BACK-SIDE ILLUMINATED SIPM PROTOTYPES: FIRST CHARACTERISATION

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on behalf of the IBIS_NEXT Bologna group

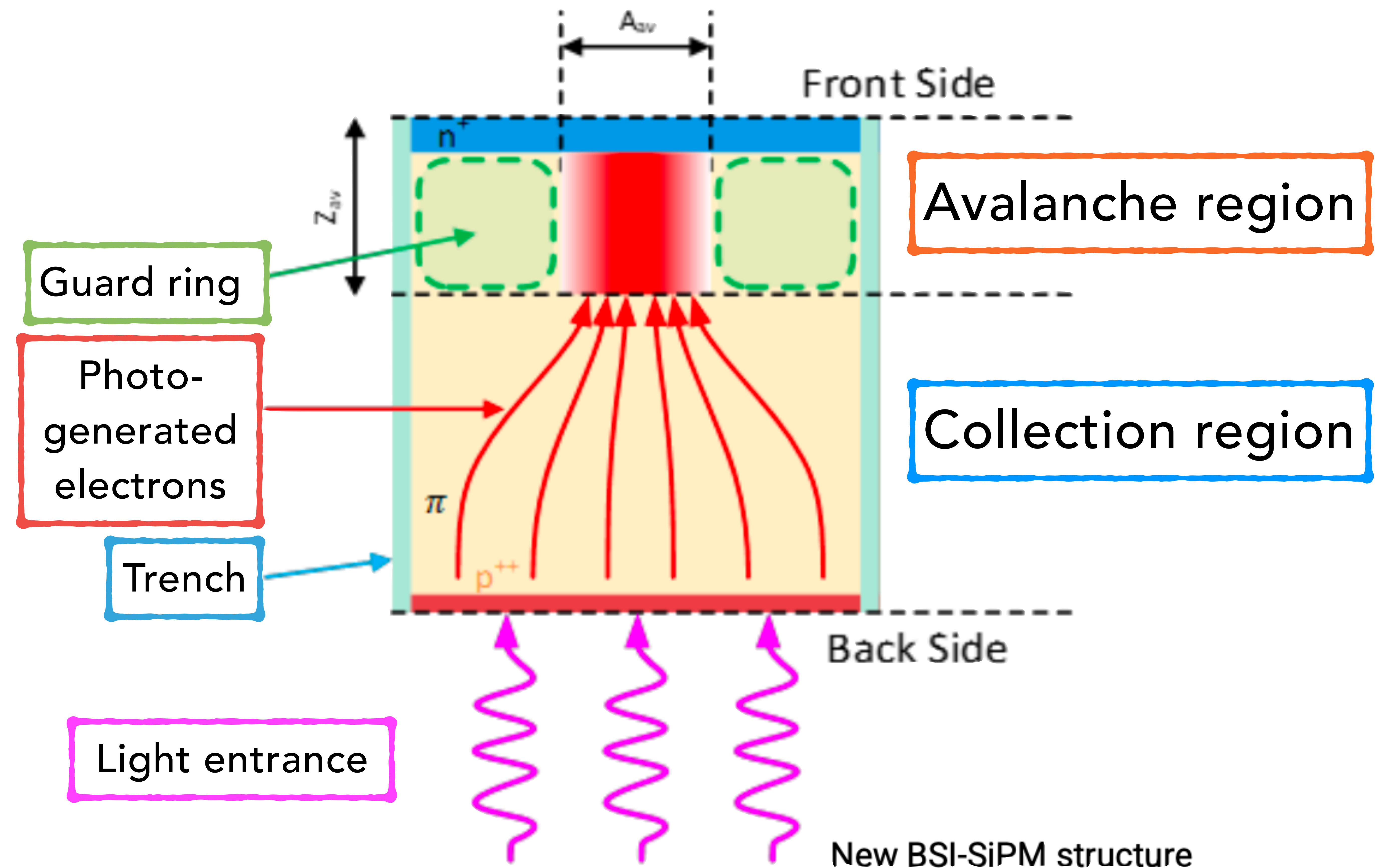
ALICE-EPIC meeting

INNOVATIVE BACKSIDE ILLUMINATED SIPM

Or just IBIS → An innovative concept of SiPM illuminated from back

Advantages:

- Up to 100% Fill Factor even w/ small cell pitch (≃ 15μm)
- Low gain and external crosstalk
- Increased radiation hardness due to smaller sensitive area
- Easy to integrate with readout electronics



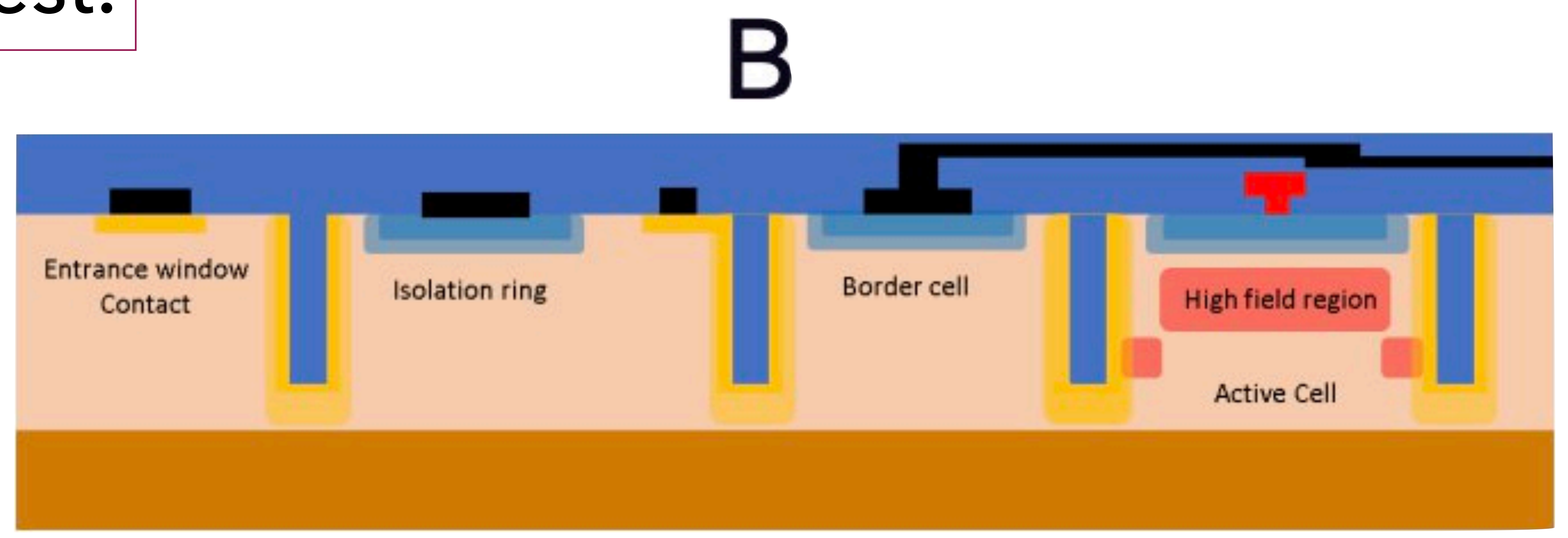
BACKSIDE ILLUMINATED SIPM IN BOLOGNA

We received two boards from FBK to test:

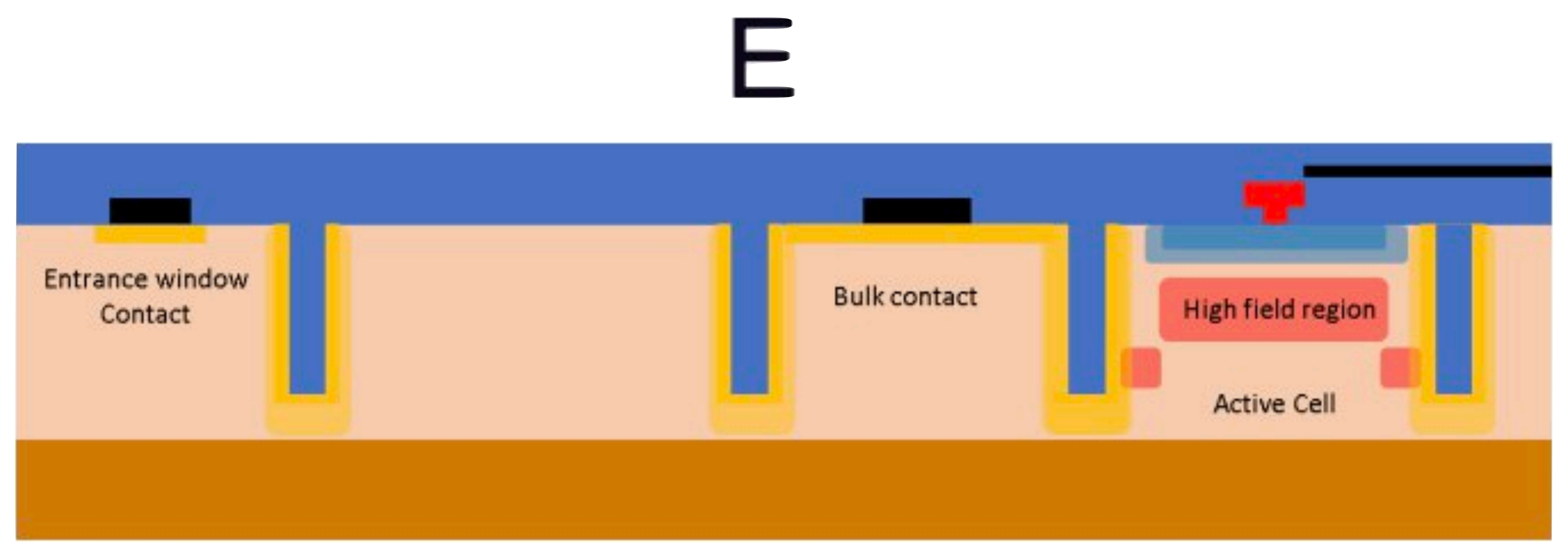
- Each board has:
  - 2 split B SiPM
  - 2 split E SiPM
- Differences among boards regard trench

PCB	Epitaxial thickness	Trench	1rst Split	2nd Split	3rd Split	4th Split
1	Thin	Medium +	B	\\	E	E
2	Thin	Medium -	B	B	E	E

