16TH PISA MEETING ON ADVANCED DETECTORS La Biodola, Isola d'Elba, May 26-June 1, 2024

The new KM3NeT Detection Units

Carlos Maximiliano Mollo (INFN Napoli)
On behalf of the KM3NeT Collaboration

KM3NeT

INFN
Istituto Nazionale di Fisica Nucleare

KM3NeT Collaboration

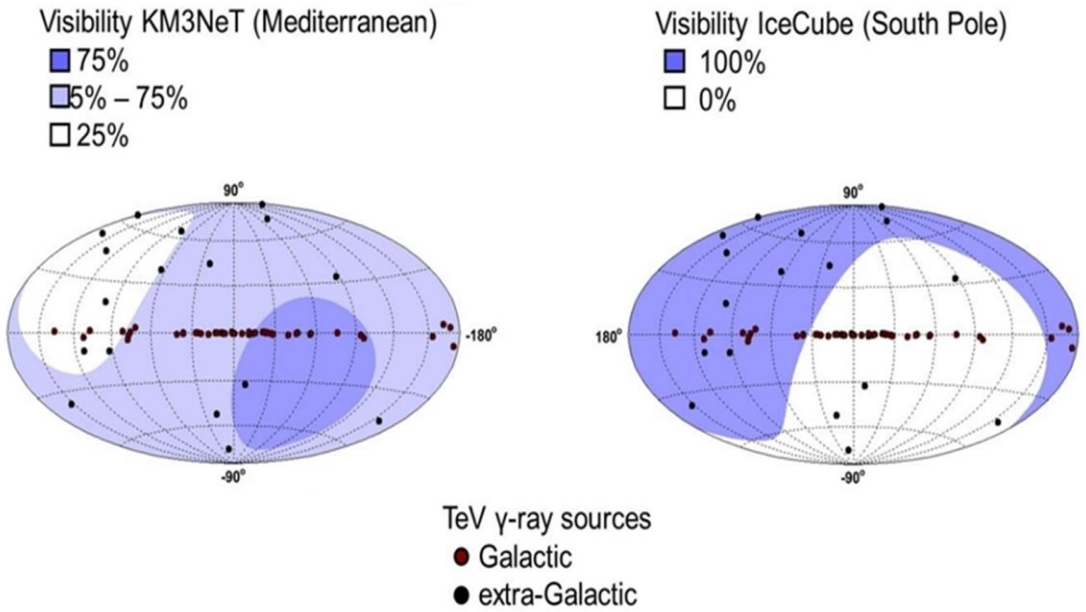
www.km3net.org

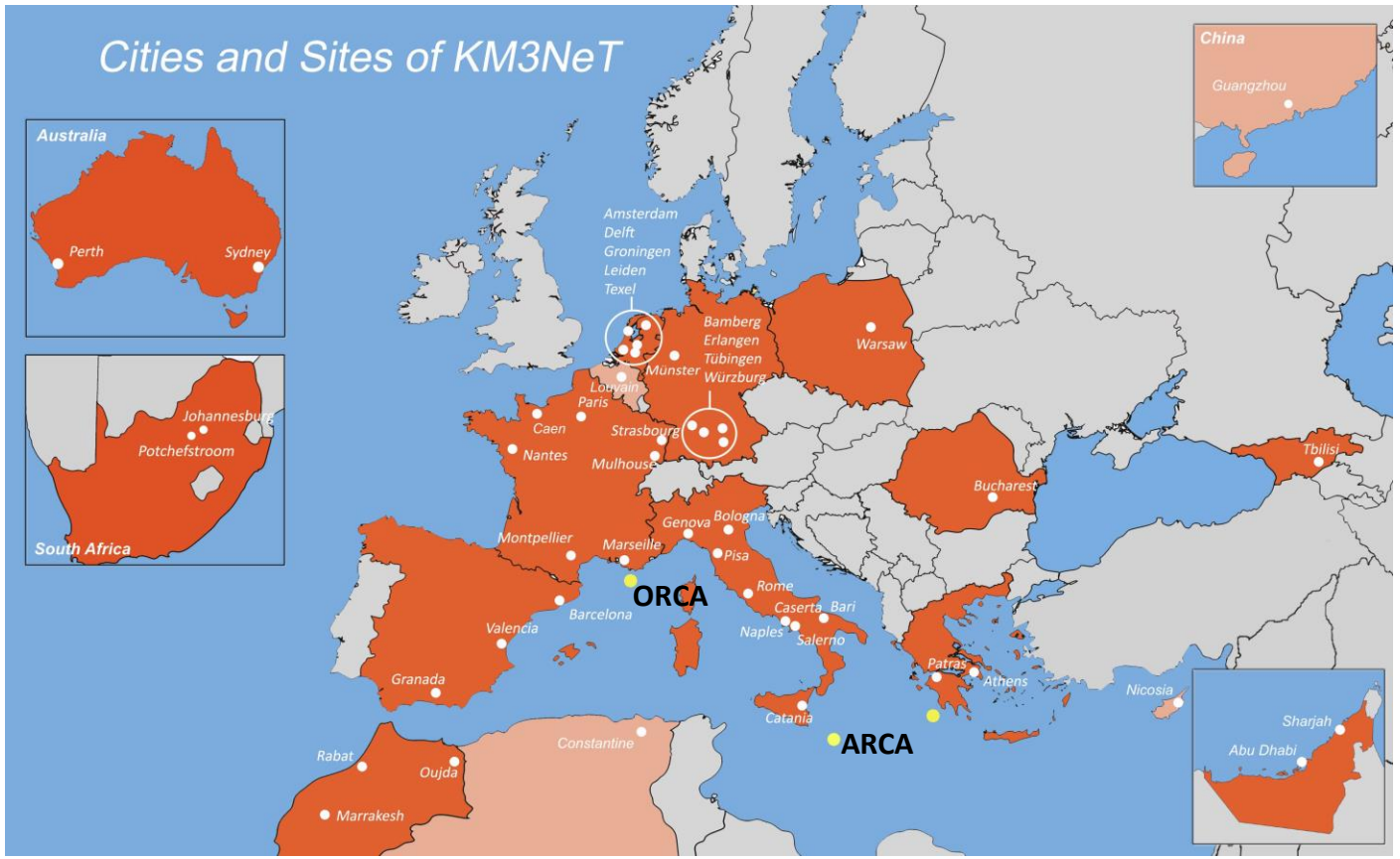
KM3NeT is a distributed, deep-sea, Cherenkov neutrino observatory under realization in the Mediterranean Sea with two detectors:

- ARCA, close to Italy, for neutrino astronomy
- ORCA, close to France, for the study of neutrino oscillations

KM3NeT in numbers

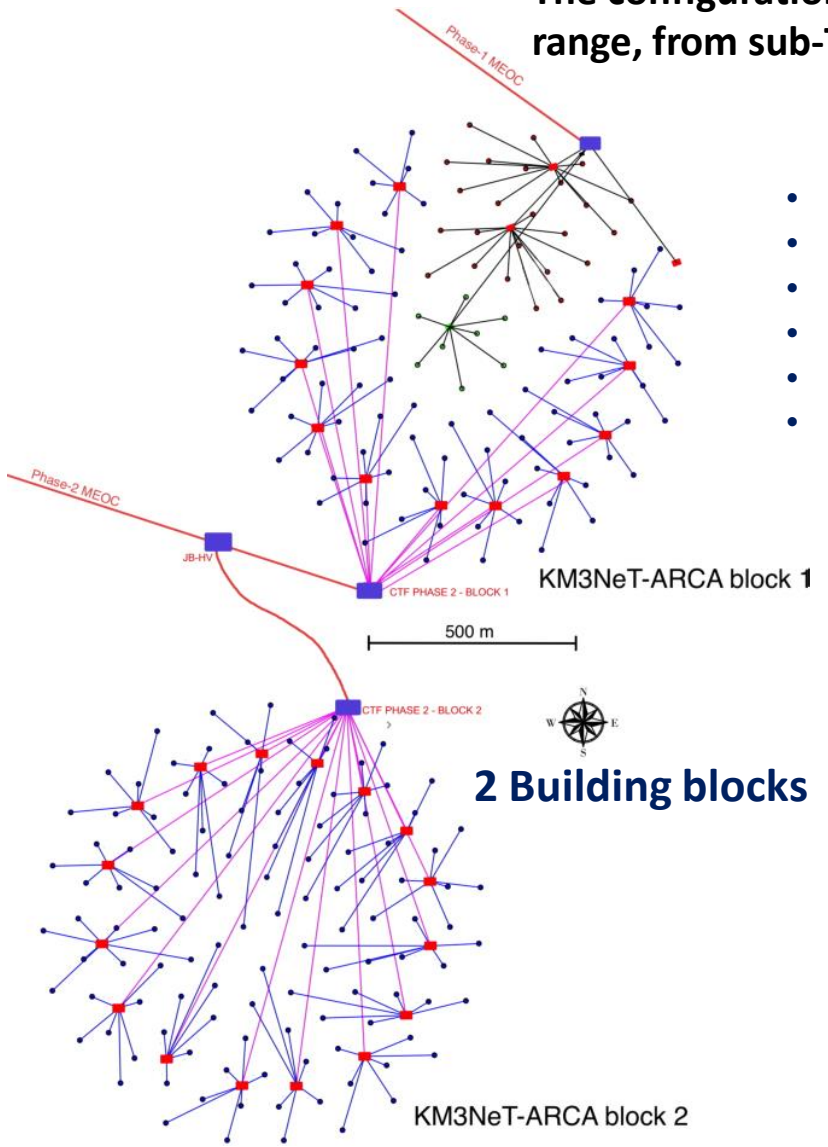
- **4 continents**
- **16 countries**
- **55 groups**
- **More than 220 scientists**





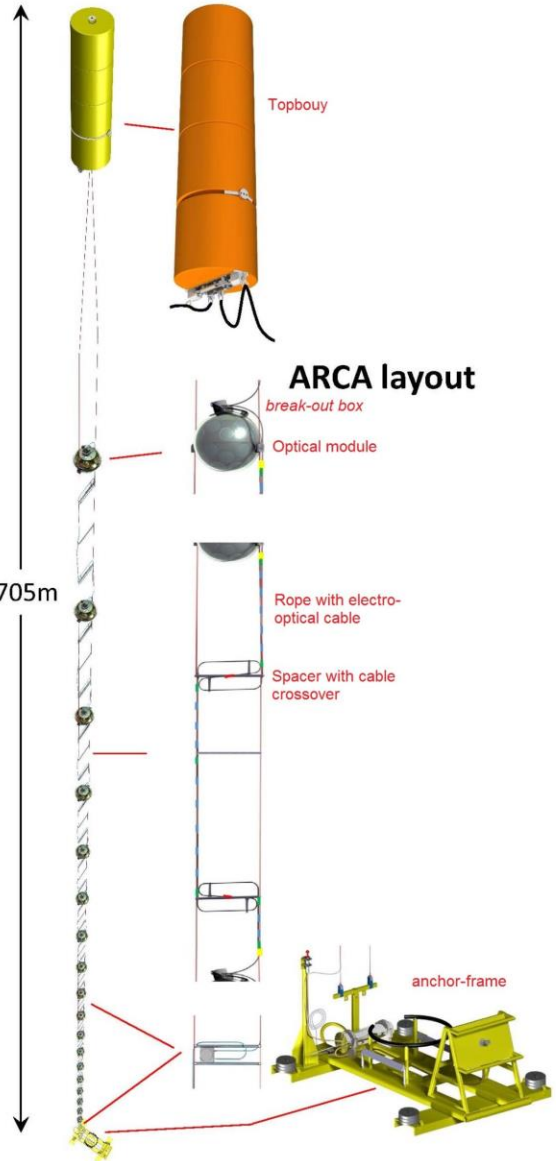
Astroparticle Research with Cosmics in the Abyss

The configuration of ARCA makes it sensitive to neutrinos in a wide energy range, from sub-TeV up to tens of PeV



2 Building blocks

- **2 Building Blocks**
- **115 Detection Units (DU) each**
- **18 Digital Optical Modules (DOM) per DU**
- **Total active volume 1 km^3, ≈ 500 Mton/block**
- **3500 m depth**
- **2 Main Electro-Optical Cables (MEOC) for connection to shore**



