KM3NeT
Opens a new window on our universe

The KM3NeT Digital Optical Module

TIPP 2017 - International Conference on Technology and Instrumentation in Particle Physics
Beijing, People's Republic of China – May 22-26, 2017

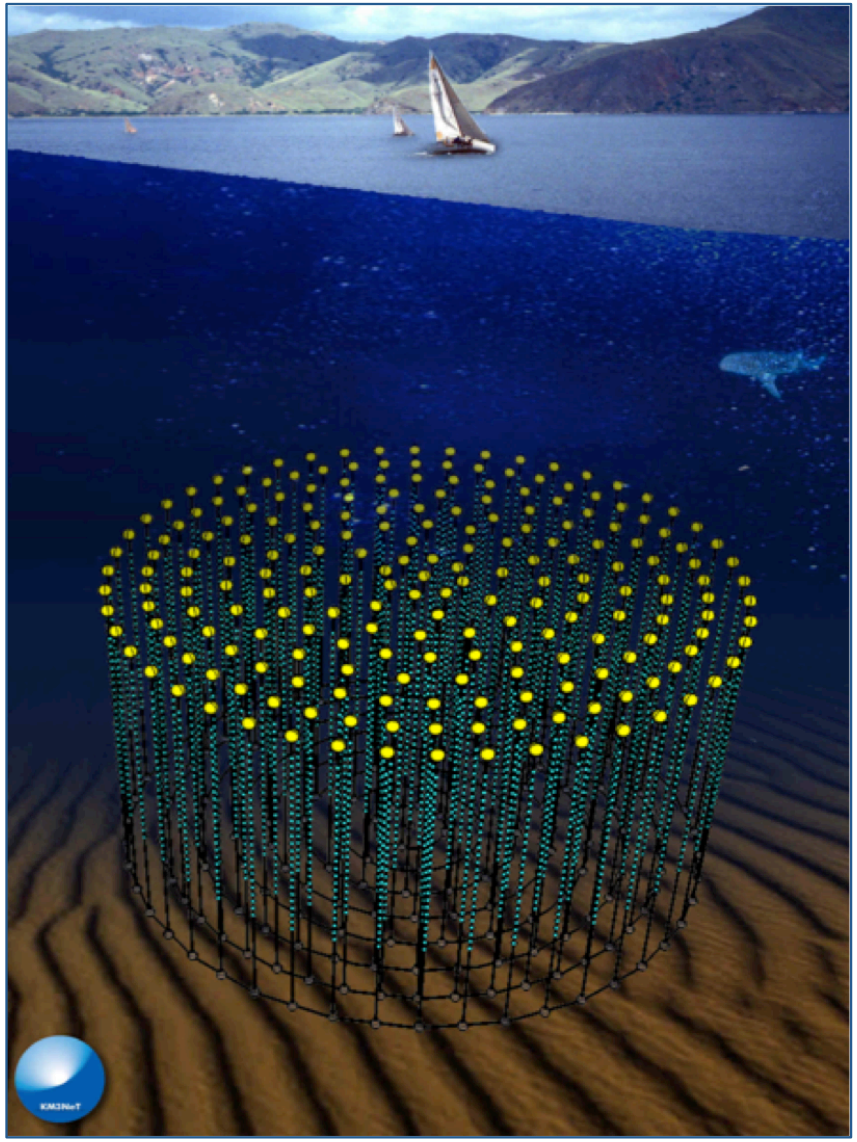
Daniele Vivolo
INFN Section of Naples

Outline

KM3NeT
Opens a new window on our universe

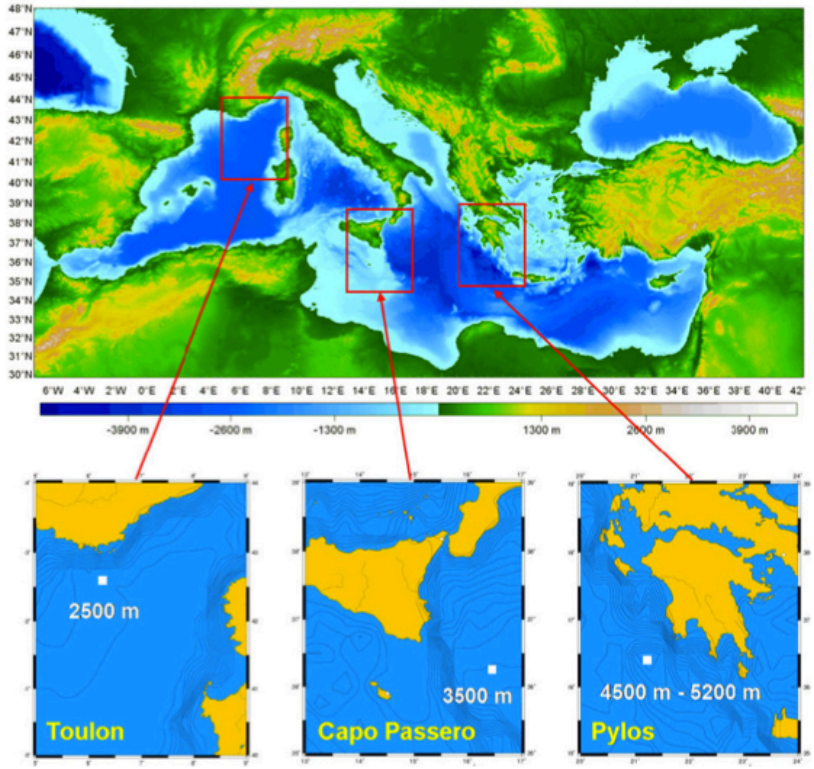
- Highlights on KM3NeT;
- the Multi-PMT concept;
- DOM components

