



JRA1 - The DEPFET sensor as the first fully integrated DUT in the EUDET pixel telescope: The SPS test beam 2008

Julia Furlletova*, Lars Reuen*

on behalf of the DEPFET collaboration

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Abstract

The DEPFET prototype system for the ILC is the first device under test using the EUDET JRA1 pixel telescope. This memo summarizes the experiences gathered during the 2008 CERN SPS test beam period. In this presentation the current status of the integration of DEPFET into the EUDET Telescope analysis frame work will be presented. An overview of foreseen future improvements of DEPFET related software will be given.

*Physikalisches Institut der Universität Bonn, D-53115 Bonn, Germany

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 the first *Device Under Test* (DUT) for this telescope system, commissioning the user interfaces of this infrastructure.

The first part of this document presents the current status of integrating the DEPFET data acquisition (DAQ) in the EUDET telescope DAQ.

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 2008 and presents first preliminary results.

The last chapter explains the next steps towards further system integration.

2 DEPFET Principle and Operation

The *DE*pleted *Field Effect Transistor* (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.

A prototype system comprising of a 64×128 ($32 \times 24 \mu m^2$ pitch, $450 \mu m$ thickness) DEPFET pixel matrix and a current based readout system has been built and operated successfully in the laboratory and in various beam tests [2].

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 2. 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 $7.7 \times 7.7 mm^2$. The sensor is divided into 4 sub-arrays of 64×256 each read out in parallel.

