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Characterization, Simulation and Test Beam Data Analysis of Stitched Passive CMOS Strip Sensors

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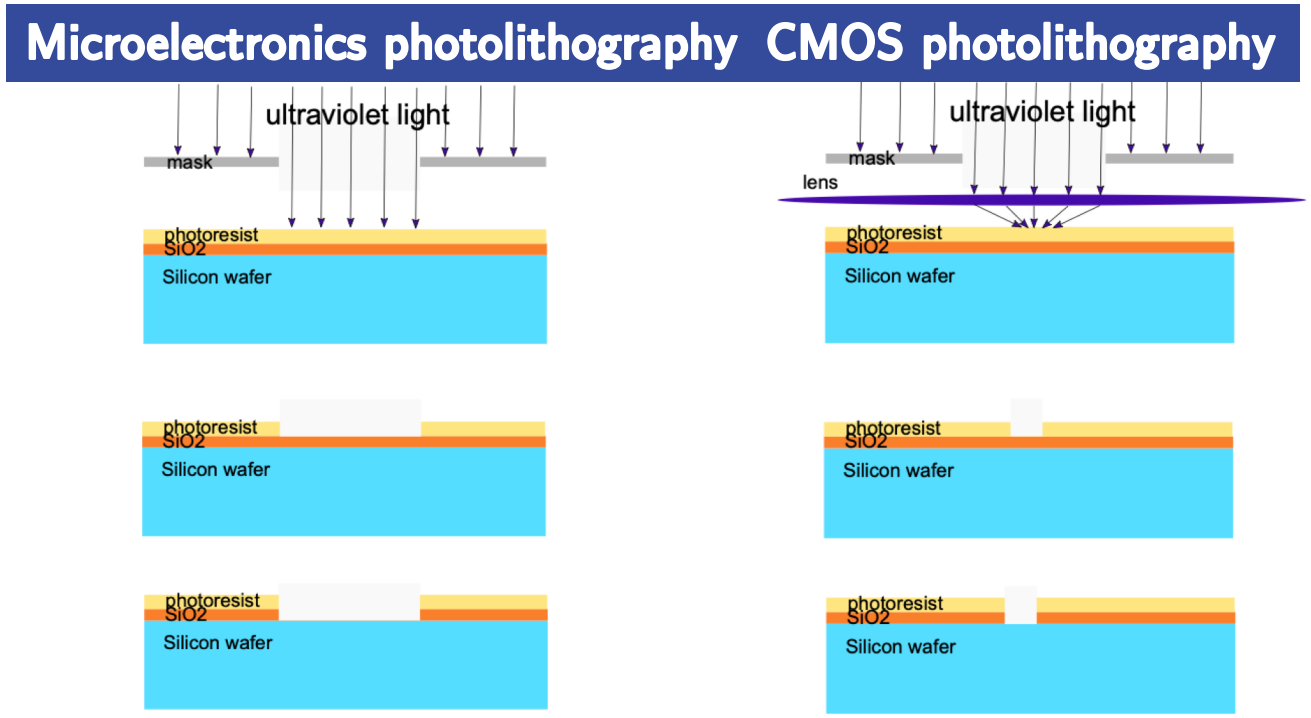
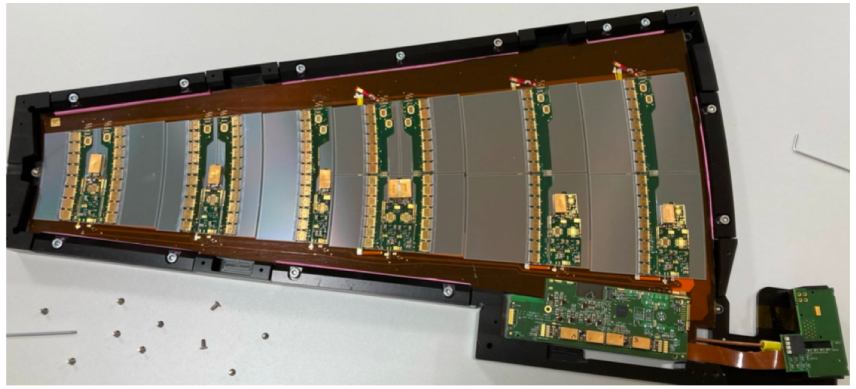
Motivation

- 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

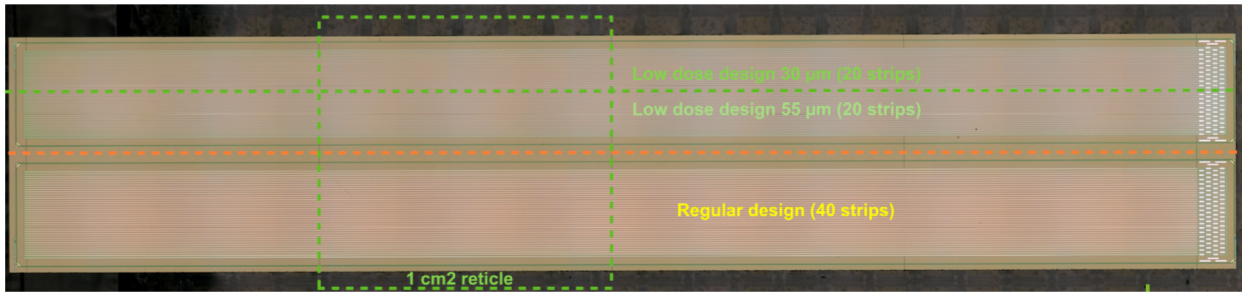


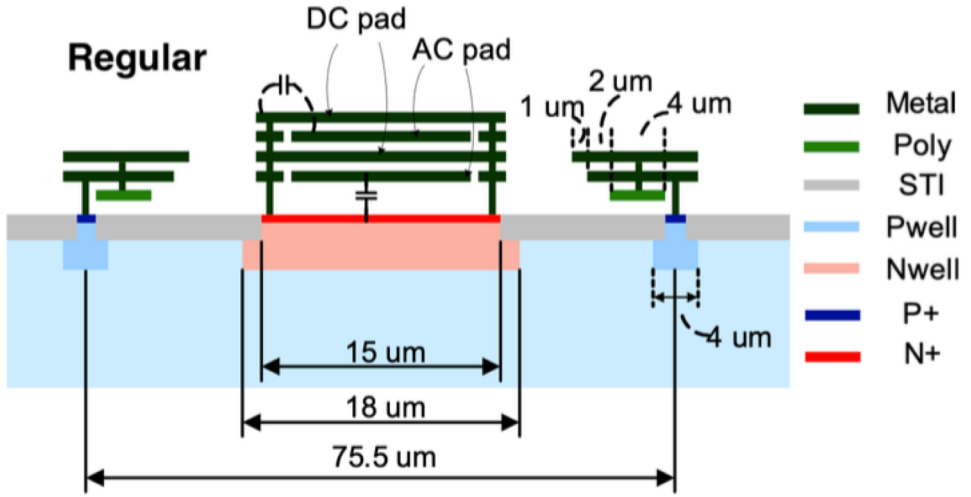


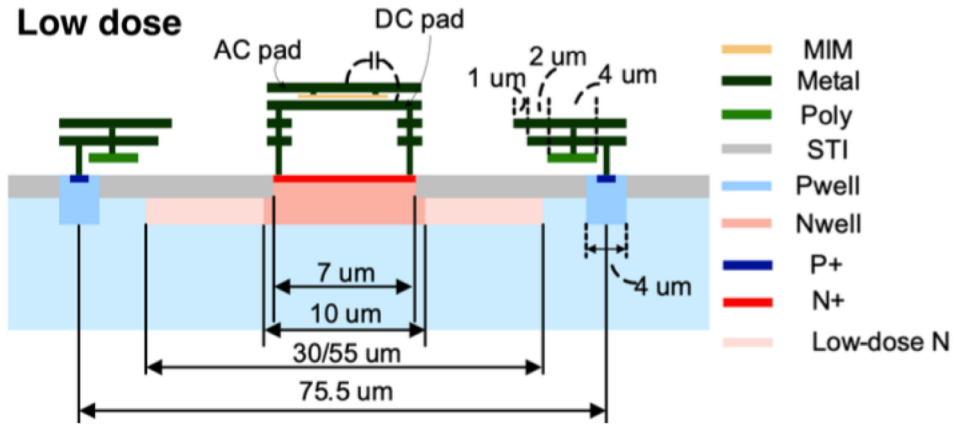
Example of ATLAS ITk end-cap petal made of large area silicon strip sensors.

