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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

INFN

SICILIAE STVDIVM GENERALE 1434

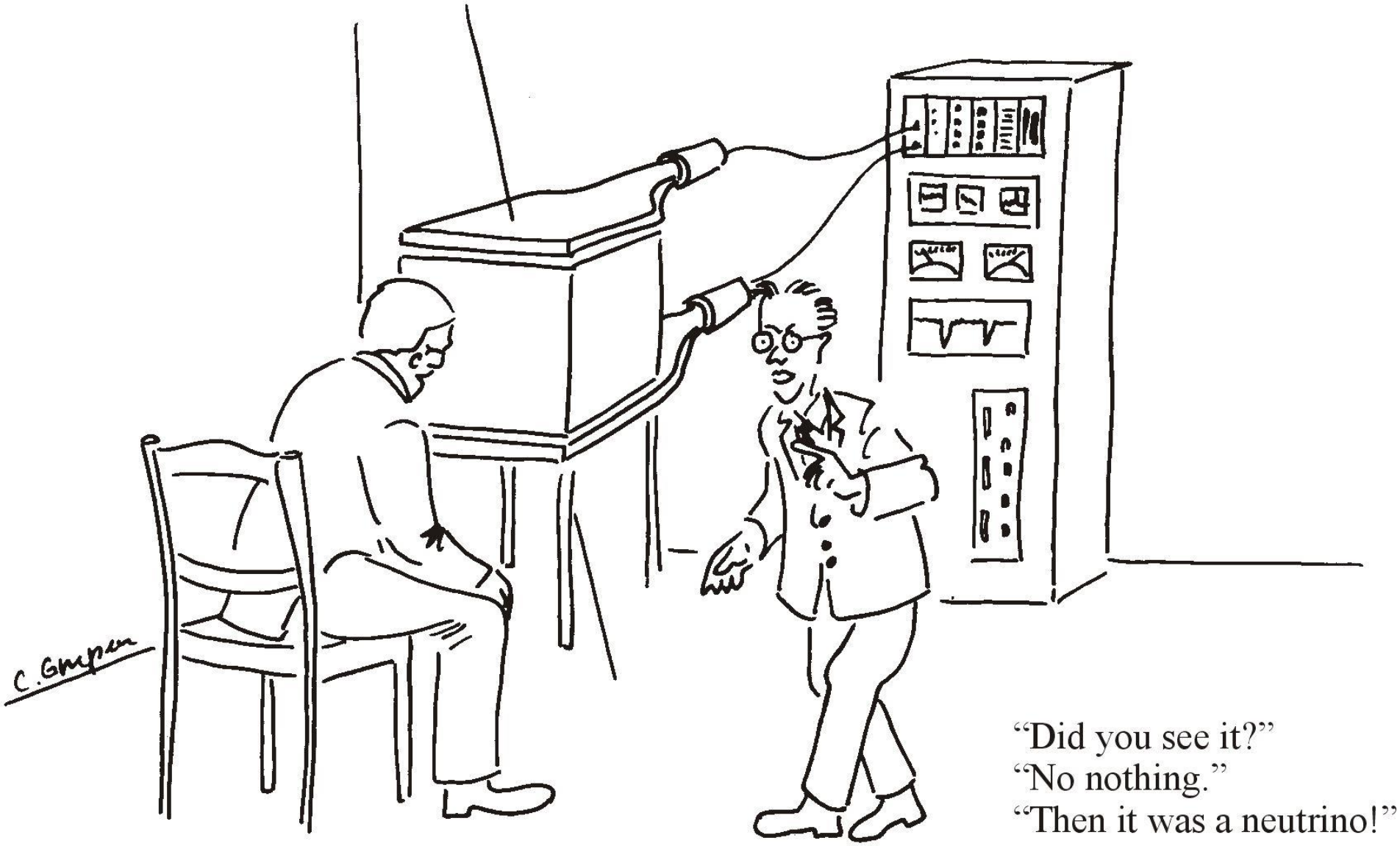
Il telescopio sottomarino alla ricerca di neutrini cosmici nel Mar Mediterraneo

