DPG 2017: Front Side Biasing of Silicon Sensors

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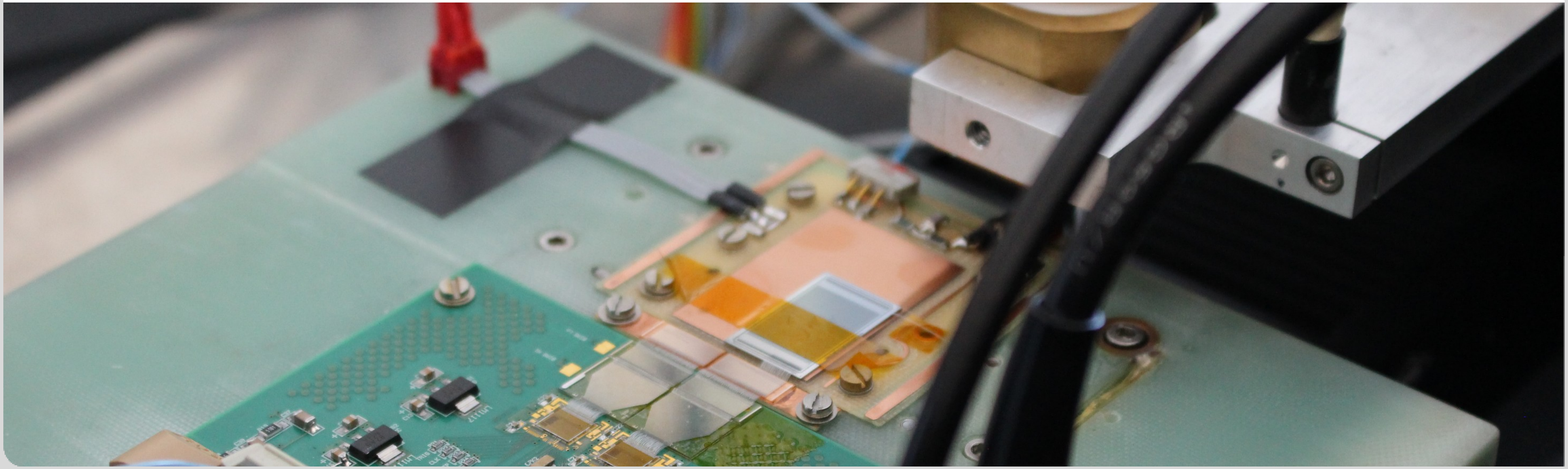

I. Motivation & Working Principle

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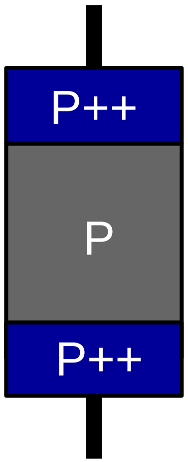
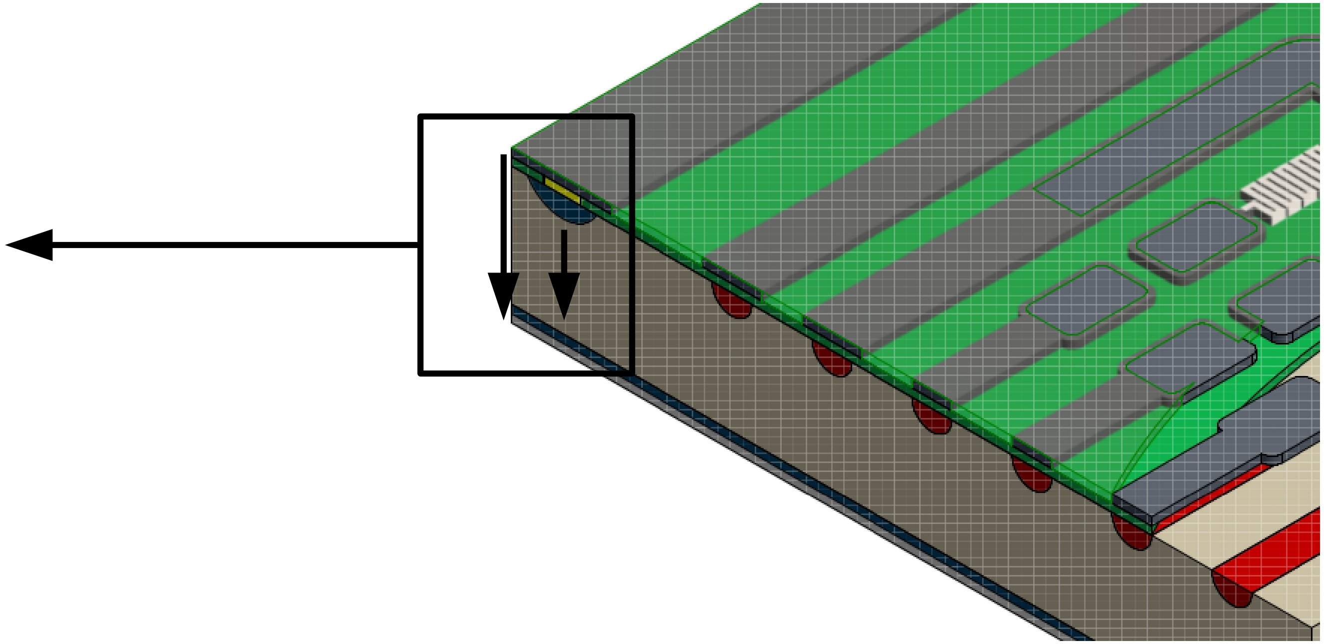
- Periphery region between top side and backplane works like a resistor made of different p-doped layers (over-simplified!)

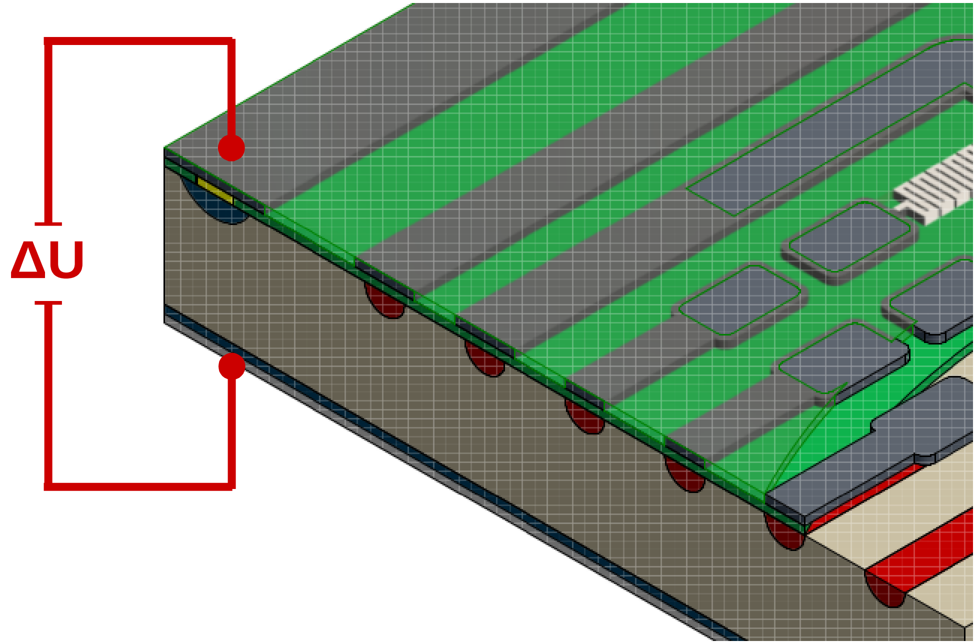




I. Motivation & Working Principle

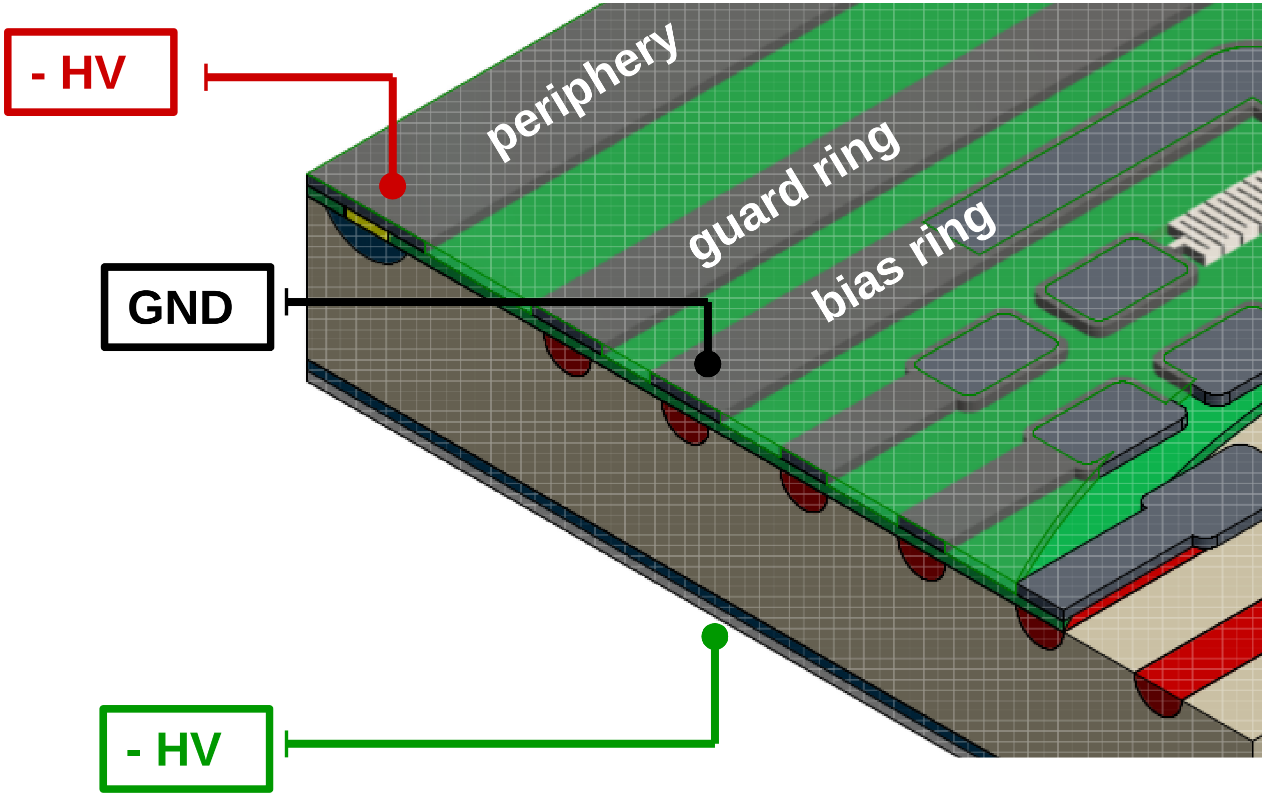
- Think of the periphery region between top side and backplane as a resistor made of different p-doped regions (over-simplified!)
- If you set the top side to a certain potential, the backplane is naturally set to a similar potential depending on the resistance of this “resistor”

