SiPM news

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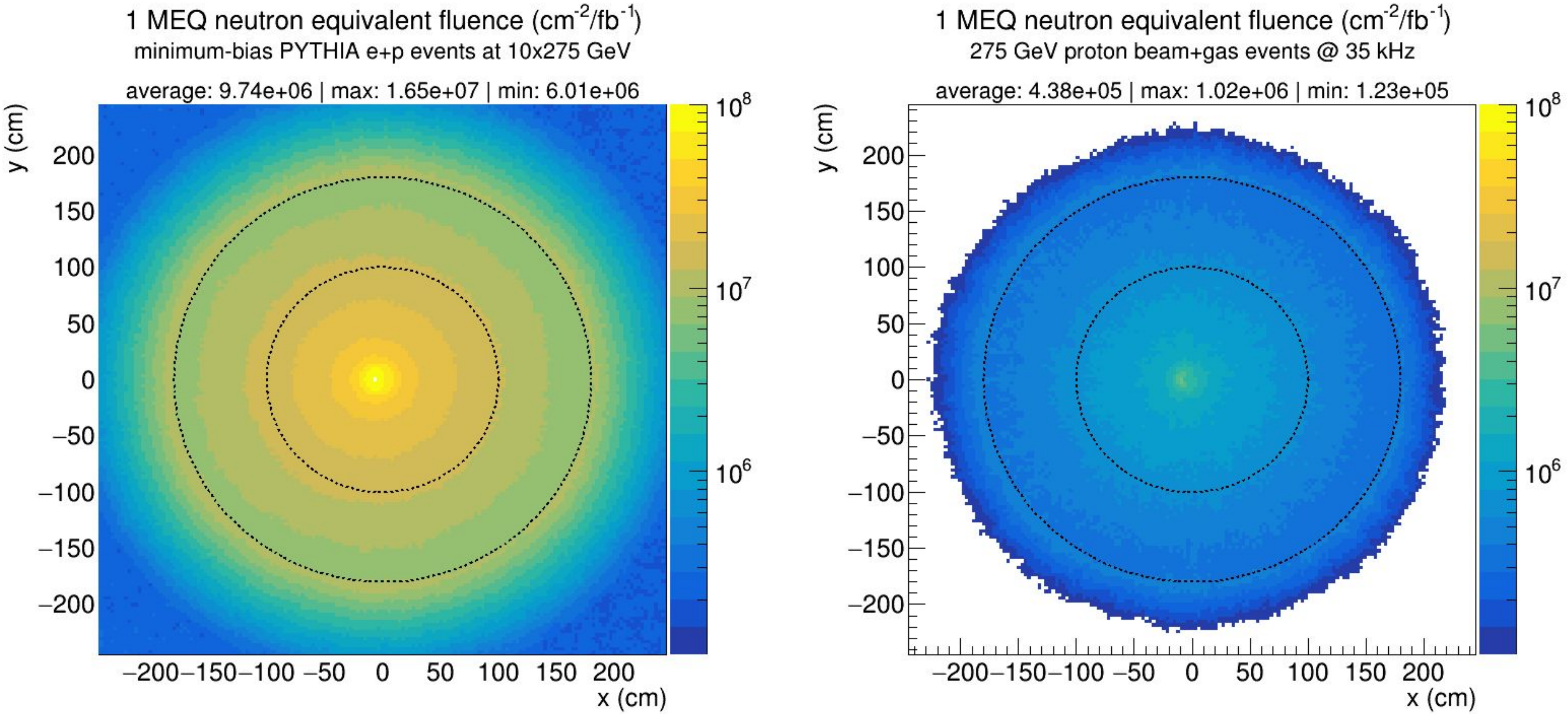
updated radiation estimates

Previous radiation damage estimates



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

Latest radiation damage estimates

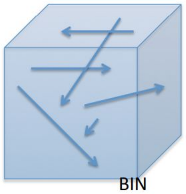
following a discussion with Alex Jentsch about the content of the 3D maps published by the ePIC background group

- **3D maps for doses**
  - bin content (voxel) is already in correct unit (rad)
- **3D maps for fluxes and fluences**
  - bin content (voxel) is a volumetric flux/fluence (cm^{-3}) and not a proper flux/fluence
  - one needs to multiply by a length
  - in Fluka this is done multiplying by the track length in the scoring volume (voxel)
- **what does it mean?**
  - our estimates need to be multiplied by the track length in the 3D bin
  - we don't know it, has to be done at simulation stage
  - estimate it by using the average length in volume
    - the 3D volume is 3 x 3 x 5 cm^3
    - average length is ~ 3.65 cm
  - **estimates of fluence/fluxes increase by 3.65x**

FLUKA

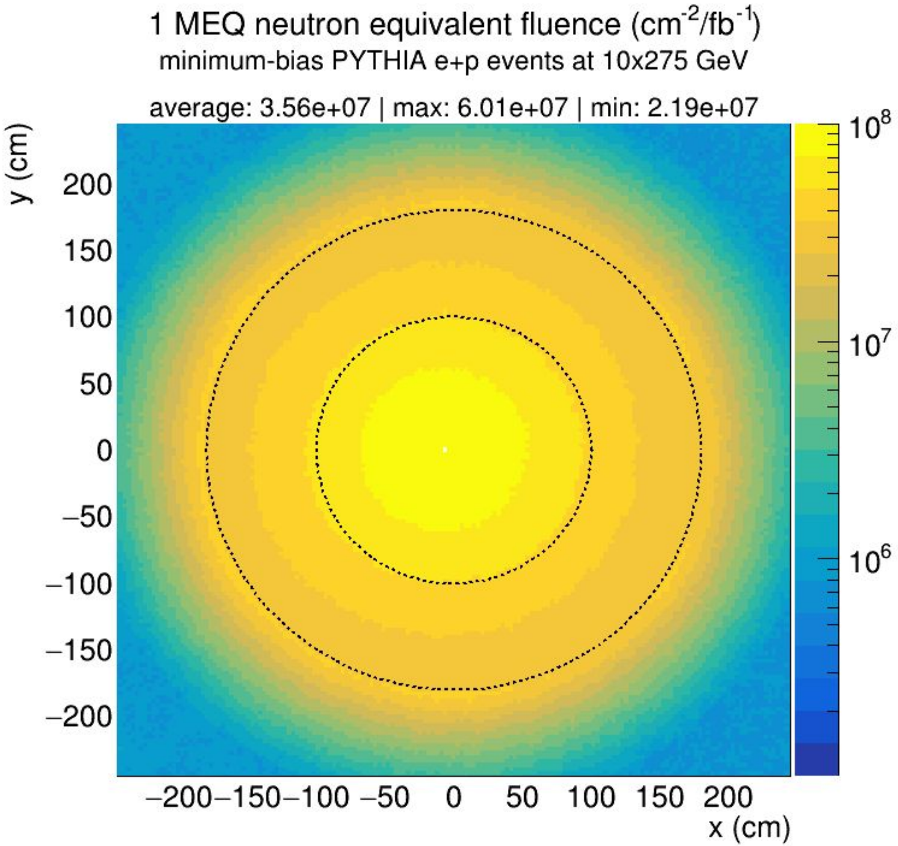
Si1MeV neutron equivalent fluence

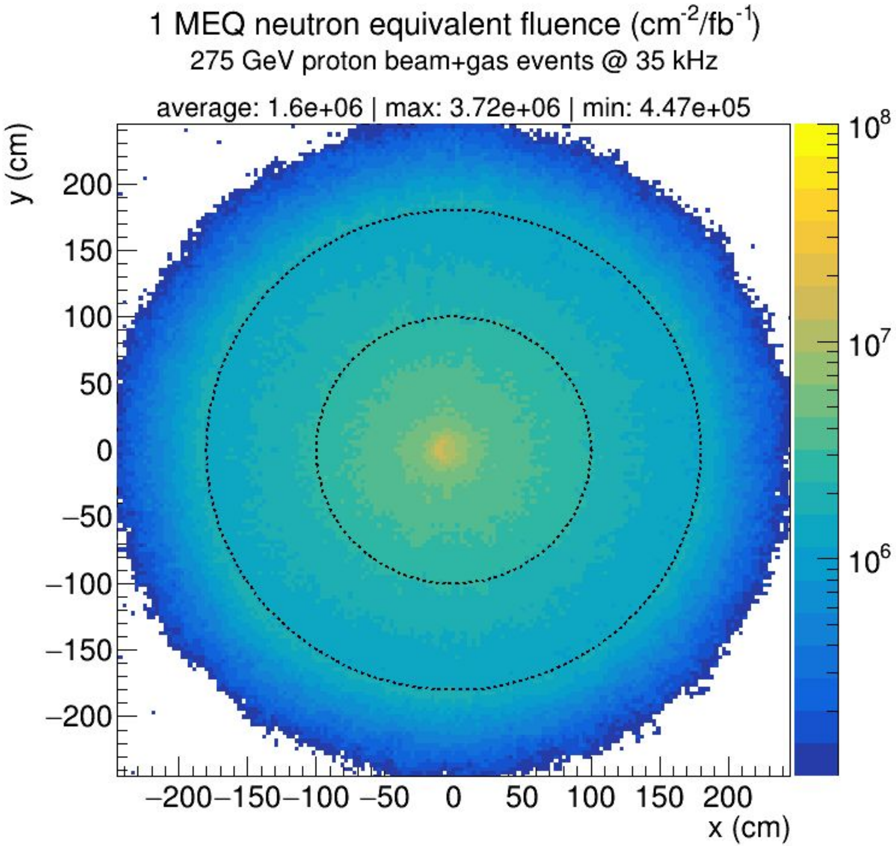
- USRBIN scoring
- What is it? What unit?
  - USRBIN scoring of SI1MEVNE: a particle fluence [cm-2], again per primary
  - In reality it's more a density of particle tracks
- Formula:



$$\frac{\sum_{i=0}^{N_{\text{tracks in bin}}} \left|\vec{l}_i\right| [cm]}{V_{bin} [cm^3]}$$

Latest radiation damage estimates (same simulation data, with a factor 3.65)





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

Updated ageing model

model input from R&D measurements (up to 2022)

- DCR increase: 500 kHz/10^9 n_{eq}
- residual DCR (online annealing): 50 kHz/10^9 n_{eq}
- residual DCR (oven annealing): 15 kHz/10^9 n_{eq}

