

The 2024 International Workshop on Future Tau Charm Facilities

January 14-18, 2024

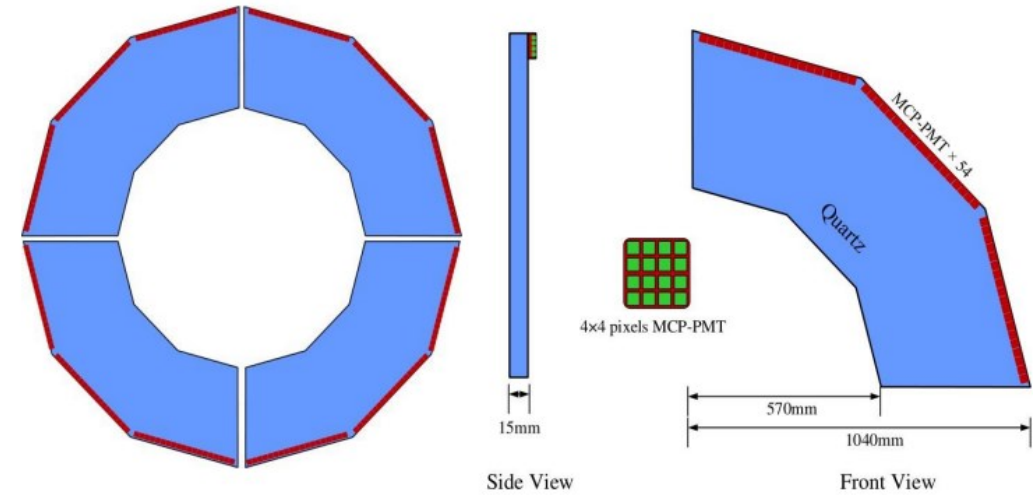
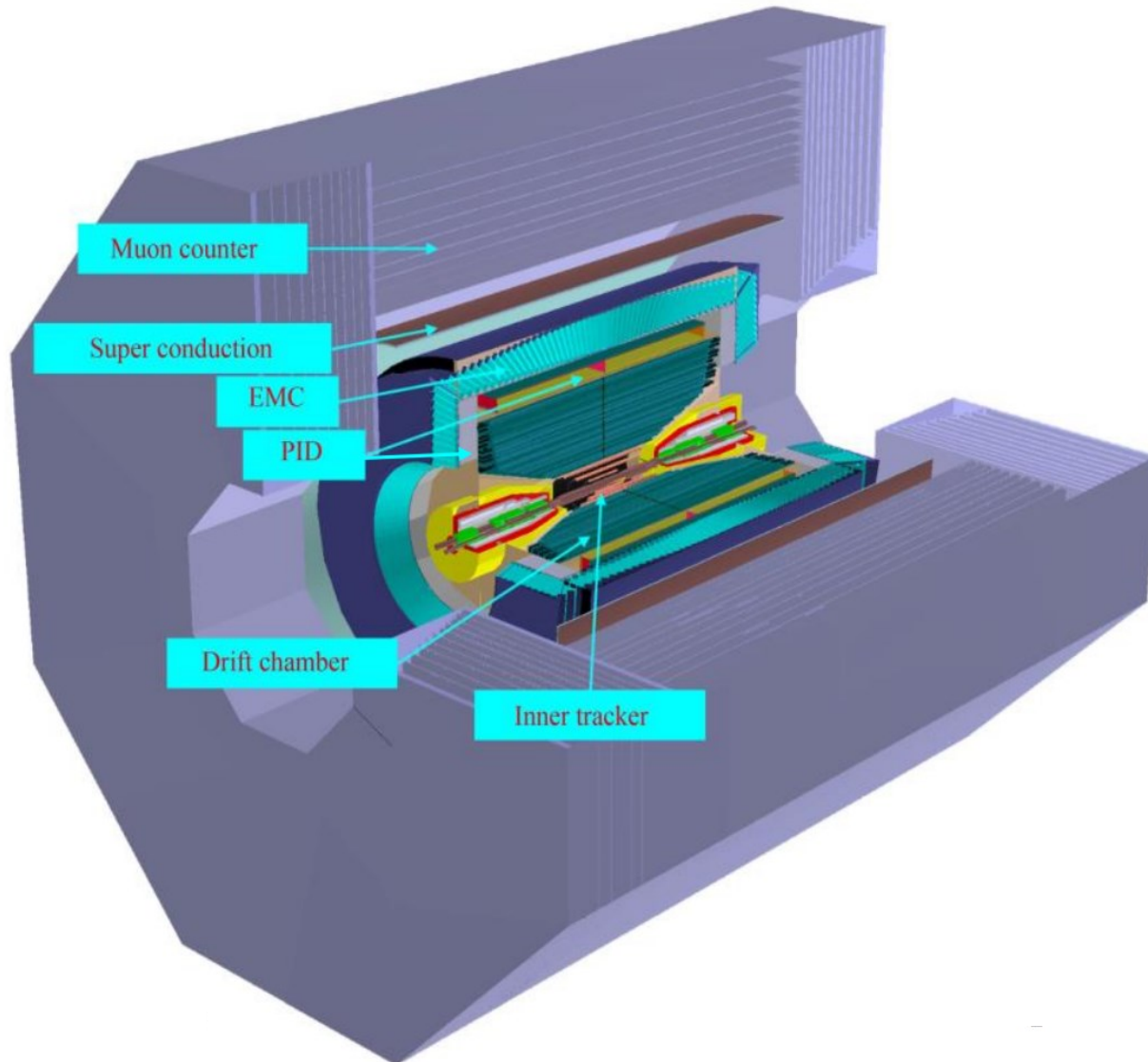
R&D of fast maMCP-PMT

Ping Chen

chenping1@opt.ac.cn

Xi'an Institute of Optics and Precision Mechanics
Chinese Academy of Sciences (XIOPM-CAS)

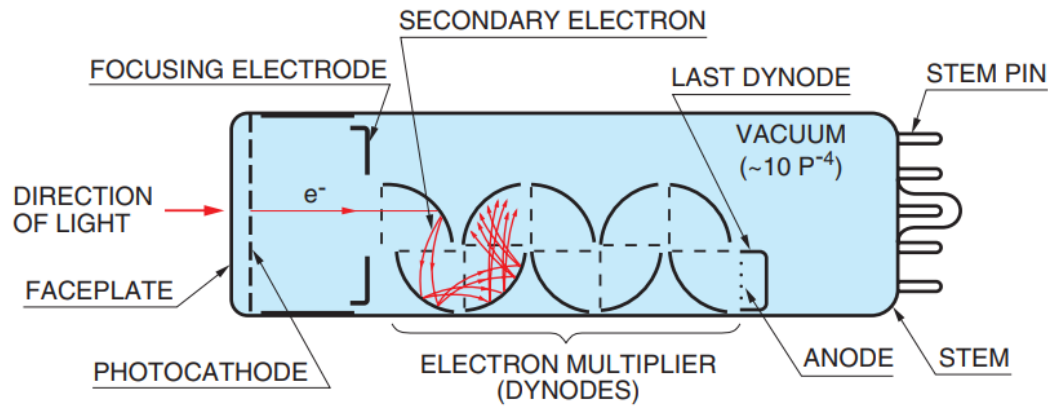
17 January 2024



MCP-PMT

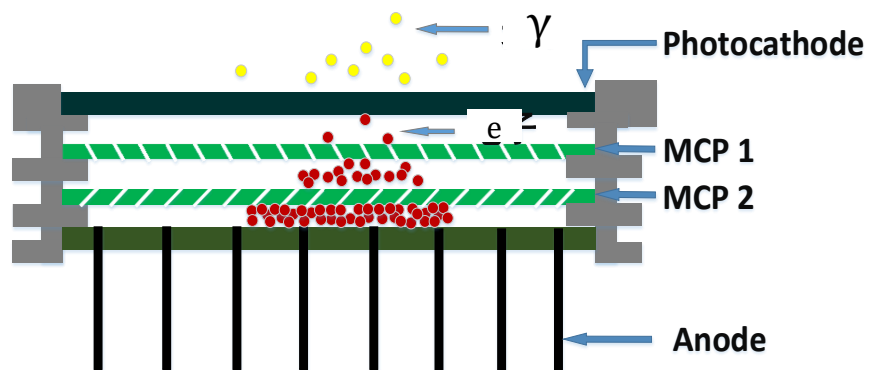
- **Gain > 1E6**
- **TTS < 100 ps** for the moment
- **QE > 20%**
- **Lifetime > 10C/cm²**

Dynode PMT



- Photon → Electron
- Electron multiplication
- Electron cloud extrication

MCP-maPMT



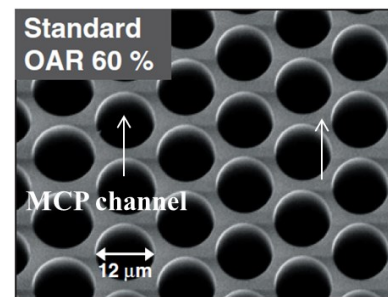
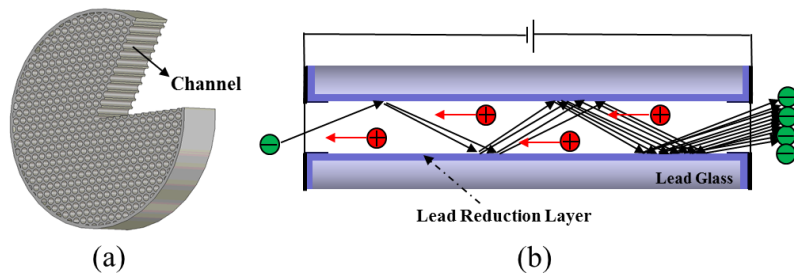
- ◆ Fast time response TTS ~tens ps
- ◆ Stable in strong magnetic field ~T
- ◆ Two dimensional detection ~tens μm
- ◆ Sensitive to X rays γ ray, neutron..

MCP & ALD-MCP



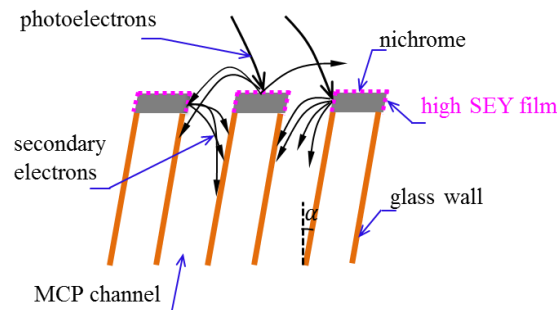
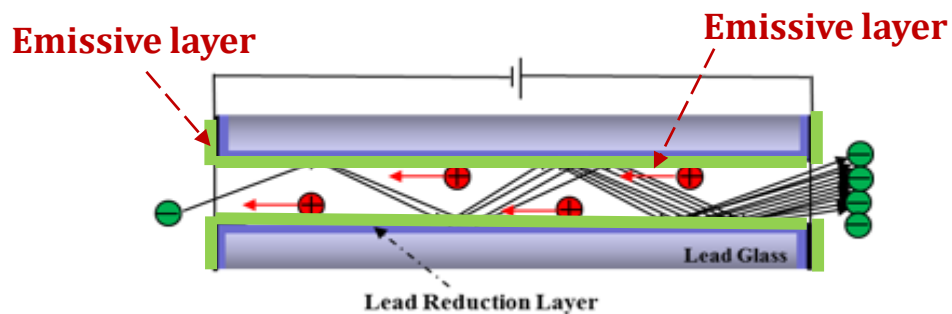
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Conventional MCP

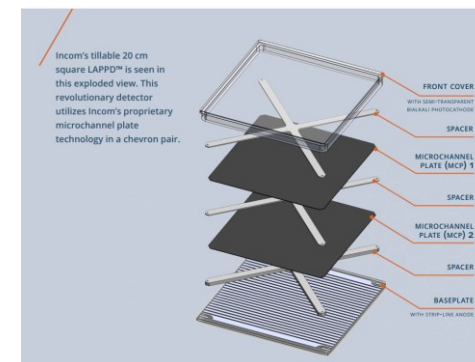


20 inch MCP-PMT for JUNO
CE 100%

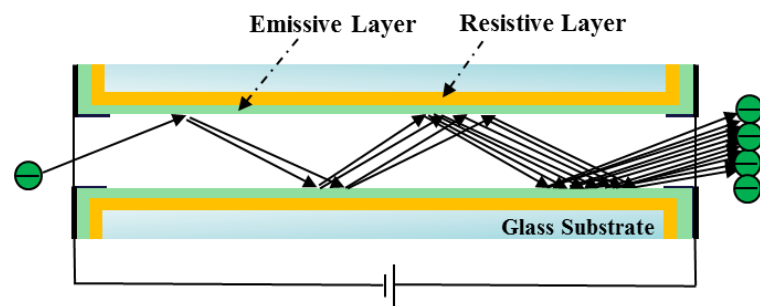
ALD-MCP based on lead glass



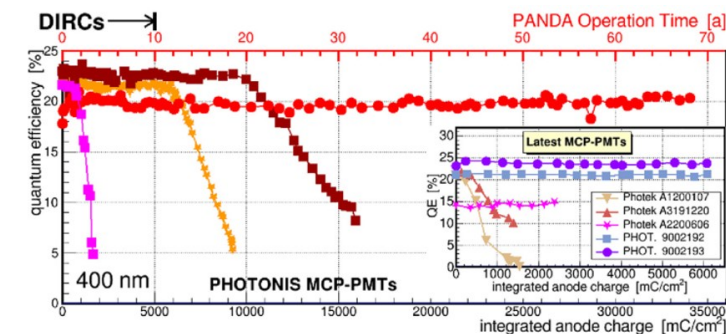
Argonne Incom. LAPPD



ALD-MCP based on lead-free glass



Lifetime extended



XIOPM MCP-PMT



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PD



Fast MCP-PMT



Gated MCP-PMT



Gated MCP-PMT



Large current
MCP-PMT



Large current
MCP-PMT

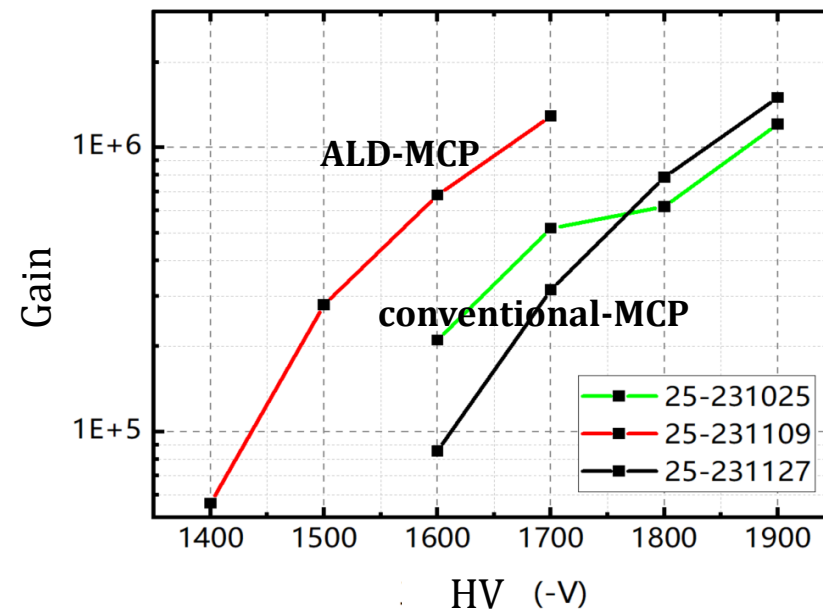
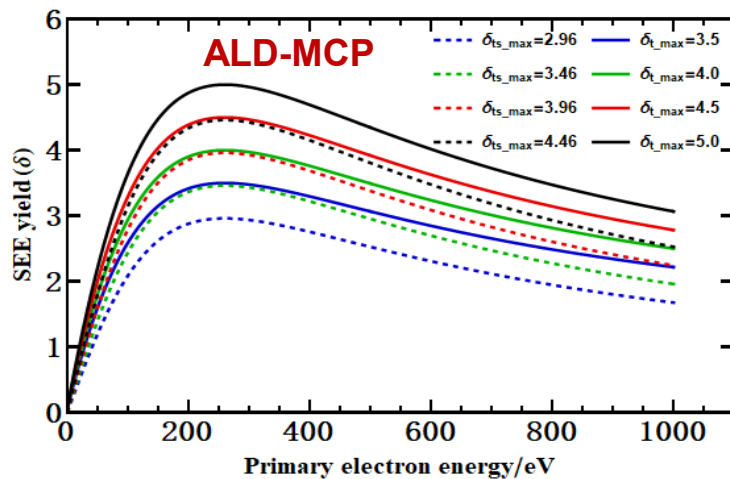
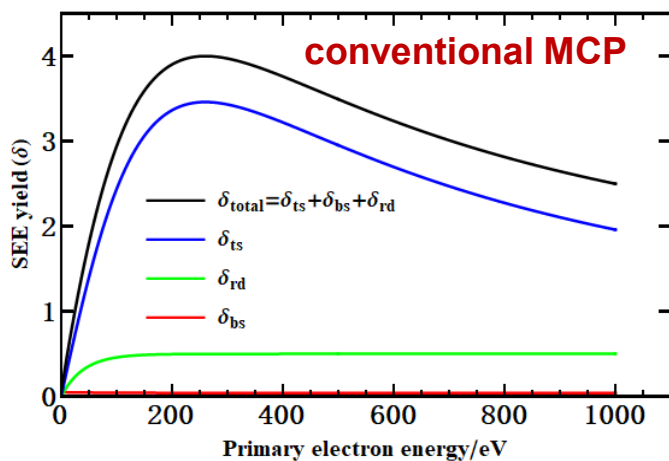