B

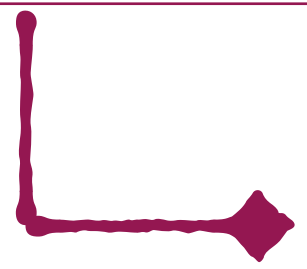


E

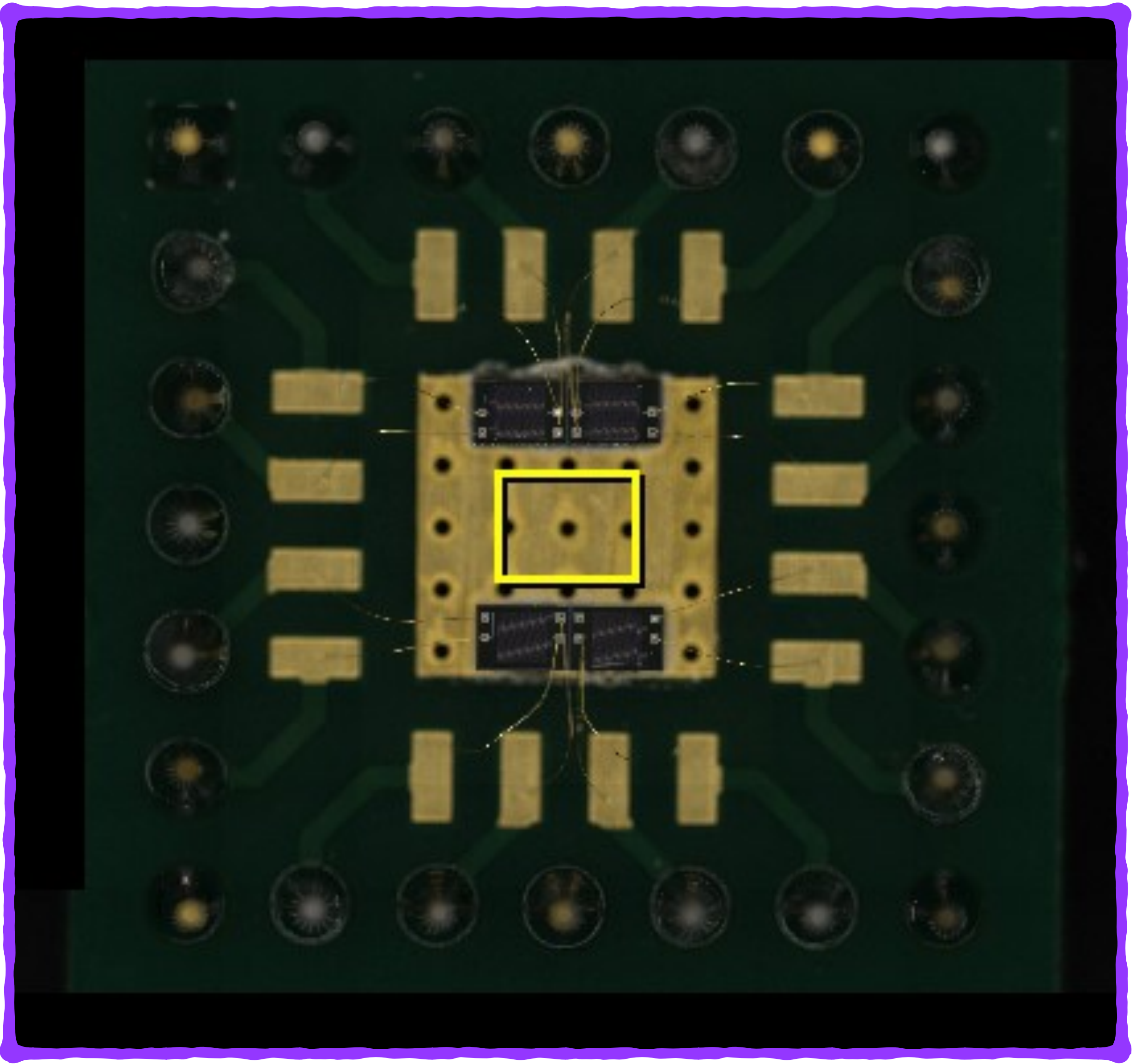


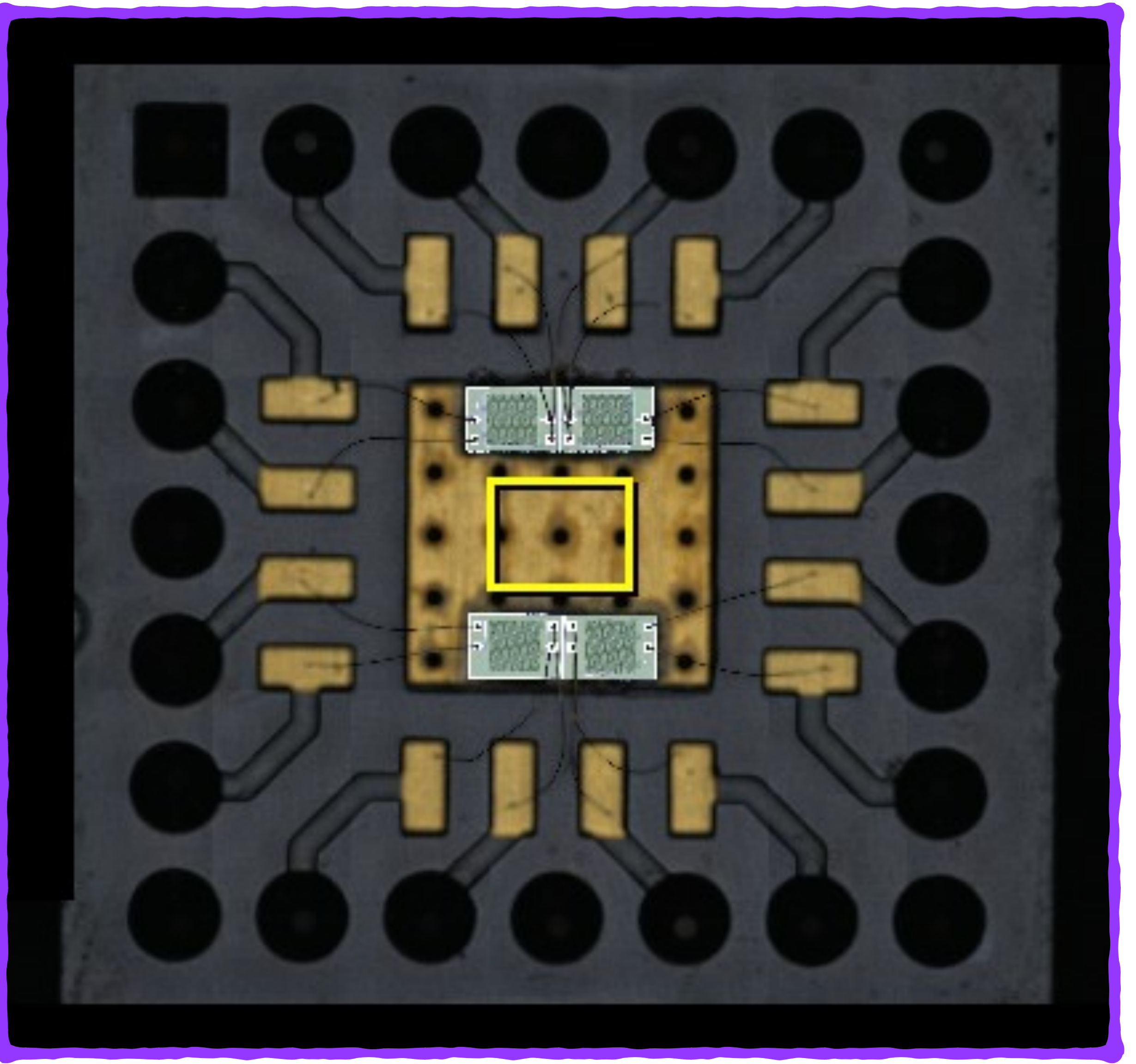
RESULTS FROM BOLOGNA

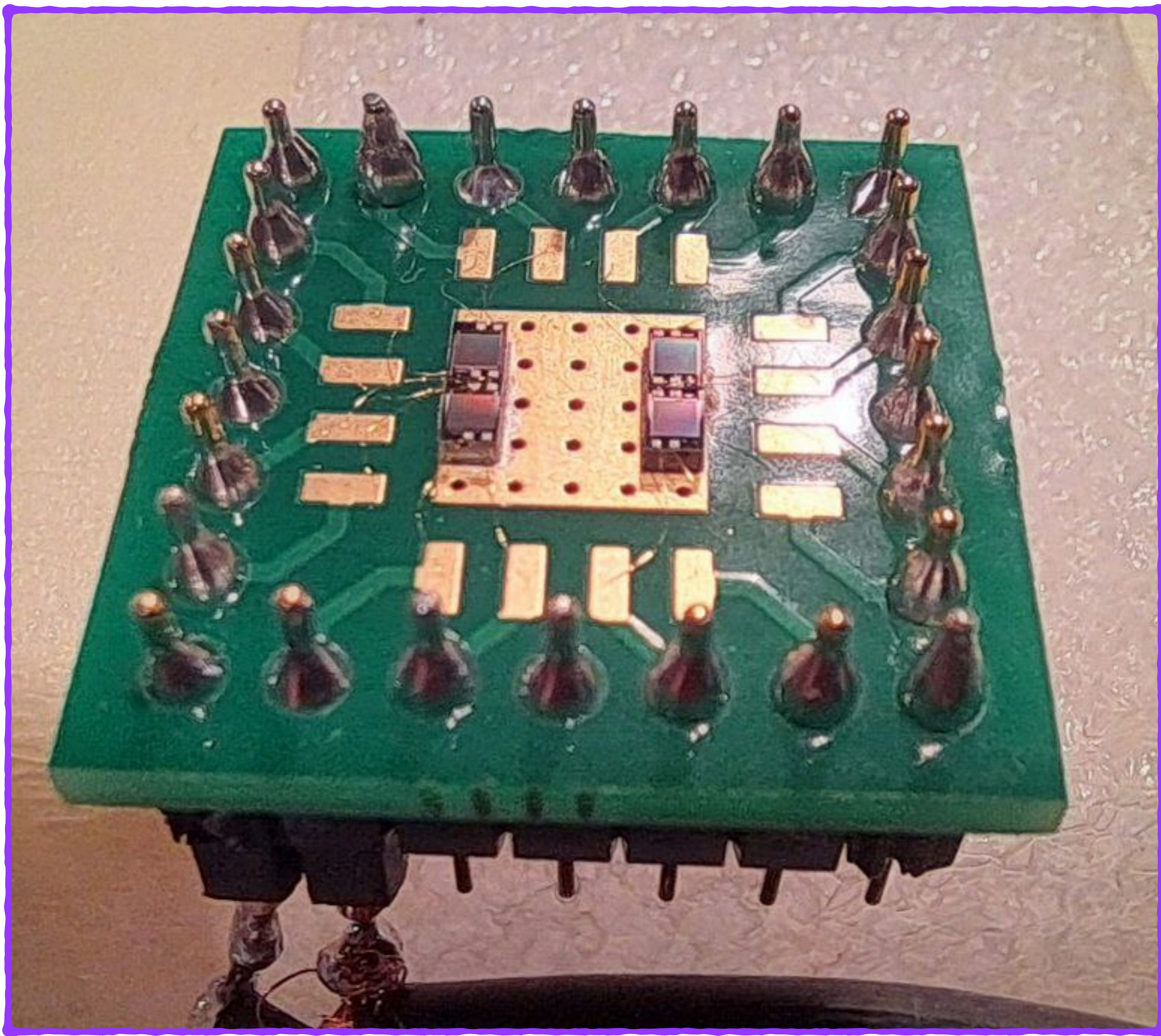
What we do?

