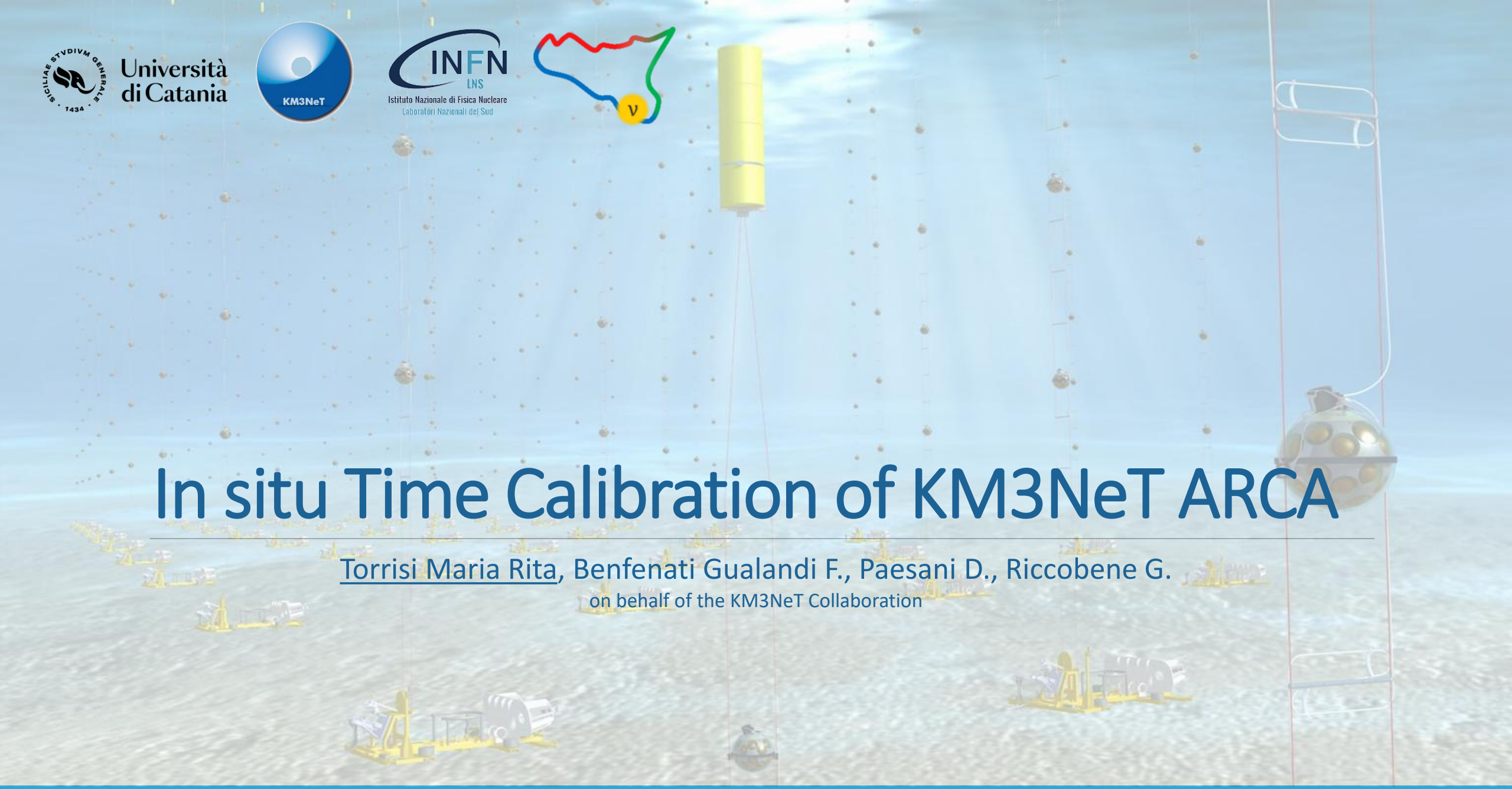


In situ Time Calibration of KM3NeT ARCA

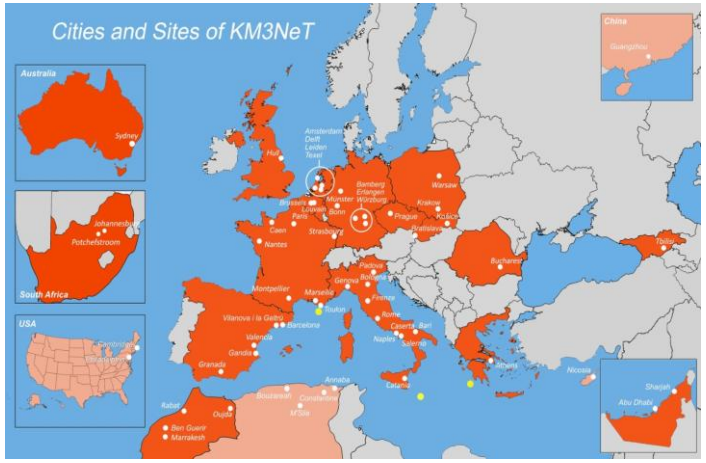
Torrisi Maria Rita, Benfenati Gualandi F., Paesani D., Riccobene G.
on behalf of the KM3NeT Collaboration

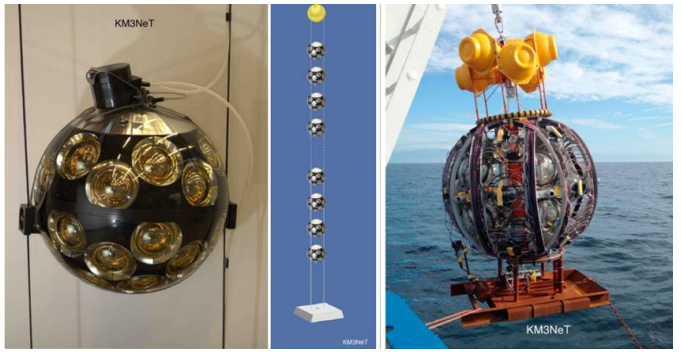
KM3NeT: Cubic Kilometre Neutrino Telescope

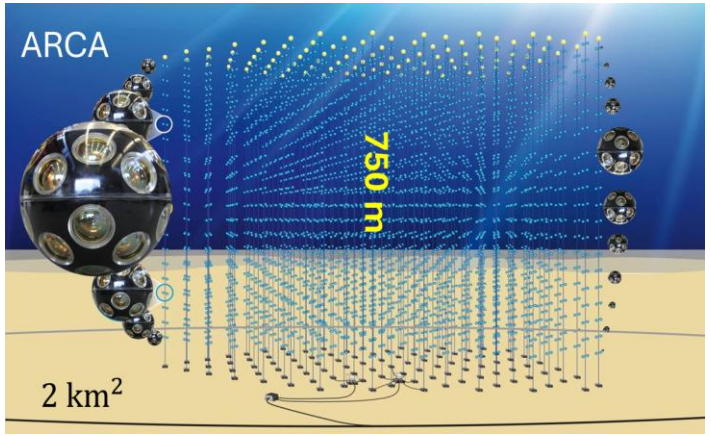
