Hyper-Kamiokande

FACULTY OF MATHEMATICS AND PHYSICS Charles University

INFN NAPOLI

Seal, mechanical and functional tests on the mPMT prototype for external vessel optimizations

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February 21st 2023

Outline...

1. Overview of the Hyper-Kamiokande experiment

2. The multi-PMT and its tests in according with the ICRR reasearch purpose

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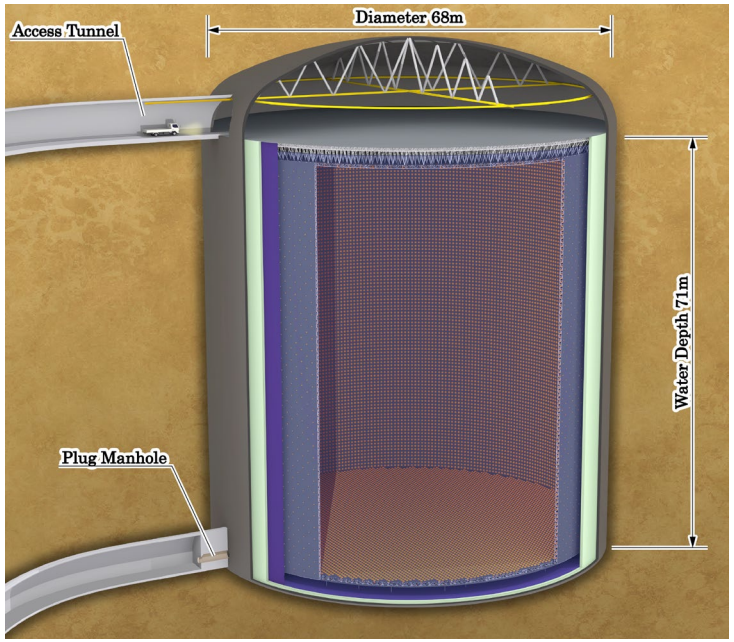
Hyper-K overview



Hyper-Kamiokande (Hyper-K, HK) is a multi-purpose **Water-Cherenkov detector** with a variety of scientific goals:

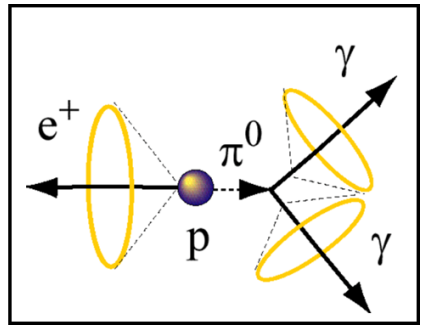
- ✧ Neutrino oscillations and CP violation (by atmospheric, accelerator and solar ν)
- ✧ Neutrino astrophysics
- ✧ Proton decay
- ✧ Non-standard physics

Hyper-K Far Detector (HK-FD)

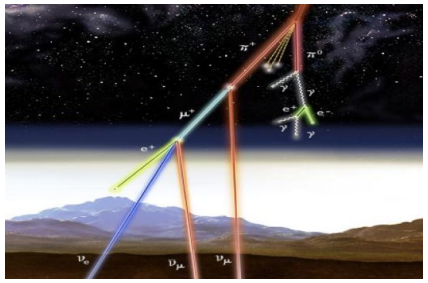
- ➢ Cylindrical tank: Φ 68 m and H 71 m
- ➢ Filled with 0.25 Mtons of ultra-pure water
- ➢ Fiducial volume: 0.19Mtons (~8 times SuperK)

Today, Hyper-K is under construction and its operation will begin in 2027!

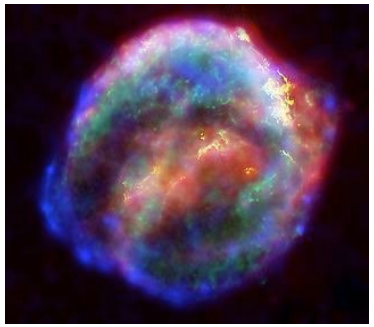
Proton decay



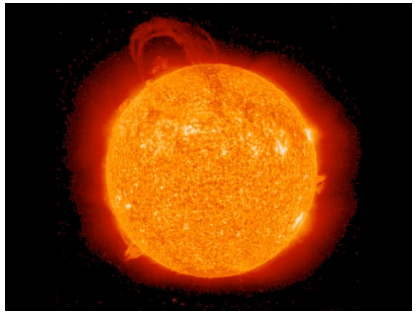
Atmospheric ν



Accelerator ν

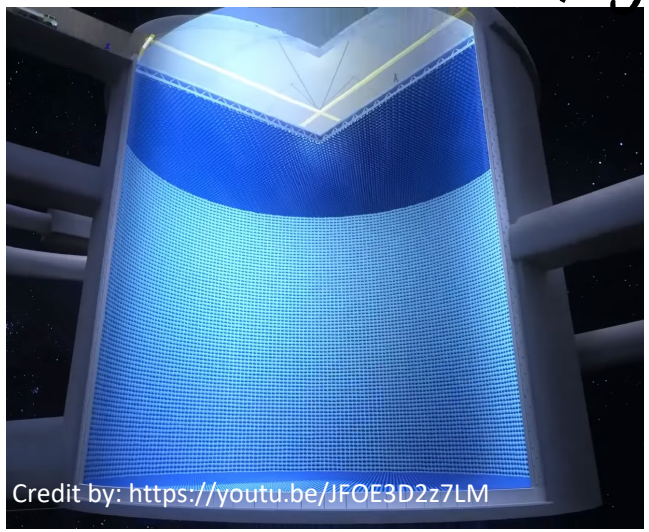


Supernova ν



Solar ν

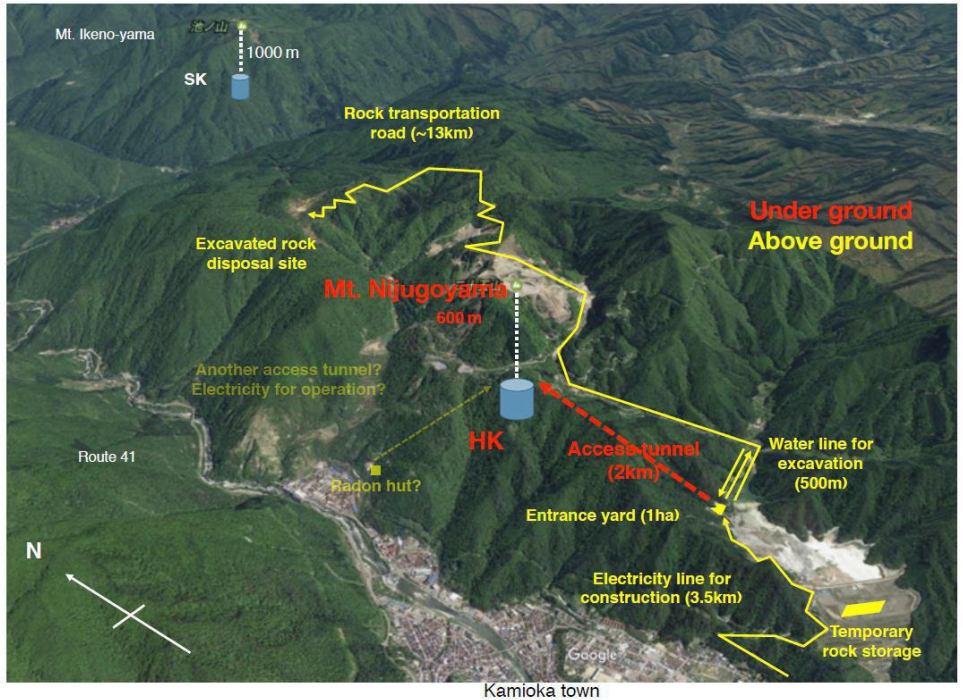
Hyper-K – Overview and its placement

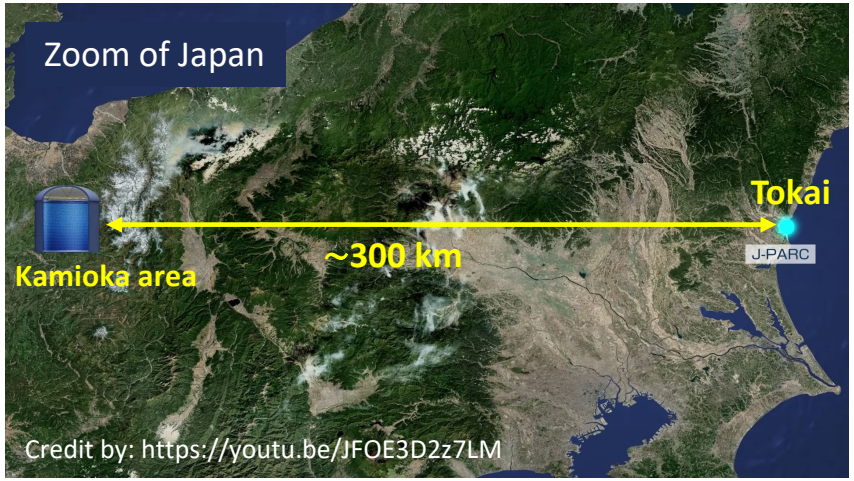


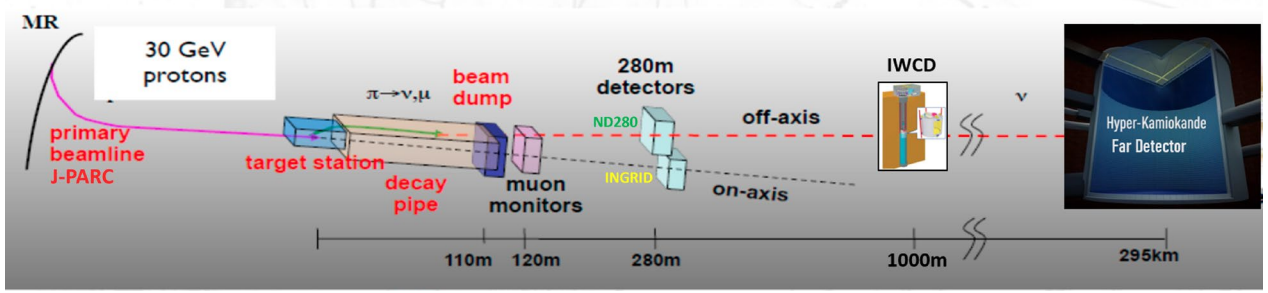
Hyper-K builds on the successful strategies used to study neutrino oscillations by Super-Kamiokande, K2K and T2K, but with some upgrades:

- Larger detector for increased statistics
- Improved photo-sensors for better efficiency
- Higher intensity beam and updated/new near detector for accelerator neutrino part

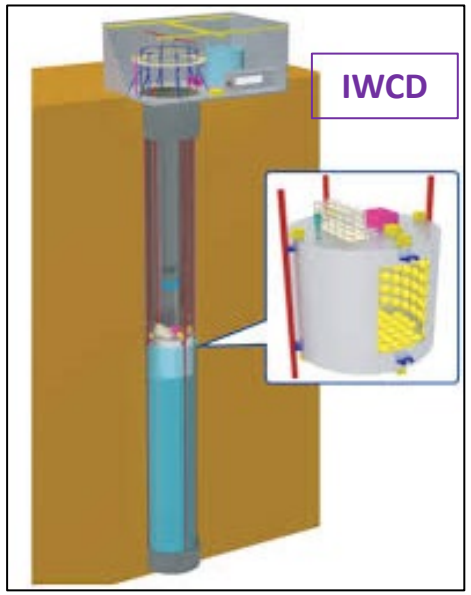
Detail of the Kamioka area (under constructions)







Hyper-K overview - The IWCD



Intermediate Water Cherenkov Detector (IWCD)

- 1 kilo-ton scale water Cherenkov detector
- It will be like an elevator, placed at ~ 1 km from the J-PARC accelerator
- mPMTs will be installed inside.

