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A new single channel readout for a hadronic calorimeter for ILC

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Within the CALICE collaboration[†] several concepts for the hadronic calorimeter of a future linear collider detector are studied. After having demonstrated the capabilities of the measurement methods in "physics prototypes" the focus now lies on improving their implementation in "engineering prototypes", that are scalable to the full linear collider detector. The Analog Hadron Calorimeter (AHCAL) concept is a sampling calorimeter of tungsten or steel absorber plates and plastic scintillator tiles read out by silicon photo multipliers (SiPMs) as active material. The front-end ASICs are integrated into the active layers of the calorimeter and are allowing the prototype to be equipped with different types of scintillator tiles as well as SiPMs. Four layers have been equipped with a novel design of scintillator tile wrapped in reflecting foil and directly coupled to a SiPM manufactured by Ketek. The blue sensitive SiPM has 2304 pixels, an average gain of 6×10^6 electrons and an average dark count rate of $2\times10^6\,\mathrm{s}^{-1}$ when operated at 2.5 V above breakdown and 22 °C. Furthermore the temperature dependence of the breakdown voltage for these SiPMs is only 17 $\frac{\mathrm{mV}}{^\circ\mathrm{C}}$, which ensures a stable operation. The operation at fixed over voltage ensures a homogeneous response and behavior of the calorimeter. Results from recent beam test measurements of minimal ionizing particles will be compared to calibrations obtained in the laboratory and the analysis on electromagnetic showers will be presented. Plans for future hadron beam tests with a larger prototype will be discussed.

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1. Introduction

The CALICE collaboration is developing new calorimeter systems for a future linear collider (ILC) [1] optimized for particle flow algorithms. The aim is a jet energy resolution of 3-4 % at 100 GeV. One of the calorimeter systems under investigation is the analogue hadron calorimeter (AHCAL), a $5-6\,\lambda$ deep sampling calorimeter with a 2 cm thick iron absorber. The sensitive layer consists of $3 \times 3 \times 0.3\,\mathrm{cm}^3$ plastic scintillator tiles, that are read out via silicon photo multipliers (SiPM). Their high current signal due to the Geiger-mode operation, low power consumption, compactness and operability in magnetic fields makes them the photo-detector of choice. Parameters characterizing the performances of the detection system are gain, dark count rate (DCR), optical cross talk, temperature dependency as well as the response of the SiPM and tile system to minimal ionizing particles (MIP). For a full AHCAL system for the international large detector (ILD) 10^7 single channels [2] will have to be produced and characterized. A design with maximum tile to tile homogeneity already in production will ensure fast characterization and a stable detector running.
A new design for the single channels has been finalized at the University of Hamburg. An extensive calibration in the laboratory with dedicated setups before mounting on the detector provides a rich data set to predict and understand the detector behavior in detail. This way different strategies how to operate the detector can be evaluated.

2. Single channel design

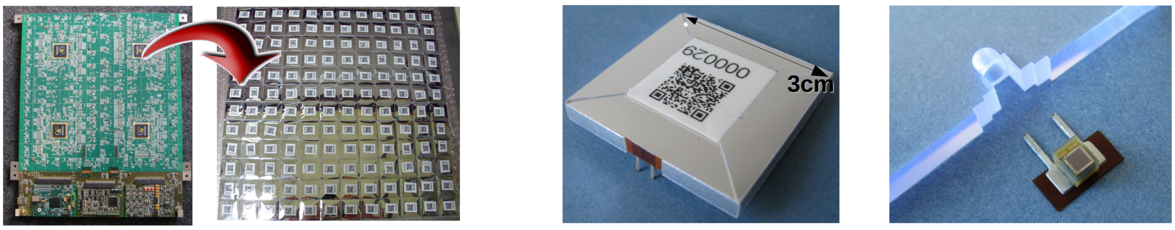

Figure 1:
Left: HBU with four Spiroc2b and 144 channels on the rear side.
Right: Single tile with cut out for SiPM.

