MEASUREMENTS OF INTER-PIXEL RESISTANCE

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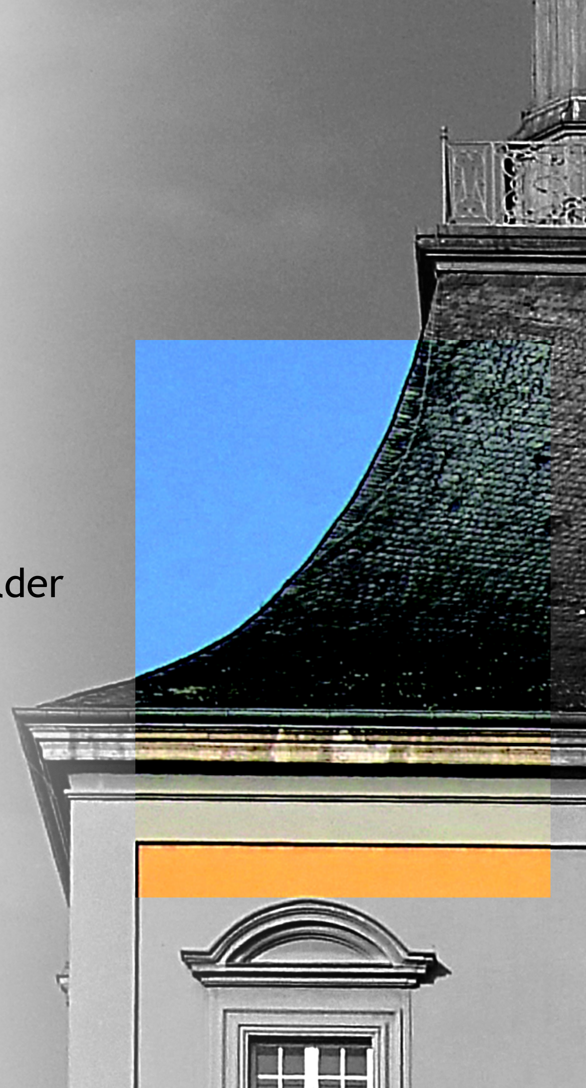
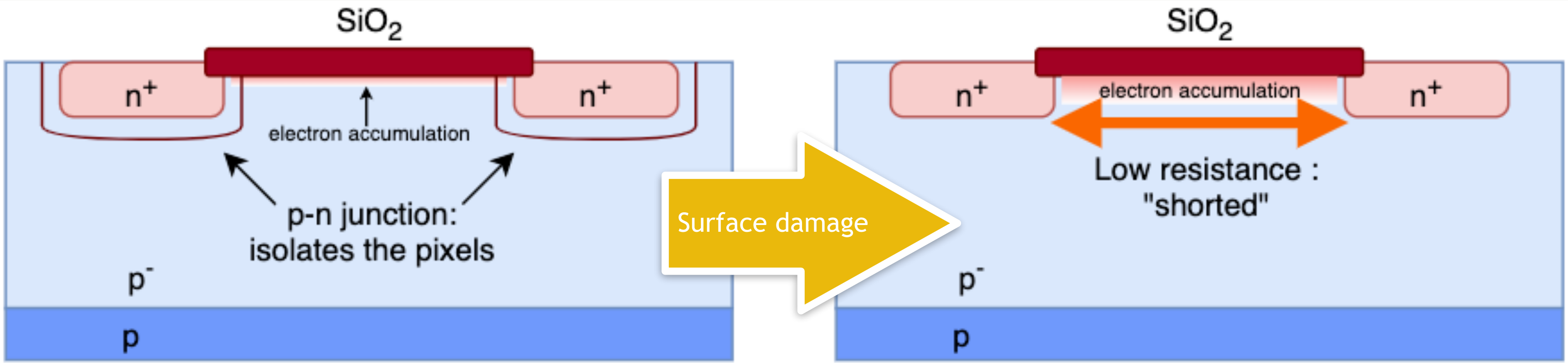


ISOLATION BETWEEN ELECTRODE IMPLANTS

- shorted electrodes degrade the spatial resolution
- N-on-P sensors: p-type bulk provides a natural isolation

