CHARACTERISTICS AND PERFORMANCE OF THE KM3NET MULTI-PMT OPTICAL MODULE

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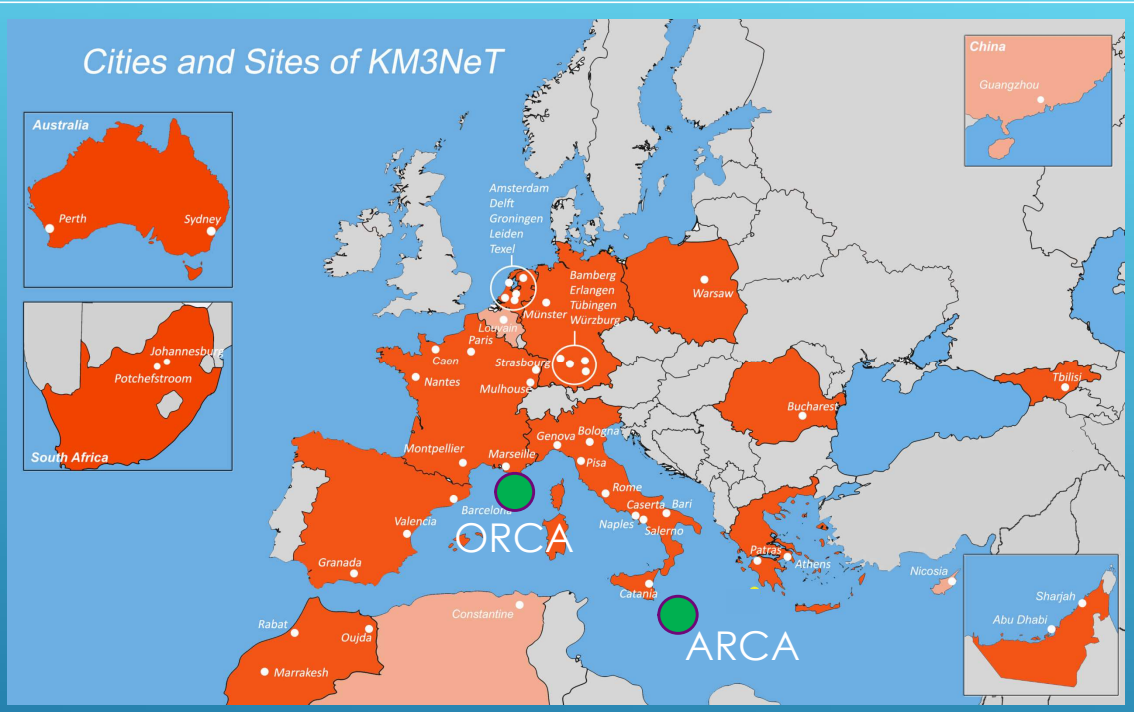
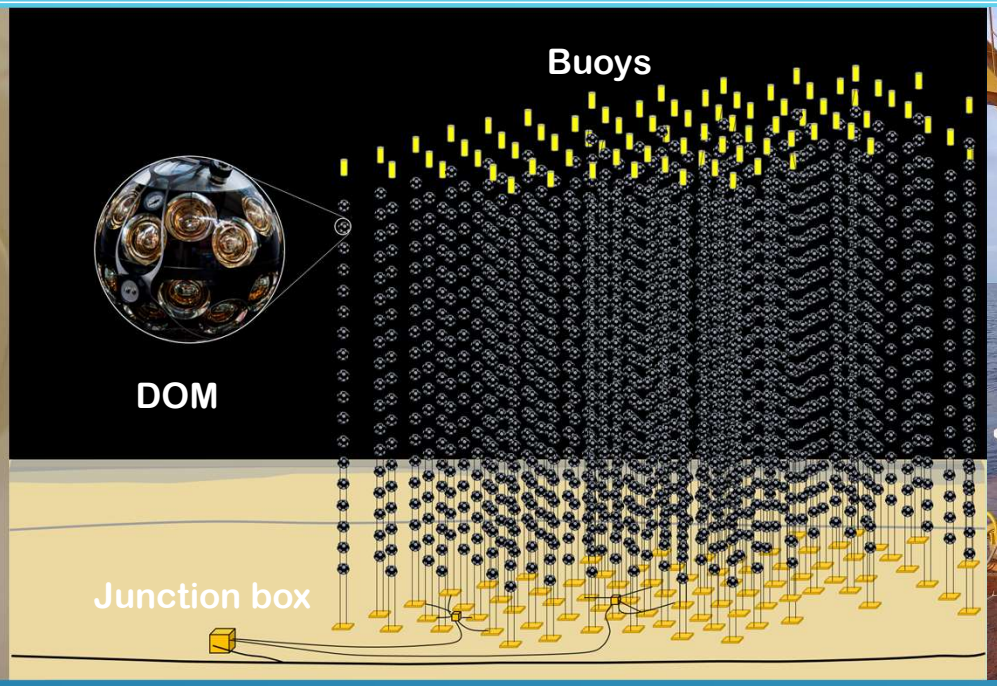
on behalf of the KM3NeT collaboration

