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Measurement of Liquid Argon Scintillation Light Properties by means of an Alpha Source placed inside the CERN 10-PMT LAr Detection System

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ABSTRACT: A particle detection system that exploits the scintillation light produced by ionizing particles in liquid argon (LAr) has been assembled at CERN. The system is based on 10 large-area photomultiplier tubes (PMT) immersed in a 1500-liter dewar filled with liquid argon and equipped with an extendible feed-through and mechanical support for an alpha source (^{241}Am). The position of the source can be changed with respect to the PMT plane in vertical and horizontal directions. Arrays of silicon photomultiplier (SiPM) photodetectors, integrated in the source support, are used for the data acquisition trigger and to define the t_0 of the light generation. PMT and SiPM signals can be recorded at different distances and different positions allowing the measurement of some of the LAr scintillation light properties. The system was studied and characterized in detail, and physics results on LAr scintillation properties are expected soon.

KEYWORDS: Photon detectors for UV, visible and IR photons (vacuum) (photomultipliers, HPDs, others); Noble liquid detectors; Scintillators, scintillation and light emission processes

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1 Introduction

The detection of light produced by the scintillation of the liquid argon (LAr) plays a crucial role for triggering and for the determination of the absolute time of events in experiments exploiting the Liquid Argon Time Projection Chamber (LAr-TPC) technique for neutrino physics and rare events search.

A LAr test facility, set up at CERN, is used to perform small-scale studies on performances of data acquisition (DAQ) and trigger electronics to be installed in larger volume LAr-TPCs, such as ICARUS T600 at FNAL (see [1] and references therein). Ionizing events were already measured by exposing the system to cosmic rays [2]. The facility is now instrumented with an alpha source mounted on an extendible mechanical handler which permits to vary the source position inside the active volume.

The main characteristics of the test facility equipped with the alpha source are described in Section 2 of this paper, while the triggering and data taking are presented in Section 3. A preliminary data analysis and the characterization of the system are reported and discussed in Section 4.

2 The CERN 10-PMT facility

The CERN 10-PMT facility, shown in figure 1, consists of a double-wall, vacuum-insulated 1.5 m³ cryostat. The dewar is approximately 2 m high and has 112 cm external diameter, 96 cm internal diameter. The cryostat is internally instrumented with 10 Hamamatsu R5912-MOD PMTs with 8 in hemispherical photocathodes. Among them, 6 PMTs are coated, by means of evaporation, with about 200 $\mu\text{g}/\text{cm}^2$ of Tetraphenyl-Butadiene (TPB), a wavelength shifter which permits the detection of the 128 nm Vacuum Ultra Violet (VUV) LAr scintillation light, while 4 PMTs are left without wavelength shifter for the detection of visible photons only [3]. The experimental set-up is immersed in LAr. Pure commercial argon (Argon-60), certified to have purity better than 1 ppm of O² equivalent, is used in the experiment. During standard functioning, the system is operated in open loop, i.e. keeping it in over-pressure with respect to the environment, and allowing LAr to evaporate.

