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Magnetic Field Dependence Studies for Silicon Photomultiplier

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Abstract

The Silicon Photomultiplier (SiPM) is a relatively new semiconductor photodetector, which has comparable performance properties to conventional vacuum multi-anode Photomultiplier. One possible application for this new kind of photodetector is the usage in calorimeter detectors for a linear collider experiment. There the SiPM has to work in a high magnetic field of about 4 T. The motivation for this study is to look for any magnetic field dependence on the SiPM. Several measurements with and without magnetic field have been performed to investigate the SiPM performance properties. No changes in the SiPM behaviour due to the magnetic field have been observed within 2 %, which is comparable with the systematic uncertainty.

1 Silicon Photomultiplier (SiPM) description

The Silicon Photomultiplier (SiPM) is described in details in ref. [1–3]. The SiPM is a new type of photodetector based on silicon. It is a combined product of MEPhI [1] and the "Pulsar" enterprise in Moscow and has been developed in cooperation with DESY [2]. In figure 1 a schematic view of a SiPM is shown.

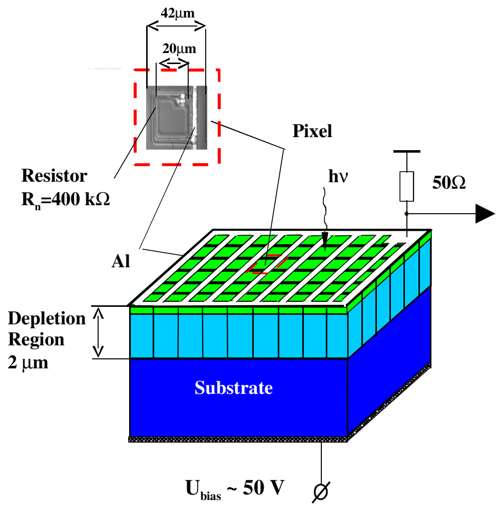

Figure 1: *Schematic view of a multipixel Silicon Photomultiplier. One SiPM covers the area of 1 mm^2 and consists of up to approximately 10^3 silicon micro pixels. The given pixel dimensions are only valid for a total number of pixels of 576.*

One SiPM covers the area of 1 mm^2 and consists of approximately 10^3 silicon micro pixels. Each of these pixels is a binary device operated in Geiger mode and provides always signals of equal amplitude. The signal from the whole SiPM is the sum of all pixels output. The combined signal from all pixels is proportional to the light intensity and therefore the SiPM is an analogue device. The Geiger mode operation leads to a large multiplication of the primary electron-hole pair of approximately 10^6. Due to the high multiplication factor a high electric field of (3-5)·10^5 V/cm in the 2.0 μm thick depletion region is needed to collect the produced pairs. Although the individual pixels are separated from each other, there is still the possibility to have optical crosstalk between the pixels. During the active time of one pixel electrons are produced in the Geiger discharge. These electrons produce photons (10^5 photons / electron), which then can initiate a discharge in a neighboring pixel. The photon detection efficiency of 10 - 20 % in a wavelength range between 400 and 700 nm and the high gain of 10^6 at a working bias voltage of approximately 60 V provide the SiPM with an output signal comparable to that of a conventional vacuum Photomultiplier tube. It also provides the possibility to resolve the photoelectron structure of the output signal, which is shown in figure 2, if a preamplifier is used additionally.

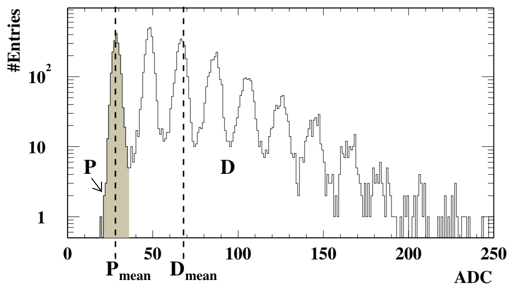

Figure 2: *SiPM pulse height spectrum D with photoelectron structure and mean value D_{mean}. The grey area indicates the pedestal P with mean value P_{mean}.*

The main noise source is the dark current, which originates from thermally produced charge carries. The dark current produces in the SiPM a signal of the same amplitude as the signal of one single photoelectron with a rate of about 1-2 MHz at room temperature. Another feature that restricts the application for SiPM is the dynamic range limited by the finite numbers of pixels. This leads to saturation effects when all pixels of a SiPM are fired.

