The Digital Optical Module of the KM3NeT project

Emanuele Leonora

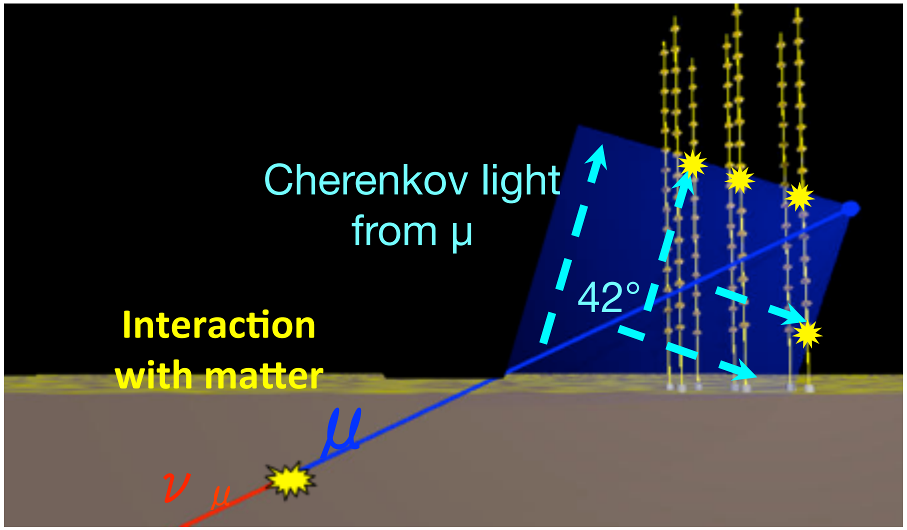
INFN, sezione di Catania
on behalf of KM3NeT Collaboration

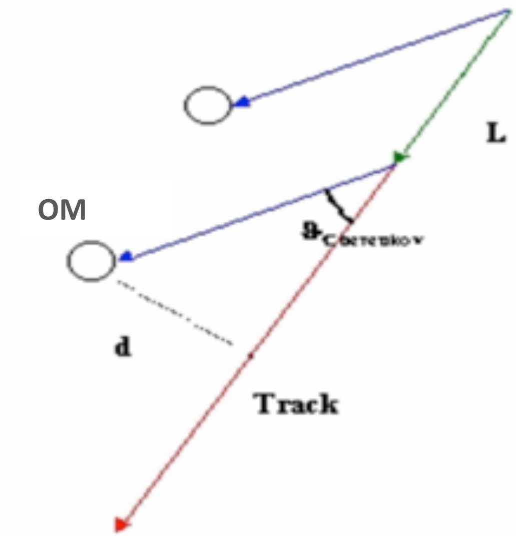
[Conference on Neutrino and Nuclear Physics (CNNP2017)]()

15-21 October 2017 ***Monastero dei Benedettini, University of Catania, Catania, Italy***

Underwater neutrino detector

The KM3NeT Collaboration started building a research infrastructure in the depths of the Mediterranean Sea hosting a new generation cubic kilometer sized neutrino telescope





The detector is a 3D array of photosensors sensitive to the Cherenkov radiation emitted by products of neutrino. The photosensors are called Optical Modules (OM)

The arrival time of the Cherenkov light, together with the knowledge of their spatial position, are used to reconstruct the trajectory of the particles.

The amount of detected light can in addition provide information about the energy of the particle

The KM3NeT scientific objectives and sites

The modular design allows different underwater layouts to target different neutrino energies

Two main scientific goals:
- **determination of the neutrino mass hierarchy**
- **discovery and observation of high energy neutrino sources in the Universe**

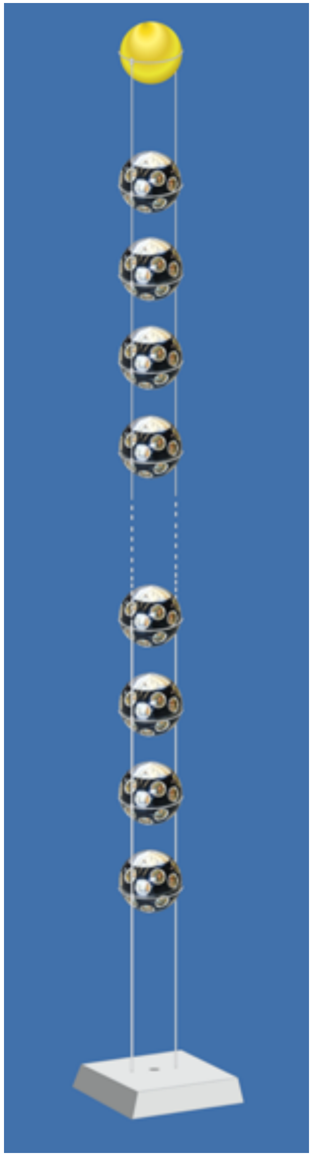
Two main research lines:
- **ORCA: Oscillation Research with Cosmics in the Abyss** targets atmospheric neutrinos oscillations in few-GeV range
- **ARCA: Astroparticle Research with Cosmics in the Abyss** targets astrophysical neutrinos above TeV energies

Two main marine sites:
- **KM3NeT-Fr site; 2475 m depth ; Toulon, France**
- **KM3NeT-It site; 3400 m depth; Capo Passero, Italy**

KM3NeT Letter of Intent, J. Phys. G 43 (2016)

The KM3NeT detection unit

- In the sea, the Optical Sensors (DOM) are suspended in vertical structures, called Detection Units (DUs).
- The Detection Unit (DU) each hosts 18 DOMs.
- Each DU comprises two thin parallel Dyneema® ropes to which the DOMs are attached by an external titanium collar.
- Each DU is anchored to the seabed and kept taut by a system of submerged buoy at the top that reduces the horizontal displacement
- Attached to the ropes is the electro-optical cable (VEOC), that contains 2 wires for power transmission and 18 optical fibres for data transmission.
- in ARCA (E > TeV) each DU is about 700 m in height, with DOMs 36-m vertically spaced. The DU horizontal spacing is about 95 m.
- In ORCA (E ≈ few GeV) each string is 200 m in height with DOMs vertically spaced 9 m. The DU horizontal spacing is about 20 m.



