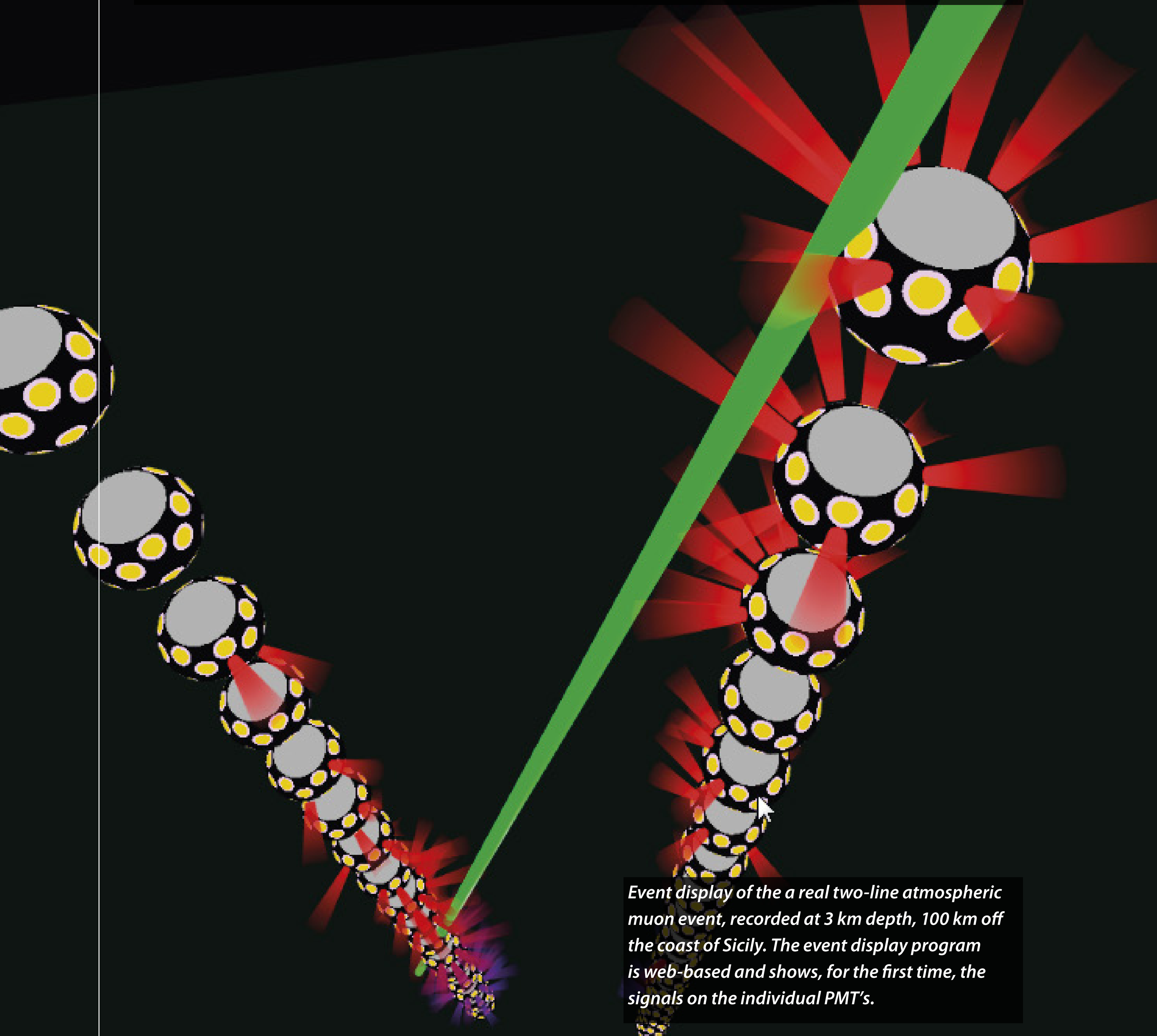
KM3NeT
Constructing the next generation neutrino telescope



Event display of the a real two-line atmospheric muon event, recorded at 3 km depth, 100 km off the coast of Sicily. The event display program is web-based and shows, for the first time, the signals on the individual PMT's.

Nikhef technician Rene de Boer is assembling one of the DOMs that soon will be lowered in the Mediterranean Sea.

Management
dr. A. Heijboer

Nikhef is heavily involved 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 levels. 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. In February 2017 Maarten de Jong's double term as spokesperson of the collaboration ends. Els Koffeman and Aart Heijboer have been elected to be part of the new management team in the role of technical coordinator and deputy spokesperson respectively.

