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Passive CMOS Strip Sensors – Characterisation, Simulation and Test Beam Results

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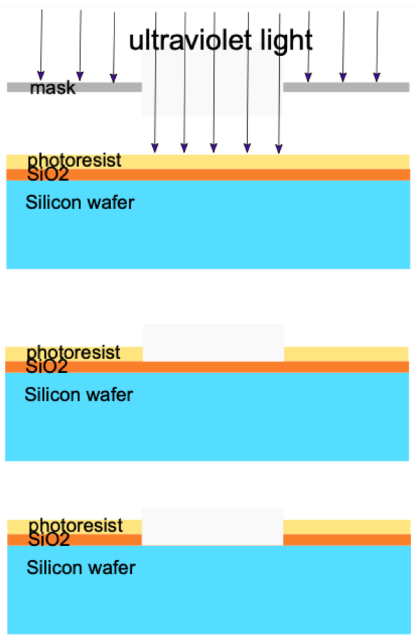
Motivation

All the ATLAS and CMS upgrade strip detectors are being fabricated by Hamamatsu Photonics

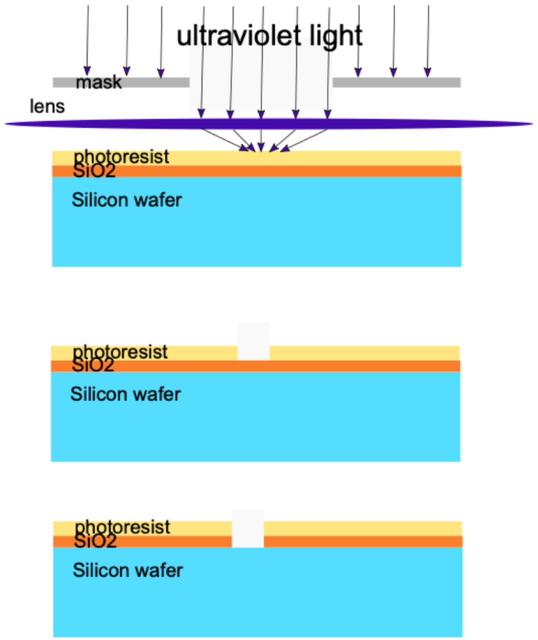
Current large area strip sensors made only by microelectronics foundries

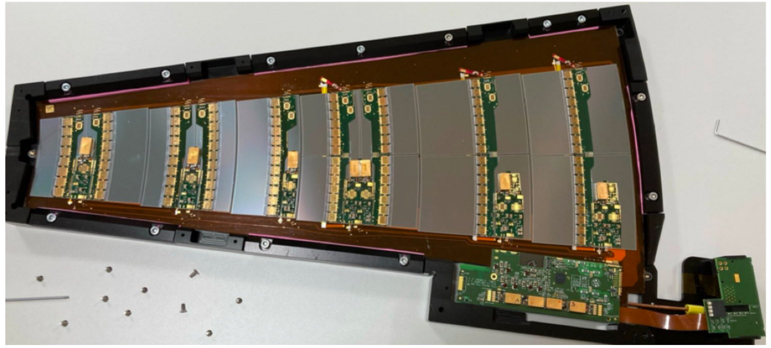
Our goal is to show that large strip detectors can be fabricated using CMOS technology with no negative impact on their performance

Microelectronics photolithography



CMOS photolithography





Example of ATLAS ITk end-cap petal made of large area silicon strip sensors.

Passive CMOS Strips

Sensors fabricated in LFoundry in a 150 nm process

Passive → no electronics included

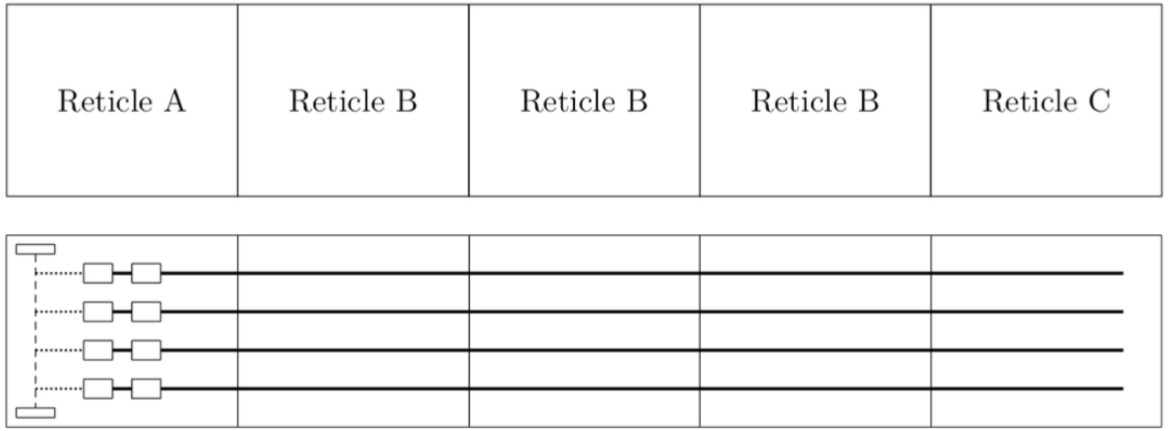
150 µm thick silicon wafer

Two lengths of strips 2.1 and 4.1 cm

- **1 cm² reticle used → strips had to be stitched**
- **Up to five stitches in each sensor**

Three different designs

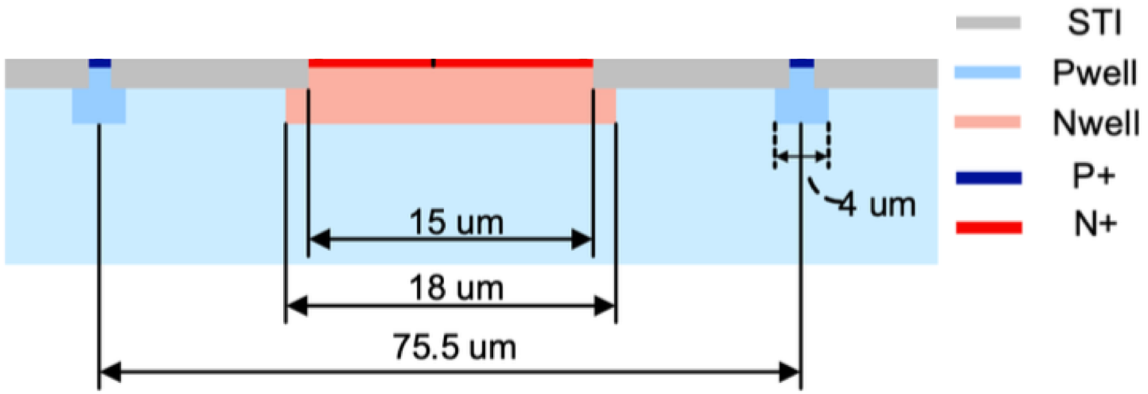
- **Regular** – similar to the ATLAS strip design
- **Low dose 30 & 55** – low dose implant and NIM capacitor



