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The Compact Muon Solenoid Experiment

Conference Report

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MPPC Photon Sensor Operational Experience in CMS

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Abstract

The CMS Outer Hadron Calorimeter (HO) is the first large scale hadron collider detector to use SIPMs. To build the system we purchased and measured 3000 Hamamatsu MPPCs. 1656 channels of MPPC with 40MHz readout have currently been installed into CMS. We report on comparisons of in situ and vendor supplied measurements. We present results on in-situ working point optimization by IV scanning and temperature vs V scanning. We have developed several techniques for determining the breakdown voltage in situ. We compare the performance of each technique and its success in working point optimization. We present results on gain, noise, and cross talk monitoring. We present results on overall system stability.

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MPPC photon sensor operational experience in CMS

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Abstract. During the first long shutdown of the LHC the Outer Hadron Calorimeter of CMS has been equipped with silicon photomultipliers that replace the existing hybrid photodiodes while maintaining most of the readout chain. The new photon sensors are Hamamatsu Multi-Pixel Photon Counters with an active area of 3 mm × 3 mm and a cell pitch of 50 µm. Different means of determining the device's breakdown voltage and gain are presented. The stability of the overall system temperature as well as the stability of the gain and the breakdown voltage of the silicon photomultipliers are studied. The correlation between the different methods of determining the gain and breakdown voltage is tested to find whether they yield comparable results.

1. Introduction

The hadronic calorimeter (HCAL) of the compact muon solenoid (CMS) detector at the Large Hadron Collider (LHC) consists of different detector subsystems, namely the barrel calorimeter (HB), the endcap calorimeters, the very forward calorimeters and the outer hadronic calorimeter (HO) [1, 2]. The HO is placed directly outside the superconducting coil and was designed as a tail catcher to improve the energy measurement of jets leaking through the solenoid [3]. In the barrel region CMS consists of five rings around the solenoid with ring 0 placed in the middle. HO is built up of two layers of scintillator in ring 0 and one layer of scintillator in rings ±1 and ±2 each. The geometry of the scintillating tiles of HO matches the projected tower geometry of HB as is shown in Fig. 1. To achieve a better light collection and to guide the light, the scintillators have grooves in which wavelength shifting (WLS) fibers are embedded. Outside the trays in which the scintillators are placed, the light from the WLS fibers is coupled to clear fibers that guide the light to the photon sensors. During the first long shutdown of the LHC (2013 - 2015) the previously used hybrid photodiodes (HPDs) were replaced by silicon photomultipliers (SiPMs) due to insufficient performance. The new readout was designed as a "drop-in" replacement in order to maintain the rest of the readout chain [4].

2. The new photon sensor readout design

The previously used HPDs had 18 individual pixels that were read out separately. To match this setup, the new printed circuit board (PCB) was designed with the SiPMs placed at the pixel positions giving the same number of readout channels as before. The arrangement of the SiPMs on the PCB together with the position of the HPD window marked by two white circles can be seen in Fig. 2. As the SiPMs are solid state devices, they are sensitive to changes of the ambient temperature. In order to stabilize the temperature environment, a Peltier element is

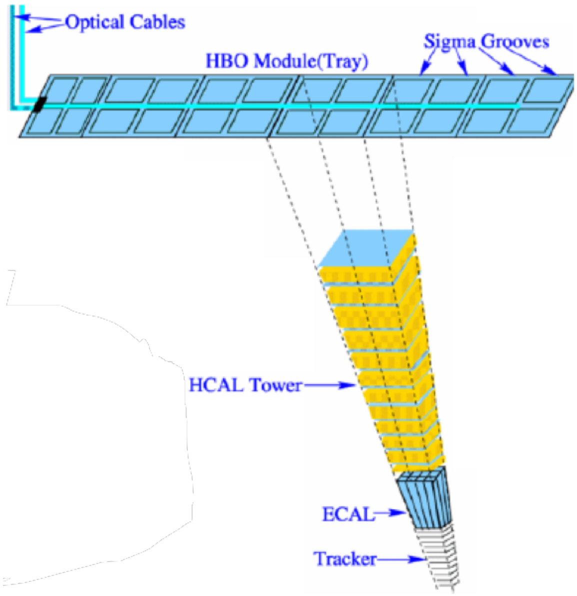

Figure 1. Geometry of the HO tiles matching the towers of the barrel calorimeter. Adapted from [3].

