Self-supported ITS 3 modules with bent thin sensors and cold gas cooling

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Reported by G.Feofilov

ITS3 Upgrade WP5 (Mechanics and Cooling) meeting 14.02.2023
https://indico.cern.ch/event/1253461/

Layout

Introduction
1) Conceptual design, Assembly procedure
2) Ultraligthweight self-supported mechanics
3) Prototyping
4) First tests of self-supported
module with bent thin sensor for ITS 3
5) Low-speed gas cooling of large area thin pixel sensors
Conclusion

Geometrical parameters of the ITS-3[1]

Beampipe inner/outer radius (mm)	16.0/16.5		
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	280×56.5	280×75.5	280×94
Number of pixel sensors / layer	2		
Pixel size (μm^2)	$O(15 \times 15)$[b]		

[a] The pseudorapidity coverage of the detector layers refers to tracks originating from a collision at the nominal interaction point ($z = 0$).
[b] For the fallback solution the pixel size is about a factor two larger ($O(30 \times 30)\ \mu m^2$).

- Power: 20 mW/cm2 in active area
- and >140 mW/cm2 in perypherу side
- Challenges: extremely low material budget,
- thermo-mechanical stability,
- Possible Assembly/dissassembly procedure

[1] ALICE-PUBLIC-2018-013

ITS-3 pixel sensor

power density below **140mWcm^{-2}**

power density below **20mWcm^{-2}**

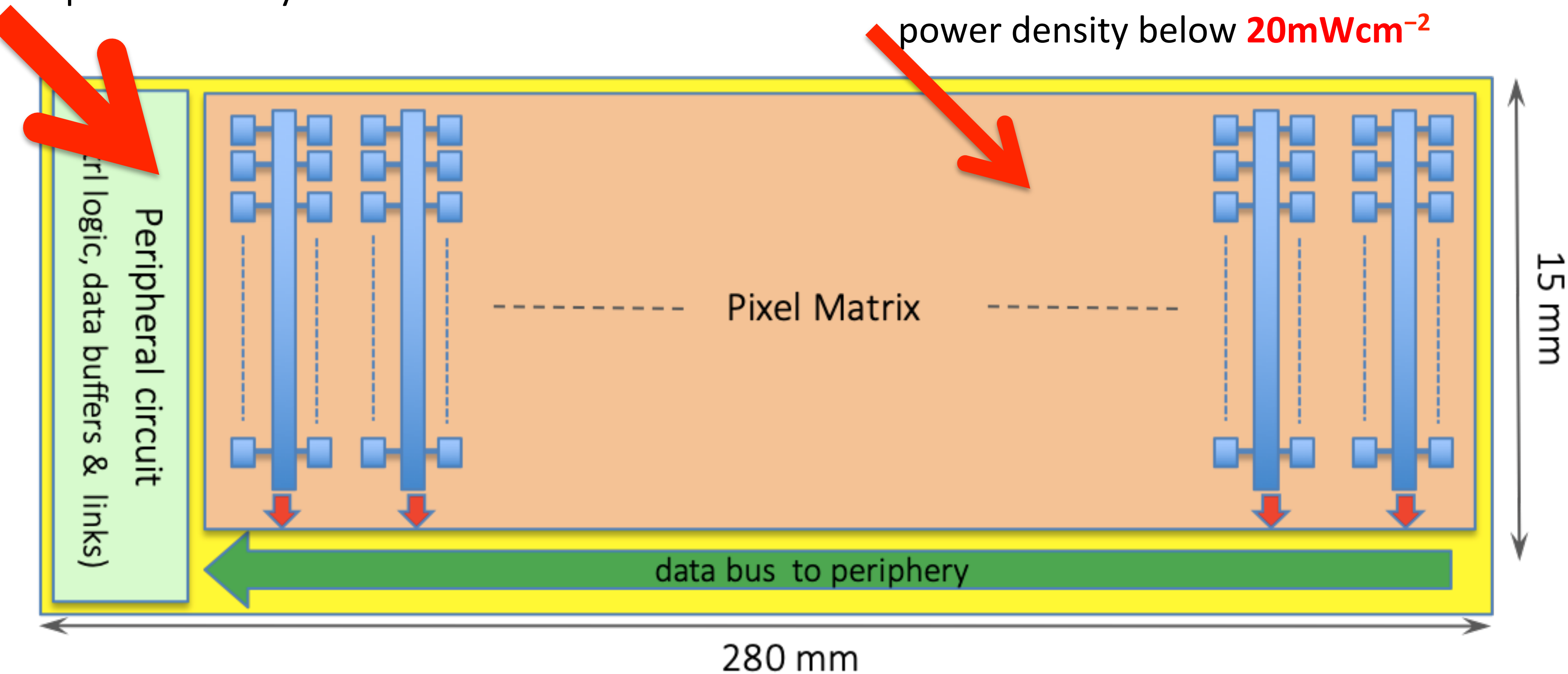
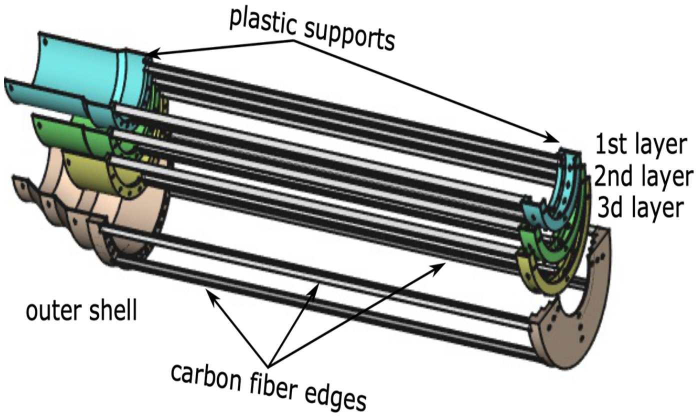


Diagram of stitched sensor in one direction (horizontal and vertical dimensions not to scale). Stitching in the vertical direction is also possible.[1]

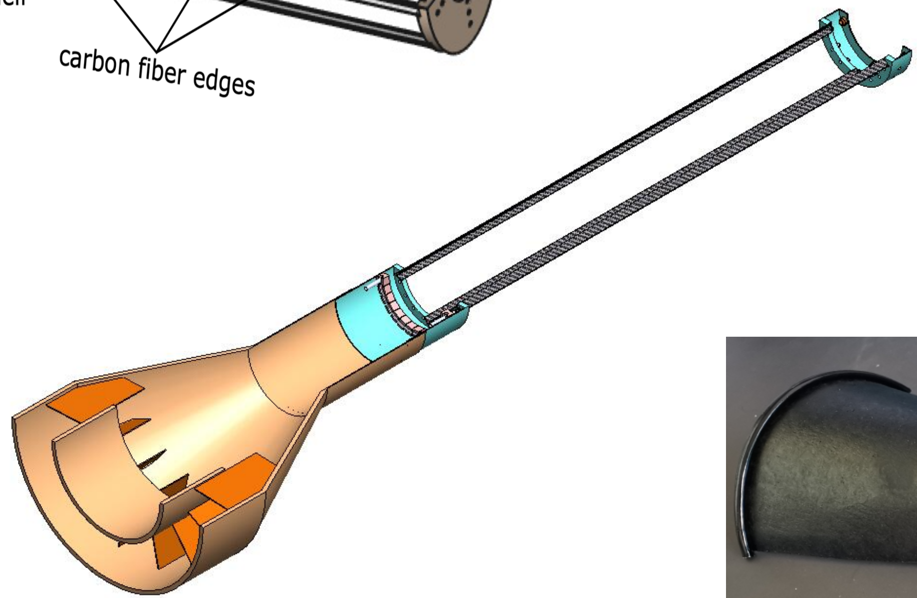
[1] ALICE-PUBLIC-2018-013

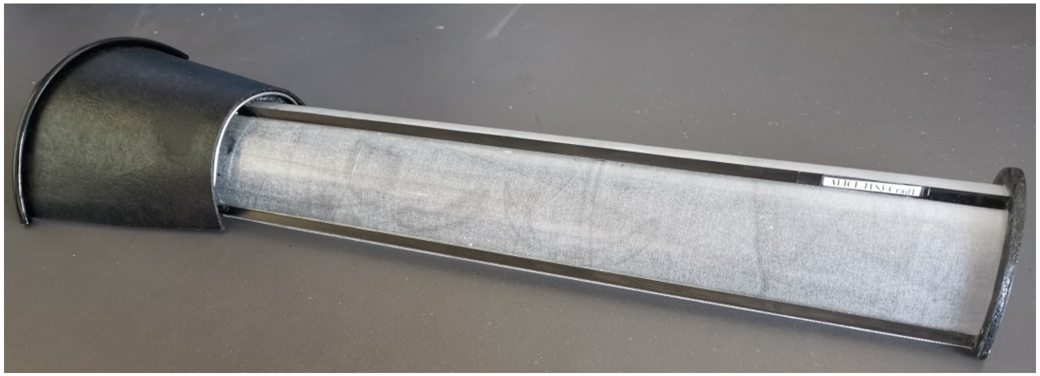
- We consider the underpressure liquid cooling as the feasible solution for power density **140mWcm^{-2}**
- **Low-speed cold gas is proposed to cool large are thin pixel sensors in order to minimize vibrations**

Conceptual design



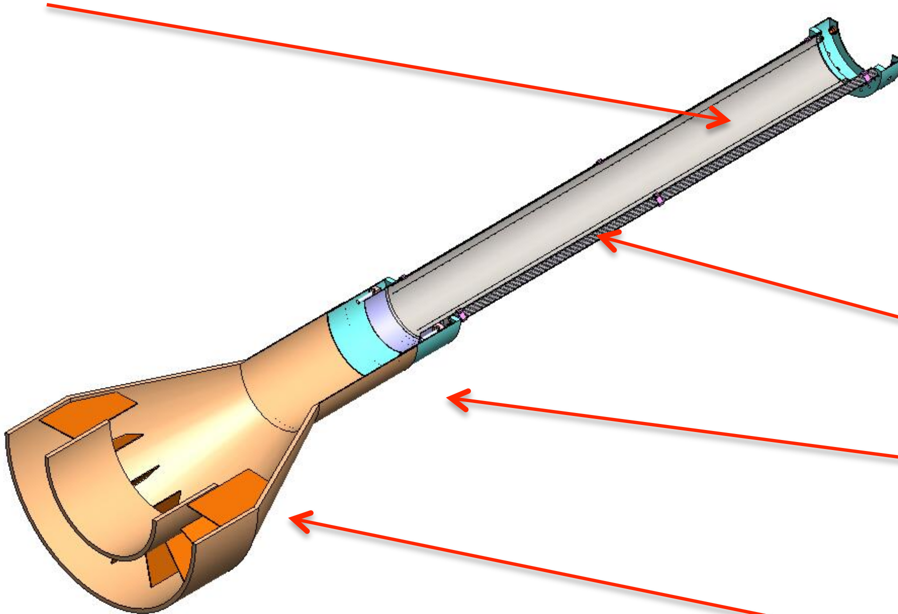
We proceed from the 1st conceptual design, May 2022, presenetd at ITS3-WP (https://indico.cern.ch/event/1158834/) to self-supported independent CF modules for bent Si-sensors, including all services: FPCs and cooling ducts for water and cold gas supply.





