KM3NeT INFRADEV – H2020 – 739560

Report on the Panel activities

KM3NeT INFRADEV GA DELIVERABLE: D9.2

Document identifier:	**KM3NeT-INFRADEV-WP9-D9.2**
Date:	**15/08/2018**
Work package:	**WP9**
Lead partner:	**NCSR-D**
Document status:	**Final**
Dissemination level:	**Public**
Document link:	

Abstract

This document reports on the activities of the Technology and Innovation Panel of KM3NeT.

COPYRIGHT NOTICE

I. DELIVERY SLIP

	Name	Partner/WP	Date
Author(s)	E. Tzamariudaki	NCSR-D / WP9	10/07/2018
Reviewed by	C. Markou	NCSR-D	02/08/2018
Approved by	PMB		15/08/2018

II. DOCUMENT LOG

Issue	Date	Comment	Author/Partner
1	10/07/2018	1st version circulated to reviewer	NCSR-D
2	02/08/2018	2nd version including comments from reviewer	NCSR-D
3	15/08/2018	Final version including comments from PMB	NCSR-D

III. APPLICATION AREA

This document is a formal deliverable for the GA of the project, applicable to all members of the KM3NeT INFRADEV project, beneficiaries and third parties, as well as its collaborating projects.

IV. TERMINOLOGY

A complete project glossary is provided:

ARCA: Astroparticle Research with Cosmics in the Abyss
ORCA: Oscillation Research with Cosmics in the Abyss
PMB: Project Management Board
ROV: Remotely Operated underwater Vehicle
SCB: Switching Core Board

The infrastructure will consist of three so-called building blocks. A building block comprises 115 strings (Detection Units – DUs) with one end fixed on the sea floor. Each DU comprises 18 optical modules (DOMs) and each optical module comprises 31 photo-multiplier tubes (PMTs) and the readout electronics. The DUs are deployed and the interlink cables are connected from the base of the DUs to the junction box.

V. LIST OF FIGURES

VI. LIST OF TABLES

None

VII. PROJECT SUMMARY

KM3NeT is a large Research Infrastructure that will consist of a network of deep-sea neutrino telescopes in the Mediterranean Sea with user ports for Earth and Sea sciences. Following the appearance of KM3NeT 2.0 on the ESFRI roadmap 2016 and in line with the recommendations of the Assessment Expert Group in 2013, the KM3NeT-INFRADEV project addresses the Coordination and Support Actions (CSA) to prepare a legal entity and appropriate services for KM3NeT, thereby providing a sustainable solution for the operation of the research infrastructure during ten (or more) years. The KM3NeT-INFRADEV is funded by the European Commission's Horizon 2020 framework and its objectives comprise, amongst others, activities on technology transfer and innovation in the KM3NeT Collaboration (work package 9).

VIII. EXECUTIVE SUMMARY

The main goal of WP9 is to establish methodologies both for exposing to interested parties in the industrial sector technological choices and innovative solutions that have been developed or adapted by KM3NeT, and for following the technological advances in key areas of interest to KM3NeT.
The first task of the work package is the observation of technological advancements in the fields of interest to KM3NeT and the presentation of technological solutions developed or modified by KM3NeT, in order to match the specifications required to achieve the desired physics goals, to other stakeholders with potential interest. For this purpose, four members of the Collaboration with expertise on related subjects were contacted and together with the WP9 coordinator formed a 5-member Technology and Innovation Panel of KM3NeT. This document reports on the activities of this Panel.

Table of Contents

1. Introduction

In the context of exposing KM3NeT to the outside world, and targeting relevant interested parties in the industrial sector, appropriate dissemination material has been developed for the participation of KM3NeT to technology and industrial exhibitions. For the purposes of the "Technology transfer and innovation" work package, a panel of members with expertise in the areas of technological interest to KM3NeT has been formed aiming to establish a sustainable methodology for the two-way flow of information and know-how between KM3NeT and the key technology areas. Four experts and the work package coordinator participate in this Technology and Innovation Panel covering the following areas of interest: Optical measurements, low power electronics, deep sea operations, communication technologies, computing and data sciences. The members of the panel have the mandate to follow technological advancements and to identify cases where the KM3NeT needs have been the driving force behind industrial innovation and cases where appropriate modifications have been implemented to existing solutions in order to comply with the requirements set by the experiment. Input and material was collected from the members of the panel and was prepared for exhibitions. This exhibition material was included in D9.1. of WP9.

