PD18 - 5th International Workshop on New Photon-Detectors
Nov. 27-29, 2018, The University of Tokyo, Tokyo, Japan

R&D on the extension of the MCP-PMT lifetime

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2018/11/29

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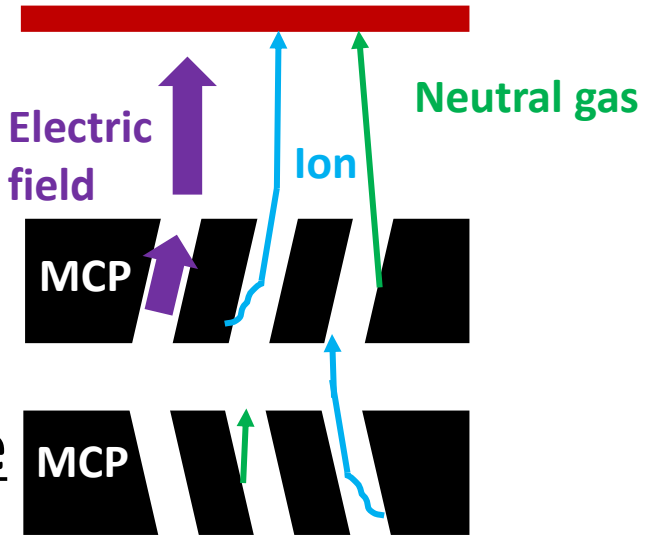
QE drops of MCP-PMT

- **The photocathode is damaged by the neutral gases and feed backed ions emitted from MCPs.**

➢ **The QE drops depending on the accumulated output charge.**

➢ **The mechanism is not known.**



1. **<u>Accumulation to the surface</u>**
   The neutral gases accumulate in the photocathode.

➢ **Change of work function.**

2. **<u>Destruction of the crystal structure</u>**
   The feed backed ions have enough energy to destroy.

➢ **Reduction in the probability of the photoelectron emission.**

Past R&D to extend the MCP-PMT lifetime

- **MCP-PMT is indispensable photo detector for Belle II TOP counter.**

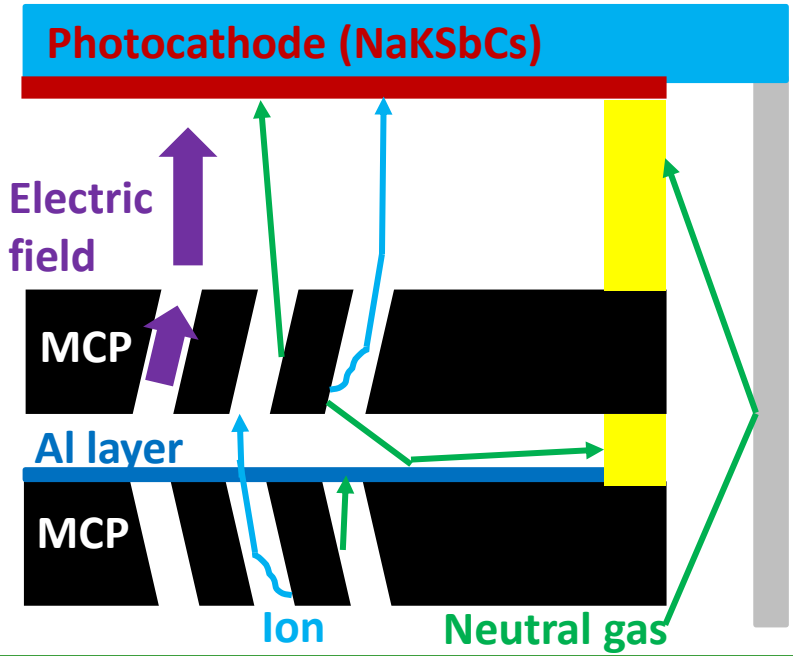
➢ **The output charge is dominated by beam background.**

- **Estimated output charge is 8 $\mathrm{C/cm^2}$ @Belle II 50 $\mathrm{ab^{-1}}$.**

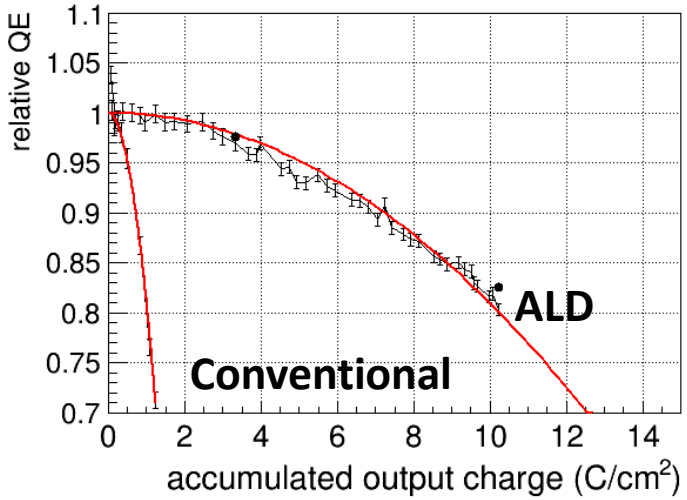
➢ **<u>Need to extend the MCP-PMT lifetime.</u>**

➢ **Ceramic block and Al layer**
- **Barrier against the neutral gas and ions**
- **⇒Conventional MCP-PMT**

➢ **ALD coating on MCP**
- **Suppression of the residual gas emission**
- **⇒ALD MCP-PMT**



Lifetime of MCP-PMT for TOP counter



Define the PMT lifetime as the total output charge where QE decreases to 80%.

