PROCEEDINGS OF SCIENCE

# Forward Calorimeters Test Beam Results for Future Linear Colliders

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Abstract

Two fully assembled sensor planes of the forward calorimeter prototypes for Future Linear Colliders were studied in an electron test beam in 2010-2011 at DESY. GaAs:Cr and Si sensors with pad structures were firstly characterized in the laboratory and then equipped with dedicated front-end electronics. The leakage current measured as a function of the bias voltage and temperature, and charge collection efficiency as a function of the bias voltage. In the beam multichannel read-out was demonstrated to match the expected performance. A signal-to-noise ratio was measured of better than or equal to 20 for minimum ionising particles. The response as a function of the position on and between the pads was studied in detail.

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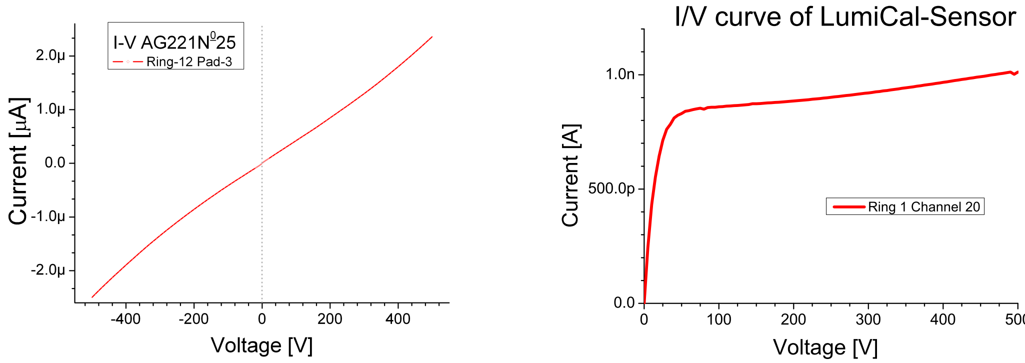



(a) (b)

**Figure 1:** (a) - The leakage current for a GaAs:Cr sensor pad measurement as a function of bias voltage. (b) - The leakage current for the Si sensor pad measurement as a function of the bias voltage.

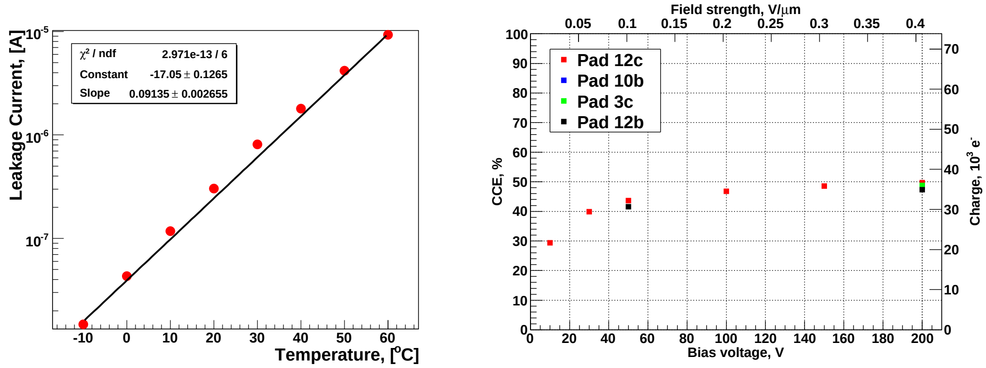
## 1. Introduction

Two calorimeters are foreseen in the very forward region of future International Linear Collider (International Linear Collider (ILC) [1] and Compact Linear Collider (CLIC) [2]) detectors. Luminosity Calorimeter (LumiCal) is for precise measurement of the luminosity and Beam Calorimeter (BeamCal) for fast estimate of the luminosity and tagging of high energy electrons. Both are cylindrical electromagnetic sampling calorimeters, centered on the outgoing beam. They will improve the hermeticity of the detector. The amount of particles scattered back into the central detector strongly depends on the design of the very forward region. The current geometry is optimized to keep the flux of back-scattered particles small. Major challenges are radiation hardness (BeamCal), high precision luminosity measurement (LumiCal) and fast readout for both calorimeters.

Both calorimeters consist of tungsten absorber disks of 3.5 mm thickness, each corresponding to one radiation length, interspersed with sensor layers. Each sensor layer is segmented radially and azimuthally into pads. Front-end ASICs (FE ASICs) are positioned at the outer radius of the calorimeters. All detectors in the very forward region have to tackle a relatively high occupancy, requiring special front-end electronics. In addition, the timing requirements for CLIC are typically in the range of nanoseconds. The read out frequency is driven by the beam-induced background.

## 2. Prototype Sensor Planes

Two sensor prototypes were tested in two calorimeter prototypes. Silicon sensor produced by Hamamatsu was used in the LumiCal prototype. A semi-insulating gallium arsenide compensated with chromium (GaAs:Cr) sensor was used in the BeamCal prototype. For both sensor types leakage current and capacitance as a function of the bias voltage were measured in the laboratory and are shown in the figure 1(a) and 1(b). For GaAs:Cr sensors leakage current was measured as a function of the temperature as shown on the figure 2(a). As BeamCal is expected to accumulate a considerable radiation dose from beamstrahlung-generated e+e- pairs, GaAs:Cr sensors were previously tested for radiation hardness in an electron beam [3].




