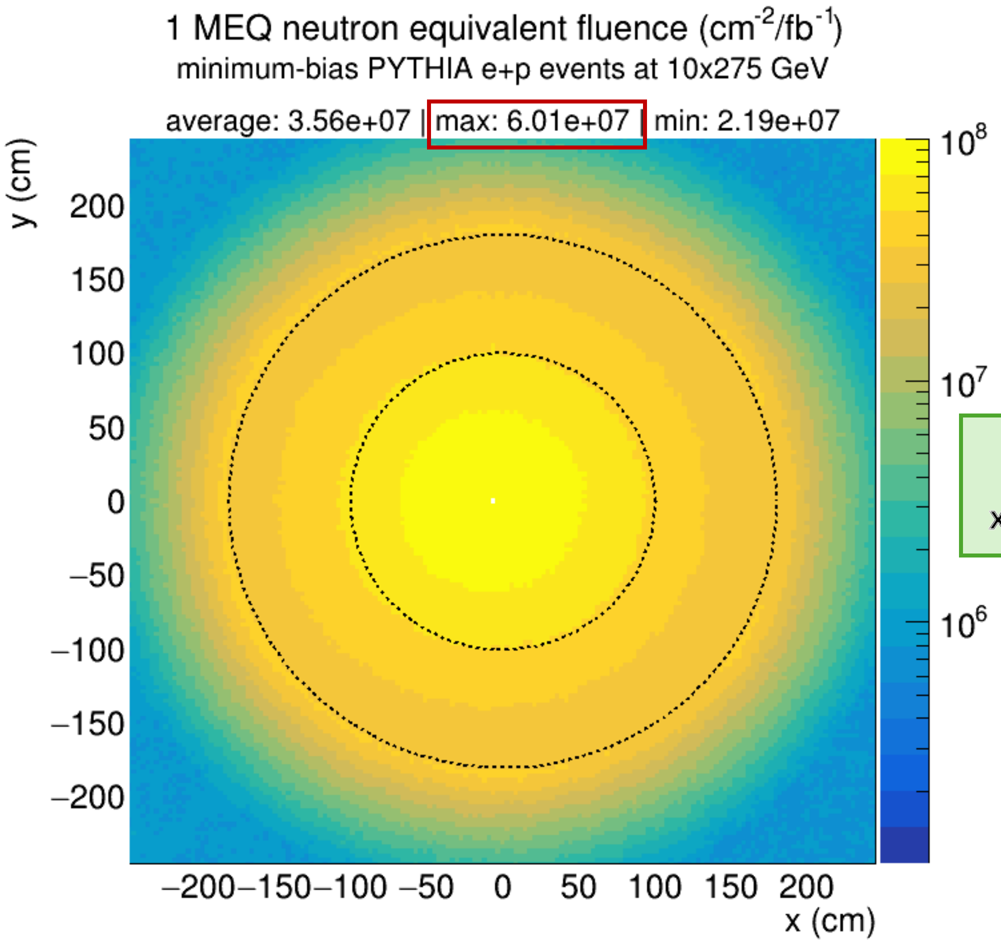
Annealing of SiPMs

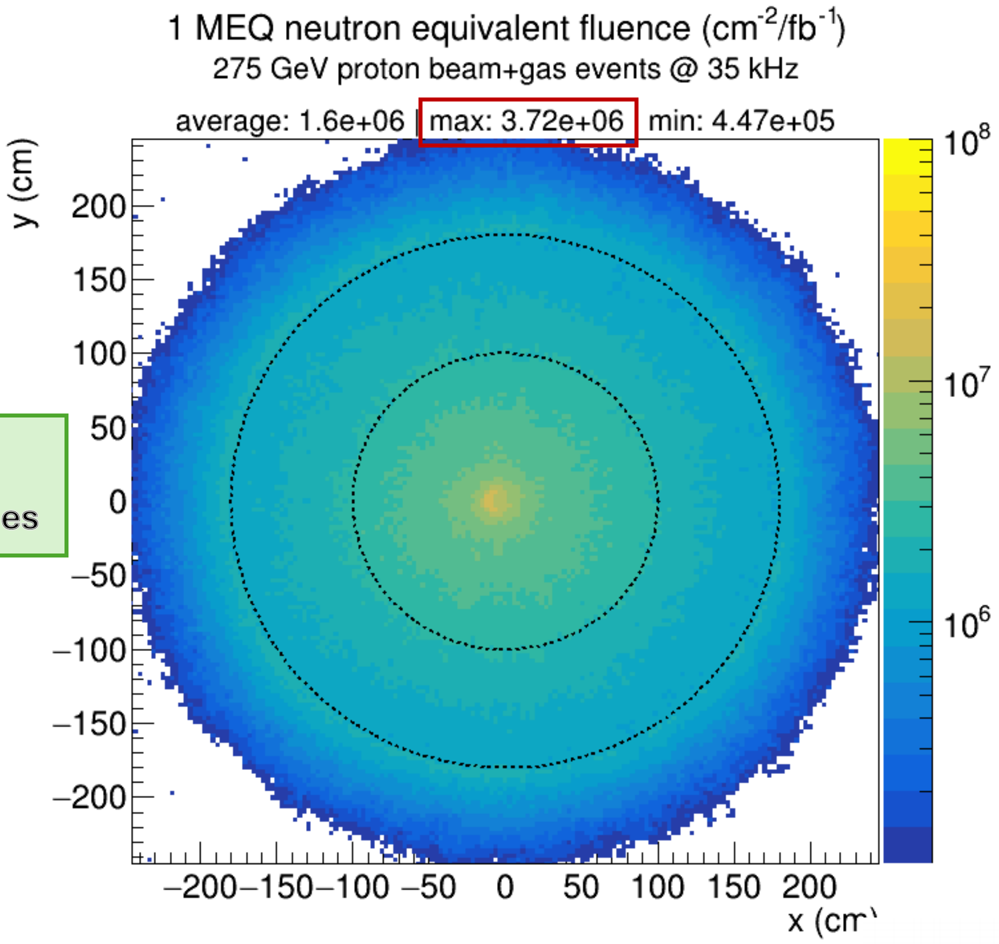
dRich meeting 12/02/2025

Latest estimates of radiation damage



6.4 10^7 n_{eq}/fb^{-1}

x 3.7 previous estimates

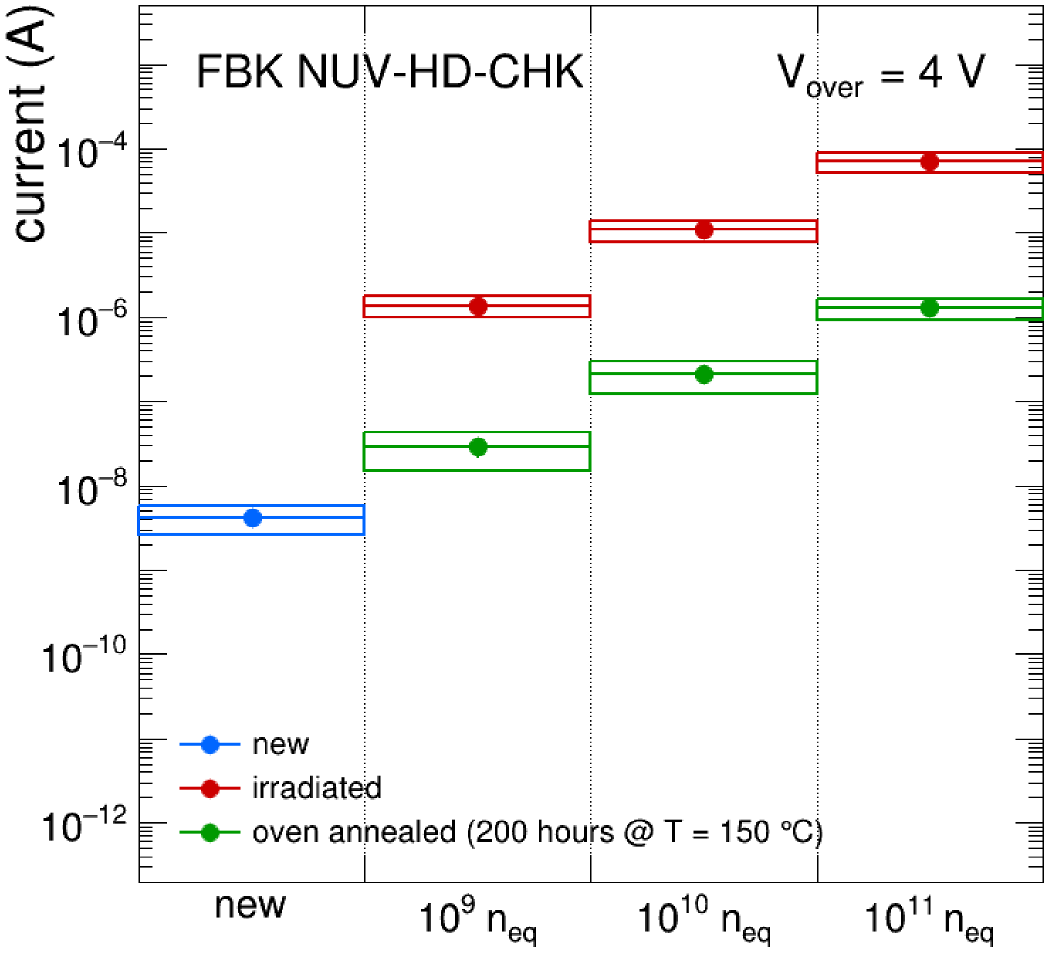


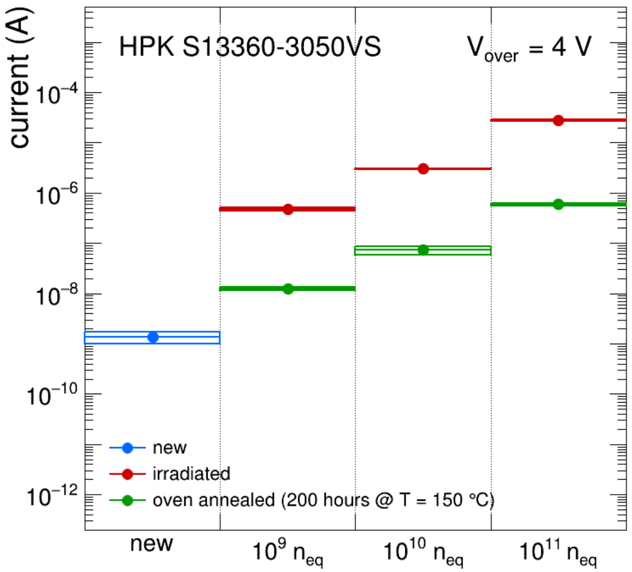
