Irradiation and annealing studies on SiPM sensors for the ePIC-dRICH detector

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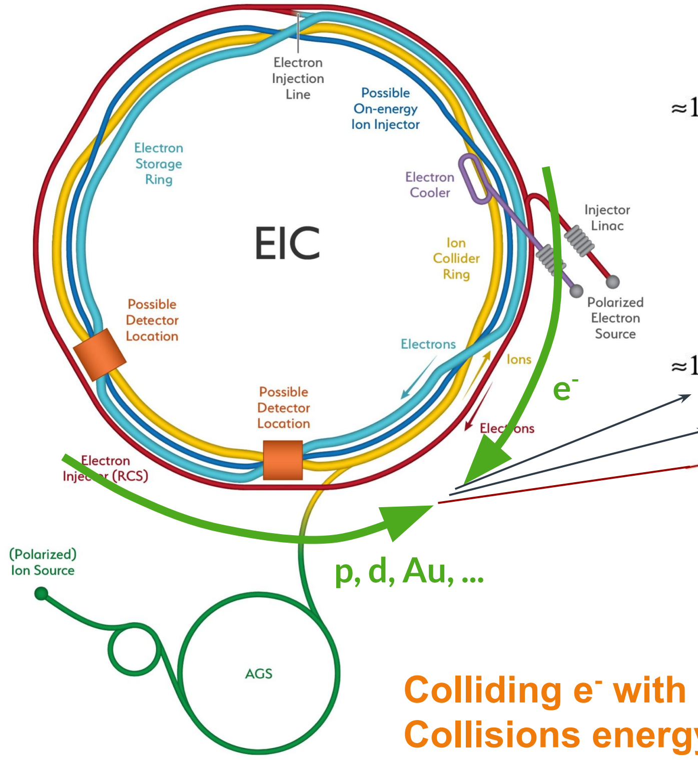
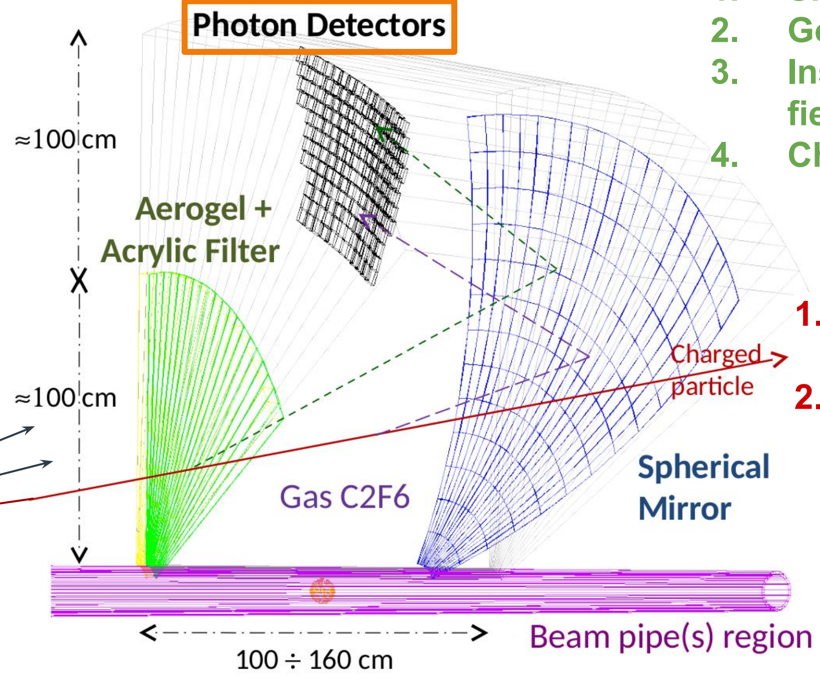
Introduction



SiPMs are investigated



Colliding e$^-$ with ions: p to Pb
Collisions energy 20-140 GeV

Pros

1. Single photon sensitivity
2. Good timing performance
3. Insensitive to magnetic fields
4. Cheap

Cons

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

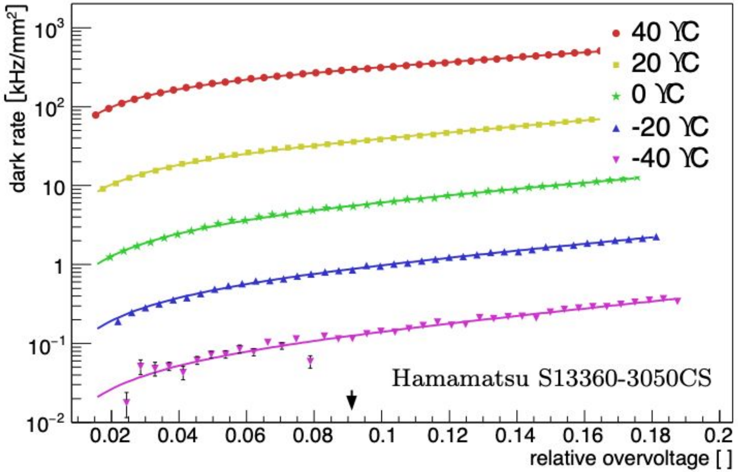
We need to find a solution

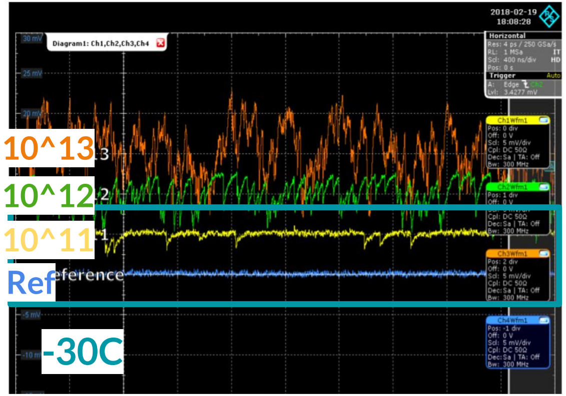
Radiation damage of SiPM - Temp

Cons

1. High dark count rate at room temperature
2. High radiation sensitivity

Acting on the operational temperature one can lower DCR up to 3-4 orders of magnitude from room temperature to -30C





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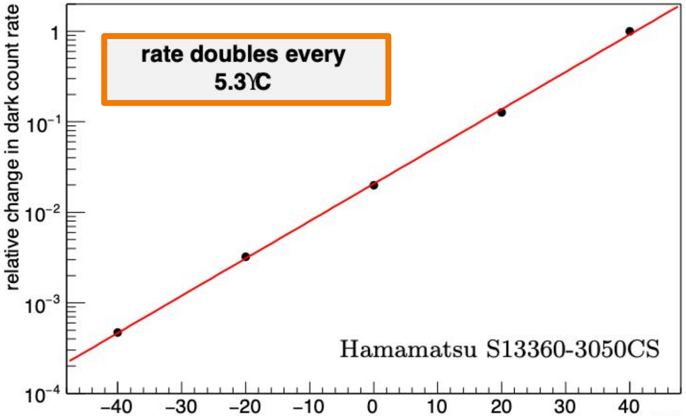
Radiation damage produces an increase in DCR up to a disruption of the baseline (no single photon detection possible).
Low temperature mitigates this effect



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Radiation damage of SiPM - Annealing

Cons

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

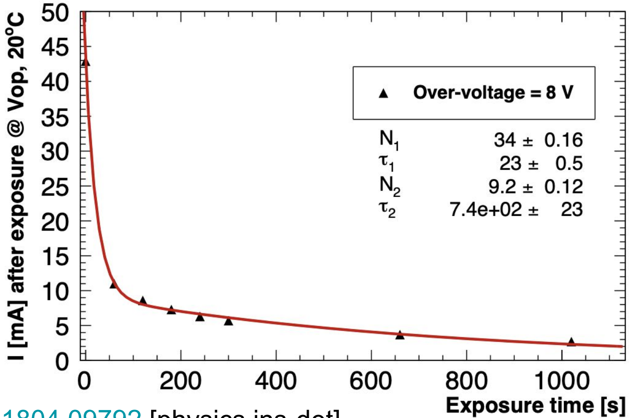
Annealing (heating to high T for a period of time) is proven to recover partially the SiPM performance

