The dRICH photosensors: SiPM studies

Giornate Nazionali EIC_NET 2024
Bologna 27 – 28 Jun 20024

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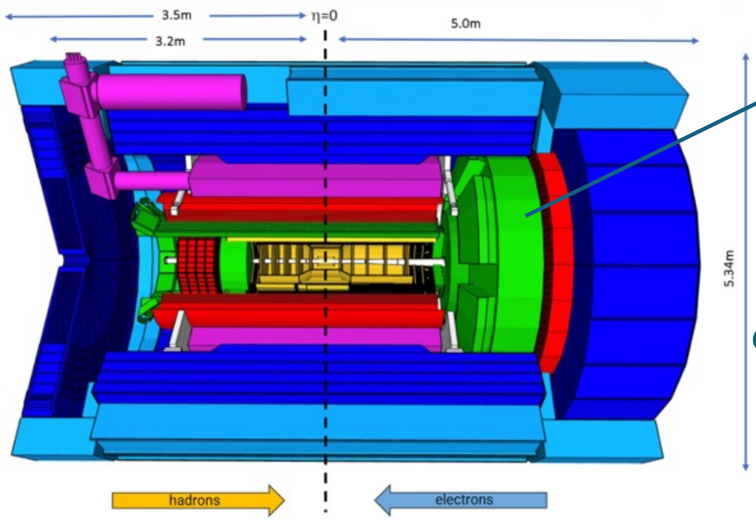
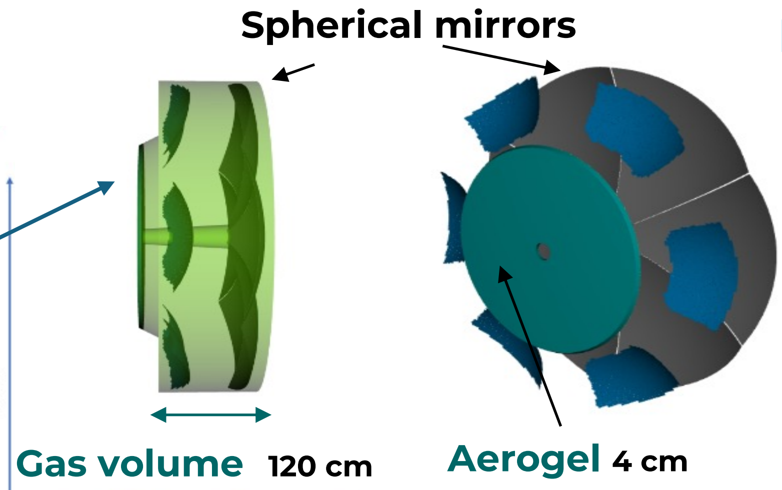
Outline

- *Introduction*
- *Current annealing update*
- *Neutron irradiation*
- *Proton energy scan*
- *Next irradiation campaigns*
- *New laser setup*
- Windows damage studies
- *New Hamamatsu prototypes*
- *Slew rate vs ToT*
- *Update radiation simulations and aging model*

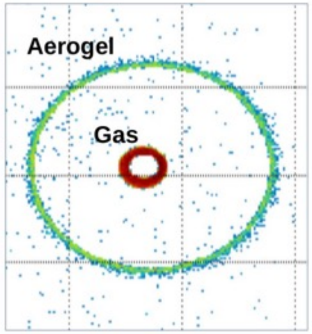
Introduction: the dual-radiator (dRICH) for forward PID

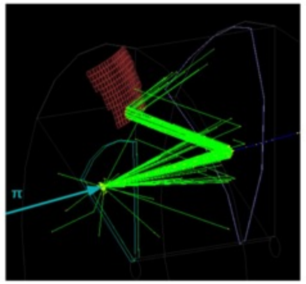
Compact and cost-effective solution for broad momentum (3-50 GeV/c) coverage at forward rapidity **π/K 3σ separation at 50 GeV/c**

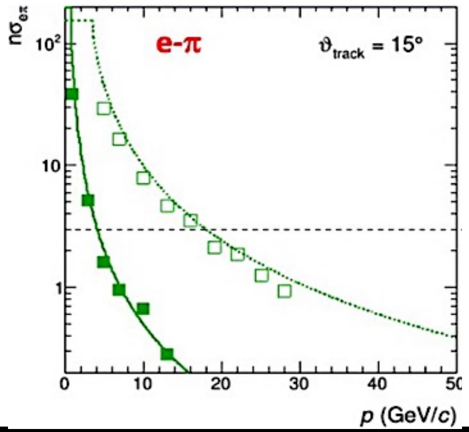




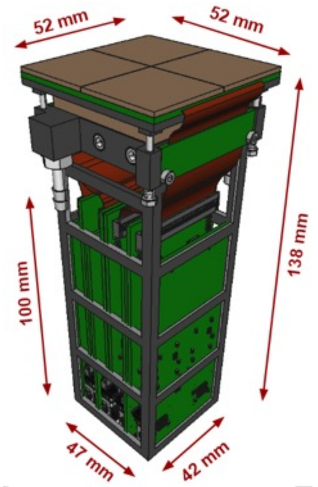
RADIATORS: aerogel (n ~ 1.02) and C_2F_6 (n ~ 1.0008)
MIRRORS: 6 open sectors of large outward-reflecting
Photosensors: 3x3 mm^2 pixels 0.5 m^2 per sector in 1 T magnetic field and radioactive environnement for low light level detection.

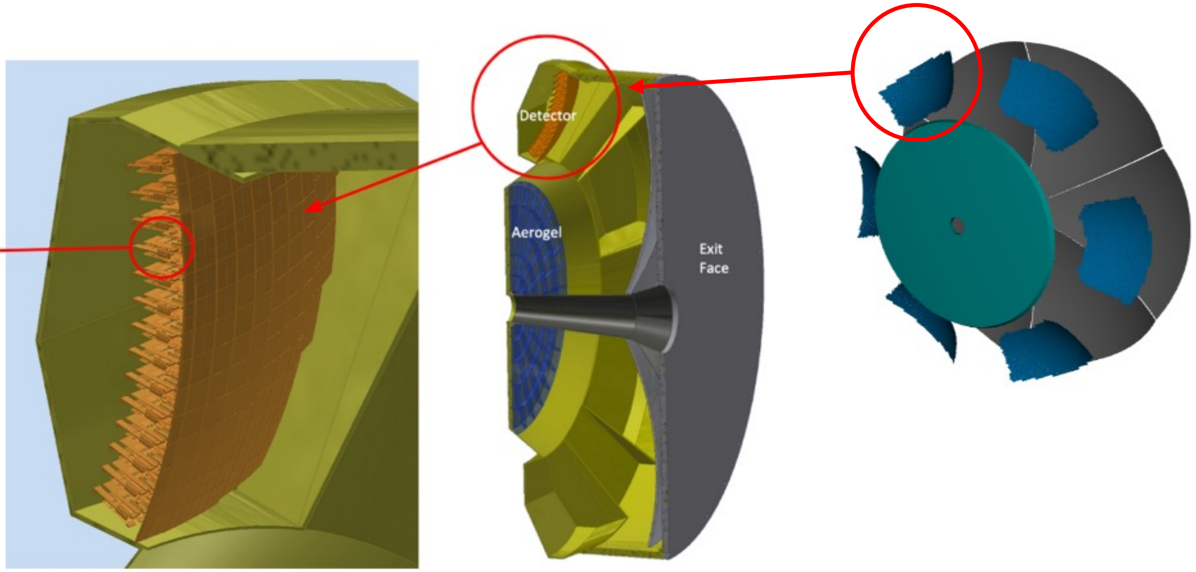


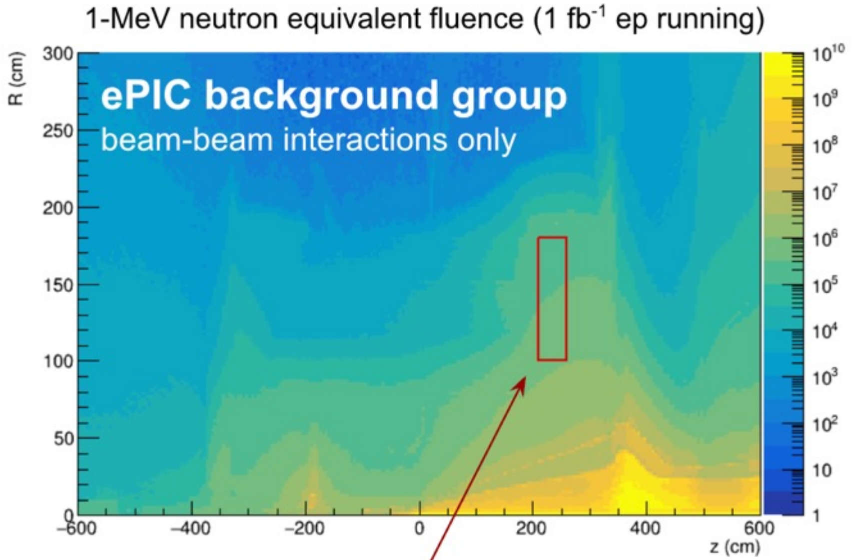




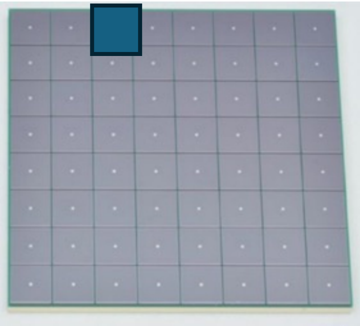
Introduction: the photosensors







3 x 3 mm^2

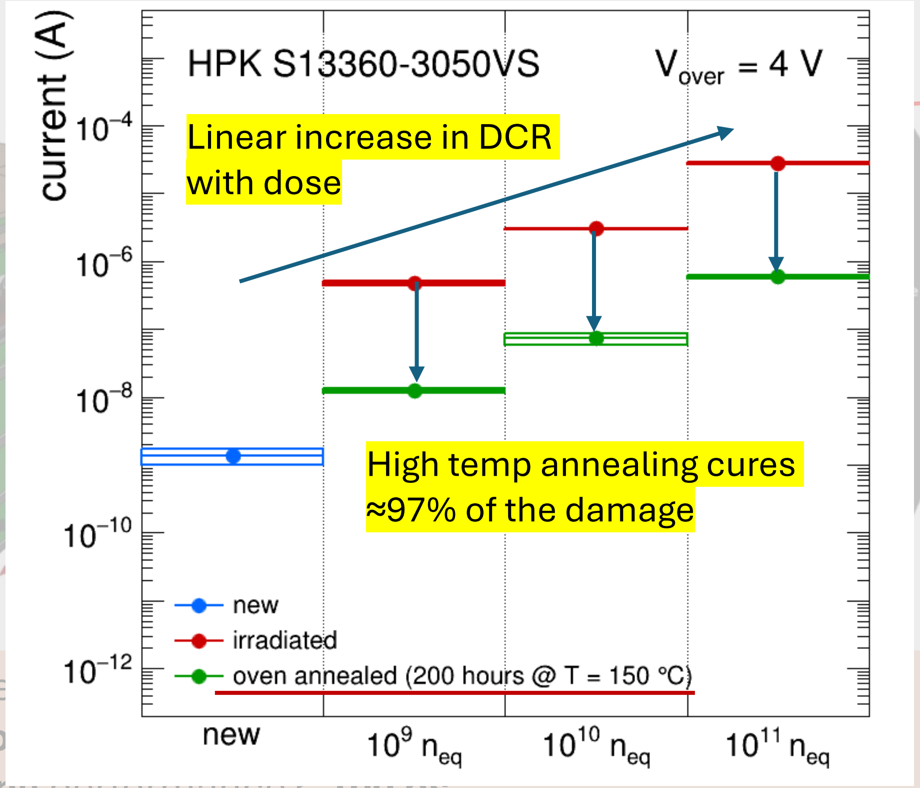


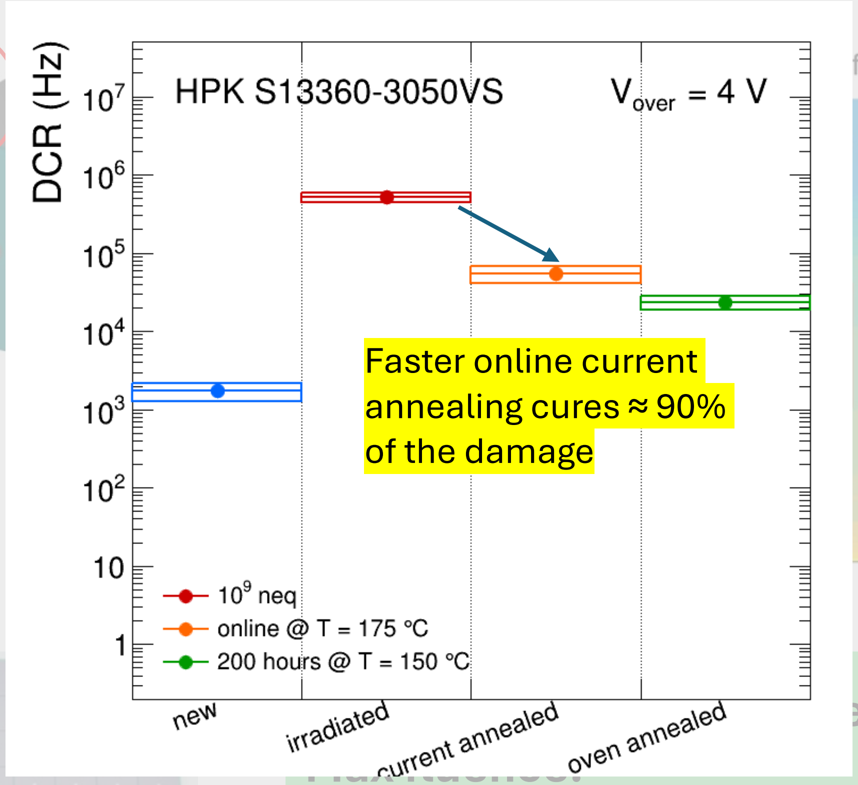
SiPM is the best **photosensor candidate:**
Single Photon sensitivity ~ 10 phs per Cherenkov event
Good **timing** performance **< 100 ps**
Cheap and **insensitive** to **magnetic** fields
BUT
High DCR @RT and **high radiation sensitivity**

Location of photosensors
Max fluence ≈ 2.25 10^7 n_{eq} / cm^2 / fb^{-1}
Max fluence (SFx2)≈ 4.5 10^7 n_{eq} / cm^2 / fb^{-1}

Values changed in the last simulations!

