MCP-PMT quantum efficiency monitoring and operation status of the TOP counter at the Belle II experiment

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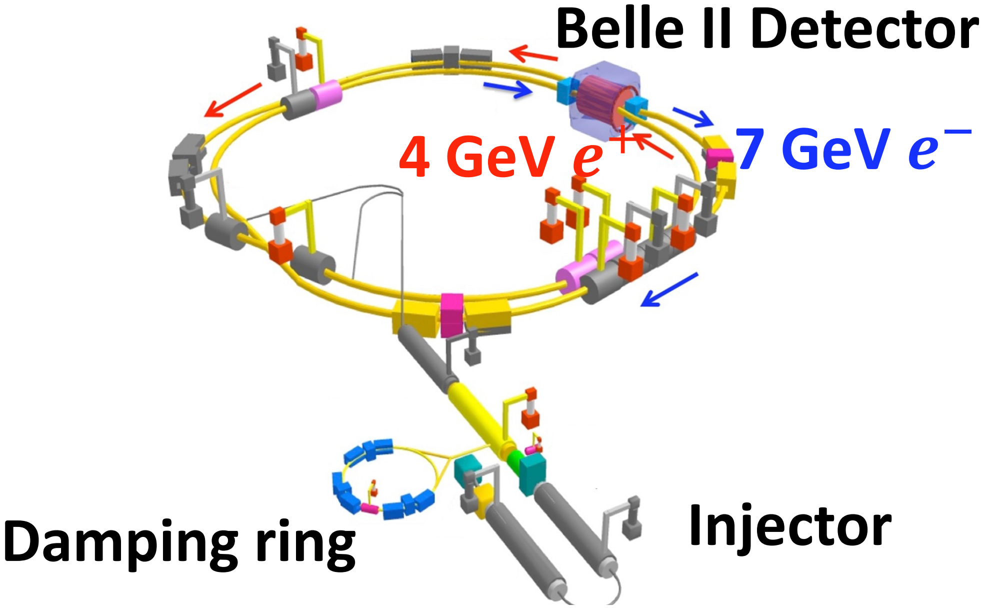
DMNet

Contents

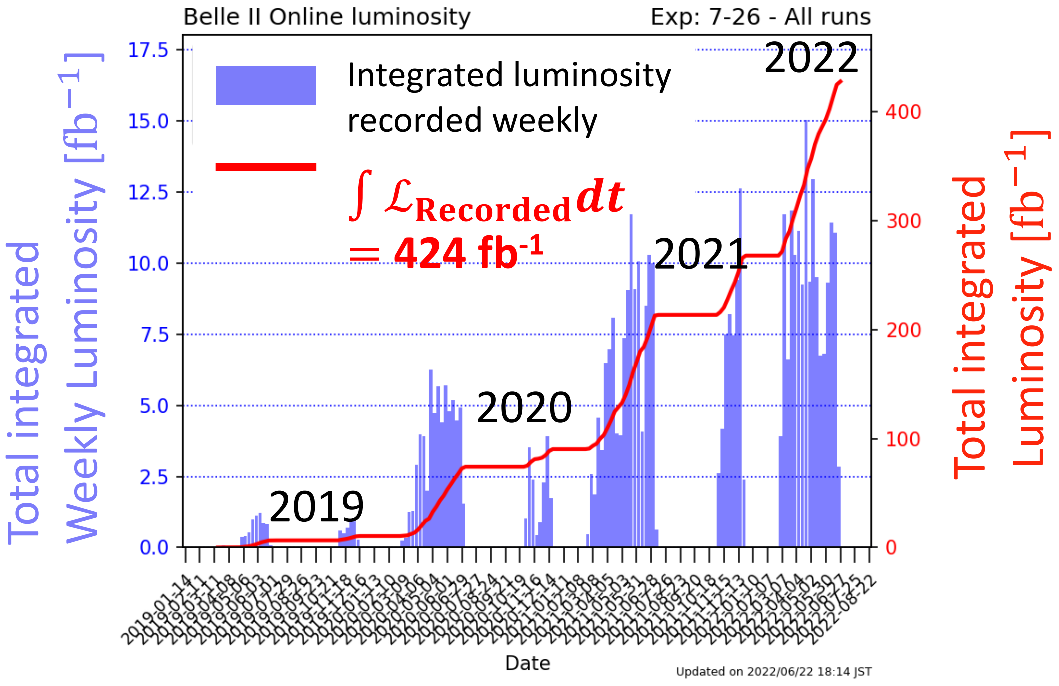
Belle II experiment



High luminosity electrons and positrons collider experiment at a center of mass energy of 10.58 GeV.

Target integral Luminosity : $50\ \mathrm{ab}^{-1}$
Target peak luminosity : $6.5\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Achieved peak Luminosity :
$\mathbf{4.7\times10^{34}cm^{-2}s^{-1}}$



<u>Our Target</u>

Search physics beyond the standard model by precise measurement of B, τ and so on using high-statistics clean data.

Belle II Detector

Vertex Detector

2 layers Pixel (Inner)
4 layers double-sided silicon strip detectors (Outer)
→ Measure decay vertex

Central Drift Chamber

→Measure track and momentum

Electromagnetic calorimeter

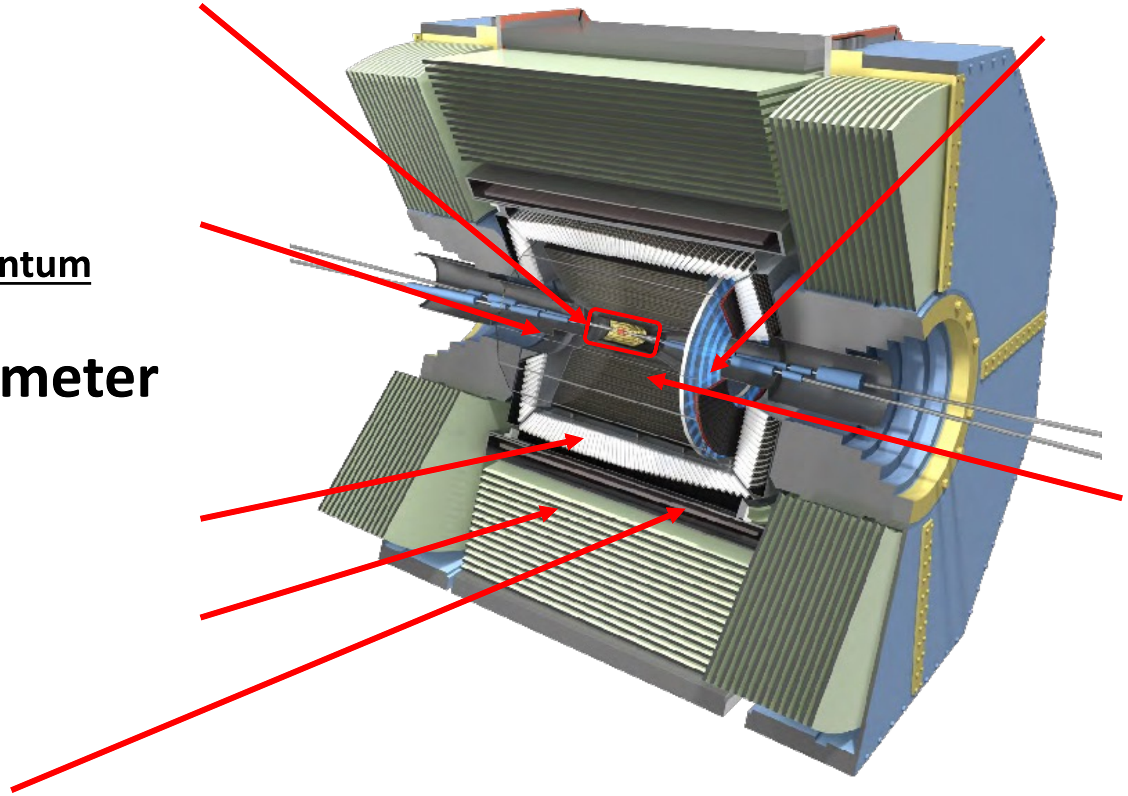
CsI (Tl) calorimeter
→ Measure the energy