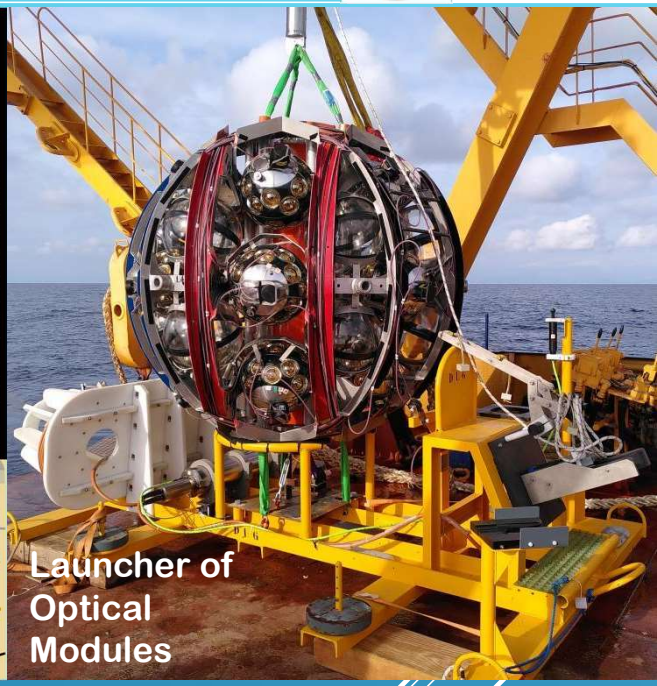
KM3NeT EXPERIMENT



- Neutrino telescopes located at two sites on the bottom of the Mediterranean Sea.
- Instrument large volumes of water and study the Cherenkov radiation generated by relativistic particles produced in neutrino interactions.
- ARCA (Astroparticle Research with Cosmics in the Abyss) search for neutrinos from distant astrophysical sources.
- ORCA (Oscillation Research with Cosmics in the Abyss) studies the fundamental properties of neutrinos.

KM3NeT DETECTORS





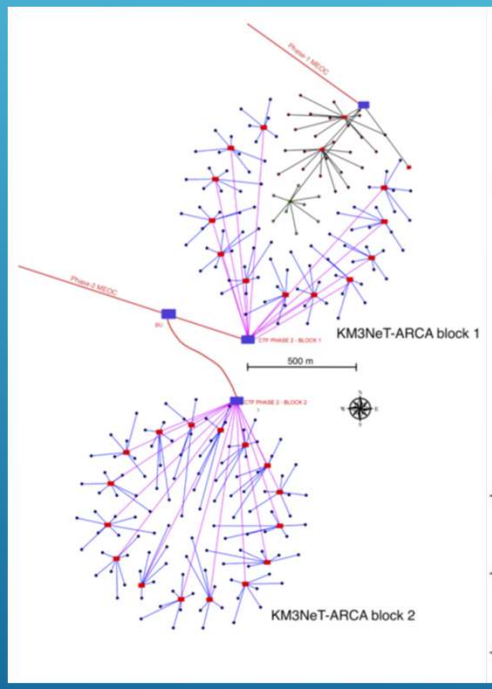
Base modules

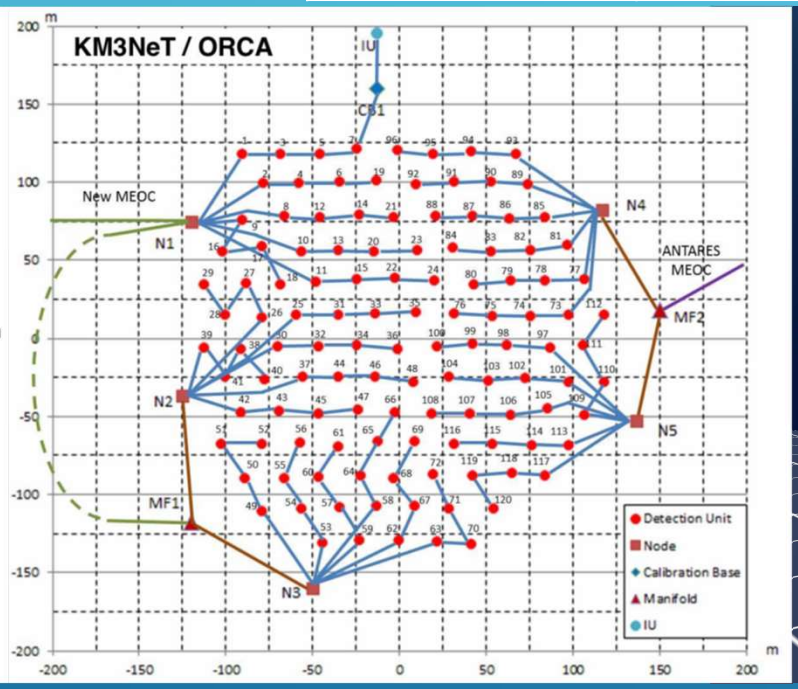
- Scalable arrays of Multi-PMT Optical Modules (18 DOMs per Detection Unit (DU)).
- ORCA 11 DUs deployed/ complete configuration 115 DUs
- ARCA 21 DUs deployed / complete configuration 2 x 115 DUs / 150 strings funded

