

Sapphire-Based Suspension at ARC-ETCRYO Laboratory

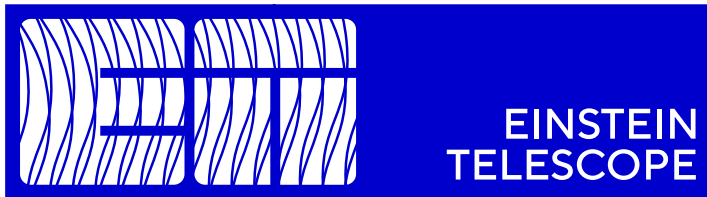
Ongoing Test Campaigns

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Berlin



SAPIENZA
UNIVERSITÀ DI ROMA



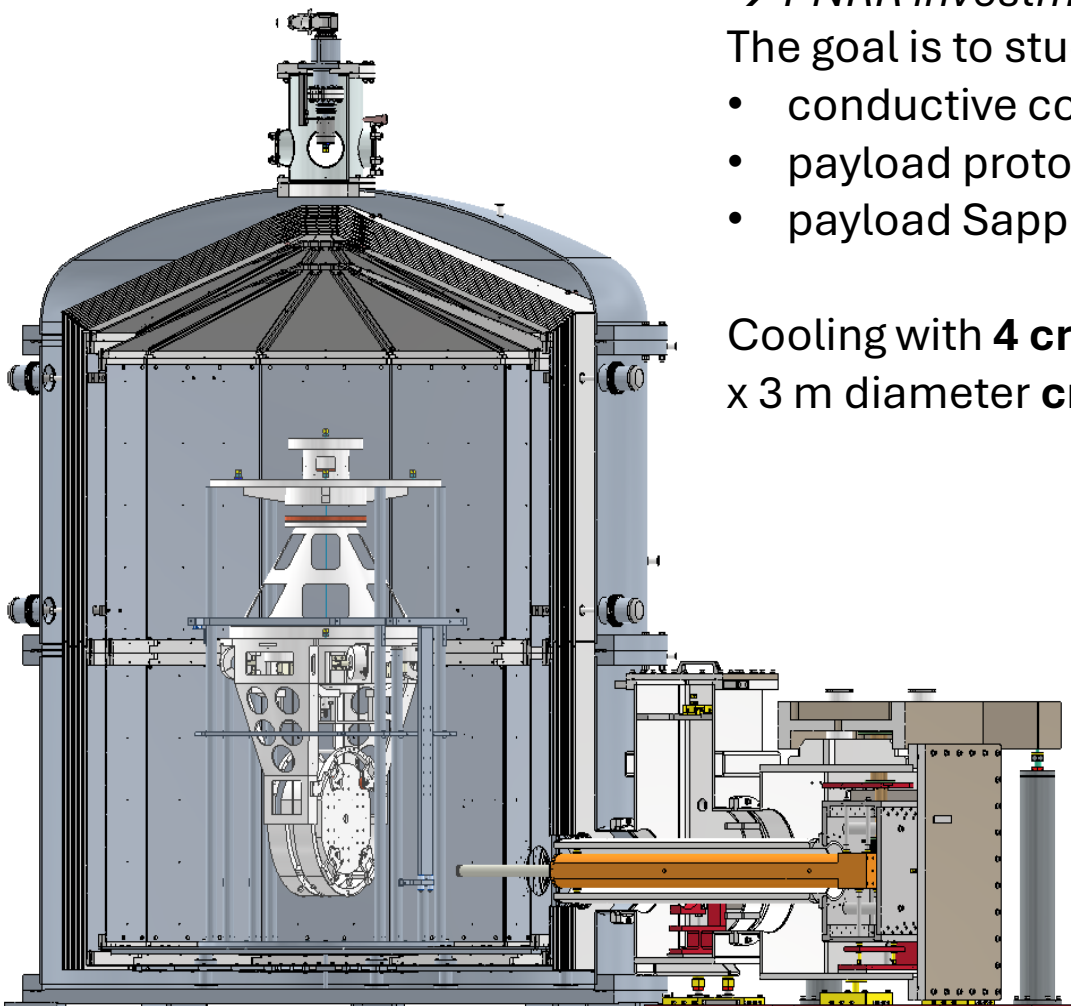
ARC-ETCRYO Laboratory in Rome is a test bed for ET LF payload and technologies

→ *PNRR investments, Sapienza and INFN project*

The goal is to study:

- conductive cooling technology
- payload prototyping
- payload Sapphire suspension

Cooling with **4 cryocoolers** on two refrigeration lines and payload hosted in a 3m tall x 3 m diameter **cryostat** (cryostat will be delivered in Dec 2025).

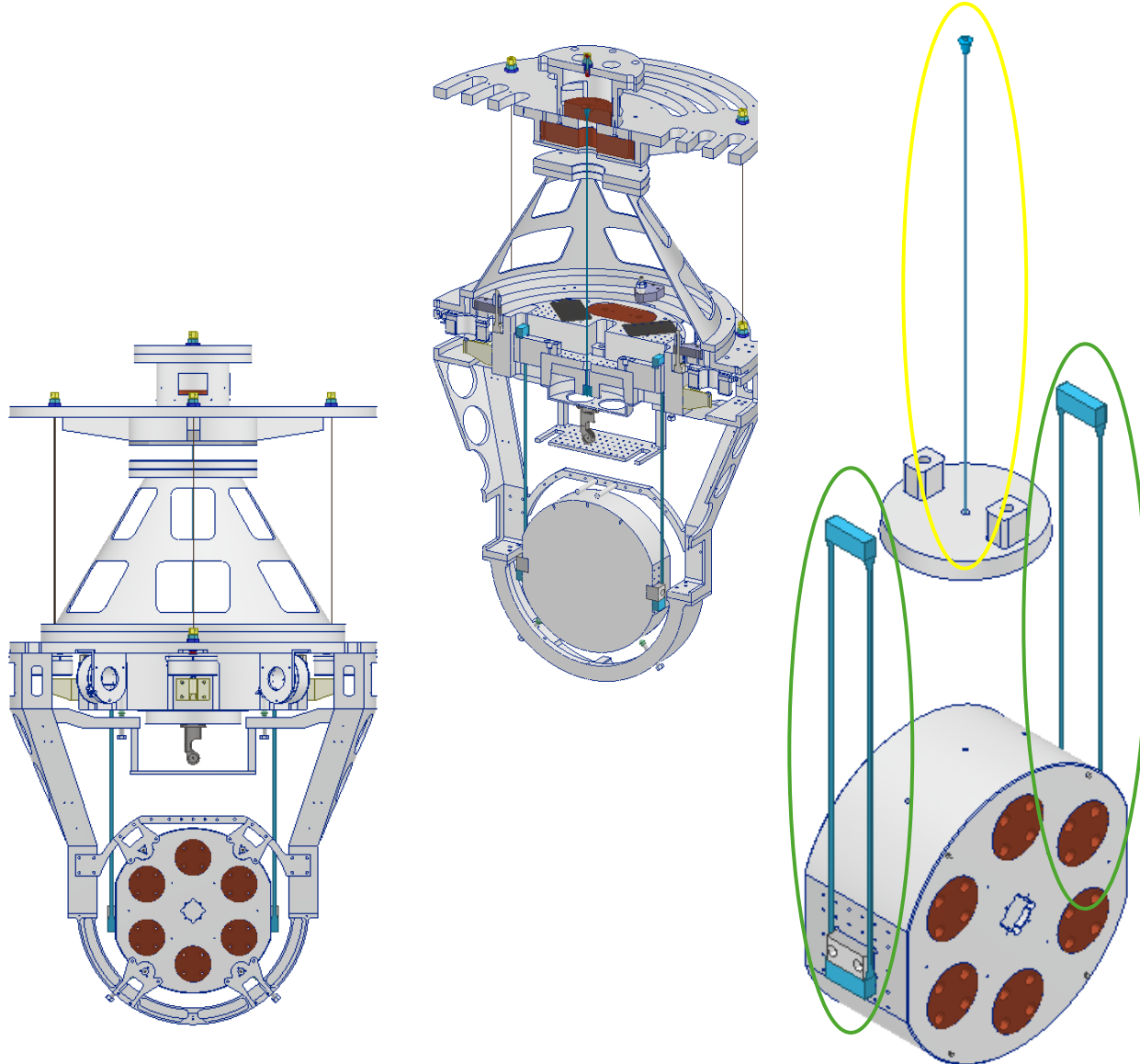


Clean Room for HCB
ISO 5 (ISO 3 under hood)



