universität freiburg

# Characterisation and TCAD Simulation Results of Stitched Passive CMOS Strip Sensors

**Iveta Zatocilova**, 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

22 February 2024, TREDI 2024, Torino

UNI BONN

DESY.

technische universität dortmund

universität freiburg

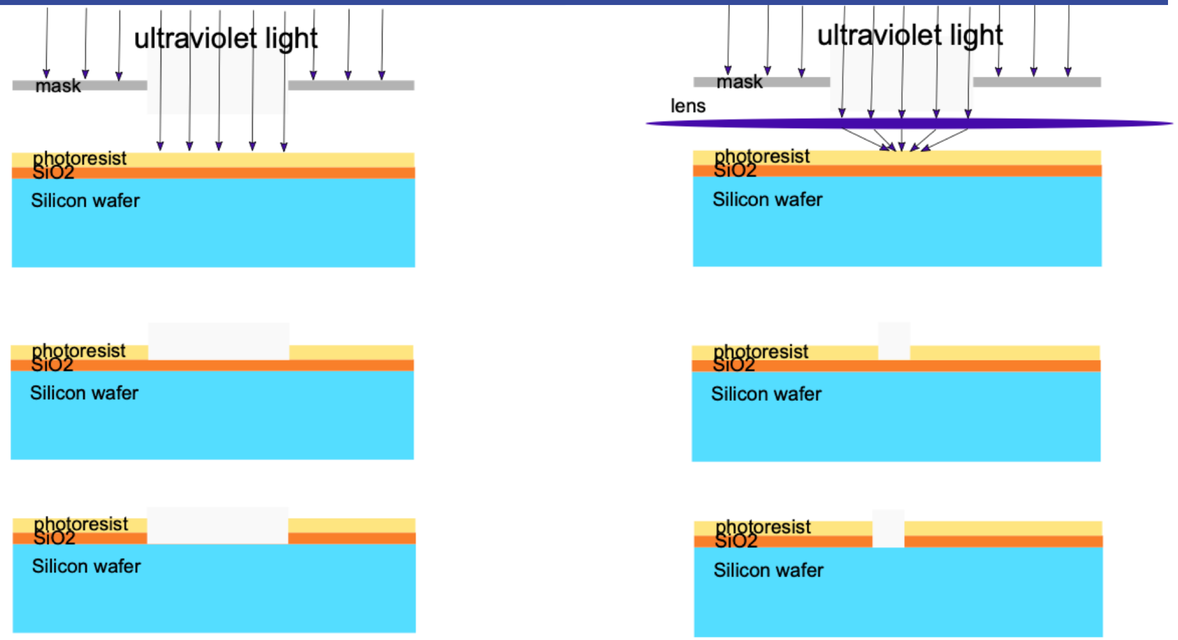
# Motivation

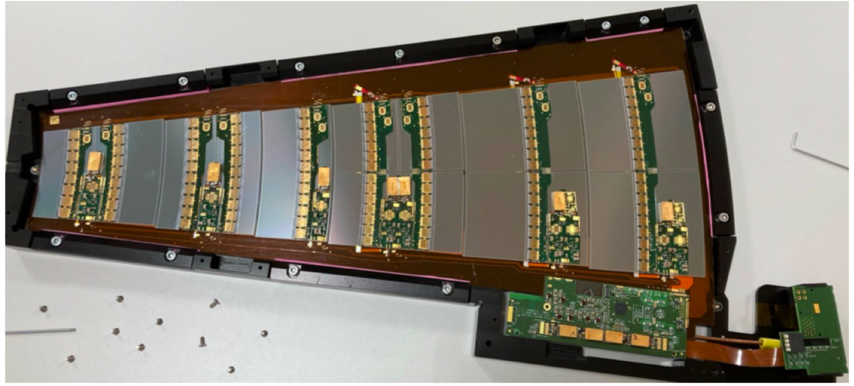
All the ATLAS and CMS upgrade strip detectors are being fabricated by Hamamatsu Photonics

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**

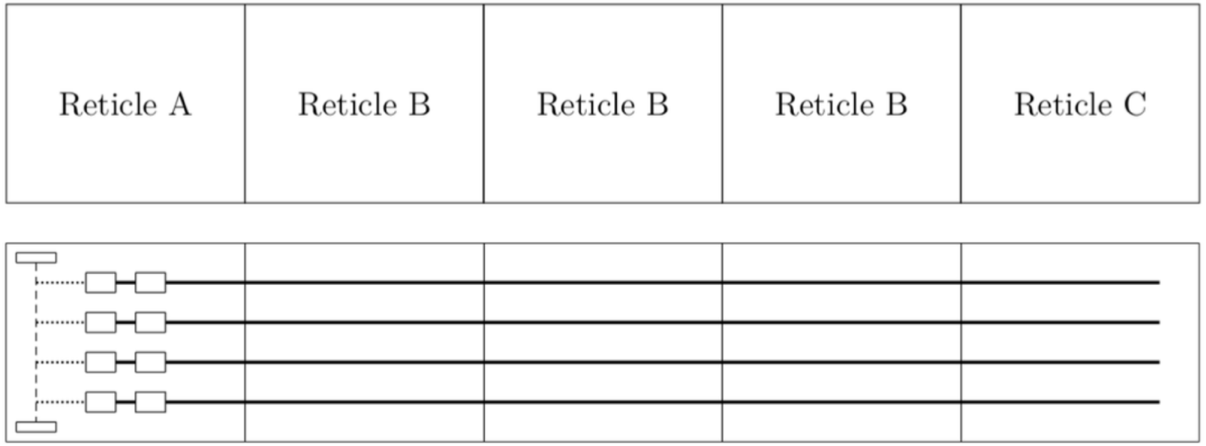


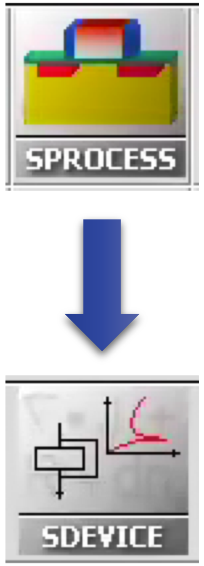
Example of ATLAS ITk end-cap petal made of large area silicon strip sensors.

# Passive CMOS Strips

- Sensors fabricated in LFoundry in a 150 nm process
- Passive → no electronics included
- $150\ \mu m$ 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