Large-scale underwater neutrino telescope designed to detect high-energy neutrinos (> 100 GeV) by observing the Cherenkov light emitted.

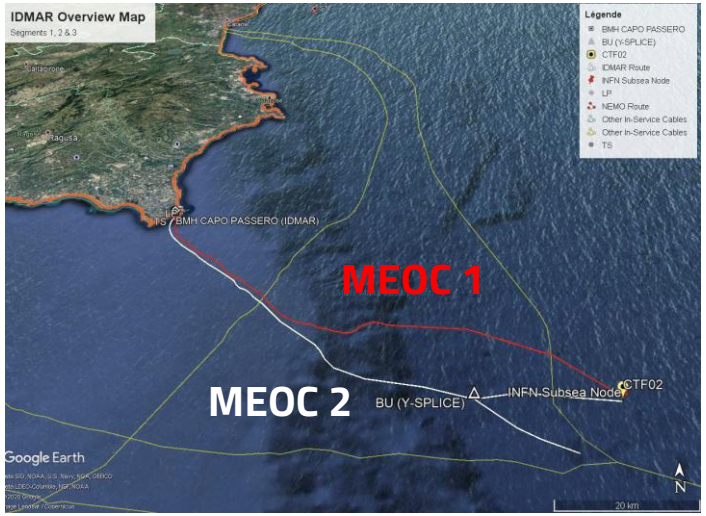
Two detectors:

- **ARCA** (Astroparticle Research with Cosmics in the Abyss), for high-energy astrophysical neutrinos.
- **ORCA** (Oscillation Research with Cosmics in the Abyss), for atmospheric neutrinos and neutrino mass hierarchy.