1-MeV neq fluence from background group

- 6.4 10^7 n_{eq} / fb^{-1}
- this is the max fluence, SiPM closest to be beam line
- without safety factor

all parameters are the same used for the previous model
only neq/fb^{-1} is updated to new estimate, without safety factor
previously we had a 2x safety factor
we increased by a 3.65x factor
→ the plot shows a slightly faster ageing than shown before

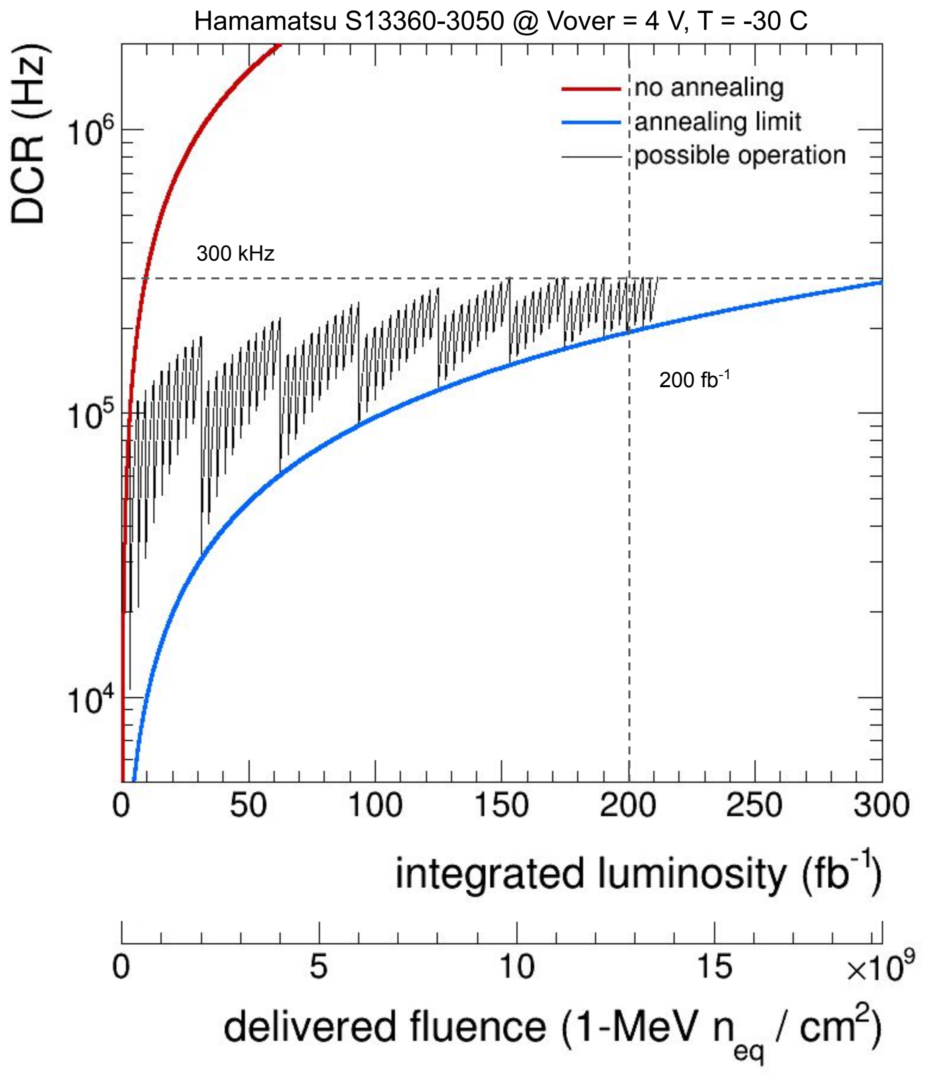
limiting integrated lumi did not drastically change
→ from 300 fb^{-1} to 200 fb-1

but always notice that this plot is made for a specific operation condition of SiPM sensors → **risk mitigations are in place**

- 4 V over voltage, reduce to 3 V and DCR will decrease
- T = -30 C operation, reduce to -40 and DCR will decrease

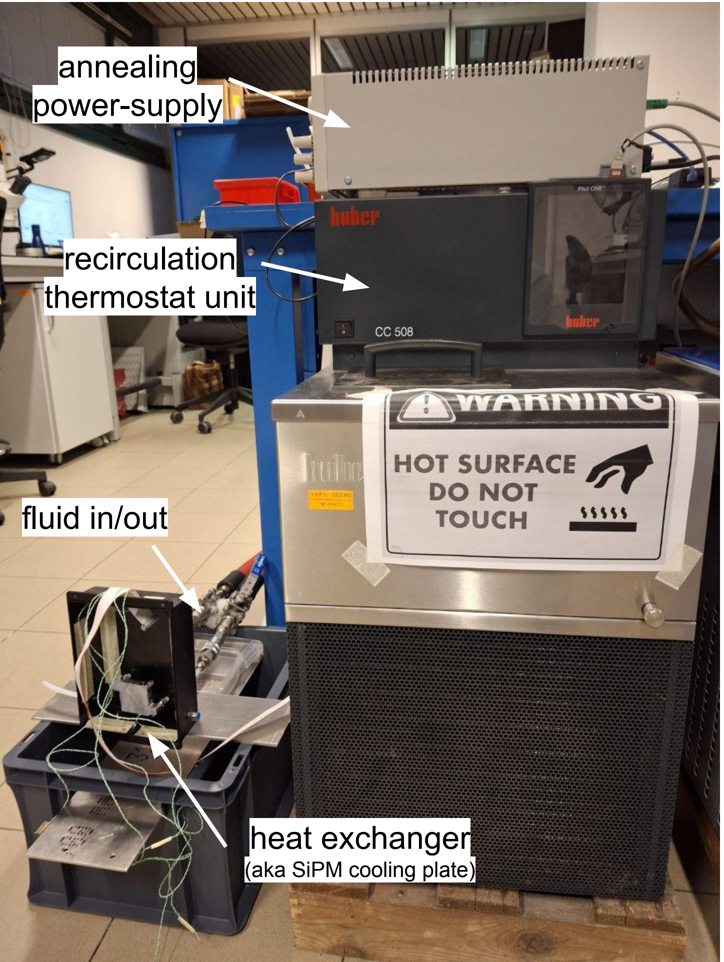
also notice that simulations using a 1 ns timing window indicate that **300 kHz is a SAFE limit with NO impact on performance**

- time resolution might allow smaller timing window,



annealing tests

Forward-bias annealing



so far: annealing studies always performed with SiPMs "floating in the air" temperature measurements only on the SiPM surface with a thermal camera

news: mounted a fluid-assisted annealing system to perform the very same studies but with a controlled temperature on the SiPM PCB carrier board

one SiPM board was mounted (not shown in the picture) in thermal contact onto the heat exchanger (aka SiPM cooling plate). With the help of the fluid and of the thermostat system the cooling plate was kept at a constant temperature.

measurements of the temperature of

- cooling plate
- SiPM PCB board away from sensor
- SiPM sensor surface

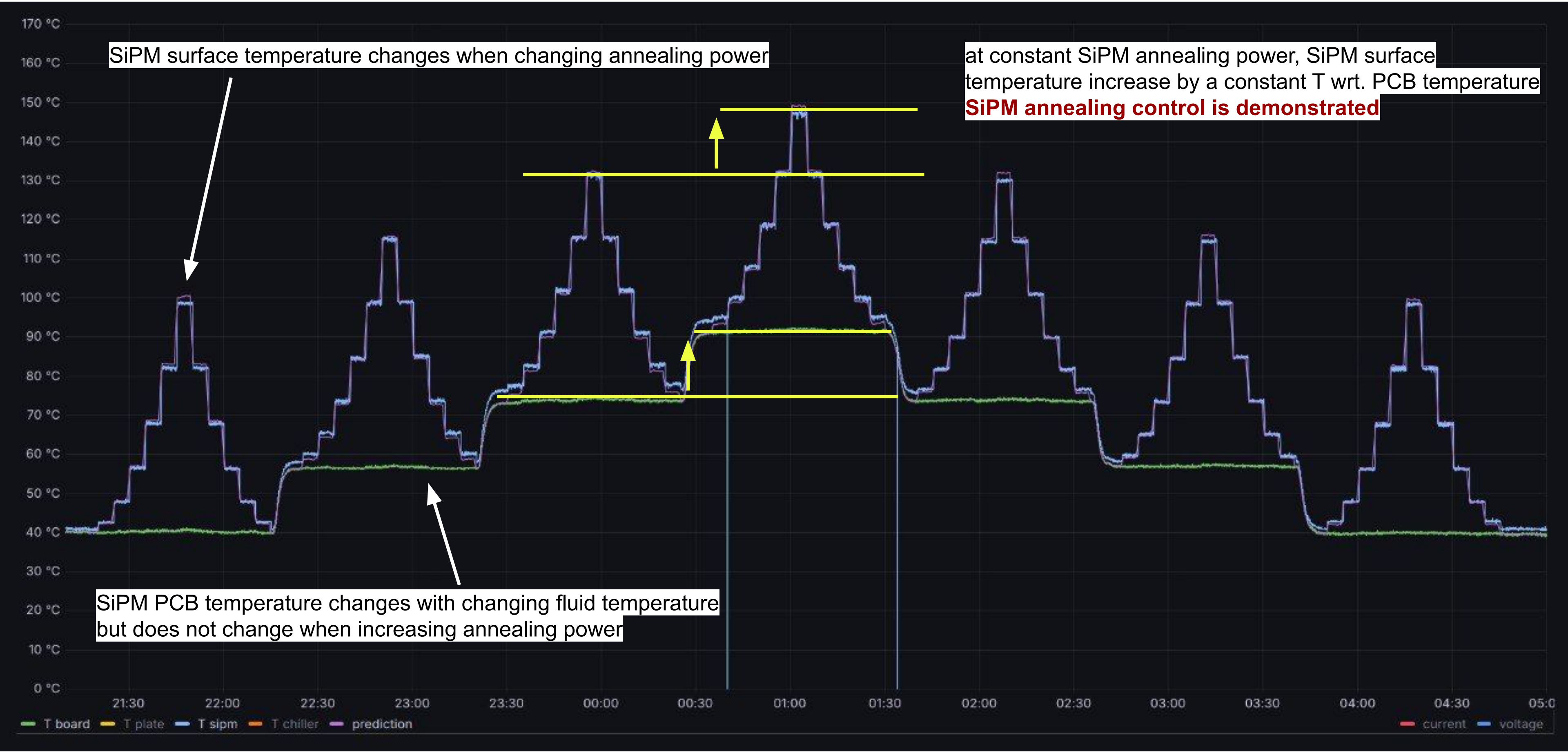
performed in this test with help of thermal camera (not shown in the picture).