Fitting function

$$\frac{QE(Q)}{QE(0)} = 1 - 0.2\left(\frac{Q}{\tau}\right)^2$$

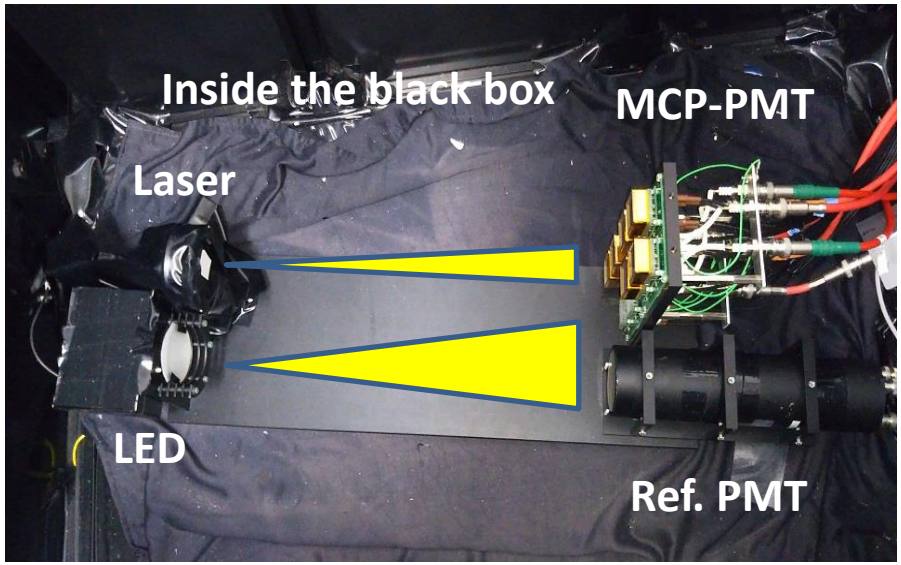
Q : output charge , τ : lifetime

- **Conventional MCP-PMT : 0.3 – 1.7 $\mathrm{C/cm^2}$ (12 samples)**
  average : 1.1 $\mathrm{C/cm^2}$
- **ALD coating MCP-PMT : 2.5 – 26.1 $\mathrm{C/cm^2}$ (8 samples)**
  average : 10.4 $\mathrm{C/cm^2}$

Developed more R&D because the lifetime of ALD PMT is not enough.

- **Life-extended ALD MCP-PMT**
  - Applied further residual gas reduction processes
  - Measured 8 samples

