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Radiation Damage on SiPM for High Energy Physics Experiments in space missions

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DIPARTIMENTO INTERATENEO DI FISICA

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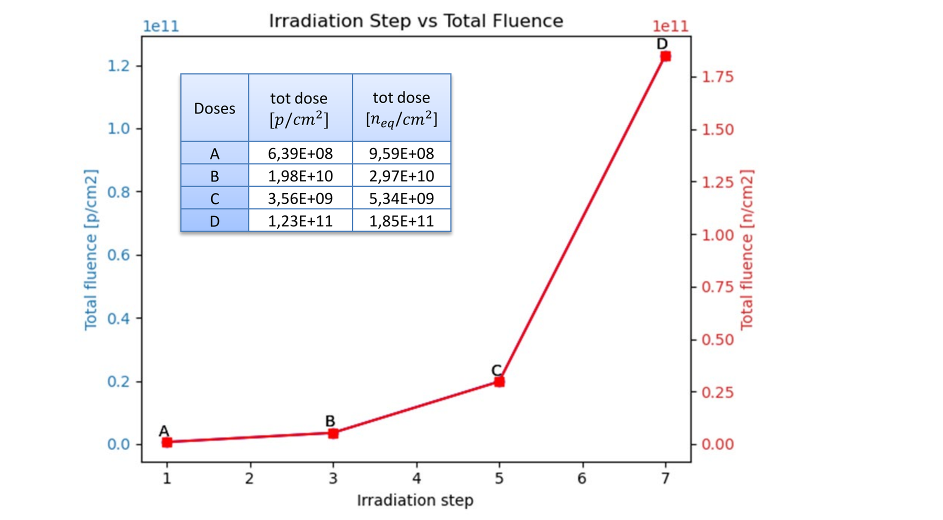
Abstract
- **SiPM** (Silicon Photomultipliers) are a very promising technology for **aerospace missions.** However, under a significant amount of radiation fluence or dose a deterioration of the detector performances is observed[1]. It is of general interest to study the effect of the radiation on the main parameters of the SiPMs [2]. Here, we report the effect of the irradiation with protons with 4 step fluencies up to $1x10^{11}\ p/cm^2$ on SPADs and SiPMs NUV-HD-lowCT, with different cell sizes (40µm and 15µm).

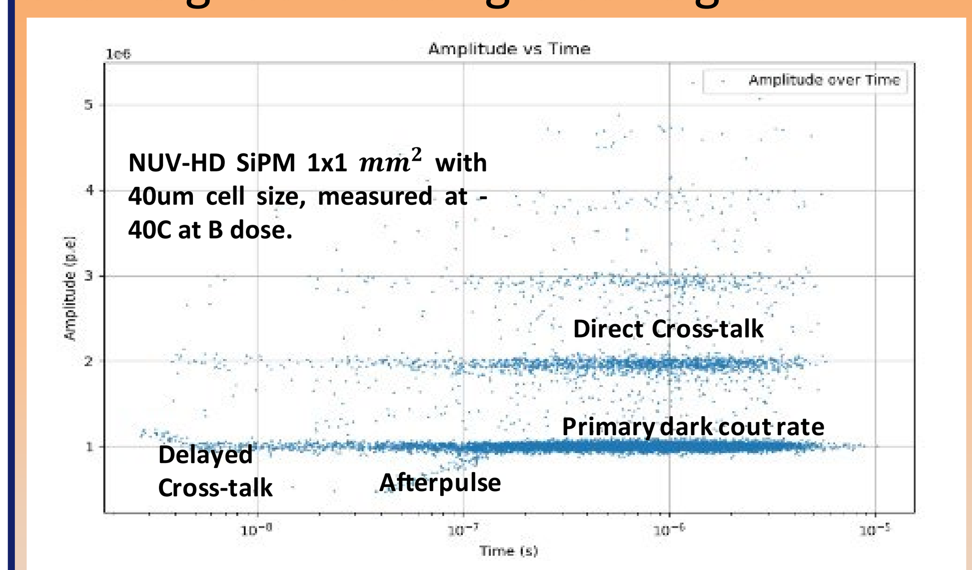
Total fluence



Steps of the total doses of protons at wich SiPM and SPADs under test have been exposed (up to $1x10^{11}\ p/cm^2$).

SiPM NUV-HD-lowCrossTalk

An array of SPADs connected in parallel. The pulse amplitude is normalized to the height of the single-cell signal.