the SiPMs where connected to the power-supply unit that could provide forward-bias voltage for the self-induced Joule annealing procedure.

measurements performed at different combinations of the

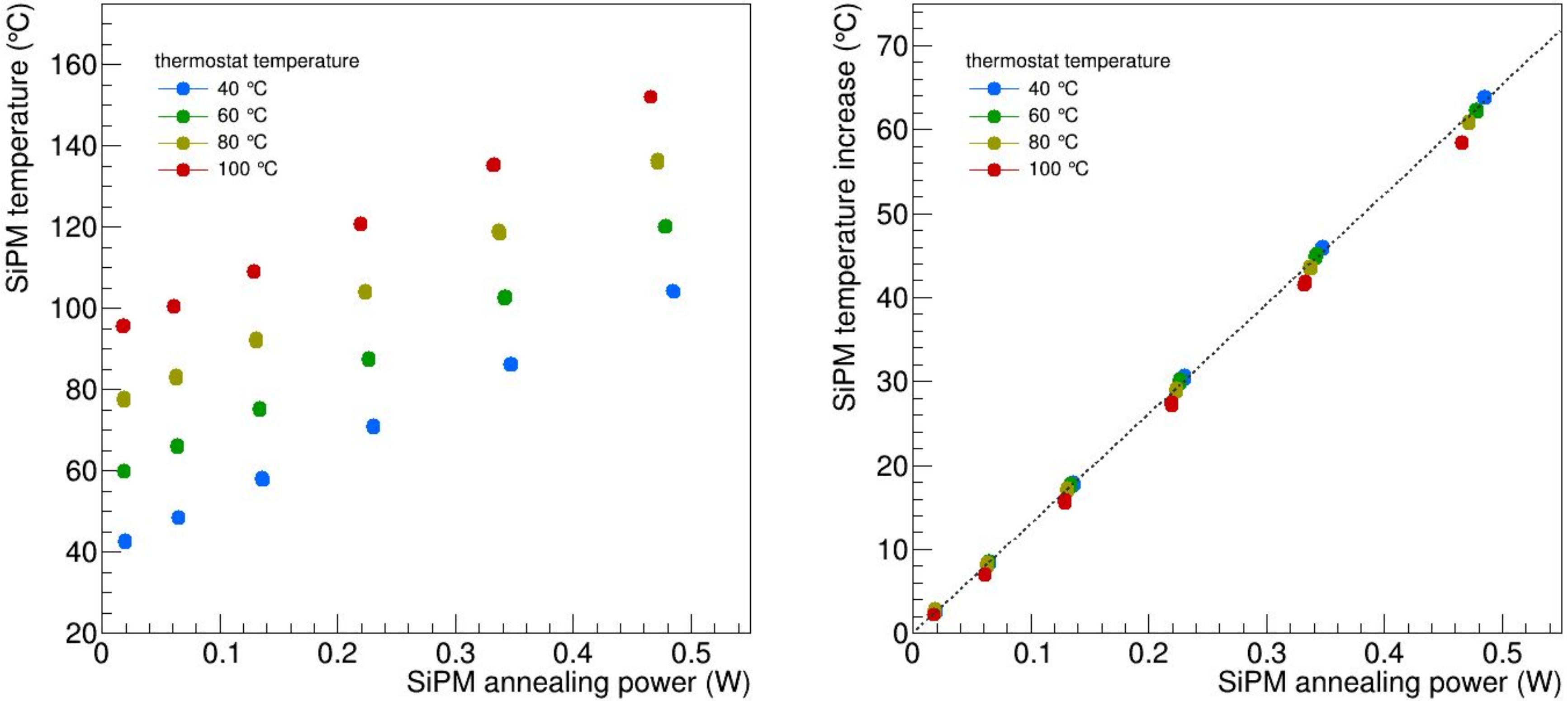
- fluid temperature
- annealing power

Forward-bias annealing control



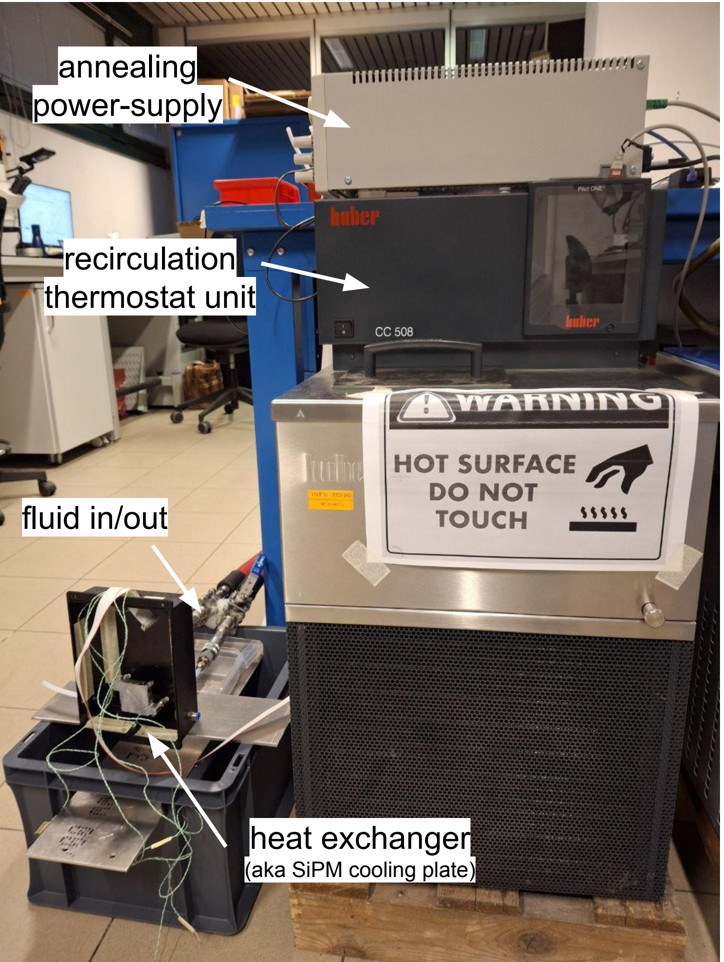
Forward-bias annealing control

if we measure the temperature of the SiPM PCB board (we do, we have 4 temperature sensors in the PDU) and we know the amount of annealing power we can predict the temperature reached on the SiPM surface. **SiPM temperature increase is proportional to the annealing power.**



SiPM cooling

SiPM cooling with silicone fluid



so far: had troubles to prevent silicone fluid leaks on the SiPM cooling plates

news: we found the solution to that, slight modification to the cooling plate and now we have no leaks at all

so, we could get into the business of testing the SiPM cooling approach expected in ePIC, namely using only a fluid circulating at low temperature in the cooling plate.

fluid is a low-viscosity silicone fluid that allows (in our system) to be used in the -60 < T < 115 C range. There are more performing fluids with lower viscosity at low temperature (which we acquired). But in our system it cannot be used at high temperature, so we stick to what we have for the moment.
Notice that in the potential ePIC cooling system (closed system) the more performing fluid would be ok to use in the -90 < T < 170 C range.

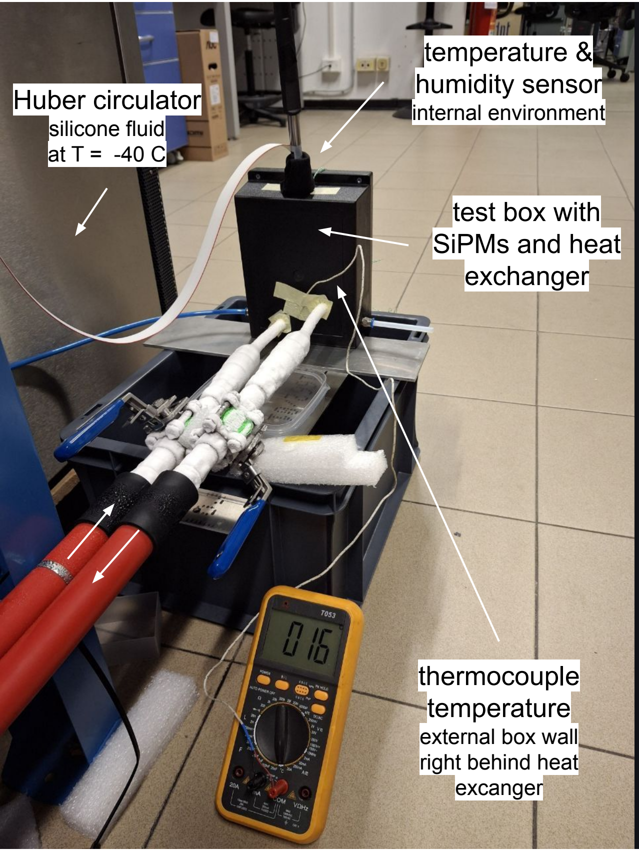
The configuration is similar to this one, but the box needed to be closed with dry air circulation to prevent frost on the SiPM when cooled at sub-zero temperature.