Setup for lifetime measurement

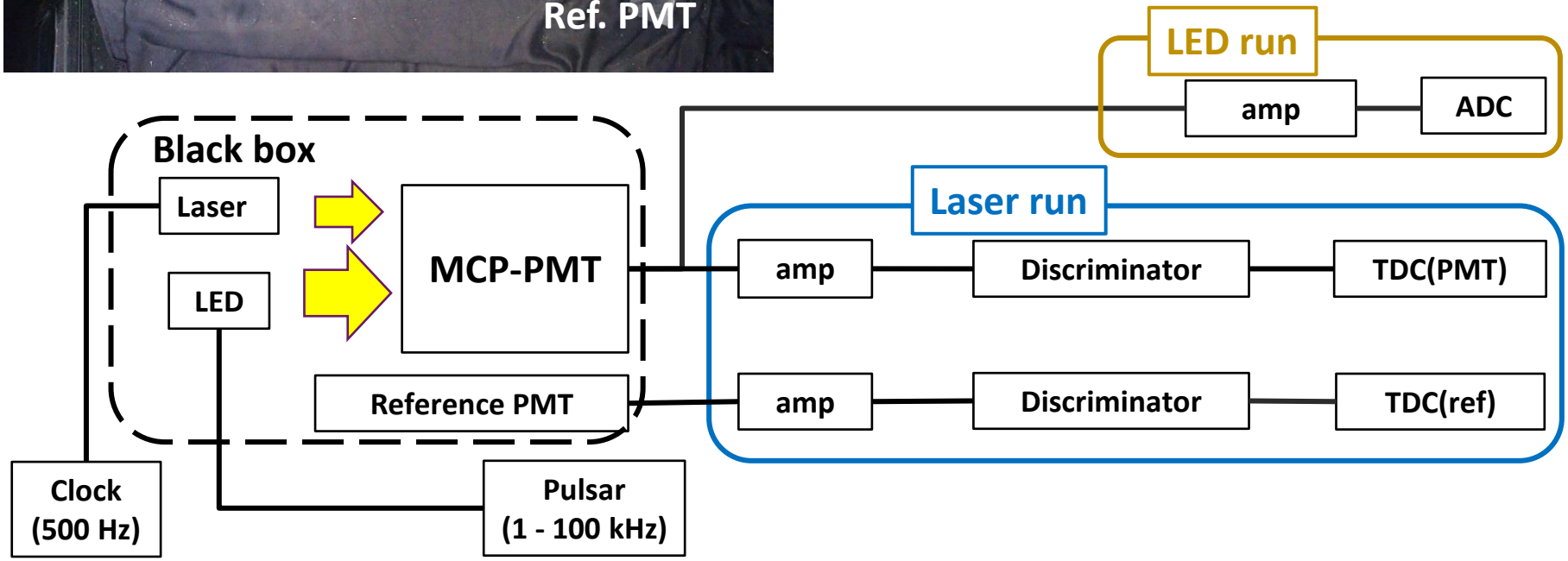


LED run

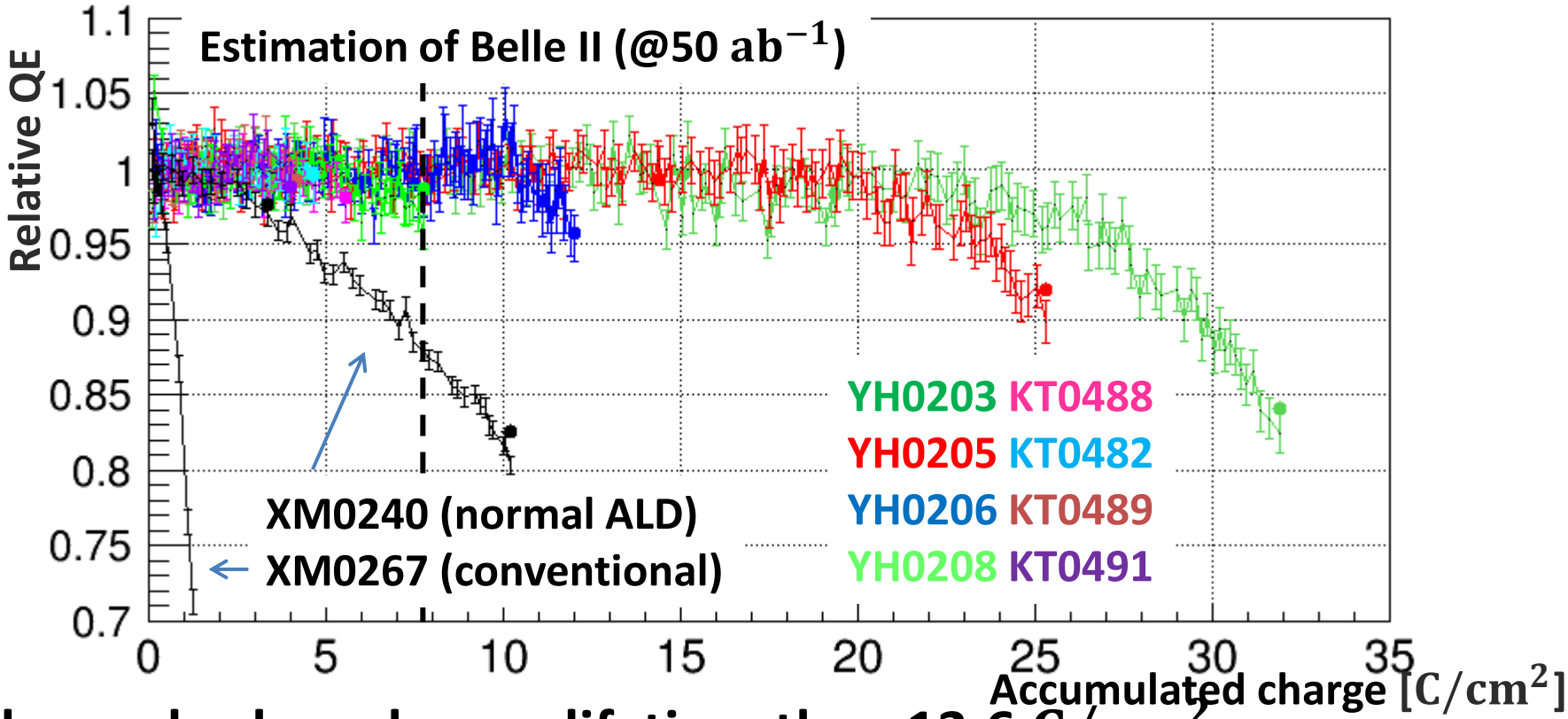
- Degrade the photocathode.

Laser run

- Monitor the hit rate to estimate relative QE.



