Annealing Characterization of Hamamatsu S13360-60xx SiPMs for Space Applications

SiPM Radiation Workshop, CERN, Geneva

Nicolas De Angelis

DPNC, University of Geneva

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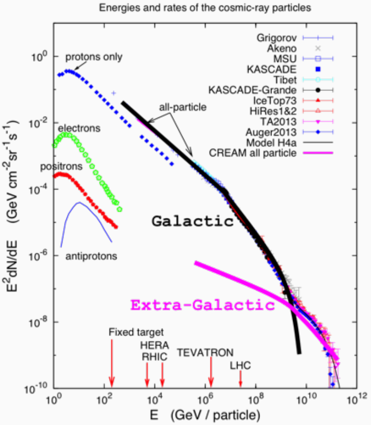
Motivation for characterizing the annealing effect

- SiPM increasingly used as photodetectors in physics experiments
- A lot of advantages over PMTs (compactness, low voltage, unsensitivity to magnetic field, mechanical robustness...)
- Only main drawback of SiPMs is the **dark noise**, which becomes even worse when the device is exposed to radiation
- This is a problem for space-borne experiments, where sensors cannot be easily changed
- Protons are dominant in LEO



Cosmic Rays and Particle Physics, T.K. Gaisser

Proton irradiation at IFJ

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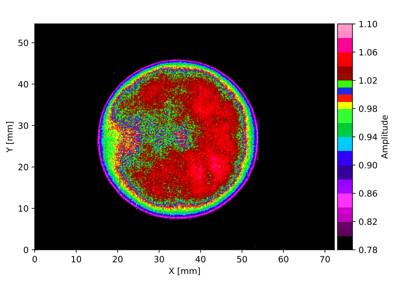
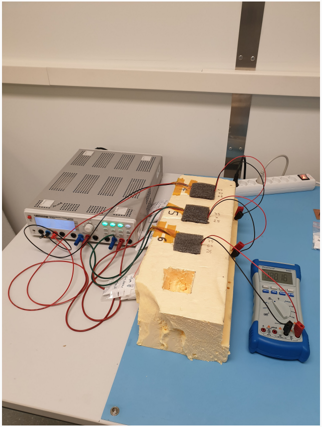
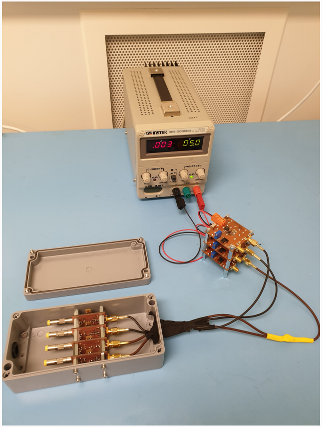
- Single channel S13360 SiPMs (25, 50, 75μm cells) have been irradiated at IFJ, Krakow
- 58 MeV protons, fluence of 10^8 p/cm^2 $\rightarrow$ dose of 133.5 mGy (13.35 rad) $\rightarrow$ 2.09 yrs in space for POLAR-2 (or 50 days for a non-shielded sensor in LEO)



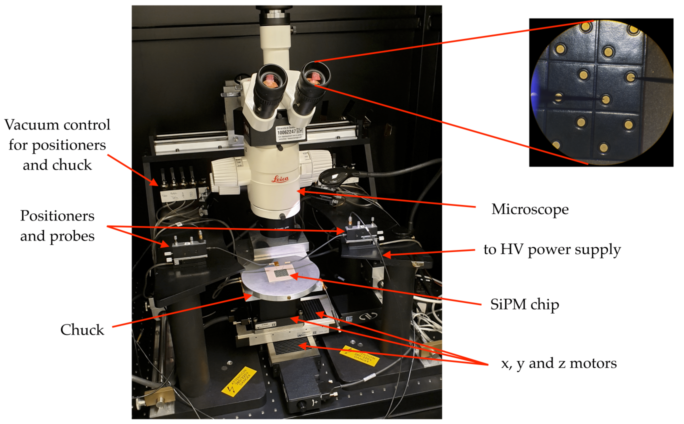
SiPM storage

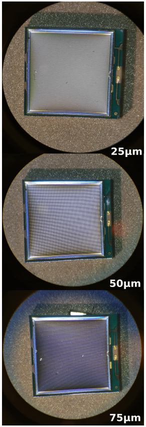
- 17 S13360-6025/50/75 SiPMs from Hamamatsu, stored at 6 different temperatures (-18, 5, 21, 32, 43, and 53°C)
- 4 S13360-6050 SiPMs biased with a DC/DC converter at room temperature with different over-voltages (2*3V, 8V, 12V)



