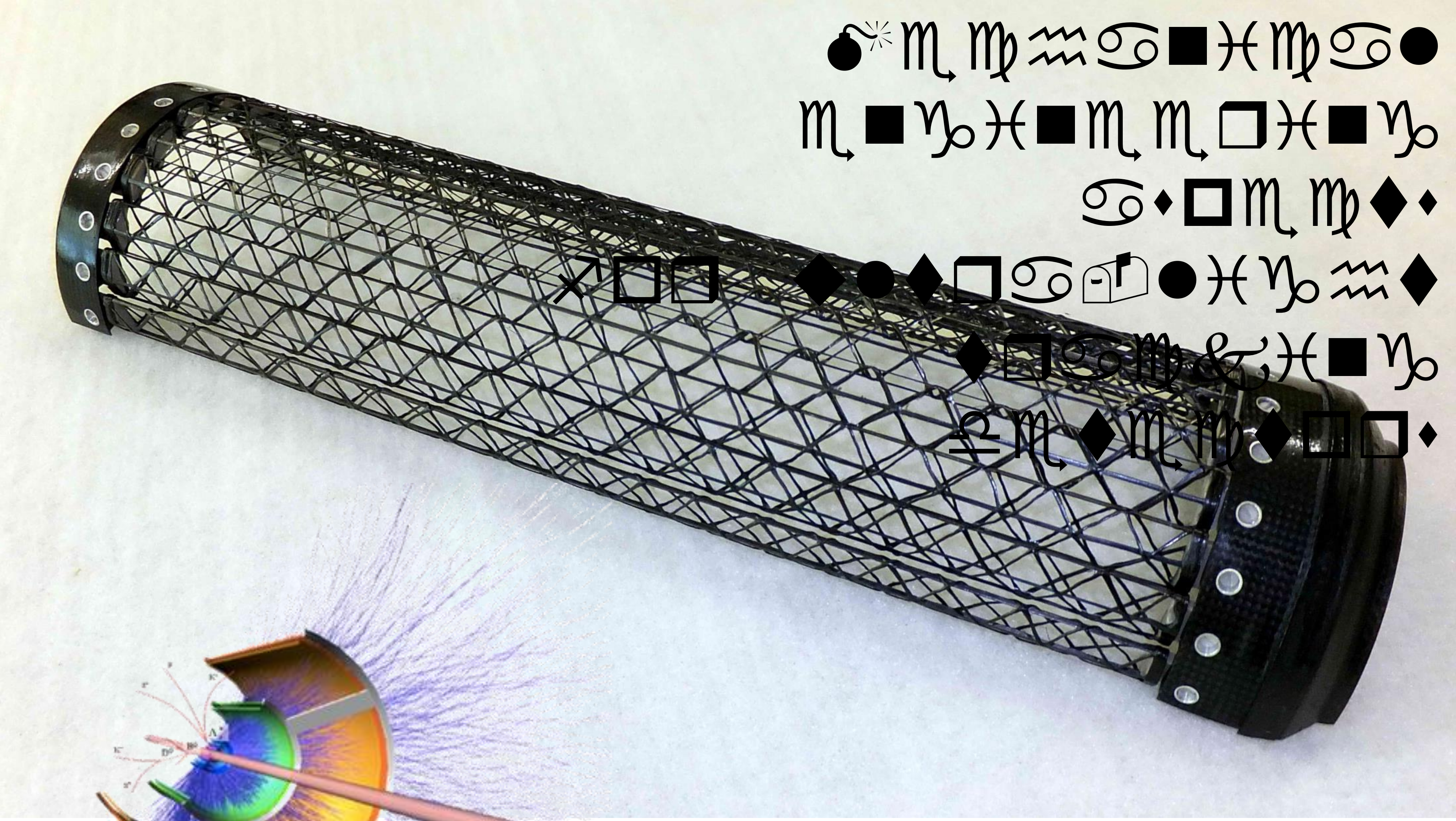
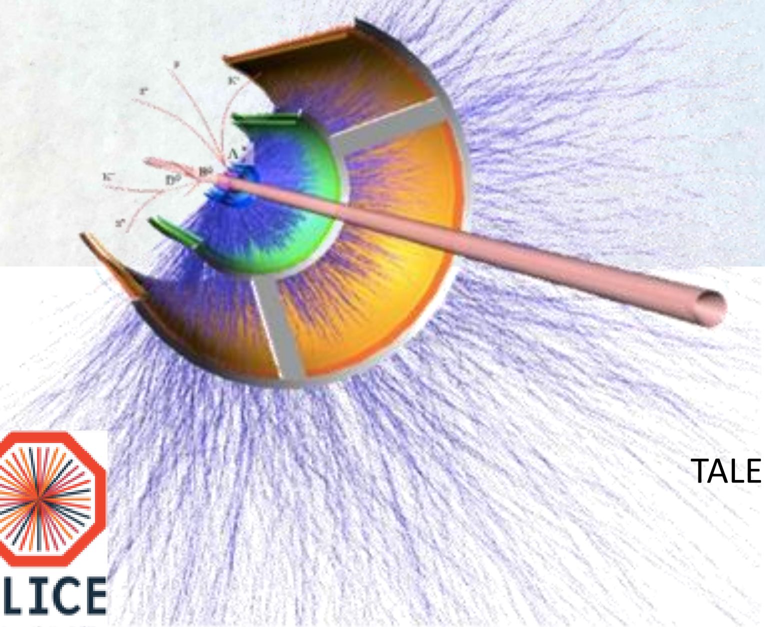


Mechanical engineering aspects for ultralight tracking detectors



TALENT Summer School , CERN -4 June 2013

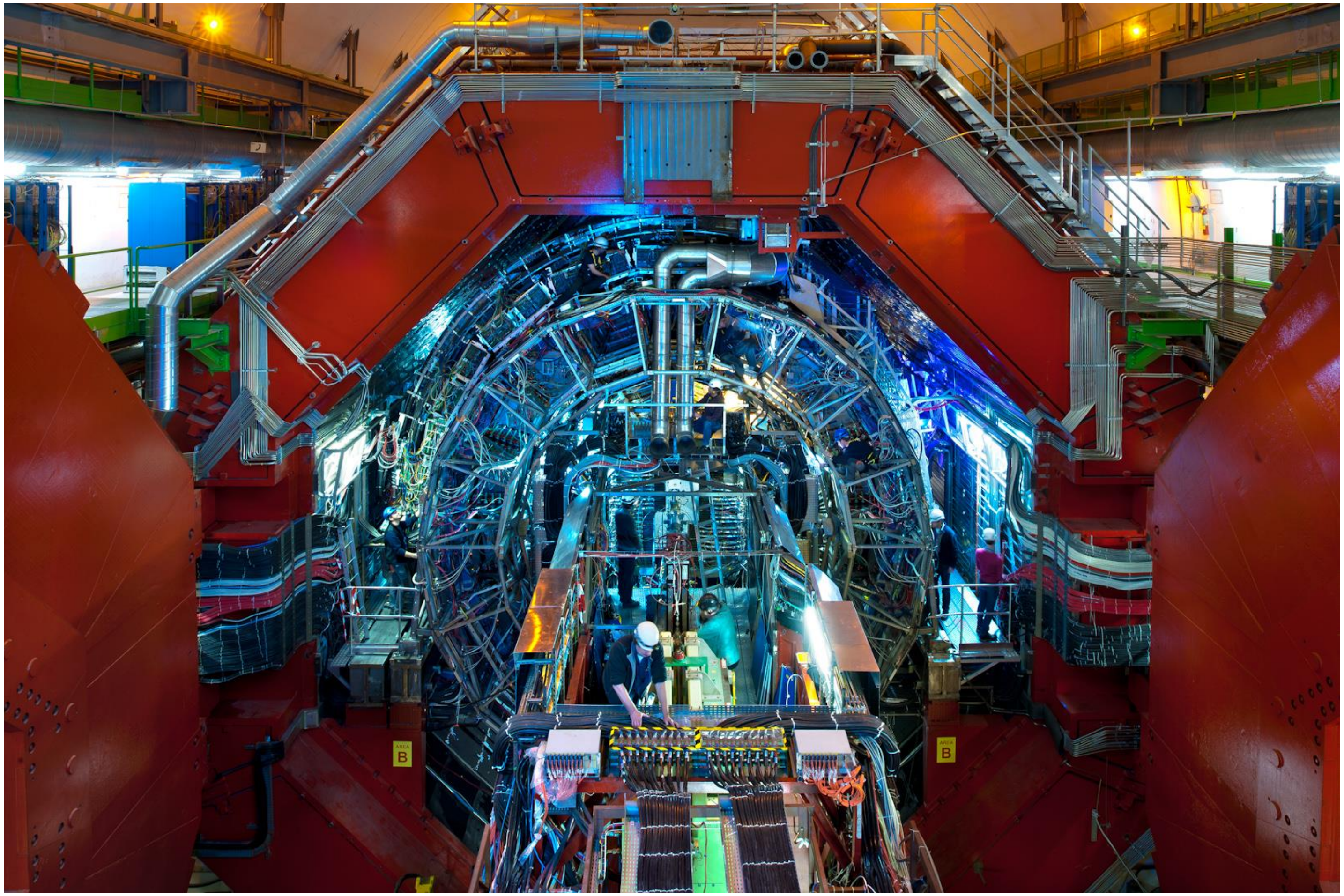
Corrado Gargiulo

Outline

Tracker Mechanical Structures

Design constraints
Materials
Production Processes
Mechanical characterization
Thermal characterization

Alice Inner Tracker System upgrade



Corrado Gargiulo
on behalf of ALICE Collaboration

New ALICE ITS Design goals

1. Improve impact parameter resolution by a factor of ~3

• Get closer to IP (position of first layer): 39mm ➡22mm

• Reduce material budget: X/X_0 /layer: ~1.14% ➡ ~ 0.3% (for inner layers)

• Reduce pixel size

- currently 50mm x 425mm

  monolithic pixels ➡ O(20mm x 20mm),

  hybrid pixels ➡ state-of-the-art O(50mm x 50mm)

2. Improve tracking efficiency and p_T resolution at low p_T

• Increase granularity: 6 layers ➡ 7 layers , reduce pixel size

3. Fast readout

• readout of Pb-Pb interactions at > 50 kHz and pp interactions at ~ MHz

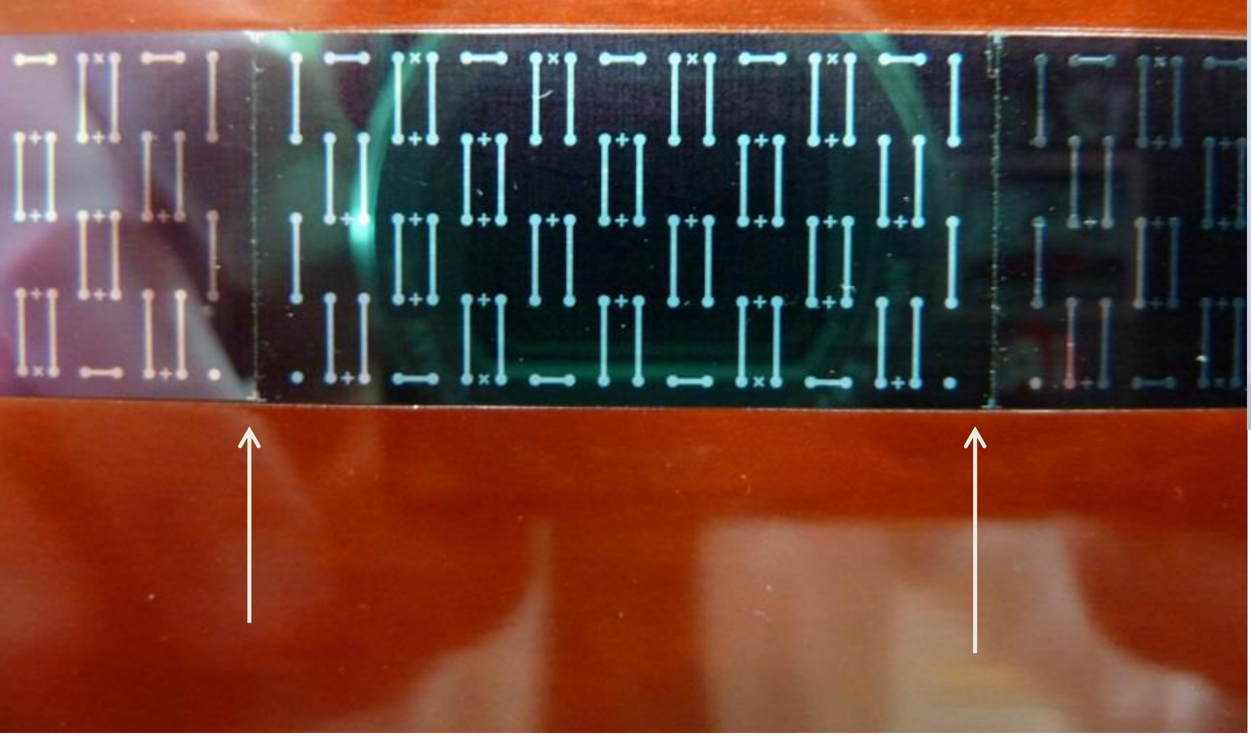
4. Fast insertion/removal for yearly maintenance

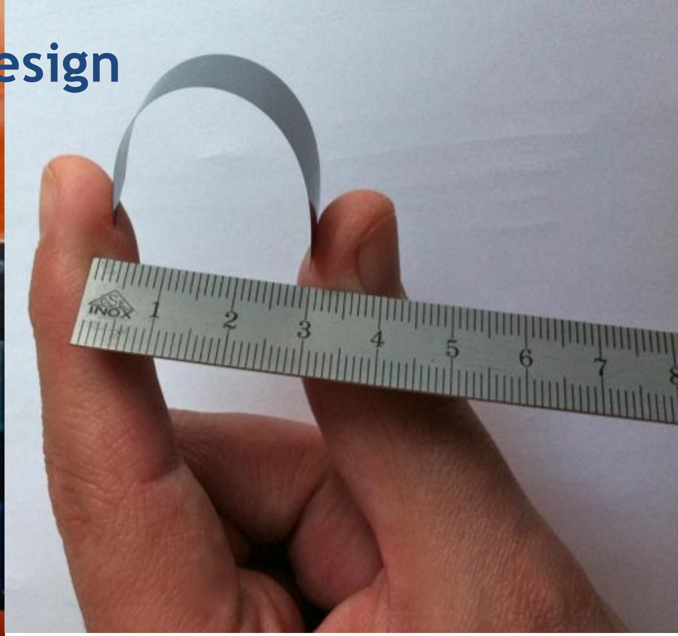
• possibility to replace non functioning detector modules during yearly shutdown

Design constraints

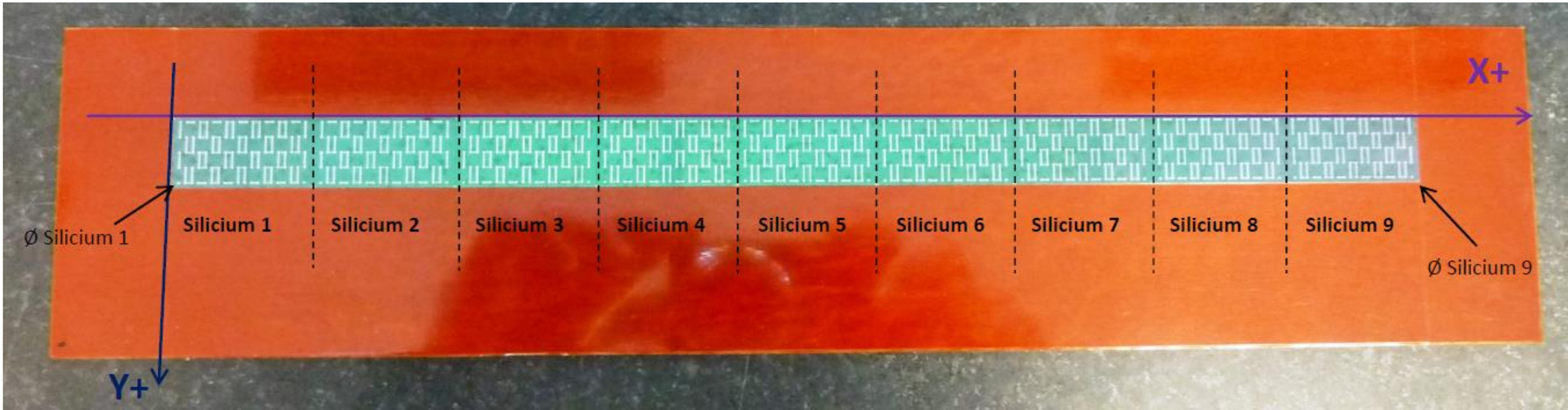
Internal Constraints to the Mechanical Design

The sensor





monolithic silicon pixel
15mmx30mm
50 µm thick



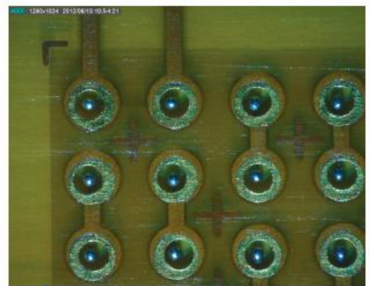
Internal Constraints to the Mechanical Design

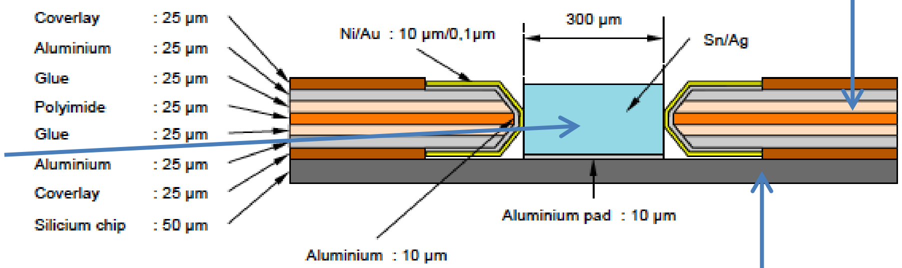
Components

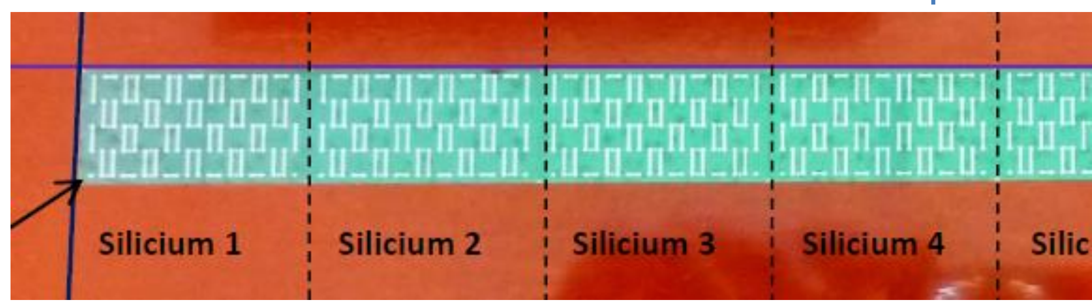
Flex-cable bus

Bump bonding

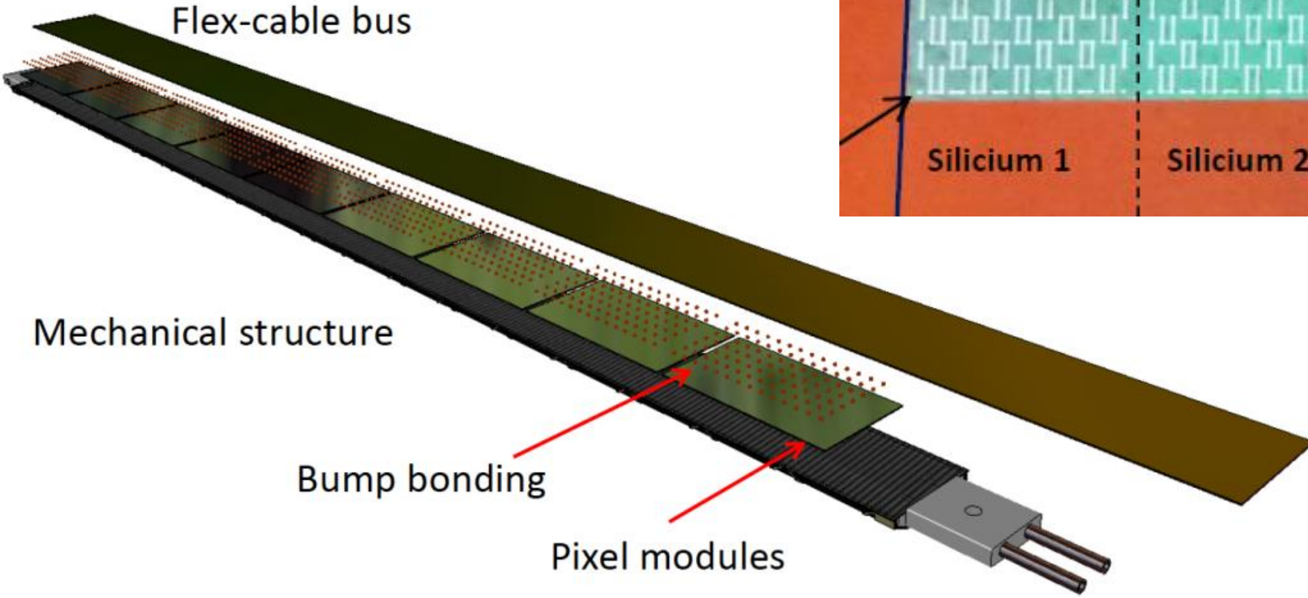
(connection between chip and bus)





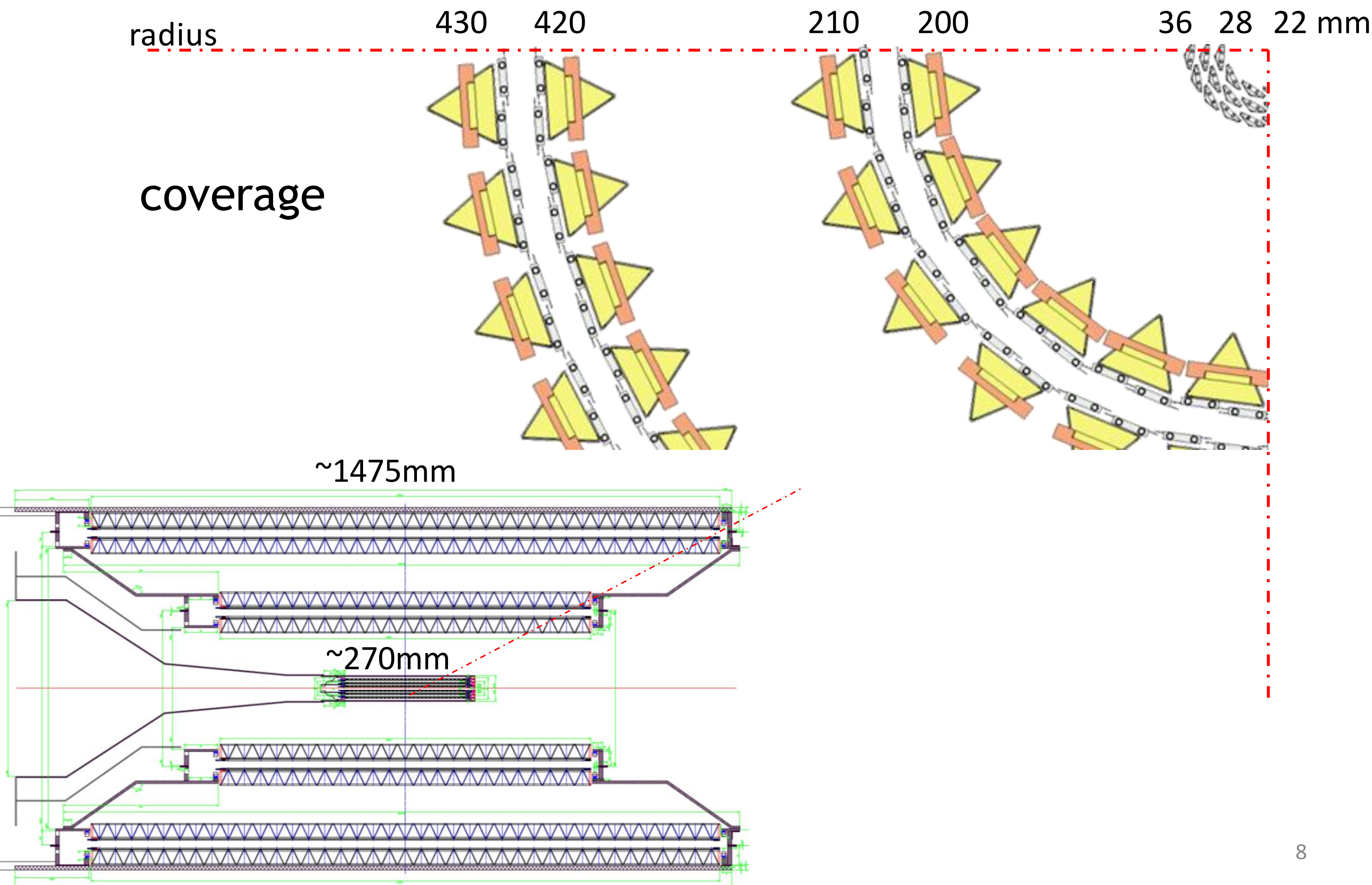


Silicon chips



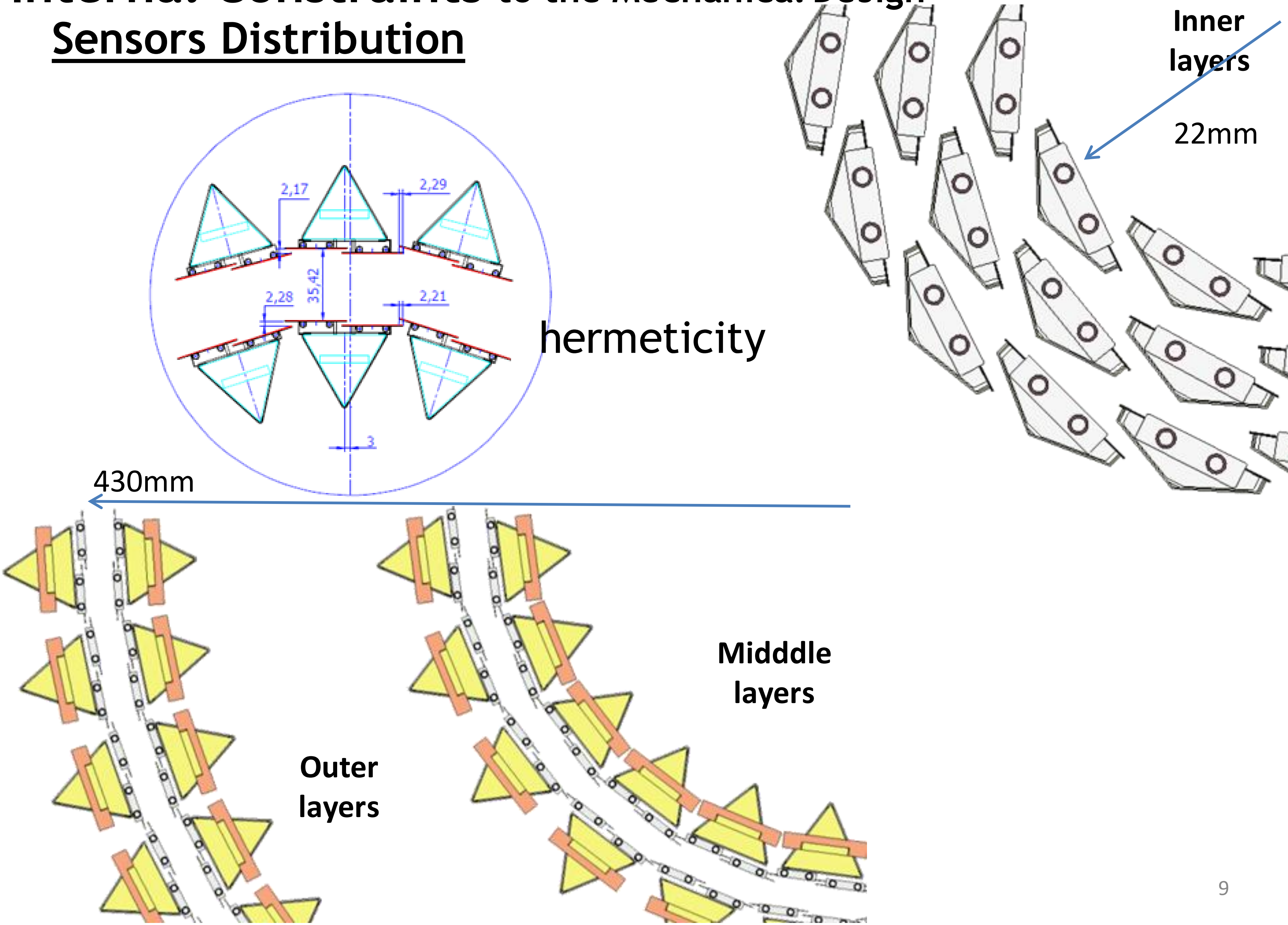
Internal Constraints to the Mechanical Design

Sensors Distribution

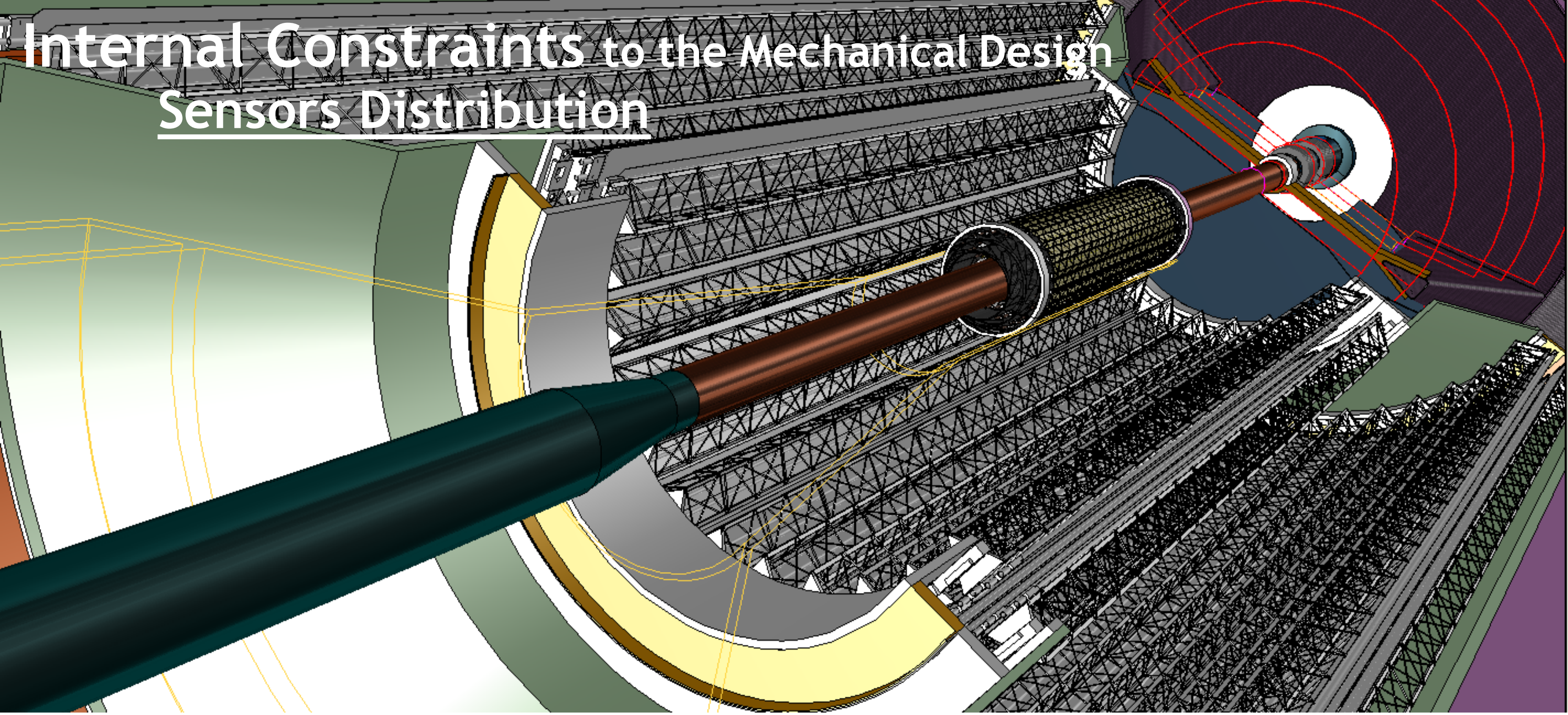


Internal Constraints to the Mechanical Design

Sensors Distribution



Internal Constraints to the Mechanical Design
Sensors Distribution



Inner Barrel (IB): 3 layers pixels

Radial position (mm): 22,28,36

Length in z (mm): 270

Nr. of staves: 12, 16, 20

Nr. of chips/stave: 9

Nr. of chips/layer: 108, 144, 180

Material thickness: ~ 0.3% X_0

Throughput: < 200 Mbit / sec•cm^2

Outer Barrel (OB): 4 layers pixels

Radial position (mm): 200, 220, 410, 430

Length in z (mm): 843, 1475

Nr. of staves: 48, 52, 96, 102

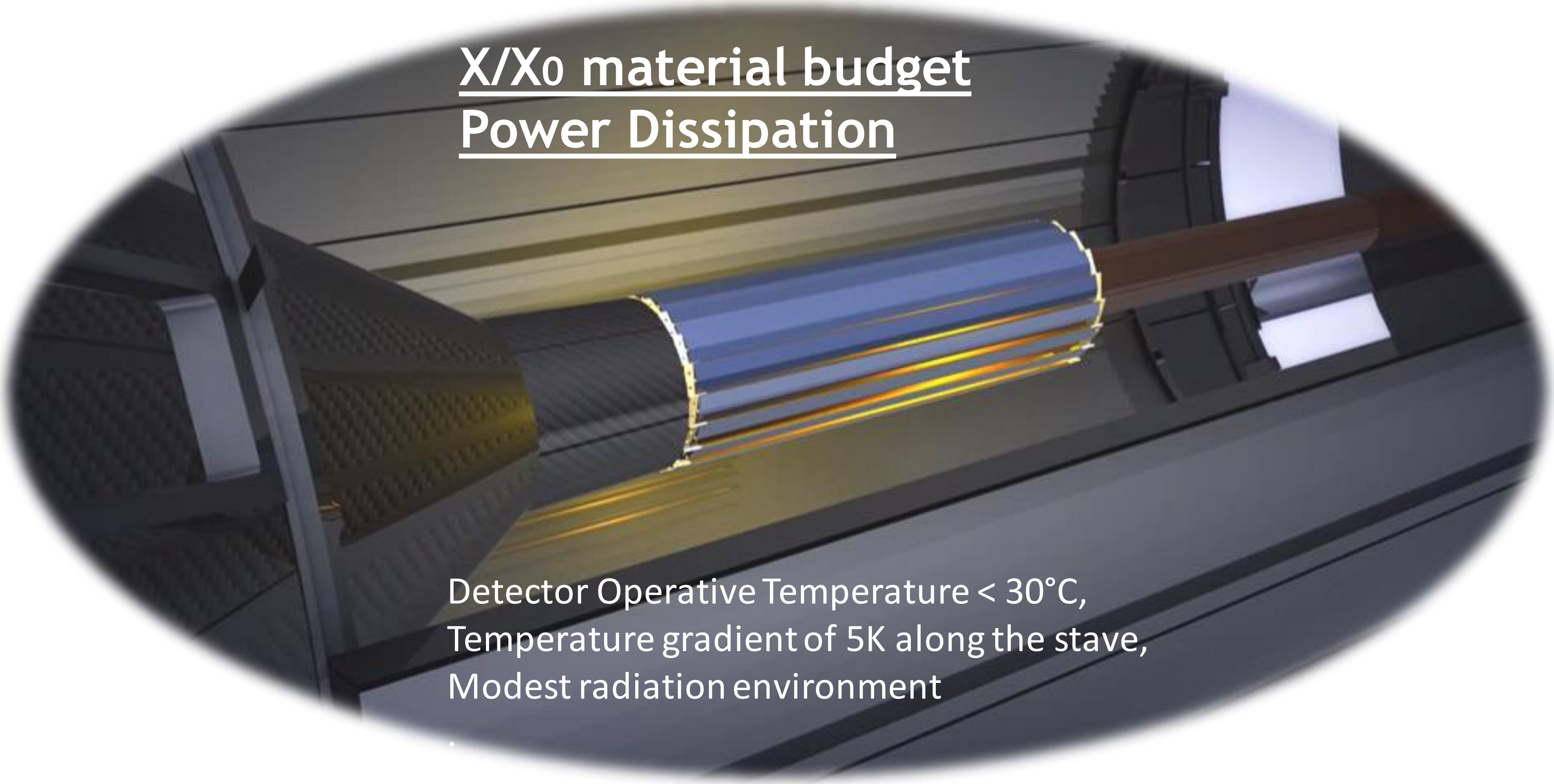
Nr. of chips/stave: 56, 56, 98, 98

Nr. of chips/layer: 2688, 2912, 9408, 9996

Material thickness: ~ 0.8% X_0

Throughput: < 6 Mbit / sec•cm^2

Internal Constraints to the Mechanical Design



	Layer 0, 1, 2	Layer 3, 4, 5, 6
Maerial Budget	X/X0 (%)~0.3	X/X0 (%) ~ 0.8
Radiation environment	700 krad/ 10^{13} n_{eq} per year	10 krad/ $3*10^{11}$ n_{eq} per year
Power dissipation	<0.3 W/cm2	<0.3 mW/cm2

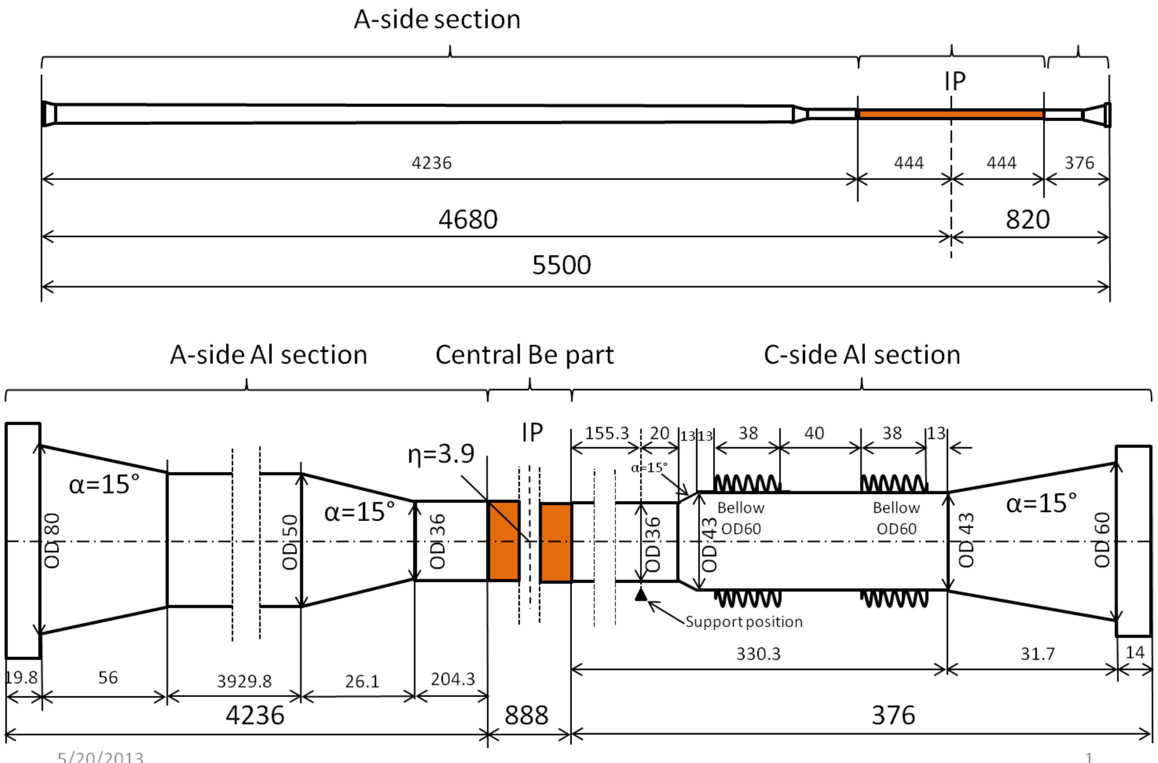
External Constraints to the Mechanical Design

Beam Pipe

Get closer to the IP

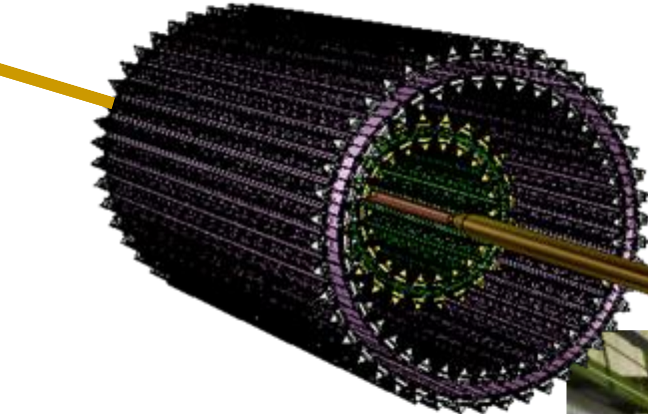
Reduce beam pipe diameter from 59.6 to 40mm
(36mm OD under study)

Tracker at 2 mm from the beam pipe wall



All dimensions in mm. Wall thickness 800μm everywhere (bellow thickness 300μm)

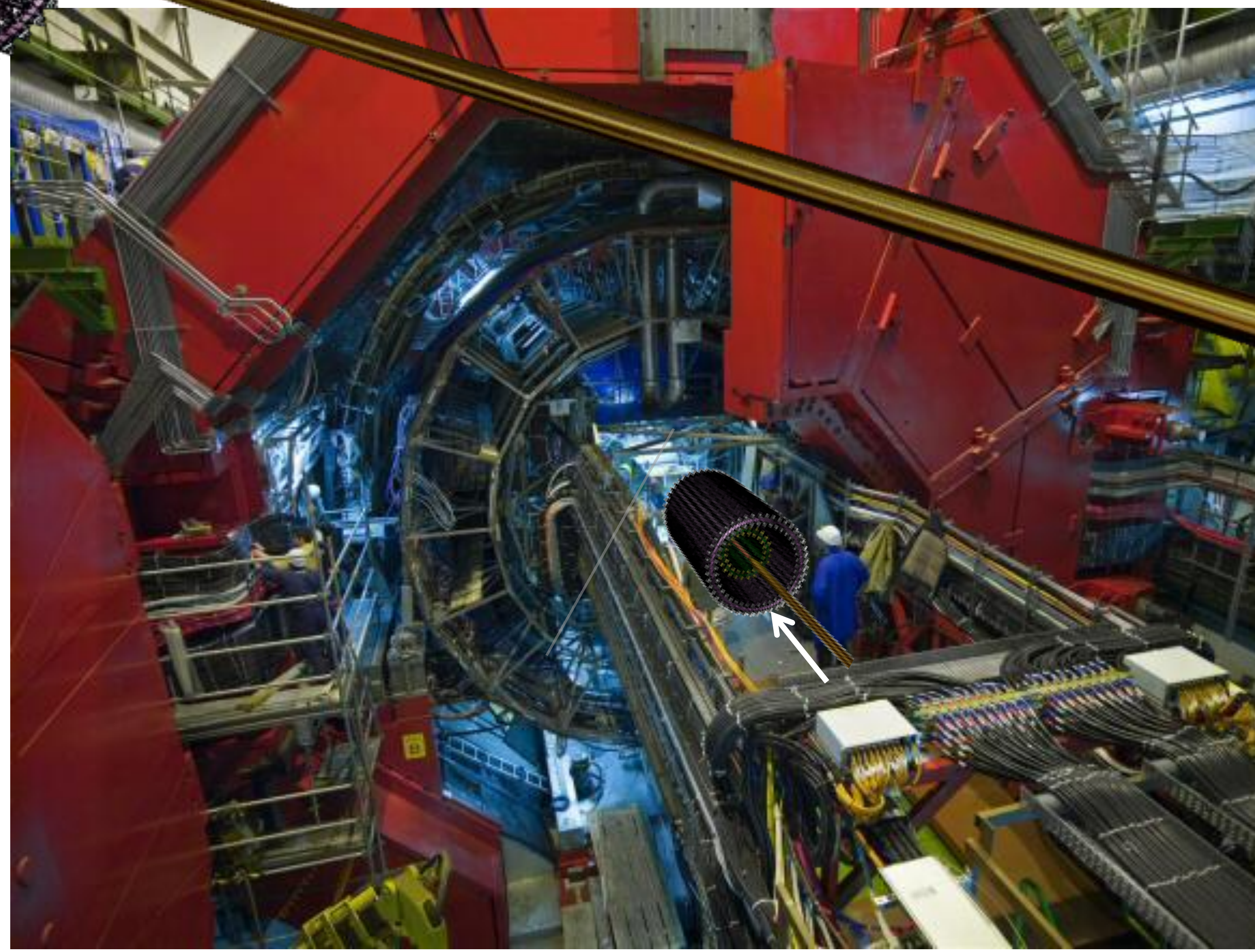
External Constraints to the Mechanical Design



Installation and access

The new Alice ITS design should ensure a rapid accessibility to the inner detectors

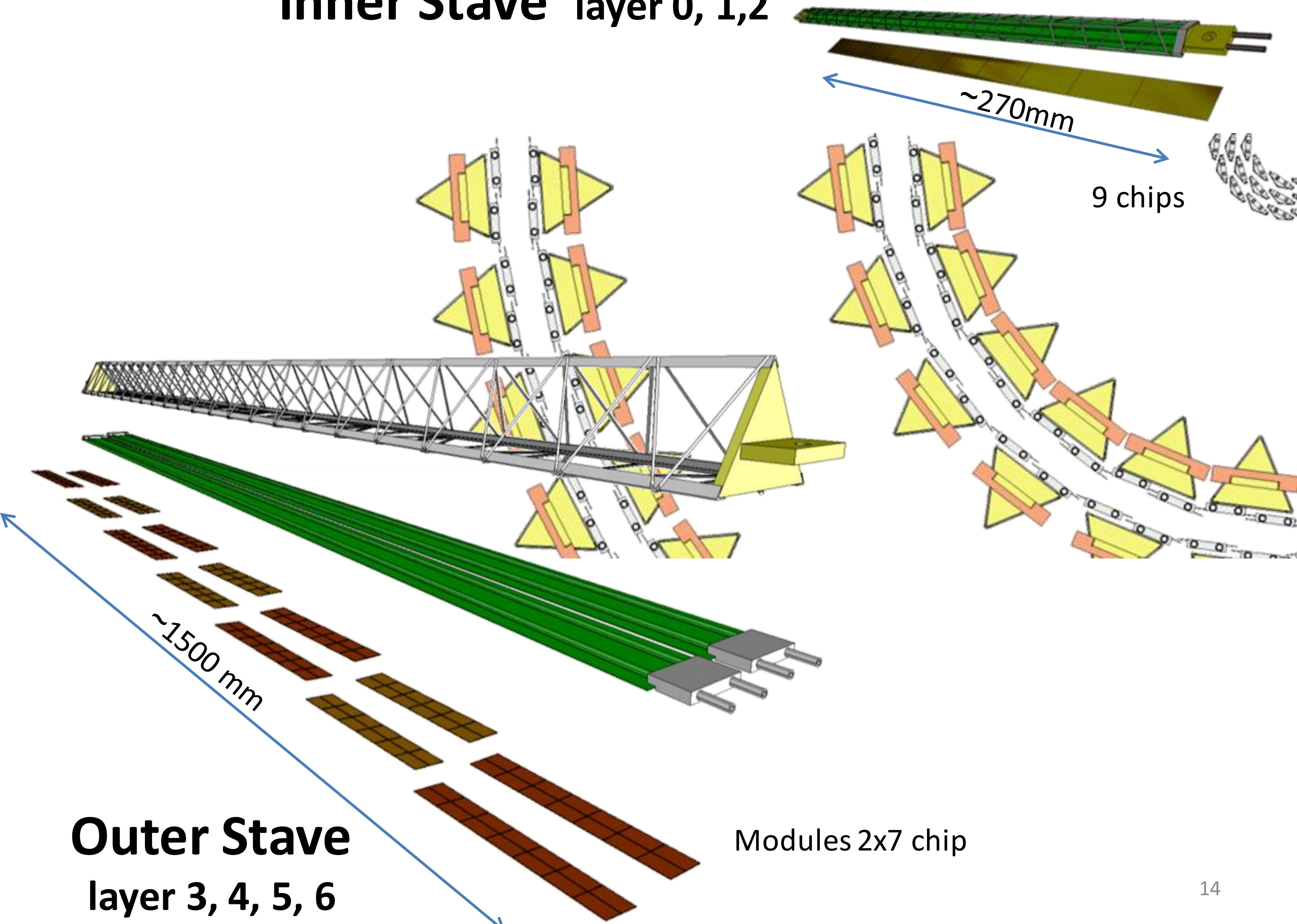
ITS (+services) insertion and extraction from one side



With the present layout, any access to the ITS requires a series of lengthy operations inside ALICE, like the displacement of the large detector TPC.

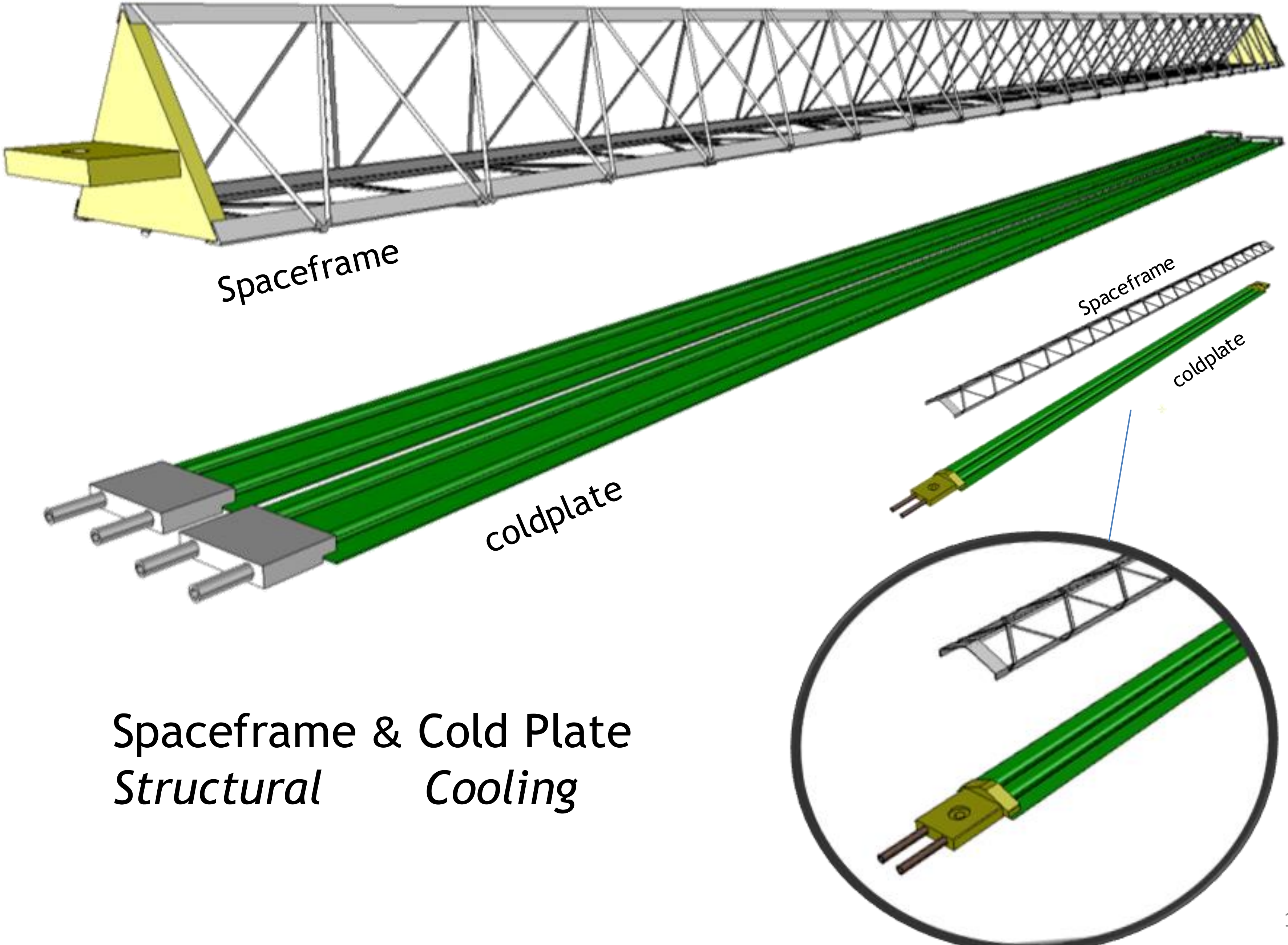
An intervention on the detector will require from 6 to 7 months

Inner Stave layer 0, 1,2



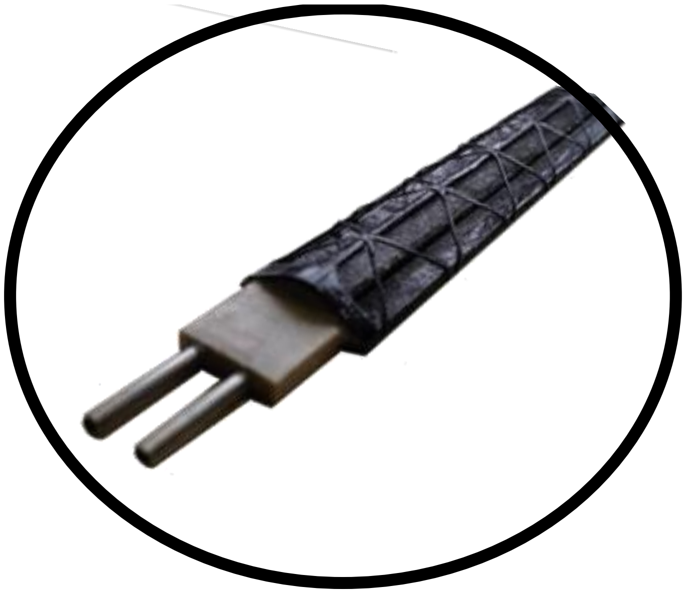
Outer Stave
layer 3, 4, 5, 6

Mechanics & Cooling *Design*



Spaceframe & Cold Plate
Structural *Cooling*

Mechanics & Cooling *Prototype*



Materials

Carbon Fleece

Carbon Roving

Carbon Fabric

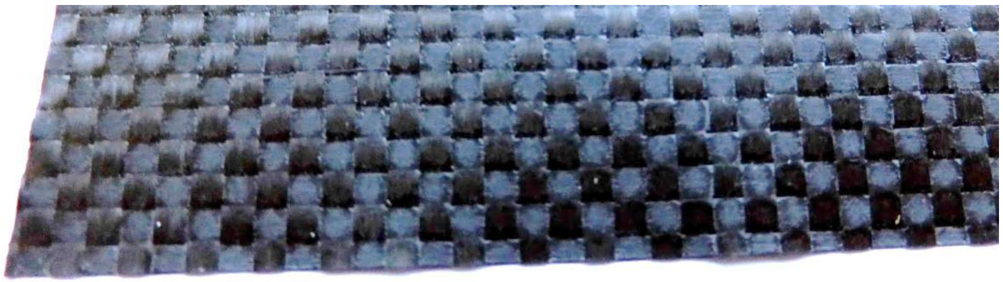
Polyimide tubes

Carbon Unidirectional Prepreg

Carbon Paper

Materials


Carbon Fleece

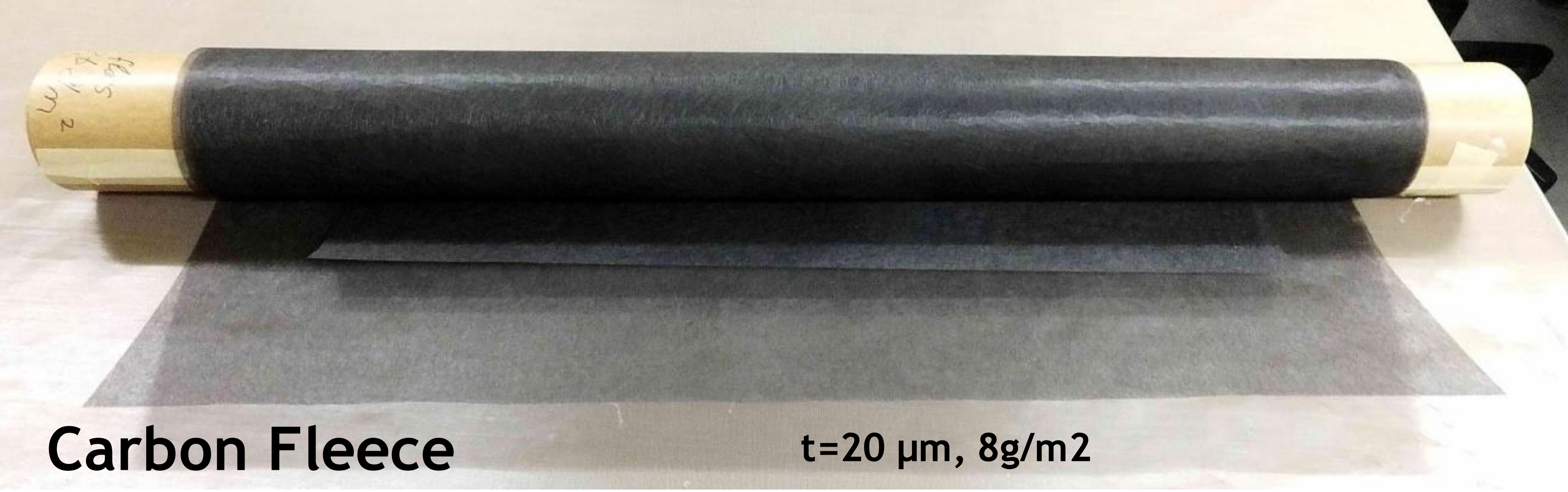

Carbon Fabric


Carbon Roving

Polyimide tubes


Carbon Unidirectional Prepreg


Carbon Paper



Carbon Fleece

t=20 µm, 8g/m2

Structural component

continuous-strand mat is formed by swirling continuous strands of fiber onto a moving belt, finished with a chemical binder to hold fibers in place. Its open (non-dense) fiber arrangement accepts a high ratio of resin to fiber, resulting in a thick, smooth, resin-rich finish.

Carbon Roving

A single fiber is usually referred to as a ***filament***.

Bunches of filament are called ***strand*** or *end*. If the filaments are all parallel to each other, the end is called a ***roving*** (graphite rovings are also referred to as ***tows***).

Rovings are usually denoted by the number of filaments. The most common graphite tows are 3K, 6K, and 12K, with K=1,000 filaments .

If instead of being straight the filaments are twisted to hold the fibers together, the bundle is called a ***yarn***.