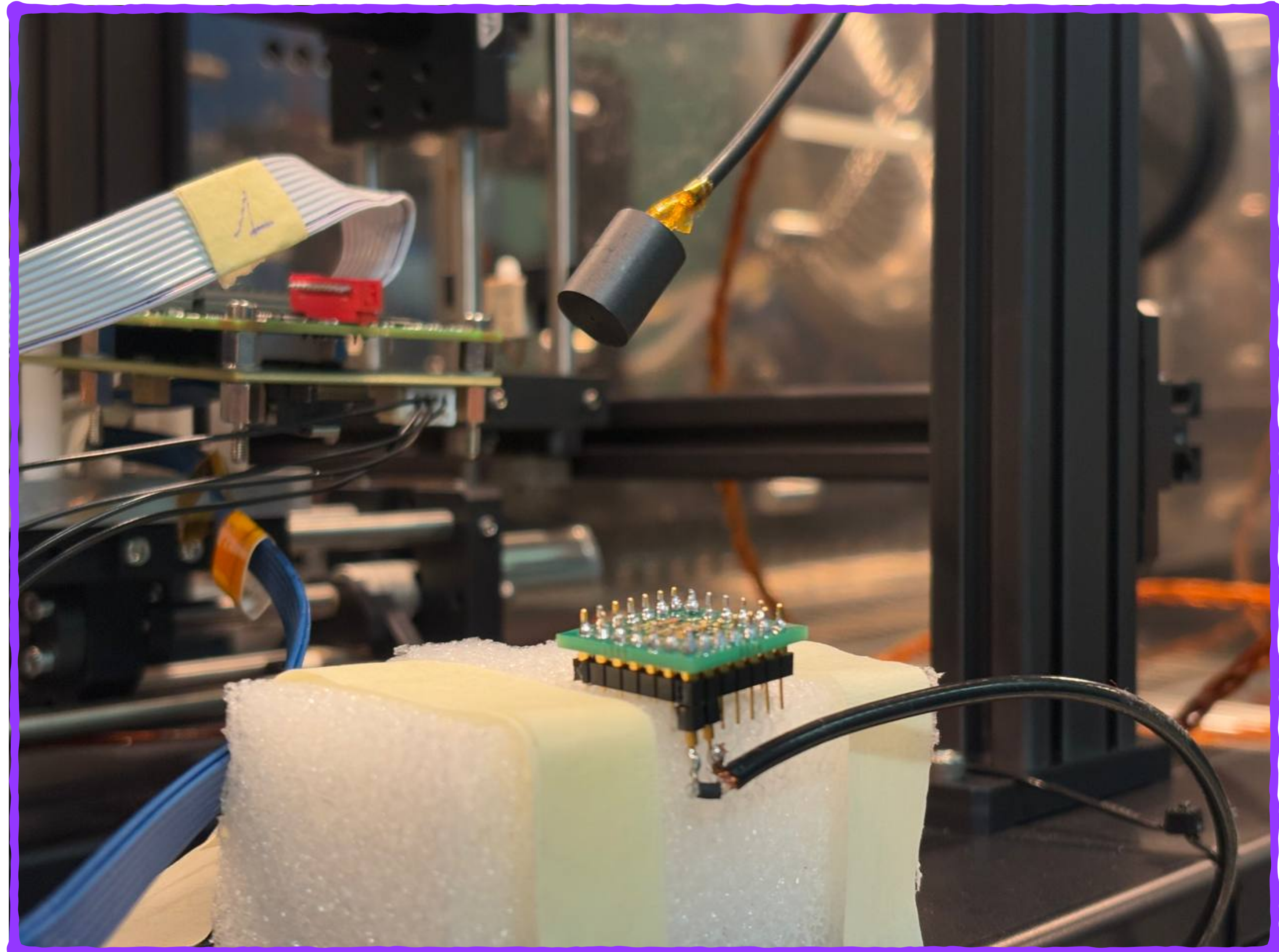


IV-characterization in climatic chamber and now w/ LED

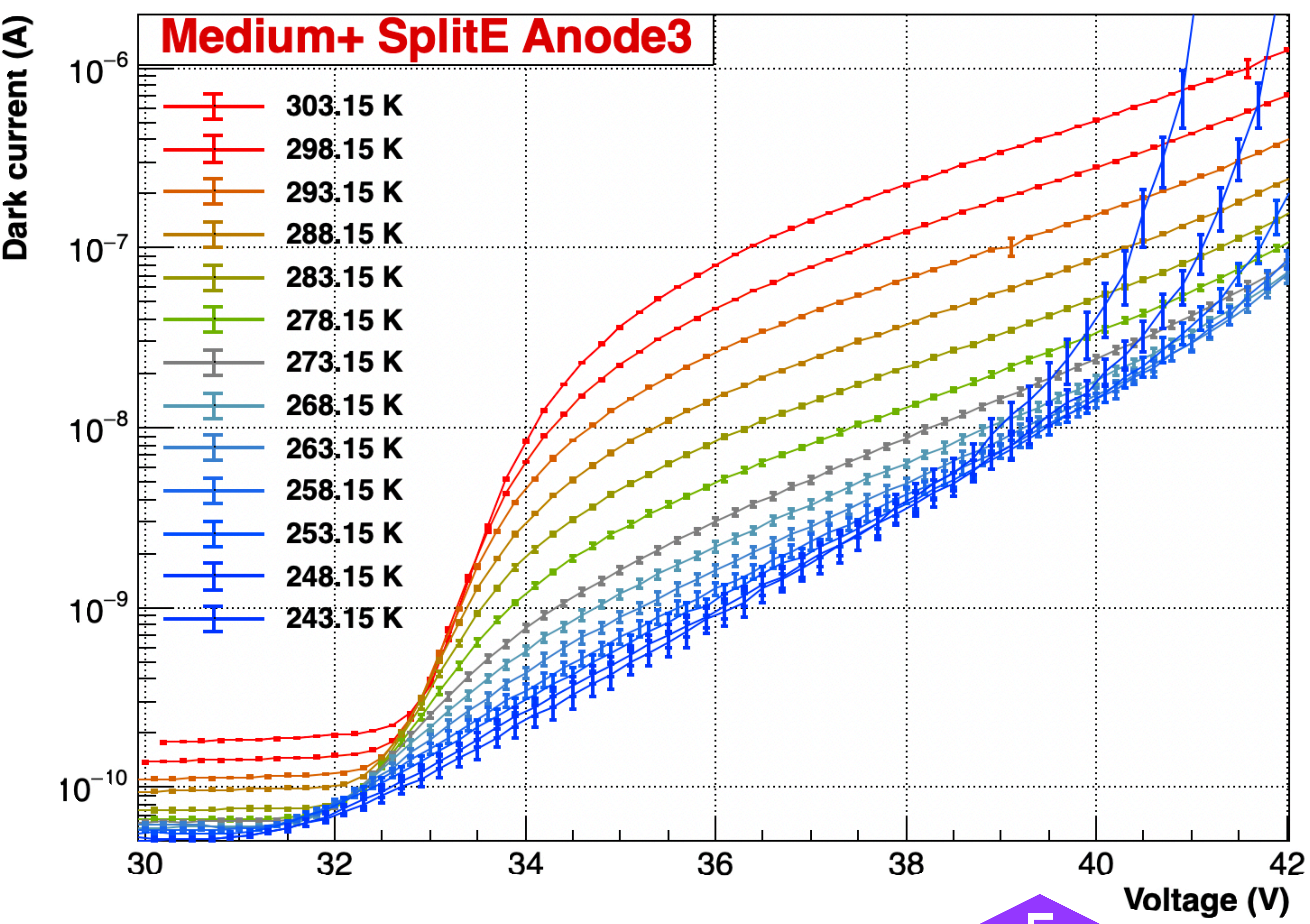








DARK CURRENT CHARACTERIZATION



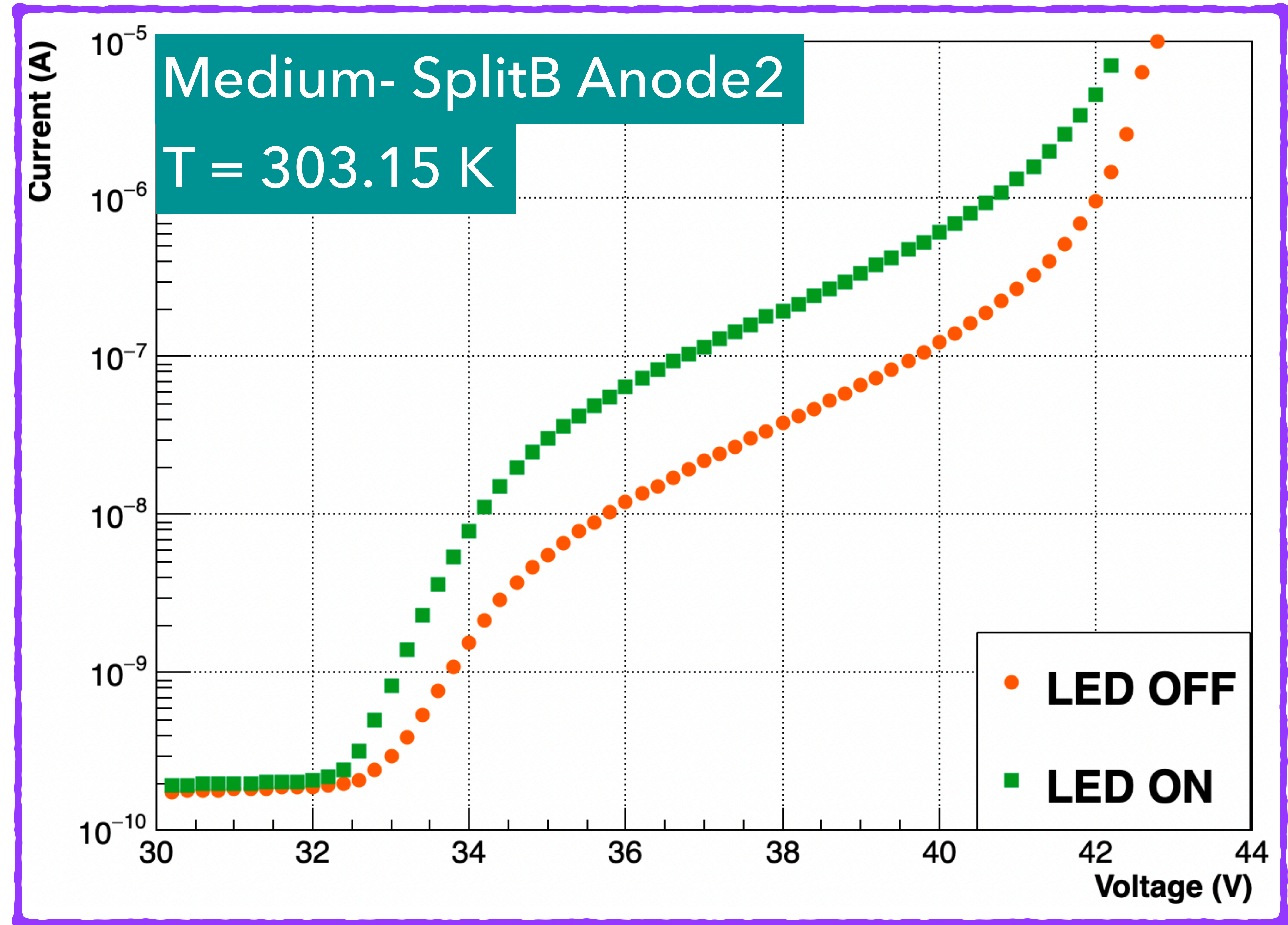
Dark current studies:

- Range from 30 to -30 °C
- Step of 5°C
- Reverse and Forward scan
- Extracting dark V_{BD}
- Extracting $R_{quenching}$
- Making a comparison among sensors

CALCULATING BREAKDOWN

Test with yellow LED:

- Sort out V_{BD} accurately
- Check V_{BD} dependence on T



Medium + SplitE:
Slope: 41.6 ± 0.1 mV/K
V_{BD} at 24°C = 32.4 ± 0.1 V

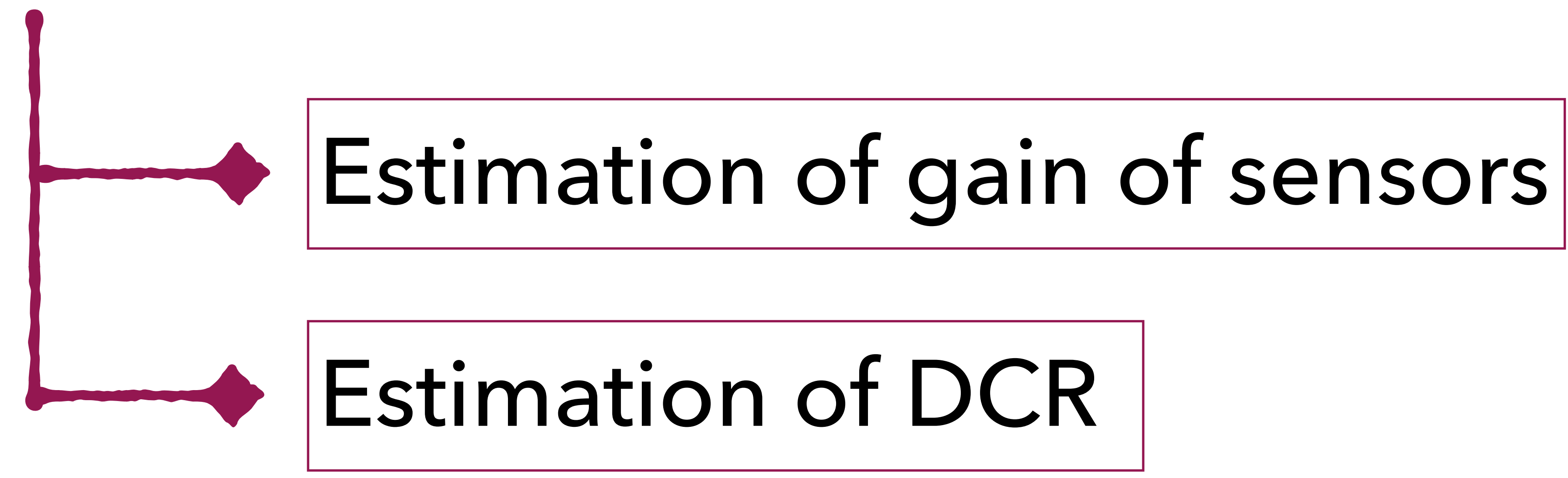
Medium - SplitB:
Slope: 36.5 ± 0.1 mV/K
V_{BD} at 24°C = 32.2 ± 0.1 V