   ➔ Voltage drop $\Delta U = I \cdot R_{Edge}$



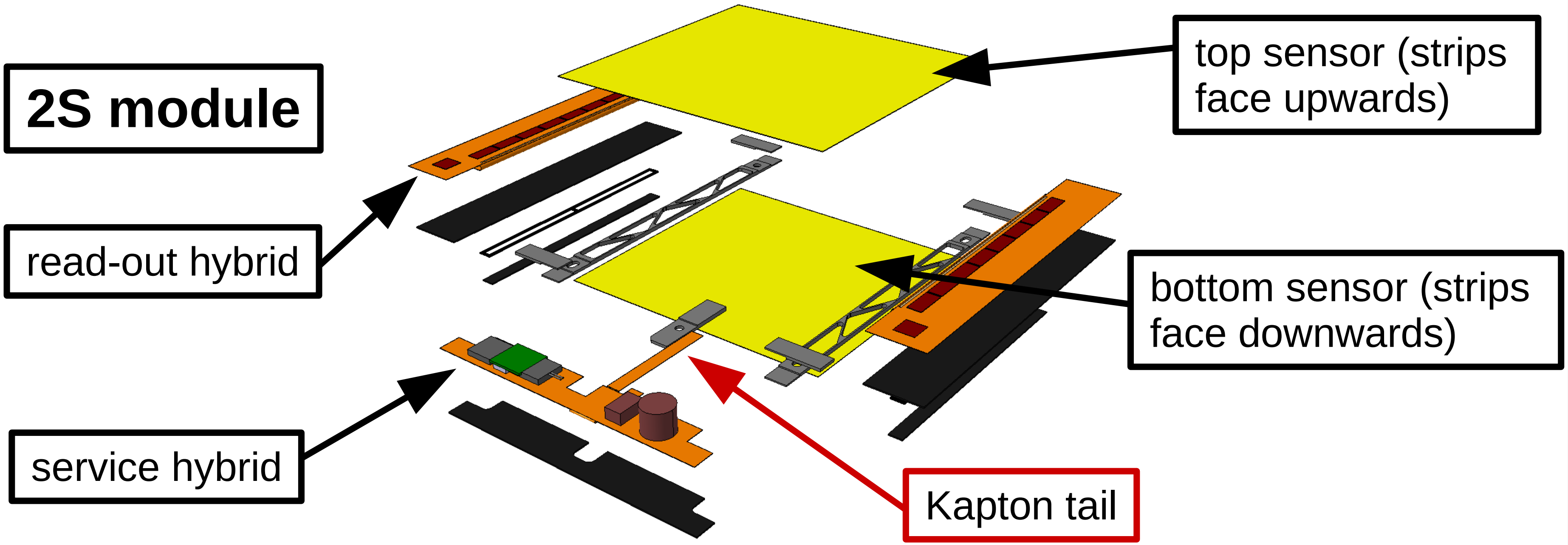
I. Motivation & Working Principle

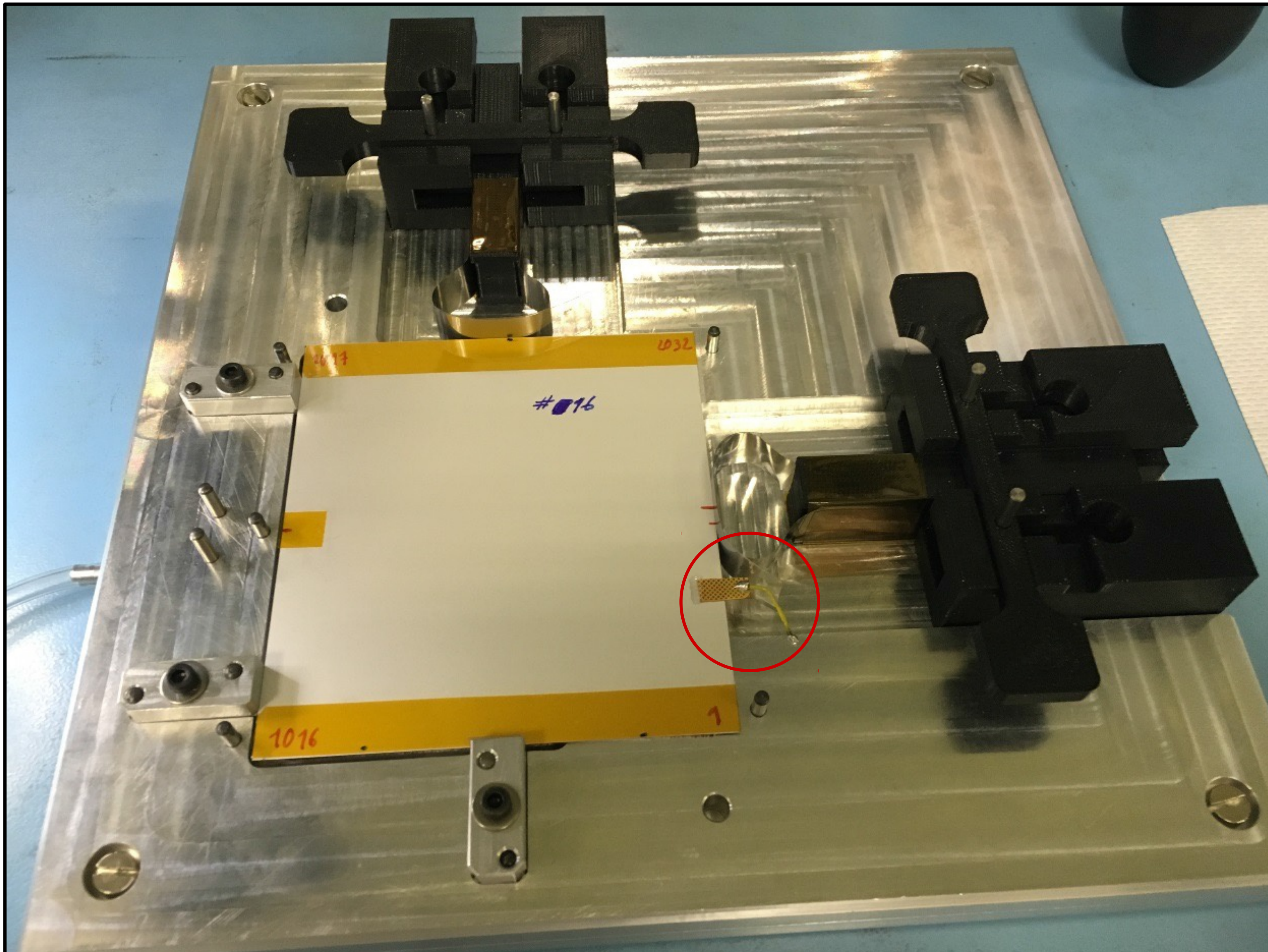
- Normal way of biasing a n-in-p sensor (back side bias)
- Front side bias



I. Motivation & Working Principle

- FSB would facilitate the module assembly because 3 time-consuming working steps would be eliminated:
  1) ~~Kapton tail attachment~~
  2) ~~Kapton tail bonding~~
  3) ~~Kapton tail encapsulation~~



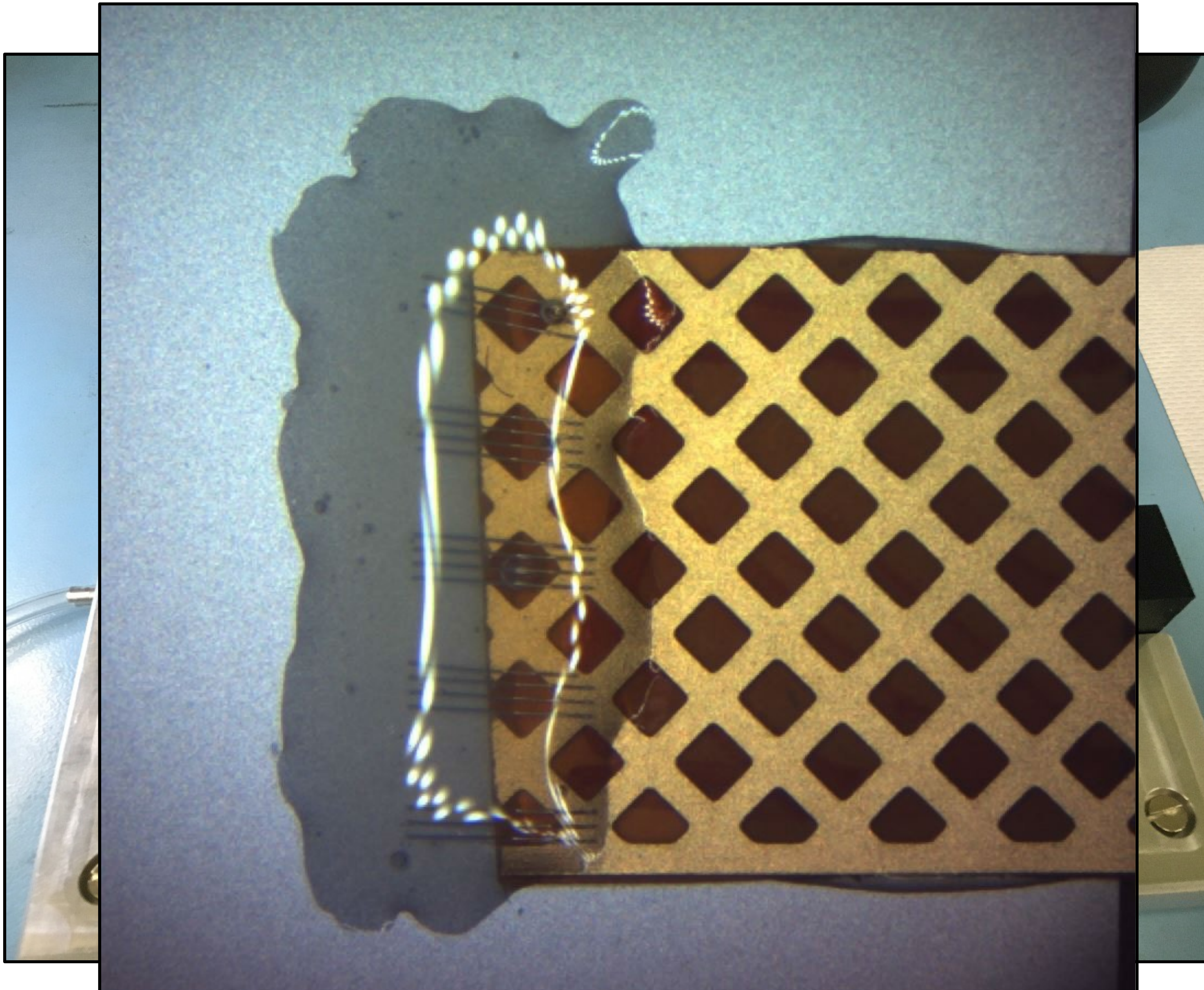


th tail has

ble

ensor (strips
pwards)

sensor (strips
wnwards)



th tail has

ble

ensor (strips
pwards)

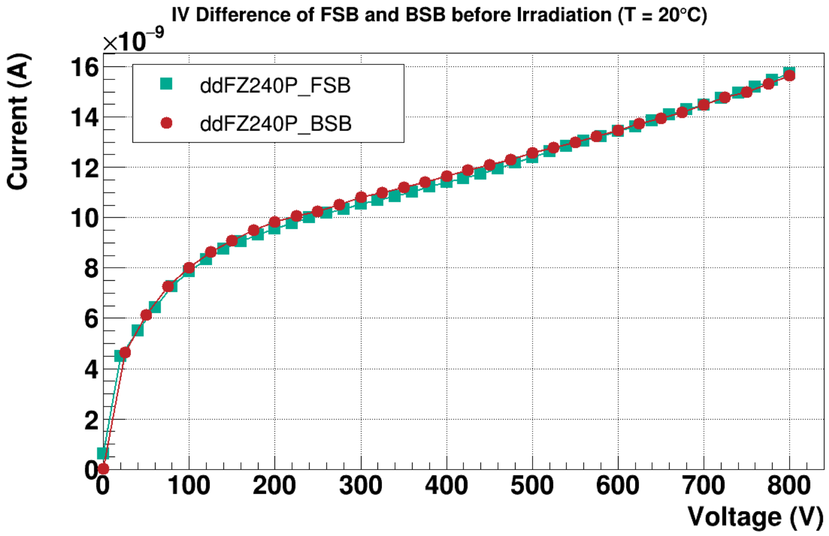
sensor (strips
wnwards)