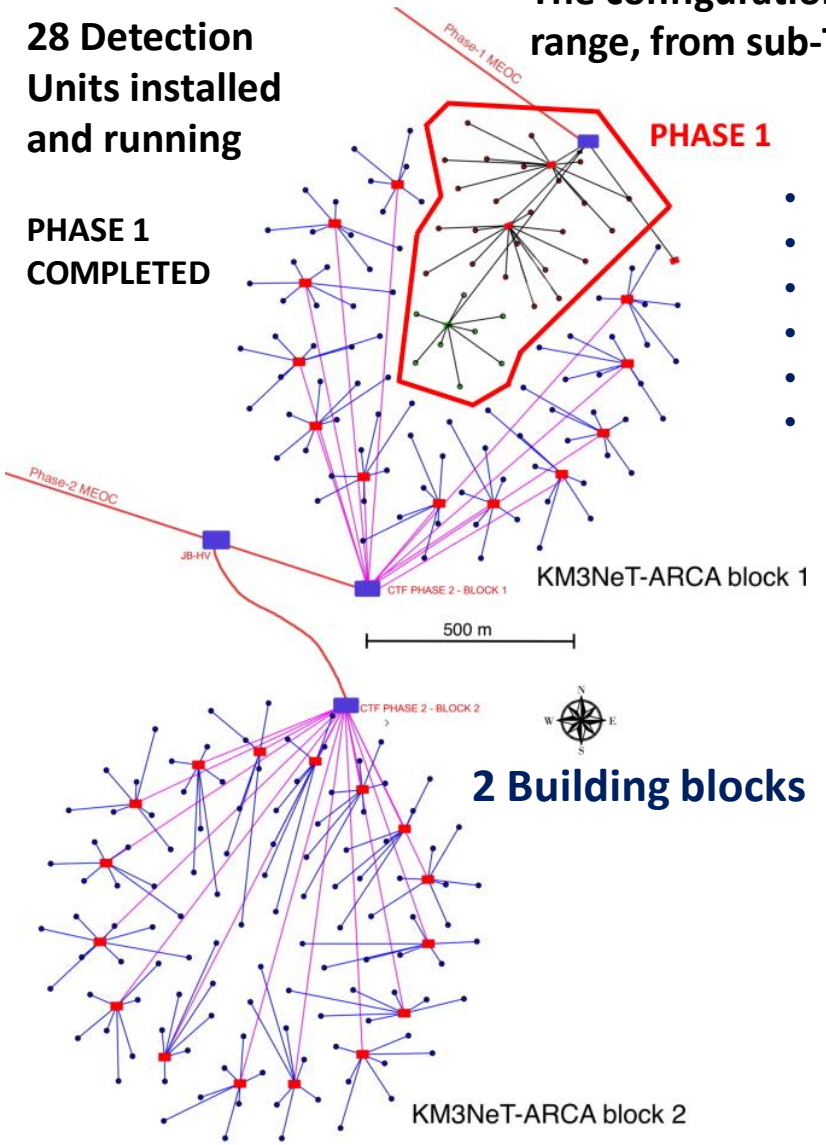
Spacing between DOMs = 36 m
Spacing between DUs = 90 m

Astroparticle Research with Cosmics in the Abyss

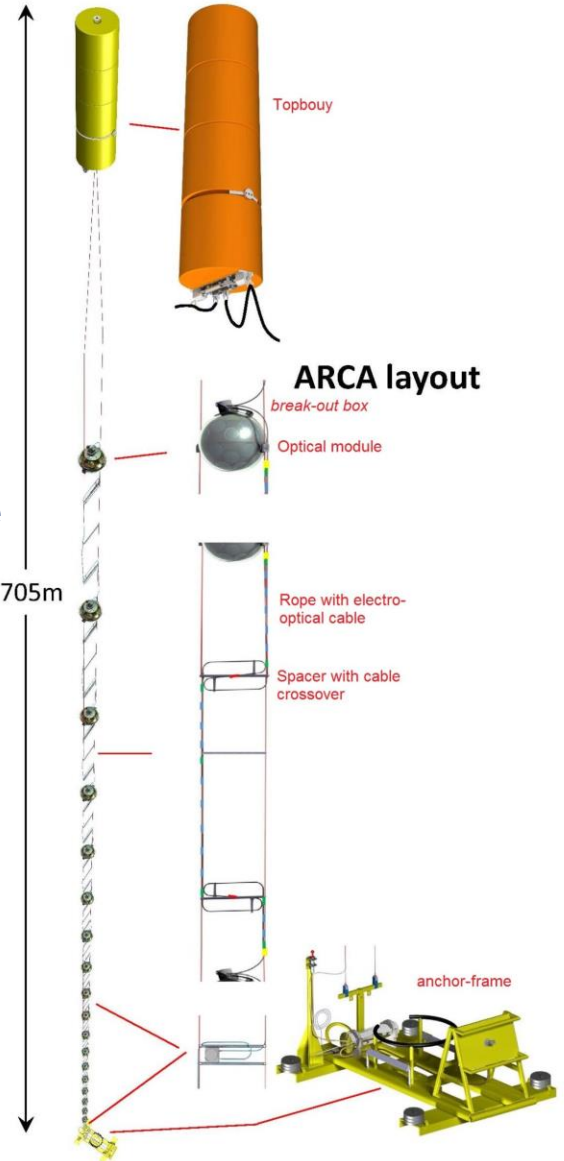
The configuration of ARCA makes it sensitive to neutrinos in a wide energy range, from sub-TeV up to tens of PeV

28 Detection Units installed and running

PHASE 1 COMPLETED



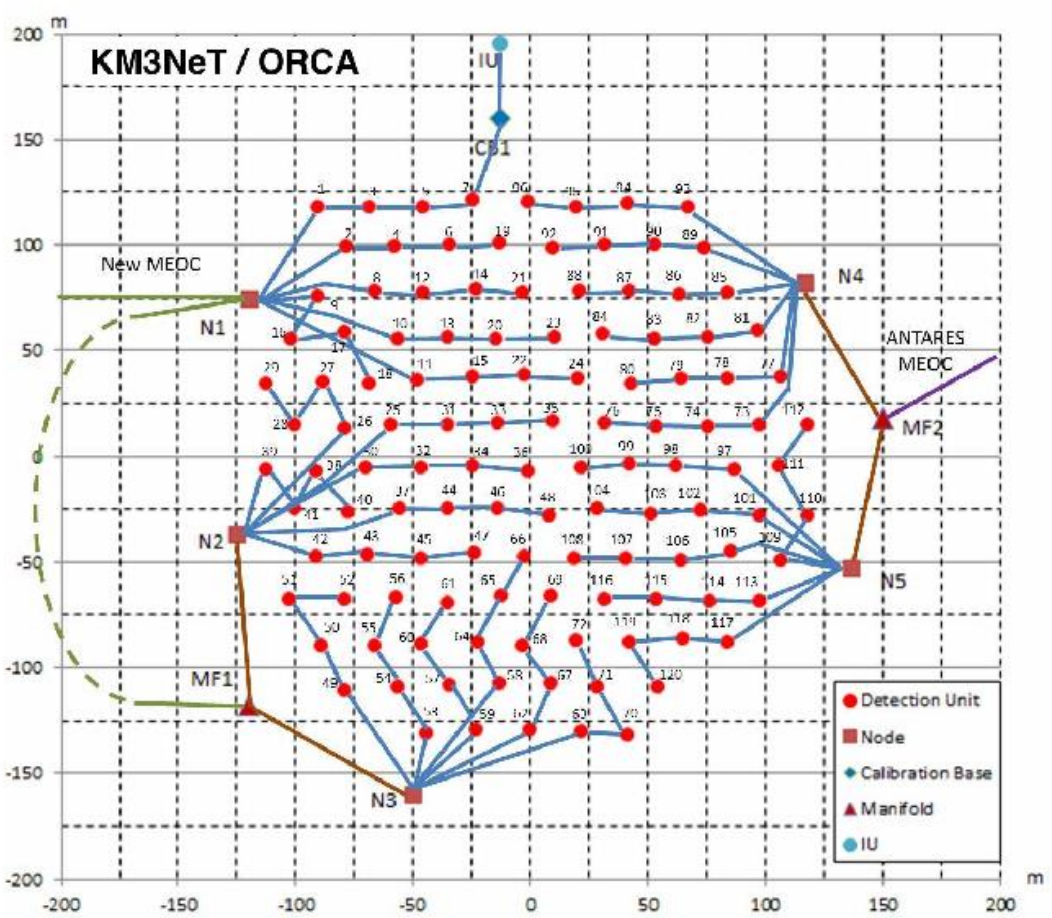
- **2 Building Blocks**
- **115 Detection Units (DU) each**
- **18 Digital Optical Modules (DOM) per DU**
- **Total active volume 1 km^3, ≈ 500 Mton/block**
- **3500 m depth**
- **2 Main Electro-Optical Cables (MEOC) for connection to shore**



Spacing between DOMs = 36 m
Spacing between DUs = 90 m

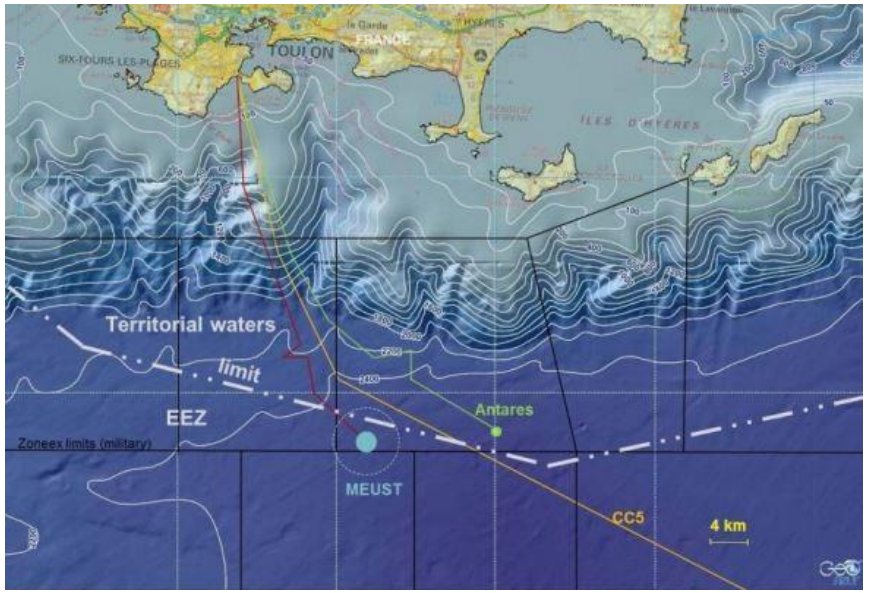
Oscillation Research with Cosmics in the Abyss

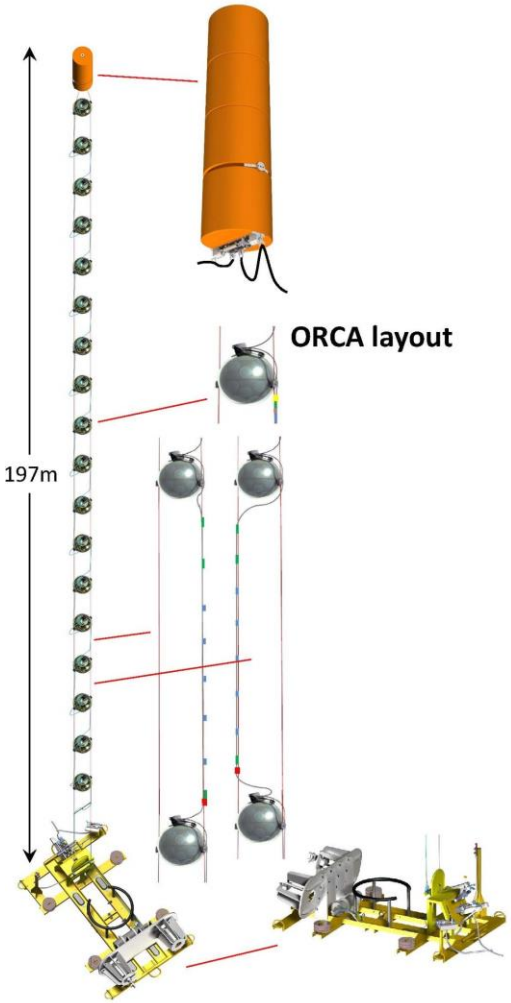
ORCA 1 Building block



Dense configuration required for detection of neutrinos with energies as low as about a GeV

- **115 Detection Units (DU)**
- **18 Digital Optical Modules (DOM) per DU**
- **Active volume ≈ 7 Mton**
- **2500 m depth, close to Toulon**
- **It will reuse the ANTARES main cable**



