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The KM3NeT project - Progress towards a large underwater neutrino telescope☆

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Abstract

The status of the design for a large underwater neutrino telescope will be presented. The design calls for a device of a size encompassing a few cubic kilometers of instrumented sea water in the deep Mediterranean Sea to be built for a total cost of 250 M€.

Keywords: Astroparticle physics, Neutrino astronomy, Marine sciences

1. Introduction

The KM3NeT Consortium[1], which consists of 40 institutes from 10 European countries, has as its objective the construction of a large underwater neutrino telescope of a size of a few cubic kilometers in a deep area of the Mediterranean Sea. The project will also host a deep-sea cabled infrastructure for marine sciences. The current status of the design for this project will be presented. The KM3NeT project is in many respects a successor and a continuation of the three earlier pilot projects : ANTARES[2], NEMO[3], and NESTOR[4] and builds on their experience. A technical design report stemming from a design study has been published[5] and more details on the results presented here can found in that report.

2. Neutrino detection

The proposed neutrino telescope is designed to detect high energy (E_ν >1TeV) neutrinos, produced in celestial sources, that interact with nuclei in the nearby rock or sea water of the telescope. Even though the device will also detect neutrino interactions without a muon in the final state (e.g. from neutral current ν_μ interactions, ν_e interactions, ...) the primary signal channel will be reactions with an energetic muon in the final state (largely from charged current ν_μ interactions). The energetic muon as it travels through the sea water emits Cherenkov radiation, and it is through this Cherenkov light that one detects the muons, reconstructs their direction, and obtains a rough measure of their energy. The neutrino direction lies close to the muon direction, e.g. to within 0.3° for 70% of detected muons due to neutrinos coming from a point source with an E^{-2} spectrum; at low energies the angular resolution is dominated by the intrinsic $\nu - \mu$ angle while at high energies it is determined by the telescope response.

The long range of the muon (e.g. $R \sim 7.8$ to 14 km for $E_\nu \sim 10$ to 100 TeV , see [6]) allows for a large target mass. As a result most of the signal events are due to upcoming neutrinos, a situation that is also driven by the fact that a major source of background is due to muons produced in cosmic ray interactions in the atmosphere and thus coming from above. Nevertheless at very high neutrino energies ($E_\nu \gtrsim 500$ TeV) the increasing cross sections for neutrino interactions make the earth opaque to neutrinos and most detected neutrino produced muons come from directions near the horizontal plane.

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Figure 1: The DOM (top left); the 6m long horizontal bar with six traditional OMs (bottom left); a string DU (center); and a tower DU (right). The vertical scale for the DU subfigures has been distorted, for the tower DU the vertical separation between the bars has been decreased by a factor of 10.

3. Design principles and options

The Cherenkov light is detected by a a large array of optical sensors. Each sensor consists of one or more photomultiplier tubes (PMT) which are mounted inside a glass sphere capable of withstanding the ambient sea water pressure. Depending on the space available within the sphere, either inside each sphere or in an auxiliary external pressure resistant container there are electronics that provide power needed to bias the phototubes, are used for data readout (in the form of a pulse which is active during the time that the PMT signal exceeds a specified threshold), and for some environmental monitors. The glass sphere/PMT assembly is called the optical module (OM). OMs are suspended in the sea water to form a vertical structure with flotation units at the top and an anchor on the sea floor at the bottom; each vertical structure is of the order of $\sim 700 - 800$m tall and the lowest OM is $\sim 100 - 200$m above the seafloor. These vertical structures, the detection units (DU), are deployed over a large area of the sea to produce a large three dimensional array of OMs.

The direction and position of muons traversing the array are reconstructed from the arrival time and detection location of Cherenkov photons registered by the OMs. Nanosecond accuracy in the timing of the pulses and a similar accuracy in the knowledge of the position of the OMs (i.e. ~ 20 cm) are required. The sea water in the clear deep Mediterranean has a peak light absorption length in excess of 50 m and has very long light scattering length, in contrast to the much shorter scattering length found in the ice in Antarctica. This allows for DUs to be positioned with a horizontal separation of ~ 150 m.

The two design options being investigated are shown in figure 1. In the first design[7], the so called string design, the optical module (referred to as the Digital Optical Module - the DOM) is a 17 inch glass sphere inside which 31 small PMTs (3 inch diameter circular face) are mounted[8]. This is a departure from the 'traditional' OM, as used in the three pilot projects and in IceCube, in which a large spherical PMT (8 or 10 inch) is mounted inside each glass sphere. Readout electronics are housed inside the OM. Advantages of the DOM are: it has a large photocathode area, approximately 3 times as large as for a single large PMT, and the directionality provided by the knowledge as to which individual small PMT was hit helps in the event reconstruction. The number of photons impinging on a DOM is obtained from the number of hit PMTs, in contrast to the case for a traditional OM where this information is derived from the pulse height. In this design 20 DOMs are mounted as beads on a string separated vertically by 30m.