2 Tile hadronic calorimeter option for a linear collider

A detector for a linear collider uses calorimeters to measure together with the inner tracking

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system the energy of particles and jets in the full solid angle around the interaction region. One option [4] for the calorimeter system is a combination of electromagnetic (ECAL) and hadronic (HCAL) sandwich sampling calorimeters inside the magnet coil, which has a diameter of 6 meters. One proposed design for the HCAL is a tile sandwich calorimeter with analogue readout. It consists of stainless steel absorber plates and scintillator tile detector plates. The magnetic field in the detector will be 4 Tesla. Therefore a readout with conventional vacuum Photomultiplier tubes (PMT) near the detector is not possible. One possible solution is to send the produced light from the scintillator using wavelength shifter fibres (WLS) and clear fibres outside the magnetic field, and place there a readout based on PMT. Another solution is to use different photodetectors like Avalanche Photodiodes (APD) or Silicon Photomultiplier (SiPM), which are insensitive to the magnetic field and place the readout inside the detector. The advantages of the second solution are manifold. A greater light yield due to shorter light transport is realised. And the number of fibres and fibre connections is minimised. More details about one proposal for the detector can be found in ref. [4].

3 SiPM magnetic field studies

The motivation for the following tests is to study any possible magnetic field dependence on the SiPM response. Several properties of SiPM with and without a magnetic field are measured.

3.1 Test setup

For the tests SiPMs with a pixel size of 42x42 μm^2 and a total pixel number of 576 on an area of 1 mm^2 are used. The setup consists of a long tube where on one end a SiPM is placed, which is connected over a preamplifier to the power supply and the readout. The preamplification is needed to resolve the photoelectron structure. A charge sensitive preamplifier with an amplification factor of approximately 27 is used. The preamplifier provides the possibility to switch the amplification factor to 1. Therefore it is possible to do measurements with and without preamplification without applying changes to the readout chain. The SiPM is illuminated by blue LED light coupled over a clear fibre. The LED signal is monitored with a photodiode.

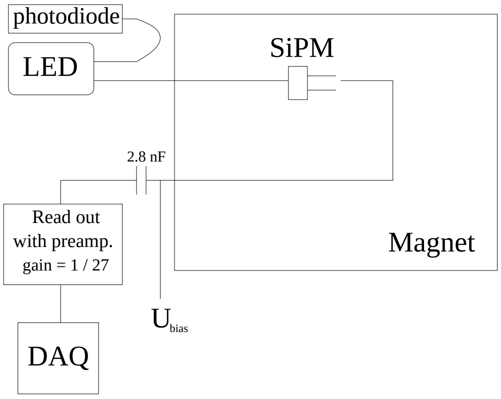

Figure 3: *top: Picture of the 5 Tesla magnet available at DESY, bottom: schematic view of the test setup.*

Figure 3 shows the tube within the superconducting 5 Tesla magnet [5], which is available at DESY. The magnet is 190 cm long and has an inner diameter of 28 cm. The magnetic field can be varied between 0 and 5 Tesla and has a homogeneity of 2 % in the center of the coil.

In the following the performed measurements are discussed and first results are shown.

3.2 SiPM dark current

When the SiPM signal is measured in absence of light the only source of signal is dark current. A scan of the dark current versus bias voltage with and without magnetic field is shown in figure 4.

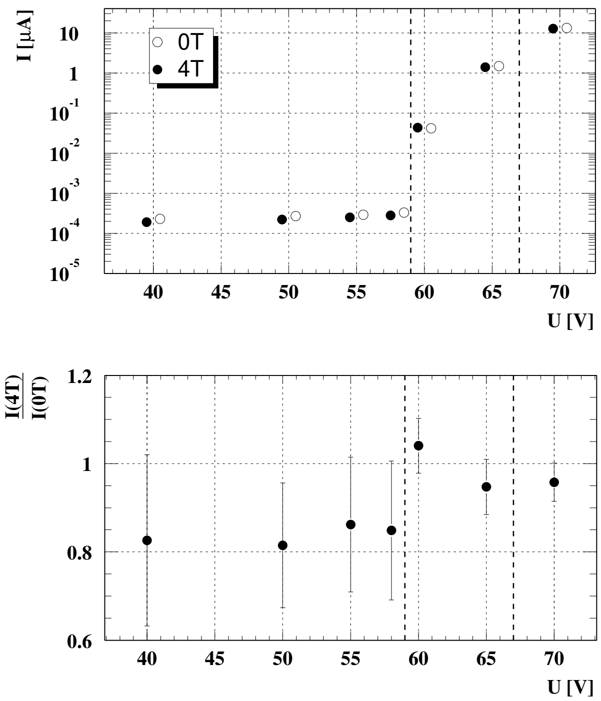

Figure 4: *Dark current measurement for 0T and 4T, absolute (top) and relative value (bottom).*

