Nuclear Inst. and Methods in Physics Research, A 936 (2019) 178–179

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

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

Experimental study of the propagation of scintillation light in Liquid Argon

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ARTICLE INFO

Keywords:
Light propagation
Liquid argon
Refractive index

ABSTRACT

Properties of the propagation of scintillation light in liquid argon (LAr), at λ ~128 nm wavelength, have been experimentally investigated in a dedicated setup at CERN. The speed of scintillation photons has been measured for the first time in this medium, refractive index and the Rayleigh scattering are being studied as well. Such measurement provides a key ingredient for the interpretation of data from the current and next generation large mass LAr detectors as those dedicated to the search for rare events such as neutrinos or Dark Matter. Furthermore the improvement on the understanding of the scintillation light propagation represent a benchmark for the multiple theoretical models and simulations for the next generation of detectors which are now based on still incomplete measurements and calculations.

Contents

1. Introduction and motivation

Liquid Argon (LAr) is one of the most exploited target media for many rare events experiments, studying neutrinos and Dark Matter [1–3]. While LAr detector technology has been developed around 1980, the need of large detector of the kilo tonne scale is today necessary to reach high precision measurements. This requirement translates into long drift volumes of the order of meters and large distances to be covered by the scintillation light produced in the interactions. On the other hand, optical propagation of 128 nm scintillation photons in LAr is not yet well understood, mainly due to a lack of measurements. In this work we present the first measurement of the propagation velocity of LAr scintillation photons and from this we derive other important optical parameters such as the refractive index and the Rayleigh scattering.

2. Experimental setup and measurement

The measurement is carried out by means of two 8" R5912-MOD photomultipliers (PMT) from Hamamatsu. The tubes were selected from the sample characterized for installation into the ICARUS T600 LAr-TPC; their windows are coated with tetraphenyl-butadiene (TPB), a wavelength shifter needed to make them sensitive to VUV light. The PMTs are facing each other at a distance of 100 cm; the measurement

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https://doi.org/10.1016/j.nima.2018.10.082
Received 27 June 2018; Received in revised form 31 August 2018; Accepted 11 October 2018
Available online 18 October 2018
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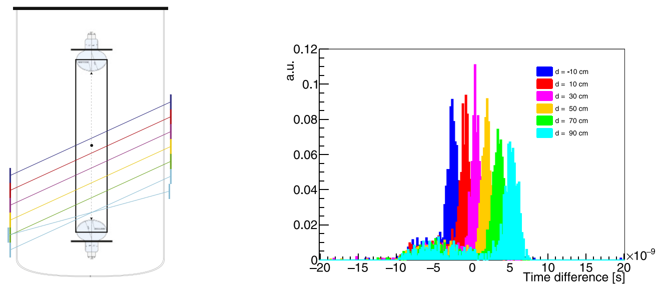

(a) (b)

Fig. 1. (a) Drawing of the setup showing the various trigger positions shifted by 20 cm each. (b) Time difference between the top and the bottom PMT for the recorded events at different external trigger positions.

volume is defined by an opaque polyethylene box 120 cm long, enclosing the tubes. The full setup is immersed in LAr, within a 1500-liters vacuum insulated dewar. Pure commercial Argon (Argon 60) is used for the experiment, whereas no dedicated purification system is used. Data quality is ensured by monitoring the time-constant of the scintillation light long-lived component: a value of ~ 1.4 μs is maintained during the data taking period, which implies negligible presence of impurities like N_2 [4]. Two external movable scintillator pads are installed at 180° around the main dewar to select cosmic muon tracks. A drawing of the setup is shown in Fig. 1a.