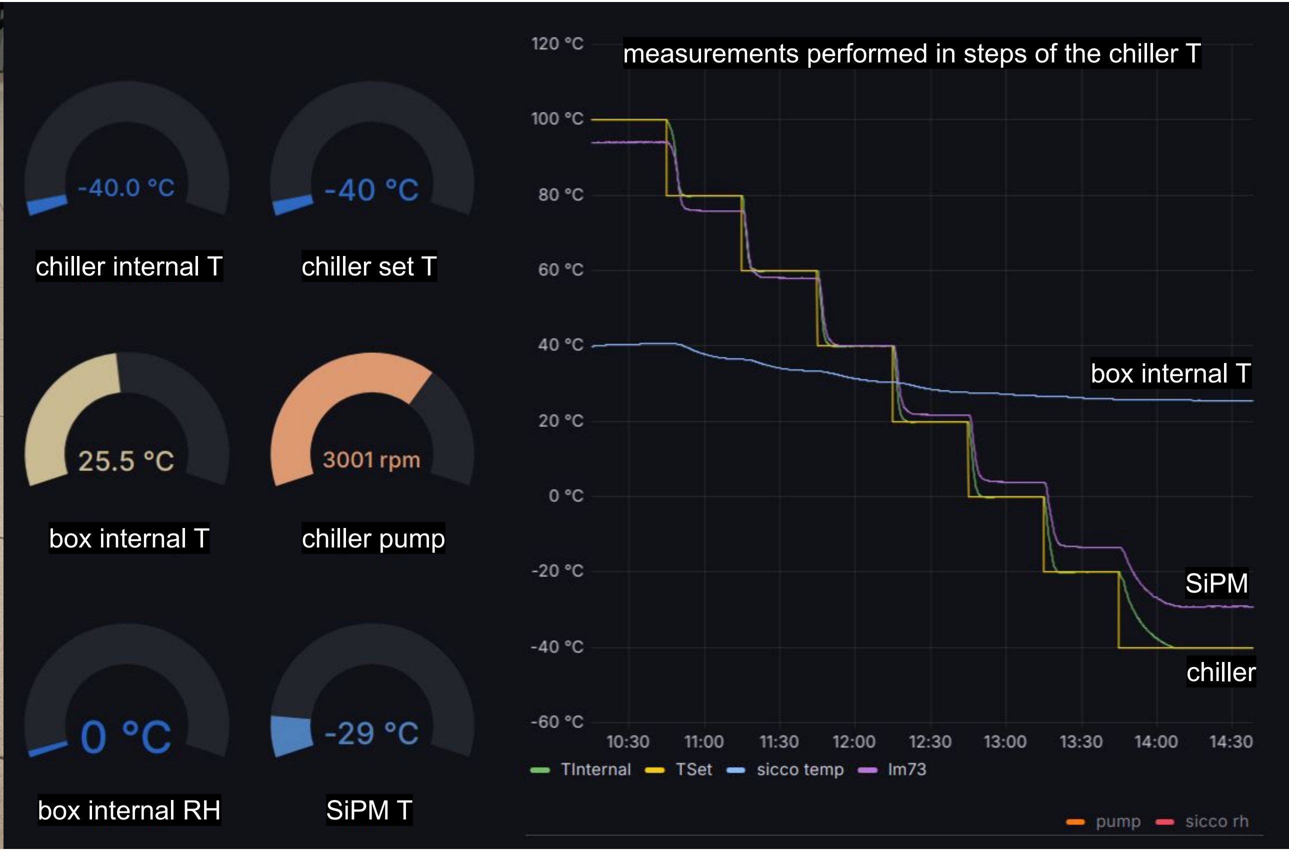
temperature measurements could not be performed with thermal camera.
Using temperature sensor mounted on the SiPM PCB board.

SiPM cooling with silicone fluid

Huber circulation system with low-viscosity silicone fluid entering the test box with inside dRICH SiPM heat exchanger and SiPM board

measurements performed in heating mode (Tchiller = 100 C) and in cooling mode (Tchiller = -40 C)
heat/cold losses during fluid transport, although **could reach T = -30 C on SiPM board** from T = -40 C
little impact on the internal and external environment, heating at T = 100 C with fluid works (annealing)





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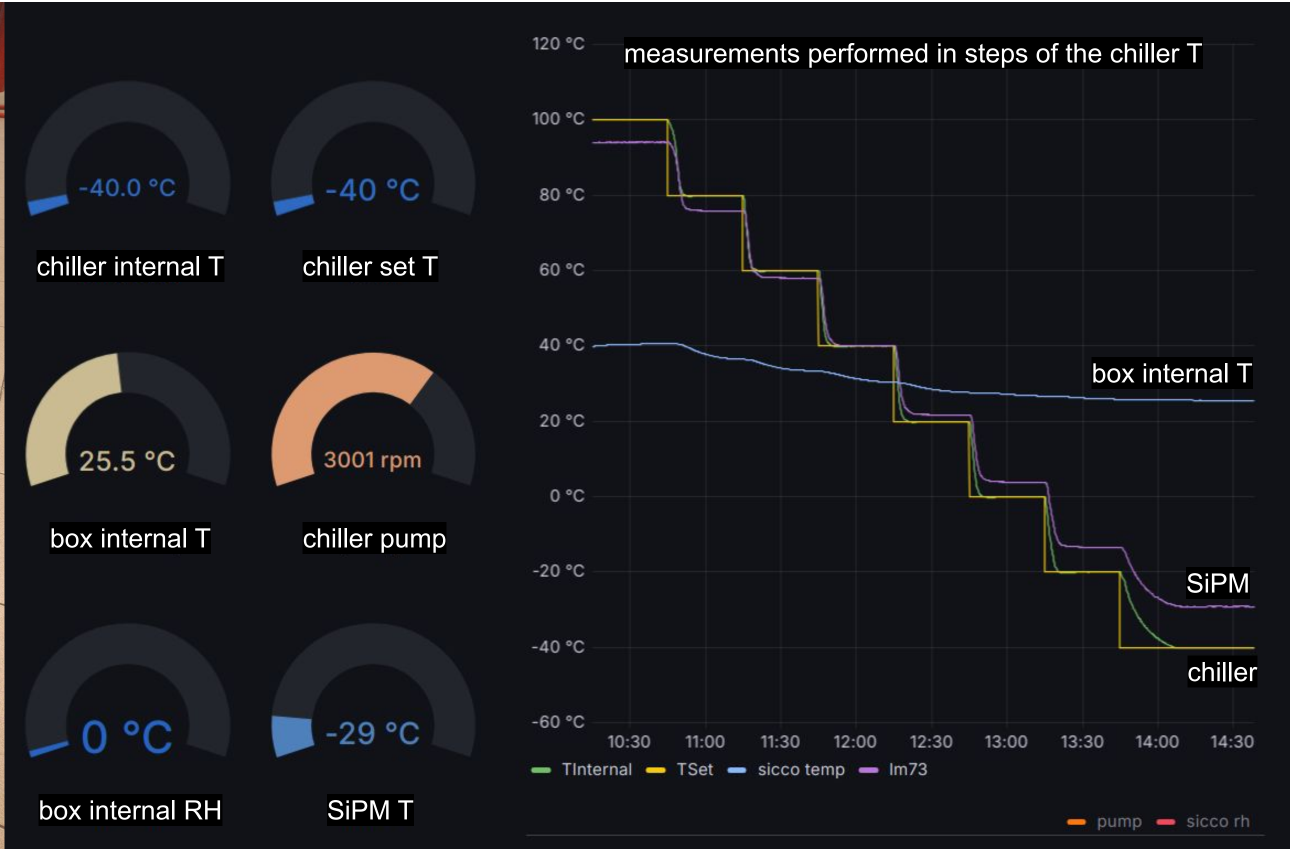
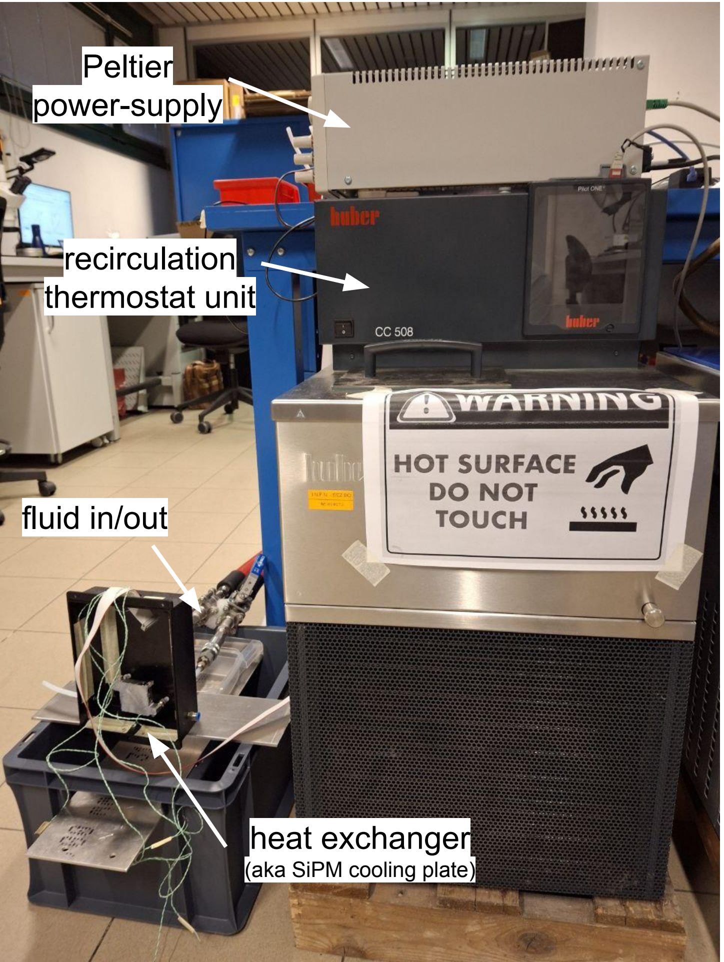


hybrid cooling
fluid + Peltier

Hybrid SiPM cooling with silicone fluid and a Peltier module



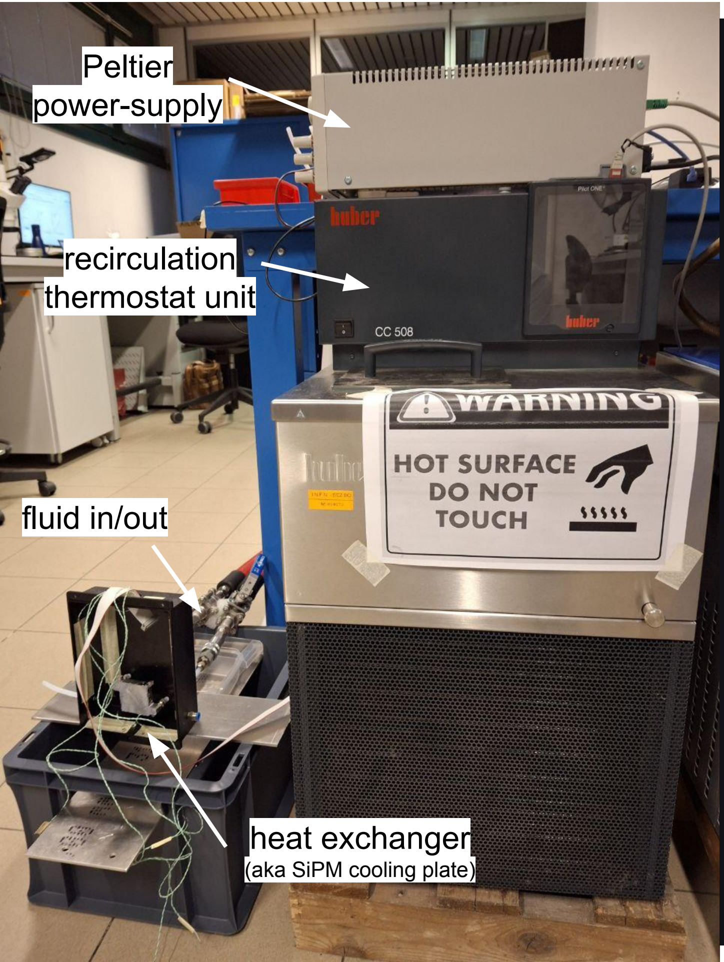
this is a brand new study, that was planned within eRD110 (but not funded)