# Simulations of CMOS Strips
## Using Sentaurus TCAD

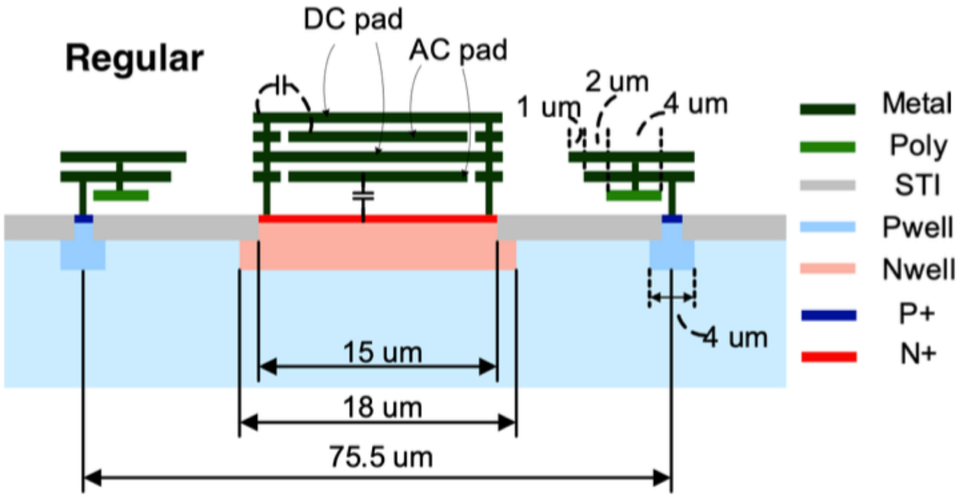


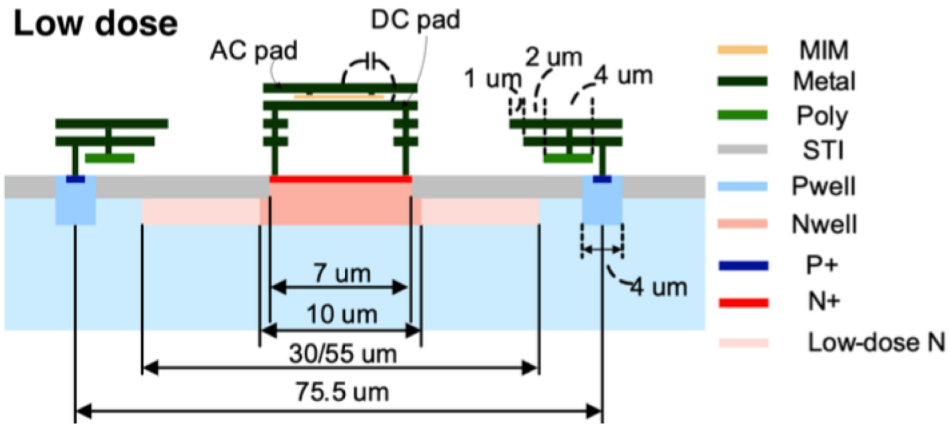

Done in order to investigate our silicon structures in detail

Both the fabrication process and electrical characteristics were simulated

All three designs simulated as 1 µm long strip segment

Results scaled in order to be comparable to the measurements

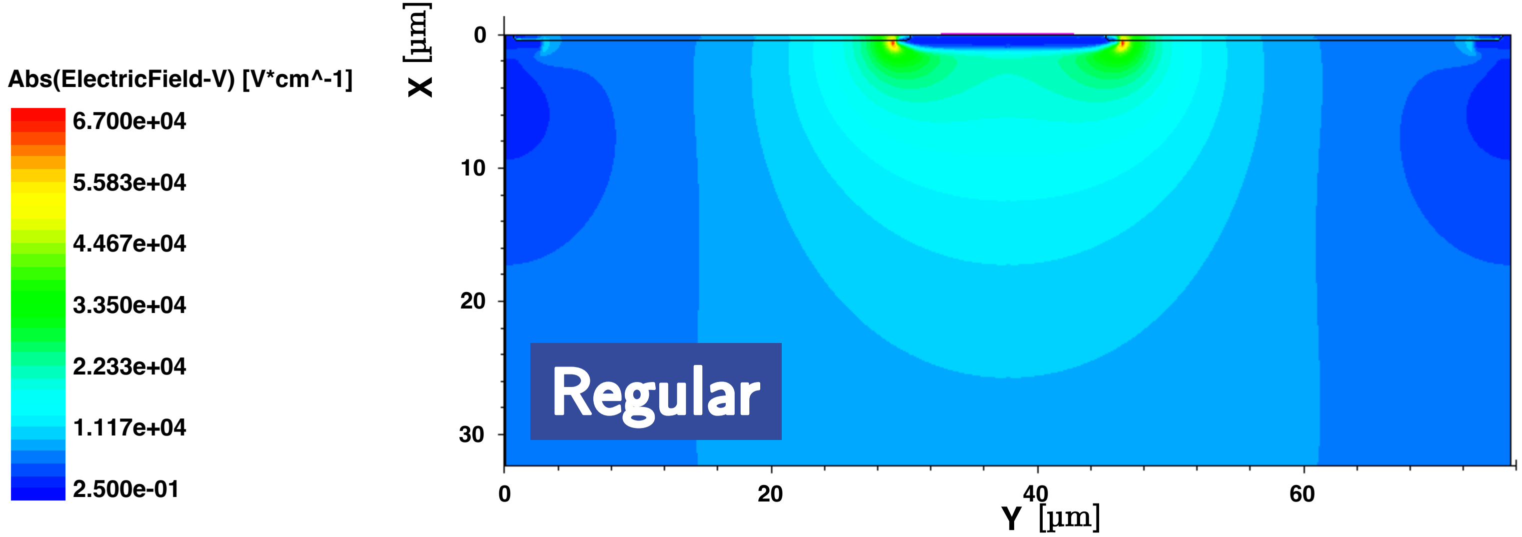


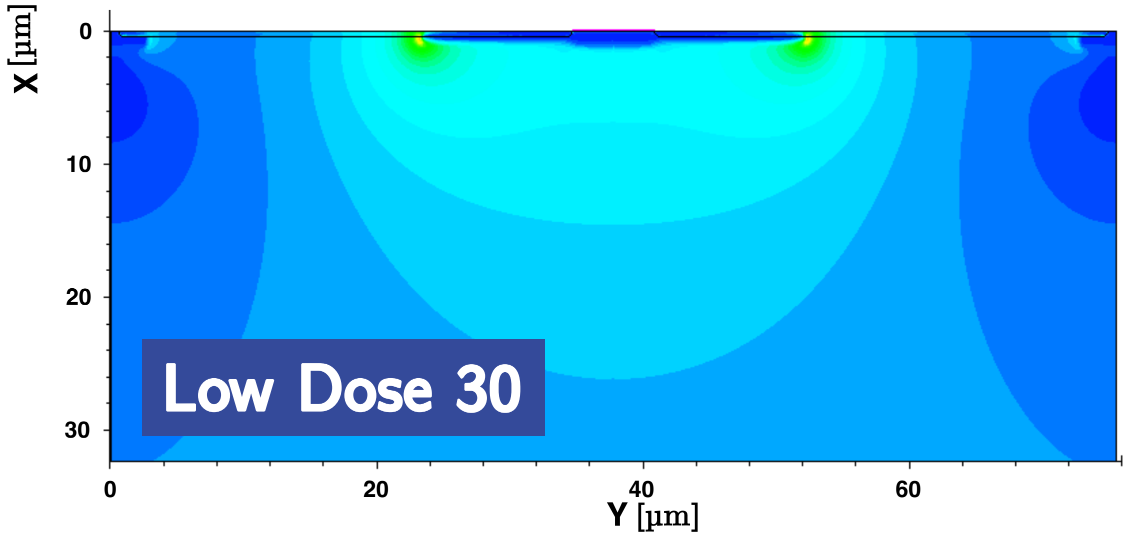



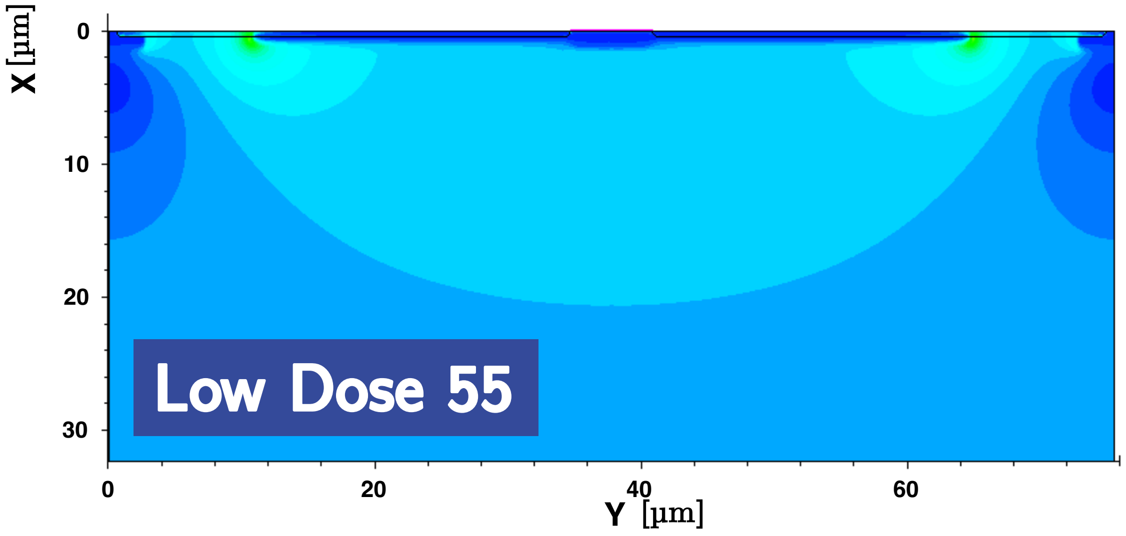
# Electrical Characterization
# Detail of the Electric Field at 100 V

The difference between the individual designs clearly observable

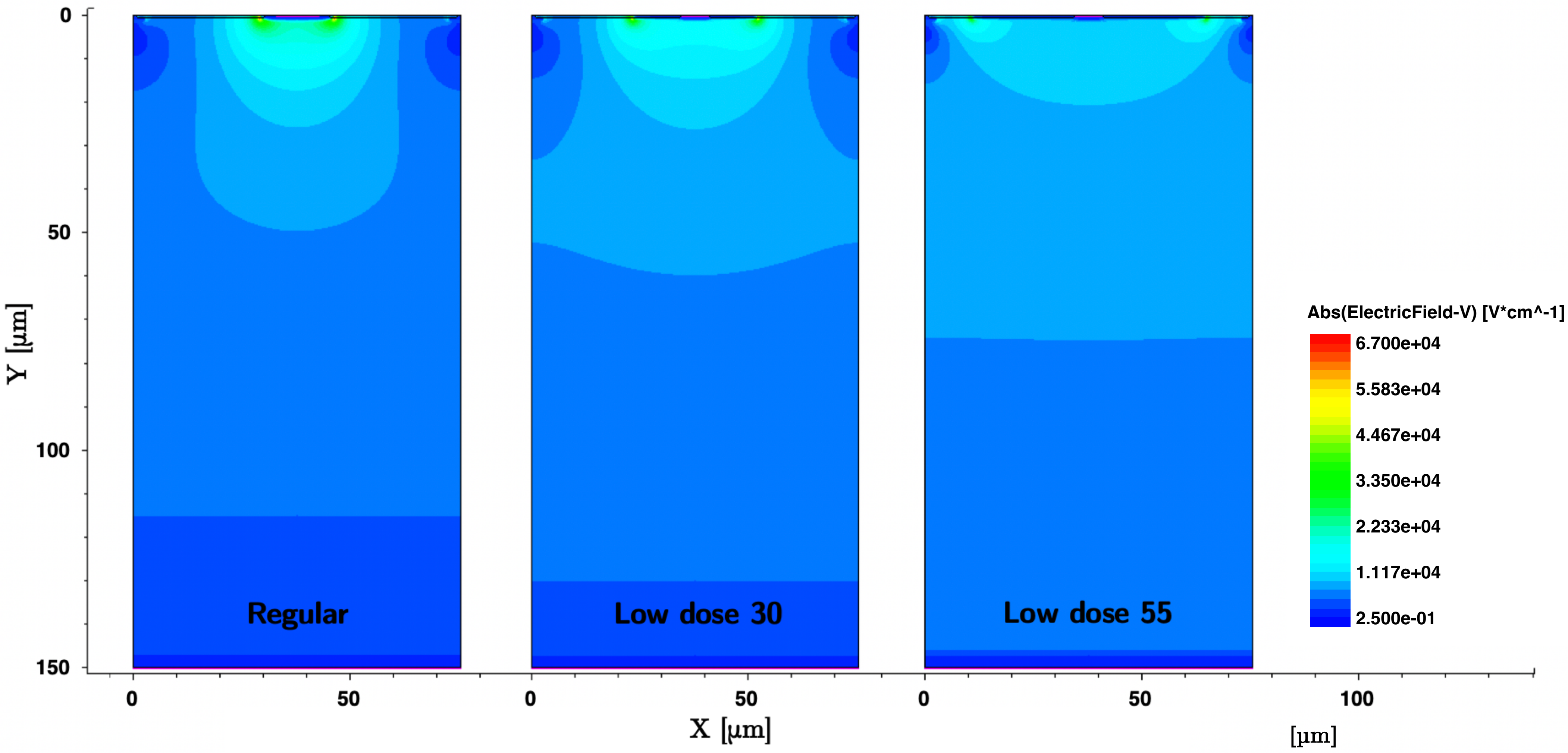
➡️ All the characteristics were studied for each design separately