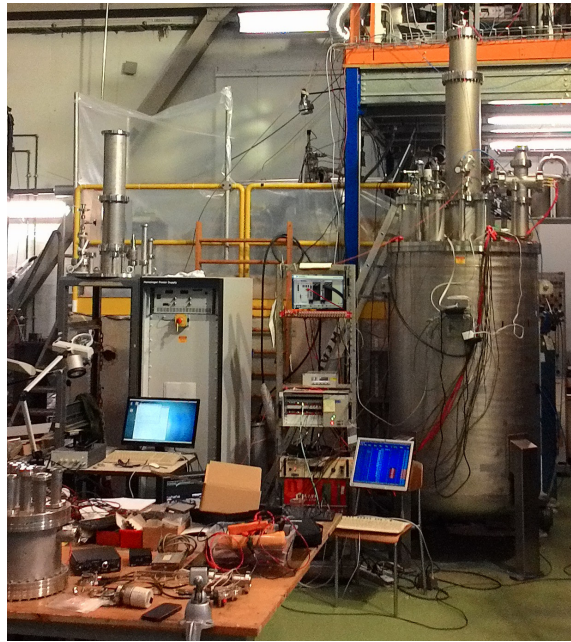


Figure 1. The CERN 10-PMT facility

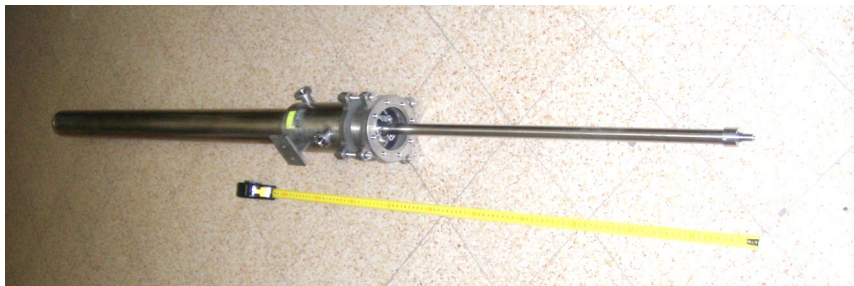


Figure 2. The adopted mechanical extendible handler.

The set-up is upgraded with the installation of a mechanical extendible handler¹, mounted on the dewar top flange, which permits the internal translation and rotation of a support holding an alpha source and a SiPM-based detection system. The mechanical handler is shown in figure 2, while figure 3 shows a picture and a schematic of the set-up.

The alpha source, shown in figure 4, consists of a 22 mm diameter, 4 mm thick, stainless steel disk with an active surface of about 2 cm². The activity of the source is 39 kBq and it is able to withstand the immersion in LAr. The ²⁴¹Am nuclide decays mainly via alpha emission, with energy of about 5.4 MeV. Due to the very short stopping power of alpha particle in LAr, the light emission can be considered point-like and occurring at the at the same position as the source. This isotropic light signal propagates with negligible attenuation through the volume of the facility [4]. Because of their short wavelength the scintillation photons are absorbed by all detector materials without reflection, leaving time and amplitude information almost unaffected along the photon path to the

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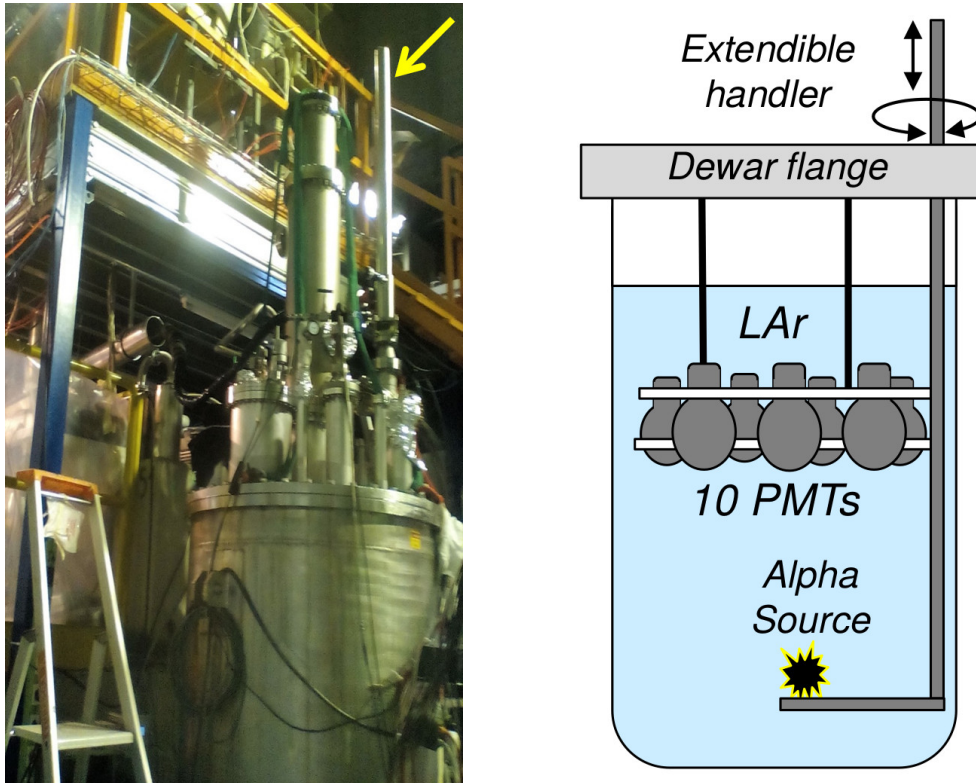