2. Plan

WP9 has the following objectives:

- Continuous observation of technological advancement in the fields of interest of KM3NeT
- Presentation of technological solutions developed and adopted/modified by KM3NeT to the relevant industrial fora
- Exploitation of KM3NeT developed solutions for specific problems, including environmental related issues.

In particular, Task 9.1 focuses on the observation of technological advancements. For this reason, the first priority was to form a Technology and Innovation Panel of KM3NeT aiming to establish a sustainable methodology for the two-way flow of information and know-how between KM3NeT and the key technology areas. Members of the KM3NeT collaboration with expertise in the fields of optical and acoustic measurements, low power electronics, deep sea operations, communication technologies, computing and data sciences were contacted to state their availability. A Panel consisting of four experts in the areas of optical measurements, acoustic receivers, low power electronics and computing and data sciences, and the work package coordinator was finally established. Although experts in deep sea operations could not make a clear commitment due to the increased load of sea operations at this phase of the experiment, they have eagerly assured their intention to cooperate with the work package coordinator on items involving their field of expertise. The first target of the 5-member Technology and Innovation Panel of KM3NeT was the preparation of exhibition material for the participation of KM3NeT in technology related events which was included in the deliverable D.9.1.

In order to build a network among the industrial sector and KM3NeT and to ensure the flow of information from the technology advancement leaders towards KM3NeT, members of the

Technology and Innovation Panel of KM3NeT and members of the related working groups have participated, presenting KM3NeT, in several Conferences and Workshops with sessions dedicated to technology innovation in the areas of interest to KM3NeT and have given dedicated University seminars. This participation is detailed below:

- International Conference on Technology and Instrumentation in Particle Physics (TIPP'17) (317 participants), Beijing, China, link: http://tipp2017.ihep.ac.cn/ (Invited talk by D. Vivolo)
- International Workshop on Next Generation Nucleon Decay and Neutrino Detectors (NNN17), link: http://nnn2017.iopconfs.org/home (~100 participants) (Invited talk on the KM3NeT/IceCube DOM electronics by C. M. Mollo)
- International Conference on Neutrino and Nuclear Physics (CNNP2017) (~100 participants), link: https://agenda.infn.it/conferenceDisplay.py?confId=12166, Invited talk on "The Digital Optical Module of the KM3NeT project" by E. Leonora
- 14th Pisa Meeting on Advanced Detectors (PM2018), (~360 participants) Elba, Italy, link: https://agenda.infn.it/conferenceDisplay.py?confId=13450 (Invited talk on "KM3NeT: next-generation neutrino telescope in the Mediterranean Sea", by R. Le Breton)
- 35th International Cosmic Ray Conference (ICRC2017), (~700 participants) Korea, link: http://www.icrc2017.org/, Poster on "Reliability studies for KM3NeT electronics: The FIDES method", PoS(ICRC2017)1003 link: https://pos.sissa.it/301/1003/ by D. Real, D. Calvo, S. Colonges, G. Illuminati
- 35th International Cosmic Ray Conference (ICRC2017), (~700 participants) Korea, link: http://www.icrc2017.org/, Poster on "KM3NeT Front-end electronics upgrade: CLBv3 and PBv3", PoS(ICRC2017)1004 link: https://pos.sissa.it/301/1004/ by D. Real, D. Calvo, P. Musico, P. Jansweijer, V. Van Elewyck
- Seminar on White Rabbit on the ETSEE - University of Valencia (an audience of ~50 faculty, postdocs and students)
- Workshop of I.N.F.N. Computing and Network Committee (talk on "Machine Learning in KM3NeT", C. Bozza) (~120 participants)
- 11th Cosmic Ray International Seminar "Entering the Era of Multi-Messenger Astronomy" (CRIS2018), link: http://cris2018.na.infn.it/ (~100 participants) ("The Detection Unit of the KM3NeT: qualification, integration procedures and technical results" by I. Sgura)
- 11th Cosmic Ray International Seminar "Entering the Era of Multi-Messenger Astronomy" (CRIS2018), link: http://cris2018.na.infn.it/ (~100 participants) ("Status and perspectives for small-size photomultipliers", by P. Migliozzi and C. M. Mollo)
- 11th Cosmic Ray International Seminar "Entering the Era of Multi-Messenger Astronomy" (CRIS2018), link: http://cris2018.na.infn.it/ (~100 participants) ("Brand-new optical modules for the KM3NeT neutrino detector", by E. Leonora)
- Machine Learning Summer School, Dortmund, Germany (Participation in Resource-aware Machine Learning Summer School, S. Geißelsöder)

