UNIONE EUROPEA
Fondo Europeo di Sviluppo Regionale
Ministero dell'Università e della Ricerca
PON RICERCA E INNOVAZIONE 2014 - 2020
INFN Istituto Nazionale di Fisica Nucleare

The KM3NeT DOM integration site of Napoli : production model, local activities, and outreach

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Bari 16 – 17 November 2022

Outline

DOM INTEGRATION PROCESS & LOCAL ACTIVITY

- Introduction: KM3NeT design & the multi-PMT design
- DOM integration process: the production
- Local activity:
  - ORCA-DU 77 & ARCA-DU 61
  - First NCR: compass test
  - Current status: ARCA-DU 60
  - Purple DOM detection efficiency study
- PNRR: new DOM LAB @ Capacity

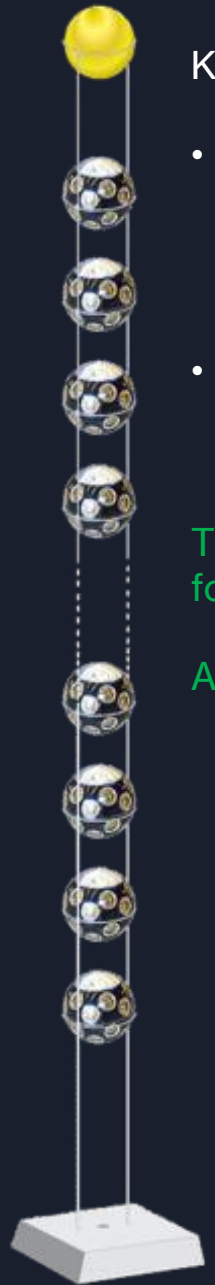
DOM QUALITY CONTROL (QA/QC) & LOCAL ACTIVITY

- New storage arrangement
- DOM integration QA/QC introduction
- DOM integration QA/QC local activity
- List of NCR (solved/still open)

OUTREACH

- ERN @ CAPACITY
- ERN @ NAPLES
- ERN @ REGGIA di CASERTA
- LICEO Scientifico Brunelleschi

The KM3NeT detector design

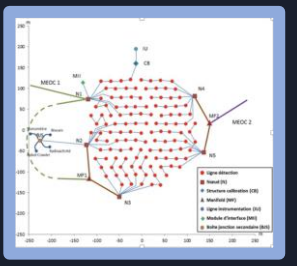


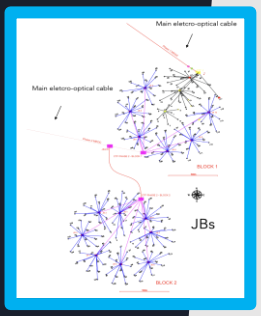
KM3NeT is currently under construction at two different sites in the Mediterranean Sea:

- **KM3NeT/ARCA** (**A**stroparticle **R**esearch with **C**osmics in the **A**byss) 90 km offshore Portopalo di Capopassero, Sicily at 3500 m depth, aiming at the detection of HE cosmic neutrino sources (E_ν ~ GeV-PeV)
  → GOAL: 1 km^3 of instrumented water
- **KM3NeT/ORCA** (**O**scillation **R**esearch with **C**osmics in the **A**byss) 40 km offshore Toulon, France at 2500 m depth, aiming at the study of the neutrino oscillations (E_ν ~ MeV - GeV)
  → GOAL: 7 megatonnes of instrumented water

The two infrastructures share the same technology with different geometries, each one optimized for its scientific goal

ARCA = 2 BB & ORCA = 1 BB ** 1 Building Block (BB) = 115 DUs: 2070 DOMs*





The Detection Unit of KM3NeT (DU) is a mooring line (~ 800 m for ARCA and 400 m for ORCA) consisting of:

- 1 Buoy
- 2 Dyneema ropes
- 18 DOMs
- 1 Anchor
- Oil-filled electro-optical backbone cables with 18 optical fibers and 2 copper wires for long-distance communication

The KM3NeT multi-PMT design

The Digital Optical Module (DOM) has an innovative design:

- 17 ” diameter high-pressure resistant glass sphere (44 cm diameter)
- dense packing of 31 **PMTs** with 3” photocathode diameter (the total photocathode area of about 1200 cm^2 in each sphere is segmented: besides increasing the DOM sensitivity, this improves the reconstruction performances)
- **calibration devices** (positioning and timing, piezo and nanobeacon)
- **electronics** for power, readout, data acquisition and transmission
- low electrical power consumption: DOM ~ 7 W
- risk of water leaks: neglectable → number of feed-throughs minimized

Implementation of the multi-PMT design:

- **Cost efficiency:** use of off-shelf components (as much as possible commercial devices)
- **Scalability:** uniform module design
- **High modules production rate:** module assembly process distributed at different sites

The KM3NeT multi-PMT optical module, S. Aiello *et al* 2022 *JINST* **17** P07038 https://iopscience.iop.org/article/10.1088/1748-0221/17/07/P07038

Production model: the integration

In its final configuration, KM3NeT will consist of more than 6000 DOMs:

a distributed production model has been established.

Staff people from many institutes and groups in the KM3NeT collaboration participate in the construction of the telescope.

- 8 KM3NeT DOM integration sites : Amsterdam, Athens, Catania, Erlangen, Nantes, Napoli, Rabat, Strasbourg

- The DOM integration procedure has been optimized for protection against errors and maximization of the production rate:
  as of today, the 8 KM3NeT DOM integration sites are able to guarantee a baseline production rate of 100 DOMs per month.

- CONS: challenging procurement and logistics → very high level of QAQC (quality assurance - quality control) is mandatory!

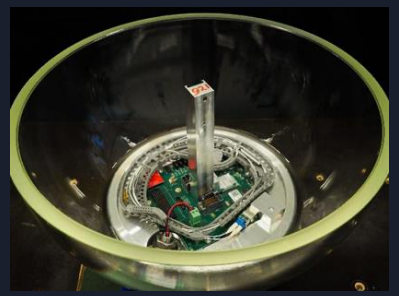
Production model: the integration

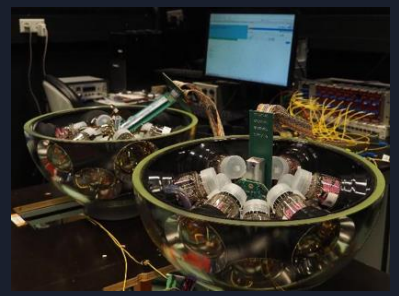
The integration process is divided into several steps, following a strict protocol.

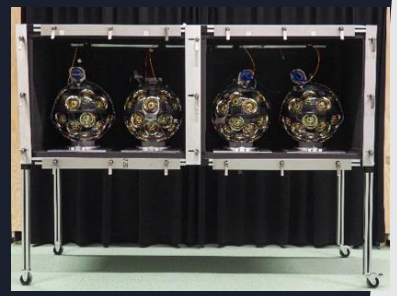
A dedicated software **(the KM3DIA)** guides the integrators through the right sequence of operations, logs all relevant information and registers all DOM details.

Each hemisphere is filled bottom-up:

1) Glueing the cooling mushroom (TOP) and acoustic piezo (BOTTOM)
2) Electronics, penetrator → helium leak test, optical fiber splicing
3) Installation of PMT and light collection rings
4) Functional test (this is the last chance to change the faulty components)
5) Gel pouring
6) DOM closure (custom made tool)
7) Acceptance test in a dark box





Minimisation of the error

Check all components

Problem?

Non-conformity report (NCR)

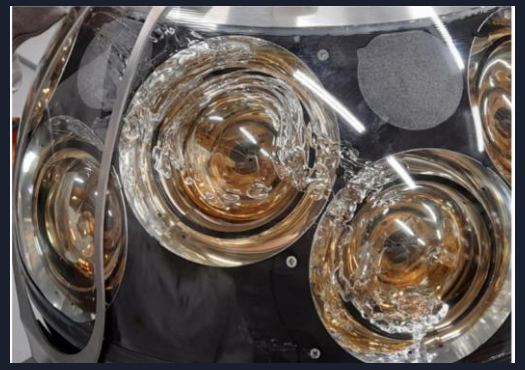
- All component are registered in a central database with a unique **product identifier code** UPI.
- The history of the components is tracked in the database and the tests values can be recovered from the database during the detector operation and data analysis.

