

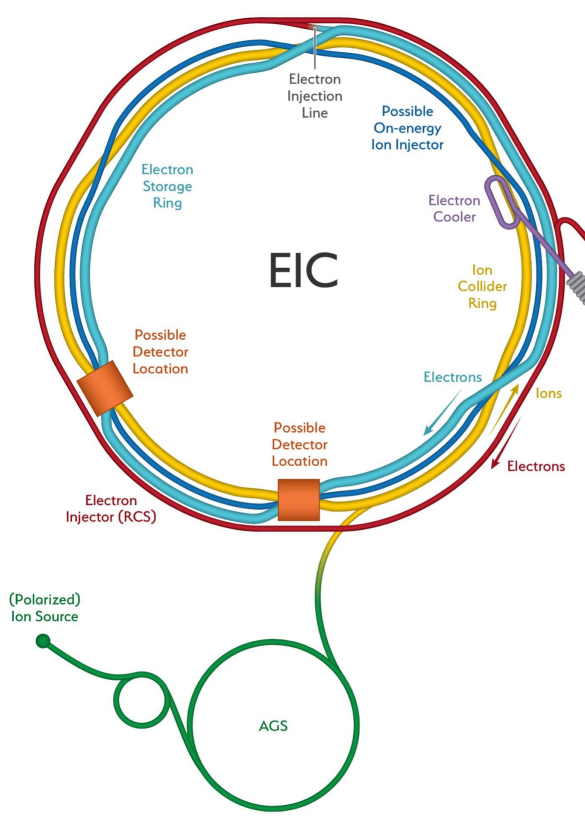
# SiPM response to radiation damage and annealing treatment for the EIC dual-radiator RICH



Nicola Rubini on behalf of the INFN EIC\_Net initiative - nicola.rubini@cern.ch



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA



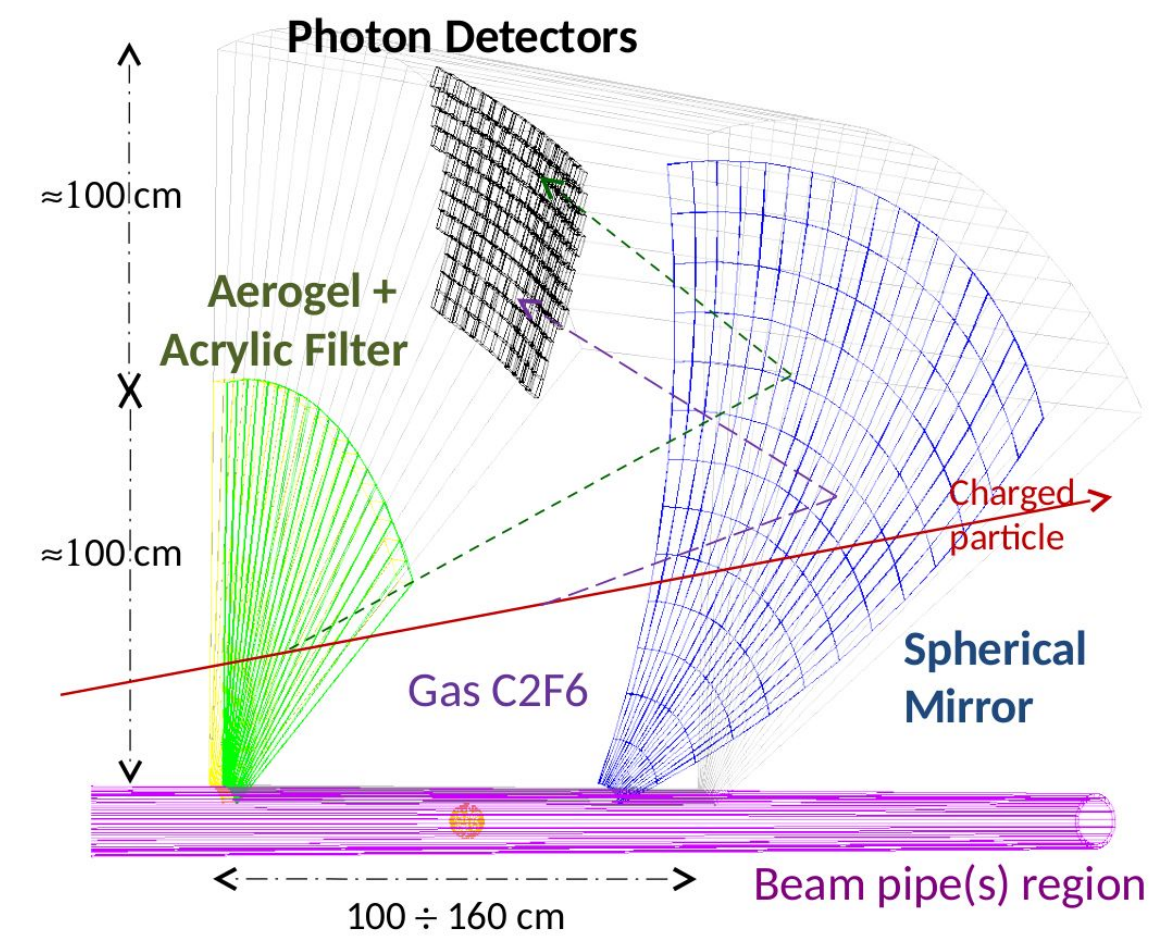
## The EIC Collider

The electron-ion collider (EIC) is a proposed large scale innovative particle accelerator that is planned to be built at Brookhaven National Laboratories at Long Island, New York (U.S.A.). The collider will circulate highly polarised beams of electrons and ions, from light ions such as deuterium to heavy ions such as lead. The center of mass energy will range from 20 to 100 GeV, with a possible upgrade to reach up to 140 GeV. The first beam operations are expected to start in the early 2030s.

<https://arxiv.org/abs/2103.05419>

## Ring Imaging Cherenkov detectors

One of the main detector technologies proposed for Particle Identification (PID) at the future experiment hosted by EIC (Detector 1) is the Ring Imaging Cherenkov. These detectors use the Cherenkov light emission angle to measure the particle velocity, which can be combined with previous detectors measurement of momentum for an efficient PID. This effect needs to be tuned based on the target momentum range and in the hadron endcap the choice was made to use a dual RICH (dRICH) which uses two radiators, one gas and one aerogel in the EIC proposal. This detector is expected to withstand about  $10^{11}$  1-MeV  $n_{eq}/cm^2$  of radiation in the experiment lifetime. This poses a serious threat to the sustainability of the use of Silicon Photomultipliers (SiPM), which are radiation sensitive. We will present preliminary studies in the radiation effects on SiPMs and possible techniques to recover partial functionality after irradiation.

