Summary of the 2023 characterisation campaign

Nicola Rubini (1)

(1) INFN Bologna

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The SiPM option and neutron fluence for dRICH sensors

Cons

1. **High dark count rate at room temperature**
2. **<u>High radiation sensitivity</u>**

What can be done?

1. Cooling can lower DCR of a factor ~2 every ~8°C
2. Timing can discard background
3. Annealing can recover DCR resulted from radiation damage

10^9 n_{eq}/cm^2 fluence:

Requirement for the key physics goals is 10 fb^{-1} per center of mass energy and polarization setting

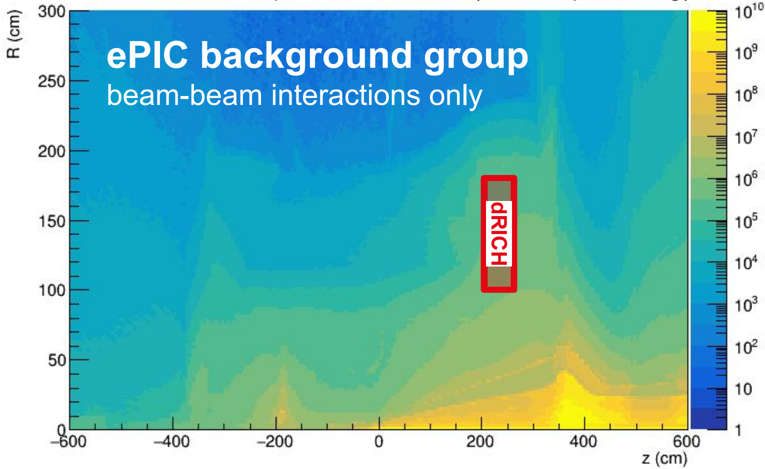
10^{10} n_{eq}/cm^2 fluence:

Requirement for the nucleon imaging programme is 100 fb^{-1} per center of mass energy and polarization setting

10^{11} n_{eq}/cm^2 fluence:

Expected fluence over 10-12 years of operation, might never be reached

1-MeV neutron equivalent fluence (1 fb^{-1} e-p running)



Expected fluence:

average: ~4 10^5 n_{eq} / cm^2 fb^{-1}

maximum: ~ 10^6 n_{eq} / cm^2 fb^{-1}

assumed: ~ 10^7 n_{eq} / cm^2 fb^{-1}

x10 safety factor

2023 activity summary

The 2023 focused on irradiations of protons (TIFPA) and neutrons (LNL)

Protons irradiation tests were performed on a target fluence of 10^9 1-MeV n_{eq} and focused on the annealing techniques for damage recovery.

Neutrons irradiation were a first and we performed a scan over a large fluence spectrum, together with annealing techniques tests.

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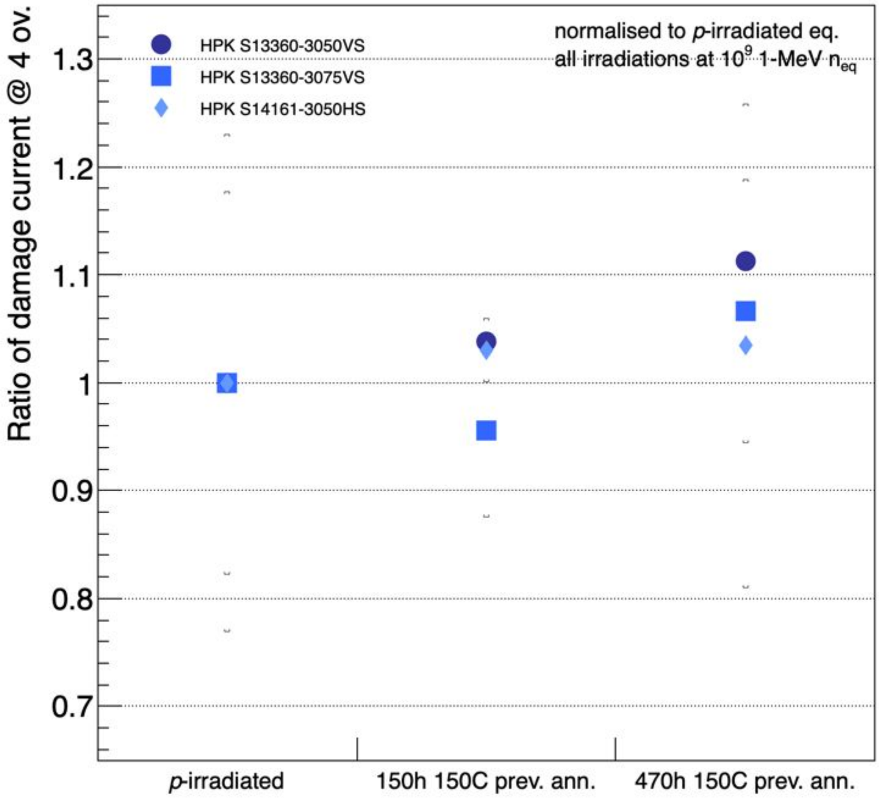
p-irr: preemptive annealing

