# NERONE: First Results

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## Abstract

A new instrument designed to measure with high accuracy and without any bias the attenuation length of light in clean water (NERONE) is presented. Several new technical solutions have been used in the design, including a small and cheap motor for deep sea water. The instrument has been debugged during four cruises, from 2001 to 2005. First results are presented, obtained in June 2006 in the Catania test site at a depth of 2000 m. Although some improvement is still necessary, the performance of the instrument was very satisfactory.

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# 1   INTRODUCTION

The attenuation length of light in water is one of the most important parameters for the design of a deep sea water telescope for neutrino astronomy, It determines the distance between PM tubes which detect the Cerenkov light generated by the $\mu$ mesons produced by deep space neutrinos. Commercial instruments are available for this measurement, and have been extensively used by the group [1] for site characterization. Unfortunately they are designed to measure rather dirty waters, and their use for extremely clear waters, like at the bottom of the Mediterranean, suffers from the need of a reference to absolutely clear water.

After preliminary tests with a manual system, NERO [2], we have designed and built NERONE, an instrument capable of measuring without the need for external calibration, by the simple method of measuring the attenuation of light over different lengths of water, up to 3 meters, moving a mirror by means of a small motor.

While this method is theoretically very simple, when applied to an instrument which has to work at 3000 m under sea level it creates a number of technical problems. Small motors for deep underwater use are not readily available commercially, and the same is true for long straight rails resistent to sea water. Moreover, a beam with acceptable dimensions from 30 cm to 3 m is difficult to build and to control.

NERONE has been tested during five cruises: on 6/11/2001 on the ship Thetis we performed th first tests at low depth[3], on 16/8/2002 we deployed it to 3100 m at the site km4 on the ship Alliance, on 20/7/2003 and 12/2/2004 on the ship Thetis we solved all movement and alignment problems, and on 1/6/2006 on the ship Universitatis we obtained the first acceptable results, but only at the Catania test site at a depth of 2000 m. We could not perform measurements at the km4 site because of weather conditions.

Fig. 1 shows NERONE in the laboratory and during deployment.

# 2   NERONE description

NERONE is a 2.1 m long structure built of anodized aluminum, with a cylinder 25 cm diameter and 50 cm long housing the laser beam generator, the photodetector system and the control electronics, a motor driving a worm gear, that moves a platform mounted on two steel rails with 4 ball bearing slides. The platform holds the mirror, actually a corner cube retroreflector, which has the property of reflecting back the incoming beam at exactly the same angle, independent of its orientation. Fig.2 shows the basic principle of the instrument.

We shall now describe in detail the most important features of the design.

## 2.1   The motor

The motor system has been designed and built at LNF.

The structure is an oil filled PVC cylindrical container, 10 cm diameter and 20 cm length, with a rubber membrane to equalize the inside and outside pressures and to allow for thermal expansion of the oil. This allows the motor to operate at any depth independently of the outside pressure. The motor itself is a standard stepper motor, therefore it has no sliding contacts and it can operate normally in an oil environment. A standard rubber gasket seals the motor axis from the water.

