SF2A 2005
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NEUTRINO ASTRONOMY WITH ANTARES

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On behalf of the ANTARES collaboration

Abstract. The ANTARES collaboration is building a high energy neutrino telescope in the Mediterranean sea, at a depth of 2500 m, 40 km off the French coast. This instrument will detect Cherenkov light produced in sea water by neutrino-induced muons. ANTARES will provide an alternative to the photon and cosmic ray observations in astrophysics. Preliminary results of a small size prototype, currently operating, will be presented. The first line of ANTARES will be deployed this Autumn and the detector should be fully operational by mid-2007.

1 The need for new messengers

Despite the great success encountered by photon observations in astrophysics, some limitations appear due to photon interactions with the infrared or cosmological diffuse backgrounds. The consequence is that photons with energy above 100 TeV cannot travel further than 10 Mpc. Cosmic Rays are another very promising probe used for the understanding of the Universe, but the GZK effect limits the observation depth to 50 Mpc above 100 EeV, whereas at lower energies magnetic fields deflect protons and make point-like source searches impossible. The neutrino does not suffer from these effects : it is neutral and interacts only weakly. It therefore appears to be an ideal candidate for high energy astronomy, and gives access to the heart of the sources.

2 Detector description and expected performances of ANTARES

ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RE-Search) is a submarine Cherenkov detector located in the Mediterranean sea, 40 km off Toulon (France), at a depth of 2475 metres. A surface of 0.06 km^2 of deep sea bed is going to be instrumented with 12 lines, each carrying 75 photomultipliers tubes (PMTs) located inside pressure resistant spheres. Three spheres and a titanium cylinder housing the electronics compose a storey. A line is a set of 25

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storeys separated by 14.5 metres, for a total height of 450 metres (figure 1). A top buoy and an anchor at the sea bed keep the line vertical. An acoustic positioning measurement set-up will provide the PMTs position with a precision better than 10 cm despite the movements of the line due to water currents.

Detection principle & Backgrounds: Depending on neutrino flavour and on current type, the interaction of neutrino in ANTARES vicinity will produce an up-going muon and a shower (ν_μ and Charged Current) or only a shower, inducing Cherenkov photon emission along trajectories of charged particles. PMTs positions and measurements will be used to reconstruct the muon track or the shower. Detection of up-going muons is the benchmark for ANTARES : thanks to their long path in matter (10km) they allow the detection of neutrino interactions far from the instrumented volume and increase significantly the event rate. However, backgrounds are provided by atmospheric showers: down-going bad reconstructed muons faking up-going muons, and atmospheric neutrinos. In the sea water two other backgrounds generate photons detected by the PMTs: the beta emitter ^{40}K produces Cherenkov photons, whereas light emitted by bioluminescent organisms mostly leads to single photoelectron production on the PMT photocathode.

Timing & Angular Resolution: From the time and amplitude of the fired PM, the muon can be reconstructed using a likelihood fit. The time resolution reachable for single photoelectrons is better than 1.5 ns, and the detection threshold will be set at around 1/3 of photoelectron. The time measurement performances, combined with the low diffusion and absorption of photons in ANTARES site sea water, allow an angular resolution better than 0.2° for muon energy above 10 TeV. At these energies the neutrino and the muon are essentially colinear.

The effective area is the number of detected events per unit of time divided by the incoming particle flux. For 10 TeV up-going muons, the ANTARES muon effective area is 20 000 m^2, reaching the geometrical surface (60 000 m^2) at 10 PeV. The neutrino effective area for muon up-going neutrinos at 1 PeV is about 10 m^2 and decreases at high energies due to the effect of neutrino absorption in Earth.

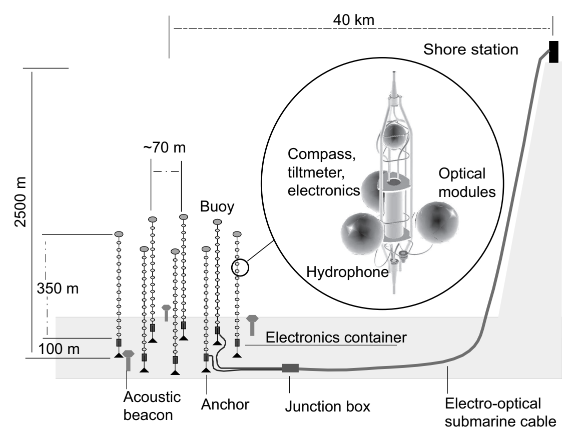

Fig. 1. Schematic view of the ANTARES detector

3 Physics goals of the ANTARES experiment

The astrophysical galactic potential sources of neutrinos are mainly supernova explosions and acceleration mechanisms in supernova remnants. The latitude of the ANTARES detector (45°50' N) will allow the observation of a large part of the sky: 3.5π sr, and especially the Galactic center during 2/3 of operating time.