First we tested whether preventive annealing could impact how the radiation damage impacts the sensors.
We compare the damage current of a sensor that had preemptively undergone a 150C annealing in the oven for 150h and 470h.

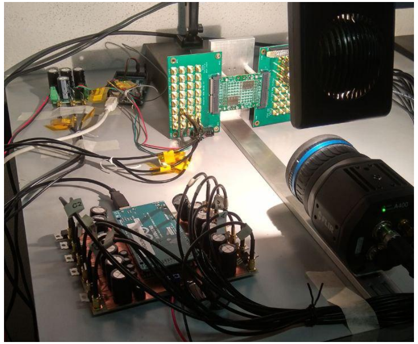
Results do not show any evidence for protective effects.



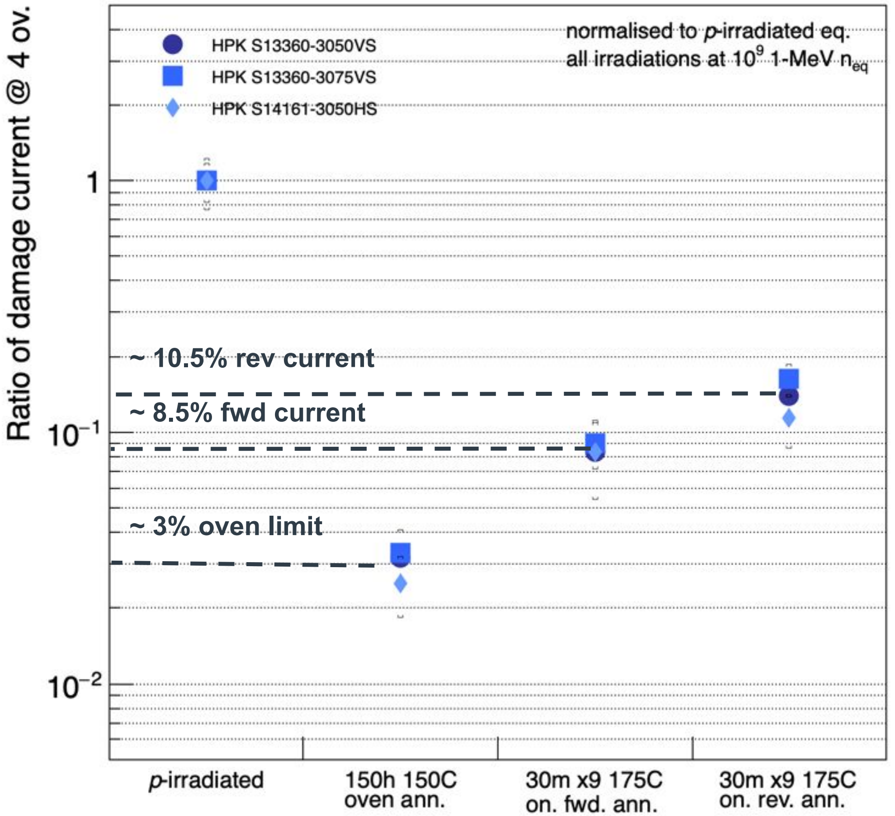
Damage current: current at given overvoltage after irradiation subtracted the current of a new sensor at the same overvoltage

p-irr: online fwd/rev ann.