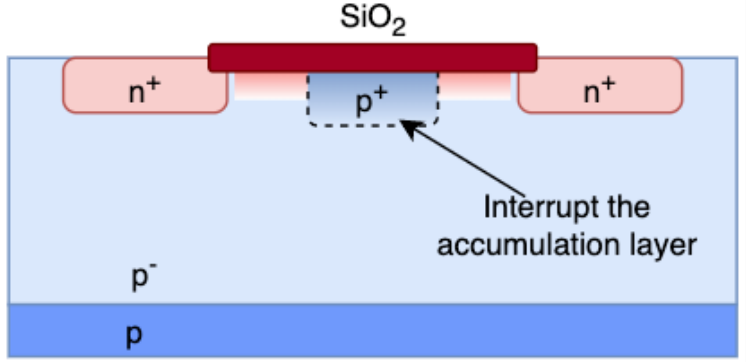


- Electron accumulation layer can present beneath the oxide (figures are not in scale)
  —> **higher bias voltages** can mitigate this problem*
- **Surface damage after irradiation*** —> higher concentration of oxide charge & interface traps
  —> more pronounced electron accumulation —>reduction of the inter-pixel resistance

*A.Dirlamm et al(2020): https://indico.cern.ch/event/813597/contributions/3727777/
(more previous studies can be found in the references of this presentation)

P-STOP ISOLATION

- **P-stop** or p-spray isolation in passive sensors is (more or less) a default implementation, since it can:
  - shape the E-field between pixels
  - enhance the inter-pixel isolation



- Problem: p-stop can introduce **higher pixel capacitances**
  H. Krüger and E. Kimmerle (2020): https://arxiv.org/abs/2010.03267

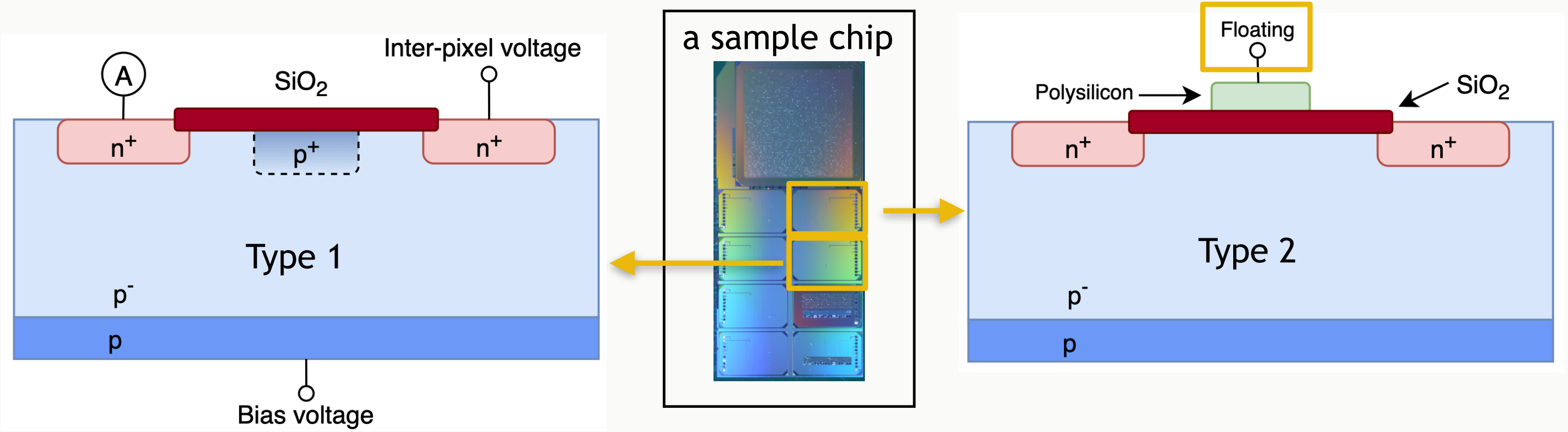
➡ How large is the impact of the p-type isolation?

➡ After proton irradiation?

➡ If p-stops can be removed —> lower pixel capacitance: a great advantage for timing resolution, power consumption, and electronic noise

TWO TYPES OF STRUCTURES

- From **passive CMOS sensor** test-structures fabricated in LFoundry 150 nm CMOS technology
- CZ wafer, thickness = $200\,\mu m$, pixel size = $50 \times 250\,\mu m^2$
- **Major difference** is the structure of the inter-pixel region:
  - type 1: p-stop
  - type 2: no p-stop; poly silicon layer above the oxide (**field-plate**).
    voltage can be applied at poly silicon to modify the field beneath (floating this time)



