UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

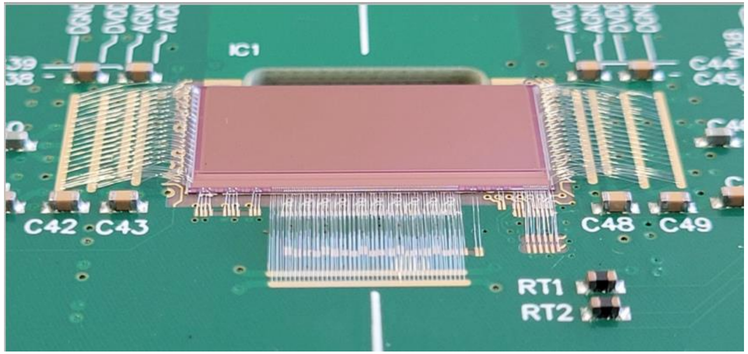
CERN

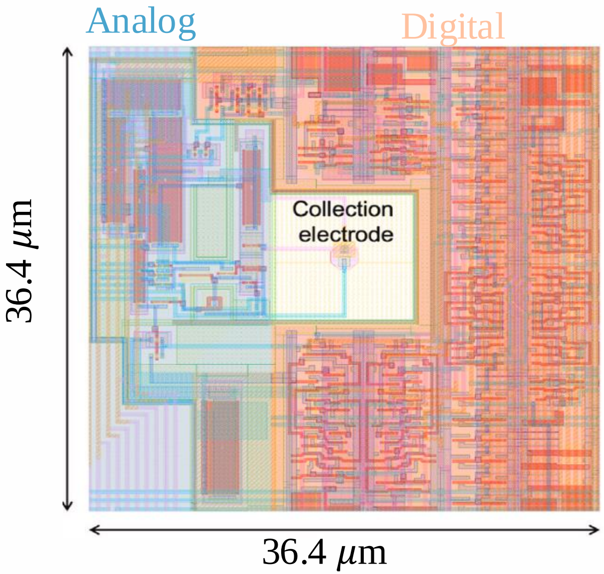
Study of MALTA2, a Depleted Monolithic Active Pixel Sensor, with grazing angle at CERN SPS 180 GeV hadron beam

P. Allport (Birmingham), I. Asensi Tortajada (CERN), P. Behera (IITM), I. Berdalovic (Zagreb), D.V. Berlea (DESY), D. Bortoletto (Oxford), C. Buttar (Glasgow), V. Dao (CERN), G. Dash (IITM), L. Fasselt (DESY), L. Flores Sanz de Acedo (CERN), M. Gazi (Oxford), L. Gonella (Birmingham), V. Gonzalez (Valencia), G. Gustavino (CERN), S. Haberl (Innsbruck, CERN), T. Inada (CERN), P. Jana (IITM), K. Kotsokechagia (CERN), **L. Li (Birmingham)**, H. Pernegger (CERN), P. Riedler (CERN), W. Snoeys (CERN), C.A Solans Sanchez (CERN), M. van Rijnbach (CERN), M. Vazquez Nunez (CERN, Valencia), A. Vijay (IITM), J. Weick (CERN), S. Worm (DESY)

PIXEL 2024, Strasbourg
19-11-2024

Introduction to MALTA2 sensor





Nuclear Instruments and Methods in Physics Research A 1057 (2023) 168787

Motivation

- Initially proposed for outmost layers of pixel tracker for experiments on HL-LHC and beyond.
- Potential for future collider experiment.
- Targeting Non-Ionsing Energy Loss of 5×10^{15} 1MeV n_{eq} /cm^2.

Depleted Monolithic Active Pixel Sensor(DMAPS)

- High granularity
- Low material budget
- Low cost

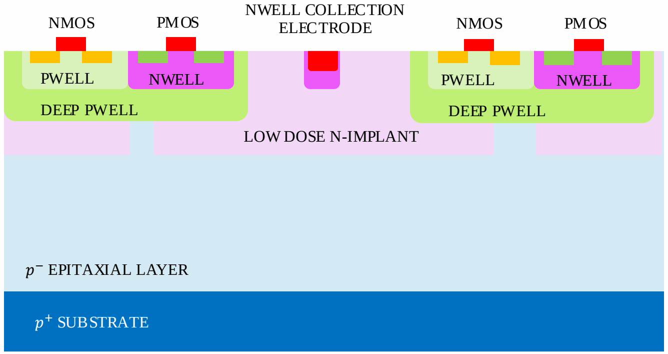
Layout

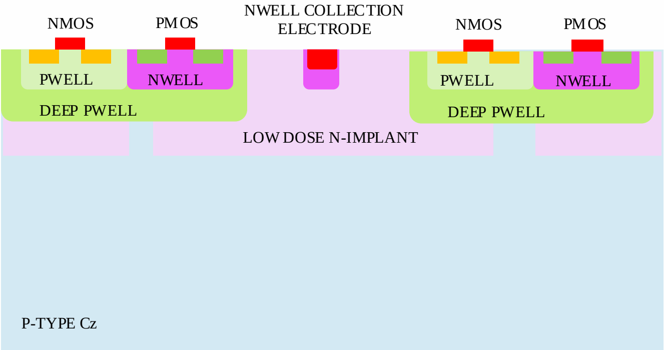
- 180 nm Tower CMOS Imaging Sensor process
- Sensor dimension: 1×2 cm^2
- Pixel Matrix: 224×512 pixels
- Pixel pitch: 36.4×36.4 μm^2

Readout

- Asynchronous readout with binary output
- Fast timing response (< 2ns)
- High data rate (> 100MHz/cm^2)

MALTA2: Pixel design based on Tower 180 nm technology



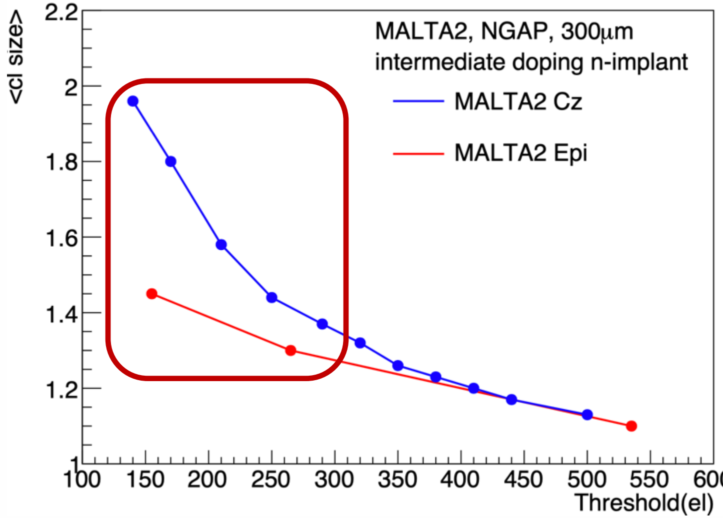


Small collection electrode design

- 3×3 μm^2
- Small capacitance(< 5fF)
- Low nosie($< 5e^-$)
- Low pixel analog power(1μW/pixel)
- Process modification with low does n-implant(STD, NGAP, XDPW)