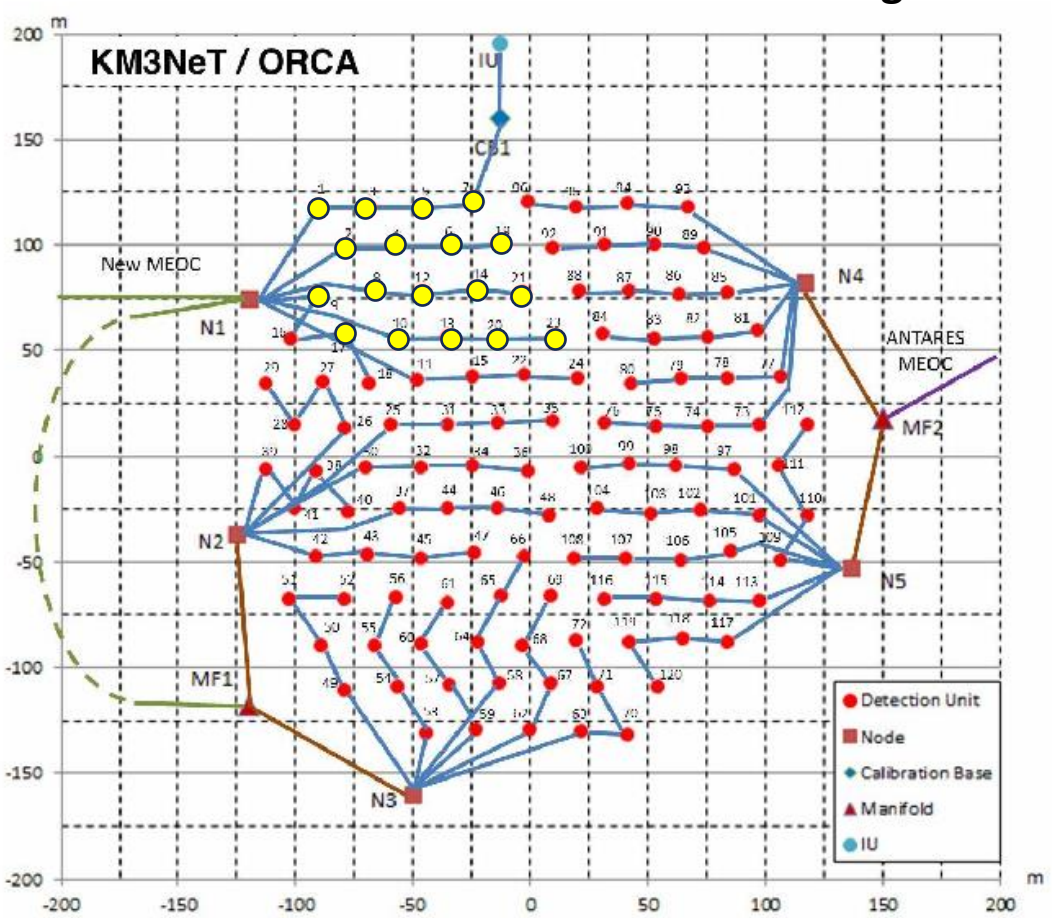


Spacing between DOMs = 9 m
Spacing between DUs = 23 m

Oscillation Research with Cosmics in the Abyss

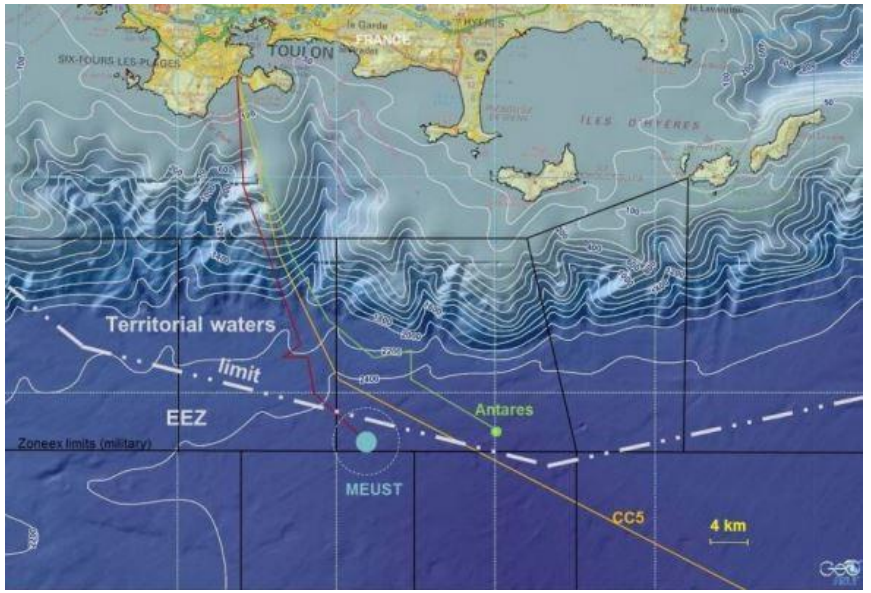
ORCA 1 Building block

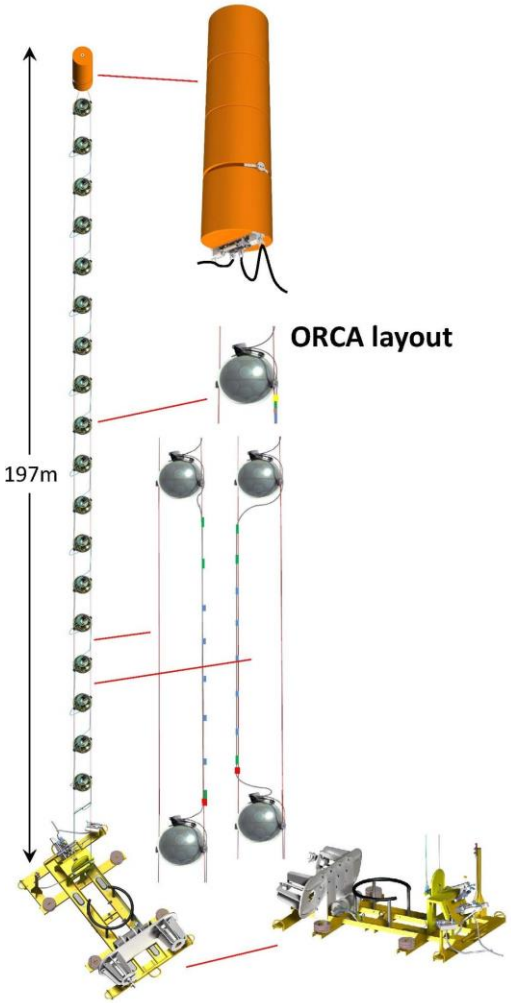
18 Detection Units installed and running



Dense configuration required for detection of neutrinos with energies as low as about a GeV

- **115 Detection Units (DU)**
- **18 Digital Optical Modules (DOM) per DU**
- **Active volume ≈ 7 Mton**
- **2500 m depth, close to Toulon**
- **It will reuse the ANTARES main cable**



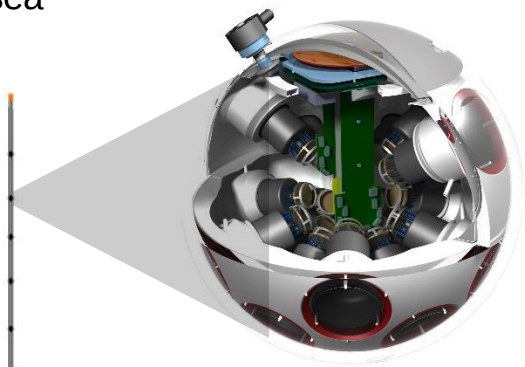


Spacing between DOMs = 9 m
Spacing between DUs = 23 m

KM3NeT phase 1 ARCA detection units

The DU top buoy is necessary to keep the DU taut within a maximum of 100 m at 0.15 m/s sea current

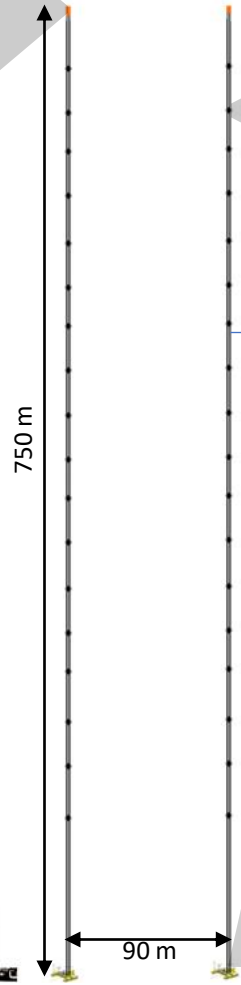
ARCA Broadcast Detection Unit

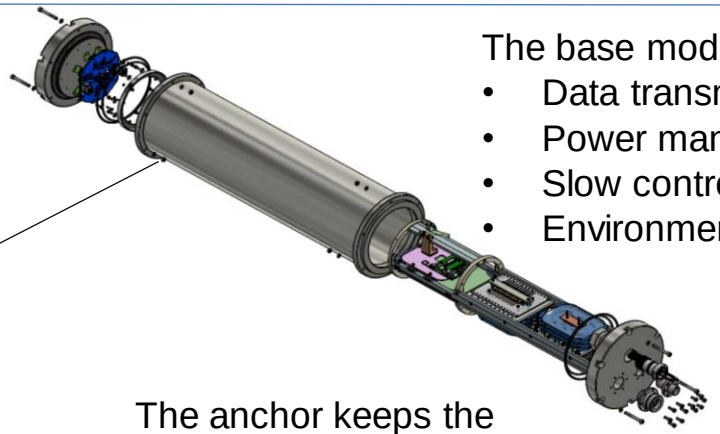


The Digital Optical Module (DOM)

- 31 3” Hamamatsu PMTs equipped with a special base board.
- Central Logic Board (CLB) allows to send the data packets adopting the WRS protocol.

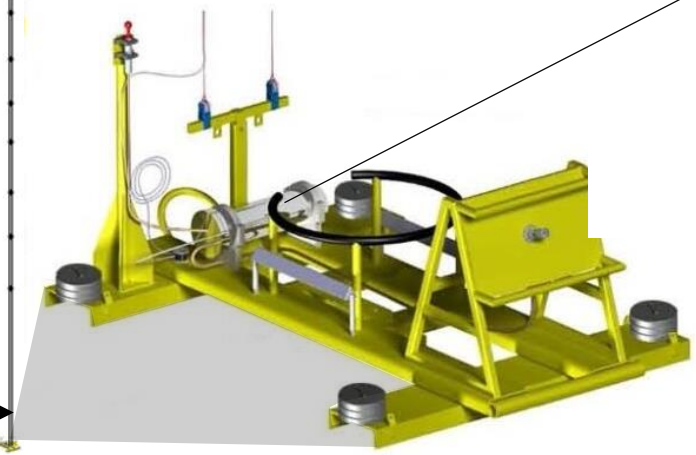
The vertical electro-optical cable (VEOC) is a pressure-compensated oil filled polyethylene (PE) assembly. Its function is to establish electrical power and optical connections to each of the 18 Digital Optical Modules



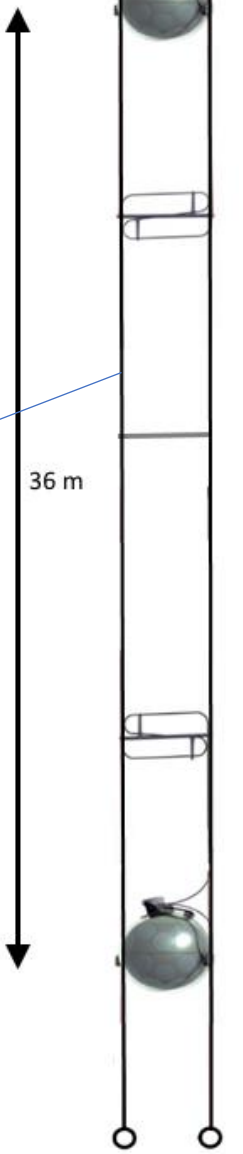


The base module (BM)

- Data transmission
- Power management
- Slow control
- Environmental interface

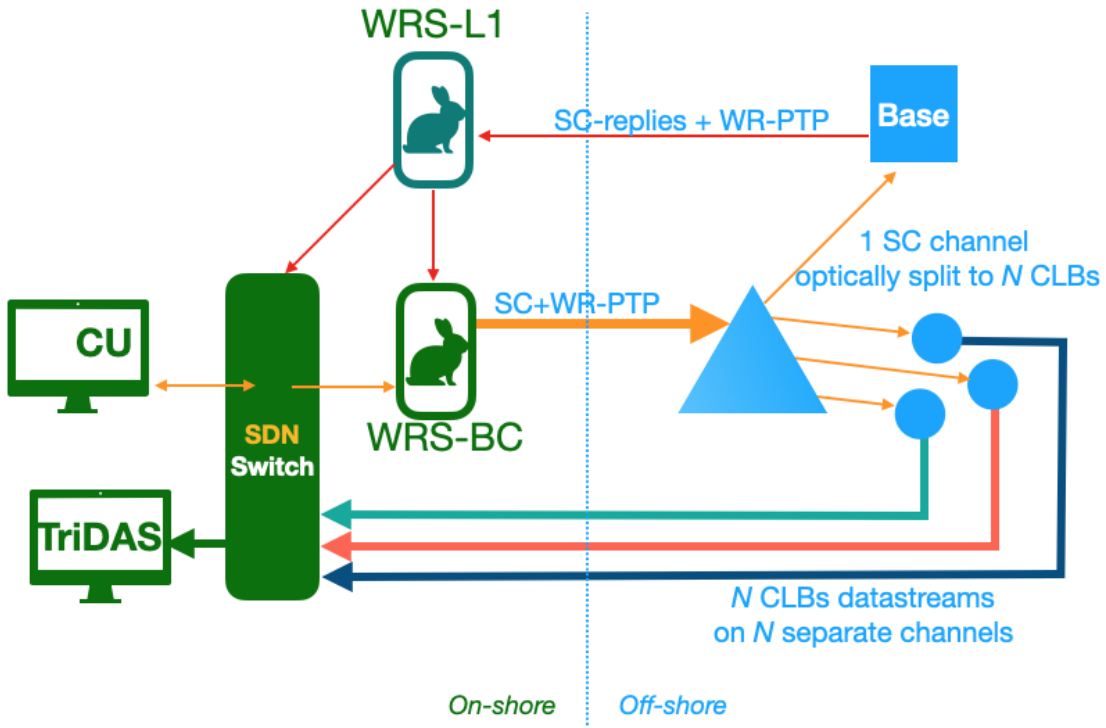


The anchor keeps the DU in its place on the seabed and allows the underwater connection with the interlink cable



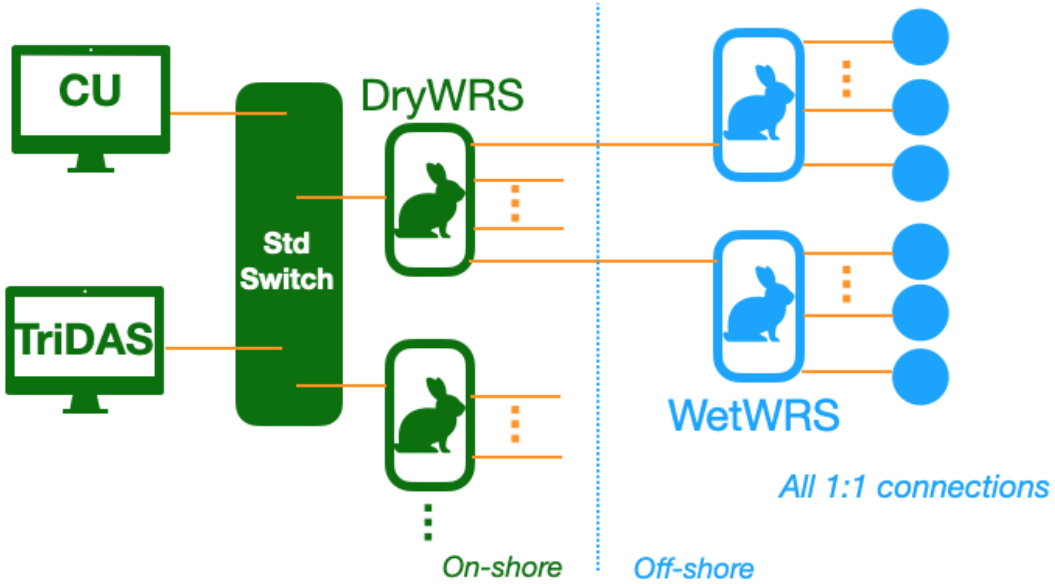
KM3NeT from Broadcast to WWRS Architecture