2 inch

$$\text{Gain} = \delta^n$$

- δ : secondary emission coefficient
 - MCP secondary emission layer
 - PC-MCP potential \rightarrow first hit energy
 - MCP voltage \rightarrow subsequent hit energy
- n : number of hits
 - MCP L/D
 - MCP voltage

High gain with lower HV for ALD-MCP but larger nonlinear deviation



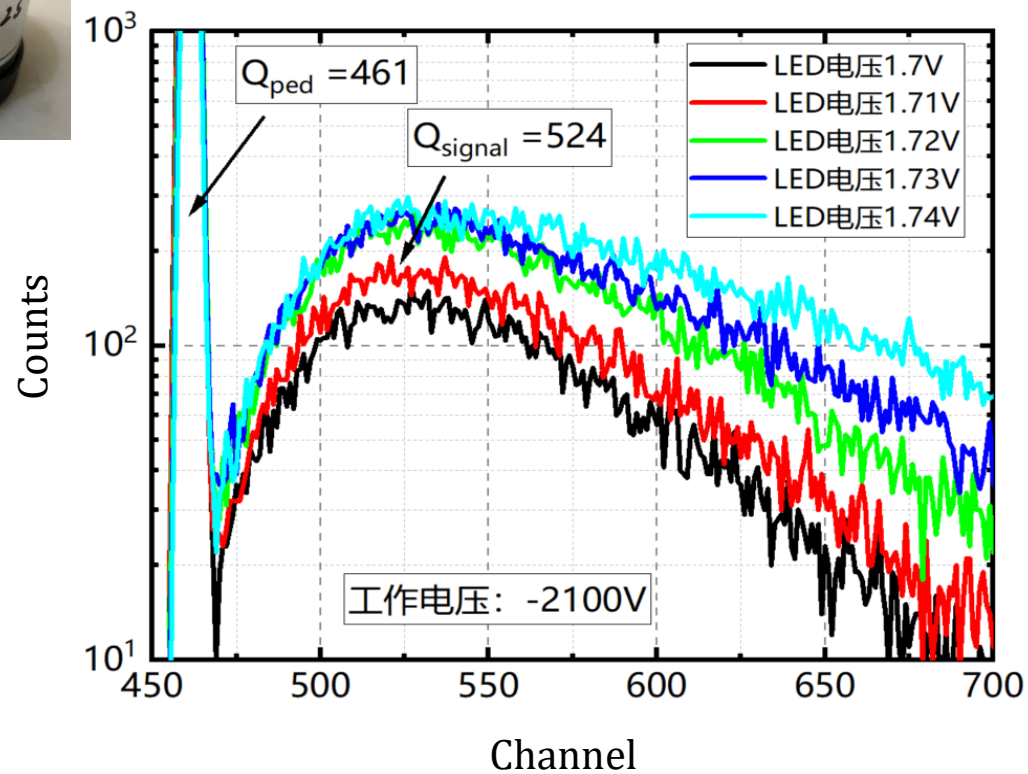
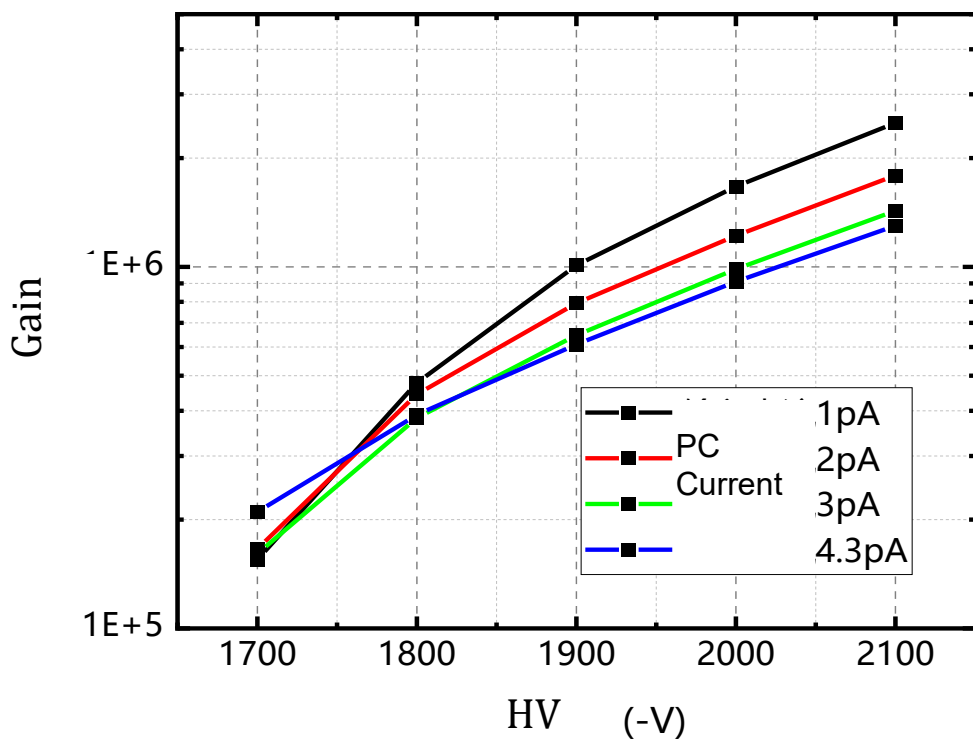
Gain



- Current gain
 < 3E6 @ 2100V



- Photon counting gain
 1E7 @ 2100V



$$G = (Q_{signal} - Q_{ped}) \times LSB / 1.6 \times 10^{-19}$$

Gain linearity



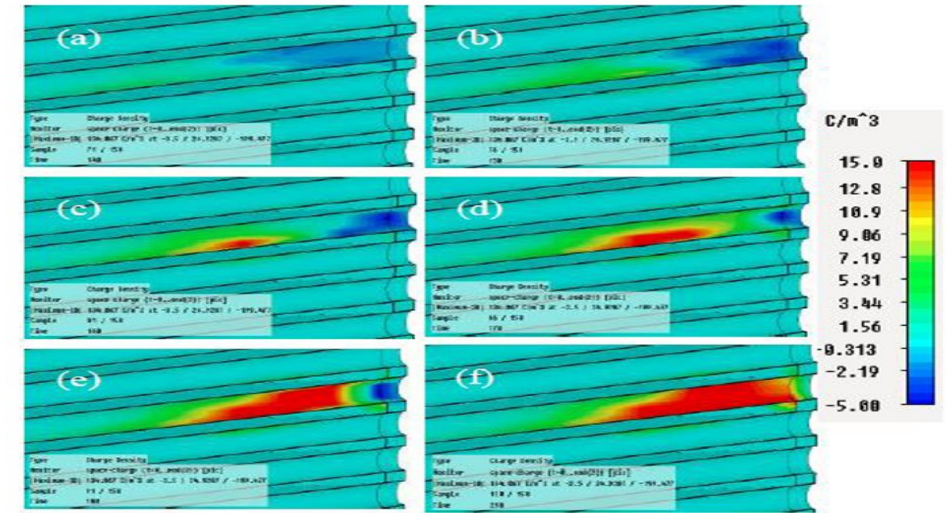
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- Space charge effect
- long recharge time leads to Positive charge accumulation

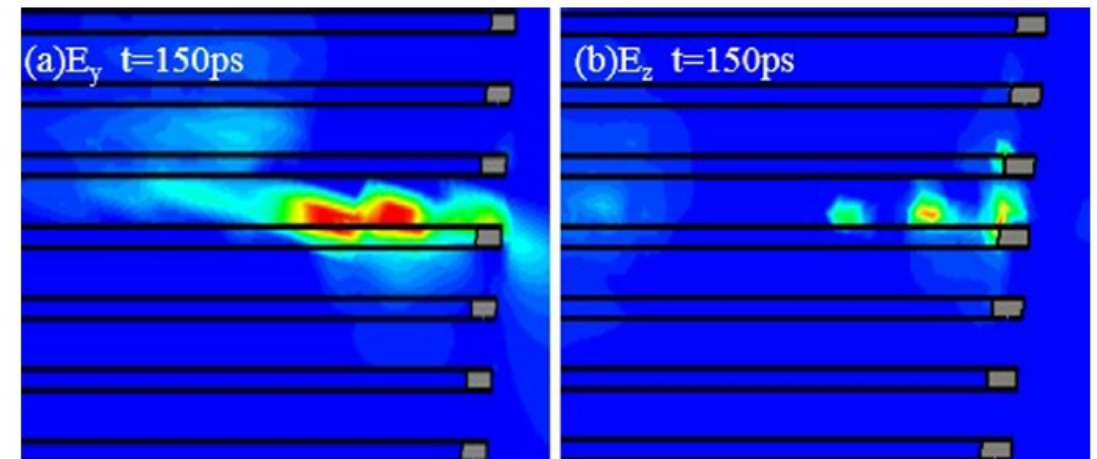
Review of Scientific Instruments **87**, 073303 (2016)



Evolution of space charge 3D distribution



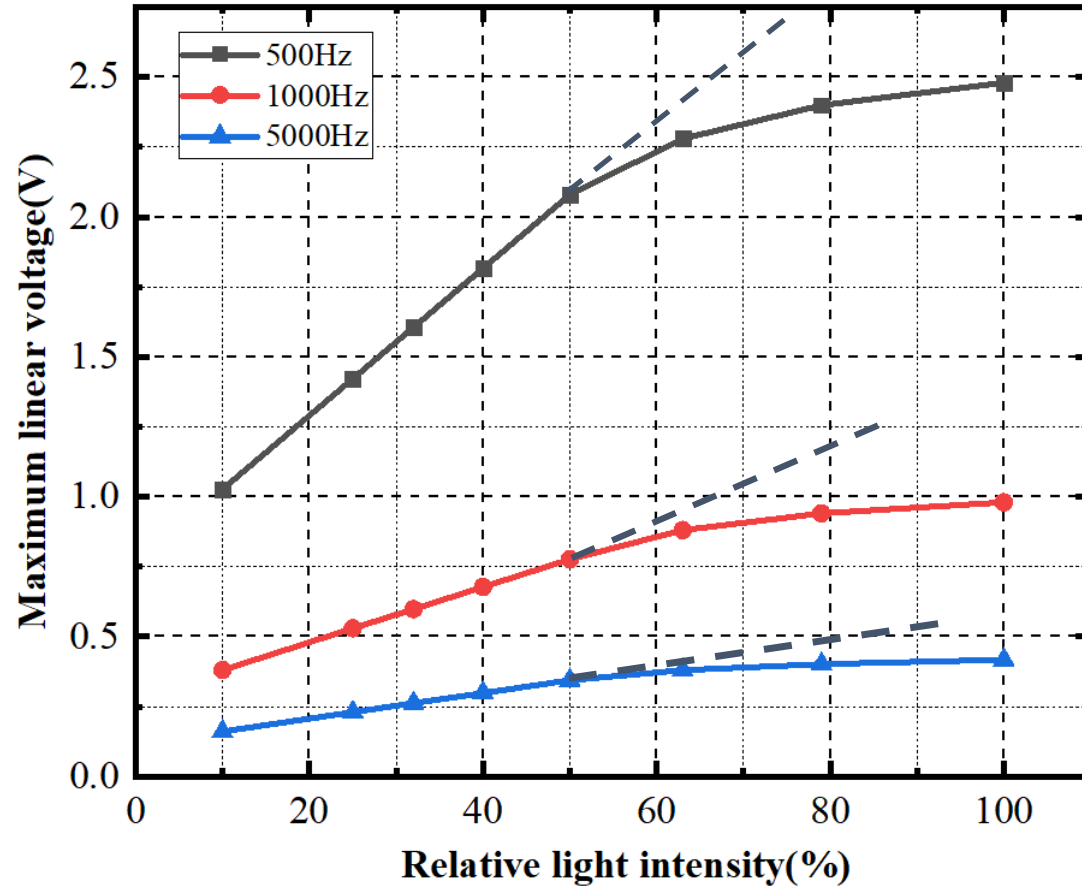
Self-consistence electric field distribution



