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Research progress on long lifetime MCP-PMT

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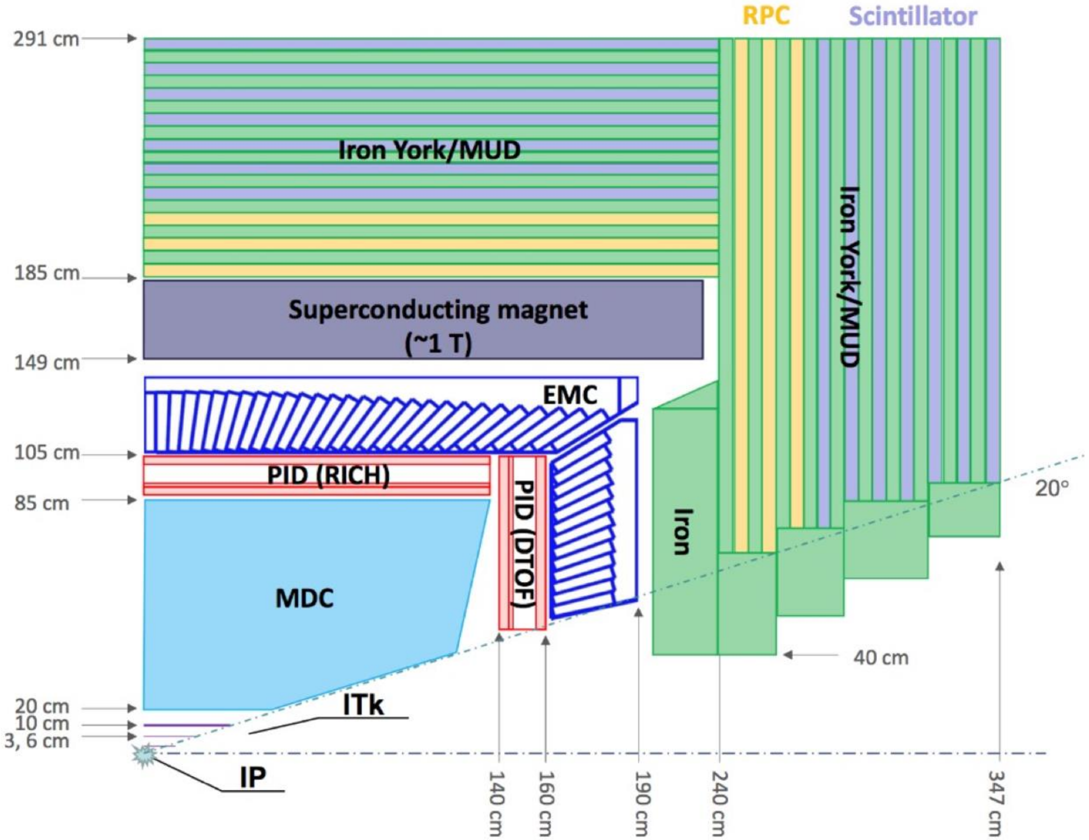
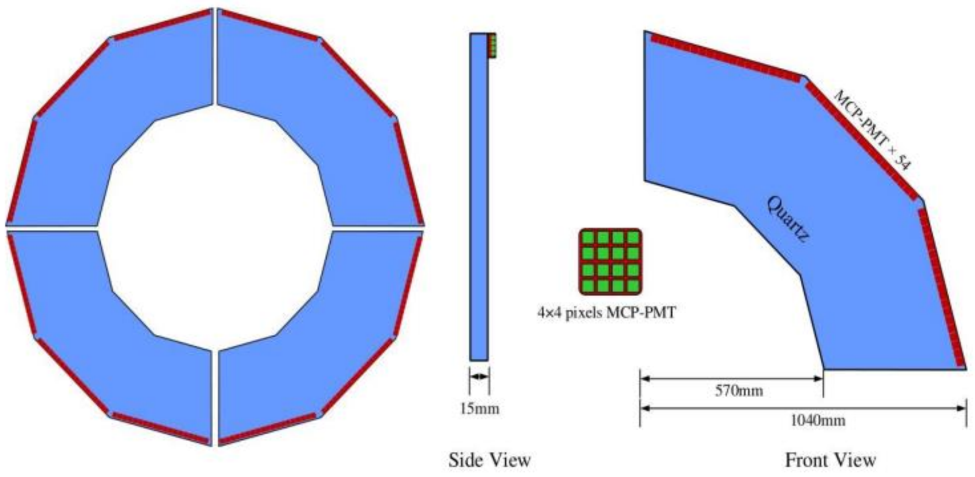
STCF PID (DTOF)



MCP-PMT requirements

- 4x4 anodes
- Gain > 1E6
- TTS < 100 ps
- QE > 20%
- Lifetime > ten years (IAC > 10C/cm2)
- High rate capability
- ……



DTOF: DIRC-like TOF

MCP-PMTs by XIOPM

20 inch MCP-PMT

Φ18mm Fast/Gated MCP-PMT

Φ25mm Fast/Gated MCP-PMT

Φ50mm Large current MCP-PMT

Φ80mm Large current MCP-PMT

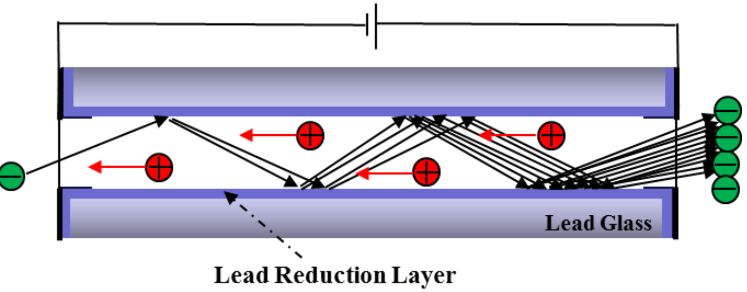
MCP-maPMT

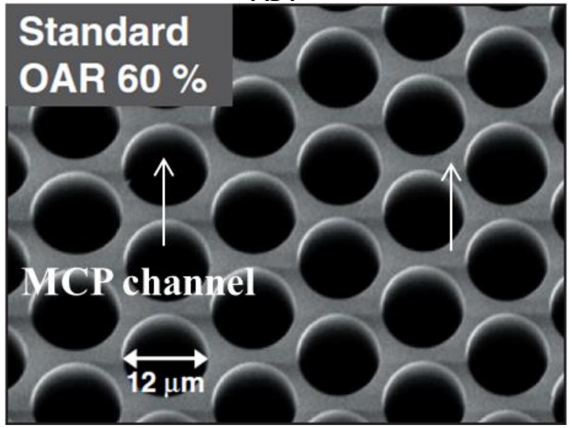
Long lifetime MCP-maPMT

Microchannel plate

❑ Conventional MCP

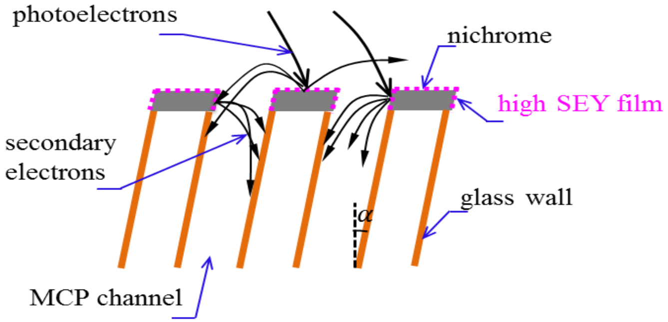
- Made of lead glass
- Collection efficiency ~60%
- Gain from lead glass
- Maximum SEE yield ～3





