ANTARES time calibration

Francisco Salesa-Greus [a] (for the ANTARES collaboration)
[a] IFIC - Instituto de Física Corpuscular, Edificios de Investigación de Paterna, CSIC-Universitat de València, Apdo. de Correos 22085, 46071 Valencia, Spain

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Abstract

The ANTARES collaboration has recently completed the construction of an underwater neutrino telescope located at 2475 km depth, 40 km away from the Toulon coast in France. The final detector consist of 885 photomultipliers distributed along 12 lines. At present, the deployed detector is the largest neutrino telescope in the northern hemisphere. The aim of ANTARES is the detection of cosmic neutrinos. A good angular resolution, which relies on a good time resolution and positioning, is required to identify the neutrino sources. In this contribution, we review the ANTARES time calibration systems, namely: 1) the on-shore dark room calibration, which allows the measurement of the relative time offsets among photomultipliers, 2) the echo-based clock system, which enables the measurement of the time delay of the signal from the clock board located on each storey to the shore station, 3) the internal LED, which monitors the photomultipliers transit time, 4) the Optical Beacons, which send light pulses that enable the relative time calibration of photomultipliers, and 5) the K40 calibration which together with the Optical Beacons allow a determination of time differences among photomultipliers of the same storey. These systems have shown that the required time resolution is achieved. Moreover, they ensure that the relative time offsets among photomultipliers are properly computed and, therefore, enable an optimized track reconstruction. The experience gained with ANTARES in the issue of time calibration is of great value in the design of the corresponding system for a VLVNT in the Mediterranean Sea.

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1. Introduction

The ability to point back to the detected source is critical in a neutrino telescope such as ANTARES. In order to get the best possible angular resolution, a good positioning and time calibration is required. In ANTARES the expected attainable angular resolution is better than 0.3° for a E_ν >10 TeV.

Referring to the time calibration, we can distinguish between the absolute and relative time resolution. The absolute time resolution corresponds to the capacity of the detector to measure the time of each event with respect to the universal time (UT), that is necessary to obtain correlations with the physics phenomena (e.g. Gamma Ray Bursts). The main uncertainty, for the absolute timing in ANTARES, comes from the electronic paths, that is, the electro-optical cable which links the junction box and the shore station. In this sense, an accuracy of $\sim$ 1 ms is required.

The relative time resolution takes into account the offsets in the photon detection time, due to the intrinsic differences among photomultipliers (PMTs). That is necessary in order to get the best angular accuracy which is limited, for E_ν >10 TeV, by the muon track reconstruction. The main uncertainties in this case come from: the transit time spread

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Email address: `sagreus@ific.uv.es` (Francisco Salesa-Greus).

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(TTS) of the signal in the PMTs which is ∼ 1.3 ns, the optical properties of the sea water (light scattering and chromatic dispersion) which is ∼ 1.5 ns for 40 meter distances, and finally, the electronics and the time calibration of the system. The latter contribution is the only one which can be improved, and in ANTARES is required to contribute less than 0.5 ns to the other relative time uncertainties, in order to guarantee the expected angular resolution.

2. Calibration methods

In order to perform the ANTARES time calibration [1], several methods have been conceived. The main features of these methods and how they can help to the time calibration are summarized here.

2.1. *Laser through optical fibre*

Each integration site of ANTARES has a setup consisting in a laser sending light through an optical fibre to the PMTs and to the LED Optical Beacons. The main purpose of the method is to compute the relative time offsets among the PMTs of the detector. Knowing the emission time of the laser light and the time when this signal is recorded by the PMTs, the individual PMT offset can be computed after correcting for the time delay of the fibre. Taking one PMT as reference, the relative offsets can be corrected for the whole detector. This calibration can be only performed on shore. It is checked with the Optical Beacons (OBs) once the lines are deployed (see Figure 1).

2.2. *Echo-based clock system*

The system consists of a 20 MHz echo-based clock signal synchronized with the GPS. Essentially, a signal is produced on shore and distributed throughout the detector. A start and stop signals are generated and sent to a TDC which measures the round trip delay. When computing the time difference between the anchor of a line and one particular storey the uncertainties are of the order of 10 ps, good enough for our pourposes in relative time calibration. Considering the time difference between the shore station and the junction box located at the seabed (link of the lines), the whole trip delay is 208 μs. The fluctuation of this value during one year is around 2 ns, which fulfills very well the requirements for the absolute time calibration.

