Calibration facility for detector strings for the KM3NeT/ARCA neutrino telescope at the CAPACITY laboratory

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on behalf of KM3Net Collaboration

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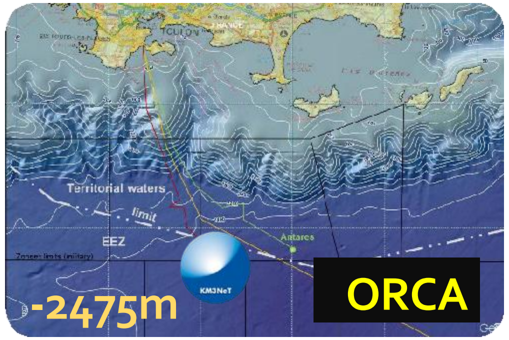
Outline

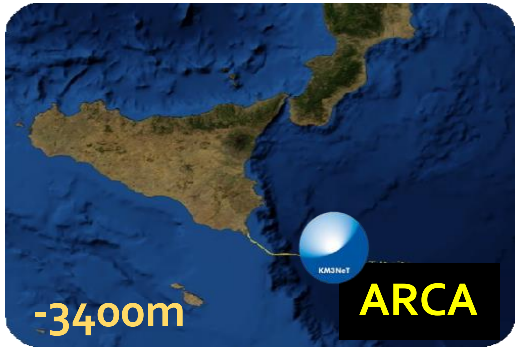
- Motivation and objectives
- The Detectors
- The KM3NeT collaboration
- The CAPACITY lab in Caserta
- DU calibration at CAPACITY lab
- Conclusions

Motivation and objectives

- **KM3NeT** is the neutrino research infrastructure under construction in two sites of the deep Mediterranean Sea
  - **ARCA** (off shore Capo Passero, It @ 3500 m depth)
  - **ORCA** (off shore Toulon, Fr @2500 m depth)
- Same collaboration, same technology

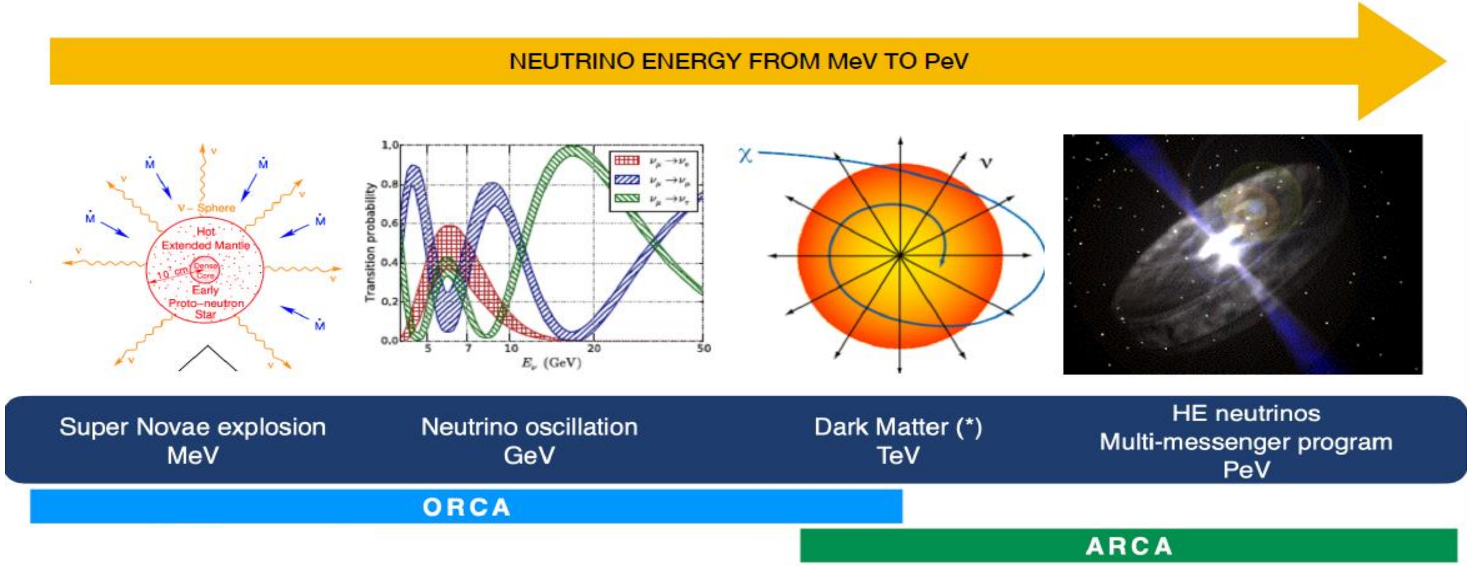


Oscillation **R**esearch with **C**osmics In the **A**byss

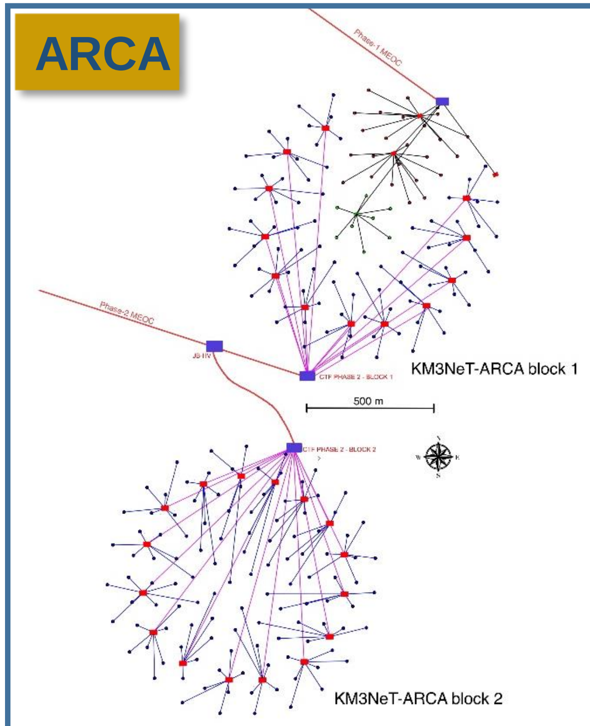


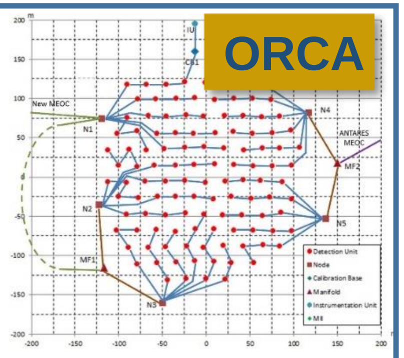
Astroparticle **R**esearch with **C**osmics In the **A**byss

