SILICON PHOTOMULTIPLIERS

Introduction

In our lives, we can see photons and photodetectors everywhere: photons are emitted by our electronic devices like mobile phones and TV, or are used in solar panels. We can find photodetectors also in medicine, or we can study photons in physics. One kind of photodetector is the Silicon Photomultipier.

Characteristics of Silicon Photomultipliers

A Silicon Photomultiplier (SiPM), as the name suggests, is a device made of Silicon, that is a semiconductor. It is a matrix of pixels made of a P-N junction that is P-type and N-type silicon put together to form a depleted region. In this region an incoming photon is absorbed by the silicon, it generates a electron-hole pair, which is then accelerated thanks to the high electric field. These accelerated charges hit against other silicon atoms creating other electron-hole pairs and thus generating an avalanche of electrons. The total number of electrons at the end of the avalanche depends on the voltage applied, on the characteristics of the SiPM itself and so on, but on average is about 10^6.

SiPMs have several important characteristics: two of them are the Gain and the Breakdown Voltage (Vbd). The gain is the number of electrons collected after the avalanche; the Vbd is the minimum bias voltage at which there is an avalanche. So we can detect a signal only if our SiPM is biased at voltages higher than the Vbd.

Other fundamental characteristics of a SiPM are the dark count rate (DCR) and the dark current. The DCR is the number of dark pulses, caused by electrons thermal excitation, that are generated in a second in a SiPM, while the dark current is the current generated by those electrons.

SiPMs can be used in radiation hard environment, but their characteristics will change. We call “fluence” the total number of neutrons passing trough one centimeter squared of material.

Experience in the lab

To characterize the SiPM, we measured the gain as a function of the voltage. We used a SiPM connected to a voltage supply and an oscilloscope to detect the signal.
The signal from the SiPM can be seen as a fast rise (few picoseconds) followed by an exponential decay lasting hundreds of nanoseconds. To calculate the gain we measured the height of the peak corresponding to a single photoelectron (that is, an avalanche generated in one single pixel), divided by the position of the baseline [1], as a function of the voltage.
[1] Gain = $(Peak_1 - Peak_0)$ x conversion factor/ q
where q is the elementary charge ($1.6x10^{19}$C).
Finally, we extracted the Vbd at a temperature of +20°C, using a linear fit.

We also performed a current-voltage (IV) measurement at a temperature of +20°C and at fluence 10^9 n_{eq}/cm^2, using a setup called “Cold Chuck” which allowed us to keep the temperatureand the humidity under control.

Cosmic rays

Cosmic rays are particles coming from the outer space. When they enter our atmosphere, due to the increase of density, they lose energy and produce other particles creating a “shower” of particles. Cosmic rays are composed by different types of particles with different energy. Some particles are charged and others are neutral this influences the way they reach the Earth. Neutral particles such as neutrinos, for example, have a straight path and they have almost no interaction, while charged particles can be deviated depending on how fast and energetic they are.

We have detected muons which are very penetrating particles. They have charge -1 (like the electron), they have a mass ~106 MeV/c2, they have no sub-structure and their lifetime is around 2.2 μs . Even if they have a very short lifetime we are able to detect muons from the ground because they experience special relativity. As a matter of fact, thanks to Einstein we know that if the speed of a particle is very closed to the speed of light it experiences a contraction of space and/or an expansion of time.

To detect muons with SiPMs it is needed a scintillator in which the energy deposited by the particles is converted into photons.

Experience in the lab

We performed an experiment in order to detect cosmic muons. We used a plastic scintillator coupled to a SiPM. First we found the operational voltage with a voltage supply (the operational voltage is the voltage needed to the SiPM to work properly). Then we chose different trigger levels in which to operate. The trigger is the level of energy in which we want to scan the signals. In this way we counted the number of muons below the trigger threshold in one minute.

With our data we plotted the results using Python, a programming language that we learned to use. From number of counts versus trigger level plot, it comes out that with low trigger level we can see only dark count rate coming from the SiPM itself, while increasing the trigger level we trigger at higher energy, meaning that those are photons coming from the scintillators produced by particles. The theory says that we should have detected 1 muon/cm^2/min, but in our results we have a lower rate. Since the number of muons detected at sea level depends on atmospheric conditions one possible explanation is related to this, but we did not have time for further investigation.

Conclusions

During this week at DESY we have discovered what Silicon Photomultipliers are and we can split our work into two main parts. In the first one we have characterized SiPMs calculating gain and breakdown voltage and giving a real contribution with new measurements useful for the group. In the second experience we detected the cosmic muons coupling a scintillator and a SiPM, and measuring the muon flux.

Outlook

Unfortunately we had a short time for doing all the things we would have liked to do. Regarding the measurements with the SiPMs we would have liked to perform more measurements with the Cold Chuck at different temperatures, while in the muon detection experiment it would have been nice to have a deeper understanding of the muon measurements.