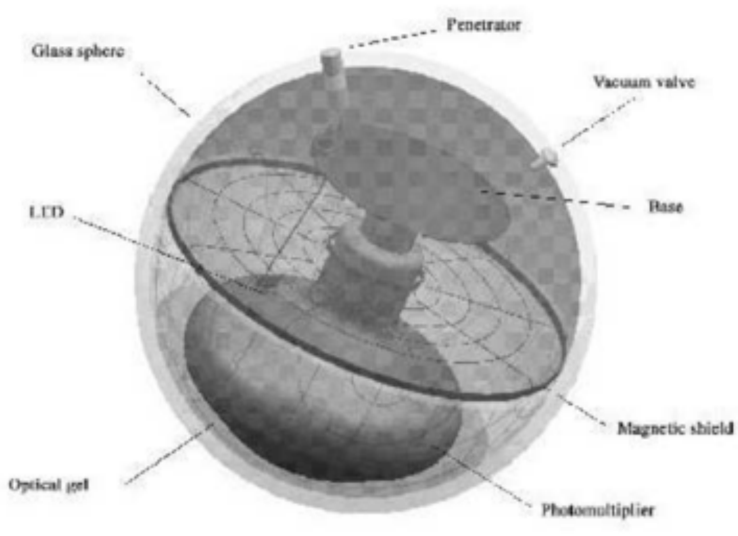
Multi-PMT digital optical module (DOM) design

Each DOM is composed of a transparent 17-inch diameter pressure resistant glass sphere that hosts inside 31 3-inch photomultipliers and all the front-end and readout electronics.

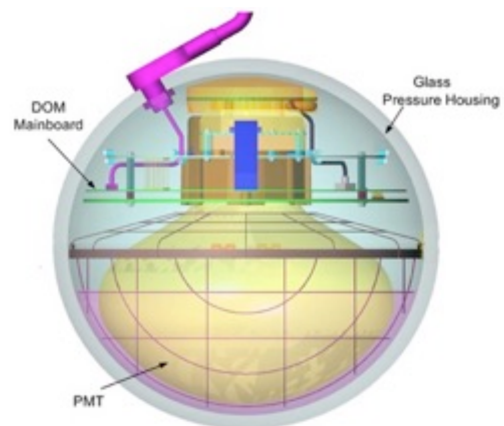
Advantages of a multi-PMT design vs. single large area PMT

- **a photocathode area almost three times of a single 10" PMT**
- **an almost isotropic field of view**
- **the influence of the Earth's magnetic field on small size PMTs is negligible and magnetic shield is not required.**
- **accurate photon counting**
- **directional information about detected radiation**
- **rejection of optical background in water at DOM detection level**

