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Comparison between large area photo-multiplier tubes at cryogenic temperature for neutrino and rare event physics experiments

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ABSTRACT

An evaluation of the behavior of three large cathode area photo-multiplier tubes, Hamamatsu R5912 Mod and R5912-02 Mod, and ETL 9357 KFLB, was carried out both at room and cryogenic temperature, using a 405 nm light source. The main electrical and optical features of the devices were studied; the obtained results were compared with the characteristics of the ETL 9357 FLA tubes, used in the ICARUS experiment. Tubes were also studied as a function of the Earth's magnetic field and an evaluation of the quantum efficiency was made in the vacuum ultraviolet light region.

1. Introduction

Measurement of scintillation light in liquefied noble gases plays a very important role in many detectors dedicated to neutrino physics and Dark Matter search. Photo multiplier tubes (PMTs) represent presently the preferred readout devices to collect the emitted light in large volume detectors, which are needed for rare events physics. Various experiments [1–3] already used large area (8 in.) PMTs are directly immersed in liquid Ar or Xe at cryogenic temperature. In view of future applications, three new large area PMTs, Hamamatsu R5912 Mod and R5912-02 Mod (see also [4–6]) and ETL 9357 KFLB, were characterized both at room (Sections 2 and 3) and at cryogenic temperature (Section 4). Collected data are compared with those obtained with 54 ETL 9357 FLA PMTs successfully employed in the ICARUS experiment [7,8]. The work on Hamamatsu R5912 Mod and R5912-02 Mod presented in [4] was completed by studying the stability of R5912 after warm up, and the behavior of a new R5912-02 specimen, cooled down with direct immersion in LN_2 (the specimen used in [4] got broken in this operation). Furthermore the characterization of ETL 9357 KFLB is presented and the PMT dependence on the Earth's magnetic field is investigated.

2. Characterization at room temperature

PMTs under analysis have an 8-in. diameter window made of borosilicate glass and a bialkali photo-cathode (K_2CsSb) with platinum undercoating, in order to restore the photo-cathode conductivity at low temperature. Hamamatsu R5912 Mod and R5912-02 Mod PMTs have 10 and 14 dynodes, respectively, while the ETL 9357 KFLB has 12 dynodes. Their main characteristics are summarized in Table 1. For the ETL 9357 KFLB no single electron response (SER) was detectable; analysis was performed with multi-electron response. PMTs were illuminated with a 405 nm laser diode,[1] using a pulse generator[2] and an optical fiber.[3] A proper support was used to maintain the fiber in a fixed orientation, normal to the PMT window, while allowing to move it in various positions on the window itself. A pre-amp[4] and an amplifier[5] were used to form PMT signals, then acquired with a Multi-Channel Analyzer.[6] See [7,4] for a detailed set-up description.

SER was studied, as a function of the position of the fiber along two perpendicular diameters, to estimate photocathode uniformity. Several measurements have been performed for each position (Fig. 1) and error bars represent the statistical errors. Hamamatsu

[1] NICHIA NDV1413 LASER diode.
[2] Avtech AVO-9A-C-P2-LARB.
[3] 7 μm core diameter, 3 m long.
[4] CANBERRA 2005.
[5] ORTEC-570.
[6] ORTEC-Easy-8k, 12 bit.

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Table 1
PMTs characteristics, from manufacturers data sheets.

Characteristic	R5912	R5912-02	ETL 9357 KFLB
Typical gain	10^7 at 1500 V	10^9 at 1700 V	10^7 at 1500 V
S.E. rise time (ns)	3.8	4	3.5
TTS (FWHM) (ns)	2.4	2.8	4
Transit time (ns)	55	68	65
Dark current (nA)	50	10^3	10
Q.E. at 390 nm (%)	25	25	18

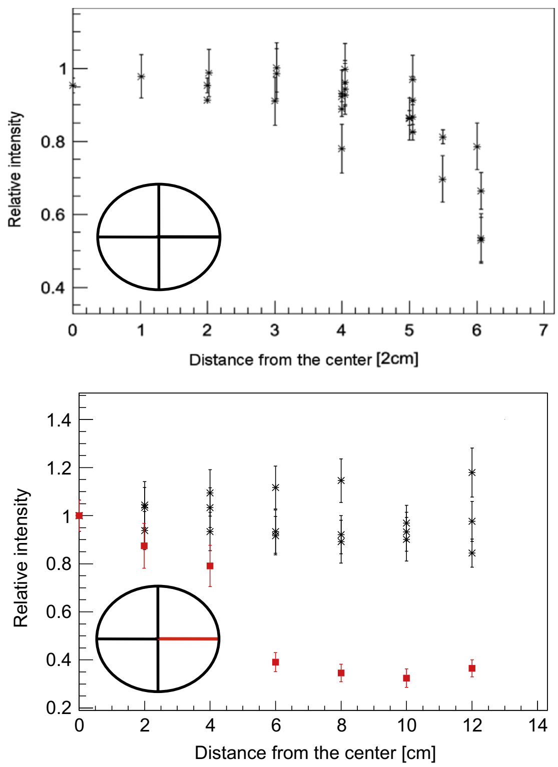

Fig. 1. Relative response as a function of the distance from the center of the window, along different diameters, for Hamamatsu R5912 (top) and ETL (bottom) PMTs. Red spots represent the problematic region of ETL 9357 KFLB photocathode. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

