universität freiburg

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

Iveta Zatocilova iveta.zatocilova@cern.ch

Jan-Hendrik Arling, Marta Baselga, Naomi Davis, Leena Diehl, Jochen Dingfelder, Ingrid-Maria Gregor, Marc Hauser, Tomasz Hemperek, Fabian Hügging, Karl Jakobs, Michael Karagounis, Roland Koppenhöfer, Kevin Alexander Kröninger, Fabian Simon Lex, Ulrich Parzefall, Arturo Rodriguez Rodriguez, Birkan Sari, Niels Sorgenfrei, Simon Spannagel, Dennis Sperlich, Tianjang Wang, Jens Weingarten

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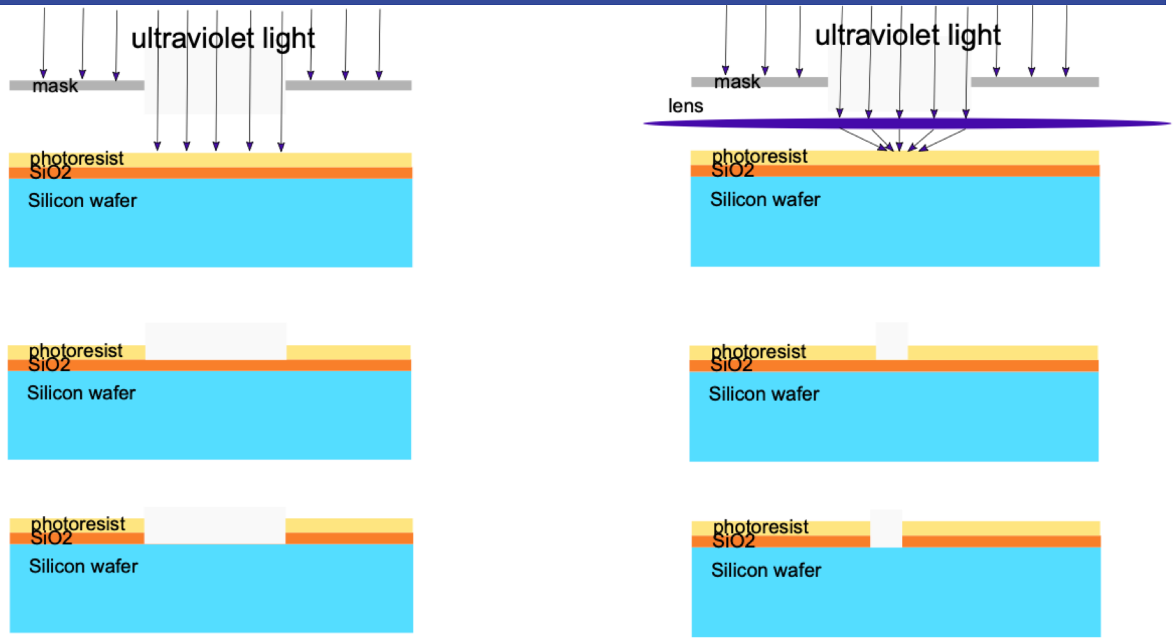
Motivation

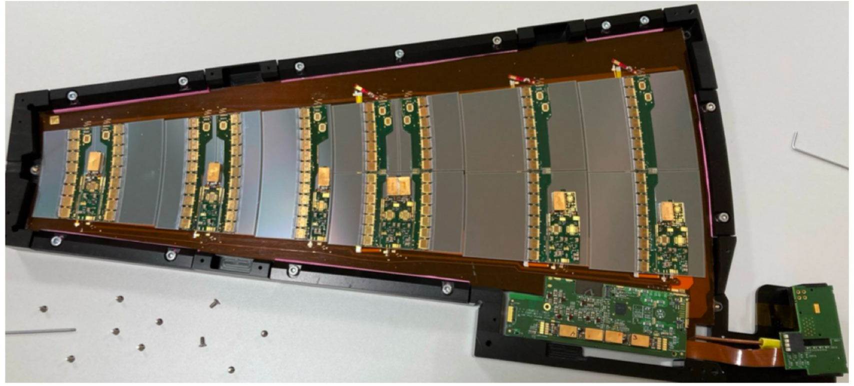
All the ATLAS and CMS upgrade strip detectors are being fabricated by Hamamatsu Photonics

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

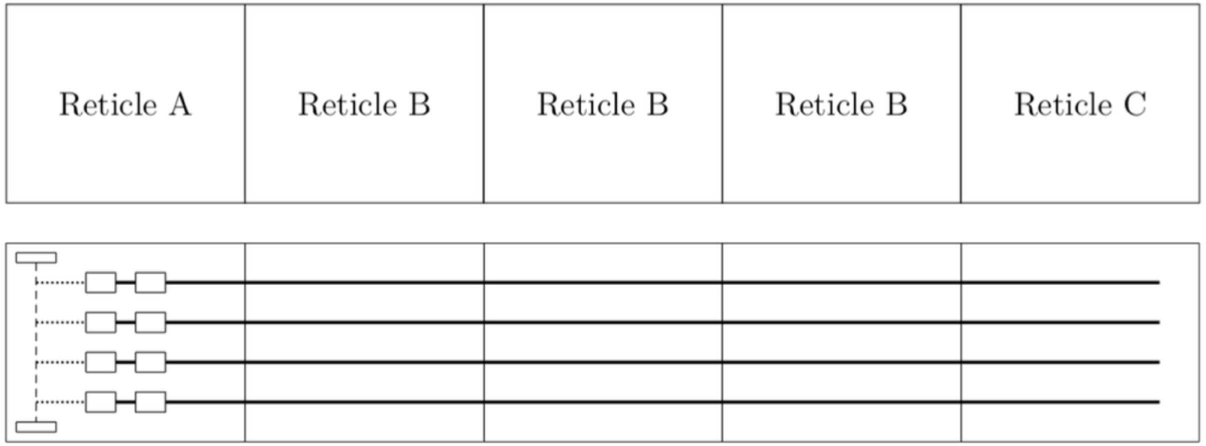
150 µm thick silicon wafer

Two lengths of strips 2.1 and 4.1 cm

- 1 cm^2 reticle used → strips had to be stitched
- Up to five stitches in each sensor

