KM3NeT: a cubic-kilometre scale deep sea neutrino telescope in the Mediterranean Sea

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Abstract. The European KM3NeT consortium is presently carrying out R&D activities towards the construction of a cubic-kilometre scale deep-sea Cherenkov detector for high-energy astrophysical neutrinos. Located in the Mediterranean Sea, KM3NeT will complement the field of view of the IceCube neutrino telescope currently under construction at the South Pole. KM3NeT will allow for observations of the Galactic Centre and most of the Galactic plane, where H.E.S.S. has discovered several TeV-gamma sources, some of which are candidate neutrino sources. The three Mediterranean pilot projects, ANTARES, NEMO and NESTOR, are actively involved in KM3NeT, which is declared a high-priority project by the astronomy (ASTRONET Roadmap) and astroparticle (ASPERA Roadmap) scientific communities and has been included in the 2006/08 Roadmaps of the European Strategy Forum for Research Infrastructures (ESFRI). Additionally, a number of oceanography, geophysics, biology, environmental sciences and geology institutions are active in the KM3NeT consortium with the aim of helping create a future multidisciplinary deep-sea research infrastructure in the Mediterranean Sea.

1. Introduction
The discovery of cosmic rays dates back more than a century, but the most fundamental questions on their origin and acceleration mechanisms remain unanswered.

Recent observations of high energy gamma rays from several Supernovae Remnants make these objects plausible sources of high energy cosmic rays [1], though the smoking gun evidence is still missing and can be provided by the detection of high energy neutrinos. Thanks to their weakly interacting nature, neutrinos represent the ideal probe to carry information from the core of very distant astrophysical objects. On the other hand the same property, together with the low expected fluxes, makes them difficult to detect and requires huge detectors. A possible solution is the exploitation of sea water and/or polar ice, equipped with a lattice of photo-sensors which are able to detect the Cherenkov radiation emitted by the charged particles, mainly muons, produced in the neutrino interactions, thus allowing for the reconstruction of their trajectories and energies [2].

A cubic-kilometre detector is currently under construction in the deep South Polar ice (IceCube) [3]. A km$^3$ detector in the Mediterranean Sea would complement the field of view of IceCube, and

1 A complete list of the authors is available here: http://www.km3net.org
would have the major advantage of looking directly at the Galactic Centre which is considered an extremely interesting region to explore, see Fig. 1.

The construction of this detector requires a joint effort of the national scientific communities. A consortium of 40 institutes from 10 European countries, including all the groups involved in the Mediterranean neutrino telescope projects: ANTARES, NEMO, NESTOR [4], the KM3NeT [5] Design Study (DS), was created in 2006 and funded in the EU 6th framework programme. Its main goal is to develop a cost-effective design for the construction of a neutrino telescope with at least 1 km$^3$ of instrumented volume. In April 2008 the consortium published the KM3NeT Conceptual Design Report (CDR) [6], which describes the scientific objectives, and the concepts behind design, construction and operation of the KM3NeT Research Infrastructure. The DS will end in October 2009, the completion of the Technical Design Report (TDR) is scheduled for December 2009. The TDR will define the technological solutions for the construction of a km$^3$ neutrino telescope in the Mediterranean Sea.

In March 2008 the Preparatory Phase (PP) project started. It is funded under the EU 7th framework programme. The PP will address legal, governance, funding and strategic issues of the construction of the KM3NeT in the Mediterranean, including site selection. The PP foresees also prototyping work, with a view to start the telescope construction in 2013.

The KM3NeT research facility will host also an earth and marine sciences observatory.

2. Design goals and technical solutions.

The CDR contains the detailed description of all the requirements for a km$^3$ neutrino telescope in the Mediterranean Sea. This neutrino telescope is planned as a long-term observatory, with a data taking period longer than 10 years. This requires a high reliability of the critical components of the telescope. The infrastructure will be designed to “survive” in the deep sea, under high pressure and in the aggressive salt water environment.

The neutrino telescope effective area increases with energy due to the features of neutrino interactions and the detection technique, while the energy spectra of neutrino fluxes are expected to fall with energy. This requires the optimisation of detector sensitivity in the energy range 1 TeV – 1 PeV.