Conceptual design

Bent Si-sensor inside the CF supporting cradle



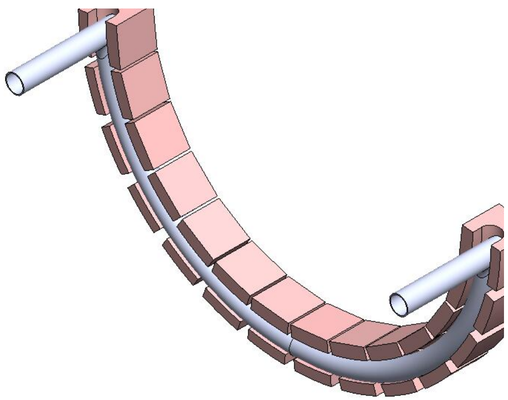
CF half-ring

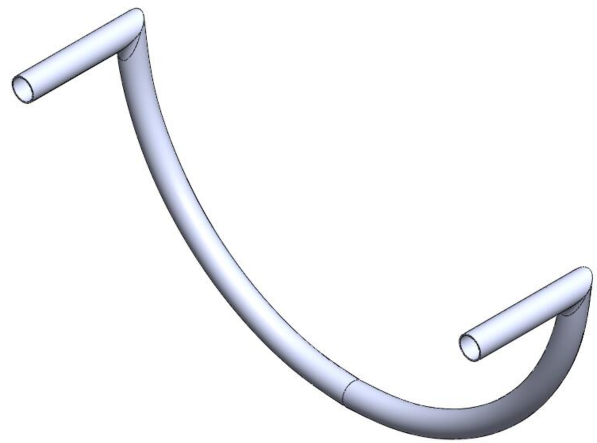
CF composite longerons

Miniature water cooling system

CF composite +ROHACELL foam service half-cone
with FPCs and cooling ducts
(water and cold gas supply)

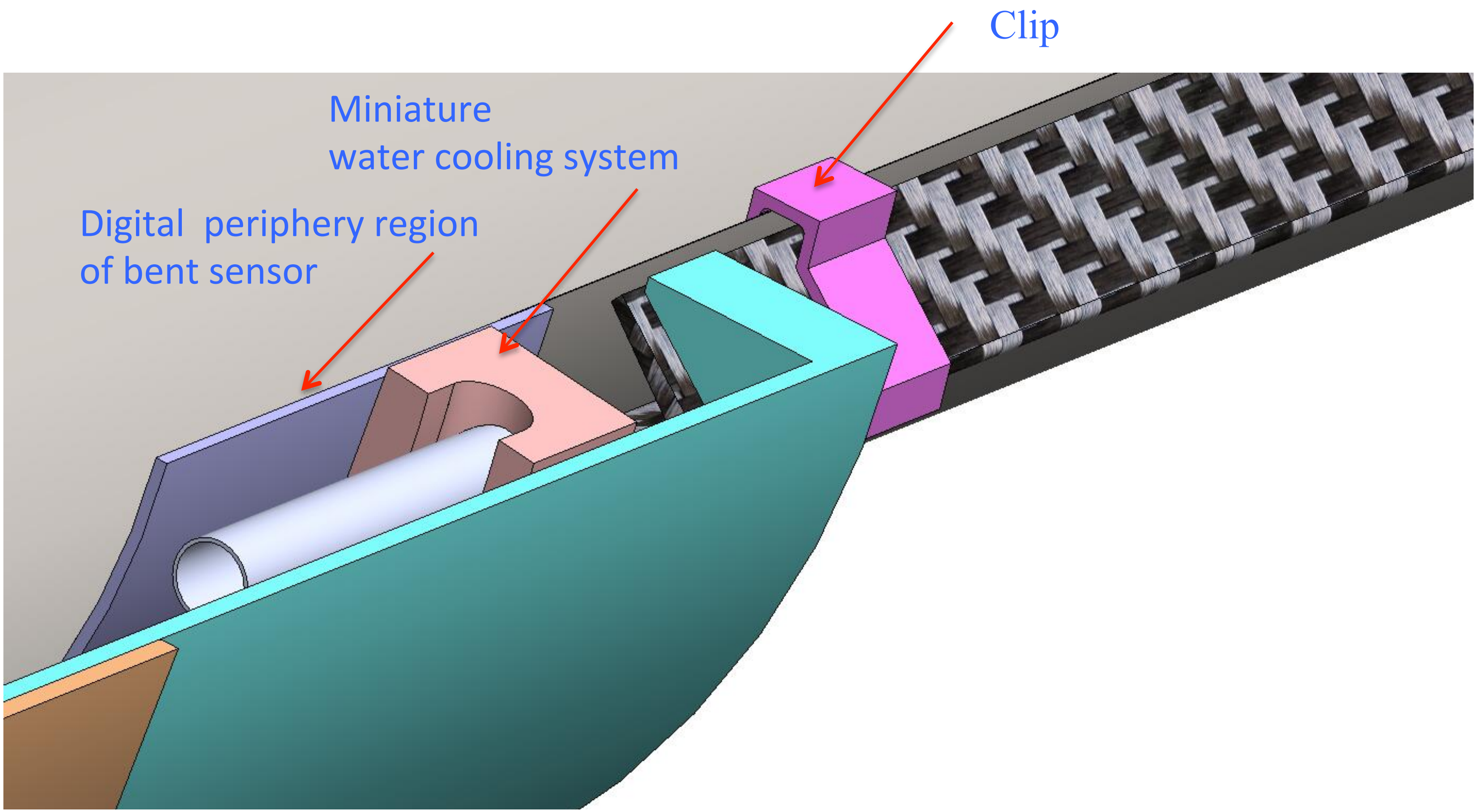
Miniature water cooling system of the digital periphery region of bent sensor: 1 mm diam. pipe placed inside Pyrolytic Graphite blocks



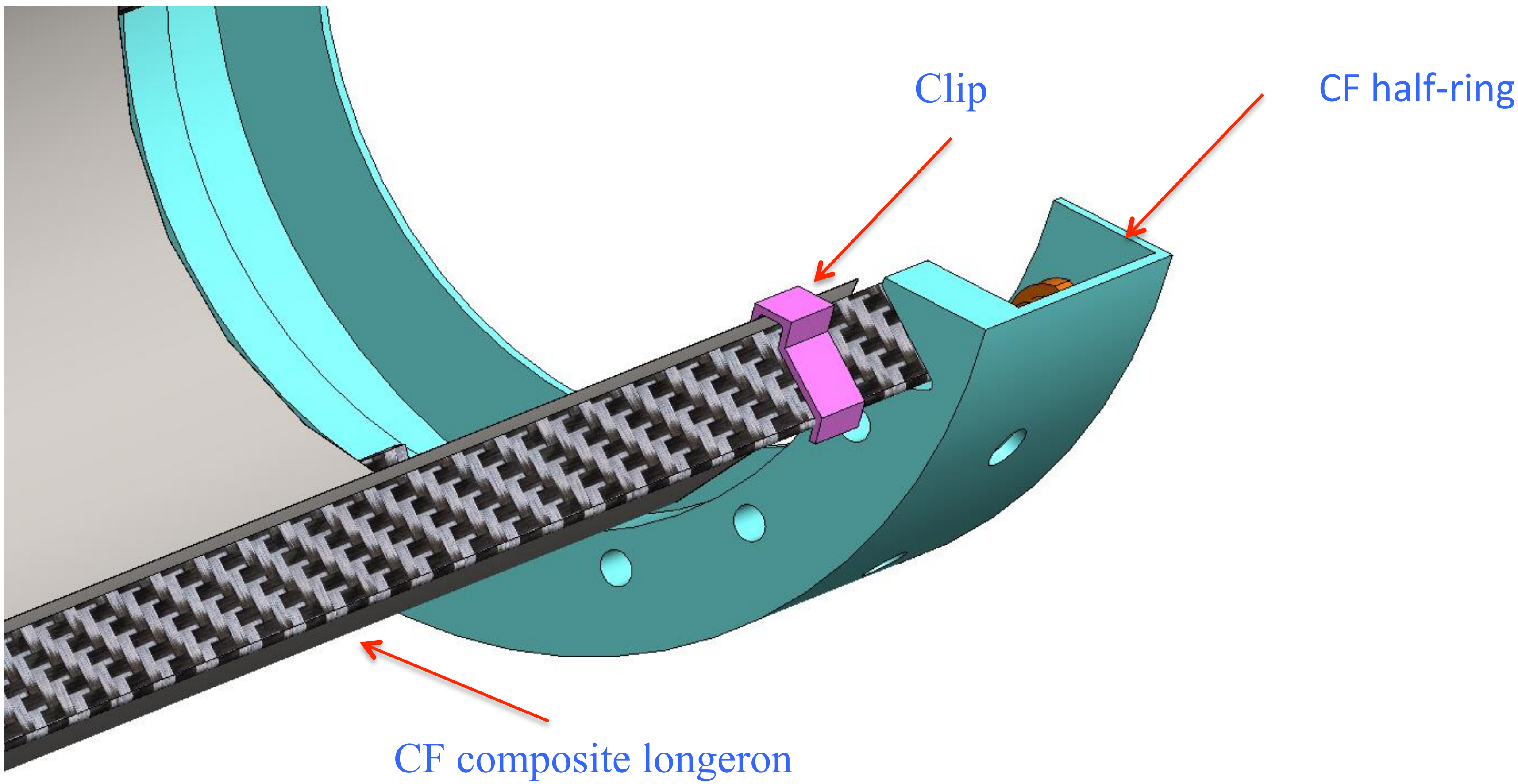


- All services: FPCs and cooling ducts (water and cold gas supply tubes) are located and fixed at the inner surface of the service cone
- The bonding (connection) of the FPCs signal lines to the bent Si-sensor readout electronic pads is performed after sensor positioning inside the CF support cradle (not shown here).