Fialment diameter= 5µm

E=588 GPa, X_T=3,9 GPa, K= 140 W/mK, 0.10g/m; CTE=-1,1 x10^{-6}1/K **M60j- 3k**

E=540 GPa, X_T=4,2 GPa, K= 150 W/mK, 0,32g/m; CTE=-1,1 x10^{-6}1/K **M55j- 6k**

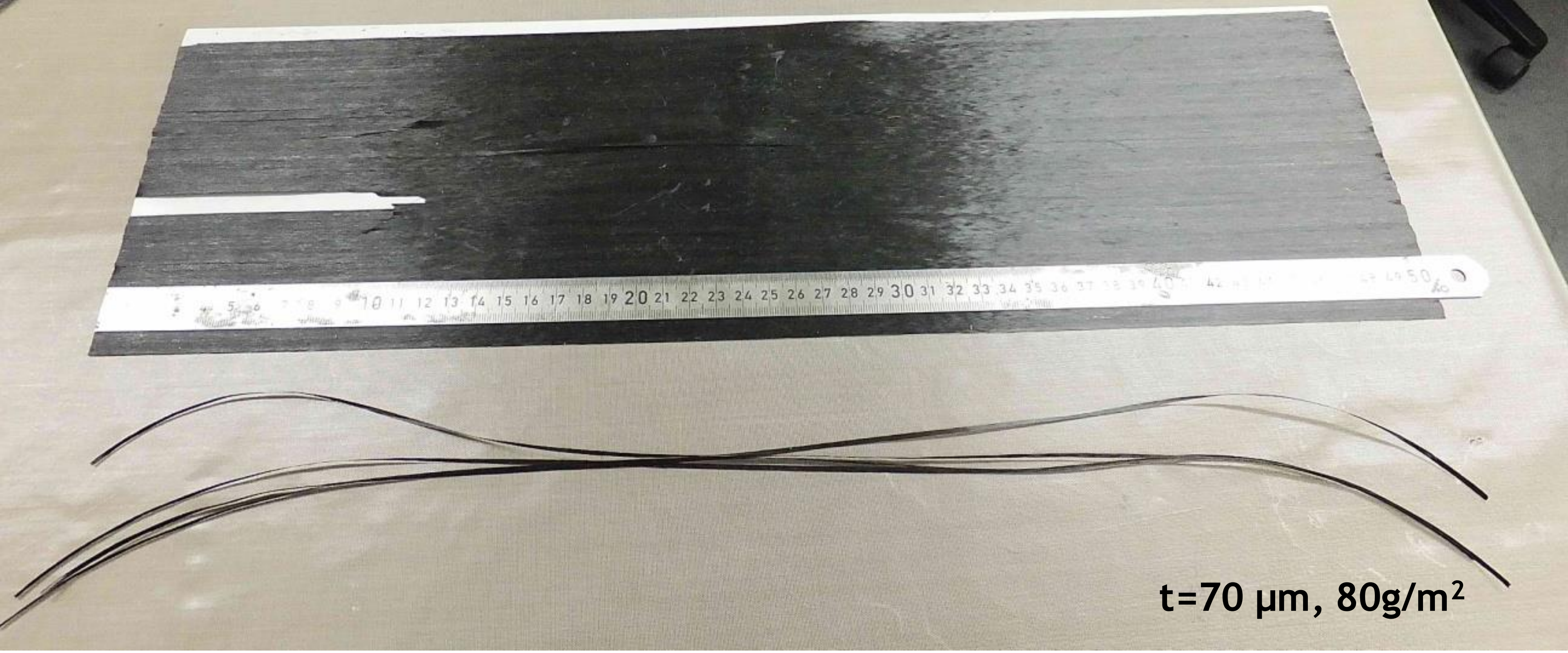
dry 92g/m2
impregnated 160g/m2

Carbon Fabric T300 1K

0°/90° Thickness 0,11mm,

Either roving (tow) or yarn can be woven into a fabric. If roving is used, the fabric is called ***woven roving***; if yarn is used the fabric is called ***cloth***. Many suppliers use the term cloth for woven roving, but refer to the weave as flat, not twisted. Cloth composites can have a slightly lower resin content than woven rovings because the yarn bundles are more compact than rovings

The last important fabric term is the ***weave***. The weave describes how the warp and fill yarns are interlaced. The most popular weaves are *plain*, *twill*, *harness satin*, and *crow-foot satin*.



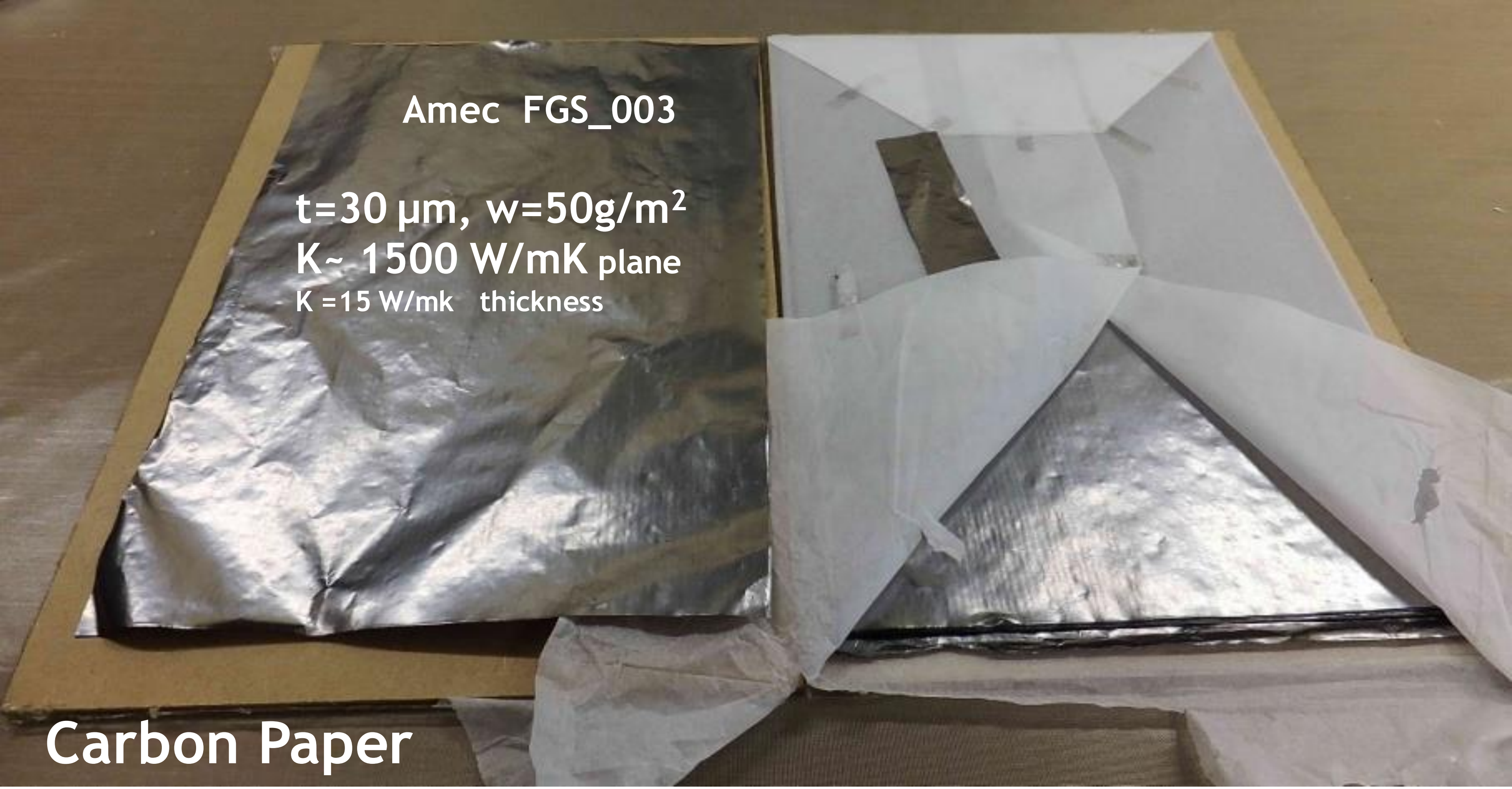
Carbon Unidirectional Prepreg

Prepreg
Ready to mold or cure material in sheet form which contains fiber all aligned in one direction

K13D2U-2k RS3 0.07mm
2000 filaments (11micron D)

FIBER **E=935 GPa, X_T=3,6 GPa, K= 800 W/mK**

PREPREG **E1=560 GPa, X_T=1,8 GPa, E2=5,1 GPa, Yt=25 MPa K1= 450 W/mK**

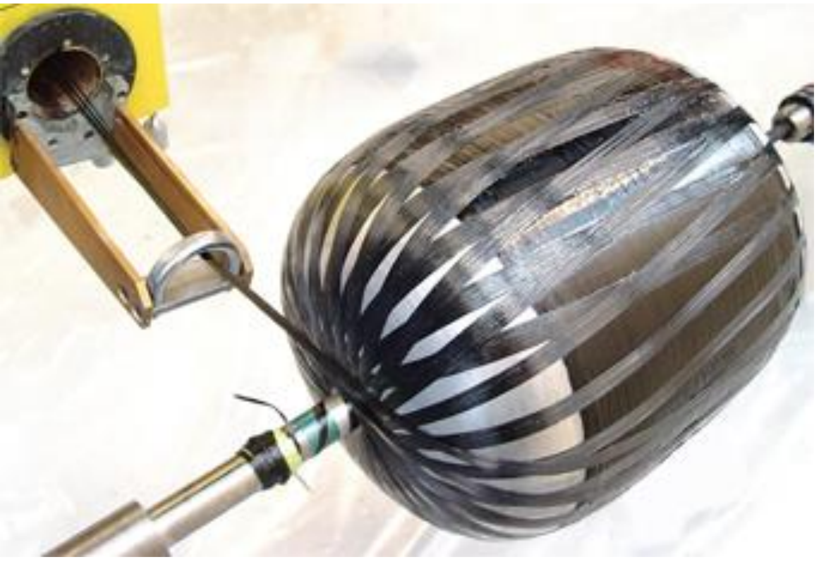


Properties	Unit	Data	Test Method
Thickness	mm	0.03	-
Density	g/cm^3	1.6	-
Thermal Conductivity Through Plane	W/m.K	1500	ASTM D5470 Modified
Thermal Conductivity Through Thickness	W/m.K	15	ASTM D5470 Modified
Operating Temperature Range	^oC	-50 ~ 500	-
Flammability Rating	-	Meets V-0	UL94
RoHS	-	Yes	-

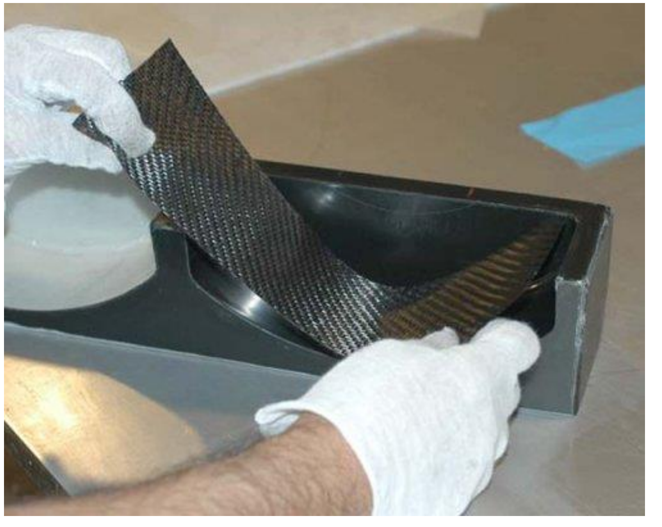
Inner Diameter 1.0 mm wall tickness 24 micron
2.6mm 64 micron

Polyimide tubes

- <u>High radiation hardness:</u> according to **CERN-98-01** report, **polyimide**:
    - No problem below 10^7 Gy
    - Mild damage between 10^7 to 5 10^7 Gy
    - 1st layer of ITS Inner Barrel will be exposed to 700 krad/yr.=7000 Gy/yr.
- <u>Ageing:</u> physical and chemical stability over time.
    - Plastic Pipe Institute states corrosion is not an issue in plastic pipes.
- Comply to **LHC Fire Safety Instruction (IS-41)**
    - **Polyimide** is allowed.
- <u>High radiation length material</u> (plastics better than metals).
    - Polyimide: X_0 = 29 cm, minimum wall thickness is 0.025 mm.
    - PEEK: X_0 = 31.45 cm, minimum wall thickness is 0.25 mm.



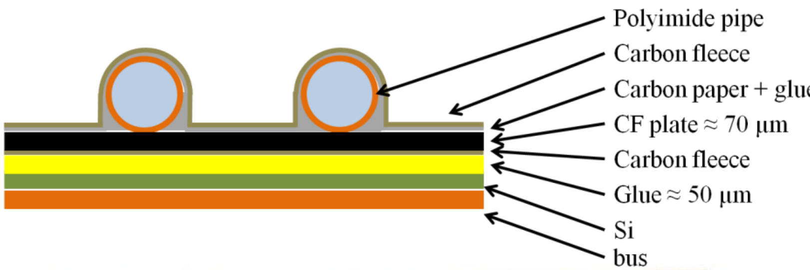
Filament winding



Manual Lay-up

Production process

Production Process:
Manual Lay-Up & Filament winding



Wound Truss Structure plus Carbon Plate with Embedded Pipes

Filament winding

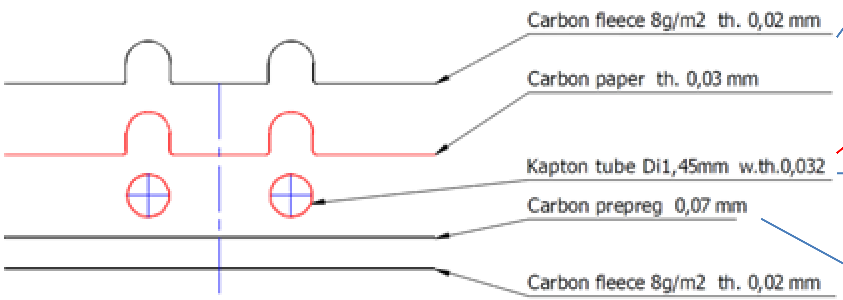
spaceframe

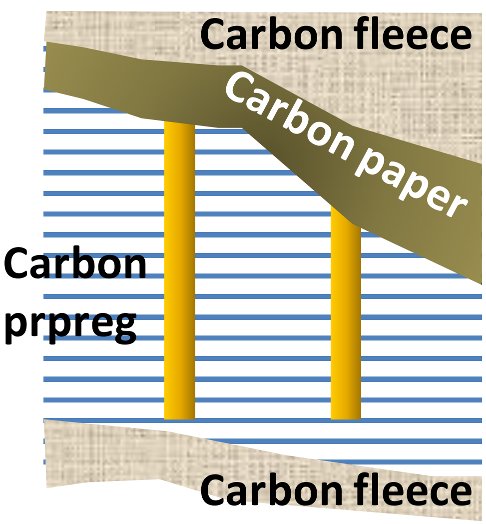
coldplate

Manual Lay-up

9 chip 15x30mm

Production Process: Manual Lay-Up

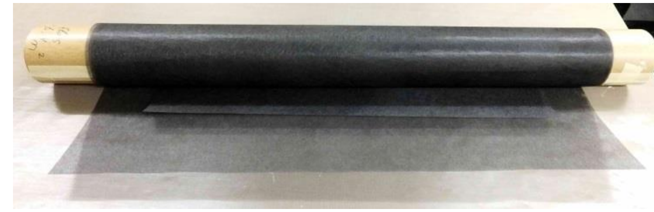




Production Process: Manual Lay-Up

Lay-up choise

Lay up samples	1	2	3	4	5
	Prepreg	C Fleece	Mylar	Fleece	Prepreg
	CF Paper	Prepreg	Prpreg	Prepreg	
		CF Paper	CF Paper	Fleece	
		C Fleece	Mylar		
thick (mm)	0.09	0.14	0.11	0.12	0.07
Weight (gram)	0.33	0.40	0.37	0.31	0.20



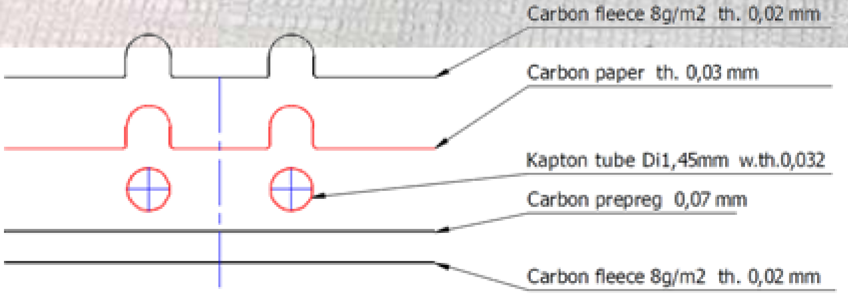
C Fleece

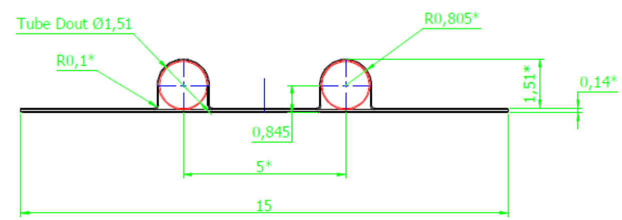
GF fabric

Prepreg

CF Paper

Production Process: Manual Lay-up





Production Process: Curing

Cyanate ester resin

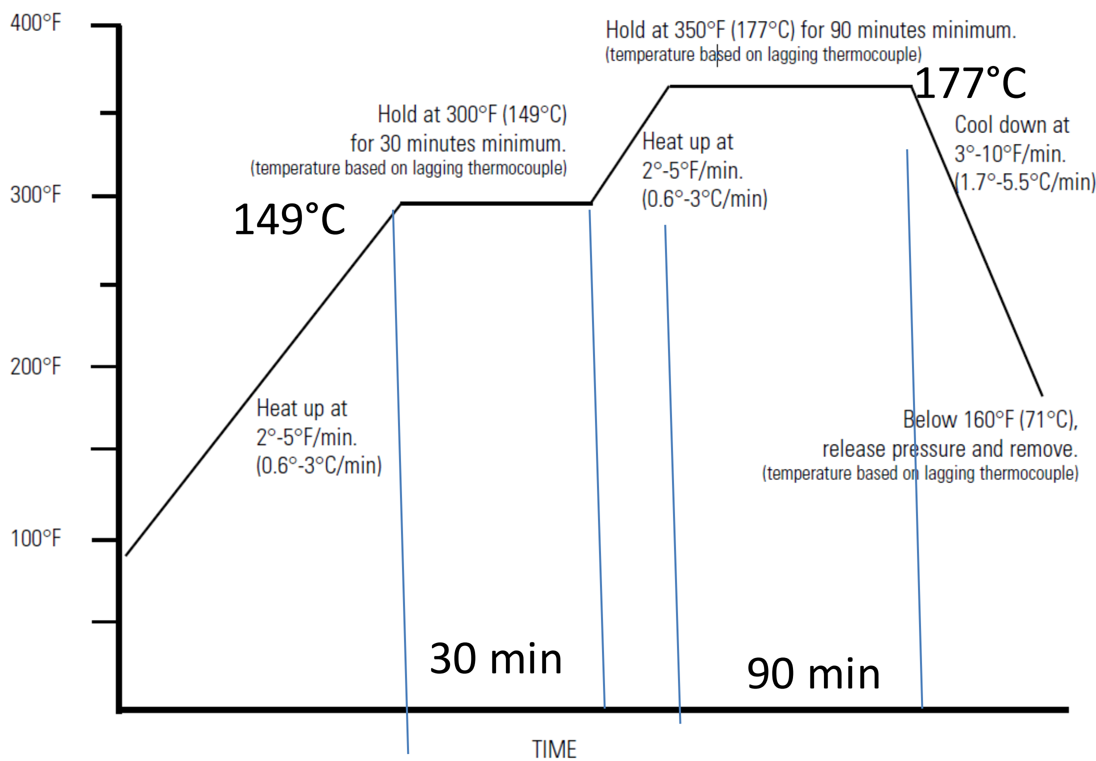
EX1515, RS3

- ✓High radiation resistance,
- ✓low moisture absorption
- ✓low outgassing
- ✓unparalleled toughness.
- ✓excellent resistance to microcracking, even when subjected to thermal cycling and high levels of radiation exposure

RS-3 NEAT RESIN MECHANICAL PROPERTIES

Property	Value
Tensile Strength	11.6 ksi
Tensile Modulus	430 ksi
Tensile Strain	4.9 %
Flexural Strength	18.4 ksi
Flexural Modulus	481 ksi
Fracture Toughness, G_{1c}	2.10 in-lb/in^2

	4581 AQ III / EX-1515
	8 HS FAW 300 gsm
Tensile Strength	109.8 Ksi (757 MPa)
Tensile Modulus	3.45 Msi (23.8 GPa)
Compression Strength	78.8 Ksi (543.3 MPa)
Compression Modulus	4.06 Msi (28.0 GPa)
Flexural Strength	107.0 Ksi (737.7 MPa)
Flexural Modulus	3.16 Msi (21.8 GPa)
ILSS	9.86 Ksi (68.0 MPa)

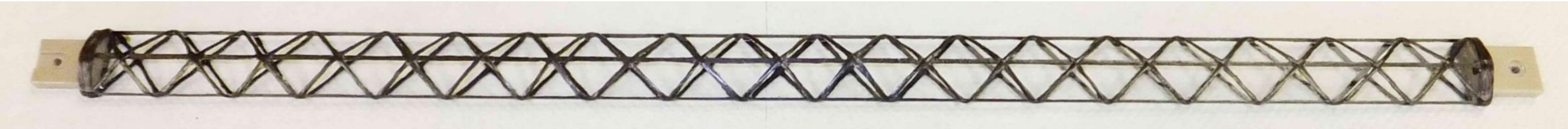


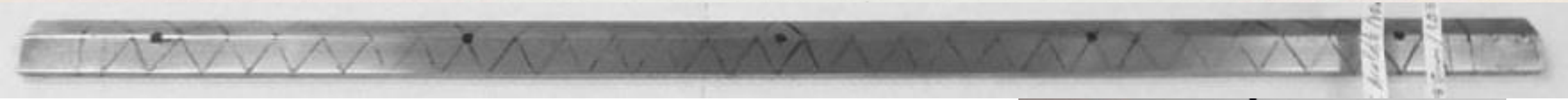
RS3

- Apply 30 - 85 psig pressure

Production Process: Mould extraction

Production Process: Filament winding

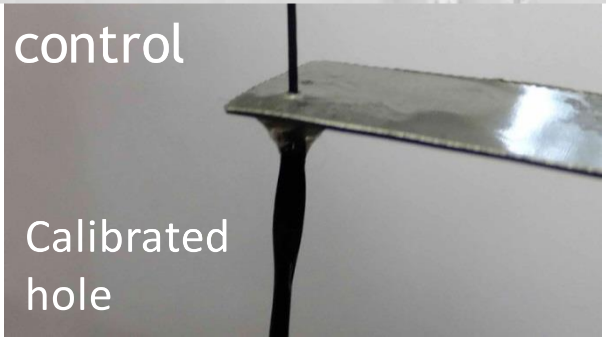




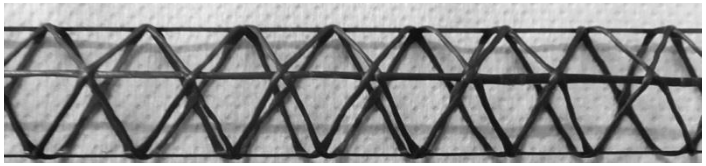
D hole=0,5mm for thread M55J
and
D hole =0,3mm for thread M60J

1. CF thread dry M55JB -**6k** (6000) 220tex (0,22g/m)
2. CF thread dry M60 -**3k** (3000) 100tex (0,103g/m)

Resin control

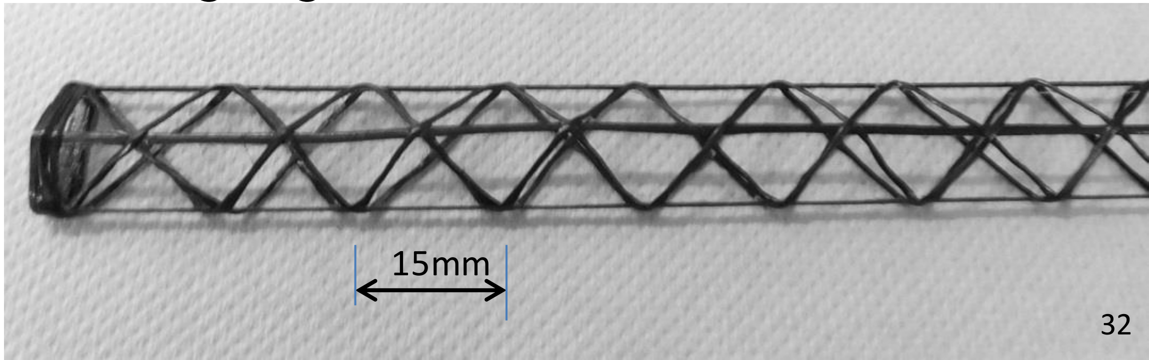


Roving Twisting

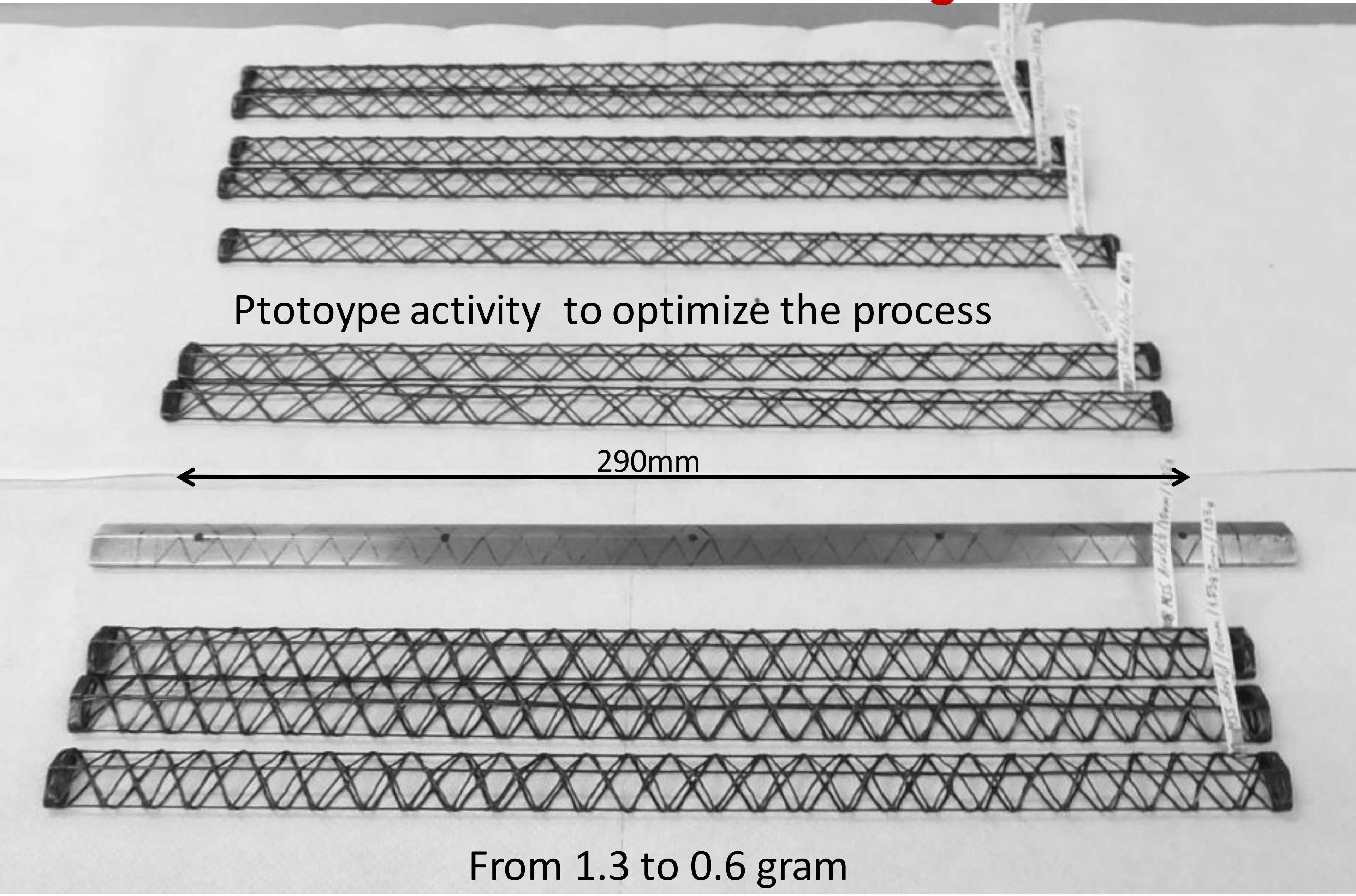


10mm

Winding Angle

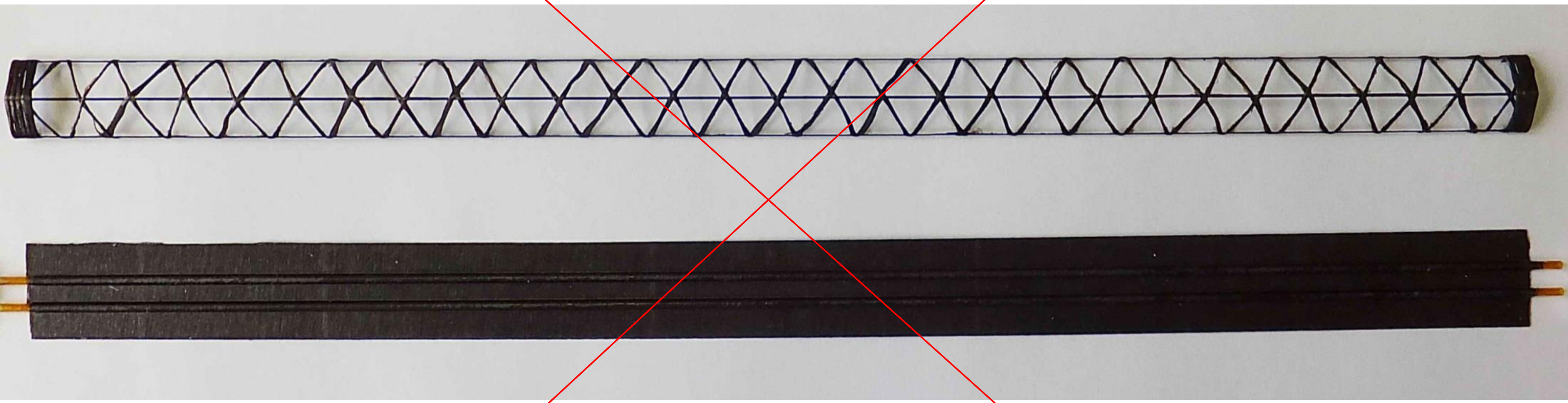


Production Process: Filament Winding



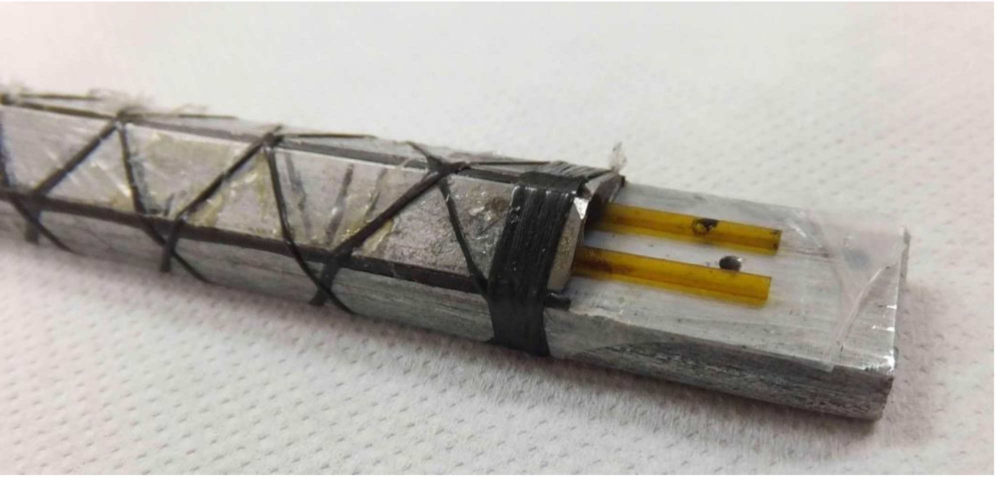
Production Process: Gluing parts

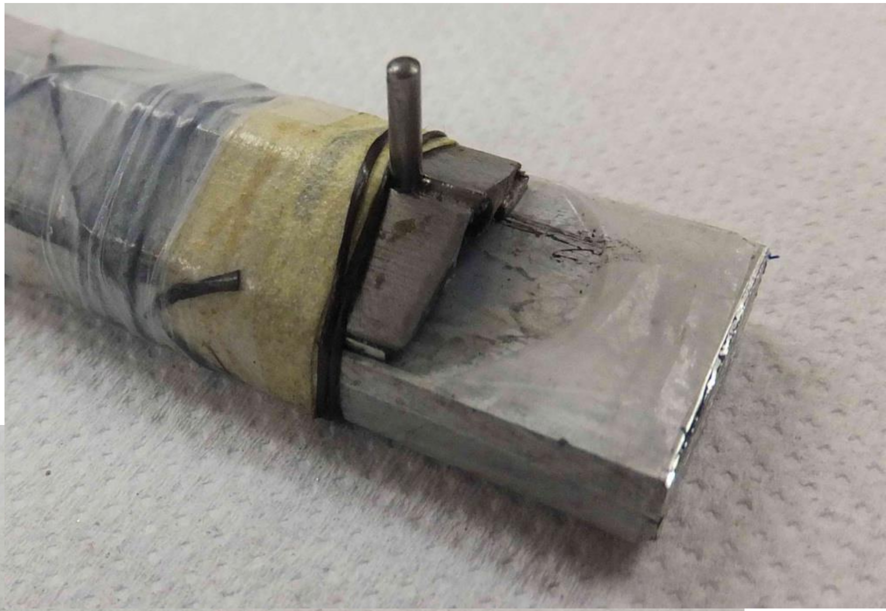
Minimize gluing steps, It is diffucult to take under control the weight of glue

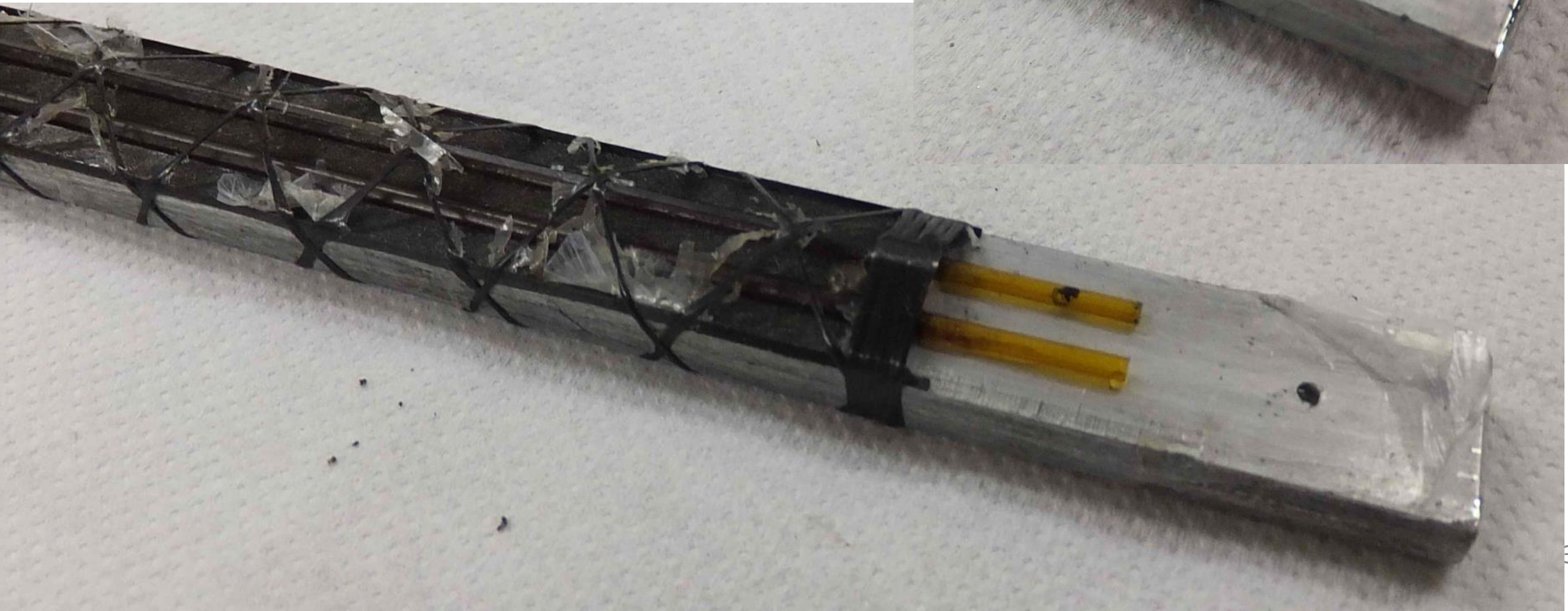


Curing process 125°C 2hours

Production Process: Filament winding



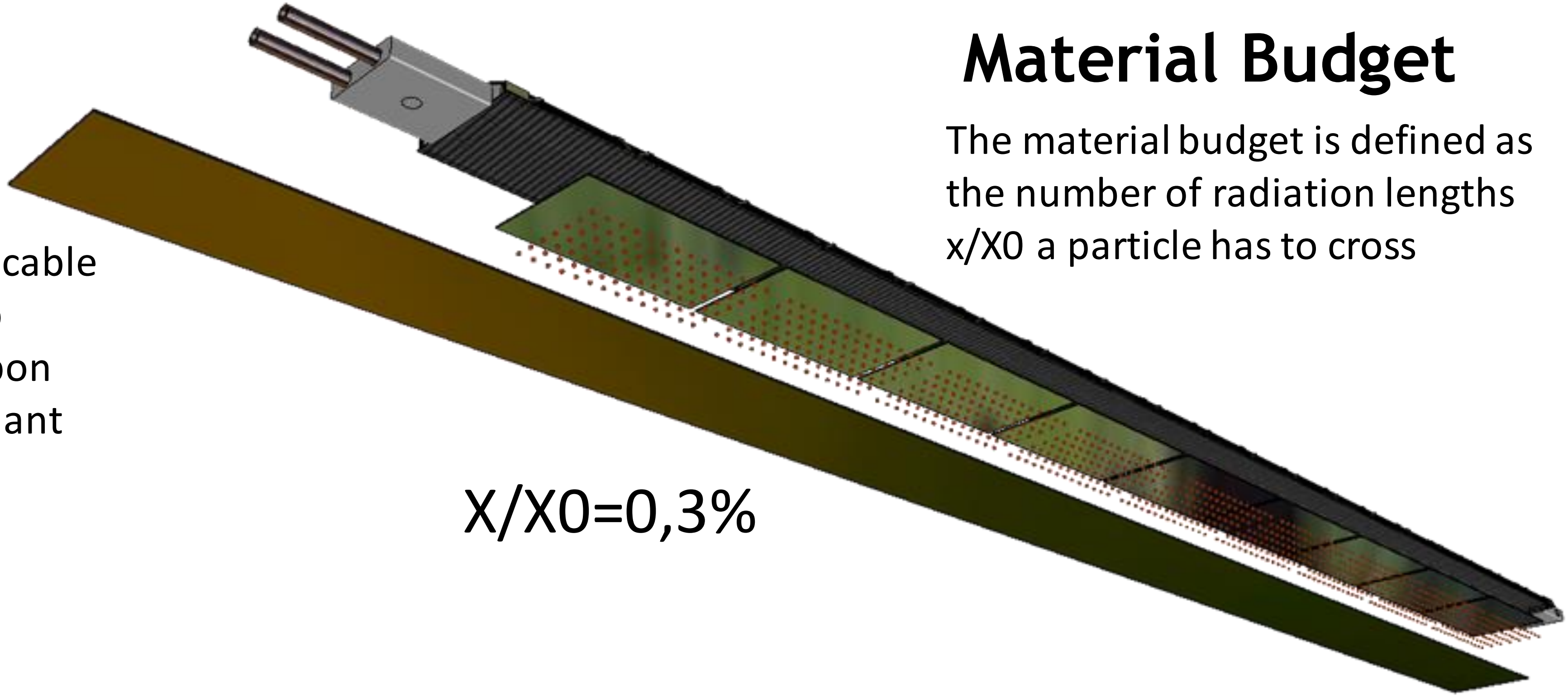




Production Process: Manual Lay-up

Material Budget

The material budget is defined as the number of radiation lengths x/X0 a particle has to cross



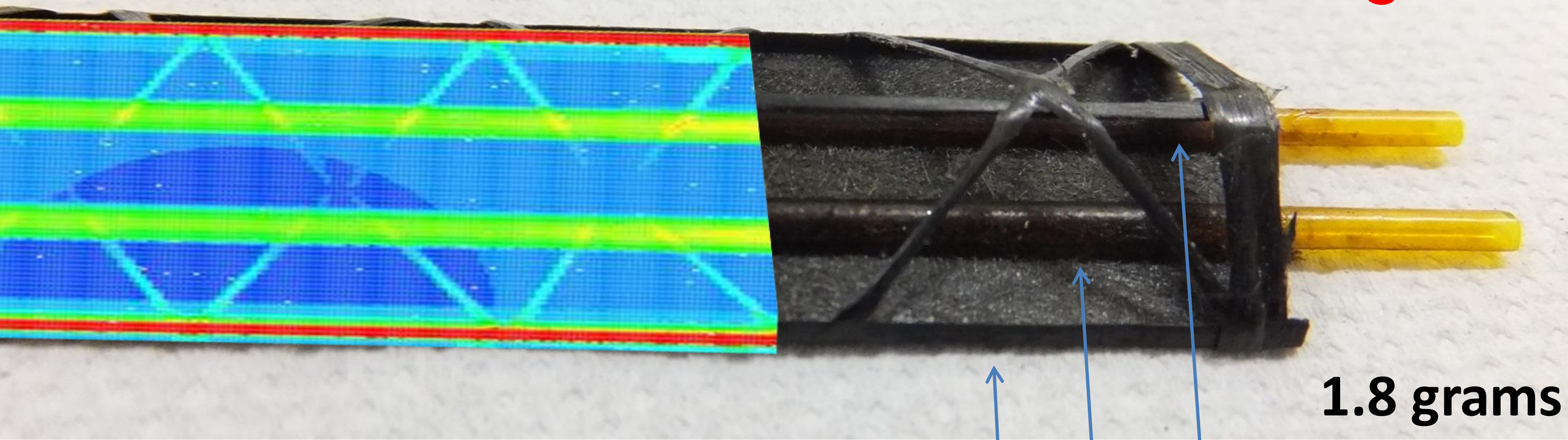
Flex cable
Chip
Carbon
Coolant

X/X0=0,3%

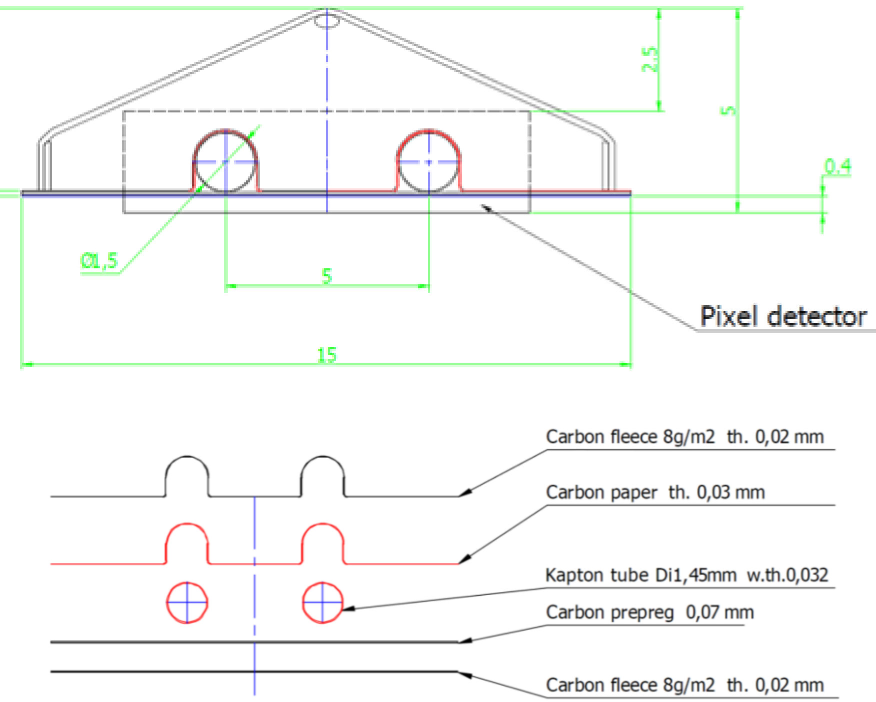
The **radiation length** of a material is the mean length (in cm) to reduce the energy of an electron by the factor 1/e

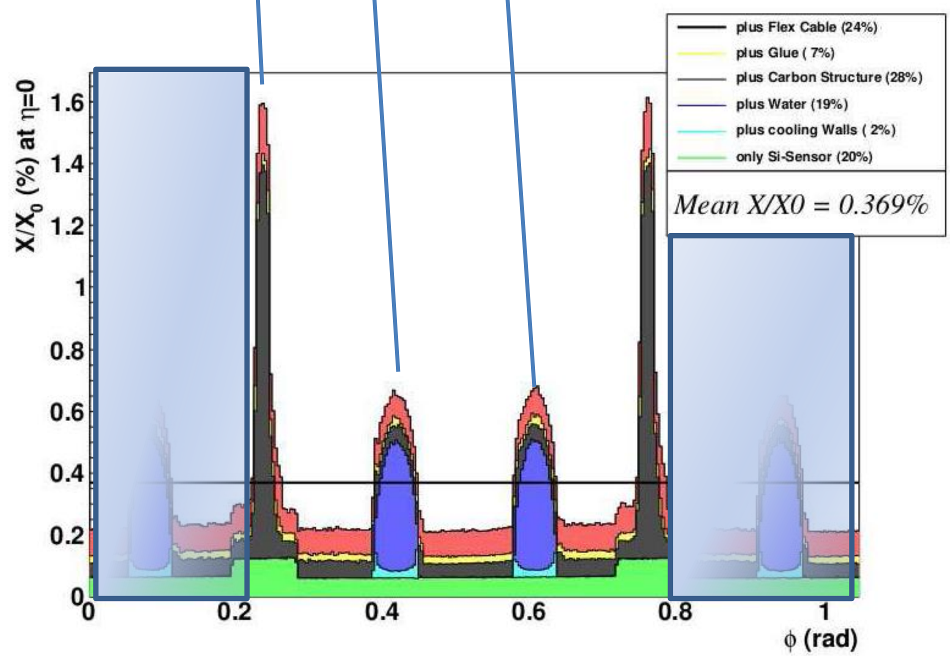
Material	Density (g/cm3)	X0 (cm)
Carbon		
CFRP filament (M60J-3K)	2.21	19.23
CFRP filament (M55J-6K)	1.63	26.07
CFRP filament (T300)	1.73	24.64
Amec Thermasol FGS 003	1.6	26.56
K13D2U-2K	1.64	25.87
C Fleece	0.4	106.24

Material Budget



1.8 grams

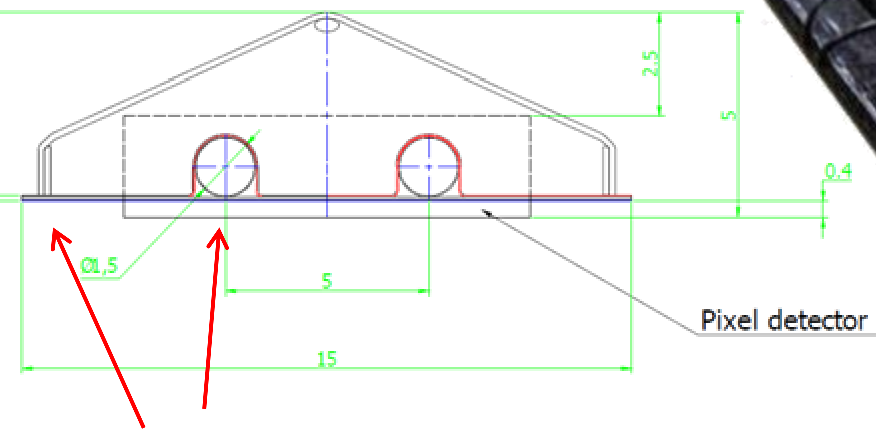


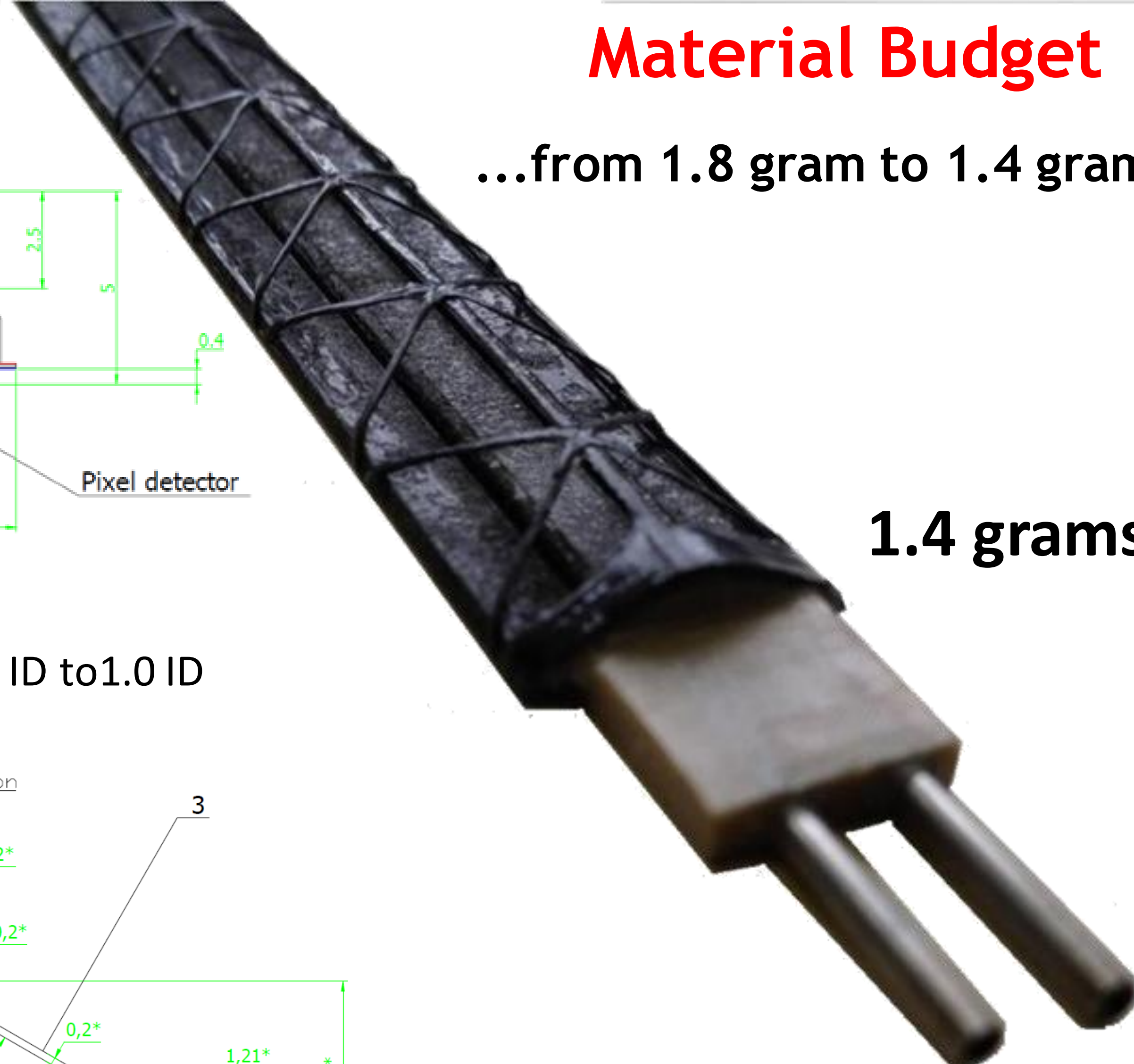


Internal section area for two tubes 3.3 mm2

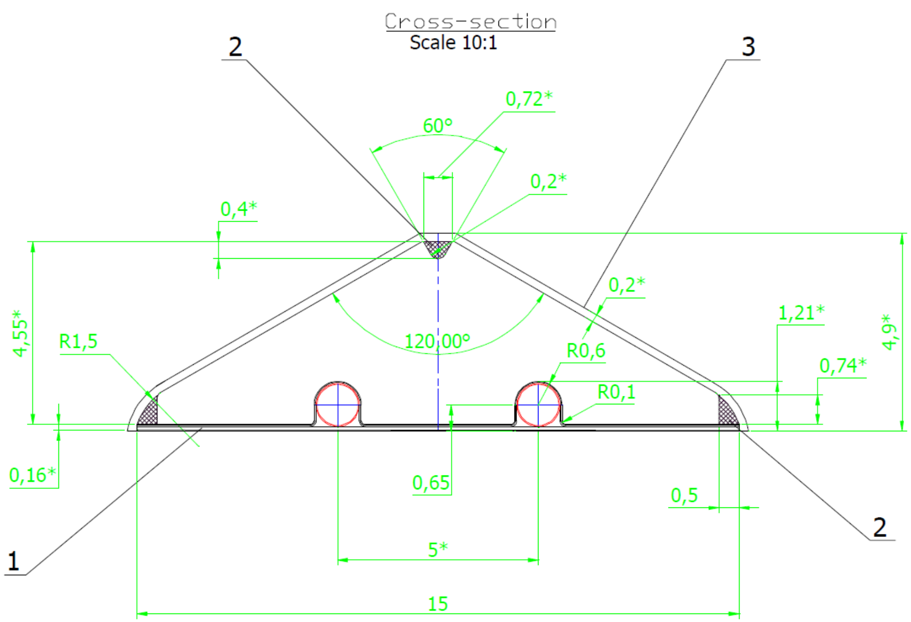
Material Budget

...from 1.8 gram to 1.4 gram



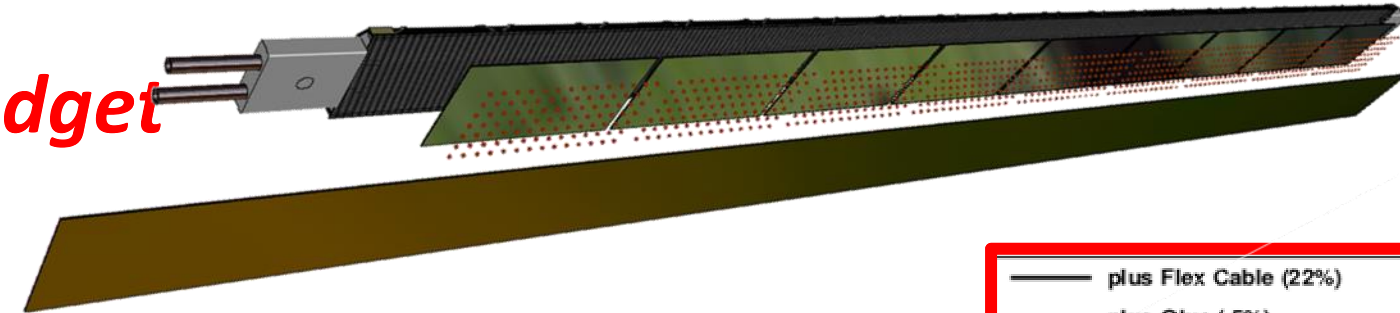


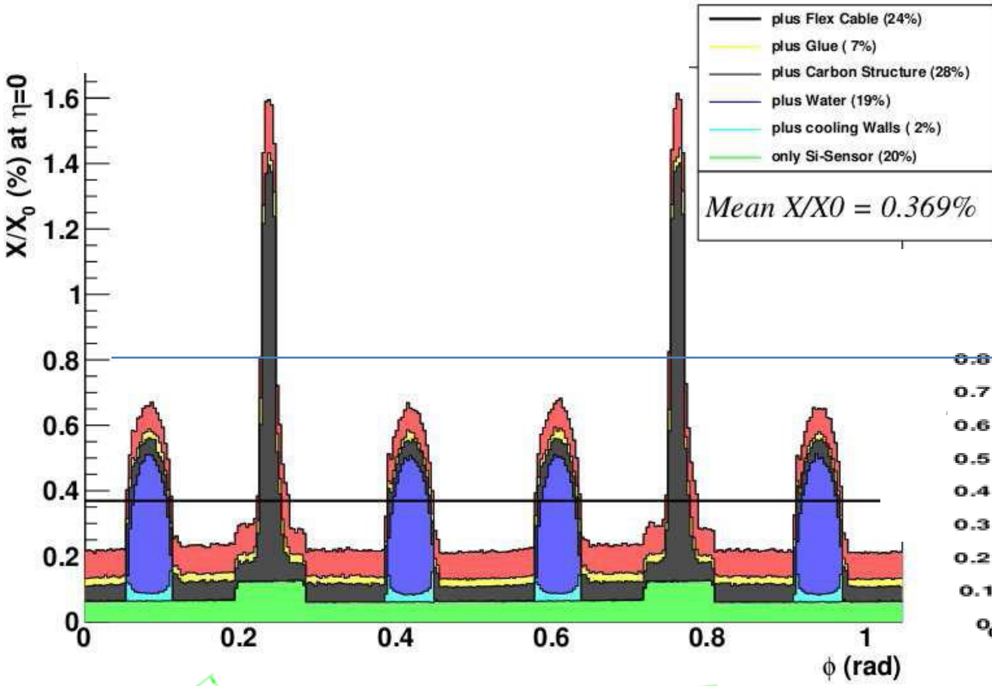
Material reduction
Smaller pipe from 1,5 ID to1.0 ID
Smaller side-walls

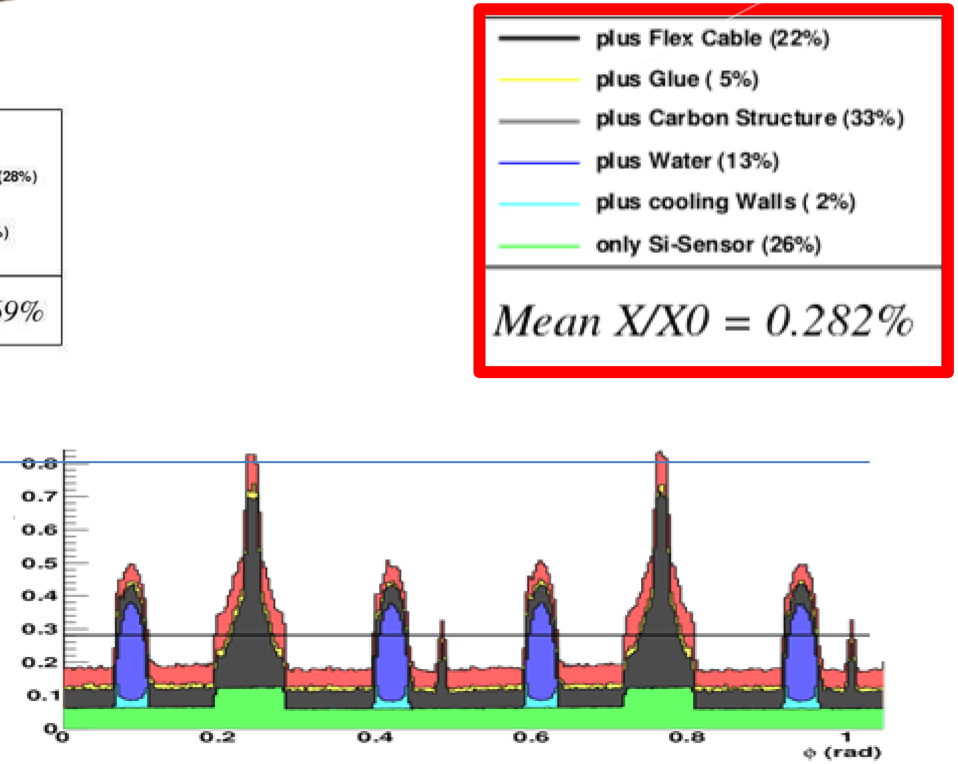


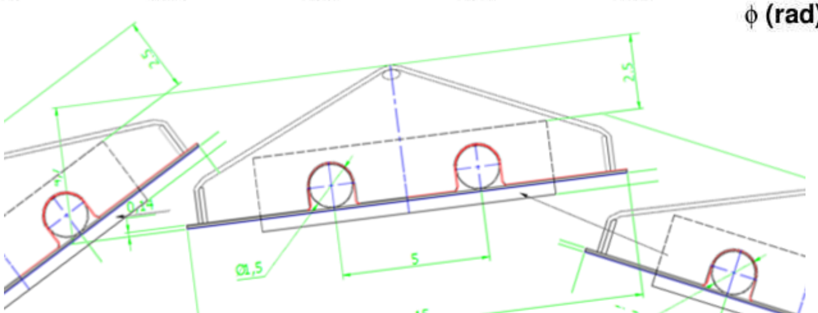
INNER BARREL

Material Budget

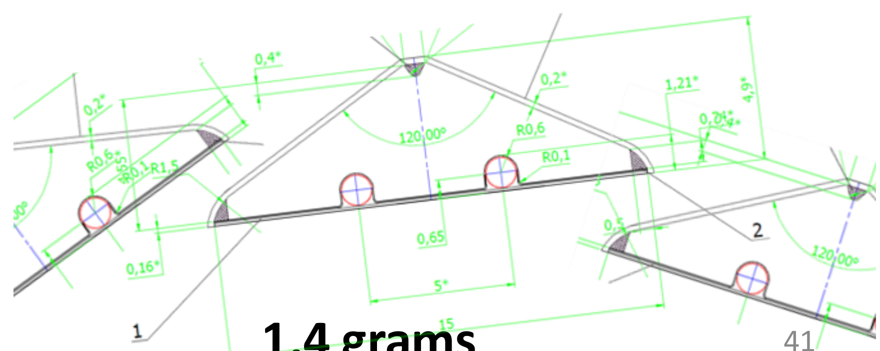








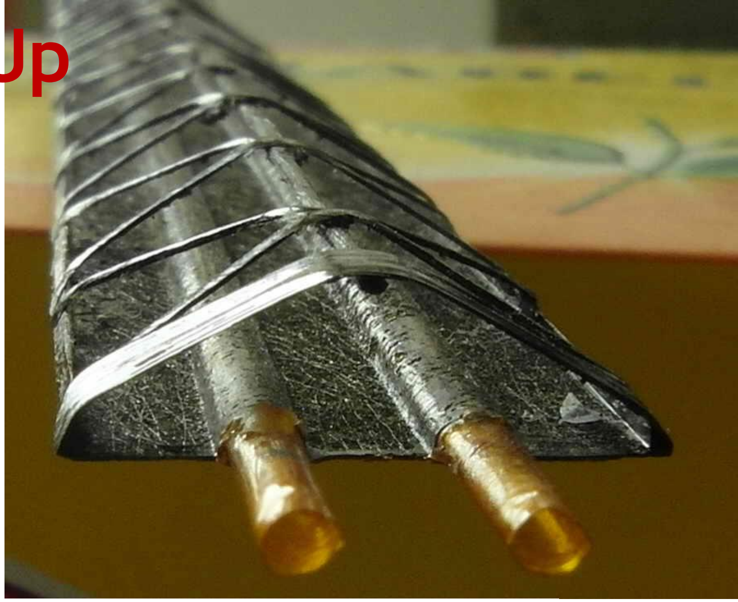
1.8 grams



1.4 grams

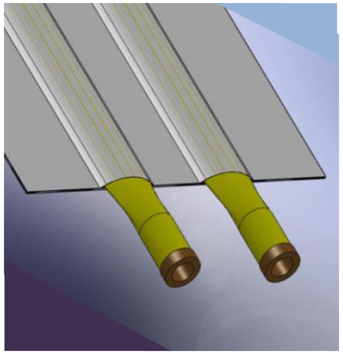
Alternative stave design

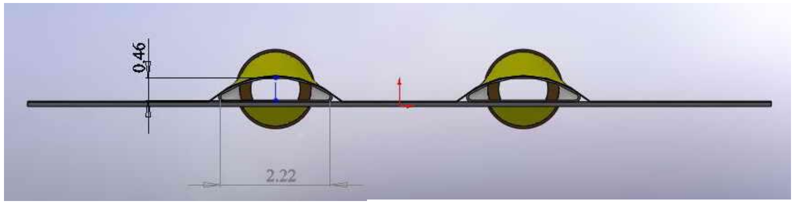
Production Process: Manual Lay-Up



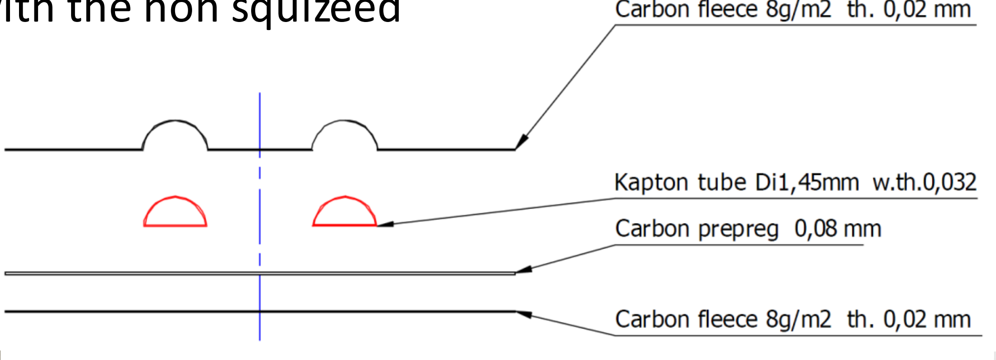
Alternative stave design

Eliminate one layer= carbon paper

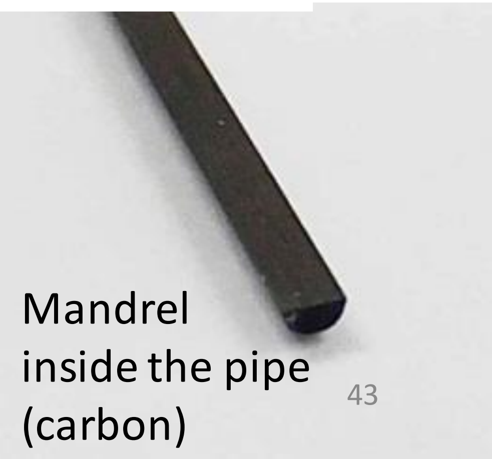




Thermal performances comparable with the non squizeed



Pipes Squizeed



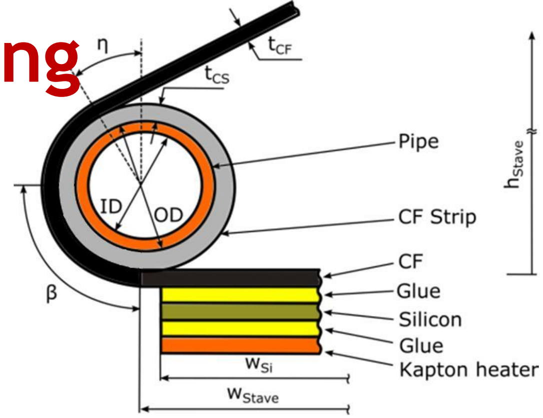
Mandrel inside the pipe (carbon)

