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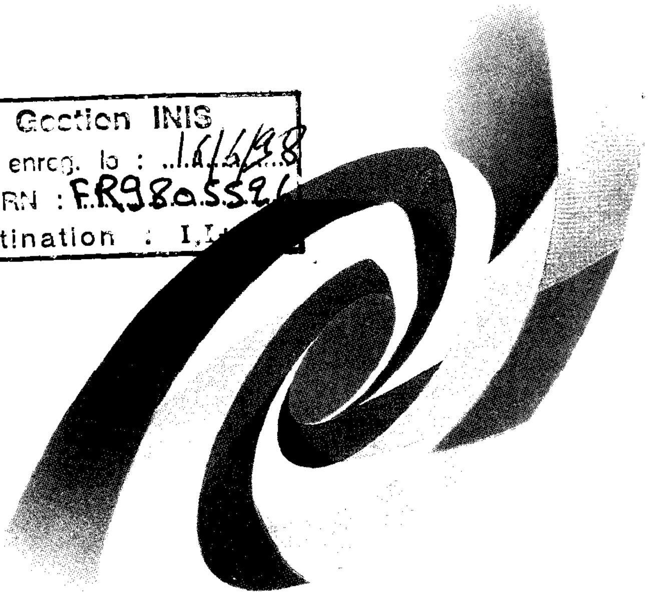

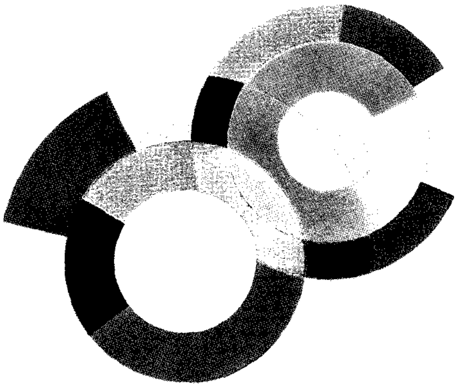

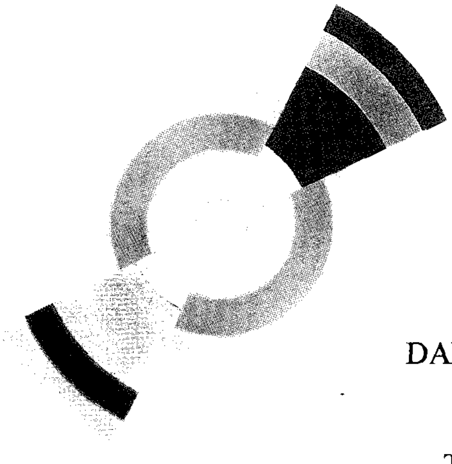

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THE CAPABILITY TO DETECT WIMPs WITH A HIGH ENERGY NEURINO TELESCOPE

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The capability to detect WIMPs with a high energy neutrino telescope

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Abstract. We studied the potential of the proposed ANTARES undersea neutrino telescope to detect muons coming from neutralinos annihilating at the center of the Earth. First results show that the full 1 km^3-scale detector can indicate, after a few years of operation, if there are indeed neutralinos trapped at the core of celestial bodies, as expected if neutralinos are the major form of dark matter in our galaxy.

1. Introduction

It is now generally considered that a very large amount of the mass of our Universe is invisible to us. Many candidates could participate to constitute this dark matter. A promising one is the lightest supersymmetric particle (LSP), often assumed to be the neutralino. In this case, neutralinos contained in the halo of our galaxy can be gravitationally bound to celestial objects like the Sun or the Earth inside which they undergo elastic collisions. Eventually they accumulate and remain trapped at the core of these bodies. Annihilations of LSPs lead to the production of various particles, among which are found ν_μ and $\overline{\nu}_\mu$. Muons are produced in charged-current exchange interactions of neutrinos with nucleons ($<E_\mu>\simeq<E_\nu>/2 \simeq m_\chi/4$) and detected by a network of photomultiplier tubes (PMTs) via the Čerenkov light they emit when travelling through a transparent medium like ice or water. Thus if a neutrino telescope detects an accumulation of events in the direction of the Sun or the center of the Earth, it would be a strong indication that the LSP exists and constitutes a large amount of dark matter in our galaxy.

