PROCEEDINGS OF SCIENCE

A novel MCP-PMT with single-chip MCP

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Microchannel Plate Photomultiplier (MCP-PMT) is a kind of photosensitive device with high gain, good detection efficiency, single photon detect ability, magnetic field resistance and ultimately good time resolution. In order to achieve single photon detection, two chips of MCP are often used together. In 2020, the proposal of roadmap toward the 10 ps TOF-PET challenge places higher requirement on the time performance of the photodetector. The single-chip MCP-PMT is expected to have a greater time resolution. In this manuscript, we introduce a new kind of single-chip MCP-PMT, with a TTS of 10 ps. The gain of the single-chip MCP-PMT was evaluated through relative tests, and the improvement of its performance was studied by investigating the voltage divider ratio.

42nd International Conference on High Energy Physics (ICHEP2024), 18th - 24th July 2024 Prague, Czech Republic

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PoS(ICHEP2024)1214

1. Introduction

Microchannel Plate Photomultiplier (MCP-PMT) is a kind of photosensitive device with high gain, good detection efficiency, and excellent single photon detection capability. The roadmap proposed in 2020 towards achieving a 10 ps TOF-PET challenge has placed heightened demands on the time performance of photodetectors [1]. The small sized MCP-PMT, also referred to as Fast-timing PMT (FPMT) stands out for its exceptional time performance, making it a preferred choice in various fields such as medical imaging [2], high energy partical detection, and biological detection [3]. Researchers at IHEP have sucessfully developed a series of FPMTs [4] [5].

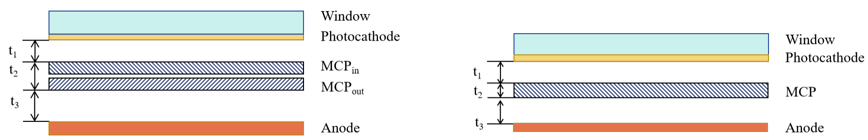

Figure 1: Schematic diagram of double-chip (left) and single-chip (right) FPMT structure.

The transfer process of photoelectrons in the FPMT can be categorized into the focusing, multiplication and transmission process. The time required for each of these three stages is denoted as t_1, t_2, and t_3 in Fig. 1. Therefore, the whole TTS of the FPMT can be expressed as:

$$TTS = \sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2 + \sigma_{t_3}^2} \tag{1}$$

To achieve high gain for single photon detection, FPMTs typically utilize two chips of MCPs, as shown in Fig. 1 right. However, the time jitter resulting from the electron multiplication process in the MCP is significantly higher compared to the other two processes. In order to further improve the time resolution, researchers have considered the potential of single-chip FPMTs, as shown inFig. 1 right. Simulation has shown the potential of single-chip FPMT to achieve a better time performance [6]. In this manuscript, we have developed a novel single-chip FPMT based on previous research and conducted a study on its performance.

2. Setup for measurement

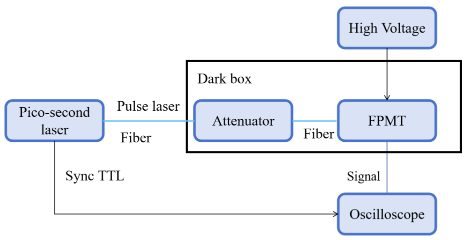

Figure 2: Setup of measurement system.

The experimental setup remained consistent with the previous configuration [7], depicted in Fig. 2. A picosecond laser (PILAS DX NKT) served as the illumination source, with light intensity regulated using an optical attenuator. The FPMT was positioned within a light-tight enclosure, and light pulses were directed to the FPMT via an optical fiber. A synchronous TTL signal was generated by the picosecond laser for triggering purposes. Data acquisition was performed using a LeCroy HDO9404 oscilloscope operating at a bandwidth of 4 GHz and a sampling rate of 20 GS/s.