The second design[9] uses traditional OMs with electronics housed in a separate container. Six OMs are mounted on a 6m long horizontal structure as shown in figure 1. Twenty such bars are connected together, with a vertical separation of 40m, to form a tower structure, where bars on alternate levels are perpendicular to each other. This design has twice as much photocathode area (per bar) as the previous one (per OM) and has fewer connections that need to be made underwater; wet mateable connectors in general, but even more so for the depths considered here, are both costly and not extremely reliable.

The design optimization is still proceeding and an alternative being considered is one that incorporates a horizontal bar but uses DOMs rather than the traditional OMs.

4. Sea floor infrastructure and readout scheme

A cabled sea floor infrastructure will be used to distribute power and control information to each DU. Data from the OMs and control signals will be transmitted via a fiber optic system to shore. The main run from shore, with a length (depending on the site to be chosen) of 20 to 100 km, will be a standard electrooptical underwater telecommunications cable with a resistance of 1 ohm/km incorporating 96 optical fibers and carrying high voltage DC power (10kV) to a main junction box located near the telescope. DC to DC power converters in this main junction box will convert the DC to a lower voltage for use by the DUs. Cabling on the sea floor from the main junction box to the DUs will be done using cables with wet mateable connectors; the cabling operations will be carried out by remotely operated vehicles.

For the readout of the sensors a technique using a dense wavelength division multiplexing fiber optic system has been proposed[5][10]. In this network each subsea electronics readout board is connected to shore via a single frequency channel. Continuous wave lasers on shore provide light of up to 80 communications wavelengths down a single fiber to a junction box on the seabed. The single fiber is in turn split into up to 160 fibers, each carrying 40 wavelengths. Each of these fibers is fed to a master module located in the junction near the anchor of each DU, where the wavelengths are de-multiplexed. Each wavelength is sent via a bidirectional fiber to an OM, where it is reflected and modulated by the data using a reflective-electro-optical-amplifier-modulator (REAM). The modulated signal is again multiplexed into 80 fibers each carrying the signals from 80 optical modules. Additionally, a system is included that allows the determination of the time delay between the REAM and shore to an accuracy of 50 ps for a distance of 100 km. Finally, the control signals from shore to the optical modules are broadcast via a modulation on the continuous wave laser. Figure 2 is a schematic view of the system.

This data transmission scheme can accommodate the anticipated overall data rate (∼ 100 to 300 Gbits/s) and with all the data available at the shore station one can implement all desired triggering and data filtering schemes, without being limited by any constraints that any local (OM or DU based) triggers would impose.

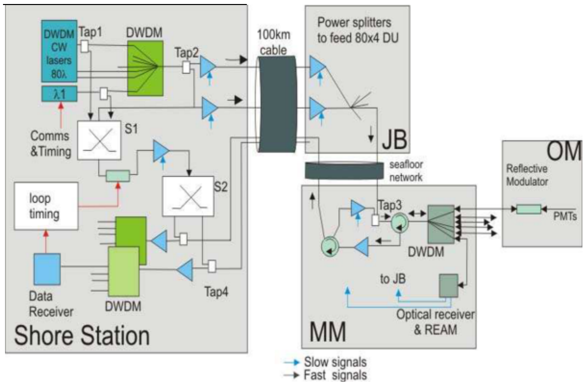

Figure 2: The readout system

5. Marine sciences

The KM3NeT infrastructure will incorporate marine science nodes (i.e. special strings) that will carry adhoc instrumentation and will be operated in conjunction with the European Multidisciplinary Seafloor Observatory (EMSO) [11]. Such observations already are part of the site related studies (see Section 7) and of the continuous data obtained by the operating ANTARES neutrino telescope. Nevertheless, KM3NeT will be a truly large permanently cabled deep sea marine science observatory that will provide continuous long term data.The instrumentation in the DUs/OMs even though limited in scope to primarily position information will provide for the first time detailed and continuous information for such a large volume of the deep sea.

6. Deployment tests

To ease logistics and transportation the DUs will be assembled as compact packages that can be deposited at the appropriate location of the sea floor, and will self unfurl upon release. Tests to verify the feasibility of such schemes are being carried out. The string unit is rolled around a spherical launching unit that unrolls and releases the optical modules one by one. The tower unit is placed as a stack on the seafloor and the horizontal bars are raised one by one by a buoy. Figures 3 and 4 show the deployment packages and photos from the first mock-up sea tests. Alternatively one could still use the more traditional but more time consuming line deployment technique.

