KM3NeT INFRADEV – H2020 – 739560

Final Report on the Panel activities

KM3NeT – INFRADEV GA DELIVERABLE: D9.6

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Abstract

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

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I. DELIVERY SLIP

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II. DOCUMENT LOG

Issue	Date	Comment	Author/Partner
1	10/10/2020	1st version circulated	NCSR-D
1	8/12/2020	2nd version circulated to reviewers	NCSR-D
2	22/12/2020	3rd version including comments from reviewer	NCSR-D
3	29/12/2020	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
- HALT: Highly Accelerated Life Tests
- HASS: Highly Accelerated Stress Screen

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, junction boxes, calibration units and the seabed network. Each DU comprises 18 optical modules (DOMs), a base module and an anchor and each optical module contains 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. 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).

VII. EXECUTIVE SUMMARY

The main goal of WP9 is twofold: 1. to establish methodologies for exposing, to interested parties in the industrial sector, the technological choices and innovative solutions that have been developed or adapted by KM3NeT; and 2. to follow the technological advances in key areas of interest to KM3NeT.
In order to achieve these goals, 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.
The first task of the Panel was 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. A description of the items that have been identified by the Members of the Panel as items easily exploited by other parties has been included in D9.2, which summarizes the activities of the Panel during the first 18 months of the project. During the second part of the project, the Panel concentrated on developing supporting dissemination material to be used for participating in technology transfer events and exhibitions; and on following the technological advancements in the fields of interest to KM3NeT. The material developed has been used for the participation of KM3NeT in a technology exhibition as reported in D9.7 and is available to the KM3NeT Collaboration to support the participation in future technology and innovation events. This document focuses on the activities of the Panel during the second half of the project.

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 (Prof. C.Bozza, Dr. C.M.Mollo, D.Real, Dr. R.Lahmann) 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 collected from the members of the panel was included in D9.2 which reports the panel activities during the first half of the project. For the second half of the project, the panel focused on ensuring that the links of the KM3NeT Collaboration with industry are strengthened and on developing relevant leaflets addressing specific technological areas of interest as well as supporting material for the participation of KM3NeT in technology and innovation events. The exhibition material has been discussed in detail in D9.7. of WP9.

2. Presentation of KM3NeT technology

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 parties in industry
- Exploitation of KM3NeT developed solutions for specific problems, including environmental related issues.

In particular, Task 9.1 focuses on the observation of technological advancements. The activities of the Technology and Innovation Panel during the first half of the project are described in the deliverable D.9.2.

2.1. Presentations

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 and innovation in the areas of interest to KM3NeT**.** This participation is detailed below:

International Workshop on Very Large Volume Neutrino Telescopes (VLVnT 2018) (~150 participants), Dubna, Russia, link: https://vlvnt2018.jinr.ru/

- Invited talk on "KM3NeT Knowledge and Technology Transfer" by E.Tzamariudaki, K. Pikounis
- Talk on "The new CLBv4 for the KM3NeT neutrino telescope" by D. Calvo, D. Real
- Talk on "The KM3NeT Digital Optical Module and Detection Unit" by R. Bruijn
- Talk on the "Nanobeacon: A time calibration device for KM3NeT" by D. Calvo
- Talk on "The Software Defined Networks in KM3NeT" by T. Chiarusi
- Talk on the "Data Acquisition and Trigger in KM3NeT" by R. Bruijn
- Talk on the "KM3NeT Acquisition Control" by C. Bozza
- Talk on "Machine Learning in KM3NeT" by C. De Sio
- Talk on "The Positioning System of KM3NeT" by G. Riccobene

15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19) (112 participants), Siena, Italy, link: https://www.bo.infn.it/sminiato/siena19.html

- Talk on the "Reliability studies for the Switching Core Board of the White Rabbit Switch: FIDES and Highly Accelerated Life Test" by P. Musico *et al.*
- Talk on the "KM3NeT electronics acquisition: the new version of the Central Logic Board and its related Power Board" by F. Versari *et al.*

- International Workshop on Marine Sensors and Systems (MARSS 2019), Granada, Spain, link: http://jlloret.webs.upv.es/marss2019/ (talk on "The simulation of the behaviour of the acoustic positioning system in the KM3NeT underwater neutrino telescope: the estimated accuracy and performances" by C. Guidi
- 6th International Electronic Conference on Sensors and Applications (ESCA-6) (84 contributions) link: https://ecsa-6.sciforum.net/ (talk on "Mechanical Line Fit Model to Monitor the Position of KM3NeT Optical Modules from the Acoustic and Compass/Accelerometer Sensor System Data" by D. Tortosa

36th International Cosmic Ray Conference (ICRC 2019) (815 participants), Madison, Wisconsin, USA, link: https://www.icrc2019.org/

- Poster on the "KM3NeT Data Acquisition and Trigger System" by R. Bruijn, T. Chiarusi
- Poster on the "The Automatic Installation And Configuration Procedure for the data acquisition system of KM3NeT" by R. Bruijn, E. Giorgio, T. Chiarusi
- Poster on "The Control Unit of KM3NeT detectors" by C. Bozza, E. Giorgio, T. Chiarusi
- Poster on "Machine Learning for KM3NeT/ORCA" by M. Moser, S. Hallmann, S. Reck, T. Eberl

In addition, KM3NeT technology and the links to environmental research have been presented in international conferences, thus emphasizing interdisciplinary collaborations and perspectives.

- International Workshop on Very Large Volume Neutrino Telescopes (VLVnT 2018) (~150 participants), Dubna, Russia, link: https://vlvnt2018.jinr.ru/ (talk on "The Italian Site for KM3NeT ARCA" by G. Riccobene)
- The 48th International Congress and Exhibition on Noise Control Engineering (INTER NOISE 2019), Madrid, Spain,

link: http://www.sea-acustica.es/fileadmin/INTERNOISE_2019/Enter.htm (talk on the "Underwater Acoustic Positioning System for the monitoring of KM3NeT Optical Modules" by D. Tortosa *et al.*)

Members of the Technology and Innovation Panel of KM3NeT and members of the related working groups have also participated in Conferences and Workshops dedicated to the ASTERICS project supported by the European Commission Framework Program Horizon 2020. ASTERICS addressed the challenge of "Big Data" by bringing together researchers, scientists, engineers, hardware and software specialists from astronomy, astrophysics and astroparticle physics, aiming to stimulate the collaboration among the different fields/communities in order to foster the development of common solutions.

- The New Era of Multi-Messenger Astrophysics International Conference (152 participants), link: http://multi-messenger.asterics2020.eu/ ("pLISA: a parallel Library for Identification and Study of Astroparticles and its application to KM3NeT" by C. Bozza, C. De Sio, R. Coniglione)