Three different designs

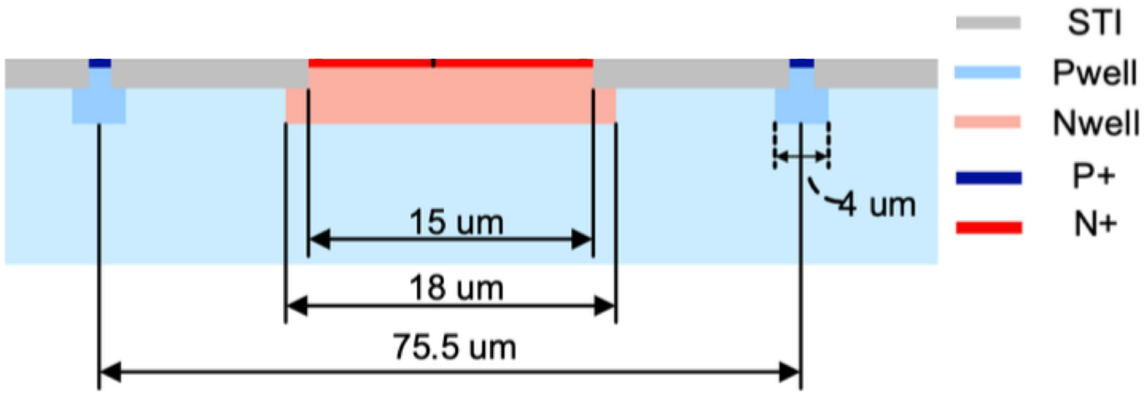
- **Regular** – similar to the ATLAS strip design
- **Low dose 30 & 55** – low dose implant and NIM capacitor



Passive CMOS Strips
Three different designs

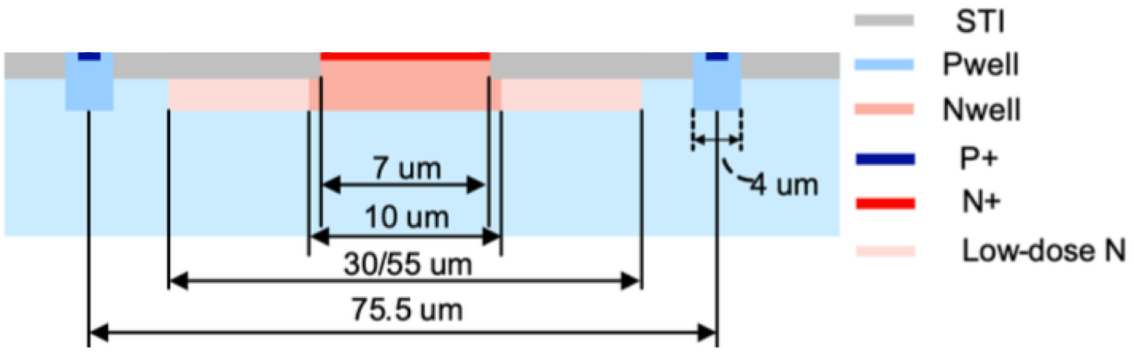
Regular

➡️ similar to the ATLAS strip design



Low Dose 30 & 55

➡️ low dose implant and NIM capacitor



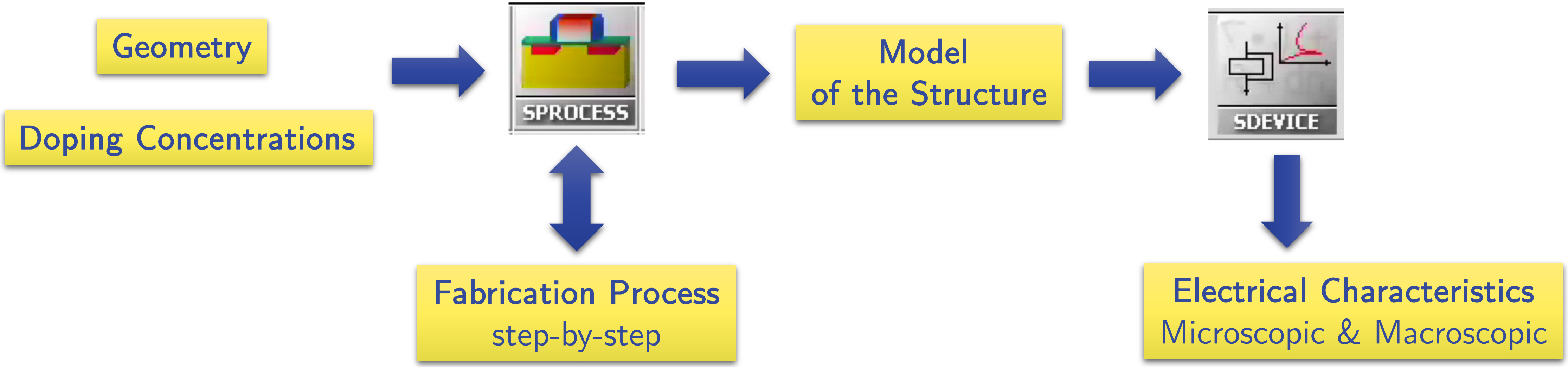
Simulations of CMOS Strips
Using Sentaurus TCAD

Done in order to investigate our silicon structures in detail

Both the fabrication process and electrical characteristics were simulated

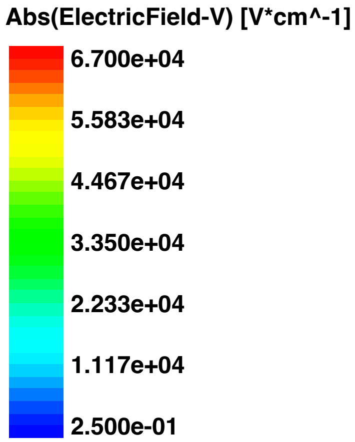
All three designs simulated as 2D strip segment

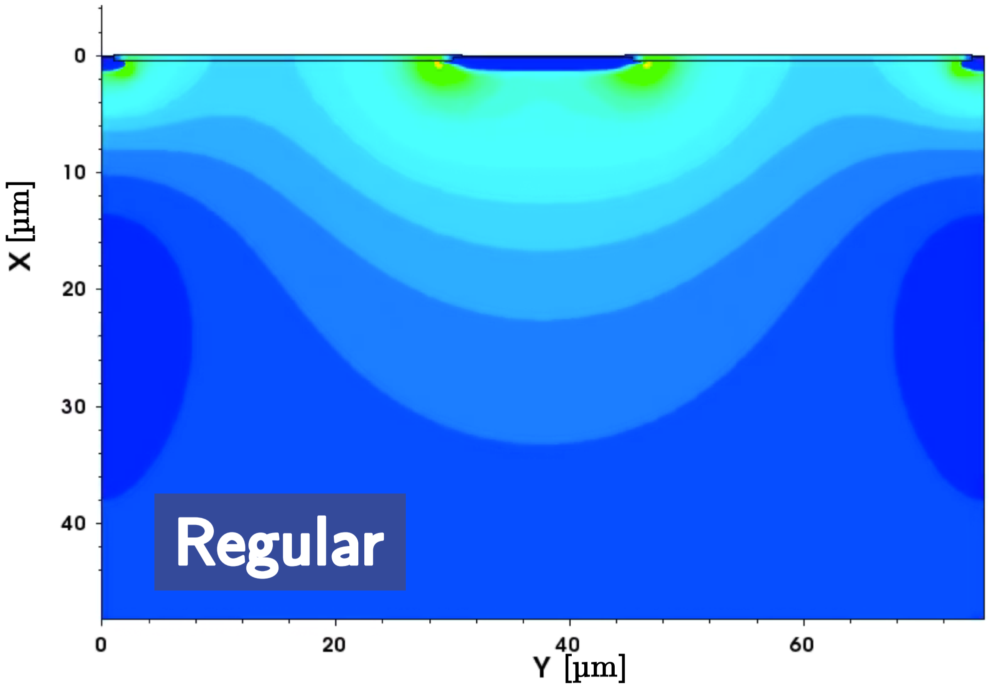
Results scaled in order to be comparable to the measurements

