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Research on time response of photomultiplier tubes

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Timing characteristic of photomultiplier tubes is very important for the applications of many high energy and nuclear physics experiments. A characterization system for photomultiplier tubes which is able to calibrate time response has been built up in our lab. Experiments were designed and completed to decide the appropriate timing calibration method for different photomultiplier tubes. The timing of light source and the illumination area during the measurements were proved to affect the calibration results in different extend for different tubes. Details of the experiments and corresponding results will be presented in this proceeding.

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1. Introduction

Photomultiplier tubes (PMTs) are preferred photodetectors in many experiments for fast time response property and good sensitivity in weak light detection. Good understand to the PMT performance is important for an experiment using large amount of PMTs. Specified to the time response of PMTs, only fast timing PMT products should be selected for experiments which demand high time resolution. Detailed PMT timing calibration is necessary for better understand to the detector performance and event reconstruction.

We have built up a performance evaluation system which is able to review diverse properties for PMTs with different sizes and dimensions, and completed intensive research and experiments on variety of PMTs. Details of all the work are introduced in a previous paper [1] and this proceeding will focusing on some deeper work on PMT time property.

2. System setups and instruments selection

The mainly concerned PMT time characteristics in many experiments are the rise time, fall time and transit time spread (TTS) of the output signal.

A schematic of the PMT time response measurement setup is shown in Fig. 1. Normally the rise time and fall time are measured by sampling the PMT output with a waveform sampling instrument, either an oscilloscope or a Flash Analog-to-Digital Convertor (FADC). And if the sampling instrument provides a sufficiently accurate trigger time stamp, further analysis on the waveforms can extract TTS information, which is usually expressed as the FWHM of a transit time spread histogram measured at single photon level illumination. On the other hand, TTS could also be measured directly by a Time-to-Digital Convertor (TDC).

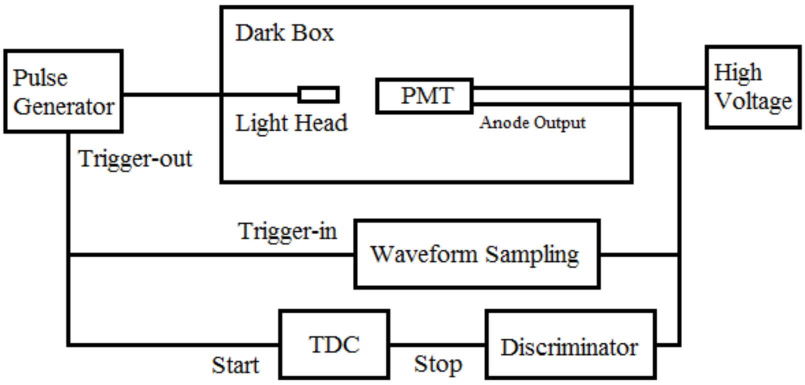


Fig. 1 Schematic of PMT time response measurement setup.

The entire system shown in Fig. 1 can be roughly divided into three parts: the light source (including the generator and head), the PMT itself and the data acquisition (DAQ) device. The measured accuracy highly depends on the properties of the light source used.

To achieve accurate TTS measurement at single photon level, a special optical device is designed and built up. As illustrated in Fig.2, this device can regulate the intensity of given incident light at single-photon level precision. The input fiber, an optical lens and a motorized precision translation stages (MPTS) constitute the first stage. Since the light beam coming out from the input fiber has a divergence angle, the intensity of the light accessing the aperture of the lens decreases as the lens moving far away from the end of the input fiber. On the other hand, the output fiber and the other MPTS constitute the second stage. The distance between the lens and the end of output fiber can also be modified using the motor in the second stage.

Only a part of the diffused light beam enters the output fiber and results into the final output, as shown in Fig.2, different distance between the input and output fibers could be modified carefully and automatically to generate the single photon mode. With high quality motors, high precision light level can be produced in the mechanical stage. By this optical device, the light generated by a picosecond laser (ps-laser) device could be modified to a single photon mode, of which the pulse width and jitter are less than 45ps and 4ps.