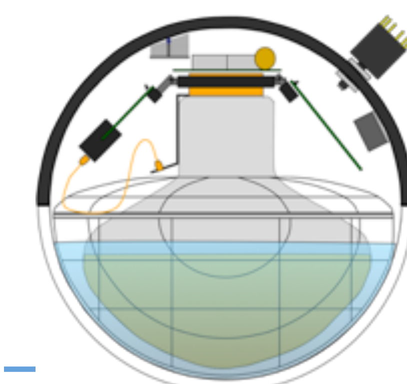
KM3NeT DOM with 31 3" PMTs



ANTARES 17" OM with 10" PMT



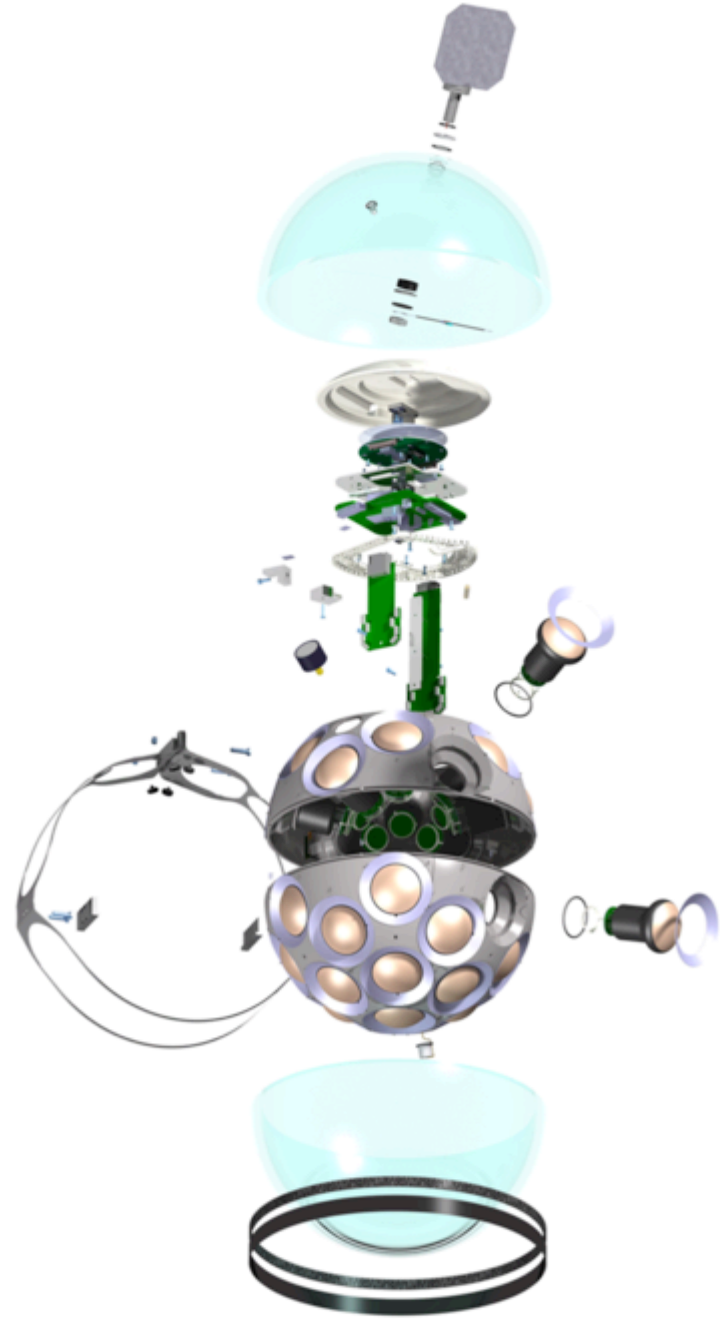
ICECUBE 13" OM with 10" PMT



NEMO 13" OM with 10" PMT

DOM main components

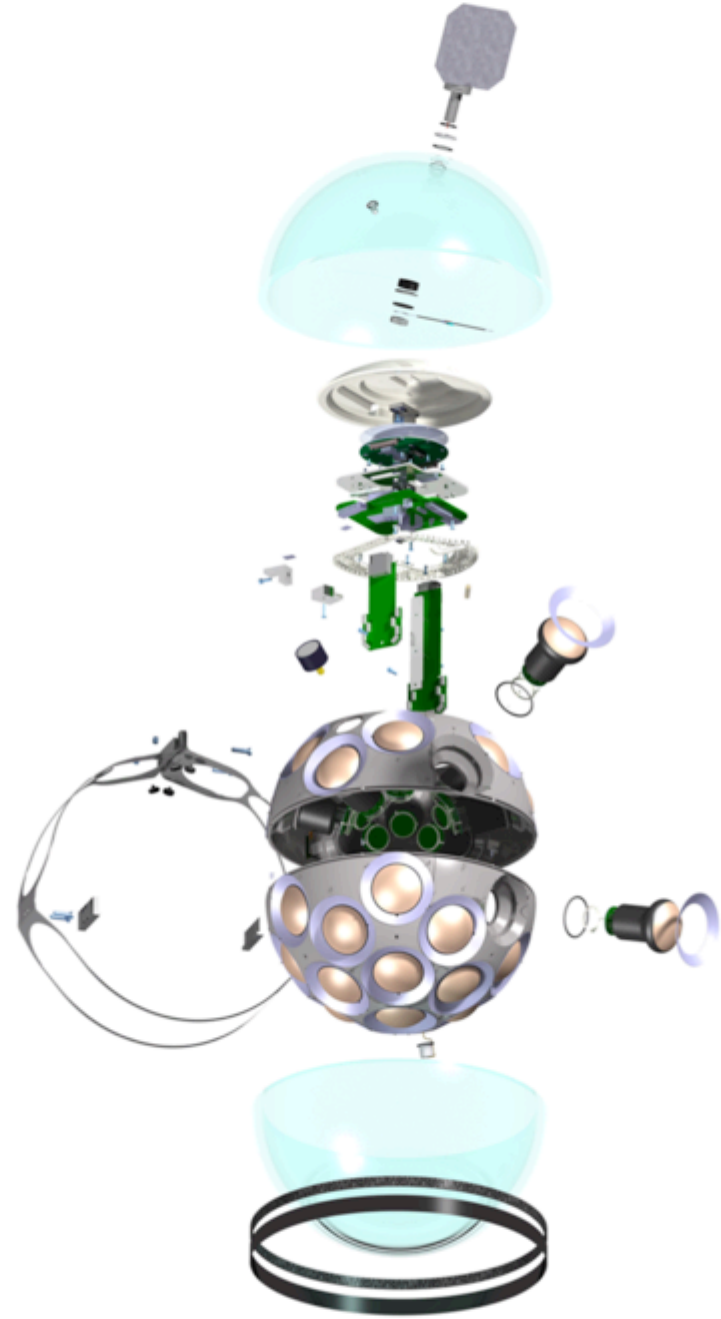
- A transparent 17-inch pressure resistant glass sphere of two separate hemispheres.
- The lower hemisphere contains 19 PMTs. The upper hemisphere 12 PMTs.
- The PMTs are kept in place by a 3D-printed support structure.
- The photon collection is increased by 20–40% by a reflector ring surrounding the face of the PMTs.
- The space between support structure, PMTs and glass sphere is filled with an optical glue
- The gel ensures optical and mechanical coupling between PMT and glass spheres



emanuele.leonora@ct.infn.it

DOM main components

- an Attitude and Heading Reference System (AHRS) provides compass, tilt- and accelerometer data, to reconstruct the orientation of a DOM in the water
- an acoustic piezo sensor is glued to the inner surface of the glass sphere for DOM acoustic positioning in water
- a LED nano-beacon injects calibrated light in water to illuminate the neighbouring optical modules above for time calibration
- An aluminium structure provides heat conduction between electronics inside and the outside
- A penetrator mounted in the upper hemisphere of the DOM contains two power cables and one optical fibre for data transmission.

