the same for every channel. This will be changed in later versions of the chip.

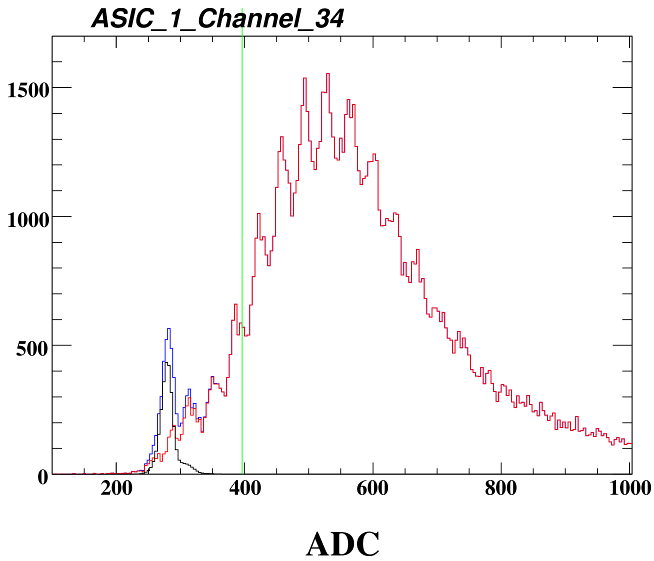

Figure 15: Result of the pedestal subtraction.

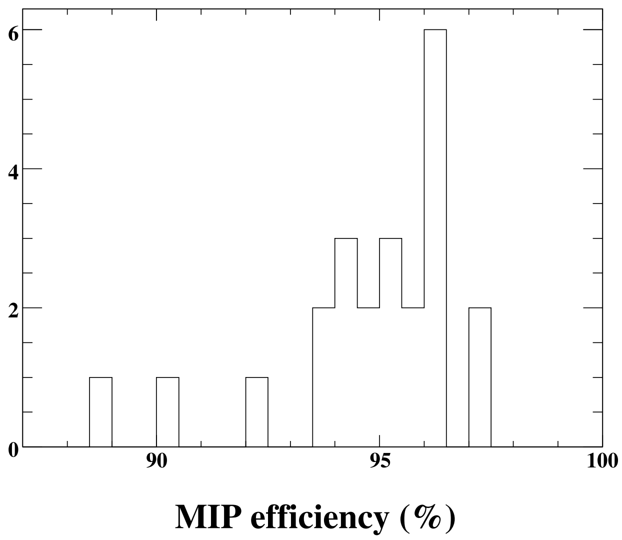

Figure 16: Distribution of the MIP efficency for several channels.

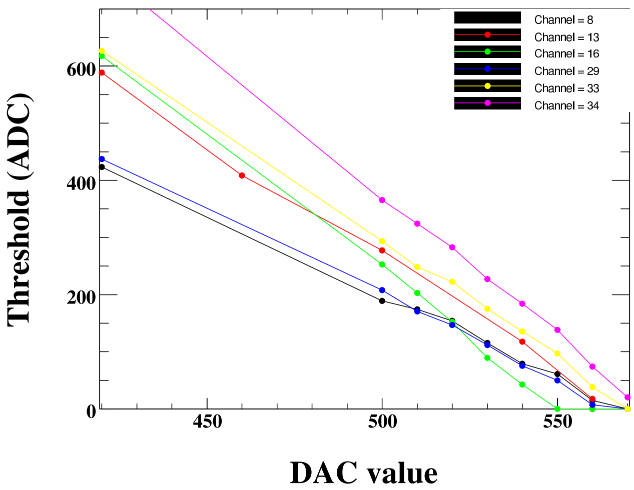

Figure 17: DAC value versus threshold (relative to the pedestal).

5.4 DAC vs threshold

With the pedestal cut study we have found to which value of the ADC we should put the threshold of the autotrigger. But we didn't directly choose the threshold in Labview but only the DAC value. That's why we should find the relation between the DAC value and the threshold in order to know which DAC value we should put to really cut where we want.

In order to have this relation I have done the same study than with the LED system. I have taken several measurements with different DAC values and have calculated the ratio between these measurements with autotrigger and a MIP signal taken with the external trigger.

On Figure 17 we can see the results of these measurements. The threshold value on these plots is relative to the pedestal value, this means the ADC value minus the position of the pedestal in ADC counts. Now we can compare the different channels which don't always have the same position for the pedestal.

We have seen that the pedestal cut is distributed around 380 ADC counts, so since the pedestal position is around 280 ADC counts our region of interest is for a threshold around 100 ADC counts. In this region the curves are less dispersed (between 530 and 560 for the DAC value) and of course this dispersion should be compared to the dispersion of the pedestal cut value.

So we now have all the information to be able to choose the value of the threshold that we want and the corresponding DAC value. Nevertheless as long as we cannot choose the threshold for each channel individually, the spread might be too large to find a good compromise between purity and efficiency for all the channels simultaneously.

