INFN
Istituto Nazionale
di Fisica Nucleare

Materials in optical sensors

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INFN Naples

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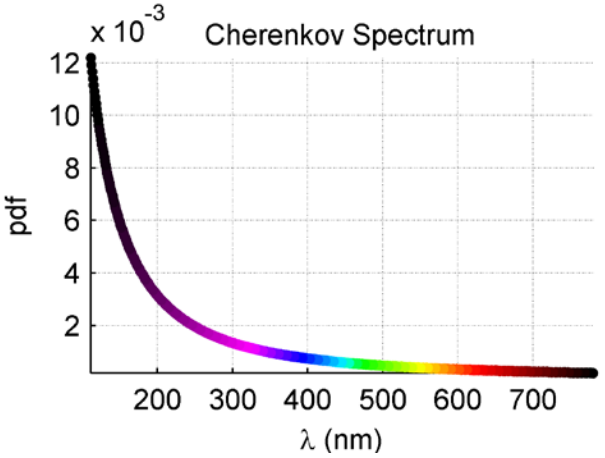
Experimental requirements

In experiments at low-energy threshold, materials have to be with low radioactive emissions (e.g., glass contains ^{40}K and other radioactive contaminations)

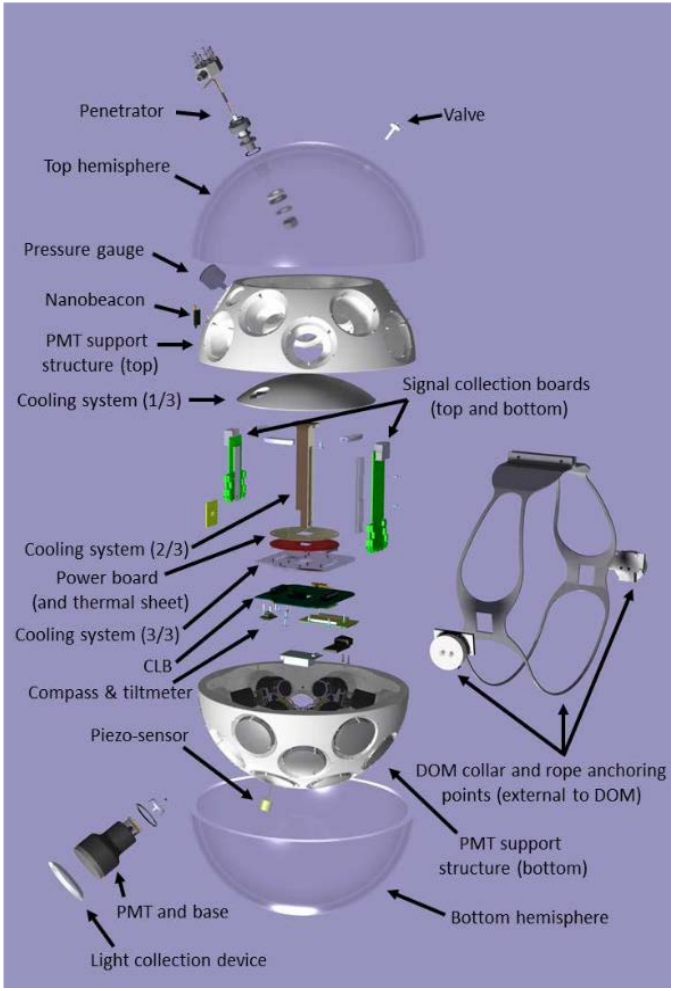
In experiment where the Cherenkov emission is the principal physical effect, UV transparency is important because of emission spectrum (more emission in UV)

Acrylic is a very good material. It's a comprimise among resistance, transmittance properties, nuclear contaminations and costs.



Credit by Jocher G.R. et al., Phys.Rept. 527 (2013) 131-204

mPMT components



mPMT example. KM3NeT DOM

Complex structure

- Acrylic vessel
- Cooling system
- Penetrator/Connector
- PMTs
- PMT bases
- PMT Read-out
- Main Logic Board
- PMT reflector rings
- PMT support structure
- Optical-gel
- Pressure gauge
- Calibration system
- Temperature/Humidy sensors

Studies about acrylic properties

The Hyper-K/E61 groups at INFN Naples and Bari have been working on the design of the initial prototype of a pressure vessel, with many small PMTs inside, for the Hyper-K/E61 experiment, in order to obtain an operative prototype with

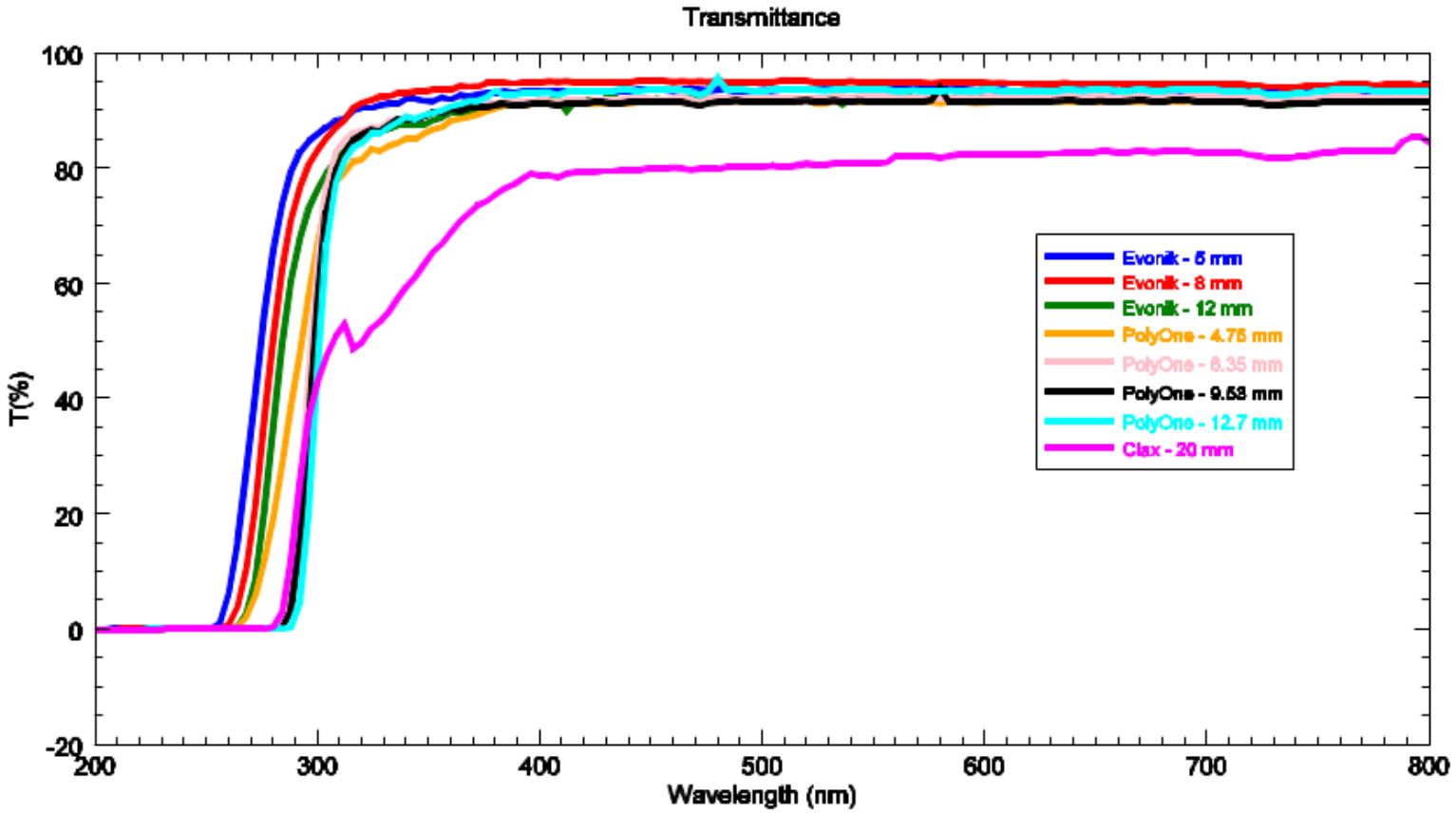
- Sufficient water-pressure resistance
- A new data acquisition system (talks by A. Evangelisti and T. Lindner in Electronics session)

Tests are conclused or ongoing so far:

- Optical tests
- Mechanical tests
- Nuclear contamination tests
- Water absorption tests (L. Gialanella's talk)

Acrylic – Transparency

Optical tests done by using a Perkin Elmer Lamda 900 UV/VIS/NIR spectrophotometer.
Transmittance comparison among all samples (Evonik, PolyOne and CLAX Italia).

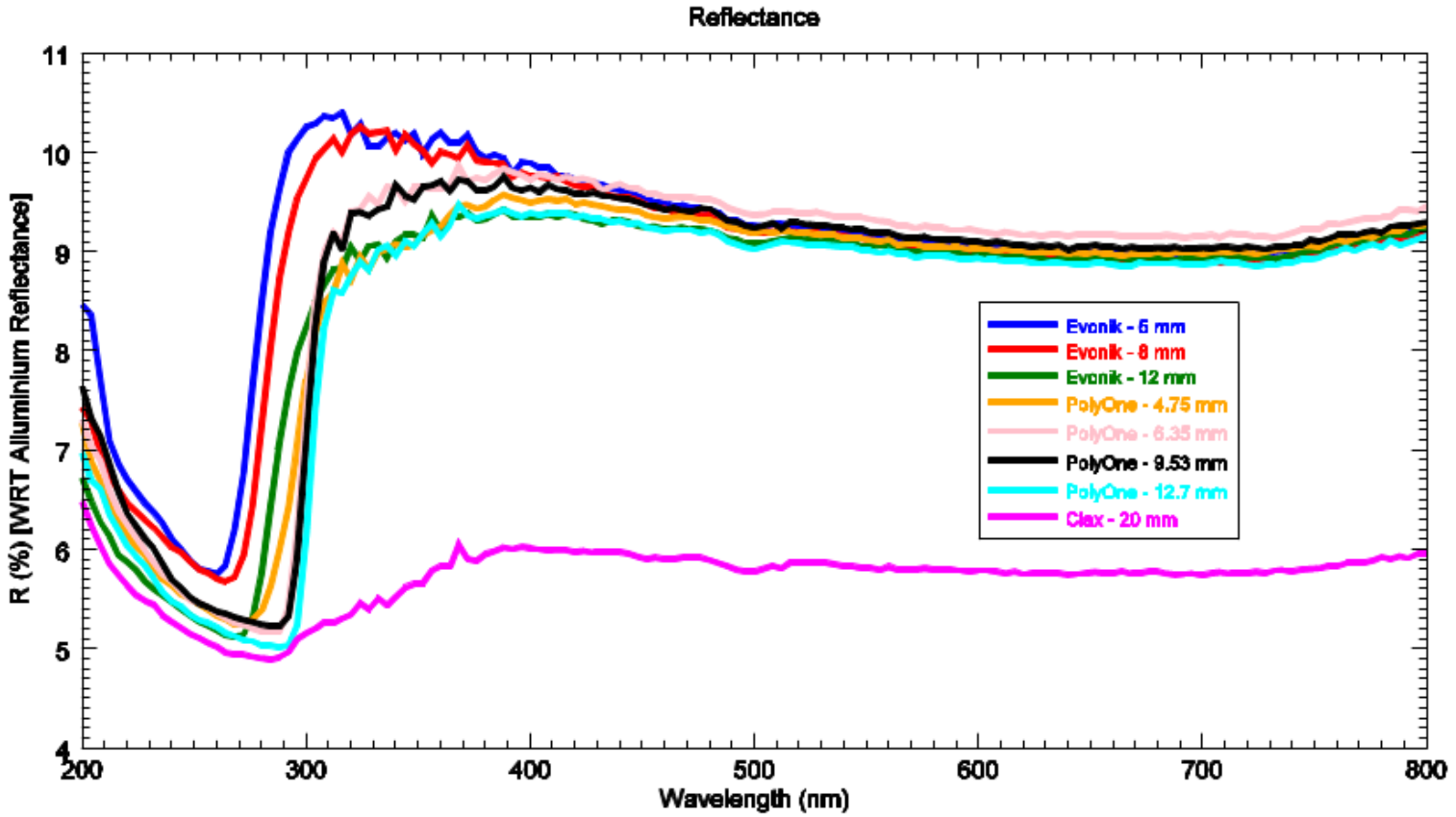


- The trending is as expected, for each group, the thinnest sample is more transmitting than the next thicker.