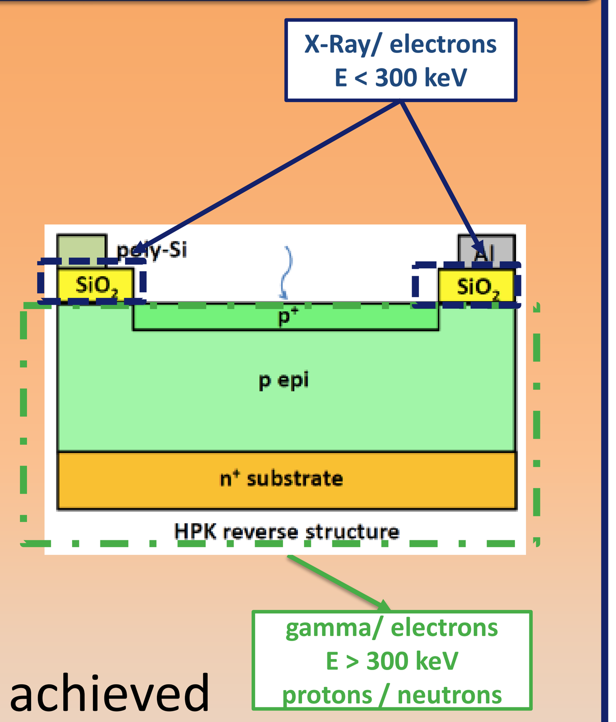


Scatter plot of the pulse amplitude as a function of its distance from the preceding event at 6V over-voltage.

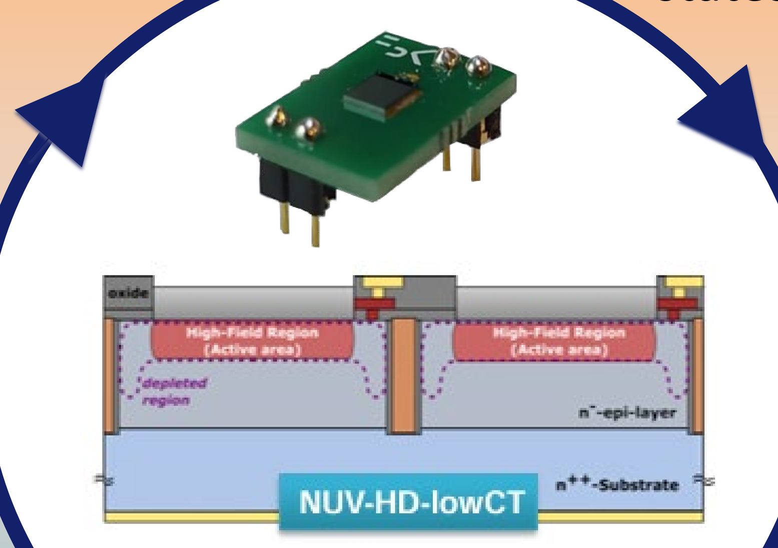
Noise components :
- **➔ Direct Cross-talk (DiCT)**
- **➔ Delayed Cross-talk (DeCT)**
- **➔ After-pulsing**
- **➔Primary dark count rate(DCR)**

Radiation damage on SiPM

- **Surface damage due to Ionizing Energy Loss (IEL):** accumulation of charge in the oxide (SiO2)
- **Bulk damage: Bulk (Crystal) damage due to Non-Ionizing Energy Loss (NIEL):** displacement damage, built up of crystal defects. Locally distorted Si lattice with new energy states
  - **➔ Increase DCR**
  - **➔ Increase after-pulsing**
  - **➔ Change in charge collection**



It is estimated a maximum fluence achieved during the tests of $6.4x10^{11}\ n_{eq}/\ cm^2$[3]