❑ ALD-MCP based on lead glass

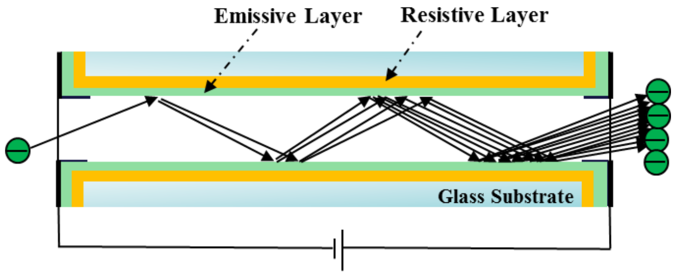
- Coating Al2O3/MgO on the lead glass MCP input surface and channel
- Maximum SEE yield over 4
- Gain mainly from ALD-layer
- Collection efficiency improved to ~100%
- Improve CE of 20"MCP-PMT for JUNO
- Lifetime extended



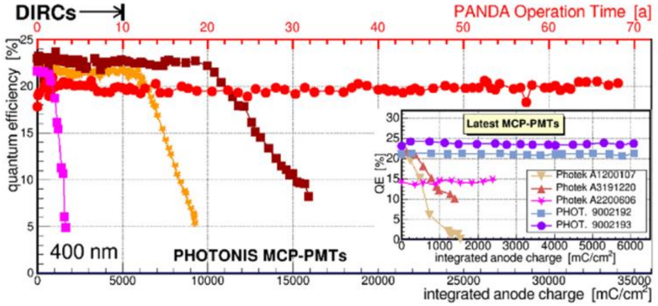
20 inch MCP-PMT for JUNO

❑ ALD-MCP based on borosilicate glass

- Lead free
- ALD coating resistive layer and emissive layer
- Gain resulted from ALD-Layer
- Maximum SEE over 4
- Lifetime extended



Lifetime extended



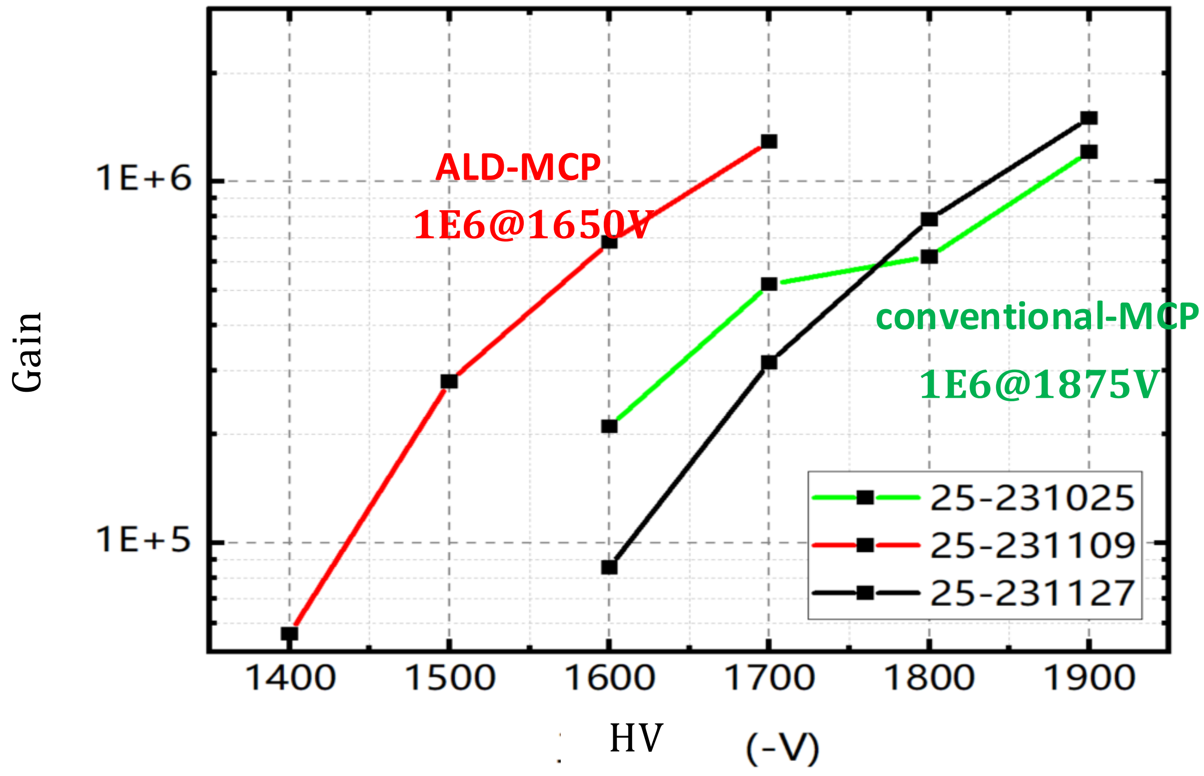
A. Lehmann et al., GSI scientific report 2022DO1:10.15120/GS1-2023-00462