Lifetime of life-extended ALD



- **All samples have longer lifetime than 13.6 C/cm^2.**

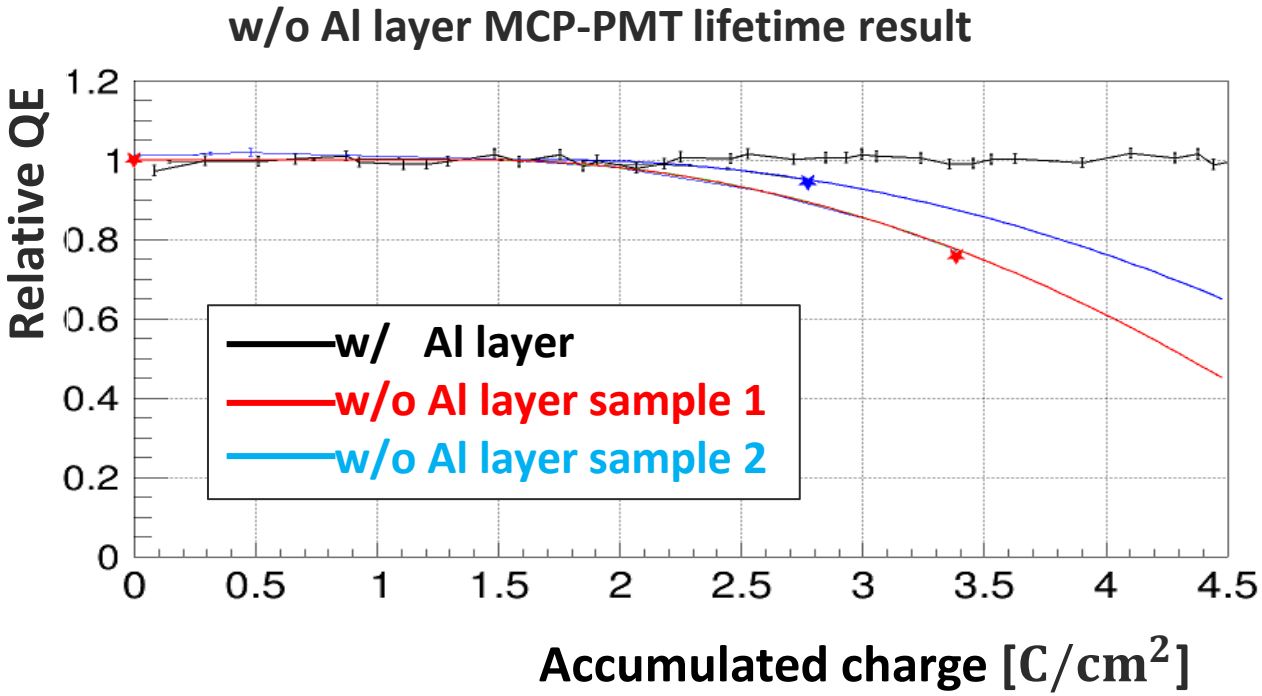
➢ **To apply this MCP-PMT in the other high intensity experiments, further extension of the lifetime is necessary.**

- The lifetime is still much smaller than usual PMT.

- <u>Need to understand the mechanism of the QE drop for further improvement.</u>

MCP-PMT w/o Al layer

- **Measured two samples w/o Al layer for studying the neutral gas emission from second MCP.**



Sample1 : $3.3\ [\mathrm{C/cm^2}]$

Sample2 : $3.6\ [\mathrm{C/cm^2}]$

- **Both samples show shorter lifetime than MCP-PMT with Al layer.**

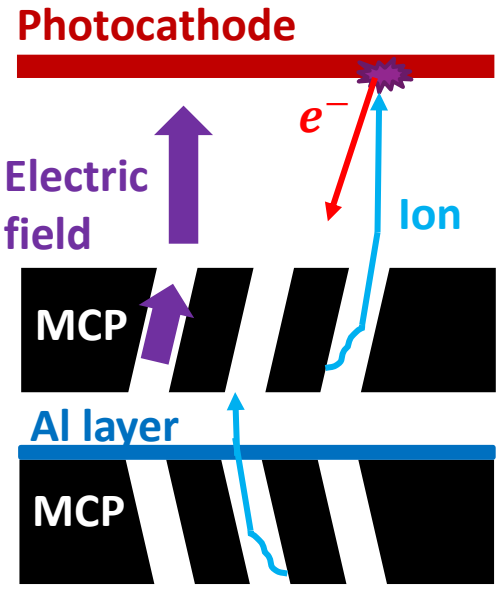
➢ **The outgas from the 2nd MCP is still a dominant factor of the QE drop.**

Ion-feedback and after-pulse

- **Checking the effect of the feed backed ions by analyzing after-pulse.**
  - ➢ **Test of the hypothesis of destruction of crystal structure.**
- **The delay time of after-pulse relates to the mass of ion and the applied voltage.**

