Calibration and Monitoring of the Analog HCAL Prototype

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A prototype hadronic calorimeter for the ILC detector is under construction at DESY by a sub-group of the CALICE collaboration. It will consist of 8000 scintillator tiles with analog readout performed via silicon PhotoMultiplier (SiPM) directly mounted on each tile. The response of each calorimeter cell (tile) needs to be calibrated, with particular attention to the non-linear response of the SiPM. A review of all calibration factors is given, based also on the successful operation of a 100 channel prototype tested last year at the DESY electron beam [1].
For the correct operation of the entire system in between subsequent calibrations, a redundant monitoring system is foreseen to stabilize temperature and voltage variations of the SiPM response.

1. INTRODUCTION

Silicon PhotoMultipliers (SiPM) [2–4] are used to read out the 8000 channels of the hadronic calorimeter prototype for the ILC detector under construction at DESY by a sub-group of the CALICE collaboration[1]. This photodetector is a pixelated avalanche photo-diode operated in the limited Geiger mode. The detector surface of 1×1 mm^2 is divided into 1024 pixels. The analog information is obtained in this device by adding the response of all pixels fired as independent digital counters. The dynamic range is determined by the finite number of pixels. The SiPM are operated at about 50-70 V, and are capable of gains of the order of 10^6.
It has been proven that SiPM can be operated in high magnetic field environments [5], such as those foreseen for the ILC detector.
SiPMs are mounted on scintillator tiles in front of the open end of a wavelength shifting fiber used to collect the scintillation light. The calibration of each tile is based on minimum ionizing particle signals which in the test beam experiment must be collected in special run configurations. During the time between such calibrations the SiPM response stability needs to be monitored. Three independent methods provide redundancy, they are based on temperature measurements and a versatile UV-LED system which is described in more detail.

2. CALIBRATION OF INDIVIDUAL TILES

The total energy collected on a tile is evaluated as the product:

$$E[GeV] = A[ADCch.] \cdot \frac{N_{pixel}}{ADCch.} \cdot pixel(pe) \cdot \frac{MIP}{pe} \cdot \frac{GeV}{MIP}. \quad (1)$$

The analog amplitude measured in ADC channels is converted into number of fired pixels by the factor $\frac{N_{pixel}}{ADCch.}$, this number includes all electronic effects. The number of photoelectrons (pe) in the signal is obtained using the inverse of the SiPM response function shown in Fig.1a). The light yield (LY) $\frac{pe}{MIP}$ is needed to calibrate the y-axis of this non-linear function; and it is obtained from the ratio of the MIP peak position and the SiPM gain, shown in Fig.1b) for a low intensity flash of LED light. The LY includes geometrical and light transport efficiency and SiPM photo-detection efficiency. Finally, the energy for one MIP is extracted from MC simulation and applied with the

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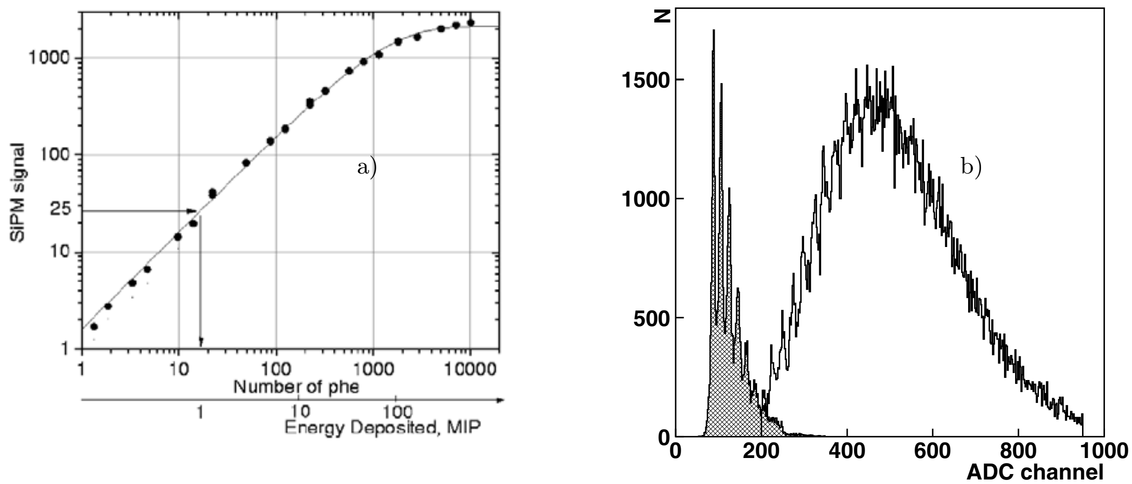

Figure 1: a) Nonlinear response to LED light for 1024-pixels/mm^2 SiPM. b) SiPM pulse height spectrum for low intensity LED light (shaded area) and for a MIP signal from β-source. The single pe peak structure is visible above the pedestal in channel 100.

