Measurement of the water transparency in the ANTARES site

N. Palanque-Delabrouille[1]
[1]*DSM/DAPNIA, CEA/Saclay, 91191 Gif-Sur-Yvette CEDEX, France*
On behalf of the ANTARES Collaboration

Abstract

A crucial quantity for Čerenkov neutrino telescopes is the transparency of the medium in which the photons propagate, since it has a strong impact both on the angular resolution with which the original muon direction can be reconstructed (the longer the scattering length the lesser will photons be deflected from their original track) and on the effective volume of the detector (the larger the attenuation length, the farther away will the detector be able to "see" muons). The ANTARES collaboration thus designed two set-ups. The first one measured the light attenuation as a function of distance using a DC source and a detector located at a variable distance away from it. The second set-up allowed an estimate of the contributions of absorption and scattering through the measure of the arrival time distribution of photons issued from a pulsed source. I here report on the results obtained from these two measurements.

1 The ANTARES site evaluation study

The ANTARES detector (more details on the status of the ANTARES experiment and its expected performance are given in (Hubbard, 1999) and (Moscoso, 1999), these proceedings) is aimed at the observation of neutrinos from astrophysical sources and at the study of neutrino oscillations. An array of photo-multiplier tubes detects the Čerenkov light emitted in the sea water from the muons produced by the neutrinos in the surrounding medium. The detector will consist of about 1000 optical modules on several strings read out via a single optical cable to shore. To optimize the lay-out of the detector and in particular the distance between various strings, a crucial issue is the transparency of the medium. It has also an impact in the angular resolution with which the muon track can be determined.

Among other site evaluation studies (see (Palanque-Delabrouille, 1999)), the ANTARES collaboration performed two types of tests dedicated to the measurement of the water transparency *in situ*, in a site located in the Mediterranean sea 20 nautical miles off the coast from Toulon (France), at a depth of ~ 2500 m. In both cases, the light source emitted at a wavelength of 466 nm, roughly where our global transmission efficiency is expected to peak (the main contributions coming from the quantum efficiency of the photomultiplier tubes and the water transmission). We also plan to do similar studies with shorter wavelengths soon, in order to measure the water transparency in the UV region where the Čerenkov spectrum rises steeply.

2 DC measurements

In December 97, DC measurements were performed with a 33 m long rigid structure holding a collimated LED source located at a variable distance from a glass sphere containing an $8''$ photomultiplier tube. For each selected distance D between the source and the detector, the LED luminosity $\Phi_{\rm LED}$ was adjusted so as to yield a constant current $I_{\rm PMT}$ on the photomultiplier tube. The set-up was calibrated with a similar experiment done in "air". The emitted and detected intensities in water being related by

$$I_{\rm PMT} \propto \Phi_{\rm LED}/D^2 \times \exp(-D/\lambda_{\rm att.eff}) \tag{1}$$

this test makes it possible to estimate the effective attenuation length from the dependence of the required LED intensity with the distance (cf. figure 1). The agreement of the data with a decrease following the formula given in equation [1] was excellent and yielded an effective attenuation length of

$$\lambda_{\rm att.eff} = 41 \pm 1 \ ({\rm stat.}) \pm 1 \ ({\rm syst.}) \ {\rm m} \quad ({\rm December\ 97}) \tag{2}$$

This attenuation length results from a combination of absorption and scattering. The aim of the test designed afterwards was to disentangle the contributions from these two components.

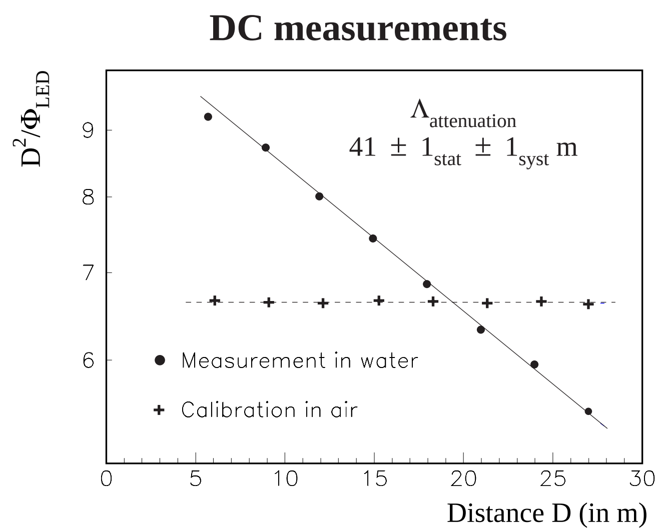

Figure 1: Effective attenuation length obtained with the DC measurements. D is the distance between the source and the phototube, $\Phi_{\rm LED}$ the LED luminosity required to obtain a constant current on the phototube.

