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Forward Calorimetry sensor test facilities

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Abstract

We report the status of the infrastructure for sensor diagnostics and sensor test facilities at testbeams developed in the framework of EUDET project. The need of such a development is caused by the requirements of extreme precision and homogeneity of Luminosity Calorimeter for future Linear Collider (ILC) and severe radiation conditions for sensors of small angle Beam Calorimeter. In this paper we describe infrastructure created at the DESY testbeam (Hamburg), laboratory equipment at DESY (Zeuthen) and specialized Silicon Laboratory at Tel Aviv University.

Introduction

The purpose of the FCAL Collaboration is to develop the design for the instrumentation of the very forward region [1] of the future detector at the International Linear Collider (ILC) and to prove the feasibility of detector technologies appropriate for this instrumentation. The following subsystems are considered: the Beam Calorimeter (BeamCal) with the dual purpose of extending the angular coverage of the electromagnetic calorimeter and of providing a fast feed-back in tuning the luminosity; and the Luminosity Calorimeter (LumiCal) for precise measurement of Bhabha event rate.

The challenge for BeamCal is that due to beam-beam interaction a large number of electron-positron pairs in the low GeV range is produced by beamstrahlung, a new phenomenon at the ILC. The pairs that will hit the BeamCal carry several tens TeV of energy per bunch crossing. The lateral distribution of the pairs is strongly dependent on the beam parameters. Fast analysis of the pairs distribution shape will be used for beam-tuning to maximum luminosity. Very large energy depositions at low angles are expected, leading to annual radiation doses up to 10 MGy. The requirements on the sensors are stable operation under huge electromagnetic doses, good linearity over a large dynamic range, very good homogeneity and fast response.

The requirements for LumiCal is to enable a measurement of integrated luminosity with a relative precision of 10^{-4}. The present design is based on a tungsten/silicon sandwich calorimeter with silicon sensor planes subdivided into pads. High manufacturing precision and very good uniformity of sensors are mandatory to achieve the required LumiCal performance.

In the following we describe the infrastructure that was developed over last years to make possible all sensor studies necessary for Forvard Calorimetry development.

1 Testbeam at DESY Hamburg

Artificially produced high purity diamond is considered as one of possible candidates for BeamCal radiation hard sensors. To characterize the ability of the given sample to work as a detector of ionizing particles and to study its performance the values of so called Charge Collection Efficiency (CCE) or Charge Collection Distance (CCD), which is proportional to CCE, are used.

CCE is defined by the ratio of the charge collected from the detector while ionizing particle crosses it to the number of electron-hole pairs produced by the particle in the detector material. To obtain a reference measurement of the energy deposited by a high energy particle of known energy in a single crystal diamond detector, we used the test beam at DESY providing a GeV electron beam and the EUDET beam telescope developed in the framework of JRA1 project.

This measurement allowed us to determine the number of electron-hole pairs created per micrometer of traversed material. In order to avoid border effects of the detector metallization, we used the EUDET telescope of the test beam facility to control the fiducial region of the device under test. Detector response was measured using charge sensitive preamplifier connected to the ADC. The system used common trigger provided by two pairs of scintillator counters placed in the beam before and after the telescope. Data were collected at different beam energies ranging between 1 GeV to 5 GeV.

More details about the experimental setup, statistics available, data acquisition system, calibration procedures and data processing could be found in [2].