Multiple wafer variants

- Epitaxial(Epi): 30 μm
- Czochralski: 50, 100, 300 μm



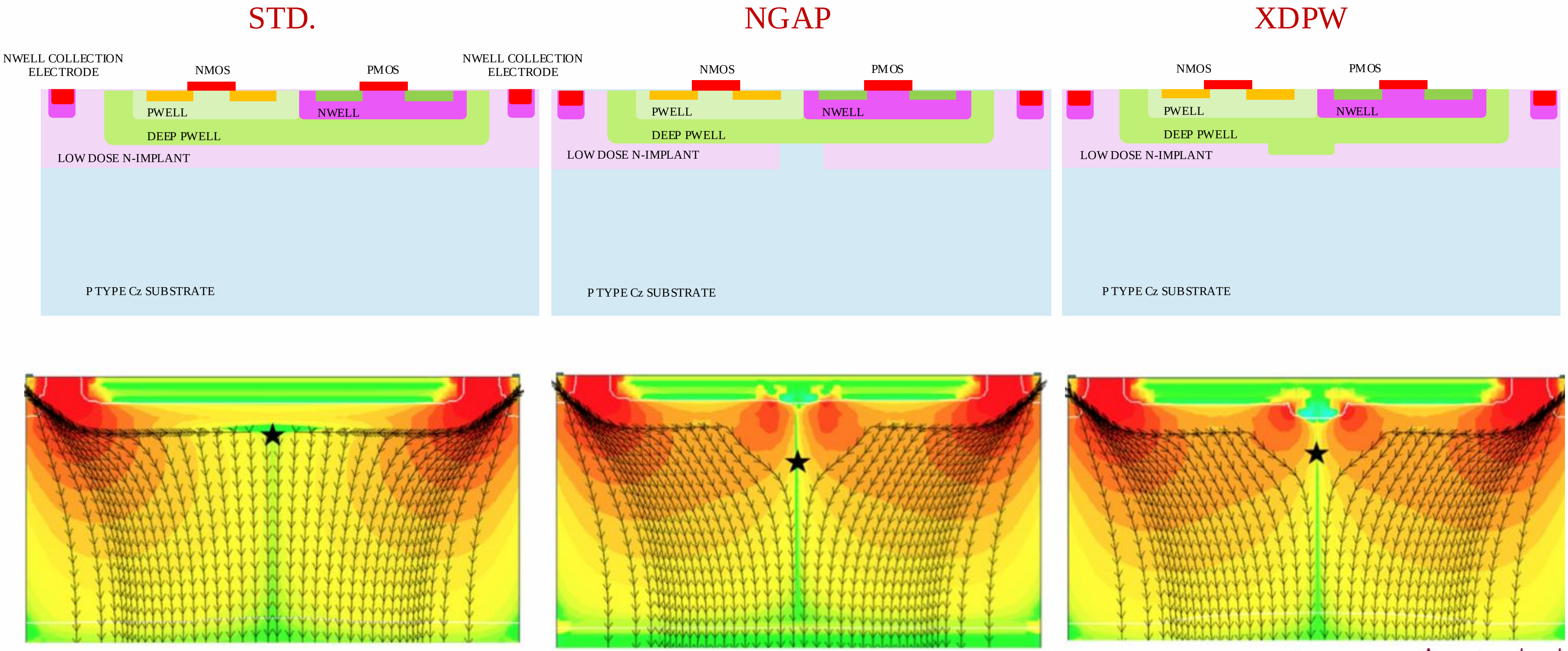
Cluster Cz > Cluster Epi

More charge diffusion in Cz substrate

Radiation hardness compared in MALTA, see backup slides

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 69, NO. 6, JUNE 2022

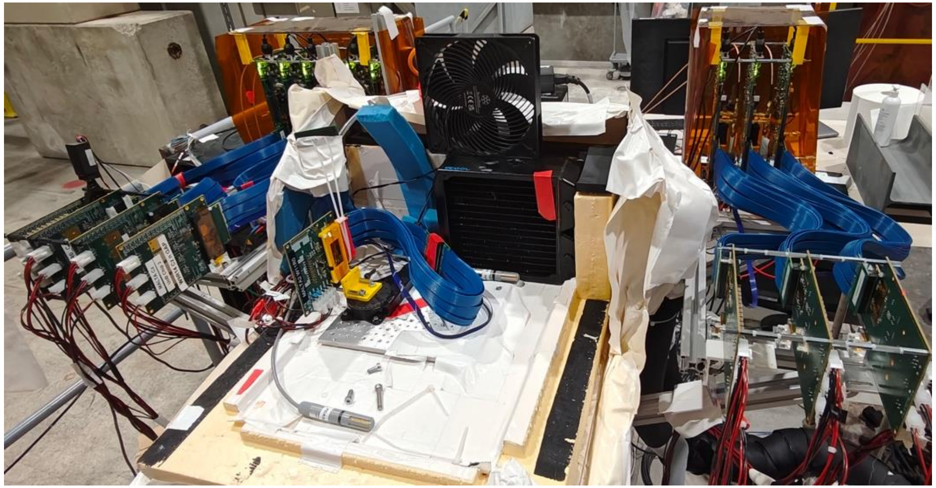
MALTA2: Process modification for better charge collection at pixel corner