3 Measurements with a pulsed LED

The set-up was re-designed so that it could be immersed under less favorable sea conditions than what was required for the test described above, and thus be operable easily on various locations at the time of the future quest for as good a site as possible for the kilometer-square neutrino detector.

In July 98 and March 99, measurements were performed with a set-up consisting of a pulsed isotropic LED source located at a distance of either 24 m or 44 m from a $1''$ fast photomultiplier tube. The frames holding the source and the phototube were connected together only by cables so as to ensure the flexibility of the structure. Buoys placed at the head of the line maintain it taut and vertical (cf. opposite figure). An 8-bit TDC measured the distribution of the arrival times of the photons. The overall time resolution was $\sigma = 4.5$ ns.

The time distributions recorded (thereafter called "spectra") exhibit a clear peak coming from direct photons, and a tail extending to larger delays due to scattered photons. For the 24 m (resp. 44 m) spectrum, 95% of the photons are collected within 10 ns (resp. 45 ns) and 99% are collected within 100 ns (resp. 160 ns). Scattering is thus a small effect in the ANTARES site, as illustrated in figure 3.

An effective attenuation length could be determined from the ratio of the integrated spectra measured at the two distances, yielding:

$$\lambda_{\rm att,eff} = \left| \begin{array}{ll} 60.0 \pm 0.4\ (\mathrm{stat.})\ \mathrm{m} & (\mathrm{July\ 98}) \\ 52.2 \pm 0.7\ (\mathrm{stat.})\ \mathrm{m} & (\mathrm{March\ 99}) \end{array} \right. \quad (3)$$

A systematic uncertainty of a few meters might affect these estimates due to the fact that the LED luminosity is not monitored and yet assumed to be the same for the time distributions collected at the two

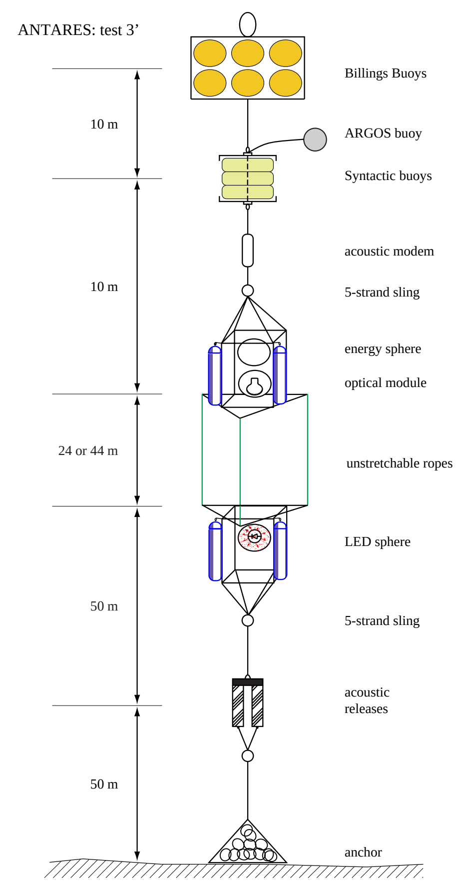

Figure 2: Sketch of the line.

distances (not done simultaneously from practical reasons). These measurements indicate more significant attenuation in March than in July.

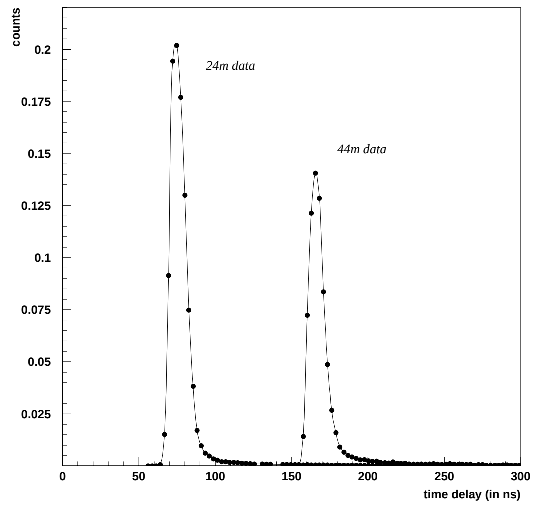

Figure 3: Distribution of photons arrival times for two source-deflector distances: 24 m and 44 m.