Il detector e i sensori di KM3NeT

Emanuele Leonora-INFN Catania

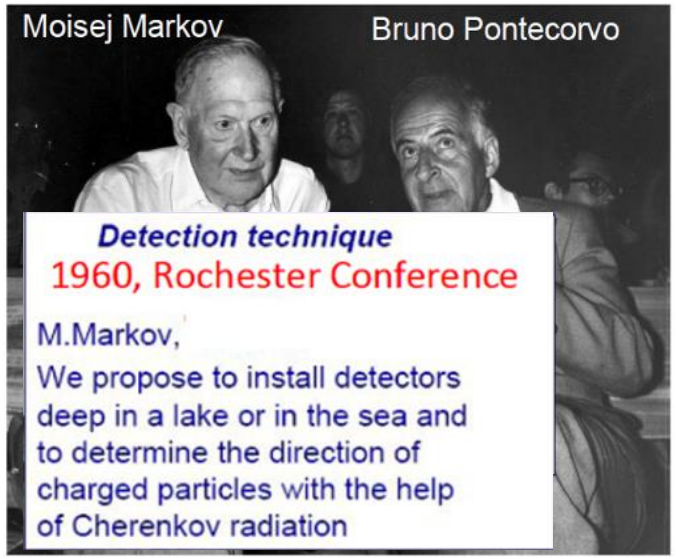
CATANIA, 21 GENNAIO 2025

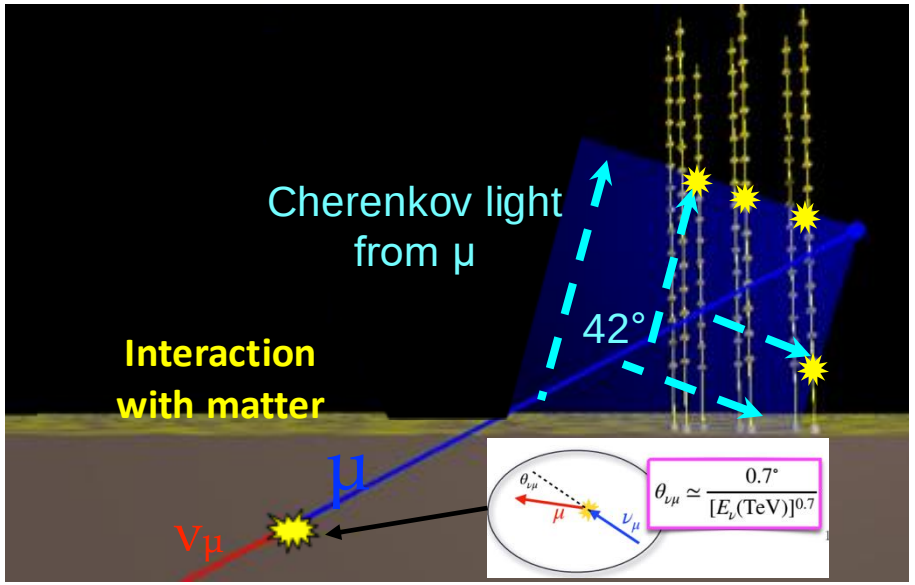
KM3NeT4RR
Kilometer Cube Neutrino Telescope for Recovery and Resilience

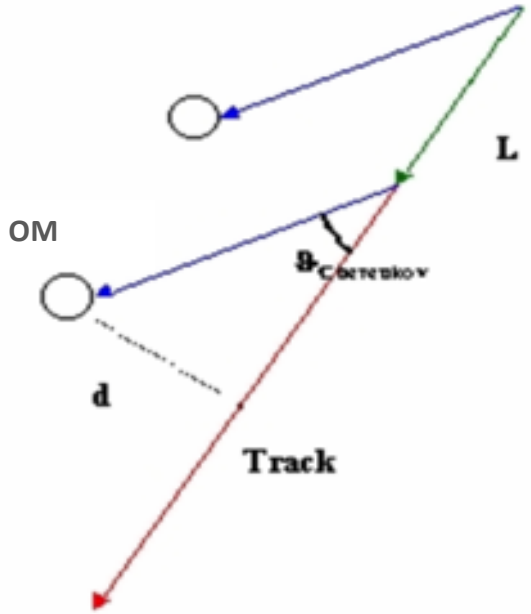


"Did you see it?"
"No nothing."
"Then it was a neutrino!"

Neutrino detection technique







The detector is a 3D array of photosensors sensitive to the Cherenkov radiation emitted by charged products of neutrino.

The arrival time of the Cherenkov light, together with the knowledge of the sensor 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 photosensors are called Optical Modules

General requirements and main components of an optical modules

- Light collection and detection must be optimized.
- Power supply and sensor signals digitization are needed
- Photosensors and associated electronics must be housed into transparent vessels resistant to water and to the hydrostatical pressure
- The vessel must withstand to environmental conditions such as corrosion and mechanical shocks
- The optical coupling between the water and photosensors must be the best possible, together with a mechanical coupling for handling and vibrations
- Outside connection for DATA transmission and control signals is needed

Photosensor to detect faint Cherenkov light

Electronics for power supply and data read-out

Externall transparent watertight vessel

Glue for optical and mechanical coupling

System to allow outside communication

KM3NeT Digital Optical Module

The digital optical module (DOM) is composed by a transparent spherical vessel that contains:

- **31 small-area PMTs**
- **the associated front-end and readout electronics,**
- **calibration components and systems for monitoring and controls.**