Science with ν telescopes at multi-energy scale



The neutrino telescopes of KM3NeT

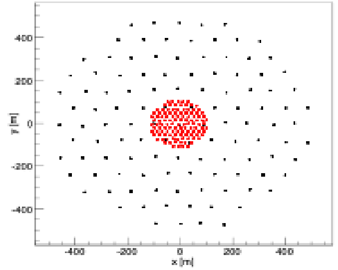




KM3NeT-ORCA
- 18 DOMs per DU
- Vertical DOM spacing 9 m
- Inter-DU spacing 20 m
- Currently 10 operating

KM3NeT-ARCA
- 18 DOMs per DU
- Vertical DOM spacing 36 m
- Inter-DU spacing 90 m
- Currently 19 operating

ARCA/ORCA



- Detection Units (DUs): vertical strings hosting 18 Digital Optical Modules (DOMs)
- 3 Building Blocks of 115 DUs each (2xBB in ARCA, 1xBB in ORCA)
- Cherenkov radiation induced by charged particles produced in neutrino interactions
- 3D arrays with a modular design
- Optical sensor: multi-PMT (DOM)
- An electro-optical backbone provides each DOM with power and an optical fiber for data communication
- All data to shore

→ next sea campaign in the fall of this year

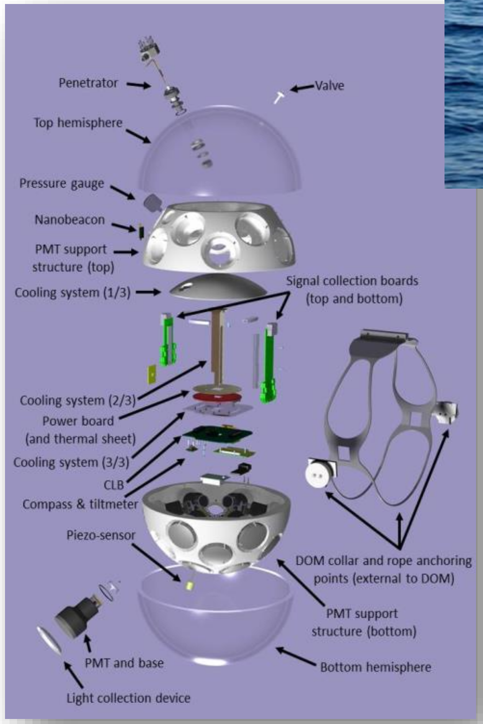
Despite currently under construction, **KM3NeT** is already operative!

DOM (Digital Optical Module)

- 31 3" PMTs (by Hamamatsu)
- a fast LED pulser (for timing calibrations)
- an acoustic piezo-sensor + a compass/tiltmeter (for positioning)
- electronics and DAQ for data taking and communication with the shore station

- All components are packed in a 17" pressure-resistant glass sphere

- Each DOM requires: electrical power (~7W @12 VDC) and one optical fiber for communication (through a penetrator)



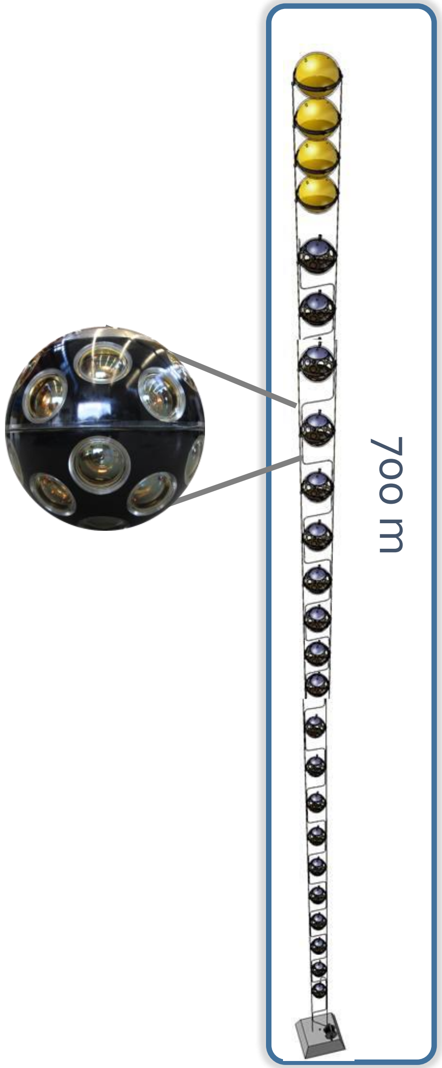
Advantages of the multi-PMT choice:

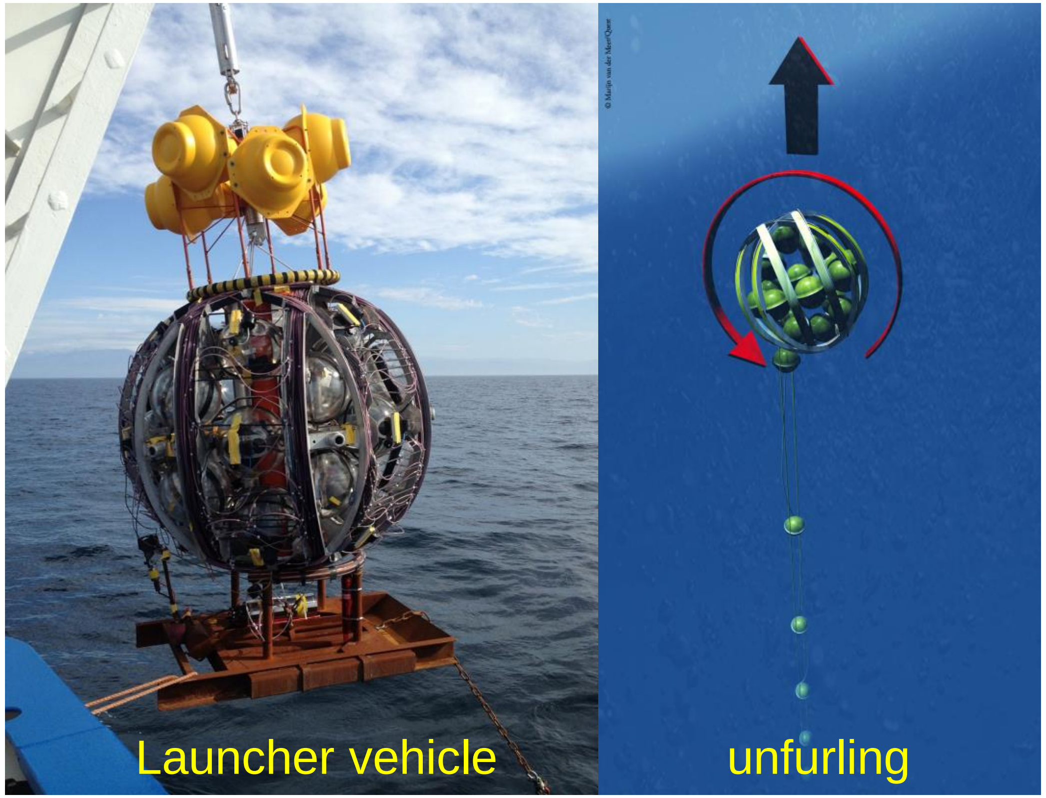
- ✓ large photocathode area
- ✓ large angular coverage
- ✓ sensitivity to photon direction
- ✓ improved photon counting capabilities
- ✓ possibility of local triggers
- ✓ simplified detector layout