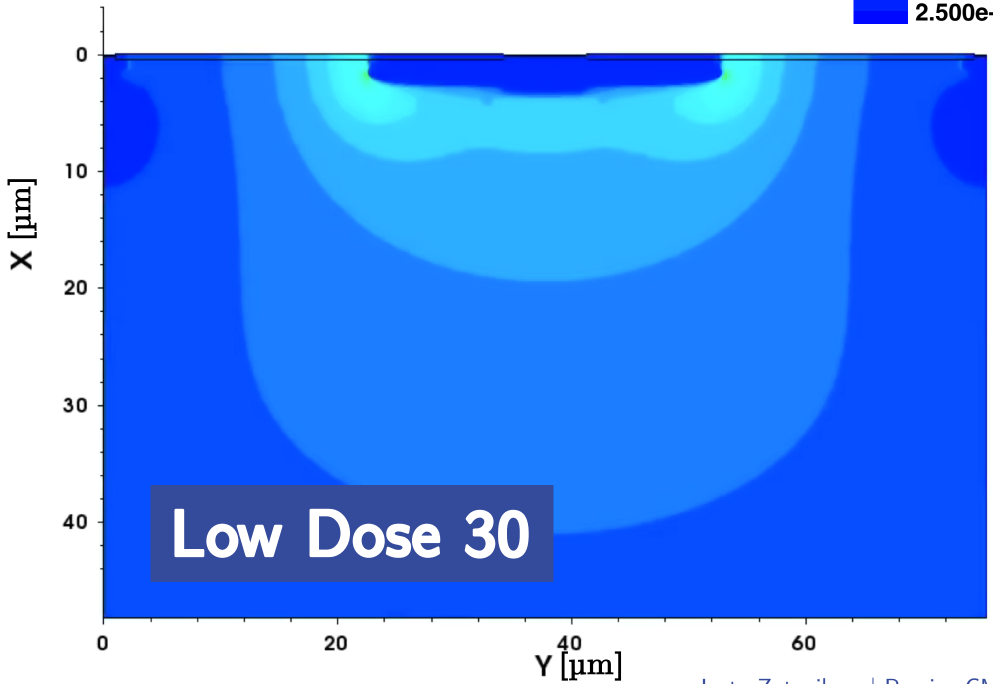


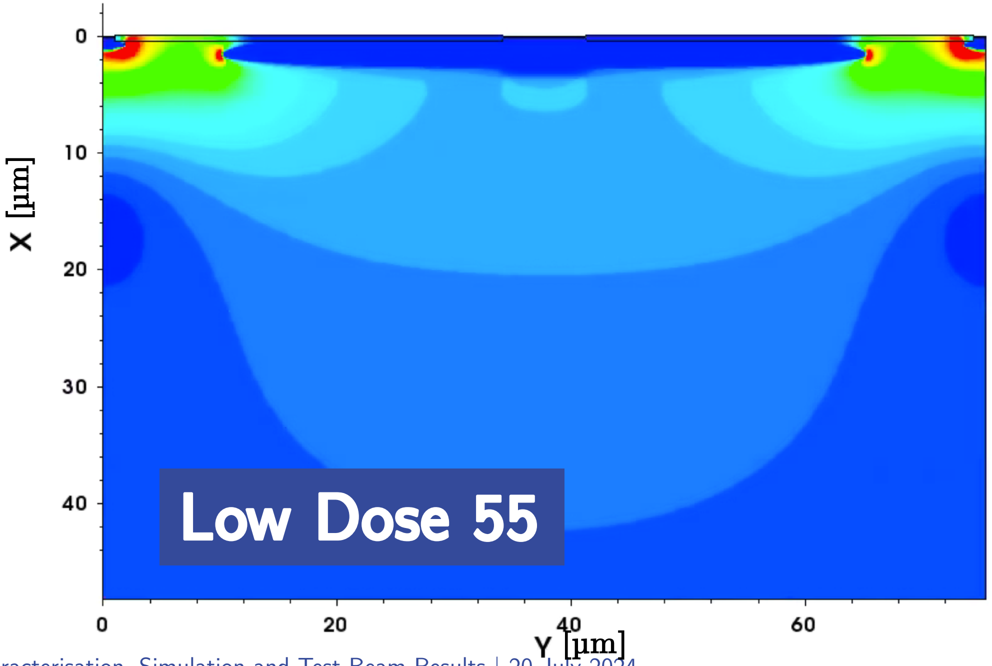
Electrical Characterization
Detail of the Electric Field at 100 V