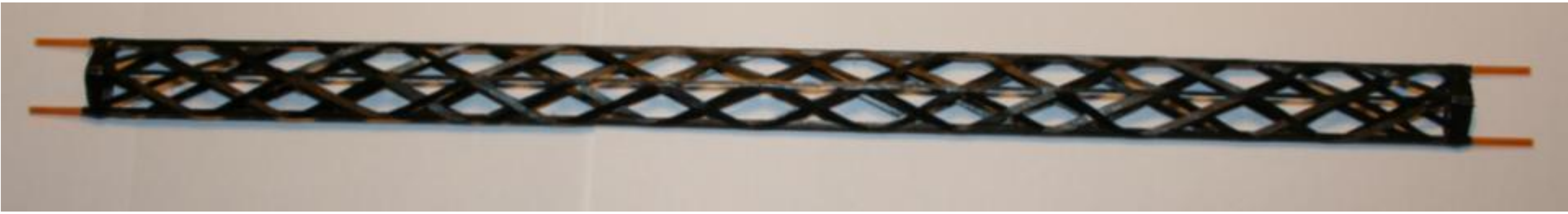
Production Process: Filament winding

Alternative stave design

Use of High thermal conductive fiber

K13D-2U 2K K= 800 W/mK





Wound Truss Structure with Pipes

Production Process: Filament winding

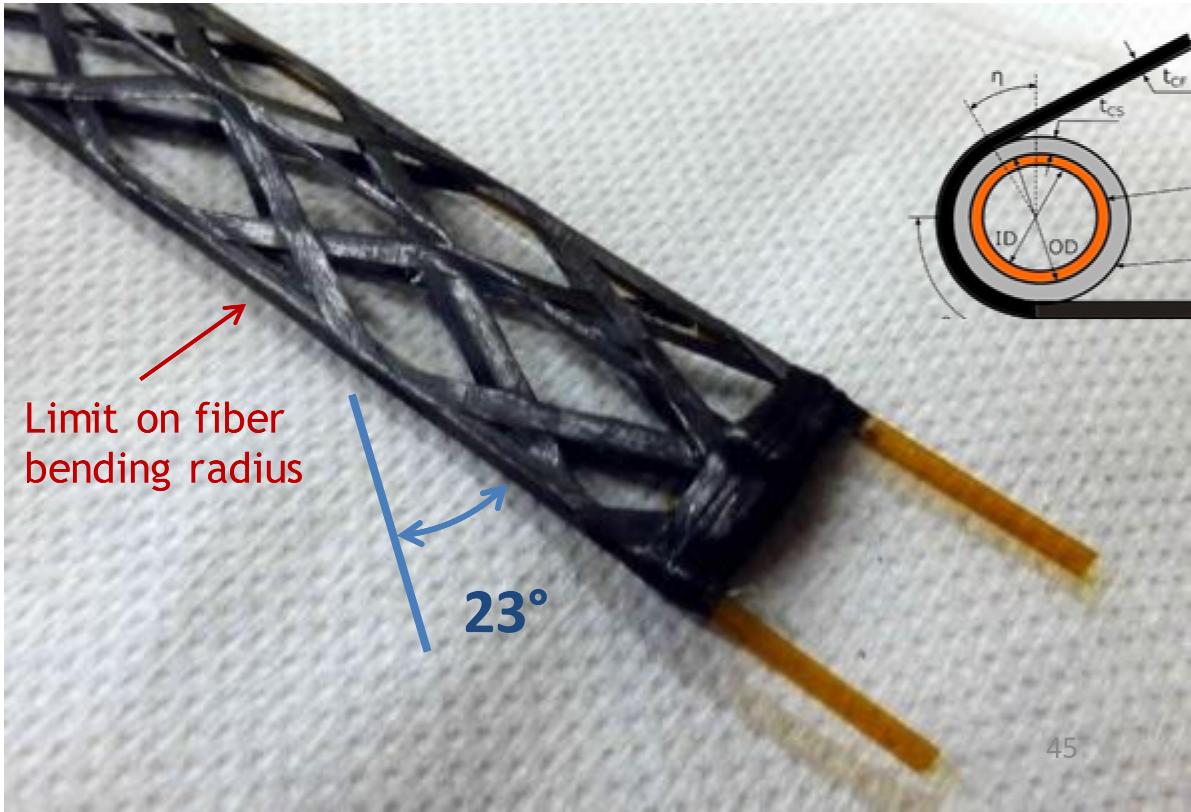
Alternative stave design

K13D-2U 2K   K= 800 W/mK

Winding angle <23° to avoid fiber break during winding due to fiber High Modulus

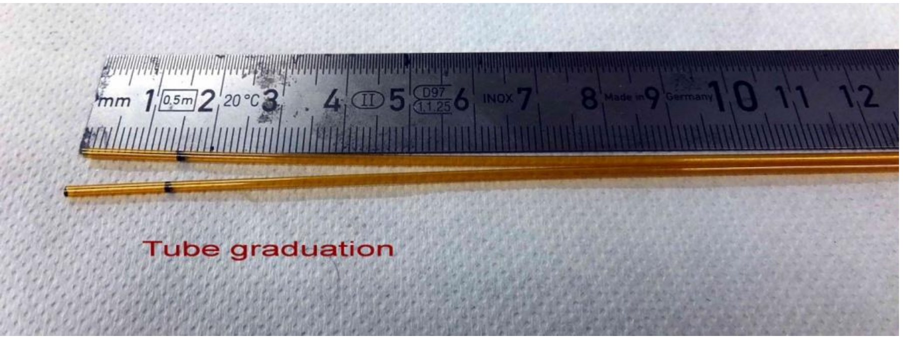
E=935 Gpa

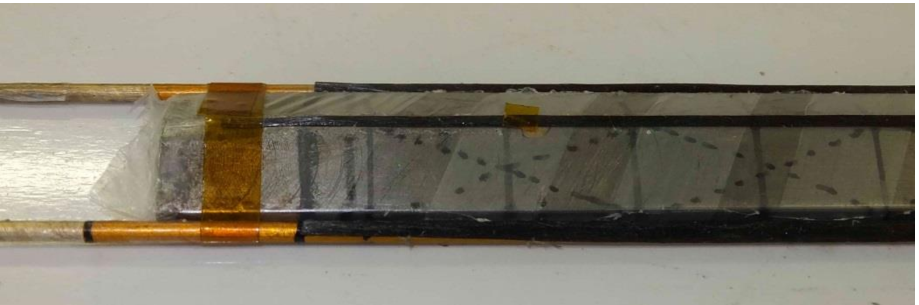
Filament radius 11 µm



Production Process: Filament winding

Alternative stave design





Carbon around the pipes

Production Process: Filament winding

Alternative stave design

Winding angle limited by the minimum bending radius of high thermal conductive fiber

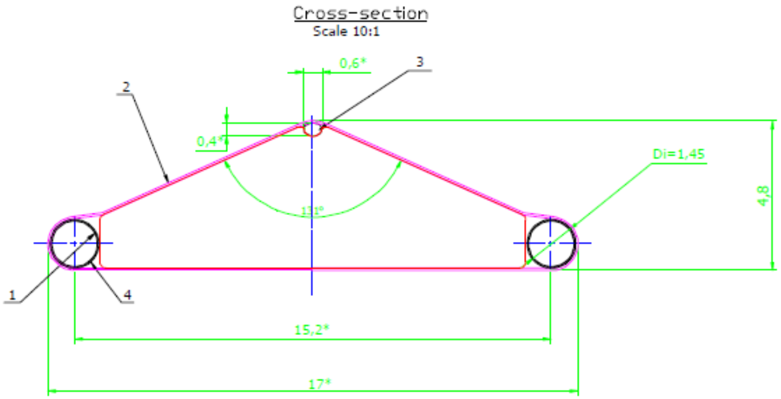
Production Process: Filament winding

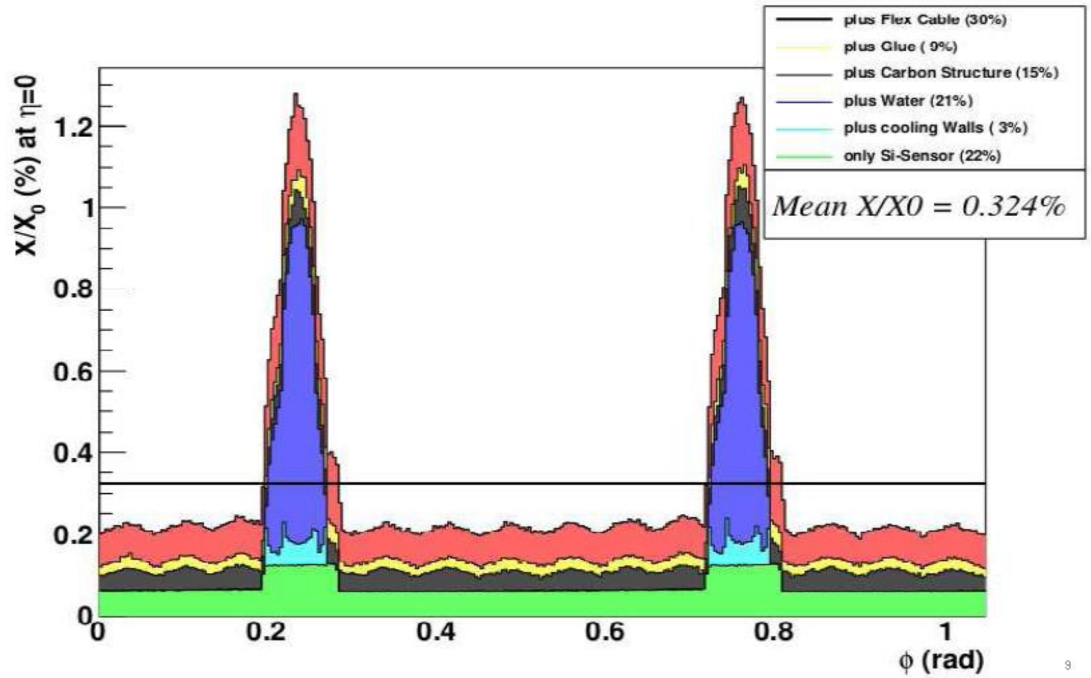
Alternative stave design

Winding Steps

Material Budget

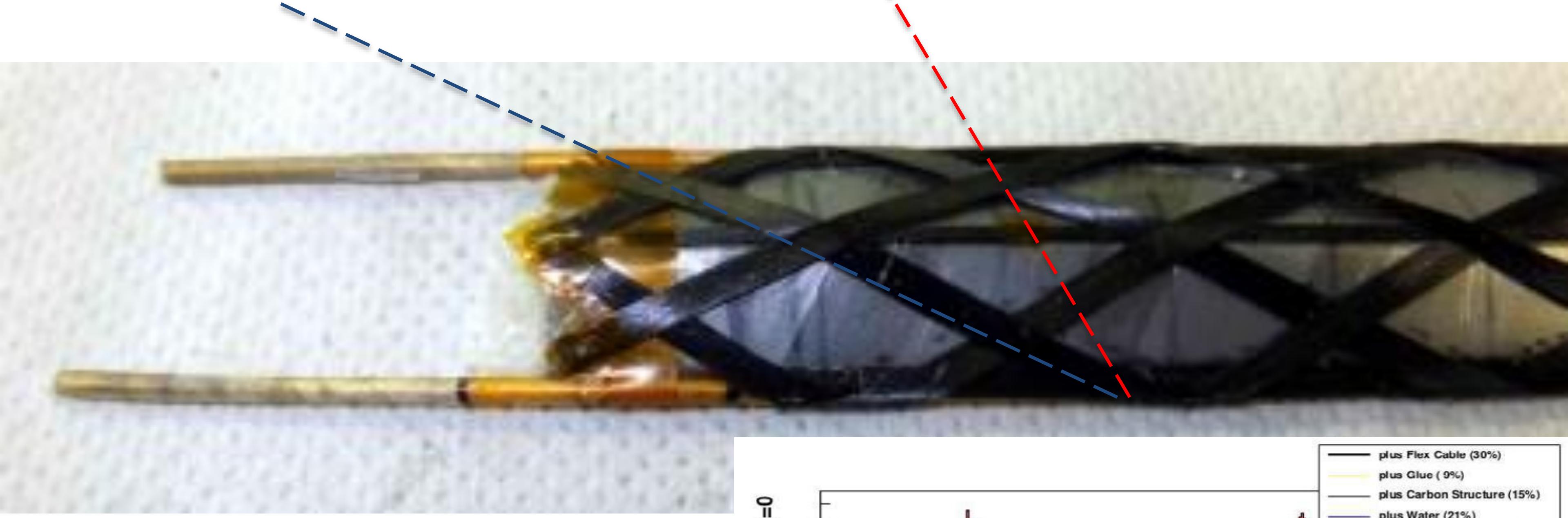
Alternative stave design

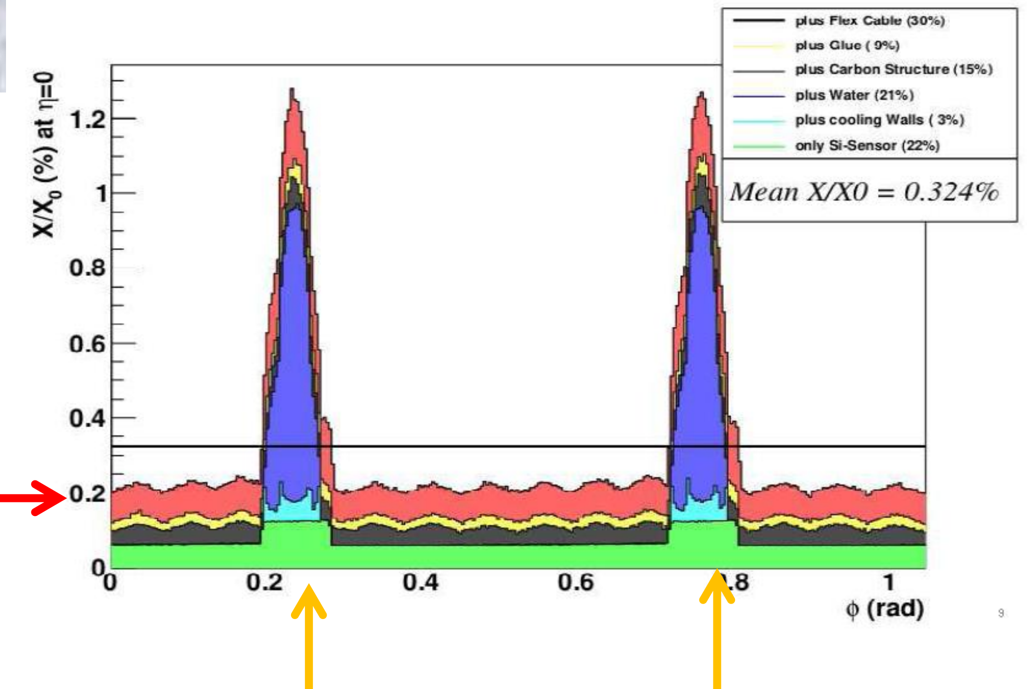




-**Reduce material by increasing the thermal effictivenss of the thermal bridge**

-**Change coolant from water to C4F10 two-phase**

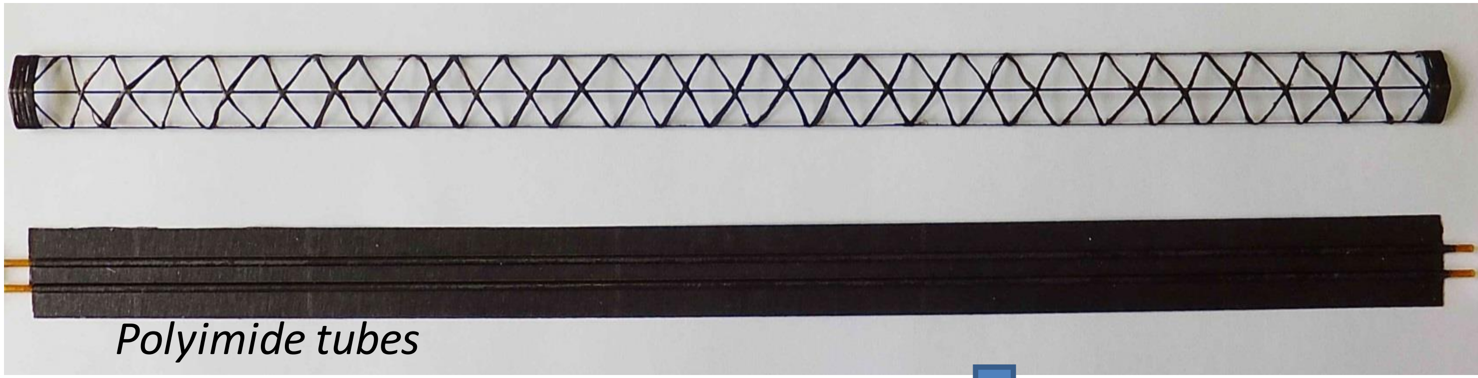




New dry Roving K13D2U 2K
will be used to verify the possibility to
increase the winding angle between
fiber and pipes

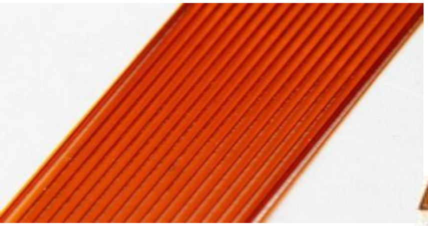
Cold plate alternative design

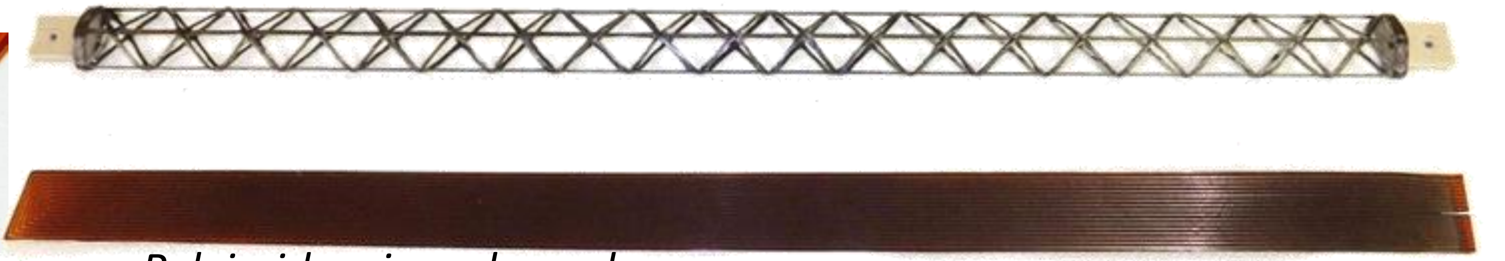
e



Polyimide tubes

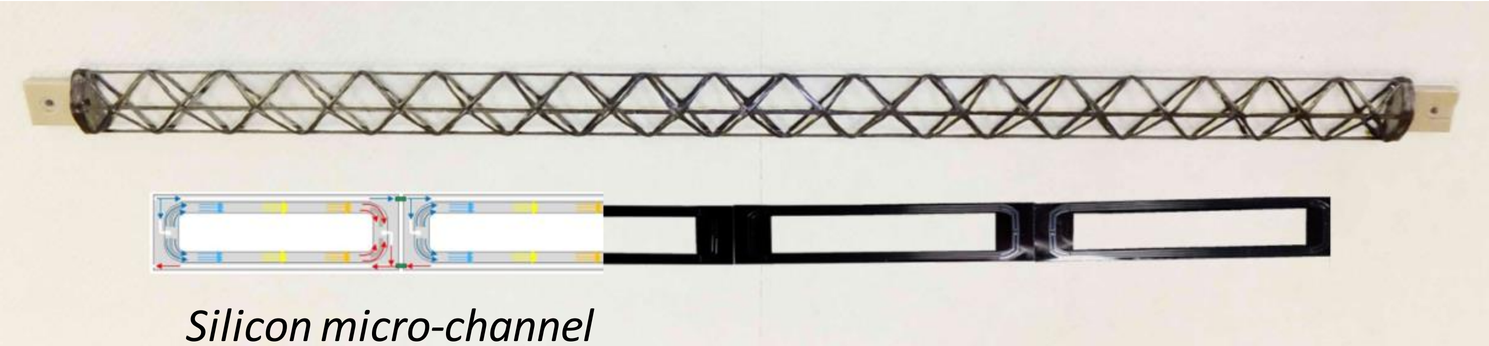
Cooling pipes



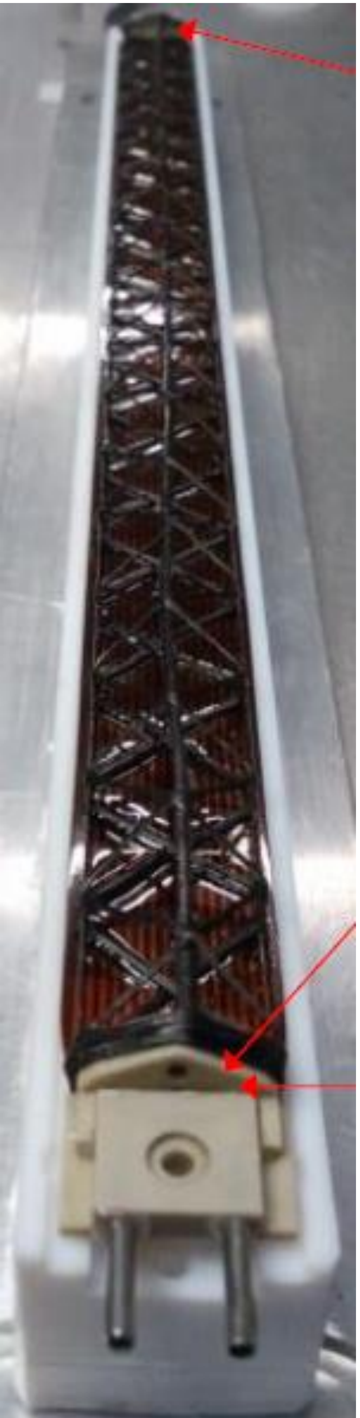


Polyimide micro-channels

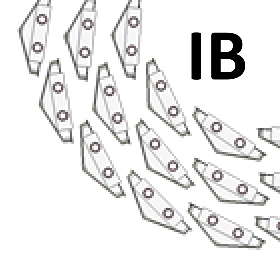
Micro-channel



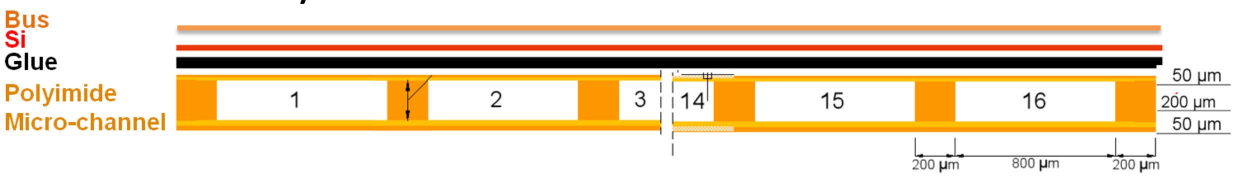
Silicon micro-channel



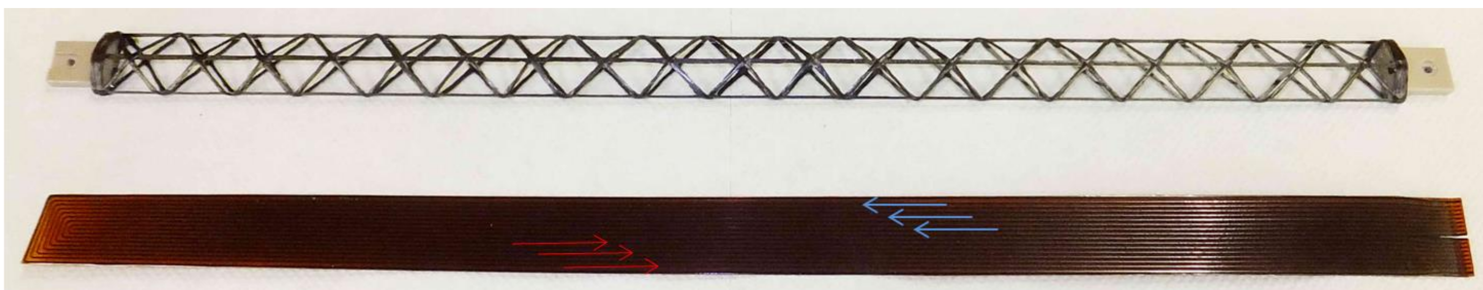
“Polyimide micro channel" IB



Polyimide section

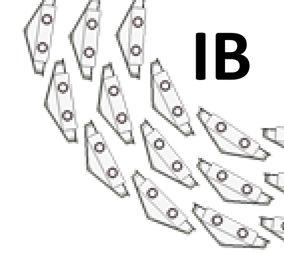


The structure is a multilayer polyimide stack-up made of a layer of Pyralux LF110 at the bottom, a Photoimageable PC 1020 layers in the middle and a Pyralux LF110 layer glued on the top. The rectangular pattern which defines the channels is created with a photolithography process

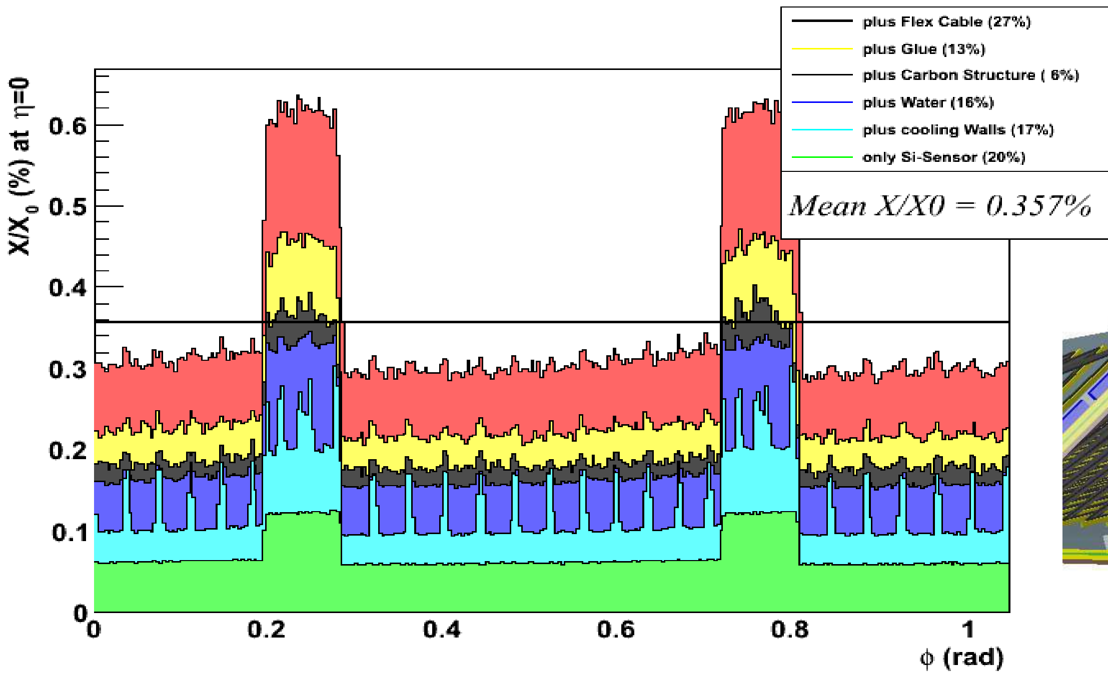


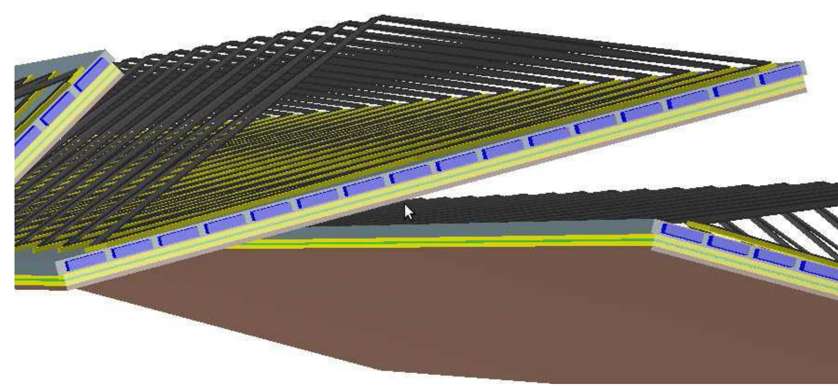
✓"Polyimide micro channel"

IB



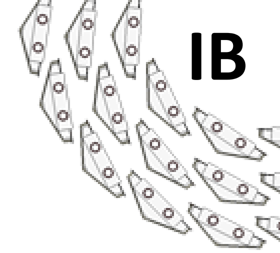
The power density is 0.2 W/cm2, the water flow rate is 1.2 l/h and water temperature at the inlet is 14.9 °C.

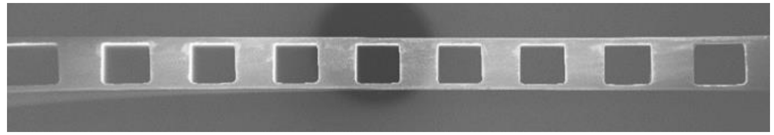


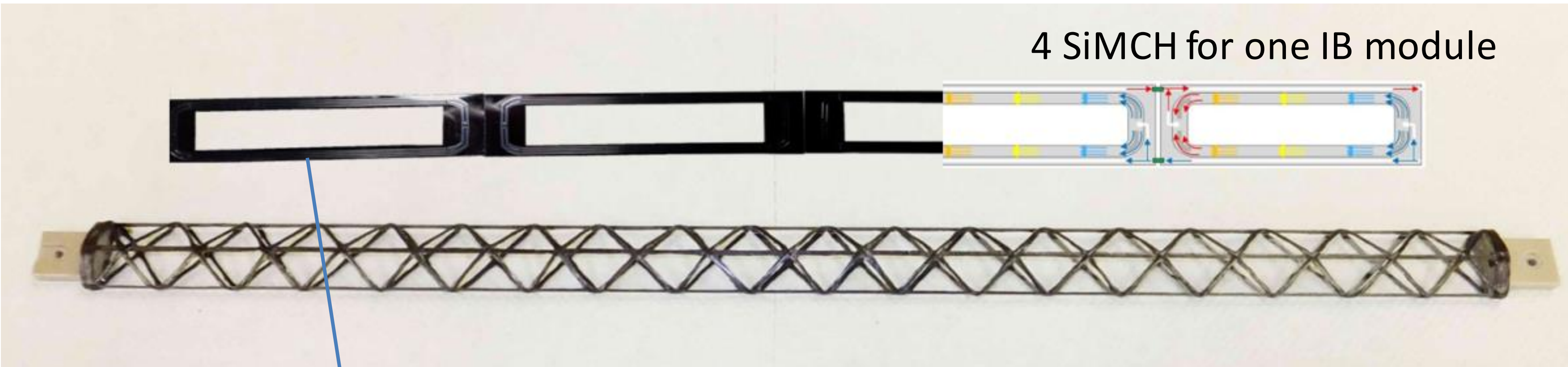


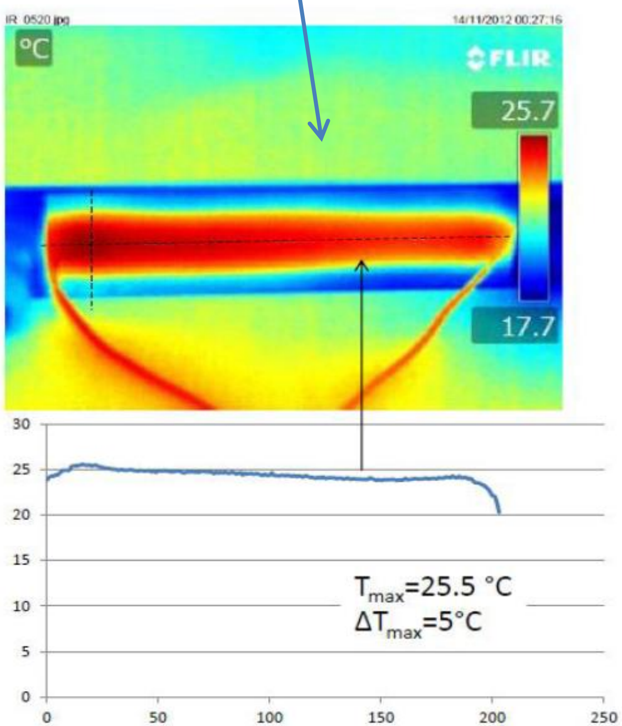
✓SIlicon micro channel

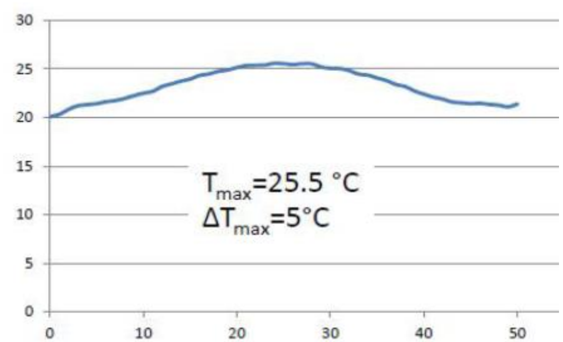
IB











Two-phase flow

P=0.3 W/cm²

Flow-rate =0.6 g/s

T_{in} **fluid=**18°C

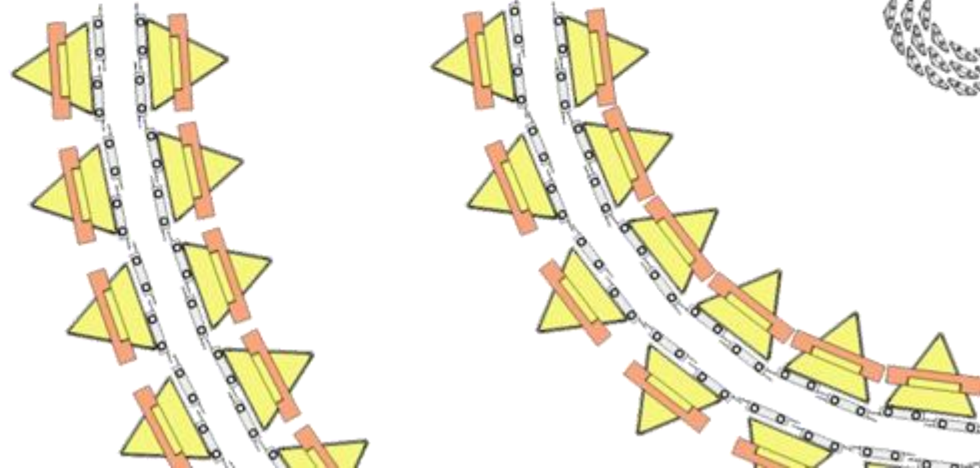
Δ (Tchip-T$_{C_4F_{10}}$)<5°C

on single module

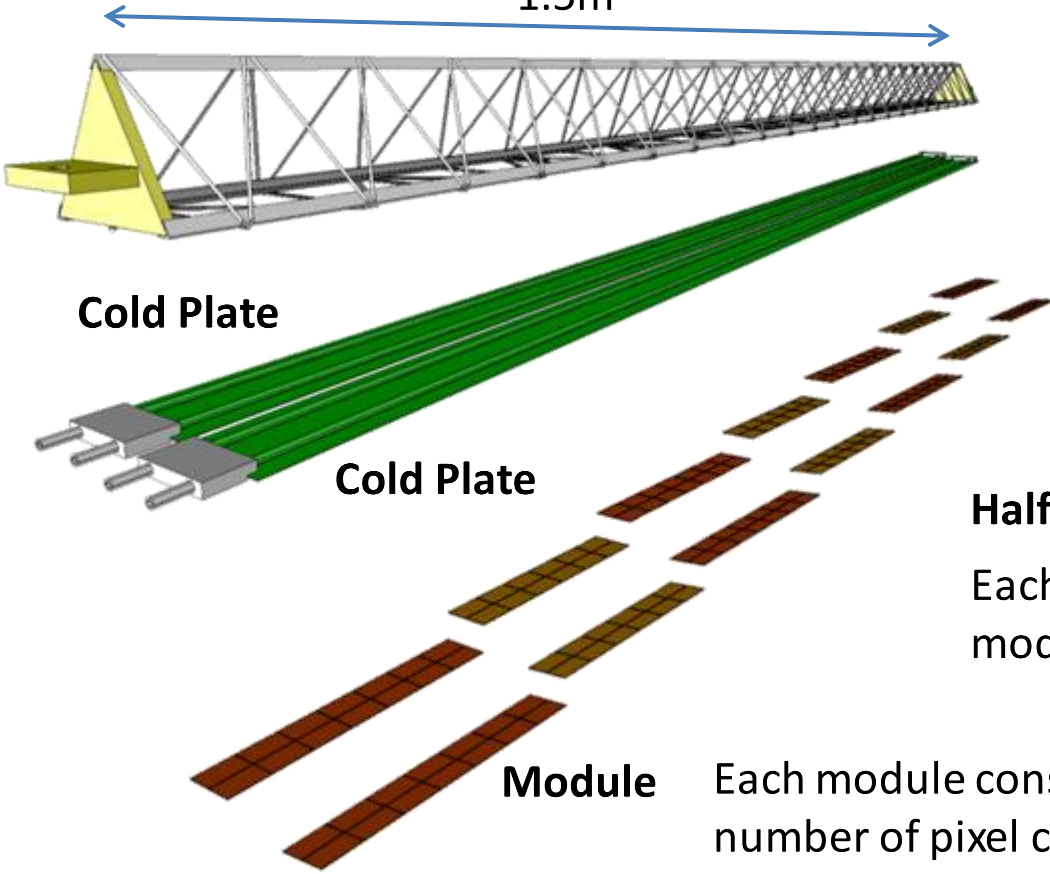
See ALESSANDRO MAPELLI presentation (next)

TRACKER
STAVE from 30cm to 1,5 m

OUTER BARREL (OB)



Stave

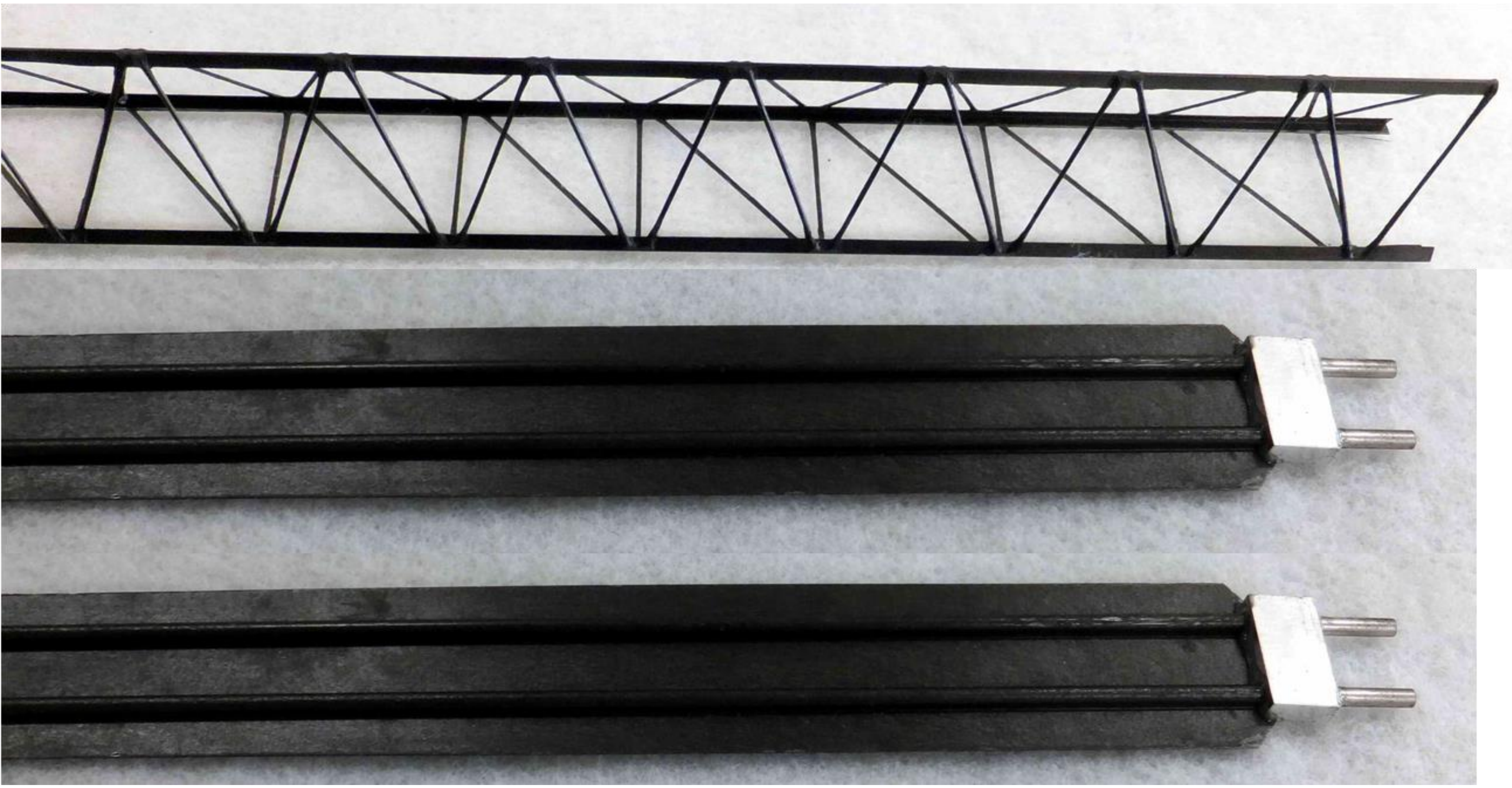


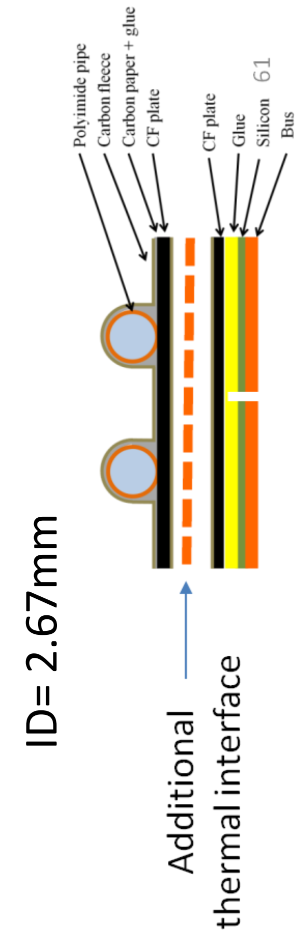
Half-Stave

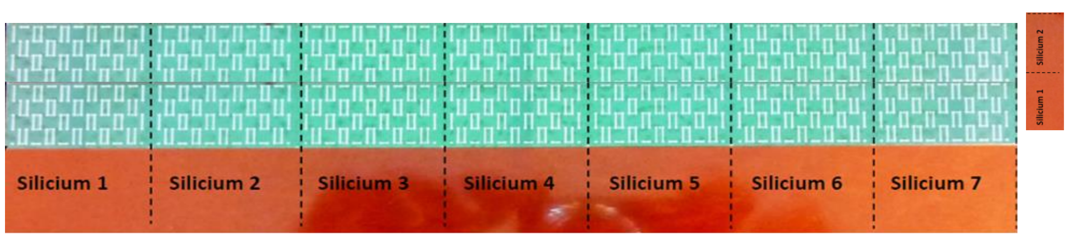
Each half-stave will consists of a number of modules glued on a common cold plate

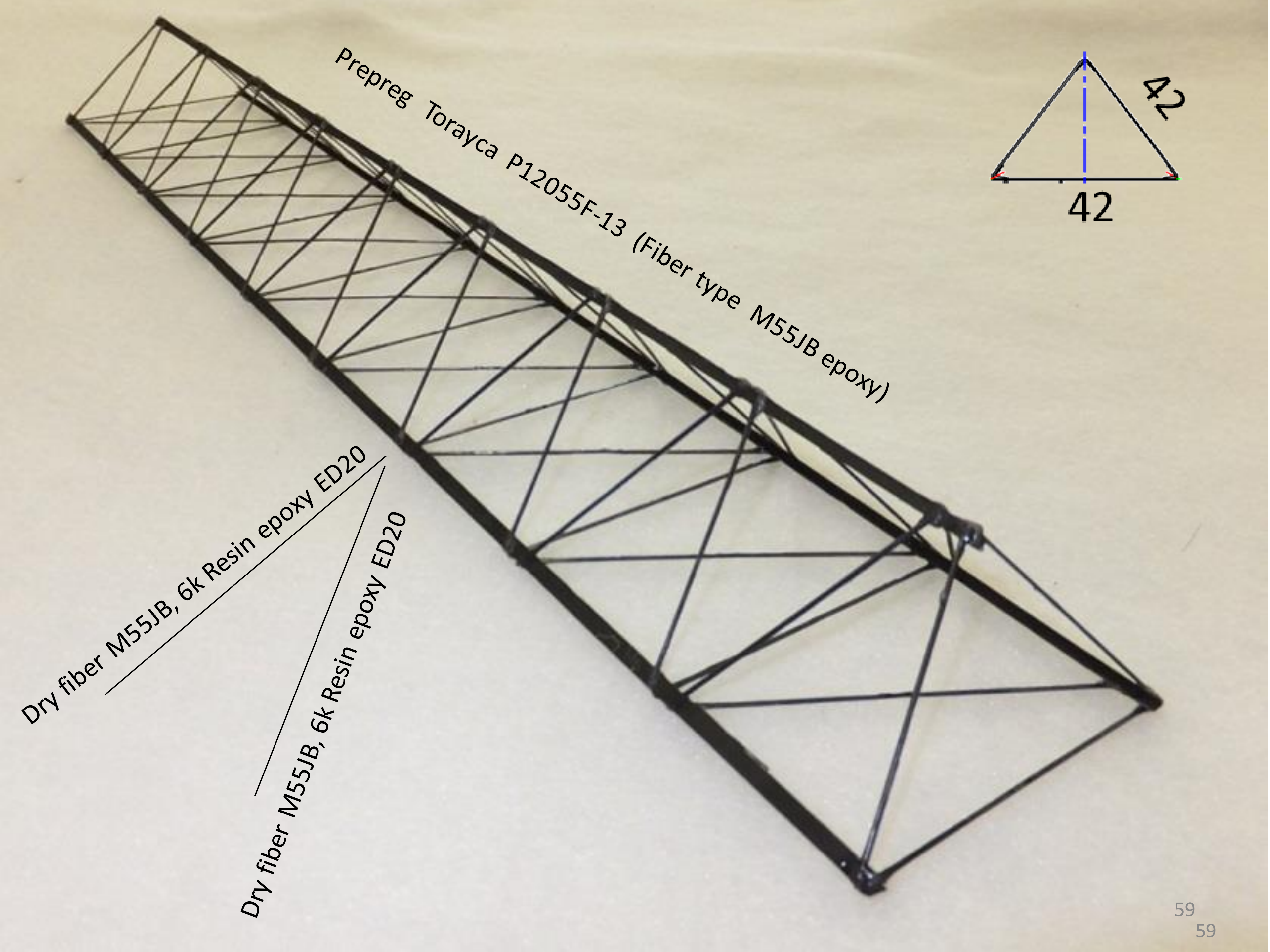
Each module consists of a hybrid integrated circuit, i.e. a number of pixel chips (e.g. 2 x 7) bonded on a flexible printed circuit, which might be glued on a carbon ply

OUTER BARREL (OB)

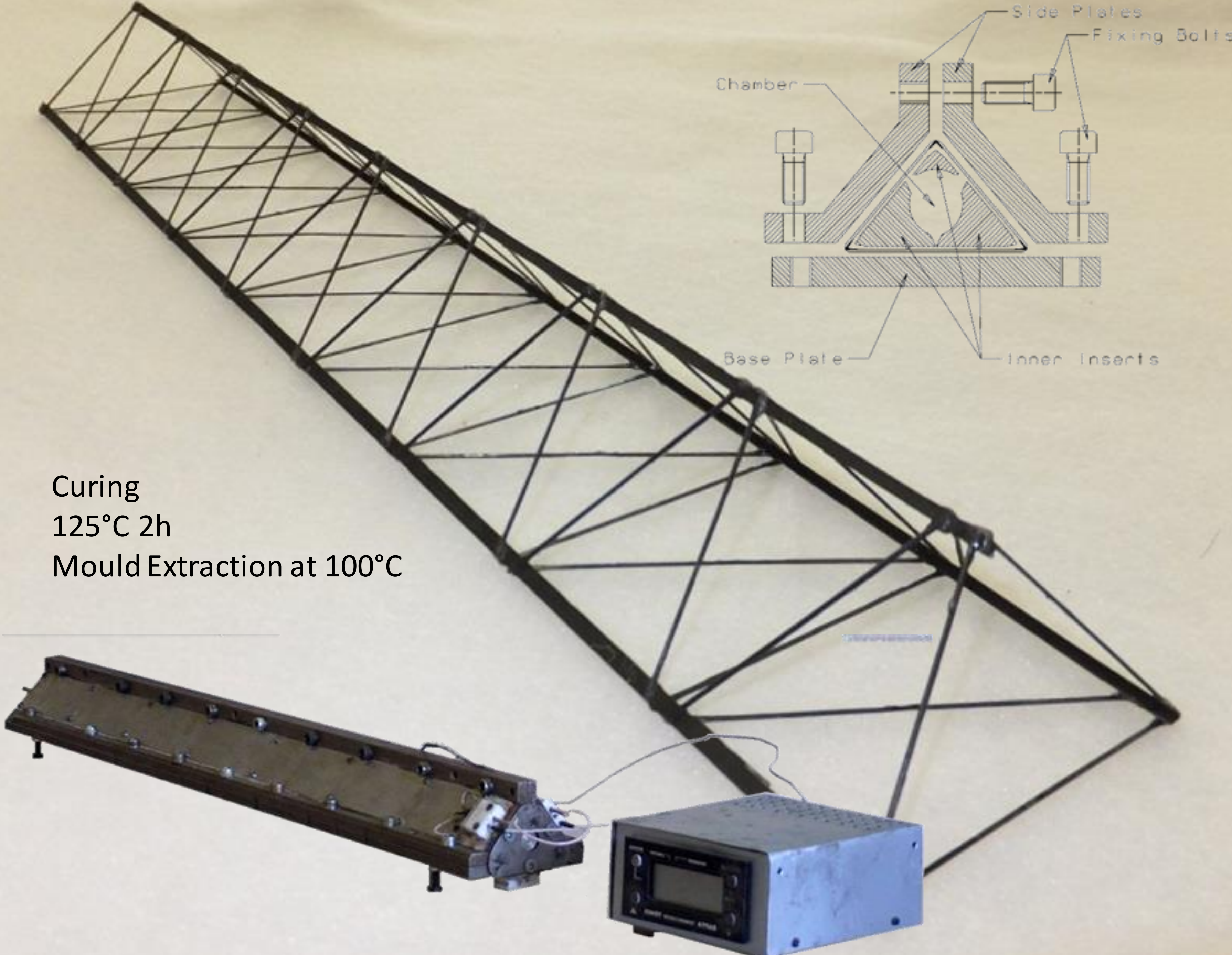




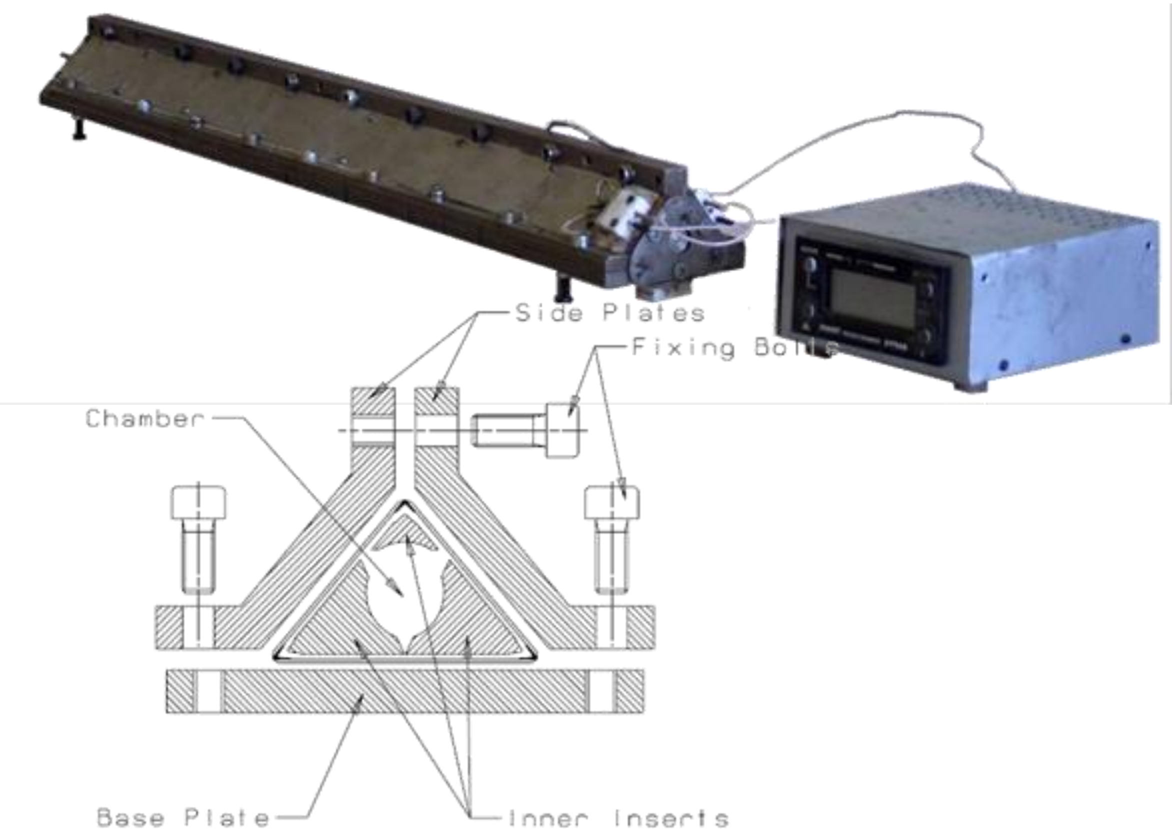


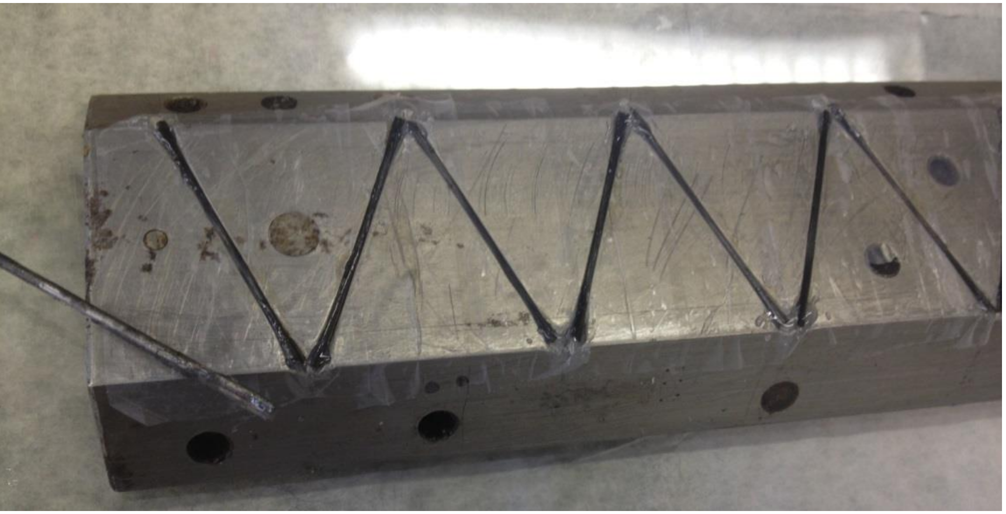

Prepreg Torayca P12055F-13 (Fiber type M55JB epoxy)
42
42
Dry fiber M55JB, 6k Resin epoxy ED20
Dry fiber M55JB, 6k Resin epoxy ED20