The Detection Unit (DU)

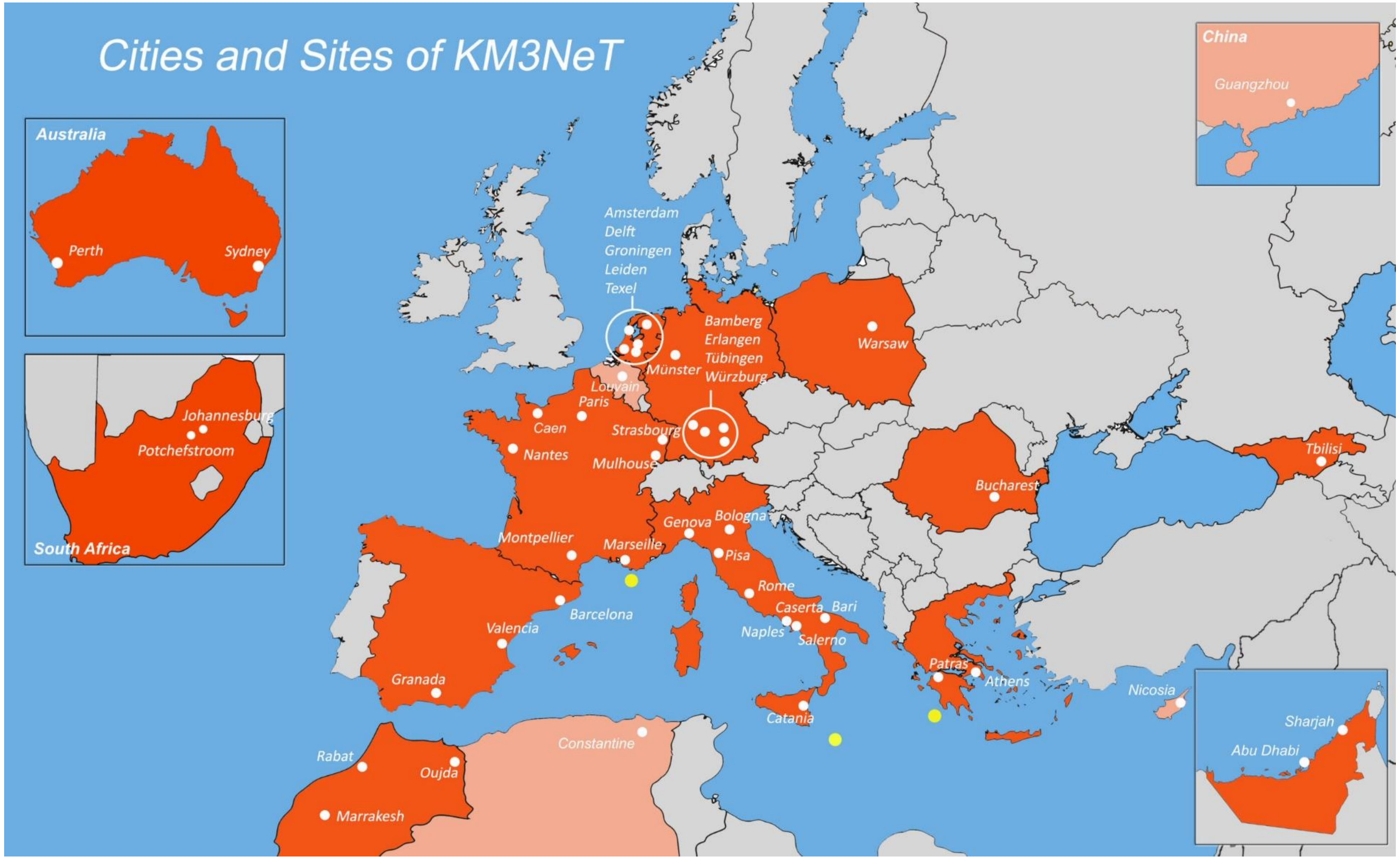
- 18 DOMs integrated on vertical slender strings supported by two parallel Dynema ropes

- The DU can be packed on a launcher vehicle (spherical, 2 m diameter) placed on the anchor for installation





The KM3Net Collaboration



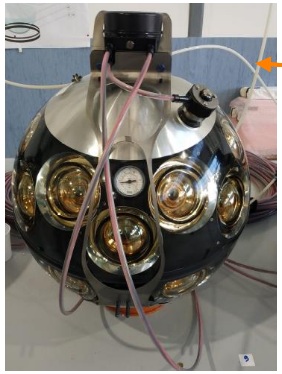
- The construction is based on a distributed architecture ==> **flexibile organization**
- The present organization will permit to complete the construction of **ORCA** by end of 2024 and of **ARCA** by end 2023 (first BB) and beginning 2026 (second BB)

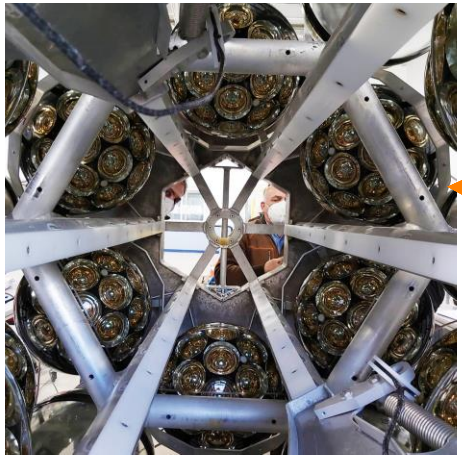
The CAPACITY lab in Caserta

The **CAPACITY** (**C**ampania **A**stro**PA**rti**C**le **I**nfrastruc**T**ure facilit**Y**) laboratory, ex **CACEAP**, is the result of a collaboration between INFN and the Mathematical Department of Università degli Studi della Campania 'Luigi Vanvitelli'