KM3NeT
Opens a new window on our universe



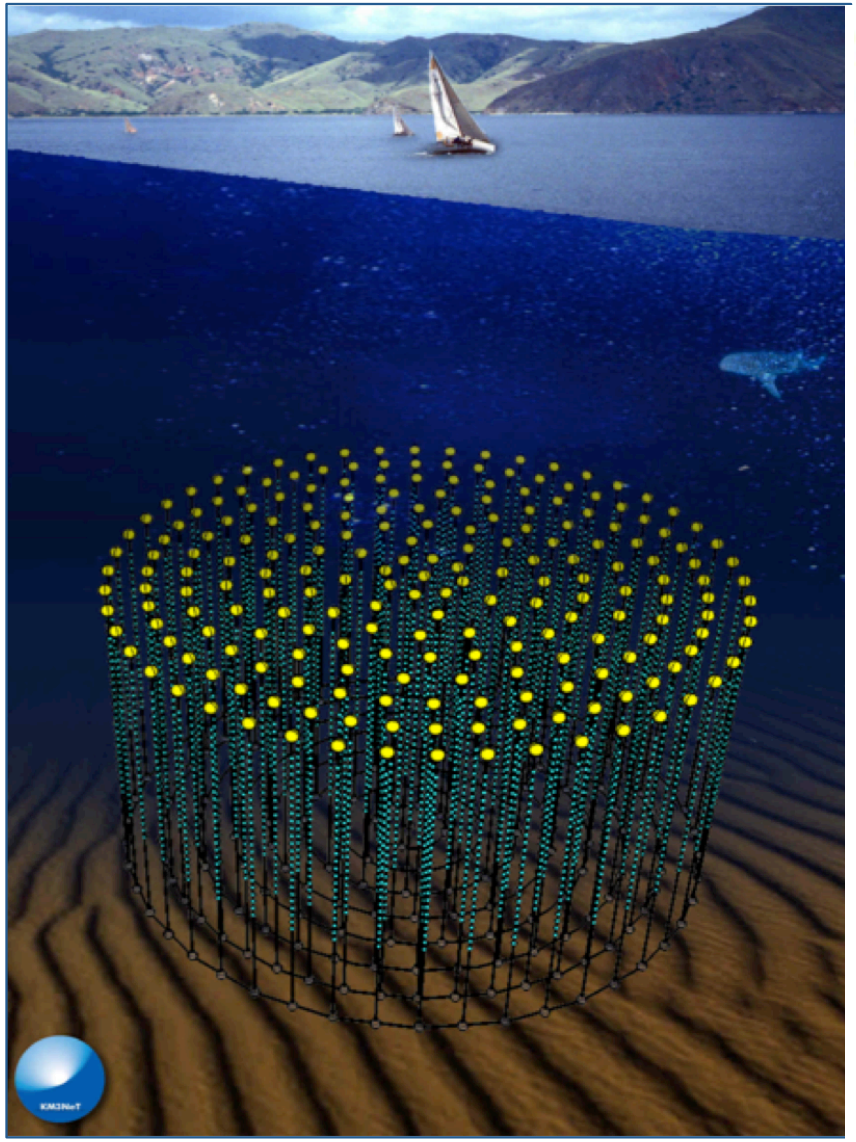
Deep-sea research infrastructure

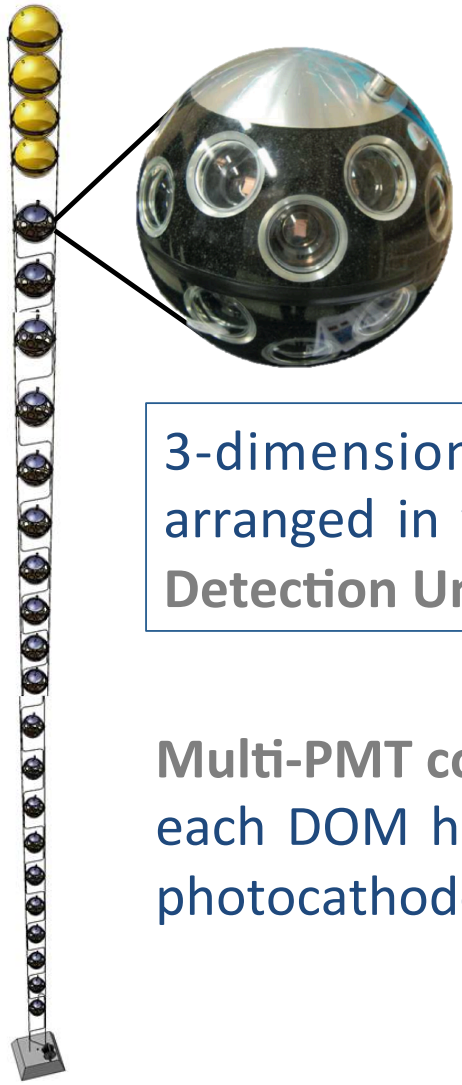
km^3-scale neutrino telescope in the Mediterranean Sea



Multi-site installation

KM3NeT
Opens a new window on our universe





Digital Optical Module (DOM)

3-dimensional array of DOMs arranged in vertical strings, called **Detection Units (DUs)**

Multi-PMT concept
each DOM hosts 31 PMTs with 3” photocathode surface

The Multi-PMT concept

KM3NeT
Opens a new window on our universe

KM3NeT Digital Optical Module

VS

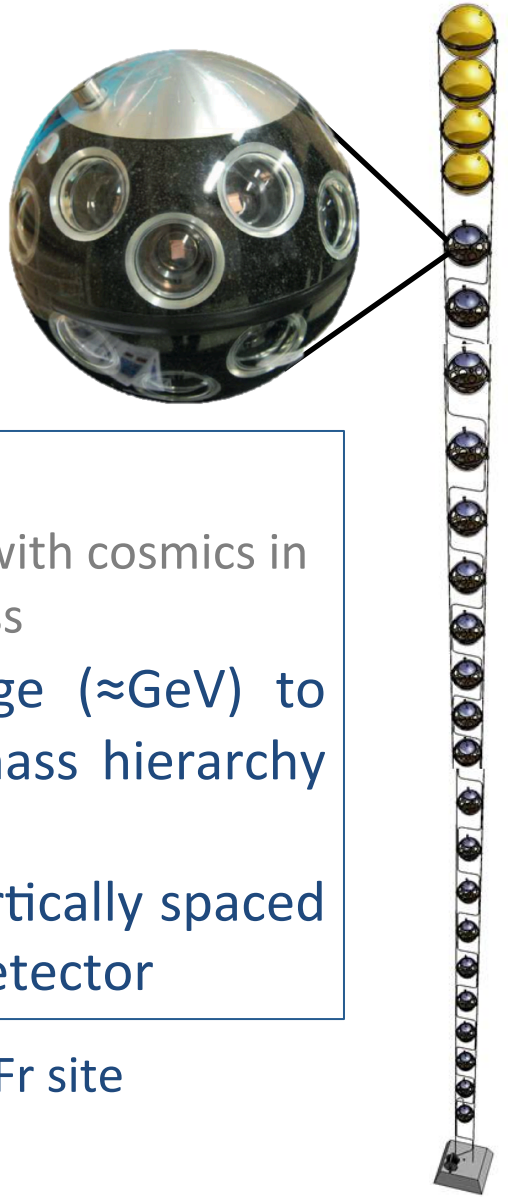
ANTARES Optical Module

Advantages:

- Photocathode **area** increased by a factor of three compared to a design with a single 10 inch PMT ➔ cost reduction;
- segmentation allows **photon-counting** with high background rejection already at DOM level (based on coincidences);
- **directional** information;
- almost **isotropical angular coverage** (PMT orientations ranging from vertically down to upwards at an angle of 58° from horizontal);
- small PMTs ➔ better timing and amplitude measurement characteristics

KM3NeT
Opens a new window on our universe

Phase 1 (currently ongoing) construction of two detectors



ARCA

Astroparticle Research with cosmics in the Abyss

- High energy (> TeV) cosmic neutrinos
- DU: 18 DOMs vertically spaced by 36 m

24 DUs in the KM3NeT-It site
total volume: ≈0.1 km3 (3 x ANTARES)

ORCA

Oscillation Research with cosmics in the Abyss

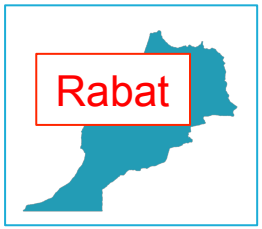
- Low energy range (≈GeV) to determine the mass hierarchy of neutrinos
- DU: 18 DOMs vertically spaced by 6 m, denser detector