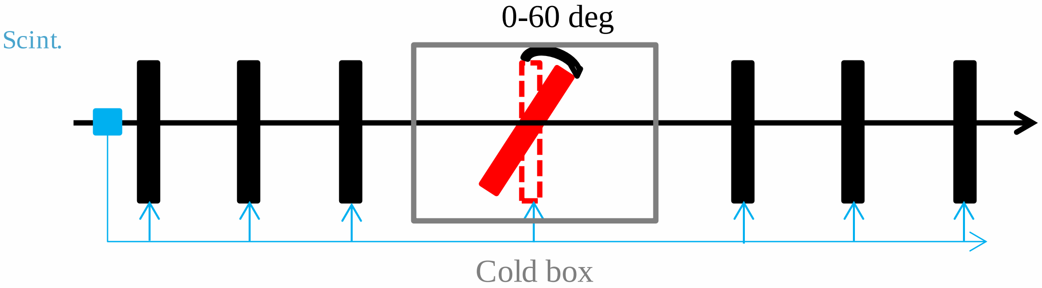
See backup slides for performance comparison

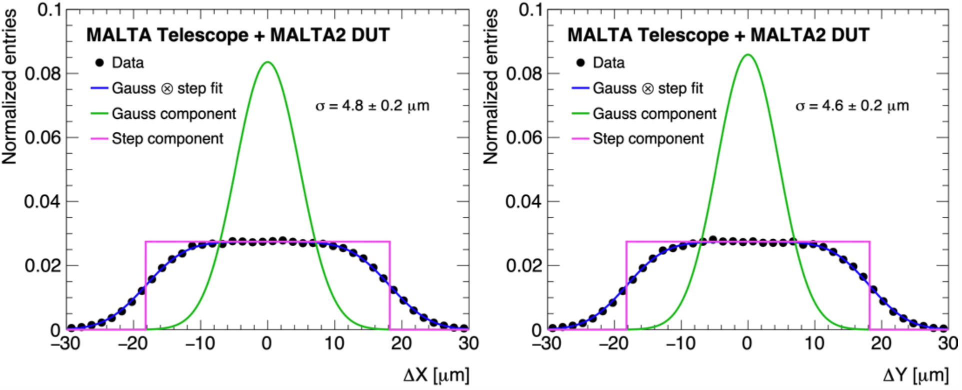
M. Munker et al, 2019 JINST 14 C05013

MALTA telescope



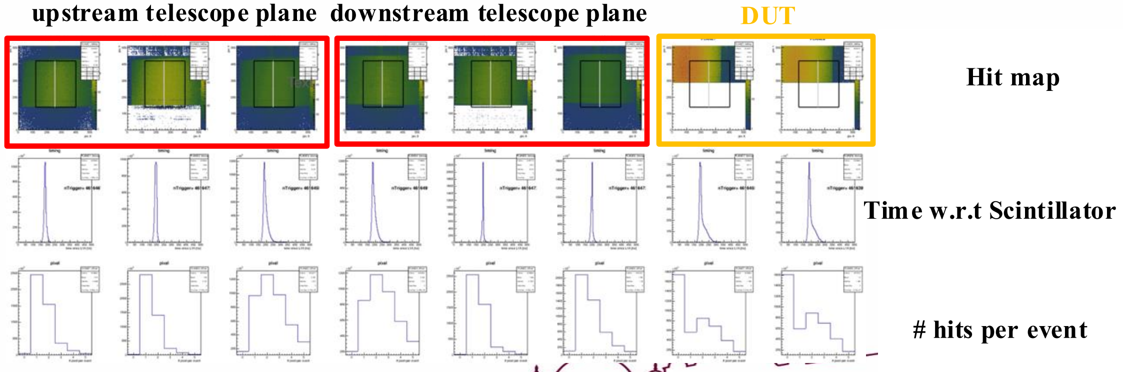
MALTA Telescope @ CERN SPS
- 180 GeV Hadron beam
- 6 tracking planes, < 5 µm spatial resolution @ DUT
- Scintillator for timing
- Flexible triggering, online monitoring
- Cold box for up to 2 DUT + rotation stage