➡️ The difference between the individual designs clearly observable

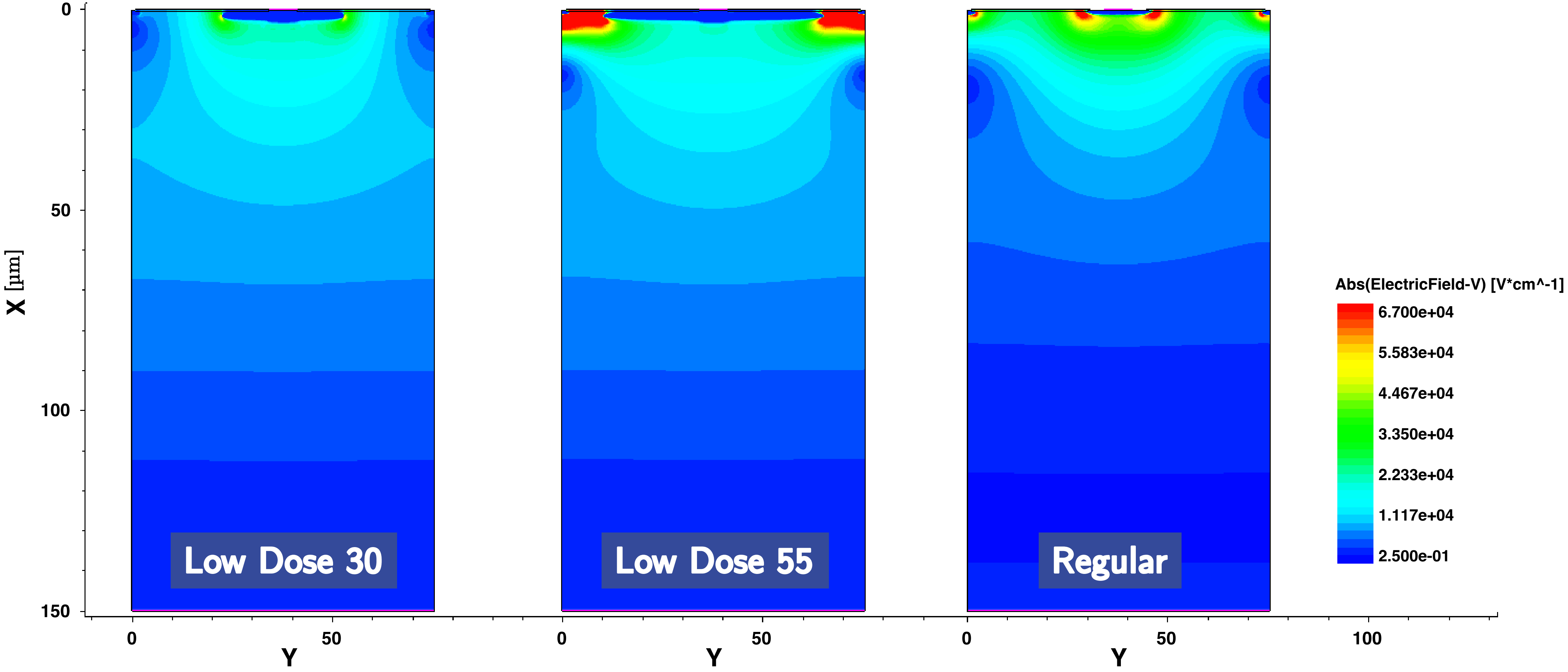






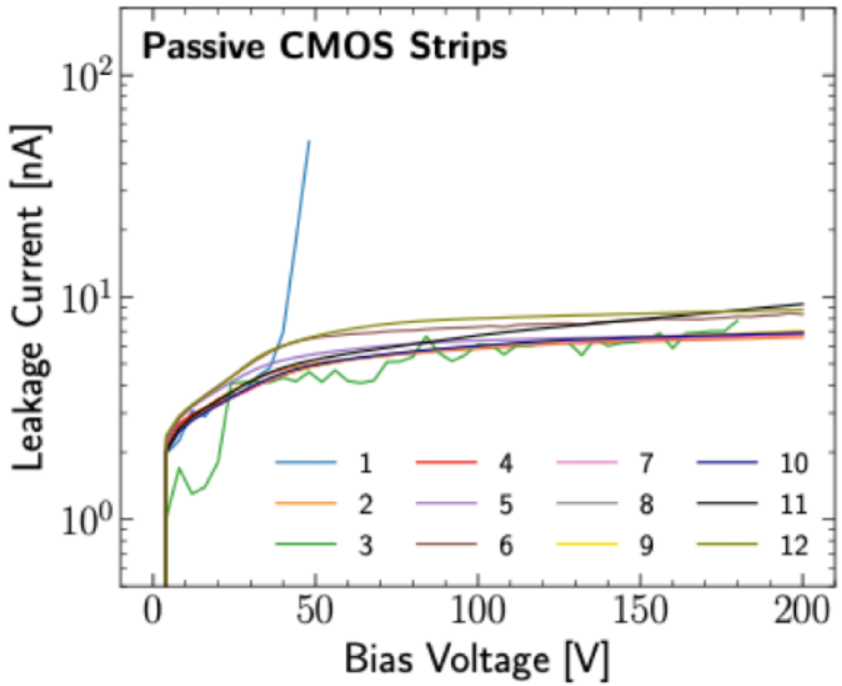


Electrical Characterization
Electric Field at 100 V



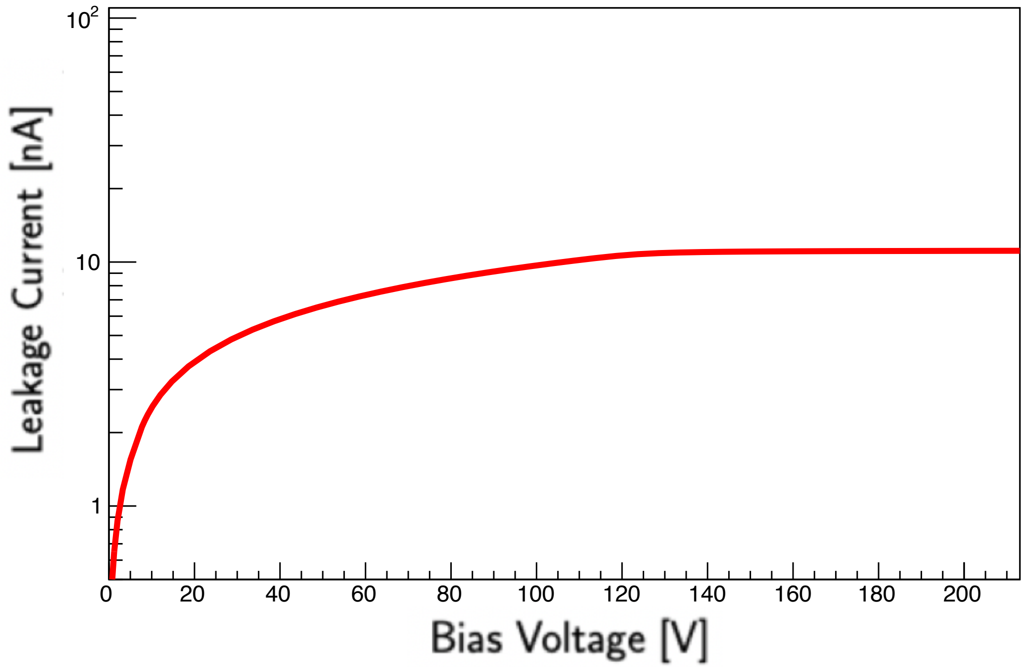
Electrical Characterization
Macroscopic Characteristics