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

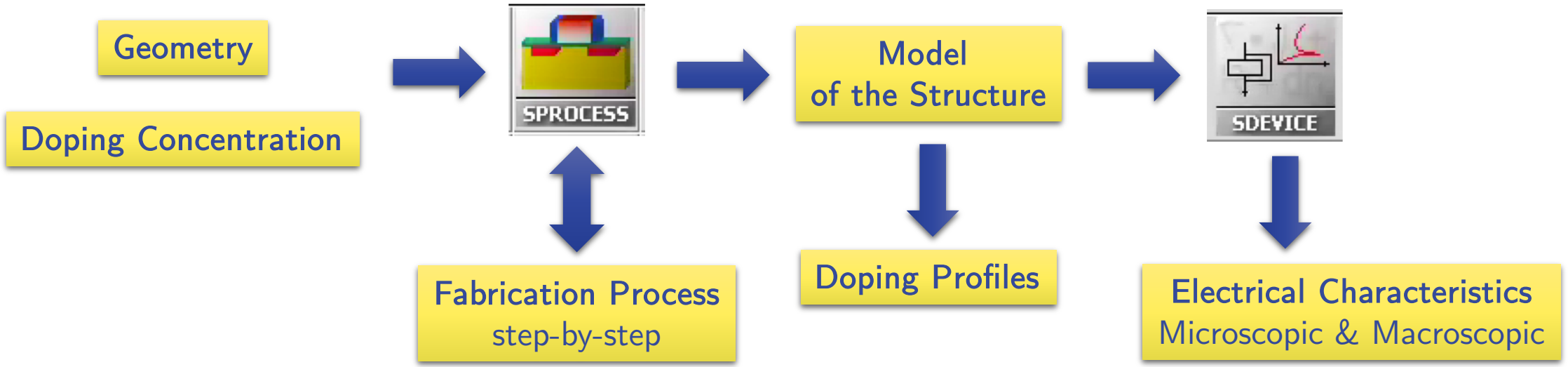






Simulations of CMOS Strips
Using Sentaurus TCAD

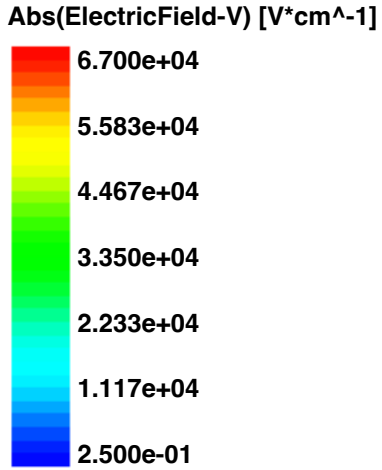
- Done in order to investigate our silicon structures in detail
- Both the fabrication process and electrical characteristics were simulated
- All three designs simulated as $1\ \mu\mathrm{m}$ long strip segment

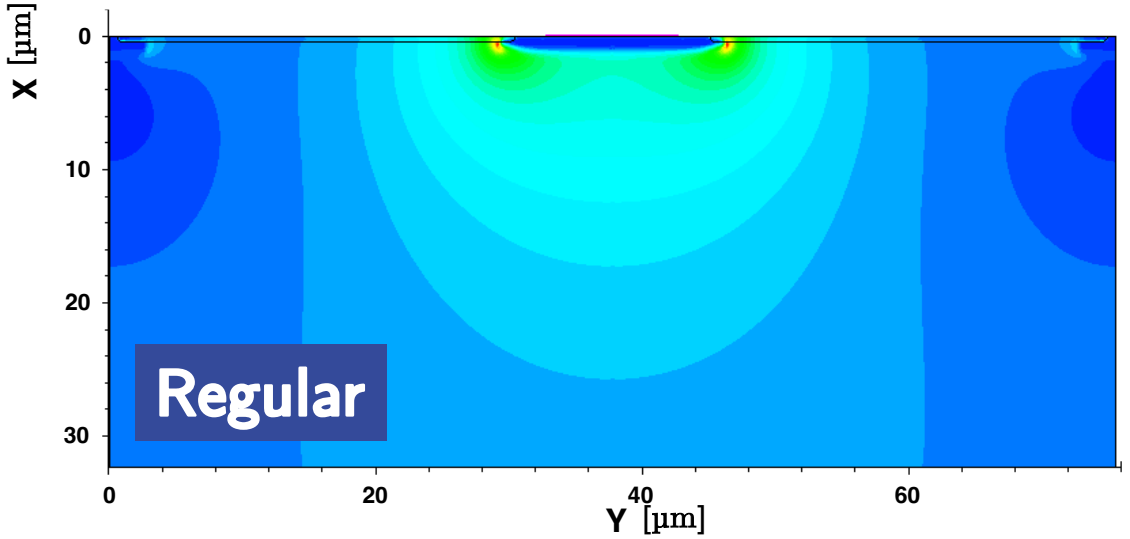


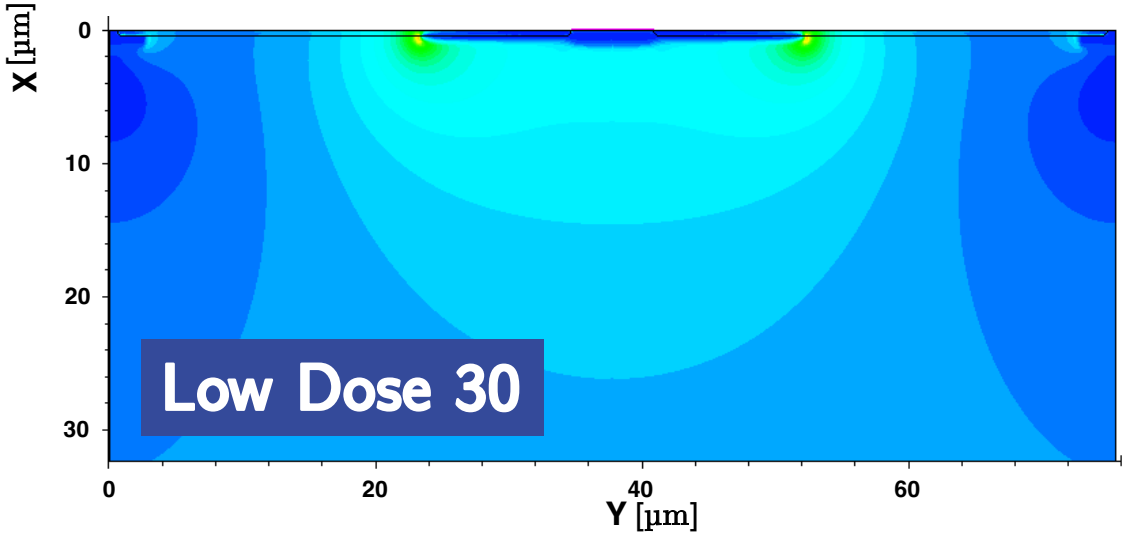
Electrical Characterization
Detail of the Electric Field at 100 V

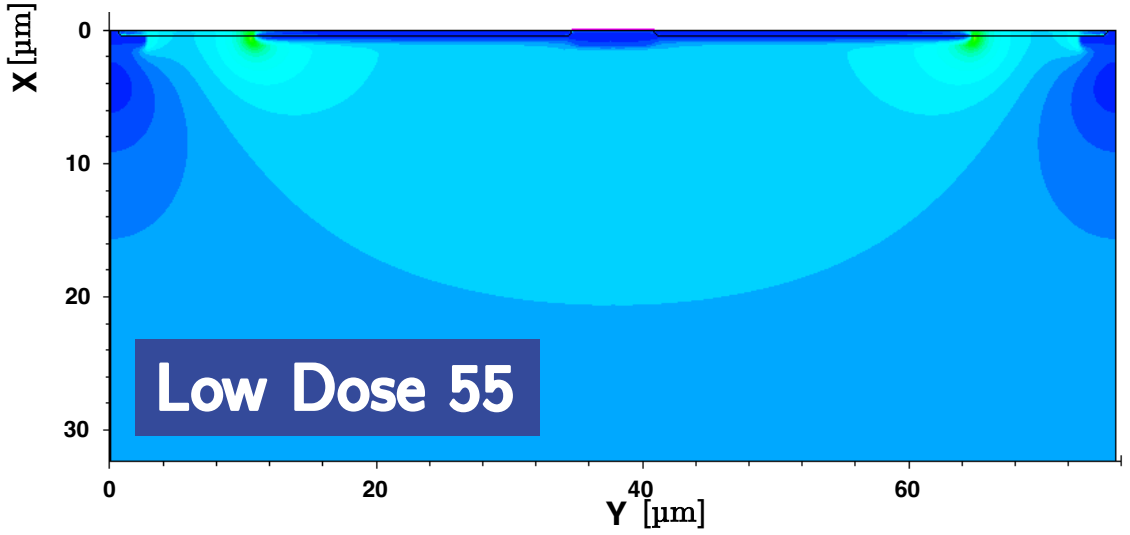
- The difference between the individual designs clearly observable

