"Conceptual ideas of ultra-ligthweight self-supported mechanics and cold gas cooling for ITS 3 , recent prototyping and thermomechanical tests, perspectives for application in ALICE 3 design. "

G. Feofilov, S. Igolkin, N. Maltsev, V. Zherebchevsky,

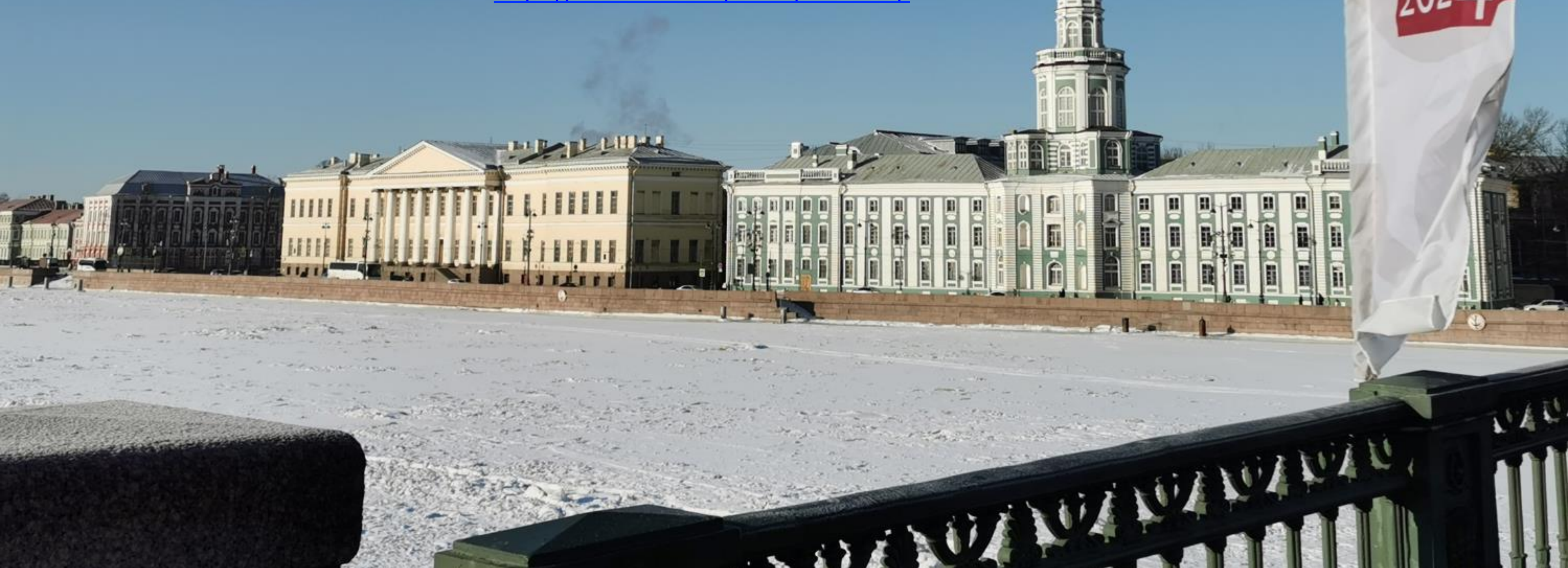
Saint-Petersburg State University

Reported by G.Feofilov

ITS-upgrade WP5 meeting, 16 Aprilr 2024,

Tuesday Apr 16, 2024, 4:00 PM → 5:00 PM Europe/Zurich

https://indico.cern.ch/event/1405488/



Layout

Introduction

Conceptual ideas for ITS-3

1) General layout of ultra lightweight self-supported mechanics
2) Cold gas cooling of self-supported ITS 3 modules
3) CTE compatibility for Si and CF -? Small samples
4) Non-uniform + uniform power generation on Si-sensor
5) CTE compatibility for Si and CF -? Large samples

Some conceptual ideas for ALICE 3

Conclusions

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 ($O(30 \times 30)$ μm^2).

- Power: 20 mW/cm^2 in active area
- >140 mW/cm^2 in periphery side
- Challenges: extremely low material budget
- thermo-mechanical stability
- Possible Assembly/disassembly procedure

