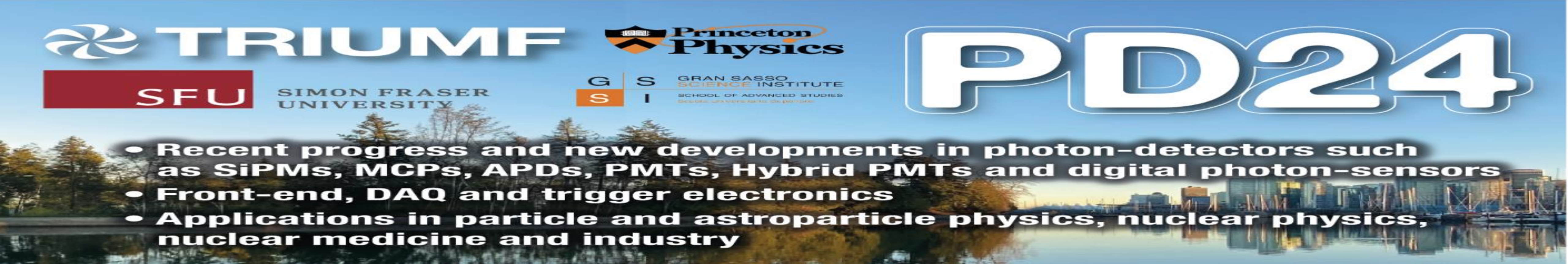

R&D of MCP-PMTs

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Chinese Academy of Sciences (XIOPM-CAS)

21/11/2024

XIOPM MCP-PMTs

XIOPM

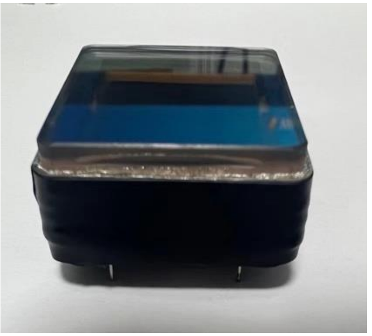
XI'AN INSTITUTE OF OPTICS AND PRECISION MECHANICS
CHINESE ACADEMY OF SCIENCES

- Participated in the development of 20-inch MCP-PMT and 3 inch dynode-PMT for JUNO from 2012-2016
- Developed Gated MCP-PMT for DCI laser fusion experiment
- Developed MCP-PMT with high current output
- Developing Long-life multi-anode MCP-PMT for STCF

20 inch MCP-PMT

Gated MCP-PMT

Large current MCP-PMT

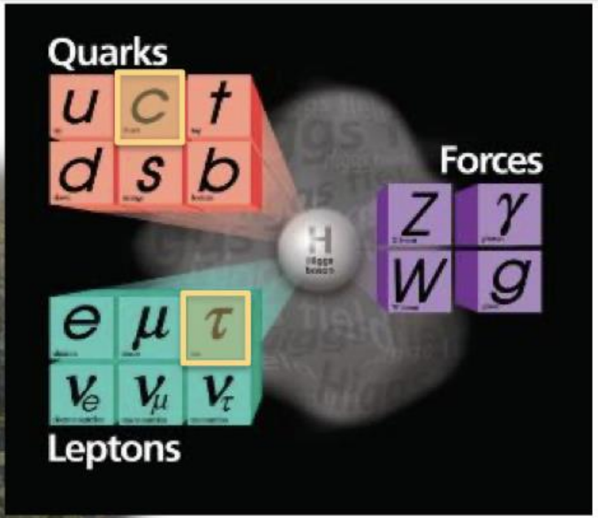


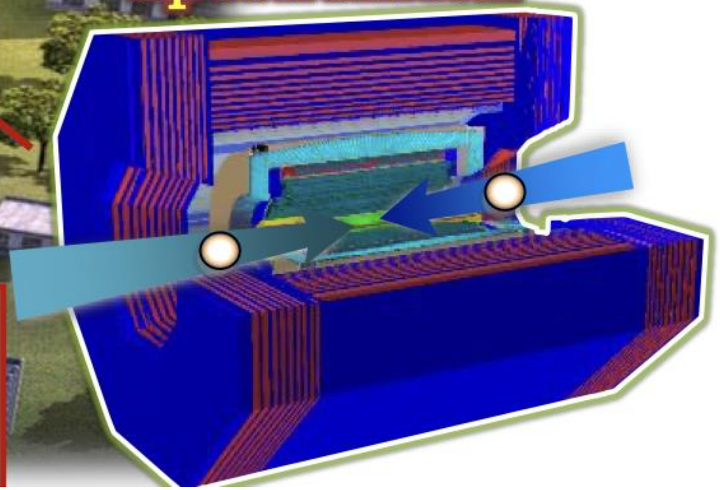
Long-life MCP-maPMT$_2$

Super Tam Charm Facility (STCF) in China

XIOPM

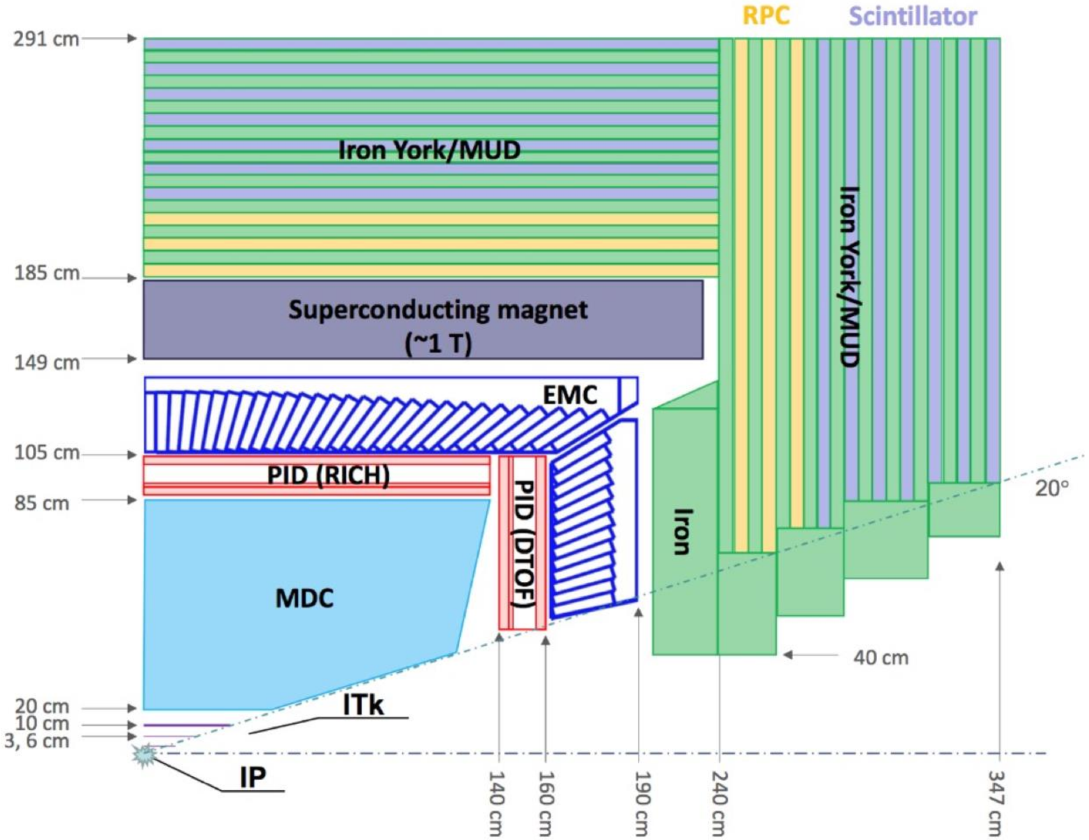
A factory producing massive **tau lepton** and **hadrons**, to unravel the mystery of **how quarks form matter** and the **symmetries** of fundamental interactions





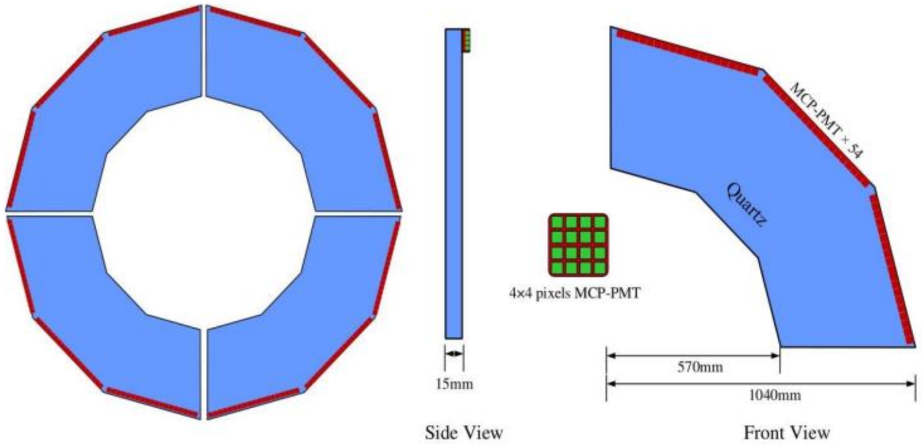
- E_{cm}= 2-7 GeV, $\mathcal{L} > 0.5\times10^{35}$ cm^{-2} s^{-1}
- Potential for upgrade to **increase luminosity** and realize **polarized beam**
- Site: 1 km^2 , Hefei's suburban "Future Big Science City"

STCF PID (DTOF)



