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DEPFET SPS beam test using the EUDET telescope

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on behalf of the DEPFET collaboration

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Abstract

In this memo the DEPFET group summarizes the experiences gathered during the 2009 CERN SPS test beam period. The current status of the integration of new DEPFET S3B system with a new PXD5 matrix into the EUDET Telescope analysis frame work and also very preliminary results will be presented.

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1 Introduction

The International Linear Collider (ILC) is a proposed linear particle accelerator with a collision energy of 500 GeV. In the scope of these efforts a number of ILC detector R&D projects have been started. Among these projects is an EU initiative to support detector R&D for a future International Linear Collider (EUDET). The DEPFET collaboration has a significant presence in this program. Also within the EUDET program a high resolution pixel telescope using monolithic active pixel sensors will be provided as test beam infrastructure. DEPFET sensors were one of the *D*evice *U*nder *T*est (DUT) for this telescope system, commissioning the user interfaces of this infrastructure.
The first part of this document presents the current status of DEPFET hardware development.
The second part describes the experiences gathered during the common test beam campaign at the SPS (Super Proton Synchrotron) facility at CERN in the summer 2009, including the integration of the DEPFET data acquisition (DAQ) in to the EUDET telescope DAQ. First preliminary results are also presented.

2 DEPFET Principle and Operation

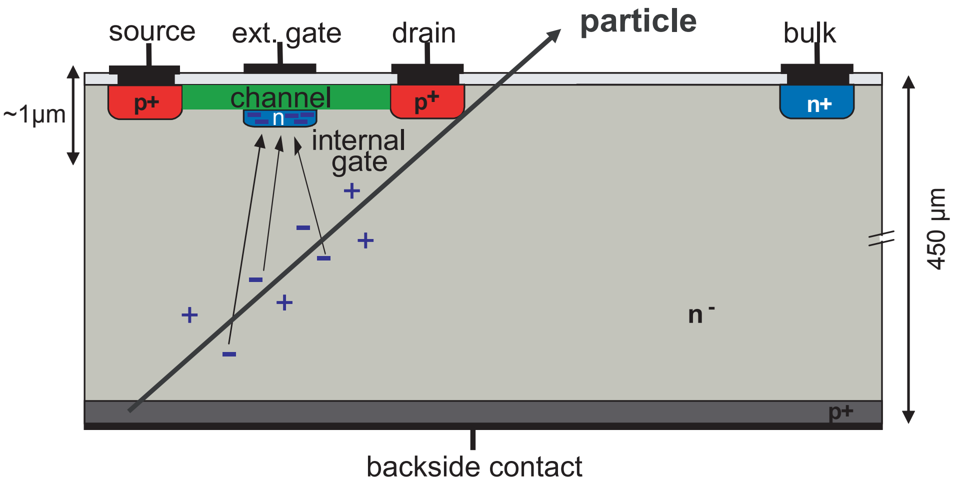

Figure 1: DEPFET Principle and Operation

The *DEP*leted *F*ield *E*ffect *T*ransistor (DEPFET) principle of operation is shown in Figure 1: A planar p-channel MOSFET structure is embedded in a fully depleted, high resistive bulk. A deep n-implant below the transistor p-channel forms a potential minimum for electrons. Collected electrons change the potential of the internal gate of the transistor and thus modulate the transistor current according to the collected charge. As this is a non destructive read out the charge has to be removed by the clear contact (not shown in the picture) [1]. DEPFET sensors offer a unique possibility for a

high spatial resolution and low noise pixel vertex detector as the innermost component of the tracking system in an ILC detector.
As an intermediate step towards a full scale ILC detector ladder a new prototype system has been developed. It consists of three major parts: a USB-Board, a DAQ-Board and a Hybrid-Board. The Hybrid-Boads hosts the DEPFET pixel matrix, the steering chips SWITCHER, the readout chip CURO II and a pair of transimpedance amplifiers (I2U) that convert the current outputs of the CURO chip to voltage signals.