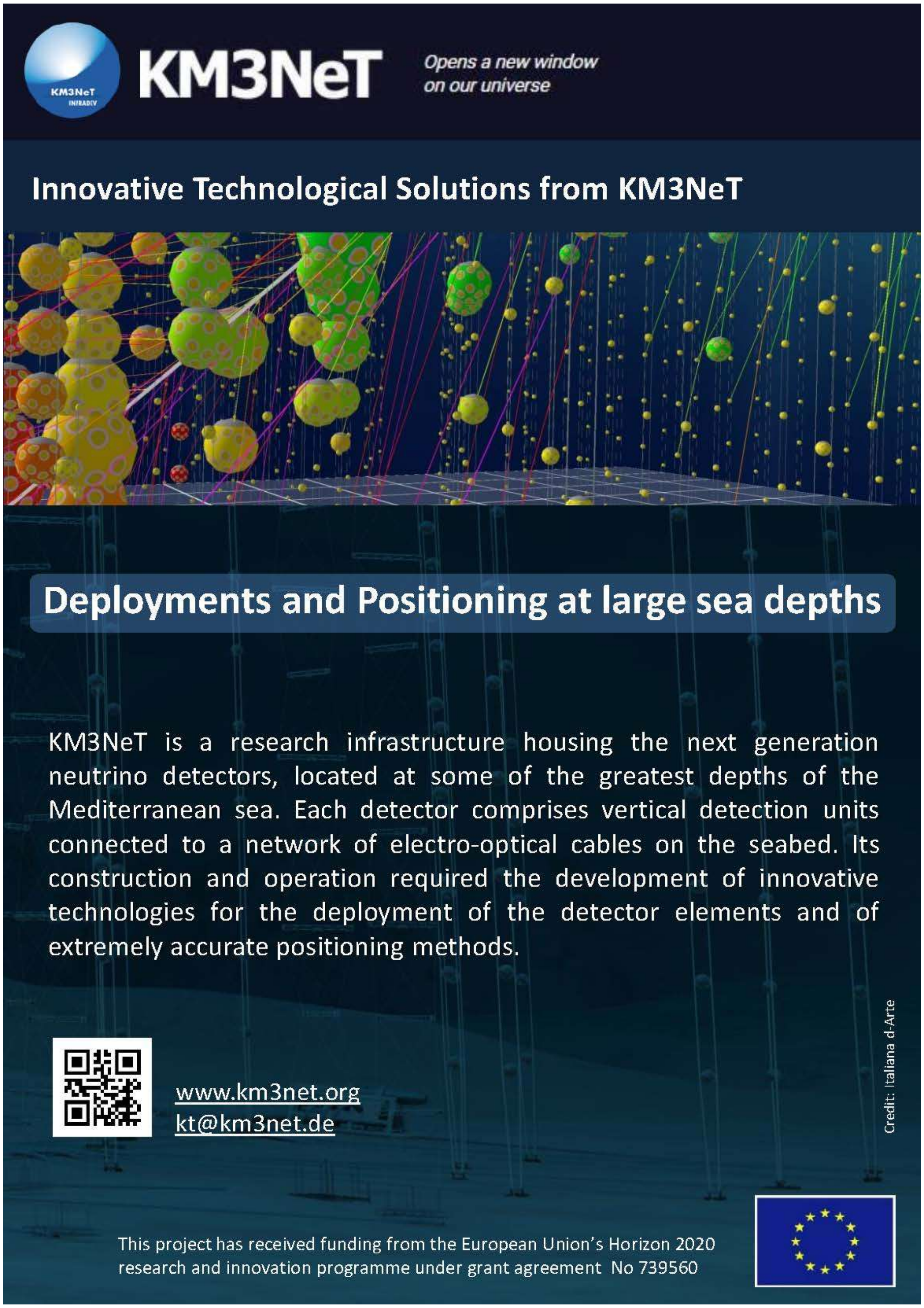
During the first half of the project, the members of the panel had the mandate to identify cases where the KM3NeT needs have been the driving force behind industrial innovation and cases in which appropriate modifications have been implemented to existing solutions in order to comply with the requirements set by the experiment. The first KM3NeT detections units (DUs) have been equipped with the innovative digital optical modules (DOMs), have been deployed to both the Italian and the French site and have operated successfully, leading to physics results which have been presented to several conferences. KM3NeT has now entered a phase during which the construction is progressing (there exist now several integration sites for KM3NeT components), the functionality of the technological solutions developed or modified by KM3NeT is proven and the data delivered by the first operating DUs have been used to validate the detector performance.

The members of the panel have identified 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. Selected items that can be easily exploited by other parties have been described in D9.2. The description of a new tool as well as updated information are included in this document in Section 3.

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. During the second half of the project, the panel focused on strengthening the existing links of the KM3NeT Collaboration with industry and on developing leaflets/brochures addressing specific technological areas of interest as well as supporting material for the participation of KM3NeT in technology and innovation events. Participation of KM3NeT in technology events can increase the KM3NeT visibility and help identify companies and Institutions with interest in potential synergies. Four brochures (also in the form of leaflets with A5 format – double sided) have been prepared by E. Tzamariudaki and G. Androulakis with the help of the members of the panel, for the exposure and promotion of the technological achievements and solutions provided by KM3NeT. In the following, the brochures are included.

2.2. Brochures

2.2.1. Brochure on the KM3NeT deployment and positioning procedure



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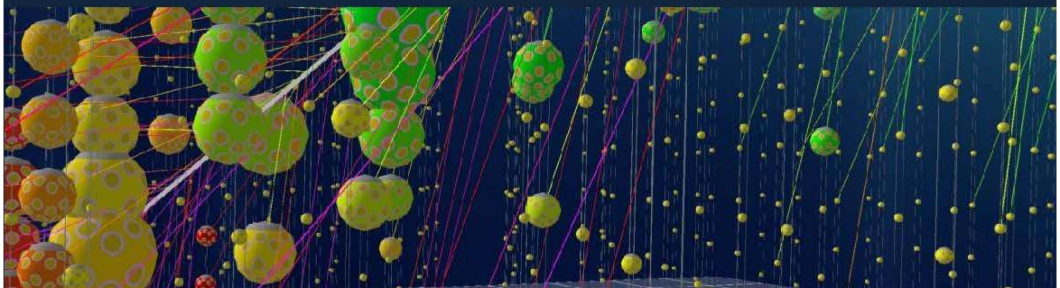
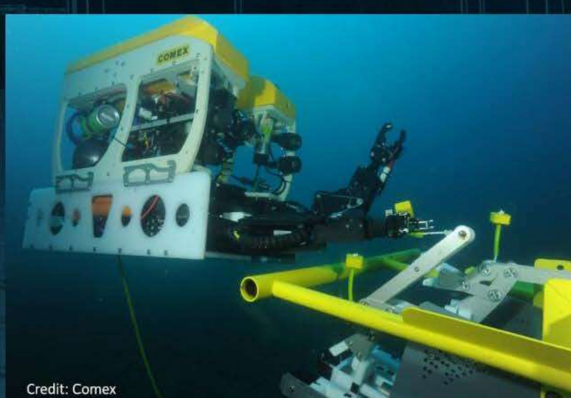


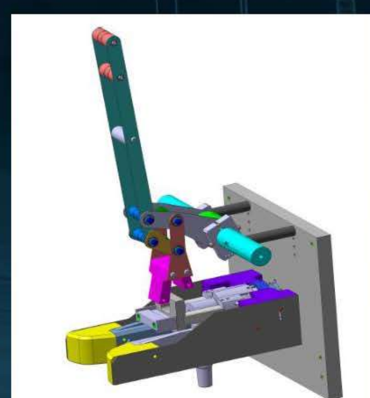
Tool for (dis-)connecting wet-mateable connectors with lightweight ROVs

The detection units are connected to the seabed network via electro-optical wet-mateable connectors. These typically require at least 60kg of force for (dis)connection, which can only be applied by a heavy duty ROV.

KM3NeT sea operations in France use a lightweight ROV, which is less expensive and has better availability. For this purpose CPPM (Centre de Physique des Particules de Marseille) developed a tool to connect wet-mateable connectors using a lightweight ROV. This tool decreases the maximum force necessary for the ROV to deliver to less than 30 kg.



Credit: Comex



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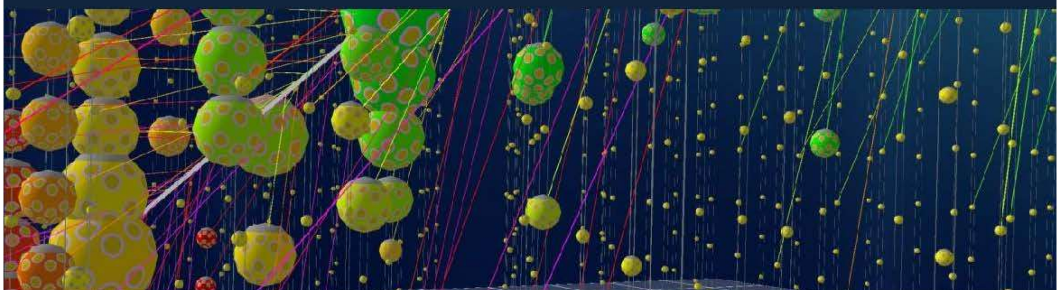
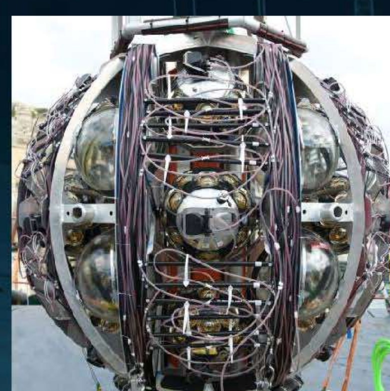


The LOM

For a fast and safe deployment, NIOZ (Royal Netherlands Institute for Sea Research) developed a spherical launching frame, the LOM. Each KM3NeT detection element is coiled like a string around the LOM in which the optical modules slot into dedicated cavities.

After deploying the LOM and connecting to the seabed network, the unfurling of the string is triggered. The LOM then starts to rise to the surface; while rotating it releases the optical modules and finally the empty LOM floats to the surface and is recovered.