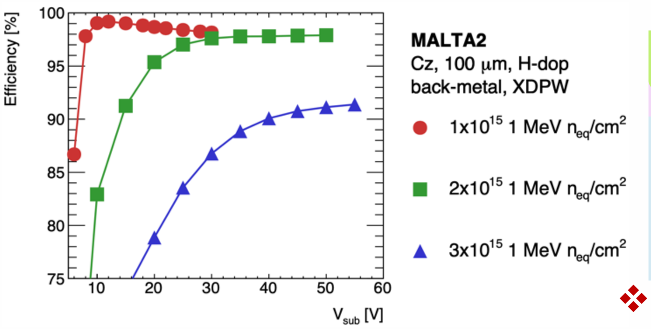


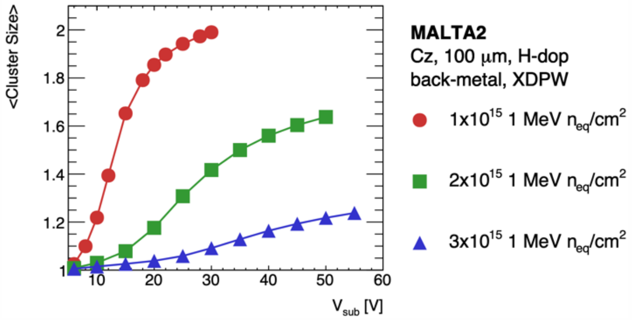
M.van Rijnbach et al., EPJC 11670

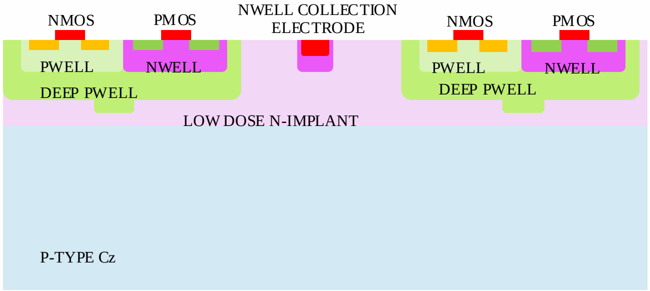
Advanced beam monitoring Infrastructure

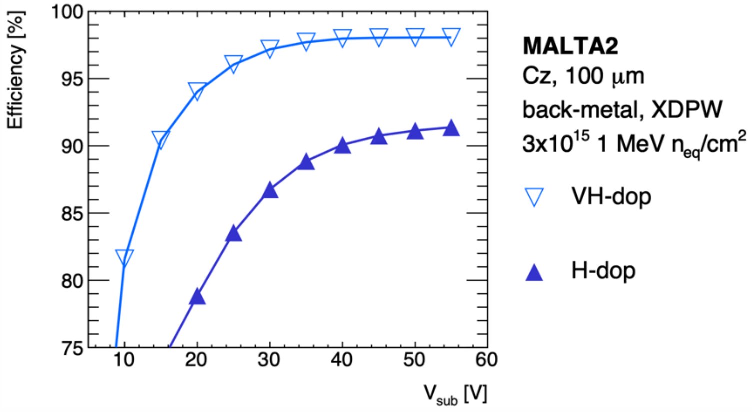


Radiation study of MALTA2





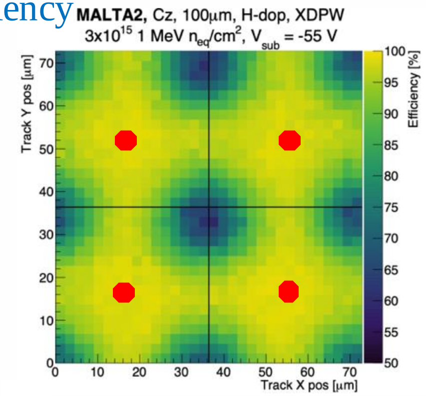


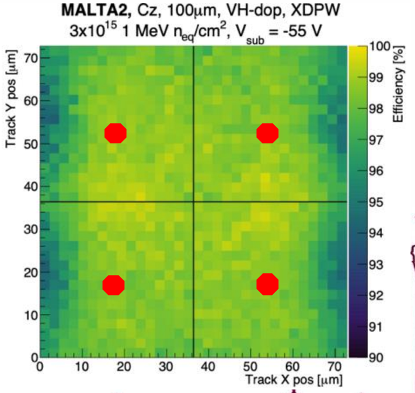


- Increase the doping of the n-implant improves the charge collection at pixel corners
  - Increase lateral depletion
  - Improve detection efficiency

H-dop

VH-dop





- **Radiation study of MALTA2 up to 3×10^{15} 1MeV n_{eq}/cm^2**
  - Efficiency > 90% recovered by increasing biasing voltage
  - Increasing the doping of the n type implant gains further improvements of detection efficiency.

G. Gustavino et al., (VERTEX2023)048 *M. van Rijnbach et al.*, *Eur. Phys. J. C* **84**, 251 (2024)

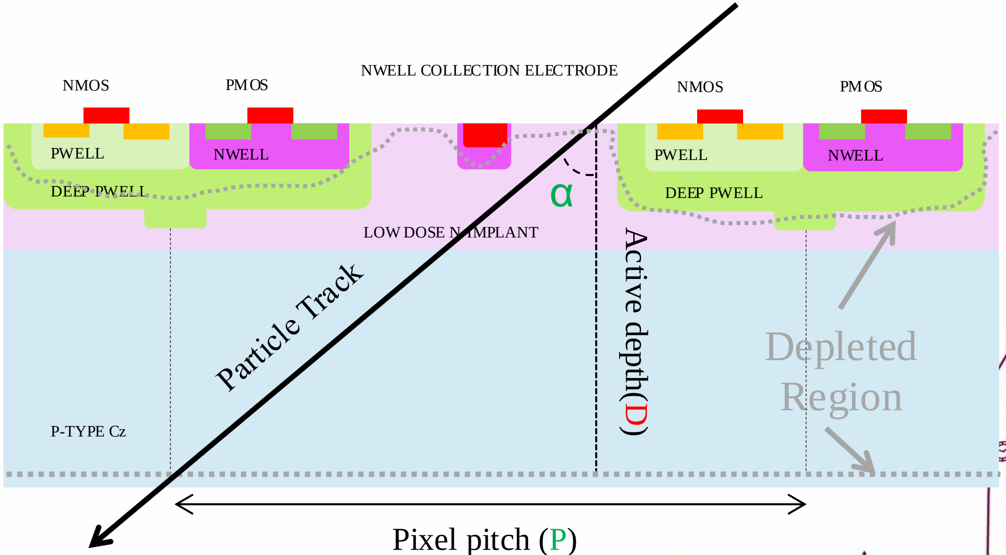
Electrode

Grazing angle study with MALTA2 Cz sensors

Parameters of MALTA2 samples for grazing angle study		
Substrate Type	Cz	
Sensor flavour	XDPW	
Doping of n-implant	High	
Irradiation(1MeV n_{eq}/cm^2)	1×10^{15}	0
Configurations for grazing angle measurements		
V_{sub}(V)	[-6, -9, -15, -20, -25, -30]	-6
Angle (deg)	0-60 with 5 as a step	

- **Motivation**
  - To understand the radiation effects on Cz MALTA2 sensors .
    - Detection efficiency
    - Cluster size
    - Active depth

$$\text{ClSize}_{\perp}(\alpha) = \frac{D}{P}\tan(\alpha) + \text{ClSize}_{\perp}(0)$$



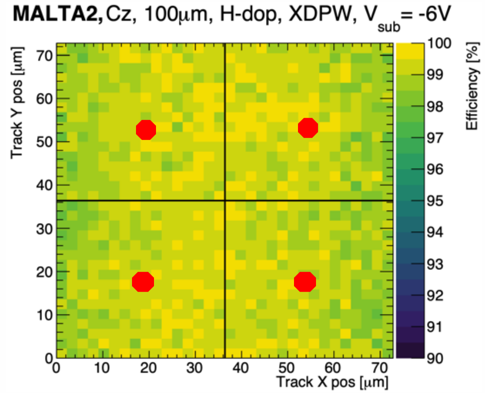
Grazing angle measurements on MALTA2 Epi sensors carried out in 2023, See backup slides for results

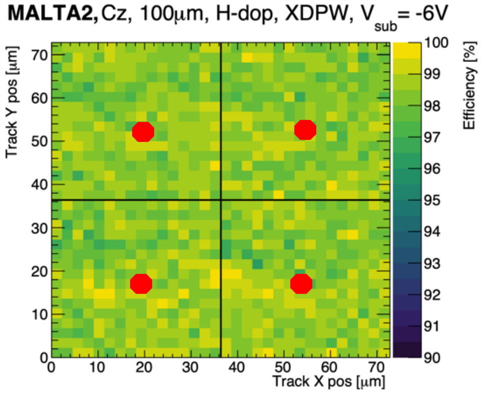
Efficiency Comparison w.r.t inclined angle

In-pixel Eff.

