SiPM Classification of the Pre-Production GCT Camera of CTA

SiPM Klassifikation der Pre-Production GCT Kamera von CTA
Master-Thesis von Ben Gebhardt aus Heidelberg
Tag der Einreichung:

1. Gutachten: Dr. Richard White (MPIK)
2. Gutachten: Prof. Jim Hinton (MPIK)
3. Gutachten: Prof. Tetyana Galatyuk (TU DA)

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Erklärung zur Master-Thesis

Hiermit versichere ich, die vorliegende Master-Thesis ohne Hilfe Dritter nur mit den angegebenen Quellen und Hilfsmitteln angefertigt zu haben. Alle Stellen, die aus Quellen entnommen wurden, sind als solche kenntlich gemacht. Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

Darmstadt, den 28. Februar 2017

(B. Gebhardt)

1 Results

Preliminary results chapter
In this chapter, I will list the final results per device in a list of measured criteria. At the end I will conclude with a comparison between devices and to the results from other groups.

1.1 Hamamatsu S12642

The Silicon Photomultiplier by Hamamatsu Photonics designated S12642 is a 3 mm by 3 mm device. One array of pixels consists of 256 pixels, 4 of which are electrically tied togother to form a 6mm by 6mm superpixel respectively. This practise is necessary for the pre-production camera CHEC-S, because the focal plane is mechanically designed to house 64 6mm^2 pixels, connected to the target modules. Furthermore I expect this to have an influence on my results due to electrical crosstalk, but this is only of minor concern due to the following. My measurements of the CHEC-S tile concentrate on the array as an as-is device. This means all results, influenced by external factors outside the actual SiPMs physics, are valid on the assumption, that the way I was conducting the measurements is the way the Photomultiplier will later be incorporated into the camera. On that ground, deviations of my results from the results of other groups and the manufacturer itself are expected. To clarify this further, I expect, for example, that the tests done at Hamamatsu Photonics where conducted on a single 3mm by 3mm pixel, not an array of 256 pixels, where 4 are tied together. Also divergence of shaping and amplification electronics between the groups will result in some differences.