Local activities:
ORCA-DU 77 & ARCA-DU 61

START → December 2021 with a huge commitment for beginners: 18 DOMs within a couple of months.

The site was in an «idle» state for 3 years: the activity has slowly been recovered completely from scratch.

Ramp-up/learning phase: as quick as possible!

From gel patterns → To “perfect" gel

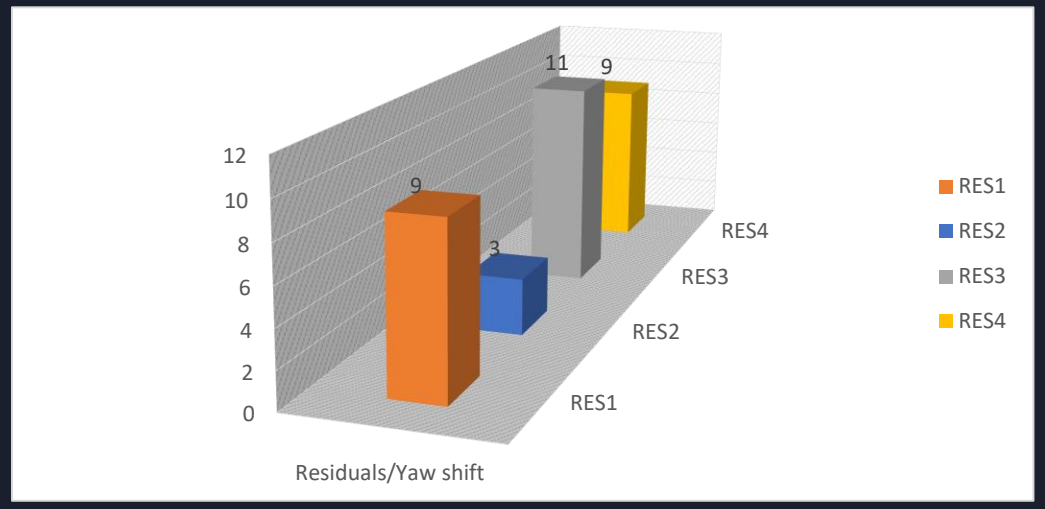
ORCA-DU 77 & ARCA-DU 61

DOM serial	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050
SFP Channel	CH55H	CH53H	CH51H	CH49H	CH47H	CH45H	CH43H	CH41H	CH39H	CH37H	CH35H	CH33H	CH31H	CH29H	CH27H	CH25H	CH23H	CH21H
Tagging	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Pressure gauge and nanobeacon glueing	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Piezo glueing	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Cooling mushroom glueing	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Mounting of electronics	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Penetrator Installation	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Helium Test	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
ADF routed on the fiber tray	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Optical splicing	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	C					
PMTs in TOP structure	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	C					
PMTs in bottom structure	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	C					
Functional test	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	C					
Glueing of the TOP support structure	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	C					
Gel pouring TOP	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	C					
Gel pouring BOTTOM	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
DOM closure	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Acceptance test	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	OK	NCR	NCR	NCR	NCR	NCR	NCR

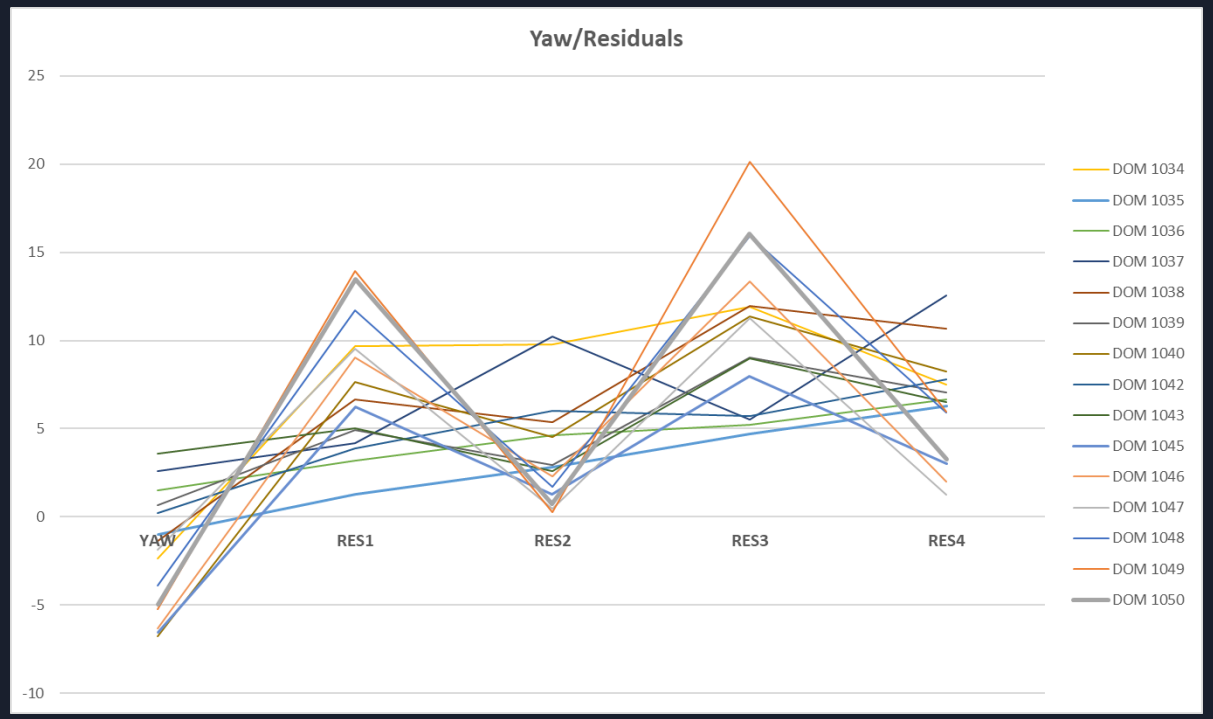
18 DOM finished and shipped to Genova: 8 for ORCA-DU77 & 10 for ARCA-DU 61

NCR: 16 compass residual calibration values out of acceptance range

ORCA-DU 77 & ARCA-DU 61: NCR



- 16 Residuals affected (1, 3 e 4 : 0 °, 180° , 270° with respect to the North)
- Starting YAW value: up to 20°
- Res 1, 2, 3, 4 up to 6°



→ Upgrades of the site

- Build a new compass test table in the upstairs lab (the one used so far is in the dark room downstairs) in order to investigate on possible sources of perturbation for the compass acceptance test

PROBLEM DISAPPEARED with ARCA-DU60:
most probably, this behaviour can be attributed to the miscalibrated CLBs

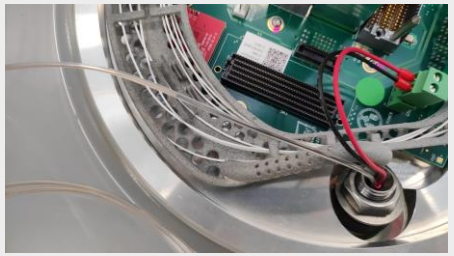
Current status : ARCA-DU60

DOM serial	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191
SFP Channel	CH56C	CH54C	CH52C	CH50C	CH48C	CH46C	CH44C	CH42C	CH40C	CH38C	CH36C	CH34C	CH32C	CH30C	CH28C	CH26C	CH24C	CH22C
Tagging	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK		OK			OK			
Pressure gauge and nanobeacon glueing	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK		OK			OK			
Piezo glueing	OK	OK	Dummy	OK	OK	Dummy	OK	OK	Dummy	OK		Dummy			Dummy			
Cooling mushroom glueing	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK		OK			OK			
Mounting of electronics	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK		OK						
Penetrator Installation	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK		OK						
Helium Test	OK (NCR)	OK (NCR)	OK (NCR)	OK (NCR)	OK (NCR)	OK (NCR)	OK	OK	OK	OK		OK						
ADF routed on the fiber tray	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK		OK						
Optical splicing	OK	OK	OK	OK	OK	OK (NCR)	OK	OK	OK	OK		**OK**						
PMTs in TOP structure	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK				
PMTs in bottom structure	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK				
Functional test	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK								
Glueing of the TOP support structure	OK	OK	OK	OK	OK	OK												
Gel pouring TOP	OK	OK	OK	OK	OK	OK												
Gel pouring BOTTOM	OK	OK	OK	OK	OK	OK												
DOM closure	OK	OK	OK	OK	OK	OK												
Acceptance test																		

