# Time Calibration of the ANTARES Neutrino Telescope

Juan-José Hernández-Rey (for the ANTARES Collaboration)
*IFIC – Instituto de Física Corpuscular, C.S.I.C – Universitat de València, Apdo. 22085, E-46071 Valencia, Spain*

**Abstract**

The ANTARES collaboration is deploying a neutrino telescope under the Mediterranean Sea [2]. A 3D array of photomultipliers (PMTs) will detect the Cherenkov light emitted by the muons produced in neutrino interactions. Since the reconstruction efficiency and pointing accuracy of the detector will depend on the correct determination of the arrival times of the Cherenkov light to the PMTs, the time calibration of the detector is a key issue. Intrinsic time fluctuations in the detector components indicate that an accuracy of $\sigma \sim 0.5$ ns in the relative time calibration among PMTs is an adequate goal. On the other hand, physics considerations indicate that an absolute time calibration of $\sigma \sim 1$ms is enough for all practical purposes. In this presentation the different sources of time uncertainties in the detector are briefly reviewed. The methods to reach the desired level of accuracy in the time calibration are shortly described emphasising the system based on optical beacons, i.e. well-controlled pulsed light sources.

## 1. Introduction

The ANTARES detector will consist of 12 strings, with 25 storeys each. A storey consists of 3 optical modules (OMs) looking downward at 45° and separated 120° horizontally from each other. An optical module [1] is basically a pressure-resistant sphere housing a 10" PMT, its base and a pulsed LED for calibration purposes. An angular resolution for the muon tracks of 0.2° is expected to be reached at high energy, provided the relative timing resolution (RTR) between OMs is achieved at the required level of precision. The RTR is limited by the transit time spread (TTS) of the signal in the PMTs, $\sigma \sim 1.3$ ns, and by the fluctuations due to the transmission phenomena of light in seawater, $\sigma \sim 1.5$ ns. Therefore, a calibration aiming at a RTR of $\sigma \sim 0.5$ ns is sufficient (one standard deviation will be understood in the following when referring to time jitters, unless stated otherwise).

Apart from the relative timing among OMs, an absolute time calibration, i.e. the appropiate correlation of the detector's clock system with Universal Time, will be required. An absolute time accuracy of ∼1 ms is enough for any conceivable

pp. 1537–1540 

physics goal (e.g. correlation with gamma ray bursts or supernova events).

## 2. Sources of time delays and uncertainties

The delay between the impingement of light on the PMT photocathode and the arrival of the signal to the time to voltage converter (TVC) of the readout chip (the Analogue Ring Sampler, ARS) is $\sim$100 ns. This delay is dominated by the transit time (TT) in the PMT with additional contributions from the cables that link the PMT base to the LCM (the local control module where the electronics of each storey is located) and from the delay in the ARS. Laboratory measurements indicate that variations of this delay with respect to the values calibrated in the laboratory and time drifts once the detector is in the sea will be small (estimated to be $<$5 ns and $<$2 ns, respectively). The output signal from the TVC is digitised relative to the clock reset time stamp issued by the clock card in the LCM of each storey. The delay between the TVC output and the local clock card is of the order of 10 ns and stable ($<$0.2 ns). An unavoidable event to event fluctuation at this level is the spread in the transit time (TTS) of the signal in the PMT, $\sim$1.3 ns. The TTS itself has been checked to be stable, without no sign of degradation due to the ageing of the PMT and with a small dependence on the photocathode to dynode voltage ($\sim$2 ps/V).

The clock signal on-shore is distributed at the seabed to the different strings by a passive splitter located at a junction box, from which all the link cables to the strings depart and where the electro-optical cable to the shore arrives. The delay between this splitter and the clock cards in each LCM will be 2 to 4 $\mu$s, depending on the position of the corresponding storey. The lab-to-sea difference in this delay is expected to be $\sim$1 ns and variations with time smaller than 0.5 ns. The jitter is better than 100 ps as determined in the laboratory. The delay between the splitter and the on-shore Master clock signal is expected to be $\sim$200 $\mu$s, mainly due to the fibre optics responsible of the signal transmission. The stability of the signal in the sea cable should be better than $<$0.2 ns. The land cable, though, may induce variations of up to $\sim$1 ns due to temperature changes. Nevertheless, this variations will only affect the absolute time calibration relative to the GPS standard time and therefore are negligible with respect to the $\sim$1 ms goal established on the basis of physics requirements. A summary of the expected time delays and jitters is given in table 1. Finally, the uncertainty in the propagation time of the Cherenkov photons from the muon track to the PMT due to scattering and to dispersion –through the wavelength dependence of the group velocity of light in water– gives an estimated $\sigma \sim 1.5$ ns at 50 m (a distance larger than the most probable value at any energy, according to simulations).