A magnet on the spindle and a Hall sensor mounted on the body allow the operator to check the effective movement of the motor, giving the actual revolution count and avoiding slipping.
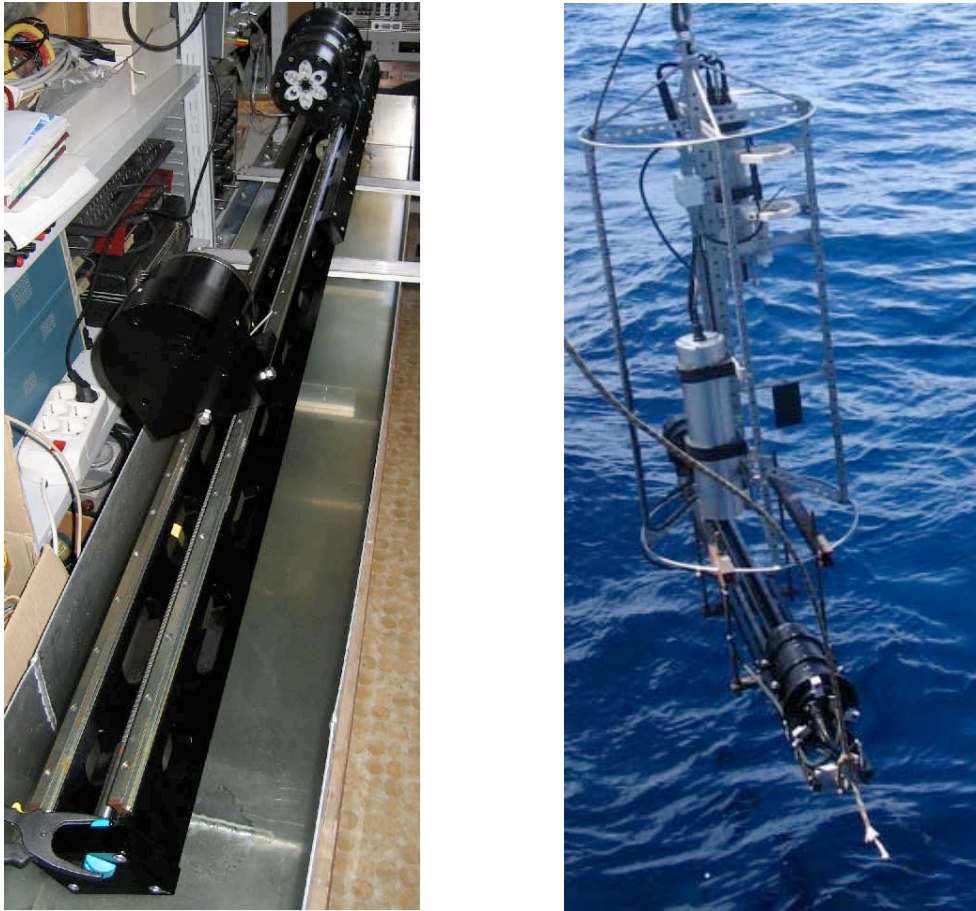
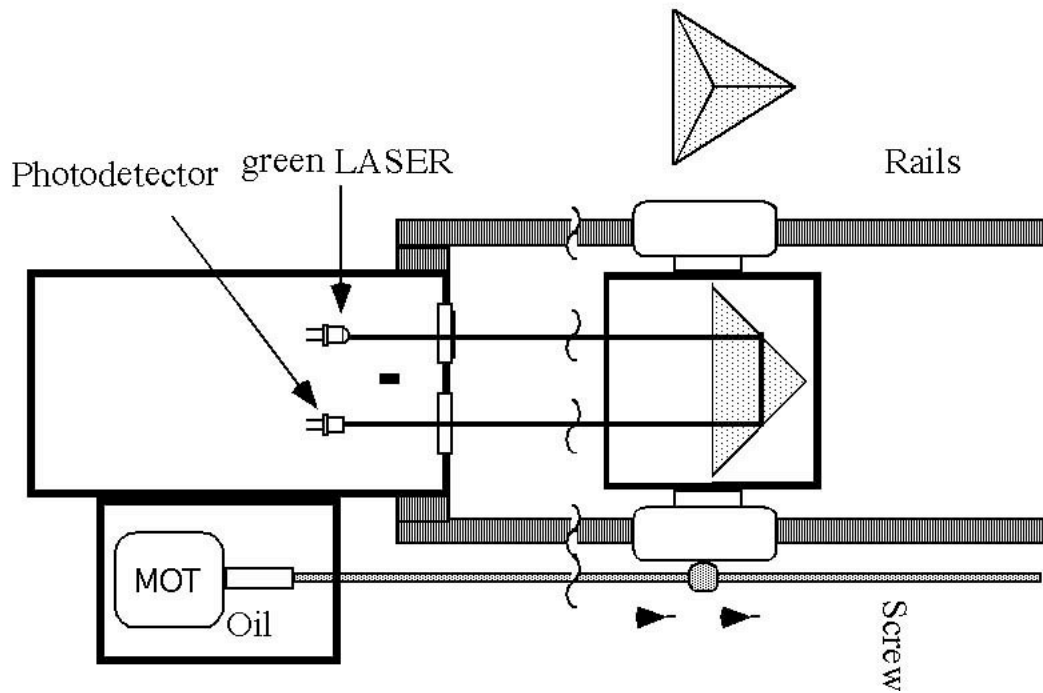Fig. 1: NERONE in the laboratory and during deployment



Fig. 2: Schematic diagram of NERONE

The motor system has been tested in the LNS pressure chamber and it operated correctly down to 3500 meters.

This design allows to build small and inexpensive motors for very high pressures.