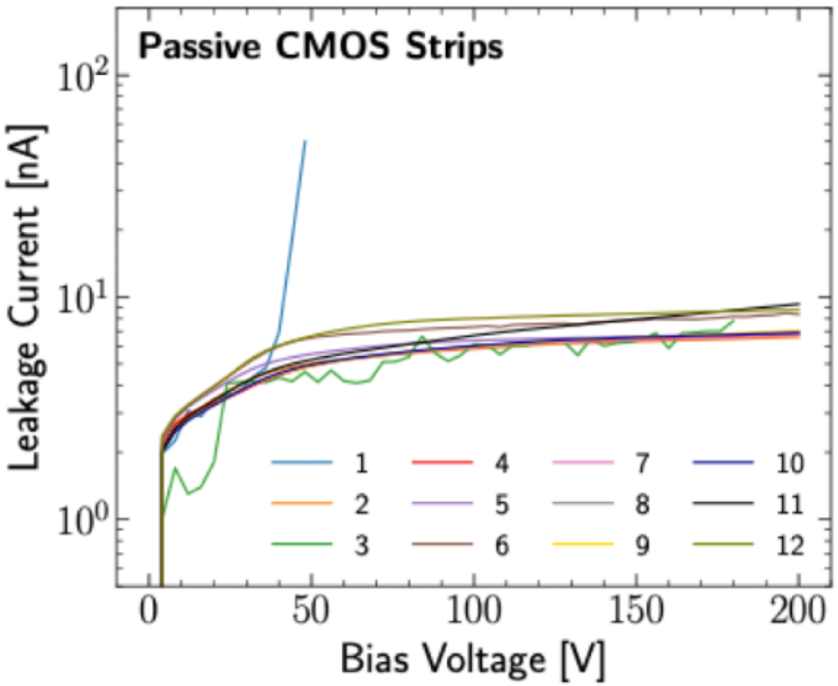



# Electrical Characterization
## Electric Field at 100 V



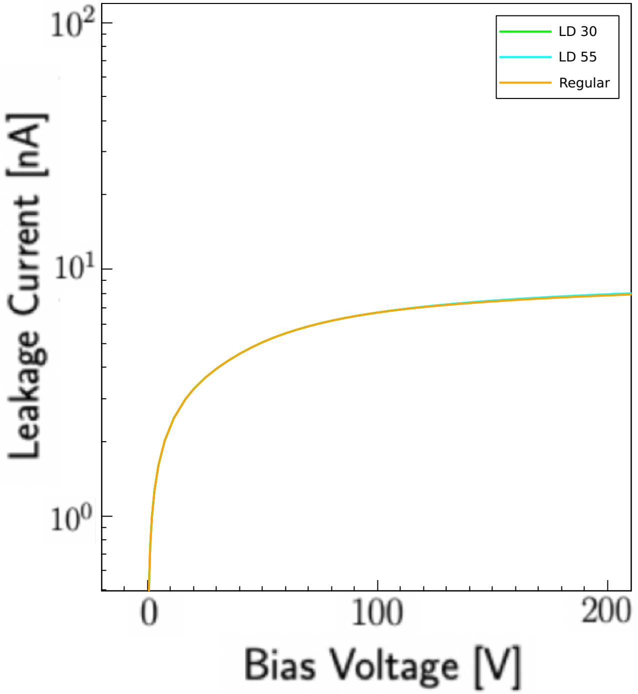
# Electrical Characterization
## Macroscopic Characteristics

### IV Measurements




Good agreement of measured values and results of the simulations

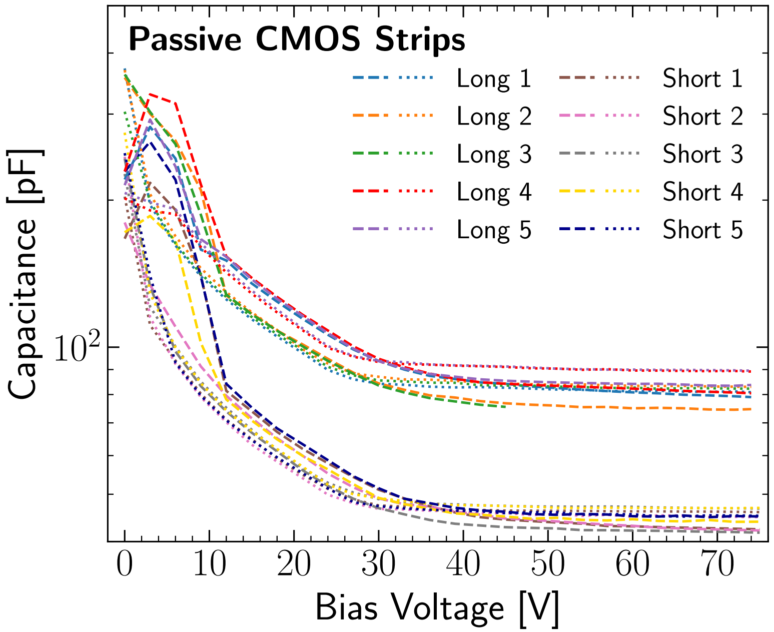
### Simulations of Leakage Current




➡️ Simulated structures describe the real ones well

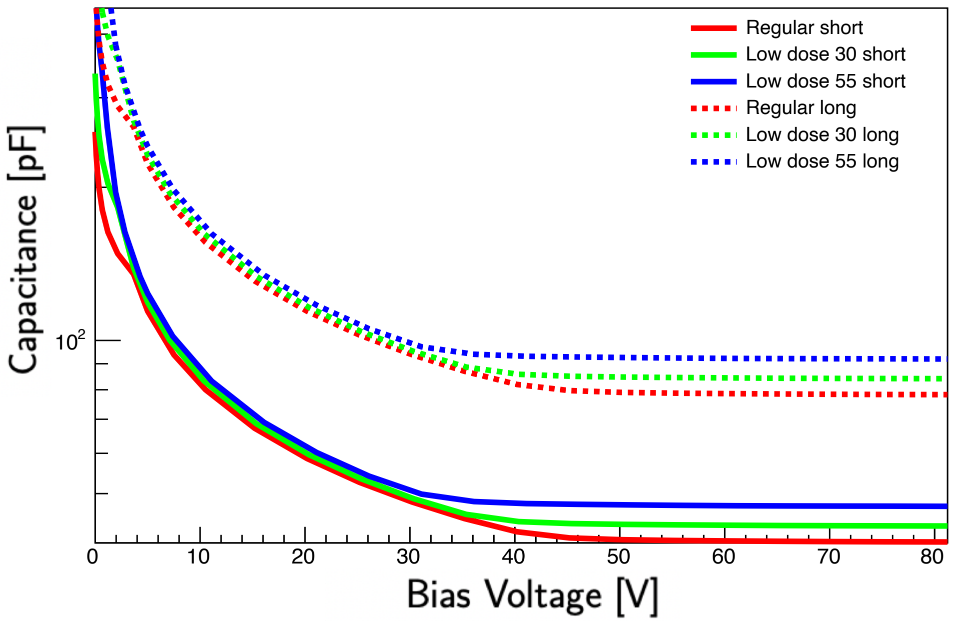
# Electrical Characterization
## Macroscopic Characteristics

### CV Measurements




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

### Simulations of Bulk Capacitance



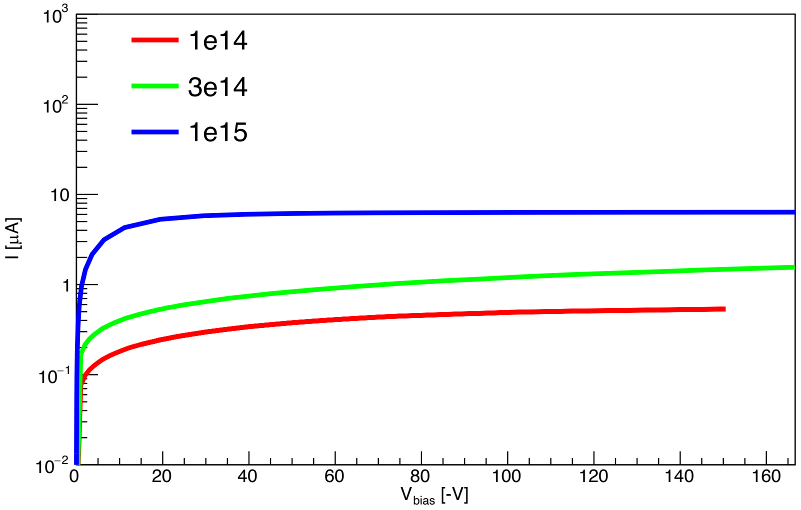

Short strips (2.1 cm) – $C_{\mathrm{bulk}} \approx 50$ pF

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

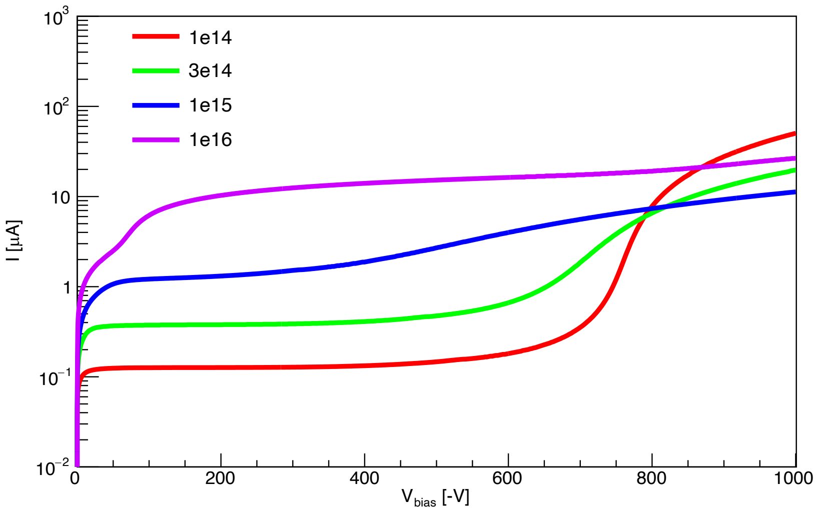
# Radiation Models in TCAD
## Leakage Current after Irradiation