- The Evonik material has given the best result in transmittance

Acrylic – Reflectance

Optical tests. Reflectance comparison among all samples



Pressure vessel closure system

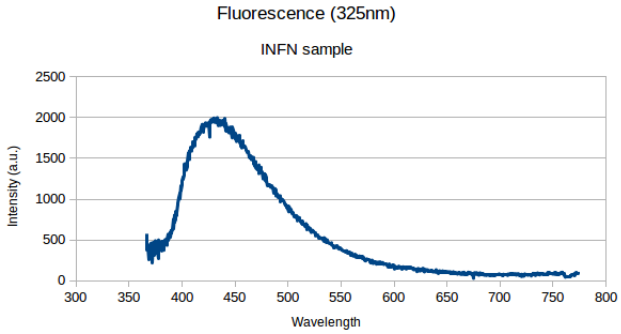
In the multiPMT option, the two acrylic hemispheres could be glued by using a specific glue for acrylics

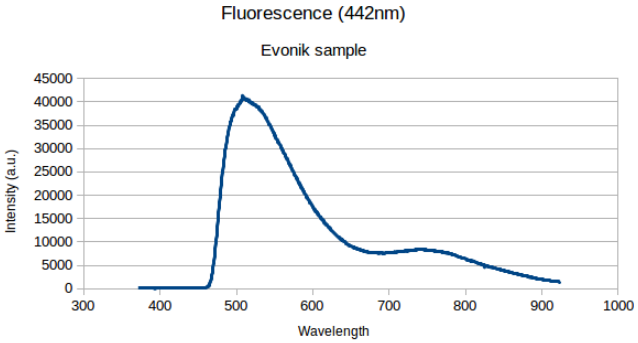
EVONIK proposed the glue Acryfix:
ACRIFIX® CA 0120 + ACRIFIX® 2R 0190

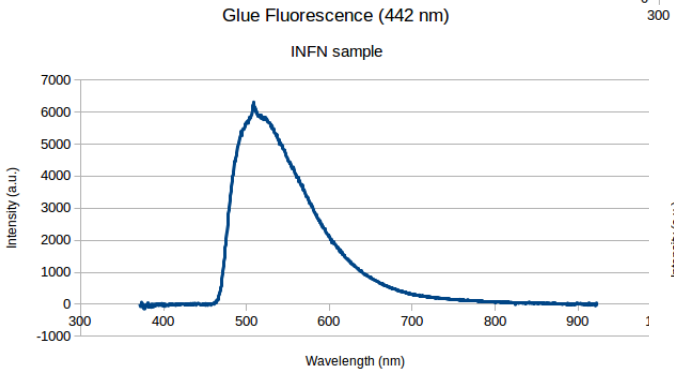
Note that none of Evonik glues are UV transparent

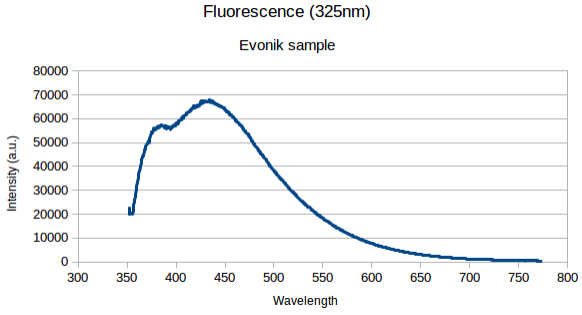
Optical fluorescence tests have been done on the glue

Alternative solution proposed by EVONIK
- Rubber + vacuum (0.2 bar)







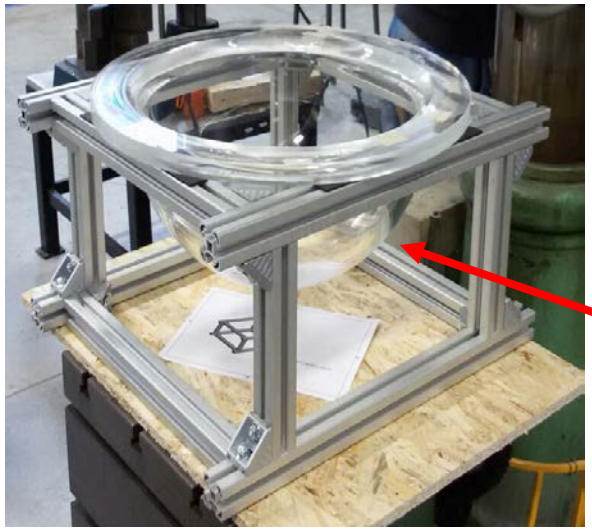


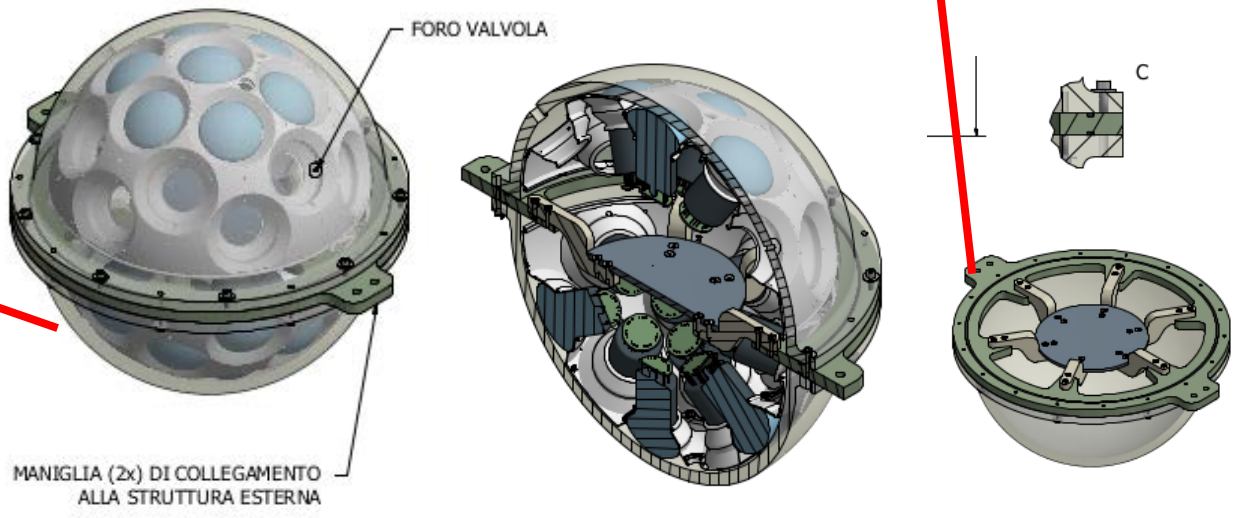
Pressure vessel closure system

In the end, the best solution has consisted in **bolts**.

Bolts are simply, handy, cheap and reliable

- In this metal (prototype) flange there are two handles too, it's been thought to fix the mPMT to the Hyper-K/E61 tank frame.
- O-ring to seal the vessel
- Needed further studies for the final mPMT design





Acrylic + optical gel + water

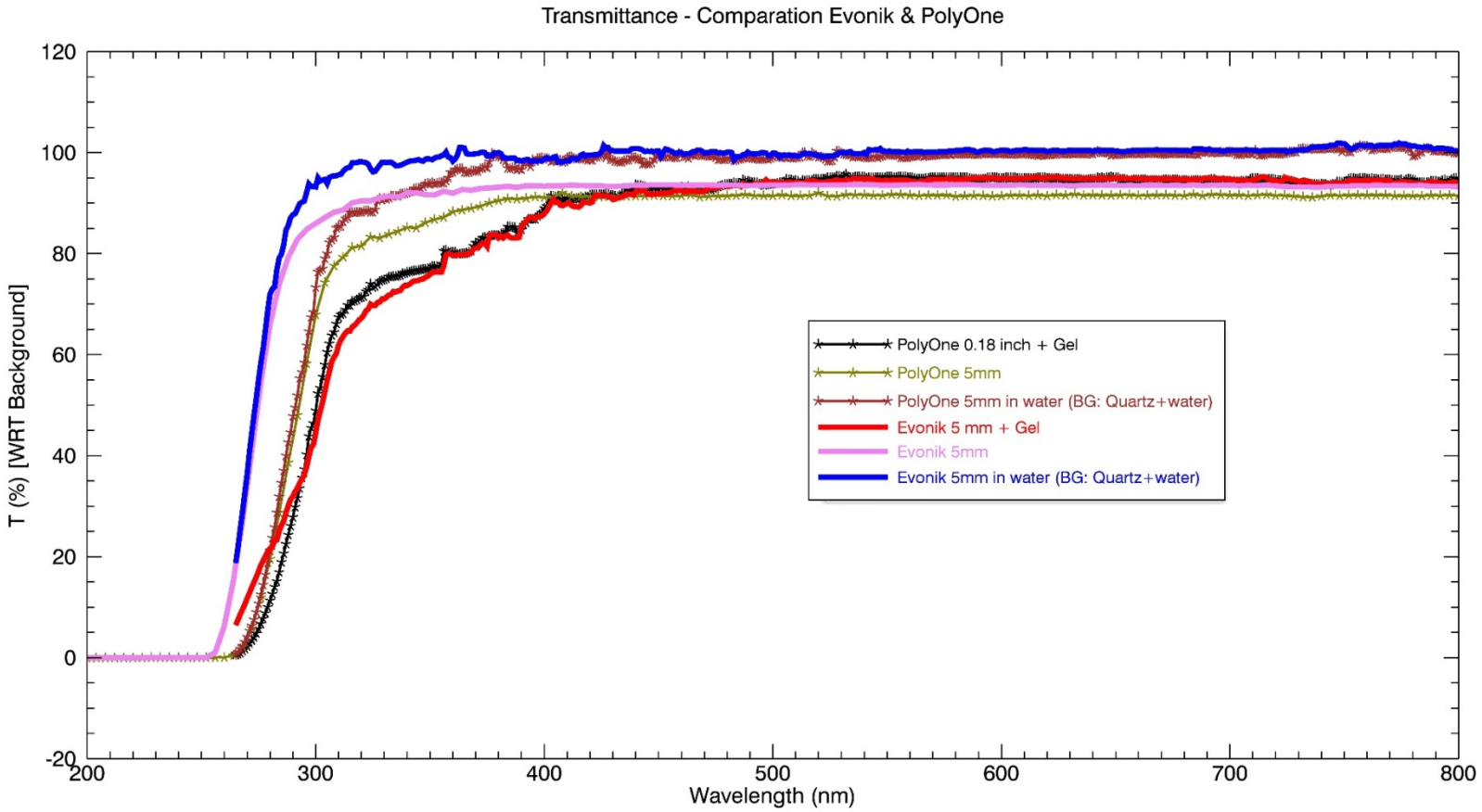
mPMT will work in ultra-pure water and a layer of optical gel is between the PMT photocatode and the acrylic vessel, so…

Optical test in ultra-pure water (total organic carbon, TOC: 2 ppb)
Samples were cut to be inserted into quartz cuvettes.

Optical gel test:
Waker SilGel 612 A + B (the same used by the KM3NeT)
A layer of optical gel was set down onto the 5mm-thick Evonik and 0.18''-thick Poly One samples and transmittance was measured.

Acrylic + optical gel + water

Comparison between Evonik and PolyOne samples in ultra- pure water and with gel.
A 6715 UV/Vis. Spectrophotometer by Jenway, Quartz SUPRASIL cuvettes by Hellma were used.



The Evonik material continues to be the best result in transmittance.

Acrylic – mechanical tests

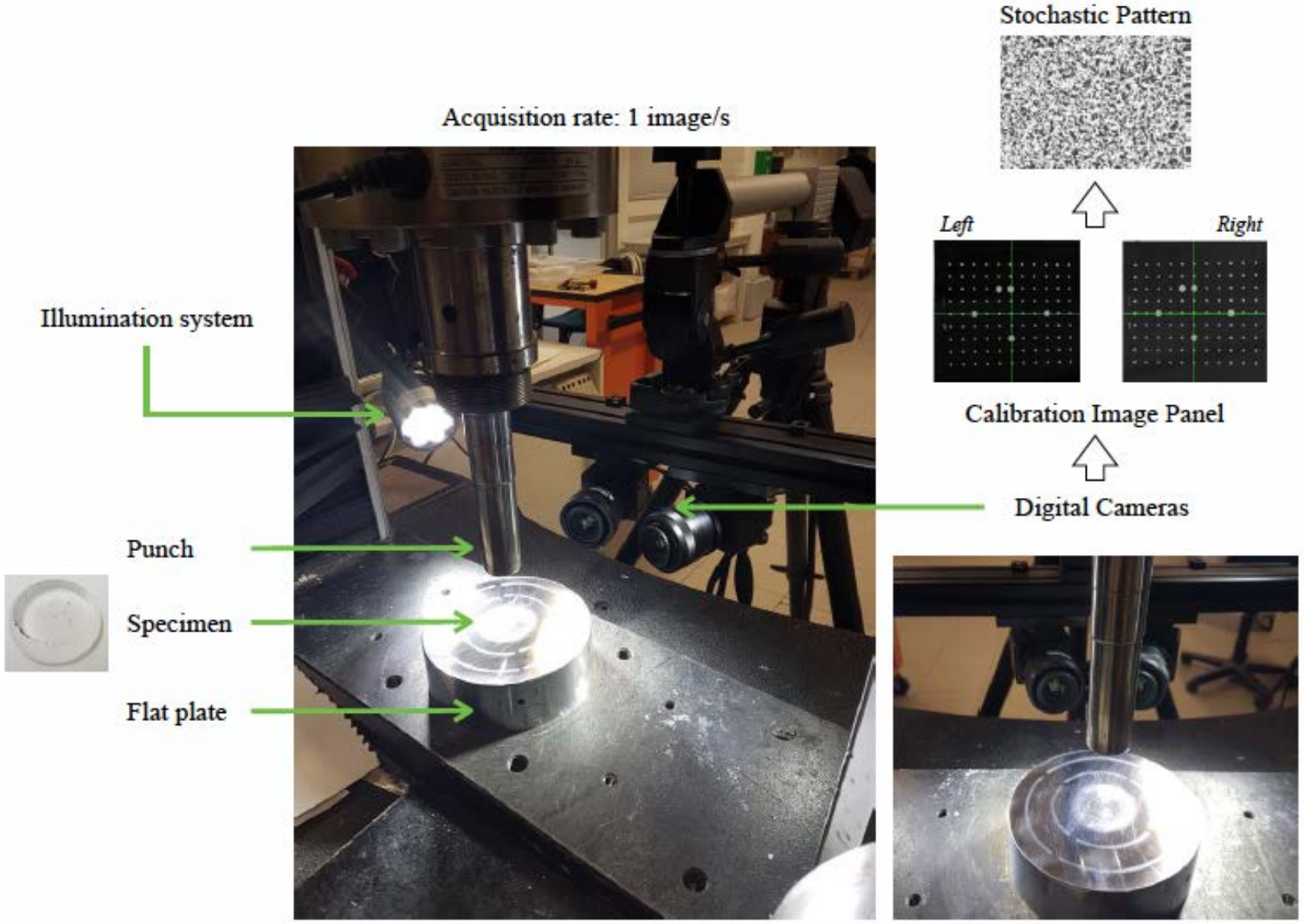
Mechanical tests were done in INFN Bari and Politecnico of Bari

Tests are carried-out on a servo-controlled 4485 machine (Instron, Norwood, USA).
The load and displacement accuracies are 0.25% with the 200 kN load cell and 2.5×10-5 mm. The cross head speed is set to 1.0 mm/s for all tests.