KLM

→μ and K_L detection

Solenoid

Magnetic Field : 1.5T



PID by ring-imaging counter

ARICH

Aerogel ring imaging Cherenkov detector

→ Forward endcap PID

TOP Counter

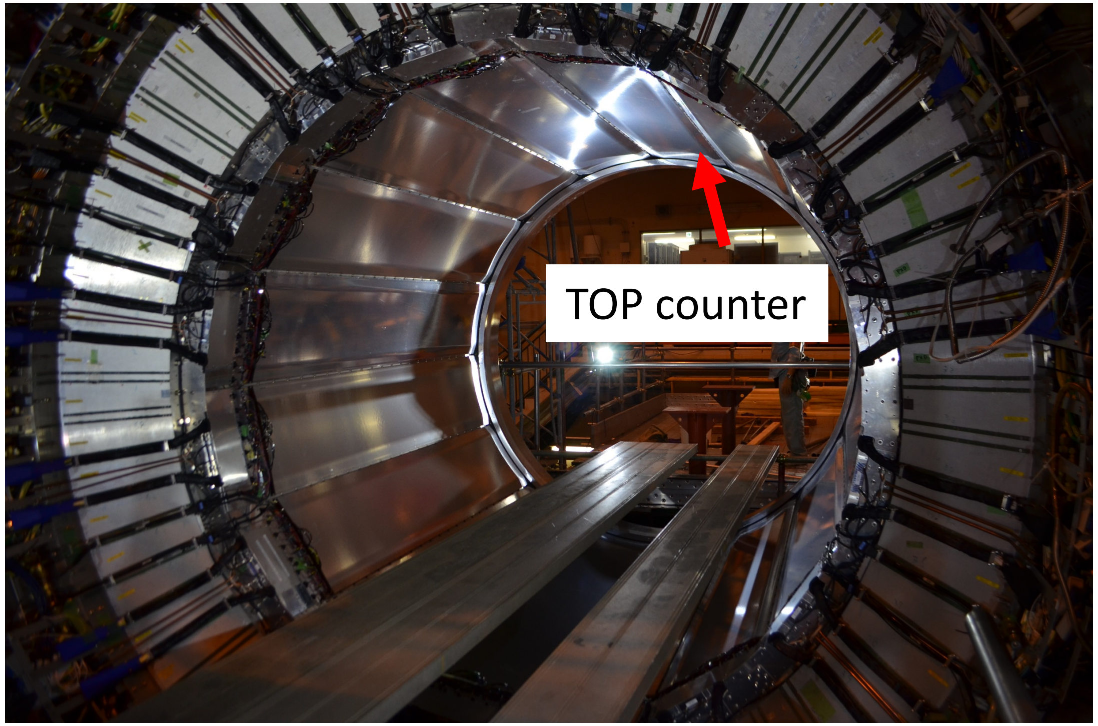
Time-of-propagation counter
16 TOP module are installed

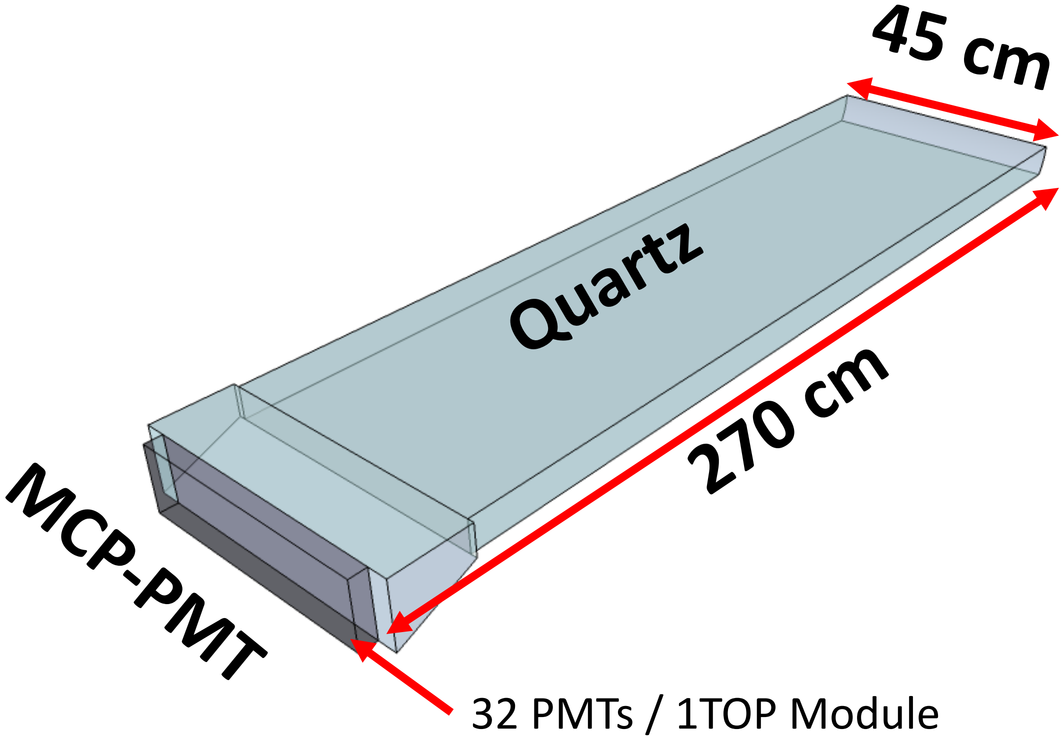
→Barrel PID

TOP counter

Time-of-Propagation counter (TOP counter)

- Belle II barrel PID detector using Cherenkov light
- 16 TOP counter (32 PMTs / SLOT) are installed