As the handling of "Big Data" is challenging, members of the Technology and Innovation Panel of KM3NeT and members of the related working groups have participated in Conferences and Workshops dedicated to the ASTERICS project supported by the European Commission Framework Program Horizon 2020 (that brings together researchers, scientists, engineers, hardware and software specialists from astronomy, astrophysics and astroparticle physics who have to face common challenges, such as the transfer, processing or storage of large amounts of data. ASTERICS aims to facilitate and accelerate the development of common solutions to these challenges by stimulating collaboration among the different fields/communities):

- Workshop on Big Data in Astroparticle Physics, 2017, Aachen, Germany (S. Geißelsöder)
- 1st ASTERICS-OBELICS International School, LAPP, Annecy, France (T. Gál, Trainer, S. Hallmann) (~80 participants)
- Deep Learning Workshop, Munich, Germany (S. Geißelsöder presenting ASTERICS work in Deep Learning)
- Machine Learning Summer School, Dortmund, Germany (S. Geißelsöder)
- 2nd ASTERICS-OBELICS Workshop, Barcelona, Spain (S. Geißelsöder, B. Spisso) (66 participants)
- Workshop on Big Data in Astroparticle Physics, 2018, Aachen, Germany (U. Katz, S. Geißelsöder)
- 2nd ASTERICS-OBELICS International School, LAPP, Annecy, France (T. Gál, Trainer) (~60 participants)
- ASTERICS European Data Provider Forum and Training Event 2018 ("KM3NeT Computing and Data Management" by K. Graf) (~40 participants)

We will also participate in the "Workshop on Very Large Volume Neutrino Telescopes 2018 (VLVnT)" in October in Dubna, Russia with a presentation of the activities of theTechnology and Innovation Panel.

In addition, during the first 18 months our efforts have been directed mainly towards the second objective, so the members of the panel had the mandate to identify cases where the KM3NeT needs have been the driving force behind industrial innovation and cases in which appropriate modifications have been implemented to existing solutions in order to comply with the requirements set by the experiment. KM3NeT has now entered a phase during which the design of the detector elements is finalized and the methods adopted for testing and for controlling the quality of the different components and the procedures followed are settled. In addition, KM3NeT Detection Units (DUs) have been deployed successfully and data have been recorded and are currently analysed. Therefore, the functionality of these technological solutions developed or modified by KM3NeT is now proven so they are mature to be presented or exposed to relevant technology developers or users. Given the status of the construction and the experience gained, we have put high on our priority list the presentation of technological solutions developed or modified by KM3NeT to industry, Institutions and other stakeholders with potential interest.

The strategy to be followed was discussed among the Panel members during the KM3NeT Collaboration meetings and during Work Package meetings. The members of the panel had to identify within the different working groups items that represented either solutions to technological problems encountered, or appropriate modifications to products provided from the industrial sector in order to meet the requirements necessary to achieve the physics goals of the experiment. Up to now we have selected the following items that can be easily exploited by other parties.