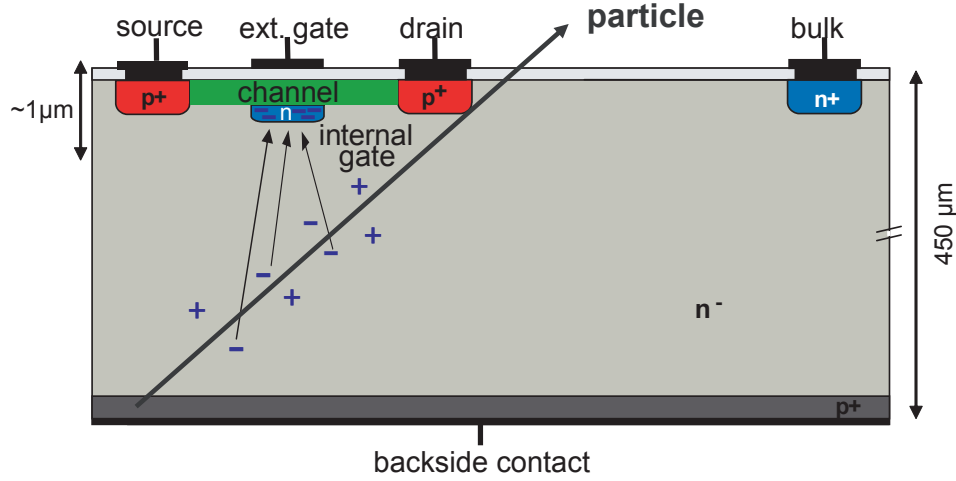


Figure 1: DEPFET Principle and Operation

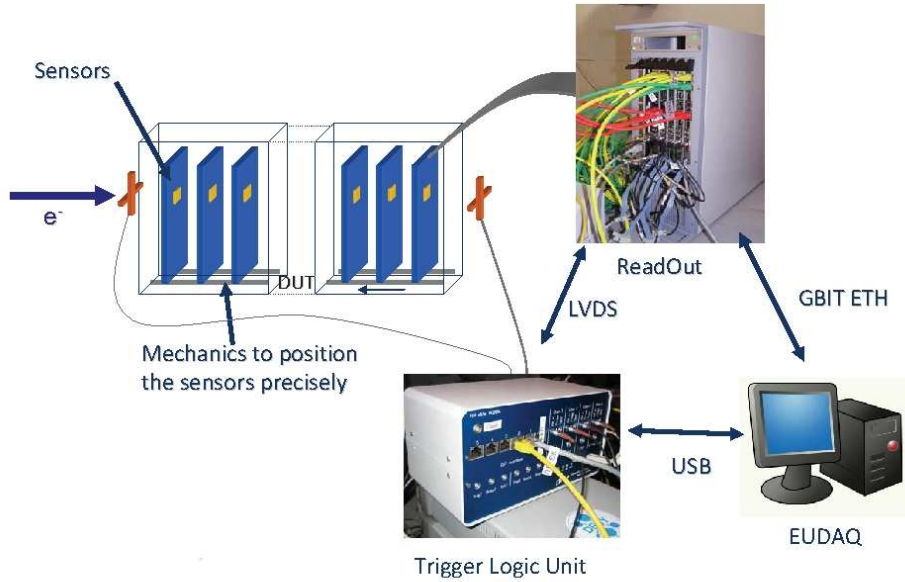


Figure 2: Components of the EUDET Telescope

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 DAQ Integration

There are several methods of integration of a device under test (DUT) into the EUNET telescope DAQ. The simplest one is by having two separated and independent DAQ systems for the telescope and the DUT. The only connection is a trigger-busy handshake protocol via a trigger logic unit (TLU) assuring that no new event is triggered while one of the participating devices is still busy with e.g. read out of the sensor. This can be expanded by receiving an individual trigger number from the TLU for each event. Using this procedure the data will be written to file in two separate data streams. A more sophisticated method is the integration of the DUT DAQ into the EUNET telescope DAQ framework. A key issue here is the modularity of the telescope DAQ which will be explained in more detail later. Here the DUT DAQ is steered by the telescope DAQ and the data is received and merged to one data stream and into one file.

The first part of this chapter will cover the DEPFET DAQ. The second part will describe the integration of the DEPFET DAQ and the EUNET telescope DAQ on a trigger level. In the third part of this chapter the integration of DEPFET DAQ into the EUNET telescope DAQ framework will be given, which was the status of the integration at the CERN test beam in 2008.

4.1 The DEPFET DAQ

To improve functionality during the test beam measurements and facilitate the integration with other detectors a new version of the DAQ software was developed. It is based on Linux OS and uses network distributed client/server architecture. The network distributed system allows sharing of resources and tasks, remote control and monitoring, and running monitoring programs on the remote computers without affecting resources of DAQ computers.

This new version of DEPFET DAQ was successfully tested in the laboratory. A schematic view of the data acquisition is shown in Figure 3.

The DAQ components are: a LINUX based USB driver for the DEPFET DAQ board, a USB readout client transferring data to an event builder via network, an event builder assembling complete events and storing them in a shared memory buffer, an event server sending complete event to consumers (file writer, DQM, upper level DAQ, histogram server) and a Data Quality Monitoring (DQM) package based on ROOT.

4.2 Integration on trigger level

The DEPFET DAQ integration during the CERN test beam season in 2007 happened only on a trigger level. The event synchronization was ensured by the trigger-busy handshake of the EUNET TLU including the transmission of event numbers for each trigger, while having two separated data acquisitions for the DEPFET DUT and the EUNET telescope. This implies that no common online monitoring was available.