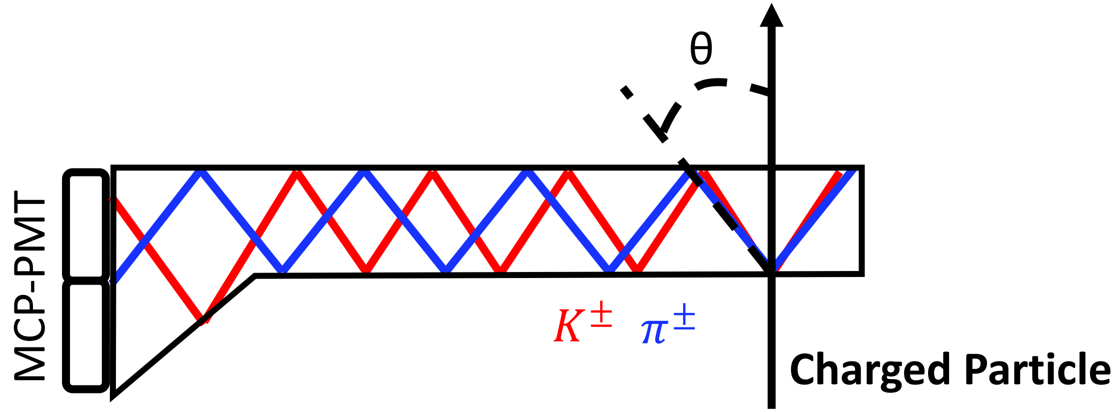




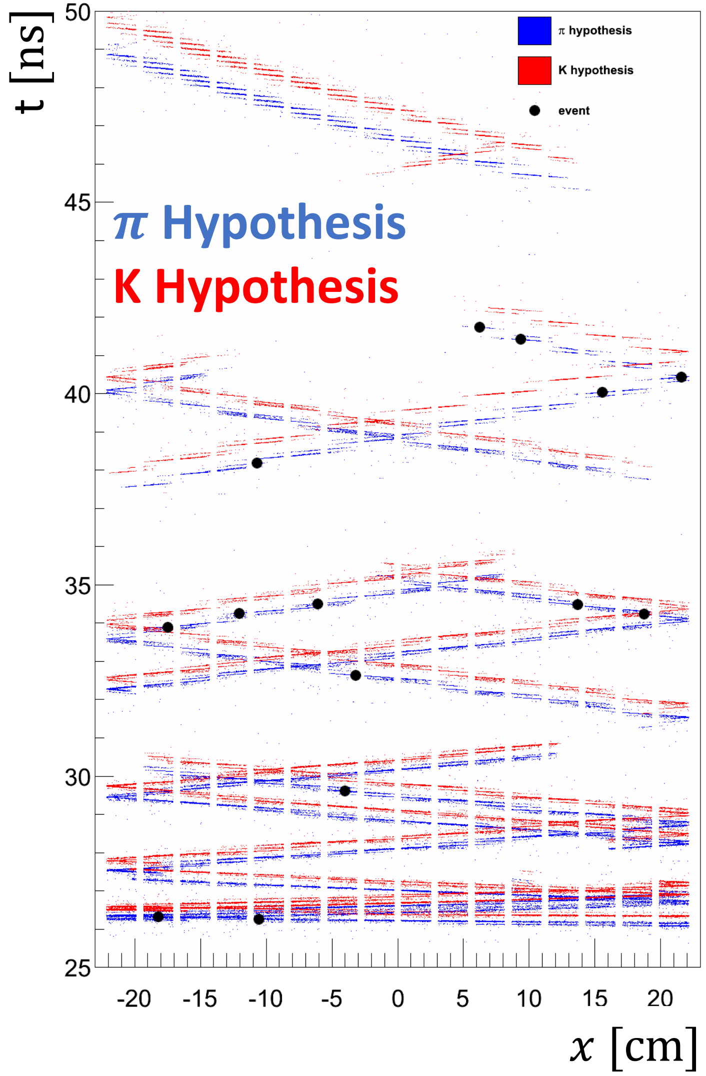
Particle identification by TOP counter

Identify particles using Cherenkov angle

$$\cos\theta = \frac{1}{n\beta} = \frac{\sqrt{m^2+p^2}}{np}$$



20 – 40 photons are detected



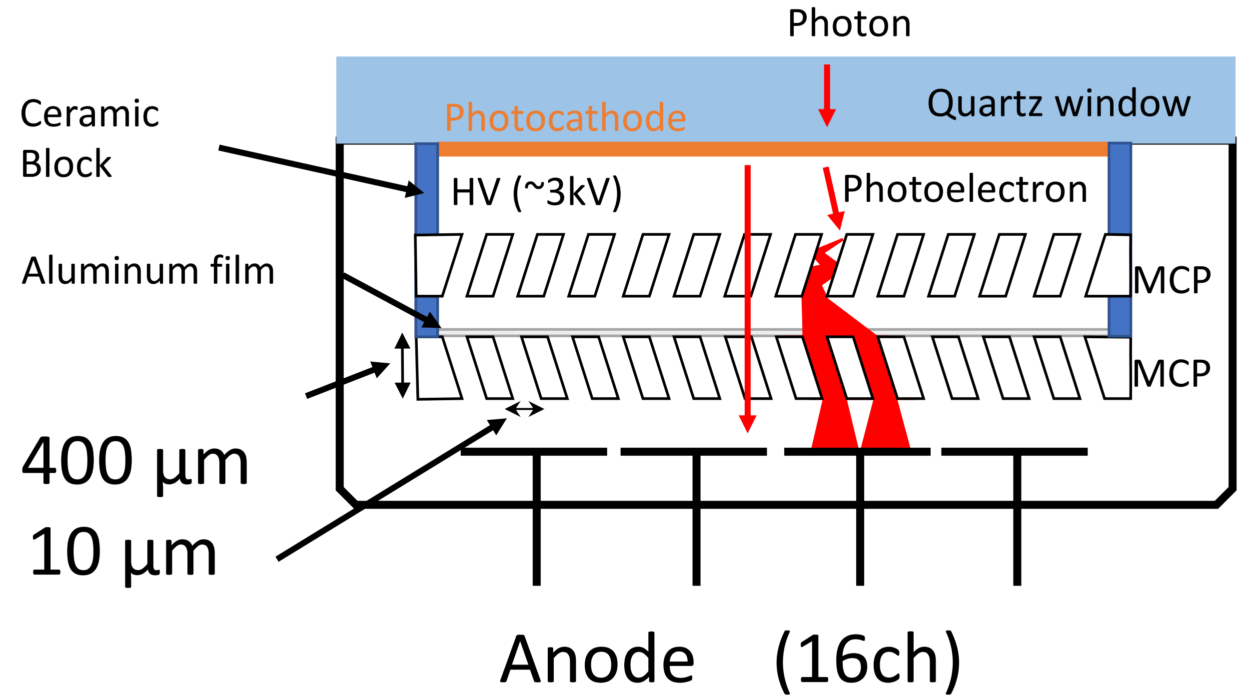
Performance $\propto \dfrac{\sqrt{\textbf{Number of detected photons}}}{\textbf{Time resolution}}$

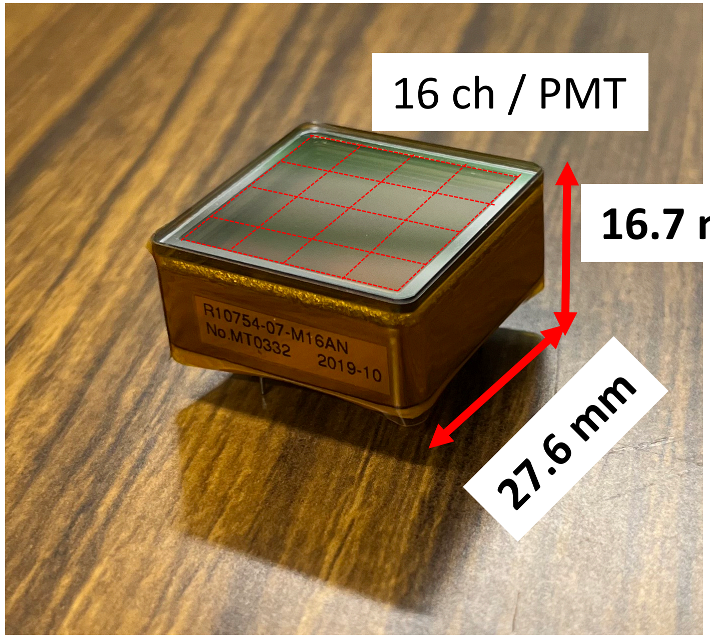
Micro-channel-Plate(MCP)-PMT

Photomultiplier with great time resolution and efficiency for TOP counter

Amplify photo electron over a short distance
→ High time resolution

Time resolution	34.3 ps
Quantum efficiency	29.3 %





Lifetime of MCP-PMT

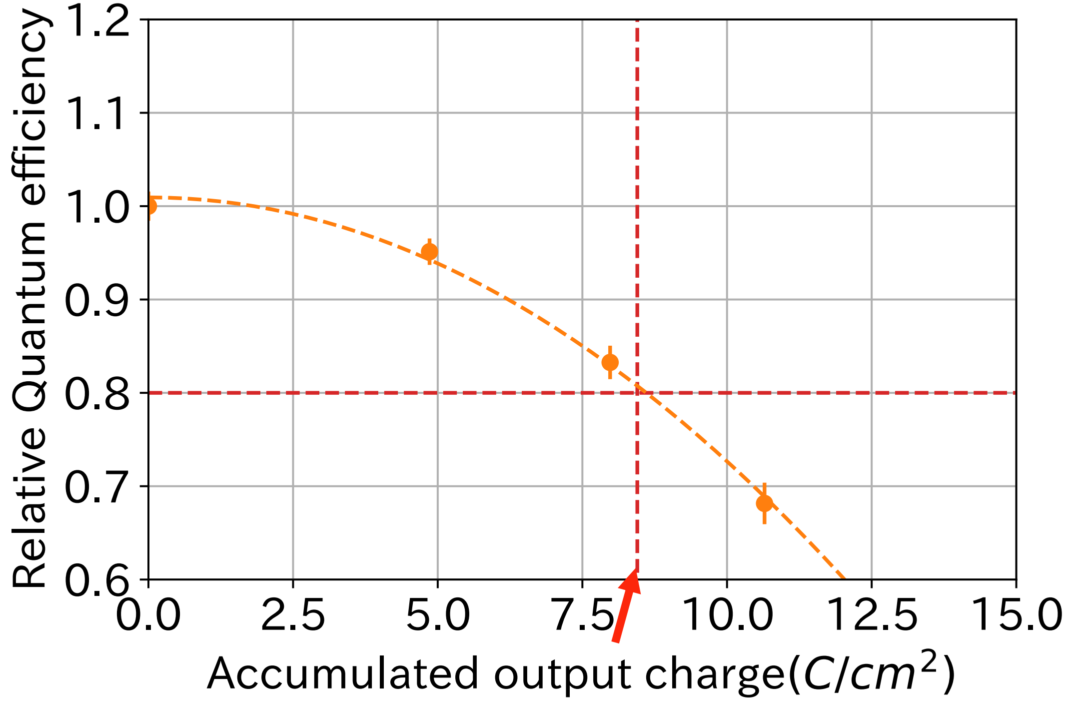
The quantum efficiency (QE) of MCP-PMT decrease with the accumulated output charge by outgassing.