(a) (b)

**Figure 2:** (a) - Leakage current for the GaAs:Cr sensor pad as a function of the temperature for the 100 V bias voltage applied. (b) - Charge Collection Efficiency for several GaAs:Cr sensor's pads as a function of bias voltage.

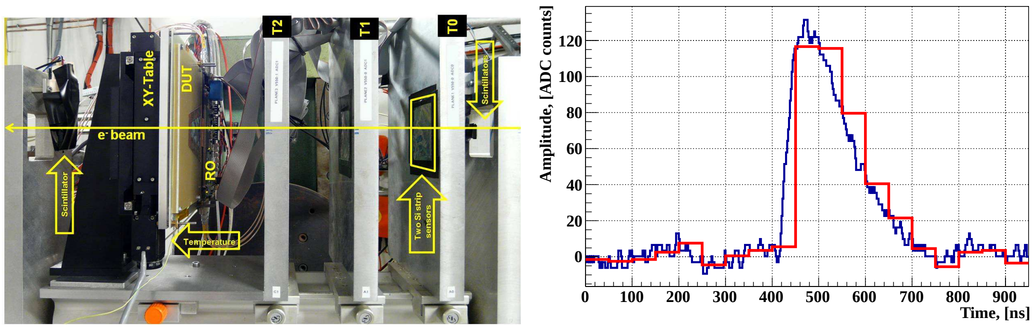
The pads of the sector shape sensors were connected to specially developed front-end ASICs and flash Analog to Digital Converter (ADC) through a fan-out. The FE and 10-bit pipeline ADC ASICs are designed to achieve readout after each bunch crossing (BX). The prototypes were designed and fabricated using 0.35 mm CMOS technology [4]. Sensors metalization segmentation and the read out electronics was shown in [5] and [6]. A FE ASIC comprises 2 feedback technologies on one chip for comparison of the performance. The total number of channels assembled with FE and ADC ASICs was 32. In addition, 8 channels were readout by a CAEN ADC. FE ASICs can be operated in 2 modes, one for physics (low amplification) and one for calibration (high amplification) measurements.

Charge Collection Efficiency (CCE) is defined as ratio between collected and created charge in the detector. For the GaAs:Cr sensor CCE vs. voltage dependence was measured and shown in the figure 2(b). It shows saturation at 50 % CCE for a bias voltage of 100V.

## 3. Test Beam

Electron beam of about 4 GeV at DESY was used. A silicon strip telescope was used for precise position measurements of the impact points of the beam particles. It consists of three reference detector modules (Ref.det 1, 2 and 3). Each of them provides three space coordinates (x, y and z) for crossing particles. The telescope position resolution in x and y coordinates amounts to 28 $\mu$m.

The device under test (DUT) and the telescope modules were mounted on a common optical bench as shown in the figure 3(a). The DUT was mounted between telescope planes. A coincidence of three scintillator fingers was used to generate a trigger. The DUT was mounted on the XY-Table to provide a wide range of x-y positions with respect to the beam. Three test beam campaigns at DESY were made in 2010-2011. In the test beam in 2010 [7] the readout chain consisted of FE-ASICs and a stand alone ADC. In 2011 ADC-ASICs were added.




(a) (b)

**Figure 3:** (a) - Test beam setup. (b) - The ADCs signals from the CAEN ADC 1721 (blue) and ADC ASIC on board (red).

## 4. Signal Processing

Several million trigger events were recorded with fully assembled sensor planes. To verify the ADC ASIC performance 8 channels were readout in parallel with a CAEN ADC v1721 ( 8 channels, 8 bit 500 MS/s ADC). The peaking time of the FE-ASIC's was designed to be 60 ns. The two ADCs showed identical signal shapes, see figure 3(b). A small Common Mode Noise (CMN) was found. CMN subtraction reduced the noise by a factor 2. Signals are processed sample by sample by using 3 methods:

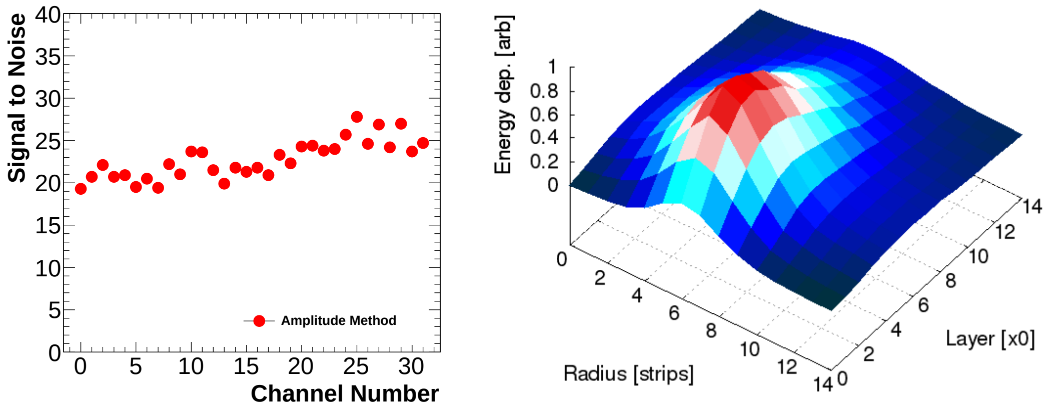
1. Amplitude defined relative to the baseline,
2. Integral over the signal,
3. Deconvolved amplitude.