We tested the online annealing technique, where you irradiate in small shots of 10^9 n_{eq} interleaved with a session of 30 min of annealing at 175 C



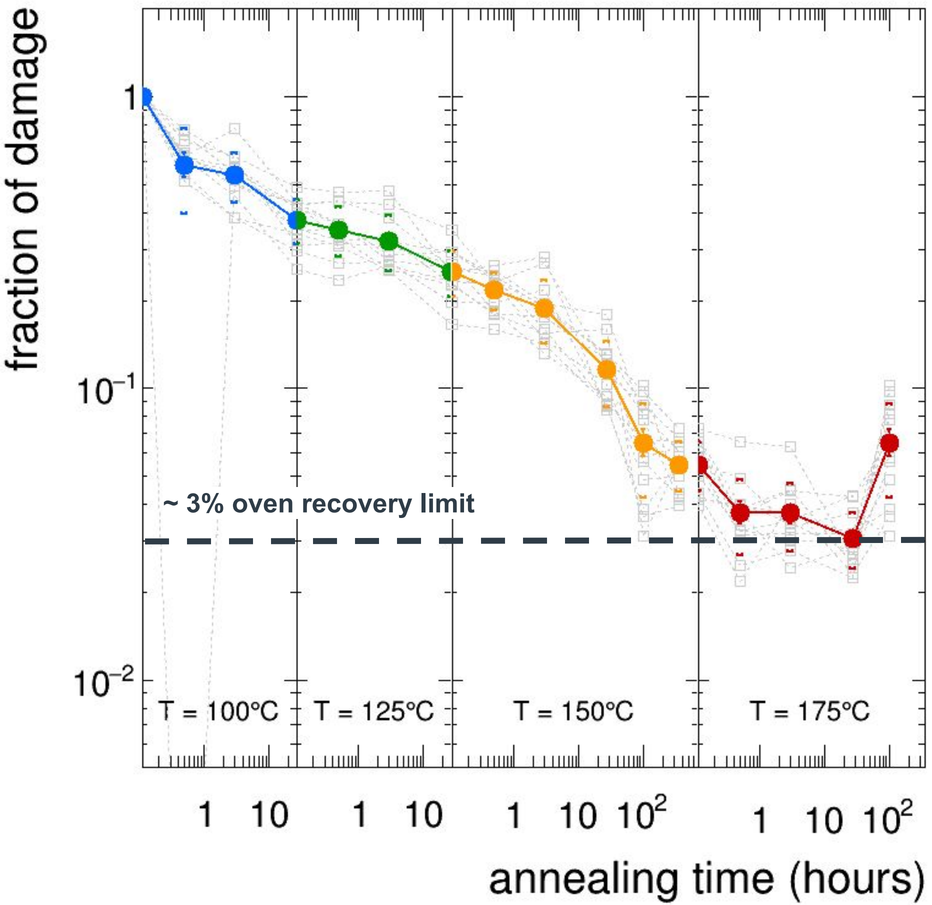
Results confirm the 2022 findings of a good recovery in a small time frame. Rev seem less effective than fwd.



Damage current: current at given overvoltage after irradiation subtracted the current of a new sensor at the same overvoltage

p-irr: reverse annealing

We also tested rev and fwd in an offline setting. The *p*-irradiated boards underwent cycles of increasing temperature and annealing time.

