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An EUDET/AIDA Pixel Beam Telescope for Detector Development

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An EUDET / AIDA Pixel Beam Telescope for Detector Development

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***Abstract*— A high resolution ($\sigma \sim 2\,\mu m$) beam telescope based on monolithic active pixel sensors (MAPS) was developed within the EUDET collaboration. The telescope consists of six sensor planes using Mimosa26 MAPS with a pixel pitch of $18.4\,\mu m$ and thinned down to $50\,\mu m$. The excellent resolution, readout rate and DAQ integration capabilities made the telescope a primary test beam tool for many groups including several CERN based experiments. Within the new European detector infrastructure project AIDA the test beam telescope will be further extended in terms of cooling infrastructure, readout speed and precision. In order to provide a system optimized for the different requirements by the user community, a combination of various pixel technologies is foreseen. In this report the design of this even more flexible telescope with three different pixel technologies (TimePix, Mimosa, ATLAS FE-I4) will be presented. First test beam results with the HitOR signal provided by the FE-I4 integrated into the triggering scheme will be shown.**

I. Introduction

DURING the R&D phase for particle detectors a number of beam tests are needed to show the performance of the newly developed devices. In order to extract parameters such as resolution and efficiency, the track of the beam particle needs to be defined precisely, and beam telescopes are ideal tools for this purpose.

Different telescopes have been built in the recent decades. As most of these telescopes are built for a specific device under test (DUT) their use by a different R&D group usually results in a lot of adjustment work such as rewriting the data acquisition code.

II. The EUDET Telescope

The motivation for the EUDET high-resolution pixel telescope was to design an easy-to-use system with well-defined interfaces allowing test beam studies on a short time scale. Furthermore, the telescope had to to perform well at both high and low momentum beams.

These goals where achieved with the final EUDET telescope[1]. Already the demonstrator version of the telescope, in use since 2007, was exhaustively exploited during beam tests by many user groups. The final telescope based on Mimosa26 sensors performed extremely well and attracted even more users.

A. Components of the EUDET Telescope

The EUDET telescope is based on monolithic active pixel sensors, specifically six planes of Mimosa26 sensors [2] with 576×1152 pixels, a pitch of $18.4\,\mu m$, an active area of $10.6 \times 21.2\,mm^2$, and thinned down to $50\,\mu m$. A lightweight mechanical frame allows easy transport of the telescope when needed, precise positioning of the sensor planes, and flexibility for the device under test (DUT), which can be moved to scan larger areas. A trigger logic unit (TLU) distributes the trigger signal from scintillators to the EUDET telescope and the connected DUTs. The signals from the sensors are sent to a custom DAQ board built on 6U VME64x cards, the EUDRBs. Figure 1 shows the schematic overview of the telescope components.

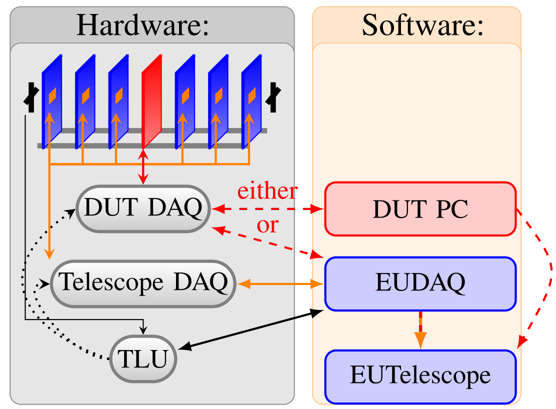

Fig. 1. Schematic overview of the components of the EUDET telescope.

A DAQ software framework, EUDAQ, allows the easy (but optional) integration of the DUT and its DAQ into the telescope data stream and offers online monitoring facilities. As final step, the EUTelescope software tools can be used for track reconstruction and data analysis.

With the EUDET telescope, a pointing resolution, i.e. the typical resolution of the interpolated space point on a DUT, of less than $2\,\mu m$ was achieved in the $120\,GeV$ pion beam at CERN when the DUT is placed in the center of the two telescope arms. Massive DUTs can be accommodated behind the telescope, with extrapolated space point resolutions of less than $5\,\mu m$ when the DUT is placed as close as possible. Even at distances of $1.5\,m$ behind the telescope, the space point prediction is accurate to $25\,\mu m$. Trigger rates of the order of $1\,kHz$ have regularly been achieved.

III. Current and Future Pixel Technologies for AIDA Beam Telescopes

A. From EUDET to AIDA

Within the European AIDA project, one work-package is devoted to the development of a precision pixel detector

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infrastructure.

Based on the EUDET telescope, a next generation device is under way, which will offer the user the choice between different detector technologies: ATLAS pixel modules based on FE-I4 allowing LHC-speed timing, TimePix sensors for high precision timing and high resolution, and extended area Mimosa MAPS offering high resolutions at low material budgets.

Furthermore, a new central dead-time-free trigger logic unit is being developed to provide high speed and thus enabling the synchronization of LHC-style systems like FE-I4 or TimePix with the rolling shutter readout of the Mimosas.