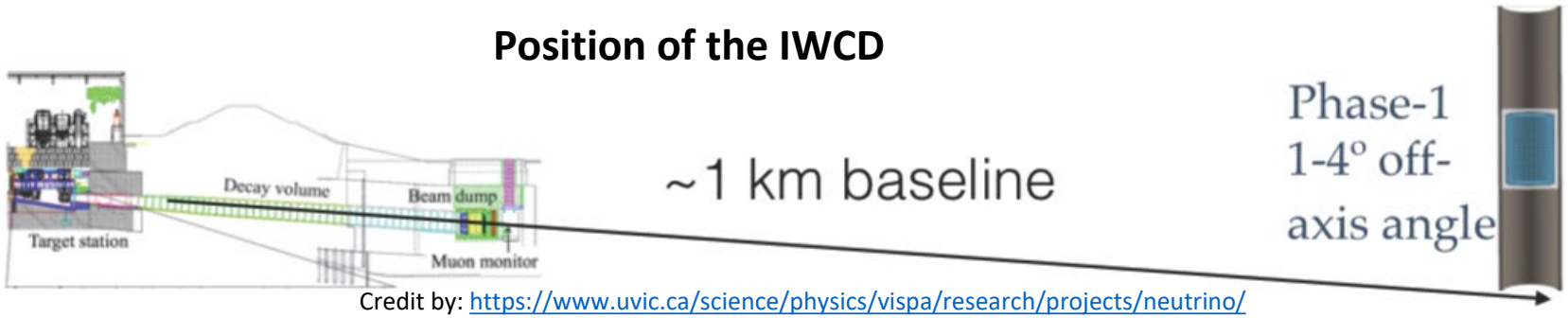
The Hyper-K IWCD

The instrumented portion will span a range of angles wrt the neutrino direction.

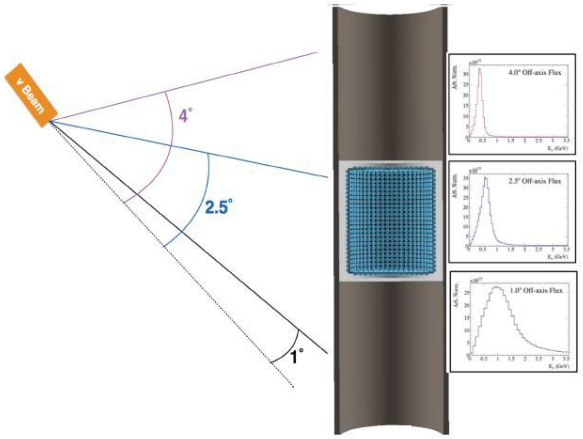
Inner detector:

- 8 m diameter and 6 m tall
- Planned to populate with ~**500 mPMT** modules.

Position of the IWCD



Credit by: https://www.uvic.ca/science/physics/vispa/research/projects/neutrino/

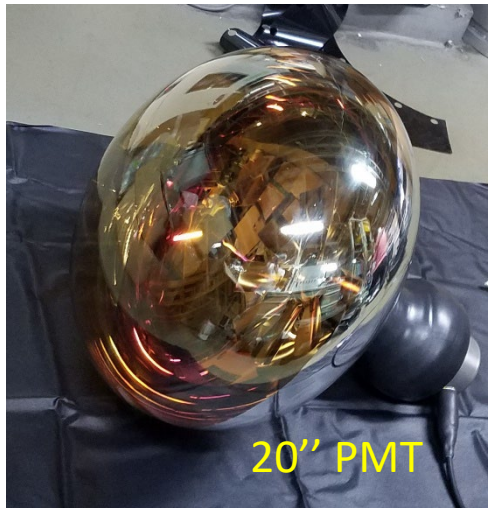


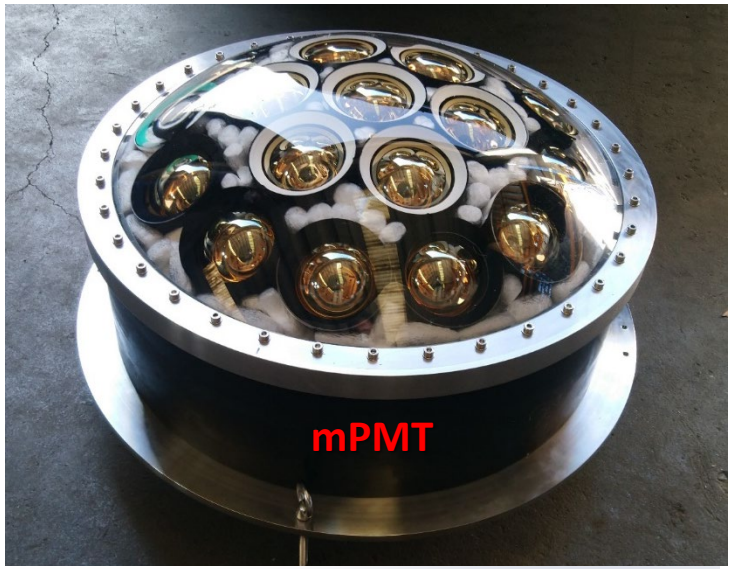
Hyper-K Far Detector inside

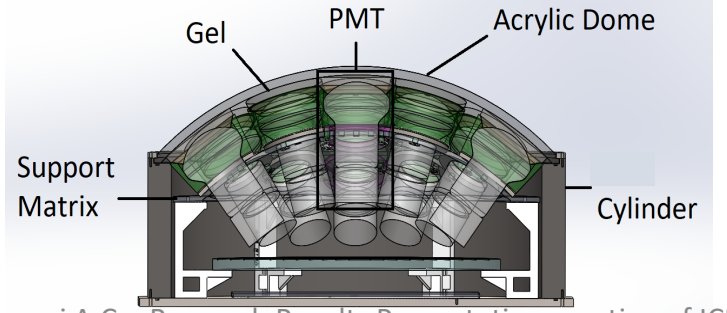
The **FD** will consist of a hybrid configuration of detectors to observe the inner and outer parts: a structure frame supports all detectors and divides the water volume into two regions.

Inner detectors (IDs):

- 20'' PMTs (#20'000)
- mPMTs (->19 3'' PMTs inside) (# ~ 850)
  - [Photo-coverage (PC) 20%)]

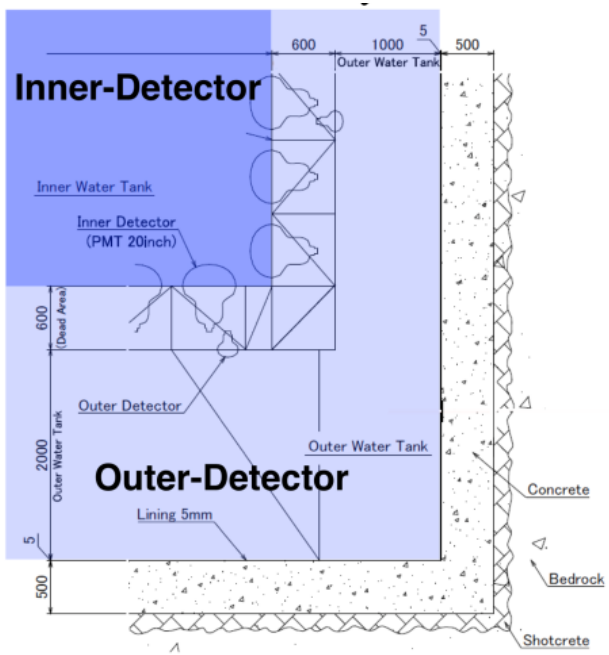






New high-QE 50-cm Box&Line PMT

If compared to the Super-K PMT:
× 2 higher pressure bearing for 60-m depth
× 2 higher detection efficiency
and half time&charge resolutions



Outer detectors (ODs):

- 3'' PMTs + Wave Length Shifter (WLS) plates

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2. The multi-PMT and its tests in according with the ICRR reasearch purpose

The multi-PMT – About its tests

Many tests on the mPMT prototype and its material/components:

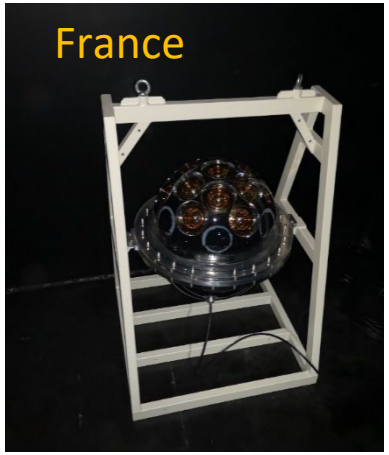
- Optical, mechanical and nuclear contamination tests on the UV-transmittance acrylic material
- Water absorption into acrylic sample
- Pressure tests of the external-component vessel
- Functional test of the first prototype in MEMPHYNO lab (a second test is scheduled soon with the last design)
- A preliminary installation into a mock-up frame in Hokkaido
- An anti-implosion test in Hokkaido
- Assembly tests
- ...

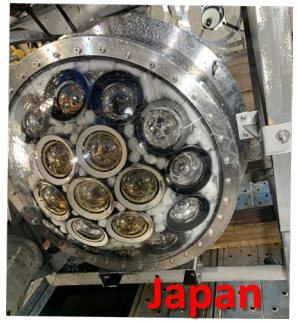
The mPMT is ready for some last verifications and final assemblies checks with the updated components.

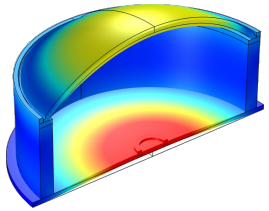
Nuclear contamination analysis at the National Gran Sasso Laboratories of INFN

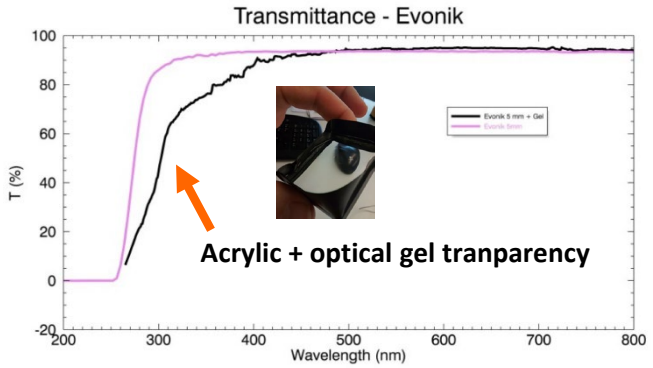
Isotope	Activity	Contamination
	^{232}Th: Thorium series	
Ra-228	< 0.11 mBq/kg	< 0.027 ppb
Th-228	< 93 μBq/kg	< 0.023 ppb
	^{238}U: Uranium series	
Ra-226	< 65 μBq/kg	< 0.0052 ppb
Th-234	< 4.6 mBq/kg	< 0.38 ppb
Pa-234m	< 2.5 mBq/kg	< 0.20 ppb
U-235	(0.15 ± 0.07) mBq/kg	$(3 \pm 1)\cdot 10^{-1}$ ppb
K-40	< 0.69 mBq/kg	< 0.022 ppm
Cs-137	< 25 μBq/kg	-

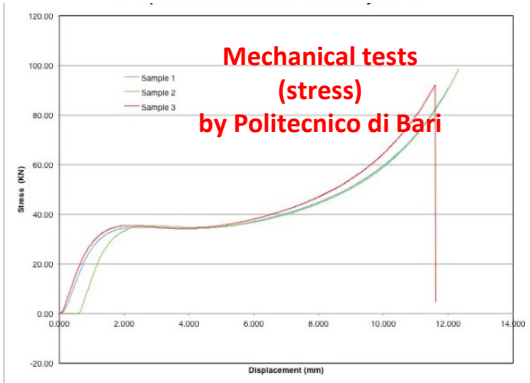
Table 5: Results of nuclear contamination of Evonik samples.