xy projections in 210 < z < 260 cm region, average and max values reported for 100 < R < 180 cm region

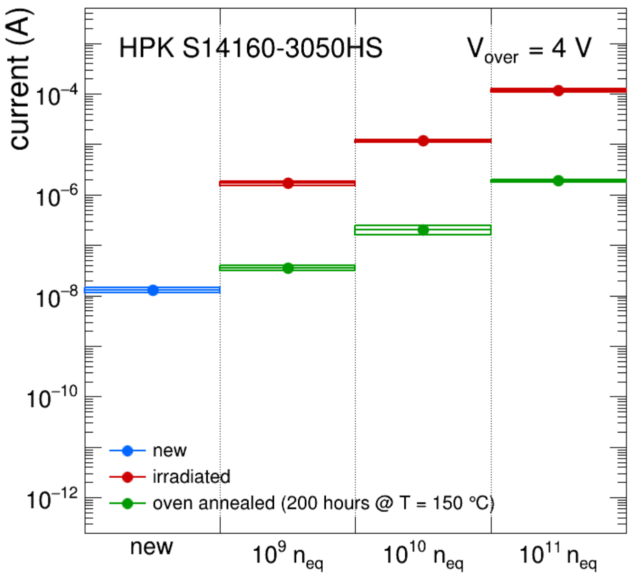
First studies on irradiated SiPMs

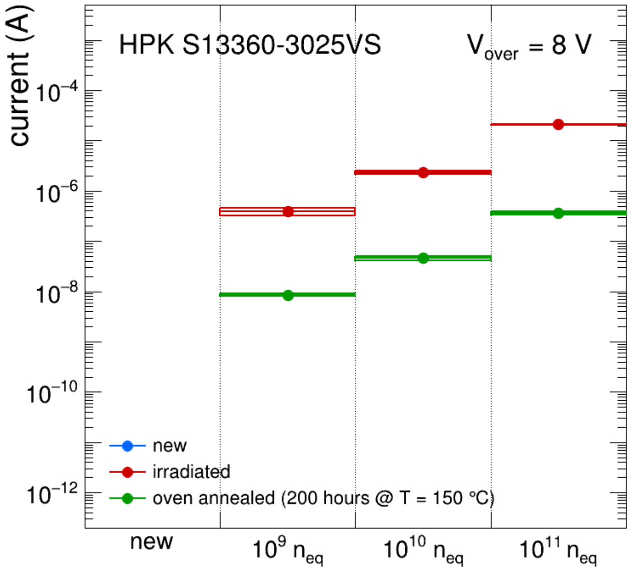
All the sensors showed the same behavior.

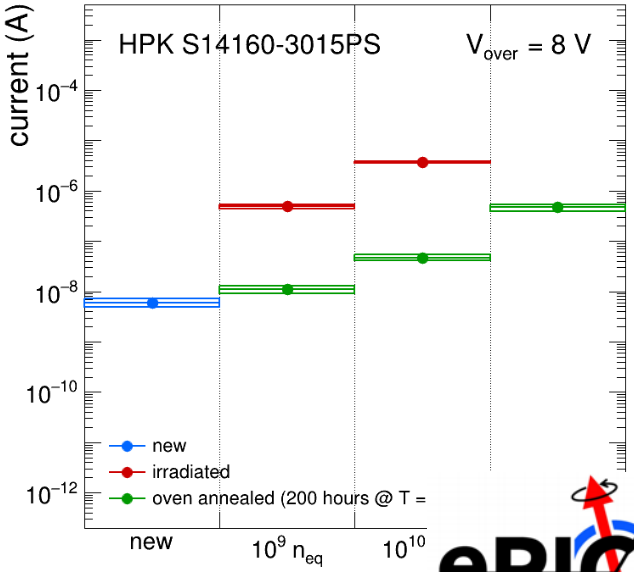
(2021-2022)