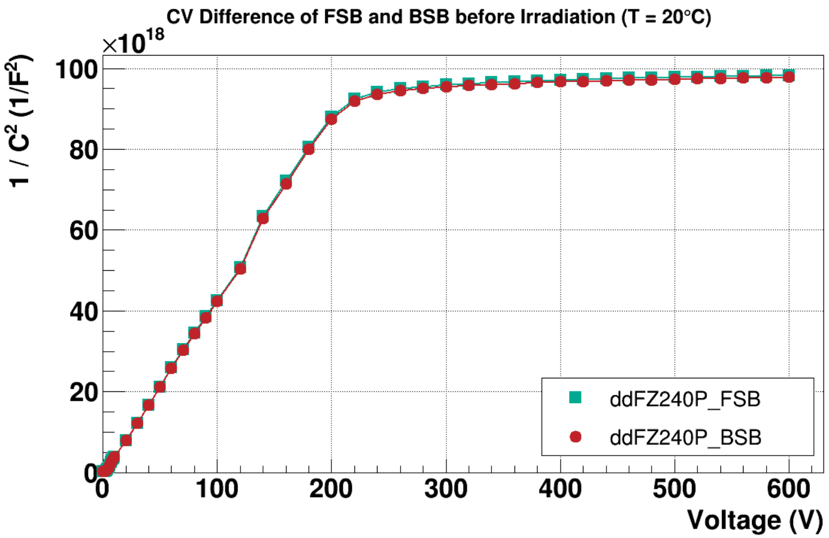
II. Evaluation Front-Side-Biased Sensor Parameters

II. Evaluation of Front-Side-Biased Sensor Parameters

- No significant difference of
  - current-voltage-characteristics (IV)
  - capacitance-voltage-characteristics (CV)

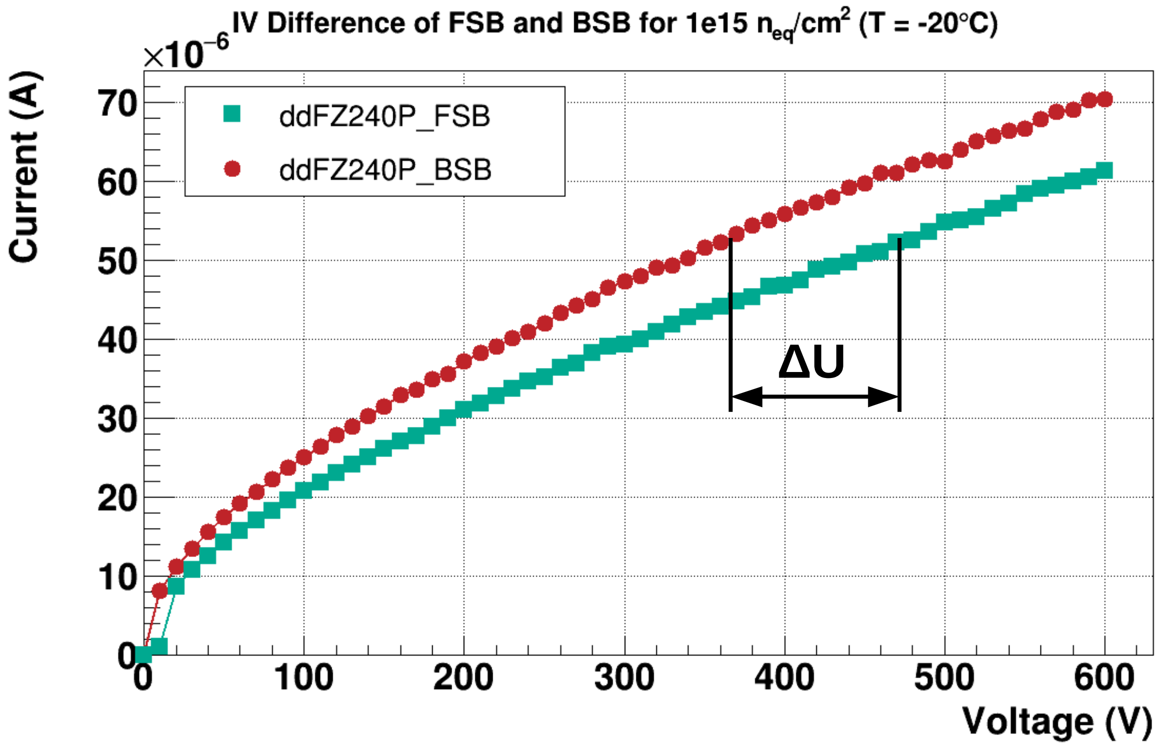
  before irradiation





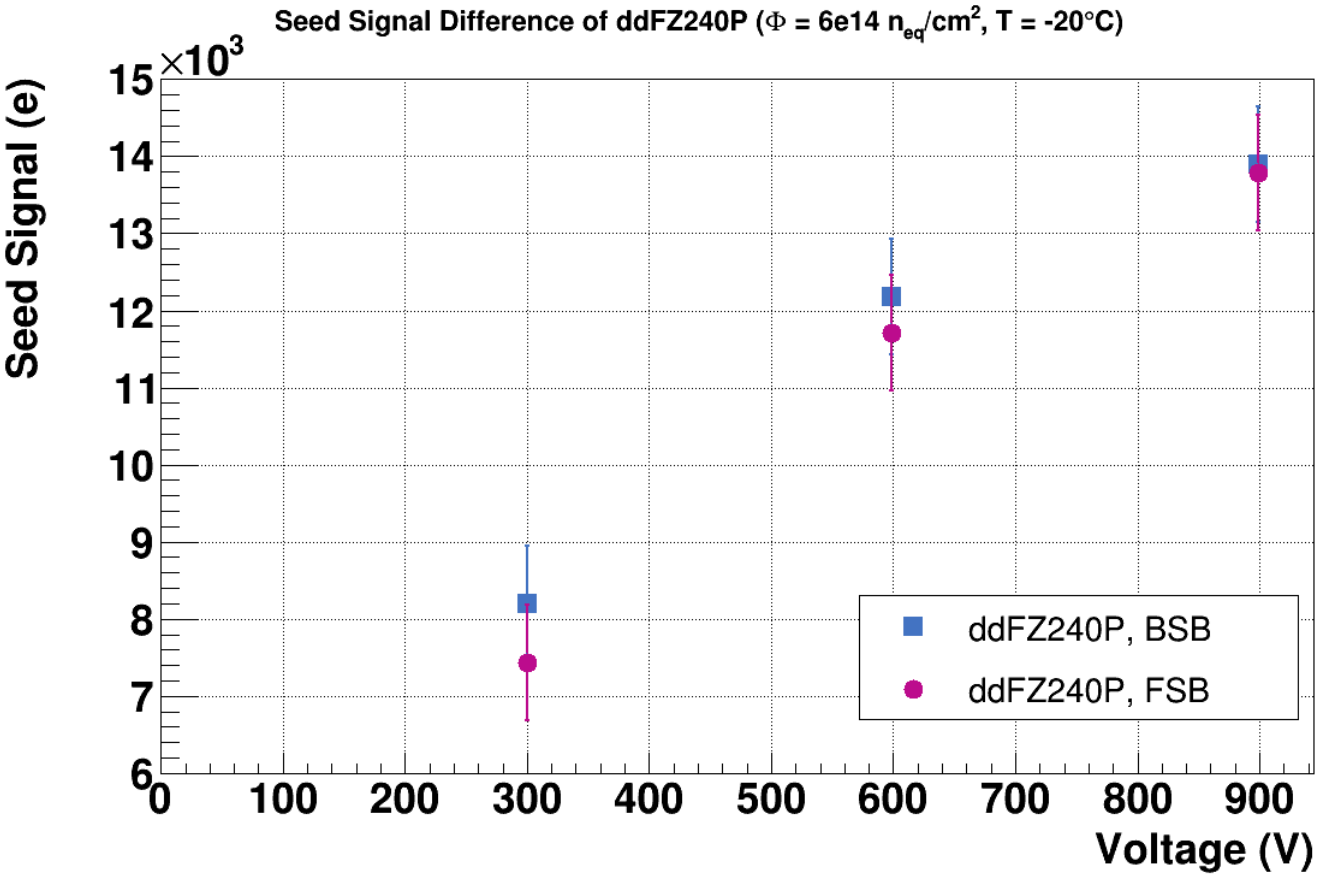
II. Evaluation of Front-Side-Biased Sensor Parameters

- However: ΔU clearly observable for fluences beyond 6e14 n_{eq}/cm^2



II. Evaluation of Front-Side-Biased Sensor Parameters

- Charge collection measurements also indicate the voltage drop
  - ➔ lower seed signal with FSB



III. Evaluation of the Sensor Edge's Resistivity

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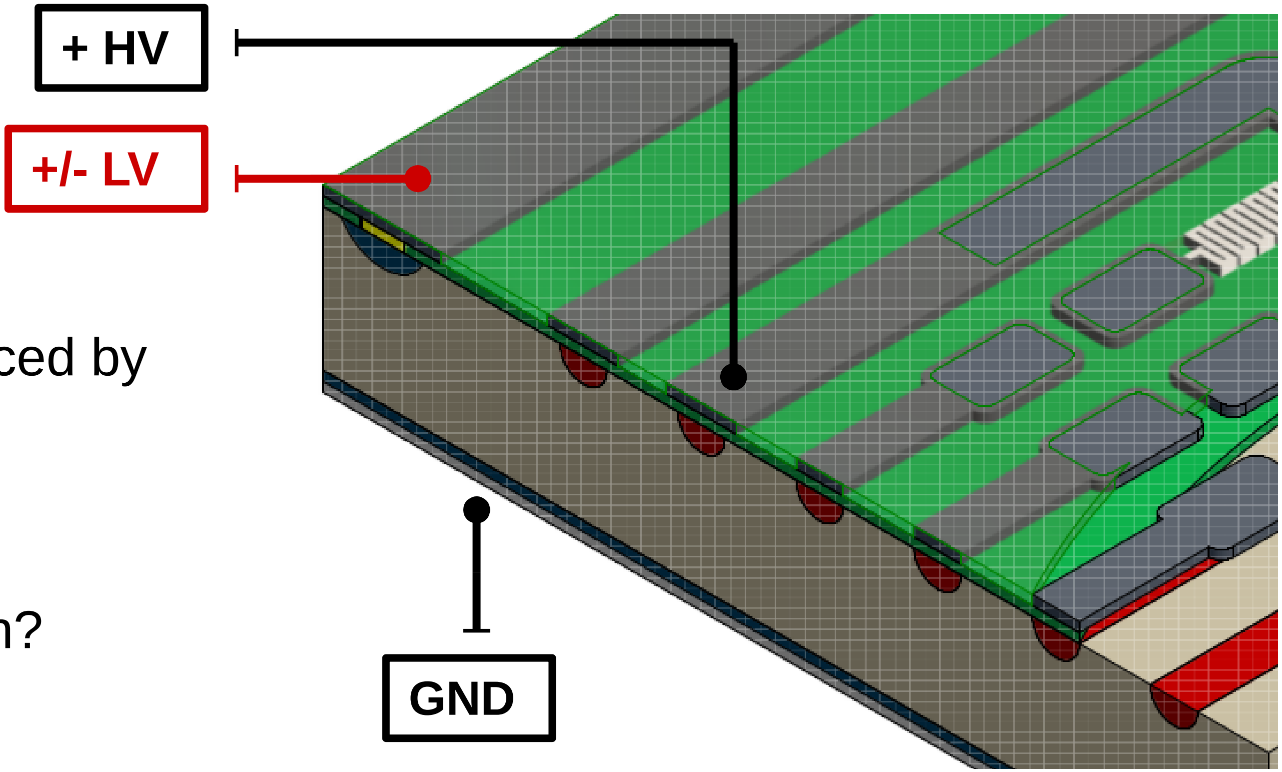
- Systematic studies of edge resistivity (ER) on mini-strip sensors with our probe station setup

- How is ER influenced by
  - temperature?
  - irradiation?
  - bulk depletion?



