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Silicon photomultipliers for future HEP experiments

Rok Pestotnik[1], Dania Consuegra[1], Rok Dolenec[2,1], Samo Korpar[3,1], Peter Križan[2,1], Andrej Seljak[1]

Jožef Stefan Institute, Ljubljana, Slovenia

Faculty of Chemistry and Chemical Engineering, University of Maribor, Slovenia

Faculty of Mathematics and Physics, University of Ljubljana, Slovenia

For the particle identification systems of the future high energy physics detectors**, single photon sensors** with sub-mm granularity and high sensitivity are needed. Due to harsh radiation environments and high track densities, they must be resilient to neutrons and have excellent timing resolution. For example, in the LHCb RICH after Upgrade 2, the expected fluence will be $3x10^{12}$ n_{eq}/cm^2. A timing resolution for single photons below 100 ps is needed to associate photons to the tracks coming from different vertices. Silicon photomultipliers are considered a baseline technology for the application due to their high photon detection efficiency, good timing resolution, and low operating voltage compared to vacuum-based photosensors. Unfortunately, they are sensitive to neutron irradiation. The dark counts increase with the neutron fluence and distort the signal baseline, making the single photons undistinguishable. Although the DCR of different unirradiated SiPM varies, the devices show very similar rates when irradiated to high doses. The operation can be recovered by lowering the operation temperature. In this work, we investigated the performance parameters of FBK NUV-HD-RH 1 mm^2 device and determined the temperature below the operation possible. The cryogenic container was used to cool the silicon photomultipliers contained in an RF-shielded box with the cryogenic preamplifier to the liquid nitrogen temperature. With two resistor heaters, the temperature was increased by 40 degrees, and different performance parameters were measured before and after irradiation. We show the results of the I-V characteristic, DCR, timing and pulse height distribution, and the determination of the working temperature. We demonstrate the sensor can be used as a single photon detector by operating silicon photomultipliers at very low temperatures.

1 mm2 FBK NUV-HD-RH samples

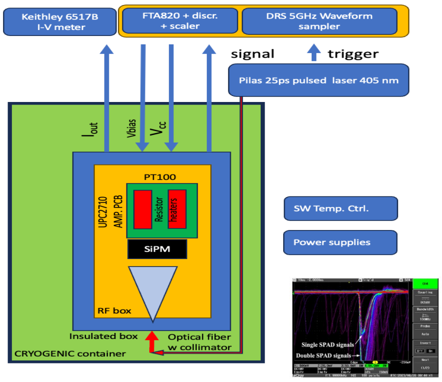
HF high power cryogenic readout

Irradiated with neutrons : 10^9 … 10^{13} n/cm2

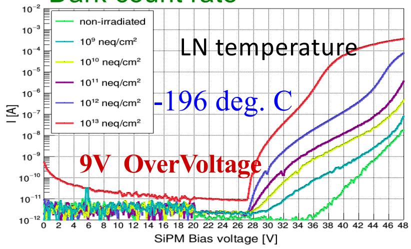
Cooled down to -196 deg. in steps of 40 deg.

T at which the SiPM are "usable" where 1 p.e. peak is separated from the background

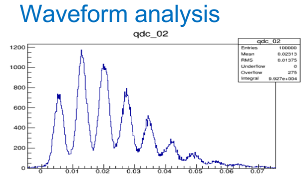
Depends on the readout electronics

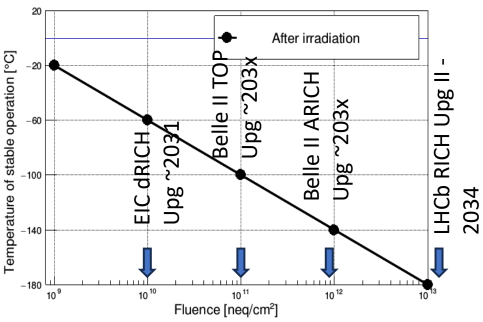


Dark count rate

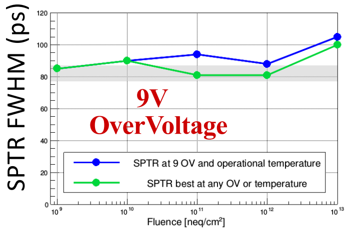


Waveform analysis

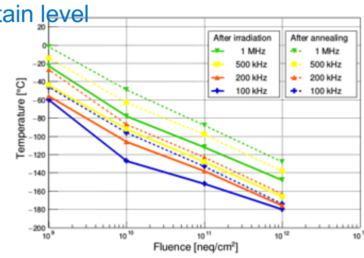




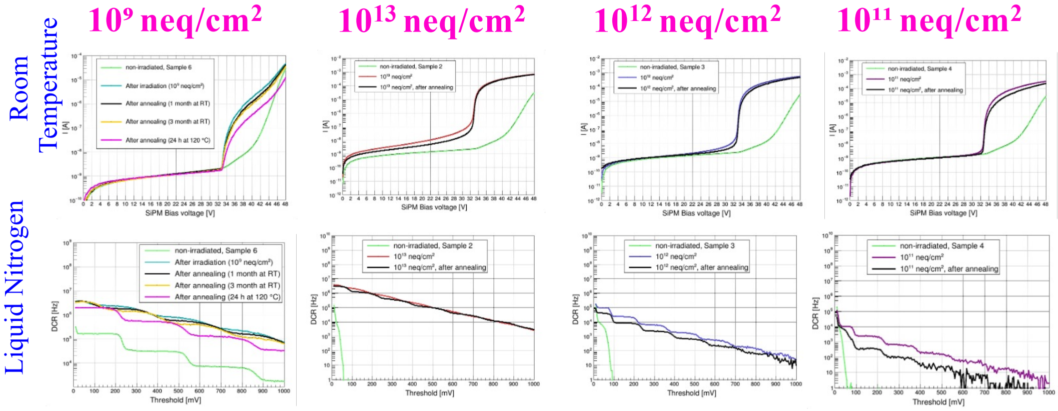
SPTR timing (FWHM)



T at which the DCR is decreased to a certain level



Annealing @80 °C 24 h



The annealing improves the operation, however the DCR is still far from the non irradiated values

*** The annealing time was short**

After annealing (black curves) a slight decrease in the current was observed. More pronounced in the leakage current for the SiPM irradiated at 10^{13} neq/cm² and in the dark current for the SiPM irradiated at 10^{11} neq/cm².

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