We have improved the lifetime and installed 3 types of MCP-PMT.

Type	Lifetime	Improvement
Conventional	$1.1\ \mathrm{C/cm^2}$ (Average)	-
ALD	$10.4\ \mathrm{C/cm^2}$ (Average)	ALD coating to reduce out gassing
Life extended ALD	$>13.6\ \mathrm{C/cm^2}$	Reduced residual gas

(ALD : Atomic layer deposition)

Lifetime = Accumulated output charge when the relative quantum efficiency at $\lambda = 400$ nm reaches 0.8



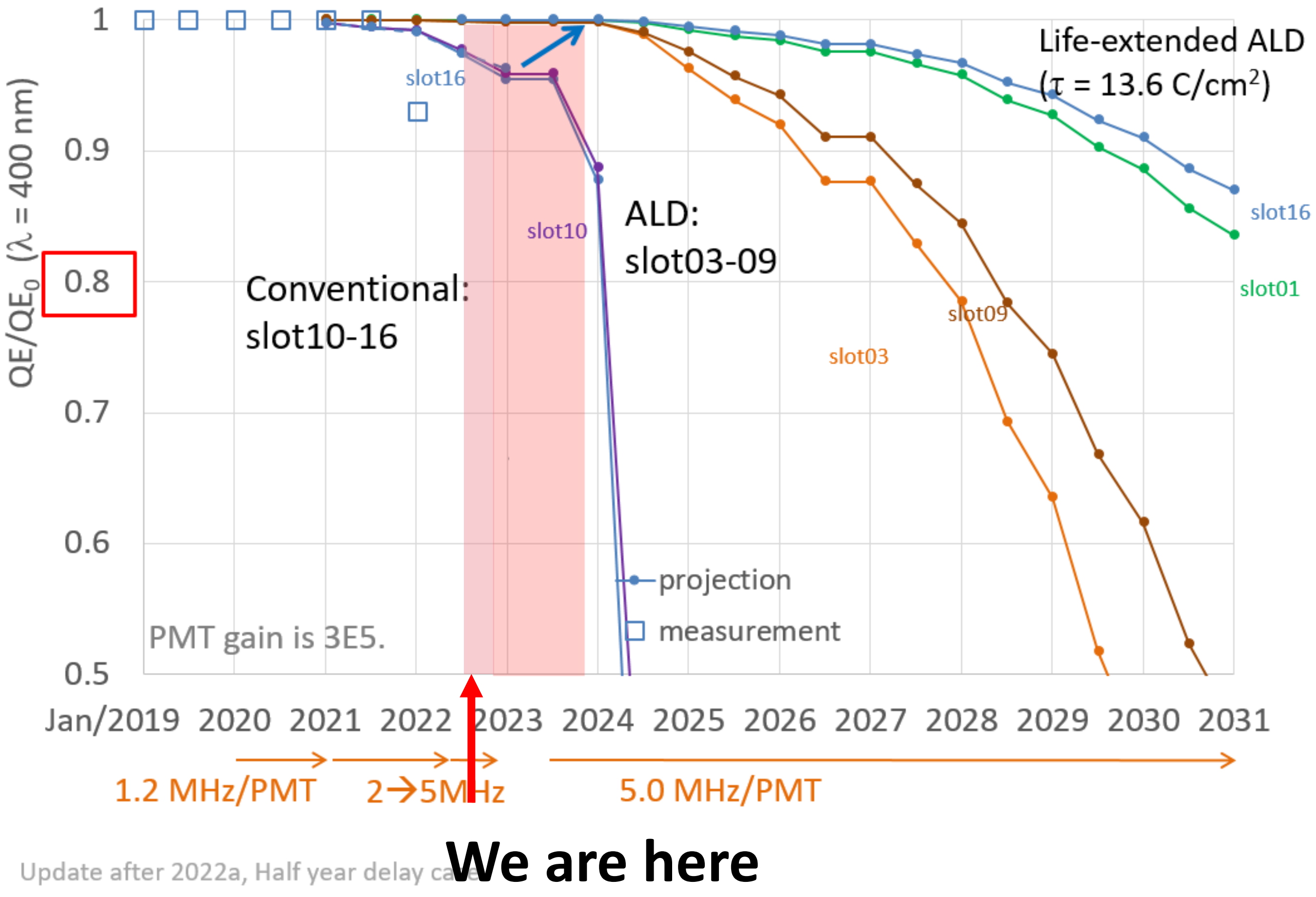
We have to operate MCP-PMT while paying attention to the lifetime

Projection of the QE degradation

QE of MCP-PMT decrease due to large environmental background rate of Belle II experiment.

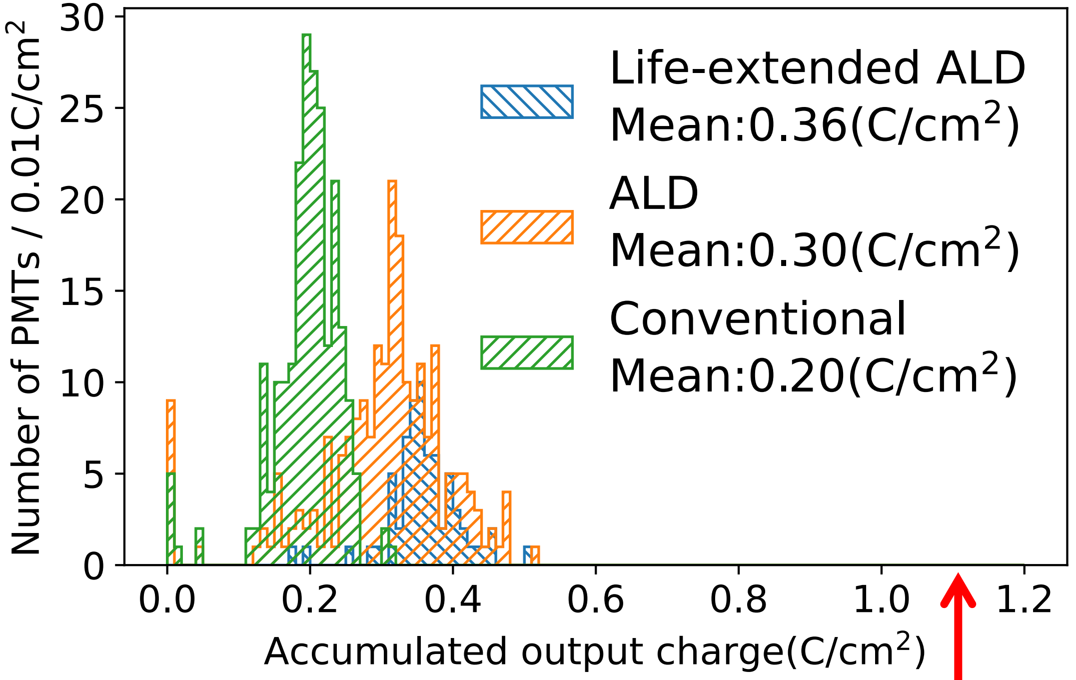
We are planning to replace conventional MCP-PMT in the near future.