Clean Booth for Payload ops.
ISO 6 at rest (ISO 7 under operations)

Payload in ARC



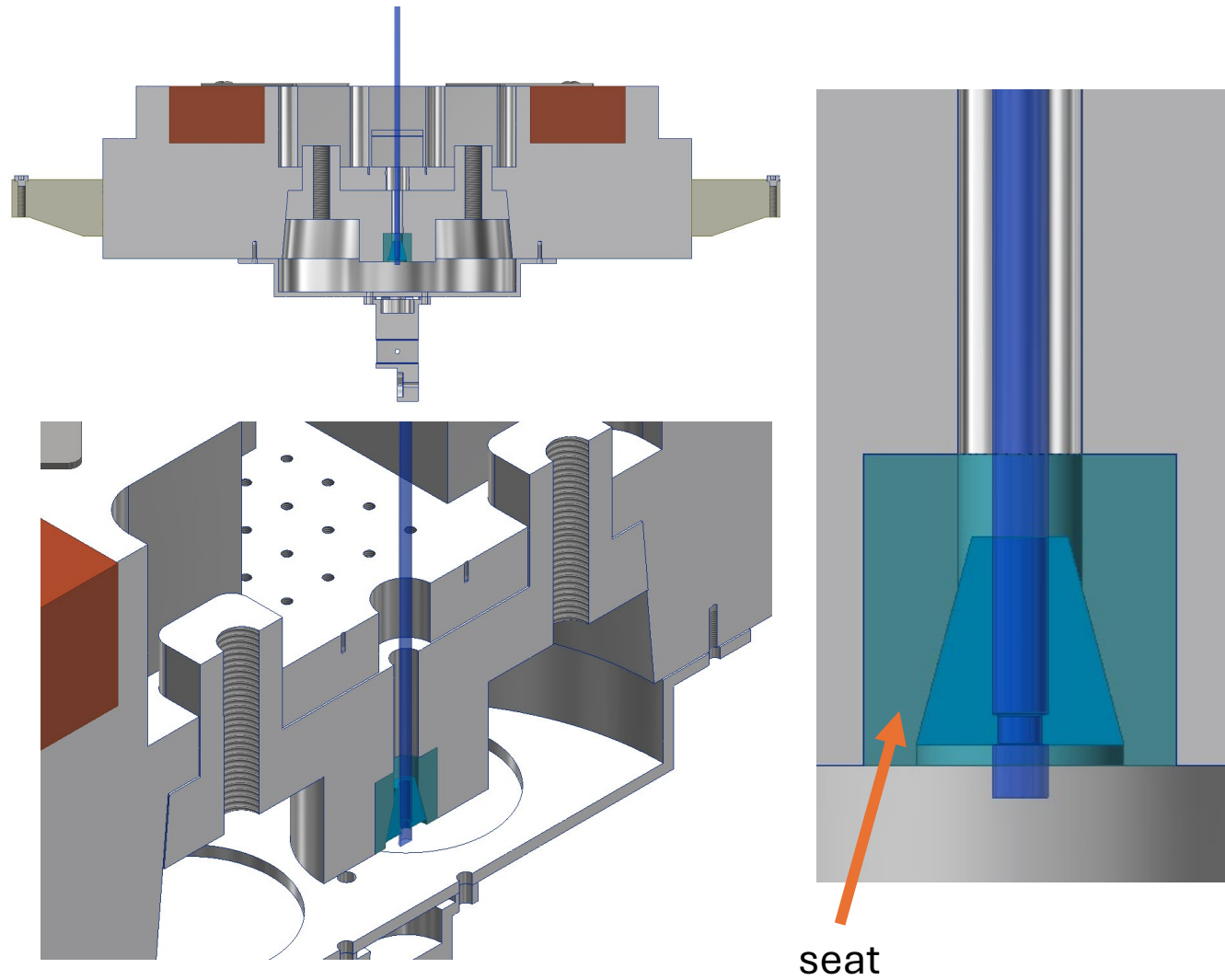
Payload total weight ~ **500 kg**
Marionette weight ~ **125 kg**
Mirror weight ~ **125 kg**

Two main sapphire suspensions:

- Marionette suspension
- Mirror Suspension

First dummy test mass in ARC-ETCRYO is made in **aluminum (and copper weights)**
In the future we hope to envisage a sapphire mirror (when technological readiness level is high)

Marionette Suspension



Two sets of **half sapphire cones** *interlock* a single **sapphire rod**.

This system *locks* in place the marionette with respect to the platform, **supporting 250 kg** (marionette + mirror)

At the marionette level, the lateral surfaces of the cones impinge on a sapphire «seat», so that heat exchange is maximized

Length: 870mm
Outer diameter: 5.4 mm

Pull test

A **Shimadzu Universal mechanical test machine** (AGS-X, max 10kN) is used to perform the tests.

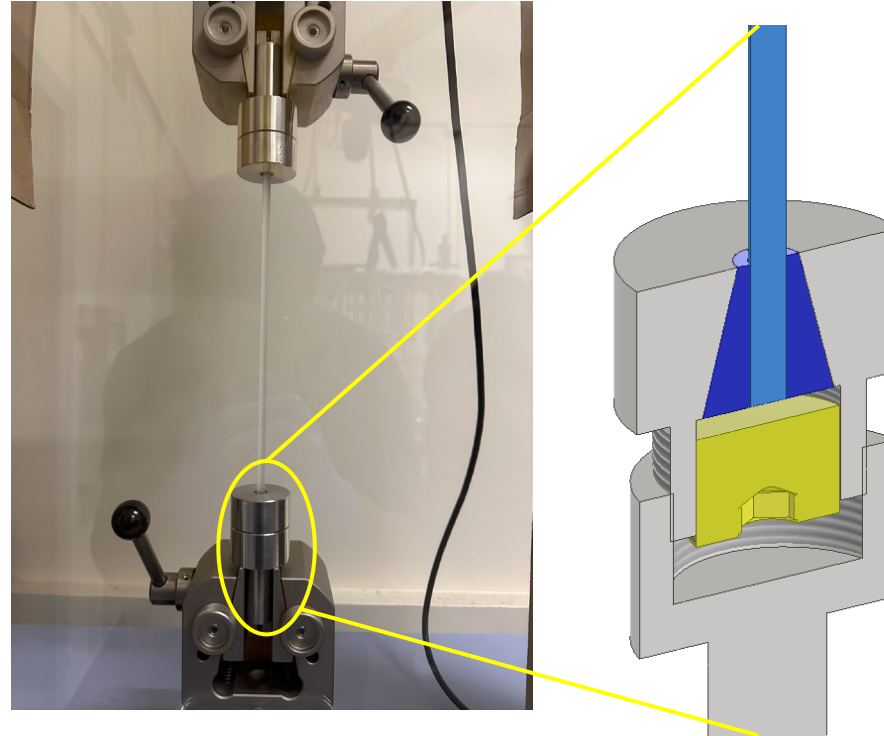
We designed and built a steel jig that could accommodate conical shapes.