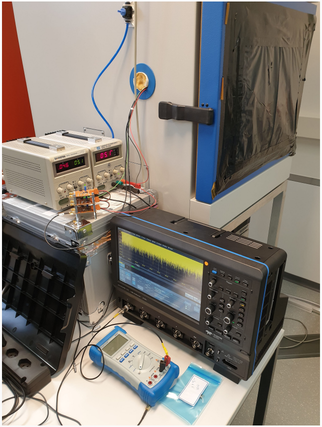


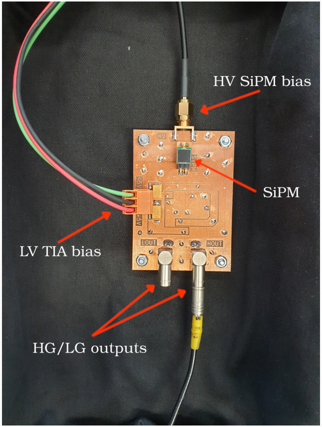
- Probe station based on Keithley picoamperemeters for SiPM I-V characterization





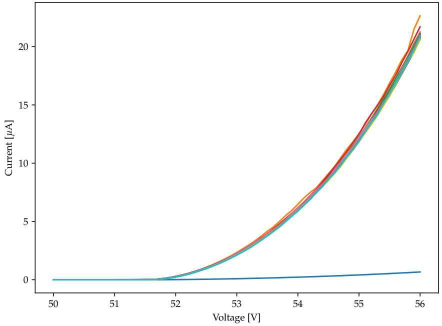
- SiPMs dark noise read out with TransImpedance Amplifier + Teledyne Wavesurfer Oscilloscope in a controlled temperature environment (Climatic Chamber)