Introduction: the photosensors



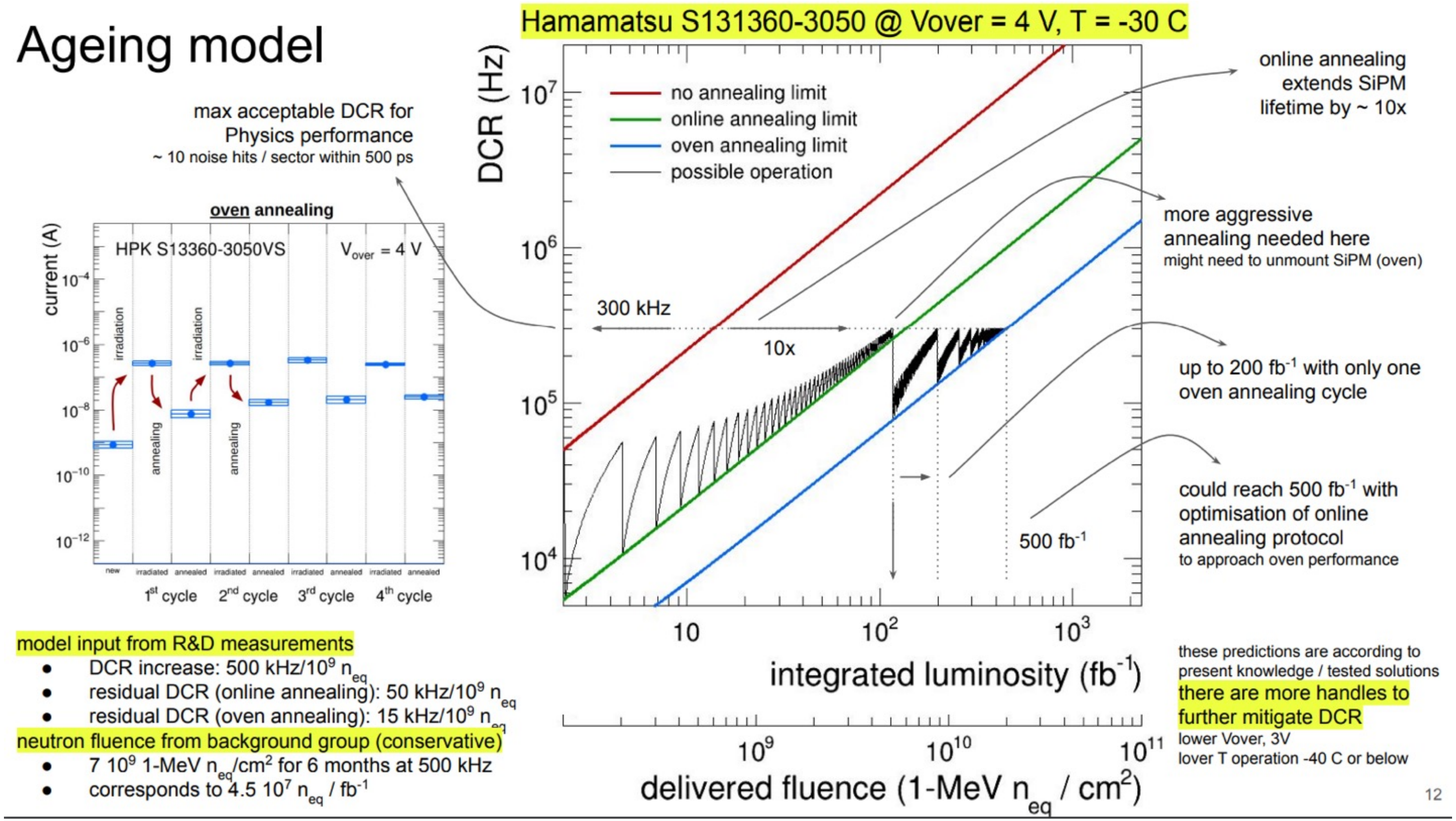


SiPM is the ...
Single Pho...
Good **timing** performance < 100 ps
Cheap and **insensitive** to **magnetic** fields
BUT
High DCR @RT and **high radiation sensitivity**

...ensors

$2.25 \; 10^7 \; n_{eq} / cm^2 / fb^{-1}$
Total fluence ($100 \; fb^{-1}$):
$\approx 4.5 \; 10^{10} \; n_{eq} / cm^2$

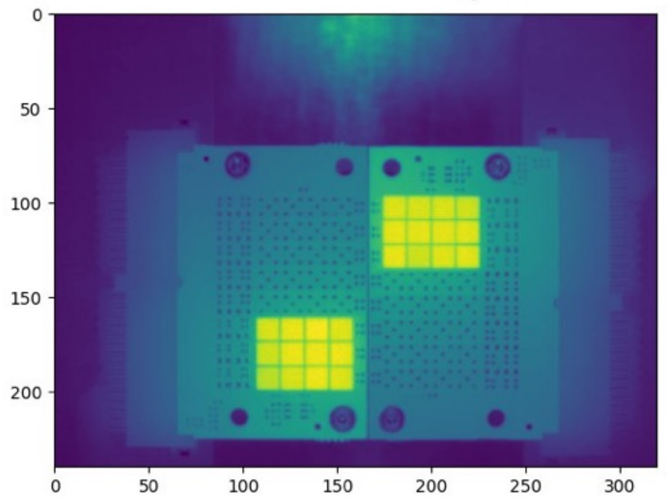
From last year Giornate Nazionali EIC_NET, 23 June 2023 by Roberto Preghenella



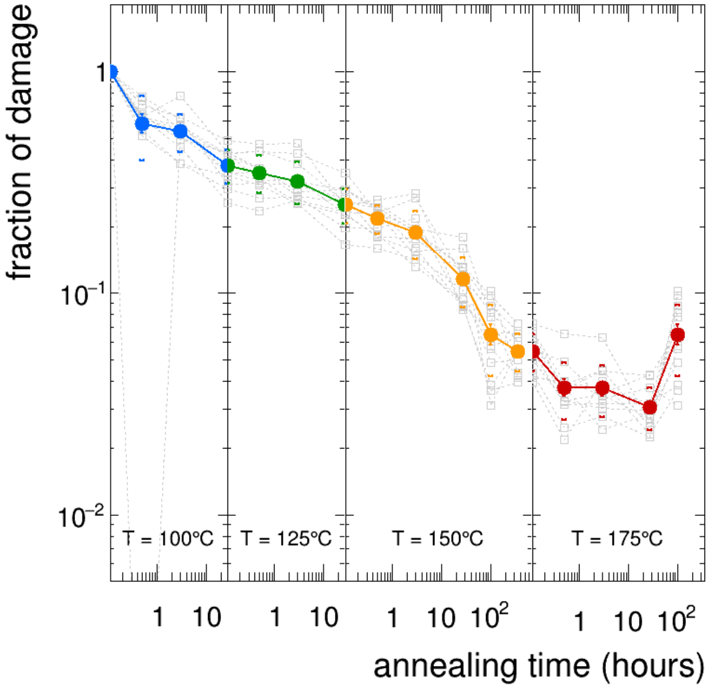
Update on current annealing

New **automated system** for **reverse** and **forward bias** allowed to test a **large number** of **irradiated** sensors at increasing **temperatures** and **time** (following procedures in literature).

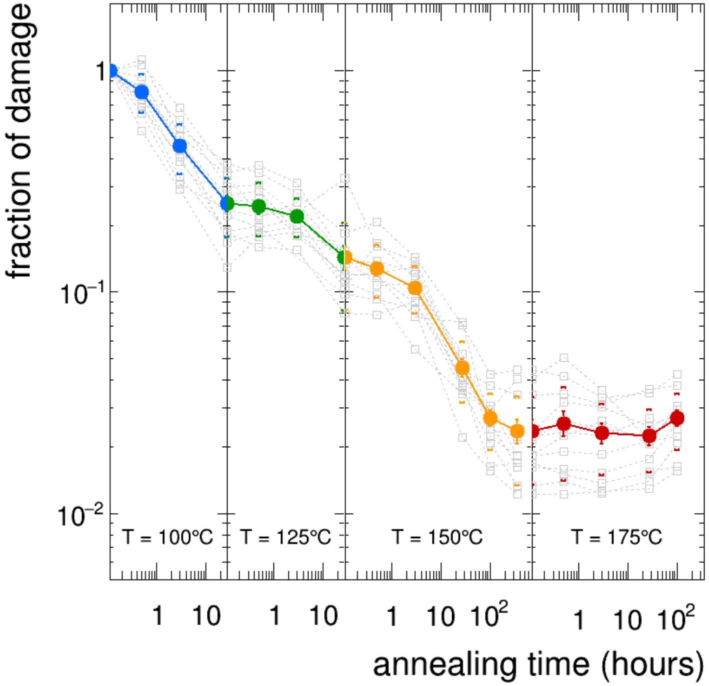
<u>Fraction of damage</u>=DCR_{ann} /DCR_{irr}

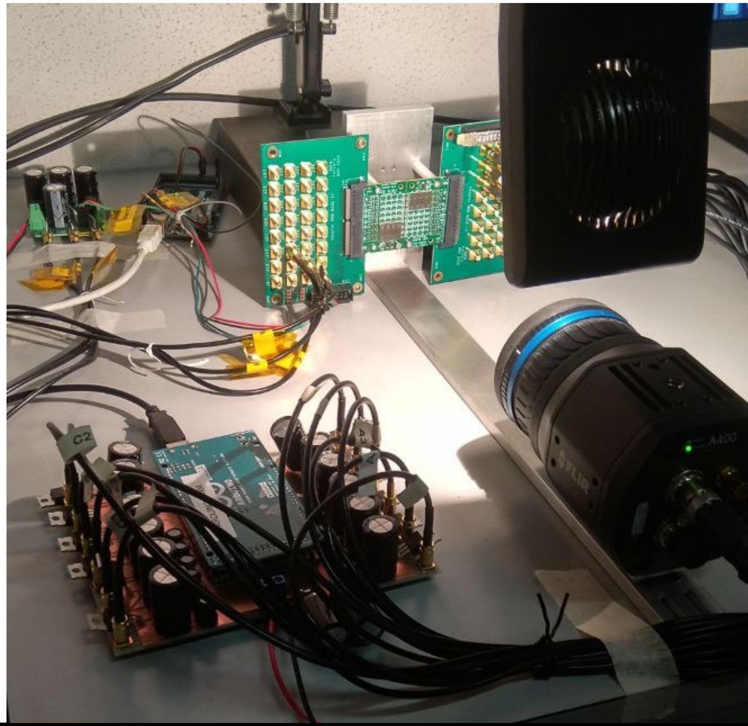


annealing **<u>reverse bias</u>**

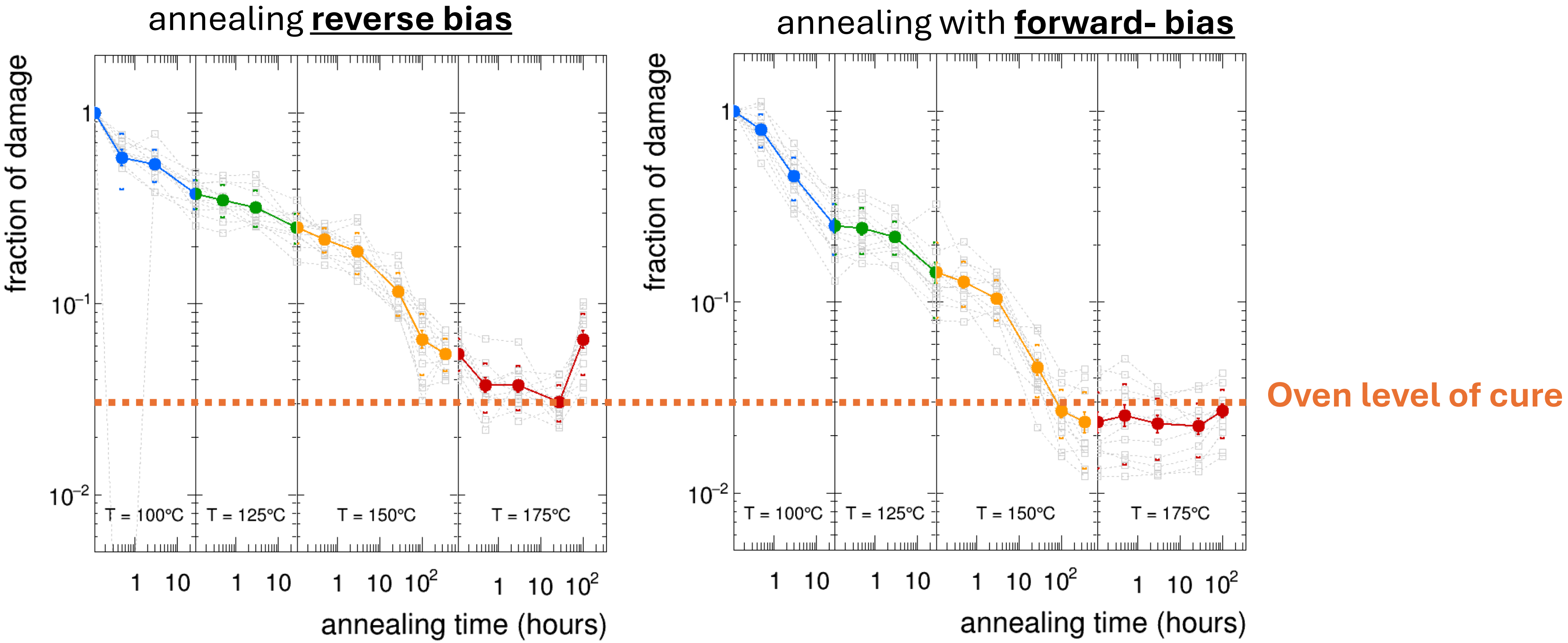


annealing with **<u>forward- bias</u>**





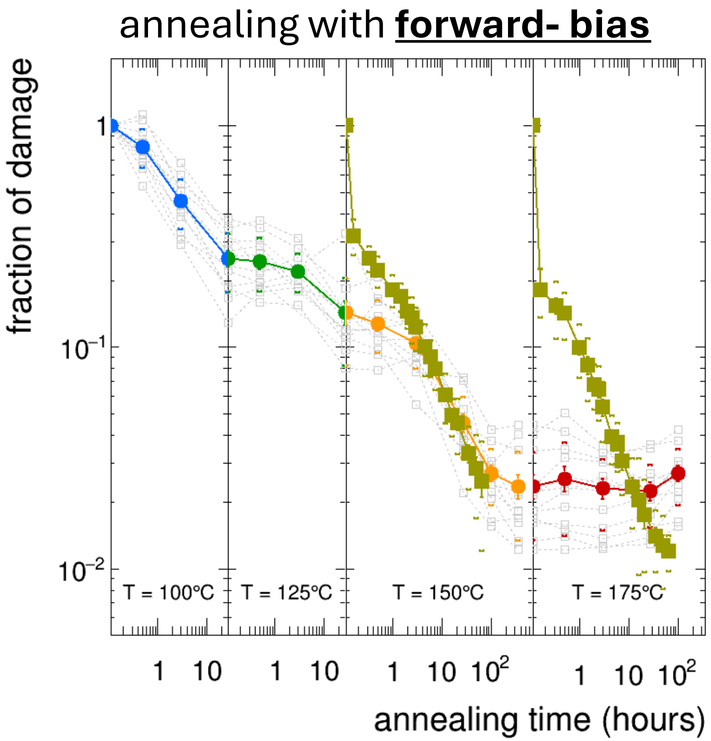
Update on current annealing

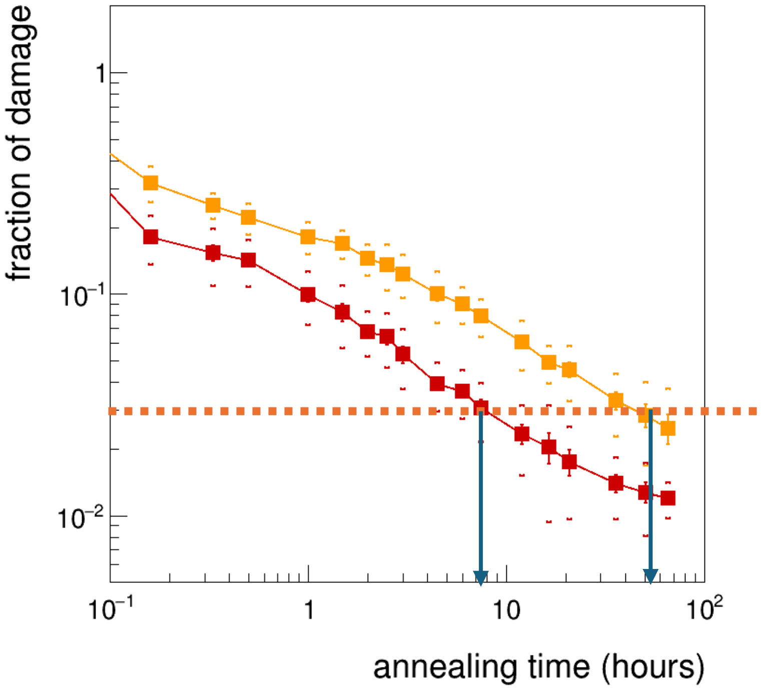


Forward bias is more effective
Fraction of damage saturates at 2-3% after 300 h @150 °C like the oven annealing
175 °C doesn't seem to cure more damage

Update on current annealing

In ocra neutron irradiated boards annealed with single temperature (150-175 °C)