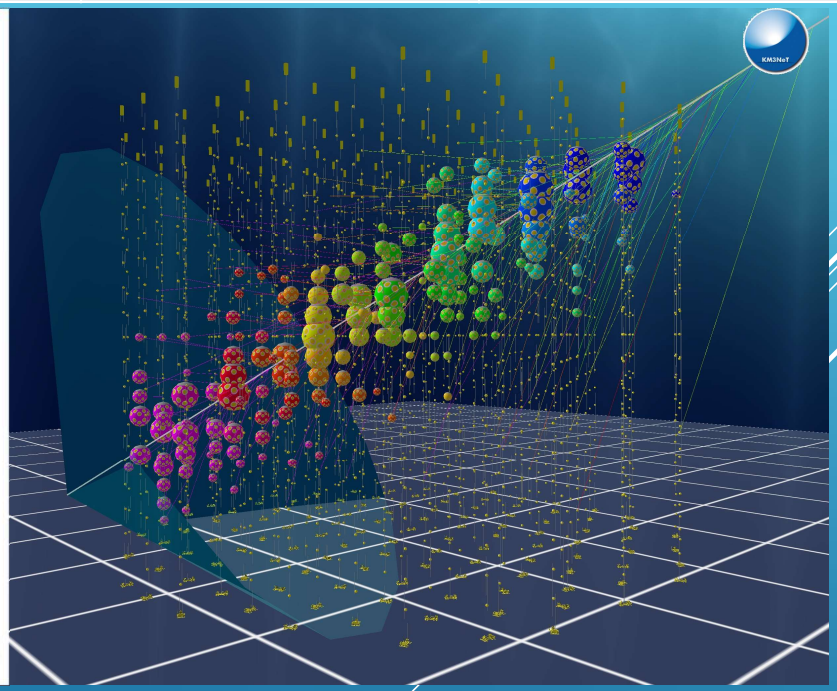
KM3NeT DETECTOR STRINGS

- 18 DOMs per DU
- ARCA: 90 km south of Capo Passero
- ORCA: 40 km south of Toulon

	Depth (m)	Horizontal spacing (m)	Vertical spacing (m)
ARCA	3500	90	36
ORCA	2500	20	9







ARCA footprint
1 BB = 115 DUs
21 DUs deployed, 150 funded

ORCA footprint
11 DUs deployed

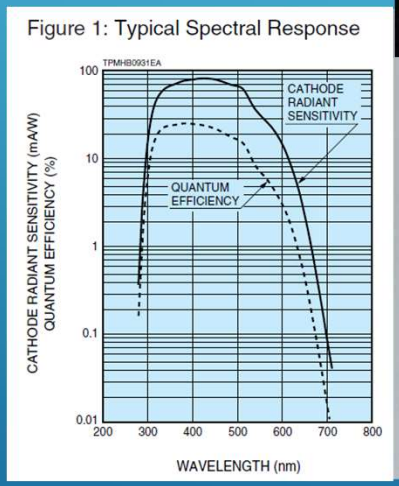
Event reconstruction

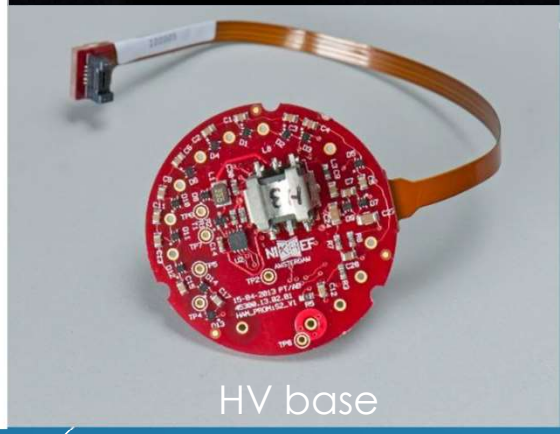
KM3NeT DOM DESIGN

- **Pressure-resistant glass sphere houses the PMTs and the FE electronics**
- **31 3'' PMTs**
  - Total detection area equivalent to 3 10" PMTs;
  - Sensitivity to the incoming direction of detected photons;
  - An almost uniform and extended angular coverage of the telescope with a field of view above the horizon;
  - At least 15 years operational time.
- **Position calibration devices**
  - Good position calibration (position Δ_x< 10 cm);
  - Timing & time calibration.
- **Digitization on board**
  - Good timing calibration (TOA $\Delta_T \approx$ 1-3 ns);
  - The possibility to define local triggers.