There are currently three ways that are under investigation

reverse polarised

directly polarised

oven



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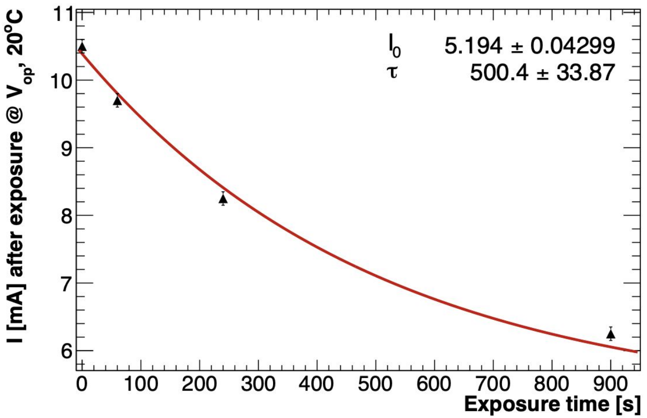

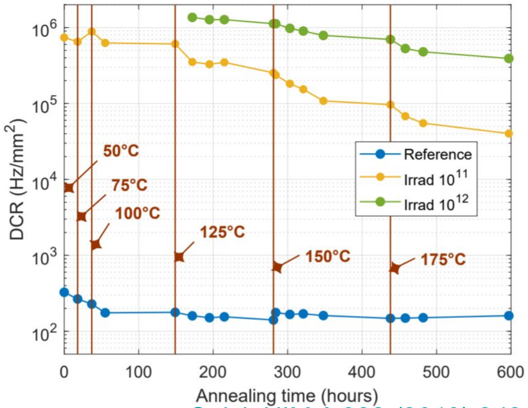

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Radiation damage of SiPM - Timing

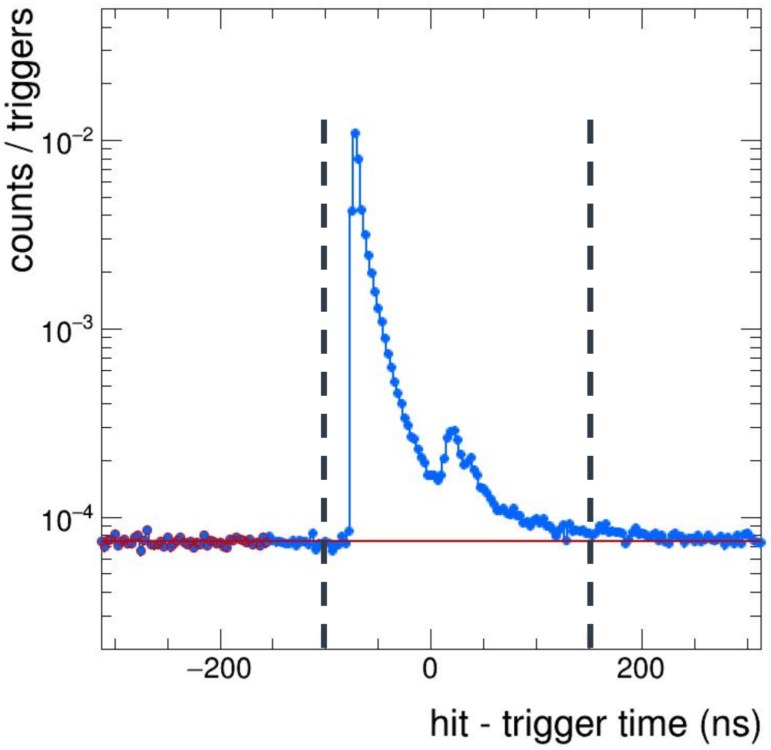
LED Setup

Cons

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

Timing cuts manage to reduce the window where we look for the signal

This allows the background reduction, i.e. mitigates the effects of irradiation damage degradation



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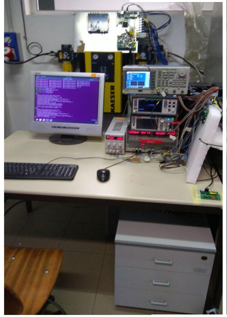
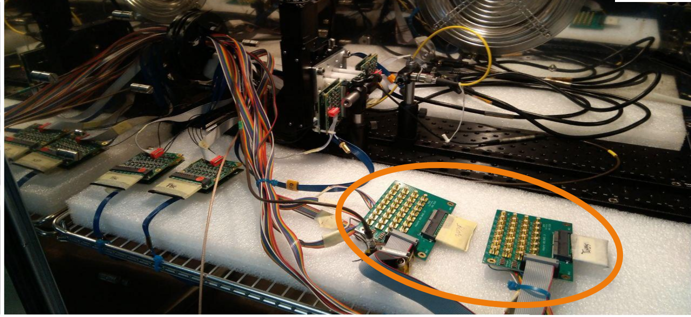
Sensors characterisation 2021

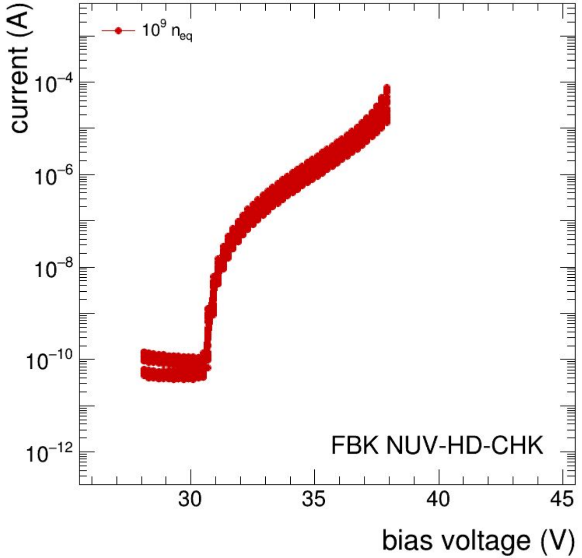
Climatic chamber low temperature of operations (-30C)
2x 40-channel multiplexers fully automated board measurement
Source meter for measurements

outside



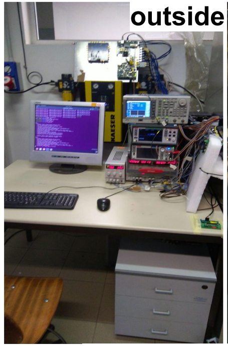
inside

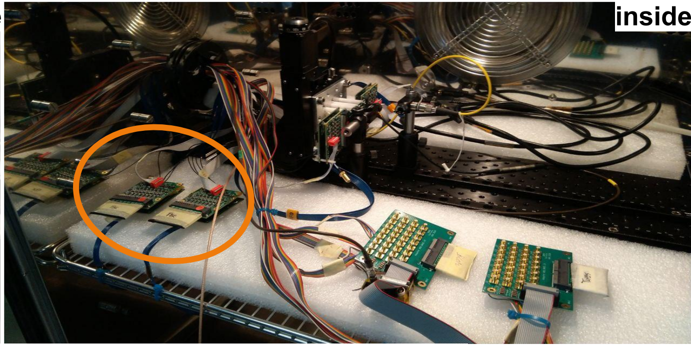


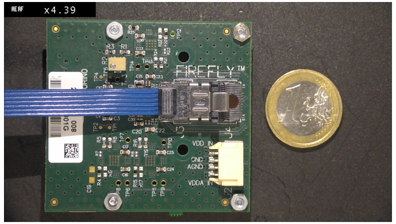


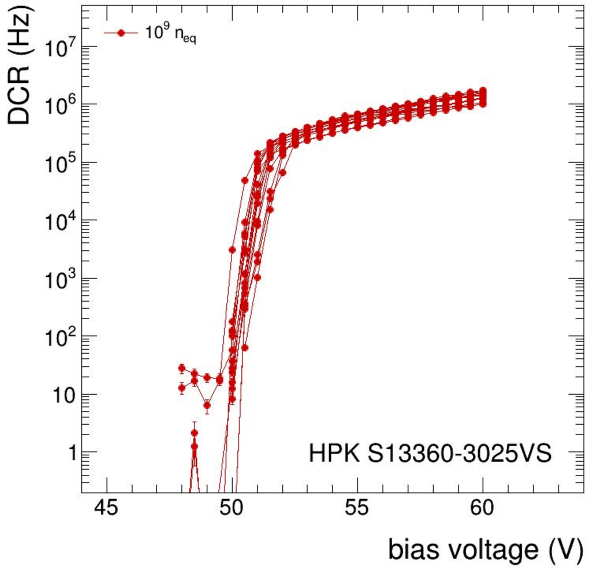
Sensors characterisation 2022

Climatic chamber low temperature of operations (-30C)
2x ALCOR-based front-end chain fully automated measurement
FPGA (Xilinx) for readout