➡️ All the characteristics were studied for each design separately







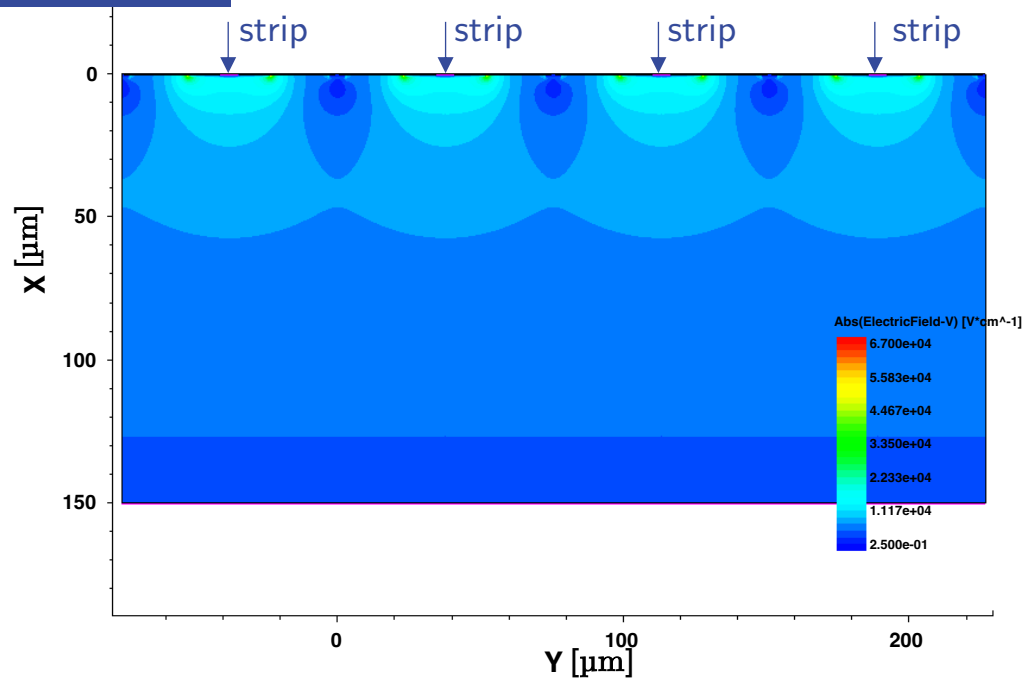


Electrical Characterization
Microscopic Characteristics at 100 V

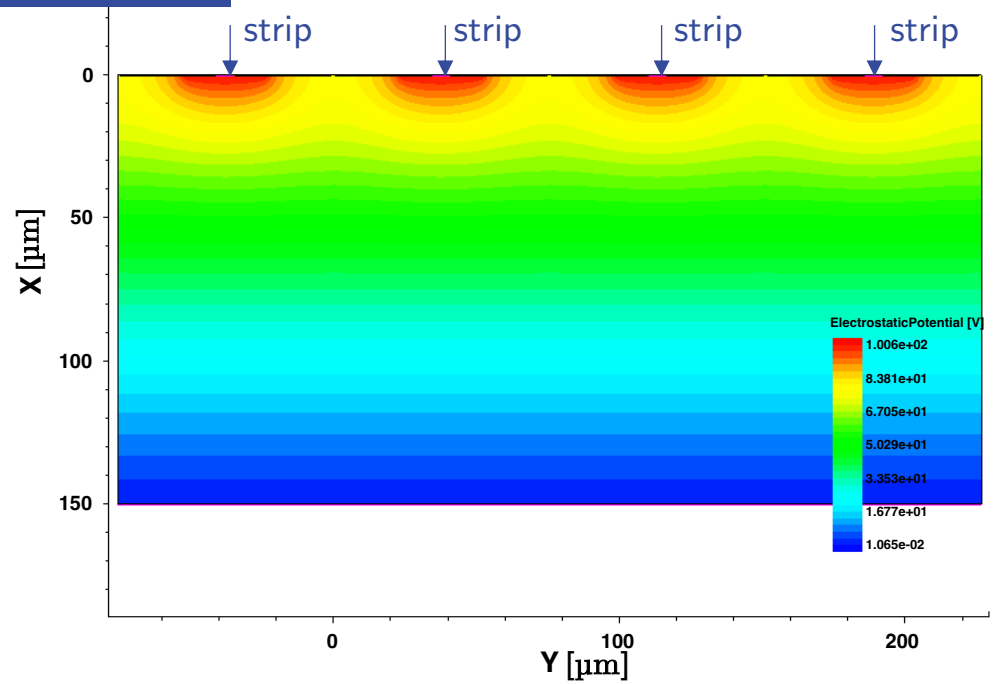
- CMOS strip sensor simulated as a 4-strip structure

➡️ enables to study effects of neighbouring strips e.g. during the charge collection

