TelePix - A fast region of interest trigger and timing layer for the EUDET Telescopes

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Abstract

Test beam facilities are essential to study the response of novel detectors to particles. At the DESY II Test Beam facility, users can test their detectors with an electron beam with a momentum from 1 – 6 GeV. To track the beam particles, EUDET-style telescopes are provided in each beam area. They provide excellent spatial resolution, but the time resolution is limited by the rolling shutter architecture to a precision of approximately 230 µs. Since the demand on particle rates - and hence track multiplicities - is increasing timing is becoming more relevant. DESY foresees several upgrades of the telescopes. TelePix is an upgrade project to provide track timestamping with a precision of better than 5 ns and a configurable region of interest to trigger the telescope readout. Small scale prototypes have been characterised in laboratory and test beam measurements. Laboratory tests with an injection corresponding to 2300 electrons show a S/N of above 20. Test beam characterization shows efficiencies of above 99 % over a threshold range of more than 100mV and time resolutions of 2.4 ns at low noise rates.

1. Introduction

Test beam measurements provide conditions very close to applications in experiments and are hence crucial for sensor R&D. DESY II [1] provides three independent user beam lines with electrons/positrons ranging from 1 – 6 GeV. Each line is equipped with a EUDET-style [2] reference tracking telescope based on MIMOSA-26 sensors [3, 4]. They provide excellent position resolution with an integration time of 230 µs. At typical operation conditions, this creates events with up to 6 particles passing the telescope, causing ambiguities. Additionally, small devices under test (DUT) are likely to not be penetrated by the particle triggered on, which causes inefficient data taking.

A new telescope plane, TelePix, is foreseen to solve both issues by providing a precise time stamp and a fast region of interest trigger output on arbitrary pixel arrangements. A similar hybrid approach with less precise timing is presented in [5].

2. TelePix Prototypes

The prototypes are designed in a 180 nm HV-CMOS process and profit from more than a decade of research and experience in this process [6, 7]. They feature a matrix of 29×124 pixels at a pitch of 165x25 μm^2 and are operated in a data driven mode with a column drain readout logic. A configurable fast digital hit-OR output (HitBus) of all unmasked pixels is foreseen as a region of interest trigger of the reference telescopes. This provides the flexibility to trigger on any subset of pixels, to optimally match the DUT. Readout is handled by the Mu3e pixel DAQ [8, 9]. Four different detector flavours from two submissions are compared. A chip split into two parts with NMOS & PMOS transistors at the amplifier input was submitted in 2020. They are referred to as Run2020-NMOS and Run2020-PMOS in the following. Improved biasing alongside NMOS and CMOS inputs are realized in two chips in a later submission (Run2021), referred to as Run2021-NMOS and Run2021-CMOS. For the presented studies, the chips are operated at a core frequency of 125 MHz and time stamp precision of 4 ns. No threshold trimming or pixel masking is applied. All samples have been thinned to 100 µm.

Laboratory Characterization

The first submission was studied in the laboratory using the charge injection feature of the chip (400mV, ≈2300 electrons) and analysing the response of the fast HitBus. Figure 1 shows the fraction of detected injections for the Run2020-NMOS and Run2020-PMOS type, exemplary for a single pixel. The NMOS generates a larger signal with less noise at the used settings. In figure 2, the sigma and mean of the s-curve fits are histogrammed for all pixels of the two types. A signal to noise ratio of above 20 was determined for the NMOS.

Test Beam Characterization

The TelePix prototypes have been characterized in test beam campaigns at the DESY II facility. The test setup, corryvreckan framework [10] based analysis as well as first measurements are presented in [11].

