EUDET-Report-2009-02

Results from the EUDET telescope with high resolution planes

A. Bulgheroni[*]

June 12, 2009

Abstract

A high resolution ($\sigma < 3\mu$m) beam telescope based on monolithic active pixel sensors is being developed within the EUDET collaboration. EUDET is a coordinated detector R&D programme for the future International Linear Collider providing test beam infrastructure to detector R&D groups. The telescope consists of six sensor planes with a pixel pitch of either 30 or 10 μm and can be operated inside a solenoidal magnetic field of up to 1.2 T. A general purpose cooling, positioning, readout infrastructure and data analysis tool is available. The telescope is now running since one and a half years at test beams at CERN and DESY. In this paper the performances of the telescope with different configurations of sensors are compared.

This work is supported by the Commission of the European Communities under the 6th Framework Programme **Structuring the European Research Area**, contract number RII3-026126.

---

[*] INFN, Milan, Italy

1 Introduction

The EUDET project, supported by the European Commission in the 6th Framework programme, aims at providing infrastructures for research and development of novel detector technologies for the future International Linear Collider. Within the EUDET project, the Joint Research Activity (JRA) 1 has the main task of developing and improving test beam infrastructures, in particular the commissioning of a high resolution pixel telescope and the characterization of a large bore 1-Tesla magnet (not covered in this paper).

The design goals of the pixel telescope include a hit position resolution ($\sigma < 3\mu$m), a readout rate at the kHz level and a very limited material budget to allow an effective operation even with high multiple scattering. The construction was planned in two stages, to quickly offer an exploitable infrastructure in parallel to the development of the final telescope. In the first stage (demonstrator telescope) a well established CMOS pixel technology was used to produce the detector planes with two different pixel pitches: 30 μm and 10 μm [1]. Thanks to the high flexibility of the mechanical support and of the readout electronics, the telescope users can decide whether to use the sensor with high or moderate granularity according to their needs and the required precision on the extrapolated position at the device under test. This paper concerns a comparison of the spatial resolution obtained using a telescope made of different configuration of high and moderate granularity sensors.

In Section 2, a brief description of the overall setup is given, while in Section 3, the spatial resolutions obtained with the different configurations are shown.

2 Experimental setup

Due to the limited amount of space for this paper, it is impossible to give a complete description of the telescope that can be found for example in [2]. For the sake of clarity, it is worth recalling that the tracking planes are divided into two arms along the beam direction in order to allow the hosting of a Device Under Test (DUT) in the middle and this space can range from 1.5 to 35 centimeters. The inter-spacing in between the sensor planes can be adjusted in order to take advantage of the lever arm in the telescope resolution; on the other hand, in the case of a low energy beam, a close compact configuration with at least two reference planes positioned as close as possible to the DUT should be used to minimize the multiple scattering contribution to the spatial resolution.

2.1 The sensor planes

The properties of the sensors equipping the reference planes are summarized in the Table 1.

Table 1: Main properties of the two detector types. (*) In both cases the overall thickness can be reduced down to 50 μm to minimize the material budget.

	Moderate Granularity	**High Granularity**
Sensor name	MimoTel	Mimosa18
Pixel pitch [μm]	30	10
Sensitive area w [mm] x l [mm]	7.68 x 7.68	5.10 x 5.12
Sensitive thickness [μm]	14	14
Overall thickness(*) [μm]	700	700

2.2 The readout electronics

The readout electronics is based on custom developed VME boards called EUdet Data Reduction Board (EUDRB) equipped with an FPGA generating the digital signals for the slow control of the sensors and steering the ADC for the analog signal sampling. The data of each sensor are then transmitted over the VME bus to a central computer in charge of the event building procedure and the data storage. A key issue of this readout electronics is the possibility to operate in two modalities: the so-called RAW mode in which all the pixel signals are transmitted to the PC and the Correlated Double Sampling (CDS) technique is applied off-line, and the Zero Suppressed (ZS) mode, in which just the signal and the position of the pixels above a certain threshold are transferred to the PC and the CDS is applied on the fly hardware-wise. When working in ZS, the threshold can be adjusted on a pixel by pixel basis.
All the detector planes and the DUT are synchronized by the Trigger Logic Unit featuring a coincidence logic circuit and distributing the trigger signal, the event number and the time stamp to all the hardware devices in the setup.

2.3 The analysis software

To analyze the collected data, the JRA1 consortium inherited the experience in pixel detector analysis and track reconstruction available among the partners and all the expertise has been coded into a new software package, EUTelescope, within the standard ILC software framework. This package takes care of all the analysis steps, from the conversion of the DAQ native data format to the track reconstruction and extrapolation on the DUT. It is worth mentioning two key points of this software:

Alignment using Millepede 2: The EUTelescope alignment procedure of the tracker ad of the DUT is based on Millepede [3].

Analytic track fitting: One of the most difficult task in track fitting is the proper estimation of the multiple scattering contribution to the spatial resolution. Within EUTelescope, the so-called analytic approach [4] has been implemented in such a way that the particle trajectory can vary after each material crossing. The χ^2 of the track fit then takes into account this scattering angle properly weighted by the impinging particle energy.

All the telescope components: mechanics, readout electronics and analysis software have been designed to guarantee the maximum flexibility and the user can decide not only the position of the reference planes, but also the granularity and the readout mode.

