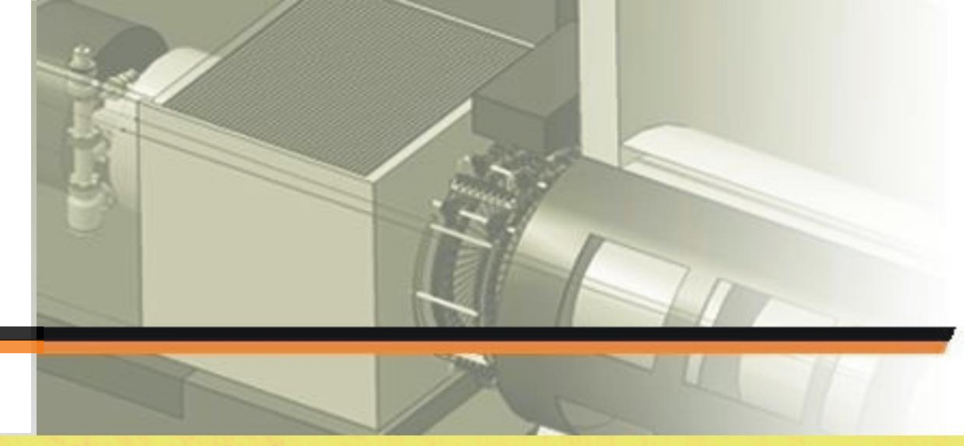
Forward Calorimeters Test Beam Results for Future Linear Colliders



FCAL Collaboration
High precision design

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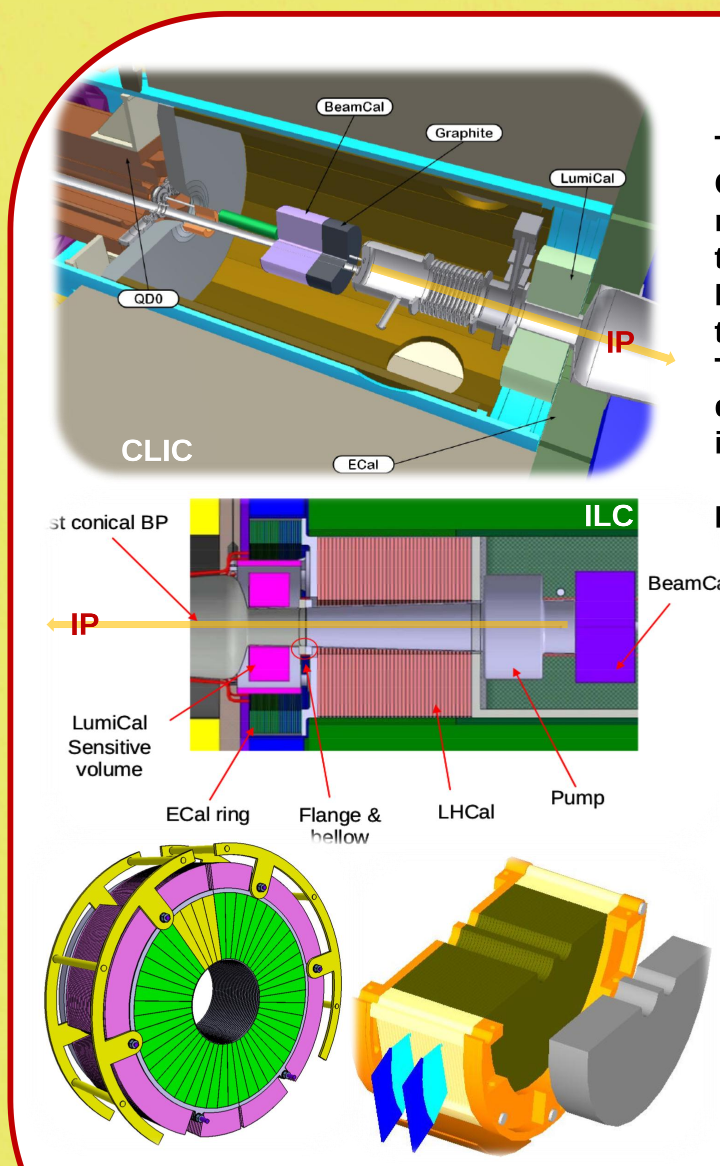
Abstract:

Two fully assembled sensor planes of the forward calorimeters for Future Linear Colliders were studied in an electron test beams in 2010-2011 at DESY. Before GaAs:Cr and Si sensors with pad structures were tested in the laboratory. And then equipped with dedicated front-end electronics. Sensor characteristics are shown - the leakage current measured as a function of the bias voltage and temperature, and the charge collection efficiency as a function of the bias voltage. Multichannel readout was proven to match the expected performance. Results are a signal-to-noise ratio 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.

