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Ionizing and non-ionizing radiation damage on Silicon Photomultipliers

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Silicon Photomultipliers are single-photon sensitive detectors that continue to attract increasing interest in several industrial and scientific applications that require fast detection speed, high sensitivity, compactness, insensitivity to magnetic fields and low bias voltages. SiPMs have been employed in a growing number of applications thanks to these properties and the good optical dynamic range. They are currently the detector of choice in scientific experiments and industrial applications, like in Positron Emission Tomography, with Time-of-flight information (ToF-PET), Cherenkov light readout, in the readout of liquid noble gases scintillators at cryogenic temperatures (e.g. LAr, LXe), and in industrial and automotive Light Detection and Ranging (LiDAR) systems. SiPMs are also quickly replacing photomultiplier tubes (PMTs), hybrid photodiodes (HPDs), or other detector technologies in high-energy physics (HEP) experiments (like CMS, LHCb, etc.), and for the readout of scintillators in gamma-ray detectors for space experiments. In such applications the SiPMs receive a significant dose of particles (e.g. protons and neutrons) as well as X and gamma rays, in the order of 10^{12} up to 10^{14} particles/cm^2 in HEP and of 10^{11} particles/cm^2 for space applications (considering for example satellites working in LEO or Polar orbit, for few years operations and with typical detector shielding).
While the effect of radiation in silicon detectors has been well studied, the literature is not as much concerning Avalanche photodiodes (APDs) and photon-counting detector, working in Geiger-mode (like SPADs and SiPMs). At FBK (Trento, Italy) we have been developing different technologies during last years for SiPMs and SPADs, optimized for different applications, e.g. with sensitivity peaked in the near-ultraviolet or in the near-infrared region. Such technologies are based on different silicon-starting-materials (with different doping species), and made with different internal layouts and micro-cell structures. It is interesting to directly compare their performance when irradiated with the same particles and fluences, also highlighting possible different behaviors in their performance with irradiation. To study the effect of radiation damage on SiPMs we performed several irradiation campaigns, using protons and X-rays, to study the effects of Ionizing Energy Loss (IEL) and Non-Ionizing Energy Loss (NIEL) on their electrical properties, on their noise characteristics and on their detection efficiency. We highlighted the main effects and differences between the SiPM technologies, and we interpreted the results with the help of TCAD simulations of the electric fields inside the SiPM micro-cells.

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