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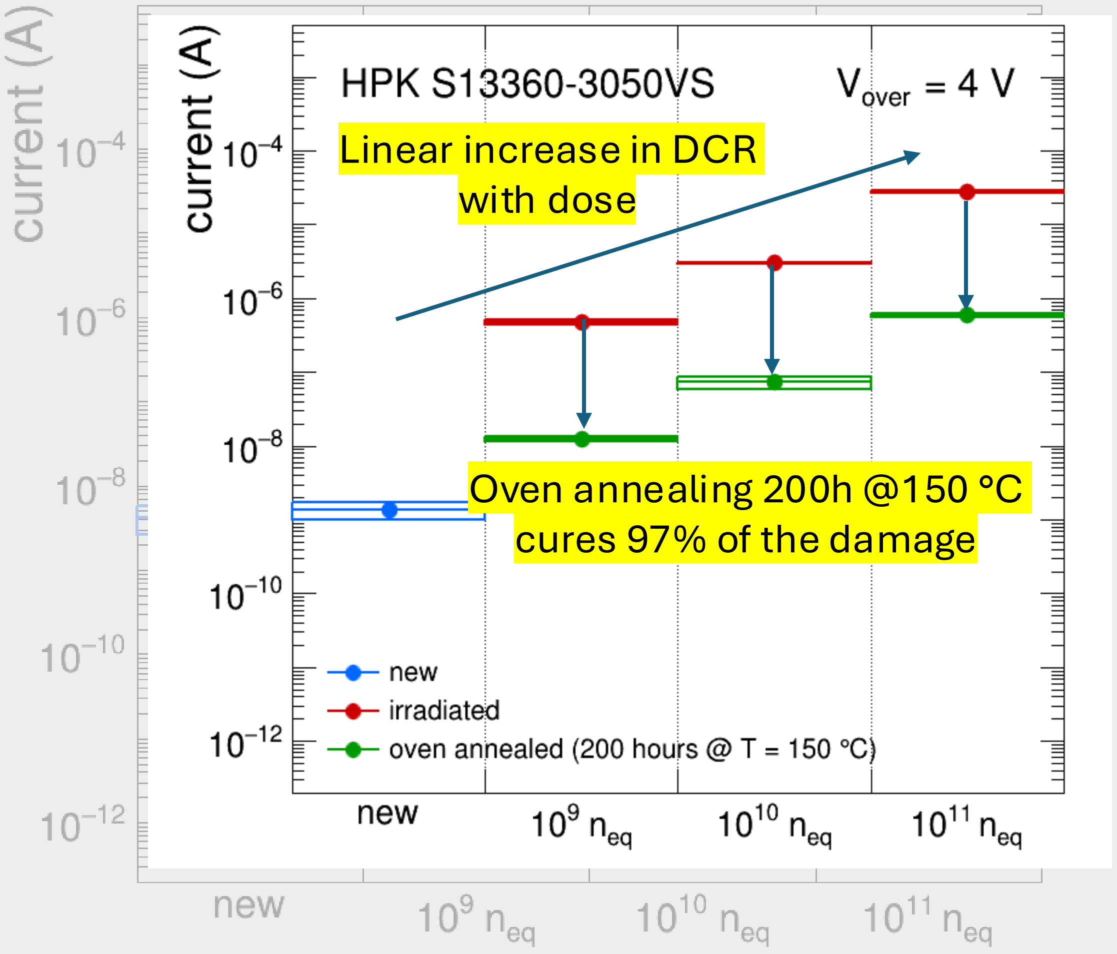
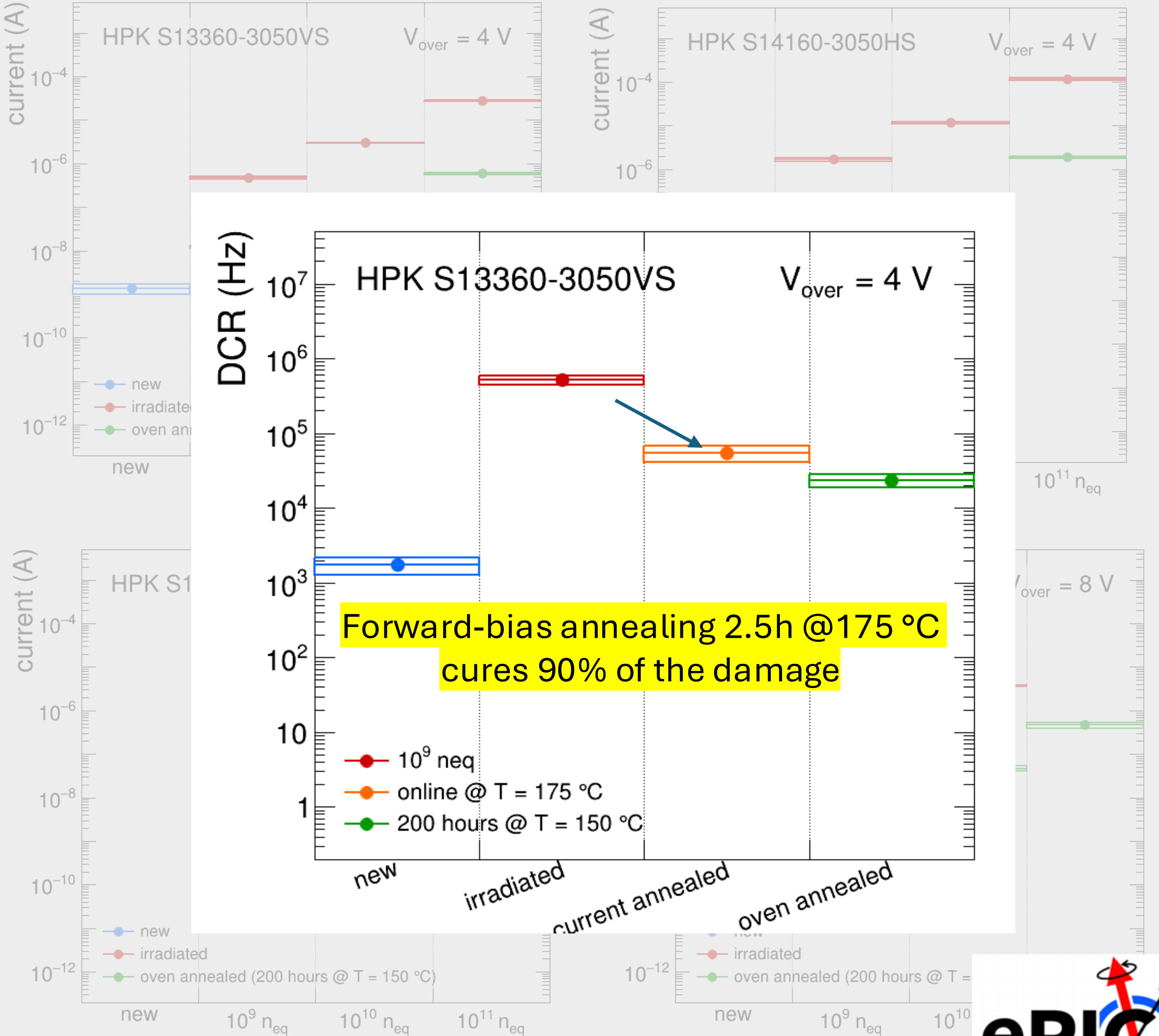
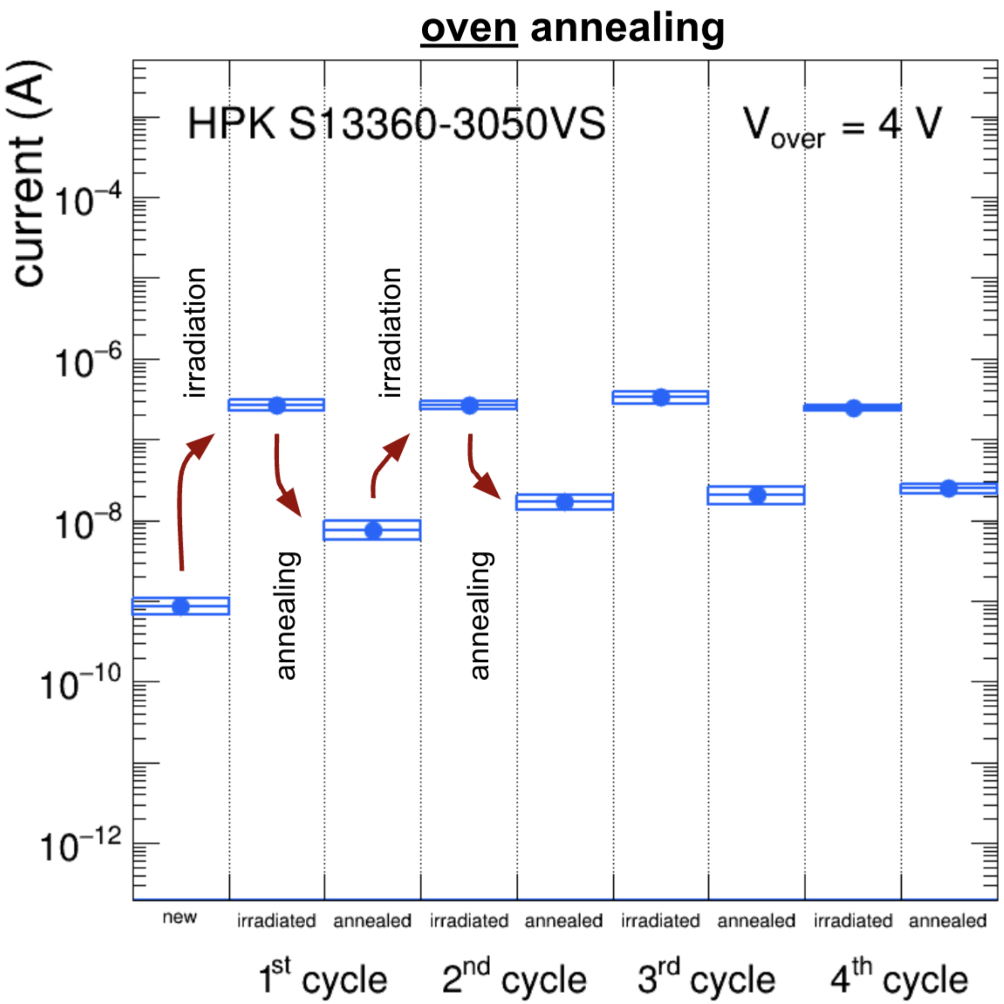