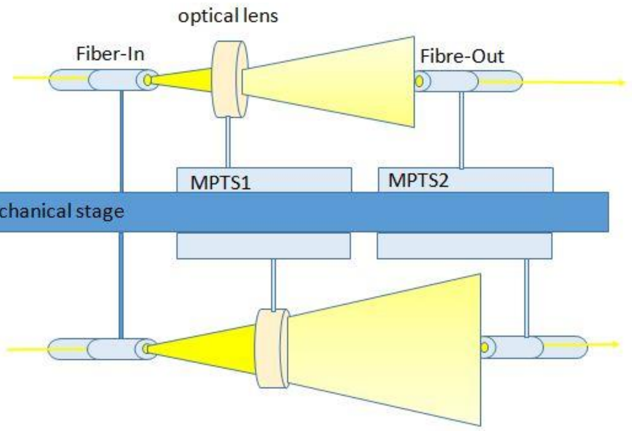


Fig. 2 Diagram of the optical setup for light intensity regulation.

Comparison of the measured transit time spread using different light sources with a Hamamatsu R5912-100 PMT is shown in Fig. 3. The results were acquired by a same TDC. The normal laser diode in Fig. 3 lighted by a Tektronix AFG3102 pulse generator emits 410nm laser. Such a light source setup is cheap and convenient in the measurements of other PMT characteristics like quantum efficiency and charge spectrum. However, both the width and jitter of its light pulse are at nanosecond level, thus resulting in a 1.45ns lager TTS than that measured by the picosecond laser (ps-laser) device.

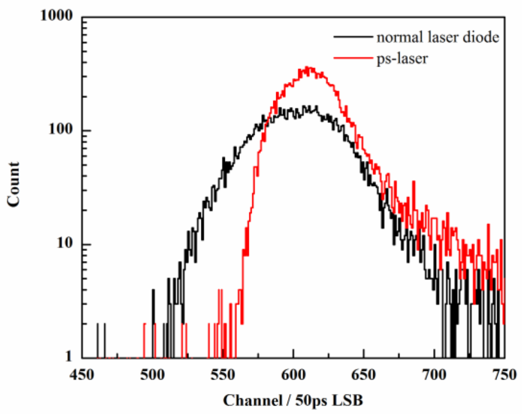


Fig. 3 Measured transit time spread using different light sources with a Hamamatsu R5912-100 PMT.

One point needing emphasis is that the TTS parameter mentioned in the PMT manufacture and application field describes the single photon illumination situation. With the same operation procedure, better TTS response would be measured with more incident photons (see Fig. 4). In general, the TTS response improves in inverse proportion to the square root of the number of photoelectrons in an appropriate range.

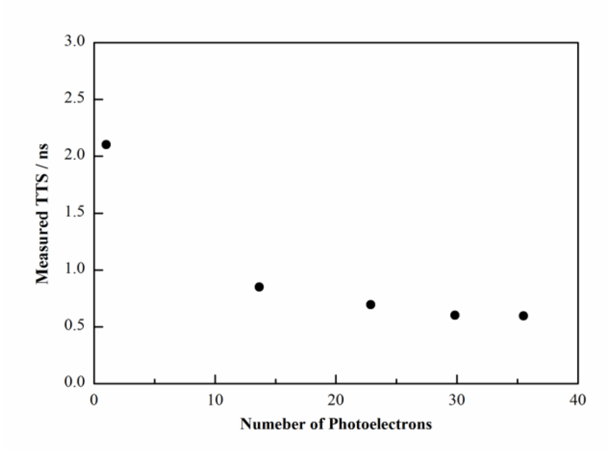


Fig. 4 Measured TTS at different illumination level with a Hamamatsu R5912-100 PMT.

3. Operation principle

Photons arriving at different positions on the photocathode will result in photoelectrons with different transit time, which will contribute to the final signal TTS [2]. Normally in the PMT manufacture, optimized electro-optical simulation and structure design should have been executed to suppress such effect. For small PMTs or small areas on large PMTs, this effect can be negligible.