Among the science goals are establishing the neutrino mass ordering and the discovery of the sources of cosmic neutrinos observed by IceCube a few years ago. New hints on mass hierarchy and even CP violation of neutrinos are coming in from Nova and T2K. KM3NeT will yield a particularly sensitive determination of the mass ordering in case the large mixing angle θ23 is in the second quadrant and the mass ordering is 'normal'; a scenario that is fully compatible with the latest data. Furthermore, other neutrino oscillation physics can be done, such as a measurement of the octant of θ23, looking for non-standard interactions, and testing unitarily using nu-tau appearance.

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 reconstruction software for this is another key contribution of our group. KM3NeT will measure the origin of cosmic neutrinos in the sky with an accuracy that is an order of magnitude better than our present knowledge from

IceCube. This leads to an image of the neutrino sky with a factor 100 more 'pixels', which greatly enhances the capacity to correlate the neutrinos to the many potential neutrino sources that are known from radio and gamma-ray observations. While identifying and studying the astrophysical sources of the cosmic neutrinos is currently a major goal in astroparticle physics, cosmic neutrinos also provide a free 'beam' to study the fundamental particle physics at energies three orders of magnitude higher than with terrestrial beam experiments. They can be used to probe several scenarios of physics beyond the standard model, which would lead to a detectable imprint on the neutrino flavour ratios detected on Earth.

Ongoing Detector construction

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. The first detection line, which was constructed in the Nikhef workshop, has been taking data in Mediterranean sea for over a year now. In May 2016, two more lines have been deployed. One of these has since been recovered due to an electrical problem, which has since

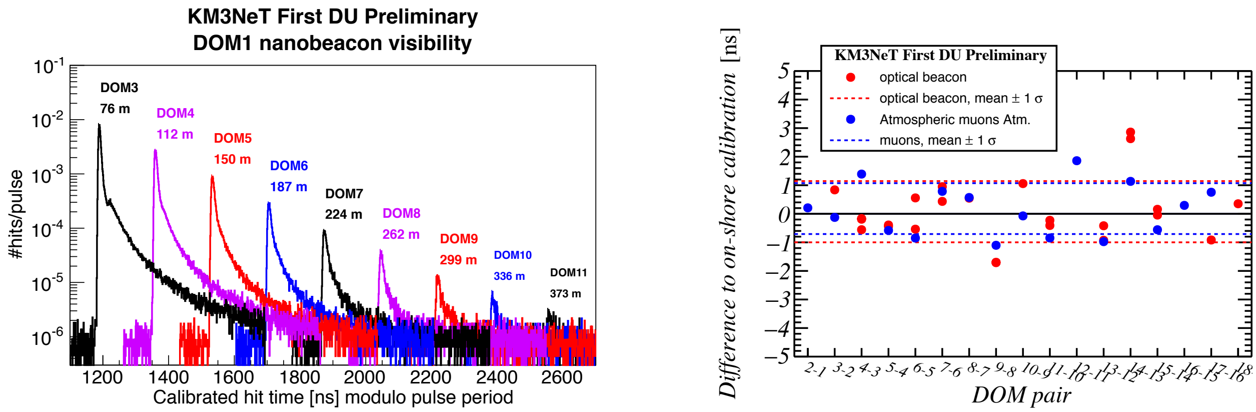
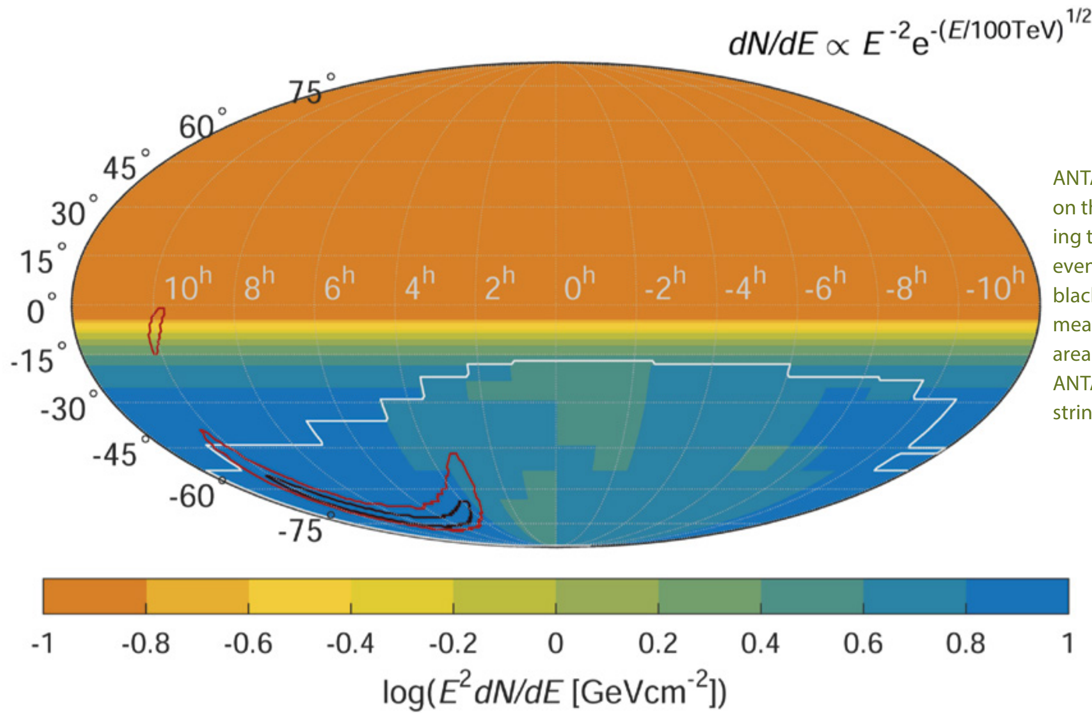


