Journal logo

Terrestrial Magnetic Field Effects on Large Photomultipliers

E. Leonora *

on behalf of the KM3NeT Consortium

INFN section of Catania, Via S.Sofia, 64, Catania, 95125, Italy

Elsevier use only: Received date here; revised date here; accepted date here

Abstract

The effects of the Earth's magnetic field on the performance of large PMTs for a cubic-kilometer-scale neutrino telescope has been studied. Measurements were performed for three Hamamatsu PMTs: two 8" R5912 types; one with a standard and the other with a super bialkali photocathode, and a 10" R7081 type with a standard bialkali photocathode. The main characteristics of the PMTs, such as detection efficiency, transit time, transit time spread, gain, peak-to-valley ratio, charge resolution and fractions of spurious pulses were measured while varying the PMT orientations with respect to the Earth's magnetic field. The measurements were performed both with and without a mu-metal cage magnetic shielding. For the 8" PMTs the impact of the magnetic field was found to be smaller than for the 10" PMT. The magnetic shielding strongly reduced the orientation-dependent variations measured for the 10" PMT and even improved the performance. Although less pronounced, improvements were also measured for the 8" PMTs.

PACS: 85.60.Ha;
Keywords: Large area photomultiplier; magnetic shielding; Earth's magnetic field

1. Introduction

The performance of a large area photomultiplier tube (PMT) is subject to significant variation due to magnetic fields, in particular of the long trajectories of electrons from the photocathode to the anode [1]. The main effect is de-focalization of the photoelectrons arriving at the first dynode, which affects timing properties, such Transit Time (TT) and Transit Time Spread (TTS), and even the energy of photoelectrons hitting the first dynode. This has an influence on detection efficiency, gain and peak to valley ratio of the PMT [2]. A secondary effect is the deviation of electron trajectory in the amplification chain, in particular between first and second dynodes, can also contribute to the decrease of the gain and to the degradation of the charge spectrum. With this in mind, the influence of the Earth's magnetic field on large area PMT candidates for a cubic-kilometer-scale neutrino telescope was measured within the

Corresponding author. Tel.: +390953785285; ; e-mail: emanuele.leonora@ct.infn.it

framework of the KM3NeT design study [3], in order to evaluate variations in PMT performance and to decide whether the use of magnetic shielding is necessary in the design of an optical module containing a single large area PMT. In this study, three large PMTs produced by Hamamatsu were measured. Two were R5912 types, with an 8” photocathode, and 10 stages. One of these (8” STD) had a standard bialkali photocathode (QE≈25% @ 400nm), while the other (8” HQE) had a super-bialkali photocathode (QE≈ 32% @ 400nm). The third PMT was a R7081 type, with a 10” standard bialkali photocathode (10” STD) and the same dynode structure as the R5912 [4].

2. Experimental procedure and setup

PMT responses to an injected light were measured while varying the orientation and inclination of the PMT relative to the Earth’s magnetic field. First, the performance of "naked" PMTs without magnetic shielding was measured. To this purpose, a light-tight dark box (1x0.5x0.5m) was constructed that can be rotated horizontally and of which the inclination can be changed. A laser source (Picoquant PDL 800-B) attenuated to the condition of single photo-electrons was used, with a head of 410nm wavelength which emitted light pulses of 50 ps FWHM. The laser was pulsed at a frequency of 10 KHz using an external generator. A second fixed PMT was used as monitor of the light source stability. An optical diffuser (Thorlabs, D1-C50 [5]), provided homogeneous illumination over the photocathode.

The measured values of the Earth’s magnetic field in the area selected for the box were around 40 micro-Tesla. The magnetic shield used was a wire cage, made of 1 mm diameter wire of mu-metal [6], composed of a hemispherical part and a second flat part with a central hole for the neck of the PMT. The shadowing effect on the photocathode was calculated to be less than 4%. The magnetic reduction factor inside the volume of the cage was measured with an average value of 4. Three PMT inclinations were studied: vertically downwards (Tilt=0°), horizontal (Tilt=90°) and 50 deg downwards (Tilt=50°). For each inclination, the PMT under test was rotated 360° in the horizontal plane in 30° steps. All PMTs were powered using an ISEG PMT active base (type PHQ7081-i-2m), and set at the same gain condition of 1.5 10^7, for supply voltages of around 1650V.

3. Measurements and results

For each PMT position, the detection efficiency, gain, peak to valley (P/V) ratio, charge resolution, TT and TTS were measured simultaneously. The fraction of spurious pulses was also measured.

Tables 1-6 show the measured values. For all sets of measured parameters, the average values are given, together with the percentage of the variation, calculated as the percentage of the difference between maximum and minimum value, divided by the average value.

