Study of Photomultiplier Tubes for the ANTARES Neutrino Telescope

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Abstract

The ANTARES Collaboration [4] is deploying a high-energy neutrino telescope in the Mediterranean sea. The Cherenkov light emitted by the muon produced in the charged current neutrino interaction will be detected by a matrix of photomultipliers (PMTs), housed in pressure-resistant glass spheres. Since PMTs are a key element of the detector, intensive R&D studies have been carried out on several models. An analysis based on the physical parameters relevant for underwater neutrino experiments like ANTARES provided the criteria for choosing a large hemispherical PMT. After a pre-selection stage, three models were studied in detail: Hamamatsu R7081-20, Photonis XP1804/D2 and Hamamatsu R8055. This contribution reports on a series of exhaustive tests which were performed at CPPM (Marseilles), DAPNIA (Saclay) and IFIC (Valencia) to measure properties such as gain, transit time spread, effective area, dark noise, peak to valley ratio, afterpulsing and ageing. Moreover, a large sample of the PMT model finally selected (Hamamatsu R7081-20) has been characterized. Some of these photomultipliers have already been installed in the so-called "Sector Line" [5], which will soon yield the first data.

1. Introduction

The ANTARES neutrino telescope will consist of a 3D matrix of photomultipliers which will detect the Cherenkov light emitted by the muon produced in the charged current interaction of a high energy neutrino. This detector is intended as a proof of feasibility of a larger telescope ($\sim$1 km^2). The scientific program of ANTARES includes the study of astrophysical objects (supernova remnants, gamma ray bursts, active galactic nuclei or microquasars), search for non-baryonic dark matter (WIMPs) and neutrino oscillations.

To this end, much work has been done during the last years, including the study of the potential sites [1,3] and tests on the deployment and connection techniques and on several detector components. One of the elements in which much effort has been put is the photomultiplier, since it is a key part of the

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detector. After describing the specifications for the photomultipliers to be used in ANTARES (section 2), we will present the results of the tests performed to compare several candidates (section 3). Finally, the results on the large sample of 912 units of the selected model (the R7081-20 from Hamamatsu) will be shown (section 4).

2. Specifications for the ANTARES photomultiplier tubes

The selection of the photomultiplier for the ANTARES neutrino telescope has been made taking into account the following specifications:

- **Dimensions:** the PMTs for neutrino telescopes should have a large sensitive surface. However, there is a limit to their size in ANTARES, since the PMT and the associated electronics have to fit in a standard pressure-resistant glass sphere [2], which has an internal diameter of 40.2 cm. Thus, the photocathode radius of curvature is limited to 19 cm (15" PMT) and the total PMT height to 35 cm.

- **Gain:** the amplitude of the single photoelectron (SPE) pulses has to be larger than 50 mV (on a 50 Ω load) to avoid problems caused by electronic noise. This value corresponds to a gain of 5×10^7. In order to have a safety margin, the PMT must be able to reach a gain of 5×10^8.

- **Nominal voltage:** the high voltage at which the gain is 5×10^7 is called nominal voltage (HV_{nom}) and should be lower than 2000 V so as to avoid ageing problems. The specifications explained in this section are required always at the nominal voltage. Moreover, the PMT is shielded against the Earth magnetic field and is homogenously illuminated with a low level of light (single photoelectron level). These are the so-called 'SPE conditions'.

- **Dark noise:** due to the existence of an optical background coming from ^{40}K decays, the dark noise limit is not very stringent in the ANTARES experiment. This limit has been established at 25% the rate due to ^{40}K, i.e. 15 kHz for a 10" PMT.

- **Peak to valley ratio:** in order to isolate properly the single photoelectron signal from the pedestal, a minimum peak to valley ratio of 2 is required.

- **Transit time spread:** transit time spread (TTS) is defined as the FWHM of the distribution of the arrival time of the electrons at the last dynode. This is one of the most important parameters since a large value of the TTS could limit the angular resolution of the detector, which depends on time resolution. For this reason, a maximum of 3 ns has been established.