Passive CMOS Strips
Three different designs

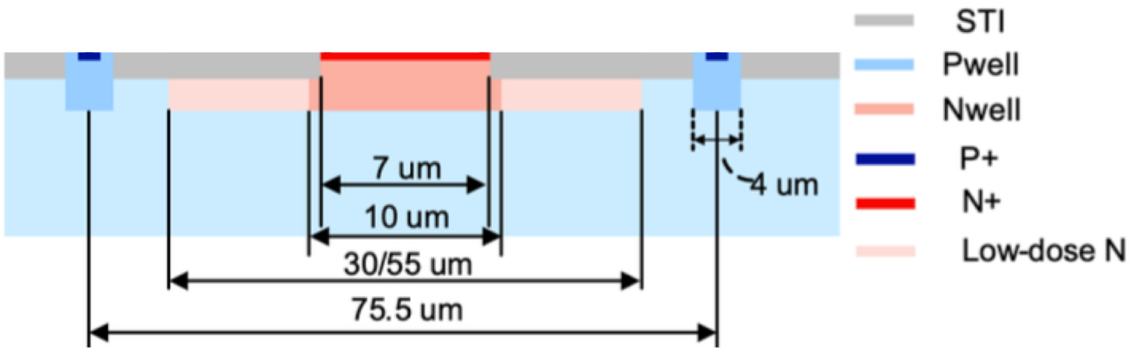
Regular

➡️ similar to the ATLAS strip design



Low Dose 30 & 55

➡️ low dose implant and NIM capacitor



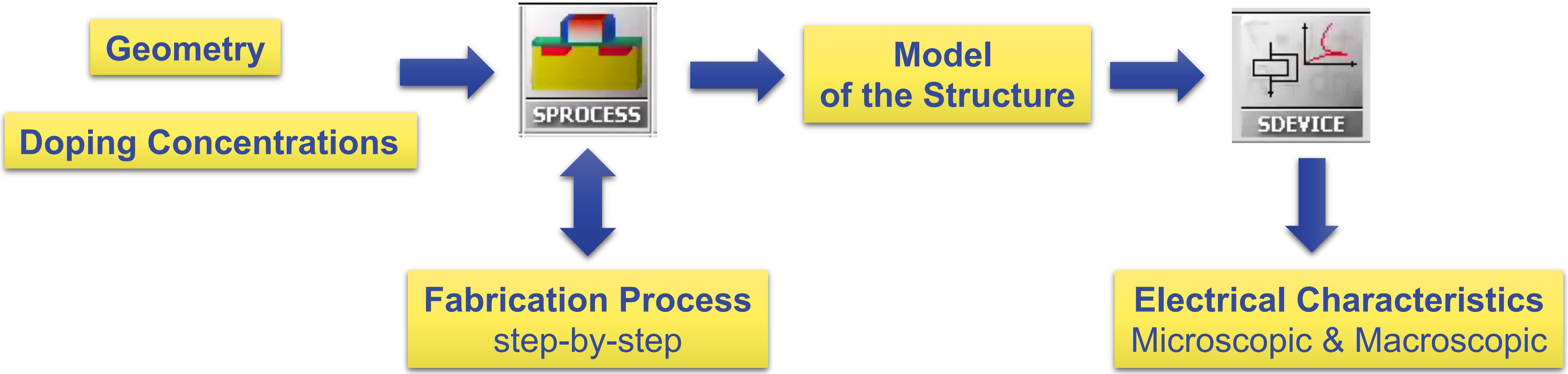
Simulations of CMOS Strips
Using Sentaurus TCAD

Done in order to investigate our silicon structures in detail

Both the fabrication process and electrical characteristics were simulated

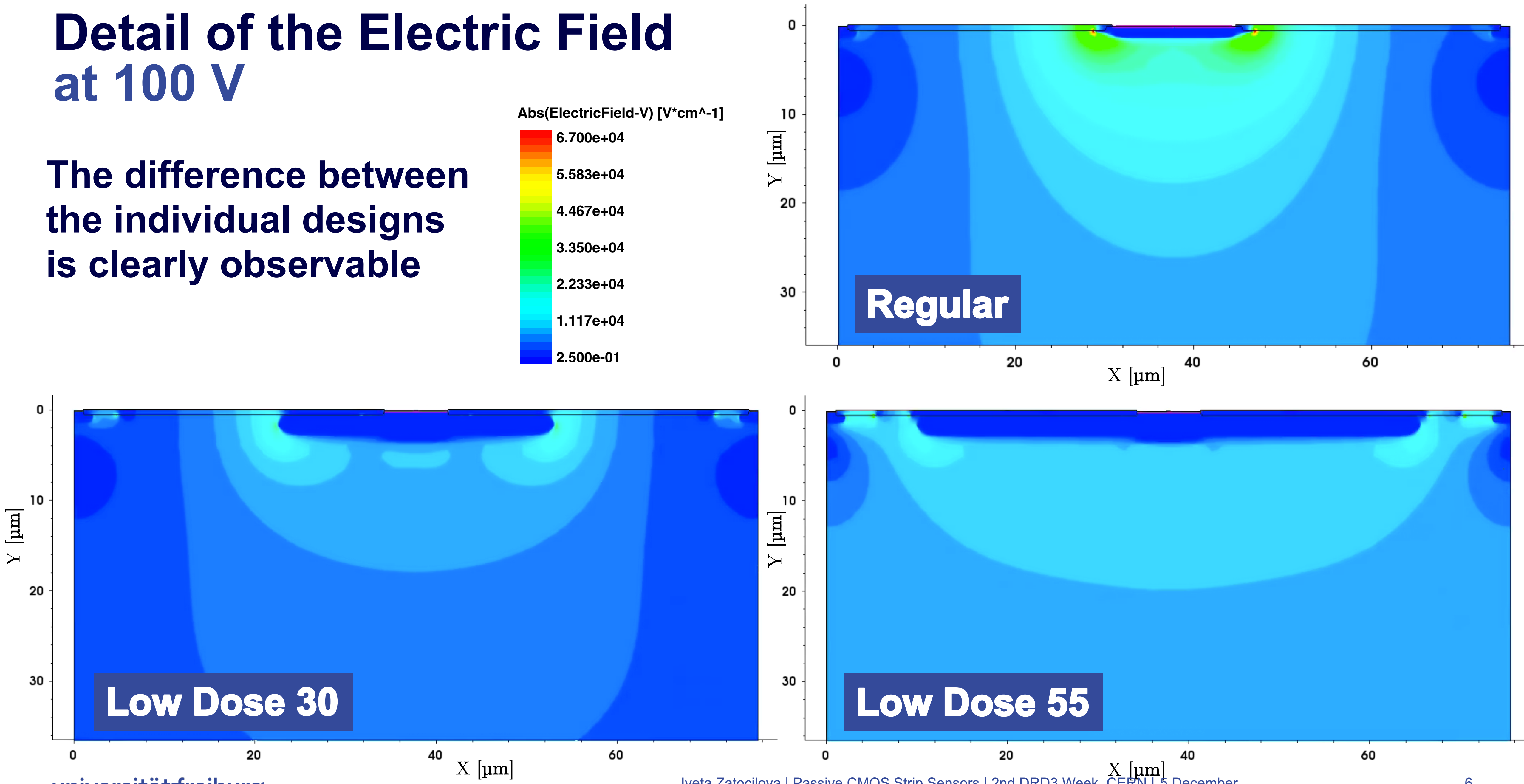
All three designs simulated as 2D strip segment