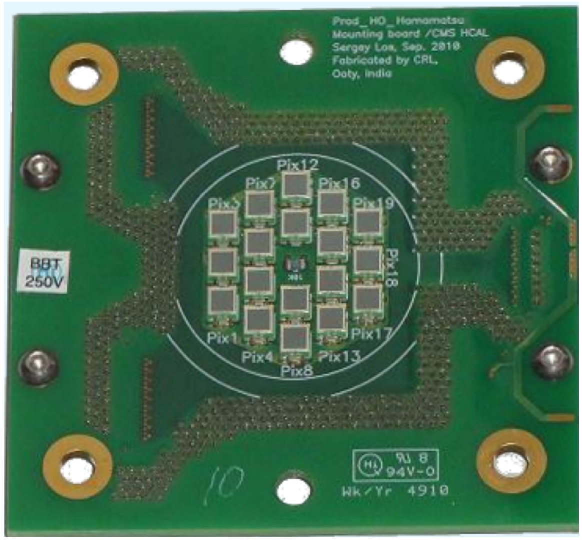

Figure 2. PCB carrying the SiPMs that are placed inside the white circles which mark the position of the old HPD. Adapted from [4].

placed on the backside of the PCB. An optical decoder unit routes the four fibers coming from one scintillator tile onto one SiPM so one channel corresponds to one scintillator tile. As ring 0 has two layers of scintillator and thus the doubled number of fibers arriving at the SiPM, the area of the SiPM is not large enough to cover all fibers. Therefore, a light mixer with a specular reflecting surface is placed between the fiber end and the SiPM surface in order to distribute the light over the whole SiPM surface. With the light mixer, the loss of light is independent of the fibre but homogeneously distributed.

2.1. The installed SiPM model

The SiPM chosen for HO is a Hamamatsu Multi-Pixel Photon Counter (MPPC) in a surface-mounted device (SMD) housing. It has a cell pitch of 50 µm and an active area of 3 mm × 3 mm. The device is identical to the Hamamatsu model S10931-050P. The required operating voltage is of the order of 70 V with a gain that is typically around 6×10^5 when operated 1 V above breakdown voltage. One important quantity of the SiPM is the change of the gain with the temperature. As the gain depends linearly on the over-voltage, which is the bias voltage subtracted by the breakdown voltage, the change of the breakdown voltage with temperature can be transformed into a change of gain with temperature which yields a value of $-8\,\%\,\mathrm{K}^{-1}$ at a foreseen operating point of 1.5 V over-voltage [5].

3. Analysis of the operating parameters

To get the first impression of the performance and the stability of the SiPMs different operating parameters are examined. These are the temperature, the gain and the breakdown voltage. While the temperature is only studied regarding the stability over time, the gain and the breakdown voltage are tested against both the stability over time and the comparability of different methods.

3.1. The temperature

Due to the fact that the breakdown voltage depends on the temperature of the SiPM, also the gain depends on the temperature if the bias voltage stays constant. This implies that the ambient temperature around the SiPM needs to be monitored to see whether possible deviations in the gain are caused by a temperature change in the device. This is depicted in Fig. 3. For clarity reasons only some selected runs are shown. As can be seen, the temperature stays well within a variation of below 0.1 °C once the set temperature at the PCB is reached. This is shown over a period in 2014 from the end of January to the beginning of March which emphasizes that any changes in gain or breakdown voltage, if observed, are not caused by changes in the temperature environment.

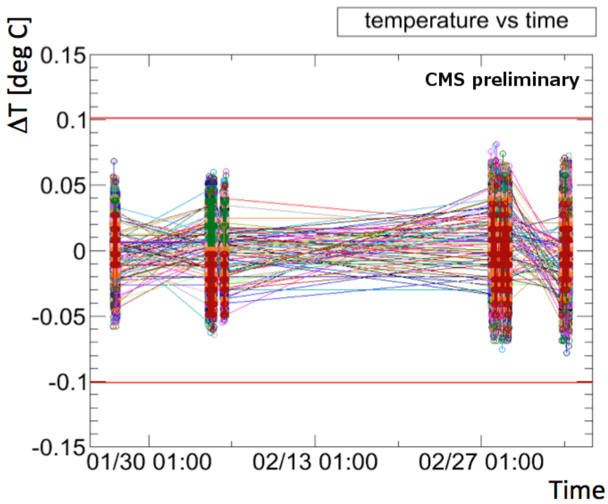

Figure 3. Temperature difference to the target temperature of the SiPMs over time for all installed SiPMs.

