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Spatial resolution performance of 65 nm CMOS MAPS with analogue output for the ALICE ITS3 upgrade

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The ALICE experiment at the Large Hadron Collider (LHC) has planned an upgrade of the Inner Tracking System, ITS3, which will be installed during the LHC Long Shutdown 3 (LS3, 2026-2028). This presentation will show fresh results about the resolution performance obtained at the end of 2024 with 65 nm CMOS MAPS Analogue Pixel Test Structures during beam tests at CERN SPS. Resolution performance results comparing different sensor configurations (different design, pitch, reverse-bias voltage) and irradiation conditions will be shown and discussed.

Summary (500 words)

The Analogue Pixel Test Structure, or APTS, is a small-scale Monolithic Active Pixel Sensor produced using the TPSCo. 65 nm technology.
The chip has been designed for the characterization and the validation of the technology for the use in ALICE ITS3.
APTS measures 1.5 mm $\times$ 1.5 mm, and it is made of a matrix of 4$\times$4 pixels, where each pixel incorporates an analog output that is individually buffered and linked to an output pad. The sensor was manufactured with four pixel pitches (10, 15, 20, and 25 μm) and in three different geometry designs (standard, modified, modified with a gap). Its performance has been studied both with laboratory and beam tests.
Important requirements for its application in the ITS3 is spatial resolution of the order of $\sim$ 5 μm also after an exposure to $\sim$ 10 kGy of Total Ionizing Dose (TID) and 10^{13} of Non Ionizing Energy Loss (NIEL). Therefore, spatial resolution of the APTS variants with different design, pitch and received irradiation dose, have been studied during beam tests at CERN-SPS H6, using a telescope implementing ALPIDE \cite{ALPIDE2016_MagnusMager} sensors as reference planes, located in a dark environment. The irradiated sensors were all kept at constant temperature of 15° C. The final results have been produced by the end of 2023.

To analyse the data, the Corryvreckan \cite{corryvreckan_2023} beam test track reconstruction framework has been used. Since the sensor is small (order of $\sim$ 60 $\times$ 60 μm^2 and 50 μm thick), a concern regarded the alignment procedure. The sensor, during the beam test, was firstly aligned thanks to a moving stage. Then, a second alignment procedure was needed via software during the track reconstruction, performed with Corryvreckan. Therefore, before coming to the resolution calculation, a dedicated procedure for the APTS alignment has been established and followed.

Spatial resolution was determined by calculating the distance between the track intercept on the Device Under Test (DUT) plane and the corresponding cluster in both the x and y directions. Standard deviation was then computed from the resulting residual distributions, with the quadratic subtraction of the ALPIDE-based telescope tracking resolution, σ_{track} = 2.1μm. The spatial resolution for $x(y)$, denoted as $\sigma_{x(y)}$, is expressed as:

\begin{equation}
\sigma_{x(y)} = \sqrt{\sigma_{meas}^2 - \sigma_{track}^2}
\end{equation}

Here, σ_{meas} represents the measured standard deviation.
Since APTS provides analogue readout, charge sharing effects and pixel clusters can be assessed.
Thus, spatial resolution was assessed using two methods: one treating the data digitally, distinguishing between hit and no-hit events, thus comparable with the binary readout planned for ITS3, the other exploiting the full potential of the sensor, by using all the analog information coming from the pixels, included the collected charge. Then, the resolutions calculated with the two methods have been calculated and compared.
This contribution describes in detail the techniques, implemented only very recently, used for the study of the sensor resolution. The latest results with different sensor designs, pixel pitches, and irradiation levels will be discussed.

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