Output linearity



Light pulse FWHM 300ns



Photon counting mode

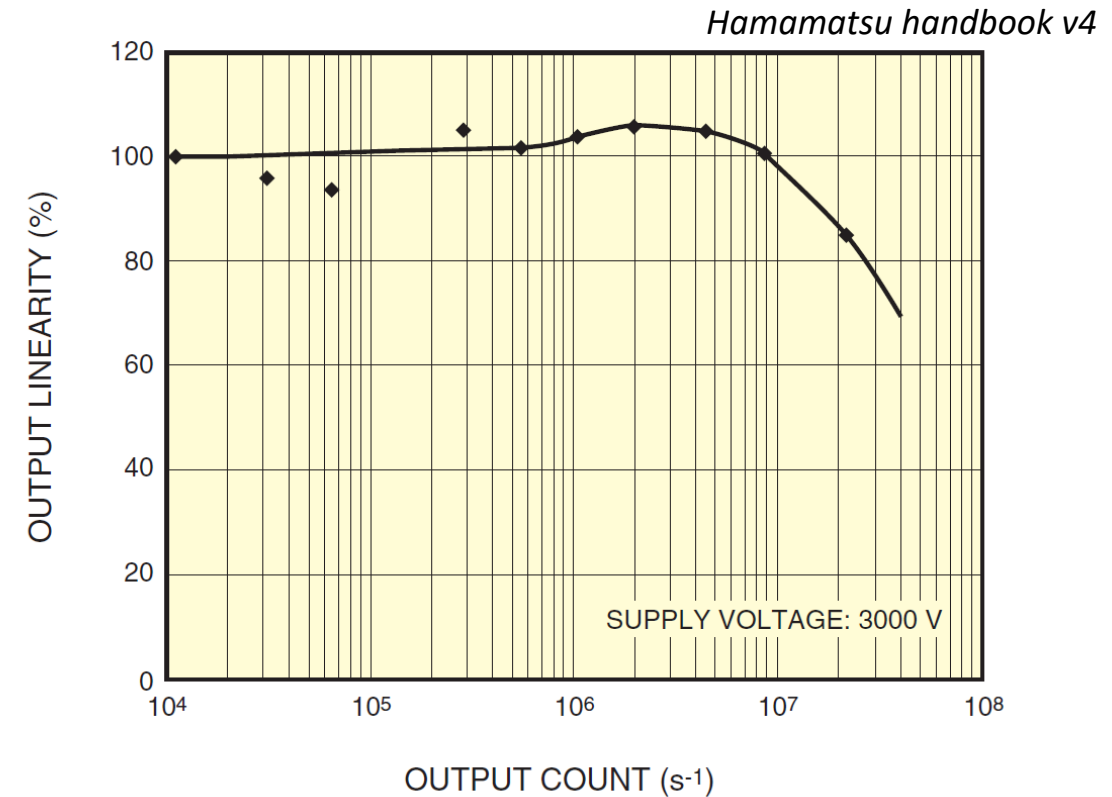


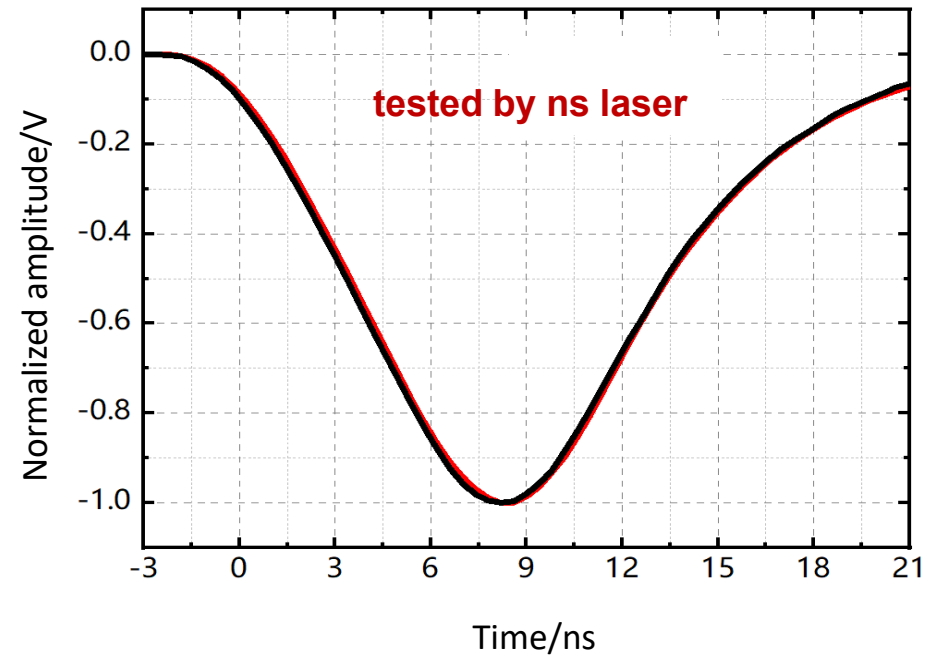
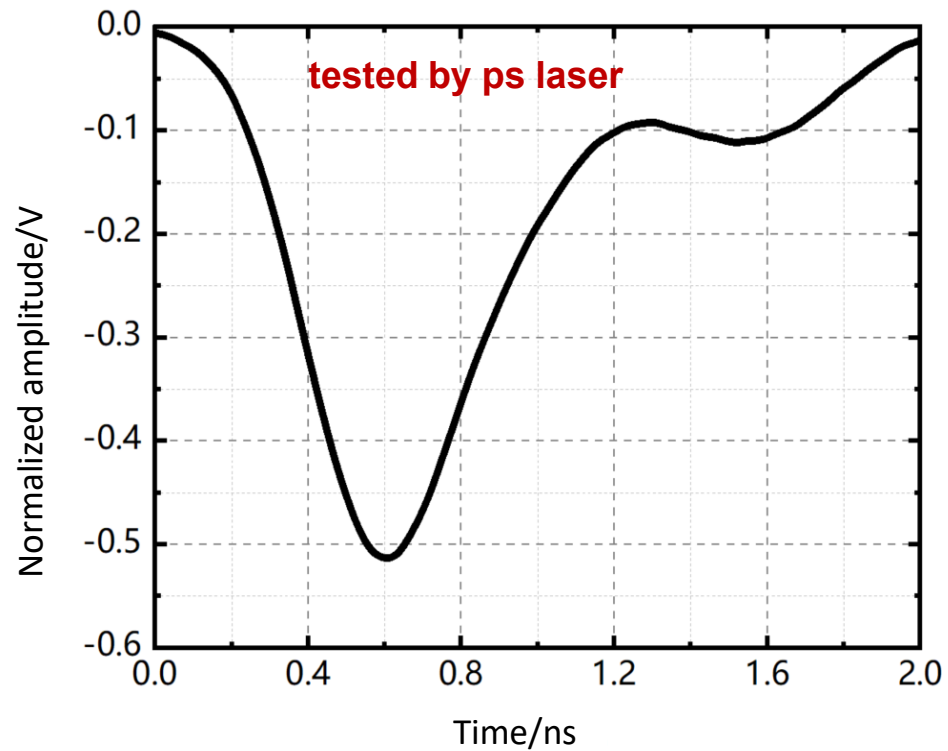
Figure 11-14: Count-rate linearity of an MCP-PMT (11 mm effective diameter, 6 mm channel diameter) in photon counting mode

TH

Time characteristics

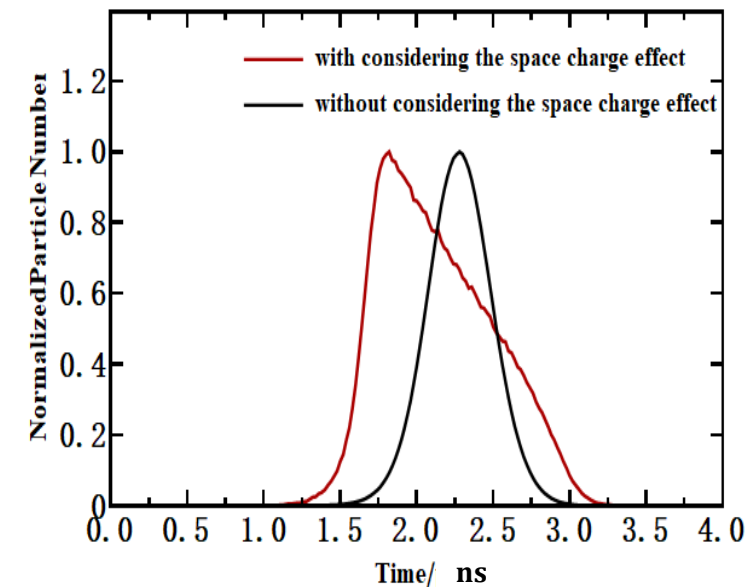
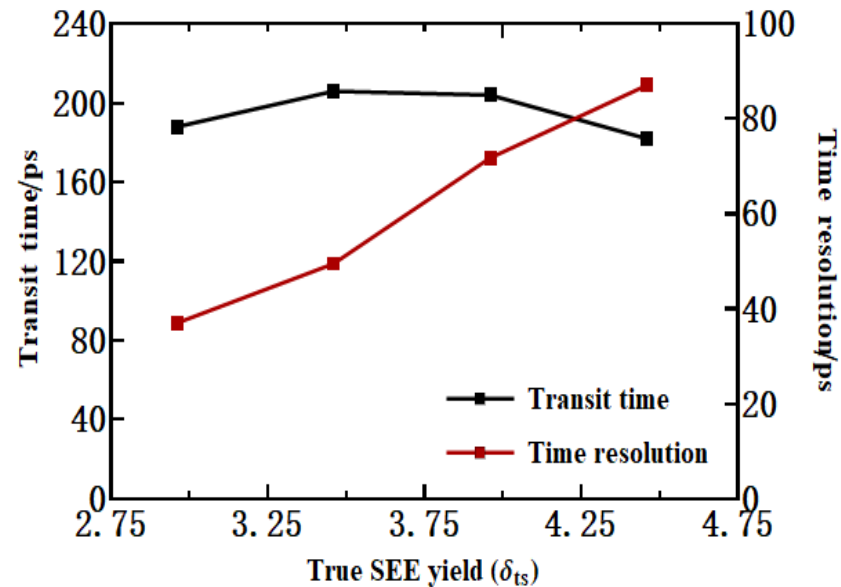
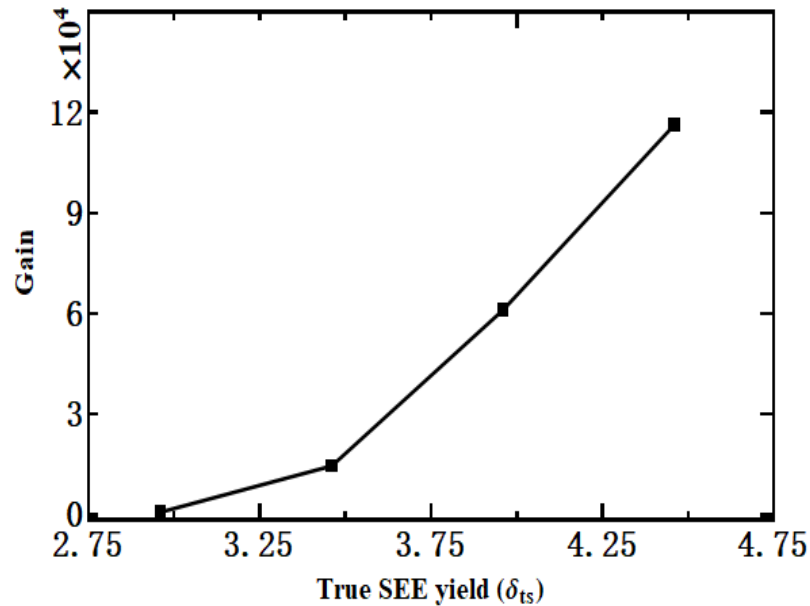


● Waveform



$$\sigma_{tts} = \sqrt{\sigma_0^2 + \sigma_{pc-mcp}^2 + 2\sigma_{mcp}^2 + \sigma_{mcp-anode}^2}$$

● TTS vs. MCP SEE simulations

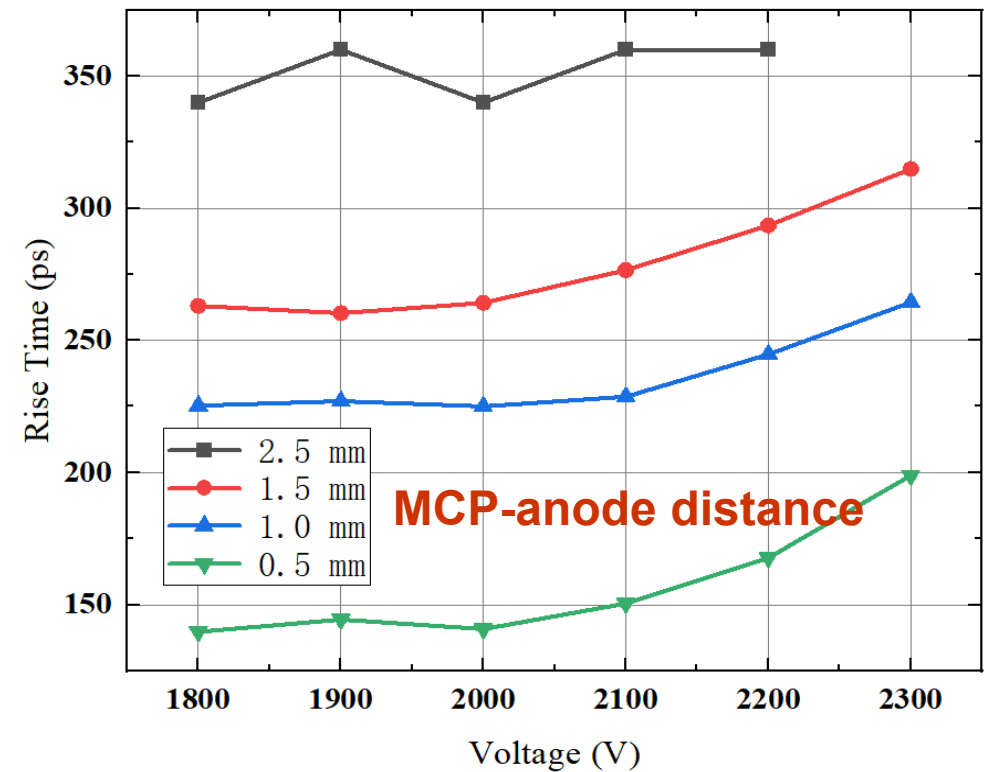
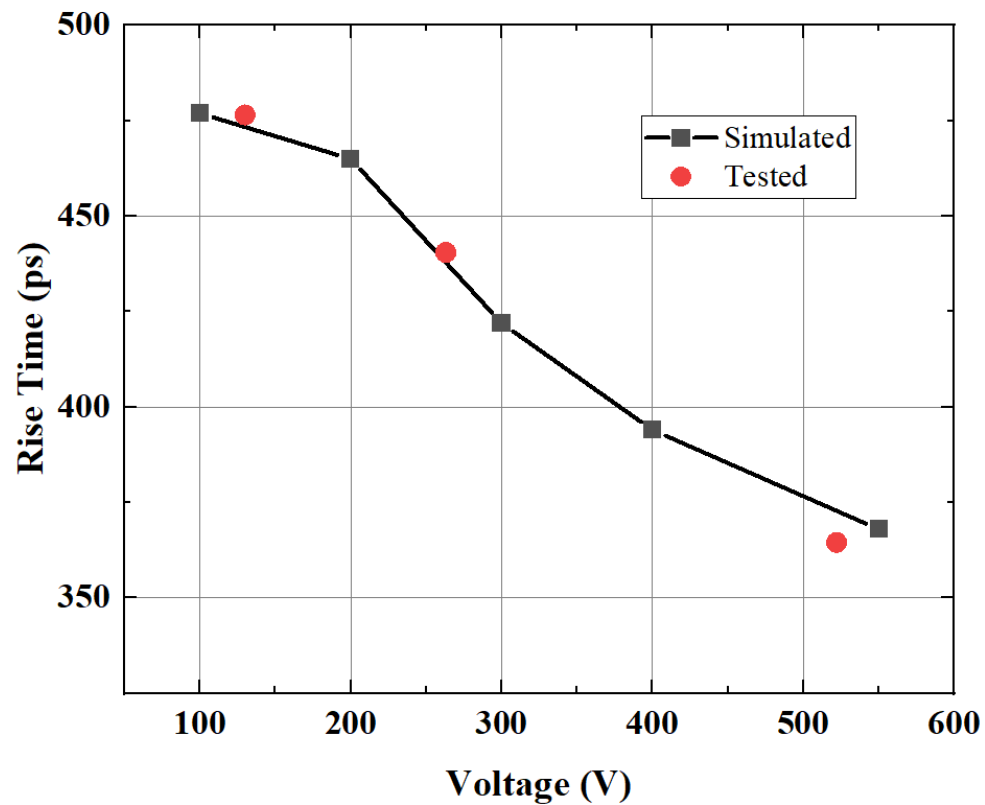