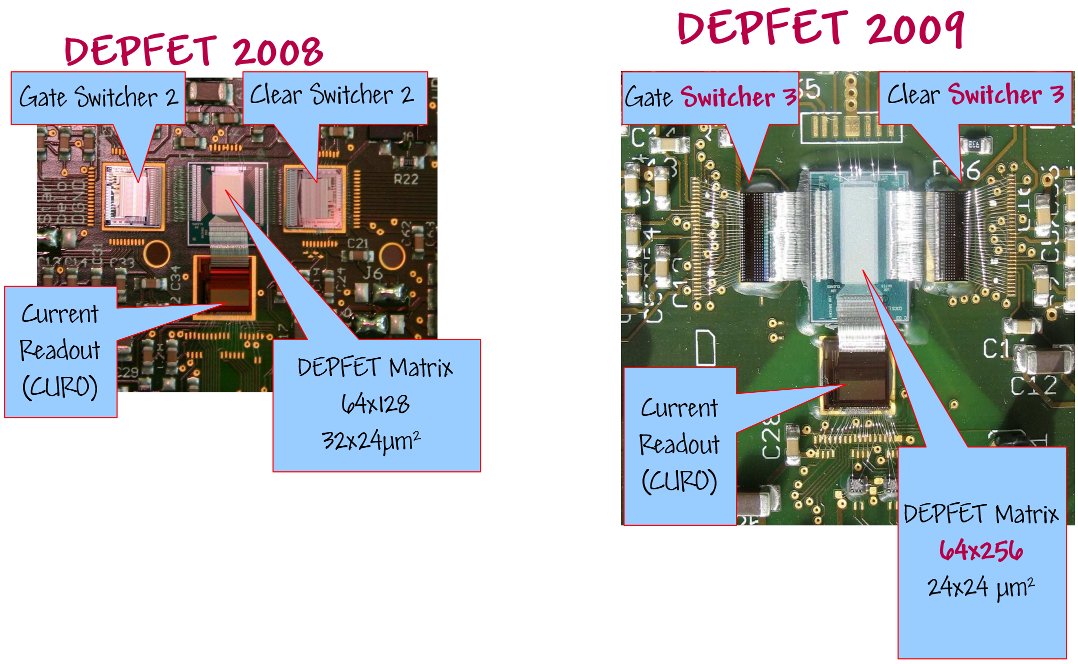

Figure 2: Chip assembly on the Hybrid-Board showing the DEPFET matrix in the middle, the two steering chips SWITCHER at the both sides and the readout chip CURO II at the bottom (PXD4 (left) and PXD5 (right) picture).

Figure 2 shows a close-up view of the chip assembly on the Hybrid-Board. A new generation of DEPFET sensors (PXD5) with bigger matrices (64x256 pixels) is situated in the center (right picture). Old prototype system is shown on the left picture.
The steering strobes for the matrix are provided by two SWITCHER chips located at both matrix sides. The new SWITCHER 3 (350nm CMOS), designed in a small chip technology, can drive a higher matrix capacitance, compare to the SWITCHER 2 used in the year 2008.
At the bottom of the matrix the 128 channel readout chip CURO II is placed.
Also a new readout system (S3B) was developed to fully utilize the new DEPFET sensor and also for testing the SWITCHER 3 (Figure 3). It contains an FPGA, ADCs, buffer RAM and a USB2.0-PC interface. Besides slow control the FPGA programming includes a flexible sequence controlling the readout. The USB-Board is based on USB 2.0 standard and provides the communication between the system and a PC.