59



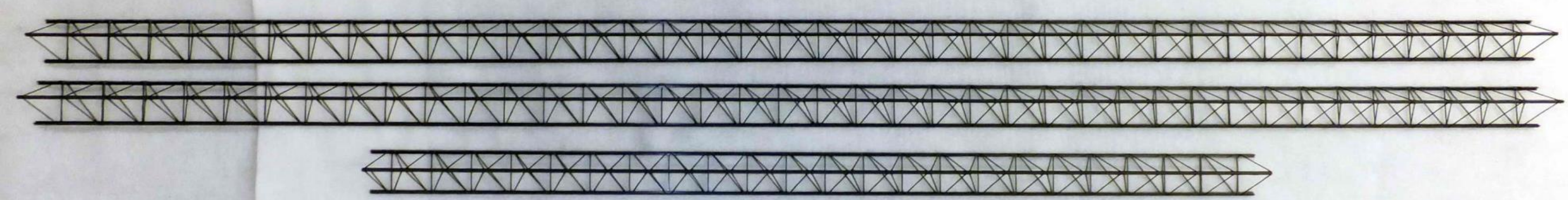
Curing
125°C 2h
Mould Extraction at 100°C


Side Plates
Fixing Bolt
Chamber
Base Plate
Inner Inserts

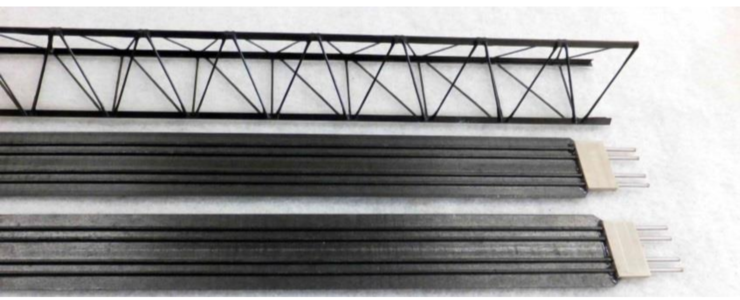


Outer barrel staves # PROTOTYPE

LAYER 5,6 length 1526mm. Weight 33,6g



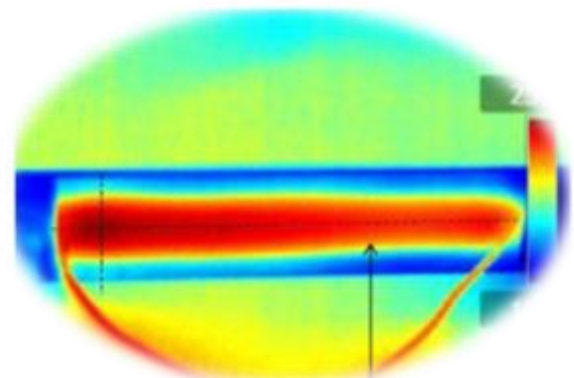
LAYER3,4 length 900mm. Weight 18g



TEST

Structural

Thermal



TEST

ENIGINEERING MODULE

Modules used for development to predict beahviour with confidence. Specifically are used to evaluate design concept, verify analytical techniques, determine failure modes or cause of failure. *Development test*

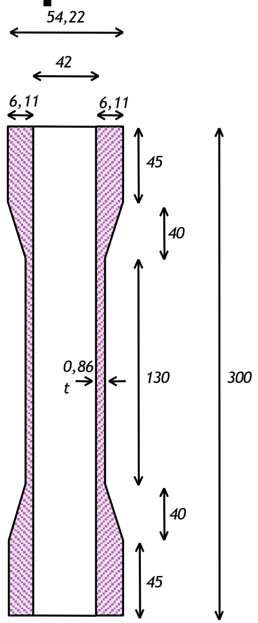
QUALIFICATION MODULE

Final quality hardware to demostrate adequacy under more stringent working condition than the worst expected ones. Test condition shall be selected to demostrate clearly that all the elements of the structure satisfy the design criteria. In defining the number and type of qualification tests, the highest level of assembly is used. *Qualification test*

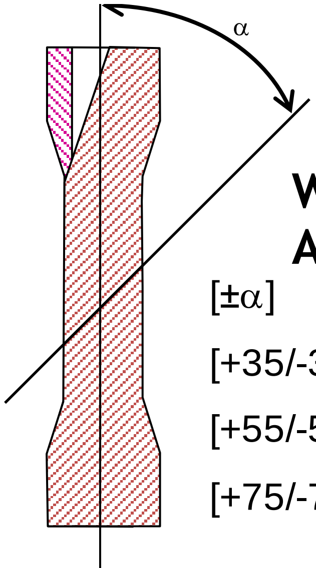
FINAL MODULE

Final hardware. Test are conducted on to verify that the materials, manufacturing, processes, and workmanship meet design specifications. Unless definite verification can be obtained by lower level test, full system test shall be conducted to verify the adequacy of the complete structure. *Acceptance test*

Composite structural behavior prediction: failure



l =130mm
r =42mm
Wall thickness = 0.86mm



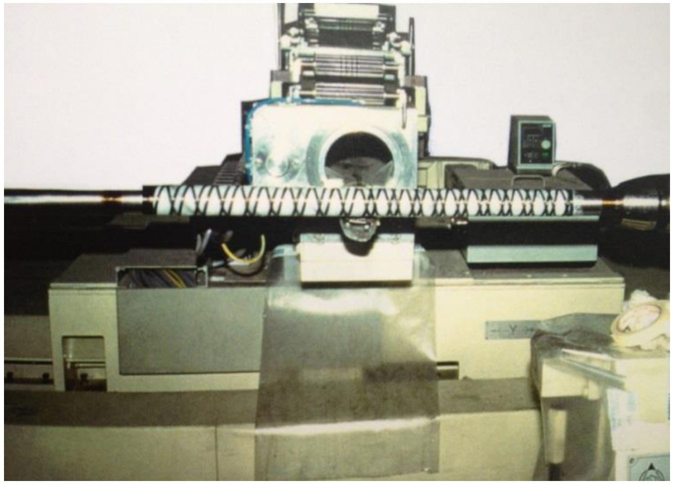
Winding Angle

[±α]

[+35/-35/+35/-35]

[+55/-55/+55/-55]

[+75/-75/+75/-75]



✓ Classical lamination theory

✓Failure criteria

are quadratic empirical formulation

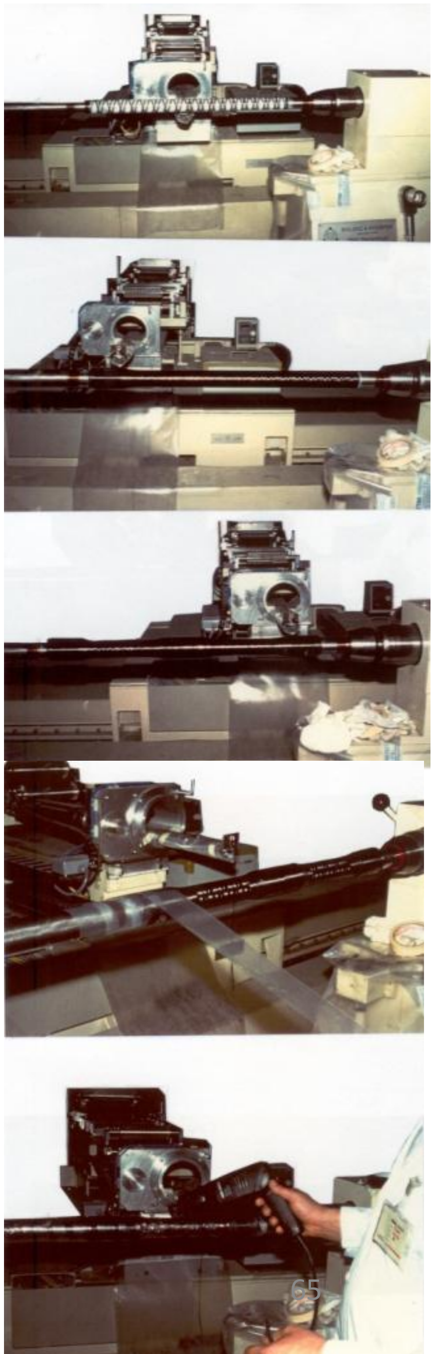
$$F_i \, \sigma_i + F_{ij} \, \sigma_i \, \sigma_j \leq 1$$

Tsai Hill, Hoffman, Tsai Wu

$$F_i, F_{ij}$$

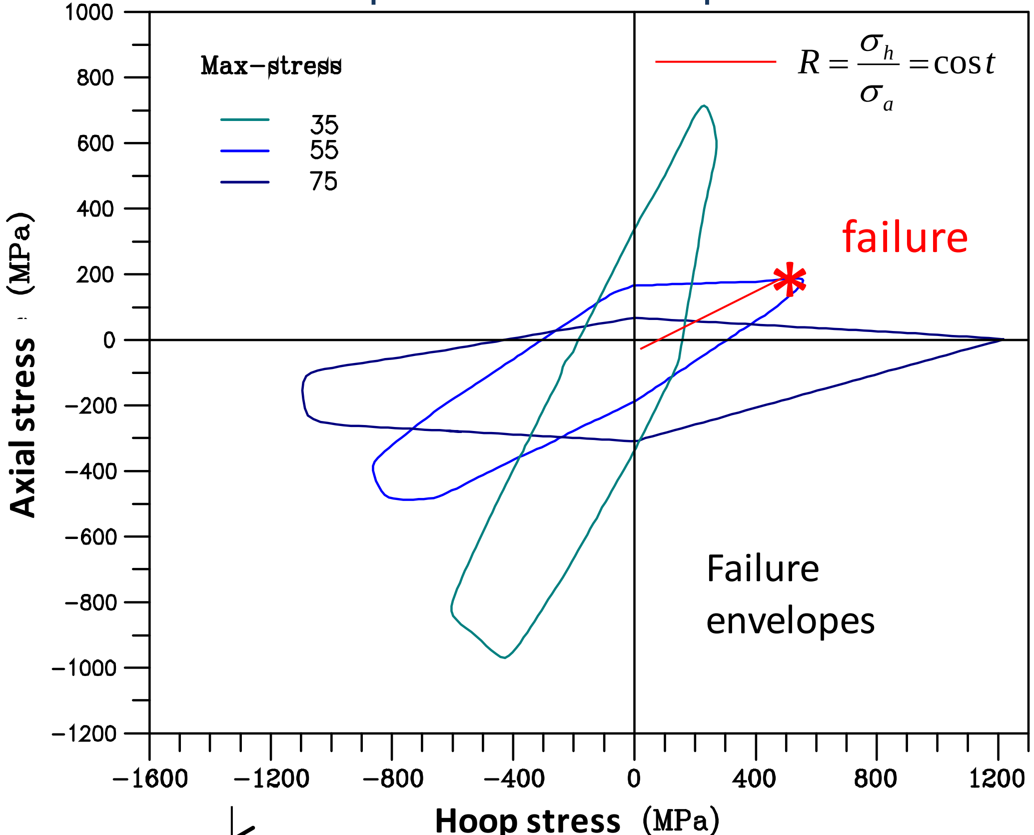
are experimentally determined material strength parameters

Multiaxial load test

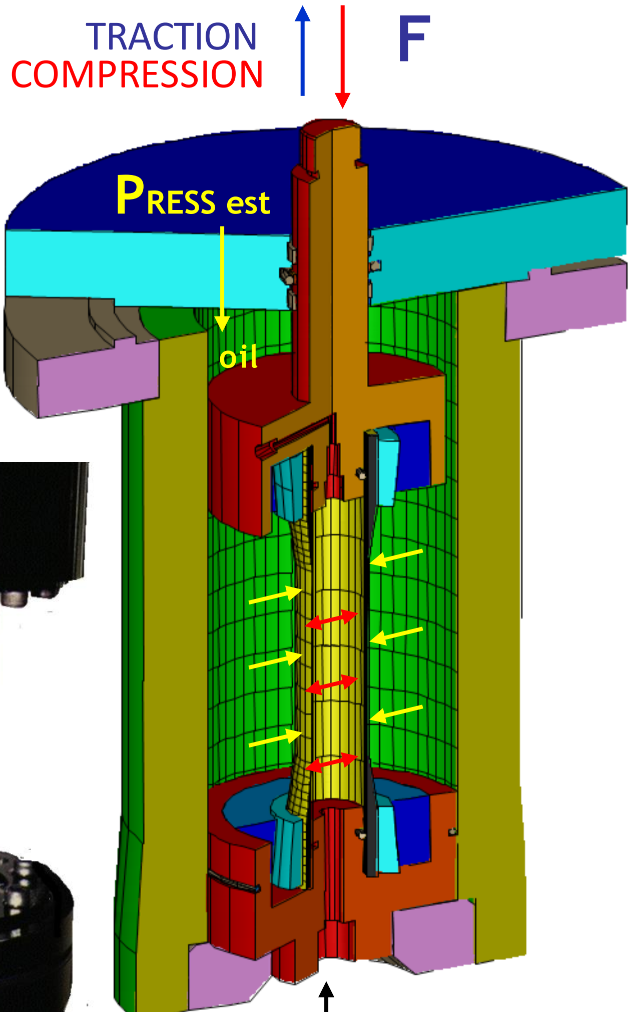


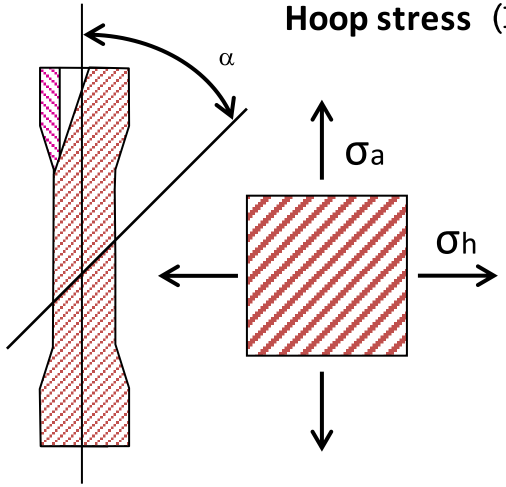
Composite structural behavior prediction: failure

Numerical prediction and Experimental test



internal/est pressure
traction/compression





$$\begin{cases} \sigma_h = \dfrac{\mathbf{P}r}{t} & \Rightarrow \text{hoopstress} \\ \sigma_a = \dfrac{\mathbf{F}}{2\pi\ rt} + \dfrac{\mathbf{P}r}{2t} & \Rightarrow \text{axial stress} \end{cases}$$

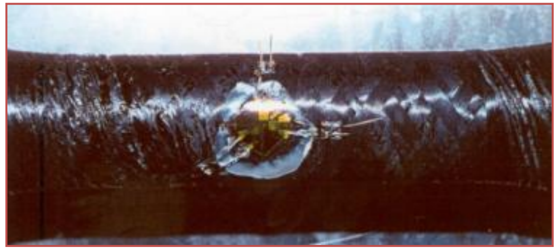
P/F= *cost*

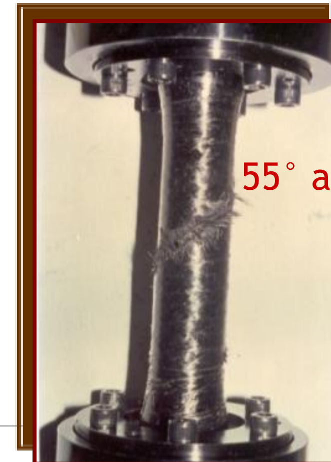
PRESS int

oil

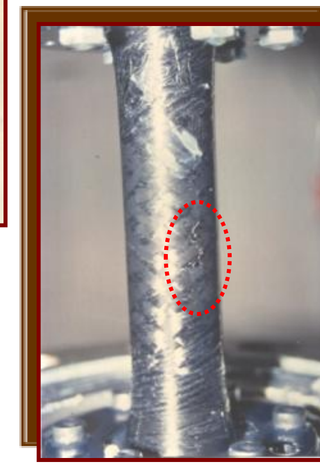
Composite structural behavior prediction: failure

Experimental test: failure

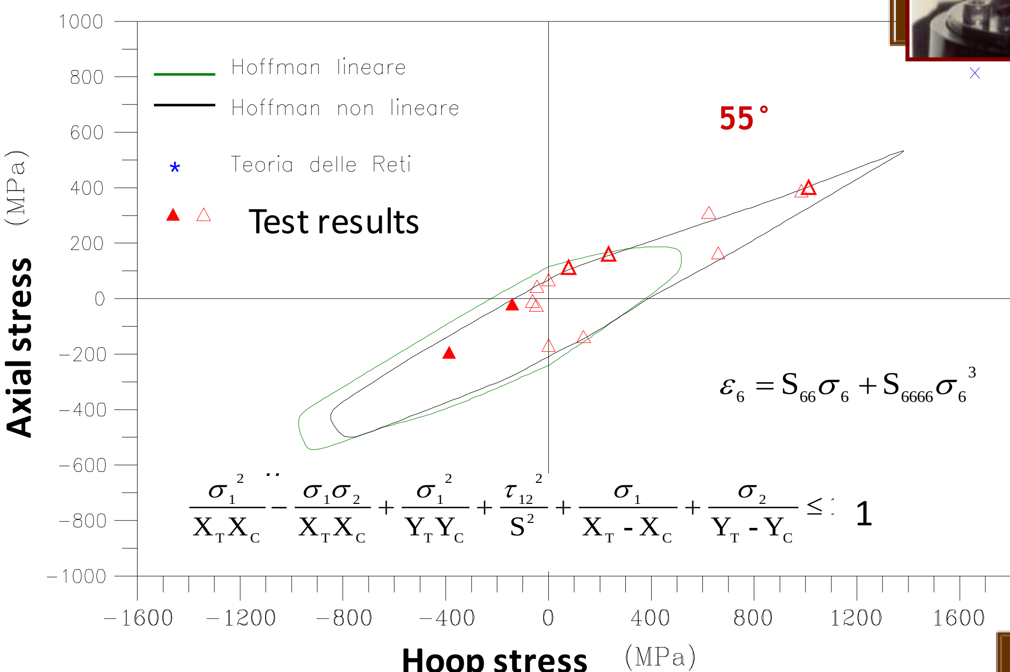


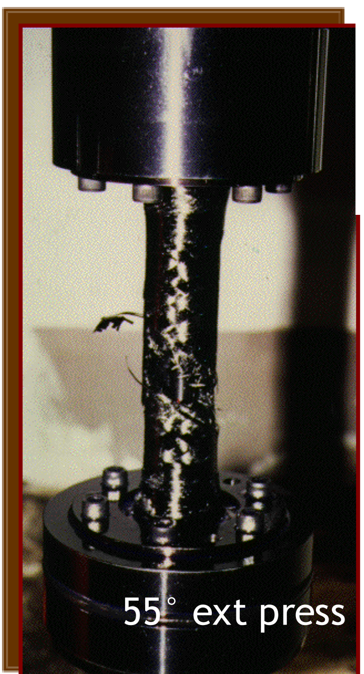


55° axial traction 7800 N

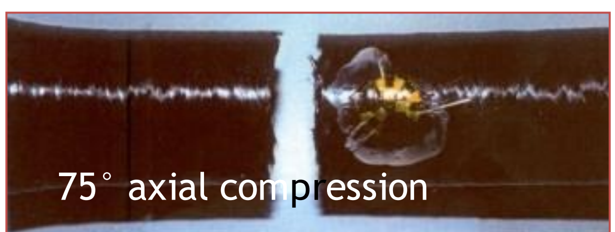


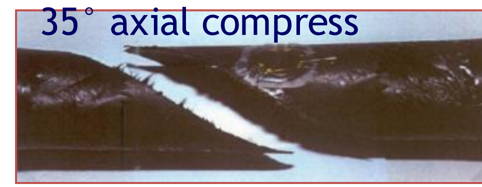
55° internal press 260 bar





25 bar

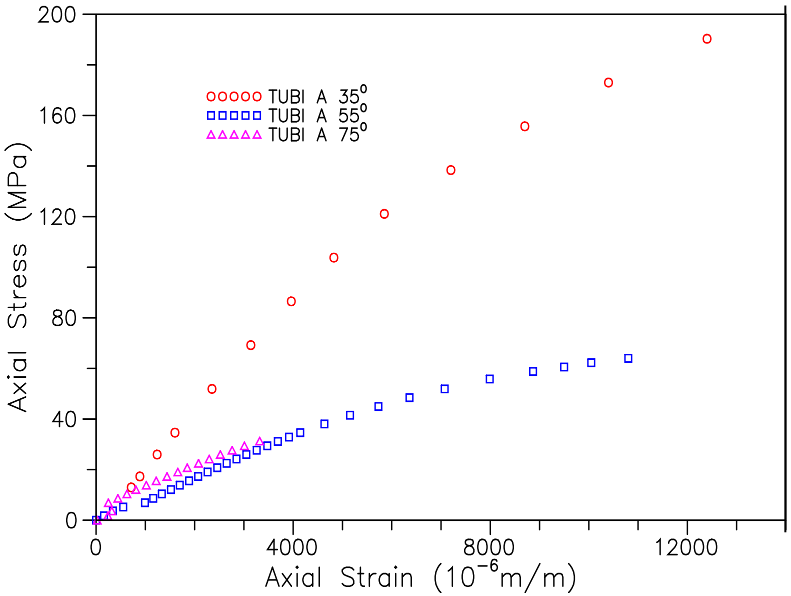


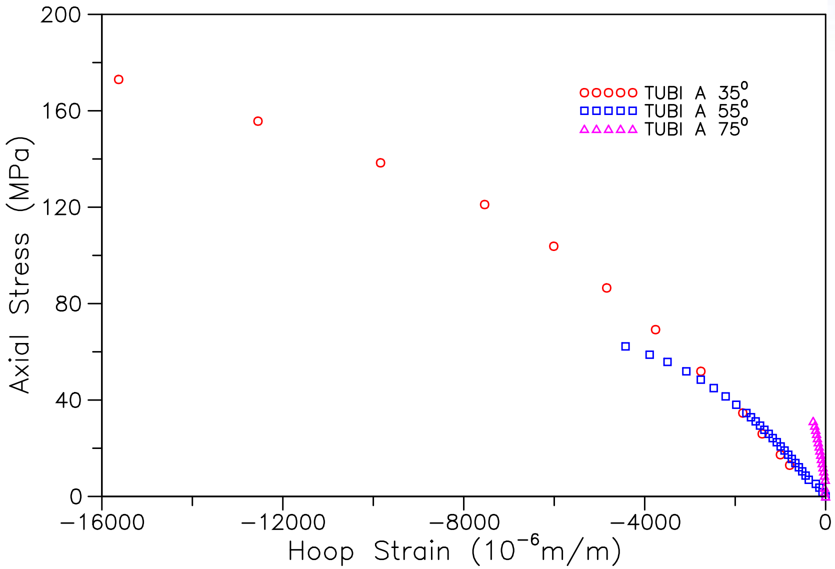


Composite structural behavior prediction: failure

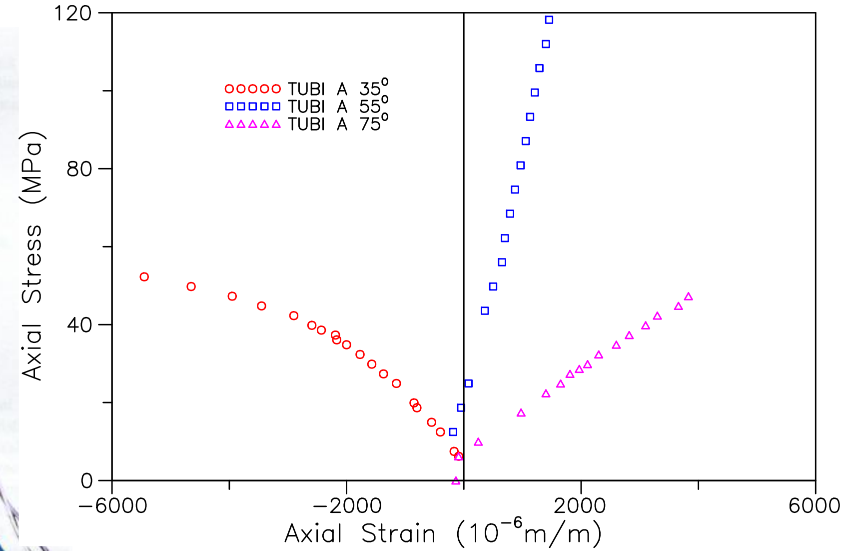
Experimental test: deformation

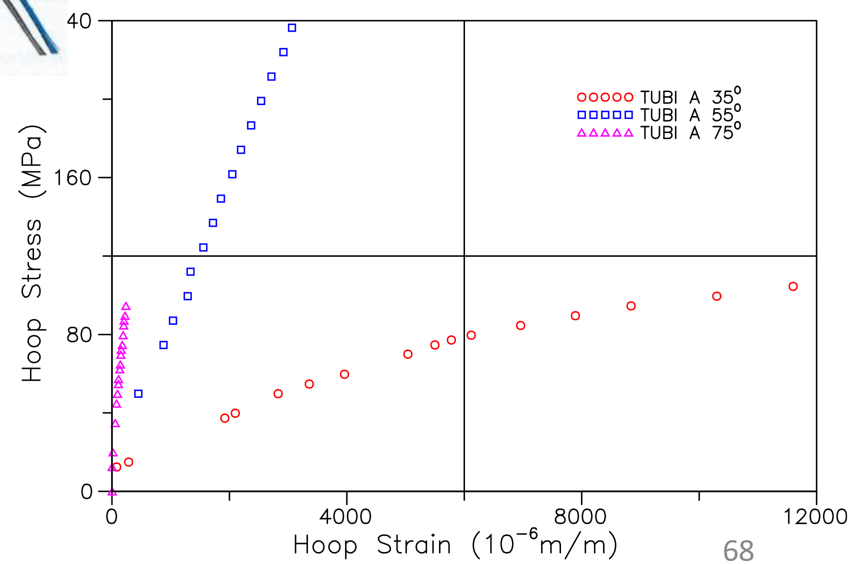
Tensile load





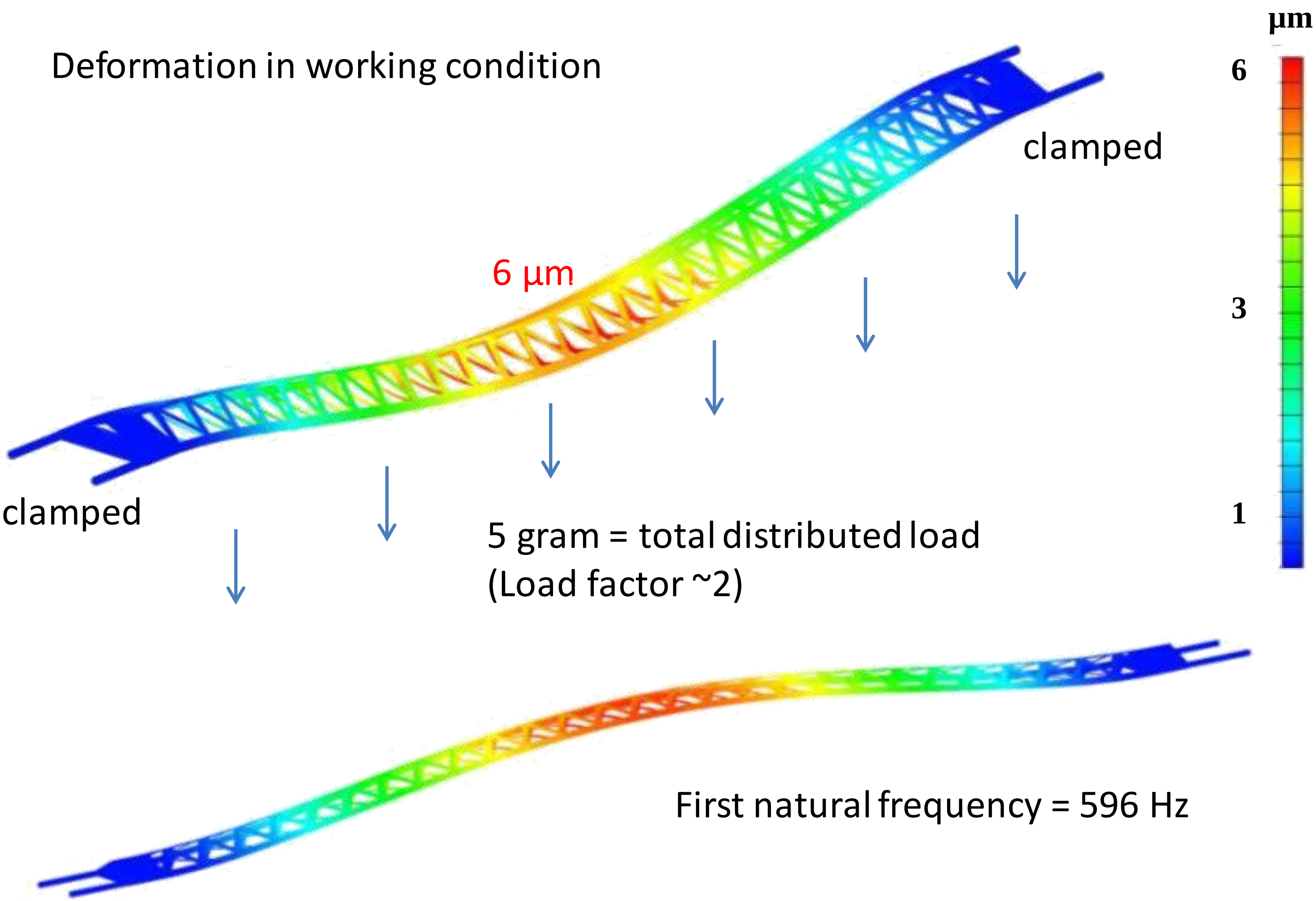
Internal pressure



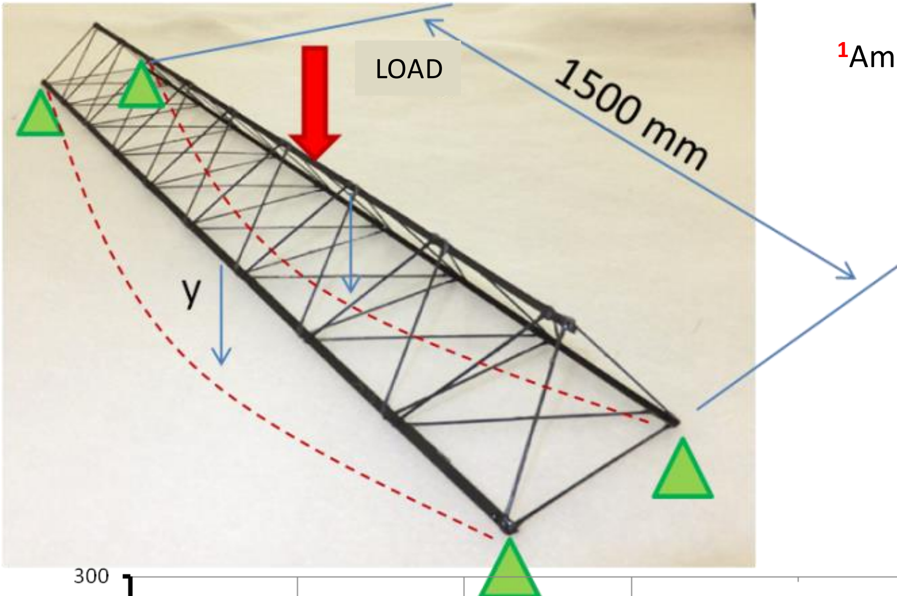


Stave characterization: Mechanical analysis

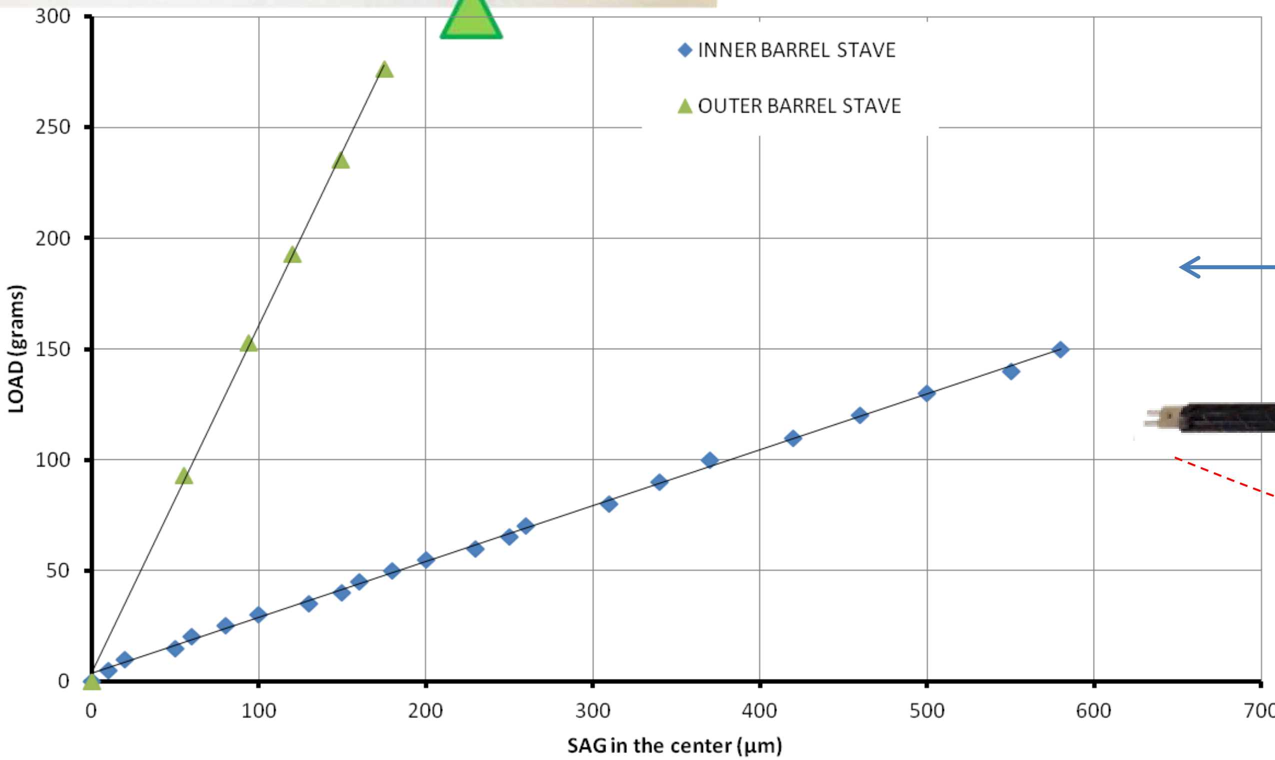
Structure Stiffness *ANALYSIS*

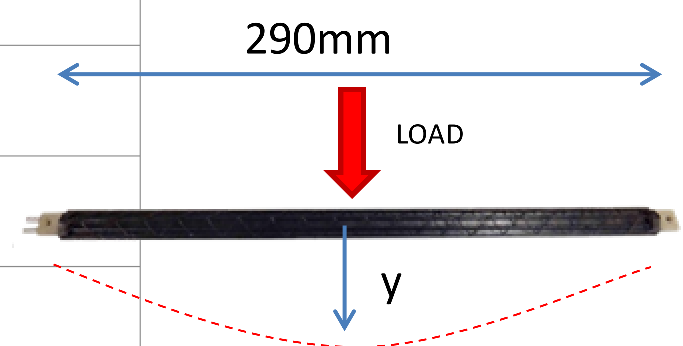


Stave characterization: 3 points bending test



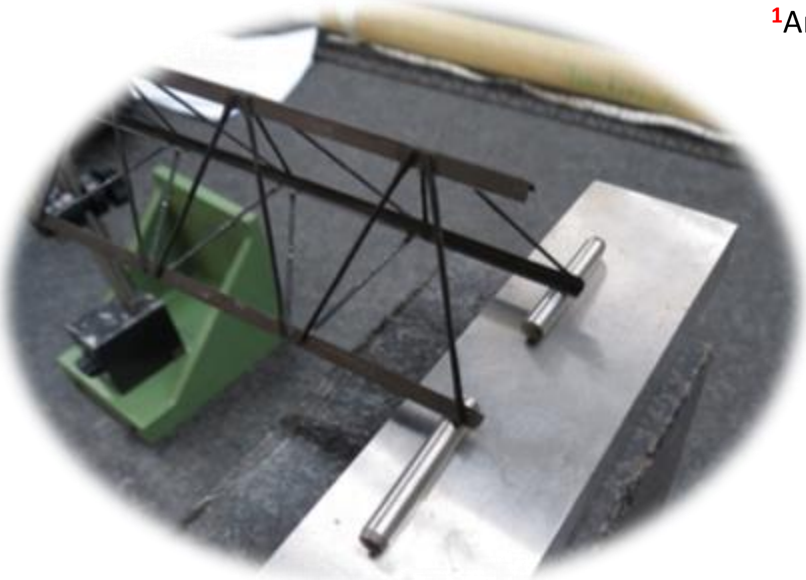
[1]American Society for Testing and Materials (ASTM) Standards: **D790**

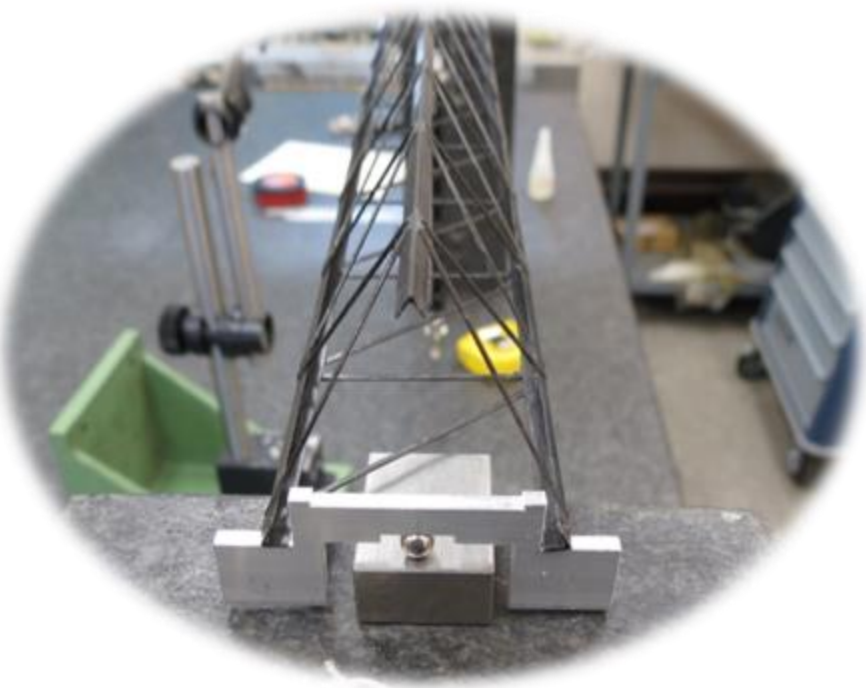


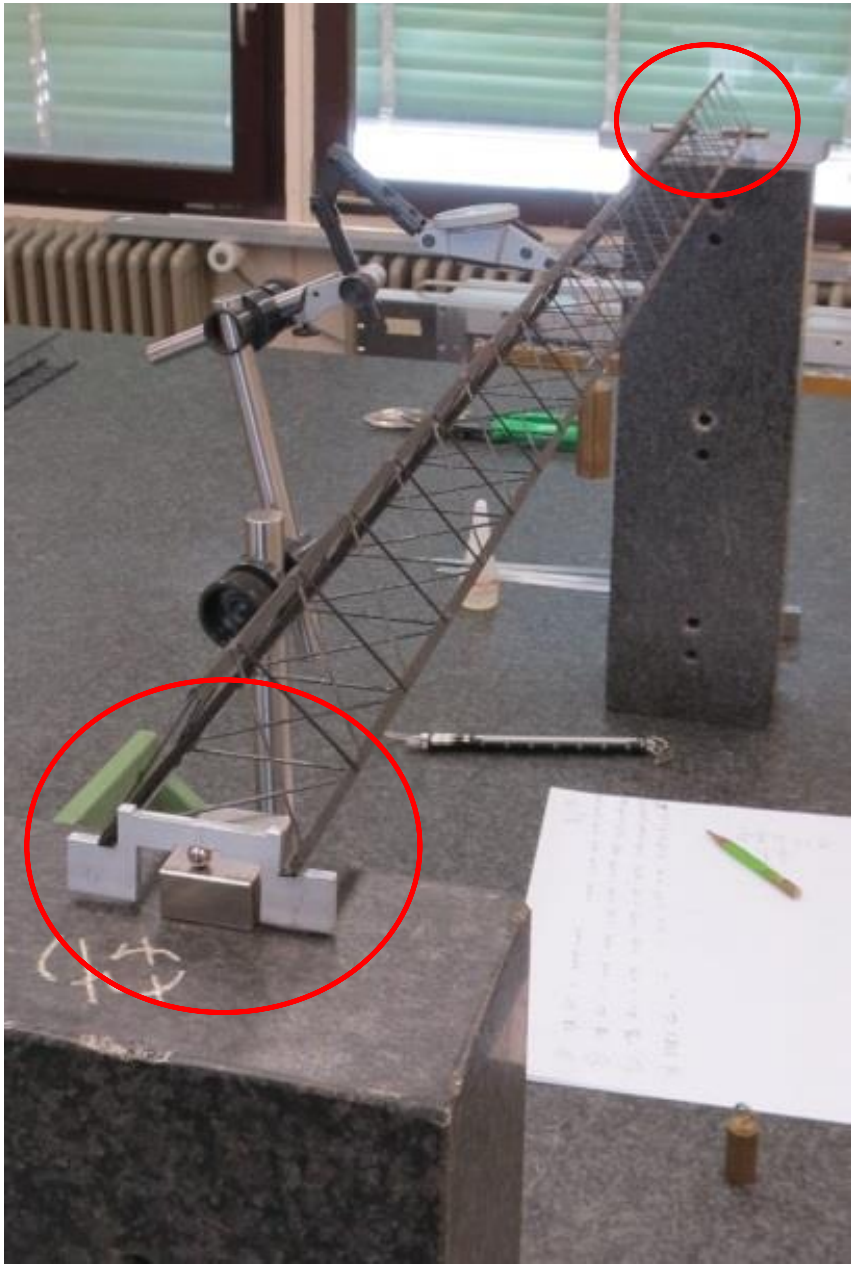


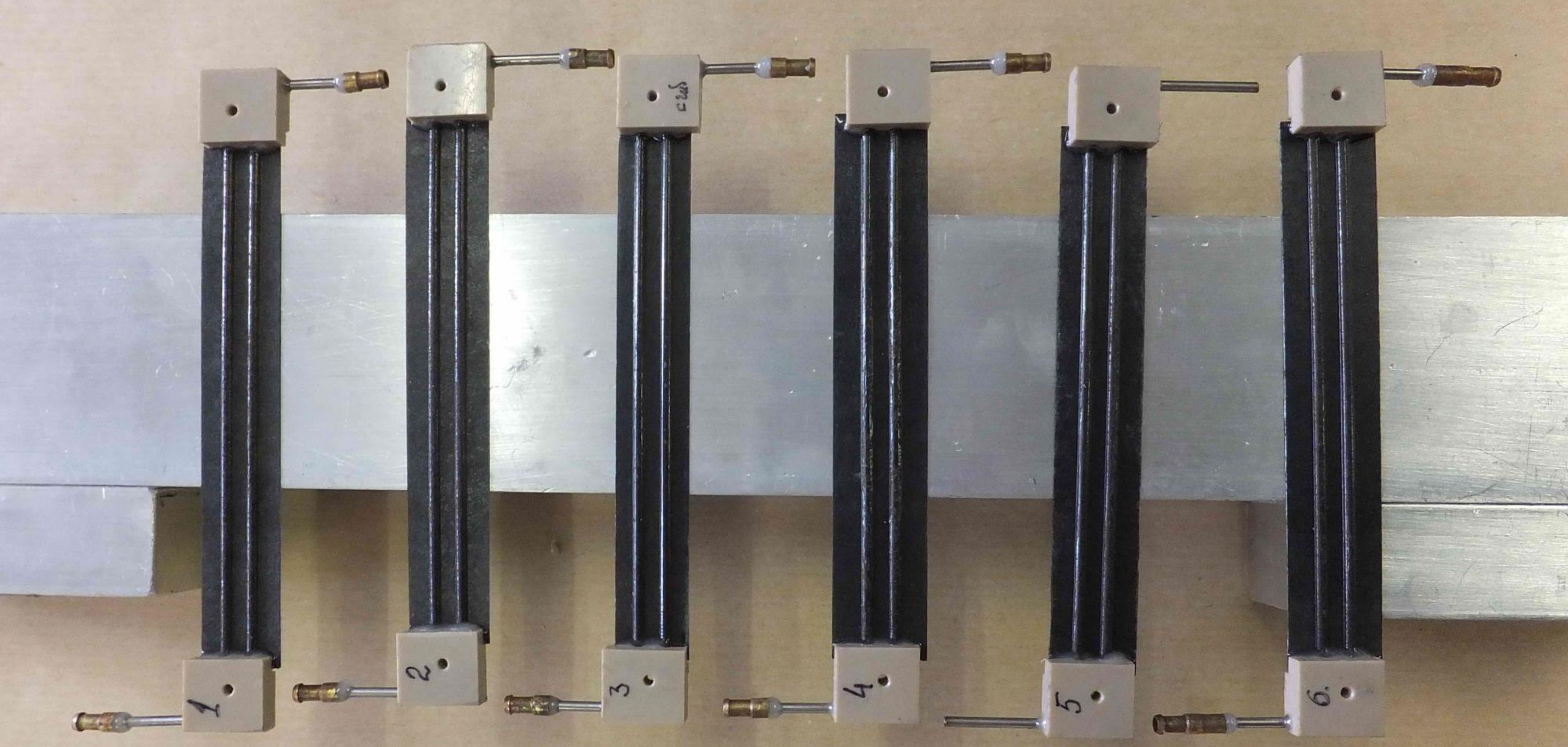
Stave characterization: 3 points bending test

[1]American Society for Testing and Materials (ASTM) Standards: **D790**

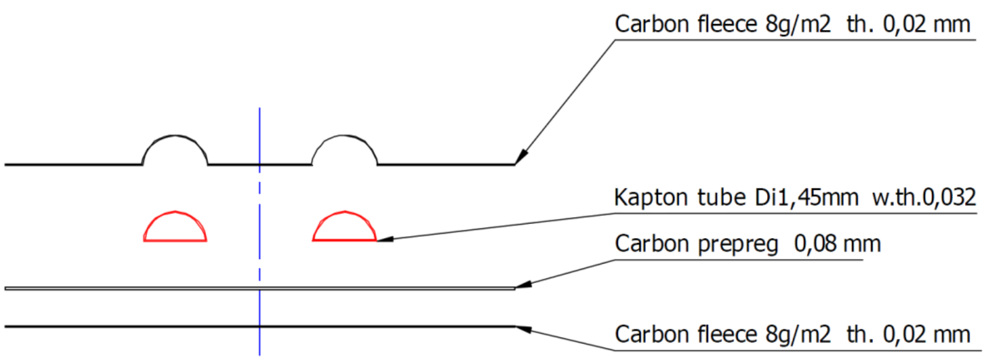








Stave Characterization: Pressure test



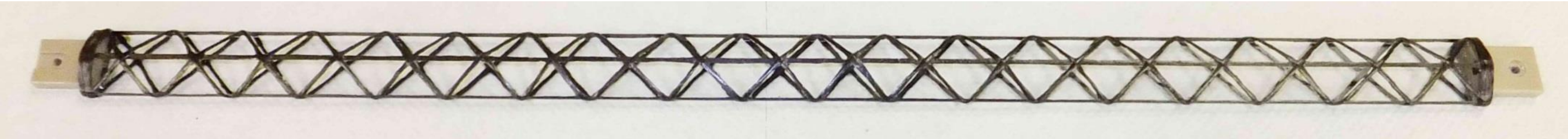
Stave Characterization: Pressure test

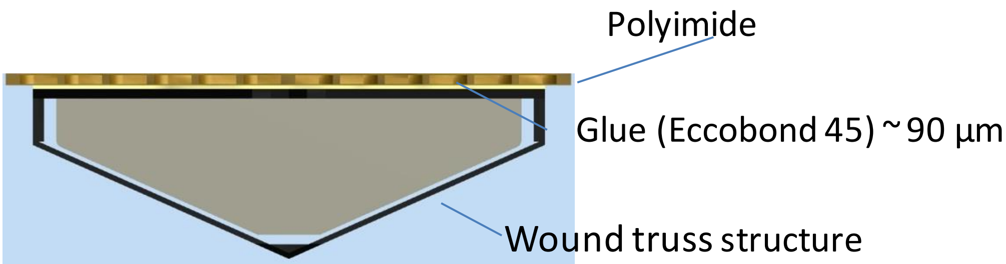
№		Burst Pressure (bar)	
1	resin standard	1	
2	resin standard+larger quantity	2,5	
3	resin viscosity increased by a pre-polimerization process (100°C , 25 min)	10	No failure
4	resin+ aerosil 3% (aerosil /resin% weight)	2	
5	resin+ aerosil 5% (aerosil /resin% weight)	3,5	
6	resin+ aerosil 10% (aerosil /resin% weight)	10	No failure

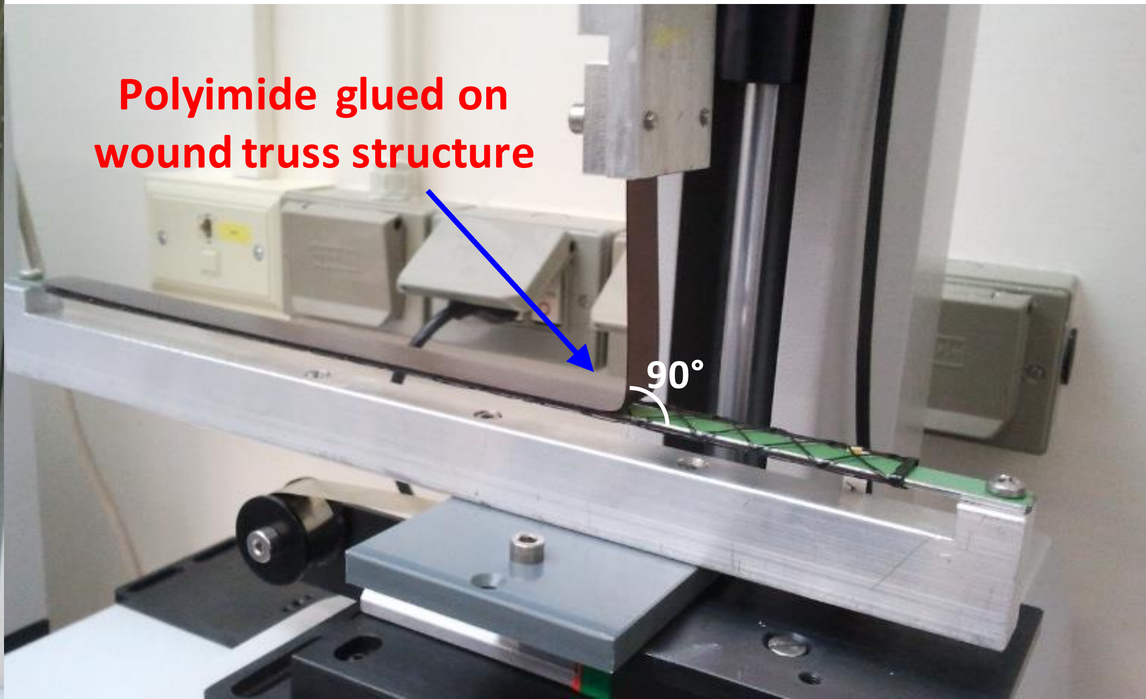
Resin standard -100g Epoxy resin ED 20

Hardener TEAT (triethanolaminetitanat)

Stave characterization: 90° Peel Resistance of Glue



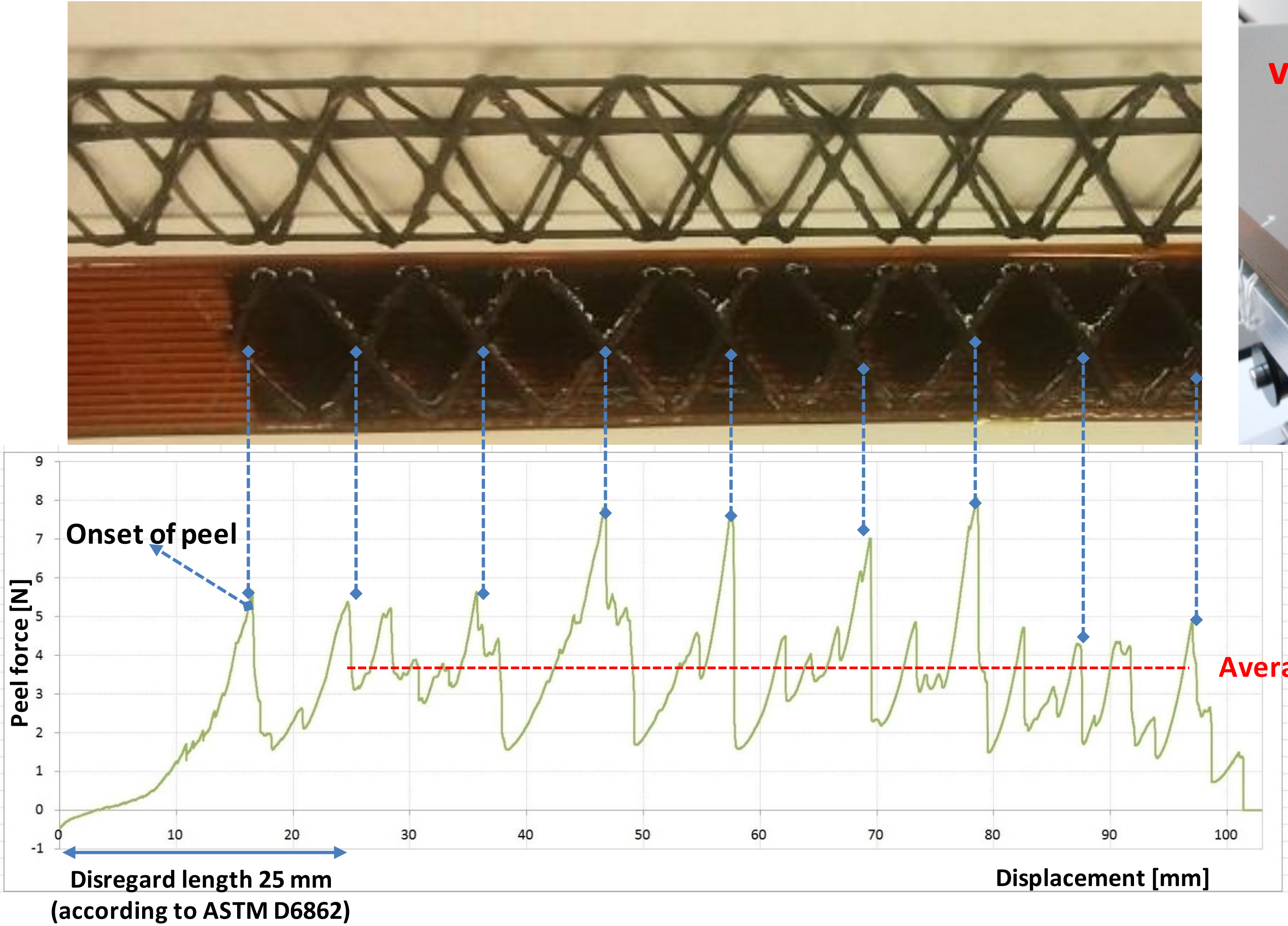


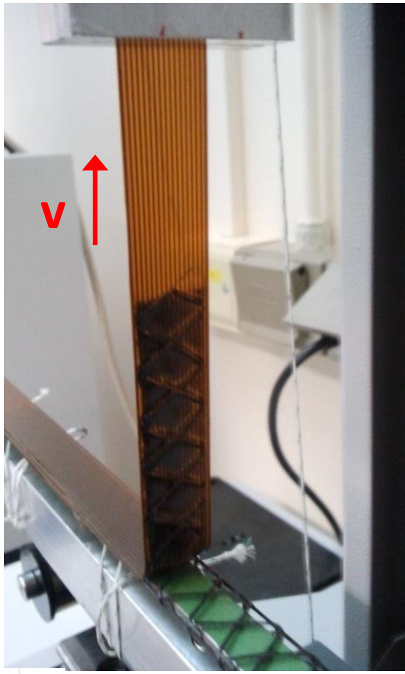


Stave characterization: 90° Peel Resistance of Glue

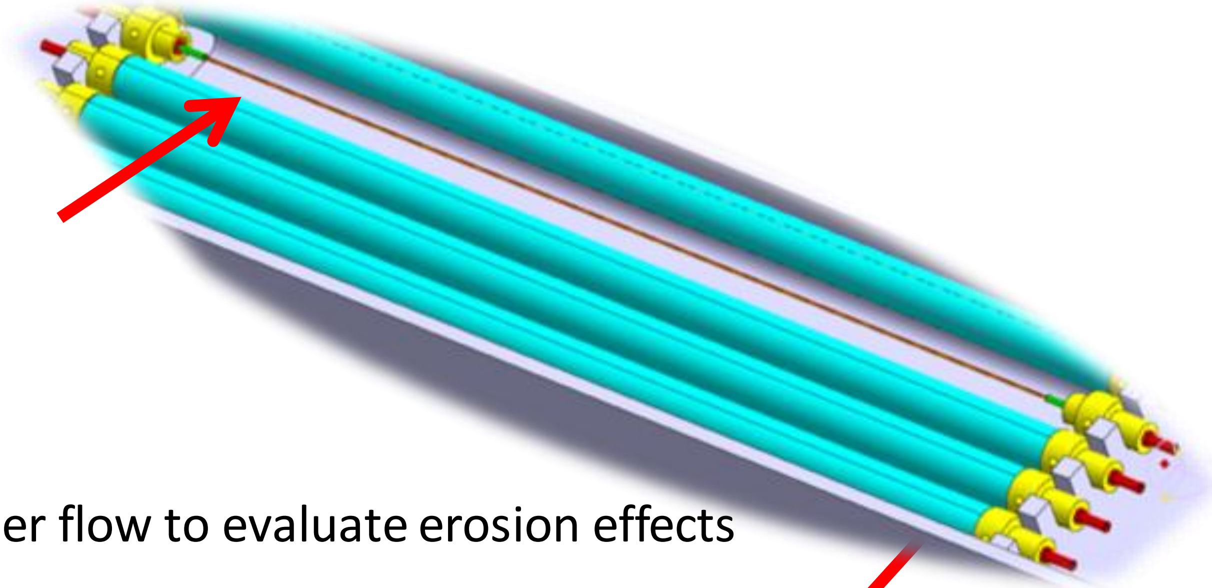
[1]American Society for Testing and Materials (ASTM) Standards: **D6862-11, D1876-08**

Peel force vs. displacement for 90° peel test at a rate of **v** = 25 mm/min





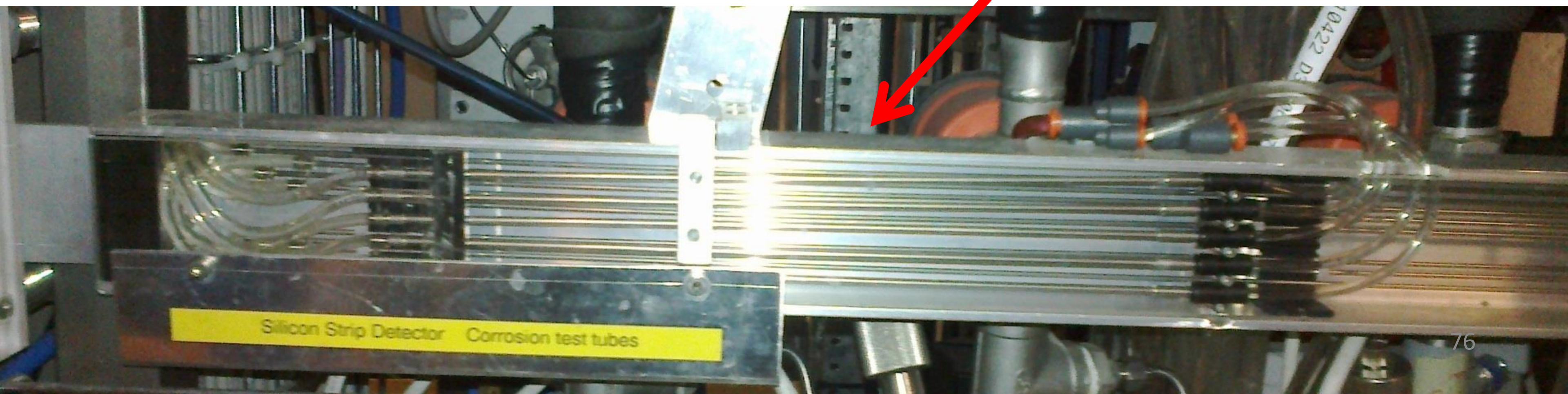
Stave characterization: Erosion Test



-Long term test with water flow to evaluate erosion effects

-AFM analysis methods before

-Test set up : test samples installed in a test set up in the cavern



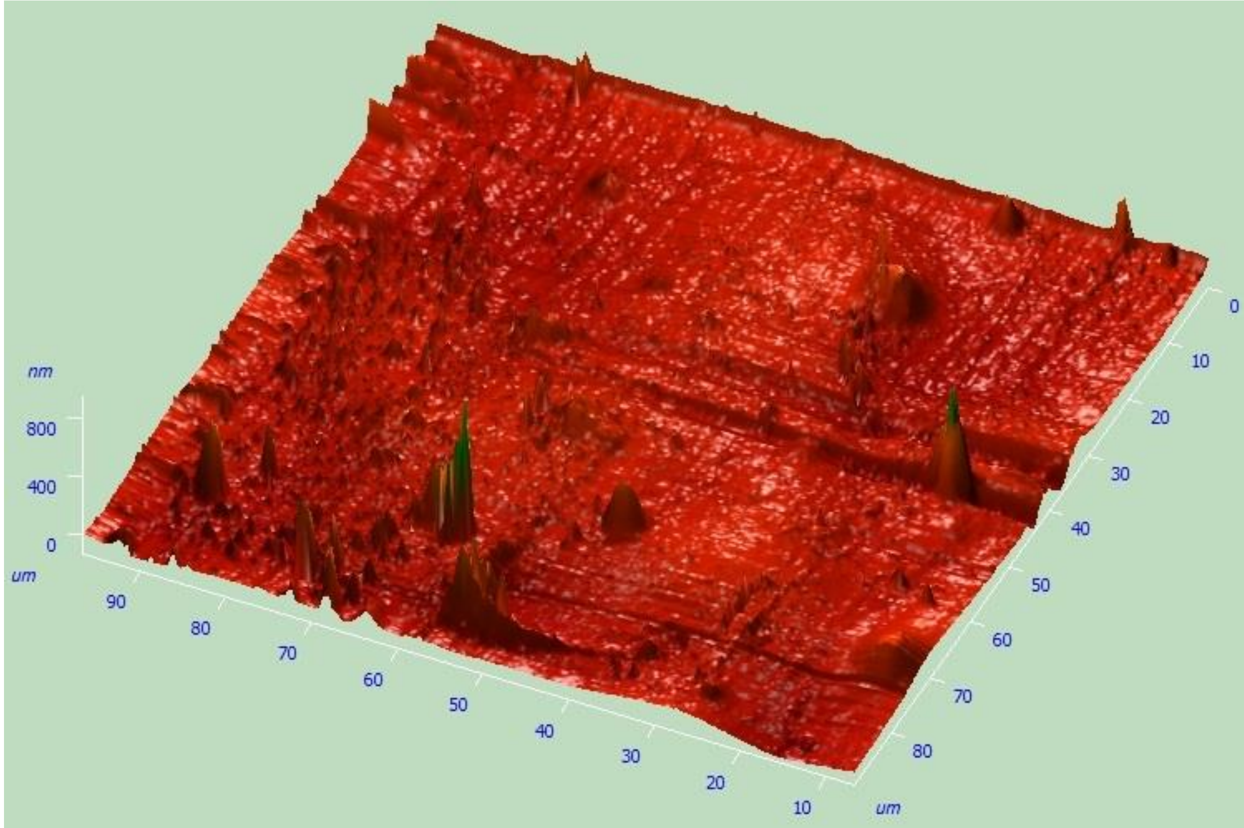
Stave characterization: Erosion Test

Water erosion effects: surface roughness measurement

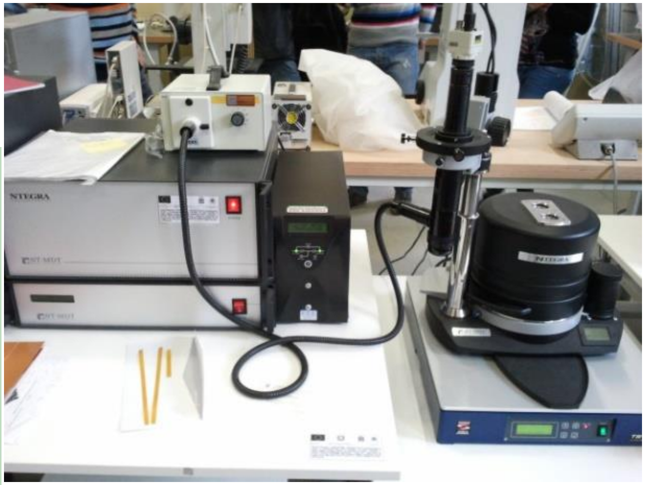
A surface roughness measurement was carried out before the water erosion test on Polyimide.