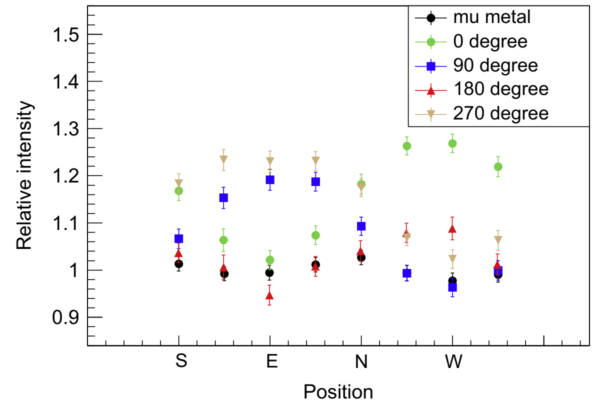

Fig. 2. Relative response as a function of the orientation with respect to the Earth's magnetic field for Hamamatsu R5912-02 Mod. The PMT was illuminated at the center of the window.

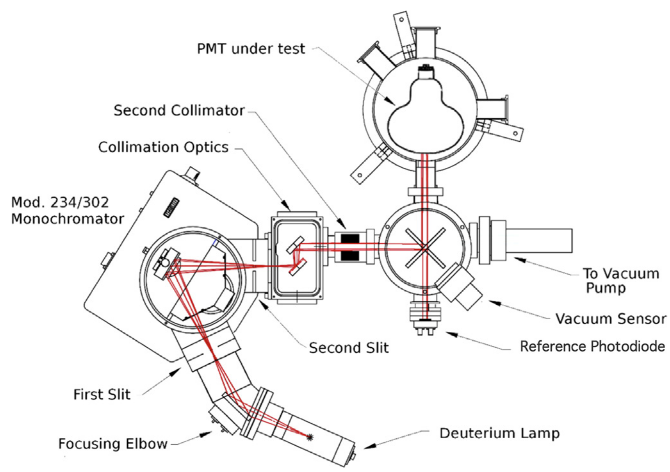

Fig. 3. Experimental setup for the evaluation of the response of PMTs to the VUV light.

PMTs showed a good uniformity, within 10%, till 10 cm from the tube axis, where a gain reduction occurs, probably due to the electric field non-uniformity in the peripheral region of the tube (see also [4]). While this behavior does not occur with ETL 9357 KFLB, lower uniformity is measured, ~20%. A very low signal was measured in a specific region of the photocathode: this can be explained by a degradation of the photocathode for the specimen under consideration.

The above measurements were repeated with the PMTs (parallel to the floor) in four different positions along the North, West, South, East directions, in order to study the dependence on the Earth's magnetic field. Gain dependence is pronounced when fixing the fiber at the center of the PMT window (up to 30–35%, see Fig. 2), while it flattens when going to the sides. Electron transit time did not seem to be affected by the Earth's magnetic field. For all PMTs, it is compatible with what is reported by the manufacturer, when measured with the fiber in the center of PMTs; it increases going further from the tube axis.

3. Quantum efficiency

A different experimental setup was used to measure the Q.E. of the photocathodes in the VUV light region. As shown in Fig. 3, the PMT under test was placed inside a steel chamber optically connected to a VUV monochromator.[7] In order to be sensitive to VUV light, the PMT windows were coated with Tetra-Phenyl-Butadiene (TPB), a wavelength-shifter, with emission peak at 430 nm. The experimental setup includes a scanner,[8] a Deuterium lamp,[9] a rotating Al+MgF_2 mirror, a reference photo-diode[10] and a collimating optics. The whole system was set under vacuum conditions, down to 10^{-4} mbar, to prevent ultraviolet light absorption. Thanks to the rotating mirror, the light spot was directed alternatively on the PMT surface or on the reference photo-diode. A wavelength-dependent analysis was performed from 120 nm to 220 nm. The Q.E. was obtained by comparing the current measured with the PMT with the same collected with the reference diode, keeping the light constant. Measurements were carried out by means of a picoammeter.[11] Results for LAr (128 nm) and LXe

[7] Model McPHERSON 234/302.
[8] Model McPHERSON 789A-3.
[9] Model McPHERSON 632.
[10] Model AXUV-100.
[11] Model Keithley 6487E.