MTTF and irradiation test for the Mu2e SiPMs

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ON BEHALF OF THE MU2E COLLABORATION

05-12-17 MUSE GENERAL MEETING

Outline

- MTTF test
  - Mu2e requirement
  - Description of the measurement
  - Experimental setup
  - Results

- Irradiation test
  - Mu2e requirement
  - Thermal simulation & experimental setup
    - FNG
    - HZDR
  - Results

MTTF Test

MTTF evaluation

The SiPMs have to grant an MTTF of 1 million hours when operating at 0 °C.

- For the MTTF evaluation the following equation is used:

$$0.5 \times N_{hours} \times AF \times N_{SiPM} \sim 0.6 \times 10^6 \text{ hours}$$

- Where N_{hours}**=2556** (start: 11/25/2016, end: 03/12/2017),N_{SiPM}**=5** (per each vendors), **AF=100.1**

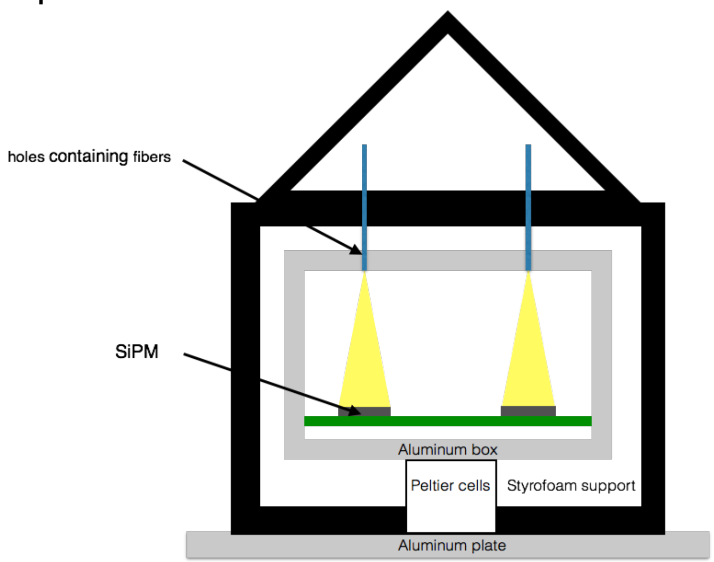
- The Acceleration Factor is extracted from the Arrhenius equation:

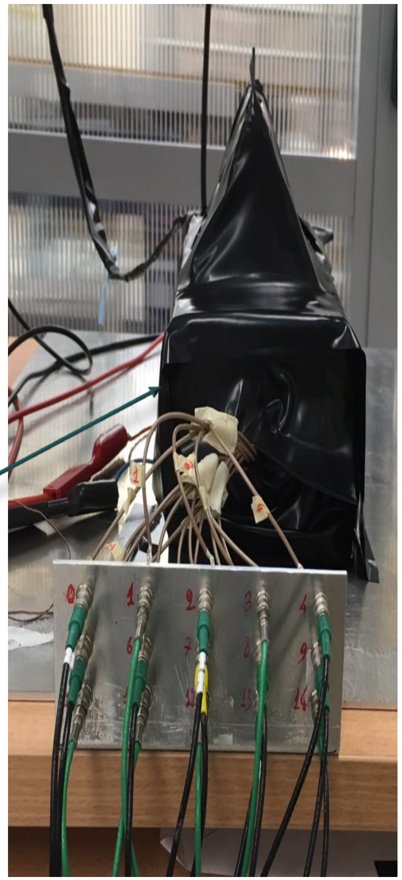
$$AF = exp\left[\frac{E_a}{k}\left(\frac{1}{T_{use}} - \frac{1}{T_{stress}}\right)\right]$$

- Where E_a=0.6 eV for Silicon, T_{use}=273 °K and T_{stress}= 323 °K

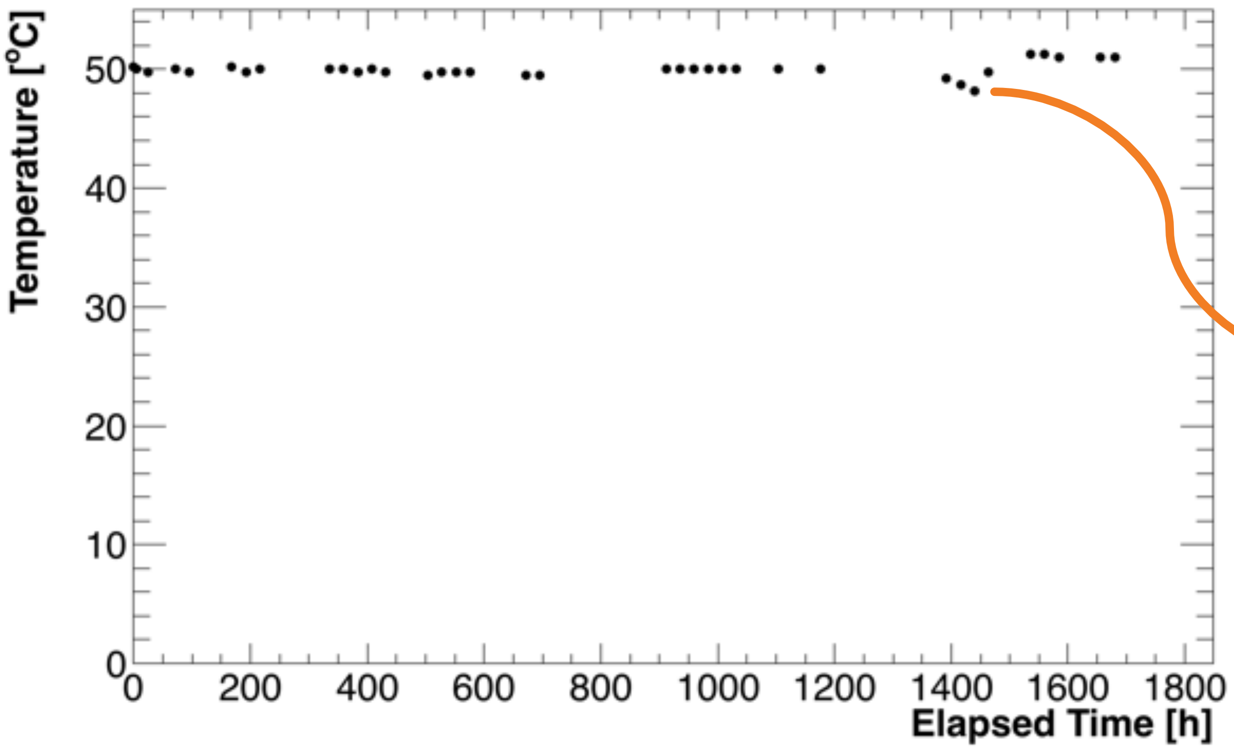
MTTF - experimental setup

- **15 SiPMs** (parallel of 2 series made of 3 6x6 mm^2 SiPMs) from different vendors tested at LNF
- Temperature **@ 50 °C** using 2 Peltier cells
- SiPM temperature monitored by a PT 1000
- Led pulse every **2 minutes**
- Current value acquired once a day if possible