MCP-PMT requirements

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

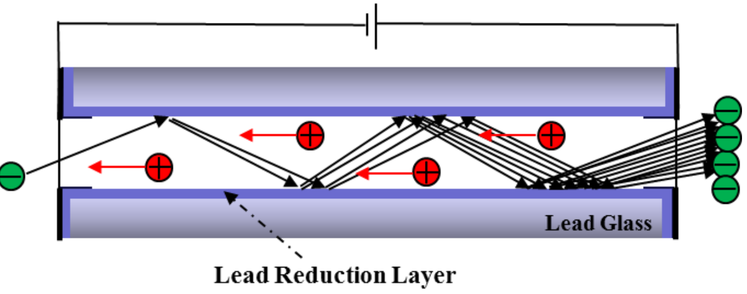


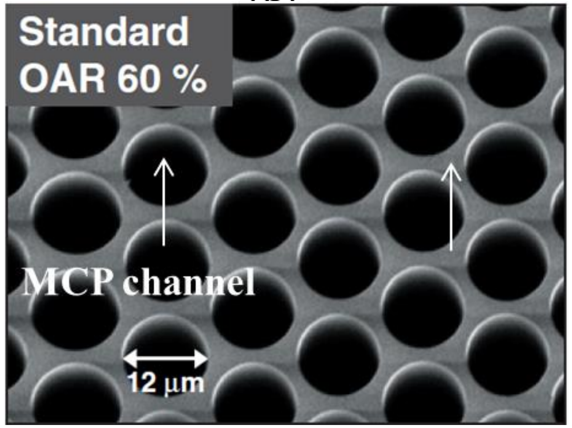
DTOF: DIRC-like TOF

microchannel plate

Conventional MCP

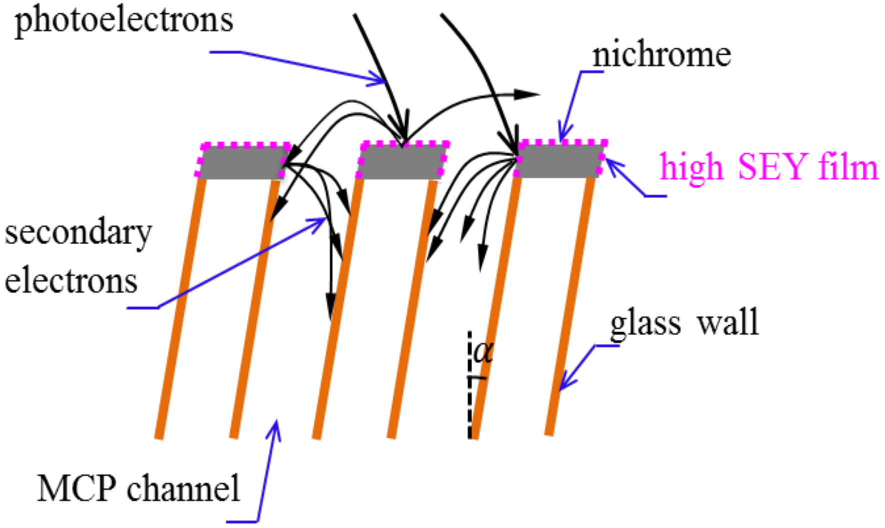
- Made of lead glass
- Collection efficiency ~60%
- Gain from lead glass
- Maximum SEE yield ～3





ALD-MCP based on lead glass

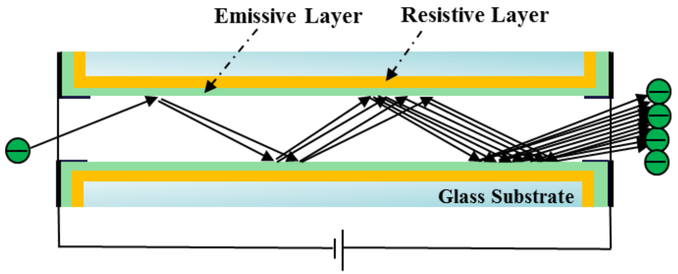
- Coating Al2O3/MgO on the lead glass MCP input surface and channel
- Maximum SEE yield over 4
- Gain mainly from ALD-layer
- Collection efficiency improved to ~100%
- Lifetime extended



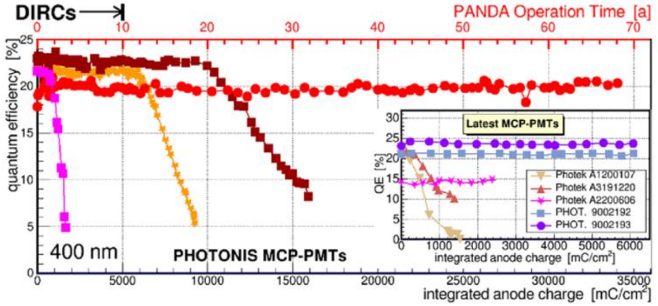
Optimization of the 20 inch MCP-PMT, NIM A

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

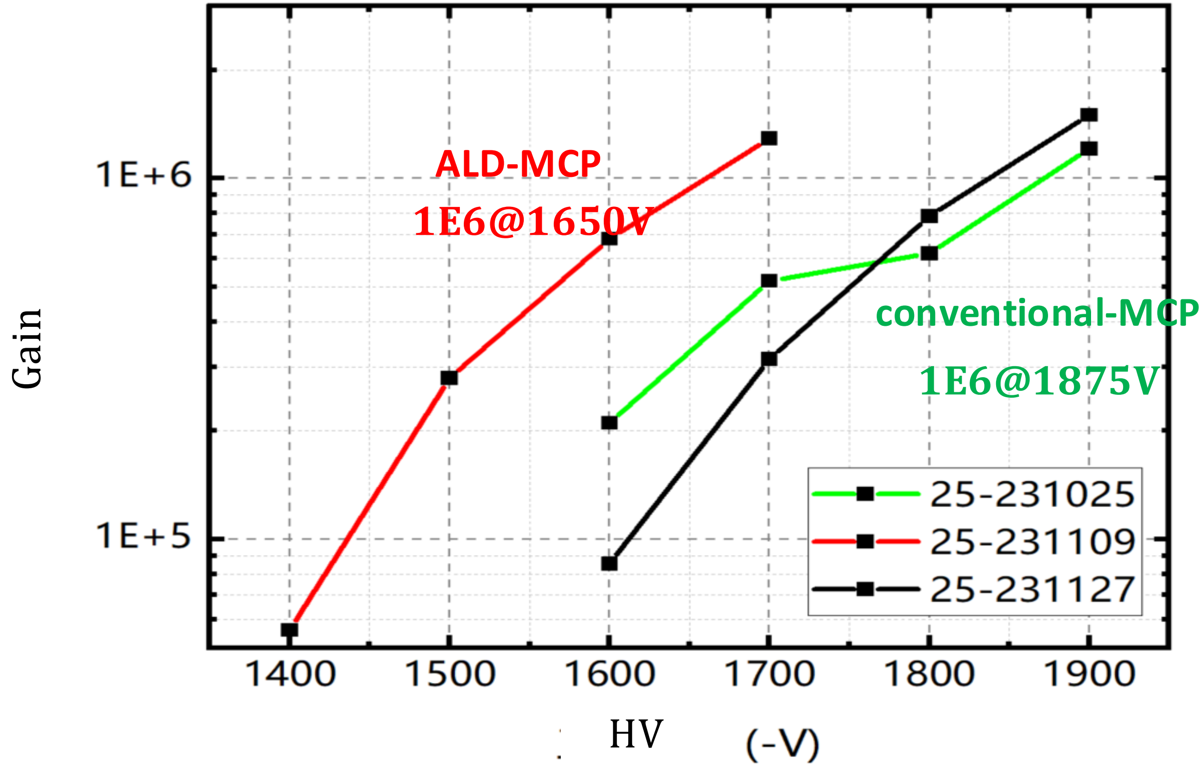


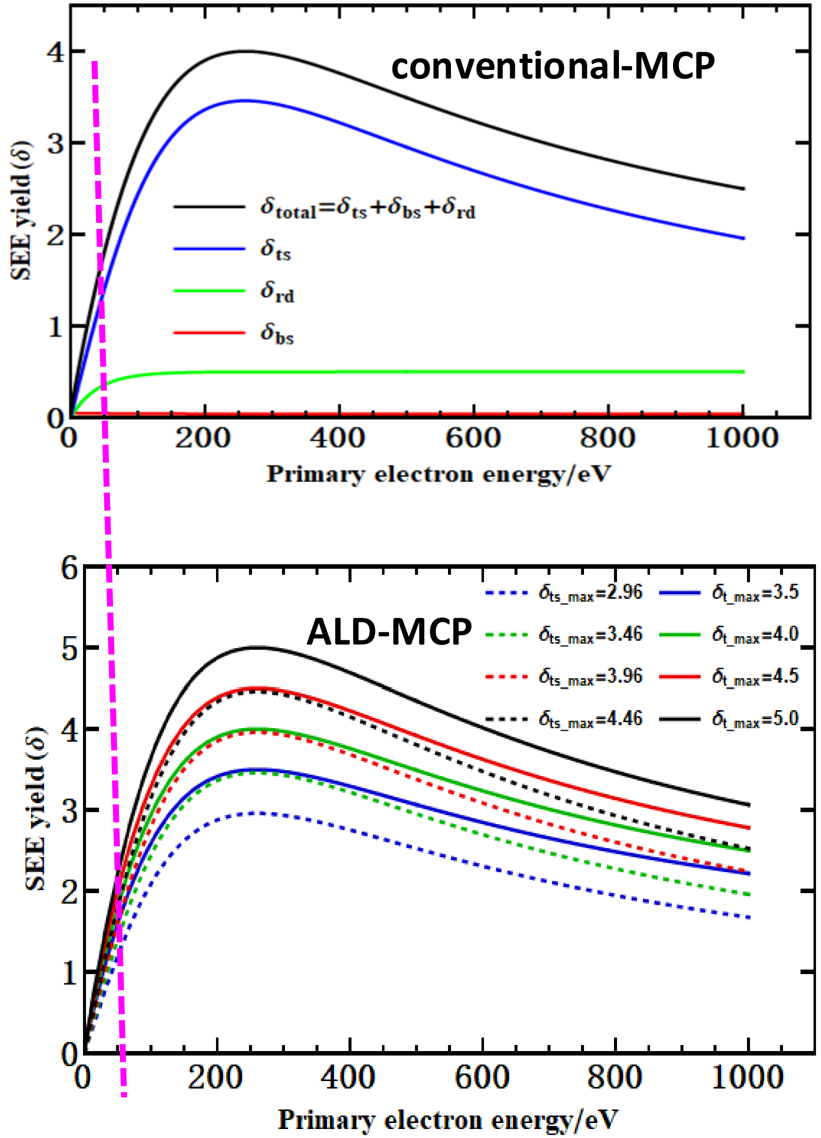
A. Lehmann et al., GSI scientific report 2022DO1:10.15120/GS1-2023-00462