IV Measurements



Good agreement of measured values and results of the simulations

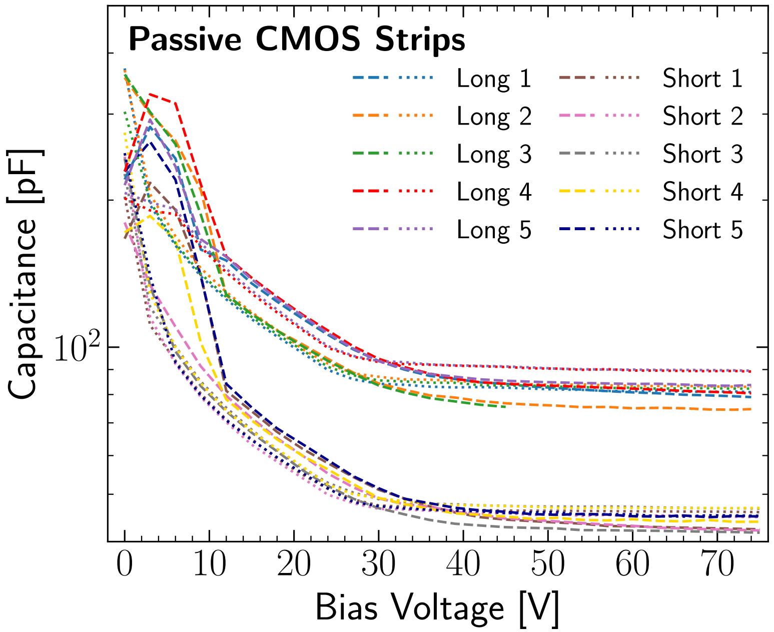
Simulations of Leakage Current



➡️ Simulated structures describe the real ones well

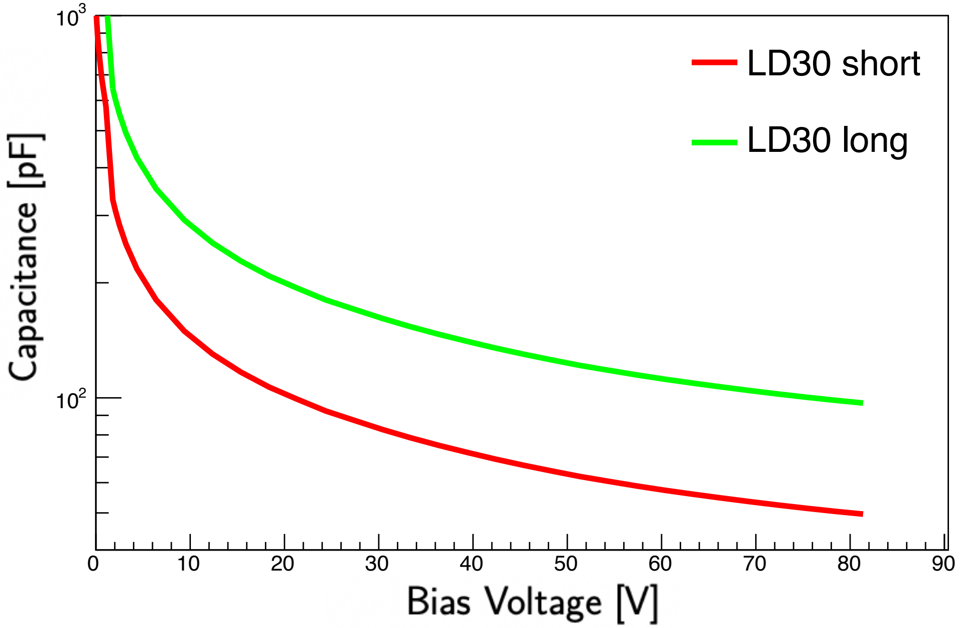
Electrical Characterization
Macroscopic Characteristics

CV Measurements



➡️ **Discrepancy between simulation and measurement needs to be further investigated**

Simulations of Bulk Capacitance

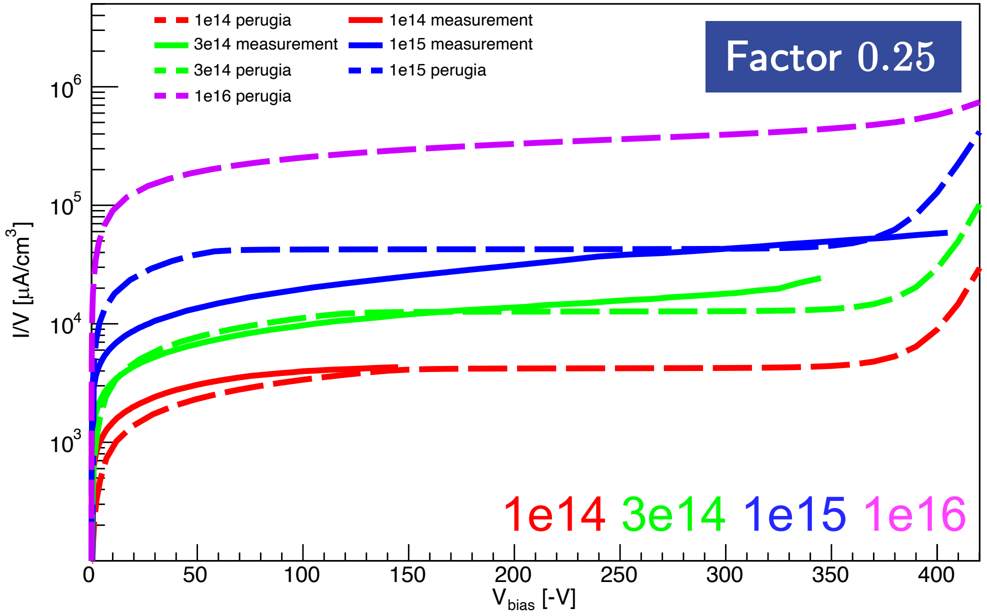


Short strips (2.1 cm) – $C_{\text{bulk}} \approx 50$ pF

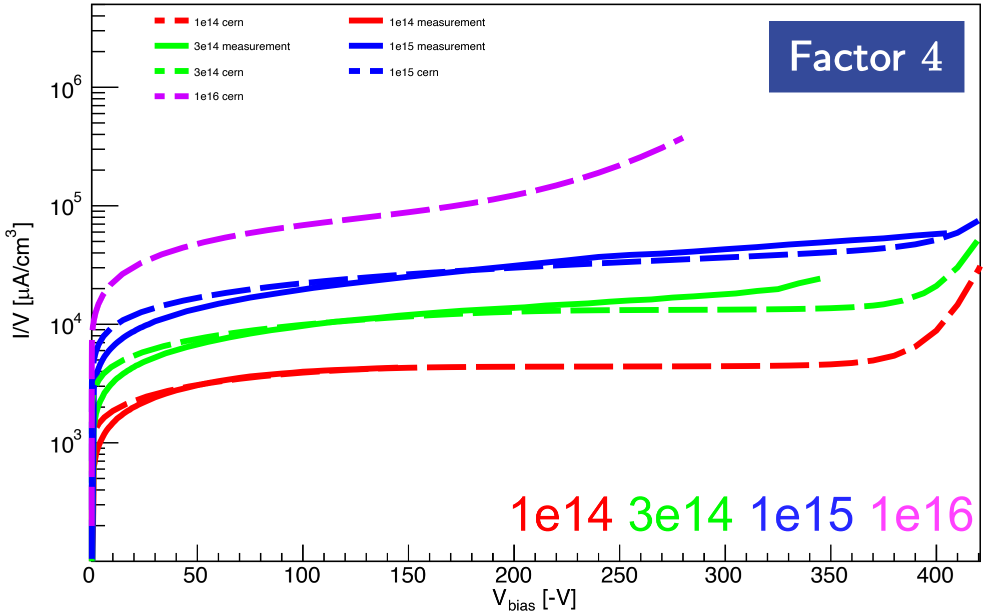
Long strips (4.1 cm) – $C_{\text{bulk}} \approx 100$ pF

