THE ANTARES NEUTRINO TELESCOPE

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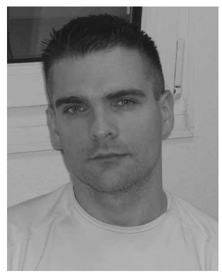

The ANTARES collaboration is building a high energy neutrino telescope in the Mediterranean sea, at a depth of 2500 m, 40 km off the French coast. This telescope will use 900 photomutiplier tubes deployed on 12 strings, providing a three-dimensional array which will detect Cherenkov light produced in sea water by neutrino-induced muons. ANTARES will mainly be sensitive to high-energy neutrinos, which may be emitted by astrophysical sources, but the indirect search for Dark Matter is also an important objective of the detector. The first line will be deployed next Autumn and the detector should be fully operational by mid-2007.

1 Principle and performances of ANTARES

ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) is a submarine Cherenkov detector located in the Mediterranean sea, 40 km off Toulon (France), at a depth of 2475 metres. An area of 0.06 km^2 on deep sea bed is going to be instrumented with 12 lines, each carrying 75 photomultipliers (PMTs) groupped into 5 sectors, for a total height of 450 metres. A sector is a set of 5 storeys, separated by 14.5 metres, each storey containing a Local Control Module housing the electronics and three 10" photomultiplier tubes located inside pressure resistant spheres. The total number of PMTs is 900 (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 due to water currents.

The interaction of neutrinos in Earth or water will produce an up-going muon and a shower (ν_μ Charged Current interaction), or only a shower (ν_e and ν_τ CC and Neutral Current interactions, ν_μ NC interaction). The generated charged particules will induce Cherenkov photon emission along their trajectories, making the reconstruction of the muon track or of the shower using the PMTs measurements possible. Thanks to its long path at high energy, the muon will

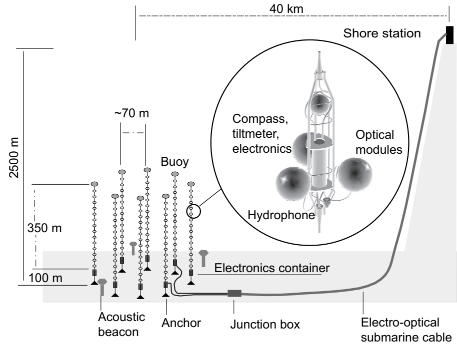

Figure 1: Schematic view of the ANTARES detector

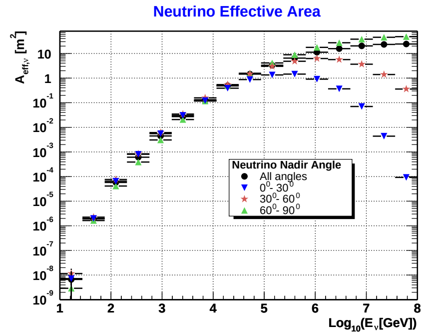

Figure 2: ANTARES effective area for muon neutrinos

provide the benefit of an effective volume of detection larger than the physical instrumented volume. Detection of up-going muons is the benchmark for ANTARES. Atmospheric neutrinos induced by cosmic ray interactions in the atmosphere are the main physical background to astrophysical neutrinos. Down-going muons produced in atmospheric showers are the second physical background: in case of bad reconstruction they may fake up-going muons coming from neutrino interaction.

In the sea two other backgrounds will generate photons detected by the PMTs: the ^{40}K present in water is a beta emitter and therefore will produce Cherenkov photons, whereas light emitted by bioluminescent organisms will mostly lead to single photoelectron production on the PMT photocathode.

The time precision is a crucial point for the ANTARES experiment. The intrinsic photoelectron transit time spread between the PMT photocathode and its first dynode is 1.3 ns. The last dynode signal is digitised by a devoted chip based on an Analogue Ring Sampler architecture (simply reffered as the ARS), located in the LCM, with a precision better than 0.5 ns. The detection threshold will be set at around 1/3 of photoelectron. Finally the hit time, amplitude, and position are the available informations used for track reconstruction, based on a maximum likelihood fit. The time calibration will be performed thanks to one laser and several LED beacons either found on some sectors or on a special so-called instrumentation line.

The quality of the sea water is a fundamental parameter for Cherenkov photon detection. On the ANTARES site[1], at a wavelength of 470 nm, the absorption length of water is 60 m and the effective scattering length is 300 m. The time measurement performances, combined with this good quality of 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 effective area is 20 000 m^2, reaching the geometrical surface (60 000 m^2) at 10 PeV. Figure 2 shows the effective area for muon up-going neutrinos. At 1 PeV it is about 10 m^2; the curves show the effect of neutrino absorption in Earth at high energies.