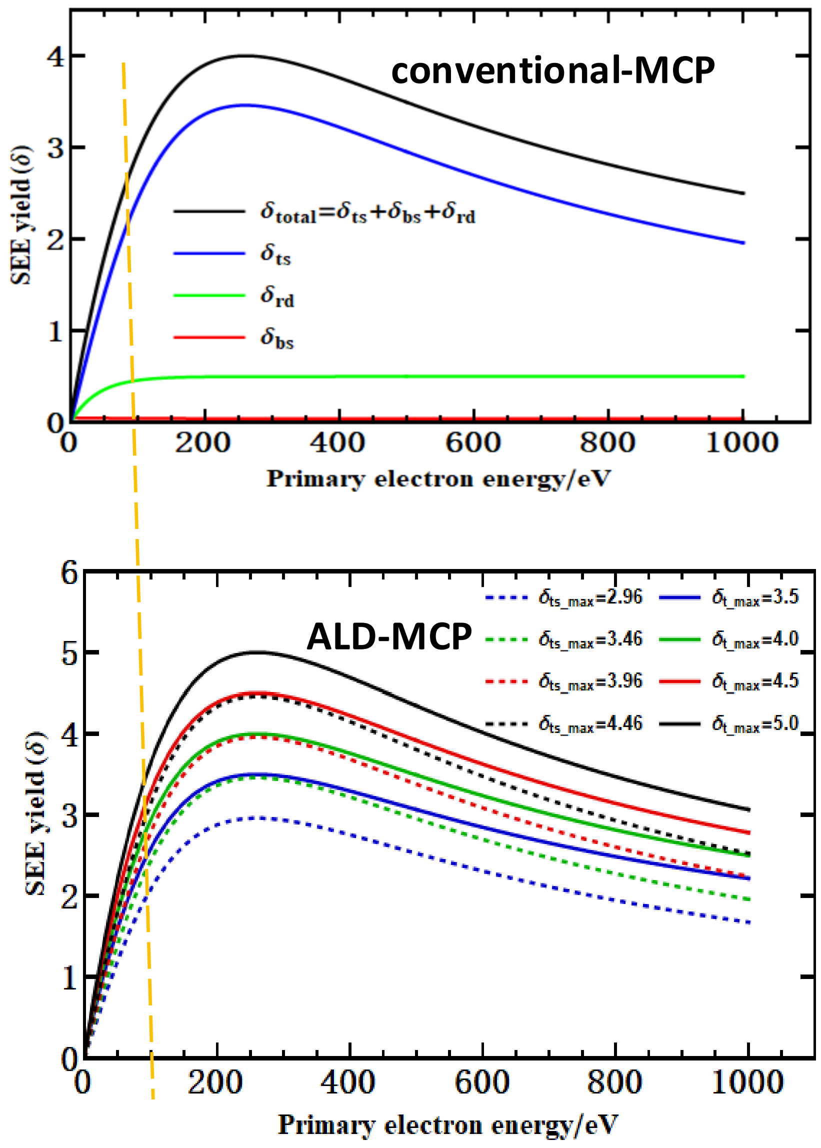
gain

ALD-MCP

Higher gain at lower HV

- Higher SEE yield for ALD-MCP





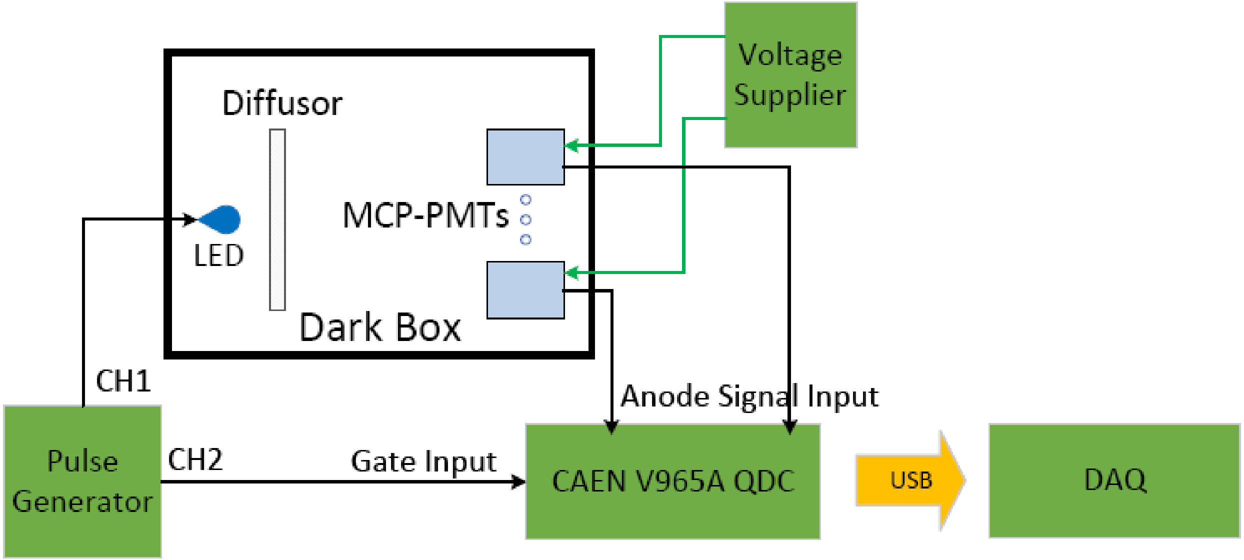
lifetime

Factors affecting the lifetime of MCP-PMT ?

- Single anode MCP-PMTs produced for lifetime study
  - 25 mm diameter
  - MCPs with and without ALD layer
  - ALD layer of 1 nm, 4.5 nm, 6nm thickness
  - MCP scrubbed amount of 0.43~0.75 uA·h/cm^2
  - Worked at gain of 5e5~1e6

- Light source
  - LED driven by a pulse generator
  - 10 ns pulse width
  - 405 nm wavelength

Integrated anode charge： $\mathrm{IAC} = \sum \bar{q} \cdot t \cdot f$



lifetime

❑ Influence of ALD film thickness

Lifetime@6 nm ＞4.5 nm ＞ 1nm ＞none

❑ Influence of scrubbing amount

Lifetime:@0.75 uA·h/cm² ＞ 0.52 uA·h/cm² ＞0.43 uA·h/cm²

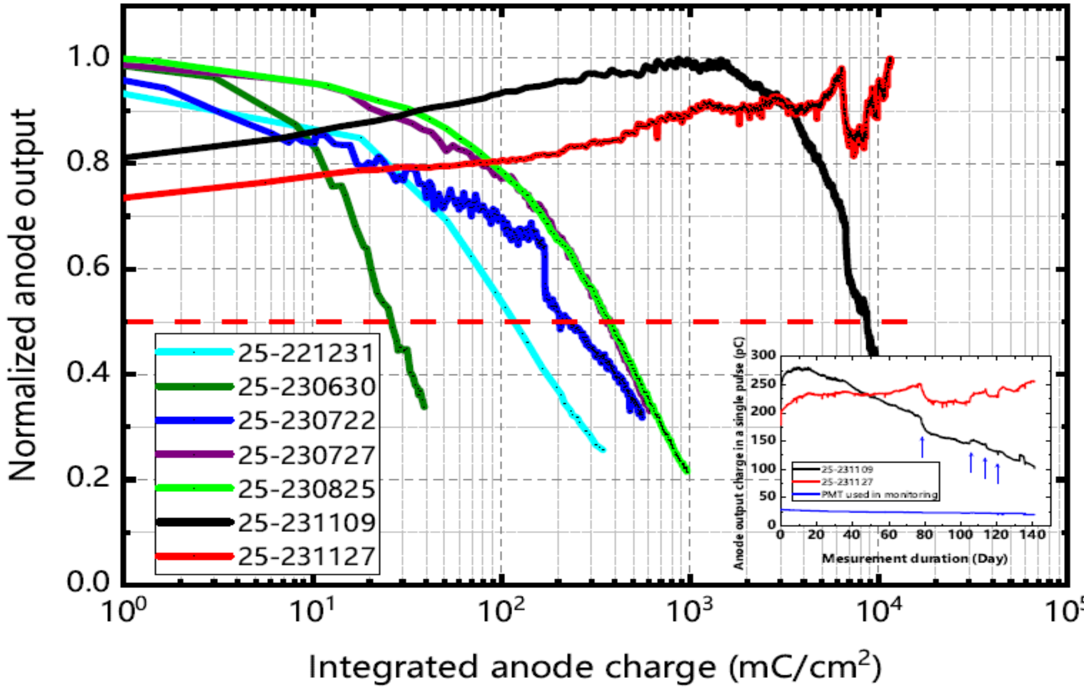


Table 2. IAC at 50% anode output degradation for the MCP-PMTs.

ID	Thickness of the ALD-layer (nm)	Electron scrubbing dosage ($\mu A \cdot h/cm^2$)	IAC at 50% degradation (mC/cm^2)
25-221231	1	0.43	117
25-230630	None	0.43	26
25-230722	1	0.52	230
25-230727	1	0.75	373
25-230825	1	0.75	373
25-231109	4.5	0.75	8800
25-231127	6	0.75	>11,000