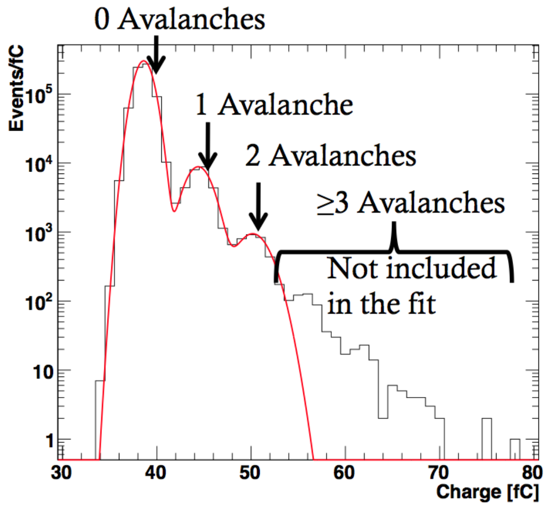

Figure 4. Pedestal spectrum of an SiPM with a fit applied to determine the gain.

3.2. The gain

There are two methods used to determine the gain of an SiPM in HO. The first uses the fact that an SiPM generates a small signal even if there is no light hitting the detector. This pedestal spectrum is exemplified in Fig. 4. The different peaks in the spectrum develop due to different numbers of cells giving a signal at the same time in one SiPM. While in general the distance between the peaks of any order can be used to determine the gain, in HO only the pedestal peak and the peaks corresponding to one and two cells giving a signal are used for measuring the gain. Alternatively, one can generate short light pulses with an LED[1] onto the SiPM. With the intensity of the light pulse being not too large and assuming N photons reaching the SiPM the signal should be equal to N×gain. Furthermore, using Poisson statistics the sigma of the photon number is $\sqrt{\mathrm{N}}$ so the sigma of the measured signal equals $\sqrt{\mathrm{N}}\times$gain. Dividing the variance of the signal by the mean of the signal one gets sigma^2/mean = gain. The relative variation of the gain versus time using the pedestal method for a single SiPM mounting board is depicted in Fig. 5. For a comparison with the LED method refer to section 4.1. As can be seen, the gain for the tested SiPMs is stable over a time from the middle of February to the beginning of March in 2014 and the relative variation of the gain lies within 2 %. Looking at the distribution

[1] **L**ight-**E**mitting **D**iode

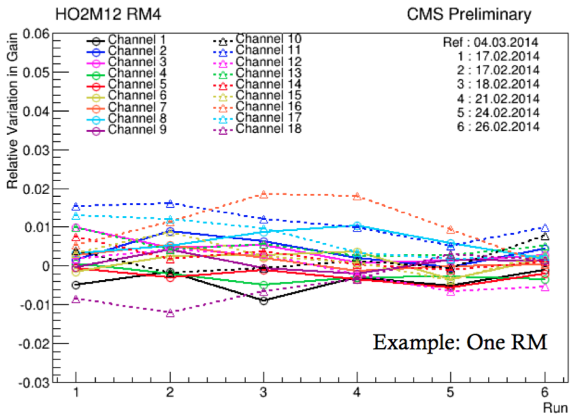

Figure 5. Relative variation of the gain over time determined using the pedestal method shown for one PCB (18 channels).