First, we used standard jigs for cylindrical samples to pull the system, but then switched to a more flexible one, using a series of eyebolts

Preliminary tests were done with steel cones and steel rods.

Sapphire samples from different suppliers were tested (*Impex and Kyocera*)

First setup

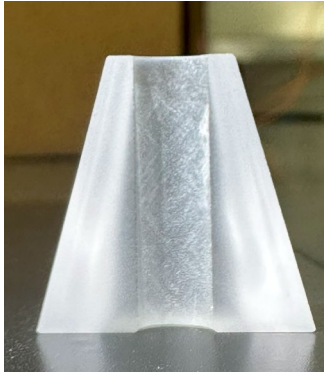


Second setup



Second setup accounts for misalignments both in the system and the test machine

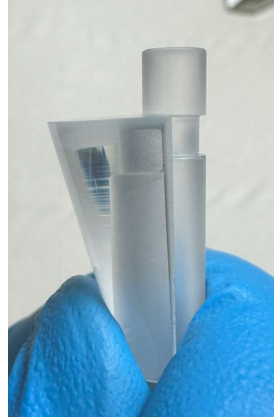
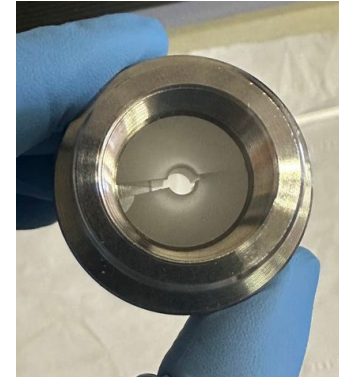
Pull test results



First generation cones/rods: only friction between inner surface of cone and outer surface of the rod

Pull tests results from first generation cones/rods were not good:

- No sufficient friction
- Too rigid setup



Second generation cones/rods: added a «tooth» to ensure mechanical interlocking.

First generation tests showed:

- Only friction is not sufficient
 - Need of a new setup

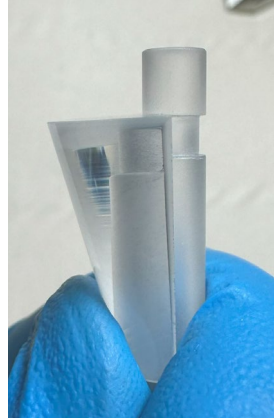
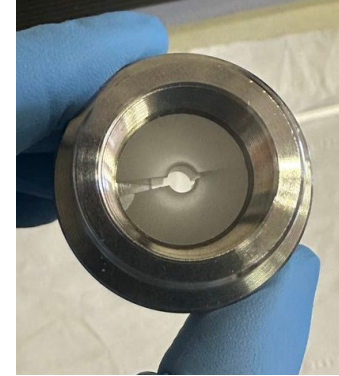
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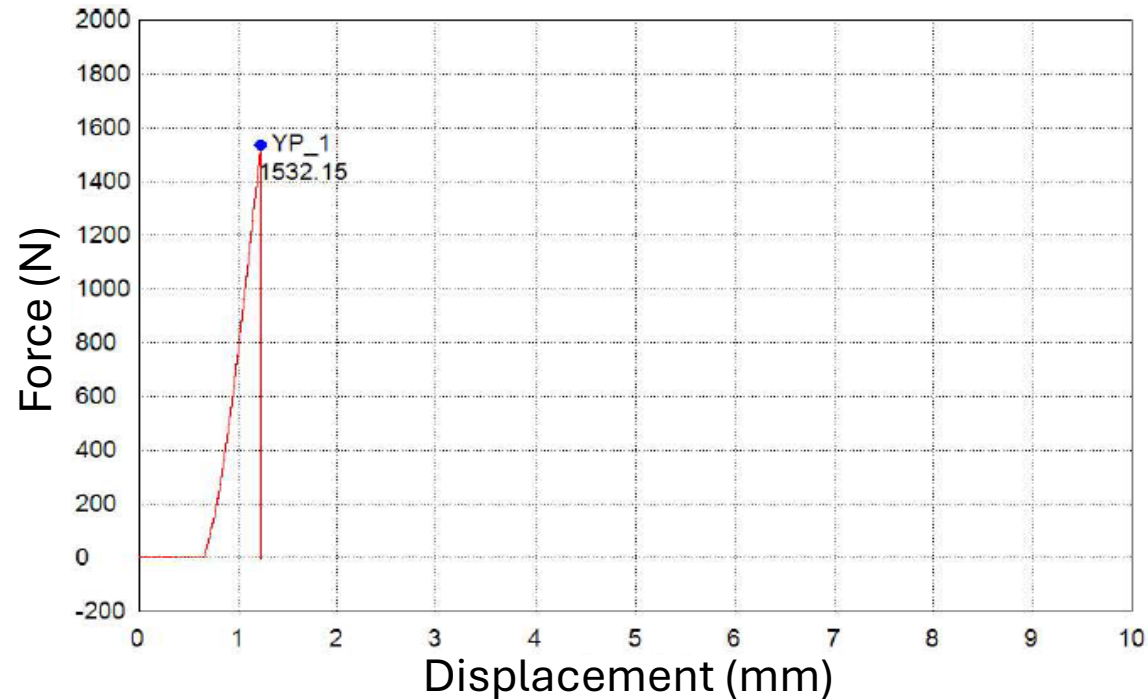


Second generation cones/rods: added a «tooth» to ensure mechanical interlocking.

First generation tests showed:

- Only friction is not sufficient
 - Need of a new setup

Kyocera Sample result



Failure surfaces of the sapphire sample by kyocera

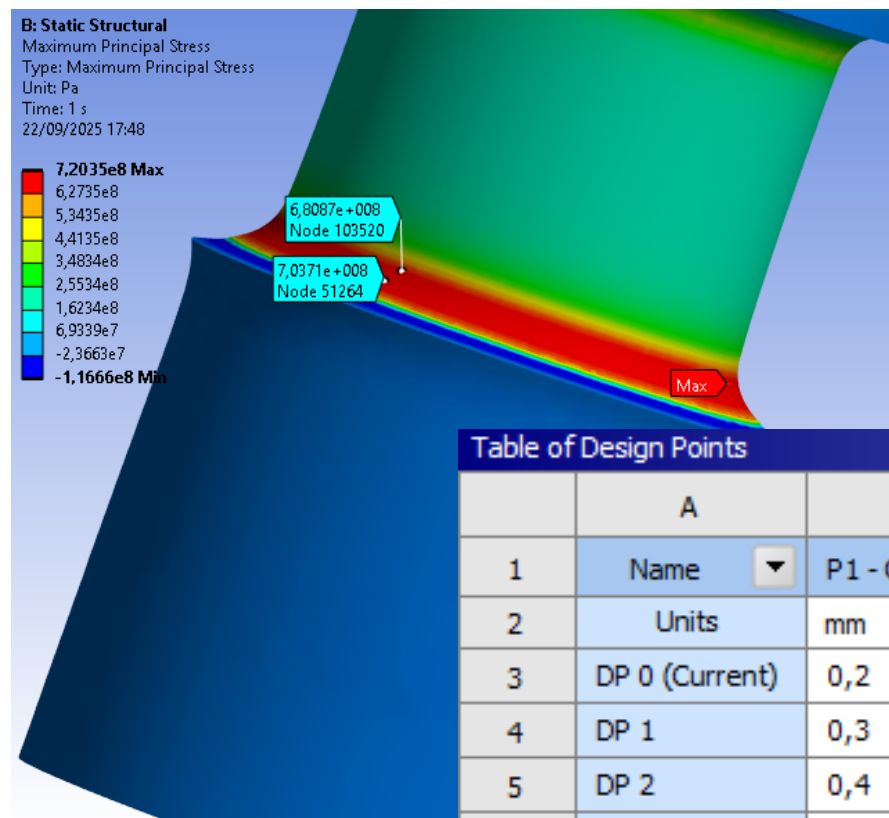
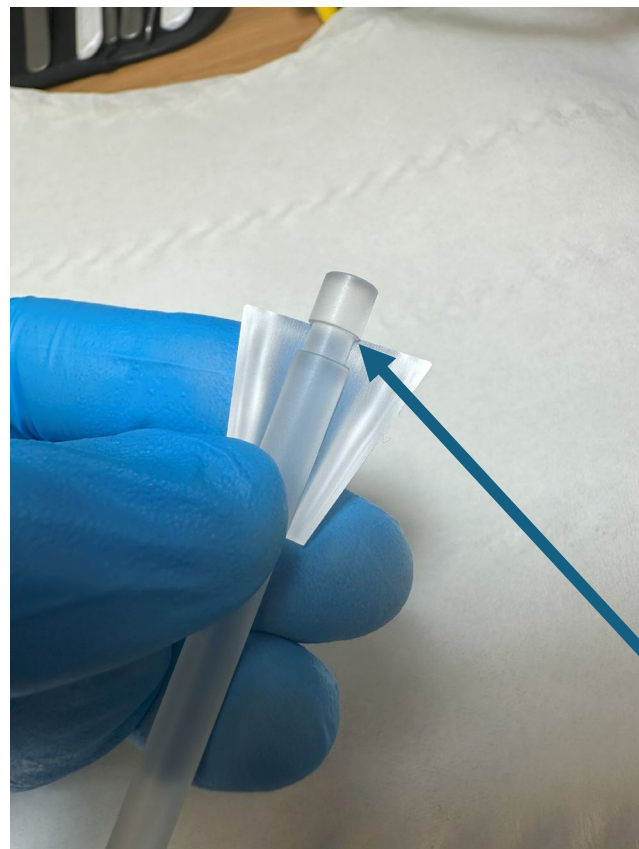


This particular fracture geometry inspired us for further crystal analysis

Second generation cone/rod system (toothed) gave better results, but not good yet.

- **Higher number of samples are needed** → statistical distribution of the results
- **Need to improve design of the system** with production engineers to decrease stress intensification

Design analysis



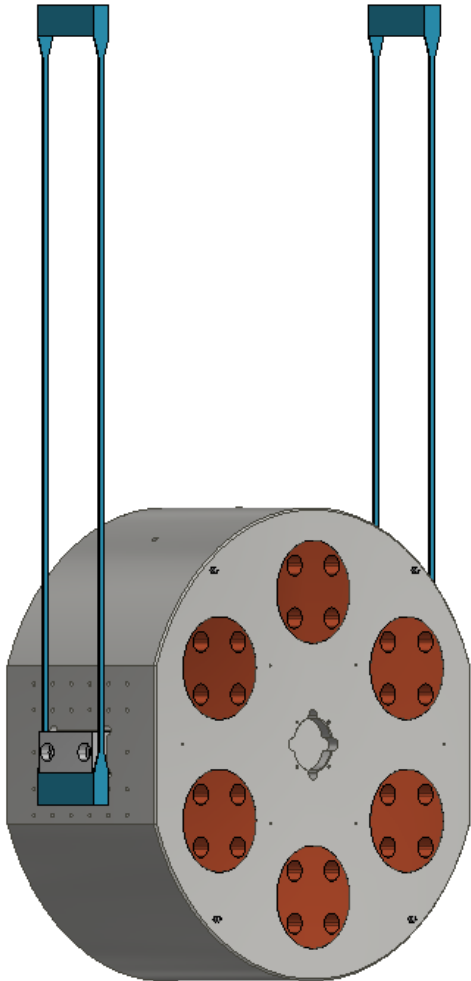
Max principal stress changing the radius

Table of Design Points				
	A	B	C	D
1	Name ▼	P1 - Group1 ▼	P2 - Maximum Principal Stress Maximum ▼	☐ Retain
2	Units	mm ▼	Pa	
3	DP 0 (Current)	0,2	8,6207E+08	☒
4	DP 1	0,3	7,2035E+08	☒
5	DP 2	0,4	7,3203E+08	☒
6	DP 3	0,5	1,245E+09	☒

Here there's a R0,2

The radius cannot be increased too much, because **contact surface** between rod and cones becomes **too little**

Mirror Suspension



Two **ribbon-like suspensions**

Length: 760 mm

Thickness: 1 mm

Manufacturing limit for this shape and length

We are studying two different approaches:

- **HCB bonding** (sodium silicate)
- **Monolithic**

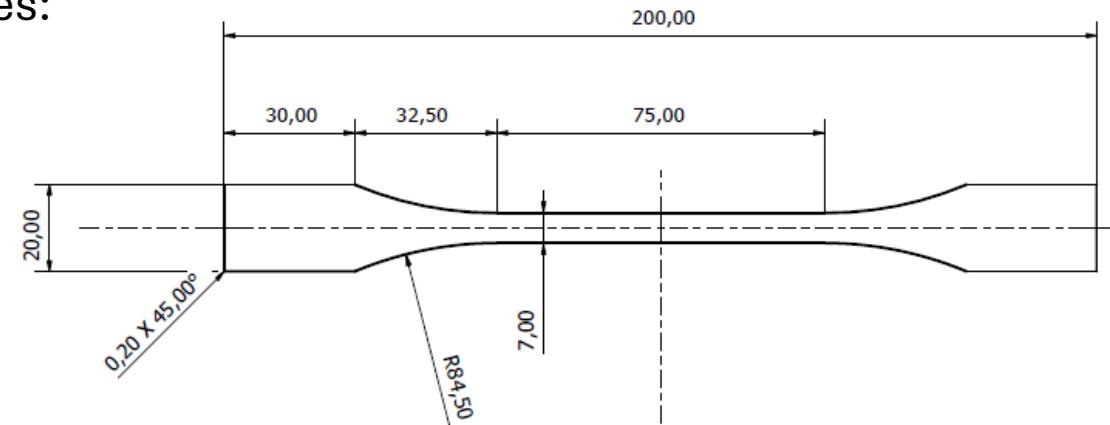
Test to be performed:

- Q test → **Mechanical quality factor**
- Pull test → **Strength**

Why Ribbon shaped?

Low thermal noise purposes

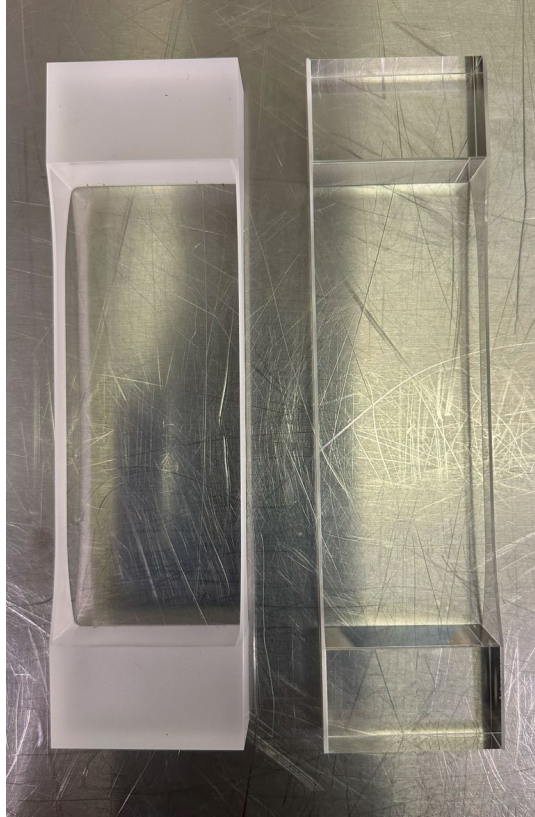
Cumming et al. Silicon mirror suspensions for gravitational wave detectors. Classical and Quantum Gravity. 31. 5017-. 10.1088/0264-9381/31/2/025017.