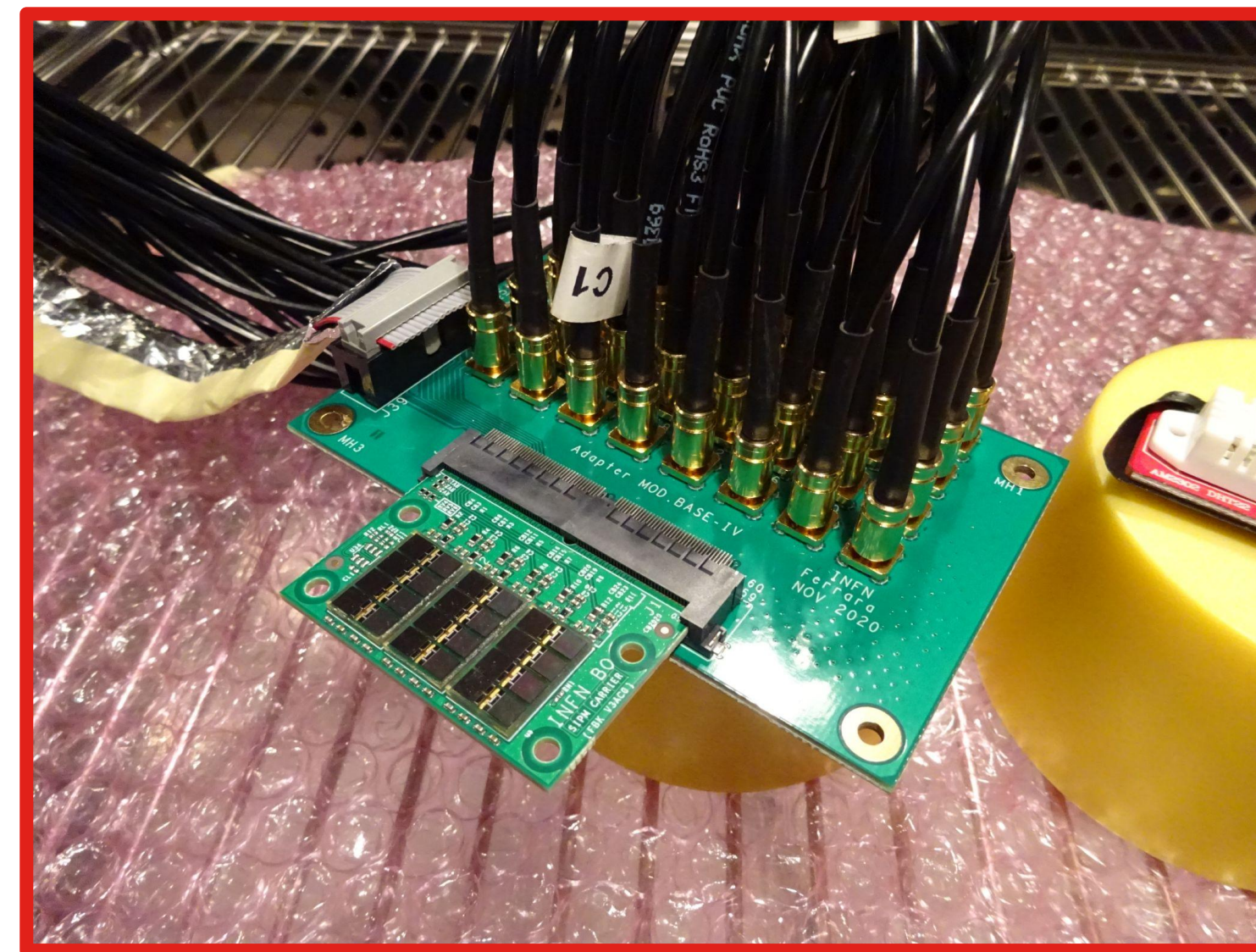


## The set-up

The sensors were placed in a climatic chamber that controlled both temperature and humidity. That is to test them in sub-zero temperatures and to avoid going above the dew point and exposing them to humidity damage, compromising them. Then all cabling was made to go through a cap that sealed the chamber to operate the machinery remotely. There were two modes of operation:

1. IV measurement
2. DCR measurement

The first one was operated with a sourcemeter and the second was



operated with an oscilloscope. After a characterisation campaign at different temperatures, a working temperature of -30°C was chosen. The sensors under test were the prototypes FBK NUV-HD-RH/CHK.

## Silicon Photomultipliers and DCR

### Pros

1. Detection down to single photon
2. Good timing performance
3. Insensitive to magnetic fields

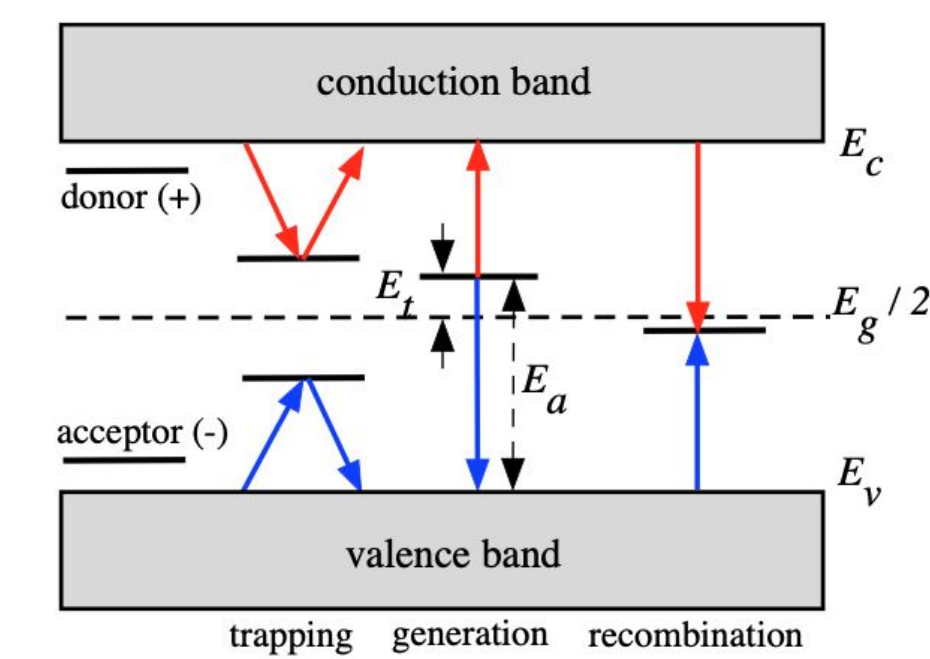
### Cons

1. High radiation sensitivity
2. High background at room temperature
3. High voltage of operation

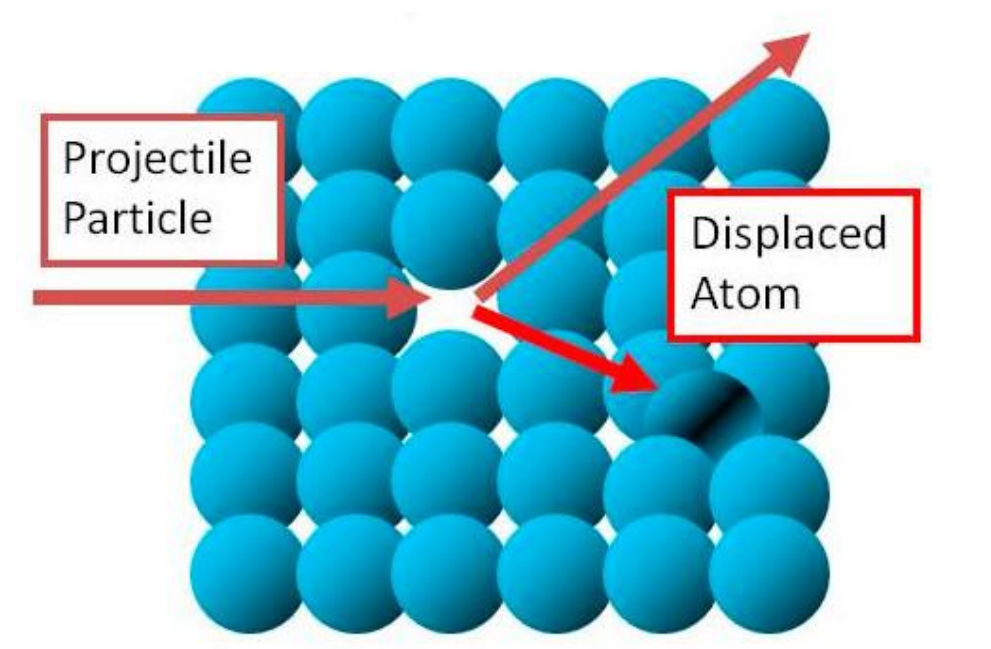
## The radiation damage and annealing procedure