The primary goal is to **integrate**, **test** and **calibrate** the detection units for KM3NeT detectors

DU integration and preparation for deployment





DOM Production

Base Penetrator Production (external producer)

VEOC Production (external producer)

Processing steps for DU production performed at CAPACITY lab

DU Prod. Process 1: VEOC, DOMs and Base Penatrator Integration

DU Prod. Process 2: Base Module Integration

DU Prod. Process 3: DU test and calibration

DU Prod. Process 4: LOM Loading

DU Prod. Process 5: DU stack preparation

DU Prod. Process 6: Pre-Deployment test

DU test and calibration (Process 3)

Stringent requirements to allow a good pointing accuracy:

- Accurate time synchronization of sensors: 1 ns on several thousands of nodes in a sparse array in deep sea
- Precise position and monitoring of sensors: 10 cm

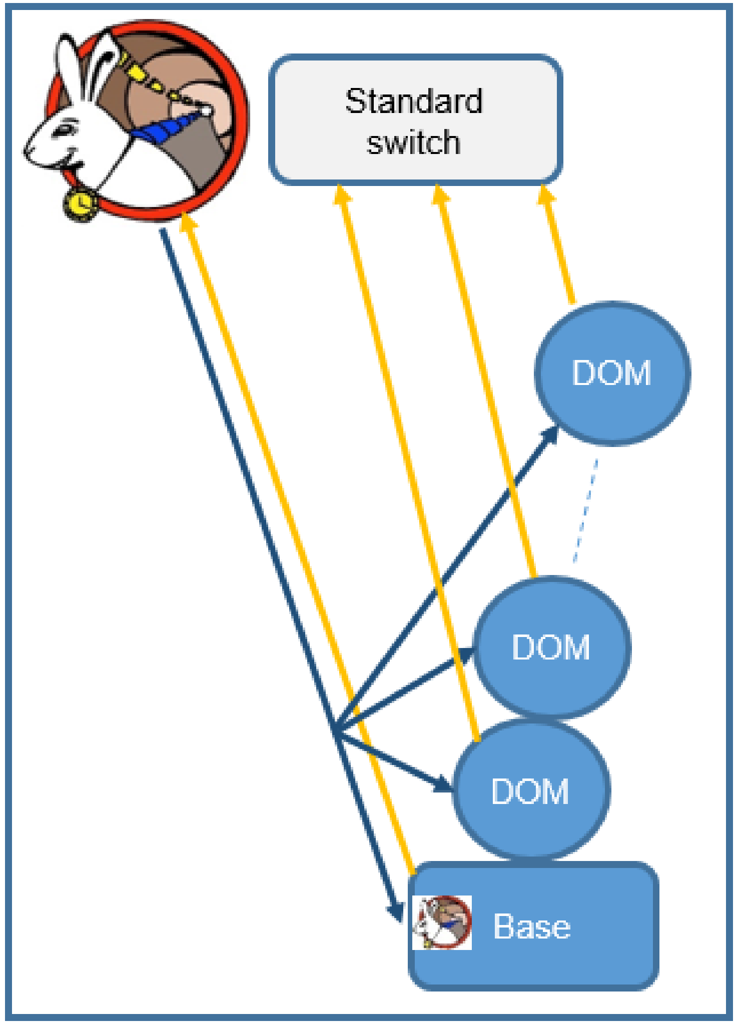
TIME Calibration:
- ✓ Calibration of White Rabbit devices
- ✓ Calibration of networks' optical fibre
- ✓ Calibration of electronic latencies of sensors and boards

Position Calibration
- ✓ check of acoustic receiver inside each moving element (DOM)
- ✓ Check of DU base digital hydrophone receiver

Preliminary steps with Process3:

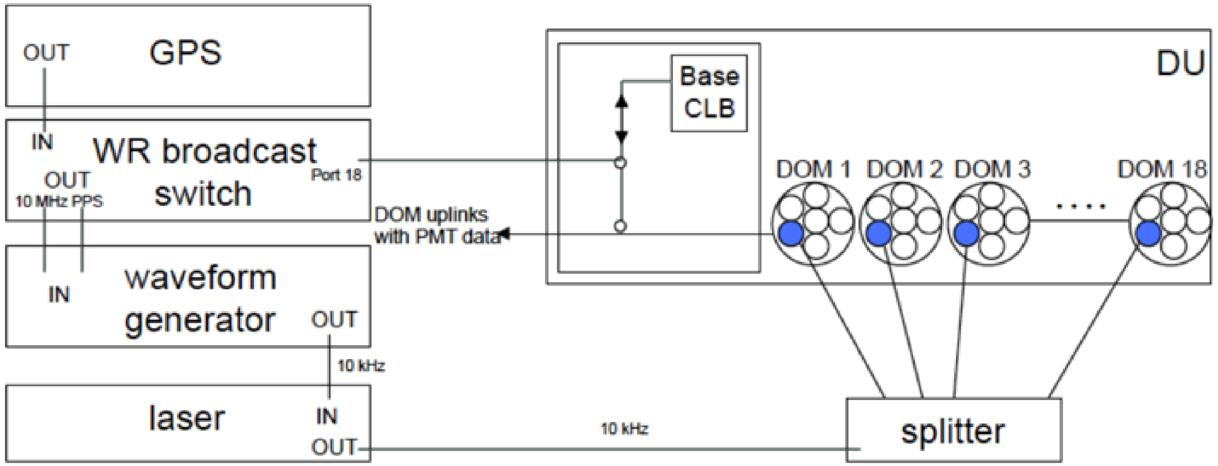
- DU setup in dark box, DU&DAQ connection/configuration
- communication checks between test station and BaseModule/DOMs
- PMT calibration and qualification
  - Darkening
  - Fully electrical power measurements
  - HV tuning
  - Transit time: TT peak