**Measurements**

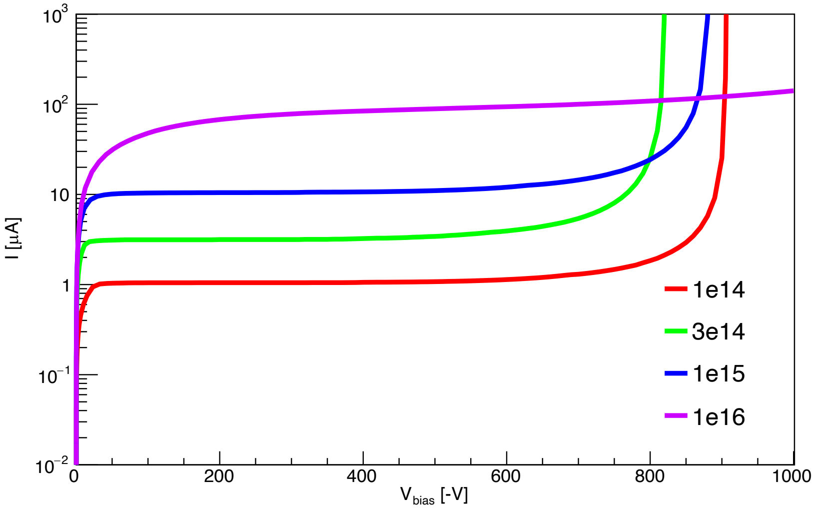
**Simulations**




CERN bulk+Perugia surface




Perugia bulk+surface



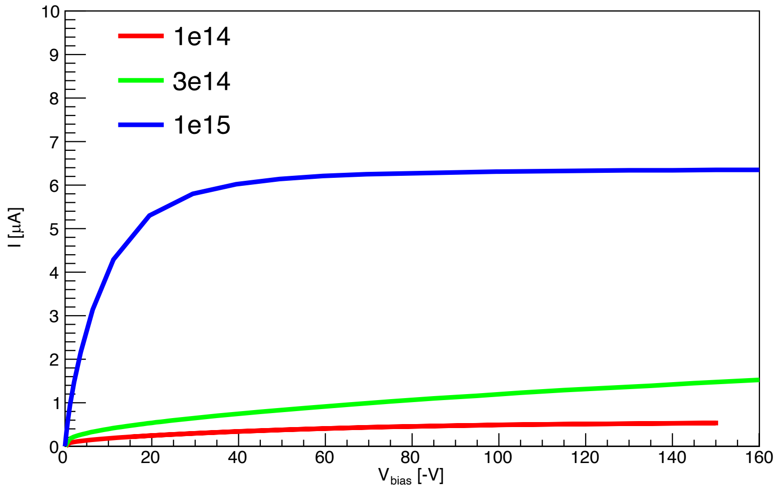

All measurements and simulation plotted for LD 30 long strips ($4.1\ \mathrm{cm}$)

➡️ CERN model underestimates measured currents by factor of 2

➡️ Currents are overestimated by the Perugia model

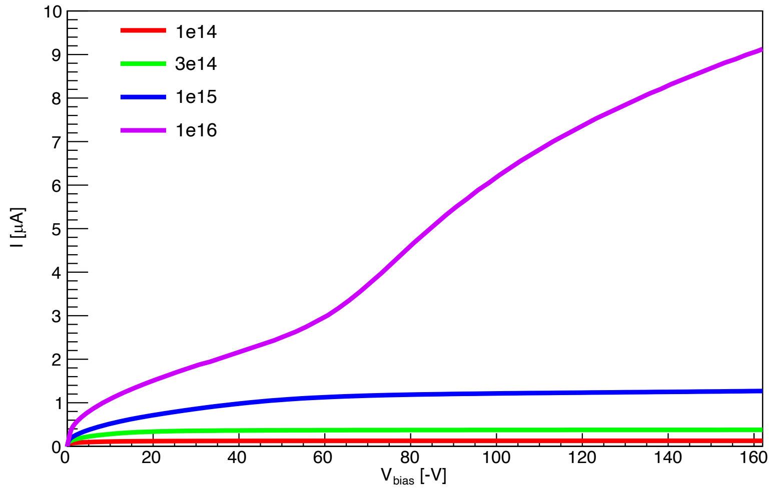
# Radiation Models in TCAD
# Leakage Current after Irradiation

## Measurements

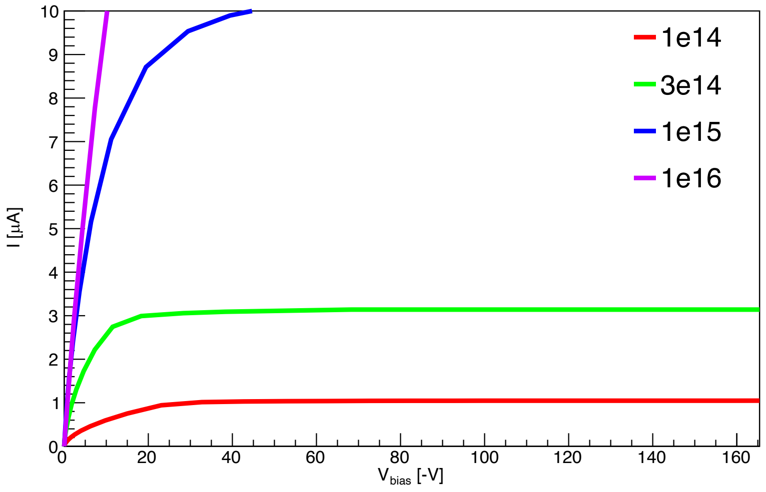



## Simulations

### CERN bulk+Perugia surface




### Perugia bulk+surface




All measurements and simulation plotted for LD 30 long strips $(4.1 \text{ cm})$

➡️ CERN model underestimates measured currents by factor of 2

➡️ Currents are overestimated by the Perugia model

# Radiation Models in TCAD
## Leakage Current after Irradiation

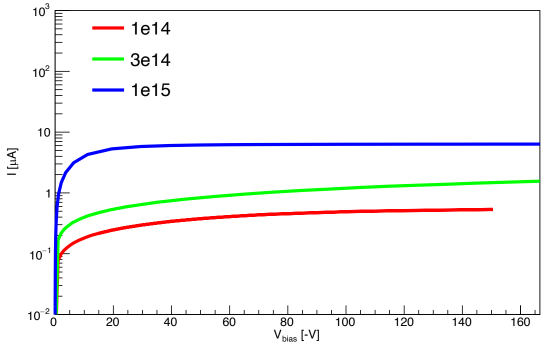
**Current values @ 100 V** for LD 30 long strips (4.1 cm)

| Fluence $[n_{eq}/cm^2]$ | Measurement | CERN model | Perugia model |
|---|---|---|---|
| $1 \cdot 10^{14}$ | ~ 0.5 μA | ~ 0.1 μA | ~ 1 μA |
| $3 \cdot 10^{14}$ | ~ 1.5 μA | ~ 0.4 μA | ~ 3 μA |
| $1 \cdot 10^{15}$ | ~ 2.5 μA | ~ 1.2 μA | ~ 10.4 μA |
| $1 \cdot 10^{16}$ | --- | ~ 6.2 μA | ~ 47.8 μA |

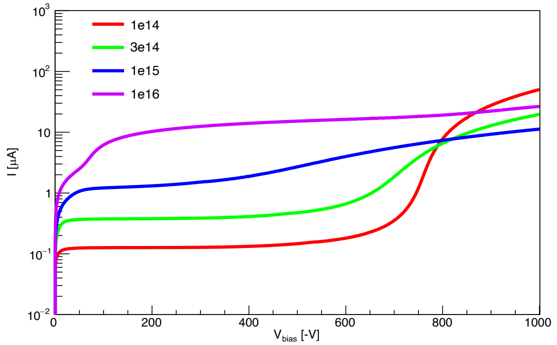
➡️ CERN model underestimates measured currents by factor of 2

