Jefferson Lab Technical Note JLAB-TN-98-006

Effect of P-Terphenyl Coating to the Quantum Efficiency of Burle 8854 Photomultiplier Tubes

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February 17, 1998

Abstract

The efficiency of Burle 8854 photomultiplier tubes coated with the organic wavelength shifter p-Terphenyl was tested. It was found that a reasonable coating increases the quantum efficiency by about 40%. However, a too thick coating inverts this effect by photon absorption in the coating.

1 Introduction

Hall A uses two high resolution magnetic spectrometers [1] for particle detection. Select types of detectors are used for timing, particle tracking, polarization and particle identification purposes. Two CO_2 gas Čerenkov detectors [2] are utilized to distinguish electrons/positrons from heavier particles. Čerenkov light produced in the gas is detected by several photomultiplier tubes (PMT). Since the energy spectrum of that radiation goes with $1/\lambda^2$ [3] Burle 8854 PMT's [4] were chosen. Their spectral response ranges from 220 to 660 nm with a maximum quantum efficiency at about 360 nm. To enhance this efficiency a group from INFN Sanita (F. Garibaldi) organized the coating of the PMT entrance windows with p-Terphenyl which acts as a wavelength shifter [5]. This organic material absorbes ultraviolet light (UV) in the range from 110 to 360 nm and emits at about 385 nm, increasing the photon yield in the sensitive range of the PMT.

However, since some of the PMT's shipped back from coating looked like there was white paint on them, it was suspected that the coating was too thick, relating to less translucence, i.e. less efficiency. For testing a setup was used comparable to the setup described by Shepherd and Pope [6]. It is sketched in Fig. 1, the electronics is depicted in Fig. 2. As an electron emitter a ^{90}Sr source of 1 μCi strength was used, emitting electrons with a maximum kinetic energy of 2.27 MeV. The electrons emitted Čerenkov light when passing through a thin fused Silica window (thickness = 3 mm, refractive index = 1.46@500 nm) [7] placed directly in front of the source. The electrons were detected in a plastic scintillator, equipped with a 2" photomultiplier (Hamamatsu). The Čerenkov light was reflected by two mirrors (aluminized Mylar foils on frames) into the 5" PMT to be tested. To avoid light contamination from the scintillator, the scintillator and the 2" PMT were wrapped together in black nontransparent foil. It was tested to be light tight.

This setup was chosen because it is quite similar to the conditions in the gas Čerenkov detector. Though the β of the electrons is less than one, the $1/\lambda^2$ spectral distribution of the produced Čerenkov light is independent of β. However, this spectrum was modified by the fused Silica window. The transmission drops at wavelengths below 200 nm and the window is almost intransparent at 150 nm. Thus, some of the produced photons, which would have

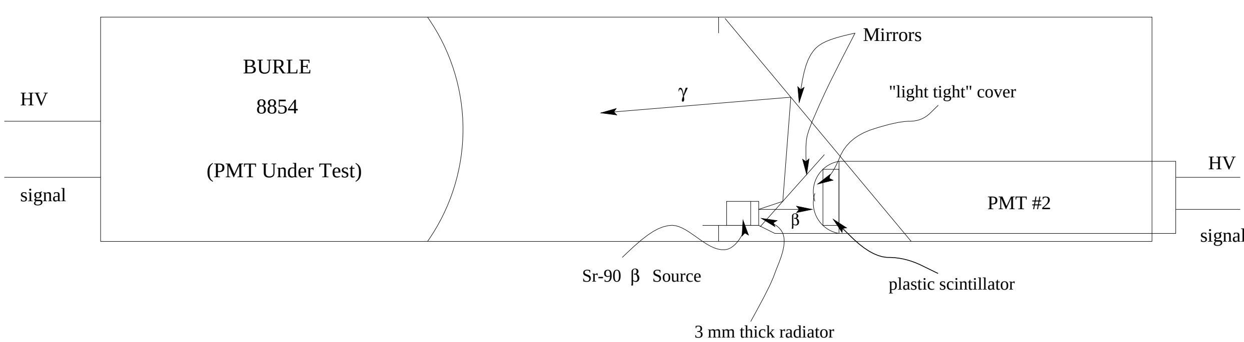

Figure 1: Schematic sketch of the test setup. Electrons from the ^{90}Sr source emit Čerenkov radiation on passing a fused Silica window. The electrons were detected in a 2" PMT, in coincidence with the Čerenkov light reflected by two mirrors onto the 5" PMT to be tested.