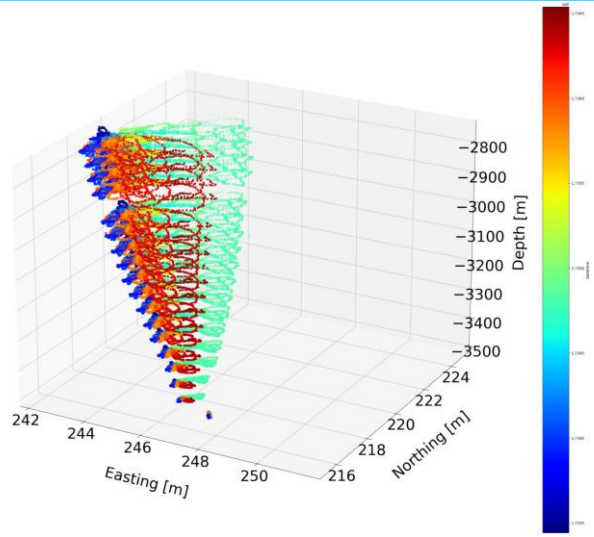




KM3NeT - The next generation neutrino telescopes, https://www.km3net.org/

Calibration of ARCA detector

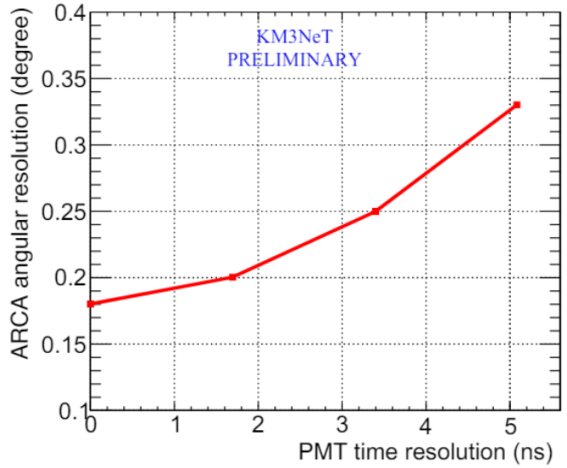
DU movements detected by acoustic positioning system in 37 days.



S. Viola. KM3NeT Acoustic Positioning and Detection system. EPJ Web of Conferences 216, page 02006, 2019.

Angular resolution (< 0.1°) requirement for accurate neutrino event reconstruction and background suppression.

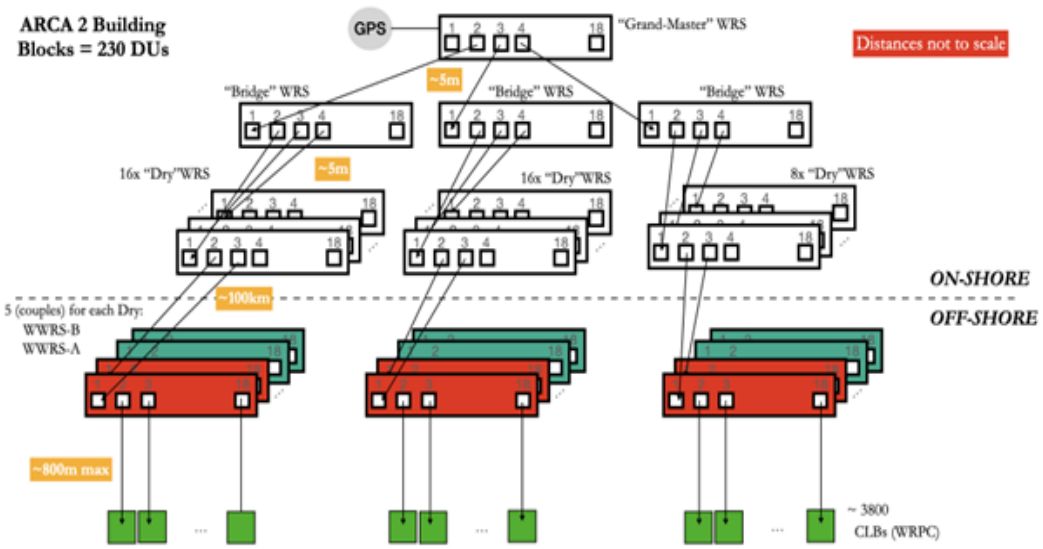
- Accurate spatial calibration through a relative **Acoustic Positioning System**.
- Accurate time calibration through a **nanosecond-level synchronization** across the detector trough several steps:
  - between PMTs within the same DOM (**intra-DOM**),
  - between DOMs in the same DU (**inter-DOM**),
  - between different DUs (**inter-DU**).