Gain

Higher gain at lower HV for ALD-MCP

Due to its higher SEE yield



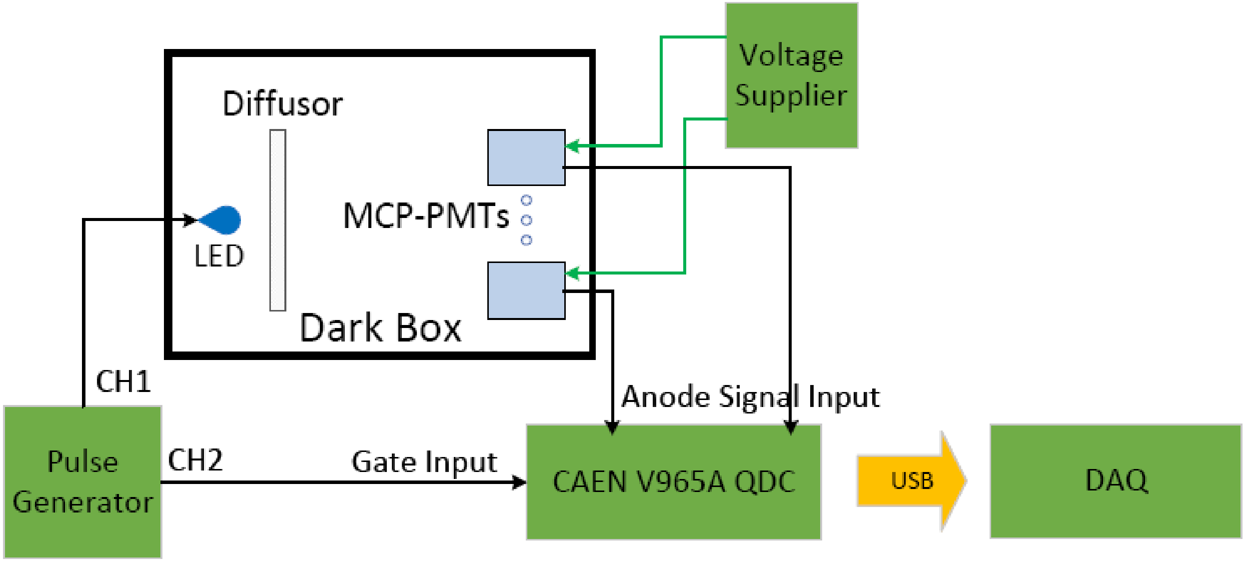


Lifetime

Factors affecting the lifetime of MCP-PMT ?

❑ ALD layer thickness and scrubbing amount

- 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/cm²
- Operated 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

- **ALD film thickness effect**

  Lifetime@ 6 nm ＞4.5 nm ＞ 1nm ＞none

- **Scrubbing amount effect**

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

IAC over 11 C/cm2

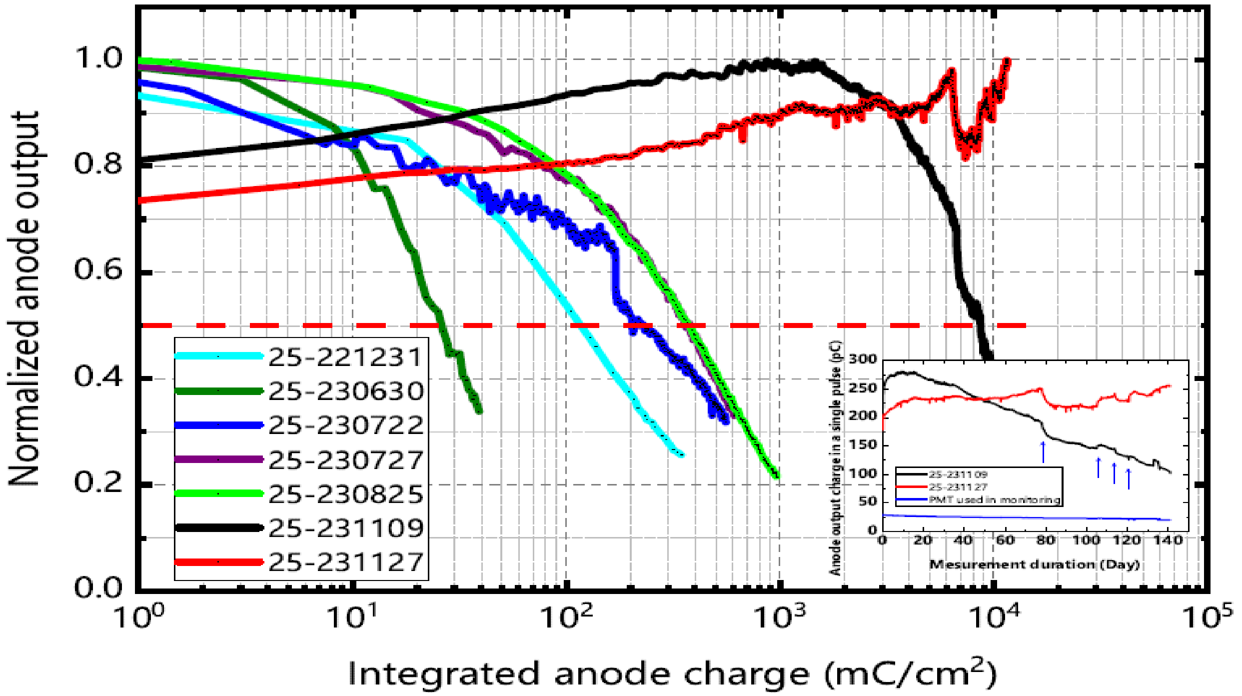


Table 2. IAC at 50% anode output degradation for the MCP-PMTs.

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

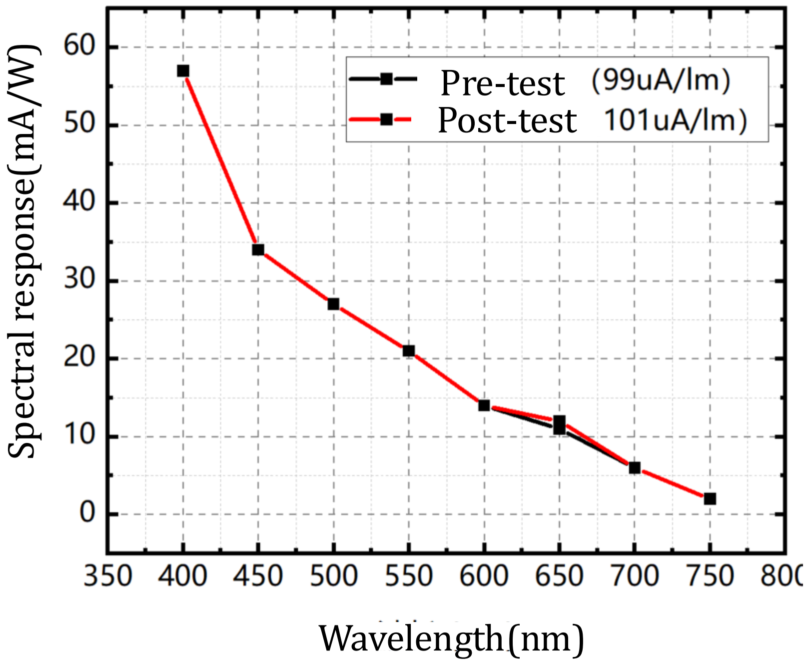
Research progress on long lifetime MCP-PMT for the DTOF detector in STCF, IJMPA's Volume No. 39, Issue No. 26n27, Article No. 2442016, Year 2024

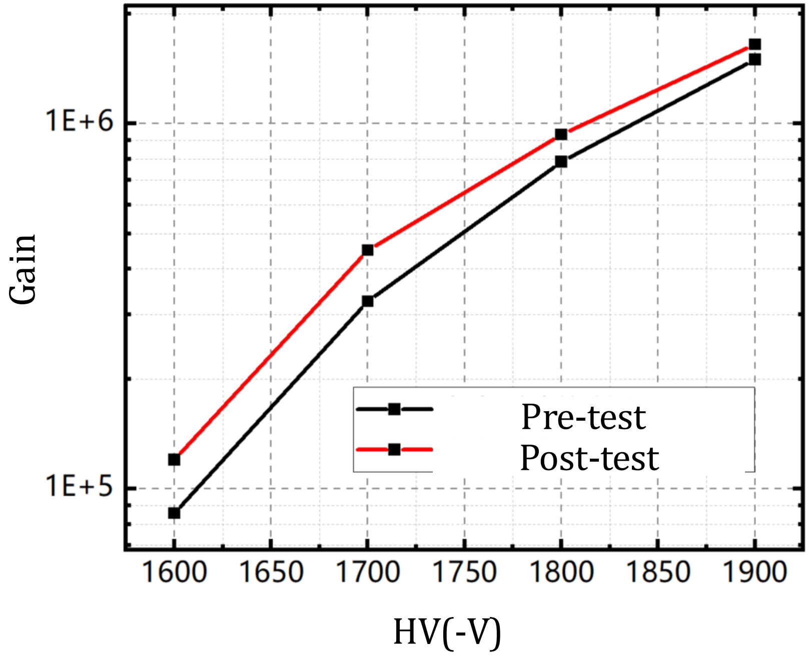
Lifetime

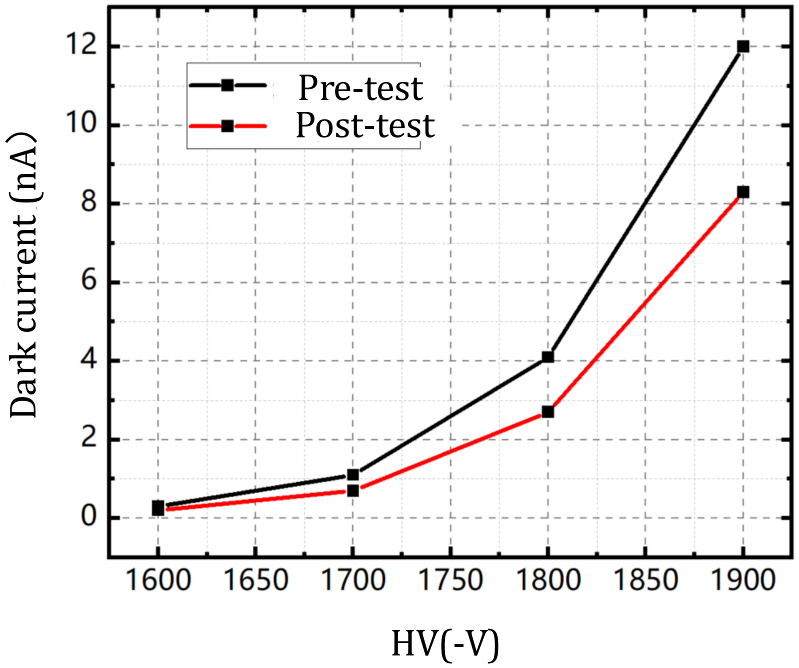
Performances before and after lifetime tests