Low Dose 30 Electric Field

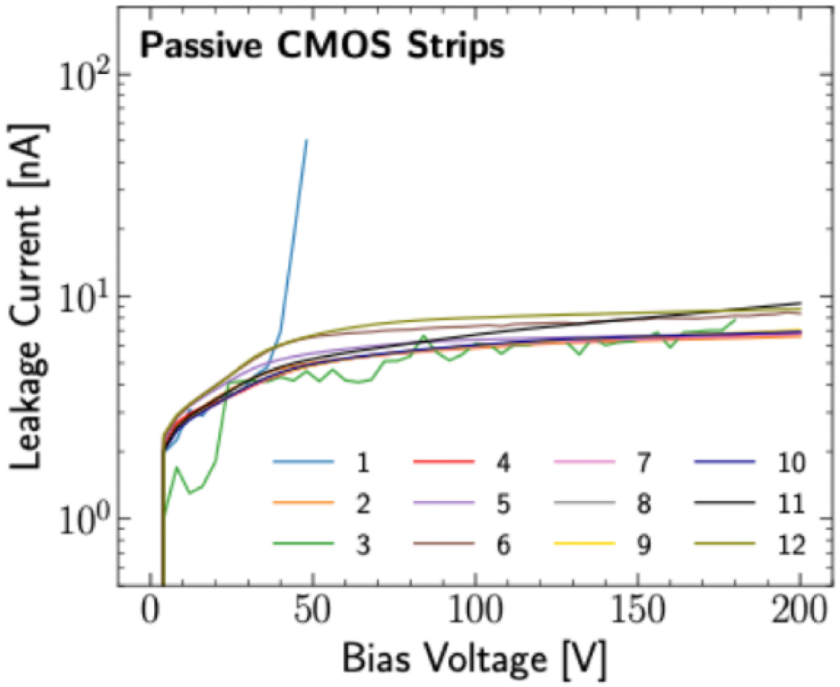


Low Dose 30 Electrostatic Potential

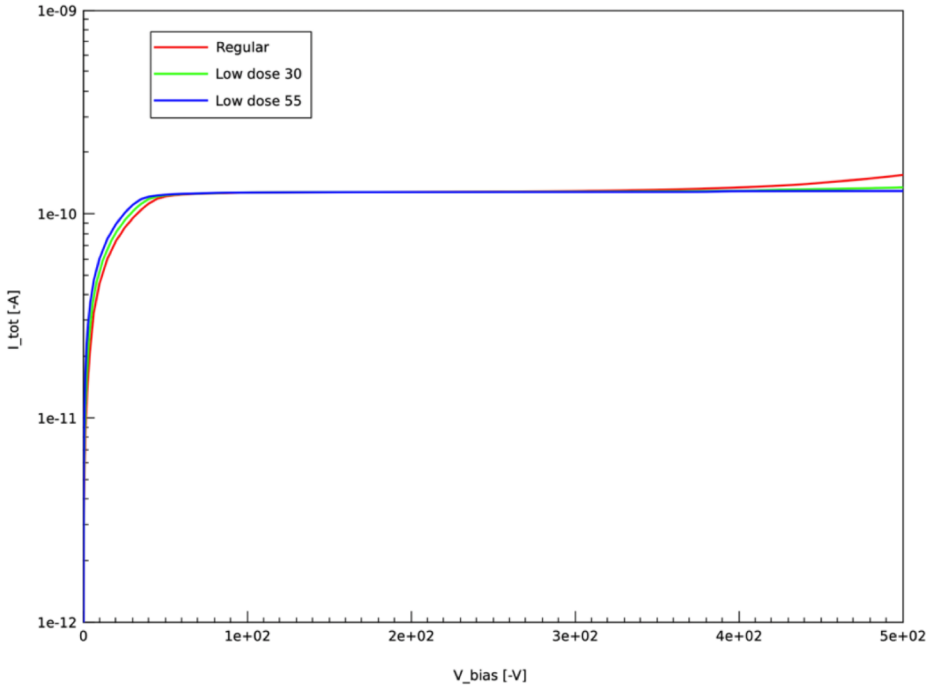


Electrical Characterization
Macroscopic Characteristics

IV Measurements



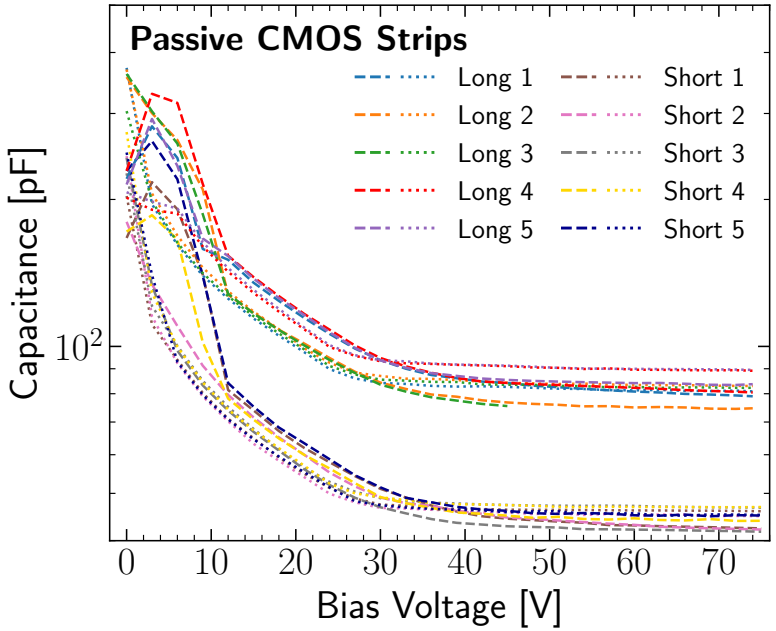
Simulations of Leakage Current



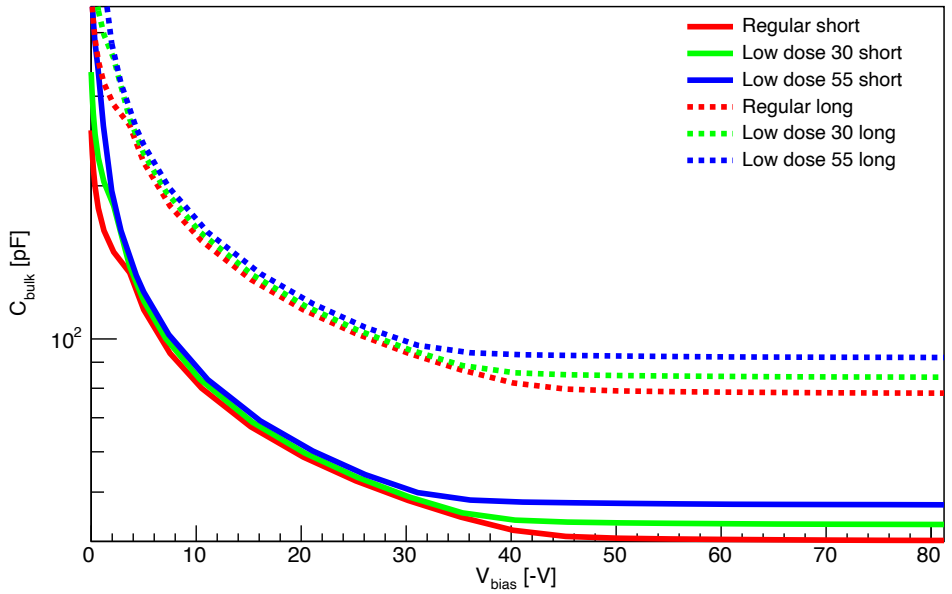
Considering that the simulation represents the ideal measurement setup with no parasitic currents ➡️ Simulated structures describe the real ones well.

Electrical Characterization
Macroscopic Characteristics

CV Measurements



Simulations of Bulk Capacitance



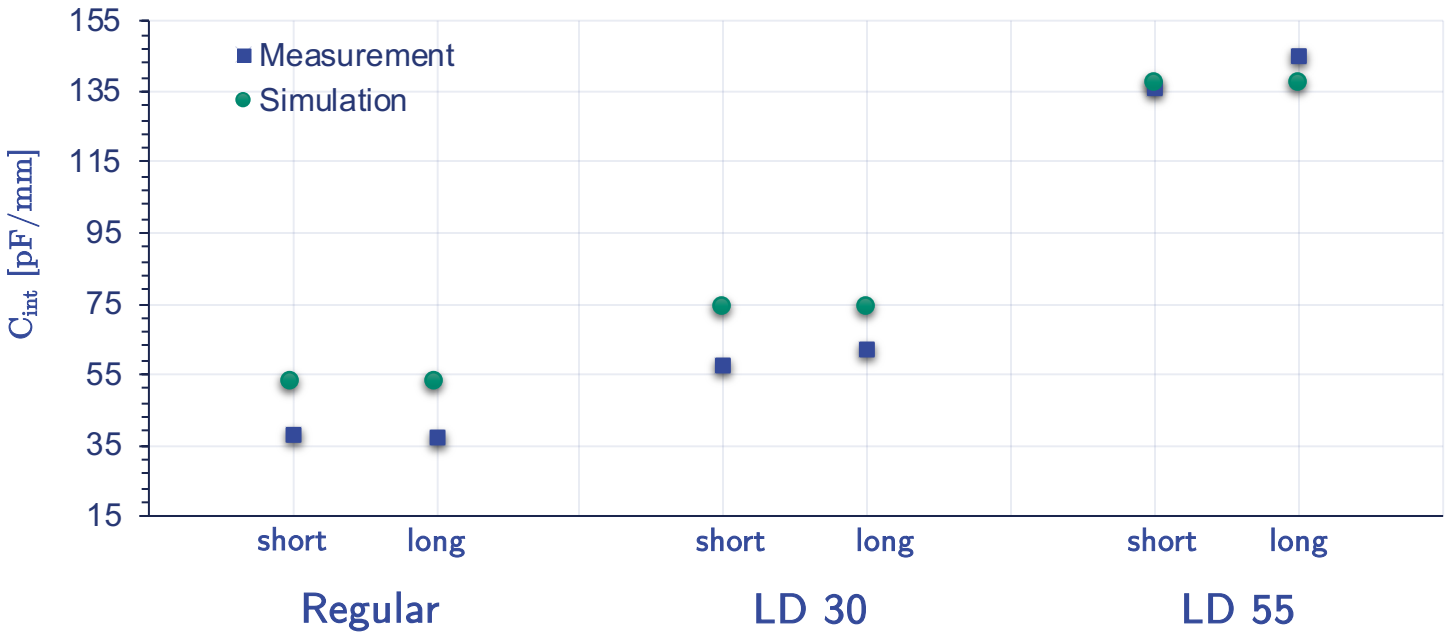
➡️ Very good agreement of measured values and results of the simulations

- Short strips $(2.1\ \mathrm{cm})$ – $C_{\mathrm{bulk}} \approx 50\ \mathrm{pF}$
- Long strips $(4.1\ \mathrm{cm})$ – $C_{\mathrm{bulk}} \approx 100\ \mathrm{pF}$

Electrical Characterization
Macroscopic Characteristics

Interstrip Capacitance C_{int} @ 500 kHz

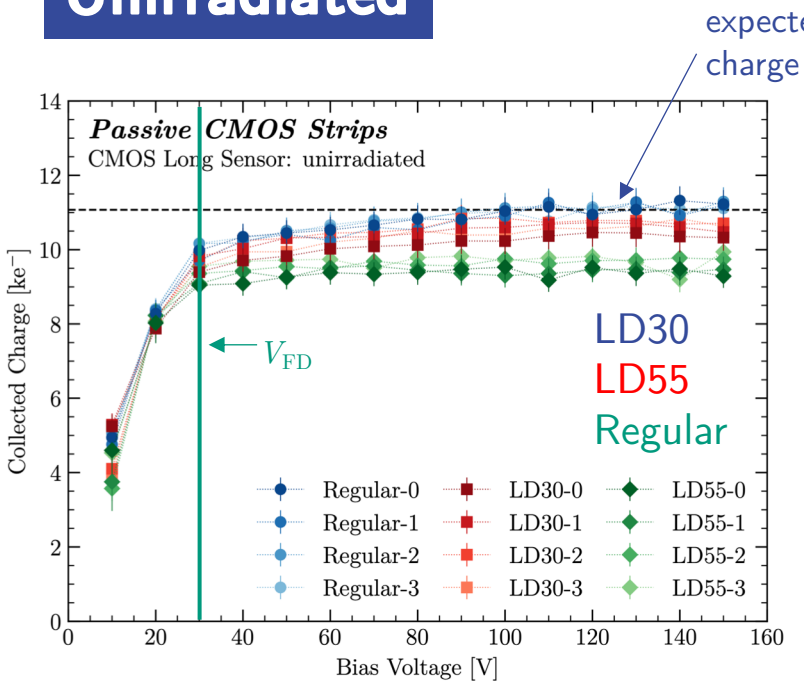
Capacitance values are means of measured/simulated values between 50 V and 80 V