Repeated irradiation-annealing cycles

(2023-2024)



Test the **reproducibility** of repeated **irradiation-annealing cycles** (10^9 n_{eq}).

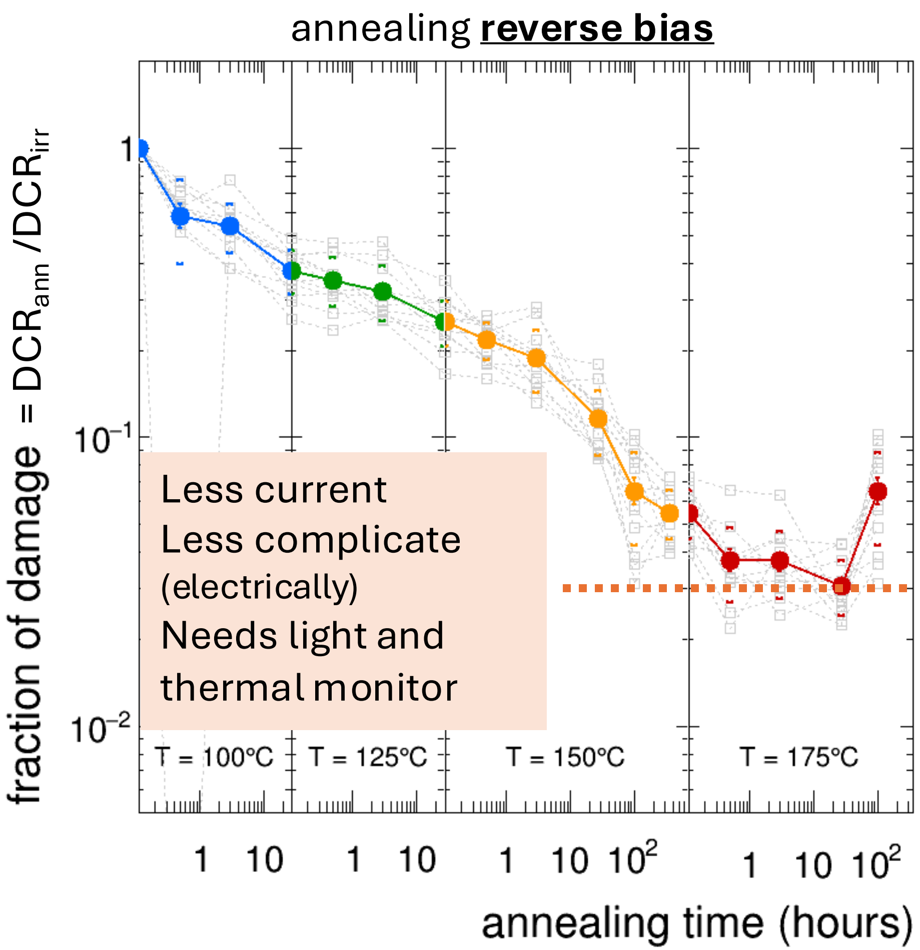
Damage is **consistent** with the delivered dose:

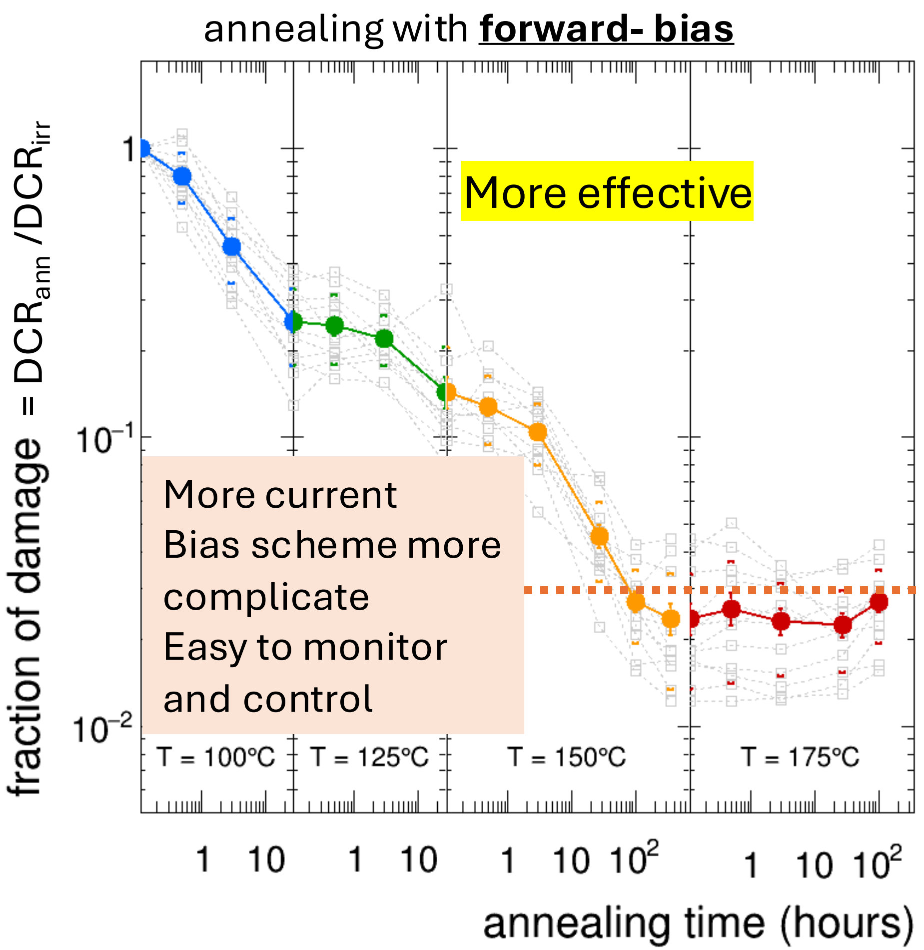
- **DCR increases constantly** (~ 500 kHz @ V_{over} = 4) after each **cycle**