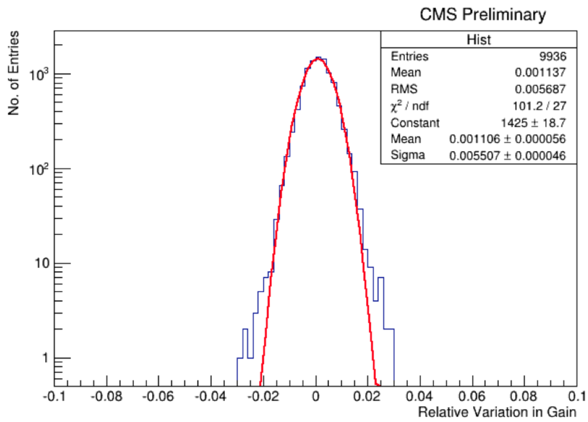

Figure 6. Distribution of the relative variations in gain for all installed SiPMs.

of the relative variation over time for all installed SiPMs, which is shown in Fig. 6, it can be found that the distribution has a width of only 0.5 % and that all variations lie within 3 %. This demonstrates that the gain determination works as expected and the operation of the SiPMs with a stable gain is possible.

3.3. The breakdown voltage

For the determination of the breakdown voltage, there is also the possibility to use either the pedestal spectrum of the SiPM or the signal of a short LED pulse. For the first method the gain is determined for different applied bias voltages. The gain depends linearly on the operating voltage so the resulting curve is a straight line which can be extrapolated to gain 0 as is shown

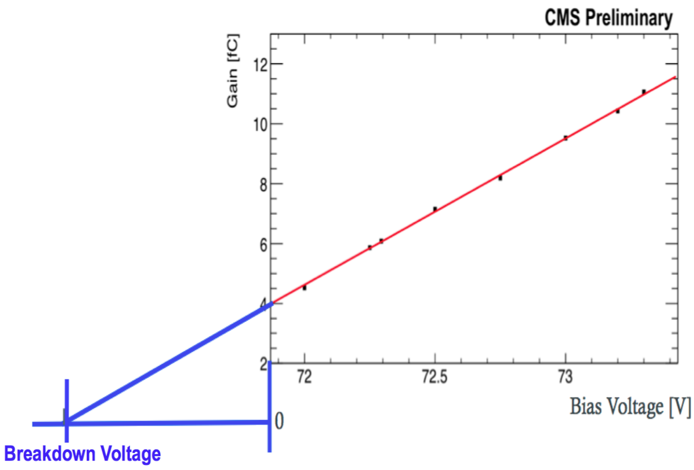

Figure 7. Distribution of the gain from the pedestal method over the applied bias voltage to determine the gain.

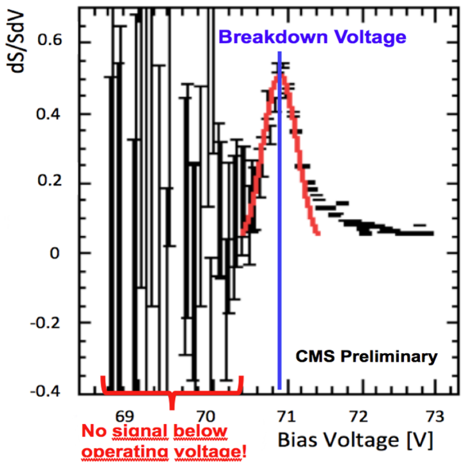

Figure 8. Exemplary distribution of the relative change of the measured LED signal with the bias voltage.

in Fig. 7. At the corresponding bias voltage the breakdown of a cell is just about to start which is the definition of the breakdown voltage. The second way is to use the relative change of the measured signal when pulsing an LED and varying the bias voltage. As shown in Fig. 8 the distribution of $\frac{\mathrm{dS}}{\mathrm{SdV}}$ peaks at that voltage, at which the change of the relative signal is at maximum which is then used as the breakdown voltage. The distribution of the variation in

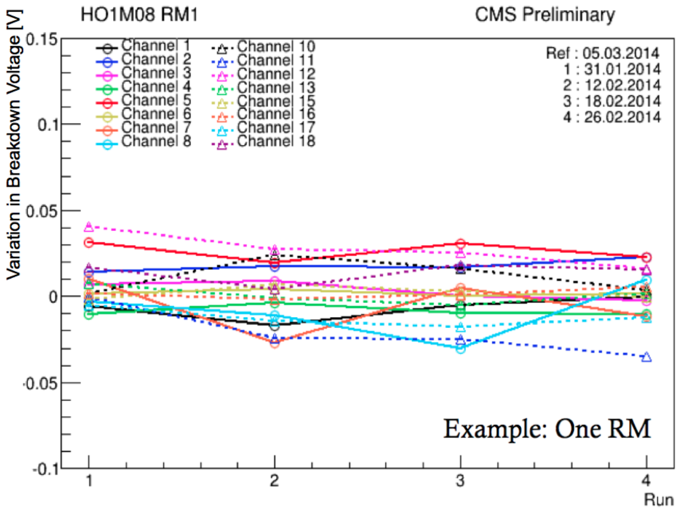

Figure 9. Distribution of the breakdown voltage over time for one PCB (18 channels).