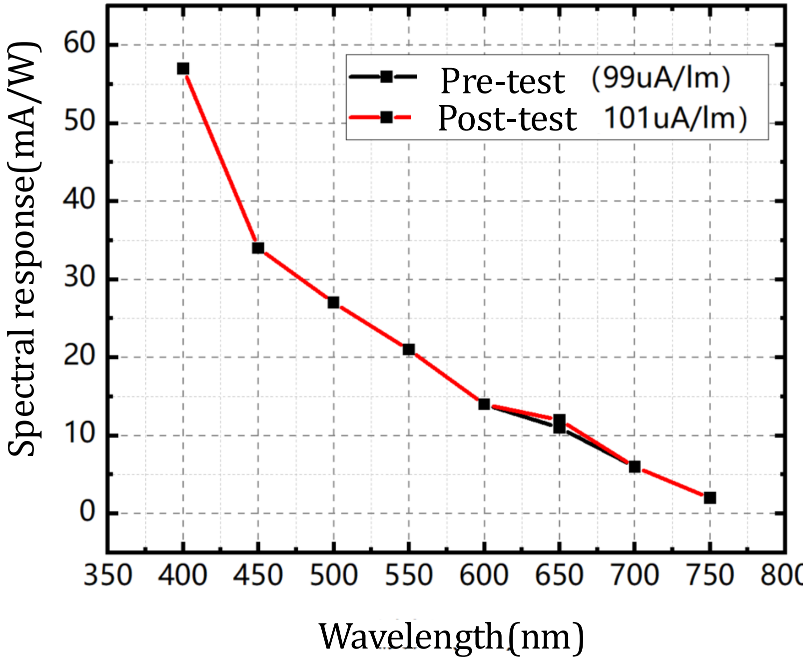
IAC over 11 C/cm2

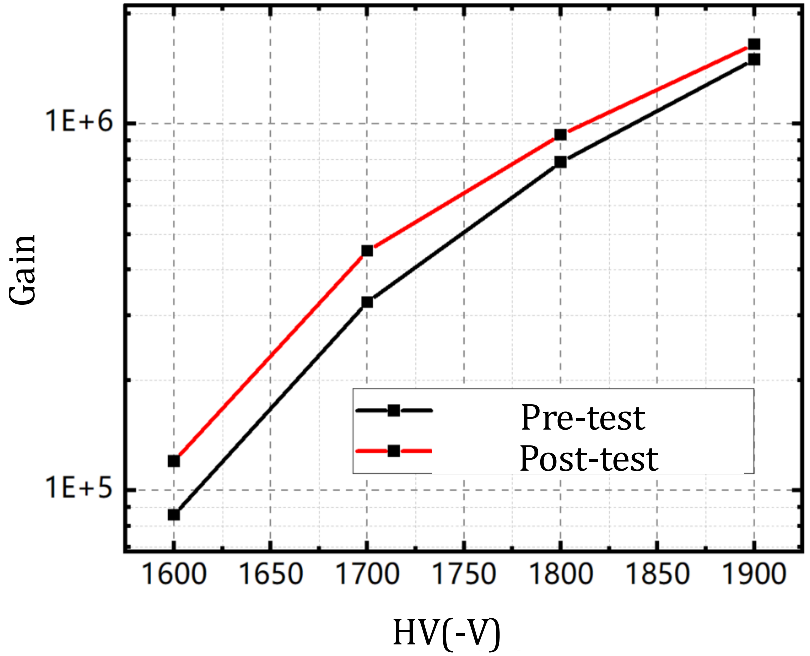
lifetime

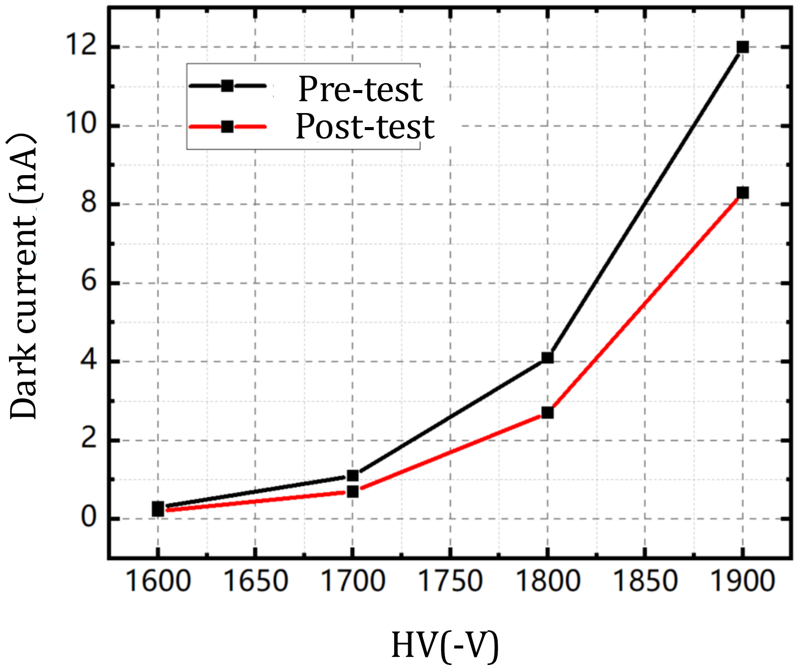
❑ Performances before and after lifetime tests

25-231127 with IAC over 11 C/cm2

none degradation on photocathode and MCP







Lifetime

Performances before and after lifetime tests

QE decreases more at longer wavelengths

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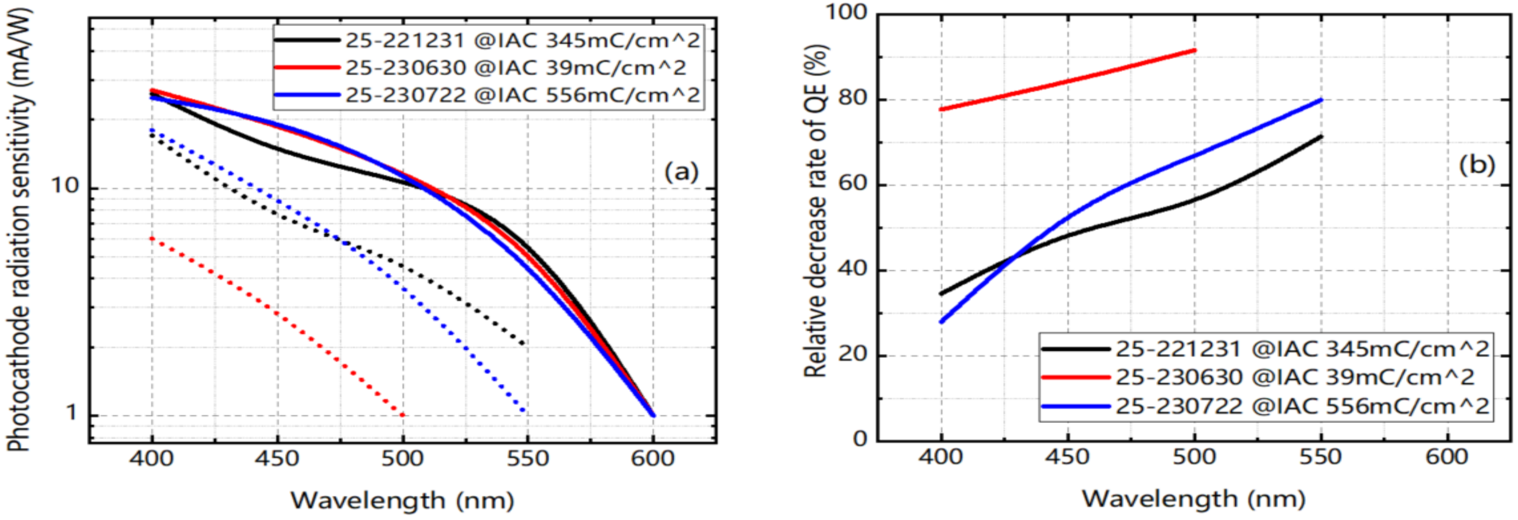
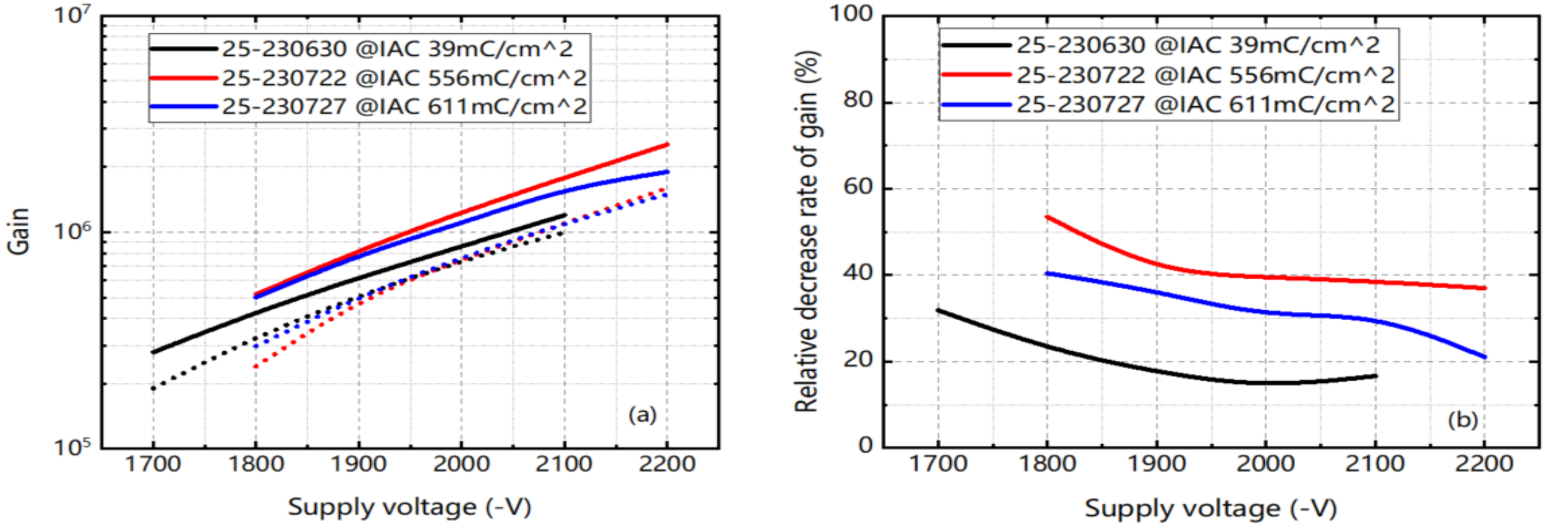
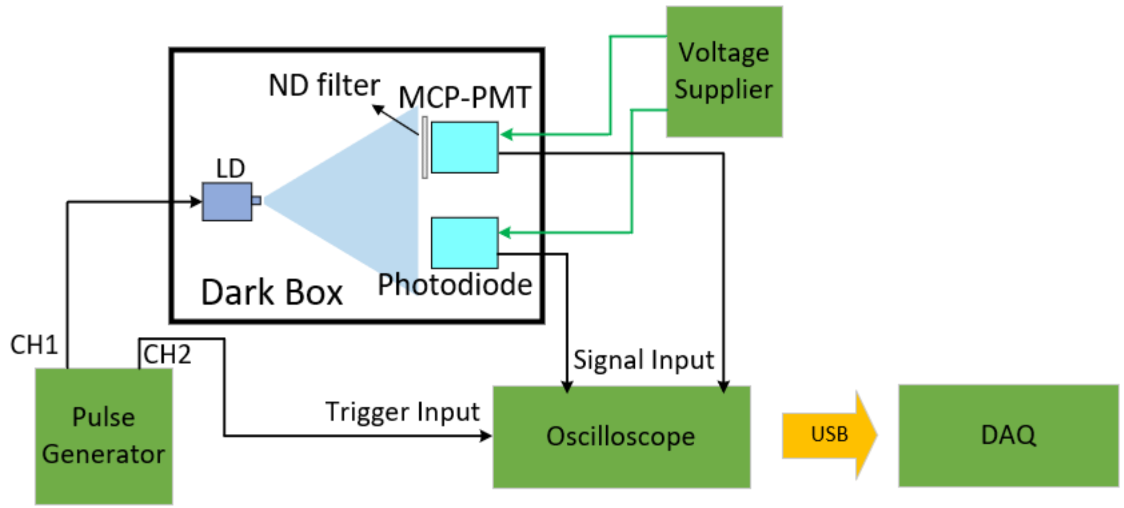