[1] ALICE-PUBLIC-2018-013

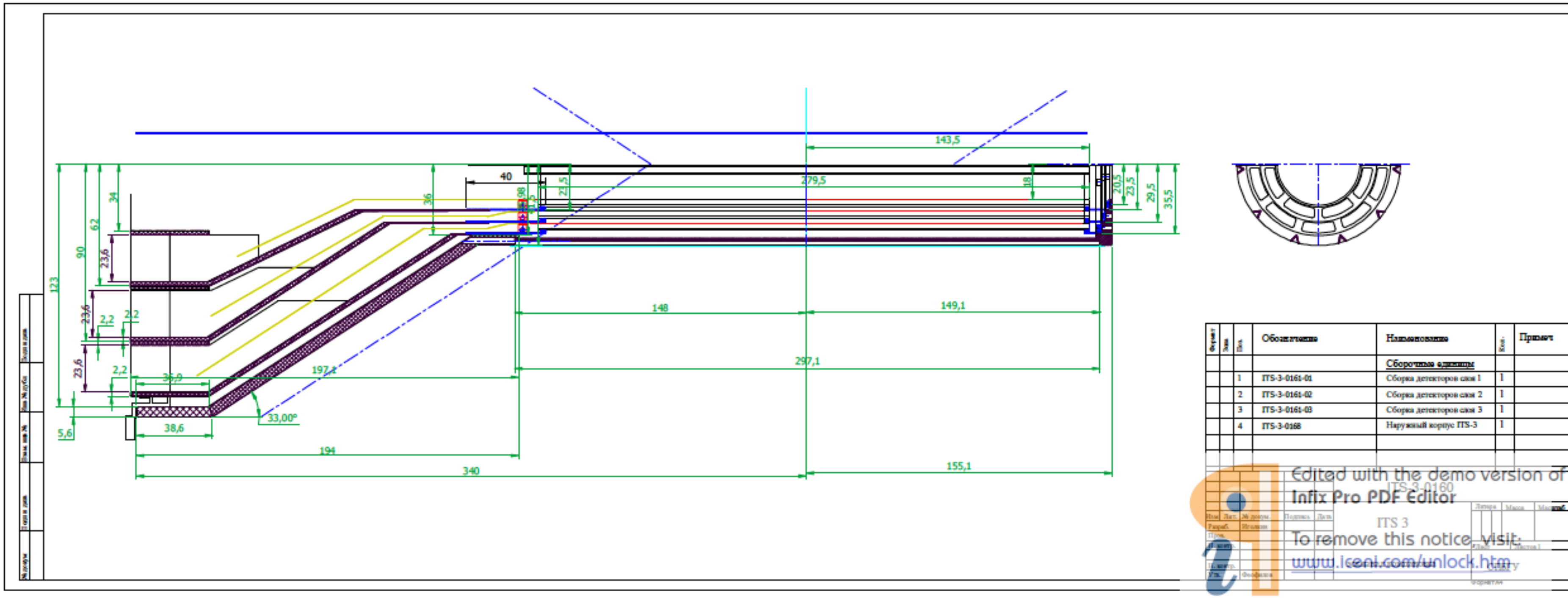
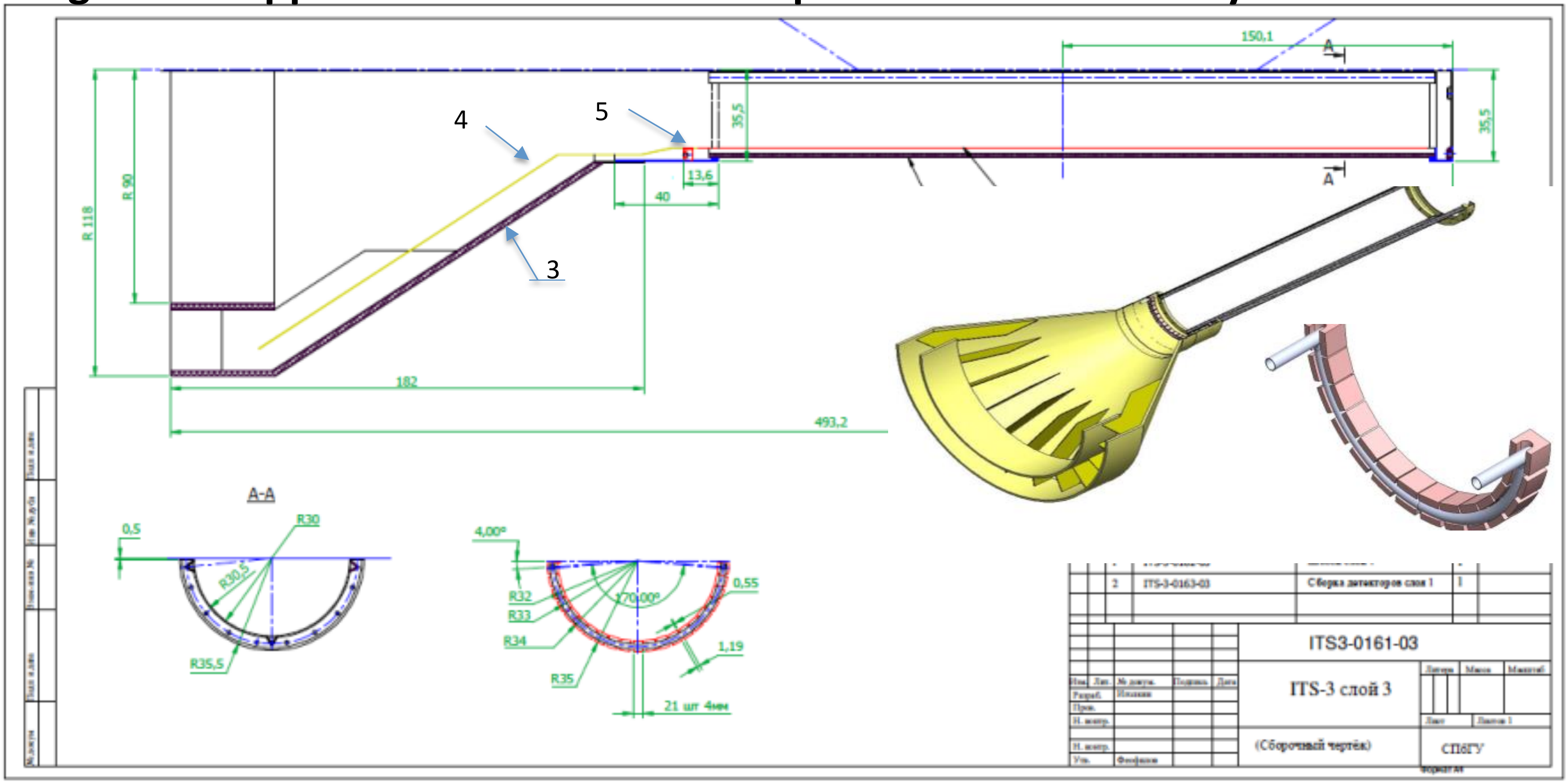


Fig. General layout of one half of the ITS3 assembly (Drawing ITS-3-0160)

- The design consists of three coaxially located, self supported half layers of detectors, each layer mounted on a common chassis. A design feature is the use of longitudinal Carbon Fiber (CF) beams of a triangular profile to connect the left and right parts of the chassis. The latter is fixed in the left, A-Side, to the **carbon sandwich composite support half cone** thus forming a half layer independent unit.
- Each carbon sandwich composite support half cone of the A-Side is housing the pipe for the liquid cooling of the peripheral digital sensor electronics, the manifold for low-speed cold gas sensor cooling, the FPCs, and, possibly, the DC-DC converters. (C-side analog & digital power FPCs are not shown here.)
- The external supporting CF chassis has a shell made of thin polyimide film (space blanket), which allows the ITS 3 detector part to be isolated from external thermal influences.