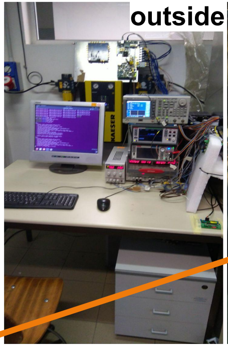


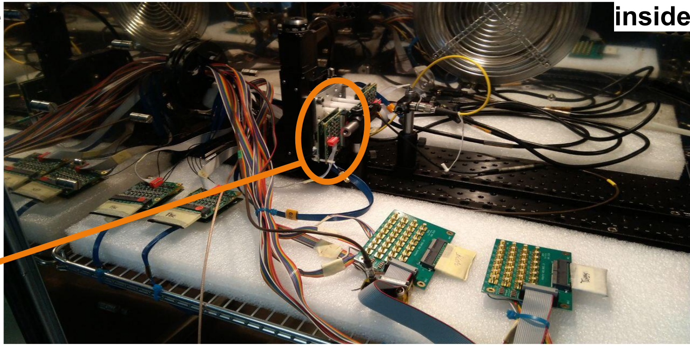


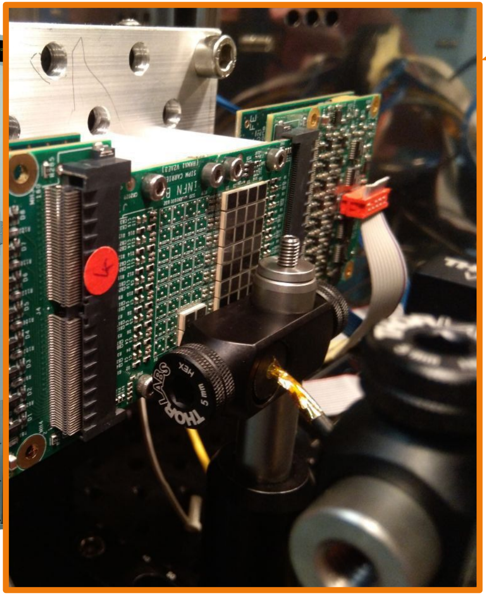


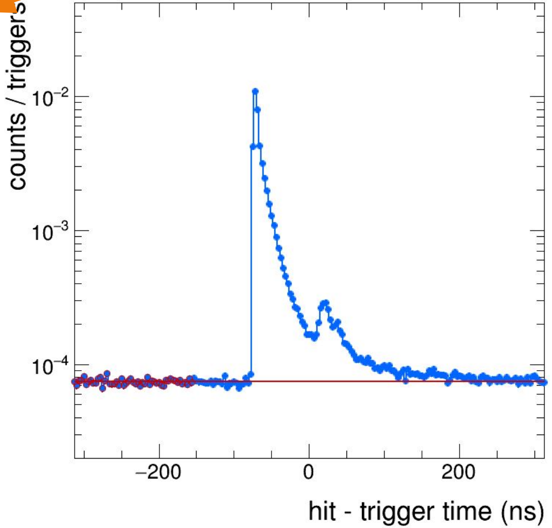
Sensors characterisation 2022

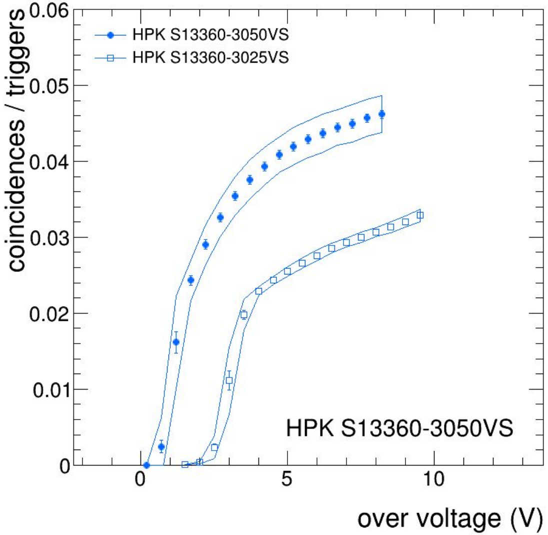
Climatic chamber low temperature of operations (-30C)
Arbitrary function generator LED impulse for light response test
Arbitrary function generator LASER impulse for light response test
2x ALCOR-based front-end chain fully automated measurement
FPGA (Xilinx) for readout



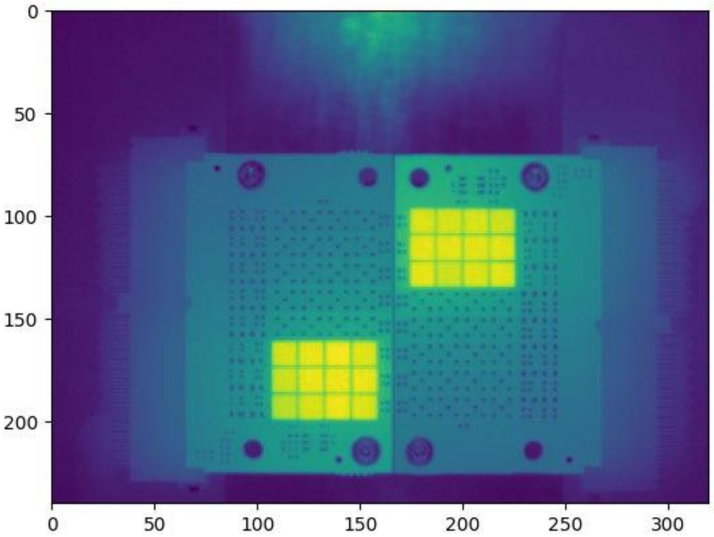


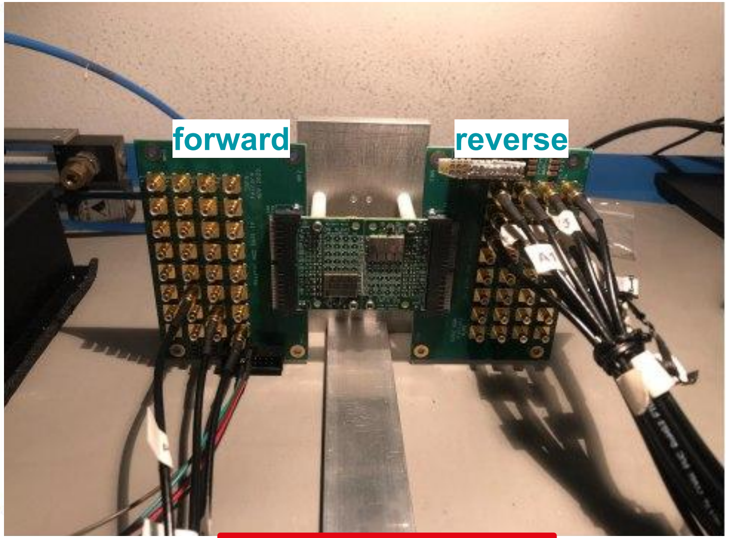






Annealing of sensors (2023 Camp.)