Type	Lifetime
Conventional	1.1 C/cm^2 (Average)
ALD	10.4 C/cm^2 (Average)
Life extended ALD	>13.6 C/cm^2



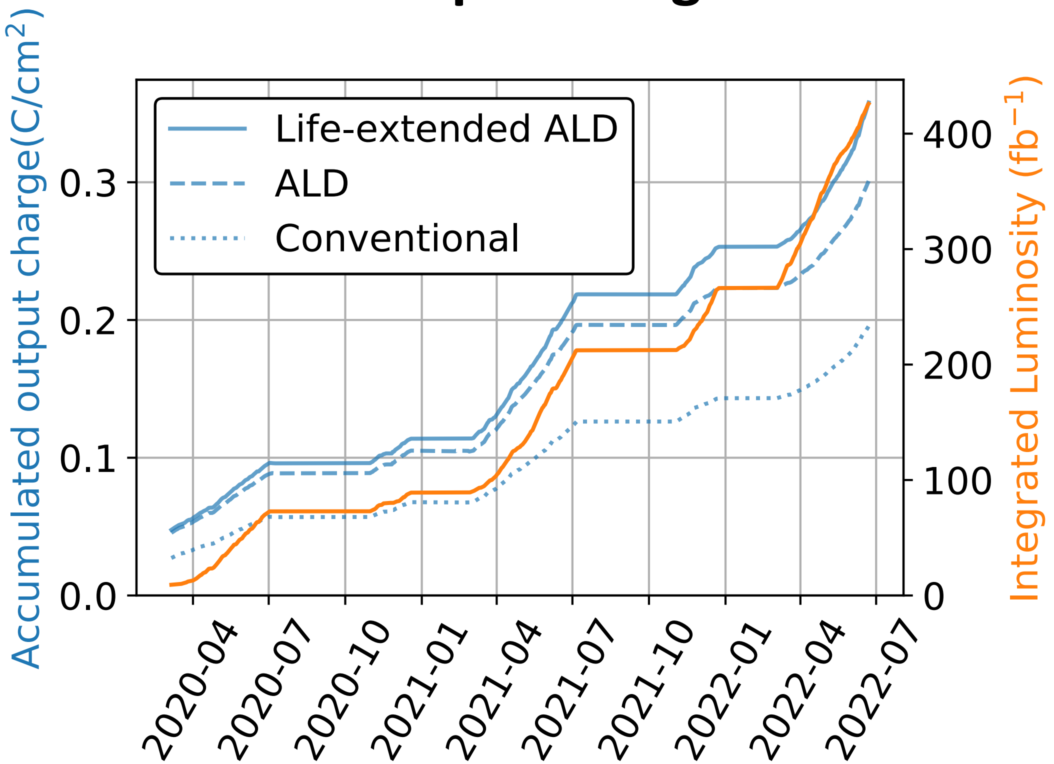
Accumulated output charge

Accumulated output charge of all MCP-PMT



Average lifetime of conventional MCP-PMT

History of Luminosity and accumulated output charge



Accumulated charge so far is still well below the limit of conventional MCP-PMTs.

QE measurement

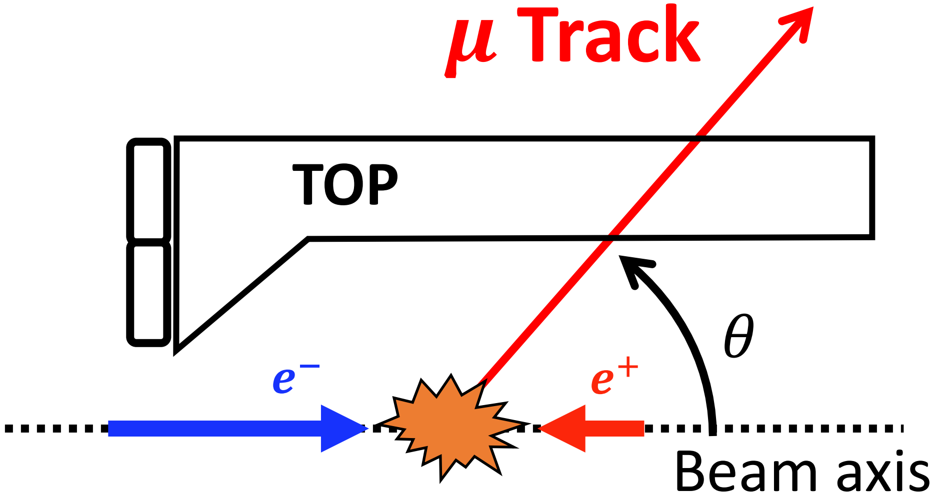
Data

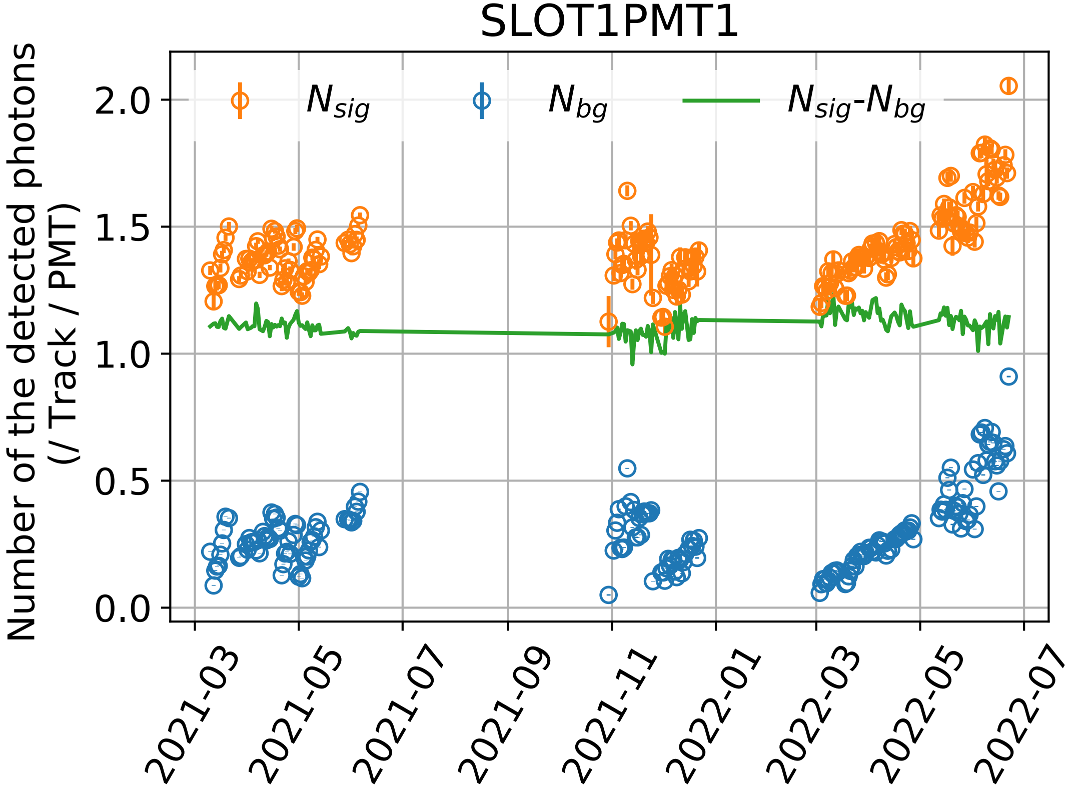
Physics run data

(Tightly skimmed for $e^+e^- \to \mu^+\mu^-(\gamma)$ events)

Selection

- $P_\mu > 1\ GeV/c$
- $-0.3 < cos\,\theta < 0.5$ (Enter to TOP counter)
- Good PMT pulse shape
  (Pulse Height, Pulse width, …)





QE ∝ N_{sig} - N_{bg}

(Photons / PMT / Track)

