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

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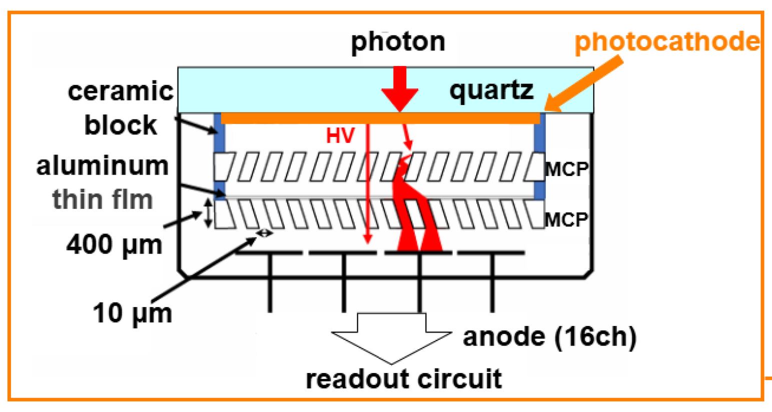
Belle II experiment

The Belle II experiment produces huge numbers of B mesons by colliding electrons and positrons at around the Υ (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 Belle experiment.

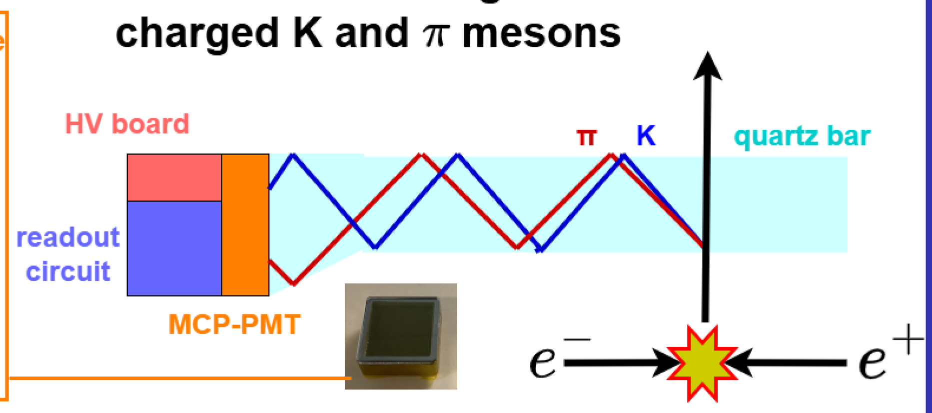
TOP counter

TOP counter is the particle identification system based on the Cherenkov ring imaging, located at the barrel region of Belle II detector