Nuclear Inst. and Methods in Physics Research, A 1005 (2021) 165369

Time characteristics



● Rise time

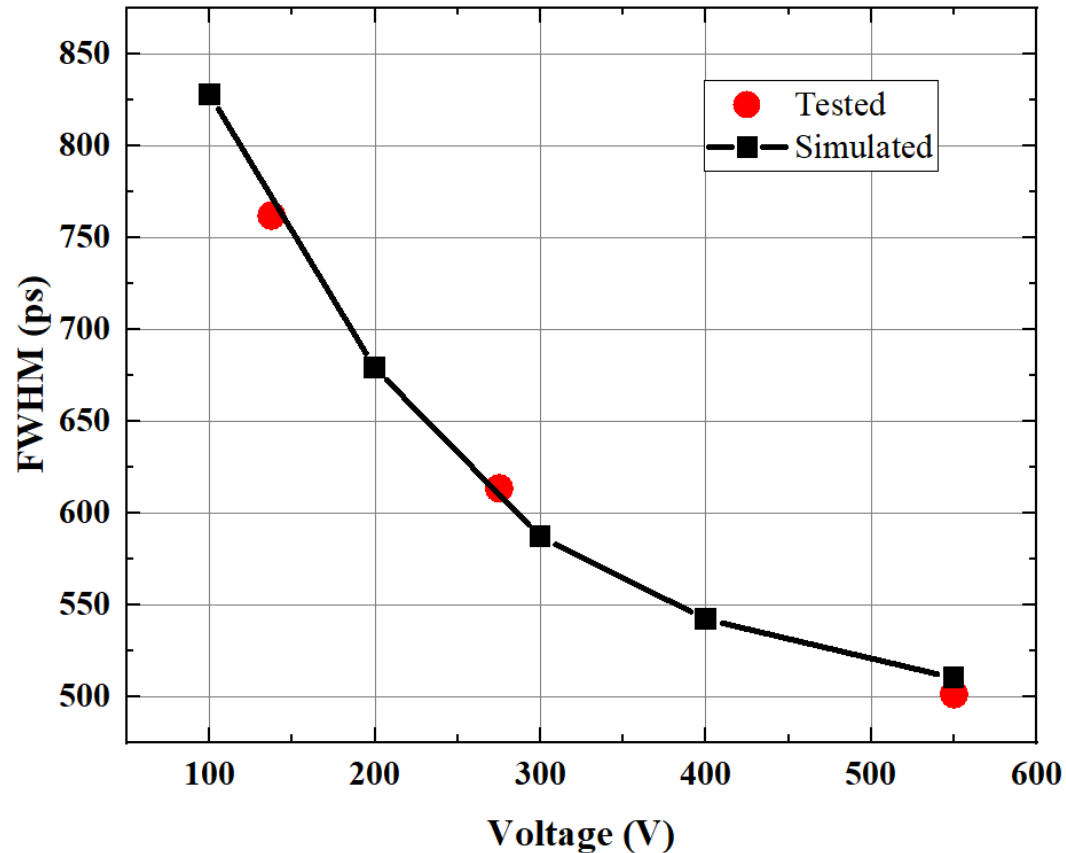


HV between PC and MCP

Time characteristics

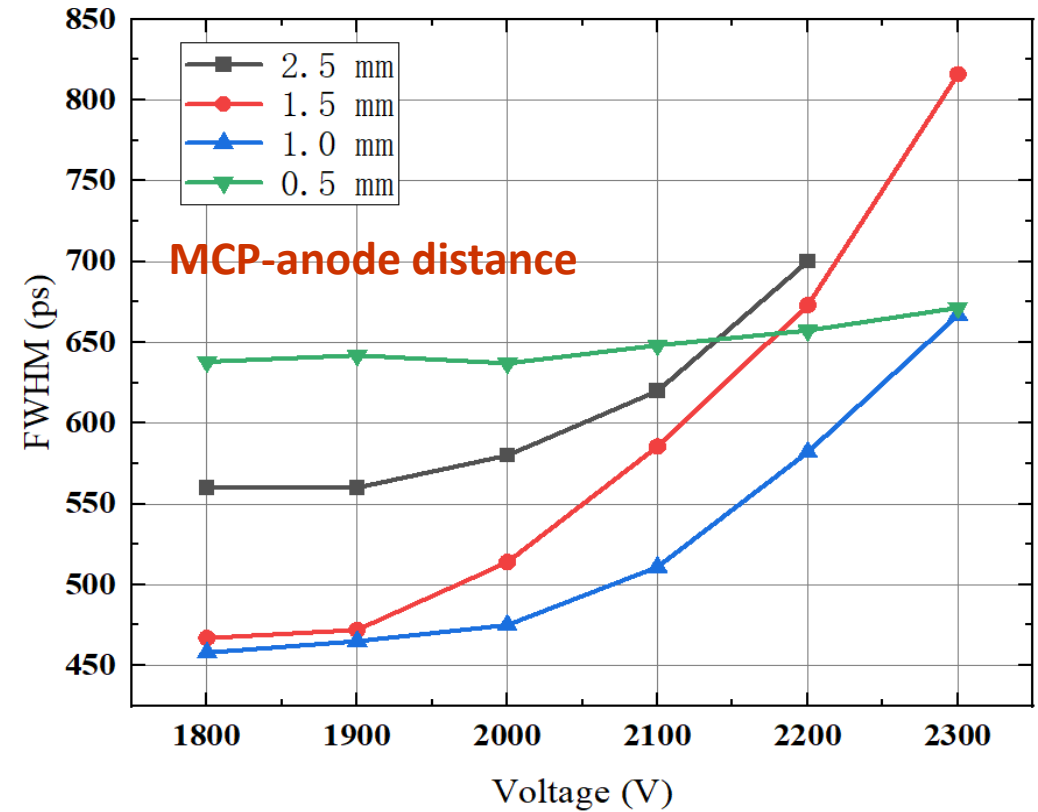


● Pulse FWHM

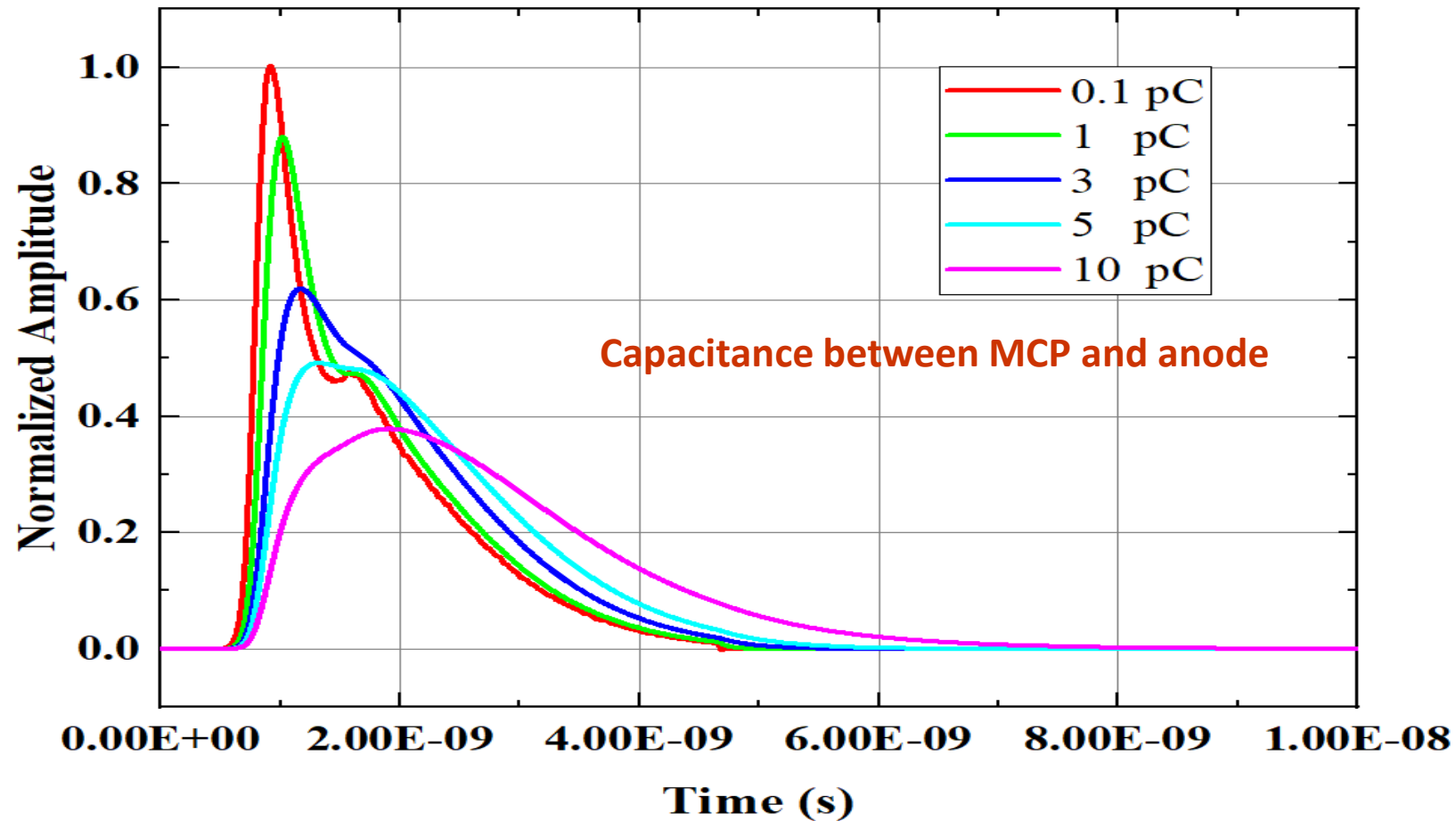


HV between PC and MCP

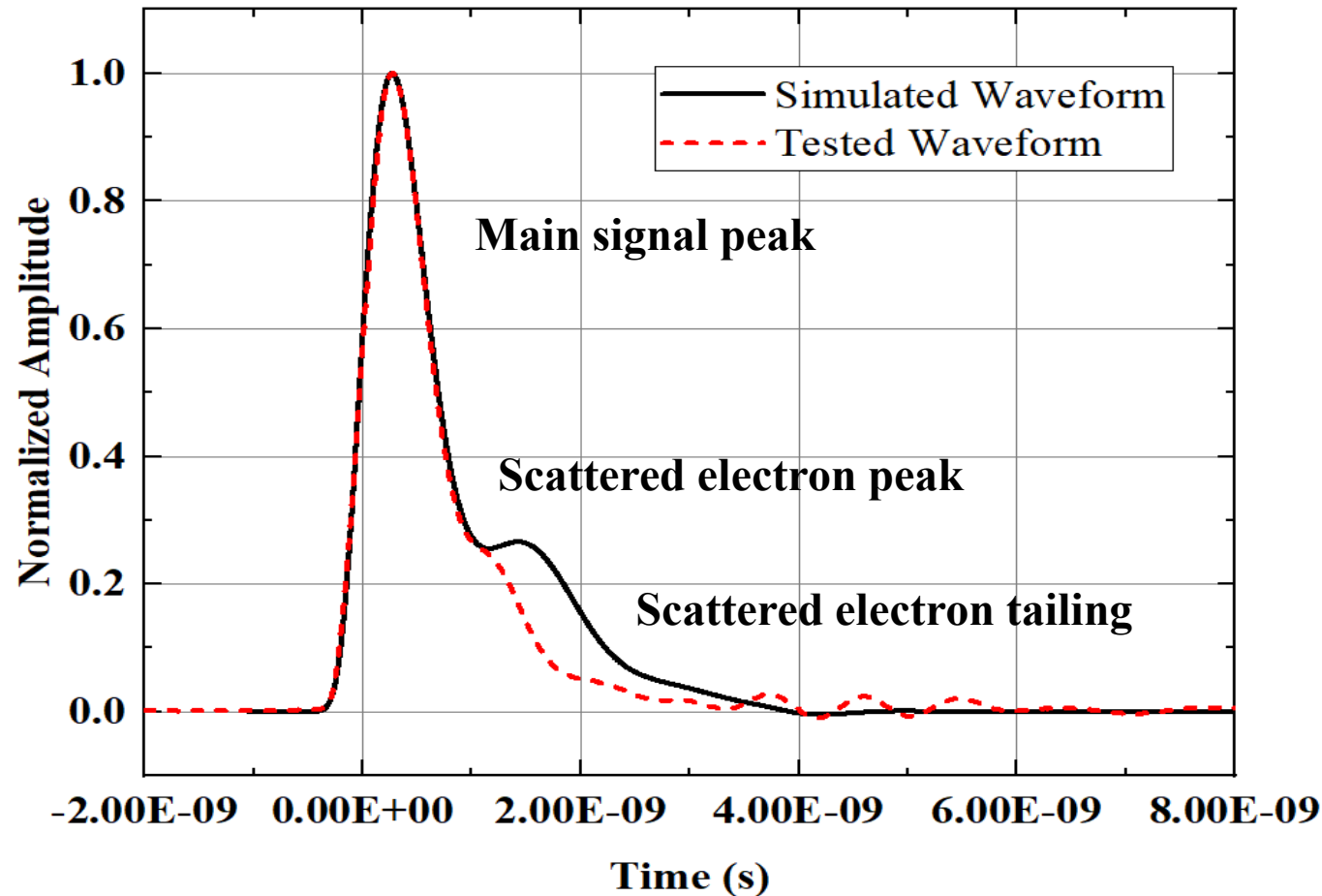
- Electron transmission
- Capacitance
- Secondary electron emission from anode
- Backscattered electrons from the 1st MCP



- **Waveform simulation vs the capacitance between MCP and anode**

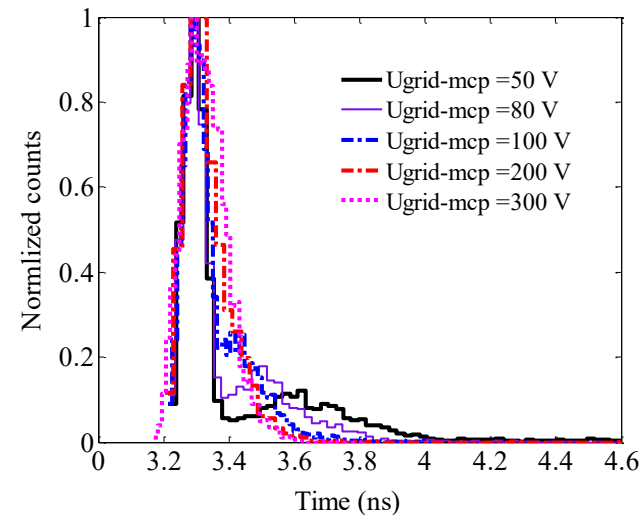
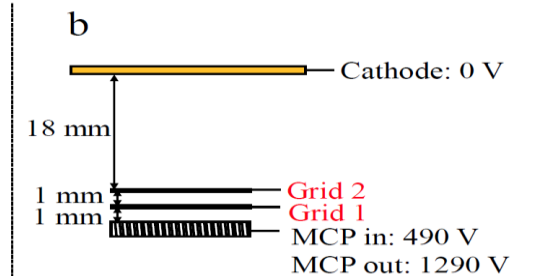
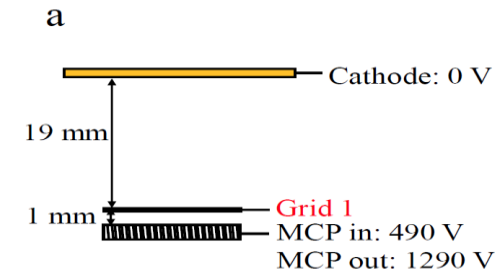
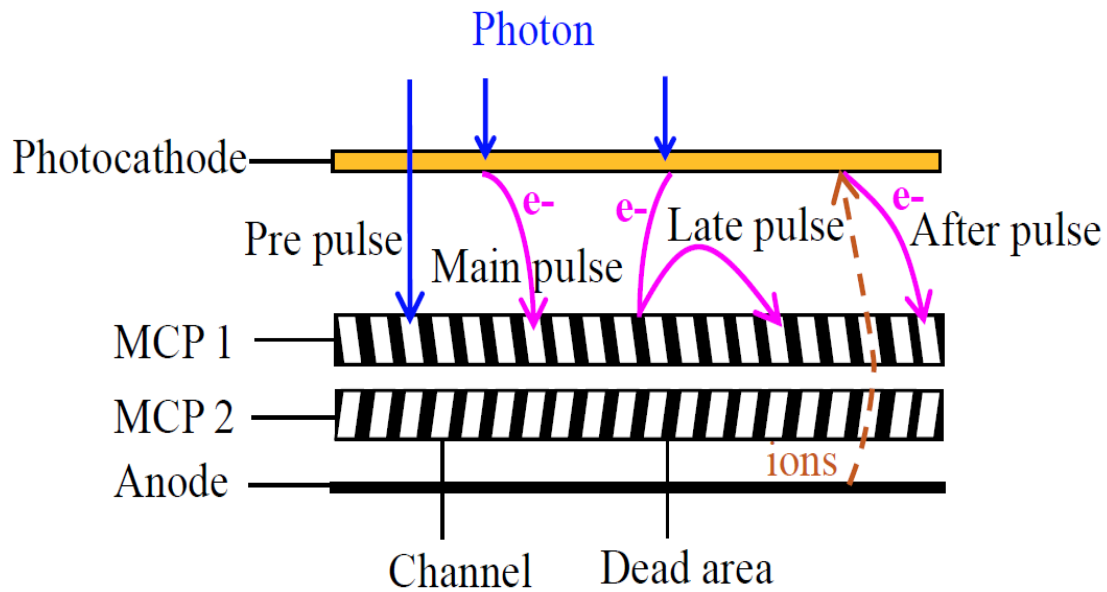


- **Waveform with considering the secondary emission of anode**

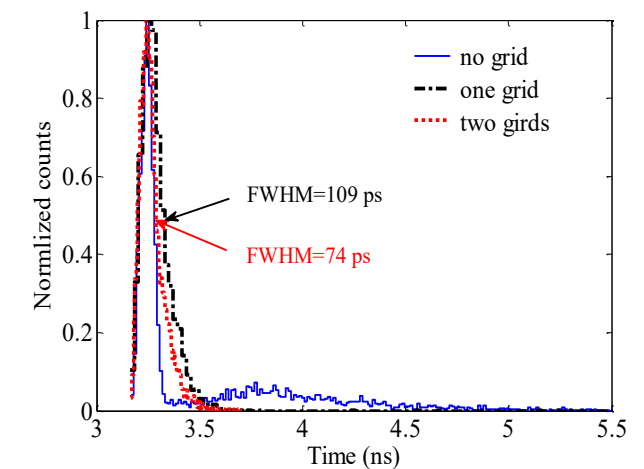


Timing distribution simulation with considering the secondary emission of 1st MCP

Physical processes that lead to an output pulse of the MCP-PMT



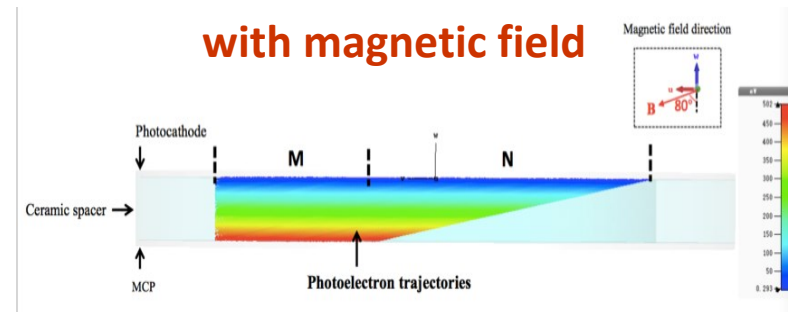
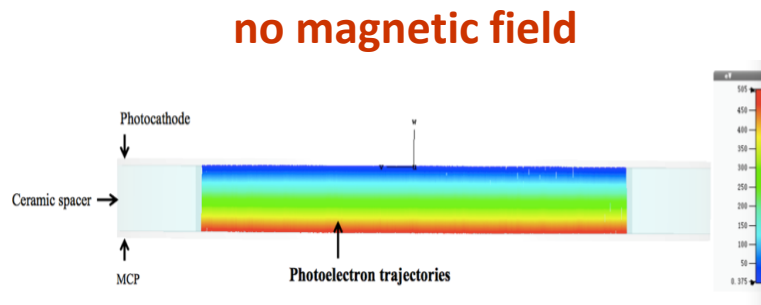
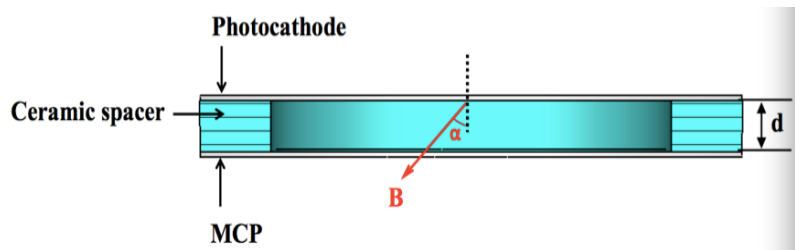
NIM A 2017, 912: 112-114.