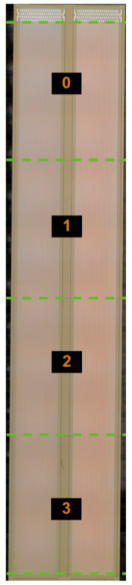


➡️ Good agreement of measured values and results of the simulations

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

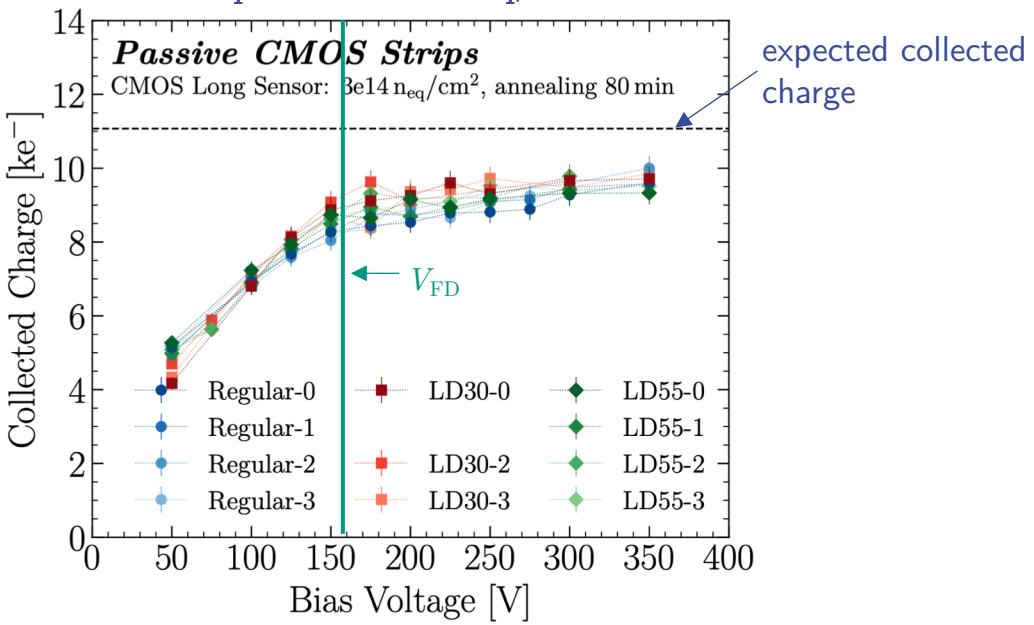
Unirradiated





Irradiated by 23 MeV neutrons

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



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

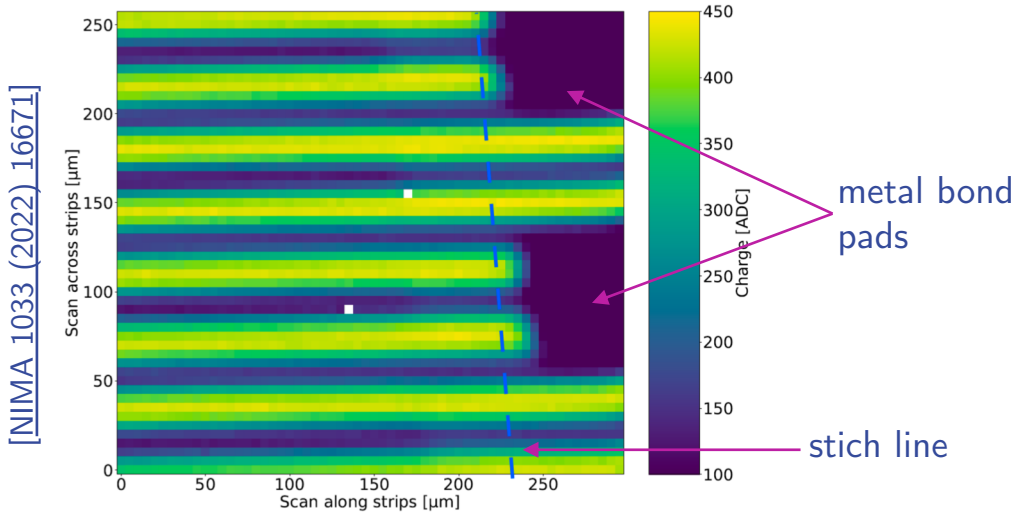
➡ Observed change in collected charge after irradiation as expected.

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

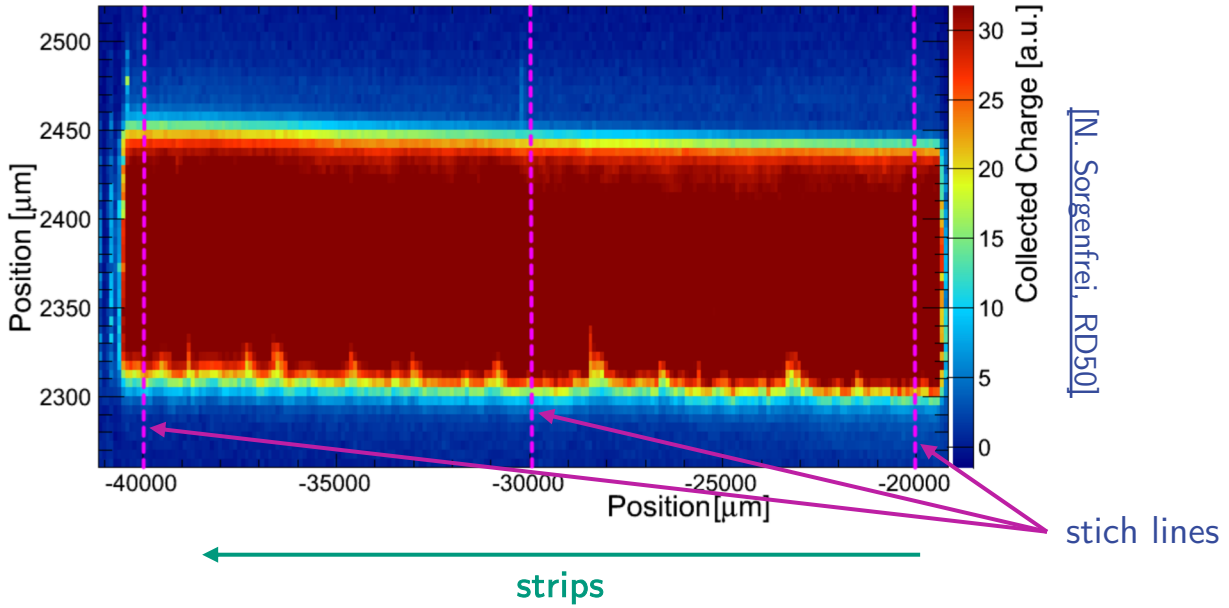
Transient Current Technique Measurements
Top- and Edge-TCT

- Collected charge as a function of the laser position

Top-TCT Regular at 50 V



Edge-TCT Low Dose 30 at 100 V

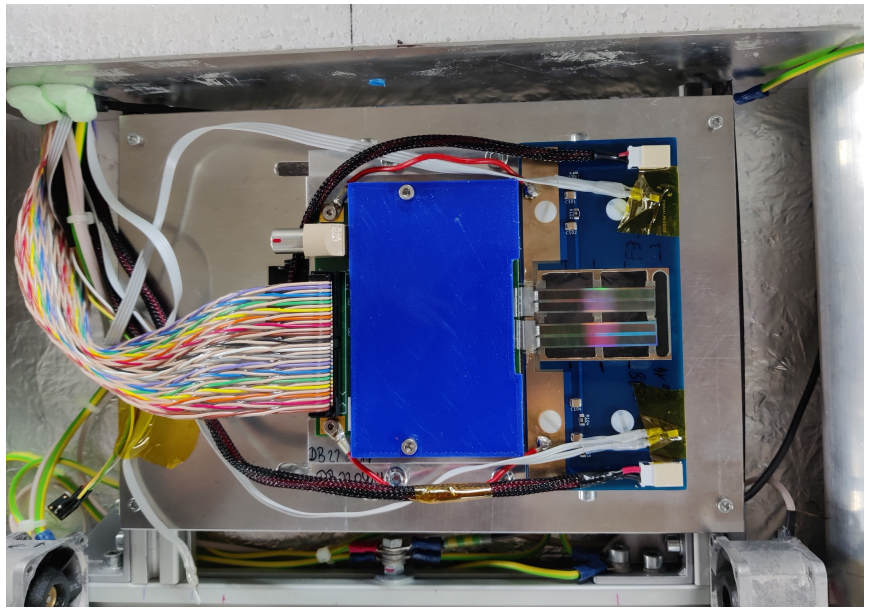


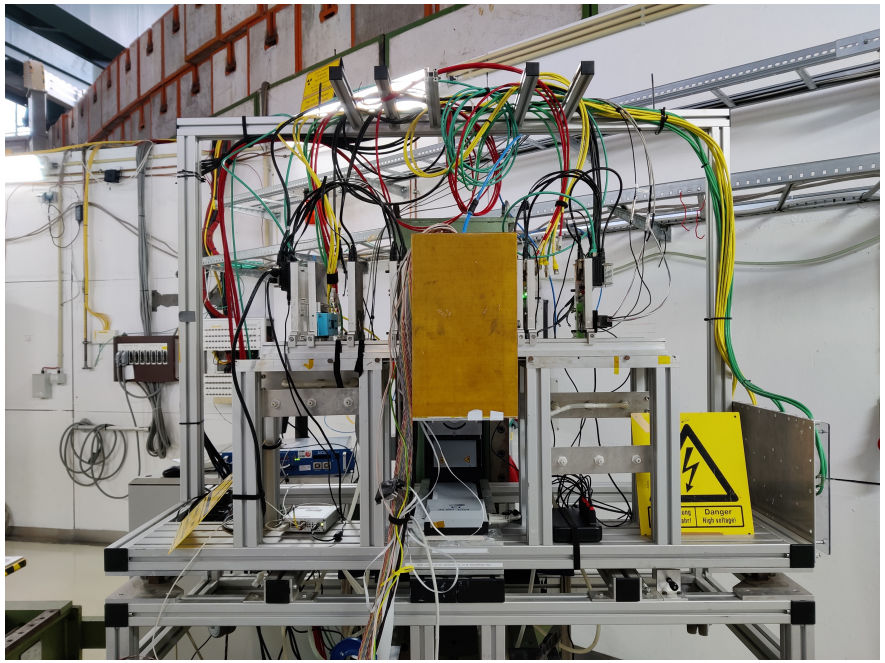
Results of both the Top- and Edge-TCT measurements show homogenous charge collection