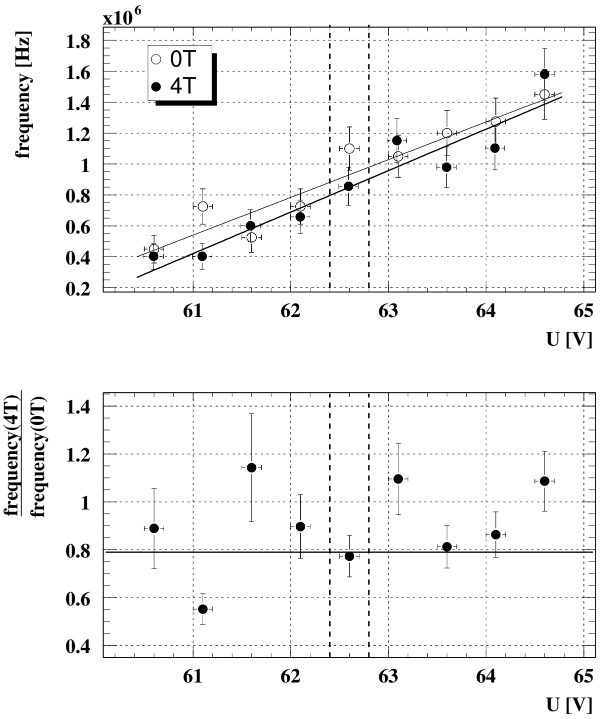

Figure 5: *Dark current rate measurement for 0 T and 4 T, absolute (top) and relative value (bottom).*

In the bottom plot of figure 4 the ratio of the two measurements is shown. The large uncertainties are mainly due to electronical noise at the measuring station. The steep rise of the dark current above 60 V indicates the range of operation voltage. Above 60 V the variations caused by the magnetic field are below the 5 % level which is the accuracy of these measurements.

3.3 SiPM dark current rate

The rate of the dark current is obtained in absence of light by counting the number of signals above a threshold in a fixed time window (e.g. 4 μs). The threshold has been chosen as one-third of the amplitude of a single photoelectron signal. This type of measurement is done on the scope screen and is affected by low statistics.

The dark current rate measurements for 0 T and 4 T are shown in figure 5. Both graphs for 0 T and 4 T show the same trend. The working bias voltage for this SiPM is fixed at 62.6 V for which the dark current rate is about 1 MHz. The quoted uncertainties are statistical only. The fluctuations of the points in the bottom plot of figure 5 are purely statistical and do not show effects of magnetic field dependence.

3.4 SiPM gain

One of the most important properties of SiPM is the gain. The gain is proportional to the distance between neighboring photoelectron peaks (figure 2). As mentioned before it is necessary to use a preamplifier in the readout chain to achieve a resolution which is good enough to resolve the photoelectron signal. To measure

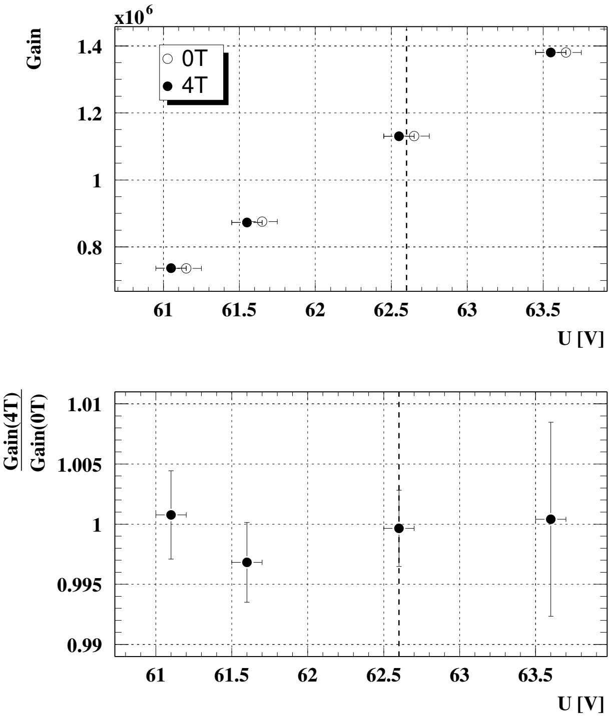

Figure 6: *Gain measurement for 0T and 4T, absolute (top) and relative value (bottom).*