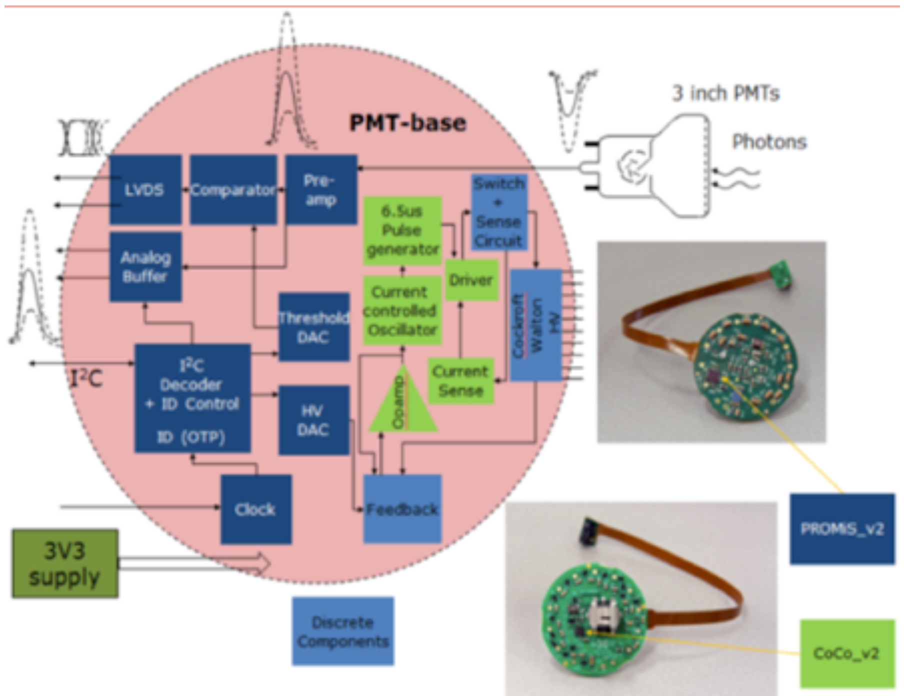


emanuele.leonora@ct.infn.it

The PMT base

Into Digital Optical Module (DOM) each PMT works as an individual optical sensor

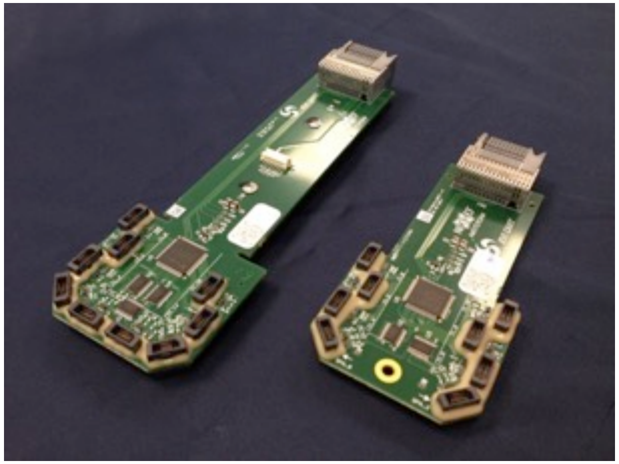
- **individual low-power active base**
- **individual integrated amplification and tunable discrimination**



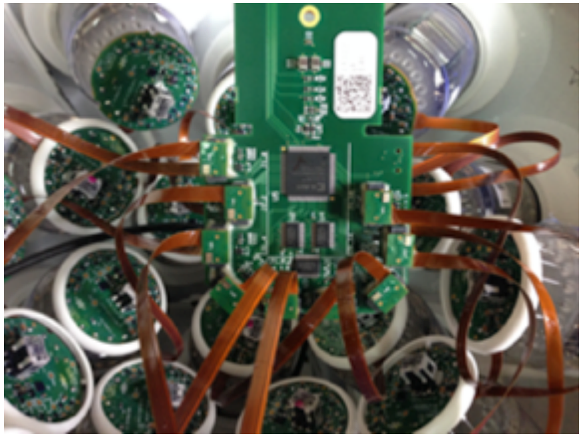
- **High voltage generated on the base**
- **The photon arrival time and the time-over-threshold (ToT) of each PMT, are implemented in an ASIC ("ProMiS")**
- **Threshold set to 0.3 single photon pulse height**
- **HV set for $3x10^6$ gain**
- **I2C communication for HV setting and base identification**
- **low power dissipated, below of 5 mW**

Octopus boards and power board

- **The data provided by the PMT bases is collected and sent to processor by means of two so-called Octopus Boards. (** ***large*** **for the 19 PMTs,** ***small*** **for the 12 PMTs)**

