NDIP20 short notice
New developments in: Detector Technology
Detector Types: solid state detector
Application: Particle Physics

Title

SiPM developments for the TOP detector of the Belle II experiment

Abstract

The Time-of-Propagation (TOP) is the particle identification detector in the barrel region of the Belle II experiment. The detector consists of quartz bars acting as Cherenkov radiators.
The arrival time and position of photons on the back side are determined through the optical coupling with Micro-Channel-Plate PMT. The data taking with SuperKEKB e+e- beam collisions started in May 2018 and is ongoing. From the technical design project relevant improvements of the MCP-PMT production processes led to a significant reduction of the quantum efficiency degradation induced by the photon background. Three generations of MCP-PMT are currently installed in the TOP detector. The SuperKEKB accelerator shutdowns of 2023 and 2027 will be used to upgrade the detector with the last generation of MCP-PMT. Many improvements in SiPM production technology have been achieved in the last years. Several radiation hardness test with SiPM will be performed in the next months and years with the aim of contributing to new SiPM developments having fast signal and higher radiation resistance. Using SiPM as photodetector inside the Belle II TOP detector is the backup solution for the 2027 upgrade and the main option for possible other upgrades with higher luminosity and higher background.

Notice

At the nominal Belle II luminosity of $6x10^{35}$ cm^{-2} s^{-1} the expected radiation dose in the TOP photodetector region is about 5 Gy/year, the expected photoelectron rate is about 7 MHz/PMT and the expected neutron flux is about 1.5 10^{10} n/cm^2 per year.
The current projection of the quantum efficiency degradation shows the two older MCP-PMT generations will reach 80% around 2023 and 2027 and must be replaced (Fig.1).

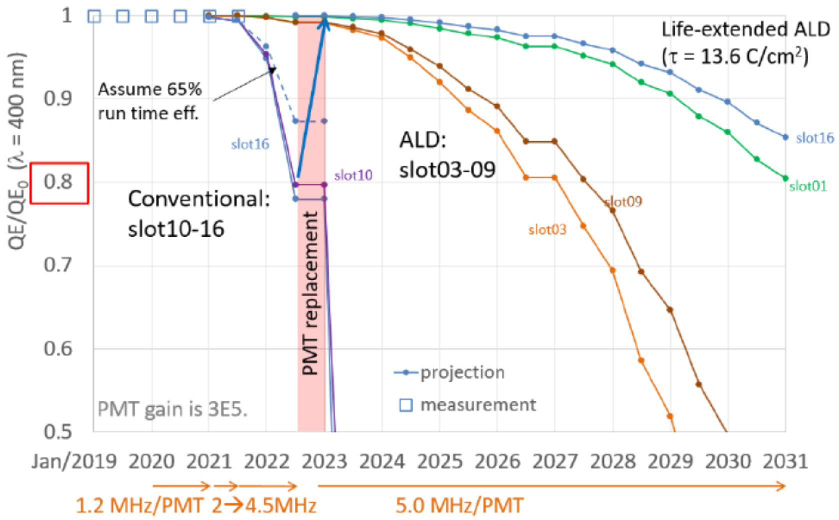
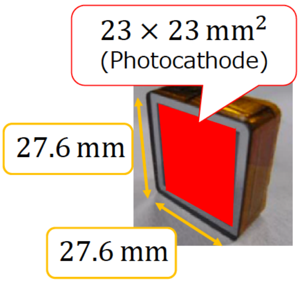


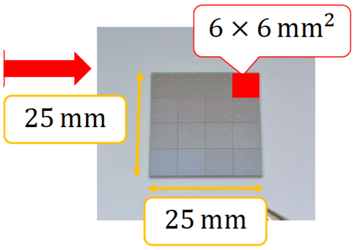
Fig. 1 Expected relative quantum efficiency degradation of the installed MCP-PMT estimated using lifetime measurements (C/cm^2 reducing QE at 80%) for the three generation of MCP-PMT.

The SiPM option is the backup solution for the 2027 upgrade if higher than expected background will significantly reduce the MCP-PMT lifetime and is the main option if the upgrade of SuperKEKB will allow to reach maximum luminosity higher than nominal.

Simple geometrical considerations lead to consider the replacement of a single 16 channel MCP-PMT 27.6 x 27.6 mm^2 size with 16 SiPM 6x6 mm^2 size.



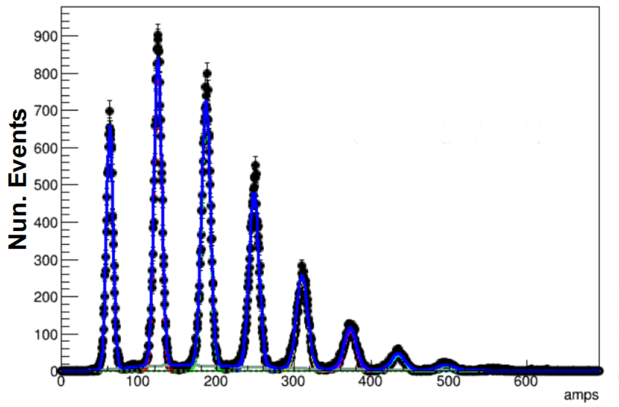
1 MCP-PMT
16 channes



16 SiPM   6x6 mm^2

SiPM have the advantages to give a better covered effective area and a higher peak photo detection efficiency (15% for MCP-PMT, 40% for SiPM).
The disadvantage of SiPM is the high dark counting rate, for 50 µm cells and 0.5 p.e. threshold the rate is about 50 kHz/mm^2. The dark counting rate increase a factor 4000 when the neutron radiation reaches 10^{11} n/cm^2 [1].

For the calibration system of the TOP detector, we are using SiPMs with 50 µm cells and 1.3x1.3 mm^2 dimension. These SiPMs are placed outside the radiation area and cooled with peltier at 15 ^{0}C. The single photon peaks can be distinguished.



Single photon peaks for SiPM HPK S13360-1350.

For the MCP-PMT replacement the strategy is to test in the next months a wide set of SiPM 3x3 mm^2 size (HPK S14160-3015PS, KETEK-PM3315-WL, FBK-NUV-HD-RH-3015, etc.).
The considered size was reduced from 6x6 mm^2 to 3x3 mm^2 to gain a factor 4 in the dark rate without increasing too much the number of channels. The test system can cool SiPMs down to -50 ^{c}C. The radiation hardness requirement leads to consider SiPMs with 10-15 µm cells with trenches. For the readout electronics an R&D in ongoing with new ASICs (from 8 to 32 channels and feature extraction included) and new data transfer boards. The new electronics can support four times more channels in the same space or less space occupancy and less power consumption with the same number of channels.

References

[1] M.Calvi, *et al.* Single photon detection with SiPMs irradiated up to 1014 cm−2 1-MeV-equivalent neutron fluence. Nucl. Instrum. Methods Phys. Res A, 922 (2019), pp. 243-249, doi: 10.1016/j.nima.2019.01.013