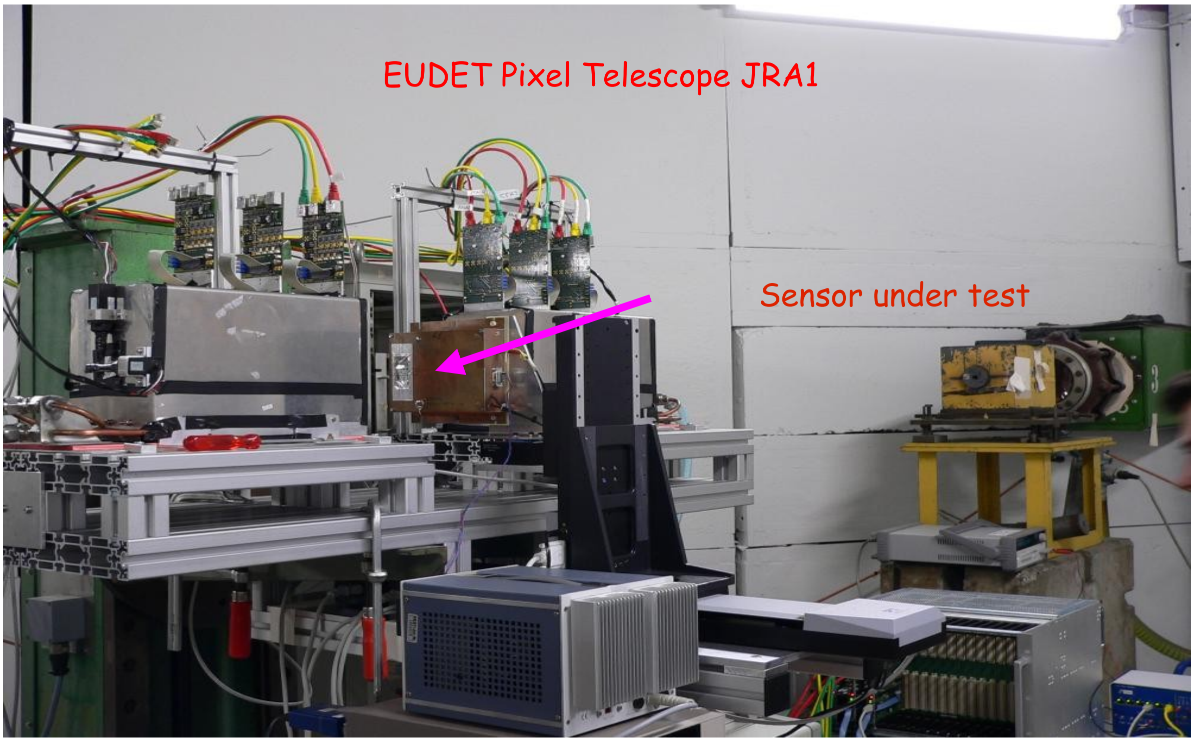

Figure1: Experimental setup at the DESY-Hamburg testbeam. The detector under study is placed in the beam line between two arms of the EUDET telescope.

Typical distributions are shown in the Figures 2 and 3. Fig.2 shows the coordinates of the beam particle impact point on the detector surface, when the detector signal is observed. Round sensor metallization of 3 mm diameter is clearly seen. Diamond signals spectrum for track selection to be in the fiducial volume is shown in the Fig.3 together with the fit by Landau distribution.

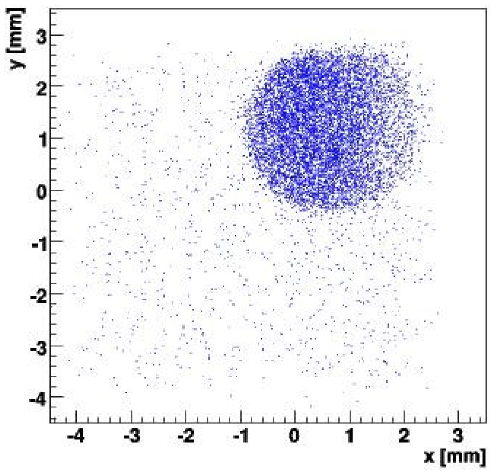

Figure 2: Reconstructed hits with detector signal.

