Neutrino telescopes
launch of KM3NeT's first detection line

After years of preparations the first KM3NeT detector line was successfully launched in 2015, 100 km off the Sicilian coast. The 780 m long line detector, tightly rolled on a special frame developed by NIOZ, was gently placed on the seabed at a depth of 3,500 m. The detector was then connected by an unmanned submarine to the existing underwater network and via a 100 km fiber cable to the control room in Porto Palo di Capo Passero in Sicily. The next step was the rollout of the line, until it came to stand upright in the water.

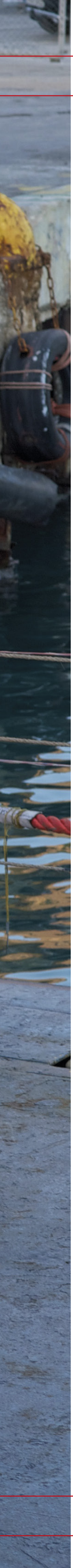
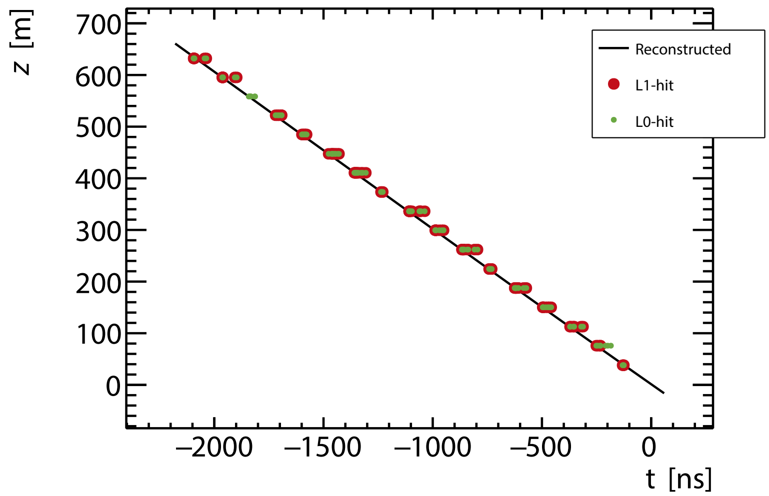


Figure 1. Event display of an atmospheric muon detected on the first deployed KM3NeT detection line. The plot shows the height of the sensors along the detection line vs. the time of the detected Cherenkov light. The line is a fit of a muon moving downwards along the detection line with the speed of light.



Management
dr. A. Heijboer

Nikhef is heavily involved in the construction of the next generation neutrino telescope in the Mediterranean Sea: KM3NeT. We have led the development of the chosen technology at both the conceptual and technical level. This cost effective technology is a major asset of the project. An example is the Multi-PMT optical module, which offers more information per detected Cherenkov photon, and a better price per unit sensor area compared to earlier options. A novel deployment mechanism developed by NIOZ and Nikhef allows for multiple lines to be deployed safely in a single sea campaign, which is essential for deploying the hundreds of lines that will make up KM3NeT. We are also involved in optical module production, mechanics and optical-network efforts, and we provide the spokesperson.
The collaboration has recently published a letter of intent, which details the science reach of the next phase of the project, KM3NeT 2.0, comprising 345 detection lines in France and Italy. On 10 March 2016 it was officially announced that KM3NeT 2.0 will appear on the renewed version of the European ESFRI roadmap for large-scale infrastructures.