Fig. 5 shows the relative transit time histograms measured with point-like light and 2-inch area diffused light for an 8-inch PMT. The difference of the two measured TTS results are less that 20ps, which is ignorable compared to the ~3ns quantity.

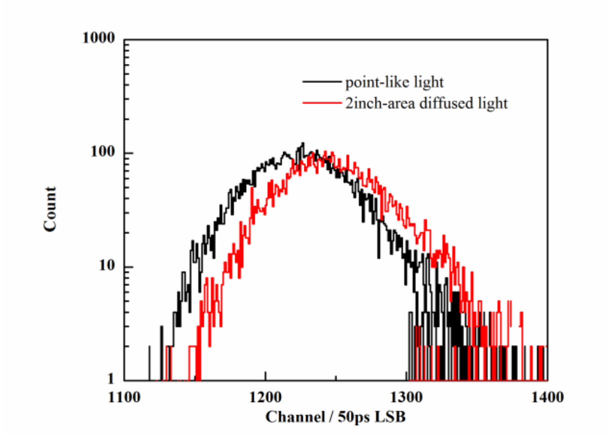
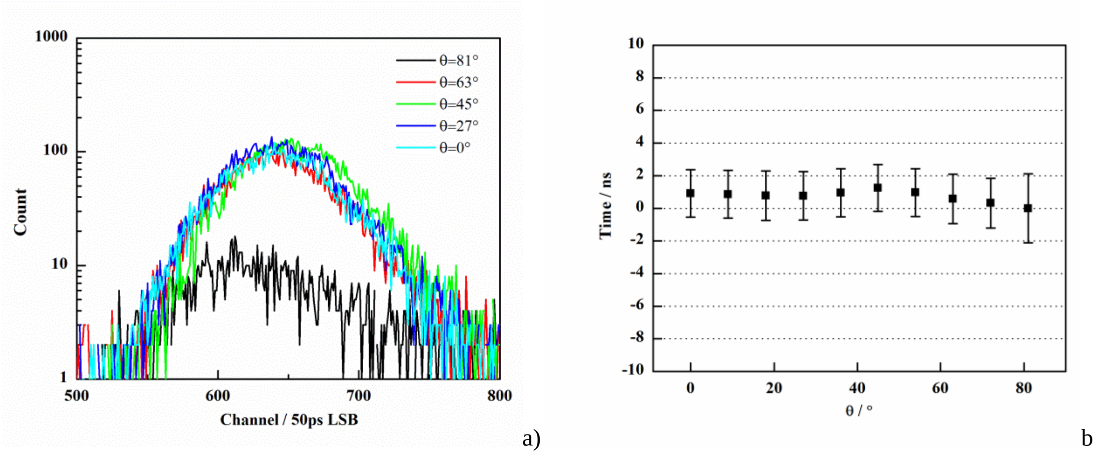


Fig. 5 Measured TTS using different light size with a Hamamatsu R5912-100 PMT.

However, it's not easy to eliminate timing position effect for the entire cathode area for PMTs with large area like 8-inch or even 20-inch. To evaluate this position effect for large PMTs, experiments with different incident light modulation were completed. In a first set of experiments, a point-like light was used to illuminate different cathode regions. When describing the position on cathode with polar angle θ and azimuth angle φ, a typical situation is moving the illumination along a fixed φ and measuring the time response at different θ. Fig. 6 lists the measurement results with a 20-inch Hamamatsu R12860 PMT [3].

Keeping the light direction perpendicular to the cathode, the light illuminates on the top center of the cathode in the θ=0° case, and the illumination position gets closer to the cathode edge while θ gets larger. In Fig. 6a the event number of θ=81° case is less than the others for the detection effeciency reduction at a large θ. The mean value and width of each histogram in Fig. 6a represent the relative transit time and TTS, respectively. Minor variations of both the two parameters happen in a small θ range, while large differences appear near the cathode edge. The differences of transit time and TTS between θ=0° and θ=81° are 0.91ns and 1.29ns respectively.