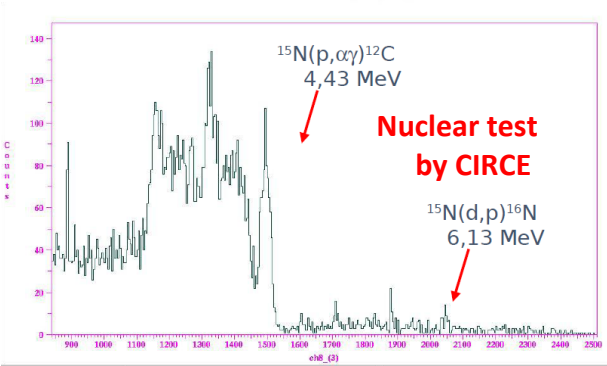


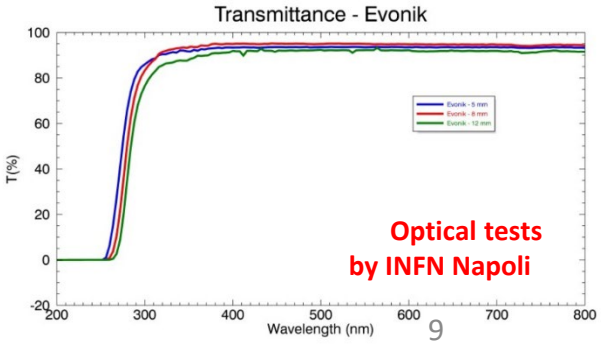












The multi-PMT – About its tests, nuclear contamination tests

UVT acrylic material (for the dome)
(Done at Gran Sasso Labs)

	mBq/kg	g/g
^{228}Ra	< 0.14	< 3.4 E-11
^{228}Th	< 0.12	< 3.0 E-11
^{226}Ra	< 0.098	< 7.9 E-12
^{234}Th	< 7.1	< 5.8 E-10
^{234m}Pa	< 6.8	< 5.5 E-10
^{235}U	< 0.13	< 2.4 E-10
^{40}K	< 1.2	< 4.0 E-8
^{137}Cs	< 0.043	

Source	Requirement
U-chain	≤ 30 Bq/PMT, ≤ 3 Bq/cover
Th-chain	≤ 10 Bq/PMT, ≤ 1 Bq/cover
K^{40}	≤ 15 Bq/PMT, ≤ 10 Bq/cover
Radon emanation	≤ 10 mBq/(PMT+cover)
Total Organic Carbon	≤ 10 mg/m^2/day/(PMT+cover)

Sample: Roehm acrylic UVT, second batch, HyperK
Weight: 12.54 kg
Acquisition time: 2348530 s (= 27.18 days)
Detector: GeMPI

Equivalent to what we measured a few years ago.
The limits are a little worse, because the tool used this time, although excellent, it has a slightly higher background

The multi-PMT – About its tests, nuclear contamination tests

HDPE material (for the cylinder)
(Done at Gran Sasso Labs)

	mBq/kg	g/g
^{228}Ra	< 0.71	< 1.8 E-10
^{228}Th	< 0.33	< 8.0 E-11
^{226}Ra	< 2.2	< 1.8 E-10
^{234}Th	< 31	< 2.5 E-9
^{234m}Pa	< 26	< 2.1 E-9
^{235}U	< 0.52	< 9.2 E-10
^{40}K	< 90	< 2.9 E-6
^{137}Cs	< 0.27	

Source	Requirement
U-chain	≤ 30 Bq/PMT, ≤ 3 Bq/cover
Th-chain	≤ 10 Bq/PMT, ≤ 1 Bq/cover
K^{40}	≤ 15 Bq/PMT, ≤ 10 Bq/cover
Radon emanation	≤ 10 mBq/(PMT+cover)
Total Organic Carbon	≤ 10 mg/m^2/day/(PMT+cover)

Sample: high density polyethylene, black colour, Hyper-K
Weight: 8.64009 kg
Acquisition time: 1179907 s (= 13.65 days)
Detector: GeMPI

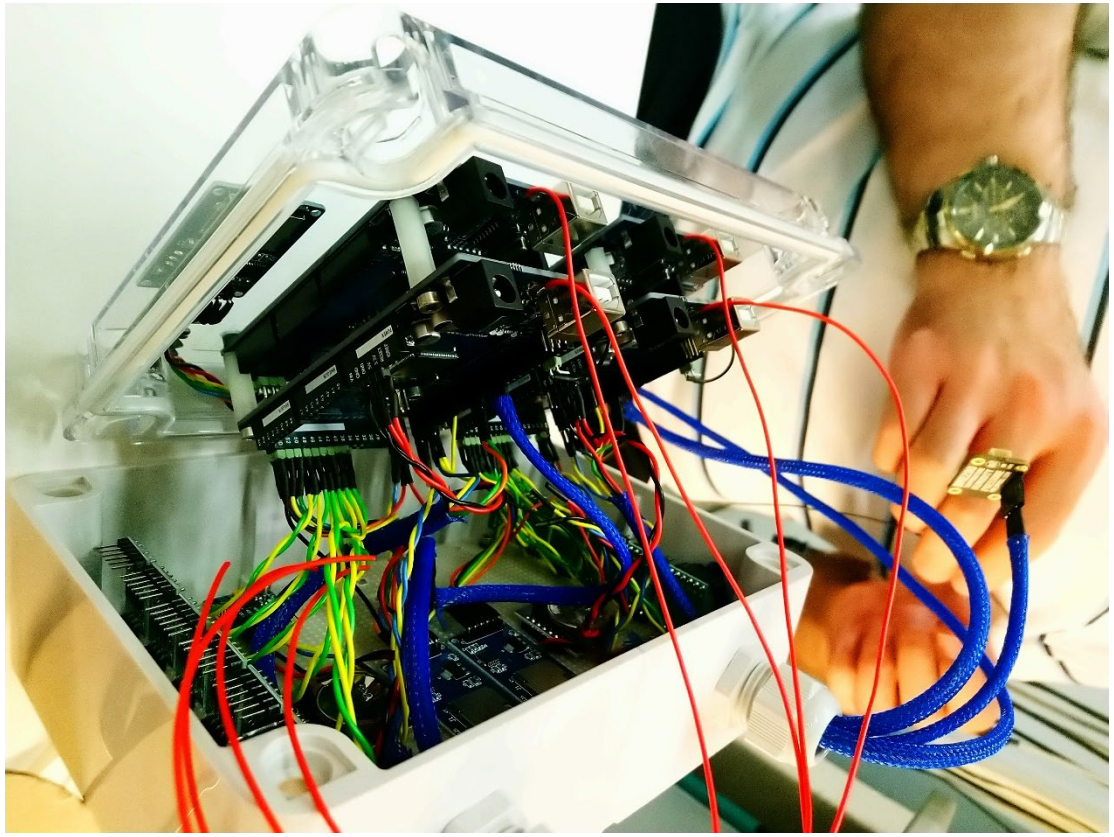
Polyethylene has a lot of potassium, probably due to coloring additive, because other measured qualities without coloring they were in the past more clean.

Contacts with companies to reduce contamination or considering no black colour

The multi-PMT – About its tests, before the pressure test

The short hydrostatic pressure test.

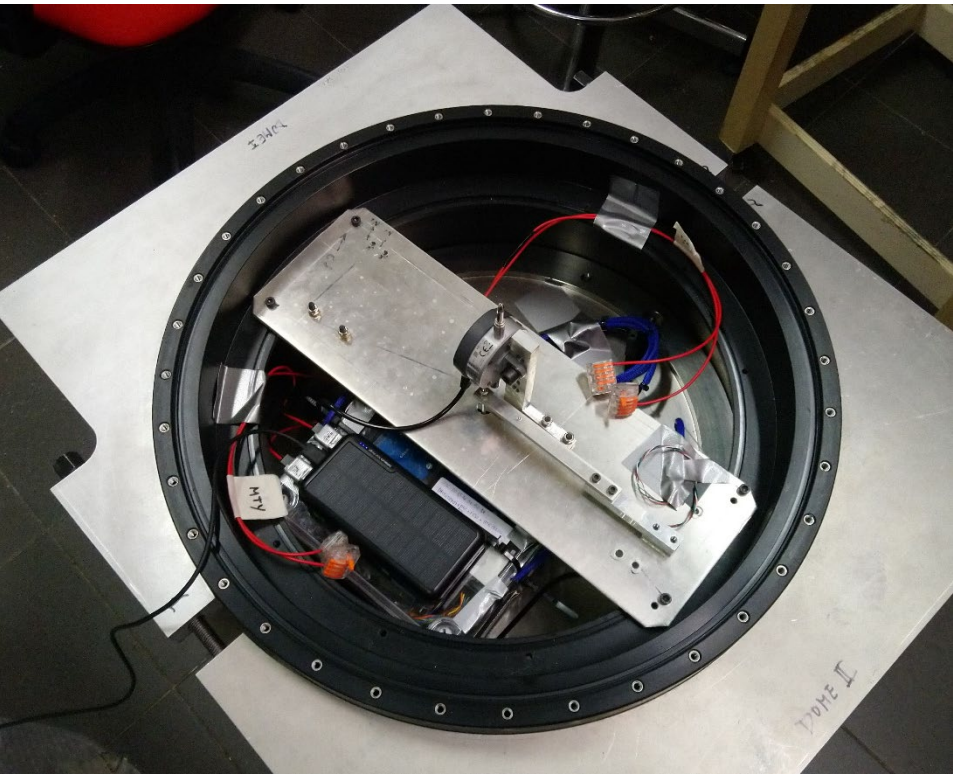
An Arduino-based acquisition system was designed. This system could measure temperature, pressure and humidity inside the mPMT, and also the vertical displacement of the dome, the vertical displacement of the back plate and the radial displacement of the cylinder. A similar system will be used in a long pressure test too, with a different power supply and accelerometers as well.