- A connection tool has been developed by C.P.P.M. (Centre de Physique de Particules de Marseille) France, to help a light ROV to perform connection of wet-mateable connectors.

- A multi-PMT testing facility has been developed by I.N.F.N. Napoli (Instituto Nationale di Fisica Nucleare). This DarkBox allows the simultaneous characterization of a large number of PMTs ensuring dark tightness with respect to the external environment, by means of light-tight supports for each PMT.
- A relative acoustic positioning system has been developed by L.N.S. – I.N.F.N. in Catania, Sicily (Laboratori Nazionali del Sud) for an accurate knowledge of the position of the detector elements.
- Machine Learning for information mining and alternative reconstruction.
- Within the framework of Task 9.4. of WP9 work has been carried out towards: 1) increasing the reliability of the White Rabbit Switch, performing the FIDES analysis to the SCB "Switching Core Board" of the White Rabbit Switch and 2) developing a carrier board for KM3NeT (the auxiliary board of the White Rabbit switch) to which also the FIDES analysis has been performed. Prototypes of these boards were developed and subjected to stress tests in order to study, improve, or qualify the reliability of the boards for the experiment lifetime. The quality of the results obtained has attracted the interest of the company "Seven Solutions" which is considering of implementing the modifications in the production of the White Rabbit SCB. This item will be described in detail in the corresponding deliverables of Task 9.4., D.9.3 and D.9.4.

These items are described in Section 3. More items have been identified by the Technology and Innovation Panel of KM3NeT and work on collecting the information needed is currently on going between the Panel members and the corresponding working groups. Exposure and recognition of the technological solutions and innovations of KM3NeT is decisive to achieve the interaction between KM3NeT and the leaders of technological advancements that KM3NeT is aiming for.

3. Description

A description of these items that can be easily exploited by other parties follows:

- Connection tool to help a light ROV to perform connection of wet-mateable connectors.

The development of a cabled submarine infrastructure is needed for the installation of a permanent instrumentation on the seabed such as neutrino telescopes or sea sciences observatories. The installation requires the instruments to be installed first and then to connect them to the infrastructure network linked to the shore. The connection of instruments is done through wet-mateable connectors, electrical, optical or hybrid. A few companies in the world manufacture these connectors and they were developed mainly for military purposes or oil and gas industry using work class ROVs for their work on the seabed. The connection/disconnection force of such connectors requires a minimum of 60kg depending on the connector type and configuration. The use of work class ROV is more expensive and their availability is restricted for science projects. Therefore, the use of a light ROV which is less expensive and with better availability but with limited capabilities, is an interesting alternative. The force of the ROV is limited so it requires a tool to connect the wet-mateable connectors. The KM3NeT infrastructure in France uses a light ROV to perform subsea operations. For this purpose, CPPM has developed a tool to help the ROV for connections.

The specifications for the tool were based on wet-mateable connectors (Nautilus and NRH types) produced by Teledyne ODI and the use of the ROV APACHE provided by COMEX, but could also be extended to other ROVs. The maximum force delivered by the ROV for the connection is 30 kg. The main specifications of the tools are:

- Maximum force applied by the ROV to connect or disconnect: 20kg
- Improve placing, guiding and alignment of the connector

The design of the tool (scheme in figure 1) is based on a pantograph system with a reduction arm to decrease the force applied and to keep an almost linear displacement. The interface between the tool and the connector is the handle, which is modified from its original shape to accommodate the V-shape of the tool. The guides are inclined, so the ROV places the connector on the guide and slightly pushes it; the connector will automatically be centred and placed in the right position in front of the bulkhead for the connection.