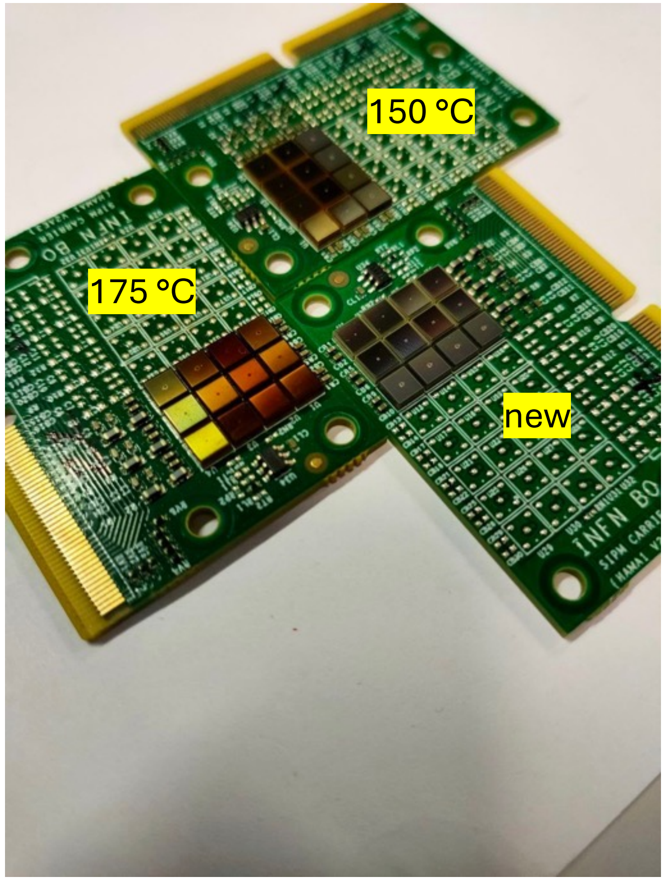


Oven level of cure reached:

T = **175 °C < 10 hours**

T = **150 °C < 100 hours**

Optical window damage

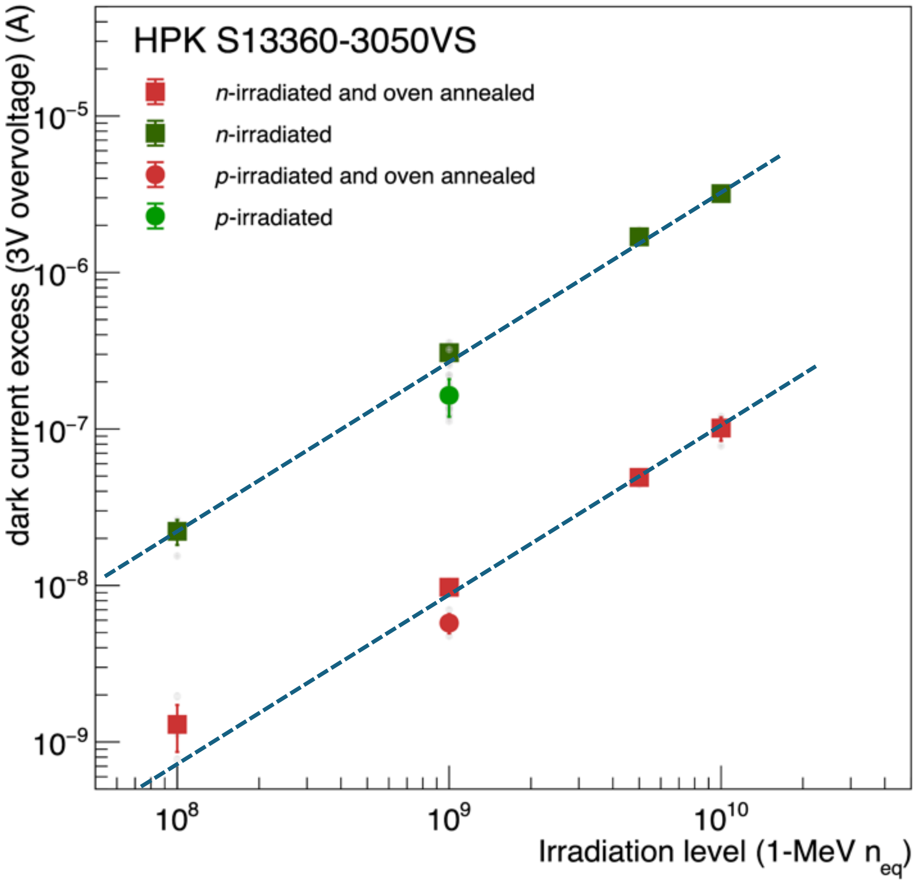


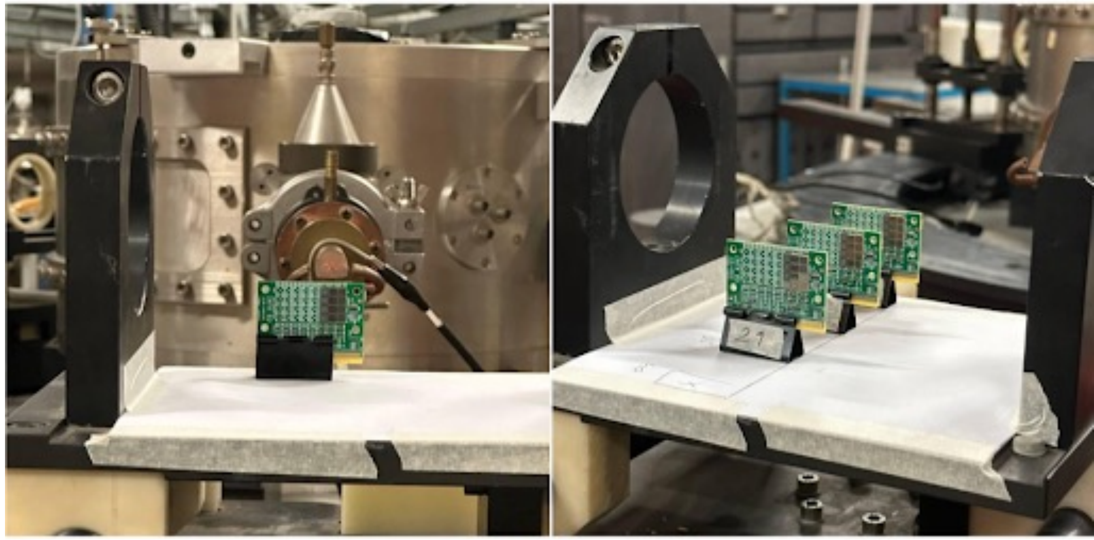
After many hours of online annealing alterations on the SiPM windows in particular **500 hours** of online annealing at **T = 175 C**

Neutron irradiation studies

Aug 2023 @ LNL

neutrons from Be(d,n) reaction with 4 MeV deuteron beam

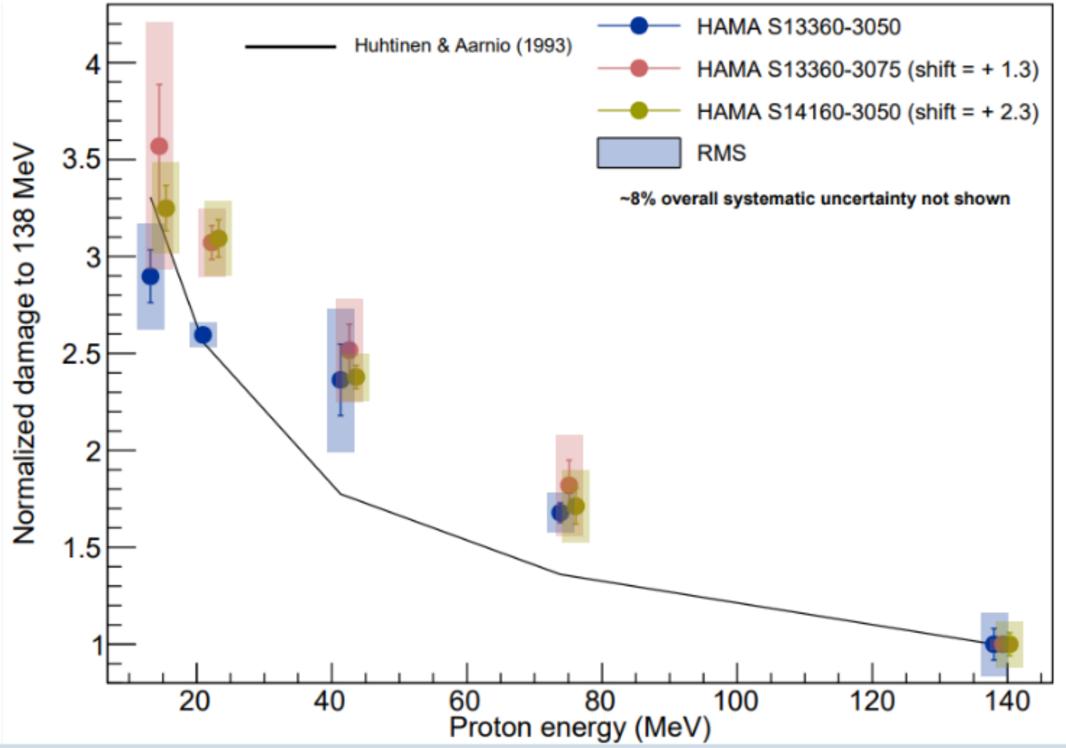




Neutron damage is **larger** after same n_{eq} fluence with protons using **NIEL scaling** for normalisation by approximately a factor of **2x**

NIEL model violation? NIEL is for devices with no gain!

Proton energy scan

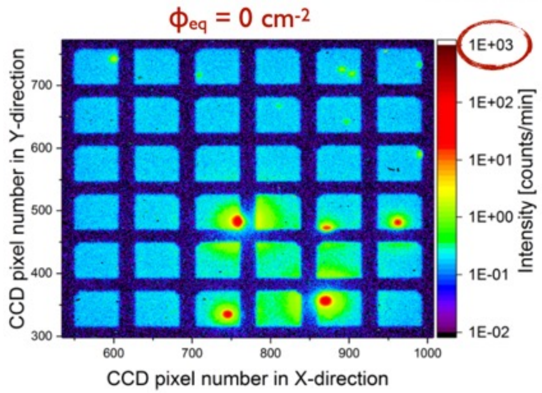


Damage vs. **proton energy** to test NIEL hypothesis

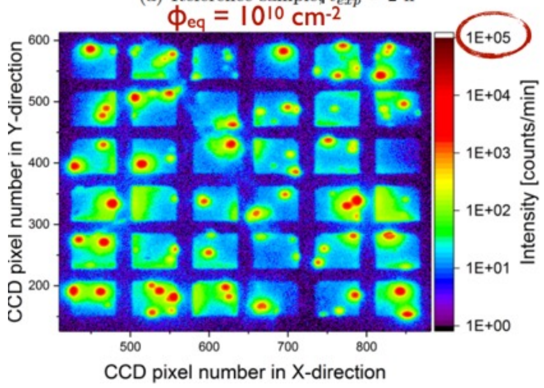
We found that the scaling is valid within 30-50% **using NIEL scaling for normalisation**

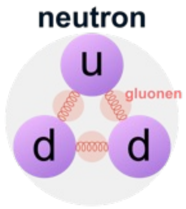
Next irradiation campaigns

Possibility to perform **lock-in thermal imaging** (**10 mK** resolution) in Dept. of Eng. in **Naples** before and after irradiation

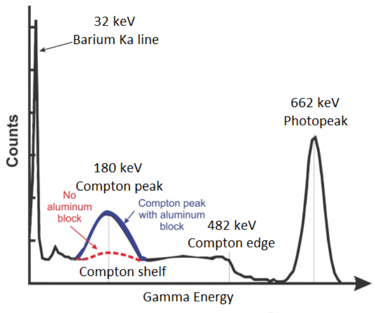


(a) Reference sample, $t_{exp} = 2$ h

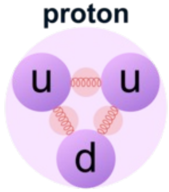




LNL: postponed to second half of **September**

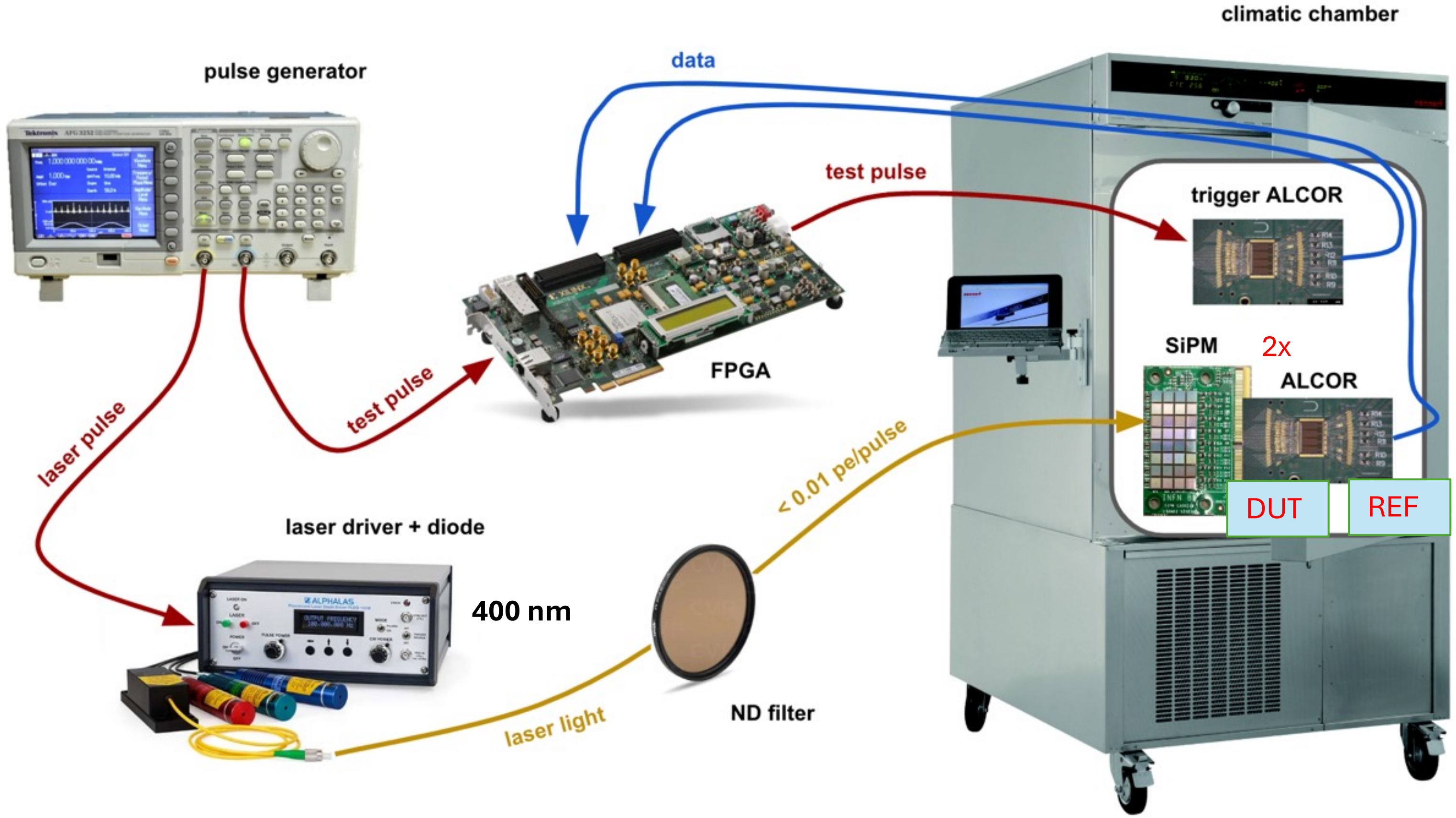


GIF++: 14, 15 ,16 **October** (first gamma irradiation)



TIFPA: 15-16 **Nov** and 20-21 **Dec** (SiPM + electronics)