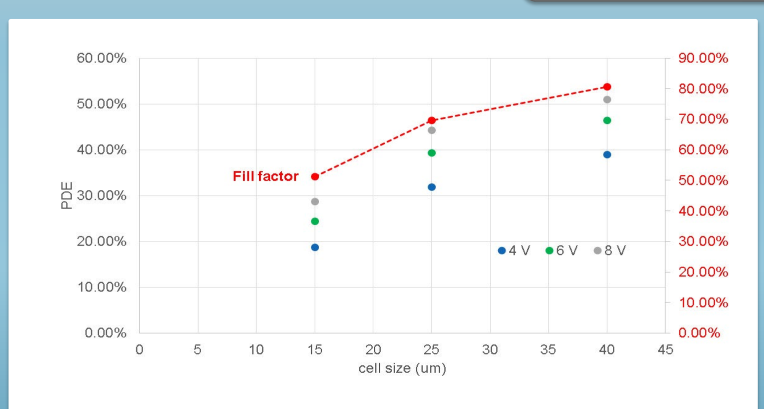


NUV-HD-lowCrossTalk
with trenches filled with polysilicon

Photo-Detection Efficiency (PDE)

The **Photo-Detection Efficiency** is defined as the probability that a SiPM detects an incoming photon.

$$PDE = FF \times QE \times T_P$$

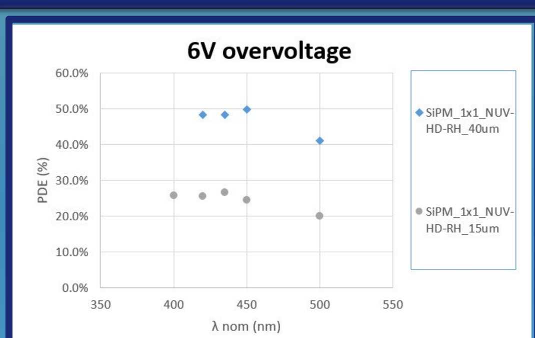


Trend of the photon detection efficiency (PDE) at 450nm and fill factor of the SiPM as a function of the cell size.

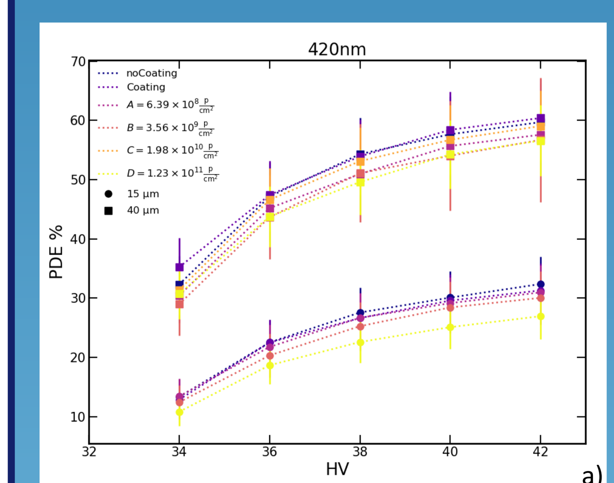
The separation between microcells and the space required for the quench resistor and tracking is more or less constant, regardless of the microcell size. Therefore, larger microcells result in a higher percentage of active surface area (active area/total area).

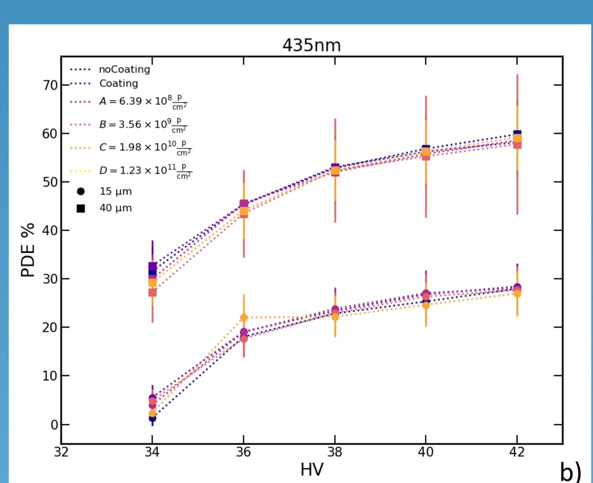
PDE - Results

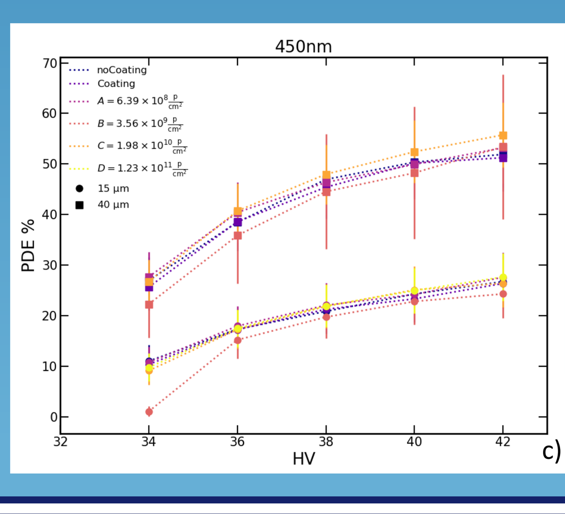
PDE of non irradiated SiPMs at different wavelenghts. We have tested the PDE in a wavelength range close to the one of plastic scintillators.