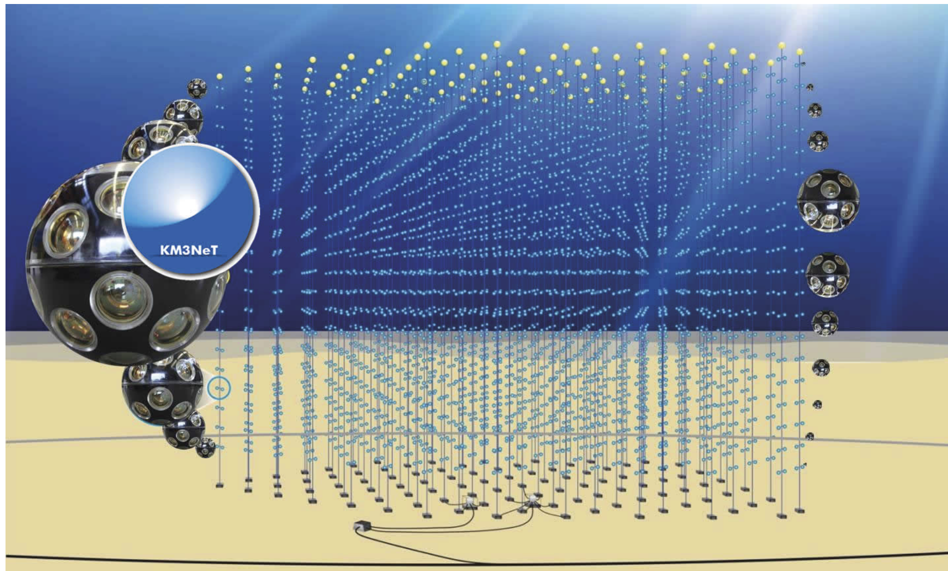
First detection line

The first detection lines of the KM3NeT detector have been constructed in the Nikhef workshop. In December 2015, the first line has been deployed at 3.5 km depth, and connected via a pre-installed 100 km long electro-optical cable to the shore station in Porto Palo, Sicily. Hours after deployment, the line was powered up and data immediately began flowing from each of the 18 optical modules. PhD students Martijn Jongen en Karel Melis have been analysing this data since the first hours. Using the signals that will eventually become the background to cosmic neutrinos, like ^{40}K decays and atmospheric muons (see Fig. 1), they were able to verify the nanosecond timing accuracy of the detector and to measure the photomultiplier sensor efficiencies. The timing accuracy, which is key for the accurate reconstruction of neutrinos, has further been verified with optical flashers. All these measurements are consistent with the internal timing system based on White Rabbit-technology, another technical Nikhef contribution.

As the moment of writing, every one of the 558 sensors in the line is functional and producing high-quality data with nanosecond timing accuracy. The next string will be deployed in May 2016; this will allow for the identification and reconstruction of the first neutrinos.

Neutrino Oscillation Physics

The Nobel prize for Physics in 2015 was awarded for the discovery of neutrino oscillations. The experiments involved detected neutrinos from the atmosphere and the Sun to show that neutrinos change flavour along the way. For the solar neutrinos, the presence of matter in the Sun allows a determination of the absolute ordering of the two mass eigenstates involved. For the atmospheric neutrinos, this has not yet been possible. Hence, it is presently unknown what the ordering, or hierarchy, of neutrino masses is. This is the next big question in neutrino research, with large implications for future efforts to detect CP-violation in neutrinos and neutrinoless double beta decay. It turns out that large volume neutrino telescopes have the ability to answer this question. By measuring, with unprecedented accuracy, the oscillation of atmospheric neutrinos with energies in the few-GeV-range, these detectors are sensitive to the hierarchy-dependent effect of matter in the Earth. KM3NeT has decided to optimize part of the detector for this goal. The resulting setup (called ORCA) will be able to determine the neutrino mass hierarchy within three years of data taking, in addition to provide precise measurements of the mixing angles, making it very competitive with other (accelerator- based) efforts which are planned on longer timescales.

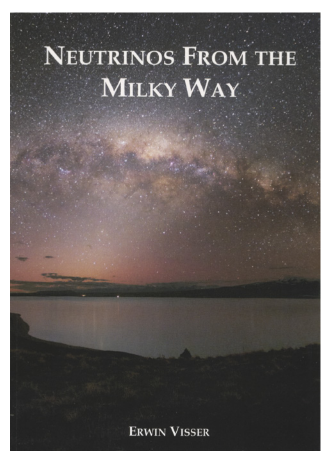


Artist's impression of the KM3Net detector with strings anchored to the sea bottom.

All-flavour neutrino detection

With the discovery of cosmic neutrinos by IceCube, it has become very clear that neutrino astronomy not only requires the ability to detect muon-neutrinos. The capability to accurately measure the other two types, electron- and tau-neutrinos, is a crucial asset. The ability to identify the sources of neutrinos depends strongly on the pointing capabilities for each neutrino type. Due to neutrino oscillations, all flavours will be present, but the precise abundances carry information on the astrophysics of the source, and on the particle-physics of the neutrino themselves. Exotic scenarios like decaying neutrinos could lead to very clear signatures in the neutrino flavour ratios.

