Preparation for the upgrade of CMS Hadron Endcap Calorimeter front-end

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Abstract. The hadron endcap (HE) calorimeter is one of the major sections of CMS detector, used for measurement of the hadrons energy. Phase1 upgrade of the front-end electronics components in the HE calorimeter is being prepared, in particular to improve ability to handle increased pile-up and mitigate radiation damage of optical system in the high eta region. Tests of Phase1 HE Front-end system including new photo-sensors, silicon photomultipliers (SiPM), as well as new charge integrator encoder (QIE11) were performed in the Burn-in station in b904 at CERN. In this note, analysis and measurement results for the new generation front-end electronics components are presented.

1. Introduction

The Hadron Calorimeter (HCAL) is an essential subsystem of the CMS detector. It is organized into barrel (HB and HO), endcap (HE) and forward (HF) sections. The HB, HE, and HO calorimeters were all originally fitted with hybrid photodiode (HPD) transducers.

During operation in the CMS magnet, a number of weaknesses in the performance of HPDs have been identified. Many of them were related to the large electric field required for these devices. The most significant issue in the operation of HPDs is the appearance of electrical discharges in the device when high voltage is applied in the presence of 4T magnetic field. This effect can enhanced depending on particular orientation and magnitude of the magnetic field relative to the HPD. The discharge effect is small in the HB/HE calorimeters, but it is a significant source of high-amplitude noise and a risk to the longevity of the HPD. For above reasons it was decided to replace all HPD on SiPMs, which are not sensitive to magnetic field. In addition, SiPM gain is two orders of magnitude higher than the one of HPD and additionally the SiPMs have higher light detection efficiency. These features allow to improve registration of weak light signals significantly due to improvement of signal to background ratio by a few orders in magnitude and refine longitudinal granularity of HE detectors [1]. CMS plans to install the new (Phase1) generation front-end electronics, including SiPMs, during the 2016/2017 year-end technical stop.

2. HE front-end upgrade phase 1 preparation

HCAL endcap front end electronics is organized in 36 Readout Boxes (RBX). Each RBX consists of four readout modules (RM) and additional "service" modules: calibration unit, clock and control module and low voltage module. Readout module is a heart of HE front-end electronics. It consists of phototransducers (formerly HPD, now Silicon photomultipliers, SiPMs) and QIE11 boards, which will be used for processing the signal from SiPM arrays.

SiPM is a multi-pixel Geiger-mode avalanche photodiode device [2]. Ones of its primary characteristic are photon detection efficiency (PDE) and the gain. The PDE is a ratio of number of primary triggered pixels to number of photons incident on the SiPM surface. The SiPM gain indicates how many times a photoelectron is multiplied as a result of the Geiger discharge inside of fired pixel. One of the most serious challenges of SiPM photodetectors is optical crosstalk. It is a stochastic process, which occurs when a primary discharge (avalanche) in the pixel triggers secondary discharges in the nearby pixels. The gain can be increased by increasing the bias voltage, but the dark count and the crosstalk also go up. SiPM working point (operational voltage) optimization is needed for selection of optimum work regime.

2.1. Choosing of SiPM working point

The voltage of SiPM installed into the RM cannot be measured directly. However, it is known, that the SiPM gain dependence on overvoltage is linear [3]. Then we assume that by equalizing of SiPM's gain, we set an equal overvoltage to all of the SiPMs used in HE and by this way we are able to fix the above SiPM parameters to be identical. It is possible due to uniformity of the produced by Hamamatsu SiPMs for HCAL phase 1 Upgrade [4].