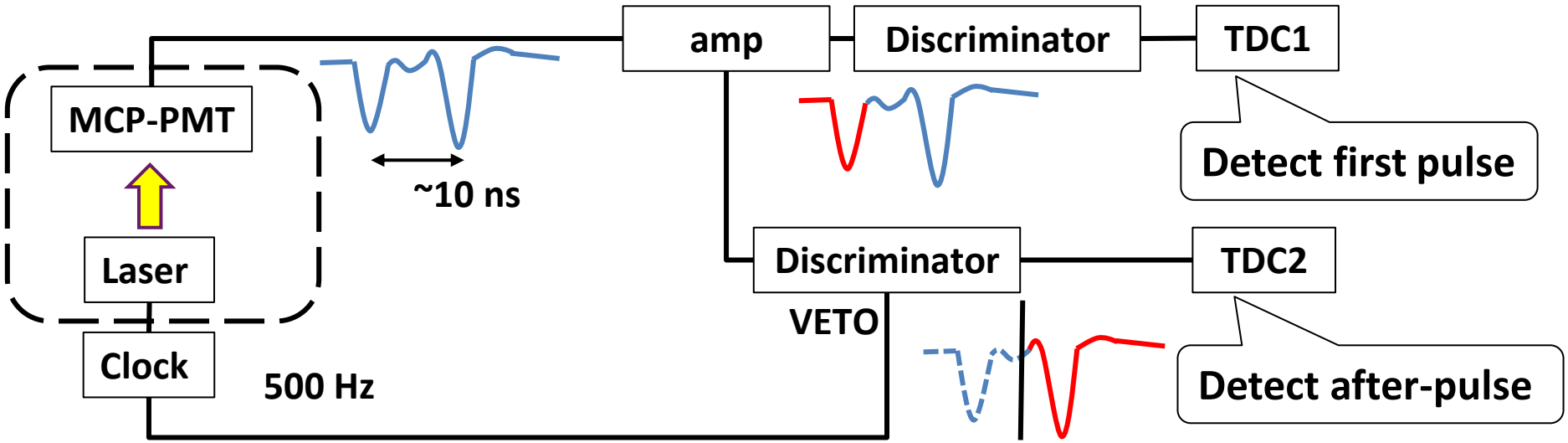
$$t \propto \sqrt{m_{ion}/V}$$

- ➢ **Identify the ion species from the timing of the after-pulse.**
- ➢ **Suppose these ion species and neutral gases are same elements.**



Ions come mostly from second MCP but heavy ones are stopped by Al layer.