In case of high energy muons, energy reconstruction in Cherenkov detectors is a difficult task. The muon energy estimate above 1 TeV is made using the amount of light seen by the detector. Due to the stochastic nature of the muon energy loss, the energy is determined with an accuracy of a factor between 2 and 3.

2 Physics goals of the ANTARES experiment

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[2] 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 has no electrical charge and therefore is not affected by magnetic fields, it interacts only weakly with other particles, and therefore appears to be an ideal candidate for high energy astronomy. Besides, it enables to access the heart of the sources.

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 jets model, an estimation of neutrino expected fluxes at Earth has been performed[3,4]. The order of magnitude of the neutrino energy is 1 TeV. To calculate the neutrino flux emitted by microquasars, the authors use jet parameters inferred from other wavelength observations, especially radio observations. For example, SS433 is an identified persistent microquasar which may be observed by ANTARES, after one year of data taking, the expected neutrino flux $E^2 dN/dE$ being $2 \cdot 10^{-7}\mathrm{GeV\,cm^{-2}s^{-1}}$ at the relevant declination.

Active Galactic Nuclei (AGN) are good candidates for extragalactic neutrino production: if hadronic models of jets emitted by AGN are favoured, 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.

Neutrinos may also be produced in gamma-ray bursts, and could be detected in a time window centered on the one given by networks of satellites and ground based alert systems. Two GRB models have been considered in the ANTARES collaboration: the fireball model[5,6] and the cannonball model[7,8]. 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.

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 (WB) limit[9]: $E^2 dN/dE < 4.5 \cdot 10^{-8}\mathrm{GeV\,cm^{-2}s^{-1}sr^{-1}}$, and Mannheim Protheroe Rachen (MPR) limit[10]: $2 \cdot 10^{-6}\mathrm{GeV\,cm^{-2}s^{-1}sr^{-1}}$. The WB limit assumes that the source is transparent to the high-energy nucleons, whereas for the given MPR limit the source is assumed to be opaque. If we assume neutrino oscillations, both limits are reduced by a factor 2. 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.

Before performing any astrophysical diffuse neutrino measurement, it is necessary to know well the atmospheric neutrino background. The AMANDA neutrino telescope, located at the South Pole, has performed an atmospheric neutrino flux measurement on a large energy range[11]. Detection of this physical background will be the first test for ANTARES.

3 The Prototype Sector Line (PSL), year 2003

A single sector was tested in 2003. A second line has been connected at the same time: the Mini Instrumentation Line (MIL). The MIL was equipped only with calibration and environmental monitoring devices. Sea operations, for deployment and recovery of lines, were successful. But, during running, problems arised at the level of the Electro Mechanical Cable (EMC) of the

PSL: the fiber transmitting the clock signal (20 MHz) was damaged between the bottom of the line and the first storey. Due to this failure, no synchronisation between PMTs was possible, so only counting rates during 13 ms frames were available. It was not possible to reconstruct atmospheric muon tracks, but a deep study of bioluminescence has been performed. In addition to the ^{40}K beta radioactivity, which produces a constant counting rate of 30 kHz, bacteria and bioluminescent organisms raise this baseline and produce counting bursts. Data analysis show a normal behaviour around 60 kHz as expected, with some period where the baseline rate reaches 300 kHz. It was shown that the burst rate is correlated to the water currents.

The recovery of PSL was done in July 2003, and the causes of failures were analysed. A new version of EMC has been designed, and a dedicated prototype was decided: the line 0.

4 The line 0 and the MILOM, year 2005

The line 0 is a line equipped with 23 storeys, each comprising the usual three pressure resistant glass spheres. Most of them have been kept empty and some are equipped with autonomous devices to record the evolution of the light propagation in the optical fibers of the main cable. The main objective of this line is indeed to check that the improved version of the electro mechanical cable behaves as expected. In addition to this remote system, signals can be sent from the coast since the line was connected shortly after it was deployed, on March this year.

During these operations, an extended version of the previous mini instrumentation line was also deployed and connected. Apart from the previous equipment devoted to the sea environment study, it contains one storey equipped with 3 optical modules. Data taken since March are currently being analysed.

5 Conclusion

Located in the Mediterranean sea, ANTARES will provide a complementary view of the sky compared to AMANDA/ICECUBE South Pole neutrino telescopes. A great advantage of ANTARES latitude is the coverage of the region around the Galactic center. Moreover, the sea water properties make possible to reach an angular resolution of 0.2° at high energy.

Line 0 and MILOM are important milestones for ANTARES. The collaboration expects further validation of the technology used for the detector from the data that are currently being analysed. The first fully equipped line, line 1, is currently under construction. Its deployemnt and connection are planned for Autumn 2005

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