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Performance evaluation in different environments of the MCP-PMT for the TOP counter in the Belle II experiment

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The Belle II experiment produces large numbers of B mesons by colliding electrons and positrons at the $\Upsilon(4S)$ resonance ($\sqrt{s}$ = 10.58 GeV). It aims to validate the Standard Model precisely, search for new physics, and elucidate the internal structure of hadrons. The target integrated luminosity is 50 ab-1, fifty times larger than the previous B-factory experiment.
The Time-of-Propagation (TOP) counter is a ring-imaging Cherenkov detector consisting of a quartz radiator and a photodetector, Micro-Channel-Plate (MCP)-PMT, which distinguishes charged K and π mesons produced by the decay of hadrons. The MCP-PMT has a good timing resolution of $\sigma \sim 34$ ps, which satisfies the requirements for K/π mesons separation. On the other hand, the MCP-PMT shows a gradual decrease in quantum efficiency (QE) with integrated output charge, which results in a deterioration of particle identification performance. Based on the collision data, the evaluated relative QE shows a more rapid drop than expected from the test bench results. It is therefore essential to identify the cause of the unexpectedly rapid QE degradation and to take effective measures to prevent it.
In this study, we performed a series of measurements using MCP-PMTs removed from the TOP counter during the long-term shutdown in 2022-2023. First, to confirm the QE degradation in the detector, we conducted laboratory measurements, which showed good linearity with those obtained in the TOP counter. Second, we investigated the temperature dependence of QE degradation. This is because the temperature during the lifetime measurements (room temperature, 25 ℃) is significantly lower than the actual operating temperature (40 – 50 ℃), which is expected to affect the amount of outgassing. Therefore, we carried out the lifetime measurements at room temperature (25 ℃) and under heated conditions (40 ℃ and 50 ℃) using the PMTs removed from the TOP counter. The results showed that no QE degradation comparable to that observed during beam operation was seen. Third, we investigated the effect of applying to a magnetic field. The lifetime measurement in the laboratory was conducted under a magnetic field of 0 T, while the actual operation occurs in a magnetic field of 1.5 T, which may affect the ionization process. Since lifetime measurements need a long time, we performed after-pulse measurements beforehand. After-pulses can be detected by a delayed pulse. They are expected to be directly associated with the presence of ions, making their measurement important for investigating potential QE degradation. As a result, we observed that the number of light ions reaching the photocathode was higher under a magnetic field than in the no-field condition. Subsequently, we evaluated the lifetime of the same PMTs. The results showed that the QE drop was observed 1.3 to 2.3 times faster at 1.5 T than at 0 T. However, the QE drop was not large enough to explain the reduction observed during the experiment.
In this presentation, we demonstrated that the presence of a magnetic field contributes to the degradation of QE. These findings provide valuable insights for improving MCP-PMTs and optimizing their operational conditions in the future.

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