R&D of the MCP based PMTs for High Energy Physics

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Introduction

Researchers at IHEP have conceived two types of MCP-based PMTs for weak light detection in particle physics. One is the Large MCP-PMT (LPMT) with small MCP units as the electron multiplication structure for neutrino detection. Over 13K pieces of LPMT have already been mass produced for the JUNO. And this kind of LPMT has also been evaluated by the PMT groups in LHAASO and HyperK. In order to particularly improve the time resolution of the LPMT, the focusing electron of the LPMT was optimized and the lotus-like LPMT was developed with TTS less than 4 ns. Another is the small-sized Fast MCP-PMT (FPMT) with fast timing resolution for the particle identification in the collider detector. The FPMT prototypes have been produced with 50 ps time resolution, and also the 8X8 readout anode for the position resolution.

1. The LPMTs for JUNO & lotus-like LPMT for LHAASO

The Core Technologies for PMTs
- High QE Photocathode
- High Gain and Low Noise MCP
- Low Radioactive Glass
- Vacuum Transfer Equipment

Ref 1. 2012 NIM A 695 113-117
Ref 2. 2021 JINST 16 C11003
Ref 3. 2020 NIM A 977 164333

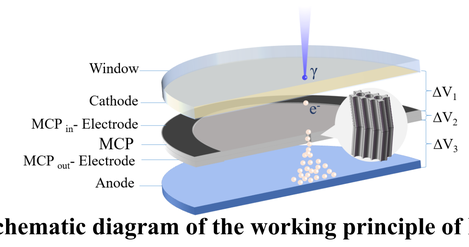
- From 2010-2020，the MCP-PMT group produced the prototypes in 2”, 5”,8” and 20”, and the performance were also improved a lot during the process.
- By August of 2020, the 15K MCP-PMTs have been delivered to JUNO.

PMTs	LPMT (Averaged)	Lotus-like LPMT
QE @ 400nm	32 %	30 %
CE	100 %	90 %
TTS@1pe	~ 20 ns	3.8 ns
DR	40 kHz	15 kHz
APR	0.4 %	0.2 %

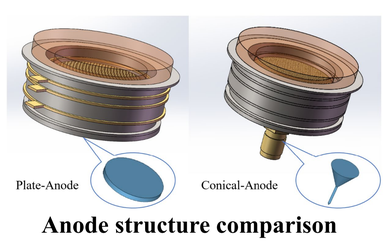
Photograph of the electrode for the LPMT (left) and lotus-like LPMT (right)

- By modifying the structure and processing of the PMT, a novel lotus-like LPMT was developed that shows improvements with respect to TTS and noise.
- The 20-inch MCP-PMTs are working well at LHAASO-WCDA and the waterproof potting failure rate is less than 1% as of June 31,2021

2. Single-anode FPMT

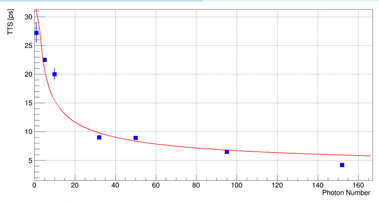


Schematic diagram of the working principle of FPMT



Anode structure comparison

FPMT	HV/V	Gain	Amplitude	RT	FT	Width	TTS@SPE
PA-FPMT	- 2000 V	1.9×10^6	7.6 mV	1.4 ns	1.4 ns	1.8 ns	71.0 ps
CA-FPMT	- 2052 V	2.3×10^6	37.6 mV	0.2 ns	0.6 ns	0.4 ns	35.8 ps
CA-FPMT Voltage Optimized	- 3181 V	2.6×10^6	53 mV	0.15 ns	0.4 ns	0.33 ns	27.2 ps

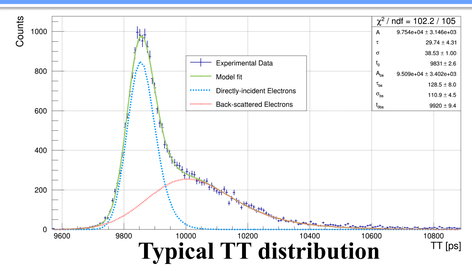


TTS versus the photon intensity for the voltage optimized CA-FPMT

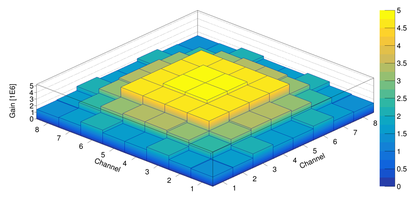
- By optimizing the anode structure from plate-anode to conical-anode, the impedance matches well with the cable which significantly improve the time performance.
- The voltage applied in the FPMT is furtherly optimized and the TTS can reach 29.2 ps at SPE. The limit TTS with the amplitude over 1 V is 4.2 ps.

3. Muiti-anodes FPMT

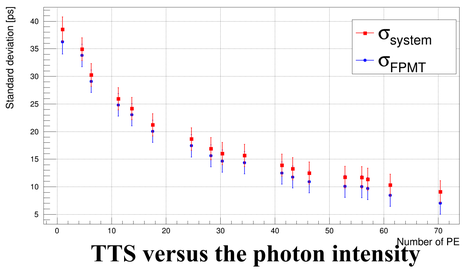
Photo of the 8×8 anodes FPMT prototype



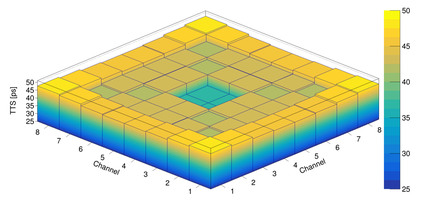
Typical TT distribution



Gain scan result



TTS versus the photon intensity



TTS scan result

- The limit TTS for the middle anodes of the MA-FPMT is around 7 ps.
- The average gain is $(2.9\pm1.2)\times10^6$ for all 64 anodes and $(3.9\pm1.0)\times10^6$ for the middle 32 anodes under 1500 V. The average TTS is 44.1±2.0 ps for all 64 anodes and 42.3±1.4 ps for the middle 32 anodes.

Ref 2022 JINST 17 T04002

4. Conclusions

- **The MCP-PMT groups in China successfully developed *two types of MCP-based PMTs for weak light detection both of which shows good performance.***
- ***The LPMT and the lotus-like LPMT have already been applied for the JUNO and LHAASO experiments. More great physical progress are expected to be achieved.***
- ***The FPMT with different anode structures all show great time performance. They are expected to be widely used in areas requiring great temporal or spatial resolution such as the TOF-PET or the Cherenkov detectors.***

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