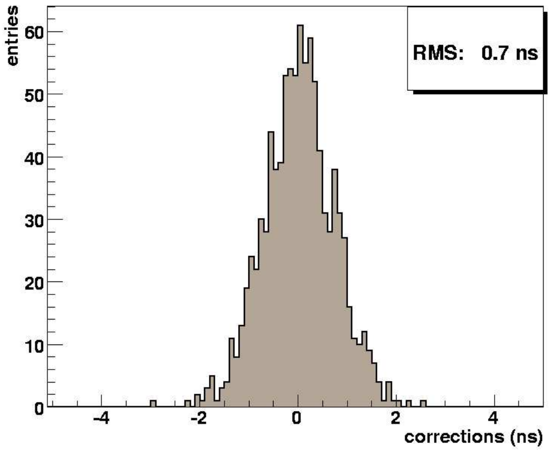

Fig. 1. Histogram with the corrections to be applied to the offsets computed in the integration sites. These corrections are obtained *in situ* by the Optical Beacons for 10 lines

2.3. *Internal LED*

Every OM has an internal blue (472 nm) LED glued to the back of the PMT which can illuminate the photocatode from inside. The aim of this system is to monitor the transit time (TT) of the PMTs measuring the difference between the arrival time of the OM signal and the time of the LED flash. The results obtained with this system have shown that the average TT of the PMTs is stable within 0.5 ns.

2.4. *Optical Beacons*

The Optical Beacons [2] are controlled sources of pulsed light with a well-known emission time. The aim of the OBs is to calibrate the detector by computing the time residuals of all the PMTs. Despite the OB were conceived mainly to compute the relative time offsets *in situ*, they can also be used with different purposes, such as measuring and monitoring the optical water properties of the sea water (absorption and attenuation length). These optical properties are an important parameter for the Monte Carlo simulation.

There are two kinds of Optical Beacons: The LED Optical Beacon and the Laser Optical Beacon.

2.4.1. *LED Optical Beacon*

The LED OB is an hexagonal prism divided in faces where 6 blue LEDs (472 nm) are on each one (see Figure 2). That gives 36 LEDs in total, which can be flashed independently and at different inten-

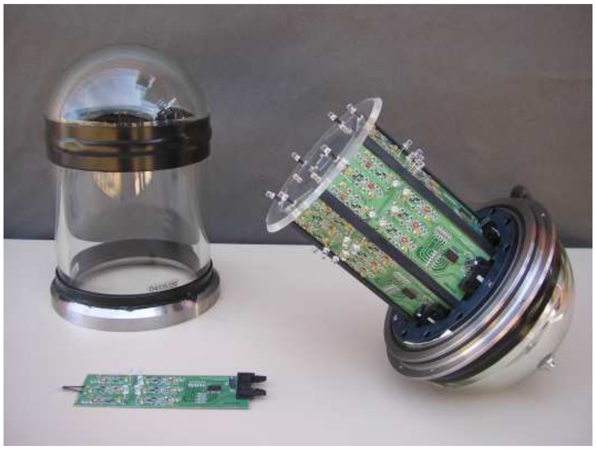

Fig. 2. View of the LED Optical Beacon used in ANTARES. The picture shows the hexagonal frame with the 36 LEDs, and the glass container devised to protect the device undersea.

sities by means of a pulsing circuit. At maximum intensity, a LED OB produces ~ 160 pJ (~ 4×10^8 photons) per pulse. A standard line of ANTARES contains 4 LED OB distributed along the line. In order to know the emission time of the light, a small photocatode PMT has been placed inside the frame of the LED OB.

With the LED OB, the time offsets of the PMTs can be measured *in situ*. The change of these offsets with respect to the measured values in the integration sites is not very large, and only the 15% of the PMTs need a correction greater than 1 ns, as can be see in Figure 1.

The LED OBs have been used also to check the ANTARES time resolution. One way to do that is flashing nearby (~ 14.5 m) PMTs. In this case, due to the big amount of light received by the PMT, the contribution of the TTS, which decreases with the square root of the number of photo-electrons, is negligible. The contribution of the photon dispersion of the light is small, since the arrival times will be dominated by the first photons. Finally, the contribution of the small OB PMT which determines the emission time of the signal is also negligible. At the end, one can safely assume that the only important contribution comes from the electronics. This contribution is ~ 0.4 ns (see Figure 3) which is lower than the 0.5 ns required for the relative time calibration. As it has been mentioned, the LED OB is a very versatile device which can be used, not only to obtain the time offsets, but also to obtain useful information concerning the detector. In this sense, an estimation of the optical properties of the water can be done. The preliminary results obtained for the measurements of the absorption and attenuation lengths seem very encouraging.