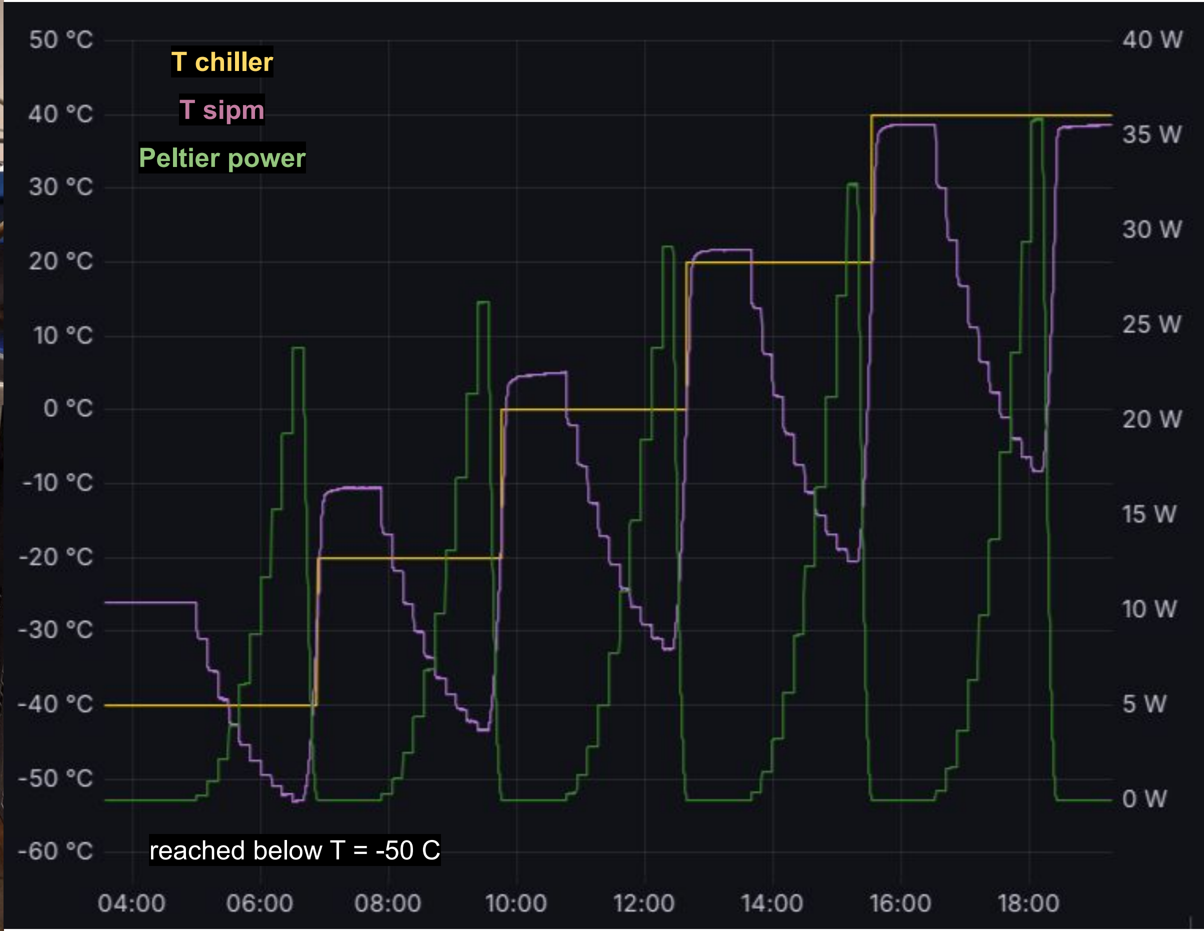
back to the same test system.
we added a Peltier module between the cooling plate and the SiPM PCB board
this is a 40 x 40 cm Peltier module, used in beam test to cool full PDU

and we ran tests with the following combinations

- changing the temperature of the thermostat
- changing the power to the Peltier module

Hybrid SiPM cooling with silicone fluid and a Peltier module





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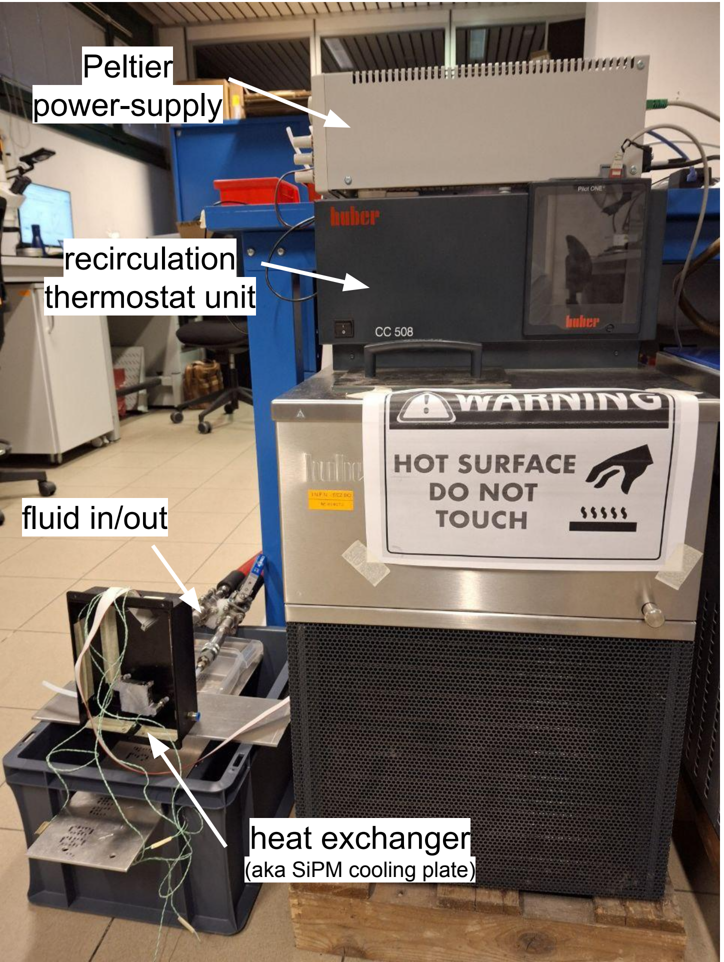
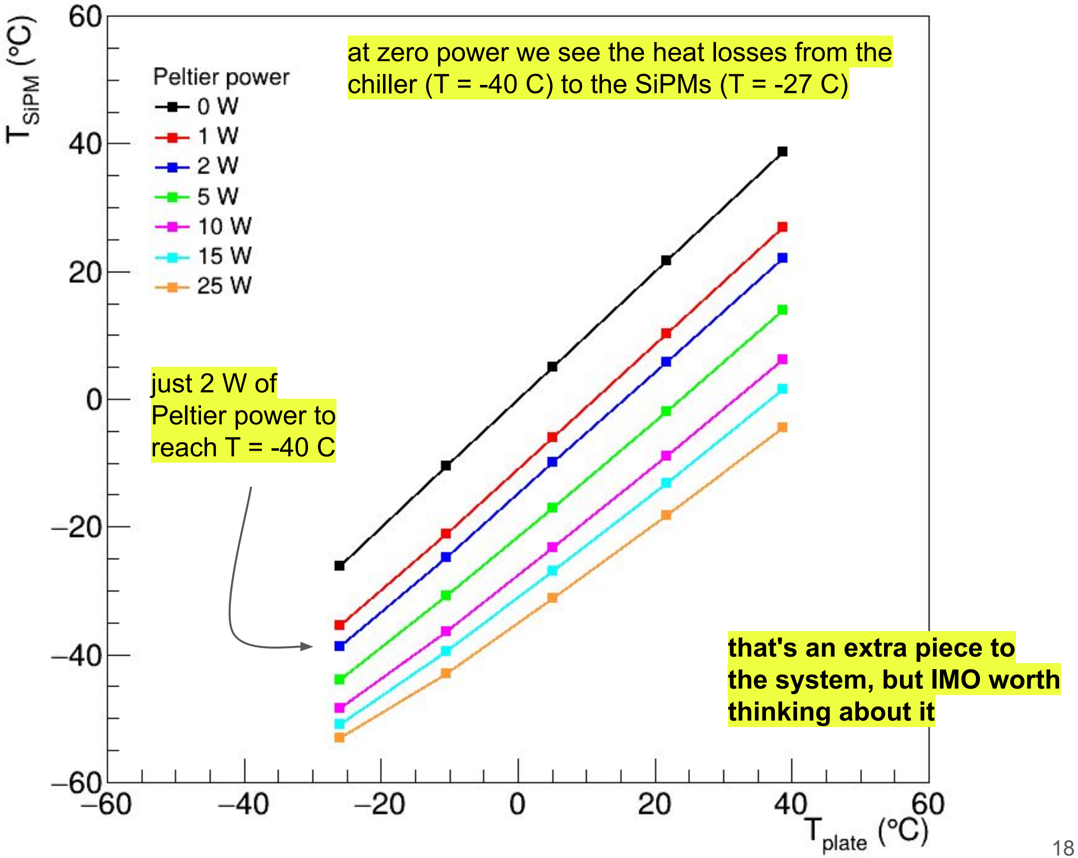
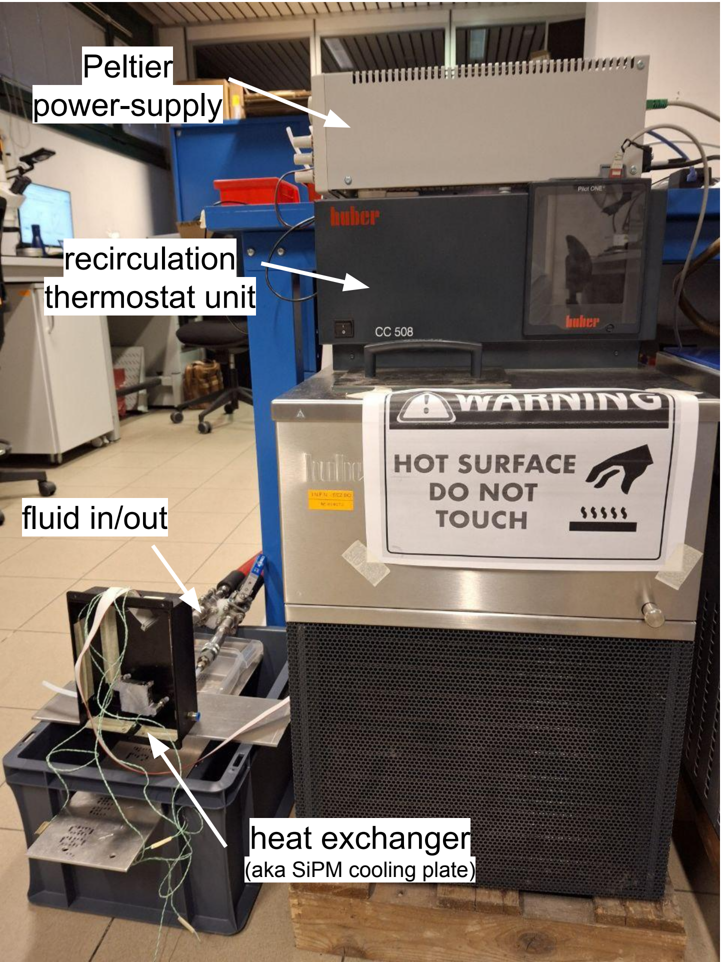