For the SiPM gain extraction we are using method based on the analysis of Single Photoelectron spectra (SPE). Figure 1 shows an example of SiPM dark events spectrum of collected charge integrated inside 100 ns long gate for one of the measured channel. Pedestal and SPE peaks are fitted with Gaussian function. The distance between first two peaks is actually the gain in units fC per SPE. Software code for automatic peaks finding and gain calculation was developed.
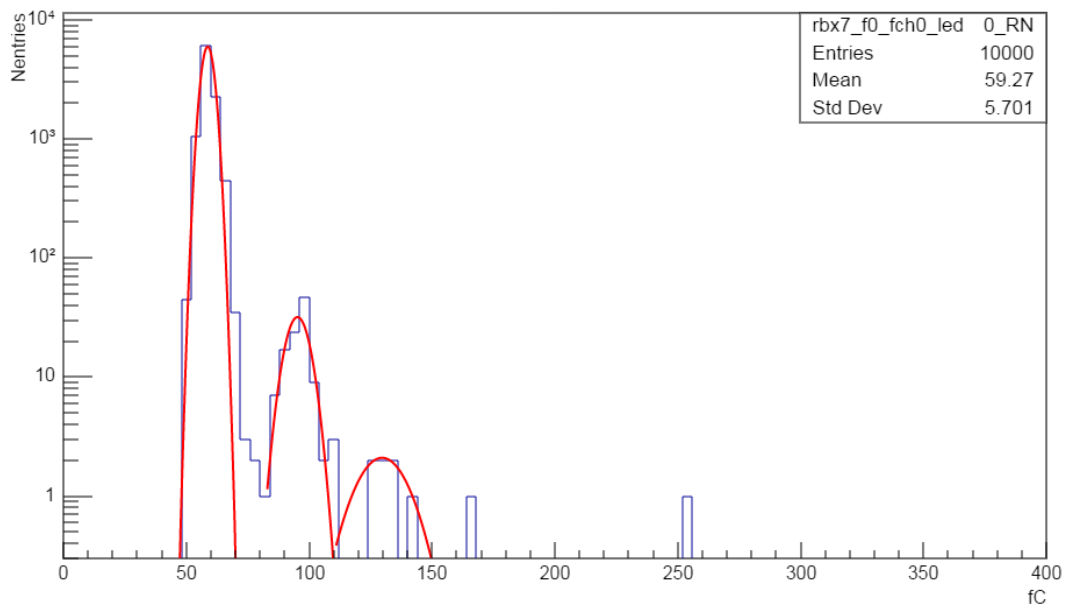

Figure 1. Collected charge distribution for a single channel.

Figure 2 presents the calculated gain versus the bias voltage. As mentioned above, the gain is directly proportional to overvoltage and its dependence is fitted by a linear function. Working point is chosen using obtained dependence to obtain the required gain.
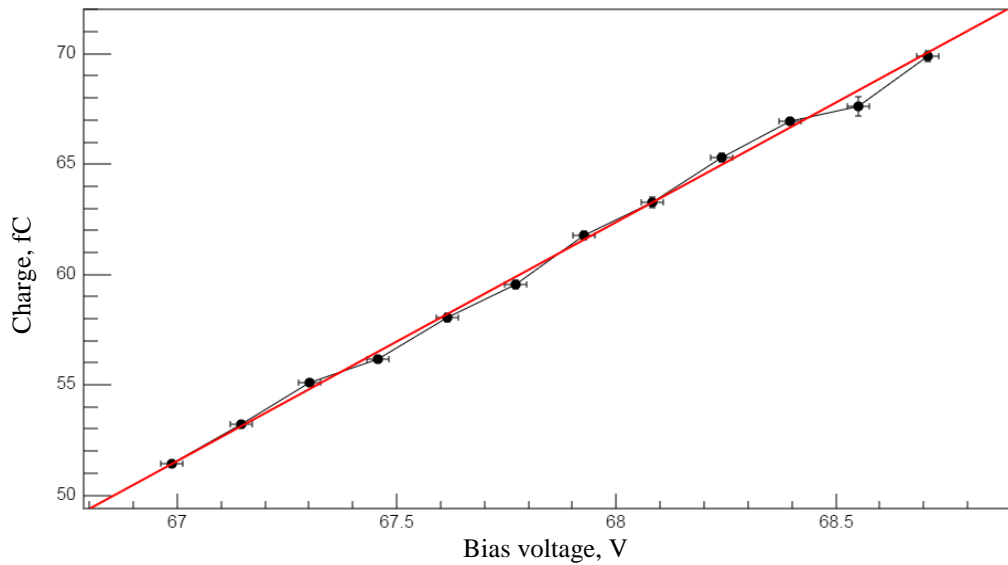
Figure 2. Gain depending on bias voltage setting.