Results scaled in order to be comparable to the measurements

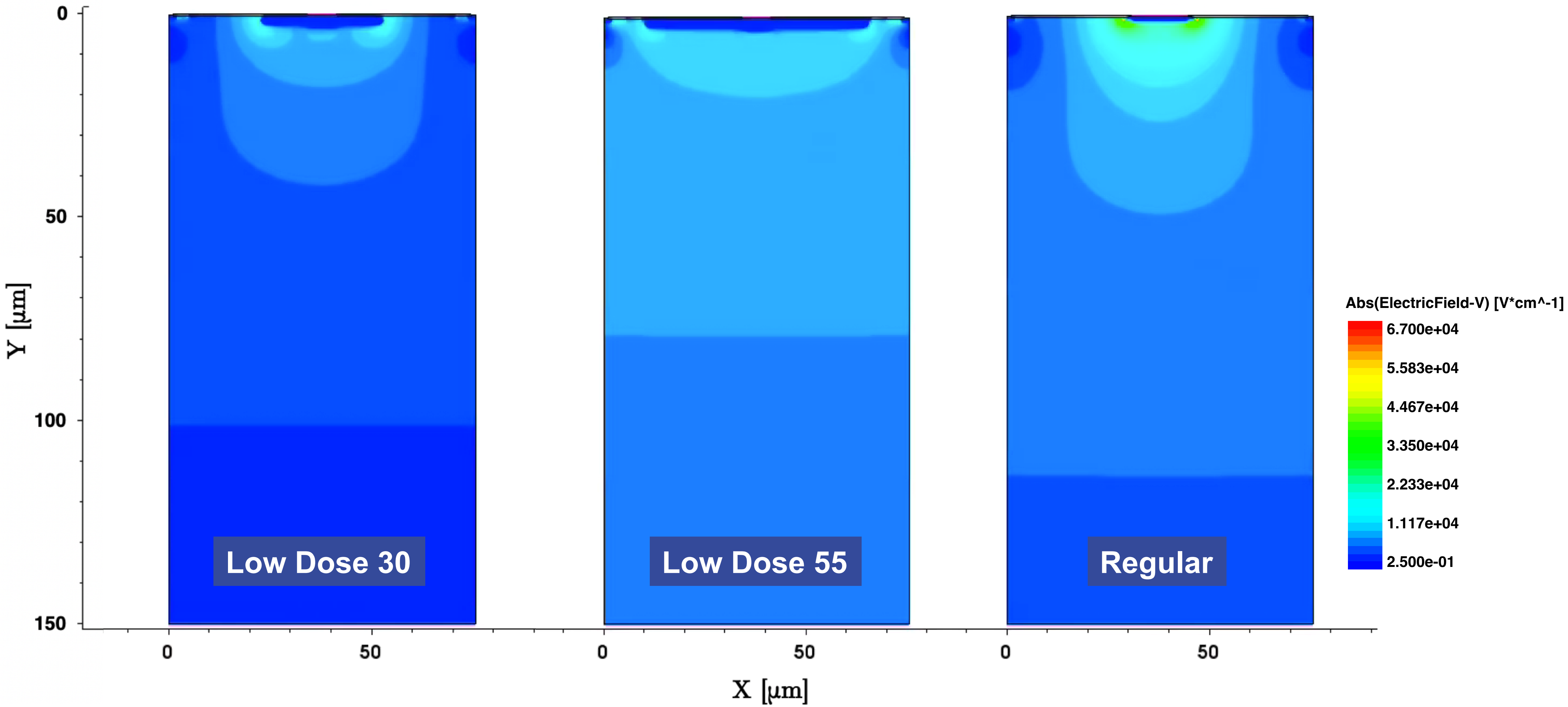


Detail of the Electric Field
at 100 V

The difference between the individual designs is clearly observable



Electric Field at 100 V



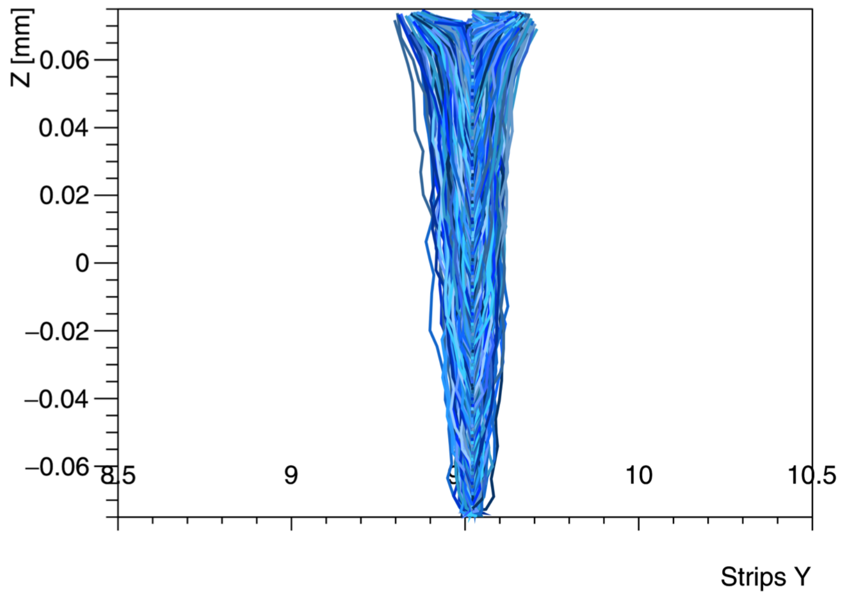
Allpix^2
Drift path of electrons

Motion of charge carriers generated by a passing MIP along the sensor thickness