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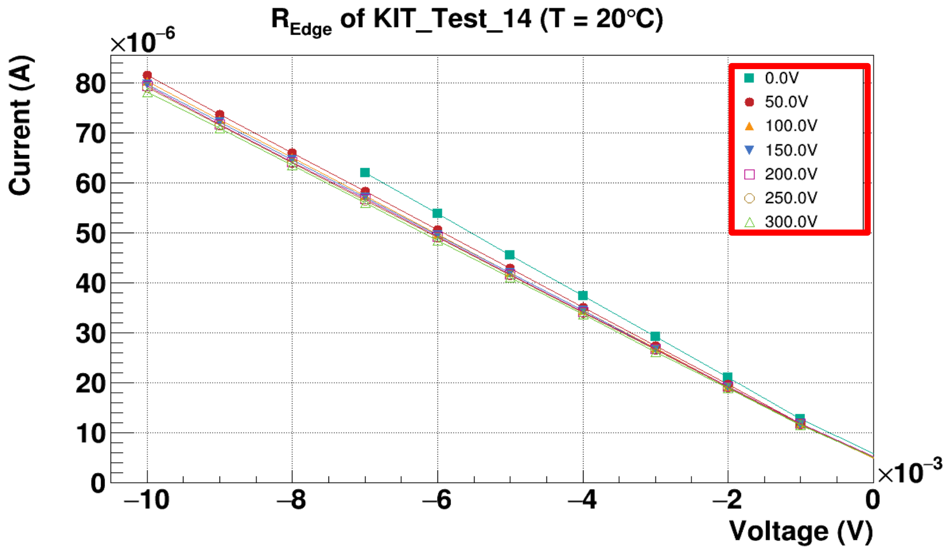

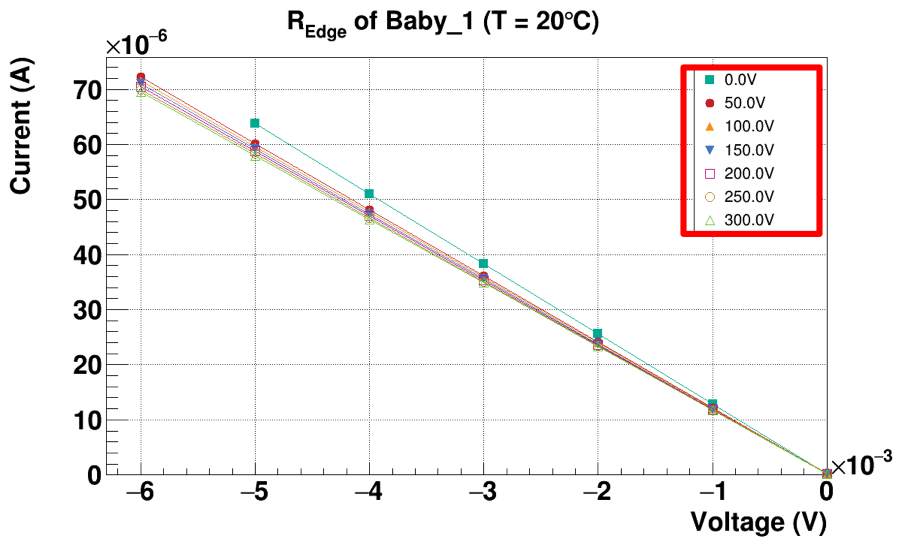

- **V_{bias} has no significant impact on R_{edge}**

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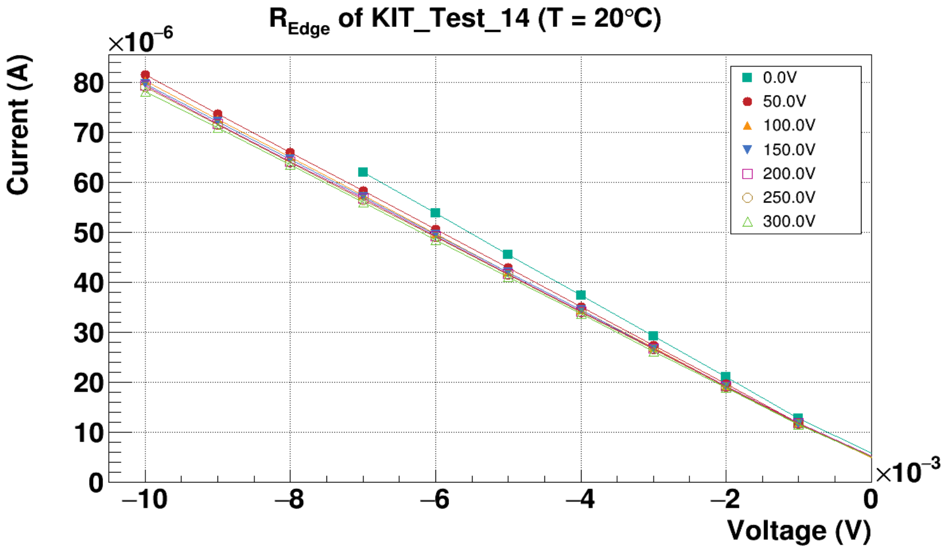

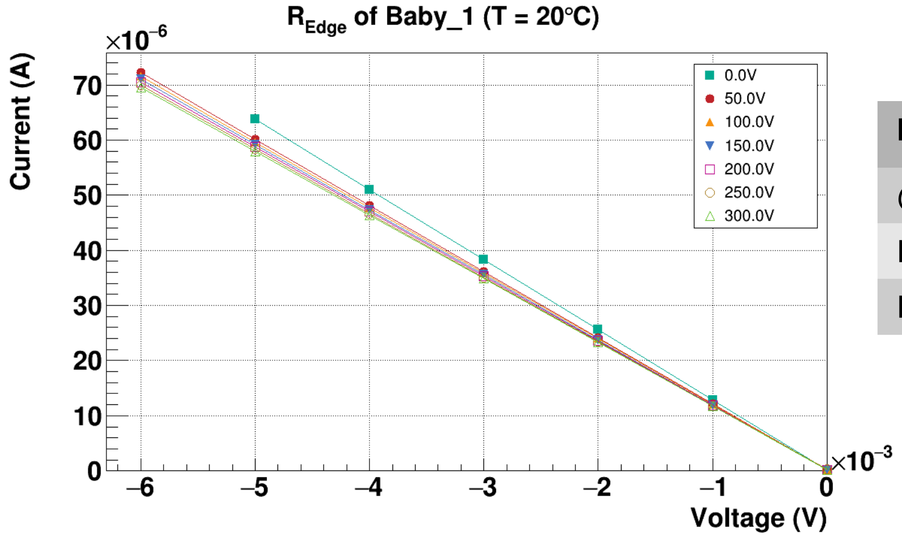

- **V_{bias} has no significant impact on R_{edge}**
- **"R ~ 1/A_{Per}":**
  - Resistor formula: $R = \rho \cdot L/A$

Name	R (Ω)	A_{Per} (cm²)	L (µm)	ρ (Ω cm)
@20°C:				
Baby_1	79	1.209	240	1.1k
KIT_Test_14	124	0.688	240	3.5k

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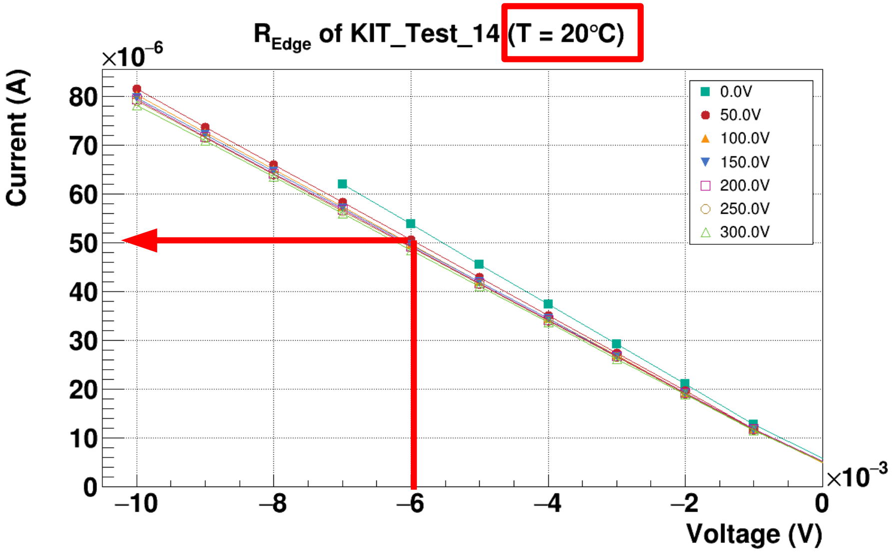

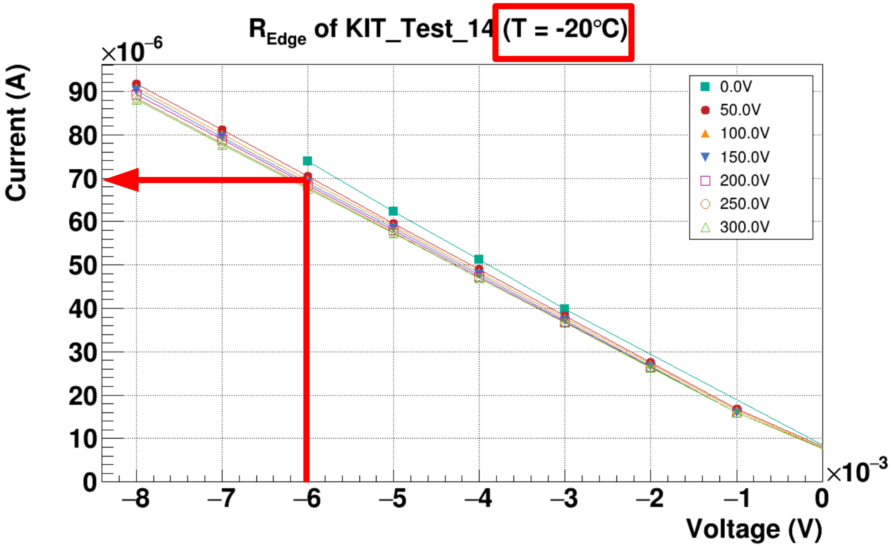

- **Before irradiation: "ρ ~ T":**
  - Resistivity of intrinsic Si: $\rho = [q(n\mu_n + p\mu_p)]^{-1}$
  - Carrier mobility of intrinsic Si: $\mu_p \sim T^{-2.3}$, $\mu_n \sim T^{-2.6}$