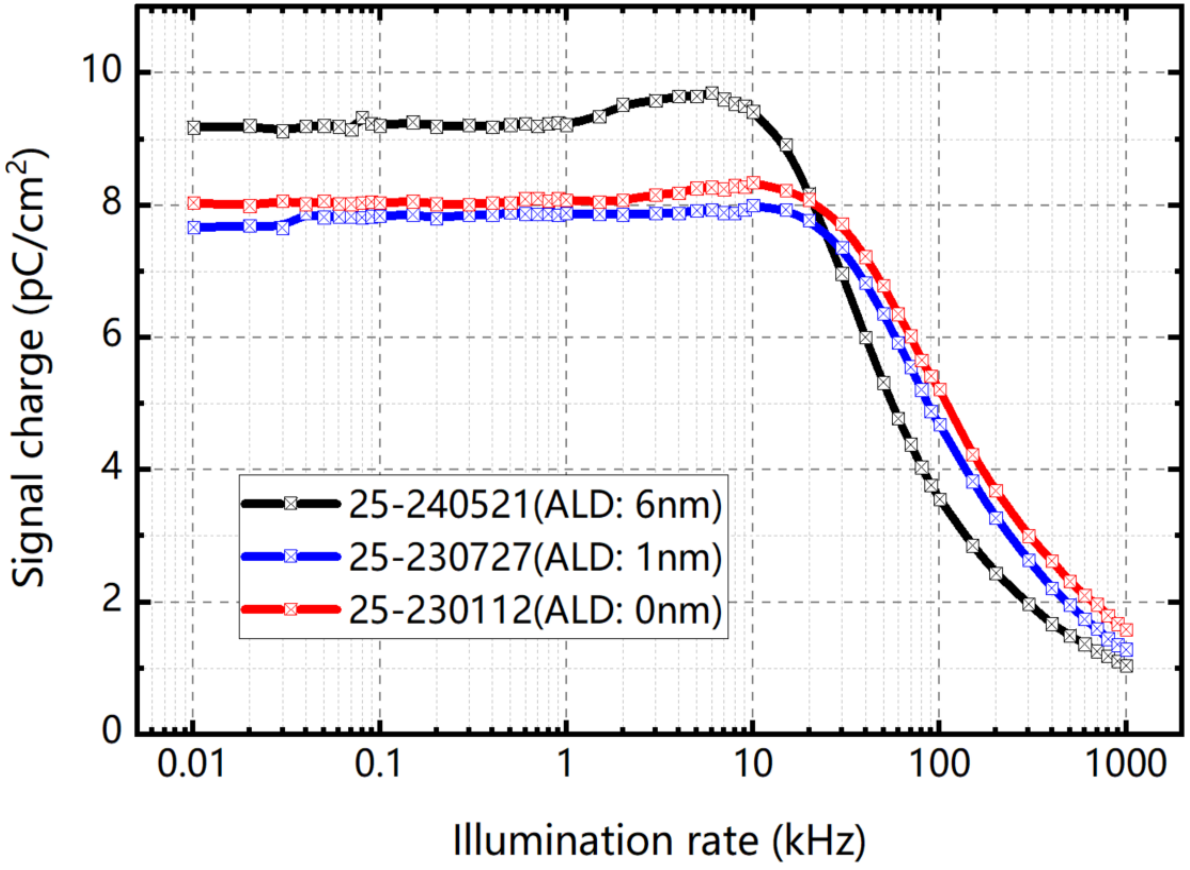


Rate capability

measurement setup

- Single-anode MCP-PMTs with 25 mm diameter
- LD driven by a pulse generator
- 10 ns pulse width
- ~3500 photons/cm2/pulse

