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SiPM developments for the Time-Of-Propagation detector of the Belle II experiment

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Belle II is a particle physics experiment planning to work in a high luminosity condition that expects a hard irradiation environment in the next few years. The Time-Of-Propagation modules surround the Belle II tracking detector on the barrel part for particle identification. Each module contains a finely fused silica bar, microchannel plate photomultiplier tube (MCP-PMT) photo-detectors, and high-speed redout electronics. These MCP-PMTs will have a lifetime of about one year at the nominal luminosity of the accelerator due to the high photon background degrading the quantum efficiency of the photocathode. An alternative for these MCP-PMTs can be multi-channel photon counters (MCPC) known as silicon photomultipliers (SiPM). The SiPMs in comparison to MCP-PMTs have a lower cost and higher photon detection efficiency, but also a higher dark count rate with an exponential increase as a function of the neutron background rate. The dark count rate can be mitigated with an annealing process and lower temperatures. We tested SiPMs from different producers and different dimensions and cell pitches to understand functionality and behavior in several conditions, e.g. irradiation up to 5x10ˆ11 n/cmˆ2 or after strong annealing for 60 days at 150 degrees Celsia. Dark count rate studies demonstrate significant recovery of the degradation of SiPMs using annealing. In the photon spectra analyses, we are able to nicely extract photon peaks and estimate breakdown voltages, which are consistent in different conditions. In time resolution examinations, the SiPMs achieve a 100 ps level, and the results are compatible in all tested conditions. A new SiPM prototype developed in collaboration with FBK with the aim of improving radiation hardness, is expected to be delivered at the end of August 2024.

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