The reduced light scattering in sea water represents a major advantage of a Mediterranean Sea neutrino telescope. To exploit this characteristic good positioning and time calibration systems are required to reduce the detector effects on the angular resolution when reconstructing muons. The goal is an angular resolution of $0.1^\circ$ for neutrino energies $\geq 30$ TeV.

A full cost of 200-250 M€ is foreseen for KM3NeT.
The technical solutions investigated have been inspired mainly by the pilot projects (ANTARES, NEMO, NESTOR), and by new developments conducted partly in collaboration with industry. Though there is a general convergence on a unique design, several technical options are still available.

- **Photo-sensor.** The rejection of optical background, consisting mainly of single photoelectrons, requires a local set of photomultipliers (PMTs) for an efficient 1-2 photon separation. This can be realised with a multi-PMT optical module (OM) option, 2 large 8”/10” PMTs or several 3” PMTs, housed in pressure resistant glass spheres, or by local groups of more single-PMT OMs.

- **Data acquisition and transmission.** The concept of “all-data-to-shore” will be applied: all PMT signals above a given threshold will be sent to shore. This implies an overall data rate of ~100-300 Gb/s for a typical threshold of 1/3 of a single photo-electron. On shore, a computer farm will reduce this rate by about 5 orders of magnitude, by online filtering. Optical fibres will be used for the communication between shore and the detection units.

- **Mechanical structures.** Simulations indicate that a horizontal spacing of a few metres between OMs on the same storey improves detector sensitivity. A possible mechanical solution is represented by a tower-like structure, made by 6-metre horizontal bars carrying 3 groups of 2 single-PMT OMs or some single multi-PMT OMs. An alternative solution can be a slender string-like structure with multi-PMT OMs.

- **Deep-sea infrastructure.** The deep-sea infrastructure consists of one or several main electro-optical cables connecting the shore station to a deep-sea network made of junction boxes and secondary cables for electrical power and data distribution. The KM3NeT infrastructure will also host nodes for earth and marine science instrumentation.

- **Calibration.** An acoustic positioning system will measure the OM positions with a precision better than 40 cm using a network of transponders and receivers. The stability of the timing calibration of the OM signals will be monitored by synchronisation signals sent from shore, and using LED/Laser flashers installed in the detector. The absolute orientation of the telescope can be evaluated using acoustic triangulation coupled to GPS positioning and precision pressure probes. An independent way to check the absolute pointing is the measurement of coincident down-going events between a sea surface detector and the deep-sea telescope. Finally, the observation of the Moon shadowing effect on cosmic rays can be used as a cross-check of the absolute orientation of the apparatus, down to the level of a fraction of a degree.

- **Candidate sites.** The Mediterranean Sea offers optimal conditions, on a worldwide scale, to host an underwater neutrino telescope. A few sites have been identified to be suitable for hosting a future KM3NeT detector. Several criteria can help to define an optimal site:
  - proximity to the coast to ease deployment and reduce the expense of the power and signal cable connections to shore;
  - a sufficient depth to reduce background from atmospheric muons;
  - good optical properties of water;
  - low level of bioluminescence;
  - low rates of biofouling and sedimentation on optical surfaces;
  - stable low sea current velocities.

The ANTARES, NEMO and NESTOR Collaborations have performed extensive studies to characterise their sites. The final decision will take into account also technological and budgetary input. A multi-site option has been proposed as well.
3. Earth and marine science observatory

The KM3NeT research infrastructure will serve also as a platform for a wide spectrum of earth and marine sciences research. It will enable continuous data to be collected without interruption over long periods. Permanent connections from the deep sea to the shore for powering and reading out instruments are rare and have a great value. The only cabled sites at present in Europe are those of the neutrino telescope pilot projects, which already feature extensive programmes in these fields.

4. Conclusions

The experience of the pilot projects demonstrated the feasibility of a cubic kilometre scale underwater high-energy neutrino telescope.

By the end of this year the KM3NeT European Consortium will publish the Technical Design Report with the definition of the technological solutions for the construction of such a detector.

In March 2008 KM3NeT entered a Preparatory Phase (PP) which aims at the definition of legal, financial, governance and strategic issues that need to be settled before the start of construction, and foresees also a prototyping activity. The KM3NeT neutrino telescope in the Mediterranean Sea will complement IceCube in its field of view, exceeding its sensitivity (Fig. 2), and looking directly at the Galactic centre. The KM3NeT detector construction is expected to start in 2013.

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