➡️ Measured currents are overestimated by the Perugia model

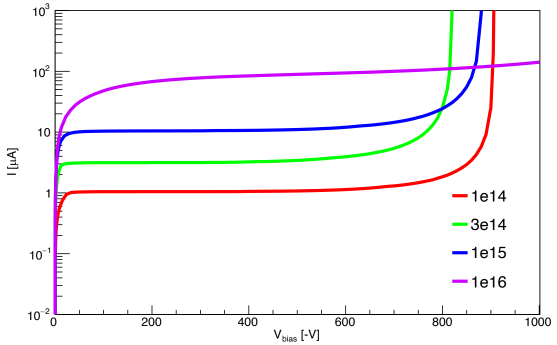
Measurement




CERN bulk+Perugia surface

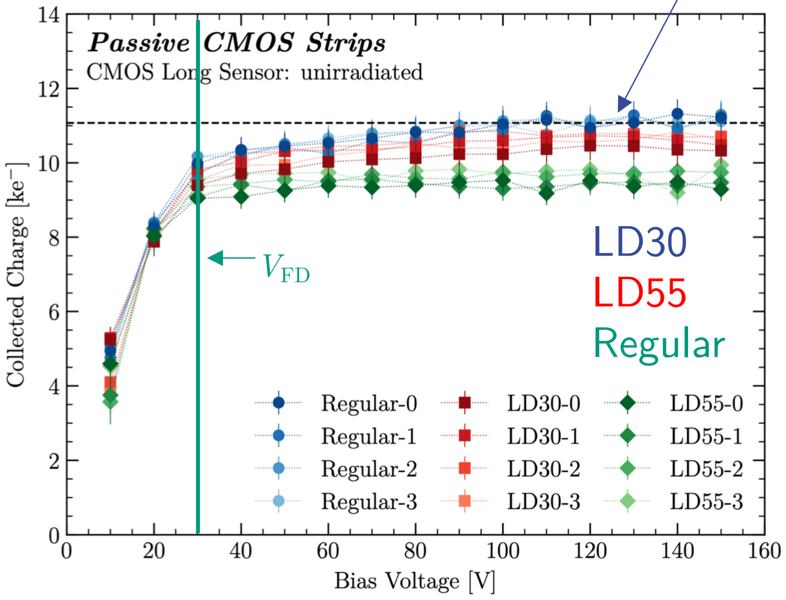


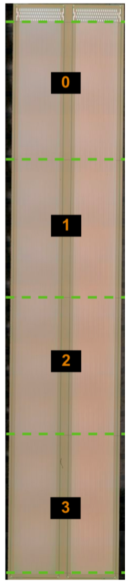

Perugia bulk+surface



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

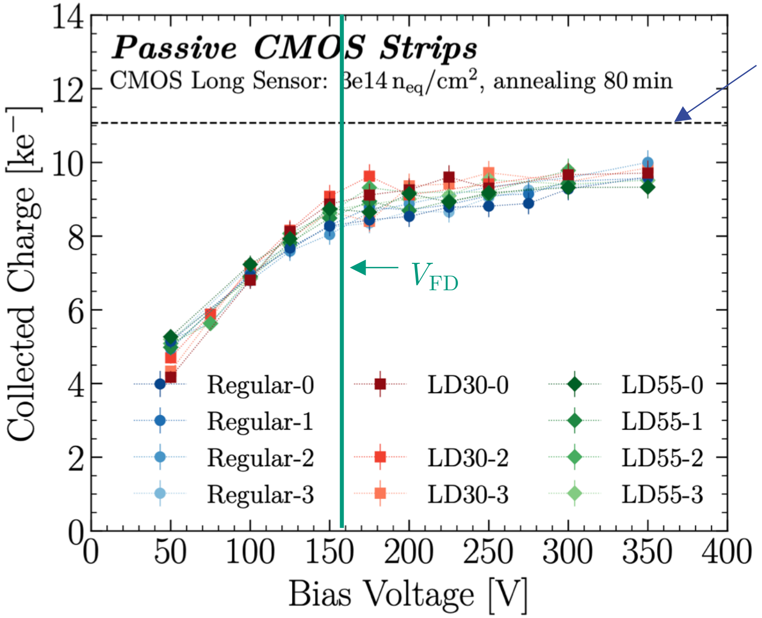
**Unirradiated**




**Irradiated** by 23 MeV neutrons

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

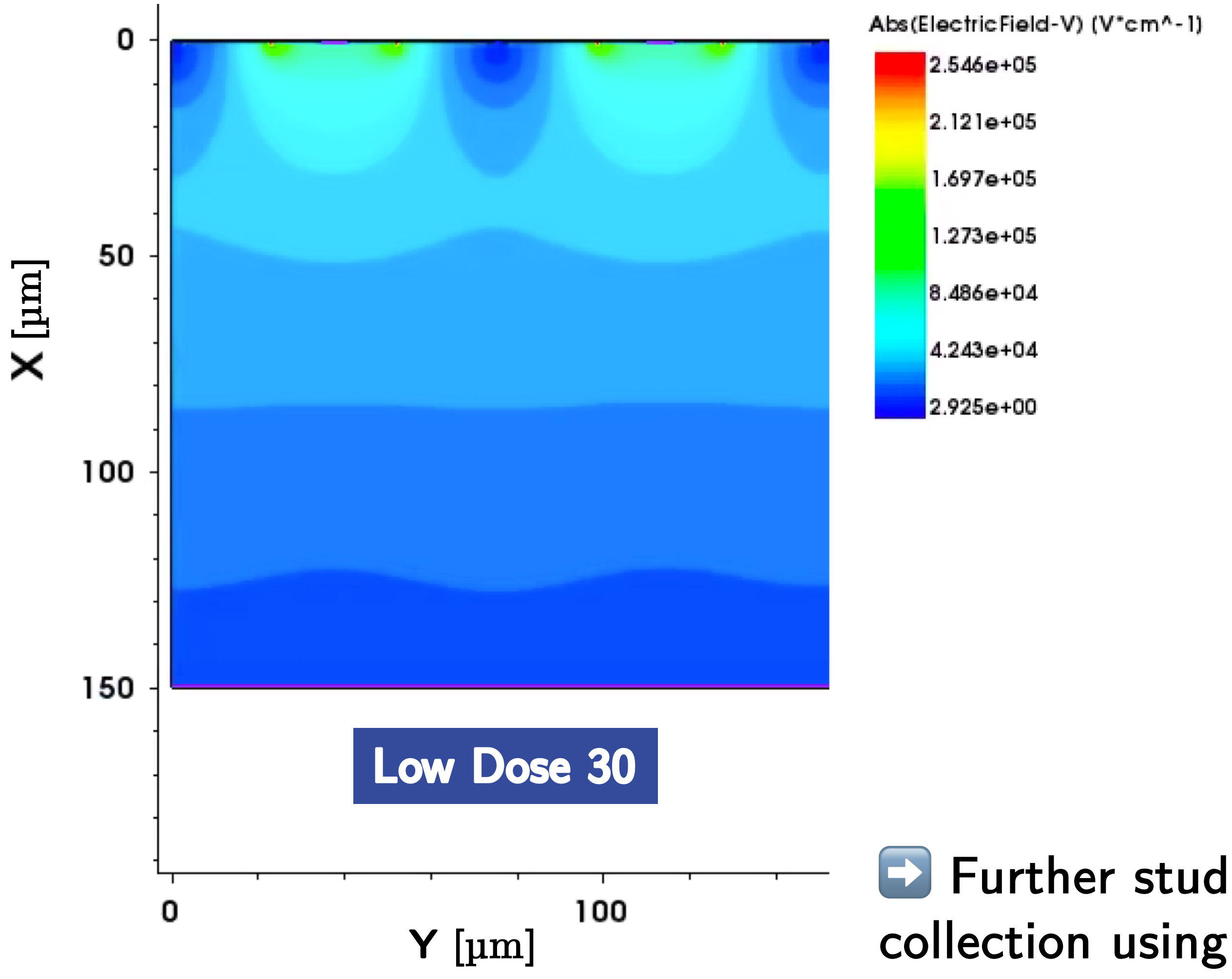



➡️ No differences in collected charged measured in the stitched areas

➡️ Observed change in collected charge after irradiation as expected

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

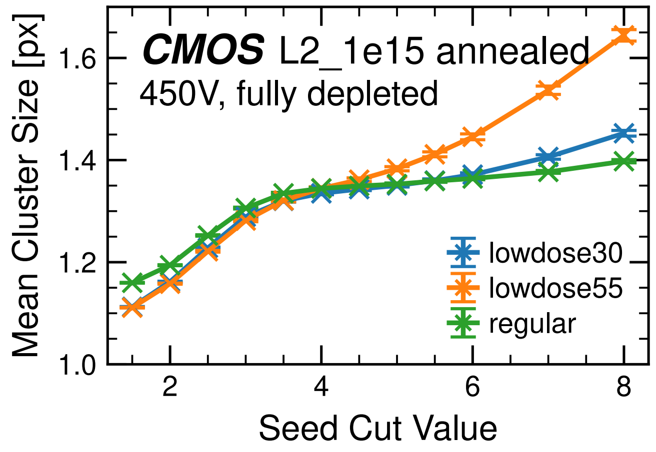
# Radiation Models in TCAD
## Electric Field $\Phi_{eq} = 1{\cdot}10^{15}\ n_{eq}/cm^2$ at 450 V