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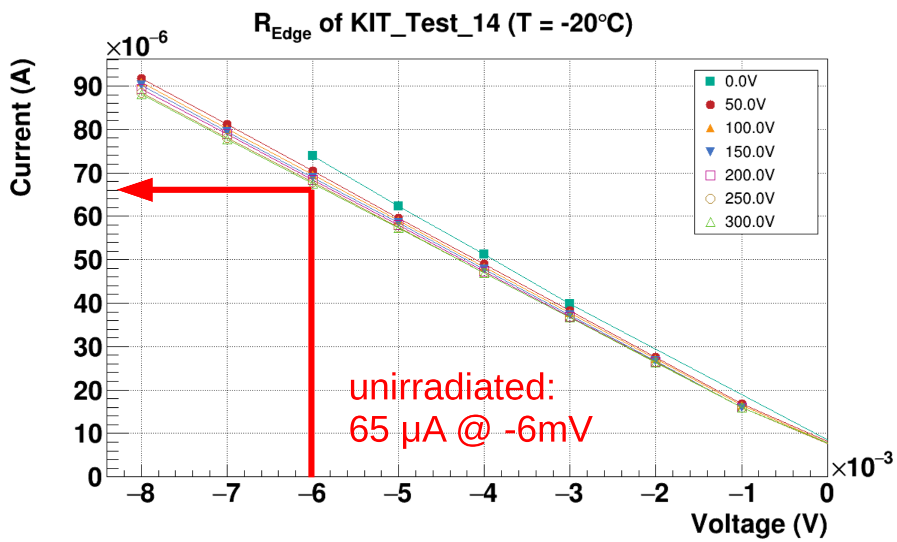
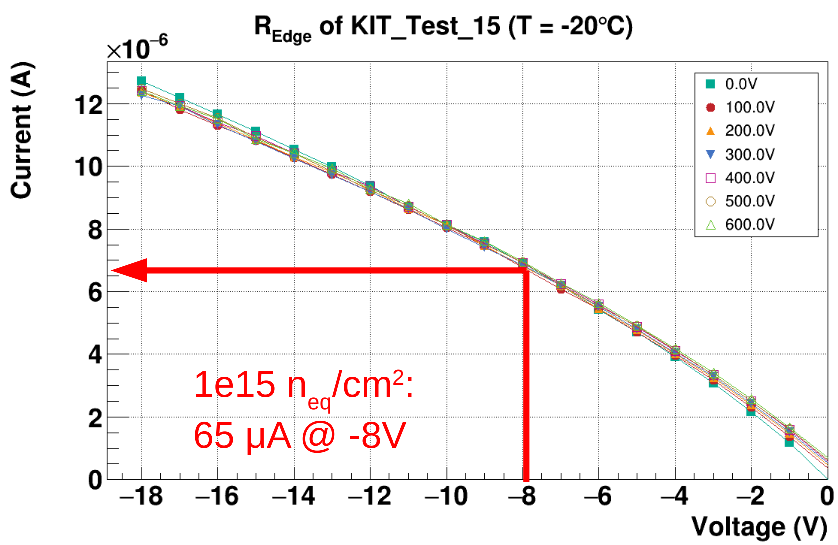
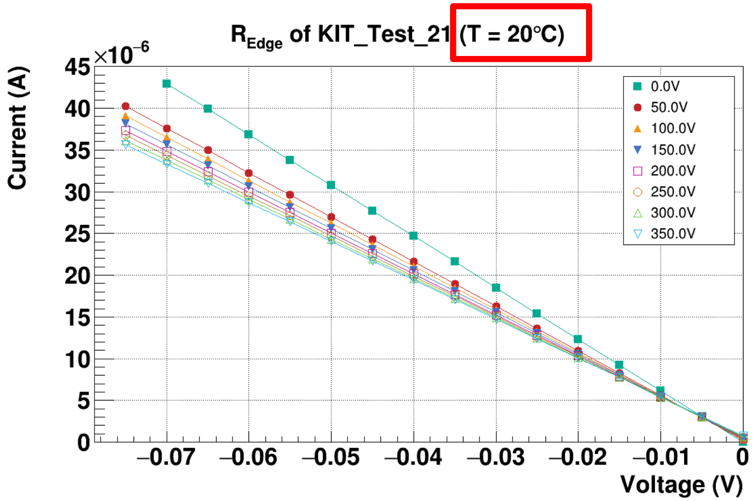


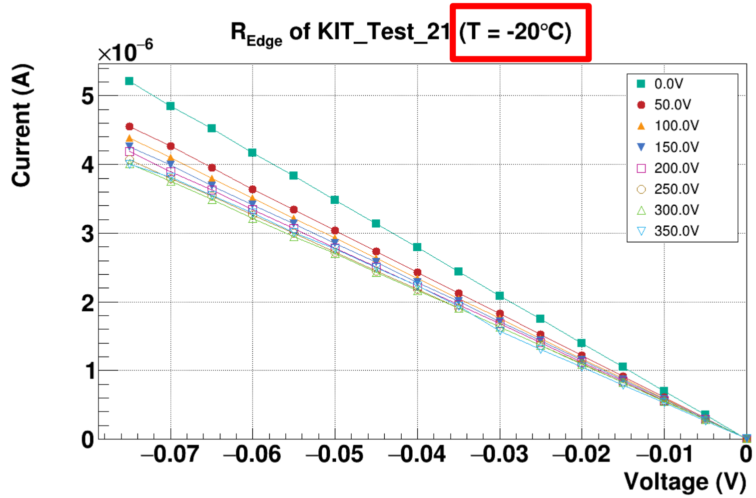


- **"$\rho \sim \varphi_{eq}$":**
  - Space-charge-limited current (SCL current)
  - ➔ emerging E-field reduces the current flow after irradiation

Name	Φ (n_{eq}/cm^2)	R (Ω)	A_{Per} (cm^2)
@-20°C:			
KIT_Test_14	-	92	0.621
KIT_Test_15	1e15p	1M	0.621

III. Evaluation of the Sensor Edge's Resistivity





- **After irradiation**

"ρ ~ 1/T":

- Trapping probability decreases with rising temperature:

P(τ) ~ 1/T [1]

➔ E-field decreases

[1] G. Kramberger et al. *Effective trapping time of electrons and holes in different silicon materials irradiated with neutrons, protons and pions.* URL: http://www-f9.ijs.si/~zavrtani/mi_02_c.pdf

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IV. Approximating the Voltage Drop of a 2S Sensor

IV. Approximating the Voltage Drop for a 2S Sensor

- Most important question: How big is the voltage drop of a 2S sensor?
- This can be approximated by using
  - the experimentally found resistivities of mini sensors $\boldsymbol{\rho_{\text{mini sensor}}}$
  - the 2S periphery area $\boldsymbol{A_{\text{Per, 2S}} = 3.846\ \text{cm}^2}$
  - the 2S leakage current using damage rate damage rate $\boldsymbol{\alpha = \Delta I/(V\varphi_{eq}) = 4 \cdot 10^{-17}\ \text{A/cm}}$:
    - $\boldsymbol{\varphi_{eq} = 6\text{e}14\ n_{eq}/\text{cm}^2}$
    - **T = -20 °C**
    - **2 weeks annealing @RT**
    - $\boldsymbol{V_{\text{Bias}} = 600\ \text{V}}$

➔ **I = 1.1 mA**

IV. Approximating the Voltage Drop for a 2S Sensor

Name	Fluenz	R (Ω)	A_{Per} (cm²)	L (µm)	ρ (Ω cm)	R_{2S} (Ω)	ΔU@1.1 mA	ΔW@1.1 mA
@20°C:								
KIT_Test_14	-	124	0.621	240	3210	20	**0.022**	0.00007
KIT_Test_21	1e13p	1630	0.621	240	42198	263	**0.290**	0.00095
MaPSA_std_9_2	-	694	0.406	200	14097	88	**0.097**	0.00032
@-20°C:								
KIT_Test_14	-	92	0.621	240	2382	15	**0.016**	0.00005
KIT_Test_21	1e13p	14415	0.621	240	373183	2328	**2.561**	0.00841
KIT_Test_16	6e14p	914000	0.621	240	23662089	147630	**162.393**	0.53294
KIT_Test_15	1e15p	1463210	0.621	240	37880312	236339	**259.973**	0.85318

Voltage drop and power loss becomes too severe for 2S sensor

V. Summary

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- Voltage drop becomes significant for high fluences
- Approximated voltage drop for 2S sensor becomes too severe
  - ➔ this needs to be experimentally verified!
- We used sensors with standard periphery design
  - ➔ there's possible room for improvement
- Even if FSB doesn't meet the requirements for CMS it might be interesting for other detectors
  - ➔ LHCb will probably use front-side-biased sensors (expected fluence here: ~ 1e13 n_{eq}/cm^2 - 1e14 n_{eq}/cm^2 [2])

[1] A. Abba et al. *Study of prototype sensors for the Upstream Tracker Upgrade.*
URL: https://cds.cern.ch/record/2137551/files/LHCb-PUB-2016-007.pdf

Backup

III. Evaluation of the Sensor Edge's Resistivity

Name	Φ (n_{eq}/cm^2)	R (Ω)	A_{Per} (cm^2)	L (µm)	ρ (Ω cm)
@20°C:					
MaPSA_std_9_2	-	694	0.406	200	14097
KIT_Test_14	-	124	0.621	240	3210
KIT_Test_21	1e13p	1630	0.621	240	42198
@-20°C:					
MaPSA_std_9_2	-	581	0.406	200	11802
KIT_Test_14	-	92	0.621	240	2382
KIT_Test_21	1e13p	14415	0.621	240	373183
KIT_Test_16	6e14p	914000	0.621	240	$23 \cdot 10^6$
KIT_Test_15	1e15p	$1 \cdot 10^6$	0.621	240	$37 \cdot 10^6$
MaPSA_edge500_2_3	1e15p	$2 \cdot 10^6$	0.236	200	$28 \cdot 10^6$
MaPSA_edge350_2_3	1e15p	$4 \cdot 10^6$	0.214	200	$51 \cdot 10^6$

II. Evaluation of Front-Side-Biased Sensor Parameters

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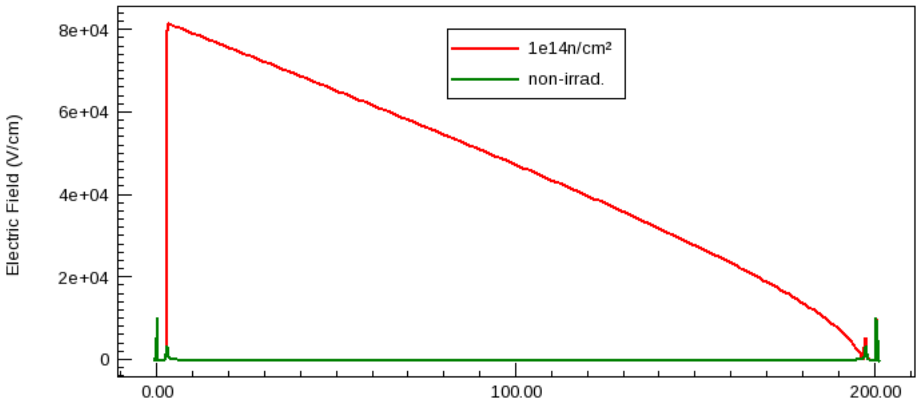
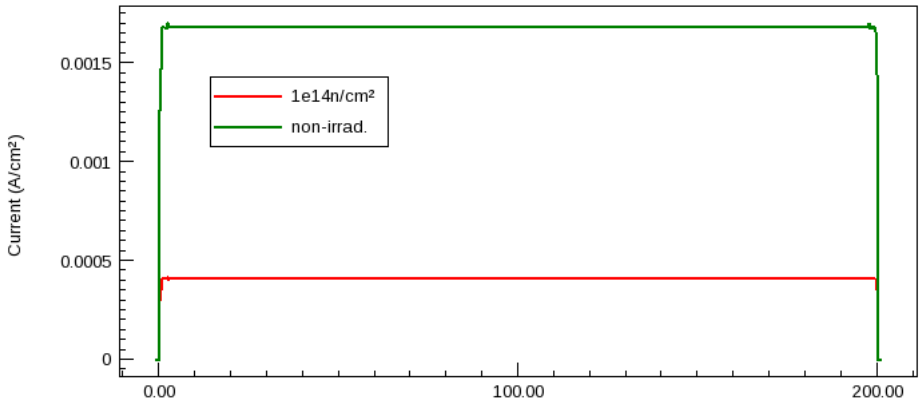
- Simulations of a 200 µm edge region support the results of the experimentally found data
  - ➔ an E-field emerges after irradiation that reduces the current flow