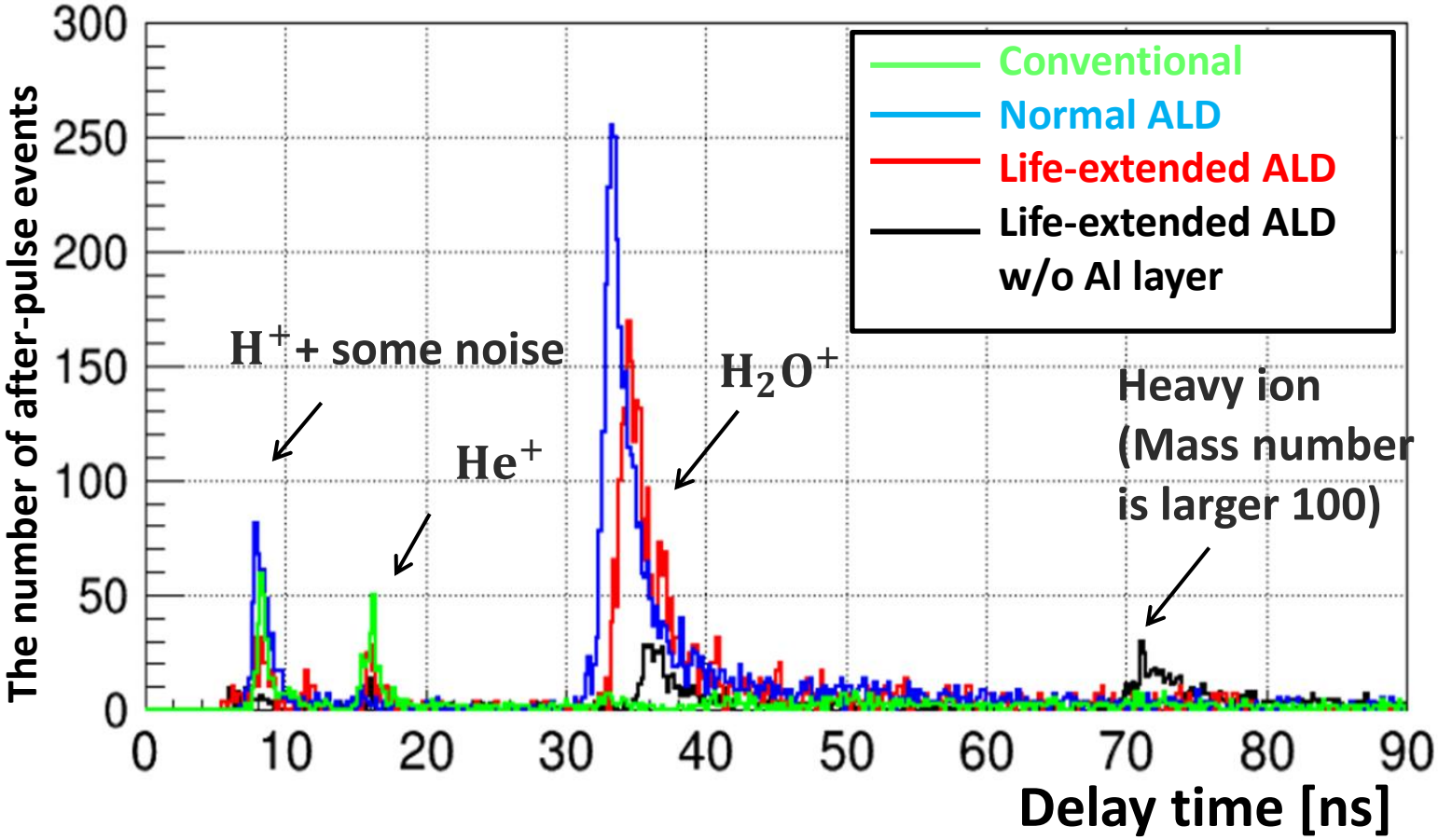
Setup for after-pulse measurement



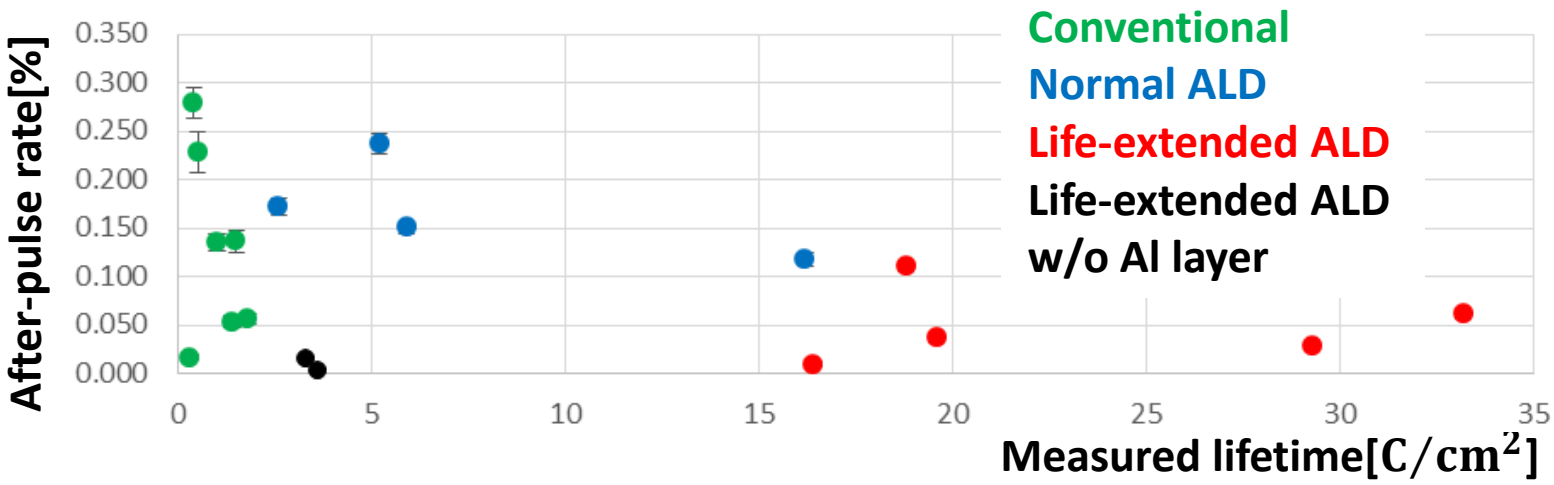
- Veto first pulse by clock synchronized to laser timing.
- Timing between TDC1 and TDC2 = The delay time of after-pulse

Type of MCP-PMT	Samples
Conventional	7
Normal ALD	4
Life-extended ALD	5
Life-extended ALD w/o Al layer	2