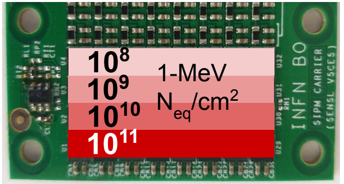
Fully automated system w/ PID feedback for long unsupervised annealing, with both reverse and forward in parallel

Thermal camera

Irradiation campaigns at TIFPA

2021 Campaign

Different radiation levels to evaluate recover potential

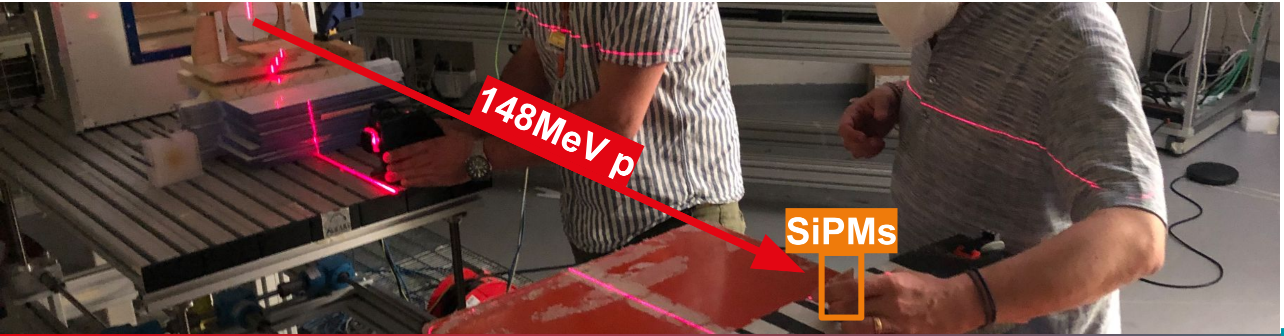


2022 Campaign

Few full boards irradiated with 10^9 1-MeV N_{eq}/cm^2 and multiple times w/ test with online annealing

2023 Campaign

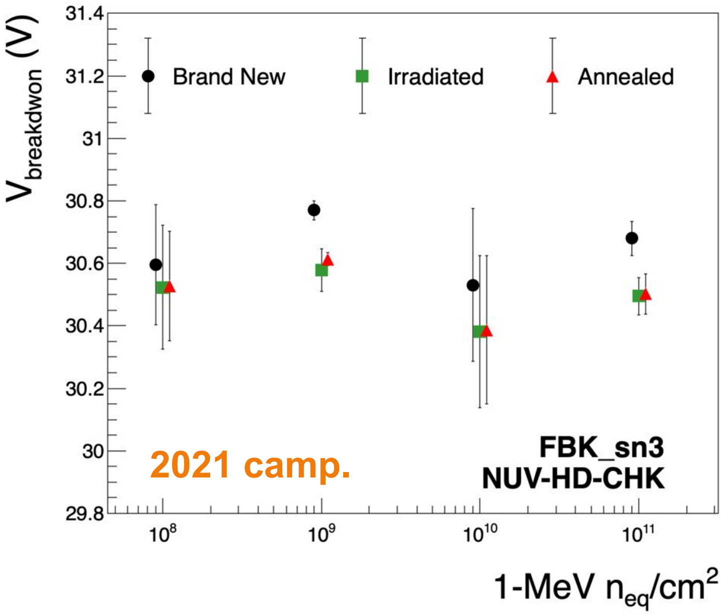
Many board irradiated with 10^9 1-MeV N_{eq}/cm^2 multiple times w/ test with multiple annealing procedures

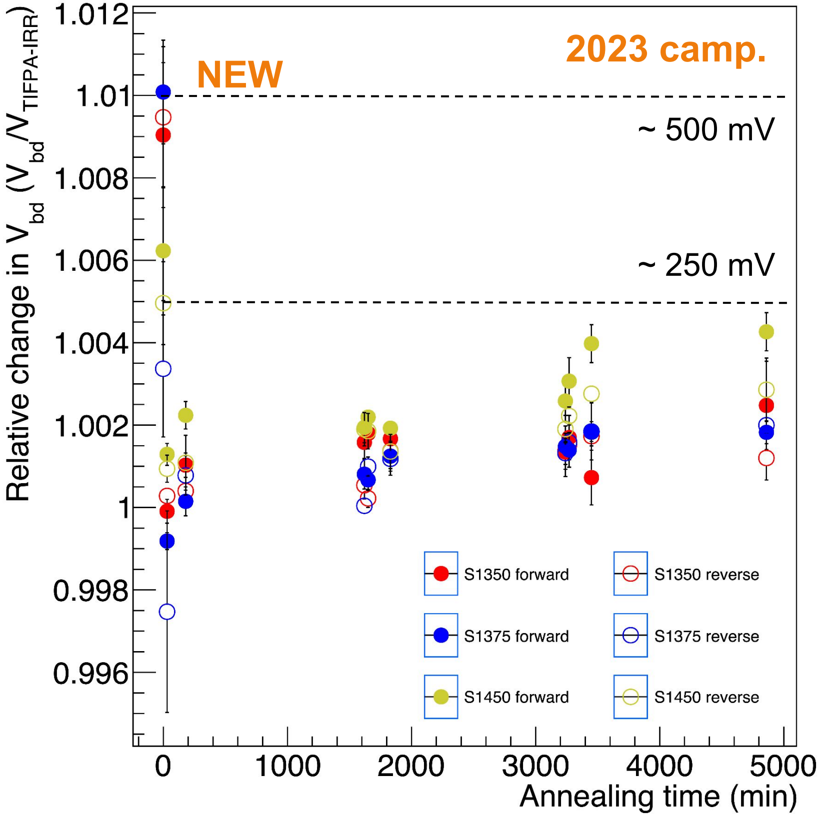


Thorough understanding of the effect of proton irradiation on many different sensors, selecting the best sensors in the process

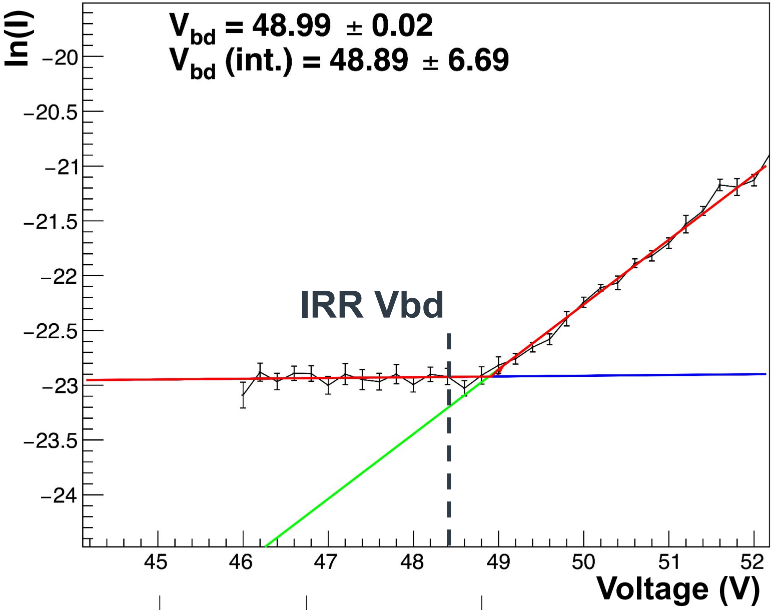
Breakdown voltage

NEW sensors have a shift of ~1% (500mV) on the breakdown voltage. This is not consistent with literature and results of 2021 campaign