Mirror Suspension Tests

Downscaled 200 mm length ribbon-shaped suspension for testing purposes.

1. **Monolithic** suspension: carving sapphire block .
2. **Bonded** suspension: applying Hydroxide Catalysis Bonding (HCB) between 2 blocks and 2 ribbons

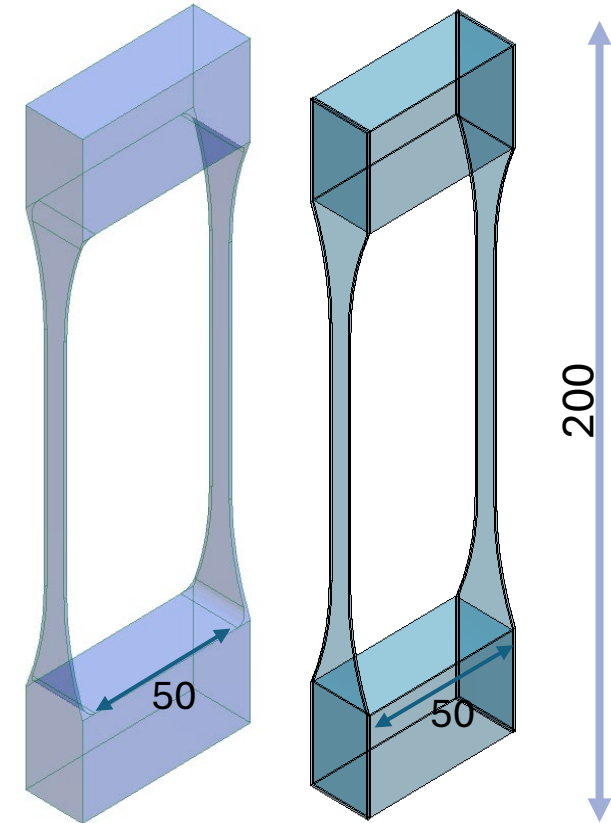


Mono

HCB

Differences

- **Surface quality.** Grinding gives worse surface quality
- **Geometric:** to ensure 50 mm flat area on the block (IF to the mirror), you will have a larger monolithic suspension, since the safest manufacturing implies presence of radius
- **Manufacturing:** in the bonded suspension, you have *operator mistakes* during HCB bonding

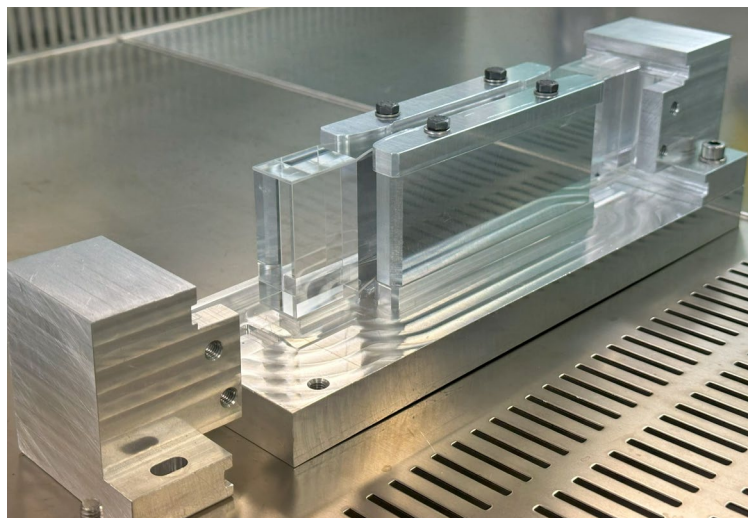
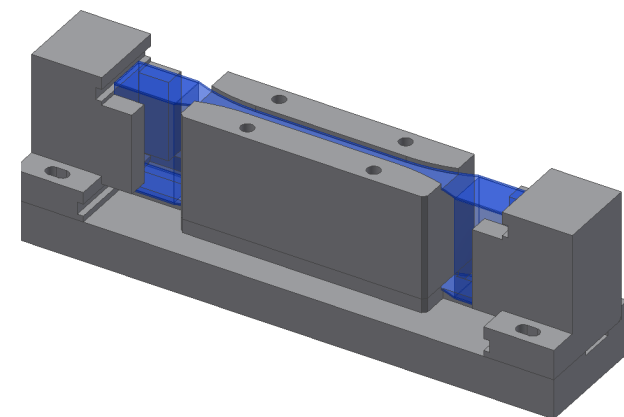


About the Monolithic suspension

- Monolithic mirror suspension obtained by milling of single monolithic sapphire block by Kyocera
- After milling, annealing was performed @Temperature close to recrystallization of Sapphire

HCB for ribbon sample

First Generation Jig for Ribbon Bonding

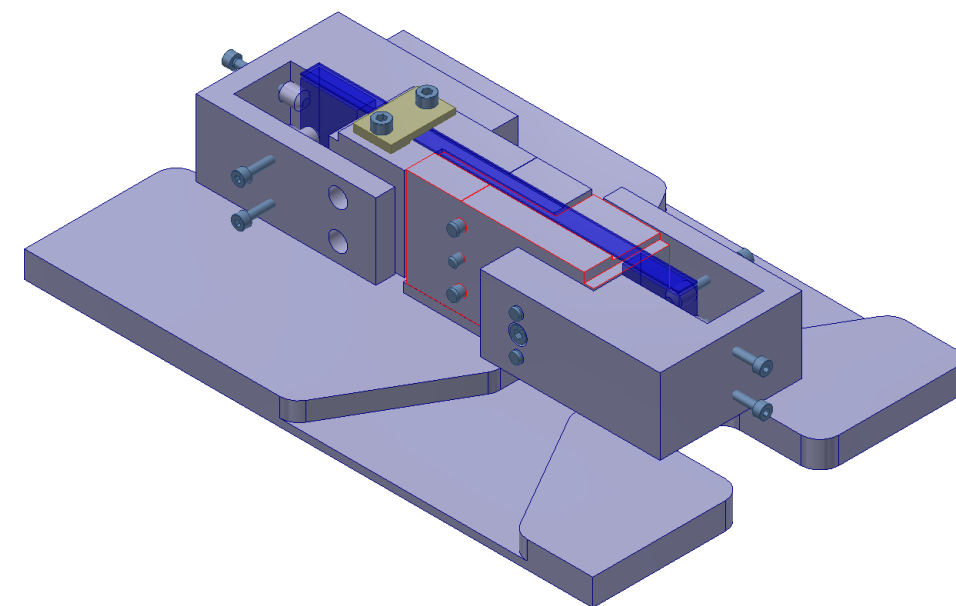


Jig design driving parameters

- Sliding components
- Parallel faces to ensure low disalignment
- Removable components to ensure extraction
- Peek tips to ensure positioning