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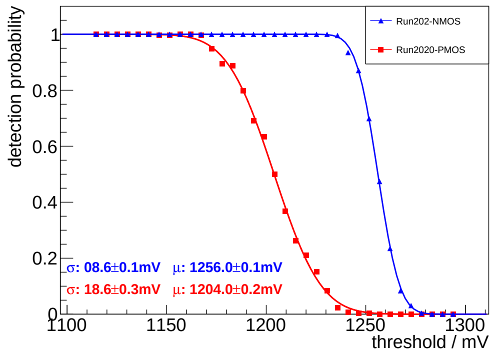
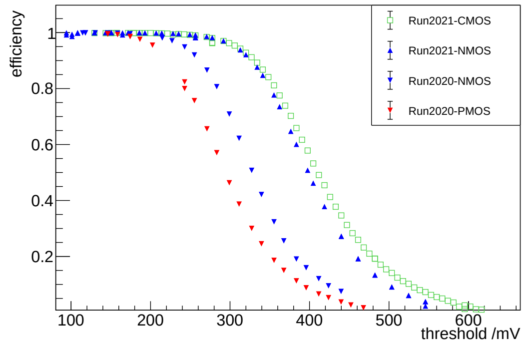


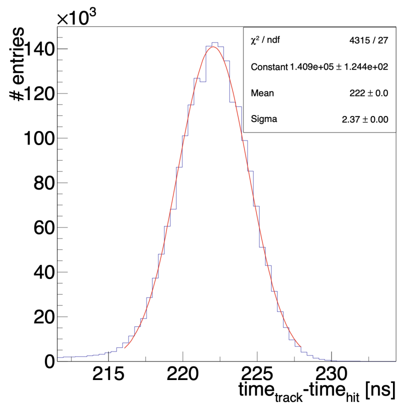
Figure 1: Exemplary response to the charge injection for Run2020-NMOS (blue triangles) and Run2020-PMOS (red squares). An s-curve is fitted to the data. The baseline is at 1 V.

Figure 3a summarizes the efficiency as a function of the threshold for all tested samples. It can be seen, that the efficiency plateau of the Run2020-PMOS is smaller than for the Run2020-NMOS. With the improvements in Run2021, a significant increase in the efficiency plateau is observed. Run2021-CMOS has a slightly wider high efficiency region. The noise levels of all prototypes are similar.

The time resolution of the Run2021-CMOS at a low detection threshold of 108 mV, with respect to a fast LySo crystal connected to a SiPM has been measured in figure 3b. For HV-CMOS an unprecedented resolution of below 2.4 ns is determined, which is significantly better than the requirements. The *region of interest trigger feature* has been evaluated in [11]. It had an absolute delay of ≈22 ns and a jitter of ≈3.8 ns for Run2020-NMOS, including pixel-to-pixel fluctuations within a column.



(a) Efficiency as a function of the detection threshold. Run2020 results from[11]. Statistical errors are too small to be seen.



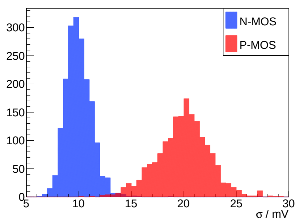
(b) Time resolution of the CMOS chip. Gaussian fit to the core of the distribution.

Figure 3: Efficiency vs threshold of all tested prototypes and time resolution of the Run2021-CMOS. The samples are biased with −70 V.

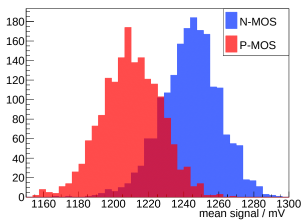
3. Summary & Outlook

The two TelePix prototype submissions have been successfully tested in beam and laboratory measurements. The Run2021 submission further improves the already excellent performance of the sensor. Threshold regions of above 100 mV with >99 % hit detection efficiency have been determined alongside excellent time resolutions of 2.4 ns. TelePix is meeting all requirements to serve as trigger and timing plane at the DESY II test beam. The region of interest trigger feature has been tested and is fully functional and already serving first users.

A chip with an active area of $2 \times 1\,\text{cm}^2$ in the Run2021-CMOS flavour has been submitted and is expected to be delivered in December 2022. Due to the experience in large scale sensor design in the process, we do not expect major issues in the submission. Deployment of the full scale sensor to all telescopes is expected during the first half of 2023. With the TelePix upgrade timing/triggering performance of the EUDET-style telescopes will improve significantly and allow for efficient future test beams.



(a) sigma of the s-curve



(b) Mean signal

Figure 2: Results of the injection scans. Run2020-PMOS (Run2020-NMOS) in red (blue).

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