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BEAM TEST OF ALPIDE SENSOR

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Abstract

The Alice Pixel Detector (ALPIDE) is developed for the upgrade of the Inner Tracking System of the ALICE experiment at CERN, which will take place during second Long Shutdown in 2019-2020. ALPIDE is a Monolithic Active Pixel Sensor (MAPS), manufactured in a 180 nm CMOS Imaging Process of TowerJazz. Forecoming tracking detectors, based on this technology, will see strong advantages with the application of these sensors as they provide the highest capabilities in spatial resolution and utmost potential for being thin. In this work, the results of the ALPIDE sensor beam test, which took place at the Beam Test Facility of Laboratori Nazionali di Frascati, are presented.

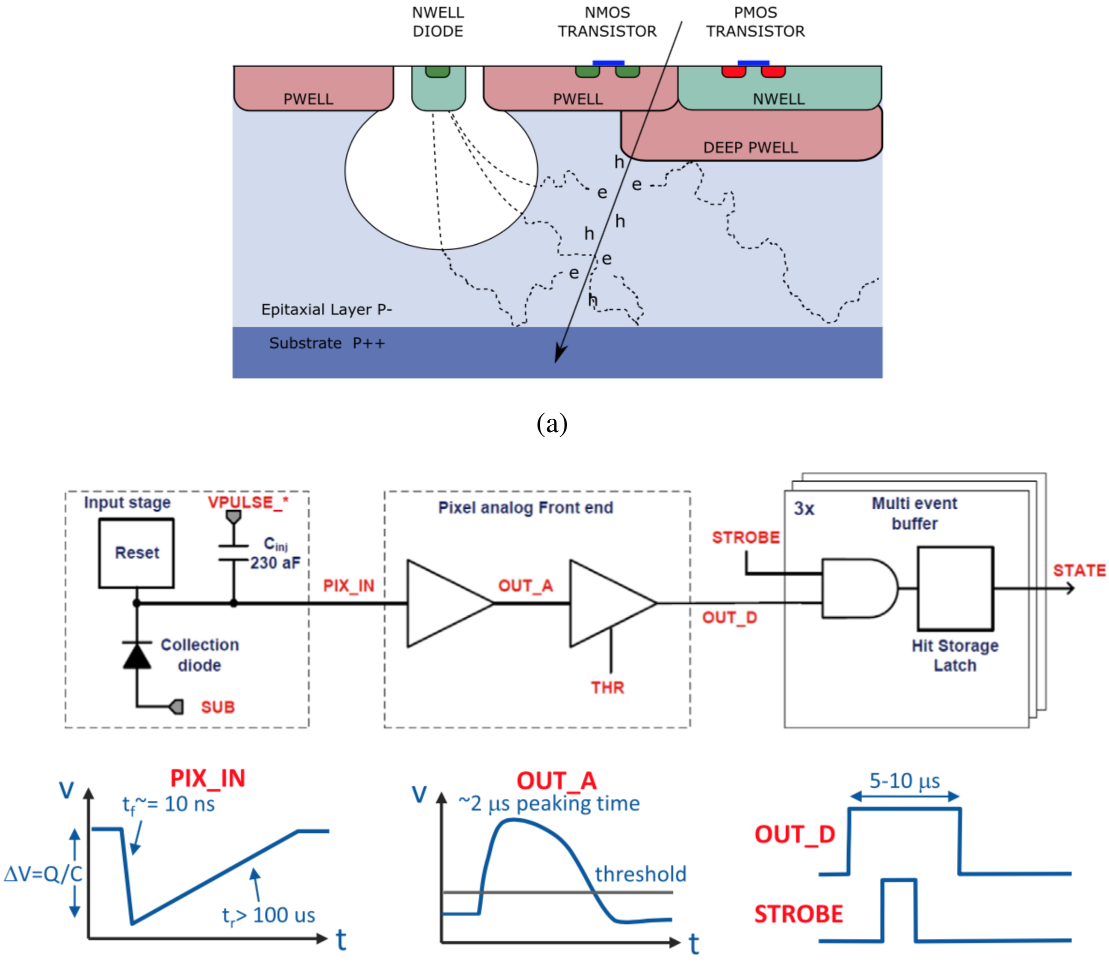
1 Introduction

The Inner Tracking System (ITS) of the ALICE experiment at CERN will undergo a major upgrade during the second long shutdown (LS2) in 2019-2020, intended to improve the tracking and vertexing capabilities of the system [1]. The present ITS will be entirely replaced with a new system based on Monolithic Active Pixel Sensors (MAPS). The upgraded ITS will be composed of 7 cylindrical barrels located at different distances from the interaction point, where each barrel is build with sensor module structures known as staves.
The Alice Pixel Detecor (ALPIDE), the main component of the new ITS, is being produced with a 0.18 µm CMOS technology feauturing a design optimized for the upgraded ITS. The ALICE group at LNF, one of the assembly and testing sites involved in the production of the Outer Barrel (OB) of the system, will produce and test 27 staves each comprising 196 ALPIDE sensors. Each OB stave will be composed of 14 Hybrid Integrated Circuit (HIC), an assembly consisting of the polyimide flexible printed circuit (FPC) on which the ALPIDE chips (2×7) and some passive components are bonded [2].
In this note, the results of a beam test performed in the BTF at LNF, devoted to the study of some basic features of the ALPIDE sensor, will be reported. For this purpose the ALPIDE sensor has been combined to a MIMOSA-28 sensor [3]. This test have to be considered as a feasibility study to work with such combined ALPIDE/MIMOSA-28 tracking system. Such a system will be helpful in order to study and test the assembled final staves.