25-231127 with IAC over 11 C/cm2

none degradation on photocathode and MCP





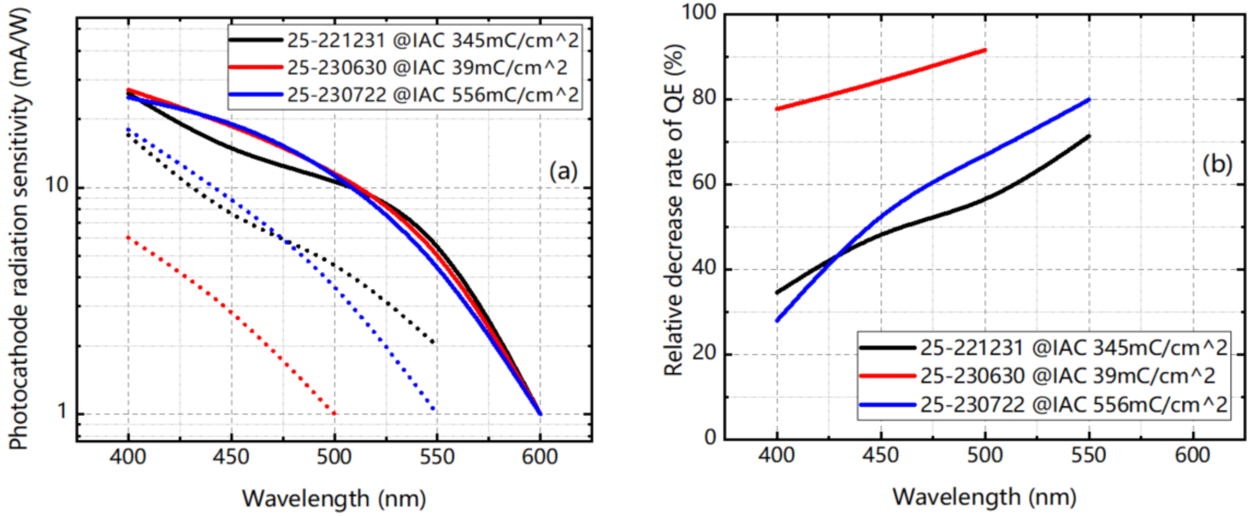


Lifetime

Performances before and after lifetime tests

25-221231、# 25-230630、
25-230722 with IACs less than 0.56C/cm2

- **Degradations on photocathode and MCP**
- **QE decreases more at longer wavelengths**



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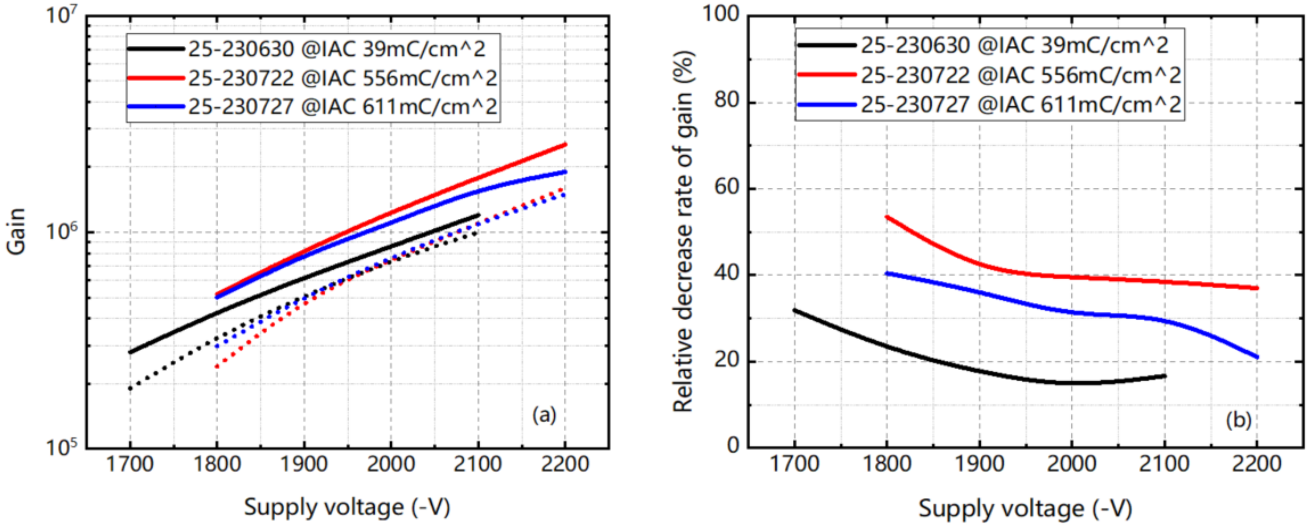
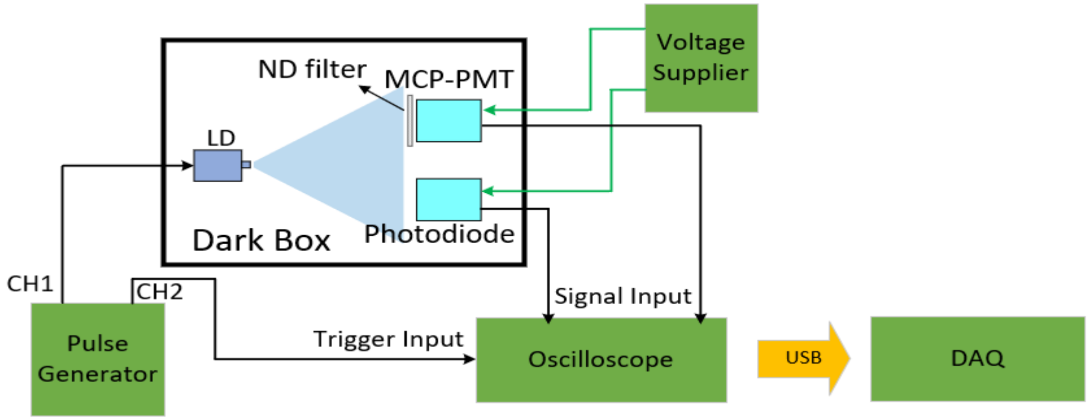
25-231127	6	0.75	> 11,000