- **Prepulses and afterpulses:** prepulses and afterpulses may induce mis-reconstructed events. In table 1, the definitions used in the tests and the corresponding maximum rates are summarized.

Table 1. Definitions of prepulses and afterpulses. The time window is defined respect to the expected time of the main pulse. The third column indicates if the pulse is correlated in time with a main pulse.

Type	Time window	Secondary pulse?	Limit
Prepulses	[-100 ns, -10 ns]	-	1%
Delayed Pulses	[10 ns, 100 ns]	no	5%
Afterpulses-1	[10 ns, 100 ns]	yes	1%
Afterpulses-2	[100 ns, 16 μs]	yes	10%

3. Comparison of the photomultiplier candidates

After the pre-selection stage, three models were considered as candidates for the ANTARES detector: the R7081-20 from Hamamatsu (10" photocathode diameter), the XP1804/D2 from Photonis (10.6") and the R8055 from Hamamatsu (13").

Table 2 shows the results of the tests performed at the IFIC laboratories in Valencia. The light source used in these measurements is a pulsed Nd-YAG green laser. This device is very stable and produces short pulses (0.8 ns FWHM).

Table 2. Results of the tests on the three PMT candidates for the ANTARES detector.

Model	HV_{nom} (V)	Peak/Valley	TTS (ns)	Dark Noise (Hz)
R7081-20	1340	2.9	3.0	1600
XP1804/D2	1680	2.7	2.0	4300
R8055	1900	3.7	2.6	6900

Model	Prepulses	Delayed Pulses	Afterpulses-1	Afterpulses-2
R7081-20	0.01%	3.6%	1.0%	3.8%
XP1804/D2	0.01%	4.7%	3.2%	18%
R8055	2.2%	5.0%	2.4%	19%

These results indicate that, in general, the three models are within the specifications. However, the XP1804/D2 and the R8055 show a high rate of afterpulsing. These tests favoured the R7081-20 as the best choice, as it was finally decided.

4. Results on the Hamamatsu R7081-20

Once the R7081-20 model was selected, a large (>900) sample of PMTs was purchased and tested at DAPNIA (CEA, Saclay). This test bench consists of a plastic cylinder in which the PMT is located and illuminated by a blue NSPB-500 LED (2 ns pulse width).

The results on the 912 available PMTs are shown in Table 3. Some other variables, not shown in the table, were also measured, such as amplitude, energy resolution, pulse rise and fall time, etc. Since a new base was used to improve the TTS, the value of HV_{nom} increased with respect to table 2.

Another relevant test concerns ageing. In order to study the long term stability, three tubes were placed in a black box and illuminated by three independent blue LEDs which reproduced two years of optical background (^{40}K and bioluminscence). There was a running-in phase (∼100 days), in which the three PMTs showed an increase of 50-70% in gain and then stabilized. Other important properties (e.g. peak/valley, TTS, etc.) were stable. An increase around 30% in the dark current rate was also observed, due most likely to the accumulation of gaseous ions.

Table 3. Mean (and RMS) values of the final sample of the R7081-20 model.

HV_{nom}	1800 (60) V	Prepulses	0.01 (0.01) %
Peak/Valley	2.8 (0.5)	Delayed pulses	3.7 (0.2) %
TTS	2.8 (0.1) ns	Afterpulses-1	1.4 (0.3) %
Dark Noise	1900 (1000) Hz	Afterpulses-2	1.2 (0.4) %

5. Conclusions

The ANTARES collaboration has tested several models of large photocathode photomultipliers suitable for an underwater neutrino telescope. After a pre-selection stage, an exhaustive study of the models R7081-20 and R8055 from Hamamatsu and XP1804/D2 from Photonis has been carried out. A large sample of the selected model, Hamamatsu R7081-20, was tested.

6. References

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