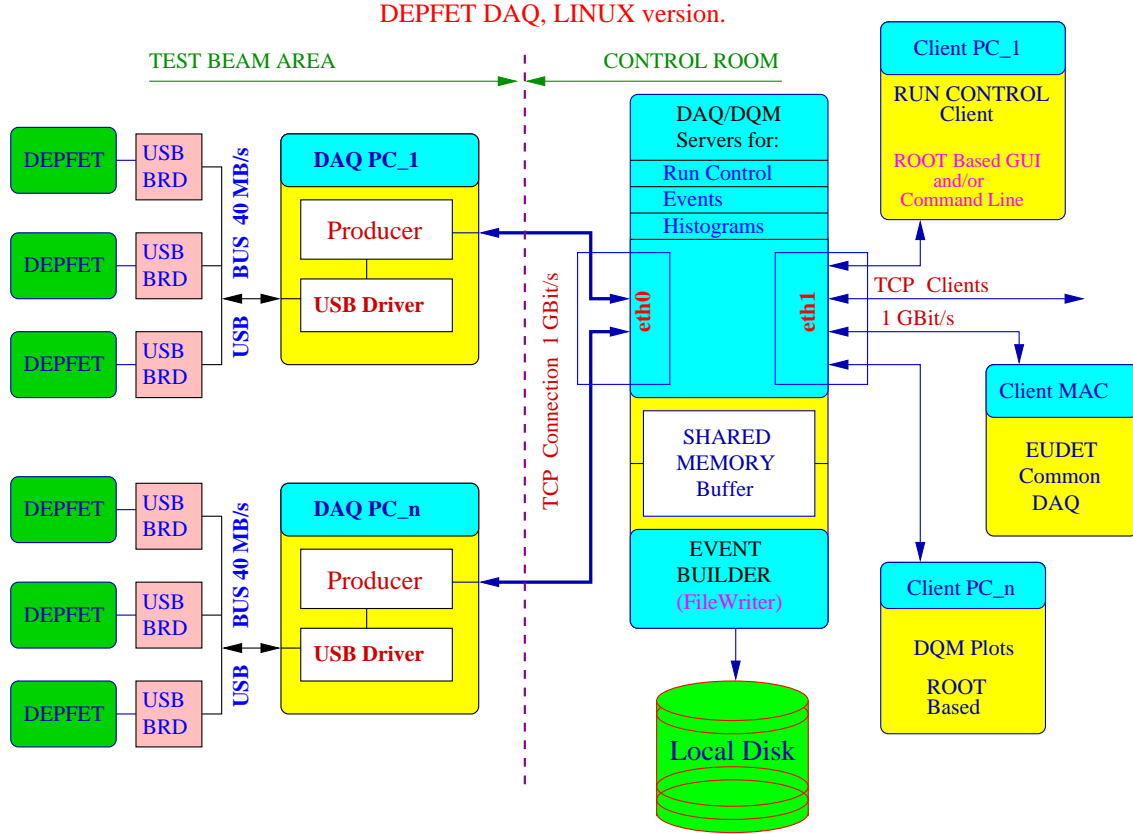


Figure 3: DEPFET Linux based data acquisition system

4.3 Integration on the DAQ level

The second level of integration was achieved during the CERN test beam season in 2008 and was accomplished by having the DEPFET system steered by the EUDET DAQ software. Here the high modularity of both the EUDET telescope and the DEPFET Data Acquisition software played a crucial role.

DEPFET and EUDET telescope Run Controls were synchronized with each other via TCP/IP and all controls such as configuration, start, and stop were done from the main EUDET Run Control window (see Figure 4). DEPFET data was sent to the EUDET PC via TCP/IP where it was received by the *DEPFET producer* software task. *DEPFET producer* is a one of several *Data Producer* tasks. These tasks are running on the EUDET DAQ and provide a software interface for any piece of hardware in the system that is producing data. At the end of each event, all Data Producers make their respective data available to the *DataCollector* task via shared memory. The collected data is then written as one data stream into a file. Furthermore the *DataCollector* passes requested data on to all online monitoring task in the DAQ.

In addition the EUDET Data Quality Monitor (DQM), a tool that provides an online quality assessment of the data currently taken, was modified in order to process data