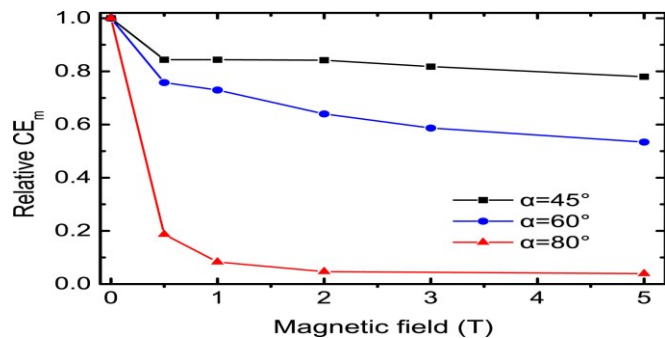
Magnetic characteristics



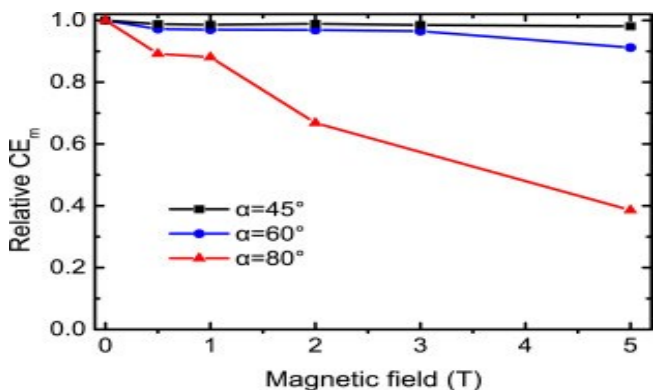
Collection efficiency



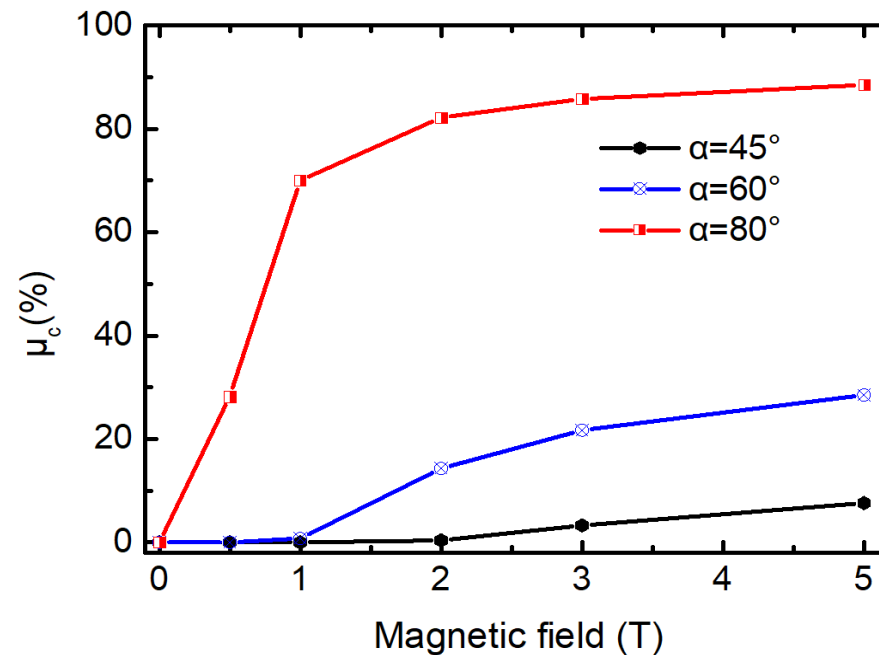
NIM A 2019, 936: 580-582.



d=2mm
U=500V



d=0.3mm
U=300V

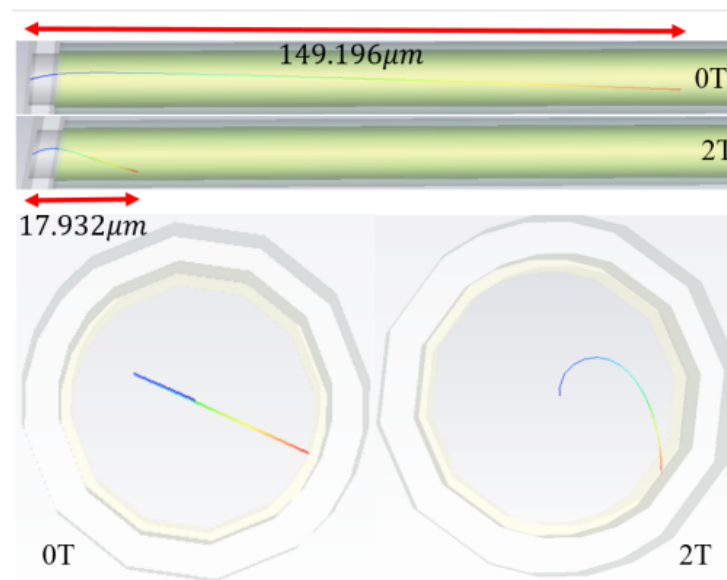
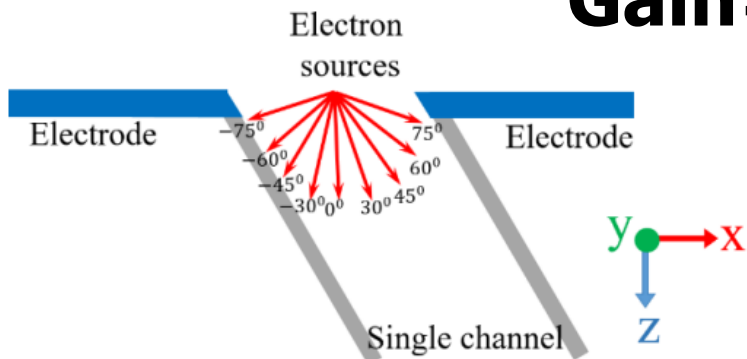


Magnetic characteristics

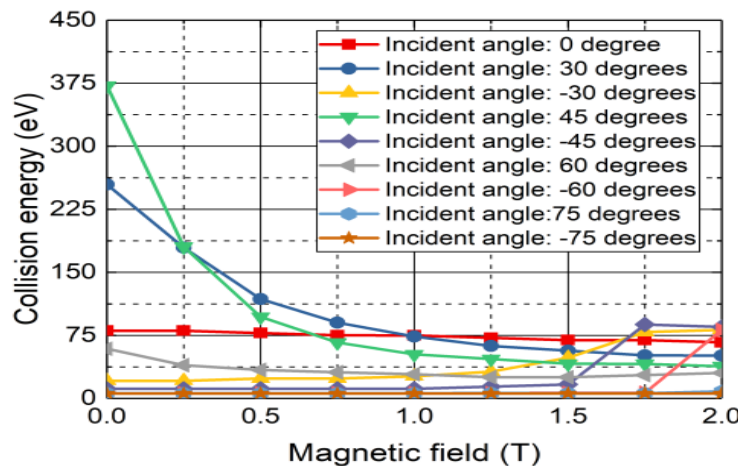
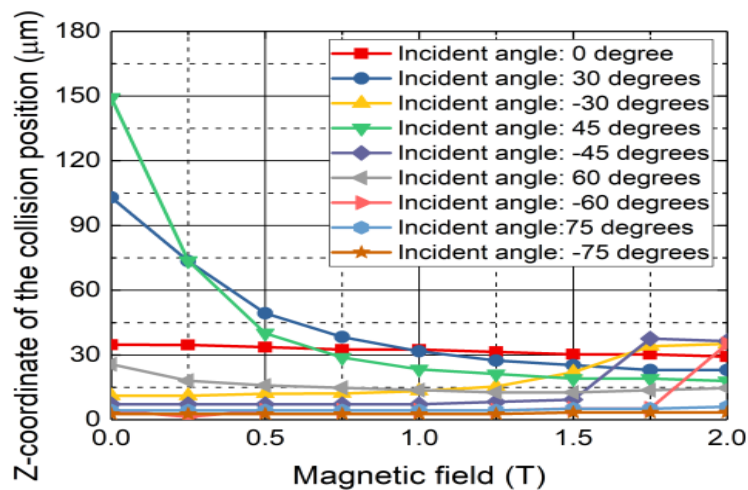


● Electrons trajectory in MCP

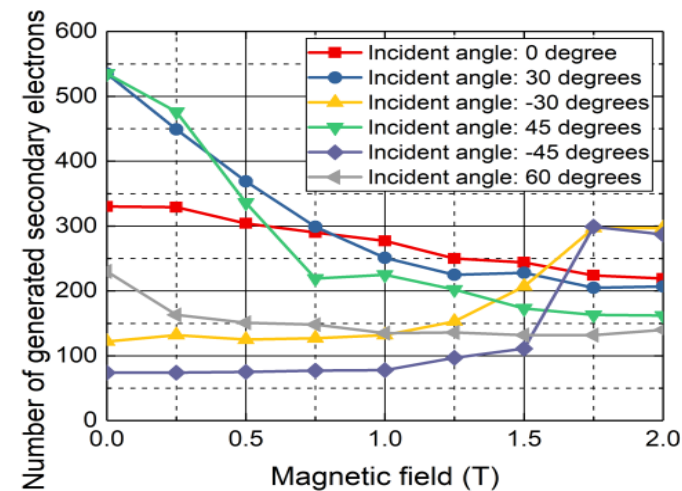
$$\text{Gain} = \delta^n$$



2020 JINST 15 C03048



(b)

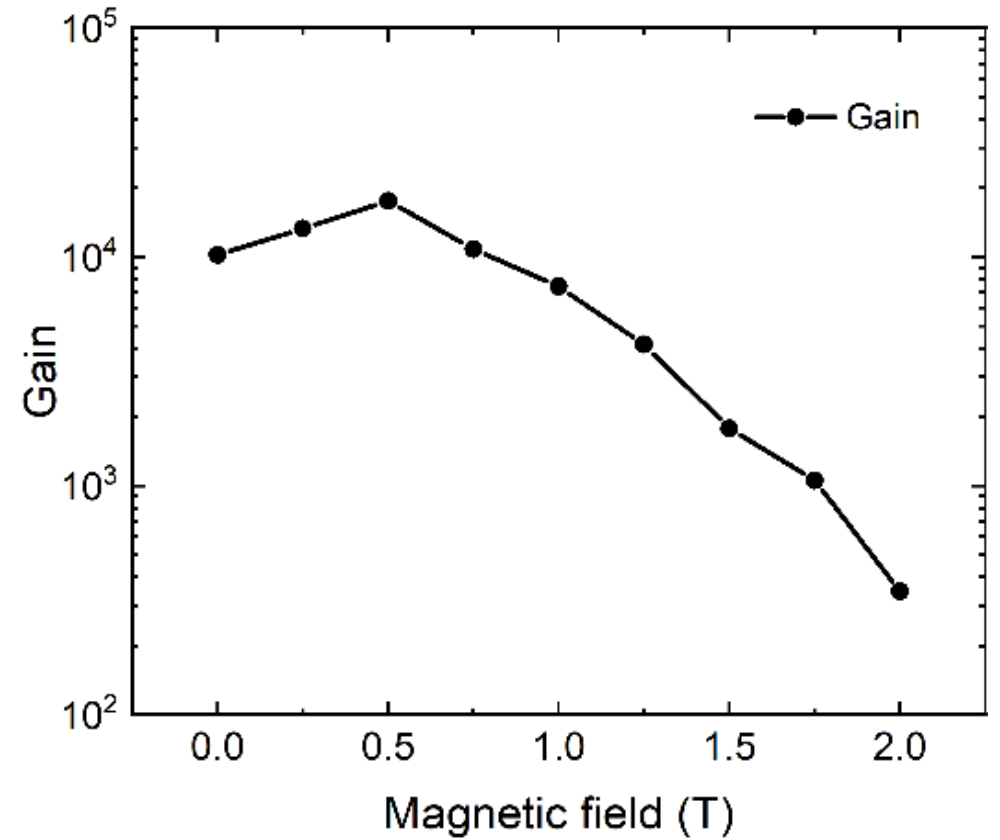
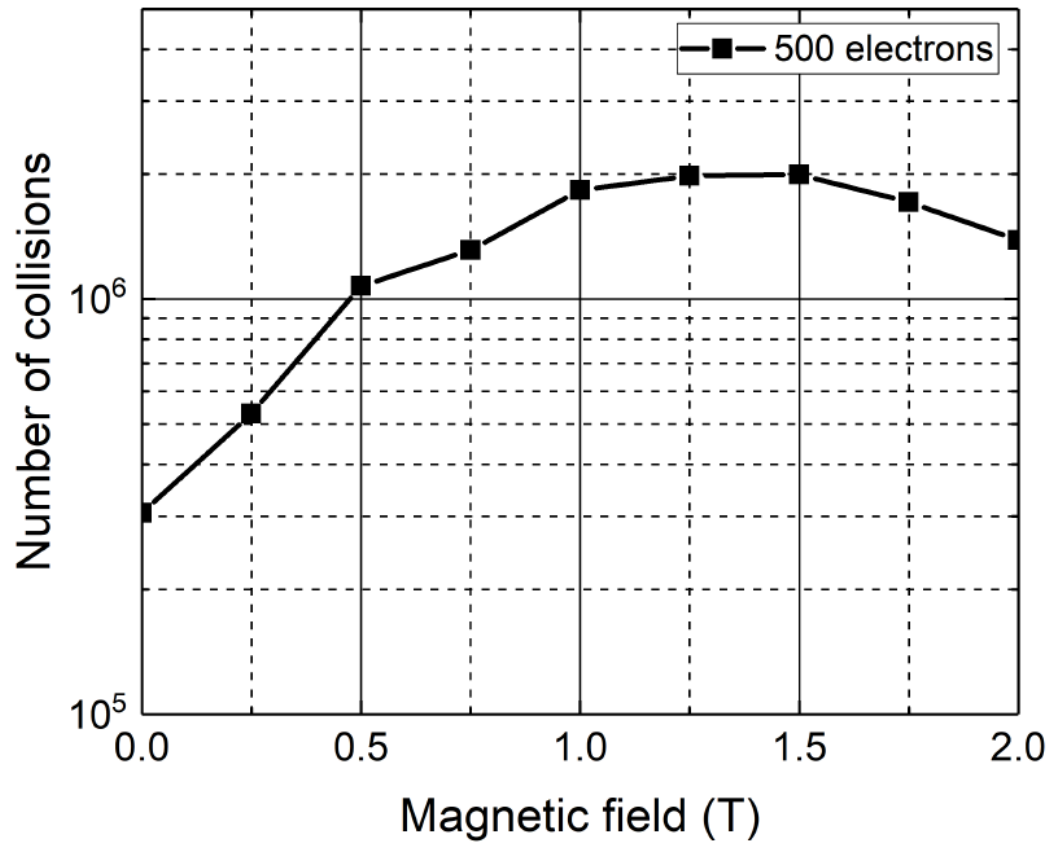