PREPARATION OF SAMPLES

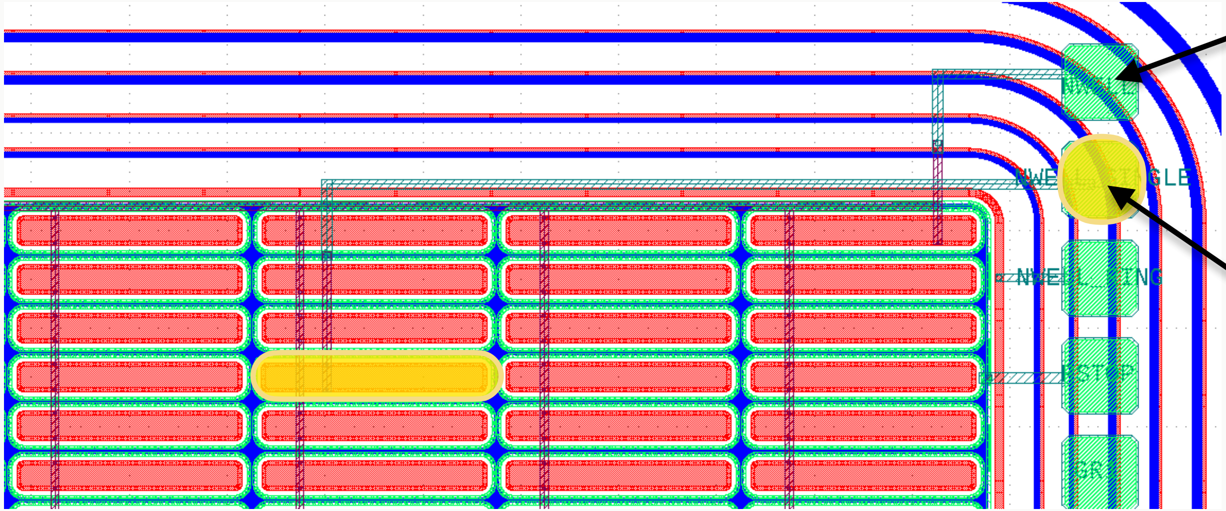
- 15 samples for measurements:
  - 3 unirradiated samples
  - 3 samples for each fluence:
    - $5 \times 10^{14}\,\mathrm{neq\,cm^{-2}}$ (one chip is damaged)
    - $1 \times 10^{15}\,\mathrm{neq\,cm^{-2}}$
    - $5 \times 10^{15}\,\mathrm{neq\,cm^{-2}}$
    - $1 \times 10^{16}\,\mathrm{neq\,cm^{-2}}$

- Facility for irradiation:
  - 14 MeV protons from cyclotron at Bonn

The Bonn Isochronous Cyclotron at Helmholtz Institut für Strahlen- und Kernphysik

P. Wolf et al. (2019): https://indico.cern.ch/event/855994/contributions/3637076/

MEASURING TEST-STRUCTURES



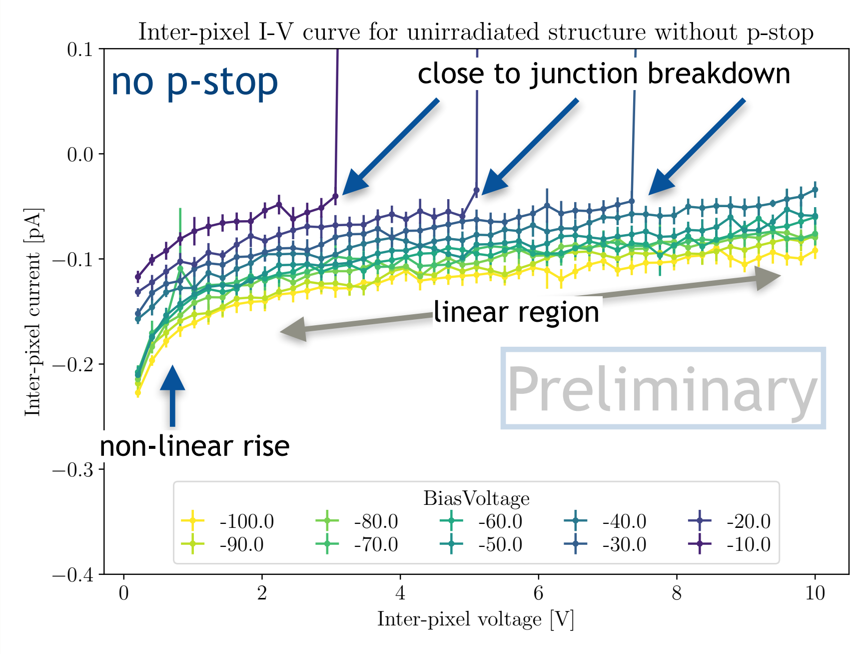
Access to the rest short-circuited pixels (apply **inter-pixel voltage**)