Medium - SplitB:
Slope: 37.4 ± 1.7 mV/K
V_{BD} at 24°C = 32.3 ± 1 V

Breakdown voltage (V)
Temperature (K)
Medium+ SplitE Anode3
Medium- SplitB Anode2
Medium- SplitE Anode3

DARK CURRENT CHARACTERIZATION

Using BD results =>
Dark current vs OV

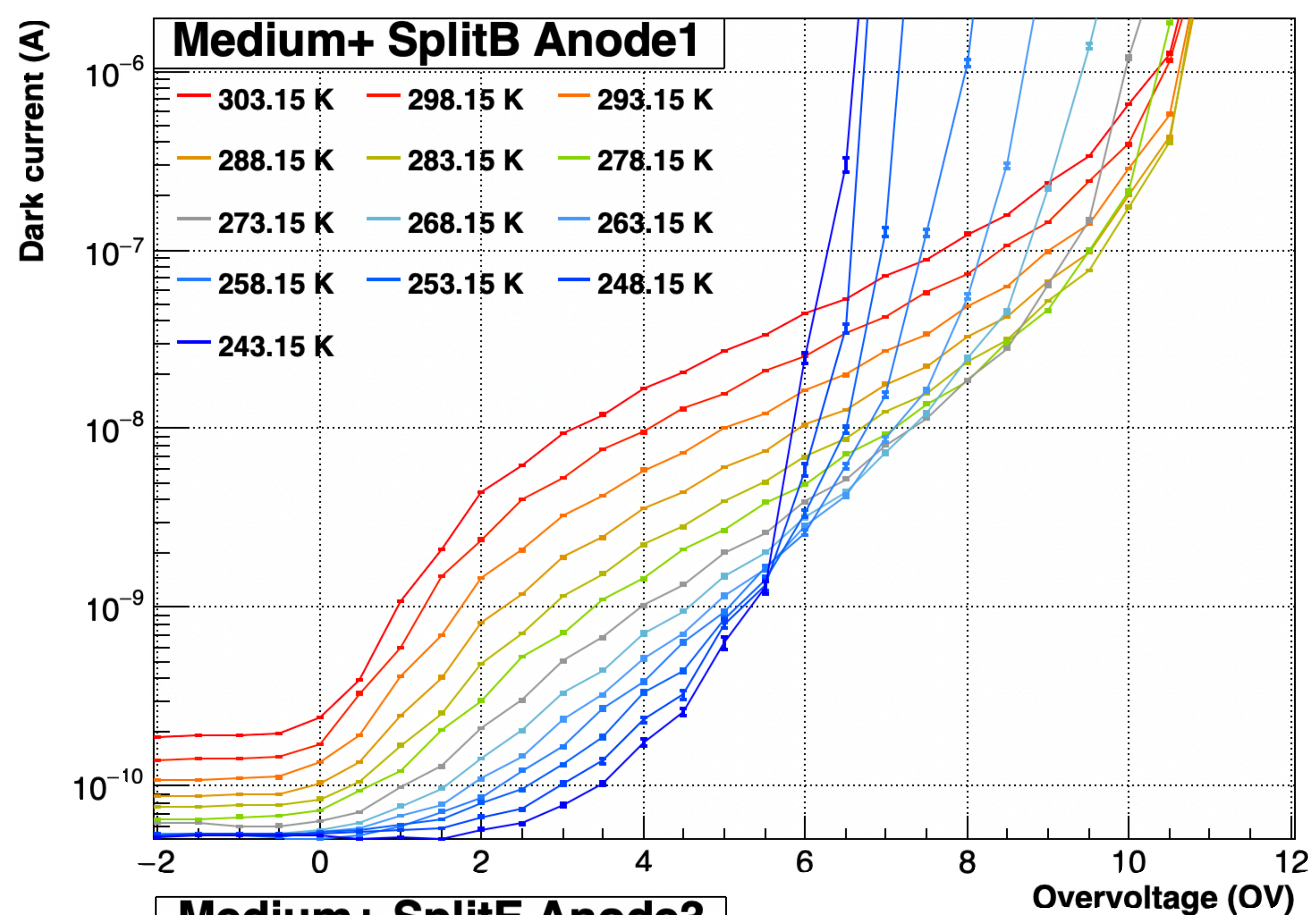


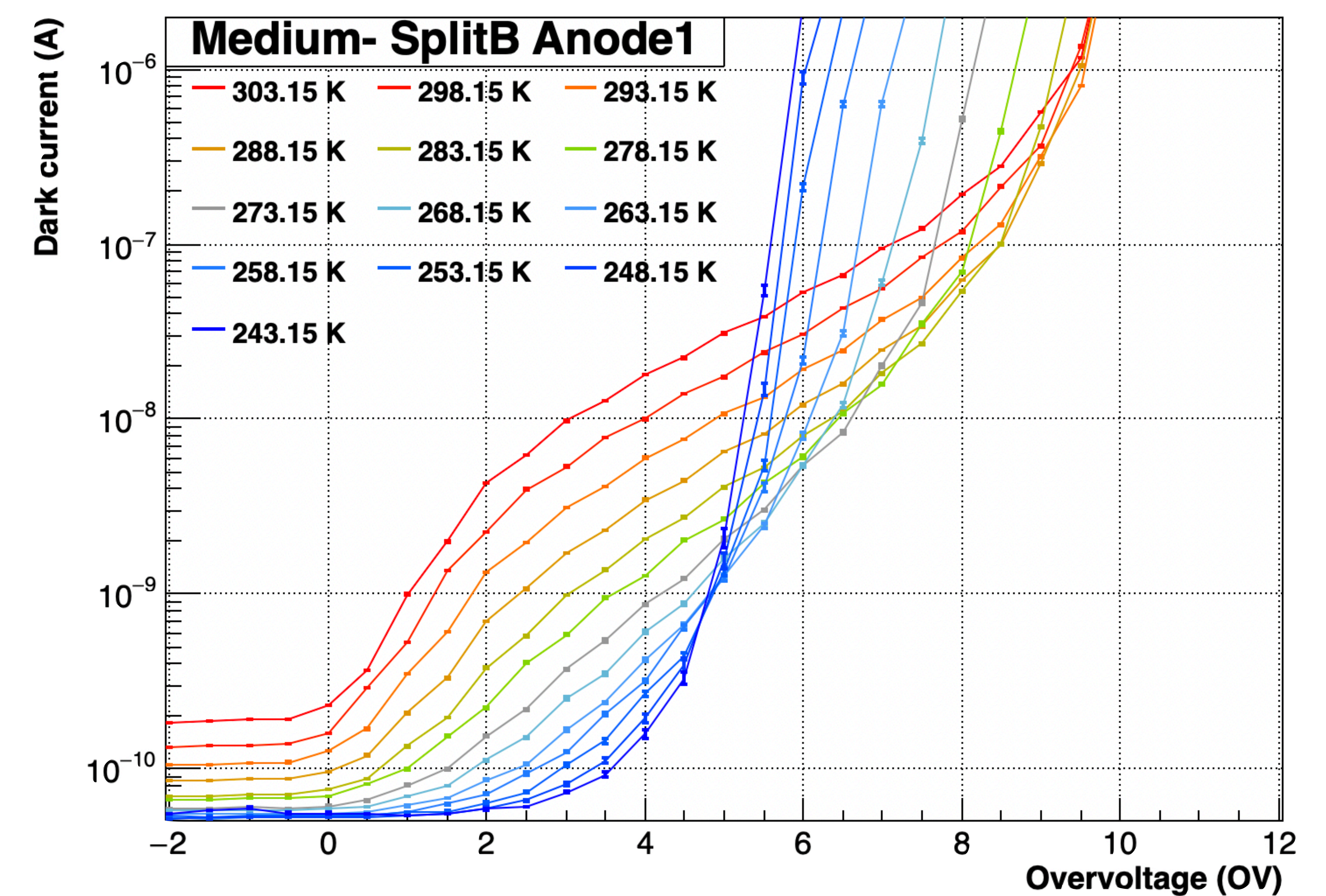
Medium+ SplitE Anode3

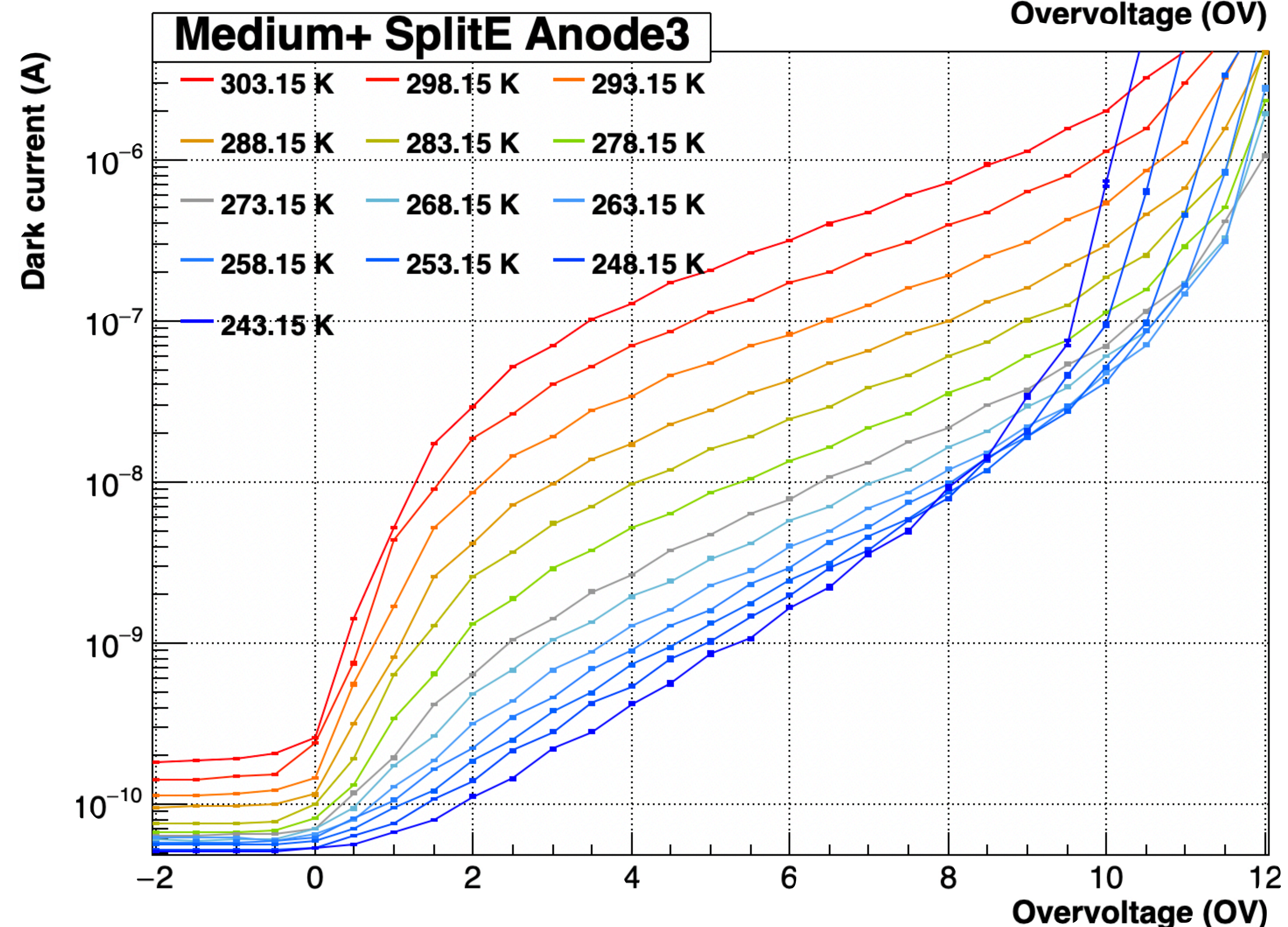
303.15 K, 298.15 K, 293.15 K, 288.15 K, 283.15 K, 278.15 K, 273.15 K, 268.15 K, 263.15 K, 258.15 K, 253.15 K, 248.15 K, 243.15 K