Radiation Models in TCAD
Leakage Current after Irradiation

LHCb/CERN Bulk +Perugia Surface Model



Perugia Bulk +Surface Model



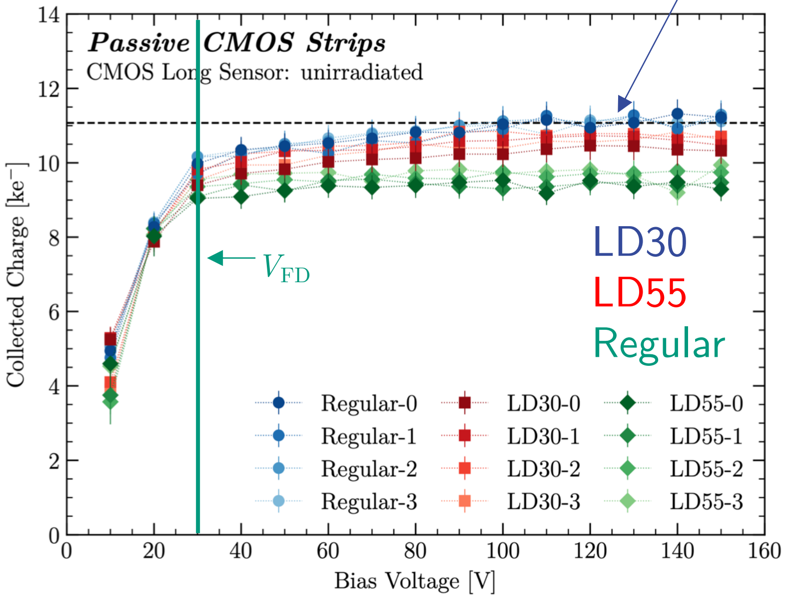
Irradiated structures can be studied in detail

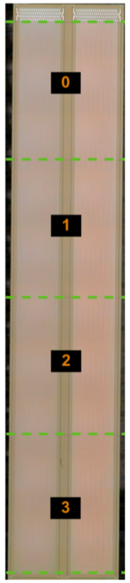
Both bulk and surface damage defects modeled

➡️ Within the factor the trends of increasing currents with irradiation described well

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

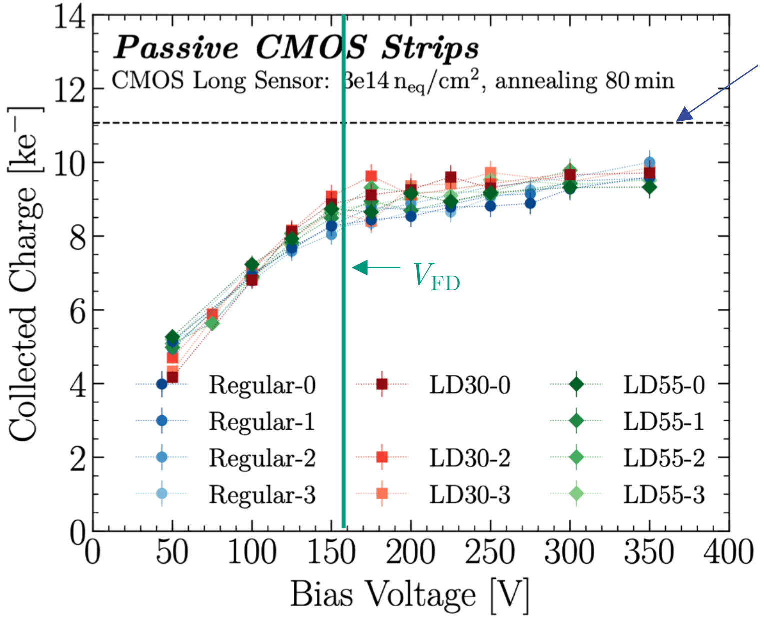
Unirradiated





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

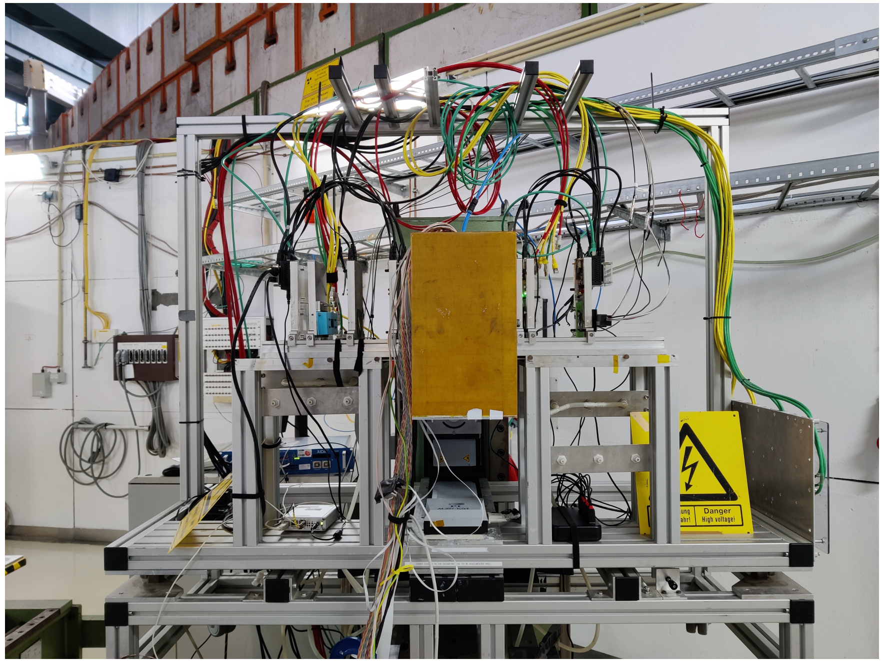
➡️ Increase of full depletion voltage V_{FD} after irradiation