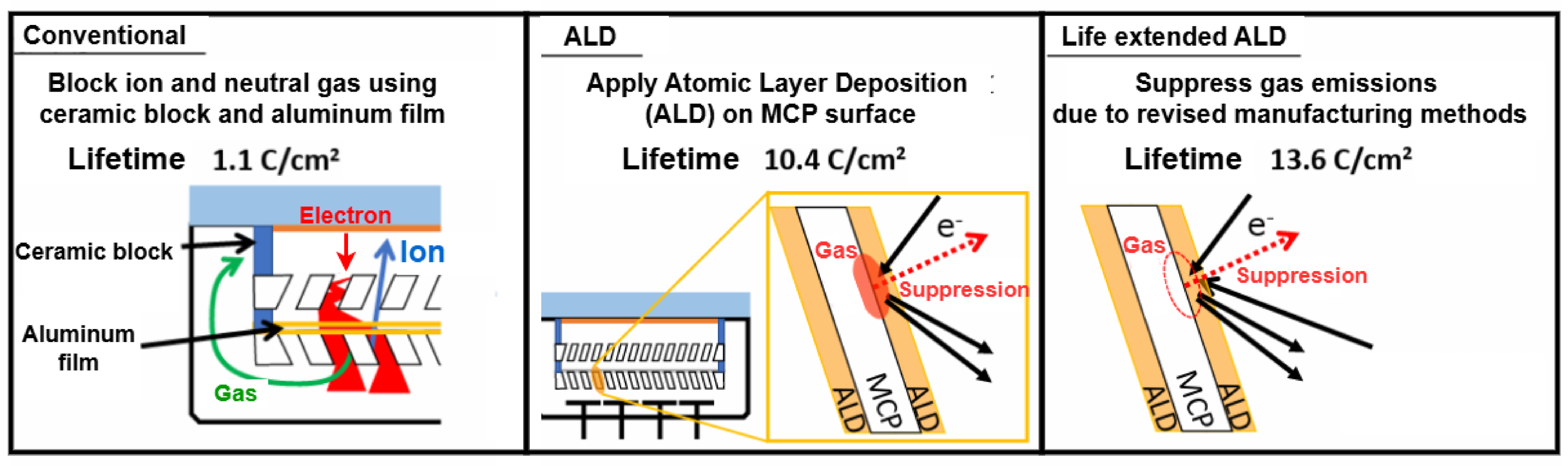
MCP-PMT's Internal structure



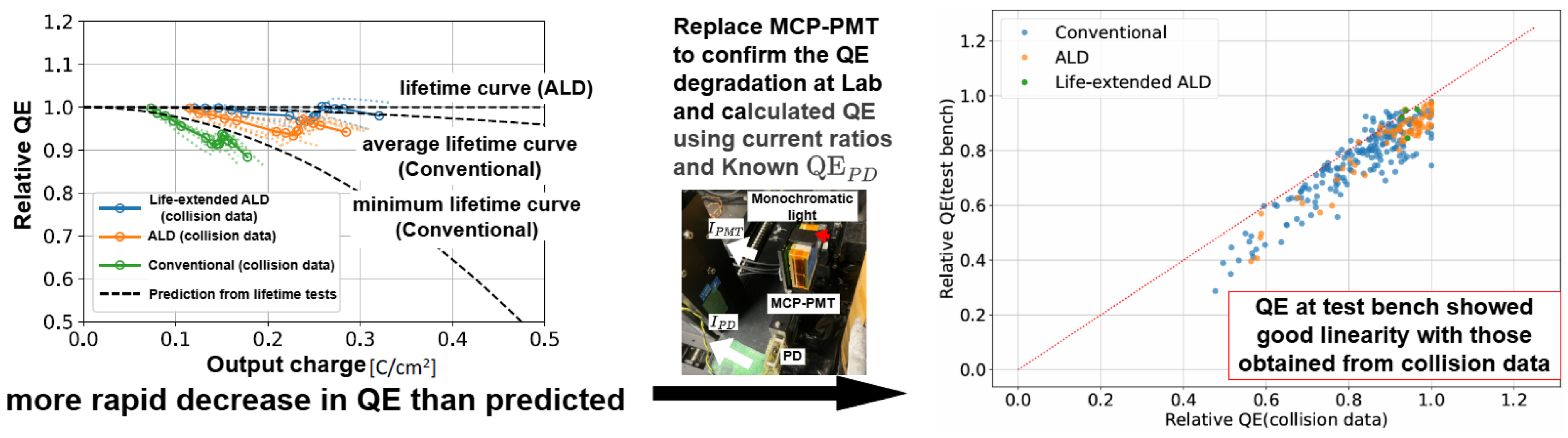
TOP counter distinguishes charged K and π mesons



- Basic property:
  Number of detected photon: 20 - 40 / 1 track Time resolution: 50 ps
  Quantum efficiency (QE): 29.3 %(nominal) Single photon detection efficiency: 18%
- Weak point : PMT's QE gradually decreases with the output charge
- Photoelectrons may ionize residual gas on the MCP surface, which drift back toward the photocathode and deteriorate the QE
- Measures:



- QE degradation during Run1 and QE measurement at Lab

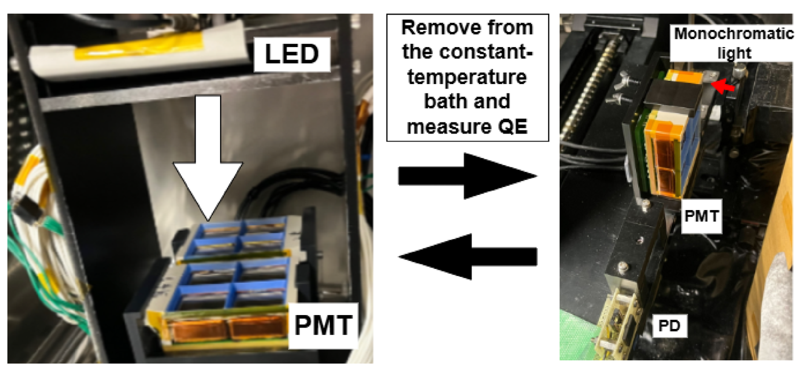


- Replaced the PMT with degraded QE in 2023

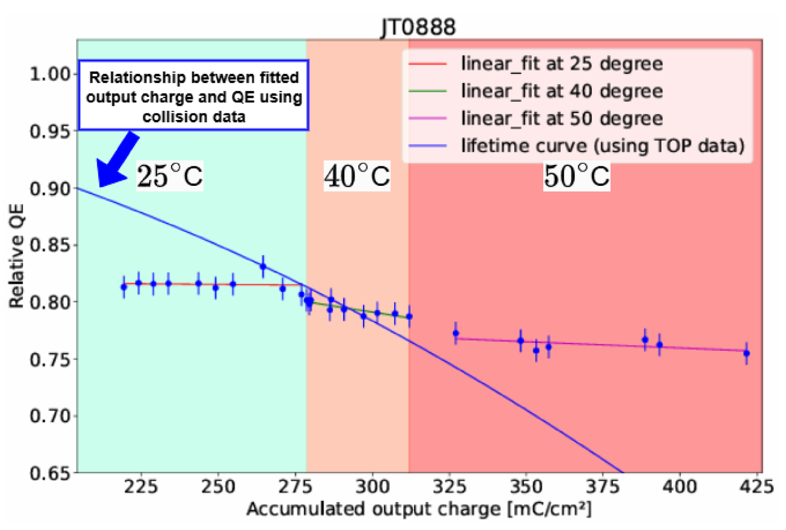
It is essential to identify the cause of the unexpectedly rapid QE degradation and to take effective measures to prevent it

The effect of high temperature

- Test bench : 25 °C Operation : 40 - 50 °C
  Hypothesis : The reaction between the photoelectric surface and ions may change with temperature
- Irradiated the 4 MCP-PMTs (conventional) with LED light inside the constant temperature chamber and measured the charge



- As the temperature rises, QE is decreasing
  - Temperature Characteristics of the Photoelectric Surface
- The results showed that no QE degradation as in beam operation was seen