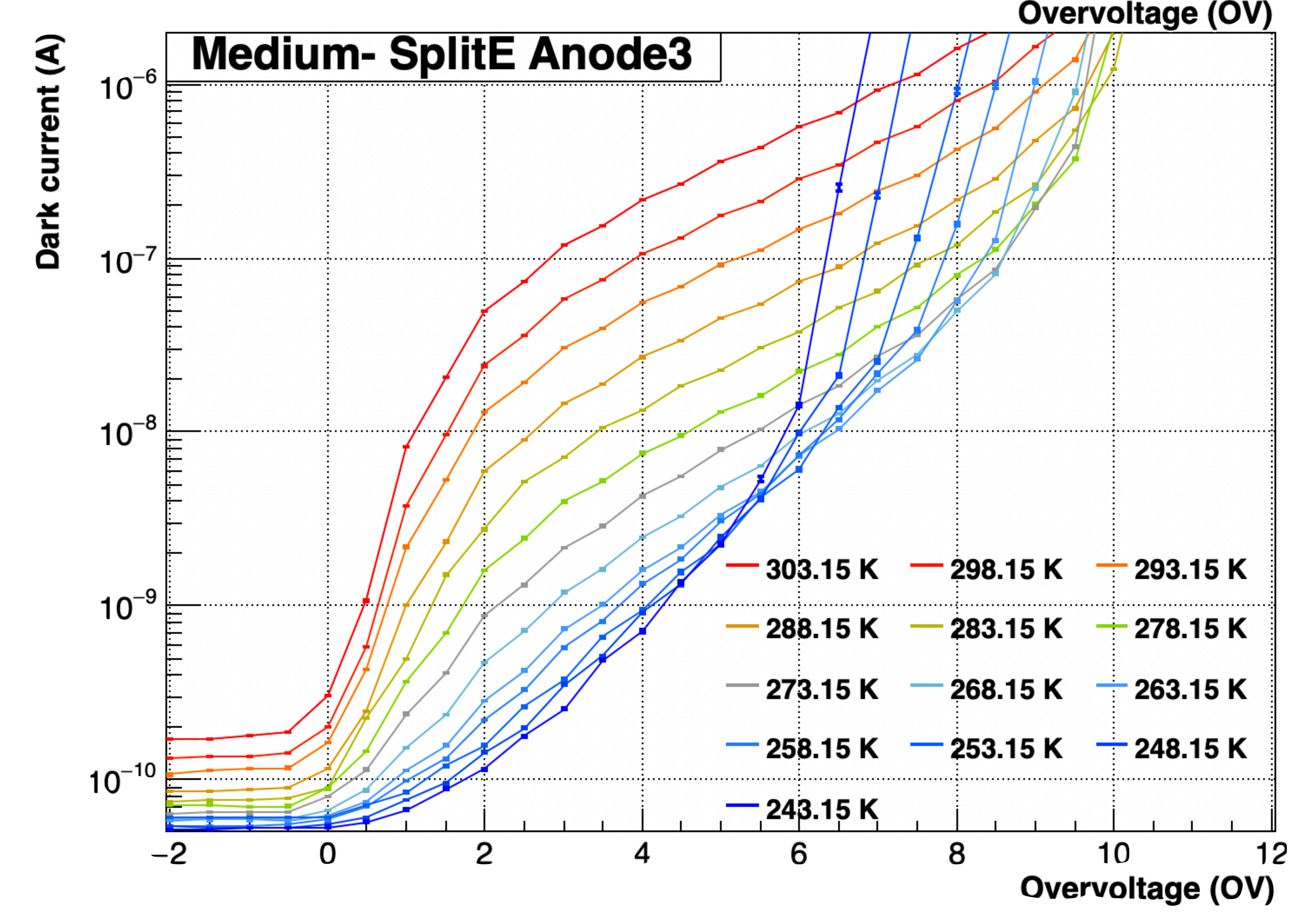
Dark current (A)

Overvoltage (OV)


Medium+ SplitB Anode1
303.15 K
298.15 K
293.15 K
288.15 K
283.15 K
278.15 K
273.15 K
268.15 K
263.15 K
258.15 K
253.15 K
248.15 K
243.15 K
Dark current (A)
Overvoltage (OV)


Medium- SplitB Anode1
303.15 K
298.15 K
293.15 K
288.15 K
283.15 K
278.15 K
273.15 K
268.15 K
263.15 K
258.15 K
253.15 K
248.15 K
243.15 K
Dark current (A)
Overvoltage (OV)


Medium+ SplitE Anode3
303.15 K
298.15 K
293.15 K
288.15 K
283.15 K
278.15 K
273.15 K
268.15 K
263.15 K
258.15 K
253.15 K
248.15 K
243.15 K
Dark current (A)
Overvoltage (OV)


Medium- SplitE Anode3
303.15 K
298.15 K
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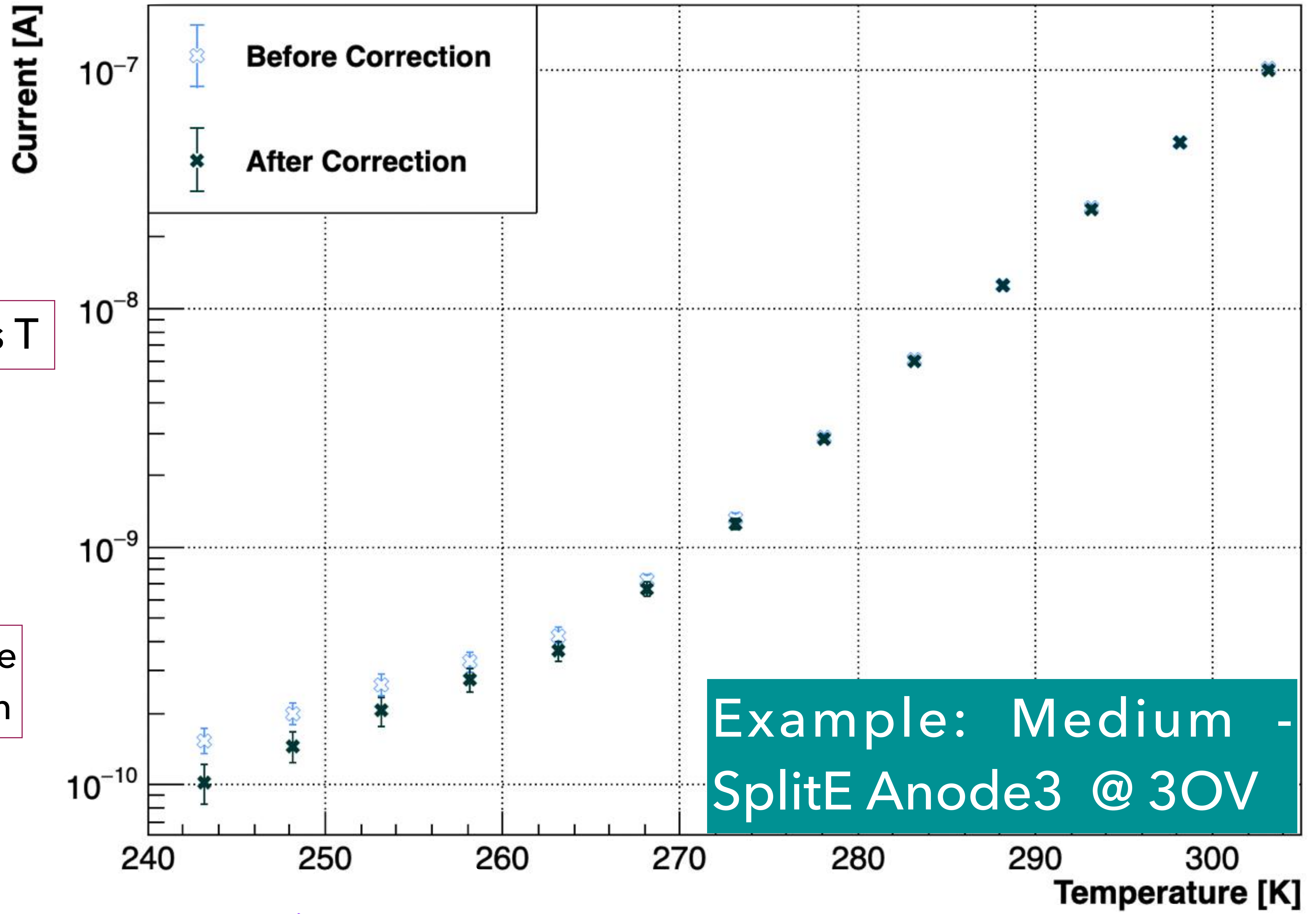
288.15 K
283.15 K
278.15 K
273.15 K
268.15 K
263.15 K
258.15 K
253.15 K
248.15 K
243.15 K
Dark current (A)
Overvoltage (OV)

ARRHENIUS PLOT

Arrhenius plot:

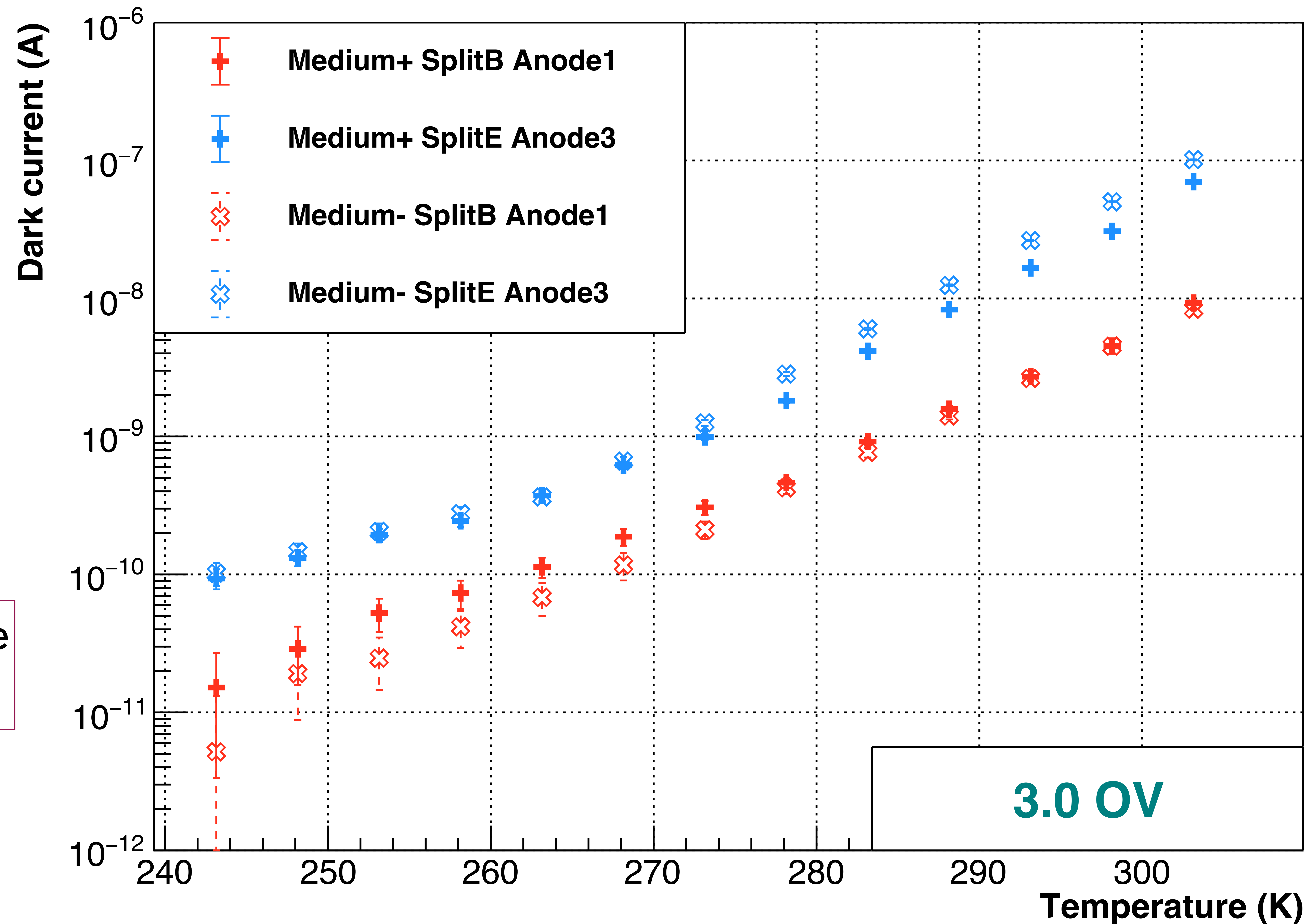
- Fixing OV (e.g. 3 OV): I vs T
- Needed to perform a correction on current
  - Subtracting the surface current term