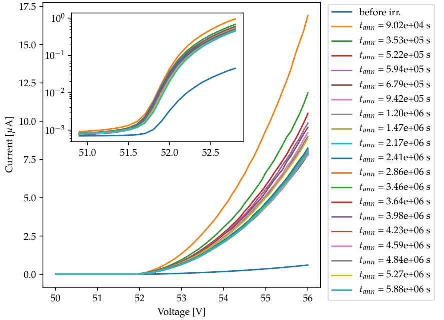


I-V characteristics of S13360-6050

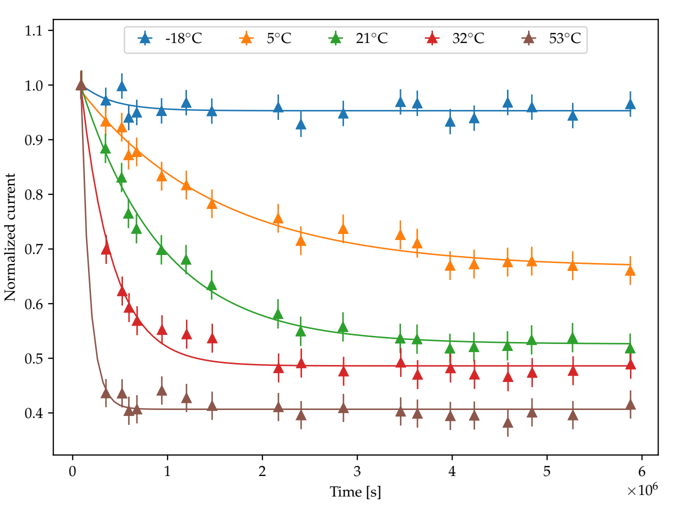
Stored at -18°C



Stored at 43°C

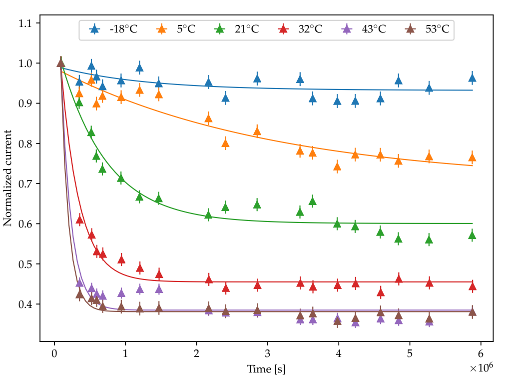


Current @3V vs. annealing time, 50μm

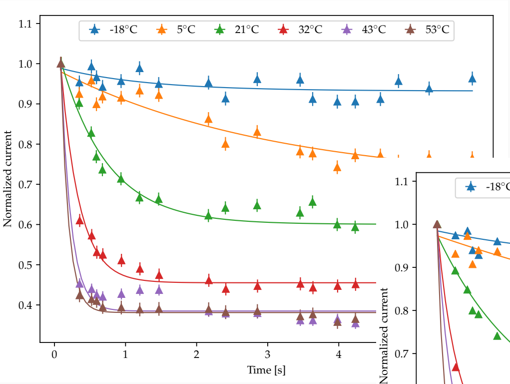


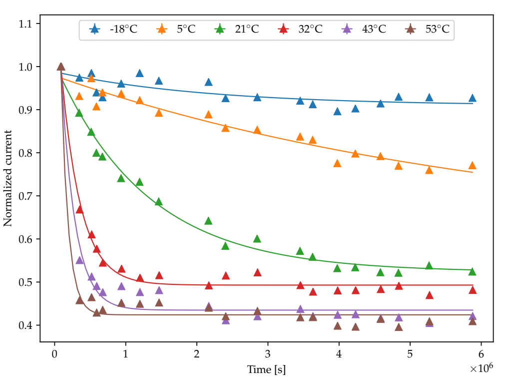
Faster decay at high temperatures + recovering a bigger fraction of the current

Current @3V vs. annealing time, 25 and 75μm



Current @3V vs. annealing time, 25 and 75μm





Exponential annealing parameters

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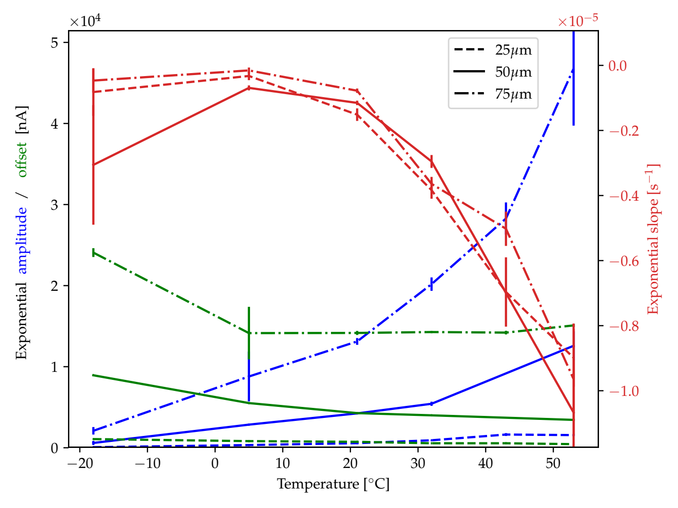
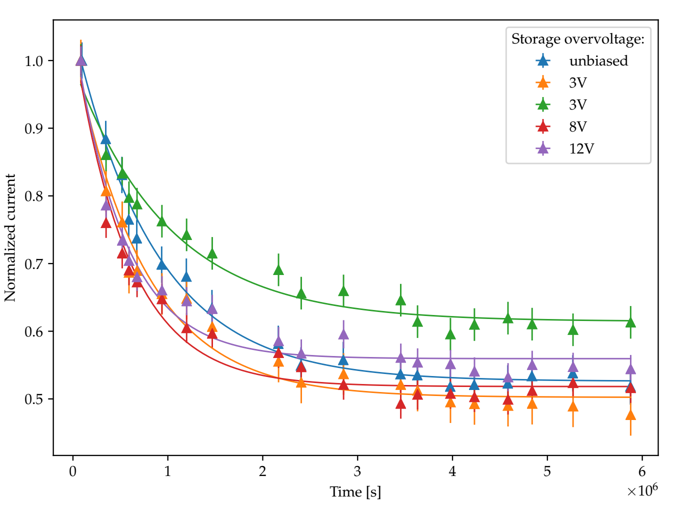
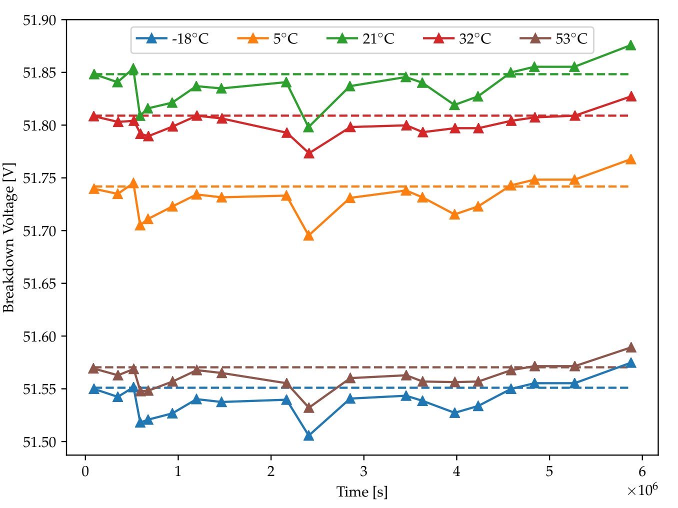
Exponential fit: $\text{amplitude} \times e^{-\text{slope} \times t} + \text{offset}$



