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A 30 ps timing resolution for single photons with multi-pixel Burle MCP-PMT

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Abstract - We have achieved ~30 psec single-photoelectron and ~12ps for multi-photoelectron timing resolution with a new 64 pixel Burle MCP-PMT with 10 micron microchannel holes. We have also demonstrated that this detector works in a magnetic field of 15kG, and achieved a single-photoelectron timing resolution of better than 60 psec. The study is relevant for a new focusing DIRC RICH detector for particle identification at future Colliders such as the super B-factory or ILC, and for future TOF techniques. This study shows that a highly pixilated MCP-PMT can deliver excellent timing ersolution.

1. Introduction

The DIRC detector for the BaBar experiment provides excellent particle identification performance [1,2]. We are developing a next generation DIRC, which is capable not only measuring an x&y coordinate of each photon with similar angular resolution to the present BaBar DIRC, but, in addition, each photon's time-of-propagation (TOP [3]) through the Fused Silica bar with ≤150ps timing resolution (the present BaBar DIRC has a timing resolution of only $\sigma \approx$1.6ns). Here we present studies of the limit of the timing resolution of a new 64-pixel Burle/Photonis MCP-PMT with 10μm holes. This tube has been shown to perform well in the magnetic field of 15kG. One expects to achieve better timing

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resolution because the tube is faster than the MCP-PMT tubes with 25μm holes used in the present focusing DIRC prototype[1]. With such tube one could achieve better DIRC performance at shorter photon path lengths.

In addition to RICH applications, there is a new interest to push the TOF performance to new limits approaching $\sigma \approx$5-10ps with new MCP-PMT type of detectors [6,7,8].

2. Photon detector and experimental setup

Figure 1 shows the 64-pixel MCP-PMT 85012-501 used in this study. The tube has 10μm holes, 6x6mm^2 pixel size, and the cathode-to-MCP distance of 6-7mm, which means that the recoiling electrons can land up to ~12mm away from the original point of impact, and this in turn causes a long timing tail. The tail can be eliminated if the gap is reduced to ~0.75mm [4].

Fig. 1. Burle/Photonis "open area" 64-pixel MCP-PMT 85012-501 (S/N 11180401) with 10 μm hole diameter.

The timing resolution study was done on a single pad, illuminated at its center, and connected coaxially to a fast amplifier ~1ns away, while all other pads were grounded; this represents an ideal case. This arrangement was fixed while varying amplifiers of various noise and bandwidth (BW) performance, coupled to two types of constant fraction discriminators (CFD), and LeCroy TDC with 24ps/count – see Table 1.

[1] We obtained σ~54ps in an ideal best case, σ~70-80ps in average case for Burle 85011 MCP-PMT with 25μm holes [4,5].

To do this measurement, we use the PiLas 635nm laser diode,[2] for which the manufacturer quotes a timing resolution of ~35ps FWHM for timing between an internal electrical trigger and a light pulse. The light was attenuated with optical filters and brought to a detector via a multi-mode 62.5μm dia. fiber, equipped with lenses at both ends to make a small sub-mm spot on the photocathode. For some measurements we tried to improve the timing resolution by triggering on light, which was achieved by an optical splitter and feeding one branch to a 2GHz bandwidth Si diode. No improvement was achieved compared to the PiLas electronic trigger.

3. Single photoelectron timing resolution

Figure 2 shows the best single photoelectron timing resolution results: $\sigma \approx 32 \pm 0.6$ps with both Hamamatsu 1.5GHz BW and Ortec VT120A ~0.4GHz BW amplifiers. The resolution was evaluated with a double-Gaussian fit function. Table 1 summarizes all results with other amplifier choices. As we pointed out in footnote 1, the best ever single photoelectron timing resolution obtained with the MCP-PMT with 25μm holes was $\sigma \approx 54 \pm 4$ps [4, 5].

The overall conclusion is that in the "single-photoelectron domain," it is sufficient to have a relatively slow amplifier (~0.4GHz BW) to achieve a timing resolution of $\sigma \approx$32ps, provided that its noise performance is good, and the amplifier is fast enough to follow fast pulses from the MCP-PMT. For example, a combination of two Elantek chips with an overall voltage gain of 130x with a rise time of ~1.5ns is too slow for this type of tube, althouh such speed is sufficient for MCP-PMT with 25μm hole diameter – see Table 1 for various examples.

For comparison, it is interesting to point out that the best result we have achieved in the same setup with a Geiger mode APD (G-APD or SiPMT) was $\sigma_{narrow} \approx$38ps and $\sigma_{wide} \approx$111ps [4]. This indicates that the new vacuum Burle MCP-PMT competes well with a G-APD performance.

[2] PiLas laser diode is made by Advanced Laser Diode Systems, D-12489 Berlin, Germany.