DU Time Calibration in dark box

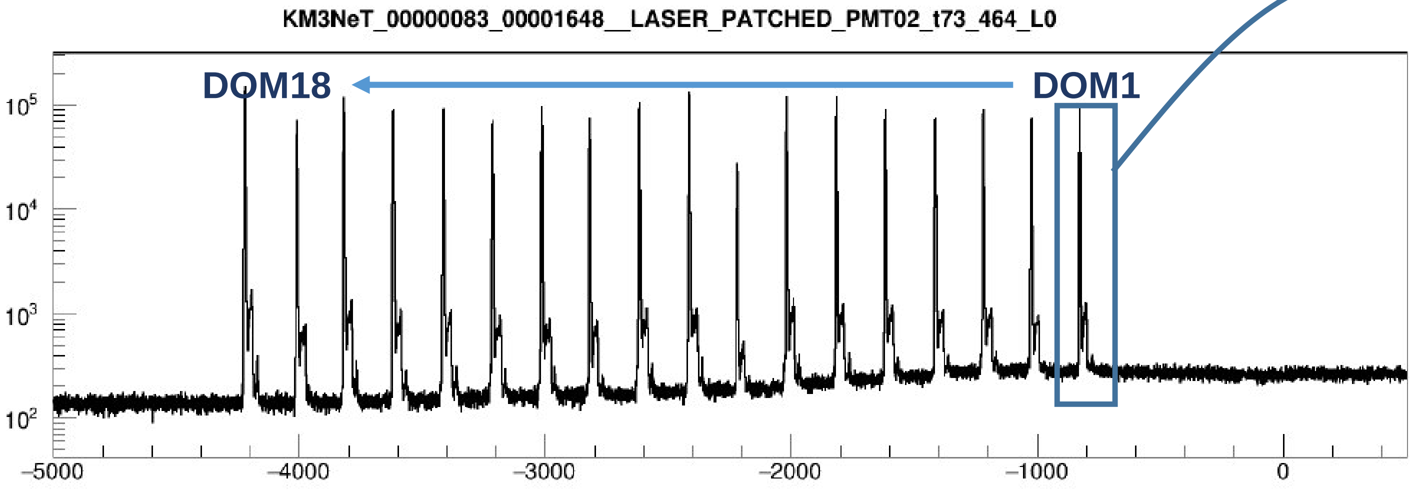


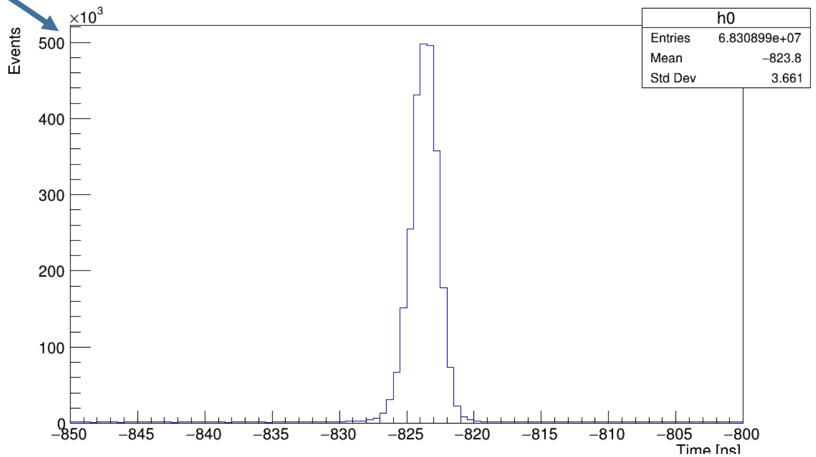
Inter-DOM time calibration:

- **to measure** the time delays between DOMs of a single DU due to the different propagation time of the clock to reach each DOM.
  - the lower DOM in the string reached earlier; the upper is reached later
- **method:** blue laser source that illuminates simultaneously 2 PMTs of each DOM at SPE level
  - light pulses time stamped ==> estimate the correction offset to add to each DOM so that the full string is calibrated with respect to the DU Base.

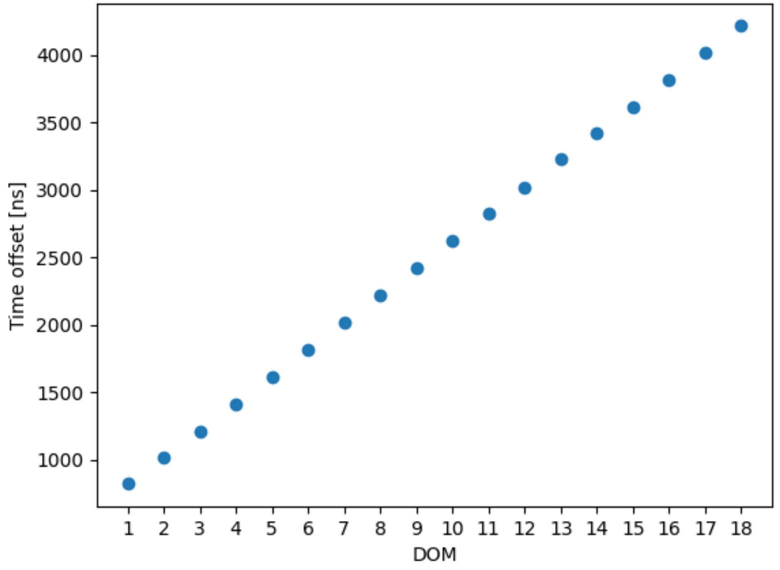


DU Time Calibration in dark box (2)





36 m inter-DOM at ≈ 5 ns/m ==> 180 ns time delay



Time measurements:

- PiLas Mod. EIG2000DX @406 nm
- **time offset** for all the DOMs in the DU with respect to the DU base
- Reference measurements of the TT distribution are also used to determine the TT distributions for the simulations

Check of acoustic receiver

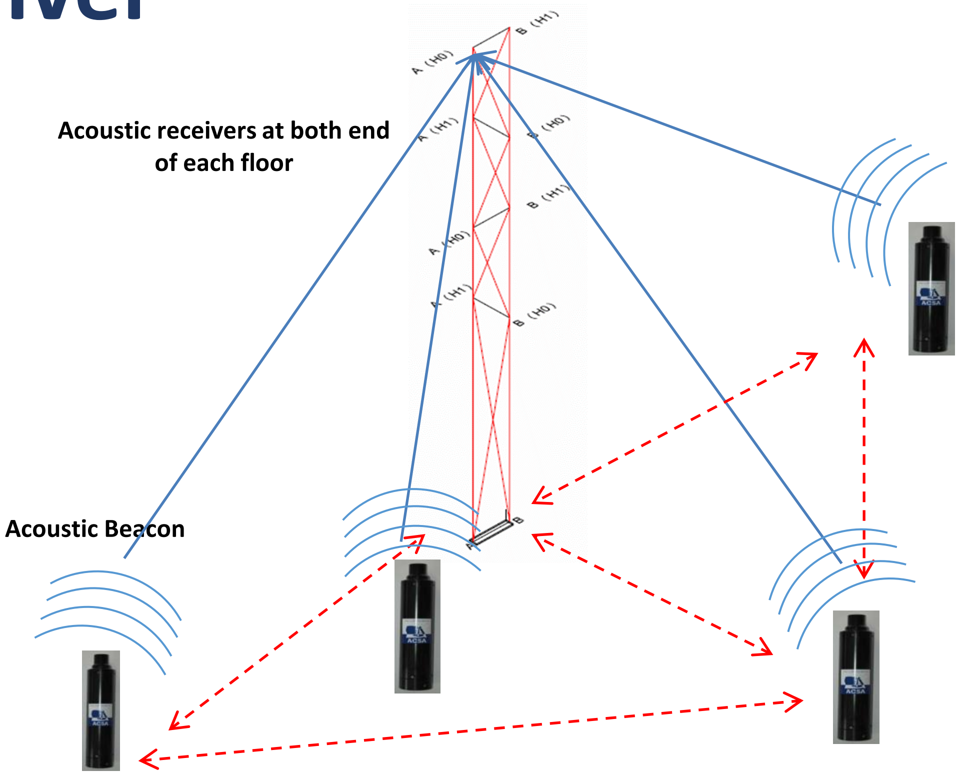
The Acoustic Positioning System (APS) requires:

- relative positioning accuracy : < 10 cm (less than DOM diameter)
- absolute positioning accuracy: < 1 m to optimize pointing resolution

Key elements:

Long Baseline of acoustic emitters (beacons) placed in known and fixed positions

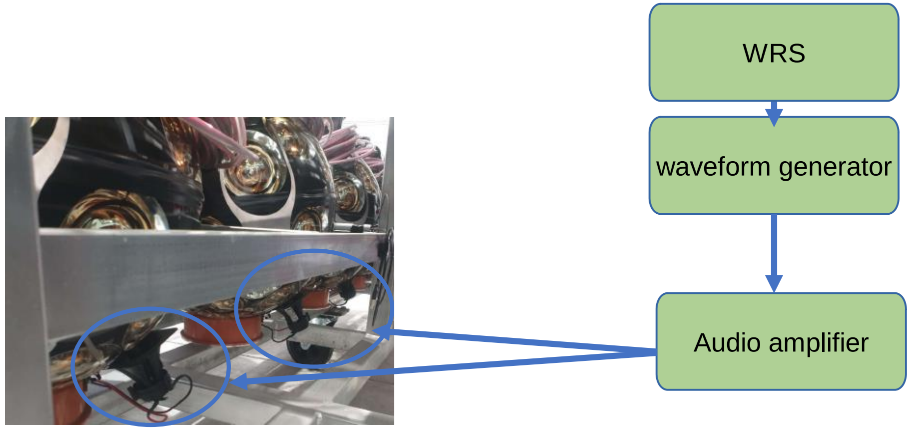
Array of Digital Acoustic Receivers (DARs) installed in each DOM and at the base of the DUs (hydrophones) moving with the mechanical structures



- The movement of the DUs is monitored by means of piezo-electric DAR glued to the glass sphere of each KM3NeT DOM
- Digital hydrophones hosted on the base of the DUs are used to measure the DUs relative distance.

Check of acoustic receiver in dark box

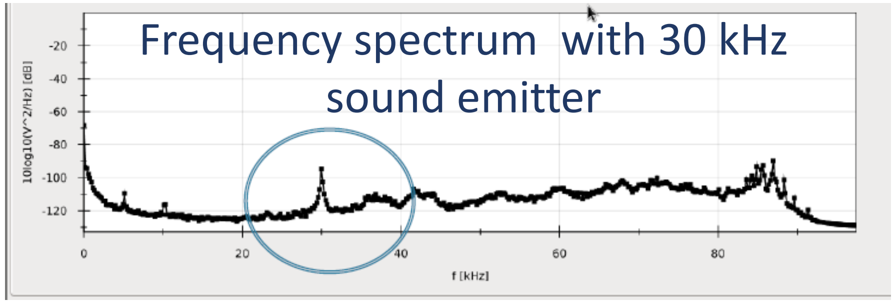
- The performance of the **digital piezo sensors** are investigated during the DU dark box calibration
- **Hydrophone** and **beacon** functionality checks are also performed in the final DU configuration



emitters are located at about 10 cm from the DOM south pole

The check of the acoustic receiving elements of a DU is performed using a set of acoustic emitters synchronized with WRS using a signal generator

- sinusoidal wave emission (30 kHz, 2 ms duration, repetition rate 1 second, V = 2 Vpp), a sound amplifier-and-splitter connected to 18 cables with the same delay of signal propagation, and 18 acoustic piezoelectric emitters



Nanobeacon measurements in dark box

Goals: Time and energy Calibration, measurement of water absorption length

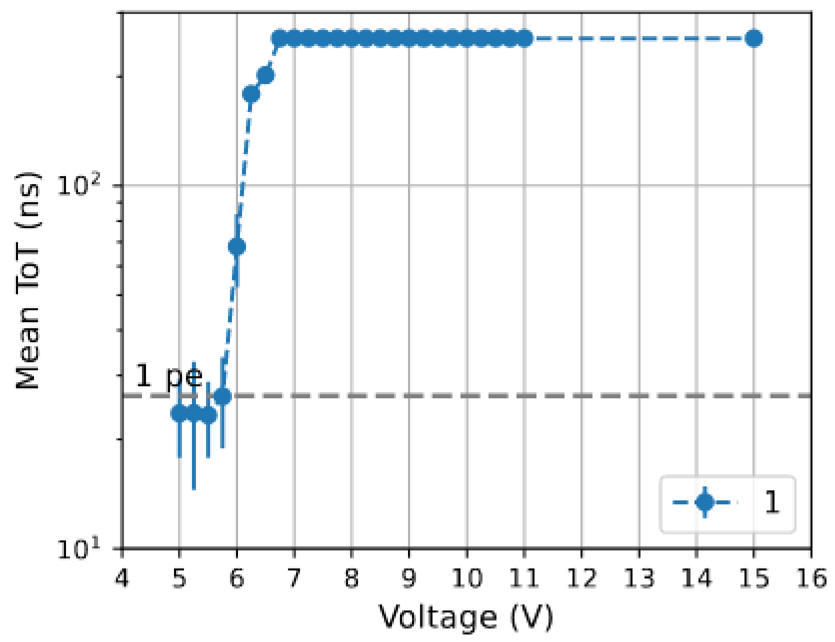
Each DOM hosts a LED beacons (Nanobeacon, NB) used to calibrate the surrounding DOMs in the same DU

- short light pulse at a fixed wavelength of 470 nm

The NB functionality tests are performed in DarkBox.

- check the hits in the PMTs closest to NB of the same DOM that emits light.
- NB pulses are emitted at a frequency of 10 kHz with a bias voltage scan per each nanobeacon.