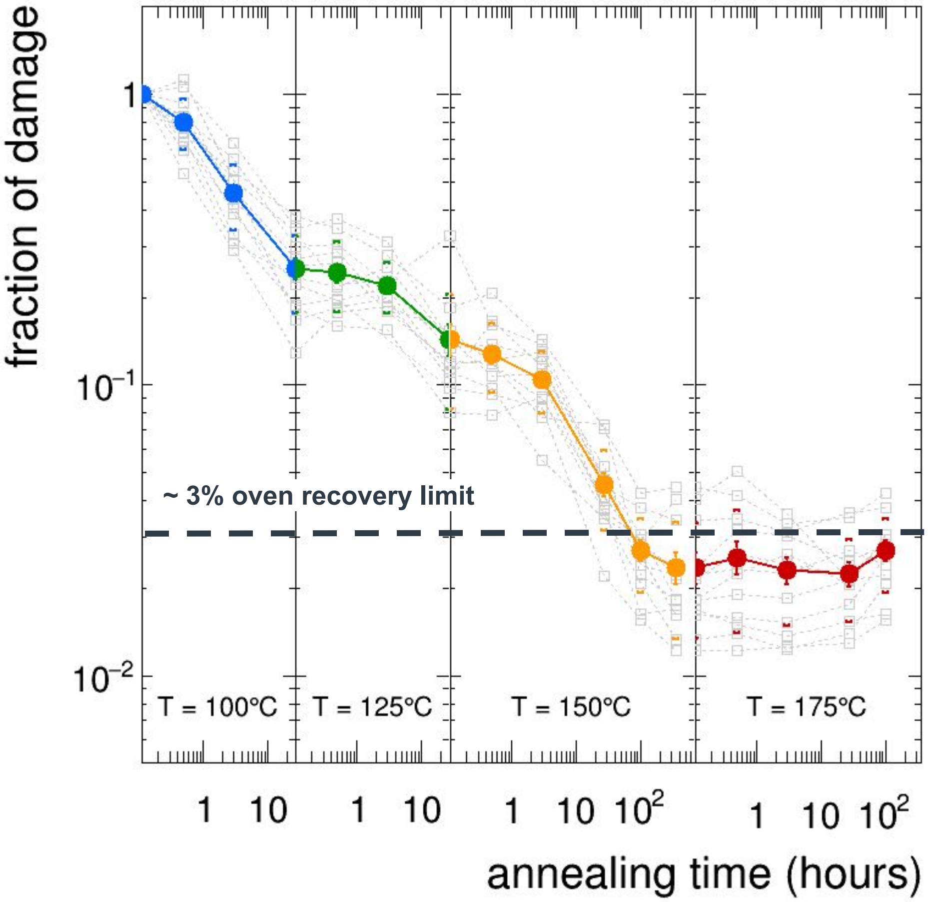


Rev seems to stop short of oven limit

p-irr: forward annealing

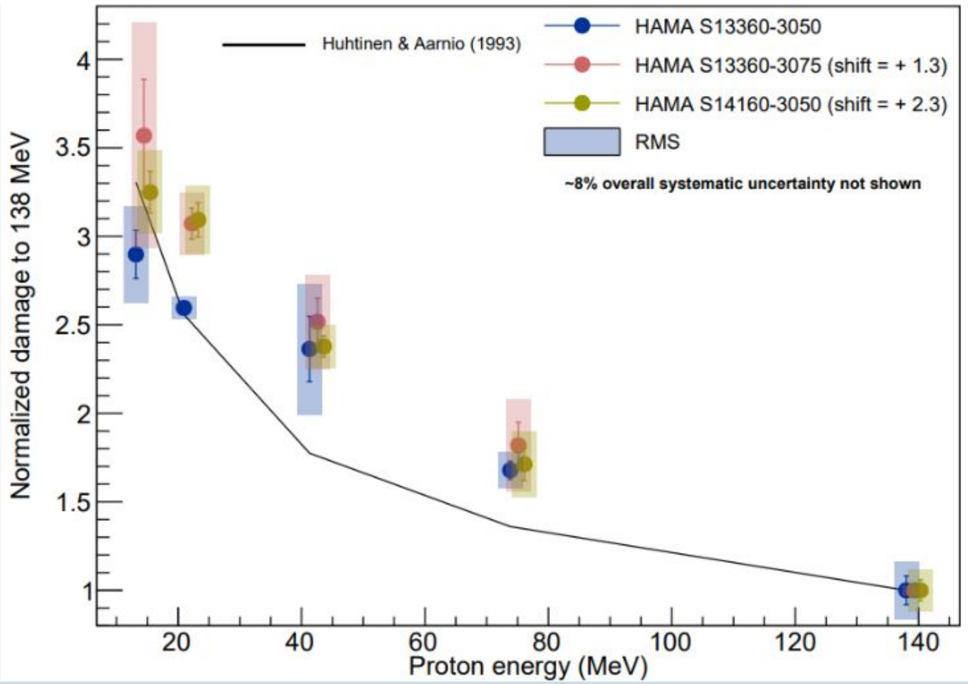
We also tested rev and fwd in an offline setting. The *p*-irradiated boards underwent cycles of increasing temperature and annealing time.