**Table 1.** Summary of ANTARES time offsets and uncertainties.

| | PMT cathode → ARS | ARS ← LCM clock | LCM clock → Junction Box | Junction Box → Master Clock |
|---|---|---|---|---|
| Delay | ∼ 100 ns | ∼ 10 ns | 2–4 $\mu$s | 200 $\mu$s |
| Stability | ∼ 2 ns | <0.2 ns | <0.5 ns | ∼ 2 ns |
| Jitter | 1.3 ns | <0.5 ns | <0.1 ns | <0.1 ns |

## 3. Time calibration systems

A relative time calibration of a string is first performed in a dedicated dark room using: 1) the clock calibration system; 2) the LEDs located in the OMs and 3) a laser-fibre system [3]. Once in the sea, four different but complementary systems will be used. The first two are the same as before. In addition, a series of optical beacons located throughout the strings provide a series of well controlled pulsed light sources that will allow a relative time calibration including all the relevant effects. Finally, the several thousand downward going muon tracks that are expected to be reconstructed per day in the detector will allow an additional time alignment.

Bi-directional components in the clock system will allow an integrated echo-based time calibration. The clock stability is $\sigma$ <0.05 ns. The precision of the clock system relative to the GPS standard time has been measured in tests to be $\sigma \sim 1.3$ ns. This system can be used to calibrate from the master clock up to the clock cards in each LCM storey. The remaining components (notably the ARS, the PMT and the relevant transmission cables) should be calibrated otherwise. In each OM, a LED driven by a pulser circuit based on the design given in [4] can be used for calibration. The LEDs emit light at 470 nm with a FWHM of 15 nm.

## 4. The Optical Beacons

The optical beacons will allow relative time calibration by means of independent pulsed light sources. Two kinds of beacons will be distributed within the detector: the LED beacons and the Laser beacons. The former will be placed every 7 storeys to a total of 4 per string and located in the upper part of the frame that supports the OMs. The latter will be placed at the bottom of the string.

The LED beacon (fig.1., left) consists of six faces fixed to an hexagonal cylinder mounted inside a cylindrical glass container. Each face has six LEDs, five looking horizontally outward and the sixth facing upward. Each LED beacon can produce between $3 \times 10^7$ and $3 \times 10^9$ photons per pulse depending on the configuration of LEDs selected and the amplitude of the driving voltage. The light

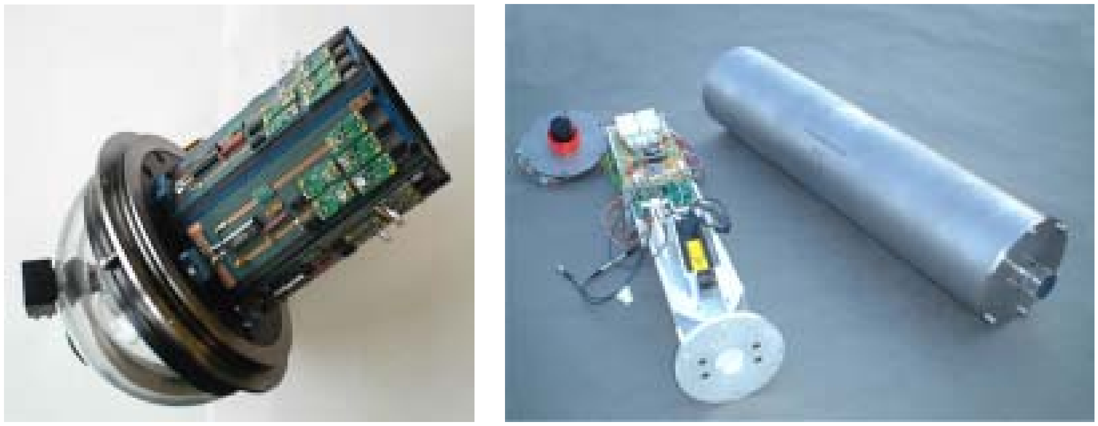

**Fig. 1.** Left: internal mounting of an LED beacon holding the 6 LED faces. Right: blow-up of a laser beacon. The internal electronics, the laser and the external titanium container with the quartz rod on its upper surface can be seen.

pulse of the LED beacon has a rise time of 2 ns and a width between 4.5 ns and 6.5 ns depending on amplitude. A small fast photomultiplier within each beacon allows a precise determination of the exact time of the light flash. The laser beacon (fig.1., right) is a much more powerful device that uses a diode pumped Q-switched Nd-YAG laser to produce pulses of $\sim 1\mu$J with a FWHM of $\sim$0.8 ns at a wavelength of 532 nm. The laser is housed in a cylindrical titanum container and points upward. The beam is widened by a diffuser which spreads the light out to a cosine distribution. A quartz cylinder is bonded to the upper surface of the diffuser, so that the light exits through the vertical walls of the cylinder, where sedimentation is negligible. A built-in fast photodiode gives the actual time of emission of the flash. Detailed Monte Carlo studies indicate that the system of optical beacons will be able to calibrate with an accuracy of $<$0.5 ns the relative time between all the PMTs of the detector.

## 5. Conclusions

The systems described to calibrate in time the ANTARES detector will allow a relative timing precision between OMs of the order of $\sim$0.5 ns, while absolute time will be determined with an accuracy better than 1 ms.

## 6. References

1. Amram P. et al. 2002, Nucl. Instr. and Meth. Phys. Res. **A484**, 369
2. Aslanides E. et al. 1999, astro-ph/9907432
3. Circella M. 2003, these proceedings
4. Kapustinsky J.S. et al. 1985, Nucl. Instr. and Meth. Phys. Res. **A214**, 612