A more thorough analysis can be done by fitting the data with a Monte Carlo distribution obtained by photon tracking. The medium is characterized by an absorption length $\lambda_{\rm abso}$, a scattering length $\lambda_{\rm scat}$ and a scattering angle phase distribution $\beta(g,\theta)$ approximated by the Henyey-Greenstein phase function:

$$\beta(g,\theta) = \frac{1}{4\pi}\ \frac{1-g^2}{(1+g^2-2g\cos\theta)^{3/2}} \tag{4}$$

where the parameter g is just the average of the cosine of the scattering angle, and quantifies the asymmetry of the distribution. Because of the 4.5 ns time resolution of the electronics, photons in the tail of the distribution have scattered with an angle at least $\sim 35°$ (resp. $\sim 25°$) for the 24 m (resp. 44 m) spectrum. Therefore, we mostly measure the scattering properties of the water for "large" scattering angles. This, however, does not restrict the implications of the test since the crucial quantity required for a neutrino telescope as ANTARES is indeed the arrival time distribution of photons that are significantly delayed (here by more than 4.5 ns) and therefore not included in the bulk of the "direct" photons. In the future, we plan to reduce the time width of the impulse-response of our set-up so as to be sensitive to smaller delays.

We nicely reproduce the data with an absorption length in the range [55-65] m, a scattering length at large angle greater than 200 m and a correspondingly roughly isotropic scattering angle distribution (parameterized by $g \simeq 0.05$). Note that in an experiment where all the scattered photons would actually be lost and not collected by the detector (as with a thin collimated beam), we would measure an "absolute attenuation length" given by the following combination of absorption and scattering lengths:

$$\frac{1}{\lambda_{\rm att,abs}} = \frac{1}{\lambda_{\rm abso}} + \frac{1}{\lambda_{\rm scat}} \tag{5}$$

Although obtained independently of the fit and completely calibration-independent, the "effective attenuation lengths" derived previously (60 m in July and 52 m in March) are indeed intermediate values between the "absolute attenuation lengths" (52 m in July and 48 m in March) and the fitted absorption lengths (65 m in July and 55 m in March). The data — plotted in log scale to enhance the scattering tail — are displayed in figure 4, along with the best-fit Monte Carlo spectra and a spectrum taken in air which illustrates the time resolution of the set-up.

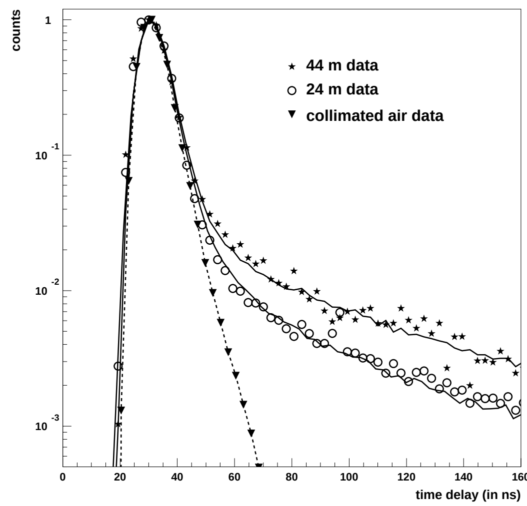

Figure 4: Distribution of photons arrival times for a collimated air spectrum (dashed curve) and for two spectra taken *in situ*, with source-deflector distances of 24 m and 44 m. All spectra are normalized to a maximum of 1. *In situ* spectra are corrected for the $1/D^2$ decrease. Note the strong suppression of the scattering tail as compared to the direct peak. The Monte Carlo spectra for the best-fit values are overlayed (full curve) on top of the data.

4 Conclusion

The discrepancy between the DC measurements and those obtained with the pulsed source are partially accounted for by the collimation of the source in the first case, whereas an isotropic source was used in the second. This different angular dependence changes the "effective attenuation length" by $\sim 10\%$.

The series of measurements presented in this paper seem to indicate that the water transparency varies with time, exhibiting a longer effective attenuation length in July 98 than in March 99, and a longer one in March 99 than in December 97. In any case, however, the water transparency in the ANTARES site is good and will allow each detector line to be sensitive to muons passing at a large distance from the line (~ 60 m). The scattering also appears to be quite insignificant since 95% of the photons emitted by an isotropic source reach a detector located 24 m away within a delay of 10 ns.

References

Hubbard, R. 1999, ICRC 99 proceedings, HE 6.3.05
Moscoso, L. 1999, ICRC 99 proceedings, HE 6.3.04
Palanque-Delabrouille, N. 1999, ICRC 99 proceedings, HE 6.3.18