New laser setup

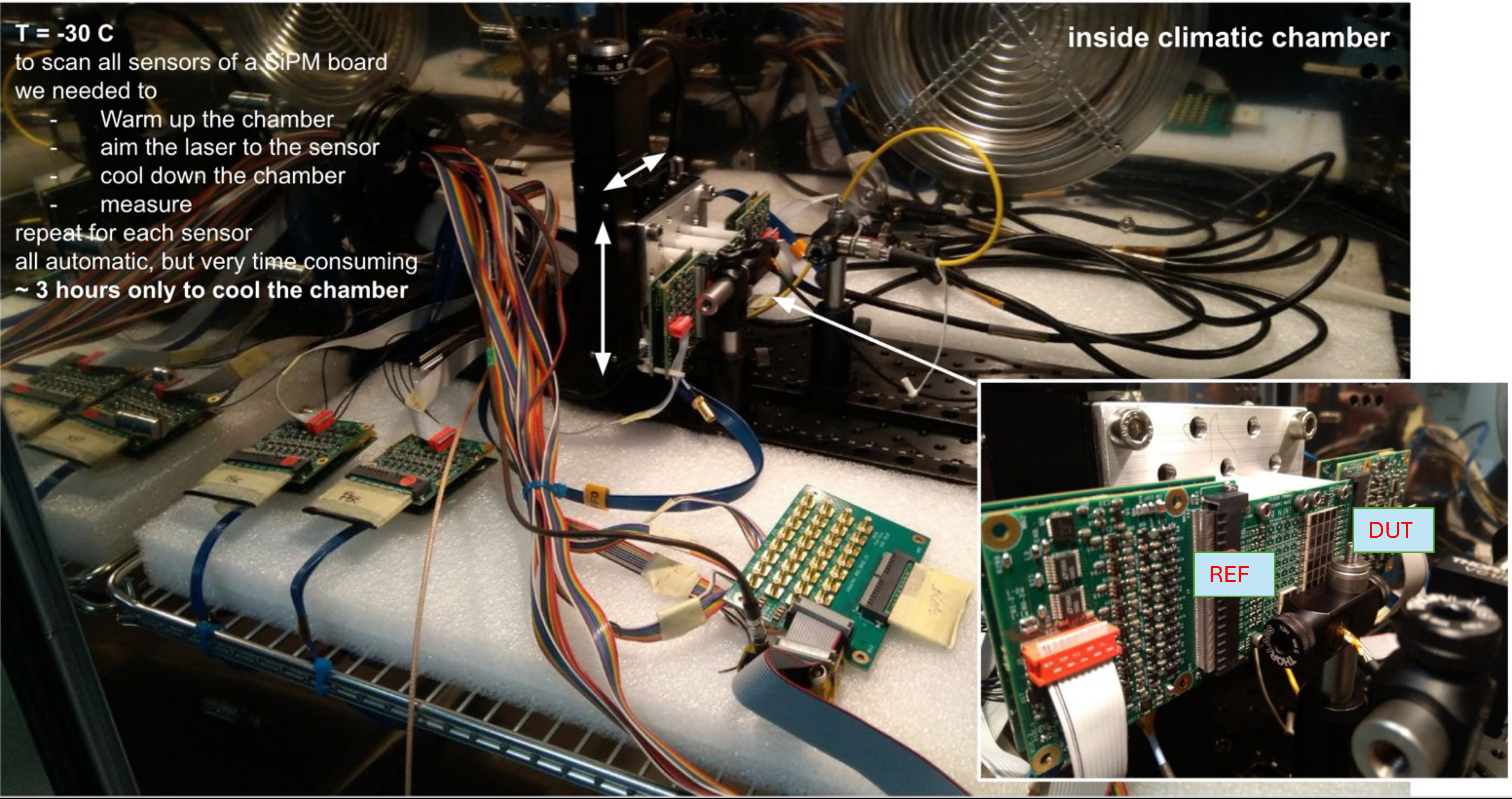


ALCOR

32-pixel matrix mixed-signal ASIC

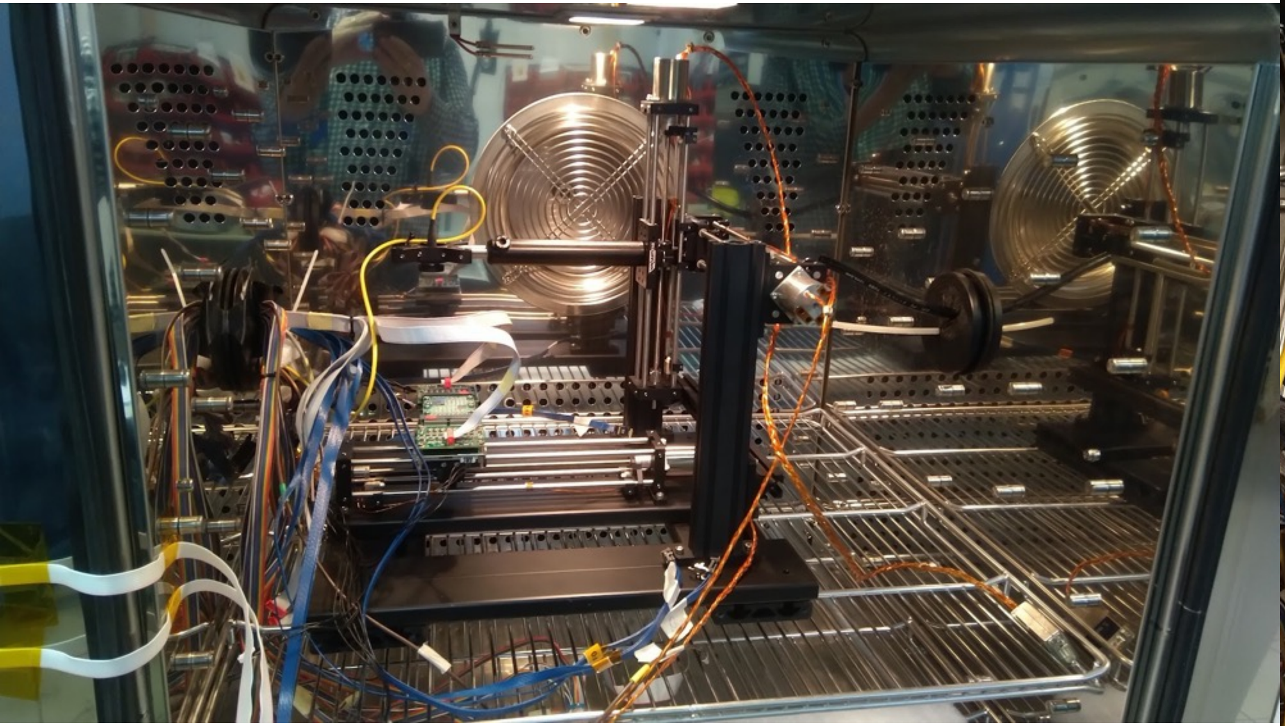
- **the chip performs**
  - signal amplification
  - conditioning and event digitisation
- **each pixel features**
  - 2 leading-edge discriminators
  - 4 TDCs based on analogue interpolation
    - 25 or 50 ps LSB (@ 320 MHz)
  - digital shutter to enable TDC digitisation
    - suppress out-of-gate DCR hits
    - 1-2 ns timing window
    - programmable delay, sub ns accuracy
- **single-photon time-tagging mode**
  - continuous readout
  - also with Time-Over-Threshold
- **fully digital output**
  - 4 LVDS TX data links

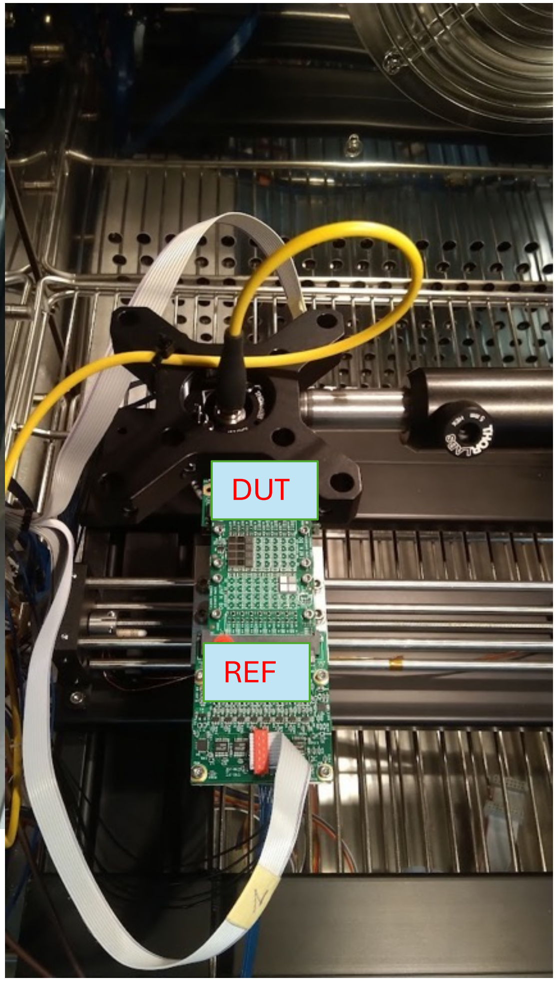
Old 2 axis stage



New laser setup 3 axis stage

λ=400 nm 1 mm² single photon spot



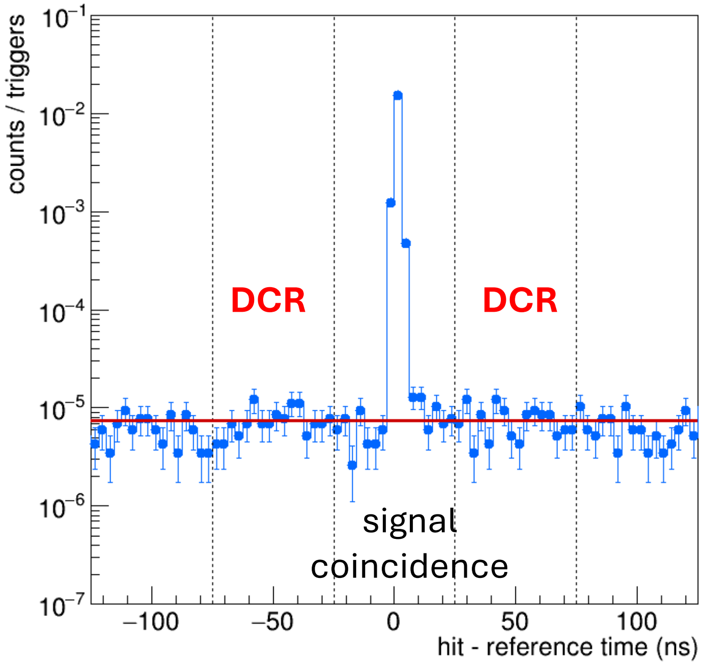


working down to -40 °C

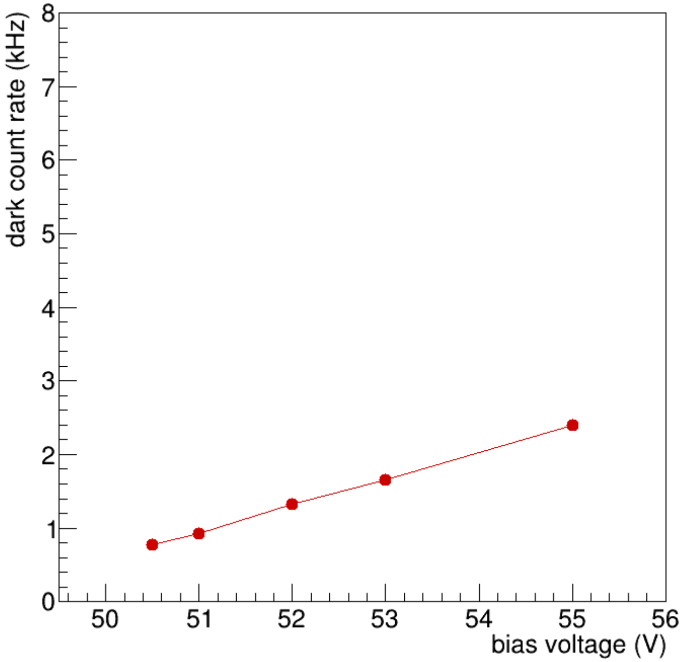
Allow to measure a DUT and the reference sensor without thermal cycling the system

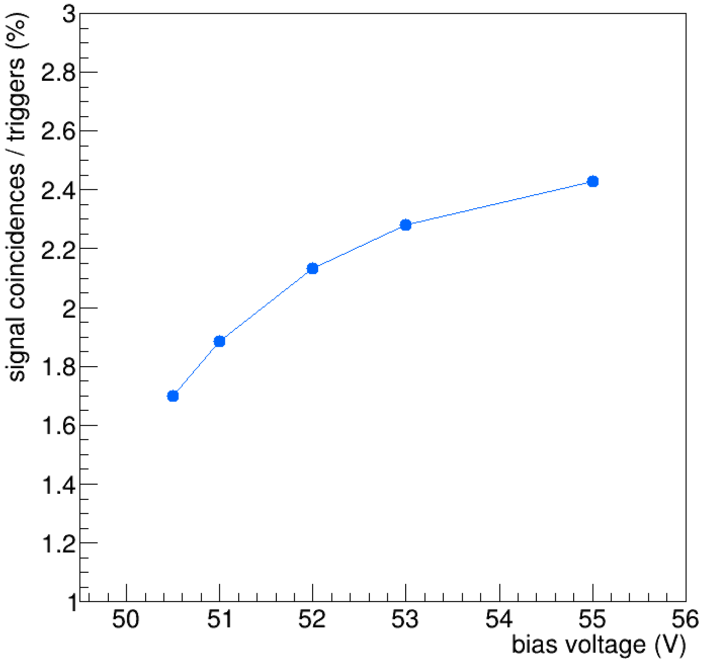
New laser setup measurements example

measured signal coincidences



background-subtracted counts / triggers





probability to detect light given laser pulse ∝ PDE

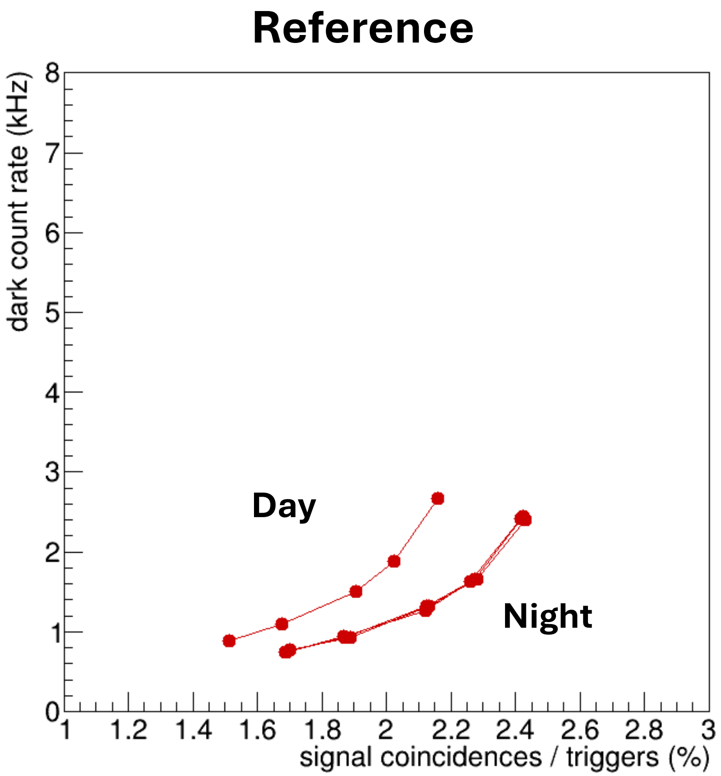
Reference-DUT

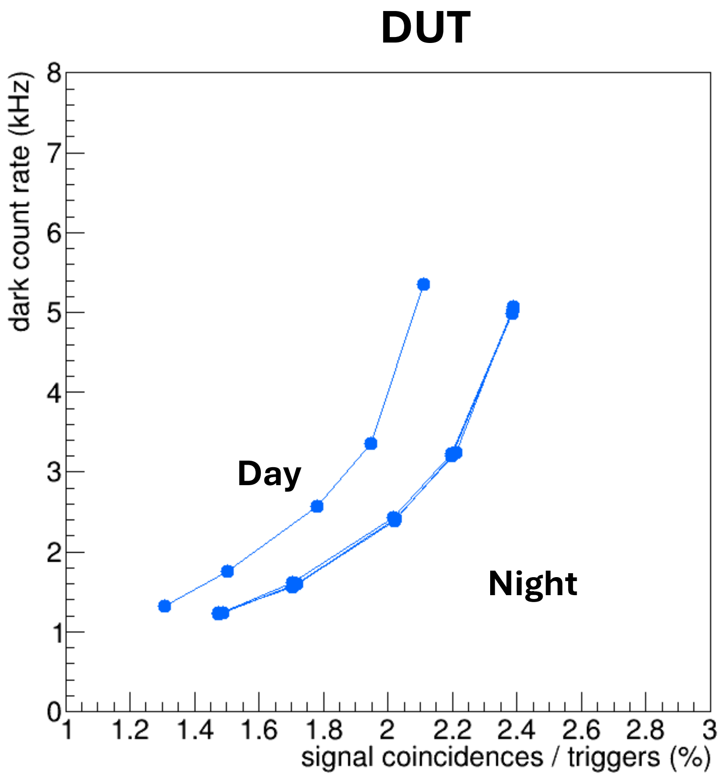
Is it really needed?