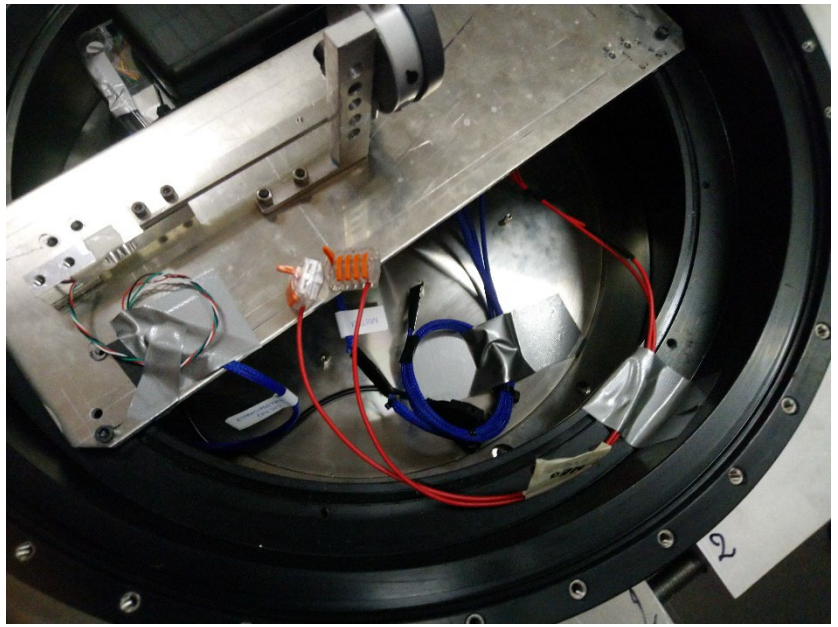


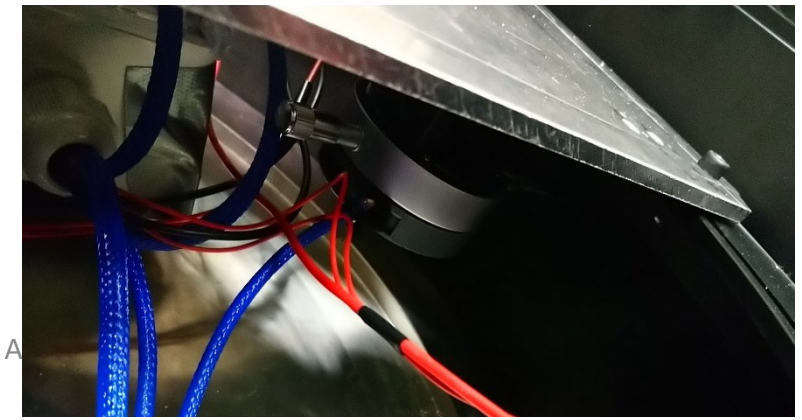
All the mentioned data were collected by two acquiition systems

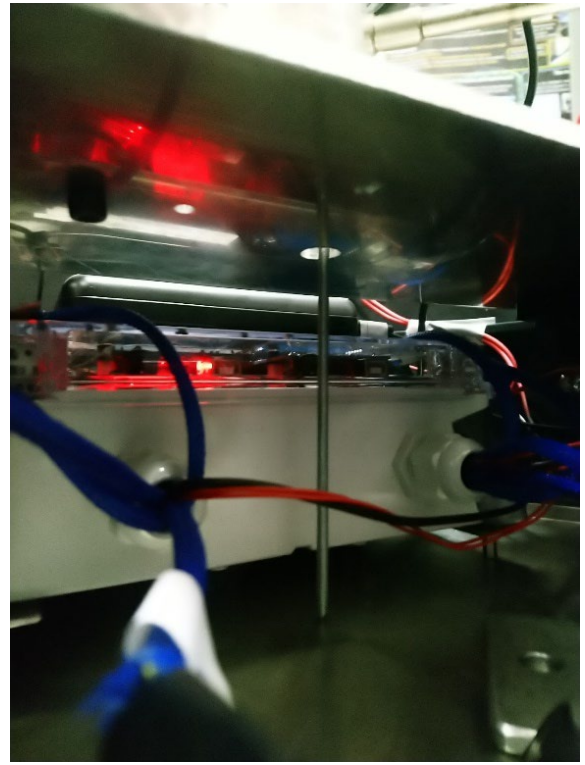
The multi-PMT – About its tests, before the pressure test

The most of measure instruments was placed in an aluminium board. After the closure, the acquisition systems were inaccessible, so they were switched on by a reed + magnet (from outside).
When the systems are ON, they transmit by bluetooth (to check them) but there are SD cards to save data during the test.





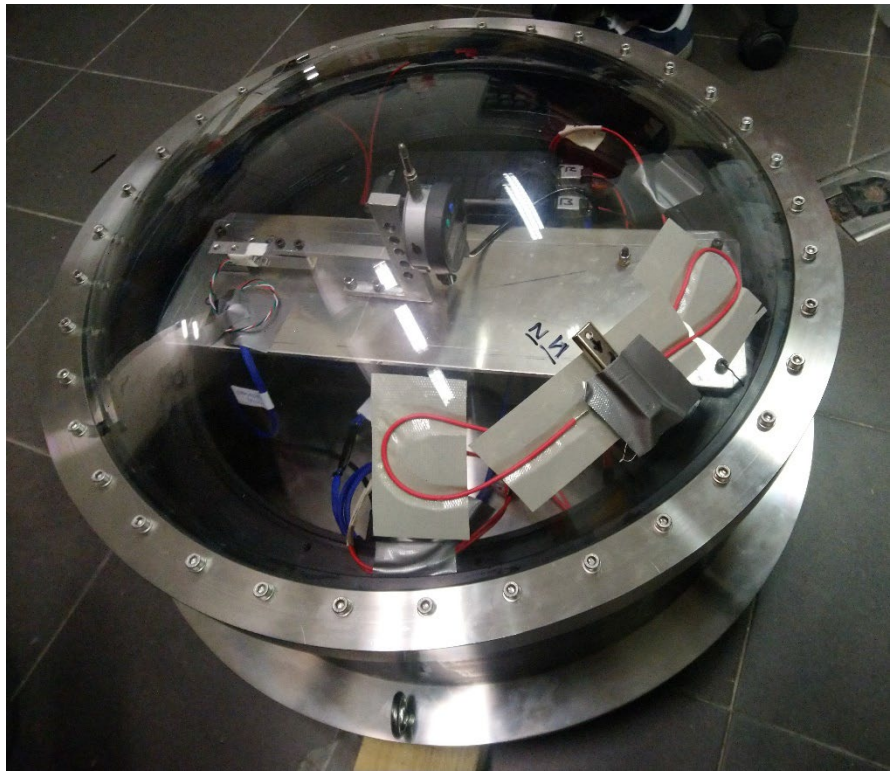




The multi-PMT – During the pressure test

At Resinex company (Italy) we tested two prototypes (3h each for test):

1. Prototype with the not-good PMTs and gel
2. Prototype with the acquisition system inside.

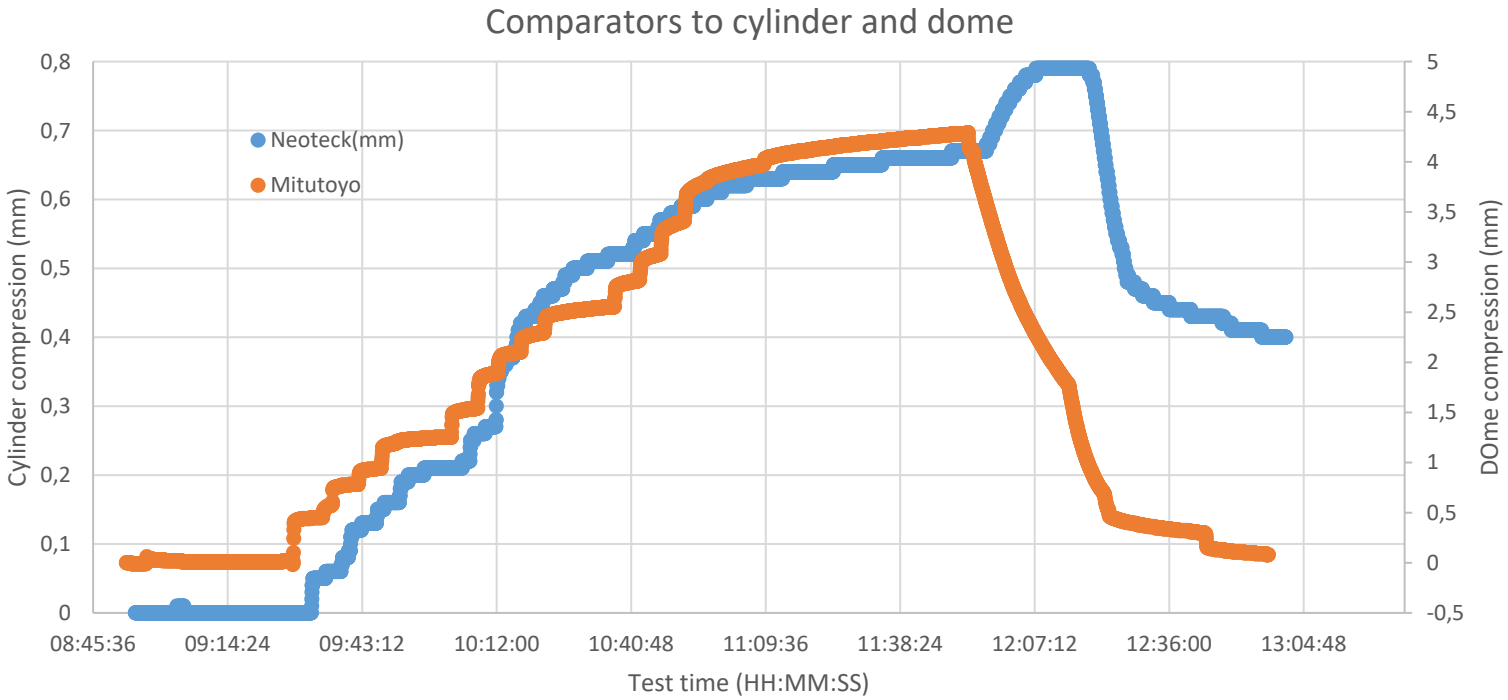


The multi-PMT – After the pressure test

Maximum compression measured of the dome: 4.29 mm
(it's the measured distance with the comparator placed on the aluminium board).

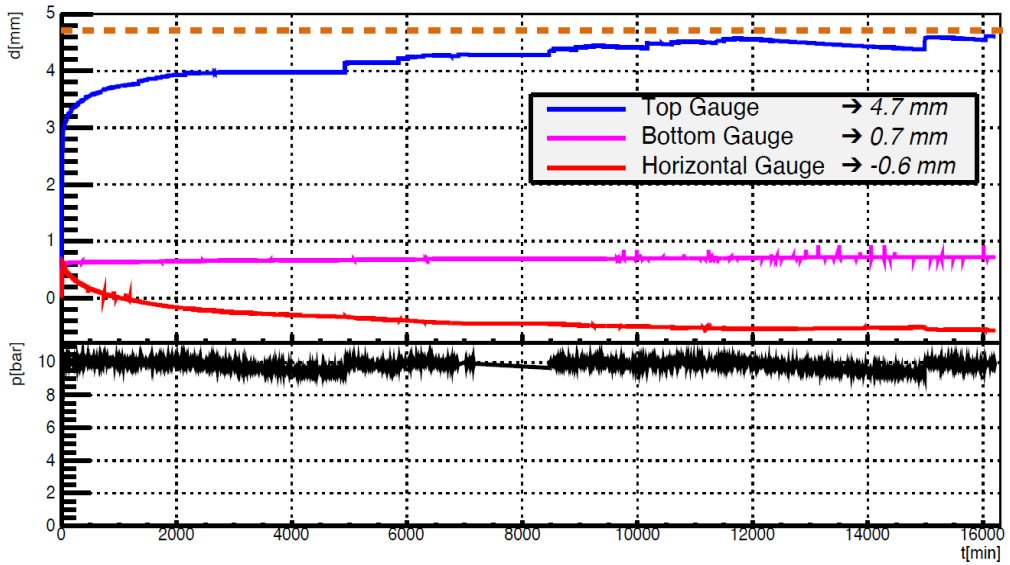
Maximum compression measured of the cylinder: 0.79 mm

In the graphs we can see that dome compression is not at a plateau, but the slope is not so critical.
Further long tests will be done.