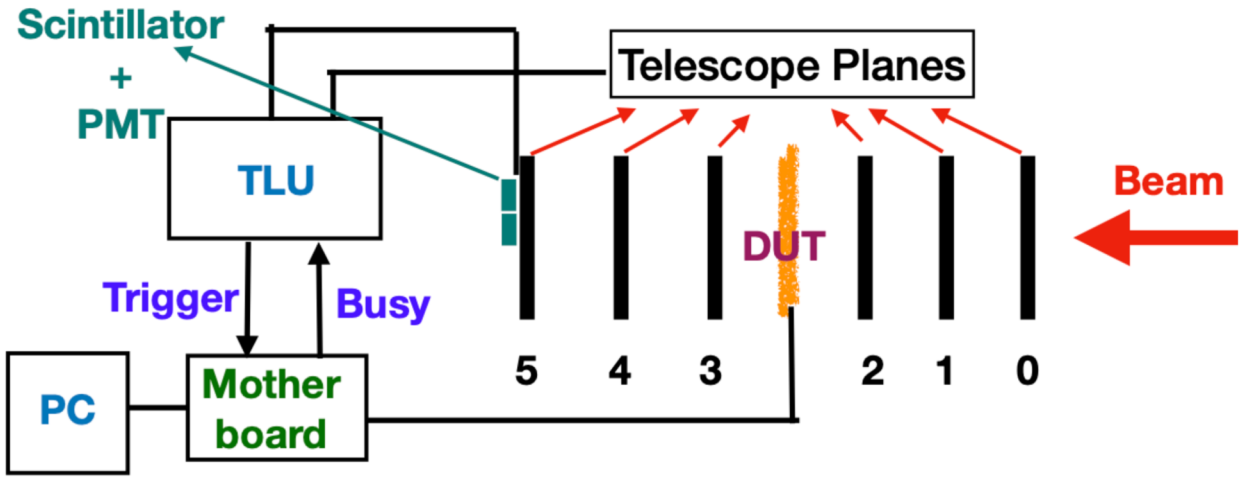
➡️ No effect of stitching observed

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

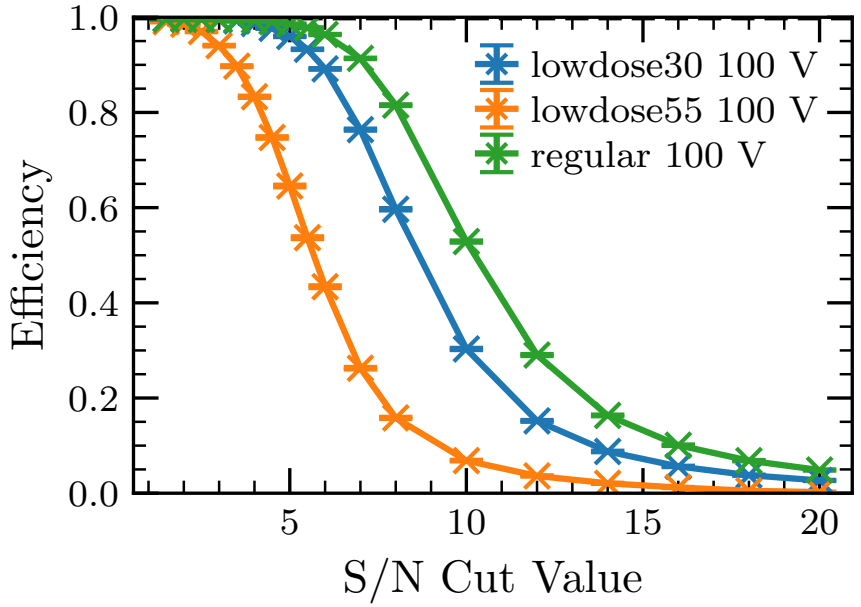






Testbeam Results
Efficiency

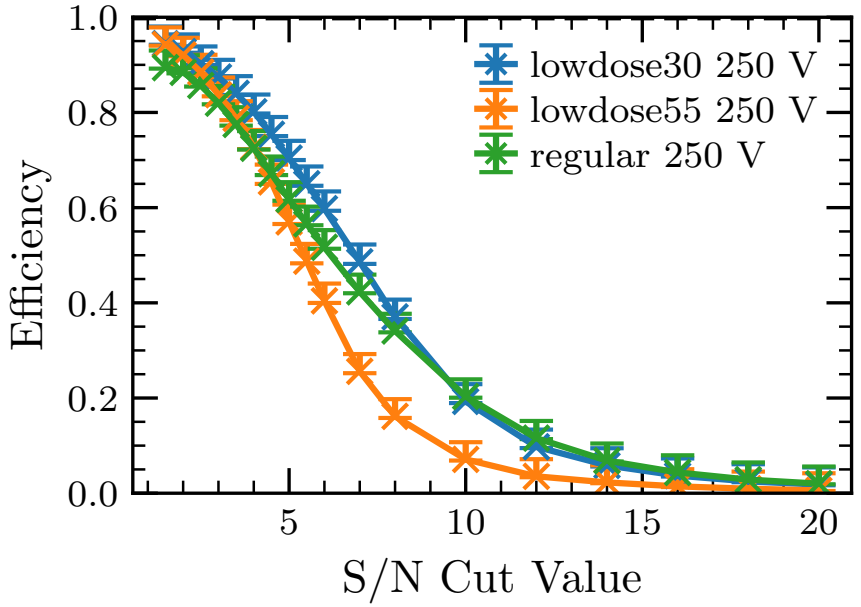
Unirradiated



➡ Expected shape of the dependence of efficiency on signal/noise cut value

Irradiated by 23 MeV neutrons

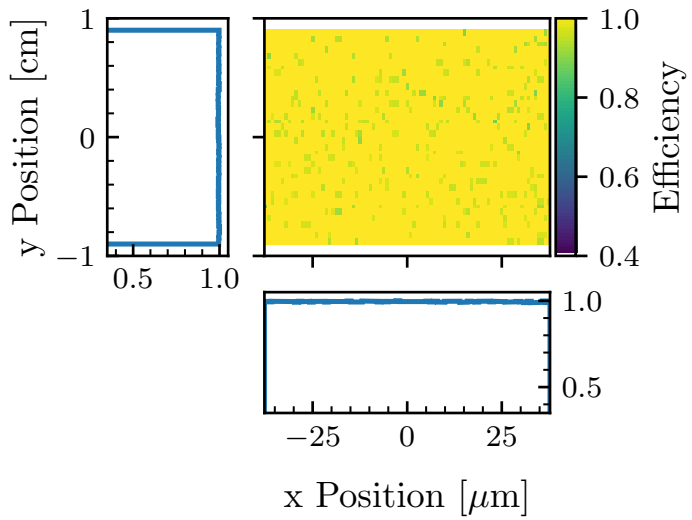
$\Phi_{eq} = 3 \cdot 10^{14}\ n_{eq}/cm^2$



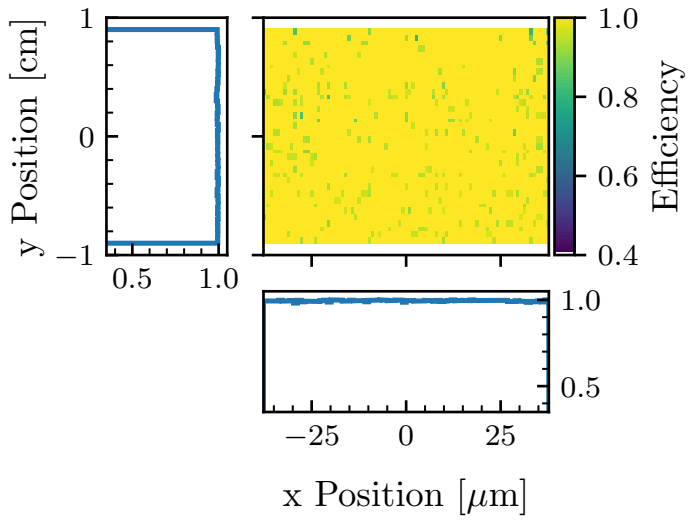
➡ Deterioration in efficiency after irradiation observed for all three designs