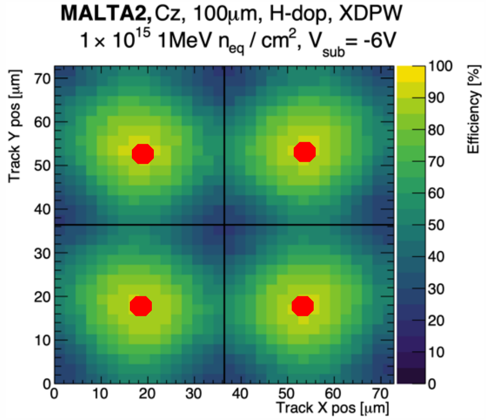
0 deg

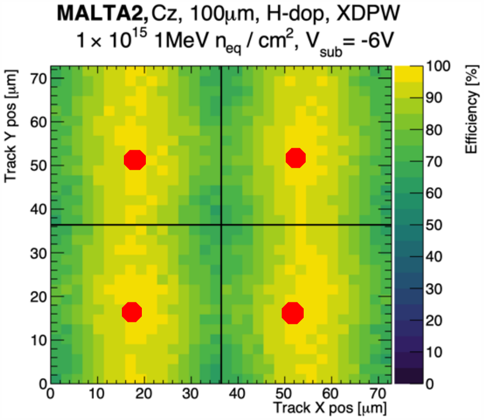
60 deg



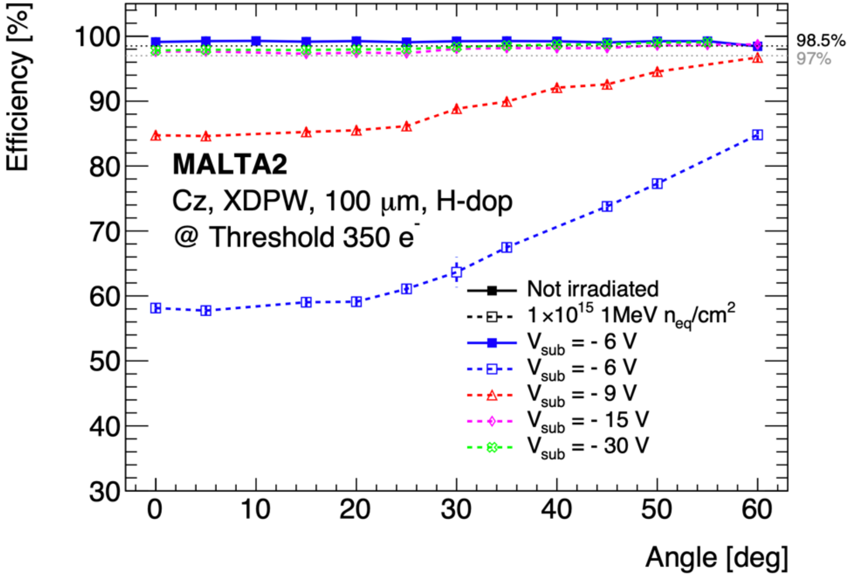


Not irradiated





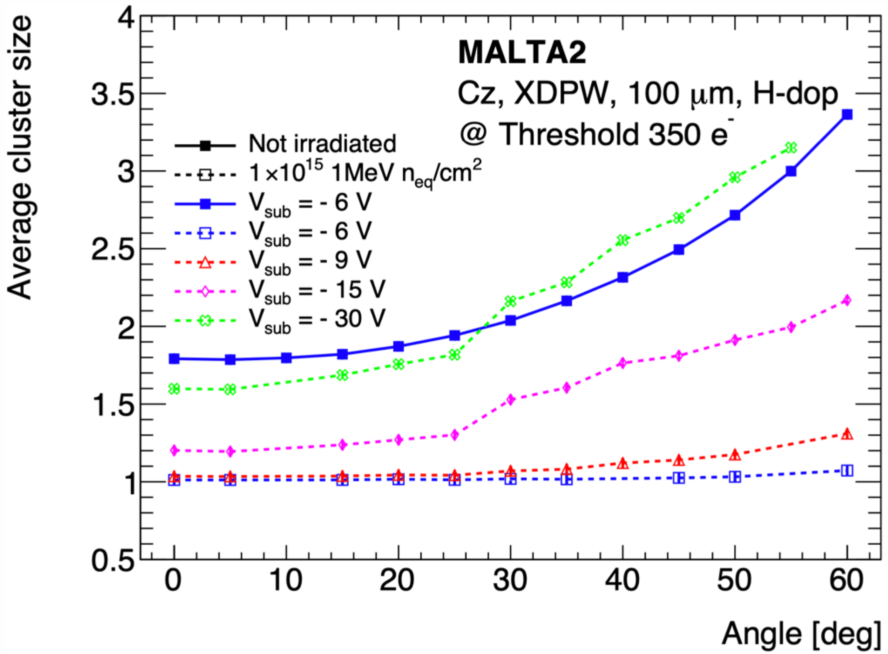
1×10^{15} 1MeV n_{eq}/cm^2

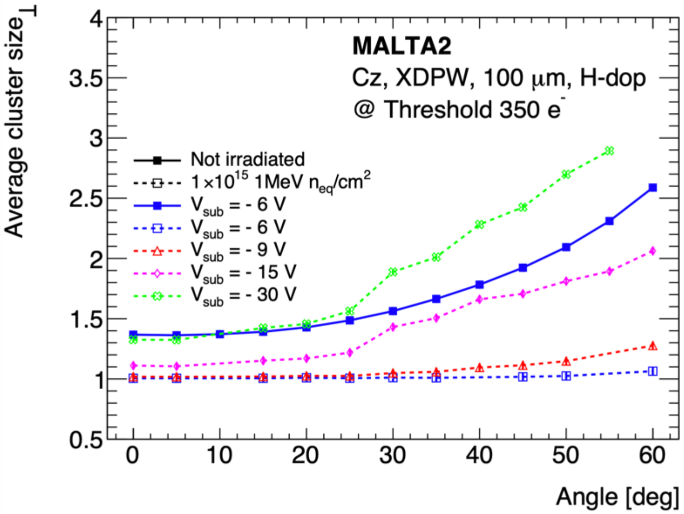


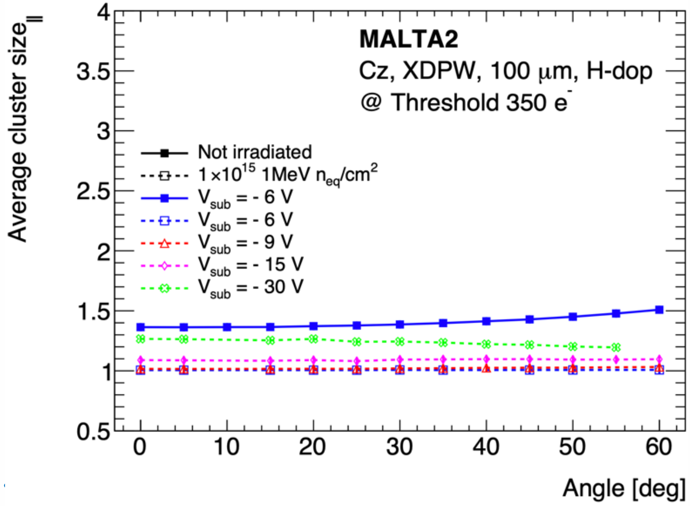
Detection efficiency w.r.t inclined angle @ threshold 350 e^-