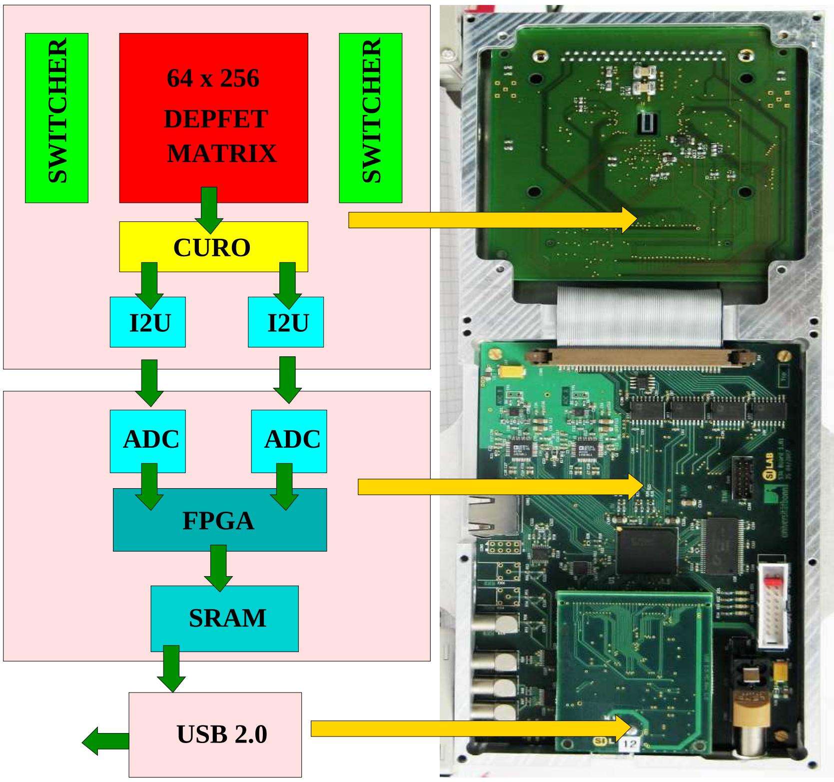

Figure 3: New S3B system consist of Hybrid-Board, DAQ-Board and USB-Board.

To improve the hardware stability of the DEPFET DUT a new DEPFET power supply has been developed. This power supply includes all necessary voltage rails (18 channels for DEPFET S3B system) in a small 15" case (see Figure 4). It provides voltage setting capability, precise voltage and current measurement as well as fixed current limits for every individual channel. For a suitable test beam operation it has remote USB connection to a PC. The GUI control software for monitoring and steering is Linux based.
The new system has been successfully tested in the laboratory using a laser and a radioactive source.

3 EUDET Telescope

The EUDET telescope provides up to six reference planes subdivided into two arms to allocate the DUT in between these two arms. Mechanical actuation helps to move the DUT, in this case DEPFET sensors, through the usable area of the telescope. The main components of the EUDET telescope system are shown schematically on the Figure 5. The reference plane sensors are based on Monolithic Active Pixel Sensors (MAPS) with 256×256 pixels and a pitch of $30\mu m$ (MimoTel)[3]. This results in an active area of

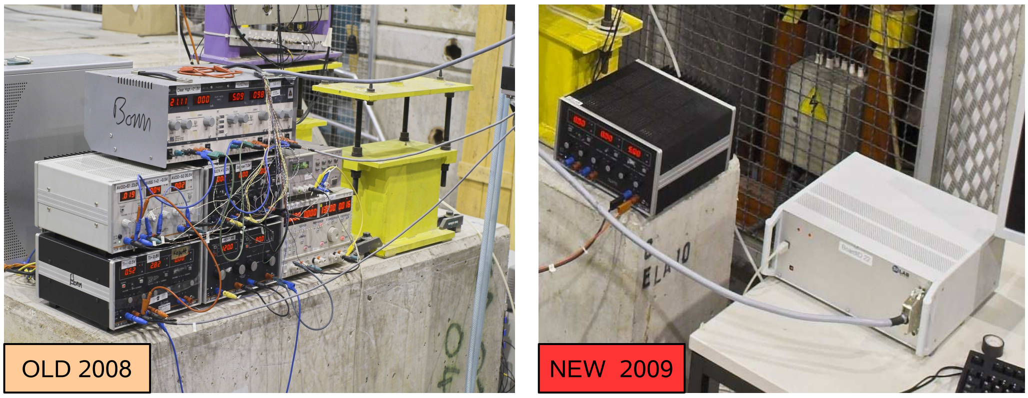

Figure 4: Old (left) and new (right) Power Supplies.