KM3NeT DOM PMTS

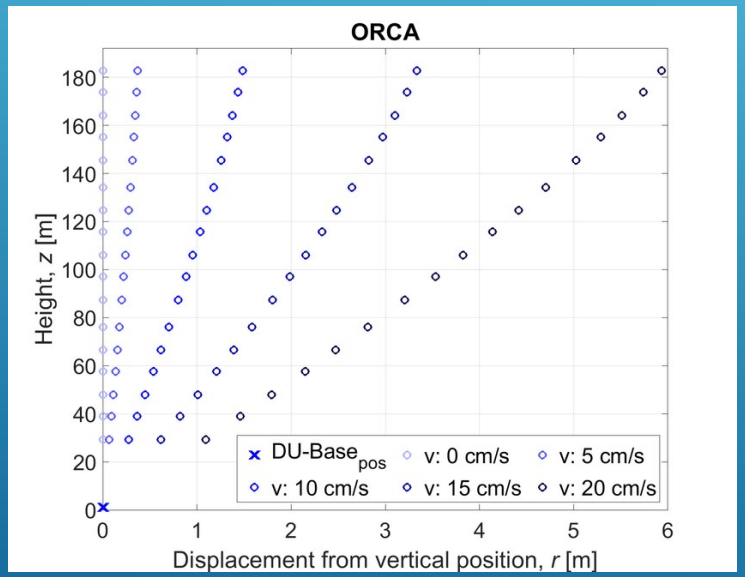
- **Hamamatsu R12199-02 3” phototube**
  - Segmented cathode
  - Spectral response > 92% in the 400-500 nm range
  - Nominal gain of $3 \cdot 10^6$ for increased stability and lifespan
  - Collection ring to enhance the sensitive area (+ 20-40%)
  - Cheap, large collection area and low power
- **Low power HV base**
  - Adjustable voltage
  - Integrated amplification
  - Adjustable discrimination threshold
- **Signal is digitised and sent to the central logic board (CLB) which extract the TOA and the TOT**





DOM POSITION AND TIMING CALIBRATIONS

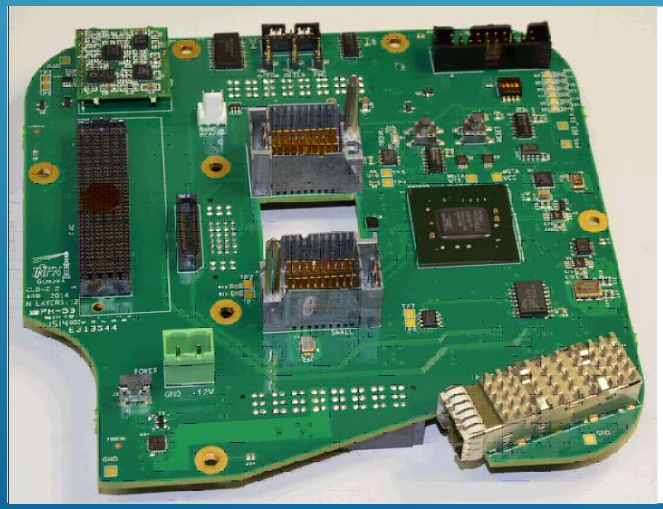
- **The shape of a detection unit is influenced by sea currents**
- Acoustic positioning system
  - Acoustic emitters, hydrophones and piezo-sensors
- Tilt and heading sensors
  - Compass and accelerometers
- 470 nm LED for timing calibrations of the neighbouring modules



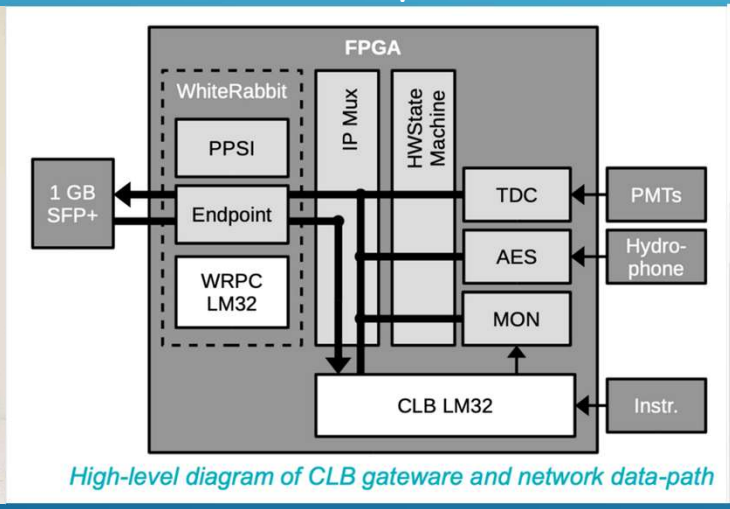
Sensors 2020, 20(18), 5116
https://www.mdpi.com/1424-8220/20/18/5116

CENTRAL LOGIC BOARD (CLB)