The basic building block is the $36 \times 36\,\mathrm{cm}^2$ HCAL base unit (**HBU**). The PCB hosts four custom made readout ASICs (**Spiroc2b**) which read out 144 channels mounted on the other side of the PCB. As an intermediate step towards the final ILC readout,the ASIC Spiroc2b has been designed by OMEGA IN2P3 - Ecole polytechnique. The ASIC has been designed for SiPM operation. It features a channel-wise SiPM bias voltage adjustment, preamplifier adjustment (4 bit range), auto trigger with adjustable threshold, shaping, integration, buffering with 16 cell deep analog memory and digitization for 36 channels. Every single feature of the ASIC would need to be calibrated in time consuming procedures before use. For detector with thousands of chips such a calibration would not be feasible.
Each active calorimeter channel consists of a plastic scintillator read out via a SiPM. The plastic scintillator (Eljen EJ-200 (BC-408)) tile is machined and polished to achieve a precision at the

$50\,\mu$m level. A cut out in front of the SiPM based on the design of the MPI Munich [3] ensures a homogeneous response to MIP. To minimize the optical crosstalk the tile is wrapped in a semiautomatic process with reflecting plastic foil (3M Vikuiti$^{\text{TM}}$Enhanced Specular Reflector (ESR), $65\,\mu$m thick, 98 % reflectivity). Two holes for LED calibration on the HBU are cut into the foil.

	Pixel	#pixel	Area	Bd	Gain	DCR	Temp. dep.	Crosstalk
Value	$25 \times 25\,\mu\text{m}^2$	2304	$1.4\,\text{mm}^2$	27.4 V	$753 \cdot 10^3$	$222 \cdot 10^3$ Hz	$17\,\frac{\text{mV}}{^\circ\text{C}}$	$< 5\,\%$
RMS				150 mV	1.7 %	19 %	30 %	

Table 1: Figures of merit for the Ketek PM1125 SiPM.

The photo-sensor is a SMD Ketek PM1125 (table 1). Due to the peak sensitivity at $\lambda = 420\,\text{nm}$ it can be coupled directly to the scintillator tile with an emission maximum at 423 nm. It features a low sensitivity to temperature changes and a good homogeneity over a large sample. The SiPM is soldered on a custom made capton holder to be compatible with the current HBU design.

3. Tile characterization

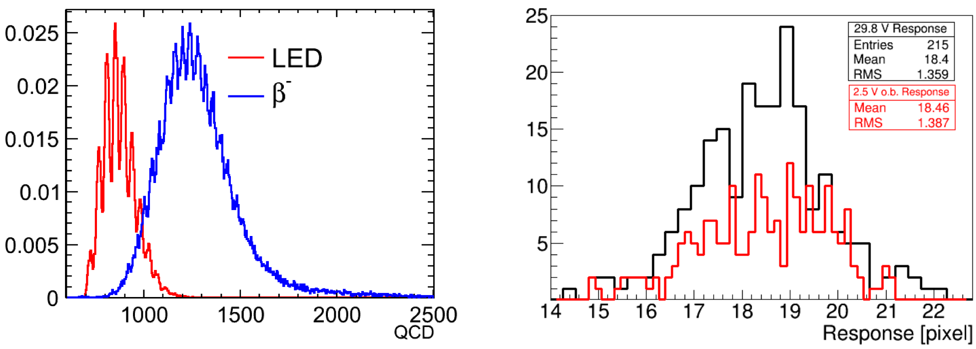

Figure 2:
Left: Low light intensity spectrum for gain measurement (red), ^{90}Sr spectrum for response evaluation (blue)
Right: Spread of tile response for 2.5 V excess bias voltage (red) and 29.8 V bias voltage (black).

In a dedicated, temperature controlled (accuracy 0.2 K) characterization setup the SiPM gain (G), dark count rate (DCR) and the tile response (R) to a ^{90}Sr source are measured at different voltages and temperatures. Extrapolation of the gain versus bias voltage to zero yields the breakdown voltage V_{bd} (3.1) with an accuracy of 30 mV. The response, defined as the most probable value (MPV) in fired pixel of the spectrum induced by MIP (3.1) is measured by placing a collimated ^{90}Sr source above the tile. The data acquisition is then triggered by the coincidence of two scintillators below the tile.

$$G(V,T) = \frac{dG}{dV} \cdot (V - V_{bd}(T)), \qquad R(V,T) = \frac{MPV(V,T) - Ped.(V,T)}{G(V,T)}. \tag{3.1}$$

With the dataset of several hundred tiles the behavior of a whole calorimeter can be predicted. Figure 2 shows the similar distributions of the response if the tiles are operated with the same operational voltage 29.8 V instead of individual over voltage (2.5 V over breakdown). The tile design makes it possible to use this simplification in detector operation without worsening the homogeneous response of the detector.