PDE measured on non-irradiated SiPM with 15 µm and 40 µm cell size at Tamb at different wavelengths







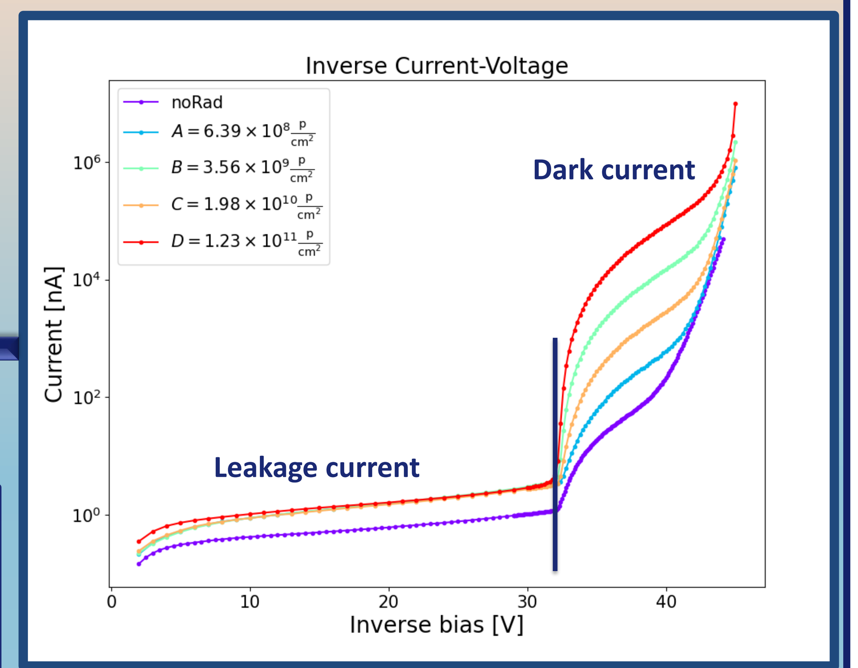
PDE measured on NUV-HD SiPMs with 15 µm and 40µm cell size at 420nm(a), 435nm(b), 450nm(c) at T amb (~20°C) for different proton irradiation fluences, for irradiated doses and no irradiated with and without coating.

PDE of irradiated SiPMs does not change with dose.

Gain and dark count rate results

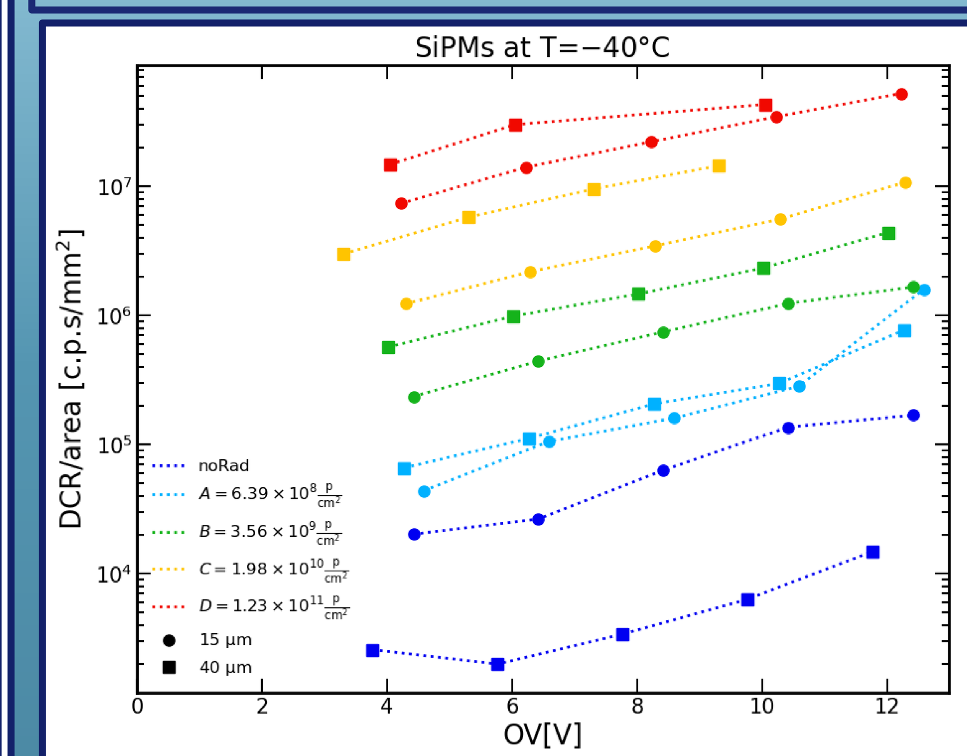
Increment of primary DCR with a fluence and excluded significant variation in breakdown voltage (V_{BD}).