Fig. 3 shows the design of the motor assembly. : Fig. 4 the motor components, disassembled in the laboratory.
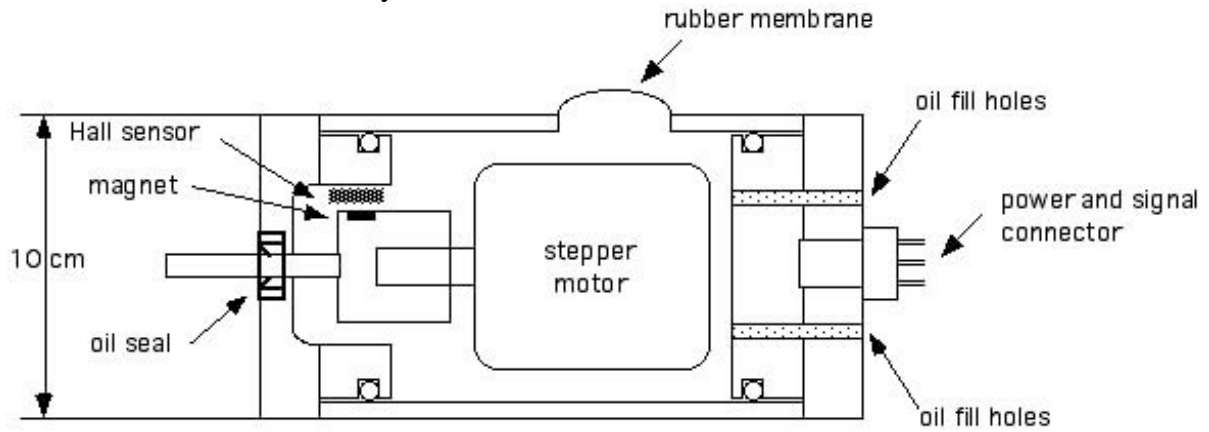
Fig. 3: Motor design

Fig. 4: The motor components, disassembled in the laboratory.

## 2.2   Optical system

The optical system is made up of 3 elements: a light source assembly. a movable reflector and a receiver assembly.

The reflector is a corner cube, 10 cm diameter, housed in an aluminum cylinder and with reflective coating on the back.

For the generator we used a solid state green laser , 532 nm wavelength and 5 mW power. The the laser beam was focused on a pinhole, .1 mm diameter, and the emerging light was collected by a lens with 10 cm focal length.

To get rid of the diffraction rings generated by the pinhole, a field diaphragm was inserted immediately before the lens. The diameter of the hole, 2.4 mm, corresponds to the second minimum of the diffraction pattern generated by the pinhole, to minimize diffraction from the field diaphragm itself.

An identical lens was used to concentrate the light on the photodetector, with a white diffusor in front of the light detector.

The system has proven difficult to manage. The intrinsical divergence of the beam is 1 mrad, given the 100 $\mu$m pinhole and the 100 mm lens focal distance. This generates a 3 mm divergence at 3 m distance. To this we must add the diameter of the field diaphragm, 2.4 mm, to obtain the beam dimension. Since the useful diameter of the detector lens is 16 mm, not much space is left for misalignments. In particular the original design of the corner cube platform  connection to the rails, which used two roller slides, allowed a small oscillation of the corner cube. While the corner cube structure guarantees the parallelism of the incoming and outgoing beams, a change in orientation of the reflector generates a lateral displacement of the beam that creates an unacceptable movement of the beam on the detector window.  A simulator program was written using LabVIEW to test this effect. We had to redesign the movement system, using 4 roller slides to achieve acceptable results. Fig. 5 shows the layout of the optical system. We are planning to modify the system, using a larger lens for the detector assembly.
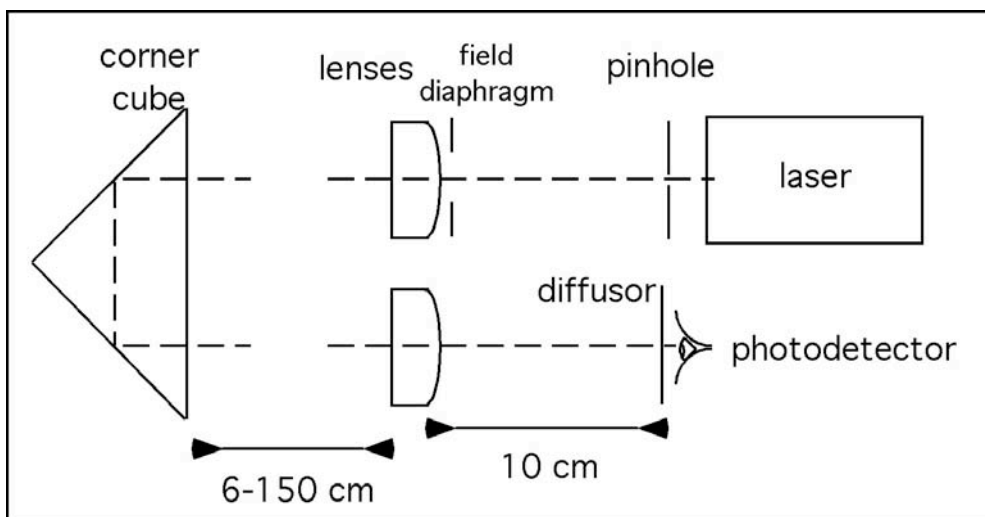