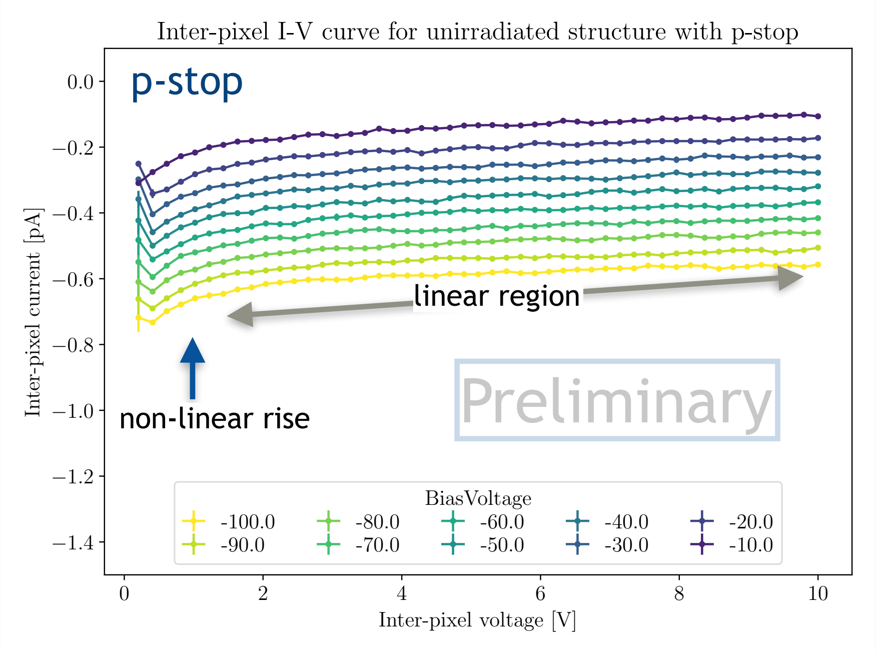
Access to a single pixel (**measure current** using electrometer: Keithley 6517A)

- Electrode implant (N-well) of the highlighted pixel can be accessed independently
- The N-wells of the rest pixels are short-circuited through a metal grid
- Measure the current-voltage behaviour **between one pixel and the surrounding pixels**
- Evaluate the resistance through fitting the inter-pixel I-V curve

INTER-PIXEL I-V BEFORE IRRADIATION

- Shows characteristics of p-n junctions
- Fitting of the linear region delivers the inter-pixel resistance