hybrid annealing
fluid + Peltier

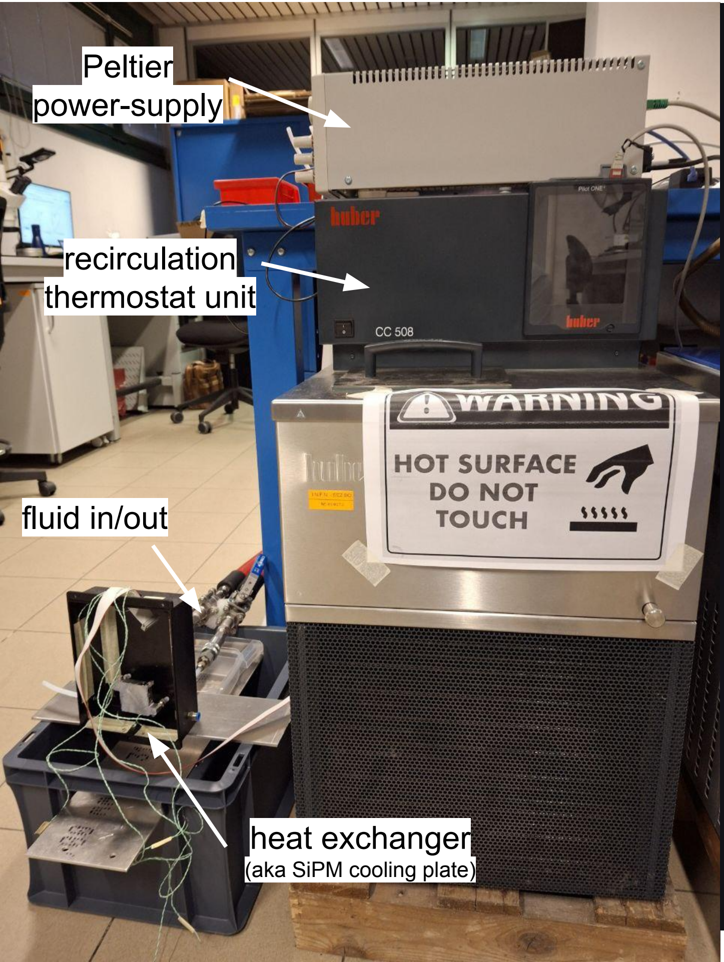
Hybrid SiPM cooling with silicone fluid and a Peltier module

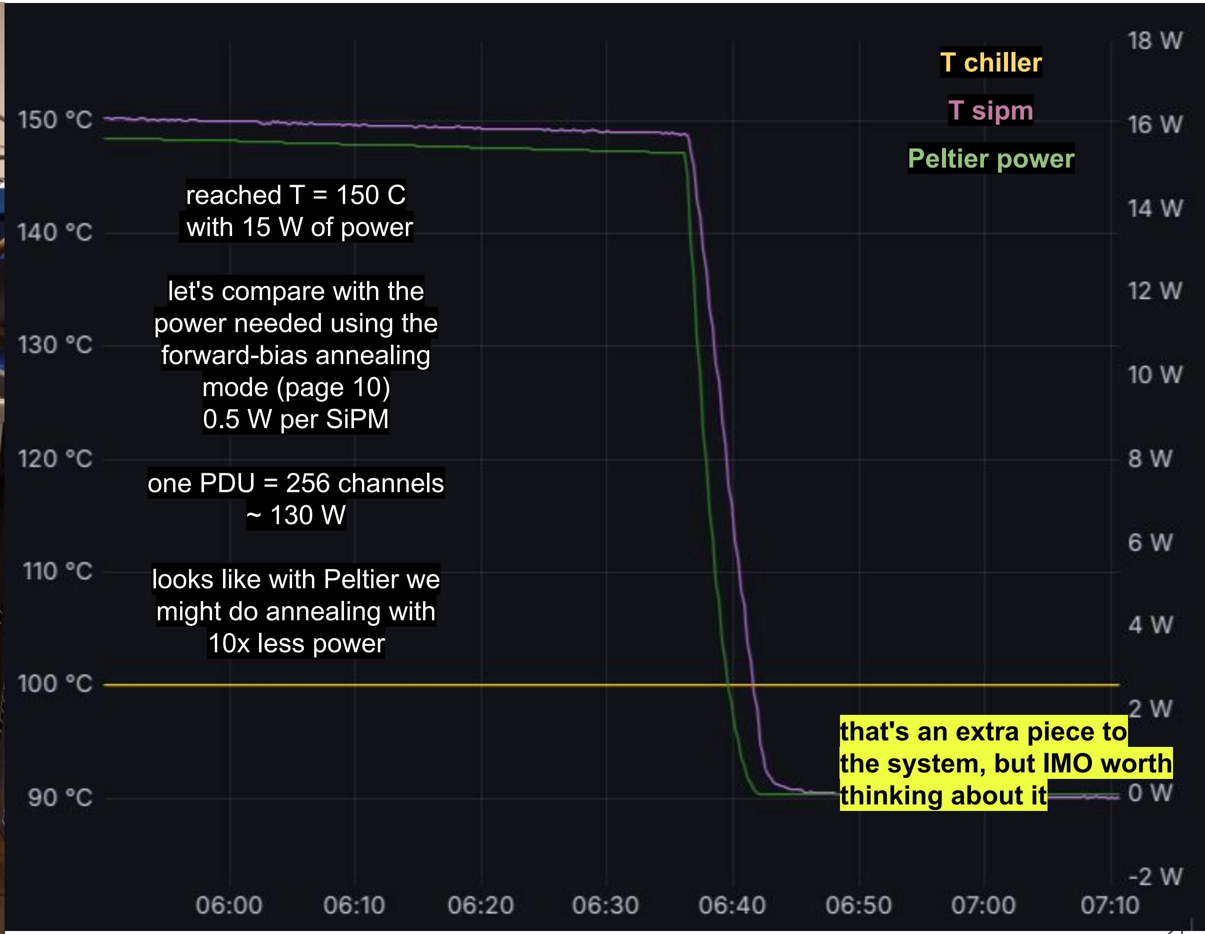


annealing with Peltier was also thought some time about

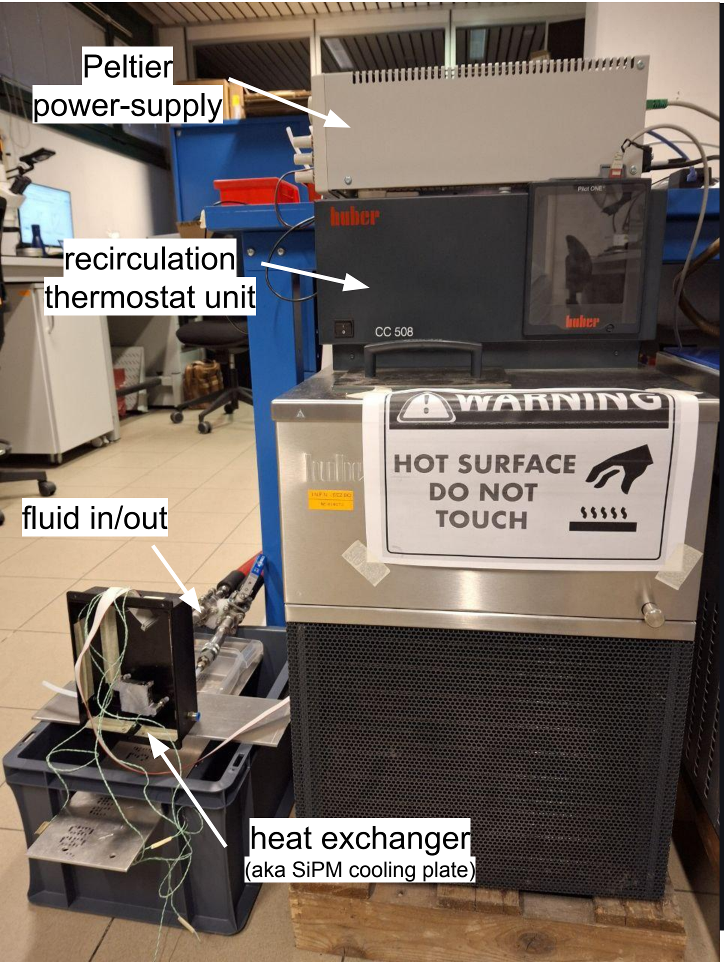
back to the same test system.
we added a Peltier module between the cooling plate and the SiPM PCB board
we swap the direction of the Peltier current, and now we use it to heat SiPMs

