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Timing Properties of MCP-PMT

Kenji Inami[*]
Nagoya university, Nagoya, Japan
E-mail: `kenji@hepl.phys.nagoya-u.ac.jp`

We have studied timing properties of 4 different types of micro-channel-plate photo-multiplier tubes (MCP-PMT) by irradiating with single photons with/without a magnetic field (B); resulted time resolutions are σ= 30 - 35 ps for single photons under $B = 1.5$T. To examine the lifetime of MCP-PMTs, we have measured its basic performance, gain, quantum efficiency and transit time spread as a function of the integrated amount of irradiated photons up to 2.8×10^{14} photons$/$cm^2, corresponding to a 14-year time duration under supposed super-B experimental conditions. The effect of the ion-feedback protection layer has been clearly detected. As an application of the good timing property, a small Time-Of-Flight (TOF) counter with a thin quartz Cherenkov-radiator has been proposed and tested using a pion beam. The time resolution of σ= 6.2 ps has been attained.

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[*] Speaker.

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1. Introduction

We have been developing a photo-device for a time-of-propagation (TOP) counter [1], a newly proposed K/π particle identification detector in terms of a Cherenkov ring-imaging counter, at a high-luminosity super B-factory [2]. TOP counter reconstructs the ring-image with the precise timing information. The photo device needs the single photon sensitivity to detect the small number of Cherenkov photons, good transit time spread (TTS) ability of < 50 ps for single photo electron under the 1.5 T magnetic field, 5 mm position sensitivity and high detection efficiency. During the course of this R&D work, we have found that a micro-channel plate (MCP) photo-multiplier tube (PMT) is a best candidate.

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2. MCP-PMT for single photon

We have studied the performance, especially timing property, for 4 different types of MCP-PMTs with single photon irradiation with and without a magnetic field ($B = 0$ - 1.5 T) [3]. The MCP-PMTs tested here are Hamamatsu (HPK) R3809U-50-11X, BINP-MCP[1], HPK R3809U-50-25X, and Burle 85001-501, which are hereafter denoted as HPK6, BINP8, HPK10, and Burle25, respectively, where the numbers indicate the hole diameters of the micro-channel-plates. The characteristics of the 4 MCP-PMTs are listed in Table 1. All MCP-PMTs are of two-stage type. The HPK6, BINP8 and HPK10 are of the single-anode type, and the Burle25 is of the 2×2 multi-anode type. Magnetic field is applied parallel to the PMT axis.

Table 1: Characteristics of tested MCP-PMTs.

MCP-PMT	HPK6	BINP8	HPK10	Burle25
size of PMT (mm)	45^{ϕ}	30.5^{ϕ}	52^{ϕ}	71×71 $^{\natural1}$
effective size (mm)	11^{ϕ}	18^{ϕ}	25^{ϕ}	50×50 $^{\natural2}$
photo-cathode	multi-alkali	multi-alkali	multi-alkali	bi-alkali
D $^{\natural3}$ (μm)	6	8	10	25
α = L/D $^{\natural3}$	40	40	43	40
max. voltage (kV)	3.6	3.2	3.6	2.5
gain	2×10^6	$\sim10^6$	$\sim10^5$	6×10^5

$^{\natural1}$ An area of MCP-PMT in mm^2.

$^{\natural2}$ An area of effective size in mm^2.

$^{\natural3}$ D and L are the diameter and length of the MCP plate, respectively, and α = L/D.

Figures 1 show the output pulses from the MCP-PMTs for single-photon irradiation under no magnetic field. HPK6 exhibits sharp and symmetrical shapes with a rise time of 300 ps and a pulse duration of $\sim$ 1 ns. BINP8 shows a broad signal over a 4 ns time duration, followed by a relatively large undershoot. The broad shape is found to be caused by the impedance between the MCP-PMT and the HV supply divider. However, the signal rise is sharp, which is similar to that of the HPK6. Therefore, the similar time resolution is found as shown later.