- The heart of the optical module electronics is the Central Logic Board
  - Dedicated FPGA
  - Stores a start-up configuration and backup image
  - I2C standard communication protocol
  - PMT data processing with 32 TDC
  - Sensor data processing and control
  - Interface and communication with the outside world via optical transceiver

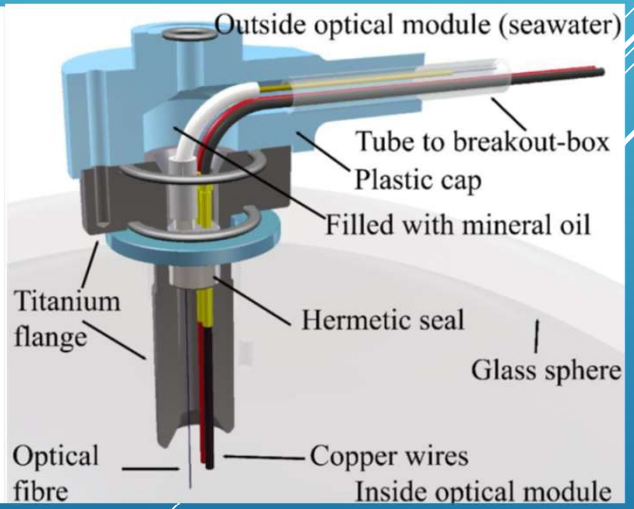


CLB



High-level diagram of CLB gateware and network data-path

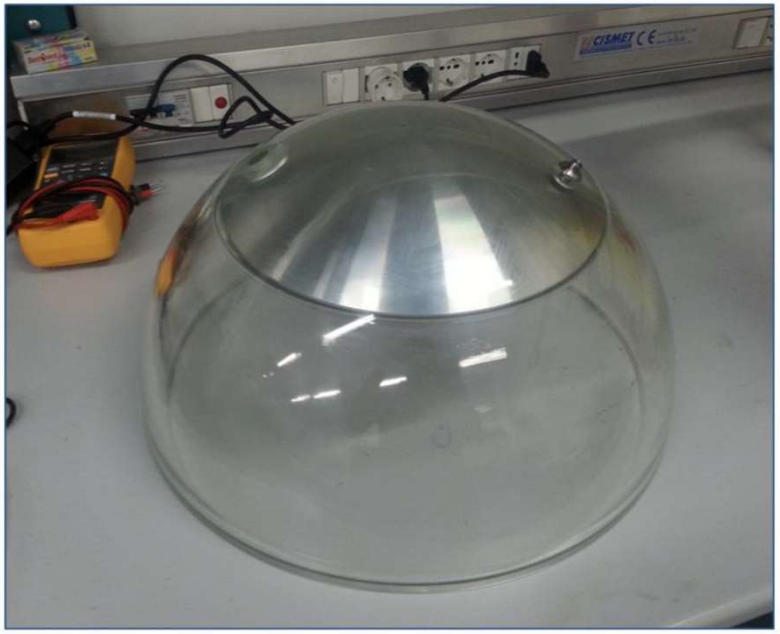
CLB block diagram



Penetrator

KM3NeT DOM INTEGRATION 1

- Install the cooling mushroom and the penetrator on the glass housing
- Install the CLB and the optical-transceiver on the cooling mushroom
- Record all the items used in the integration an their position on the DB
- Optical fibres splicing and LV connections



Glass sphere and cooling mushroom

CLB and electronics installed

KM3NeT DOM INTEGRATION 2

- Inserting the collection rings and PMTs in the mechanical structures
- Install the nano-beacon
- Install the CLB and the opto-transceiver on the cooling mushroom
- Record all the item used in the integration an their position on the DB

Mechanical structure (bottom)

Mechanical structure (top)

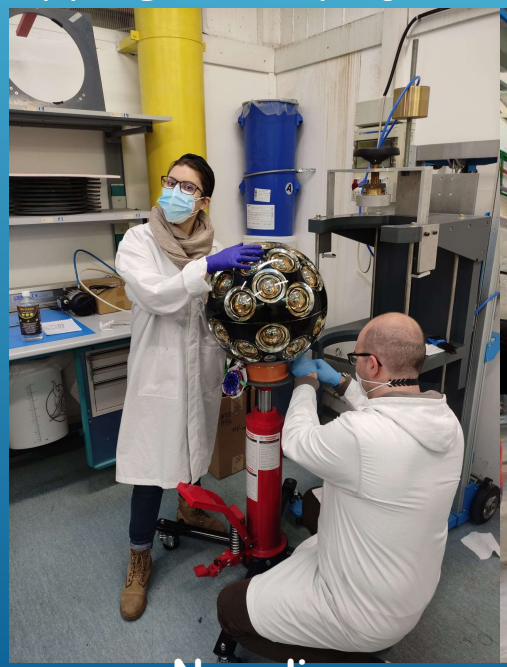
PMTs after integration in the mechanical structure

KM3NeT DOM INTEGRATION 3

- Inserting the mechanical structures in the glass housing
- Connect the electronics
- Pour the gel
  - Transparent gel
  - Soft gel (Very good mechanical damping property)