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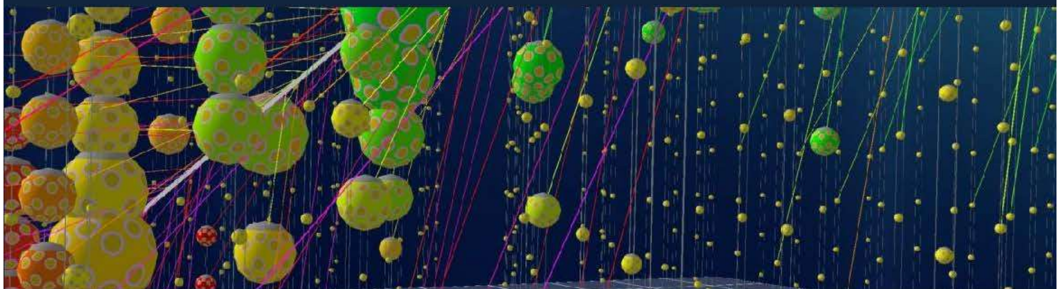
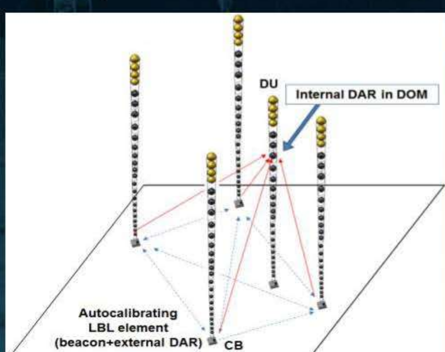
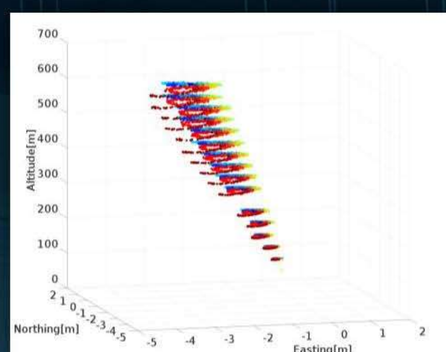


Precision in-water positioning

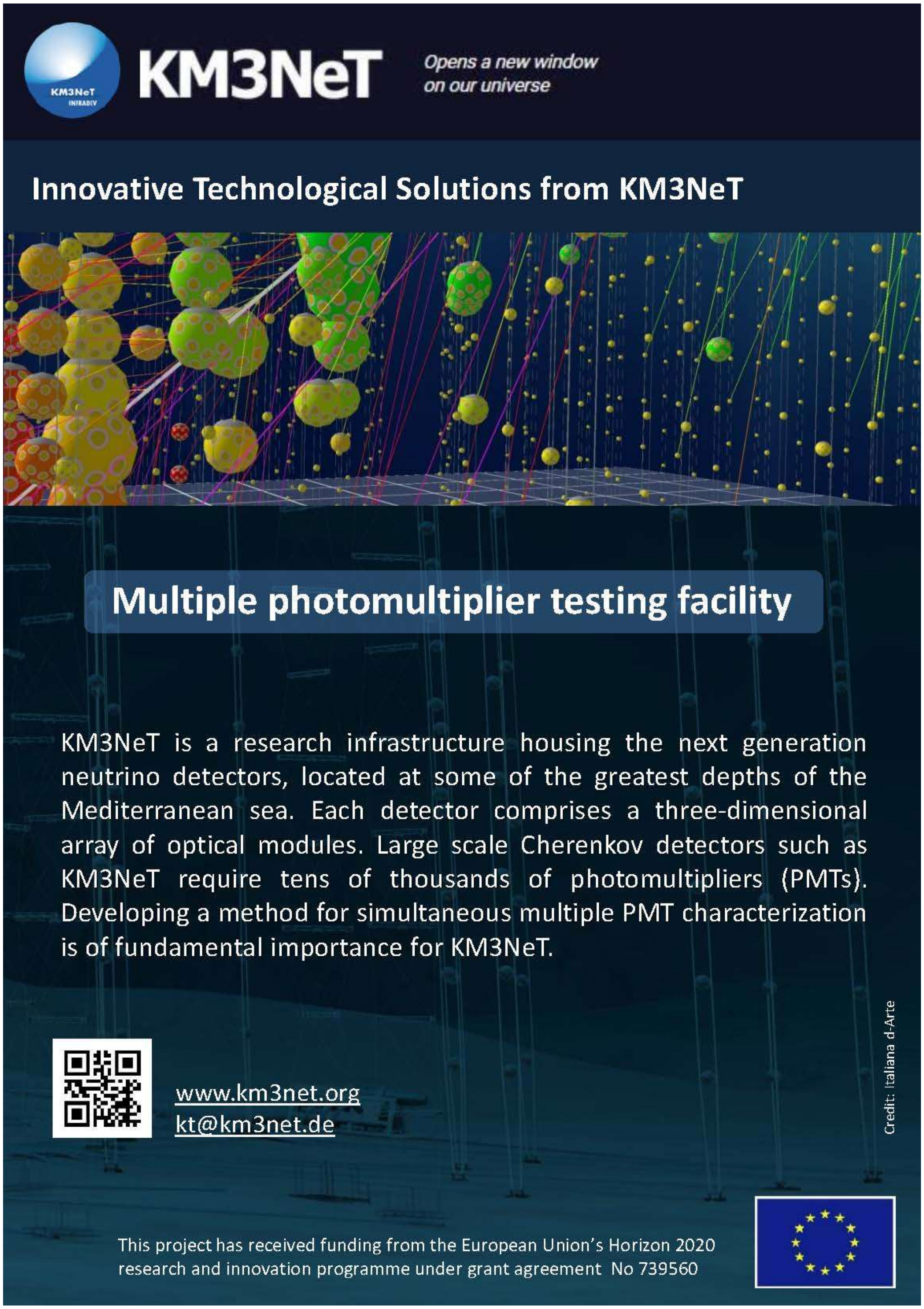
During the deployment phase, the absolute positioning of the mechanical structures on the seafloor is provided by commercial instrumentation that allows a precision of about 0.5m to 2m depending on the deployment site.

For the needs of the experiment, INFN-LNS (Laboratori Nazionali del Sud) developed a precise relative acoustic positioning system (RAPS) for the floating optical modules along the detection units (DUs). This is achieved by a Long Baseline (LBL) of acoustic transmitters (beacons) and receivers (hydrophones) placed on the seafloor in fixed positions and acoustic sensors mounted along the DUs, to monitor the movements of the structures under the effect of sea-currents. This method results in position accuracy of ~10 cm.





2.2.2. Brochure on the KM3NeT multiple photomultiplier testing facility



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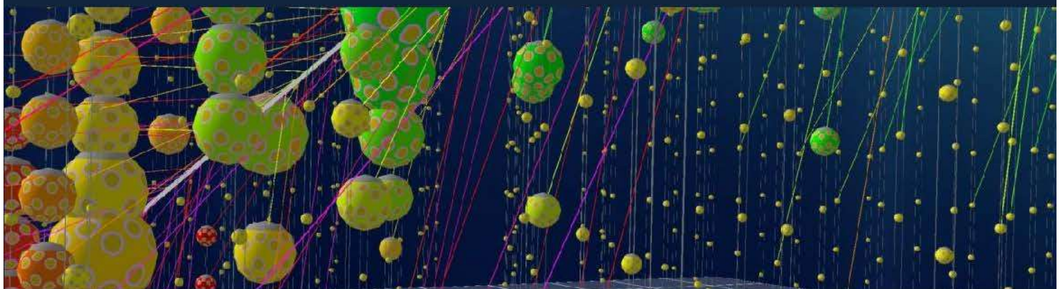

The DarkBox

A "DarkBox" system has been developed which is capable of measuring the characteristics of 62 PMTs simultaneously twice a day. This is crucial for experiments demanding large numbers of PMTs.

The DarkBox design allows easy, fast and safe loading and unloading of the PMTs, thus optimizing the operation time. The PMTs are maintained in a vertical position using PVC collars and elastic bands. Darkening is reinforced by means of light-tight supports for each PMT.

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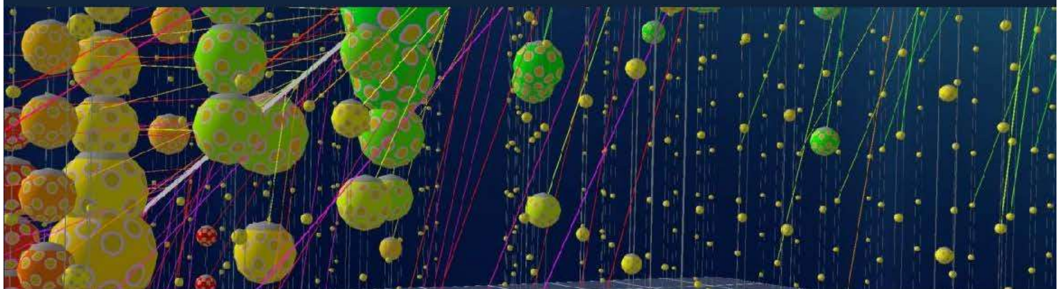
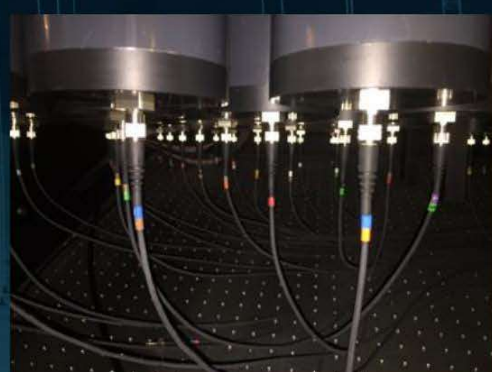


Optical System

A time-calibrated electrical cabling system was realized to connect PMTs to the DAQ system placed outside the box, maintaining for all PMTs an equal time delay from the base to the DAQ. A picosecond accuracy laser and a calibrated optical 1x70 splitter are used to distribute single photon signal to all PMTs. Tunable optical attenuators are used to enforce the single photon condition.