ARCA Broadcast architecture



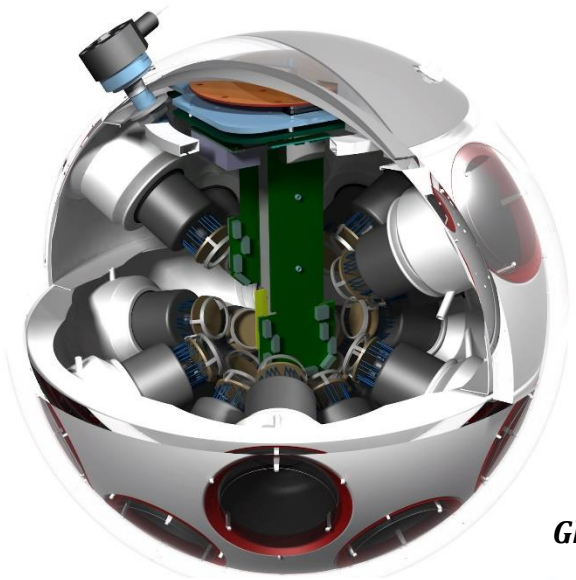
- **A single downlink channel from the shore-station**
- **One direct uplink per CLB back to on-shore resources**
- **Firmware of the White Rabbit switches customised, diverting from the CERN Standard**
- **Software Defined Networking technology needed**

ARCA Wet-WRS architecture



- **Two WRS switches per BM, called *Wet*-WRSs (WWRS), connects all the CLBs of a DU**
- **Wet-WRS counterpart on-shore are equivalent WRS called *Dry*-WRSs (DWRS).**
- **Point-to-point connection in a standard and symmetric Master-Slave design.**
- **DWRSs are Master for the WWRSs which, in turn, are Master for the CLBs in the DU**

KM3NeT WWRS DOMs



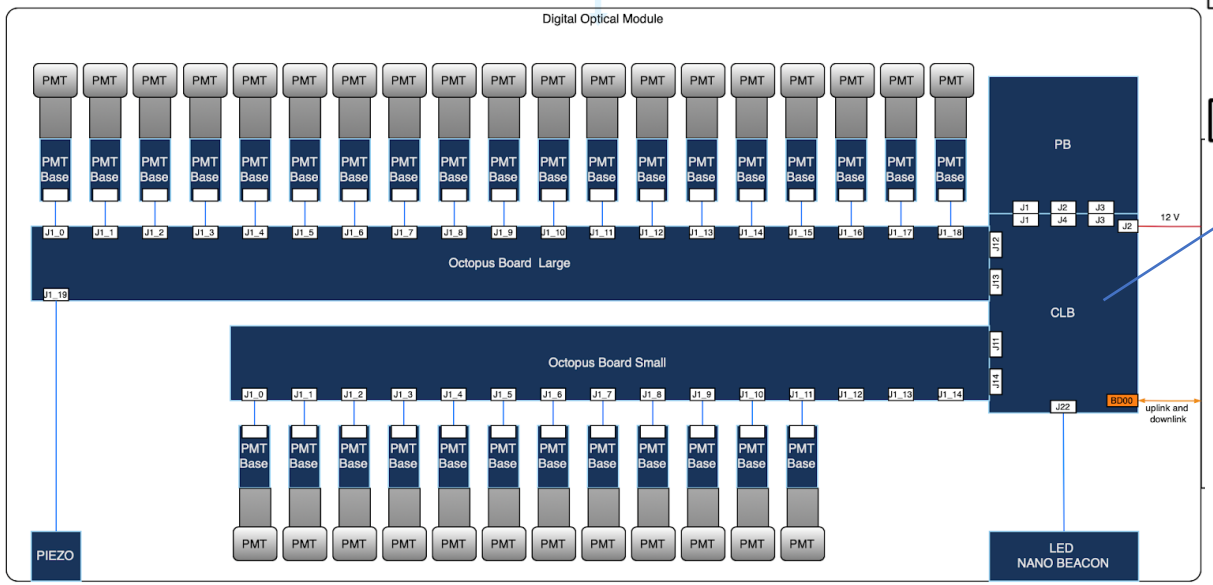
Glenair optical transceiver

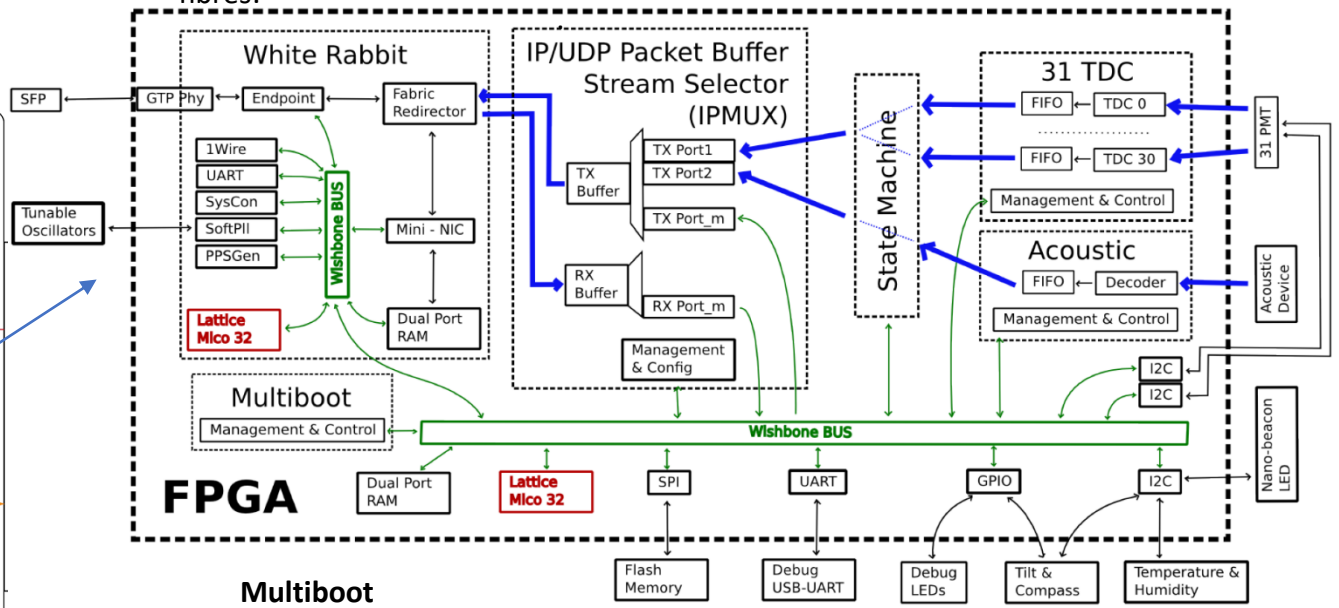
- **Use of WR technology (and standard WRPC provided by CERN)**
- **Subnanosecond resolution**
- **31 PMTs + acoustic sensors**
- **Central Logic Board (CLB) to orchestrate the readout of sensors**
  Dedicated embedded software to drive the DOM operations

White Rabbit Precision Time Protocol core for time Synchronization and Ethernet over optical fibres.

IP/UDP (ethernet) packet Creation
Multiple streams (PMTs, acoustic, monitoring)

High-Speed TDCs
LVDS inputs from PMTs Hit time and ToT. 800ps/√12 resolution

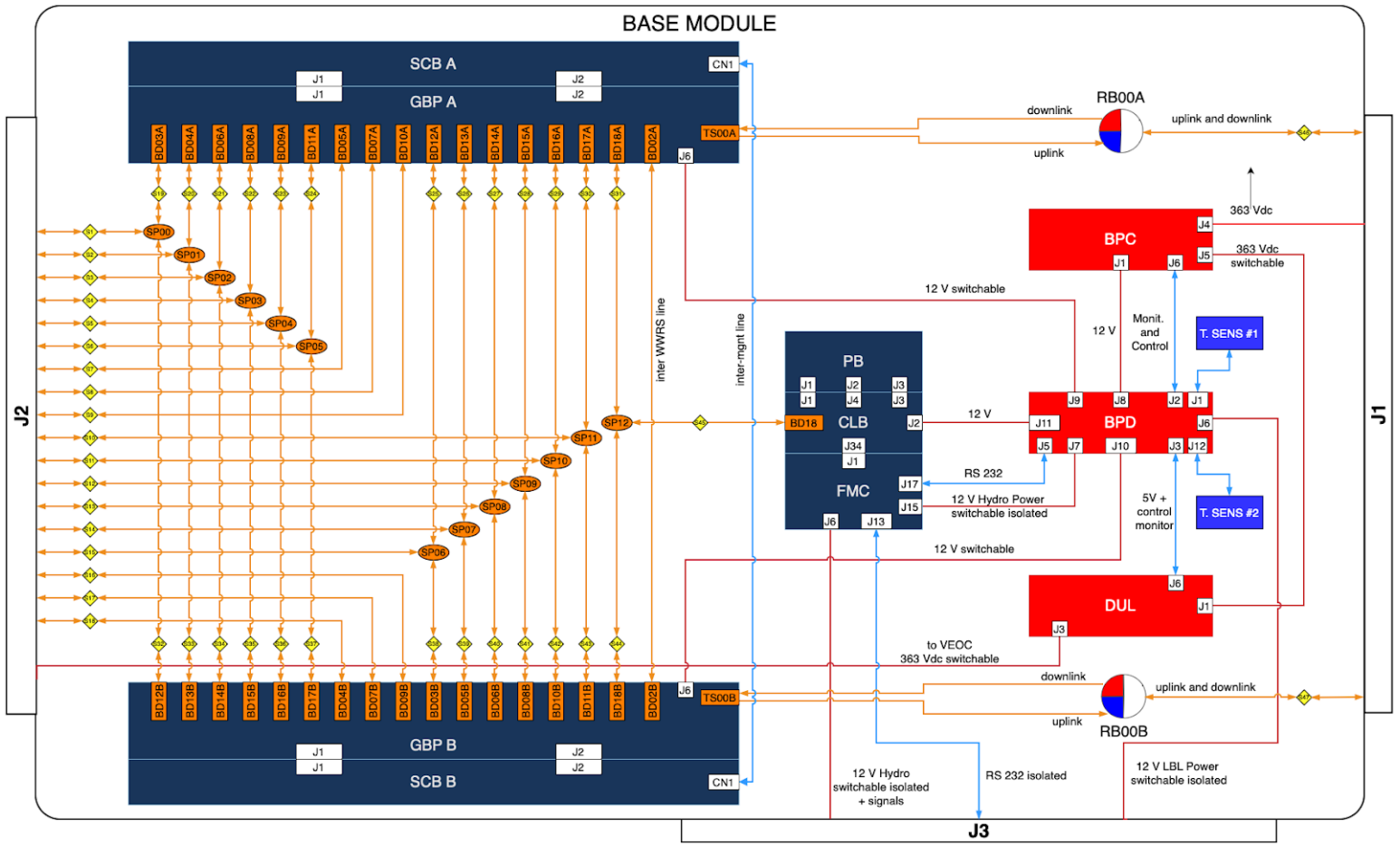


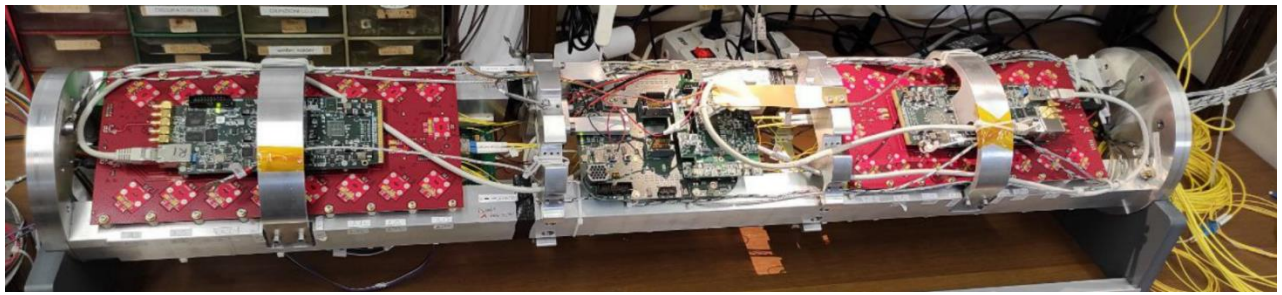


Multiboot system
Fail-safe reprogramming

I2C communication
HV and thresholds, Compass/tiltmeter, Led Flasher Temperature/Humidity