Fig. 5: Optical system

## 2.3    NERONE: data acquisition system

The data acquisition system and the motor control have been designed and built at LNF. The board is based on a PIC 16F873 microcontroller, that reads the photodetectors through embedded 10 bit ADC's, sends out the averaged data on the RS/232 link to the ship, and receives commands to move the motor. Fig. 6 shows the electronics diagram.
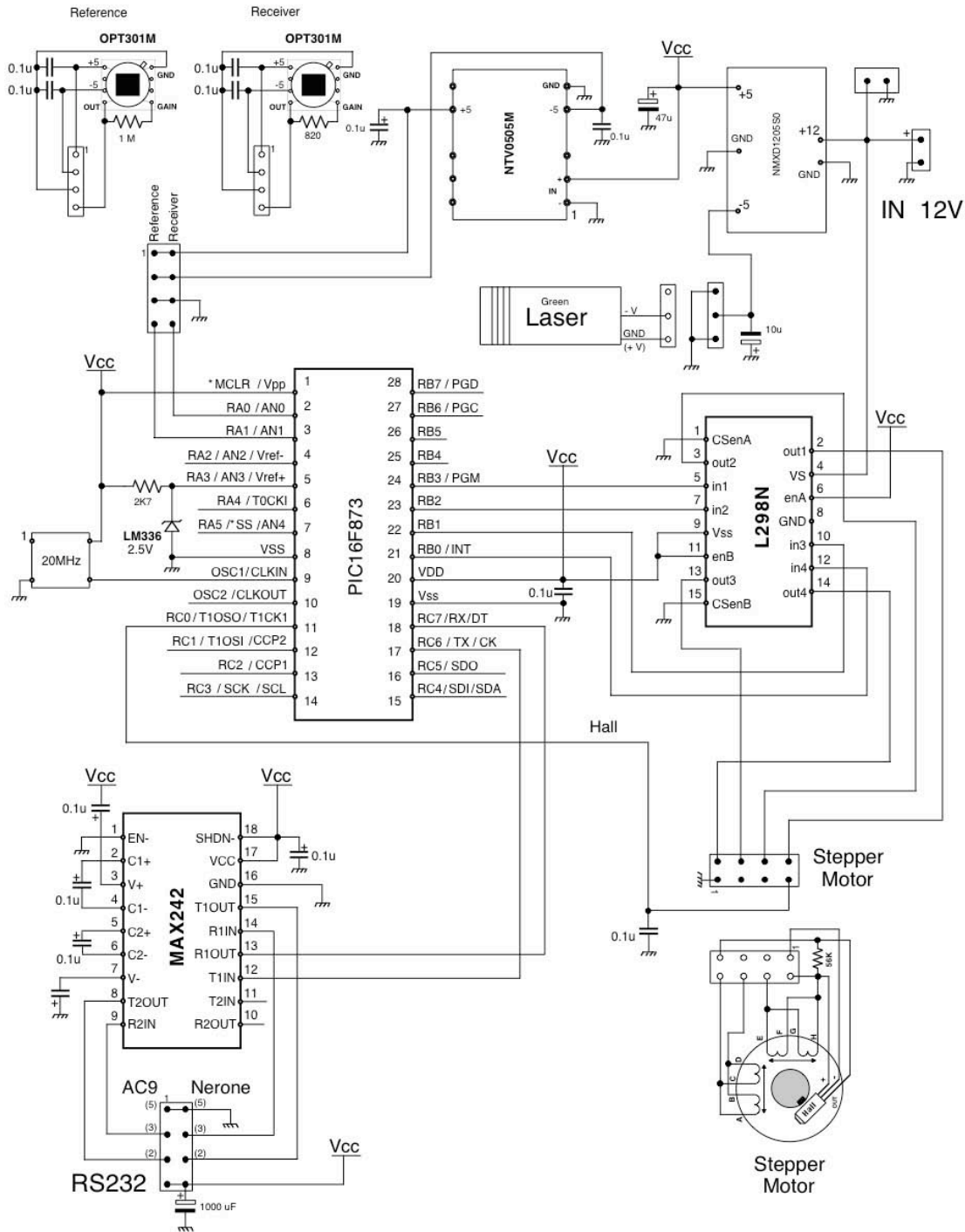


