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# Developments and Characterisation Results of DMAPS in TowerJazz in 180 nm for High Luminosity LHC

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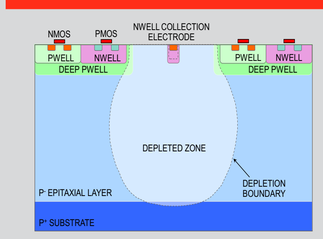
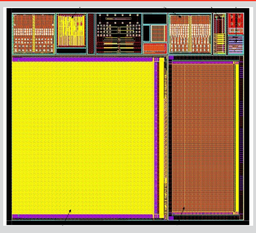
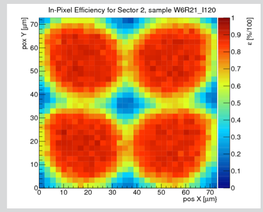
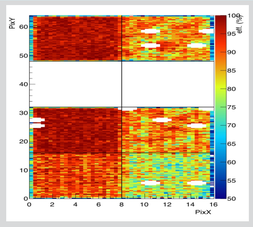
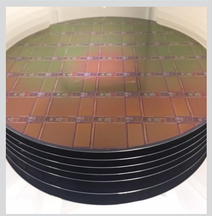
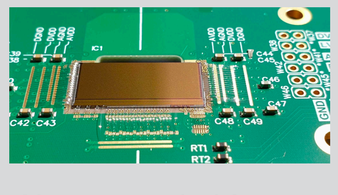
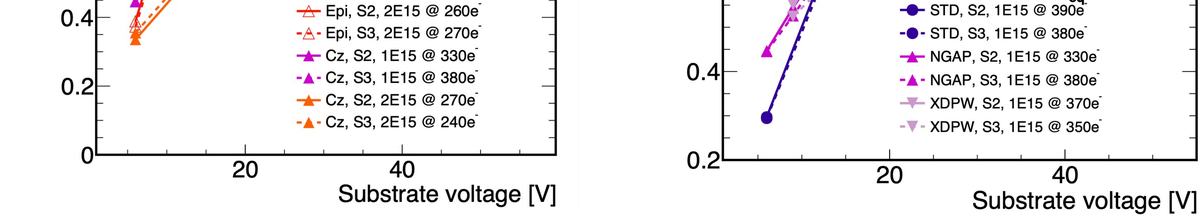
## Introduction

The MALTA family of Depleted Monolithic Active Pixel Sensors (DMAPS) have been produced in TowerJazz 180 nm CMOS technology with small collection electrode and a novel asynchronous read-out that reduces the front-end power needs that allows to capture 100 MHit/s. Prototypes have been produced with several process modifications to improve the charge collection on high-resistivity epitaxial silicon and Czochralski (Cz.) substrates. Our developments focus on providing large pixel matrices with excellent time resolution (<2 ns) and detection efficiency after irradiation.

## DMAPS Timeline

| 2014 | 07/2017 | 01/2018 | 09/2018 | 09/2019 | 01/2021 | 2023 |
|---|---|---|---|---|---|---|
| Standard Modified process | MALTA and Monopix designs | Sensor characterization | Further improvements miniMALTA | MALTA-C | MALTA2 | MALTA3 |
|  |  |  |  |  |  |  |
| First promising measurements | First engineering run with large designs | Efficiency/charge loss at the corner of pixels | Pixel modifications and RTS improvements | Epi and CZ starting material | New cascoded front-end and slow control | Time resolution, full reticle size |

## MALTA Pixel Flavours




From left to right: standard (std) modified process, extra deep p-well (xdpw) process modification and mask with gap in the n-well (n-gap).

## MALTA-Cz Performance

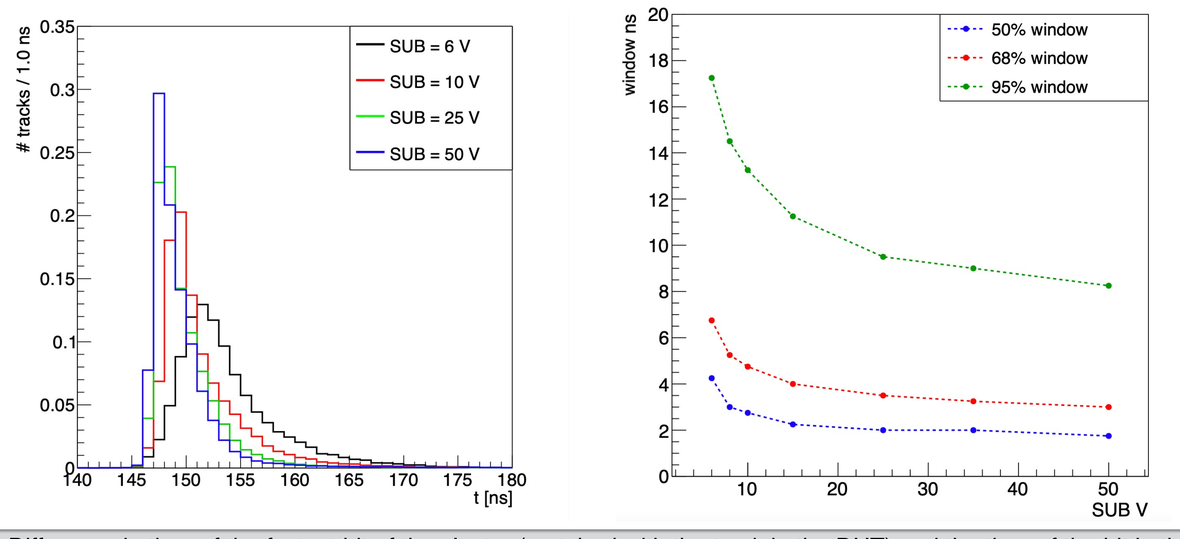
- The efficiency of MALTA-Cz samples increases substantially with substrate voltage as the depleted region in the substrate increases. Epitaxial sensors achieve a maximum efficiency at -12 V.
- Corner efficiency is improved on sensors with either a gap in the n-blanket or an extra deep p-well along the pixel edge.