Second Generation Jig



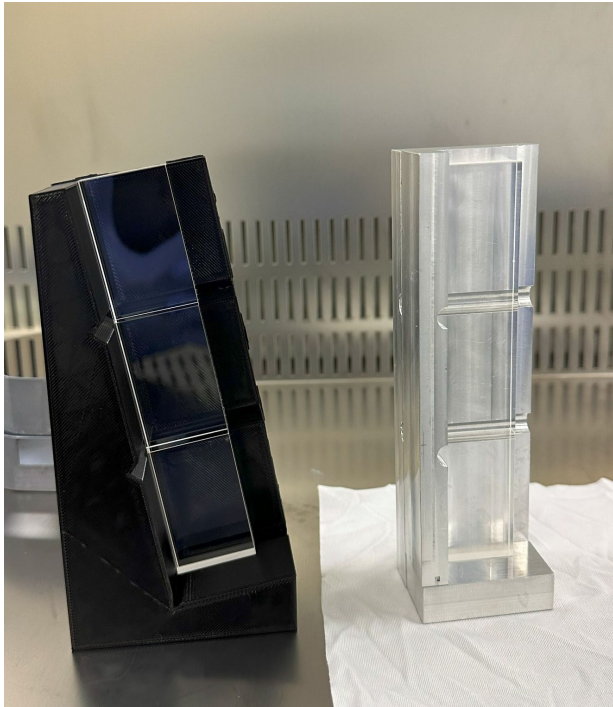
Design by G.Galimberti @INFN Cagliari

This new design (still under construction) ensures:

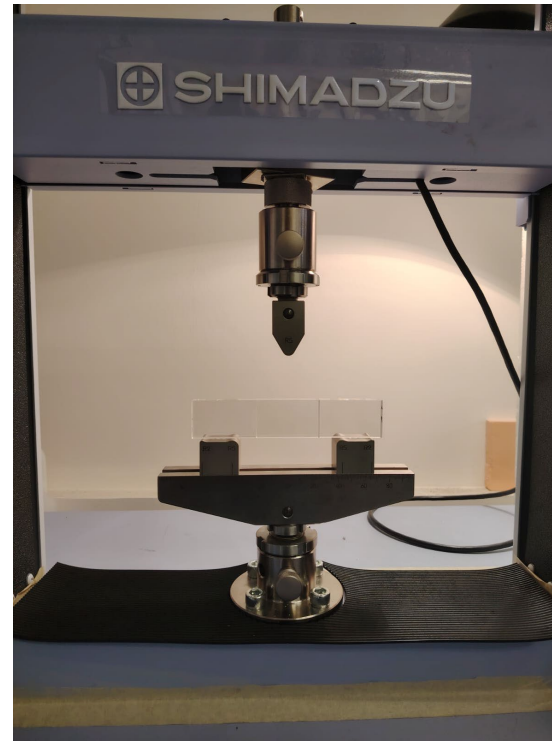
- Better cleanliness
- Better ribbon positioning
- Safer and more fluid extraction

Preliminary shear tests

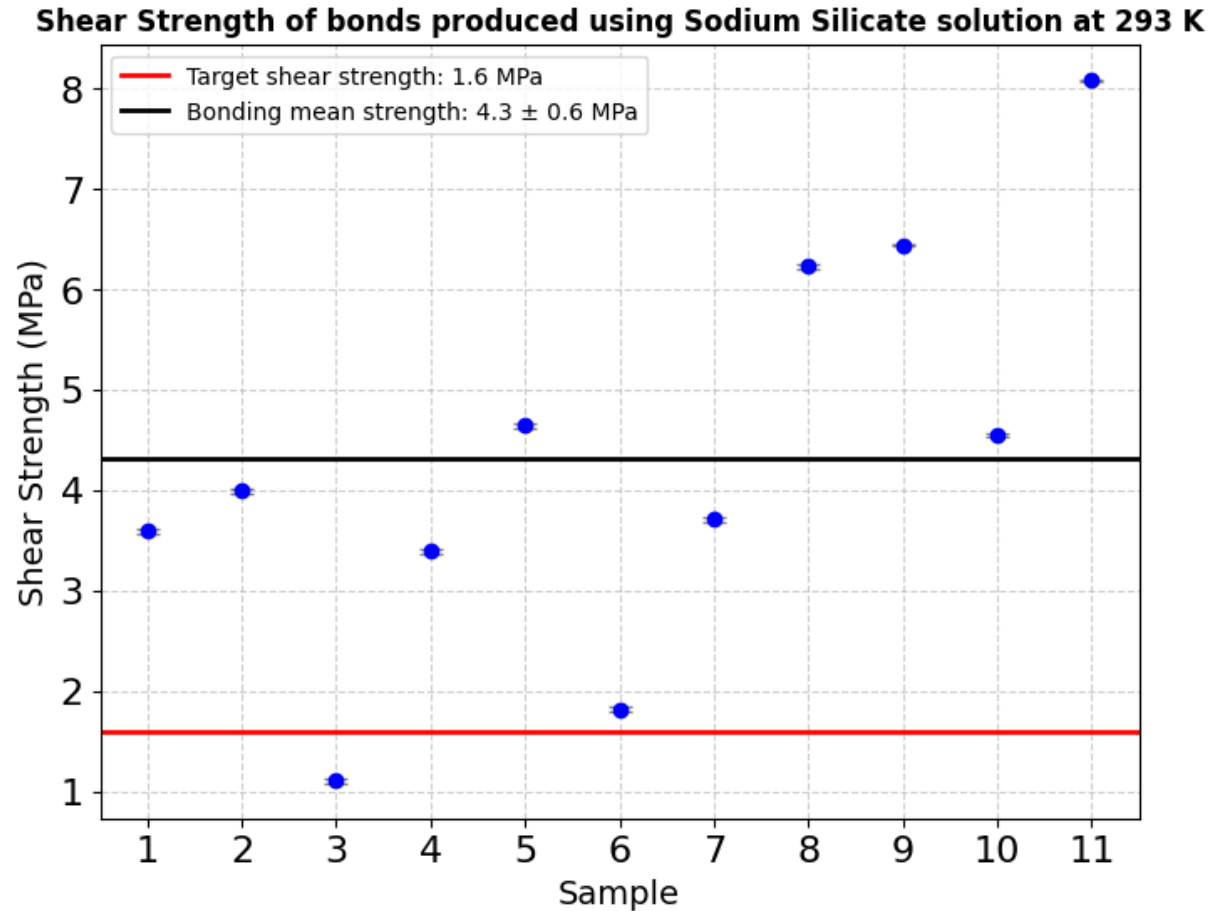
To study how our HCB would perform in our facility, we first decided to bond 3 sapphire blocks (equal to the size of the block sustaining the ear of the mirror).