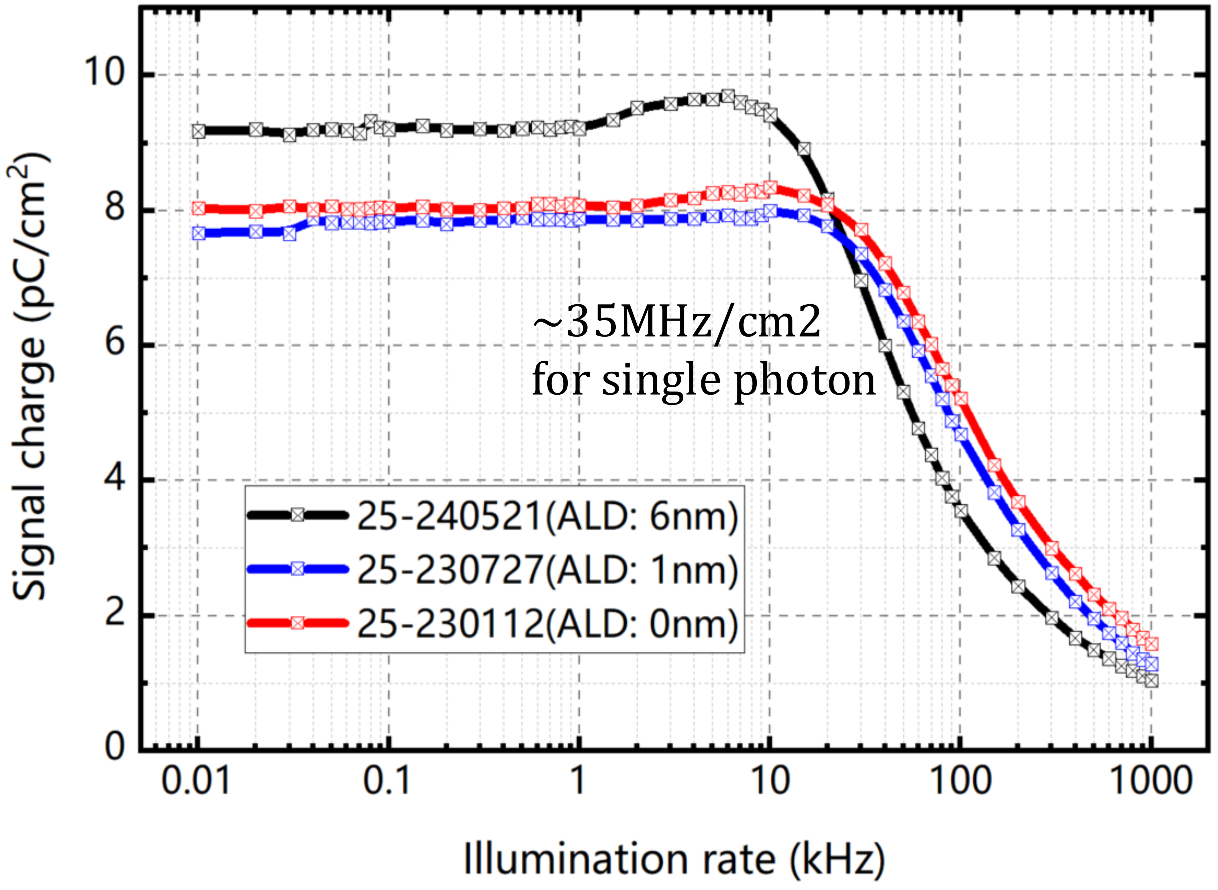


Rate capability

measurement setup

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



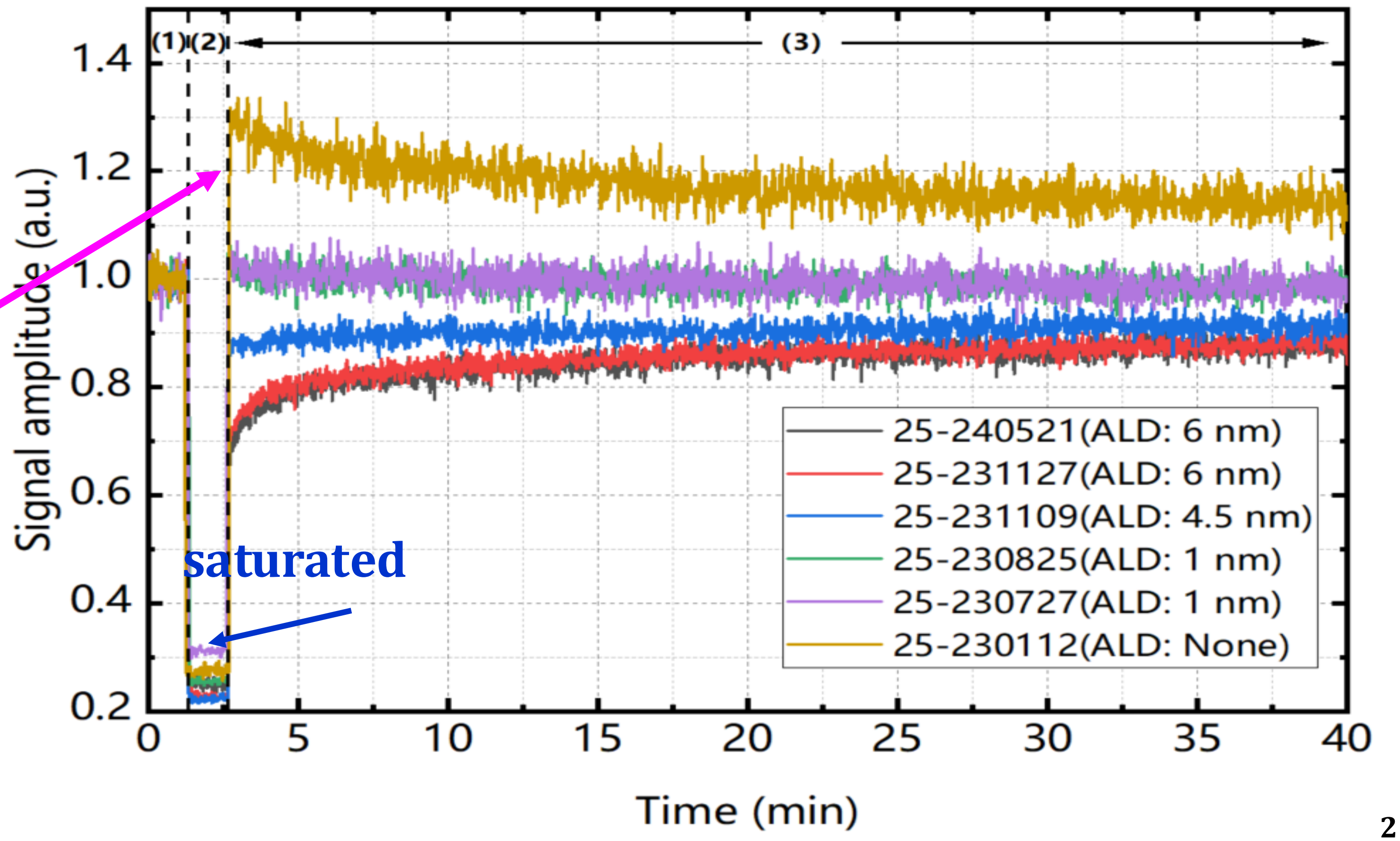


Recovery behavior

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

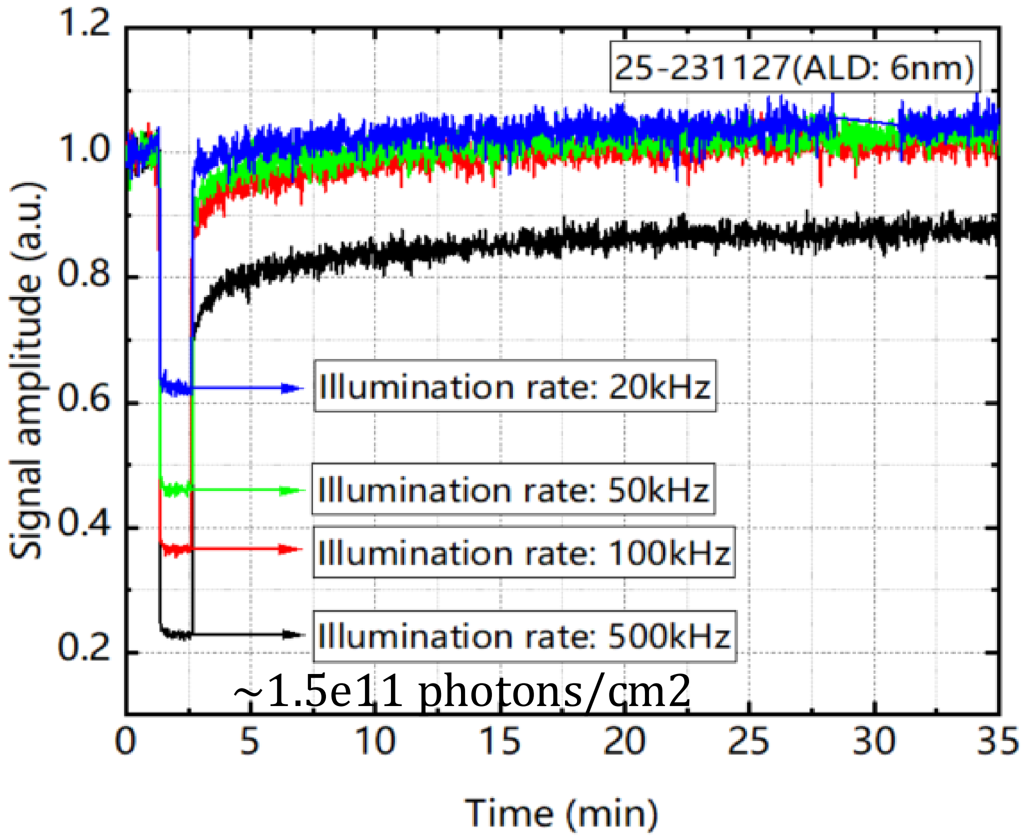
- **Longer recovery time for thicker ALD-layer MCP**
- **Super linearity for none-ALD MCP ?**

