
# 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 400 m 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 physics topics : neutrino oscillations, dark matter searches and high energy neutrino astronomy.
The last topic is developed in this poster and the diffuse neutrino flux analysis is presented.


## 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.

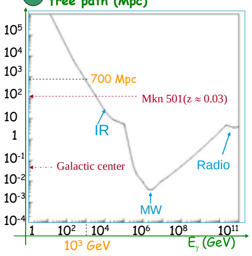
Charged particles are also absorbed in the same ways. Moreover they are deflected by magnetic fields and lead to a very poor pointing accuracy.

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

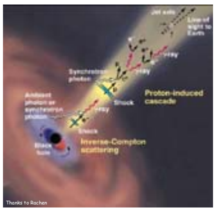
Neutrinos are neutral, stable, interact weakly (2). They are good candidates for high energy astronomy.

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.

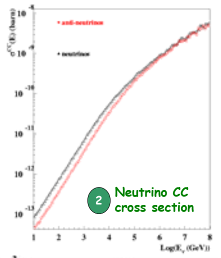
Different models provide estimates of the neutrino flux (5) from these sources. They can be divided in two classes, depending on whether the normalisation is computed from detected cosmic rays or gamma rays. They could lead to an event rate of 1 to 100 events per year in the 0.1 km² detector.



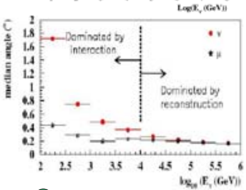

1 GZK effect : Mean photon free path (Mpc)




4 High energy source Acceleration of particles in a jet

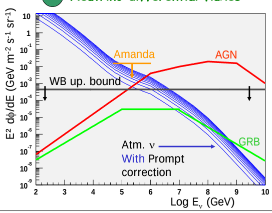



2 Neutrino CC cross section



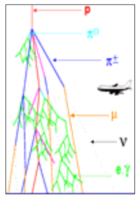

3 ANTARES Angular resolution in degrees as a function of the neutrino energy

5 Neutrino differential fluxes




### Diffuse neutrino flux analysis

The atmospheric background is created during the shower development initiated by the interaction of a cosmic ray with an air nucleus (1). In the hadronic cascade, mesons decay into muons and neutrinos. The atmospheric neutrinos can reach the detector from every direction but only down-going muons can (2).



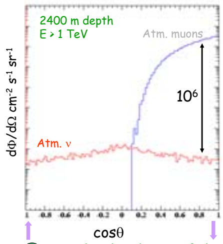

1 Muons and neutrinos production in an air-shower

Apart from point like source search, some models predict diffuse neutrino fluxes based on unresolved sources distribution.

The background is due to up-going muons coming from atmospheric neutrino interactions close to the detector.

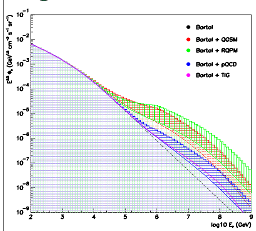
The atmospheric neutrino flux is composed of :

- the « conventional » atmospheric neutrino flux, due to pions and kaons decay, dominant at low energy ;
- and the so-called « prompt » neutrino flux, due to charmed particles decay, dominant at high energy.




2 Angular distribution of the Atmospheric background

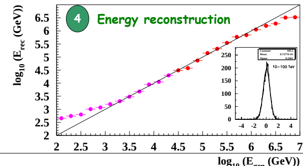
The conventional neutrino flux is under control with an uncertainty of around 20 % but the discrepancy between different prompt flux predictions can reach 2 orders of magnitudes (3).




3 Comparison between conventional and conv + prompt neutrino fluxes

The signal exceeds the background for energies above 1 - 10 TeV. The muon energy estimator is built from the amount of detected light and leads to a factor 3 on the energy resolution above 1 TeV (4).

The table below shows the ANTARES expected event rate for signal and background and for various energy cut (5).




4 Energy reconstruction

5 Number of events per year above a given Monte-Carlo muon energy in ANTARES

| | 1 TeV | 10 TeV | 100 TeV |
|---|---|---|---|
| conv. | 240 | 19 | 0,2 |
| conv. + prompt | 243 - 273 | 20 - 30 | 0,2 - 1,1 |
| AGN | 29 | 25 | 14 |
| GRB | 0,5 | 0,3 | 0,1 |

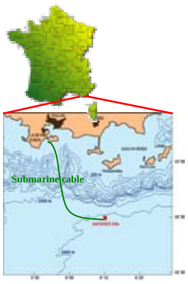
## Overview of the ANTARES project

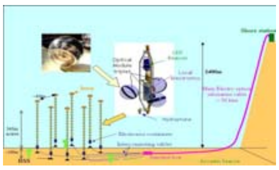
### Detector and ANTARES site

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 looking optical modules. Each optical module is a pressure resistant glass sphere containing a 10" photo-multiplier.

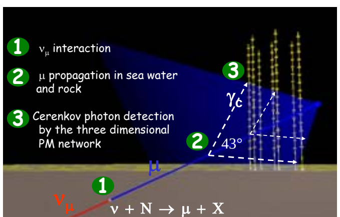
Other instruments, such as hydrophones and LEDs, are installed along the string in order to monitor the detector performance and position.

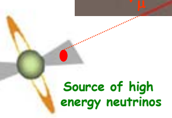


### Detection principle

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.



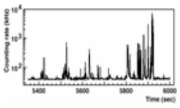



Source of high energy neutrinos

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)

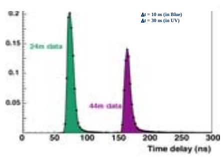
2 Light attenuation and diffusion

Photon arrival time from pulsed LED sources at various distances

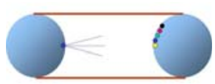
Peak height -> absorption length

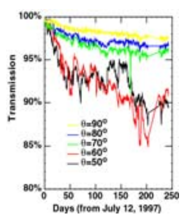
Tail -> diffusion

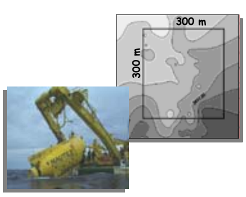
➡ $\lambda_{att}$ > 100 m (UV light)




3 Glass sphere bio-fouling






4 Deployment area survey with the IFREMER submarine

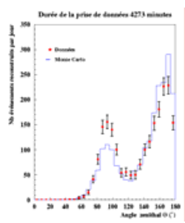
### Demonstrator line (Nov. 1999 – June 2000)

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).

Down-going muon were recorded and sent to the shore station through a 37 km long electro-optical cable.

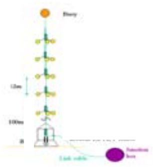
The zenith angular distribution obtained from reconstruction is in good agreement with the Monte-Carlo simulation.




### Status and perspective

- October 10th, 2001 : successful deployment of the ANTARES cable;

This 40 kilometre long electro-optical cable connects the ANTARES site to the shore.



Sector line structure

- End of 2002 : operation of a sector line prototype;
- 2003 – 2004 : deployment of line 1 - 10;
- End of 2004 : ANTARES detector is complete.