3.1 Detection Efficiency

The ratio between the number of detected pulses and the number of pulses emitted by the laser source defines the detection efficiency. Figure 1 shows the detection efficiency for the three PMTs vertically inclined (tilt=0°) as a function of orientation, with and without the mu-metal cage. Table 1 summarizes the measurements at the three different inclinations. Values were normalized to the maximum over all measurements.

Efficiency		**naked**			**shielded**		
Tilt		**8'' STD**	**8'' HQE**	**10'' STD**	**8'' STD**	**8'' HQE**	**10'' STD**
0°	**Ave**	0.80	0.91	0.89	0.80	0.93	0.97
	Var$_{\%}$	13.08	6.63	22.51	3.27	1.39	6.27
50°	**Ave**	0.73	0.87	0.76	0.77	0.93	0.97
	Var$_{\%}$	22.15	15.68	48.82	3.89	4.28	5.75
90°	**Ave**	0.70	0.82	0.66	0.76	0.93	0.95
	Var$_{\%}$	2.86	3.67	15.27	1.59	2.37	1.79

Table 1. Detection efficiency measurements

In the “naked” 8” PMTs the impact of the magnetic field was smaller than that measured in the “naked” 10” PMT. The use of the magnetic shield reduces considerably the variations for the 10” PMT. The increased Quantum Efficiency (QE) in the HQE

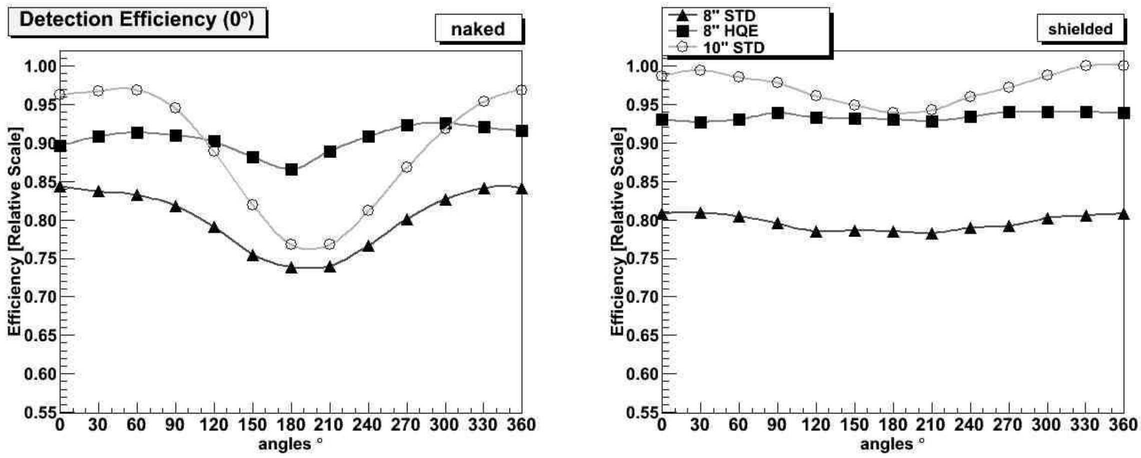

Fig. 1. Detection efficiency for PMTs vertically inclined (Tilt = 0°). On the left: PMTs naked. On the right: PMTs shielded°

8" PMT seems to compensate the smaller detection area with respect to the 10" PMT.

3.2 Charge Properties

The single photo-electron charge spectrum was acquired for each PMT using a calibrated charge-amplitude converter (mod. 7422 SILENA). Table 2 shows the results for each set of gain measurements.

Gain [1xE7]		naked			shielded		
Tilt		8'' STD	8'' HQE	10'' STD	8'' STD	8'' HQE	10'' STD
0°	**Ave**	1.51	1.63	1.50	1.59	1.63	1.56
	Var%	9.33	10.46	17.32	3.40	4.49	6.85
50°	**Ave**	1.45	1.64	1.35	1.56	1.67	1.53
	Var%	10.18	5.00	31.80	3.97	4.50	6.88
90°	**Ave**	1.42	1.60	1.35	1.54	1.64	1.52
	Var%	8.04	8.48	30.68	3.30	3.72	5.79

Table 2. Gain measurements

The variation in gain in the three orientations was less than 10% for both "naked" 8" PMTs, and considerable (up to 30%) in the case of the "naked" 10" PMT. The magnetic shield reduces variations in both 8" PMTs, with larger effect in the case of the 10" PMT. Considering the P/V ratio (Table 3), considerable variations for all the PMTs were measured without the shield. Significant reductions of these variations were seen with the magnetic shield, with a small improvement in the average values.