5.5 Amplitude shift in Autotrigger mode?

We have already seen in section 5.2 on page 13 that the autotrigger histogram is shifted relative to the one of the external trigger (Figure 12 and Figure 19). The amplitude is lower with the autotrigger since the histogram is shifted to the left. We have investigated this shift by checking several things:

- We have checked if the gain could have changed. The gain is defined as the distance between two pixels. But the shift is constant so the gain is still the same in both cases and the shift doesn't depend on the amplitude.
- We have checked if the width of the shaped signal has changed, but as you see on Figure 18 the shaped signal didn't change when we use the autotrigger, and even for different DAC values.
- The constant shift may come from a pedestal shift, which can't be seen on the oscilloscope.

The underlying electronical reason for this effect needs further investigation.

Another behavior of the autotrigger can be seen on Figure 19. Here you see that for low values of the threshold we have a huge number of noise events. For this problem we may be safe depending on the DAC value that we choose with the pedestal cut study. But we have seen that the DAC vs Threshold curves have a certain spread and if we choose a too high DAC value some channels may have a threshold which gives such a huge number of noise events. So we also have to consider this when we will choose this DAC value or add to the chip the possibility to choose one DAC value for each of the channels.

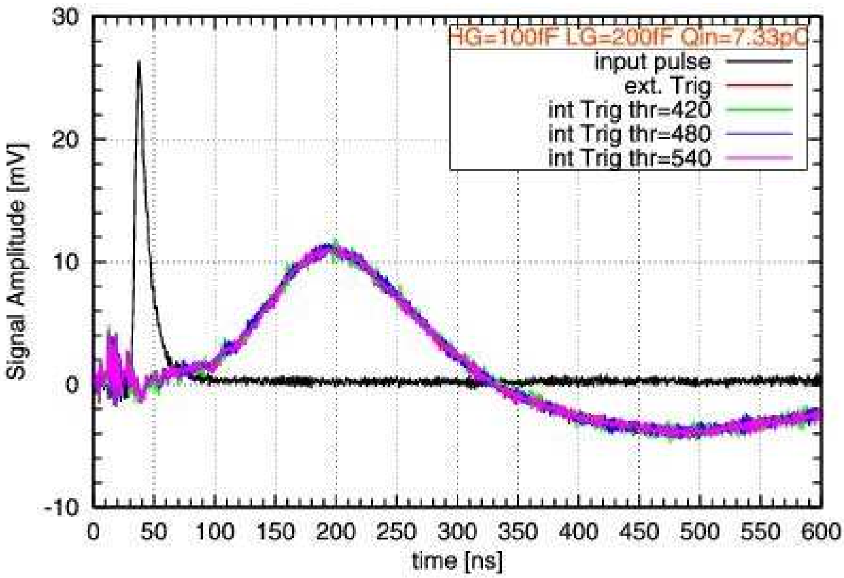

Figure 18: Shaped signal in different trigger configurations.

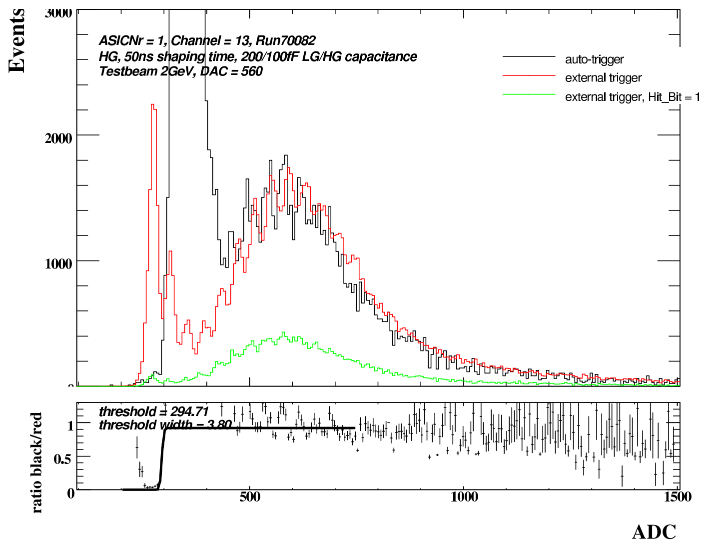

Figure 19: Overview of the problems of the autotrigger.

6 Conclusion

During these three months at DESY I have started the tests of the autotrigger of the chip SPIROC 2 for the HCAL of the ILC. I have shown that the autotrigger mode is working and that we can choose the threshold that we want. By using different kinds of measurements we have been able to show, step by step, different features of the autotrigger. We also have found some issues that should be explained:

- Why does the *Hit_Bit* seem to work with the LED and not with the beam?
- Where does the amplitude shift come from?

These issues should be answered in order to be able to correct these problems in the next version of the SPIROC chip.

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A DESY Summer Student Programme

During my work at DESY I also participated in the DESY Summer Student Programme. During this programme undergraduate students in physics or related natural science disciplines have the possibility to participate in the research activities of the laboratory. While the work in the groups is the main activity, there is also a series of lectures (given in English) related to the research done at DESY. We have also visited the accelerators and experiments at DESY. During the time of this programme I continued to work on my project but I have also attended the lectures during the mornings. These lectures gave me an overview of the Standard Model that we already saw during the Magistère. But there were also less theoretical lectures about accelerators and detectors that we didn't saw during the Magistère. We also had an overview of DESYs experiments like HERA or the XFEL which allowed me to discover this huge laboratory. I also learned something about less commonly teached fields of particle physics like computing and simulation. I think that this experience will help me for my next year of master where the lectures will be given in English and will also deal with particle physics and accelerators.