Choice of SiPM working point has been implemented so as to get the gain of 50 fC for all SiPMs. Such gain value should correspond to 3.5V overvoltage applied to SiPMs. Individual operational bias voltages have been applied to each SiPM. The obtained gain distribution is presented in figure 3 for 192 SiPMs installed at one RBX. The obtained value of standard deviation is 0.38 fC. Therefore this particular working point for SiPM Bias Voltage allows to equalize the gain of each SiPM channel with precision better than 1%.
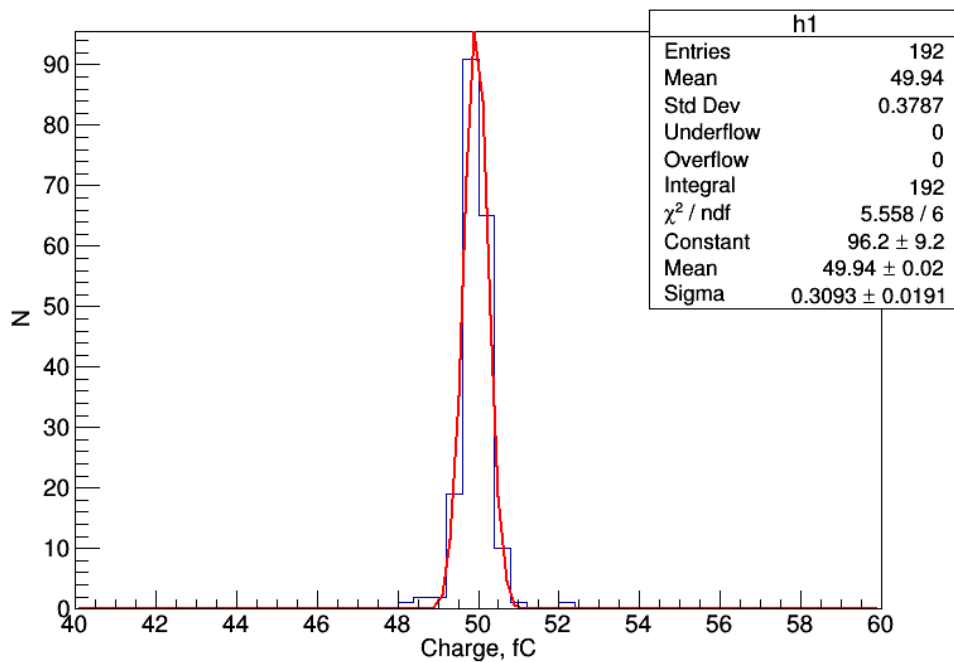

Figure 3. Gain distribution for 192 SiPMs with applying found working operational voltage.

2.2. QIE Card shunt tests

The dynamic range of QIE card is 2 fC to 380 pC. For the selected bias voltage one photoelectron produces 50 fC of charge. Muon signal (traversing 4 scintillator layers in HE) is equivalent to 80 photoelectrons or 4 pC of charge and is equivalent to the deposition of 1 GeV energy. In this particular case, saturation of QIE card would be achieved for energy of 95 GeV. As in CMS Hadron Endcap we expect a large energy deposits, with equivalent energy ranging between hundreds of GeV to a few TeV, it is necessary to divide the input signal to avoid saturation.