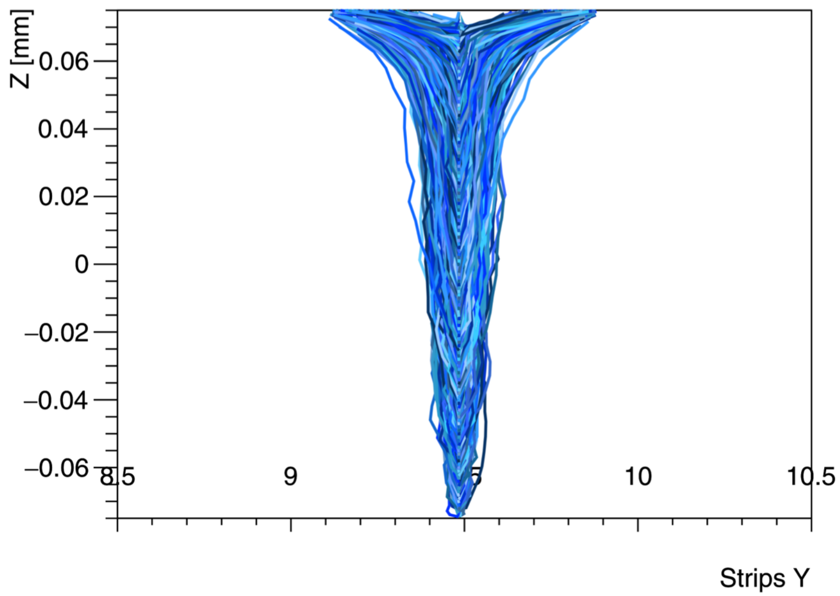
➡️ Charge carriers experience a strong drift towards the collection electrodes

Regular design
➡️ stronger drift
➡️ larger electric field

Low Dose 55



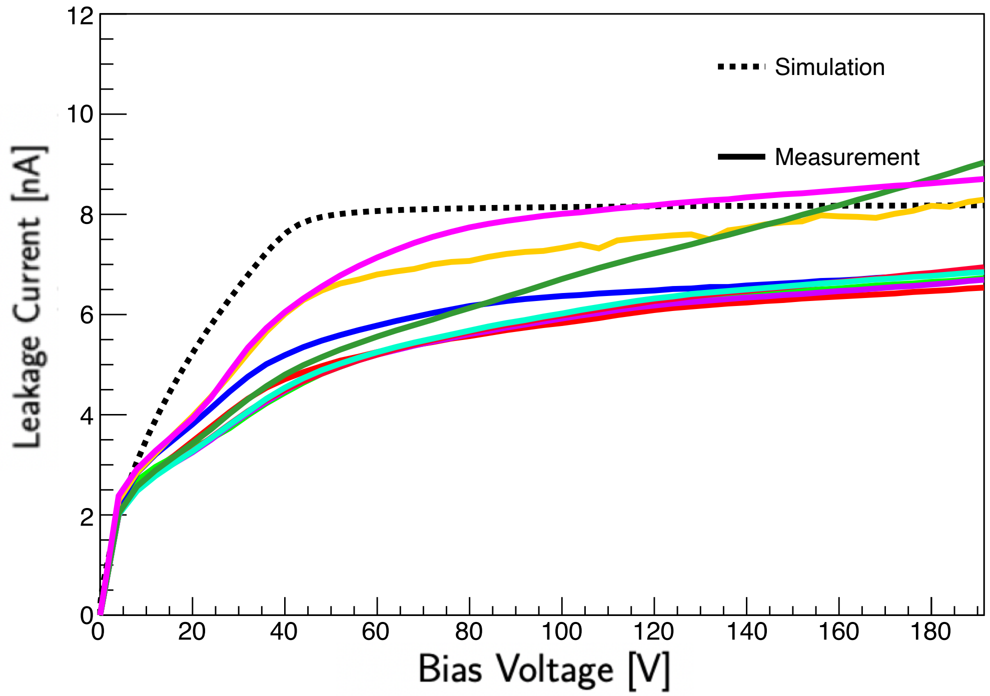
Regular



https://doi.org/10.1016/j.nima.2024.169407

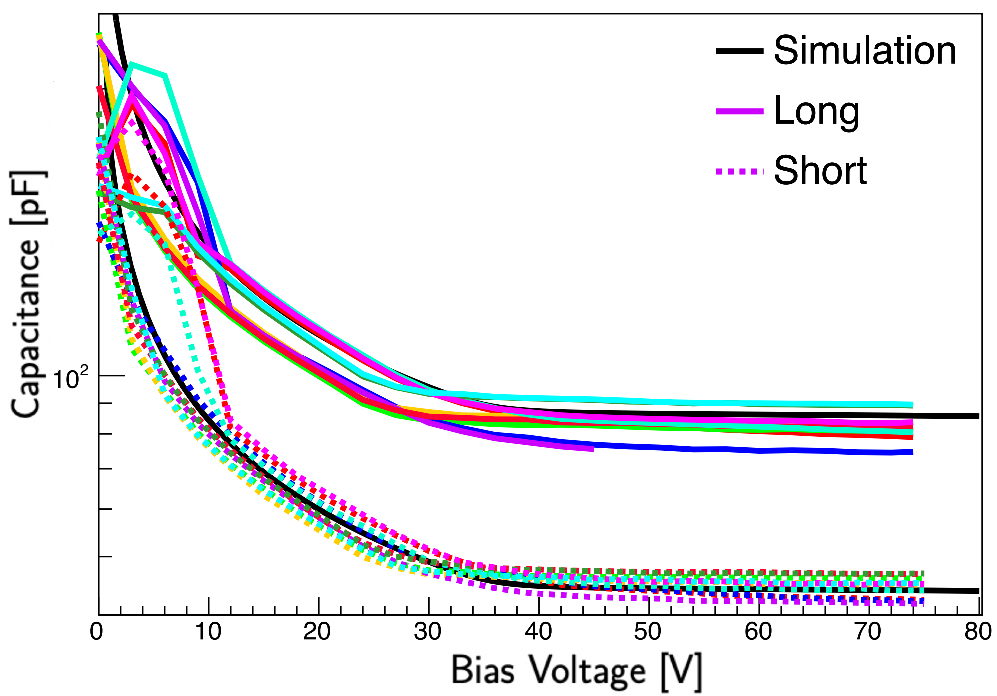
Electrical Characterisation
Macroscopic Characteristics