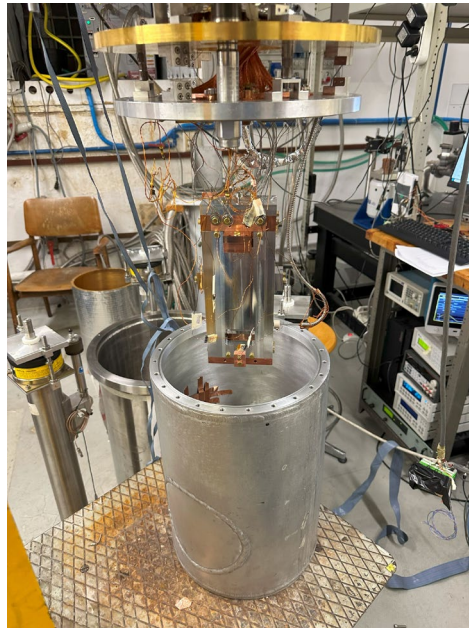
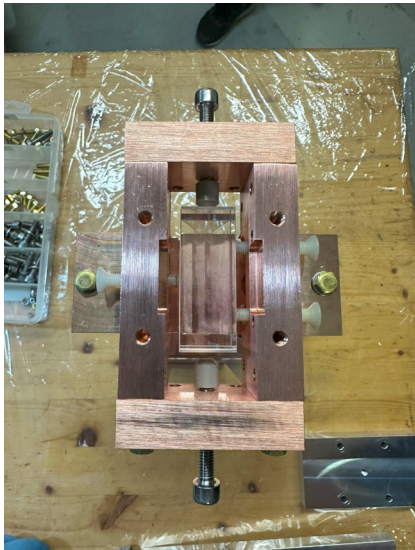
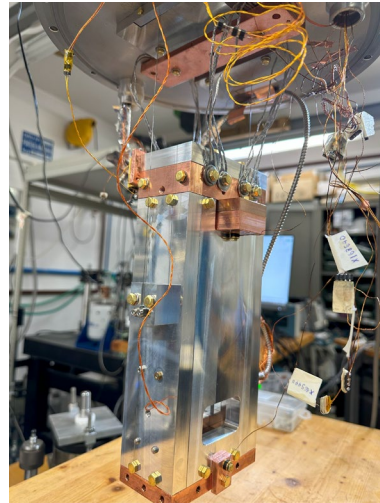
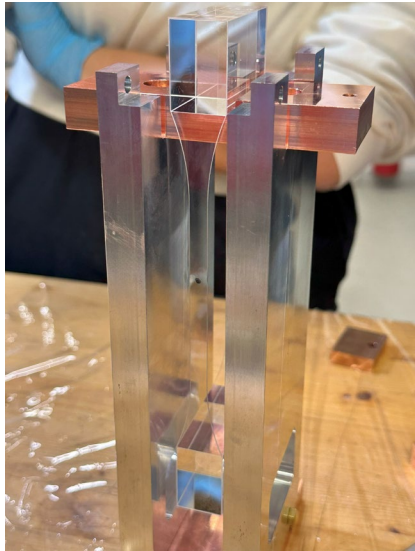
2 different jigs were used
(3D printed & aluminum)



3 point bending setup



Thanks to Benedetta Kalemi for this measurements



Setup

- Suspension from above
- excitement from a PCB on the bottom
- displacement measurement via optical fiber
- Test box designed by E. Benedetti, manufactured by Galli&Morelli
- Pulse Tube cryocoolers for cooling down

Open problems

Cryogenic environment tests not yet performed, one possible cause is PCB burnt.

In air test and vacuum test performed on *HCB bonded sample*: **low Q**. Cause: Probably due to the test box, which has a resonance frequency very close to that of the ribbon (not on purpose). So we might not be measuring the right resonance.

Test with monolithic sapphire suspension can help us identifying whether is a problem of the setup or of the frequencies.

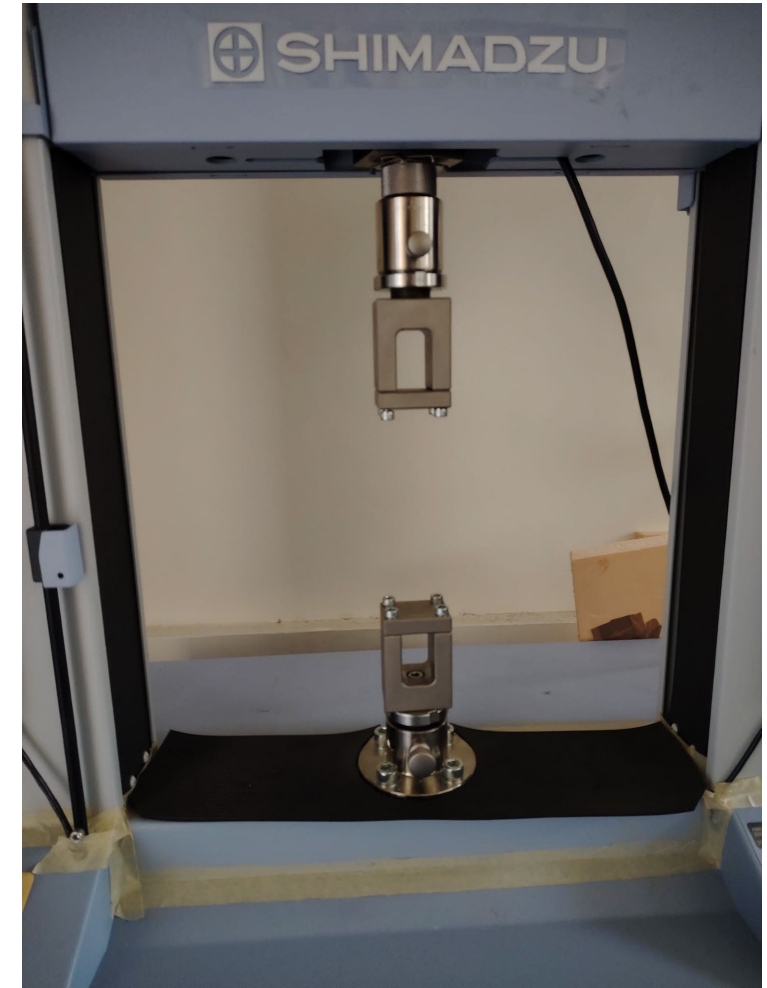
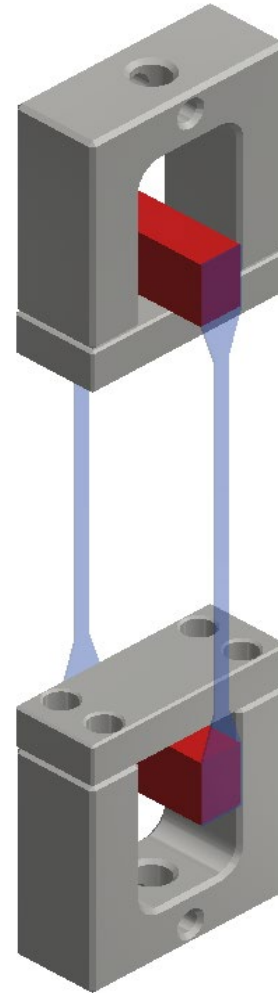
Obviously tested Q of these two samples cannot be compared, because of different suppliers and different methods. There is an ongoing deal to buy the respective counterparts

Pull tests on Ribbon

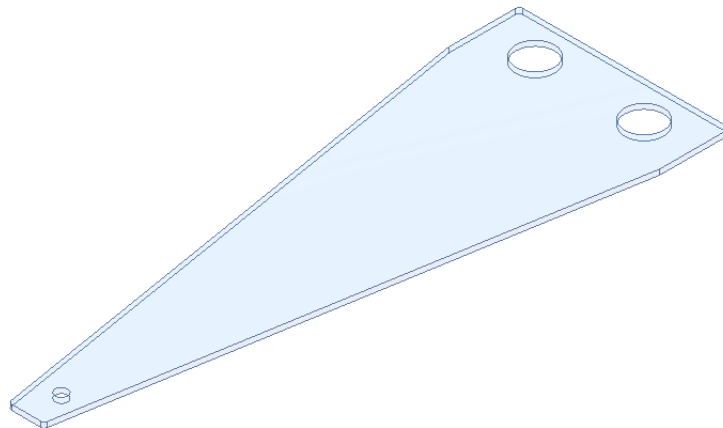
Basic jig for pulling ribbon is already available

Q test comes first, because pull test can (and will surely be) be destructive.

Design changes might be implemented in the pulling system (like in marionette suspension case) to ensure more flexibility during test



INFN
Istituto Nazionale di Fisica Nucleare



Bending stress on such a geometry and material will surely end up destructively, so test setup must be well designed



We want to perform crystal analysis on samples of both our suppliers, for the sake of comparison

Crystal analysis comprise of:

- Optical microscopy
- Raman spectroscopy
 - Laser ablation
 - SEM

Studies in collaboration with Prof. Claudia Romano, Roma Tre

At Rome, in ETCRYO Lab we are working on sapphire systems for the ET-LF cryogenic payload.