$7.7 \times 7.7\ mm^2$. The sensor is divided into 4 sub-arrays of 64×256 each read out in parallel.
The MAPS sensors are read out by general purpose acquisition boards (EUDRB). A MVME6100 Power PC computer collects the data from the different EUDRBs inside the VME64x crate and sends it via Ethernet to the main DAQ PC.
A dedicated Trigger Logic Unit (TLU), with a built-in scintillator signal discriminator and coincidence unit, synchronizes the read out with a system wide coincidence trigger signal. Furthermore each trigger carries a trigger number and time stamp.

4 The 2009 CERN Test Beam Campaign

A new DEPFET DUT has been tested in a 120GeV pion beam at the CERN SPS. The setup is shown schematically in Figure 6. The device under test was placed in between two arms of EUDET telescope (see Figure 7). The setup is triggered by a coincidence signal of two scintillators in front of and behind the setup. A Trigger Logic Unit (TLU) synchronized the read out of all telescope planes and DUTs. The initialization and configuration of the system was carried out from the main EUDET run control window running on the EUDET DAQ PC, while a *Data Collector Processor* running on the

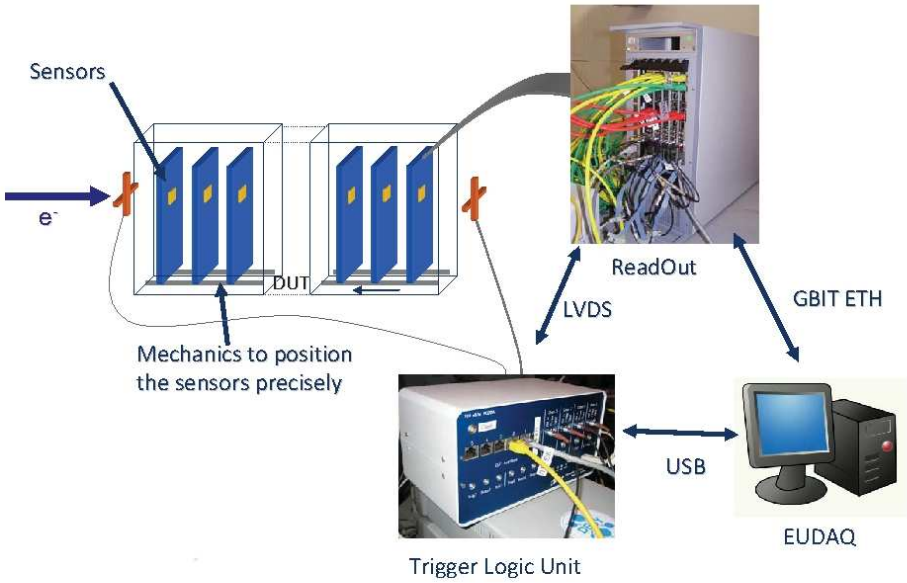

Figure 5: Components of the EUDET Telescope

same PC merged both the EUDET telescope and the DEPFET DUT data streams into a common file [4], [5]. In addition DEPFET only data was stored on the local disk of the DEPFET DAQ computer as a backup. A DEPFET data format has been changed due to an increased amount of information from larger DEPFET sensor compare to the year 2008.
A new *DEPFET Converter Plugin* has been developed to decode a raw DEPFET data and also to convert it into the “standard plane” and into the LCIO format which is used later for data analysis.
A using of a new *Plugin* mechanism helped to upgrade the online Monitor more efficient and also to simplify a combined offline data analysis.
The position of DEPFET DUT has been adjusted using a remote controlled motor stage. The alignment of DEPFET DUT with respect to the beam and to the telescope planes was achieved online.
For the beam tests a DEPFET COCG SE (H3.0.03) matrix with pitch size $24 \times 24 \mu m$ and thickness of 450 μm was chosen. Pedestal and noise as a function of the pixel are shown in a Figure 8 lower plots. The average noise is about 11 ADC units. As one can see from the upper plots pedestal and noise are very homogenous along the sensor. Two different levels in pedestal map corresponds to the two different ADCs.