Fwd seems to fit well the oven limit, in a shorter time frame w.r.t. rev



p-irr: energy scan

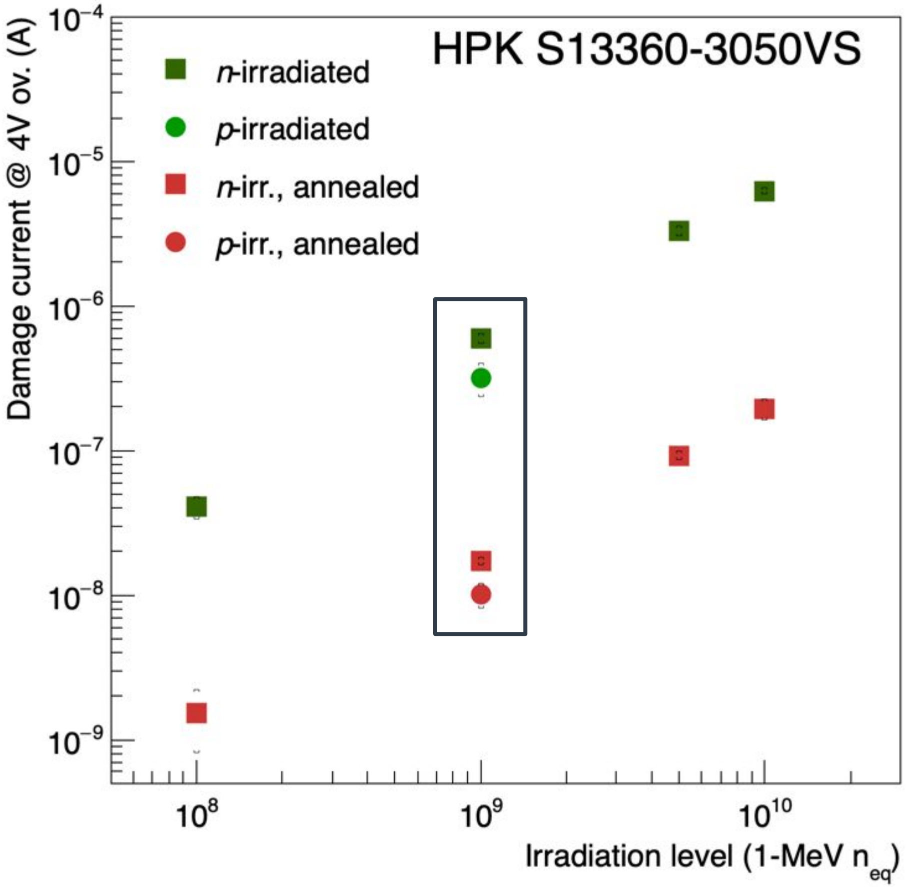
We also tested different incident proton energies.
The theoretical calculations refer to pure Silicon.



Results are fitting nicely theoretical predictions within few tens of percent

n-irr: fluence scan

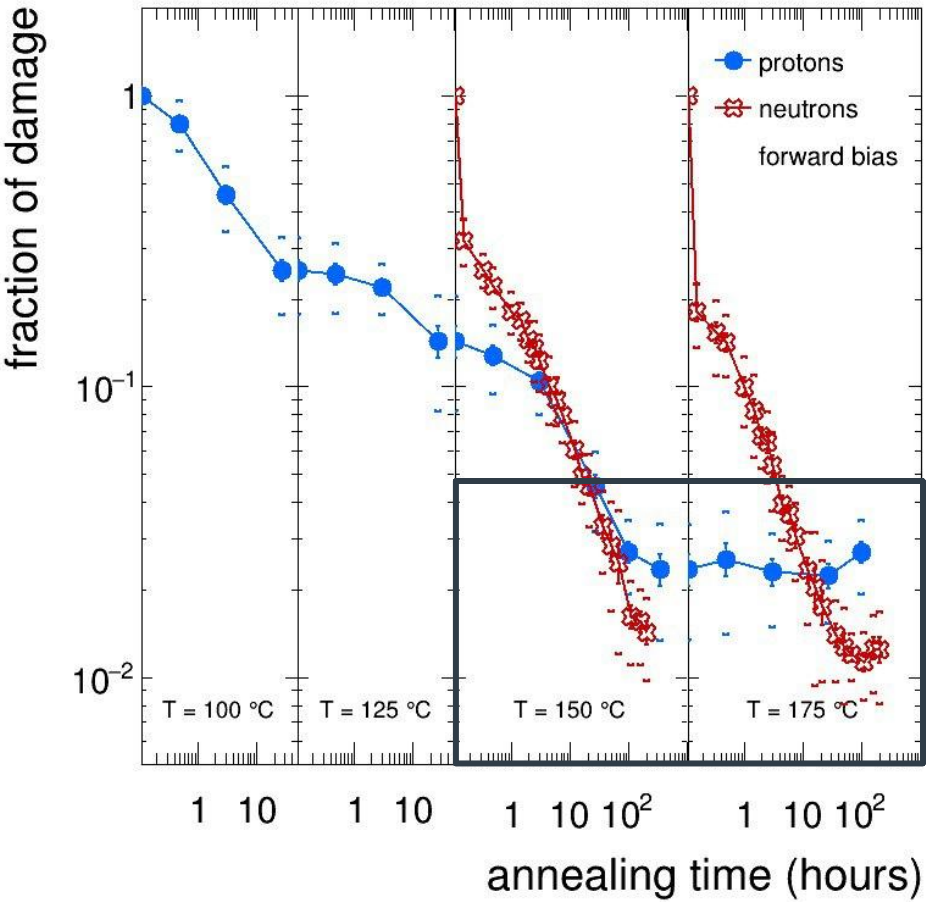
We covered a large range of different fluences with the *n*-irradiation. The most puzzling result was a factor 2 difference between *p*-irr and *n*-irr results, in violation of NIEL hypothesis.



