Radiation hardness and timing performance in MALTA monolithic Pixel sensors in Tower 180 nm

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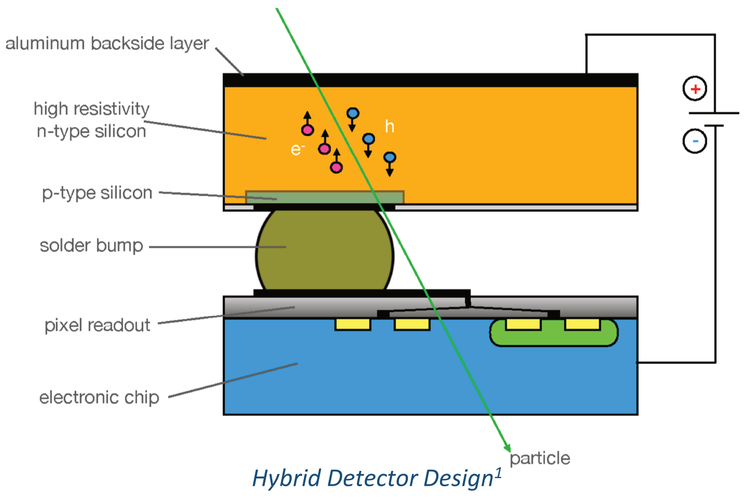
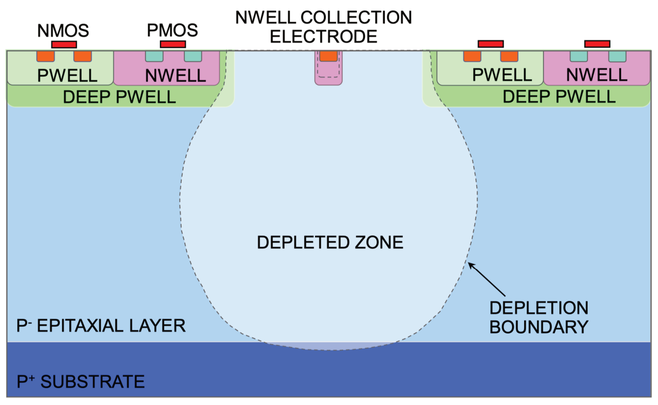
On behalf of the MALTA collaboration

Motivation for Monolithic Pixel Sensors



Hybrid Detector Design[1]

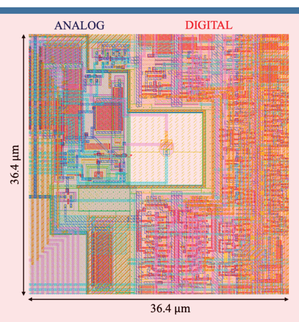


Monolithic Pixel Detector Design (ALPIDE[2])

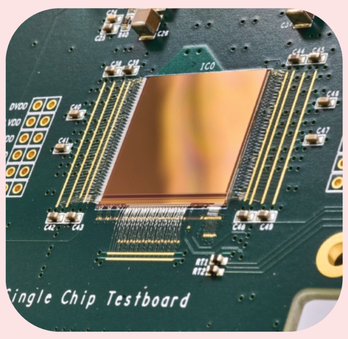
- **+ Large detector area**
- **+ Reduced costs (no bump bonding)**
- **+ Material reduction**
- **+ High S/N ratio**
- **- Still under (radiation hardness) development**

MALTA Sensor Development

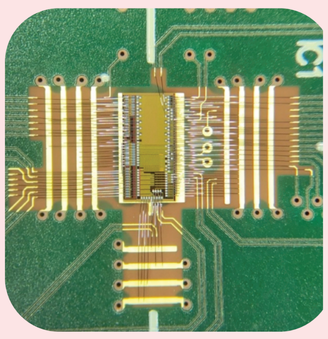
The first MALTA sensor was built as a full-scale demonstrator developed using 180 nm TowerJazz CMOS imaging technology. It comprised of 512 x 512 pixels and is 21 x 20 mm^2 in size. Originally targeting application within the ATLAS Inner tracker for the HL-LHC, this sensor has since undergone numerous iterations and branched out into different formfactors.



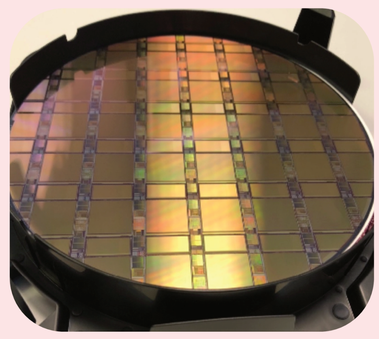
The MALTA pixel analog/digital circuit



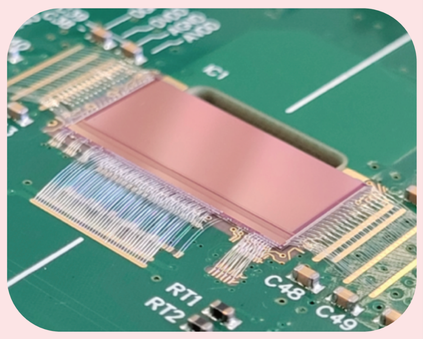
MALTA1
Jan 2018
Full sized demonstrator
Asynchronous readout
Variations in electrode size and reset mechanisms
Suboptimal depletion after irradiation