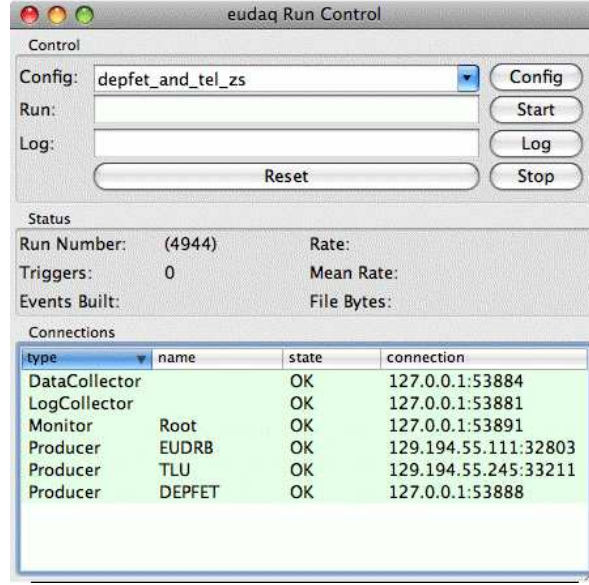


Figure 4: EUDAQ Run-control with DEPFET Producer

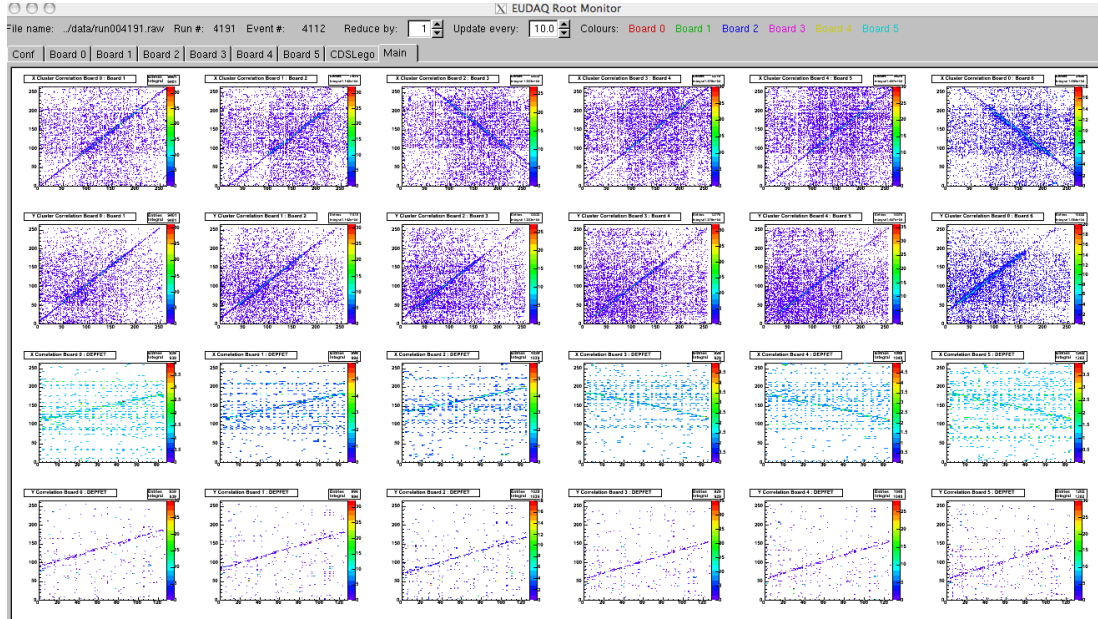


Figure 5: EUDET Telescope online root monitor with a correlation plots between DEPFET DUT and EUDET telescope sensors

from the DEPFET DUT, thus allow for instance correlation plots between MAPS and DEPFET sensors hit positions (see Figure 5). These plots have been used for a quick online alignment of DEPFET DUT during the test beam 2008 data taking period and

therefore allowed us to use the precious beam time more efficiently.

5 Integration on the analysis level

As the DEPFET system is primary developed for ILC, the integration of DEPFET software into the ILC analysis framework is a natural choice and has been started recently. This approach has several advantages: a standard data format allows sharing of DEPFET data for analysis, standard analysis tools include tracking and position reconstruction software developed by the large ILC community, and the availability of GRID computing for data processing.