- Before irradiation, detection efficiency ≥ **98.5%** achieved.
- Visible efficiency decrease after irradiation, especially at lower angles.
- In pixel scale, large efficiency lost after irradiation at pixel edge for the lack of active region
- Significant efficiency improvement at higher angles, due to longer trajectories in depletion region.
- For the irradiated sensor, Efficiency meets the ITK requirement of **97%** when **$V_{sub} \le -15V$.**

Average cluster size comparison



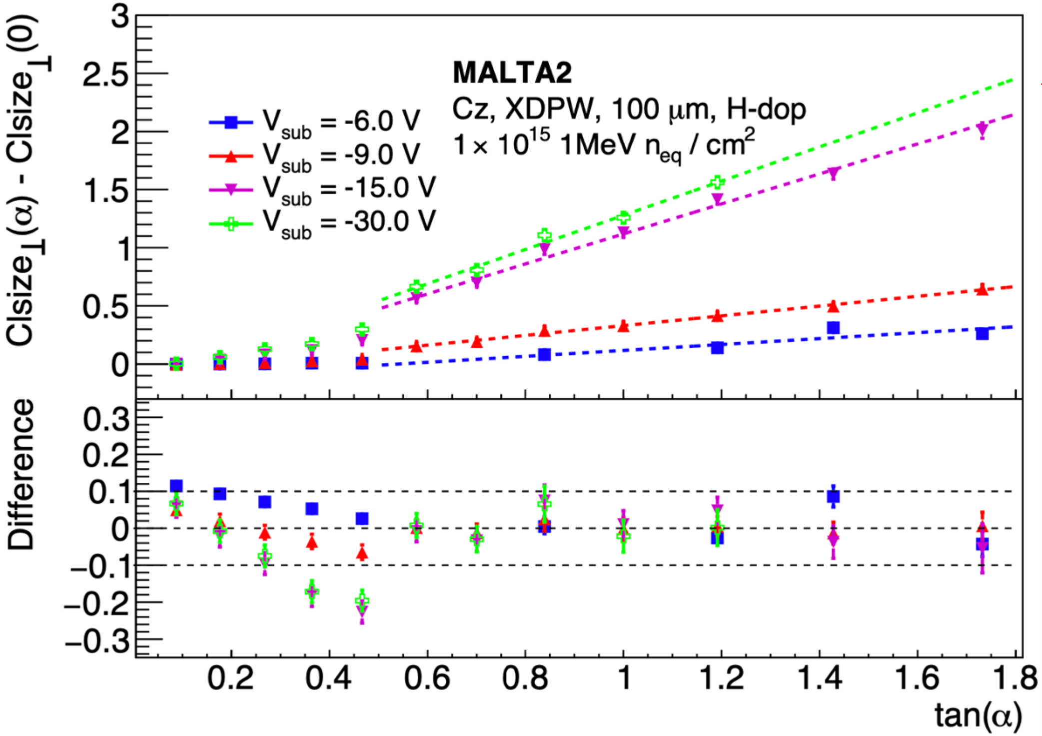




❖ **Cluster size against inclined angle @ threshold 350 e^-**

- Obvious increase of cluster size against inclined angle before irradiation.
- The increase is mainly from Cluster Size$_\perp$.
- After irradiation, decrease of cluster size in both directories because of degradation of depleted region.
- For the irradiated sensor, cluster size recovers with higher biasing voltage.

Active Depth Estimation of MALTA2 sensor



❖ **Estimation of active depth under various biasing voltage**

- $\text{ClSize}_{\perp}(\alpha) = \frac{D}{P}\tan\alpha \; + \; \text{ClSize}_{\perp}(0)$
- Linear function not applicable at lower angles, because charge diffusion dominates.
- Results not shown here, verifications from Edge-TCT measurements is in need.

Summary

- **Detection performance of Cz MALTA2, before and after irradiation, is measured with inclined angle @ CERN SPS using MALTA telescope.**
  - ✓ Excellent track detection (> **98.5%** efficiency) and sufficient charge collection/sharing.
  - ✓ After irradiation, visible decrease of detection efficiency & cluter size(charge collection/sharing) observed, due to the degradation of active region
  - ✓ Detecting performance of irradiated sensor recovers with increased biasing voltage, and **97%** efficiency is guaranteed when $\mathbf{V_{sub}} \leq \mathbf{-15V}$.
  - ✓ Sufficient active depth of MALTA2 sensor achieved, according to the grazing angle metheod.
  - ✓ Radiation hardness up to of 3×10^{15} 1MeV n_{eq}/cm^2 (> **97%** efficiency)