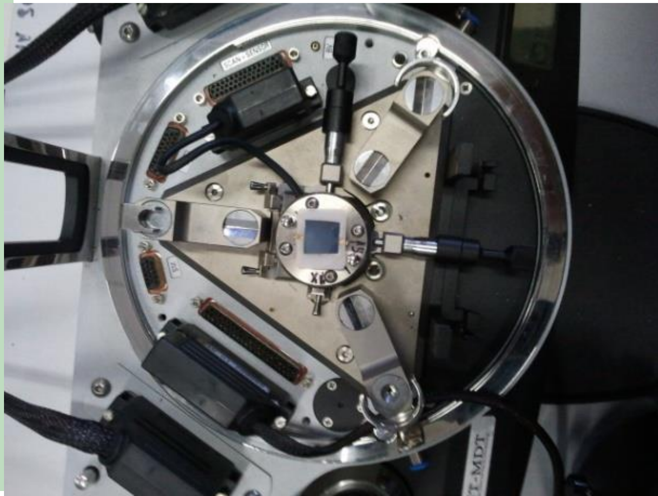
3D reconstructed roughness on 100 x 90 μm² polyimide MCHS surface

The statistical average roughness, on an area of 100 x 90 μm² with 256 x 256 points is 34.94 nm.



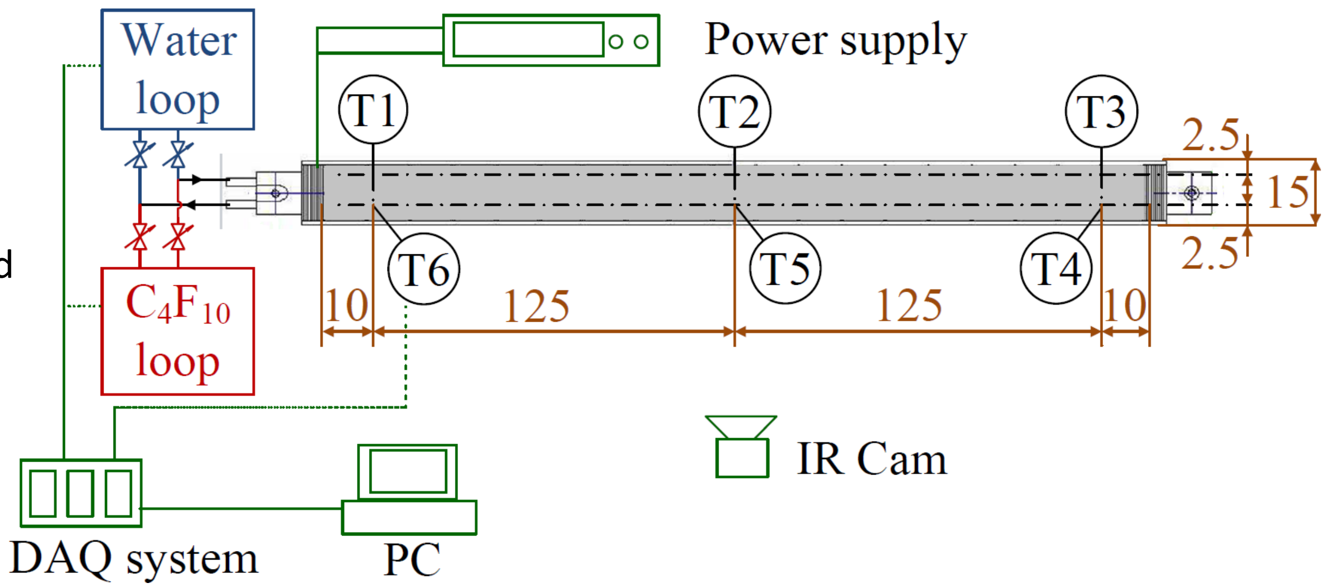
Atomic Force Microscope





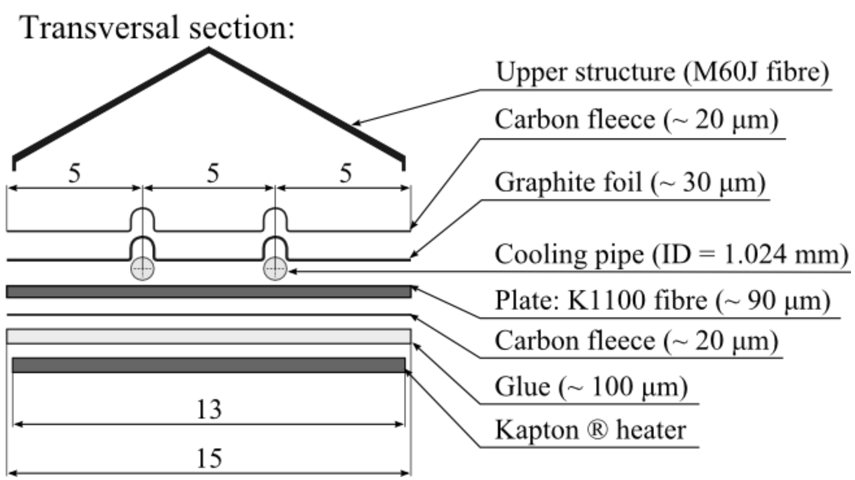
Stave characterization: Cooling test

Both
two phase (C4F10)
and
single phase (water)
have been considered

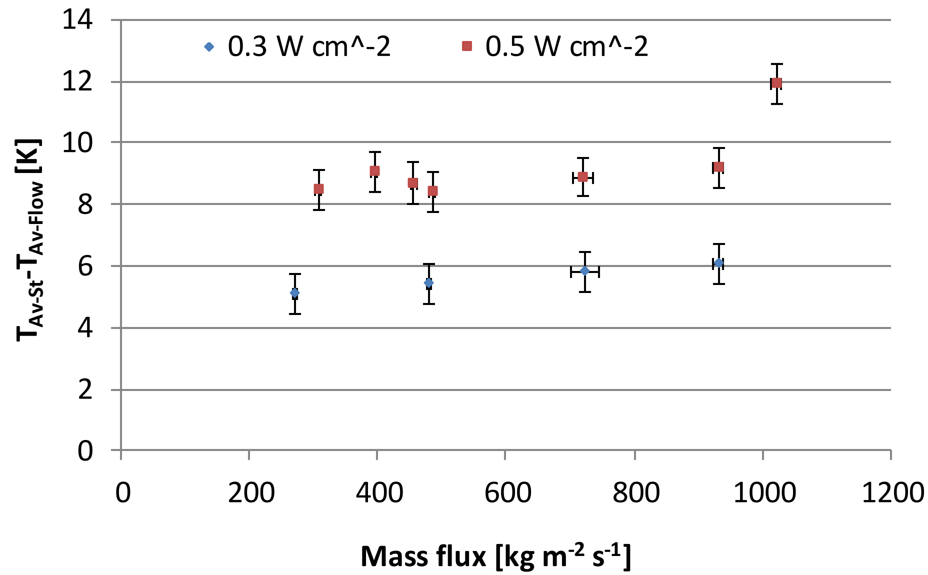


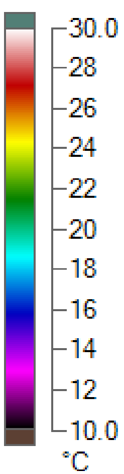
Perfluorocarbons (C4F10), cooling fluids have a higher dielectric strength than water, as well as a good stability in radioactive environments and full compatibility with polyimide

Stave characterization: Cooling test



The main thermal resistance of the cooling system is due to conduction heat transfer in the structure itself, the choice of the refrigerant and the flow is not of major importance, from a thermal point of view

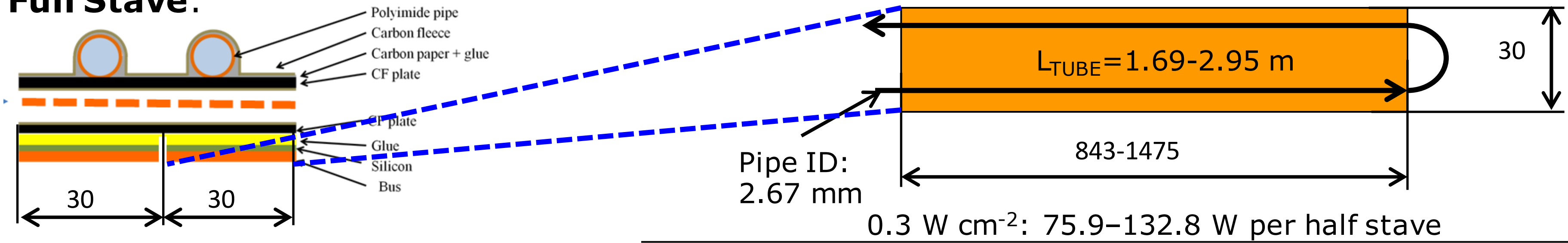




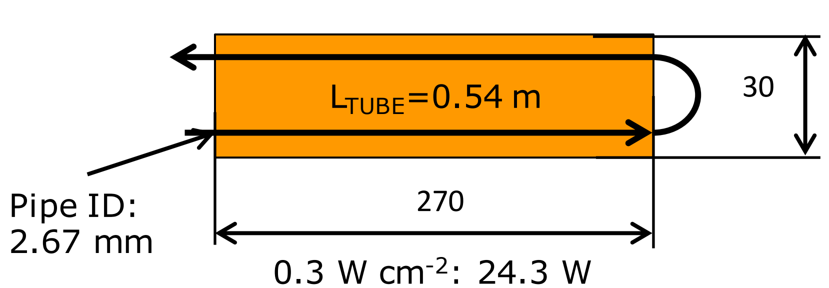
Evaporative C_4F_{10}	q [W cm^{-2}]	m [g s^{-1}]	Δp_{St} [bar]	Av.T_{C4F10} [°C]
BEND OUTLET/INLET 	0.3	0.22	0.29	13.9
	0.5	0.40	0.39	16.1

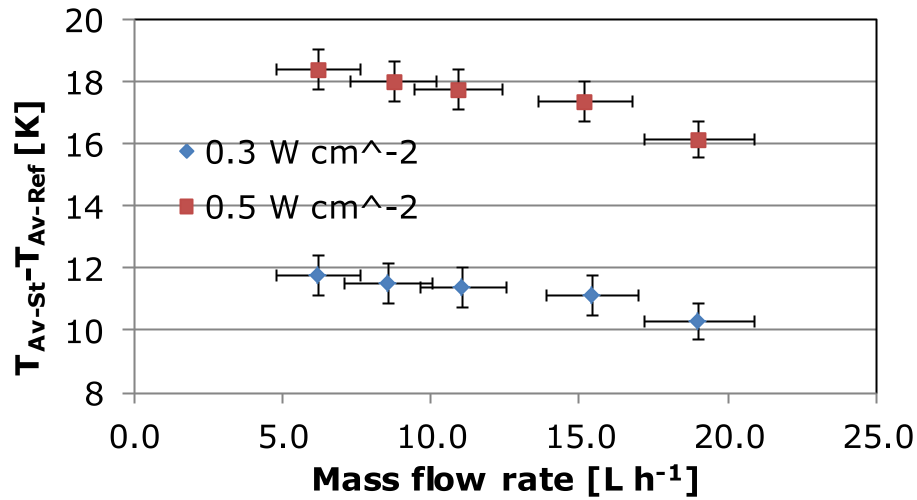
Stave characterization: Cooling test

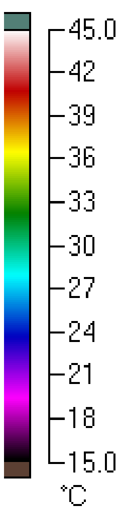
Full Stave:

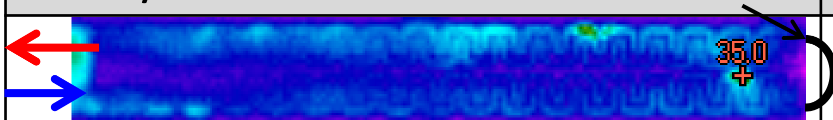
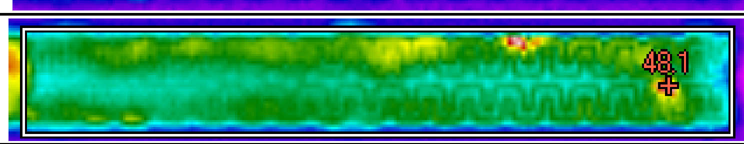


Tested prototype: shorter version

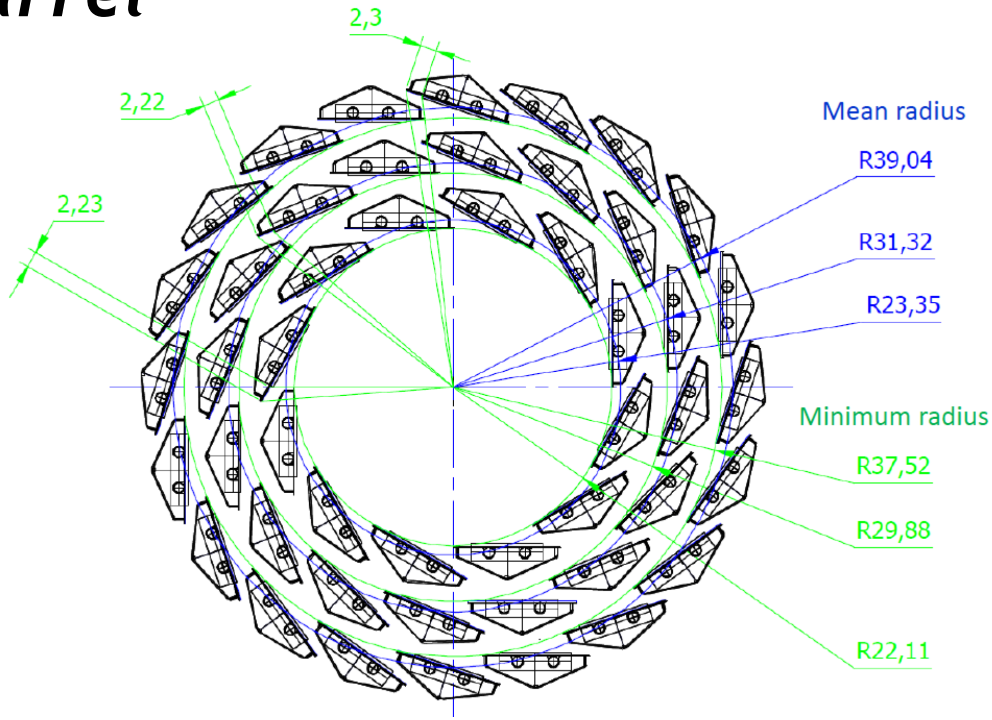






Liquid Water OUTLET/INLET BEND	q [W cm^{-2}]	m [L h^{-1}]	Δp_{St} [bar]	Av.T_{Water} [°C]	ΔT_{Water} [K]
	0.3	15.5	0.14	13.7	1.0
	0.5	15.2	0.13	14.0	1.6

From stave to Barrel



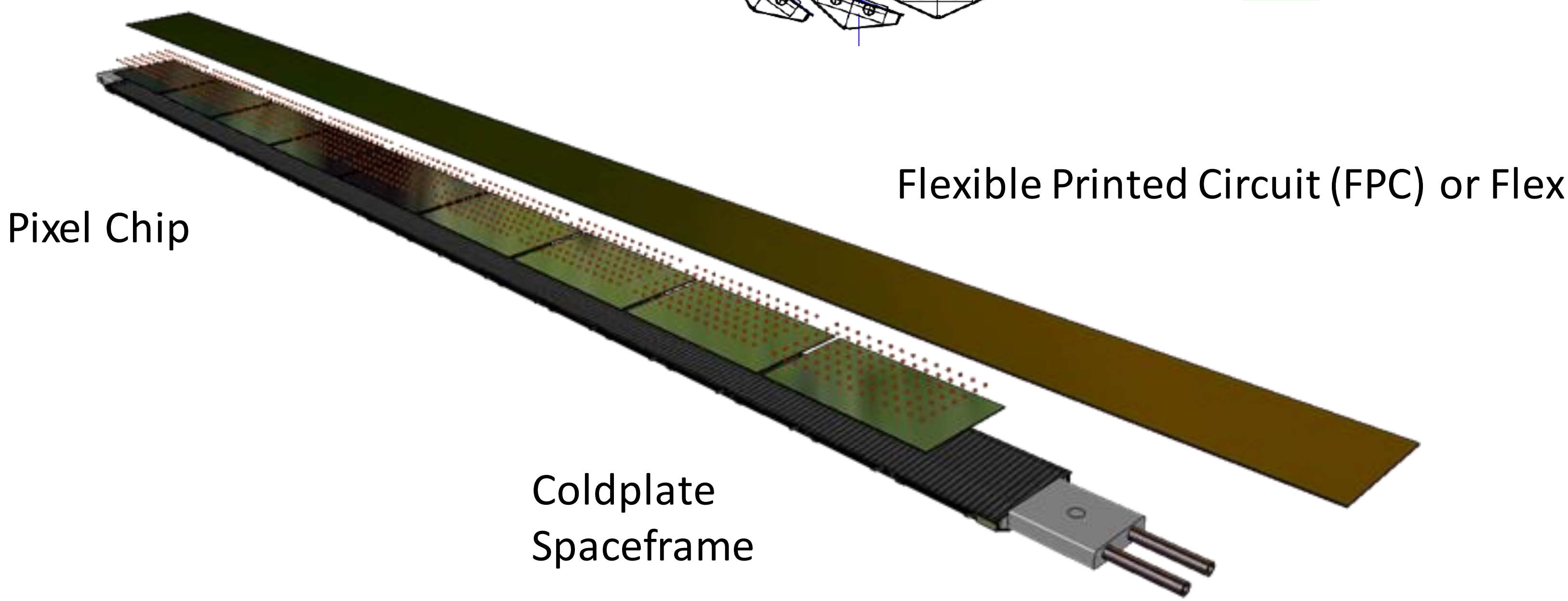
Inner Barrel (IB)

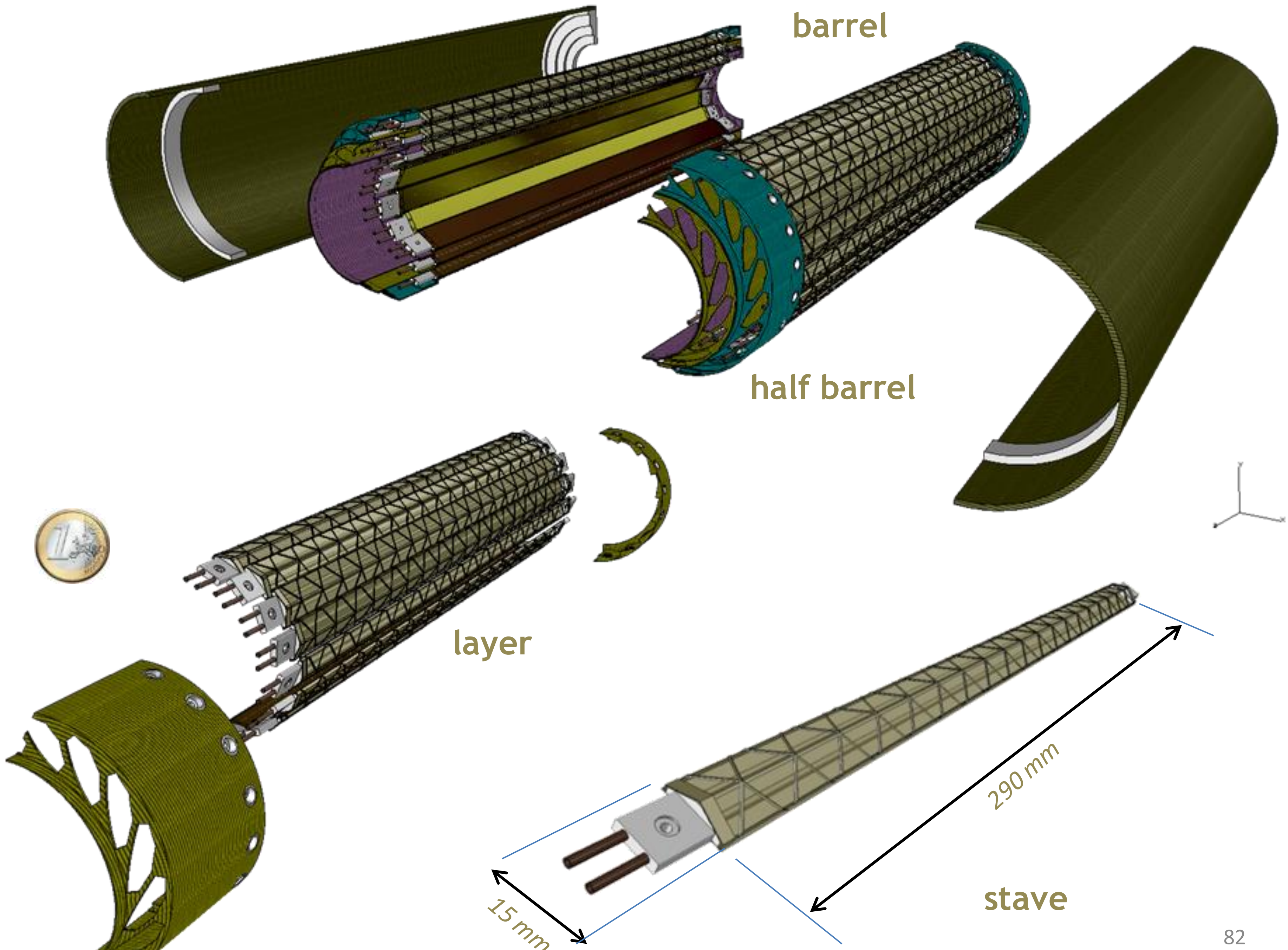
The Inner Barrel consists of the three innermost layers:

Inner Layers

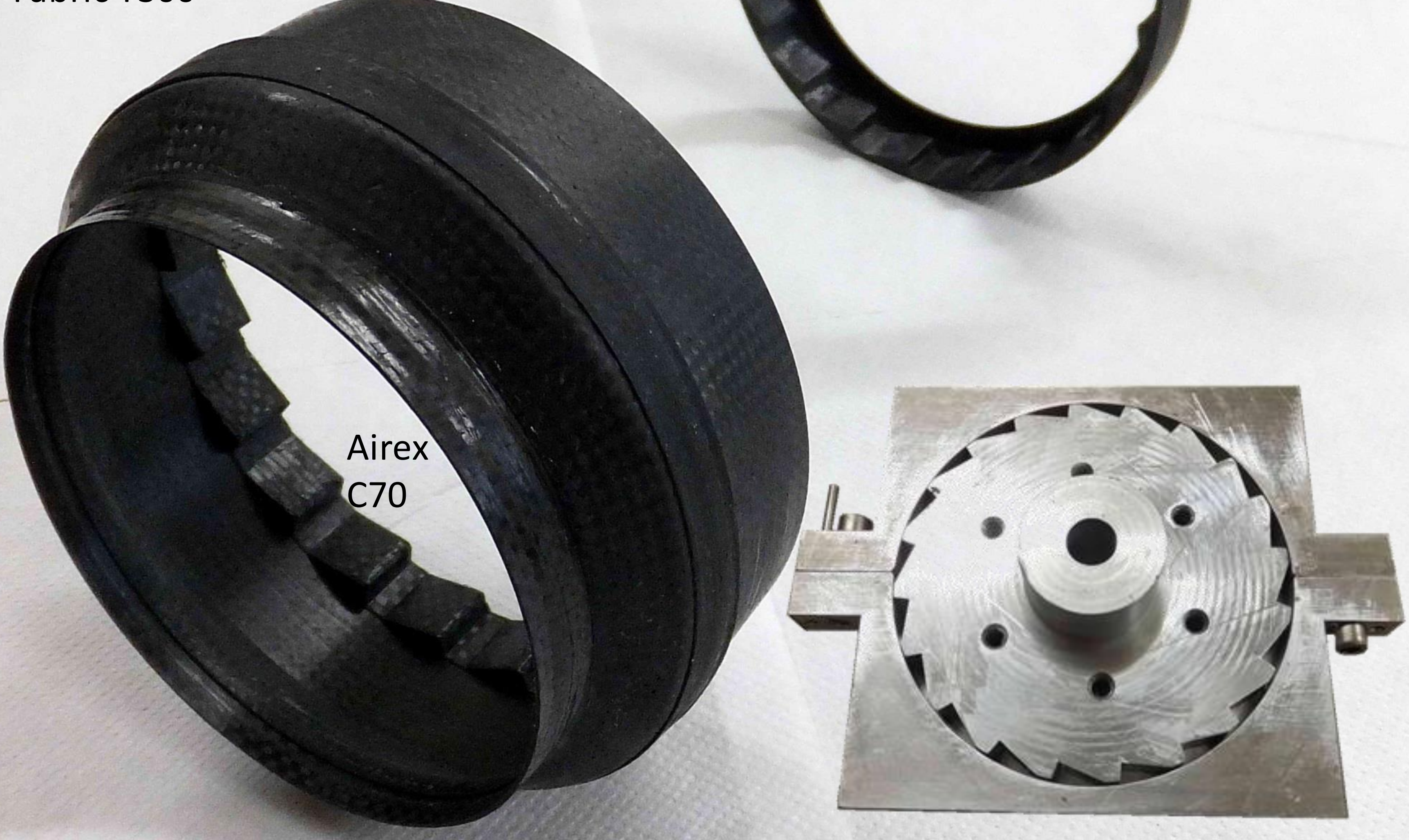
layer 0, layer 1 and layer 2.

Stave

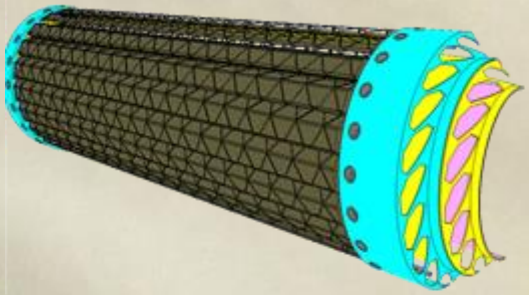


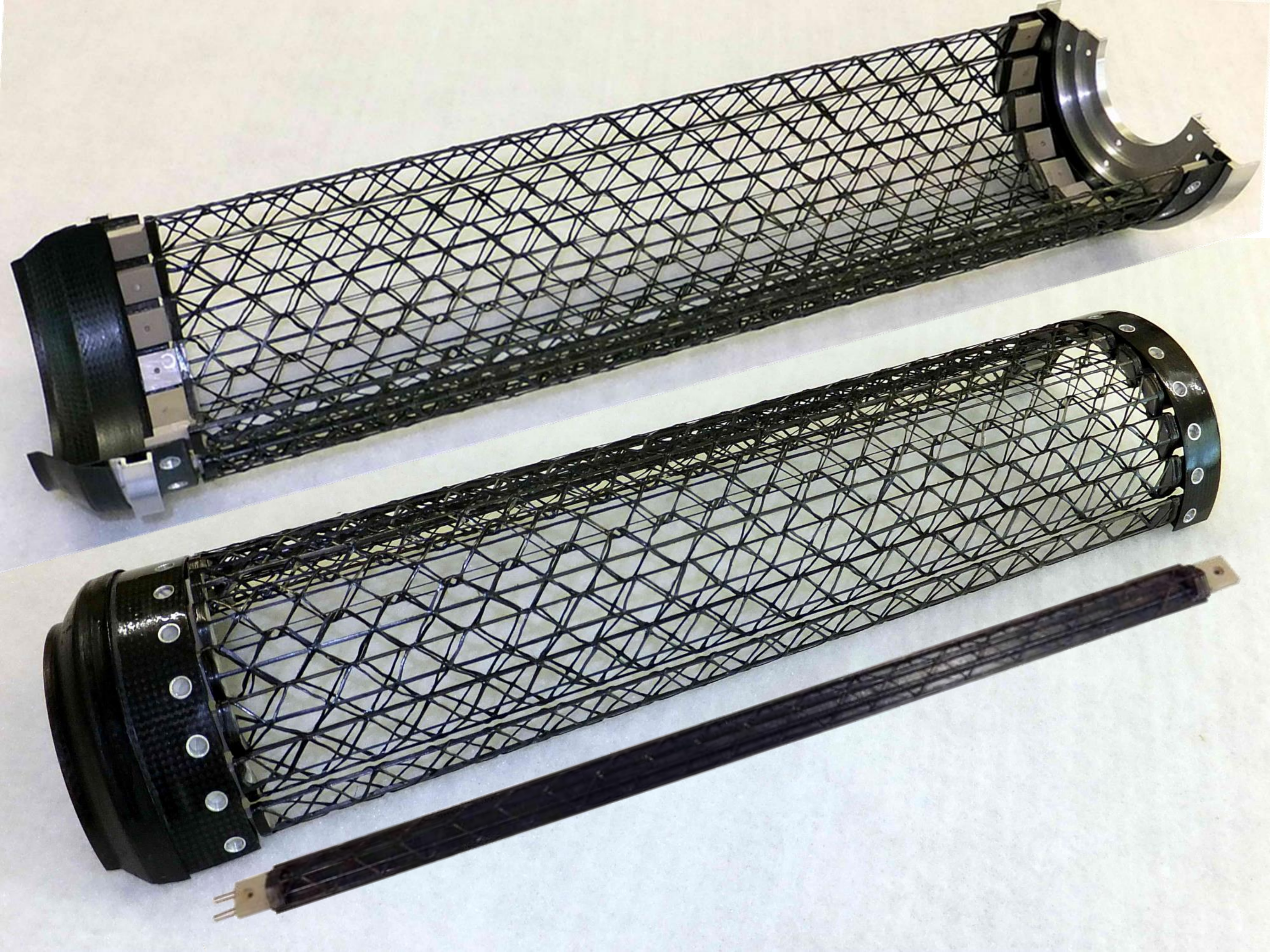

barrel
half barrel
layer
290 mm
15 mm
stave

End-wheels

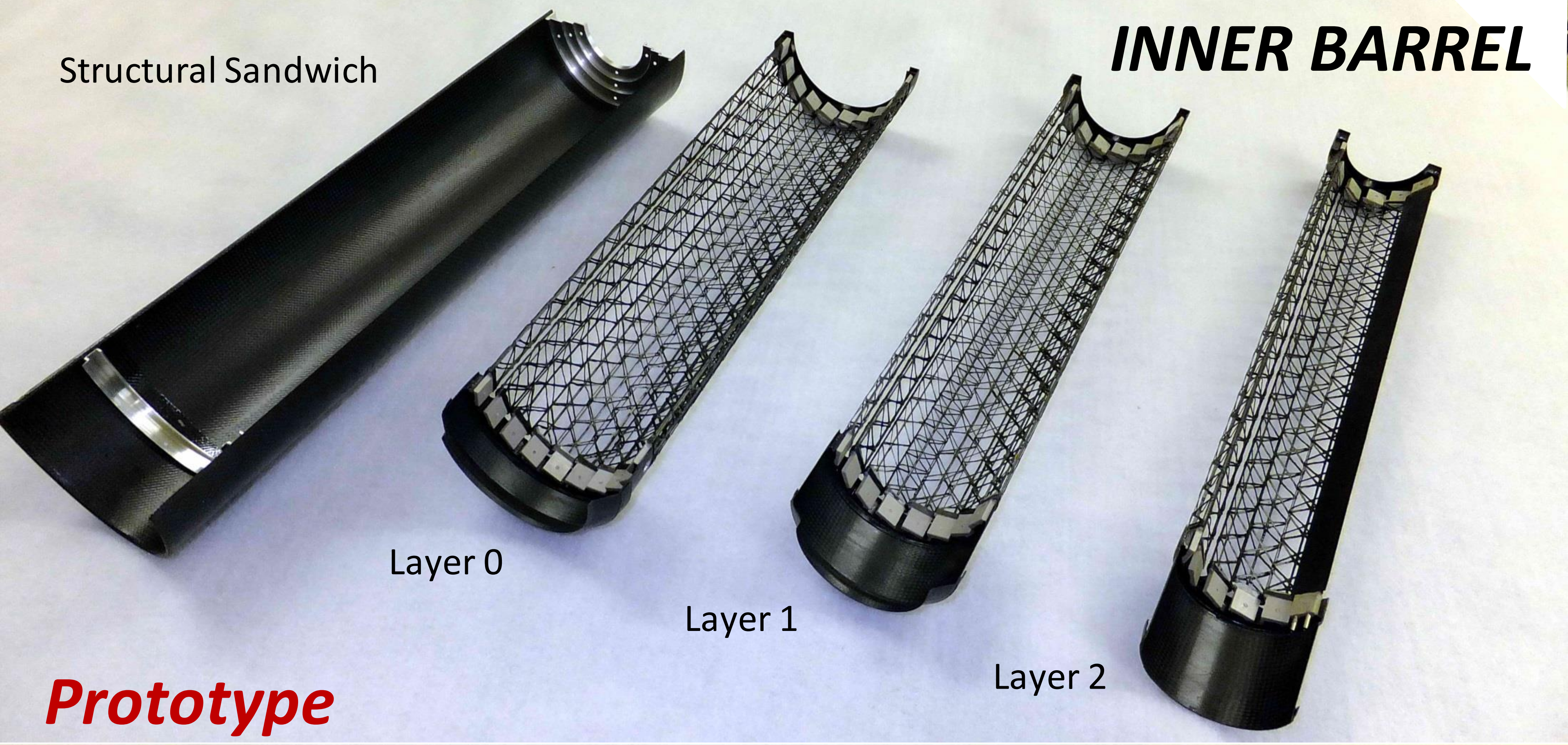


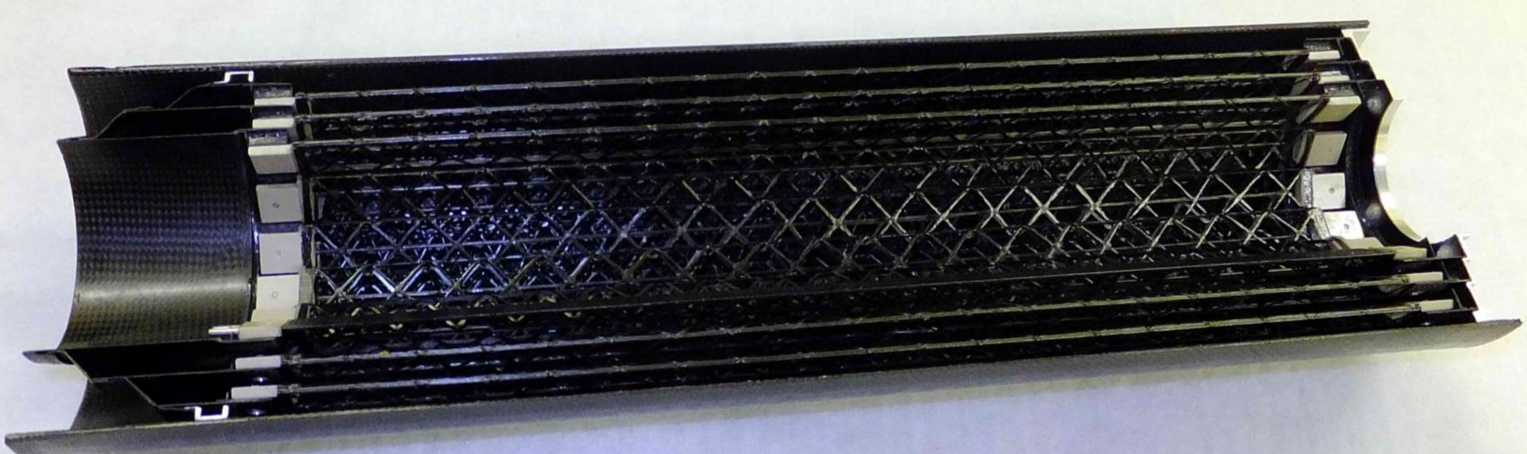
Service feed-through

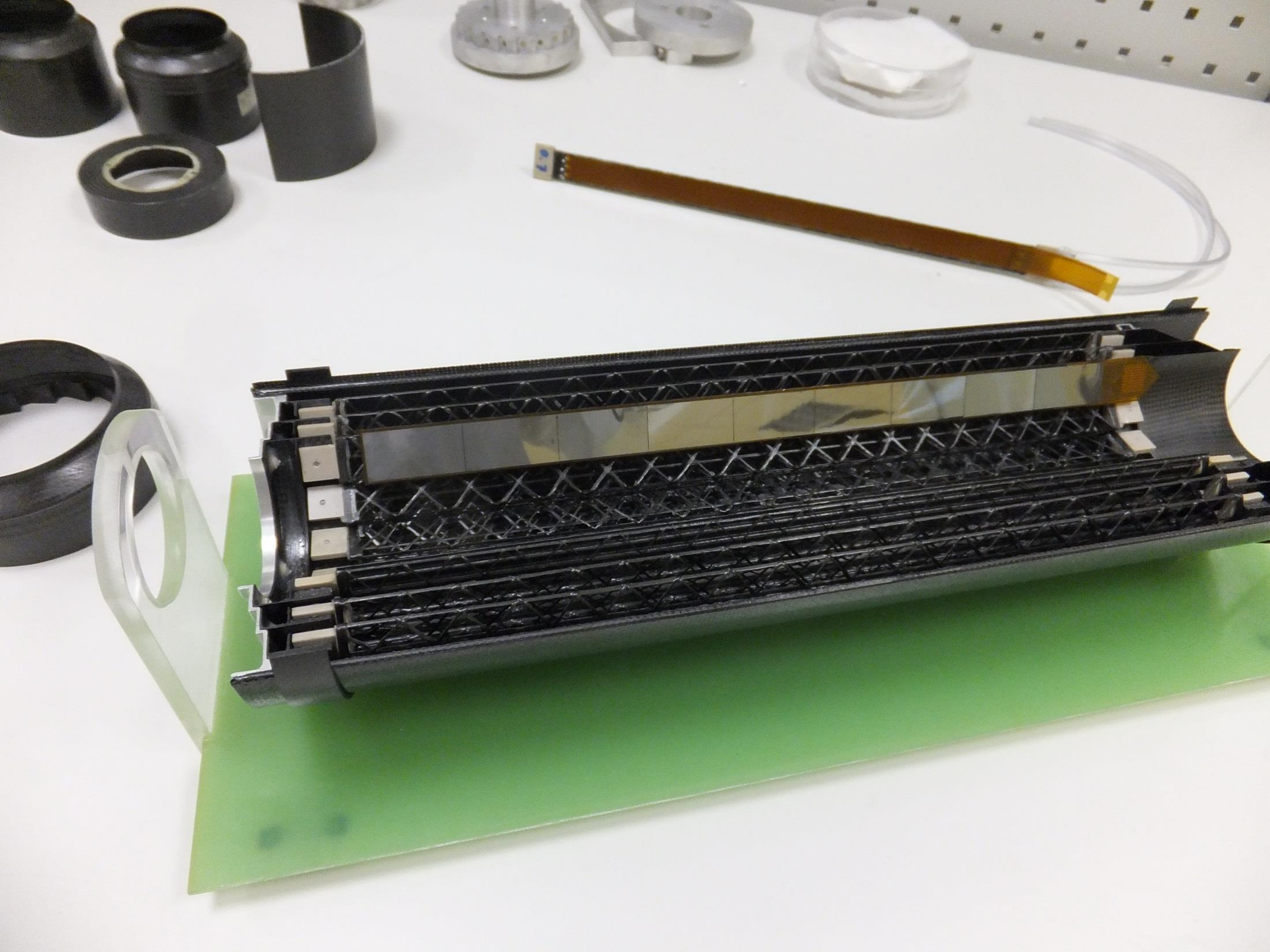


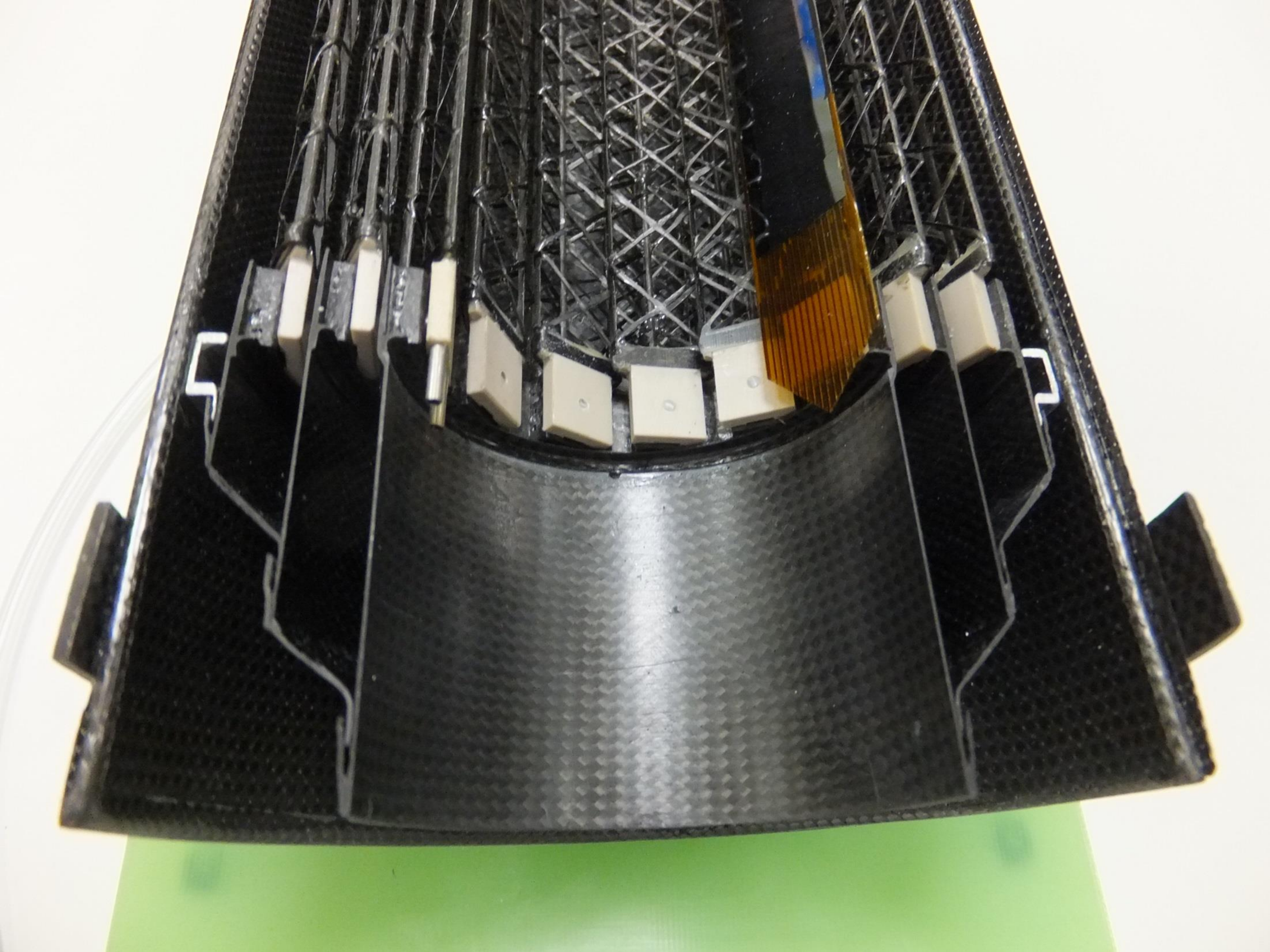


INNER BARREL









Production process
moulds & mandrels

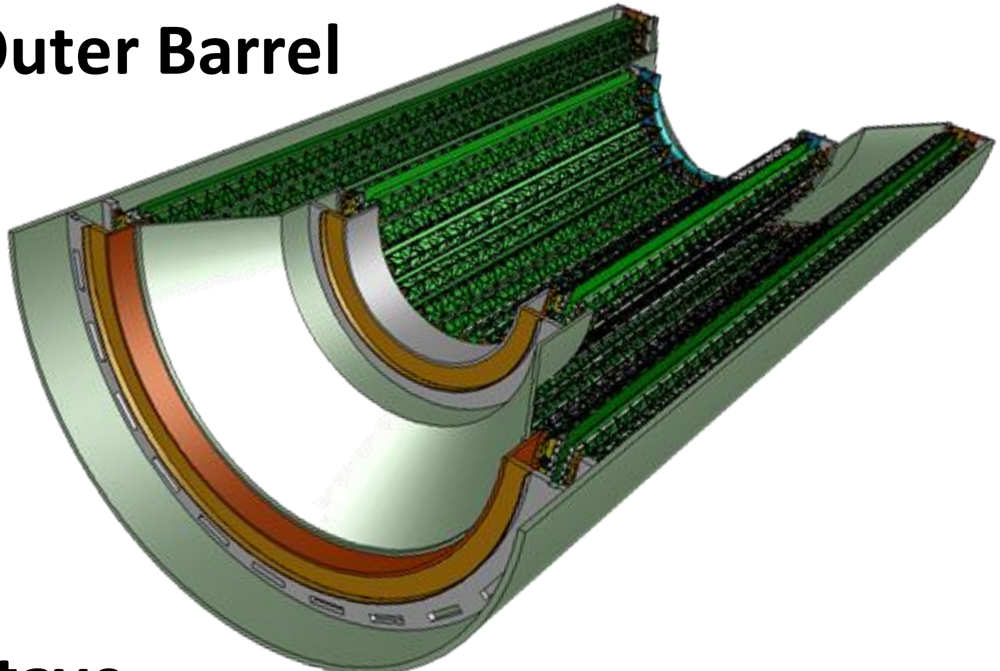
Metallic: steel

Ceramic: Macor

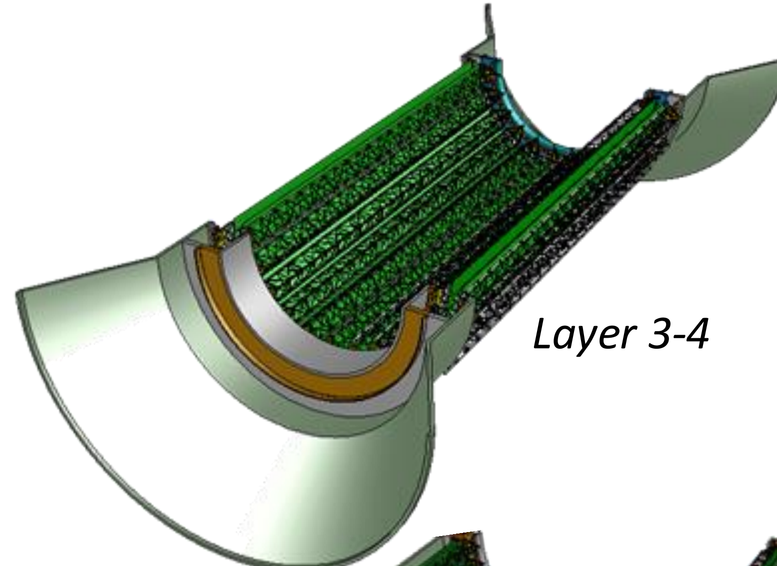
Plastic: Carbon

Thermal stability, low CTE

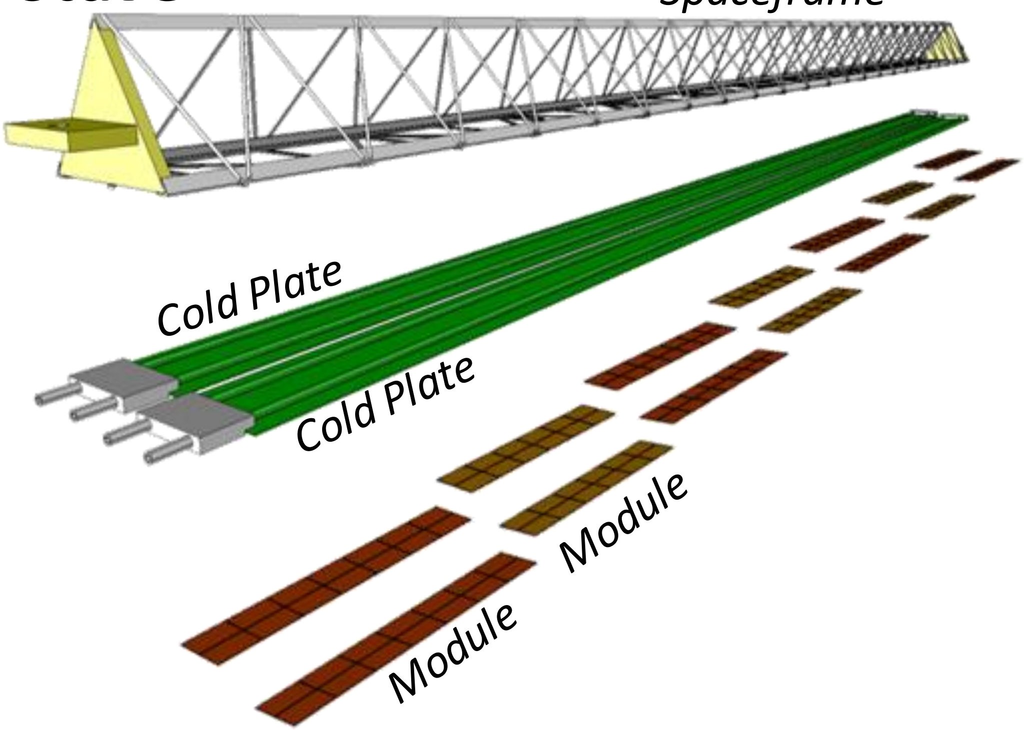
Outer Barrel

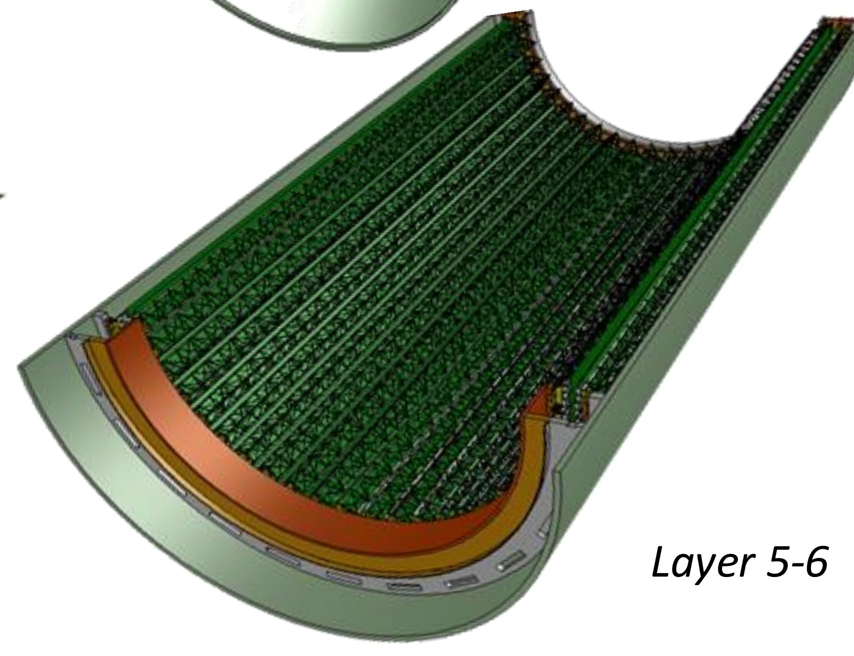


Outer Layers

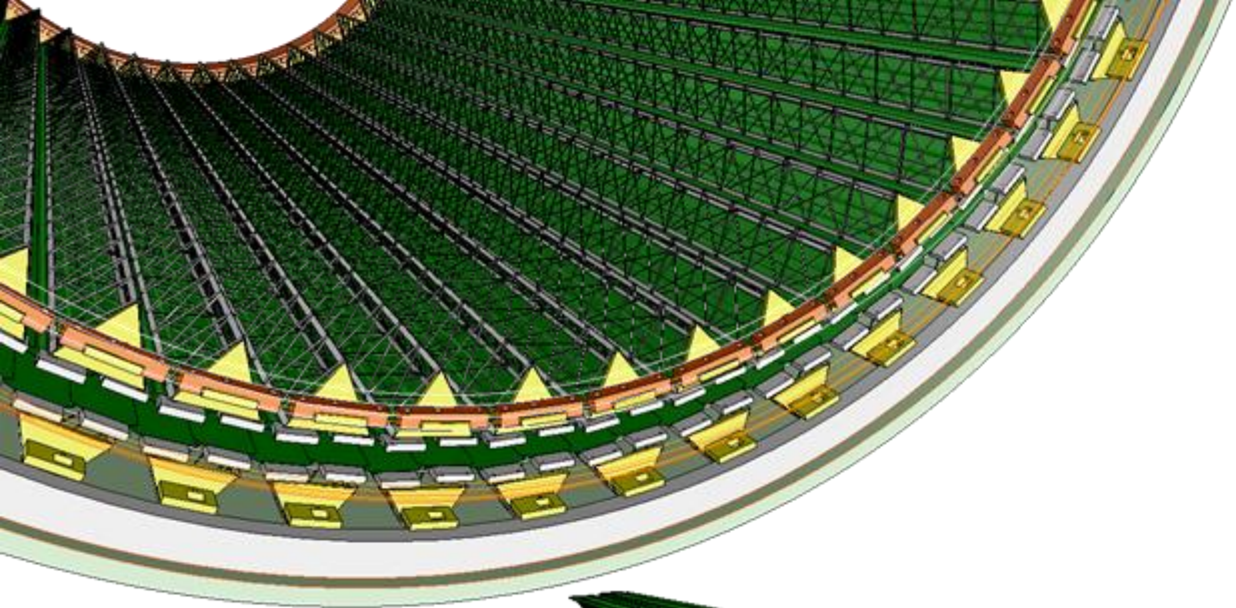


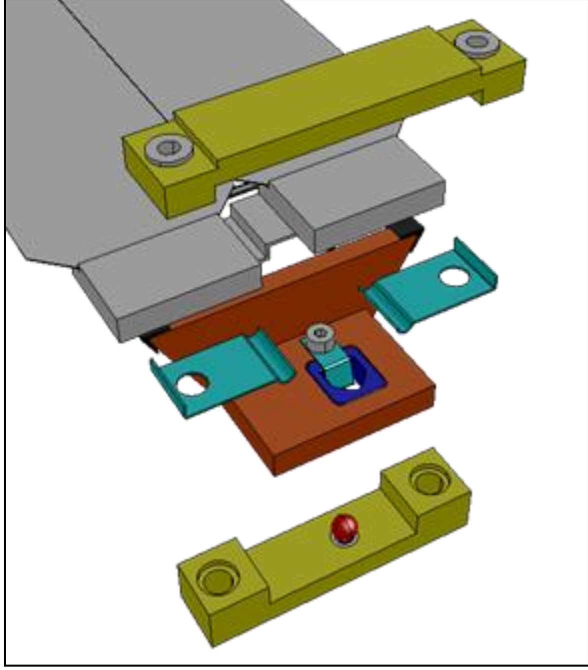
Stave



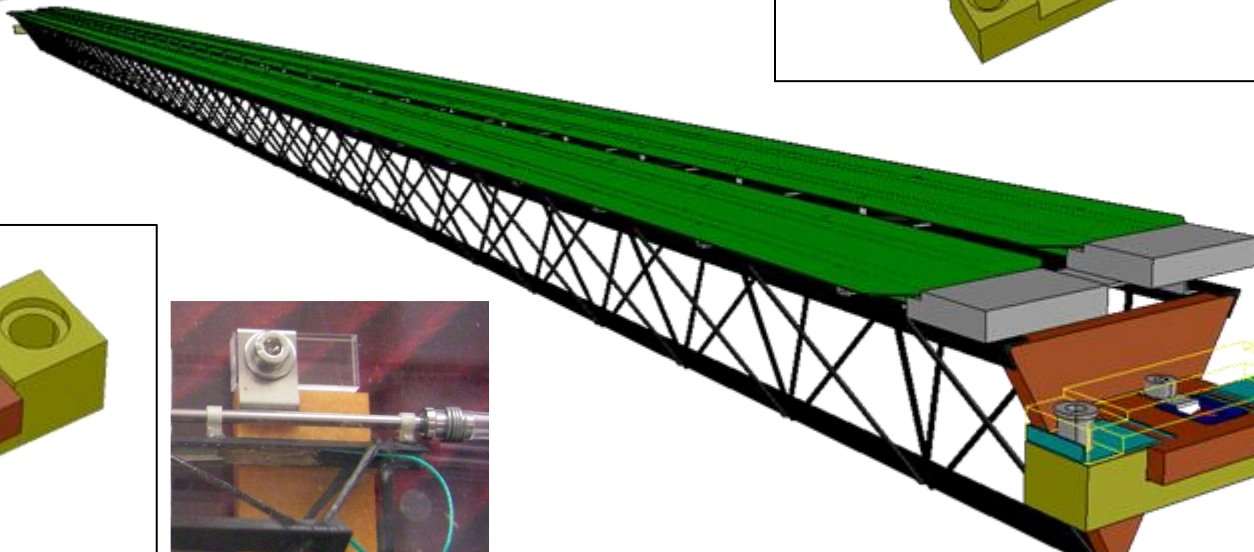


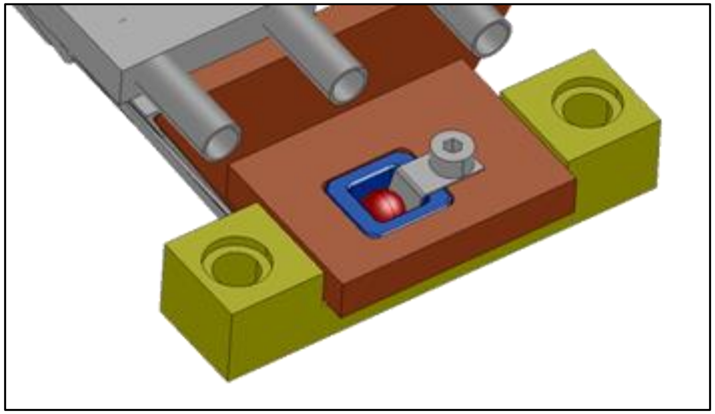
Middle Layers



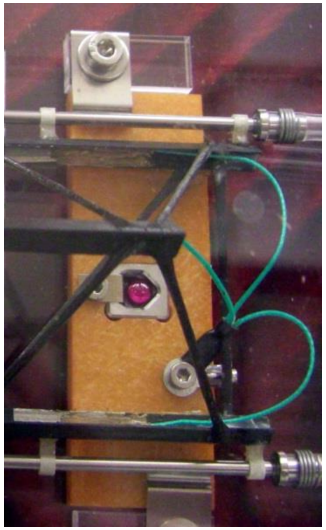


Precise positioning



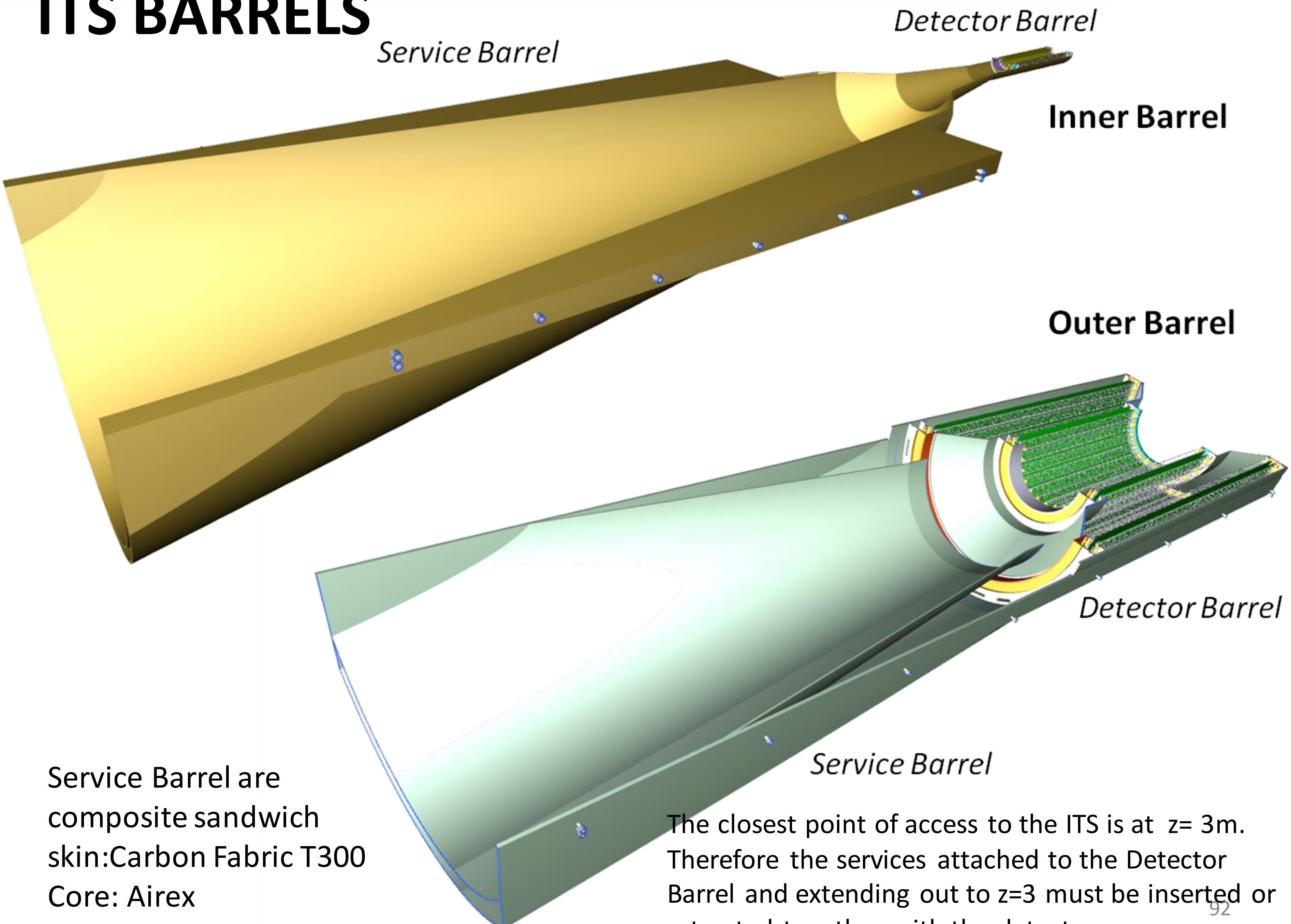


The position of the stave in the reference plane is fixed by a ruby sphere



This system ensures accurate positioning, within **±10 µm**, and provide the possibility to dismount and reposition the stave with the same accuracy in case of maintenance