7 DUs in the KM3NeT-Fr site

DOM integration sites

KM3NeT
Opens a new window on our universe

- 5 DOM integration sites over 4 countries are already fully functioning;
- 3 DOM integration sites are in preparation (ready before end 2017);
- DOM design and integration procedure have been finalized;
- 3 Detection Units already integrated, 12 are on the bench;
- Mass production rate (36 DOMs in 2 months) has been tested. Ready for mass production

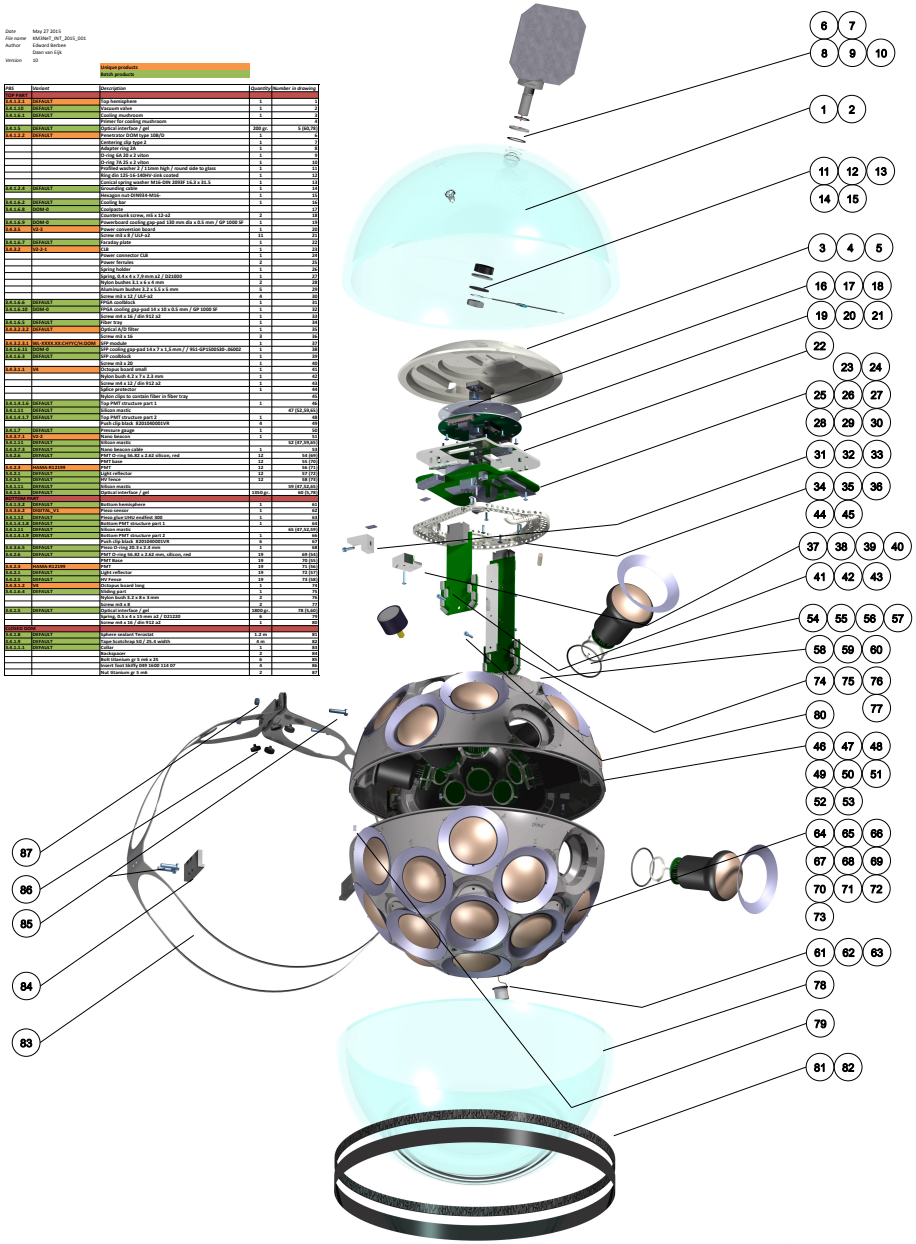


KM3NeT
Opens a new window on our universe

Exploded view

DOM components

- 31 three-inch PMTs
- Power system
- Digitization and communication electronics
- Fibre-optic communication system
- Acoustic sensor for positioning
- Nanobeacon
- Compass/tiltmeter

