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

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Motivations

Evidences of a contamination of the physics data with an instrumental background arising from light signals produced inside the photomultipliers assembly have been reported by several experiments over the past years: Super-K, SNO, KamLAND, … [1-5]. The possible flashing or glowing of the optical units is considered a potential concern for the future giant neutrino detectors equipped with several thousands of PMTs.

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: an unexpectedly high PMT coincidence rate was measured during the preliminary tests of the far detector and before the detector was filled with liquid scintillator. The effect remained unchanged after the filling of the detector. The pulses were able to trigger the DAQ and contaminate the physics data sample.

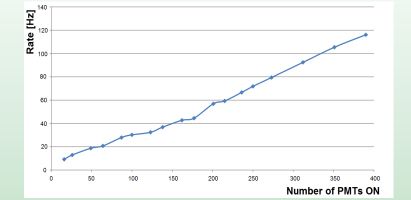

Fig. 1 - Coincidence rate measured with 16 monitor PMTs versus total number of PMTs ON (DC far detector)

Laboratory Tests and Light Emission Mechanism

Data were acquired with three 1" Hamamatsu R6095 PMTs placed on top of the base of a 10" R7081 PMT (Fig. 2). Another R7081 PMT was placed in front of the tested unit in order to investigate the light escaping its reflector shield. The PMTs were located in a light-tight climate chamber allowing us to carry out the tests in a controlled environment of humidity and temperature. The LN (Light Noise) events were identified by the coincidence of the three 1" PMTs signals.

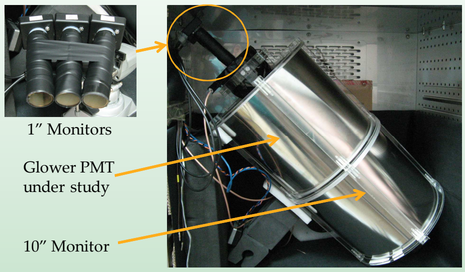

Fig. 2 - Experimental setup used for the tests in the laboratory

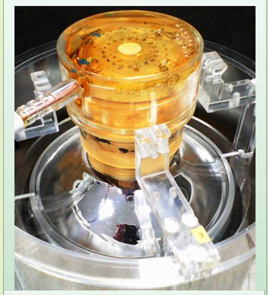

Fig. 3 - Picture of the optical unit

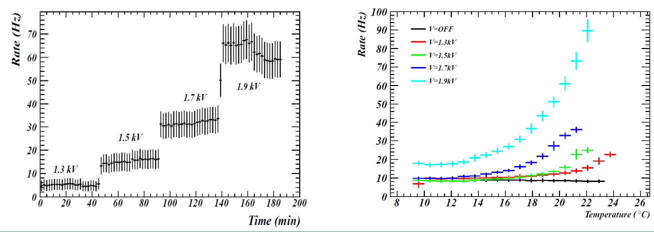

Fig. 4 - Variation of the light noise emission rate (3-fold coincidence) for different PMT high voltage values, keeping stable @21°C (*left*) or changing (*right*) the temperature

The dependence of the LN signal amplitude and rate on temperature and high voltage has been evidenced during the tests in laboratory (Fig. 5). Additionally a temperature hysteresis behavior has been detected: a rise of the temperature always produced an increase in the light rate, however, the corresponding decrease of the temperature was not able to lower the emission in the same way.

Two different LN waveforms were typically detected (Fig 5). While the first one is characterized by a big flash of light of some hundreds of ns, the second one is a train of small pulses during some µs. However, the integral signals obtained by summing up the total charge detected on large time scale (1s) is similar for both, suggesting a possible common physical process that releases the same stored energy through complementary light production mechanisms.

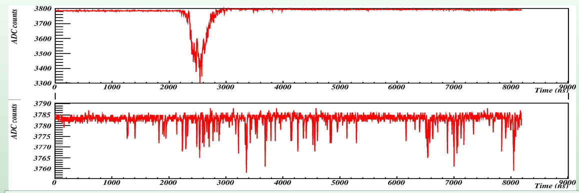

Fig 5 - Different *light noise* pulses detected during the tests in laboratory

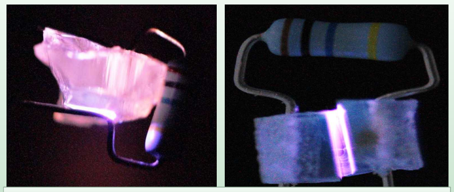

Fig. 6 - Glowing of the PMT base epoxy samples. Image recorded by the camera in dark conditions

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. 3), a small sample has been placed between the two pins of a 10 M resistor and 3 KV were applied to the resistor pins which acts as heater for the epoxy. In Fig. 6-left 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 glowing emission has been observed with two different pieces of epoxy in contact with the resistor pins and separated in the middle by a small gap (Fig. 6-right).

The previous results fully proves that the epoxy used to cover the PMT base electronic components can cause the emission of light under certain conditions of voltage and temperature, thus explaining the light emission from the Double Chooz PMTs base. A possible simple explanation of the effect can be given considering that, due to the polarization of the epoxy, a strong field is present around the electrodes. According to that scenario photons can be produced by the glowing of the air trapped between the epoxy and the pins through a corona effect.

Effects @ Double Chooz Experiment

Knowing the characteristics of the light noise emission, a set of cuts was developed to select the physics events in the off-line analysis. One time-based as well as three charge based variables were designed to identify and reject the different types of light noise detected at low and high energy with an estimated combined signal inefficiency of 0.0124±0.0008 %, which was considered negligible for the analysis.

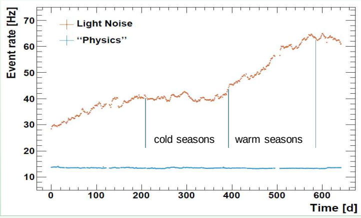

Fig. 7 - Evolution of the rates over time for physics (blue) and *LN* events (orange).

The overall trigger rate increased during the physics runs although the rate of the physics events was stable in the same period of time. Even small increases of the temperature (0.5 ºC) have a clear impact rising the event rate, while any temperature decrease does not reverse the effect. As result a total trigger rate measured at the end of 2014, after three years of operations, was more than double the initial value. That could be explained because the rise of the temperature allows the polarization of epoxy molecules but negative temperature gradients freezes the status and do not reverse the effect, as was already observed during the laboratory test.

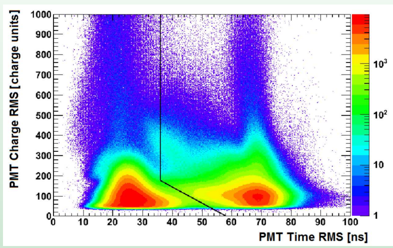

Fig. 8 - Charge vs time plane. The black line represents the cuts. Events of interest belong to the left side of this line whereas *LN* events belong to the right side of this line.

References

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