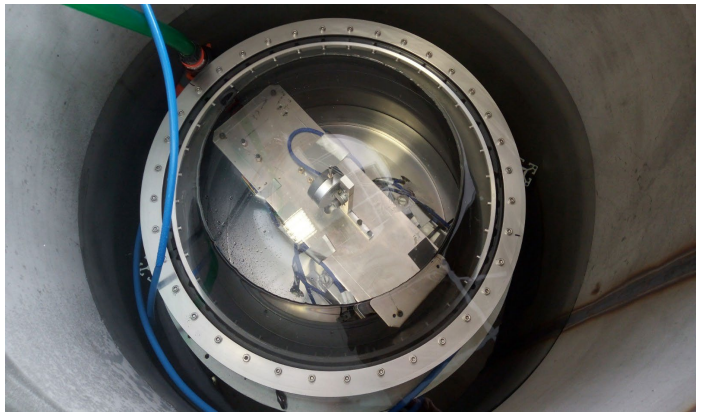
The multi-PMT – About its tests (long pressure test)

Cylindrical mPMT prototype, new Arduino monitoring system
At IPNP at Charles University (Prague) (2022)

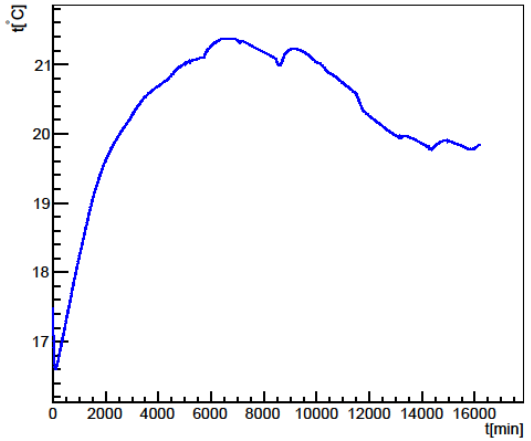


The vessel was tested until **10 bars for 11.1 days**.

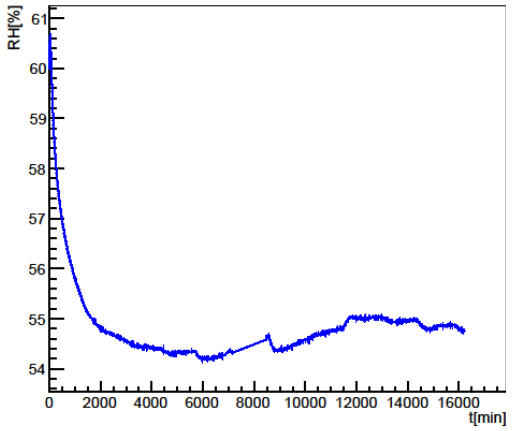
Deformations are in a good range, humidity and pressure inside the vessel are related to the inner temperature.
No leakage! The vessel manitaned the sealing!



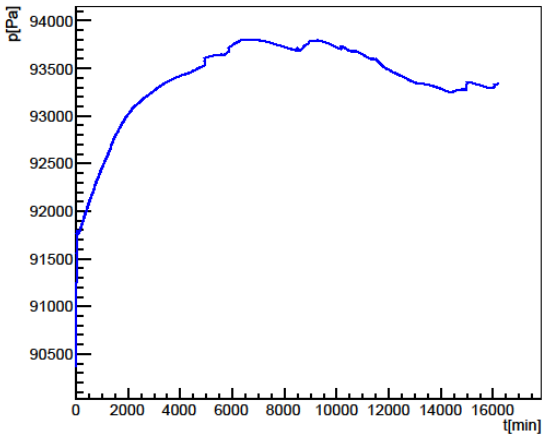
Inner temperature Graph



Inner humidity Graph



Inner pressure Graph



The multi-PMT – Optimizations

Many upgrade to optimize the mPMT:

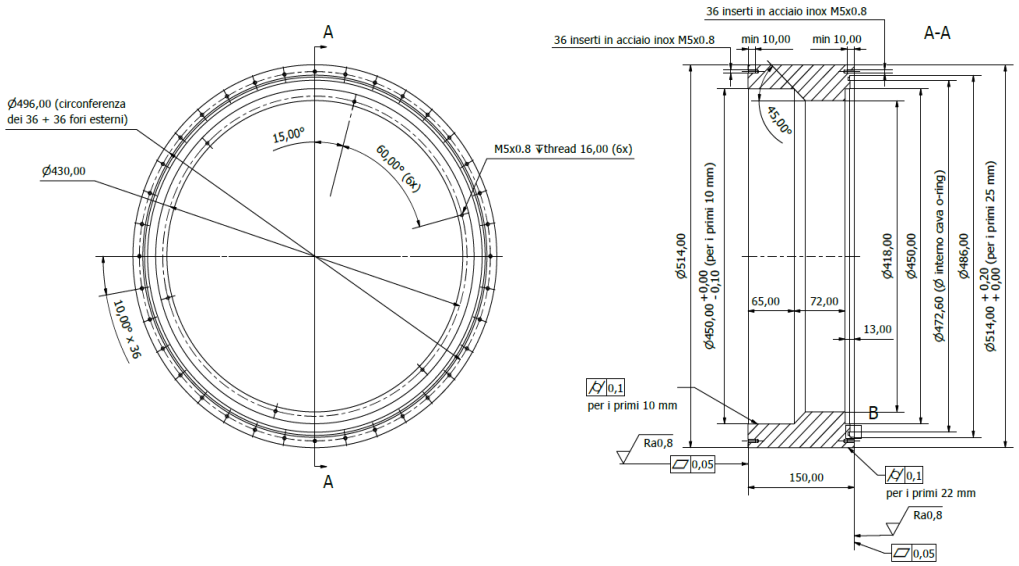
- **Cylinder** from HPDE material was updated with POM-C material
  - The HPDE material showed some defect because of its intrinsic properties, amplified with the big size of the cylinder (i.e., ovalizzation). Difficult match with the others components.
  - The POM-C cylinder did not show any mismatch and it was perfect in the last assembly.

- The **PMT support** was modified many times to find the best compromise with the production.
  - Me and a INFN designer (many thanks to Maurizio Mongelli) worked, uploaded and developed:
    1) the original configuration was modified for the gel pouring
    2) a design to reduce the gel quantity
    3) A design to consider the injection molding
    4) A design for the 3D-print production

After that the number of mPMT was defined (~850), the best solution pointed on the 3D printer.
The final design will be a combination of all previous versions.

The multi-PMT – Optimizations (cylinder)

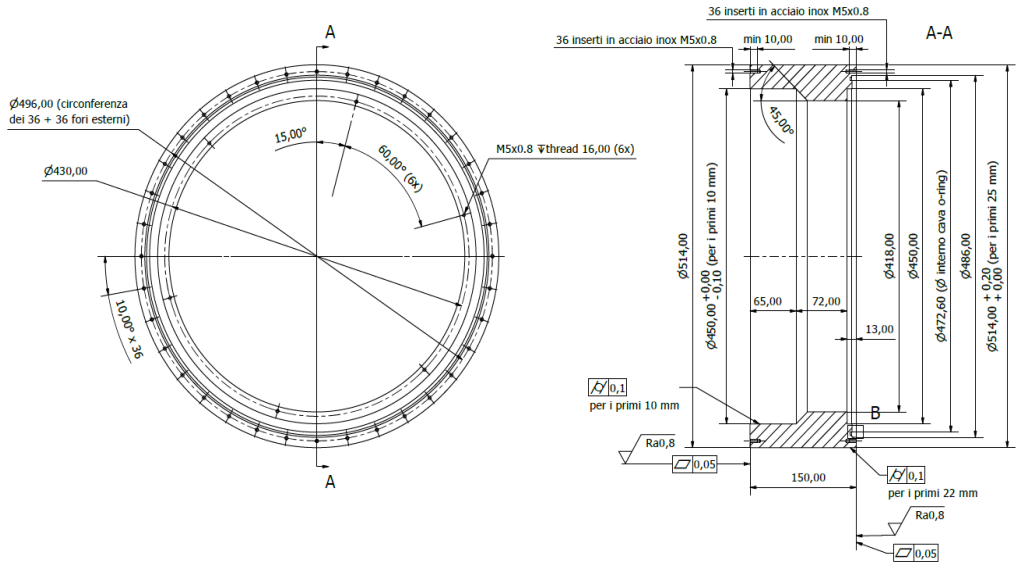
The HDPE cylinder didn't pass very well the assembly test, because of an ovalizzation. It was NOT a bad manufacture, but internal forces find a new equilibrium when the manufacture is completed. This behaviour is diffucult to prevent, so...

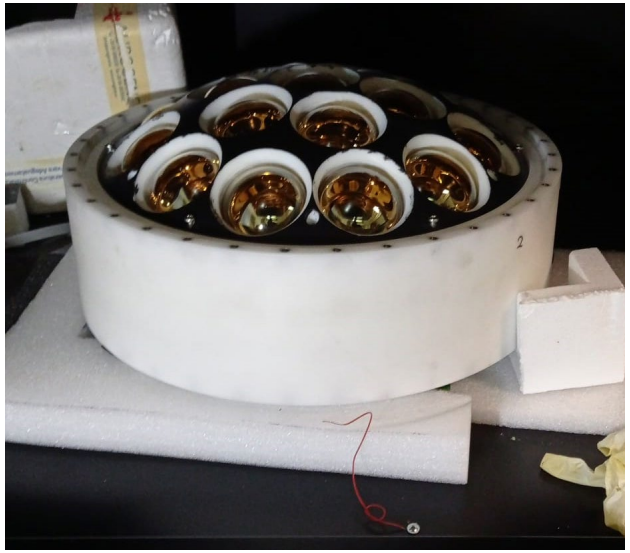


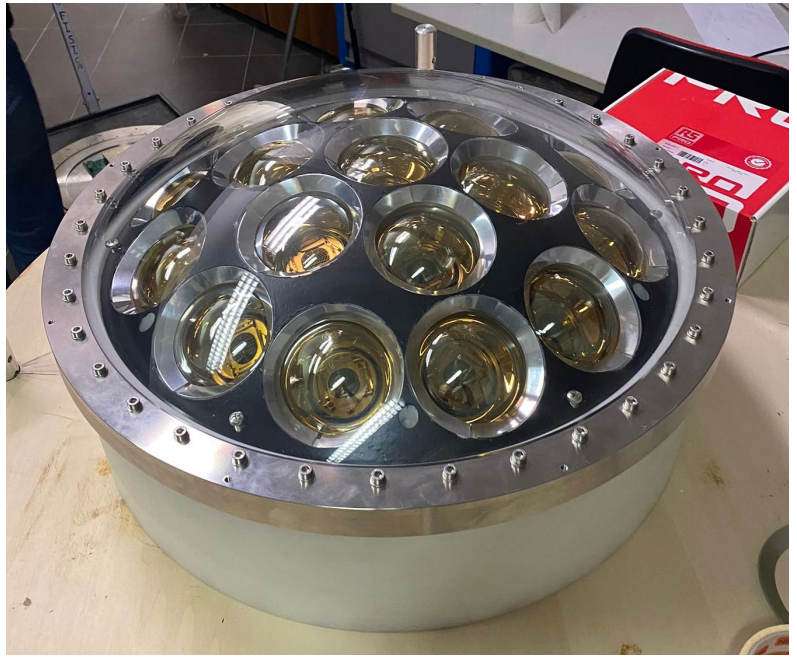
The multi-PMT – Optimizations (cylinder)

The HDPE cylinder didn't pass very the assembly test, because of an ovalizzation. It was NOT a bad manufacture, but internal forces find a new equilibrium when the manufacture is completed. This behaviour is diffucult to prevent, so...

