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Feasibility Studies for a Mediterranean Neutrino Observatory - The NEMO.RD Project

C. De Marzo for the NEMO.RD Collaboration*

The NEMO.RD Project is a feasibility study of a km^3 underwater telescope for high energy astrophysical neutrinos to be located in the Mediterranea Sea. At present this study concerns: i) Monte Carlo simulation study of the capabilities of various arrays of phototubes in order to determine the detector geometry that can optimize performance and cost; ii) design of low power consumption electronic cards for data acquisition and transmission to shore; iii) feasibility study of mechanics, deployment, connection and maintenance of such a detector in collaboration with petrol industries having experience of undersea operations; iv) oceanographic exploration of various sites in search for the optimal one. A brief report on the status of points i) and iv) is presented here.

1. A km^3 Detector for ν-Astronomy

Measurable fluxes of high energy neutrinos ($E_\nu > 100$ MeV) of astrophysical origin are predicted by various models mainly based on the existing fluxes of high energy gamma rays and/or cosmic rays. The discovery of these astrophysical neutrinos would open the new field of the ν-astronomy. Because the neutrino interaction length is many order of magnitude larger than the photon's one, they are subject to minor absorption and therefore can bring information on the deep interior of sources. The observation of tens of TeV γ-ray emitters (Thompson et al., 1995, Krennrich et al., 1998) reinforces the possibility of existence of "beam dump sources", accelerated proton beams interacting with gas of matter or photons. Among the possible sources are active galactic nuclei (AGNs), binaries where a non compact companion transfers mass to the compact one (neutron star or black hole), supernova remnants and γ-ray bursts (Gaisser, Halzen & Stanev, 1995). Both the very low level of the predicted fluxes at Earth and the smallness of the neutrino interaction cross section require detectors at the km^3 scale. Underwater Cherenkov arrays of phototubes (PMTs) can satisfy these requirements, provided they are located at depths larger than 3000 m where the atmospheric muon background is reduced with respect to surface by a factor of $\sim 10^{-6}$. Because for a survey of the full sky one detector in each emisphere is needed, a neutrino telescope in the Mediterranean Sea results to be complementary to Ice Cube at the South Pole (Halzen, 1999). Moreover, because in these apparatus neutrinos are detected as upward going muons, the northern telescope will be able to observe the galactic center. NEMO.RD (NEutrino Mediterranean Observatory) is an R&D project of INFN for a ν-telescope to be deployed in the best site in the Mediterranean Sea. In order to optimize the physical performance of the neutrino telescope versus the number of PMTs

*M. Ambriola, R. Bellotti, F. Cafagna, M. Calicchio, F. Ciacio, M. Circella, C. De Marzo, T. Montaruli: INFN and University, Bari, Italy; D. Falchieri, A. Gabrielli, E. Gandolfi, M. Masetti, C. Vitullo, G. Zanarini: INFN and University, Bologna, Italy; R. Habel, I. Usai: INFN and University, Cagliari, Italy; S. Aiello, G. Burrafato, L. Caponetto, E. Costanzo, D. LoPresti, L. Pappalardo, C. Petta, N. Randazzo, G. V. Russo, O. Troia: INFN and University, Catania, Italy; R. Barnà, V. D'Amico, E. De Domenico, D. De Pasquale, S. Giacobbe, A. Italiano, F. Migliardo, G. Salvato, A. Trafirò, M. Trimarchi: INFN and University, Messina, Italy; F. Ameli, M. Bonori, S. Bottai, A. Capone, P. Desiati, F. Massa, R. Masullo, E. Salusti, M. Vicini: INFN and University "La Sapienza", Roma, Italy; R. Coniglione, E. Migneco, P. Piattelli, R. Riccobene, P. Sapienza: INFN-Laboratori Nazionali del Sud, Catania, Italy; M. Cordelli, L. Trasatti, V. Valente: INFN-Laboratori Nazionali di Frascati, Italy; G. De Marchis, L. Piccari: Fondazione Ugo Bordoni, Roma; E. Accerboni, R. Mosetti: Osservatorio Geofisico Sperimentale di Trieste, Trieste, Italy; M. Astraldi, G. P. Gasparini: Consiglio Nazionale delle Ricerche, IOF-CNR, La Spezia, Italy; A. Ulzega, P. Orrù: CIRCAM, Universit di Cagliari, Italy.

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we have investigated the response of various arrays of phototubes using a 'fast' Monte Carlo in which Cherenkov light emission by high energy muons and detector response are simulated. The speed of the simulation is an important feature at this stage of the feasibility study because it allows to easily change various input parameters, such as the geometry of the array, the PMT characteristics and the kinematics of the events. Moreover, it allows a fast propagation of muons above 10 TeV. In order to be fast this code transports muons but not hadronic or electromagnetic showers. A more accurate study will be performed with a full GEANT-based (Brun et al., 1987) simulation that we are developing (Bottai, 1998). This will be used for real data analysis more than for detector design. The fast simulation uses parametrizations to describe the energy losses of muons by ionization and by stochastic processes (pair production, bremsstrahlung and nuclear interactions). The Cherenkov light emitted by electromagnetic showers is produced according to the parameterization in Belyaev et al., 1979. Light is attenuated as a result of absorption, which affects the amplitude of signals, and of scattering, which affects both the signal amplitude and the arrival time of photons on the PMTs. In our simulation an attenuation length of 55 m has been assumed for the Cherenkov light, as due to absorption only. Scattering of light is not simulated, but this is a reasonable approximation since measurements of the scattering length show that it is ≥ 70 m in the Mediterranean sites surveyed so far and the fraction of backscattered light is quite small.

