Correction of SiPM Temperature Dependencies

A. Kaplan (on behalf of the CALICE collaboration)[1]

Kirchhoff Institute University of Heidelberg, INF 227, 69120 Heidelberg, Germany

Abstract

The performance of a high granular analogue hadronic calorimeter (AHCAL) using scintillator tiles with built-in Silicon Photomultiplier (SiPM) readout is reported. A muon beam is used for the minimum ionizing particle (MIP) based calibration of the single cells. The calibration chain including corrections for the non-linearity of the SiPM is presented. The voltage and temperature dependencies of the SiPM signal have been investigated using the versatile LED system of the AHCAL. Monitoring and correction methods are discussed. Measurements from the operation 2006 and 2007 at the CERN SPS test beam and data provided by the Institute for Theoretical and Experimental Physics (ITEP) in Moscow are compared.

Key words: calorimeter, International Linear Collider, scintillator, silicon photomultiplier, temperature, voltage
PACS: 07.20.Fw, 29.40.Wk, 29.20.Ej, 29.40.Mc

1. Introduction

The CALICE collaboration has constructed a high granular analogue hadronic calorimeter (AHCAL) as prototype for a calorimeter detector at the future International Linear Collider. It is an 1 m^3 sampling calorimeter alternating 2 cm steel as absorber with 38 active layers covering 4.5 interactions lengths λ. Each active layer is a matrix of plastic scintillator tiles individually read out by Silicon Photomultipliers (SiPMs). The SiPMs used have been developed by MEPhi/PULSAR - more details on their working principle and properties are described in (1). The total number of channels of the calorimeter is 7608. More details on the prototype can be found in (2).

Calibration data at different temperatures and using different bias voltages have been acquired in 2006 and 2007 at the CERN SPS test beam to complement the physics program. These data are used to study the response of the SiPMs at different working conditions with the goal to find a calibration procedure to compensate for their temperature dependence. For the purpose of monitoring a complex UV LED system was developed capable of covering the full dynamic range of the SiPM from a few photons firing single pixels up to saturation. For each active layer of the calorimeter 12 LEDs illuminate 18 tiles via light guiding fibres. The signal of each LED is monitored by a PIN diode.

For temperature measurements five sensors placed vertically along the centre axis of each layer in the AHCAL have been used.

2. Calibration

At first order the calibration of the single cells is done using muons acting as minimum ionizing particles (MIP). Fig. 1 shows a MIP spectrum in comparison to the pedestal distribution. A Landau convoluted Gaussian is fitted to the MIP spectrum to determine the MIP value for each cell.

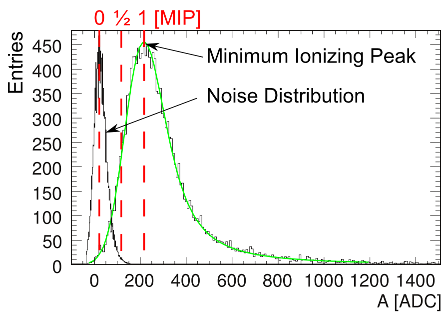

Figure 1: Muon spectrum and SiPM pedestal used for MIP calibration.

Email addresses: kaplan@kip.uni-heidelberg.de ()
[1] *Tel:* +49-40-8998-3421, *Fax:* +49-40-8998-1812

For the full calibration one has to account for the non-linearity of SiPM due to its limited number pixels (1156) and the pixel recovery time of 20-500ns (range results from variation of the quenching resistors as part of an optimization study). Thus, for each of the SiPMs a saturation curve was measured by the Institute for Theoretical and Experimental Physics (ITEP) Moscow - shown in fig. 2. The correction of the non-linearity is discussed below.

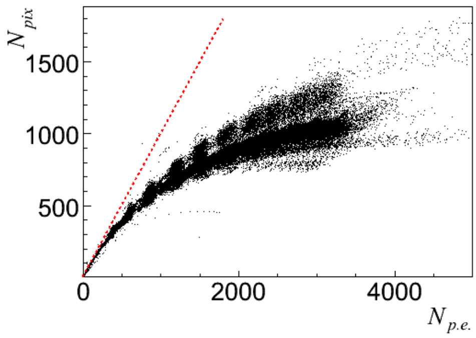

Figure 2: Number of pixels fired vs. number of photo electrons for all SiPMs of the AHCAL measured at ITEP. A clear deviation from linear behaviour (dashed line) is observed. The band like structure and the wide spread is due to variations of production parameters in the SiPM sample used. Some SiPMs show a N_{pix} larger than the actual number of pixels (1156) - reason for this can be after pulsing and the usage of light pulses longer than the pixel recovery time.