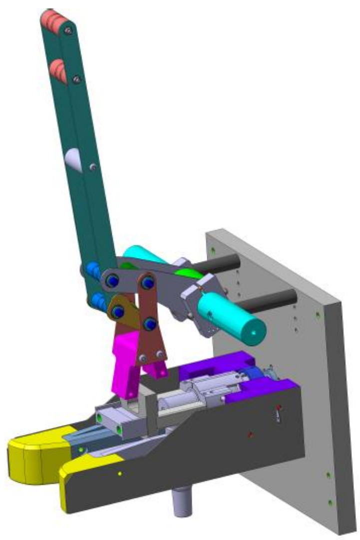

Figure 1: Schematics of the tool

A prototype tool was built and tested first in the lab and then in shallow water with the ROV. Some modifications and improvements were made and finally validated during a shallow water test with the ROV (picture in figure 2).

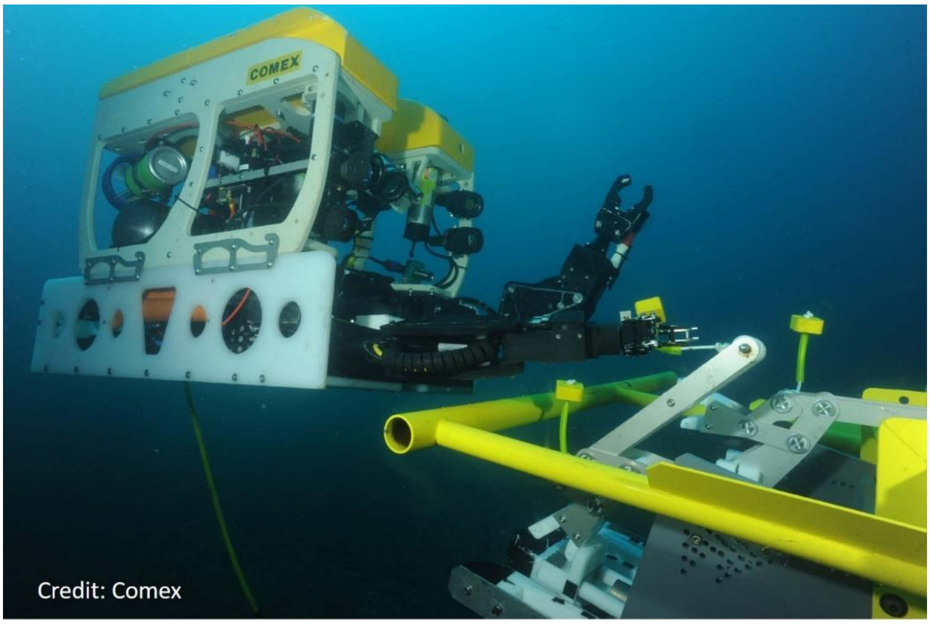

Figure 2: Picture of a connection with the ROV using the tool

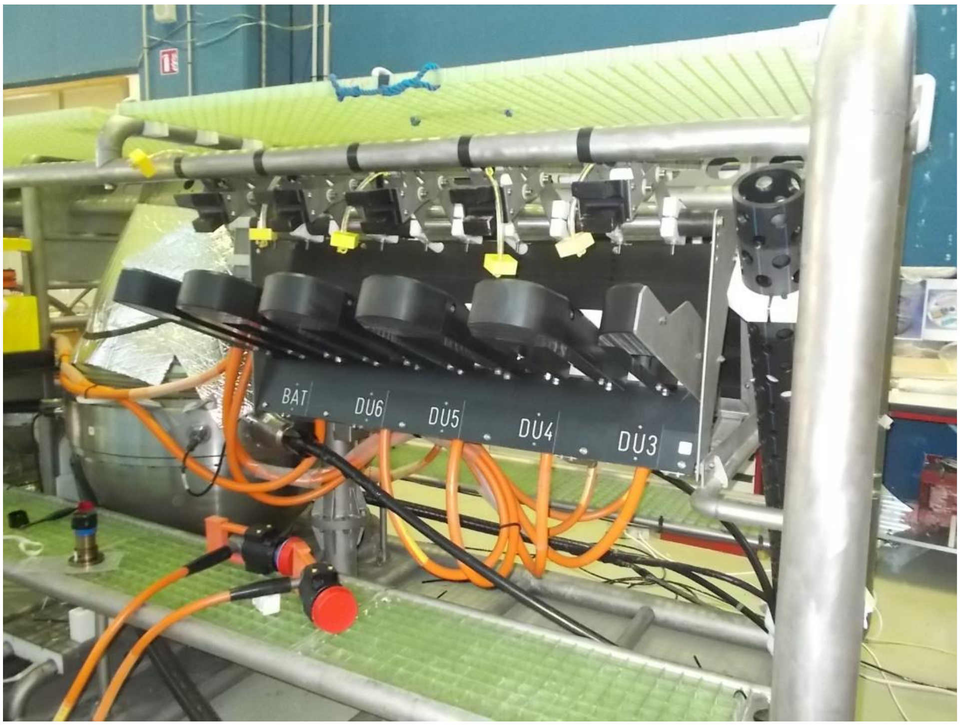

Figure 3: Picture of a set of 5 tools installed on the node 1.

The tool is implemented on the Node 1 of the KM3NeT-Fr infrastructure. The 9 node outputs using wet-mateable connectors to interface DUs, Sea Sciences instruments and the battery are equipped with this tool. Tools are grouped by 5 on one side of the node (picture in figure 3) and by 4 on the other side. The ORCA DUs are connected in series, a set of 4 DUs are linked together in a “4-DU chain”. A tool is installed on the wet-mateable connector of each DU to allow the connection by ROV of the next DU in the chain. It was successfully used few times in real conditions to disconnect plugs and then to connect connectors during the installation of an ORCA DU and a sea science module.

- Multi-PMT testing facility.

The DarkBox consists of a light-tight wooden box and removable trays designed to host PMTs under test (Figure 4). A time-calibrated electrical cabling system was realized to connect PMTs to the DAQ system placed outside the box, maintaining for all PMTs the same time delay from the base to the DAQ. A picosecond accuracy laser and a calibrated optical splitting system are used to distribute single photon signal to all PMTs. Tunable optical attenuators are used to reach the single photon operation. The optical system has a dynamic range of about 20 dB, in case more optical power is needed. Particular attention has been devoted to the edges and the corners, which are usually the most critical regions to guarantee light tightness. Removable trays, loadable with PMTs before the insertion into the DarkBox, allow easy and fast loading and unloading of the photomultipliers, thus optimizing the operation time. During the measurement the box is filled with two trays that can accommodate 31 PMTs each. The photomultipliers are maintained in a vertical position thanks to PVC collars and elastic bands.