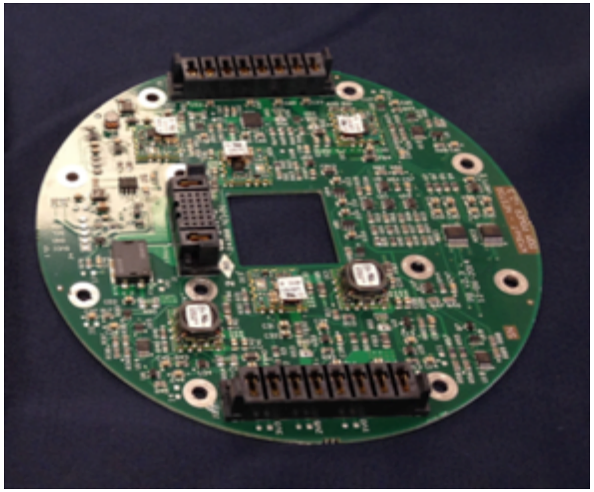


octopus board, large and small



pig tails from the PMT bases to octopus board

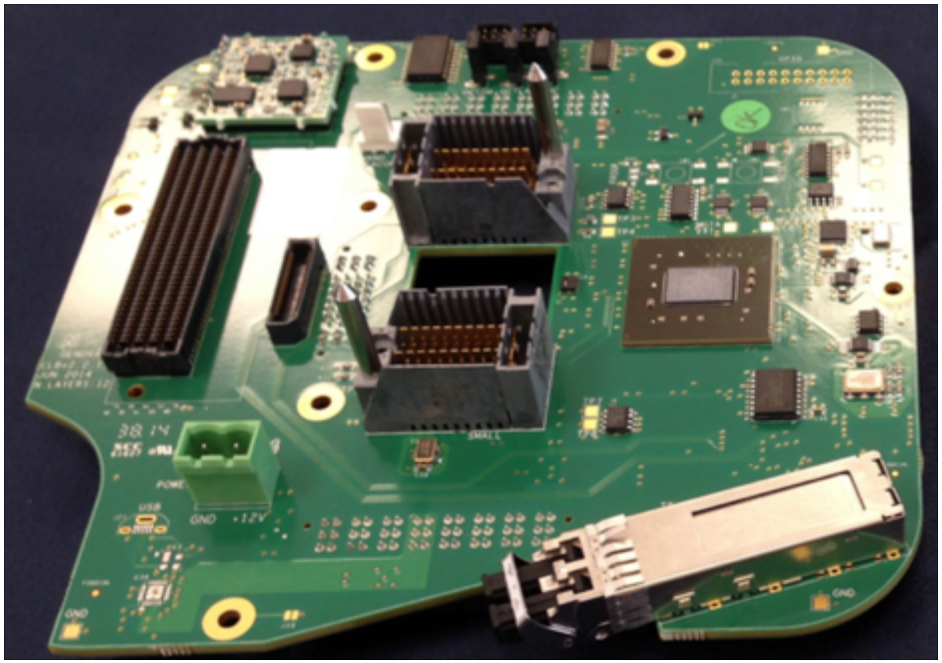
- **A power board (PB) provides the DC power for all the systems inside the DOM**
- **PB is powered with 12V DC supplied via the penetrator connected to a DC/DC converter outside the glass sphere**
- **PB is monitored and controlled by the FPGA mounted on the Control Logic Board**



Power Board

The Control Logic Board (CLB)

The CLB is the main board for signal processing, communication and control.



- **FPGA (Xilinx Kintex 7)**
- **TDC channels for signals from PMTs and acoustic sensor**
- **White-Rabbit precision timing protocol core**
- **Laser emitter/transceiver system**
- **The CLB transfers the data to shore via a Gb- Ethernet network of optical fibers**

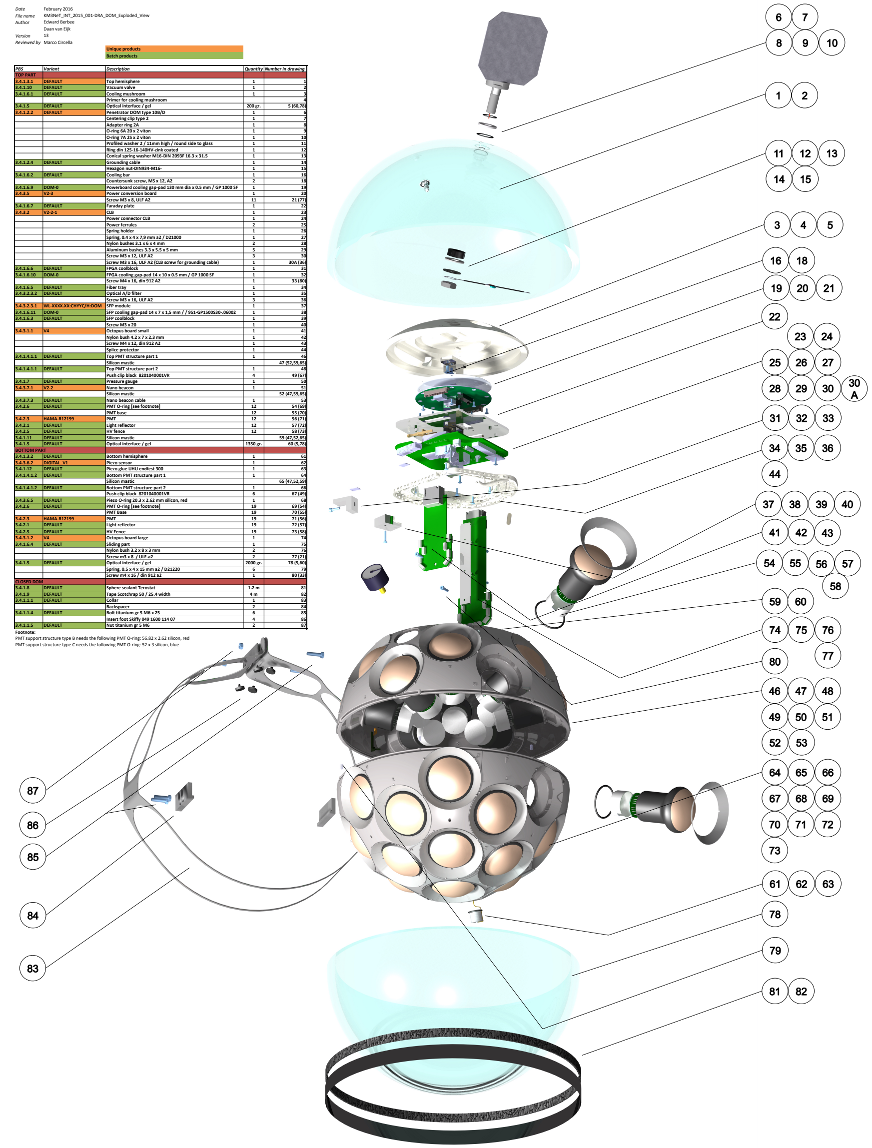
- **Each DOM in a detection unit communicates at a dedicated wavelength**
- **The White Rabbit protocol implements the broadcast of the clock signal allowing for synchronization of all the PMTs and all the DOMs with 1 ns resolution**