Fig. 6 : NERONE DAQ schematic

Two photodetectors have been used: one for the light detector and one mounted laterally in the laser housing, to get rid of the laser intensity fluctuations, which did not allow enough precision in the measurements.

The PIC 16F873 microcontroller reads the photodetectors using two 10 bit ADC's, controls the stepper motor operation generating the appropriate 4 bit driving sequence which is amplified by the L298N driver, and handles the two RS/232 connections, one with the ship, receiving commands and transmitting the measured data, all in ASCII format, and the other with a separate channel going to the AC9, which is the instruments used up to now to measure light transmission. It is possible from the ship to put the NERONE system in a Transparent mode, thereby connecting to the AC9 and allowing to take measurements with both instruments during the same deployment to compare results.

A LabVIEW interface was designed to drive the whole system from the ship. Fig. 7 shows the internal arrangement of the NERONE DAQ and optic system in the aluminum pressure housing.



Fig. 7: NERONE DAQ BOARD and blu laser

## 2.4    Sea connections

Fig. 6 shows the connection system for NERONE. A 4 pin connector  serves the cable to the IDRONAUT Ocean Seven-MK317 CTD, which contains the half duplex modem talking to the ship via the 4000 m cable. Another 4 pin connector goes to the battery pack, a 4 pin connector drives the motor and the last connector carries the RS/232 signals to the AC9.

All connectors are from SEA-CON® BRANTNER & ASSOCIATES, INC.
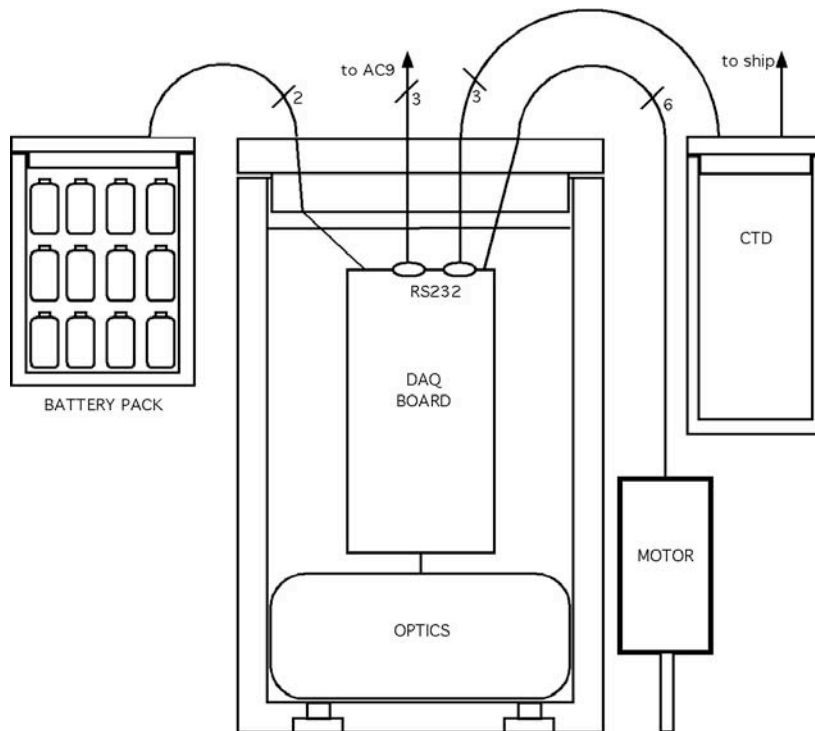


Fig. 6: Schematic diagram of the NERONE connections

## 3   The measurements

The measurement campaign took place at the Catania test site , 2 miles outside the Catania harbour, in June 2006.