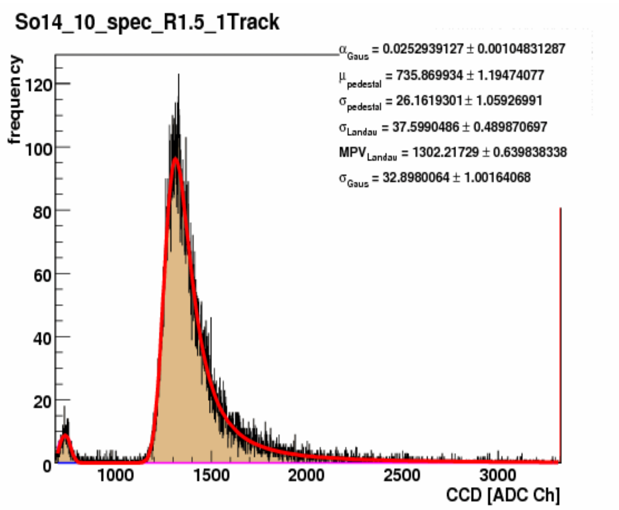

Figure 3: Sensor response with the track inside the active detector area.

2 Infrastructure at DESY-Zeuthen

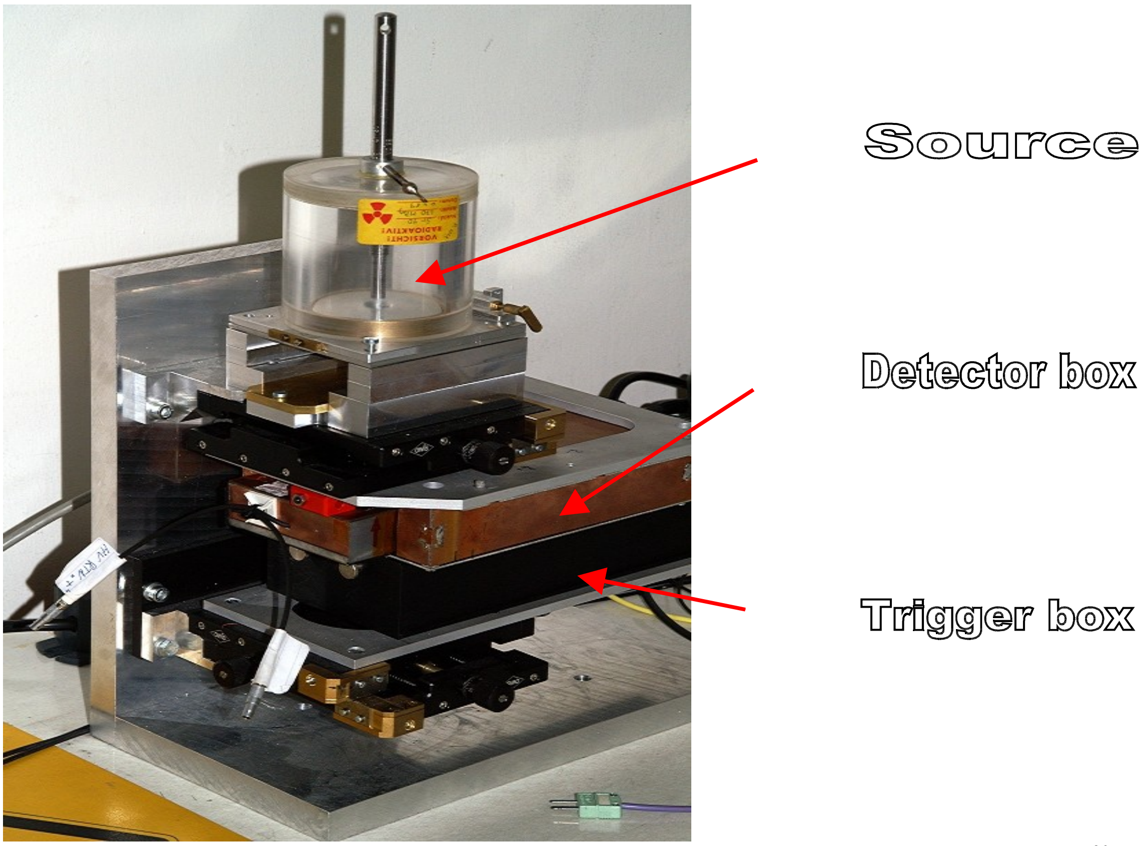

Figure 4: Experimental setup at DESY-Zeuthen for detector CCE measurements using ^{90}Sr source. The box, containing the detector under test and trigger counter box are placed onto adjustable XY-supports for the precise alignment.