Still missing CLBs to complete the 18 DOM

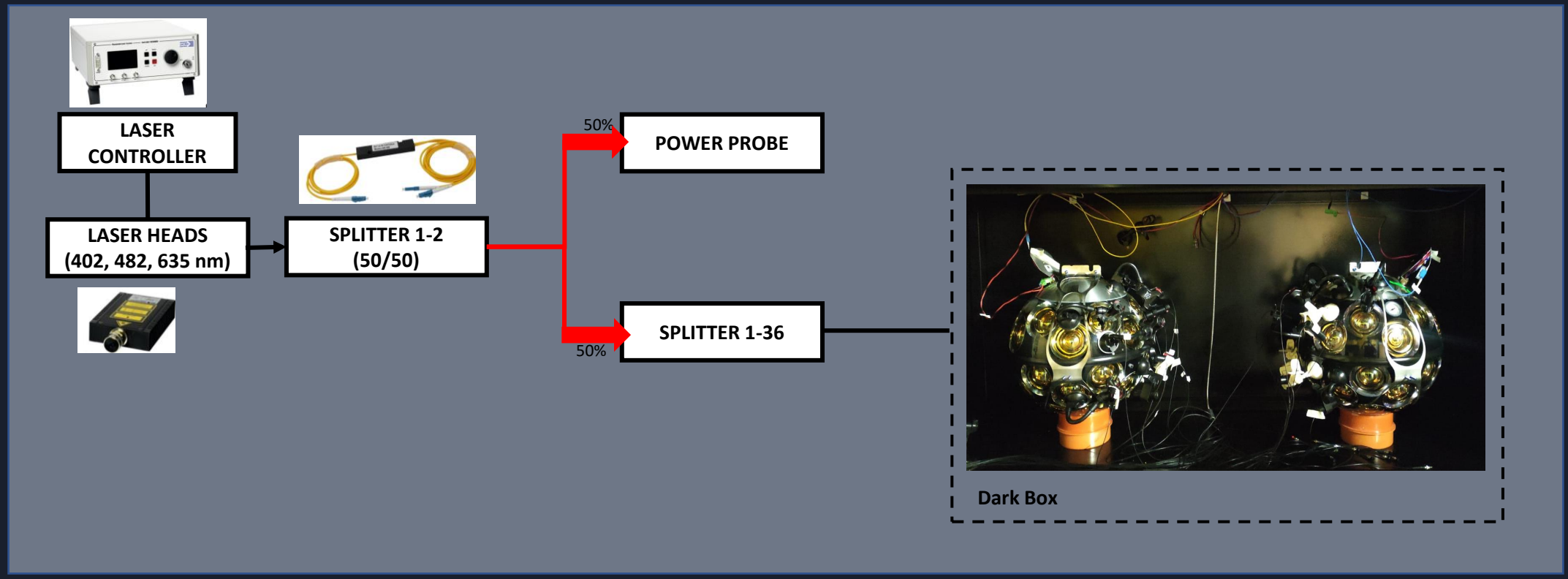
- 6 DOMs closed:
  - ✓ compass test, done!
  - ✓ in pre-darkening phase, ready for the acceptance test
- 4 DOMs ready for GEL POURING
- 2 DOMS ready for functional test

- New penetrators require a new splicing procedure



Purple DOM: detection efficiency test

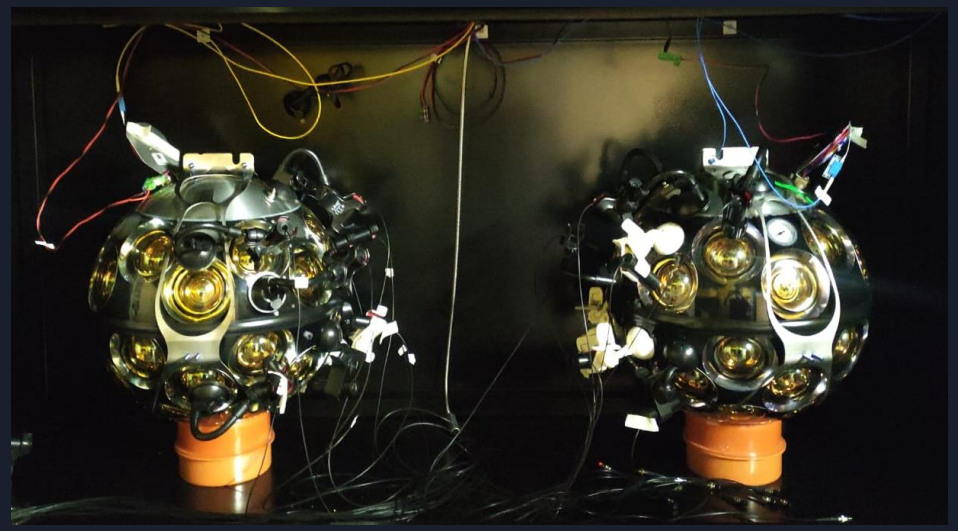
GOAL: quantitative estimation of purple gel effect on the photon detection efficiency

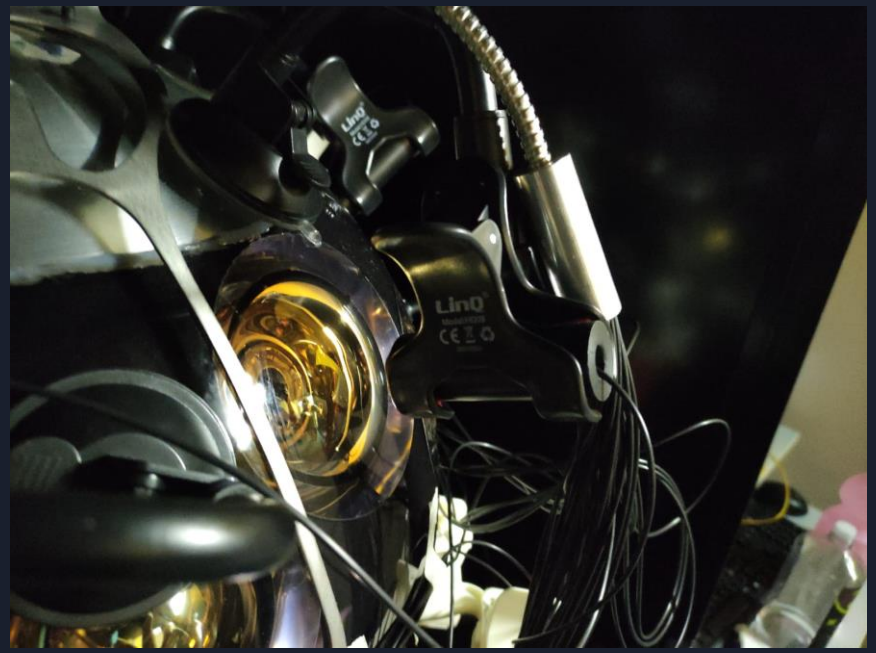


Setup main parts:

- Laser controller and laser heads with different wavelengths
- Splitter 1-2, 50-50
- Power probe
- Splitter 1-36