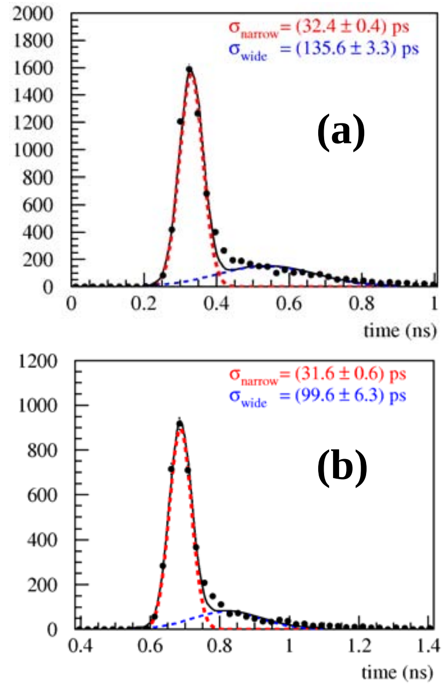

Fig. 2. Single photoelectron timing resolution in Burle 64-pixel MCP-PMT 85012-501 with 10 µm hole diameter, and B = 0kG, using (a) Hamamatsu C5594-44 1.5GHz BW amplifier, and (b) Ortec VT120A ~0.4 GHz BW amplifier.

4. Single photoelectron timing resolution at 15kG

This particular measurement was performed with Burle 4-pixel MCP-PMT 85001-501 P01 with 10 µm hole diameter (a different tube than the tube used for the rest of the measurement in this paper). The MCP-PMT was placed in a dipole capable of reaching ~15kG. The magnetic field direction was nominally perpendicular to MCP face, however, this angle could be changed in small steps up to an angle of 15^{o}. We have achieved the timing resolutions close to $\sigma \approx$50ps at 2.7kV (~150V lower than allowed maximum voltage, which means we have not reached the best possible limit of the resolution) – see Fig. 3. The measurement was made using the Ortec VT120A amplifier with a voltage gain of 200x (in this case we did not use a 6 dB att.). Larger amplifier gain was necessary in this case as there is a large MCP gain drop at higher magnetic field (more than a factor of five as one goes from B = 0kG to B = 15kG).

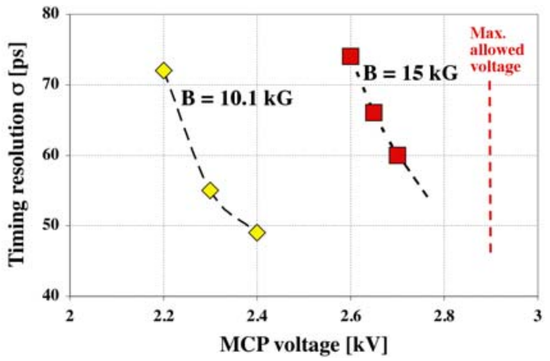

Fig. 3. Single photoelectron timing resolution using Ortec VT120A ~0.4GHz BW amplifier connected to Burle 4-pixel MCP-PMT 85001-501 P01 with 10 µm hole diameter, and B = 10.1 & 15 kG.

We also found that the MCP can be tilted by 3-5^{o} (angle between a normal to the MCP face relative to the field axis) with no effect on the pulse height. At 10^{o}, one observes a factor of two in reduction of the pulse height, i.e., the tube can still be used. However, above 15^{o} angle, the pulse height is reduced by a factor of ten.

5. Multi-photoelectron timing resolution

The aim of this measurement was (a) to determine the electronics contribution to the measurements shown in Fig. 2, and (b) to investigate the limit of the MCP-PMT resolution for a larger number of photoelectrons, a region relevant to the TOF counters.

Fig. 4 shows that the limiting resolution is reached for Npe >20 photoelectrons, and is $\sigma \approx$13ps for Hamamatsu 1.5GHz BW, and $\sigma \approx$24ps for the Ortec VT120A ~0.4GHz BW amplifiers. No matter how hard we tried, we could not reduce the 24ps resolution. We conclude that in the "multi-photoelectron domain" the speed of the amplifier is crucial. One is tempted to follow a simple explanation: the expected timing resolution with a CFD discriminator is $\sigma_t \approx \sigma_A/(ds_o/dt)_{t=0}$, where σ_A and $(ds_o/dt)_{t=0}$ are the noise and the slope measured at the zero-crossing point. Based on these measurements we would then expect to obtain $\sigma_t \approx$12ps for the Hamamatsu amplifier, and $\sigma_t \approx$17ps for the Ortec

VT120A amplifier. However, reality in the "10ps resolution domain" is more complicated as t resolution is fine tune of signal/noise ratio, detector response, amplifier and CFD bandwidths, amplifier pulse shape uniformity (partial saturation), CFD delay, CFD threshold, amplifier-to-CFD delay, TDC resolution, TDC diff. linearity, wiring impedance, thermal drifts, ground loops, etc.