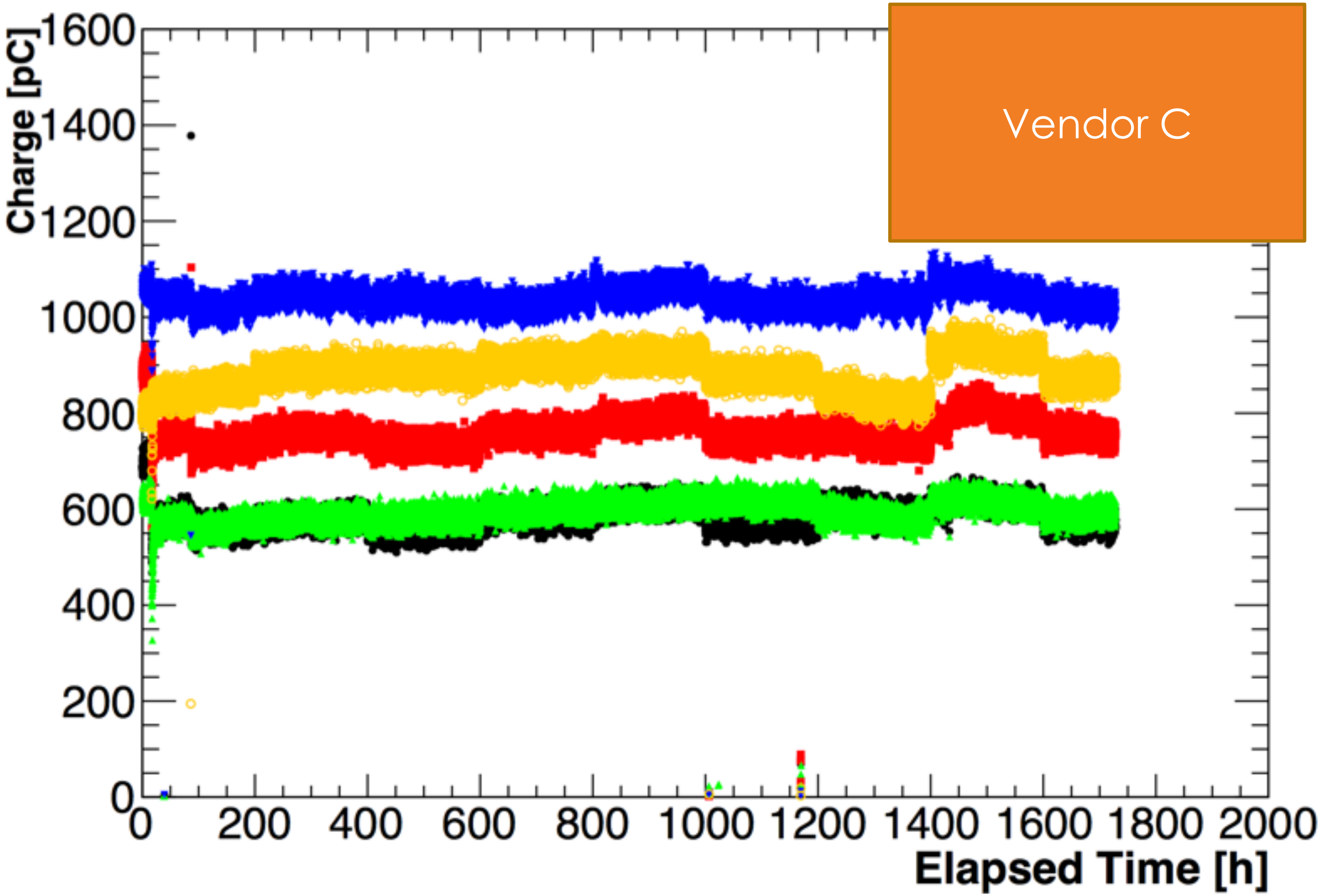
Temperature behavior



Due to unexpected changes in the clean room temperature we have adjusted the box temperature

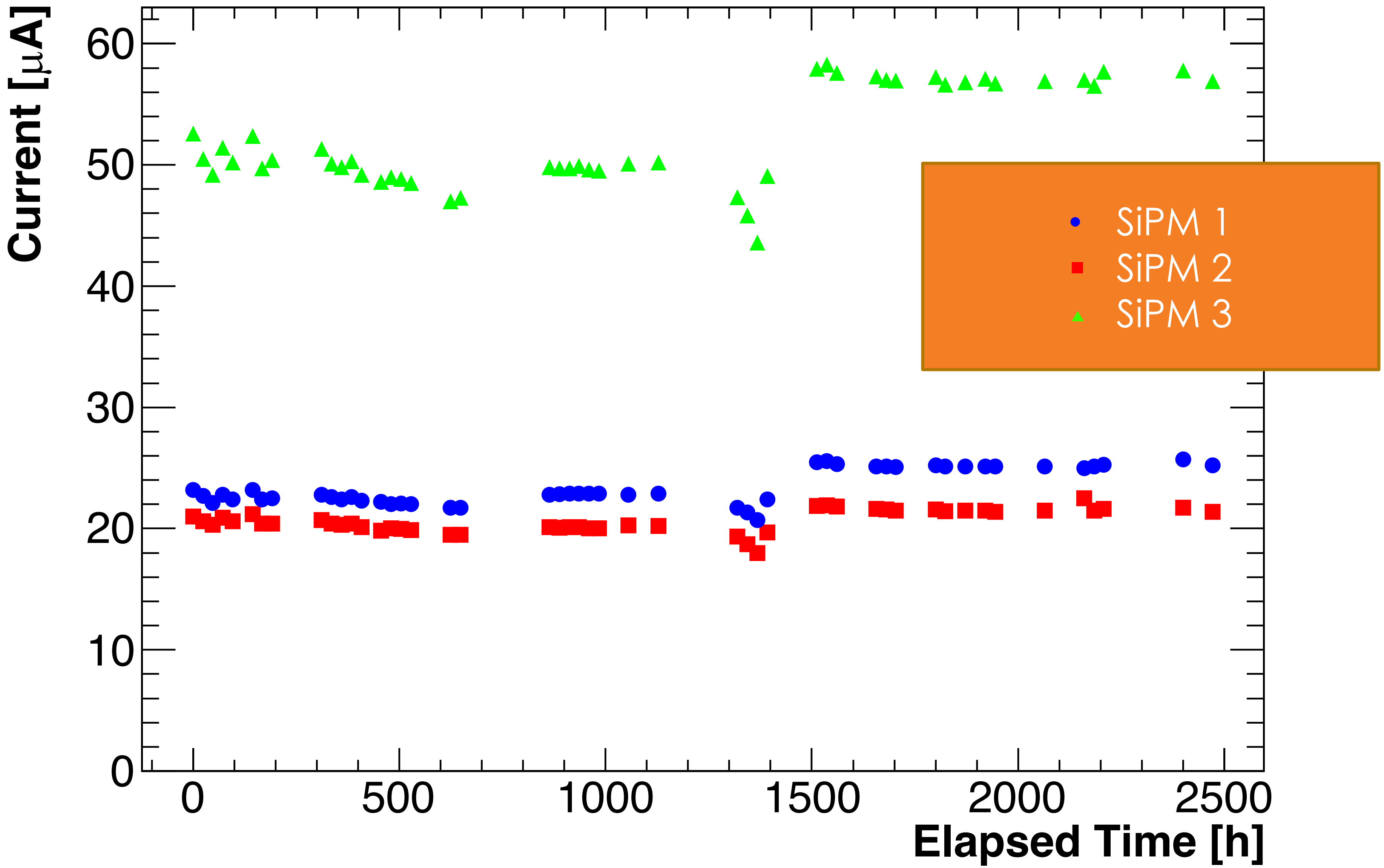
Now $\mathbf{T_{box}}$ **= 51.03 °C**

SiPM charge



Vendor C

Current acquired



Irradiation test

Mu2e requirements

*Irradiation with both **neutrons** and ionization dose (for a randomly selected sub-sample) is one of the evaluation criteria for the qualification of the pre-production SiPMs (DocDB 7052, 6.2).*
It is required that:

- When the SiPM is exposed to a **neutron fluency of $3x10^{11}$ $n_{1MeV\ eq}/cm^2$, the acceptable levels of deterioration** (for each 6x6 mm^2 SiPM cell in the array) **are**:
  - a dark current smaller than 10 mA
  - a gain reduction of up to a factor of 4
- The test will be done reading the dark current with a picoammeter and measuring the response to a UV led during the irradiation while keeping the array at 20 °C

1st neutron test @ FNG

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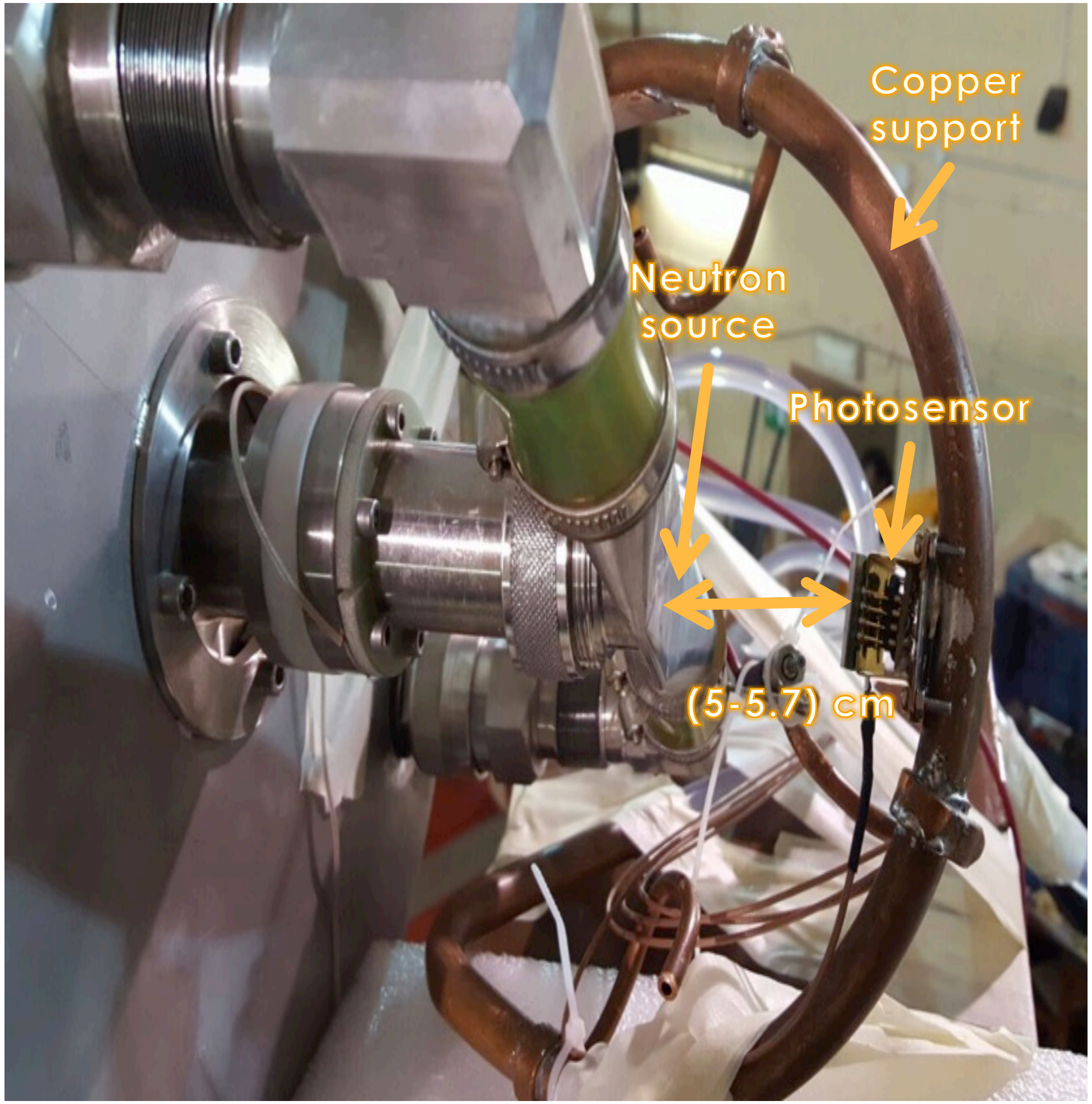

Frascati Neutron Generator Facility (FNG, ENEA-Frascati, Italy) test in January. It provides 14 MeV neutrons
Scaled damage (w.r.t. 1 MeV n) ~x1.8

Expected Max Integrated flux:
$1.1 \times 10^{12}\ n_{1\ MeV}/cm^2$

- SiPM current acquired with a Keythley
- Temperature monitored with a PT 100
- Waveform acquisition with a digital scope

Cooling system @ FNG

- Temperature @ 20˚ using a chiller filled with water
- Photosensor in thermal contact to the copper support using glue
- PT100 glued to the back side of the SiPM to monitor the temperature

Cooling system @ FNG

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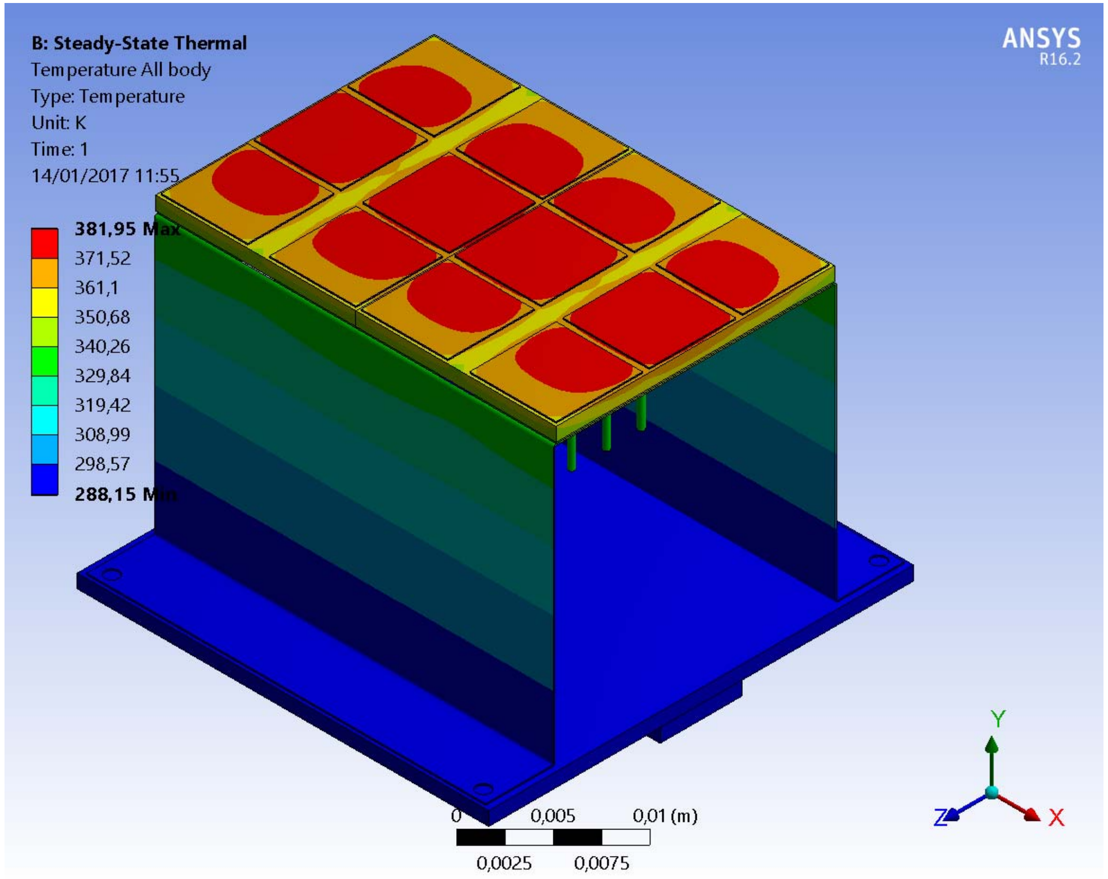
- Temperature @ 20° using a chi[illegible] with water
- Photosensor in thermal c[illegible]er support using glue
- PT100 glued to the bo[illegible]nitor the temperature