Single self-supported module with bent pixel Si-sensor of L2 layer of the ITS 3

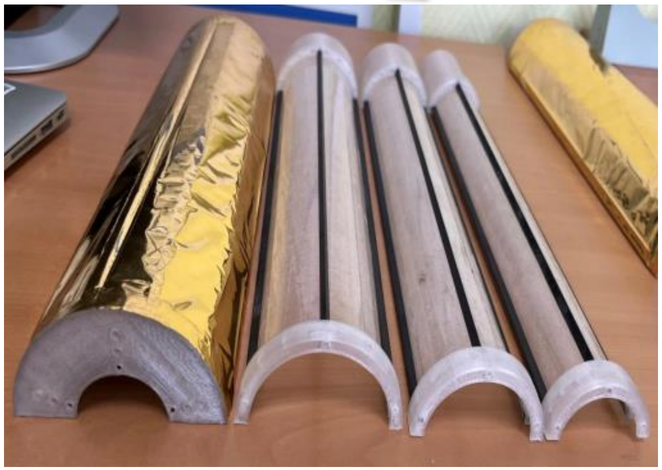


- ➢ The design consists of a CF chassis (position 1), on which a silicon pixel sensor (position 2) is mounted
- ➢ The CF chassis is rigidly fixed to the **carbon sandwich composite support half cone** (position 3)
- ➢ **The support half cone** is equipped with the FPCs (position 4) for power supply and readout. The peripherial electronics area (position 5) is cooled by liquid. The low-speed cold gas is used for sensor cooling. (The DC-DC converters and C-side analog & digital power FPCs are not shown here.)
- ➢ A similar design is used for the layers L0 and L1.

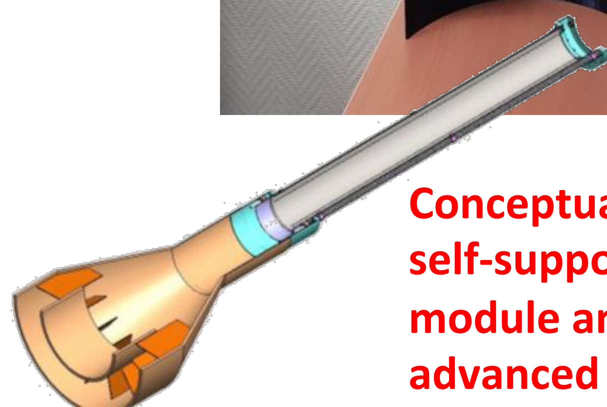
The 1st mechanical mock-up of ITS-3

A fiberglass plate as a suitable substitute of silicon thin sensors was used.
The stiffness was estimated to be similar to ~30μ Si plate.

October 2022



New
September 2023

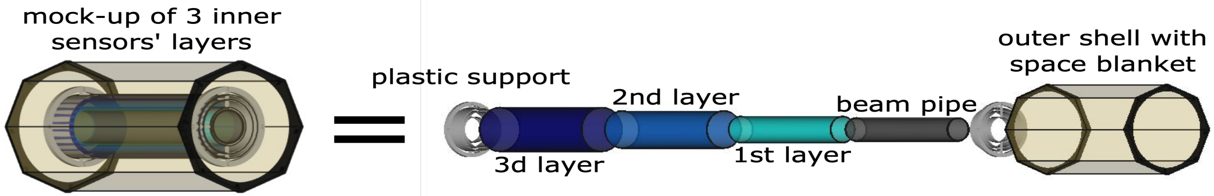


Conceptual design of self-supported module and advanced mock-up with bent Si

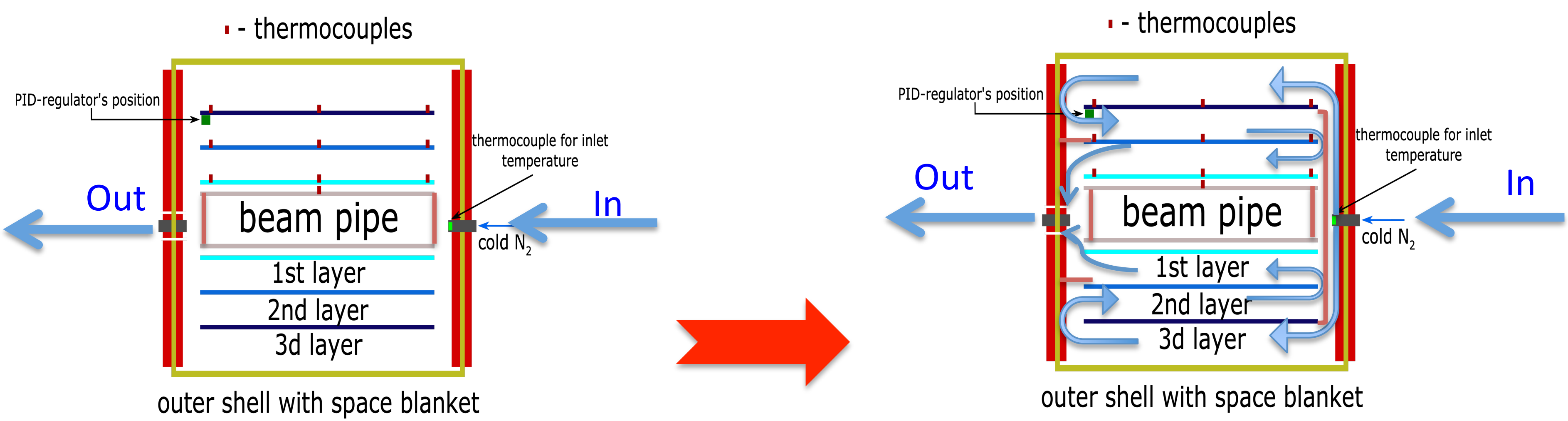
Tests were performed at CERN

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

Cold gas cooling of self-supported ITS 3 modules



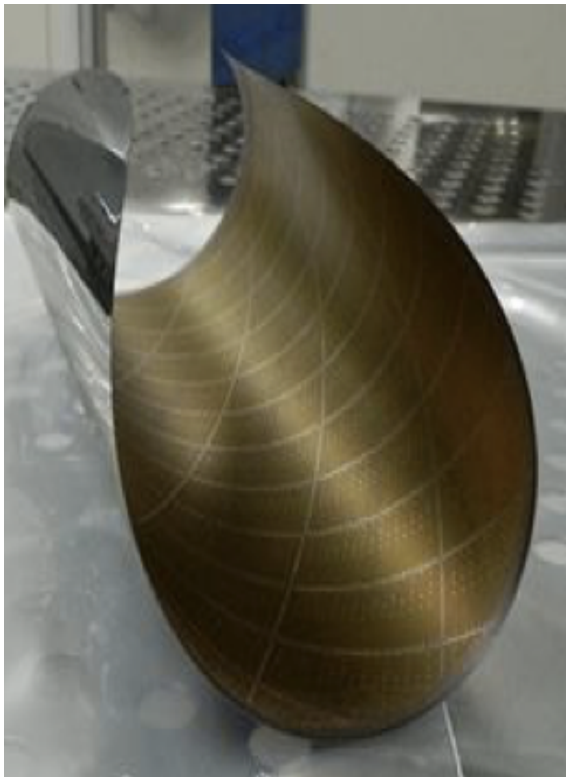
Scheme of cooling system with mock-up of 3 silicon cylinder layers and outer shell with space blanket (in dimensions of the Table 1, slide 3)



- Better uniformity of the temperature field may be achieved by special flow distribution manifolds

CTE compatibility for Si and CF -?
Small samples

CTE compatibility for Si and CF -?