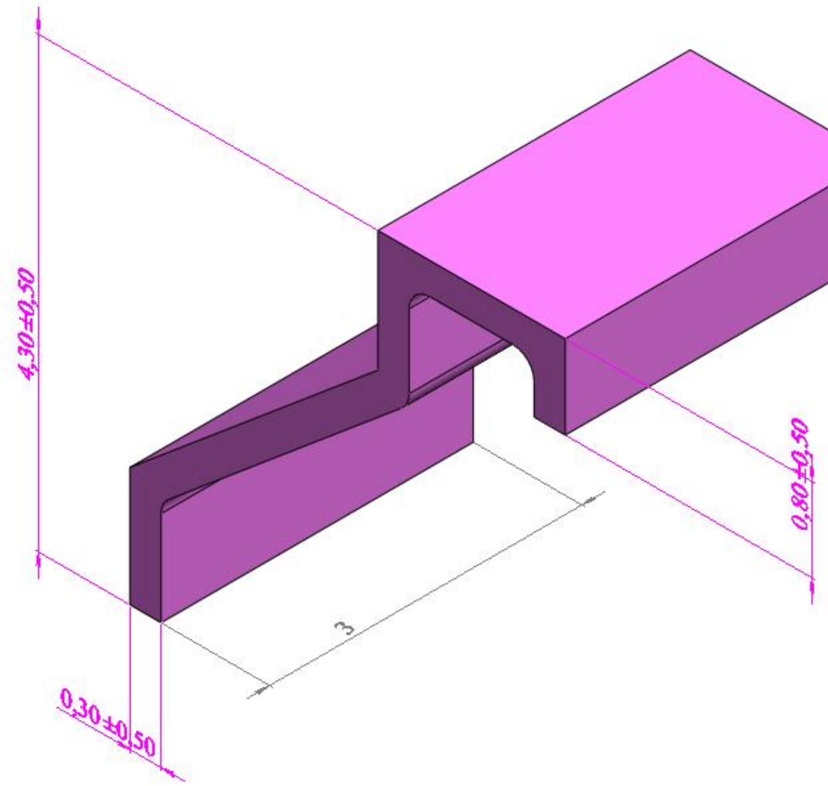
Conceptual design, Assembly procedure



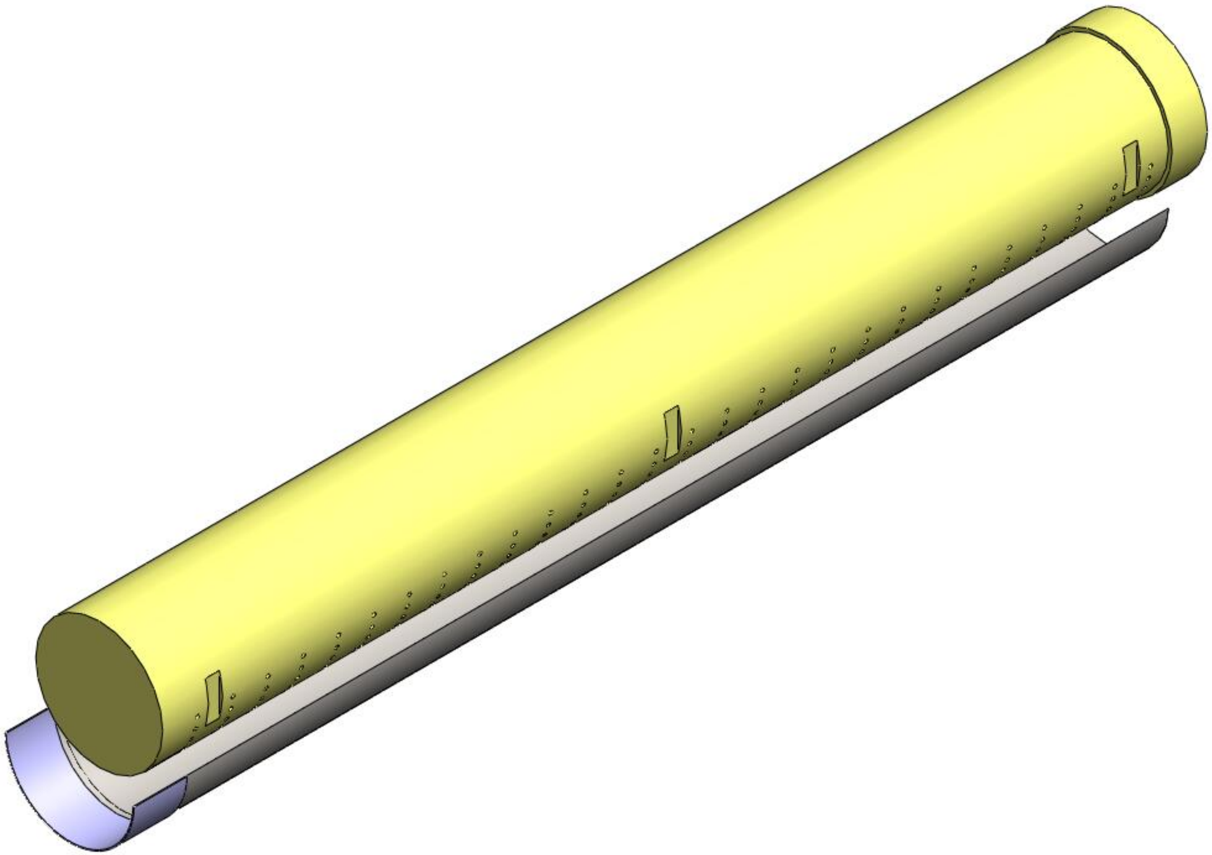
Conceptual design, Assembly procedure



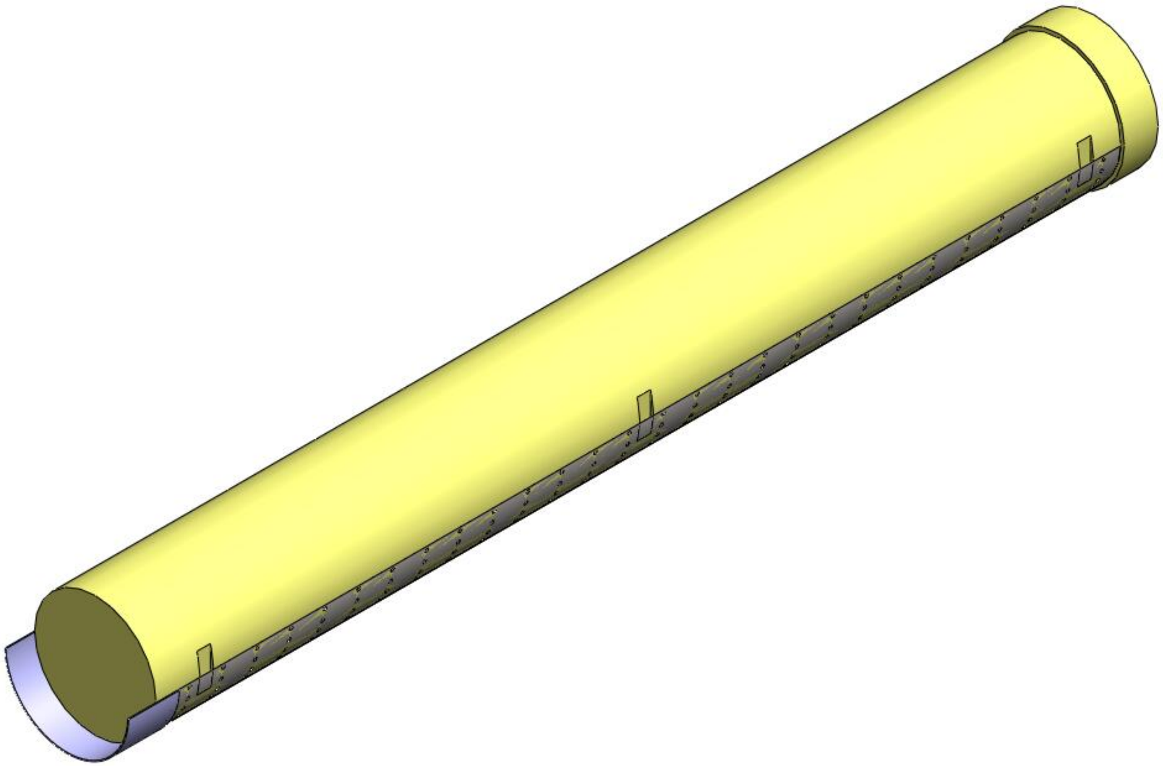
Conceptual design, Assembly procedure: clip