For characterization of electrical properties of sensors fully equipped stations for I/V and C/V measurements were build. All measurements there are automatized and computer controlled.

To measure the response of a sensor to charged particles we are using the setup shown in Fig.4. An electron from a ^{90}Sβ source traversing the sensor and generating a signal in the scintillator below has sufficient energy to be regarded as a MIP. The two photo-multipliers readout the light from the scintillator via WLS fibres and generate a trigger signal. The charge sensitive ADC digitizes the signal from the sensors. The similar setup is used for the monitoring of sensor properties during the irradiation studies at TU-Darmstadt (see below).

3 Upgrade of ^{90}Sr setup triggering scheme

To improve the performance of the ^{90}Sr setup described above, we performed a detailed Monte-Carlo simulation of electron energy losses in the setup as well as an optimization of collimators used. It was shown that two separate counters of the optimized thickness are able to select well defined high energy tail of the strontium spectrum and thus to ensure the detector response very close to the one expected from MIP. Moreover with due regard for multiple scattering it is possible to optimize the transversal counter dimensions as well as collimation scheme to improve signal-to-noise ratio and to increase effective trigger rate. The photograph of new trigger counters is shown in Fig.5, spectra from single crystal diamond detector before and after upgrade could be seen in Fig.6 and Fig.7 respectively. The quality of the spectrum (for example an absence of hits in between the pedestal and the signal) as well as trigger rate have been clearly improved.

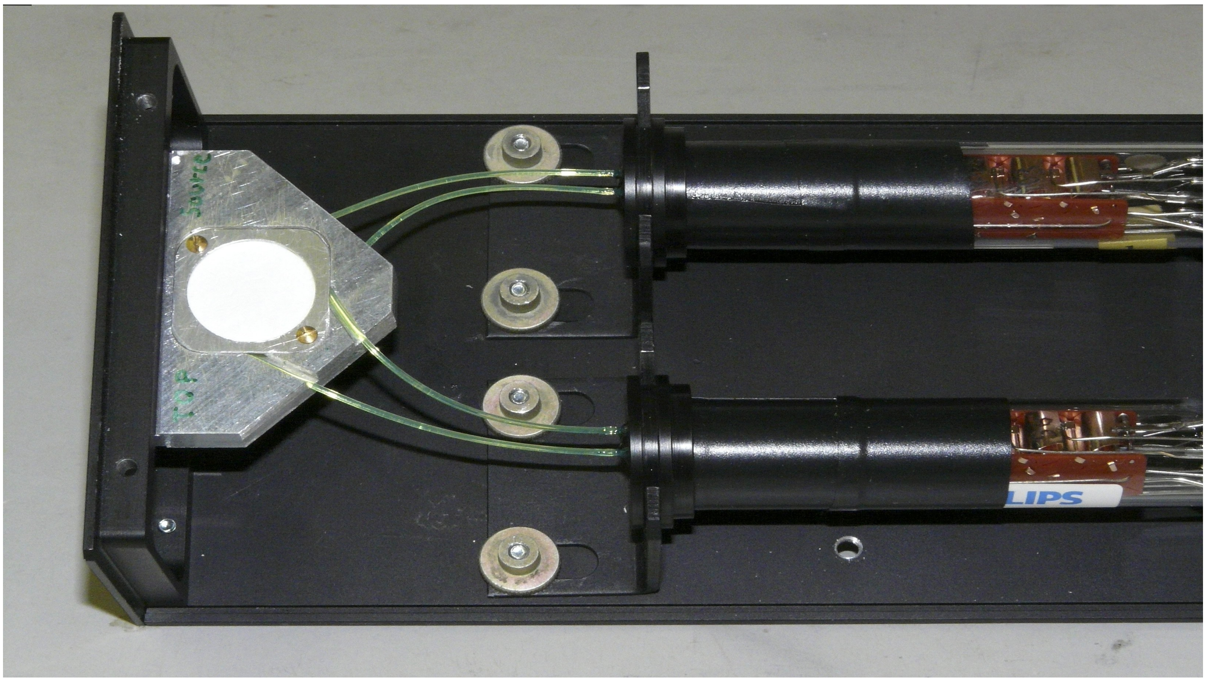

Figure 5: New trigger counters for ^{90}Sr setup. Counters are mounted in the metal holder and covered by thin reflective TYVEK paper. The light is readout by helix-like WLS fibres and registered by photo-multipliers. Light-tight cover of the box (not shown) has a thin entrance window above the counters.