Leakage Current



➡️ **Simulated structures describe the real ones well**

Bulk Capacitance



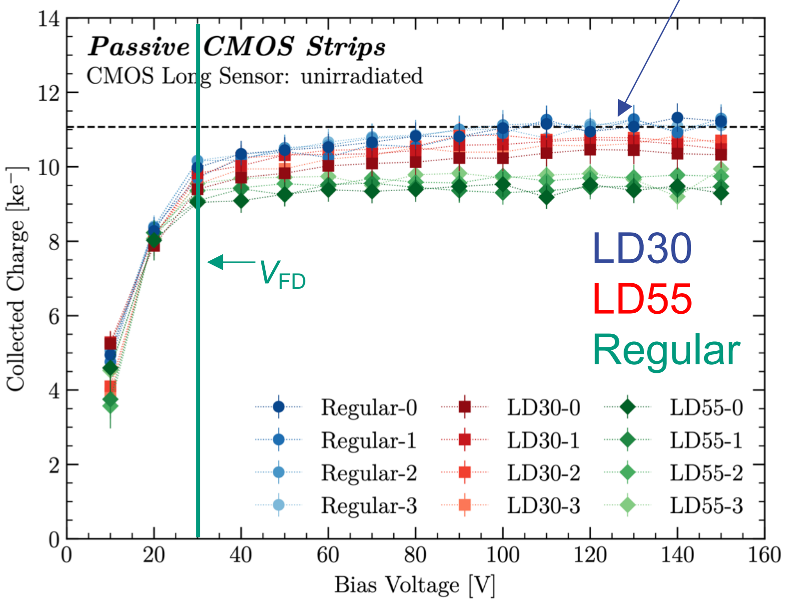
Short strips (2.1 cm) – $C_{bulk} \approx 50$ pF

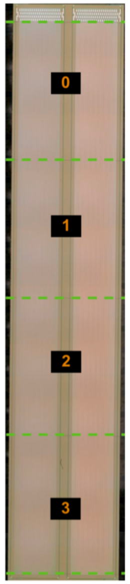
Long strips (4.1 cm) – $C_{bulk} \approx 100$ pF

Determination of Collected Charge
Using the ALiBaVa Setup and ^{90}Sr-source

Unirradiated

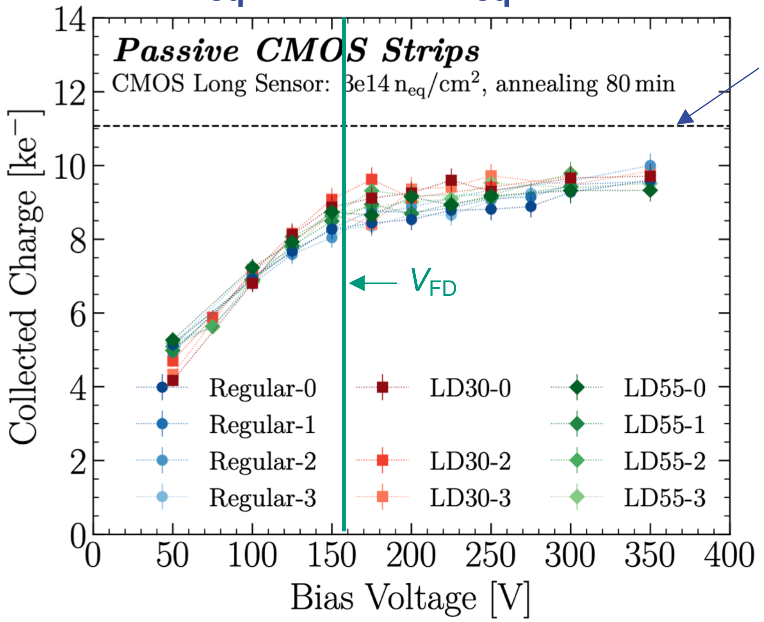
expected collected charge





Irradiated by 23 MeV neutrons

Φ_{eq} = 3·10^{14} n_{eq}/cm^2



expected collected charge

➡️ **No differences in collected charged measured in the stitched areas**

➡️ **Observed change in collected charge after irradiation as expected**

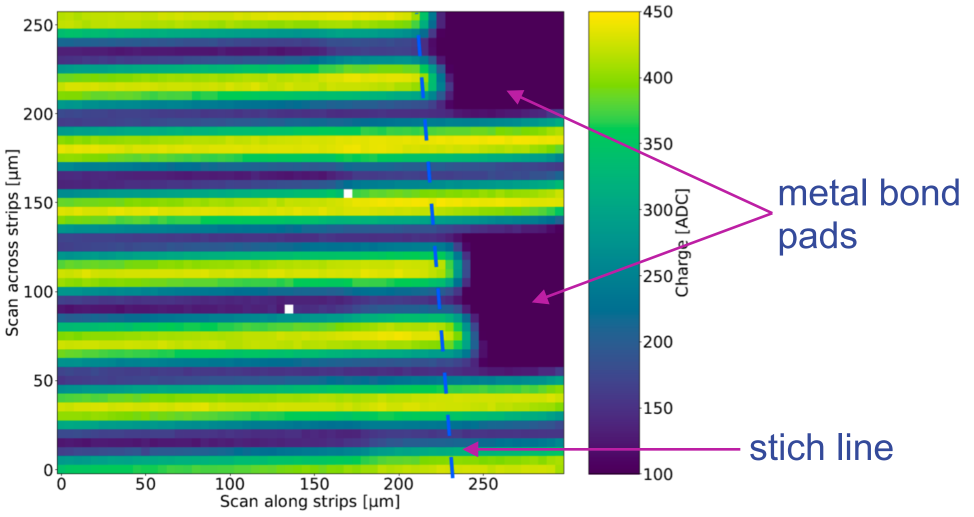
➡️ **Increase of full depletion voltage V_{FD} after irradiation**

https://doi.org/10.1016/j.nima.2022.167031

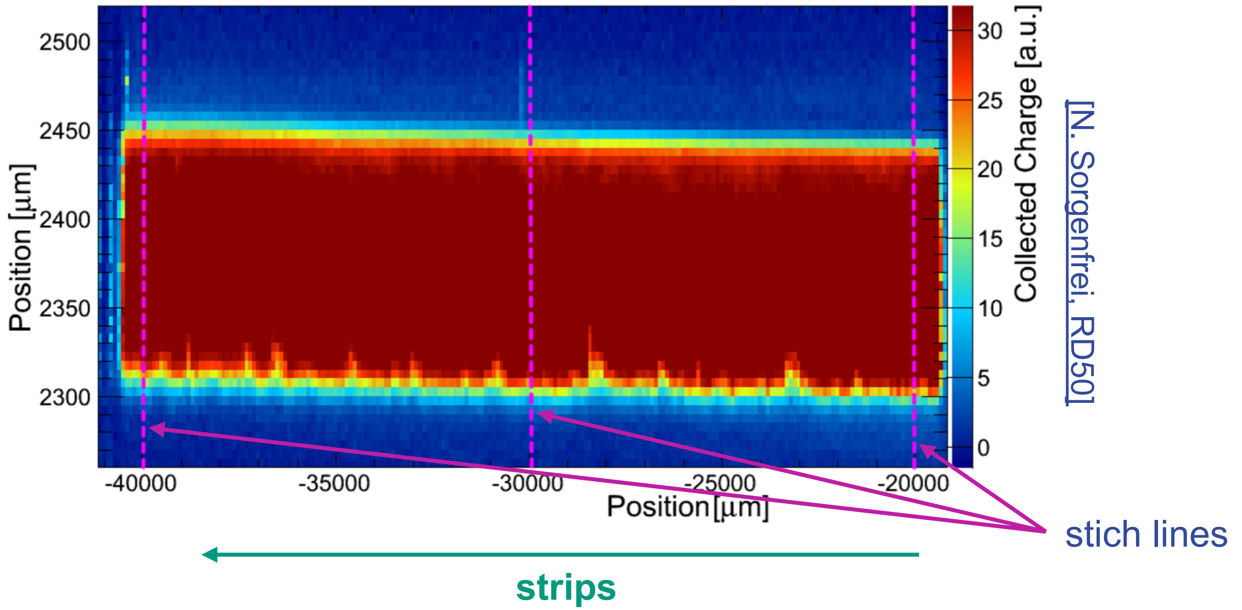
Transient Current Technique Measurements
Top- and Edge-TCT