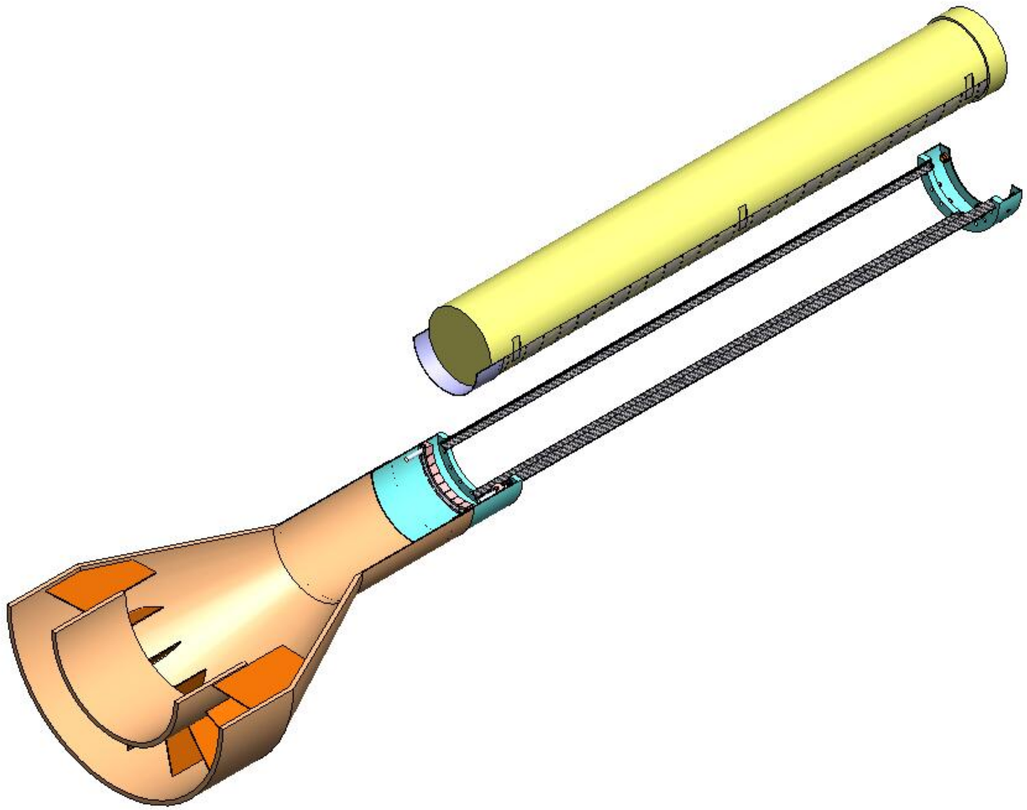
Assembly procedure



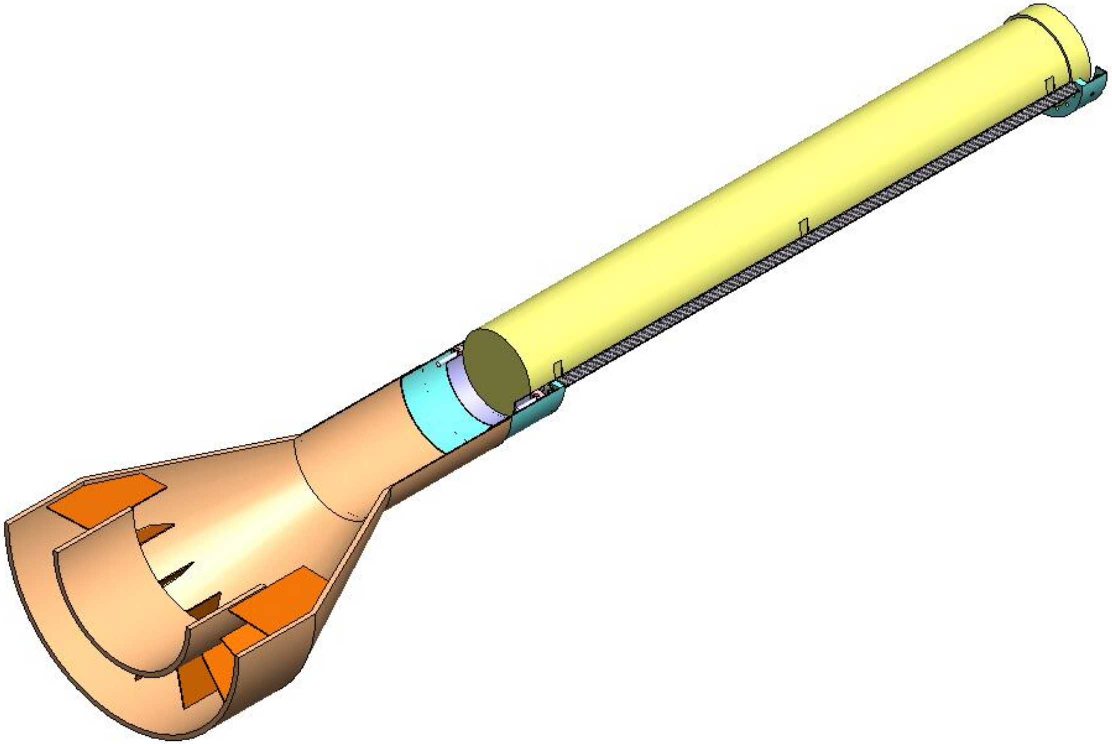
Assembly procedure



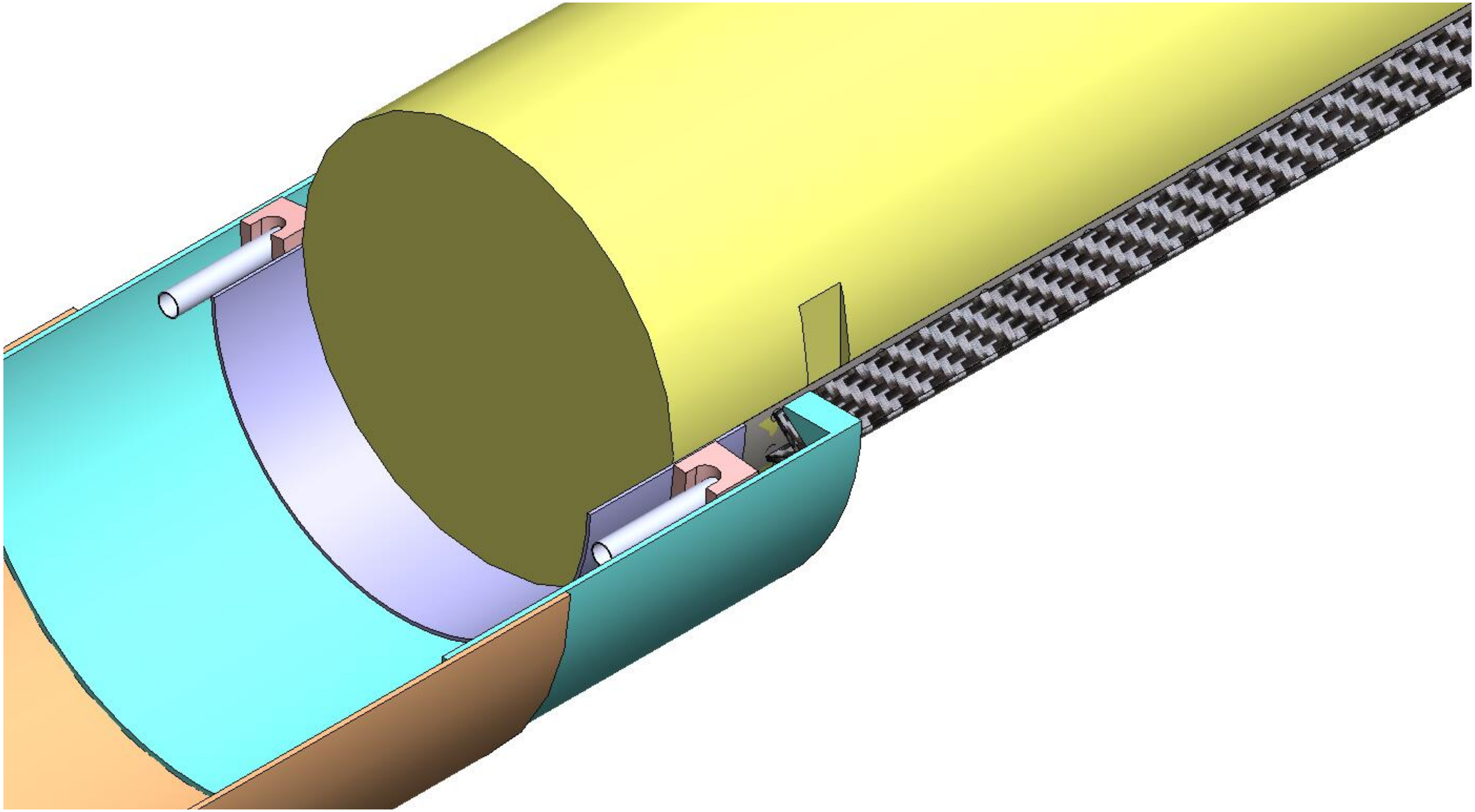
Assembly procedure



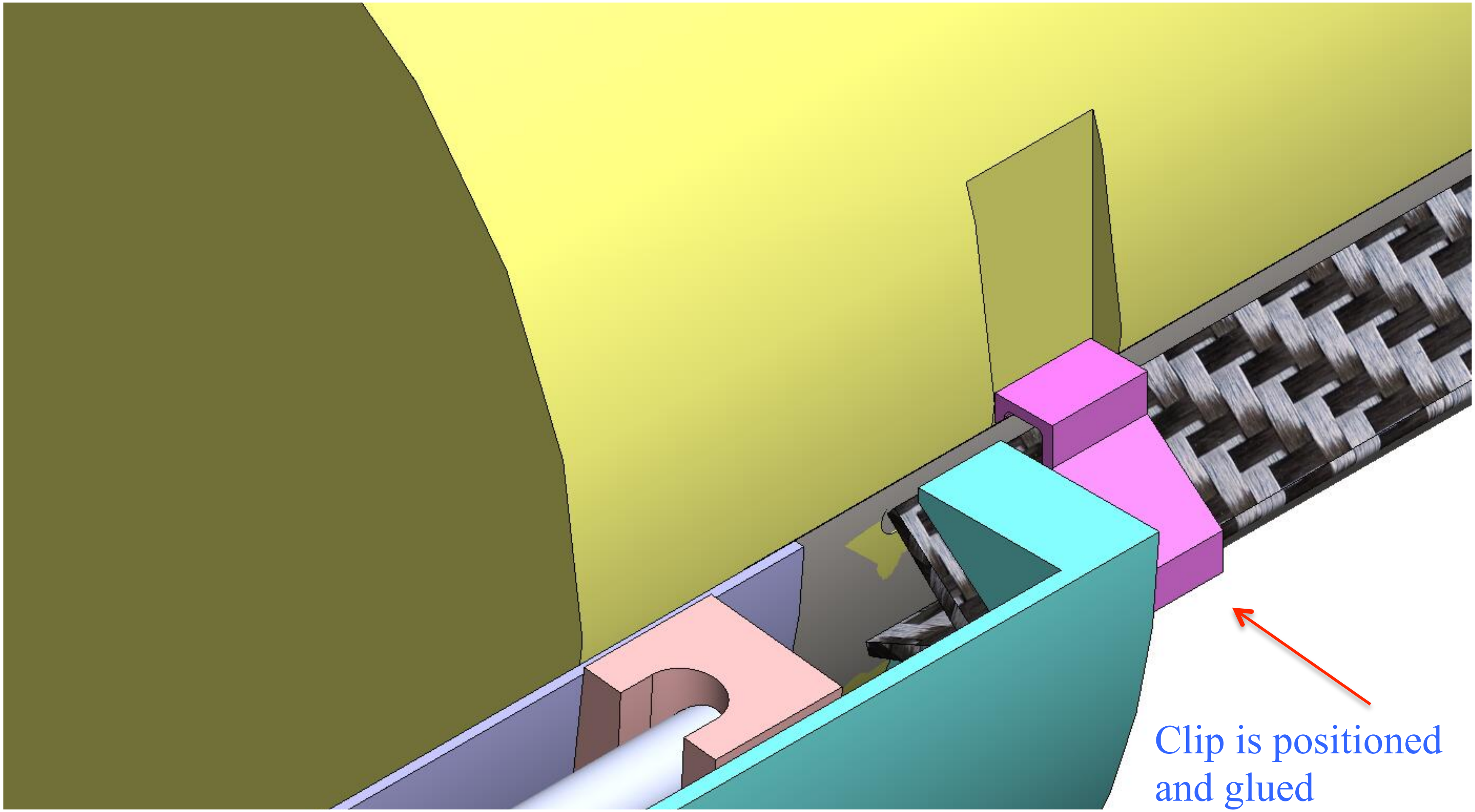
Assembly procedure



Assembly procedure



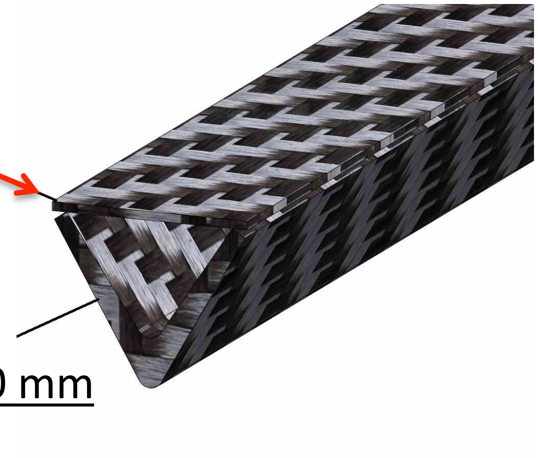
Assembly procedure



Clip is positioned
and glued
to the CF longeron

New technology was tested in SPbSU for longerons using the available CF prepreg

CF longeron + CF fleece panel



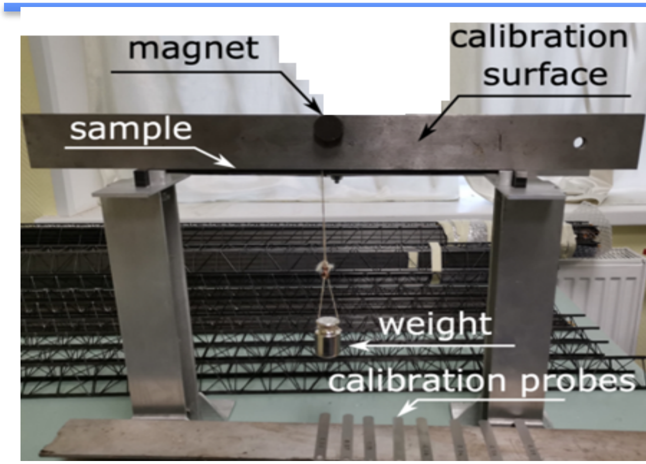
CF rib, L=300 mm

Longerons with CF prepreg NIICAM: sagging under central load

Rib No.	Edge length,mm	Profile hight,mm	Weight of rib, g	Weight of rib+plate, g
SPBU-ITS3-CF4	4,11....4,40	3,43...3,60	1,68г	1,85г
SPBU-ITS3-CF5	3,97....4,12	3,44...3,62	1,74г	1,89г
SPBU-ITS3-CF6	4,08....4,44	3,85...3,59	1,73г	1,89г