3 Experimental results

The first step in the characterization of the telescope as a tracking device was the measurement of the intrinsic resolution of the reference planes and the ultimate spatial resolution achievable combining all the hits into a track. The single plane resolution (σ_{DUT}) can be obtained from the measured residual width (σ_{meas}) and the telescope resolution (σ_{tel}) using Equation (1)

$$\sigma^2_{\mathrm{meas}} = \sigma^2_{\mathrm{DUT}} + \sigma^2_{\mathrm{tel}} \tag{1}$$

The telescope resolution can be determined assuming that the reference planes all have the same intrinsic resolution using Equations (2)

$$\sigma^2_{\mathrm{tel}} = k\,\sigma^2_{\mathrm{plane}} \tag{2a}$$

and

$$k = \frac{\sum_i^N z_i^2}{N\sum_i^N z_i^2 - \left(\sum_i^N z_i\right)^2} \tag{2b}$$

The formula for the geometrical scaling factor k defined in (2b) is based on the assumption that the DUT is positioned at $z = 0$ and it reduces to $1/N$ if the reference planes are is symmetrically distributed around the DUT and the beam and telescope axes are parallel.
In the limit case in which the device under test is of the same type of the reference planes, combining Equations (1) and (2), the intrinsic resolution of the single telescope plane and of the overall telescope can be derived directly from measured residual width (3)

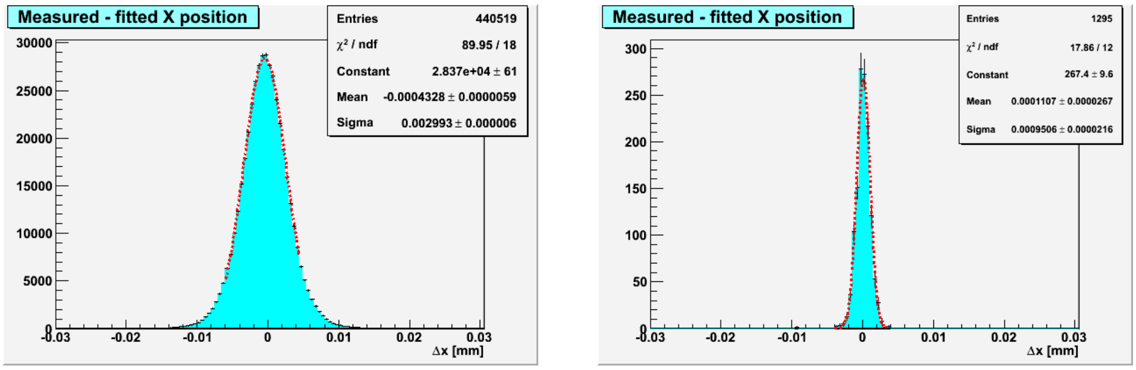
$$\sigma^2_{\mathrm{plane}} = \frac{\sigma^2_{\mathrm{meas}}}{1+k} \tag{3a}$$

and

$$\sigma^2_{\mathrm{tel}} = \frac{k}{1+k}\sigma^2_{\mathrm{meas}} \tag{3b}$$

During summer 2008, the pixel telescope was installed in the H6 SPS beam line at CERN and several million 120 GeV pion tracks were collected. A small fraction of these data was acquired with the main goal of measuring the intrinsic spatial resolution of both

types of reference planes.
Two main configurations were considered, the *low resolution* in which the six planes were all equipped with moderate granularity sensors and the *high resolution* with six high granularity planes. The two data samples were analyzed in the same way leaving one plane out of the fit. The residual distributions measured on this plane are shown in Figures 1 for both cases. Applying Equations (3) it was possible to calculate the intrinsic resolution of all planes and the telescope resolution. Results are shown in Table 2.



(a) Moderate granularity (b) High granularity

Figure 1: Residual distribution for a telescope plane used as a DUT. In a configuration (a) with all moderate granularity sensors, the measured residual distribution width is found to be 3.0 μm, corresponding to a single plane resolution of about 2.7 μm. In a configuration (b) with all high granularity reference planes the measured residual width is 0.9 μm corresponding to a single plane resolution of 0.85 μm.

Table 2: Comparison between the two different configurations

	Moderate granularity	**High granularity**
Measured width [μm]	3.00	0.95
Scaling factor k	0.23	0.25
Single plane res. [μm]	2.70	0.85
Telescope res. [μm]	1.30	0.42

4 Conclusion

Within the EUDET project a pixel telescope has been designed and commissioned with the main goal of fostering the detector R&D for the future International Linear Collider.

The first prototype of telescope with analog signals can be used with both high and moderate granularity reference planes in order to better fulfil user needs and requirements. The performance in terms of spatial resolution of this telescope demonstrator has been measured with a 120 GeV pion beam at CERN last year and the results obtained for the single plane and telescope resolution are well in agreement with the design specifications. The results will be soon validated also on a low energy electron beam at DESY where the multiple scattering contribution is not negligible.

Acknowledgement

This work is supported by the Commission of the European Communities under the 6th Framework Programme Structuring the European Research Area, contract number RII3- 026126.

References

[1] W. Dulinski, *et al.*, Beam telescope for medium energy particles based on thin, submicron precision MAPS In *Nuclear Science Symposium Conference Record 2007*, pages 995–1002, 26 October 2007.

[2] A. Bulgheroni First test beam results from the EUDET pixel telescope. In *Nuclear Science Symposium Conference Record 2007*, pages 1878–1884, 26 October 2007.

[3] V. Blobel. Software alignment for tracking detectors. *Nuclear Instruments and Methods in Physics Research. Section A, Accelerators, Spectrometers, Detectors and Associated Equipment*, 566:5–13, 2006.

[4] A.F. Zarnecki and P. Niezurawski, EUDET telescope geometry and resolution studies, EUDET-Report-2007-01, arXiv:physics/0703058.