The ANTARES neutrino telescope

Y. Becherini for the ANTARES collaboration
Physics Department, University of Bologna and INFN,
viale C. Berti Pichat 6/2,
I-40127 Bologna, Italy
Yvonne.Becherini@bo.infn.it

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Abstract

The ANTARES collaboration is building a deep underwater neutrino Cerenkov telescope at 2400 m which will be located off the Mediterranean sea coast near Toulon, France. The main scientific aims of the experiment are the detection of high energy upgoing muons coming from astrophysical neutrinos, indirect dark matter searches, the study of atmospheric neutrino oscillations. The detector will be completed in the end of 2004.

1 Introduction

Neutrino telescopes use the detection of upward-going muons as a signature of $\nu_\mu$ CC interactions in the matter below or inside the detector. The ANTARES muon detection medium is sea water through which the muon emits Cherenkov light. The light detection allows the determination of the muon trajectory. The detection technique requires discriminating upward going muons against the much higher flux of downward atmospheric muons, and for this reason the detector is installed deep underwater. Since neutrino cross sections are very small, the detector mass must be very large.

2 ANTARES scientific programme

The ANTARES scientific programme can be summarized in three main subjects: neutrino astronomy, neutralino dark matter searches and atmospheric neutrino oscillation studies.

Neutrino astronomy. Photon astronomy gives an essential contribution to the understanding of the Universe, it has many advantages because photons are produced in large quantities and can be detected over a wide energy range, but it also has some disadvantages. Some hot and dense regions of the sky, like star cores, are completely opaque to photons; moreover, high energy photons ($E > 10$ TeV) can interact with IR radiation, with the cosmic microwave background and radio waves through pair production, preventing the observation of regions at distances larger than 50 Mpc. Many models predict that sources in the Universe may emit high energy ($\gtrsim 1$ GeV) neutrinos. These neutrinos could be produced by cosmic accelerators, such as gamma ray bursters (GRB), active galactic nuclei (AGN), supernova remnants, and binary systems. Neutrino astronomy could open a new exploratory window in the Universe, complementing high energy gamma ray astronomy.

Indirect Neutralino dark matter searches. Neutralinos could be part of the dark matter halo in our Galaxy and could appear as Weakly Interacting Massive Particles (WIMP). Neutralinos could slow down by elastic collisions in celestial bodies like the Earth, the Sun or the Galactic Centre and
could gravitationally become trapped in their cores. Here, neutralino pair annihilation could take place, producing Standard Model particles decaying into neutrinos. In a neutrino telescope like ANTARES, such processes could be observed as an excess signal of induced muons from the celestial body direction.

**Neutrino oscillation studies.** Evidence for atmospheric neutrino oscillations has been shown by the MACRO [1], SuperKamiokande [2], and Soudan 2 [3] collaborations. ANTARES will have a muon energy threshold of $\sim 5$ GeV, making the detector capable to measure the atmospheric muon neutrino flux. An estimate of the ratio $E_{\nu}/L$, where $E_{\nu}$ is the neutrino energy and $L$ is the distance travelled by the neutrino from the production point to the interaction point, will be done to investigate atmospheric muon neutrino deficit.

3 Detector design

The ANTARES neutrino telescope will be installed in the next two years at 2400 m depth in the Mediterranean sea, 37 km off shore of La Seyne sur Mer, near Toulon, France. Many environmental site measurements have been done to test sea bed, sea currents, water transparency, bio-fouling, sedimentation [4].

The detector consists of 900 optical modules in 10 identical 400 m long mooring lines ("strings") anchored to the sea bed. The distance between the strings will be about 60 m. Each string holds 30 storeys separated by a distance of 12 m; each storey consists of 3 optical modules oriented at 45° below the horizontal, see the centre of Fig. 1. The storeys are interconnected by an electromechanical cable.

An ANTARES optical module (OM) [5] is composed of a 17" diameter pressure resistant glass sphere containing a 10" Hamamatsu photomultiplier tube with its associated electronics. The angular acceptance of the optical modules is broad, and it falls to half maximum at 70° from the axis. The OM configuration allows to detect light with high efficiency in the lower hemisphere, and has some acceptance for downgoing muon tracks. The relative positions of all optical modules in the detector are given in real time by an acoustic positioning system and by compasses and tilt-meters installed along the line which allow the reconstruction of the shape of the line and the orientation of each storey.

The electronics related to a given storey is contained in a local control module (LCM), which contains the boards for readout, DAQ, power, clock and trigger. At the base of each string there is a string control module (SCM), which contains the electronics concerning the Slow Control, clock, and instruments for acoustic positioning and measurements of sea properties. The individual SCMs are linked to a
common junction box (JB) by electro-optical cables which are connected using a submarine. A deep sea telecommunication cable links the JB with a shore station where the data are filtered and written to disk.

A prototype of the detector string (sector line) will be deployed in November 2002.

4 Detector expected performances

The relevant parameters which characterise a neutrino telescope are its effective area, total mass, its angular resolution (for astronomy) and energy resolution.

Effective area. Fig. 2 on the left shows the effective area computed using a Monte Carlo simulation of isotropic neutrino events as a function of neutrino energy after quality cuts on the reconstruction and how the effective area depends on the required pointing accuracy. For a typical $E^{-2}$ cosmic neutrino spectrum 96% (72%) of the events are reconstructed with an error smaller than 1° (0.3°).

Angular resolution. The intrinsic angular resolution of the telescope is defined as the median angular separation between the real and the reconstructed muon track. The angular resolution of a neutrino telescope depends on reconstruction algorithms, selection programs and timing accuracy. In Fig. 2 (on the right) the median value of the distribution of the angle between the reconstructed muon and the simulated muon, and between the reconstructed muon and the parent neutrino versus the neutrino energy are shown. Below 10 TeV the median angle between the muon and the neutrino is dominated by the kinematics of the interaction, while at larger energies it is limited by the intrinsic angular resolution. At higher energies the neutrino pointing accuracy $<0.2°$. This estimate takes into account of the light scattering in water.

Energy resolution. Below 100 GeV, the muon energy is determined from the range in the detector, while above 100 GeV it is estimated by the quantity of light detected by the optical modules. For $E_{\mu} = 1$ TeV the muon energies are reconstructed within a factor of 4, decreasing to a factor of 3 at 10 TeV, reaching the value of 2 for $10 < E < 10^7$ TeV. Fig. 3 shows the comparison between the generated and the reconstructed integrated muon spectra for several neutrino flux models.

References

[1] S. P. Ahlen et al., Phys. Lett. B 357 (1995) 481. P. Ambrosio et al., Phys. Lett. B 434 (1998) 451; hep-ex/0206027.
Figure 3: Comparison between the predicted (solid lines) and reconstructed (dashed lines) integrated spectra for the atmospheric neutrino flux, and for two different astrophysical neutrino fluxes WB98 and MPR98.

[2] SK Coll., Y. Fukuda et al., Phys. Rev. Lett. 81 (1998) 1562; 85 (2000) 3999.
[3] Soudan 2 Coll., W. W. M. Allison et al., Phys. Lett. B 449 (1999) 137.
[4] P. Amram et al., Astr. Phys. 13 127-136 (2000); Amram P. et al., astro-ph/0206454.
[5] P. Amram et al., NIM A 484 (2002) 369.
[6] T. Montaruli, ANTARES collaboration, astro-ph/0207531.