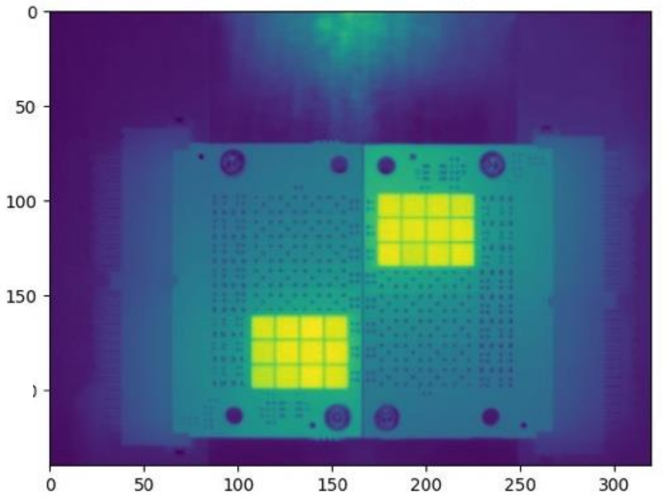
The **annealing** cures the same fraction of newly-produced damage (~ 97%):

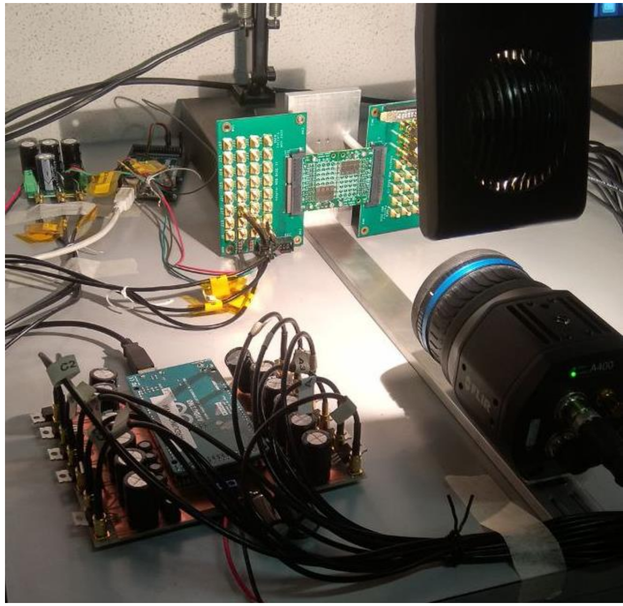
- ~ **15 kHz** (@ V_{over} = 4) of **residual DCR** builds up after each cycle

New **automated system** for **reverse** and **forward-bias annealing** allowed to test 24 SiPMs, at increasing **temperatures** (100 °C-175 °C) and **time** (total ≈ 500h).
97 % of **damage reduction** achieved (like the oven).
(2023-2024)





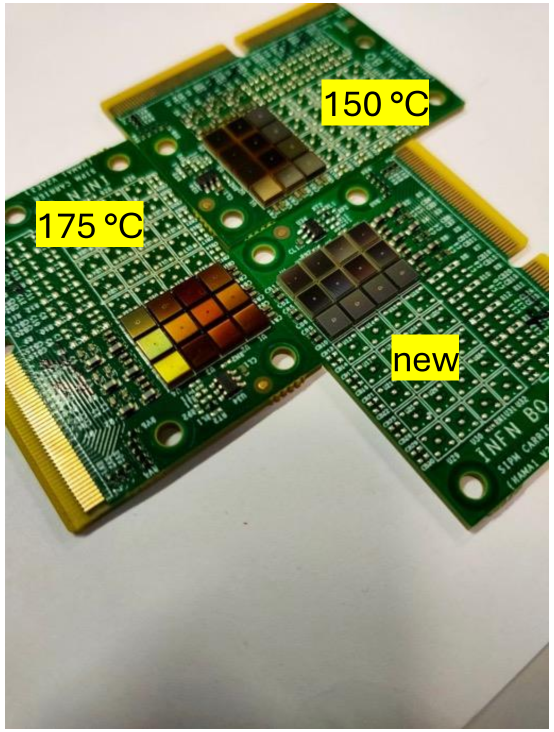




Optical window damage

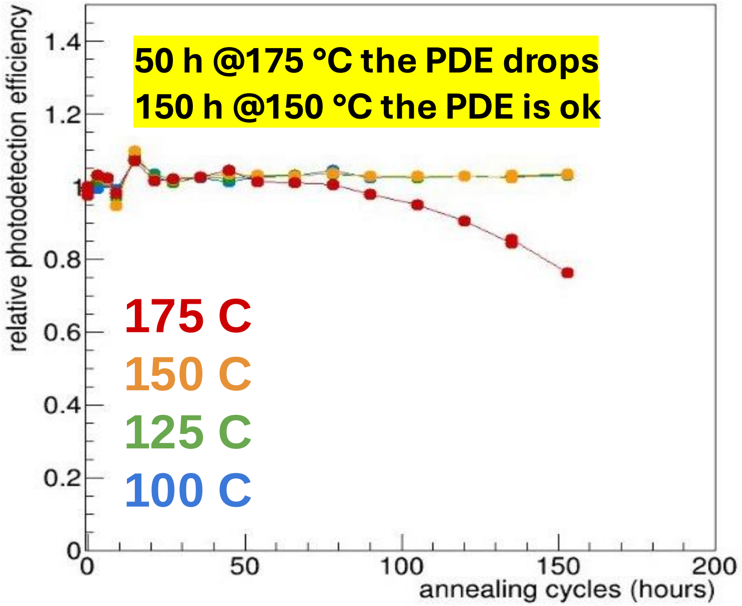
(2024)

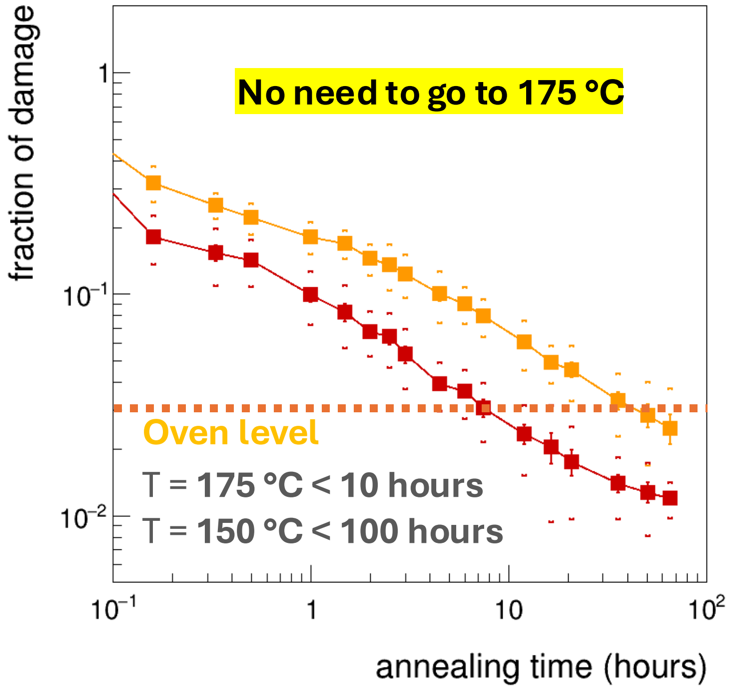
After 500h of forward-bias annealing alterations on the SiPM windows



- **90%** efficiency loss after **500 h** online at 175 C
- **25%** efficiency loss after **500 h** online at 150 C
- **no** efficiency loss after **500 h** oven at 150 C

Unclear why oven annealing is less critical on the optical window (hypothesis: humidity)