ILC & CLIC



The proposed LumiCal and BeamCal design. This picture shows a LumiCal and BeamCal with 30 layers, as proposed for ILC, while the CLIC version has 40 layers.

Two calorimeters are foreseen in the very forward region of the ILC and CLIC detectors: The Luminosity Calorimeter (LumiCal) for the precise measurement of the luminosity and the Beam Calorimeter (BeamCal) for the 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 backscattered particles small.

Forward Calorimeter Challenges:
- **→Radiation hardness (BeamCal),**
- **→High precision (LumiCal) and fast readout (both)**

		ILC(ILD)	CLIC_ILD
LumiCal	geometrical acceptance [mrad]	31 – 77	38 – 110
	fiducial acceptance [mrad]	41 – 67	44 – 80
	z (start) [mm]	2450	2654
	number of layers (W + Si)	30	40
BeamCal	geometrical acceptance [mrad]	5 – 40	10 – 40
	z (start) [mm]	3600	3281
	number of layers (W + sensor)	30	40
	graphite layer thickness [mm]	100	100

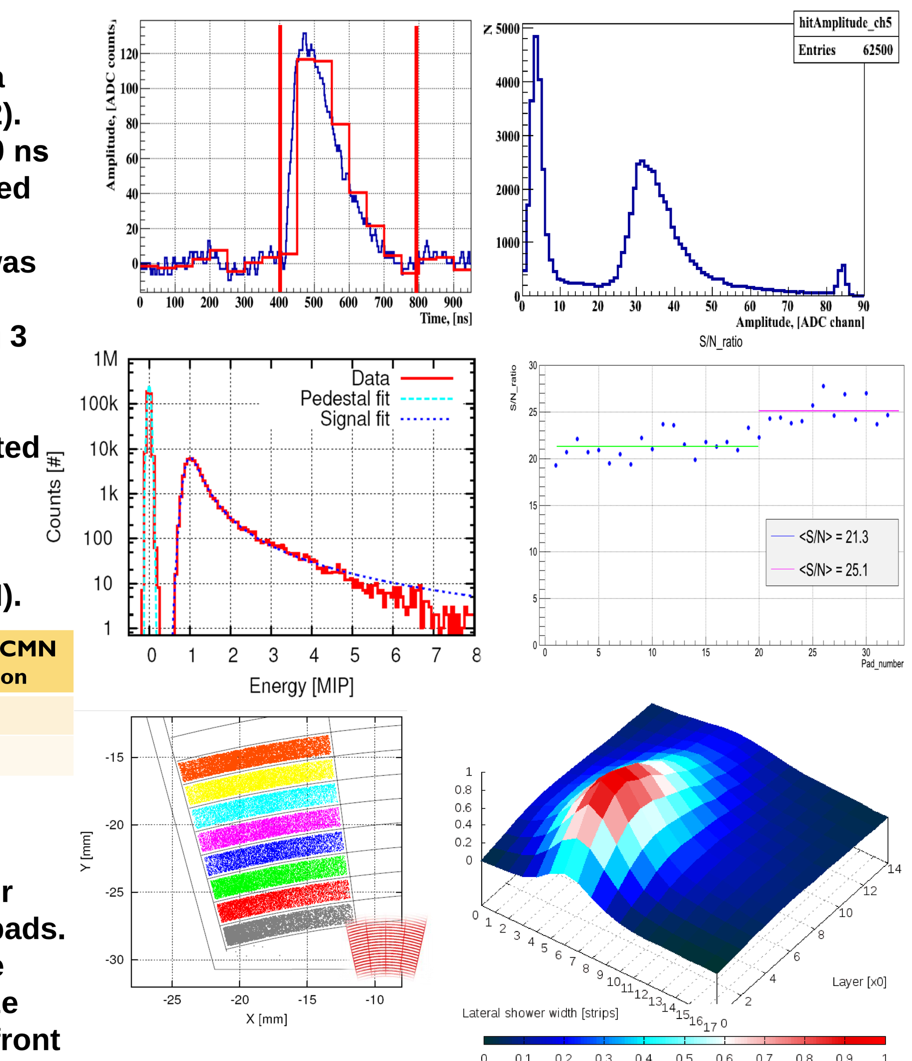
Both Calorimeters consist of tungsten absorber disks of 3.5 mm thickness, each corresponding to one radiation length, interspersed with sensor layers. Each sensor layer is segmented radially and azimuthally into pads.
Front-end ASICs are positioned at the outer radius of the calorimeters. All detectors 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 from 1 ns to 10 ns and are principally driven by the beam-induced background.