Left: Sensor efficiency for $1x10^{15}$ $n_{eq}/cm^2$ and $2x10^{15}$ $n_{eq}/cm^2$ irradiated epitaxial and Cz sensor with n-gap as function of threshold. Right: Sensor efficiency for $1x10^{15}$ $n_{eq}/cm^2$ irradiated Cz sensor for the three MALTA pixel flavours.

## MALTA-Cz Timing Properties

- Difference in time of the fastest hit of the cluster and the time of the hit in the scintillator is measured with PicoTDC with $^{90}Sr$ source.
- At large substrate voltages, the signal is faster and has a higher amplitude, which reduces time-walk and results in a narrow time-difference distribution.
- MALTA sensors on Cz-substrate are capable of full in-time efficiency up to bunch crossing rates of 100 MHz.



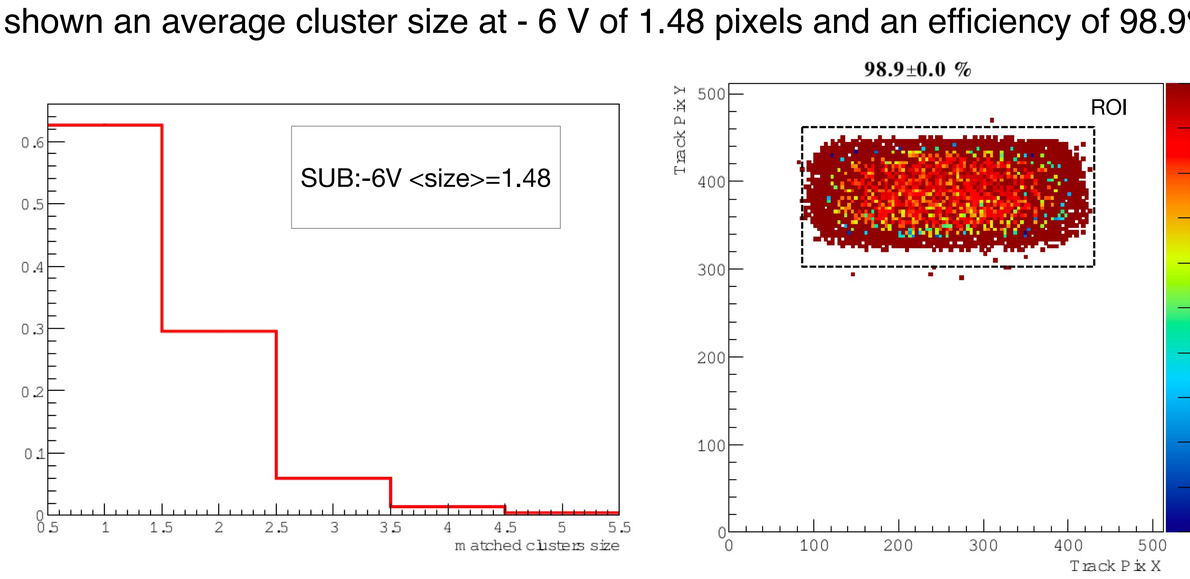

Left: Difference in time of the fastest hit of the cluster (matched with the track in the DUT) and the time of the hit in the scintillator for a MALTA non-irradiated Cz std. sample versus substrate bias. Right plots represents the 50%-, 68%- and 95%-integral of the time-difference distributions. Measurements were done with low energy electrons from Sr-90 **β**-decay. The time difference between the fastest MALTA signal and the trigger scintillator is measured using the PicoTDC.

## MALTA2

- 20 x 10 $mm^2$ size demonstrator with three different pixel flavours of the same demonstrator.
- 224 x 512 pixels with pixel size 36.4 x 36.4 $\mu m^2$
- New transistor series, increased size for selected transistors for optimization of RTS noise and threshold reach.

## MALTA2 Threshold

- Lab tests have shown full functionality of the chip: source scans, threshold, DAC linearity, and noise scan.
- MALTA2 proves to be fully functional at low threshold and low noise.




Left plot shows noise scan at ITHR=15 and IDB=50 with a mean at 9.51 electrons. Right plots shows threshold scan at the same configuration with a mean value of 136.6 electrons for the Gaussian fit.

## MALTA2 Efficiency and Cluster Size

Measurements on MALTA2 Cz. Sample in laboratory with $^{90}Sr$ source have shown an average cluster size at - 6 V of 1.48 pixels and an efficiency of 98.9%.




Left: Cluster size distribution for an unirradiated Cz n-gap MALTA2 sample at IDB=50 and ITHR= 50. Right plot shows 2D efficiency map for the same sample. Threshold was measured for 44000 pixels where the mean of the Gaussian fit lies at 246.3 electrons and the RMS at 22.44 electrons. Measurements were done with low energy electrons from Sr-90 **β**-decay.

## Outlook

Test beam efforts at SPS CERN ongoing dedicated to demonstrate MALTA2 performance in terms of radiation hardness (>1E10[15] MeV neq/cm²) and timing performance.

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**References**

Dyndal, M., et al. "Mini-MALTA: Radiation hard pixel designs for small-electrode monolithic CMOS sensors for the High Luminosity LHC." *Journal of Instrumentation* 15.02 (2020): P02005.