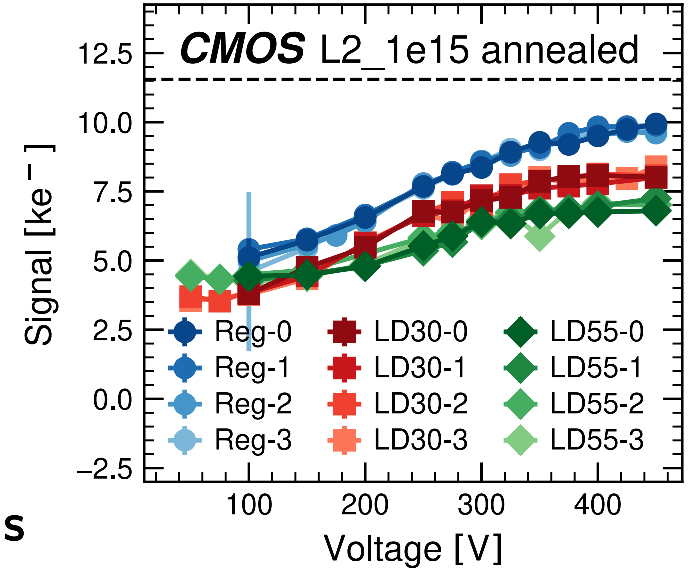



Mean cluster size ➡ Testbeam data

Collected charge ➡ ALiBaVa Setup and $^{90}$Sr-source

⬇ Experimental data

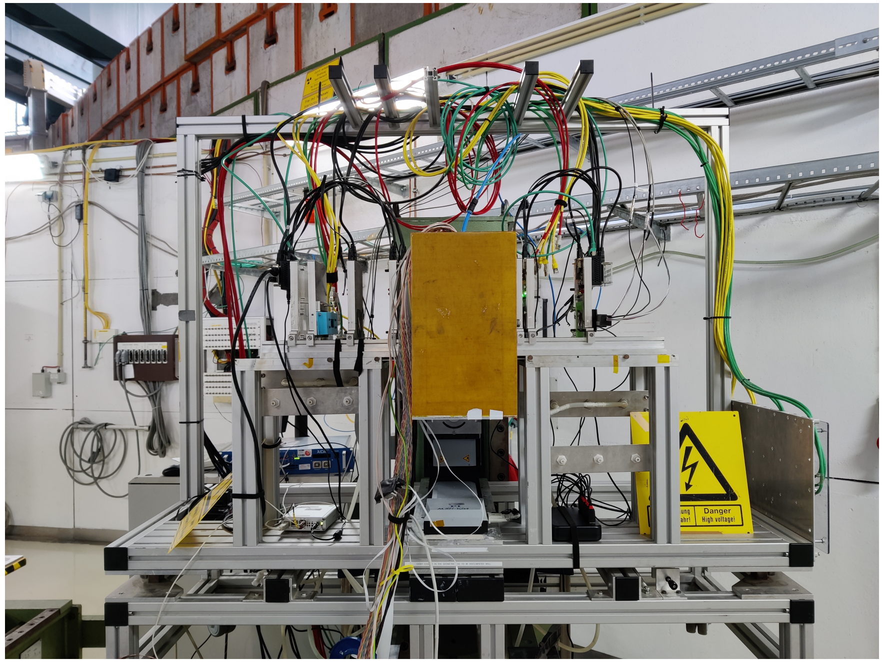


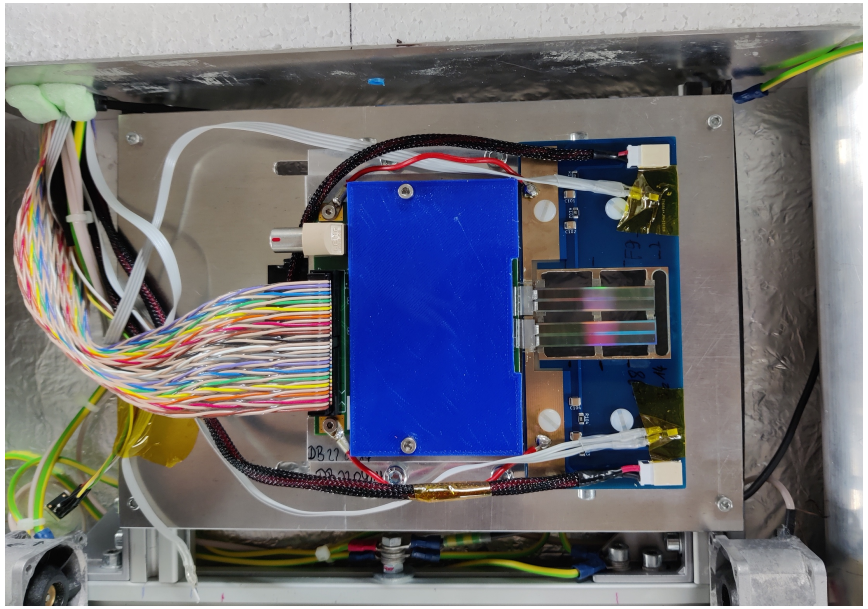



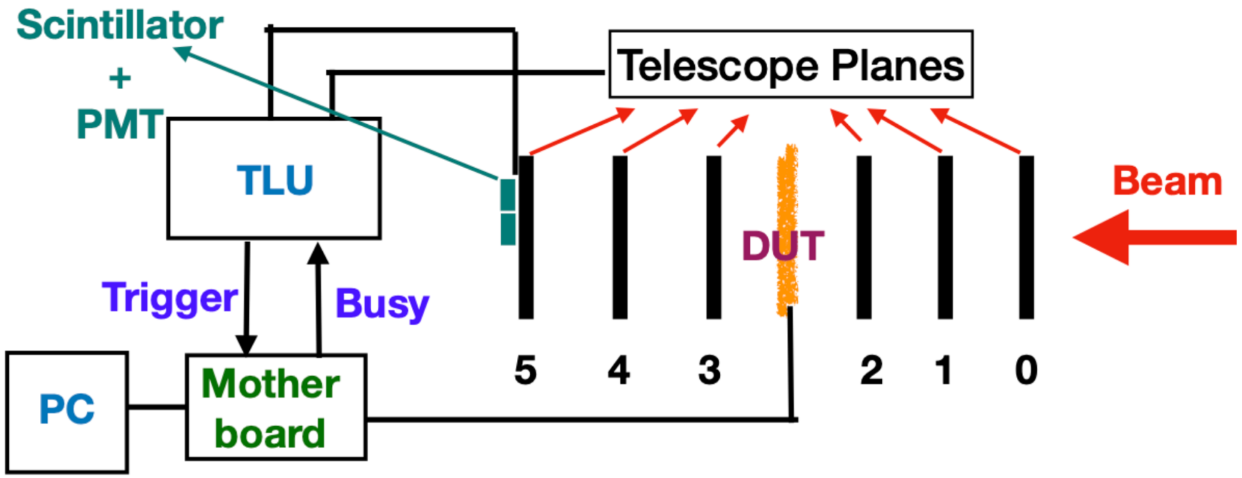

➡ Further studies of charge collection using the Allpix² simulations

# 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

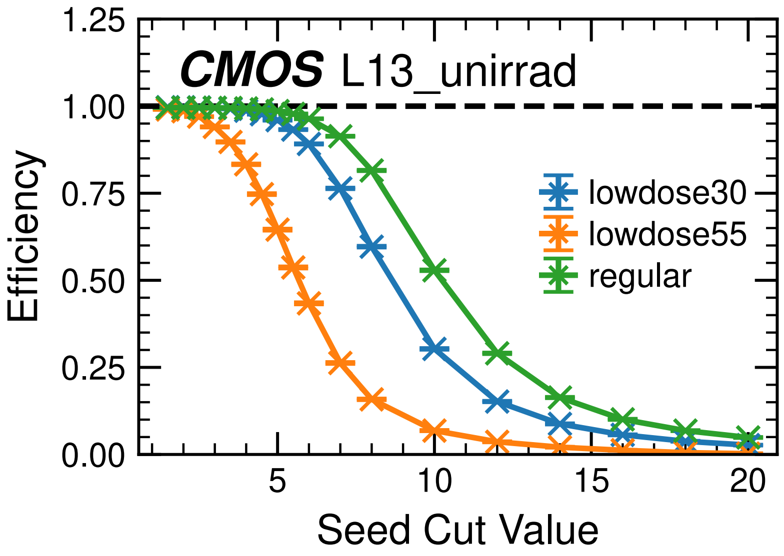






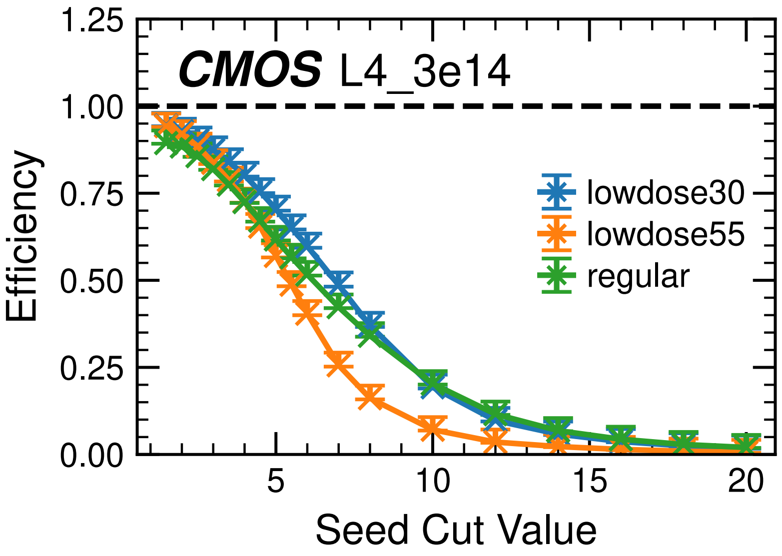
# Testbeam Results
## Efficiency

**Unirradiated**



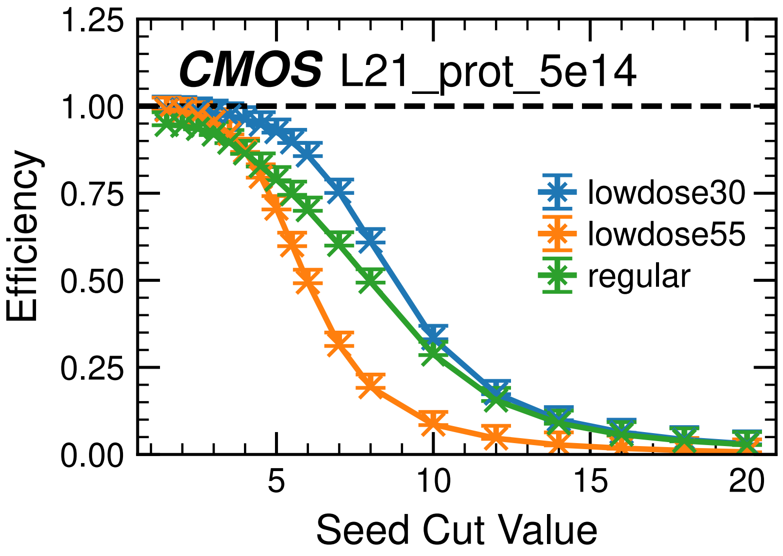

**Neutron Irradiated**

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




**Proton Irradiated**

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



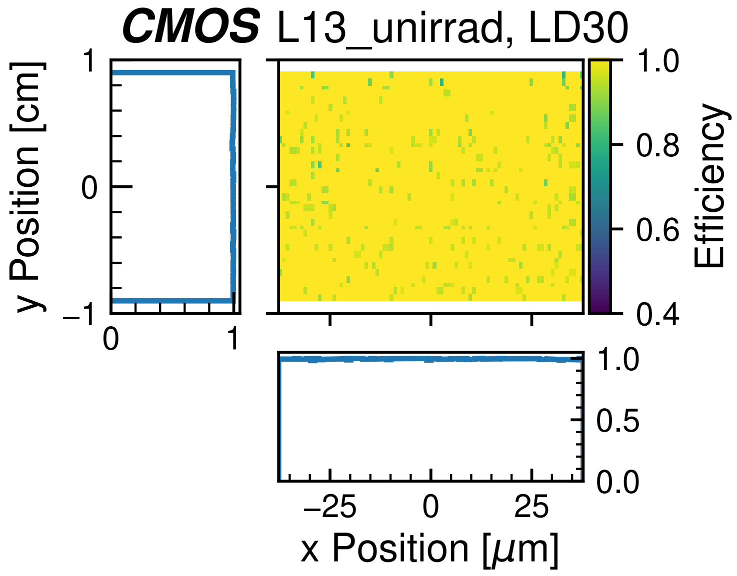

➡️ Expected shape of the dependence of efficiency on signal/noise cut value

➡️ Clear deterioration in efficiency after irradiation

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

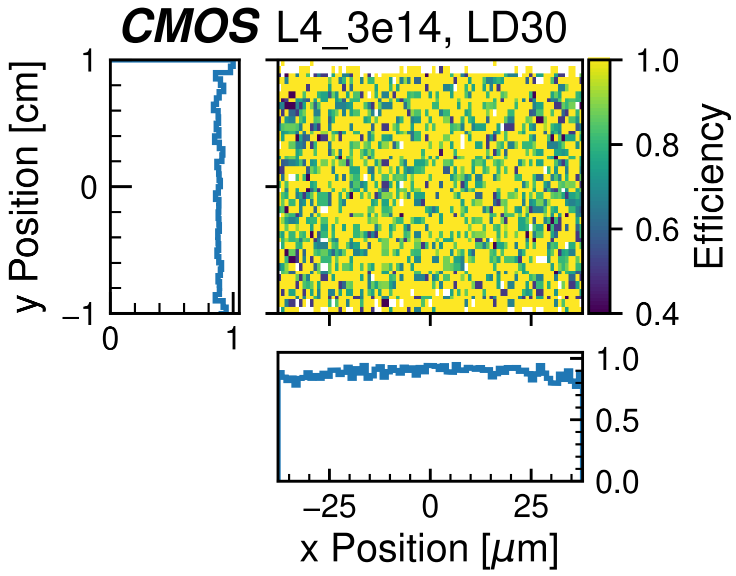
# Testbeam Results
## In-strip Efficiency of Irradiated Sensors