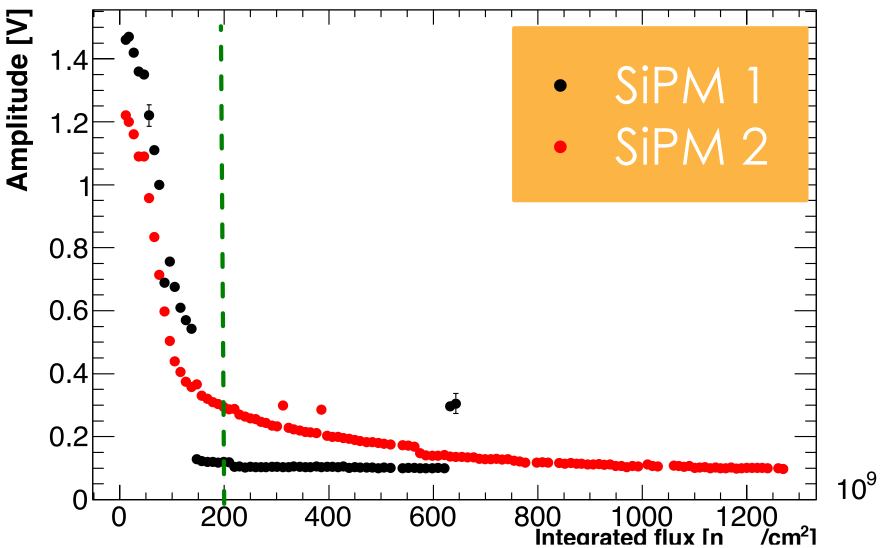
Thermal simulation



Considering 2.5 W/SiPM

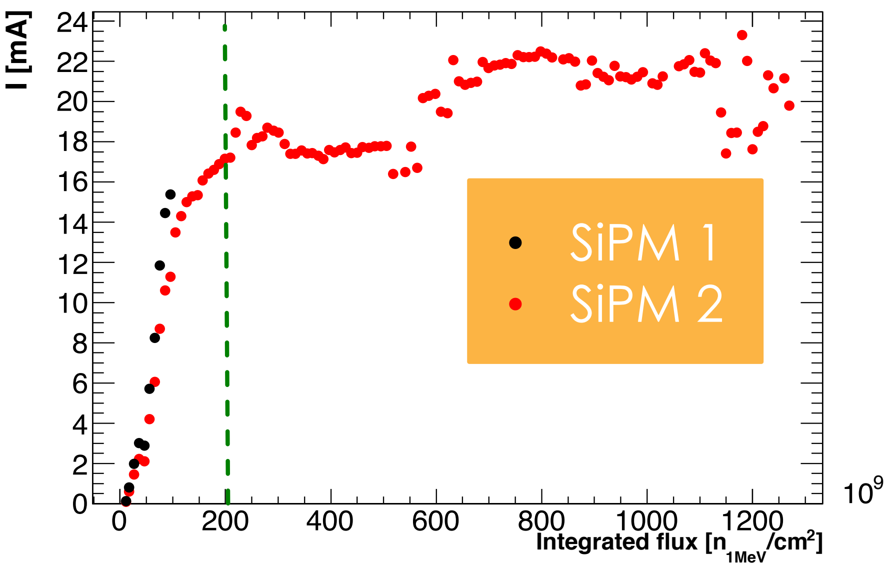
Temperature > 100˚C

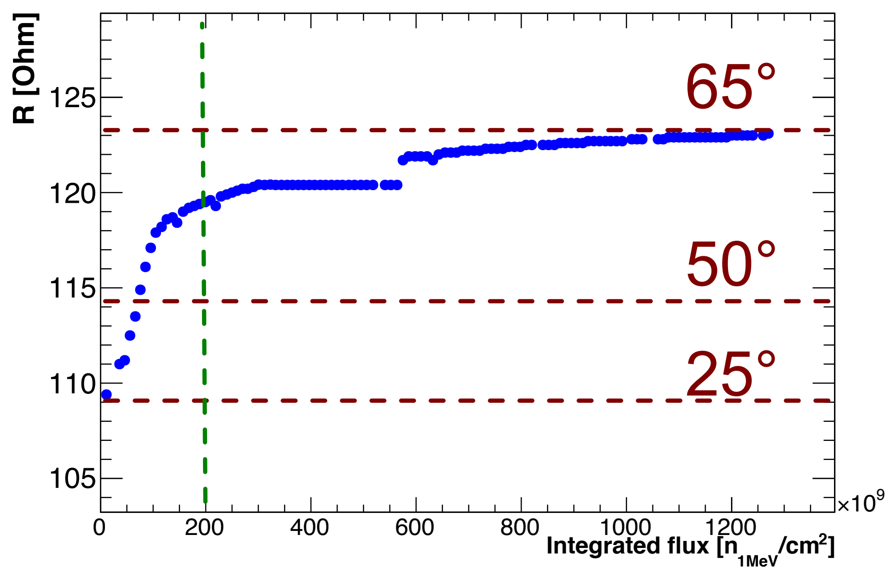
Results



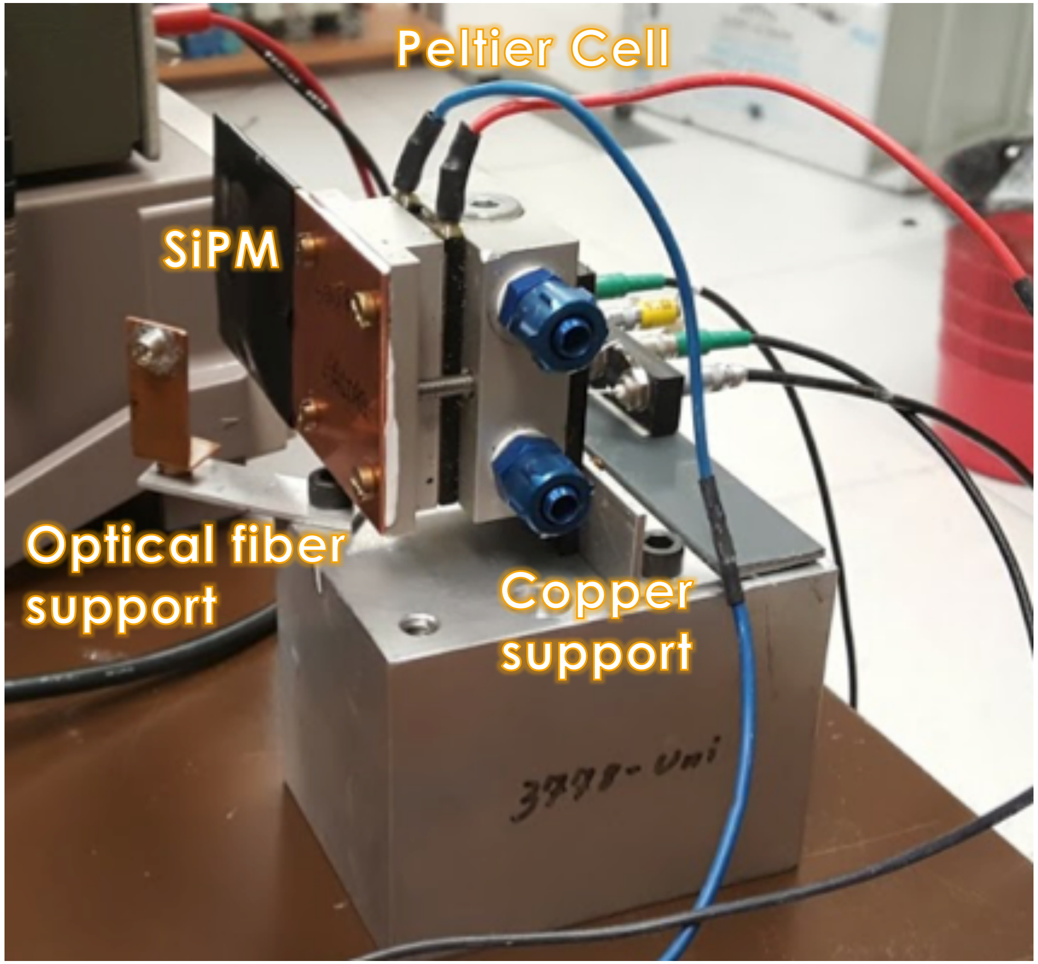
We were not able to keep the temperature stable

