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Detection of the VUV liquid argon scintillation light by means of glass-window photomultiplier tubes

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Abstract

The experimental results coming from an intense R&D study about the possibility of detecting the light produced by the liquid argon scintillation certify the use of glass-window photomultiplier tubes. The devices, working in cryogenic liquid, are made sensitive to the VUV photons by means of a wavelength shifter coating. This is a useful detection method to provide an effective way for the absolute time measurement and trigger of ionizing events occurring in Time Projection Chambers.

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1. Introduction

The liquid argon (LAr) is successfully used for nuclear particle detection, thanks to the possibility to measure ionizing events with high energy and high spatial resolution by means of the Time Projection Chamber (TPC) technique [1].

The particles interacting with the LAr produce free electrons and scintillation radiation in the VUV spectrum. The scintillation light can be used to define the interaction absolute time and to trigger the events in TPC detectors [2,3].

The experimental results presented in this paper certify the use of glass-window photomultiplier tubes (PMTs) directly immersed in LAr to detect the scintillation light.

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2. Liquid argon scintillation

Charged particles interacting in LAr create ionized and excited molecular states which produce scintillation radiation through recombination and deexcitation processes [2,3]. This scintillation is characterized by a prompt ($<2\ \mu s$) photon emission in the VUV spectrum with $\lambda = 128$ nm and by a yield of about 5×10^4 photons MeV^{-1}.

In a TPC detector, the photon emission is a function of the electric field intensity used to drift the free electrons (300–500 V cm^{-1}). Moreover the presence of impurities limits the photon transmission in the liquid.

3. Detection system

The most practical and straightforward method to detect the light coming from the LAr scintillation makes use of photomultiplier tubes.

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Conventional glass-window photomultipliers with bialkali photocathode are not fit for this purpose since they are not sensitive to VUV photons and they do not work at LAr temperature (87 K). Moreover the use of magnesium-fluoride window photomultipliers is not an economical solution when used in large detectors.

The suitable solution makes use of large surface glass window photomultipliers specifically manufactured to work at cryogenic temperatures. The sensitivity to VUV photons is achieved coating the window with a proper compound which acts as fluorescent wavelength shifter to the PMT sensitive spectrum.

3.1. Photomultiplier

The 9357FLA Electron Tubes photomultiplier was chosen as detection device. The model, shown in Fig. 1, is an 8 in. diameter photomultiplier with hemispherical glass window, manufactured in a single carrying glass structure without welded or glued parts. The bialkali photocathode is deposited on a platinum under layer which allows the low-temperature working. Table 1 shows the main physical and electric characteristics of the device.

The PMT working parameters at cryogenic temperature are good enough for the LAr scintillation detection, though the PMT gain at 87 K is only ≈20% of the nominal one.

3.2. Wavelength shifter

The VUV detection needs a 128 nm radiation sensitive compound with a high emission probability in the blue region, such as the tetraphenylbutadiene (TPB). If we prepare a solution with the proper solvent (toluene) the compound can be easily deposited on glass surfaces by means of a nebulizer. This method provides fine-grained and uniform layers on large surfaces.

We tested coatings of different thickness at cryogenic temperature. We found that layer thicknesses under 200 μg cm^{-2} do not present mechanical instability after immersion in LAr. Moreover the glass sand-blasting makes the coatings more adherent and abiding.

Fig. 1. 9357FLA Electron Tubes photomultiplier with blasted glass window.

Table 1
Nominal physical and electric characteristics of the 9357FLA Electron Tubes photomultiplier

Length and diameter	293 mm; 203 mm
Cathode size	190 mm
Spectral response	300–500 nm
Dynodes	12LF CsSb
SER p/v	2
Rise time and FWHM	5 ns; 8 ns
Maximum gain	5×10^7
Quantum efficiency (blue)	≈20%
HV supply	1200 V

4. Quantum efficiency measurement

We measured the global quantum efficiency of the system (PMT + wavelength shifter) as a function of the following parameters: the TPB coating thickness, the photon angle of incidence and the backing surface type (smooth or blasted glass) [4]. The measurements were performed by means of a monochromator and the results were obtained comparing the PMT output current[1] to the intensity of a 128 nm light beam.

The system quantum efficiency as a function of the coating thickness is presented in Fig. 2; some values obtained with a sodium-salicylate coating,

[1] We used for this purpose a flat 30-mm-diameter PMT, manufactured by the Electron Tubes with the same cathode and main characteristics of the 9357FLA.

which is the most used as reference shifter, are plotted in the same figure. The measurements show a high conversion efficiency of the TPB coatings, no angular dependence and, on the whole, a better and uniform response of the coatings on blasted glass. As a result, we found out that the response of the PMT with the optimized shifter thickness allows a VUV quantum efficiency around 10%.

Our data, together with the value of the 128 nm light attenuation length in LAr (≈90 cm [5]) allows the evaluation of the detection efficiency as a function of the deposited energy and to define the best PMT assembling geometry by means of Monte Carlo programs.