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[1] MCP-PMT especially made to order by Ekran-FEP Ltd. for Budker Institute of Nuclear Physics

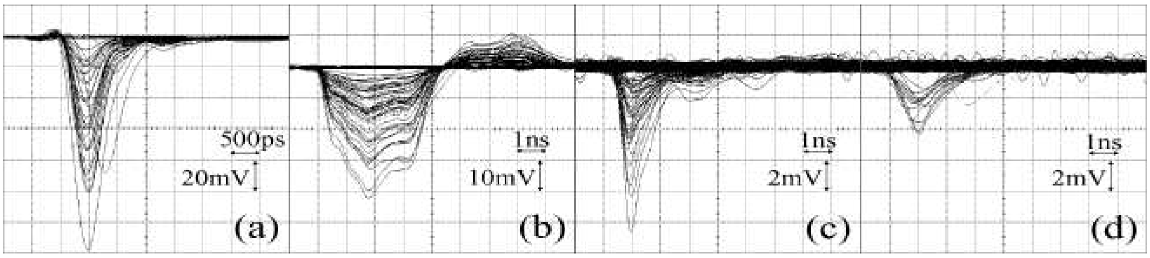

Figure 1: MCP-PMTs output signals for single-photon irradiation under no magnetic field. (a) HPK6 (HV =3.6 kV), (b) BINP8 (3.2 kV), (c) HPK10 (3.6 kV), and Burle25 (2.5 kV). A digital oscilloscope (Hewlett Packard, Infinium) with a frequency band of 1.5 GHz is used with a 50Ω SMA cables in these measurements.

From the ADC peak channel for single photo-electrons, we have evaluated the gain as a function of magnetic field strength, B, as shown in Figure 2(a). HPK6 and BINP8 provides gains at the 10^6 level and shows the small gain variation, while HPK10 and Burle25 has the gain of $\sim 5\times10^5$ at best. The achieved maximum gain is $\simeq 3\times10^6$ for both HPK6 (HV = 3.6 kV) and BINP8 (3.2 kV), and 2×10^5 for HPK10 (3.6 kV) under $B = 1.5$ T, and 2×10^5 for Burle25 (2.5 kV) under 0.8 T. Burle25 can not be operational at a higher HV and magnetic field. From the results, we have found that the smaller channel diameter shows the smaller gain variation, which seems to be related with the hole size and the Larmor radius of the multiplied-electron motion under the magnetic field.

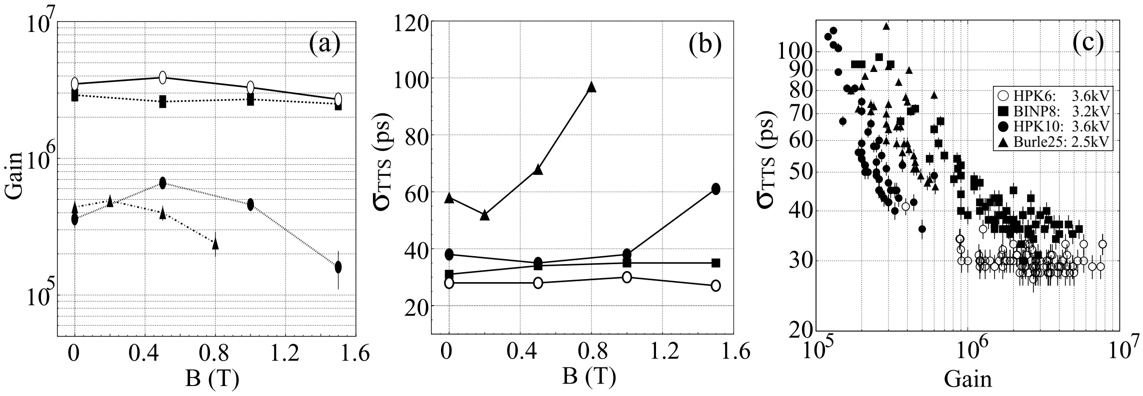

Figure 2: Measured gain (a) and TTS (b) for single-photon irradiation as a function of B, and time resolutions as a function of the gain (c). The marks denote HPK6 (○), BINP8 (■), HPK10 (●) and Burle25 (▲).