N_{sig} : 1 Muon track

→ Cherenkov light signal

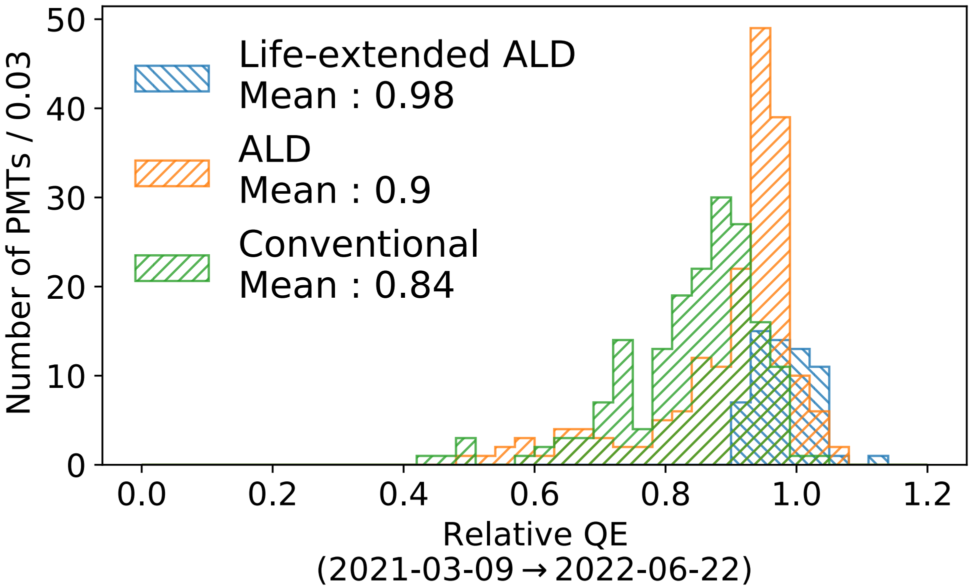
N_{bg} : No Muon track

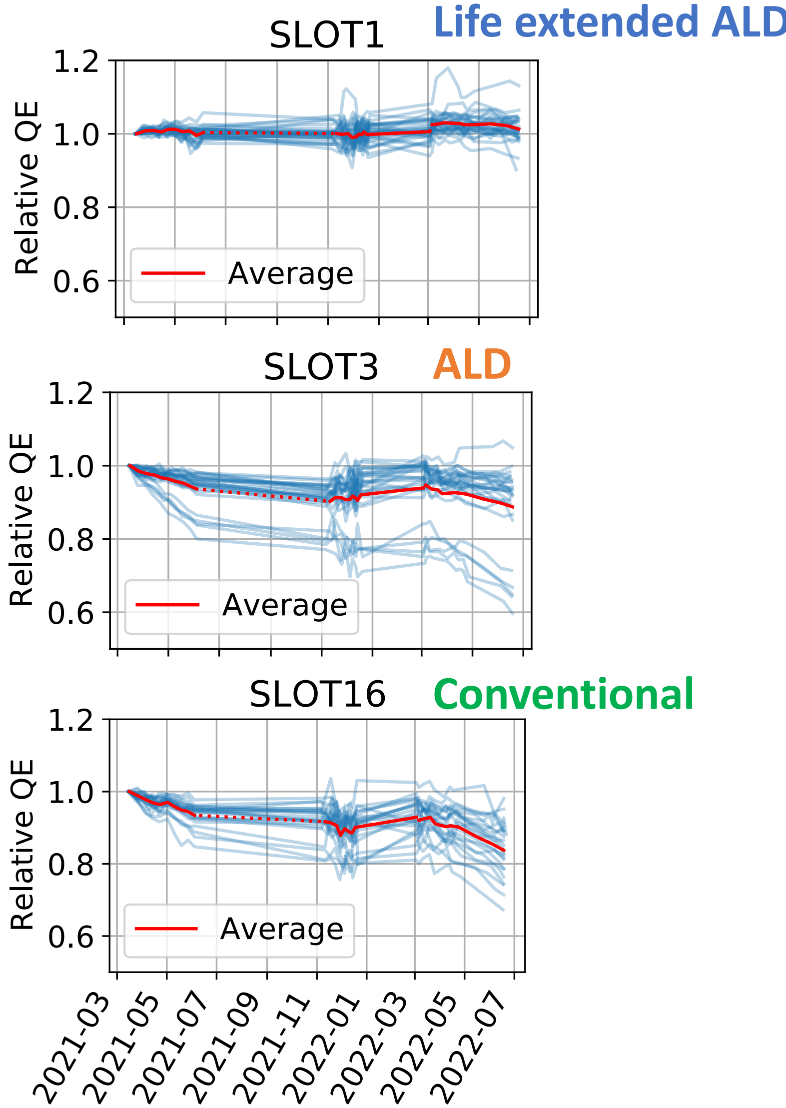
→ Beam background, physics background dark noise, …

Result of the QE measurement

QE seems to be decreasing about a few percent.
Accumulated charge so far is still well below the limit of conventional MCP-PMTs.
→ We need to understand if this degradation is real or not.

$$\text{Relative QE} = \frac{\text{QE at the end of 2022}}{\text{QE at the beggining of 2021}}$$





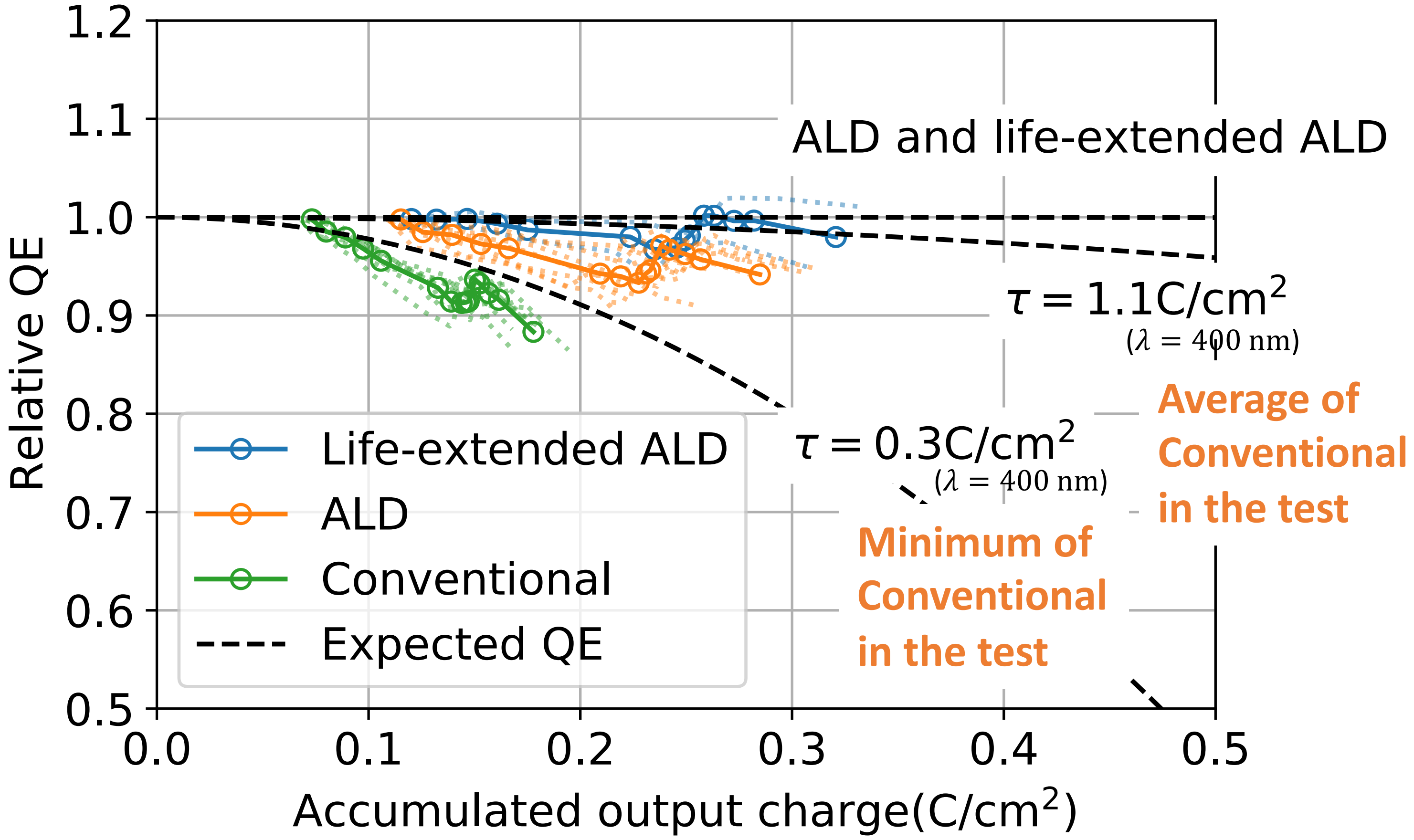
Comparison with our expectation

QE seems to be decreasing, but this degradation appears strange

In the test before installation,
QE drops as a quadratic function of
the accumulated output charge.