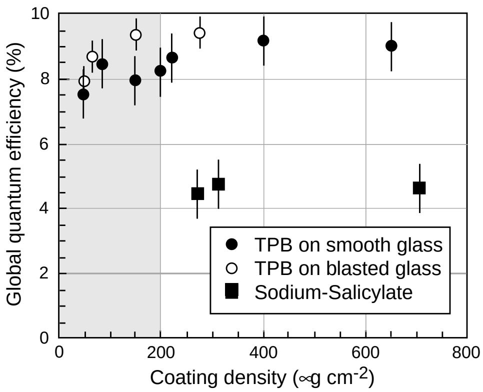

Fig. 2. Quantum efficiency measurement as a function of the TPB coating thickness. The gray area refers to thickness values with no adhesion instabilities at cryogenic temperature.

5. LAr scintillation light measurement in large detectors

A demonstration of our detection method capability to define a PMT-based trigger and to determine the particle absolute interacting time in a LAr TPC is given by the recent results obtained by the ICARUS Collaboration [6]. Twenty 9357FLA TPB-coated photomultipliers, assembled in the first 300 t LAr cryostat of the T600 detector, were extensively used during the test run in Pavia in 2001 summer. Fig. 3 shows the two-dimensional image (about 1.5 m× 1.5 m) of three muon tracks crossing a TPC drift volume region. The event was recorded by means of a trigger logic based on a four-fold coincidence of the photomultipliers (2 m spaced) placed behind the TPC wire planes. The PMT output, facing the event, was shaped (10 μs) and sampled at 200 MHz by means of an FADC, as shown in the plot on the right in Fig. 3. The different time position of the PMT

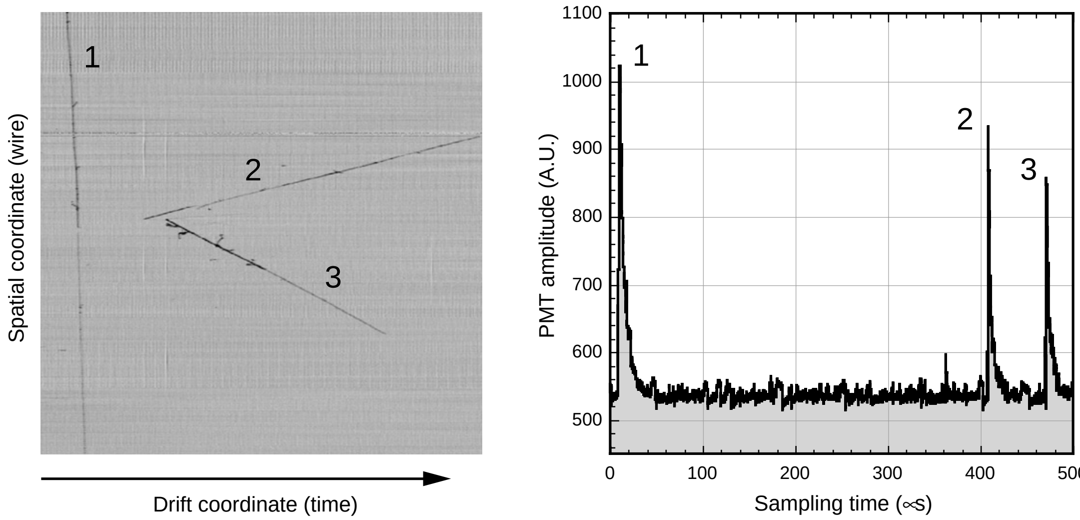

Fig. 3. Image of three muons crossing the first cryostat of the T600 ICARUS detector. The PMT output looking the drift volume is shown in the plot on the right. A detailed description of this event is given in Ref. [6].

pulses, due to the scintillation light, shows that the tracks correspond to consecutive events crossing the detector drift volume at three different times.

6. Conclusions

A PMT system sensitive to the LAr scintillation is able to provide an effective method for the trigger and for the absolute time measurement of ionizing events occurring in Time Projection Chambers. Our results testify the good confidence and reliability of the detection method making use of glass-window photomultipliers. A full demonstration is given by the recent results obtained by the ICARUS collaboration during the T600 detector test run.

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References

[1] For a complete set of references and documents about the LAr TPC functioning and the ICARUS project see the following web pages: http://www.aquila.infn.it/icarus/ http://www.cern.ch/icarus/
[2] P. Cennini, et al., Nucl. Instr. and Meth. A 432 (1999) 240.
[3] C. Vignoli, Studio della luce di scintillazione dell'argon liquido per la determinazione del tempo assoluto degli eventi nel rivelatore ICARUS, Ph.D. Thesis, Univ. degli Studi di Pavia, AA 1995/1996 (in Italian).
[4] G.L. Raselli, M. Rossella, C. Vignoli, A. Votano, LAr scintillation light detection in the ICARUS T600 apparatus, INFN Report FNT/AE-2001/12, 2001.
[5] ICARUS Collaboration, private communication.
[6] ICARUS Collaboration, A second-generation proton decay experiment and neutrino observatory at the Gran Sasso laboratory, LNGS-EXP 13/89 addendum 2/01, 2001.