Mini-MALTA
Jan 2019
Small demonstrator
Process and mask modifications
Full efficiency after 10^{15} n_{eq}/cm^2

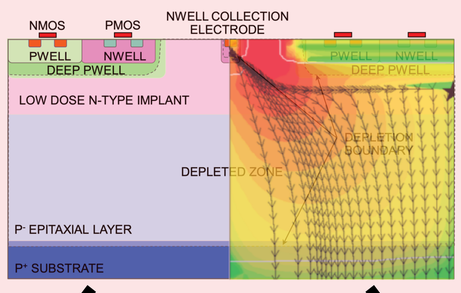


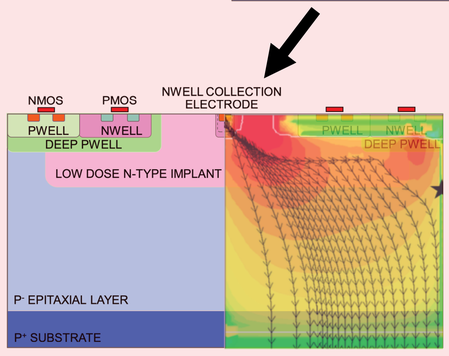
MALTA C
Aug 2019
Improved slow control on EPI & Cz substrates
Enlarged cluster size and improved time resolution on Cz



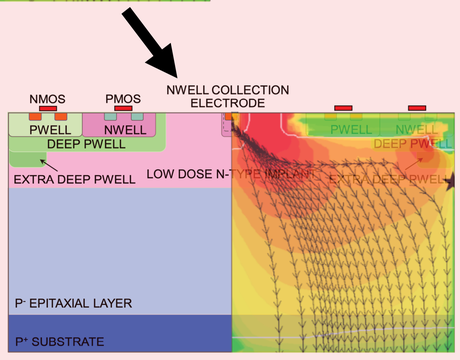
MALTA2
Jan 2021
New FE with additional process modifications
Improved time resolution & slow control

STD
Standard pixel design with continuous low dose n-type implant



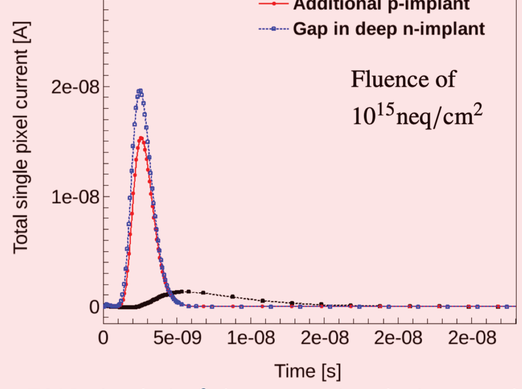


N-Gap
Gap in the low dose N-type implant



XDPW
Extra Deep P-Well

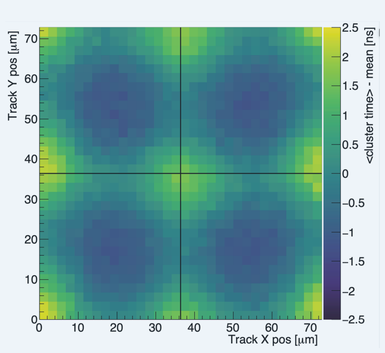
- The electric field strength in pixel corners can be significantly increased by **process modifications**.
- Czochralski samples allow for **large depletion volumes** with increasing substrate voltage, yielding **large cluster size** as well as **enhanced radiation tolerance**.



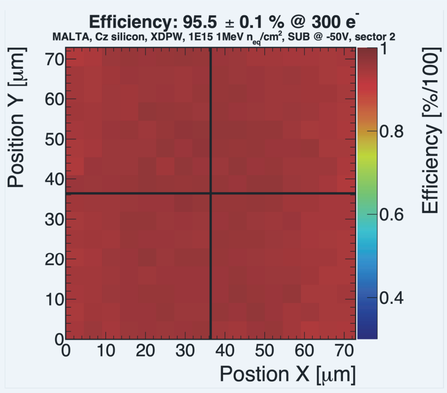
TCAD simulation[3] demonstrating the increased charge collection time efficiency through the use of N-Gap and XDPW design modifications

Radiation & Timing Performance

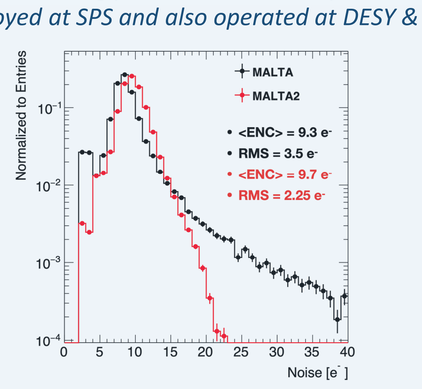
A multitude of characterisation measurements have been conducted on the MALTA sensor designs. These include studies probing FE-specific improvements as well as ones assessing the sensor's overall charge-collection efficiency.