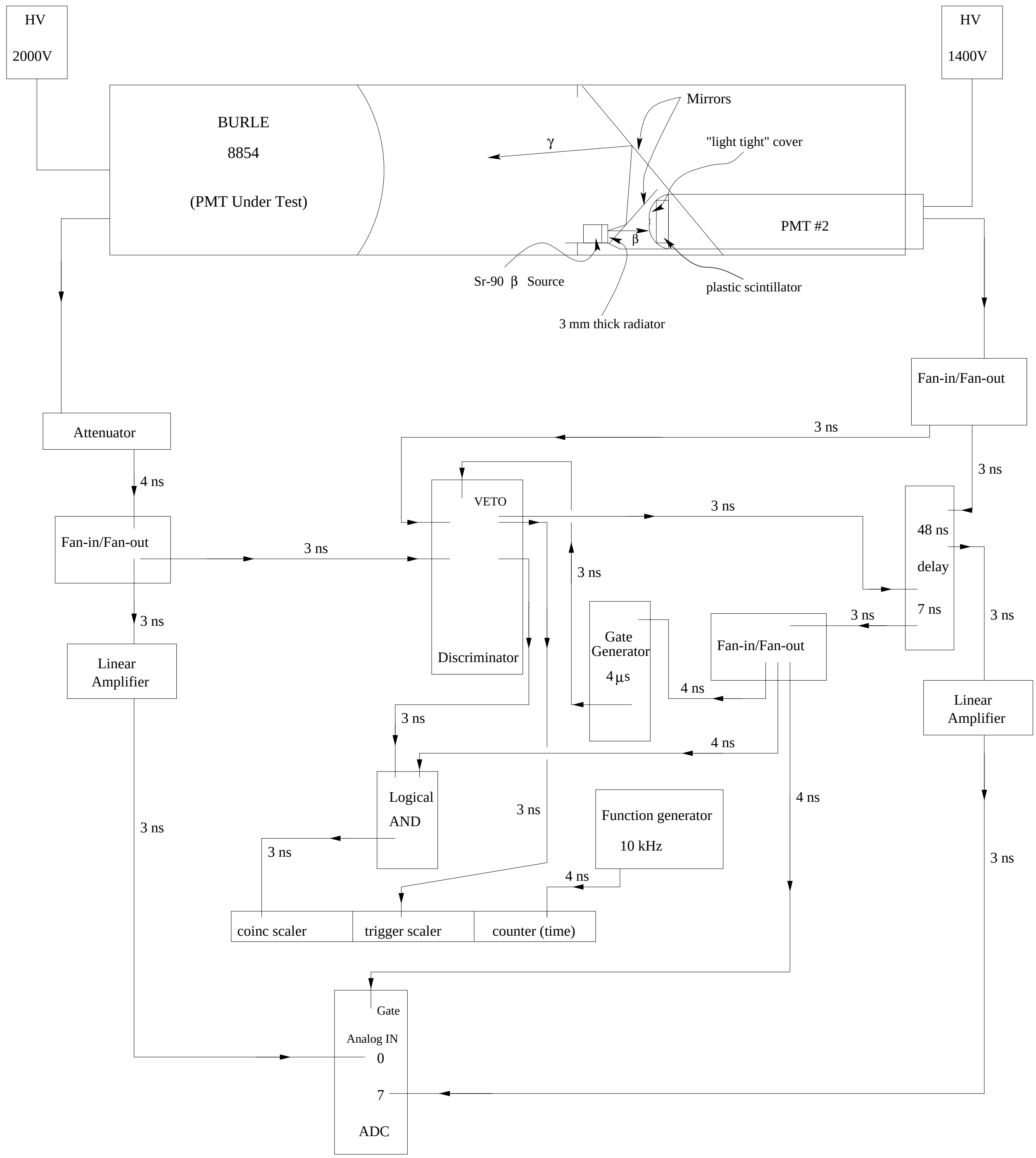

Figure 2: Electronic setup. The signals of the 5” and the 2” PMT were fed into a discriminator. The data acquisition was triggered by the 2” signal. Afterpulses were inhibited using a 4 μs signal from a gate generator.

been absorbed by the p-Terphenyl and shifted to larger wavelengths, were lost. Anyway, the setup established a test of the capabilities of p-Terphenyl coated PMT's, which should show a somewhat better performance under realistic conditions.

The signals of both PMT's were fed into a discriminator. The data acquisition was triggered by the 2" signal. Afterpulses were inhibited using a $4\,\mu$s signal from a gate generator. The program KMAX running on a Macintosh read out the ADC and displayed graphically the data on the screen.

To keep constant conditions, the 2" PMT was always operated at a voltage of 1400 V. The measurement was not started unless the dark noise (a spectrum versus time is shown in Ref. [6]) in both tubes was negligible. This was checked by counting the number of triggers and of coincidences on scalers, the time accumulated was measured counting the pulses of a function generator. After these rates had converged from a higher level to saturation at lower rates, the measurement was started. The high voltage of the 5" PMT was adjusted to produce the one-photoelectron (1pe, i.e. the pulse of photons generates exactly one single photoelectron on the photocathode) peak with an accumulated charge of about 20 pC. Because the ADC used (Le Croy 2249W) had a gain of 0.25 pC/count the peak was expected to show up at channel 80. Figure 3 shows the ADC spectrum of the Burle PMT #C68336. The peak around channel 80 is the 1pe-peak, the strength at larger channels is due to two or more photoelectrons emitted off the photocathode. The origin of the events at lower channel numbers is discussed in Ref. [6].