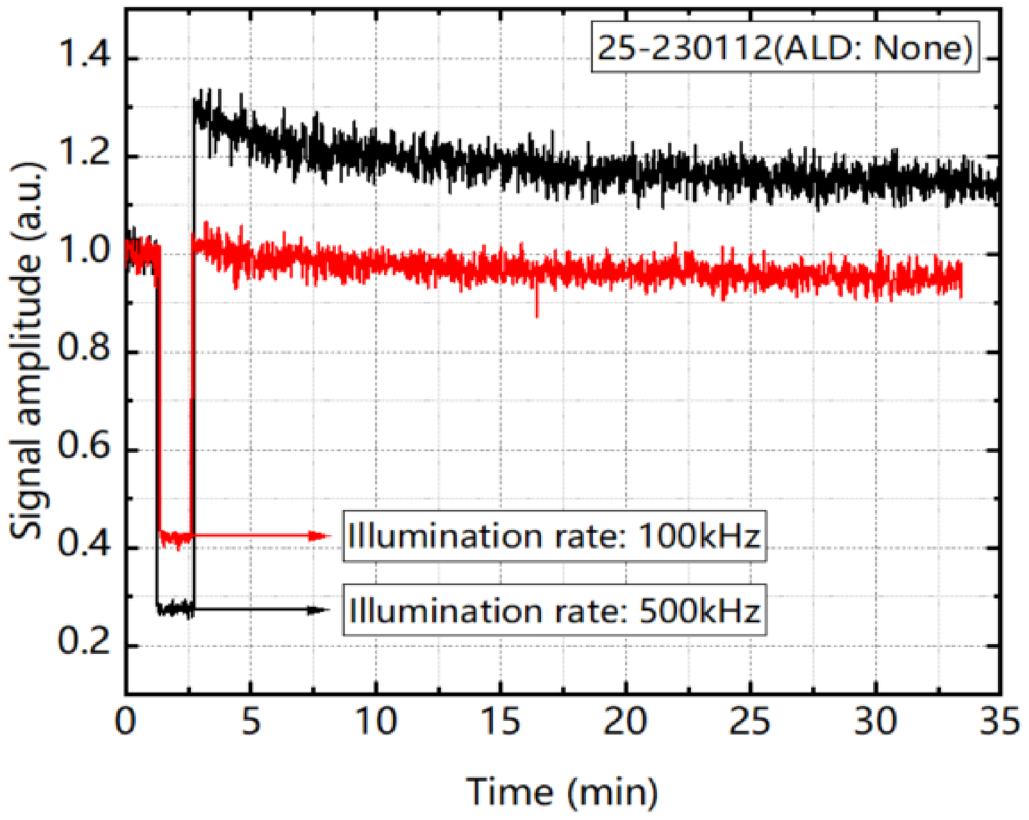


Recovery behavior

❑ Illumination rate effect

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



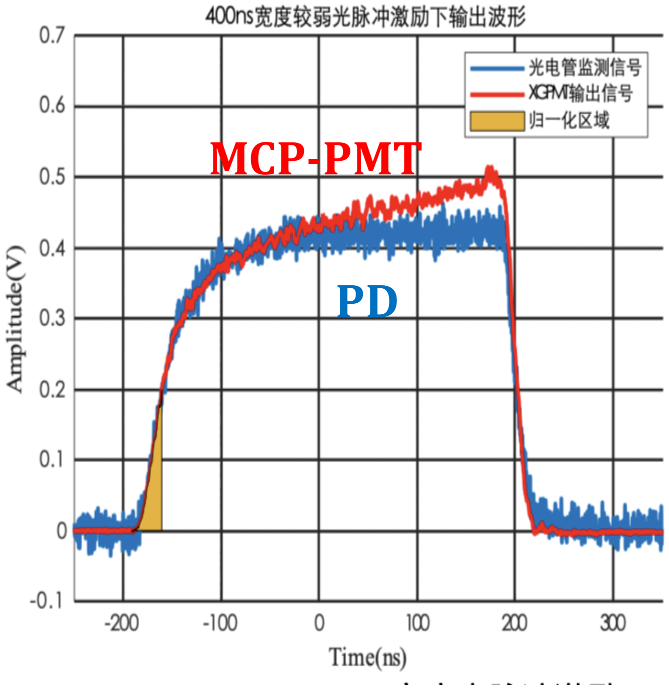


Recovery behavior

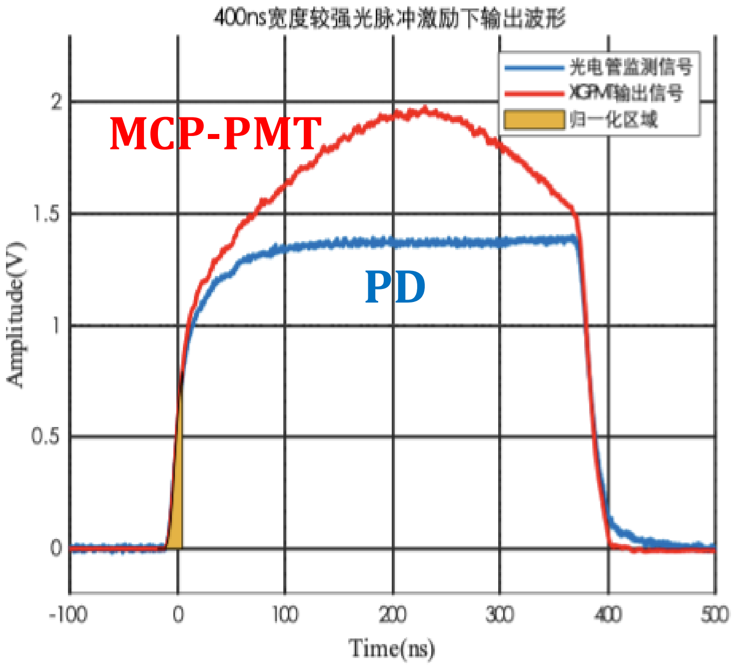
❑ Super linearity for none-ALD MCP

Super linearity is worse for stronger illumination

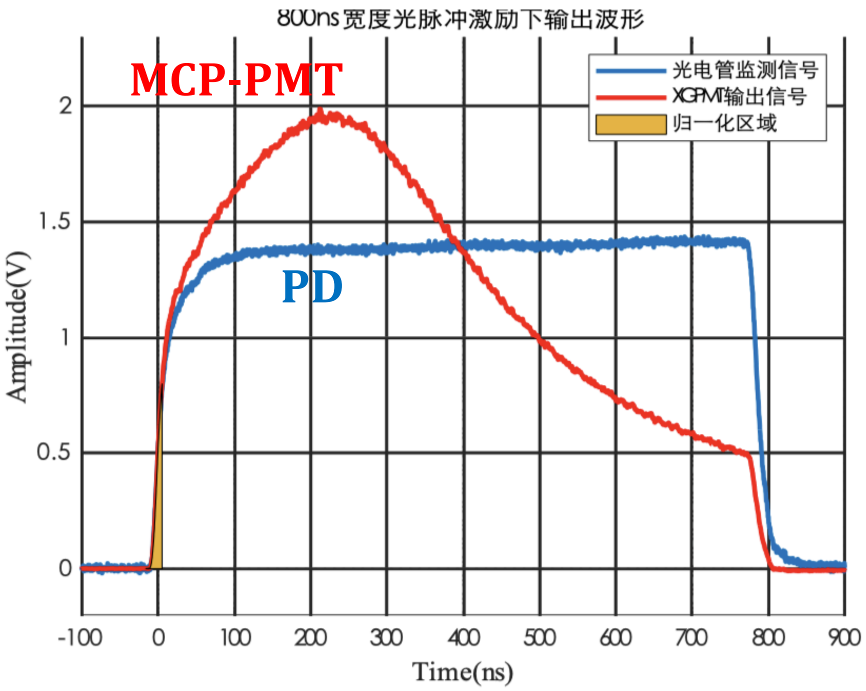
Light source 400ns, 0.4V



400ns,1.4V



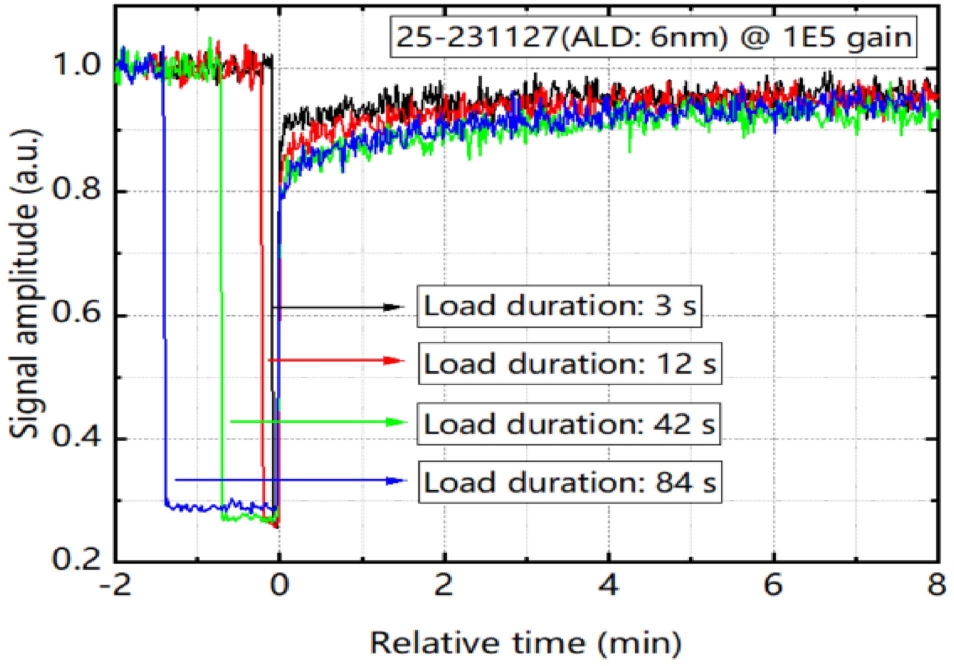
800ns,1.4V

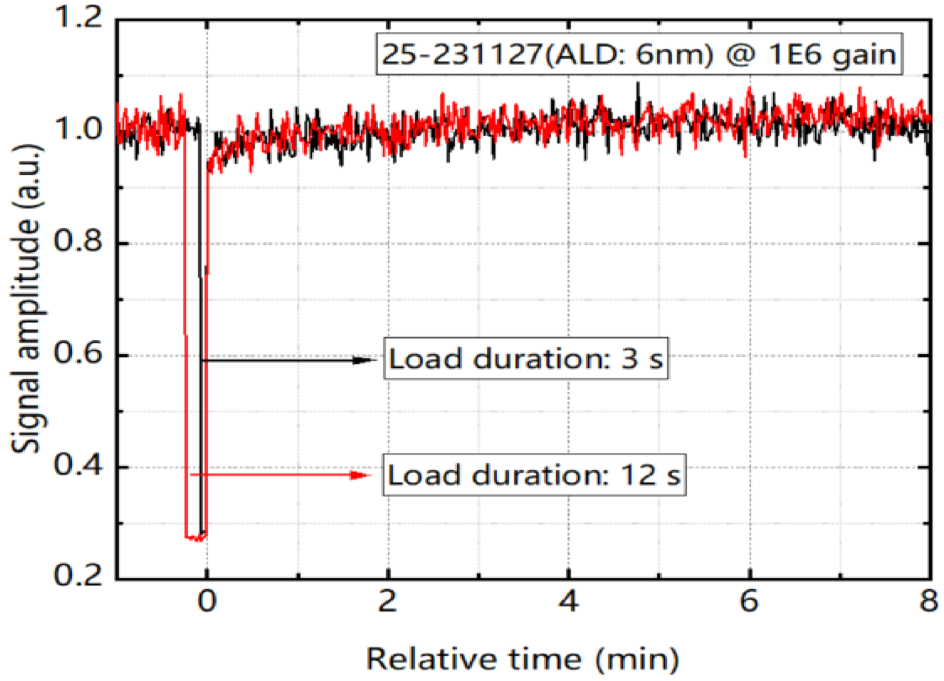


Recovery behavior

❑ 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.**

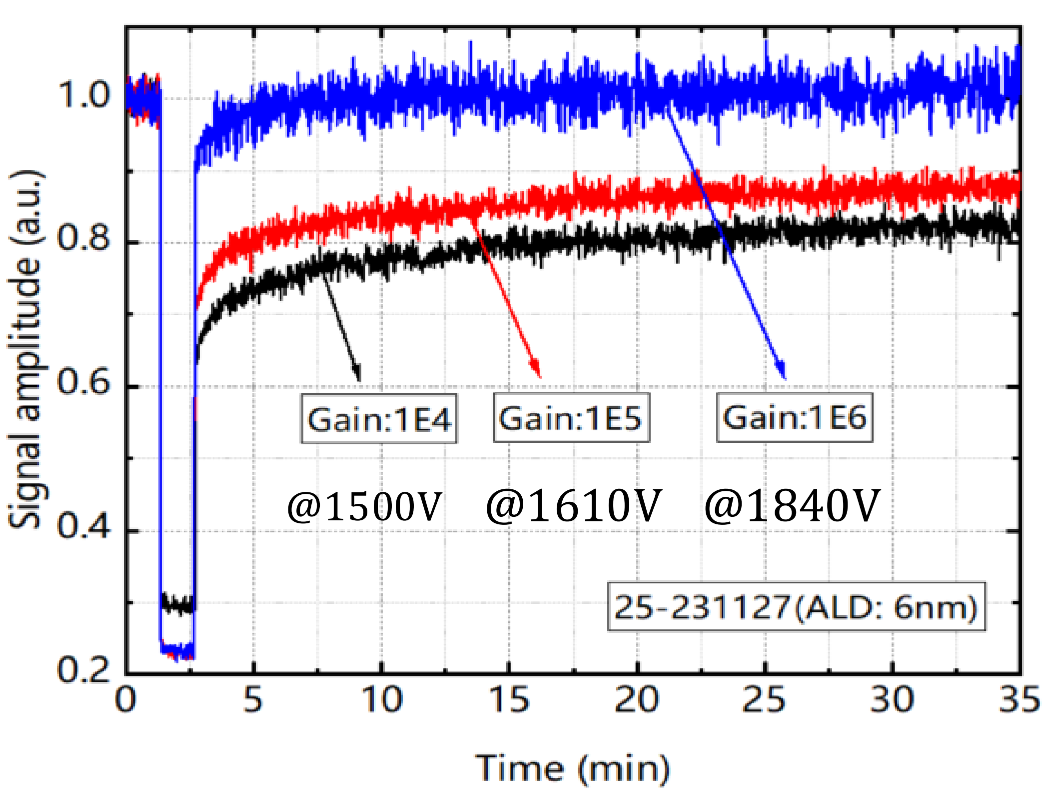