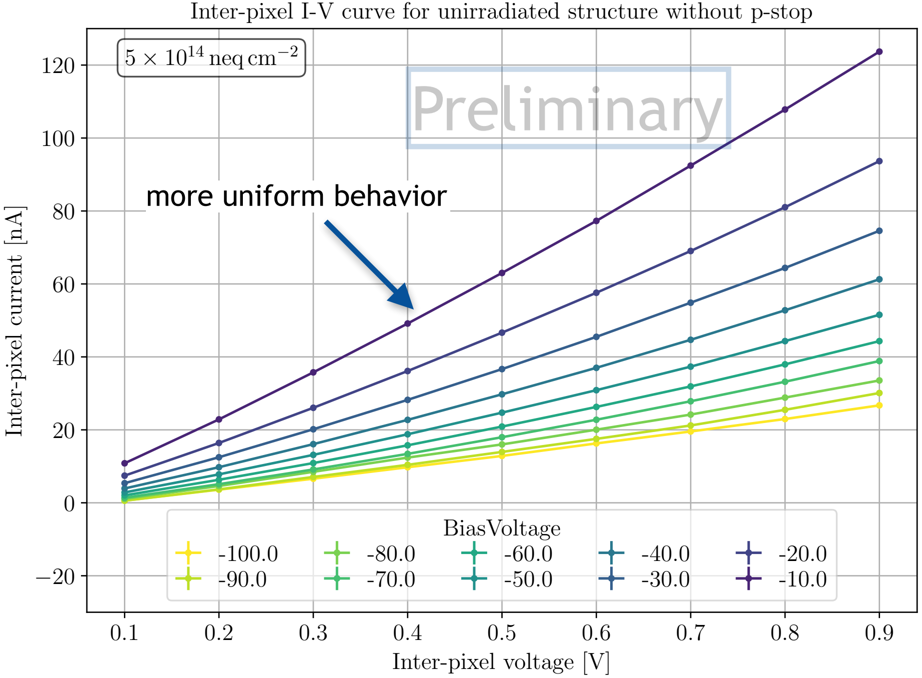




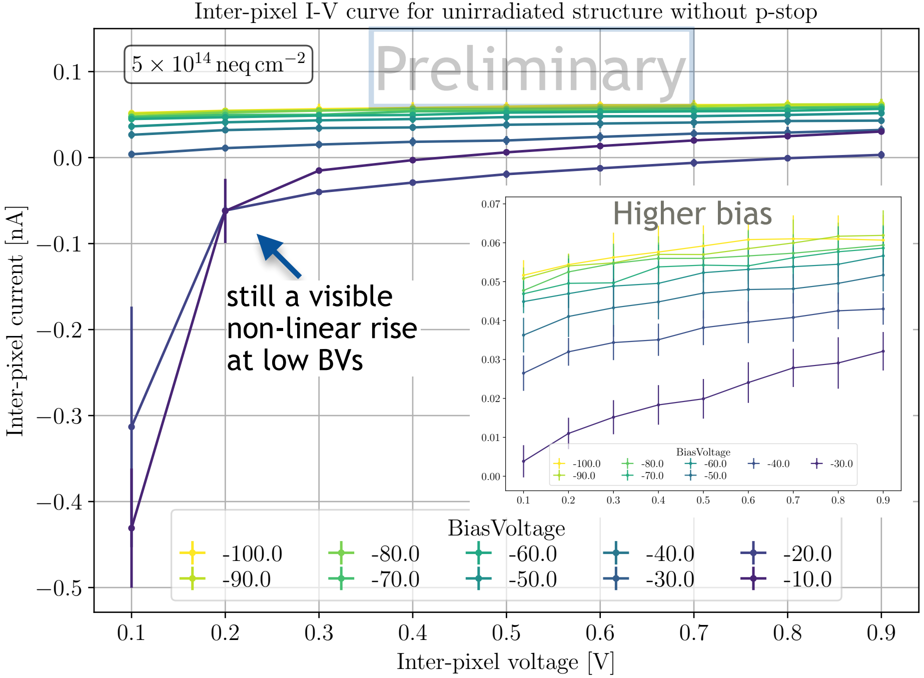
INTER-PIXEL I-V AFTER IRRADIATION

- Shows more uniform (linear) behavior, especially for higher bias voltages

no p-stop



p-stop

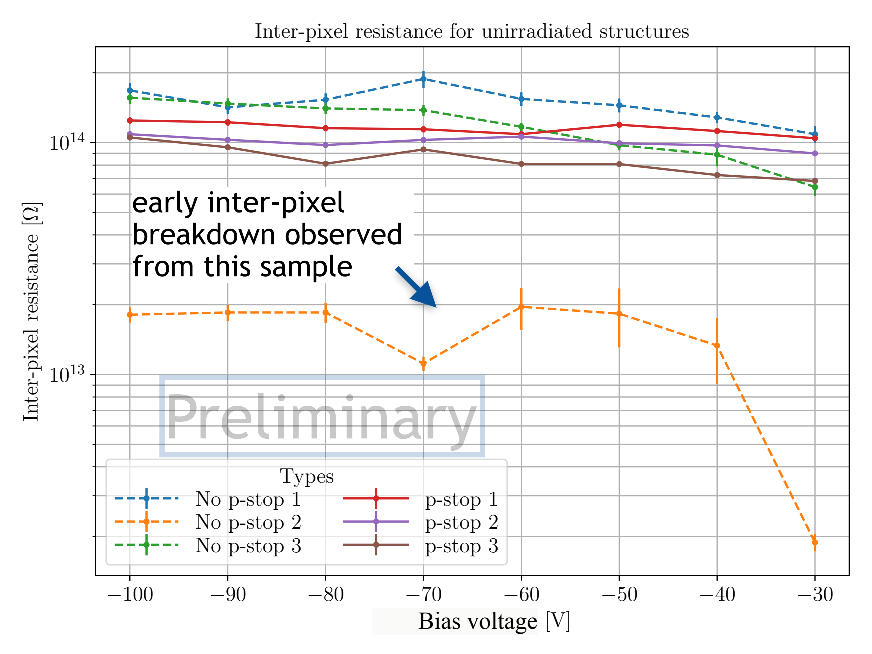


INTER-PIXEL RESISTANCE BEFORE IRRADIATION

- Measured at $T \approx 20^{\circ}\,\mathrm{C}\,(293\,\mathrm{K})$

- **WITH** p-stop (**solid lines**):
  - resistances are approximately $1 \times 10^{14}\,\Omega$
- **WITHOUT** p-stop (**dashed lines**):
  - 2 samples reveal a similar resistance of $1 \times 10^{14}\,\Omega$
  - One sample has a lower resistance, the difference is approximately 1 order of magnitude
  - this sample shows an early breakdown at approximately 3 V inter-pixel voltage

