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P2.49: First measurements and results of monolithic active pixel test structures produced in a 65 nm CMOS process

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The ALICE Inner Tracking System (ITS) [1] at CERN will undergo an upgrade during the LHC long shutdown 3, in which the three innermost tracking layers will be replaced. This upgrade, named the Inner Tracking System 3 (ITS3) [2], employs stitched wafer-scale Monolithic Active Pixel Sensors 280 mm in length fabricated in a 65 nm CMOS technology thinned to < 50 µm and bent to form truly cylindrical half-barrels. The feasibility of this technology for the ITS3 was explored with the first test production run (MLR1) in 2021, whose goal was to evaluate the charged particle detection efficiency and performance under non-ionising and ionising radiation up to the expected levels for ALICE ITS3 of 1×10^{13} 1 MeV n_{eq} cm^{-2} (NIEL) and 10 kGy (TID). Three sensor flavours were produced to investigate this technology: Analog Pixel Test Structure (APTS), Circuit Exploratoire 65 (CE65) and Digital Pixel Test Structure (DPTS) each measuring 1.5 mm × 1.5 mm in size.

The APTS incorporates a 6×6 pixel matrix with direct analogue readout on the central 4×4 pixels. Two versions of the output buffer were implemented: a source-follower (APTS-SF) and a fast operational amplifier (APTS-OA). In addition, the sensor was produced in four different pixel pitches ranging from 10 µm to 25 µm. The CE65 is a "large"area chip with an analogue rolling shutter readout. The pixel matrix either consists of 64×32 or 48×32 pixels implemented in two pixel pitch sizes: 15 µm and 25 µm. The DPTS features a 32×32 pixel matrix with a pitch of 15 µm and a digital front-end with asynchronous readout. All the pixels are read out simultaneously via a differential digital output that time encodes the pixel position and Time-over-Threshold (ToT).

The performance of the MLR1 chips was evaluated through extensive characterisation in the laboratory and with in-beam measurement. The measurements show that the MLR1 was a success due to the large number of operational prototypes that allow the parameter space of the technology to be mapped out. Furthermore, the MLR1 exhibits excellent performance in terms of detection efficiency (> 99%) and spatial resolution (3-4 µm) from the in-beam measurements for all three sensor flavours. The radiation hardness is demonstrated by the sensors maintaining a detection efficiency of 99% for APTS-SF and DPTS chips irradiated with a dose of 1×10^{15} 1 MeV n_{eq} cm^{-2} and operated at +15 °C and +20 °C, respectively. The detection efficiency and the fake-hit rate for DPTS sensors irradiated to different levels are shown in Fig. 1. In addition, a time resolution of < 100 ps for the APTS-OA and < 10 ns for the DPTS has also been measured.

This contribution will cover an overview of the MLR1 submission, a description of the different sensor flavours and present the results of the performance measurements in the laboratory and with particle beams at various settings and irradiation levels for all three sensor flavours.

[1] ALICE Collaboration, doi:10.48550/arxiv.2302.01238
[2] ALICE Collaboration, doi:10.17181/CERN-LHCC-2019-018
[3] G. Aglieri Rinella et al., doi: 10.48550/arXiv.2212.08621

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