2 Setup

2.1 ALPIDE

ALPIDE is a CMOS MAPS sensor developed by the ALICE collaboration and manufactured by TowerJazz on high-resistivity epitaxial silicon layer with a highly doped p-type substrate (Fig. 1a). The sensor features a matrix of 512 rows and 1024 columns of pixels where a single pixel measures 27 µm × 29 µm in $r\phi$ and z planes, respectively [2]. Each pixel hosts the front-end electronics, which includes an analogue section with signal amplification, shaping and discrimination as well as the digital section which includes pixel storage and masking registers (Fig. 1b). The 3-bit in-pixel buffer allows to store the discriminated hit information, which is read-out when a global strobe signal arrives by the priority encoder circuits [4]. The front-end parameters of the chip were optimized in order to achieve the readout capability of 100 kHz, which is beyond the expected scenario of the luminosity increase after the LS2. In this work, the final prototype of the sensor, ALPIDE v4, was used.



(a)

(b)

Figure 1: (a) Schematic view of the ALPIDE pixel sctructure [2]; (b) Schematic view of the front-end part of the ALPIDE pixel [4].

2.2 MIMOSA-28

The MIMOSA-28 or *Ultimate* sensor was developed for the upgrade of the inner tracking system of the STAR experiment at RHIC [3]. It has a pixel matrix of 928 (rows) $\times$ 960 (columns) with a single pixel size of 20.7 $\times$ 20.7 µm^2. The sensor employes a rolling shutter readout technique with a 185.6 µs frame readout time.

2.3 Beam Test Facility

The testbeam have been performed at the Beam Test Facility of Laboratori Nazionali di Frascati. The BTF provides electron and positron beams of an energy up to 500 MeV in bunches, with a 1-50 Hz repetition rate and the maximum beam current of 500 mA (e^-) and 100 mA (e^+), which turns into approximately a factor of 5 difference in electron and positron bunch multiplicites [5]. In this work, both electron and positron beams of a 450 MeV energy, were used at the maximum repetition rate of 50 Hz.