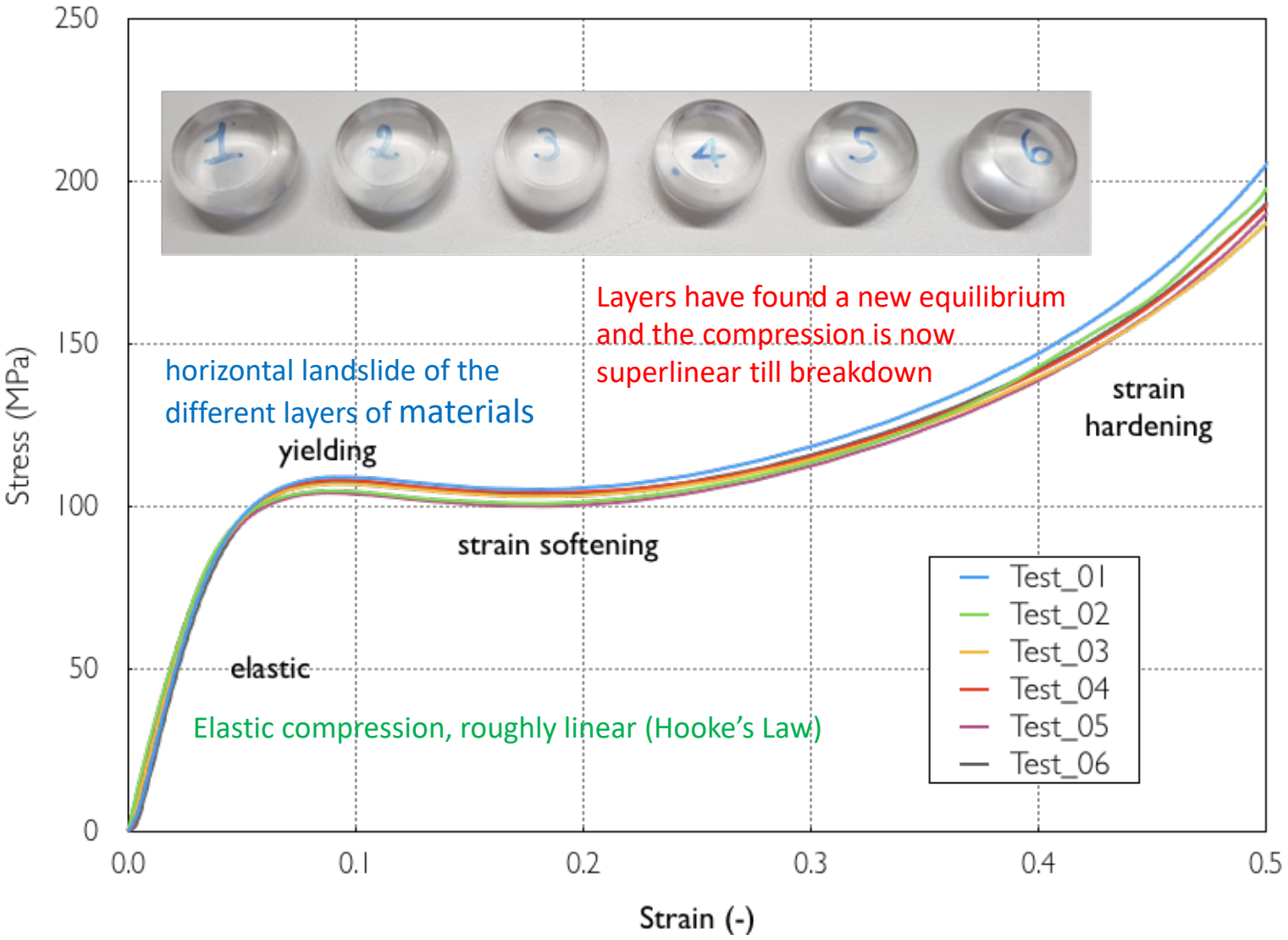
Testing procedure

Tensile and compression tests are performed according to UNIENISO 527.
A digital correlation image (DIC) system is used to acquire deformation during tensile test for each specimen. 3 specimens are tested for each different Acrylic plate. Total elaboration time for each specimen is about 3 hours.

Mechanical tests

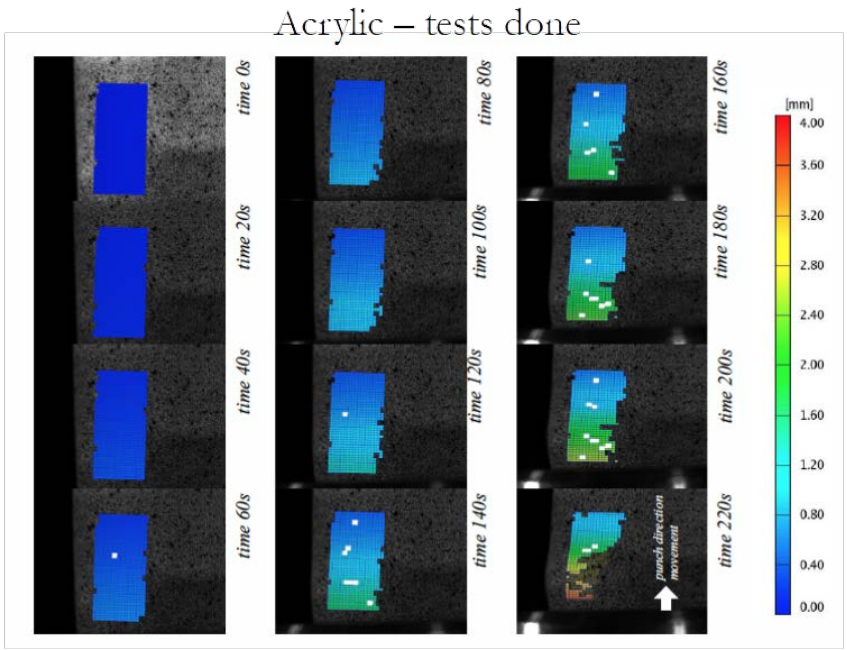


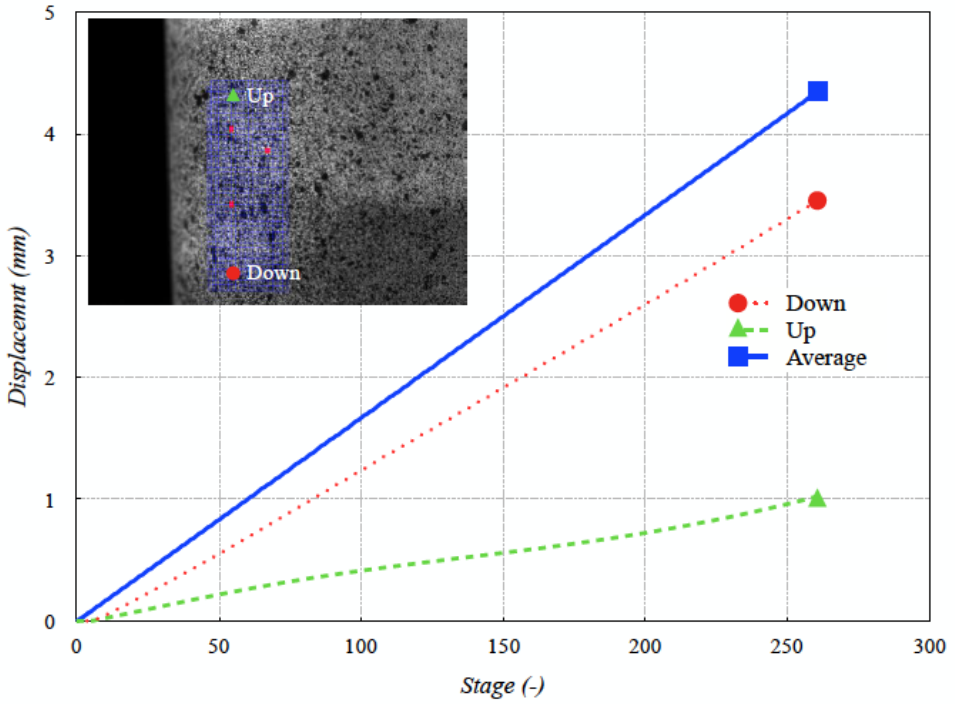
Mechanical tests



Mechanical tests

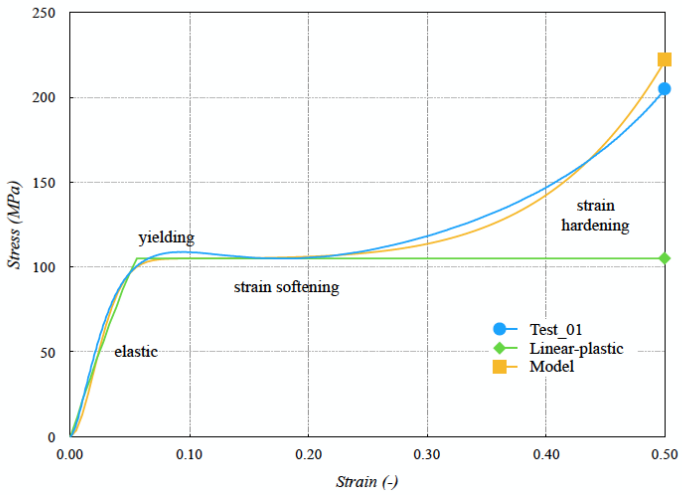
A particular of images of the cameras and sample deformations