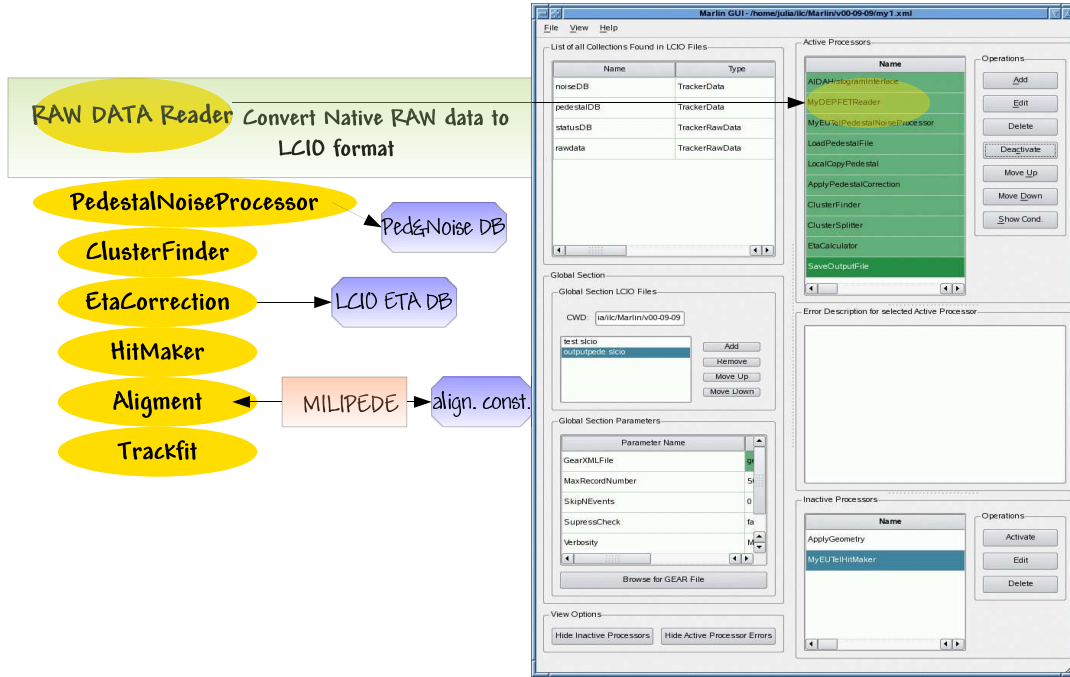


Figure 6: *Marlin GUI*

EUTelescope [4] is a package targeted at the analysis of data from the high resolution, low material pixel telescope that is developed within the EUDET project. It provides functionality for calibration, alignment and data reduction. Additionally pattern recognition and determination of the resolution of the DUT is possible.

By converting the native DEPFET data raw format to the LCIO (Linear Collider Input/Output) format and extending the *EUTelescope* analysis to facilitate DEPFET specific data reduction steps (e.g. double row wise common mode corrections), this powerful test beam analysis tool can now be used for analyzing the DEPFET DUT.

Figure 6 show schematically the main analysis strategy. The very first step in the analysis procedure is the conversion from the native format used by the DEPFET DAQ software

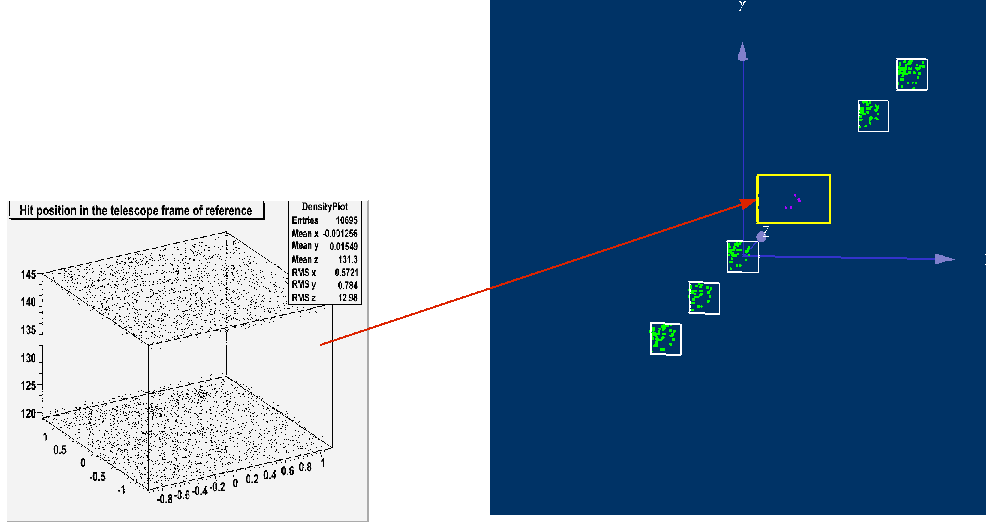


Figure 7: *Event display with a EUDET telescope and DEPFET DUT hits*

to the LCIO format. A special processor called *DEPFETReader* has been written for this purpose. This processor is taking care of extracting all data streams corresponding to the involved DEPFET detectors and transferring them into a corresponding LCIO event structure. Currently a *UniversalFileReader* designed for readout of the common EUDET Telescope and DUT data files is under development.

The second step in the analysis procedure is the calculation of pedestals and noise. A *EUTelescope PedestalAndNoiseProcessor* has been adjusted to DEPFET specific properties. Furthermore a row wise common mode correction has been added as an option to this processor.