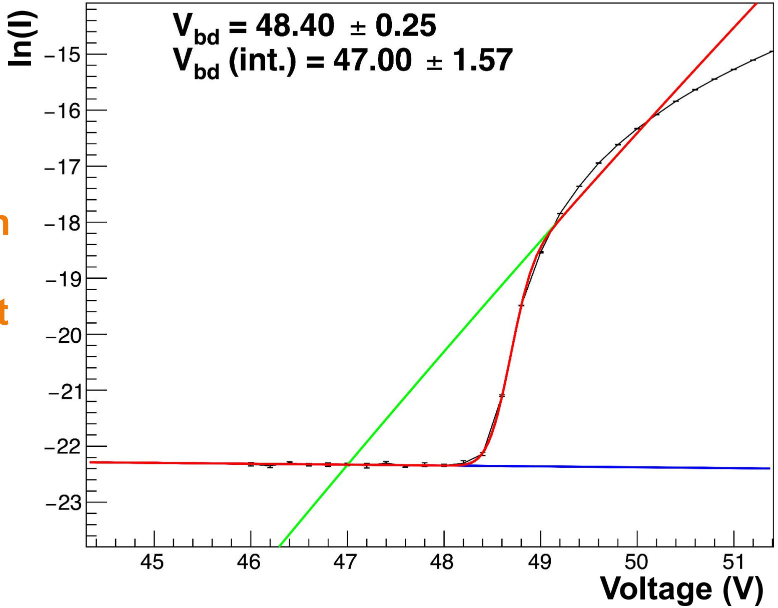


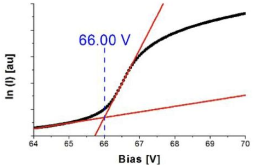


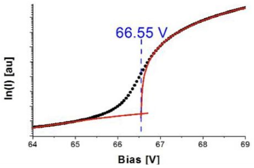
Breakdown voltage



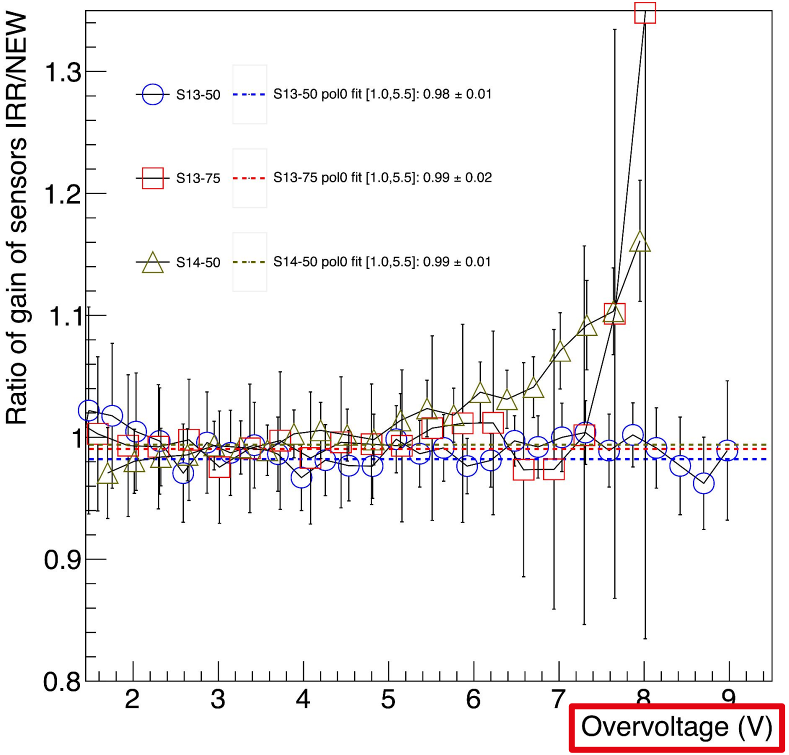
Very low currents on the new sensor are preventing an efficient Vbd measurement



Tangent	Linear fitted "baseline" and tangent drawn to $ln(I)$	Intercept of tangent and the "baseline"	

Parabolic fitting	Linear fitted "baseline" and parabola fitted to I	Intercept of the fitted parabola and the "baseline" on semi-log scale	

Breakdown voltage



Using the ratio of sensor gain before and after irradiation as a function of overvoltage measured on the irradiated IV, one can see this is the real Vbd

There is literature on the erroneous measurement of Vbd in NEW sensors without light (low current)

Nuclear Inst. and Methods in Physics Research, A 1040 (2022) 167284

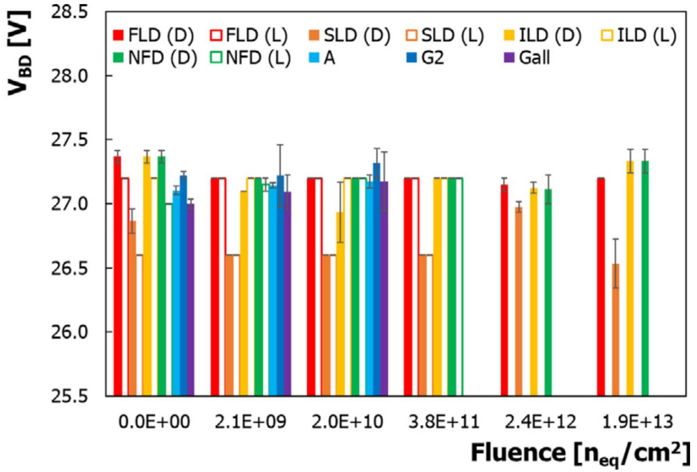
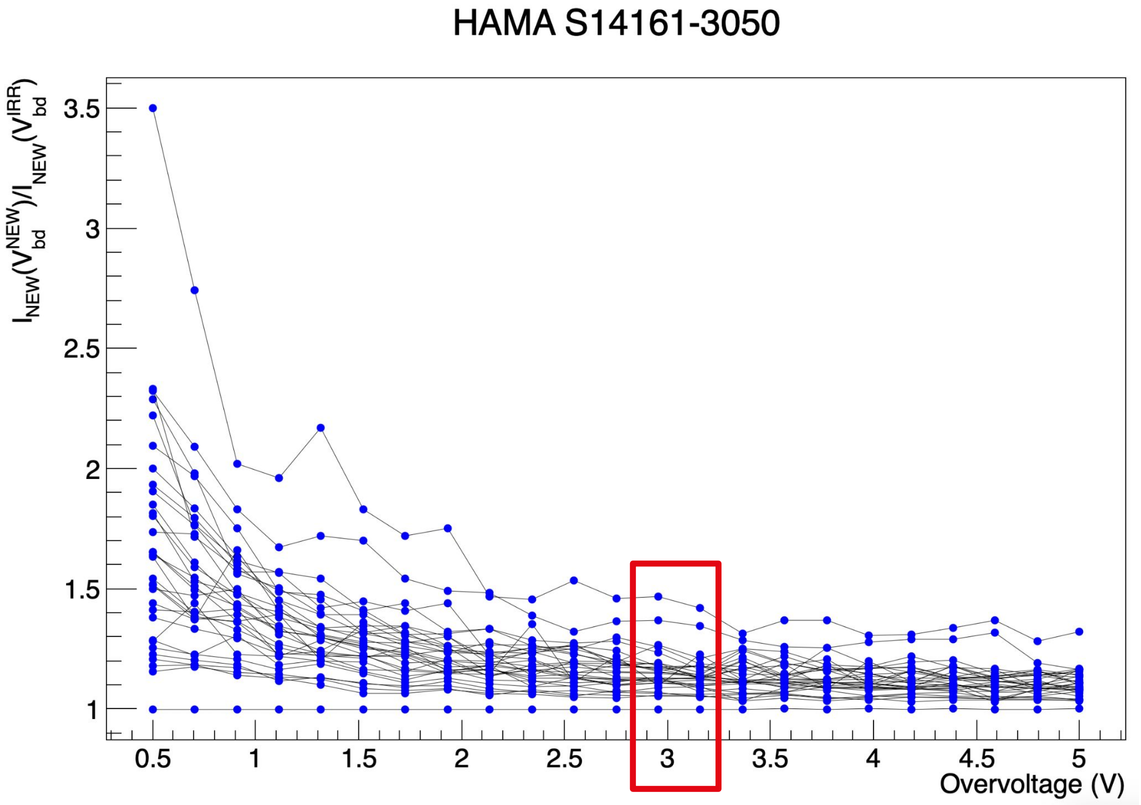


Fig. 7. Example of estimated breakdown voltage values for the NUV-HD SiPM with 35 μm cell pitch, obtained with the different estimation methods in dark (D) and light (L) conditions at −20 °C. Error bars identify the spread of values obtained among repeated measurements.