We have assumed optical modules made of couples of typical bi-alcali PMTs, one looking upward and the other downward, with a photocathode diameter of 15 inch, time resolution of 2.5 ns and quantum efficiency of 0.25. The detection threshold has been assumed at 0.5 photoelectron. The events are assumed to give a trigger if they hit at least 5 PMTs. We perform the muon tracking by means of a minimization procedure of the χ^2 between expected and measured arrival times of photons. Possibility to use charge information is also under study. In order to minimize the cost of km^3-size detectors, a structure made of towers of

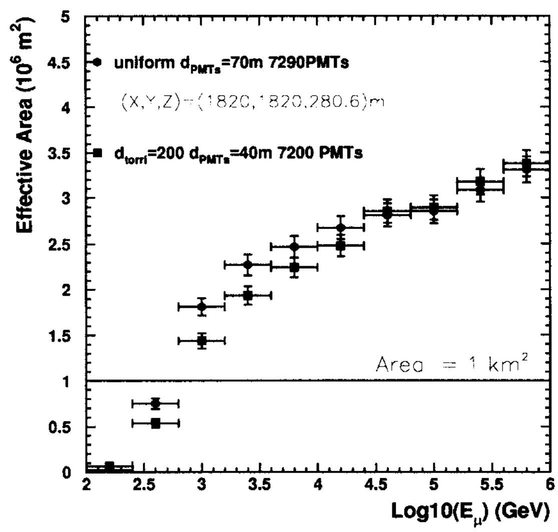

Figure 1. Effective area vs muon energy for 3 PMT arrays: a parallelepiped with distance between PMTs of 70 m; square tower configuration with distance between centers of towers of 200 m and between PMTs in each tower of 40 m. Total numbers of PMTs are indicated for each array. The error bars are due to the Monte Carlo statistics.

strings of PMTs can be the alternative solution to the uniformly spaced arrays. In both cases the active section of the array is 300 m high. Since we are interested in determining the response of the detector to high energy ν-induced muons produced by astrophysical sources, we consider that a relevant parameter is the effective area as a function of energy for muons coming from outside the 'horizon' of the detector. As an example of the fast simulation outputs, in Fig. 1 we compare the effective areas of a uniformly spaced array with an array made of towers. Each tower has a square section with 4 strings at the corners. The 2 arrays have comparable numbers of PMTs ($\sim$ 7000) and effective areas. Nevertheless, the tracking capabilities are slightly better for the uniform array than for towers, with no analysis optimization (angular resolution $\sim 0.41^\circ$ and 0.95°, respectively). We conclude that a volume of the order of 1 km^3 can be covered by about 7000 PMTs with very good efficiency and pointing capabilities.

2. Site characterization for a km^3 ν-telescope

The choice of the ν-telescope location is such an important task that a careful survey of four candidate sites has been planned and partially carried out in order to identify the most suitable one. Careful and extensive measurements are routinely made on deep-sea water optical properties (absorption and diffusion) and on environmental properties: water temperature, biological activity, water current, salinity and sedimentation. The selection of the site where the km^3 detector can be located implies several requirements. The site has to be deep enough to filter out the downgoing atmospheric muon background. At 3500 m depth the level of the ratio of upgoing neutrino induced events to downgoing muons is of order 10^{-5} which can be coped with by a detector with a good reconstruction capability. In addition, the distance from the coast should be as short as possible, since data transmission to the on-shore counting room as well as transmission of power to the off-shore detector will be obtained via an electro-optical multi-fibre cable. A length of cable up to 100 km is still suitable for data transmission. The site needs to have good optical underwater properties because the detector effective area is not only directly determined by the extension of the instrumented volume but is also strongly affected by the light transmission in water. The 'sedimentation' in the selected site must have very low values. The site has to be 'quiet', i.e. the water current has to show low intensity and stable direction. We have identified four sites, close to the Italian coast, candidates for the construction of the km^3 neutrino detector. They have co-ordinates:

i) 35° 50′ N, 16° 10′ E in the Ionic Sea, South-Est of Capo Passero in Sicily;

ii) 39° 05′ N, 13° 20′ E in the Tyrrhenian Sea, North-Est of Ustica island, Sicily;

iii) 39° 05′ N, 14° 20′ E in the Tyrrhenian Sea, North of Alicudi island, Sicily;

iv) 40° 40′ N, 12° 45′ E in the central Tyrrhenian Sea, South of Ponza island.

To measure these properties, since July 1998 we have started extensive survey campaigns in the above mentioned sites which are still going on. We plan to collect data on deep-sea currents on a period longer than one year in order to monitor seasonal dependence. To characterize the optical properties of deep-sea water we have measured the absorption and attenuation coefficients, down to 3500 m, at 9 different wavelengths in the range 412-715 nm. Also data on water temperature and salinity are measured. During several cruises of the Italian Research Vessel URANIA we have been able to collect data in two sites close to Ponza Island, in two sites close to Capo Passero and in the vicinity of Matapan Abyss (Eastern Ionic Sea). Bio-fouling and sedimentation are also relevant parameters to consider in our search of the optimal site. We will soon deploy, at the Capo Passero site, a deep-sea station to measure sedimentation and bio-fouling rate for at least one year. Sedimentation information will be integrated over one month period. The deep-sea station will be also equipped with a CTD (Current, Temperature and Density meter) and a current-meter in order to relate bio-fouling data to oceanographic parameters. An acoustic modem will allow us to download data up to the sea surface at any time. The station will provide data almost in real time.

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