A new cylinder was made in POM-C material (more stable and more rigid than HDPE), even if it was very hard to find a suitable sample to make a cylinder so big.

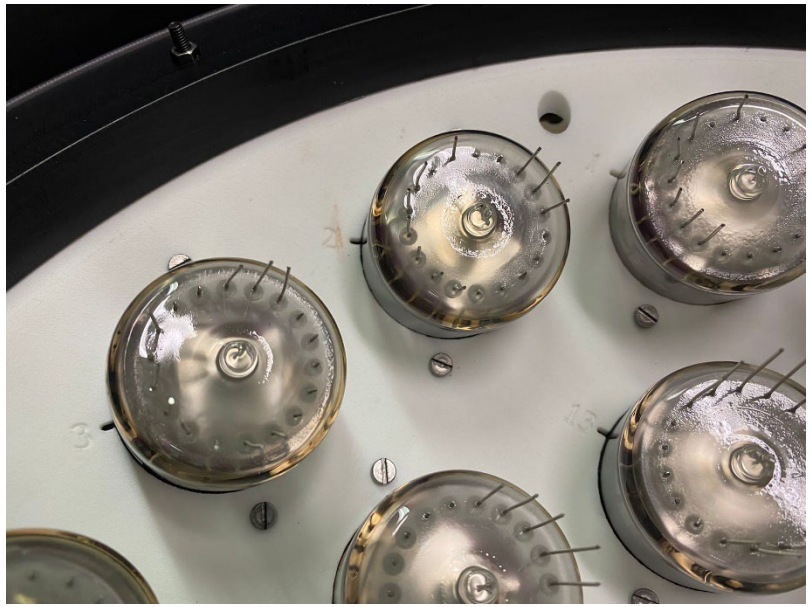


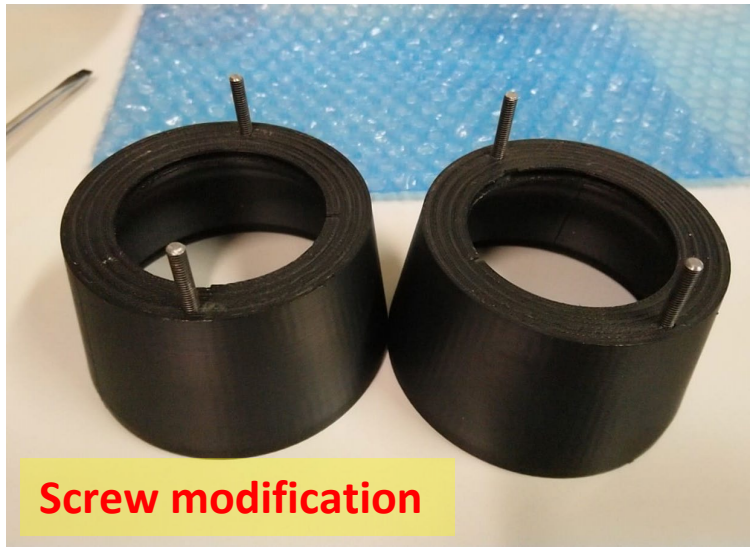




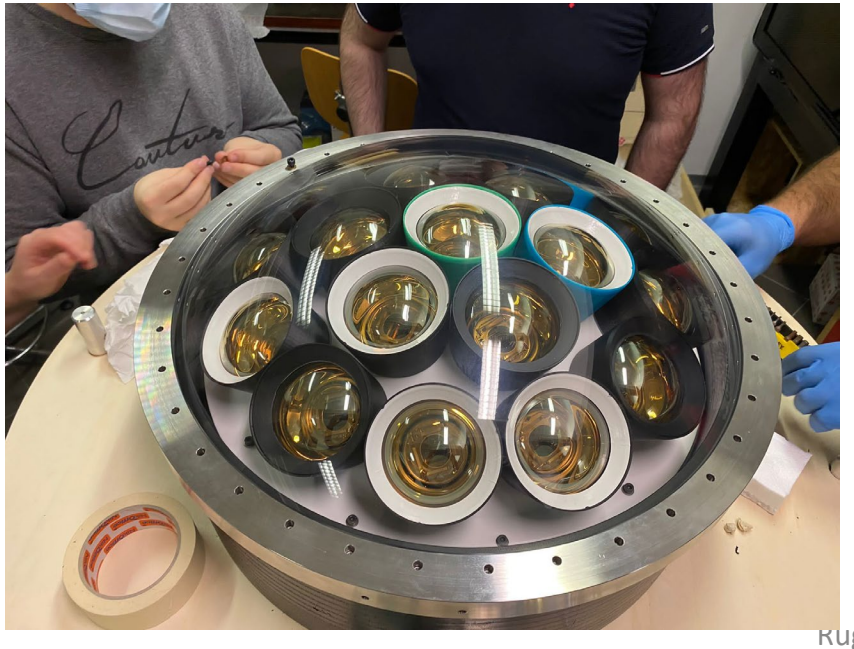
Excellent match during the assembly!

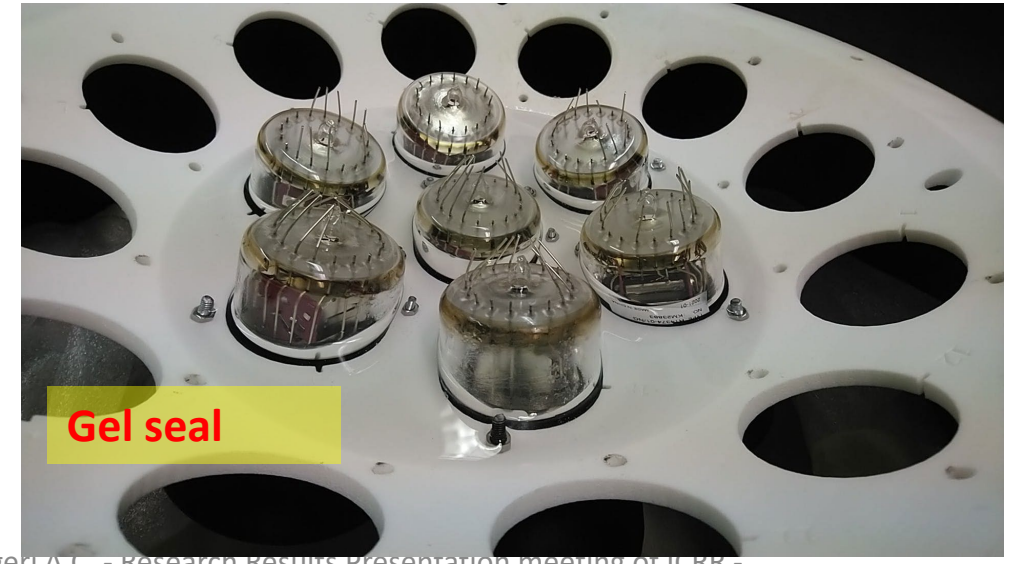
The multi-PMT – Optimizations (PMT support)



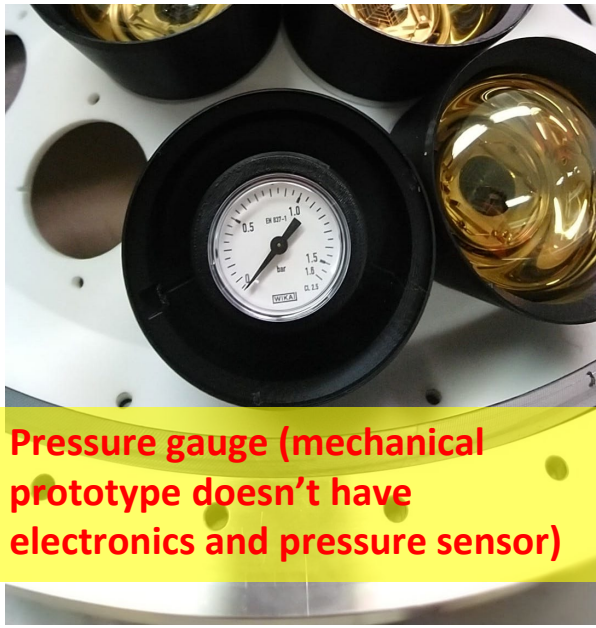


Screw modification



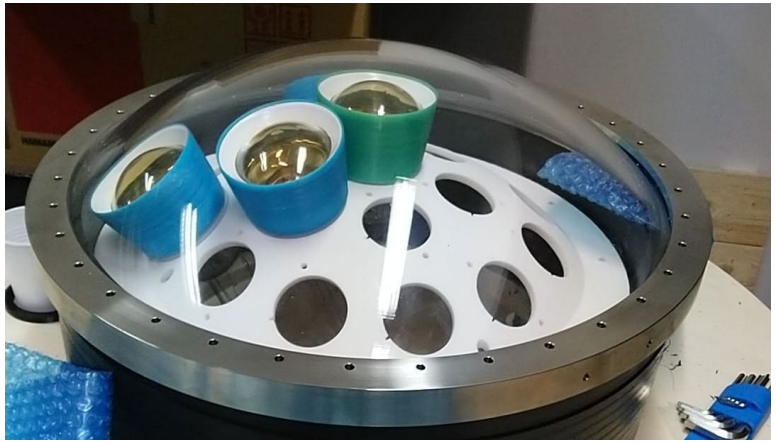


Gel seal

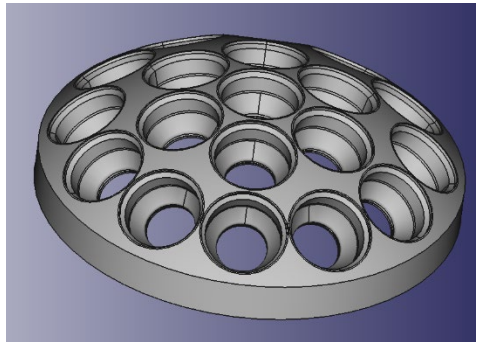


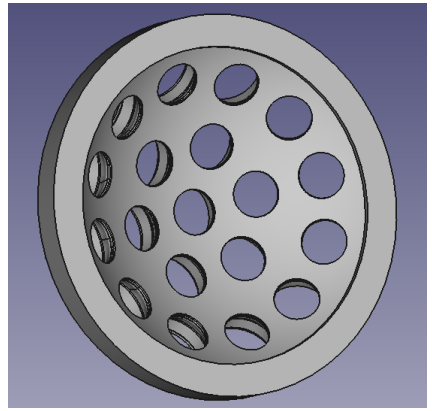
Pressure gauge (mechanical prototype doesn't have electronics and pressure sensor)

The multi-PMT – Optimizations (PMT support)

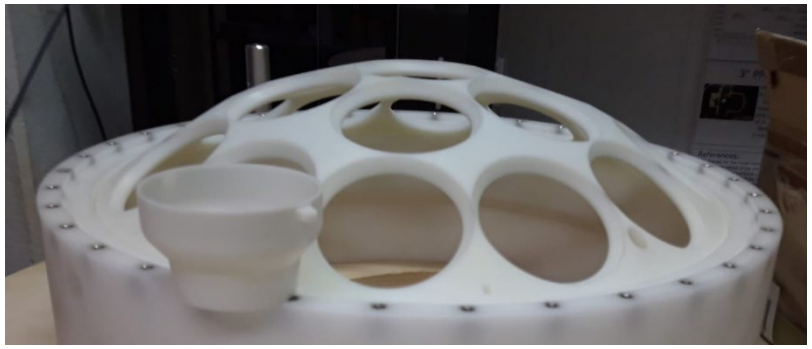


First design (prototype made by 3D printer)
[thermo-forming (base) + injection (cups)]