- CF longeron + CF fleece panel could be a more stable option useful for gluing

Deformation of 30 cm V-shaped NIICAM CF longerons + CF panel



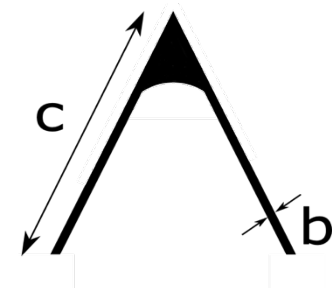
Prepreg: NIICAM

Tests with central load at SPbSU

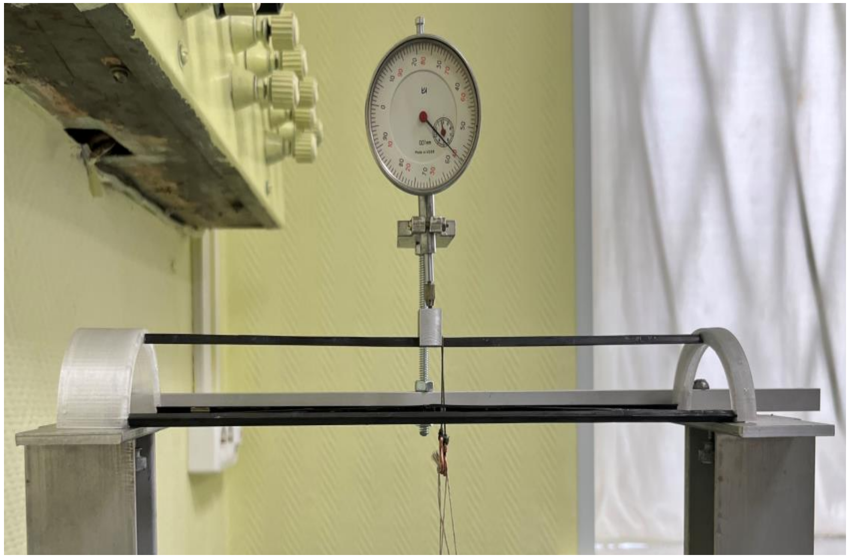
Rib+panel	Load,g			
	100g	200 g	300g	400 g
	sag, mm	sag, mm	sag, mm	sag, mm
SPbSU-ITS3-CF-4	0.50	0.94	1.52	2.01
SPbSU-ITS3-CF-5	0.50	0.96	1.54	2.06
SPbSU-ITS3-CF-6	0.49	0.97	1.37	1.87

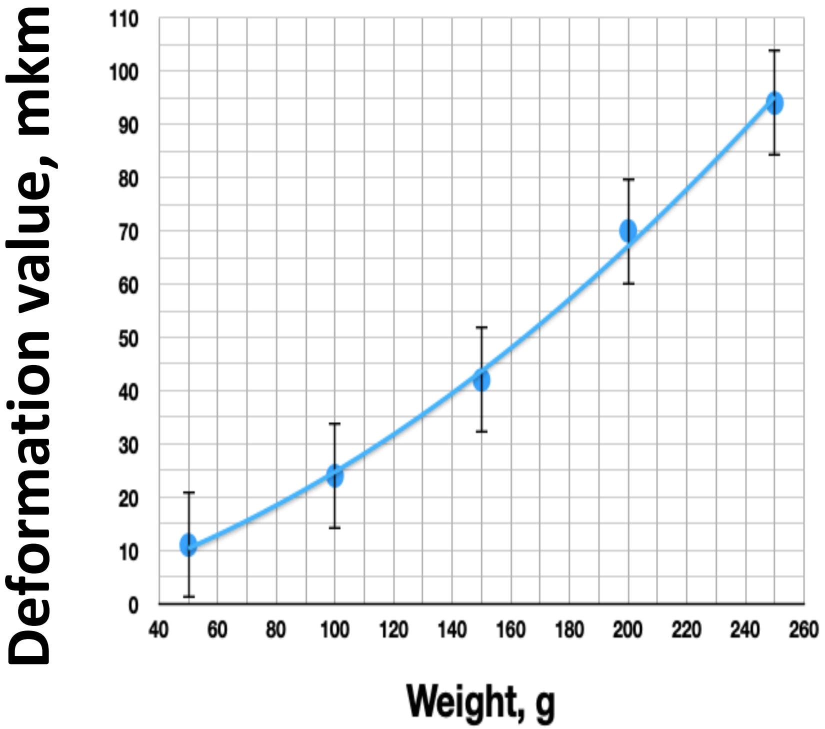
- **Results could be improved by using the high performance carbon fiber like (THORNEL X1100 or** TORAYCA® T1100G **Tensile Strength ~7,000 Mpa) instead of** NIICAM .

Deformation value of V-shaped CF longerons under the influence of different weights



Longerons with high performace carbon fiber TORAYCA M55J

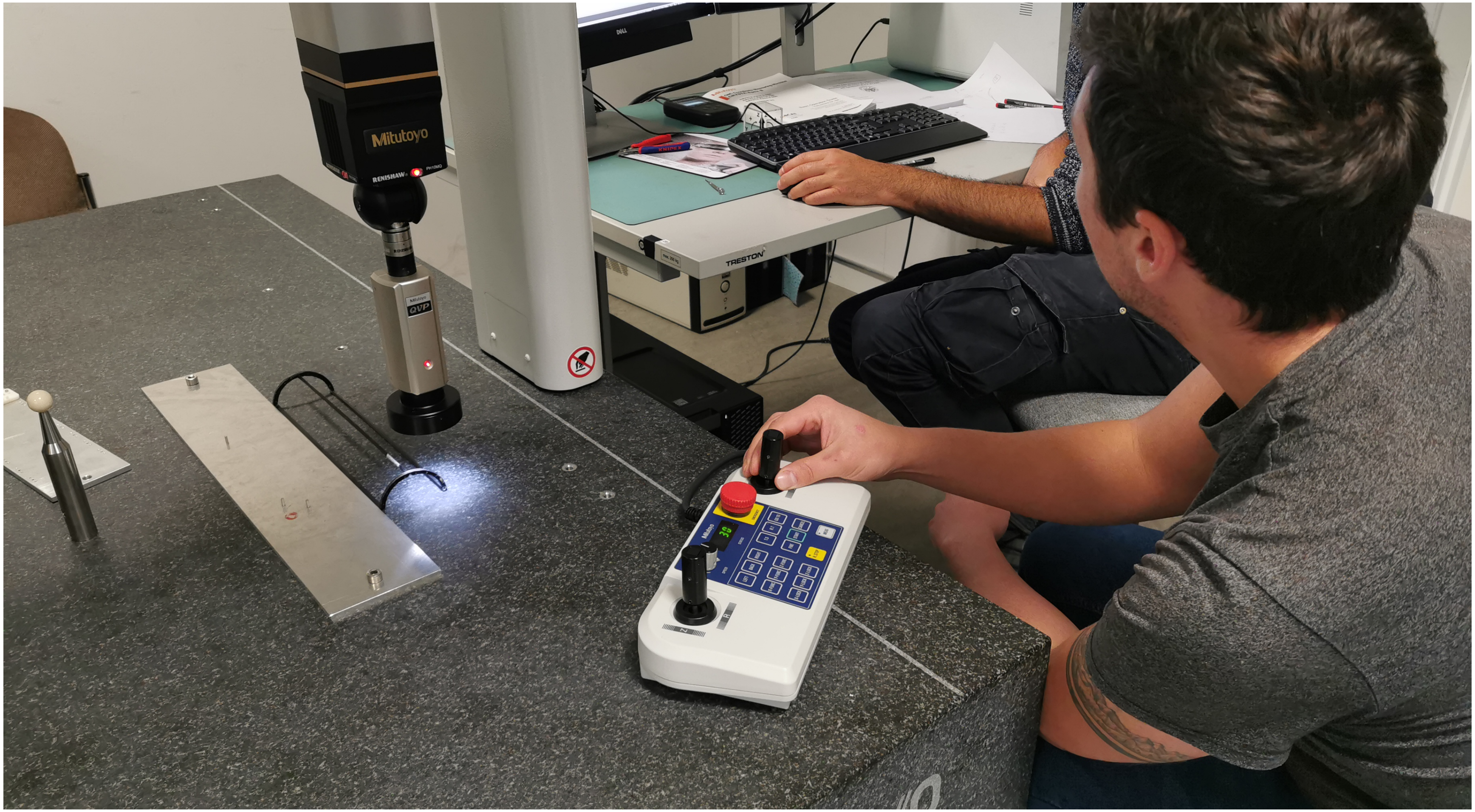




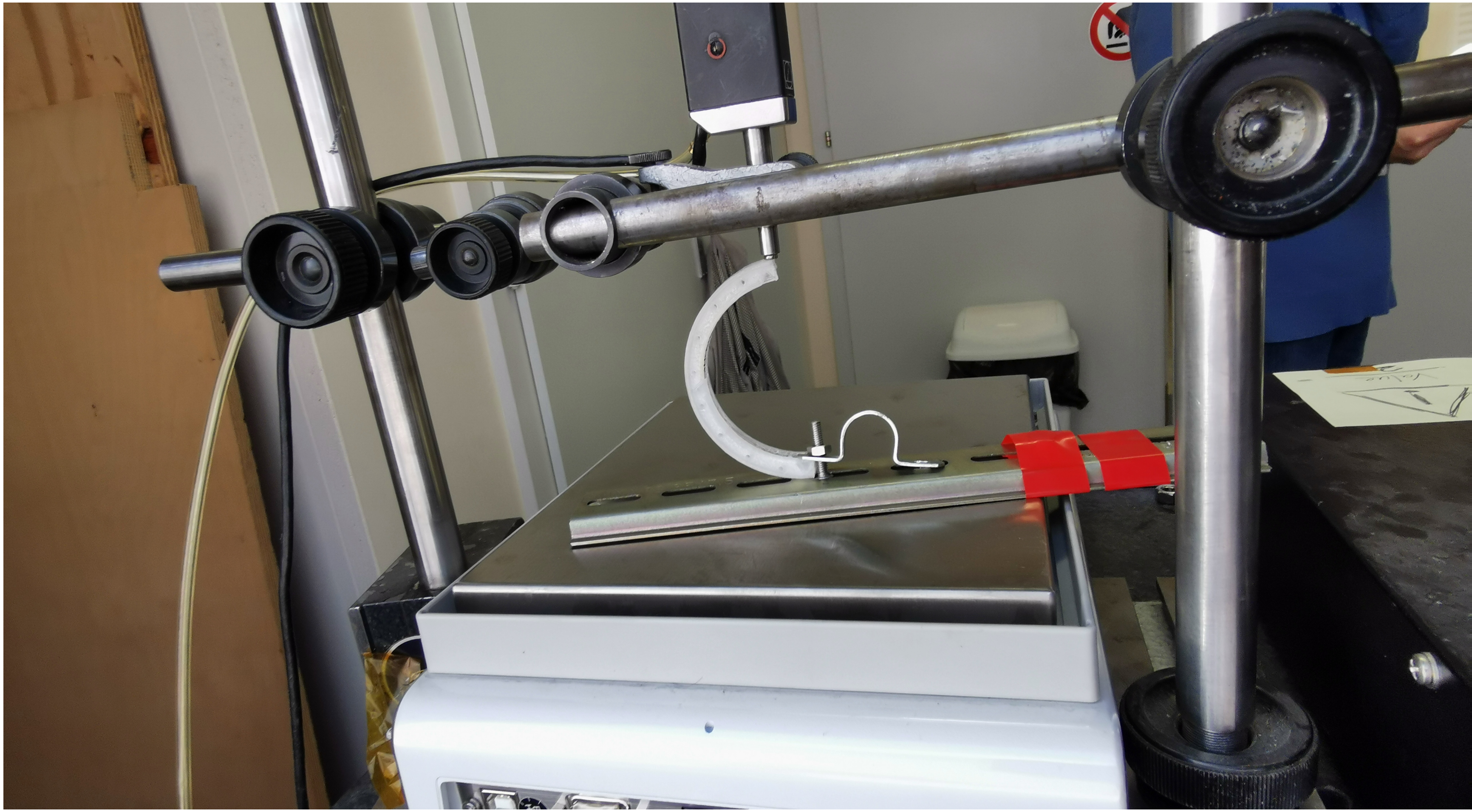
➢Longerons with TORAYCA M55J : very nice rigidity!