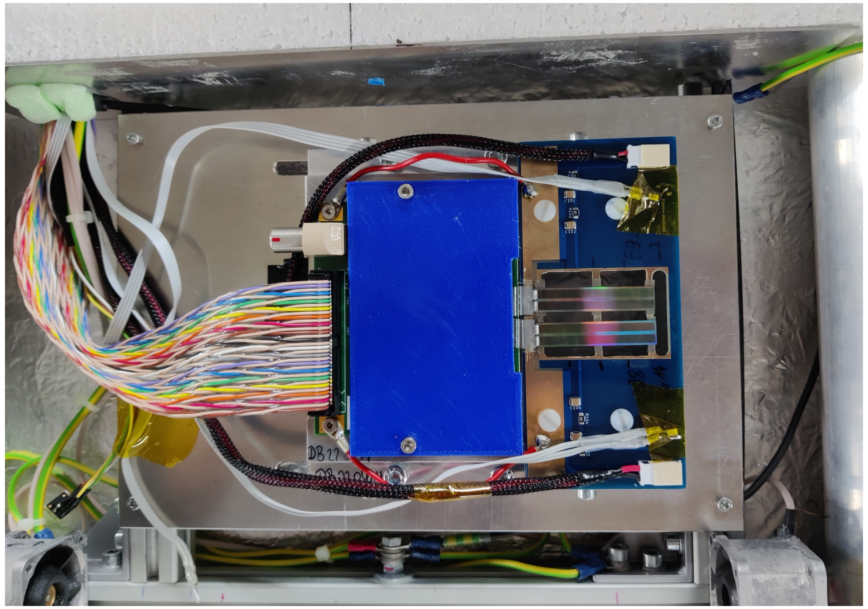
Testbeam Campaigns
Done at DESY

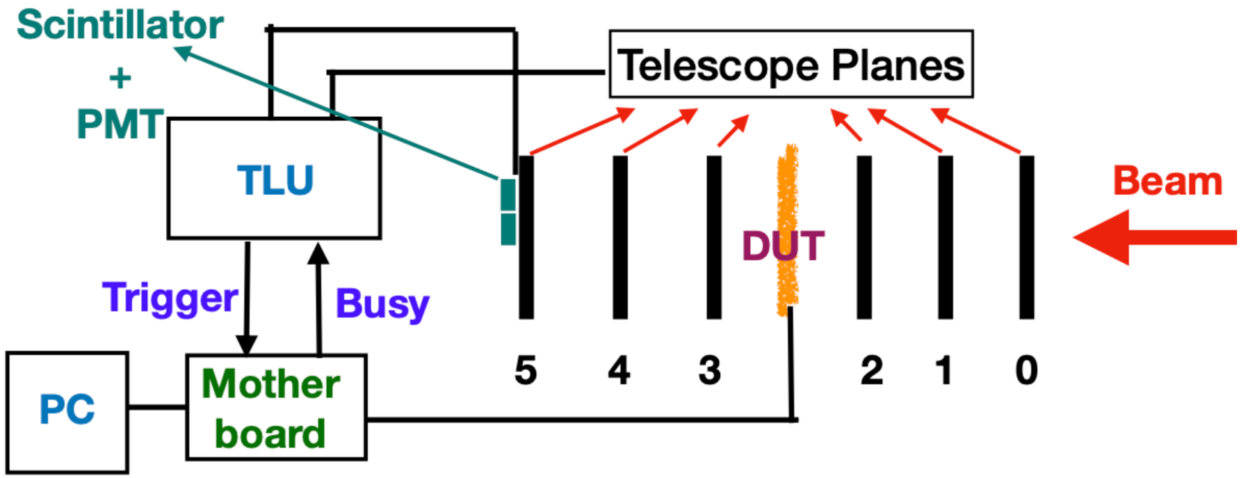
Several testbeam campaigns took place at DESY