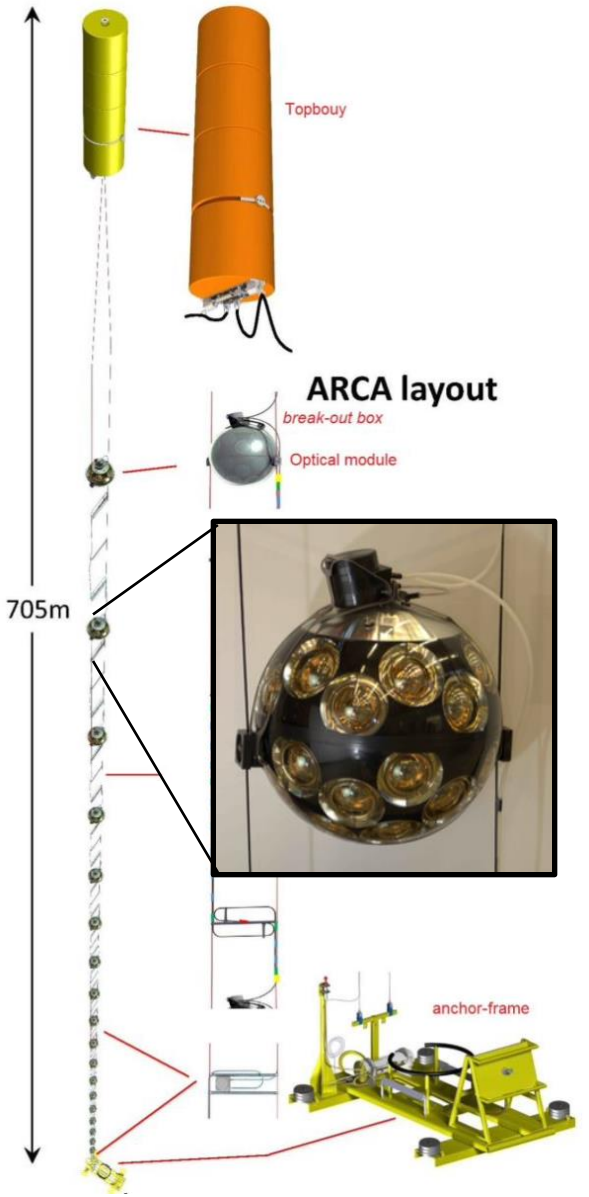
In the sea, the DOM are suspended in vertical structures, called Detection Units (DUs).

The Detection Unit (DU) each hosts 18 DOMs, 36-m vertically spaced.

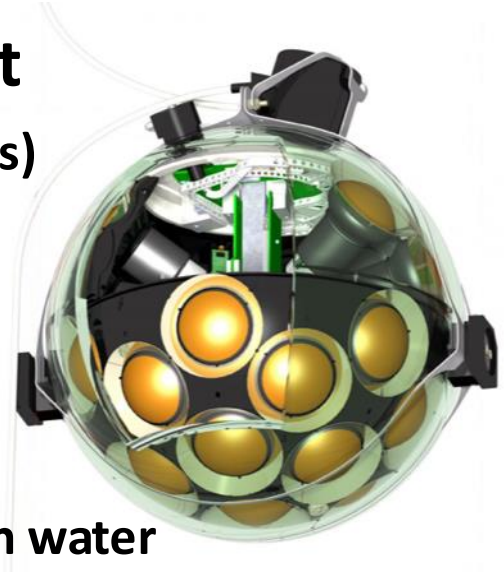
Each DU comprises two parallel Dyneema® ropes to which the DOMs are attached by an external collar.

Each DU is anchored to the seabed and kept taut by a system of submerged buoy at the top

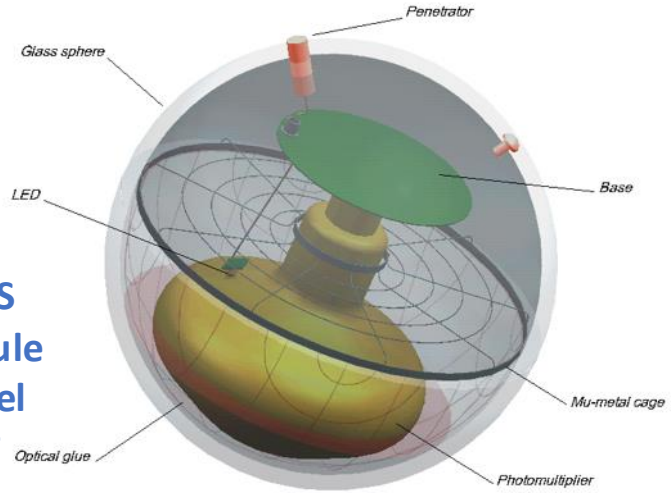
Each DU is about 700 m in height, with an horizontal space of about 90 m.