DOM mass production

Over 80 elements to be integrated for each DOM

- mechanics
- electronics
- sensors

Five integration sites are involved at moment in mass production of KM3NeT DOMs.

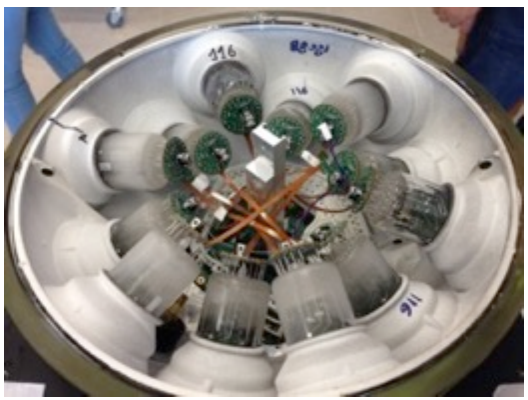


Digital Optical Modules mass production phases

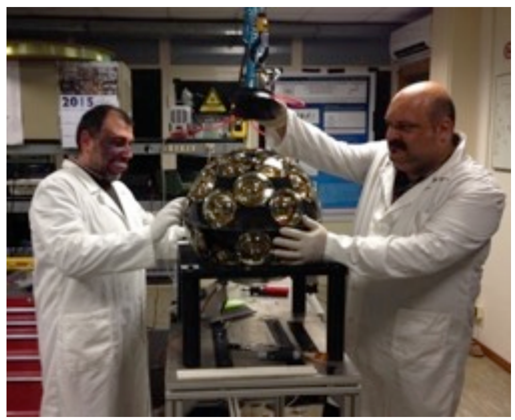
Picture of a DOM integration site

Gluing of the cooling system

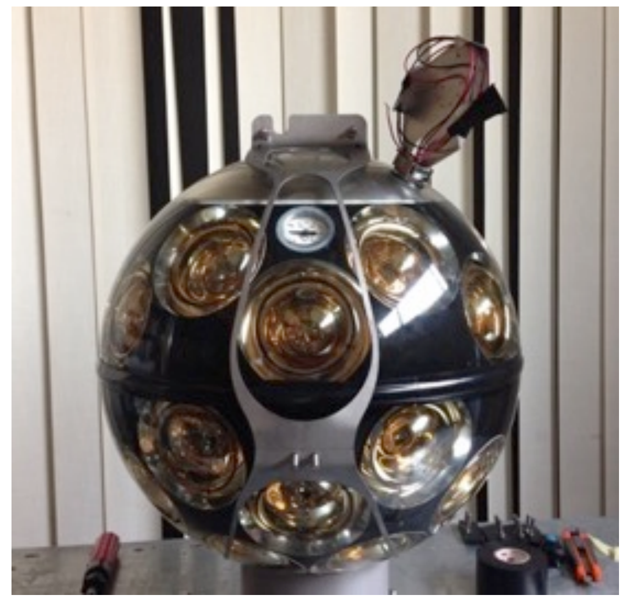
Cabling of electronic and optical parts



PMT mounted on the 3D structure



Closure and sealing of DOM



Picture of a produced DOM

Each DOM is submitted during assembling to functional test for all components

Each produced DOM is submitted to acceptance test and calibration

Conclusions

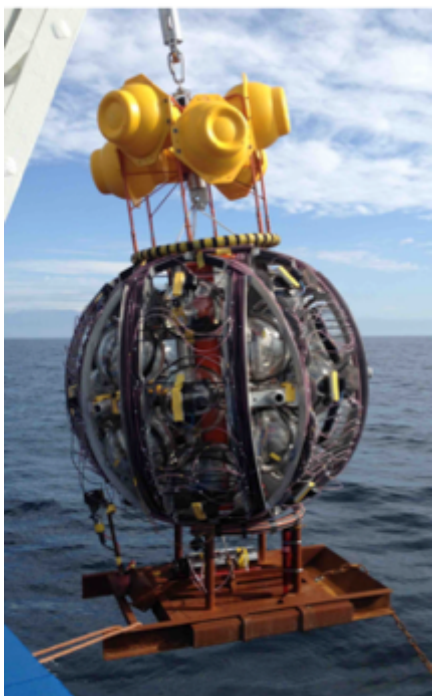
- An innovative optical module with a multi-PMT layout was designed for the KM3NeT neutrino telescope.
- Mass production of the KM3NeT DOMs is on-going in different integration sites.
- Installation of operative Detection Units at the two KM3NeT sites in the Mediterranean Sea has already started.
- ARCA 1 DU at sea and taking data in Italian Sea-site from December 2015.
- ARCA 2 DU at sea and taking data in Italian Sea-site from May 2016.
- ARCA 3 DU at sea in Italian Sea-site from May 2016. Recovered on July 2016.
- ARCA detector is temporary power off from April 2017.
- ORCA 1 DU at sea and taking data in France Sea-site from September 2017.