B. ATLAS FE-I4

The ATLAS hybrid pixel assembly is based on the FE-I4 chip [3], and is fabricated using the IBM $130\,\mathrm{nm}$ CMOS process. It was designed for high particle rates at high occupancies allowing up to $\sim 10\%$ fired pixels per sensor.

The pixel size is $50\,\mu\mathrm{m} \times 250\,\mu\mathrm{m}$ arranged in an $80\,\mathrm{col} \times 336\,\mathrm{rows}$ array and giving $\sim 4\,\mathrm{cm}^2$ active sensor area. The total thickness is $\sim 400\,\mu\mathrm{m}$. The chip readout is based on the USBPix system and has already been successfully integrated into both the EUDET and TimePix telescope DAQs. This integration is of special interest due to the the self-triggering capabilities of the FE-I4 chip which will be described in more detail in section V.

C. MimAIDA

New sensors are being developed in collaboration of IRFU-Saclay and IPHC-Strasbourg based on the current Mimosa26 MAPS sensors. They will offer a significantly larger detection area of $4 \times 6\,\mathrm{cm}^2$ at a thickness of only $50\,\mu\mathrm{m}$. Similarly to the Mimosa26, the MimAIDA sensors will be read out in rolling shutter mode and feature an intrinsic spatial resolution of $\sim 4\,\mu\mathrm{m}$. The final sensors are planed to be available for users by 2015.

D. TimePix

The TimePix family readout chip [4] is based on a $250\,\mathrm{nm}$ CMOS IBM process. The square pixels have a $55\,\mu\mathrm{m}$ pitch and are arranged in a 256×256 pixel matrix, covering a detection area of $14.1 \times 14.1\,\mathrm{mm}^2$. The sensor-chip assembly operates in a global shutter mode where the shutter signal controls when the pixels are active.

There are three distinct operation modes of the TimePix chip: counting, time over threshold for tracking and time of arrival for time stamping, with a time resolution of $\sim 10\,\mathrm{ns}$.

IV. Current Generation of Telescopes and their Performance

The move to a more easily available National Instruments based DAQ system using a PXI express bus, and thus replacing the EUDRBs of the EUDET telescope, allowed to fulfill the user demand for additional beam telescopes. The DATURA beam telescope at DESY (fig. 2, bottom) is the most recent replica in a series evolved from the original EUDET telescope. Further copies include the ANEMONE (ELSA, Bonn) and ACONITE (SPS, CERN) telescopes. With this EUDET family of telescopes, a track-pointing resolution of $< 2\,\mu\mathrm{m}$ at the DUT position with trigger rates up to $4.3\,\mathrm{kHz}$ has been measured in the $120\,\mathrm{GeV}$ pion beam at CERN. Similar results can be achieved at the 1–6 GeV electron beam lines at DESY with an appropriate sensor plane geometry to minimize multiple scattering.

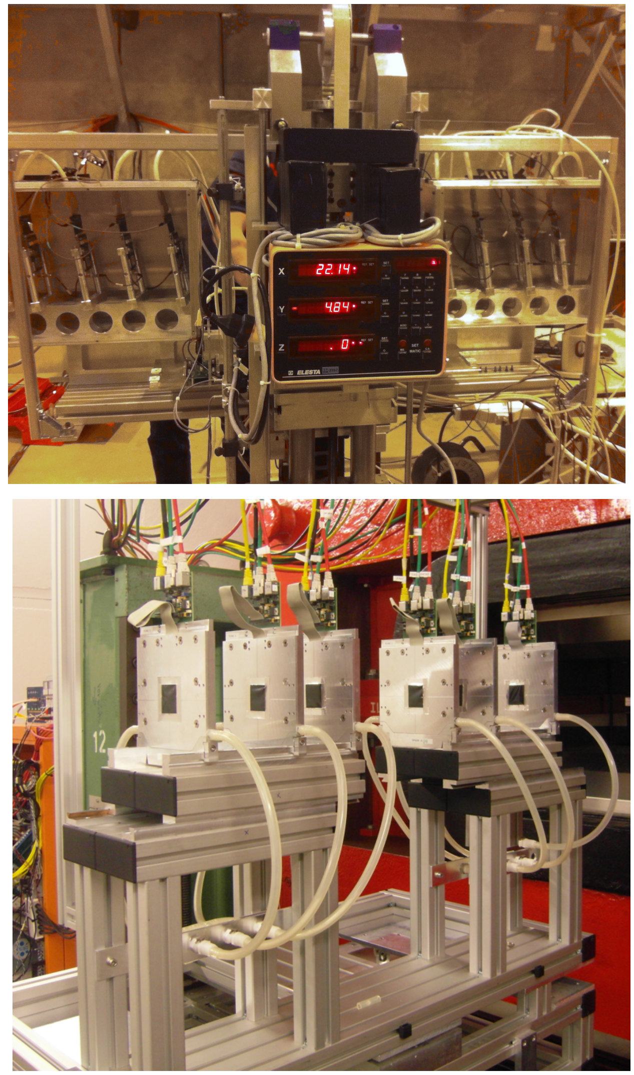

Fig. 2. *Top:* The TimePix telescope at CERN consisting of 9 planes of TimePix ASICs with $300\,\mu\mathrm{m}$ silicon sensors and featuring a $x - y - z$ table at the DUT position. *Bottom:* The DATURA beam telescope at the DESY test beam is the most recent replica in the EUDET family of telescopes and consists of six planes of Mimosa26 sensors.