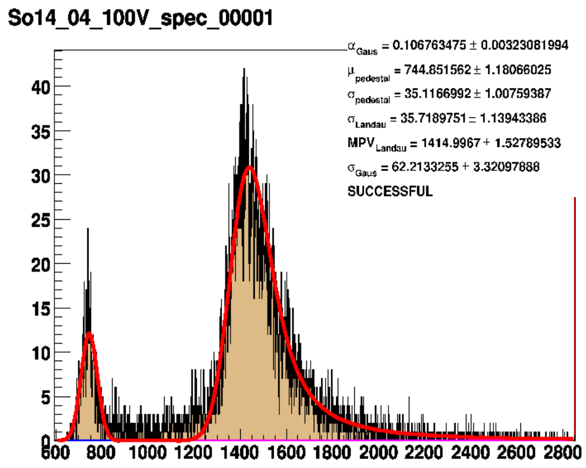

Figure 6: Single crystal diamond spectrum before the upgrade.

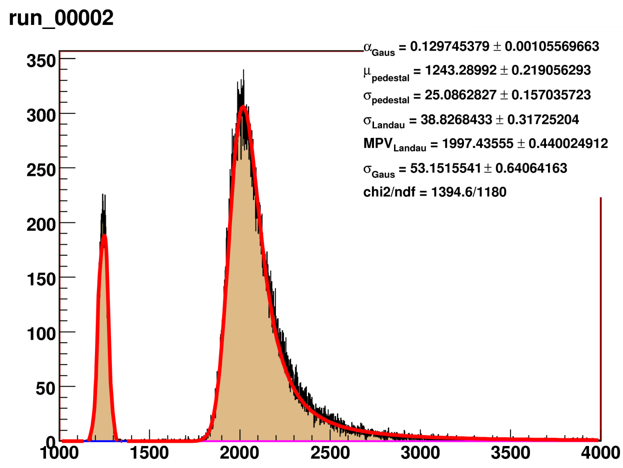

Figure 7: The spectrum after upgrade. The spectrum quality and trigger rate are improved.

4 TSC measuring setup

An important information about the nature of crystal defects and their concentration could be extracted from the measurements of so called Thermally Stimulated Current (TSC). We have build the computer controlled setup shown in the Fig. 8 and plan to use it for systematic studies of radiation damaged detectors.