The next step is a cluster search. Once a DUT cluster is found it can be translated from pixel unit of the sensor's local frame of reference to a space point in the global telescope frame of reference (Figure 7).

In case of separate data streams the EUDET telescope data could be merged with the DUT data at the hit level.

Finally an advanced alignment procedure of the telescope based on the Millepede II package as well as a multiline track fitting processor is available for users.

As the ILC analysis framework has a large momentum and will be fostered in the future this step is also recommended for other telescope users in spite of the initial extra work.

6 The 2008 CERN Test Beam Campaign

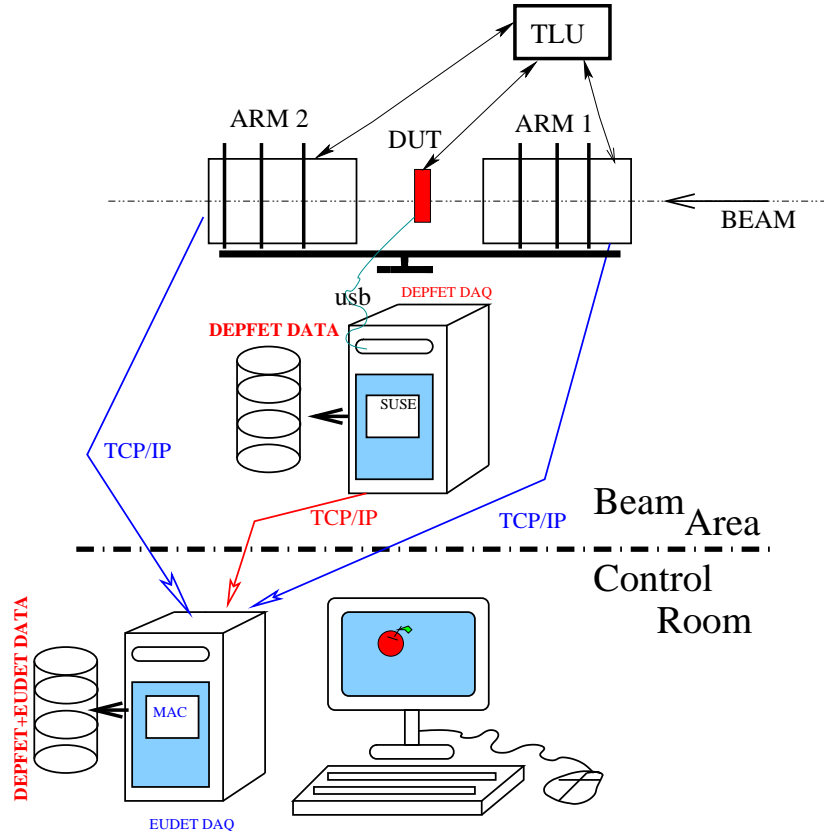


Figure 8: Test beam setup, schematic view

Two DEPFET DUTs have been tested in a 120GeV pion beam at the CERN SPS. The setup is shown schematically in Figure 8. The device under test was placed in between two arms of EUDET telescope. (see Figure 9). 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 same PC merged both the EDUET telescope and the DEPFET DUT data streams into a common file. In addition DEPFET only data was stored on the local disk of the DEPFET DAQ computer as a backup.

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. In figure 5 columns and rows of the DEPFET DUT versus columns and rows of the EUDET telescope sensors are shown. A clear linear correlations can be seen.

A total of roughly 2 Million events were taken with the DEPFET as a DUT. At the



Figure 9: Test beam setup

time of writing the data analysis is still ongoing. Some of the obtained results are still preliminary and a deeper investigation is needed to confirm them.

Pedestal and noise as a function of the pixel are shown in figure 10. The average noise for both DEPFET DUTs is about 13 ADC units which corresponds to roughly 300 electrons.

After pedestal and common mode subtraction a cluster search is started. A cluster seed is defined as the highest pixel in a frame which is over a noise threshold $5\sigma_{noise}$. The seeds are combined with neighboring pixels which are over the neighbor threshold $2\sigma_{noise}$. The cluster pixels are then blocked and the seed is reiterated until no further unblocked pixel with a signal greater than $5\sigma_{noise}$ are found.