Tests at CERN:
CF samples - prepreg NIICAM

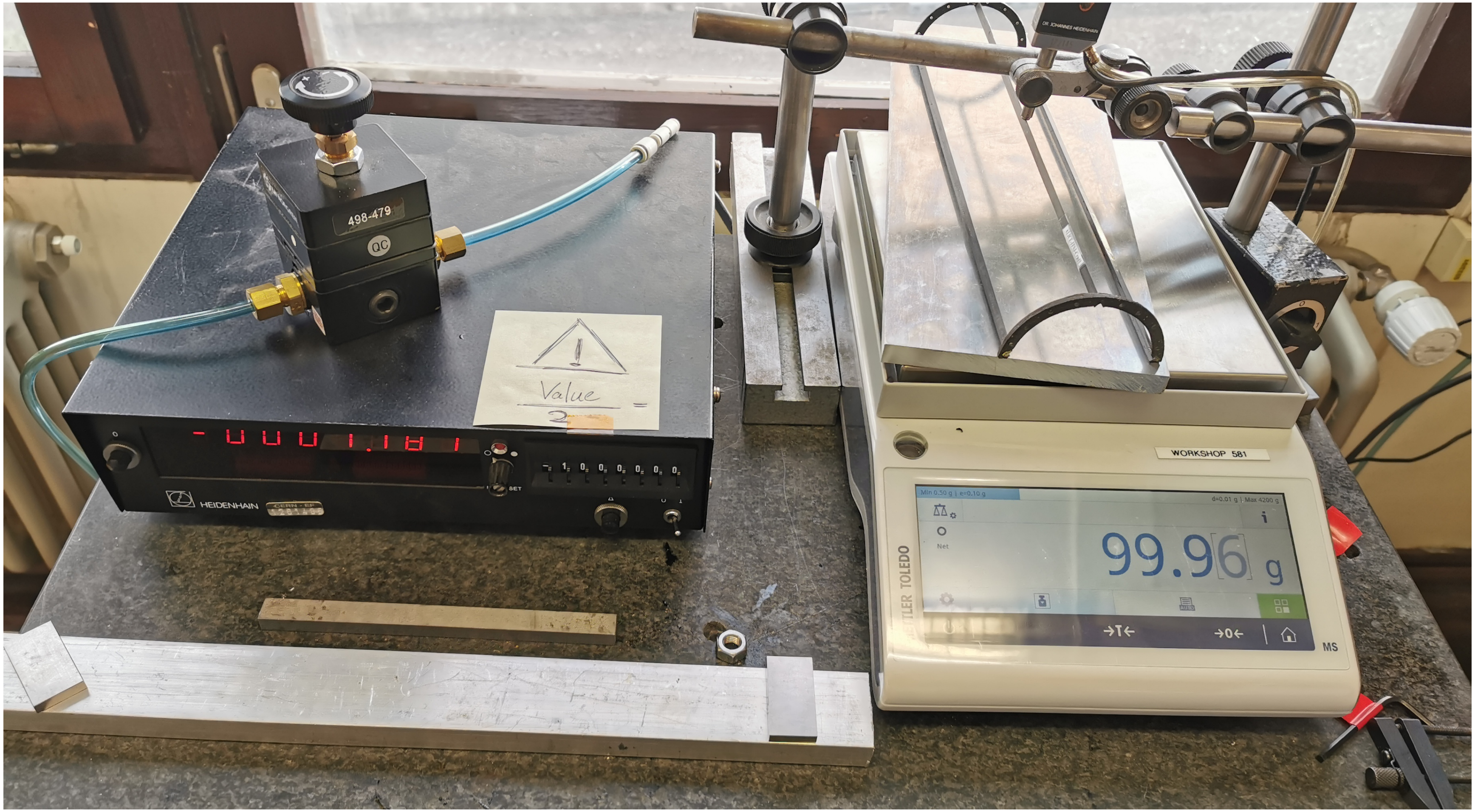
Tests at CERN – see report by Vladimir Zherebchevsky (today)



Tests at CERN



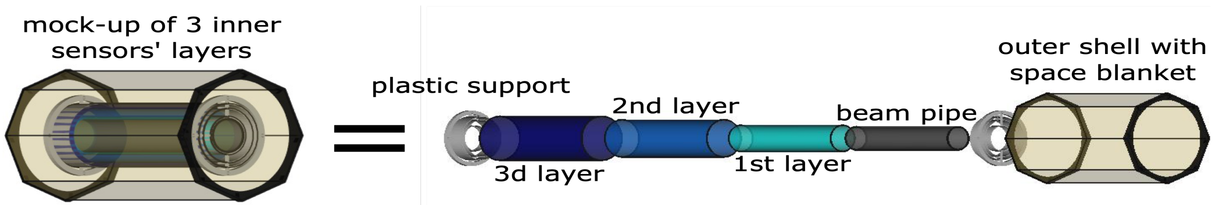
Tests at CERN



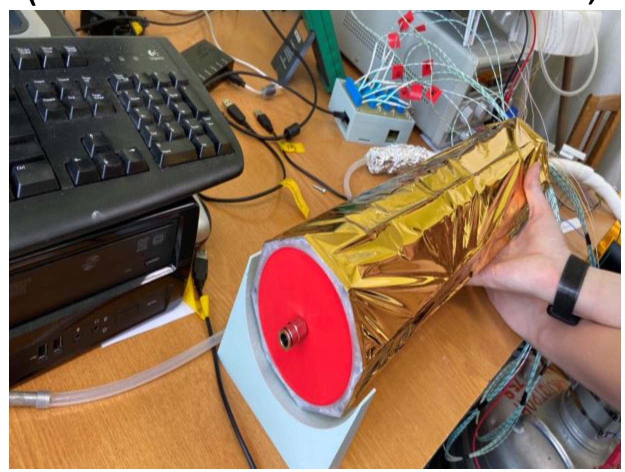
Summary of test at CERN :

1. The CF composite technology for production of low-mass longerons and carbon fiber supporting semi-rings was developed in SPbSU and tested at CERN.
2. The carbon fiber semi-rings with CF low-mass longerons could be used to form a cradle to support thin large area Si-sensors.
3. The low mass CF composite cradle has sufficient rigidity and thermo-mechanical stability to house thin large area Si detector sheets. Stiffness could be improved further by using the longerons produced with higher modulus carbon fibers.

Gaseous cooling of self-supported ITS 3 modules



Scheme of cooling system with mock-up of 3 silicon cylinder layers and outer shell with space blanket (in dimensions of the Table 1, slide 3)



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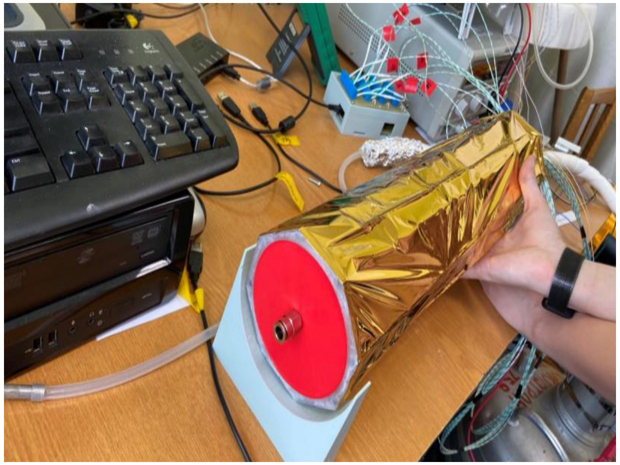
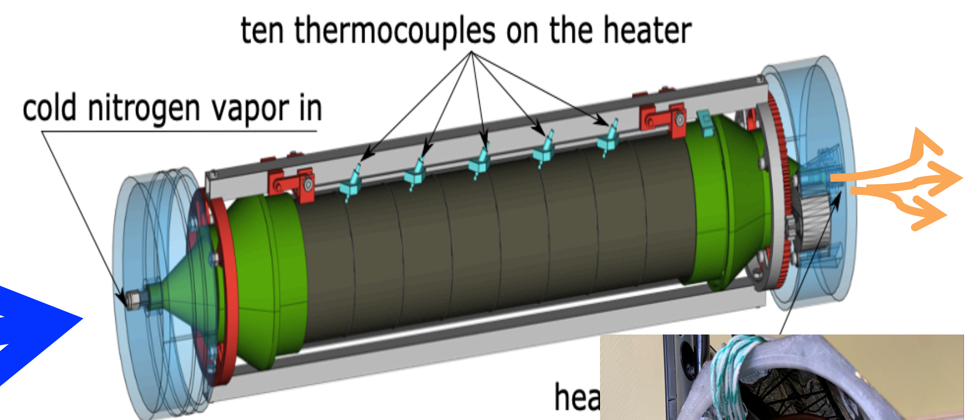
https://indico.cern.ch/event/1158834/

Space blanket isolated ITS-3 mock-up barrel.