Advantages of multi-PMT design respect to a single large PMT layout

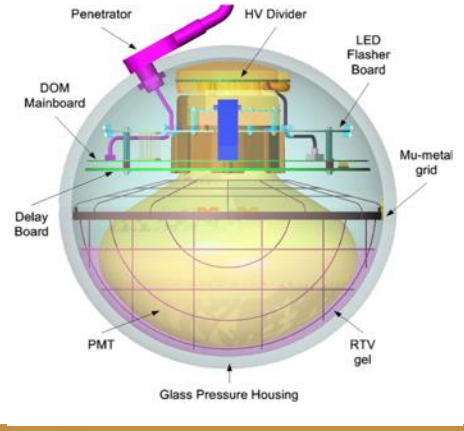


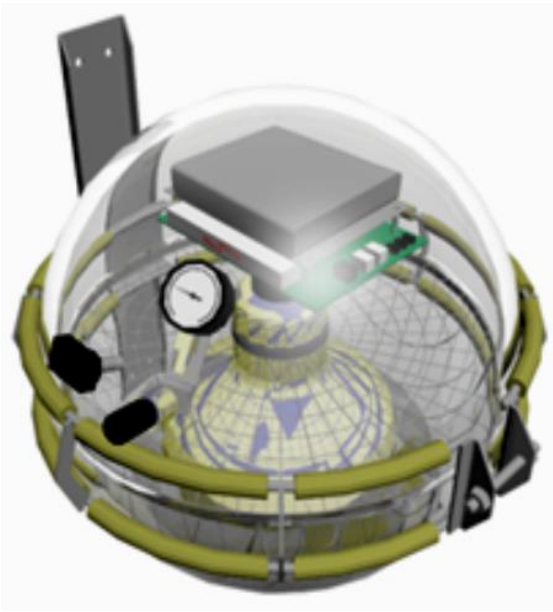
- a photocathode area almost three times of a single 10” PMT (used by other the projects)
- an almost isotropic field of view
- the influence of the Earth’s magnetic field on small size PMTs is negligible
- a magnetic shield is not required.
- accurate photon counting of the detected radiation
- directional information about the detected radiation just at a single DOM level
- more efficient rejection of the optical background caused by K^{40} and bioluminescence in water
- lower impact of single PMTs failure



The ANTARES optical module 17-inch vessel 10-inch PMT

The ICECUBE optical module 13-inch vessel; 10-inch PMT





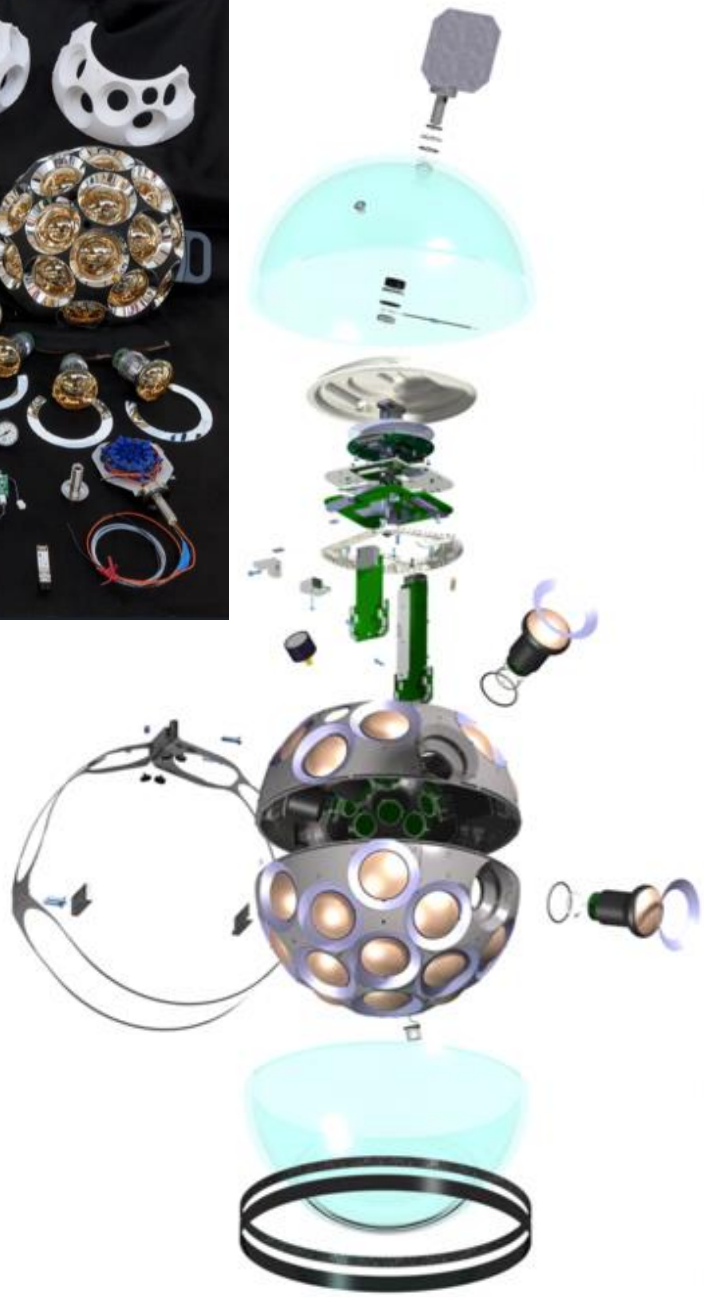
The GVD- Baikal optical module 17-inch vessel 10-inch PMT