ToT vs nano-beacon voltage



Conclusions

- KM3NeT is going to become a key infrastructure for neutrino astronomy in the next decade
- Detector mass production in regime stage. Production rate will increase in the next years
- Stringent requirements to allow a good pointing resolution → timing and positioning calibration
- The CAPACITY lab (Caserta, Italy) is an important site for ARCA DU production, integration and calibration
  - Several functionality tests, data taking and calibration runs are performed
  - Results stored in main database allow the final in-situ setup and calibration

Thanks
for your attention!

PMT

Quantum Efficiency: 22% at 470 nm, 27% at 404 nm

Transit Time Spread (TTS): < 5 ns (FWHM)

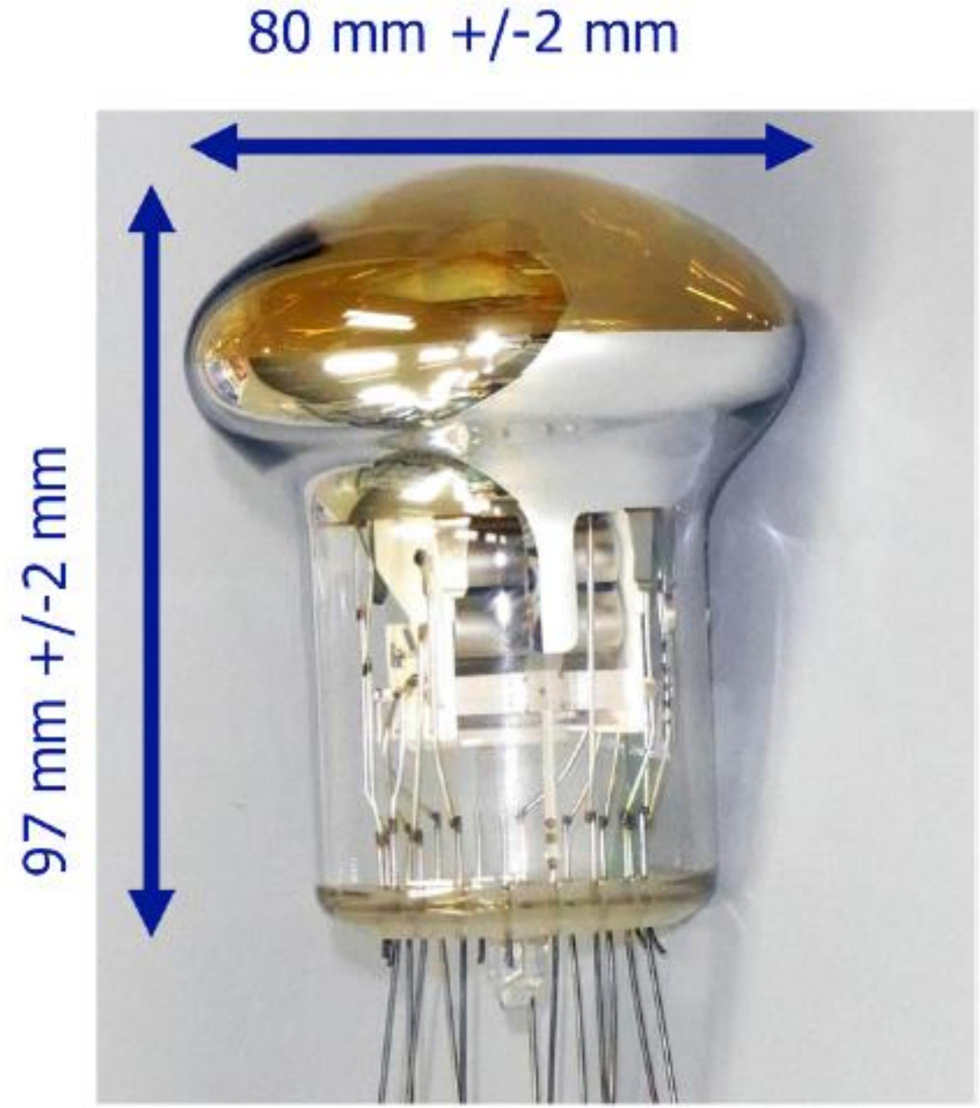
Time-Over-Threshold (ToT): 26.4 ns for a single photoelectron

Gain: 3 x 10^6

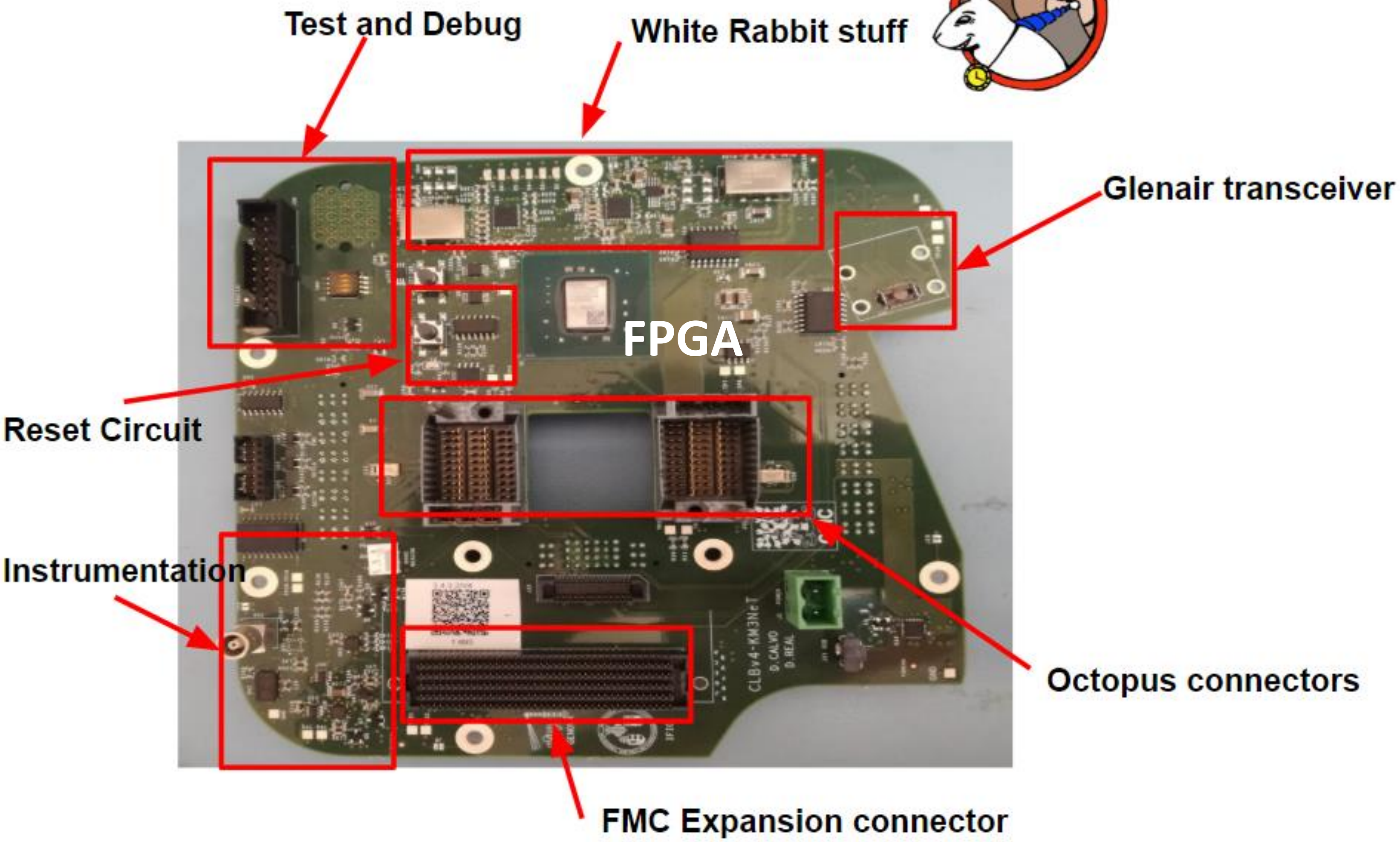
Dark count rates: 200-1500 Hz @ 0.3 photoelectrons threshold