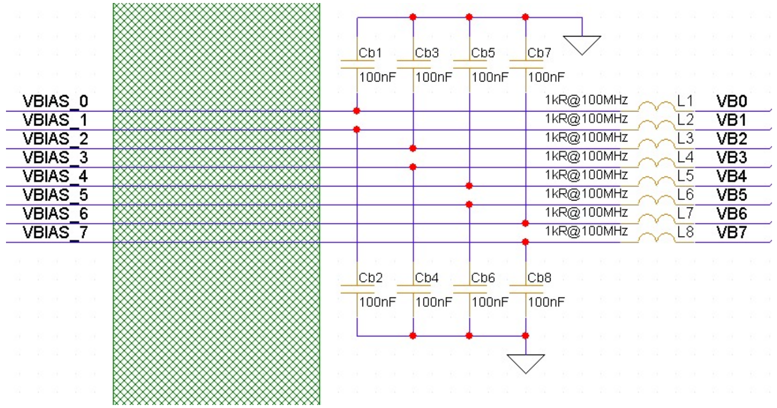
Electronics

(2024-2025)

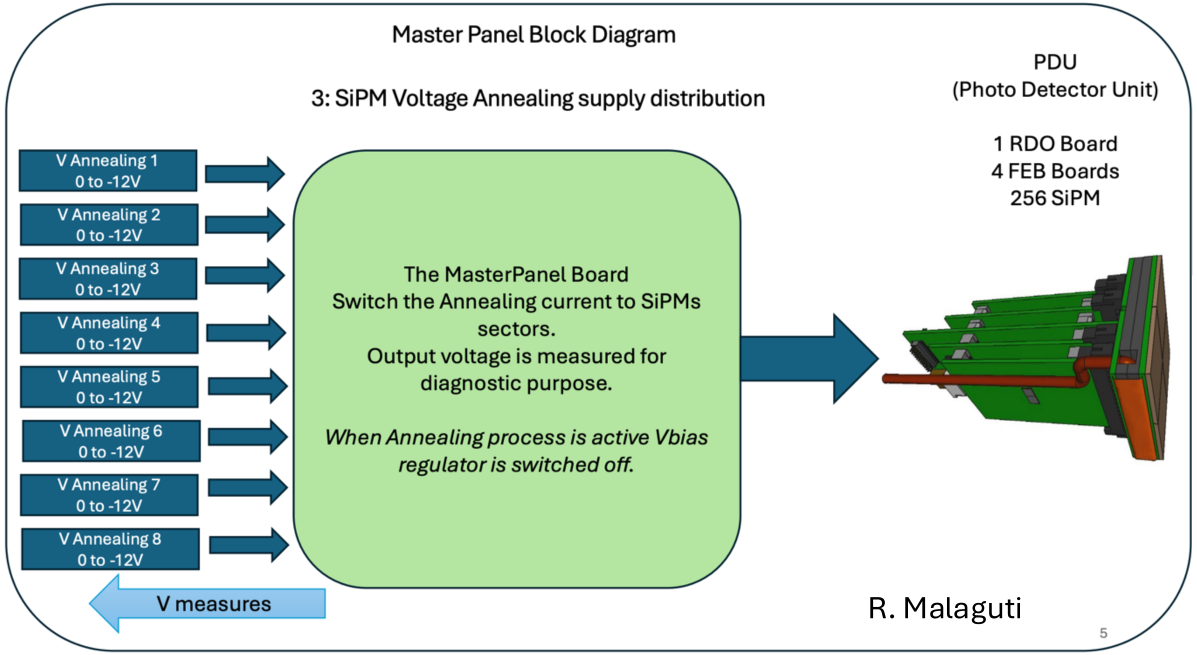
Annealing specifications:

- **1 W** per **SiPM** (100 mA, 10 V)
- **Remotely controlled** (MasterPanel INFN FE)
- **Safe** for the **front-end** (AC coupling, diode bypass INFN TO)
- **Vbias filtering** (LC filtering SiPMCarrier INFN BO)

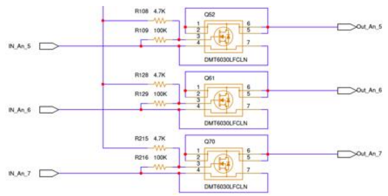
Feasibility tests on a final carrier in the **next months**