KM3NeT DOM components

Over 80 different elements

- Photosensors
- Mechanichs
- Electronics
- FPGA processor
- Electrical-Optical transmission
- Heat dissipation

All is inside the DOM !!!
Electronics, power and sensors.



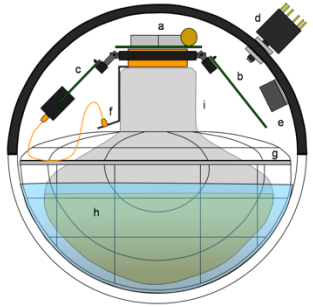
- A transparent 17-inch Nautilus pressure resistant glass sphere
- 31 PMTs of 3-inch. 19 in the lower hemisphere. 12 in the upper hemisphere.
- Each photomultiplier works as an individual optical sensor with a 1-ns synchronization
- The PMTs are kept in place by a support structure
- The photon collection increases by 20–40% by a reflector ring surrounding the PMTs.
- The space between support, PMTs and glass sphere is filled with an optical gel
- An alluminium mushroom allows heat dissipation towards outside
- An external titanium collar close the DOM and take it in place in the Detection Unit

A DOM integration site in Catania

In March 2013, in the NEMO-Phase 2 a prototype has been installed in the Capo Passero site at a depth of 3500 m

32 Optical Modules with a single 10' PMT designed and produced in INFN-Catania

Since 2008 the Catania group is involved in design and construction of Optical Modules for Underwater Neutrino Telescopes

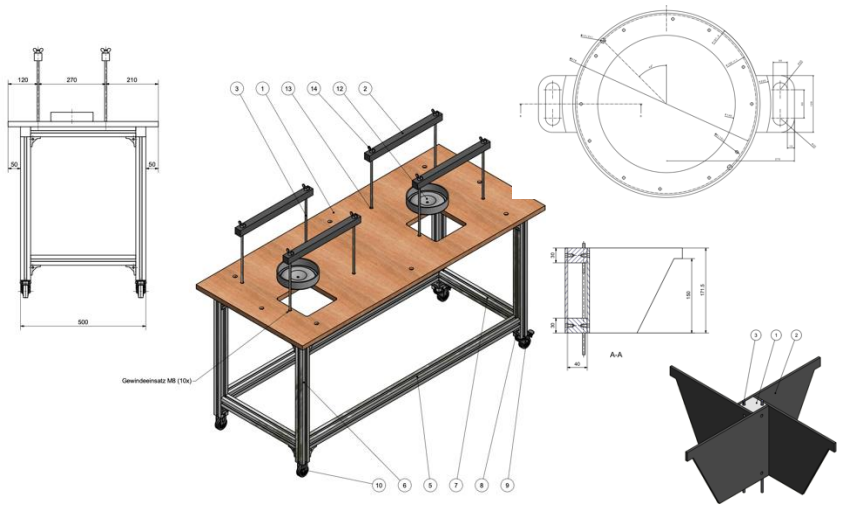


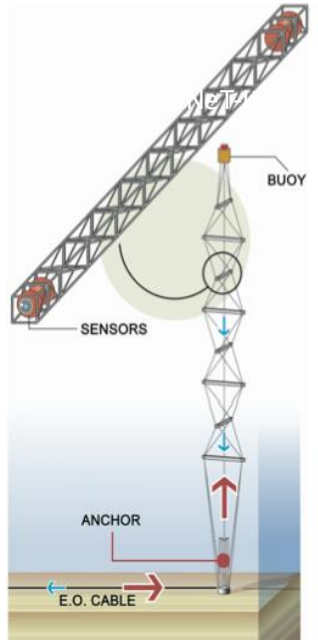
Since 2014 we joined the design of KM3NeT DOM

- Long phase of R&D of the components
- Design of all the custom tools to perform all the integration phases

