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NEWS FROM ANTARES

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Abstract. The ANTARES collaboration is constructing a high energy neutrino telescope in the Mediterranean Sea at a depth of 2500 metres. With an angular resolution better than 0.3° above 10 TeV, ANTARES could detect neutrinos from known sources and explore the deep Universe.

1 Why neutrino astronomy ?

Tremendous progress has been made within the last century on the understanding of the most powerful objects of the Universe, thanks to observations at many wave lengths and today at higher and higher energies. However, photon observations have their limitations. Because of the interaction with the infrared or cosmological diffuse backgrounds, photons with energies above 10^{14} eV cannot travel further than 10 Mpc.
Another view of the sky is given by cosmic rays. This is particularly true with the new generation of ground observatories that will detect particles of extreme energies. Such observations could help us to understand the origin of cosmic rays. However, here again, the GZK effect [1] limits the observation depth to 50 Mpc above 10^{20} eV. Moreover, at lower energies intergalactic magnetic fields deflect protons making point source searches difficult.
The neutrino appears to be an ideal candidate for high energy astronomy : it is neutral and therefore unaffected by magnetic fields. It essentially does not interact with matter. It can give unique information from the core of the sources.
High energy neutrinos could be produced from proton acceleration in all places where highly energetic photons are believed to be produced from accelerated electrons. The production would result from proton interaction on the surrounding matter or photon fields ($p + A/\gamma \rightarrow \pi^o + \pi^\pm + ...$ followed by $\pi^\pm \rightarrow \mu\nu_\mu$ and $\mu \rightarrow \nu_\mu \; \nu_e \; e$).

[1] CEA/Saclay DSM/DAPNIA Service de physique des particules

2 Detecting neutrinos with ANTARES

Neutrino detection needs very large instrumented volumes. The Earth is used as a target in which a neutrino interaction produces a muon. The muon emits Cerenkov light when going through a transparent medium, like ice or water. This light is detected by an array of photomultipliers whose signals allows the muon track to be reconstructed and the neutrino characteristics obtained. A neutrino emitted from a cosmic accelerator is seen as a high energy up-going muon. Down-going muons produced in atmospheric cosmic ray showers are a potential background when badly reconstructed. This is why these detectors are installed deep under the sea (or under the ice). So-called atmospheric neutrinos are also produced in these showers. These are a serious background to astrophysical observations, but can provide data on neutrino oscillations at energies up to 100 GeV. Finally, if the dark matter consists of supersymmetric neutralinos, these would accumulate in the centres of celestial bodies such as the Sun and the Earth, and their annihilations may produce a detectable neutrino flux.
The ANTARES detector [2] will consist of 12 mooring lines anchored at a depth of 2475 m in the Mediterranean sea 40 km from Toulon. Each line is 450 m high, equipped with 25 storeys, each comprising 3 downward-looking photomultipliers (Hamamatsu 10"). The lines are spaced by 65 m on average and connected to a "junction box". An electro-optical cable connects the junction box to a shore station, supplying electrical power and control and returning the signals.

3 Physics and performance

In most models, high energy neutrinos are believed to be produced by a Fermi mechanism (E^{-2} energy spectrum).

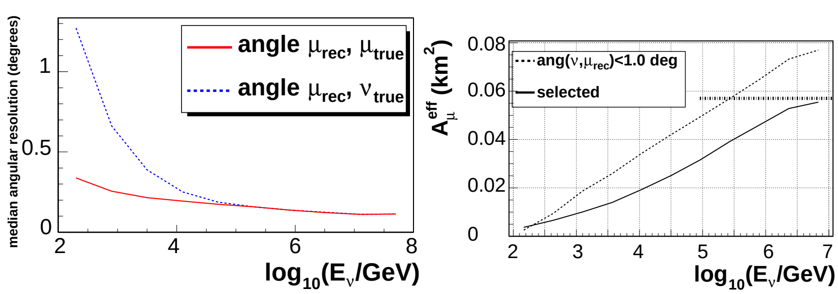

Fig. 1. Both figures are drawn versus the incident ν energy. Left: angular resolution for ν and μ. Right : Muon effective area for a 1° angular resolution and for the best selection criteria. The horizontal line represents the geometrical surface.