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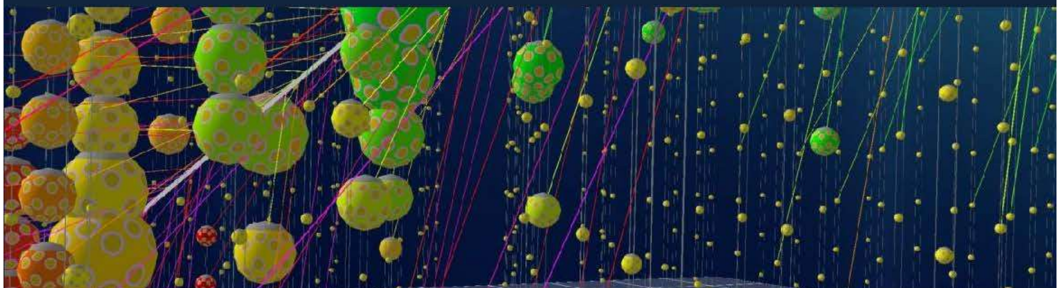


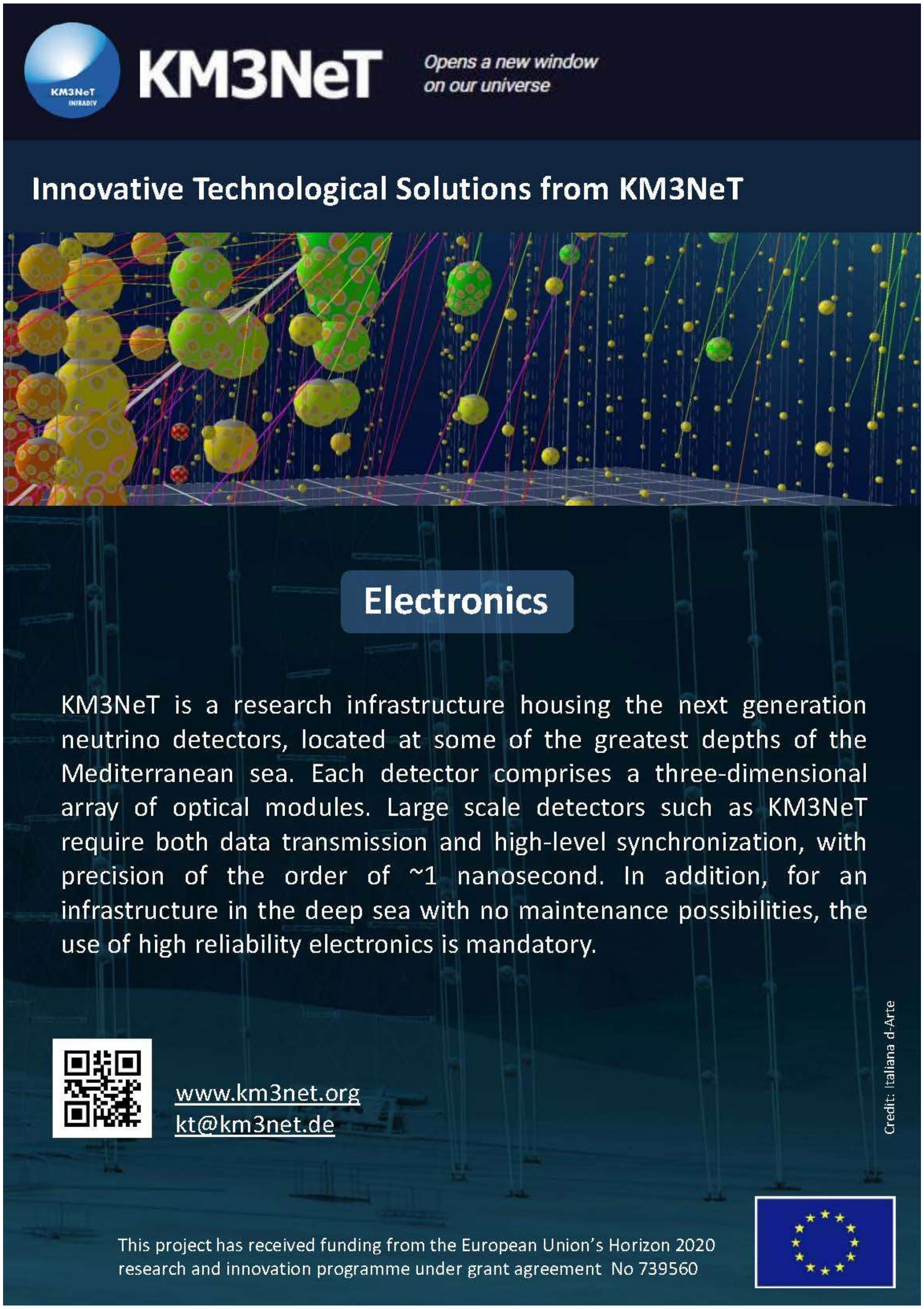
Multi-PMT testing facility

The "DarkBox" is used to measure the PMT dark rates and timing characteristics such as transit time and transit time spread, equalize their gain and determine spurious pulses. A complete calibration takes about 10 hours of which 9 hours are spent for PMT conditioning in darkness. 7000 3-inch PMTs have already been tested at Naples using the "DarkBox".

The "DarkBox" apparatus and the associated calibration procedure is extremely flexible and can be adapted to other PMT types or data acquisition electronics with minimal changes.

The "DarkBox" system has been developed by INFN (Instituto Nationale di Fisica Nucleare) - Napoli.

2.2.3. Brochure on the KM3NeT electronics



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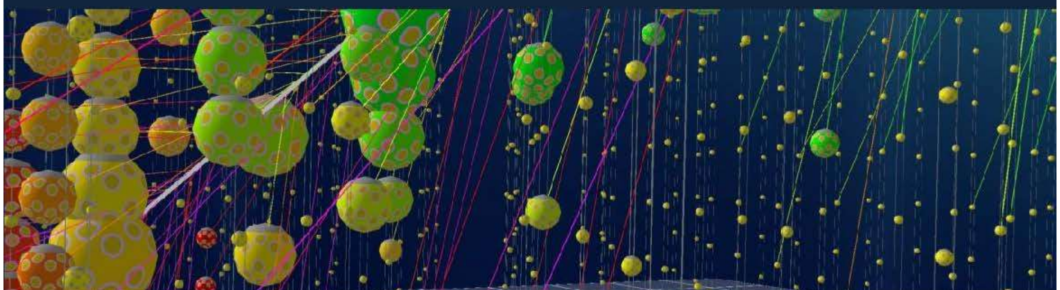

The Electronics Acquisition Boards

The Central Logic Board (CLB) contains a Field Programmable Gate Array (FPGA) whose cores capture the PMT signals. The PMT base board generates and adjusts the High Voltage (HV) supply of the PMTs and converts the analog PMT signals to Low Voltage Differential Signaling (LVDS). Signal Collection Boards (SCBs) are the interface between the CLB with the PMTs allowing for Slow Control and DAQ signal transfer. The light detected by a PMT is converted into an electrical pulse and when a predetermined threshold is surpassed, the PMT base board triggers its LVDS output. The time of the first threshold surpassing and the Time over Threshold (ToT) are measured by the Time to Digital Converters (TDCs) implemented in the CLB. A Power Board (PB) provides all the voltages needed by the Acquisition Electronics.