4. Detector operation

The goal of a good tile design is to homogenize the detector response and the precision level on which it can be calibrated. With every tile having the same behavior and the same response to particles, the detector operation, like setting thresholds, is simple and calibration of every single channel is not necessary. To equalize the response of the tile, every SiPM needs a separate voltage to be set.

The power supply that supplies all ASICs with voltage has a limited precision of 10 mV. The Spiroc2b channel wise internal voltage adjustment has an uncertainty on the set voltage, depending on the range used. So using a wider range of bias voltages to equalize the detector response worsens the precision with which the single channels can be calibrated. This uncertainty is directly responsible for the constant term of the calorimeter energy resolution. Two different operational modes are considered:

A: Response equalization: All channels are set to have same response in fired pixel per MIP. A voltage range of 3.3 V for the operational voltages is needed. A realistic calibration scheme introduces an uncertainty on the bias voltage of **100 mV**.

B: No individual voltage adjustment: All SiPMs are supplied with the same bias voltage and the internal ASICs voltage setting is not used. No calibration of the ASIC is needed. The uncertainty on the operational voltage is caused only by the power supply and is about **10 mV**.

5. Results and Discussion

Table 2 shows the spread of operational parameters for the two modes. The use of a wider range homogenizes the detector response, but the calibration precision reduces because of additional uncertainties introduced by the ASIC regulation.

Op. Mode	Bias	Min to Max	Response	Error	RMS	Gain	RMS
A	30 V	3.3 V	18.1 px	1.5 %	2 %	$649 \cdot 10^3$	17 %
B	29.8 V	0 V	18.4 px	0.5 %	7 %	$653 \cdot 10^3$	5.8 %

Table 2: Spread of operational parameters for the two modes.

If the tile design discussed is operated in mode **A** with the gain spread of 17 % no further adjustment of the preamplifier or threshold settings of the ASIC is needed to operate the detector. The uncertainty in setting the bias voltage also smears out the desired response by about 2 %. In mode **B** the ASICs voltage setting is not used, which results in a better precision on calibration. The spread in response on the order of 10 % makes a separate auto trigger threshold adjustment unnecessary.

If the detector is operated in mode **B** no time consuming calibration of the ASIC is necessary. The precision with which the detector can be calibrated is higher than setting every SiPM voltage separately (mode **A**).

6. Conclusion and Outlook

The finalized and commissioned tile design shows a low spread in operational parameters, demonstrating the possibility for an easier and faster commissioning of an analogue hadron calorimeter with a large number of channels, introducing only a spread of 10 % in response per channel if all channels are operated at the same voltage and an uncertainty of 0.5 % on the single channel calibration, which enters the constant term of the energy resolution.
In 2014 a prototype will be commissioned for test beam at the PS, CERN, to be tested with pions from 3 GeV to 15 GeV. The goal is a high level electronics test and proof of the scalability of the AHCAL technology as well as a rich physics program focusing on the timing of hadronic showers. Eight HBUs with 1200 channels are equipped with the design discussed here while eight more of the same design are produced in cooperation with the University of Heidelberg to be equipped with SensL SiPMs, which show a similar small spread in operational parameters.

References

[1] Jean-Claude Brient and Henri Videau. The Calorimetry at the future e+ e- linear collider. *eConf*, C010630:E3047, 2001.

[2] K. Krüger. Integration concepts for highly granular scintillator-based calorimeters. *Proceedings of the CHEF2013 Conference - Eds. J.-C. Brient, R. Salerno, and Y. Sirois*, pages 230–236, 2013.

[3] F. Simon and C. Soldner. Uniformity studies of scintillator tiles directly coupled to sipms for imaging calorimetry. *Nucl.Instrum.Meth.*, A620:196–201, 2010.