Thanks

KM3NeT
Opens a new window on our universe

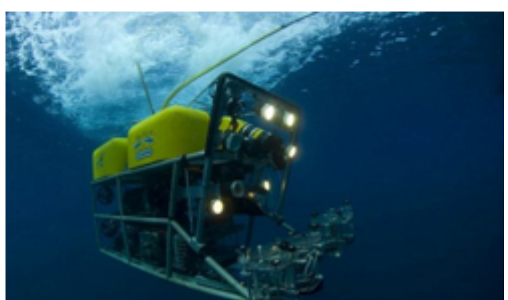
KM3NeT marine deployment principle

The DU string is coiled around a large spherical frame, the launcher vehicle, in which the DOMs slot into cavities.

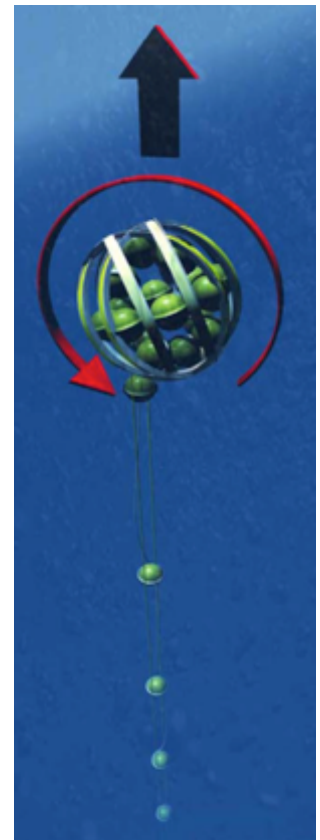


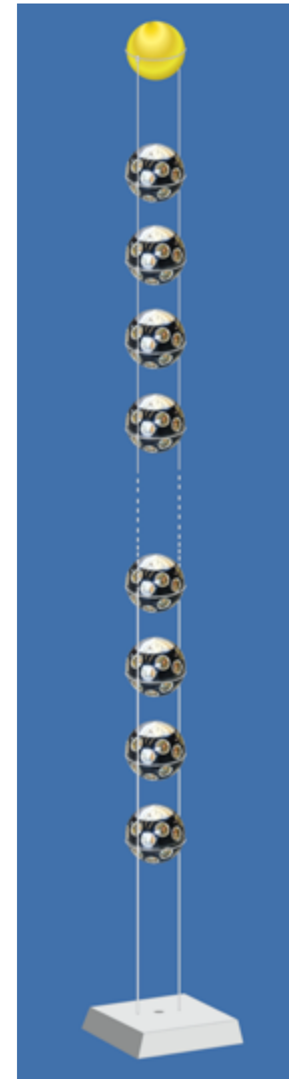
A surface vessel is used to deploy the launcher vehicle at its designated position on the seabed with a 1-m accuracy

A mechanical system activated by a ROV triggers the unfurling of the string.

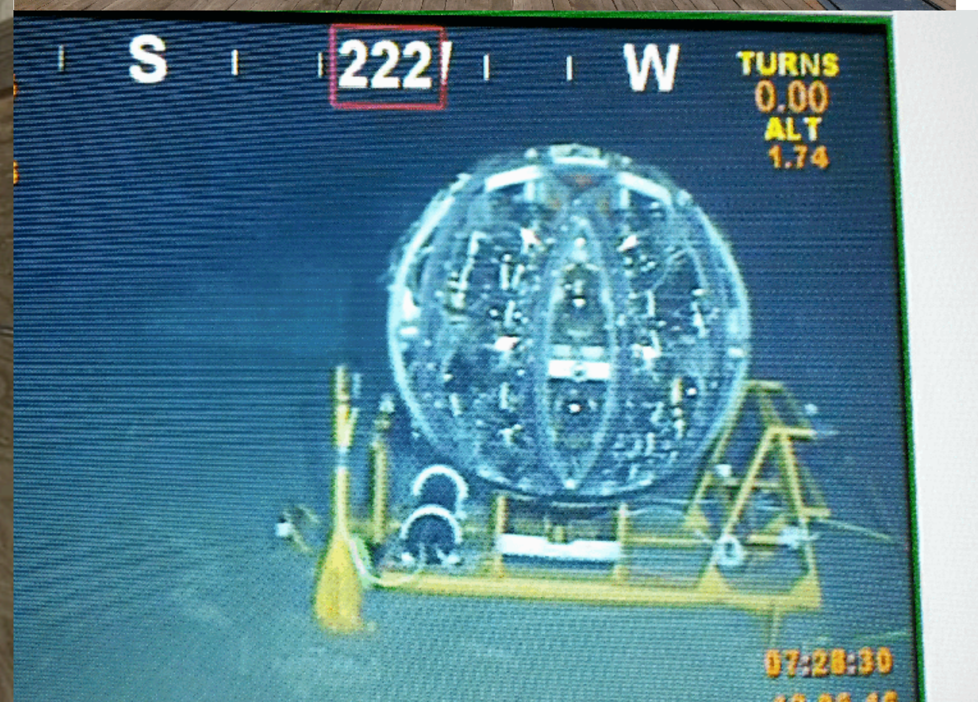


The launcher vehicle starts to rise to the surface while slowly rotating and releasing the DOMs.
The empty launcher vehicle floats to the surface and is recovered