2.1. Total Number of SiPM Pixels

The total number of pixels N_{tot} can be determined using a simple model,

$$N_{pix} = N_{tot} \cdot \left(1 - \exp\left[\frac{-N_{p.e.}}{N_{tot}}\right]\right),$$

where N_{pix} is the number of pixels fired and $N_{p.e.}$ the number of photo electrons created. A study by the CALICE group in Bergen (3) shows a difference of roughly 20% between the CERN and ITEP data - see fig. 3. The reasons for this are the different setups used: While for ITEP measurements single 'bare' SiPMs were used, the CERN measurements were done with SiPMs mounted on tiles, where only parts of the surface were illuminated by a wavelength shifting fibre due to geometrical missalignment. The measurements have been confirmed by measurements at DESY and ITEP and a scaling factor to account for this was introduced (4).

2.2. Calibration Chain

To determine the number of pixels fired a single pixel spectrum is measured for each channel of the calorimeter using dedicated calibration runs with an integration

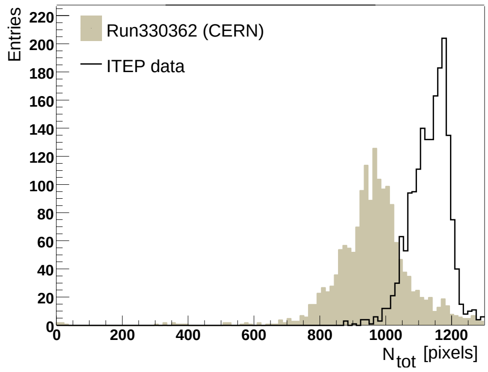

Figure 3: Total number of pixels, N_{tot}, for the SiPMs used in the AHCAL. The white histogram shows N_{tot} obtained by ITEP, the gray histogram was measured using 2007 CERN test beam data (see text).

time of approx. 50ns (fig. 4). The distance between two peaks in the single pixel spectrum then determines the gain in ADC counts. By dividing the observed amplitude of a SiPM signal A_i[ADC] by the gain G_i[ADC] one obtains the number of pixels fired:

$$A_i[\text{pixels}] = \frac{A_i[\text{ADC}]}{G_i[\text{ADC}]}.$$

The number is used to correct for SiPM non-linearity via the predetermined saturation function $f_{sat}\,(A_i[\text{pixels}])$. The deposited energy per tile i in units of MIP is then given by:

$$E_i\,[\text{MIP}] = \frac{A_i\,[\text{ADC}]}{A_i^{\text{MIP}}\,[\text{ADC}]} \times f_{sat}\,(A_i[\text{pixels}])\,.$$

Where A_i^{MIP} [ADC] is the peak position of the measured MIP spectrum (c.f. fig. 1).

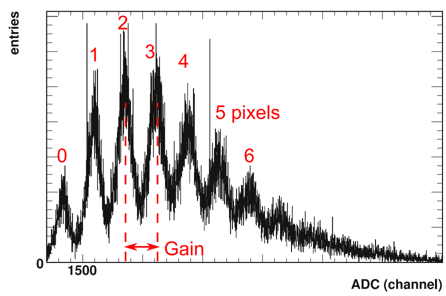

Figure 4: Single pixel spectrum of one AHCAL channel - used for gain determination.

2.3. SNR and Detection Efficiency

The average signal-to-noise ratio (SNR) is given by the ratio of MIP amplitude and the pedestal width

(FWHM). It measures the seperability of the MIP peak from the pedestal. The mean SNR as observed in the 2006 and 2007 test beam period is shown in fig. 5 (top) as a function of the AHCAL layer – in 2006 an average SNR of 12, in 2007 of roughly 9 to 10 is measured.

The MIP detection efficiency is determined from the MIP spectrum (fig. 1); it is defined as the ratio of the number of entries with ADC values above the 0.5 MIPs threshold ($\sim$ 100 ADC counts) and the total number of entries. The MIP detection efficiency at CERN in 2006 and 2007 is plotted for each layer in fig. 5 (bottom) - in average it is 96 % and 93 %, respectively.