Bent Si-plate

(A)

(B

Photos of end-view (A) and side views (B)of extra-lightweight trihedral CF longerons

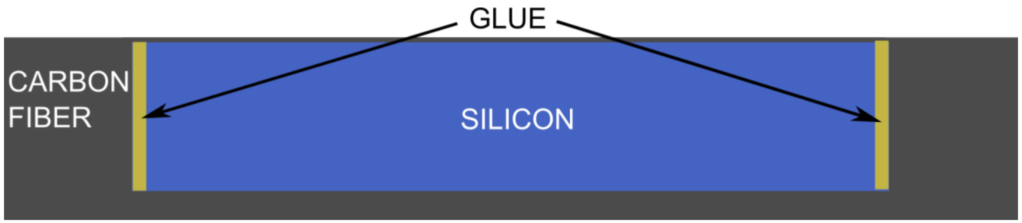
CTE Si =

Si sensor CTE = (2.6–3.3) x 10^{-6}/K^{-1}

And up to 5.1 x 10^{-6}/K^{-}

CF composite *CTE* =from ~ 0 to −0.64 × 10^{-6}/°K

SAMPLE № 3



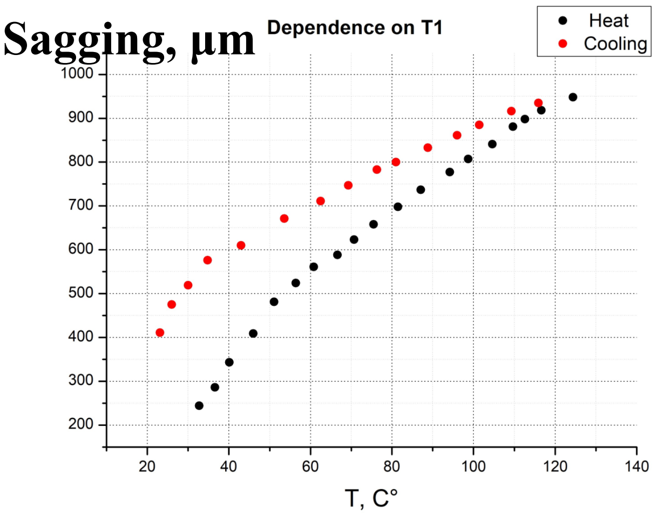
Gluing scheme

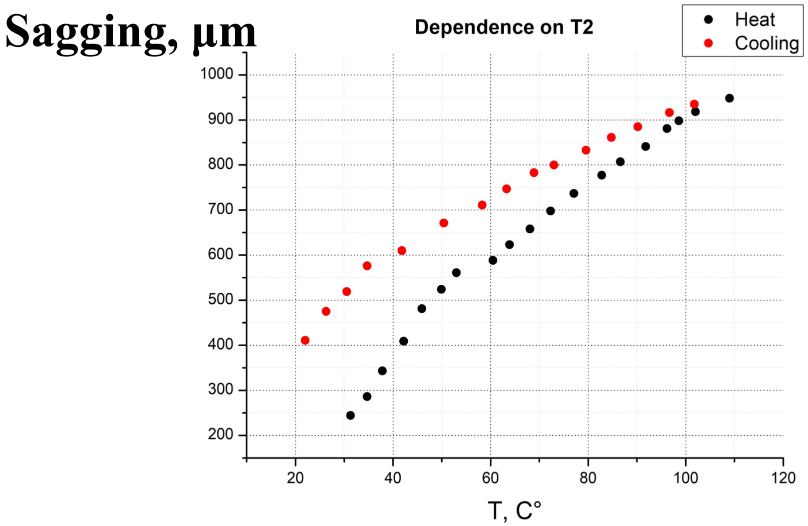
Silicon 22 mm wide, glued to a carbon fiber substrate 150 mm long, 27 mm wide and 0.8 mm thick. Epoxy adhesive ED-20 with hardener Etal-45M was applied in the form of strips 2 mm wide on the edges of the silicon wafer, the distance between the glues was 95 mm.

ITS-upgrade WP5 meeting, 10 October 2023, 16300 → 17:00 Europe/Zurich
https://indico.cern.ch/event/1334873/

Thermal measurements

The distributions along the Y axis show the deflection of the silicon wafer when it is heated. Along the X axis is the temperature at the entrance to the installation - thermocouple T1 and the temperature at the outlet of the experimental installation. The measurements were carried out when heated to 120-130 °C (black circles - Heat), and then immediately when the sample was cooled down (red circles - Cooling)





The conclusions here:

- **When heated, flat silicon plate bends almost linearly**
- **After considerable heating, the following cooling process generates Hysteresis in sagging of silicon plate.**
- **Important: Si plate does not break in these temperature variations with 8 cm distance between gluing point!**

ITS-upgrade WP5 meeting, 10 October 2023, 16300 → 17:00 Europe/Zurich

https://indico.cern.ch/event/1334873/

New!