Purple DOM: detection efficiency test



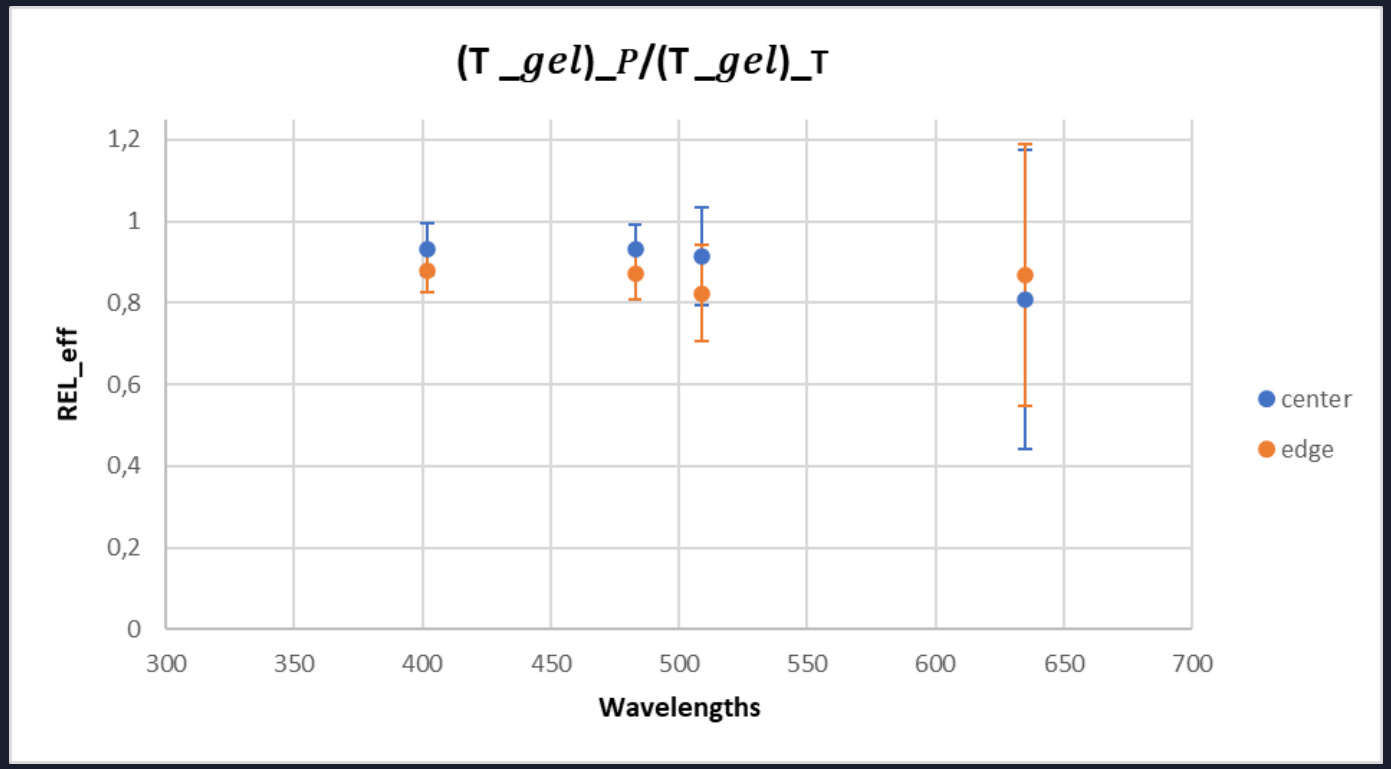


Using the DOM acceptance test facility, it is possible to operate the two DOMs simultaneously.

- Comparison between the “purple DOM” 3.4/TSFP/6.687 and a “transparent DOM” 3.4/CH53H/4.1137
- 1-to-36 splitter illuminates simultaneously and homogeneously different PMTs of both DOMs
- 5 channel chosen for each DOM: CH0, CH2, CH3, CH4, CH5 (top hemispheres)
- Suction cups + custom-made fiber holders
  (as for DU calibration)
- Laser heads: λ = 402 nm, λ = 482 nm, λ = 509 nm, λ = 635 nm

Purple DOM: detection efficiency test

Following Ronald's suggestions we have changed the position of the fibers taking the measurements at the center and on the edge of the photocathode: can we detect a greater absorption effect?



The relative transmission efficiency is what we want to evaluate $R_{ij} = \frac{T_{gel_P}}{T_{gel_T}}$

Rij(402nm) = 0,93 ± 0,06
Rij(483nm) = 0,93 ± 0,06

Rij(509nm) = 0,91 ± 0,12
Rij(635nm) = 0,81 ± 0,37

Rij(402nm) = 0,88 ± 0,05
Rij(483nm) = 0,87 ± 0,06

Rij(509nm) = 0,82 ± 0,12
Rij(635nm) = 0,87 ± 0,32

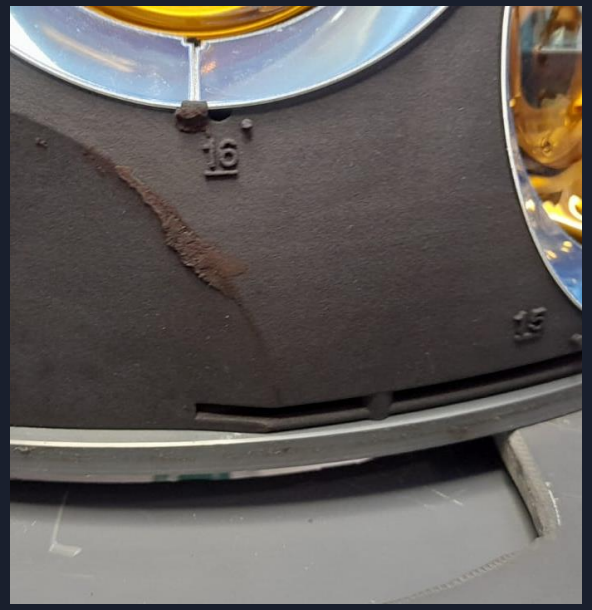
NRB discussion:
purple DOM issue closed!

- The measured relative transmission efficiency is ~ 1 for 402 nm and 483 nm in both positions.
- For 509 nm and 635 nm we considered the same Q.E. for all PMTs. Anyway, as the q.e. decreases for this spectrum region, the measurements' variations are greater.

Validation of the black paint

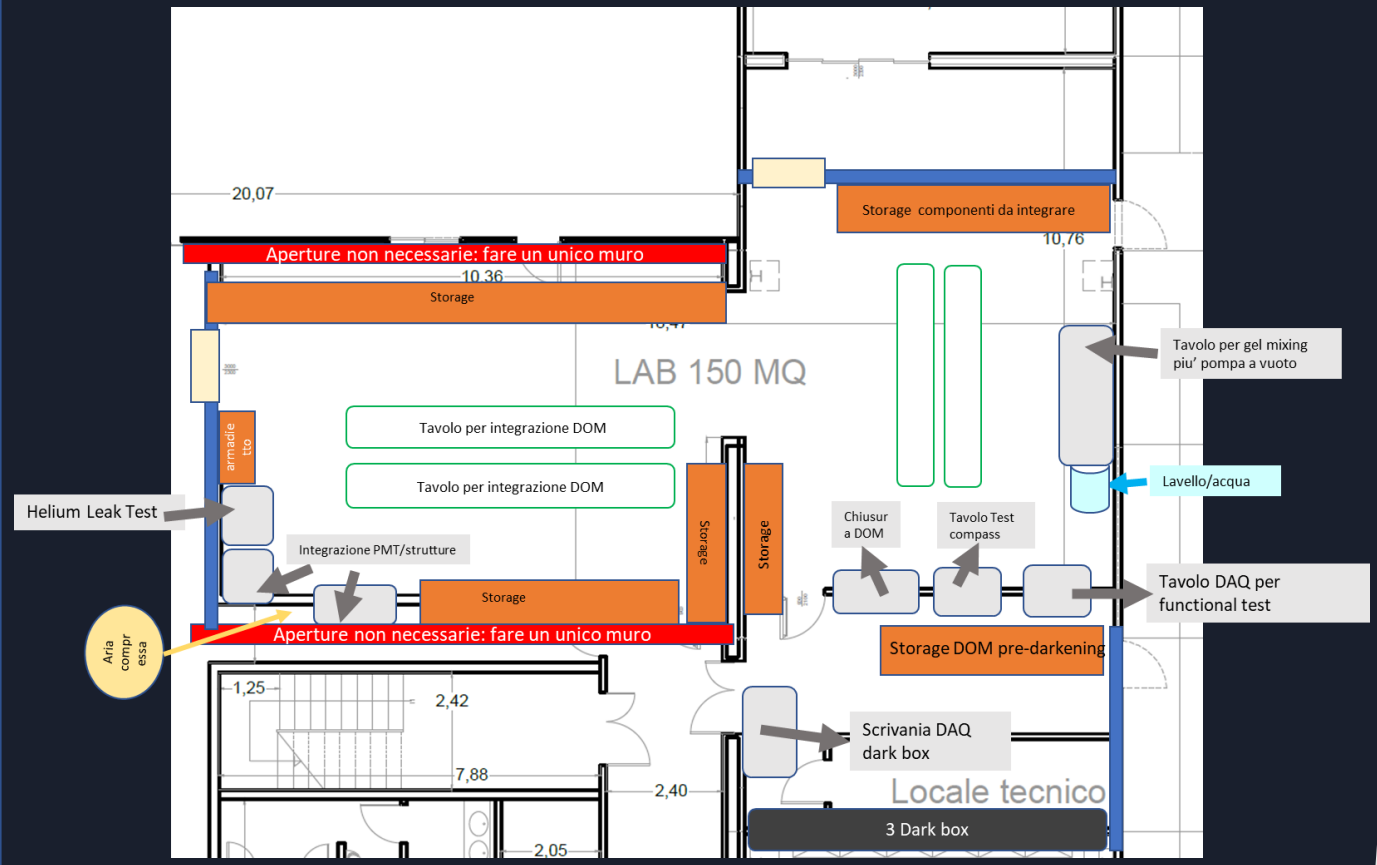
As a consequence of the PURPLE effect of the DOM, we decided to paint the 3D printed BOTTOM structures with Black Paint