Top-TCT Regular at 50 V

[NIMA 1033 (2022) 166671]



Edge-TCT Low Dose 30 at 100 V



[N. Sorgenfrei, RD50]

Collected charge as a function of the laser position

Results of both the Top- and Edge-TCT measurements show homogenous charge collection

➡️ **No effect of stitching observed**

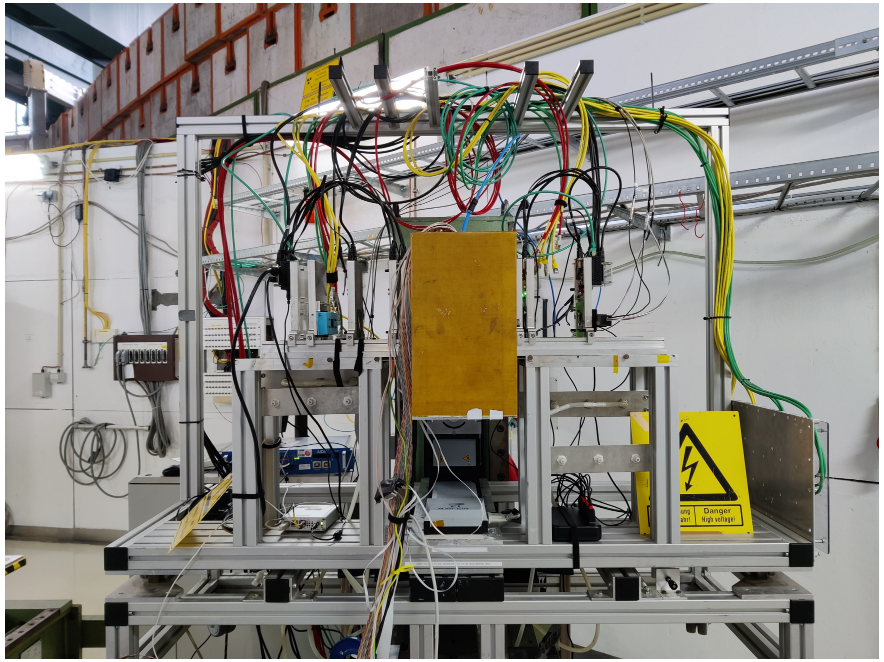
https://doi.org/10.1016/j.nima.2022.166671

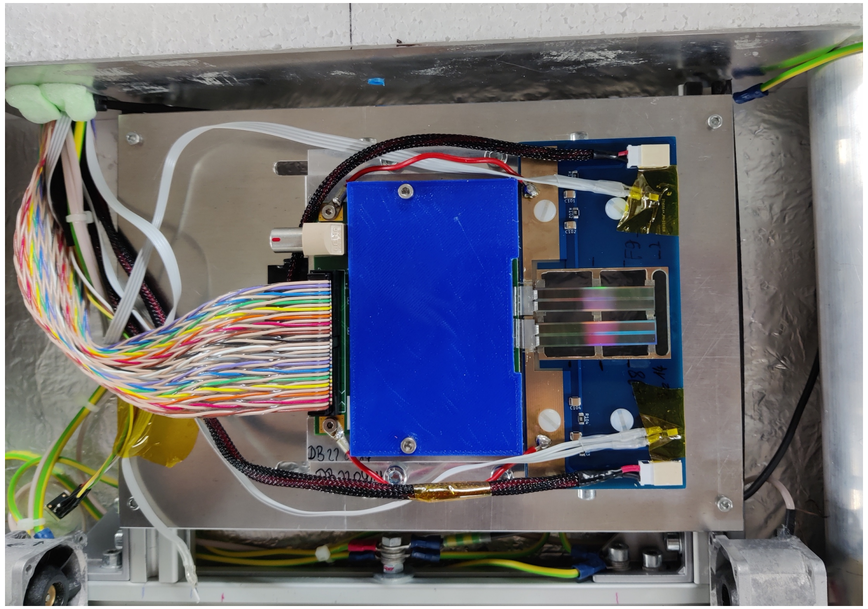
Testbeam Campaigns
Done at DESY

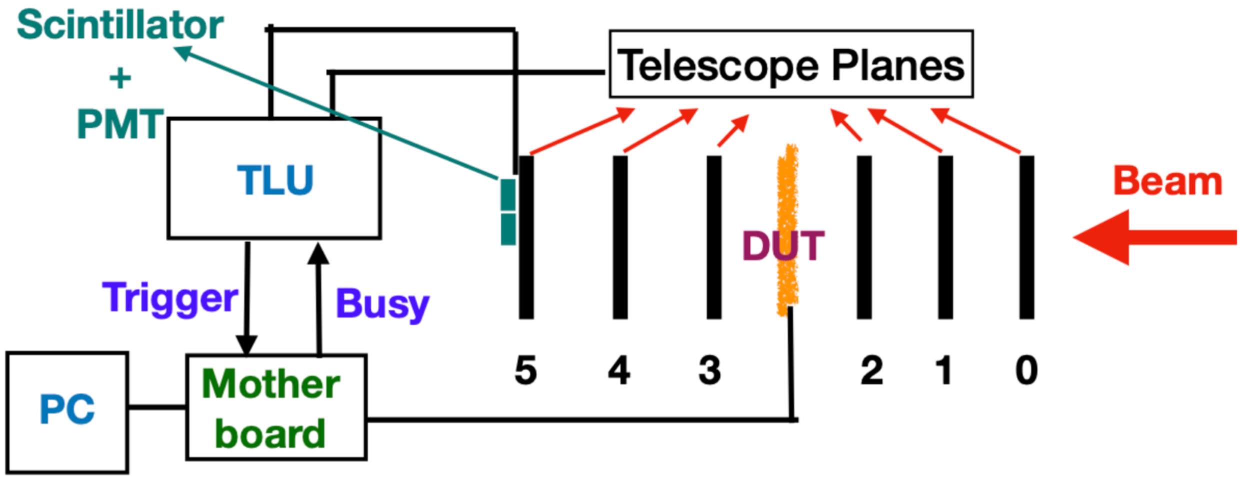
Several testbeam campaigns took place at DESY