Figure 3. Setup of the cryogenic facility with the mechanical extendible handler.

light detectors.

A dedicated support with hexagonal shape (110 mm width, 60 mm high), made of ABS by a 3D printer, hosts the source and supports 6 SiPM arrays (16 Hamamatsu S12572-050P for each array) used for the data acquisition trigger and for the definition of the t_0 of the light generation (see figure 5). In each array the devices are connected in a hybrid configuration (4 parallel arrays of 4 units in series) [5]. Each array is coated with TPB to make the devices sensitive to VUV light. The 16-SiPM arrays are electrically coupled in parallel in two groups of 3 arrays, in order to have two independent trigger lines, one of which is used as backup. Being the SiPM arrays combined with the source support, they also provide the t_0 signal for timing studies. A protecting cap (110 mm diameter) with a 40 mm hole is used to shade the SiPM arrays from the direct light produced by cosmic rays in the detector active volume.

The mechanical extendible handler permits to vary the source distance from the PMT surface plane in a $0 \div 90$ cm range. The rotation, is in a $0 \div 90$ degree range allowing the positioning below different PMTs as shown in figure 6. The translation and rotation take place by means of a rack and two pinions, these last controlled by hand by means of two graduated knobs.

3 Trigger and DAQ

Preliminary data are acquired by means of a digital oscilloscope (Tektronix MSO64, 2.5 GHz bandwidth, 12-bit 25 GSa/s) used to record for each run the signals from a SiPM array and 3 PMTs



Figure 4. Picture of the the used alpha source.

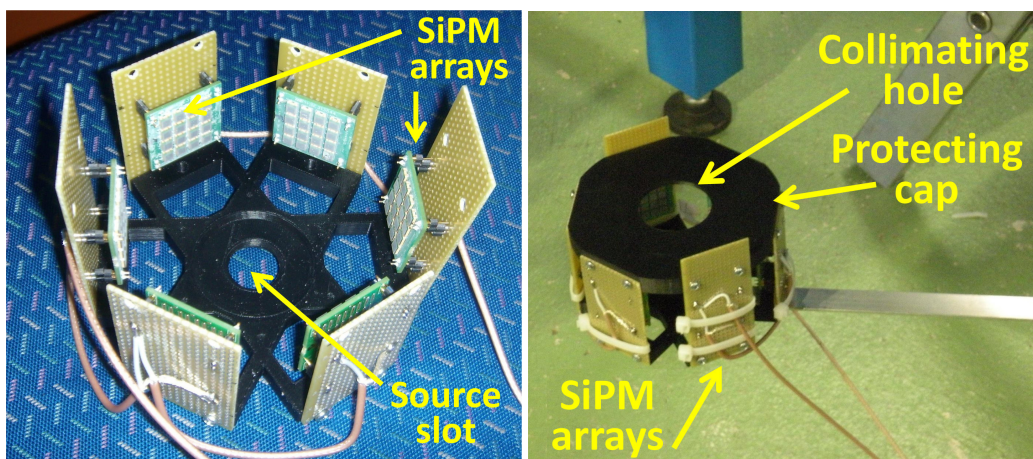


Figure 5. Pictures showing the support used to handle the alpha source and the SiPM arrays.

over a $1 \mu\text{s}$ window. An example of a SiPM and a PMT signal is shown in figure 7. As expected the shapes of the two signals are significantly different. Typically SiPM pulses have longer trailing edges than PMT signals, because of the recovery time of the sensor. Anyway the SiPM timing properties of are not affected, relying upon the fast (few nanoseconds) leading edge of pulses [5].