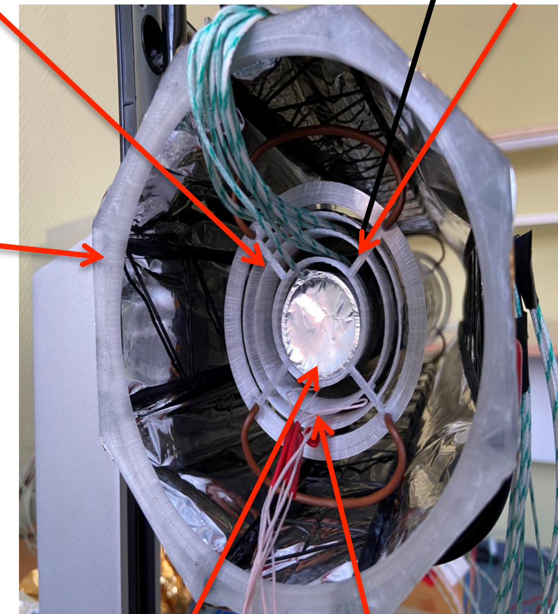
V.I. Zherebchevsky, G.A. Feofilov et al.
ITS3 Upgrade WP5 (Mechanics and Cooling) meeting 06.07.2021

3 layers

The 3d layer

The 2n

Space blanket outer thermal shell

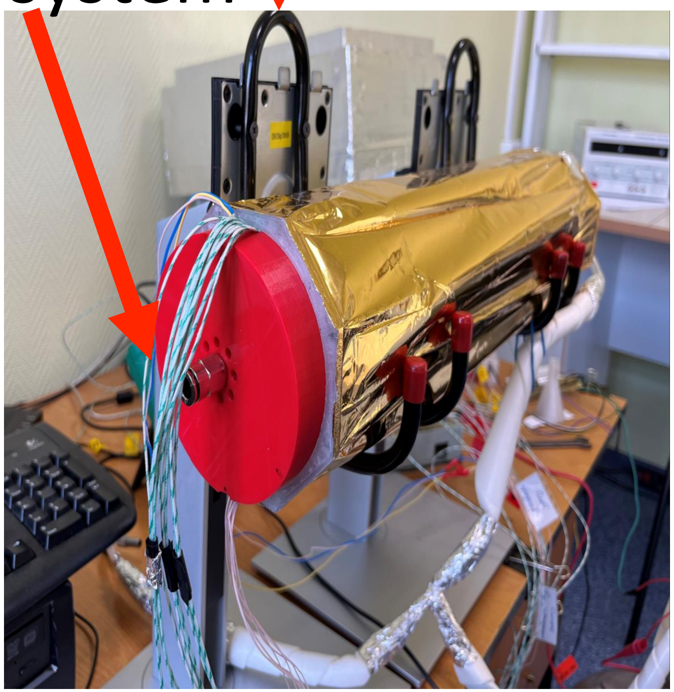


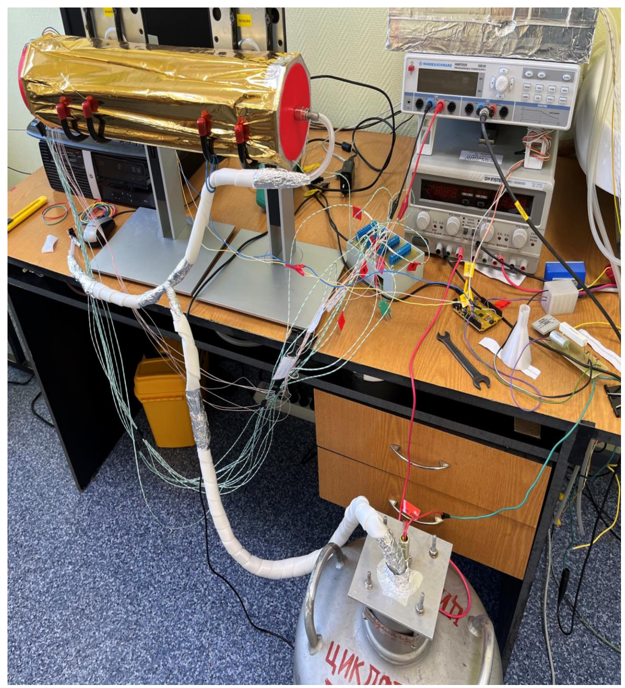
The 1st laye

The beam pipe mock-up

New cold nitrogen supply system

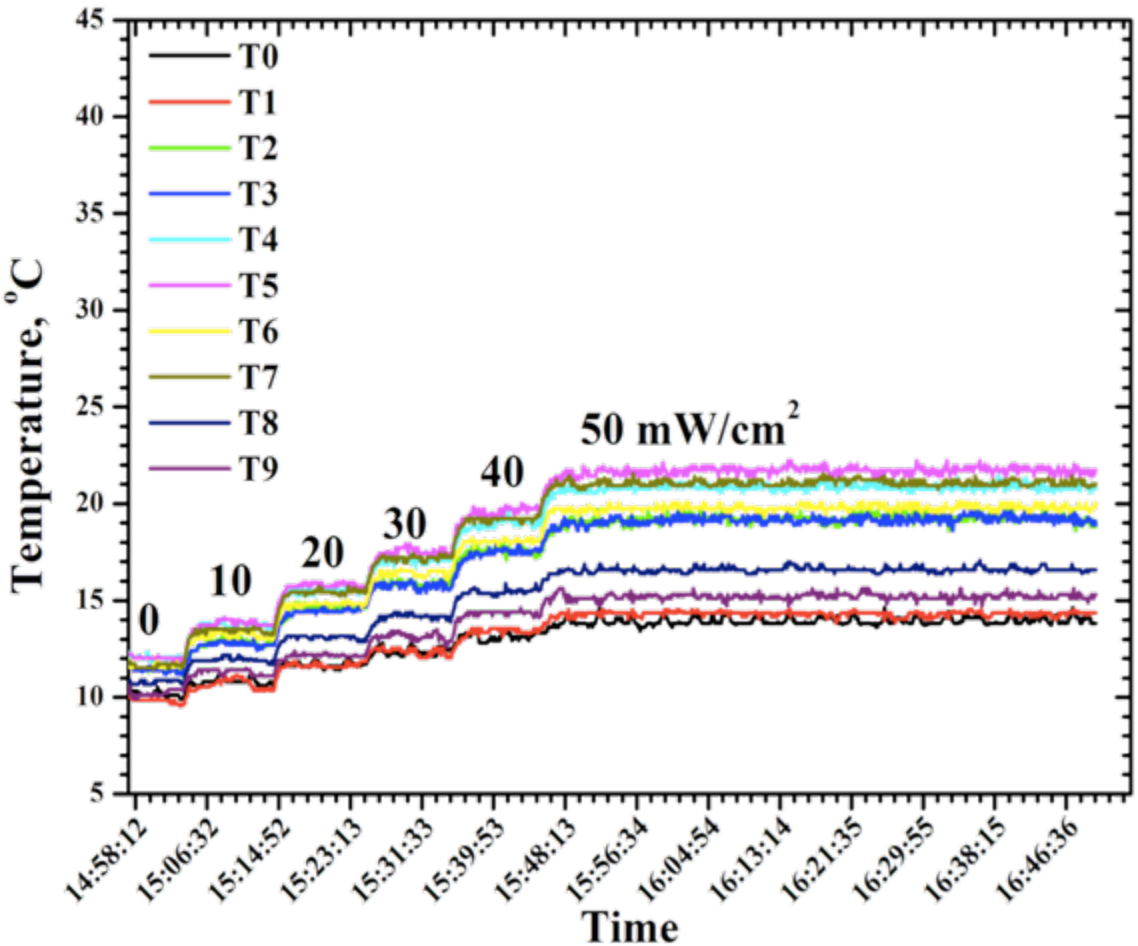
The experimental set-up was modernized

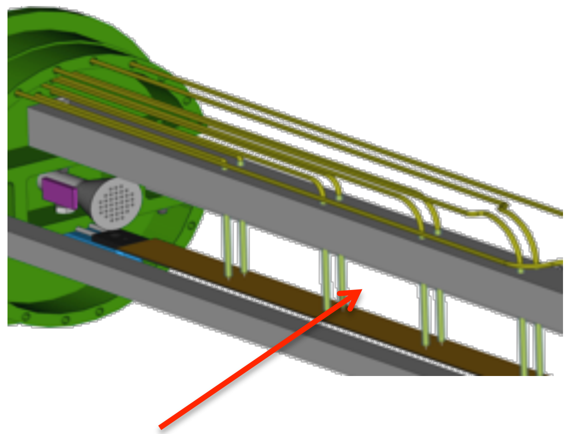




Thermal tests with ~ zero-flow cold Nitrogen

- Heat power up to 50 mW/cm²
- Ten double thermocouples: T0,T1…T9





30 cm stave with 10 thermocouples (T0,T1…T9) mounted along the heater

The first results are good:

- Temperature<25 °C for all heat loads
- Speed of N_2 gas flow ~0

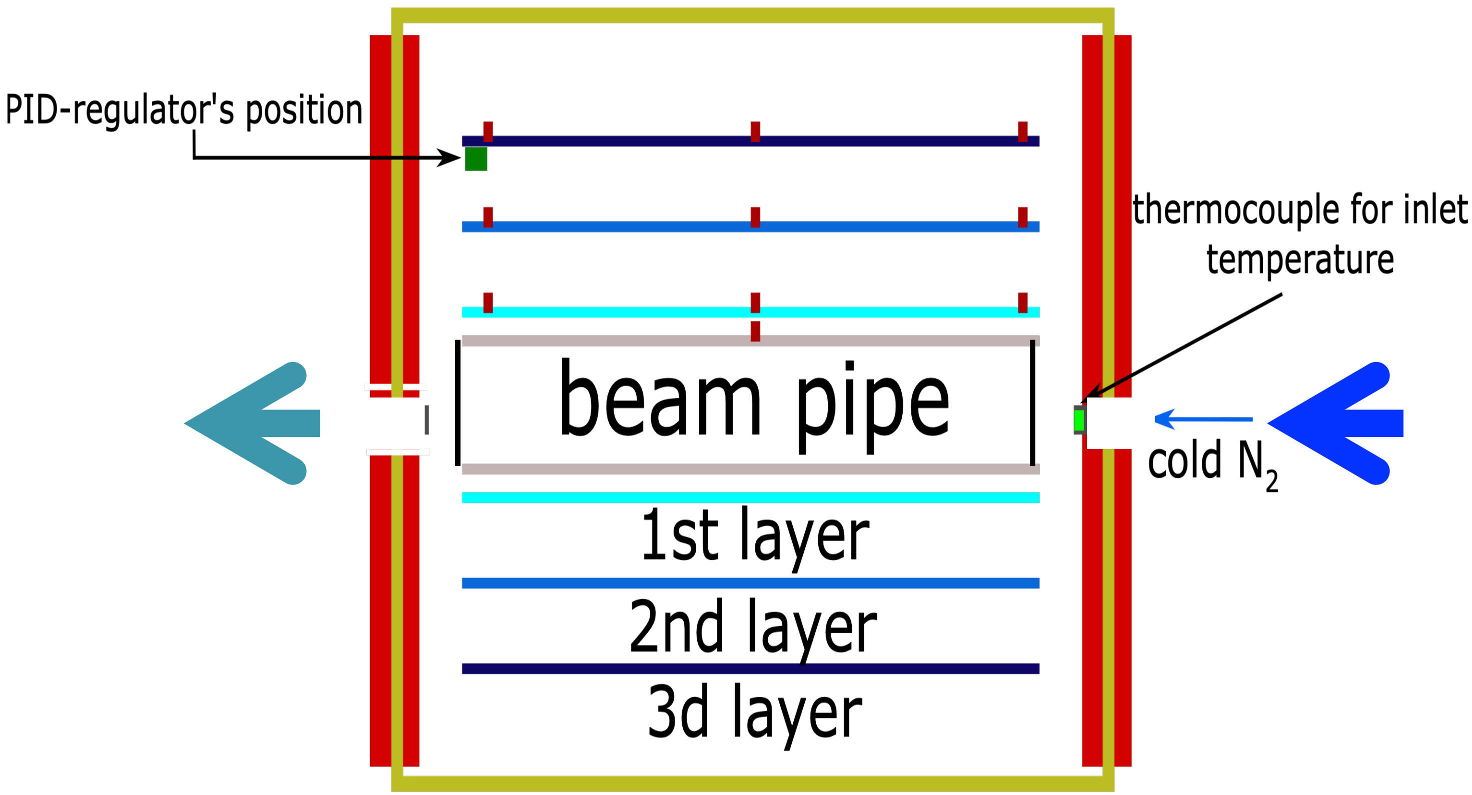
3 layers

blowing from one side

Return to previous configuration without special spreaders.