P/V ratio		naked			shielded		
Tilt		8'' STD	8'' HQE	10'' STD	8'' STD	8'' HQE	10'' STD
0°	**Ave**	2.19	2.15	1.61	2.41	2.22	1.90
	Var%	32.34	23.93	37.27	11.86	10.28	15.39
50°	**Ave**	1.92	1.93	1.39	2.30	2.22	1.83
	Var%	34.01	27.94	53.10	11.60	9.64	14.95
90°	**Ave**	1.73	1.77	1.21	2.24	2.12	1.76
	Var%	15.50	9.97	17.16	6.34	7.18	10.95

Table 3. Peak to Valley ratio measurements

With regard to the charge resolution measurements (Table 4), the large effects due to the magnetic field measured for the "naked" 10" PMT were largely reduced through use of the magnetic shield.

Charge Res. %		naked			shielded		
Tilt		8'' STD	8'' HQE	10'' STD	8'' STD	8'' HQE	10'' STD
0°	**Ave**	49.31	55.59	64.18	46.02	55.66	57.90
	Var%	17.18	14.57	47.35	10.28	9.13	23.56
50°	**Ave**	51.66	55.78	87.38	46.63	54.70	60.49
	Var%	17.98	13.36	73.81	9.80	9.98	22.62
90°	**Ave**	53.24	57.51	97.73	46.98	55.89	62.70
	Var%	16.23	15.11	68.13	6.34	10.73	13.05

Table 4. Charge resolution (sigma) measurements

3.3 Time Properties

The results for TT on “naked” PMTs (Table 5), although not showing significant variations due to magnetic field, were slightly improved through the use of the mu-metal cage. Considering the TTS, calculated as FWHM, large variations for all “naked” PMTs were measured (Table 6). Strong reduction of these variations was seen with the magnetic shielding, but it was not accompanied by significant improvement of average values.

TT [ns]		**naked**			**shielded**		
Tilt		**8'' STD**	**8'' HQE**	**10'' STD**	**8'' STD**	**8'' HQE**	**10'' STD**
0°	**Ave**	103.0	101.6	110.0	103.0	101.6	109.9
	Var$_{\%}$	0.49	0.27	0.52	0.24	0.05	0.16
50°	**Ave**	103.3	101.9	110.1	103.2	101.5	110.1
	Var$_{\%}$	0.56	0.25	0.37	0.23	0.13	0.26
90°	**Ave**	103.5	101.8	110.3	103.2	101.7	110.1
	Var$_{\%}$	0.21	0.34	0.38	0.11	0.03	0.25

Table 5. Transit Time measurements

TTS [ns]		**naked**			**shielded**		
Tilt		**8'' STD**	**8'' HQE**	**10'' STD**	**8'' STD**	**8'' HQE**	**10'' STD**
0°	**Ave**	2.40	2.27	3.34	2.29	2.17	3.13
	Var$_{\%}$	22.13	11.88	15.28	7.85	5.52	1.60
50°	**Ave**	2.58	2.35	3.25	2.44	2.18	3.14
	Var$_{\%}$	16.69	12.74	11.07	8.20	4.14	4.14
90°	**Ave**	2.66	2.42	3.24	2.47	2.24	3.15
	Var$_{\%}$	10.52	7.43	10.18	5.67	1.79	5.72

Table 6. Transit Time Spread measurements (FWHM).

3.4 Fraction of Spurious Pulses

Spurious pulses are noise pulses, time-correlated with the PMT main response, which can be categorized into four different groups according to their causes and arrival times [7]: pre-pulses , delayed pulses, type 1 and type 2 after pulses. The percentage of spurious pulses with respect to the number of true pulses was measured for each of these groups. No significant magnetic field effects on the fraction of pre-pulses were measured. Considerable variation in delayed pulse fraction was measured only for the “naked” 10” PMT which was significantly reduced by the mu-metal cage. In the case of type 1 and type 2 after pulses, no significant variations due to magnetic field were measured. Moreover, the standard bialkali 8” and 10” PMTs had similar fractions of type 1 and 2 after pulses, while the super bialkali photocathode 8” PMT had a larger fraction of type 1 and type 2 after pulses [8].

4. Summary

The influence of the Earth’s magnetic field on performance of three large photocathode area (8” and 10”) Hamamatsu PMTs was measured with and without magnetic shielding. Results confirmed that the performance of large area PMTs is significantly affected by orientation with respect to the Earth’s magnetic field. For the 8” PMTs the impact of the magnetic field was found to be smaller than in the 10” PMT. The magnetic shield significantly reduced the rotation and orientation-dependent performance variations in the 10” PMT and improved its performance. Less improvements were also seen in the case of 8” PMTs. The increased QE in the super bialkali 8” PMT almost compensates its smaller detection surface compared to the 10” PMT. No significant magnetic effects were measured on Transit Time and on the fraction of spurious pulses.

Acknowledgment

The KM3NeT project is supported under EU FP6 Contract no. 011937 and FP7 Grant agreement no. 212525. The author thanks O. Kalekin, P. Keller and P. Vernin for their presence and technical support at the start of this work.

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