breakdown voltage over time for one PCB using the LED method is shown in Fig. 9. The time period reaches from the end of January to the beginning of March in 2014. The breakdown voltage is found to be stable within 50 mV which demonstrates the reliability of the breakdown voltage determination. For comparison with the pedestal method refer to section 4.2.

4. Correlation of the employed methods

To estimate the comparability of the two methods for determining the gain and the breakdown voltage it is useful to plot the result of one method against the result of the other method for each channel. This helps spotting systematic differences between the procedures.

4.1. Gain correlation

The correlation plot for the gain measurements for all installed SiPMs for a specific run is shown in Fig. 10. All gain values are centralized around a certain value close to the design gain of 6 ADC counts per photoelectron and the distance in gain between most of the SiPMs is small. The difference in the center of the distribution on the y-axis compared to the center on the x-axis can be explained with the fact, that the noise of an SiPM is not Gaussian, which is assumed when calculating the gain with the pedestal method. This way, a systematic offset between the two methods is introduced which shows itself in the correlation plot. However, the plot shows that the different means of determining the gain yield comparable results.

4.2. Breakdown voltage correlation

The correlation plot for the breakdown voltage is presented in Fig. 11. Here the values follow a straight line which is expected as the different SiPMs do not all have the same breakdown voltage. The offset can be explained with the fact that the breakdown voltage is defined differently for the two methods. For the pedestal method the breakdown voltage is the point where amplification starts while for the LED method the breakdown voltage is defined as the point of maximum relative change of the signal with respect to the bias voltage, which lies above the breakdown

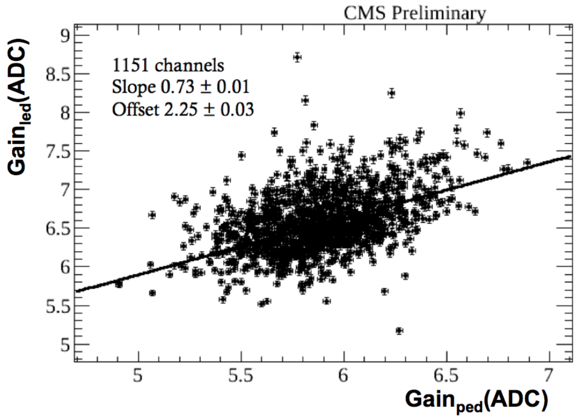

Figure 10. Correlation plot for the gain measurements.

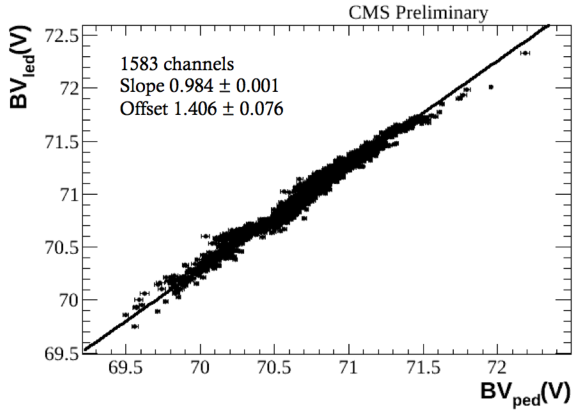

Figure 11. Correlation plot for the breakdown voltage measurements.

voltage from the pedestal method. It is possible to use the offset from the correlation plots to correct the breakdown voltage obtained with the LED method for this shift.

5. Summary

It was shown that the newly installed SiPMs in HO are operated in a stable temperature environment. With this precondition it was possible to perform measurements of the gain and the breakdown voltage of the devices. Two methods using the pedestal spectrum of an SiPM or light from an LED were introduced. It was found that both yield comparable results for the gain and for the breakdown voltage. Furthermore, it was demonstrated that in HO the SiPMs can be operated in a stable way over a long time.

Acknowledgments

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