Since 2015 is active a DOM integration site at INFN-sezione di Catania: 100 m²

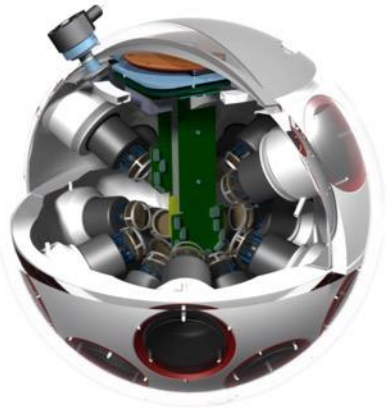
- Dark room for DOM storage temperature and humidity controlled : 10 m²
- Storage for components and consumables : 18 m²





DOM production and test phases

- The integration process is divided in many phases of a well defined procedure
- Extensive Quality Control activities follows the whole production
- A dedicated software (KM3DIA) guides all the production phases.
- All components are registered with a Unique Product Identifier code (UPI).
- Many components are tested before their integration
- Each DOM is submitted to functional tests during the integration
- Each completed DOM is submitted to an acceptance test



DOM integration phases
Bending of deflect. rings
Gluing of P. gauge and NanoBeacon on TOP
Piezo glued on BOTTOM
Mushroom glued on TOP
Electronics in TOP
Penetrator on TOP
Helium test
fiber routed on fiber tray
optical splice and test
PMTs in TOP structure
PMTs in BOTTOM structure
BOTTOM instrumentation
Functionality test
Gluing of the TOP structure on mushroom
Gel pouring on TOP
Gel pouring on BOTTOM
Closure and sealing with collar
Acceptance test

Currently the KM3NeT project has 8 different DOM integration sites

They allows a production rate of about 100 DOMs per month.

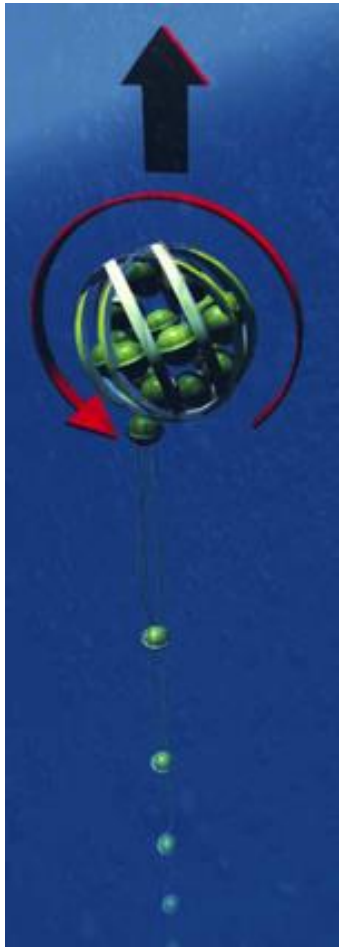
KM3NeT marine deployment principle

At the DU integration site 18 DOM are connected to a 700-m cable for power and data transmission and to the ropes to compose a string (DU)

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

The launcher vehicle starts to rise to the surface while slowly rotating and releasing the DOMs.

A vessel is used to deploy the launcher vehicle on the seabed with a 1-m accuracy



PNRR Activity 2.4: upgrade of the Catania DOM integration site in order to increase the mass production rate.

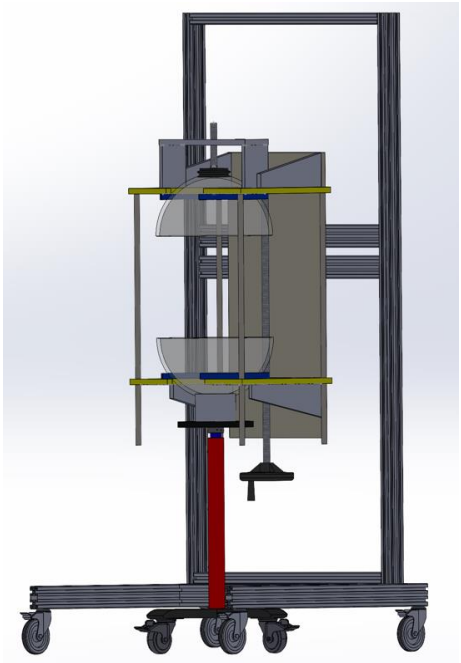
Design and construction of new tools and scientific instruments to speed up the production