Possible cause of the QE degradation

- Production process?
- Threshold efficiency degradation during the physics run?



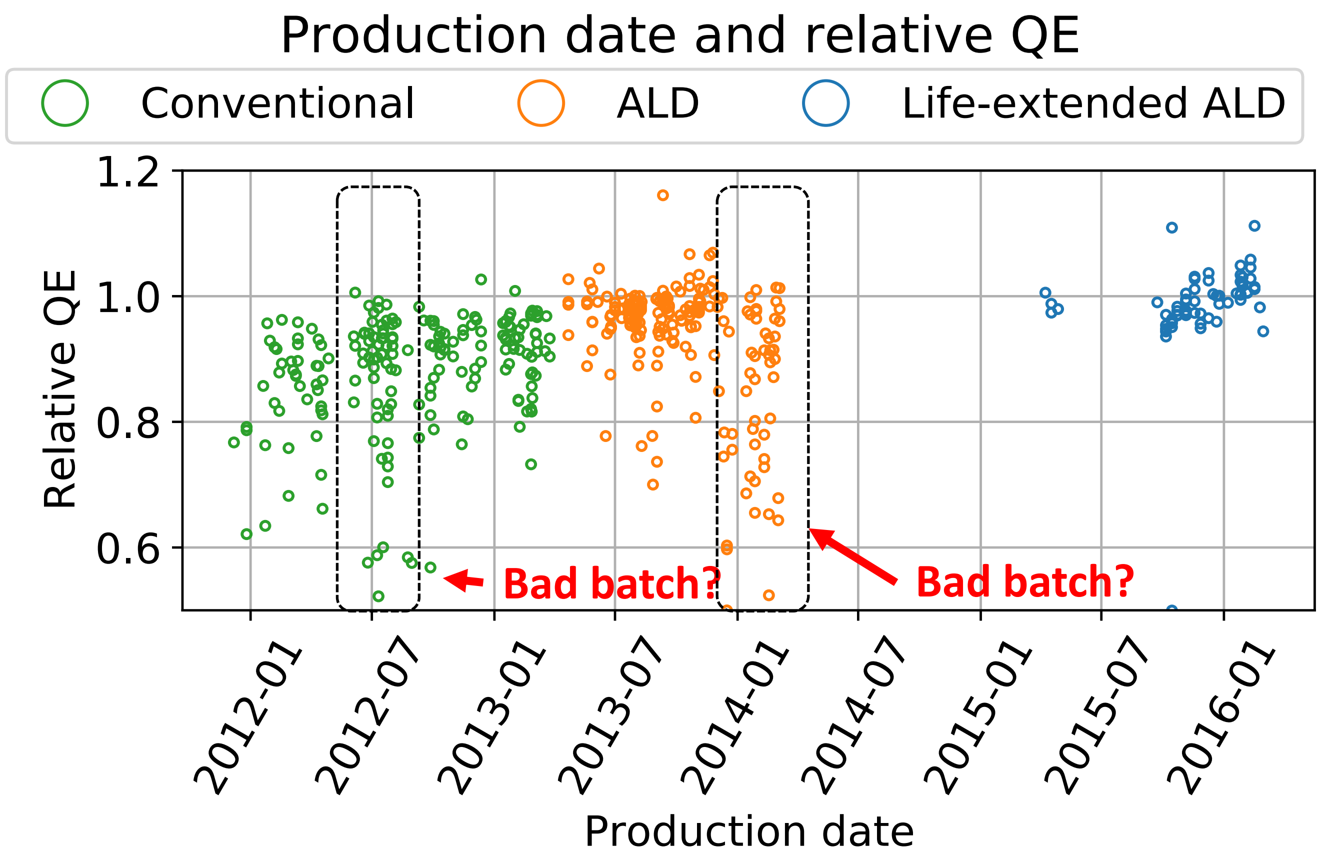
Dotted line : SLOT average
Solid line : Type average

Production date and QE

Some of the PMTs whose QE decreased have similar production date.

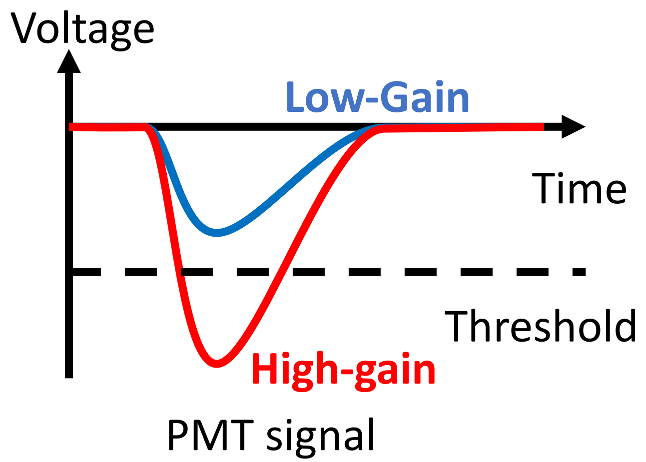
→ One of the causes of the QE degradation might be related with MCP-PMT production.

However, we can find QE degradation of the PMTs that are not in bad batch.