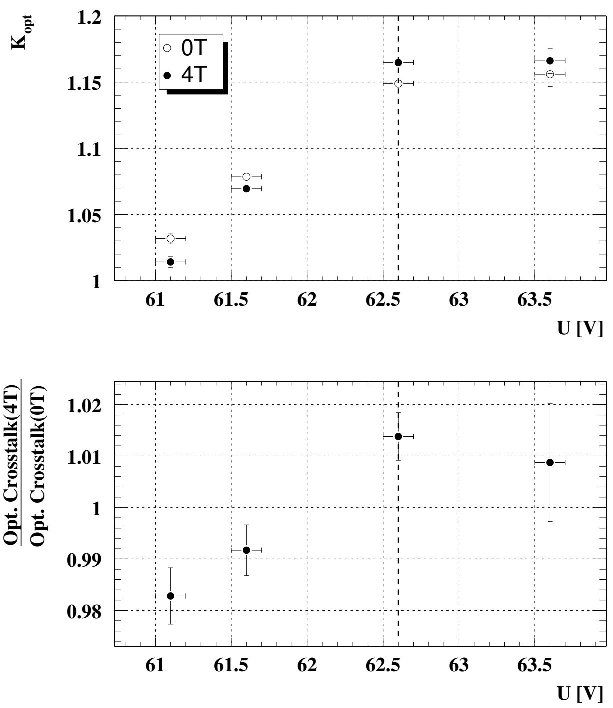

Figure 7: *Crosstalk measurement for 0T and 4T, absolute (top) and relative value (bottom).*

the gain of the preamplified SiPM, signal spectra are recorded for several bias voltages. After determing the distance Δ between the first photoelecton peak and the pedestal in ADC channels, it is possible to calculate the gain according to the following equation,

$$gain = \frac{\Delta \cdot \frac{charge}{ADC\ channel}[C]}{e[C] \cdot preamp.\ factor},$$

where

$$\frac{charge}{ADC\ channel} = 0.25\ pC$$

and

$$preamp.\ factor = 27.$$

Note that the quantity $\frac{charge}{ADCchannel}$ is dependent on the readout system.

The gain for 0 T and 4 T is shown in figure 6 as a function of bias voltage. It is visible, that the gain is strongly dependent on the bias voltage. At the chosen bias voltage of 62.6 V the SiPM has a gain of $1.1 \cdot 10^6$. The gain is independent of the magnetic field.

3.5 Optical crosstalk

The optical crosstalk is the probability that a Geiger discharge in a fired pixel, also fires one or more neighboring pixels. Defining the total signal distribution in figure 2 as D and the noise distribution (the first peak of D) as P, then the optical crosstalk can be monitored according to the following equations.

$$K_{opt} = \frac{A_{phy}}{A_{pois}},$$

with

$$\begin{aligned} A_{phy} &= \frac{D_{mean} - P_{mean}}{\Delta}, \\ A_{pois} &= \ln \frac{\int D}{\int P}. \end{aligned}$$

Only the quantity A_{phy} is sensitive to optical crosstalk, since the mean value of the distribution is shifted to higher values for larger crosstalk while the area, which enters A_{pois}, stays constant. Therefore, the ratio of these two quantities should change if the crosstalk is magnetic field dependent.

In figure 7 it is shown that the crosstalk is dependent on the applied bias voltage but not on the magnetic field with a precision of 2 %.

3.6 Magnetic field dependence of SiPM signal for different light intensities

This measurement addresses the magnetic field dependence of the SiPM signal for different light intensities. The LED light intensity is varied over a large range. Measurements are performed with and without preamplifier for the same light intensity to estimate a systematic uncertainty. The signal amplitude of SiPM and photodiode (PIN) are recorded at 0 T and at 4 T.

No change of the SiPM signal is observed with and without magnetic field applied for different light intensities. In figure 8 three ratios of measurements with and without magnetic field are shown. The closed circle represents a measurement with relatively low light intensity, which corresponds to $\sim$ 30 photoelectrons and with preamplified SiPM signal. The star represents a measurement with the same light intensity but without using the preamplifier. The open square is a measurement also without preamplification but with $\sim$ 6 times higher light intensity, which corresponds to $\sim$ 200 photoelectrons. This measurement gives an estimate of the systematic uncertainties using the variation of the photodiode. The assigned systematic uncertainties is 2 %.