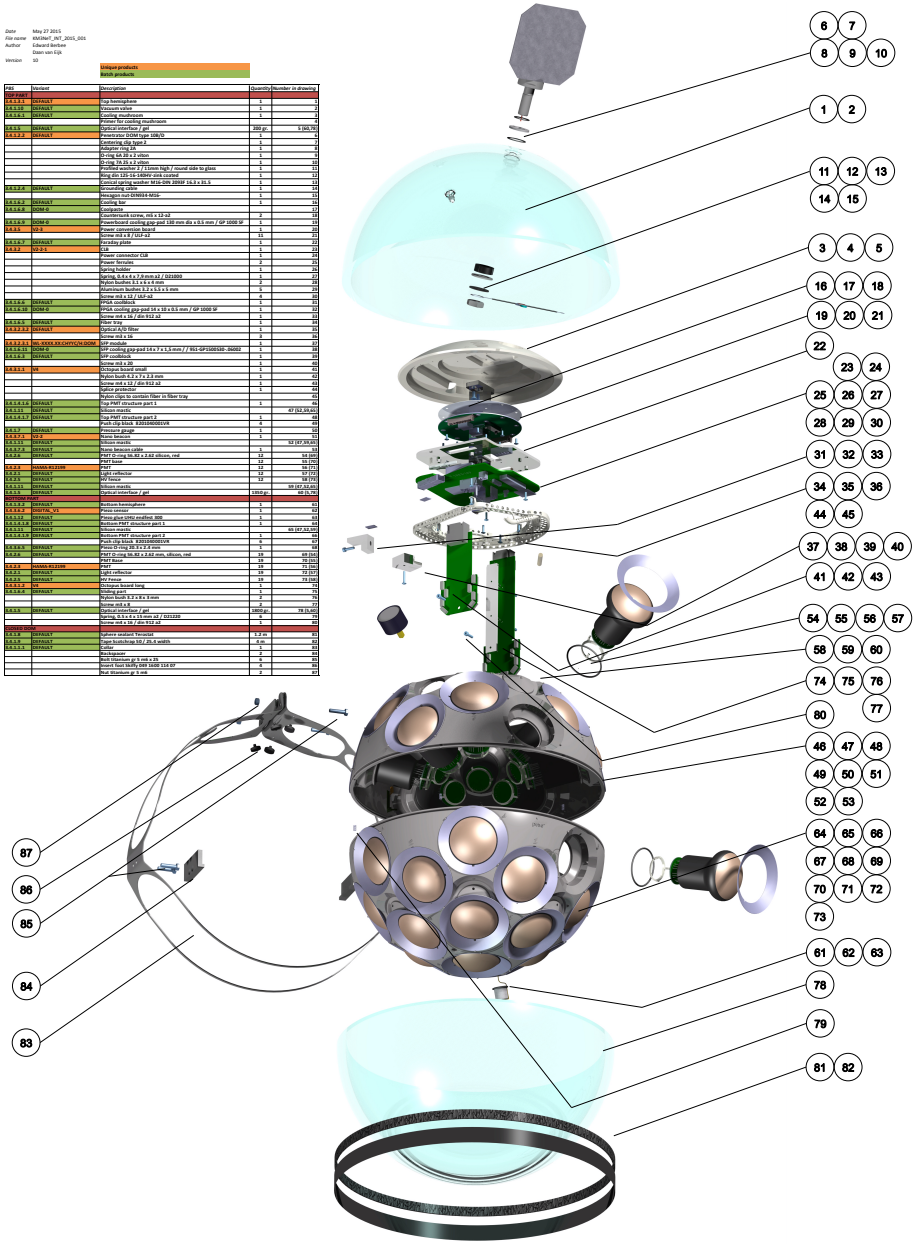


KM3NeT
Opens a new window on our universe

Exploded view

Outline

- Glass sphere;
- cooling system;
- penetrator;
- PMT support structure;
- PMTs and PMT bases;
- collection rings;
- octopus boards;
- Central Logic Board.



KM3NeT
Opens a new window on our universe

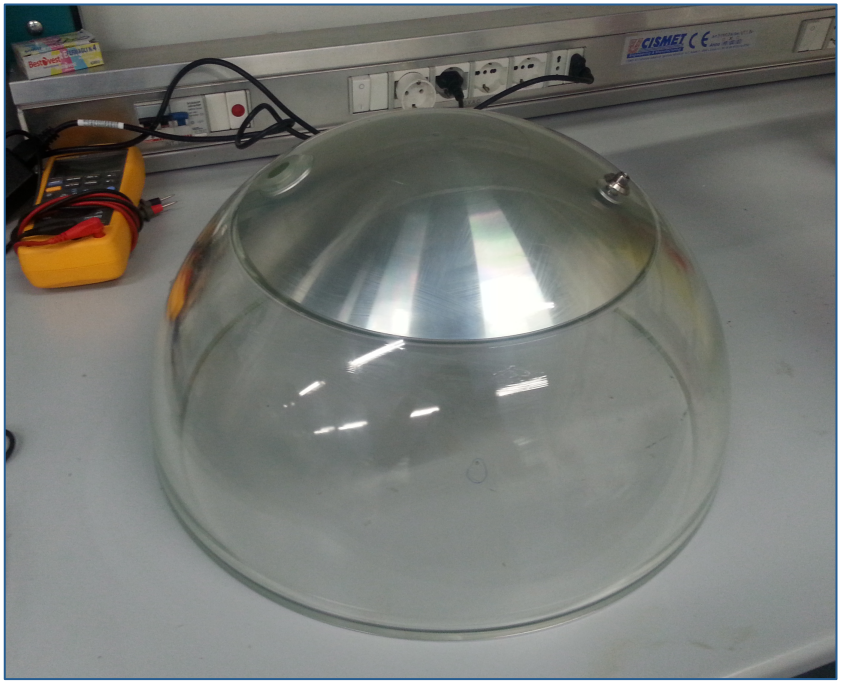
Glass spheres

17-inch, 14mm thick borosilicate glass (Vitrovex) spheric vessel

Two hemispheres

Requirements

- Mechanical resistance to the extreme compressive stresses of deep-sea environment
  (hydrostatic pressure up to 500 bar)
- Low activity
- Good transparency
  - refractive index: 1.47,
  - transmissivity: > 95% at a λ = 350 nm
- Resistance to corrosion, shocks and vibrations

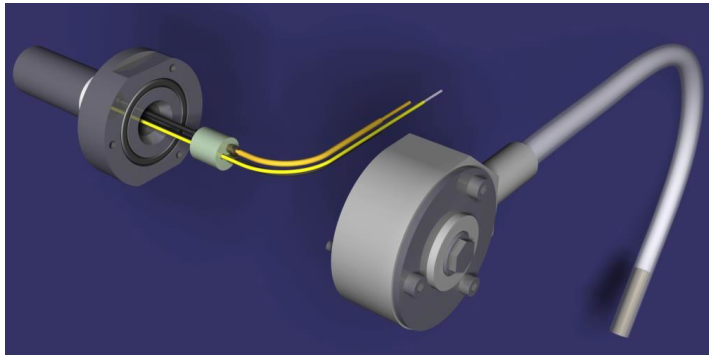


KM3NeT
Opens a new window on our universe

Glass spheres: cooling mushroom and penetrator

17-inch, 14mm thick borosilicate glass (Vitrovex) spheric vessel

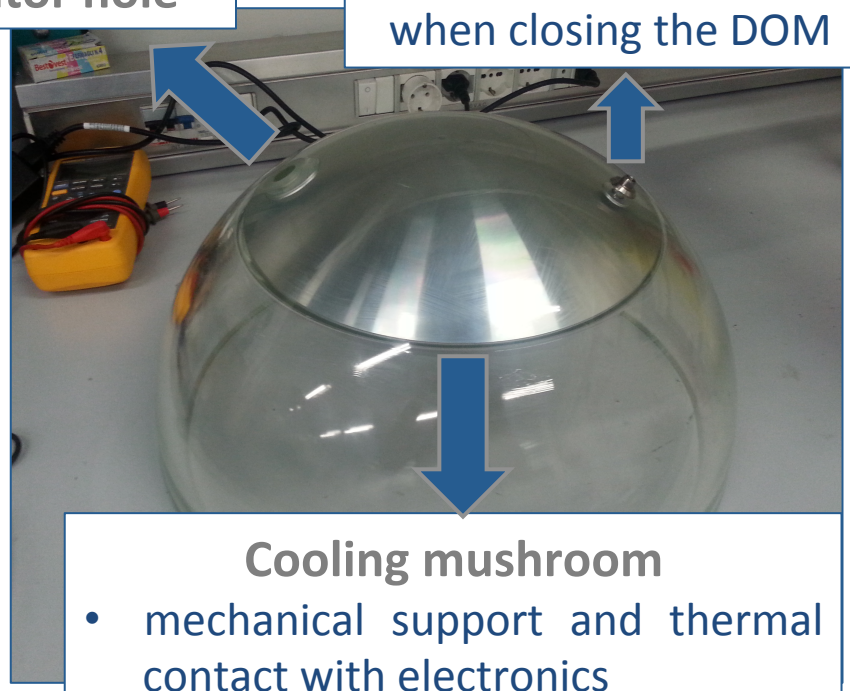
Penetrator



- Custom-designed
- Titanium housing
- Feedthrough for two power cables and one optical fibre for bi-directional communication

Penetrator hole

Vacuum valve
0.2 bar underpressure when closing the DOM



Cooling mushroom

- mechanical support and thermal contact with electronics
- keeps T below 30°C for an overall power dissipation of up to 20 W.