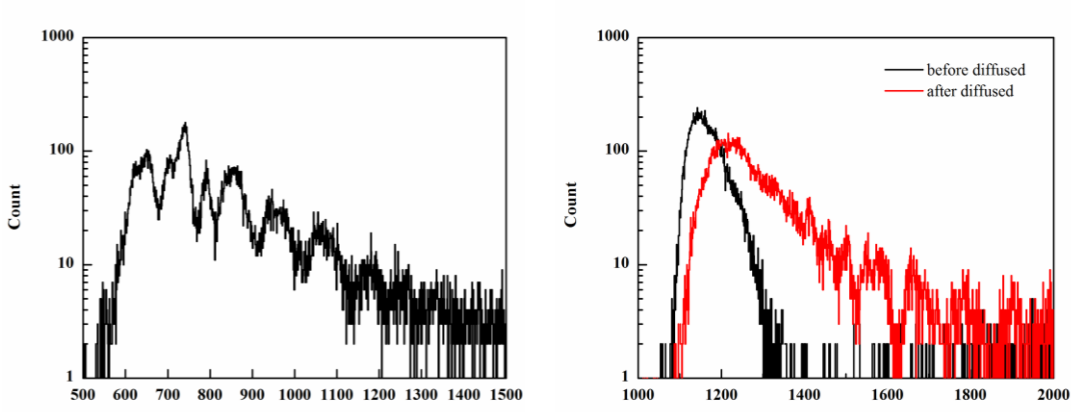


a) b)

Fig. 6 a) Relative transit time histograms and b) variation of mean and FWHM value of th histogram with light illuminating at different polar angles on the cathode measured with a 20-inch Hamamatsu R12860 PMT.

Considering that in the practical PMT applications in HEP experiments scintillator or Cherenkov photons are possible to reach the full cathode area, a good understand to the PMT timing characteristcs under full illumination is necessary for offline data analysis like vertex and track reconstruction.

There is a preference for light spot of several millimeters or ~1 centimeter in laboratory-based PMT characterization systems [4-6] since that is convenient to produce with LEDs or many laser sources. Then the problem is how to diffuse the small area beam to large enough. An integrating sphere was firstly considered for light diffusing. However, as shown in Fig. 7a, several peaks appear in the relative transit time histogram measured with the integrating sphere, which can be explained as that the timing of light is distorted by the integrating sphere. Thus, the integrating sphere is not acceptable in the timing measurement for PMTs.



a) b)

Fig. 7 Relative transit time histograms measured with light diffused by a) an integrating sphere and b) a diffused ball for an 8-inch PMT.

By employing a diffusing ball, and meanwhile increasing the distance between the light source and PMT input window, full illumination on several-inch area can be achieved. TTS results measured with light before/after being diffused for an 8-inch tube are shown in Fig. 7b. Obvious differences of the measured TTS between different illumination modes can be observed from Fig. 7b. A ~1.5ns larger TTS was measured with the diffused light for this PMT. However, there should also be some timing distortion caused by the diffusing ball which needs to be corrected.

Results in both Fig. 6 and Fig. 7 show that a full illumination on the cathode area is necessary in the measurement of the PMT TTS property to mimic a similar situation as the practical applications in HEP experiments. However, while the trend of building larger detectors in HEP experiments field leading to requirements for larger area PMTs, like 10-inch or even 20-inch [7-8], it is technically difficult to produce light beams with equivalently large diameter. In other words, full illumination measurements for large area PMTs are hard to achieve in laboratory environment. In our lab, an alternative method of producing large area parallel light beam for the timing measurement of large area PMTs is under development.

4. Conclusion

Based on a PMT performance evaluation system built in our lab, extensive experiments have been completed to characterize the time response of various types of PMTs, via which appropriate method for PMT timing measurement was researched. Fast light source should be used to minimize the influence to the results from the light itself. In addition, since photoelectrons emitted from different cathode area may result in transit time difference, parallel light beam with equivalent size as the PMTs is necessary to include this effect in the PMT timing calibration. And further research on the quite large area PMTs like 20-inch ones is ongoing.

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