Results out of the requirements of the bid





2nd neutron test @ FNG



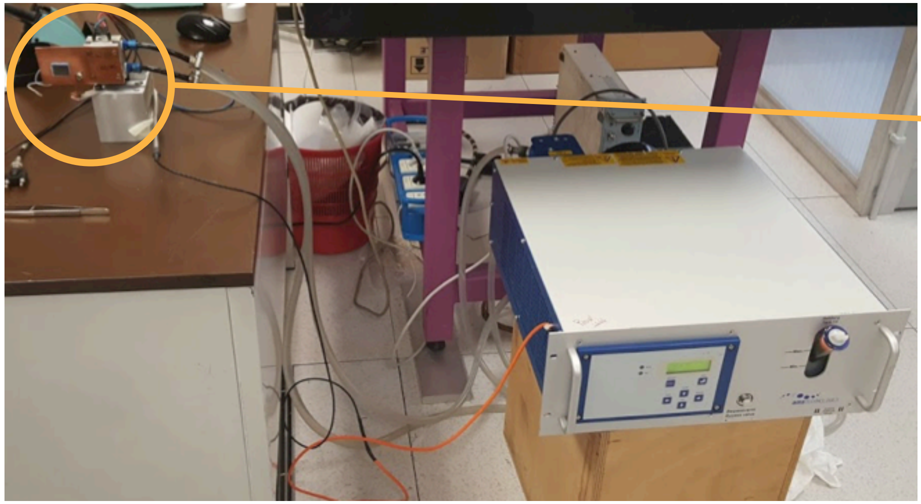
Frascati Neutron Generator Facility (FNG, ENEA-Frascati, Italy) test in January. It provides 14 MeV neutrons
Scaled damage (w.r.t. 1 MeV n) ~x1.8

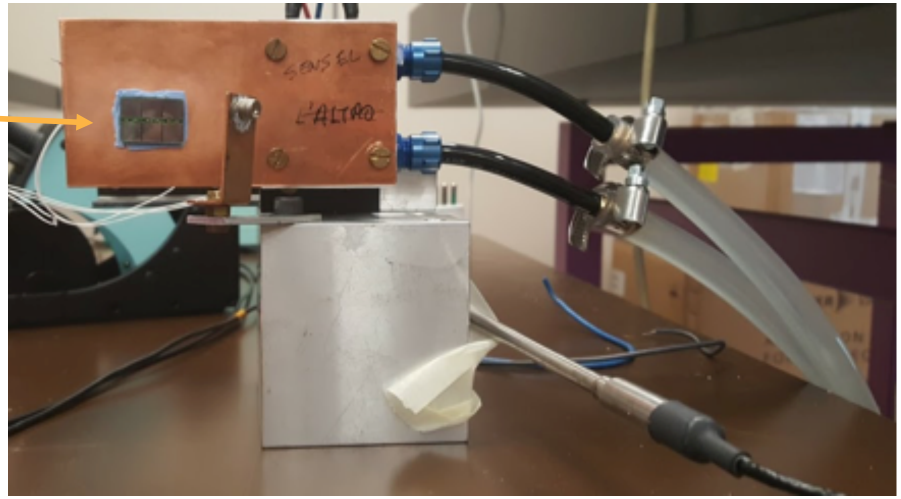
Expected Max Integrated flux:
1.1×10^{12} $n_{1\ MeV}/cm^2$

- **2 cells out of 6 biased**
- 1 cell used to monitored the temperature with a PT100
- 1 cell under test :current acquired with a Keythley
- Waveform acquisition with a digital scope
- PMT waveform used as referece

Cooling system @ FNG

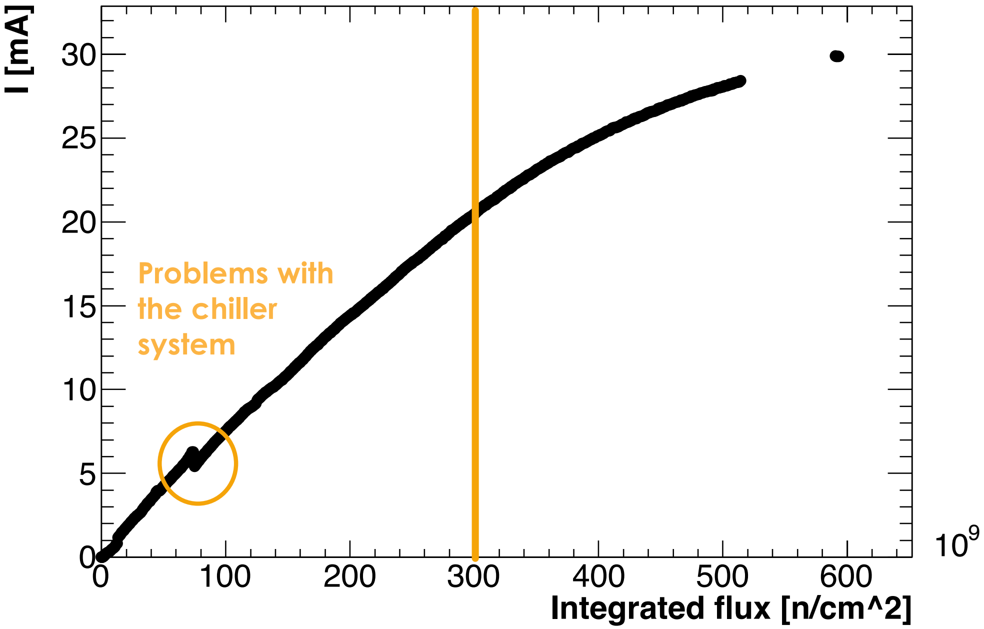
- A system of a **Peltier cell and a chiller filled with water** is used
- Chiller temperature ~ 15- 20˚
- Water used to cool the hot side of the Peltier cell
- Thermal pad to connect the SiPM to the copper support
- Peltier cell used to mantain the temperature stable: feedback connected to the Peltier cold side itself