Non-uniform + uniform power generation on Si-sensor

New: non-uniform + uniform power generation on Si-sensor (current ALICE specifications)

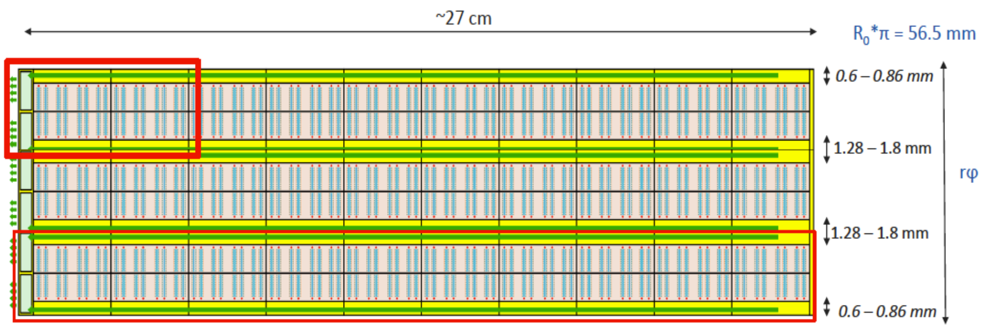
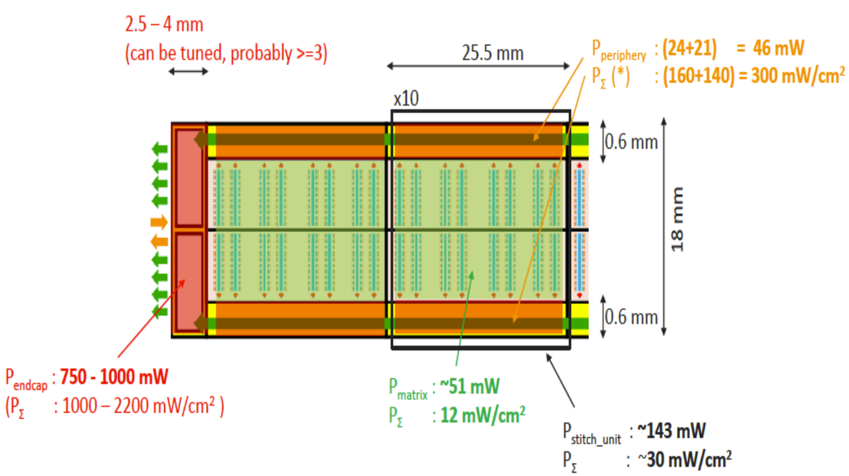
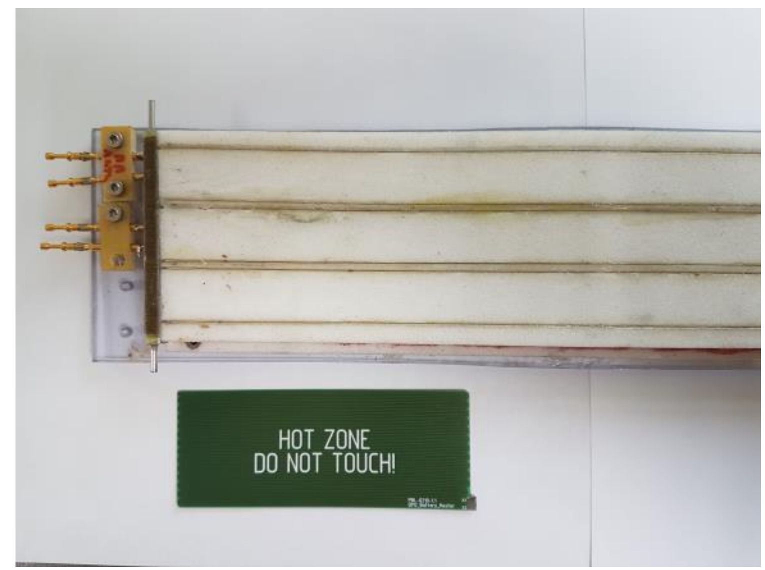


Fig.1. Layout of Half Layer 0 Sensor of the ITS 3
(see in https://indico.cern.ch/event/1253461/)

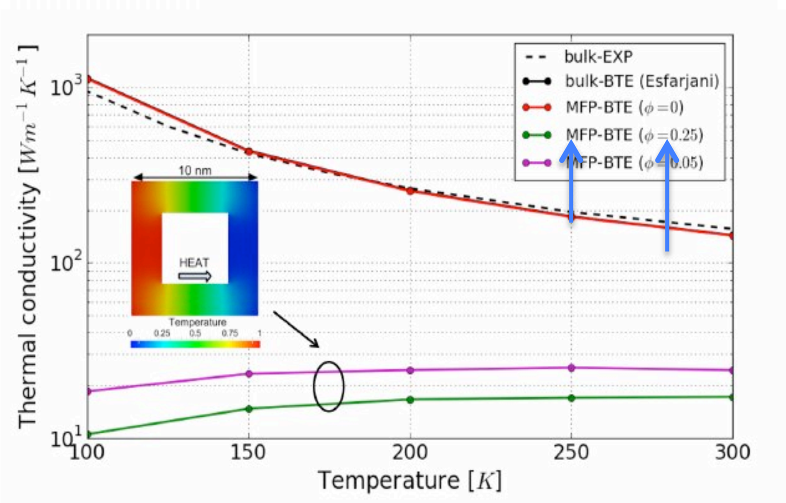




- Test sample No.1 was prepared
- Temperature maps registration
- Thermal conductivity of **Silicon** is **148** W/(m·K) at 273 K (0 °C).
- For Aluminium : 235W/(m·K)

Thermal conductivity of bulk Si at different temperatures

The thermal conductivity for different temperatures of bulk Si and np-Si. For bulk Si, the experimental data, 14 bulk-BTE and MFP-BTE calculations are shown and agree with [1]