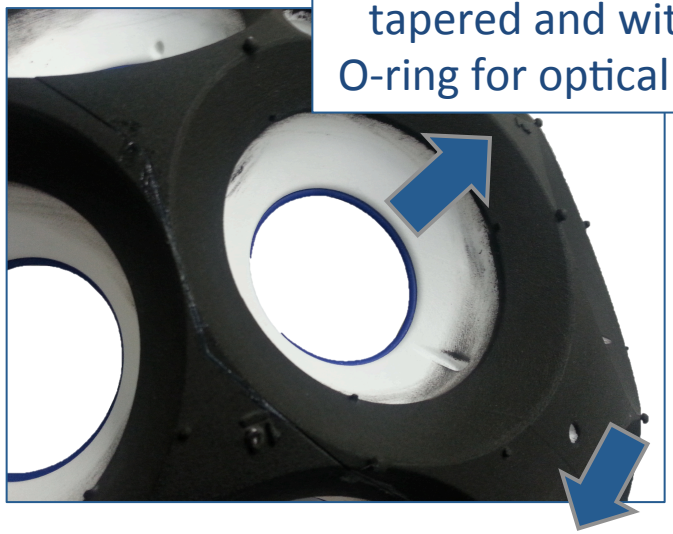
KM3NeT
Opens a new window on our universe

PMT support structure

Nylon 3D-printed (SLS) custom design with the selective laser sintering method

Main functions:

- structural support for PMTs, defining positions and distances from glass;
- housing for accessory instrumentation;
- guides for integration



PMT housing
tapered and with a silicone O-ring for optical gel tightness

Mount for reflector rings

KM3NeT
Opens a new window on our universe

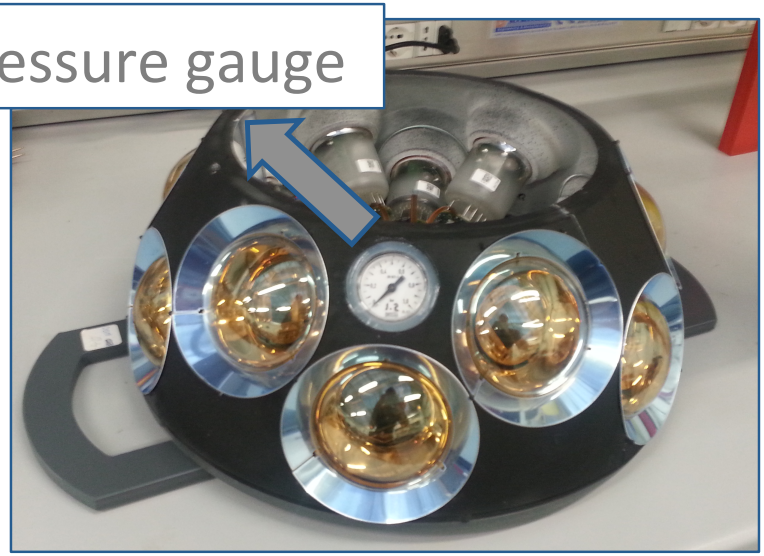
PMT support structure/2

Nylon 3D-printed (SLS) custom design with the selective laser sintering method

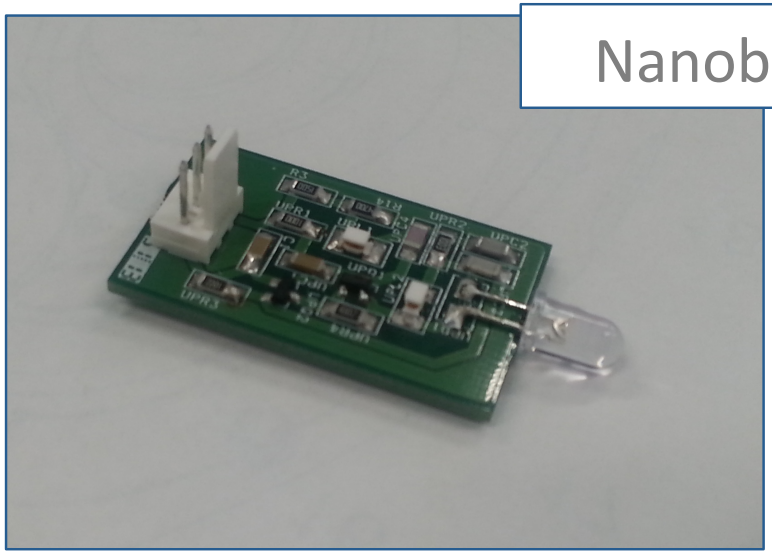
Upper hemisphere

- 12 PMTs;
- nanobeacon: LED flasher (470nm) with adjustable frequency and intensity pointing upwards for timing calibration between DOMs;
- pressure gauge to monitor the pressure inside the DOM

Pressure gauge



Nanobeacon



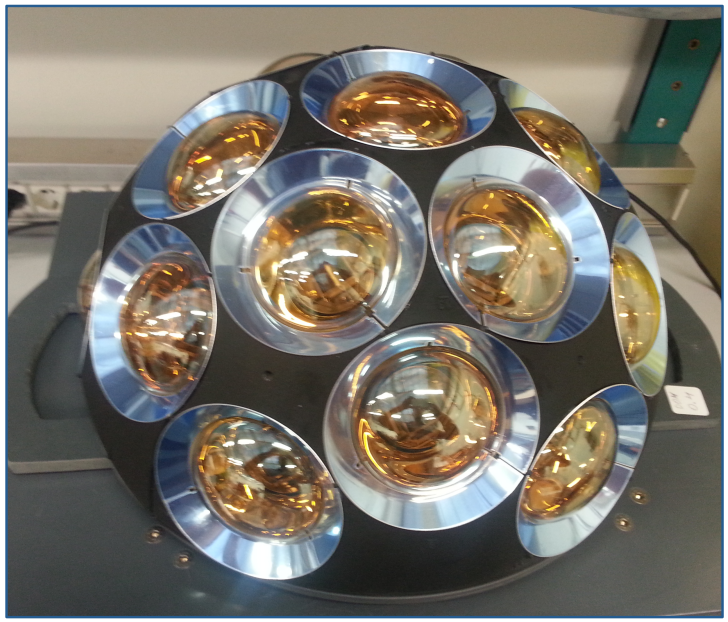
KM3NeT
Opens a new window on our universe

PMT support structure/3

Nylon 3D-printed (SLS) custom design with the selective laser sintering method

Lower hemisphere

- 19 PMTs;
- feedthrough for the piezo sensor (piezo) attached to the glass sphere, for acoustic positioning