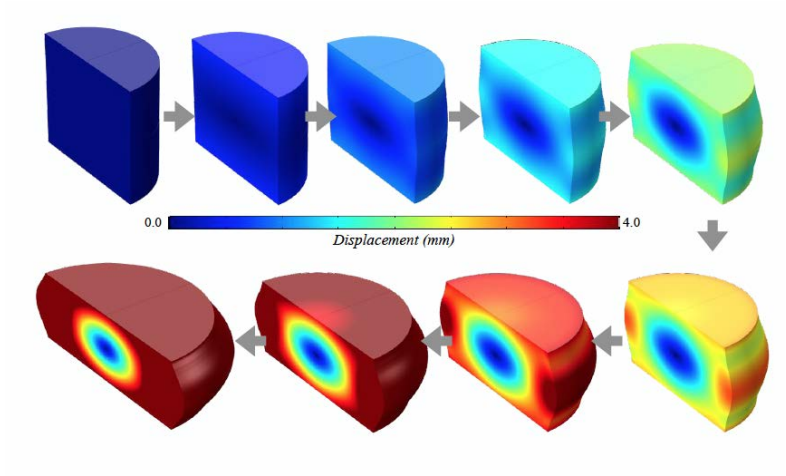


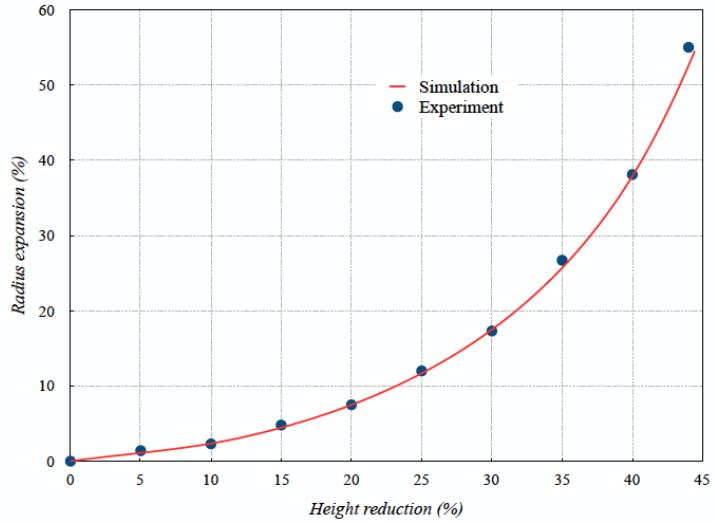


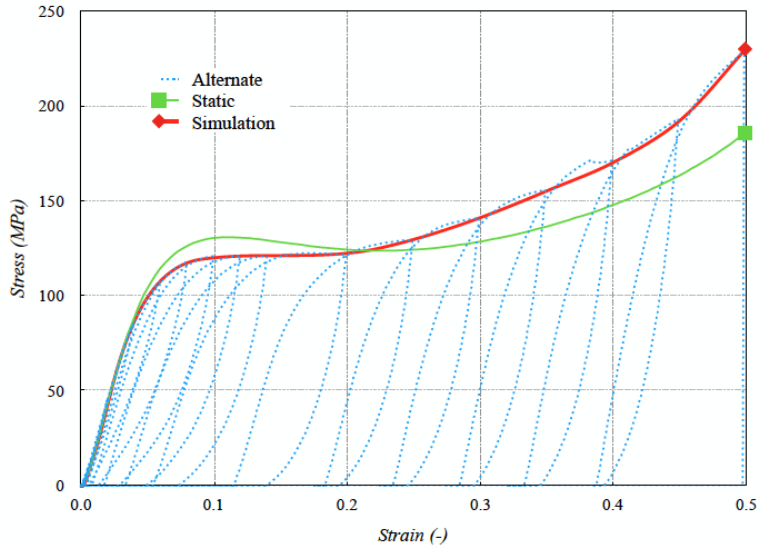
Simulations

Simulations based on the previous mechanical test…



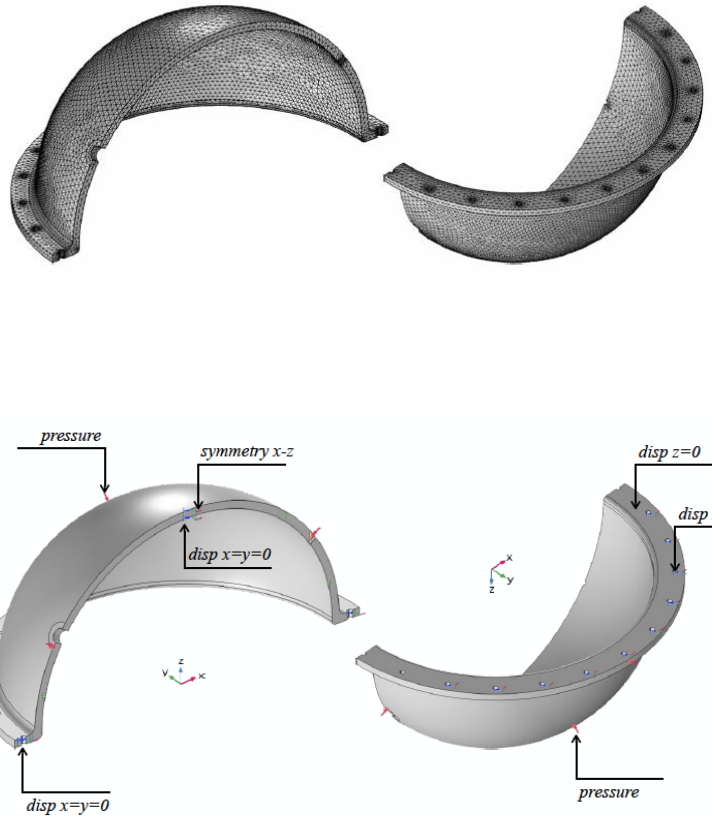


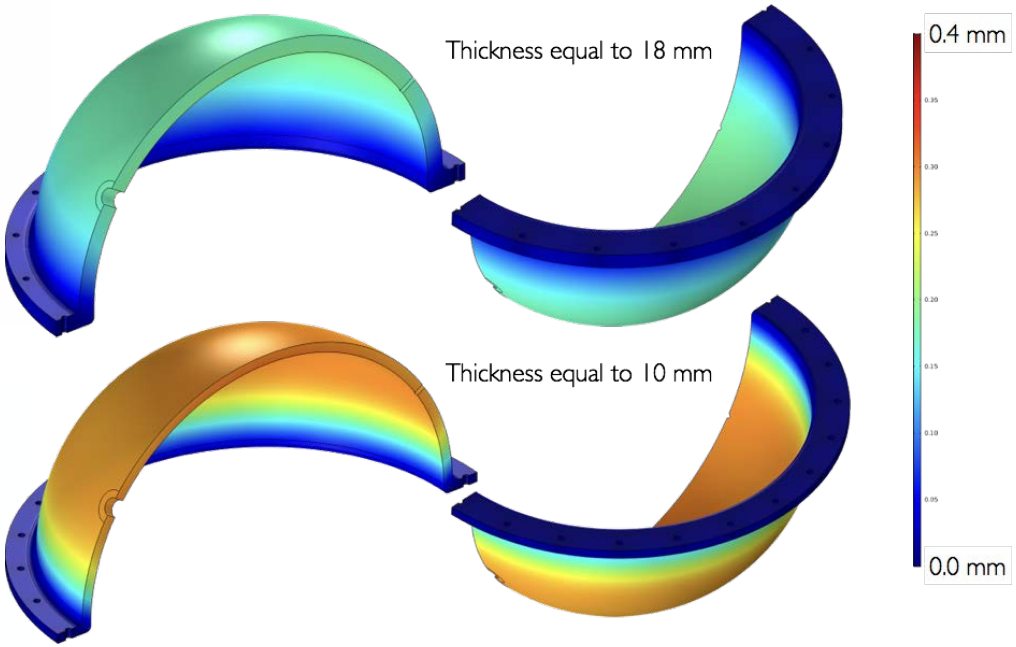




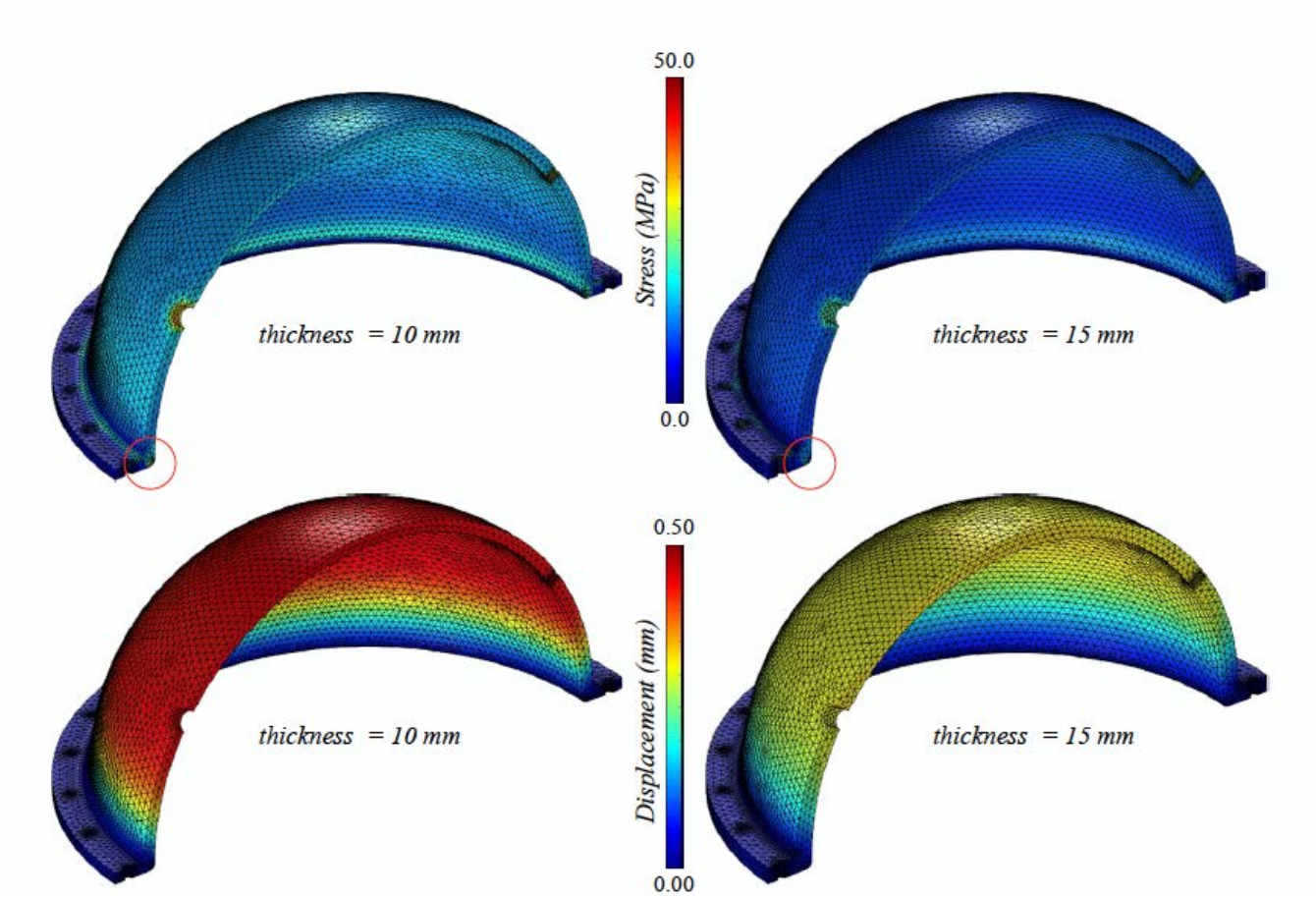
Simulations

FEA simulations and displacements





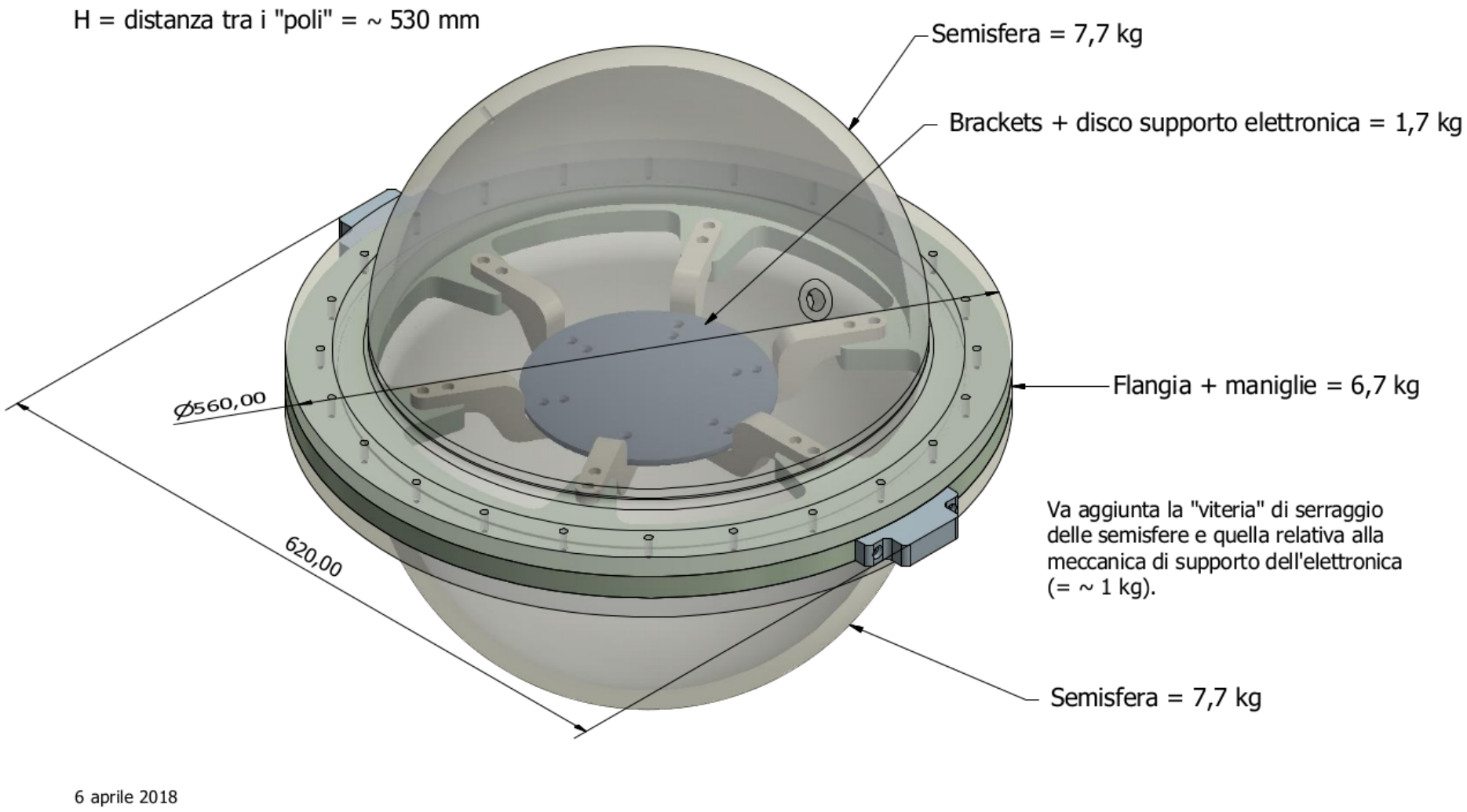
Simulations



FEA simulation done on the 10 mm and 15 mm thick vessels under a pressure of 1.5 MPa gives a maximum displacement of 0.50 mm.