Reference-DUT

Is it really needed?

Yes

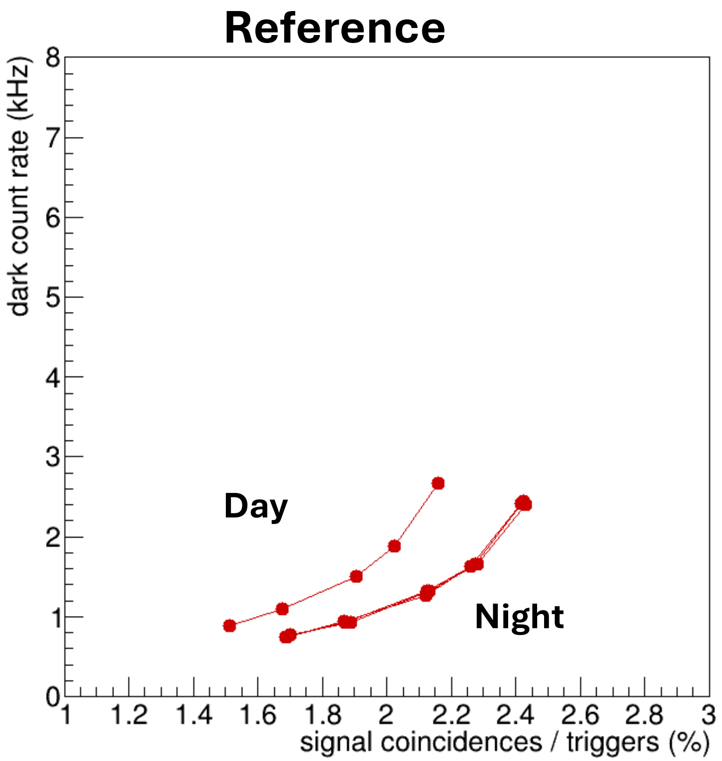


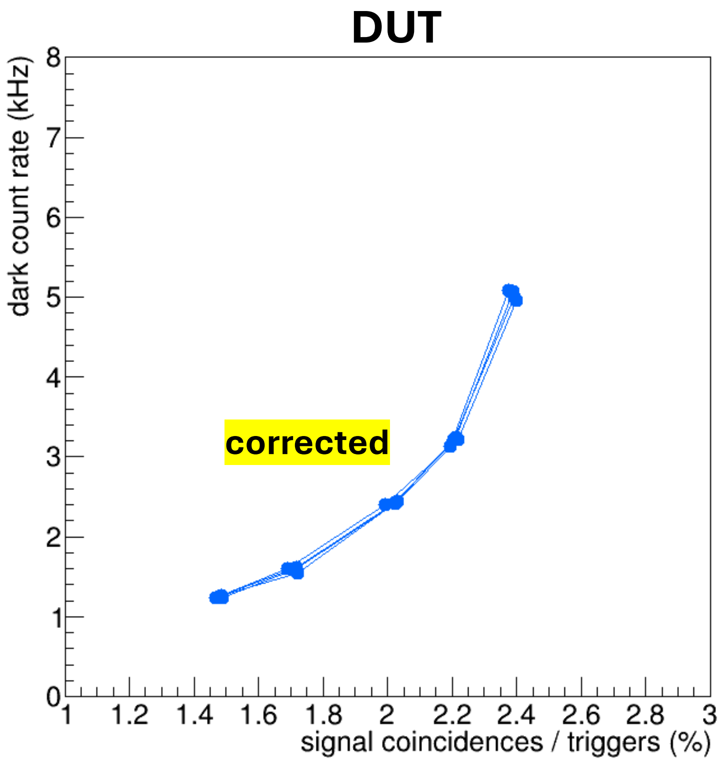


Reference-DUT

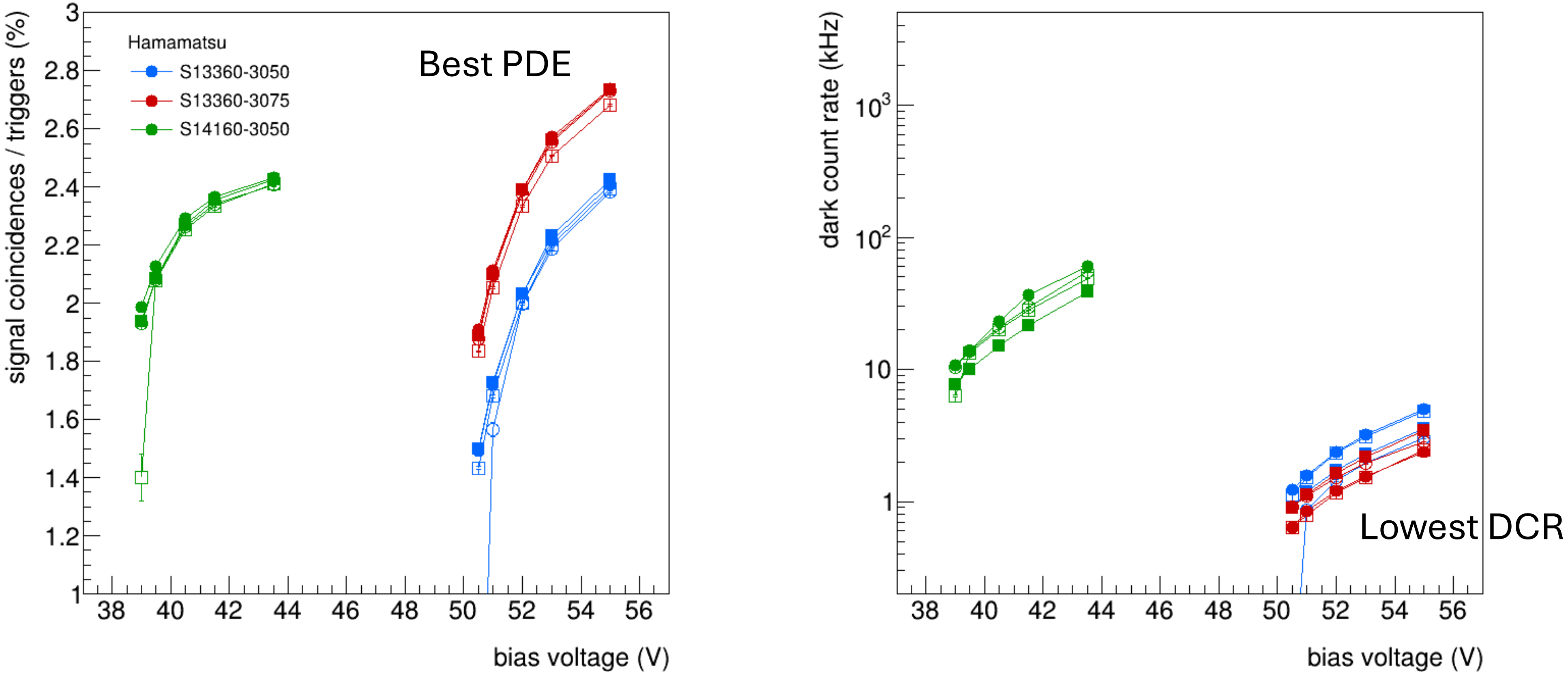
Is it really needed?

Yes





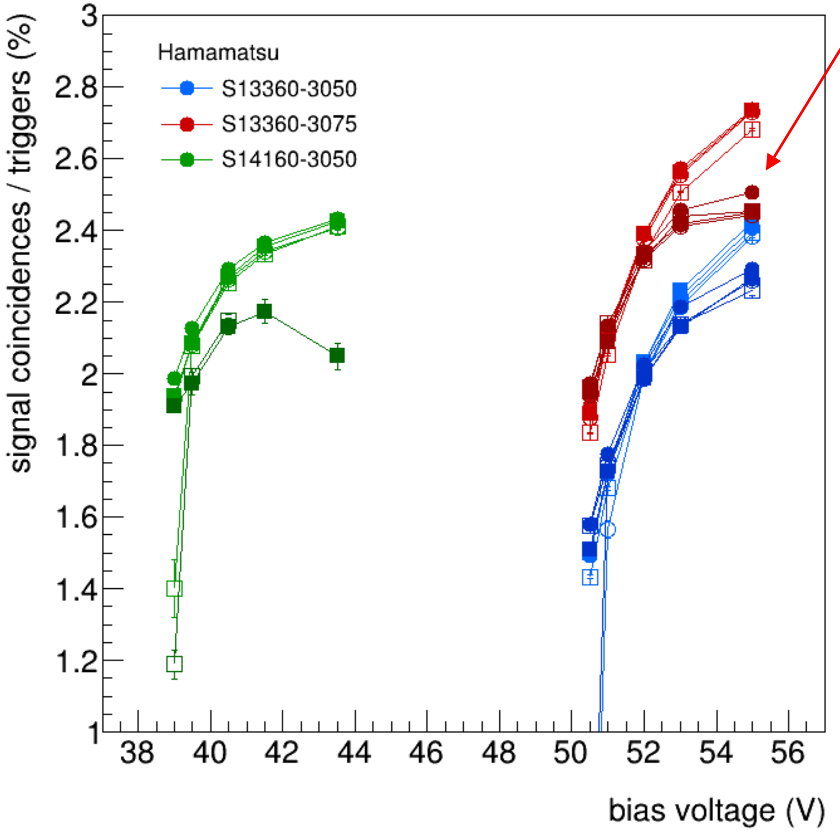
Pseudo efficiency: new boards

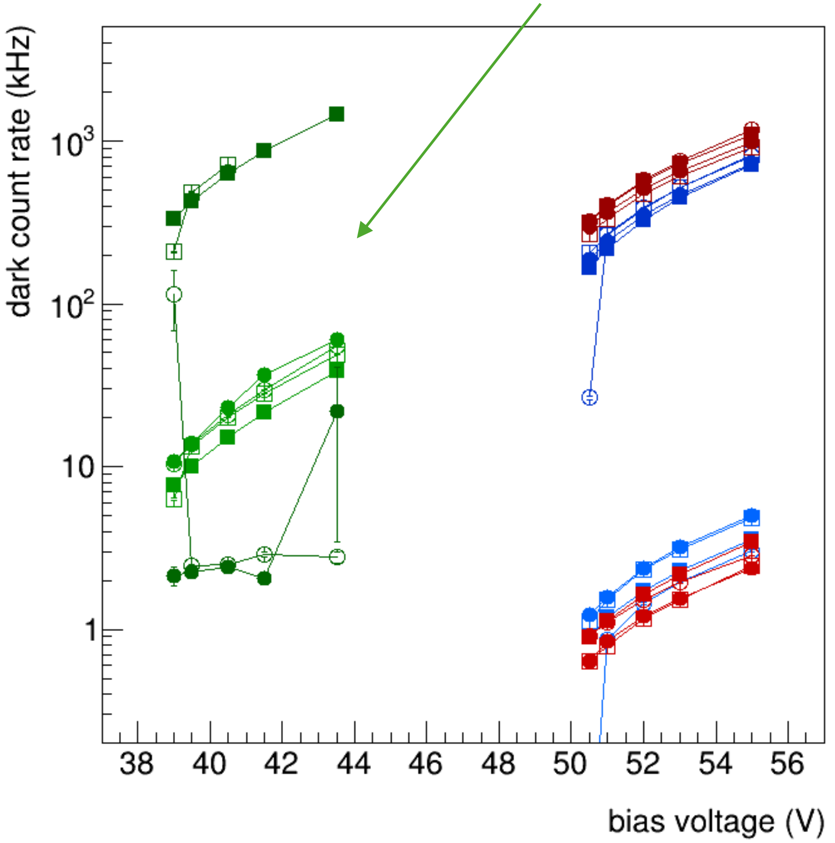


Pseudo efficiency: new and 10^9 n_{eq}

AP suppression algo reduces PDE

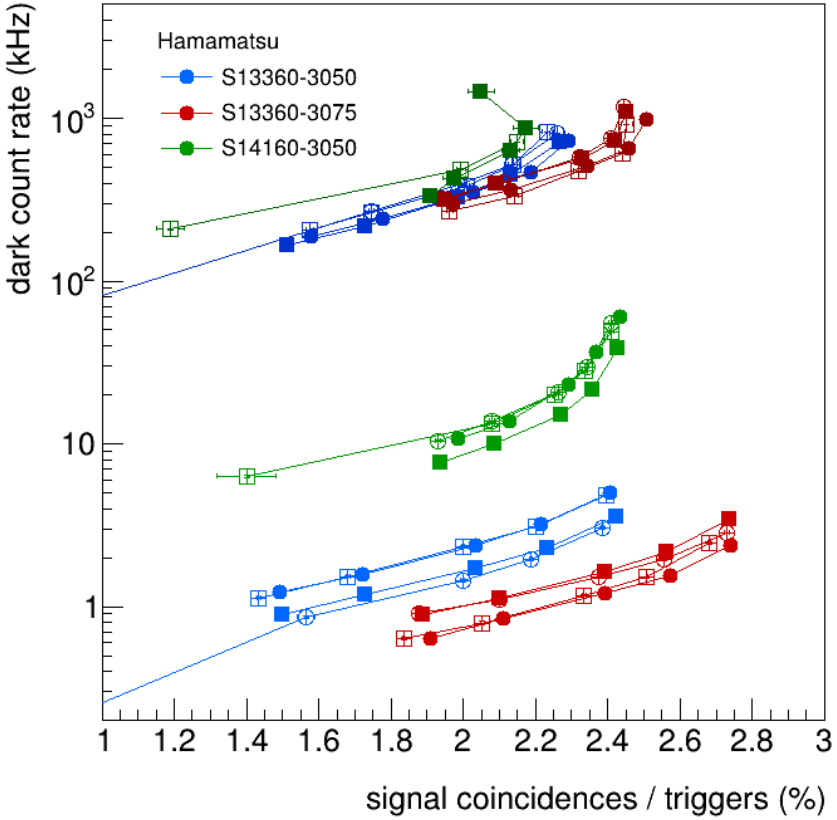
Troubles in reconstruction after irradiation

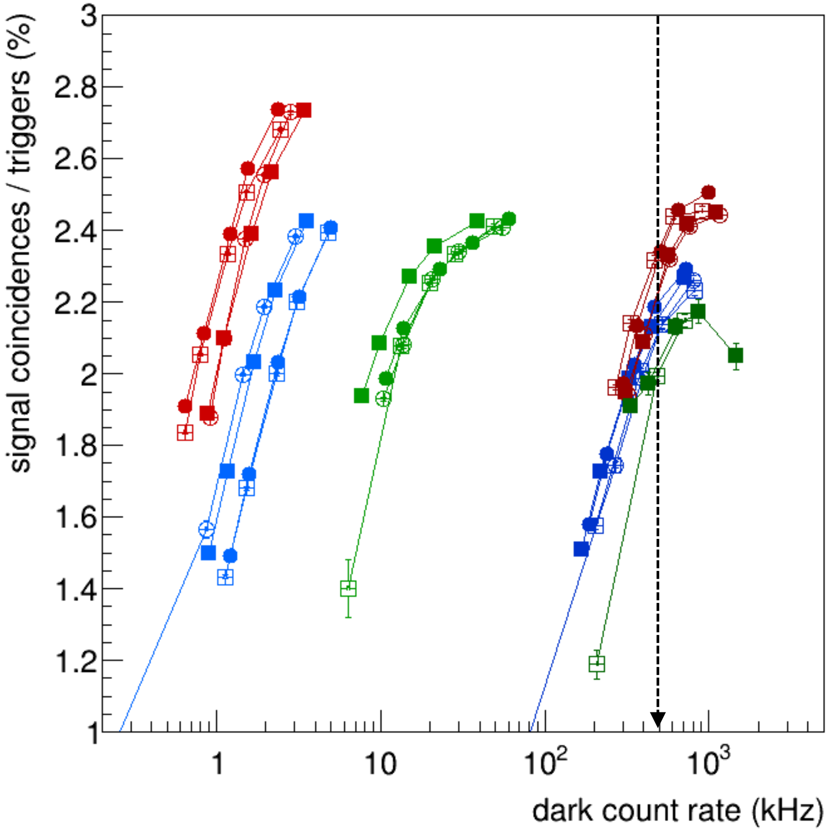




Pseudo efficiency: new and 10^9 n_{eq} better view

@500 kHz S13360-3075 best PDE (20% larger)

