Nuclear Instruments and Methods in Physics Research A ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Study of the light production mechanism of epoxy resins in an electric field

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ARTICLE INFO

Article history:
Received 25 March 2016
Accepted 8 May 2016

Keywords:
Neutrino
Double Chooz
Photomultipliers
Instrumental background
Glowing

ABSTRACT

During the commissioning of the Double Chooz experiment light signals not related to light leaks were detected by the photomultiplier tubes. A specific study of the so-called *light noise* has been carried out, and it has been found that an emission of light could be produced by the epoxy covering the photomultiplier base circuit under certain conditions of high voltage and temperature. Several tests have been carried out in laboratory with different resins, which evidenced the emission of light pulses through a corona effect and the relationship of the rate and amplitude of the light pulses with temperature and high voltage across the base circuit. The results of these investigations can be particularly relevant for several other neutrino experiments that are known to use similar optical units and base assembly.

1. Introduction

An instrumental background arising from light signals produced inside the photomultipliers assembly has been reported by several experiments over the past years [1–5]. In some cases it has been described as a fast, ns-scale, flash of light or, in other cases, as a train of pulses of several μs. The possible *flashing* or *glowing* of the optical units is considered a general problem and it is a potential concern for the future giant neutrino detectors equipped with several thousands of PMTs [6].

A similar instrumental background has been detected in the Double Chooz detector, a reactor neutrino experiment which recently measured the θ_{13} mixing angle through the reactor antineutrino disappearance [7]: an unexpectedly high PMT (HAMAMATSU R7081 Fig. 1) coincidence rate was measured during the preliminary tests of the far detector and before the detector was filled with liquid scintillator (Fig. 2). The effect remained unchanged after the filling of the detector, and the light pulses detected by the optical units were able to trigger the DAQ and contaminate the physics data sample. A set of cuts, based on the event topology, have been used to reject the instrumental background off-line, and the variation of its rate over time had to be carefully monitored. Currently more than 75% of the total triggers in the far detector are identified as instrumental background.

Detailed tests at the CIEMAT laboratory evidenced some dielectric properties of the epoxy resin used to cover the PMT's base in order to insulate the circuit from the buffer oil, thus correlating the light emission to the epoxy polarization in the electric field. It could be demonstrated that possible chemical changes in the polymeric structure of the epoxy, eventually enhanced by a temperature rise, increase the polarization status, thus leading to large amount of electrostatic energy stored in the epoxy.

2. Study of the light emission mechanism

In order to characterize the light emission features, investigating at the same time the underlying mechanism of the effect, dedicated tests have bee carried out in laboratory. Data were acquired with three 1 in HAMAMATSU R6095 PMTs placed on top of the base of a 10 in R7081 PMT (Fig. 1) of the same type of the ones used in the Double Chooz experiment. Another R7081 PMT was placed in front of the tested unit in order to investigate the light escaping the reflector shield surrounding the optical unit. The PMTs were located in a light-tight climatic chamber allowing us to carry out the tests in a controlled environment of humidity and temperature (Fig. 3). The light noise (*LN*) events were identified by the coincidence of the signals of the three 1 in monitor PMTs and a negligible coincidence rate was measured with the PMT under test turned OFF. Even in stable conditions, the *LN* detected was unstable, quickly changing its features in terms of rate, amplitude and pulse shape without an apparent explanation. At the same time the overall rate constantly increased after several days of operations in laboratory.

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http://dx.doi.org/10.1016/j.nima.2016.05.028
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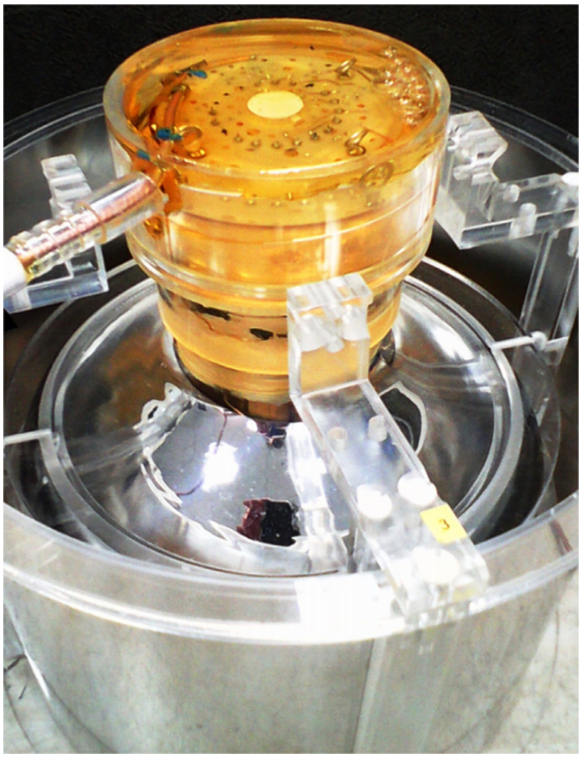

Fig. 1. Optical unit used in the Double Chooz experiment: the epoxy covering the base circuit is evidenced in the picture.