Electron beam energies 3.4 and 4.2 GeV

Data acquisition using ALiBaVa setup

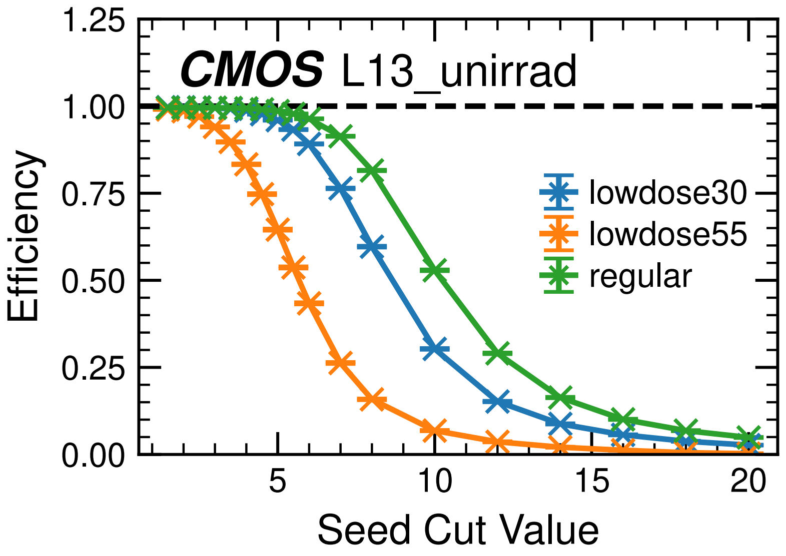






Testbeam Results
Efficiency

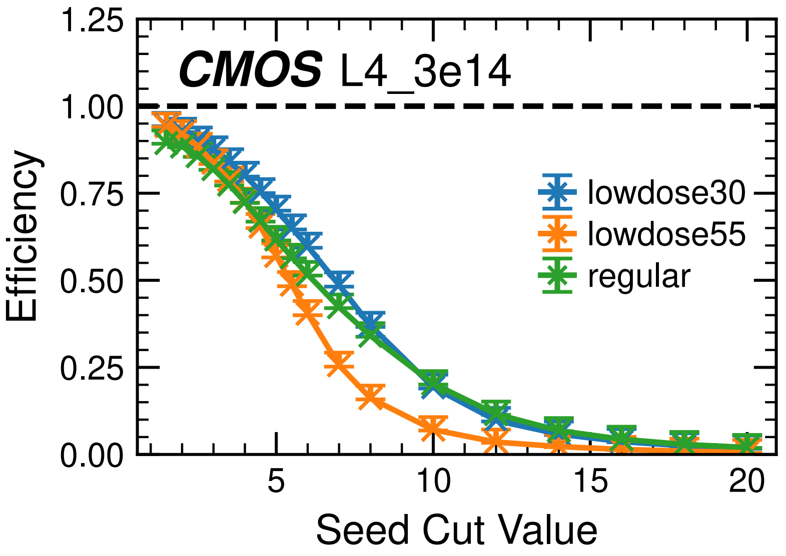
Unirradiated



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

Neutron Irradiated

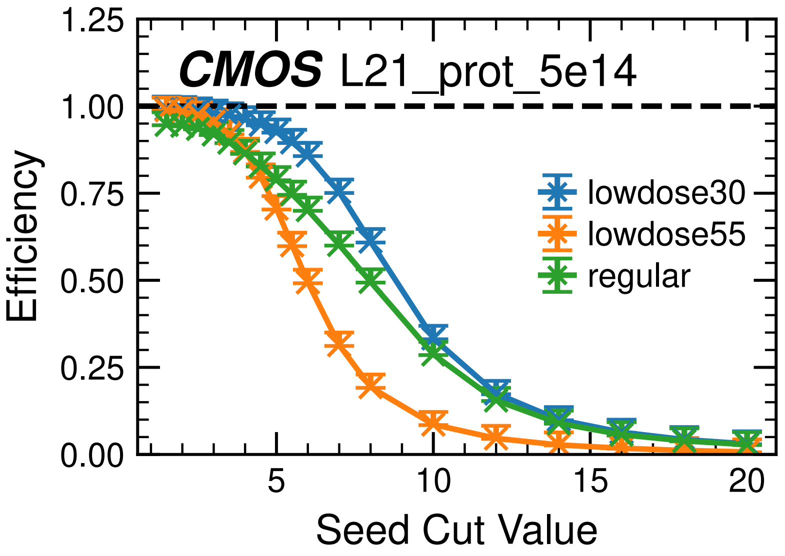
$\Phi_{eq} = 3 \cdot 10^{14}\ n_{eq}/cm^2$



➡️ Clear deterioration in efficiency after irradiation

Proton Irradiated

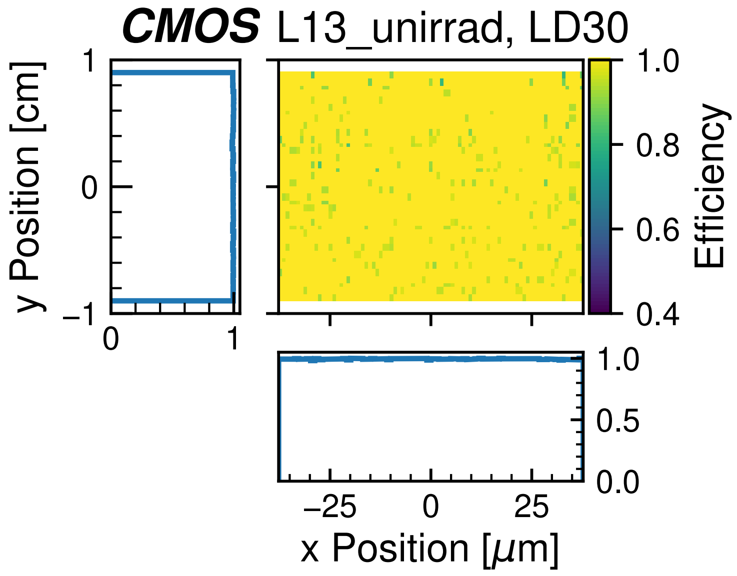
$\Phi_{eq} = 5 \cdot 10^{14}\ n_{eq}/cm^2$



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

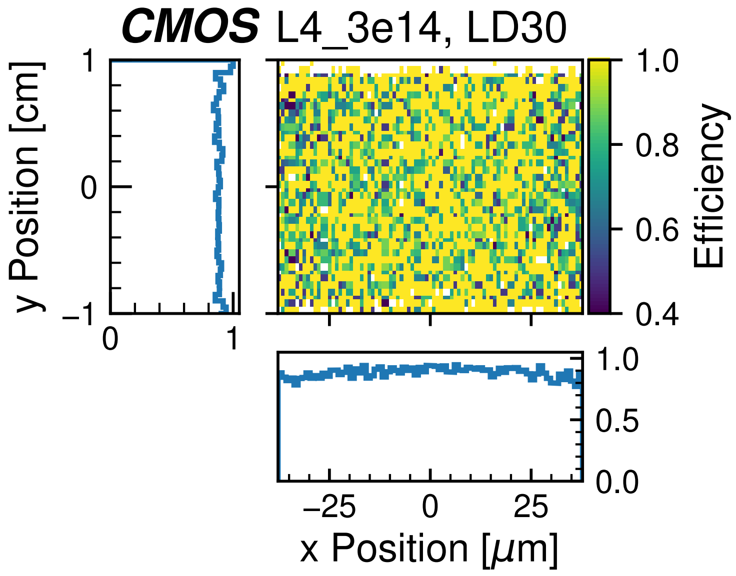
Testbeam Results
In-strip Efficiency

Unirradiated



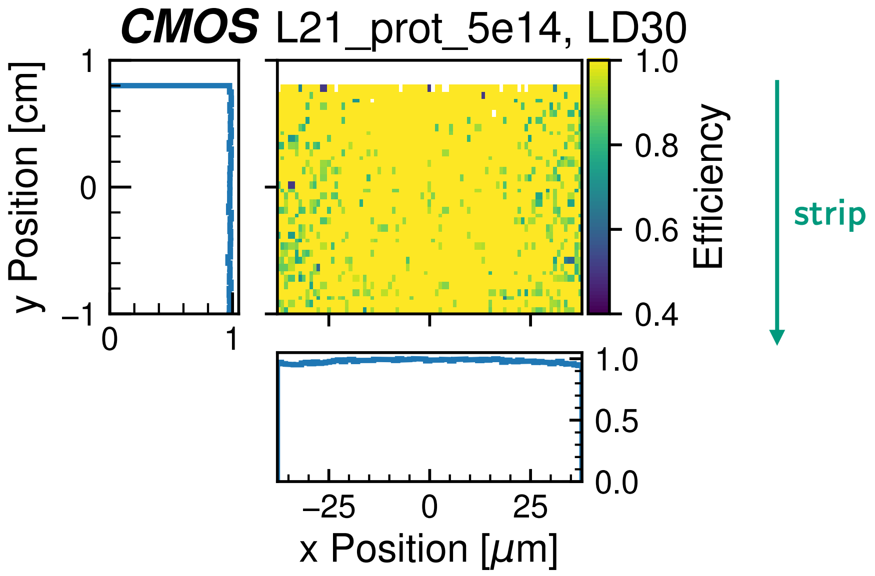
Neutron Irradiated

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



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

Conclusions and Outlook

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

Electrical characteristics measured and investigated by TCAD 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