Hybrid SiPM cooling with silicone fluid and a Peltier module





Hybrid SiPM cooling with silicone fluid and a Peltier module



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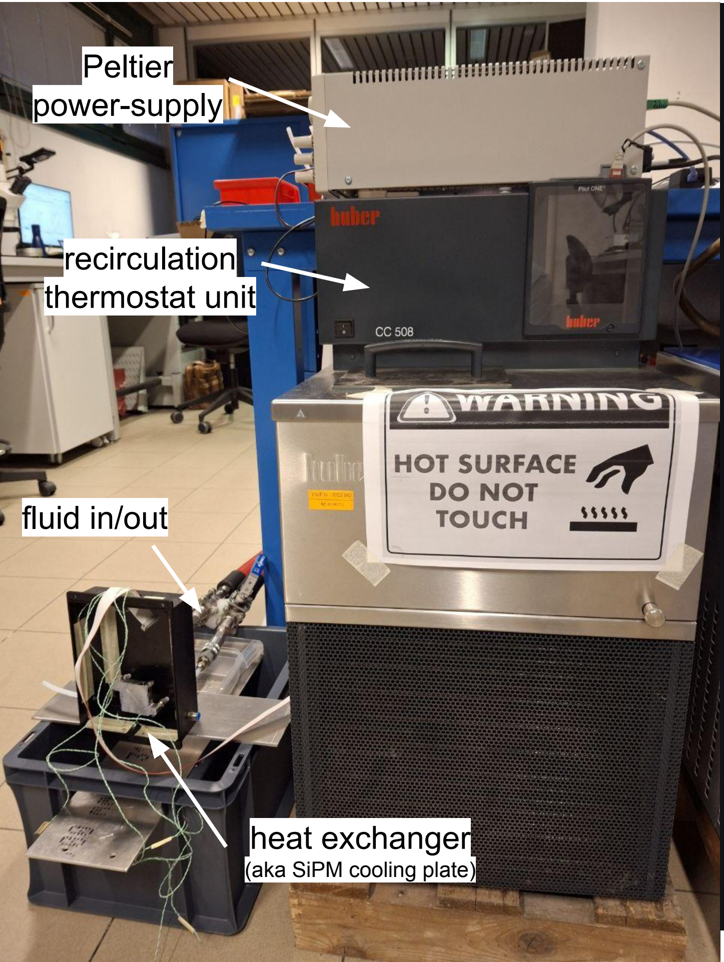

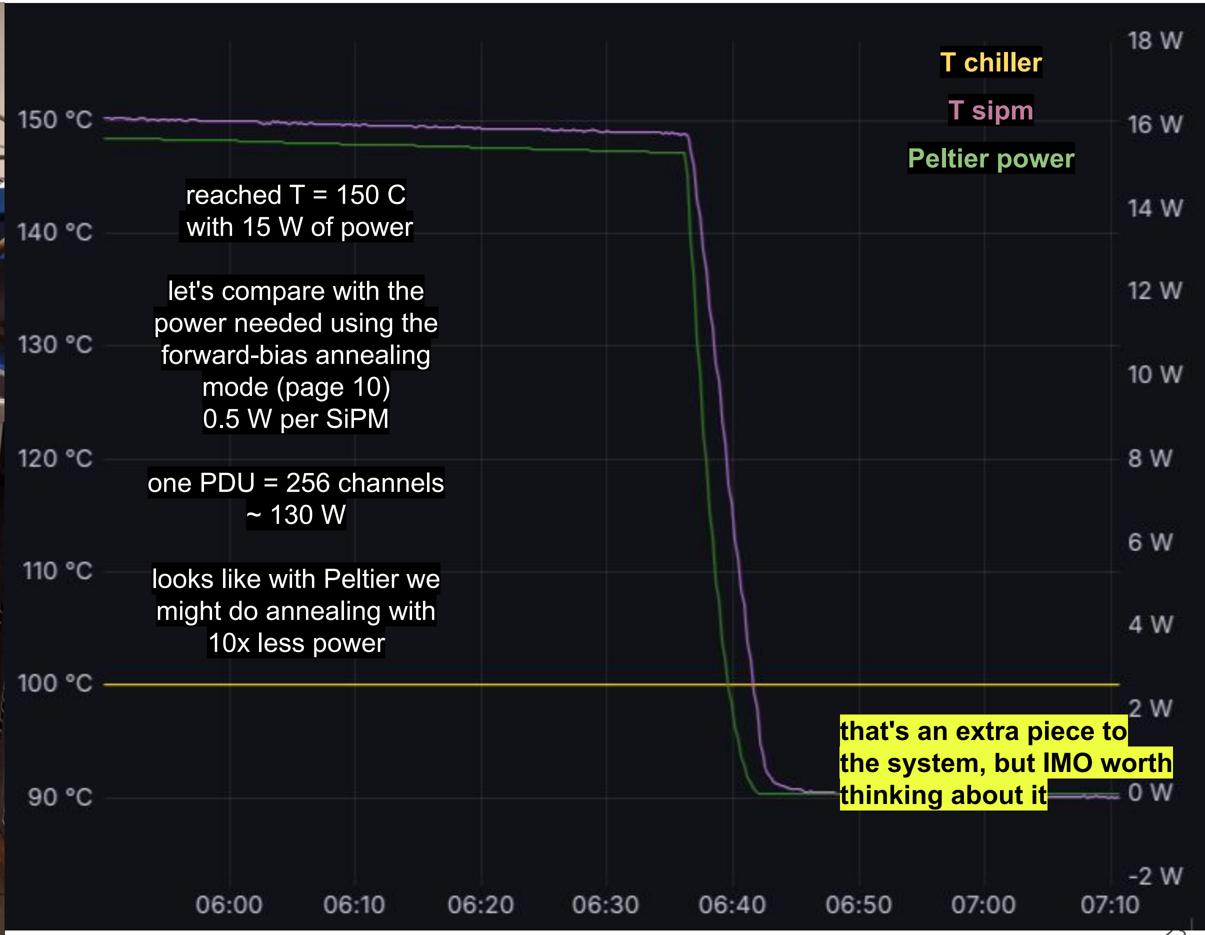

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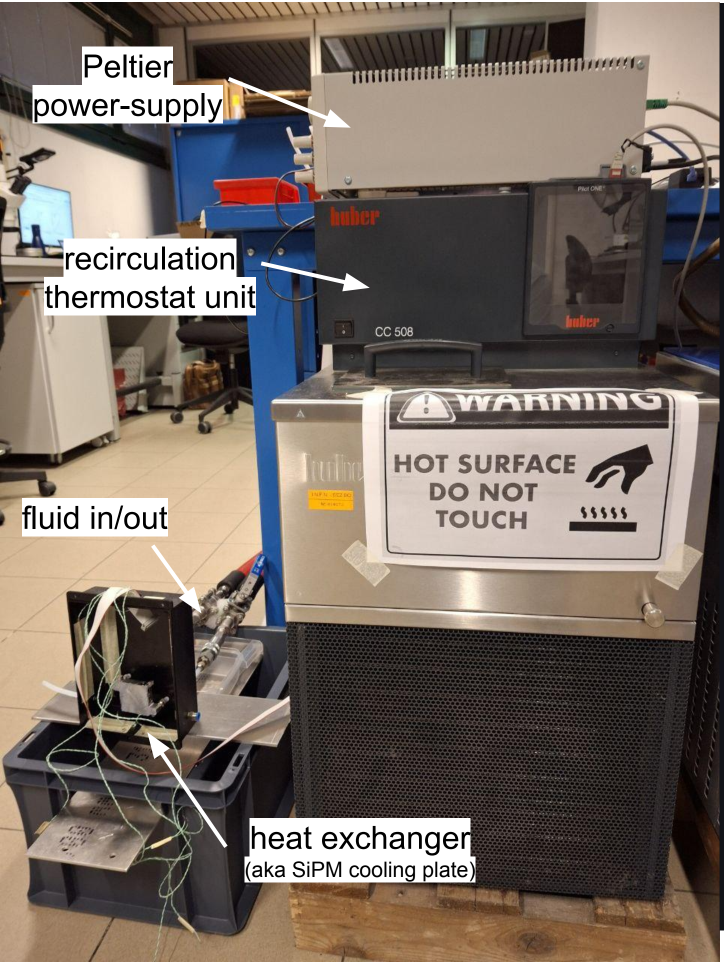
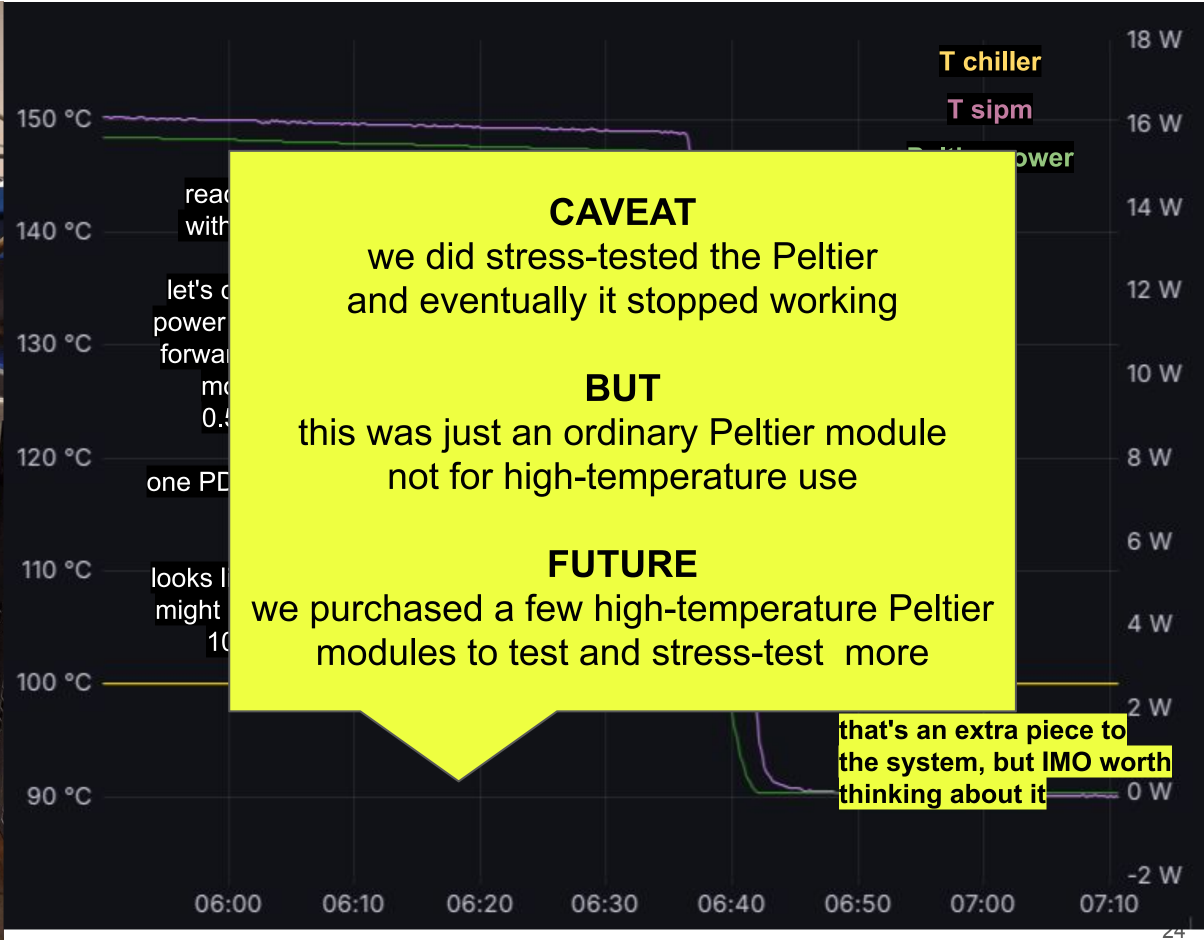