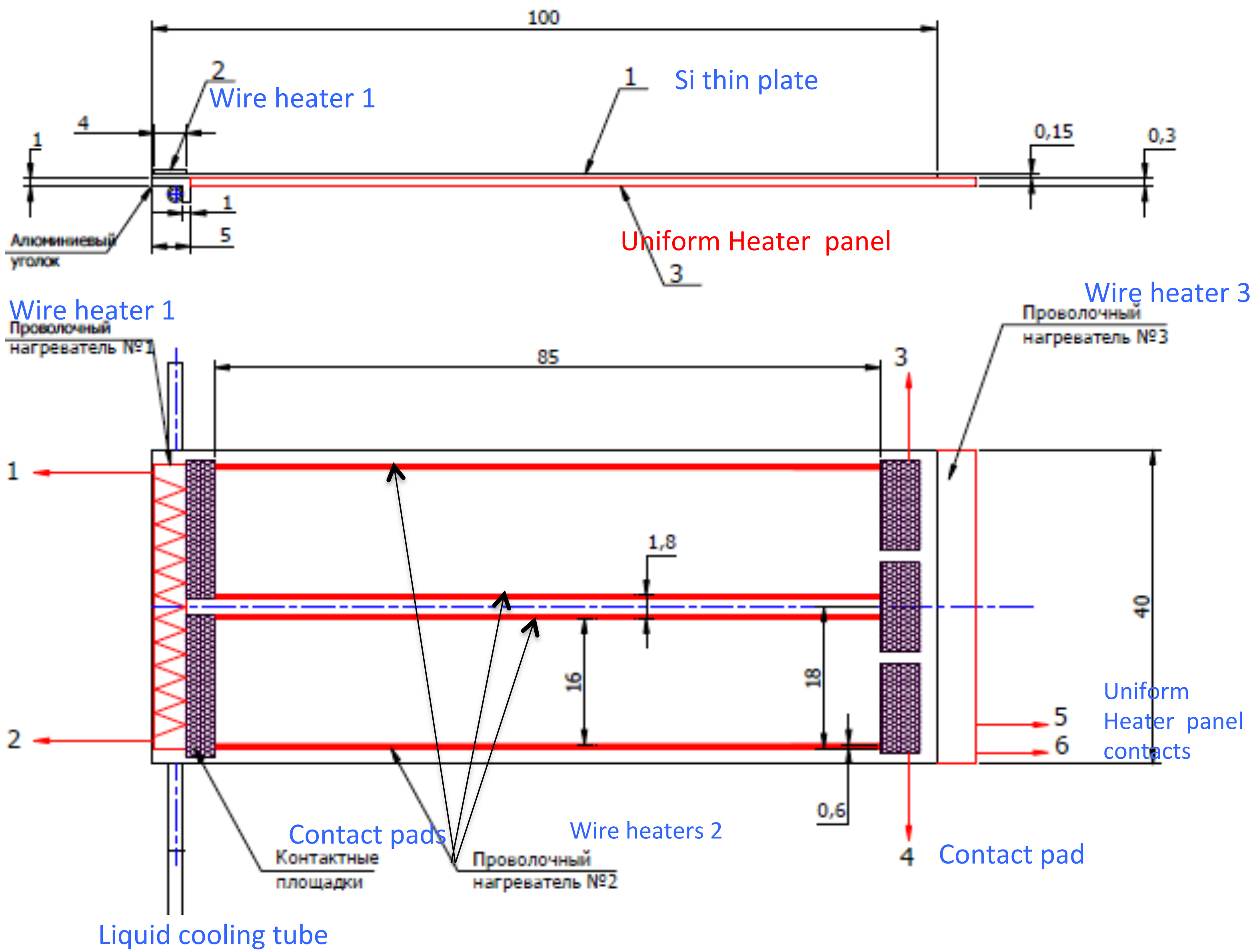
- At 273 ºK (**0.15 ºC)** Thermal conductivity of **Silicon** is **148** W/(m·K).
- At 250 ºK= **-23.15 (ºC)** Thermal conductivity of **Silicon** is **200**W/(m·K).

Compare to Aluminium : 235 W/(m·K)

- Uniform temperature field over Si-plate is expected for non-uniform heat loads

[1] https://www.researchgate.net/publication/277144799_Temperature-dependent_thermal_conductivity_in_nanoporous_materials_studied_by_the_Boltzmann_Transport_Equation/figures?lo=1

Test sample No.2 for non-uniform heat loads



Test sample No.2 for non-uniform heat loads

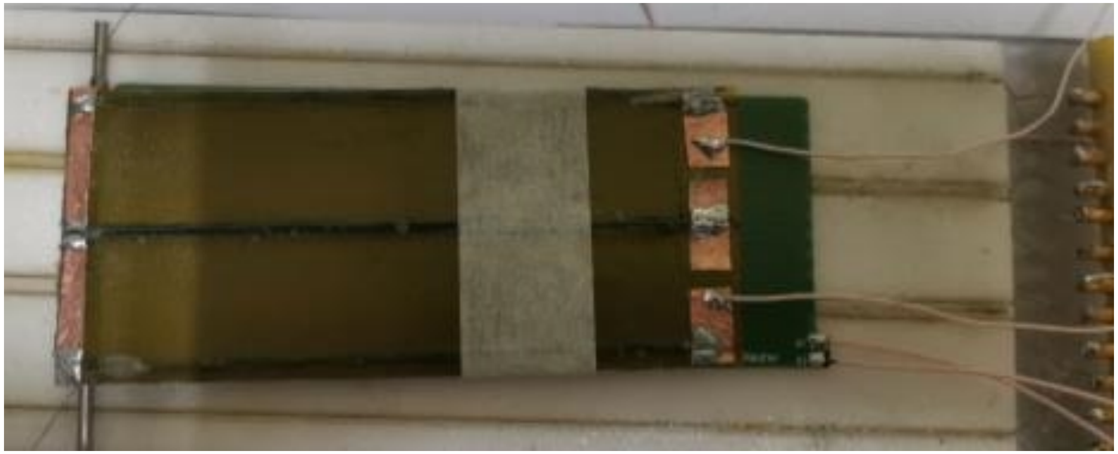


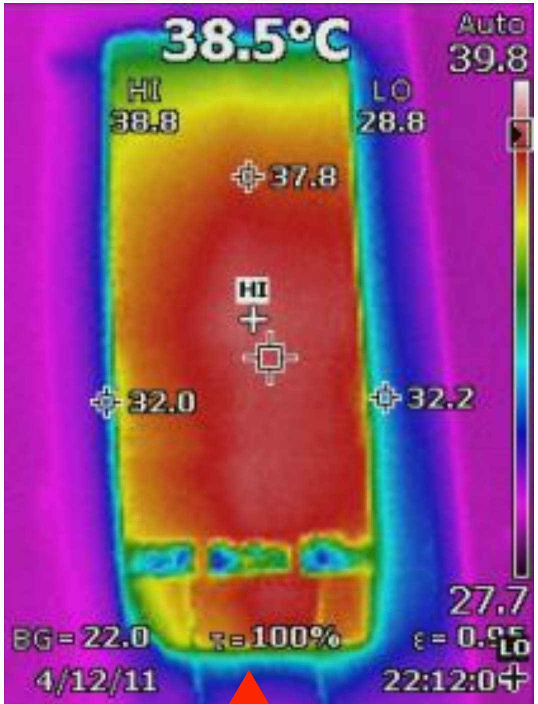
Photo shows a silicon wafer encapsulated in polyamide (to impart plasticity and prevent breakage) and glued to a general heating board.

