Astronomy with a Neutrino Telescope
ANTARES
and Abyss environmental RESearch

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The European ANTARES collaboration aims at operating a large submarine neutrino telescope in the Mediterranean sea. Neutrino detection is an opportunity to improve our knowledge on cosmic ray origin and physical properties of the most powerful astrophysical sources in the universe. The detector consists of 10 mooring lines, each about four hundred meters high, equipped with photo-multipliers. The main objective is to observe upward going muons resulting from charged current interaction of neutrinos in the Earth. The PMTs record Cerenkov light emitted by the muons. ANTARES can investigate three different physical topics : neutrino oscillations, dark matter searches and high energy neutrino astronomy. The two last topics are developed in this poster.

Physics

Neutrino astronomy

Photon observation is limited to close regions of the universe due to their interactions on the infra-red and micro-wave cosmological backgrounds (1 a γ of 1 TeV can travel only 700 Mpc, z <0.3). Furthermore photons cannot escape from dense regions of the universe.

Charged particles are also absorbed in the same ways. Moreover they are deflected by magnetic fields and lead to a very poor pointing accuracy.

Neutrons are not deflected by magnetic fields but cannot be used because of their too short life time.

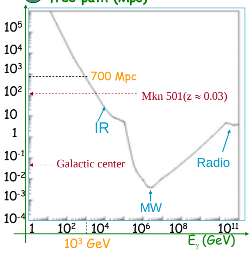
Neutrinos are neutral, stable, interact weakly (2). They are good candidates for high energy astronomy.

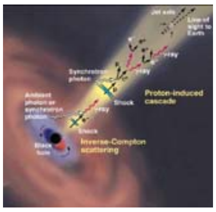
The astronomical mechanisms likely to produce high energy neutrinos are hadronic processes (through pion decays). Potential sources are particle accelerators in the universe (4):

- extra-galactic sources like Active Galactic Nuclei (AGN) or Gamma Ray Bursts (GRB);
- galactic sources like supernova remnants and binary stars.

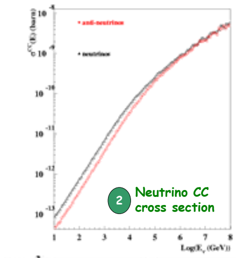
Different models provide estimates of the neutrino flux (5) from these sources. They can be divided in two classes, depending on whether the normalisation is computed from detected cosmic rays or gamma rays. They could lead to an event rate of 1 to 100 events per year in the 0.1 km² detector.

1 GZK effect : Mean photon free path (Mpc)

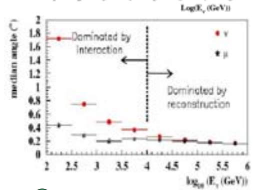




4 High energy source Acceleration of particles in a jet

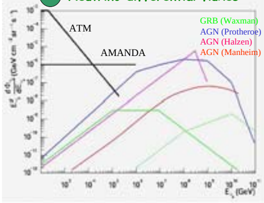


2 Neutrino CC cross section



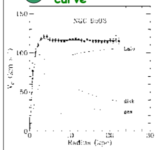
3 Angular resolution in degrees as a function of the neutrino energy

5 Neutrino differential fluxes

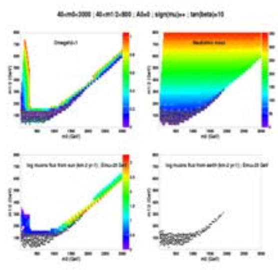


Dark matter research

1 Galaxy rotation curve



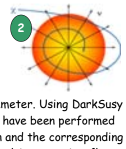
Experimental evidence of some « dark matter » can be inferred from Galactic rotation curves. These curves imply existence of a « dark » halo in each galaxy (1). Theoretically, combining this information with the baryonic density inferred from nucleosynthesis implies that there is a substantial non-baryonic contribution to the composition of the Universe. WIMPs (Weakly Interacting Massive Particles) is the most favoured explanation.
In the MSSM, if the R-parity ($R=(-1)^{3B+L+2S}$) is conserved, then the LSP (Lightest Supersymetric Particle) is stable. A few seconds after the Big Band, many LSP will be produced and, as they are unable to decay, they will remain until today. They will cross massive structures such as the Sun or the Earth, and will undergo elastic scattering during their path through, loosing energy and becoming trapped in the core of these structures (2).
After accumulation, they can annihilate at rest producing Standard Model particles including neutrinos. An excess of events in the direction of the centre of the Sun or Earth may be a signature of LSP as dark matter.



3 Allowed cosmological region and estimated ν flux

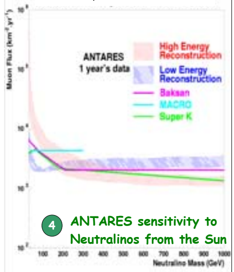
The Msugra model, a parameter-space restriction of the MSSM, gives a mechanism for EWSB (ElectroWeak Symetry Breaking) and the unification of masses and gauge couplings at M GUT ≈ 2 10^{16} GeV. In this model, there are only 5 free parameters : a common gaugino mass $M_{1/2}$, a common scalar mass M_0, a common trilinear coupling A_0 the ratio of the Higgs vacuum expectation value tan β and the sign of μ, the higgsino mass parameter. Using DarkSusy code and RGE (Renormalisation Group Equation), $M_{1/2} - M_0$ scans have been performed (3). The top left plot shows the cosmologically allowed region and the corresponding neutralino masses are presented in the top right one. The resulting neutrino fluxes (bottom left) and muons fluxes (bottom right) with a muon-energy threshold of 25 GeV are shown for the Sun. A pair of neutralino will annihilate to a pair of Standard Model particles.