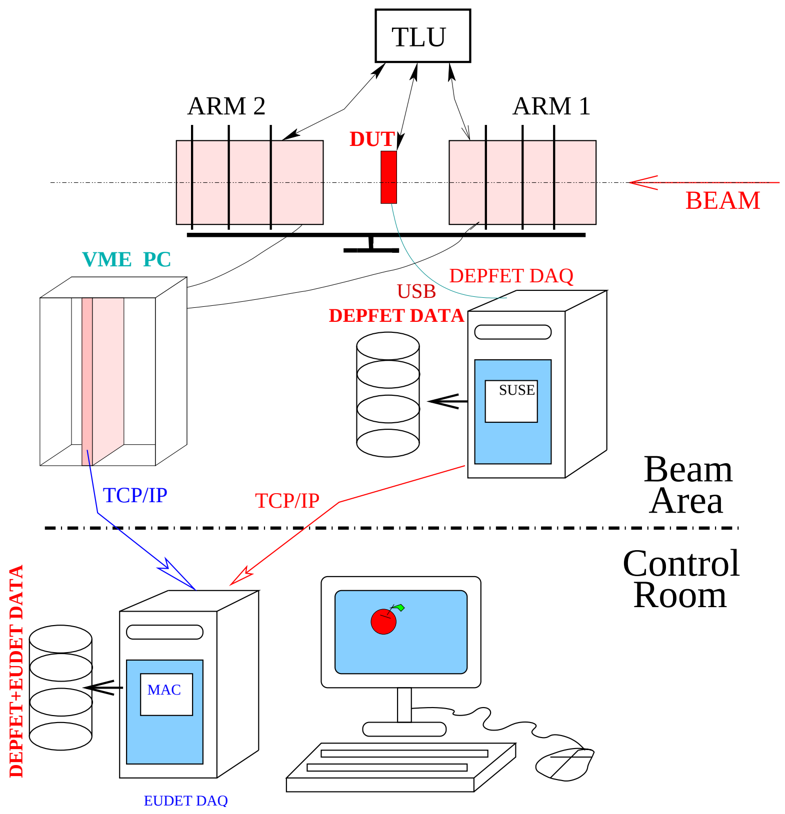

Figure 6: Test beam setup, schematic view

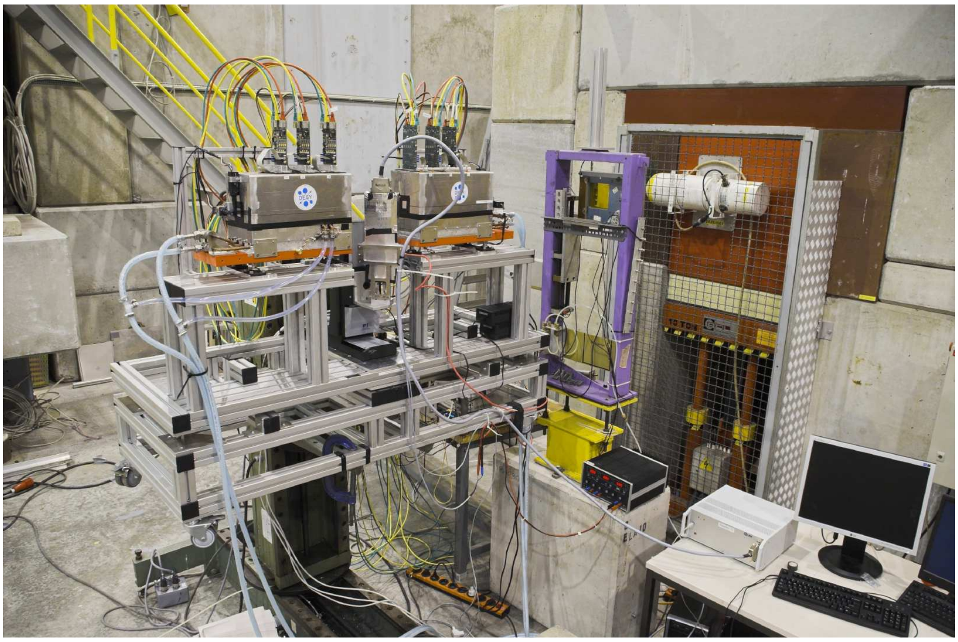

Figure 7: Test beam setup

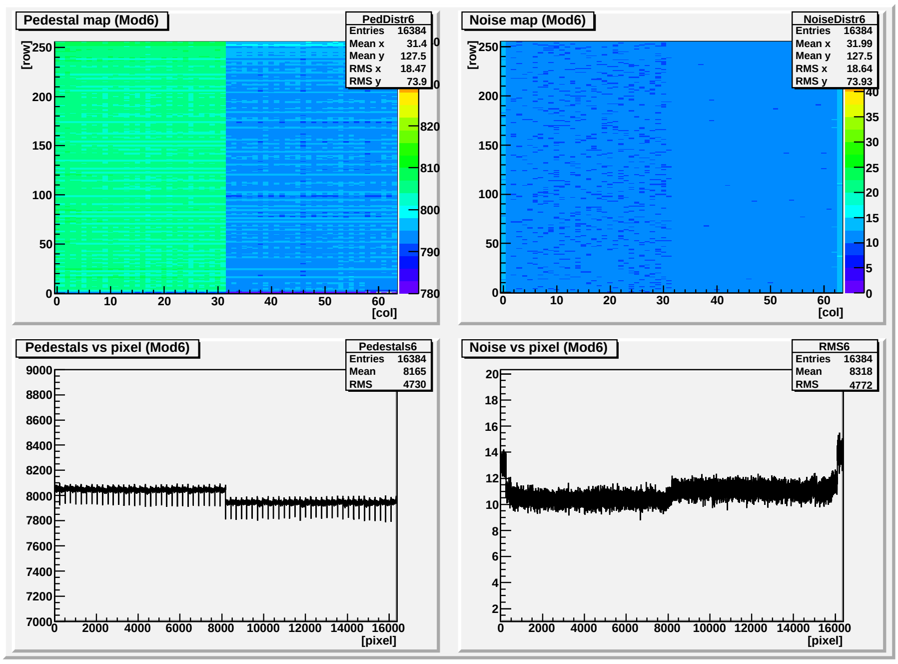

Figure 8: Pedestal and noise map (upper left and right plot). Pedestal and noise as a function of a pixel id (lower left and right plot). Average noise is about 11 ADU.