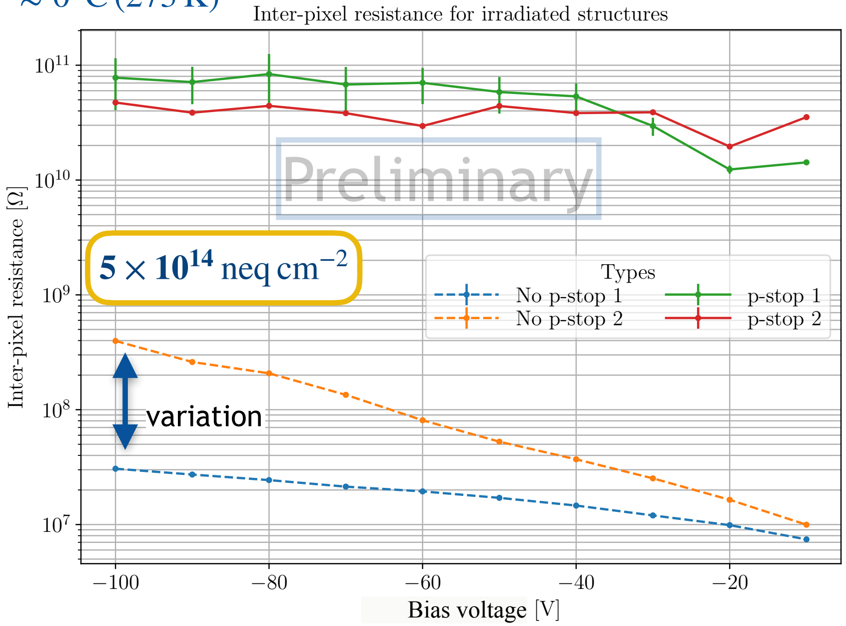
➡ Before irradiation, high inter-pixel resistance can be achieved without using p-stop



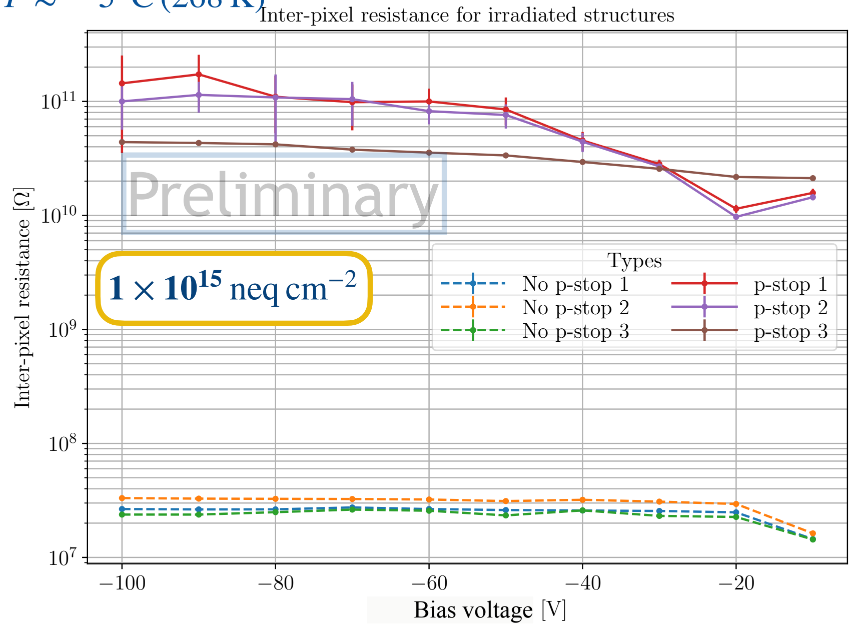
INTER-PIXEL RESISTANCE AFTER IRRADIATION (LOWER FLUENCES)

- Decrease of resistance is observed (**WITH** p-stop: **solid lines**; **WITHOUT** p-stop: **dashed lines**)
- Increases with bias voltage
- P-stop provides a higher resistance