2. The ANTARES project

Two large neutrino telescopes are currently under operation : AMANDA [1] at the South Pole and Baikal [2] in Lake Baikal. Both already reported limits on the search of the LSP [2,3]. A third project, NESTOR [4], is under development off the shores of Greece. The ANTARES collaboration [5] runs an intensive R&D program aiming at the deployment and operation of a large neutrino telescope in the Mediterranean Sea. The site chosen for the first phase of the program is located by 42°50'N - 6°10' E, 40 km away from the shore of Toulon (France) at a

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[*] on behalf of the ANTARES collaboration

depth of 2350 m. This phase will end with the operation of a "demonstrator," the construction and operation techniques of which will be extrapolated to a larger detector.
The demonstrator consists of two strings about 300-m long and equipped with optical modules (OMs). An OM consists of a large PMT housed together with minimal electronics inside an oceanic glass sphere. The first string is made of 16 closeby pairs of glass spheres separated by 15 m. Four of those pairs will be regular OMs; others will be equipped with mechanical sensors in order to study the mechanical behaviour of the line. The second string will include 30 to 50 OMs. Each string is equipped with tiltmeters, compasses, and hydrophones that will allow (in association with ground based acoustic beacons fixed around the detector) the position of each OM to be determined with an accuracy better than 20 cm. Each string is anchored on the sea floor and maintained in tension with buoyancy. The distance between two strings is of the order of 100 m. The lines are linked together with an electric cable. Slow control, power supply, and data transmission to the shore are achieved using an electro-optical cable. All connections are performed at depth by a manned submarine. The first string is scheduled to be deployed in October 1998. The connection to the electro-optical cable will be performed on the deck of the dynamic positioning ship used for the immersion. The second line should be deployed by the end of 1999 and connected at depth. Analogue electronics is used for data transmission.
The next step consists of operating a larger detector ($1/10^{\mathrm{th}}$ of km^3) and having digital electronics. The final goal is the management of a neutrino telescope on the order of 1 km^3, the size required to have a significant number of events from the expected extraterrestrial neutrino sources. (For a review of physics motivations for building such a detector, refer to [5].) This detector could be made of 100 strings similar to the ones of the demonstrator. An important feature in the operation of a large undersea neutrino telescope is the quality of the site in which it is located. The ANTARES collaboration has also designed and uses intensively three kinds of autonomous mooring lines to measure the crucial environment parameters : water transparency, background light, sedimentation, and biofouling rates on OMs. A suitable site should be chosen by the end of 1999. Another activity of ANTARES is developing simulation and reconstruction tools adapted to a large neutrino telescope.

3. The potential of ANTARES to detect WIMPs

Large neutrino telescopes are mainly designed to study neutrino astronomy above 1 TeV. The threshold of the total detector ($\simeq$ 500 GeV for ANTARES "$1/10^{\mathrm{th}}$ of km^3 detector" is foreseen) is therefore too high to look for muons associated with LSP annihilations: if one expects to find the LSP in the range 40–1000 $\mathrm{GeV/c}^2$, then the muon energy will be roughly between 10 and 500 GeV. The muon detection threshold can be lowered to about 20 GeV by considering each string as a single detector and looking for muons coming from the center of the Earth. It must be pointed out that the mass of the neutralino can be inferred from the angular distribution of the detected muons with a root mean square value of $\alpha = 23°/\sqrt{M_\chi(\mathrm{GeV})}$ [6].