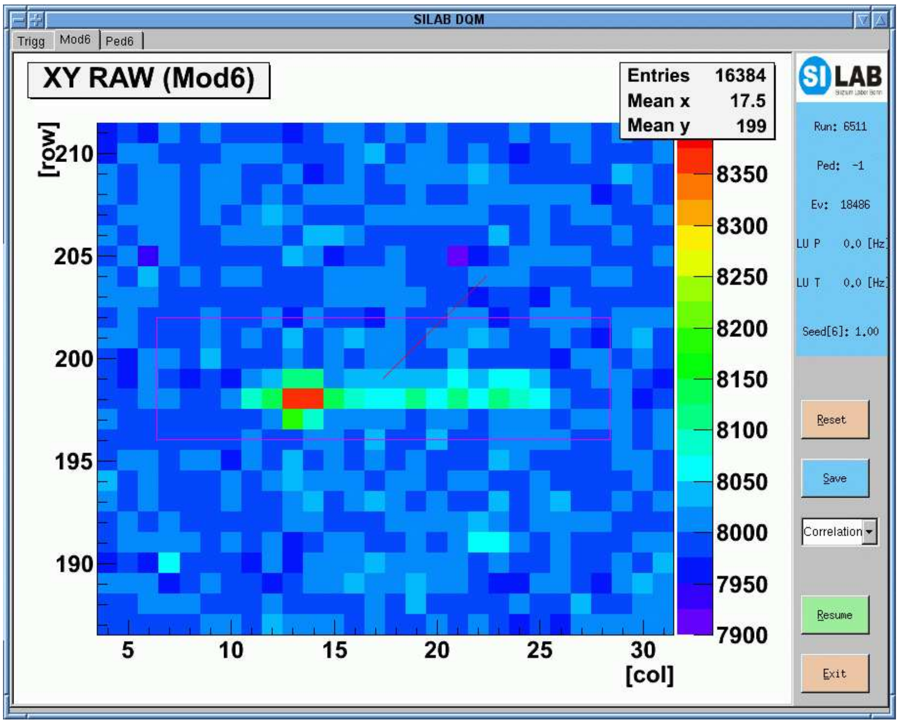

Figure 9: An event display for DEPFET module rotated at 26 degree. Red box corresponds to the area about 21x5 pixels around reconstructed track.