Total in-situ count rate: 5-10 kHz

Peak to valley ratio: >3

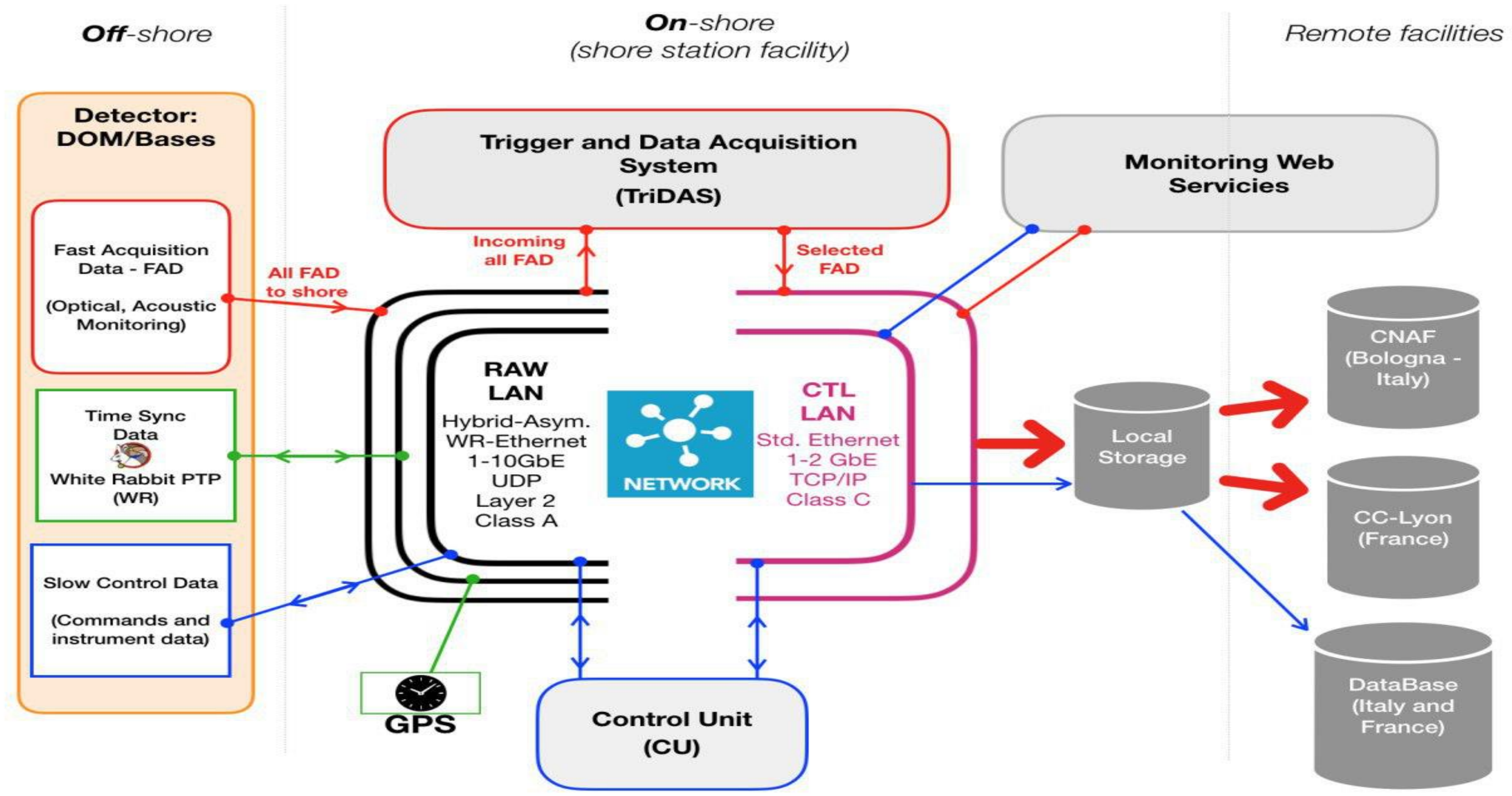


CLBv4



- **Two Flash memories** (Previous version only one. Now logout separated from FPGA image)
- **New** Glenair optical **transceiver with better reliability**
- **New sensors**: Gyroscope, accelerometer, compass and pressure
- **Hardware Watchdog and new reset scheme**
- **Several clock schemes** to evaluate the best solution for WR from the point of view of stability and phase noise:
  - Crystek (125 MHz and 124.99 MHz)
  - 25 MHz connected to clock generators

DAQ


Off-shore
On-shore
(shore station facility)
Remote facilities
Detector:
DOM/Bases
Fast Acquisition
Data - FAD
(Optical, Acoustic
Monitoring)
Time Sync
Data
White Rabbit PTP
(WR)
Slow Control Data
(Commands and
instrument data)
All FAD
to shore
Trigger and Data Acquisition
System
(TriDAS)
Incoming
all FAD
Selected
FAD
Monitoring Web
Servicies
RAW
LAN
Hybrid-Asym.
WR-Ethernet
1-10GbE
UDP
Layer 2
Class A
NETWORK
CTL
LAN
Std. Ethernet
1-2 GbE
TCP/IP
Class C
Local
Storage
CNAF
(Bologna -
Italy)
CC-Lyon
(France)
DataBase
(Italy and
France)
GPS
Control Unit
(CU)