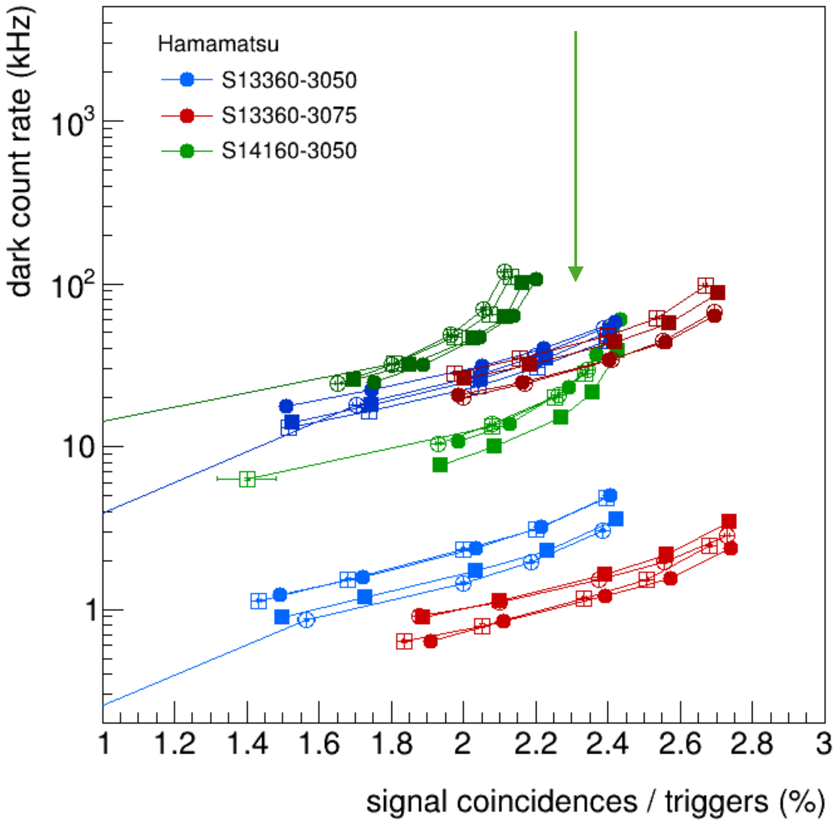


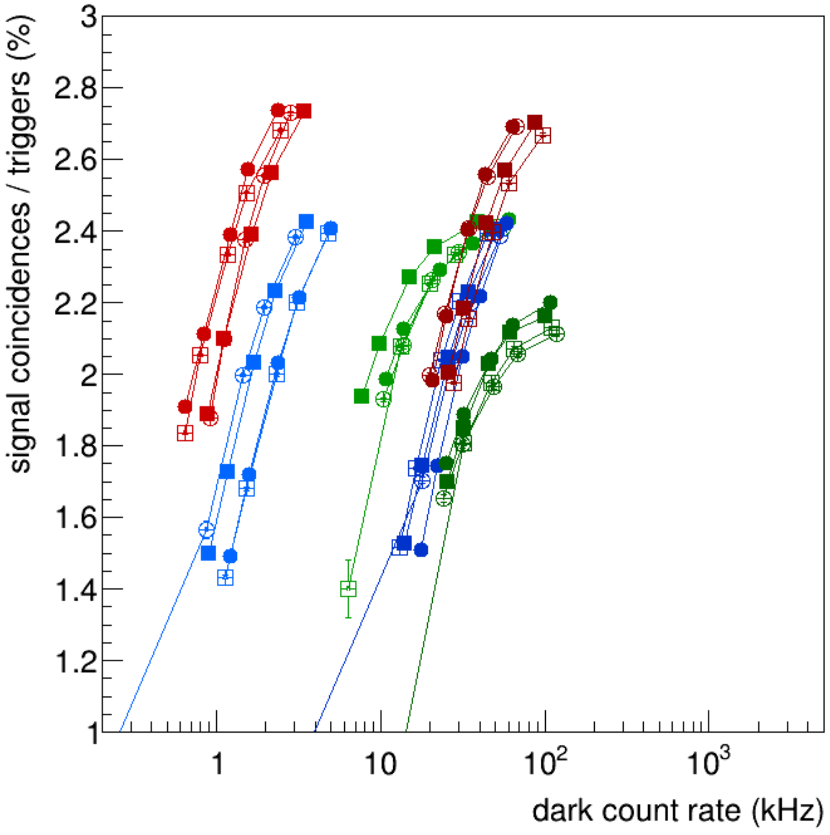


INFN

Pseudo efficiency: new and annealed

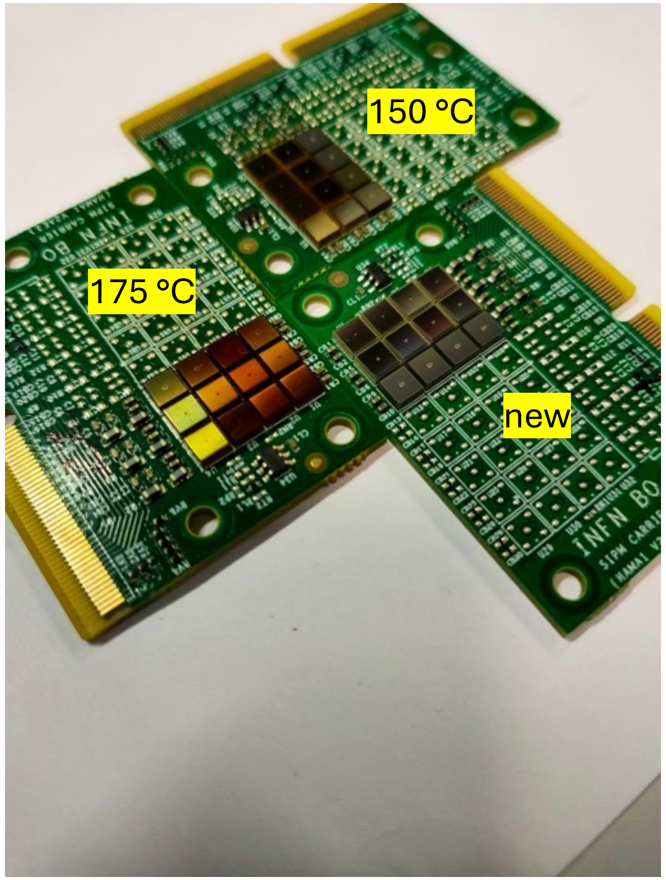
S14160-3050 lost PDE in irradiation/annealing



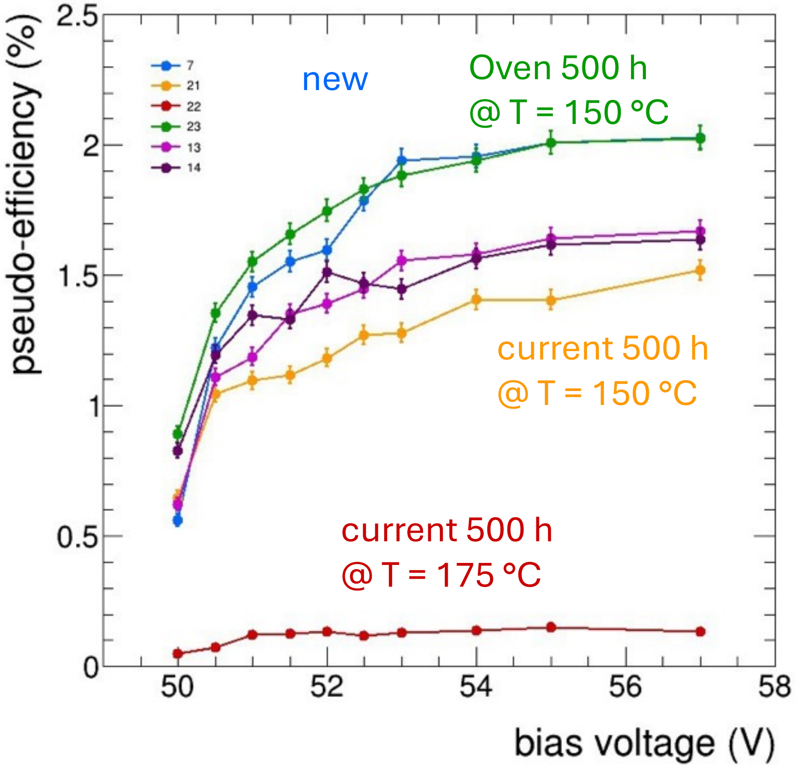


S13360-30xx no PDE loss, only increase in DCR

Windows damage studies



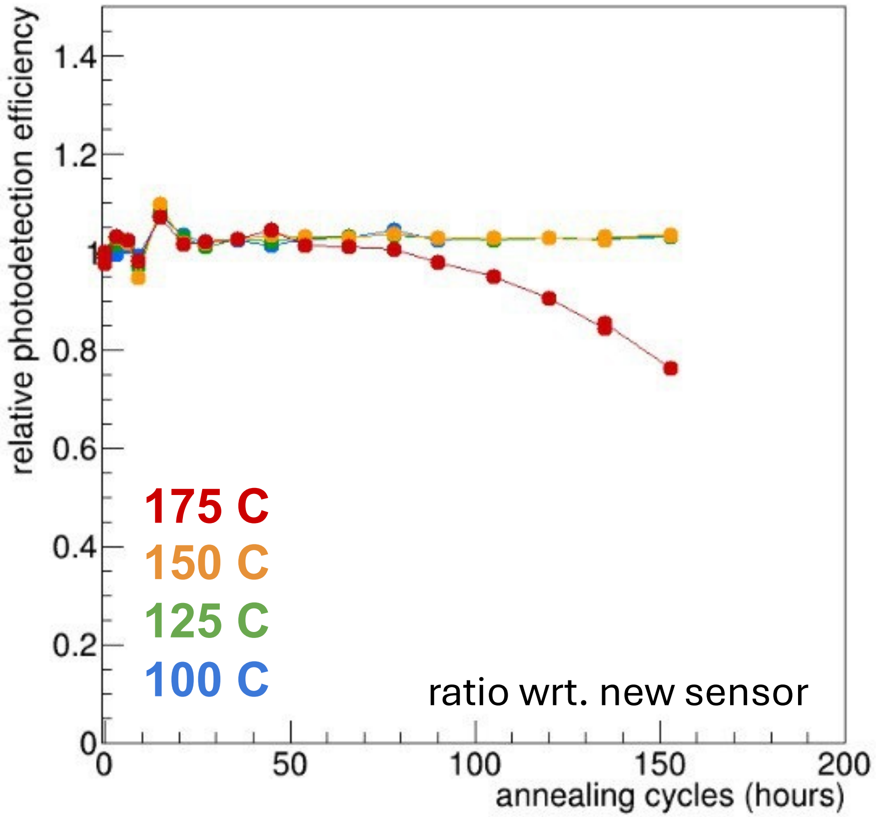
After many hours of online annealing alterations on the SiPM windows in particular **500 hours** of online annealing at **T = 175 C**



- **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 window

Windows damage further studies

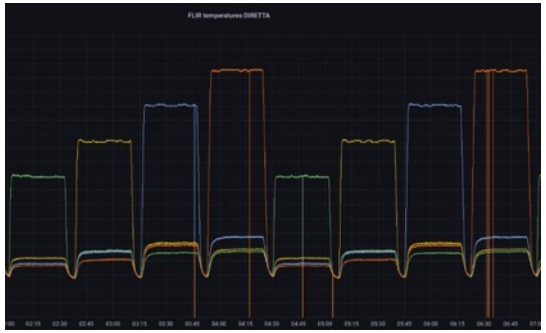


4 SiPMs under study at forward bias and different temperatures.

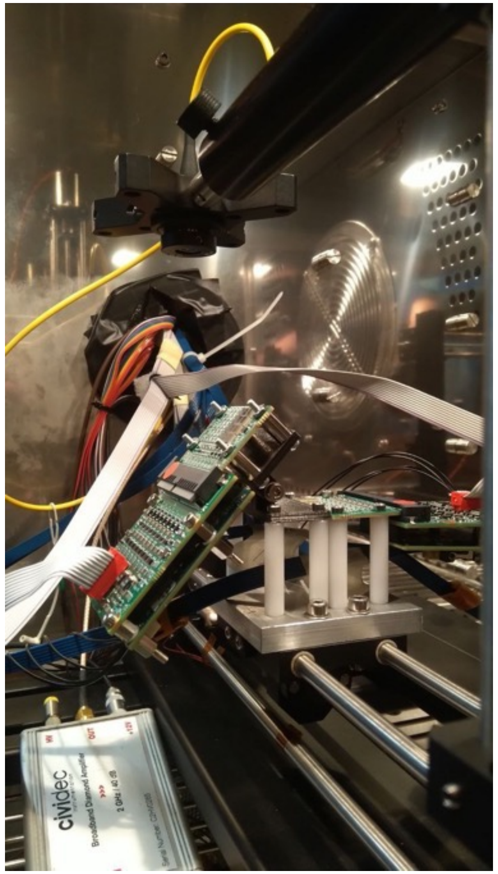
After 50 h @175 C the PDE starts to drop

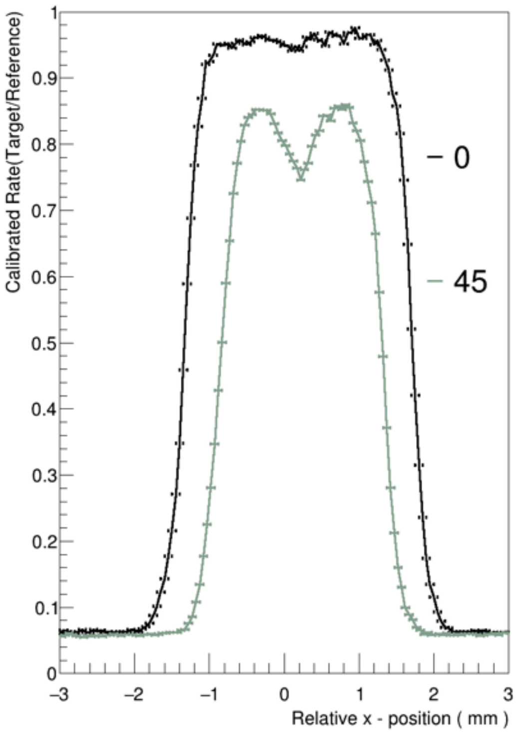
After 150 h @150 C the PDE is still ok

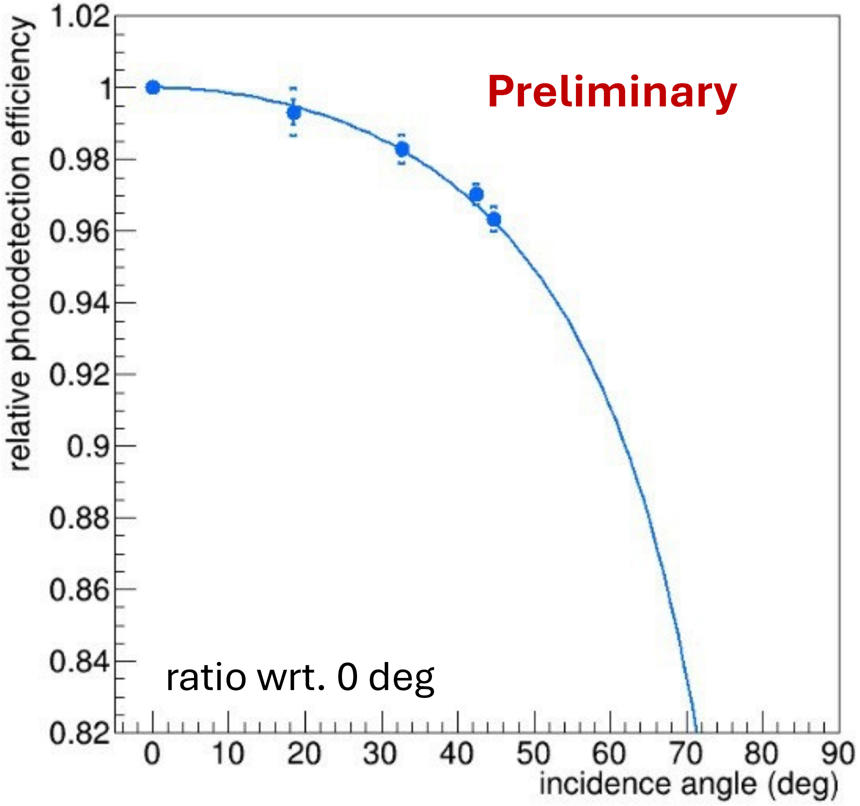
The point before the last one was taked after 20 days and the results are the same (20 days no annealing)