After-pulse distribution

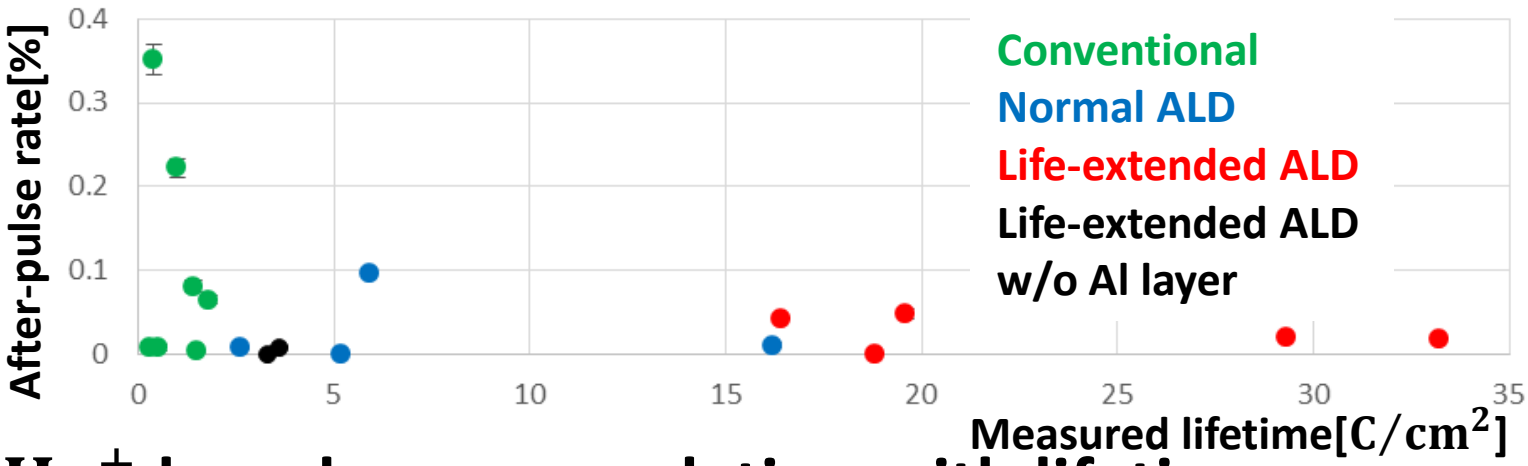


Hydrogen ion rate VS lifetime



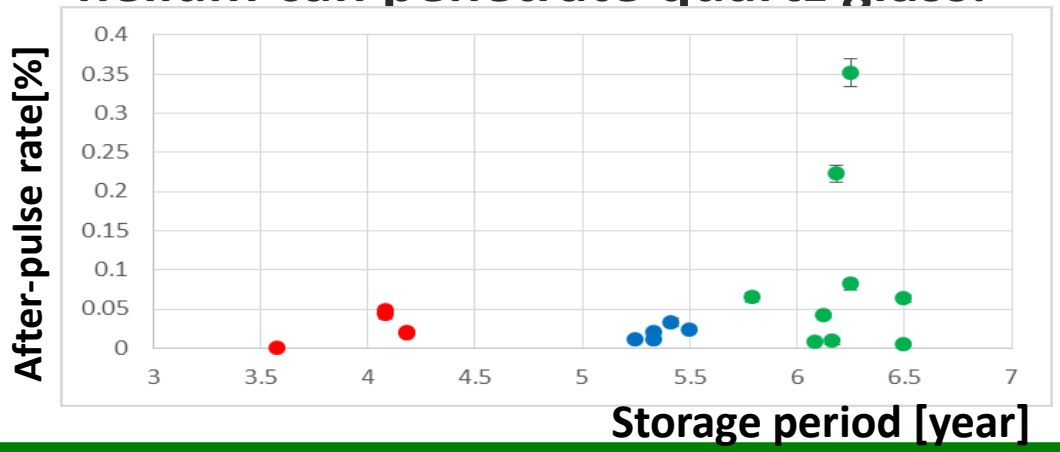
- **It looks like no correlation between the after-pulse rate and lifetime.**
  - ➢ **But effect of the noise is not clear.**