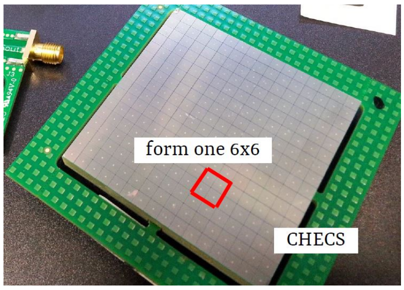

Abbildung 1: CHEC-S tile

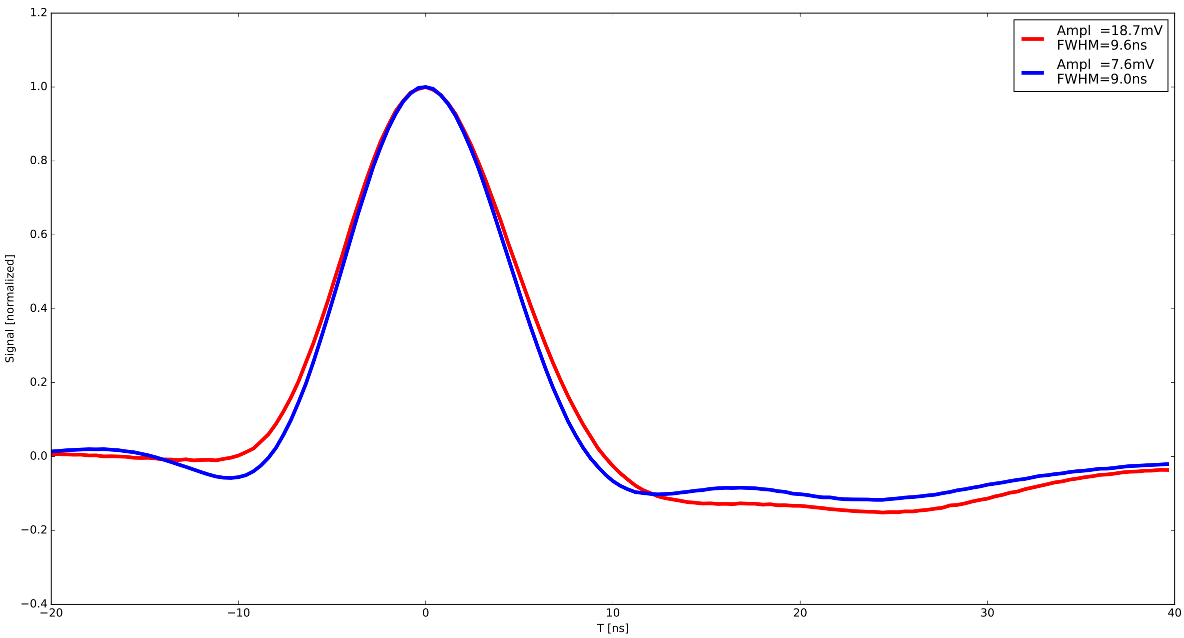

Abbildung 2: The average pulse shape of the 1photoelectron in blue and the 2photoelectron pulse in red of HPK S12642 at 25° C and 67.8V, which is around the proposed operating point. Both pulses are averaged over »1000 events and normalized to illustrate possible differences in pulseshape resulting from the utilized shaping electronics. Both pulses have a FWHM of around 10ns and are nearly free of ringing. The resulting average amplitude of the 1p.e. pulse is later used to calculate the Gain in [mV/p.e.] instead of [V*IntWin] by cross-referencing the 1p.e. amplitude at multiple bias-voltages.

1.1.1 Gain

As descibed above, the average pulse shape fig(2) is used to convert the relative gain from the analysis procedure to an absolute gain in sensible units. This is necessary, because the analysis aims to use pulse-area rather than -height. In Figure (3) (left) the relative gain is shown, the right side shows the gain after conversion. A lower gain with increasing temperature is expected and described in detail in the chapter (physics of SiPMs i guess). In short, increased lattice movement due to higher temperature hinders photoelectron transport. The effects visible at extreme bias-voltages at both ends are analysis related. The gain of a SiPM is expected to be linear over bias-voltage at a constant temperature. In the lower regime at Vb 66.5V my analysis method struggles to pick up pulses, because of the low gain compared to the noise. Depending on the chosen peak-finding threshold I expect the analysis to interpret noise peaks as 1p.e. peaks at an increasing rate, the lower the overvoltage is. This is visible in the sudden break in linearity at 30° C and 35° C , where the gain is almost in a plateau, due to this effect. At the highest bias-voltages the influence of the noise is similar. The point at Vov 5V,which is way over the proposed point of operation at Vov 3V. The same threshold is again counting noise peaks as 1p.e. peaks, but due to the abundance of 1p.e. pulses this just results in an apparent lowering of the gain.

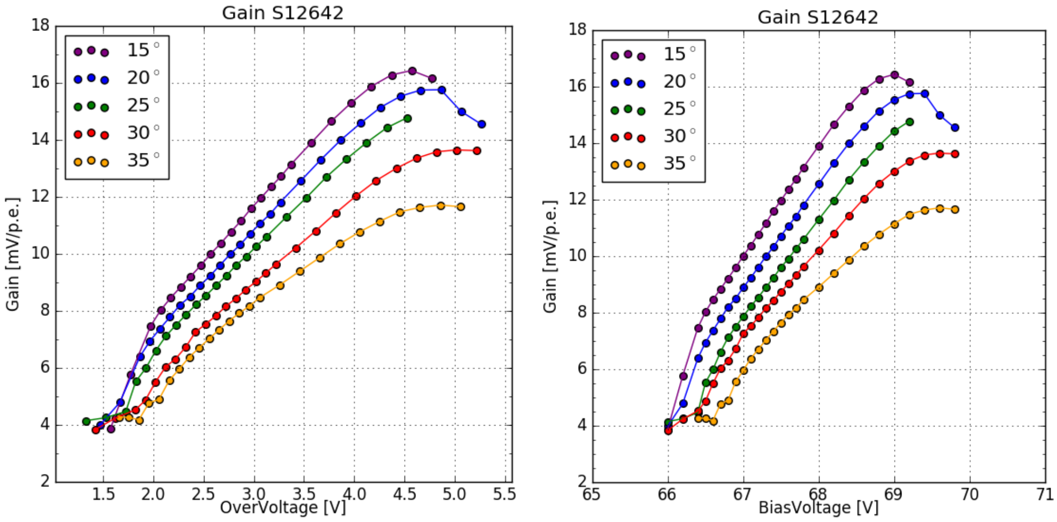

Abbildung 3: Gain of the HPK S12642 pixel, plotted against bias-voltage and temperature.