**Unirradiated**



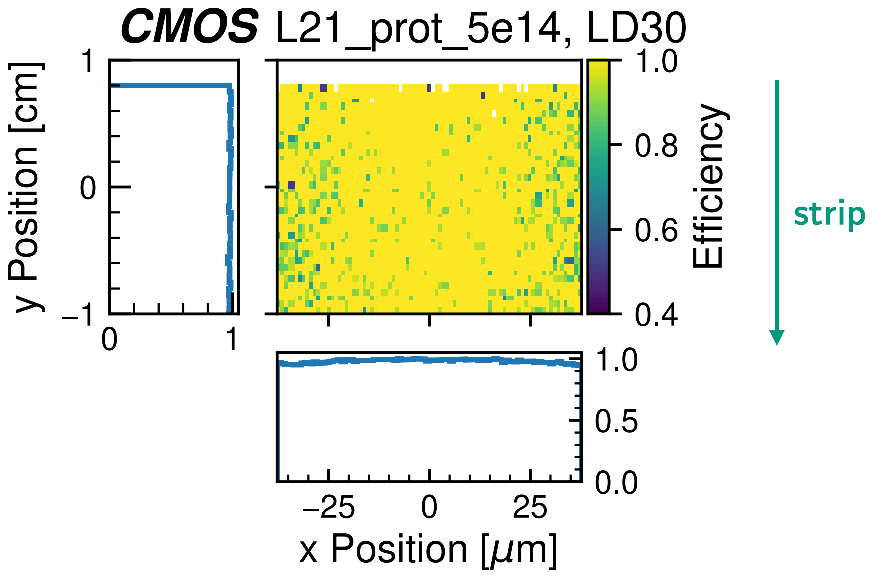

**Neutron Irradiated**

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




**Proton Irradiated**

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




➡️ No change in efficiency observed due to the stitches

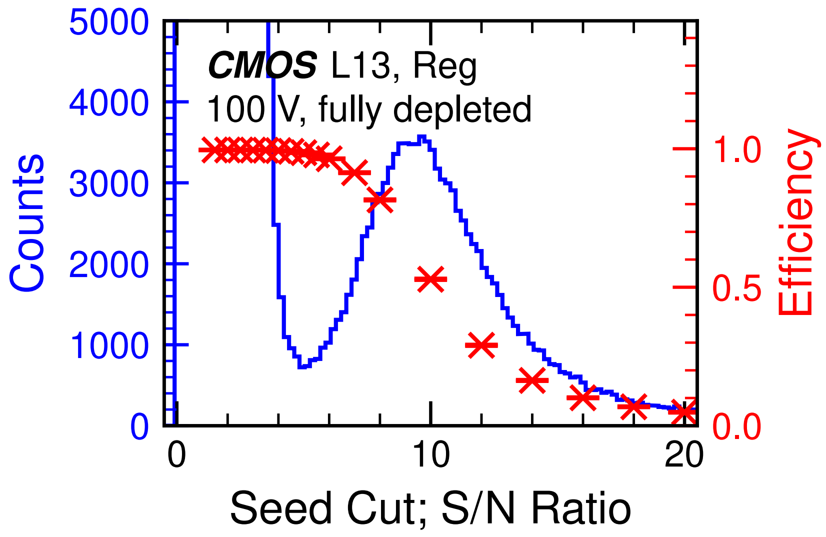
➡️ Efficiency of proton irradiated sensor higher than the one of neutron irradiated sensor

# Conclusions and Outlook

- Passive CMOS strip sensors fabricated in LFoundry in a 150 nm process
- 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 neutron and proton irradiation was observed**
- Design of the new sensors with implemented electronics in progress

# Testbeam Results
## Efficiency

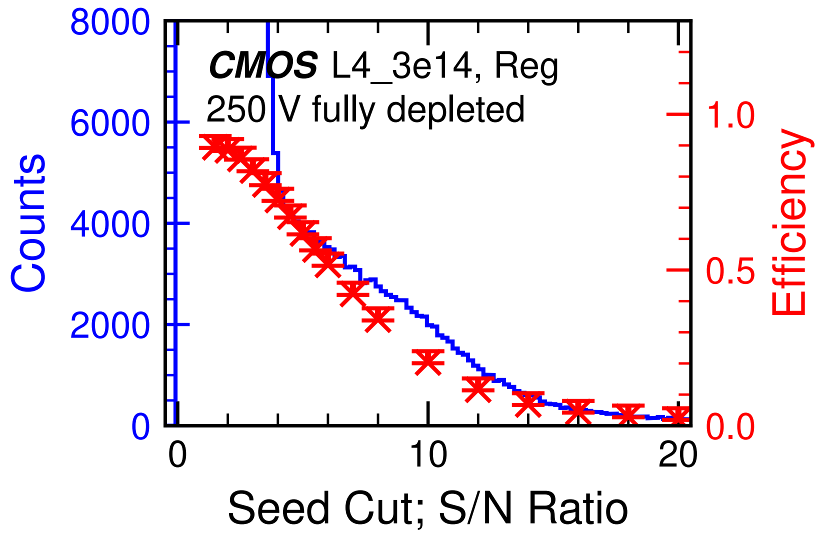
**Unirradiated**




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

**Neutron Irradiated**

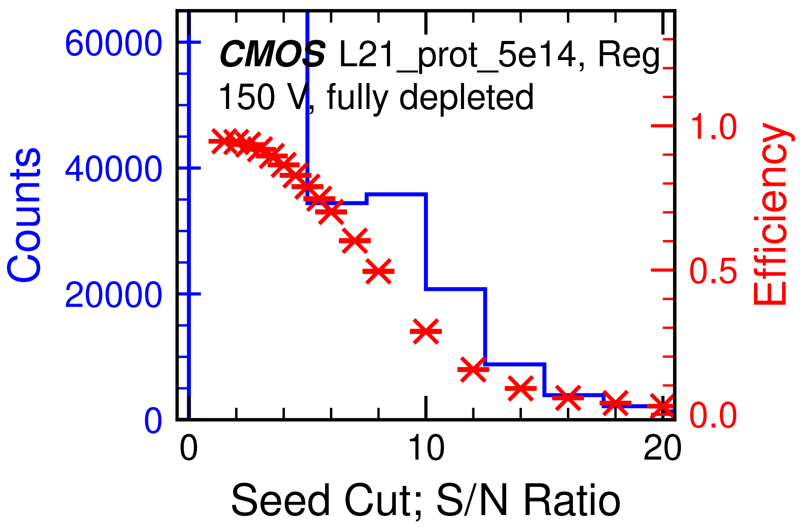
$\Phi_{eq} = 3{\cdot}10^{14}\ n_{eq}/cm^2$




➡️ Clear deterioration in efficiency after irradiation

**Proton Irradiated**

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



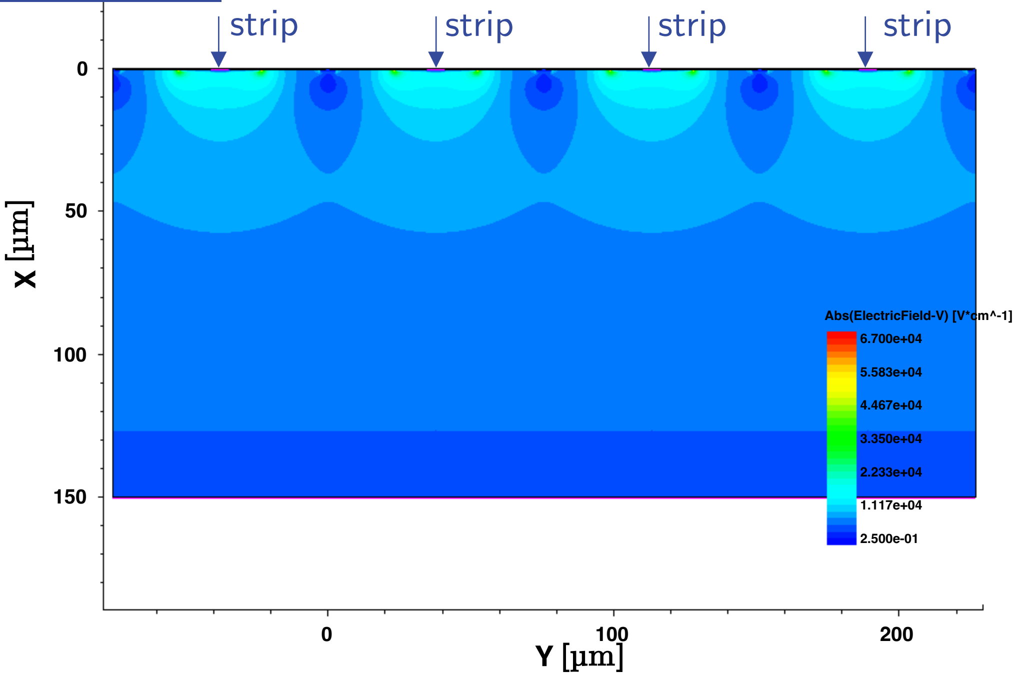

➡️ Efficiency of proton irradiated sensor higher than the of neutron irradiated sensor

# Electrical Characterization
## Microscopic Characteristics at 100 V

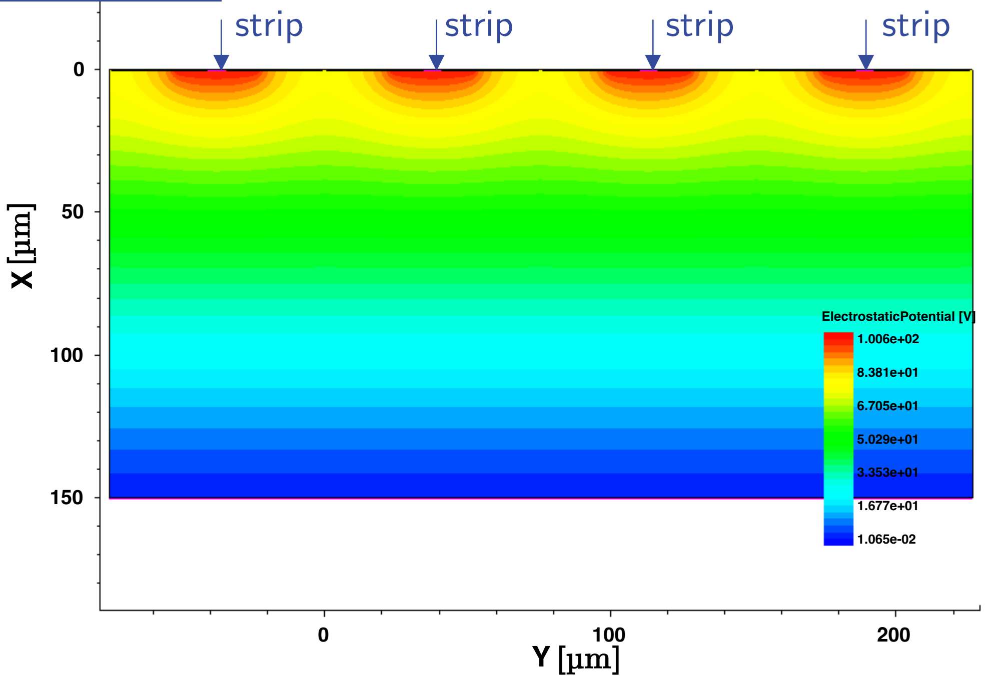
- CMOS strip sensor simulated as a 4-strip structure