Signal Processing

Several millions of triggers 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), (2). The peaking time of the FE-ASIC's is designed to be 60 ns and full signal length is ~ 300 ns. The two ADCs showed identical signal shapes. A small Common Mode Noise (CMN) was found. A method for the CMN subtraction was implemented and the noise was reduced by a factor 2. Signals are processed sample by sample and by using 3 methods:
1. **Amplitude defined relative to the baseline,**
2. **Integral under the signal or as integral under the fitted signal,**
3. **Deconvoluted amplitude.**

All methods are compared by signal to noise ratio (S/N).

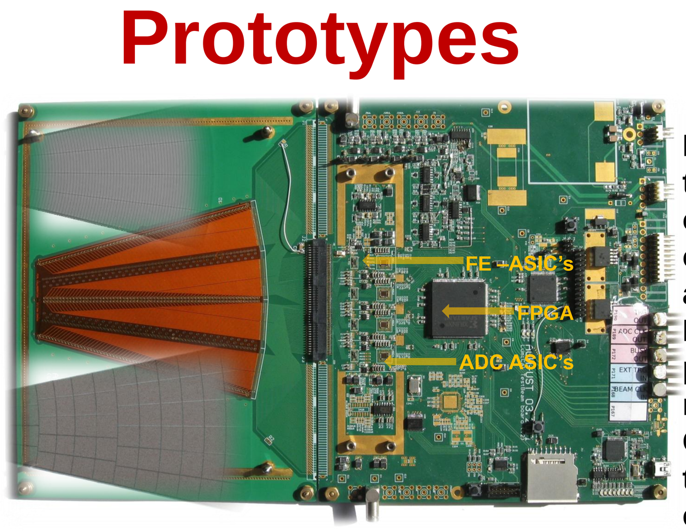
	S/N TB1	S/N TB1 CMN subtraction	S/N TB2	S/N TB2 CMN subtraction
LumiCal	~20	~30	~12	~20
BeamCal	~20	-	~22	~30



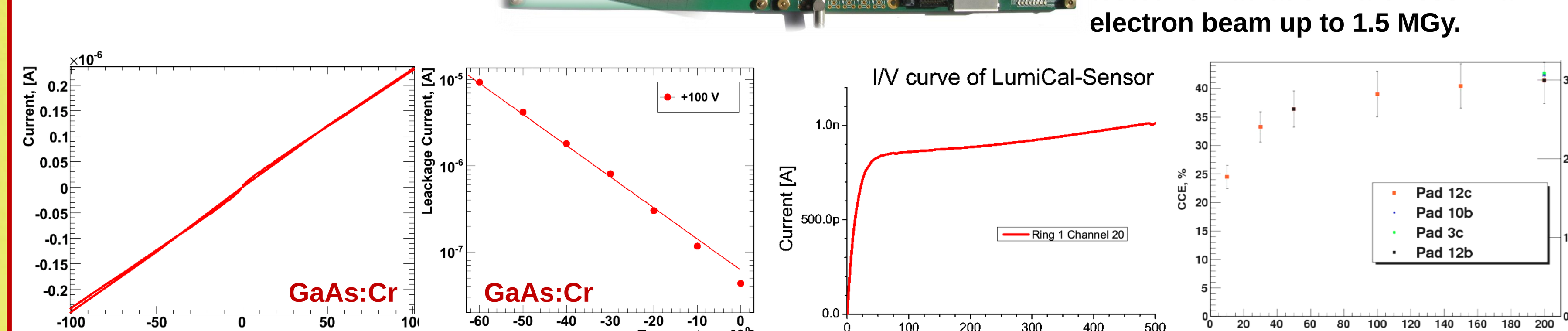
Test beam 1 (TB1) – FE-ASIC's only
Test Beam 2 (TB2) – FE-ASIC's + ADC-ASIC's
From the telescope data the impact point on the sensor plane was predicted, and compared to signals on the pads. Using a color coding for the different pads there shape became visible. Near the pad boundaries the signal size drops by 10 to 20%. Tungsten plates were installed in front of sensor planes for a first studies of the shower development period.

Prototypes

The FE and ADC ASICS are designed to achieve readout after each BX.
The sensors were connected to a fan-out, and specially developed front-end ASIC and flash ADC. A DAQ was developed for the tests.