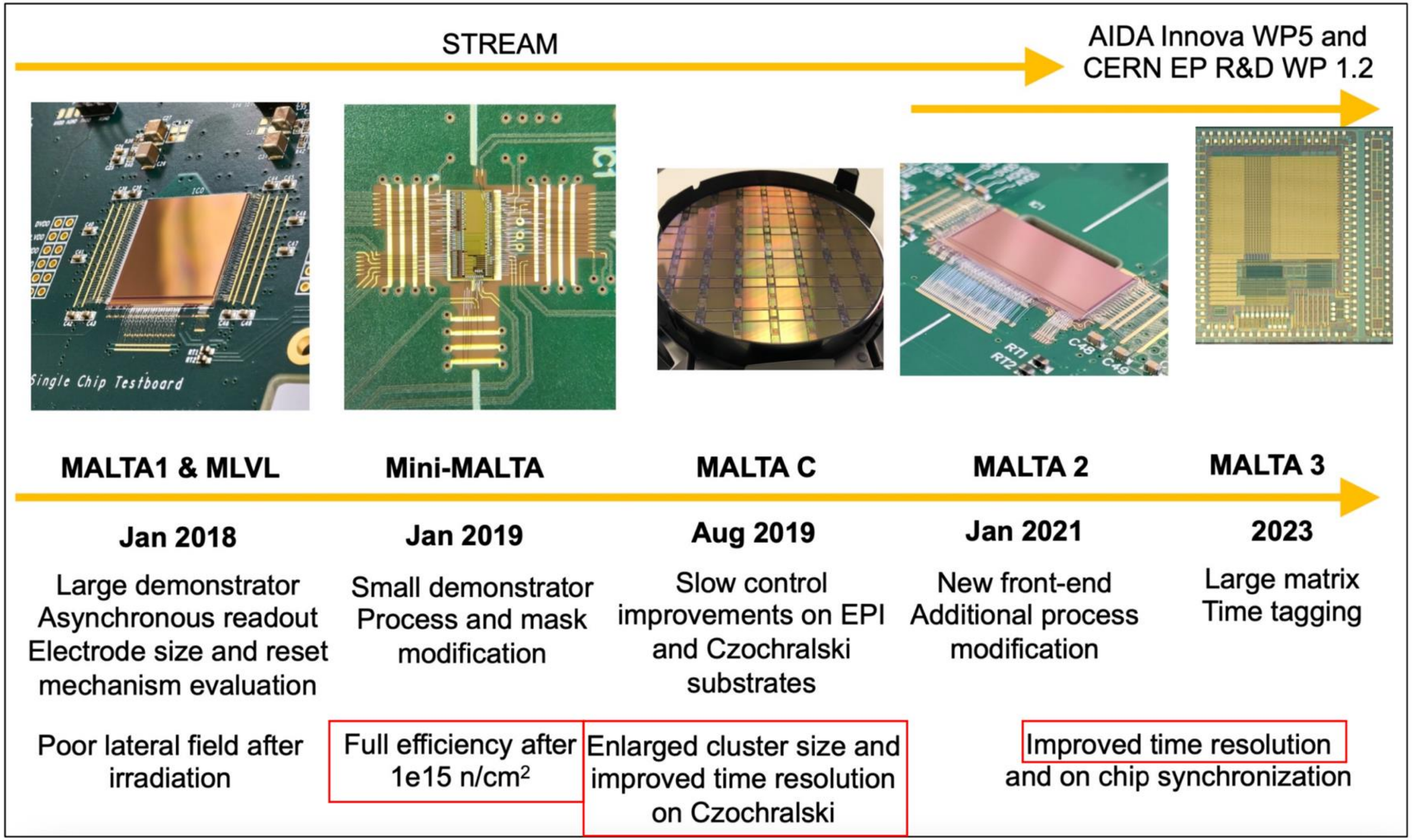
Outlook

- **Radiation study of Cz MALTA2 up to 5×10^{15} 1MeV n_{eq}/cm^2.**
- **Depletion depth study**
  - ✓ Edge TCT measurements of Cz MALTA2

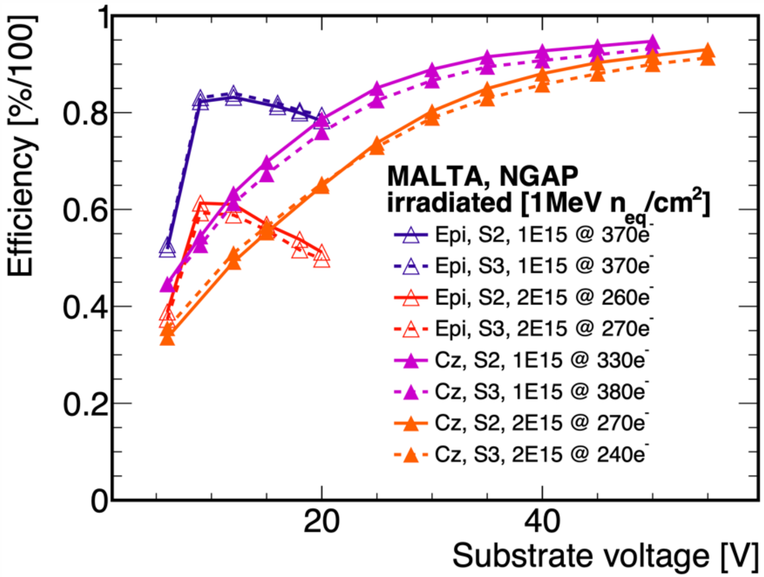

Thank you!

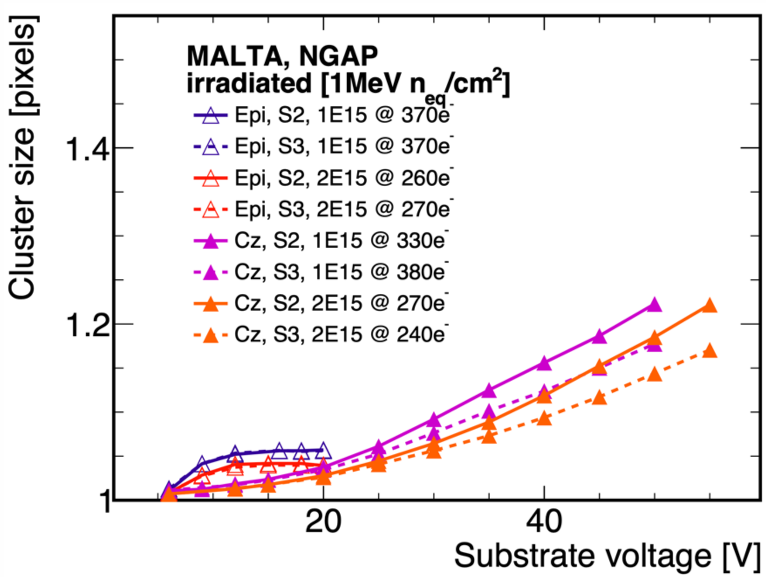
Backup

MALTA History



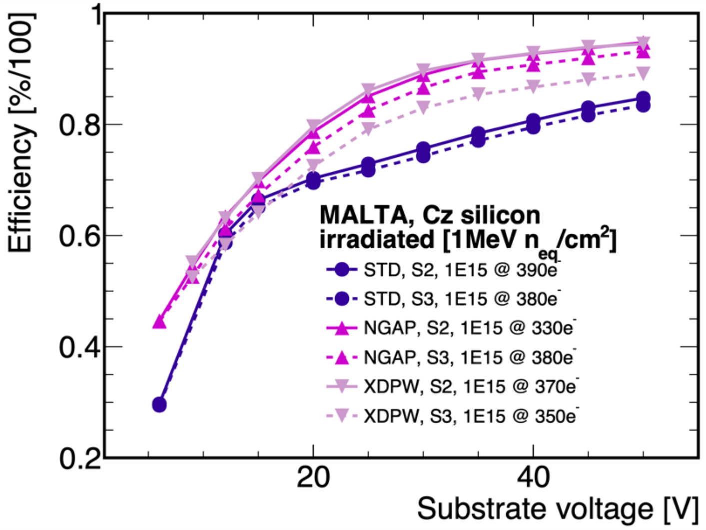
Radiation hardness comparison between Epi and Cz