Development of CLB, SCB, PB: IFIC Valencia, INFN Genova, NCSR Demokritos Greece, NINKEF Netherlands

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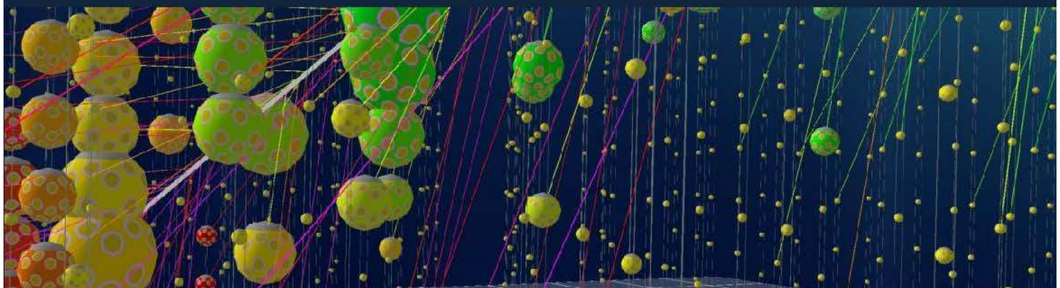
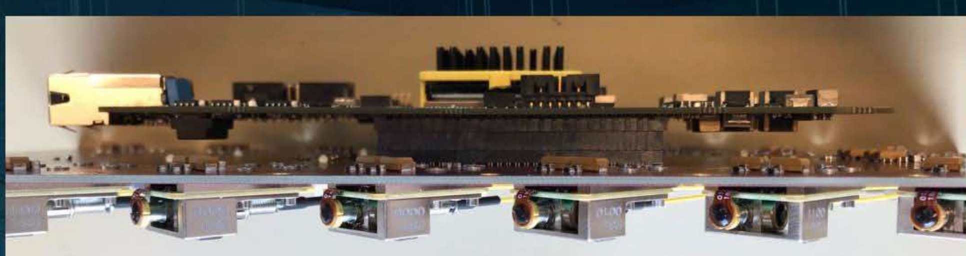


The "Wet White Rabbit Switch" (WWRS)

The White Rabbit (WR) is a fully deterministic Ethernet-based communication protocol which provides both data transmission and accurate timing. The WR technology allows for a synchronization of the clocks of all Central Logic Boards (CLBs) in the telescope at nanosecond precision. KM3NeT already uses the WR Switches at the on-shore DAQ facilities; in addition the so-called WWRS is due to be implemented by installing WR Switches in the base modules of the Detection Units.



Developed at IFIC (Instituto de Física Corpuscular), Valencia & Nikhef, Netherlands

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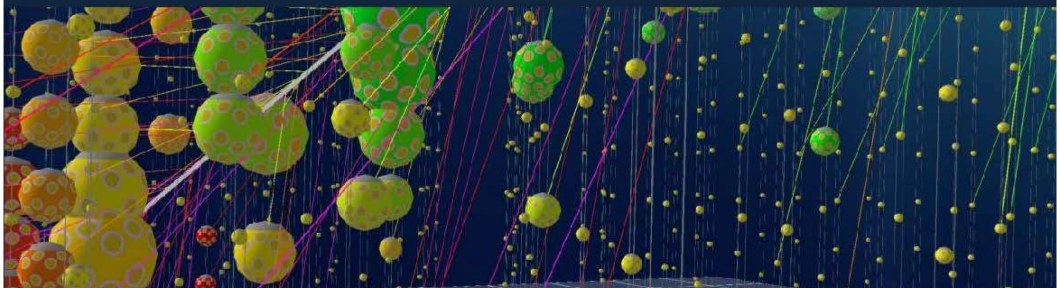
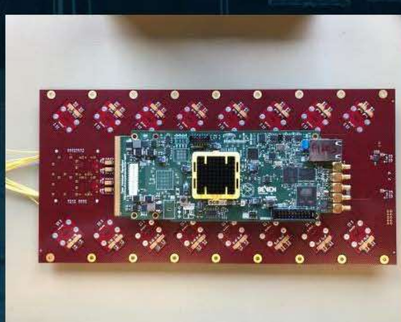
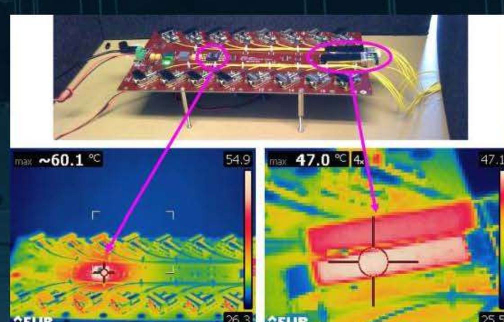


Qualification of the Electronic Boards

For the qualification of the electronics the FIDES method has been used to study and optimize the reliability of the hardware. In addition, the HALT (Highly Accelerated Life Test) methodology has been employed to improve the reliability of the White Rabbit Switch configuration. Stresses beyond the specified operating limits have been applied in order to identify weak points in the design at an early stage and take the appropriate corrective actions. Long term reliability is of extreme importance for KM3NeT as the detectors will operate at a depth of 2500 / 3500 meters, with no maintenance possibilities.





Developed at IFIC (Instituto de Física Corpuscular), Valencia & APC (Centre de Physique des Particules de Marseille) France

2.2.4. Brochure on the KM3NeT computing and software

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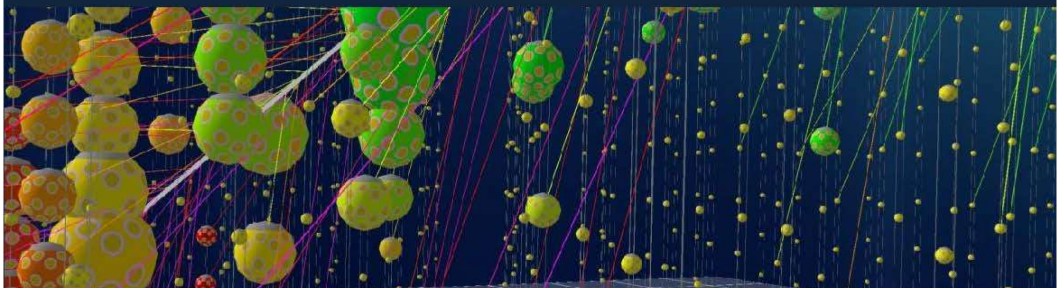

Lightweight Web server library

KM3NeT uses in-house made Web server libraries to simplify the development of Graphical User Interfaces for the Detector and Acquisition Control system (Control Unit) and for the central Data Base Web Application Server.

The application program does not suffer from typical constraints posed by hosting in a Web server process. The HTTP(S) interface is a thin library (36 KiB) that can be incorporated also into existing applications. Overriding one virtual method is enough to implement the Web interface. While the library (developed at the University of Salerno, Italy) is feature-rich, the simplicity of code and the lack-by-design of dangerous functions (e.g. page upload) reduces the attack surface and simplifies secure application development.

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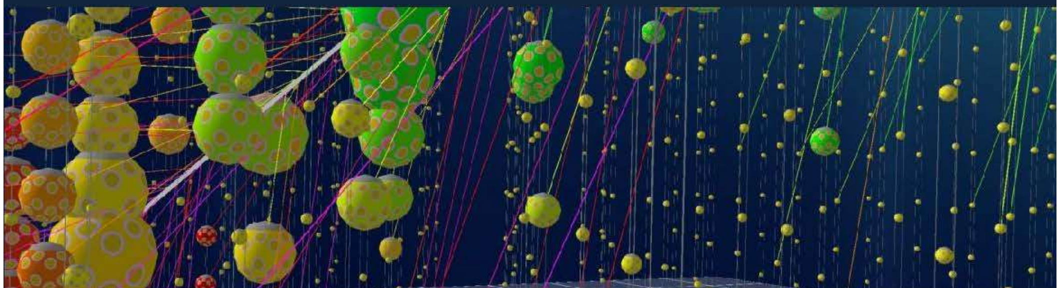
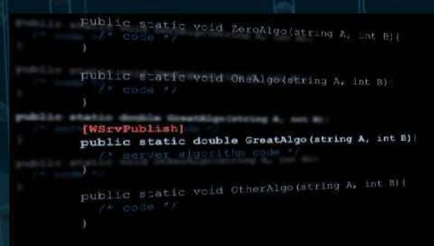