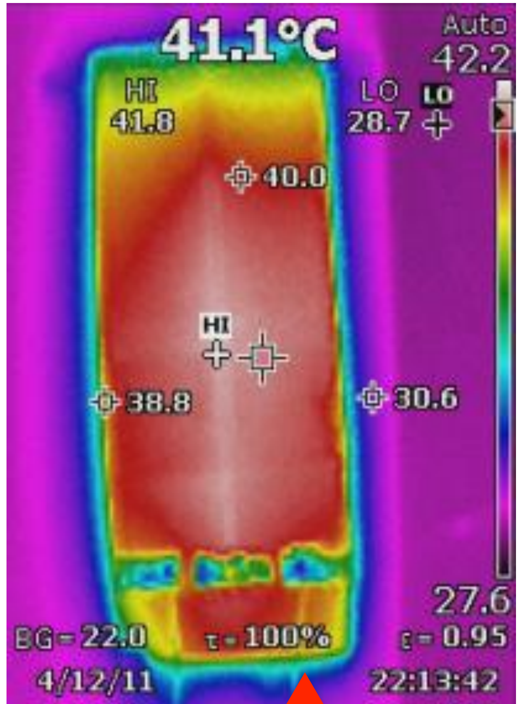
- **Longitudinal heaters(the length is 8.5 cm) were mounted on the silicon wafer. Two single heaters (one nichrome conductor) run along the edges of the wafer, we consider it 0.6 mm wide. Thus, one such heater has an area of 8.5 cm x 0.06 cm = 0.51 cm^2.**
- **There is a double heater (two nichrome conductors) in the center , they are 1.2 mm wide. The area of such a heater is: 8.5 cm x 0.12 cm = 1.02 cm^2. The total area of the longitudinal heaters is 2.04 cm^2.**
- **As a result of the supply of current to the longitudinal heaters, thermal power was generated:**

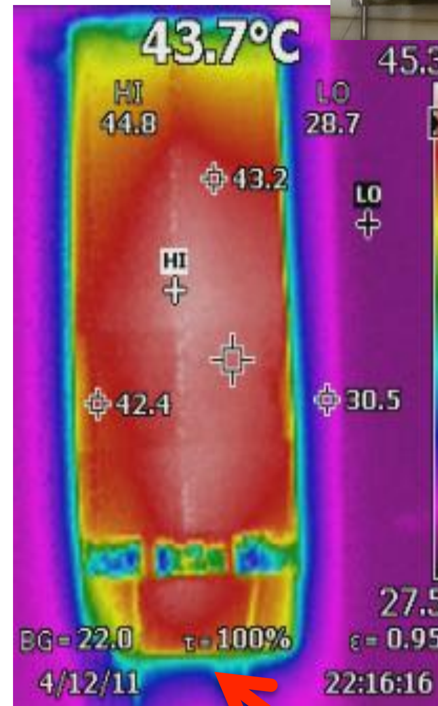
---60 mW/cm^2 (the total power of 122 mW) and

---120 mW/cm^2 (the total power of 245 mW).

Test sample No.2 for non-uniform heat loads







Conclusion: non-uniform (localized) thermal loads are averaged due to the high thermal conductivity of silicon

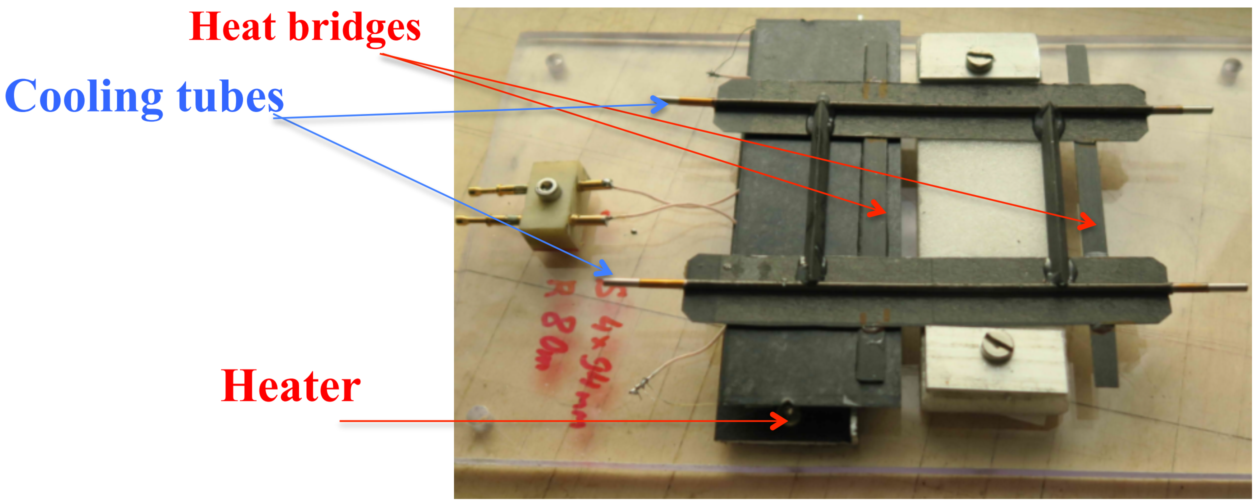
Thermal imaging of a silicon wafer with a power density on the flat heater (board) of 20 mW/cm2, while on the longitudinal heaters 60 mW/cm2

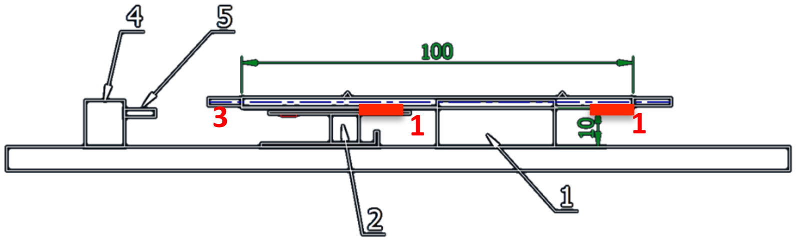
Thermal imaging of a silicon wafer at a power on the flat heater (board) of 20 mW/cm2, while at the longitudinal heaters 120 mW/cm2. To assess possible local heating in the area of the longitudinal heaters, the power on them was doubled.