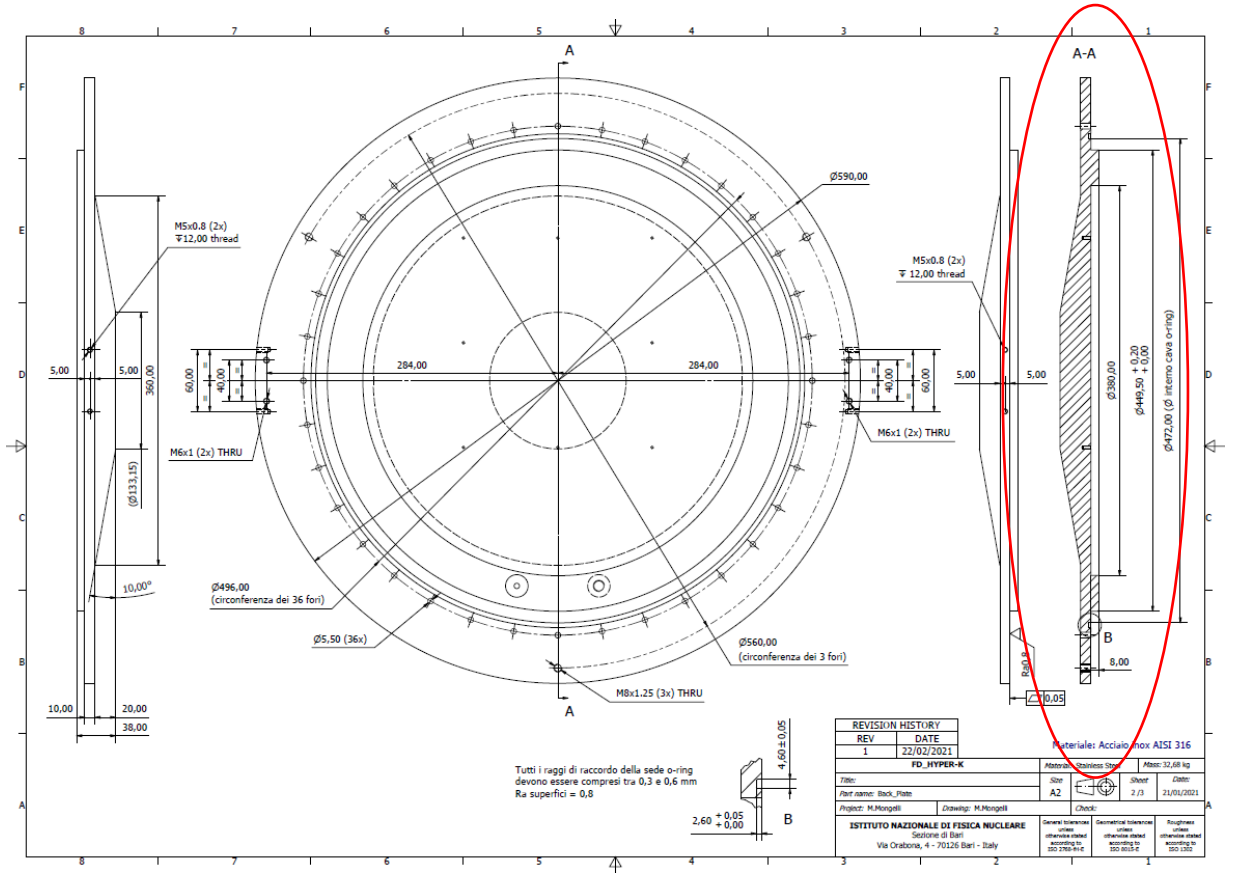
Second design
(prototyped for some check)



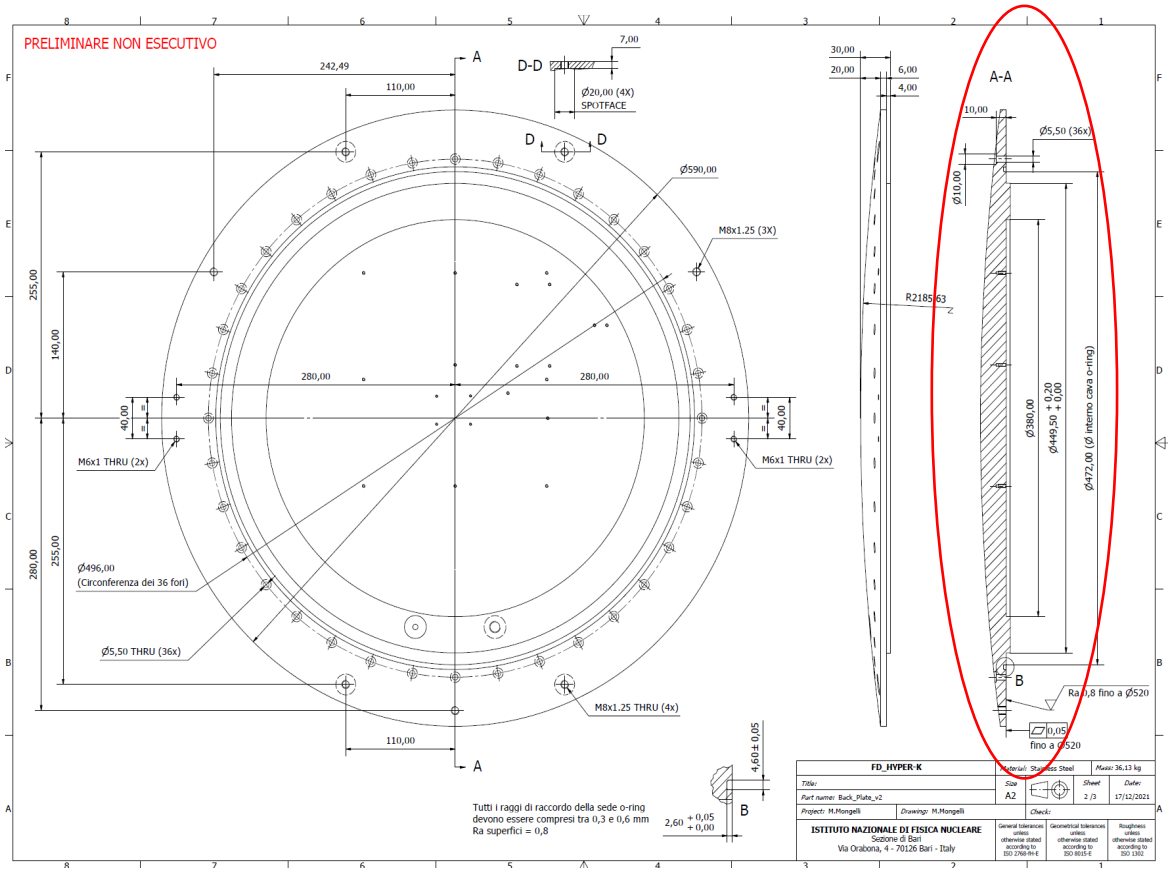
Third design
(for injection molding)

Fourth design
(like the third but in a
unique piece for 3D printer)

The multi-PMT – Optimizations (Backplate)

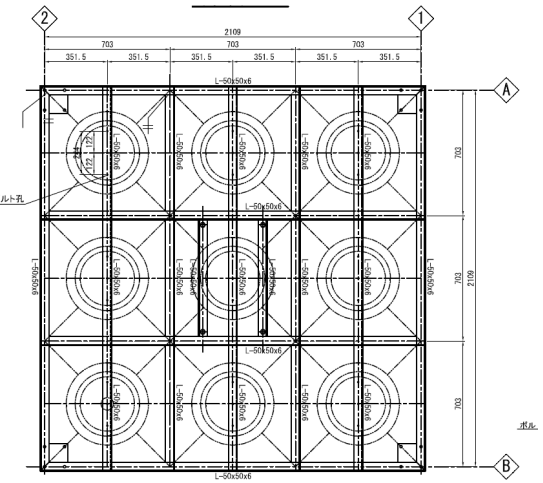


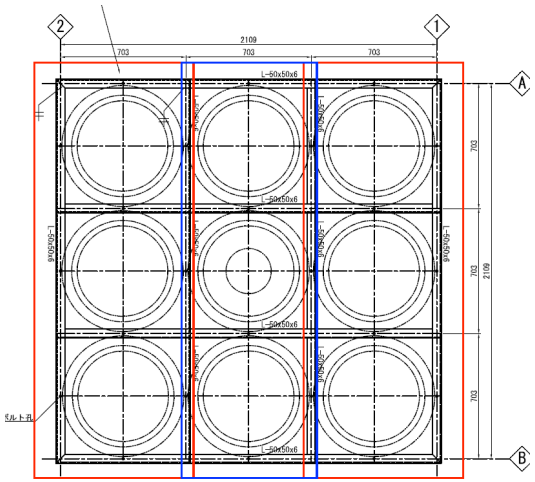
Trucated-conical profile

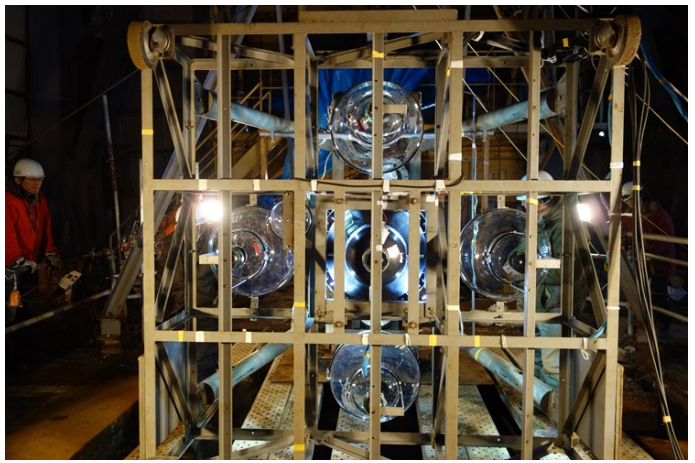


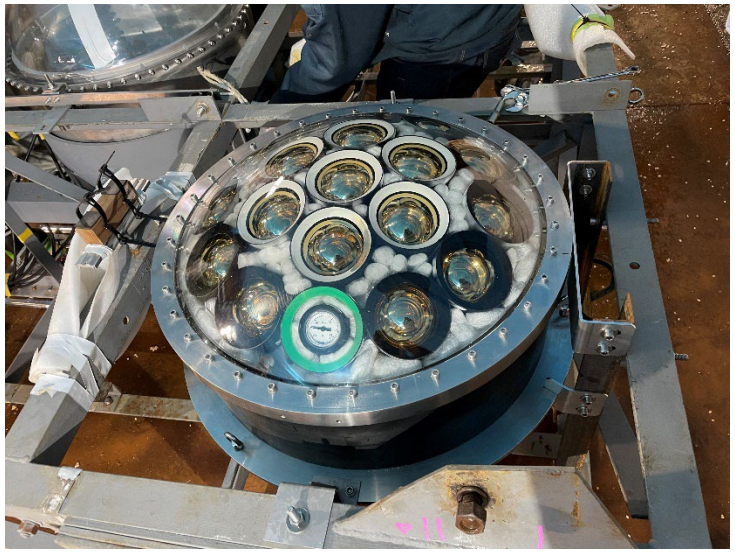
Curvilinear profile and lighter

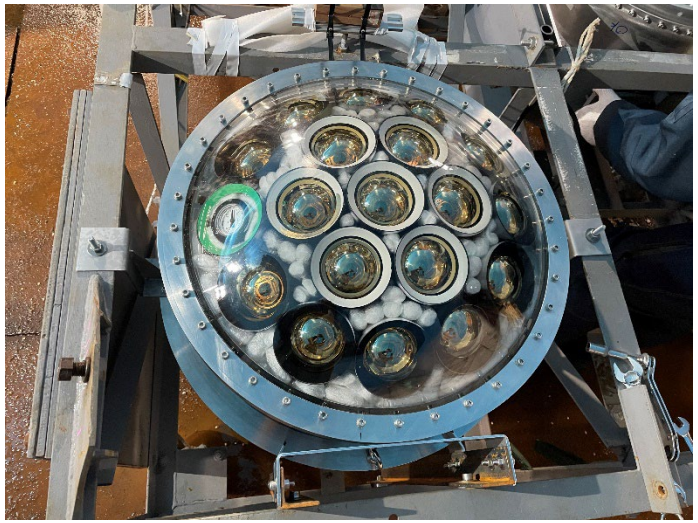
The multi-PMT – Anti-implosion and installation tests