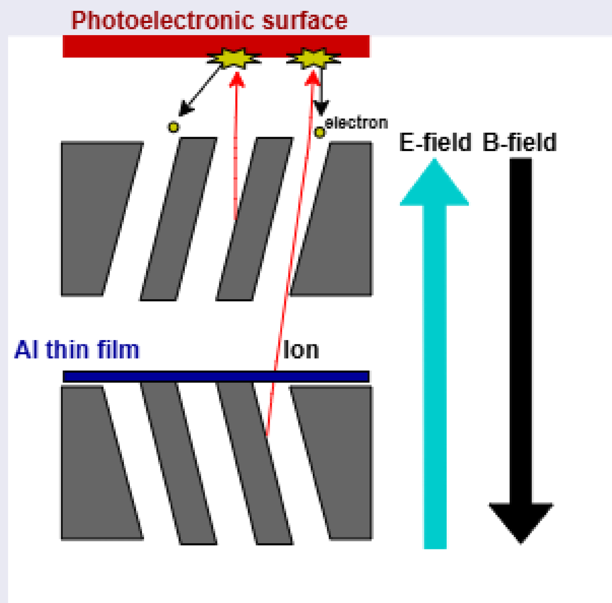


The effect of magnetic field

- Test bench : 0 T Operation : 1.5 T
- Gain decreases in a magnetic field, so we increase the voltage applied to the PMT during Belle II experiment
- Hypothesis : By increasing the voltage, the amount of ions emitted from MCP may increase

Afterpulse measurement

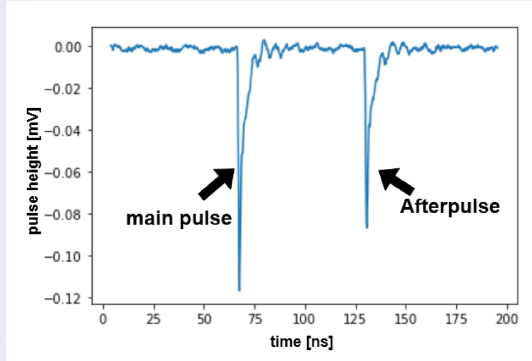
- Afterpulse : Ions collide with the photocathode surface, ejecting electrons, and the signal is amplified within the MCP
- The time it takes for ions to reach the photocathode surface is determined by the ion's mass and charge, as well as the applied voltage across the PMT

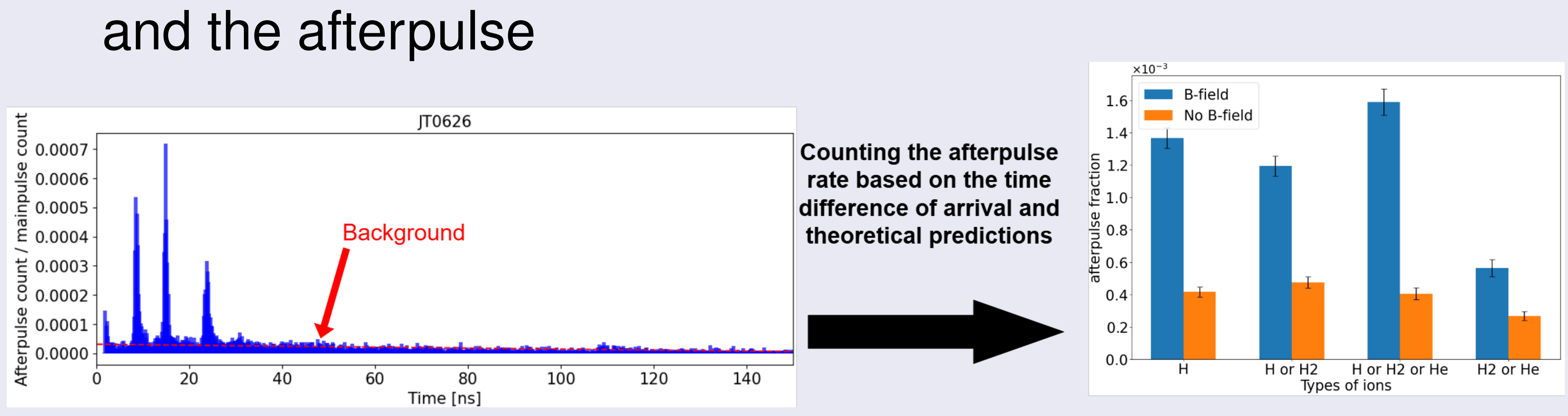


- The time required for ions to reach the photoelectric surface was calculated based on the equations of motion $m\boldsymbol{a} = q\boldsymbol{E}$