- We validated the paint by immersing some pieces of structure, that have been previously painted, in a cup of gel
- No visible interaction between paint and gel.
- We painted all the bottom structures for ARCA-DU60



PNRR: new DOM LAB @ Capacity

- @NAPOLI:
  - ✓ increased dark box positions from 3 to 6
  - ✓ increased gel/gluing workbench position from 4 to 8 → up to 3 DOM closures in 1 day (with the current manpower)
  - ✓ Our technician Filippo Masci will finish his period with us at the end of November.Hopefully, with a new call, we will increase again the manpower.
- @CASERTA:
  - new DOM integration lab of about 150 mq (plus new storage) @ CAPACITY (Caserta) thanks to the PNRR funds.
    Construction work will start in 2023. It will take the place of the current site of Naples (we will move everything to Caserta).
  - The workflow has been planned in order to work on two DUs simultaneously. Also, the acceptance test dark box positions will increase from the current 6 to 9.



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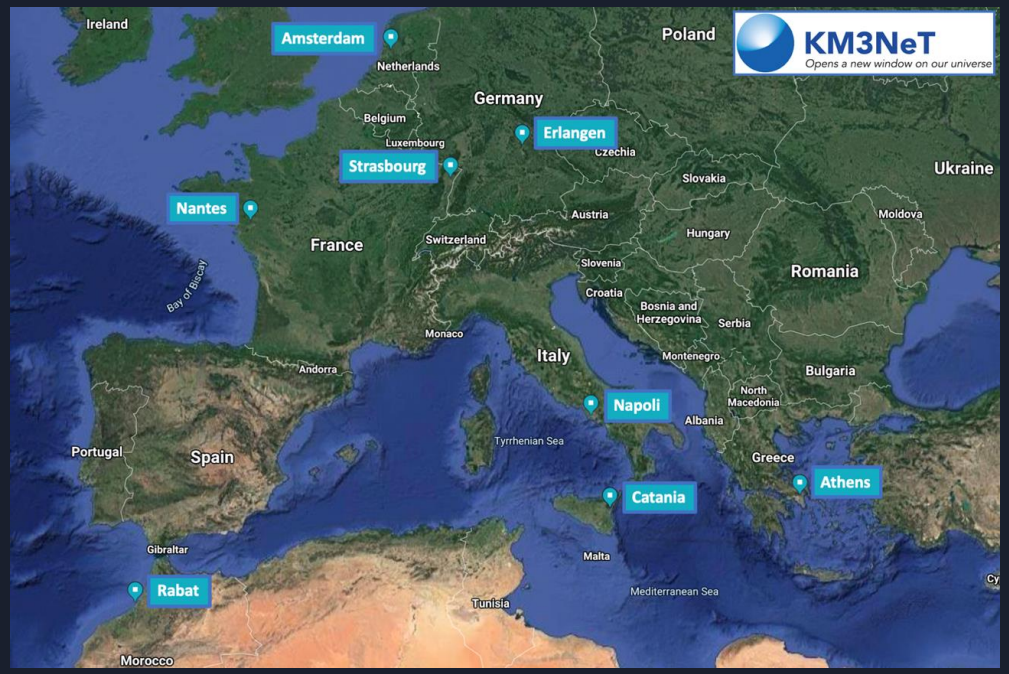
KM3NeT DOM integration QA/QC

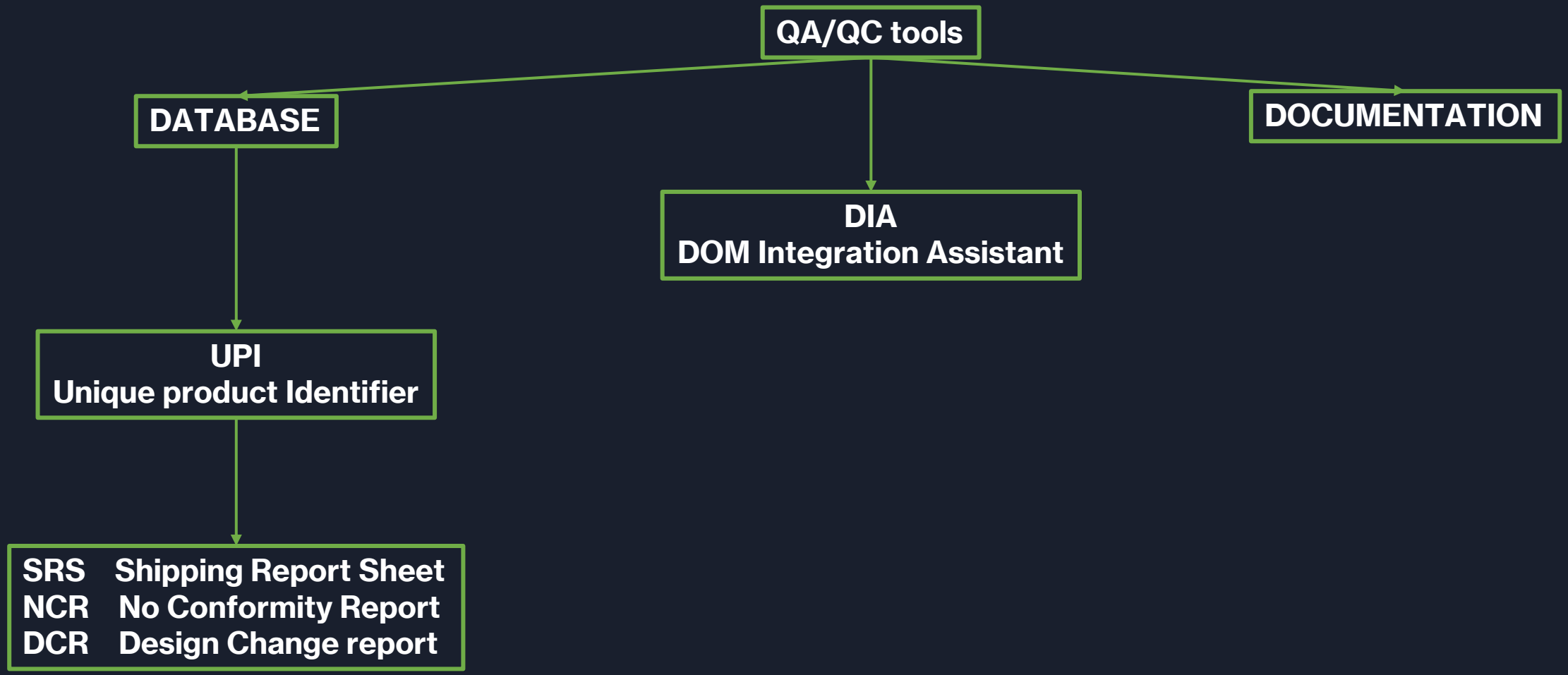
A distributed production model has been established to produce more than 6000 optical modules for the KM3NeT telescope.