Using this setup the photocathode is not in contact with the structure. This is mandatory for PMTs fed with negative voltage at the cathode. Indeed, the imperfect contact with the mechanical structures may produce electric discharges, dramatically increasing the PMT noise [7]. In order to prevent the photomultipliers from falling off, trays have tiny teeth on the lower openings that are able to hold the photomultiplier during loading and unloading. The trays are placed on a flatbed made of PVC with 62 dark cylinders in front of each PMT. The cylinders are used to optically isolate each single PMT.

Figure 4: PMTs in the tray before the test.

Figure 5: The DarkBox inner structure.

A custom tool named Dark Box Manager was developed based on Java that is interfaced with the KM3NeT software tools to read-out PMT data from the CLBs and upload/download recorded parameters into a relational database performing the following operations:

- define an ID for each test;
- create a directory where data and information for each test are stored;
- interface with the KM3NeT database;
- using PROMIS identification code recover from DB the default PMT assembly settings;
- interface with KM3NeT detector control and data acquisition software;
- set proper threshold and HV for each PMT assembly;
- set test run numbers (to identify different measurement phases);
- start and stop run;
- record raw PMT data;
- create ROOT files for data analysis;
- analyze ROOT files to measure the required PMT assembly characteristics;
- Produce XML and PDF files with the results to be uploaded into the database.

The characterization of each PMT assembly consists of three main phases:

1. Determination of the operational HV (high voltage tuning procedure);
2. Measurement of dark counts;
3. Measurement of PMT time characteristics and of spurious pulses.