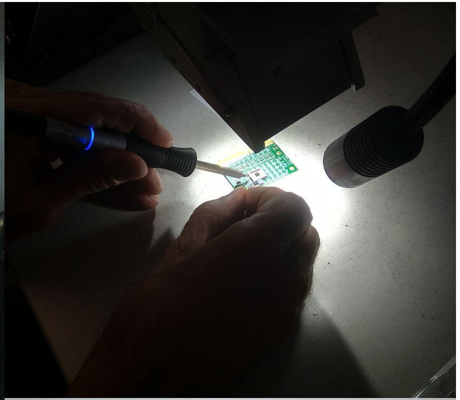
CAVEAT
we did stress-tested the Peltier
and eventually it stopped working

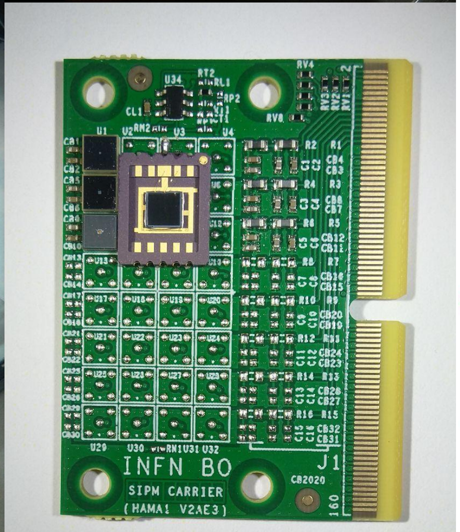
BUT
this was just an ordinary Peltier module
not for high-temperature use

FUTURE
we purchased a few high-temperature Peltier
modules to test and stress-test more

UV enhanced Hamamatsu SiPMs

New Hamamatsu SiPM prototypes





S13360-3050UVE

newly-developed Hamamatsu SiPM sensors

based on S13360 series

few samples of 50 µm and 75 µm SPAD sensors

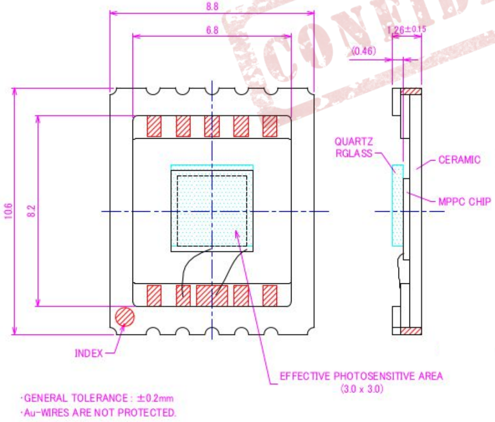
on paper they look VERY promising

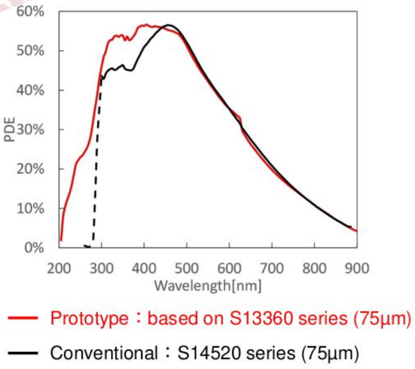
- improved NUV sensitivity
- improved signal shape
- improved recharge time

mounted on EIC SiPM test boards

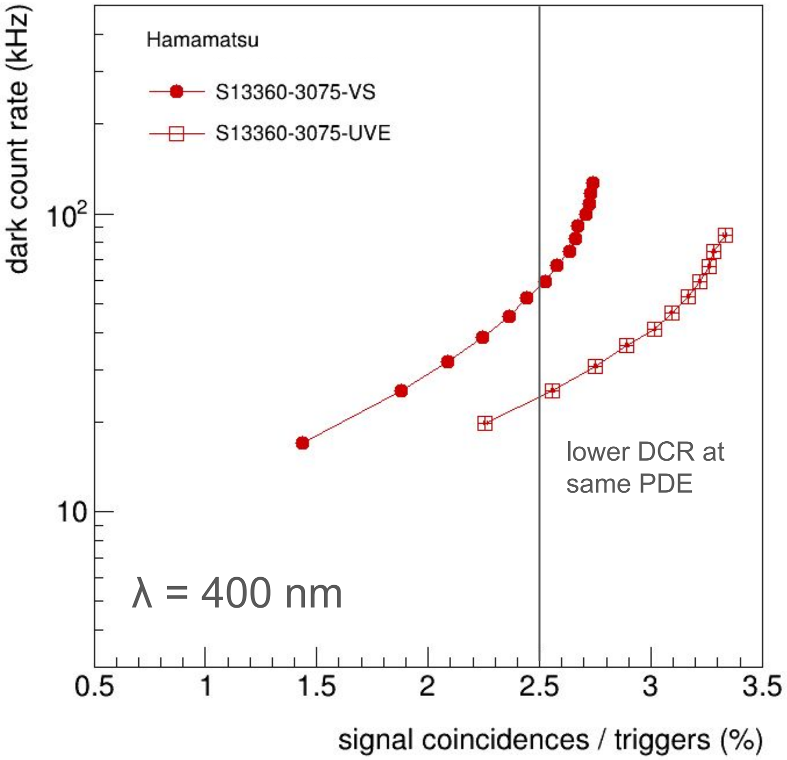
we will characterise and test them in full

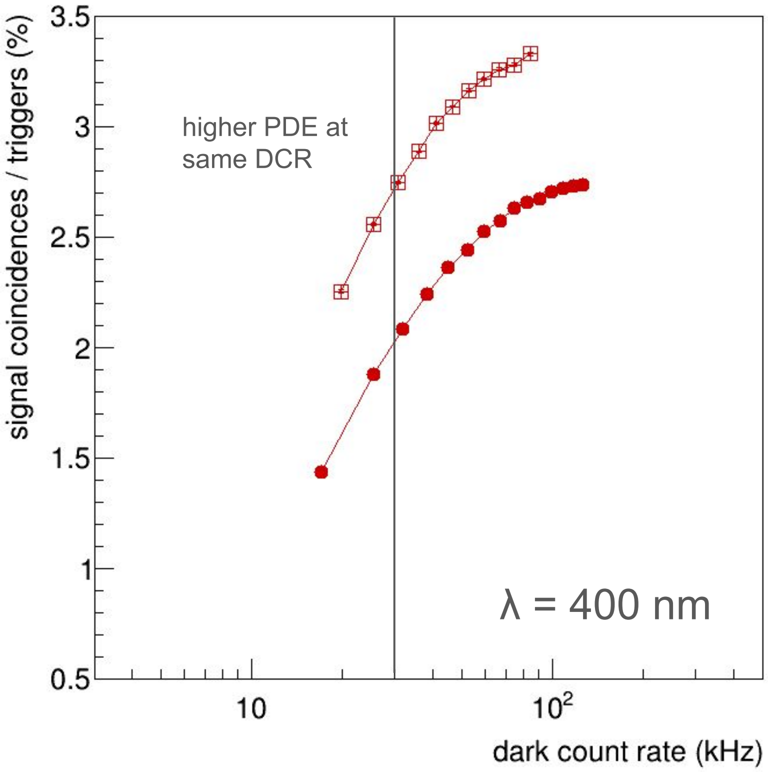
irradiation, annealing, laser, …





prototype Hamamatsu sensors (10^9 neq after oven annealing)





prototype Hamamatsu UVE sensors have significantly higher efficiency than standard sensors
caveat: we only measure PDE at the fixed **laser wavelength of ~400 nm**, larger PDE expected because…
prototype sensors have a NUV-enhanced behaviour.
we will study them further, currently asking Hamamatsu status for production and quotation of this product

Discussion with Hamamatsu engineers + shopping

- **had a meeting with Hamamatsu engineers about UV enhanced (UVE) sensors**
  - we wanted to understand if they could provide us with UVE sensor matrices
  - also if they could produce them with the silicone protective resin, rather than a quartz window
    - this because quartz would have added some little complications
    - ask if interested to know more
  - productive meeting, they confirmed they could provide us with what we wanted, namely
    - SiPM matrices 8x8 with UVE sensors
    - SMD mounting
    - silicone resin
- **purchase of single-SiPM sensors Hamamatsu UV enhanced**
  - 30x S13360-3050VS-UVE
  - 30x S13360-3075VS-UVE
  - goal
    - assemble a few small tests boards (6x boards, each with 4 + 4 sensors)
    - perform irradiation and annealing tests on SiPM UVE with silicone window
- **purchase of 8x8 SiPM matrices Hamamatsu UV enhanced**
  - 12x S13361-3075NS-08-UVE
  - 4x S13361-3050NS-08-UVE
  - goal
    - assemble a few PDUs to be used for the upcoming beam test
    - evaluate the expected improved PDE performance with Cherenkov light

sensor irradiation

Irradiation tests

- **neutron irradiation campaign 2024 (LNL-CN)**
  - irradiation done on 9-11 October
  - several SiPM boards, several fluences
  - also irradiated aerogel, quartz and other optical matetials
- **gamma irradiation campaign 2024 (CERN-GIF)**
  - irradiation done on 14-16 October
  - from 10 to 1000 rad
- **proton irradiation campaign 2024 (Trento-TIFPA)**
  - will be done on 12-14 December
  - we will also irradiate several pieces of electronics