Figures 3 show the ADC spectra under $B = 1.5$ T for different angles ϕ, which are the tilt angles between the direction of magnetic field and the MCP-PMT axis. HPK6 demonstrates the highest gain and sharpest ADC distribution at ϕ = 45°, while BINP8 does so at ϕ = 15°. It is because of the relation among the bias angle, hole size and the Larmor radius.

The transit time spread ($\sigma_{\rm TTS}$) for single-photon irradiation as a function of the magnetic field strength is obtained as shown in Figure 2(b). HPK6 and BINP8 shows a stable $\sigma_{\rm TTS}$ of 30 ps and 35 ps, respectively, over wide B ranges from 0 to 1.5 T. HPK10 and Burle25 exhibits, on the other hand, a strong dependence on the magnetic field, and the $\sigma_{\rm TTS} \sim 60$ ps and 100 ps, respectively, under $B = 1.5$ T and 0.8 T with the maximum applicable HV.

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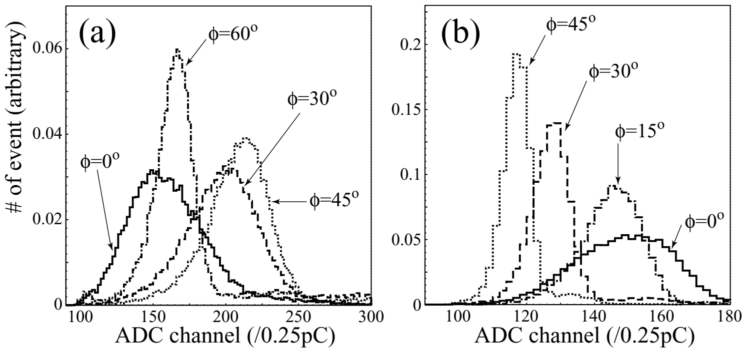

Figure 3: ADC spectra for several angles ϕ under 1.5T magnetic field, for (a) HPK6 and (b) BINP8.

Figure 2(c) shows the σ_{TTS} as a function of the gain for several HV and magnetic field conditions. It is found that the 30 to 40 ps time resolution can be obtained in case of the gain $> 10^6$. From above results, the channel diameter needs to be less than 10 μm in order to obtain the < 40 ps time resolution under the magnetic field.

3. Lifetime

To employ this superb timing property for practical use, its lifetime should be long enough under experimental conditions of high counting rate. Therefore, we have measured the lifetime of MCP-PMT [4], assuming a possible circumstance at a super KEKB factory with a luminosity of $2 \times 10^{35}/\mathrm{cm}^2/\mathrm{s}$, by linearly extrapolating the current experimental condition at KEKB-Belle experiment. The present luminosity of the KEKB collider is $\sim 2 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$, under which the background rate at the barrel region is about 792 kHz, mostly of spent electrons. Our specific configuration of the TOP counter is expected to have a detected Cherenkov photon rate of 68 $\mathrm{kHz}/\mathrm{cm}^2$ on a PMT. This corresponds to an integrated number of photons over a one-year period of $N_\gamma = 2 \times 10^{13}$ $\mathrm{photons}/\mathrm{cm}^2/\mathrm{y}$; this number is taken to be a time unit, one super KEKB year equivalent, in our lifetime evaluation.

One of the primary sources that shorten the lifetime of a PMT is positive ion-feed back. Positive ions could be produced in the multiplication process of secondary electrons by collisions with residual gas or MCP material, and accelerated backward by a high voltage. The quantum efficiency (QE) deterioration could be caused by their adsorption on the photo-cathode surface and by their damage on chemical bonds of the photo-cathode material. A bias-angle of the MCP is then introduced to reduce these feedback effects. Moreover, in order to protect the photo-cathode from these feedback-ions, a thin metal protection layer is sometimes placed on the surface of the first MCP-layer at its photo-cathode side. However, it inevitably introduces transmission inefficiency for photo-electrons, typically about 40%, and accordingly causes a correction efficiency (CE) reduction.