- **8 integration sites**: Amsterdam, Strasbourg, Erlangen, Nantes, Napoli, Catania, Athens and Rabat (Salerno is joining the fight)
- Throughput **100 modules** per month by the end of 2021
- Delays due to the supply chain disruption (pandemic, war, cavallette?)
- 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



KM3NeT UPI

3.4.3.2/V2-2-1/2.221

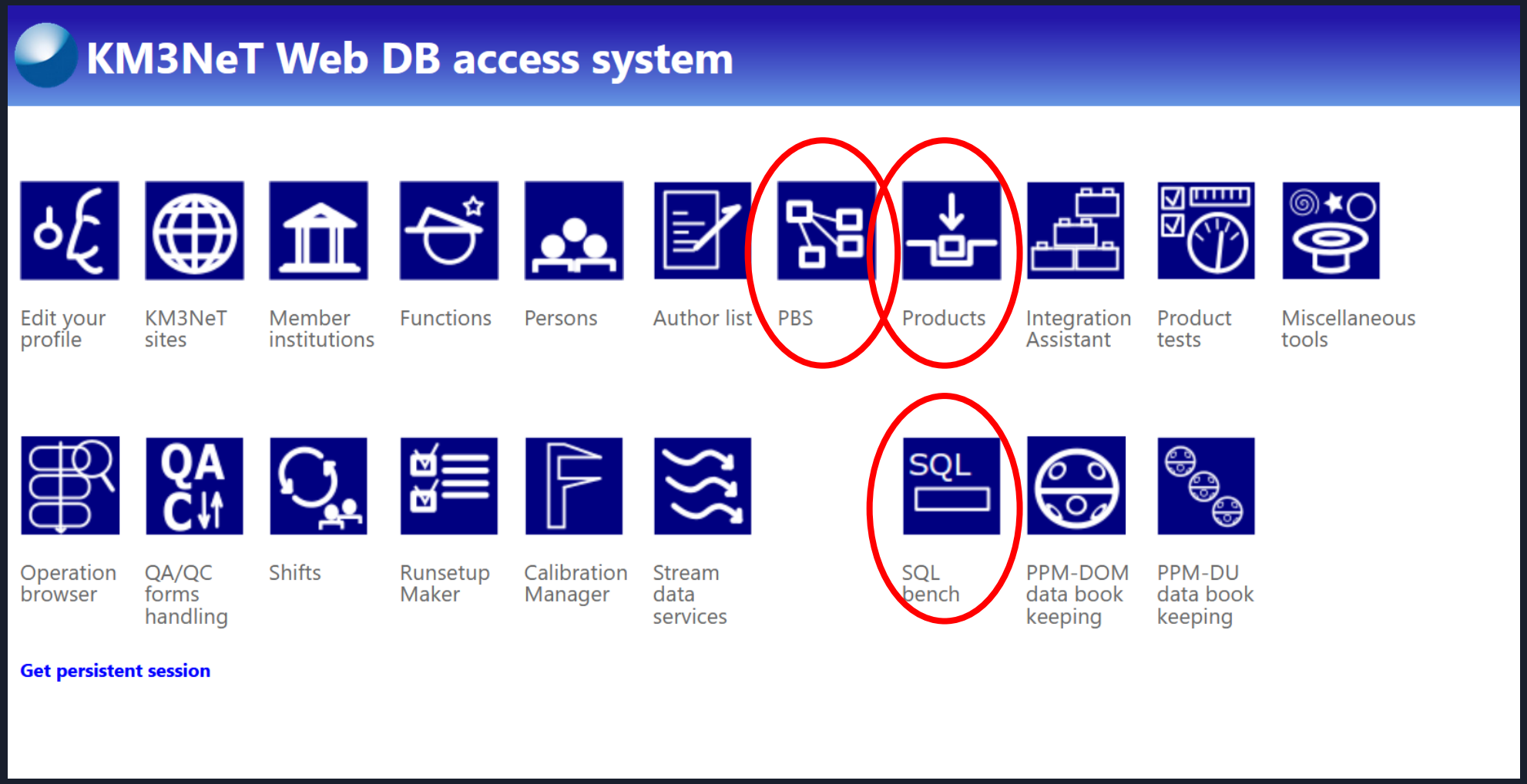
PBS/ VERSION/ VARIANT. SERIAL

PBS Product Breakdown Structure
3. 4. 3. 2
DU -> DOM -> Electronics -> CLB

Version: V2-2.1 Updated from the relevant WGs
Variant: used for minor changes and/or to define different integration sites
Serial: it is used to indentify the specific part

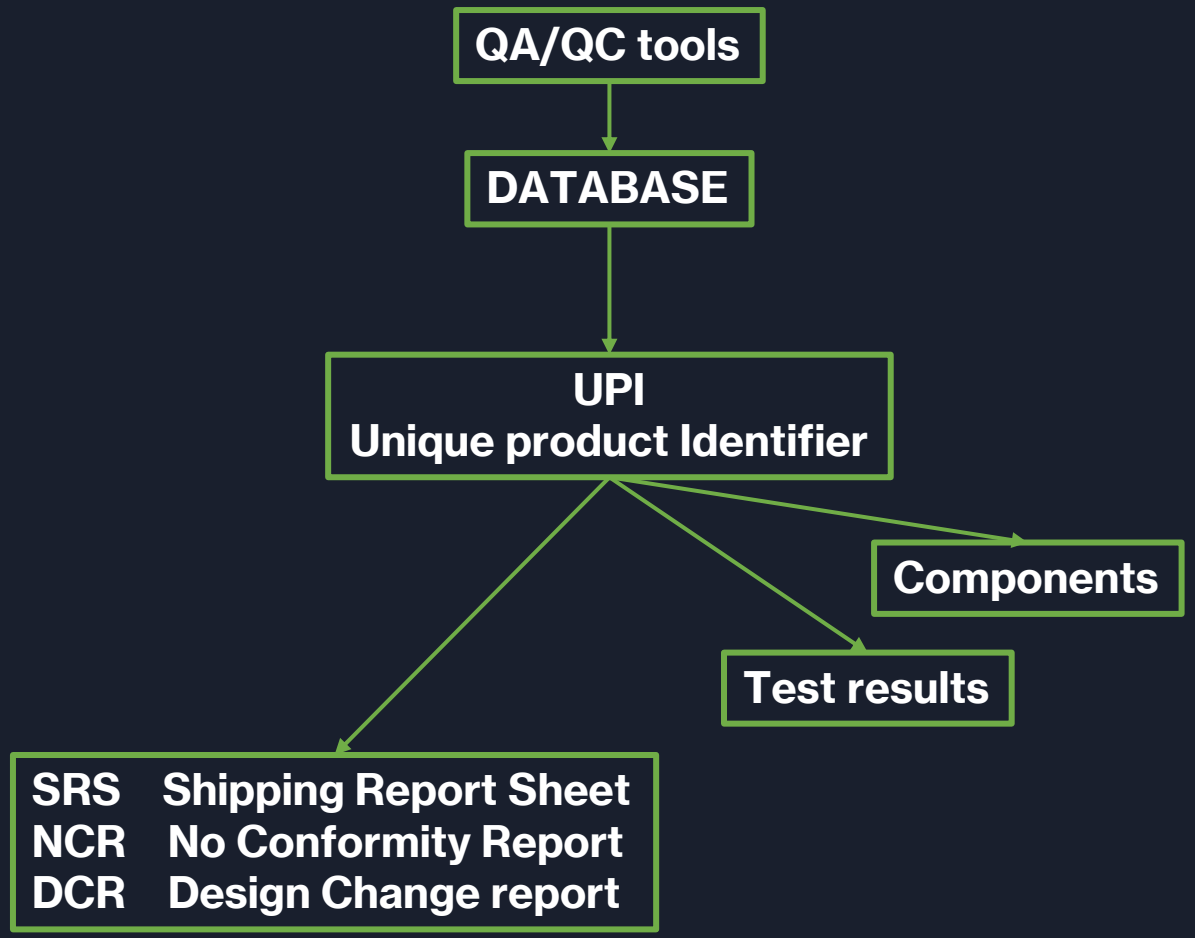
KM3NeT DB interface

Random DOM 3.4/CH48C/1.11



KM3NeT DOM integration QA/QC

Random DOM 3.4/CH48C/1.11



DATABASE 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)	3.4.2.3/HAMA-R12199/1.414	detail
A00238750	PM_T05_F5 (5)	3.4.2.3/HAMA-R12199/1.405	detail
A00238750	PM_T06_E2 (6)	3.4.2.3/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