Electron beam energies 3.4 and 4.2 GeV

Data acquisition using ALiBaVa setup

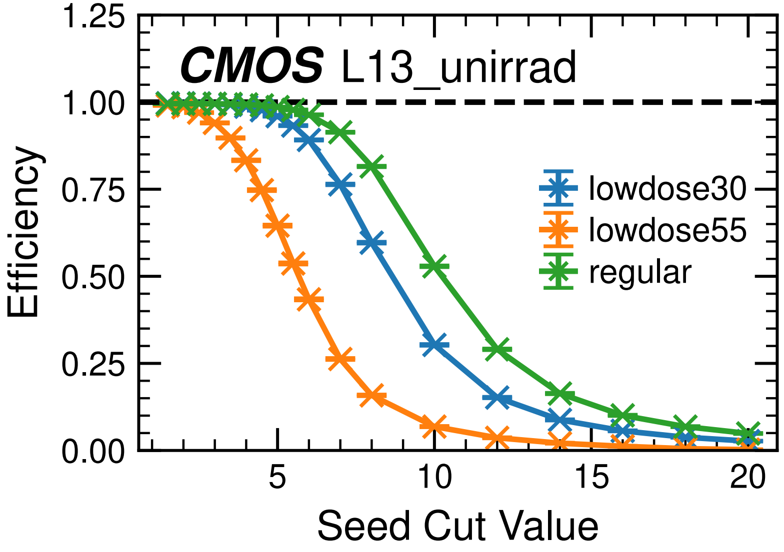






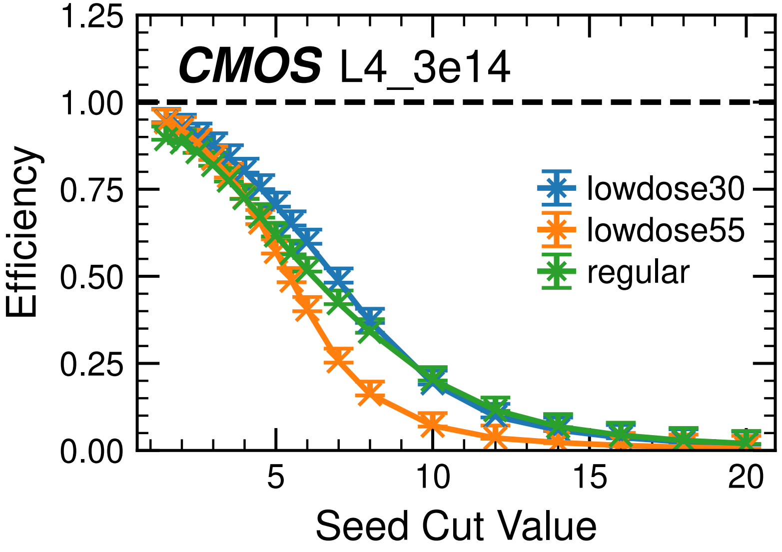
Testbeam Results
Efficiency

Unirradiated



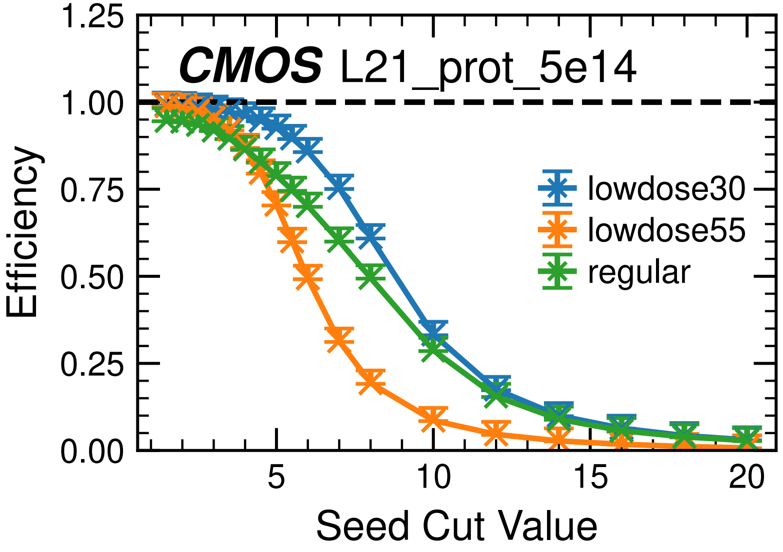
Neutron Irradiated

$\Phi_{eq} = 3 \cdot 10^{14}\ n_{eq}/cm^2$



Proton Irradiated

$\Phi_{eq} = 5 \cdot 10^{14}\ n_{eq}/cm^2$



➡️ **Expected shape of the dependence of efficiency on S/N cut value**

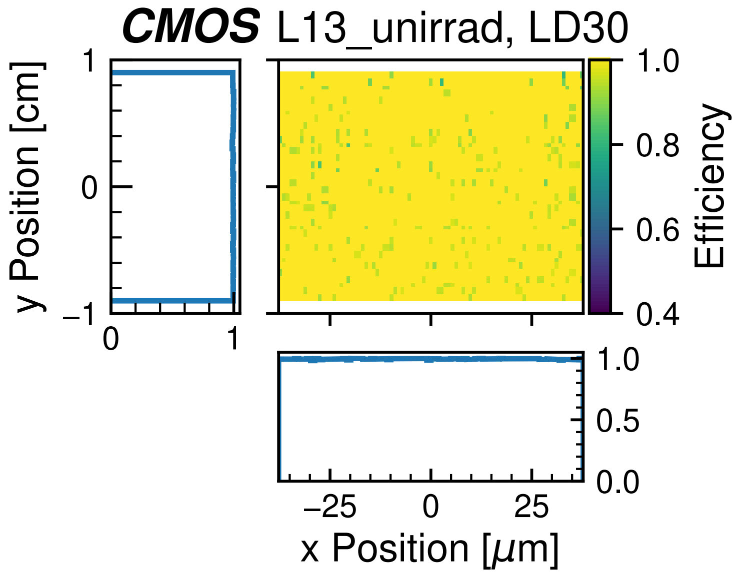
➡️ **Clear deterioration in efficiency after irradiation**