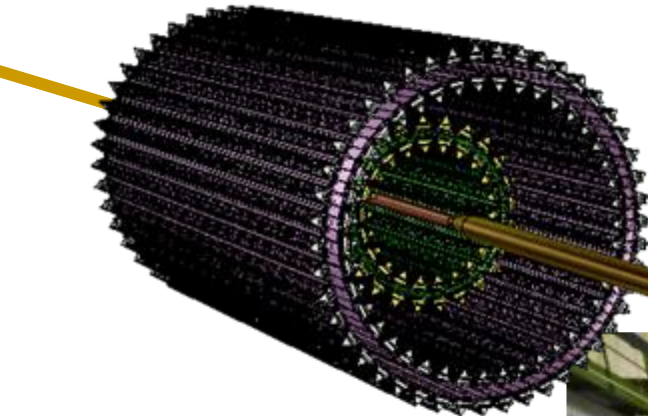
ITS BARRELS



Service Barrel are composite sandwich
skin:Carbon Fabric T300
Core: Airex

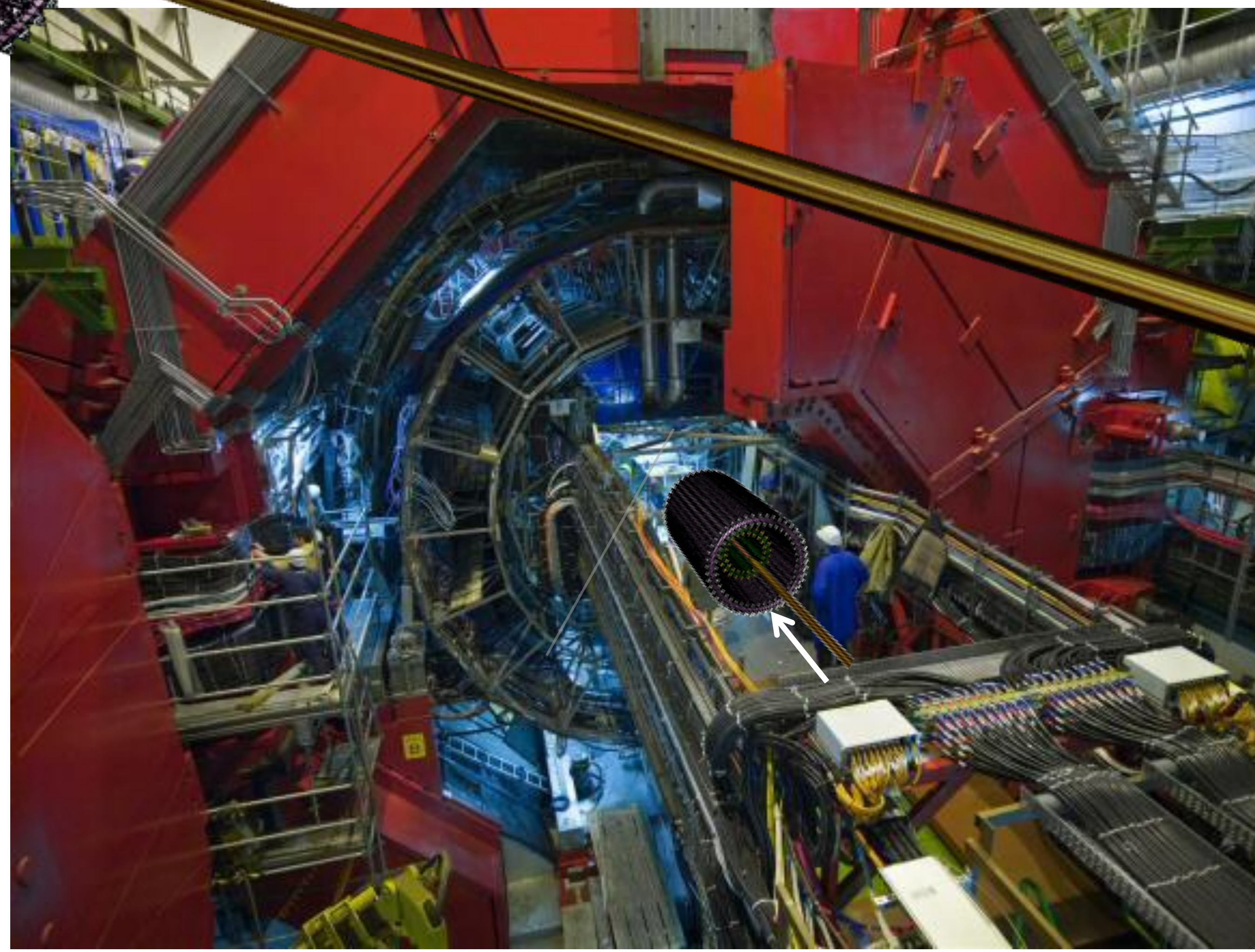
The closest point of access to the ITS is at z= 3m. Therefore the services attached to the Detector Barrel and extending out to z=3 must be inserted or retracted together with the detectors.

Installation

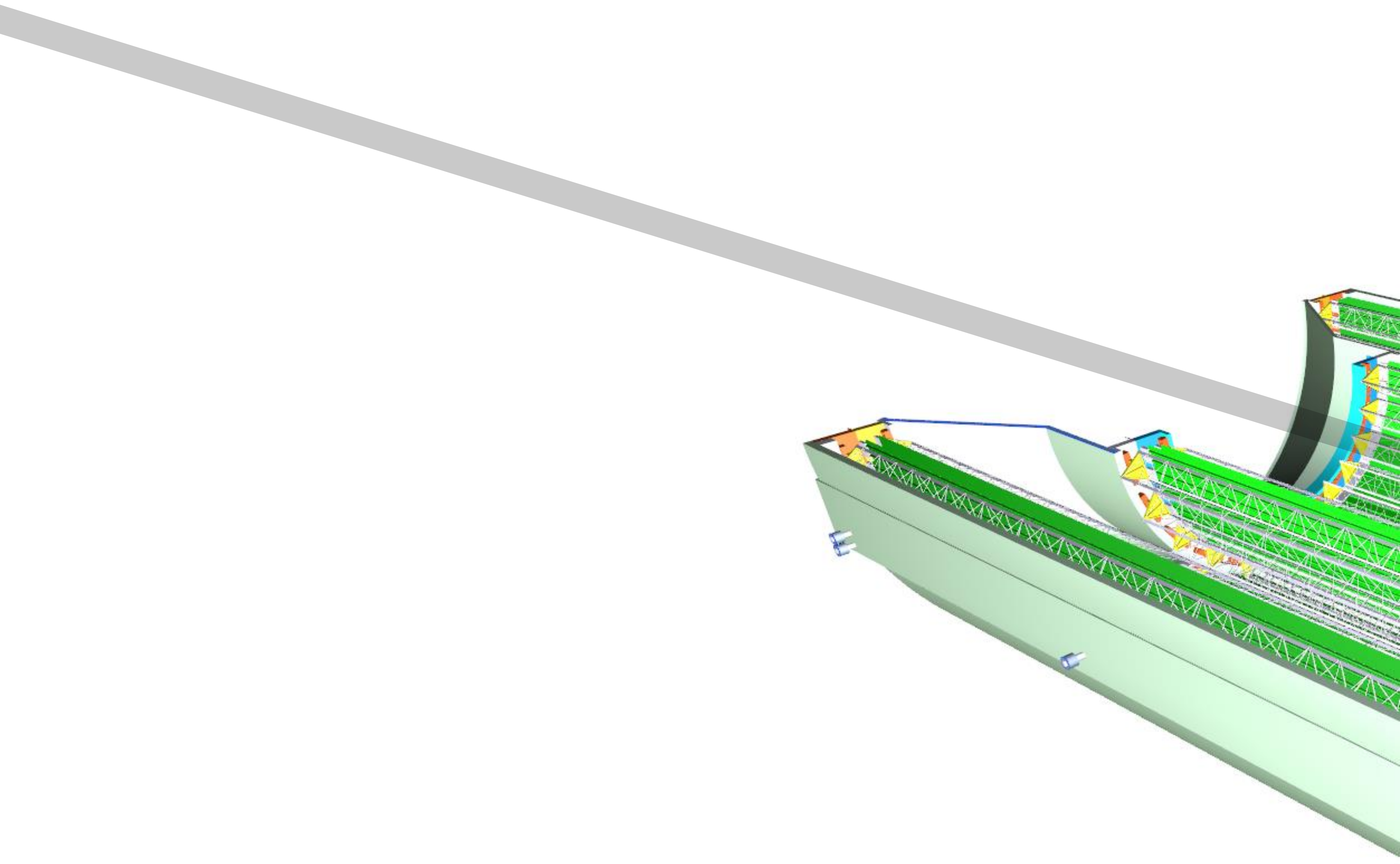


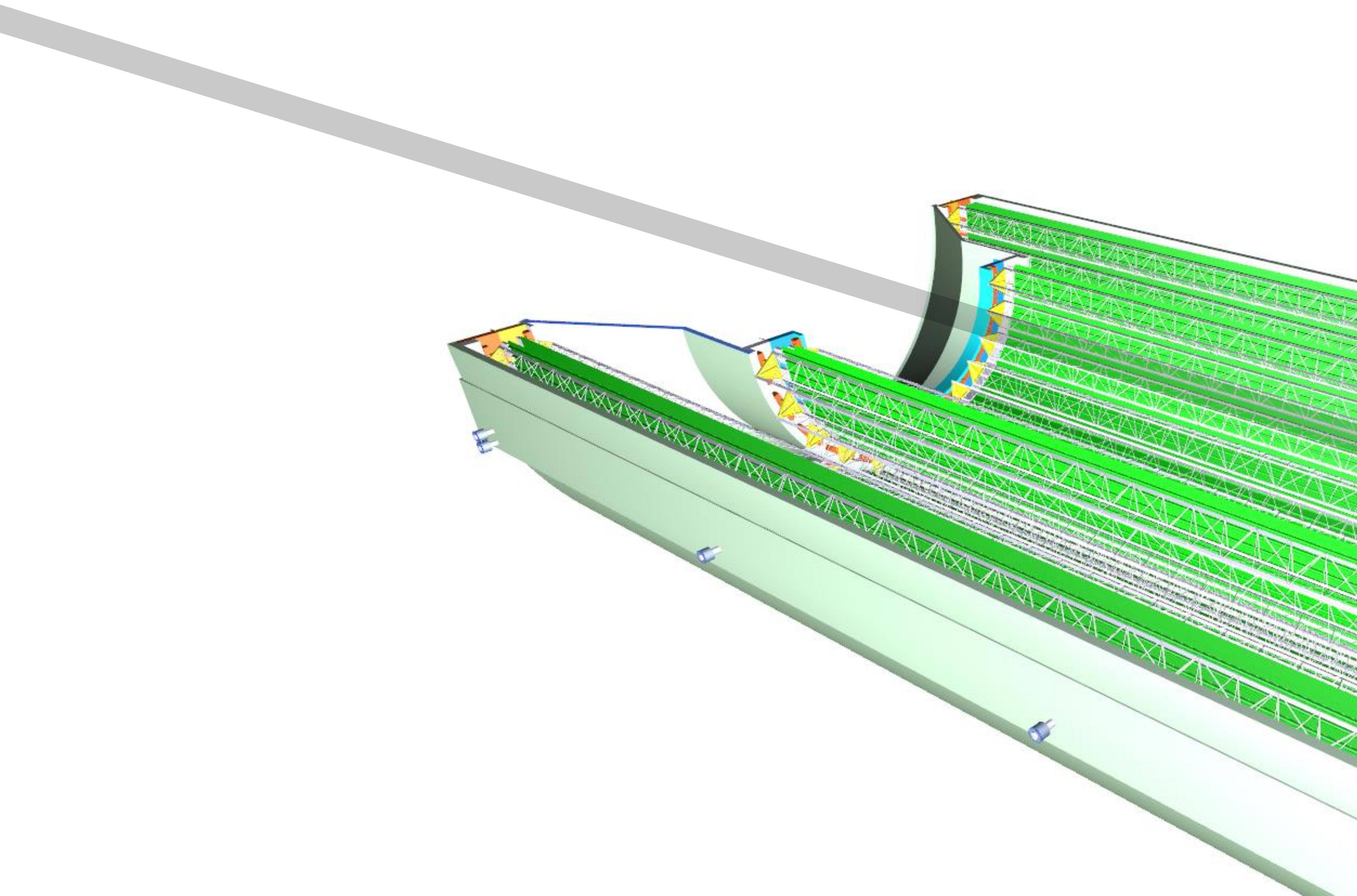
The new ALICE ITS installation scheme is driven by the requirement of a rapid access to the ITS modules during the yearly LHC shutdown (3-4 months time)

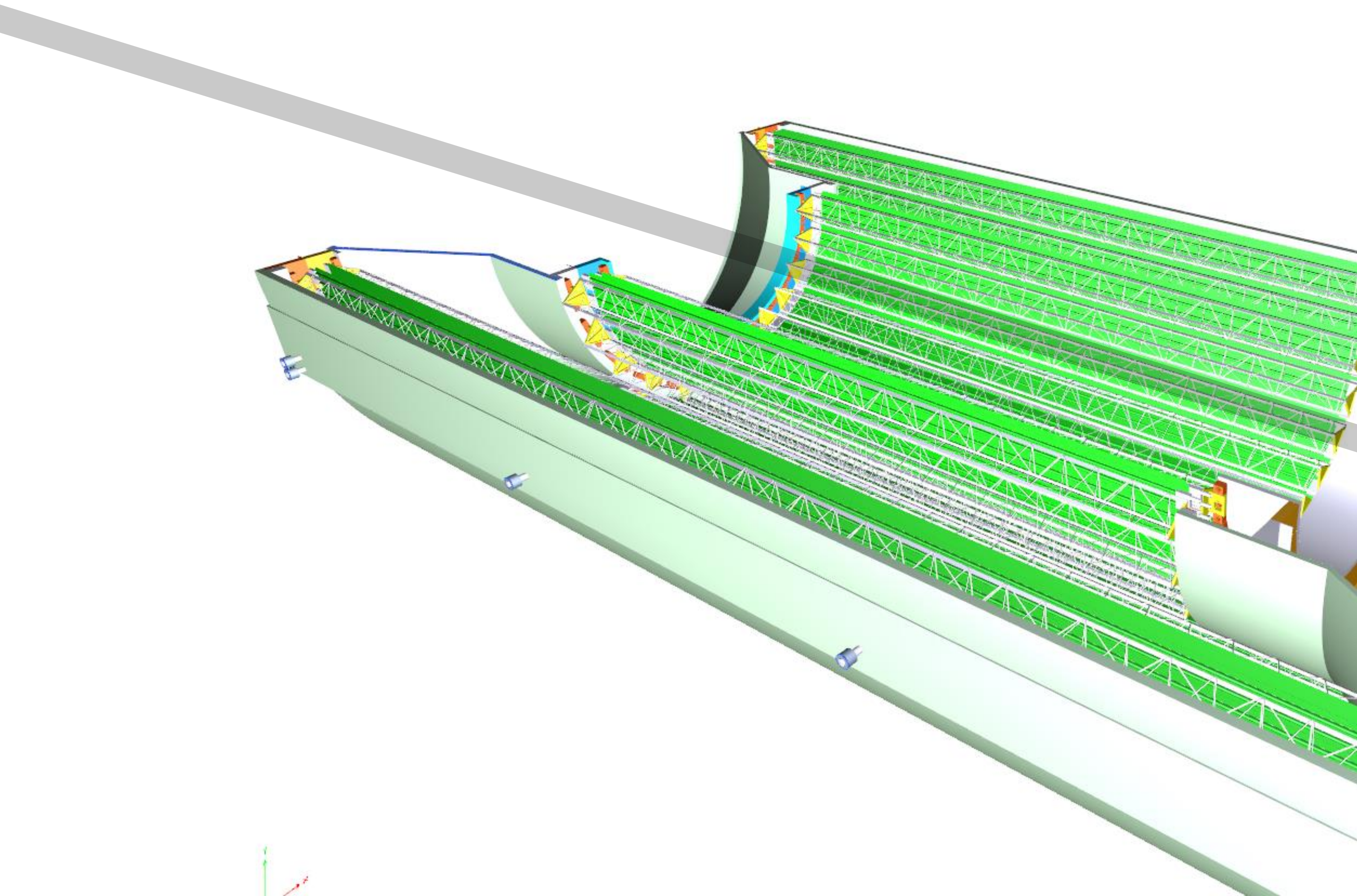
6-7 months are neded to interviene on the present ITS, TPC needs to be moved

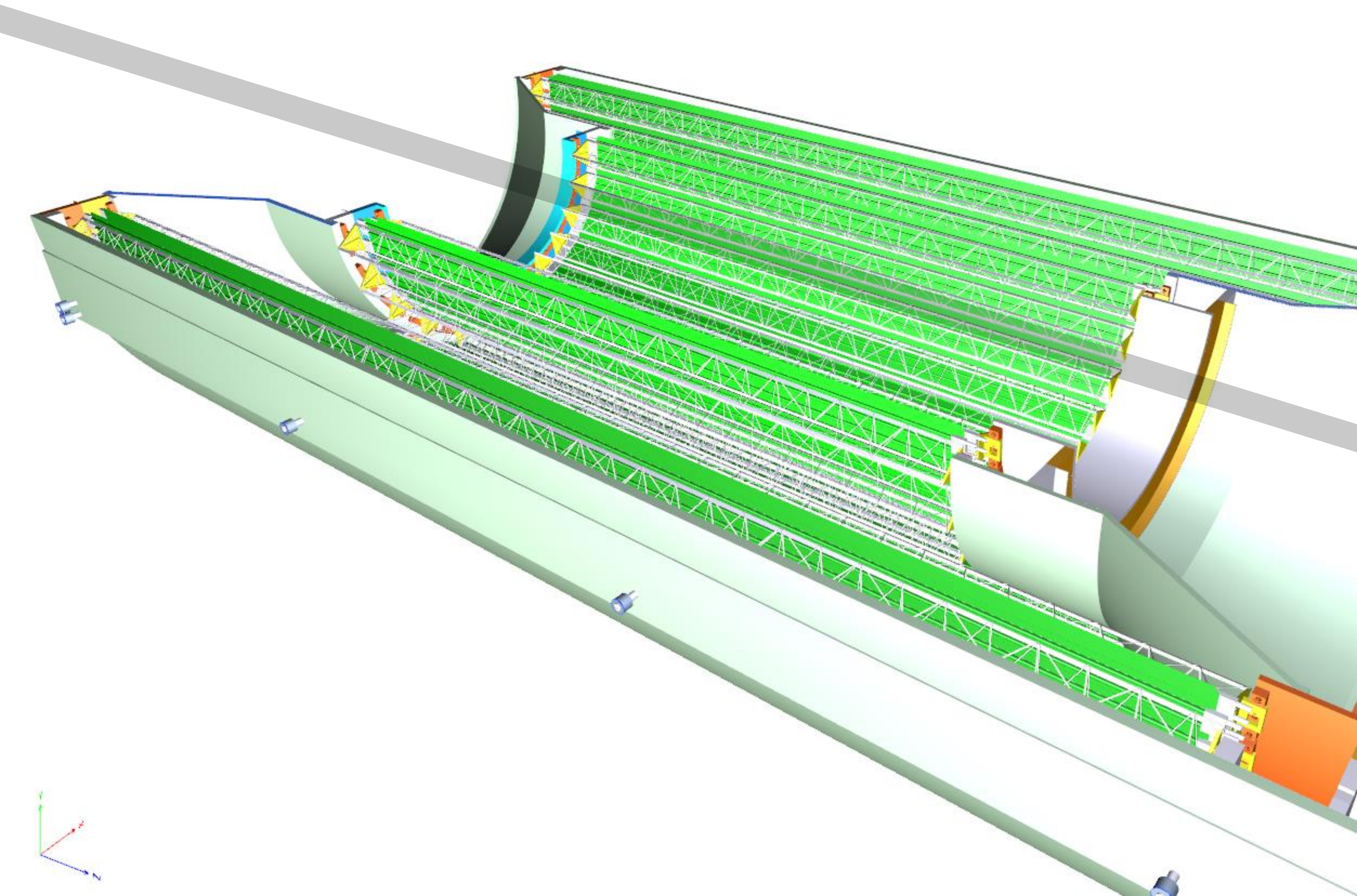


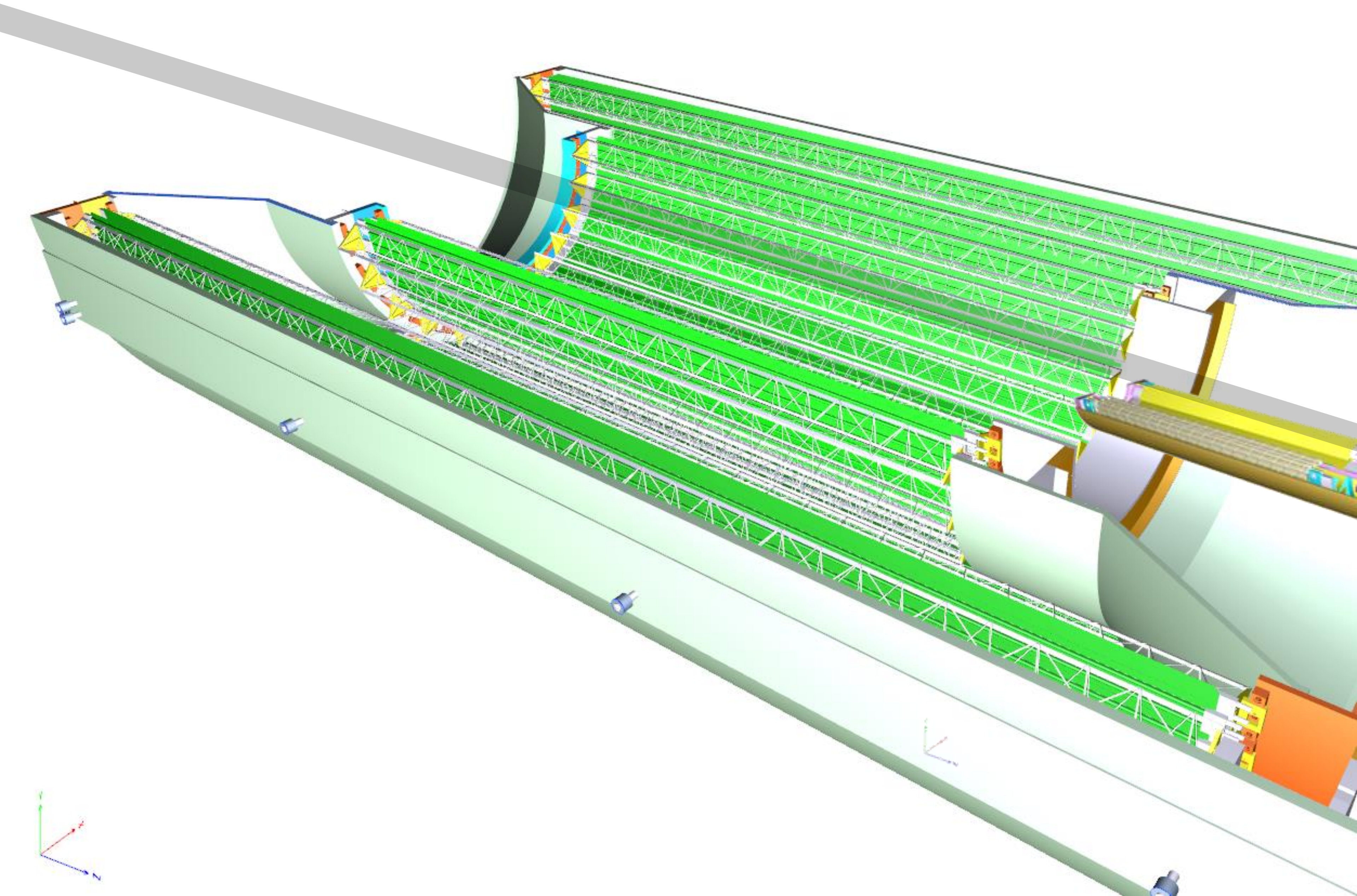
The chosen scheme foresees a translation of the ITS by approximately 3 meters along the beampipe to allow for this accessibility

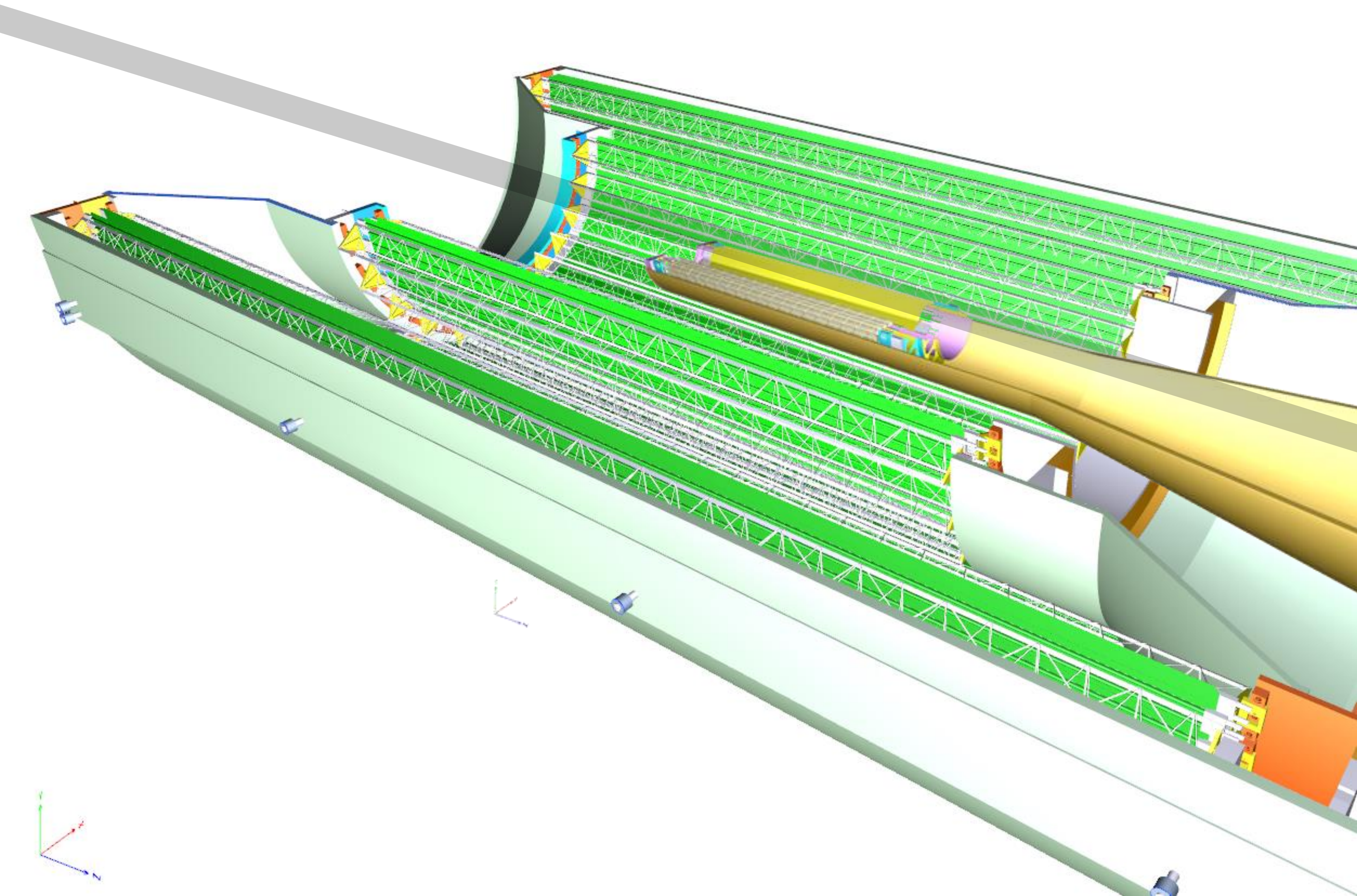


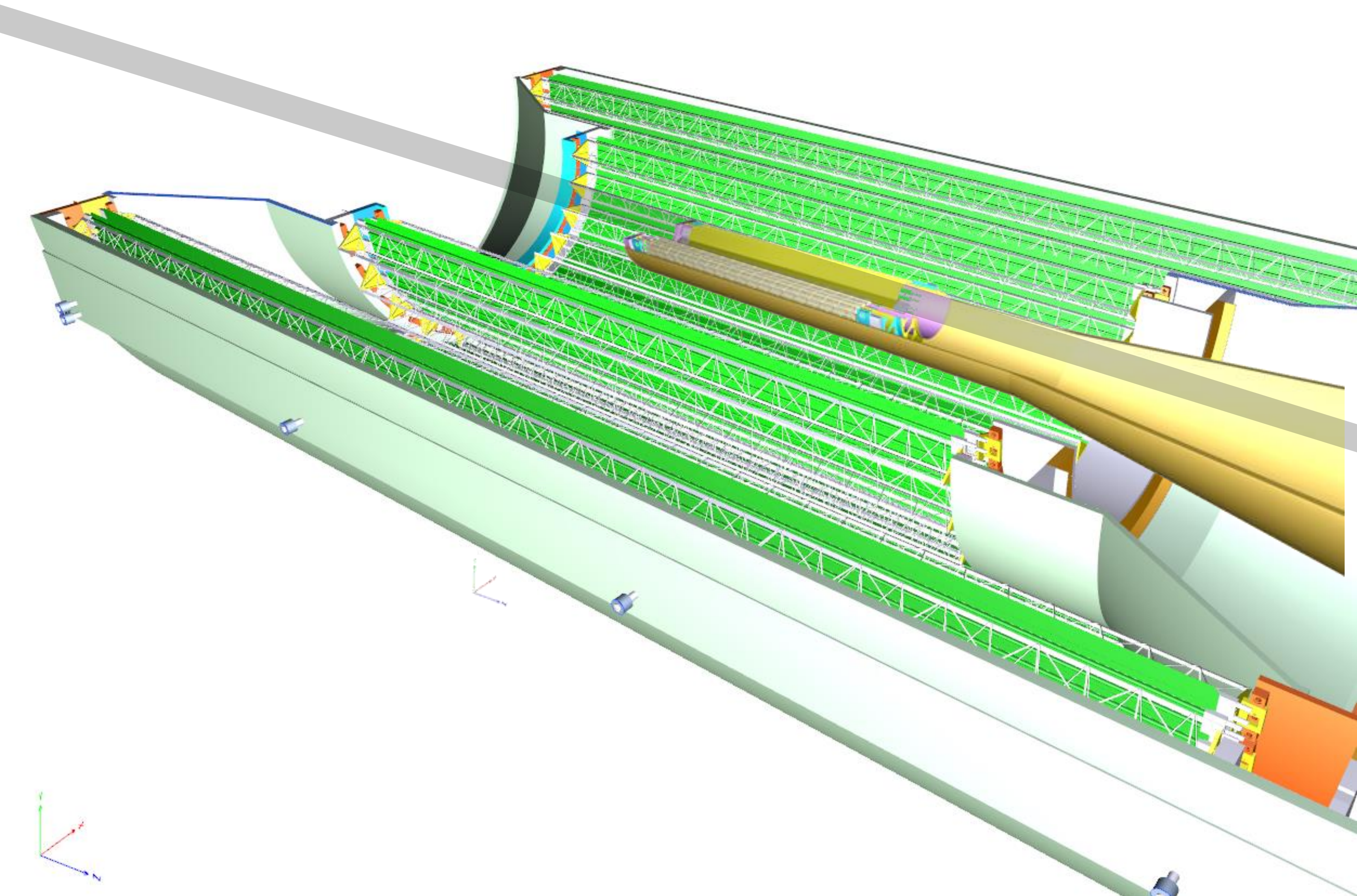












Summary

◆●⧫❒♋📪●♓♑♒⧫ Tracker Mechanical Structures

✓Challenging requirements on low material budget drive the choice of the materials to be used in the mechanical structures

✓The use of carbon composite materials offerS the possibility to tailor the mechanical and thermal properties of the material to fulfill the design requirements.

✓Extensive prototyping and test are needed to qualify these structures: different testing phases have to be foreseen at the level of development and qualification during the design phase and at acceptance level during production and assembly

…if you want to send a TRACKER to space

Corrado Gargiulo
on behalf of AMS

…needs to be ultraligth
(not only for physics)

	Space Shuttle *	Russian Progress	Commercial Resupply Services (CRS)
Approximate cost per pound to ISS	$21,268	$18,149	$26,770

…needs to survive LAUNCH LOADS

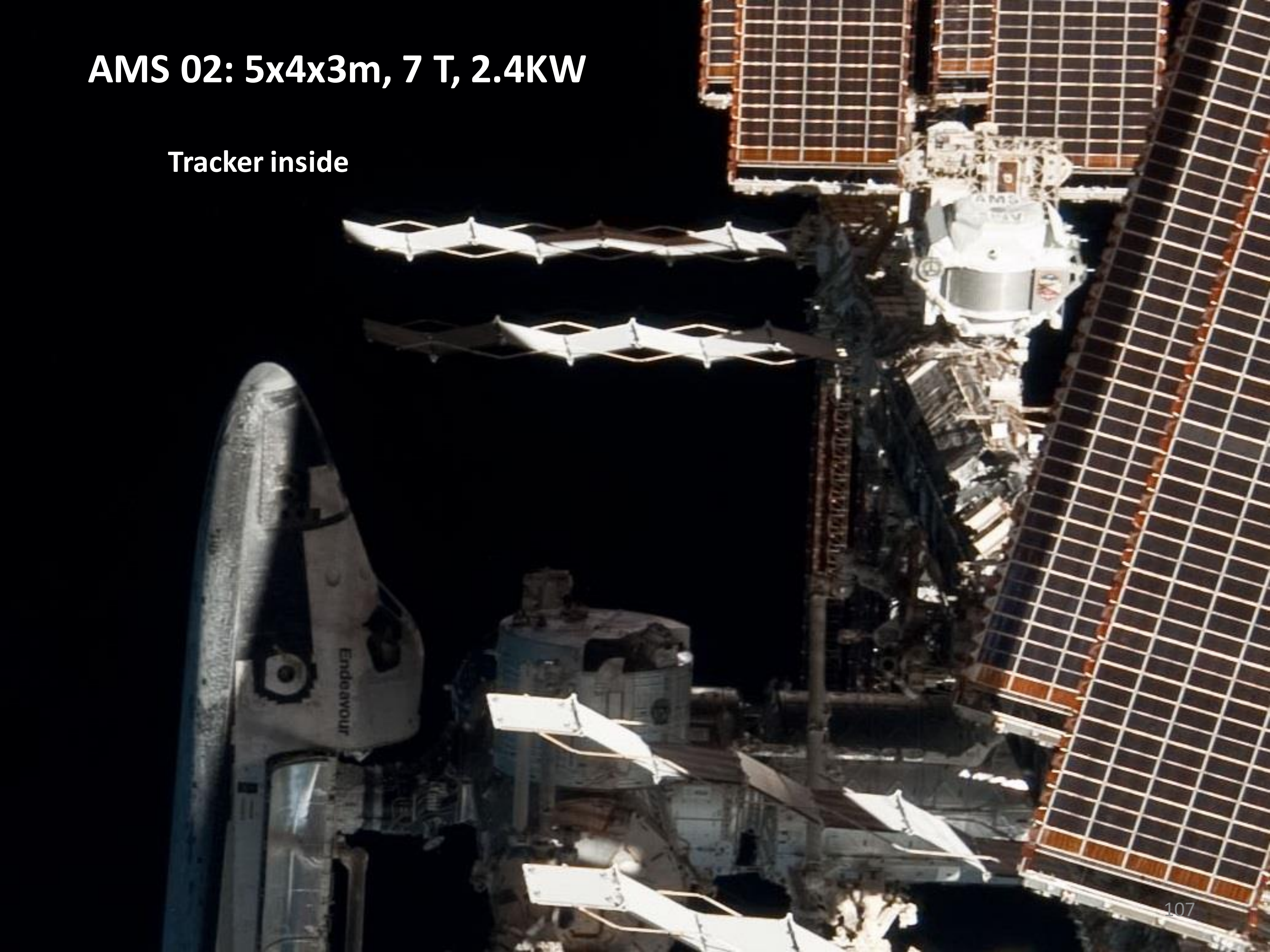
The critical load conditions affecting the payload occur primarily during liftoff

...needs to survive SPACE ENVIRONMENT

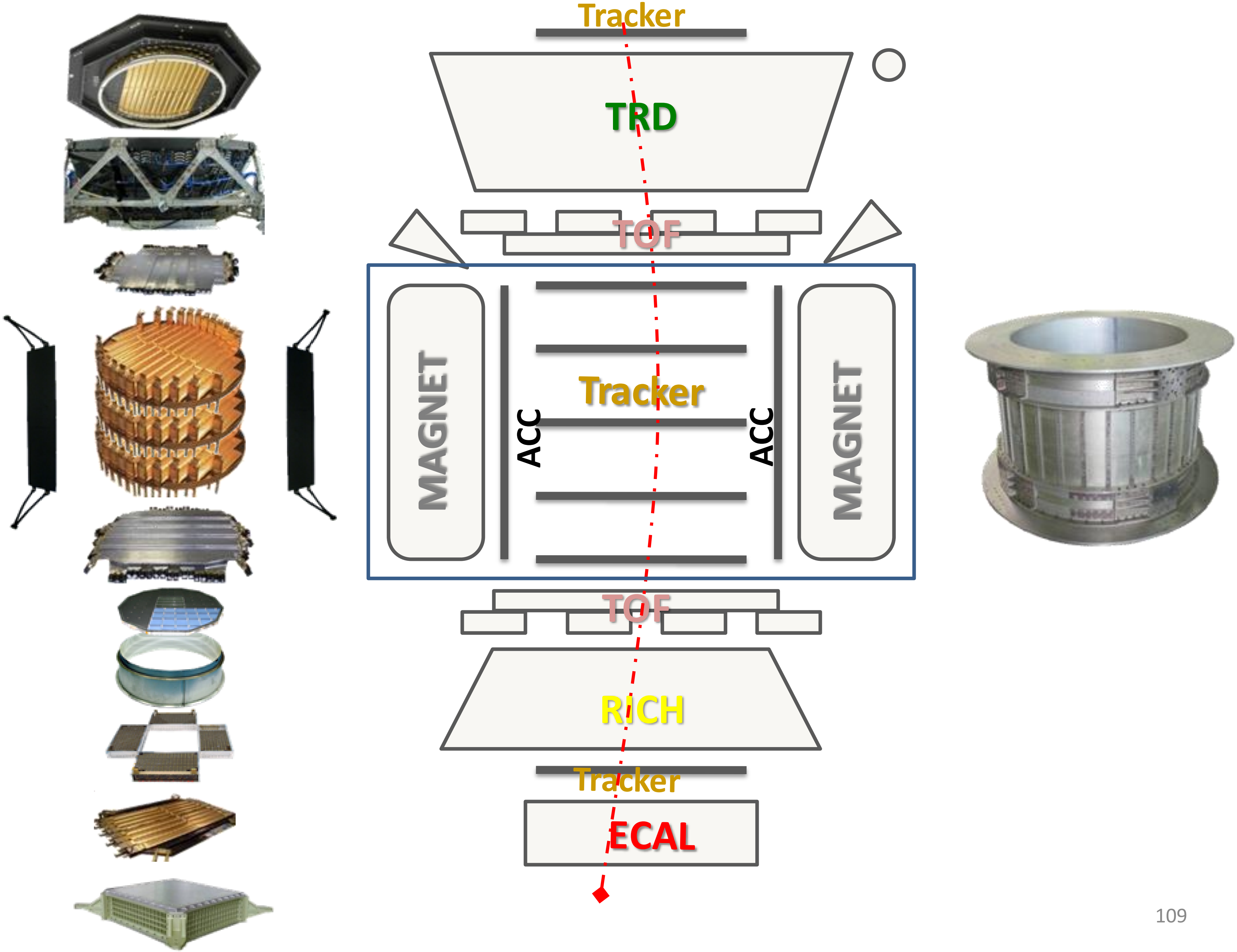
… no chance to repair a fault

AMS 02: 5x4x3m, 7 T, 2.4KW

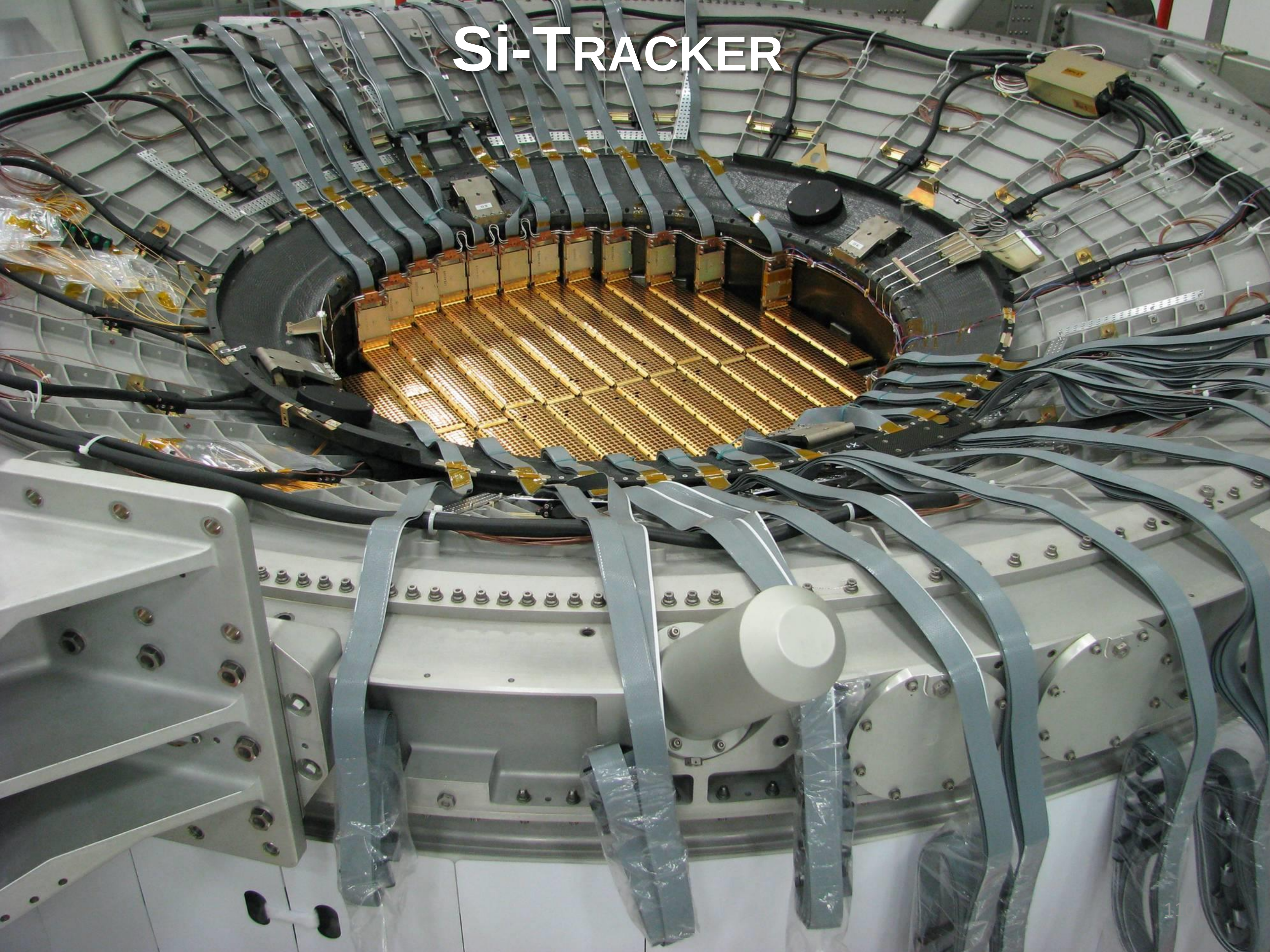
Tracker inside



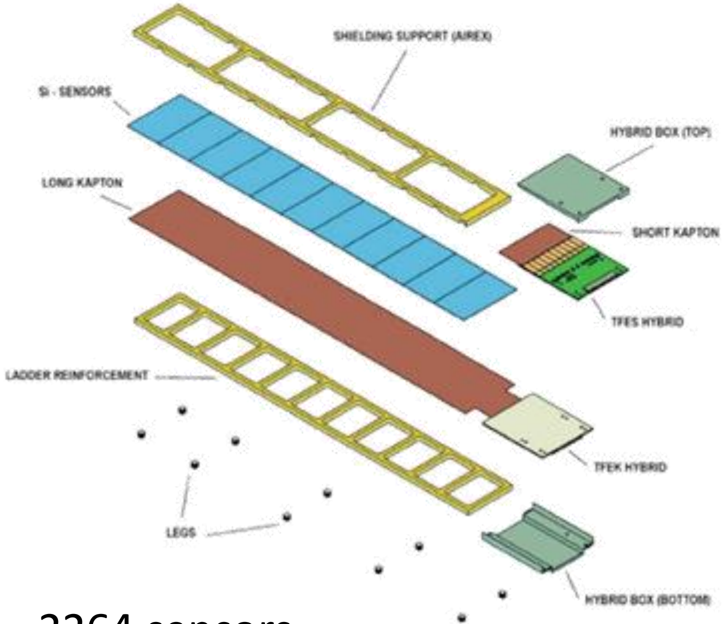
AMS in the CERN clean room


Tracker
TRD
TOF
MAGNET
ACC
Tracker
ACC
MAGNET
TOF
RICH
Tracker
ECAL

Si-Tracker



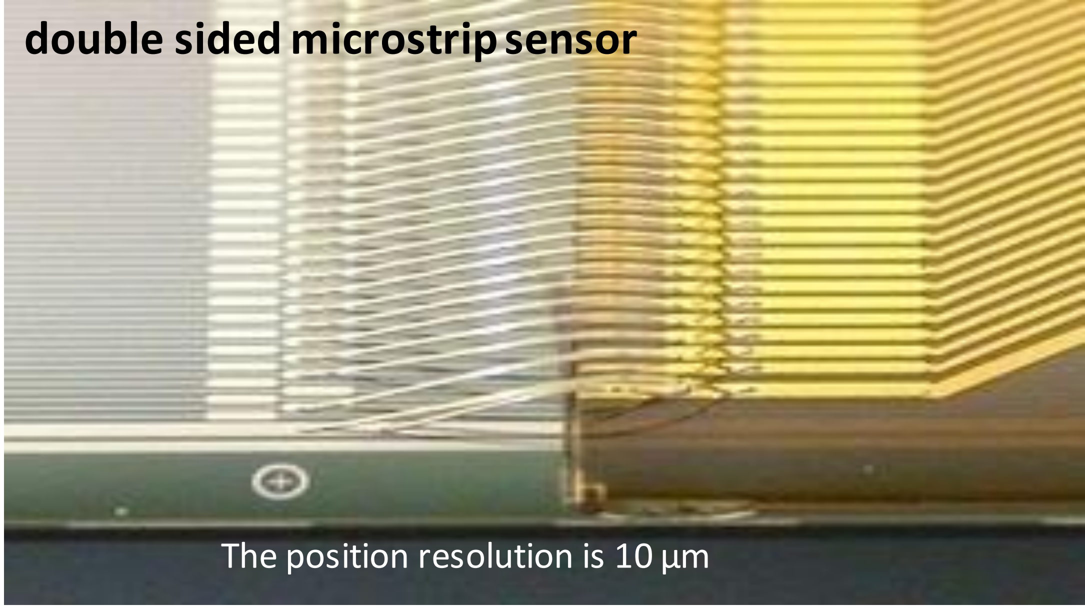
Tracker in Space

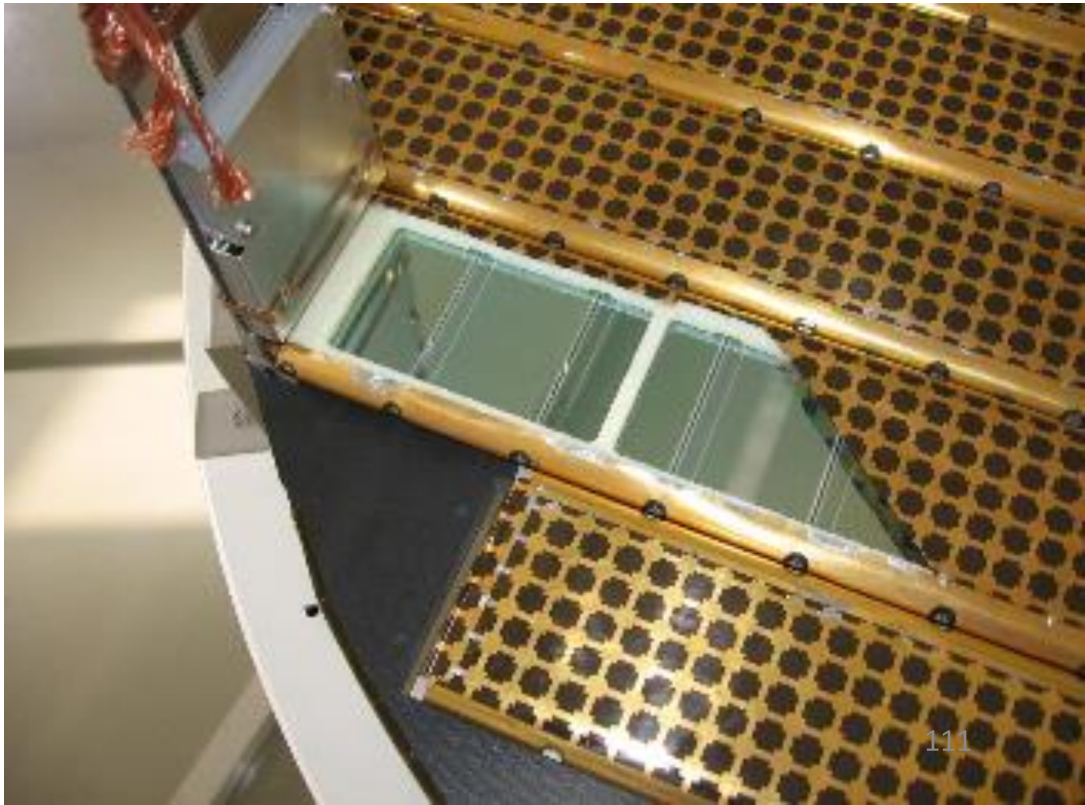


2264 sensors

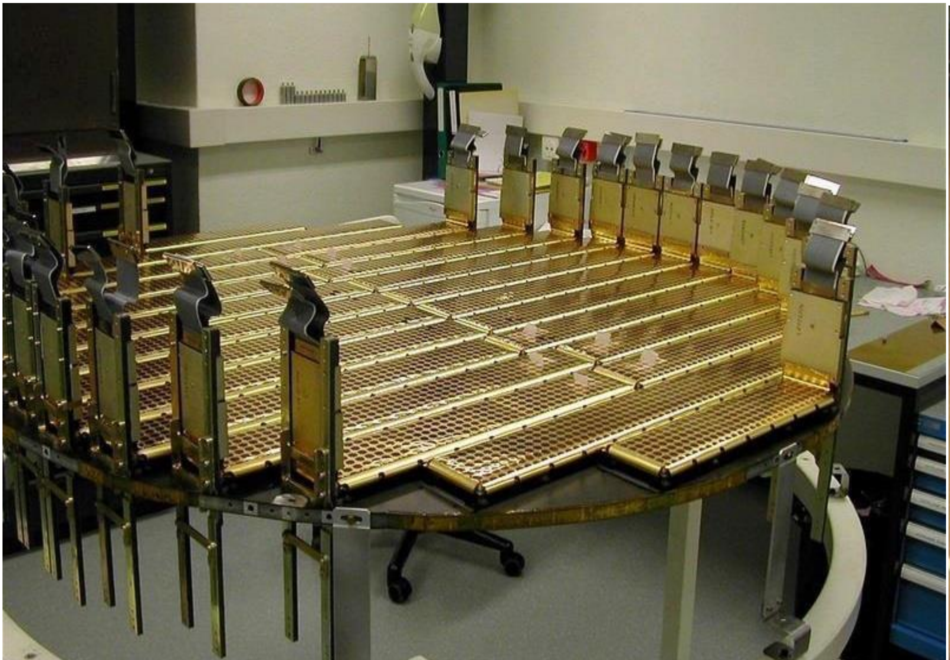
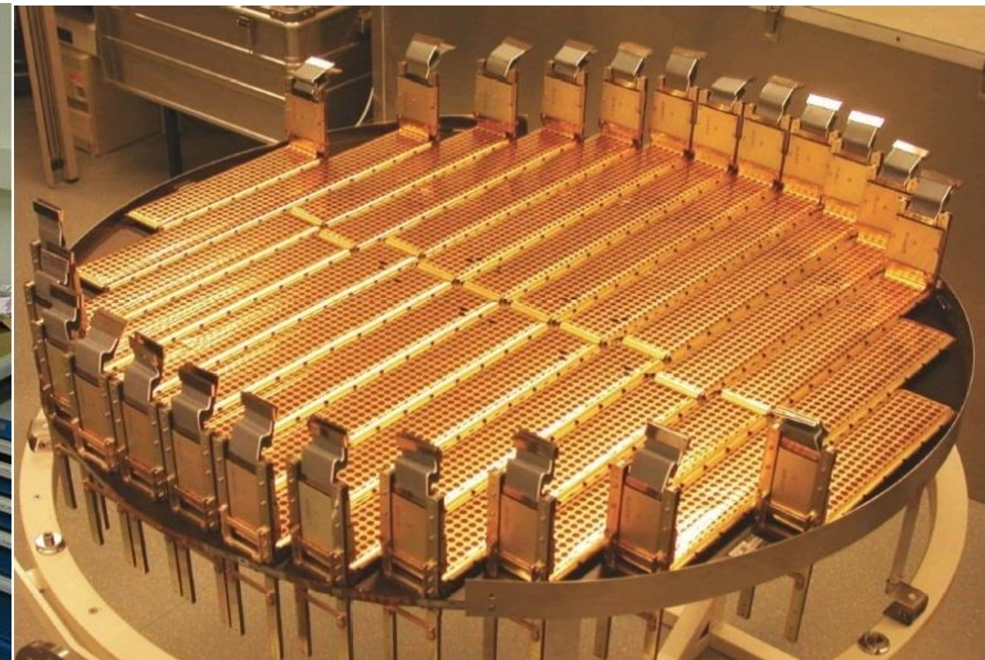
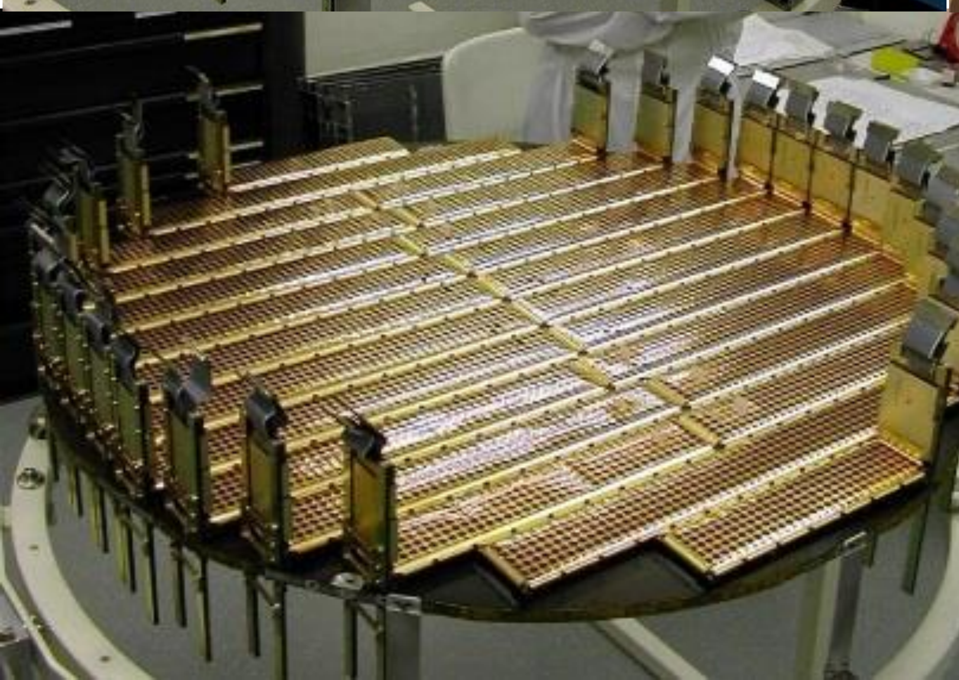
Double sided microstrip sensor

Each sensor consists of a substrate high purity doped silicon 300 um thick.