Library for Remote Procedure Call over HTTP

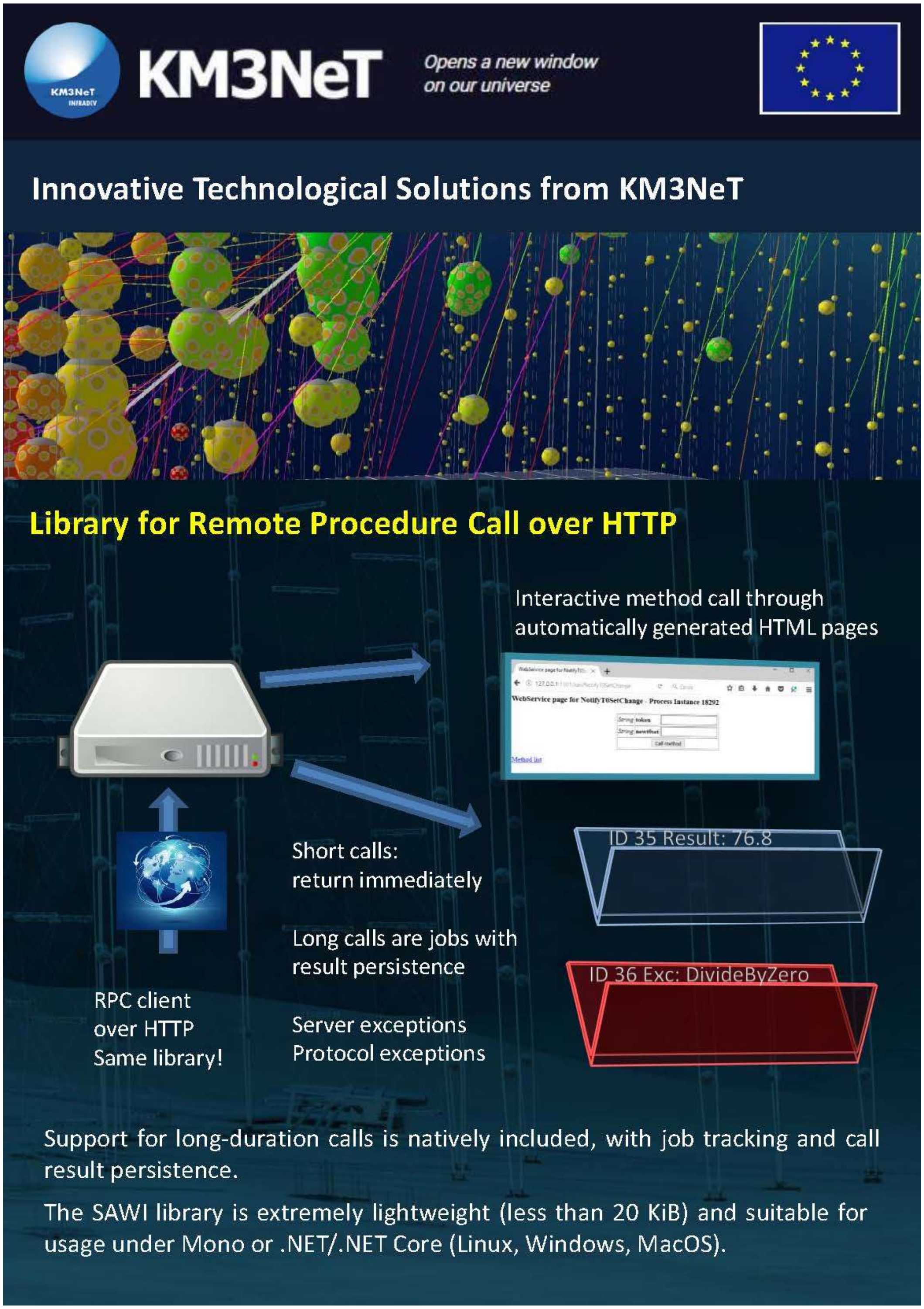
SAWI: Server Application with Web Interface

The software that controls detector operation and data acquisition in KM3NeT (Control Unit) runs as separate processes possibly hosted on different machines and interconnected by a remote procedure call network protocol. Given the availability of in-house Web access instead of using a different messaging protocol, KM3NeT developed its own remote procedure call technique, named “Server Application with Web Interface” (SAWI) that uses HTTP(S) as transport protocol.

The SAWI has been developed at the University of Salerno, Italy.



A developer who wants to incorporate SAWI as a library is only required to tag methods to be made publicly available for access through HTTP(S) with a specific attribute. A virtual directory allows browsing the set of published methods and calling them, interactively as well as programmatically.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Innovative Technological Solutions from KM3NeT
Library for Remote Procedure Call over HTTP
Interactive method call through
automatically generated HTML pages
ID 35 Result: 76.8
Short calls:
return immediately
Long calls are jobs with
result persistence
ID 36 Exc: DivideByZero
RPC client
over HTTP
Same library!
Server exceptions
Protocol exceptions
Support for long-duration calls is natively included, with job tracking and call result persistence.
The SAWI library is extremely lightweight (less than 20 KiB) and suitable for usage under Mono or .NET/.NET Core (Linux, Windows, MacOS).

3. Description

As already mentioned in Section 2, the members of the panel have identified within the different working groups items that represent 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. A selection has been made of items of potential interest to other parties and which can easily be exploited. These are described in D9.2. In addition, within the framework of Task 9.4. of WP9 the reliability of the White Rabbit Switch has been significantly increased, performing the FIDES analysis (a reliability analysis) to the SCB “Switching Core Board” of the White Rabbit Switch and a carrier board has been developed for KM3NeT (the auxiliary board of the White Rabbit switch) to which also the FIDES analysis has been performed. These have been described in detail in D9.3 and D9.4. During the second half of the project, the construction of KM3NeT has advanced, both ARCA and ORCA have collected data, the calibration procedures have been verified and physics analyses have been carried out using these data. The capabilities, competency and effectiveness of the KM3NeT technology have therefore further been tested.

- As an example, the relative acoustic positioning system developed and used by KM3NeT has delivered excellent results:

The relative acoustic positioning system (RAPS) has been described in D9.2. KM3NeT aims for reconstructing neutrino events with an unprecedented resolution. In order to achieve this, accurate positioning (about 10 cm) of all the digital optical modules (DOMs) of KM3NeT is required. The custom RAPS of KM3NeT has been developed by L.N.S. – I.N.F.N. in Catania, Sicily (Laboratori Nazionali del Sud). It is formed of an auto-calibrating Long Baseline (LBL) of acoustic emitters (beacons) and receivers (hydrophones) placed on the seafloor in pre-defined positions and acoustic sensors (piezo in the DOM) mounted in each DOM of the detection unit (DU). The piezo element in the DOM was designed and manufactured by KM3NeT. The KM3NeT RAPS allows measuring and monitoring of the displacement of the DUs under the effect of sea-currents via Time of flight measurements of acoustic signals, multi-lateration and fit. A mooring line, equipped with sound velocimeters and current meters is placed close to the detector footprint, to monitor in real-time acoustic properties of the water columns enclosed by the detector to allow accurate range calculation. Three major aspects (described in D9.2) make this system innovative with respect to the commercial systems.

During the second half of the project, the RAPS provided excellent results as it was put in operation both in ARCA and ORCA. Despite the limited number of LBL elements still present in both sites, the system showed already optimal performances, with estimated uncertainty of few tens cm. Positions of acoustic elements are therefore further optimized using a fitting procedure based on a global fit and mechanical model of the DU that allows recovery of positions of DOMs for which the acoustic element is not working. Full implementation of long baseline and use of Kalman filtering is expected to improve the accuracy to about 10 cm.

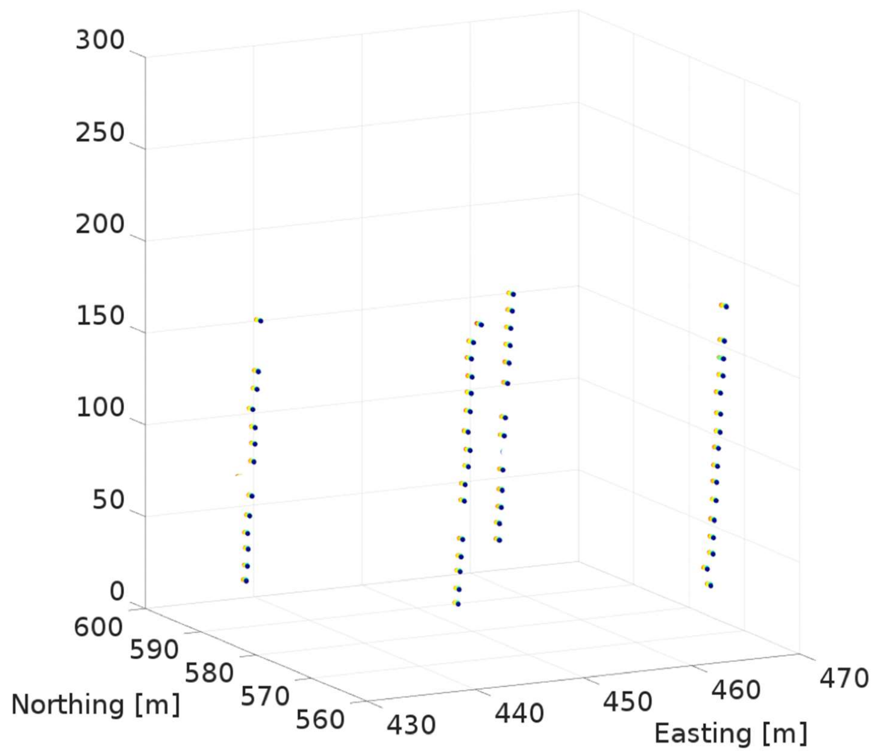


Figure 1. Positions of the ORCA detector with 4 strings, colors indicate time evolution on 5 minutes.

A qualification program was defined and carried out to validate all components to ensure system reliability for 20+ years, following deep-sea industrial standards. Commercial hydrophones and beacons have been qualified and, when necessary, they were partly re-designed and re-worked and tested based on HALT/HASS criteria.

In parallel, the analysis of recorded data aiming at identification and tracking of biological signals and acoustic noise in situ, has already started.