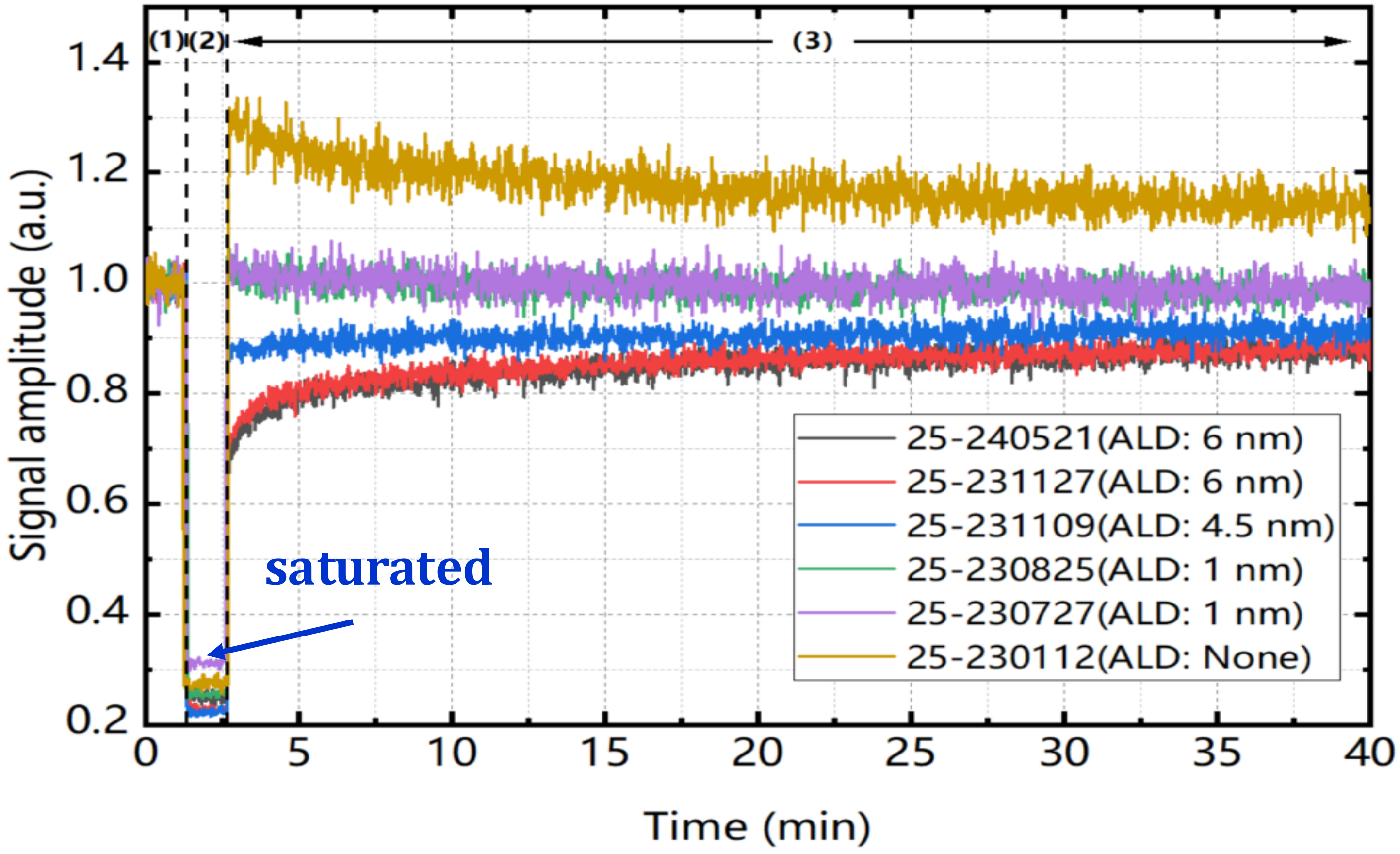




Recovery behavior

❑ ALD film effect

- MCP-PMTs with different thickness of ALD film operated at 1E5 gain
- illuminated by LD at rates of 10 Hz、500 kHz、10 Hz for 84 seconds to be saturated

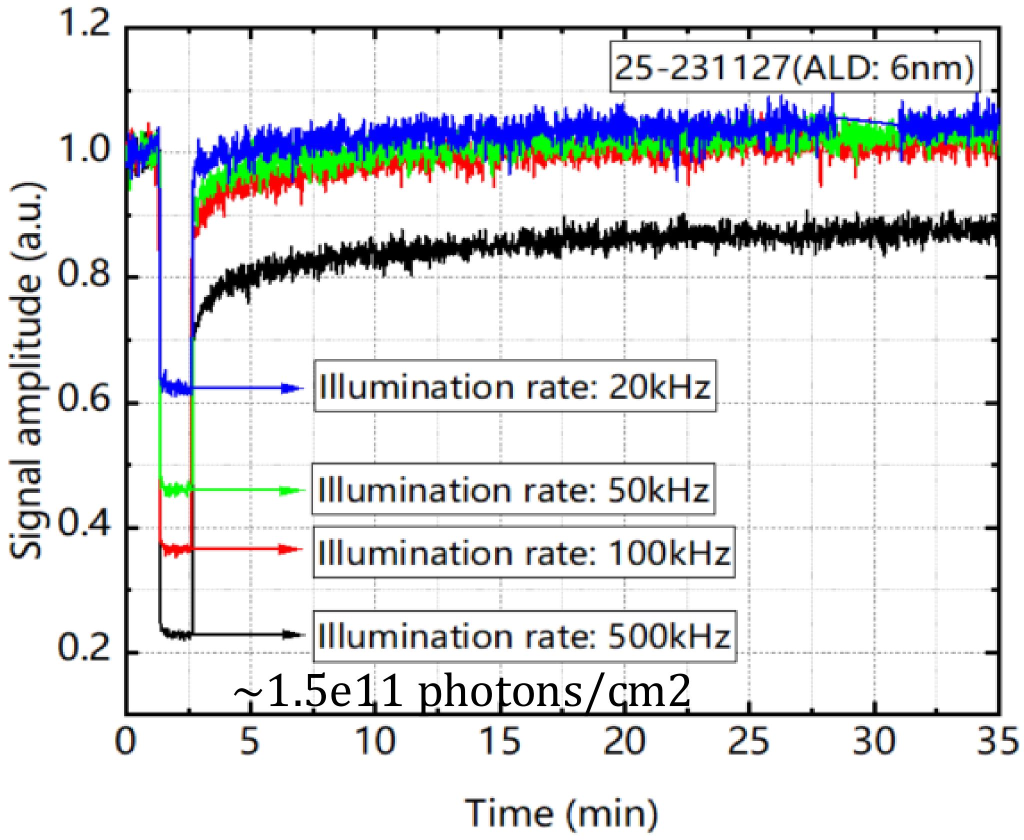


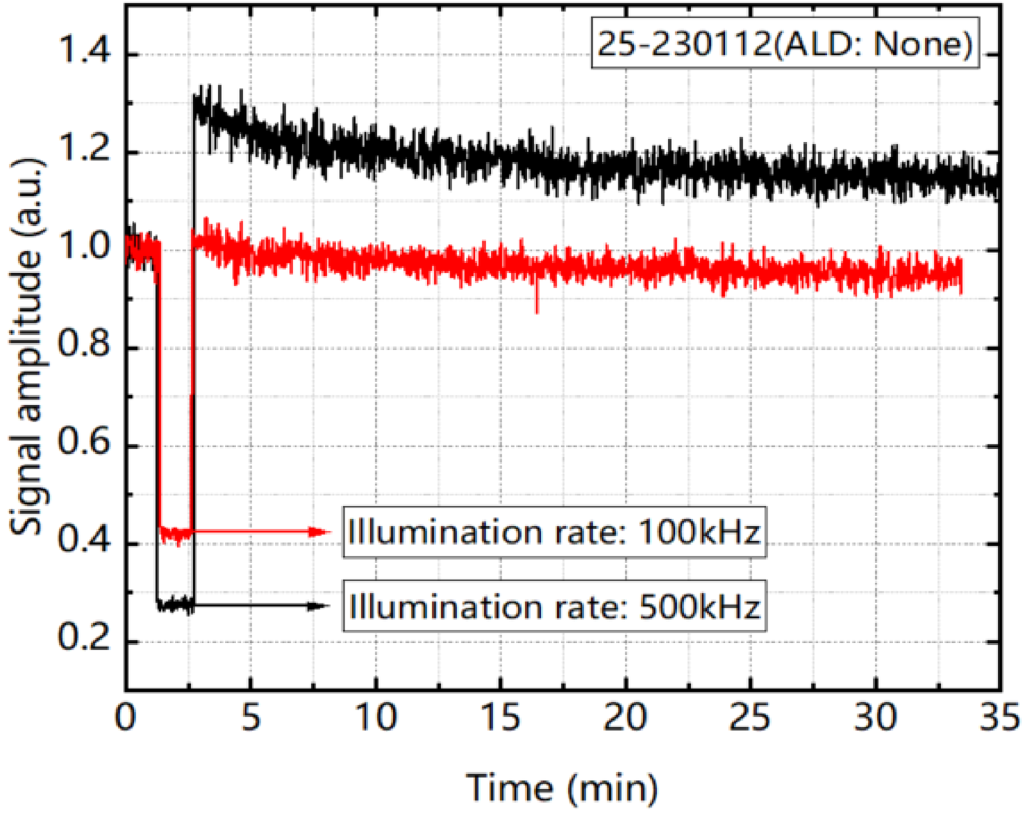
- **Longer recovery time for thicker ALD-layer MCP**
- **Super linearity for none-ALD MCP ?**

Recovery behavior

❑ Illumination rate effect

- The greater the degree of saturation, the slower the recovery
- Super linearity is worse at higher rate for none-ALD MCP