### Defects:

1. Close the band gap: favours DCR
2. Long capture traps: smaller signal amplitude
3. Doping: change in  $V_{BD}$

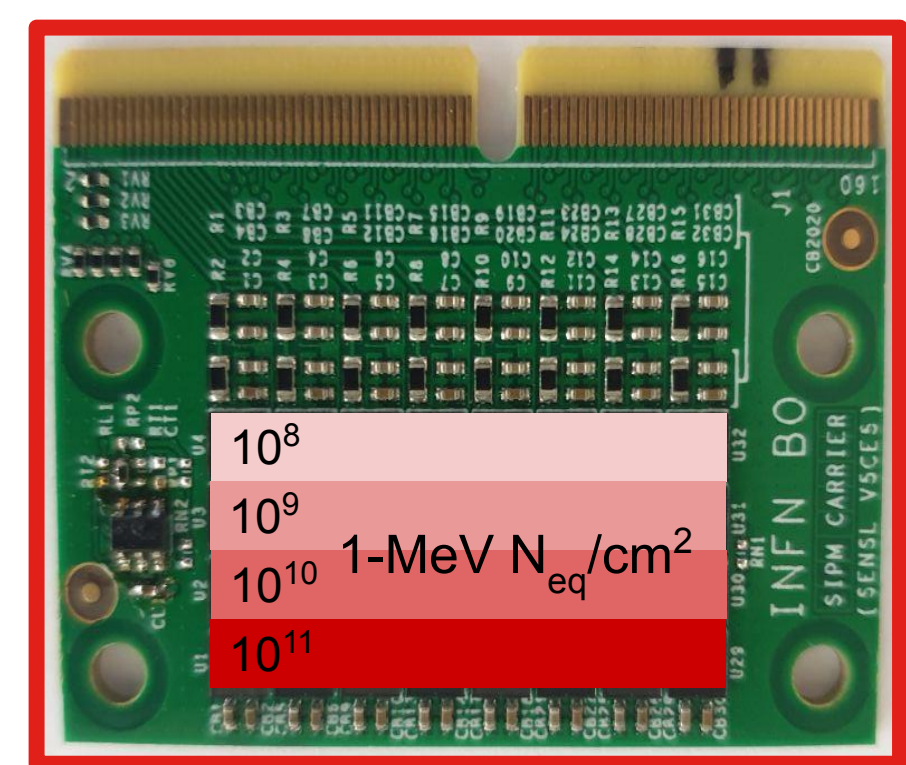


Annealing uses thermal excitation at high temperature to re-order out-of-lattice atoms to their former positions, recovering performance



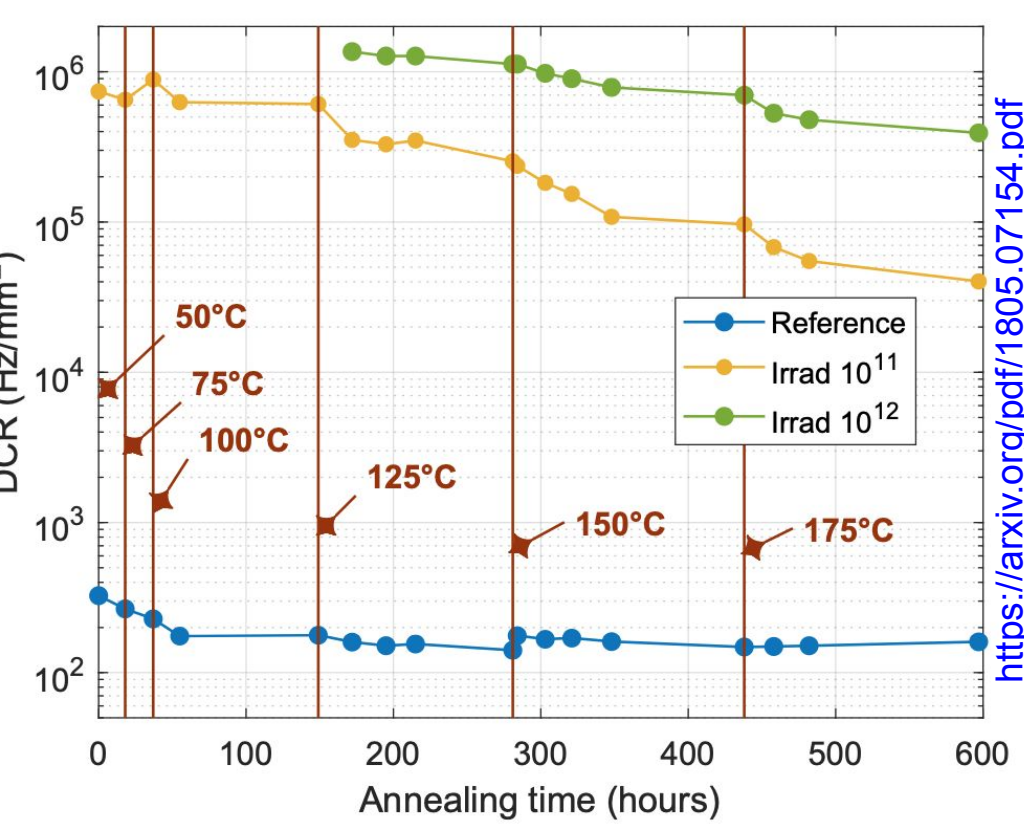
## Irradiation campaign

Irradiation at INFN TIFPA facility in Trento. Differential approach to test different levels of damage