The slightly worse values for SNR and detection effiency in 2007 result from the operation at higher temperatures compared to 2006.

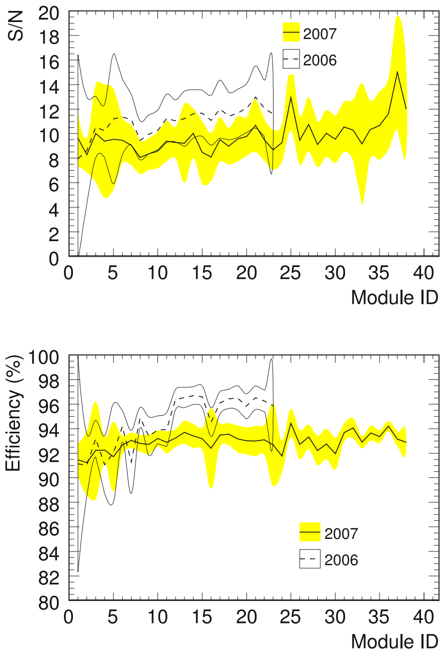

Figure 5: Mean signal-to-noise ratio (top) and muon detection efficiency (bottom) as a function of the AHCAL layer using a threshold of 0.5 MIPs. The data were taken during the test beam period at CERN in 2006 and 2007.

3. Temperature and Voltage Dependence

The temperature and voltage dependencies of the SiPM gain G and signal amplitude A have been measured during the CERN 2007 test beam period (Fig. 6). Using a linear function the data are fitted for each SiPM separately to determine $\frac{dG}{dT}$ and $\frac{dA}{dT}$. Fig. 7 shows the temperature dependencies of the gain and of the signal amplitude; their mean values are summarized in tab. 1. The higher value for dA/dT compared to dG/dT results from the fact that the amplitude depends on both, the photo detection efficieny ϵ and the gain: $A \sim \epsilon \cdot G$.

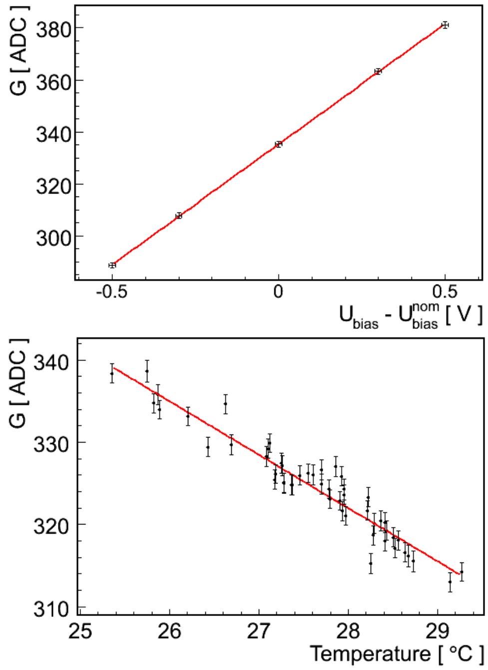

Figure 6: Temperature and voltage dependence of the gain for a single SiPM.

	mean	σ	rel.
dG/dT	-4.6 [ADC/K]	1.6 [ADC/K]	-1.7 [% / K]
dA/dT	-13.7 [ADC/K]	6.7 [ADC/K]	-4.0 [% / K]

Table 1: Mean temperature dependence of the SiPM gain $\left(\frac{dG}{dT}\right)$ and signal amplitude $\left(\frac{dA}{dT}\right)$ as measured using 2007 CERN test beam data.

In the following it is assumed that the observed temperature dependence of the SiPM is only due to the dependence of the breakdown voltage on temperature. With this assumption one gets: $\frac{dA}{dT} = \frac{dA}{dU}\frac{dU}{dT}$ and $\frac{dG}{dT} = \frac{dG}{dU}\frac{dU}{dT}$.

Dividing these two equations yields $\frac{dA/dT}{dG/dT} = \frac{dA/dU}{dG/dU}$. This relates four dependencies to each other and gives us two methods to calculate the dependence of the amplitude on the gain $\frac{dA}{dG}$. One is based on temperature measurements, $\left(\frac{dA}{dG}\right)_T = \frac{dA/dT}{dG/dT}$ – and the other based on voltage measurements, $\left(\frac{dA}{dG}\right)_U = \frac{dA/dU}{dG/dU}$. These two methods are used for gain based corrections described below (see 4.2).