A distribution of seed (black) as well as a 3x3 (blue) and 5x5 (magenta) cluster signal distributions for two different DEPFET DUTs types are shown on the Figure 11. Both DUT matrices have a signal-to-noise (S/N) ratio of about 130.

EUTelescope software has also been used for standalone DEPFET Telescope data analysis. Preliminary residual distributions for one of the plane are shown on the Figure 12.

7 Conclusion

During the CERN test beam season in 2008 the DEPFET prototype system for the ILC has been successfully operated as a DUT with the EUDET pixel telescope. The DAQ integration on the online level has been done. The DEPFET Linux based DAQ software showed a good performance. During the test beam DEPFET system has been successfully steered by the EUDET DAQ software. Software tools towards the combined offline analysis frame work are under development. Next test beam period for the testing of a new generation of the DEPFET sensors are foreseen during the next summer.

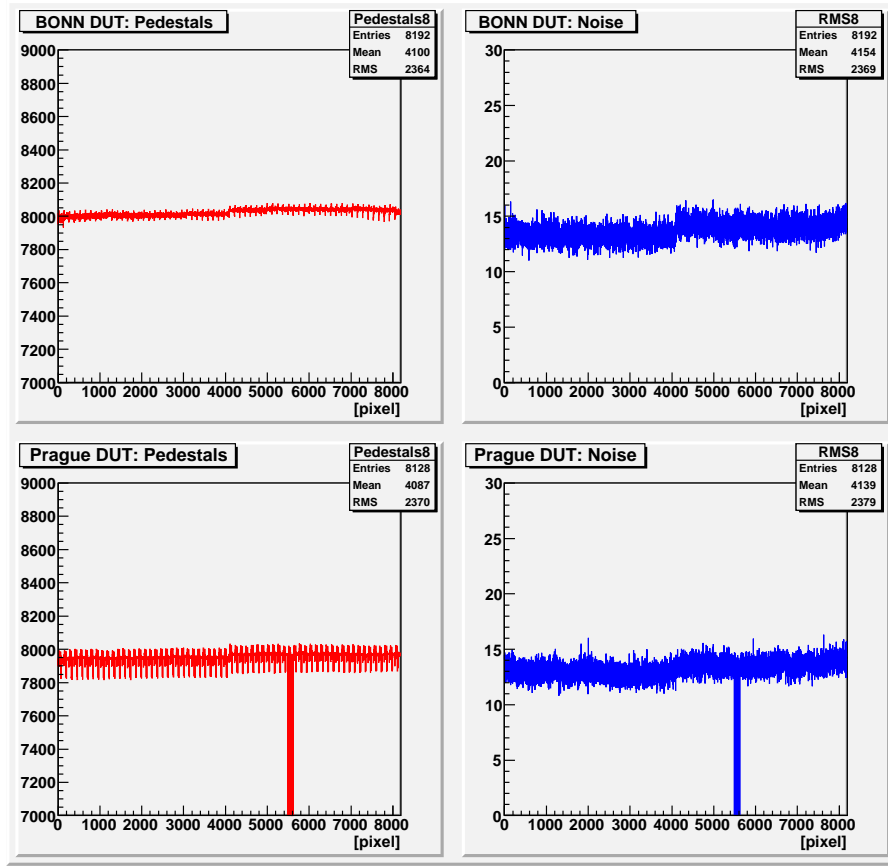


Figure 10: Pedestal and noise distributions

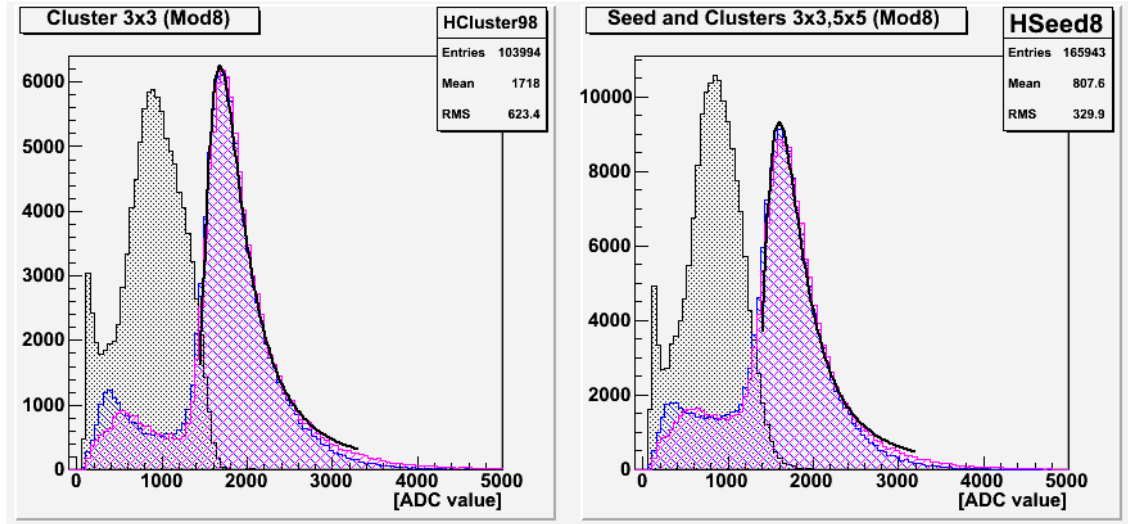


Figure 11: Seed only (black), 3x3 (blue) and 5x5 (magenta) clusters for two different DEPFET DUT

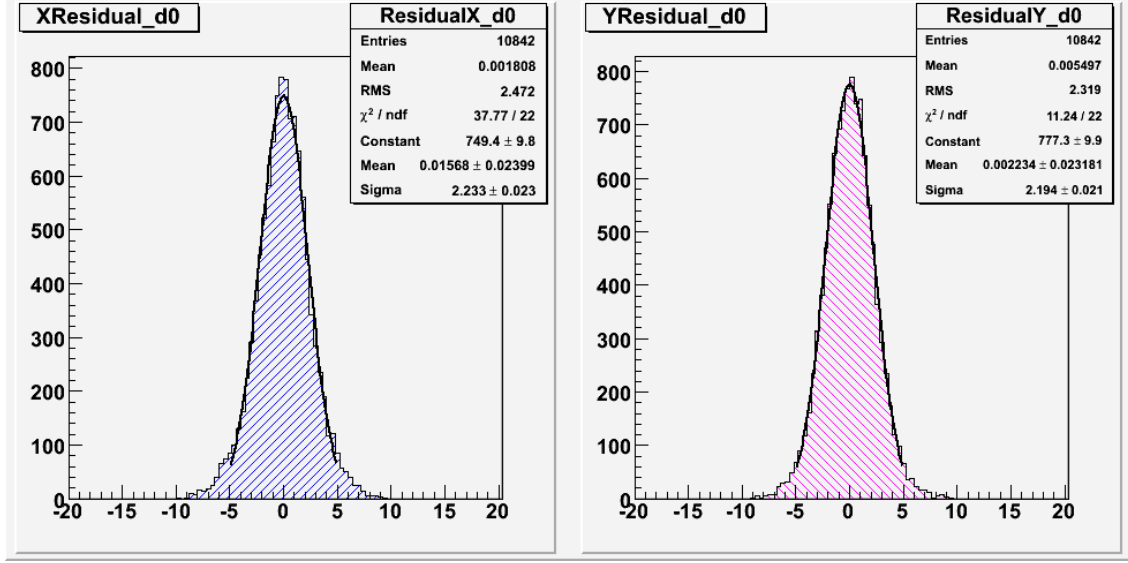


Figure 12: Residual distribution of one of DEPFET sensor

Acknowledgment

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References

- [1] J.J. Velthuis *et al.* , "DEPFET, a monolithic active pixel sensor for the ILC " [Nucl. Instr. Meth. A 579, 685 - 689 (2007)]
- [2] P. Fischer *et al.* , "Progress towards a large area, thin DEPFET detector module " [Nucl. Instr. Meth. A582, 843-848 (2007)]
- [3] E. Corrin, I.M. Gregor "JRA1-Status of the Demonstrator Telescope" [EUDET-Memo 2007-19]
- [4] A. Bulgheroni, T. Klimovich, P. Roloff, A.F. Zarnecki, "EUTelescope: tracking software" [EUDET-Memo-2007-20]