Bias effect on the annealing, 50μm



Breakdown voltage stability, 50μm



Breakdown rather stable, corrected for temperature of the room

Dark spectrum, 50μm (0, 20°C)

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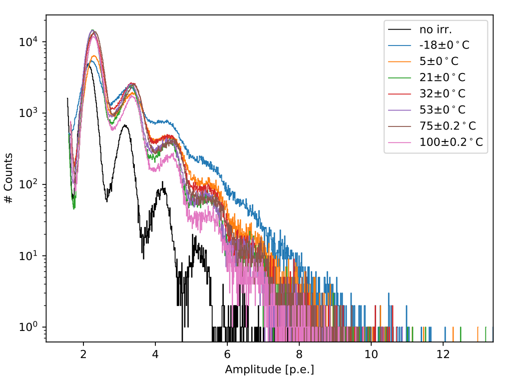
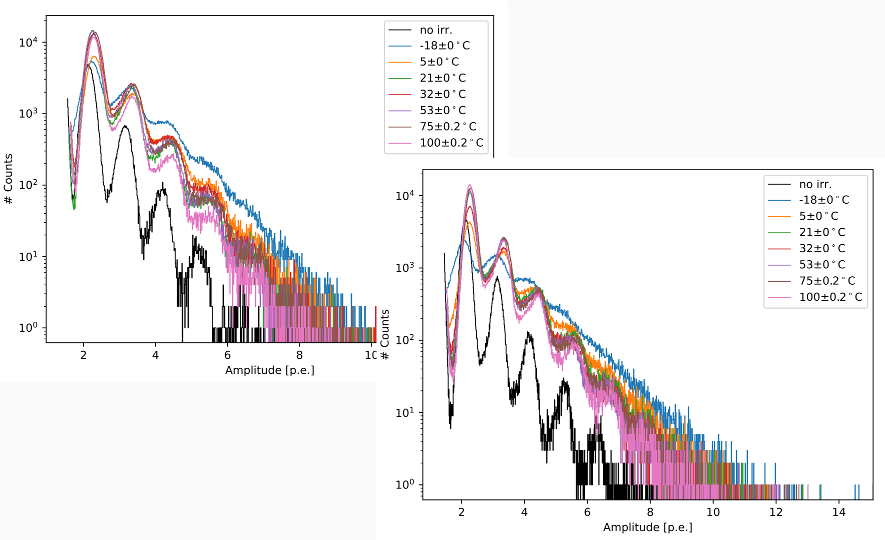
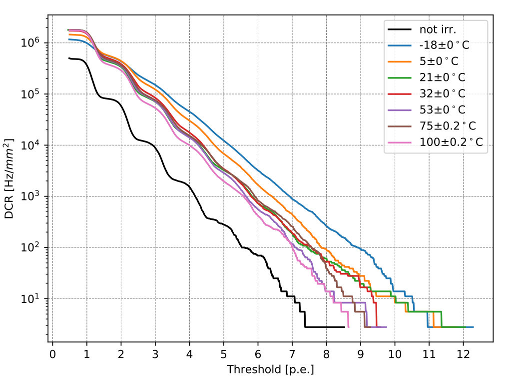