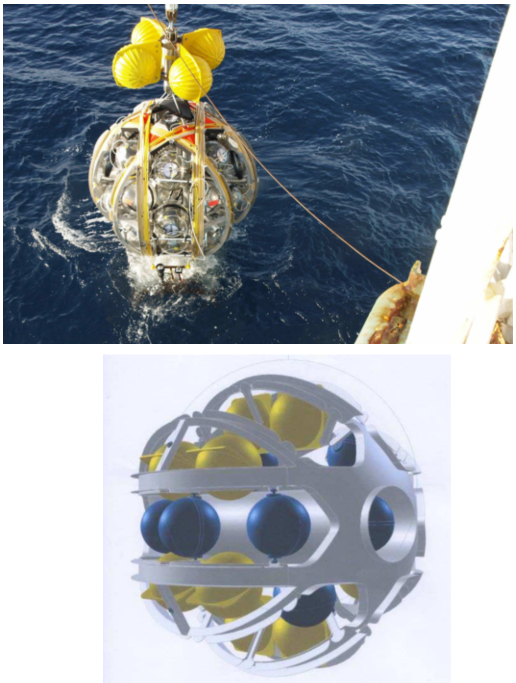

Figure 3: Test deployment of a string DU mock-up and its computer model. The yellow spheres in the model indicate the ones that are empty and are used to provide flotation.

7. Site studies

Three sites are presently under consideration. They are listed below, with their coordinates, the sea depth (*d*) at each site, and the cable length to shore (*s*):

(i) Toulon - Ligurian Sea
 42°48′N , 6°10′E ; *d*=2475 m ; *s*=40 km.

(ii) Capo Passero - West Ionian Sea
 36°16′N , 16°06′E ; *d*=3500 m; *s*=100 km.

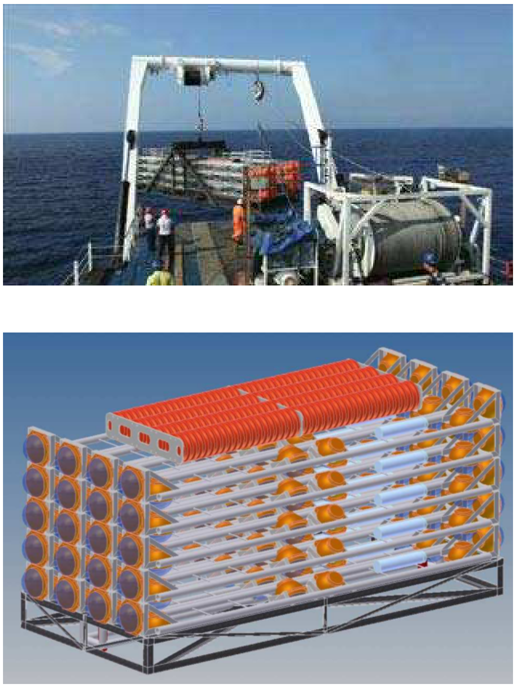

Figure 4: Test deployment of a tower DU mock-up and its computer model. The orange structure on the top shown in the model is used to provide flotation.

(iii) Pylos - East Ionian Sea
 a) 36°33′N , 21°08′E ; *d*=5200 m; *s*=50 km;
 b) 36°33′N , 21°29′E ; *d*=4500 m; *s*=30 km;
 c) 36°38′N , 21°35′E ; *d*=3750 m; *s*=20 km;
 d) 36°50′N , 21°32′E ; *d*=3000 m; *s*=15 km.

The final choice of a site has not yet been made. The choice will be determined by such factors as water quality (i.e. water clarity), depth, distance from shore, biological activity (since a significant background is due to bioluminescence, i.e. the presence of luminous creatures in the water), sedimentation, etc. Political considerations may also influence the selection.

Meanwhile studies of the relevant properties at all three sites are being carried on on a continuing basis. As an example we refer to a recent series of water transparency measurements[12]. Another example is given in Figure 5 which shows the seasonal variation of bioluminescence, which together with Cherenkov light due to natural radioactivity (^{40}K β-decay in the sea) are the major sources of random ambient light.

8. Performance

Starting from a budget of 250 M€ we expect that 650 string DUs (or 320 tower DUs) can be built. With a

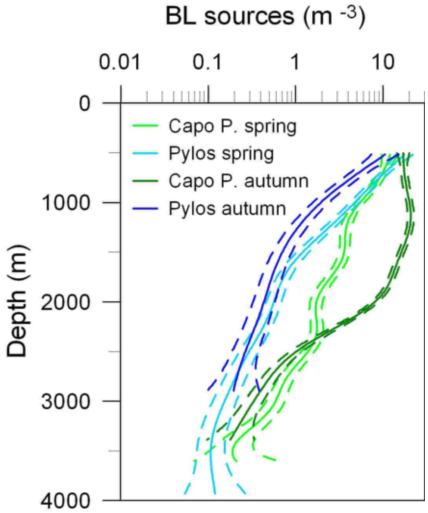

Figure 5: Density of bioluminescent animals at the Capo Passero and Pylos sites, in autumn 2008 and spring 2009. (Dashed lines show 95% c.l.) Data from Ref. [13]. The traces from left to right are: Pylos autumn, Pylos spring, Capo P spring, Capo P autumn.

horizontal separation of 130 m between the string DUs (or 180 m between the tower DUs) we obtain an instrumented detector volume of 5-6 km^3. A construction time of four to five years is anticipated.