Visible increment of dark current (primary noise) with dose. Small change in leakage current



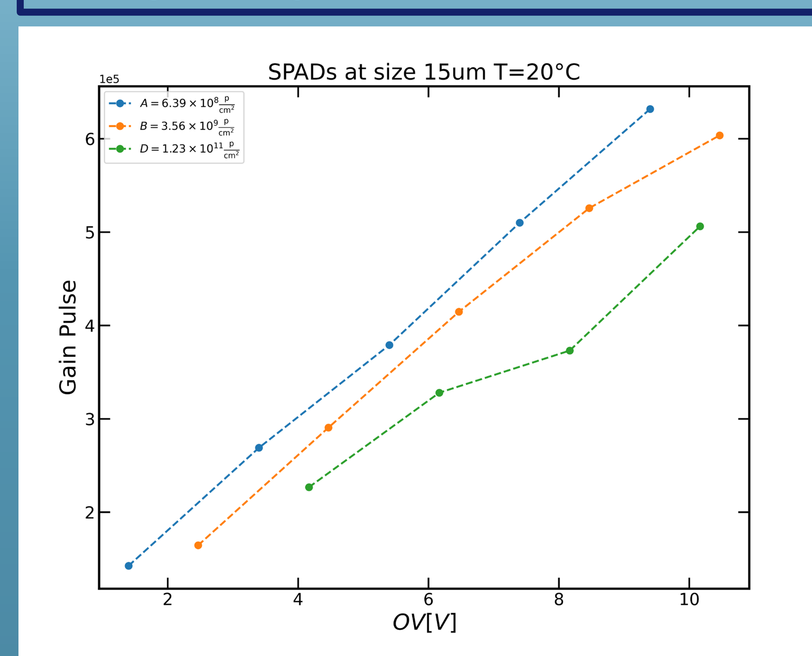
Measured reverse current-voltage curves of NUV-HD SiPM, with 15µm cell size, at different proton irradiation fluences.

DCR increases with dose and it is slightly dependent on single cell size. For 15 µm SPADs the SiPMs DCR value increases of up to 10^2 when the doses increases from 0 to $1.23e^{11}$ p/ cm^2, due to the increase of the DCR of every single SPAD, which composes the SiPM.



DCR normalized at $1mm^2$ for the NUV-HD SiPM with 15µm and 40 µm cell size.

Gain ➔ amount of charge flowing per each avalanche, small changes in gain observed.



Gain measured at 20C for NUV-HD SPAD with 15 µm cell size

Conclusion

We performed functional tests on the irradiated samples (SPADs), which confirmed primary DCR increment, and excluded significant variation in breakdown voltage and gain with absorbed doses. These results are in good agreement with the evaluation of the effects of NIEL and IEL damage on Silicon photomultipliers reported in literature for space application [4]. New solutions, for mitigating the SiPMs and SPADs performance degradation, will be investigated.

References

[1] A. Heering, "Effects of very high radiation on SiPMs," NIM-A 824, 111-114, 2016.
[2] E. Garutti, et al., "Radiation damage of SiPMs", Nuclear instrument and method A, 926, pp. 69-84, 2019.
[3] A.R. Altamura et al., "Characterization of Silicon Photomultipliers after proton irradiation up to $10^{14}n_{eq}/cm^2$", Nuclear instrument and method A, 1040, 167284, 2022.
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