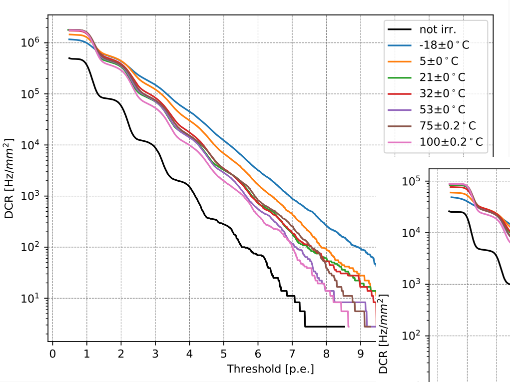
Dark spectrum, 50μm (0, 20°C)

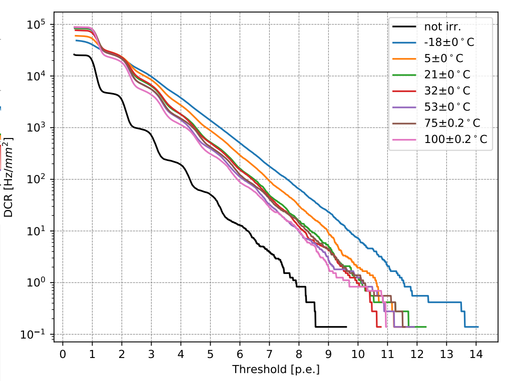


DCR vs. threshold, 50μm (0, 20°C)

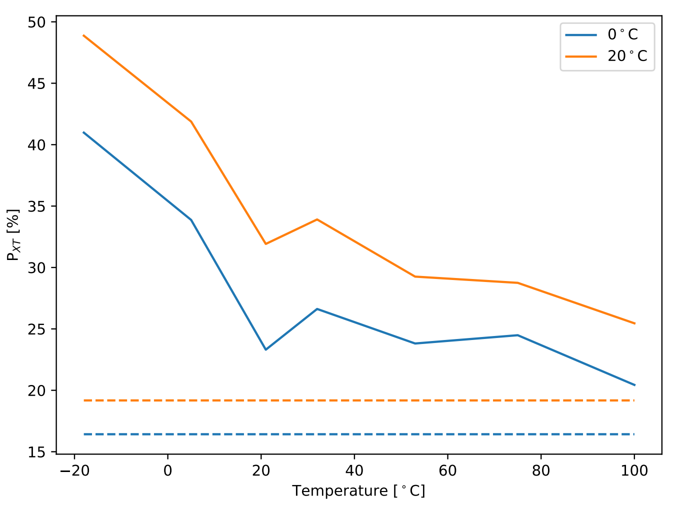


DCR vs. threshold, 50μm (0, 20°C)





Cross-talk probability, 50μm



Preliminary plot, no error bars yet

Single photoelectron peak width, 50μm

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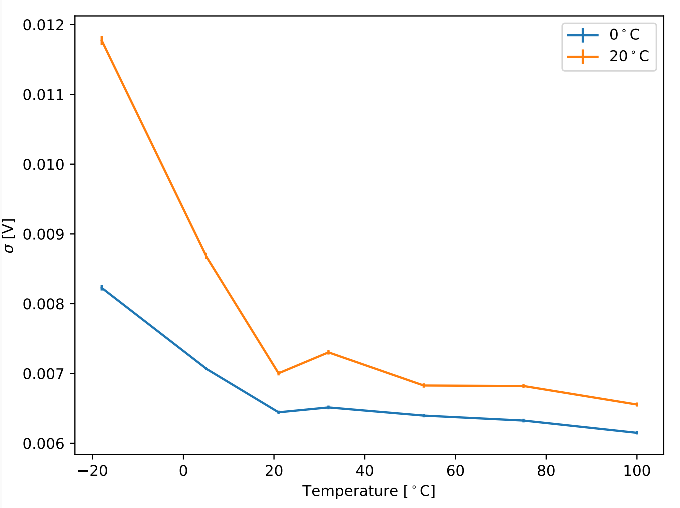