The site coordinates, measured by GPS, were  37 28 00 N and 15 27 04 E at the beginning of the measurements.

We used a 5 mW green laser with a wavelength  of 532 nm.

Two drops were performed:

0 - 1800 m - 0

0 - 600 m – 0

Fig 8 shows the data taken during descent and rise in the 1800 m drop. The data were taken with 3.8 m distance between laser and detector. The step at the end was determined by moving the corner cube close to the optics container before recovery to the ship for safety reasons.
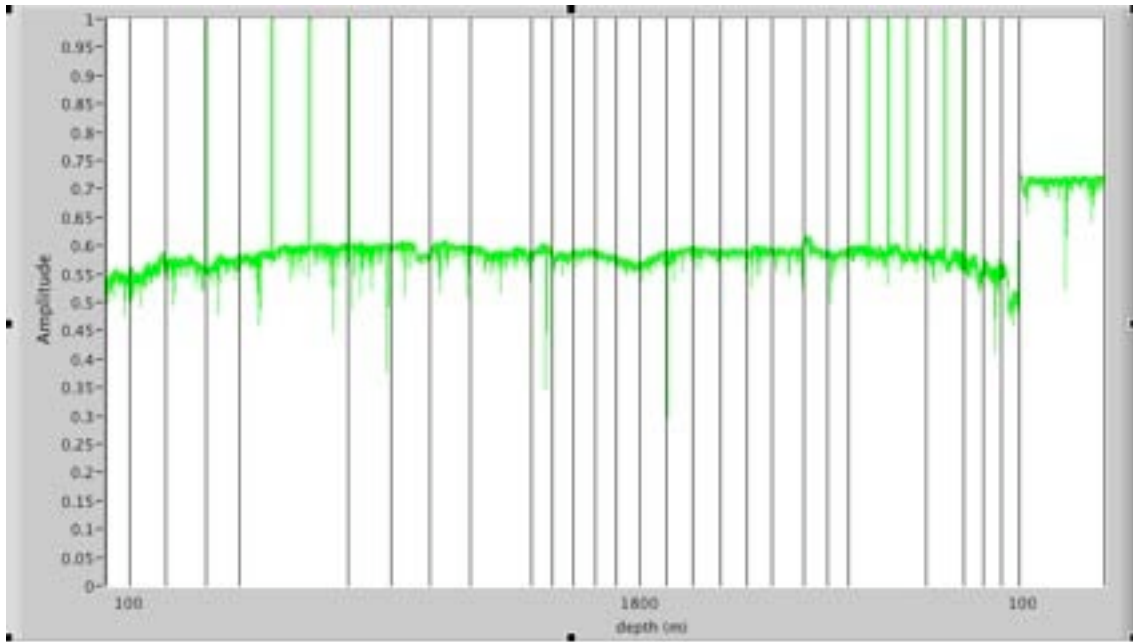
Fig. 8: Raw data taken during descent and rise down to 1800 m.

Stops were made during descent and rise at depths of 100, 200, 300, 600, 1200, 1800 m
At each stop we performed a scanning from 3.8 m to .65 m and back. We took 40 steps (3.5 cm each), and for every step 100 measurements, each the average of 32 individual measurements, were taken and saved on the ship computer. Fig. 9 shows an example of a scan and the exponential fit to the data. The fit residues were of the order of $10^{-5}$. The depth was 300 m.