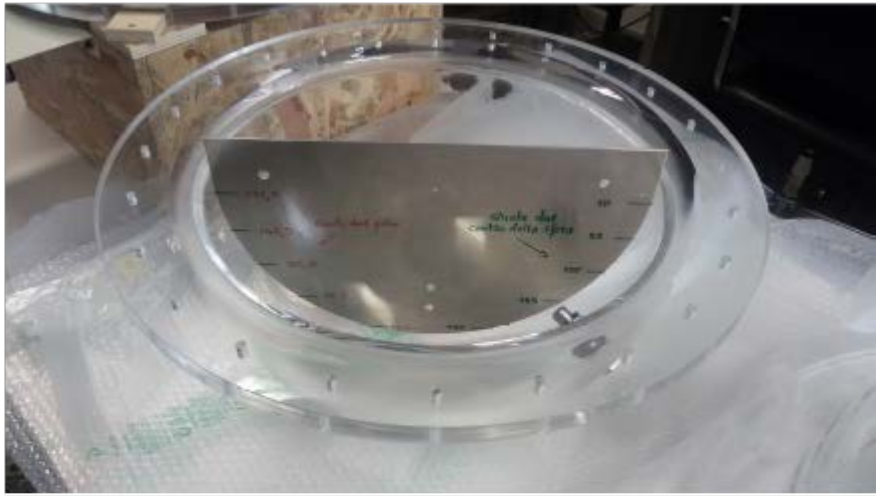
During the pressure test at the Resinex, we reached 1.8 MPa with the 15mm-thick vessel and 86 bar with the 20mm-thick vessel.

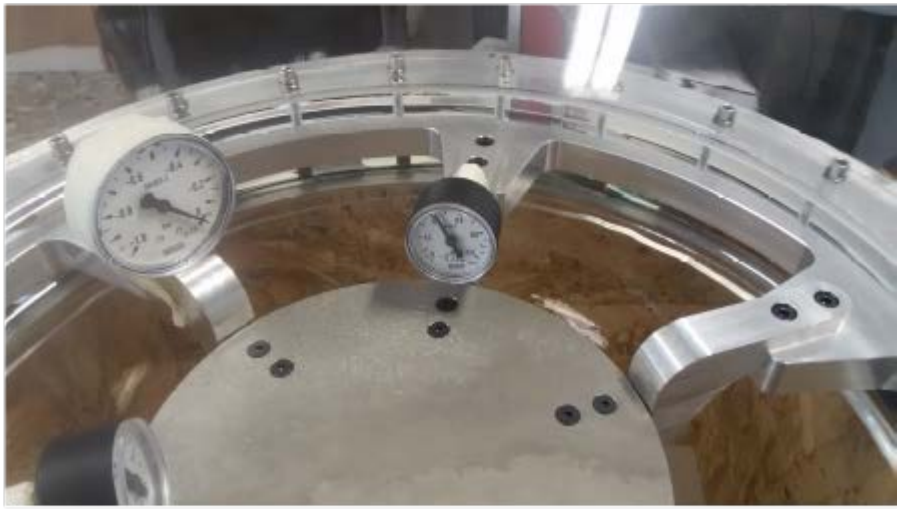
Drawing of the first prototype of the vessel



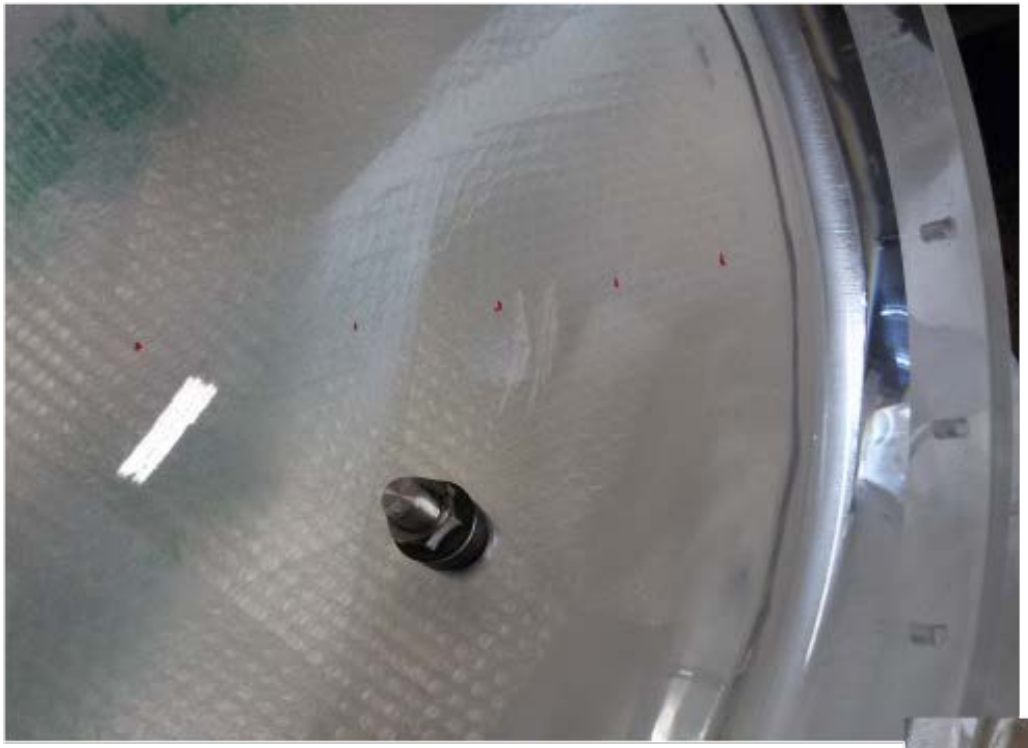
Pressure vessel

From simulations to a vessel made by Liras Company using the Evonik Plexiglas.





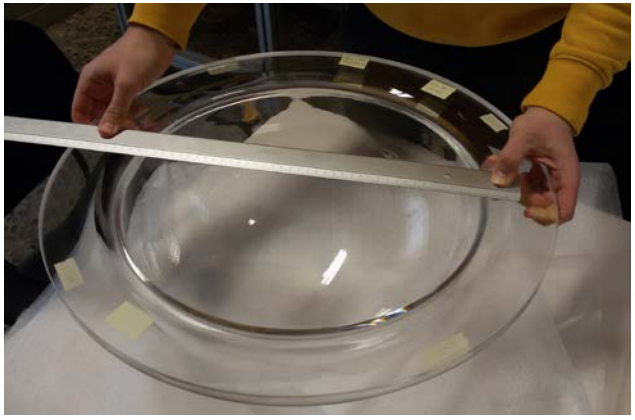
Pressure vessel

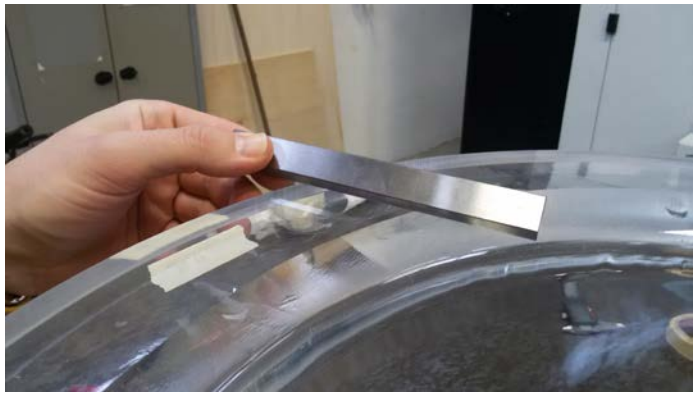


On the left ‘’cork’’ bolt

Pressure valve

Pressure vessel



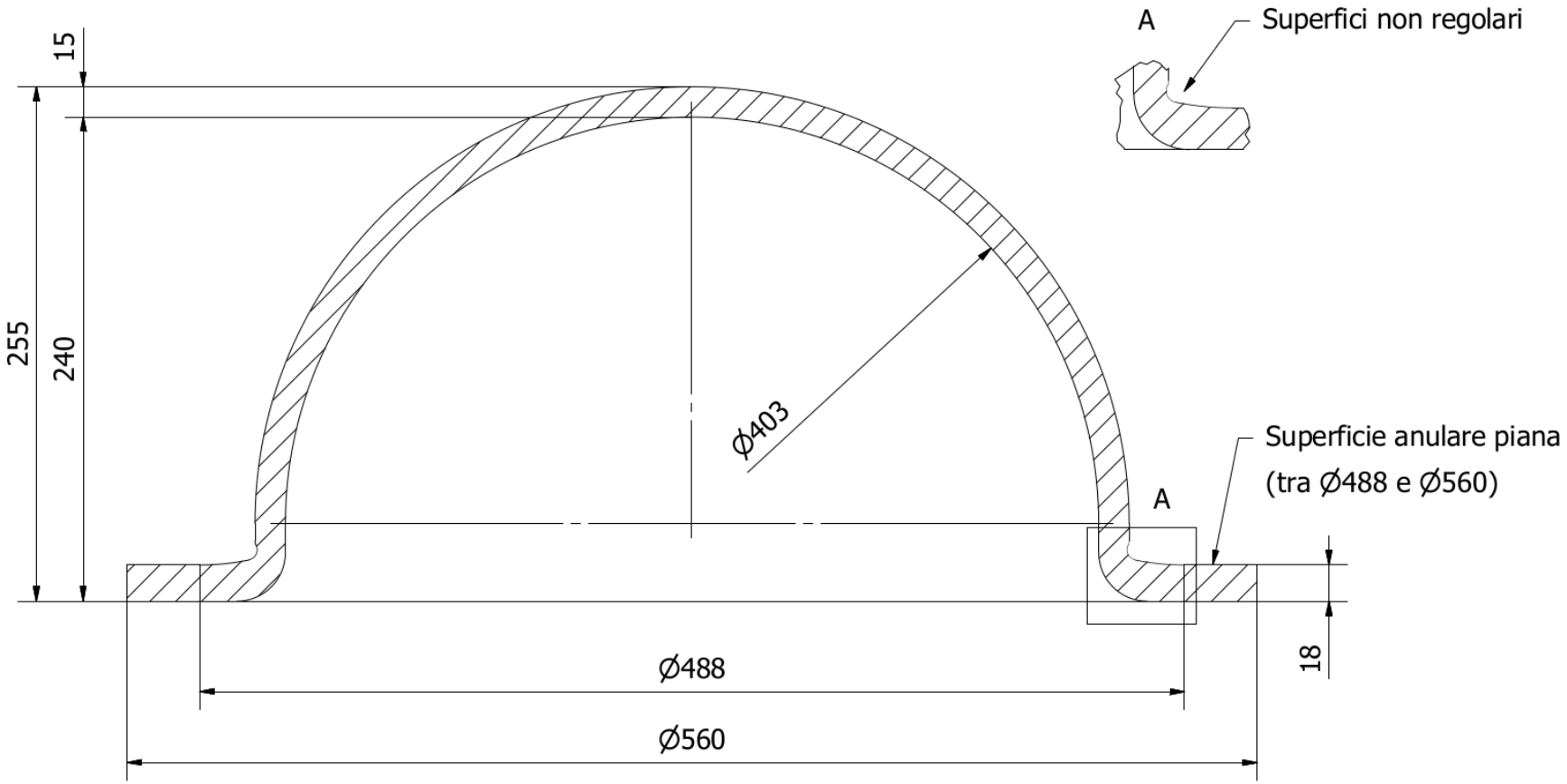


Planarity is OK!

Pressure vessel

Plastic materials are not like metal, hence tolerances should be less "rigid". This because acrylic is very sensitive to heat and also during (our) installations, a plastic component risks to crack if the thermal dilatation is too much bounded.

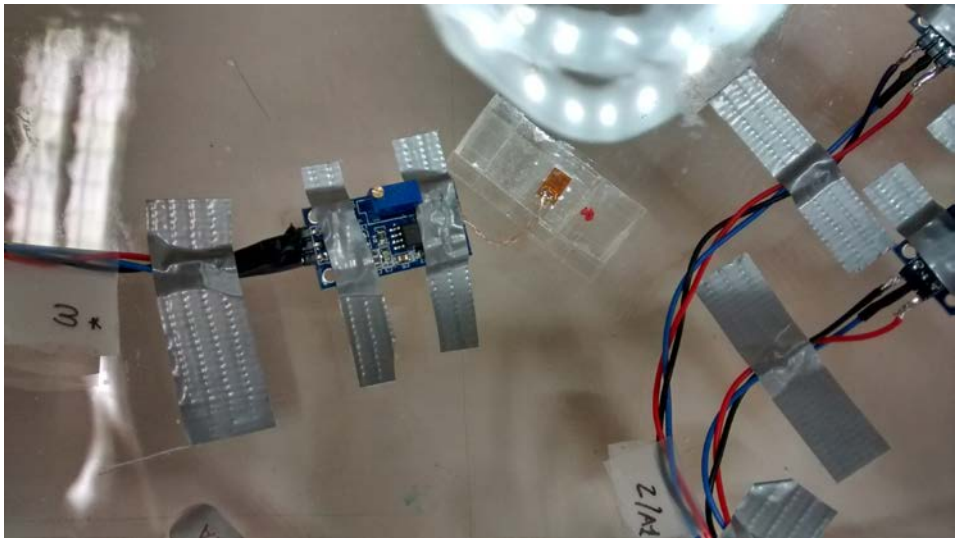
Resulting vessel checked: very good with respect to our requests.
Better results can be obtained!