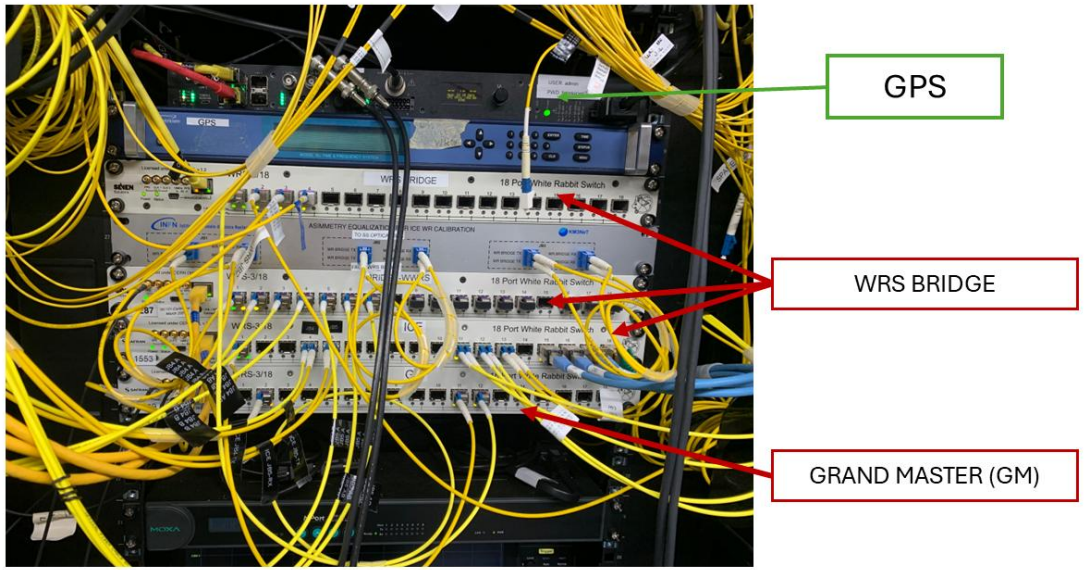


KM3NeT internal note, R. Coniglione et al.