- **Sapphire suspension for the marionette**
 - Pull test on the locking system
 - Design improvement on crucial parameters
- **Sapphire suspension for the mirror**
 - Two different approaches: HCB and monolithic
 - Design improvement on the bonding jig
 - Q test for mechanical quality factor
 - Investigating main problem on the setup and resonance frequency
 - Pull test
- **Mechanical test machine**
 - Design improvement on test jigs to avoid misalignment on the samples
- **Sapphire blades**
 - Ongoing design
- **Crystal studies on broken samples**
- *Purchase campaign ongoing*
 - Statistical measurements
 - According to FEM analysis and first test results, following design improvements

Thank you for your attention

- Sapphire is very expensive (we cannot produce internally)
- Just one test is not enough: statistics is needed
- Improvement on shape/tolerances on samples and jigs after first results (and failures)
- Improvement on the tests setup

IMPEX

Blocks

Ribbons (to bond and test)

Rods+half cones with only friction

Rods+ half cone with tooth

KYOCERA

Monolythical Ribbon

Rods+half cone with tooth

Acquistato SEAT

Sapphire samples are very expensive, so so far we've been acquiring and testing samples for the sake of proving the validity of the system. But we need more samples to do statistics.

BACKUP SLIDES

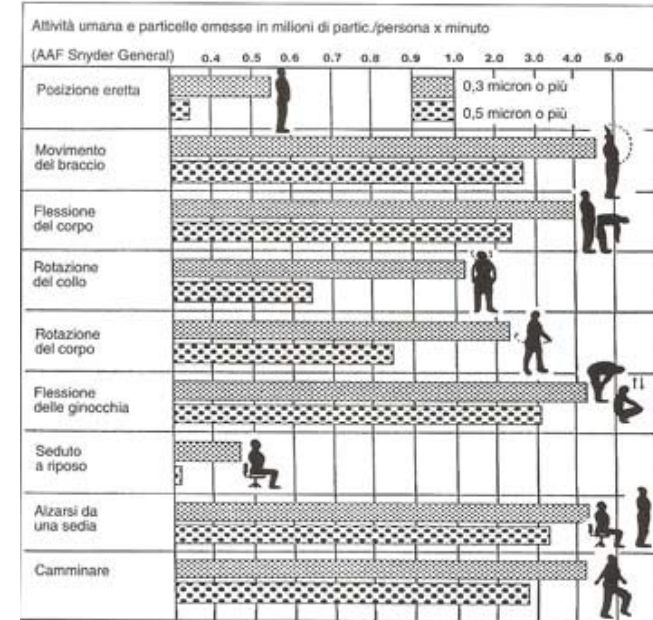
These slide is a courtesy of Marco Orsini

CLEANLINESS ISSUE: CLEAN BOOTH

The purpose of this facility is to ensure an environment with controlled contamination of air particles with use of high efficiency filters (HEPA).

Our aims is to achieve standard level of **ISO 6 'AT REST'** and **ISO 7 'IN OPERATION'** for size particles fo 0,5 μm as required by UNI-EN-ISO 14664-1.

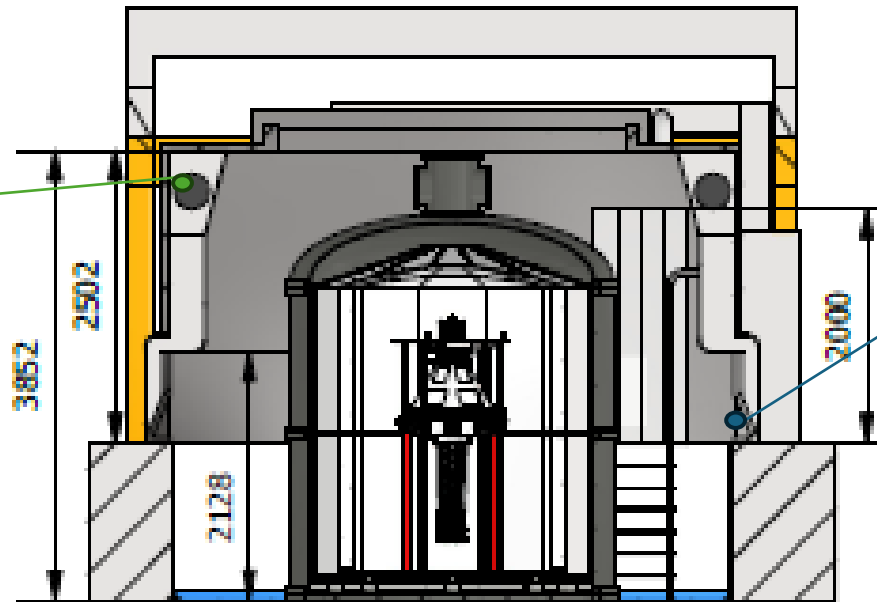
ISO classification number (N)	Maximum concentration limits (particulate/m ³ of air) for particles equal to and larger than the cosidered sizes shown below					
	0,1 μm	0,2 μm	0,3 μm	0,5 μm	1 μm	5 μm
ISO Class1	10	2				
ISO Class2	100	24	10	4		
ISO Class3	1000	237	102	35	8	
ISO Class4	10000	2370	1020	352	83	
ISO Class5	100000	23700	10200	3520	832	29
ISO Class6	1000000	237000	102000	35200	8320	293
ISO Class7				352000	83200	2930
ISO Class8				3520000	832000	29300
ISO Class9				35'200,000	8320000	293000



The contribution of the different activities carry out inside the clean booth increase the dust production

CLEANLINESS ISSUE: CLEAN BOOTH

There are the air treatment points, here find the mechanical ventilation systems followed by filter batteries F9 and then H14.



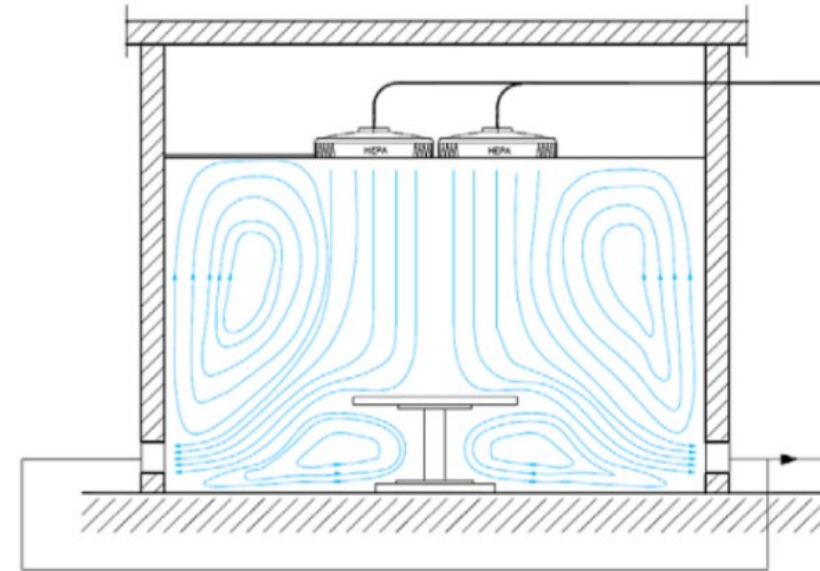
From here the air that passes through the HEPA filters and the chamber is recirculated and then partly reintroduced into the structure and partly evacuated

SEZIONE C-C

CLEANLINESS ISSUE: CLEAN BOOTH

- The effort in this facility is focused in fluidodynamics issues;
- Temperature, humidity and concentrations of contaminant are the value to estimate more carefully for a good project;
- The flowrate is very important for ensure a good air quality and the ISO class condition.
(for ISO 6 or 7 turbulent flow is assumed)

As first calculation estimate a flowrate of 6000 m³/h and an air change rate (1/h) between 70/100 are needed



[An example how turbulent flow passes trough the chamber]