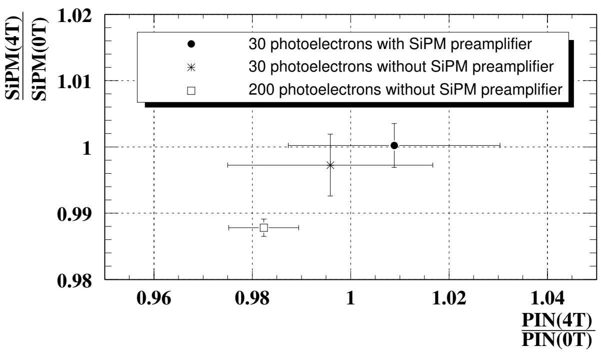

Figure 8: *SiPM signal amplitude for various LED light intensity compared to the change in the photodiode (PIN) amplitude.*

3.7 Magnetic field dependence of SiPM signal

For this measurement the optimal bias voltage of 62.6 V is applied and the LED light is fixed to an intensity, which corresponds to $\sim$ 200 photoelectrons. With these constant parameters the magnet is ramped down from 4 T to 0 T.

In figure 9 the ratio between SiPM signal with and without magnetic field in the range between 0 T and 4 T is shown. The black points correspond to the SiPM and the open points to the photodiode measurements. The photodiode reports a constant signal at the 1 % level.

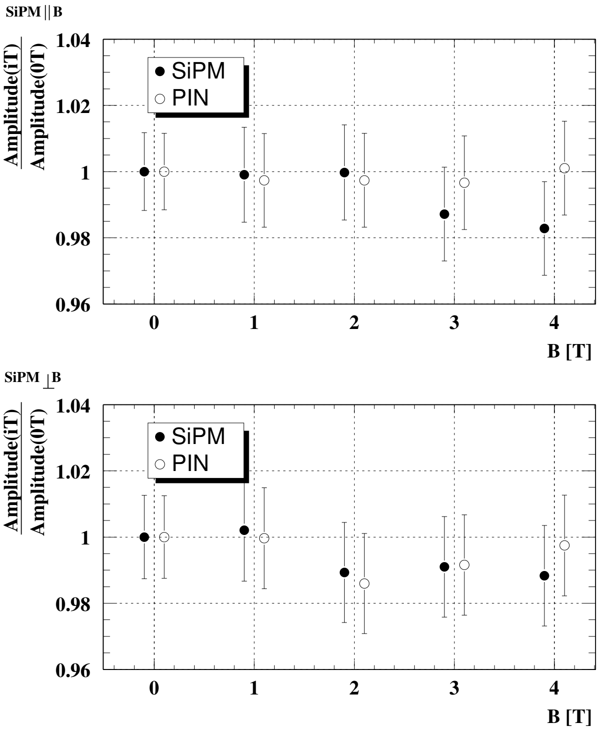

Figure 9: *Magnetic field dependence of SiPM signal for a fixed LED intensity, normalised to zero field. The orientation of the magnetic field is parallel (top) or perpendicular (bottom) to the SiPM active area.*

The SiPM signal is corrected for this light fluctuations. This measurement is performed for a parallel and perpendicular orientation of the SiPM with respect to the magnetic field. In both orientations no change in the SiPM signal output is observed at the 2 % level. One should note that the total signal depends on the gain, the efficiency and the crosstalk.

4 Conclusions

Several measurements to determine the SiPM properties and their dependence on the magnetic field have been performed. All possible changes are within a range of 2 % comparable to the systematic uncertainty. Therefore, it is possible to conclude that there is no magnetic dependence of the SiPM signal at the 2 % level.

References

[1] G. Bondarenko, P. Buzhan, B. Dolgoshein, V. Golovin, E. Guschin, A. Ilyin, V. Kaplin, A. Karakash, R. Klanner, V. Pokachalov, E. Popova, K. Smirnov, NIM A442, 187 (2000) and references therein.

[2] P. Buzhan, B. Dolgoshein, L. Filatov, A. Ilyin, V. Kantzerov, V. Kaplin, A. Karakash, , F. Kayumov, S. Klemin, A. Pleshko, E. Popova, S. Smirnov, Yu. Volkov, Proceedings of the 7th Internaional Conference on Advance Technology & Particle Physics, 717 (2002).

[3] P. Buzhan, B. Dolgoshein, L. Filatov, A. Ilyin, V. Kantzerov, V. Kaplin, A. Karakash, F. Kayumov, S. Klemin, E. Popova, S. Smirnov, NIM A504, 48 (2003).

[4] Tesla Technical Design Report, Vol. 3,4, DESY 2001-011, March 2001.

[5] E.Gadwinkel. et al., Advances in Cryogenic Engineering, Vol. 49, 50.