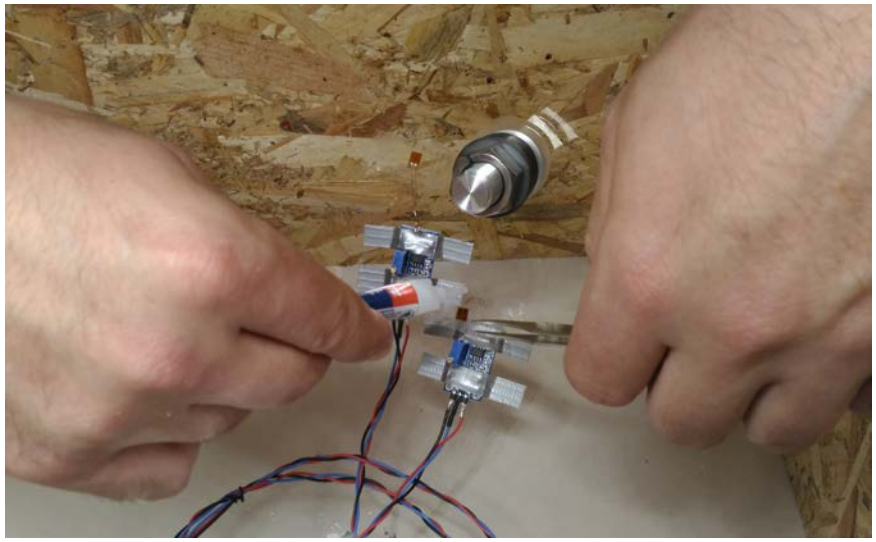


Acrylic vessel - Hydrostatic Pressure test

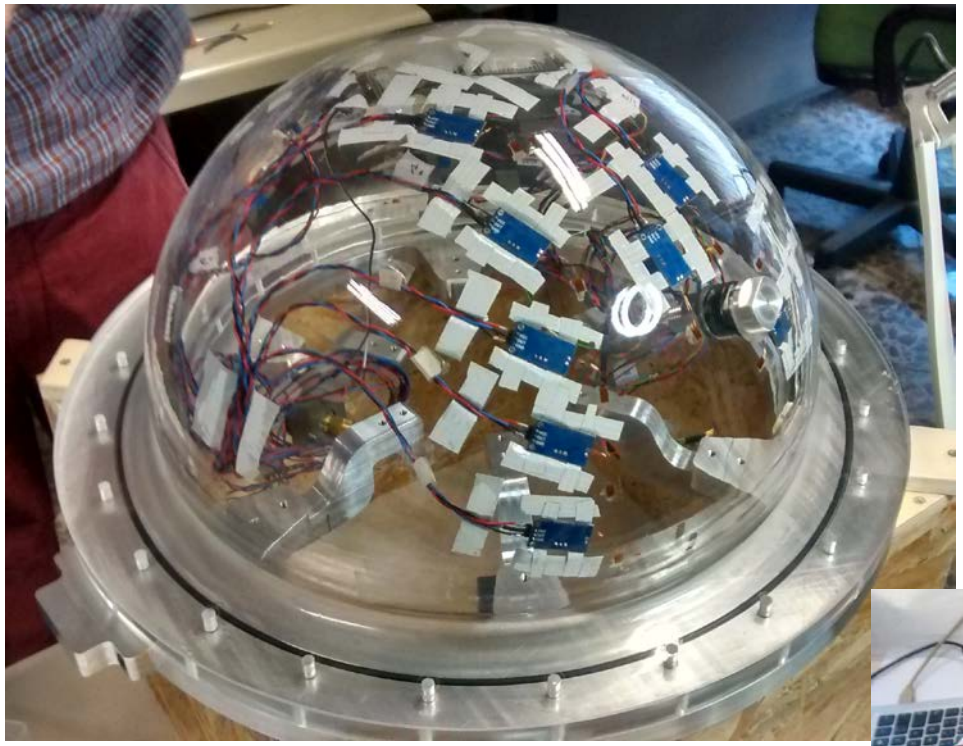
A low cost acquisition system was used for this potential crash test.
It was based on Arduino hardware, with strain gauges, rain sensors, temperature and pressure sensors, remote control

Placement of strain gauges

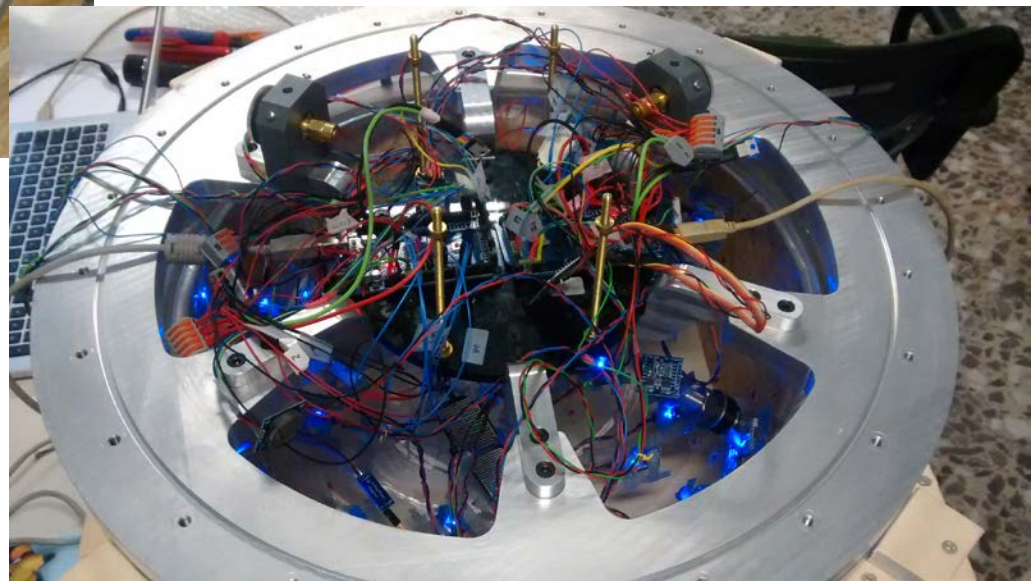




Acrylic vessel - Hydrostatic Pressure test



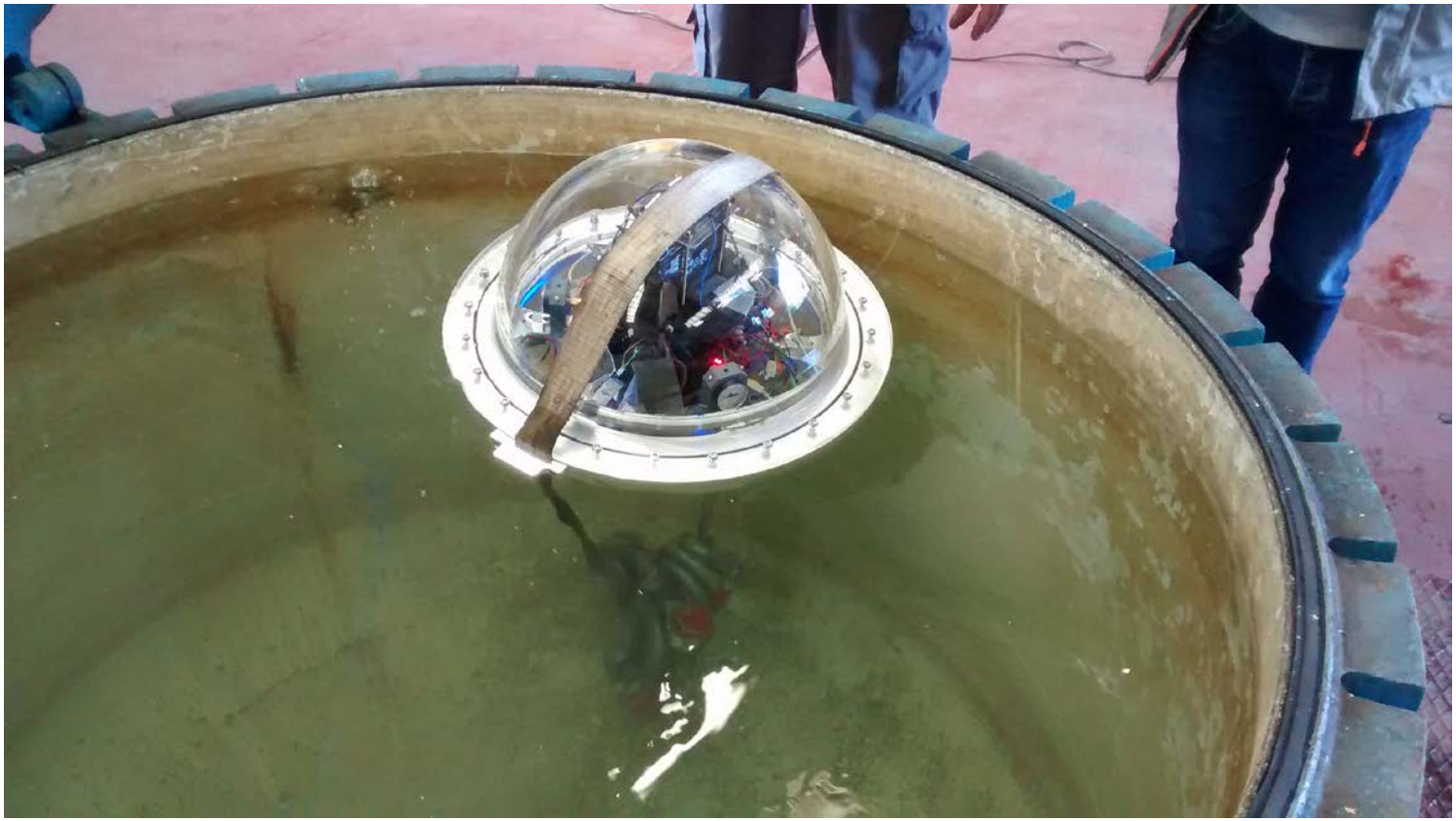
All strain gauges placed and actived for some checks



Acrylic vessel - Hydrostatic Pressure test

Acrylic vessel - Hydrostatic Pressure test

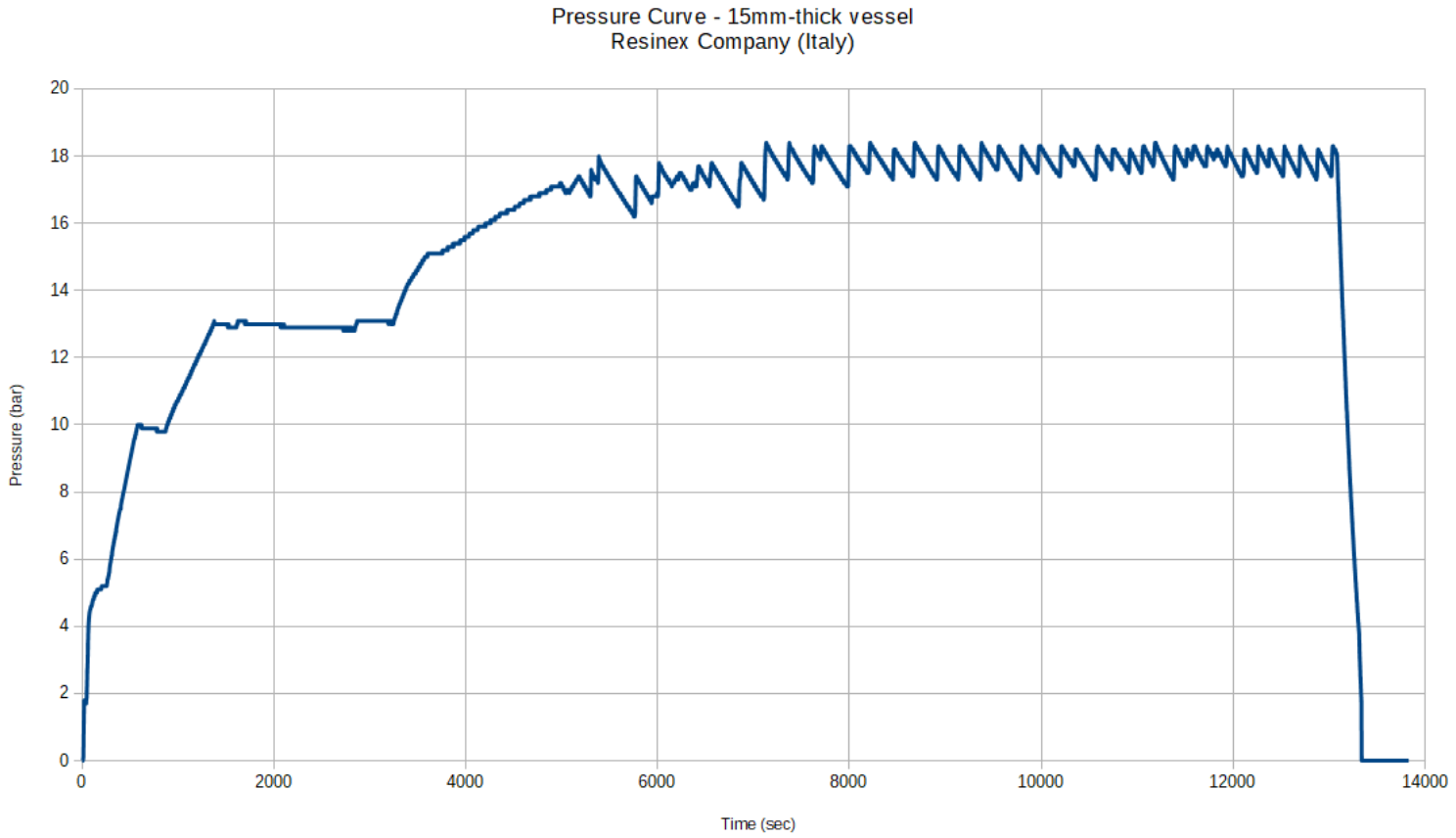
The 15mm-thick vessel before the first test at the Resinex Company, in a 25-bar tank.