Micro-quasars are also galactic neutrino emitter candidates, which may be detected by the ANTARES experiment. Depending on model of jets, an estimation of neutrino fluxes at Earth has been performed (Distefano et al. 2002; Levinson & Waxman 2001). The order of magnitude of the neutrino energy is 1 TeV. For example, SS433 is an identified persistent microquasar which may be observed by ANTARES, after one year of data taking, the expected neutrino flux E^2dN/dE being $2 \cdot 10^{-7}\mathrm{GeV\,cm^{-2}s^{-1}}$ at the relevant declination. Using recent results from HESS gamma observations for LS5039 microquasar, A. Aharonian et al. have given an estimation of the potentiel neutrino flux, and conclude that ANTARES could be sensitive after a few years of observation (A. Aharonian et al).

Active Galactic Nuclei (AGN) are good candidates for extragalactic neutrino production: In the case AGN jets allow hadronic interactions to take place, the charged pion production inside these jets will lead to neutrino generation, while decay of neutral pions will contribute to the observed gamma spectrum. Currently, gamma observations are compatible with inverse compton gamma production, but the jet composition and internal mechanisms are still open.

Gamma-ray bursts can also produce neutrinos, and could be detected in a time window centered on the one defined by networks of satellites and ground based alert systems. Two GRB models have been considered in the ANTARES collaboration: the fireball model (Waxman & Bahcall 1997; Kouchner 2001) and the cannonball model (Dar & De Rùjula 2001 and 2004; Ferry 2004). The typical energy of neutrinos produced in the fireball model is above 10 TeV, while it is below 1 TeV in the cannonball model. The good angular resolution of the detector could allow the discrimination between the two models if the event rate is high enough.

Unresolved Sources: ANTARES could also put stringent limit on neutrino diffuse flux models that accounts for the neutrino emission of all unresolved sources in the Universe. Limits for the muon neutrino expected flux at the Earth level have been estimated using Cosmic Ray normalisation methods, for example the so-called Waxman Bahcall limit (Waxman & Bahcall 1999 and 2001): $E^2dN/dE < 4.5 \cdot 10^{-8}\mathrm{GeV\,cm^{-2}s^{-1}sr^{-1}}$, which is reduced by a factor 2 if we assume neutrino oscillations. ANTARES sensitivity for muon neutrinos is $8 \cdot 10^{-8}\mathrm{GeV\,cm^{-2}s^{-1}sr^{-1}}$ (90% C.L.) after one year of data taking, but will increase when cascade reconstruction (ν_e, ν_τ) will be accounted for in computations.

4 The Mini Instrumentation Line with Optical Modules (MILOM)

A small line called MILOM equipped with calibration and environmental monitoring devices, and containing a storey with three optical modules, was deployed and connected in March 2005. Data analysis is under progress. Several encouraging results have already been obtained: time calibration performances are inside expected specifications, as well as single photoelectron sensitivity. Figure 2 displays the charge collected by one PMT, and shows the single photoelectron peak mainly due to bioluminescent activity. The counting rates observed are similar to the ones mesured by the previous prototype (2003): in addition to the ^{40}K beta radioactivity, which produces a constant counting rate of 30 kHz, bacteria and bioluminescent organisms raise this baseline at a level of about 100 kHz, and produce counting bursts 20% of time.

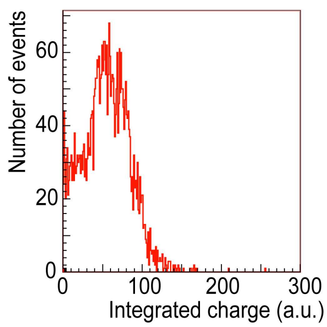

Fig. 2. MILOM data : single photoelectron signal

5 Conclusion

Located in the Mediterranean sea, ANTARES will provide a complementary view of the sky compared to AMANDA/ICECUBE South Pole neutrino telescopes (Geenen H.). A great advantage of ANTARES latitude is the coverage of the region around the Galactic center. Moreover, the good sea water properties make possible to reach an angular resolution of 0.2° at high energy (> 10 TeV). The analysis of the data so far has validated the technologies chosen by the collaboration. The first fully equipped line, line 1, is currently under construction. Its deployement and connection are planned for end 2005.

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