This procedure takes about 9 hours to be completed. The largest fraction of this time is devoted to the darkening, i.e. the PMTs, with power ON, are left in the dark to recover from the light exposure.

HZC Photonics has expressed interest in adopting the multi-PMT testing facility.

➢ Relative acoustic positioning system

During the deployment phase, the absolute positioning of the mechanical structures of the detector on the seafloor KM3NeT is provided using commercial instrumentation, that permits the deployment of structures with a precision of about 2m on the seafloor. This is important for a safe deployment procedure. To reach the goal of accurate positioning (about 10 cm) the KM3NeT detector is equipped with a relative acoustic positioning system (RAPS). The RAPS is formed by a Long Baseline (LBL) of acoustic transmitters (beacons) and receivers (hydrophones) placed on the seafloor in fixed positions and acoustic sensors (piezo in the DOM) mounted along the DU to measure and monitor the displacement of the DUs under the effect of sea-currents. Additional elements are the sound velocimeters placed along the water columns enclosed by the detector.

Three major aspects make this system innovative with respect to the commercial systems:

1. All the elements of the system are synchronized with the detector master clock, that dispatches the on-shore GPS time and permits in-situ data time-stamp with a precision and accuracy of about 1 ns. This feature, having first characterized on-shore all the electronics

latencies of the RAPS elements, enables the system to act as an innovative and precise Underwater GPS system, not affected by any relevant uncertainty of electronics delays and water properties measurement.

2. All the acoustic receivers are wideband (few tens Hz to 70 kHz) and come with a digital front-end to sample the pressure data with high accuracy, whose clock is the detector master clock. All data are transmitted to shore for real-time analysis. This permits a constant monitoring of the sea environment since it does not only record the beacons signals but the recording extends to a large variety of anthropic, biological and geophysical sources.
3. The emitters signal can be set from shore (waveform, amplitude, repetition rate), allowing optimization of the beacon signal to improve the detection and to reduce the acoustic noise pollution.

Prototypes of the first KM3NeT DUs deployed have already demonstrated the wide range of capabilities of the acoustic system. First data on positioning have been analyzed and an uncertainty of 50 cm has been obtained although the full LBL system is not yet deployed. Biological signals and acoustic noise in situ have been recorded and can be analyzed for the EU MSFD Directive. Moreover, beacon signals can be set to test and optimize in situ (in real time) acoustic communication underwater and from seafloor to the surface.

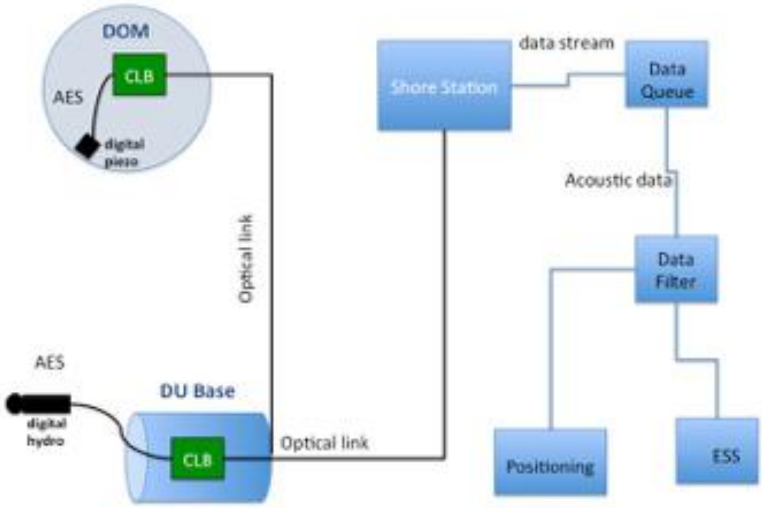

Figure 6: Data acquisition chain of the proposed Digital Acoustic Receiver array, both for the hydrophone and the internal piezo-sensor.