Resulting Signal to Noise Ratio (SNR) of the amplitude method is shown in the figure 4(a). All methods show almost the same signal-to-noise ratio for both calorimeter prototypes. The signal-to-noise ratio for the BeamCal GaAs:Cr sector sensor values for all 32 channels are presented in the figure 4(a).

The impact point on the sensor plane was predicted from the telescope data, and compared to signals on the pads. Near the pad boundaries the signal size was found to drop by 10 %. Tungsten plates were installed in front of sensor planes for first studies of the shower shape as a function of the absorber thickness. The LumiCal shower profile is shown in the figure 4(b).

## 5. Deconvolution Method

The deconvolution method enables reduction of the amount of data and recovery of pile-up signals, keeping precise time and amplitude measurement. Here the deconvolution method is used to decompose the initial input signal from the sensor by assuming a known pulse shape. The deconvolution method is applied in the data analysis [8, 9]. Part of the data was synchronised with the beam clock.




(a) (b)

**Figure 4:** (a) - The signal to noise for all 32 instrumented channels obtained with amplitude method. (b) - The LumiCal sensor plot with reconstructed impact point from telescope.

For the sampled output of a CR-RC shaper with the step response

$$v(t) = \frac{-t}{\tau} e^{\frac{-t}{\tau}}$$

the deconvoluted function can be implemented by forming the weighted sum of three successive samples

$$V_k = w_1 * V_k + w_2 * V_{k-1} + w_3 * V_{k-2}$$

with the weights $w_1 = \frac{1}{x} e^{x-1}$,$w_2 = \frac{-2}{x} e^{-1}$, $w_3 = \frac{1}{x} e^{-(x+1)}$ The weights depend on the sampling interval and the shaping time constant $x = \frac{t}{\tau}$.

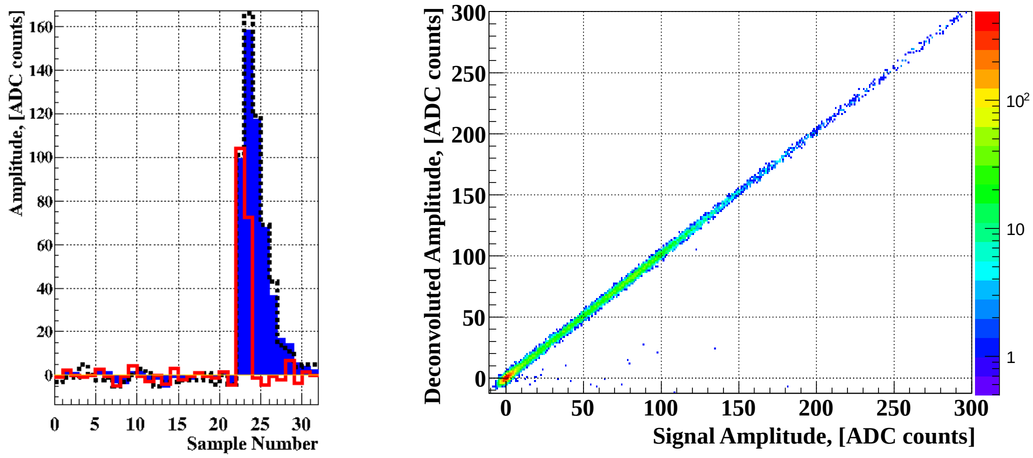
From the deconvoluted information the signal amplitude and the charge has been reconstructed and compared to the measurement of the full signal. Excellent proportionality was found as shown in the figure 5(b).

## 6. Conclusions

Beam tests has been performed to investigate the response of large area pad sensors assembled with a full readout chain. The results demonstrate very good performance of the response of full readout chain to single charged particles both for GaAs:Cr for BeamCal and silicon sensors for LumiCal. A S/N ration is measured larger than 20 for LumiCal and BeamCal. A signal reduction of 10 % was observed in the space between pads. In addition, the first studies of the shower development using tungsten absorber planes were performed.

## 7. Future Steps

For the measurement of the performance of a prototype calorimeter the infrastructure is prepared within the European Community supported AIDA project. It will allow to hold up to 30 tungsten absorber planes interspersed with fully assembled sensor layers. It allows for both LumiCal and BeamCal sensor tests with different front-end electronics.




(a) (b)

**Figure 5:** (a) - The raw signal (black dotted), the signal shape after CMN subtraction (blue), the deconvoluted signal shape (red). (b) - The correlation between deconvoluted amplitude and the signal amplitude.

## 8. Acknowledgments

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