➡️ **Efficiency of proton irradiated sensor higher than the one of neutron irradiated sensor**

https://doi.org/10.1016/j.nima.2024.169132

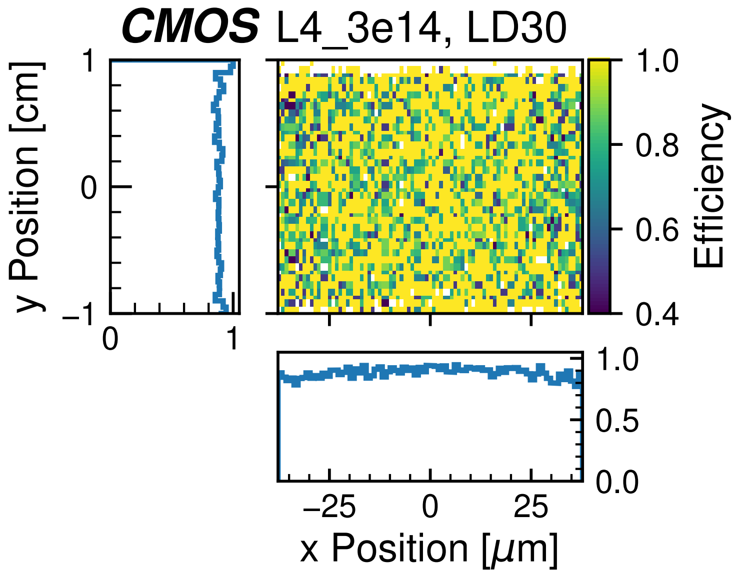
Testbeam Results
In-strip Efficiency

Unirradiated



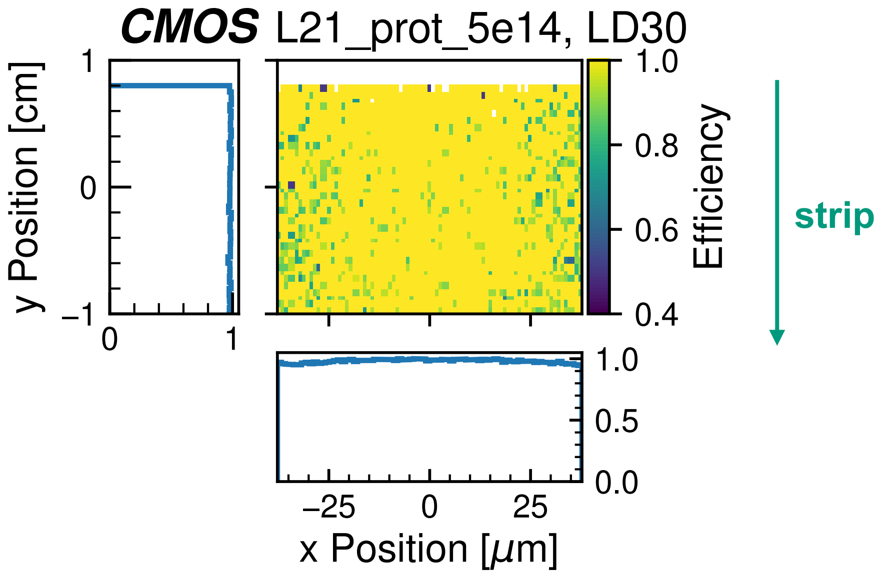
Neutron Irradiated

$\Phi_{eq} = 3 \cdot 10^{14}\ n_{eq}/cm^2$



Proton Irradiated

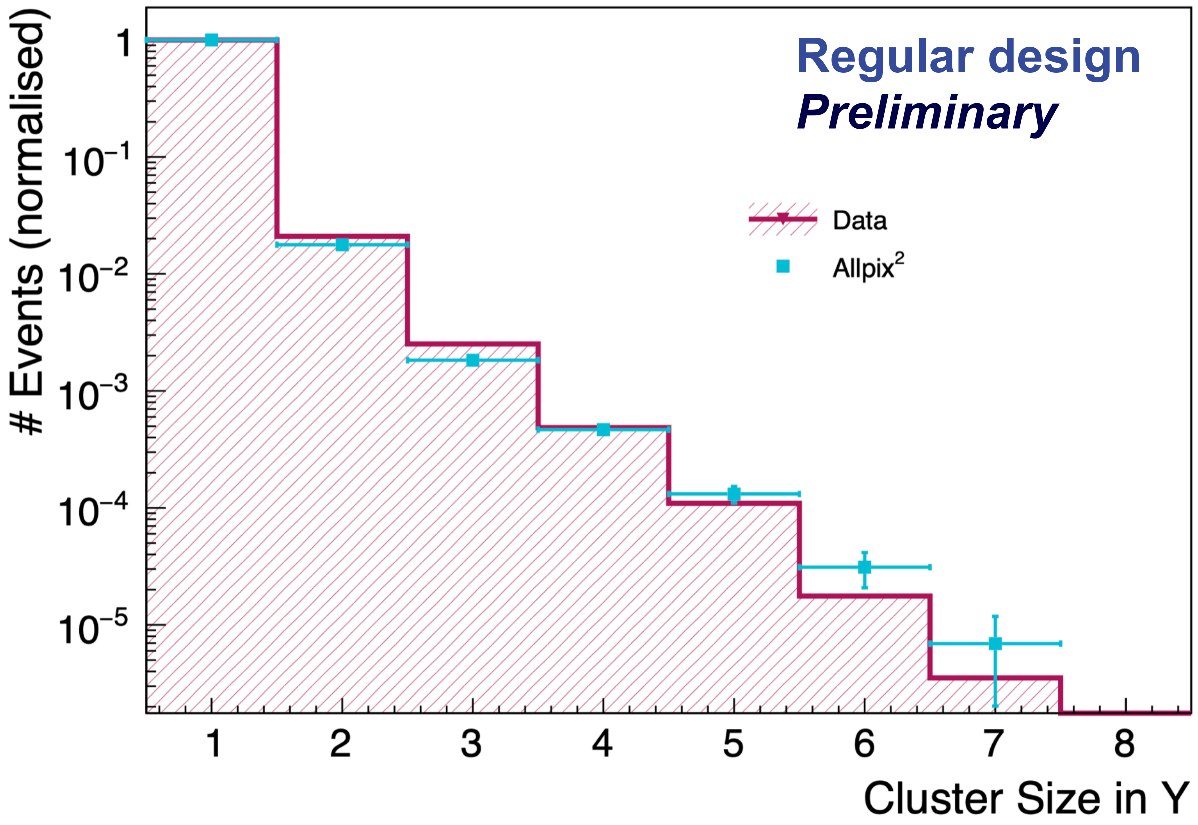
$\Phi_{eq} = 5 \cdot 10^{14}\ n_{eq}/cm^2$



➡️ **No change in efficiency observed due to the stitches**

➡️ **Efficiency of proton irradiated sensor higher than the one of neutron irradiated sensor**

Allpix^2
Cluster size



➡️ **Comparison of simulation and test beam data**

➡️ **Good agreement between simulation and test beam data even at higher cluster sizes**

Conclusions and Outlook

Passive CMOS strip sensors fabricated in LFoundry in a 150 nm process

Electrical characteristics measured and investigated by TCAD and Allpix^2 simulations

No observable effect of stitching on the performance of the strip detectors before and after neutron and proton irradiation

Up to 5 stitches used to achieve 2.1 and 4.1 cm strip lengths

Several testbeam campaigns carried out in order to evaluate charge collection efficiency

Design of the new sensors with implemented electronics in progress