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ANTARES : PRELIMINARY DEMONSTRATOR RESULTS

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ANTARES : Preliminary demonstrator results

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On behalf of the ANTARES collaboration

The ANTARES collaboration is building an undersea neutrino telescope off Toulon (Mediterranean sea) with effective area $\sim 0.1\ \mathrm{km}^2$. An extensive study of the site properties has been achieved together with software analysis in order to optimize the performance of the detector. Results are summarized here.
An instrumented line, linked to shore for first time via an electro-optical cable, has been immersed late 1999. The preliminary results of this demonstrator line are reported.

1 Introduction

The ANTARES (**A**stronomy with **N**eutrino **T**elescope and **A**byss environmental **RES**earch) project is a European collaboration involving physics laboratories as well as sea science experts to rise a deep-sea neutrino telescope in the Mediterranean sea [1].

1.1 *physics goals*

The first scientific motivation for a neutrino telescope is to undertake astronomy studies at high energy (above 1 TeV) using neutrinos as new probes. Indeed, at such energies the universe becomes impervious to photons, gamma rays being absorbed by the infra-red and the cosmological backgrounds (GZK effect). Neutrinos should thus allow the study of the origin of cosmic rays up to 10^{20} eV, but also the detection of extragalactic point-like sources such as Active Galactic Nuclei or Gamma Ray Bursters. Neutrinos are also likely to come from binary stars, black holes, supernovae or young supernova remnants of our galaxy.

Another interesting topic is the indirect search for the Lightest Supersymetric Particle of the Minimal SuperSymetric Model as a weakly interactive massive particle (WIMP). According to different scenarios the neutralinos gravitationally trapped in the centre of the earth [2], in the core of the Sun [2] or even in the galactic centre [3] annihilate yielding a significant flux of neutrinos with typical energy around one half of the neutralino mass and producing an excess of events in the detector according to the source direction.

The recent results [4] from the SuperKamiokande experiment show evidence for atmospheric neutrinos $\nu_\mu \leftrightarrow \nu_\tau$ oscillations with most favored parameters $\sin^2 2\theta > 0.88$ and $3.10^{-3} < \Delta m^2(eV^2) < 5.10^{-3}$. An independent measurement of the region $60 < L_\nu/E_\nu < 1250$ km/GeV where L_ν and E_ν represent respectively the path length and the energy of the neutrino could clarify the interpretation of the observed deficit. ANTARES seems suited for this task given its low energy threshold (5 GeV) for the observation of oscillation structures in contained event spectra.

1.2 *Detection principle*

Neutrinos interact with the nucleons surrounding the detector and produce charged leptons which can be identified by the Cherenkov light they emit. The telescope is a 3 dimensional array of photomultipliers, mostly aimed to detect upward going particles. The knowledge of the position of the PMTs as well as the time of the hit allow the reconstruction of the particle trajectory. The down-going particle flux is dominated by atmospheric muons which constitute the main background. Only ν_μ and $\bar{\nu}_\mu$ and corresponding $\mu^\pm$ are detected ($\tau^\pm$ decay too fast and $e^\pm$ get absorbed too quickly).

2 The ANTARES project

2.1 *Expected performance*

The objective of ANTARES is to build a first undersea neutrino telescope with an effective area of the order of 0.1 km^2 (cf. figure 1) to prove the feasibility of an even larger telescope on the km scale. Many simulation studies have been performed to characterize the performance of the detector which should benefit of a very good angular distribution, better than 0.5° for energies greater than 1 TeV. A deep site evaluation program has also been fullfiled to take into account the environmental properties of the detector.