KM3NeT Phase 2: White Rabbit standard architecture

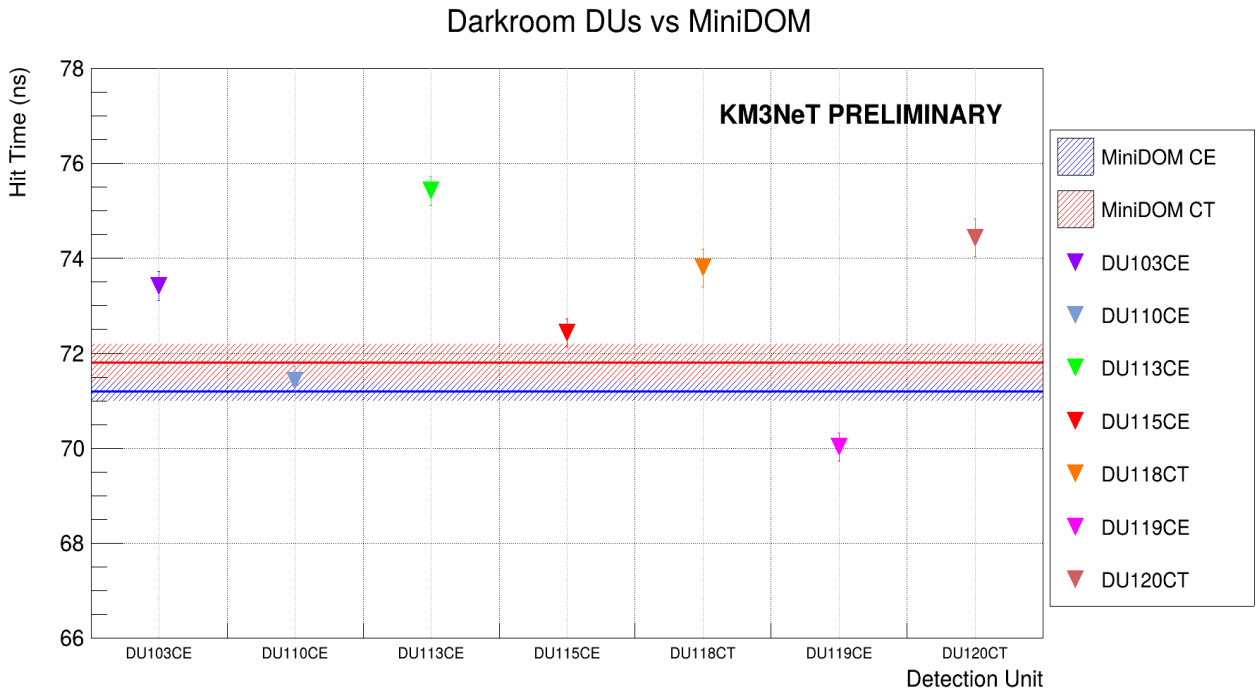
- **Sub-nanosecond** time and synchronization via optical fiber links.
- Master-slave protocol over **point-to-point** optical links, using round-trip-time measurements to a common reference.
- Shore master clock distributes timing through WR switch hierarchy to each DOM via CLB and WWRS.