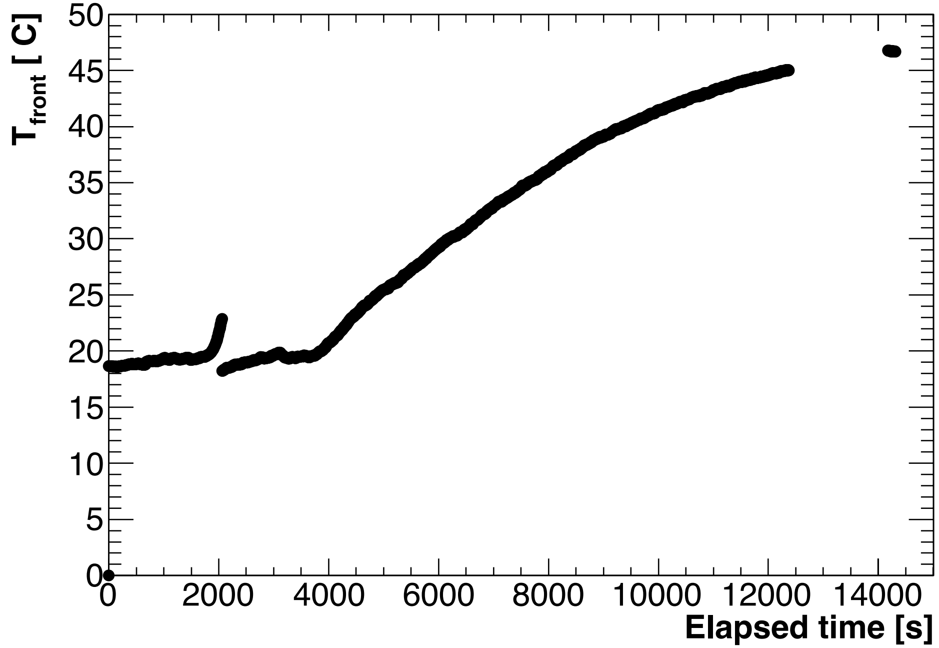




Results

Total neutron fluency:
$5.9 \times 10^{11}\ n_{1MeV}/cm^2$

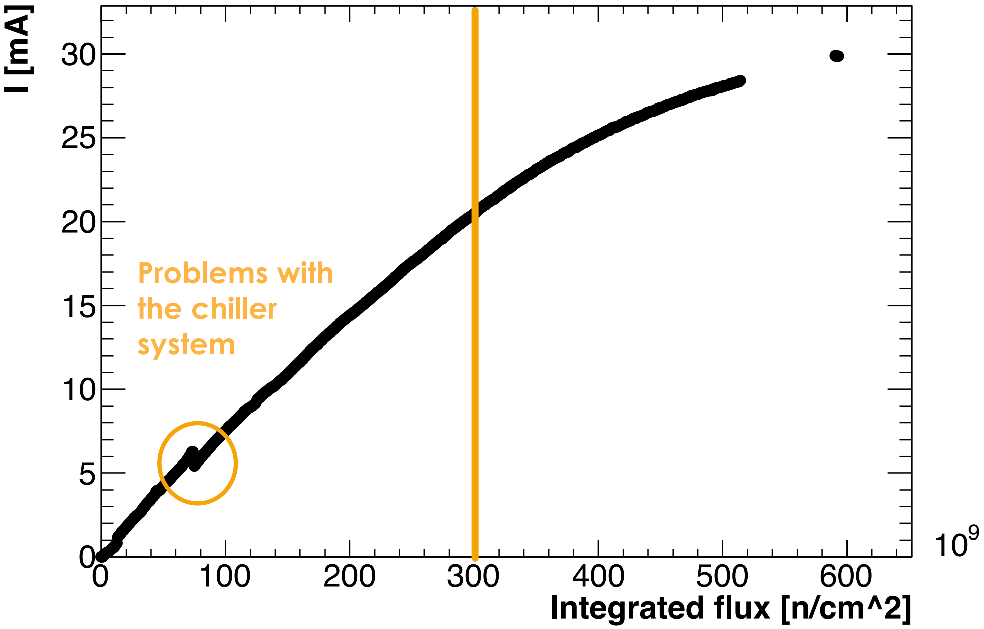


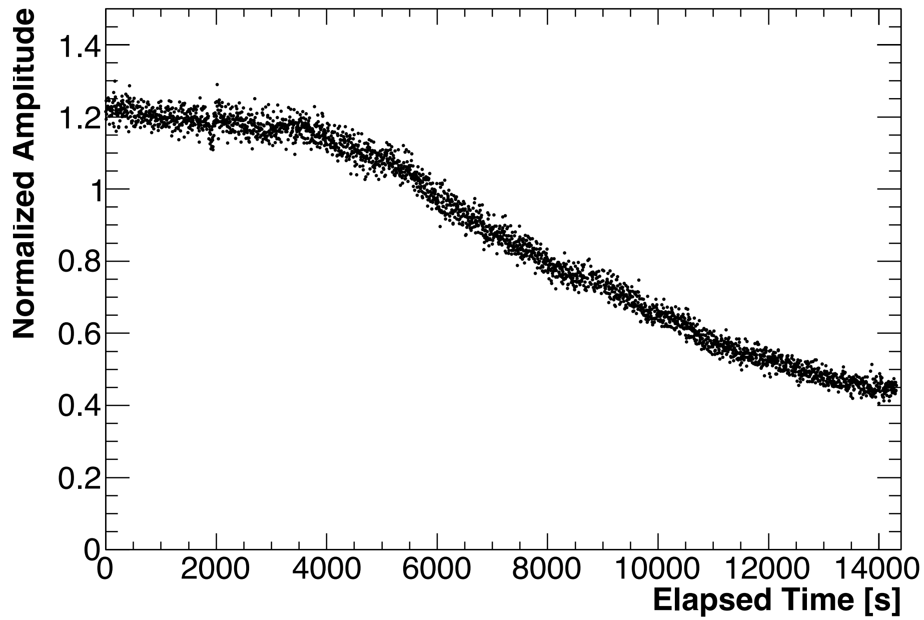


- I ~ 21 mA at the bid limits
- Temperature increases from 20 ˚C to 45 ˚C

Results

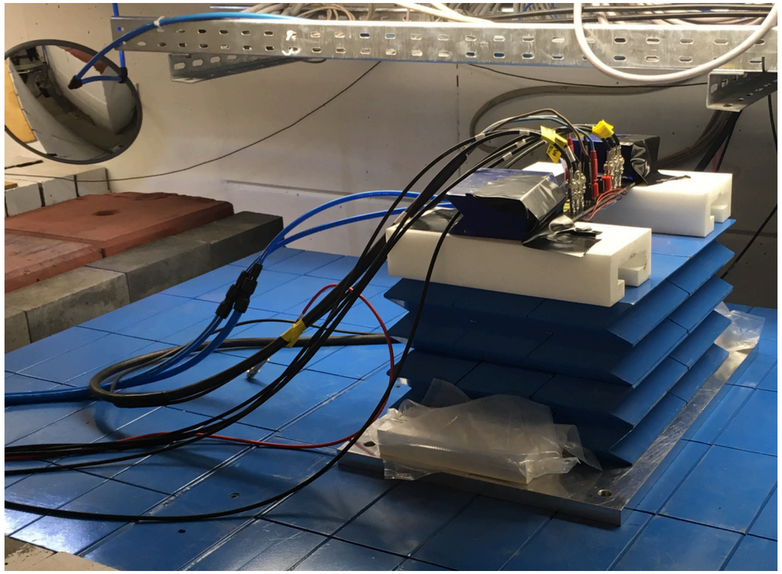
Total neutron fluency:
$5.9 \times 10^{11}\ n_{1MeV}/cm^2$





