Impact of X-Ray Irradiation on CMOS Sensor Performance

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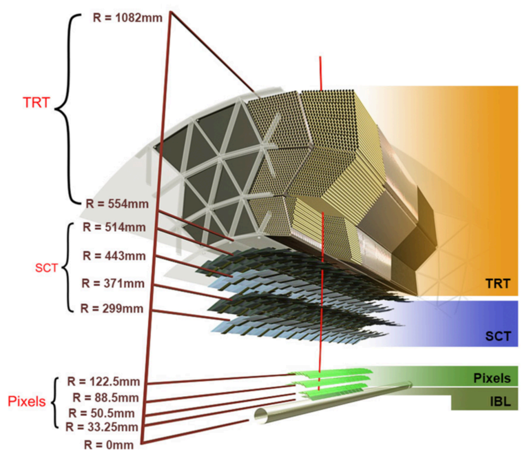
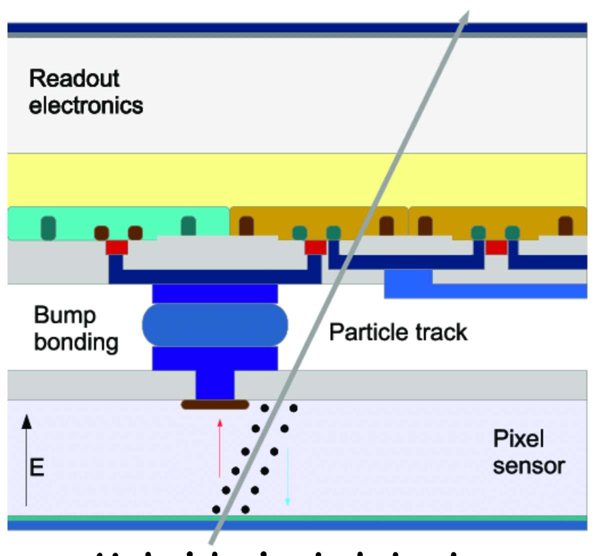
Aim

To investigate the performance of a CMOS monolithic sensor by comparing DAC responses and evaluating the effect of X-ray irradiation at a specified dose.

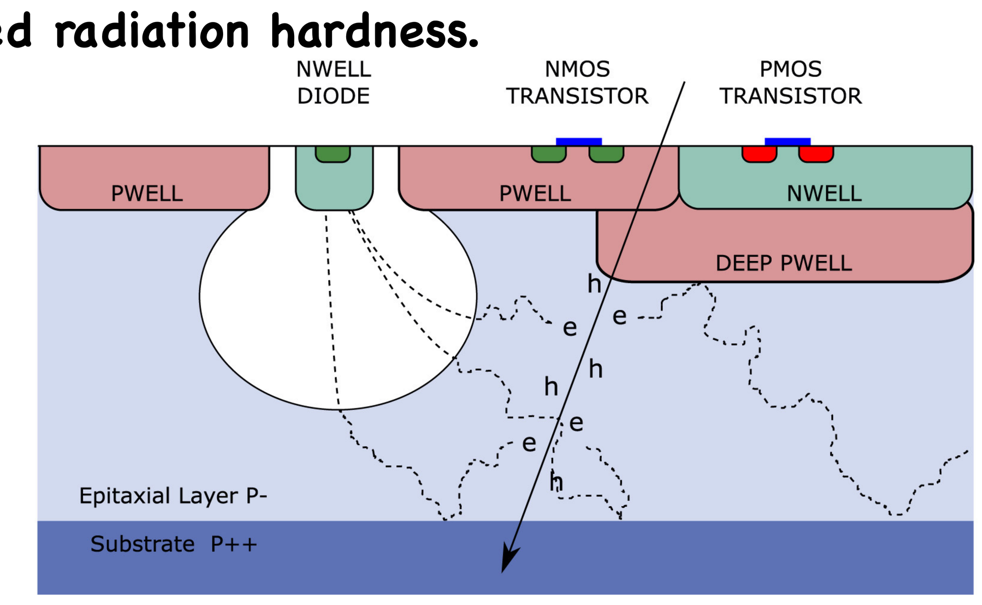
Motivation

Precise tracking and vertexing are crucial for any LHC experiment. The Tracker sub-detector utilises hybrid pixel detectors and silicon strip sensors, with silicon pixel detectors known for their exceptional spatial resolution, fast response, and radiation hardness. An emerging alternative is Depleted Monolithic Active Pixel Sensors (DMAPS), built with CMOS technology. DMAPS simplify design by integrating sensing and readout on a single substrate, reducing material budget while offering faster signal processing and enhanced radiation hardness.