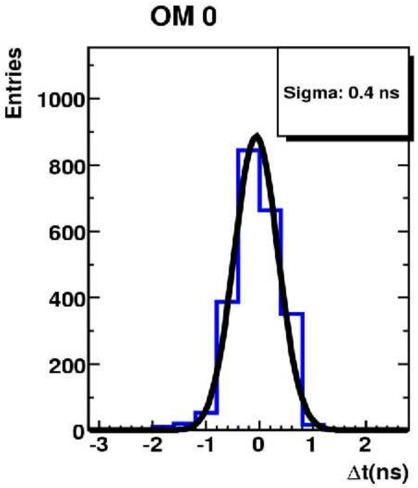

Fig. 3. Histogram with the time difference distribution between a PMT and a LED OB placed 14.5 m away. The standard deviation of 0.4 ns can be understood as an estimation of the ANTARES time resolution from the electronics.

2.4.2. *Laser Beacon*

The Laser Beacon is a calibration device based on a diode pumped Q-switched Nd-YAG laser. It produces short pulses (< 1 ns) of green (532 nm) light with an energy of ~ 1 μJ (~ 10^{12} photons). In ANTARES there are 2 Laser OBs placed at the bottom of two central lines which are able to light up most of the PMTs in the detector. The emission time of the light is given by a very precise internal photodiode.

Apart from time calibration the Laser OB can also be used to perform cross-checks with the positioning system due to its fixed and well-known position at the anchor of the line. The idea is to compute the time difference, for a given time period, between the Laser OB and some particular storeys. The distribution of the values obtained improves significantly when considering the detector as made with lines with the shape provided by the positioning system (RMS ~ 0.6 ns) or when considering it as made with rigid straight lines (RMS ~ 2.3 ns).

2.5. *Potassium 40*

The K40 present in the salt water can be used for charge and time calibration of the detector. The idea is to take advantage of the Cherenkov light cone in-

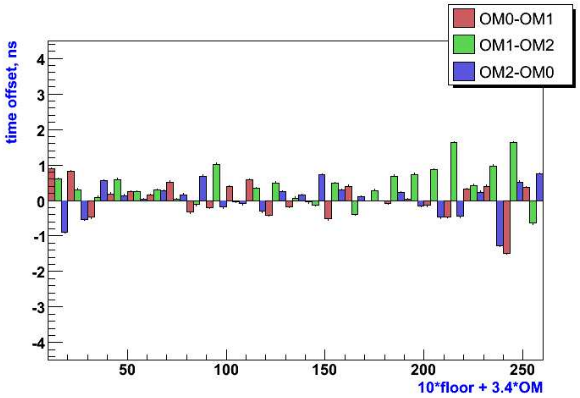

Fig. 4. Time difference between the 3 PMTs (OMs) on the same storey computed with K40 method. This is used to check the ANTARES calibration. If the calibration were perfect these bars should be essentially 0. This bar histogram has a very good agreement with the one obtained with the OBs.

duced by the electron coming from the K40 decay. Then, the distribution of the relative time differences, between the 3 PMTs on each storey, should present a bump due to the hits detected by 2 PMTs simultaneously. This is a method to check the offsets computed previously in the integration sites or *in situ*, since if the calibration were perfect these relative time differences should be 0 (see Figure 4). This offset check is done with the LED OB with more precision and with a more intense light source, but having an alternative and independent method which cross-checks the results, makes the test more robust. The results obtained show an agreement of RMS ~ 0.4 ns when comparing the LED OB results and the K40 results. Hence, two independent methods provide very similar results, confirming the good time calibration of the ANTARES detector.

3. Conclusions

The methods used to perform the time calibration of the ANTARES neutrino telescope have been reviewed in this paper. They have been succesfully tested in the laboratory and in situ. The results confirm that the required absolute time resolution of ~ 1 ms is provided by the high precision of the clock system. With regard to the relative time resolution, the only contribution which can be improved is the one coming from electronics and calibration. This contribution is ~ 0.5 ns as it is confirmed by the Optical Beacon system. In addition, the different calibration methods have shown a good agreement among them as, for instance, the Optical Beacons and the K40 calibration. Moreover, the time calibration and positioning systems have been cross-checked each other. Therefore, the angular accuracy of the detector, better than 0.3° for high energy neutrinos, can be reached.

Acknowledgements

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