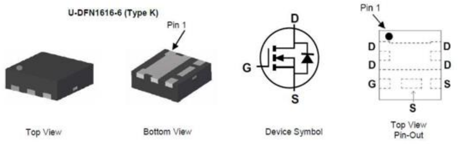


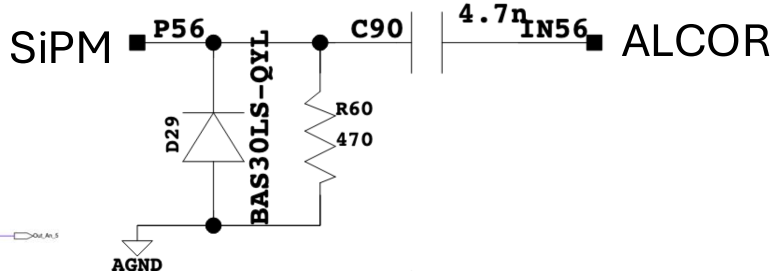
C. Baldanza



R. Malaguti

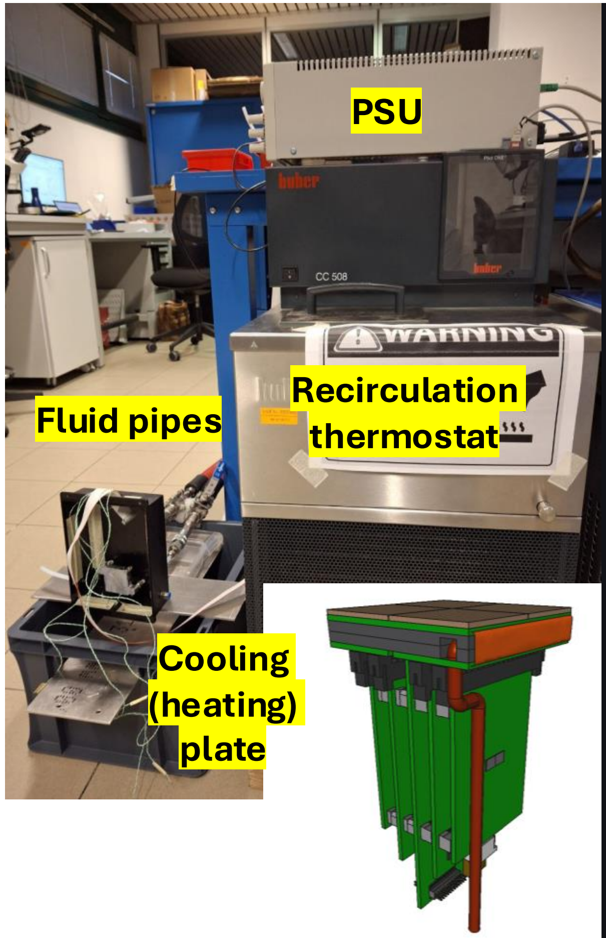


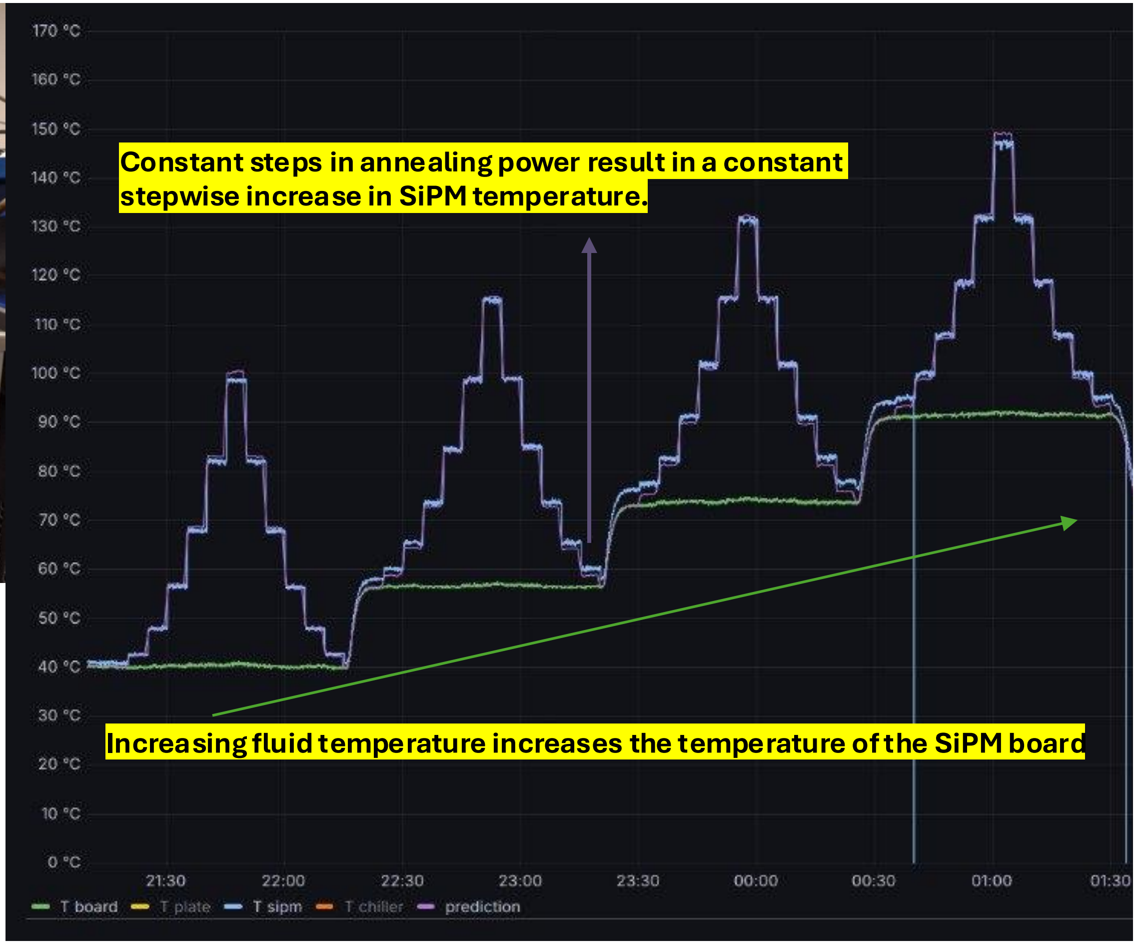




M. Mignone

Fluid-assisted annealing
(2024-2025)





Temperature readings:

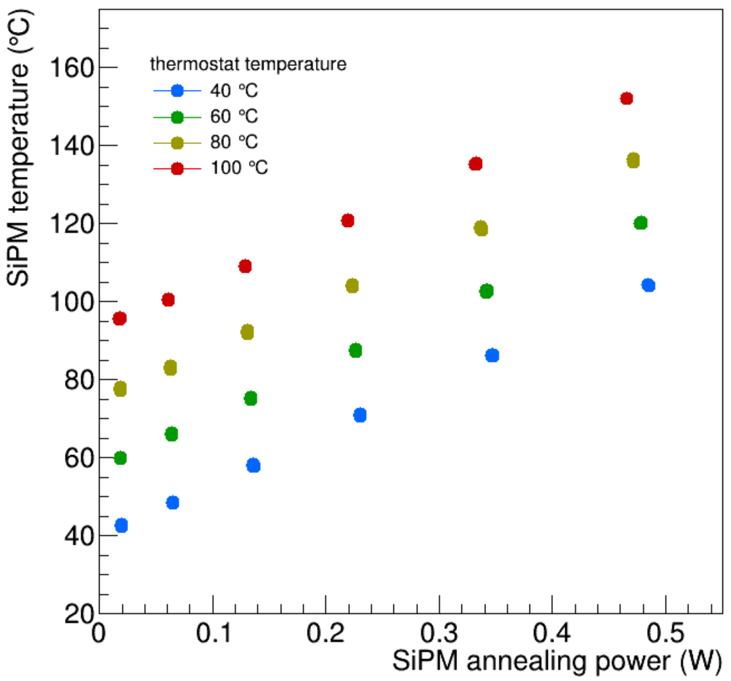
Boards (NTC)
Plate (Thermocouple)
SiPMs (Thermo-camera)

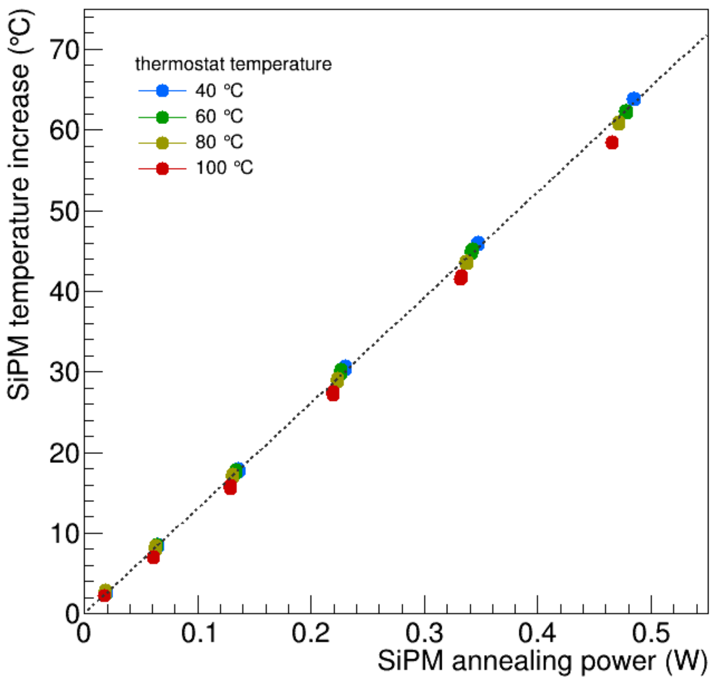
By knowing the plate/board temperature and the power delivered by the PSU for the annealing, the temperature of the SiPM can be easily determined.

We have control on the annealing temperature without a thermo-camera

Fluid-assisted annealing

(2024-2025)