Hybrid pixel detector

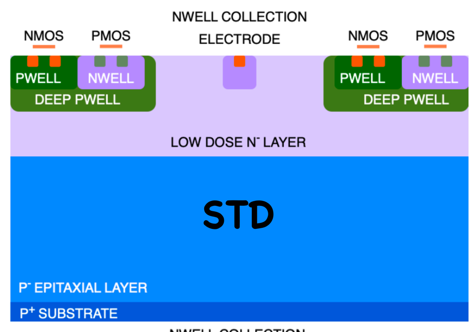


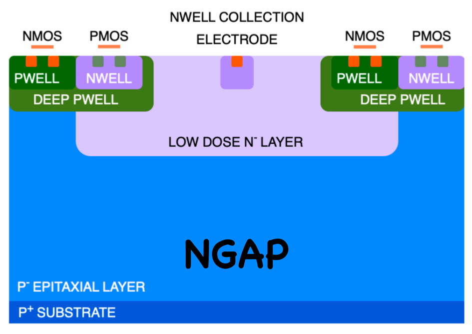
DMAPS: standard process

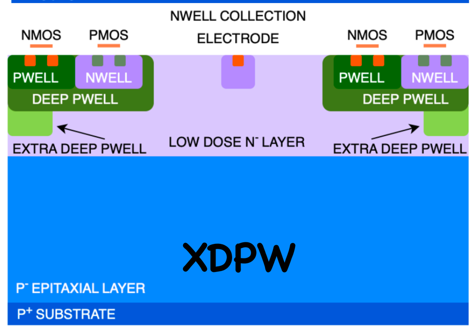
MALTA

MALTA is a DMAPS built using Tower 180 nm imaging technology, featuring a 512x512 pixel matrix with a compact pixel size of 36.2 x 36.2 μm^2. It delivers low noise, low power consumption, and fast signal response (25 ns bunch crossing), utilising an advanced high-speed asynchronous readout. The sensor comes in three variants: Standard Modified Process (STD), NGAP with an n^- layer gap, and XDPW with an added deep p-well implant.

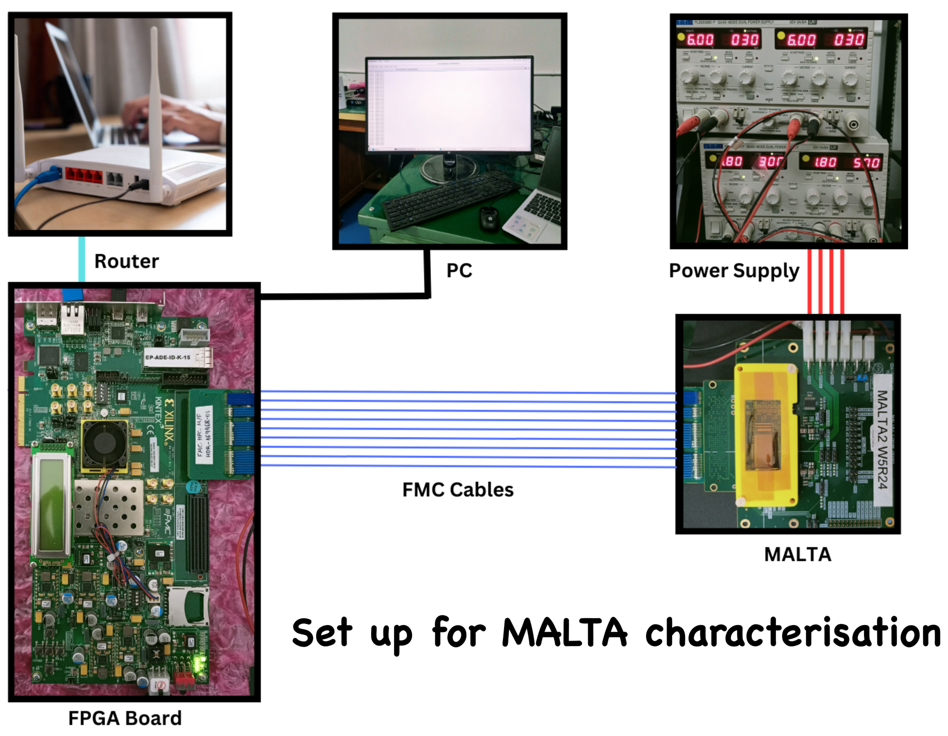
MALTA2, the next-generation MALTA detector, improves radiation hardness, ensures uniform in pixel charge collection, and reduces RTS noise. It consist of 224x512 pixel matrix and retains its asynchronous readout of its predecessor but introduces improvements in slow control and Front end design.