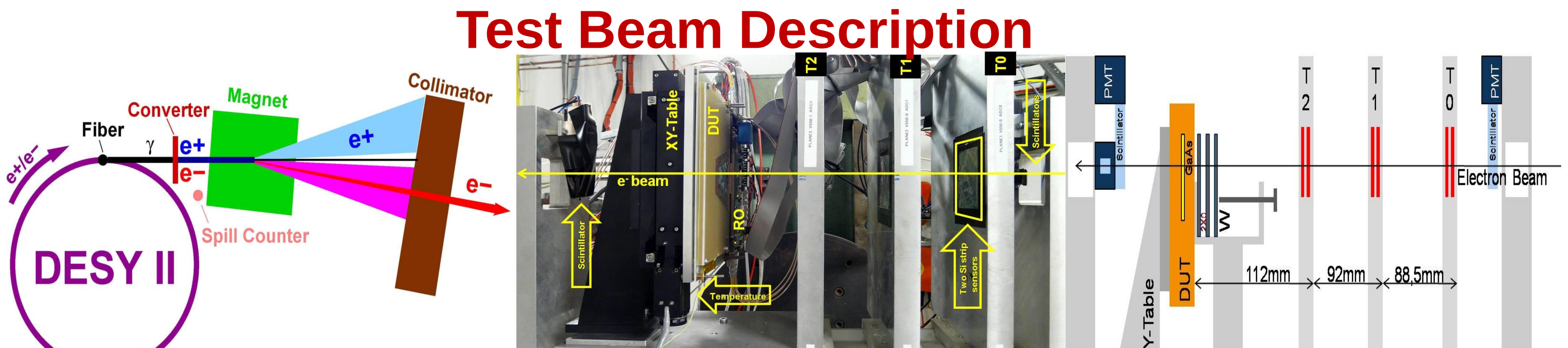
FE ASIC comprises 2 feedback technologies (4 channels each per chip) . The number of assembled channels was 32, 8 channels were additionally readout by a CAEN ADC. FE can be operated in 2 modes for physics and calibration measurements.
GaAs:Cr sensors were previously tested for radiation hardness in an electron beam up to 1.5 MGy.



The leakage current was measured for all GaAs:Cr and silicon sensors as a function of the bias voltage. in addition, for GaAs:Cr sensors as a function of the temperature. The leakage current for GaAs:Cr was measured at different temperatures and falls exponentially with decreasing temperature.

Charge Collection Efficiency (CCE) – is defined as ratio between collected and created charge in the detector. For the GaAs:Cr CCE vs. voltage showed saturation at 40% for a bias voltage 100V.

Test Beam Description

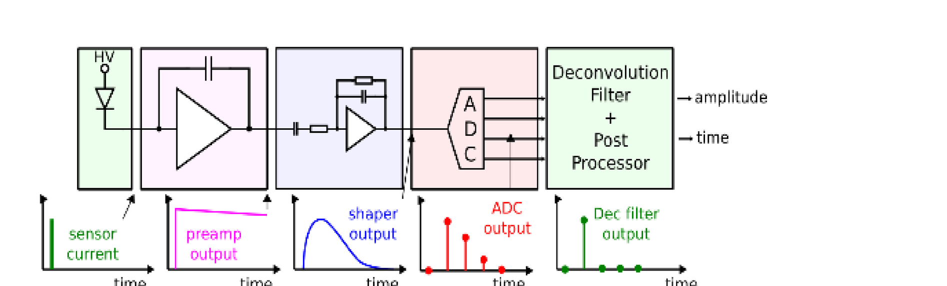


The beam telescope consists of three reference detector modules (Ref.det 1, 2 and 3). Each of them provides three space coordinates (x, y and z) for particles crossing the telescope. Modules consist of two 300 µm thick single-sided silicon sensors of 32mm x 32mm size with a strip pitch of 25 µm and a readout pitch of 50 µm; the strip directions of the two sensors in a module are perpendicular to each other. S/N ratio for MIP, 80 < S/N < 130, and a high intrinsic position resolution, 28 µm. The device under test (DUT) and the telescope modules are mounted on a common optical bench. The DUT was mounted between telescope planes . A coincidence of three of the four scintillator fingers located at both ends of the optical bench is used to generate a trigger. The DUT was mounted on the XY-Table to provide wide range of x-y positions for the DUT. Irradiation studies were done for a few GeV electron beams.

Three test beam campaigns at DESY were made in 2010-2011

Deconvolution Method

The deconvolution method allows to reduce the amount of data and to recover 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 knowing the pulse shape. This method provides information about time and amplitude of the signals. Here the deconvolution method is applied in the data analysis. Part of the data is syncronised with the beam clock.