Members of the Nikhef group have developed methods to reconstruct the experimental signatures produced by electron- and tau neutrinos. We have shown KM3NeT will achieve degree-level pointing accuracy for



Erwin Lourens Visser
12 May 2016

these events: an order of magnitude better than the current accuracy of IceCube. This is made possible by the clarity of the Mediterranean sea water, combined with the multi-PMT design. This capability, which came as a surprise to many of our colleagues, now underpins a large part of the planned science programme as described in the recent Letter of Intent.

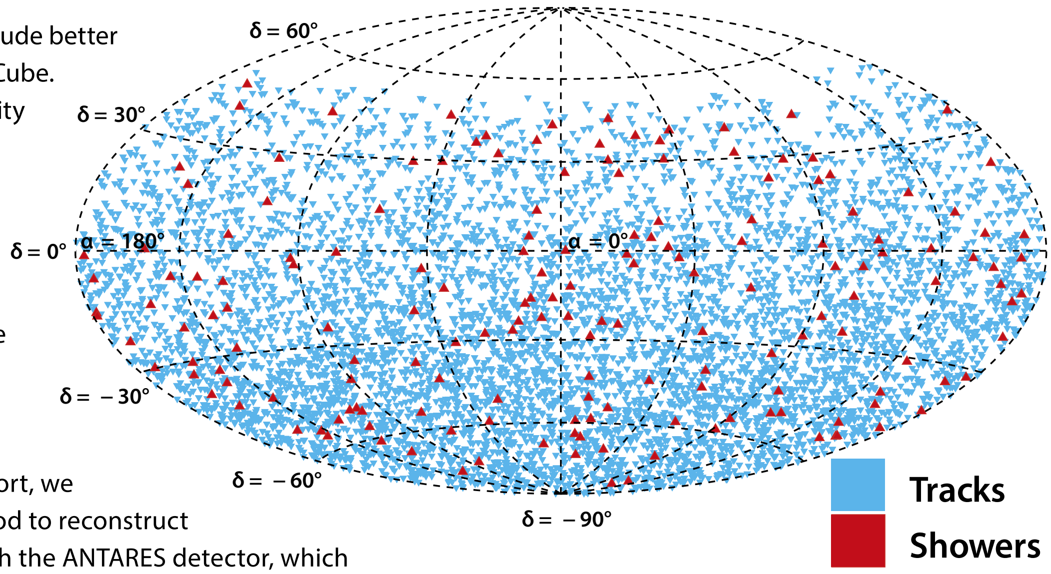


Figure 2. A sky map of neutrino candidates detected in ANTARES from the most recent cosmic source search. The blue dots represent muon-neutrino candidates (most of which are real atmospheric muon neutrinos), whereas the red dots are electron- or tau-neutrino candidates, which have a significantly reduced background. The angular resolution of these events is roughly the size of the dots. The corresponding analysis is the world-first search of cosmic neutrino point sources using all neutrino flavours.

In synergy with the KM3NeT effort, we have also implemented a method to reconstruct electron- and tau-neutrinos with the ANTARES detector, which has been taking data for eight years now. The ability to detect these signatures has been used to significantly enhance the search for cosmic neutrino sources (see Fig. 2). These results, which are the topic of Tino Michael's PhD thesis, represent the most sensitive exploration of the Southern neutrino sky, including the Galactic Centre, to date. While Nikhef's activity on ANTARES data analysis is decreasing, the tools to use all flavours of neutrinos, will be used by the collaboration to enhance many other analyses in the next few years. The ability to detect all flavours, and to accurately distinguish between them also underpins the measurement of the neutrino mass hierarchy with ORCA.

NLeSC Grant
Dorothea Samtleben

NLeSC Grant
Ronald Bruijn

NLeSC Path-finding grants

The Netherlands eScience Center (NLeSC) approved the Nikhef proposal *"Real-time detection of neutrinos from the distant Universe"* by **Dorothea Samtleben** together with **Ronald Bruijn** for a so-called Path-finding project. NLeSC funds these projects by in kind provision of eScience research engineers. The Path-finding grants are intended to develop new lines of eScience research that may develop into bigger programs and projects.