Although the resolution in Fig. 4b is constant for Npe >20, there is a walk of the mean value even with the CFD discriminator, and therefore it is necessary to measure a pulse height (ADC), if Npe is varying in a real application. One is therefore tempted to conclude that a simple discriminator coupled to a TDC with an ADC off-line correction is sufficient to do a good timing in a practical application.

Acknowledgments

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References

[1] I. Adam et al., "Particle Identification System for the BaBar experiment," Nucl. Instr.&Meth., A538(2005)281-357.

[2] B.N. Ratcliff, Nucl. Instr.&Meth., A502(2003)211.

[3] Definition: TOP(Φ, θ_c, λ) = [L/$v_g(\lambda)$] $k_z(\Phi,\theta_c)$, θ_c - Cherenkov angle, L - distance of light travels in the bar, $v_g(\lambda)$ - group velocity of light, λ - photon wavelength, and $k_z(\Phi,\theta_c)$ - z-component of the unit velocity vector.

[4] C. Field, T. Hadig, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff, J. Schwiening, J. Uher and J. Va'vra, "Development of photon detectors for a fast focusing DIRC," Nucl. Instr.&Meth., A553(2005)96-106.

[5] C. Field, T. Hadig, M. Jain, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff, J. Schwiening, and J. Va'vra, "Novel photon detectors for focusing DIRC prototype," Nucl. Instr.&Meth., A518(2004)565-568.

[6] M. Akatsu et al., "MCP-PMT timing property for single photons," Nucl. Instr.&Meth., A528(2004)763-775.

[7] "10 ps workshop," Arlington, TX, USA, March 28, 2006, organizer A. Brandt.

[8] T. Credo et al., "Picosecond TOF measurement for Colliders using Cherenkov Light," IEEE Nucl. Sci. Conference Recorfs, Vol. 1, 16 Oct., 2004.

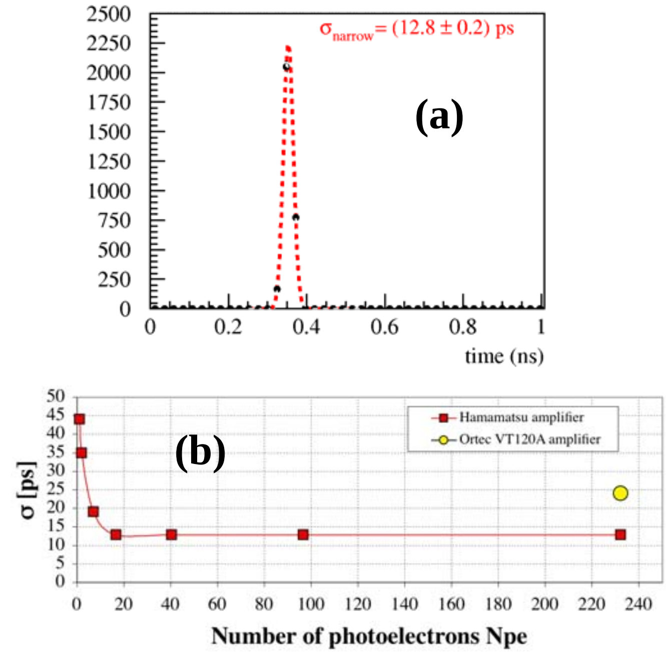

Fig. 4. Multi-photoelectron timing resolution using Ortec VT120A ~0.4GHz BW amplifier connected to Burle 64-pixel MCP-PMT 85012-501 with 10μm hole diameter, and B = 0kG, for (a) Npe ~232, and (b) varying Npe.

Table 1

Single photoelectron timing resolution = f (amplifier bandwidth) for 64-pixel MCP-PMT with 10μm holes, at 2.80kV, and B = 0kG

Amplifier type	Bandwidth [GHz]	Total voltage gain	V_{pp} Noise/Signal [mV]	CFD type	Resolution σ_{narrow}, σ_{wide} [ps]	Comment
Ortec VT120A + 6dB att.	~0.4	100x	~1/450	Phillips 715	32, 100	The best result
Hamamatsu C5594-44	1.5	63x	1-2/450	Phillips 715	32, 135	Very good
Ortec 9306	1.0	100x	~8/400	Ortec 9307	43, 134	Worse S/N
Tandem of 2 THS-4303[a]	~0.5	30-40x	~8/200	Phillips 715	47, 120	Fast, but bad S/N
Tandem of 2 Elantek-2075[b]	~0.2	130x	~10/50	Phillips 715	-	Slow, bad S/N

[a]THS-4303 and Elantek-2075 chips have a bandwidth of 1.5GHz for a gain of 10x.