Experimental Setup at IITM



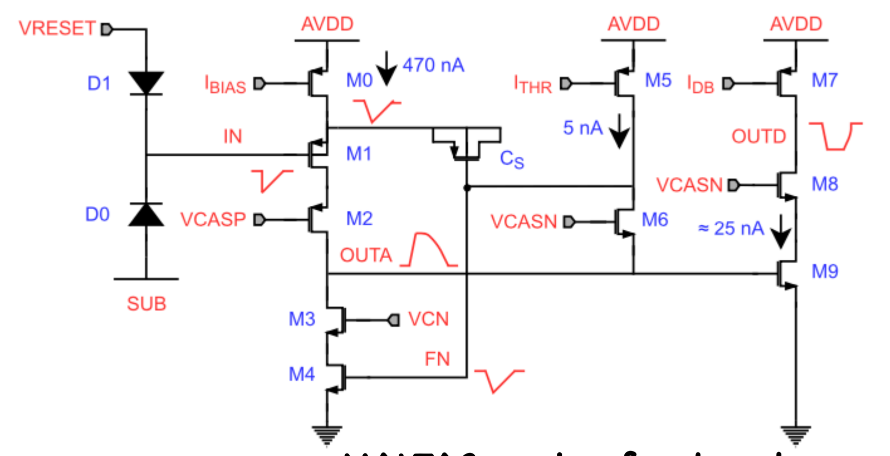
Set up for MALTA characterisation

X-ray irradiator: Use tungsten target, capable of generating x-rays upto 160 kVp.

Characterisation of MALTA2 sensor

Understanding the impact of ionising radiation is essential for ensuring the reliable operation of the sensor in high-radiation environments. In this study, X-ray irradiation was employed to evaluate the Total Ionising Dose (TID) effects on the MALTA2 sensor. Two MALTA2 chips, the NGAP and XDPW flavours, fabricated on epitaxial substrates with thicknesses of 300 μm and 100 μm, respectively, were investigated. The DAC parameters (ITHR, IDB, ICASN) were systematically varied to study their influence on pixel threshold behaviour. Furthermore, the sensor with 300 μm thickness was irradiated with a total X-ray dose of 10^4 Gy, and its pre and post-irradiation performance was compared to evaluate degradation.

- ITHR: set the pulse duration of the amplifier output.
- IDB: set the threshold of the discriminator.
- ICASN: set the baseline of the amplifier.



