



Experimental study of the propagation of scintillation light in liquid Argon

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Motivation

- Broad use of Liquid Argon based detectors in rare event searches as neutrino and dark matter [1][2][3]
- Phenomena related to the propagation of scintillation photons in LAr still not fully understood
- Better knowledge of the scintillation light photons is of deep interest for future kton scale detectors
- Propagation velocity of scintillation photons never measured before

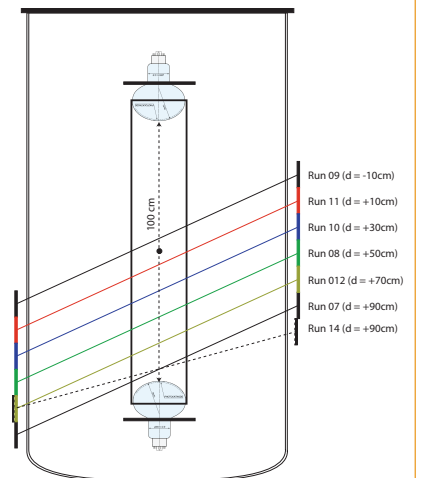
Experimental Setup

- 2 8" R5912-MOD PMTs with TPB coating turned face to face in a opaque polyethylene box of 120 cm length
- Box immersed in LAr within a 1500 litre vacuum insulated cryostat
- No purification system included. Dataset consistency ensured monitoring the time constant of the scintillation light slow component $\sim 1.4 \mu\text{s}$ implying a negligible absorption on impurities (e.g. N_2)

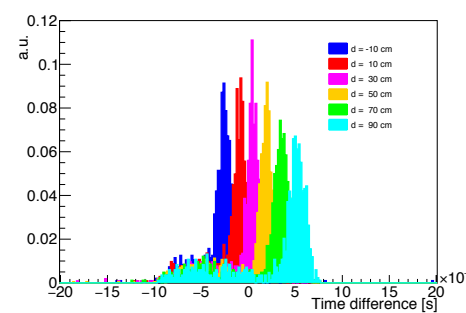


The Measurement

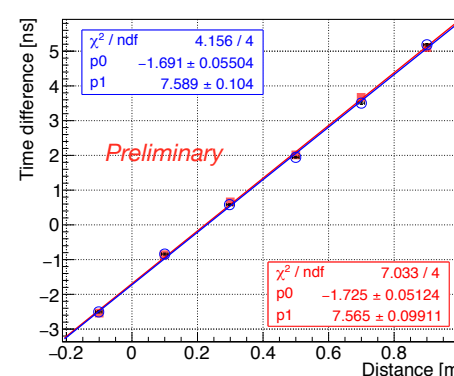
- Event samples from cosmic tracks selected by an external trigger made by two movable scintillator pads
- Cosmic tracks selected at a number of distances from the PMTs and at two different inclinations
- Scintillation photon velocity determined from the difference in time of the signals in the two PMTs as a function of the track position



- The measurement relies only on the external trigger position. No calibration of the PMT transit time is required
- No selection of events, only rejection of empty or saturated events: MIP tracks clearly isolated from shower background
- The PMT signals were recorded using waveform digitisers (5GHz) and their timing was determined using a software constant fraction technique



- For each track inclination a number of constant fraction have been studied and found fully compatible. Two sets of measurements by track inclination are in perfect agreement
- Analysis performed with two independent frameworks



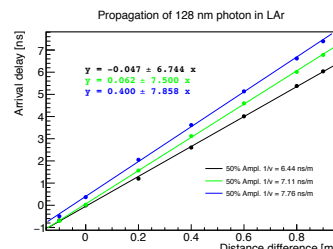
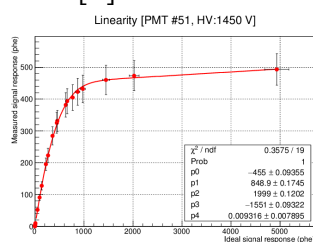
Framework	Track sample 1 [ns/m]	Track sample 2 [ns/m]
A	7.6 ± 0.1	7.6 ± 0.1
B	7.4 ± 0.1	7.4 ± 0.1

$$1/v_g = 7.50 \pm 0.07 \text{ (stat) ns/m}$$

Systematics related to different analyses under investigation

Simulation studies

- Simulations performed with FLUKA [4]
- Single photoelectron signal simulated with triangular shapes and rise time of $\sim 3\text{ns}$
- PMT QE and response simulated based on ICARUS measurements [5]



Further Results

- The measurement of the velocity of the scintillation photon can be used to derive the refraction index in the VUV region
- Rayleigh scattering length can then be determined [7]:

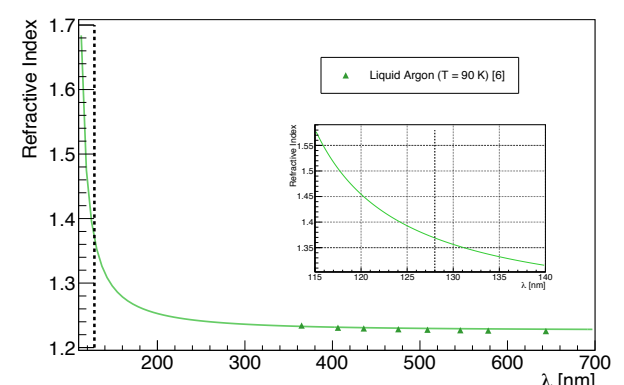
$$v_g = \frac{c}{n - \lambda_0 \frac{dn}{d\lambda_0}} \quad \text{with} \quad n^2 = a_0 + \frac{a_{UV} \lambda^2}{\lambda^2 - \lambda_{UV}^2} + \frac{a_{IR} \lambda^2}{\lambda^2 - \lambda_{IR}^2}$$

$$l^{-1} = \frac{16\pi}{6\lambda^4} \left[kT \rho k_T \left(\frac{(n_\lambda^2 - 1)(n_\lambda^2 + 2)}{3} \right)^2 \right]$$

$$\ell_{\text{Ray}} = 91.0 \pm 2.8 \text{ (stat) cm}$$

Systematics due to analysis and temperature fluctuation still to be evaluated.

$$n = 1.369 \pm 0.004 \text{ (stat)}$$



References

- [1] R Acciarri *et al.*, A Proposal for a Three Detector SBN Oscillation Program at Fermilab arXiv:1503.01520
- [2] R Acciarri *et al.*, The LBNF and DUNE Projects, arXiv:1601.05471
- [3] DarkSide Collaboration, DarkSide-50: A WIMP Search with a Two-phase Argon TPC, Physics Procedia 61, 124 - 129 (2015)

- [4] <http://www.fluka.org>
- [5] G.L. Raselli *et al.*, Test and characterisation of 20 pre-series Hamamatsu R5916-MOD photo-multiplier tubes for the ICARUS T600 detector DOI:10.1109/NSSMIC.2016.8069768 (2017)
- [6] A.C. Sinnock, L. Smith, Refractive Indices of the Condensed Inert Gases, Phys. Rev. **181**, 1297
- [7] L.D. Landau and E.M. Lifshitz. volume 8. Pergamon Press, 1960.