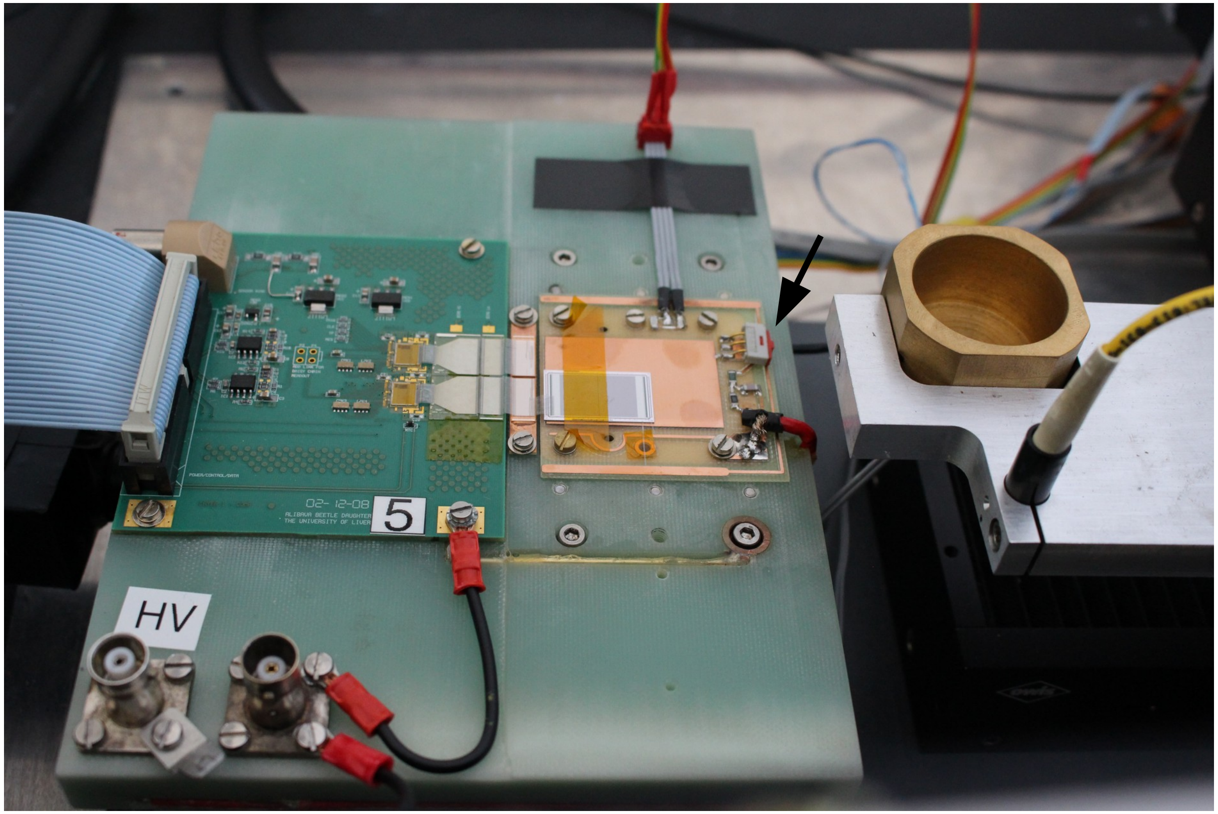




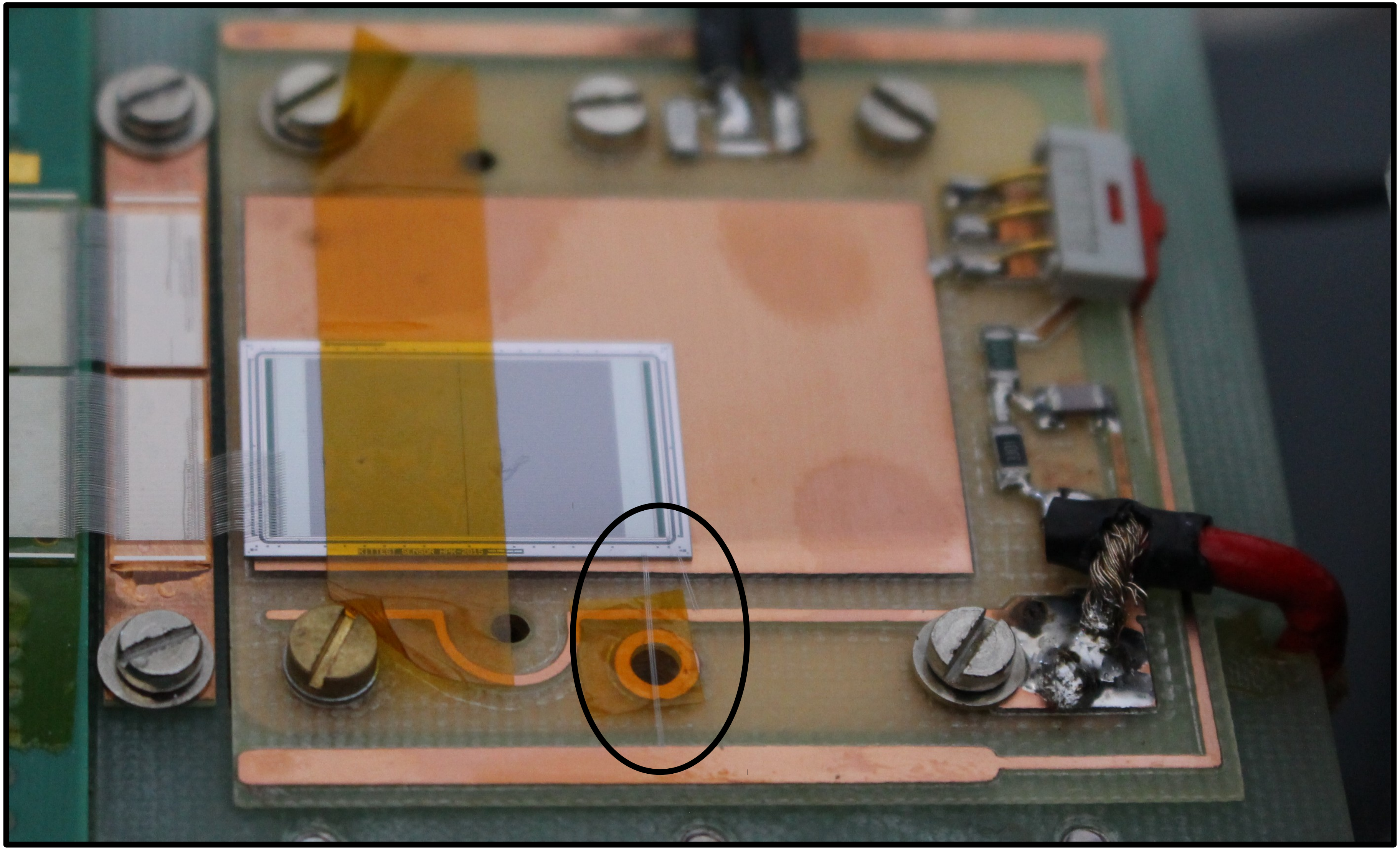
- E-field over x: shows an emerging E-field after irradiation
- Current over x: shows how the current is reduced by ~70% after irradiation

II. ALiBaVa Measurements

- Board modulation allows switching back and forth between FSB and BSB while measuring CCE with the ALiBaVa setup

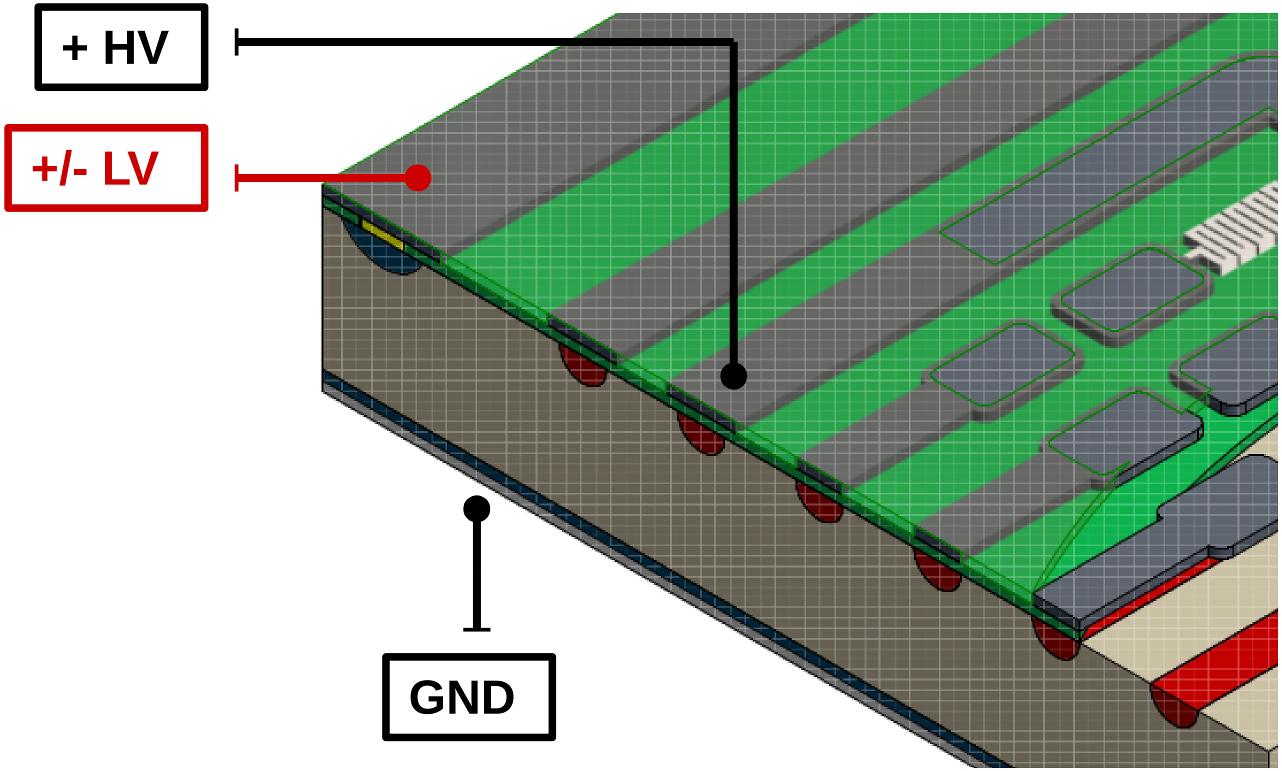


II. ALiBaVa Measurements: HPK Campaign



ER Measurements: Basic Idea

- Therefore a new probe station measurement was implemented, which is able to control all those parameters and facilitates the data acquisition