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

**Low Dose 30** Electric Field




**Low Dose 30** Electrostatic Potential

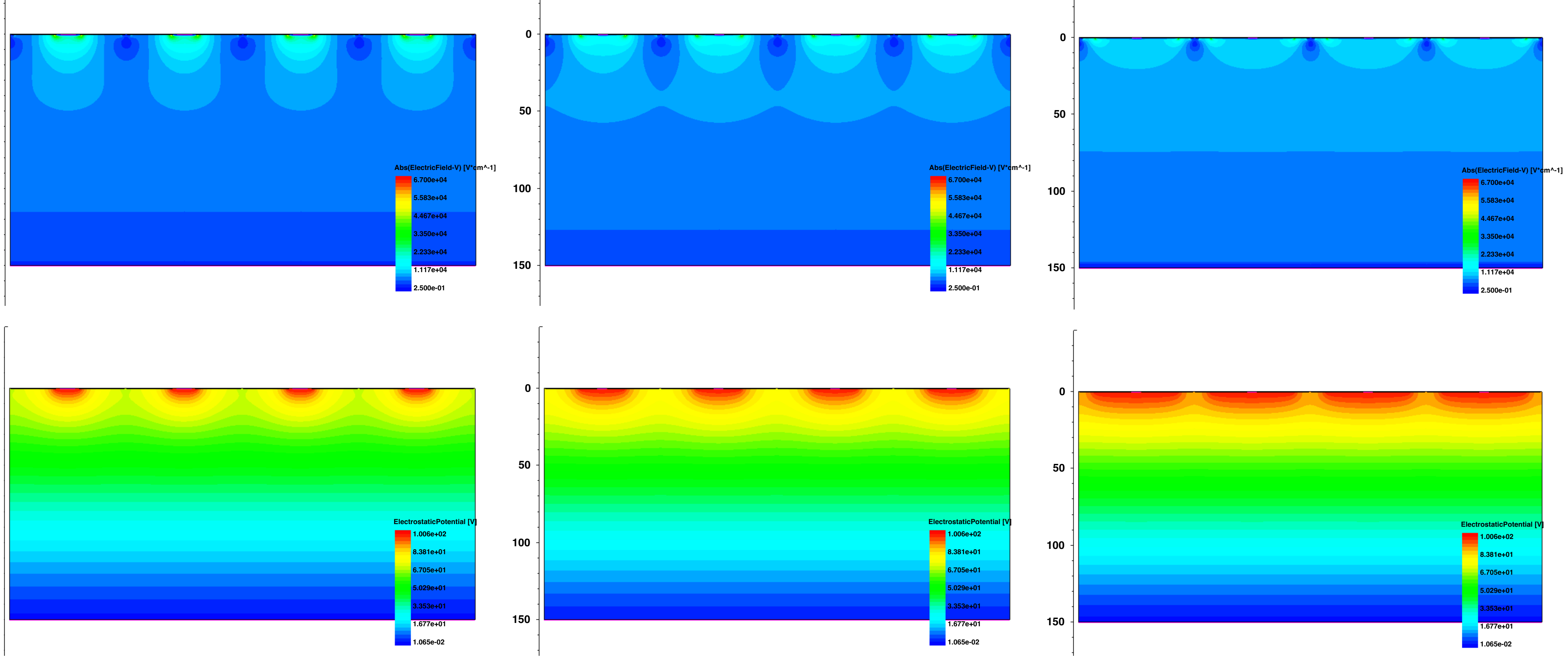


# Electrical Characterization
## Microscopic Characteristics at 100 V

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

Electric Field

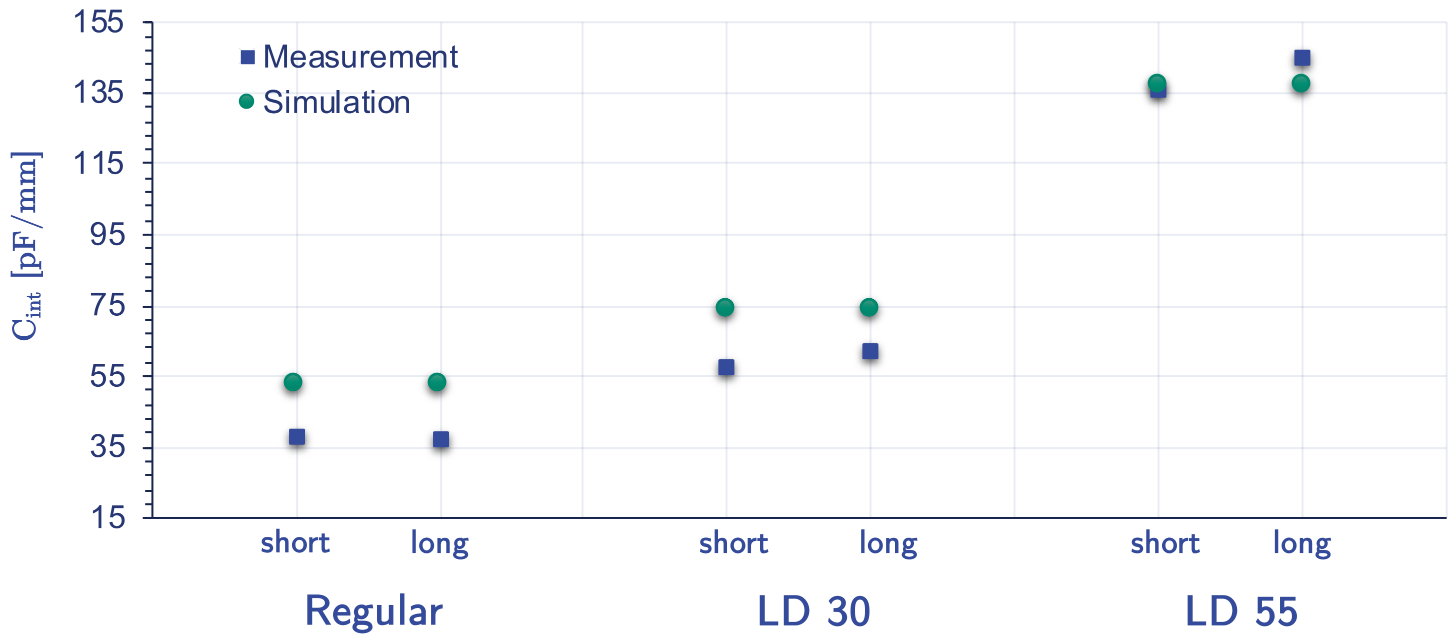
Electrostatic Potential



# Electrical Characterization
## Macroscopic Characteristics

### Interstrip Capacitance  $C_{int}$ @ 500 kHz

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

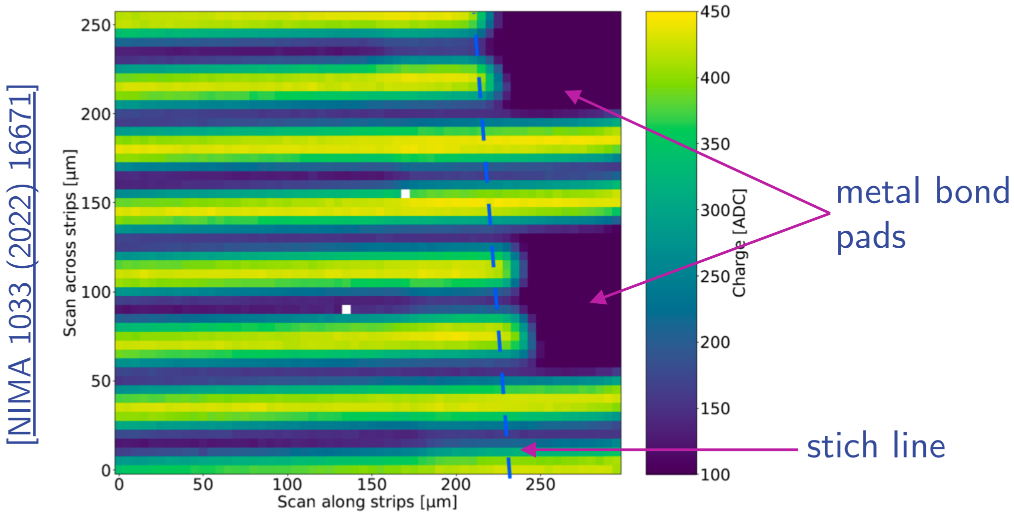



➡️ Good agreement of measured values and results of the simulations

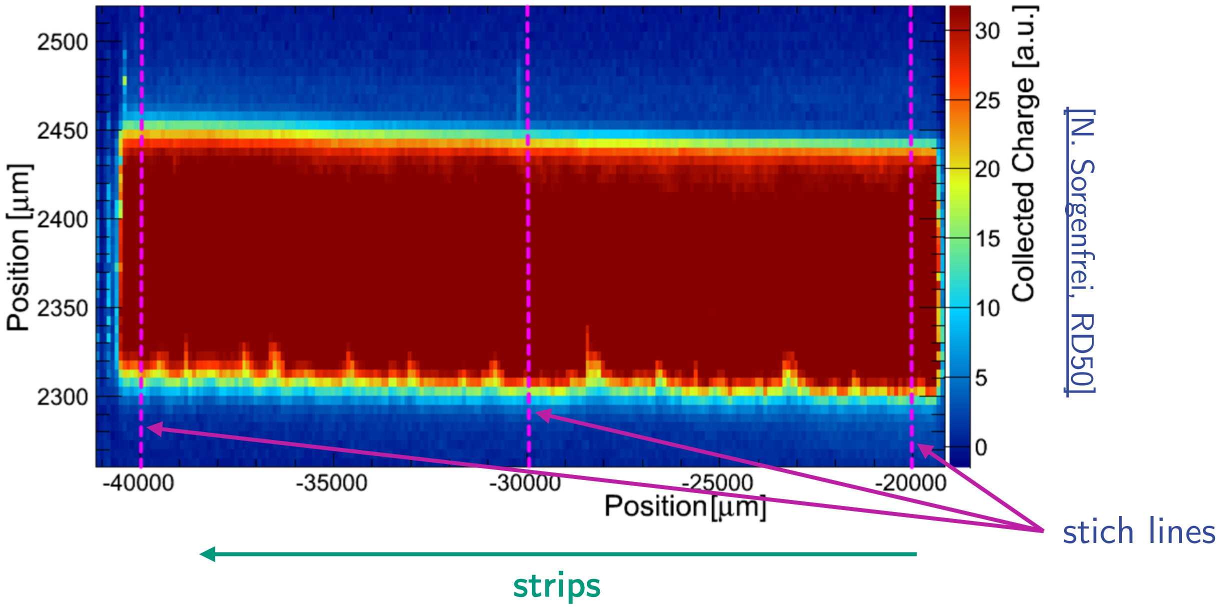
# Transient Current Technique Measurements
## Top- and Edge-TCT

- Collected charge as a function of the laser position

Top-TCT Regular at $50\ \mathrm{V}$




Edge-TCT Low Dose 30 at $100\ \mathrm{V}$




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

➡️ No effect of stitching observed