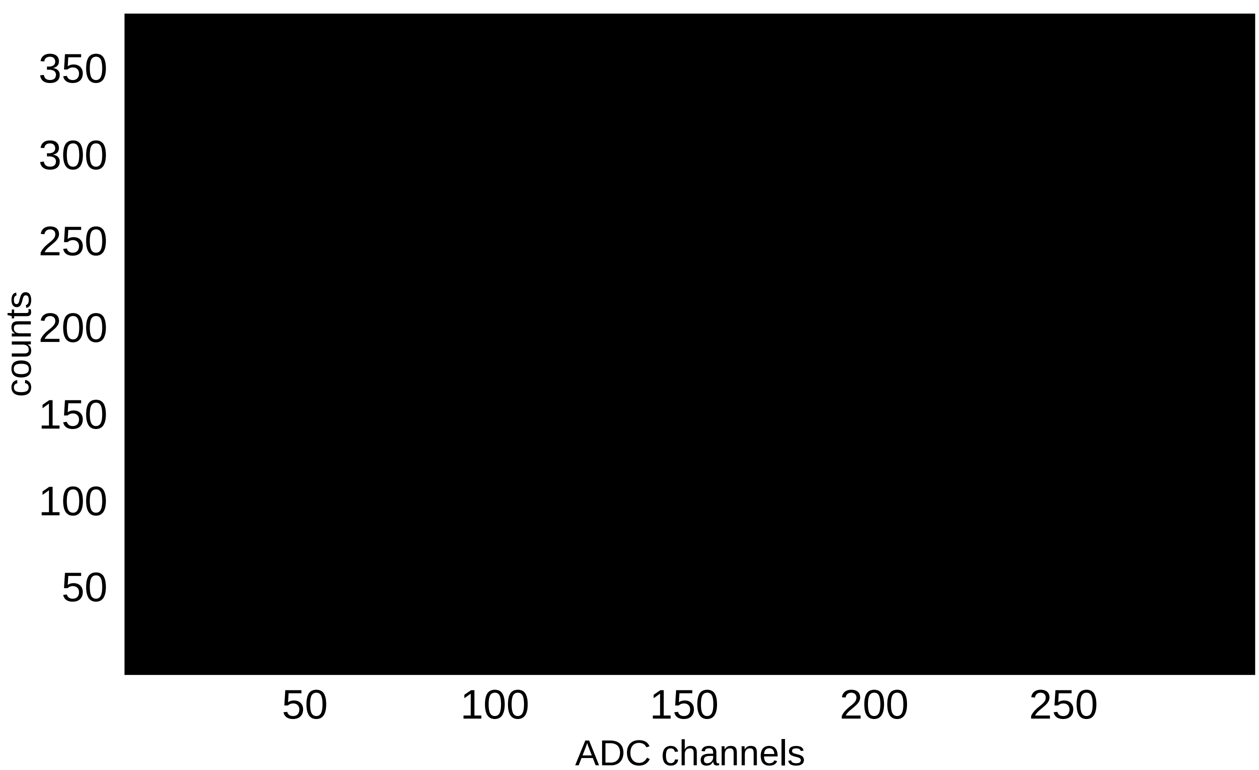

Figure 3: ADC spectrum of the Burle PMT #C68336. The peak at channel 80 is the one-photoelectron peak.

Because the PMT's were not tested before coating, the efficiency could not be determined absolutely. The position of the 1pe-peak was determined by fitting. A cut was applied to the spectrum at the channel at 30% of the 1pe-peak channel. Everything on the right of this channel was considered "good" events. The efficiency was defined as the number of "good" events divided by the total number of counts:

$$\text{efficiency} = \frac{\text{number of “good” events}}{\text{total number of counts}} \tag{1}$$

2 Results

As mentioned before, the p-Terphenyl coated PMT's occasionally looked painted white. After testing a few PMT's a correlation between optical appearance and measured efficiency was suggested. Thus, the PMT's were sorted into five categories, based on the saturation of the coating, from 0 (not coated) to d (opaque). The notation is shown in Tab. 1.

code	description
0	uncoated
a	coated, hardly cloudy
b	coated, cloudy
c	coated, almost opaque
d	coated, opaque

Table 1: Notation of visual appearance of the PMT's, sorted in ascending order of saturation from 0 (not coated) to d (opaque).

In Tab. 2 the results are grouped into these categories. Because the notation was modified (finer steps) during testing but could not be applied to the PMT's tested first (which were immediately installed) groups a and b are not distinguished in Tab. 2. To repeat, since the efficiency was not tested for each PMT before and after coating, a gain of the efficiency of each PMT cannot be given. However, the average efficiency of each group should be a measure of the gain. The uncoated PMT's, a number of five, have efficiencies in the range of 7.0 to 9.5, with an average of 8.8. Compared to this number, the groups of "hardly cloudy & cloudy" and "almost opaque" PMT's show a gain of efficiency, while the "opaque" group is somehow unchanged, as far as that can be concluded from testing only three PMT's. The PMT's of the "a-b" group show a 40% higher efficiency than the uncoated ones, a clear message that p-Terphenyl coating increases the efficiency of PMT's used for the detection of Čerenkov light. However, the more opaque the coating turns out the less the gain is. It seems the effect of gaining visible photons by converting UV light is countered by the absorption of visual light in the coating, which indeed is visually opaque.