The SiPM arrays voltage is set to 224 V. The corresponding amplitude distribution of the recorded pulses is shown in figure 8. The PMT voltage is set in order to have a gain of about 10^7 . The adopted SiPM threshold level is 1 mV, while the PMT thresholds are tens of mV, corresponding to discrimination values of few photoelectrons. The DAQ trigger is performed by the oscilloscope, requiring a coincidence in the acquisition windows of a signal above threshold from the SiPM array

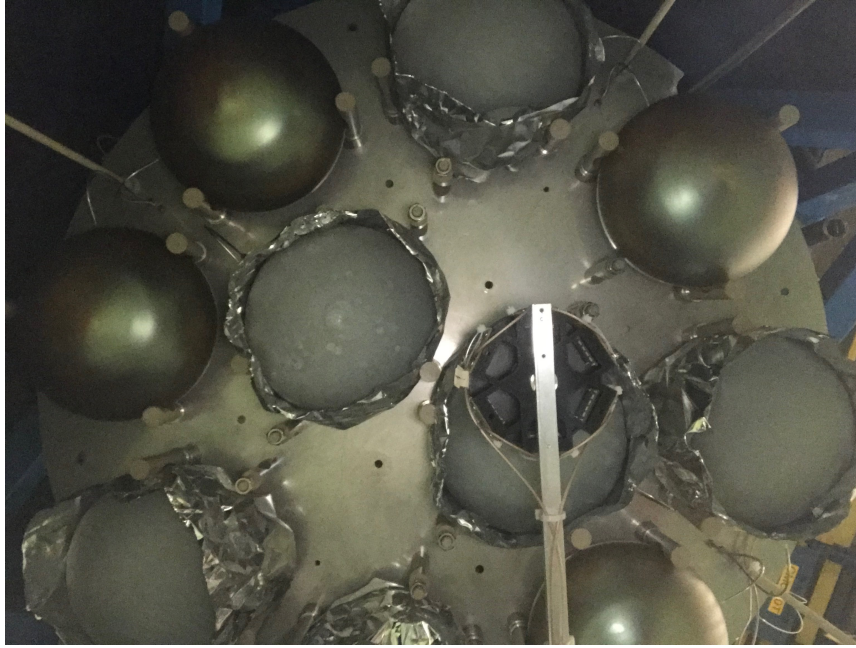


Figure 6. Pictures showing the alpha source support below the PMT plane.