Helium ion rate VS lifetime

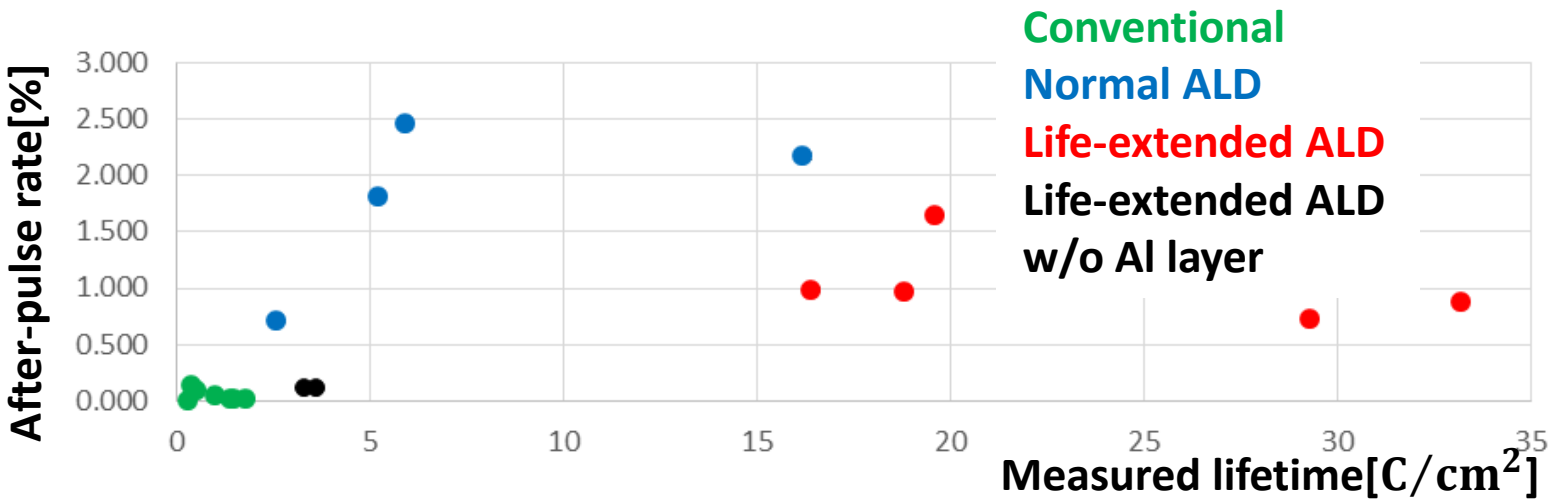


- He^+ has also no correlation with lifetime.

➢ The Life-extended ALD has small after-pulse rate because helium can penetrate quartz glass.



Water ion rate VS lifetime



- **ALD coating MCP-PMTs have many water ions.**
  - **They may come from ALD process because water is usually used in this process.**
- **Rate of H_2O^+ do not have a correlation with lifetime.**

Summary of the feed backed ion effect

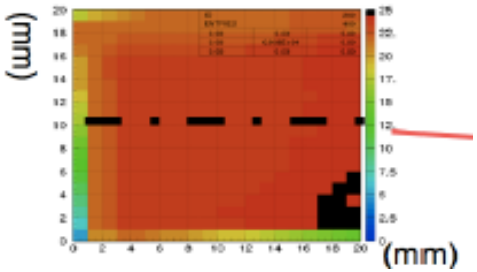
Summary

Residual gas	H^+	He^+	H_2O^+	Heavy ion	Neutral gas
Effect on lifetime	Not clear	No	No	No	Yes

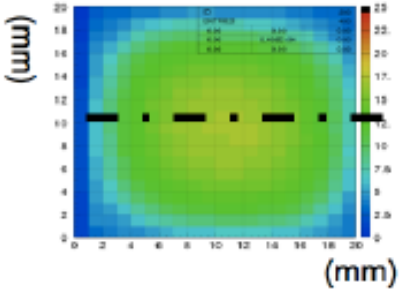
Heavy ions

Heavy ions appear only without the aluminum layer and have no correlation with lifetime.

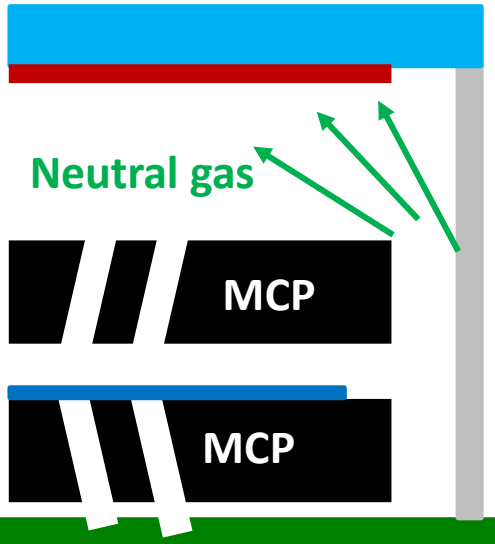
Neutral gas



Before lifetime test



After lifetime test



T.Jinno et al., Nucl. Instr. and Meth.A629 (2011) 111

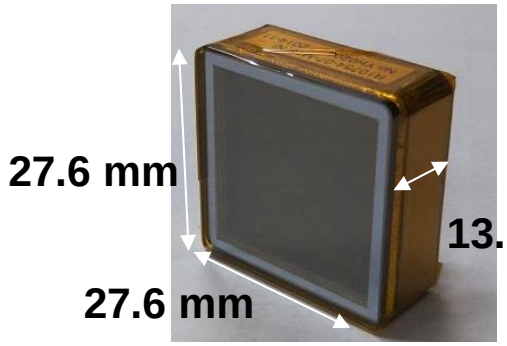
Conclusion

- **We succeeded in improving the lifetime of the MCP-PMT by suppressing the residual gas.**
  - **Life-extended ALD : at least 13.6 $\mathrm{C/cm^2}$.**
- **To understand the mechanism of the photocathode deterioration, we analyzed after-pulse.**
  - **To make a conclusion of the mechanism, we need to check more.**
  - **The cause of the photocathode deterioration has been narrowed down to hydrogen ions and neutral gases.**

BACK UP

Micro Channel Plate (MCP)-PMT

- Developed at Nagoya and HAMAMATSU photonics.
- High gain : $O(10^6)$
  - ➢ Use two Micro Channel Plates
- Good time resolution : ~ 30 ps
- Available in magnetic field
- High QE : 28.8% (@360 nm)
  - ➢ Use Multi Alkali photocathode
  - ➢ Short photocathode lifetime



MCP-PMT for TOP counter