factor $\frac{GeV}{MIP}$.
The LY calibration requires collecting high statistics of MIP like events, this can be achieved using cosmics muons, a broad muon beam or a hadron beam when placing a thick metal brick in front of the calorimeter to initiate an hadronic shower. In all these cases the calibration requires several hours and cannot be used to monitor the system stability.
The other ingredient for the LY calibration is the SiPM gain which is obtained as the separation between two subsequent single pixel peaks when illuminating the SiPM with low intensity LED light. Assuming to be limited by a DAQ rate of 100 Hz it requires about 20 min to collect 10^5 events, yielding a precision of 1-2% on the gain determination.
In order to control the response function of the SiPM the LED monitoring system is required to deliver light in a range from few photoelectrons up to 80-100 MIP. Due to the fast recovery time of the SiPM ($\sim$10 ns) the duration of the LED pulse is crucial in the determination of the proper response function. Fig. 2 shows two examples of response functions obtained with an LED pulse signal shorter or longer than the MIP pulse.

3. MONITORING SYSTEM

During the calorimeter operation possible variations in the system are detected by a threefold monitoring system. A slow control system reads the SiPM bias voltage and the temperature of each cassette with a 5 points interpolation. The SiPM gain is measured at the beginning of each run with low LED light intensity. The total temperature and voltage dependence of the SiPM gain at room temperature is measured to be 1.7%/°C and 2.5%/0.1V. Finally, the peak position of a medium amplitude LED signal is monitored. LED light fluctuations are corrected using the light amplitude read out by a PIN diode. Variations in the response to UV-LED light reflect the SiPM signal amplitude dependence on T and V. This dependence is expected to be larger that that of the gain given that the SiPM signal amplitude is the product of SiPM gain, quantum efficiency and Geiger efficiency; and that all three factors depend on temperature and voltage. It is indeed found that the signal amplitude varies according of 4.5%/°C and 7%/0.1V. The combined information from the monitoring system is used to correct the calorimeter response to an expected stability of 1-2%.

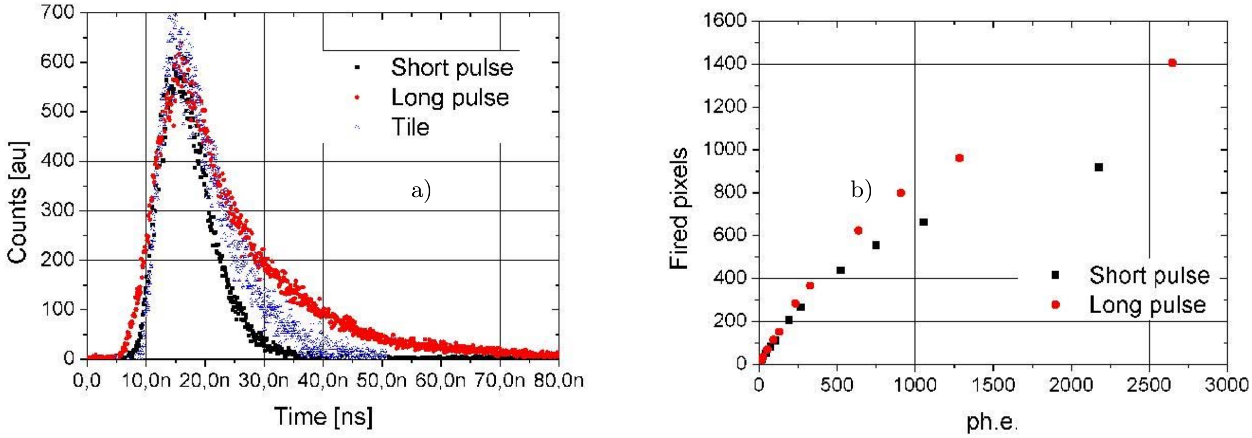

Figure 2: a) Comparison of pulse shapes from LED and MIP signals. b) SiPM response curve obtained with two different LED pulse shapes [6].

References

[1] V. Andreev et al. *Nucl. Instrum. Methods* A**430** (2004) 22.

[2] G. Bondarenko, P. Buzhan, B. Dolgoshein, V. Golovin, E. Guschin, A. Ilyin, V. Kaplin, A. Karakash, R. Klanner, V. Pokachalov, E. Popova, K. Smirnov, *Nucl. Instrum. Methods* A**442** (2000) 187.

[3] 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).

[4] P. Buzhan, B. Dolgoshein, L. Filatov, A. Ilyin, V. Kantzerov, V. Kaplin, A. Karakash, F. Kayumov, S. Klemin, E. Popova, S. Smirnov, Nucl. Instrum. Meth. A **504** (2003) 48 (2003).

[5] E. Garutti *et al.*, LC note, LC-DET-2004-025, http://www-flc.desy.de/lcnotes/.

[6] E. Popova *et al.*, "Prospects to Use Silicon Photomultipliers for the Astro Particle Physics Experiments EUSO and MAGIC" submitted to IEEE, Rome, Italy, 16-24 Oct. 2004.