Pseudo-efficiency vs incident angle

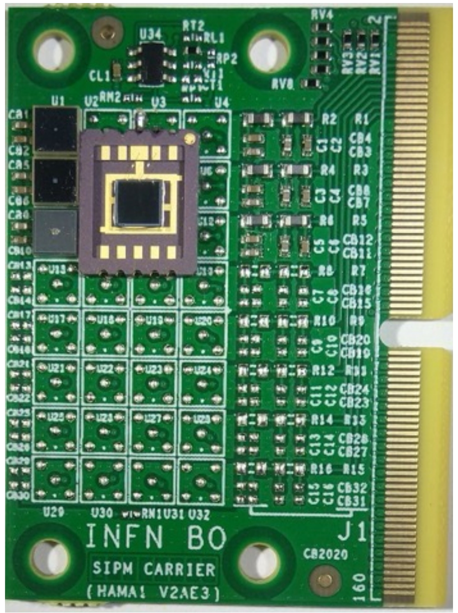




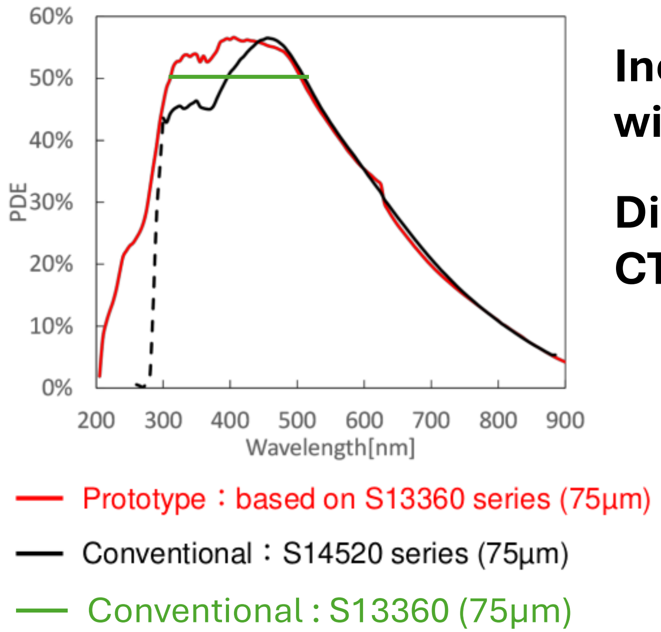


Measurement is still ongoling. Up to now the lost in efficiency doesn’t seem problematic

New Hamamatsu prototype



Prototype S13360-3075-UVE

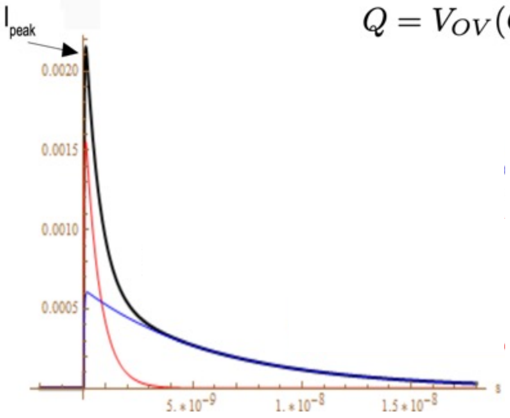


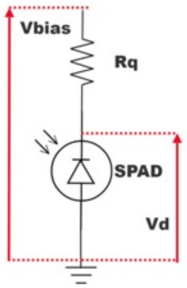
Increased PDE in the blue region thanks to quartz window and different passivation

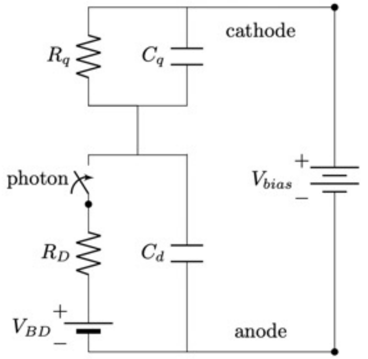
Different quenching resistor: faster signal, less AP and CT

$$I(t) \simeq \frac{Q}{C_q + C_D}\left(\frac{C_q}{\tau_{fast}} e^{\frac{-t}{\tau_{fast}}} + \frac{C_D}{\tau_{slow}} e^{\frac{-t}{\tau_{slow}}}\right)$$