1.1.2 Dark Count Rate

I expect the Dark Count Rate to increase with temperature, which is the case fig(4). I also expect it to follow a nearly linear progression, a sudden turn-up or turn-down of the Dark Count Rate would be analysis related. The turn-up at a certain point is visible in Figure (4), particulary for 15° C (purple) and 20° C (blue) respectively. At 15° C and an Overvoltage of 4V, the Dark Count Rate starts to deviate from the previously linear behaviour. It starts to rise more rapid than before, which I can attribute to the fact, that the Optical Cross Talk at that point is very high; higher than 50% fig(5) (left). I suspect that I do not reach this critical point for the higher temperatures of 25° C (green) and 30° C (red), so the effect is barely, if not at all visible. At 35° C (yellow) I suspect my analysis is not able to count every pulse, due to the high rate of 9-10 MHz. A majority of the pulses overlapping each other and being counted as a 2p.e. event rather than 2 1p.e. events would reduce the Dark Count Rate significantly. At this point, heating of the Silicon Photomultipliers surface due to the high rate could also affect the Dark Count Rate through shifting the temperature slightly upwards, away from 35° C . So that the Dark Count Rate declared at 35° C is in reality the rate at higher temperatures.

At the lower end of the bias-voltage range, I suspect, that a major part of the found 1p.e. pulses are actually noise related. So the Dark Count Rate changing to a plateau is expected. This is also due to the fact, that my measurements are done with a fixed bias-voltage range. Due to the increase of the breakdown-voltage with rising temperature, part of the measured bias-voltage range being a very low over-voltage, attributes to this effect. In order to reliably measure beyond an overvoltage of 2.5V in the lower range, the noise would need to be improved.

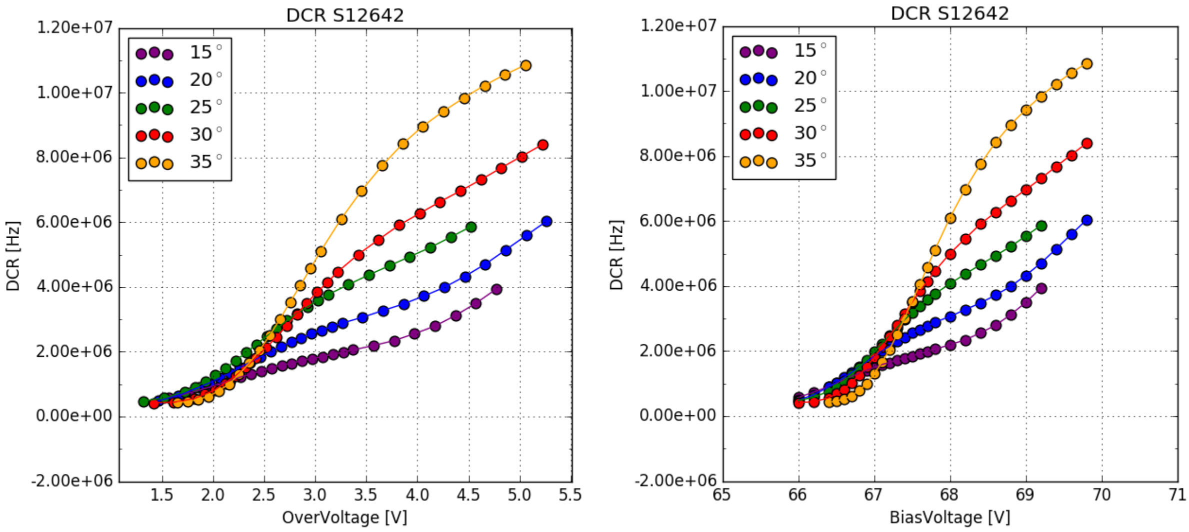

Abbildung 4: Dark Count Rate of the HPK S12642 pixel, plotted against over-voltage, bias-voltage and temperature.

