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Hybrid pixels for the $\overline{\text{P}}$ANDA Micro-Vertex Detector

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Summary. — $\overline{\text{P}}$ANDA is a fixed target experiment that will be carried out at the future FAIR facility. The $\overline{\text{P}}$ANDA experiment will perform precise studies of antiproton-proton and antiproton-nuclei annihilations, allowing to investigate different physics topics. The Micro-Vertex Detector (MVD), which represents the innermost part of the central tracking system, features good spatial resolution, limited material budget, radiation hardness and PID capability. To cope with this requirements the MVD is composed by pixel and strip detectors. The custom pixel detector design foresees thin epitaxial sensors and a readout electronics developed in 130 nm CMOS technology able to work in a triggerless environment. The first single chip assembly prototype for the pixel detector of $\overline{\text{P}}$ANDA is composed of the ToPix3 readout chip and a dedicated epitaxial silicon sensor matching in size the 640 readout channel matrix of the ASIC prototype. The bump bonding connection was done by IZM company. To perform the first beam test, a pixel tracking station composed by 4 planes was assembled and tested with 2.7 GeV/c protons at Forschungszentrum Jülich. The data analysis is presented.

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PACS 29.85.Fj – Data analysis.

1. – The Micro-Vertex Detector

The Micro-Vertex Detector (MVD) is the silicon high-resolution detector of $\overline{\text{P}}$ANDA [1]. It is located in the inner part of the central tracker, and it extends on the beam direction for about ±23 cm, with respect to the nominal interaction point. The MVD will be composed by silicon hybrid pixel detector and silicon double-side micro-strip detector, for a total amount of readout channels of about 10^7 and $2 \cdot 10^5$, respectively. The MVD is composed of 6 forward disks and 4 barrels arranged around the beam pipe.

The MVD will allow to reach a spatial resolution of the secondary vertices better than 100 μm. Moreover, the MVD points will impose important constraints on the global tracking algorithm leading to a momentum resolution of the order of $\delta p/p \sim 1\%$. The detector will have a time resolution better than 10 ns, which is essential in the $\overline{\text{P}}$ANDA experiment due to the annihilation rate that will be of the order of $2 \cdot 10^7$ per second. For this reason the electronics have been studied to handle a high data rate. The material choice has been dictated by the low material budget issue, and it will not exceed 10% X/X_0. Furthermore, the sensors, the electronics and all the material will be radiation tolerant up to $10^{14}\,n[1\,\text{MeV eq}]\,\text{cm}^{-2}$.

2. – The MVD hybrid pixels

The inner part of the MVD is composed of the hybrid pixel detector. The hybrid pixel concept design foresees each pixel connected by the bump bonding technique to the corresponding readout cell of a custom ASIC developed in 130 nm CMOS technology [2]. Then this assembly is glued to a carbon foam layer to improve heat dissipation towards the cooling pipe as a part of a cooling system working in depression mode and based on water as cooling fluid. A structure made of carbon fiber with suitable shape is used as mechanical support. In order to have a high radiation hardness sensor the pixel will be made of epitaxial silicon. The epitaxial layer, featuring a high resistivity of the order of $\sim$ kΩ will be grown on a Czochralski (Cz) substrate (with a low resistivity). Each pixel will have a size of $100\,\mu\text{m} \times 100\,\mu\text{m} \times 100\,\mu\text{m}$. The pixel readout chip, called ToPix, will provide for each hit a simultaneous position, time, and energy loss measurement (via the time-over-threshold technique).

3. – The Jülich beam test results

A beam test of the $\overline{\text{P}}$ANDA MVD hybrid pixels has been performed at the COSY synchrotron of FZ Jülich with 2.7 GeV/c protons, in order to test the first single chip assembly prototype composed of the ToPix3 readout chip [3] and a dedicated epitaxial silicon pixel sensor.