For this purpose every QIE chip is equipped with internal programmable shunt (signal divider) to reduce the input signal up to factor of 12. QIE card shunt tests were performed for estimate of shunt reduction factors. The data has been taken using signal generated by light emission diode (LED) from calibration module. The following shunt factors were used: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12. Figure 4 presents attenuation factor (average relative LED signal normalized to signal without shunt) in depending on shunt setting for 188 channels (one RBX). Distribution of shunt attenuation factor for shunt value of 6 for 188 channels is shown in figure 5. The mean value of attenuation factor has been found as 0.26. Applying shunt value of 6 corresponds to reducing of signal by 3.7 times. Accuracy of shunt setting is about 1%. The shunts were working as expected, namely the charge is going down with increasing of shunt factor.
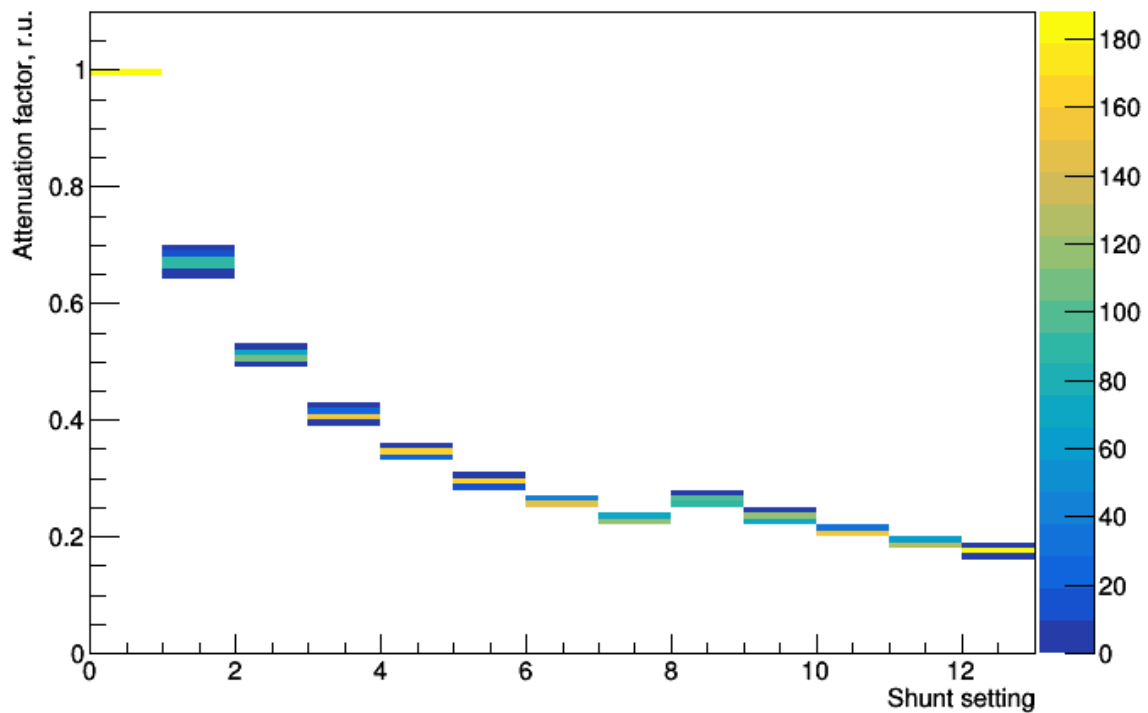

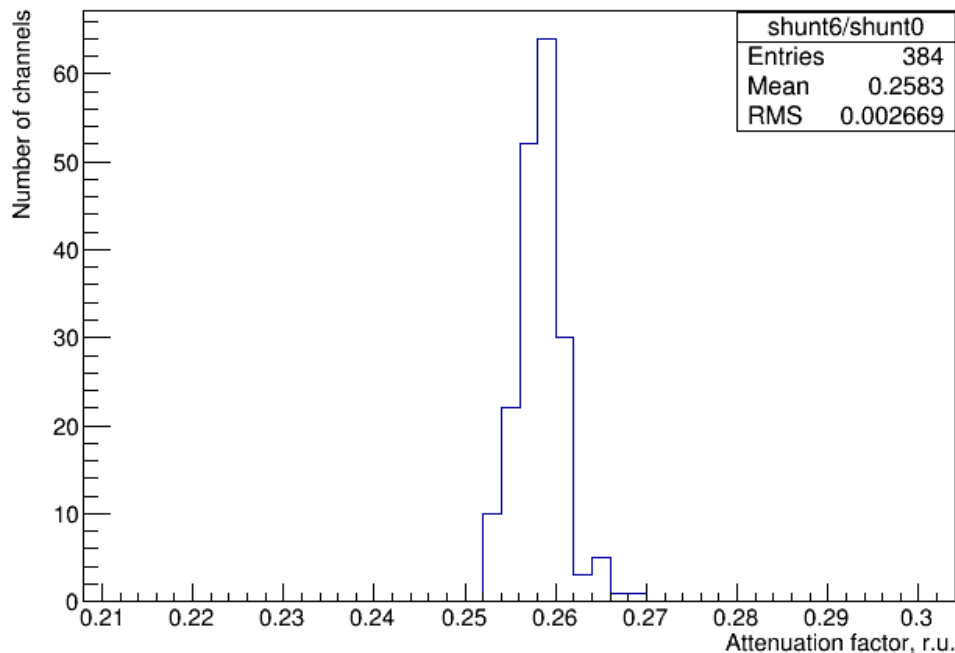**Figure 4.** Attenuation factor versus shunt setting for all channels.

Figure 5. Distribution of shunt attenuation factor for shunt value of 6.

3. Conclusion

Procedures of gain measurement were developed for commissioning of CMS HCAL upgrade front-end components. The gain of 50fC has been applied to all SiPMs. The standard deviation for obtained gain distribution is 0.38fC, therefore working point optimization allows to equalize the gain of individual channel with precision better than 1%. The QIE card shunt tests were carried out in preparation for the phototransducers replacement. The results of shunt measurement are presented.

Acknowledgement

References

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