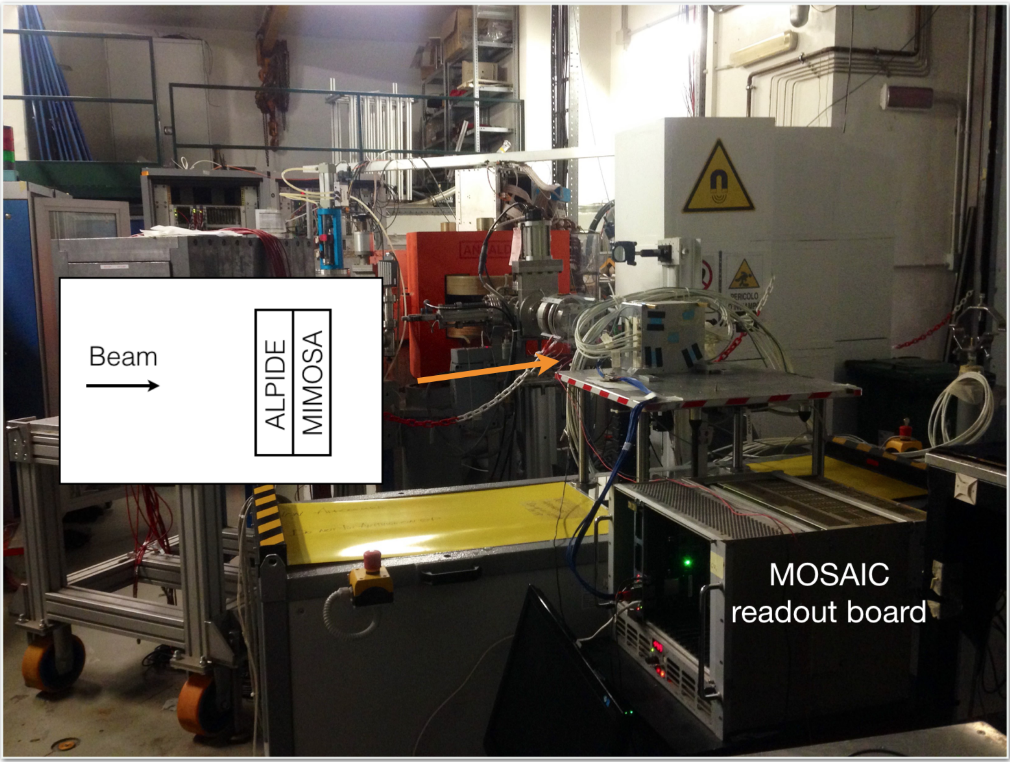


Figure 2: General view of the test setup assembled in the BTF hall.

2.4 Setup arrangement

The setup, consisting of one ALPIDE and one M28 sensors, was mounted on a precision remotely controllable table located several tens of centimeters far from the beam extraction window (Fig. 2). The sensors were mechanically assembled on custom made aluminum frames which were mounted on a rail like structure. Here, the ALPIDE sensor was placed inside a carrier board that provides the required power connection to the front-end part of the chip and to its biasing structures (Fig. 3).

2.5 Data acquisition

The readout of the ALPIDE sensor was performed using an FPGA (Field Programmable Gate Array) based MOSAIC board [6]. The M28 sensor was read-out via a system based on a SoCKit development kit [7]. In order to synchronize both acquisition systems, the BTF bunch crossing trigger was connected to the input of the MOSAIC board and an output signal [1] of the MOSAIC board was used as a trigger for data acquisition of the M28 system. In this case, only the events counted by the MOSAIC board were registered by the MIMOSA data acquisition.

[1] VETO signal of the bunch crossing trigger and the BUSY state of the MOSAIC board.