Monte Carlo simulations have been performed to study the capability of ANTARES to detect the neutralino. Neutrino interactions with nuclei are generated using the CTEQ parameterization and muon tracking in rock is achieved with the Fréjus program [7]. Inside the detector, muon tracking and Čerenkov light emission/detection are achieved using the DADA code developed by the Baikal collaboration. This code is based on GEANT 3.21, which was corrected to perform an accurate treatment of very high energy particles. The PMT response, electronics behaviour, and a constant counting rate due to the luminous background from ^{40}K decay in the salty water are then taken into account, and the muon track is reconstructed. We studied two different possible geometries for a string: the first consists of 16 pairs of 8-inch PMTs looking downward and separated by 15 m; the second comprises 16 clusters of 4 horizontal PMTs also separated by 15 m. Both configurations give approximately the same effective area per string. It was required that at least 5 clusters are hit along the string. A cluster is hit if 2 photons are detected. We also required the track to be reconstructed with a fitted error on the zenithal angle smaller than 1°. Figure 1 displays the effective area seen by a string as a function of muon energy. The detection threshold is around 50 GeV, and the effective area is $A_{\mathrm{Eff}} \simeq 400$ m^2 at 200 GeV. For comparison, Baikal foresees a value of 50 to 100 m^2/string [2]. This value can be extrapolated up to a 100–string km^3 detector which would then have an effective area on the order of 40,000 m^2 for 200 GeV muons. This value is much larger than the 1000 m^2 of MACRO or SuperKamiokande and shows that ANTARES has a true discovery potential. This is also stressed on Figure 2, where the exposure (m^2.yr) needed to detect a significant signal (see [8] for more details) is shown as a function of the neutralino mass. Superimposed is the exposure of the 1 km^3 detector after 5 years of operation. The range of 50 GeV/c^2 $\leq$ M$_\chi$ $\leq$ 200 – 500 GeV/c^2 is entirely covered.

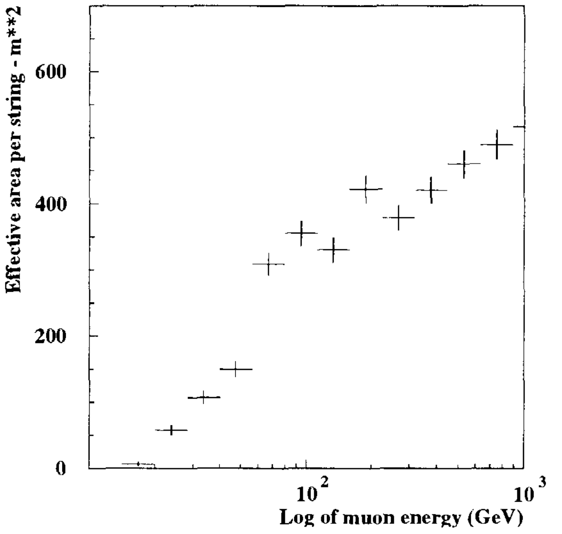

Figure 1. Effective area of an ANTARES string (with 16 clusters of 4 horizontal-looking OMs) as a function of muon energy.

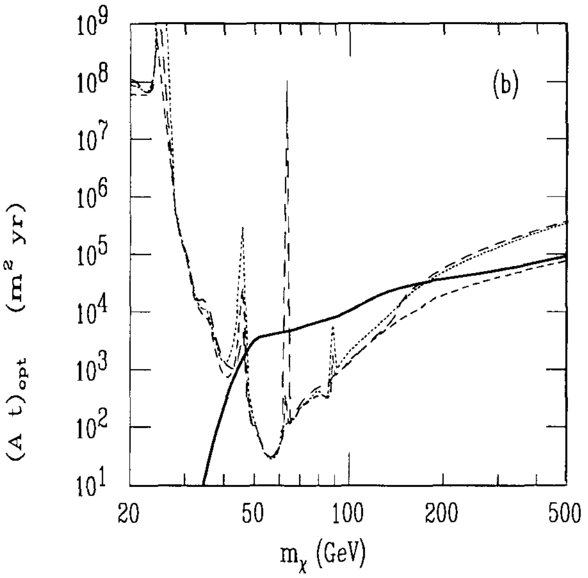

Figure 2. Total exposure needed to detect a significant signal (refer to [8] for explanations) and total exposure of a "km^3" detector after 5 years of operation. This detector probes the range 50 GeV/c^2 $\leq$ M$_\chi$ $\leq$ 200 GeV/c^2.

4. Conclusion

First results of simulations show that a detector made of 100 ANTARES-type strings can confirm or deny within 5 years the existence of neutralinos annihilationg in the core of the Earth, in the range 50 $\mathrm{GeV/c^2} \leq \mathrm{M}_\chi \leq 200 - 500\ \mathrm{GeV/c^2}$. These results are encouraging, since the reconstruction algorithms and the trigger used were designed for neutrino astronomy. Future investigations will look for better reconstruction techniques, which will improve the detector capabilities, and exploration of the SUSY parameter space with the help of theorists.

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