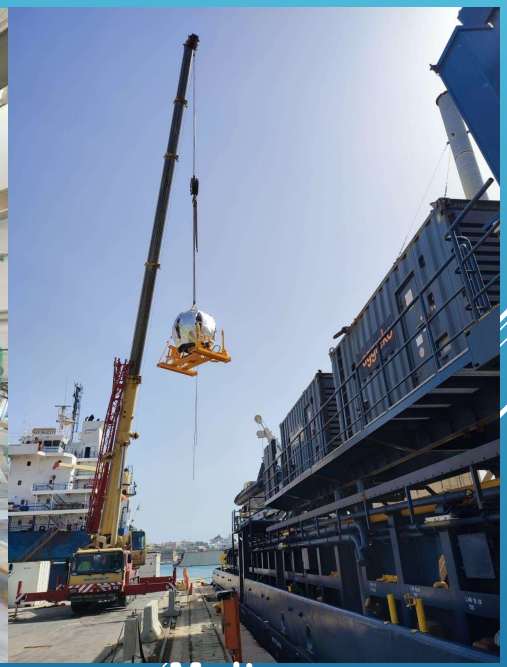
KM3NeT DOM INTEGRATION 4

- Closing the two halves, seal the interface and install the titanium collar
- Testing and calibration of the PMTs and electronics (HV, compass, communications …)
- Integration in the DU
- Shipping and deployment