ARRHENIUS PLOT

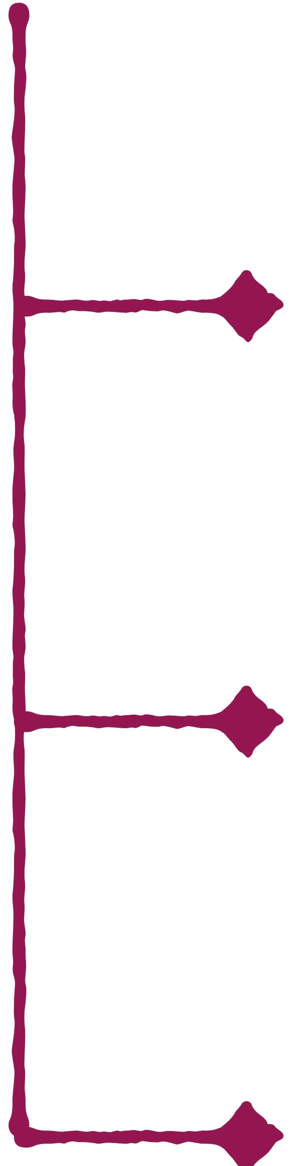
Arrhenius plot of tested sensors:

- Agreement among same split sensors
- Useful to determine T dependence of current
- Useful to determine activation energy of SiPM



ARRHENIUS PLOT

First we determine the T dependence of current



There's a transition around ≃ -3°C

$T_{1/2}$ is the T required to halve the current.

Useful to determine activation energy of SiPM

Medium+ SplitE Anode3

Fit function : $I_{dark} = I_0 e^{T/T_0}$

Thermal model:

Slope = 0.115 ± 0.041 K^{-1}

$T_{1/2}$ (at 273.15 K) = 6.002 ± 2.105 K

Trap effect:

Slope = 0.069 ± 0.024 K^{-1} *

$T_{1/2}$ (at 273.15 K) = 10.056 ± 3.523 K

≃ 270 K

Dark current (A)

Temperature (K)

Dark Current at 3 OV

Fit for T > 270.15 K

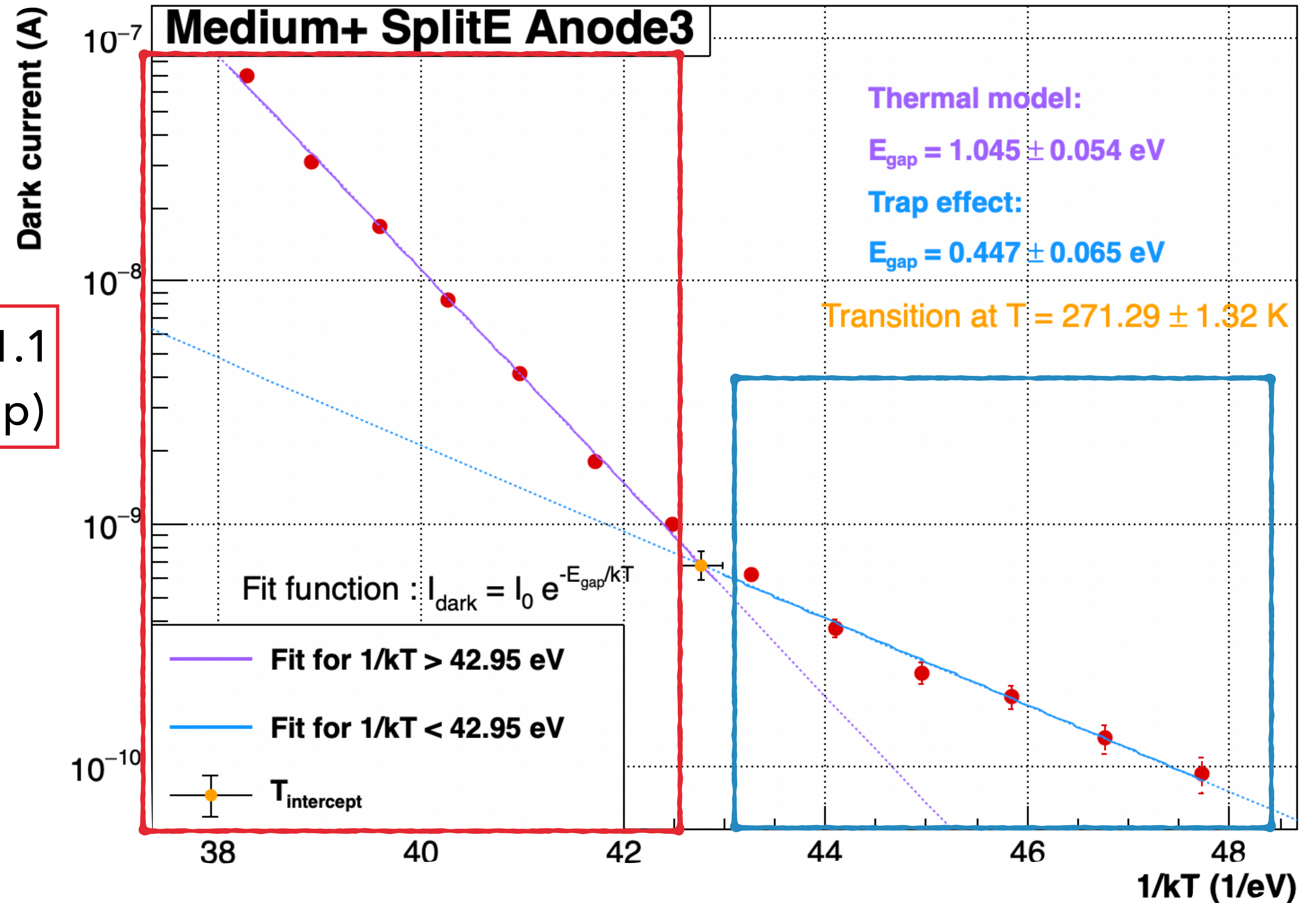
Fit for T < 270.15 K

* $$T_{1/2} = \frac{ln(2)}{slope}$$

ACTIVATION ENERGY

We then tried to extract the activation energy

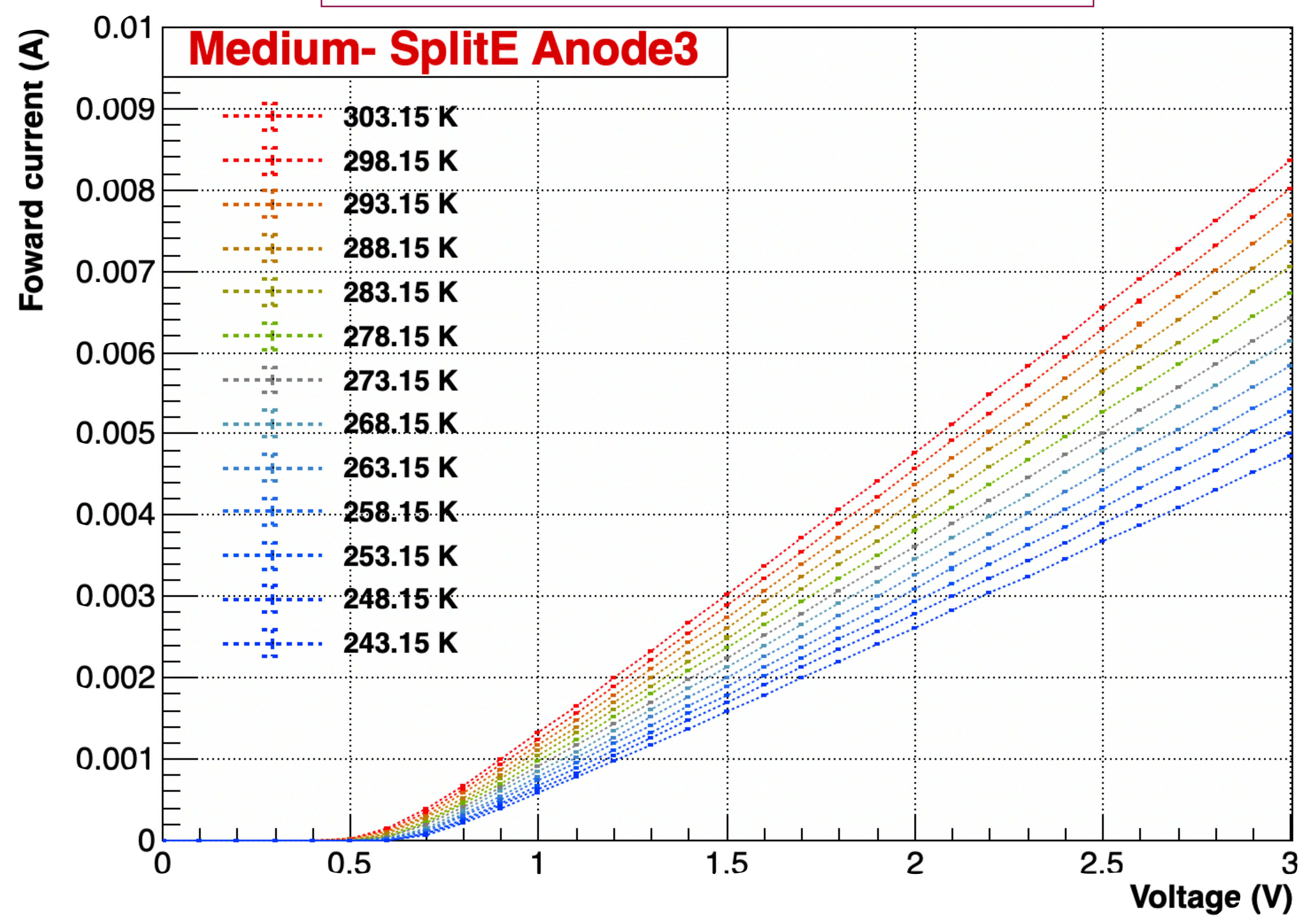
- At high T: you expect ≃ 1.1 eV (silicon energy band-gap)
- At low T: you expect less since presence of trap in the band-gap
- Transition checked to be around -3°C



QUENCHING RESISTANCE

Determine $R_{quenching}$:

- Extracted using Shockley formula: $V = RI + V_T ln(1 + I/I_S)$
- Results found less than kΩ



$R_{quenching}/N_{cell}$ (kΩ)

Temperature (K)