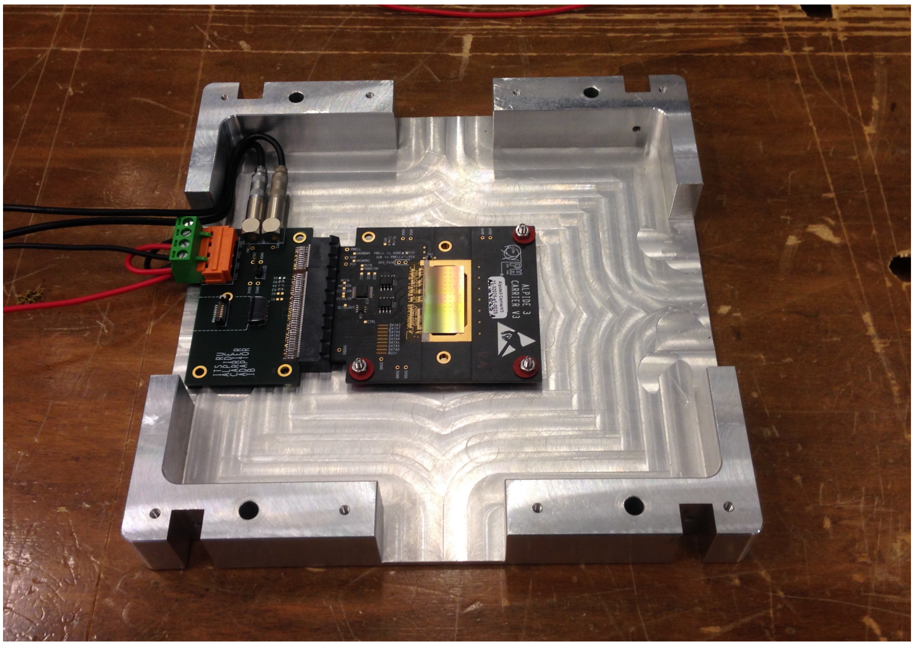


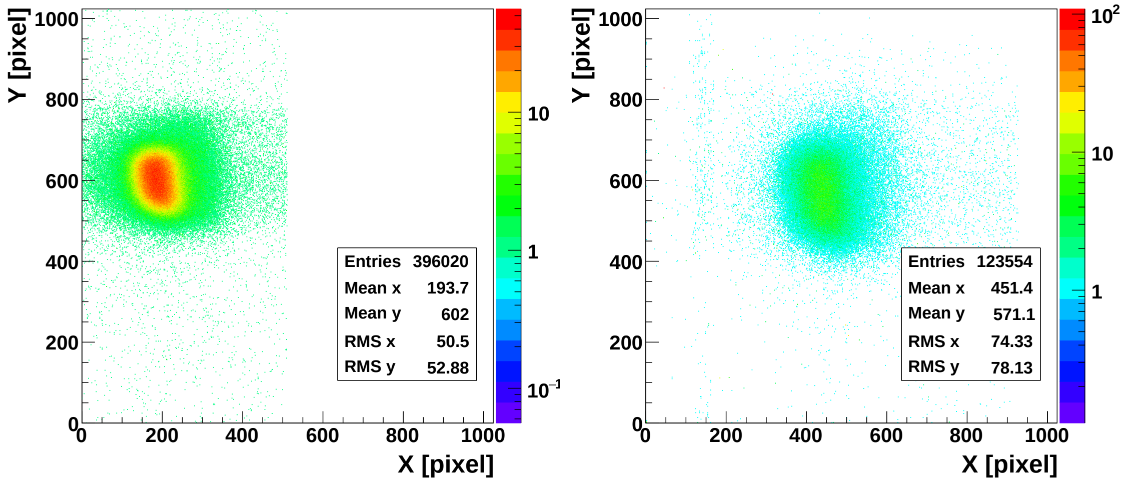
Figure 3: Carrier board with the ALPIDE sensor mounted on the supporting aluminum frame.

3 Results

For each sensor a raw data output file is produced containing a list of the fired (hit) pixels with the corresponding trigger numbers. Each pixel is identified by a row and a column number. An ionizing particle impinging a MAPS produces charge carriers that are collected by one or more adjacent pixels. Such a group of pixels is called a cluster. A clustering algorithm based on the first neighbour search approach has been used to identify clusters for each sensor. Two pixels are called first neighbours if they are contiguous in row or column, i.e. if their row (column) number is the same and the difference between their column (row) number is equal to one. The clustering algorithm produces, for each trigger number, a list of reconstructed clusters, their cluster size (the number of pixel per cluster), the X and Y positions of the cluster center of gravity (CoG) in pixels unit and the RMS values of the latter.

The X-Y position of the reconstructed clusters is shown in Fig. 4a for ALPIDE and in Fig. 4b for M28 sensor. The difference in the number of entries in case of ALPIDE and M28 sensors depends on different setting of the thresholds of the two sensors. The difference in the beam profile by looking at the X-Y RMS for ALPIDE and M28 sensors, is compatible with the multiple scattering of 450 MeV electrons and positrons in 100 µm of silicon (ALPIDE thickness). The beam spot size measured by ALPIDE is $RMS_x \approx 1.4$ mm and $RMS_y \approx 1.5$ mm, including the multiple scattering of the beam in the air between the beryllium exit window of the beam pipe and the ALPIDE sensor.