components

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	

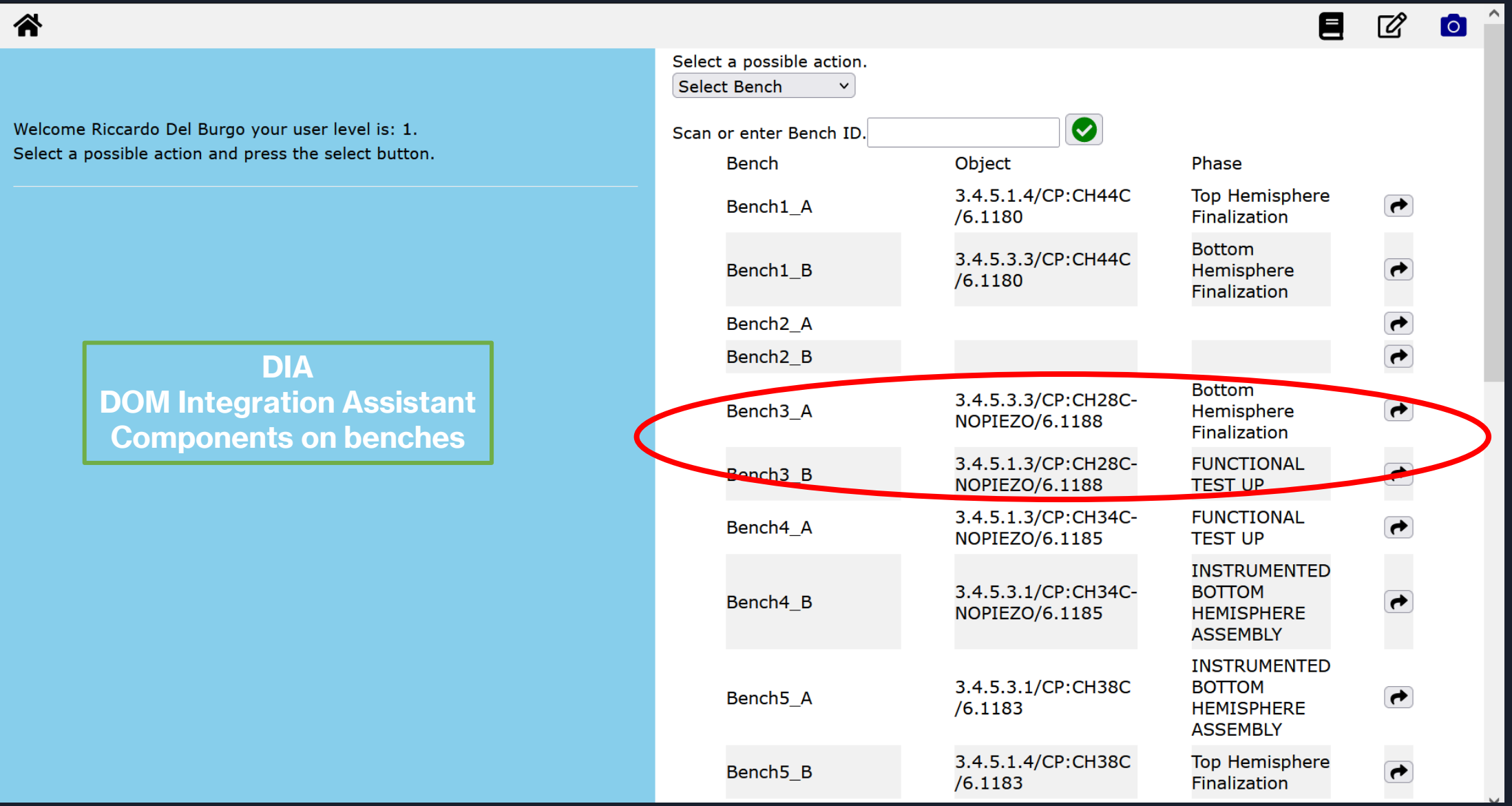
SRS

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

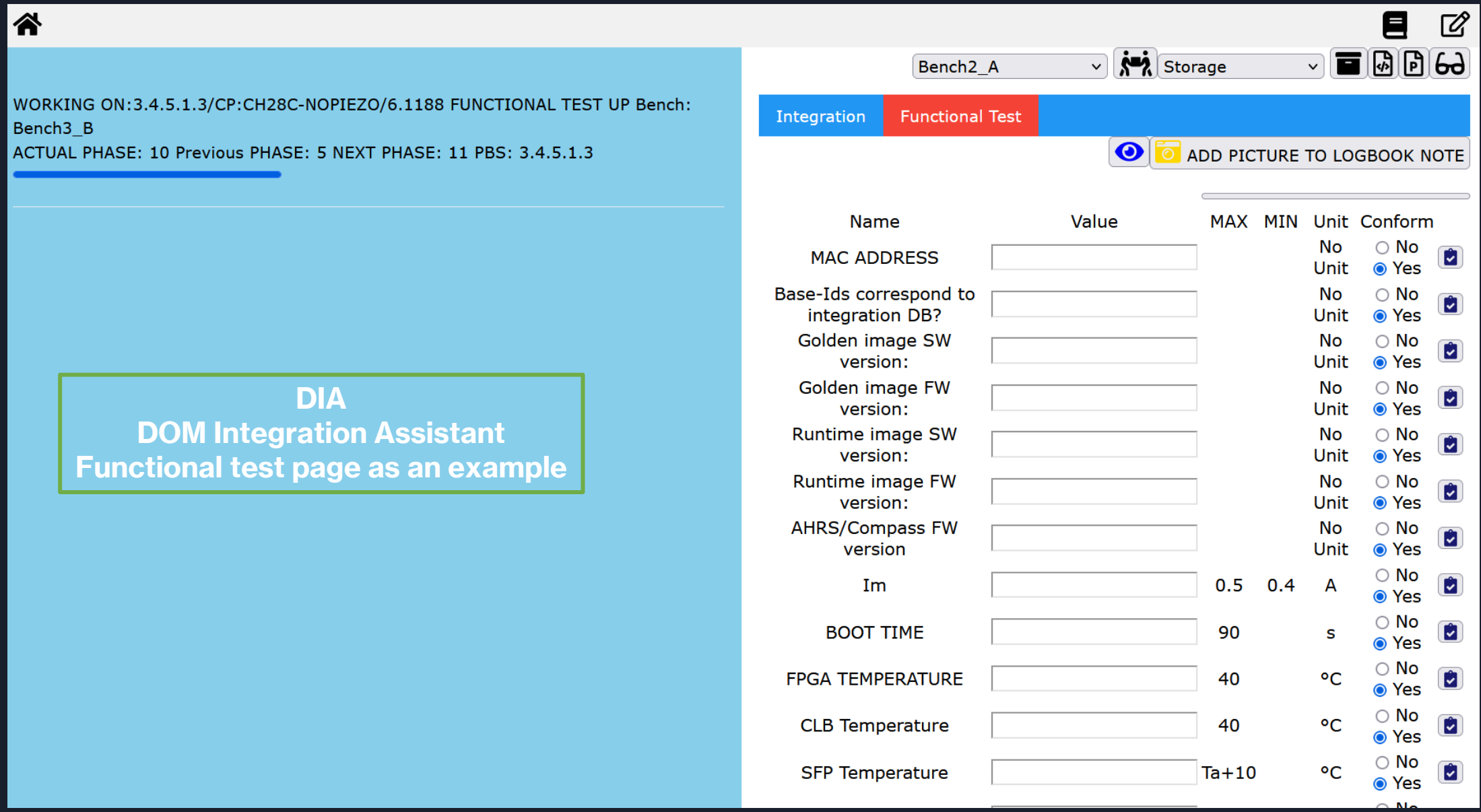
NCR

KM3NeT DIA interface



DIA
DOM Integration Assistant
Components on benches

KM3NeT DIA interface



DIA
DOM Integration Assistant
Functional test page as an example

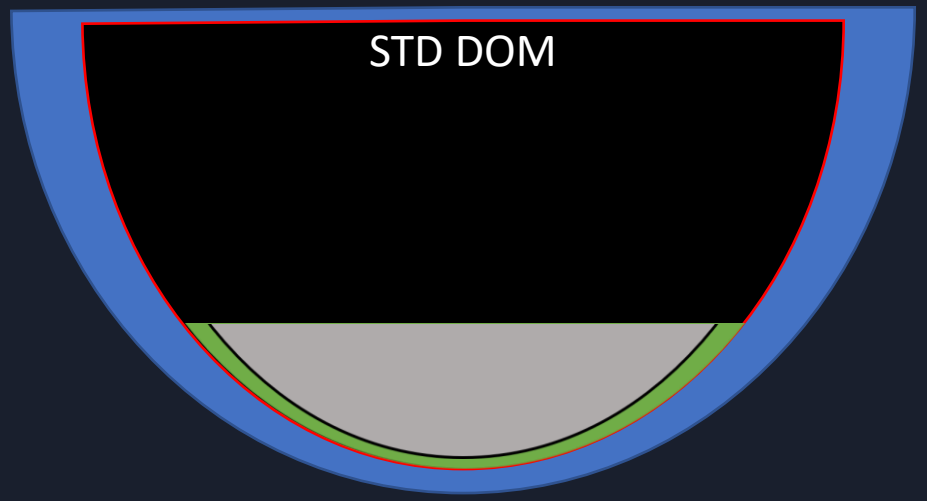
KM3NeT DOM integration QA/QC

Files	
WAIVE	KM3NeT_QA_2022_405-NCR_0031_Compass_residuals_out_of_range
WAIVE	KM3NeT_QA_2022_406-NCR_0032_Humidity_sensor_out_of_range
OPEN	KM3NeT_QA_2022_407-NCR_0033_Splice_test_Difference_post_pre_power_out_of_range
OPEN	KM3NeT_QA_2022_410-NCR_0034_base_pmt_association_failed
OPEN	KM3NeT_QA_2022_412-NCR_0035_SFP_Opto_Transceiver_wrong_UPI
OPEN	KM3NeT_QA_2022_458-NCR_0036_base_pmt_association_failed
OPEN	KM3NeT_QA_2022_566-NCR_NCR_0037_DOM_closed_using_Gel_components_from_different_batches
OPEN	KM3NeT_QA_2022_567-NCR_NCR_0038_Penetrator_Helium_Leak_test_pressure
OPEN	KM3NeT_QA_2022_568-NCR_NCR_0039__pre-post-splice_value_diff_OOR

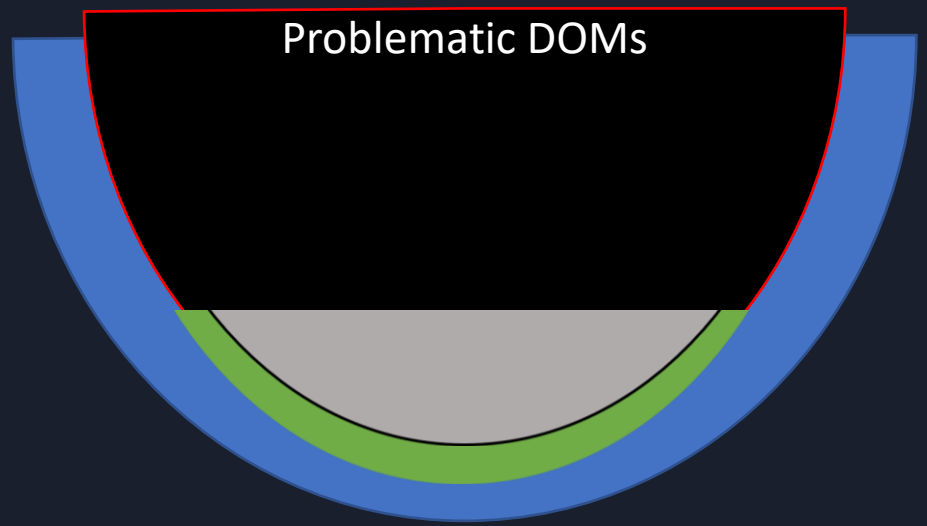
Napoli NCR list
2 main categories:
DOMs & PMT registration issues

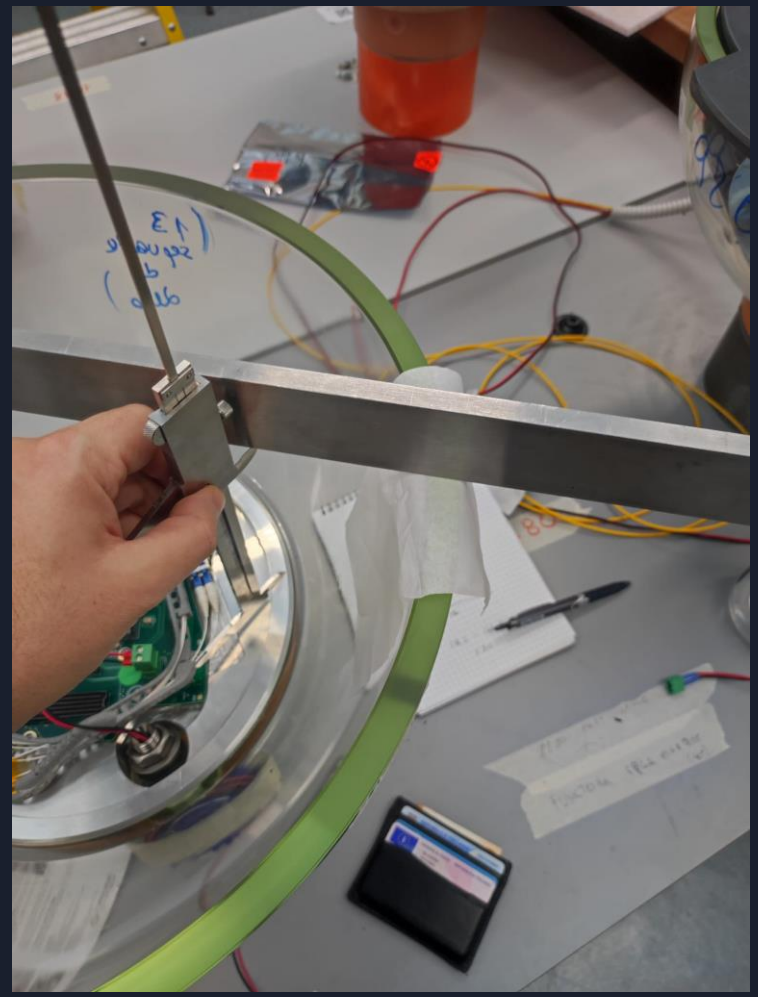
Files	
REPAIR	KM3NeT_QA_2015_028-NCR_NAP002_DuplicateInAssociationFile_CLOSED.xlsx