The multi-PMT – Anti-implosion and installation tests

By this test, many checks:

- ✓ The **installation procedure** was done only following my written instructions
- ✓ The **mPMT vessel passed successfully** a failure of the **anti-implosion test**
  - ✓ It means that it resisted to many implosions and chain implosions (extremely worst case)
  - ✓ Only some PMTs were damaged, in particular in the side where the first shock wave was generated
  - ✓ No problem at the fixing system

Because of the covid restrictions, I could be there in **Hokkaido**. Many many thanks to Luis Labarga and the Spanish group there, Kameda-san, Nishimura-san and the whole team of the company. Their help and availability were really precious and fundamental!

Conclusions

Successes and delays among pandemic, war and change of contract…

- Some tasks were late or had to be postponed because of difficulty to find material and cost increase
- Fortunatelly, the main tests were done and passed successfully

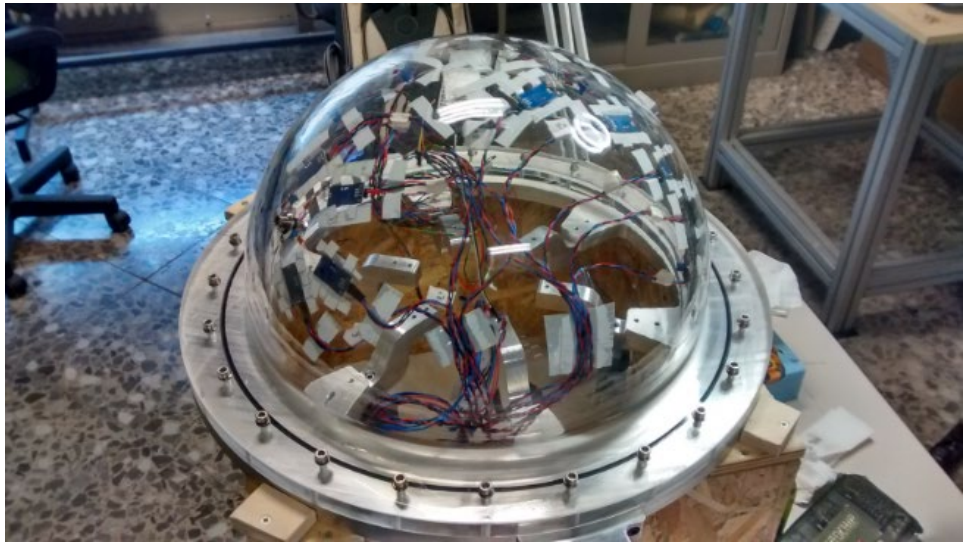
mPMT status:

- Its design is on the way to be concluded
  - Last details for the best tuning among the PMTs, PMT support and reflector rings.
- The POM-C cylinder components passed the assembly check
  - Nuclear tests will start coming soon at the Gran Sasso labs
- Soak test ongoing in Prague
  - POM-C
  - UVT acrylic (+ high pressure test to do in CIRCE labs (Caserta, Italy)
- Radon tests were redirected to France
  - The whole final mPMT (+ cable) will be shipped to Bordeaux for this measurement
- 5 mPMTs will be produced this year to install them into the Water Cherenkov Test Experiment (WCTE) at CERN
  - Orders of components have been already done

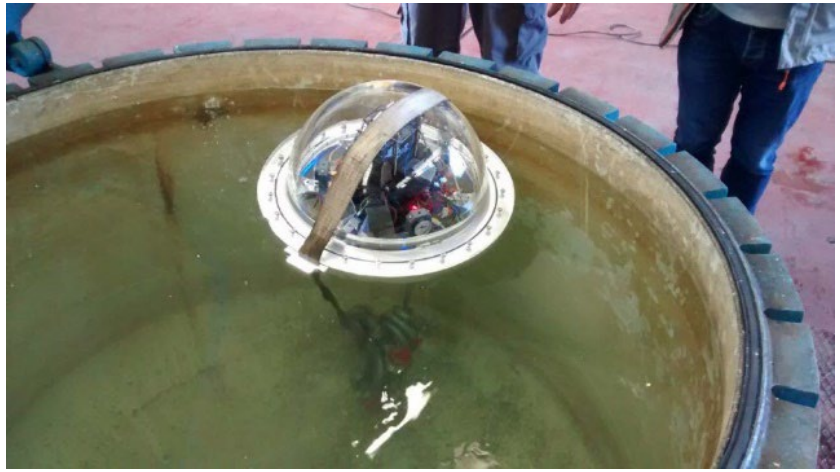
Thank you!!!

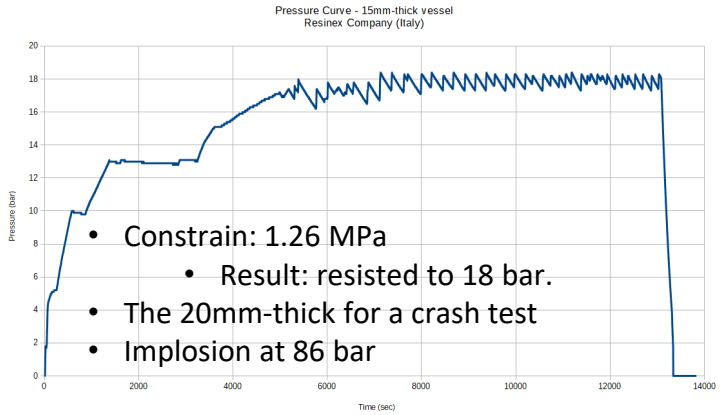
Backup slides...

The multi-PMT – About its tests



15mm and 20mm-thick vessels tested
Arduino pressure sensors for monitoring
At Resinex Company (2018)





- Constrain: 1.26 MPa
  - Result: resisted to 18 bar.
- The 20mm-thick for a crash test
- Implosion at 86 bar

The multi-PMT designs

The mPMT is a vessel which houses and protects an array of 19 3” PMTs, and the original concept was realized for the **KM3NeT** experiment.
WRT single 20’’ PMTs the mPMT configuration:

- ✓ improves the granularity and timing response over larger number of photo-sensors
- ✓ has got an additional intrinsic directional information

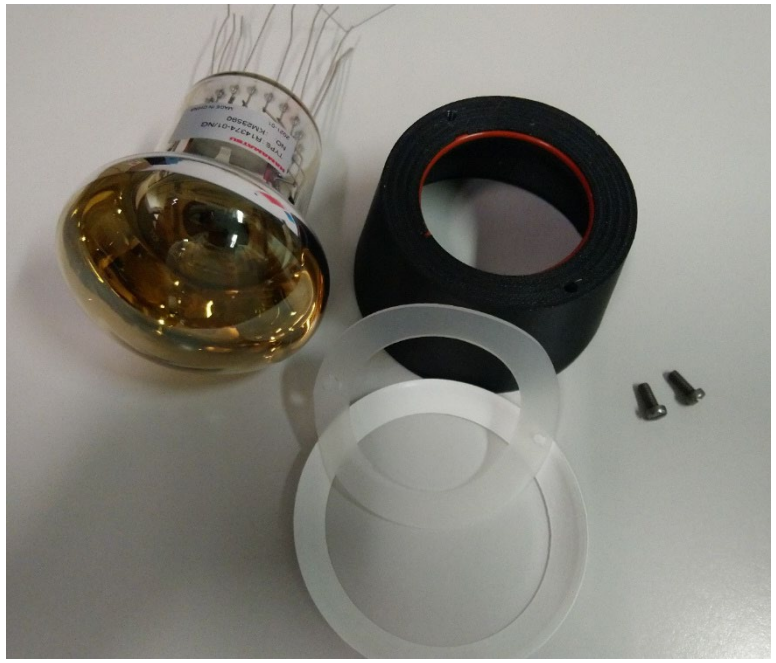
This detector is a common effort from Italy, Canada, Czech Republic, Mexico and Poland.
Two mPMT designs are planned, but very similar each other ⟹ Same assembly, similar components where possible.

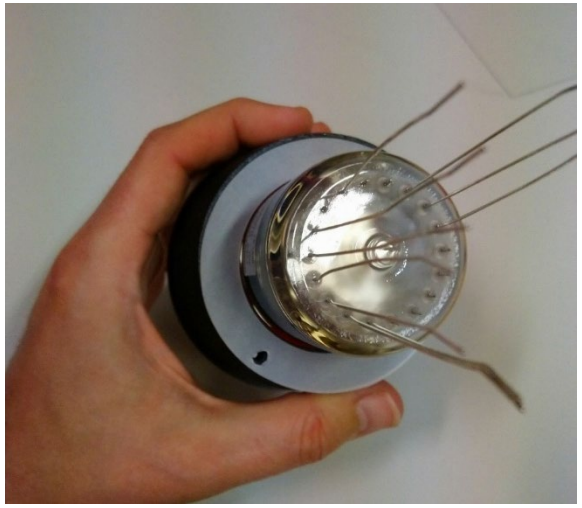
Different constrains for the IWCD and FD mPMTs:
- in the FD a higher resistance to pressure is required (in comparison with IWCD)
- in the IWCD mPMT electronics needs to be able to distinguish between different hits in different bunches

➢ Currently, the number of the mPMT for the HK FD is under discussion.

Principal mPMT componets	Characteristic for the FD	Caracteristic for the IWCD
Dome	UV-transmitting acrylic	UV-transmitting acrylic
3’’ PMT	19 items	19 items
Vessel cylinder	POM-C material (TBC)	PVC material
Back plate	AISI-304 stainless steel (SS)	AISI-304 SS
Optical gel	For an optical connection between the acrylic dome and the PMT photo-cathode	For an optical connection between the acrylic dome and the PMT photo-cathode
Clamping ring	AISI-304 SS	AISI-304 SS
Electronic board	Q/T digitization based on discrete components	FADC digitization, with on-board signal processing

The multi-PMT – Its optimizzation (details of the first PMT support)





In this prototype, the KM3NeT o-ring was used because it better fits with the cup groove for PMT

3 holes done in the cup for discharging air during gel filling

Silicon grease was used to seal the wire groove, and to wet o-ring and gasket