Medium+ SplitE Anode3

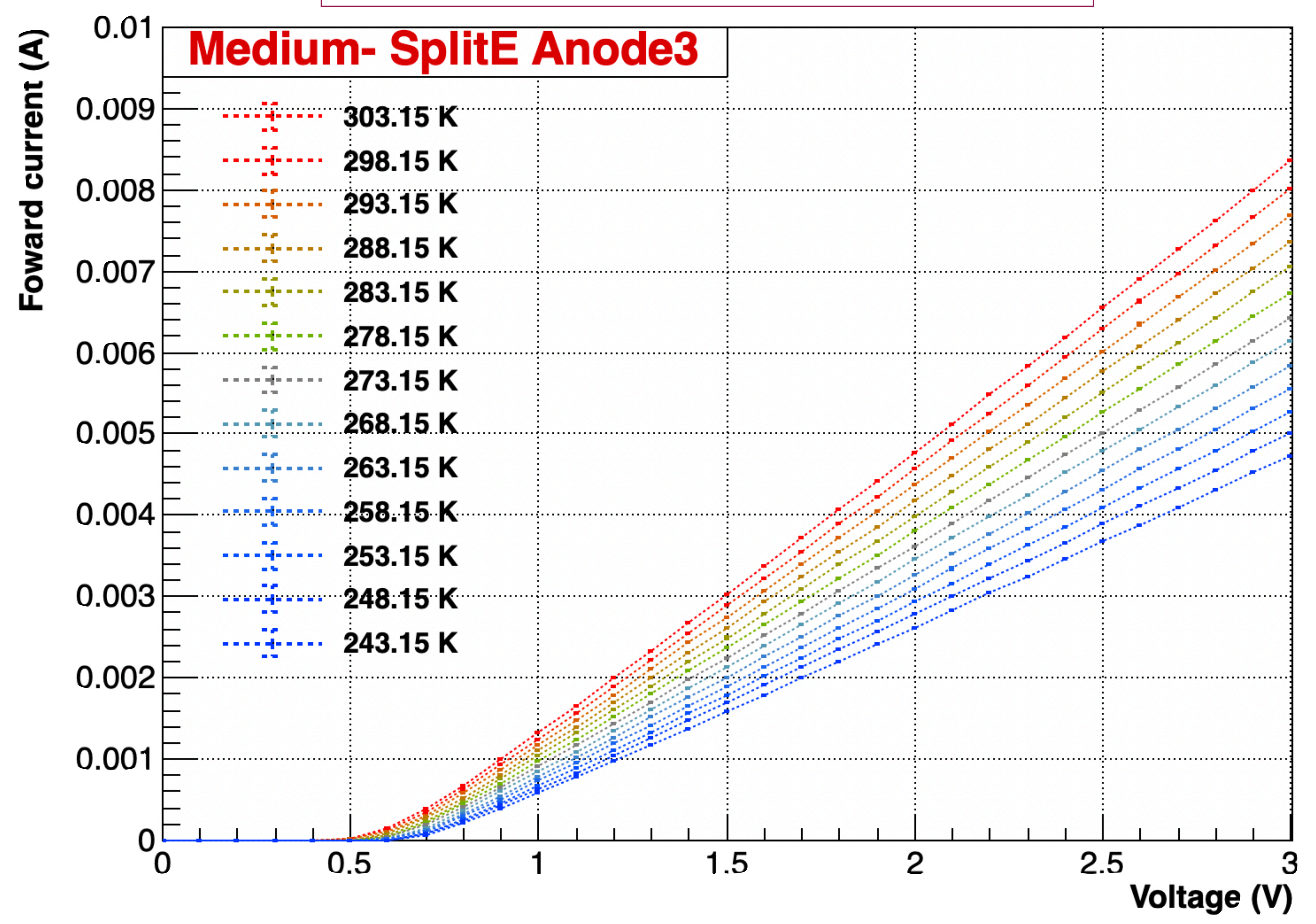
Medium- SplitE Anode3

We count 62x72 SPADs => 4464 cells

QUENCHING RESISTANCE

Determine $R_{quenching}$:

- Extracted using Shockley formula: $V = RI + V_T ln(1 + I/I_S)$
- Results found around MΩ



Total $R_{quenching}$

$R_{quenching}$ (MΩ)

Temperature (K)

Medium+ SplitE Anode3

Medium- SplitE Anode3

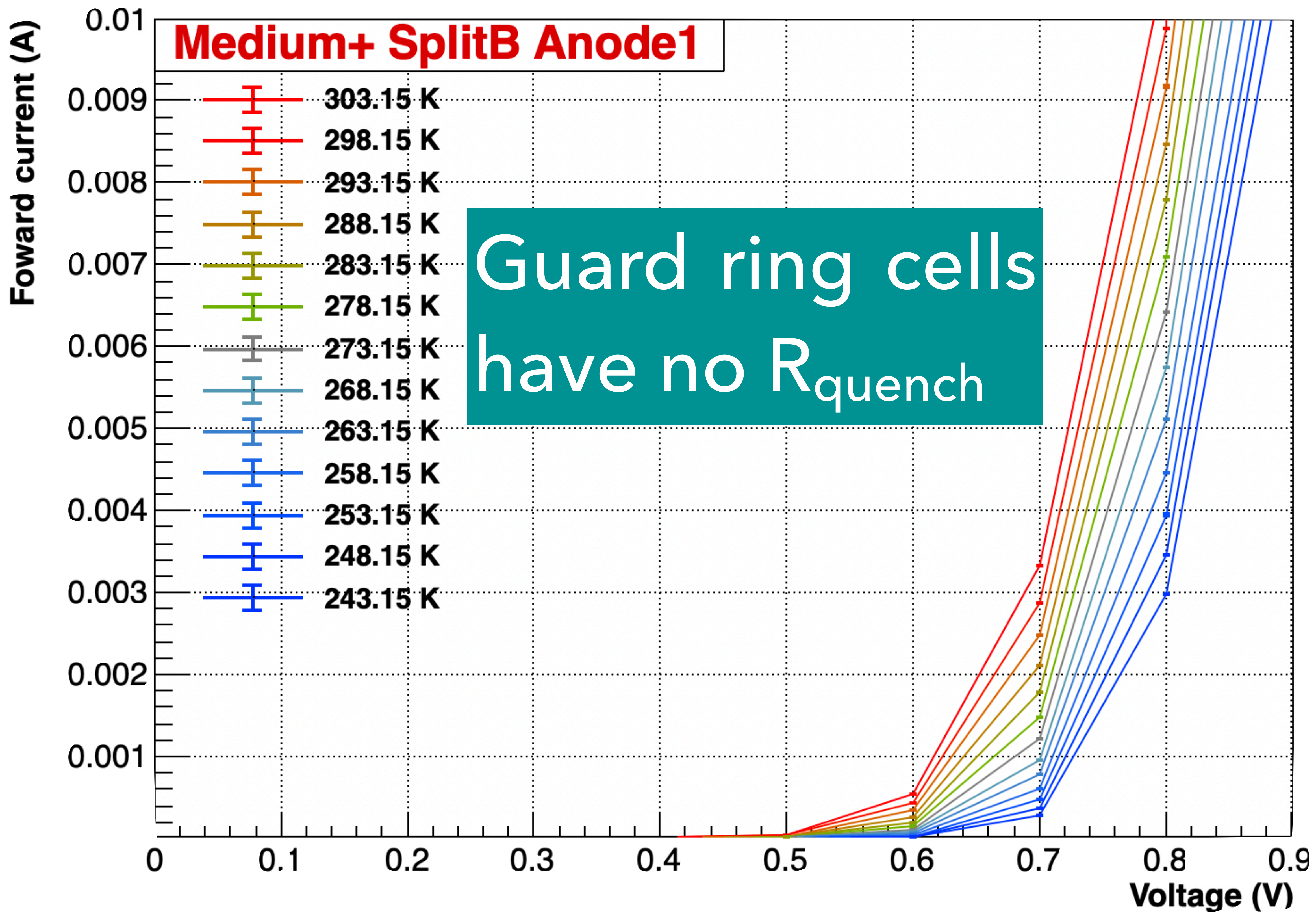
2.2 2 1.8 1.6 1.4 1.2

240 250 260 270 280 290 300

For what concerns Spilt B guard ring cells have no $R_{quenching}$

QUENCHING RESISTANCE FOR ANODE 1 AND 2

Let's have a look on Anode 1&2 results of $R_{quenching}$



Guard ring cells have no R_{quench}

Medium+ SplitB Anode1

Medium- SplitB Anode1

$R_{quenching}$ (MΩ)

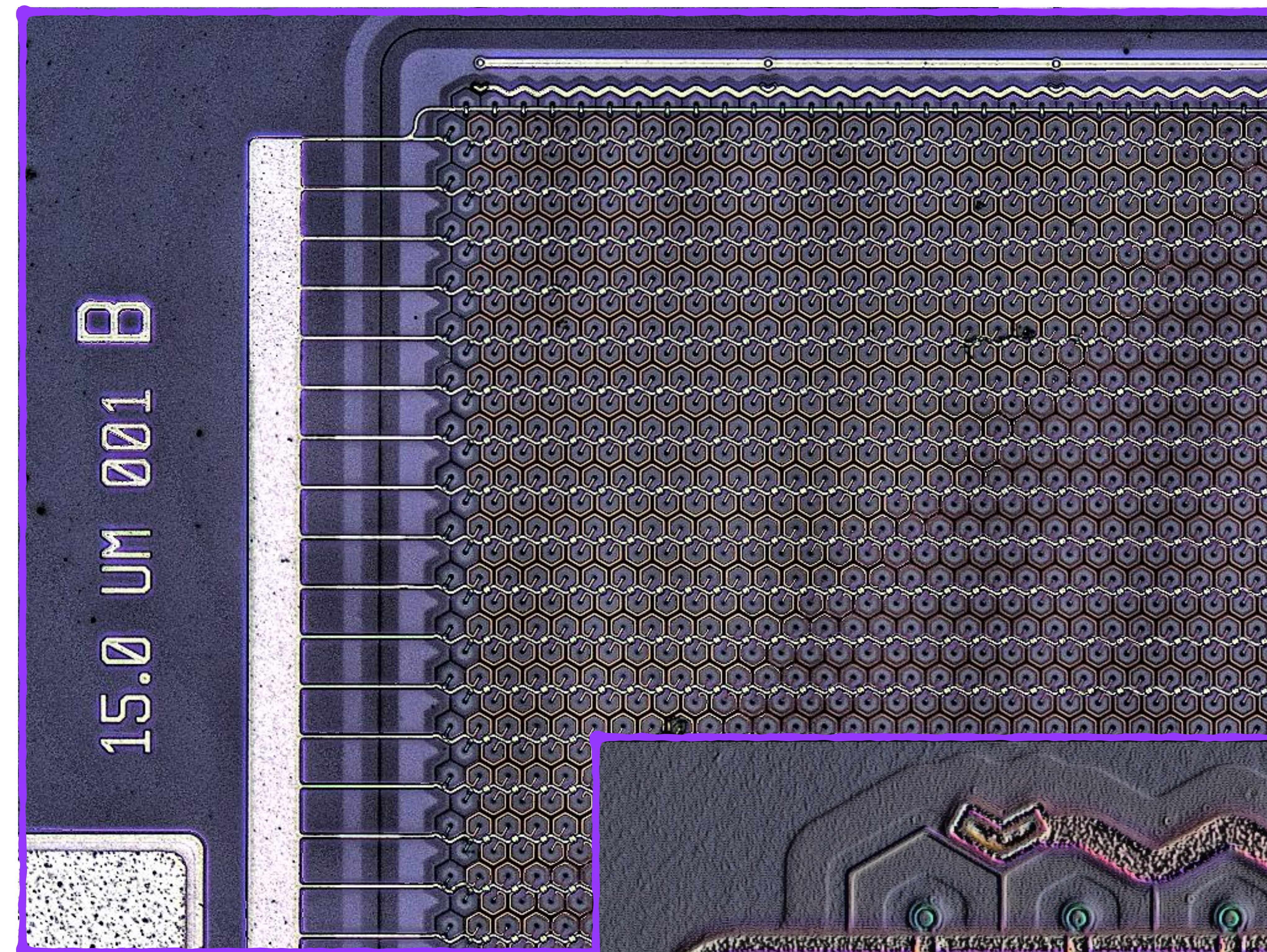
Temperature (K)