## Annealing

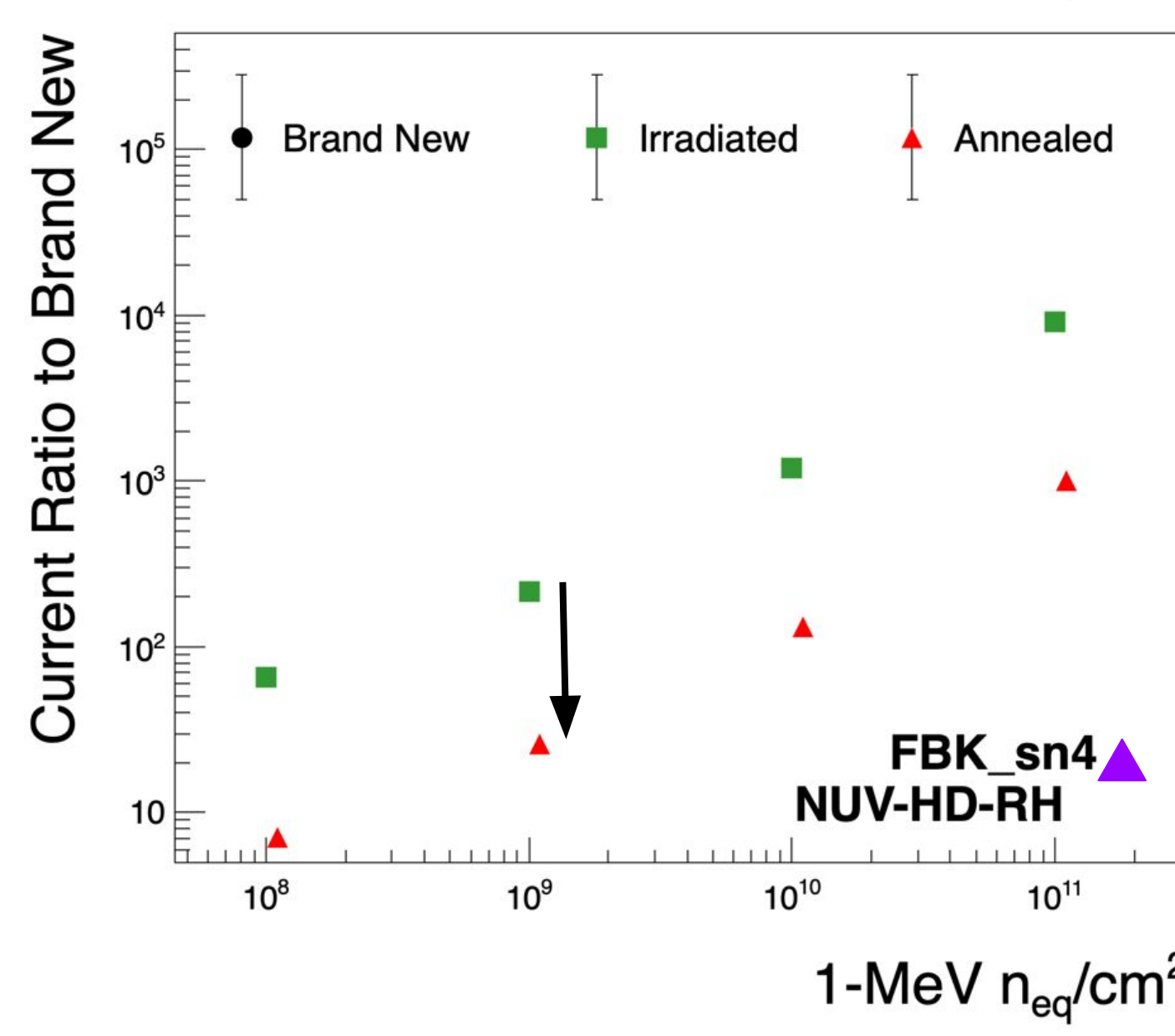
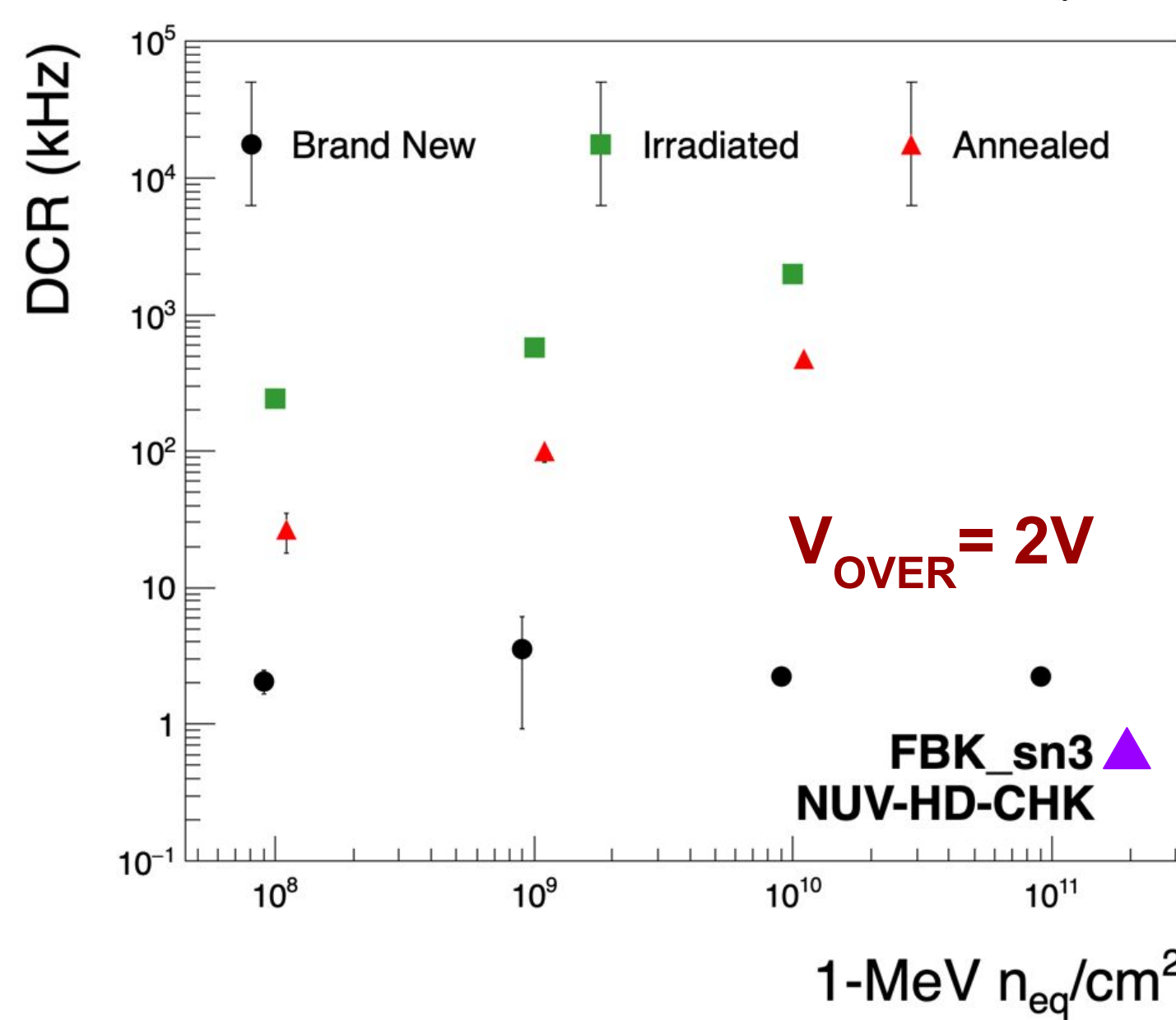
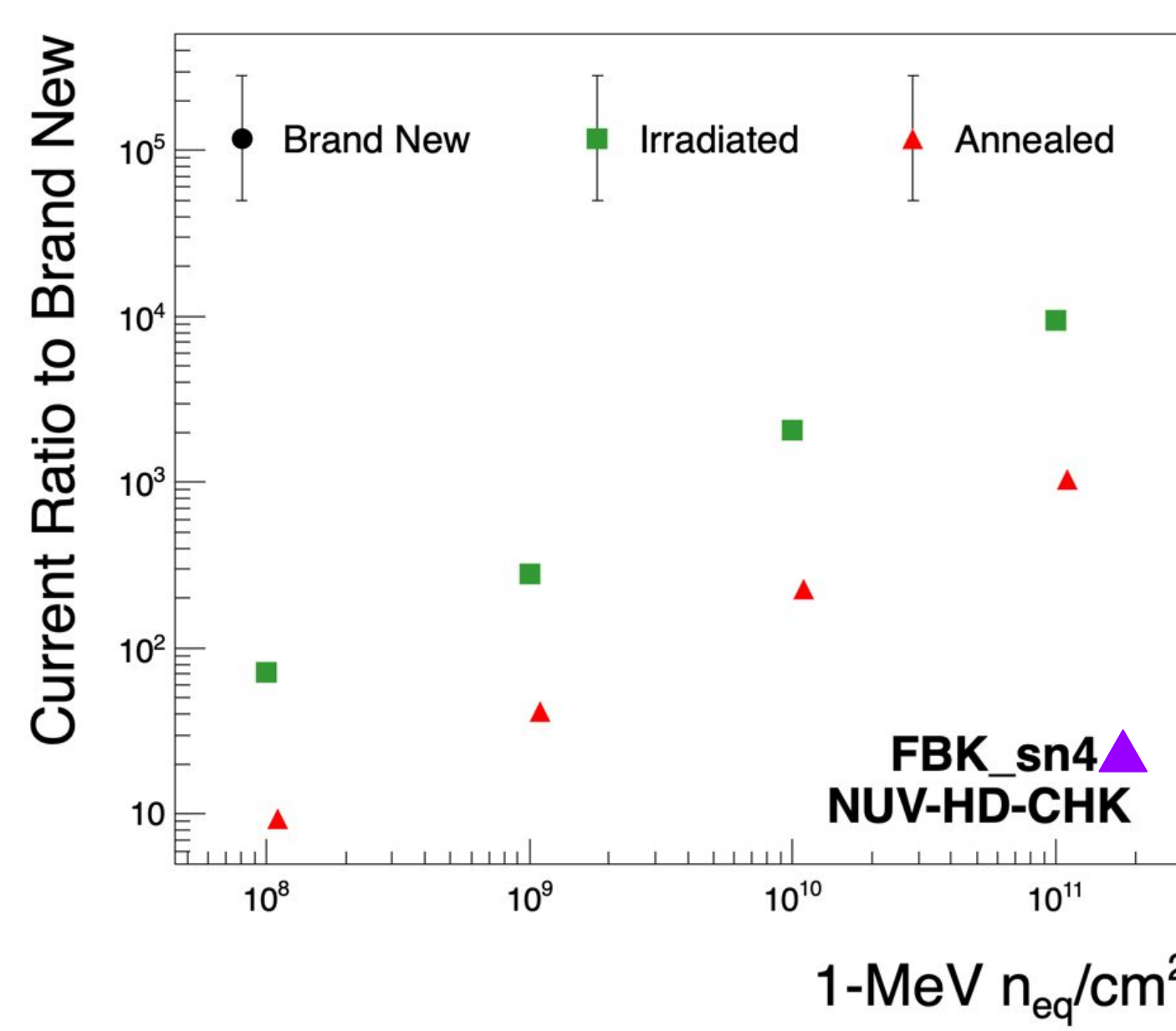
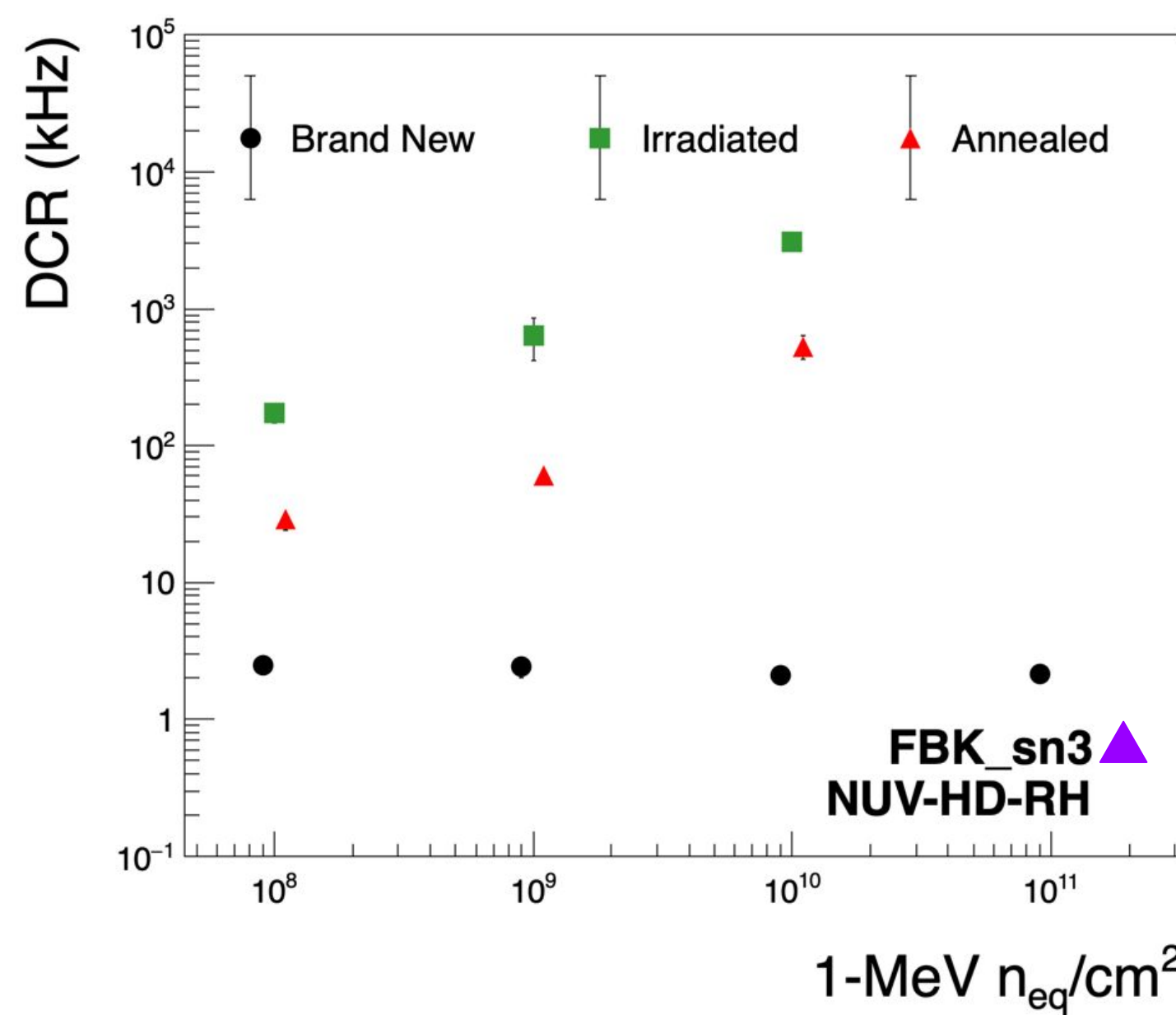
Work of Calvi et al. demonstrate the potential recovery of heating sensors up to 175°C for a few hundreds of hours. We started with 24h at 100°C and for 168h at 125°C. The limiting factor has been the soldering paste, which had the melting point at 150°C