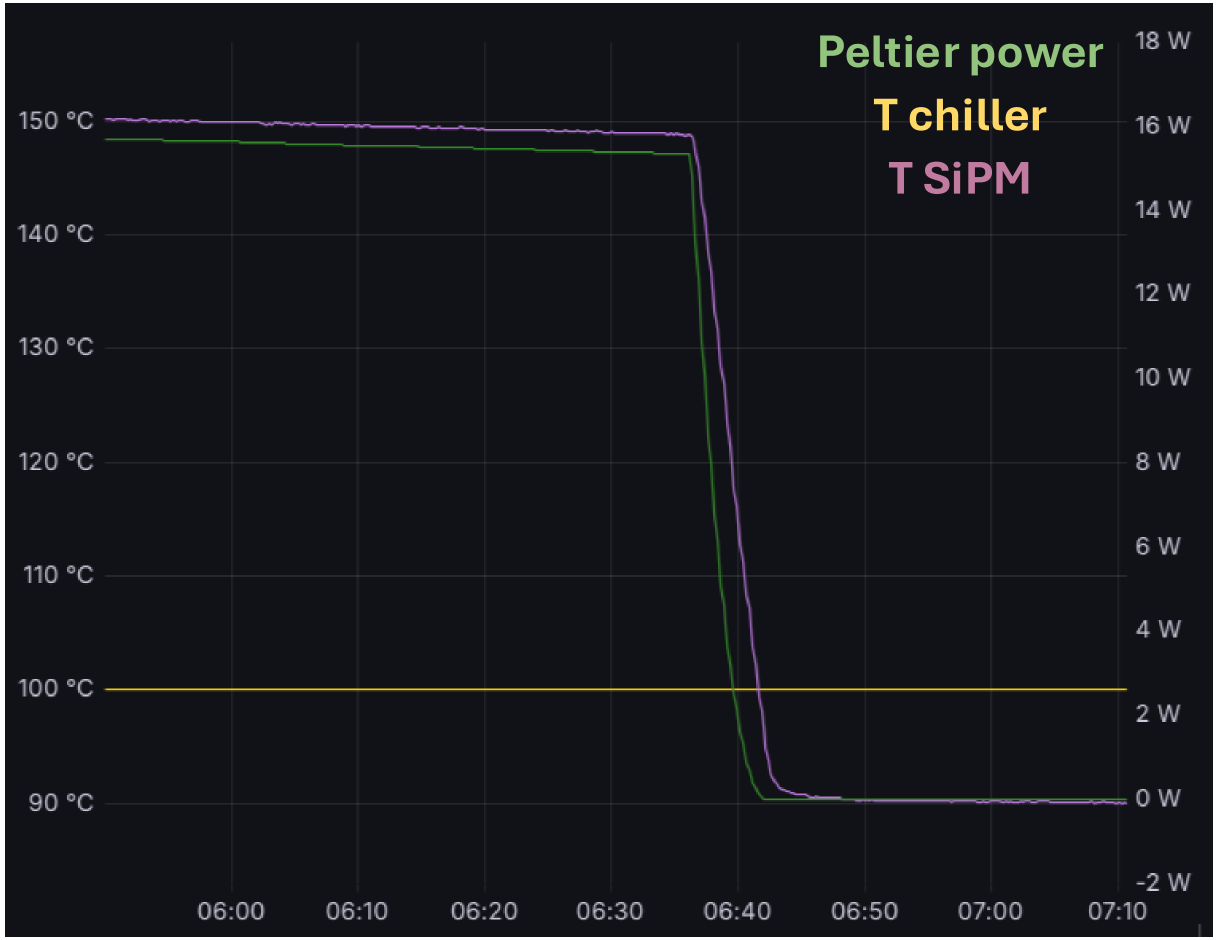


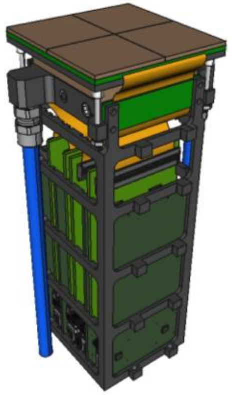


Hotter plate/board allows a reduction of the forward-bias power to 0.5 W @ fluid 100 °C, SiPM 150 °C

Fluid-peltier-assisted annealing

(2024-2025)





To reach 150 °C -> 0.5 W per SiPM
Power per PDU = 256*0.5 W ~ 130 W (8 annealing ch. 16.5 W)
15 W delivered to the peltier to reach the same temperature for the entire PDU

10x reduction of power needed for the annealing. Reduction of the forward-bias annealing current.

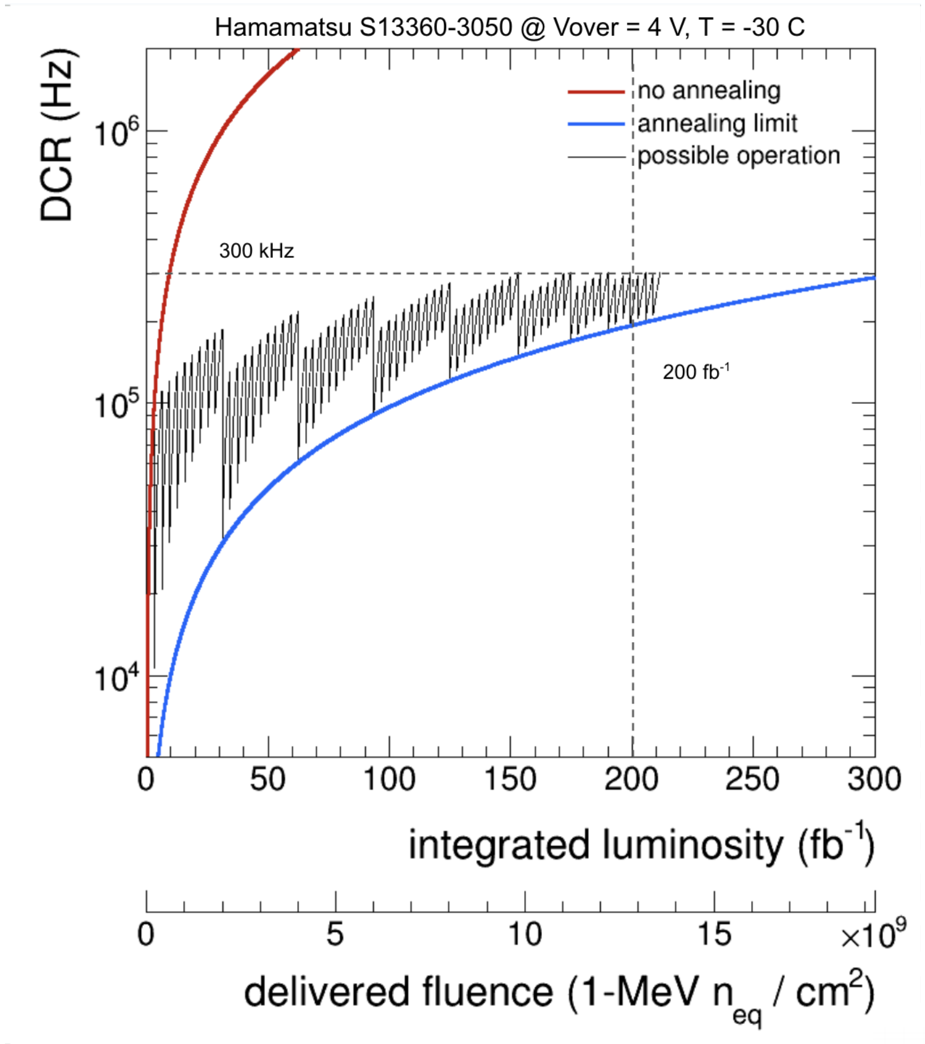
Peltier adds material budget.
High temperature peltier to be tested.

Ageing model

Model assumption:
•DCR increase: 500 kHz/10^9 n_{eq}
•residual DCR (soft <2 h@150C annealing): 50 kHz/10^9 n_{eq}
•residual DCR (hard <100 h@150C annealing): 15 kHz/10^9 n_{eq}
1-MeV neq fluence from background group:
- 6.4 10^7 n_{eq} / fb^{-1}
- Max fluence for SiPMs closer to the beam line
- No safety factor

Risk mitigation strategy:
- Reduce the over-voltage reduces DCR at the expense of PDE
- Reduce the operative temperature down to -40 °C;

The model assumes a time window of 1 ns and 300 kHz as a SAFE limit. Time resolution in laboratory reached 150 ps. If we reach 500 ps of time resolution, the safe rate doubles.



Proposed operation scenario:
10 soft-annealing (<2h @150 °C) cycles per each of the 7 hard-annealing cycles (<100 h @150 °C)

Summary and Next Steps

Our studies demonstrate that the annealing is a viable solution to mitigate the radiation damage.
Damages at the entrance window can be a problem for longer annealing time
Fluid-assisted forward-bias annealing is the baseline for the experiment
Electronics is in development
Fluid-peltier-assisted annealing is very promising

Entrance window:

- Optical and Chemical analysis of the yellowed sensors
- Forward bias annealing in dry air/Nitrogen (hypothesis: moisture enhanced effect)

Annealing of 256 SiPM on a carrier:

- Annealing FEB will arrive before summer
- Integration test with MasterPanel

Fluid-peltier-assisted annealing:

- Use of a high temperature peltier
- Evaluate the impact of material budget