The sensor was produced at FBK (Trento, Italy), the bump bonding connection was realized by the IZM company (Berlin, Germany). This first batch of assemblies was obtained without removing most of the Cz substrate of the epitaxial sensor wafer by thinning. As a consequence in each assembly the sensor is composed of a 100 μm thick epitaxial silicon layer (resistivity: 3610 Ω·cm) on the low resistivity 525 μm Cz substrate, which will be removed by back grinding in the final design. The sensor surface was not aluminized so a direct Ohmic bias connection was realized taking advantage of the Cz substrate low resistivity. The ToPix3 chip was designed at INFN-Torino and produced with a MPW (Multi Project Wafer) run at CERN. To verify the performance of the prototype a bench including, the testing board housing the assembly, and a Xilinx evaluation board equipped with the Virtex 6 FPGA, was used. The testing board was not pierced in the corresponding area of the sensor, leaving a none negligible amount of material (with layers of copper and FR4), which has been estimated of the order of 20% X/X_0. The acquisition system was based on a LabVIEWsoftware. The experimental setup was made of 4 planes of assembly positioned at 6 cm each other, for a total length of the pixel tracking station of about 20 cm. The acquisition was performed with a 50 MHz clock. The raw data contains the position information, the leading and the trailing edge information (for charge measurement) and a 44bit timestamp, essential to perform a triggerless acquisition.

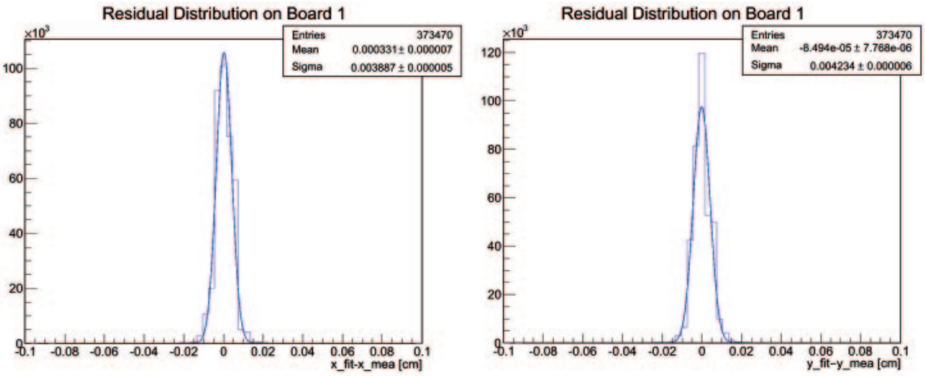

Fig. 1. – Residual distribution of x and y coordinates for the second plane of pixel.

3˙1. *Analysis results.* – The analysis has been performed with the PandaRoot framework [4]. Because of the triggerless acquisition the events have to be defined looking at the correspondence of the timestamp on the four assemblies. Since the data collection is not time ordered, it was necessary to perform a time calibration. The calibration allows to obtain time ordered data, and then to perform a faster timestamp matching. Due to the low thickness of the sensors, the multiplicity of hit pixels per tracks is most of the time 1. A cluster size of 2 pixels can be found with a statistics smaller of more than one order of magnitude. This multiplicity situation is reflected in the reconstructed coordinate, that assumes a discretized shape. The alignment method was based on the residual distributions, a straight line is fitted to the track data, and the residuals (difference between measured and fitted coordinates) are histogrammed, separately for each plane. The mean value of the residuals is taken as correction to the plane position, and the procedure is repeated iteratively. The obtained residual distributions of the second plane of pixels is shown in fig. 1, the hit resolution, represented by the sigma of the fitted Gaussian, is $\sim 40\,\mu$m.

Using the following estimator $\sqrt[4]{\sigma_{1(x,y)} * \sigma_{2(x,y)} * \sigma_{3(x,y)} * \sigma_{4(x,y)}}/\sqrt{4}$, where $\sigma_{i(x,y)}$ is the x-y resolution of the i-th plane, a tracking resolution of the order of $28\,\mu$m has been obtained.

4. – Conclusion

The first beam test shows satisfactory results, the hybrid pixel bump bonding process was successful and the ToPix3 chip showed good performance. Future tests will focus on the determination of the resolution and the efficiency of the sensors. This will be investigated with beams of higher momentum and a low material budget setup, in order to extract the real sensors resolution.

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