Magnetic characteristics



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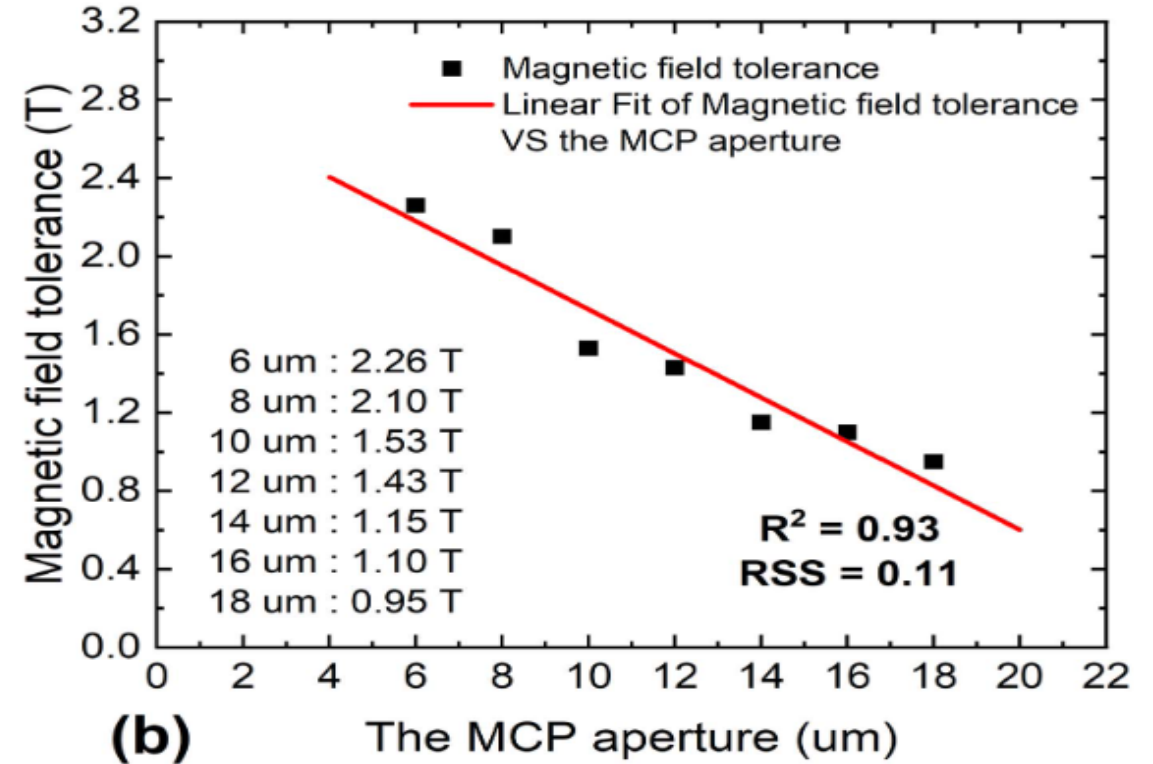
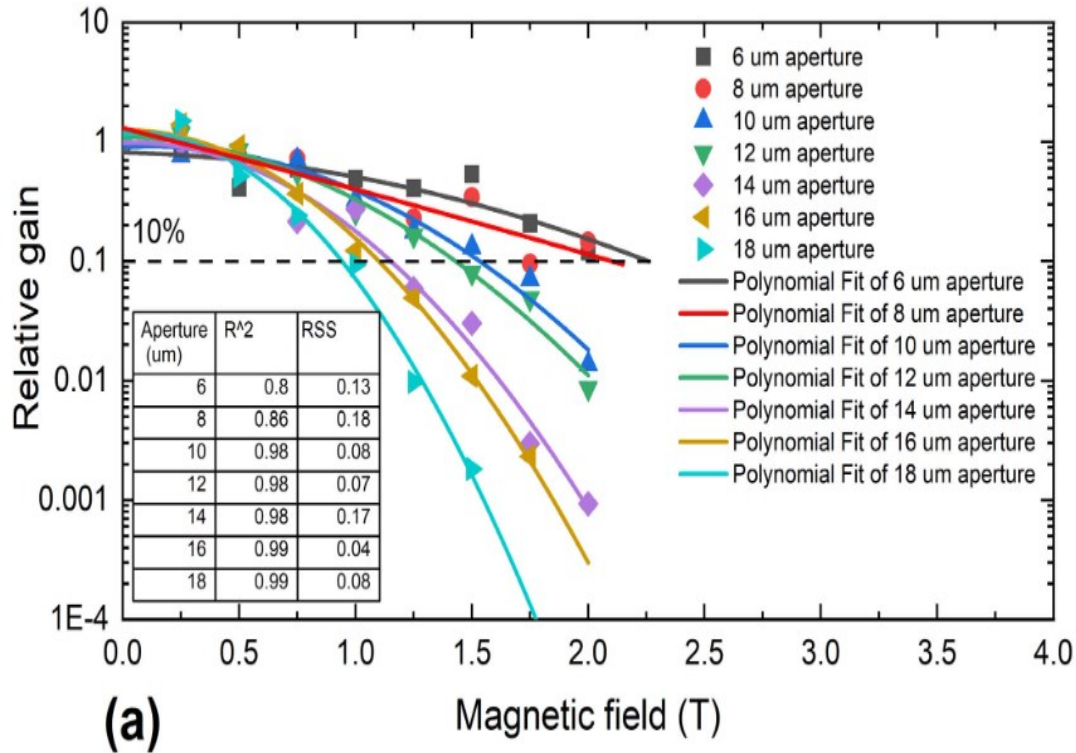
- Gain



Magnetic characteristics



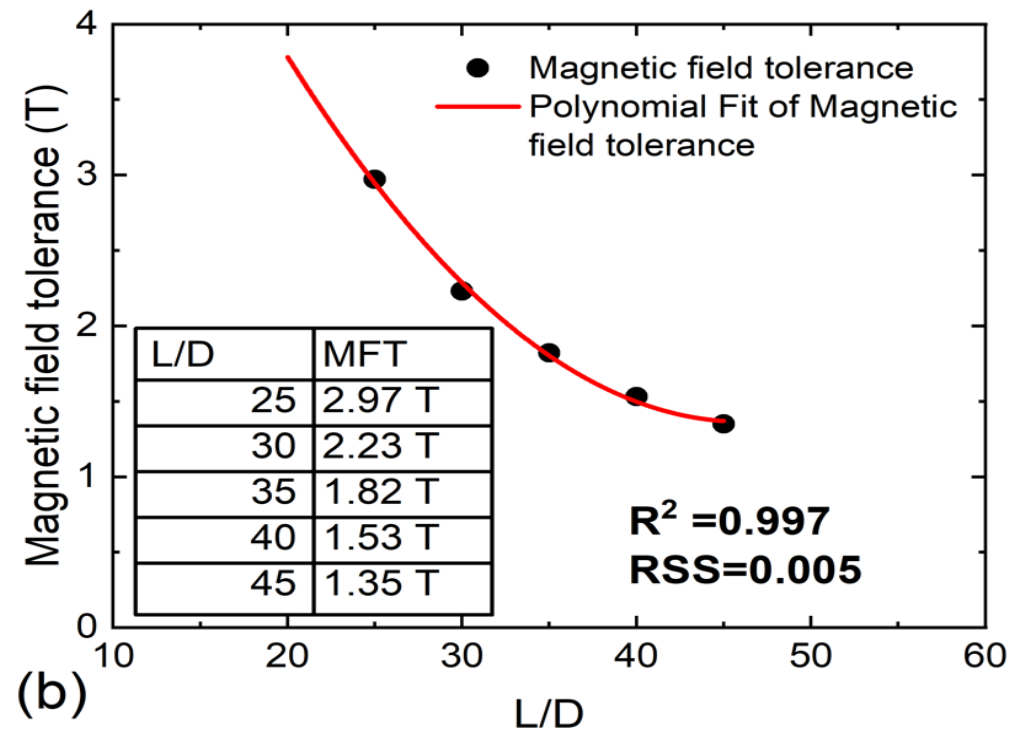
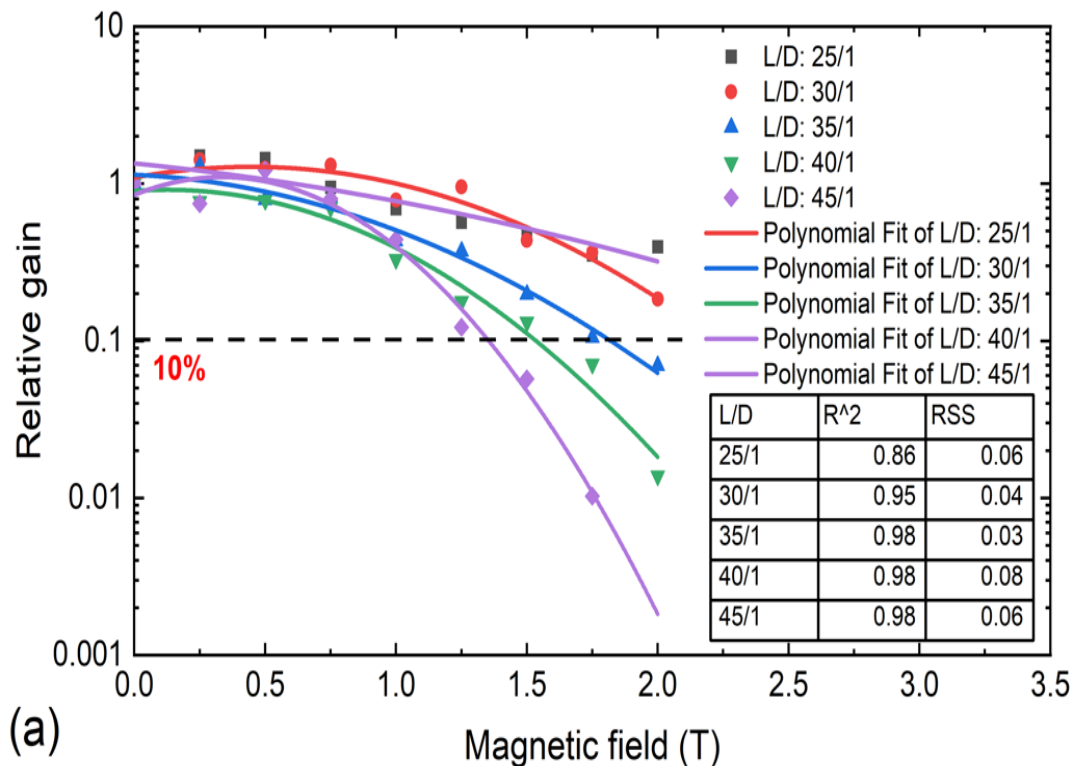
Gain vs. MCP aperture



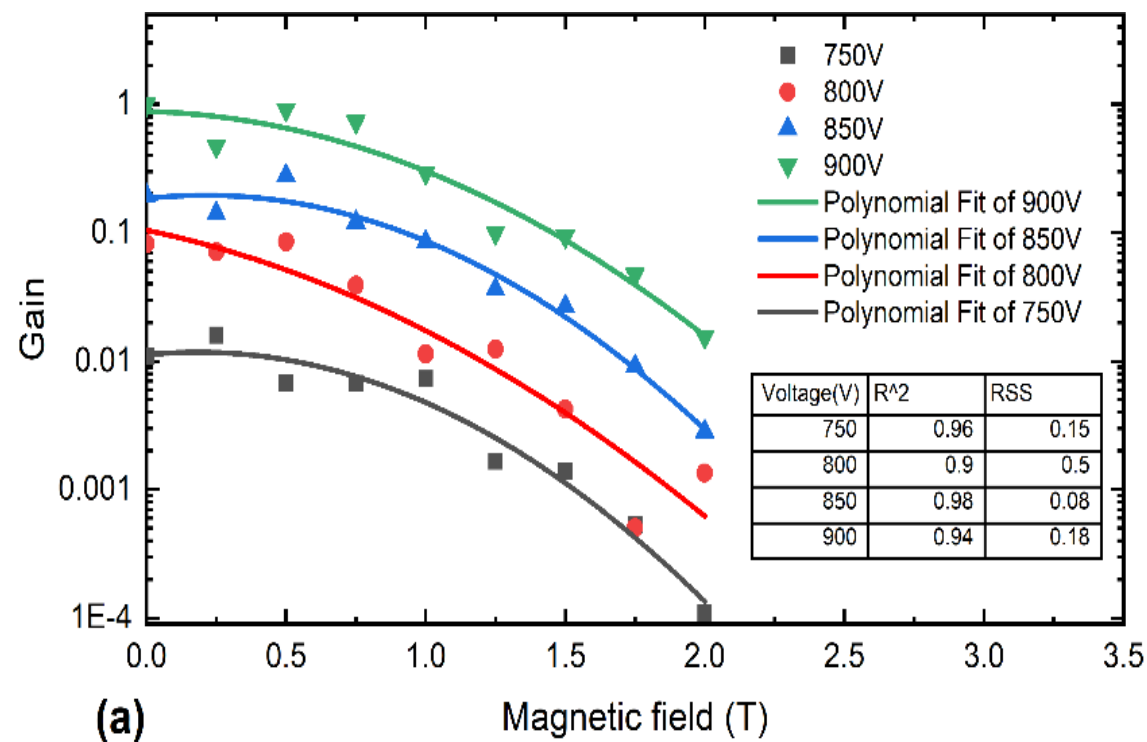
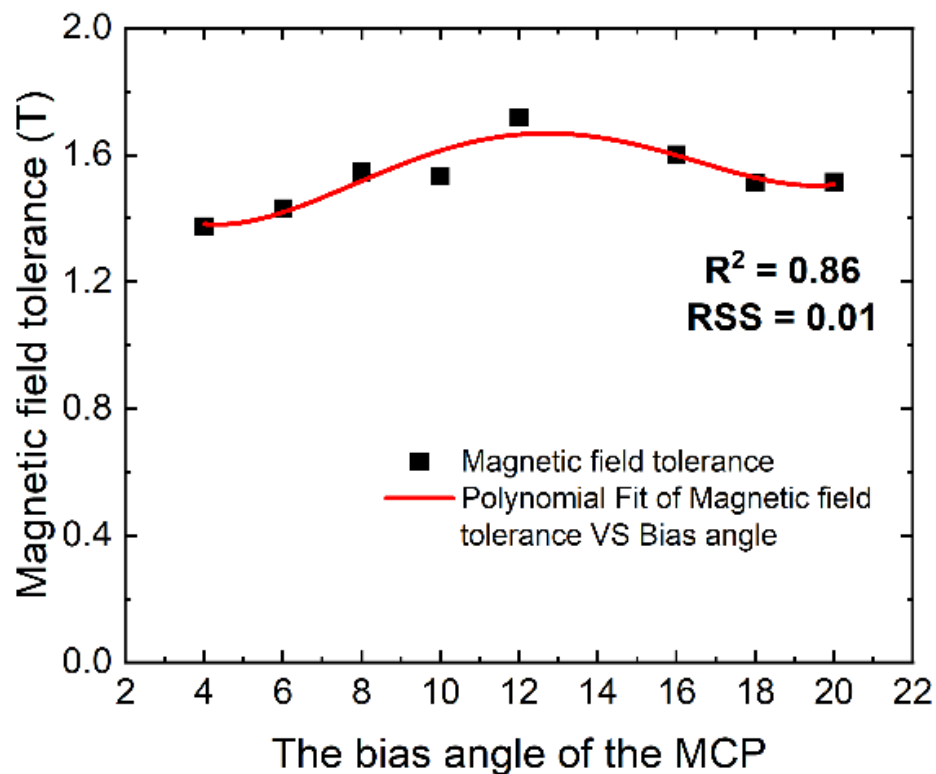
Magnetic characteristics