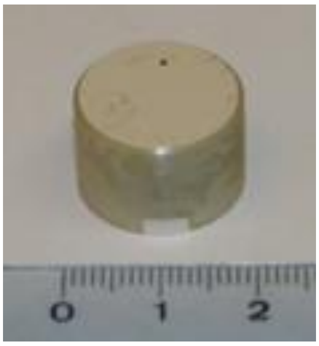

Figure 7**:** A bare piezo ceramic.

Figure 8**:** The integrated piezo and electronics before insertion into the aluminum tube.

Figure 9**:** Fully assembled prototypes of the piezo sensors with digital readout.

Figure 10**:** an autonomous acoustic emitter.

➢ Machine Learning

Mining information in very big data sets, possibly of petabyte (PB) scale, is an inherent task for the KM3NeT Collaboration. Detecting faint signals, usually buried under an overwhelming amount of background events, requires careful statistical treatment. The approach followed in KM3NeT at the beginning has always been very pragmatic, exploiting features that are hand-crafted or provided by traditional reconstruction algorithms and shallow learning techniques when suitable for the goal. Correlation of single neutrino events to predefined sources and event shape analysis (track/shower discrimination to differentiate between modes of nu) are successfully carried out through random forests using open-source tools such as ROOT TMVA. Boosted decision trees have proven successful in discriminating interactions occurring in the detector fiducial volume from particles entering from outside and in event shape classification. Multi-layer perceptrons can be used to estimate neutrino energies. Recently, interest is shifting and growing around Deep Learning applied to raw data with minimal filtering and preprocessing (triggering) because of several reasons:

1. reduced dependency on human guesswork in feature identification;
2. ability to identify unforeseen patterns in data;
3. shifting the set of skills required for analysis away from Computer Science, allowing physicists to focus better on their primary target, which is Physics analysis.

Event shape classification is a natural target for Deep Learning. More ambitious goals, aiming at neutrino energy estimation and direction fitting have been set, and preliminary results are encouraging. The sequence of hits in KM3NeT photomultipliers constitutes a 6D dataset, involving three spatial coordinates per hit, two angular coordinates (the direction of the photomultiplier firing) and a time coordinate. This is out of reach for the currently available machine learning frameworks, as they have mostly been optimized for RGB images and videoclips, i.e. three-channel 2D sequences of images (3+1D, 4D). As a consequence, using currently available machine learning software implies a reduction in the number of dimensions by summing over neglected dimensions (typically one goes from 6D to 3+1D or 4D). Even so, the full treatment of these problems is challenging because of:

1) the very fine time granularity (1 ns whereas the total duration spans 10^3-10^4ns);
2) shape distortion of the detector due to water currents dragging the detection units;
3) possibly dead photomultipliers.

With such high dimensionality, the training datasets cannot span the full space of input parameters. Therefore, the Deep Learning approach must model also the ability to abstract and generalize input patterns that appear only one or few times, while avoiding overfitting. Although more powerful computing hardware may help, there is no doubt that software improvements on the network structure and logic can greatly improve the performance.

KM3NeT is now among the pioneers in this field of multidimensional movie reconstruction. Partnerships and other forms of cooperation with software and hardware producers could easily turn out to be beneficial for quick advance of knowledge.

4. Next steps

The objective of this WP is to set up a framework to:

i. observe the technological advancements in the areas of interest to KM3NeT
ii. register and communicate technological choices, innovative solutions and methods that have been developed by KM3NeT or existing ones that were adapted appropriately to fit the needs of KM3NeT, which could be of potential interest to the industrial sector

The immediate next step is putting this information – in a suitable form - in the KM3NeT website so that it can be publicly available. Note that, concerning the posters prepared for the participation of KM3NeT in technology related events, it was our intention to avoid including detailed descriptions and technical information as the technological solutions presented cover several unrelated areas. For this reason, although we consider the result (posters and presentation) very satisfactory, we decided to prepare additional, more specialized material in the form of leaflets, each of them addressing a specific item separately.