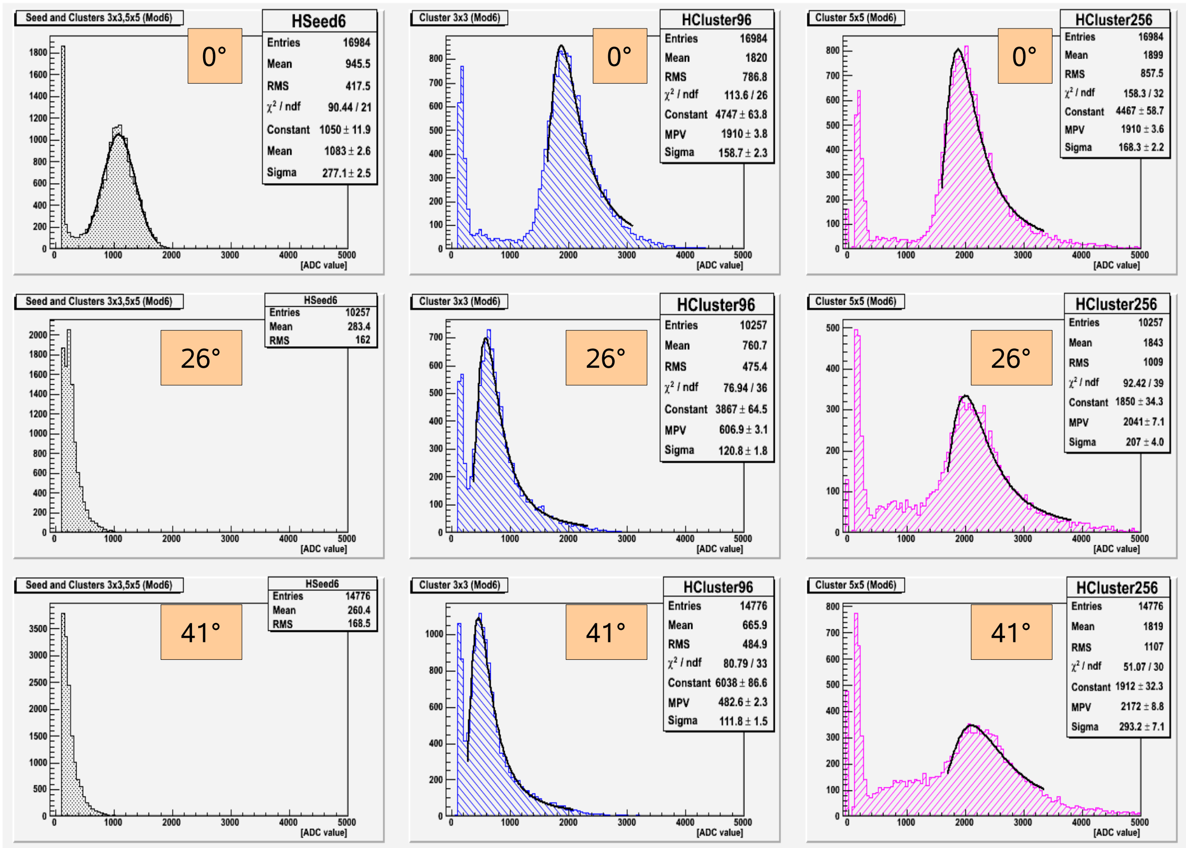

Figure 10: Three histograms in the upper row represent seed, 3x3 and 5x5 clusters for DEPFET module at 0 degree. Middle histograms for module rotated at 26 degree, and lowest histograms for DEPFET module rotated at 41 degree. Seeds (black, left), 3x3 clusters (blue, middle) and NxM clusters (magenta, right), where M=5, N=5, 21 and 41 for the angle of 0, 26 and 41 respectively.

One of the test beam measurement program for this year was a testing of a performance of a DEPFET matrix rotated at a certain angle. Due to the problem with mechanical setup, the DEPFET DUT has been turned only on a limited number of angles 0, 26, 36, 41. The distributions in the Figure 10 shows seed and cluster distributions for nominal position of the DEPFET module (0 degree, three upper plots), DEPFET module rotated at 26 degree (three middle plots) and DEPFET module rotated at 41 degree (three lowest plots). A seed (black) distributions for different angles are shown on the left plots and 3x3 clusters (blue) in the middle. In magenta 5x5 cluster signal distributions for 0 degree, 15x5 cluster signal for 26 degree rotated module and 20x5 cluster signal for 41 degree rotated module are shown on the right plots.
The signal per pixel from a traveled charged particle for the detector under angle is smaller due to a smaller traveling path for the particle inside one pixel (for example, for a 26 degree rotated detector the path per pixel is about $55\mu m$ instead of $450\mu m$ and thus the signal will be $\sim$ 9 times less). Therefore standard methods of a cluster reconstruction are not properly working anymore. To reconstruct such clusters we used the reconstructed track information from EUDET telescope. An example of such a cluster is shown on an event display for a DEPFET module rotated at 26 degree (see Figure 9). Here a red box corresponds to an area of about 21x5 pixels around the reconstructed track. All pixels inside the box are used for cluster reconstruction.
Signal-to-noise (S/N) ratio is about 170 for a $450\mu m$ thick module. We can use a 3x3 clusters to estimate the response from a $55\mu m$ thick detector in case of the module rotated at 26 degree and from a $37\mu m$ thick detector in case of a 41 degree rotated module. A signal-to-noise ratio for those two cases are about 55 and 43 respectively.
Energy scans with electron and pion beam has been done.

5 Conclusion

During the CERN test beam season in 2009 the DEPFET prototype system for the ILC has been successfully operated as a DUT with the EUDET pixel telescope. New generation of DEPFET sensors showed very good performance with average noise about 11 ADU and S/N ration about 170. The analysis are still ongoing.
Many thanks to the JRA1 EUDET Collaboration for their help during the test beam period.
Next test beam period for the testing of a new generation of the DEPFET sensors are forseen during the next summer.

Acknowledgment

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References

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