In-pixel timing projected over a 2x2 pixel matrix for a MALTA2 Cz, XDPW, 100 µm thick at -6 V SUB & PWELL bias. Threshold = 170e⁻

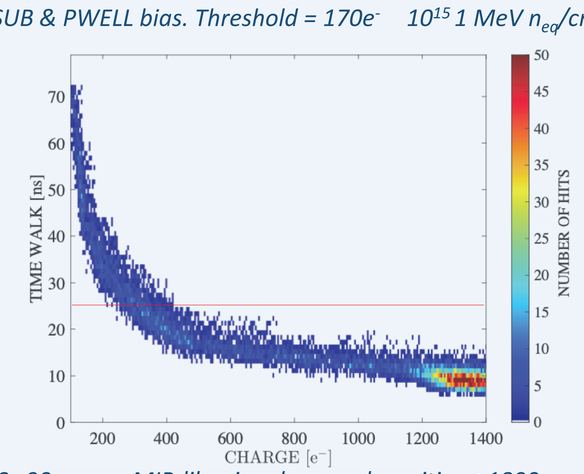


Best efficiency reached with a Cz MALTA sample with XDPW modification irradiated to 10^{15} 1 MeV n_{eq}/cm^2, with -6V biasing at -20°C

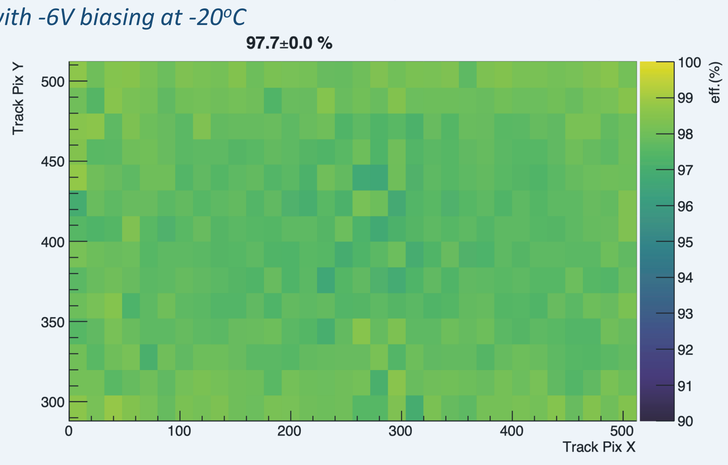


Noise comparison of MALTA & MALTA2 at comparable thresholds (~340e-)

The 6-tracking plane MALTA telescope seen here deployed at SPS and also operated at DESY & ELSA



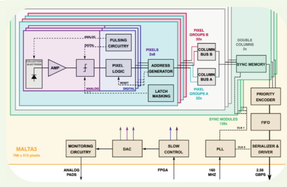
Sr-90 source MIP-like signals, avg. deposition ~1800e⁻ 90% of all hits arrive within the 25 ns window (red line)[4]



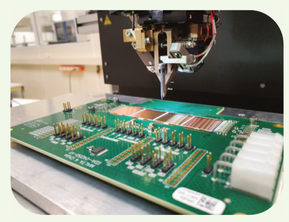
2D Efficiency map of full matrix of non-irradiated MALTA2 (Cz, NGAP at -6 V SUB bias and -6 V PWELL bias. Threshold = 320e⁻

Next Steps & Parallel Developments

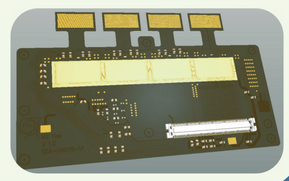
- **MALTA3 full size sensor[5]** under design
  - improved in-pixel digital electronics
  - <1 ns time-stamping in periphery
  - >1 Gb/s serial output communication



- **Chip-to-chip communication** assessments being conducted via dedicated 4-chip board using wire-bond connections with alternative interconnection techniques being investigated.



- **Module formfactor design[6]** underway with very low material budget (50 um thick) flex PCB.



Bibliography

[1]A. Rizzo et al., Sensors (2022), 22, 516.
[2]W. Snoeys et al., NIMA, 871, (2017), 90-96.
[3]M. Munker, JINST 14 (2019) C05013
[4]F. Piro et al., IEEE (2022), vol. 69, no. 6, pp. 1299-1309
[5]D. Dobrijević et al., NIMA (2022), 1040
[6]Talk by J. Weick, *"Development of novel low-mass module concepts based on MALTA monolithic pixel sensors"*

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