KM3NeT WWRS Base Module

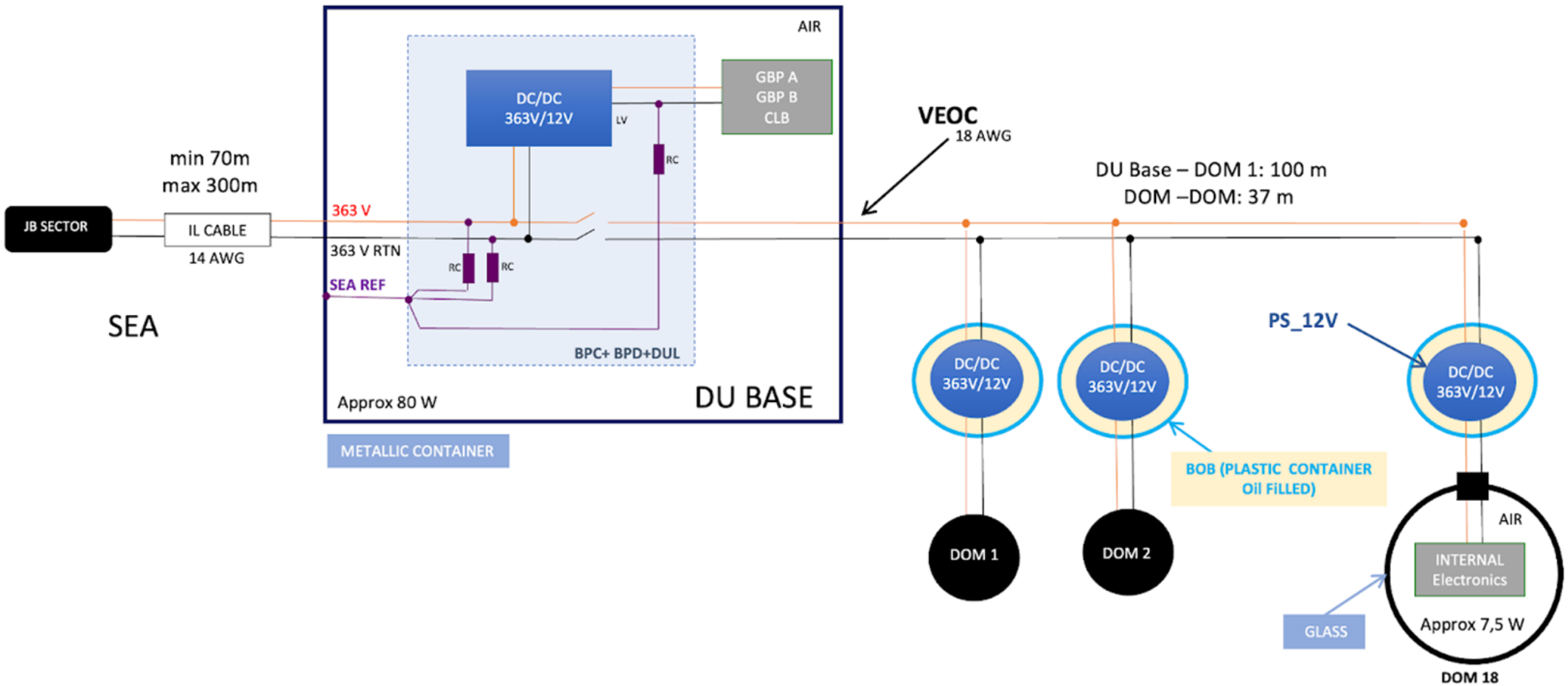




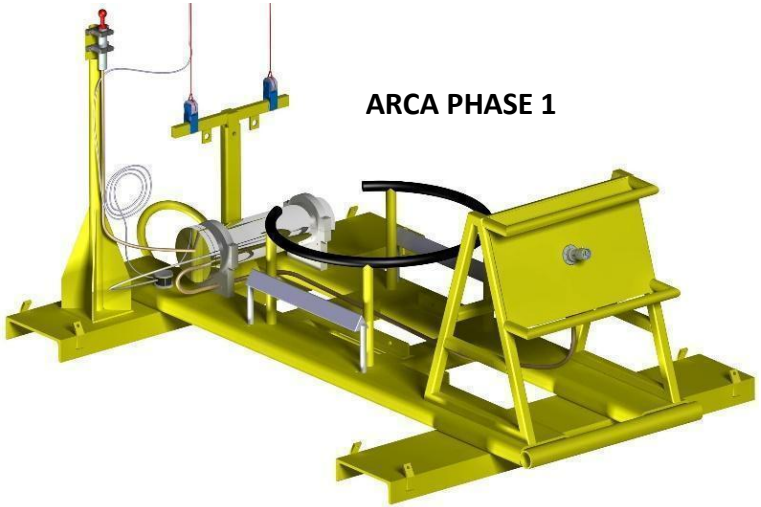
- All 1:1 connections
- Cold redundancies implemented (DOM channels, WWRS interlinks)
- Tuneable SFPs for the uplink (DWDM compliant - channel aggregation in the JB)
- WWRS manageable from remote
- 2 Glenair Backplane (GBP A and GPB B)
- Two Switch Core Boards (SCB A and SCB B)

See I. Sgura's poster

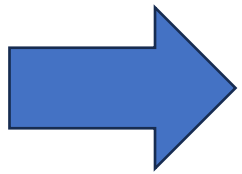
ARCA Detection Unit Power Distribution Scheme

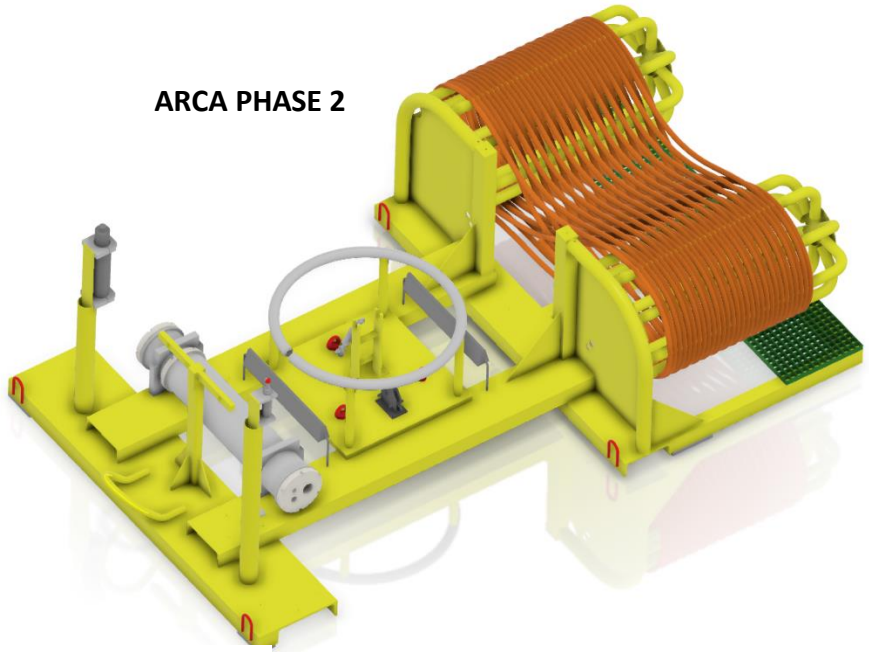


KM3NeT Phase 2 anchors

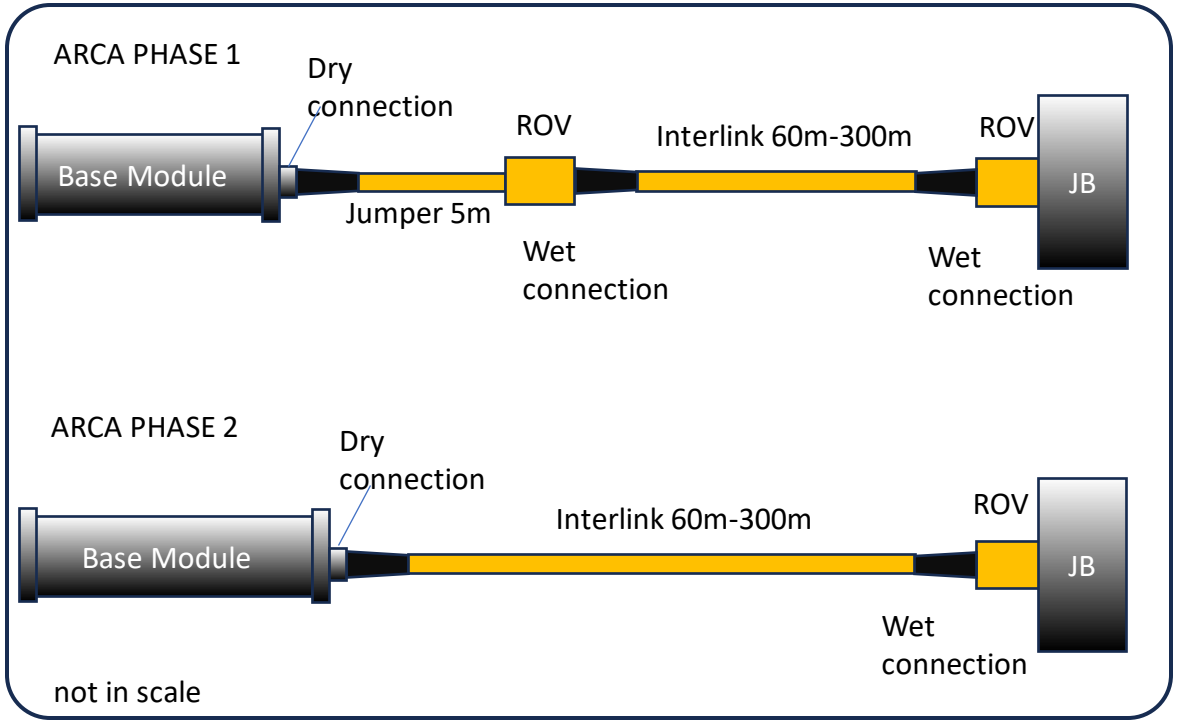


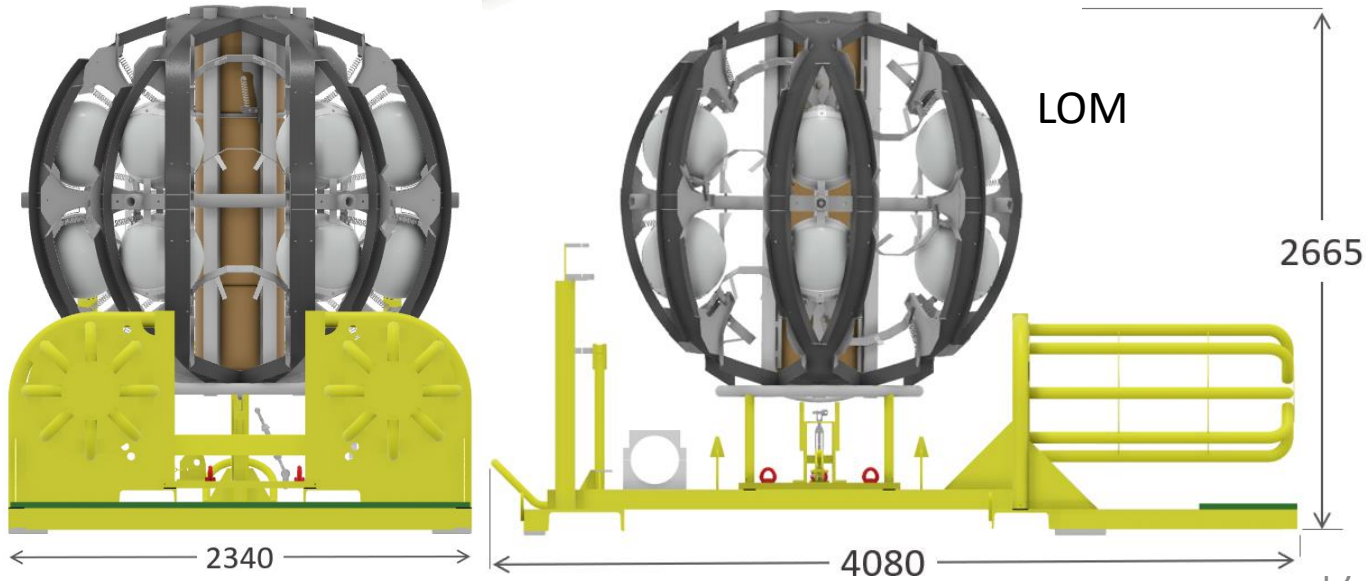
ARCA PHASE 1





ARCA PHASE 2





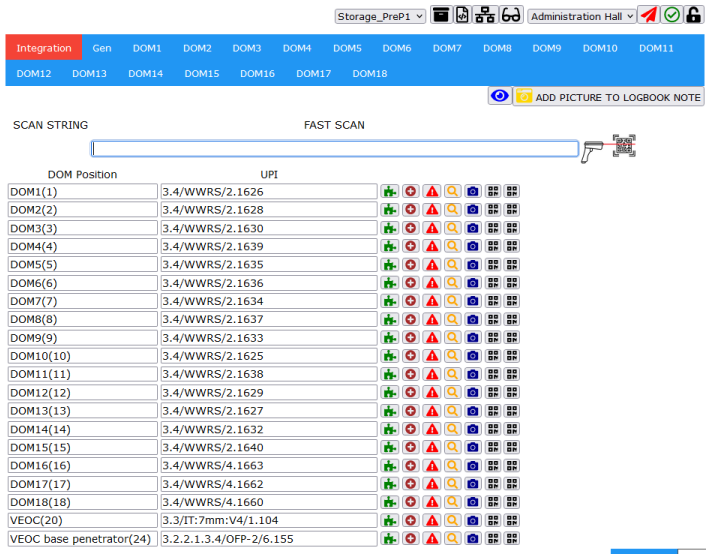
KM3NeT DU Integration processes

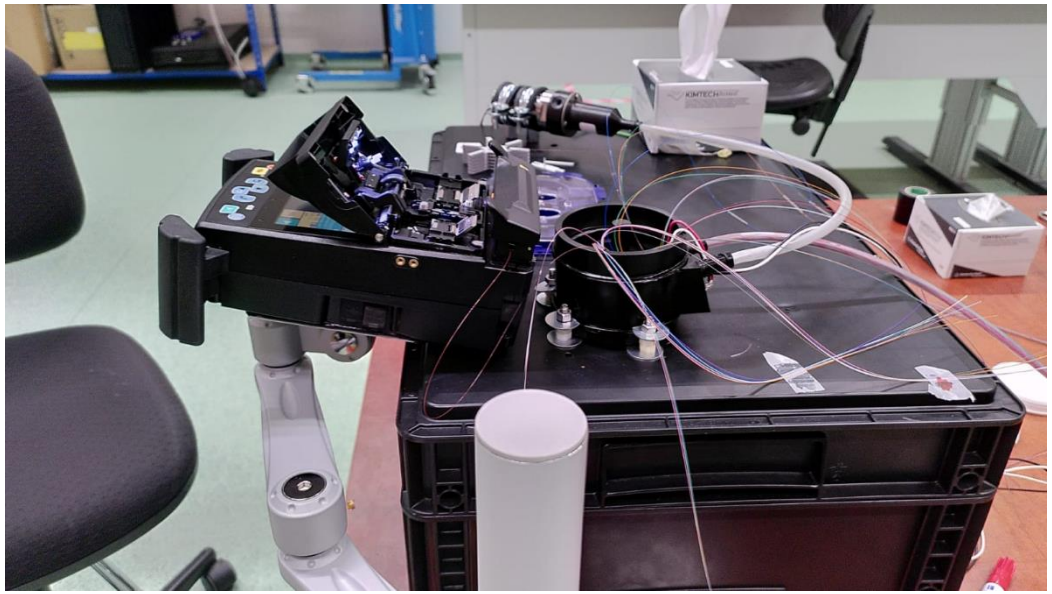
Process 1

Initiates the integration by the connection between the VEOC (Vertical Electro-Optical Cable), DOMs (Digital Optical Modules), and a titanium base penetrator