Figure 2: Left: the piezo element placed inside the KM3NeT DOM (close to lower pole); right: the DOM in the TNO anechoic water pool.

Figure 3: The Colmar DG330 Hydrophone

Figure 4: The acoustic beacon MSM MAB100Ti

Figure 5: Autonomous Beacons hosted on tripods: mechanical structures and battery packs are designed and qualified by KM3NeT

- An Attitude and Heading Reference System (AHRS) developed in KM3NeT for the orientation of the DOMs:

The orientation of the floating DOMs of KM3NeT is provided by a custom Compass and tilt board, a piggy-back board soldered permanently on the Central Logic Board (CLB) as shown in Fig.6. Two kinds of boards have been used in KM3NeT: the LNS-AHRS and the LSM303-AHRS. Both are based on commercial tri-axial accelerometer/magnetometer chips manufactured by STM.

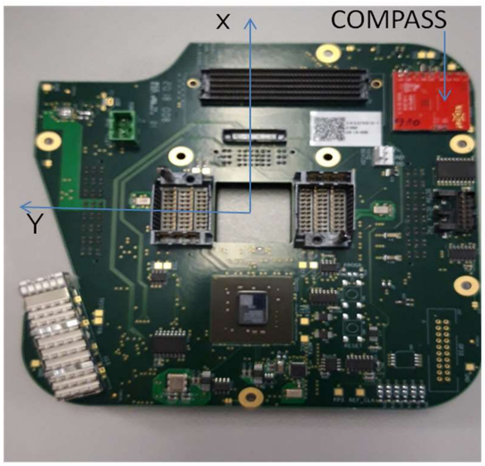
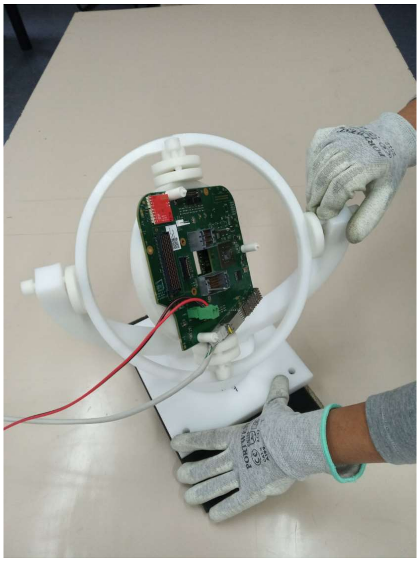


Figure 6: Left: The Compass and tilt board soldered on the CLB. Right: The Nikhef design LNS303 compass and tilt board.

The AHRS calibration procedure developed in KM3NeT determines the values of the calibration parameters of accelerometers and magnetic gauges. A plastic gimbal has been designed in order to measure hard/soft iron calibration parameters of the naked board by manually wobbling the compass covering the full space angles (Fig. 7). For a successful calibration two conditions are essential: rotations need to be performed smoothly and the apparatus should be placed in a location where gradients of external magnetic field are kept below a few hundreds of nT. The calibration process is accompanied by a software package that calculates the calibration values, prints the output in xml format and a graphical user interface (GUI) that guides the user through the calibration, appropriately designed for dynamic interaction with the central KM3NeT database. The aforementioned calibration procedure achieves an accuracy of ≤3.5 degrees during the DOM operation. Moreover, checking of calibration of the AHRS boards of fully integrated DOMs indicates that for the vast majority of DOMs, the calibration coefficients determined with naked CLBs are consistent with the final AHRS configuration when the CLB is integrated in the DOM.



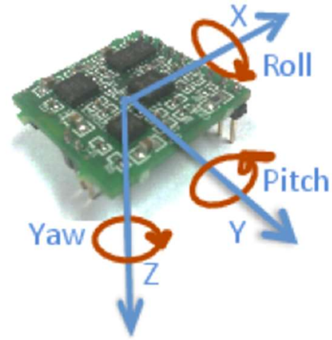


Figure 7: Left: Measurements performed manually in the lab. Right: A series of rotations is performed with the CLB placed in different orientations.

In order to improve and standardize the calibration procedure, a fully automated gimbal was designed and put in operation at the INPP in N.C.S.R. “Demokritos”, Athens (Figs. 8, 9). All parts are 3D printable whereas the rotations along all 3 axes are performed via Arduino controlled stepper motors. Accordingly, one has to mount the CLB on the mechanical gimbal, which in turn performs automatically all required rotations with pre-defined angular speed and breaks between successive rotations, thus eliminating the human error factor in the final calibration quality. Care has been taken to keep the gimbal’s construction and maintenance as easy as possible, as all parts are either easily printable by standard 3D printers or standard, easy to find commercial products. Compass calibration requires a multi-step procedure involving hardware and firmware checks and operations, data acquisition and analysis. The expertise required is diverse and usually provided by several persons. In order to support the operators that calibrate the compass, simplify their task and to prevent human mistakes, an effort has been made to automatise the procedure. A complete automatization of the process requires a further integration of the calibration software with the gimbal so that the GUI includes also the latter’s control parameters. An interactive tool has been developed in the University of Salerno for this purpose, named “Compass Calibration Assistant” (Fig. 10). It is a Python application built on the GTK library, hence designed with cross-OS portability in mind. The interface guides the operator step-by-step, automatically checks data quality and takes care also of the necessary book-keeping and interaction with the remote central database. The procedure can be interrupted at various steps and restarted later. Functionalities to manage the library of calibration datasets are provided, including uploading test results to the central database or local archiving. As AHRSs are used in a wide variety of applications, it is expected that the aforementioned automatised calibration process would be of interest to industry.

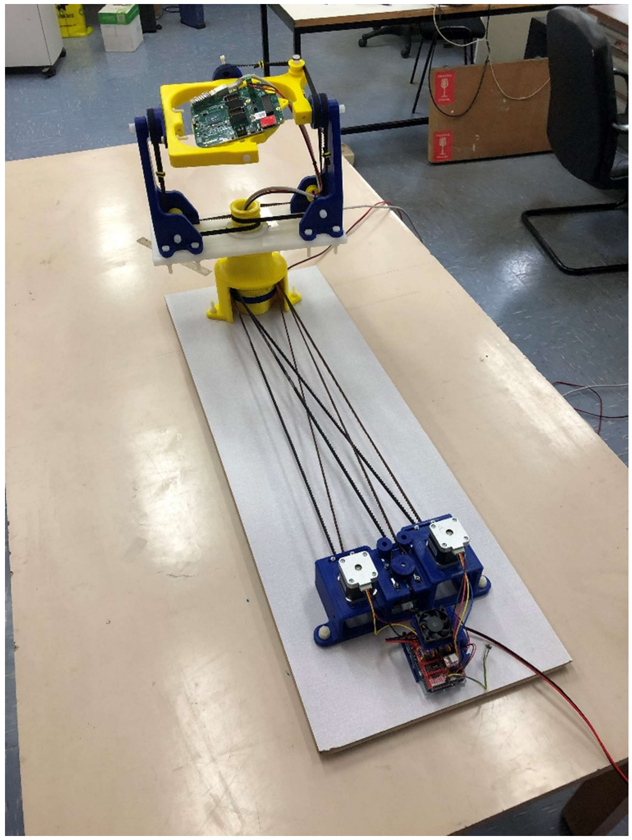


Figure 8: The fully automated gimbal designed and put in operation in N.C.S.R. “Demokritos”.

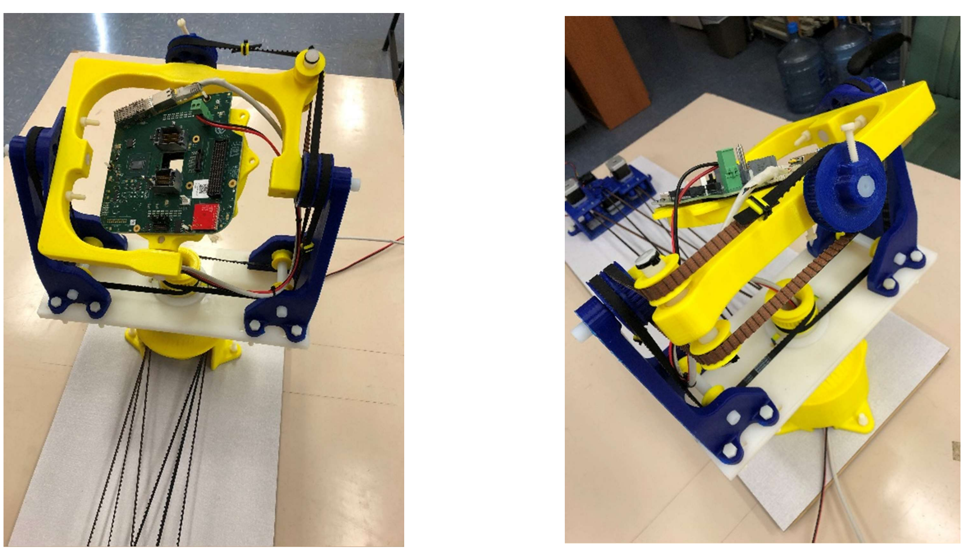


Figure 9: Details of the fully automated gimbal.