$T = -30^\circ C$

DCR

$V_{OVER} = 3V$



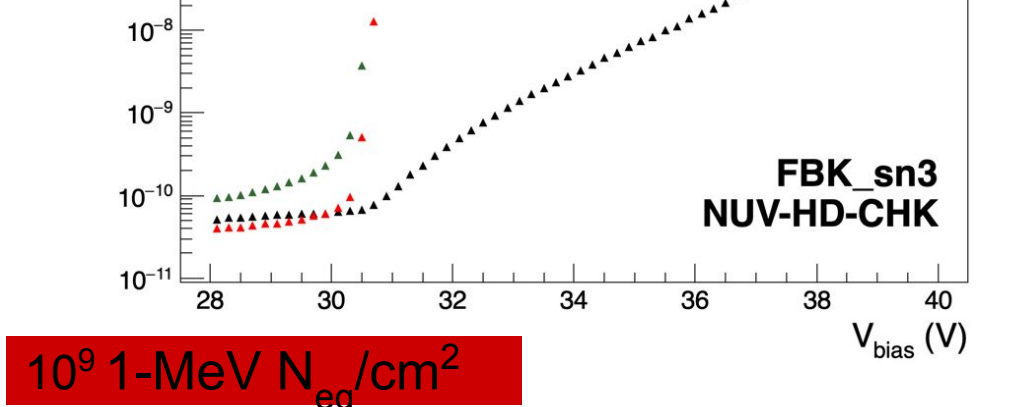
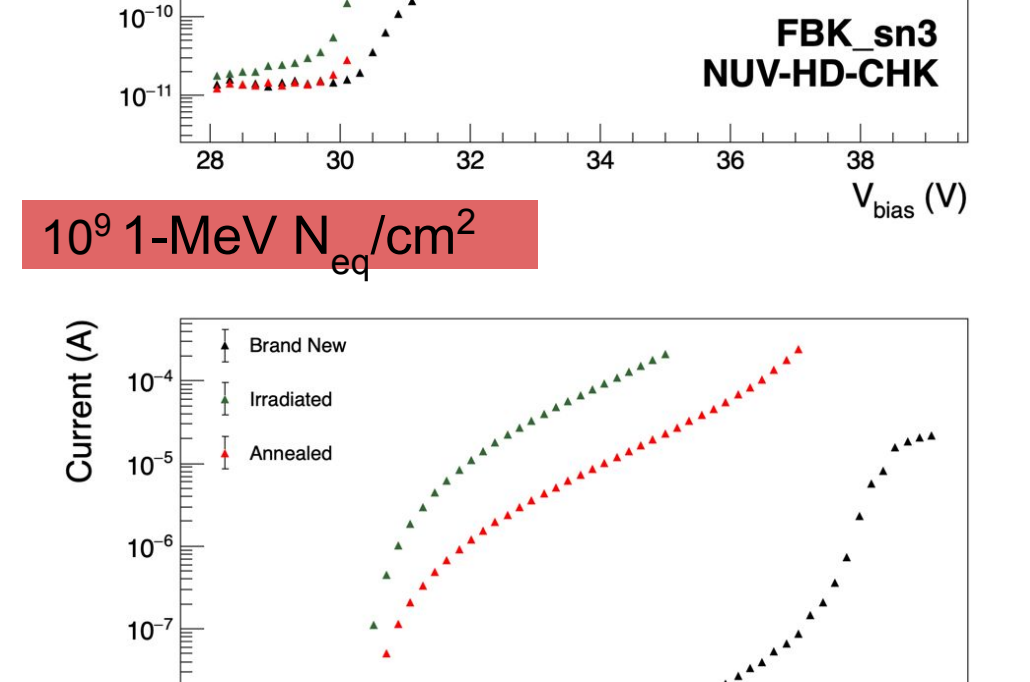
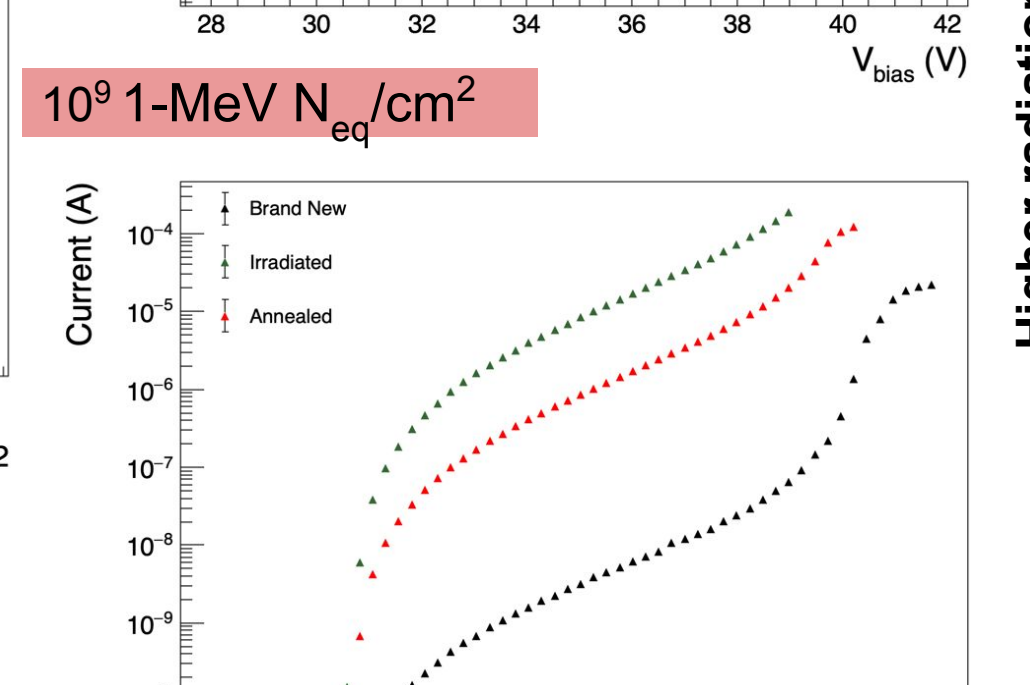
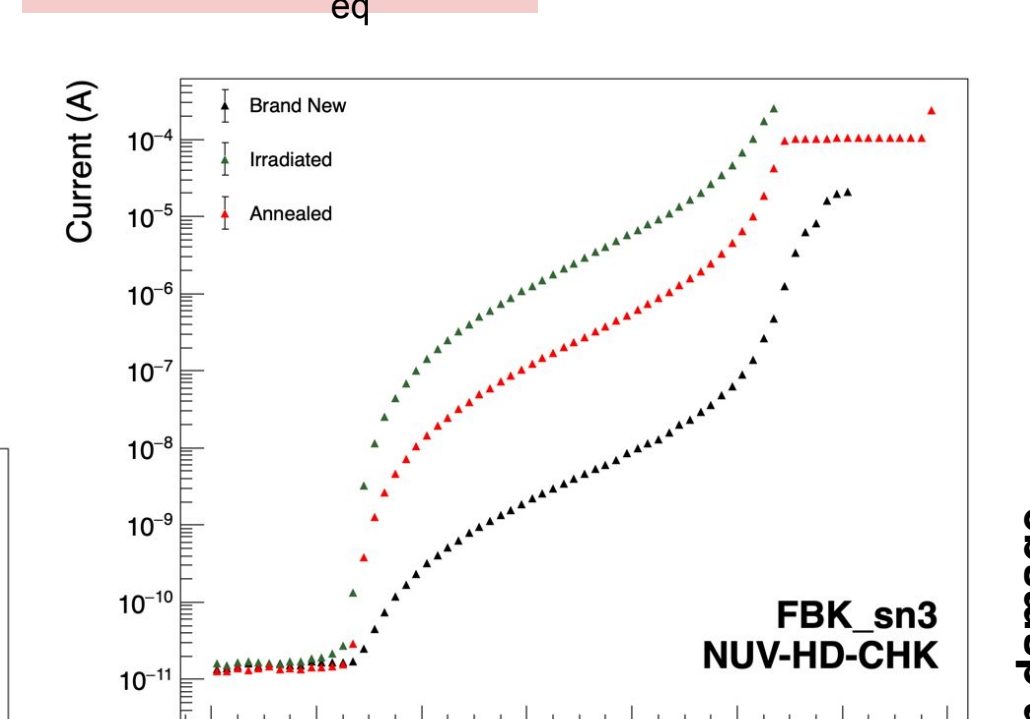
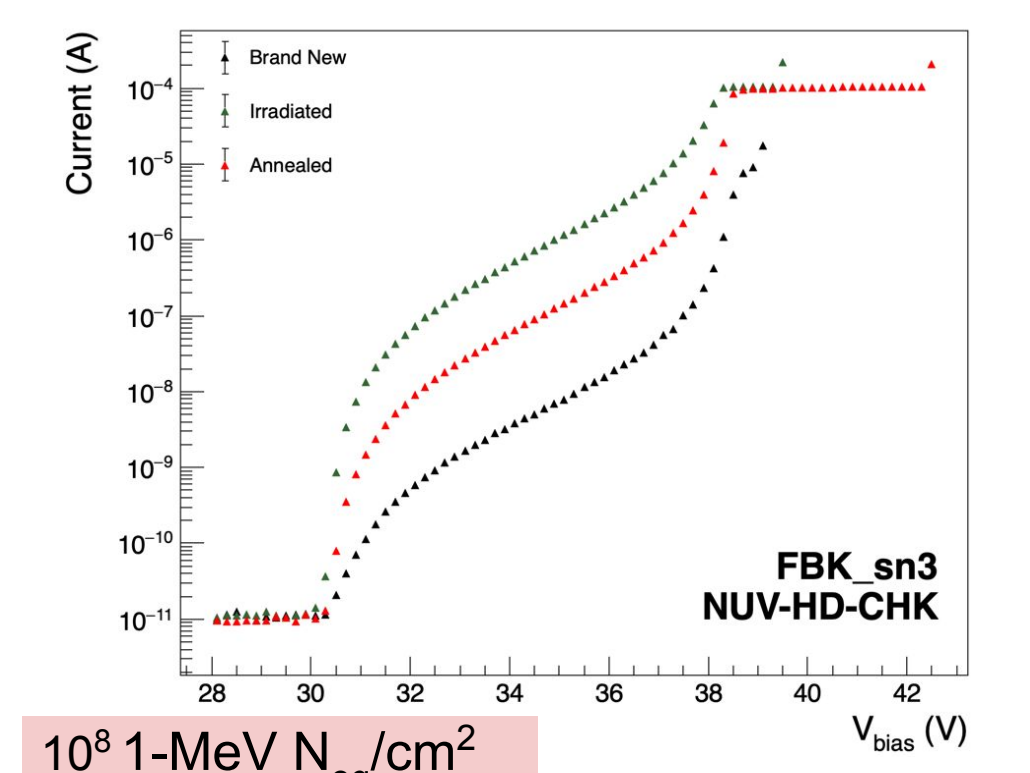
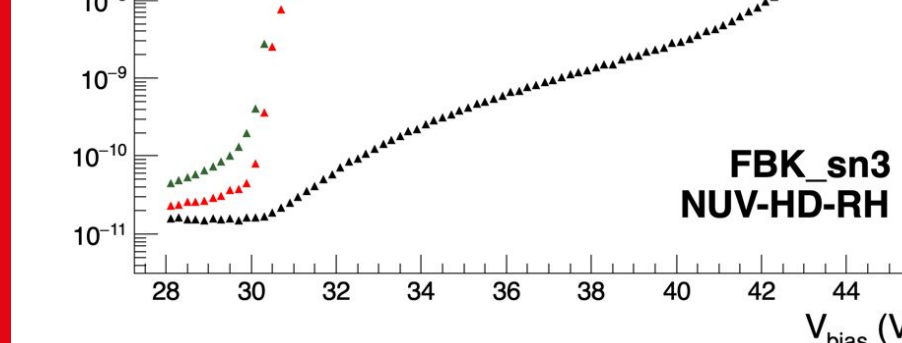