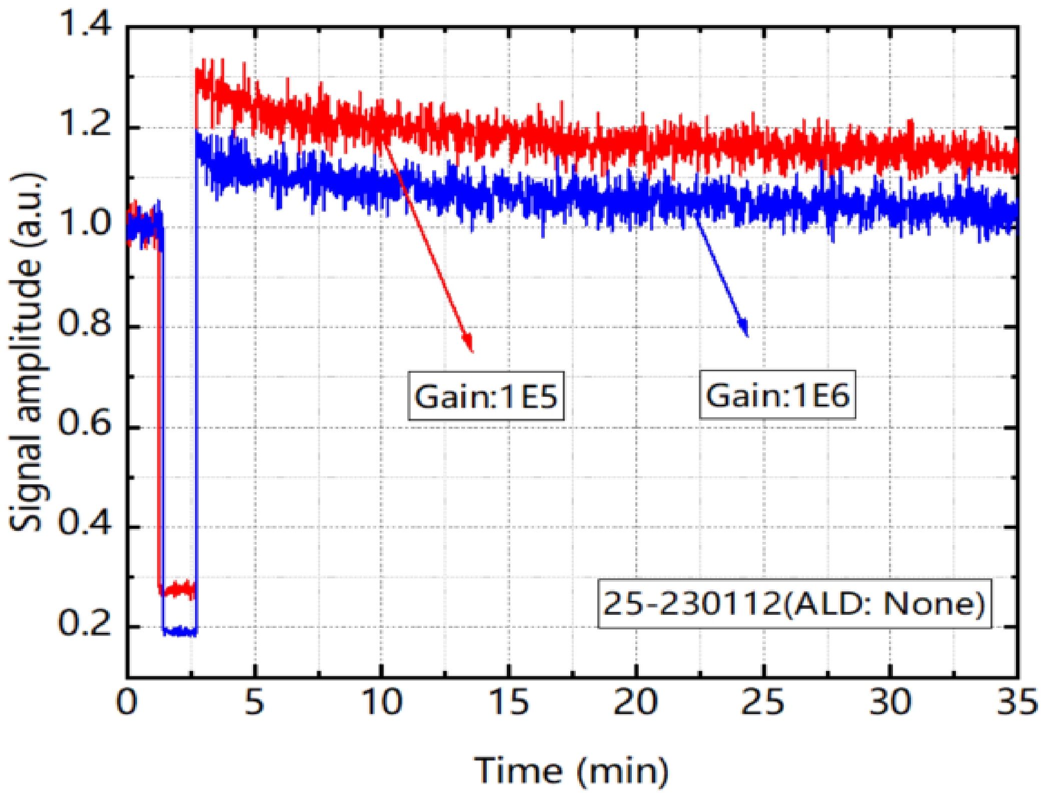


Recovery behavior

❑ Supply voltage effect

- **Higher supply voltage seems better for recovery for the ALD-MCP**
- **Super linearity can be less for higher HV**



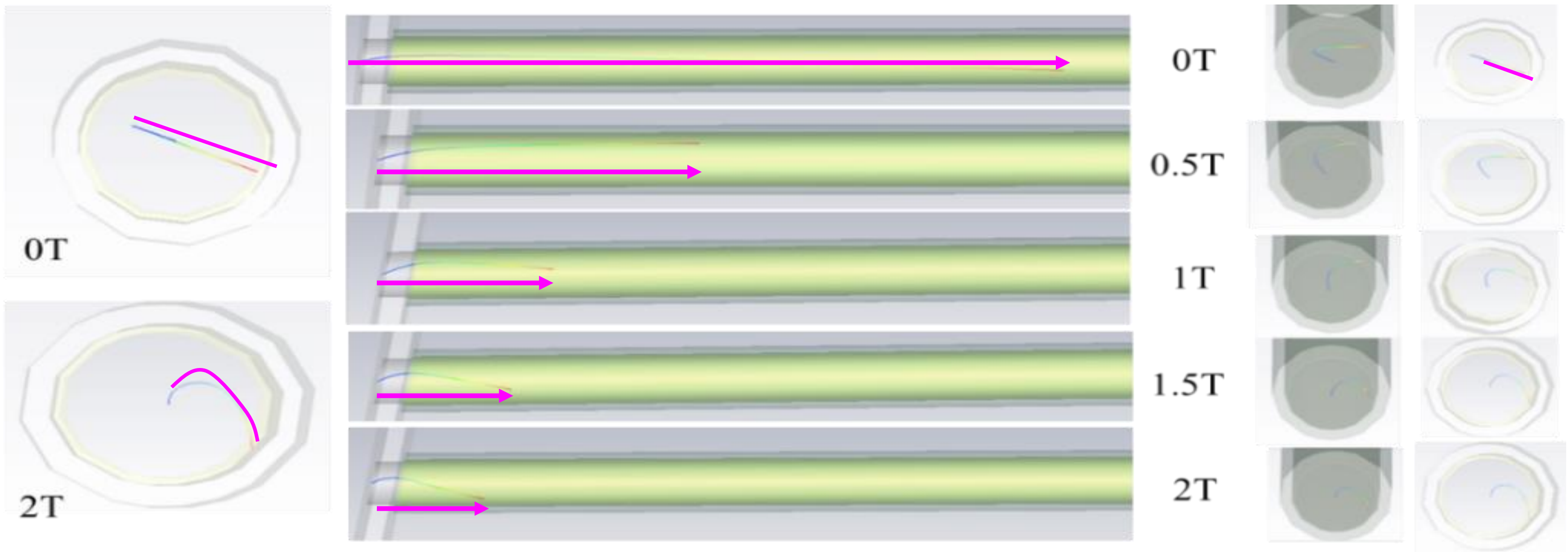


Magnetic fields effects

How magnetic fields decrease gain

Electron trajectories in the MCP channel under the magnetic fields are simulated with CST program.

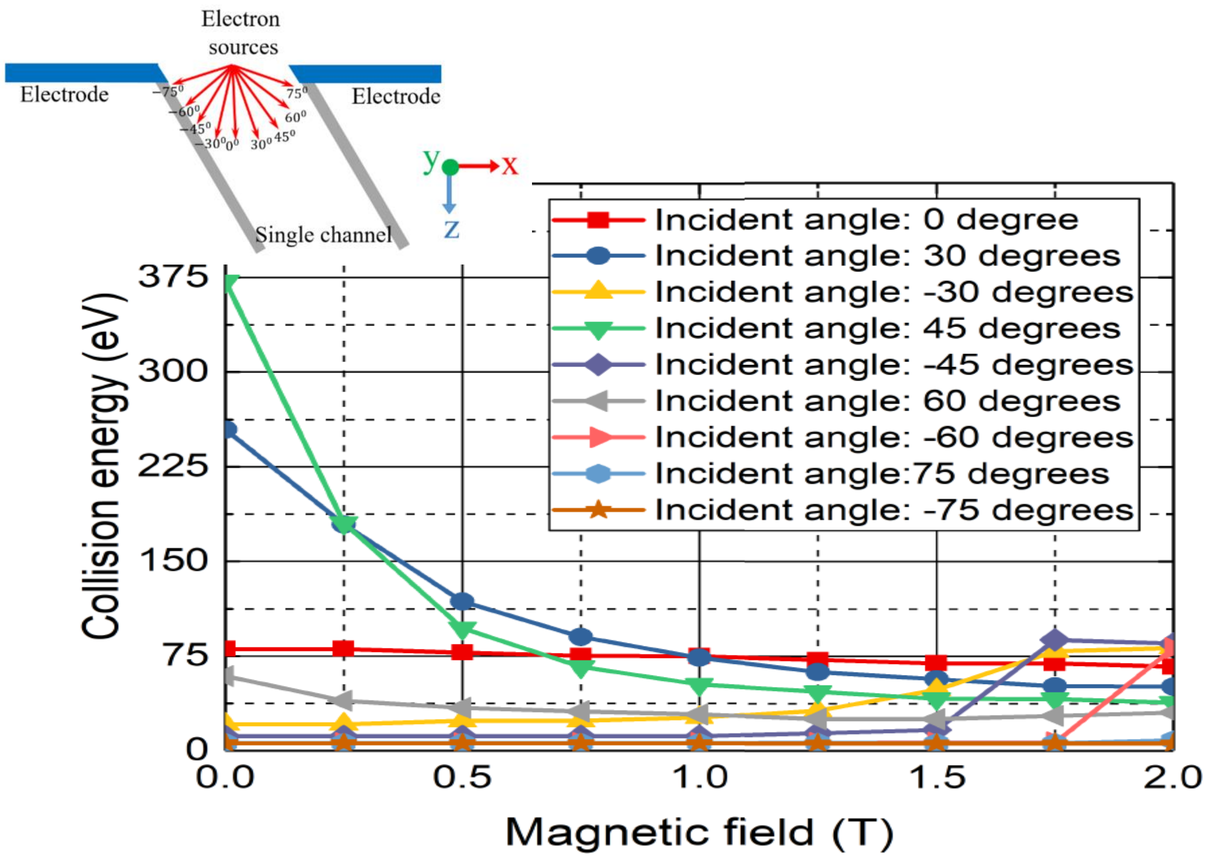
- **Electrons move in a spiral under the influence of a magnetic field.**
- **This causes the electrons to be accelerated over a shorter distance.**
- **Reduction in the energy of electrons hitting the microchannel plate.**