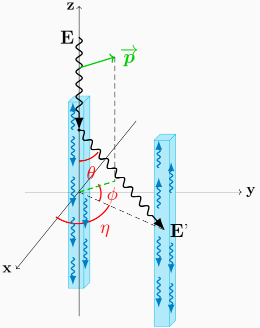

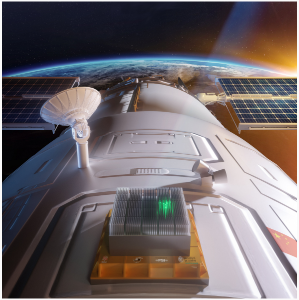

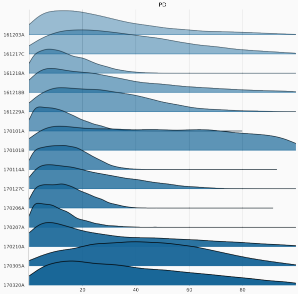

PoS, 395, 580 (ICRC2021)

A&A 644, A124 (2020)

- GRBs are the most powerful astrophysical events, the polarization of their prompt emission can help understanding their structure + emission mechanisms at play
- This polarization can be measured using Compton scattering thanks to a segmented array of scintillators $\Longrightarrow$ POLAR, 40×40 elongated plastic scintillators
- Divided into 25 modules, each readout by MA-PMTs. 50-500keV, half-sky FoV
- Launched in Sept 2016 on the TG-2 Chinese space lab for 6 months of operation
- Detected 55 GRBs, 14 GRBs analyzed, globally low PD, hint for time-evolving PA
- More statistics are needed $\Longrightarrow$ bigger and more sensitive instrument: POLAR-2

The POLAR-2 mission Instrument design and collaboration

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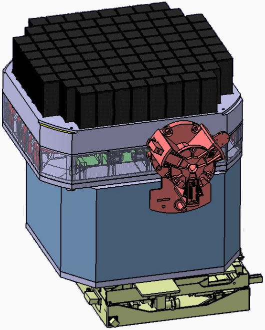
- 4 times bigger than POLAR (from 25 to 100 polarimeter modules), 10 times more efficient (thanks to an improved design of the modules)
- Main technological upgrade: **MA-PMTs** $\rightarrow$ **SiPMs**
- Lowered energy threshold to a few keV, equipped with spectrometer modules (CeBr3 or LaBr3)
- Launch to China Space Station planned for 2024
- Swiss (UniGe), Chinese (IHEP), Polish (NCBJ), and German (MPE) collaboration, more info on **https://www.unige.ch/dpnc/polar-2**



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Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
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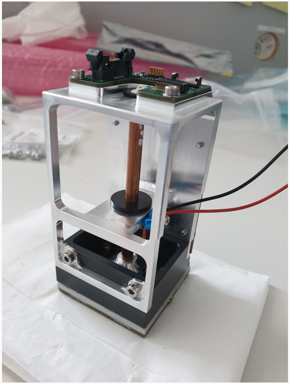
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

MPE
Max-Planck-Institut für extraterrestrische Physik

POLAR-2
GRB polarimeter

POLAR-2 annealing strategy "Bake it until you make it"

- POLAR-2 will be operating SiPMs as cold as possible to reduce the dark noise (ideally down o -20°C)
- Operating at low temperatures implies negligible annealing effect
- Active cooling system of POLAR-2 based on Peltier
- $\Longrightarrow$ the polarity of the Peltier elements can be inverted once a year for a few days in order to heat up the sensors
- This will allow to recover part of the dark current and p.e. resolution



Summary & Outlook

- Presented results to be published soon, to be completed with DCR data for 75μm + I-V/DCR data for annealing at higher temperatures (75 and 100°C)
- Annealing effect allow to recover 60% of the dark current above 40°C
- No significant effect on the annealing due to bias $\implies$ the study on non-biased sensors presented here is representative of real physics experiment where the SiPMs are biased
- Comparative study with the 4*4 arrays from Hamamatsu will be performed soon (based on the data presented by Slawek)