2



The resulting neutrino will depend on M_χ and on Branching Ratio. As the efficiency of the Reconstruction is strongly energy-dependent, the shape of the neutrino spectrum will affect the limits on the muon flux at the detector.

We use two extreme cases : hard spectrum (WW channel or $\tau^+\tau^-$ channel if $M_\chi < M_W$) and soft spectrum corresponding to bb channel. The reconstructed sample of events can be reweighted to a particular neutrino flux to give the rate of atmospheric neutrinos expected within a 3 degree bin. Taking into account the position of the Sun during the year and using the Bartol neutrino flux, we can obtain the ANTARES Dark Matter sensitivity for the Sun, within a 3 degree cone surrounding the source direction as a function of neutralino mass (4).
The width of each band gives the range corresponding to hard and soft spectra in the neutralino annihilation.



4 ANTARES sensitivity to Neutralinos from the Sun

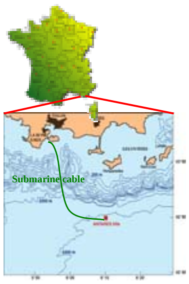
Overview of the ANTARES project

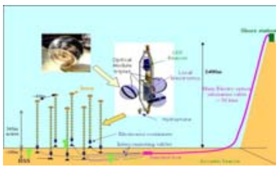
Detector overview and ANTARES site

The 0.1 km² detector project will be installed in the Mediterranean sea, 2400 m deep, 40 km from La Seyne sur Mer. The data are transferred to the coast through an electro-optical cable.

The detector consists of 10 identical strings composed of 30 storeys. Each storey has 3 downward optical looking modules. Each optical module is a pressure resistant glass sphere containing a 10" photo-multiplier.

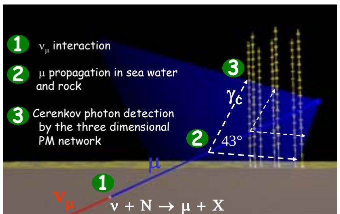
Other instruments, such as hydrophones and LEDs, are installed along the string in order to monitor the detector performance and position.

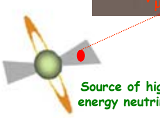




Detection principle

High energy neutrinos produce charged current interactions in the earth or in the medium surrounding the detector.
The muon emits Cerenkov light in water which is detected by the three dimensional PM network. The time and the position of hits allow the reconstruction of the muon track.



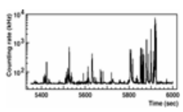


Source of high energy neutrinos

At high energy, the muon is almost parallel to the neutrino and therefore indicates the source position in the sky.

Site and water properties

In order to reconstruct the muon track with good accuracy, the positions of photomultipliers have to be known at the level of 10 cm. The knowledge of the sea water optical properties is therefore essential.
The ANTARES site has been studied since 1996 : evaluation of the optical background (1), measurement of the attenuation and diffusion of the light (2), estimation of photomultiplier efficiency loss as a function of the immersion time due to bio-fouling (3). Moreover the ANTARES site was explored using a submarine (4).



1 Optical background

Two contributions :
- ~ 60 kHz (Potassium 40) on 10" PMT
- bioluminescence bursts

(→ < 5% dead time / PMT)

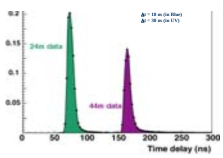
2 Light attenuation and diffusion

Photon arrival time from pulsed LED sources at various distances

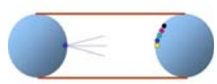
Peak height -> absorption length

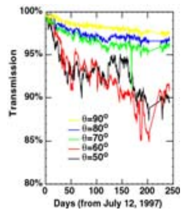
Tail -> diffusion

➡ λ_{att} > 100 m (UV light)



3 Glass sphere bio-fouling





4 Deployment area survey with the IFREMER submarine

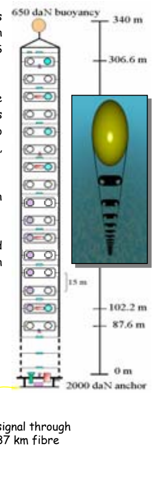
Demonstrator line (Nov. 1999 – June 2000)

From November 1999 to June 2000 a demonstrator line was operated at 1200 m depth, 30 km away from Marseille, in order to perform a complete test of the 0.1 km² ANTARES concepts and determine some of the performance capabilities.

The line was equipped with 8 photo-multipliers. Some instruments were used to measure the site properties (bioluminescence, temperature, salinity and pressure) and to monitor the line behaviour in sea currents (hydrophones, inclinometers and compass).

Physics events were recorded and sent to the shore station through a 37 km long electro-optical cable.

The zenithal angular distribution obtained from reconstructed events is in good agreement with the Monte-Carlo Simulation (see below).



Arrival times (t) of photons as a function of the altitude (z)