ACCEPT	KM3NeT_QA_2016_089-NCR_NAP003_PMT_TestData_not_uploaded_CLOSED.xlsx
REPAIR	KM3NeT_QA_2017_168-NCR_NAP0015_PiezoNotWorking
WAIVE	KM3NeT_QA_2018_025-NCR_NAP_0016_DOM_Compass_NotWorking
REPAIR	KM3NeT_QA_2018_053-NCR_NAP_0017_ShortOctopusMalfuntion
REPAIR	KM3NeT_QA_2018_54-NCR_NAP_0018_FibreBroken_CLOSED
OTHER	KM3NeT_QA_2018_225-NCR_NP_0019_PMTBaseTags_unreadable
REPAIR	KM3NeT_QA_2019_099-NCR_NAP_0020_PMTConnectorUnsoldered
REPAIR	KM3NeT_QA_2020_264-NCR_NAP_0021_ODITestCable_not_working
REPAIR	KM3NeT_QA_2020_283-NCR_NAP_0022_BaseModuleIncomplete
OPEN	KM3NeT_QA_2020_336-NCR_NAP_0023_Unresponsive_base_module_CLB_at_Process_3_level
MODIFY	KM3NeT_QA_2020_359-NCR_NAP_0024_CLB_Exhange_DU40
WAIVE	KM3NeT_QA_2021_296-NCR_NAP_0025_bad_hemispheres_version
OPEN	KM3NeT_QA_2022_114-NCR_NAP_0026_DOM1033_PMT_Gains
OPEN	KM3NeT_QA_2022_117-NCR_NAP_0027_DOM_Compass_out_of_range
OPEN	KM3NeT_QA_2022_273-NCR_NAP0028_PMTs_withNotRegisteredBases
WAIVE	KM3NeT_QA_2022_274-NCR_NAP_0029_otherPMTs_with_notRegisteredBases
WAIVE	KM3NeT_QA_2022_311-NCR_NAP_0030_DOM_FailingAcceptanceTest

QA/QC: ARCA-DU60 integration process



The difference is about 1mm





Measurement process

New organization of the STORAGE

2022 European Researchers' Night

Liceo Brunelleschi

Altre due scuole interessate

Come si diceva ieri a cena ci si puo organizzare sia per andare la sia per visite ai lab!

Grazie!