DOM Components

KM3NeT
Opens a new window on our universe

The PMT adopted for KM3NeT 1.0

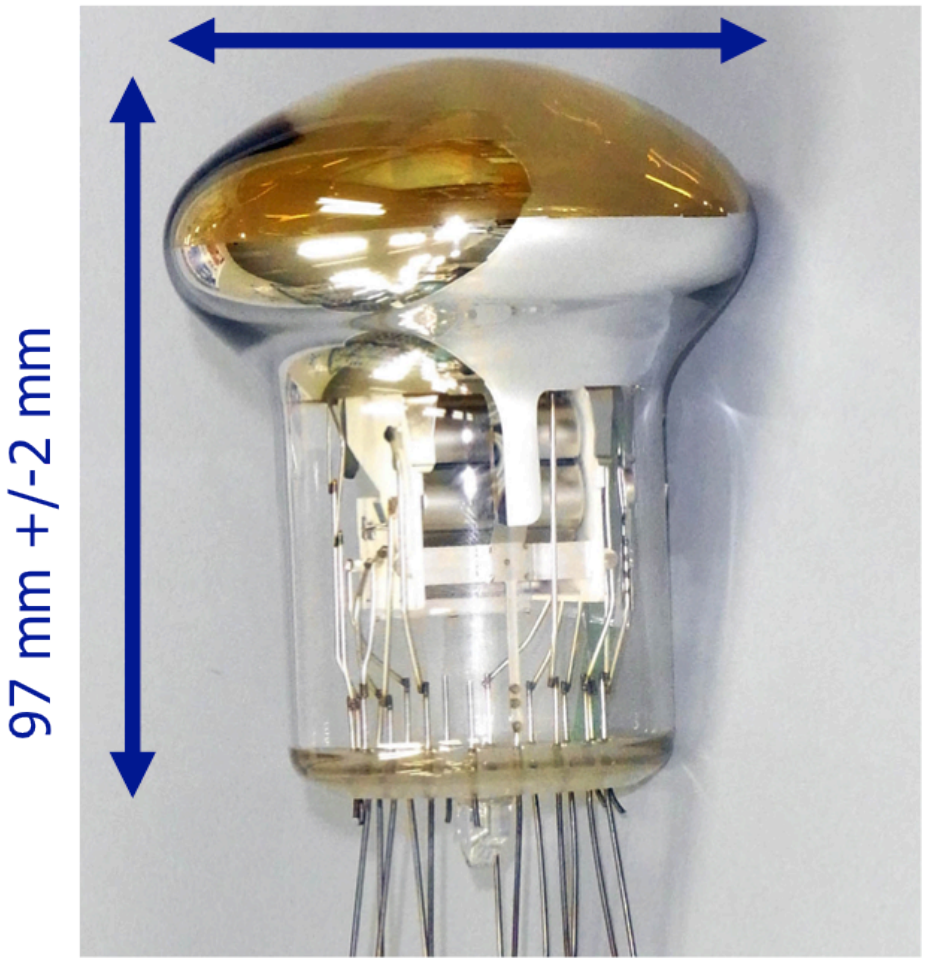
HAMAMATSU
PHOTON IS OUR BUSINESS

Type Number: R12199-02
Outer Diameter: 80 mm
Length: 97 mm
Window Shape: Concave-Convex
Window Material: Borosilicate Glass
Photocathode Material: Bialkali
Number of Dynode Stages: 10

KM3NeT 1.0 requirements

Quantum Efficiency: 22% at 470 nm, 27% at 404 nm
Transit Time Spread (TTS): < 5 ns (FWHM)
Time-Over-Threshold (ToT): 26.4 ns for a single photoelectron
Gain: 3 x 10^6
Dark count rates: 200-1500 Hz @ 0.3 photoelectrons threshold
Total in-situ count rate: 5-10 kHz
Peak to valley ratio: >3

PhotoMultiplier Tubes

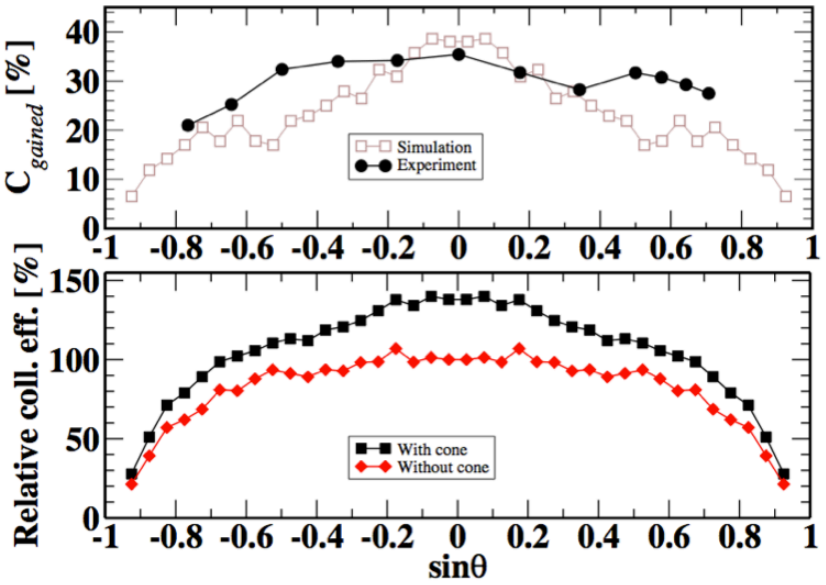


KM3NeT
Opens a new window on our universe

PMT reflector rings

Each PMT is surrounded by a reflector ring, designed to collect the photons that would otherwise miss the photocathode

- Aluminium structure,
- 45° tilted reflective surface improved by silver evaporation
- maximized effective sensitive surface

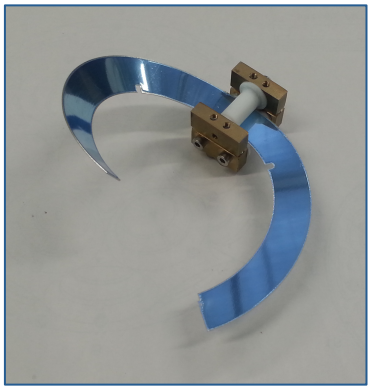
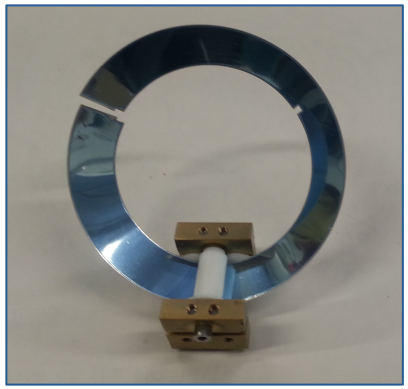
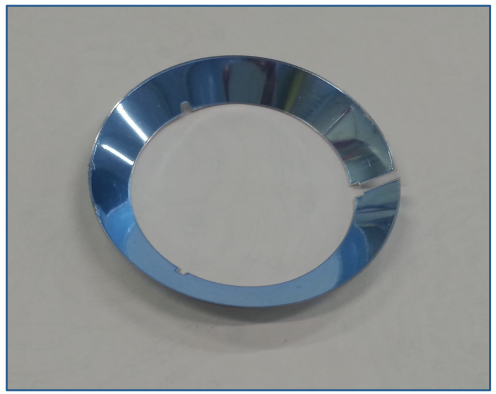