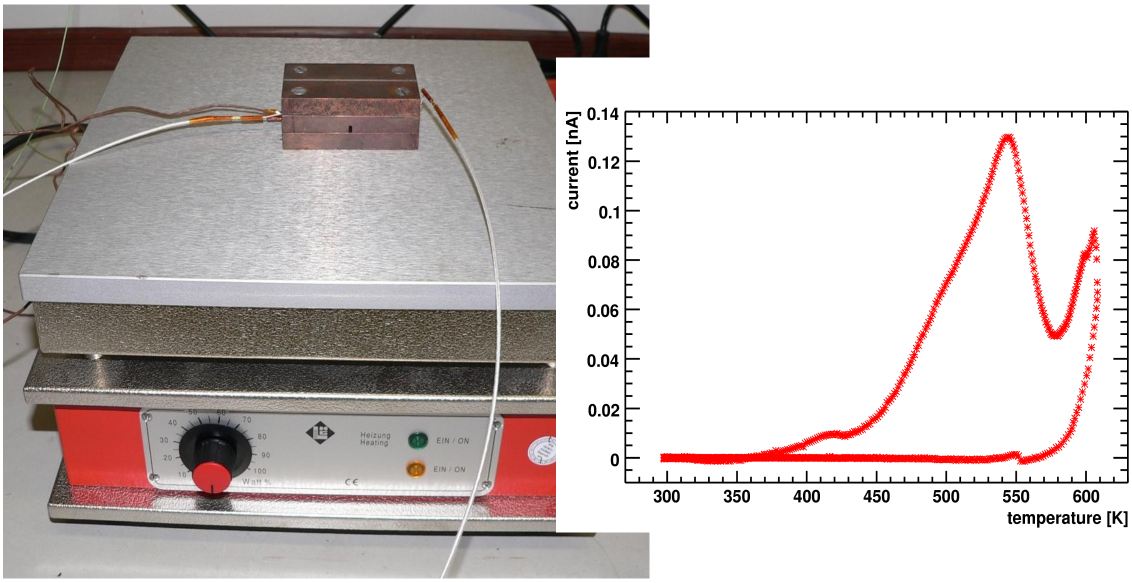

Figure 8: Setup for measurements of Thermally Stimulated Current (TSC). In the inset the typical dependence of TSC on temperature is shown for radiation damaged diamond detector.

5 Testbeam at TU-Darmstadt, radiation hardness study

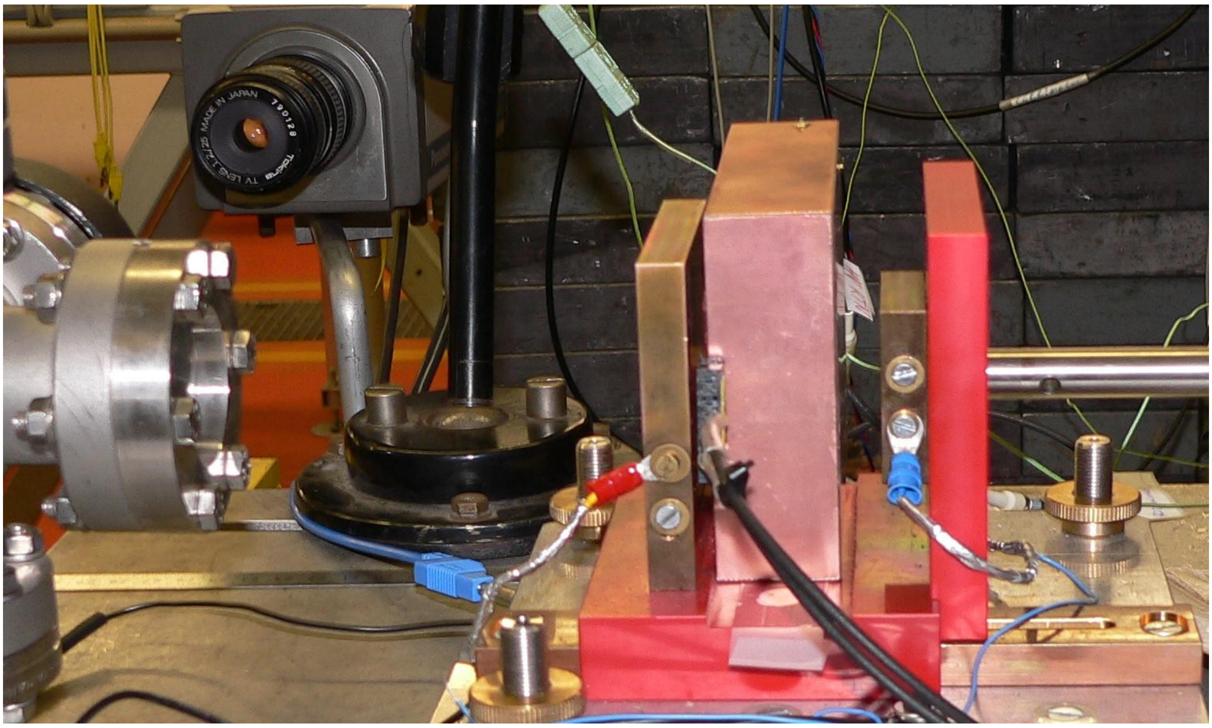

Figure 9: Equipment for radiation hardness studies at the Superconducting Darmstadt Linear Accelerator. The beam of 10 MeV electrons passes collimator, detector box and stops at the Faraday cup which is used to evaluate the absorbed dose.