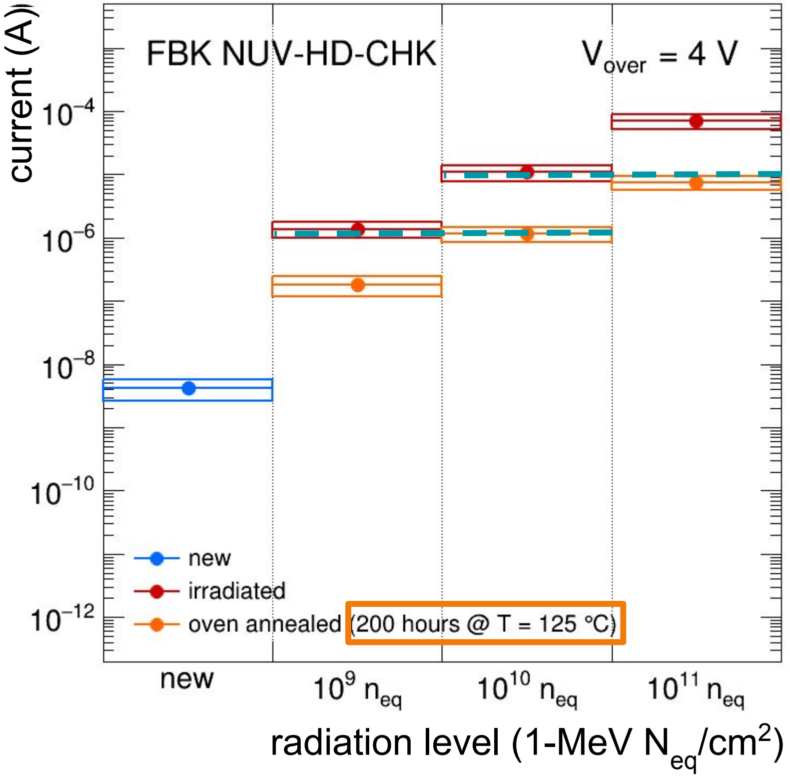
Breakdown voltage



A relatively small difference (~500mV) in the Vbd measurement can generate a significant effect in the current and in general in overvoltage quantities

The ratio for the Hamamatsu S14161-3050 of the current as a function of the overvoltage, when the Vbd is measured from the NEW IV w.r.t. when it is measured from the IRR IV generates fluctuations of up to 50%

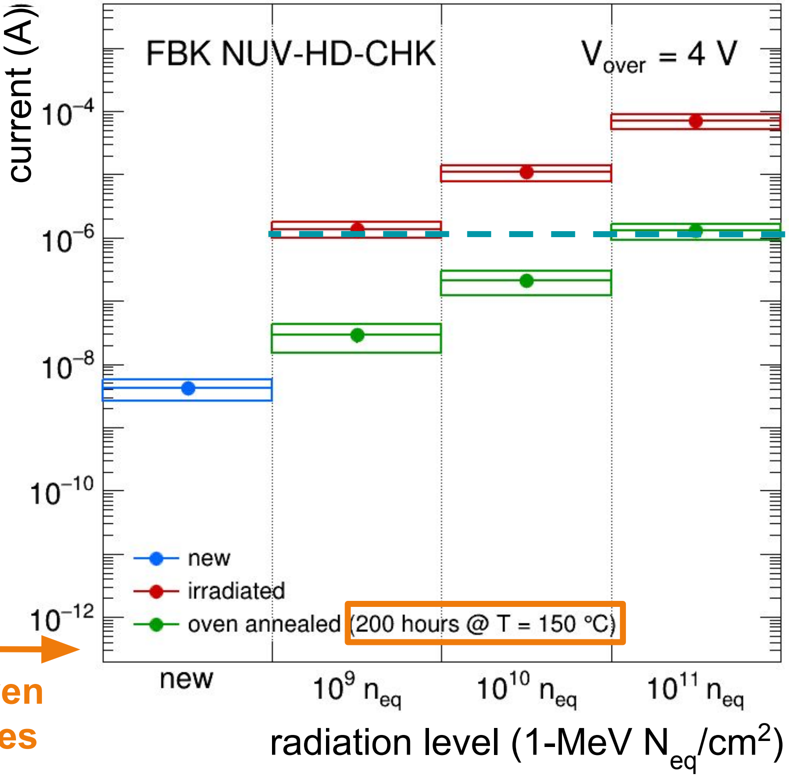
Current recovery after annealing cycles (2021 camp.)



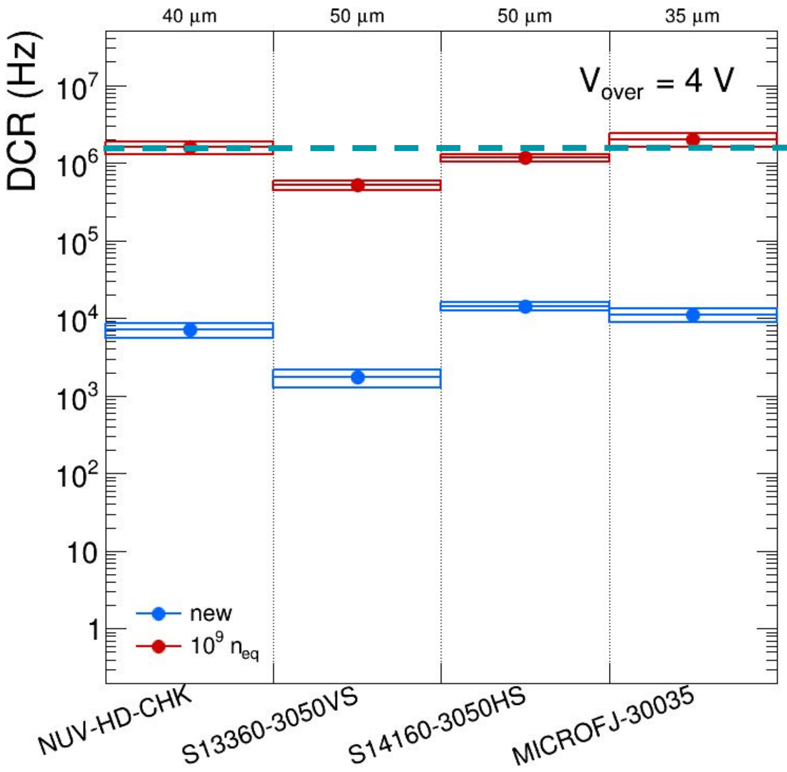
First cycle sensors recover roughly x10 in irradiation levels

Second cycle sensors recover roughly x100 in irradiation levels

Subsequent oven annealing cycles

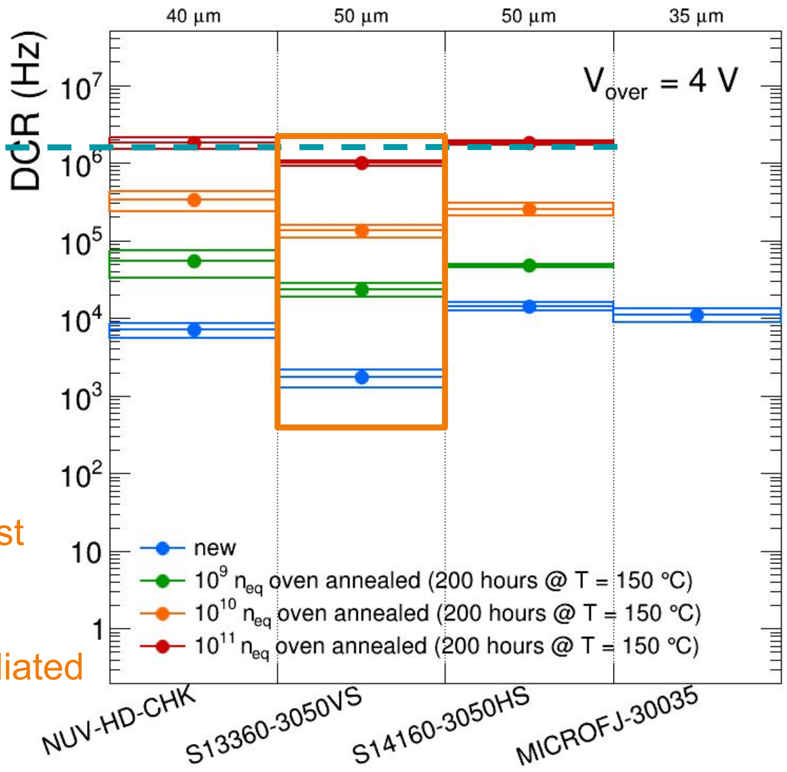


DCR recovery after annealing cycles (2021 camp.)