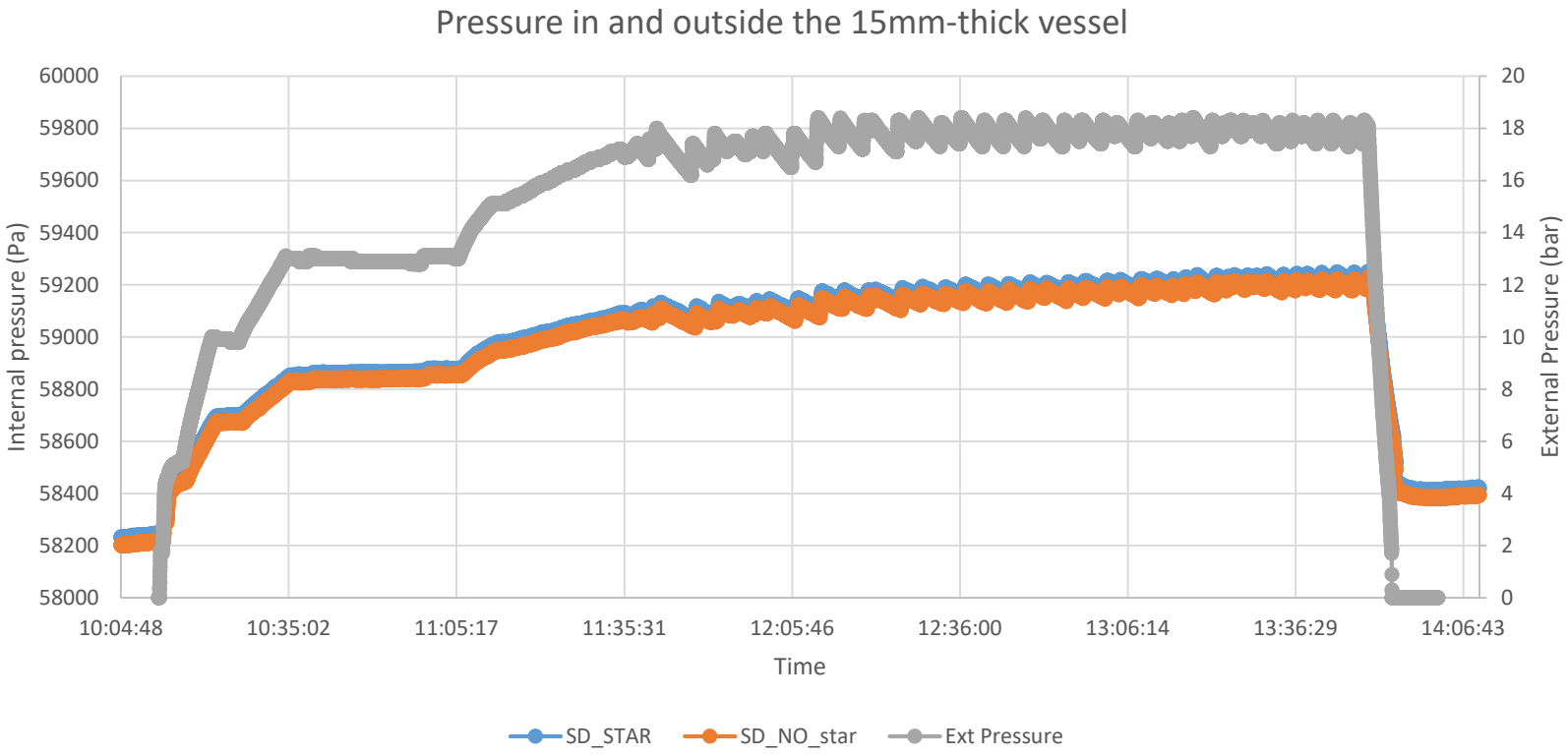
Acrylic vessel - Hydrostatic Pressure test

Our constrain was to resist up to 1.26 MPa and our vessel resisted to 18 bar. Strain gauge analysis will be done as soon as possible.

<u>No damage at the 15mm-thick vessel!</u>



Acrylic vessel - Hydrostatic Pressure test



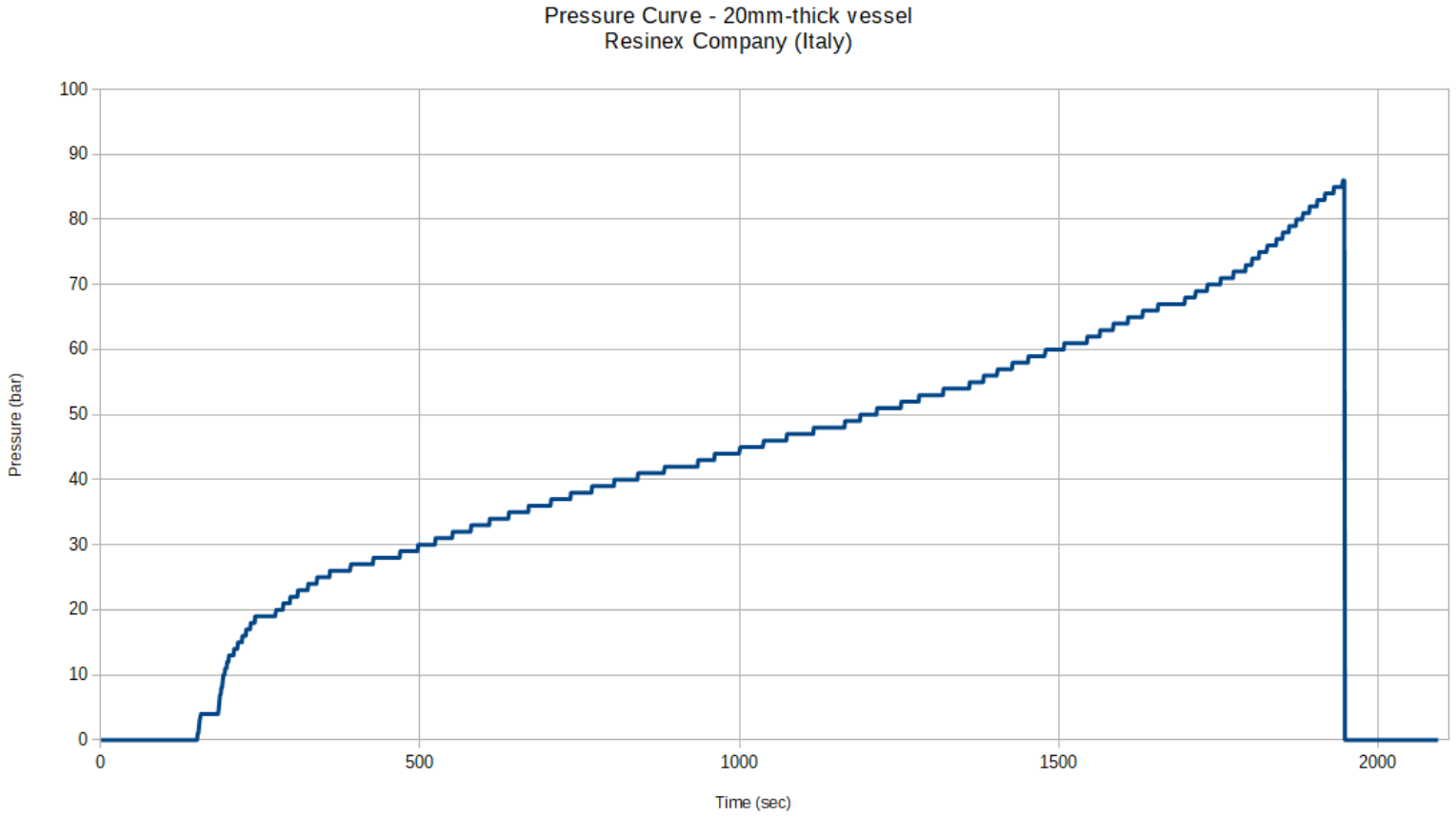
The responses of Arduino pressure sensors (below) which perfectly follow the external pressure (up) inside the tank.

Other data are under study.

Acrylic vessel - Hydrostatic Pressure test

A 20mm-thick vessel was inserted into a 400-bar tank for a crash test

Acrylic vessel - Hydrostatic Pressure test

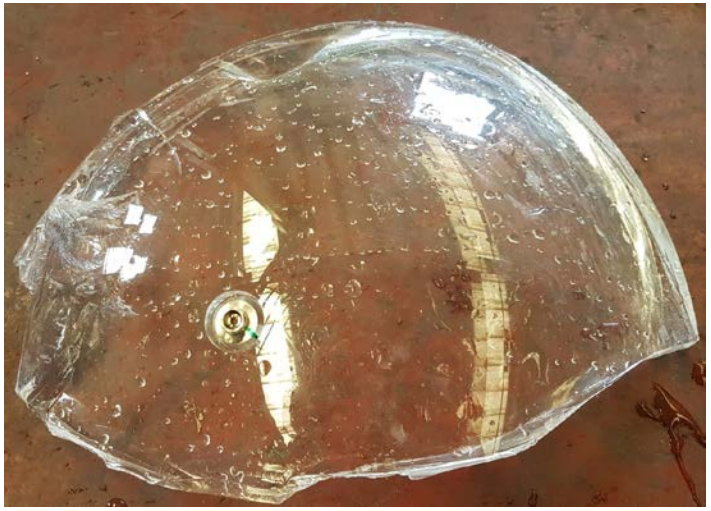


Crash test of the 20mm-thick vessel…
A first thud at 50 bar and a second thud at 53 bar. Apparently no crash until to those moments.

<u>Implosion (with a real bang) at 86 bar.</u>

Much higher than our constrains. Thinner vessels can be used for a pressure of 1.26 MPa.

Acrylic vessel - Hydrostatic Pressure test



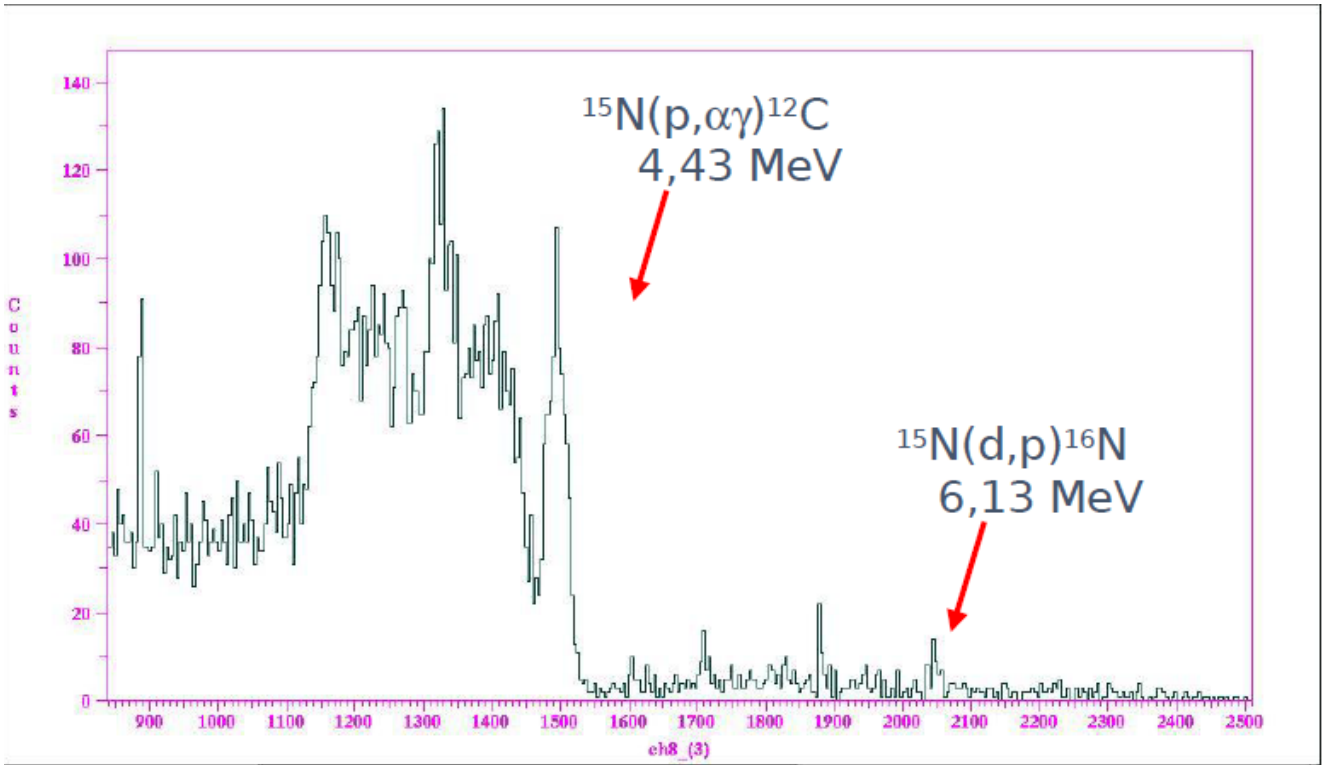
1 out of 2 hemispheres was totally destroyed…
The rests of the second hemisphere were recouped the next day.
The pressure valve and the dummy penetrator don't seem damaged. We are waiting for a shipping of these two pieces.