Gain vs. MCP L/D



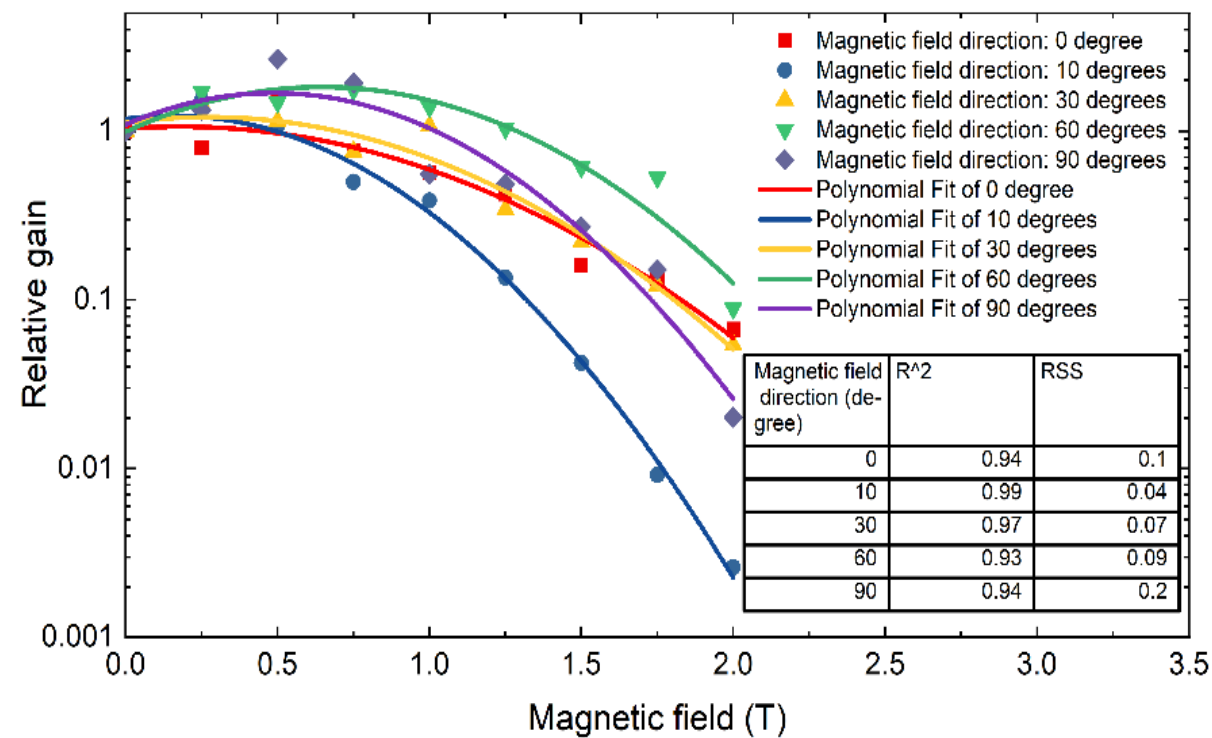
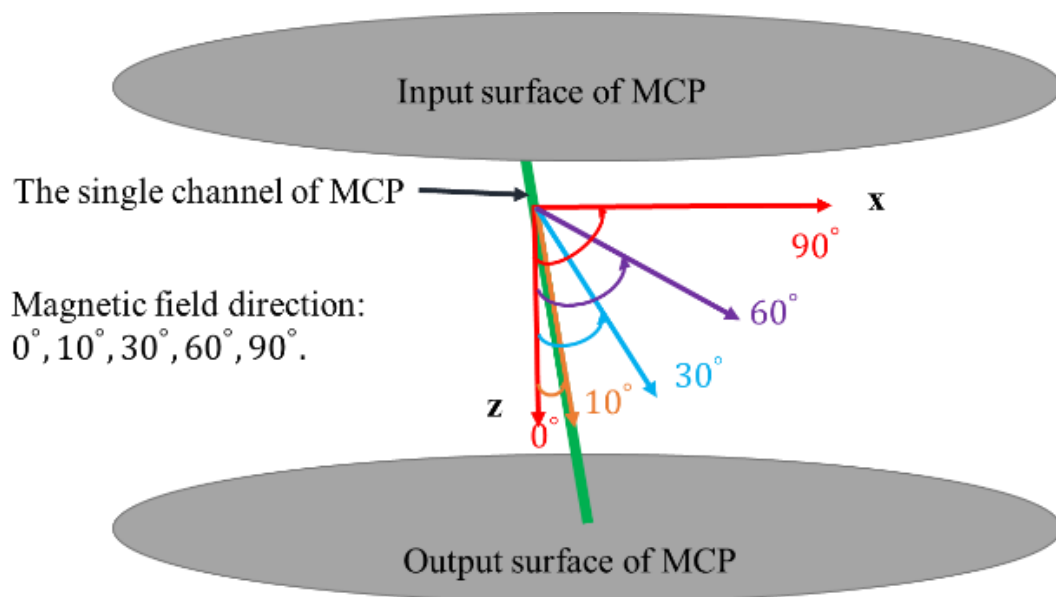
- Gain vs. MCP bias angle/HV



Magnetic characteristics



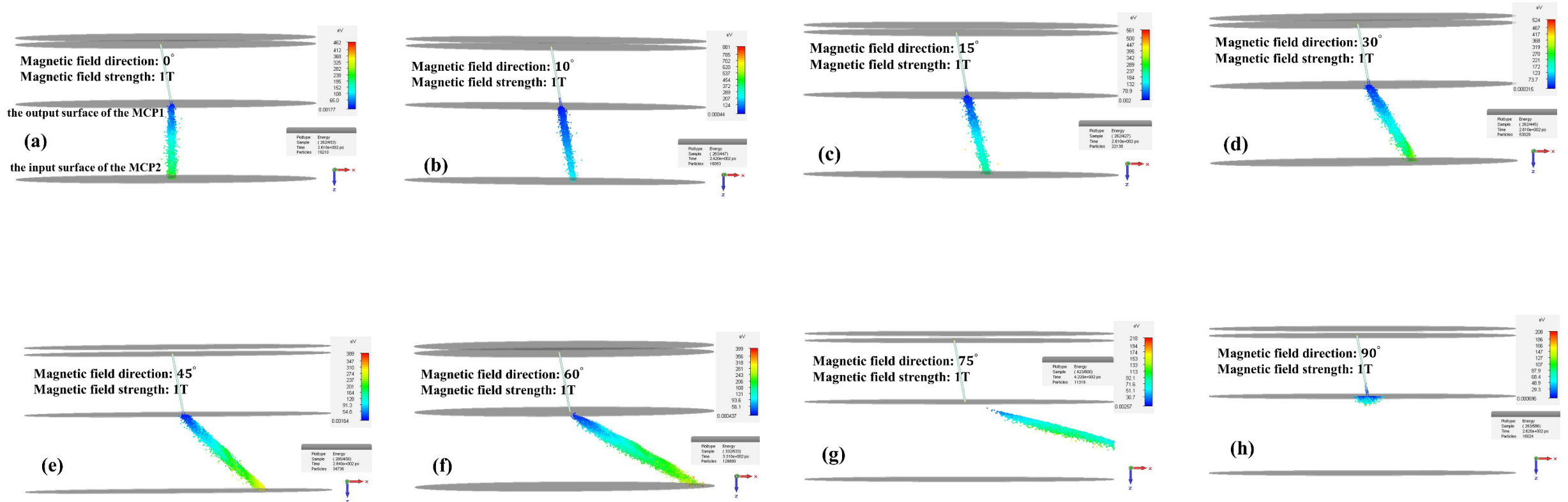
Gain vs. magnetic field direction



Magnetic characteristics



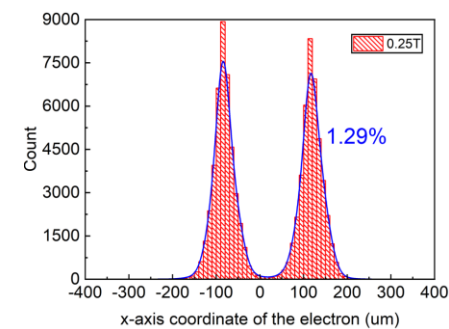
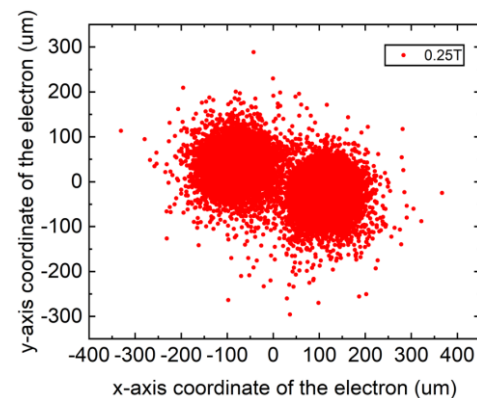
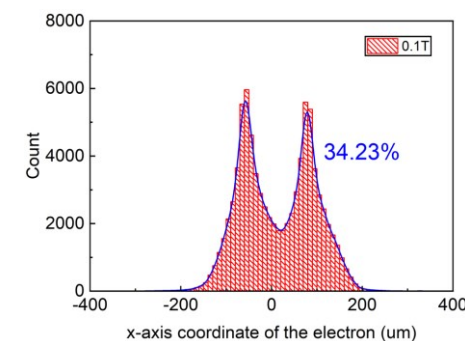
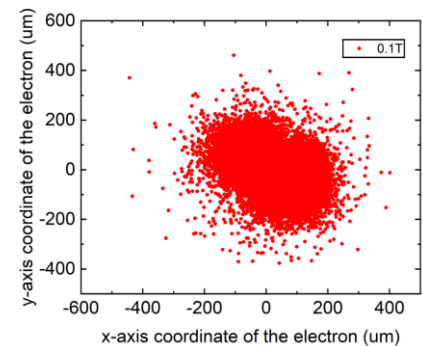
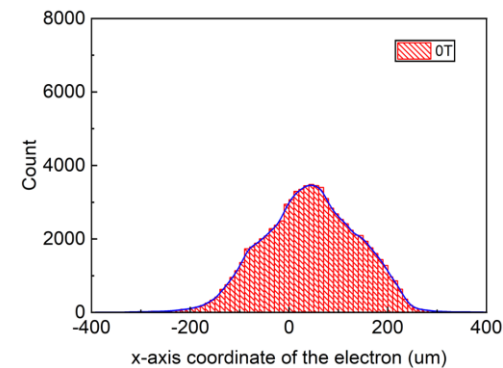
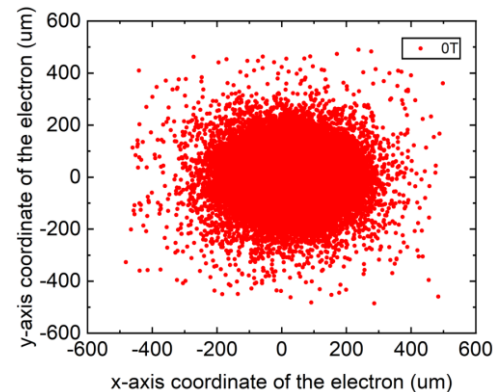
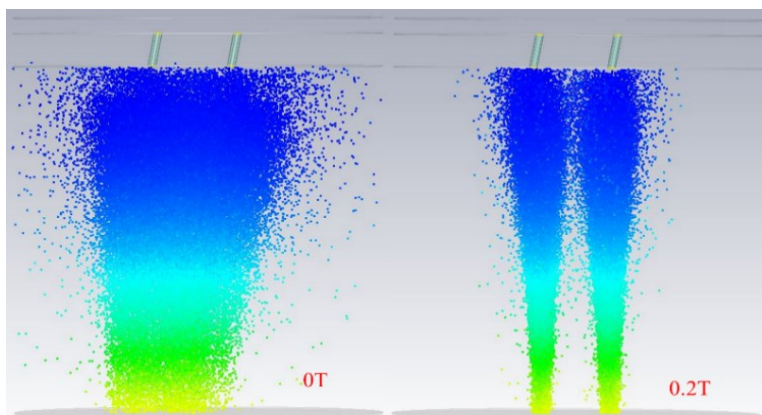
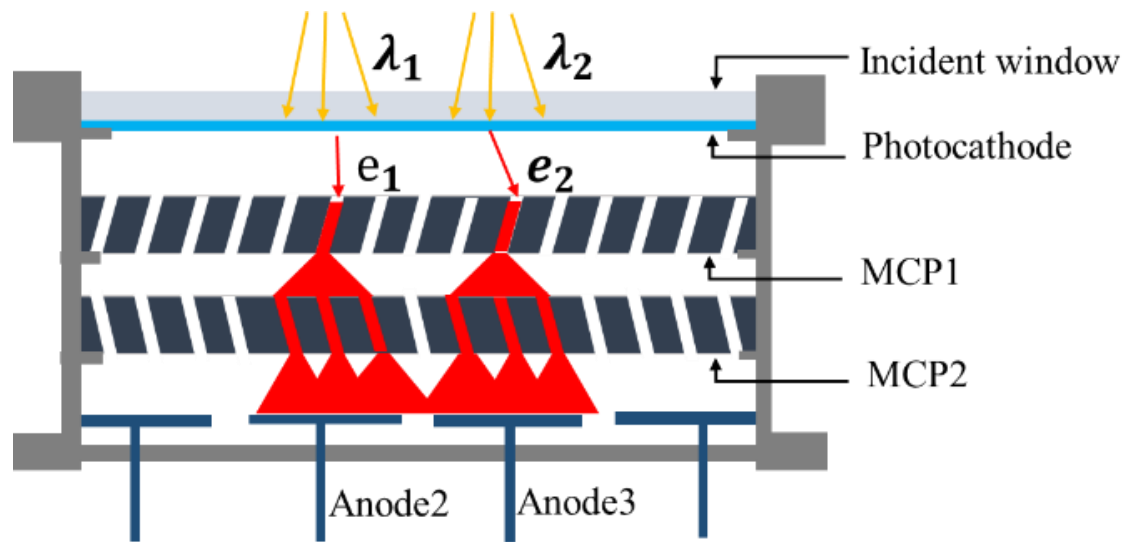
Gain vs. magnetic field direction

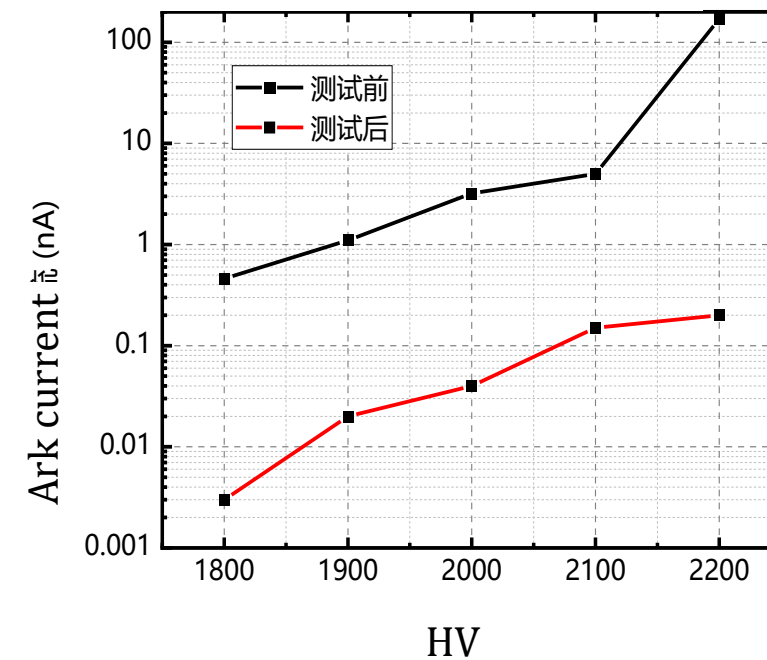
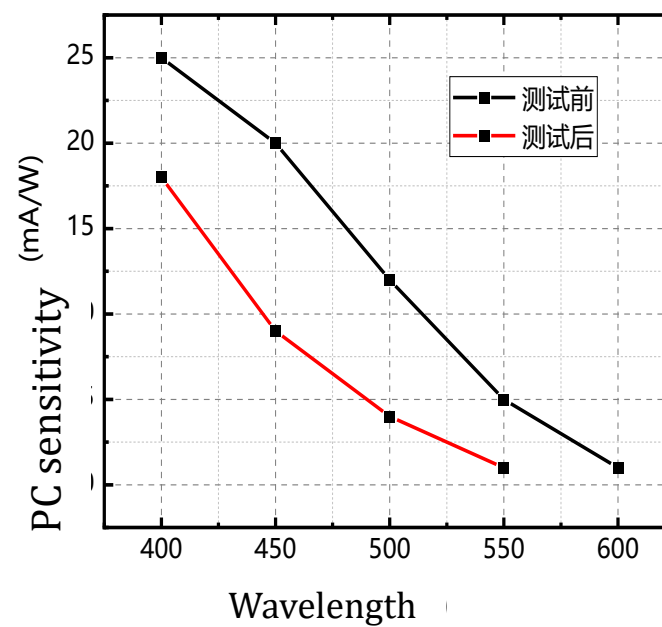
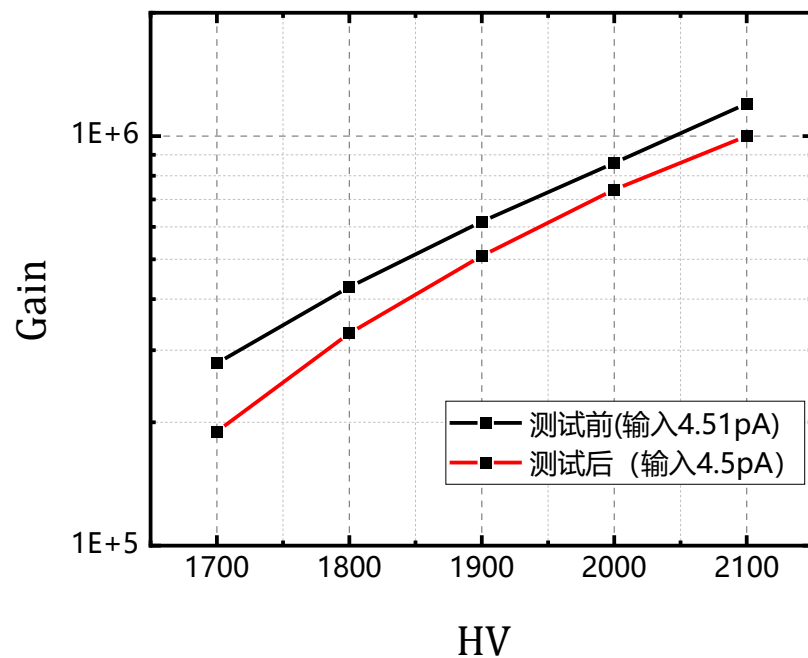