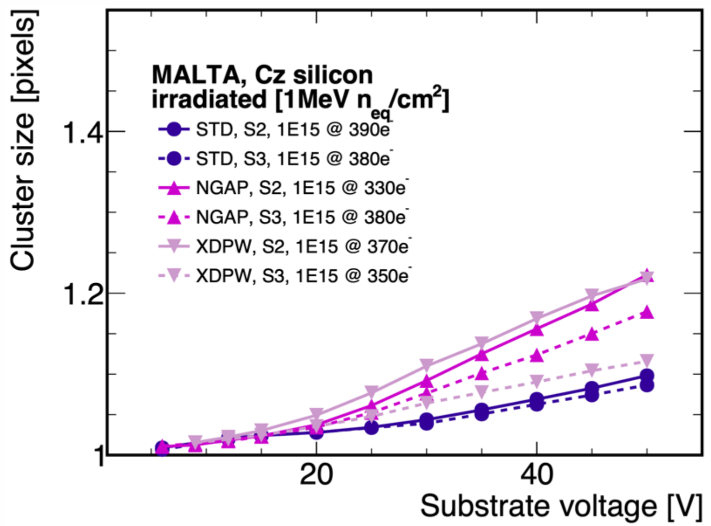




❖ Higher efficiency and larger cluster could be achieved in Cz MALTA sample, as higher biasing voltage is available in Cz sensor after irradiation.

Comparison among process modifications

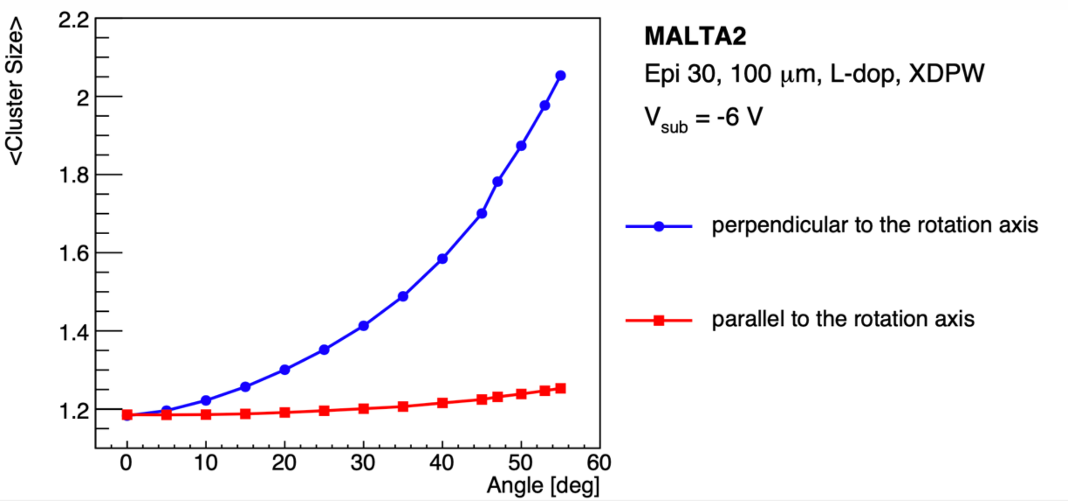


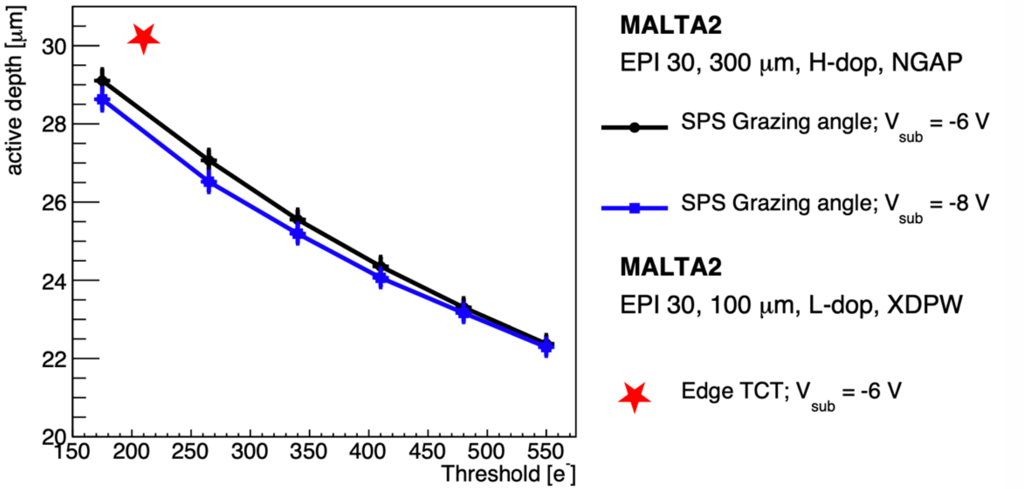


Efficiency & cluster size comparison among modifications

- All samples irradiated to 1E15 1MeV n_{eq}/cm^2.
- Measurements done @ DESY with 4GeV electron beam in 2019.
- NGAP & XDPW show better performance in both efficiency & cluster size, espeically with higher biasing voltage

Grazing angle study on MALTA2 Epi sensors





Grazing angle + Edge TCT measurements

- Active depth measured by two separate methods
- SPS threshold: pixel discriminator Edge TCT threshold: oscilloscope trigger
- Almost no change in active depth vs. bias
- Grazing angle vs. Edge TCT results mach at low threshold

Nuclear Instruments and Methods in Physics Research A 1063 (2024) 169262

Validation of the matched track