KM3NeT
Opens a new window on our universe

PMT reflector rings

Each PMT is surrounded by a reflector ring, designed to collect the photons that would otherwise miss the photocathode

- Aluminium structure,
- 45° tilted reflective surface improved by silver evaporation
- maximized effective sensitive surface
- custom tool for bending flat rings

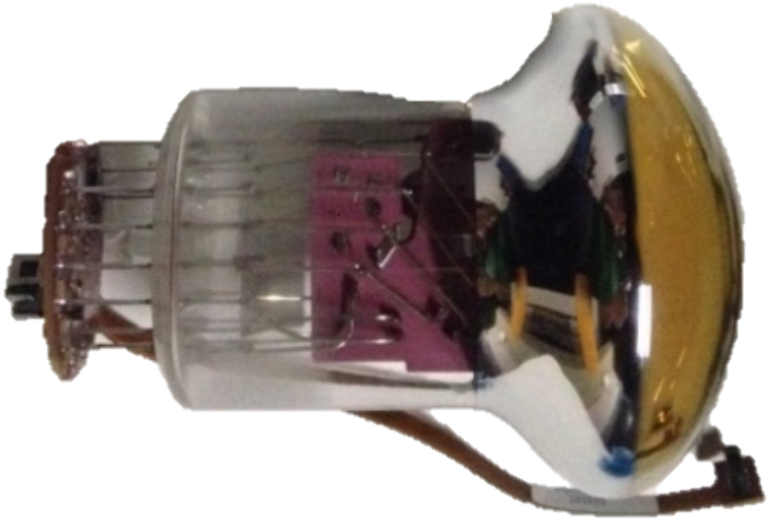





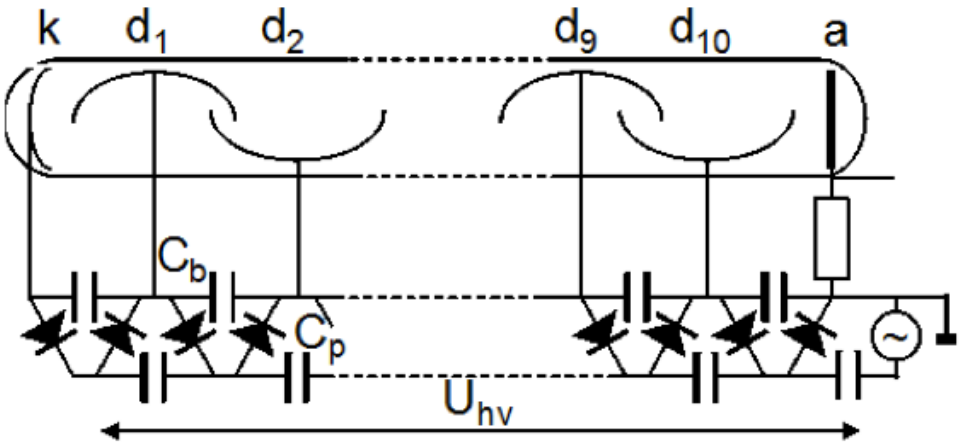
KM3NeT
Opens a new window on our universe

PMT base

Custom-design, low-power base

- High voltage fed to the PMTs generated from a 3.3 V DC;
- adjustable gain tuned to the operating HV of each PMT (controlled from shore);
- discriminate hits above variable thresholds, LVDS ToT readout (PROMIS ASIC);
- ASIC-controlled **Cockroft-Walton** circuit ("CoCo");
- I2C communication for HV and threshold setting and id. with unique number;
- low power dissipated by each PMT (ranging between 2 and 4.5 mW).





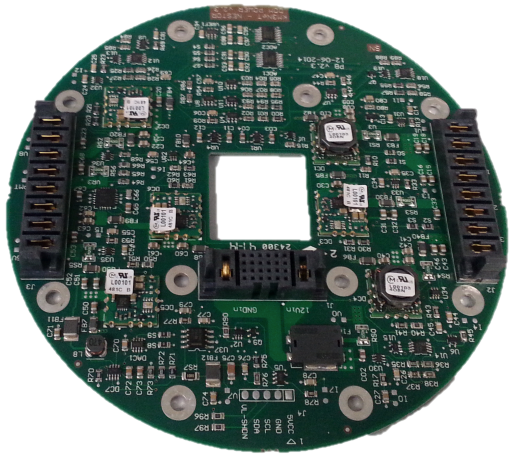
KM3NeT
Opens a new window on our universe

PMT electronics: power and octopus boards

Two signal collection boards (**octopus boards**) carry the LVDS signals from the PMT base to a **Central Logic Board** from where the signals are routed to an FPGA.

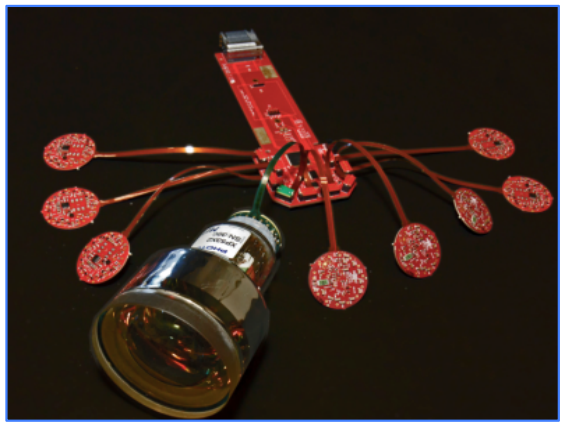
Power board:

- Feeds 12V from external DC/DC converter
- Supplies power to all systems
- Monitored and controlled



Small octopus board: connects the 12 PMT bases of the top hemisphere.

Large octopus board: connects the 19 PMT bases of the bottom hemisphere and the acoustic sensor.