MALTA2 analog front end

Results

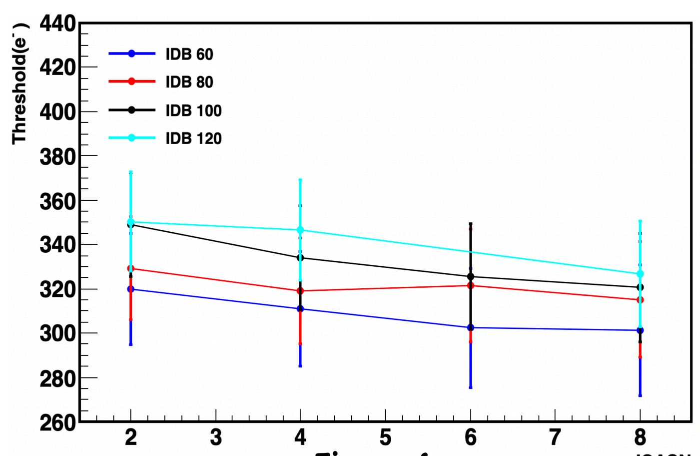


Figure 1

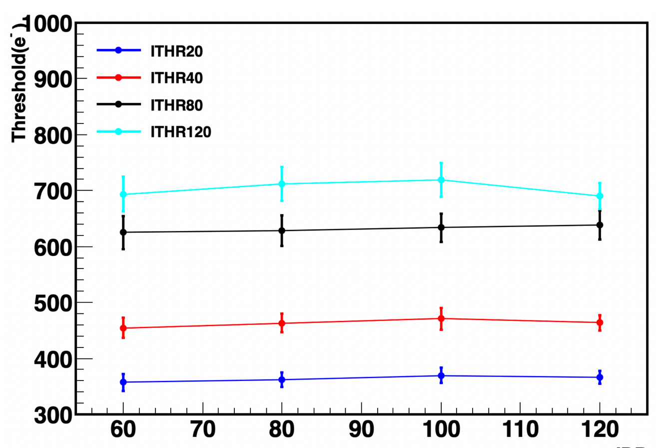


Figure 2

Figure 1 illustrates the threshold distribution as a function of ICASN for various IDB values on the non-irradiated 100 μm chip at a fixed ITHR60. The data shows a slight decrease in threshold with increasing ICASN, while threshold increases with higher IDB values. Figure 2 presents the threshold distribution as a function of IDB chip of 300 μm thickness. The results indicate an overall increase in threshold with rising ITHR. The chips are operated at substrate voltage -6V.

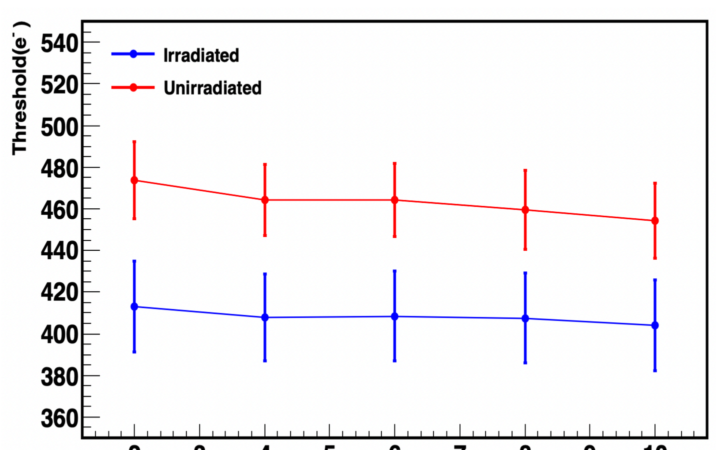


Figure 3

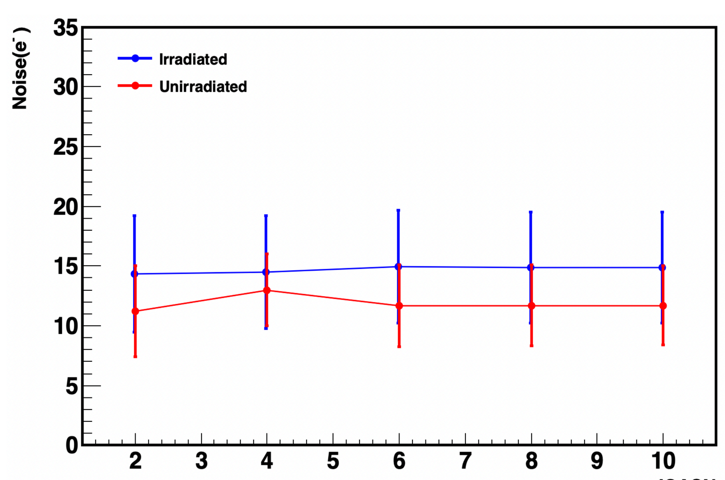


Figure 4

Figure 3 presents a comparison of the threshold for a 300 μm NGAP flavour before and after irradiating the chip to a dose of 10^4 Gy with X-ray. The figure demonstrates a reduction in threshold following irradiation. Figure 4 compares the noise levels of the chip before and after irradiation, showing that the noise remains consistent for both the irradiated and non-irradiated chips and remains constant across different ICASN settings.

Summary and Outlook

- Threshold studies on MALTA2 chips were conducted across various DAC settings and the obtained results are consistent with the design expectations.
- Threshold and noise levels were compared before and after irradiation, confirming that irradiation reduces the threshold, as predicted. The noise level remains consistent before and after irradiation.
- Future work will involve evaluating chip performance under higher X-ray irradiation levels.
- Comprehensive chip characterisation using a MALTA telescope with cosmic muons is also planned.

References

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