$T \approx 0^\circ\,\mathrm{C}\,(273\,\mathrm{K})$



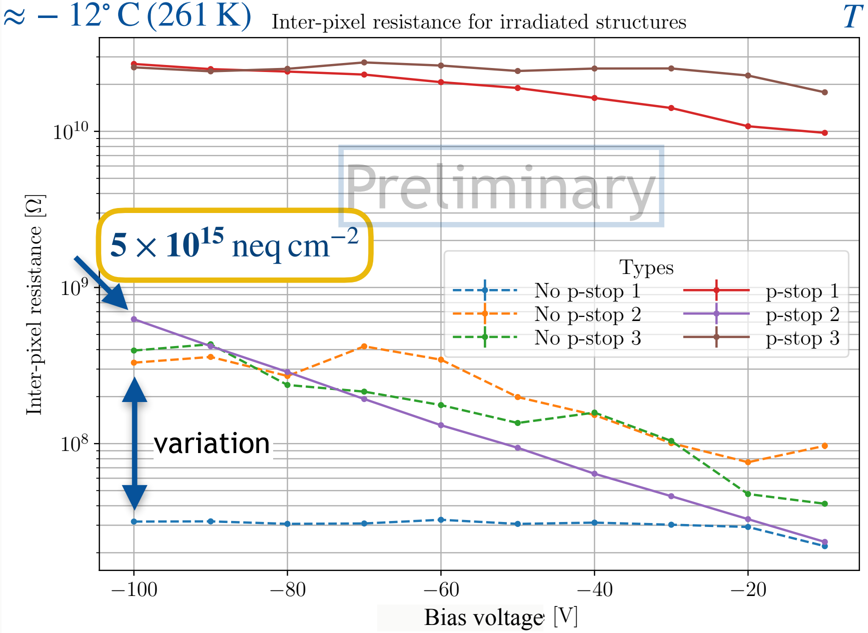
$T \approx -5^\circ\,\mathrm{C}\,(268\,\mathrm{K})$



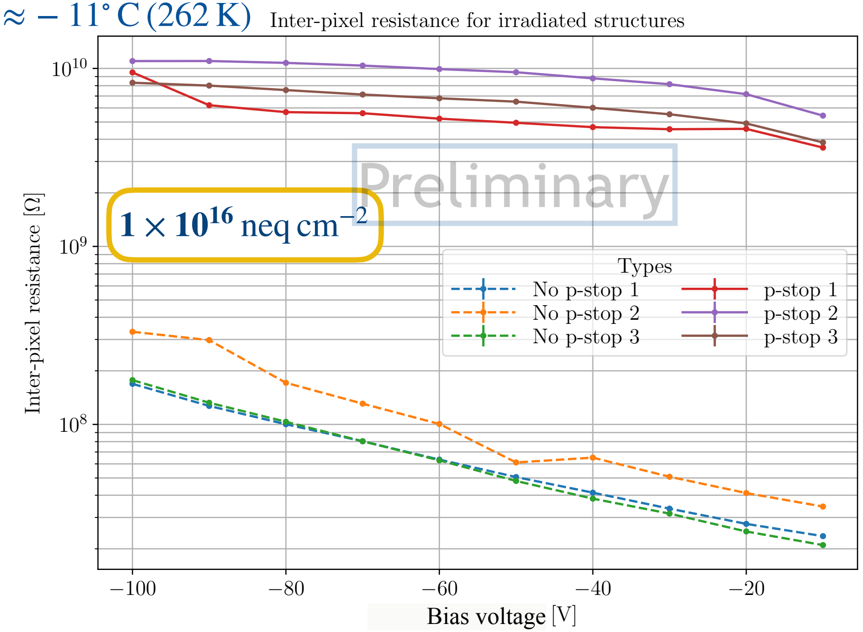
INTER-PIXEL RESISTANCE AFTER IRRADIATION (HIGHER FLUENCES)

- Resistances are similar as with lower fluences (**WITH** p-stop: **solid lines**; **WITHOUT** p-stop: **dashed lines**)
- Increases with bias voltage; p-stop provides a higher resistance
- A sample **WITH** p-stop gives unusually low resistance (left figure, label: "p-stop 2"), guess: malfunctioning sensor

$T \approx -12^{\circ}\,\mathrm{C}\,(261\,\mathrm{K})$



$T \approx -11^{\circ}\,\mathrm{C}\,(262\,\mathrm{K})$



SUMMARY OF THE PRELIMINARY RESULTS

Fluence	Resistance BV=-100 V	Resistance (p-stop) BV=-100 V	Temperature & Relative Humidity
0	$\sim 10^{13} - 10^{14}\,\Omega$	$\sim 10^{14}\,\Omega$	$\approx 293\,\mathrm{K}\ \& \approx 8\,\%\,\mathrm{RH}$
$5 \times 10^{14}\,\mathrm{neq\,cm^{-2}}$	$\sim 10^{7} - 10^{8}\,\Omega$	$\sim 10^{10}\,\Omega$	$\approx 273\,\mathrm{K}\ \& \approx 12\,\%\,\mathrm{RH}$
$1 \times 10^{15}\,\mathrm{neq\,cm^{-2}}$	$\sim 10^{7}\,\Omega$	$\sim 10^{11}\,\Omega$	$\approx 268\,\mathrm{K}\ \& \approx 13\,\%\,\mathrm{RH}$
$5 \times 10^{15}\,\mathrm{neq\,cm^{-2}}$	$\sim 10^{7} - 10^{8}\,\Omega$	$\sim 10^{8} - 10^{10}\,\Omega$	$\approx 261\,\mathrm{K}\ \& \approx 13\,\%\,\mathrm{RH}$
$1 \times 10^{16}\,\mathrm{neq\,cm^{-2}}$	$\sim 10^{8}\,\Omega$	$\sim 10^{10}\,\Omega$	$\approx 262\,\mathrm{K}\ \& \approx 15\,\%\,\mathrm{RH}$