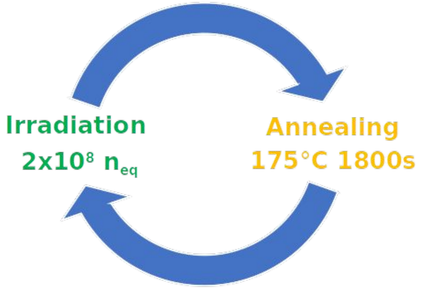


10^{11} after annealing cycles performs similarly to irradiated 10^9 untreated

HPK S13360 lowest DCR, in all circumstances annealed and irradiated



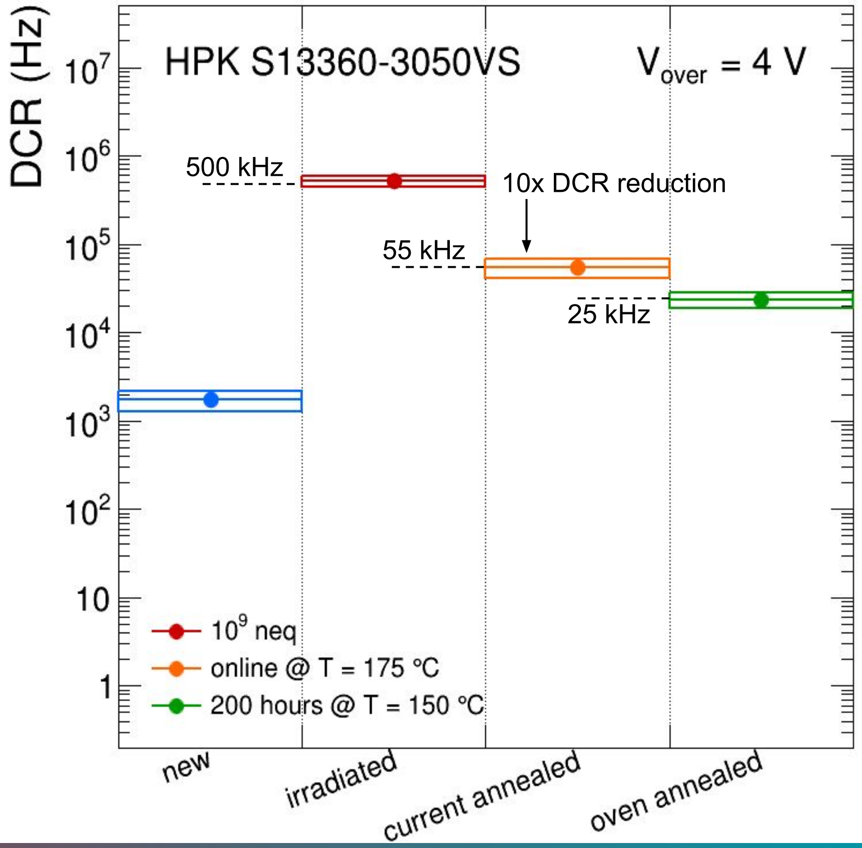
Direct current annealing (2022 camp.)



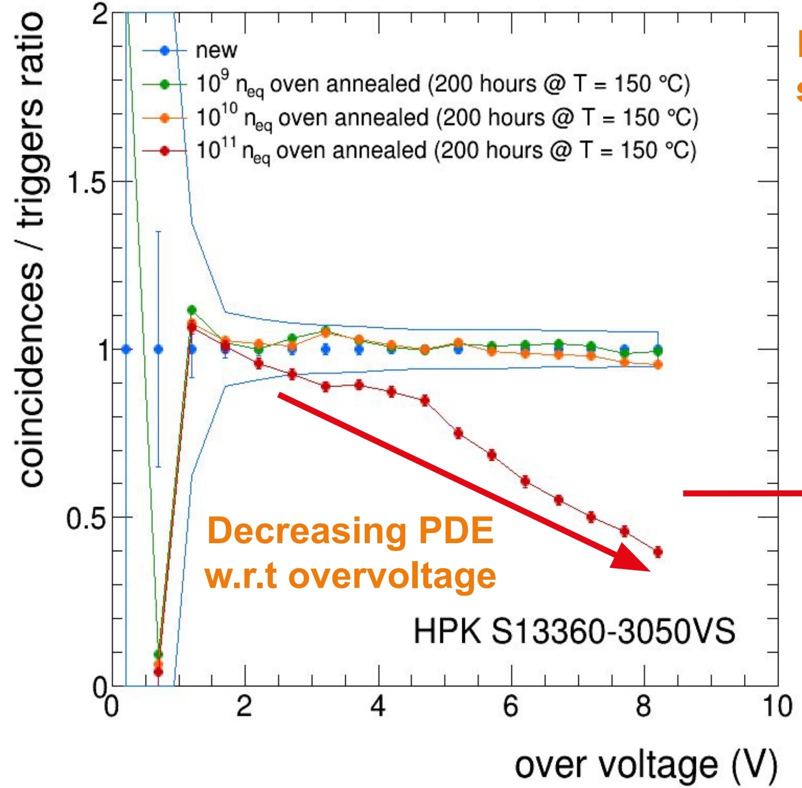
Total: 10^9
Time: 15min

Very promising technique!
Does not reach oven recovery, but:

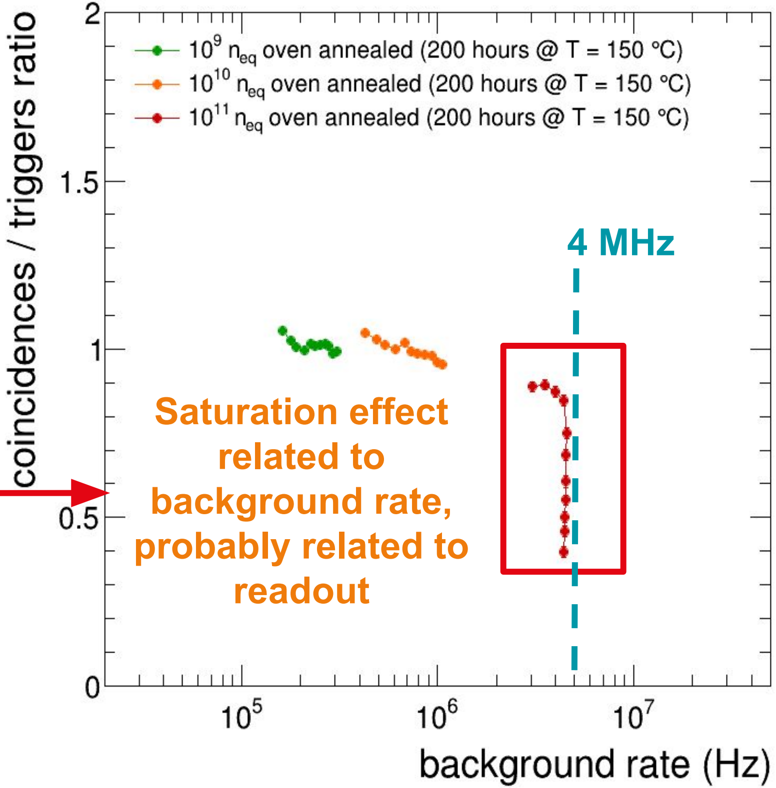
- 100 times faster
- Can be done in-situ
- Repeated many times



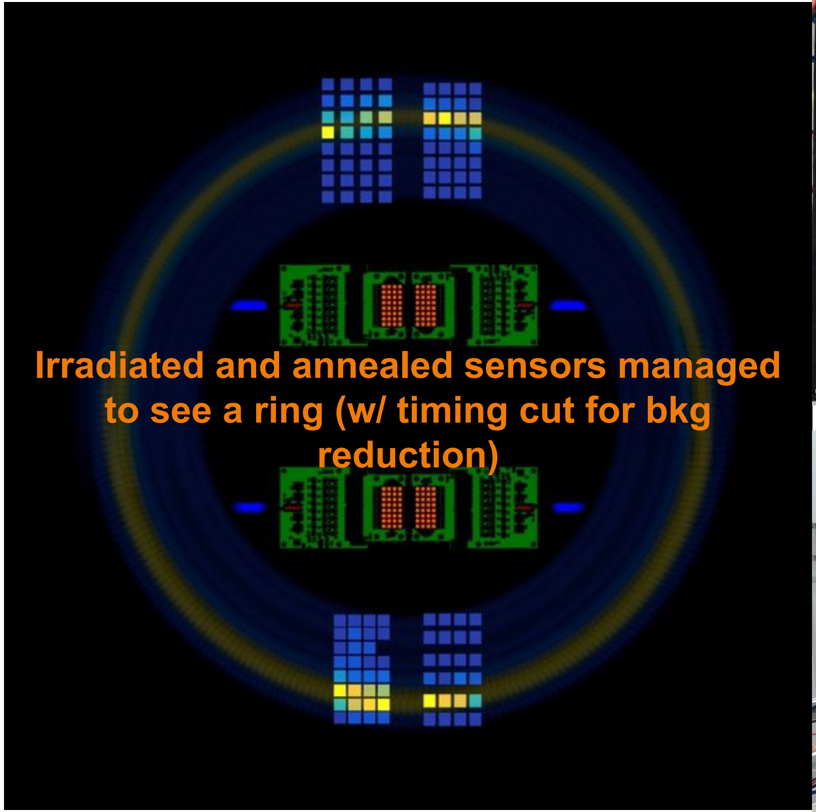
Light response (2022 camp.)