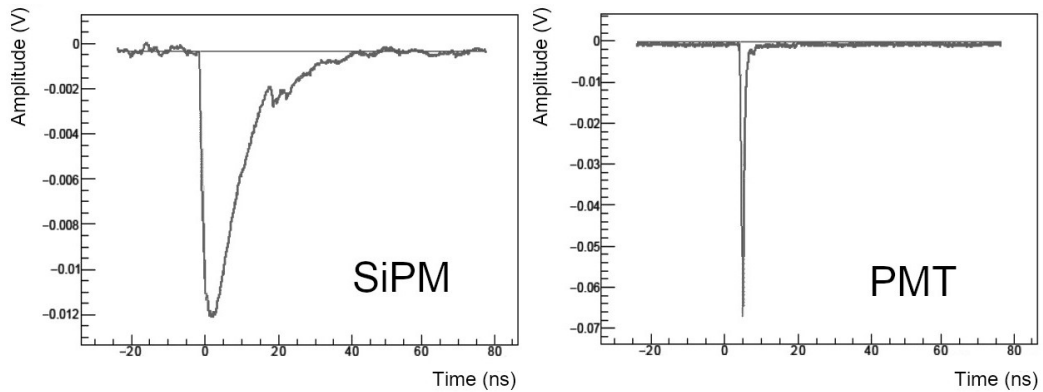


Figure 7. Example of recorded signals for SiPM and PMT. Pictures show a 100 ns zoom around the trigger time. The SiPM pulse is characterized by a trailing edge longer than that of the PMT.

a signal above threshold from the PMT positioned above the source.

4 Data analysis and system characterization

A preliminary data set is acquired to demonstrate the effectiveness of the experimental apparatus. In each set of acquisition runs the horizontal position of the source is set below the axis of one of the 3 recorded PMTs and this position is kept during the source vertical translation, leading to different values of delay ($t_1 - t_0$) between the PMT activation and the SiPM response.

Two different methods are taken into account for the determination of this delay: 1) by means of a Constant Fraction process, i.e. by measuring, event by event, the difference of the sampling points

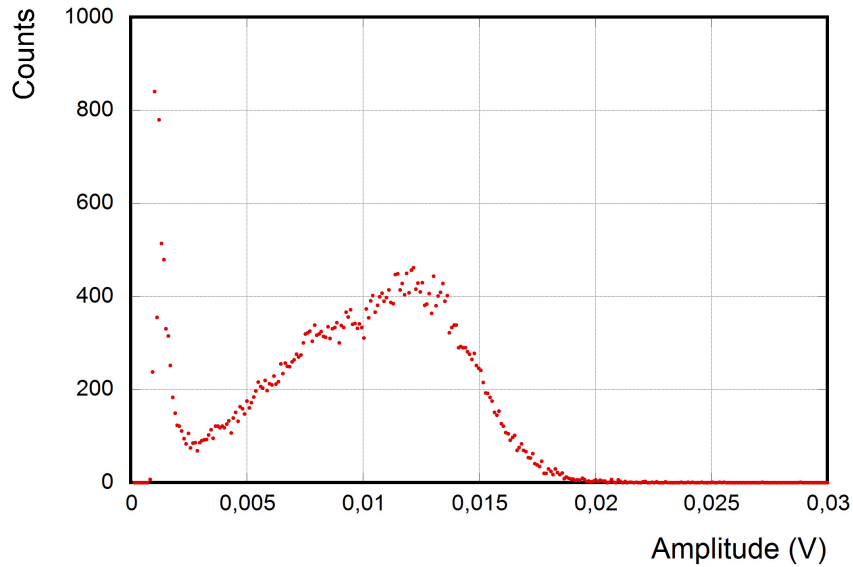


Figure 8. Spectrum of alpha events recorded by one of the SiPM arrays of the setup.

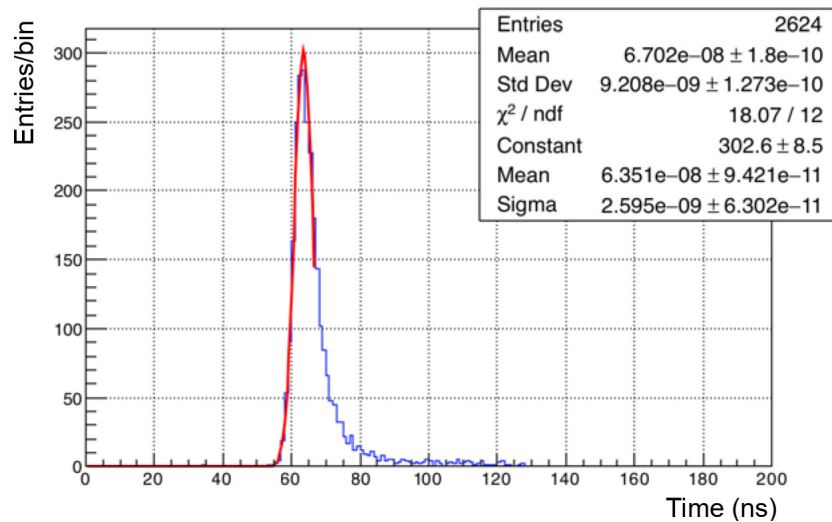


Figure 9. Example of distribution of time difference between PMT and SiPM. The result of a partial Gaussian fit is shown in the figure.