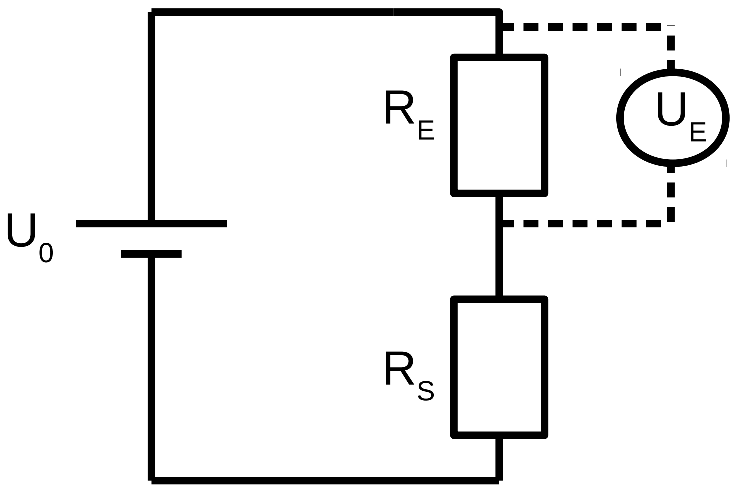


III. ER Measurements: Basic Idea

- BSB: $I_{BSB} = U_0/R_S$
- FSB: $U_E = I_{FSB}/R_E$

$\rightarrow I_{FSB} = U_0/(R_S + R_E) = U_0/(R_S + U_E/I_{FSB})$

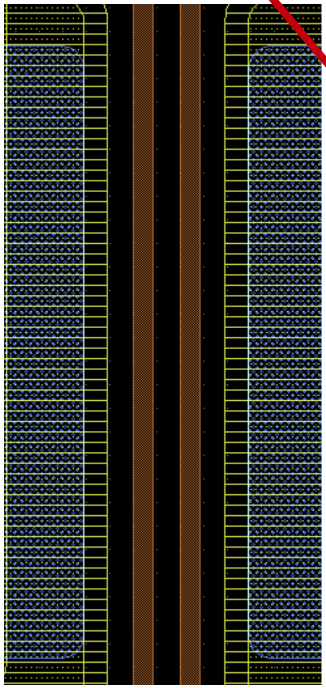
$\rightarrow U_E = U_0 - I_{FSB}R_S$

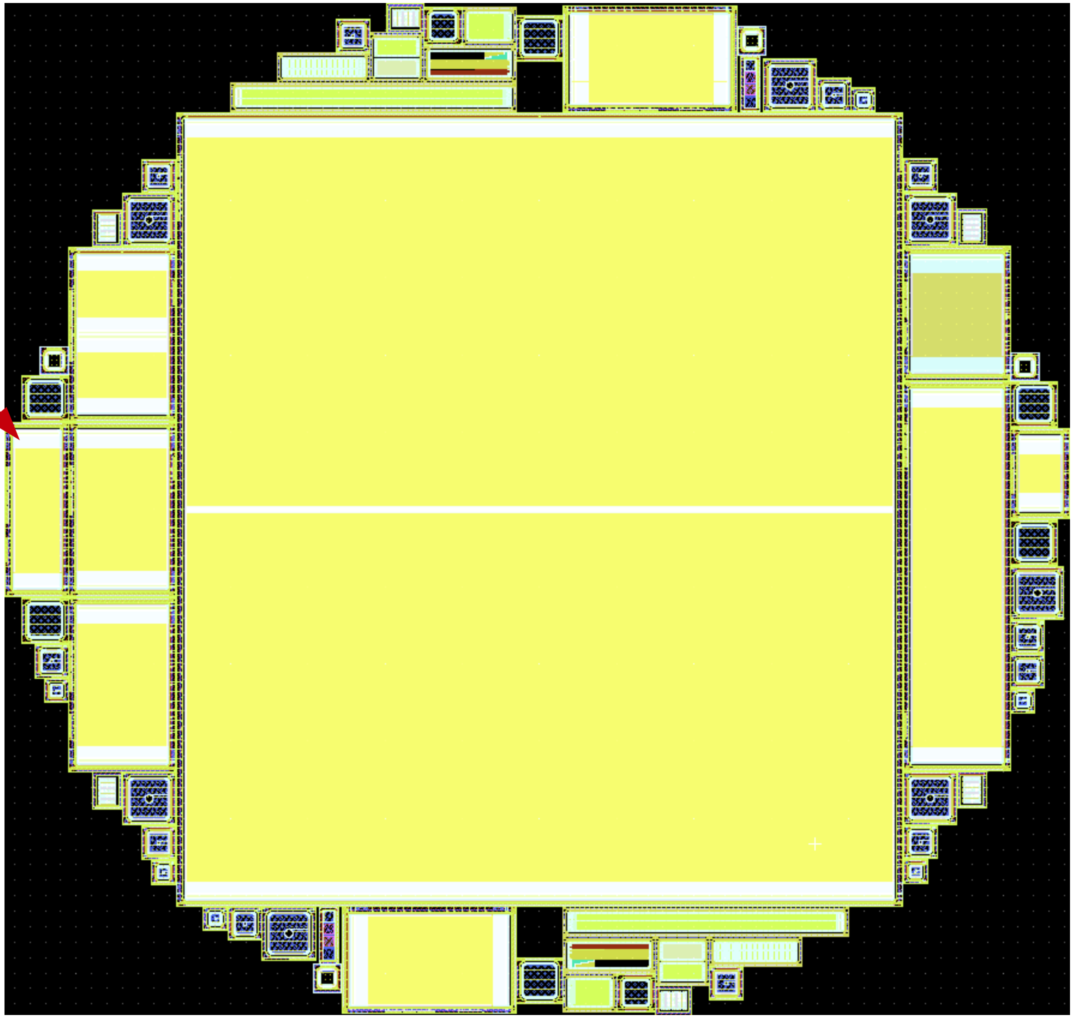


I. FZ240dd Sensors: The HPK 2S Wafer

Irradiation

64 strips with p-stop isolation

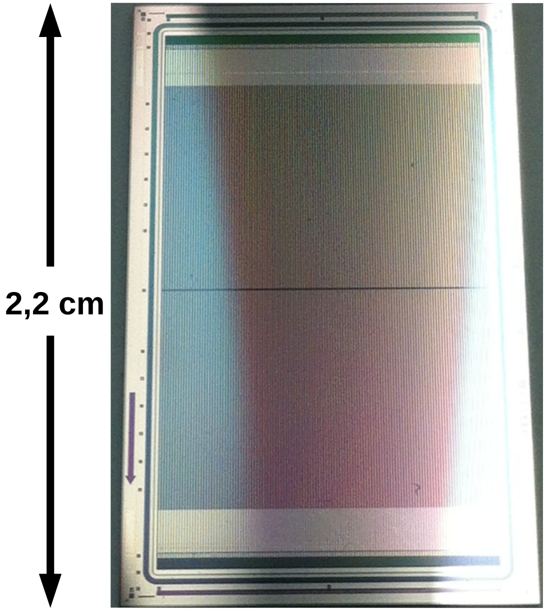


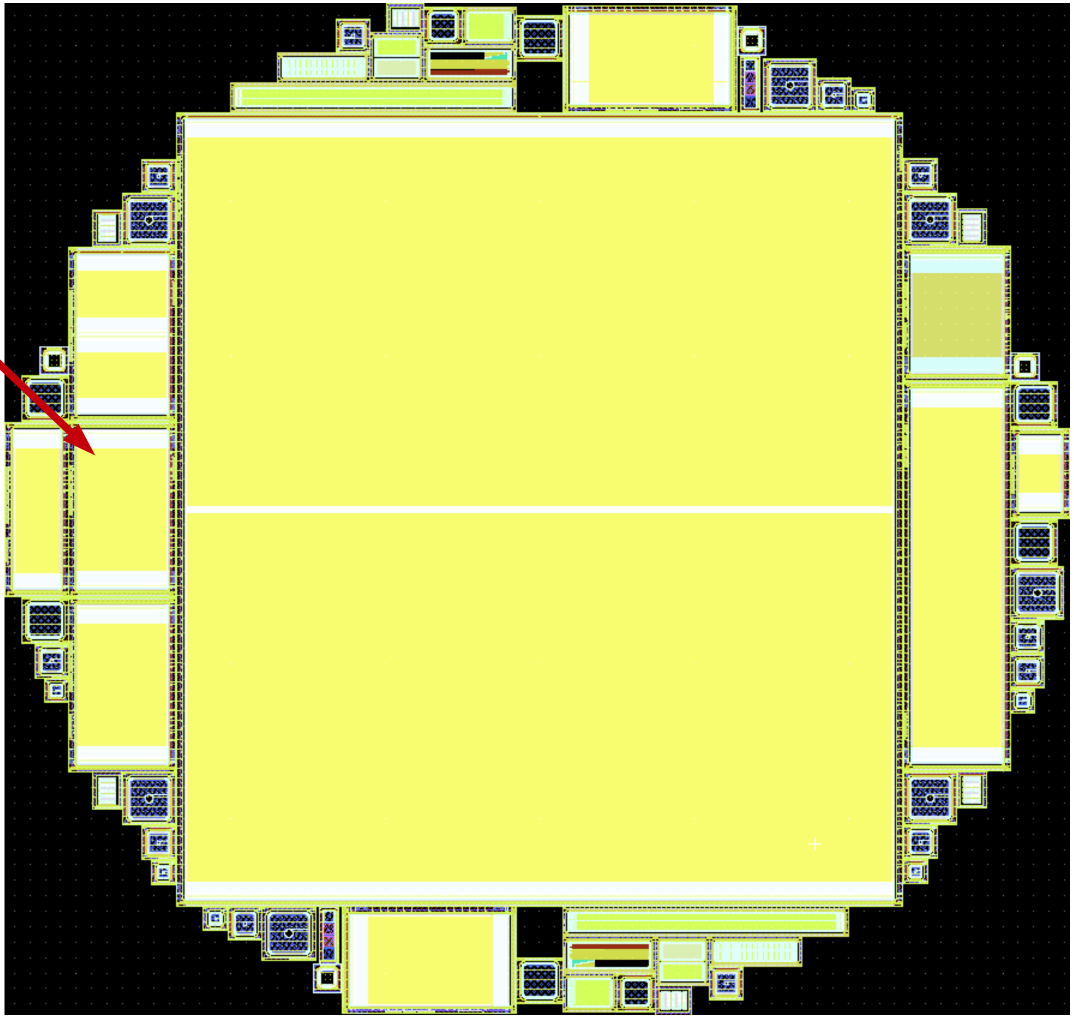


I. FZ240dd Sensors: The HPK 2S Wafer

KIT Test

127 segmented or respectively 254 strips with p-stop isolation