Seven MCP-PMTs have been tested: Two were HPK6 and the others were BINP8. All PMTs have a multi-alkali photo-cathode, and are two MCP-layer type; half of the PMTs are equipped with a protection layer and the other half are not. They are labeled by “w” and “wo”, respectively. The light load is generated by LED pulse of 1 - 5 kHz with 20 - 100 photo-electrons / pulse.

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QE has been measured as the ratio of the number of detected signals to the number of irradiated single-photons, whereof the *CE* is factored out. Figure 4(a) shows the relative variations of *QE* as a function of the number of irradiated photons. Without the protection layer, *QE* rapidly has dropped to less than 50% within a tenth of a super-B year and reached a few 10% at one year. Even with the protection layer equipped, BINP8 has exhibited a sharp drop, reducing to $QE < 60\%$ at one half year. Only HPK6 with the protection layer has exhibited a gentle slope. It became around 90% after 14 super-B years.

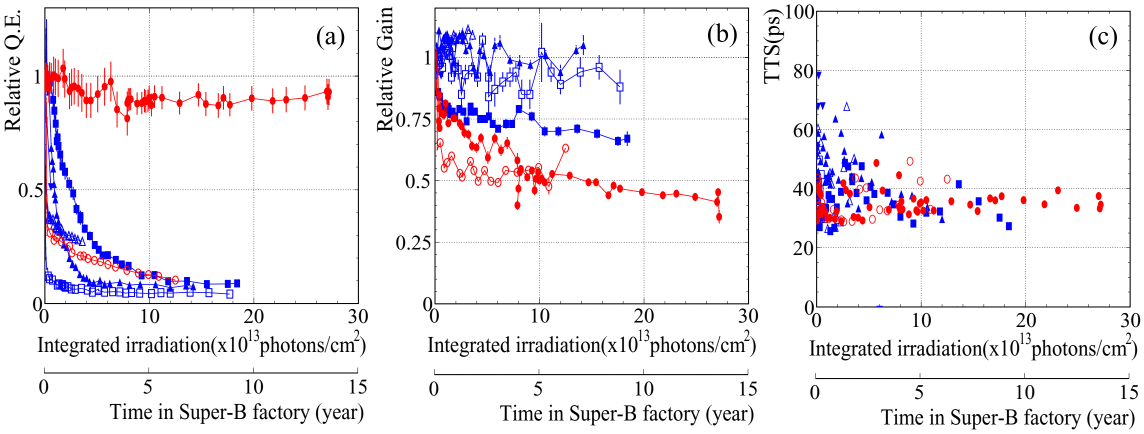

Figure 4: Relative *QE* (a), relative gain (b) and TTS (c) variations under LED irradiation. The marks denote HPK-w (●), HPK-wo (○), BINP-1w (■), BINP-2w (▲), BINP-3w (▼), BINP-4wo (△) and BINP-5wo (□).

The gain is the multiplicated number of charges, evaluated at the peak channel of ADC distribution under single-photon irradiation. Figure 4(b) shows the relative variations of gain as a function of N_γ. All PMTs show a similar behavior, especially, at $N_\gamma > 5 \times 10^{12}$ photons/cm^2. They are quite stable within the observed time period over 4 - 9 super-B years, and no obvious difference between PMTs with and without the protection layers can be found. On the other hand, during the first quarter of one super-B year, the gains of both HPK6's and one BINP8 has dropped greatly, while the other BINP's have not.

The variation of TTS is shown in Figure 4(c). In general, it does not deteriorate with N_γ, but remains stable keeping $\sigma_{\rm TTS} = 30$ - 45 ps, which is because the gain of $O(10^6)$ was maintained.

4. High resolution TOF

As an application of MCP-PMT with the reported good time resolution for single photons, we propose a high resolution TOF counter, which consists of a quartz Cherenkov-radiator and MCP-PMT [5]. In order to reduce the time fluctuation of photon emission, the quartz Cherenkov-radiator is employed, whose emission time is 1 ps or less that is much smaller than the decay-time constant of plastic scintillators, about 2 ns. MCP-PMT provides the time resolution of $\sigma_{\rm TTS} < 50$ ps for single photon. This feature gives a good performance, even though the number of Cherenkov photons are much smaller ($100 \sim 200$ photo-electrons) than that of scintillation lights.