Use of the ***Detector Integration Assistant*** (Developed by G. Levi INFN BO) in any step of the integration:

- Components traceability
- Test results stored in the DB
- Integration wizard
- Checks non conformities



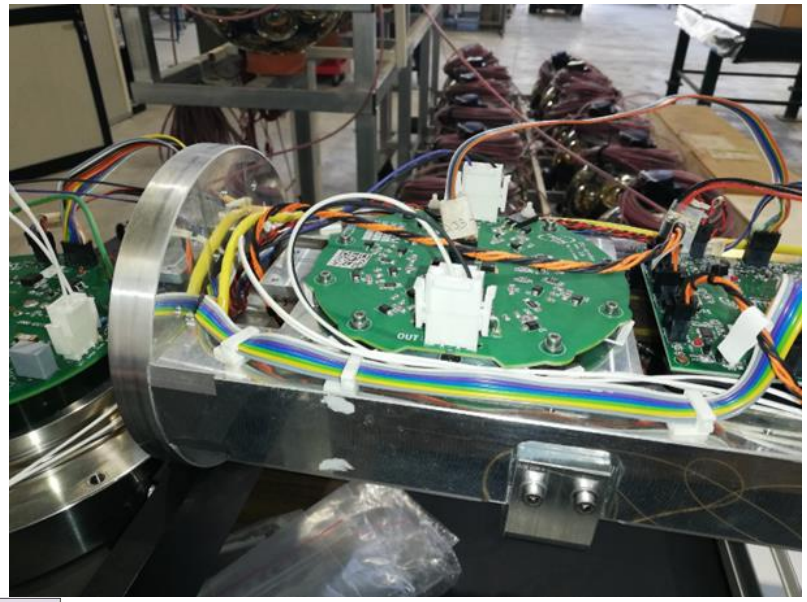


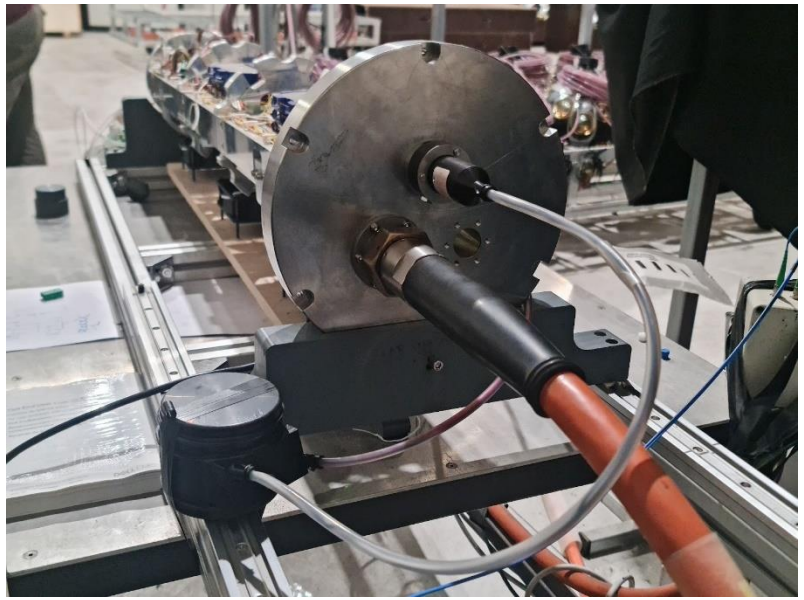
KM3NeT DU Integration processes

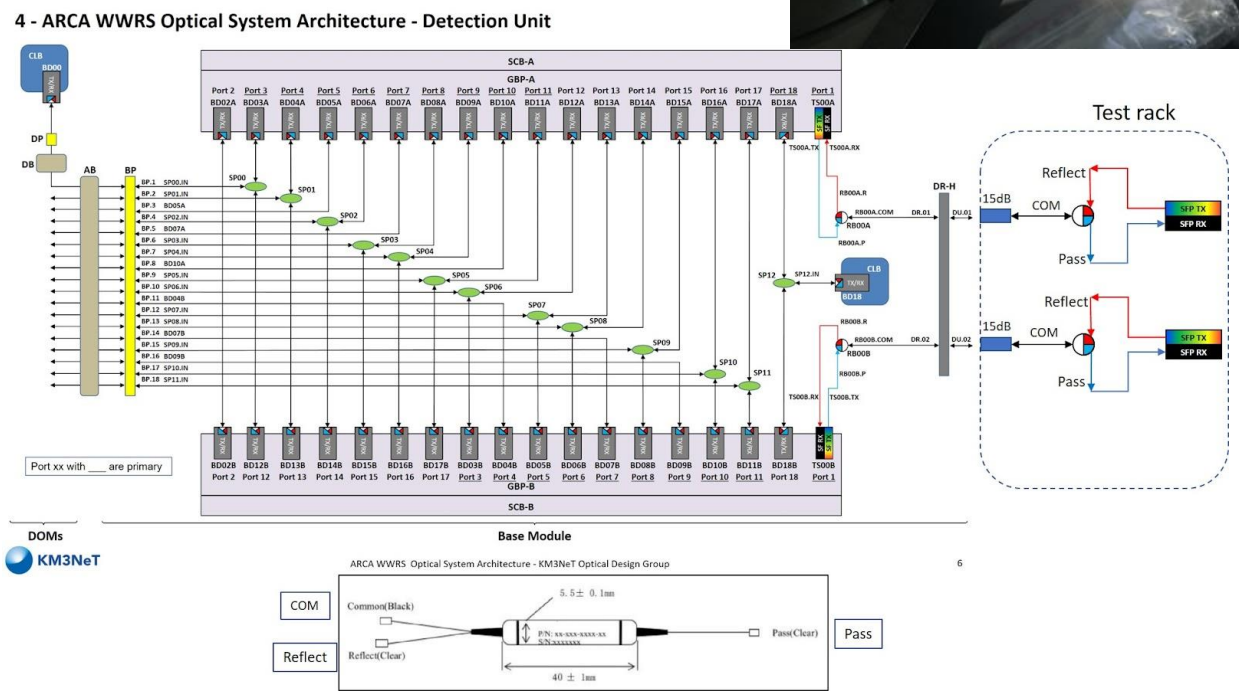
Process 2

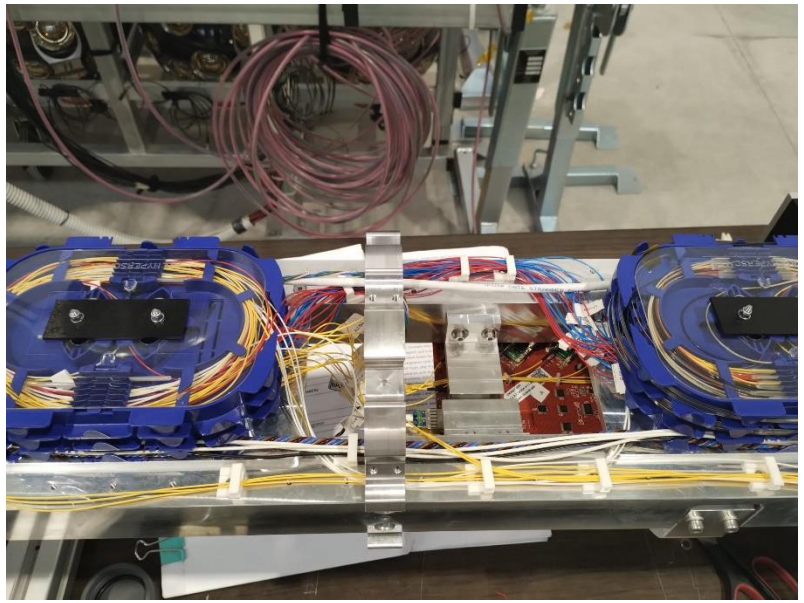
Integration with the base module, achieved through intricate electro-optical connections

Optical splices from the base penetrator are tested using a special setup that allows to communicate with the GBP boards.