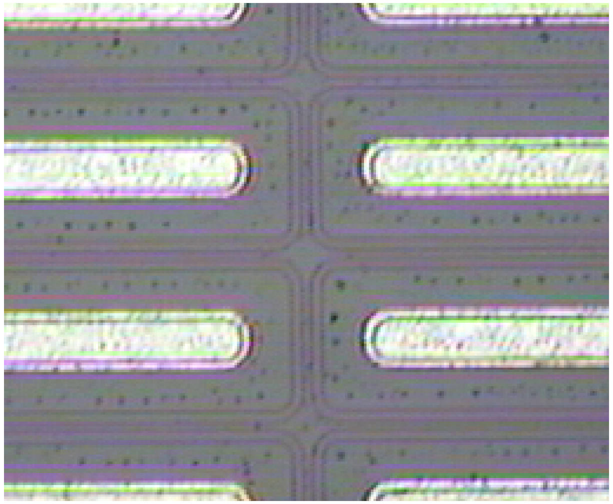


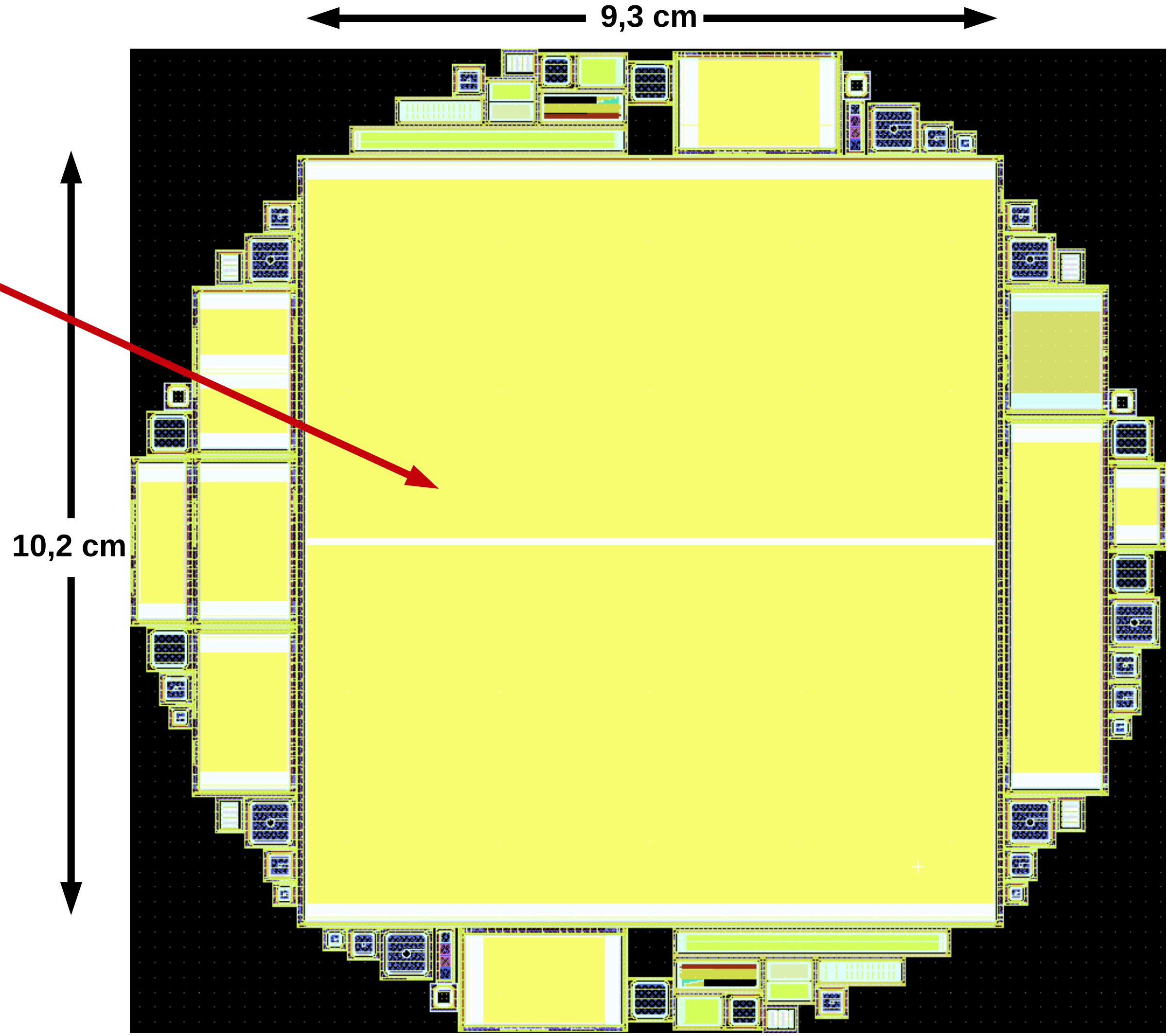


I. FZ240dd Sensors: The HPK 2S Wafer

2S Sensor

1016 segmented or respectively 2032 strips with p-stop isolation

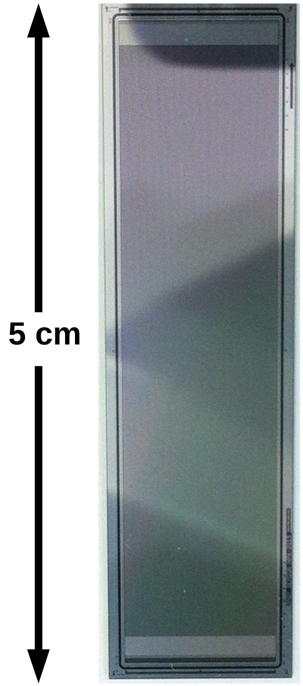


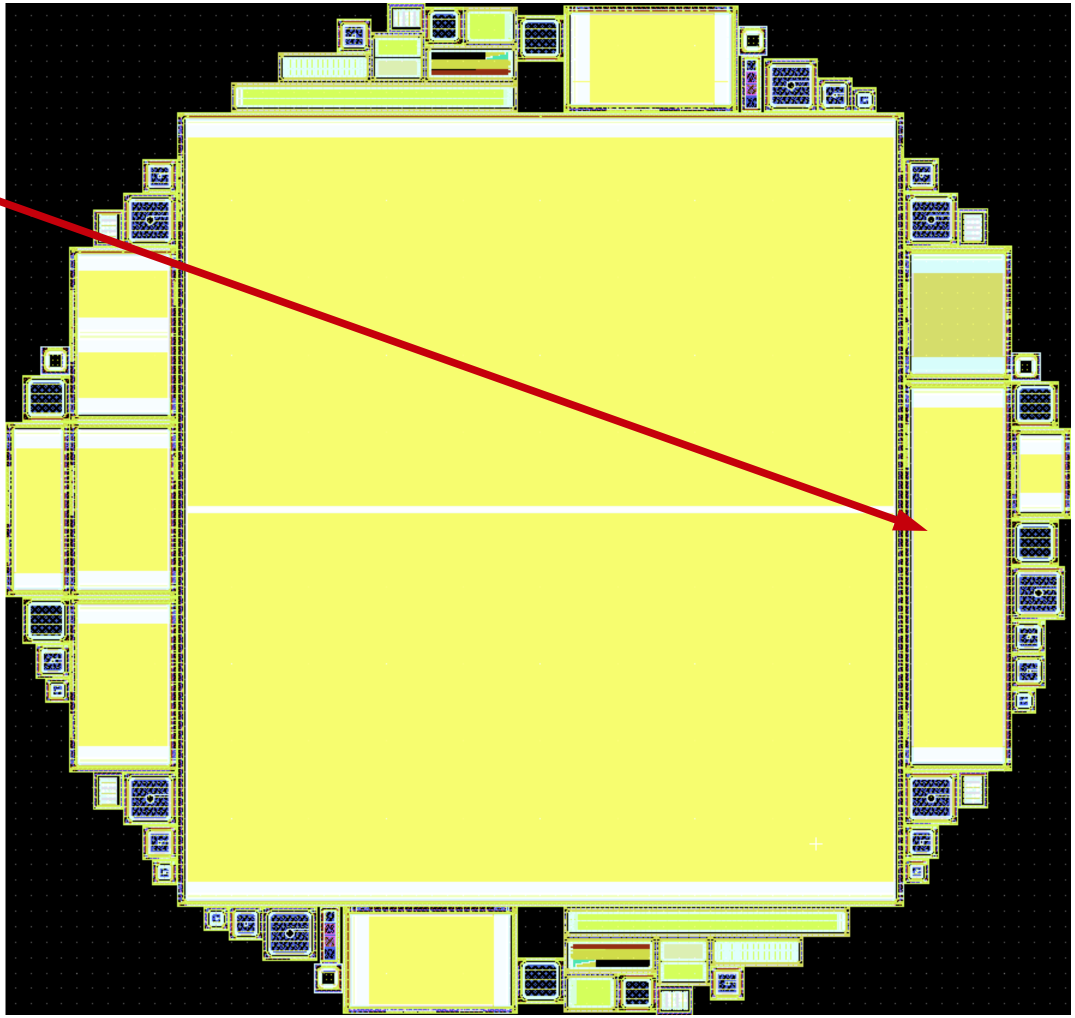


I. FZ240dd Sensors: The HPK 2S Wafer

Baby

127 strips with p-stop isolation of almost the same length as the 2S strips





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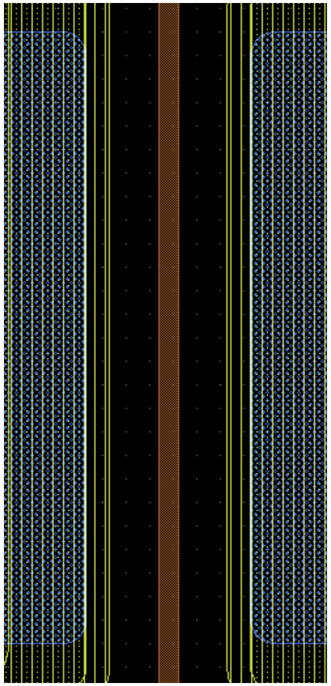

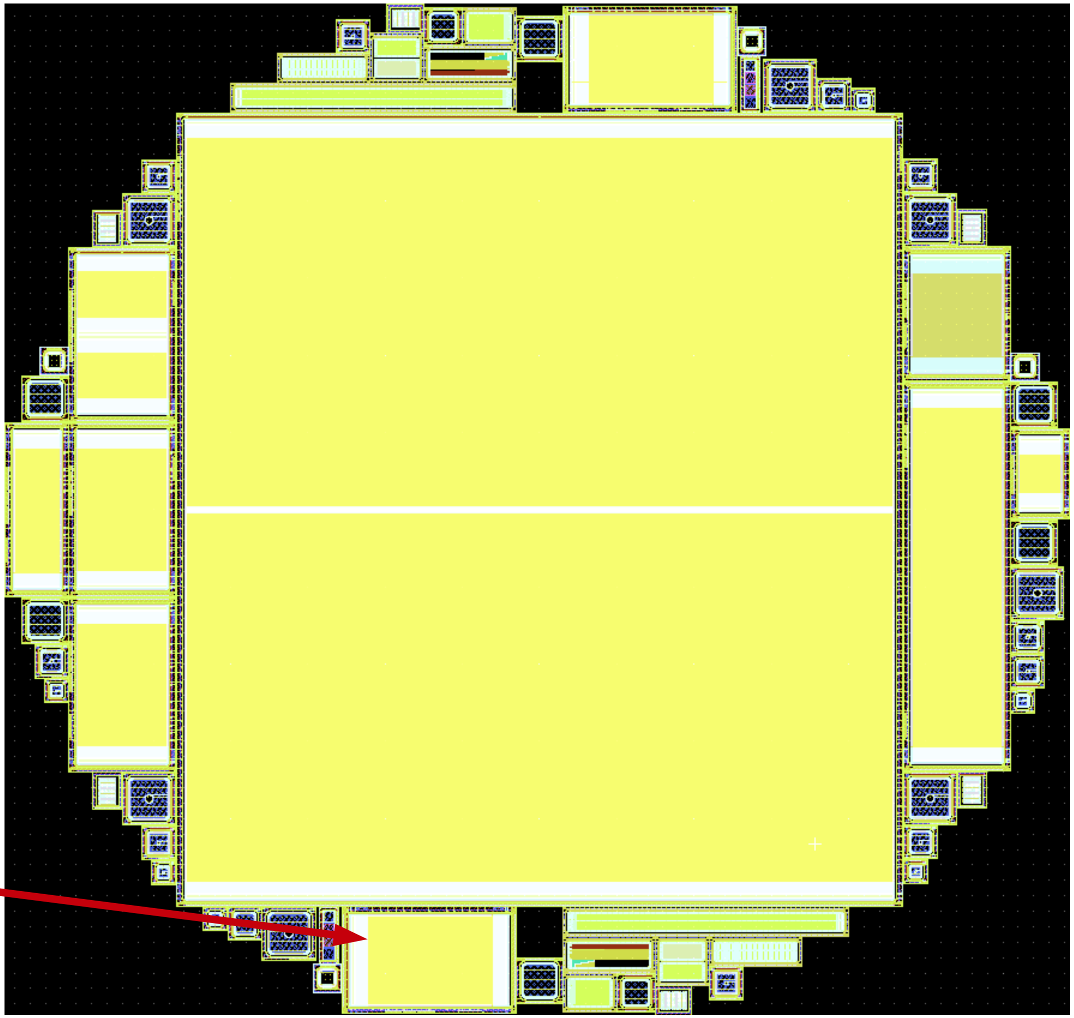

PCommon

127 strips with common p-stop isolation