PMT serial number	Voltage (V)	efficiency (a.u.)	transparency
77604	2020	9.5±0.2	0
F93880	2130	9.4±0.2	0
F93882	2120	8.0±0.2	0
N93633	2060	9.3±0.2	0
N95002	2260	7.8±0.2	0
average 8.8			
C65093	1980	12.9±0.2	b
C68335	1960	8.4±0.2	a
C68336	1960	11.8±0.2	a-b
C68339	2150	13.2±0.2	b
J85456	2040	12.3±0.2	a
J94787	2060	10.0±0.2	a-b
J94788	2020	11.6±0.2	a
J99241	2030	12.6±0.2	a
J99252	1990	12.3±0.2	a-b
N27702	2070	17.4±0.2	a-b
N90861	1990	13.0±0.2	a
V26079	2030	13.5±0.2	a-b
average 12.4			
C65094	1980	10.7±0.2	c
J92743	2010	11.1±0.2	c
J94786	1950	8.5±0.2	c
J94791	2017	8.7±0.2	c
J99248	2060	11.9±0.2	c
average 10.2			
32P100X55	2180	7.1±0.2	d
J81255	2060	10.5±0.2	d
V26393	2160	7.1±0.2	d
average 8.2			

Table 2: Efficiency of all PMT's, grouped by visual appearance, as shown in the last column. In the first column the serial number is given, in the second the applied voltage, and in the third the obtained efficiency. The error of 0.2 includes both statistics and systematics.

3 Conclusion

P-Terphenyl coating enhances the efficiency of Burle 8854 PMT's for UV light by about 40%. A thick coating counters this effect due to absorption of visual light. Thus, a first selection can be made by visual inspection directly after coating. Of the twelve PMT's of group "a-b" only four had an efficiency less than 12. The only other PMT hardly reaching that number was #J99268 with 11.9. Because the PMT's are coated off site and have to be shipped to Jefferson Lab for testing, identifying unreasonable coating directly at the contractor will enable an immediate retry of the coating and thus speed the process up.

A Tested photomultiplier tubes

For easier reference, Tab. 3 lists all PMT's tested sorted by the serial number.

PMT serial number	Voltage (V)	1pe-peak channel	efficiency (a.u.)	transparency
32P100X55	2180	81	7.1±0.2	d
V26079	2030	86	13.5±0.2	a-b
V26393	2160	75	7.1±0.2	d
N27702	2070	82	17.4±0.2	a-b
N32161		broken		d
C65093	1980	81	12.9±0.2	b
C65094	1980	81	10.7±0.2	c
C68335	1960	82	8.4±0.2	a
C68336	1960	76	11.8±0.2	a-b
C68339	2150	79	13.2±0.2	b
77604	2020	83	9.5±0.2	0
J81255	2060	81	10.5±0.2	d
J85456	2040	79	12.3±0.2	a
N90861	1990	81	13.0±0.2	a
J92743	2010	76	11.1±0.2	c
N93633	2060	78	9.3±0.2	0
F93880	2130	81	9.4±0.2	0
F93882	2120	79	8.0±0.2	0
J94786	1950	76	8.5±0.2	c
J94787	2060	81	10.0±0.2	a-b
J94788	2020	86	11.6±0.2	a
J94791	2017	80	8.7±0.2	c
N95002	2260	72	7.8±0.2	0
J99241	2030	79	12.6±0.2	a
J99248	2060	85	11.9±0.2	c
J99252	1990	84	12.3±0.2	a-b

Table 3: List of all PMT's tested. The first column is the serial number, second the applied voltage, third the position of the one-photoelectron peak, fourth the determined relative efficiency and the last column the visual appearance, as given in Tab. 1. The error is as given in Tab. 2.

References

[1] Hall A Operations Manual, Ed. S. Nanda, http://www.jlab.org/Hall-A/document/OPMAN/index.html, and printed version

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[3] Claus Grupen, *Particle Detectors*, Cambridge University Press, 1996, pp. 193

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[5] E.L. Garwin, Y. Tomkiewicz, and D. Trines, *Method for Elimination of Quartz-Face Phototubes in Čerenkov Counters by Use of Wavelength-Shifter*, Nucl. Inst. and Meth. 107 (1973) 365

[6] M. Shepherd and A. Pope, TJNAF technical report 97-028, *Investigation of BURLE 8854 Photomultiplier Tube*, August 26, 1997

[7] OptoSigma Catalog 1997/98, http://www.optics.org/optosigma/windows/fusedsilicaw.html