PID-regulator on exit, so we control of the outlet nitrogen temperature

▪ - thermocouples



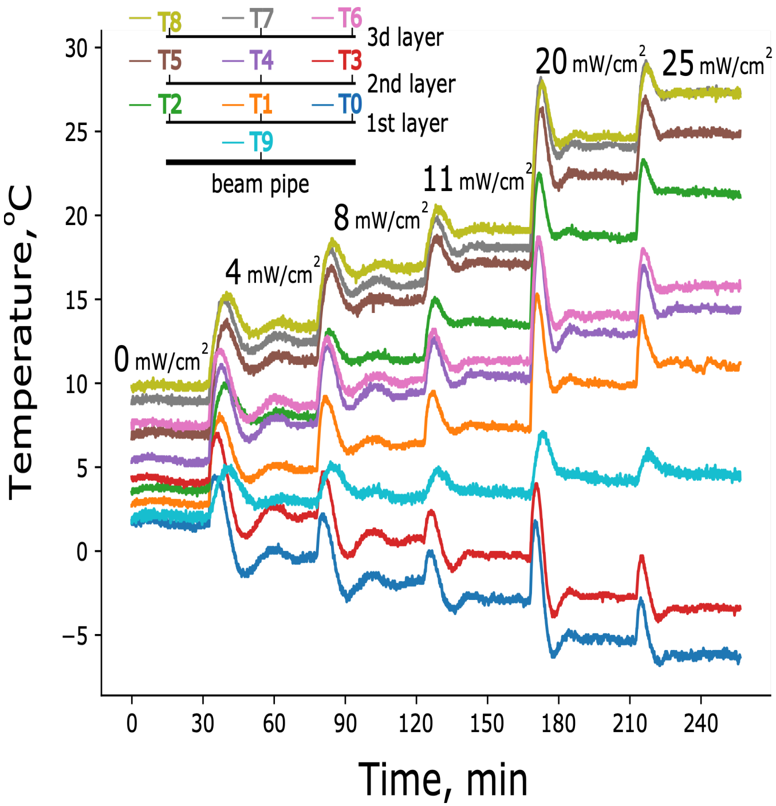
outer shell with space blanket

3 layers

blowing from one side

Results of temperature distributions measured at different heat loads with cold nitrogen

- Gas flow from from one side
- Control of the outlet temperature at 15° C



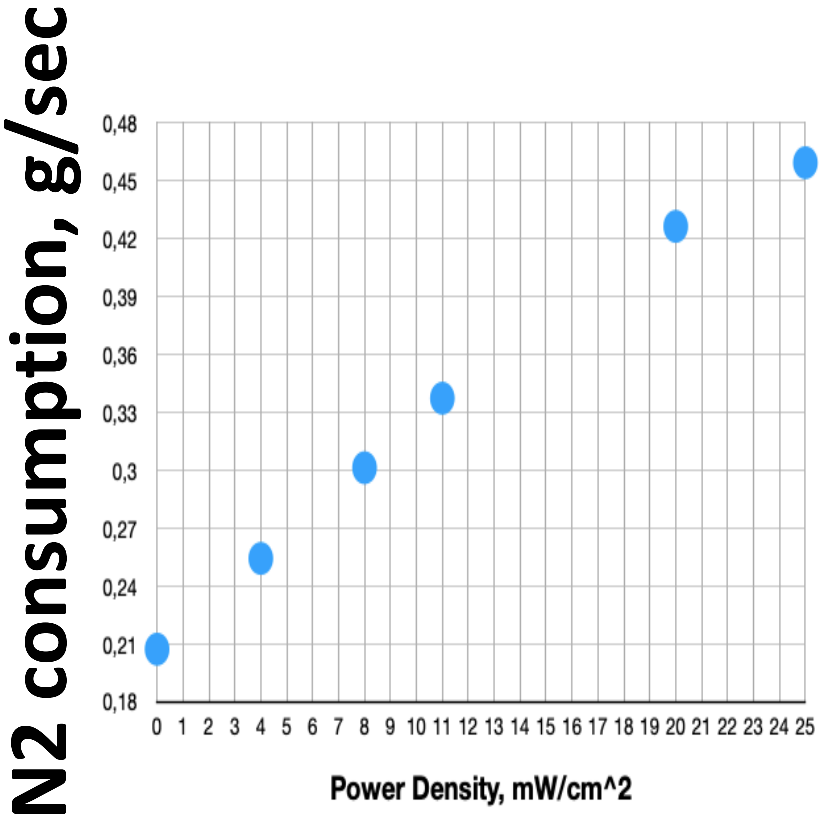
Density of power is the same for each layer.

Temperature of the beam pipe is ~ +5° C

3 layers

blowing from one side

Nitrogen consumption vs. density of power for mock-up of 3 silicon cylinder layers



- at 25 mW/cm^2 the nitrogen consumption is ~1653g/hour

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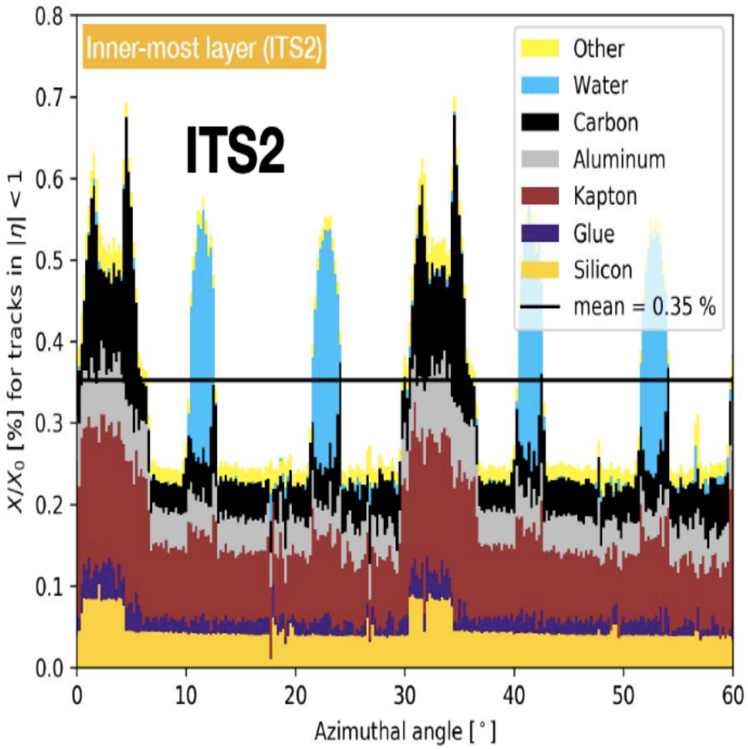
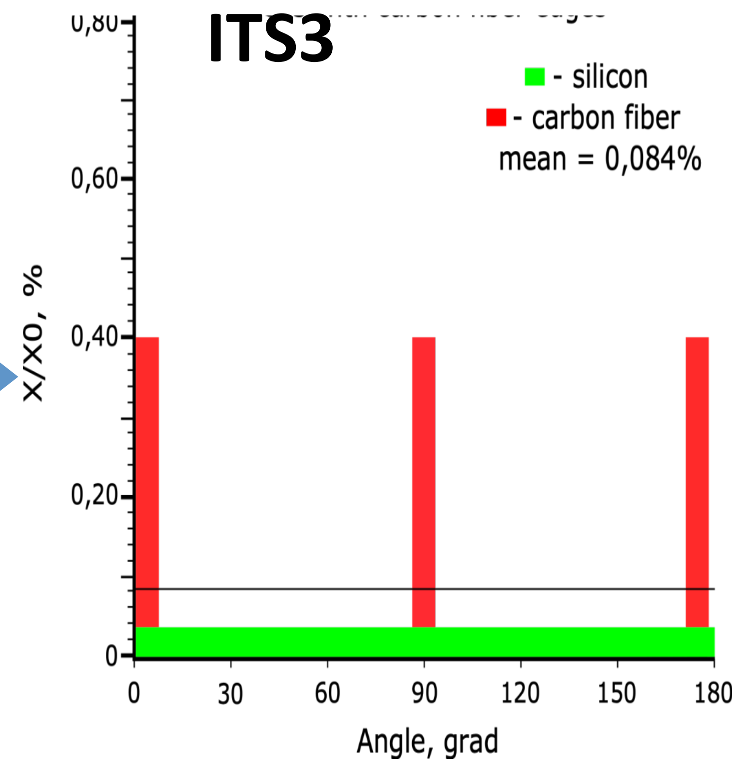
Radiation transparent design of ITS 3 layer with bent Si sensors and carbon fiber longerons





- ➢Red spikes in the right are due to the CF longerons (Note different scale in X axis)
- ➢The thickness of CF V-shaped longerons might be decreased by applying the high stiffness, high tensile strength and low weight THORNEL X1100 or TORAYCA® T1100G (Tensile Strength ~7,000 Mpa)

Conclusions

- Feasibilty of the concept of self-supported ITS 3 modules with bent Si- sensors positioned inside carbon fiber composite cradle is tested using the mechanical and low speed cols gas cooling mock-ups
- Th ultraligthweight self-supported mechanics for ALICE ITS-3 modules is based on the ITS 1 and ITS 2 carbon fiber ALICE technology
- New technological exercises were successfully performed for production of CF composite semi-rings and CF longerons, using available carbon fiber.
- Thickness of CF V-shaped longerons, holding the bent-Si sensors and the outer shell, might be further decreased.
- All ITS 3 LO, L1 and L2 modules and the outer space blanket thermal shell are self supported.
- Self-supported mechanics may allow to use, before the overall ITS 3 assembly, the individual operations for mounting and characterization of each LO, L1 and L2 modules of bent MAPS sensors.
- The overall ITS 3 assembly/disassembly will not require any gluing/ungluing of modules.
- The performance of low-speed gas (nitrogen)cooling of the full scale mock-up of three layers of the ITS 3 was demonstrated.
- Further work is planned for optimization of distribution of low-speed gas (nitrogen) flow between layers.

Thank you for your attention!

Assembling of mechanical mock-up of ITS-3

We use a fiberglass plate as a suitable mock-up of silicon thin sensors. The stiffness was estimated to be similar to ~30μ Si plate.