We attribute the difference between the incoming and the outgoing measurements to actual differences in the sea opaqueness. It must be considered that a scan lasted about 20 minutes and that during the drops the ship was drifting at about 1 knot because of the wind.
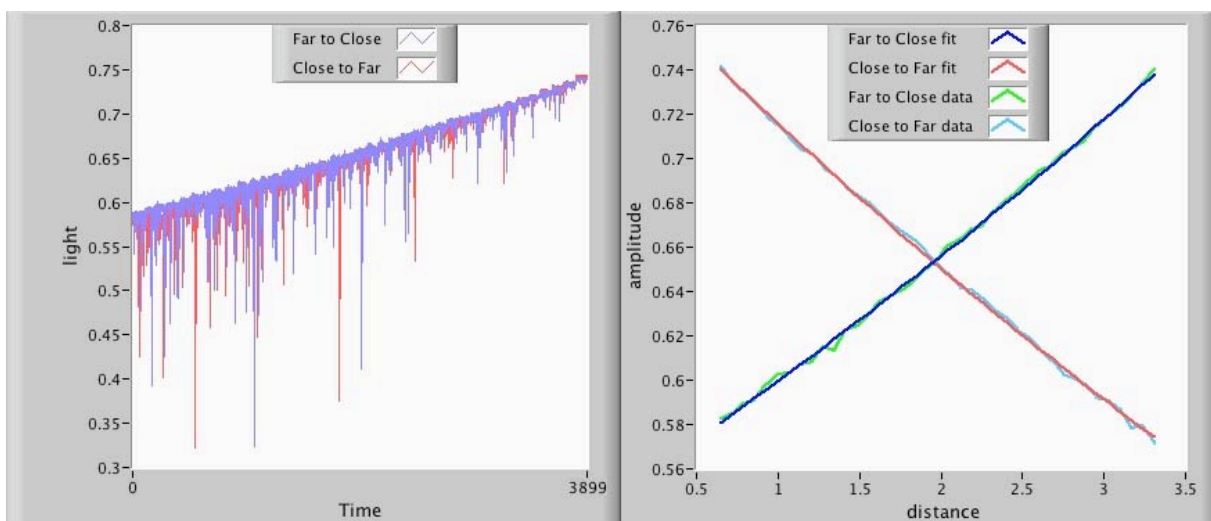


Fig. 9: Example of a scan and the exponential fit to the data at 300 m depth.

## 4  Data analysis

Fig. 10 shows the reconstructed attenuation lengths for the two drops. There are four points for each depth: during descent and during rise (down and up), and in each case a measurement while the distance was decreased and one while it was increased (far to close and close to far).

We are confident that our measurements are reliable for two reasons: internal consistence and comparison with data taken by the AC9.

### 4.1 Internal consistency

We have a method for checking that our instrument is behaving correctly. If a measurement is taken in air, the attenuation length should be infinite. We checked this by performing a measurement on the deck of the ship between the two drops.

Immediately after recovery, the attenuation length was  79 m. After cleaning the windows we measured 177 m. After realignment  we had 276 m. This shows that our system is stable and not influenced by the drop process, but on the other hand puts the emphasys on the dirt that can be deposed on the windows while going through the surface layers of the sea, that are known to be very dirty.

### 4.1 Internal consistency

We have compared our data with data taken with the AC9 in a location close to ours a few years ago (private communication by Giorgio Riccobene)[4]

The results are summarized in table 1.

| Depth m | $L_c$ NERONE m | $L_c$ AC9 m |
|---|---|---|
| 300 | 9.9 | 10 |
| 600 | 11.2 | 11.4 |
| 1200 | 12.8 | 13.3 |
| 1800 | 10.4 | 13.3  (best 15) |

The results are in good agreement between themselves, axcept for the 1800 m depth measurements. However, it must be pointed out that we could not go under 1800 m because we were almost at the bottom of the sea, as measured by the ship sonar. The AC9 data, on the contrary, were taken down to 2000 m. This shows that we were not in the same position, and we probably were closer to the bottom than they ever went. It is expected for the attenuation length to decreae close to the bottom due to dirt moved by underwater currents.

Furthermore, they quote a "best" $L_c$ of 15 m, obtained by a fit over the best results close to the bottom. It must however be taken into account that the angular acceptance of NERONE is 1 mrad, while the AC9 beam divergence is much higher. Therefore small angle scattering could play a different role in our two systems. This could be further explored.