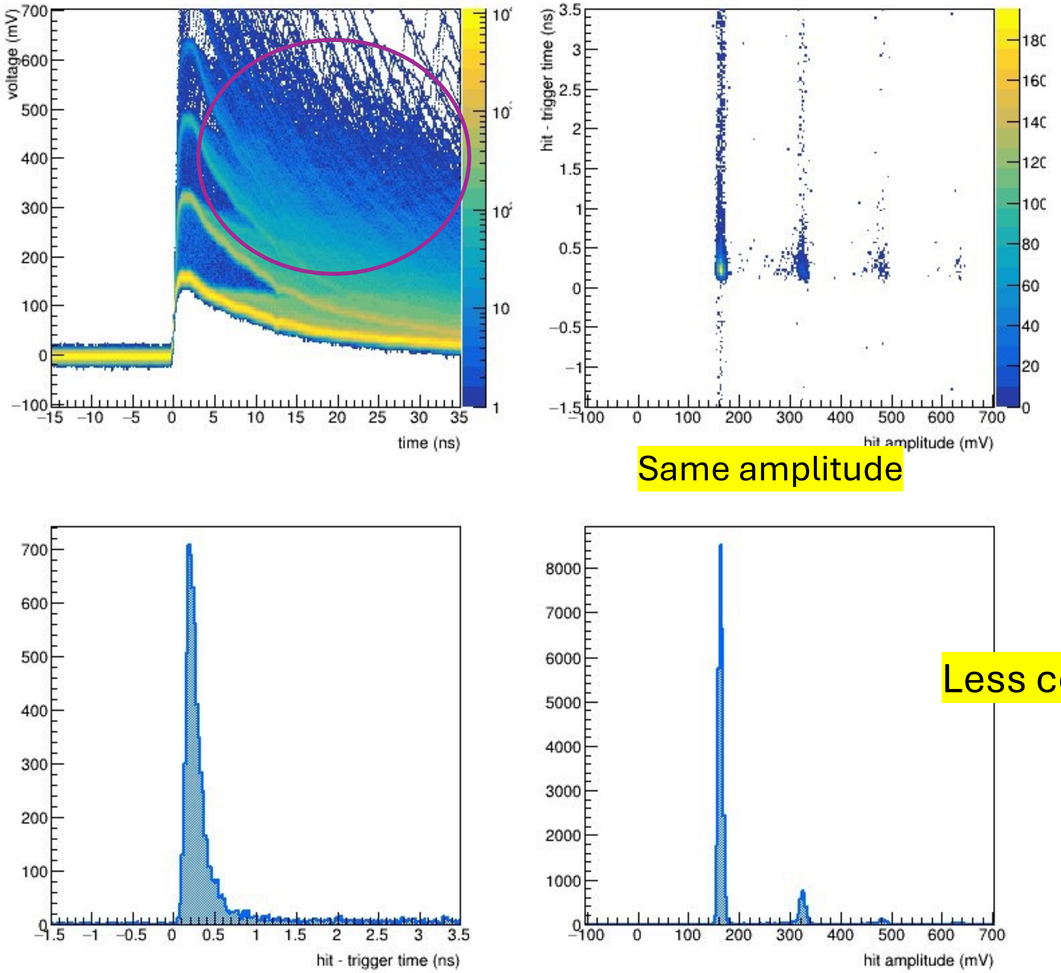
$$Q = V_{OV}(C_D + C_q)$$





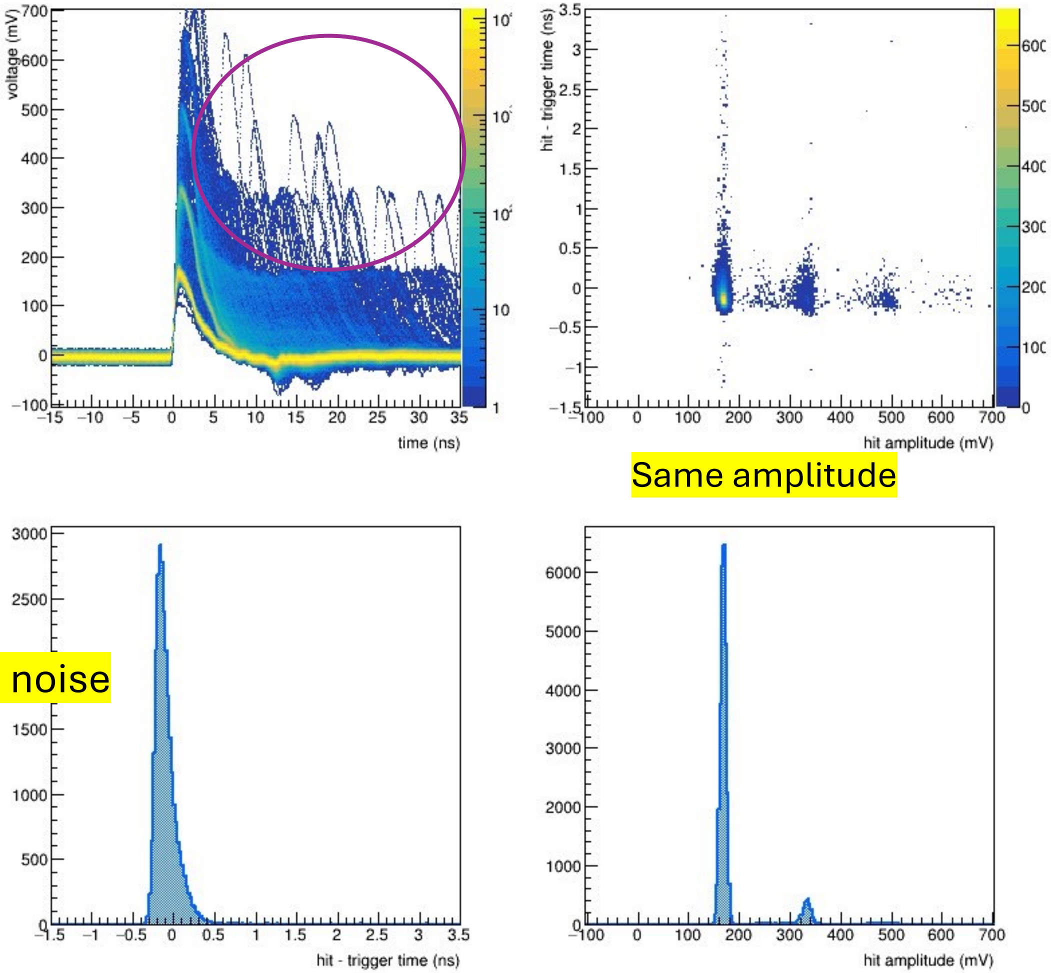


Conventional S13360-3075-VS



Same amplitude

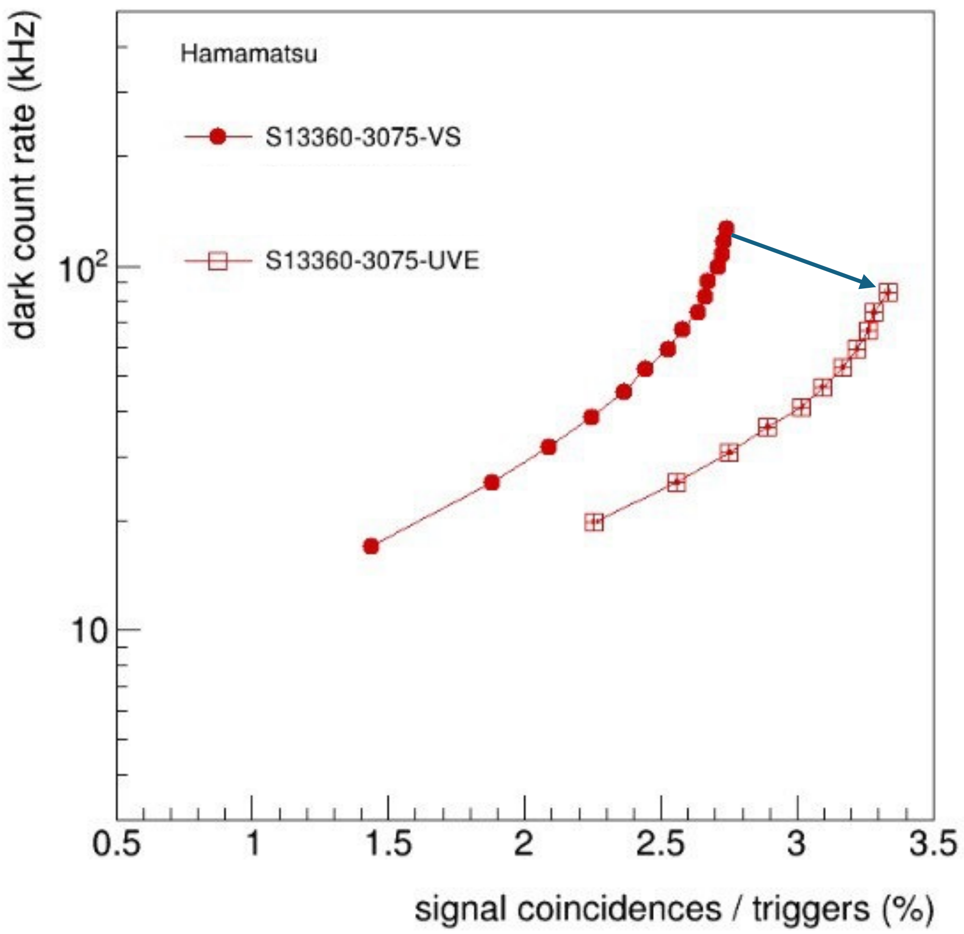
Prototype S13360-3075-UVE



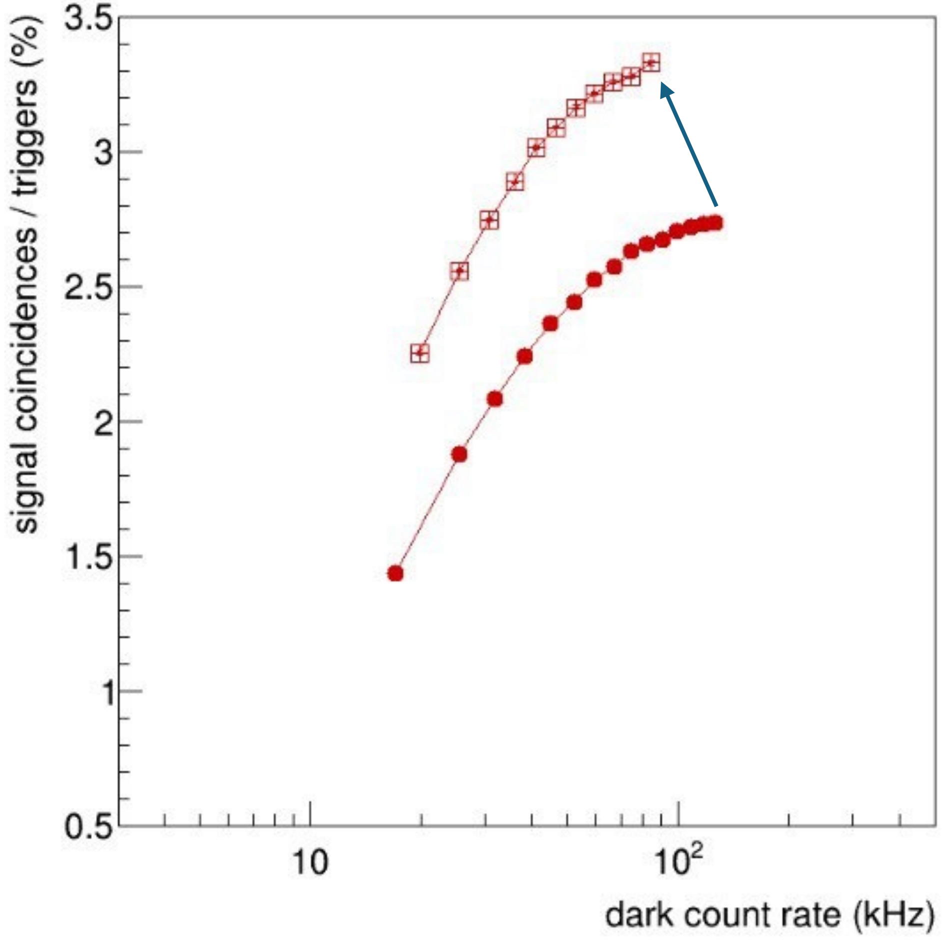
Same amplitude

Faster
Less correlated noise

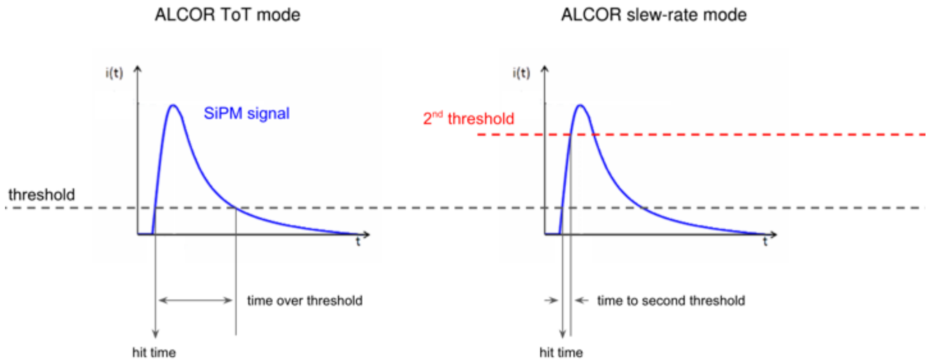
Increase PDE
With lower DCR

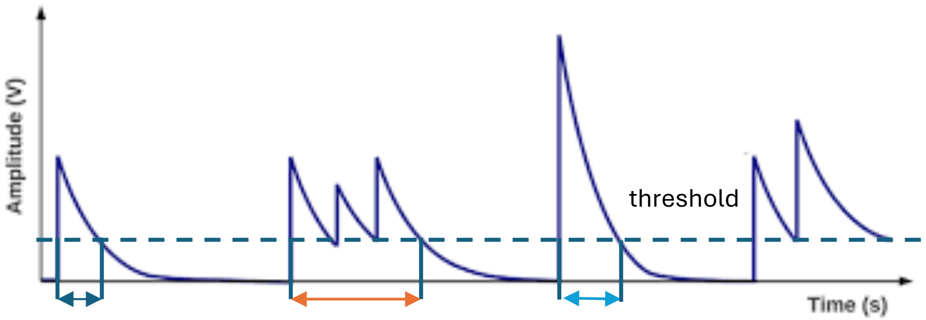


Increase PDE
With lower DCR



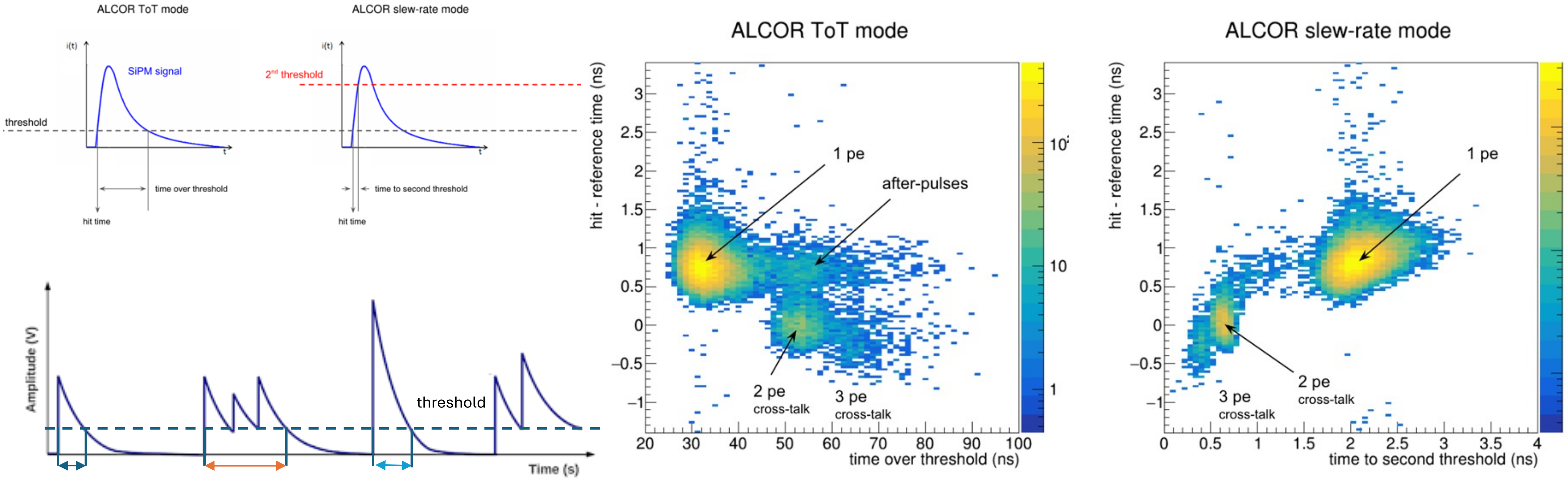
Alcor ToT vs Slew rate mode



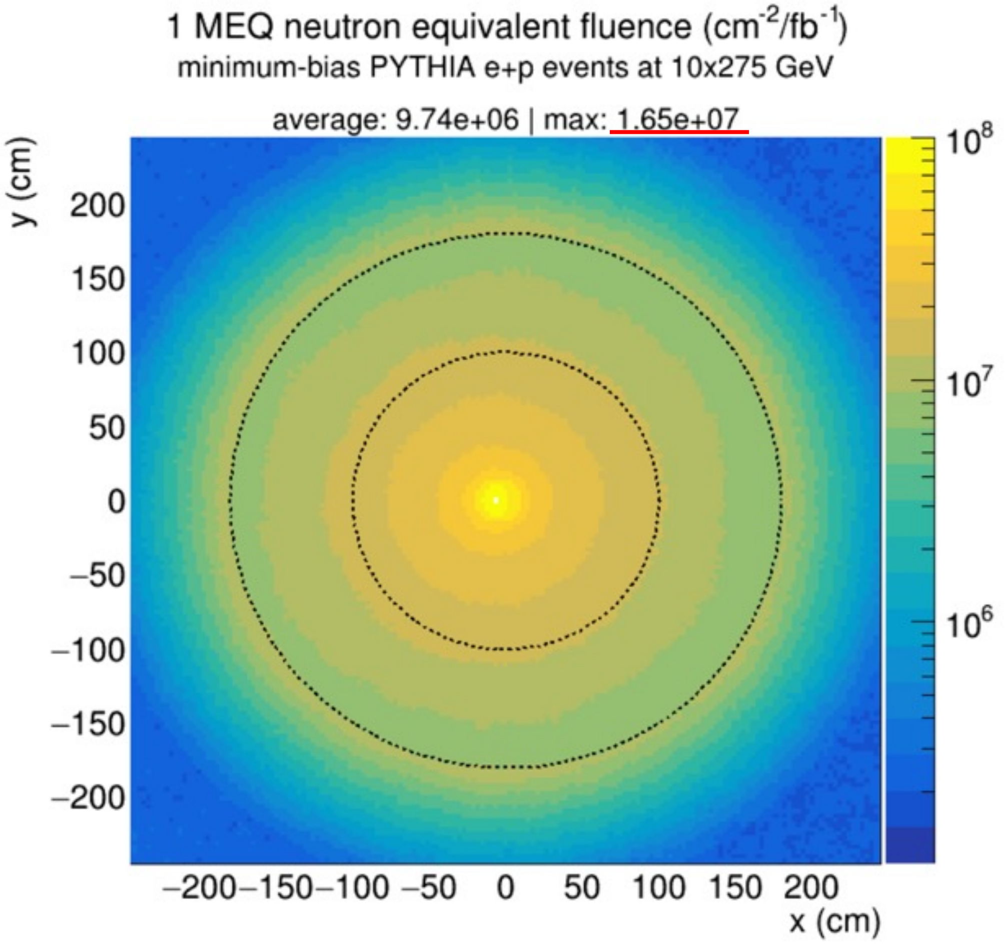


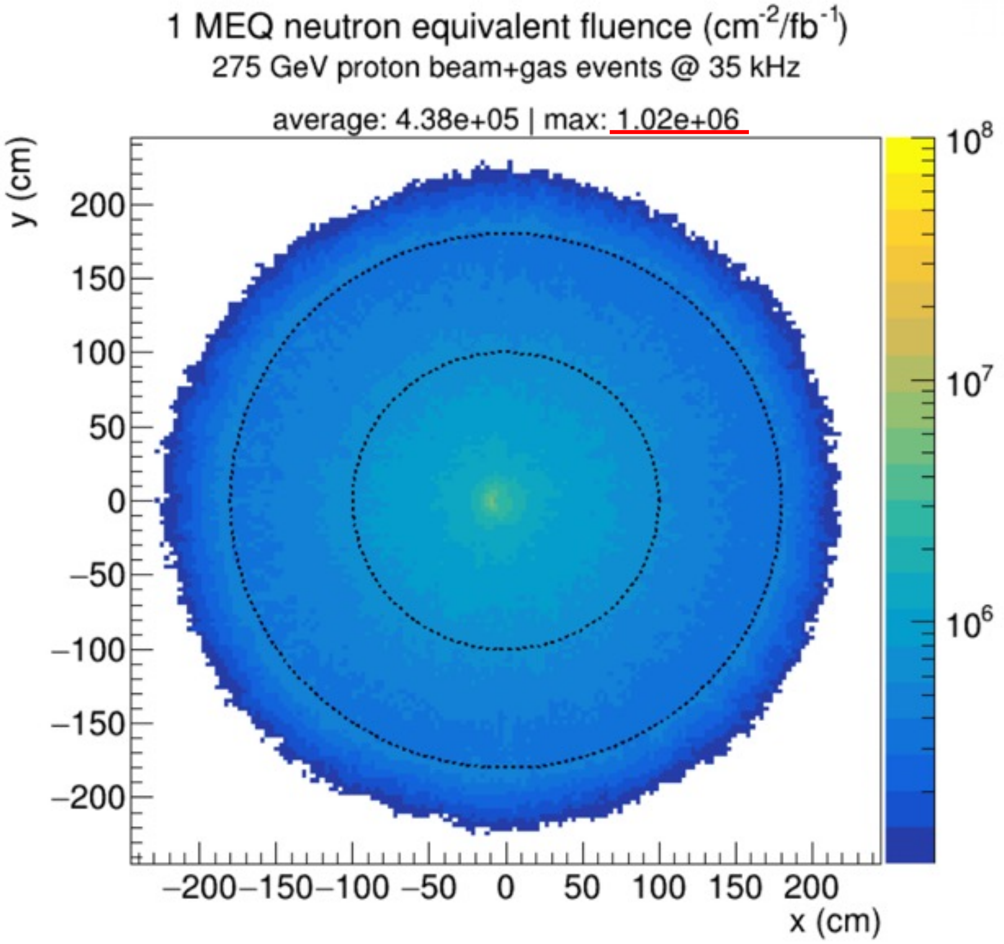
Hit time defined by when the signal goes over a fixed threshold.
Time walk correction is needed: bigger signals arrive in advance.
ToT is proportional to the number of detected PEs (signal amplitude) but what if afterpulses?

Alcor ToT vs Slew rate mode



New dose estimates





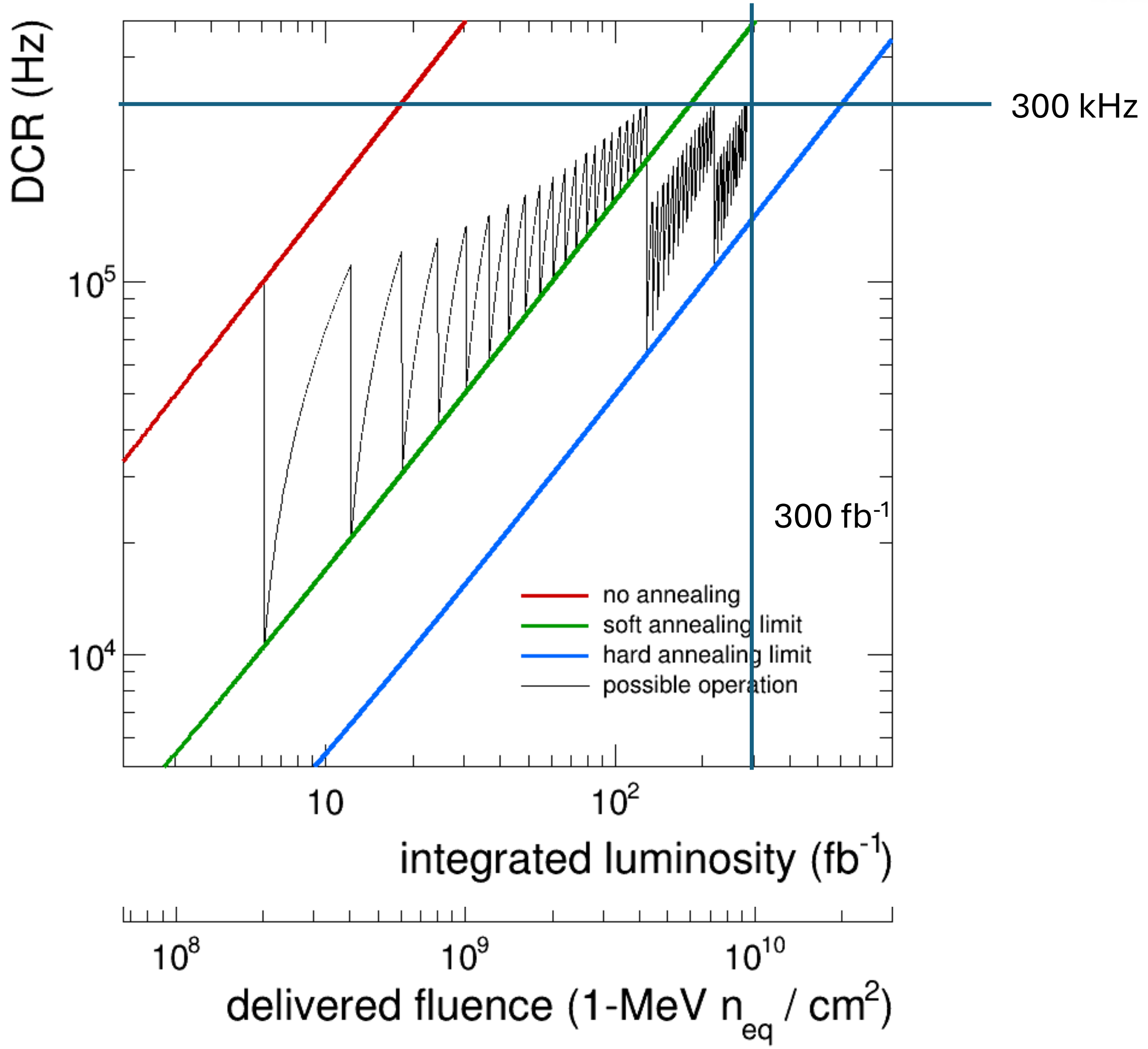
Last year estimation with a safety factor x2
Max fluence ≈ 4.5 10^7 $n_{eq}/cm^2/fb^{-1}$

Latest simulations give us
Max fluence ≈ 1.75 10^7 $n_{eq}/cm^2/fb^{-1}$

New 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
  - 1.75 10^7 n_{eq} / fb^{-1}
  - Add 2x safety factor

Hamamatsu S13360-3050 @ Vover = 4 V, T = -30 C



Proposed operation scenario:
44 soft-annealing cycles and 3 hard-annealing cycles