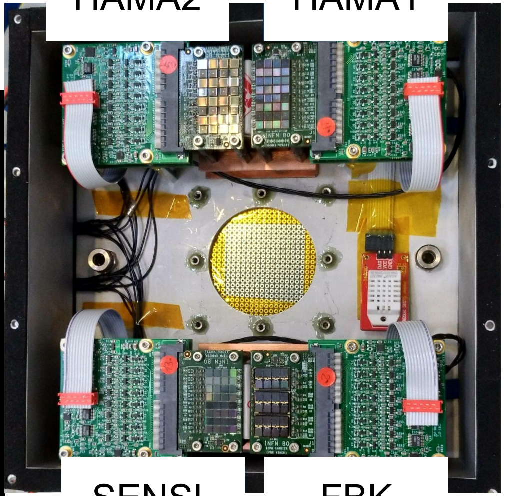
Ratio w.r.t. to new sensors, no signs of loss of efficiency up to 10^{10} radiation level



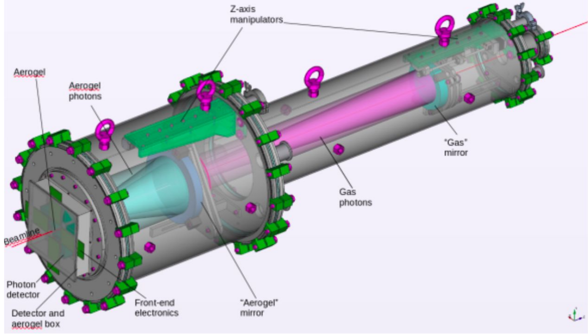
Test beam (2022 camp.)

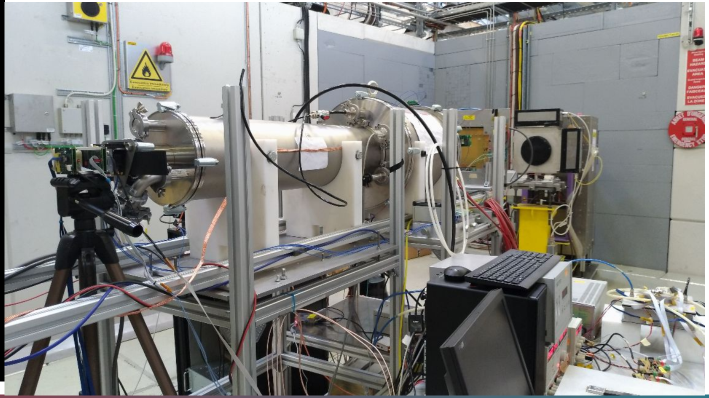


Irradiated and annealed sensors managed to see a ring (w/ timing cut for bkg reduction)

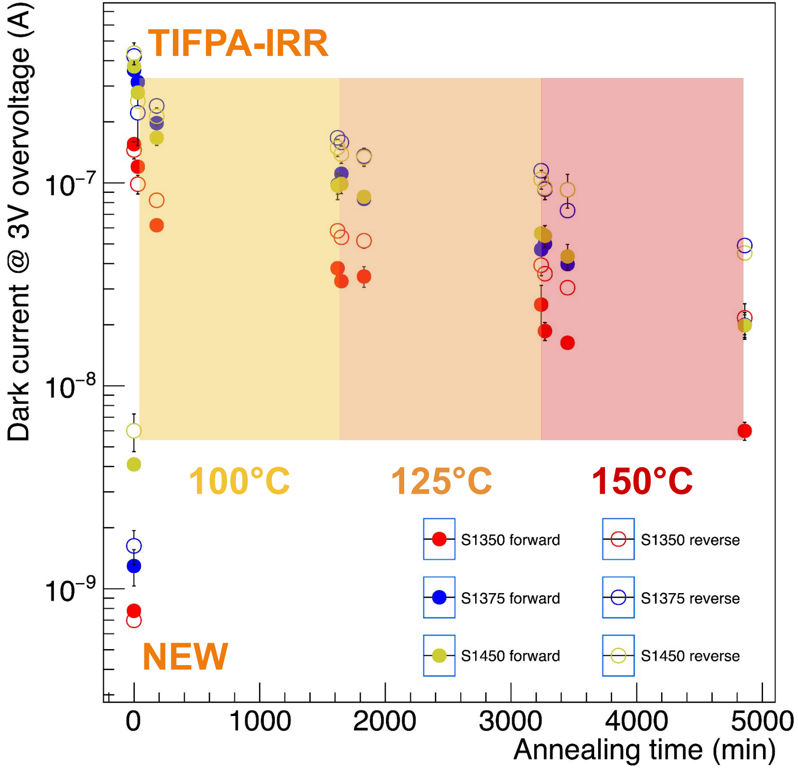


2022 Campaign also saw a very fructuous Test Beam @CERN T10 PS beam line

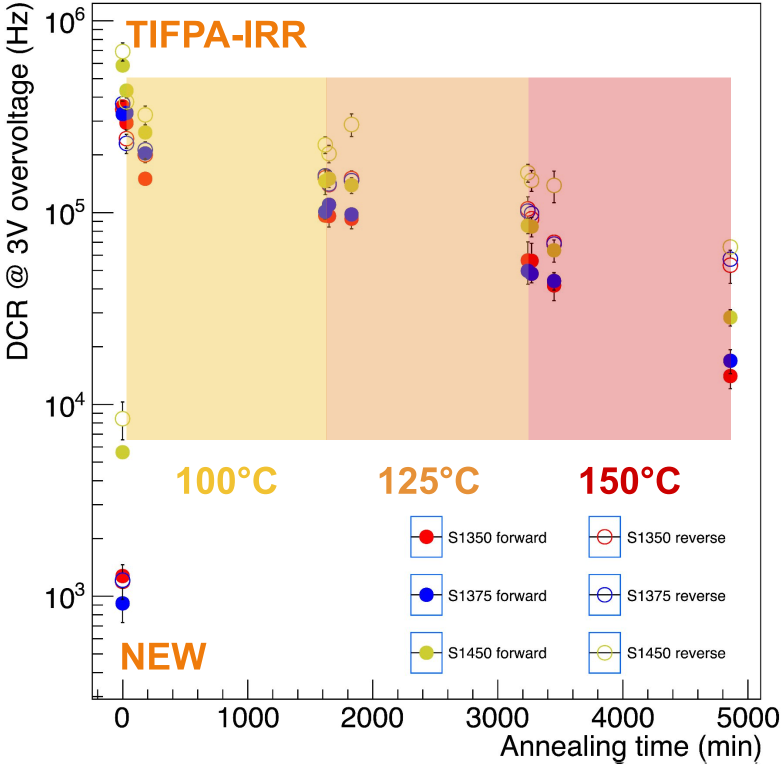




DCR and Dark current (2023 camp.)



There is a worsening of around 2.5 orders of magnitude after 10^9 1-MeV N_{eq}/cm^2 and a recovery of around 1.5 orders of magnitude in ~150h



Summary

- A three years effort of characterisation, irradiation and annealing to explore different sensors and their behaviour in the foreseen circumstances

- Different levels of irradiation have been analysed in the 2021 campaign to understand the effects of low to high radiation damage and potential for recovery through annealing

- online (small irradiation-annealing cycles) have been tested for in-situ solutions in the 2022 campaign, with a start on the light response using a LED and a on-field test w/ a Test Beam @CERN

- three most promising candidates are under test in the 2023 irradiation campaign, with a focus on different annealing solutions to define the proposed sensor to be used in the dRICH

- We have a reliable setup that is able to thoroughly caracterise sensors in many ways consistently

Thank you!

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