We want to stress that NERONE, with suitable modifications, could be used to measure small angle scattering, if it is made clear that this measurement is relevant to the design of the kilometer cube detector.
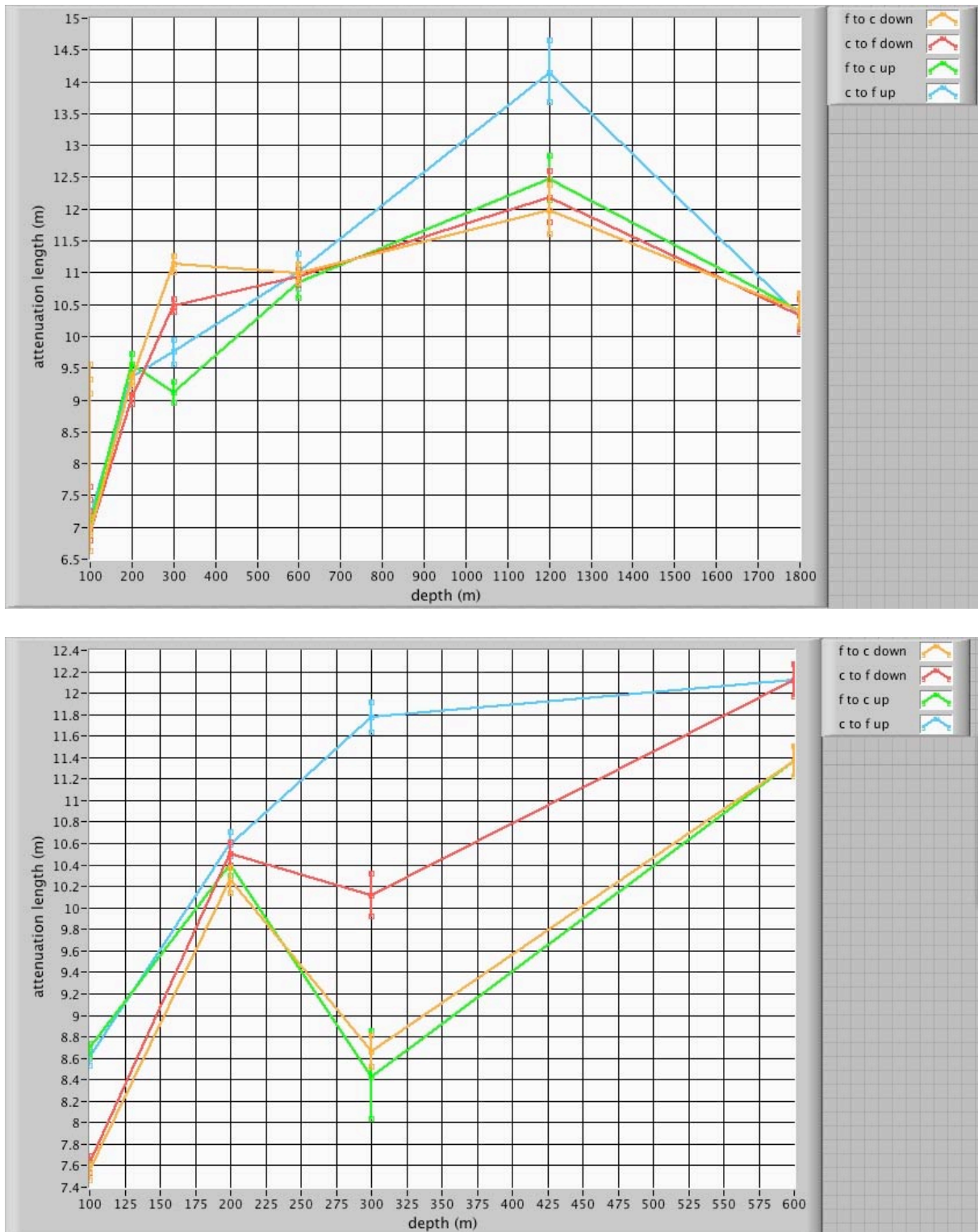
Fig. 10: Attenuation length fit during the two drops

## 5  THE FUTURE

Analyzing our data, we have found that it will be possible to speed the data acquisition by a factor of 20, reducing the number of data taken in any position without any appreciable increase of the statistical error and increasing the speed of the motor. This will allow us to make more measurements at different depths.

We clearly need further tests and measurements, and to be able to make drops at the km4 site down to 3000 m.

An interesting possibility is to redisign NERONE to make it more resistant to sea water corrosion, to be able to install it permanently in underwater experiments.

## 6  ACKNOWLEDGEMENTS

### REFERENCES

(1)    G. Riccobene et al.: Deep seawater inherent optical properties in the Southern Ionian Sea, astro-ph/0603701.
(2)    Roberto Habel et al.: NERO, AN INSTRUMENT TO MEASURE LIGHT ATTENUATION LENGTH IN WATER (LNF-99-015(NT))
(3)    Marco Cordelli et al.: NERONE: FIRST TESTS IN SEA WATER (LNF-01/015(NT)
(4)    Private communication with Giorgio Riccobene, LNS.
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