Ion	1st MCP	2nd MCP	Ion	1st MCP	2nd MCP
H^+	8.20 ns	8.15 ns	H_2O^+	35.9 ns	35.7 ns
H_2^+	15.8 ns	15.7 ns	O_2^+	47.2 ns	46.9 ns
He^+	17.9 ns	17.8 ns	CO_2^+	55.0 ns	54.7 ns

- Checked the Conventional MCP-PMT inside the electromagnet at the same gain in both 0 T and 1.5 T
- Triggered by wave height, acquired waveform, and calculated the time difference between the main pulse and the afterpulse

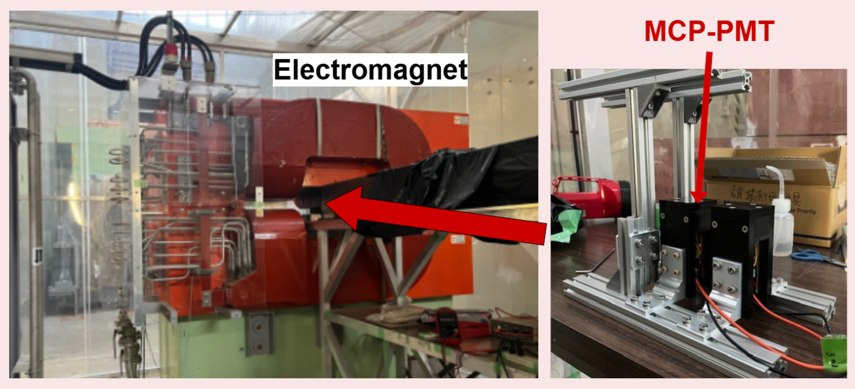




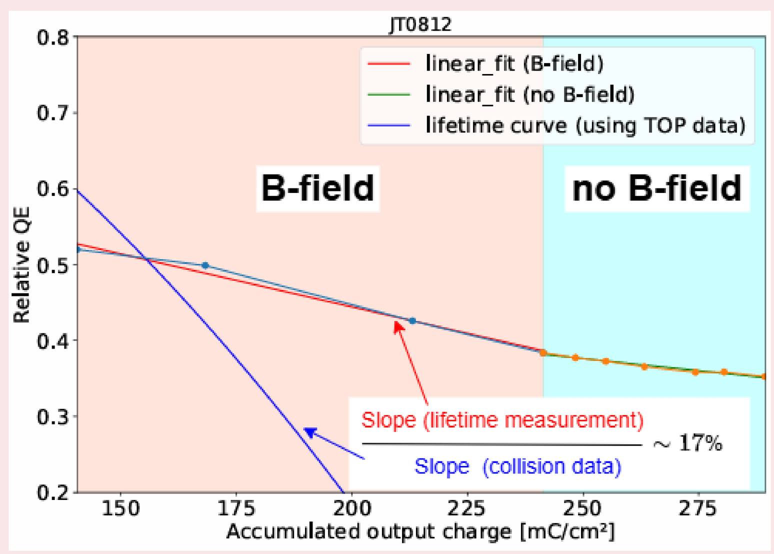
The number of light ions reaching the photocathode was higher under a magnetic field than in the no-field

lifetime measurement

- Installed the Conventional MCP-PMT inside the electromagnet at the same gain in both 0 T and 1.5 T and irradiated the MCP-PMT with LED light



- Remove from the electromagnet and measure QE
- QE decreased rapidly in a magnetic field environment
- It has been discovered that the magnetic field effect can explain part of the reason why QE declines faster than expected



Measurements in a magnetic field suggest that light ions may explain part of the unexpectedly large decrease in quantum efficiency

Prospects

- We plan to measure afterpulse and lifetime under various voltage conditions to investigate the correlation between ion type, quantity, and lifetime
- We also plan to measure afterpulse and lifetime measurements under conditions closer to those in the Belle II experiment (High temperature and high magnetic field) for understanding the QE degradation