- I ~ 21 mA at the bid limits
- Amplitude reduction of ~40 % due to temperature increase
- No waveform acquisition in the following irradiation tests

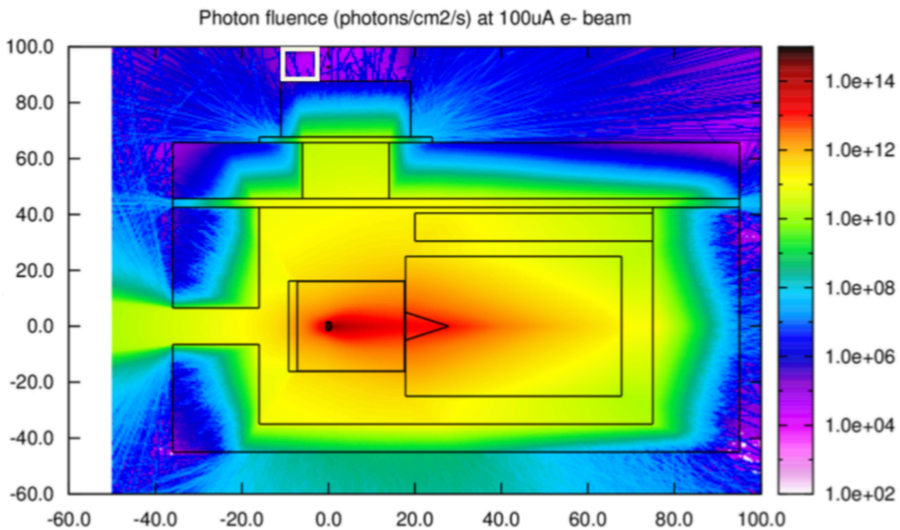
Neutron test @ HZDR



Helmholtz-Zentruf Dresden Rossendord (HZDR, Dresden , German) test in March. It provides neutrons of 1 MeV

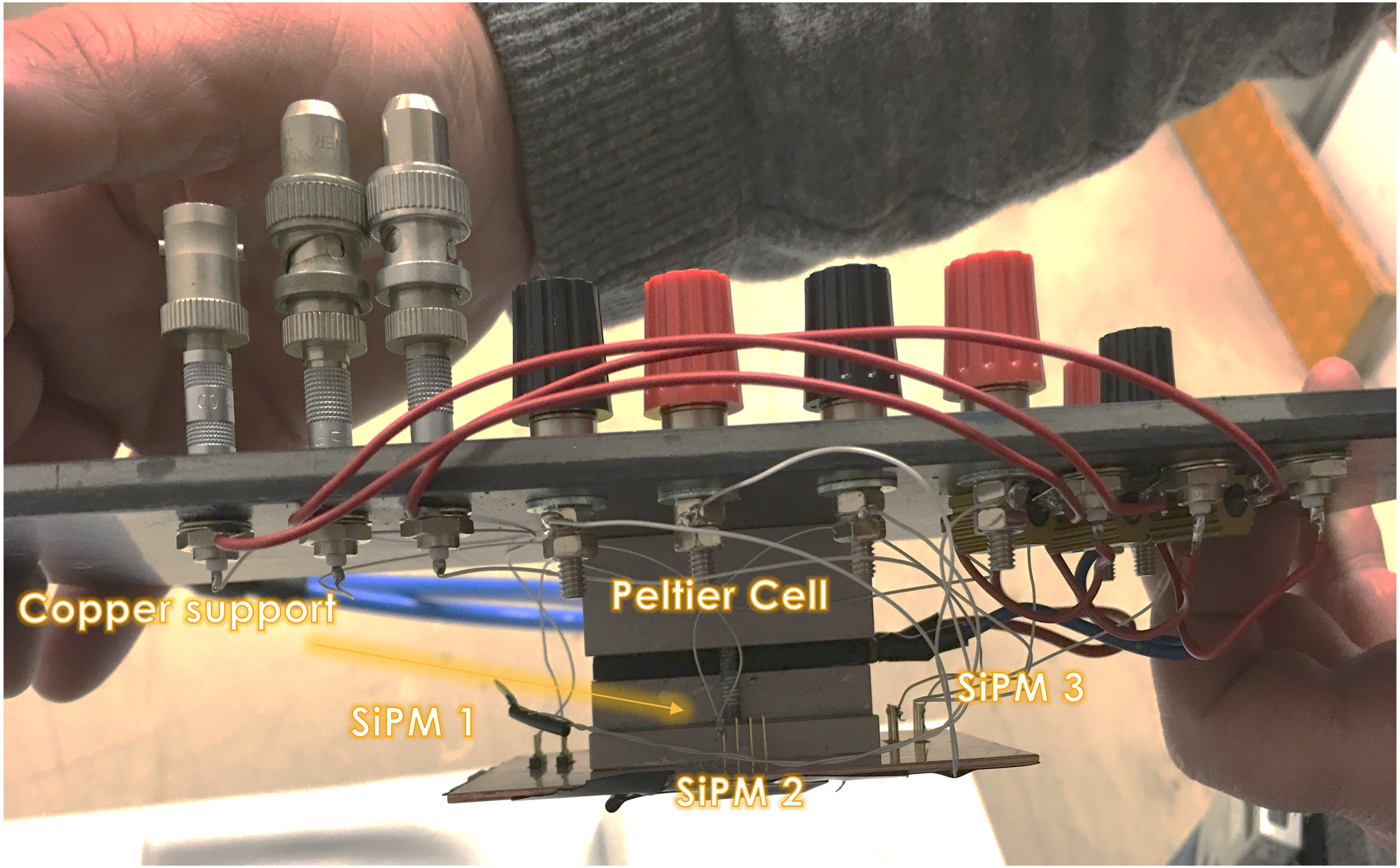
Max Integrated flux:

$8x\ 10^{11}\ n_{1\ MeV}/cm^{2}$

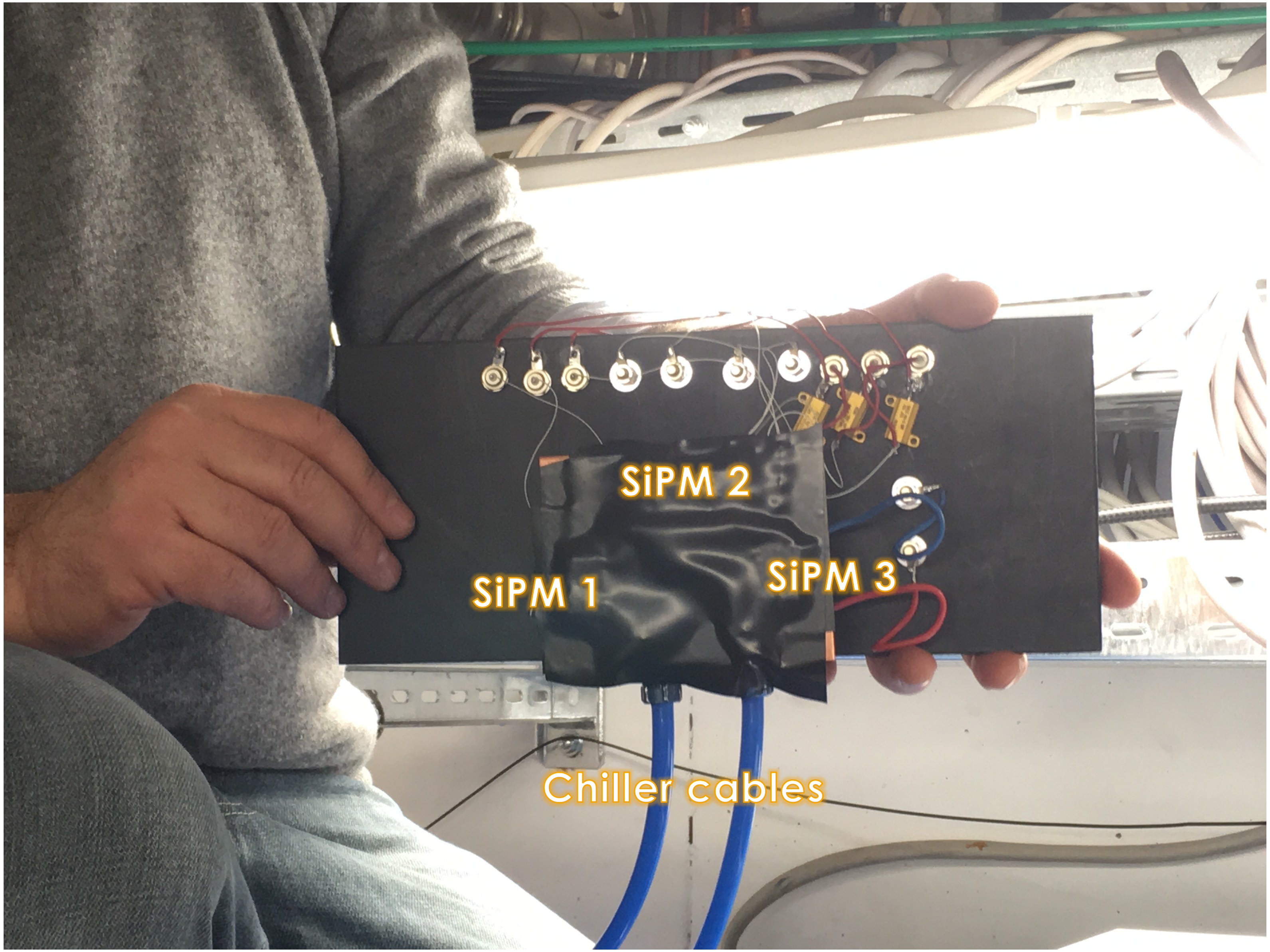


- **3 Sipm tested at the same time**
- Single cell current acquired with a Keythley
- Chiller+ Peltier cell
- T_{back} monitored with a PT 100

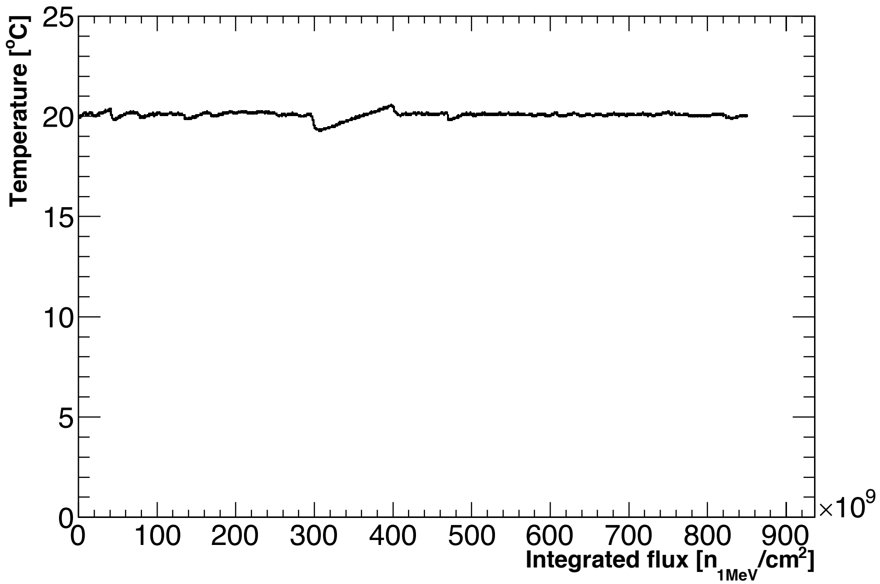
Setup(1)



Setup(2)



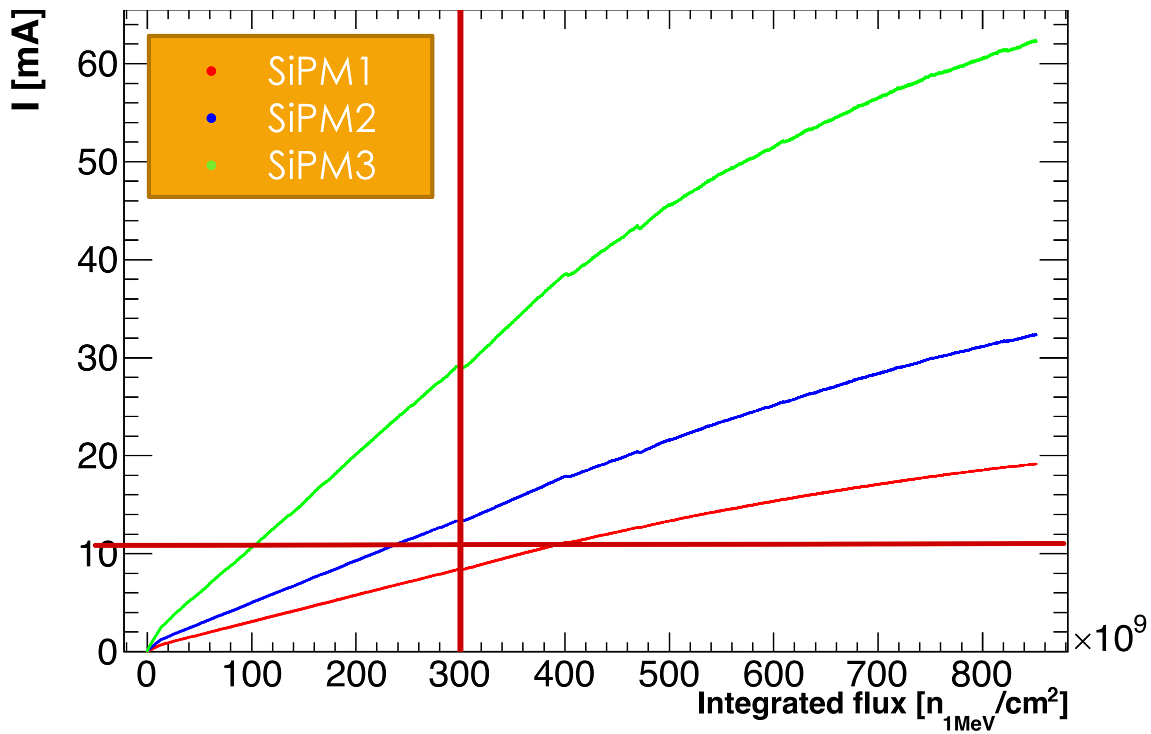
Results



Temperature kept almost stable during all the irradiation test

Considering the flux limit imposed in the bid we obtained that:

- I_SiPM1 = 8.39 mA
- I_SiPM = 13.33 mA
- I_SiPM 3 = 28.98 mA



Conclusions

- MTTF Test
  - November 25 2016 – March 12 2017
  - All the 15 SiPMs under test were alive at the end of the test
  - No changes in performances

- Irradiation test
  - 3 irradiation campaigns performed in 2017
  - The new setup ensure a stable temperature and an efficient SiPM cooling thank to the usage of a Peltier cell
  - Measurement performed allowed us to estimate the radiation hardness for the different photosensors