Recovery behavior

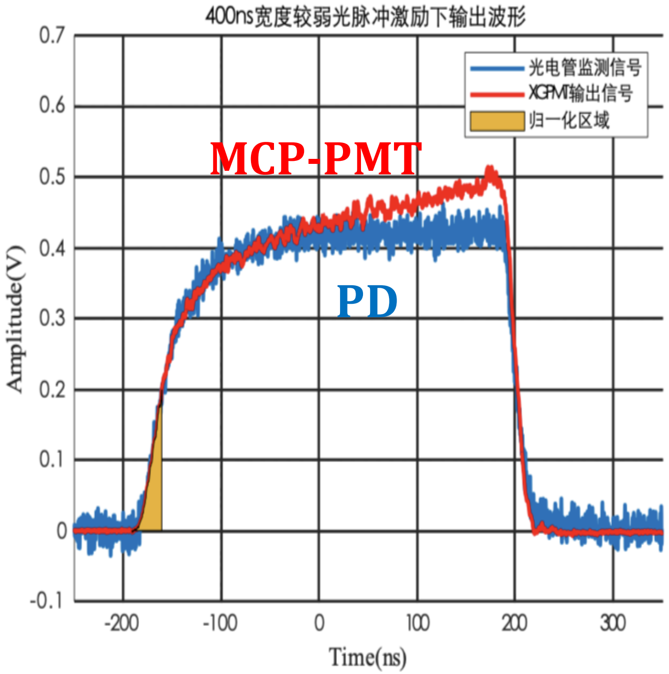
❑ Super linearity for none-ALD MCP

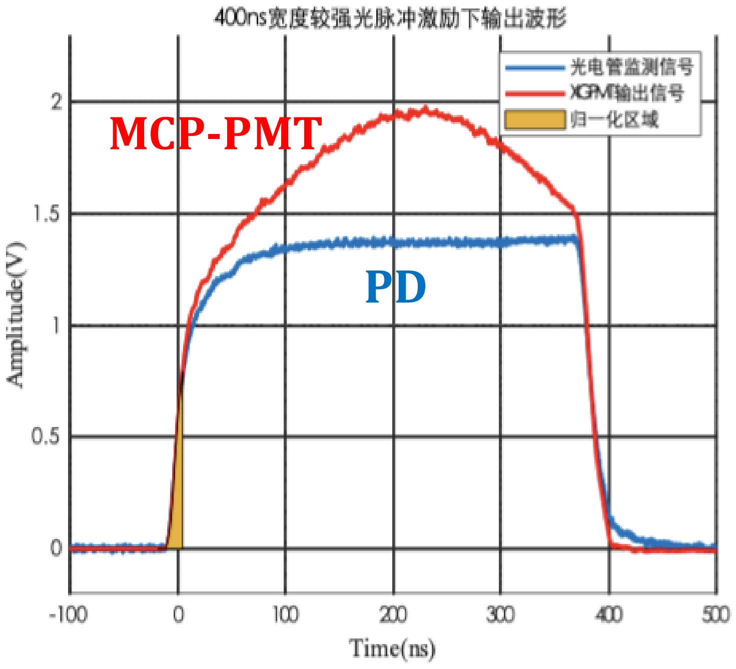
- Single-anode MCP-PMT with 50 mm diameter
- PD for monitoring light source

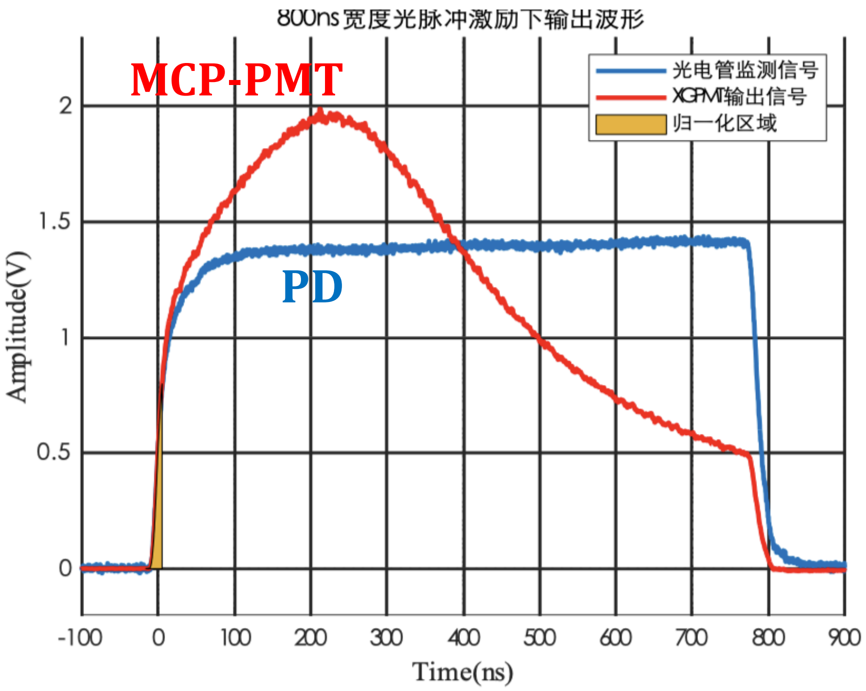
● **Super linearity is worse for stronger illumination**