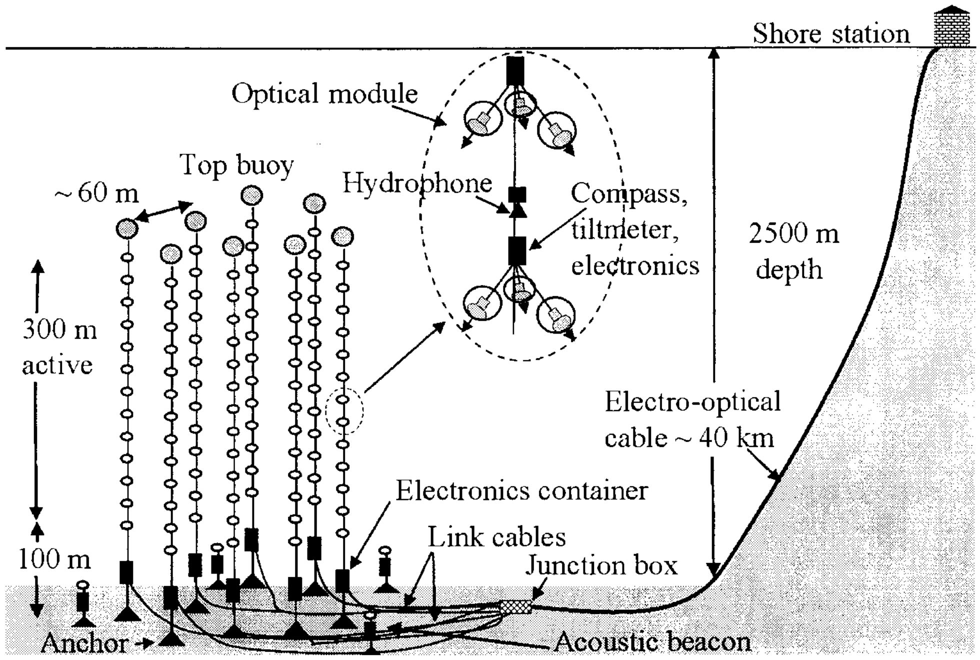

Figure 1: The ANTARES detector. It consists of thirteen 400 m long strings equipped with several 12 m distant storeys each bearing three down-looking photomultipliers. Each string can be used as a single detector for lower energy studies (oscillation and neutralino search). All lines are also equipped with positioning control devices such as compasses, hydrophones, tilt-meters. On the sea bed 3 acoustic beacons will be installed to perform a spatial monitoring by triangulation. Data handling as well as power supply will be monitored through optical fibres.

2.2 Site evaluation

The ANTARES site, at a depth of 2400 m, is located $\sim$ 40 km south of La Seyne (42°50 N, 6°10 E) which offers the advantage of the IFREMER (French national institute for sea-science) facilities. The site evaluation program covers three main orientations.
Concerning *background light* (see also section 3.3), a continuous rate of roughly 40 kHz (per 8" PMT) mainly due to ^{40}K disintegrations has been observed [6]. Bioluminescent flashes (with rates exceeding 200 kHz lasting a few seconds) attributed to abyss animal populations are found to induce an overall dead time lower than 5% and can be handled with an appropriate trigger strategy.
Deposits on optical module have been carefully studied in situ. The various tests reveal a negligible loss (less than 1.5% after a one year immersion) of the glass transparency due to *bio-fouling*. Moreover this phenomenon seems to reach a plateau after several months probably because of the water current cleaning the glass spheres.
Water transparency is a crucial point for ANTARES [7]. Several measurements have been made using isotropic LEDs (466nm, blue) illuminating a PMT at various distances. They lead to a value of absorption length between 55 and 65 m. The scattering length, for photons which are diffused at large angle and produce late hits (those photons will not be taken into account in the reconstruction procedure) is found to be greater than 200 m.

3 The ANTARES demonstrator

The crucial difference from all the other tests previously performed lies in the fact that the prototype line is entirely functioning in a remote mode from the shore. Any input or output information is transmitted through 37 km of optical fibre.
The demonstrator line has been immersed on the 30^{th} of November 1999, 30 km south of Marseilles at a depth of 1200 m (42°59 N, 5°17 E). This site which differs from the ANTARES site, has been chosen for reason of accessibility to an electro-optical cable linking Marseilles to the island of Corsica