The sensitivity of these detectors has been determined by Monte Carlo simulation. The sensitivity for neutrino point sources with an E^{-2} energy spectrum is shown in Figure 6 as a function of declination angle. The sensitivity turns out to be largely independent of the chosen design. Also shown are the positions of known high energy gamma ray sources and the sensitivity that can be obtained with the IceCube detector. For sources near the galactic center, where IceCube has very low sensitivity, KM3NeT has significant sensitivity. Even at the declination where IceCube has maximum sensitivity KM3NeT is better even though this region of the sky is visible to it only 15% of the time. In addition KM3NeT will outperform IceCube in the search for a diffuse cosmic neutrino flux by a factor of three.

KM3NeT will also be a tool for studying transient sources, such as neutrinos from gamma ray bursts, and will allow for indirect dark matter searches. More importantly KM3NeT will allow us to observe the Universe using the new modality offered by a neutrino telescope, with significantly better sensitivity than the one obtained by IceCube. And every time we have turned our eyes to the sky with a novel modality surprises and wonders have been encountered!

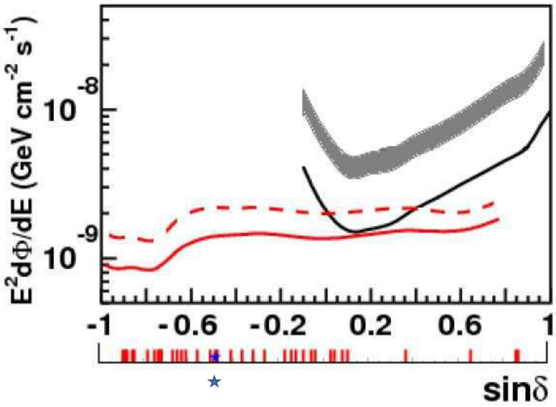

Figure 6: Sensitivity for the KM3NeT detector as a function of the sine of the declination angle. The solid red curve indicates the 3σ exclusion limit and the dashed red curve the 5σ discovery for a one year exposure. The black line and the grey shaded area above it are the same but for IceCube, respectively. The dashes below the abscissa indicate the positions of known high energy gamma ray sources, and the star shows the position of the galactic center.

References

[1] KM3NeT web page: `http://www.km3net.org`

[2] ANTARES (web page:`http://antares.in2p3.fr`) is the only undersea neutrino telescope in operation.

[3] NEMO web page: `http://nemoweb.lns.infn.it`

[4] NESTOR web page: `http://www.nestor.noa.gr`

[5] *KM3NeT: Technical Design Report.*, ISBN 978-90-6488-033-9, 2011; also available online from the KM3NeT web page.

[6] D.E. Groom, N.V. Mokhov, and S.I. Striganov, *Atomic Data and Nuclear Data Tables* **78** (2001) 183; also tabulated in `http://pdg.lbl.gov/AtomicNuclearProperties.`

[7] E. de Wolf *et al.*, in Proc. of VLVnT09, Athens, Greece, Oct. 13-15, 2009; published in *Nucl. Instrum. Methods. A* **626-627** *Supplement 1*, (2011) S193.

[8] P. Kooijman *et al.*, in Proc. of VLVnT09, Athens, Greece, Oct. 13-15, 2009; published in *Nucl. Instrum. Methods. A* **626-627** *Supplement 1*, (2011) S139.

[9] M. Musumeci, *A New Design for the Tower Detection Unit*, presented at VLVnT09, Athens, Greece, Oct. 13-15, 2009; slides available at: `http://www.nestor.noa.gr/vlvnt09/programme.htm`

[10] J. Hogenbirk *et al.*, in Proc. of VLVnT09, Athens, Greece, Oct. 13-15, 2009; published in *Nucl. Instrum. Methods. A* **626-627** *Supplement 1*, (2011) S166.

[11] EMSO : The European Multidisciplinary Seafloor Observatory, web page: `http://www.emso-eu.org`

[12] E.G. Anassontzis *et al.*, *Astroparticle Physics* **34**, (2010) 187, and references to earlier measurements contained therein.

[13] J. Craig *et al.*, *Deep Sea Research, Part I* **57**, (2010) 1474. J. Craig *et al.*,in Proc. of VLVnT09, Athens, Greece, Oct. 13-15, 2009; published in *Nucl. Instrum. Methods. A* **626-627** *Supplement 1*, (2011) S115.