Water absorption into plastic material

Water absorption tests are ongoing.

At the CIRCE laboratories the best nuclear reaction has been identified (15N(d,p)16N) for analyzing absorbed (heavy) water without burning samples because of the beam.

More details in the Lucio Gialanella's talk



Radioactivity measurements

Nuclear contaminations test are carried out firstly in the INFN-Naples, and secondly at the Laboratori Nazionali del Gran Sasso (LNGS), thanks to Matthias Laubenstein

Contamination results are here reported

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.

Sample: Evonik acrylic.
Weight: 13.4567 kg;
Live time: 22 days

This positive concentration of U-235 has been investigated in detail.

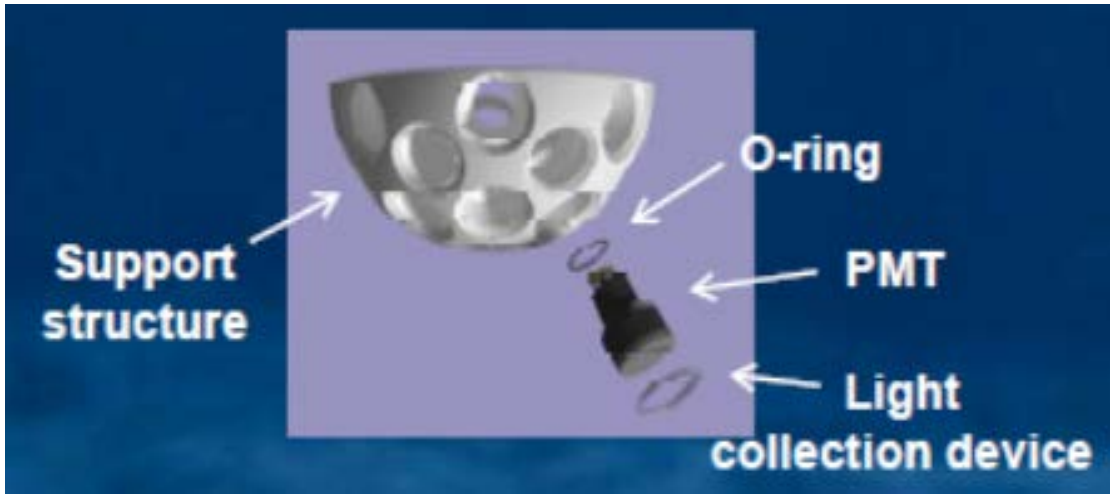
The Evonik acrylic is very clean, no radioactivity contamination

Requirements for HyperK:
U-238 < 0.3 ppb
Th-232 < 1 ppb
K-40 < 0.3 ppm

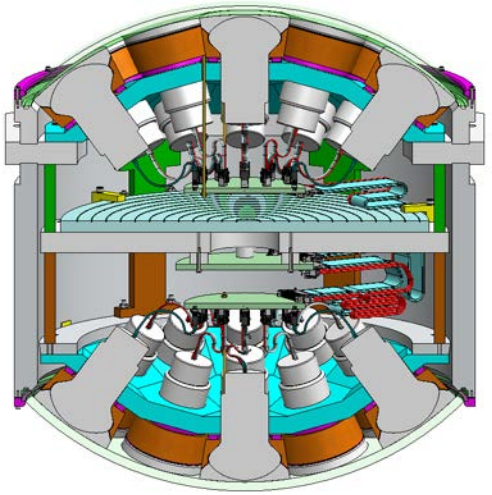
PMT Support - Design

A 3D support was printed at the INFN, thanks to Edward Berbee (KM3NeT Collaboration), on the basis of the KM3NeT drawings

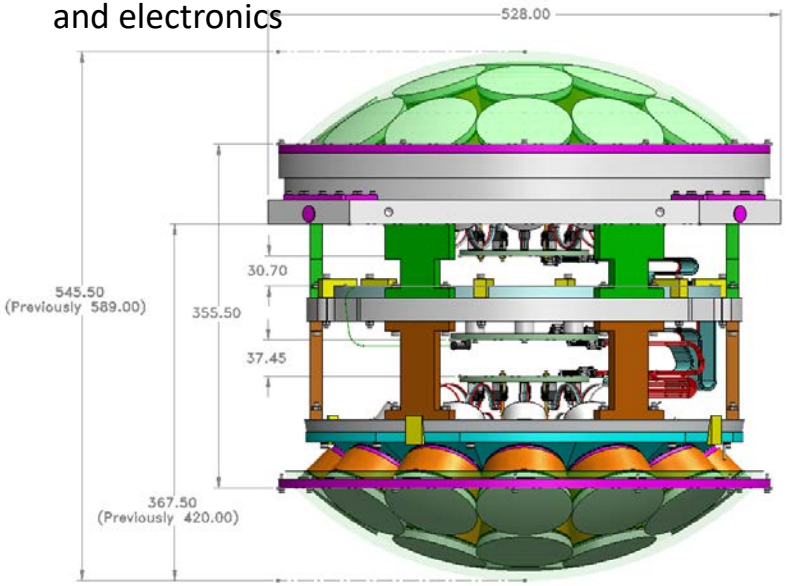
Some considerations:
ABS material is cheap enough, but 3D printing is expensive for machine time because the support is very complex



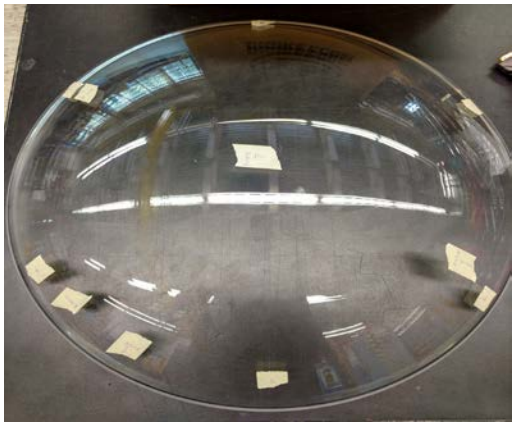
mPMT – Alternative Design



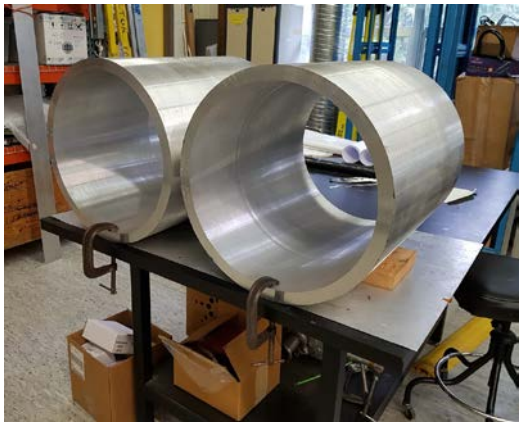
INFN purposes: test acrylic and electronics



Designed by TRIUMF

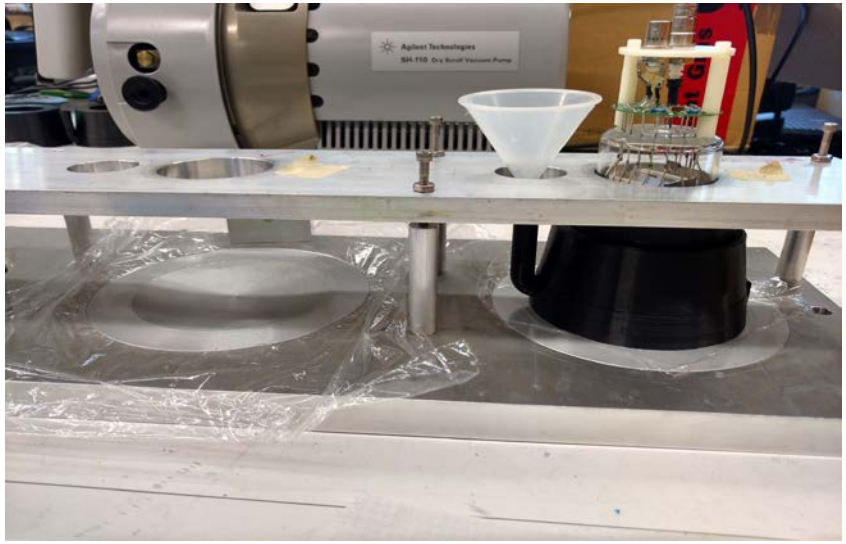


Acrylic Evonik cover molded by Liras



Aluminium cylinders for mPMT body

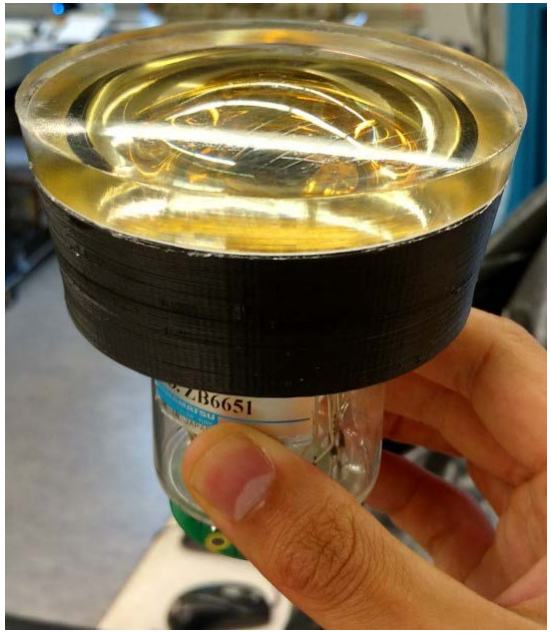
mPMT – Alternative Design



As an upgrade, a nice option has been developed by **TRIUMF** for support:

- Simplier shape for the support
- Gel deposited only on PMTs

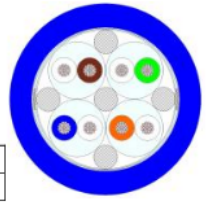
More details in the Mark Scott's talk.



mPMT connections

CRE

CRE14211



Issue	Date	Approved	Note
1	18/09/13	PM	Initial release

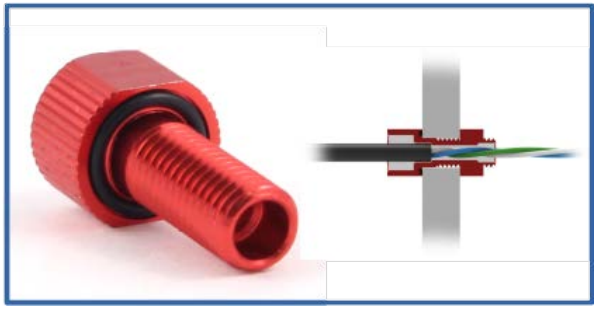
DESCRIPTION
Reinforced Data Cable for use in Subsea applications.

Product Details (Insulated Cores)

Component Description	Qty	Conductor Stranding	Max DCR @ 20oC [Ω/Km]	Weight [Kgs/Km]	Nominal Diameter [mm]
0.22 mm^2 Data Pairs	8	19/0.127mm TC	81.7	2.8	1.20mm

CONSTRUCTION
0.22mm² Ethernet / Cat 5

Colours	White/Green, White/Orange, White/Blue, White/Brown
Insulation	Cellular polyolefin
Insulation Diameter	1.20mm Nominal
Component Bedding	Olefinic based elastomer
Component Diameter	2.70mm Nominal



Example of vessel penetrator

Ethernet cable by CRE. Option for the prototype.

It works at 6000 m depth
7-9 £/m (depending on quantity)

A probable solution for the prototype: short seal ethernet cable through a penetrator; inside RJ-45 connection for the motherboard; external RJ-45 for our tests.

Needed more studies for the final mPMT design and measures will be done on cables and other components.

Conclusions

- Tests show that a mPMT detector with acrylic pressure vessel can be realized, but further analyses are ongoing.
- UV transmittance is ~ 75% at 280 nm
- Machanical tests show that acrylic is a good material for our aims
- Acrylic satisfies requiriments for low-energy threshold measurements for its low nuclear contamination
- In short time we will complete an operative prototype for first detection tests