KM3NeT
Opens a new window on our universe

PMT electronics: the Central Logic Board

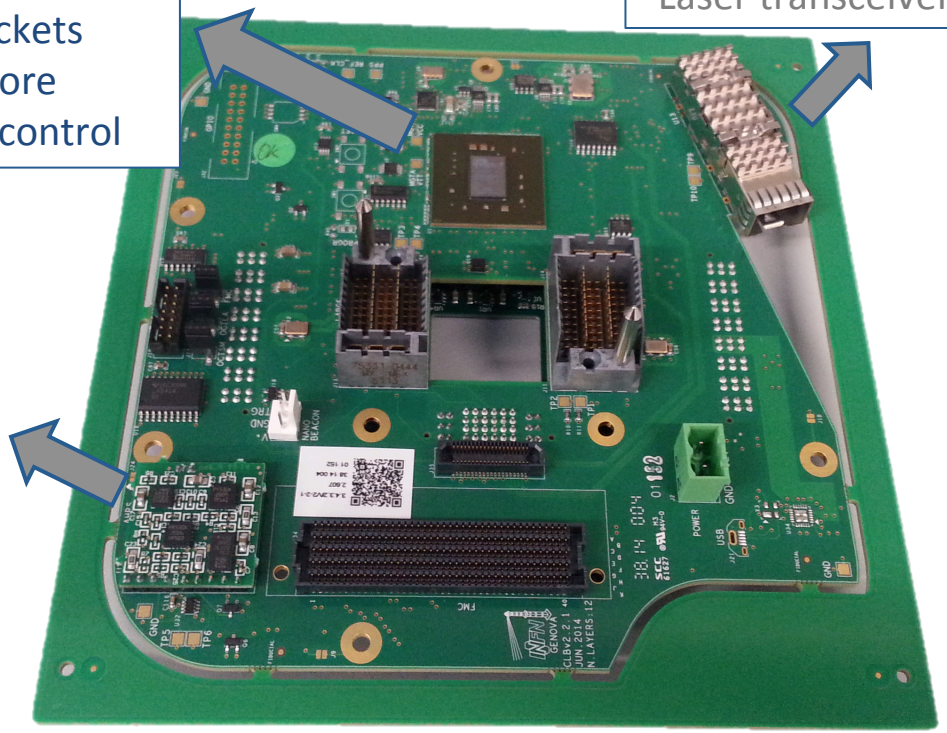
Main board for signal processing, communcation (IP) and control. All recorded photons are sent to shore

Temperature/humidity sensors

Laser transceiver cage

Xilinx Kintex 7 FPGA containing:

- TDC channels for PMTs and acoustic sensor
- pipeline to process all data to IP/UDP packets
- White-Rabbit precision timing protocol core
- LM32 processor for communication and control



AHRS mezzanine board

(attitude and heading reference system)

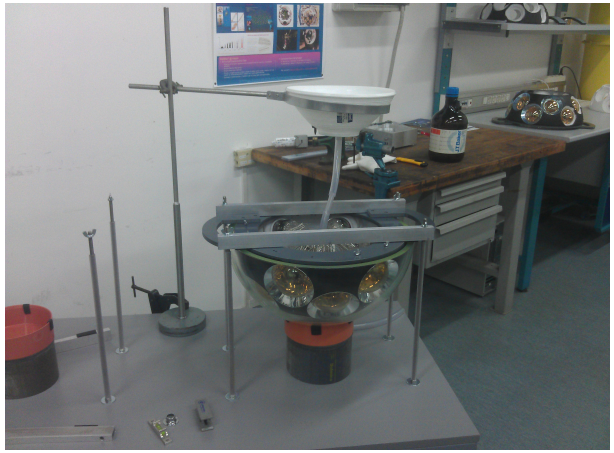
provides compass and tiltmeter data used to reconstruct the orientation and position of DOMs in water, in conjunction with the acoustic positioning system

KM3NeT
Opens a new window on our universe

Optical gel

The photomultipliers are glued in the glass vessel by means of a two-components transparent silicon optical gel (Wacker 612):

- refractive index ≈ 1.40, close to both the refractive indexes of the glass vessel (1.47) and of the PMT window (1.51-1.54)
- attenuation length greater than 40 cm for wavelengths above 350 nm
- fills the cavity between the support structure and the glass
- assures optical contact, reducing the unwanted reflections,
- provides absorption of the shocks and the vibrations induced by transportation and deployment
- contributies to accommodate the shrinkage of the glass vessel under the high hydrostatic pressure.



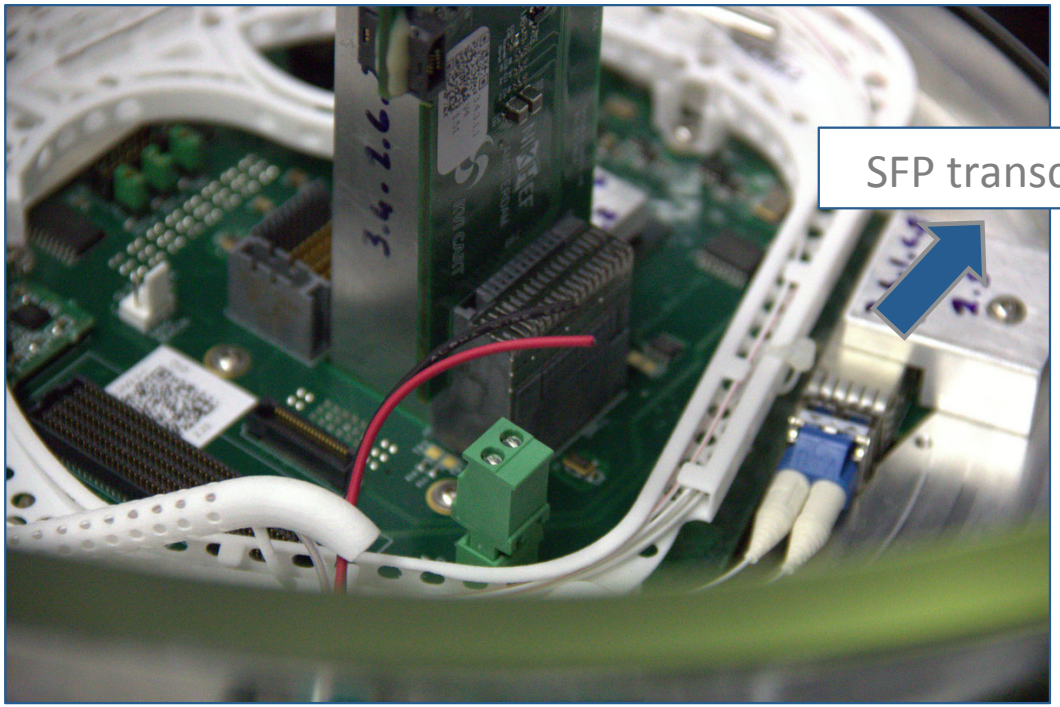
KM3NeT
Opens a new window on our universe

Fiber optics system

Single-mode laser transceiver installed in a Small Form-factor Plugable (SFP) cage on the CLB

- Each DOM within a detection unit uses a unique wavelength for transmitng data.
- Add/drop filter used to combine the transmit and receive channels onto the one fibre passing through the penetrator.

Splicing of optical fibres is required to create the connection between the SFP transceiver and the fibre leading to the outside through the penetrator.



Conclusions

KM3NeT
Opens a new window on our universe

The KM3NeT multi-PMT Digital Optical Module will offer an attractive solution to study cosmic neutrino sources and neutrino properties with an unprecedented accuracy.
A prototyping program has successfully concluded validating the DOM design and proving its performances in terms of

- photon counting,
- background rejection capabilities
- direction sensitivity.

DOM design and Integration procedure have been completed
Mass production rate of 18 DOMs in 2 months has been fixed (feasibility test has been passed).

Five DOM integration sites are ready to start the mass production of KM3NeT DOMs. Three more DOM integration sites are in preparation (expected to be ready by end 2017).