Testbeam Results
Efficiency of Unirradiated Sensors

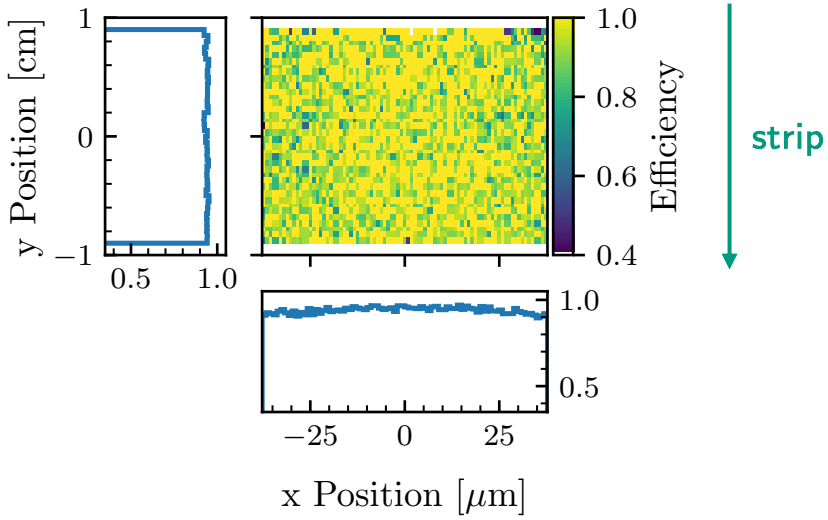
Regular



Low Dose 30



Low Dose 55



➡ **Regular & Low Dose 30** efficiency close to 1 over the entire area

➡ **Low Dose 55** slightly lower over all efficiency, minor decrease towards the interstrip region

- Small fluctuations due to limited available statistics

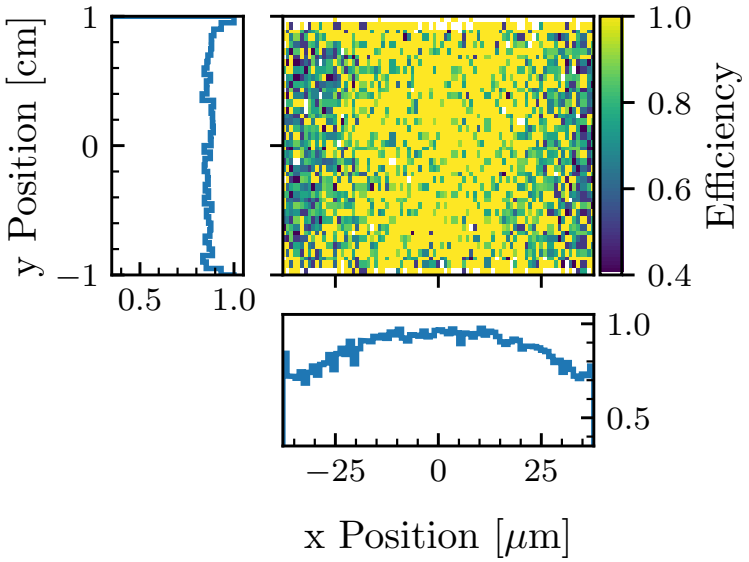
➡ **No change in efficiency observed due to the stitches**

Testbeam Results
Efficiency of Irradiated Sensors

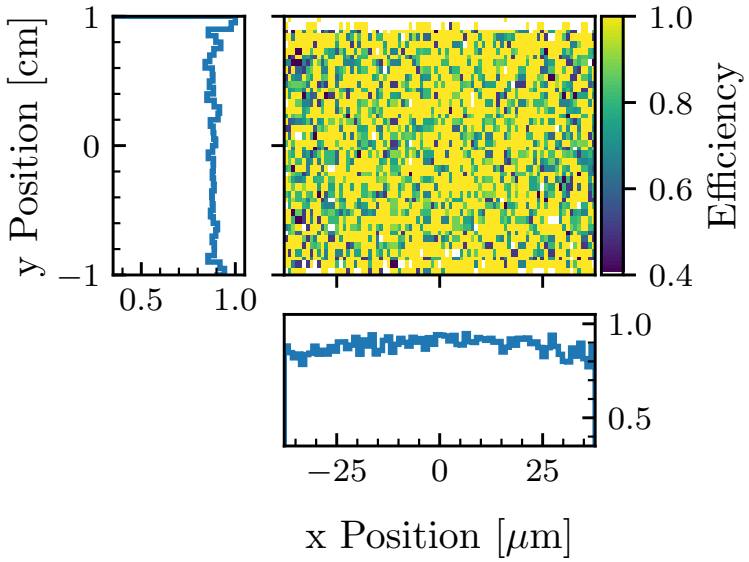
$\Phi_{eq} = 3 \cdot 10^{14}\ n_{eq}/cm^2$

Irradiated by 23 MeV neutrons

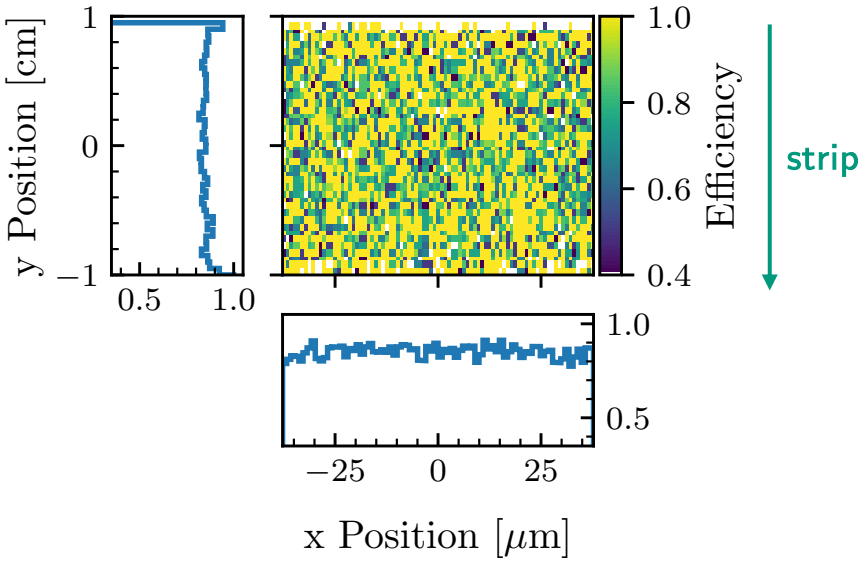
Regular



Low Dose 30



Low Dose 55



➡ Decrease in efficiency towards the interstrip region for the **Regular** design

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

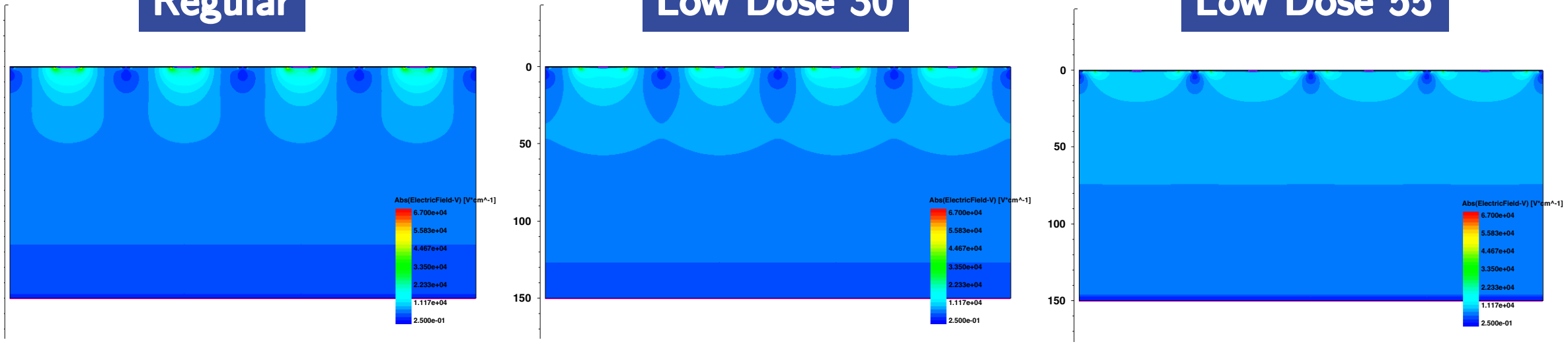
Conclusions and Future Outlook

- Passive CMOS strip sensors fabricated in LFoundry in a 150 nm process
- Up to 5 stitches used to achieve 2.1 and 4.1 cm strip lengths
- Electrical characteristics measured and investigated by TCAD simulations
- Several testbeam campaigns carried out in order to evaluate charge collection efficiency
- **No effect of stitching on the performance of the strip detectors before and after irradiation was observed**
- Design of the new sensors with implemented electronics in progress