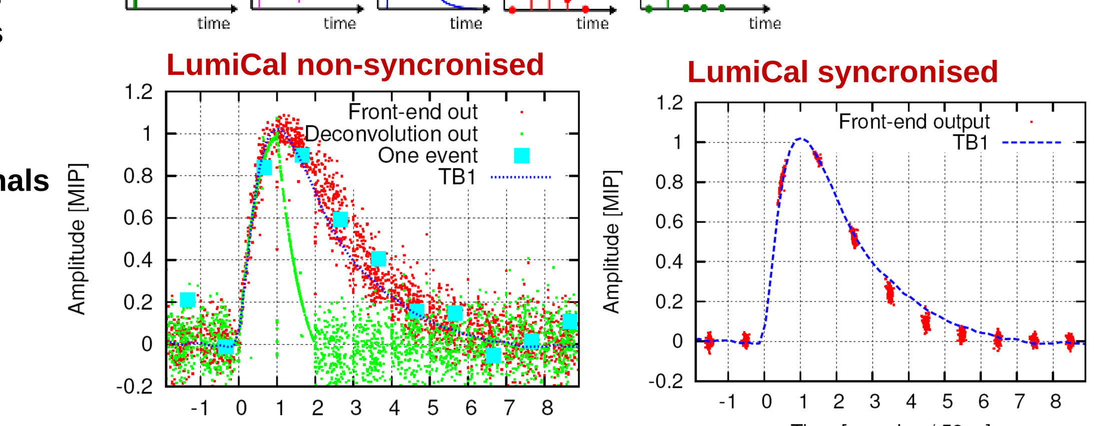


How it works:
In case of the CR-RC shaping of the input signals deconvoluted amplitude is calculated by :

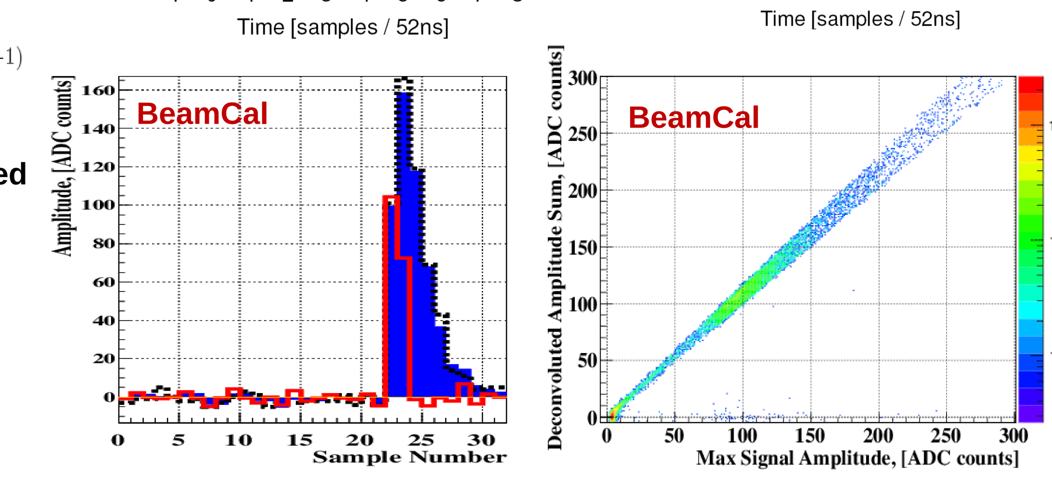
$$V_k = w_1 V_k + w_2 V_{k-1} + w_3 V_{k-2}$$

with the weights

$$w_1 = \frac{1}{x} e^{x-1}, \quad w_2 = -\frac{2}{x} e^{-1}, \quad w_3 = \frac{1}{x} e^{-(x+1)}$$



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.



Conclusions:

Test Beams of electrons are used 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 and silicon sensors. A S/N ration is measured of about 20 for LumiCal and of about 30 for BeamCal. A signal reduction of 10 to 20% was observed in the space between pads. In addition, first studies of the shower development using tungsten absorber planes were done.

Future Steps:

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

DESY, CERN, AGH, IFIN-HH, ISS, NC PHEP, JINR, LAL Laboratoire de l'Accélérateur Linéaire, Pontificia Universidad Católica de Chile, Tohoku University, Brandenburgische Technische Universität Cottbus, Argonne National Laboratory, Royal Holloway University of London, SLAC, Stanford University, University of California Santa Cruz, University of Colorado, AIDA