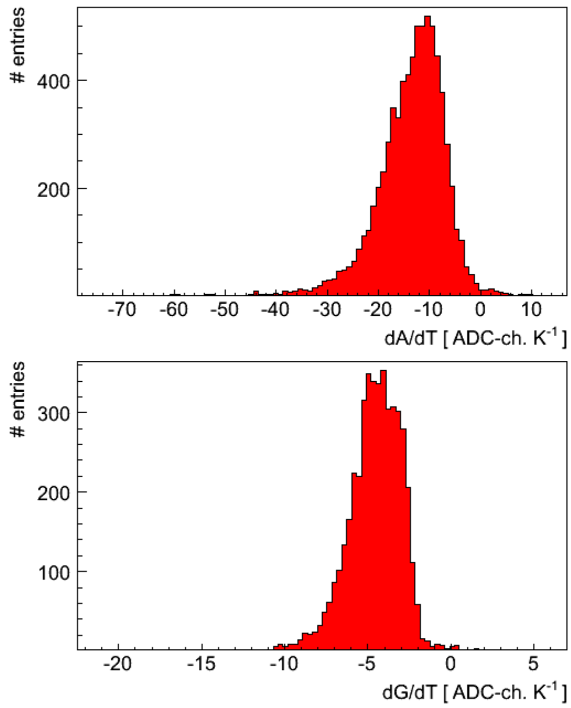

Figure 7: Slopes of the temperature dependencies of the gain and the signal amplitude for all SiPMs of the HCAL.

4. Correction methods

Several methods to correct for the effects of temperature changes have been investigated.

4.1. Simple 1st order correction

$$X = X_0 + \frac{dX}{dT} \cdot \Delta T$$

where X is either the signal Amplitude A or the gain G. For this corrections frequent temperature measurements are necessary, which are done during the data taking. One disadvantage of this method specific to our calorimeter is that there are only 5 temperature sensors per layer. A more precise correction would require a separate temperature sensor for each SiPM.

4.2. Gain Based Correction of Signal Amplitude

Another method to correct for the temperature dependence of the signal amplitude is to take the gain of the SiPM as measure of the temperature:

$$A = A_0 + \frac{dA}{dG} \cdot \Delta G$$

The coefficient $\frac{dA}{dG}$ has been determined for all SiPMs - the large spread (approx. 20%) requires individual correction for each sensor. The advantage of this method is that in the AHCAL the gain for each channel is determined in dedicated runs and no direct temperature measurements are necessary. However, a high accuracy gain determination is quite time consuming such that it is possible only a few times per day. Thus, for a sufficiently accurate correction of the temperature dependence of the signal amplitude via this method more frequent gain measurements would be necessary.

4.3. Working point adjustment

Temperature differences result in a gain G_{off} which is shifted with respect to the working optimal point. This can be corrected for by adjusting the bias voltage: $G_{corr} = G_{off} + \frac{dG}{dU} \cdot \Delta U$. The necessary voltage shift is $\Delta U = (G_{ref} - G_{off})/\frac{dG}{dU}$. This method has been proven to work during this years test beam at Fermilab.

5. Conclusions

The AHCAL prototype is the first detector using SiPMs on a large scale. All channels have been calibrated and the temperature and voltage dependencies of their gain and signal amplitude were individually determined. As the SiPMs show a large spread concerning their properties the calibration procedure requires the use of a data base containing single channel information.

A method for the correction of the temperature effects has been developed and shown to work in test beam measurements. As an alternative a gain based correction using gain monitoring is described which has the advantage of being independent on direct temperature measurements.

As a possibility to regulate gain shifts, adjustments of the operating voltage are proposed to compensate for temperature fluctuations during data taking. Such an online gain adjustment would minimize the data corrections to be applied offline.

References

[1] P.Buzhan et al. Nulc. Instrum. Meth. A 504 (2003) 48

[2] G. Eigen, The Calice scintillator HCAL testbeam prototype, in Proc. of XII International Conference on Calorimetry in High Energy Physics, Chicago, IL, 2006.

[3] CALICE group Bergen (Norway), private communication

[4] CALICE collaboration, "The scintillator ECAL beam test at DESY, 2007", CALICE note, CAN-012