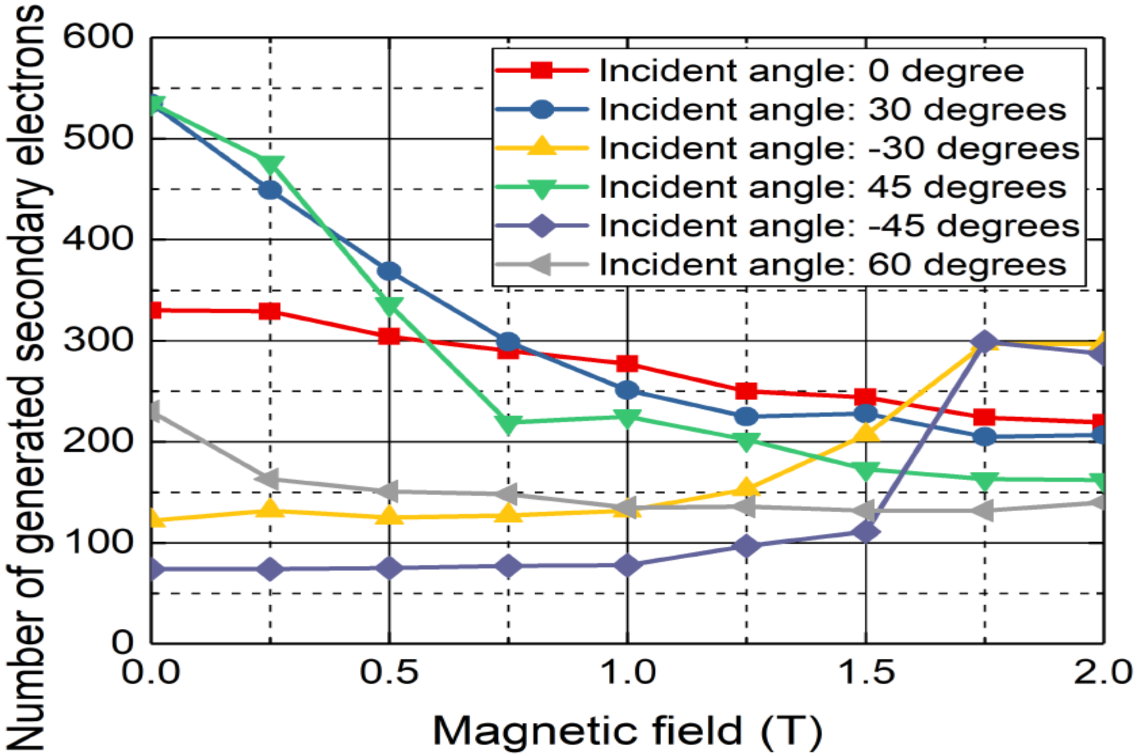


Magnetic fields effects

XIOPM

- **Reduced number of secondary electrons produced due to lower impact energy**

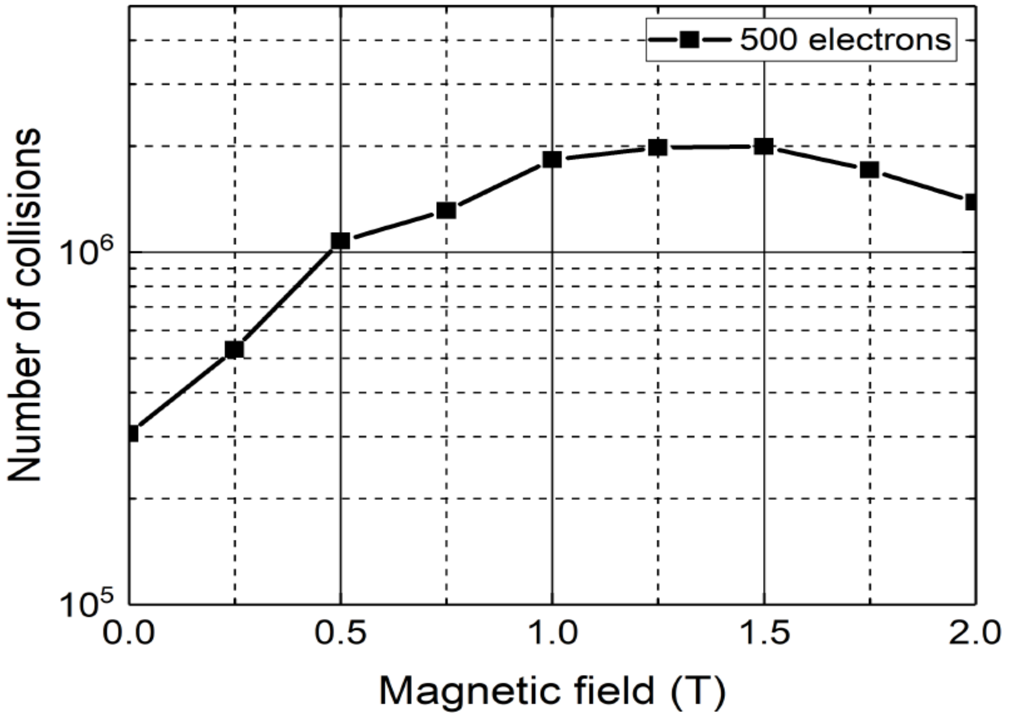


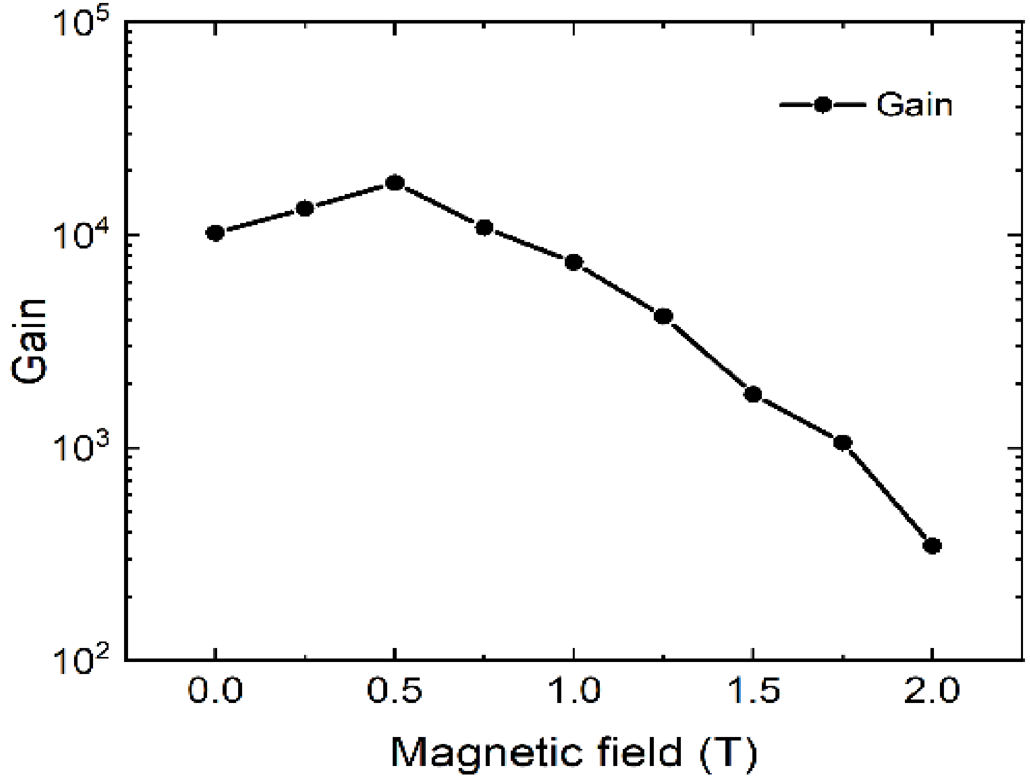


Magnetic fields effects

- **The number of electron collisions in the microchannel increases and then decreases.**

❑ **Gain is the result of the combined effect of the number of collisions and collision energy.**



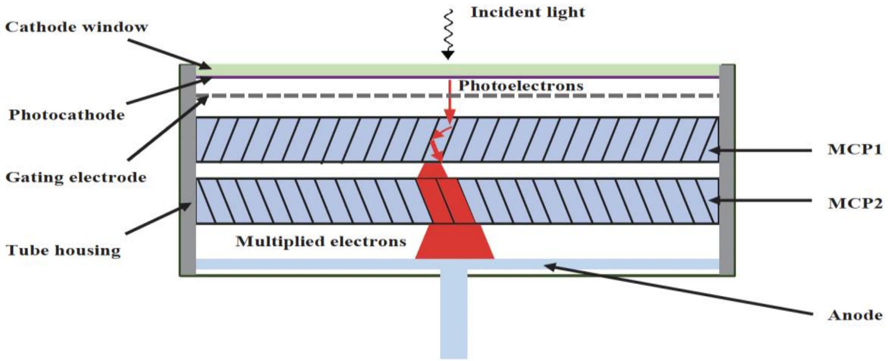


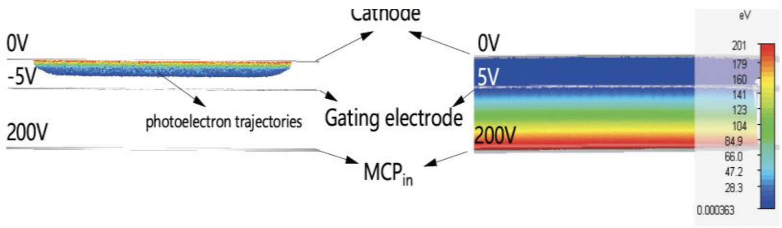
Gating function

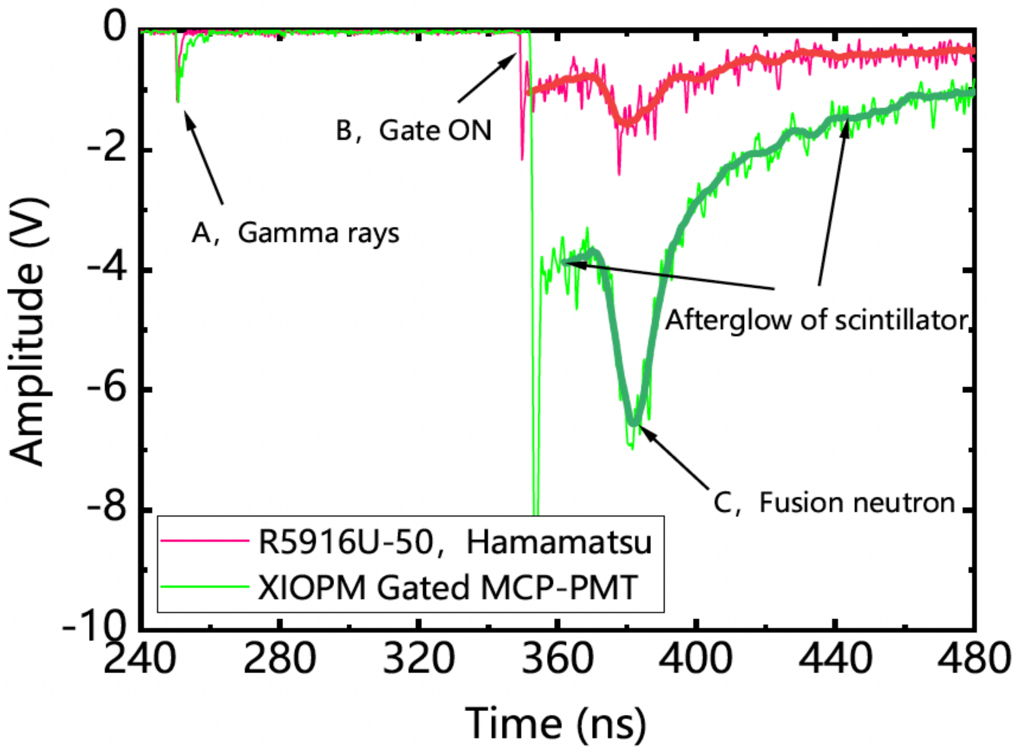
XIOPM

- **MCP-PMT with gating function is developed to detect a weak neutron signal in the presence of strong gamma noise.**

A gating electrode was incorporated between the cathode and the microchannel plate to control the voltage between the cathode and the gating electrode.







An enhanced gated MCP-PMT for neutron detection in laser fusion experiments, NIM A

Thank you for your attention！