Figure 2. Left: Calibration signals: an optical beacon is flashed and the signal observed over a large part of the detection line. A precise measurement of the arrival time of the light is used to check the detector's timing calibration. Right: comparison timing offsets from optical beacon analysis and an analysis using muon tracks with the calibration from the lab; all analyses agree within ~1 ns.

been investigated and understood in the Nikhef workshop. The line will be redeployed after refurbishment. In the meantime, the two remaining detection lines have yielded a wealth of information on the timing performance, allowing the verification of the time calibration system that was developed at Nikhef. The timing accuracy has been verified with optical flashers as well as signals that will eventually become the background to cosmic neutrinos, like 40K decays and atmospheric muons; see Fig. 2.

Production of the digital optical modules (DOMs), see Fig. 3, is progressing steadily. Collaboration-wide the DOM production is led by Nikhef postdoc Daan van Eijk, while Ronald Bruijn in responsible for the local coordination. Production of modules has reached 155 – most of them at Nikhef. The other four production across Europe have also started production.

Figure 3. The components for a KM3NeT optical module. This picture first appeared in an article about KM3NeT in *Nederlands Tijdschrift voor Natuurkunde*.



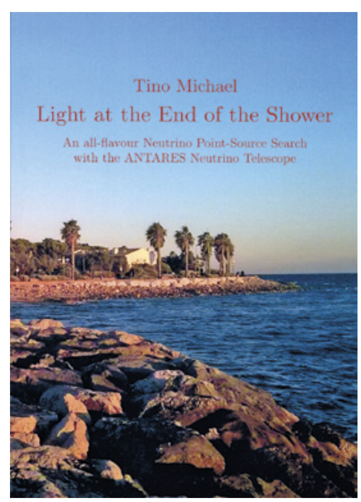
ANTARES and IceCube joint limit on the neutrino flux accompanying the first gravitational wave event GW150914. The red and black contours show the position measured by LIGO/VIRGO; the area below the white line is where ANTARES provides the most stringent limit.

Together, they are scheduled to complete the modules for the first phase of the project. DOM production has so far only been limited by the supply of components, which testifies to the skill of the Nikhef workshop, as well as the efficacy of our design.

Antares

While building KM3NeT takes most of our time, our group still harvests the results from earlier efforts in ANTARES, which has been taking data since 2007. ANTARES has been providing competitive results on neutrino astronomy and indirect dark matter searches. Dorothea Samtleben coordinates the point source analysis and has been involved in many of the key publications. A reconstruction for cascade events with high angular resolution, as developed at Nikhef in 2015, is now an established ingredient in many of the new analyses that are expanding the sensitivity to all neutrino flavours. Using nine years of data the world-best limits on high energy neutrino emission in the Southern sky were set. The cascade events were also included in a new analysis of the Galactic plane based on the likelihood framework as developed at Nikhef. The new limit is by now only 20% above the most optimistic models, and almost identical to the IceCube limits. Despite the small size of ANTARES, these results clearly illustrate the power of a water-based detector in the Northern Hemisphere. For both analyses the combination of Antares and IceCube data is underway.

ANTARES has a broad multi-messenger program, where the neutrino data are compared to optical, radio and gamma-ray measurements. When high energy neutrinos are measured, real time alerts are distributed for fast optical follow up. In similar spirit, the spectacular discovery of the first gravitational wave event by LIGO/VIRGO was followed up by a fast analysis of the neutrino data in both ANTARES and IceCube. As the event concerned a merger of two bare black holes, no neutrinos were expected, which was confirmed by the data. The unique, joint publication by the three collaborations provides limits on the neutrino flux.



Tino Michael
13 May 2016