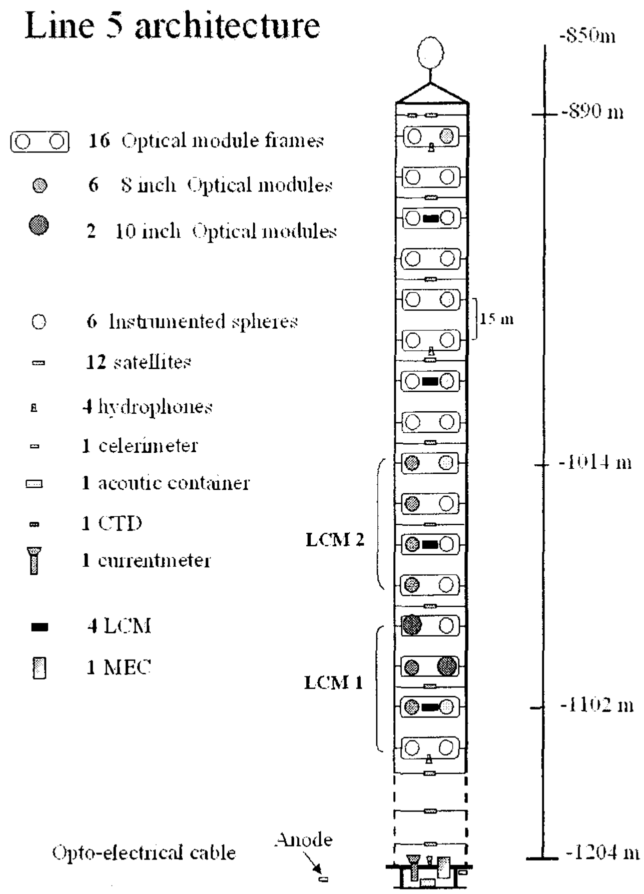

Figure 2: Demonstrator architecture

and lent by the France Telecom company. The pressure at this depth is measured to be $89,9 \pm 0.1$ bar on average and temperature varies from $13.24°C$ to $13.45°C$ as expected.

3.1 Demonstrator layout

The demonstrator (called "line5") consists of a 16 floor line 354 m long from lest to buoy. Distance between storeys is set to 14.6 m, and each storey is carrying two 17" Benthos spheres 1.5 m apart. Eight of these spheres contain an optical module (six 8" Hamamatsu PMTs and two 10" Hamamatsu PMTs with their associated electronics). All the optical modules also contain a blue (480 nm) LED glued to the internal surface of the Benthos sphere to allow calibration tests. The design of the prototype is shown in figure 2.
The different floors are linked by two cables maintained separated from each other by spacers bearing 12 devices called "satellites" providing cap and tilt measurements as well as 4 hydrophones for acoustic positioning and 1 celerimeter. The connection to shore is ensured by a 37 km long electro-optical cable.

3.2 Positioning and slow control

The line shape monitoring is achieved with the tilt-meter and compass data (satellites) . The reconstruction accuracy is better than $\sim$ 10 cm in the horizontal coordinates and of the order of 1 cm in vertical position.
The detector appears to be very stable and quite straight. Deviation from vertical is less than 3°. The different measurements performed show a coherent behavior: cap variations are correlated all along

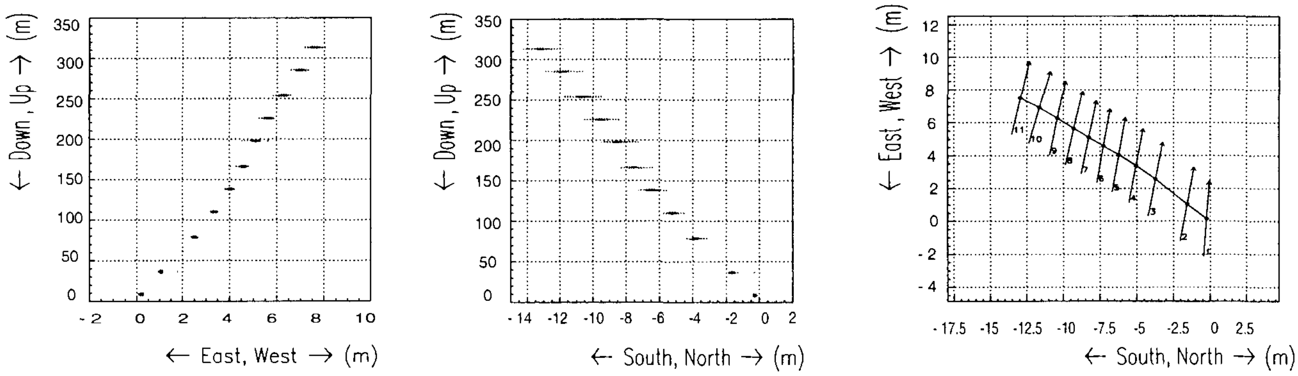

Figure 3: The left two plots represent a side view of the line during 17 days. It reveals an extremely stable behavior: the detector is almost straight and the horizontal relative displacement of each module is less than 3 m. The right plot is a top view of the prototype. The top spacer lays $\sim$ 14 m away from the vertical axis passing through the lest of the demonstrator. The arrows display the measured heading of the spacers: the line does not seem to be twisted.

the line. These variations never exceed 1° which establishes the line stability. From Jan 10^{th} to Jan 27^{th}, 2000 top spacer relative displacement was found to be less than 3 m as can be seen in figure 3. The position of the elements of the prototype does not seem to vary from more than 1 cm within 10 s, which is an important information for the future detector slow control acquisition rate.