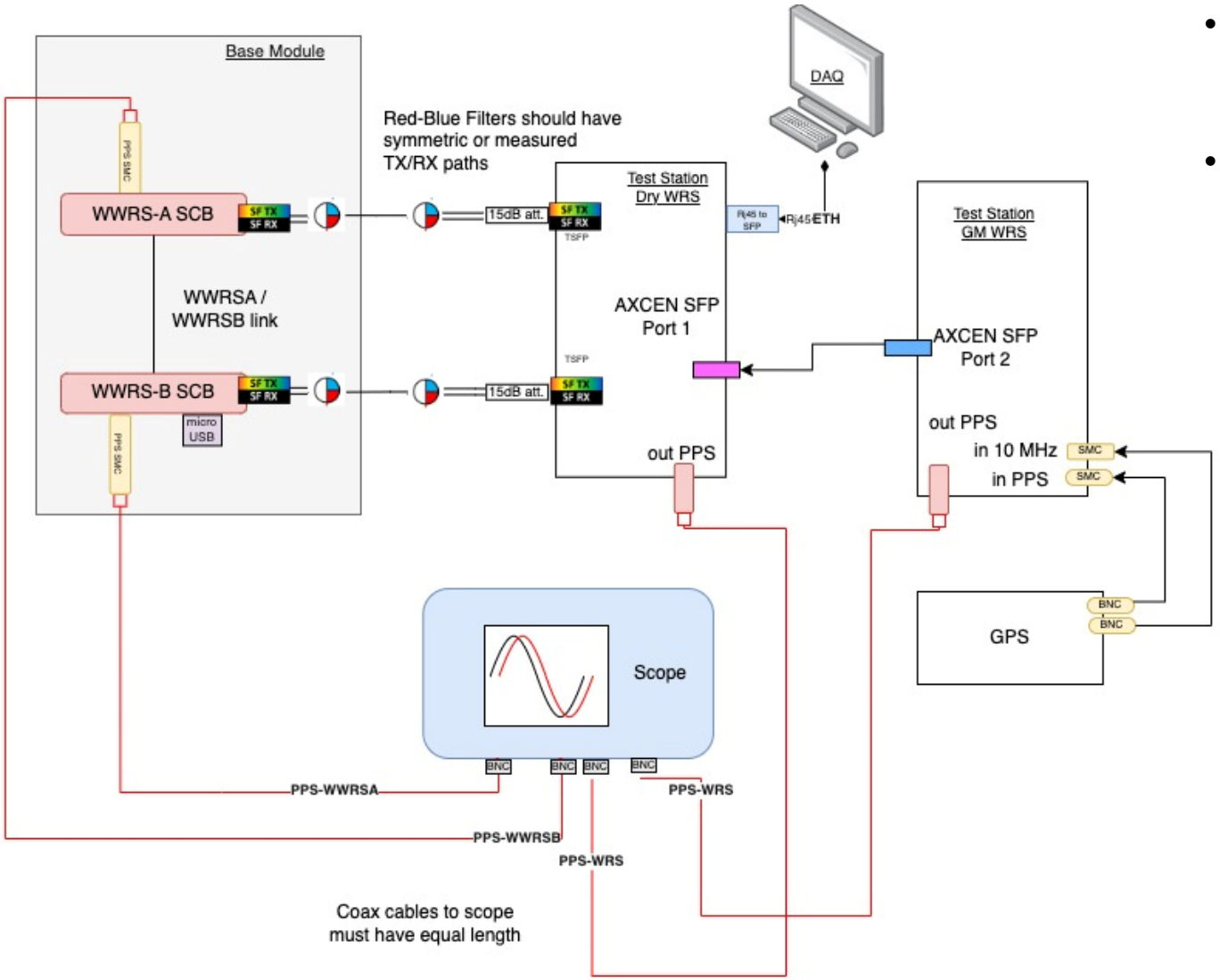




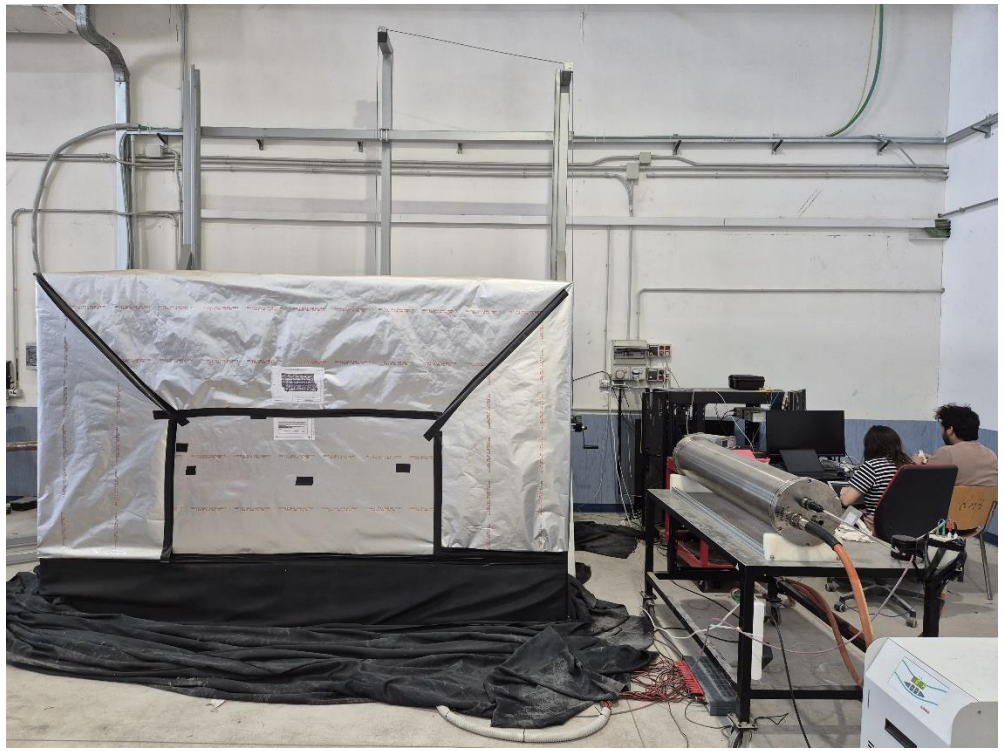


KM3NeT DU Integration processes

Process 3



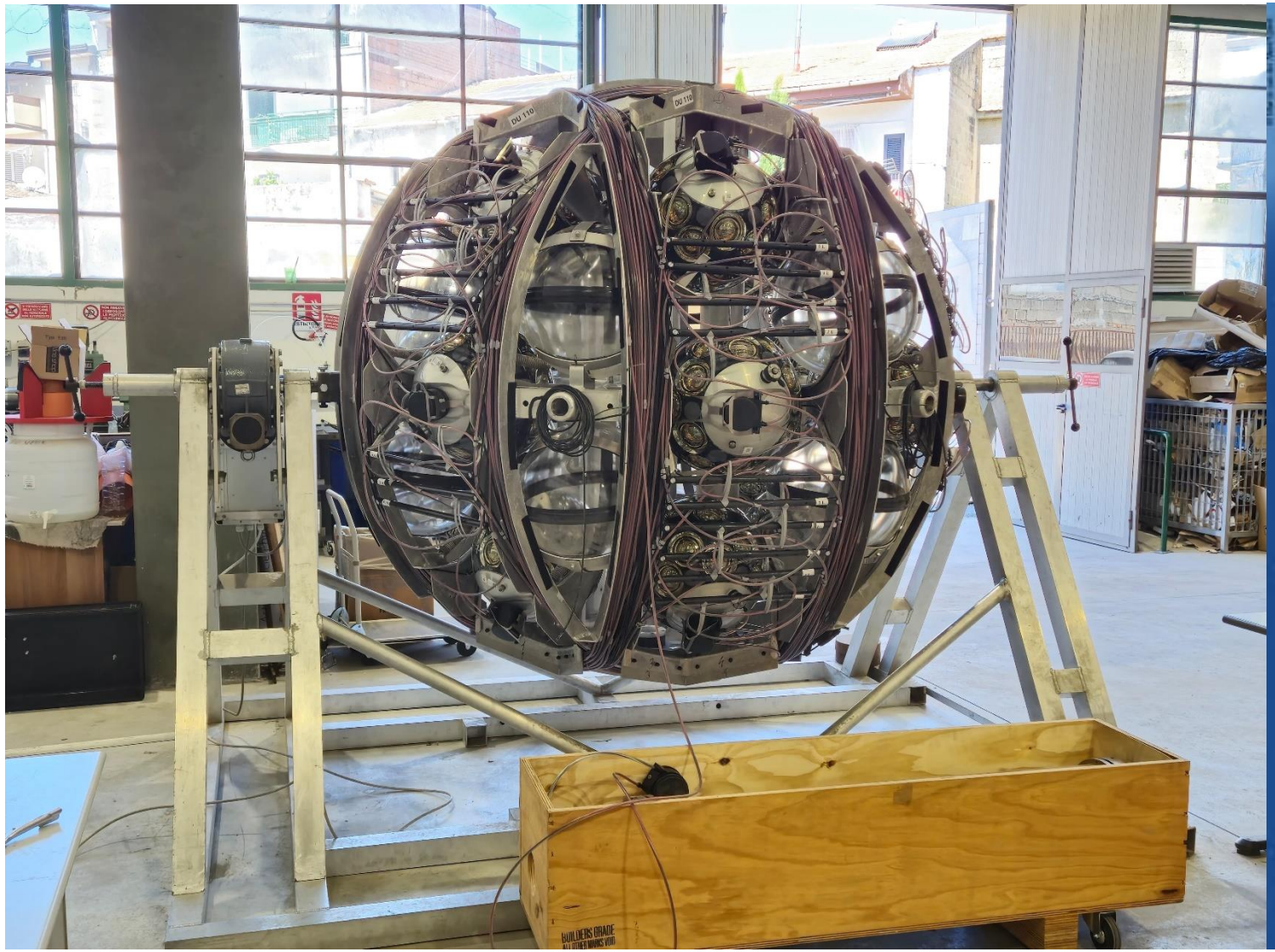
- **Calibration and check of synchronization of WWRS A and WWRS B (The 2 Wet-WRS in the BM)**
- **Inter-DOM time delay measurements using a darkbox and a laser system**

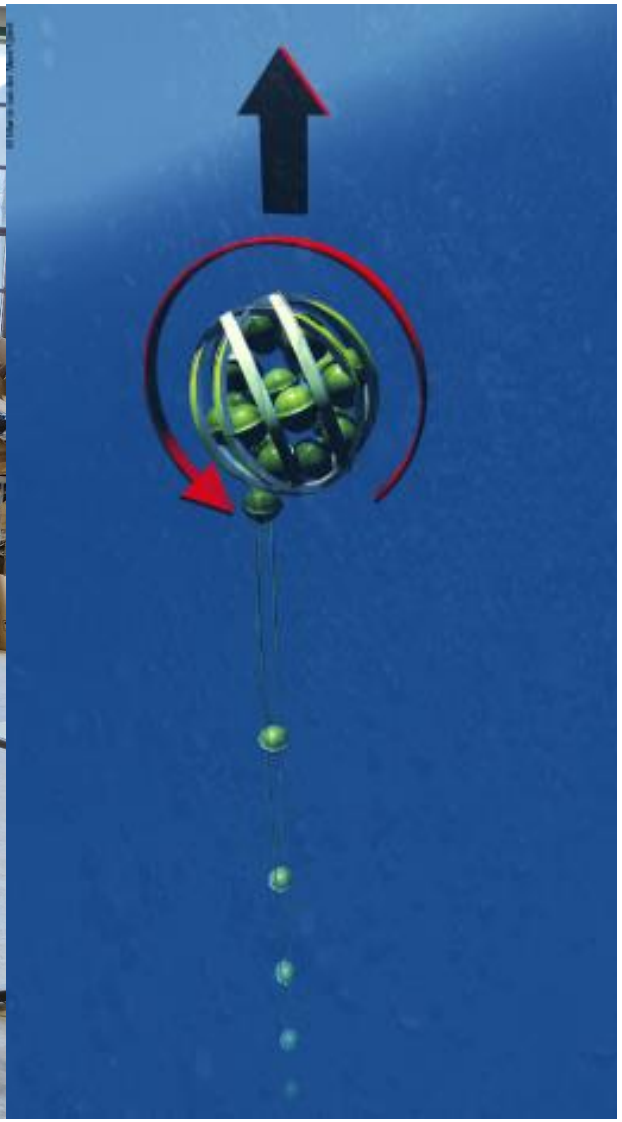


KM3NeT DU Integration processes

Process 4

The fully calibrated detection unit is loaded onto the Launch module for Optical Modules (LOM)





KM3NeT DU Integration processes

Process 5

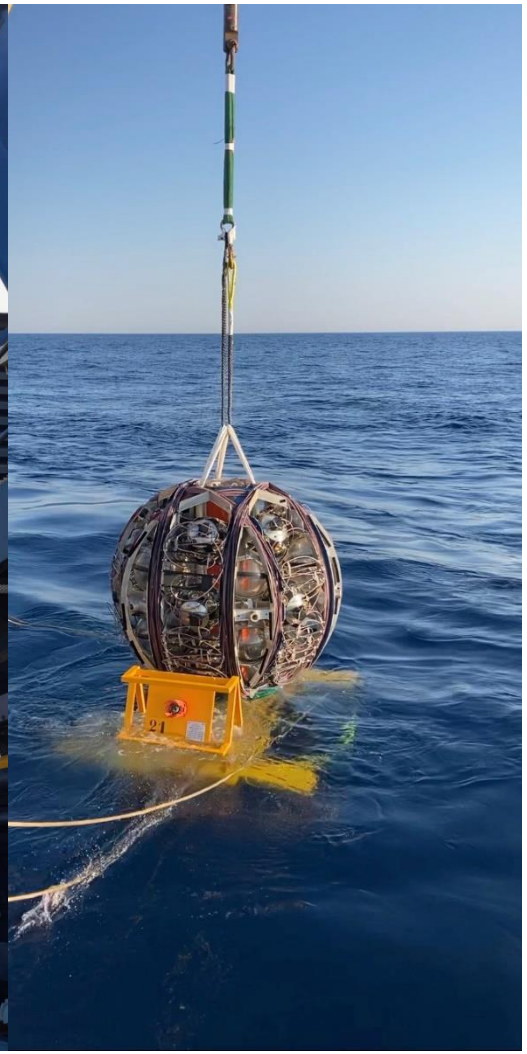
the LOM, now housing the integrated detection unit, is carefully positioned onto the anchor, where the interlink cable has already been securely mounted.
A functional test of the DU is done through the Interlink cable connector

KM3NeT DU Integration processes

Process 6

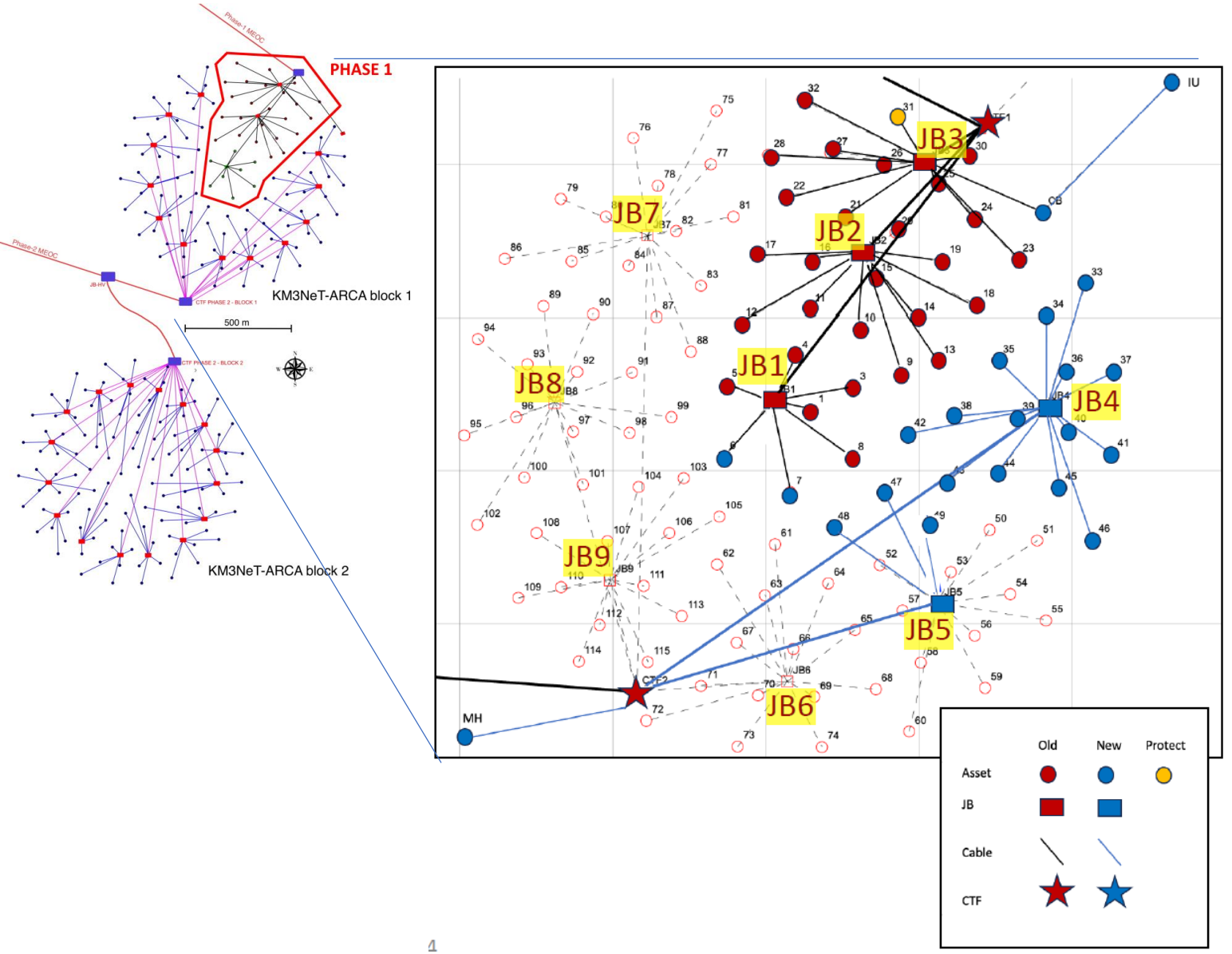
Final functional test and mechanical checks before the deployment