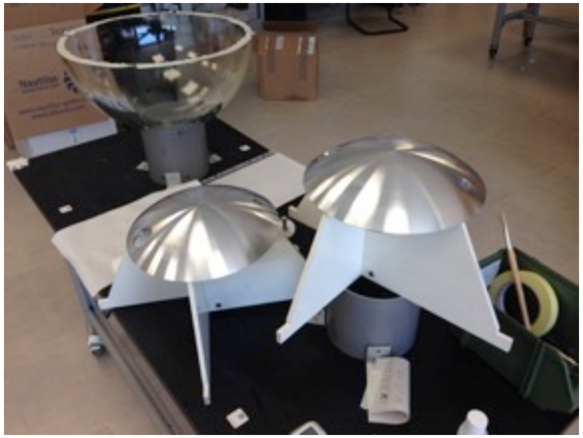




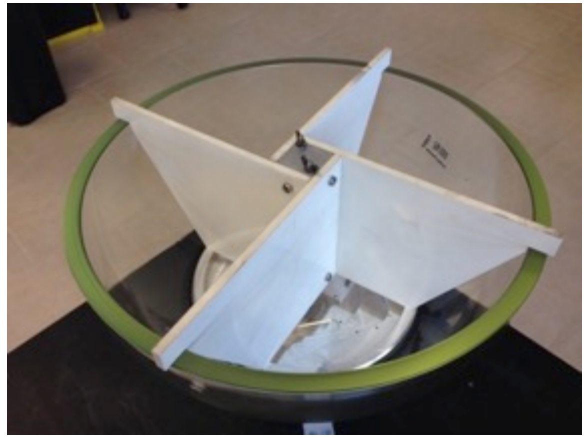
Pictures from the marine operations of May 2016



Pictures from DOM Integration site in Catania

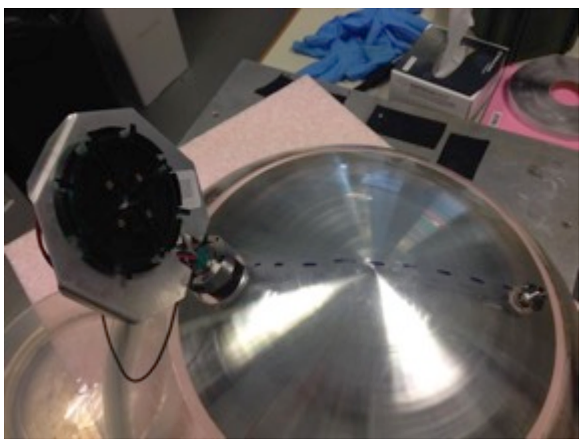


Preparation of components



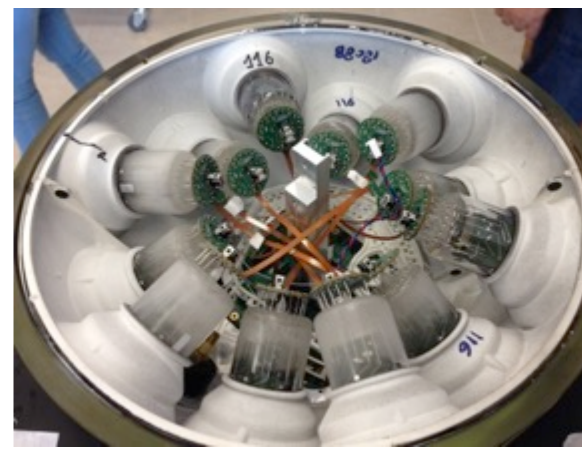
Gluing of the aluminium heat dissipator

Mounting of the electronics



Mounting of the external penetrator

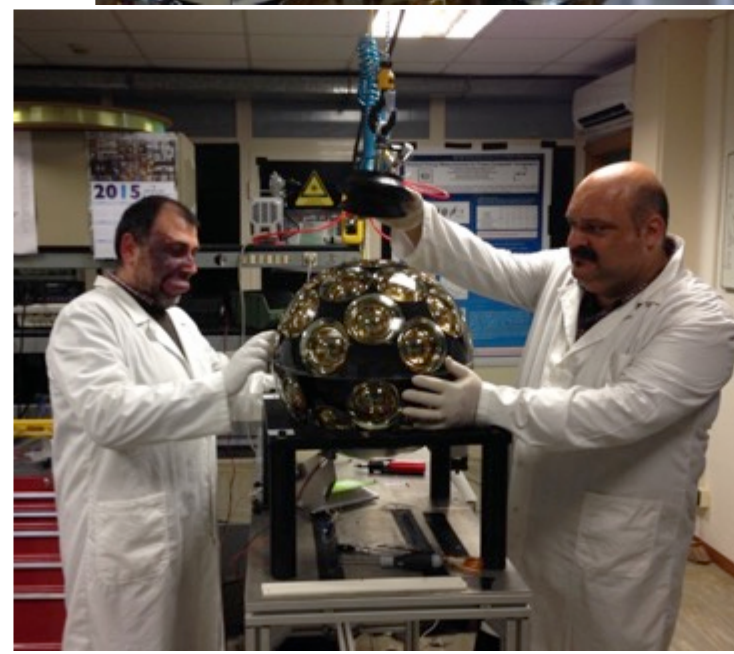
PMTs insertion in structure



Lower part of the DOM

Pictures from DOM Integration site in Catania

Optical gel pouring



DOM closure with an internal 0.2 Bar underpressure

Test and Calibration

- **Each DOM is submitted during assembling to test functionality of all components**
- **Each produced DOM is submitted under acceptance test and calibrations**

  - **PMT DC rate**
  - **PMT gain**
  - **piezo acoustic sensor**
  - **LED nano beacon**
  - **Calibration of position sensitive devices**

All test and calibration results are stored in digital module stored in KM3NeT Data Base