3. Group velocity measurement

Waveform digitizers at 5 GHz are used to record the PMT signals. Multiple datasets are collected at different position of the external scintillator pads. No cut-based selection is performed, apart from rejecting empty events and saturated signals, produced by electromagnetic showers. The velocity of scintillation photons is then derived from the difference in arrival time of the two PMT signals, as a function of the average track distance from the PMTs. An example of the arrival time differences (dT) for the different external trigger position is shown in Fig. 1b. From such distributions Minimum Ionizing Particles (MIP) can be easily identified from the background of cosmic showers, the latter having a broad dT distribution and always located at the same position. The precise knowledge of the external trigger position is sufficient to perform the measurement, while there is no need of time calibration on the PMT signals (e.g. transit time). Therefore, for each trigger position, one obtains two values (Δt, Δs) that can be put on a *space vs time* plot. The light velocity can then be extracted as the slope of the straight line fitting the data points. The photons arrival time is determined by using a software constant fraction technique. The validity of that method is verified by testing it on a number of fractions and on datasets with two different tracks slope. Furthermore simulation studies have been carried out using FLUKA. Fig. 2 shows the comparison of the measurements for the two independent track slopes considered which are well in agreement. In this case a constant fraction at 50% is considered.

The resulting value for the inverse velocity of VUV photons in LAr is 7.5 ± 0.07 ns/m. Systematics uncertainties are under evaluation. Data analysis is performed within two independent frameworks, which produced compatible results.

3.1. Further interesting results

The measurement performed can be used to extract the refractive index n of LAr in the VUV region, particularly at 128 nm. To do that, we used data recorded at 90 K for wavelengths between 350 and 650 nm [5] and our group velocity measurement. The latter is used as a constraint in the region of interest where n varies very rapidly. The obtained curve is shown in Fig. 3. The resulting refractive index

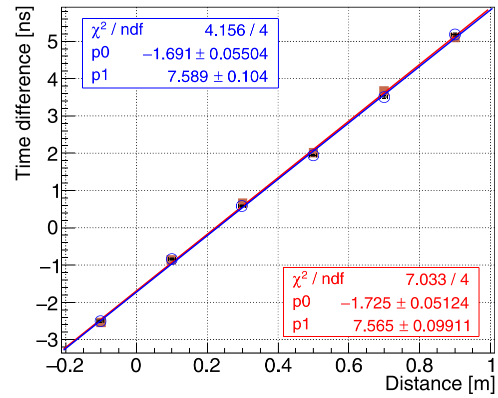

Fig. 2. Comparison of the speed of light in Argon measurements performed with the two samples of tracks having two different slopes.

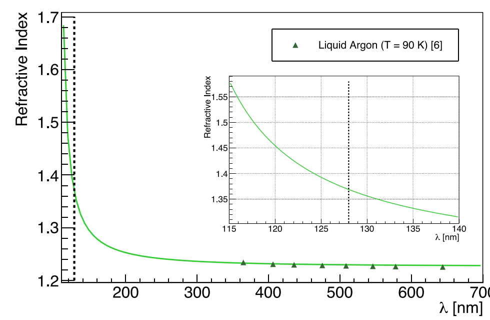

Fig. 3. Extraction of the refractive index in the VUV region. The dotted line shows the value at 128 nm. The box is a zoom in the region of interest.

at 128 nm is 1.369 ± 0.004 (stat). Using the extracted refractive index, the Rayleigh Scattering length, l, is obtained to be 91.0 ± 2.8 cm (stat). The systematic uncertainties determined for the velocity measurement will be propagated. The optical parameters derived from this work are in good agreement with previous publications [6].

4. Conclusion

In this study we present the measurement of the light group velocity in LAr realized with a dedicated setup. From this measurement, estimation of n and l have been derived and are respectively 1.369 ± 0.004 (stat) and 91.0 ± 2.8 cm (stat). Systematics uncertainties are being estimated. The presented results are an important contribution for future LAr TPC experiments investigating in the fundamental research of neutrino and Dark Matter physics.

Acknowledgment

The authors thank the CERN Neutrino Platform for providing the necessary infrastructures to perform the measurement.

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