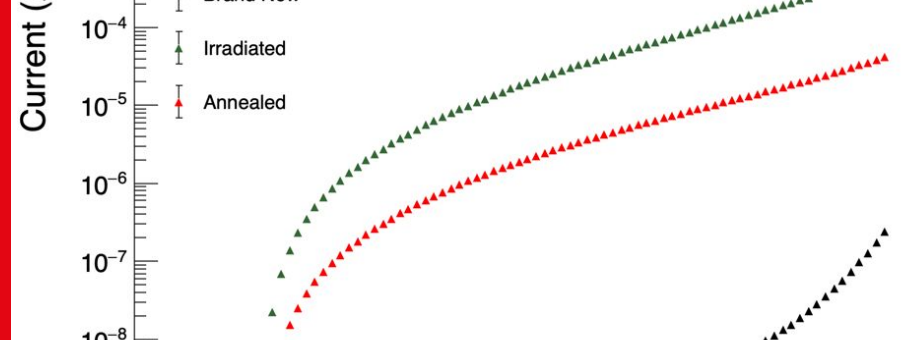
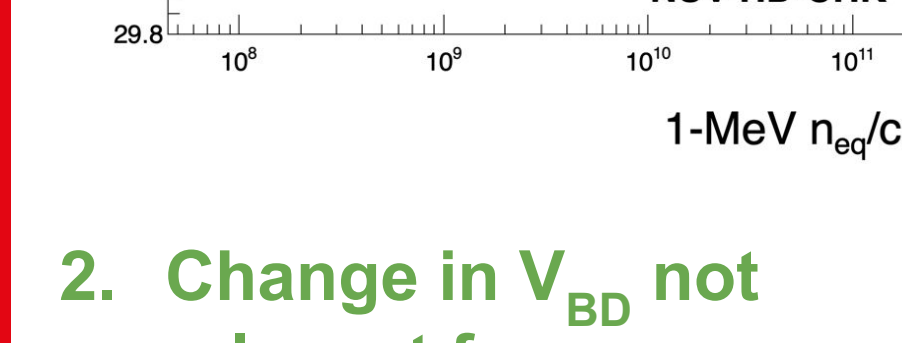
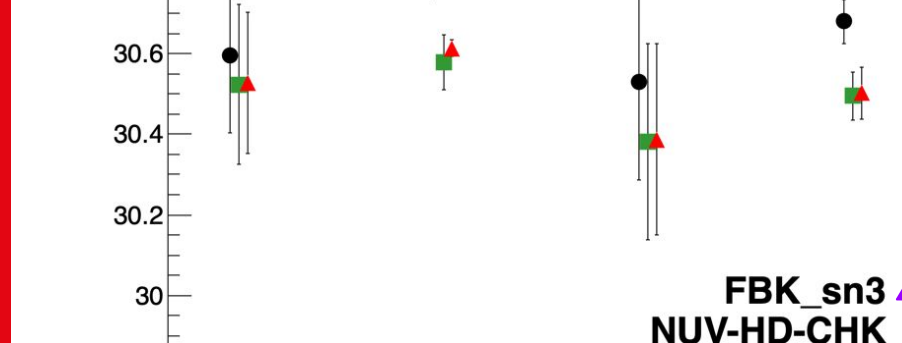
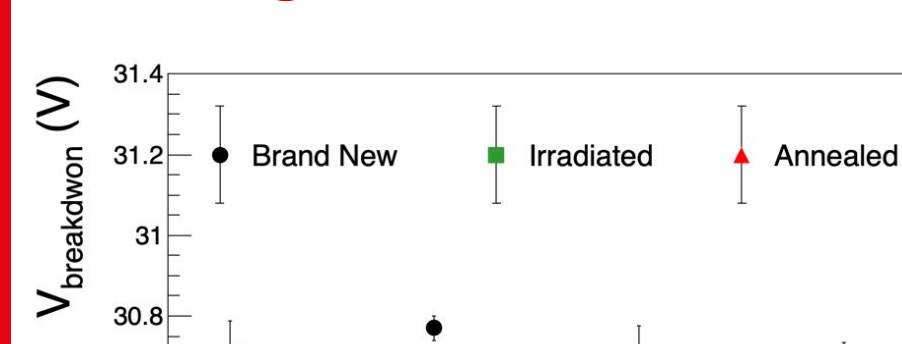
Sensors have a high background at subzero temperatures after suffering radiation damage, DCR is higher from  $\sim 10^2$  to  $\sim 10^3$