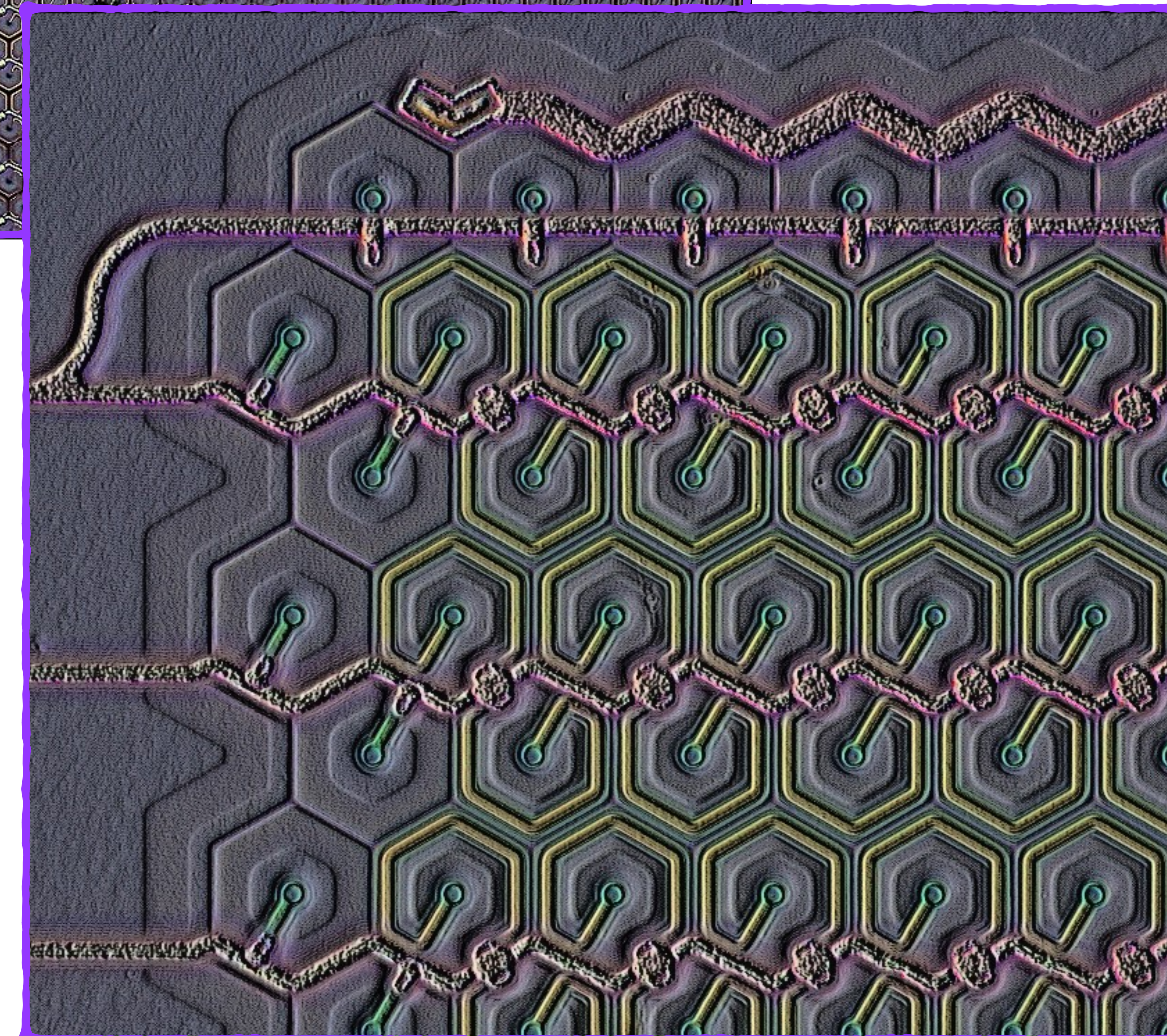
Fitted again with $V = RI + V_T ln(1 + I/I_S)$

CONCLUSION:

In conclusion:

- V_{BD} scales as $\simeq$ 37-41 mV/K
- Second divergence happens at lower OV when decreasing T
- SiPM from same split behaves similarly at fixed OV
- $R_{quenching}$ for split E SiPM is $\simeq M\Omega$, while for split B is not connected
- We sort out activation energy and temperature dependence at fixed OV

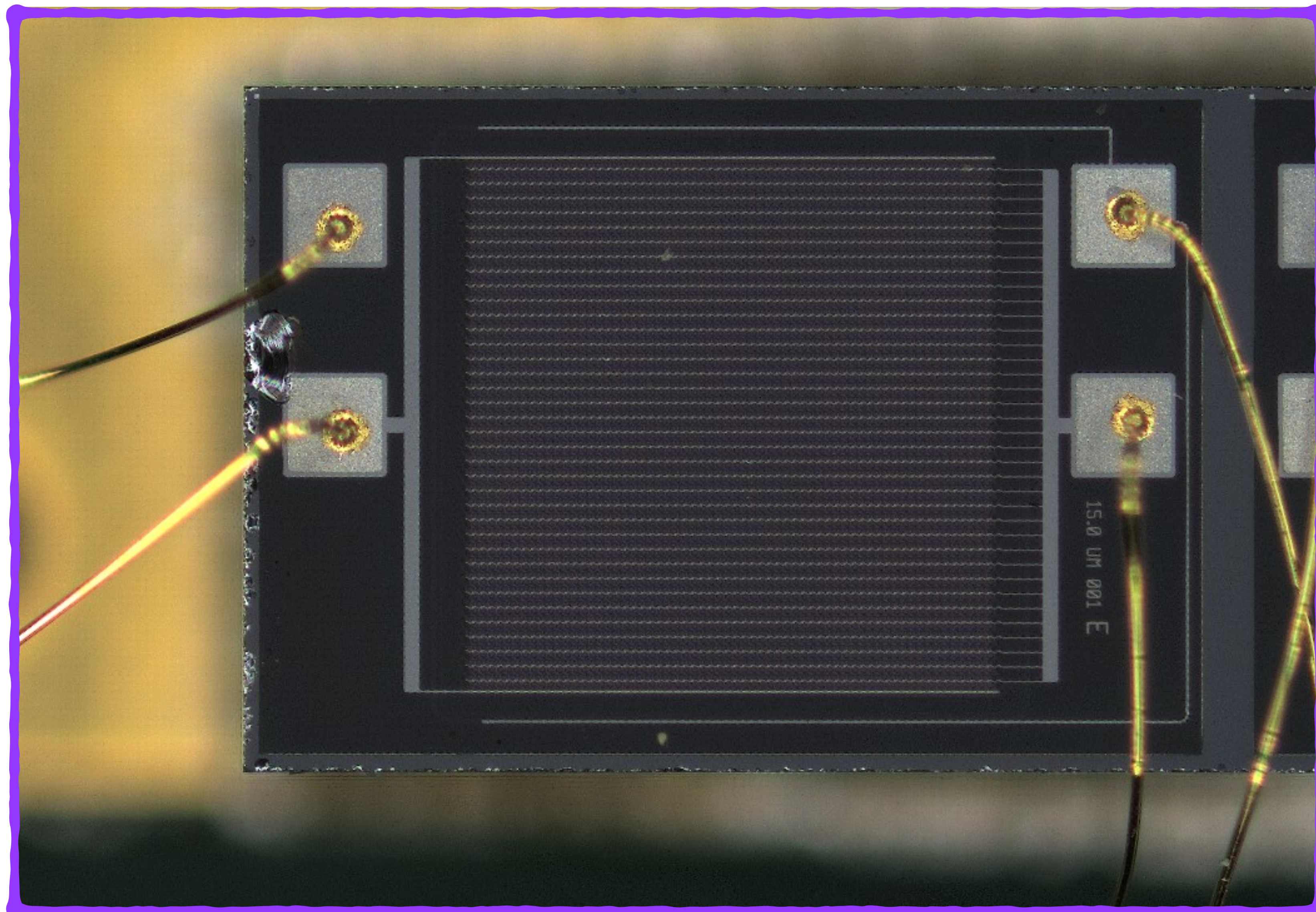


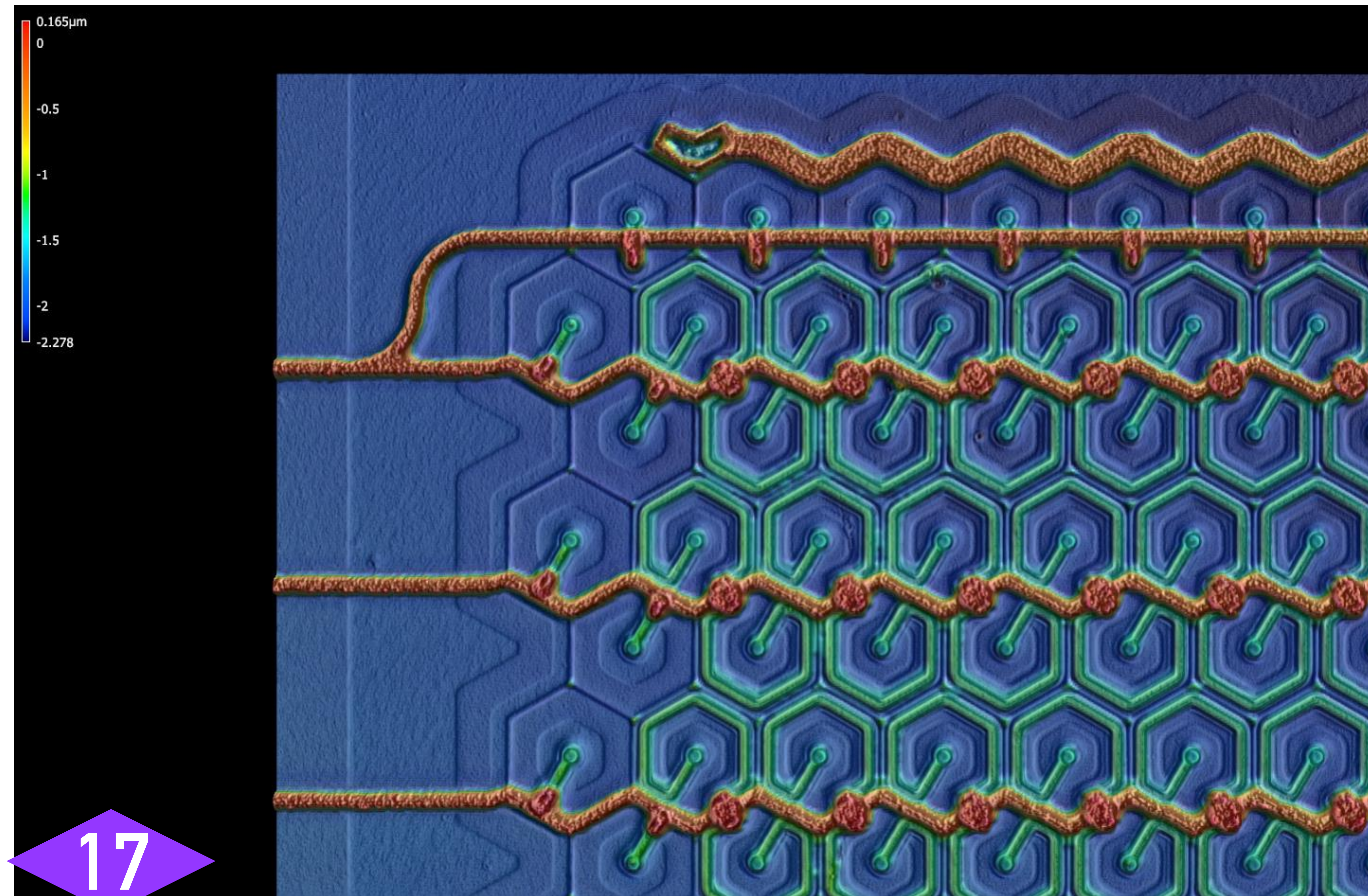


FUTURE WORK:

We plan to do:

- Extracting V_{BD} for all sensors w/ LED (to be ended)
- Cryogenic measurements
- DCR and signal studies
- Laser and irradiation studies





THANK YOU FOR YOUR ATTENTION