For time effective radiation hardness studies of prospective samples we need the source of charged particles with intensity much higher than it is expected for BeamCal sensor working conditions at ILC. Simulations show that the largest damage in the BeamCal will occur near the shower maximum depth, where typical energy of electrons and positrons is close to 10 MeV.

An electron beam of 10 MeV energy at the Superconducting Darmstadt Linear Accelerator, S-DALINAC, was used to irradiate the samples. Fig.9 shows a photograph of the irradiation setup. The electron beam arrives from the left side and is transversely shaped by 1 cm thick copper collimator. It crosses then the sensor, housed in a light tight box, and is dumped on a Faraday cup made of copper. The beam current crossing the sensor is measured as the current released by the Faraday cup.

The beam current was varied between 2.5 nA and 50 nA corresponding to dose rates in the sensor from 20 kGy/h to 400 kGy/h respectively. The electron transport in the setup has been simulated with GEANT4 to convert the beam current into a dose rate and to determine the dose profile.

6 Sensors under test

The choice of materials for the BeamCal sensors is determined by the following constraints: to fulfil the physics goals the effective Moliere radius of BeamCal medium should be as small as possible, sensor should withstand extremely high radiation dose, operate at room temperature and the power consumption has to be minimal. For that reasons we consider a class of solid state detectors having very low leakage currents at room temperature, preferably large area and low cost. Widely used silicon detectors have far insufficient radiation hardness.

Among the possible candidates we are studying GaAs crystals, which have become available in wafer sizes. Diamonds grown by chemical vapor deposition, CVD, are also a potential sensor material. Although showing excellent radiation hardness, diamond detectors are still very expensive and not available as large wafers (at least in single crystal form).

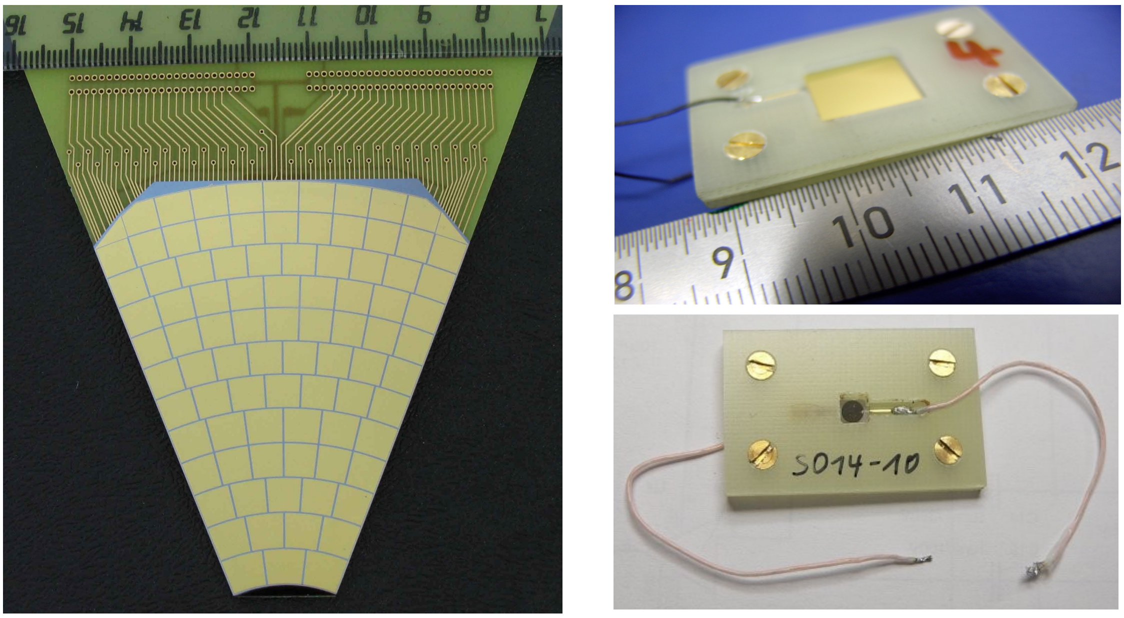

Figure 10: Examples of sensors under test. (Left):Small scale prototype of BeamCal sensor sector on the GaAs basis. (Right-top): Polycrystalline CVD Diamond detector. (Right-bottom): Single crystal CVD Diamond detector.