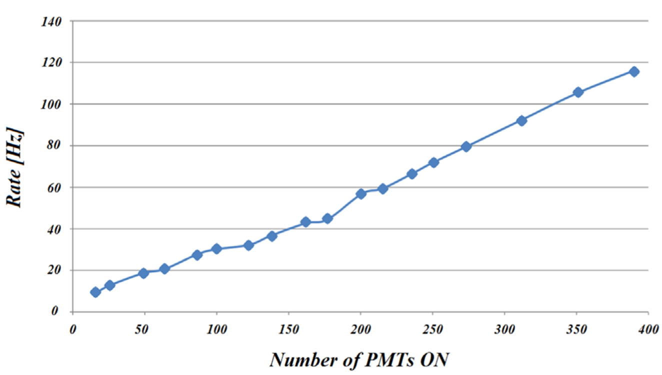

Fig. 2. Coincidence rate measured with 16 monitor PMTs versus the total number of Double Chooz PMTs switched ON (DC far detector).

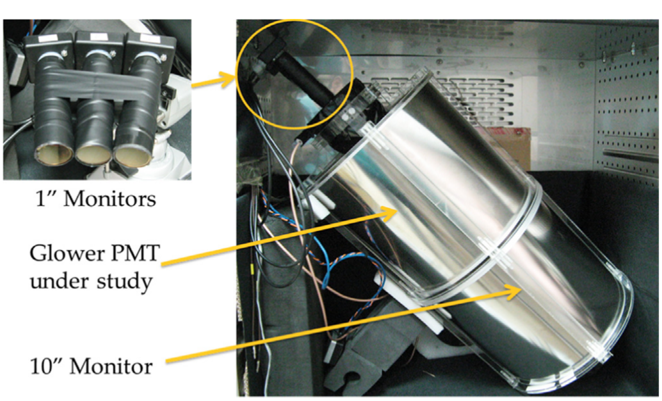

Fig. 3. Experimental setup used for the tests in the laboratory.

A dependence of the light emission on the PMTAs temperature and high voltage has been evidenced during the tests, such that a clear increase of the emission rate and the signal amplitude could

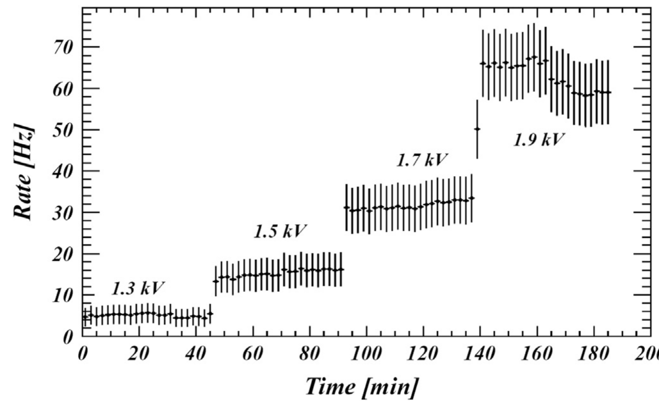

Fig. 4. Variation of the light noise emission rate (3-fold coincidence) for different PMT high voltage values at a temperature of 21° C.

be produced by setting higher temperature or larger high voltage values (Figs. 4 and 5). Additionally an hysteresis behavior has been detected since it was not possible to restore the original signal rate and amplitude setting the initial high voltage and temperature values.

Two different types of light emission were typically detected during the tests. While the first one is characterized by a major flash of light of a few hundreds of ns, the second one is a train of small pulses at the level of the single photoelectron during some μs (Fig. 6). The integral signals obtained by summing up the total charge detected on larger time scale (1 s) is similar for both, suggesting a possible common physical process that releases the same stored energy through complementary light production mechanisms. A comparison of the light signal detected by two different monitor PMTs suggested that more than one emission point can be identified on the base (Fig. 7) with distinctive emission features.

In order to fully prove that the light emission of the PMTs can be produced by the combined effect of heat and high voltage on the epoxy glue covering the base circuit (Fig. 1), a small sample has been placed between the two pins of a 10 MΩ resistor and 3 kV were applied to the resistor pins which acts as heater for the epoxy. In Fig. 8[left] a clear bright spot is evidenced where the cathode pin is in contact with the epoxy, while the illumination of the sample body is probably given by the diffracted light. No light emission has been recorded by the camera after removing the epoxy or isolating the metal pins from the epoxy. A similar

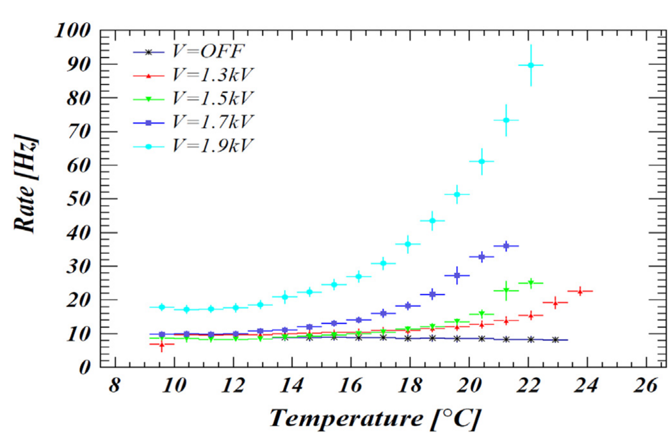

Fig. 5. Variation of the light noise emission rate (3-fold coincidence) as a function of the temperature for different high voltage values.

Please cite this article as: R. Santorelli, A. Verdugo, Nuclear Instruments & Methods in Physics Research A (2016), http://dx.doi.org/10.1016/j.nima.2016.05.028