3. Result

A high-gain double-chip FPMT was used as a reference to evaluate the gain of a single-chip FPMT. Both FPMTs were tested under intense light conditions to measure charge quantities without saturation. Single-photon spectra were then acquired while keeping the standard FPMT gain constant. This methodology facilitated the determination of the gain of the single-chip FPMT:

$$Gain_{single-chip} = \frac{Q_{single-chip}}{Q_{stantard}} \times Gain_{standard} \tag{2}$$

Where $Gain_{single-chip}$ and $Gain_{standard}$ represent the gains of the single-chip FPMT and the standard FPMT, respectively, while $Q_{single-chip}$ and $Q_{standard}$ represent the charge quantities of their respective signals.

Two single-chip FPMTs were tested in this experiment. As depicted in Fig. 3, the gain of the single-chip FPMT varies exponentially with voltage. Due to the low resistance of a single MCP, applying higher voltages across both ends of the MCP to increase the gain is unsafe. Single-chip FPMT1 has a relatively high gain but limited high-voltage tolerance, reaching only a gain of 8.7×10^4. In contrast, single-chip FPMT2 has a lower gain but can withstand higher voltages, achieving a gain of 2.3×10^5.

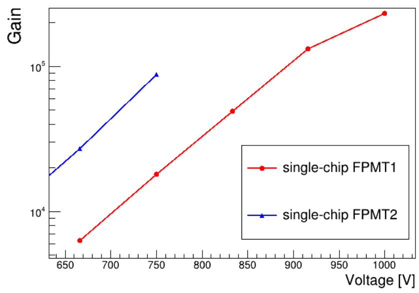

Figure 3: The variation of gain with voltage.

To further improve the performance of the single-chip FPMT, adjustments were made by optimizing the voltage division. The voltage between the cathode and the MCP (ΔV_1) was adjusted while keeping the MCP voltage constant. The gains of a single-chip FPMT at different ΔV_1 levels were assessed based on the relative charge quantity of the signal under the same light intensity. As illustrated in Fig. 4, with the increase of ΔV_1, the gain of the FPMT improved. However, after ΔV_1 exceeds 240 V, this enhancement becomes relatively weak. The TTS of single-chip FPMT under strong light conditions also decreased with the increase of ΔV_1, and can reach 9.4 ± 0.05 ps when ΔV_1 increased to 450V.

4. Conclusion

In this research, we introduced a novel single-chip FPMT and conducted an investigation into its performance. Utilizing relative testing, the gain of the single-chip FPMT was quantified, and the

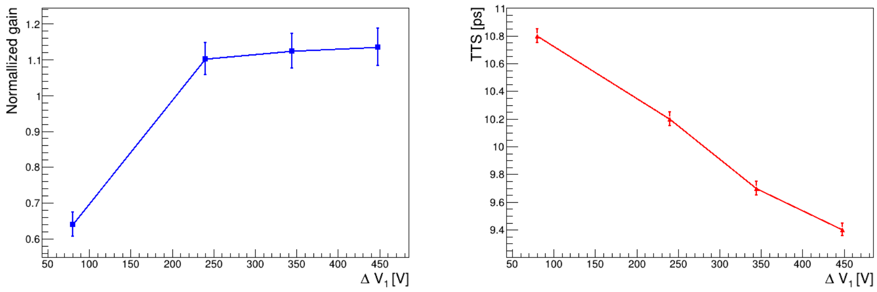

Figure 4: The variation of gain (left) and TTS (right) with ΔV_1.

impact of voltage on gain was analyzed. Through adjustments in the voltage divider ratio, the gain and time resolution of the FPMT were optimized. Remarkably, under intense light conditions, the time resolution of the single-chip FPMT can achieve a remarkable low value of 9.4 ± 0.05 ps.

Acknowledgments

This research has been supported by the Key project of National Natural Science Foundation of China (No.12335012) and Youth Innovation Promotion Association CAS (YIPA2017017).

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