The acoustic system (acoustic beacons together with hydrophones) also contributes to provide an absolute spatial positioning. The method applied assumes a precise knowledge of the sound velocity which relies on the measured salinity ($39.1 \pm 0.1°/_{\circ\circ}$).

3.3 Photomultiplier data

The timing calibration of the demonstrator is done using LED pulses which are shining light vertically. Figure 4 shows histograms of the distribution of the time difference between the bottom three PMTs of the string and the top optical module LED pulse. Taking into account the left HWHM of the distribution (the right side being affected by scattering induced delays), one can conclude to an overall time resolution of the order of 5 ns for each PMT.

The seven vertically aligned phototubes of the demonstrator constitute a $\sim$ 100 m long sensitive detector. They allow the reconstruction of atmospheric muon tracks using a 4-parameter hyperbolic fit involving only the arrival time of the Cherenkov photons and the altitude of the hit PMT. 65 000 triggers have been recorded per day leading to $\sim$ 6500 reconstructed tracks per day. The amount of data collected will allow the study of the angular distribution of atmospheric muons and the comparison with predictions. The result of such a comparison will be published soon.

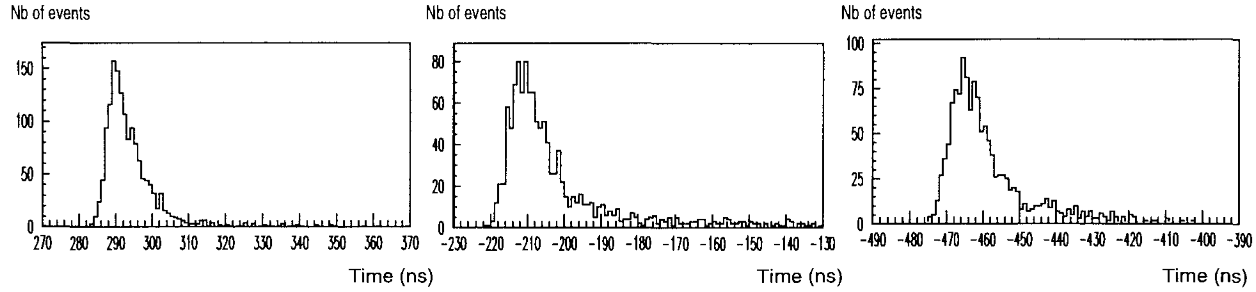

Figure 4: Histogram distribution of PMT time response illuminated by a LED with own pulsing jitter of 7.3 ns. From left to right the three histograms correspond to the three bottom PMT of the line. The asymmetry of the distribution is mainly due to diffusion process.

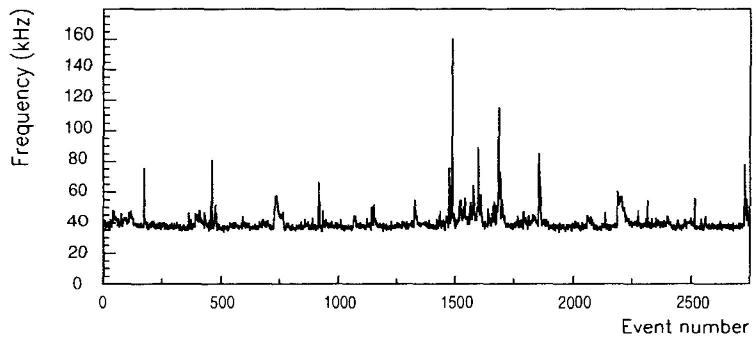

Figure 5: Example of bioluminescence time stream observed with an 8" PMT. The lasting time of high counting rate is only of the order of a few seconds.

Information about the bioluminescent background around the demonstrator is in excellent agreement with the previous measurements performed in the ANTARES site. As shown in figure 5 a flat component of $\sim$ 40 kHz per 8" photomultier is easily distinguishable from spikes of high counting rate that we usually attribute to living creatures.

4 Conclusions and outlook

The deployment of the ANTARES demonstrator has successfully concluded the R&D phase of the ANTARES project. The prototype is foreseen to be recovered for inspection during summer 2000.
The construction of a deep-sea 13 string detector is now fully started. The first completely equipped line should be immersed in 2001 followed by six additional lines in 2002 and 6 more in 2003.
The ANTARES collaboration is still following its site evaluation program as an exploratory stage for a km^3 project which is advocated for high energy astronomy.

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