A dedicated acquisition of the noise has been performed in order to mask the noisy pixels in both sensors. In the case of ALPIDE, three noisy pixels have been masked. After the



(a) ALPIDE

(b) M28

Figure 4: Distribution of the clusters' center of gravity in X-Y for ALPIDE (a) and M28 (b) sensors

masking, the fake hit rate was reduced to 10^{-12} hits/pixel/event. The fake hit rate for M28 sensor is $< 5 \times 10^{-9}$ hits/pixel/event: some noisy hits is still clearly visible (see Fig. 4b for X $<$ 200 pixels). This noise can be removed for future beam tests by masking further remaining noisy pixels.

In Fig. 5a the number of the clusters per event versus the event number is shown for both sensors. The number of the clusters per event depends on the bunch multiplicity. Looking at Fig. 5a it is possible to distinguish between electrons and positrons, as the electron multiplicity in BTF is in average about 5 times the positron one (see Sec. 2.3). No beam is present during the switch from electrons to positrons. In Fig. 5b the distribution of the number of clusters per event is shown in the case of the ALPIDE sensor. Here it was possible to distinguish between positrons and electrons, selecting on the basis of the event number from Fig. 5a the two different contributions. The electron and positron distributions are poissonian with mean number of clusters per event 7.4 and 1.7 respectively. For each event all the available combinations of the clusters CoG of the M28 sensor and of the ALPIDE have been considered in order to select the clusters correlated to the passage of a particle through both sensors. These combinations are shown in Fig. 6 for both the X (top) and Y (bottom) positions of the cluster center of gravity. The correlated clusters are the ones lying along the line clearly visible in both the plots of Fig. 6, while all the other cluster combinations form a combinatorial background corresponding to the blob visible in each of the two plots of Fig. 6. Such combinatorial background is due to the matching of two clusters not belonging to the same particle, considering that the average multiplicity is greater than one. Another contribution to such combinatorial background comes from the matching of a cluster due to an impinging particle with another one due to noise. The latter case is mainly due to the noise from the M28 sensor, as clearly visible

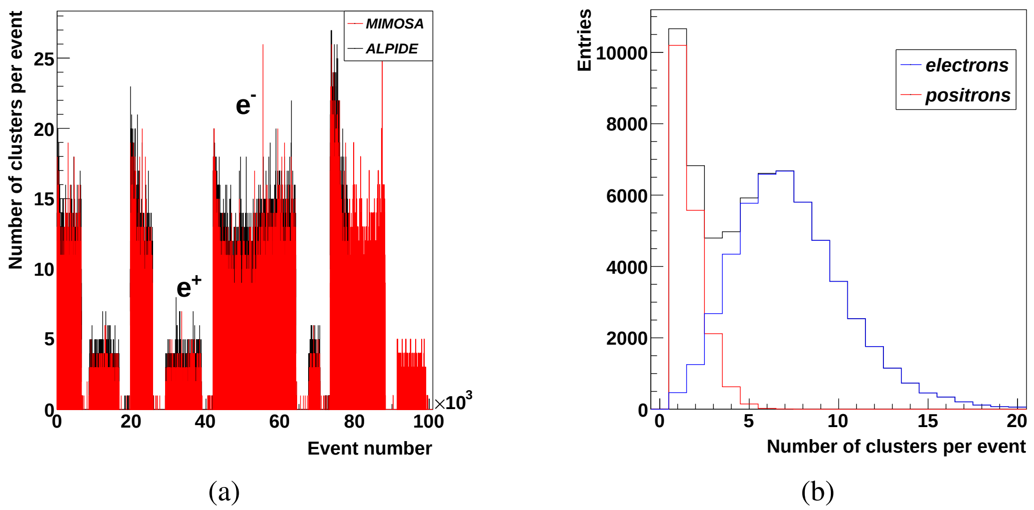


Figure 5: (a): Distributions of the number of clusters per event versus the event number for both the sensors. (b): Distribution of the number of clusters per event for ALPIDE.

in the top of Fig. 6: the vertical line for X_MIMOSA<50 corresponds to a noisy cluster of M28 sensor that matches with all the available clusters from ALPIDE for that event. In