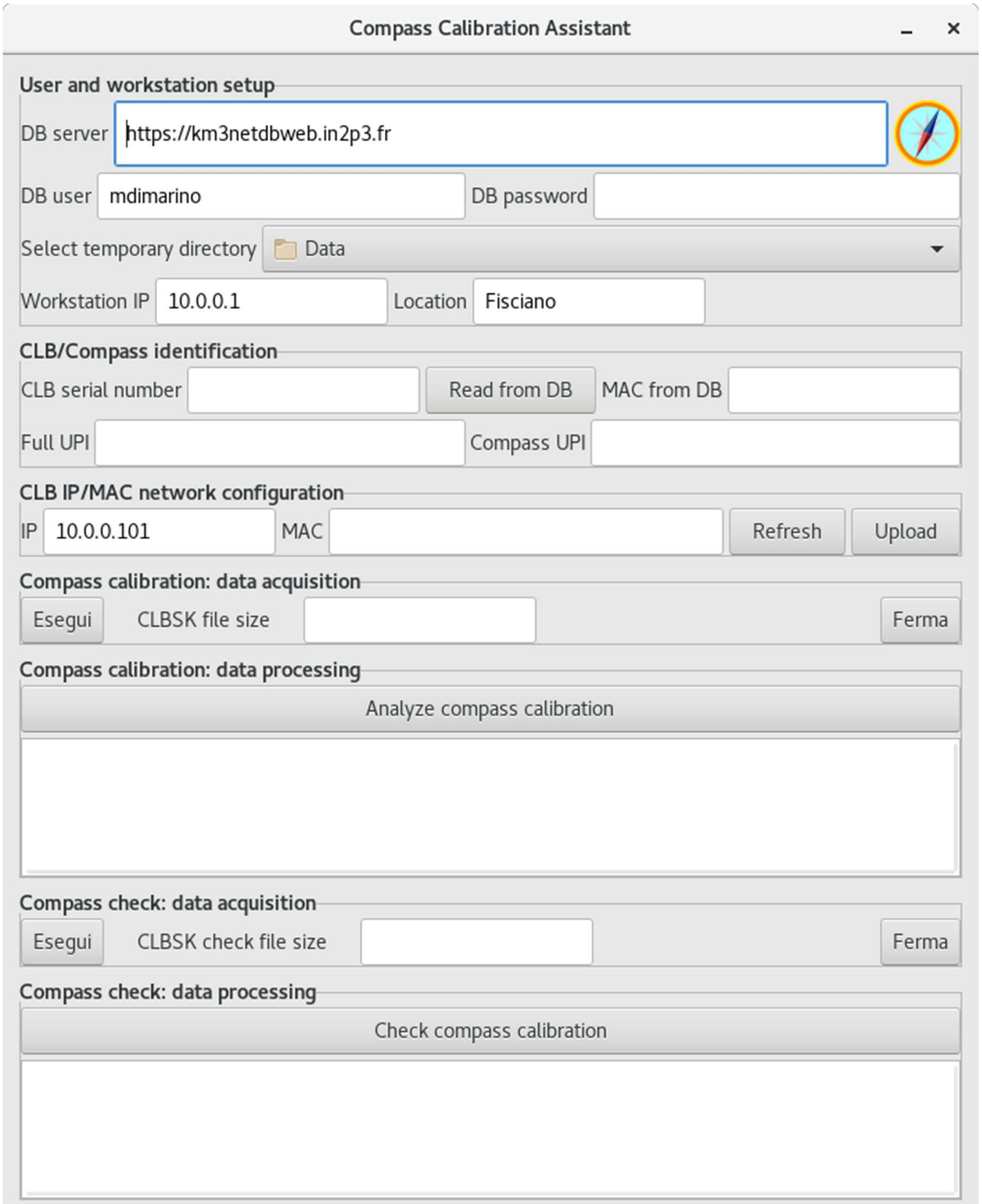


Figure 10: The “Compass Calibration Assistant” developed at the University of Salerno.

- Multi-PMT testing facility

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. The multi-PMT testing has been described in D9.2.

Photomultiplier developers have expressed interest in adopting the multi-PMT testing facility and/or reproducing it for sample testing of the characteristics of the PMTs they produce. In addition, the analysis of the test data of nearly 7000 photomultipliers for Phase 1 of KM3NeT, resulted in revealing features that suggested significant improvements in the performance of the photomultipliers. The results have been shared with the manufacturer and allowed to obtain, for Phase 2 of KM3NeT, more efficient and less noisy photomultipliers.

Finally, continuous observation of technological advancements in the fields of interest of KM3NeT has been proven valuable and there are several cases in which KM3NeT benefited from industrial products and solutions. As examples, one could mention:

- The vertical electro-optical data cable (VEOC) that is the backbone of the KM3NeT DU and the machine for welding the breakout boxes to the DU (for each DOM, a breakout box provides electro-optical connection between the DOM and the VEOC) and the base module to the DU. The VEOC design has been significantly improved during the last years. Several iterations with the companies involved played an important role in this improvement. The welding machine ensures reliable sealing which is mandatory for water-tightness of the components to be deployed and has accelerated the VEOC production and DU integration.

- The DOM and base module penetrators through which electrical wires (for powering the DOM) and optical fibres (for slow control and transferring data from the DOM) are fed into the DOM. As the DOM and base module penetrators need to operate reliably for the expected lifetime of the KM3NeT experiment, extensive tests have been carried out which have proven the desired reliability of the penetrators for pressures up to 600 bars.

- Production of the main component used in KM3NeT for the communication with the onshore station, the Small Form-factor Pluggable (SFP) transceiver which interfaces the electronics with the optics system has been discontinued by the vendor. It has been decided to use the new technology Tunable SFP which, in addition, avoids the complications arising from the non-exchangeability of DOMs.

For the SFP in particular, during the design phase the fixed frequency SFP transceiver was chosen due to its low power consumption, the small form factor and the very wide use in the telecommunication market. Low power consumption is important as the Field Programmable Gate Array (FPGA) and the SFP are the main power consumers inside the Central Logic Board (CLB). There has been an extensive market survey and a test campaign as KM3NeT required the manufacturer to assure the stability of the SFP frequency over the expected long lifetime of the experiment (larger than 15 years). This resulted in the selection of two manufacturers who offered the possibility to fine-tune the transceiver by tuning the temperature at which the device is operated. The fine-tuning feature is non-standard, but it is required to ensure operation and performance for the long lifetime of the experiment. The choice was then restricted to one manufacturer only, taking into account costs and overall reliability figures (risk for the project in case of obsolescence of the chosen product). However, the main drawback when using fixed frequency SFPs is that the full set of frequencies used in the DU needs to be procured beforehand, thus adding a significant unnecessary complication to the procurement and stock management. Moreover, once an SFP is integrated in a DOM or Base Module (DM) the DOM or BM frequency is fixed, therefore making changes gets difficult as any change would result in affecting the logistics of DOM/BM production.

Besides the complications linked to the fixed frequency, the overall experience with the SFP was positive until the device was discontinued. This was of course a problem for KM3NeT as it affected our stock management; industry faced the same problem to a much greater extent, hence the market pushed for a device with frequency that could be tuned onsite. The tunable SFP (TSFP) was launched (first manufactures launched it around 2013) but only in the past year the price and size of the manufactured devices reached a level which is comparable to the one of the SFP around 2003. Since the technology can now be considered mature, we introduced it as one-to-one substitute of the obsolete SFP, enabling a much higher level of flexibility for the construction of the detector since its internal wavelength locking system keeps the frequency stable, once tuned, for the entire project lifetime.

4. Conclusions

A Technology and Innovation Panel was established in KM3NeT with collaboration members having expertise in technology related fields (optical measurements, acoustic receivers, low power electronics and computing and data sciences). The main duties of the Panel have been: 1) the observation of technological advancement in the fields of interest of KM3NeT and 2) the presentation of technological solutions developed and adopted/modified by KM3NeT with potential interest for industrial applications. Material has been prepared, within the framework of this work package, for exposing the KM3NeT technological solutions to the industrial sector and to other Institutions. The technological solutions and innovations of KM3NeT are broadly recognized within the corresponding technological community. In addition, KM3NeT has shared the outcome of extensive and thorough tests and analyses performed for the validation of the different components. This knowledge transfer has been decisive for reinforcing the interaction between KM3NeT and the leaders of technological advancements and industrial innovations in the relevant fields and for ensuring the flow of information towards KM3NeT. Finally, KM3NeT succeeded in more than one occasion to have significant benefit return from disseminating its technological accomplishments.