We have carried out a beam-test at KEK-PS using 3 GeV/c pions. The MCP-PMTs for TOF counters are Hamamatsu (HPK) R3809U-50-11X. The quartz radiator of 10 mm$^\phi$ is attached

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in front of the MCP-PMT. Two TOF counters have been located along the beam lime within two trigger scintillation counters, and separated by 30 cm. Trigger counters with scintillators of $5\mathrm{mm}^W \times 5\mathrm{mm}^H \times 10\mathrm{mm}^t$ define the beam position. The output signals of the TOF and trigger counters are directly fed to readout modules, named Time-correlated Single Photon Counting Module (SPC-134 by Becker & Hickl GMbH), which is composed of 4 modules, each of them comprising a constant fraction discriminator, a time-to-amplitude converter, an ADC and a multi-channel analyzer. The time resolution of readout system is evaluated to be $\sigma_{\mathrm{circuit}} = 4.1$ ps. A coincidence between the two trigger counters is prepared to give a stop timing signal for the SPC's. We take a difference between TDC outputs of the two TOF counters in the analysis, so that timing fluctuation of the stop signal is ineffective. As the result, our TOF counters have achieved $\sigma_{\mathrm{TOF}} = 6.2$ ps, or its intrinsic resolution of 4.7 ps by subtracting the readout electronics uncertainty.

5. Summary

We have studied timing properties of 4 different types of MCP-PMTs by irradiating with single photons with/without a magnetic field; resulted time resolutions are σ= 30 - 35 ps for single photons under $B = 1.5$ T. To examine the lifetime of MCP-PMTs, we have measured its basic performance, gain, QE and TTS as a function of the integrated amount of irradiated photons up to 2.8×10^{14} photons/cm^2, corresponding to a 14-year time duration under supposed super-B experimental conditions. The effect of the ion-feedback protection layer is clearly detected. In order to satisfy the use of MCP-PMT with TOP counter under super-B condition, it is found that the MCP-PMT needs the $< 10\mu$m hole size to obtain the gain of $O(10^6)$ and the TTS of ~ 30 ps under $B = 1.5$ T and protection layer to keep the QE.

As an application of such a fast MCP-PMT, a small TOF counter comprised a thin quartz Cherenkov-radiator and a MCP-PMT has been tested using pion beam. The time resolution of σ= 6.2 ps has been attained using 10 mm thick radiator with the 4.1 ps readout jitter.

Acknowledgments

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References

[1] M. Akatsu *et al.*, Nucl. Instr. and Meth. **A 440** (2000) 124-135; T. Ohshima, Nucl. Instr. and Meth. **A 453** (2000) 331-335; T. Ohshima, ICFA Instr. Bull. **20** (2000) 2, (15pages); M. Hirose *et al.*, Nucl. Instr. and Meth. **A 460** (2001) 326-335; S. Matsui *et al.*, Nucl. Instr. and Meth. **A 463** (2001) 220-226; Y. Enari *et al.*, Nucl. Instr. and Meth. **A 494** (2002) 430-435; T. Hokuue *et al.*, Nucl. Instr. and Meth. **A 494** (2002) 436-440; Y. Enari *et al.*, Nucl. Instr. and Meth. **A 547** (2005) 490-503.

[2] S. Hashimoto, (ed) *et al.*, Letter of Intent for KEK Super B Factory, KEK-REPORT-2004-4 (jun 2004).

[3] M. Akatsu *et al.*, Nucl. Instr. and Meth. **A 528** (2004) 763-775.

[4] N. Kishimoto *et al.*, Nucl. Instr. and Meth. **A 564** (2006) 204-211.

[5] K. Inami *et al.*, Nucl. Instr. and Meth. **A 560** (2006) 303-308.

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