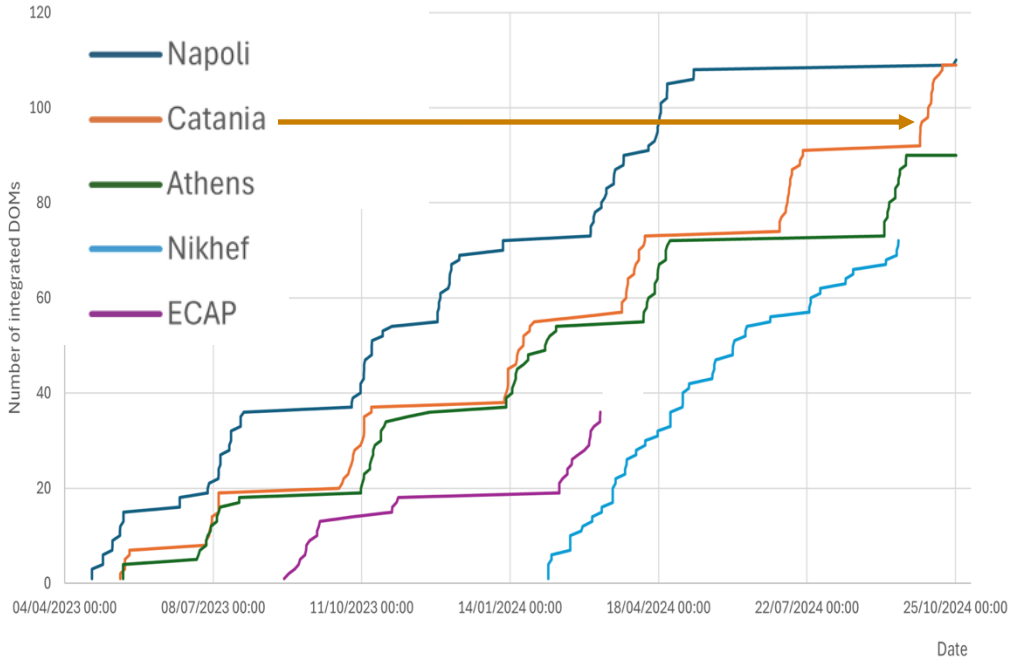
- purchasing of gel mixing machines
- design and construction of machines to rotate and close the DOM

Increasing the technical personnel full-time working in integration

- high skills required: electronic, optical and mechanical procedures

Construction of a second DOM site to proceed with a parallel production





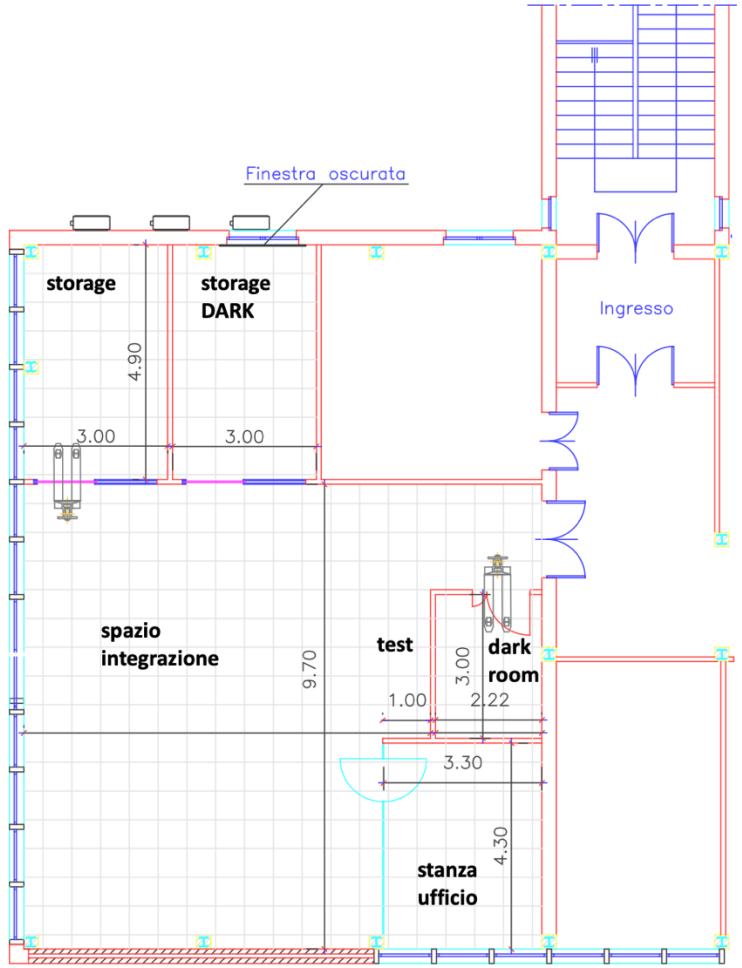
Catania DOM production from May 2023:

- **stable production rate of 5 DOM/week**
- **over 120 DOMs produced**

Construction of the second DOM integration site

- The civil infrastructure already exists at 1^ floor of Edificio 10 of Cittadella Uiversitaria di Catania.
- Refurbished with all the KM3NeT requirements (Storage, Test room, LED illumination, antistatic floor, temperature and humidity control…)
- Equipped with all the tools and scientific instrumentation
- An external lift has been constructed for moving all the components and the produced DOM