Napoli

Caserta

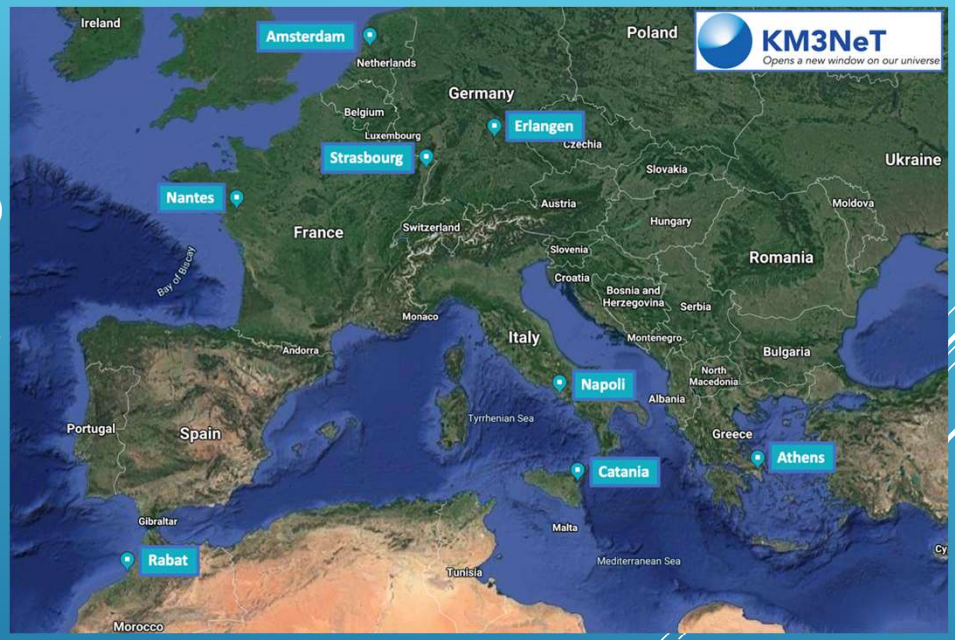


Malta

KM3NeT DOM INTEGRATION QA/QC

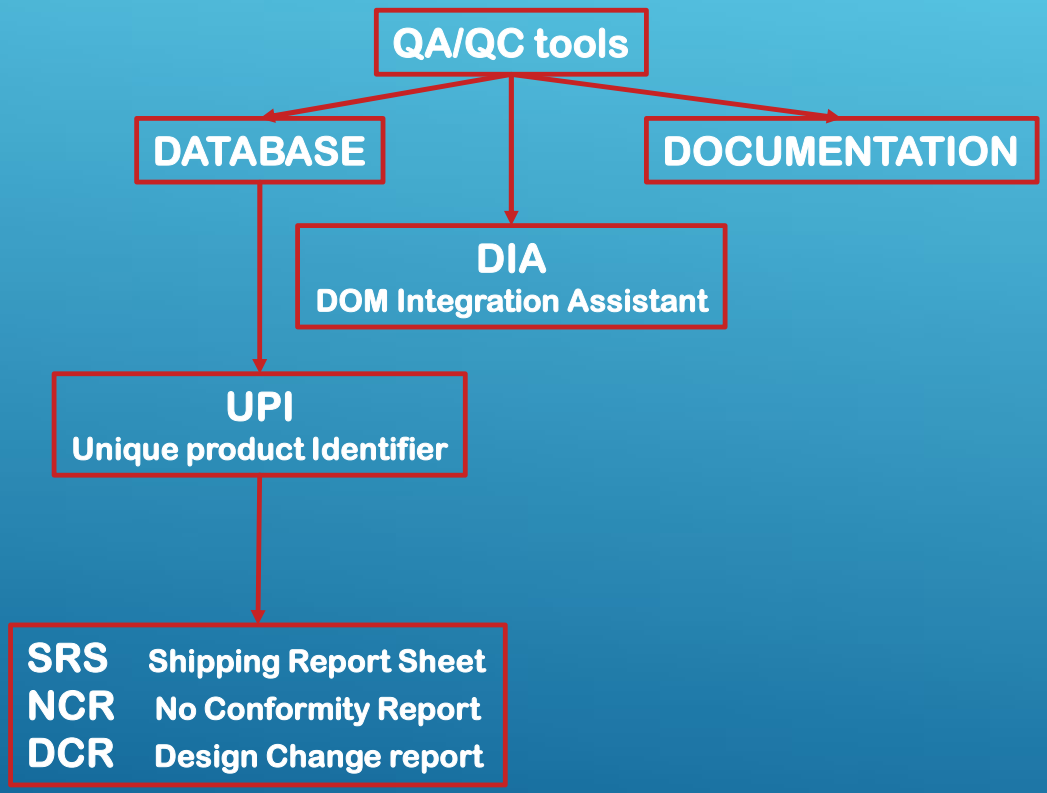
For the production of the more than 6000 optical modules for the KM3NeT telescope, a distributed production model has been established.

- 8 integration sites: Amsterdam, Strasbourg, Erlangen, Nantes, Napoli, Catania, Athens and Rabat
- Throughput 100 modules per month by the end of 2021
- Delays due to the supply chain disruption (pandemic, war)
- QA/QC priorities
  - Produce and update documents that clearly describe all the integration and testing procedures
  - Track the location and status of all the components
  - Store all the relevant information in a readily available format
  - Test the components during multiple phases of the integration



KM3NeT DOM INTEGRATION QA/QC

- Random DOM 3.4/CH48C/1.11



Current integration status

Operation	Position	Content UPI	
A00238750	PM_T00_F4 (0)	3.4.2.3/HAMA-R12199/1.407	detail
A00238750	PM_T01_E5 (1)	3.4.2.3/HAMA-R12199/1.433	detail
A00238750	PM_T02_E4 (2)	3.4.2.3/HAMA-R12199/1.467	detail
A00238750	PM_T03_E3 (3)	3.4.2.3/HAMA-R12199/1.416	detail
A00238750	PM_T04_F3 (4	.4.2.3/HAMA-R12199/1.414	detail
A00238750	PM_T05_F5 (5	.4.2.3/HAMA-R12199/1.405	detail
A00238750	PM_T06_E2 (6	.4.2.3/HAMA-R12199/1.439	detail
A00238750	PM_T07_F6 (7)	3.4.2.3/HAMA-R12199/1.406	detail
A00238750	PM_T08_F2 (8)	3.4.2.3/HAMA-R12199/1.412	detail
A00238750	PM_T09_F1 (9)	3.4.2.3/HAMA-R12199/1.426	detail

DATABASE

Anomaly reports

Integration level	Operation	Container	Position	Content	Logs	Warnings	NCRs

Location tracking

Op. Type	City	Start	End	Operation	Report sheet
INTEGRATION	Amsterdam	25/01/2015	25/01/2015	A00238750	
INTEGRATION	Amsterdam	05/04/2016	05/04/2016	A01429628	
INTEGRATION	Amsterdam	05/04/2016	05/04/2016	A01429627	
DISINTEGRATION-CONTENT	Marseille	14/07/2020	14/07/2020	A02831628	
SHIPPING_RECORD_SHEET	Erlangen	15/07/2020	16/07/2020	A02831629	KM3NeT_QA_2020_209-SRS_Old-DU1_DOMs_From_CPPM_To_Erlangen_v1
NON_CONFORMITY_REPORT	Erlangen	23/11/2020	25/01/2021	A02904800	KM3NeT_QA_2020_376-NCR_DOM23_AHRS_V00_no_calib_in_DB
NON_CONFORMITY_REPORT	Erlangen	01/12/2020	29/01/2021	A02922408	KM3NeT_QA_2020_404-NCR_DOM11_wrong_plugged_3_PMT_connectors
NON_CONFORMITY_REPORT	Erlangen	04/12/2020	29/01/2021	A02922496	KM3NeT_QA_2020_415-NCR_NCR_DOM11_FPGA_temperature_too_high
SHIPPING_RECORD_SHEET	Genova	21/06/2021	21/06/2021	A03179799	KM3NeT_QA_2021_352-SRS_18_DOMs_from_Erlangen_to_Genova_v1
INTEGRATION-CONTENT	Napoli	26/07/2021	26/07/2021	A03202576	