Puzzling factor 2 w.r.t. to *p*-irradiation

n-irr: forward annealing

We focused on fwd annealing for the *n*-irradiated boards at two different temperatures.
There seem to be a more significant recovery, that is due to the factor 2 in damage w.r.t. *p*-irradiated boards.



***p*- and *n*-irr. sensors show similar behaviours to annealing**

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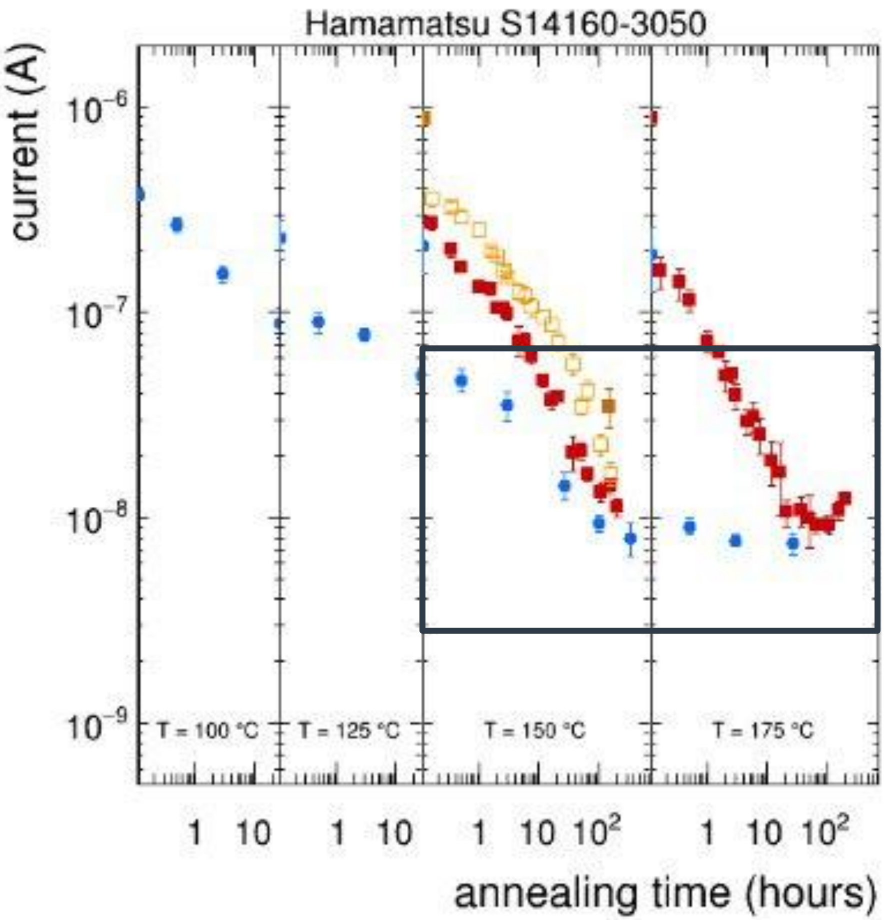
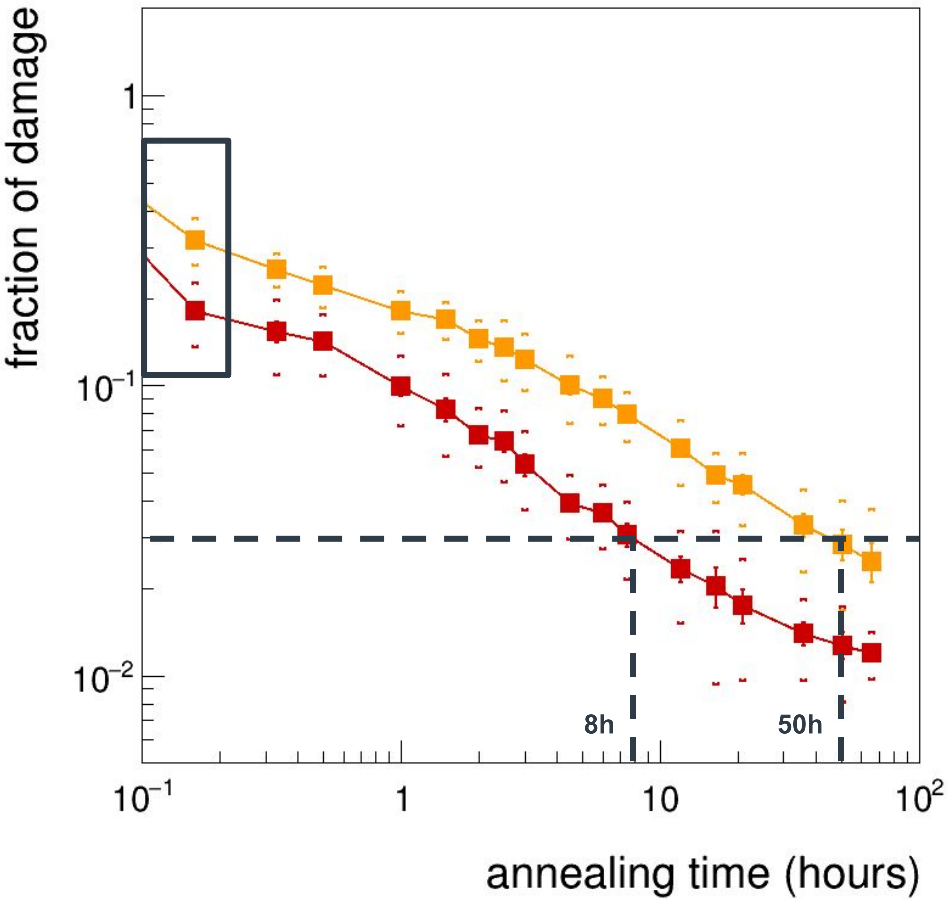