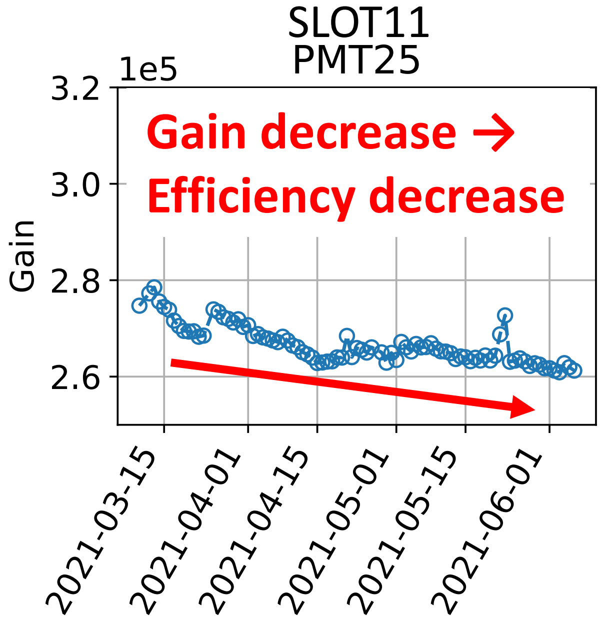


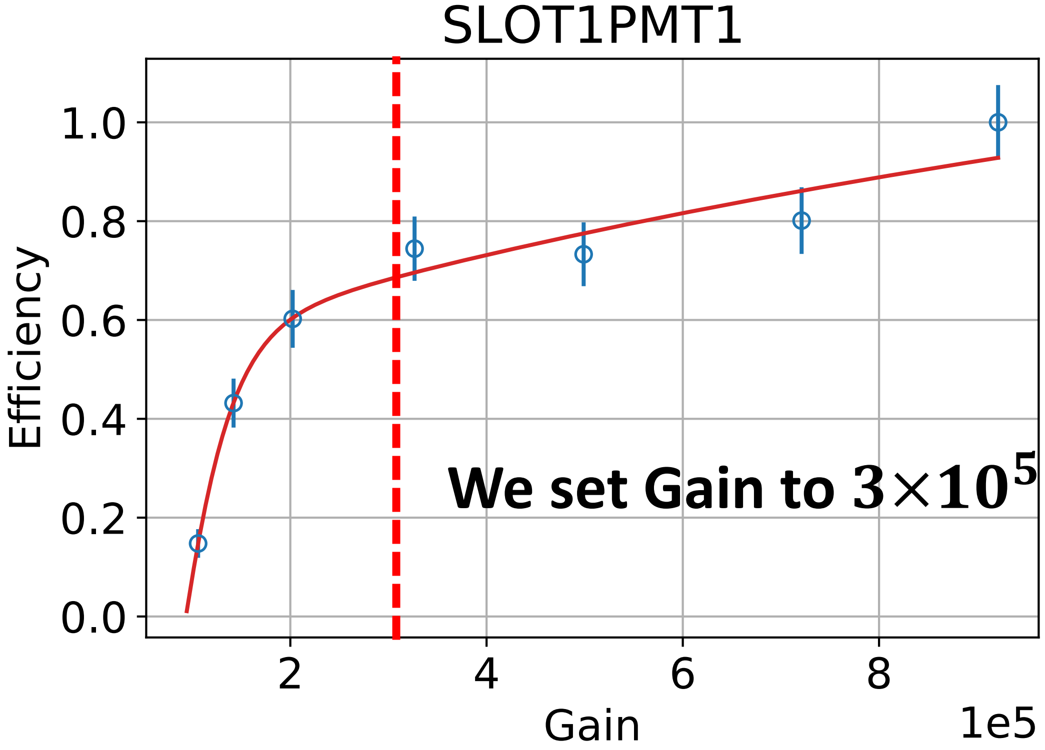
Gain degradation

The gain of MCP-PMT decrease during the physics run, and the efficiency decreases with the gain



Typical gain degradation of MCP-PMT





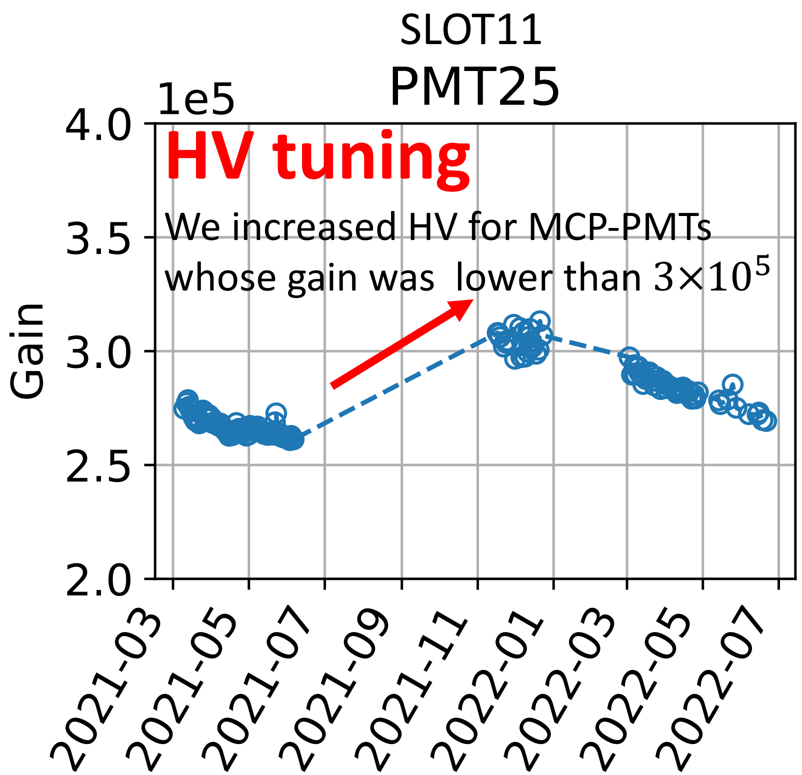
HV tuning and gain variation

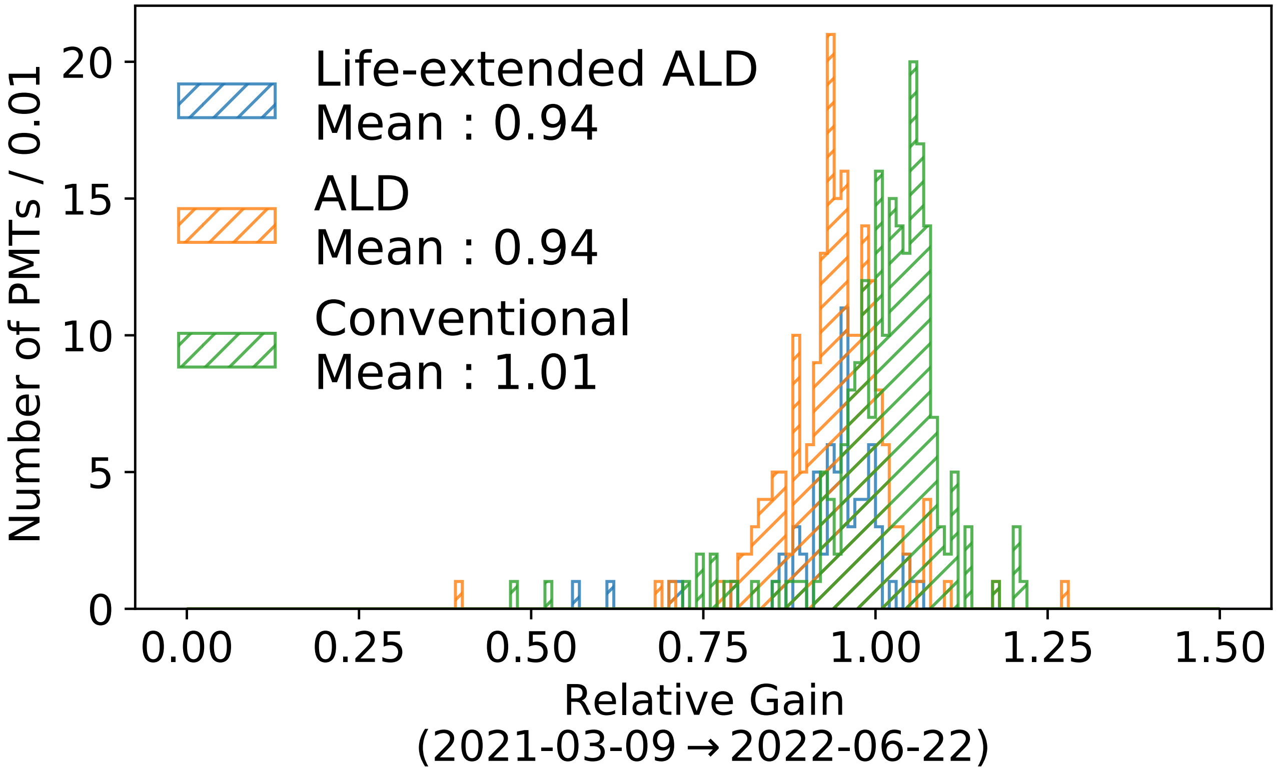
Purpose of HV tuning

1. Avoid the efficiency drop by gain degradation
2. Reduce the uncertainty of the efficiency correction by adjusting gain to constant

No significant gain drop after the HV tuning in conventional MCP-PMT, so threshold efficiency should be constant.

→ It is not the cause of the QE degradation





Other possible cause and Plans

Other possible cause

Background rejection?
Noise from PMT?
Temperature of PMT?
(TOP : 40℃, Test bench : Room temperature (20 -25 ℃))

Plans

- Try tighter track and PMT pulse selection to increase S/N ratio
→ Reduce the effect from background and noise

- Test spare PMTs in the similar temperature with TOP.

- Pick up some of the Conventional PMTs from TOP and measure QE in the test bench (Planning to do in November)

Summary

MCP-PMT is photon detector for TOP counter, and QE of the photocathode will decrease during physics run.

- Accumulated output charge
  - Accumulated output charge is about 0.2 – 0.4 C/cm^2, and it is enough shorter than the lifetime of Conventional MCP-PMT.
- QE
  - Looks like decreased about a few percent, but possibly it is not lifetime of the MCP-PMT
  - Large QE degradation was observed in similar batch, so production might be one of the cause of QE degradation
  - Gain changes during the run and it affects efficiency, so we performed HV tuning.