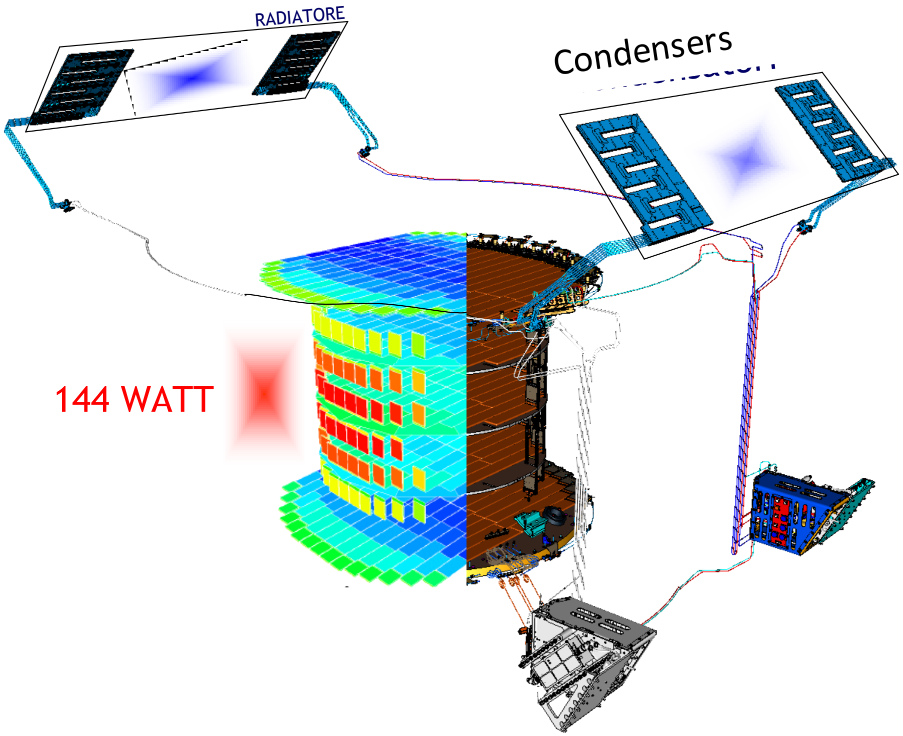


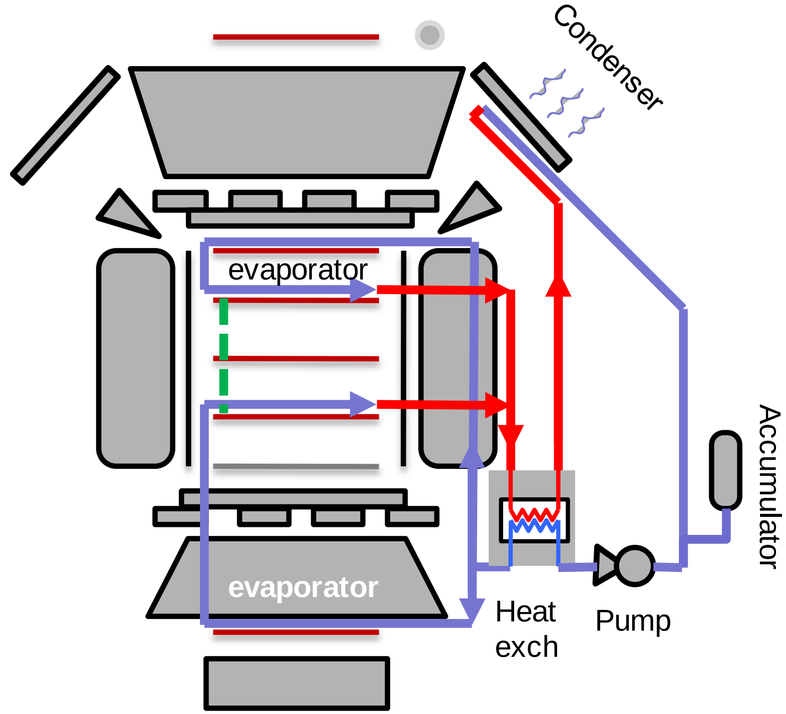


There are 9 planes with 200,000 channels aligned to 3 microns


Tracker in Space: cooling





The tracker front-end electronics generate in the tracker 144 W of heat which are removed by a

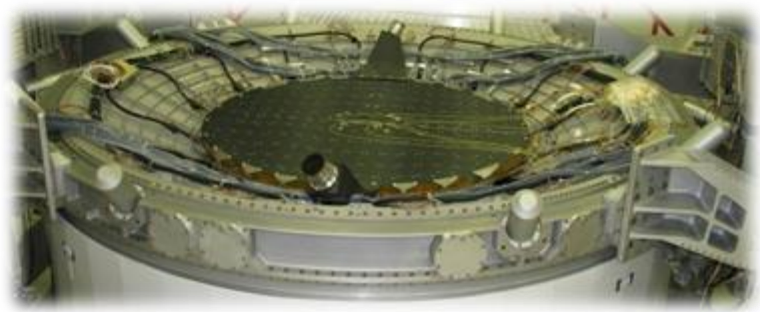
two phase CO_2

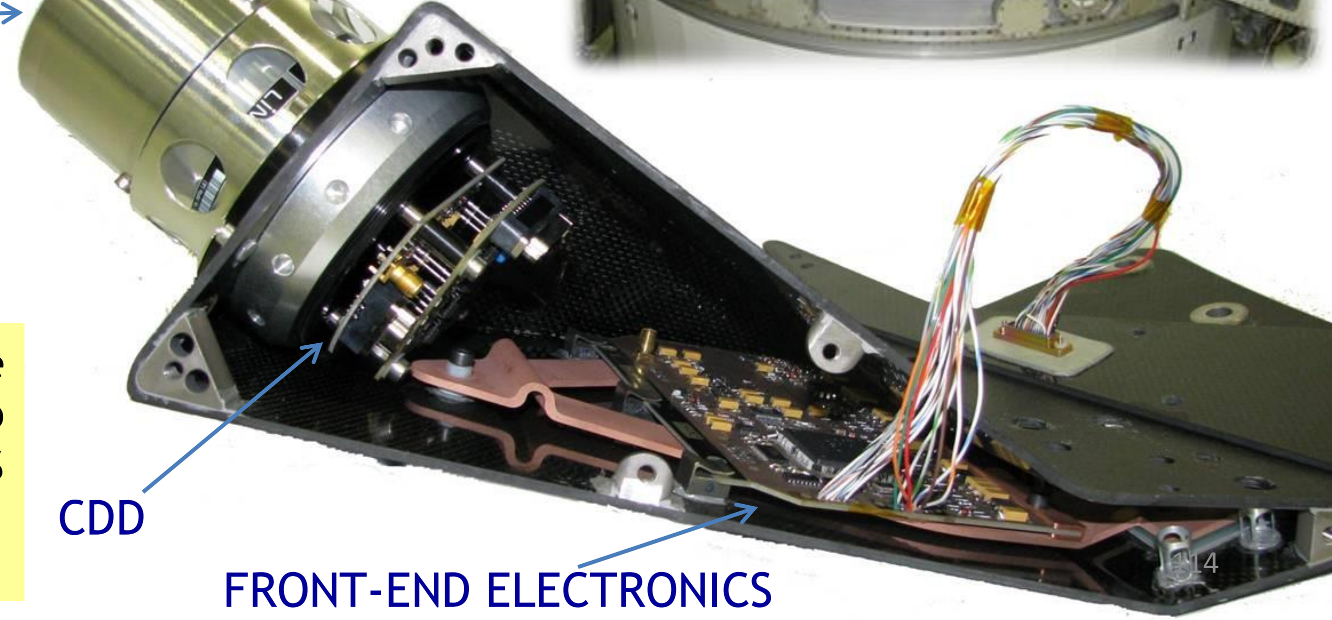
cooling loop system, the Tracker Thermal Control System

Tracker in Space: orientation

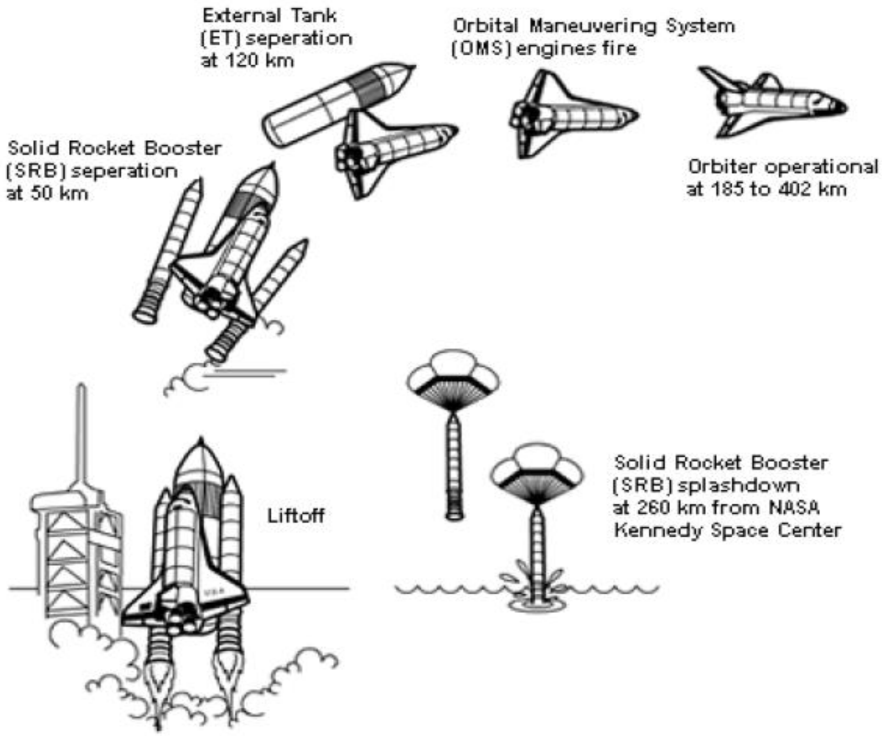
STAR TRACKER

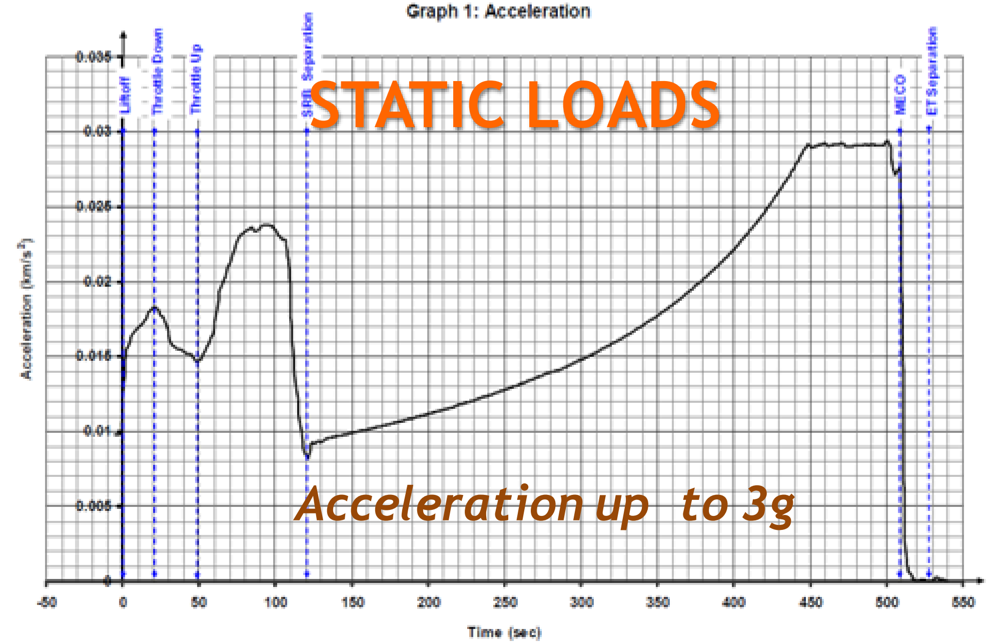
Provide AMS orientation with accuracy of few arcsec

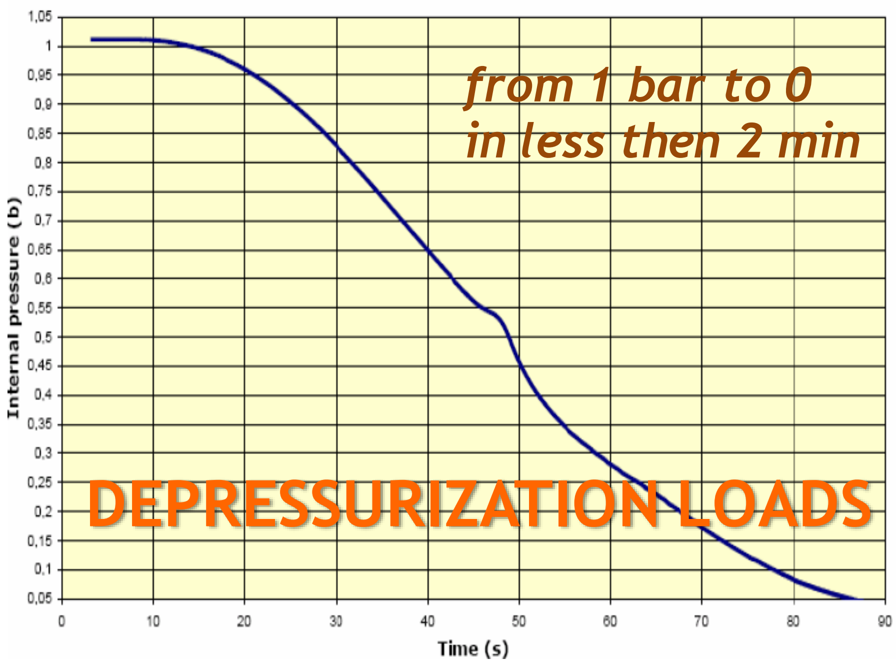


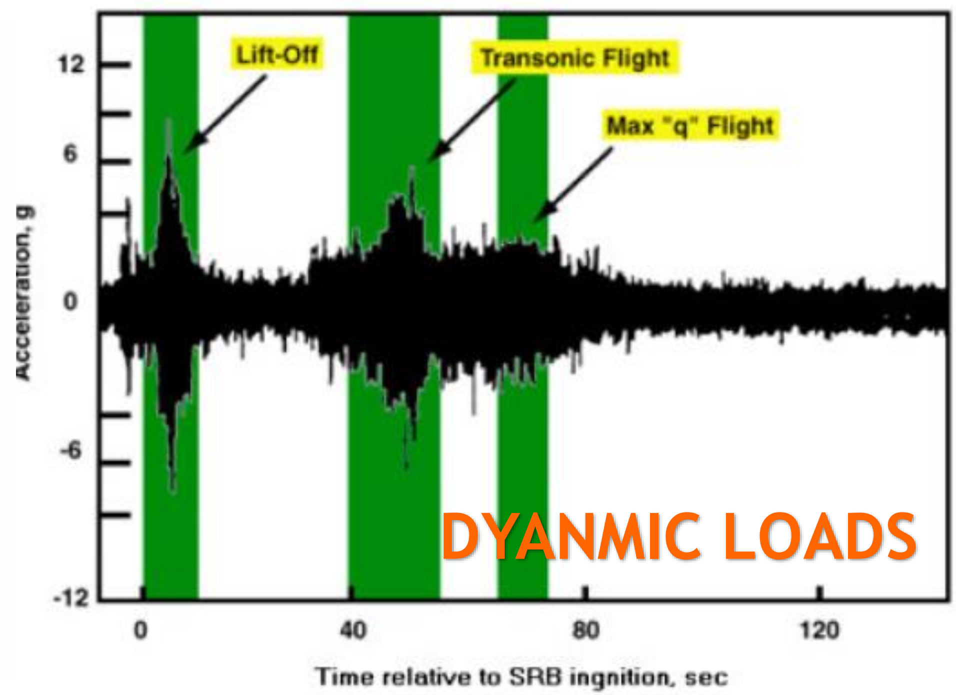


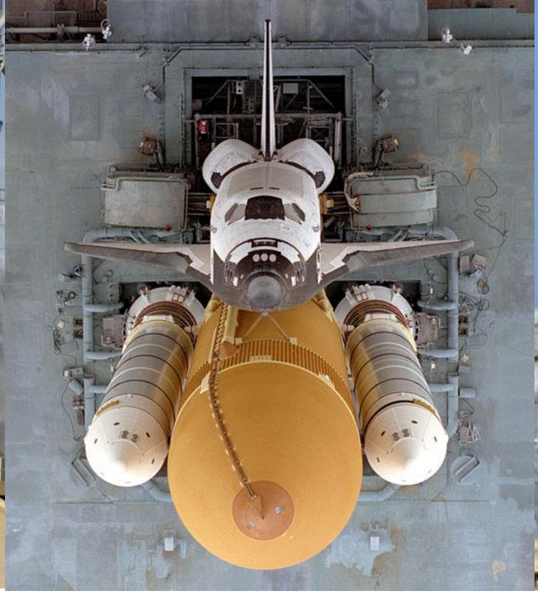
To optimize science from the tracker it is important to know the position of AMS with a precision of few arc-seconds.


External Tank
(ET) seperation
at 120 km
Orbital Maneuvering System
(OMS) engines fire
Solid Rocket Booster
(SRB) seperation
at 50 km
Orbiter operational
at 185 to 402 km
Liftoff
Solid Rocket Booster
(SRB) splashdown
at 260 km from NASA
Kennedy Space Center


Graph 1: Acceleration
STATIC LOADS
Liftoff
Throttle Down
Throttle Up
SRB Separation
MECO
ET Separation
Acceleration (km/s²)
Acceleration up to 3g
Time (sec)

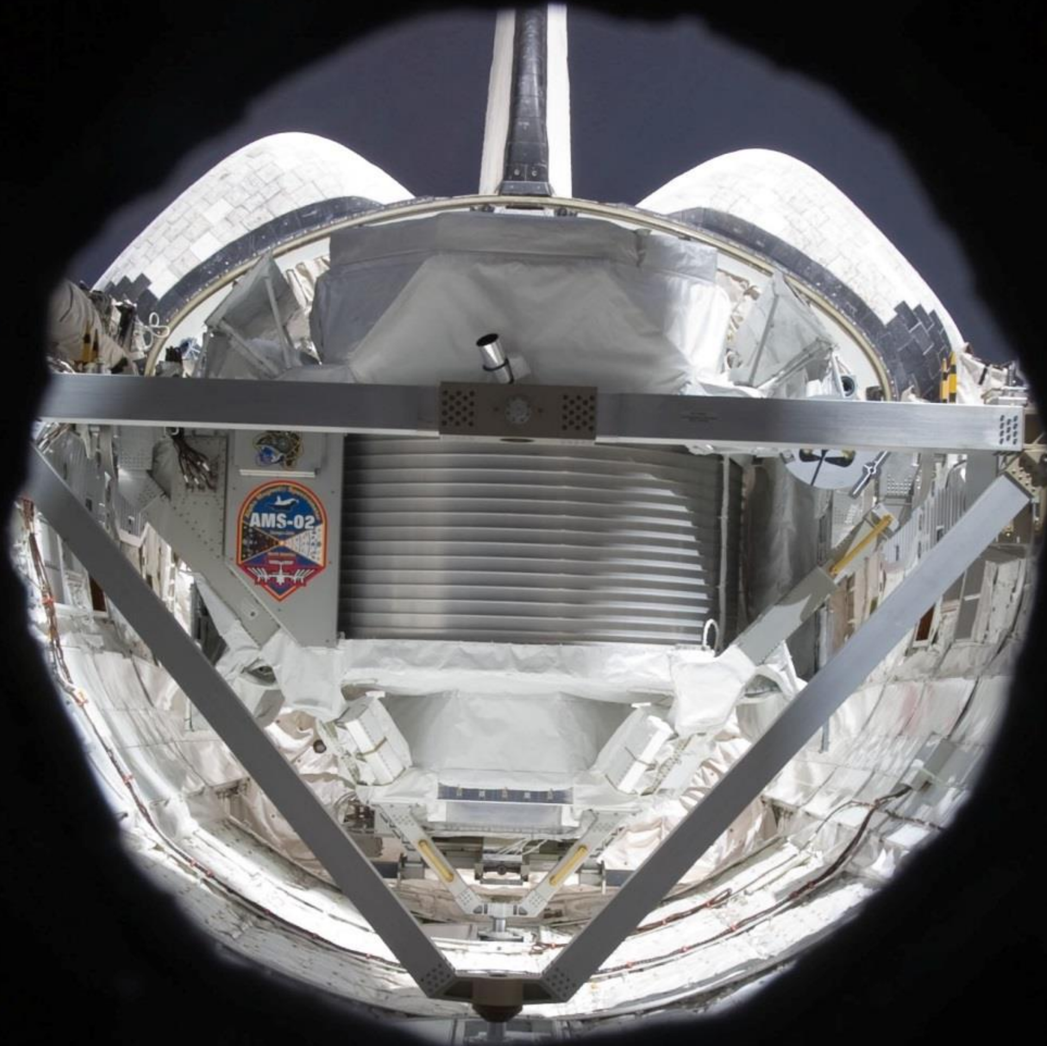

from 1 bar to 0
in less then 2 min
Internal pressure (b)
DEPRESSURIZATION LOADS
Time (s)


Lift-Off
Transonic Flight
Max "q" Flight
Acceleration, g
DYANMIC LOADS
Time relative to SRB ingnition, sec

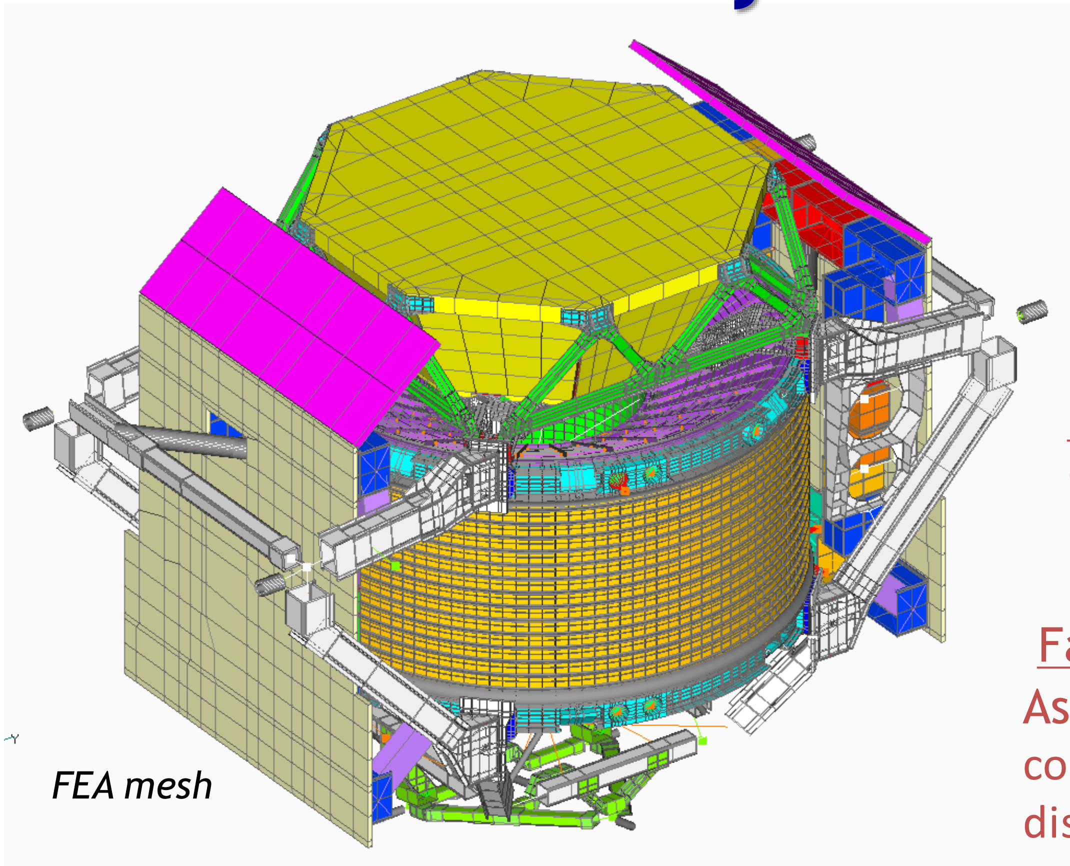

ACUSTIC LOADS reflected pressure wave from boosters (water barrier)

SHOCK LOADS pyrotechnic explosions

STRUCTURAL ANALYSIS & TEST

STRUCTURAL analyses



FEA mesh

Static analysis

provides critical stresses, displacements and Margin of Safety based on Load Factor and Safety Factor considered.

Bolts analysis

Calculate bolts load and preload

Fail safe analysis

Assumes failure of the maximum stressed component and calculate the new stress distribution

Modal analysis

Predicts the structures natural modes of vibration and frquencies

Dynamic analysis

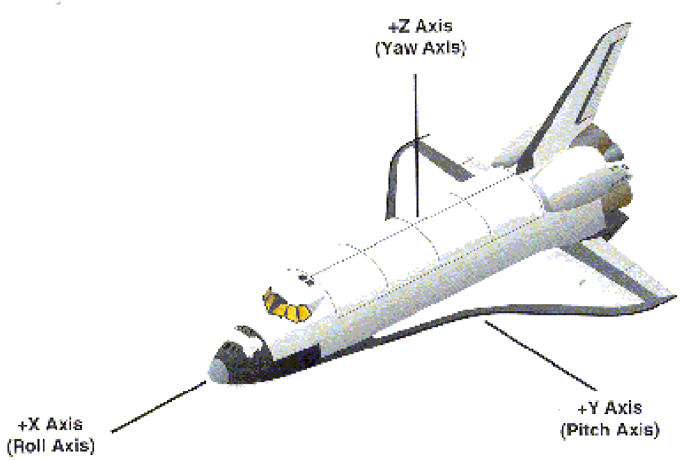
Provides the structures responce to the dynamic environment

STRUCTURAL ANALYSES: *STATIC*

The "Limit load" is the maximum load expected on the structure during its design service life.

Limit load = Load factor x weight
(up to 40)

is derived from the design load coupled analysis with the Shuttle Orbiter



Primary structures

structure that provides the primary load path for all subsystems and secondary structural components

N represents translational load factors in terms of gravities;
R represents rotational load factors in terms of rad/sec2.

Event	N_x	N_y	N_z	R_x	R_y	R_z
Liftoff	±5.7	±1.6	±5.9	±10	±25	±18
Landing	±4.5	±2.0	±6.5	±20	±35	±15

Secondary structures

components of the payload that are not a part of the primary load path and that can be treated as separate entities for the purpose of loads analysis

Weight (pounds)	Load Factor (g)
<20	40
20-50	31
50-100	22
100-200	17
200-500	13

The Limit Load is applied in worst direction with 25% (±g) applied simultaneously in the other two orthogonal directions

STRUCTURAL ANALYSIS: *STATIC*

Ultimate load = Ultimate factor of safety x Limit load
Yield load = Yield factor of safety x Limit load

Factor of safety (Yield=1.25, Ultimate=2)

Margin of safety (result form the structural analysis)
Ratio between material strength –Yield and Ultimate-and calculated Limit Stress

$$FS = Factor\ of\ Safety$$

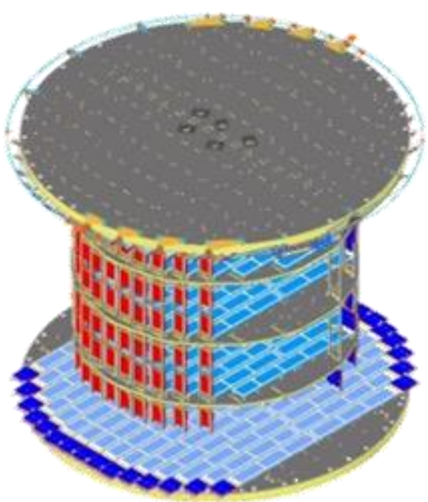
$$FS_y = 1.25$$

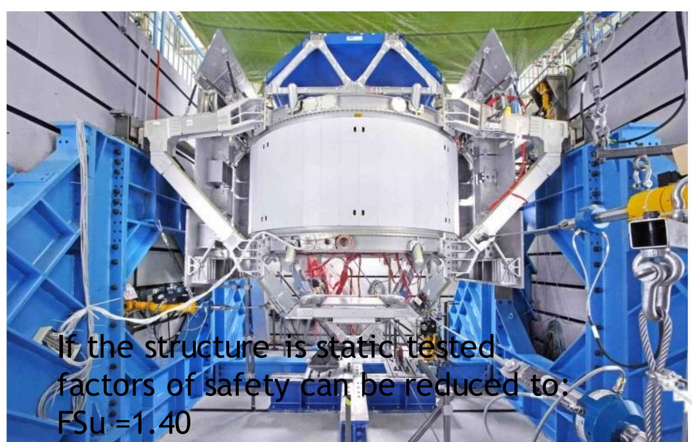
$$FS_{ult} = 2$$

$$MS_{yield} = \frac{Yield\ \ Stress}{FS_y \times Limit\ \ Stress\,(Von\ Mises)} - 1$$

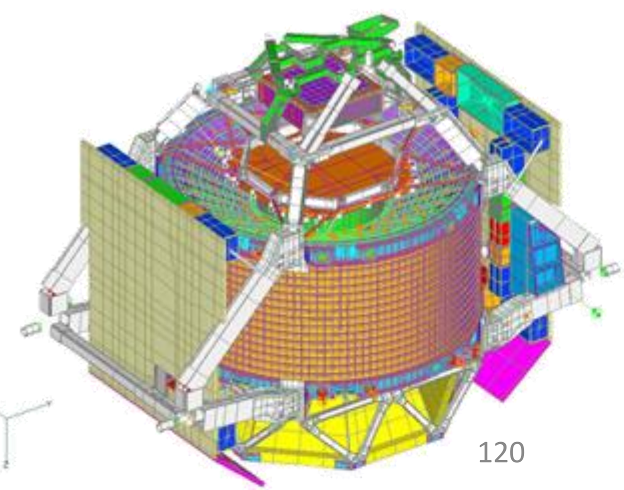
$$MS_{ult} = \frac{Ultimate\ \ Stress}{FS_{ult} \times Limit\ \ Stress\,(Max\ \Pr incipal)} - 1$$

The margins of safety for all structural components must be greater than or equal to zero (0) for all combined load conditions





If the structure is static tested
factors of safety can be reduced to:
FSu =1.40
FSy = 1.10



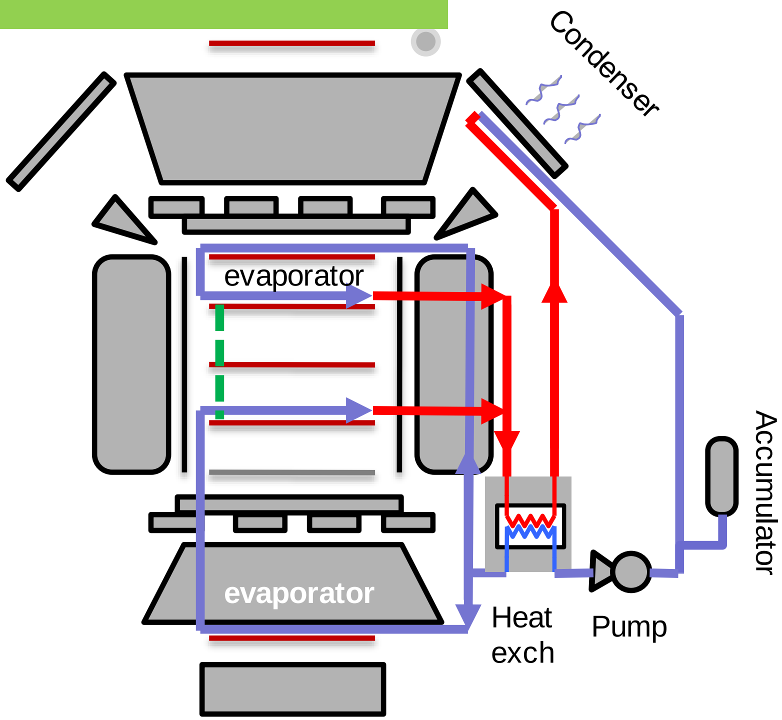
STRUCTURAL ANALYSIS: *PRESSURE*

MDP= Maximum Design Pressure

MDP is the highest pressure the system will see during all its life by design

Ultimate Pressure= Ultimate pressure factor x MDP

Ultimate Pressure Factor **Burst 4.0, Proof 1.5**

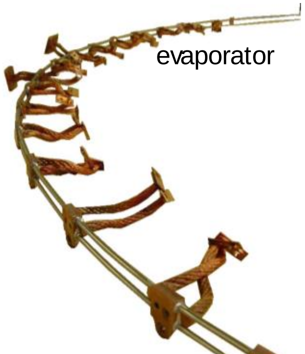


Leak test	*helium vacuum*
Pressure test	*240 bar*
Leak test	*helium vacuum*

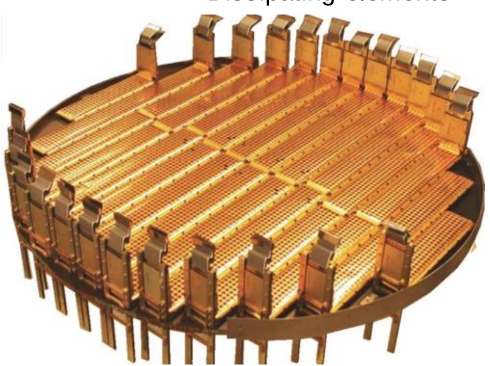
- Max Design Pressure 160 [Bar]
- Max Design Temperature 65 [˚C]

. Proof Pressure 240 [Bar]

. Burst Pressure 640 bar



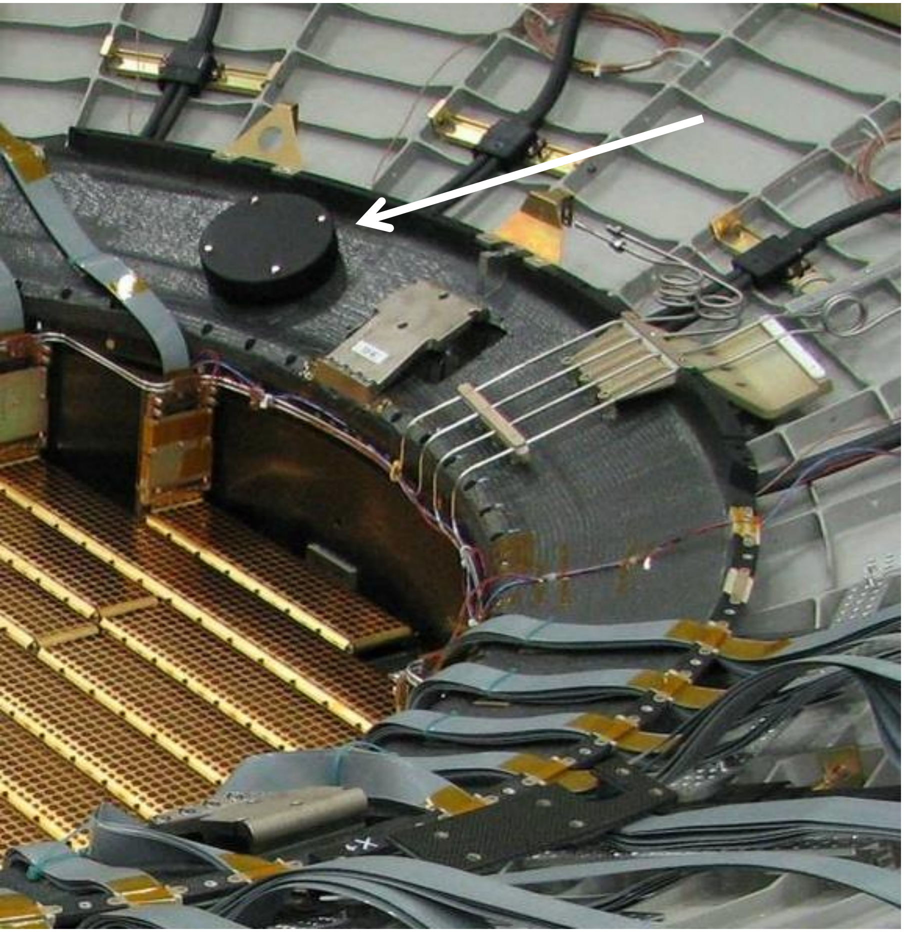
Dissipating elements



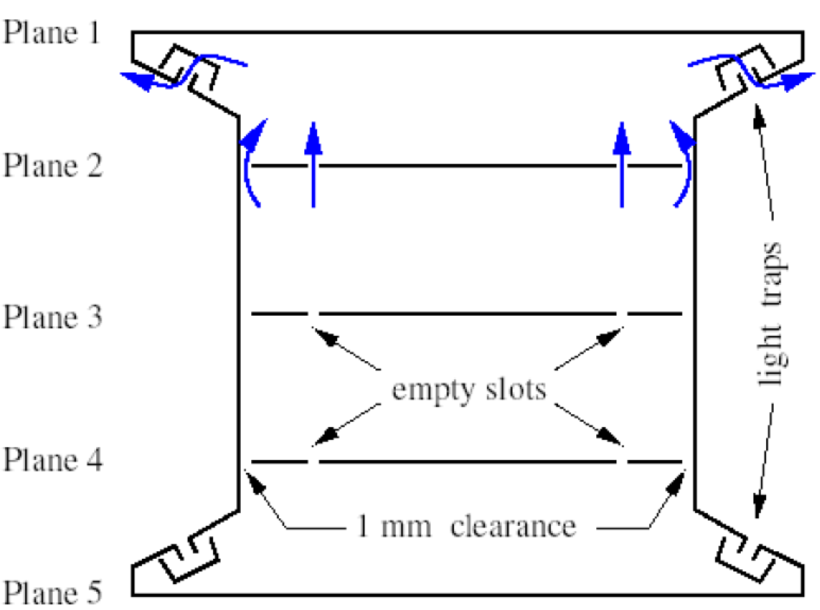
Accumulator

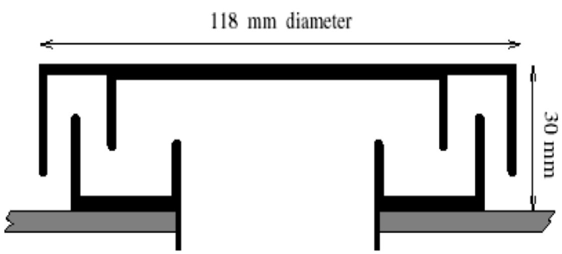
Heat Exchanger

STRUCTURAL ANALYSIS: *DE PRESSURIZATION*



An example of AMS 02 tracker venting





To equalize the pressure inside the Tracker with the pressure in the payload bay during launch, the Upper and Lower Conical Flanges each contains two light tight, filtered vents that permit air to exit or enter the enclosed Tracker volume of 1.14m^3

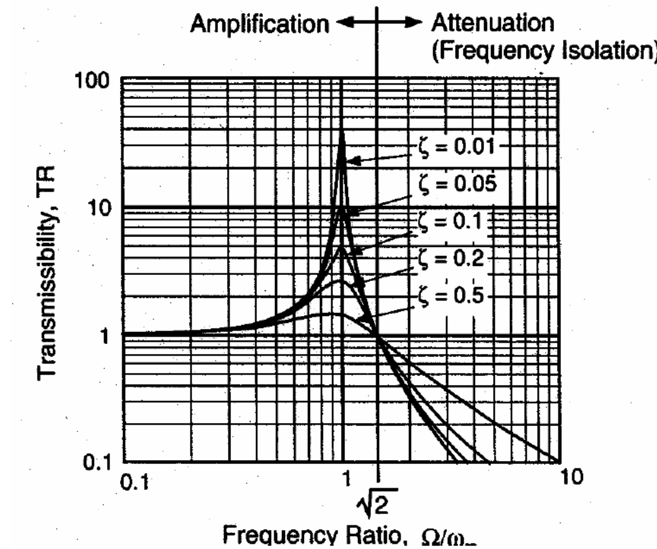
STRUCTURAL ANALYSIS: *MODAL*

All the hardware needs to have a first resonance frequency higher than **50 Hz**,

than no dynamic tests are required. If the resonance frequency is lower than 50 Hz but higher than 35 Hz, a sine sweep, smart hammer or modal testing is required

Launch System	Foundamental Frequency (Hz)	
	Axial	Lateral
AtlasII, IIA	15	10
Ariane4	(1)	10
Delta 6925/7925	35	15
Long March 2E	26	10
Pegasus	20	20
Proton	30	15
Scout	18	20
Space Shuttle	13	13
Titan II	24	10
Titan III	26	10

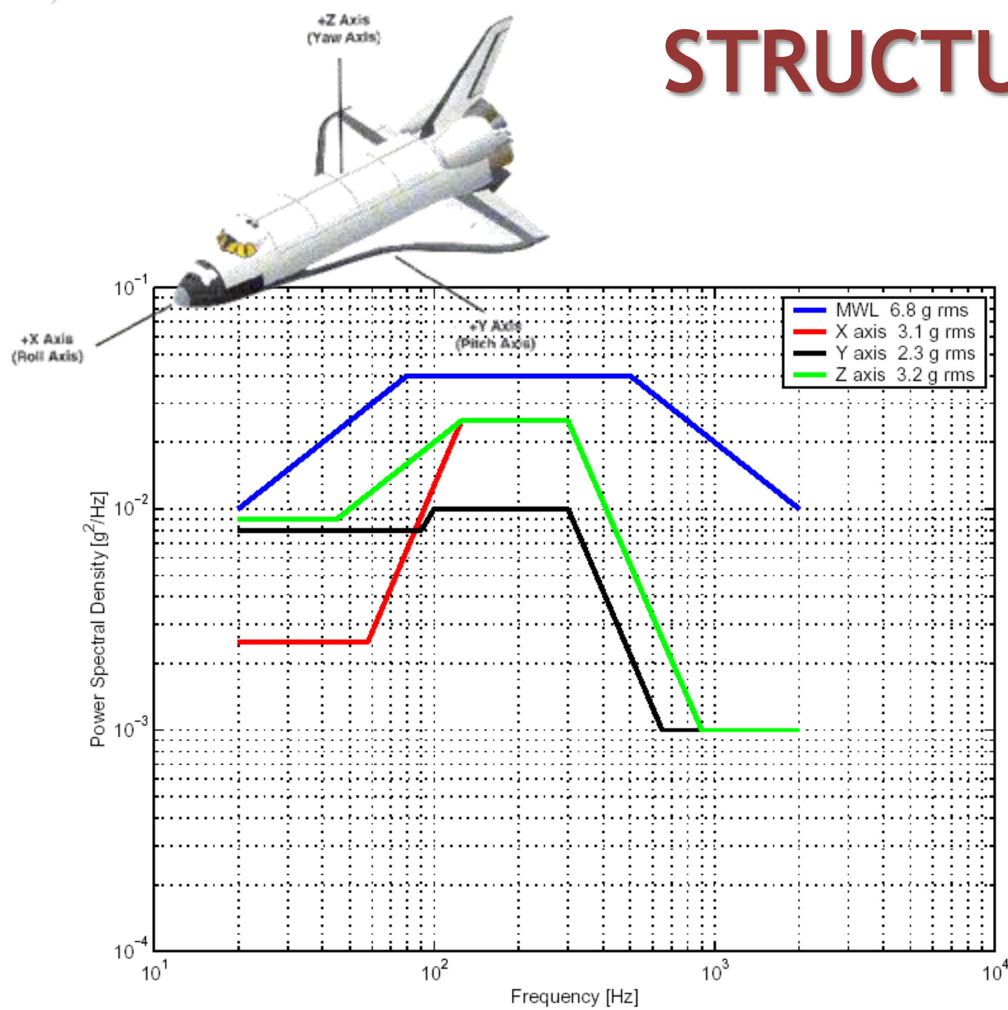
(1) 31 Hertz for dual payload, 18 Hz for single payload



In the table the frequency requirements of different launchers are illustrated. Frequency should be higher than the reported values to avoid resonance and amplification of the vibration.

Amplification of the dynamic response of a single degree of freedom damped system

STRUCTURAL ANALYSIS: *dynamic*



X Axis	20-58 Hz 58-125 Hz 125-300 Hz 300-900 Hz 900-2000 Hz Overall = 3.1 Grms	0.0025 g2/Hz +9 dB/Octave 0.025 g2/Hz -9 dB/Octave 0.001 g2/Hz
Y Axis	20-90 Hz 90-100 Hz 100-300 Hz 300-650 Hz 650-2000 Hz Overall = 2.3 Grms	0.008 g2/Hz +9 dB/Octave 0.01 g2/Hz -9 dB/Octave 0.001 g2/Hz
Z Axis	20-45 Hz 58-125 Hz 125-300 Hz 300-900 Hz 900-2000 Hz Overall = 3.2 Grms	0.009 g2/Hz +3 dB/Octave 0.025 g2/Hz -9 dB/Octave 0.001 g2/Hz

(MEF Maximum expexted flight: 90 sec per axis)

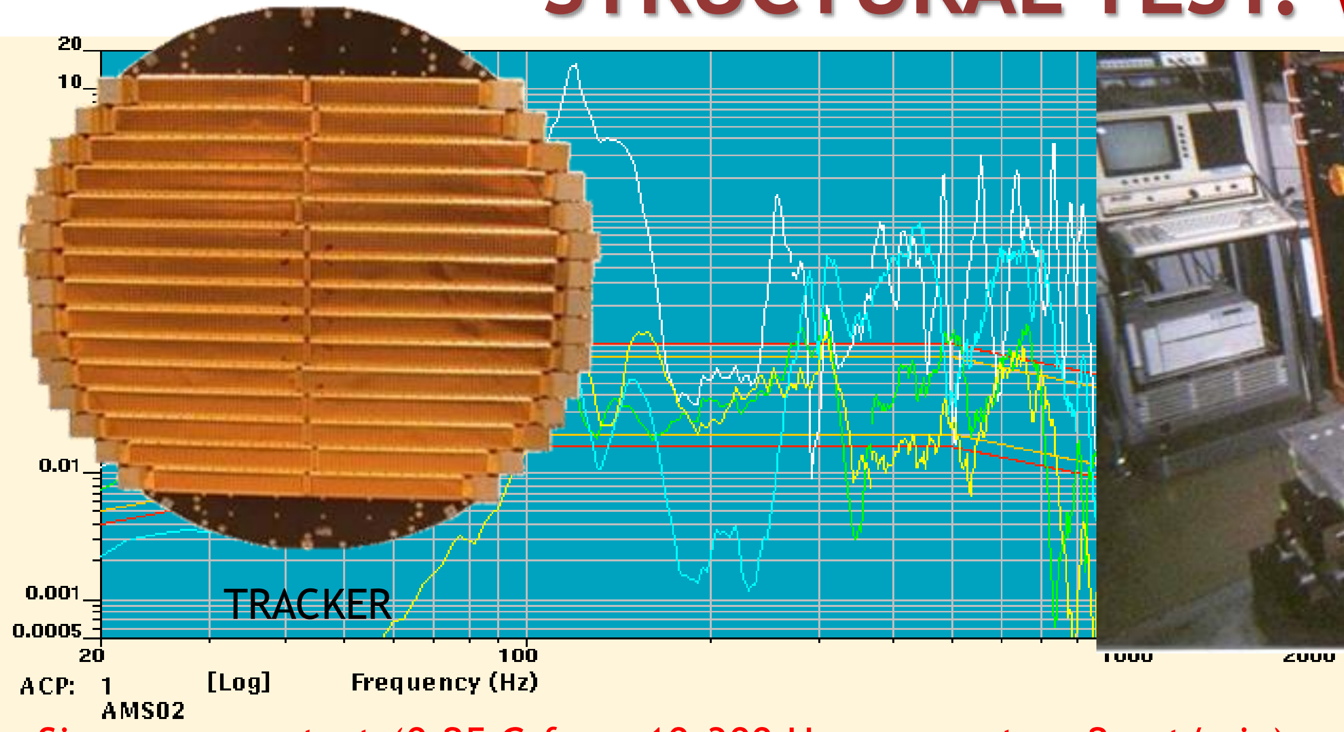
Random vibration testing has two principal objectives:

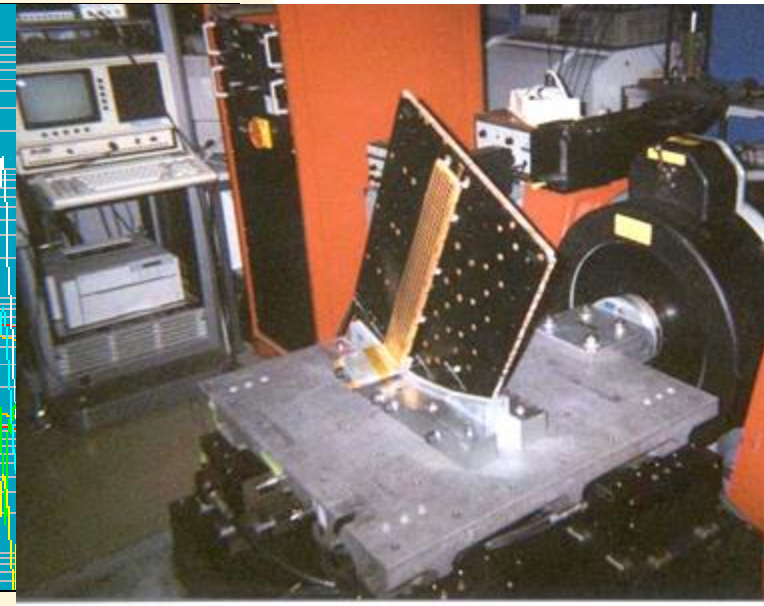
1. to verify the tested item design's capability, with some margin, to withstand the launch vibroacoustic environment, and
2. to screen the workmanship integrity of the equipment

All Axes	20 Hz 20-80Hz 80-500Hz 500-2000Hz 2000Hz Overall= 6.8 Grms	0.01g^2/Hz +3dB/Octave 0.04g^2/Hz -3dB/Octave 0.01g^2/Hz

(MWL Test Duration: 60 seconds per axis)

STRUCTURAL TEST: *vibration*





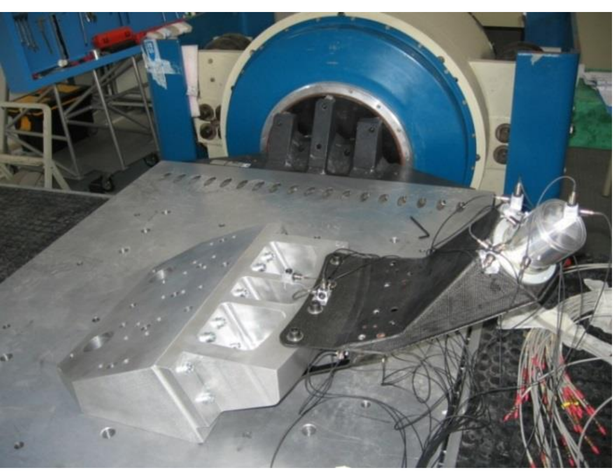
Sine sweep test (0.25 G from 10-300 Hz, scan rate = 2 oct/min) .

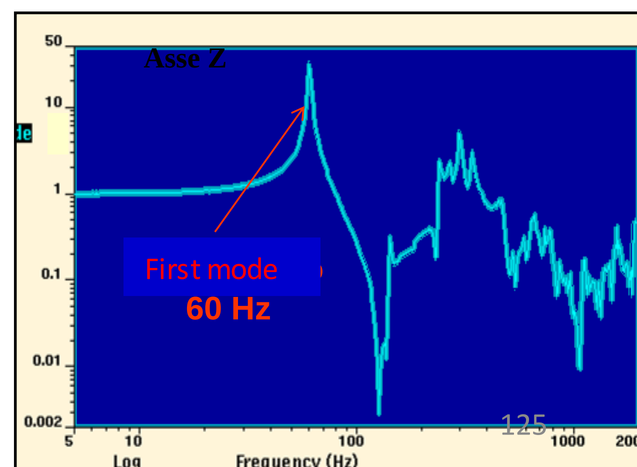
Random vibration test to the Minimum Workmanship level

Sine sweep test to verify that there is no change when compared to the first sine sweep test.