We measure a reduction of a factor 10 in DCR rates and Dark currents

The error bar represents the dispersion of the distribution

## IV curves

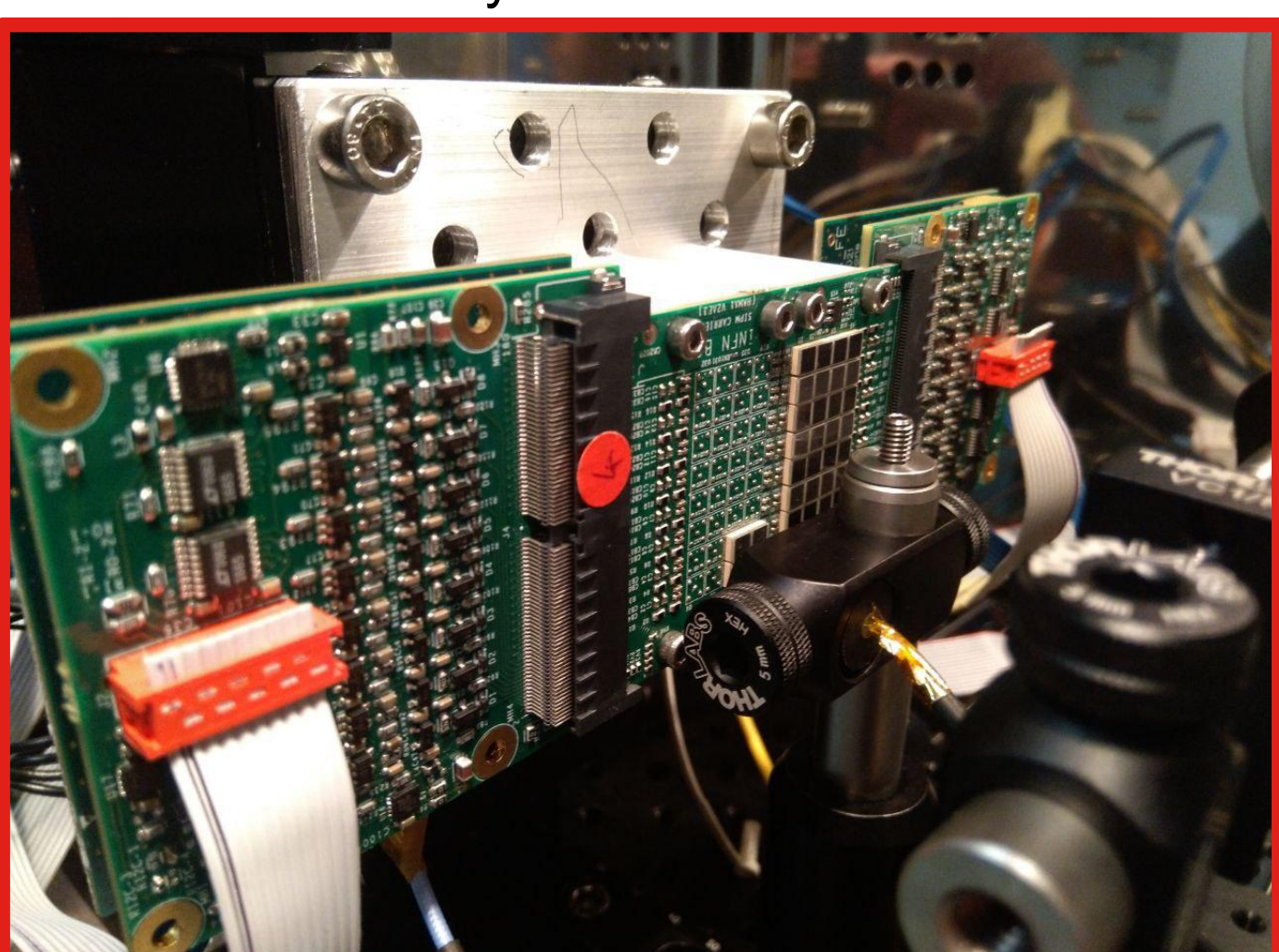
1. Higher currents (DCR) of a few orders of magnitude



Higher radiation damage

## The set-up for a full readout chain with ALCOR ASIC Chip

The Set-up discussed above provides a direct measurement of current and signal. In an experiment set-up a threshold is set and any voltage variation above it is considered signal. To achieve this a full read-out chain has been set up inside the climatic chamber by the mean of the ALCOR ASIC chip and masterlogic boards for remote HV delivery. A linear moving stage provides pointing capabilities on a single sensor for a LED to test the light response. Two sensor matrices have been mounted in the system, a reference and a target. The sensor acts as a check to periodically measure the light source stability, the target board is the device under test. Adding a light source provides a very useful tool to test the Photon Detection Efficiency (PDE) and timing capabilities after irradiation and annealing



## Photon detection efficiency

To measure the photon detection efficiency the LED light source have been powered with a pulser with a 100 kHz frequency, for 50ns providing the possibility to make a first test on the goodness of the sensor timing. The first sensors tested are the Hamamatsu S13360-3050VS series with a 50  $\mu m$  SPAD. The procedure requires a first measurement in dark conditions to determine the DCR baseline. Then, the LED source is switched on and the Light rate is measured. The plots below show the rate of DCR subtracted light rates normalised to the pulser frequency, effectively measuring the probability of photodetection.

[https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc\\_array/S13360-3050CS.html](https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_array/S13360-3050CS.html)