***p*- and *n*-irr. sensors show similar behaviours to annealing**

n-irr: annealing temperature

Directly comparing 150C and 175C in forward annealing we see that we have an initial decrease that is proportional to the ann. temperature.
Moreover the speed of recovery is also greatly enhanced with a relatively small increase in ann. temperature.



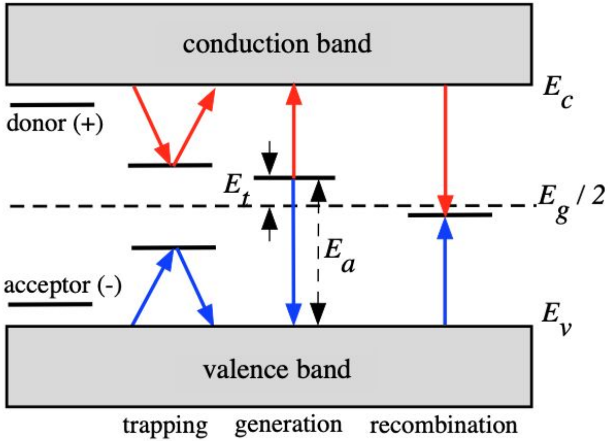
We reach the same cure level, but faster with higher temperatures. (*)

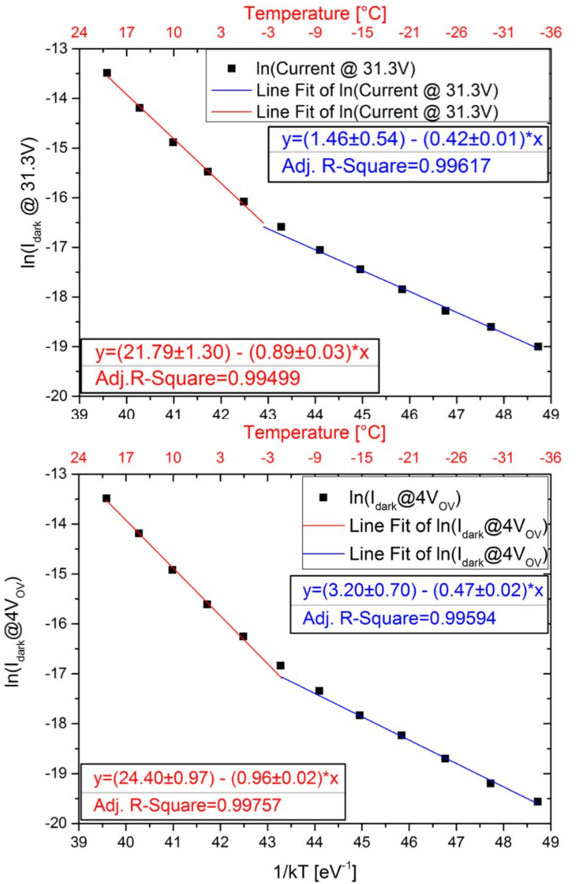
Activation energy

Activation energy can be measured with Arrhenius plots, DCR as a function of temperature at a given overvoltage or at a fixed voltages. The linear dependence of the dark current (log) dictates the activation energy and the dominant process for DCR generation:

high temperature:
thermal generation

low temperature:
trap assisted generation

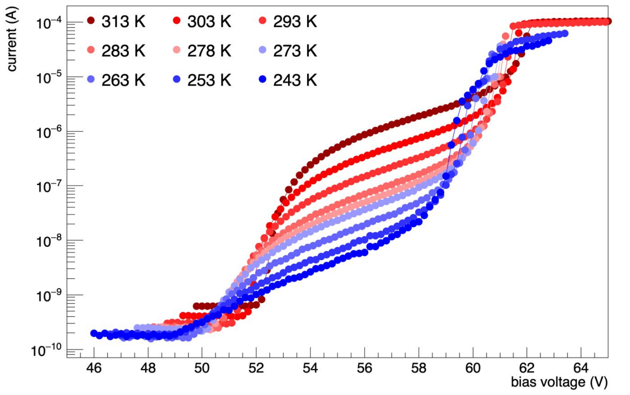




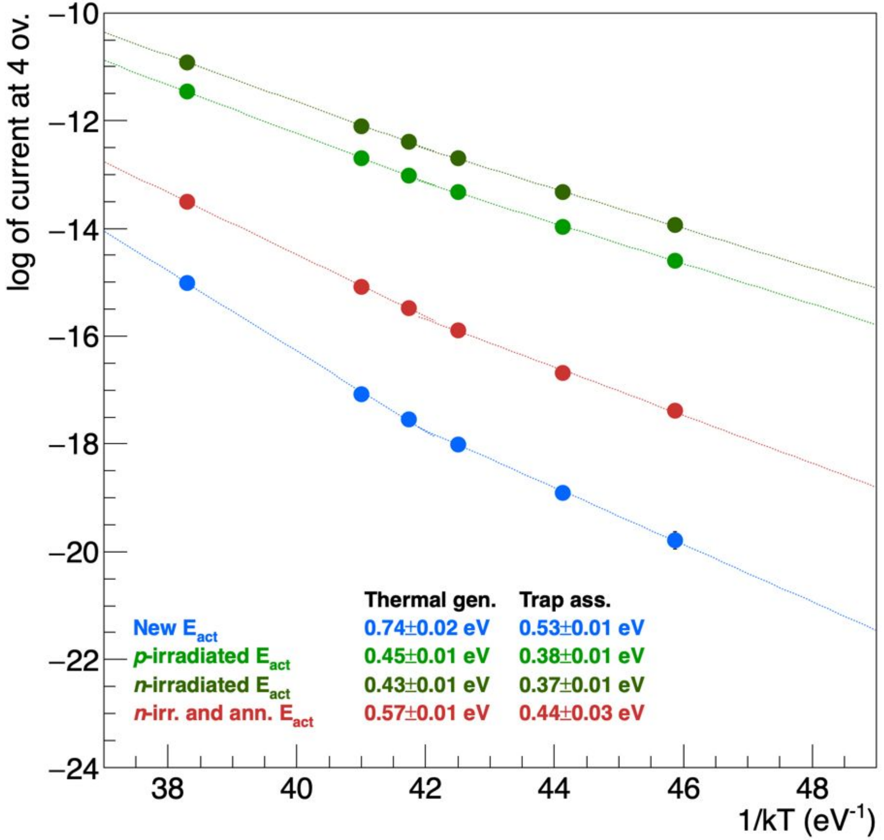
https://iopscience.iop.org/article/10.1088/1742-6596/675/4/042049/pdf

Activation energy

We measured the activation energy with the overvoltage method.



Results follow the expectations of a decrease of the act. en. in irr. sensors and an increase with annealing



Conclusions

- Preemptive ann. do not show beneficial effects
- Confirmed the ‘22 online annealing effectiveness
    - good recovery in a small time frame
    - rev seems to fall short both in time and recovery potential w.r.t. fwd
- Energy scan show a nice agreement w/ theoretical expectations
- Puzzling factor 2 for *n*-irradiation w.r.t. to *p*-irradiation
- *p*- and *n*-irr. sensors show similar behaviours to annealing
- We reach the same cure level, but faster with higher temperatures. (*)
- Decrease of the act. en. in irr. sensors and an increase with annealing

(*) In the next update: higher temperatures show damages to sensor window

 nicola.rubini@bo.infn.it

Thank you!
Any questions?

nicola.rubini@bo.infn.it

Back-up