Light source 400ns, 0.4V

400ns,1.4V



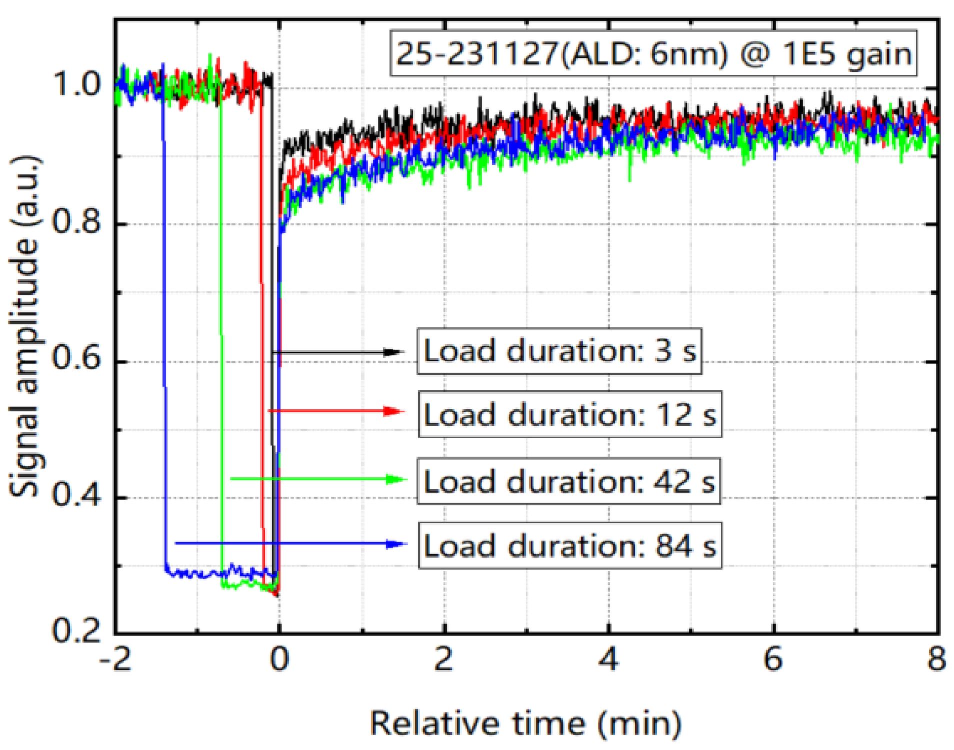


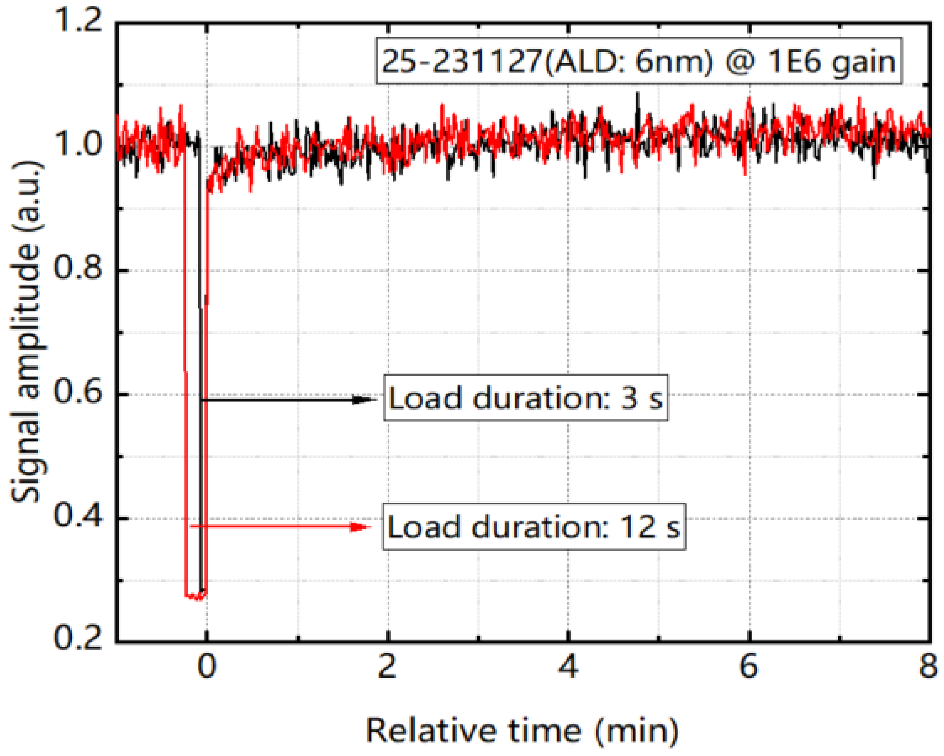


Recovery behavior

❑ Saturation duration effect

- The longer the saturation duration, the slower the recovery.
- When the saturation duration exceeds a certain value(e.g. 42s), the recovery behavior no longer changes.

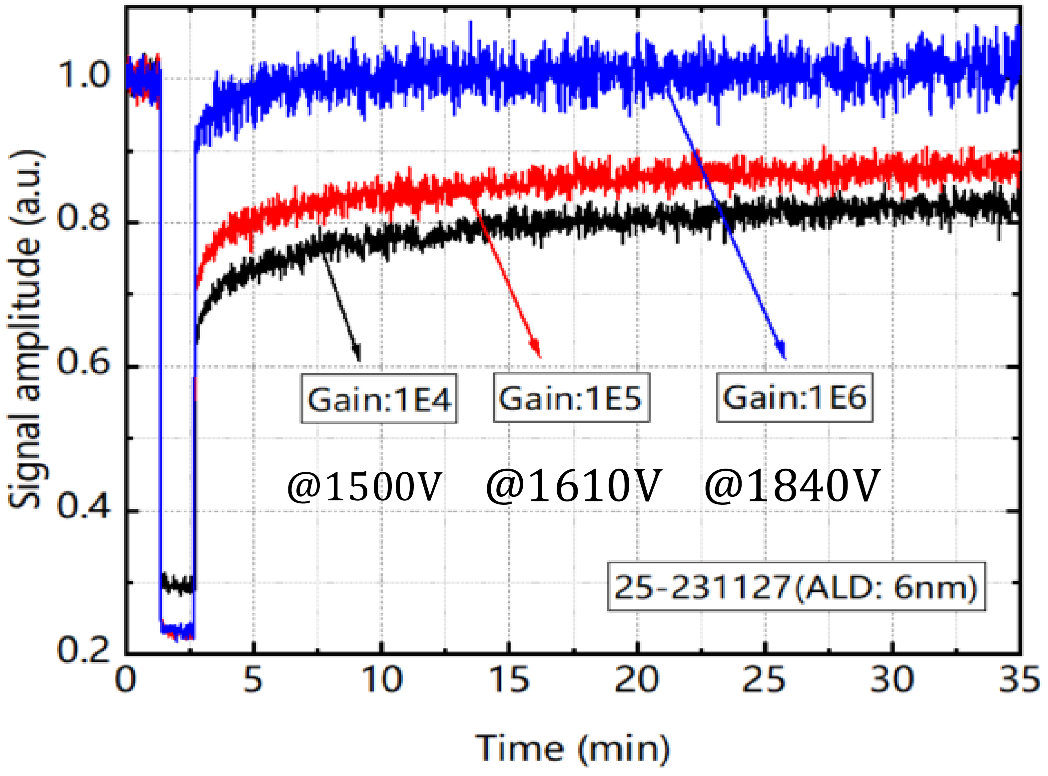


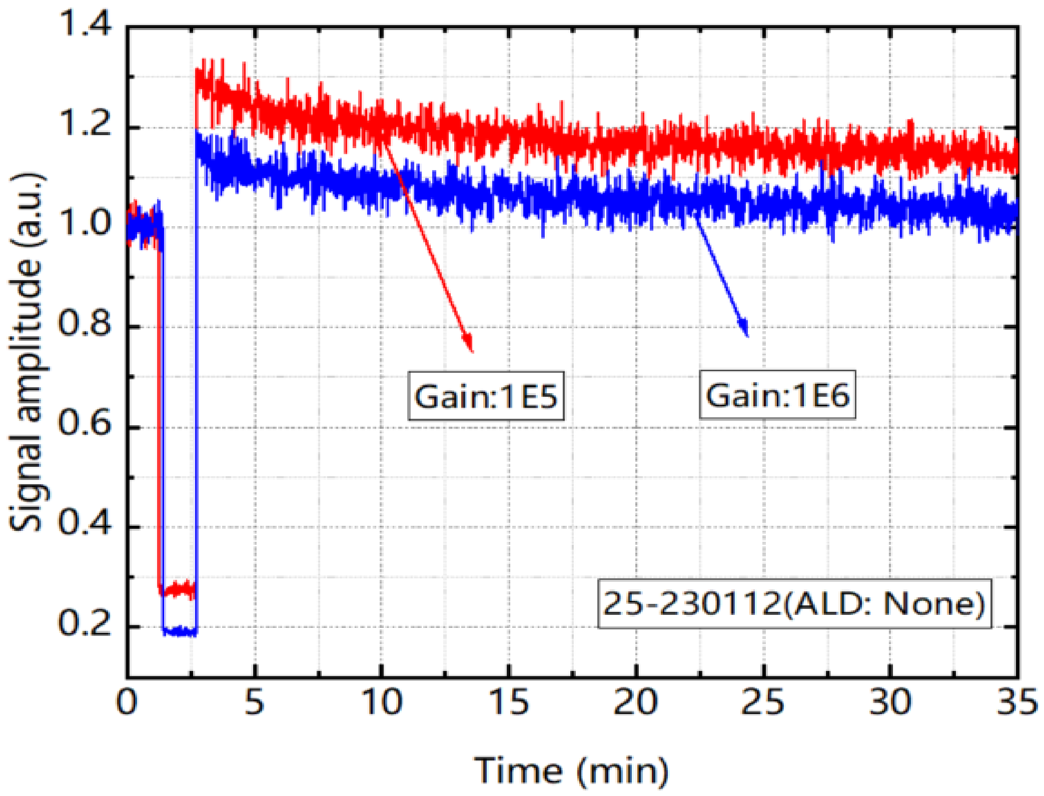


Recovery behavior

❑ Supply voltage effect

- Higher supply voltage is better for recovery for the ALD-MCP
- Super linearity is less for higher HV





Summary & outlook

- ALD film on lead glass MCP is efficient for improve the lifetime.
- Increasing scrubbing amount for MCP is also good for lifetime.
- Thicker ALD-MCP has longer recovery time.
- The ALD film should be optimized considering the gain, lifetime and rate capability.
- Super linearity is found in the non ALD-MCP, which needs to be studied further.
- Higher supply voltage seems better for gain recovery.
- The ALD-film and scrubbing amount for MCP will be optimized for improving lifetime further.
- The single photon rate capability will be evaluated.

Thank you for your attention！