5 purchasing procedures for building, tools and instrumentation: 450 k euros

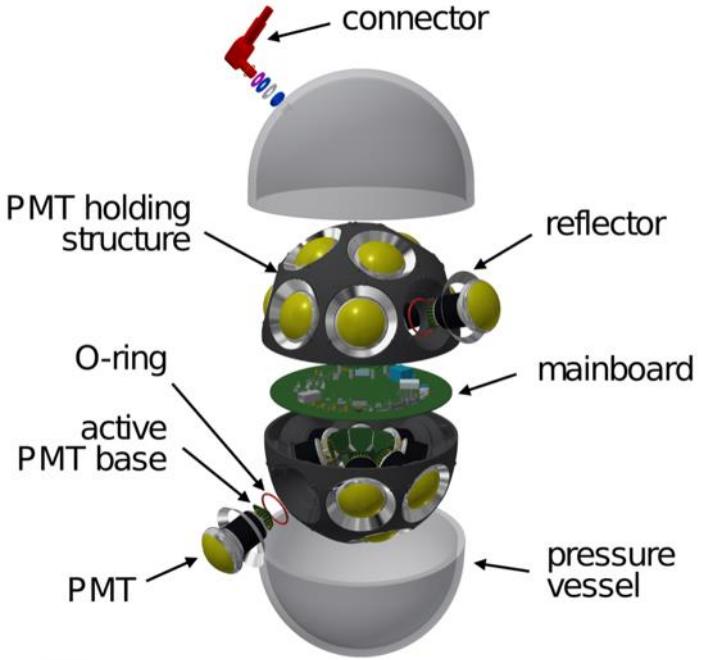


KM3NeT Multi-PMT layout: a design for next Water Cherenkov detectors

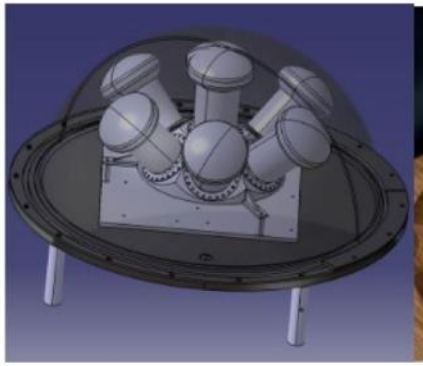
A multi-PMT Optical Module for the IceCube Upgrade

Lew Classen, Alexander Kappes, Timo Karg (for the IceCube Collaboration)

Following the first observation of an astrophysical high-energy neutrino flux with the IceCube Neutrino Observatory in 2013 and the identification of a first cosmic high-energy neutrino source in 2017, the detector will be upgraded with about 700 new advanced optical sensors. This will expand IceCube's capabilities both at low and high neutrino energies. A large fraction of the upgrade modules will be multi-PMT Digital Optical Modules, mDOMs, each featuring 24 three-inch class photomultiplier tubes (PMTs) pointing uniformly in all directions, thereby providing an almost homogeneous angular coverage. The signal from each PMT is digitized individually, providing directional information for the incident photons. Together, the 24 PMTs provide an effective photosensitive area more than twice than that of the current IceCube optical module. The main mDOM design challenges arise from the constraints on the module size and power needed for the 24-channel high-voltage and readout systems. This contribution presents an mDOM design that meets these challenges and discusses the sensitivities expected from these modules.



SWGO
The Southern Wide-field Gamma-ray Observatory
[SWGO]
SOUTHERN WIDE-FIELD GAMMA-RAY OBSERVATORY



Multi-PMT modules for Hyper-Kamiokande

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Hyper-Kamiokande, a 260 kton water Cherenkov detector to be built in Japan, is the next generation of the Super-Kamiokande experiment. Its broad physics program includes nucleon decay, neutrinos from astronomical and human-made beam, with the main focus to determine the leptonic CP violation. To detect the weak Cherenkov light generated by neutrino interactions or proton decay, the primary photo-detector candidate are 20-inch "Box & Line" PMTs (Hamamatsu R12860). In order to enlarge Hyper-Kamiokande physics program, the use of multi-PMT modules is considered as a complement of the primary candidates. A multi-PMT Optical Module based on a pressure vessel instrumented with multiple small diameter photosensors, readout electronics and power, offers several advantages as weaker sensitivity to Earth's magnetic field, increased granularity, reduced dark rate, improved timing resolution and directional information with an almost isotropic field of view.
We will present the multi-PMT module developed for Hyper-Kamiokande and its near detector, E61, as well as the measurement of the performances of its individual 3-inch PMTs (R14374). We will finally show the impact of these modules in Hyper-Kamiokande physics in both the high and low energy sectors.

KEYWORDS: Neutrino, Hyper-Kamiokande, Multi-PMTs, R14374











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Thanks for your attention

…all of you are invited to visit the new DOM integration site at Edificio 10 !!!