The TimePix-based telescope [5] shown in figure 2 offers a track-pointing resolution of $\sim 1.5\,\mu\mathrm{m}$ in high-energy beams at a track rate of $\sim 12\,\mathrm{kHz}$. By matching coarsely timestamped hits with scintillator information offline, a track timestamping precision of $\sim 1\,\mathrm{ns}$ can be achieved. Various readout systems have been successfully integrated into the TimePix telescope, including ATLAS FE-I4, silicon strips using e.g. Beetle chips, and PXI-based MediPix readout systems.

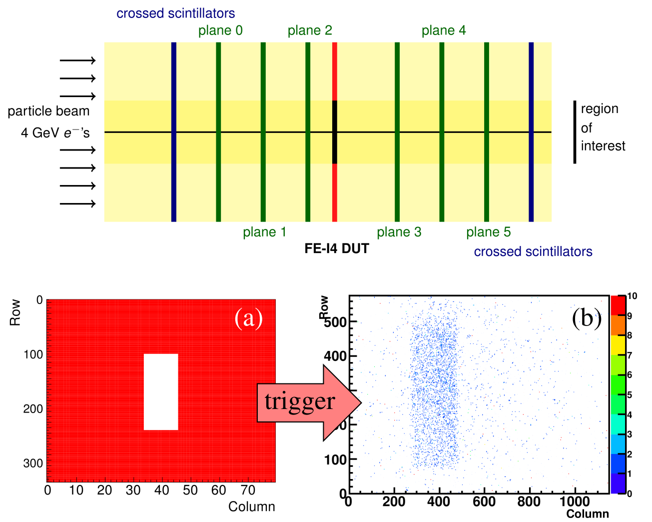

Fig. 3. *Top:* The schematic setup of the ATLAS FE-I4 in-between the two arms of the ANEMONE telescope at DESY. *Bottom:* (a) active pixels of the FE-I4 in white defining the region-of-interest, (b) resulting $x - y$ distribution of triggered pixel hits in the first telescope plane.

V. Integrating the ATLAS FE-I4 into an AIDA Telescope

By making different sensor technologies available to the telescope user, the combination most appropriate or convenient for the intented measurement can be selected. The choice can be based on criteria such as intrinsic resolution, hit-rate capability, active area or material budget. Additionally, some technologies offer specific features that make them attractive for the use in a beam telescope. An example is the self-triggering capability of the ATLAS FE-I4.

The ATLAS FE-I4 chip features a fast (20–30 ns) HitOr signal formed from an OR of the discriminator output of all pixels. Since each pixel's HitOr can be switched on/off individually, a *region of interest* can be defined. Using the HitOr as input to the triggering scheme of the telescope and the DUT readout, the FE-I4 can provide a very flexible tool for the selective measurement of particle tracks.

This was successfully demonstrated e.g. using the ANEMONE telescope at the DESY test beam with 4 GeV electrons [6]. As illustrated by the schematic drawing in figure 3, the FE-I4 was set up as DUT in between the two telescope arms with three planes of Mimosa26 sensors each. The HitOr of the FE-I4 was used to define a $3\,\mathrm{mm} \times 7\,\mathrm{mm}$ region of interest. Together with the signal from three scintillators the HitOr was sent as input to the TLU which was configured to generate a trigger if all four inputs coincide.

Figure 3b shows the $x - y$ distribution of the measured hits in the first telescope plane. The rectangular shape of the HitOr region is clearly visible and of approximately the same shape. The occurrence of hit pixels outside the region of interest is caused by additional hits during the rolling shutter readout of the Mimosa26 sensors.

To make the ATLAS FE-I4 a fully integrated reference plane in the EUDET family of telescopes, the FE-I4 has also been incorporated into the EUDAQ and EUTelescope software packages, allowing easy DAQ control, online monitoring and track reconstruction.

VI. Summary

The telescopes available through AIDA provide an excellent track pointing resolution of better then $2\,\mu\mathrm{m}$ at track rates of several kHz. Still, further development of the telescopes within the AIDA project is under way, and partially already achieved. One example is the integration of TimePix family and FE-I4 chip based sensors into the EUDET-family type DAQ and data analysis chain. This will give the telescope user the choice of the reference sensor best suited for the measurement at hand and will make the AIDA telescopes an even more flexible tool.

Ultimately, the test beam particle rate can be significantly raised, which will allow to collect 1–2 order of magnitude data more over the same beam time. The future beam test campaigns are aimed at the detector R&D for the LHC upgrade, Linear Collider and other HEP experiments.

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