corresponding to a constant fraction (around 50%) of the leading edge of the photo-detector signals; 2) by determining for each event the arrival time of the first detected photon, i.e. the intersection point between the baseline and the line best fitting the signal leading edge. For each source position a distribution of delay values is obtained as shown in figure 9. A slightly asymmetric shape with a tail is observed particularly for the longest distances between source and PMT, where the number of photons hitting the PMT is low. This is due to the intrinsic timing uncertainties of the PMT from small signals [6]. So, each distribution is only partially fitted with a Gaussian curve.

The peak value of each distribution is plotted as a function of the distance between the SiPM

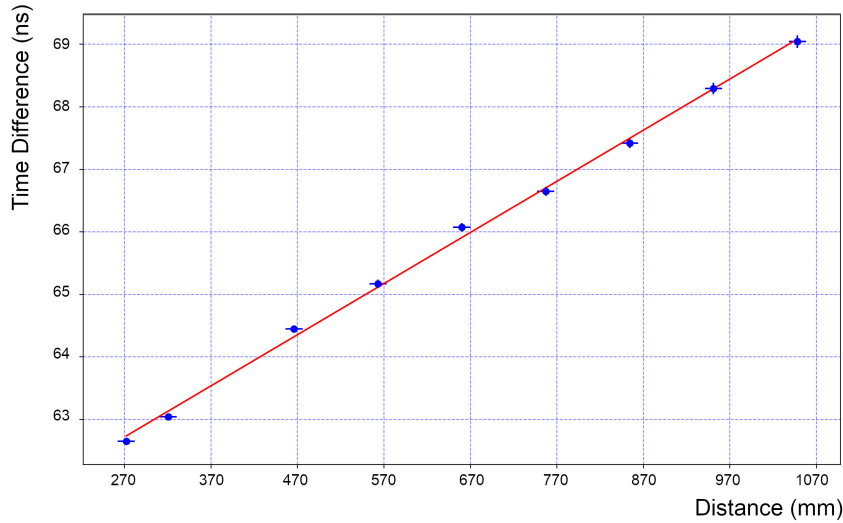


Figure 10. Example of distribution of time difference between PMT and SiPM.

and PMT to have an estimate of the delays between the response of the two photodetectors, as shown in figure 10. The slope of the straight line fitting the delays for different position gives an estimation of the velocity of VUV photons in liquid argon. Results of measurement for the inverse of the speed of light gives values which strongly depend on the framework followed to determine the time differences, as well the selected PMT for the measurement. In order to obtain valuable results, the knowledge of all the factors that determine experimental uncertainties is required. To this purpose a complete Monte Carlo simulation of the facility would be useful. The precise geometry of the adopted instrumentation (shape of PMTs and SiPM, actual path of photons in active volume) and their physical characteristics, such as LAr properties and the interference of visible photons, should be taken into account.

5 Conclusions

A particle detection system which exploits the scintillation light produced by alpha particles produced by a source mounted on an extendible handler has been assembled at CERN. A set of 10 PMTs and 6 SiPM arrays allows the detection of the scintillation photons at different distances between the different photodetectors.

Preliminary measurements demonstrate the capability of this system to measure some of the properties of the LAr scintillation light. Results are still affected by systematic errors and uncertainties which should be derived by means of a complete Monte Carlo simulation of the detector.

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