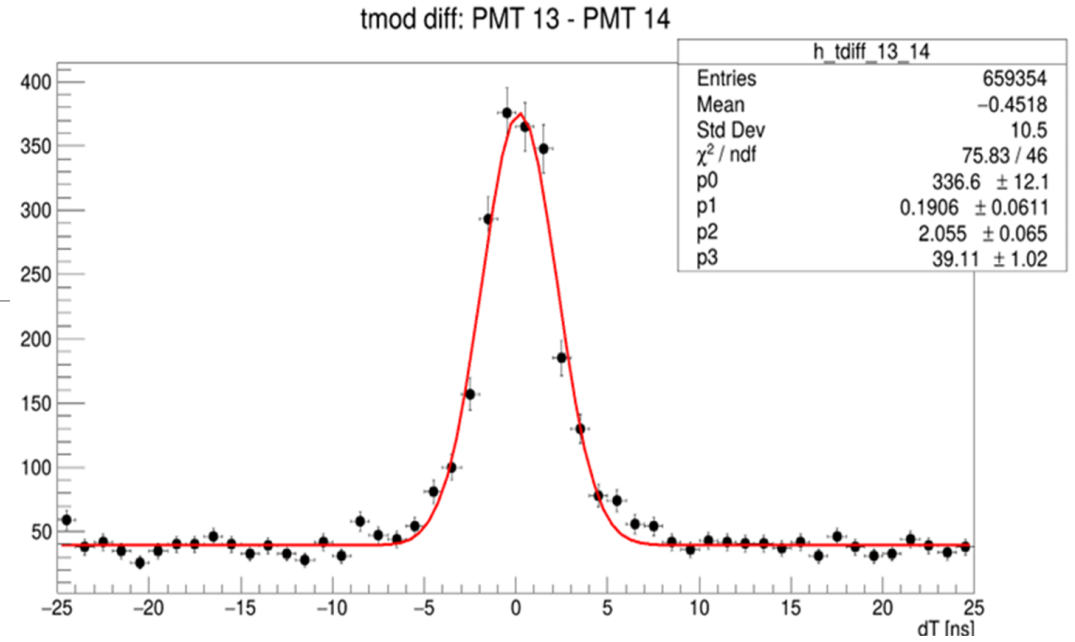
The Darkroom Calibration

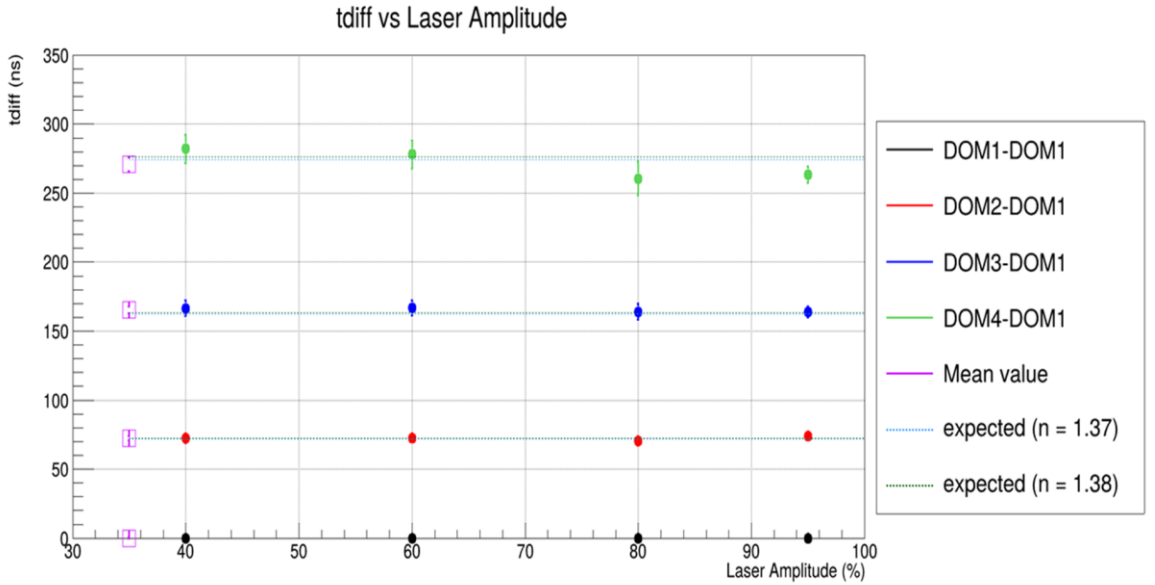
- Prerequisite for time calibration: High-Voltage (HV) tuning, setting the PMT gain to detect photons equal to **$3x10^6$** and to ensure a uniform response among PMTs.
- Laser runs then measure inter-DOM timing using two reference PMTs per DOM, correcting the average hit times for known delays.
- DU time calibration performed at three different darkrooms: Catania, Caserta and Genova with systematic differences due to the **different darkroom setups**. **Intercalibration of the three darkrooms** performed with a portable DOM (the MiniDOM).



The Laser Beacon

- Auxiliary device, installed on the seafloor onboard ARCA-JBs, designed to perform **in situ time calibration** of the detector.
- Emits short, intense and isotropic green laser pulses (532 nm) with **sub nanosecond light width.**
- Time differences **between PMT pairs** within the same DOM, finding **mean values close to 0** and **sigma values** in a range around **2.2-2.3 ns**, consistent with the PMT Transit Time Spread (TTS).
- Time differences calculated by the time of flight measurements, considering **the relative distances between each DOM and the LB** and varying laser amplitudes.