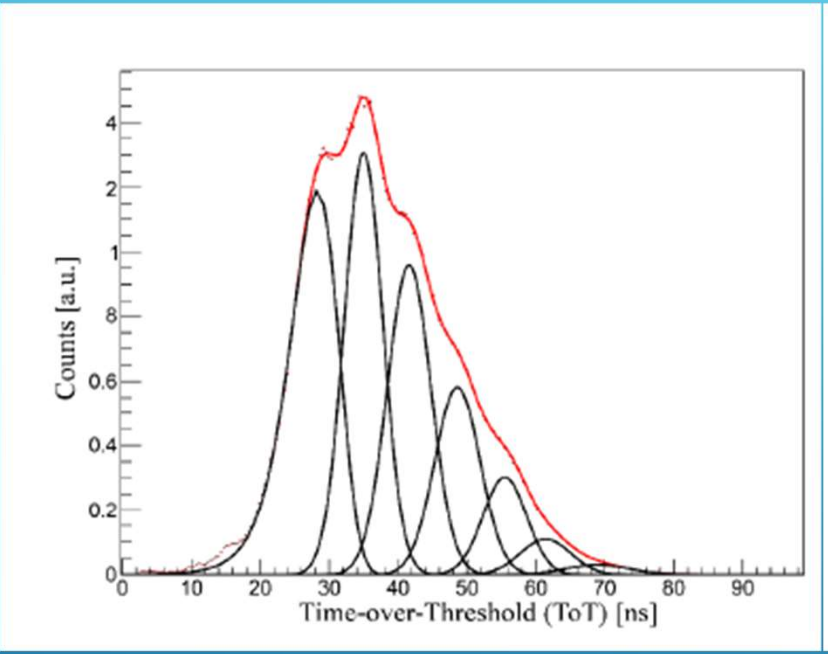
SRS

Related QA/QC reports

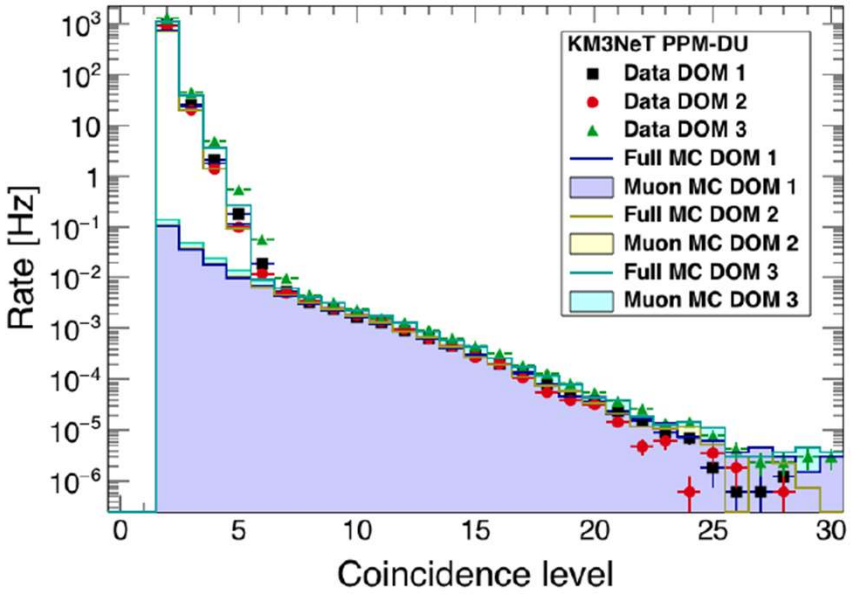
ID	Status	Doc
404/2020	REPAIR	KM3NeT_QA_2020_404-NCR_DOM11_wrong_plugged_3_PMT_connectors
415/2020	REPAIR	KM3NeT_QA_2020_415-NCR_NCR_DOM11_FPGA_temperature_too_high
352/2021	DOCUMENT	KM3NeT_QA_2021_352-SRS_18_DOMs_from_Erlangen_to_Genova_CLOSED
376/2020	WAIVE	KM3NeT_QA_2020_376-NCR_Old_ORCA-DU1_DOMs_AHRS_old_firmware
209/2020	DOCUMENT	KM3NeT_QA_2020_209-SRS_Old-DU1_DOMs_From_CPPM_To_Erlangen_CLOSED

NCR

KM3NeT DOM PERFORMANCE



Lab measurement of time-over-threshold response of the Hamamatsu R12199-02 PMT to different numbers of photo-electrons



In situ rate of coincident photon detection as function of the number of coincident PMTs.

JINST 2022, 17, P07038
https://iopscience.iop.org/article/10.1088/1748-0221/17/07/P07038/pdf

CONCLUSIONS

Different aspects of the KM3NeT experiment were presented, with a focus on the DOM characteristics and Integration

- KM3Net Collaboration and detector sites
- The detection unit
- The DOM
  - Characteristics
  - The integration
  - The performance
  - The integration distributed model
- Some aspects of the QA/QC

More than 6000 modules will be delivered in the coming few years!

Looking forward to take part in the coming sea operation and the improvements of the detectors!