- High resistance before irradiation at 293 K
- No significant changes between different fluences at similar temperatures

- Resistance decreases by approximately **6 orders of magnitude**
- Large variation among samples is observed

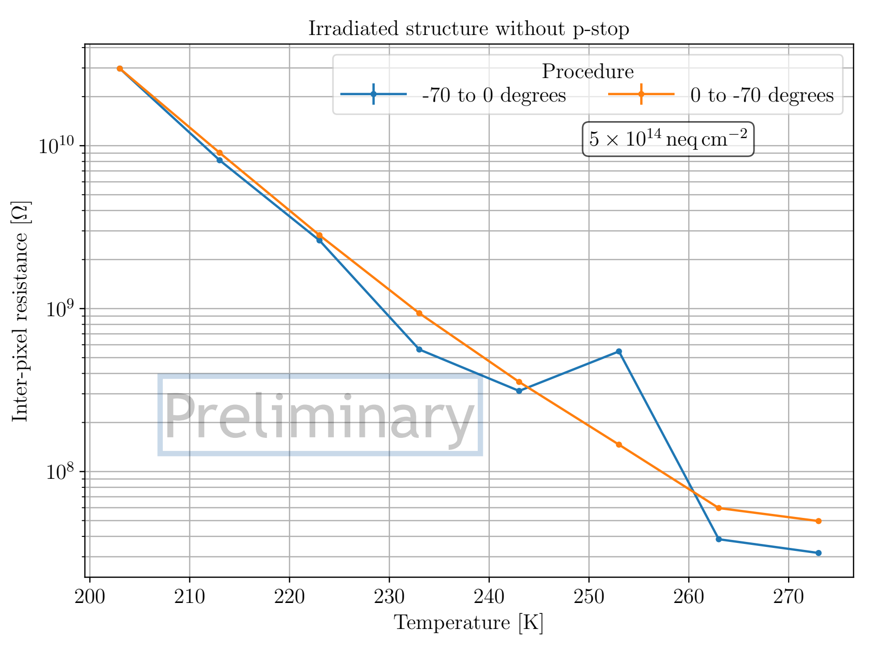
- Resistance decreases by approximately **3 orders of magnitude**
- Stable among samples

PROBLEMS & QUESTIONS

- Large variation of resistance among samples:
  - appears often for the sensors **WITHOUT** p-stop
  - assumption:
    the floating poly silicon field-plate may “pick up” different unknown voltages for each measurement

- Temperature dependent resistance
  - a test of an irradiated sample at $T \in [203,273]\,\mathrm{K}$
  - resistance increases (exponentially) with decreasing temperature
  - ➡ systematic error of the measurement
  - ➡ What is the main mechanism of this effect?
    Mobility?
    Generation & recombination?
    Issue of the measurement setup?

Test: irradiated sensor without p-stop at BV=-100



FUTURE INVESTIGATIONS

- Temperature dependent resistance:
  - perform measurements at the same temperature
  - take into account the systematic error
  - search for the main mechanism

- Apply voltages at the field-plate:
  - determine the influence on the resistance
  - search for optimum potentials

- Contribution from TID
  - X-ray irradiation (Bonn) up to ~1 Mrad (Saturation of oxide charge)

SUMMARY & CONCLUSION

- Inter-pixel resistance of passive CMOS test structures with two different types of inter-pixel isolation have been measured before and after proton irradiation
- Resistance BEFORE irradiation:
  test-structures WITH & WITHOUT p-stop reveal a similar value in the order of $10^{14}\,\Omega$
  ➡ ability of isolation is the same
- Resistance AFTER irradiation:
  - WITH p-stop: drops by ~3 orders of magnitude
  - WITHOUT p-stop: drops by ~6 orders of magnitude;
    variation of approx. 1 order of magnitude has been observed

  ➡ p-stop provides better inter-pixel isolation after irradiation

  ➡ WITHOUT p-stop, we can still get a resistance $\sim 100\,\mathrm{M}\Omega$
  - temperature dependence has been observed
    ➡ the influence needs to be considered as a systematic error
- Is p-stop necessary?
  ➡ Improvements of the experiment and further investigations are required