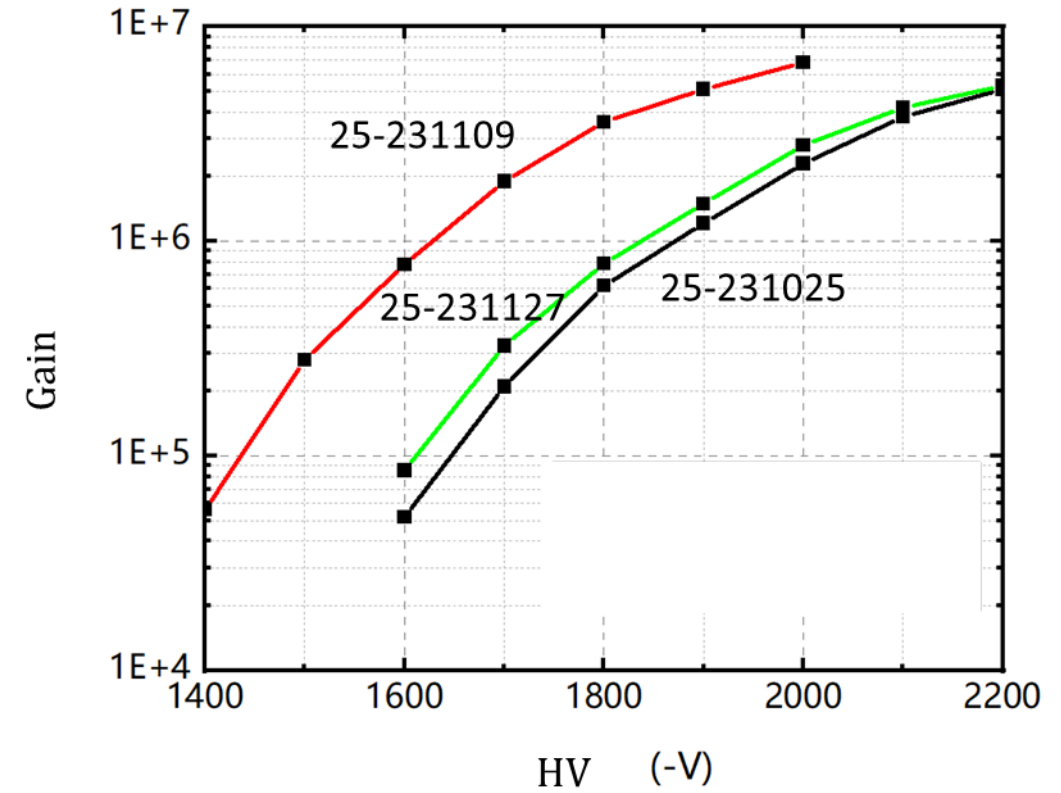
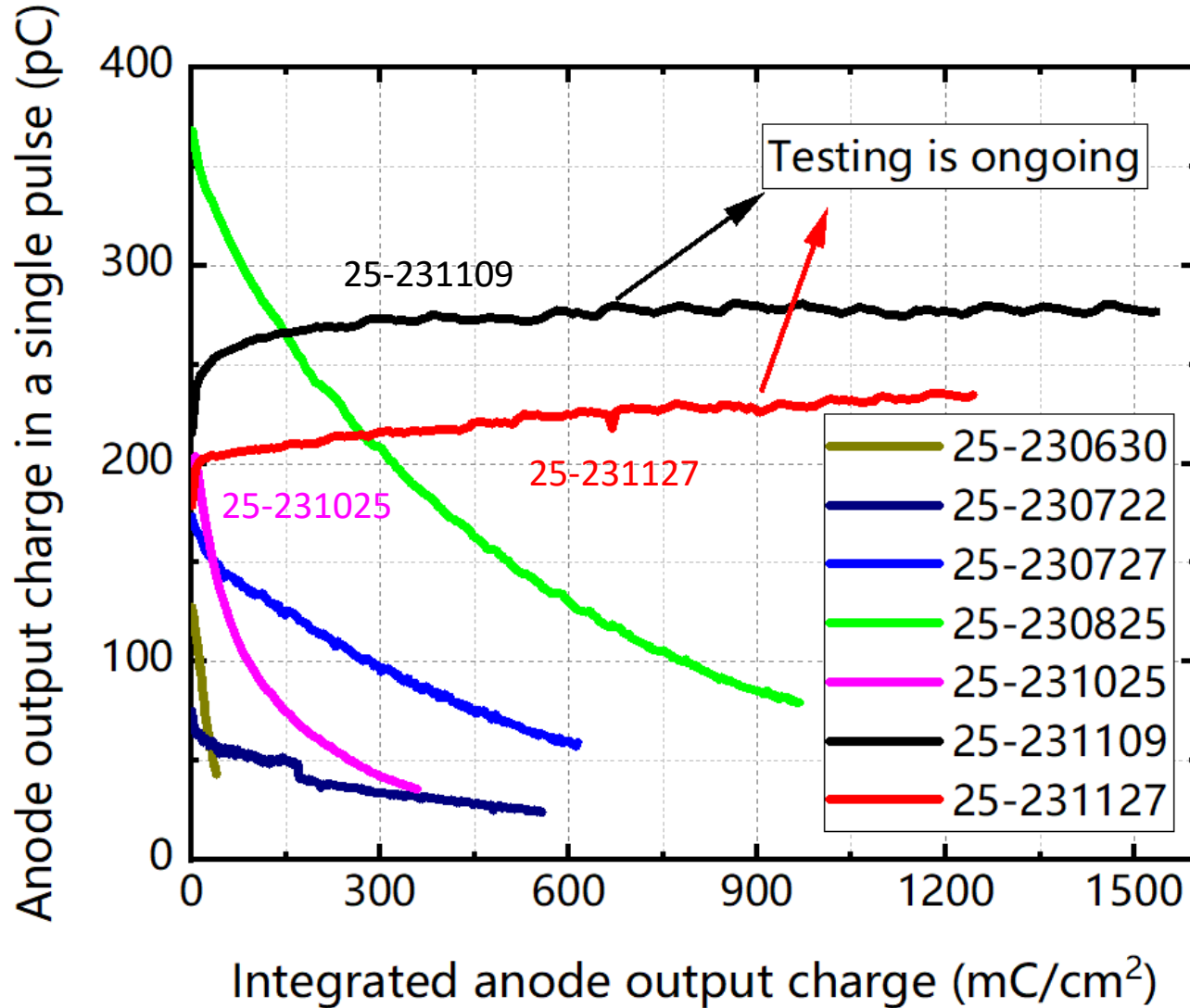
Magnetic characteristics



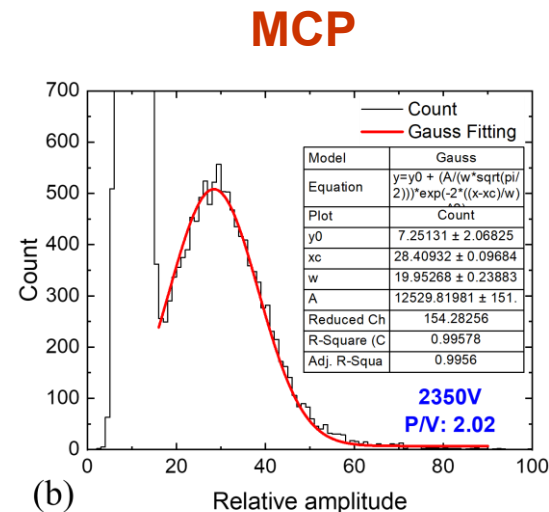
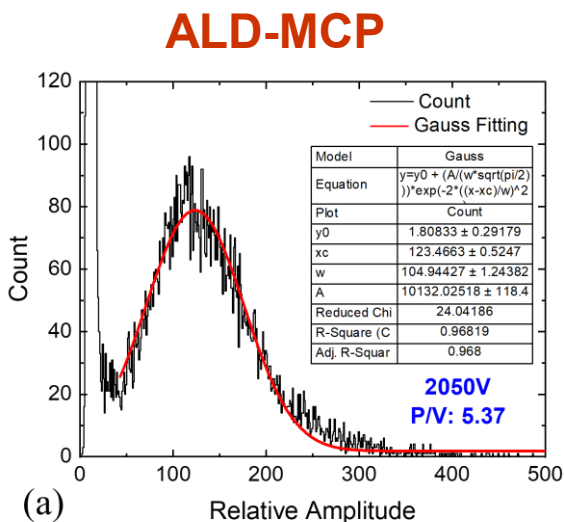
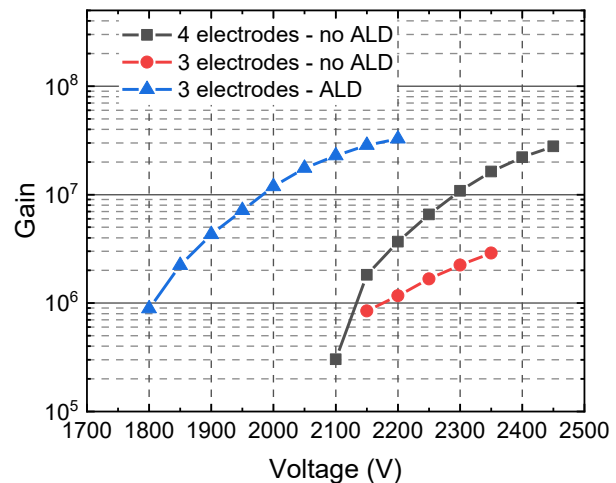
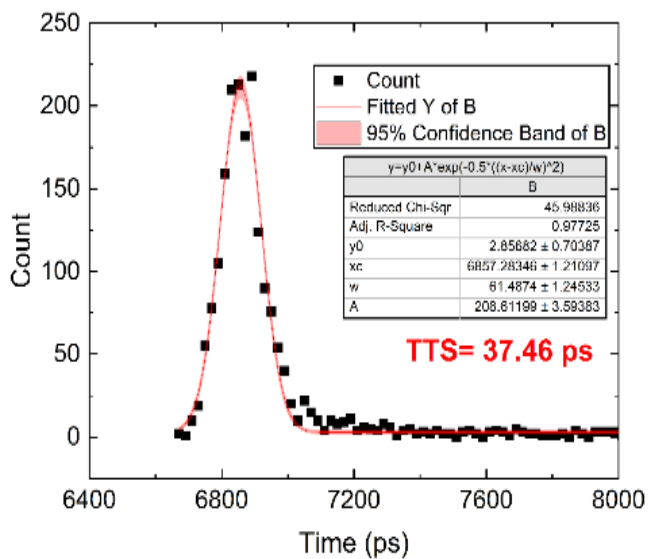
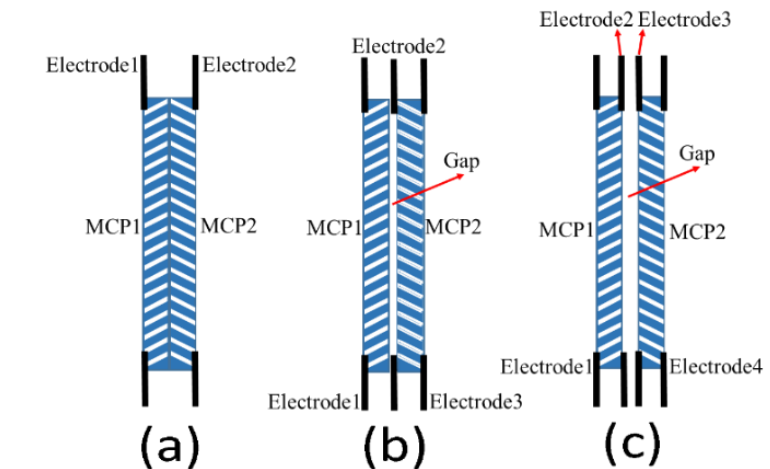
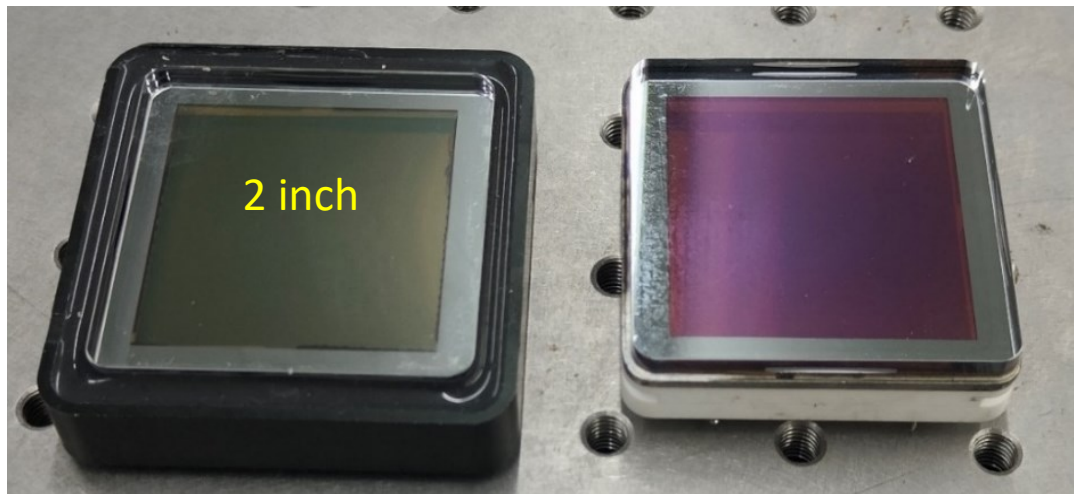
● Spatial resolution







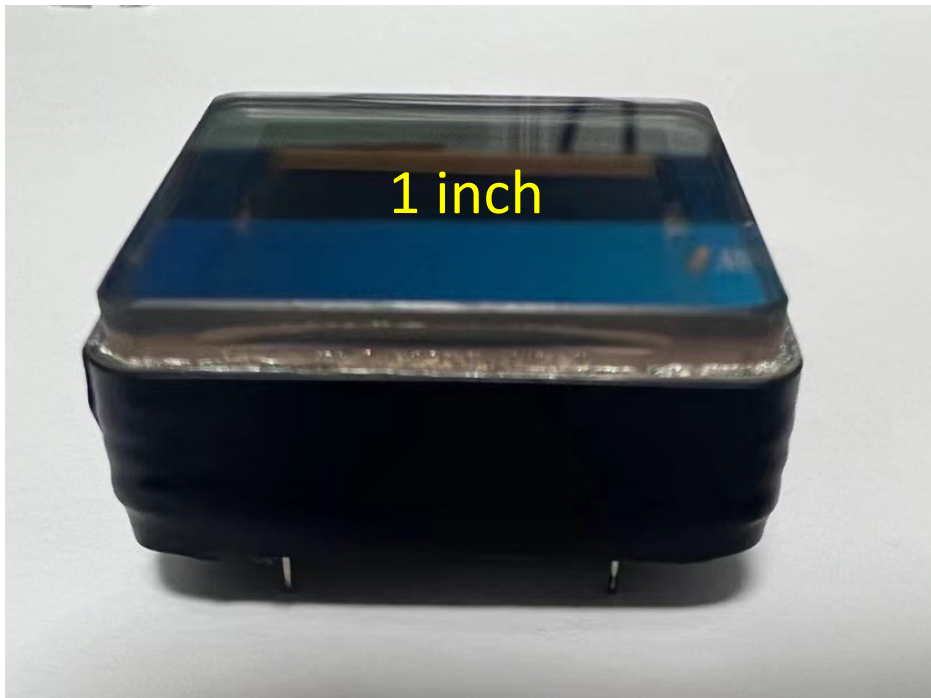
Prototype



Prototype



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Thank you for your attention!