Structure responce

Sine sweep

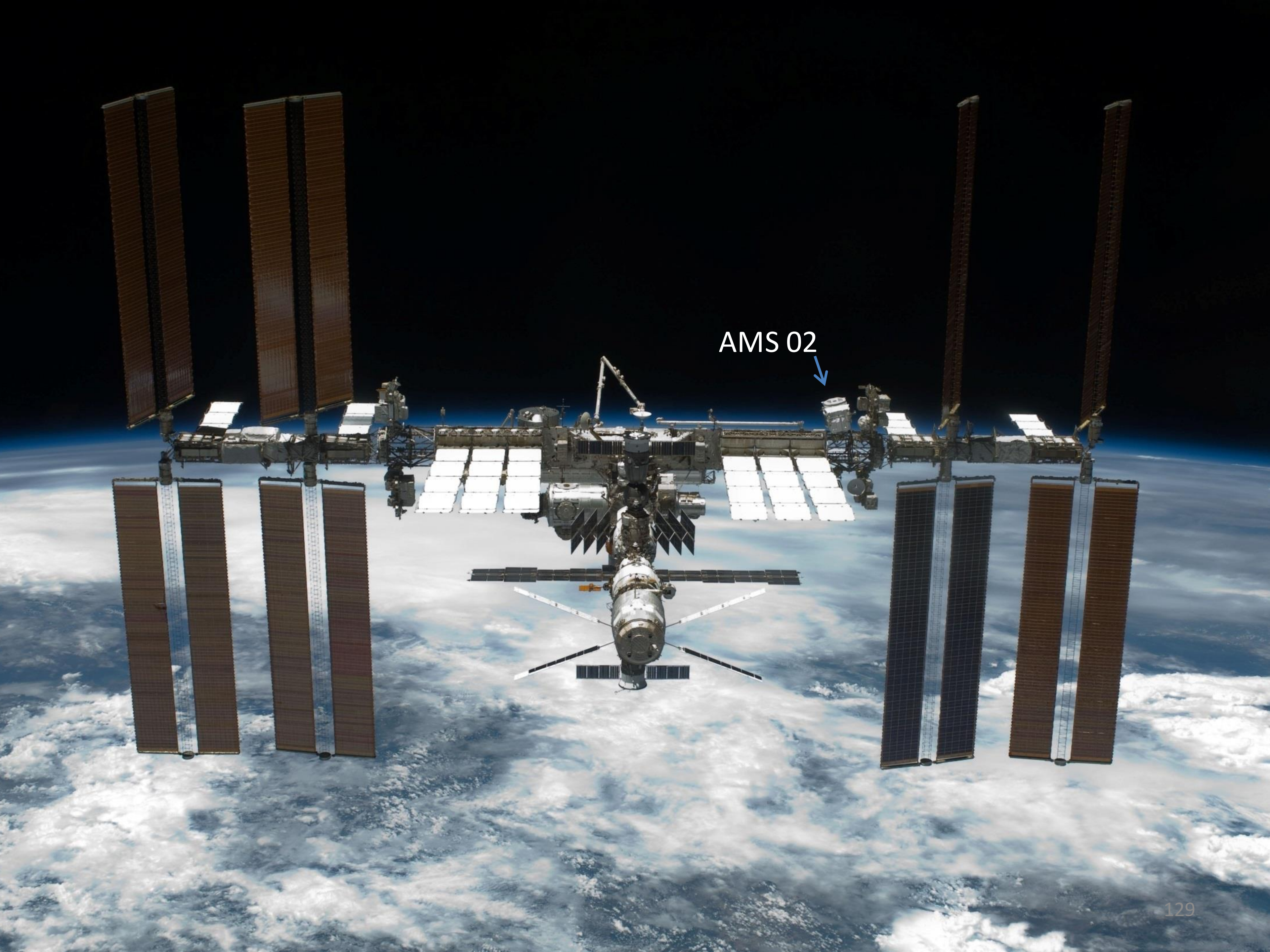




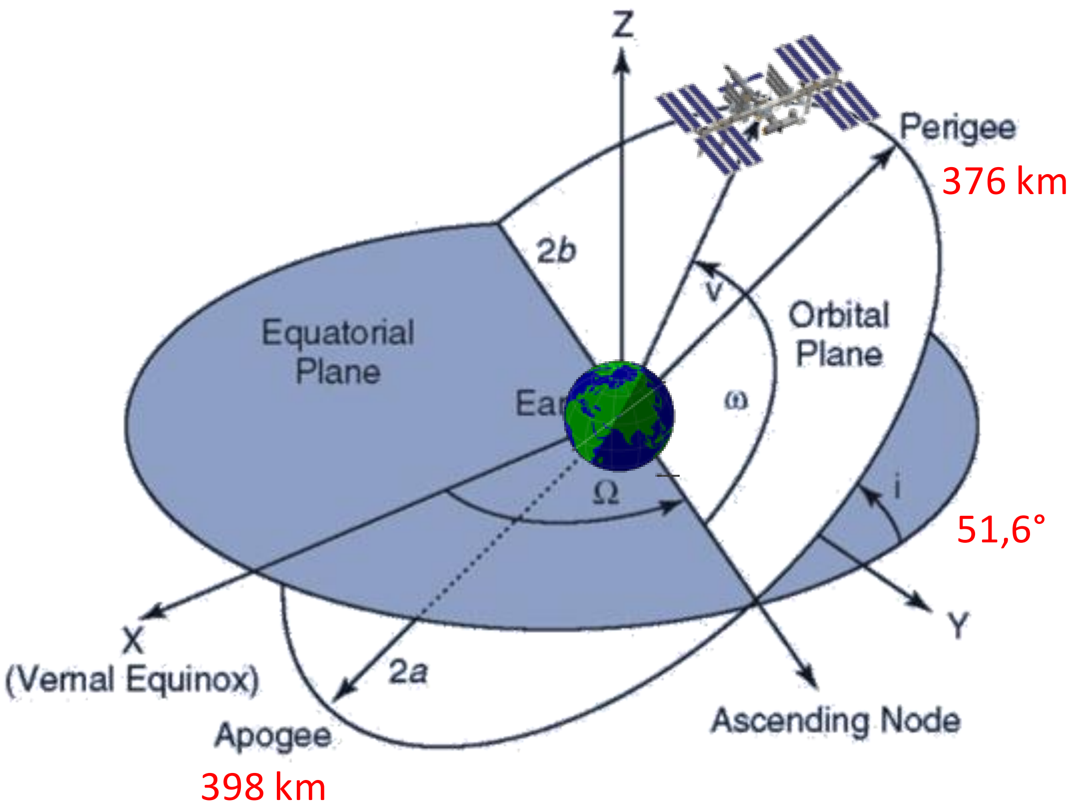
ENVIRONMENTAL ANALYSIS

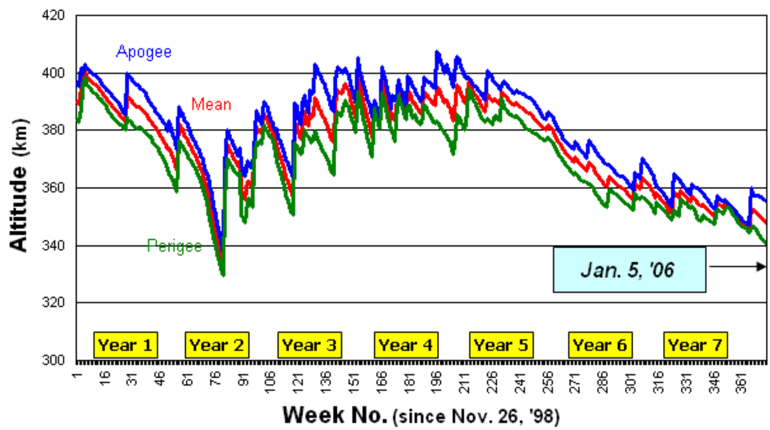
ON ORBIT

ON ISS


AMS 02

INTERNATIONAL SPACE STATION ORBIT





Perigee	376km
Apogee	398 km
Orbital inclination	51,6 degres
Average speed	7706,6 m/s (27743,8 km/h)
Orbital Period	91 minutes
Orbital Decay	2km/month

ENVIRONMENT

Charged particle

GeV

MeV

KeV

eV

COSMYC RAY

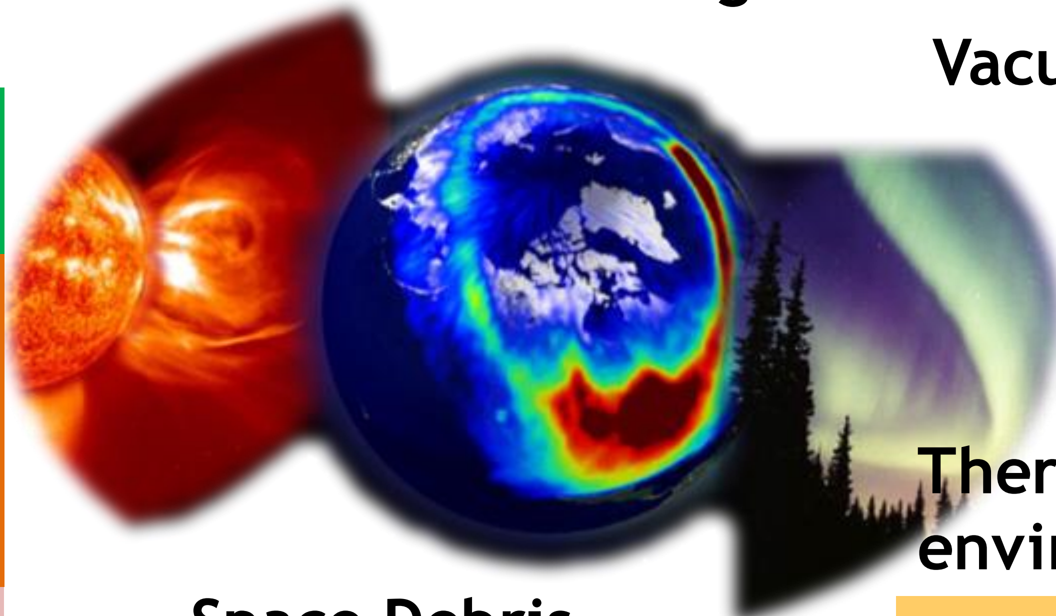
SOLAR EVENT

RADIATION BELT

ENERGETIC PLASMA

LOW ENERGY PLASMA

Atomic Oxigen



Vacuum

Space Debris

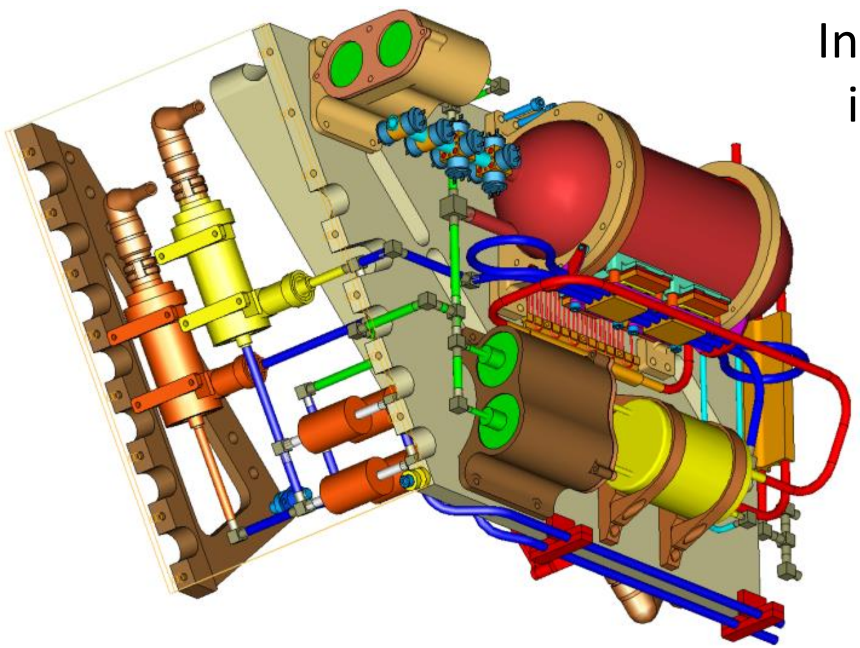
Thermal environment

SOLAR RADIATION

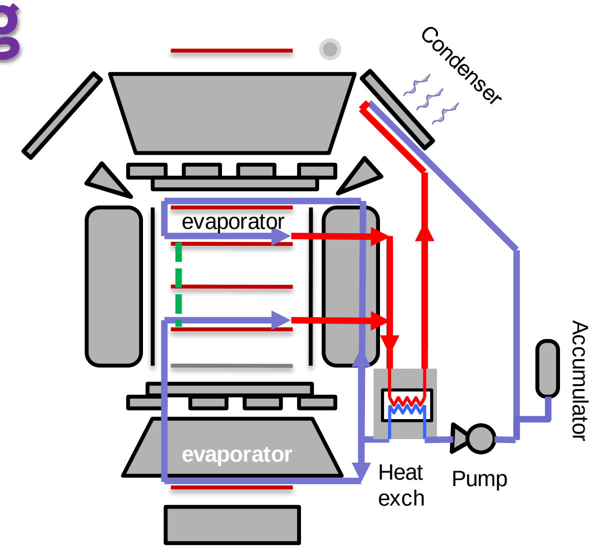
ALBEDO RADIATION

PLANETARY RADIATION

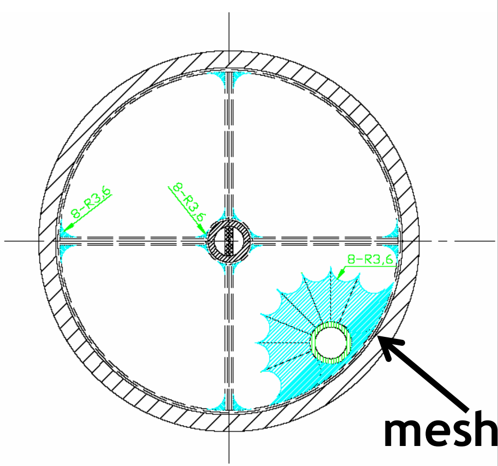
Tracker in SPACE: weightless zero-g

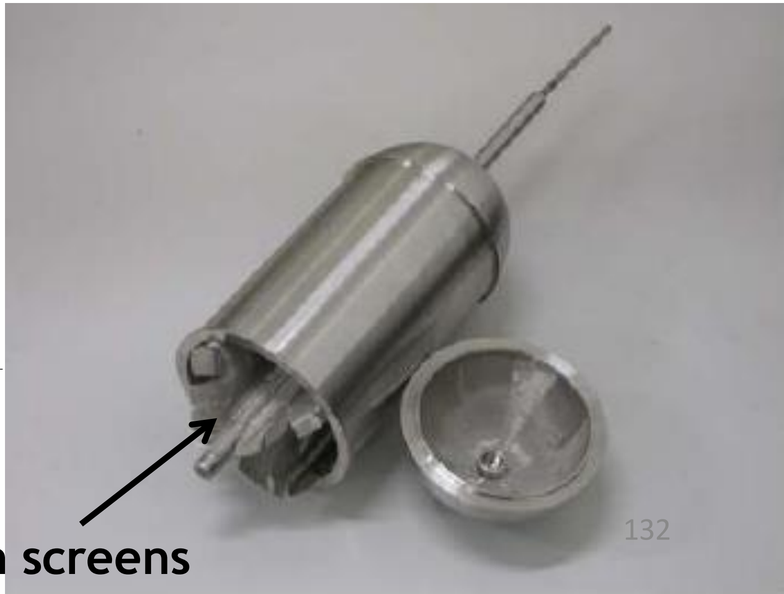


In a two phase fluid it is ncessary to keep the liquid phase where needed



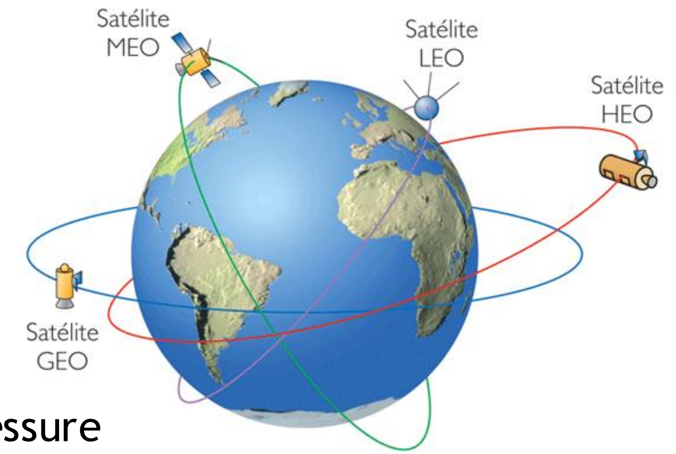
A series of intricate 316L CRES mesh screens are mounted inside the tanks to act as a capillary wicks to assure that the liquid CO2 is drawn to the inner surface of the tank and to the plumbing junction to the loop





mesh screens

VACUUM



SPACE

p90 = 1x10^{-3} mbar (90 Km)
p200 = 1x10^{-6} mbar (200 Km)
p1000 = 1x10^{-10} mbar (1000 Km)
p10000 = 1x10^{-13} mbar (10000 Km)

Up to 100 km altitude (troposphere and stratosphere) the pressure decreases quite regularly by a factor of 10 per 15 km altitude

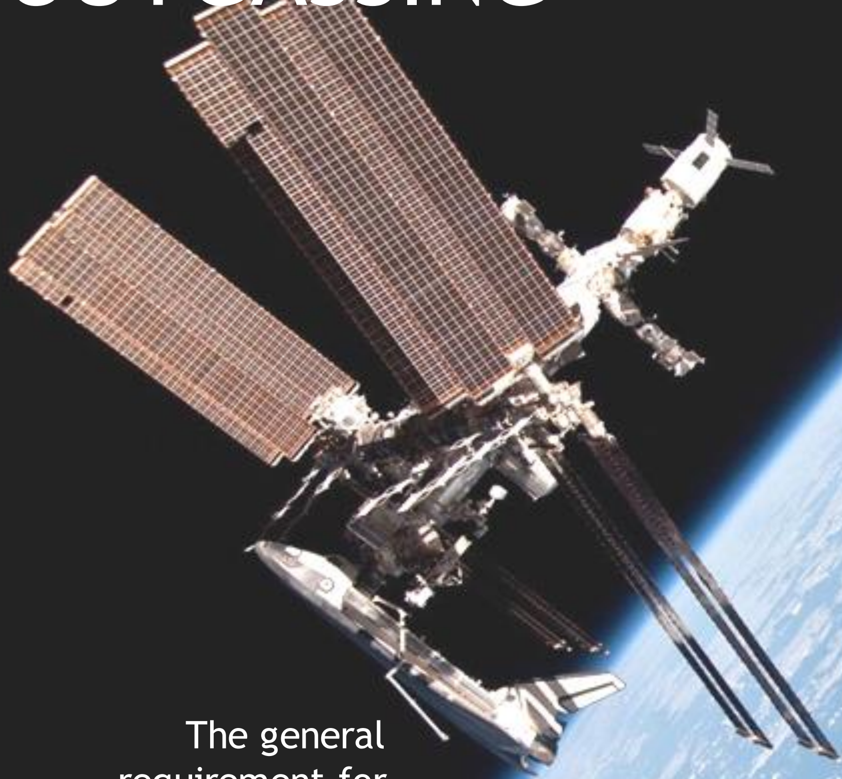
The ionosphere (100-400 km) contains a large number of ionized atoms, and its pressure decreases only by a factor of 10 every 100-200 km

LEO *Low Earth Orbit: from 200 to 700 km; orbital period of 60-90 m*in
MEO *Middle Earth Orbit: from 700 to 35000 km, their period is smaller than 1 day*
GEO *Geosynchronous Orbit: altitude of about 35800 km; period of 1 day*

LHC

-BEAM VACUUM 10^{-9} mbar (over 54 km)
 -Cold beam vacuum (50km),
 cryogenic temperature 1.9 k
 -LSS beam vacuum
 -Detectors beam vacuum
-insulation vacuum for cryomagnets 10^{-6} mbar
-insulation vacuum for helium distribution line (QRL)

OUTGASSING



For **AMS 02** outgassing has two indesirable effects

1) **can cause certain key material properties to degrade**

2) **the gaseous emission can condense on critical surfaces like Star Tracker lenses, sensors and thermal coating**

The general requirement for materials outgassing is

RML<1.0%

CVCM < 0.1%

(RML) recovered mass loss

(CVCM) collected volatile condensable material

(WVR) water vapour regained

(TML) total mass loss

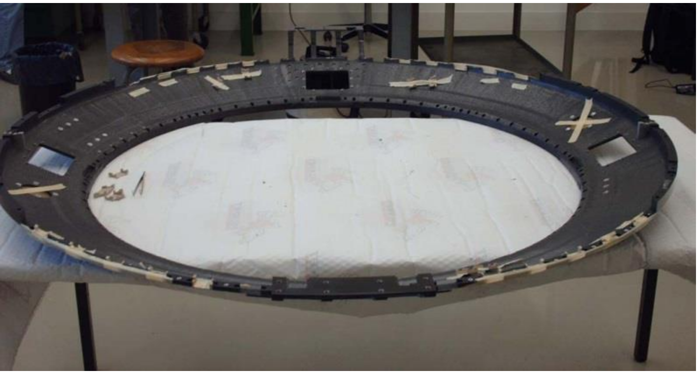
ASTM E595 and ASTM E1559 testing

To determine the TML in the ASTM E595 test, a sample is heated to 125C for 24 hours at a pressure of 7E-03 Pa (9E-05 torr).

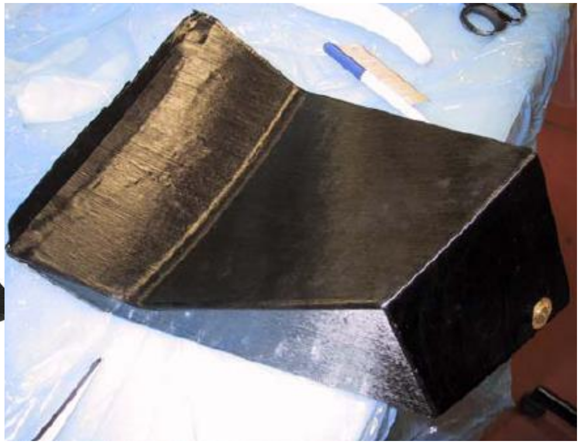
CVCM, is determined by using a collector plate that is held at 25C for the same 24-hour period. CVCM is a measure of what fraction of the TML will condense on a 25C surface.

The ASTM E1559 method tests materials over a wider range of temperatures and over a longer period of time than the E595 tests. E1559 testing uses Quartz Crystal Microbalances (QCMs) to measure mass deposition as a function of temperature and time.

STRUCTURAL MATERIALS



Maximum dimensional stability in thermal vacuum environment

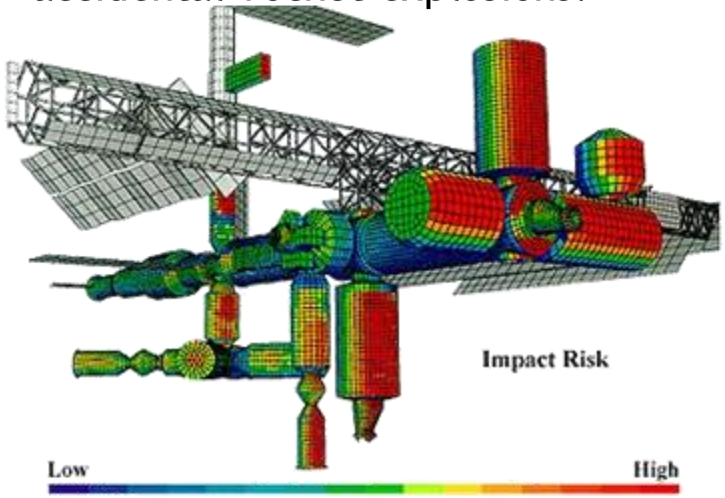


**M55J/
cyanate ester resin LTM123**

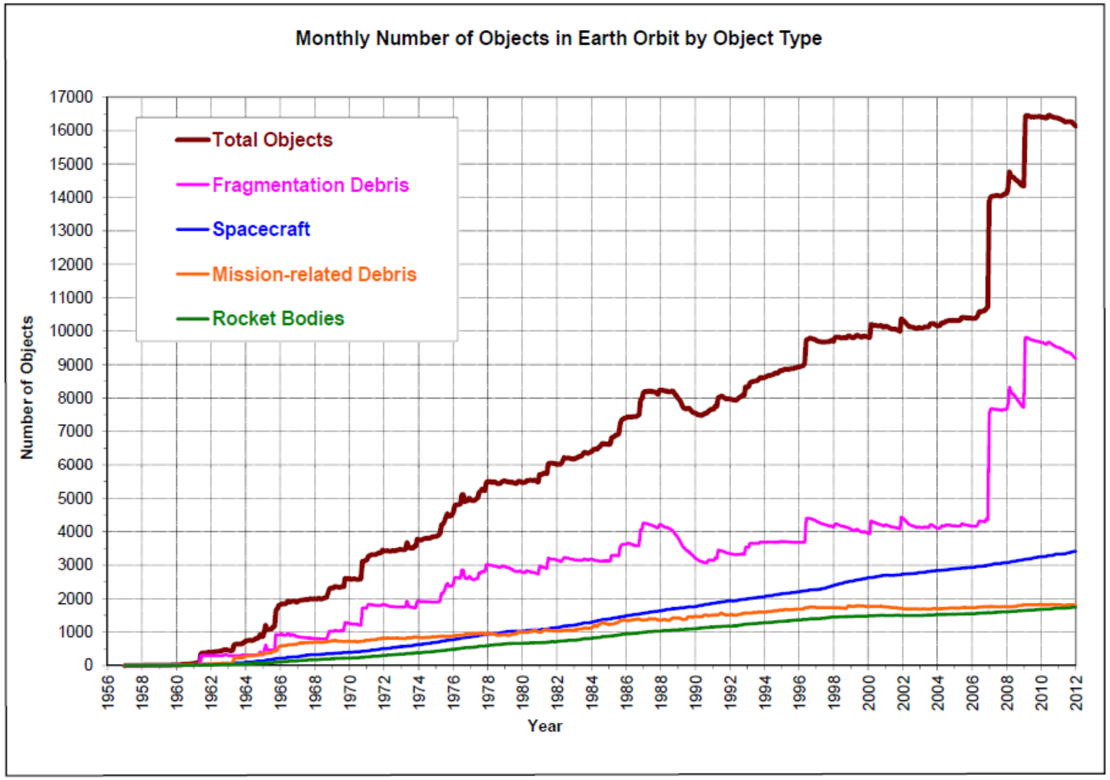
- A versatile range of initial cure temperatures between 70°C and 135°C.
- A flexible range of postcure temperatures up to 240°C, with glass transition temperature (Tg) values varying from 90°C to 240°C.
- Very low moisture absorbency characteristics, with Coefficient of Moisture Expansion (CME) values lower than epoxies and comparable with high temperature (HT) curing cyanate esters.
- LTM123 can be hot-melt prepregged with a wide range of unidirectional (UD) and fabric reinforcements.

DEBRIES

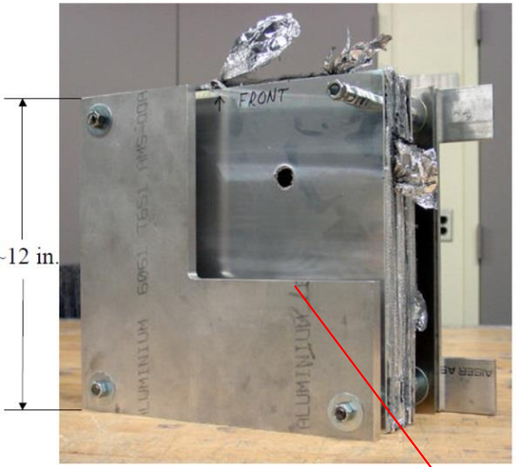
Space debris are man-made and they consist of inactive satellites or spacecraft, non-operational payloads and fragments from separation or deployment procedures, accidental rocket explosions.



The AMS-02 Micro Meteoroid Orbital Debris (MMOD) Shield analysis was performed using the Fortran program BUMPER-II. BUMPER-II was used to determine the MMOD risk assessments for AMS-02 pressure systems to a **Probability of No Penetration (PNP)** of 0,997 required for safety

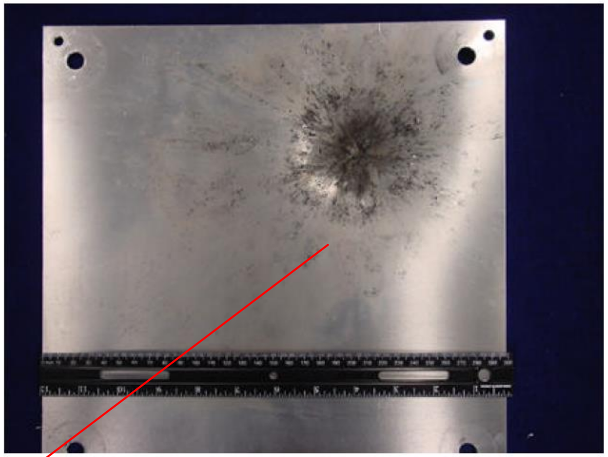


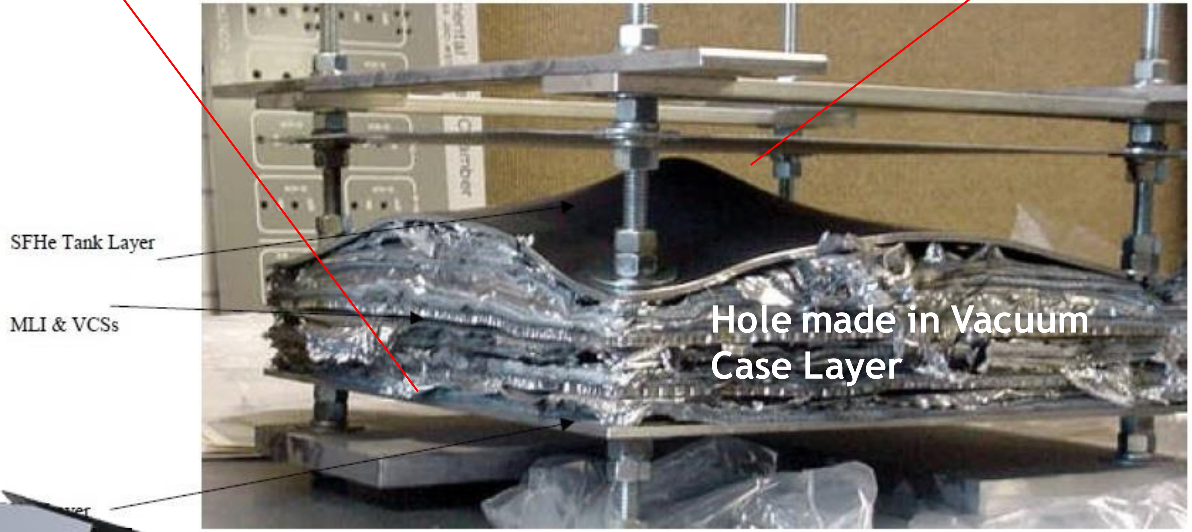
Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.



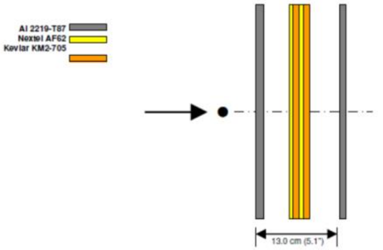
DEBRIS:

MICROMETEOROID SHIELDING





Test #3 – 7 mm diameter aluminum sphere shot at 6.92 km/sec (15,480 mph)



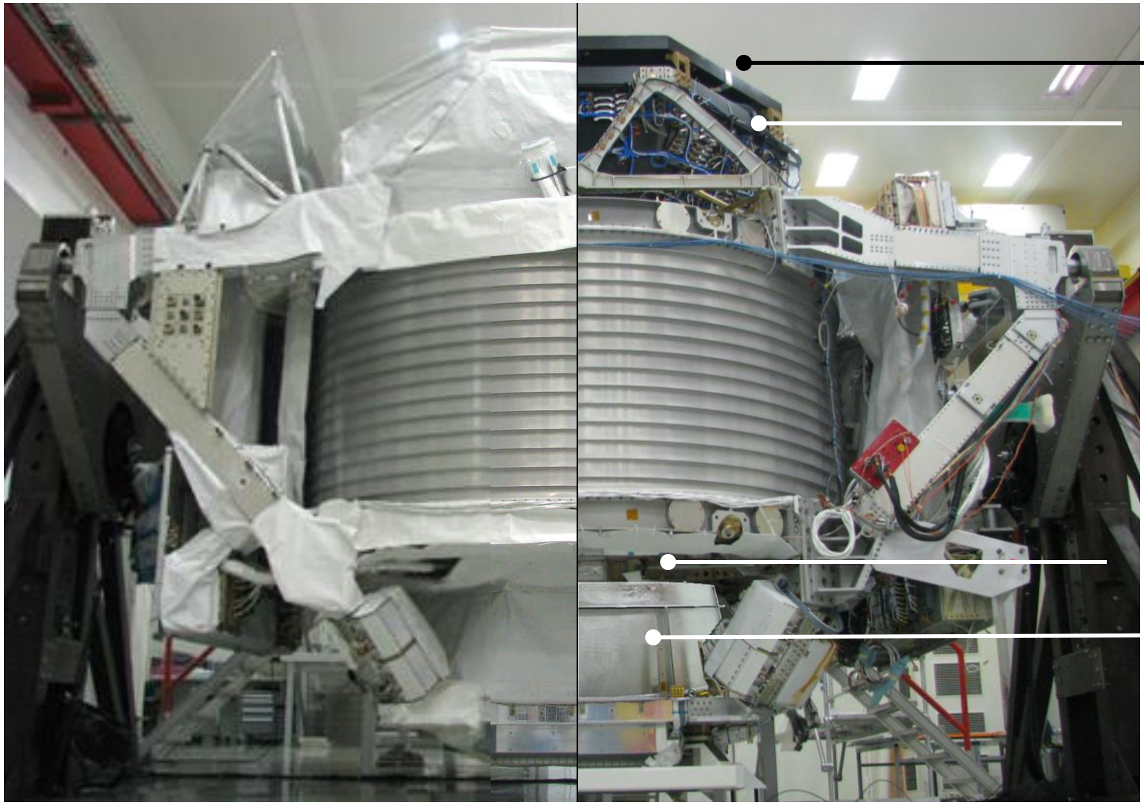
Stuffed Whipple Shield Configuration:
(From impact side to tank side)

- Bumper: Al 7075-T73
- Nextel AF62, 2 layers
- Kevlar KM 2-705, 2layers
- Rear wall, Al 7075-T73

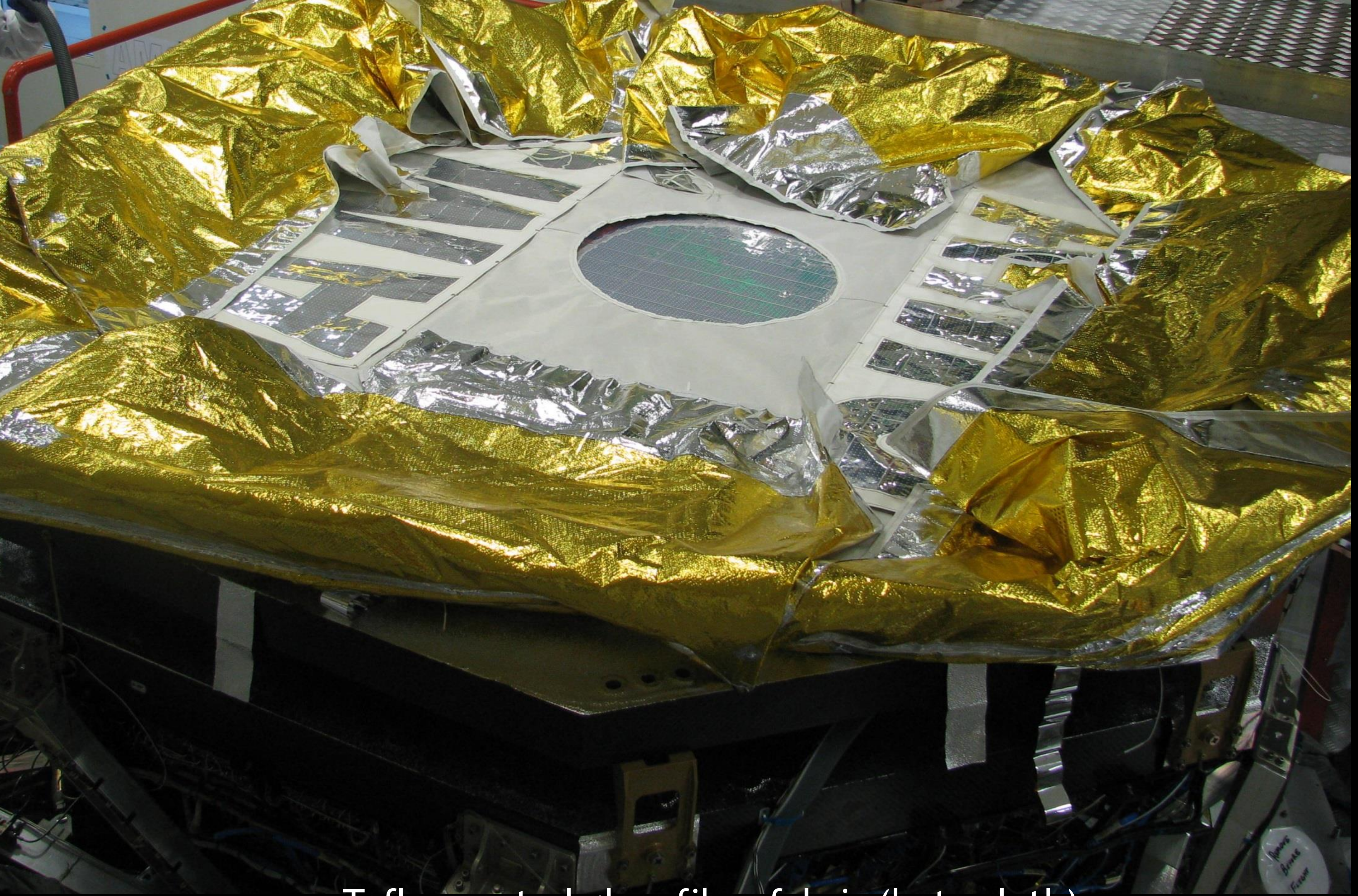
• Total Thickness, approximately 13.0 cm (5.1"

ATOMIC OXIGEN/Vacuum UltraViolet

All exposed materials have resistance to AO/VUV degradation or protected from AO fluence by AO/VUV resistant thermal blankets.

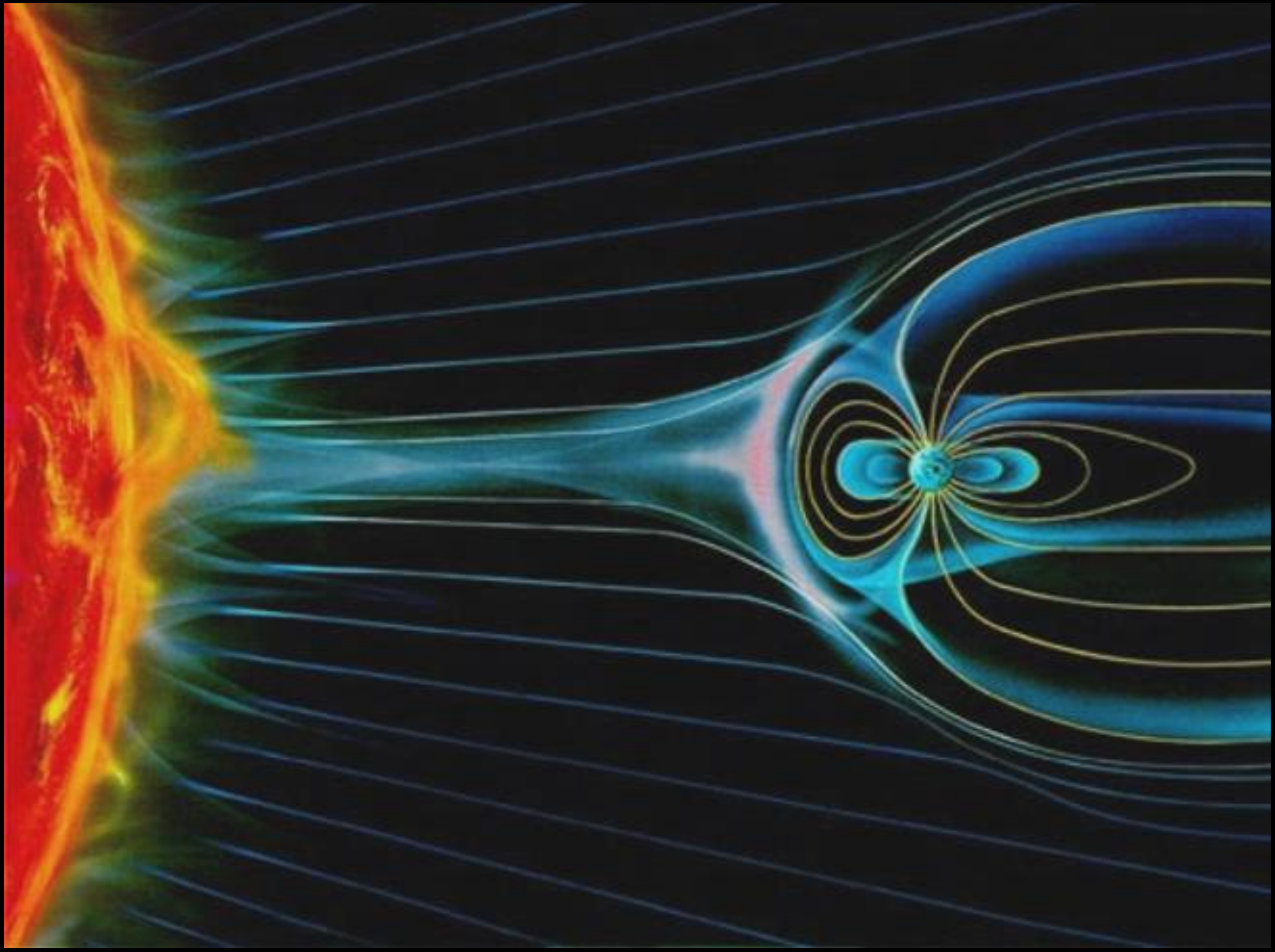


- Thermal Blankets cover all of the major exposed non-metallic components.
- All exposed integration electrical cables are wrapped with Permacel P213 Glass tape.



Teflon coated glass fiber fabric (beta cloth)
Aluminized mylar+plastic scrim (up to 20 layer)
Aluminized kapton for abrasion resistance

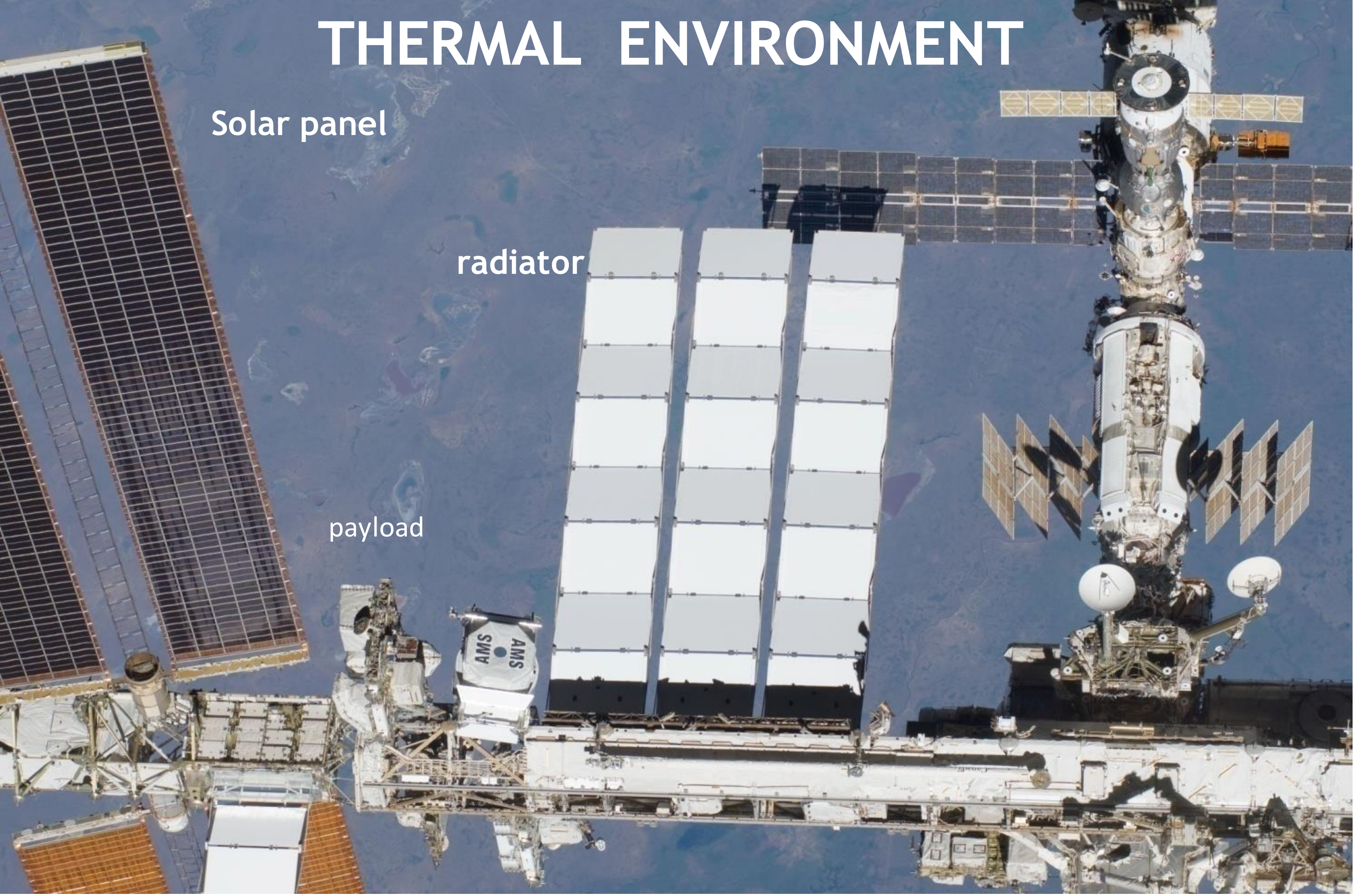
RADIATION ENVIRONMENT



PLASMA
RADIATION BELTS
SOLAR EVENTS
COSMIC RAYS

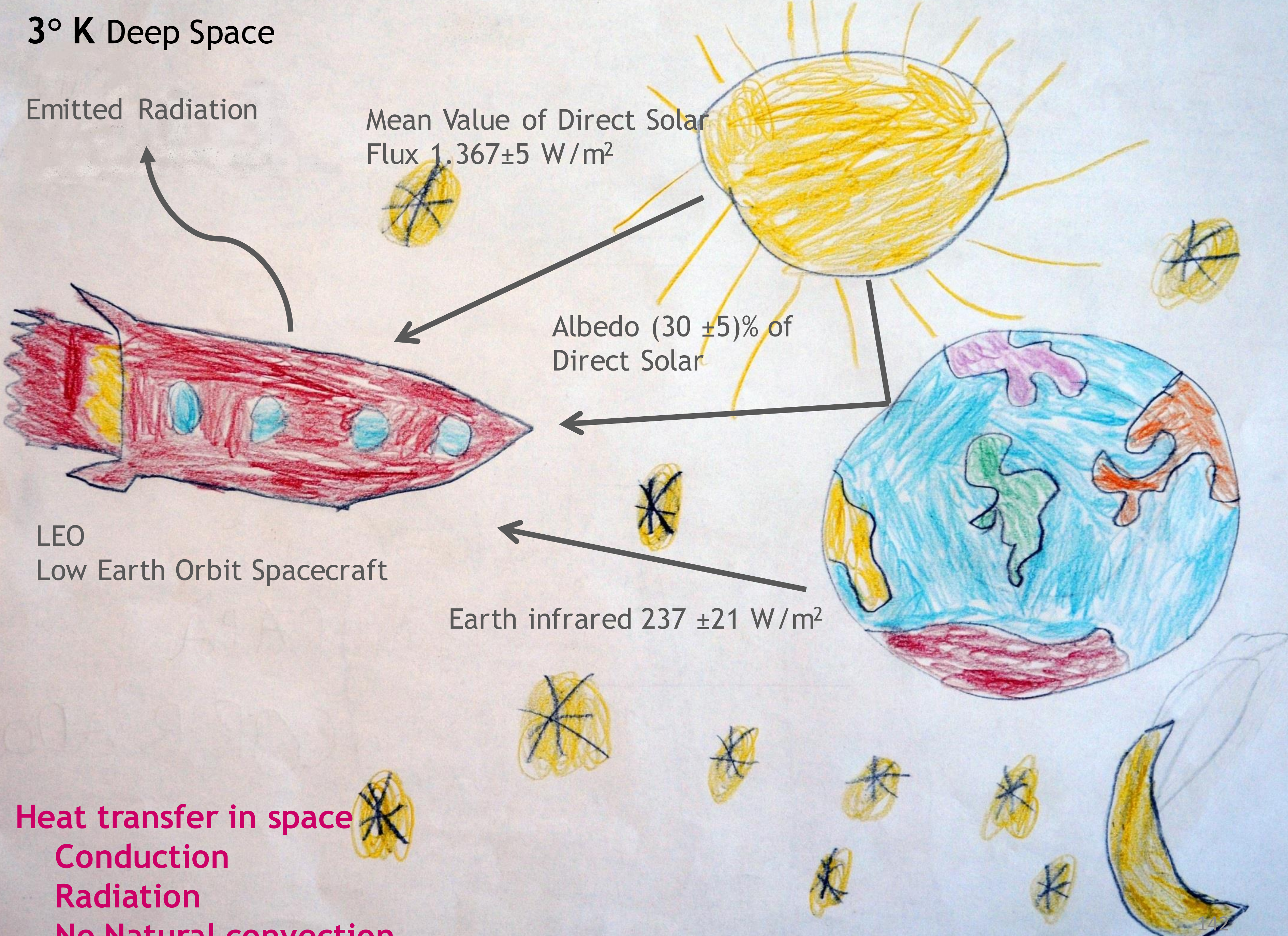
The interaction of the radiation takes place primarily with the MATRIX of composite materials. Resin becomes plastic at high temperature and fragile at low temperature.
This causes micro crack during fatigue thermal process.
Chose very low CTE , protection and surface coating-

THERMAL ENVIRONMENT



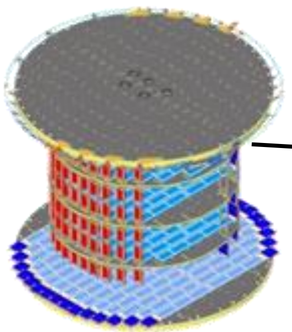
BETA ANGLE + **THERMAL INTERACTIONS WITH OTHER ON-ORBIT SEGMENTS+…**

3° K Deep Space

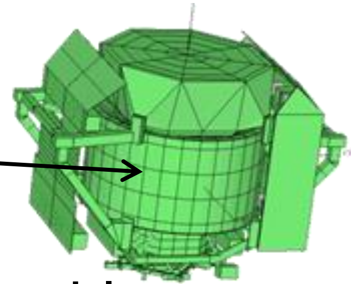


Heat transfer in space
- **Conduction**
- **Radiation**
- **No Natural convection**

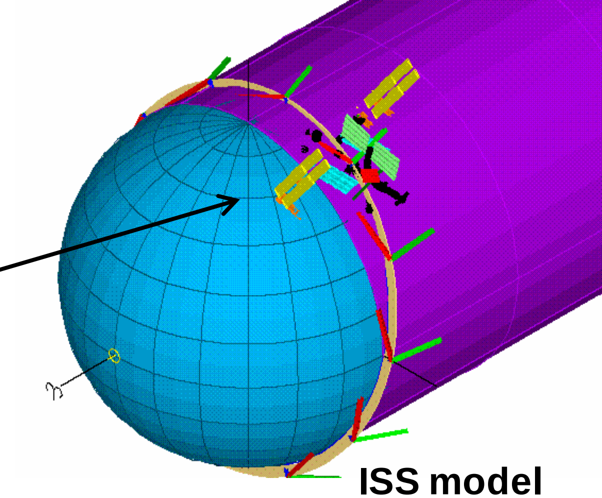
Tracker in SPACE: thermal analysis



Tracker thermal model



AMS model



ISS model

A simplified Detector model is integrated in AMS model, integrated in ISS model

The analysis over orbital cases provides the Interface Data

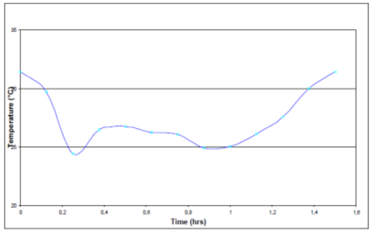
The Interface data are used as input for the Detector detailed thermal analysis

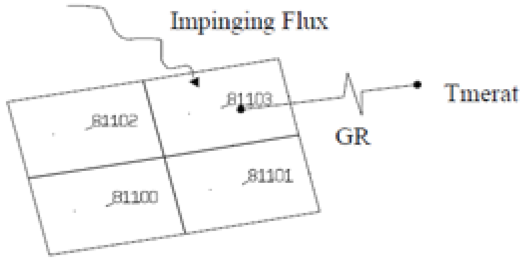
Interface Data (I/F D) time-dependent:

- **Merat** (Mean Effective Radiating Temperature): the average temperature environment seen from an outer surface
- **Orbital loads**: the orbital solar fluxes, albedo, IR
- **GR** (radiative couplings), or the "radiative conductivity" between the outer surface and the environment

- **CC** (conductive coupling) at the mechanical interface

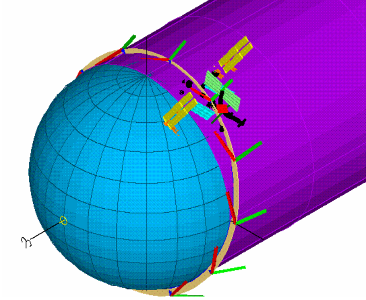
TRD conductive sink

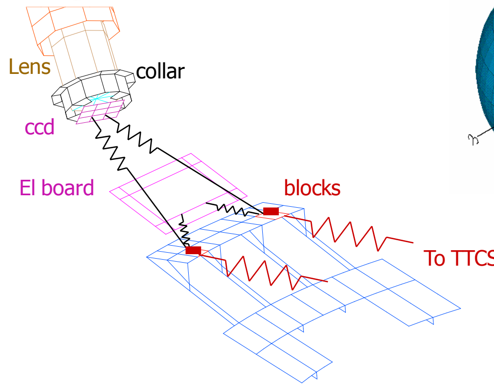




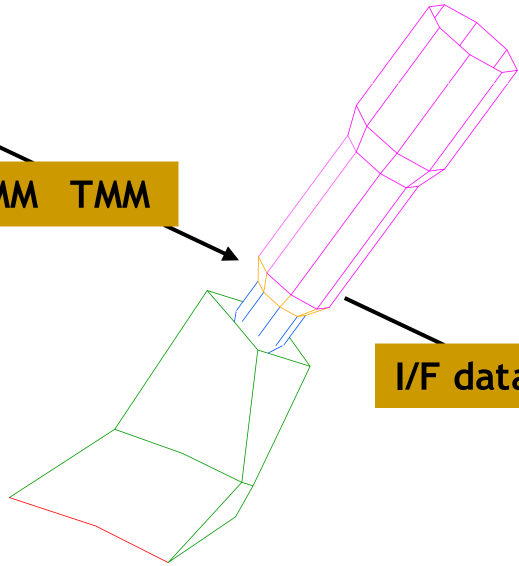
I/F data are provided in each orbital case, and are 13 positions along the same orbit, the last position coincident with the first.

Tracker in SPACE: thermal analysis example



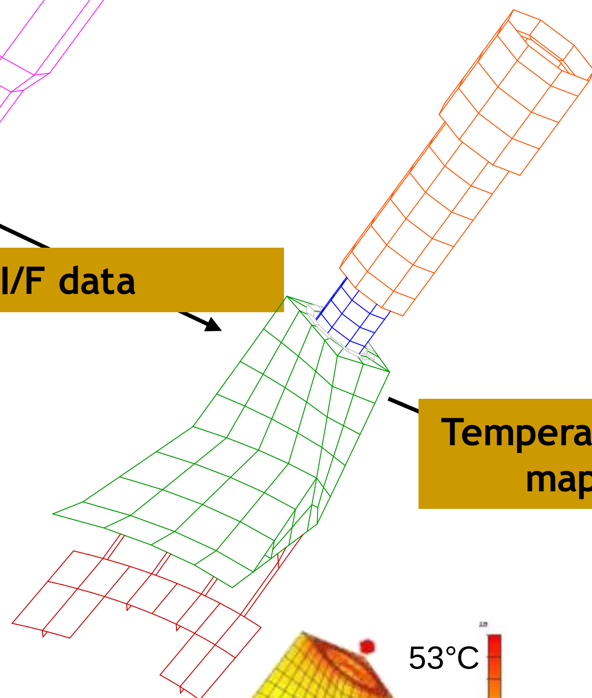


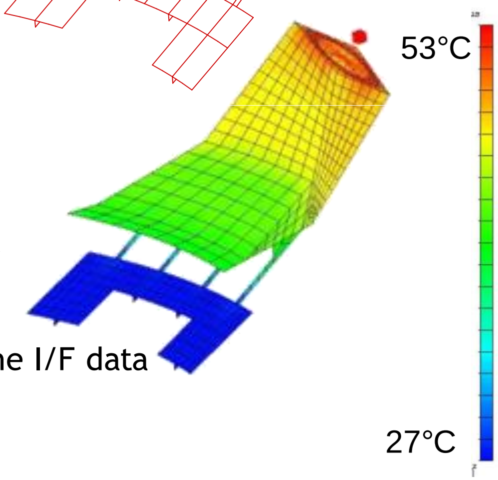
GMM TMM



Simplified
GMM and TMM
Integrated in
AMS/ISS model
for Orbital loads
determination

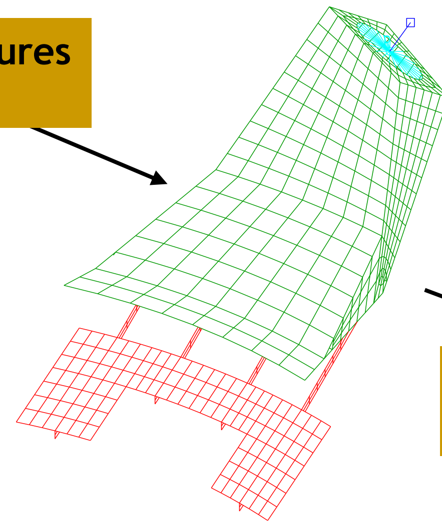
I/F data



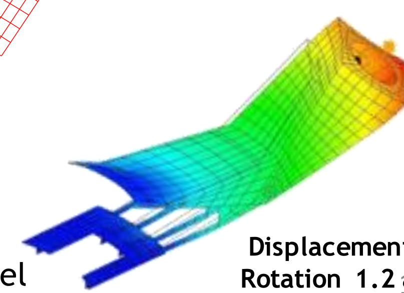


Detailed
GMM and TMM
for components
temperature
Determination
Uses as input the I/F data

Temperatures map



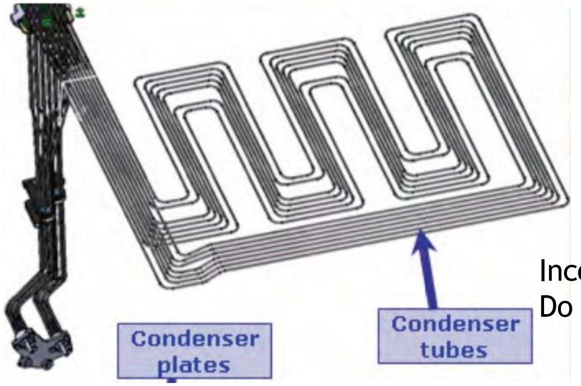
Thermoelastic deformation



Structural model
for thermoleastic analysis

Displacement 0.01mm
Rotation 1.2 arcsec

Tracker in SPACE: thermal analysis freezing



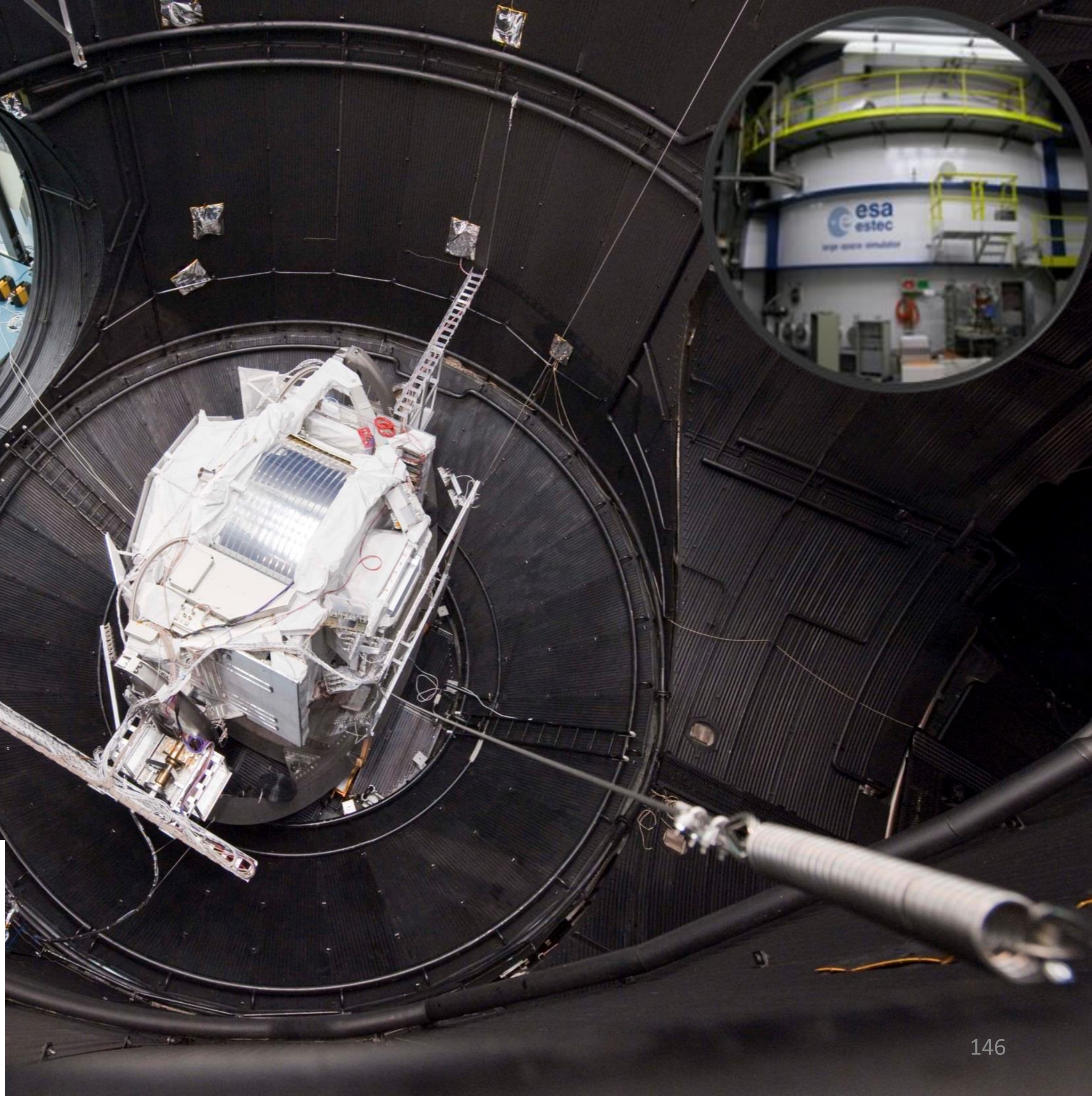
Inconel hardened 718 tubing
Do = 3.15±0.05 mm, Di = 1±0.2 mm

TTCS loop has a net of heaters devoted to its operation and to avoid freezing that nevetherless cannot be prevented in case of a power outage. The consequence of freezing can be an increase in pressure up to 3000 bar.

MASTERBOND EP21TDC-2LO glue in order to cope with the CTE-difference between Inconel and aluminium.

Freezing problem.
In case of a full AMS power shutdown the temperature of the condenser section drops below the freezing temperature of CO2 (-55 ºC). In case the condenser heats up in an un-controlled manner, liquid CO2 can be present in enclosures surrounded by solid parts. Rising temperatures can then induce high pressures. This is a potential safety risk.

In a special test programme it was showed the maximum pressure during CO2 thawing was **3000 bar** at a -5 º C. It was also shown that a small diameter **Inconel 718 tube** (din = 1.0 mm, dout = 3.0 mm) can withstand this pressure



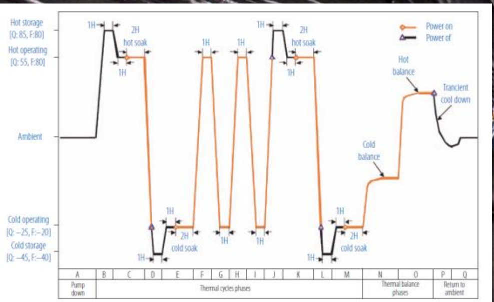
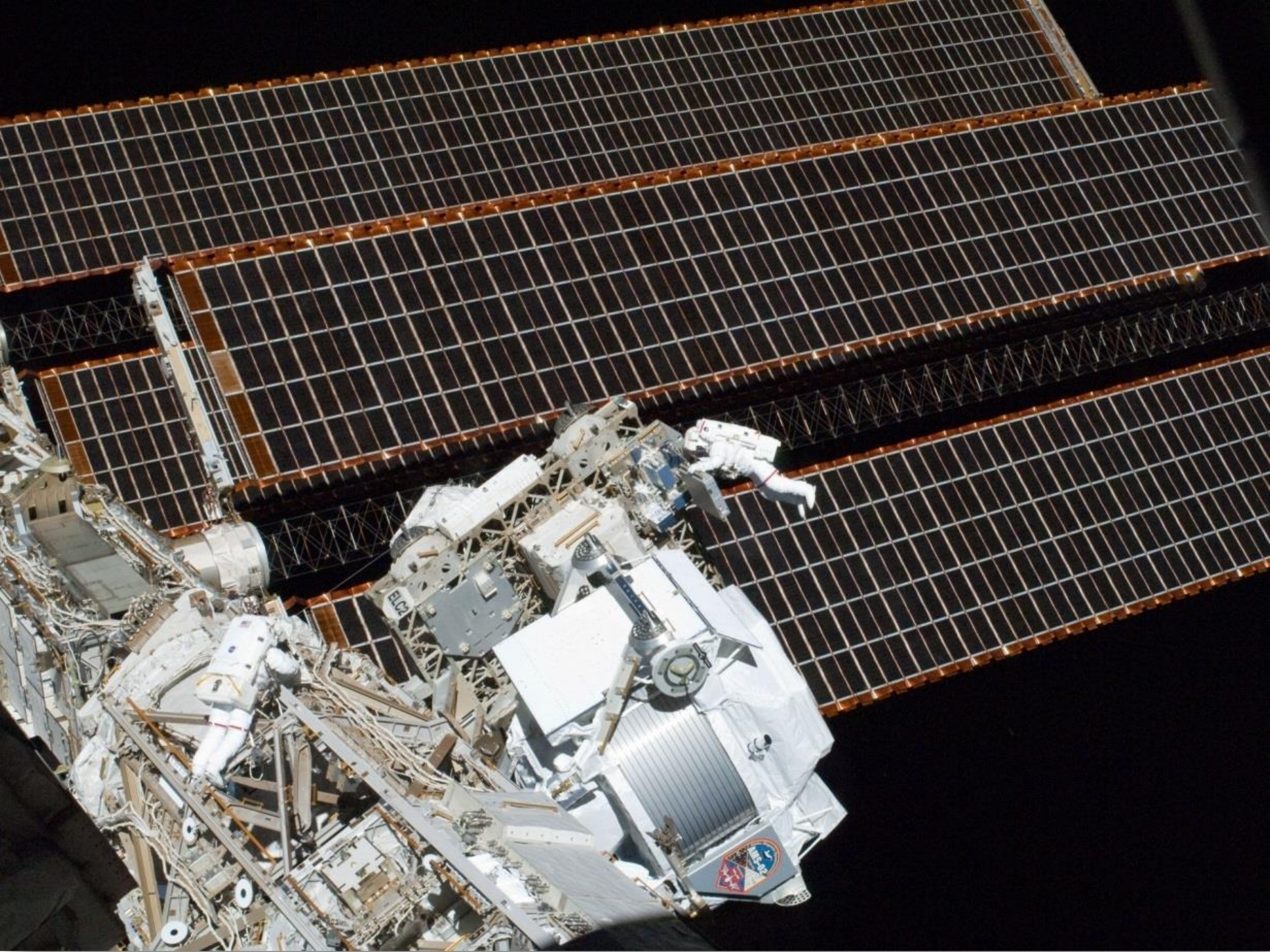


Fig. 6.3.7. Typical Thermal Vacuum Cycling test profile for a payload to be operated on a LEO orbit on the ISS [41].


ELC2