Recently we performed preliminary studies of other possible candidates: Quartz and Sapphire sensors, that could be produced in large wafer sizes and have relatively low cost. Both materials were found to show potential. When a voltage was applied the corresponding current registered an increase when subjected to radiation. The detailed studies are still have to be done.

7 Silicon Laboratory at Tel Aviv University

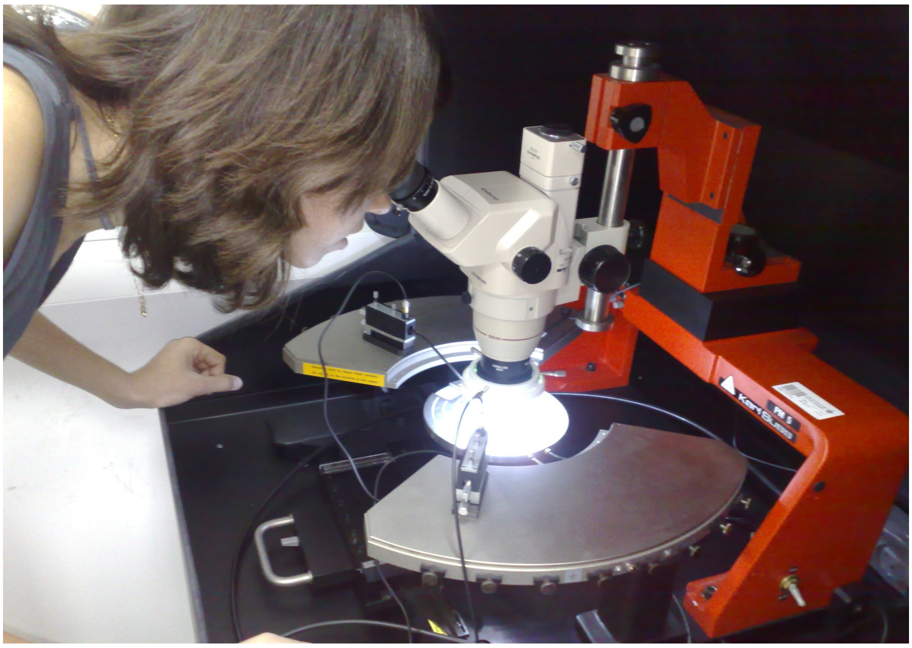

Figure 11: Computer monitored probe station at Tel Aviv University

In the last months dedicated HEP laboratory building was designed (including a Silicon Laboratory for future detectors R&D). About 25 squared meter laboratory area will be dedicated only for the Silicon Lab. The new building is expected to be ready in the middle of 2009. The laboratory room was designed to accommodate future installation of a clean room infrastructure. Fully equipped, computer monitored probe station is ready. The equipment is set up for I/V, C/V measurements. For the time being the equipment is set up in a temporary lab. To complete the setup the probe station camera will be purchased in the near future.

8 Conclusion

The laboratory infrastructure for sensor diagnostics is created/improved and completed. Testbeam equipment for sensor radiation hardness tests is completed and used. Tesbeam equipment successfully operated in the joint experiment with EUDET JRA1 pixel telescope at DESY Hamburg. VFCAL sensor test facilities are on schedule.

Acknowledgement

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References

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[2] A. Bulgheroni, T. Klimkovich, P. Roloff and A.F. Zarnecki, *EUTelescope: tracking software*, EUDET-Memo-2007-20.

[3] Ch. Grah et al, *Towards a Measurement of the Mean Number of Charge Carriers Created by a MIP in sCVD Diamond using the EUDET Telescope*, EUDET-Memo-2007-58.