ARCA pre deployment site at Malta



Deployment

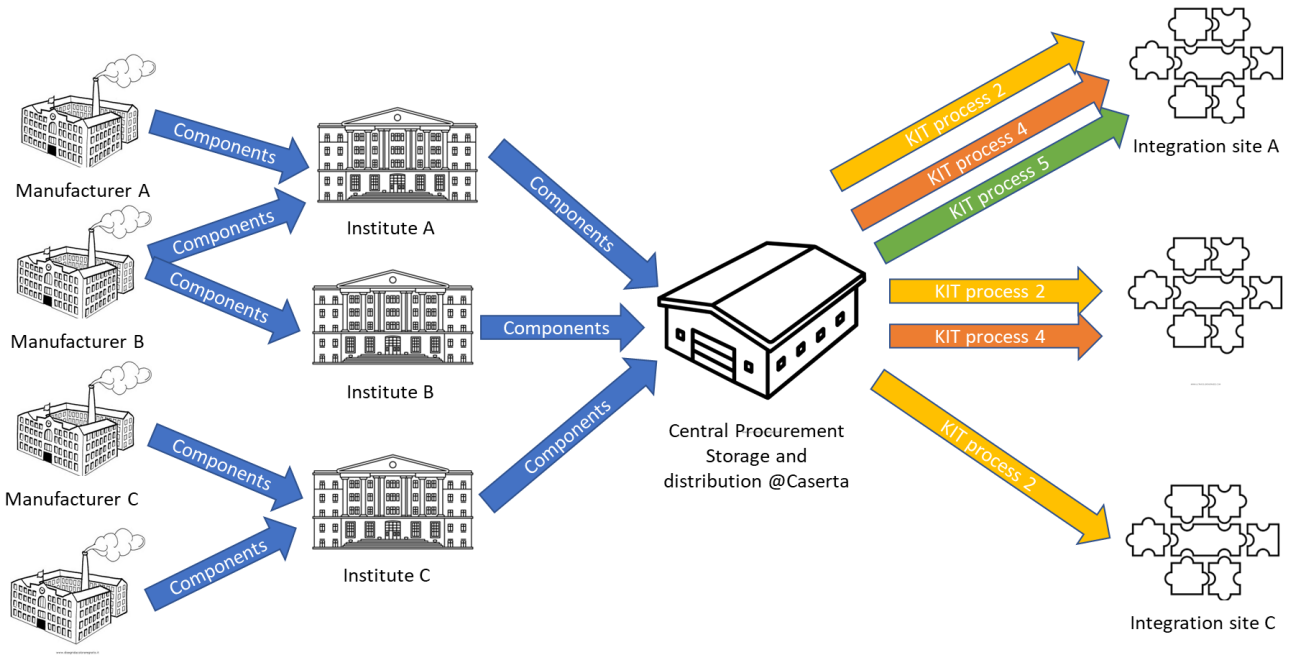
KM3NeT ARCA phase 2 next sea campaign



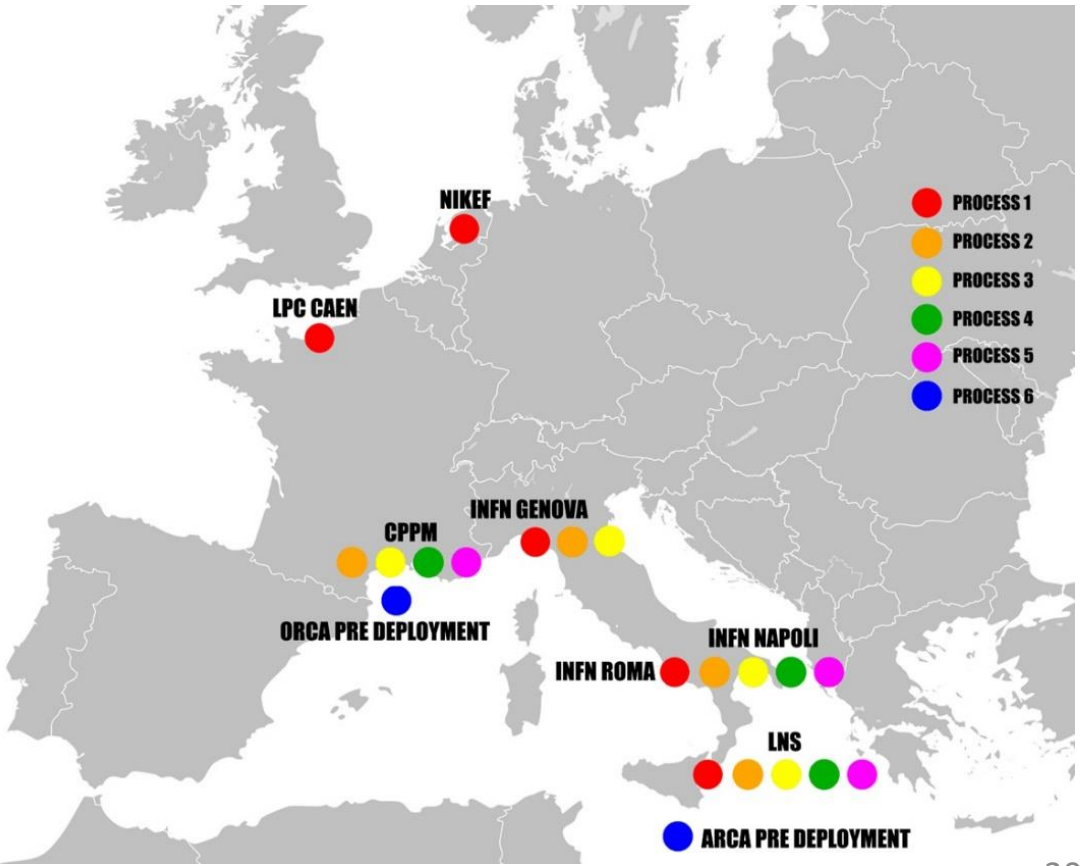
Installation of multiple ARCA WWRS detection units (DU), additional junction boxes (JB) and other instrumentation is scheduled after the summer

Procurements for additional 50 DUs in progress

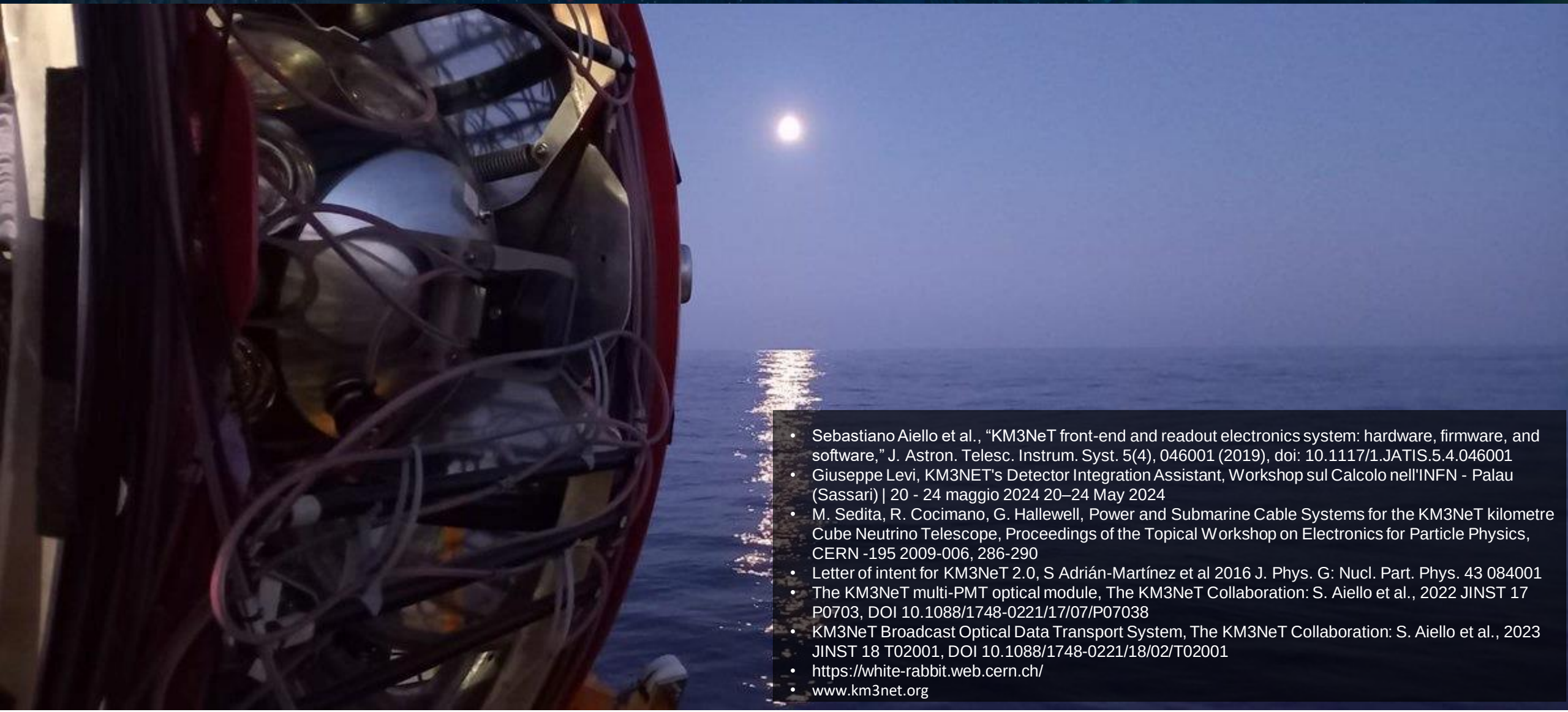
KM3NeT Central storage and logistics



- Quality checks
- Registration of products
- Components distribution



The new KM3NeT Detection Units



- Sebastiano Aiello et al., “KM3NeT front-end and readout electronics system: hardware, firmware, and software,” J. Astron. Telesc. Instrum. Syst. 5(4), 046001 (2019), doi: 10.1117/1.JATIS.5.4.046001
- Giuseppe Levi, KM3NET's Detector Integration Assistant, Workshop sul Calcolo nell'INFN - Palau (Sassari) | 20 - 24 maggio 2024 20–24 May 2024
- M. Sedita, R. Cocimano, G. Hallewell, Power and Submarine Cable Systems for the KM3NeT kilometre Cube Neutrino Telescope, Proceedings of the Topical Workshop on Electronics for Particle Physics, CERN -195 2009-006, 286-290
- Letter of intent for KM3NeT 2.0, S Adrián-Martínez et al 2016 J. Phys. G: Nucl. Part. Phys. 43 084001
- The KM3NeT multi-PMT optical module, The KM3NeT Collaboration: S. Aiello et al., 2022 JINST 17 P0703, DOI 10.1088/1748-0221/17/07/P07038
- KM3NeT Broadcast Optical Data Transport System, The KM3NeT Collaboration: S. Aiello et al., 2023 JINST 18 T02001, DOI 10.1088/1748-0221/18/02/T02001
- https://white-rabbit.web.cern.ch/
- www.km3net.org

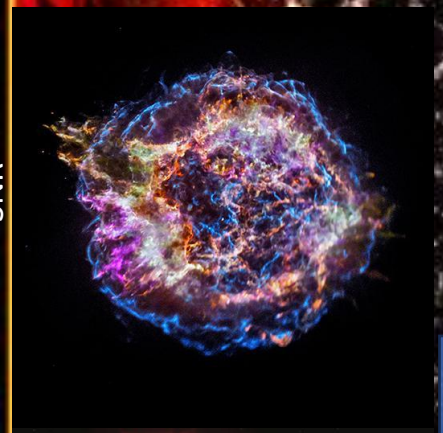
Carlos Maximiliano Mollo (carlos.mollo@na.infn.it)

ARCA DU integration Coordinator for KM3NeT

The new KM3NeT Detection Units

Backup slides

KM3NeT neutrino astronomy


SNR


GRB


quasar


AGN

Charged particles: deflected by magnetic fields, interaction with CMBR (leptonic or hadronic processes)

$$p + \gamma_{CMBR} \rightarrow \Delta^{+} \rightarrow n\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$
$$\rightarrow n\pi^{0} \rightarrow \gamma\gamma$$

Neutrinos: not absorbed nor deflected, Signature of hadronic processes

$$p + \gamma \rightarrow n\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$
$$P + \gamma \rightarrow p\pi^{0} \rightarrow \gamma\gamma$$
$$n + \gamma \rightarrow p\pi^{-} \rightarrow \mu^{-} + \nu_{\mu}^{*}$$
$$n + \gamma \rightarrow n\pi^{0} \rightarrow \gamma\gamma$$

Photons: absorbed by interstellar medium, interaction with CMBR

$$\gamma + \gamma_{CMBR} \rightarrow e^{+} e^{-}$$

KM3NeT Experiment

KM3NeT is a distributed, deep-sea, Cherenkov neutrino observatory under realization in the Mediterranean Sea with two detectors: ARCA, for neutrino astronomy close to Italy and ORCA, for studying the neutrino oscillations close to France.