Point source searches: The left-hand plot in figure 1 shows the evolution of the angular resolution (difference between the reconstructed and generated angles) for muons and neutrinos versus the neutrino energy. At low energies, the neutrino angular resolution deteriorates because the emitted muon is no more collinear to the incident neutrino. Above 100 TeV the resolution is better than 0.2° for both muon and neutrino and is mainly limited by the light diffusion in water and the muon discrete energy loss. This resolution allows the study of point sources with high performances either in standalone mode or for already observed sources.

Event rate: The event rate is related to the neutrino cross section and the quality of muon reconstruction. For vertical up-going neutrinos, it increases with energy as the neutrino cross section does, and starts to decrease at 10^5 GeV due to the fact that the neutrino interacts early in the Earth and leads to a muon stopped before the detector. Higher energy domains can be reached with nearly horizontal muons. The muon effective area is the ratio of detected muons per unit of time, divided by the incident muon flux. Its dependence on energy is shown on the right-hand plot in figure 1 for best selected events and events reconstructed at the 1° level. It exceeds the geometrical surface (~ 0.1 km^2) at high energy. Expected event rates vary from a few to a hundred per year after background rejection [3].

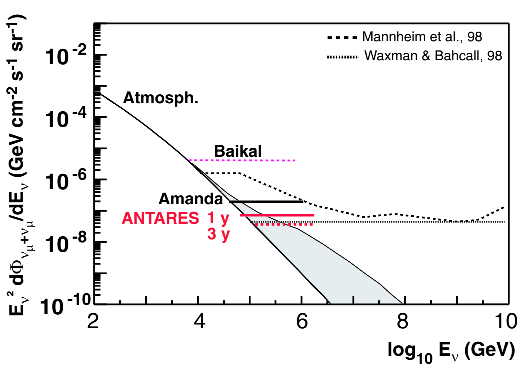

Fig. 2. Atmospheric neutrino spectrum including current theroetical uncertainties (grey band), a few diffuse flux predictions, and some experimental limits (see text).

Diffuse fluxes : The contribution of all neutrino emitters in the Universe, the high energy neutrino diffuse flux, is one of the first physics goals that ANTARES could achieve [3].

The key point is to reduce the atmospheric neutrino background, consisting in events with a softer ($E^{-2.7}$) spectrum (figure 2). Above 1 TeV, the muon energy loss rate, estimated from the detected light and the muon visible path, becomes correlated with its energy. It allows a determination of the energy at a factor 2 to 3. After a cut at E > 50 TeV, the sensitivity to a neutrino diffuse flux is found to be $8{\cdot}10^{-8}$ GeV$\cdot$ cm$^{-2}\cdot$ s$^{-1}\cdot$ sr^{-1} in one year, corresponding to 0.3 surviving background events. After 3 years of data taking the experiment reaches the conservative limit from Waxman & Bahcall [4].

4 First steps toward the final detector

The ANTARES collaboration involves 150 technicians, engineers and physicists in Europe. A first period of extensive R & D began in 1996 with water property and site studies and ended in 2000 with the operation of a demonstrator string which qualified most of the concepts [5]. In October 2001, the 40 km electro optical cable was deployed from the underwater site to the La-Seyne-Sur-Mer beach. In December 2002, the junction box was released on the sea bed. At the same time the "sector line", was deployed. This 5 storey prototype is equipped with the final components of the experiment. In February 2003, a special instrumented line was immersed and both lines were connected to the junction box using the manned Ifremer submarine (Nautile). The shore station immediately registered the first data on disk. This major step proved the ability of the collaboration to deploy the final detector. It was a test of the mechanics, digital electronics, slow control and acquisition chain through the 48-fibre cable and allowed in situ measurements of various environment parameters with the final components. It also exhibited some defects to be corrected for the nearby production (o-ring seal out of specification leading to a water leak, one optical fibre failure resulting in a lack of communication).

5 Conclusion

Two high energy telescopes have already been constructed in the world : the first in lake Baikal, which is intrinsically limited in size and depth, and AMANDA that observed the northern hemisphere from the south pole ice without evidence for energetic neutrino sources. AMANDA is now being upgraded toward the much larger IceCube experiment. A 0.1 km^2 experiment in the northern hemisphere, like ANTARES, gives a complementary view of the sky, including coverage of the important region around the Galactic centre. Moreover, the Mediterranean sea water presents a light diffusion length such that $0.2°$ angular resolution may be achieved. Today the full ANTARES R&D programme has successfully ended. Master components of the experiment have been installed. The deployment of the 12 line detector is planned to be completed by 2006. Discussions are under way for the installation of a km^3 high energy neutrino detector in Meditterranean.

References

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