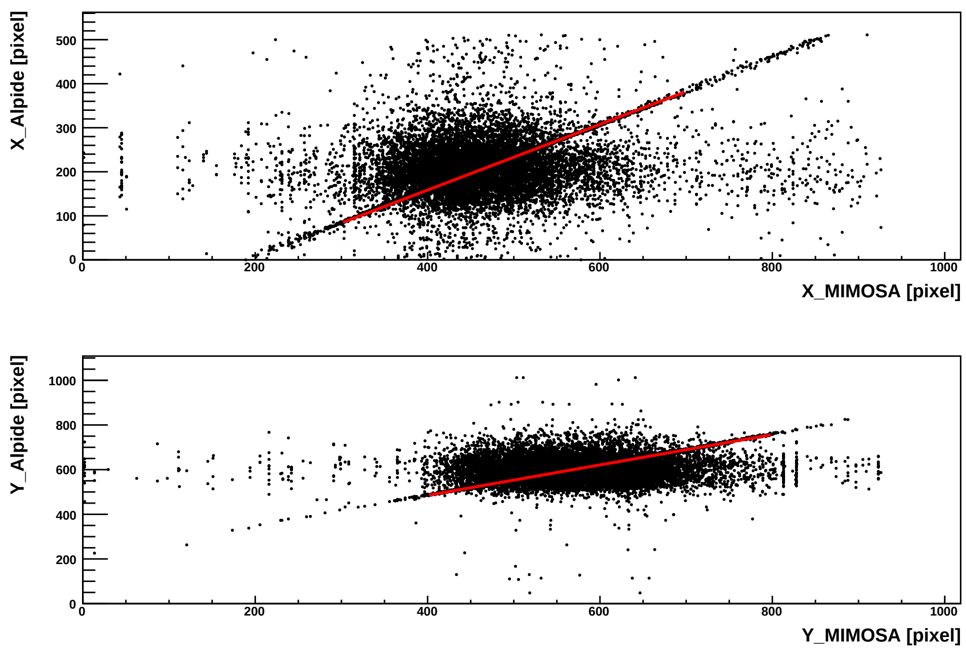


Figure 6: Combinations between all the clusters positions in x (top) and y (bottom) of the two sensors. The correlated clusters are the ones lying along the line.

order to select only the correlated clusters, a linear fit has been done as shown in Fig. 6 and the distance between all the clusters' positions and the line has been computed, selecting as good events the ones within a distance of 5σ. Using only such selected events, the mean cluster size of the M28 and ALPIDE sensors was measured to be approximately

2.5 and 1.8 pixels respectively.

4 Conclusions

The ALPIDE chip has been developed for the upgrade of the ITS of the ALICE experiment at CERN, foreseen for the LS2 of the Large Hadron Collider (2019-2020). The ALICE LNF group will participate in the assembly of the detector, taking care of the production and tests of 27 OB staves.
In this work, the results of a beam test performed in the BTF at LNF with an ALPIDE and a M28 sensors, have been presented. This test has to be considered as a preliminary test exploring the possibility to work with the combined ALPIDE/M28 system, never used together until now. The clusters spatial distribution was exploited to study the beam size ($RMS_x \approx 1.4$ mm and $RMS_y \approx 1.5$ mm) and the number of clusters per event was used to monitor the beam multiplicity. The system was succesfully syncronized and it was possible to correlate the clusters of the two sensors related to the same particle, event by event. The cluster size was found to be approximately 1.8 for ALPIDE and 2.5 for M28 sensor in pixel unit, selecting just the correlated events.
No tracking algorithm has been implemented in this preliminary test with only two sensors, but it will be developed for future beam tests exploiting more M28 and ALPIDE sensors together to form a tracking telescope. With such apparatus it will be possible to study the ALPIDE efficiency detection at different back bias voltages and threshold conditions. It is also planned to test a HIC in laboratory and in a future beam test at the BTF facility.
Last but not least, it is worth to stress that the development of the MAPS sensors and the related assembly technologies is not only restricted to the field of high energy physics experiments but also opens a range of new opportunities for applications that benefit from high spatial resolution devices.

5 Acknowledgements

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