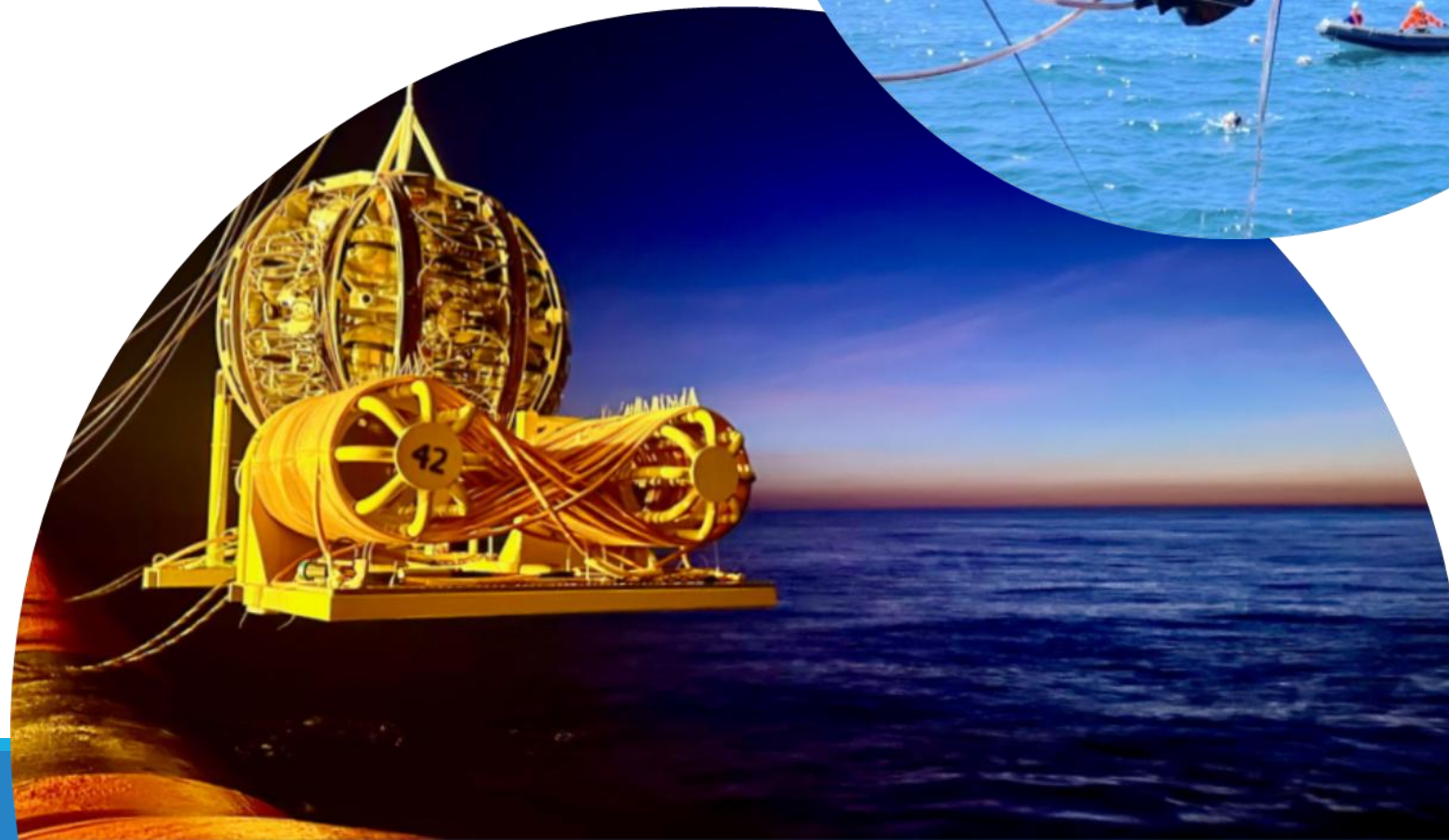




Conclusions:

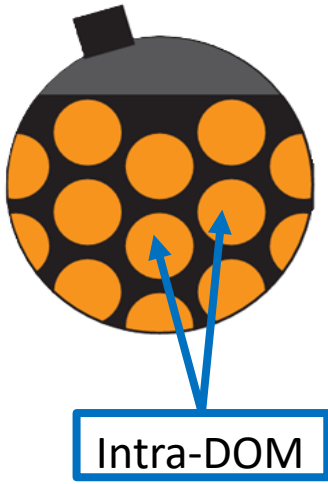
- White Rabbit Standard successfully implemented, improving time synchronization across the detector.
- A new device, called MiniDOM, developed and used to cross-calibrate the darkrooms laser systems.
- First in situ application of the Laser Beacon for: intra-DOM calibration and inter-DOM calibration. Results consistent with ^{40}K decays and muon track residuals.
- The laser beacon will be further exploited for inter-DU calibration during the next sea campaign.

Thank you for your attention



Backup Slides

Time Calibration: overview



$$^{40}K \rightarrow {}^{40}Ca + \overline{\nu_e} + e^-$$

Intra-DOM time calibration:

- between PMTs within the same DOM.
- based on the detection of light from ^{40}K decays in sea water.

Inter-DOM time calibration:

- between DOMs in the same DU.
- dedicated darkroom calibration before DU deployment

Inter-DU time calibration:

- between different Dus.

In situ checks:

- through two independent methods: atmospheric muons and laser beacons.