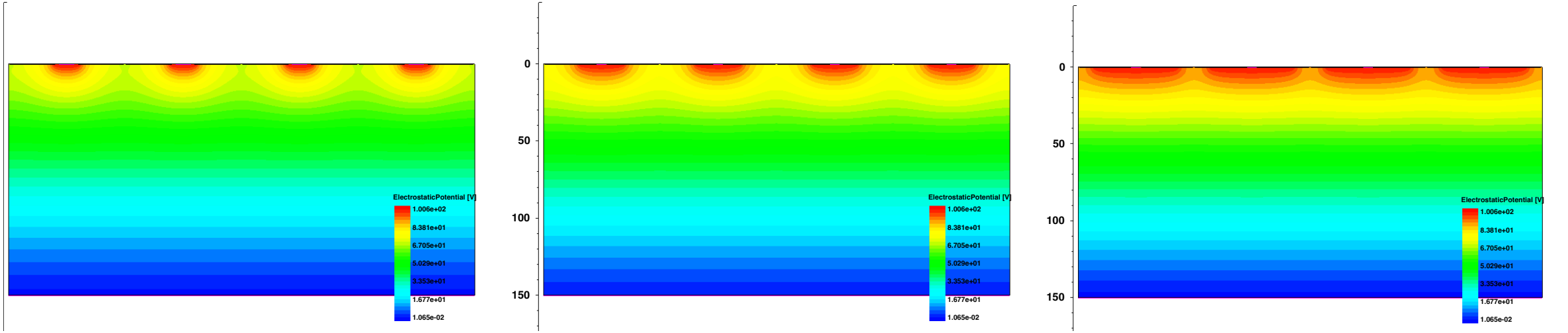
Electrical Characterization
Microscopic Characteristics at 100 V

Regular | **Low Dose 30** | **Low Dose 55**

Electric Field



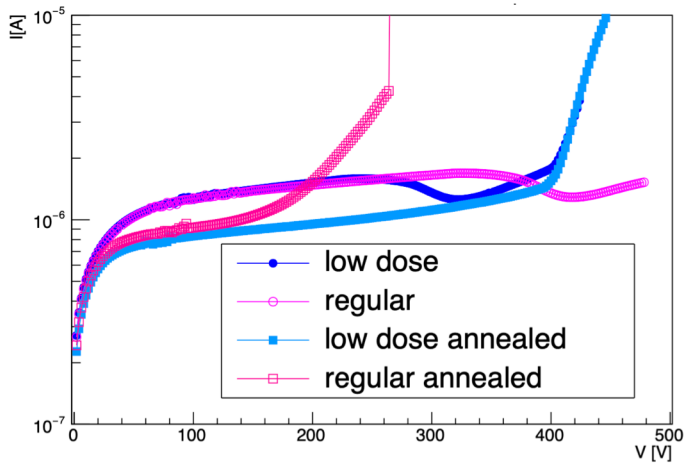
Electrostatic Potential

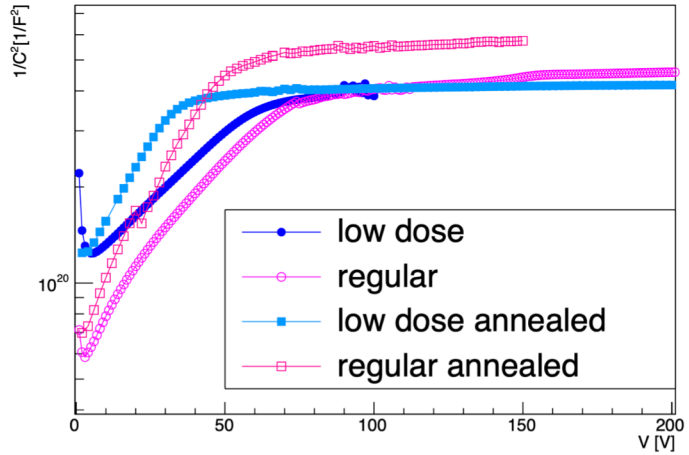


Irradiated CMOS Strip Sensors
IV&CV Measurements

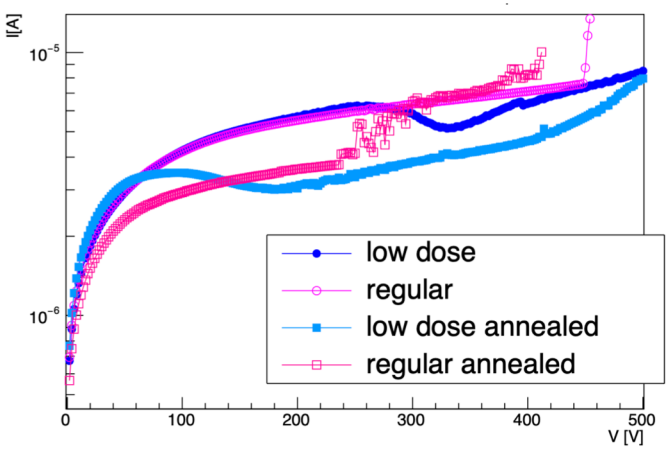
- Sensors irradiated by 23 MeV protons at KIT
- CVs measured using frequency of 1 kHz

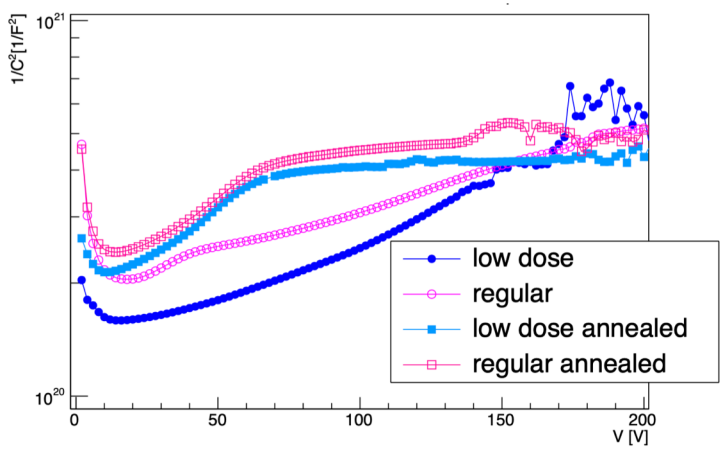
$\Phi_{eq} = 1 \cdot 10^{14}\ n_{eq}/cm^2$





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

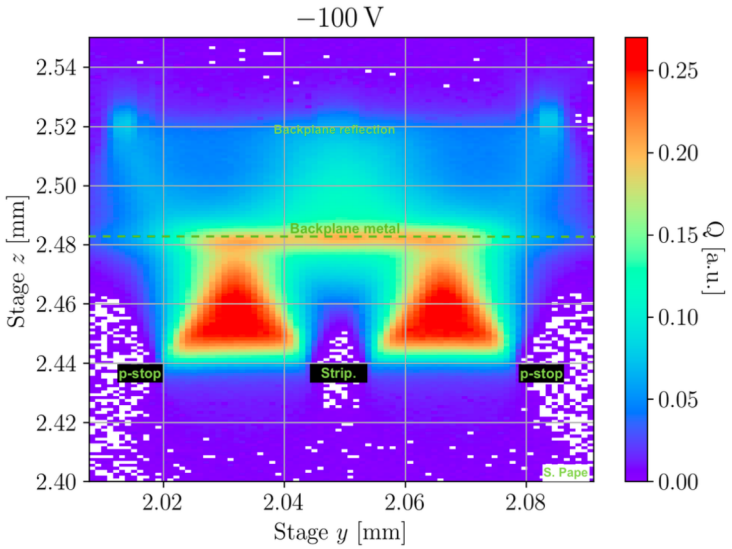




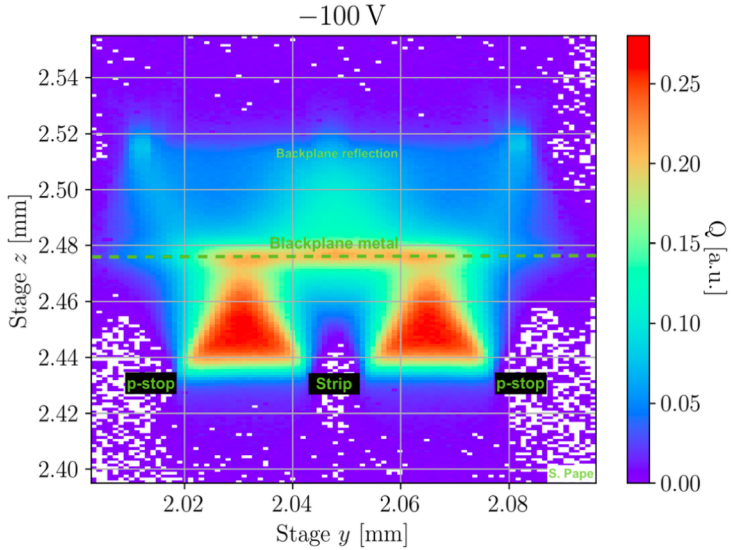
Transient Current Technique Measurements
Two Photon Absorption-TCT

- TPA-TCT measurements performed at CERN SSD [setup]

In the Stitch Area



Outside the Stitch Area



➡️ No difference in the charge measured in and outside the stitched area