1.1.3 Optical Cross Talk

Vbr slightly off, oct should overlap, does to an extend The Optical Cross Talk should be linear and independent from temperature. This is confirmed for HPK S12642. Minor diviations from that are probably due to slight errors in the breakdown-voltage calculation from the gain regression line. The diviation for 30° C and 35° C below an over-voltage of 2V stems from the way the gain regression line is used to calculate both Dark Count Rate and Optical Cross Talk. At higher temperatures the lower voltage range is dominated by noise, so using the gain regression line to calculate the Optical Cross Talk at those low voltages leads to the visible effect of the first few datapoints of 30° C and 35° C.

The deviations between the different groups results at 25° C (green) are caused by 4 major contributions. Firstly the difference in the tested device. While I take measurements on 4 3mm by 3mm pixels electricaly tied together, the way the device will later be implemented into CHEC-S, the groups in the US and Hamamatsu Photonics are likely to run tests on 1 3mm by 3mm pixel only. Secondly I suspect a difference in amplification and shaping electronics. The measurements I conducted as well as the measurements of Leicester are done with the same shaper and buffer configuration. The difference here is, thirdly, my measurements are done with dark counts only, while measurements in Leicester are conducted with a pulsed light source and reading out timed windows. This causes the results from Leicester to be difficult to compare against, their surface temperature of the SiPM is likely much higher than 25° C, and thus, a misinterpreted breakdown-voltage at 25° C causes a shift of the Optical Cross Talk to the right. Lastly the difference in actual data taking and analysis procedure must be mentioned, also this is only of minor concern, as we will see with other measured devices.

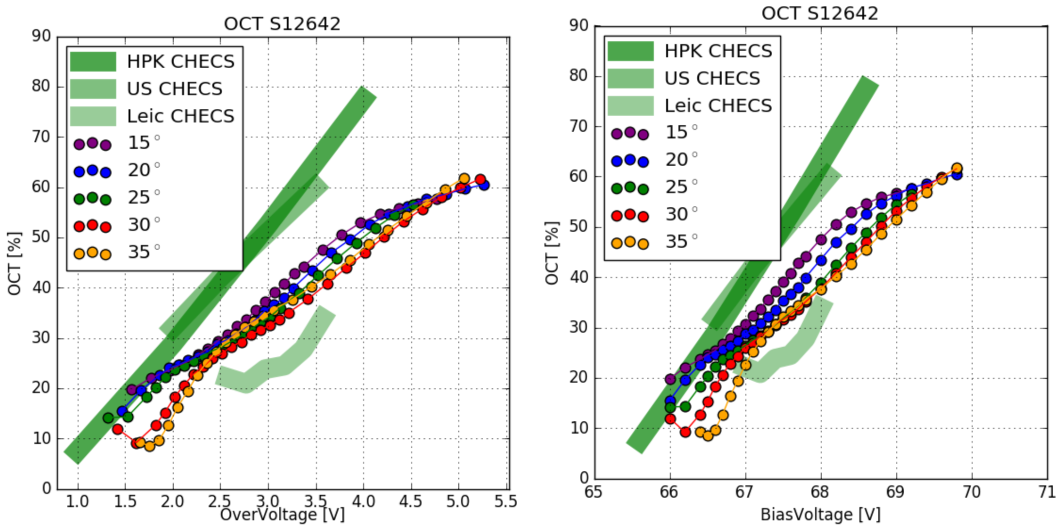

Abbildung 5: Dark Count Rate of the HPK S12642 pixel, plotted against bias-voltage and temperature.

1.2 Hamamatsu

1.2.1 Gain

1.2.2 Dark Count Rate

1.2.3 Optical Cross Talk

Appendices

1. Jim Hinton et al. Teraelectronvolt Astronomy Ann. Rev. Astron. Astrophys., 47:523
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9. http://astro.desy.de/gamma_astronomie/cta/medien/ueber_cta/index_ger.html
10. http://www.ung.si/en/research/laboratory-for-astroparticle-physics/projects/cta/