Thermal imaging of a silicon wafer with a power density on the flat heater (board) of 25 mW/cm2, while on the longitudinal heaters 120 mW/cm2

New cooling set-up for heat bridges for ALICE 3

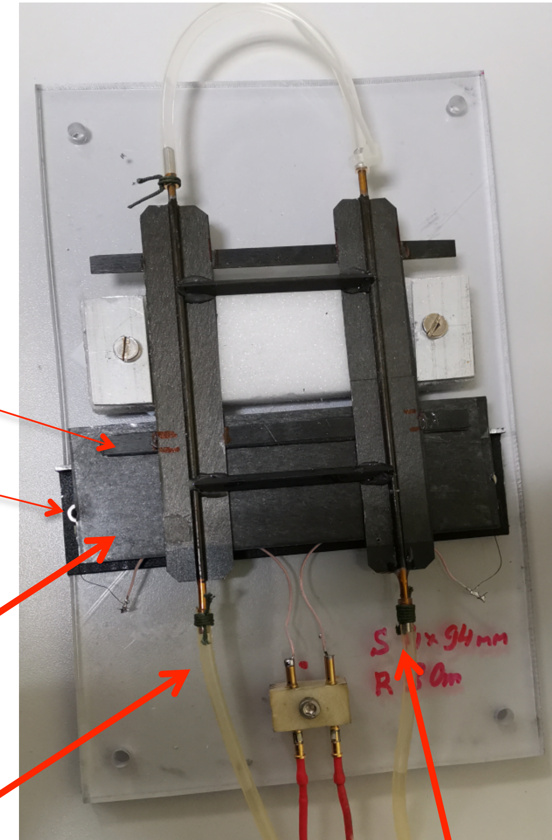
New!





1- Heat bridges
2. Heater
3. CF cooling panel with tubes
4,5 – contact pad for heater

New cooling set-up for heat bridges for ALICE 3



Heat bridge

Heater

Test panel

Small diameter (2mm) cooling tubes are connected to the chiller

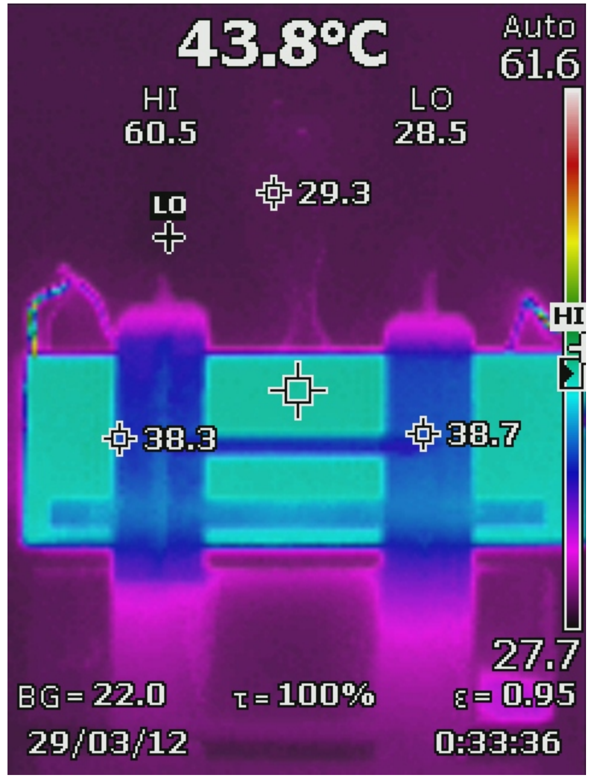
New cooling set-up for heat bridges for ALICE 3

TESTS:

1) No heating, no cooling supply

Heater +test plate

2) Heating, no cooling supply



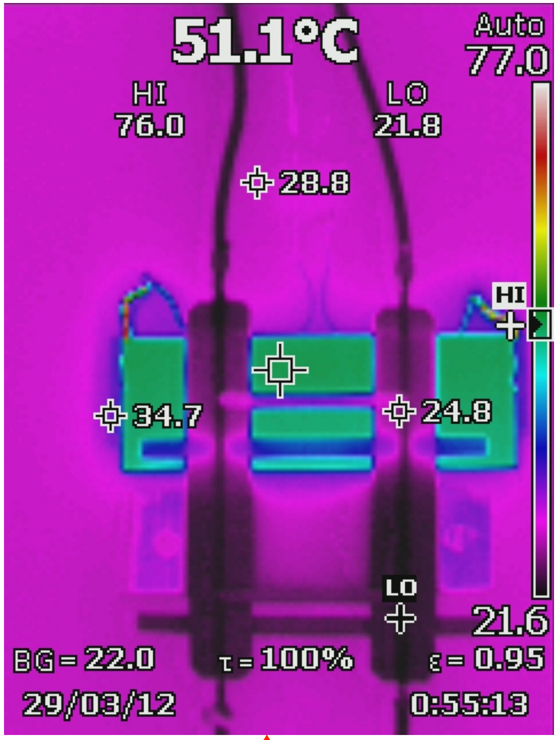
After 8 min.

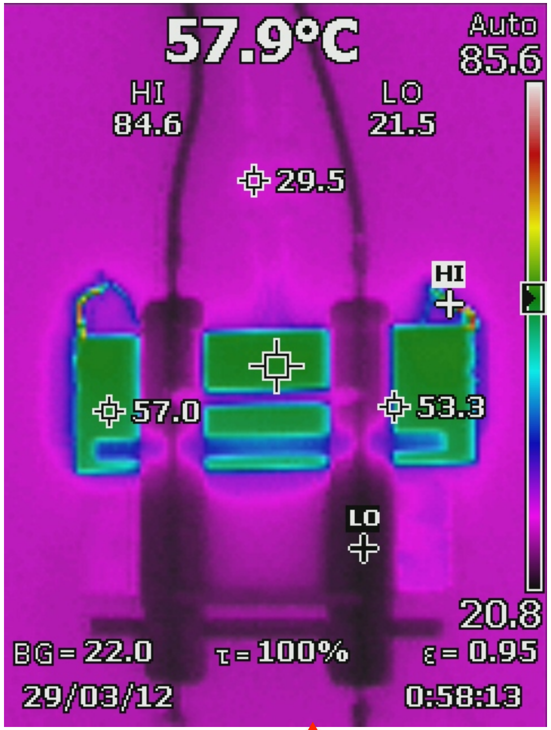
The heater power is 2.9 W
The power density is 0.8 W/cm^2

New cooling set-up for heat bridges for ALICE 3

TESTS:

3) Heating + cooling supply





The heater power is 2.9 W.
The power density is 0.8 W/cm^2

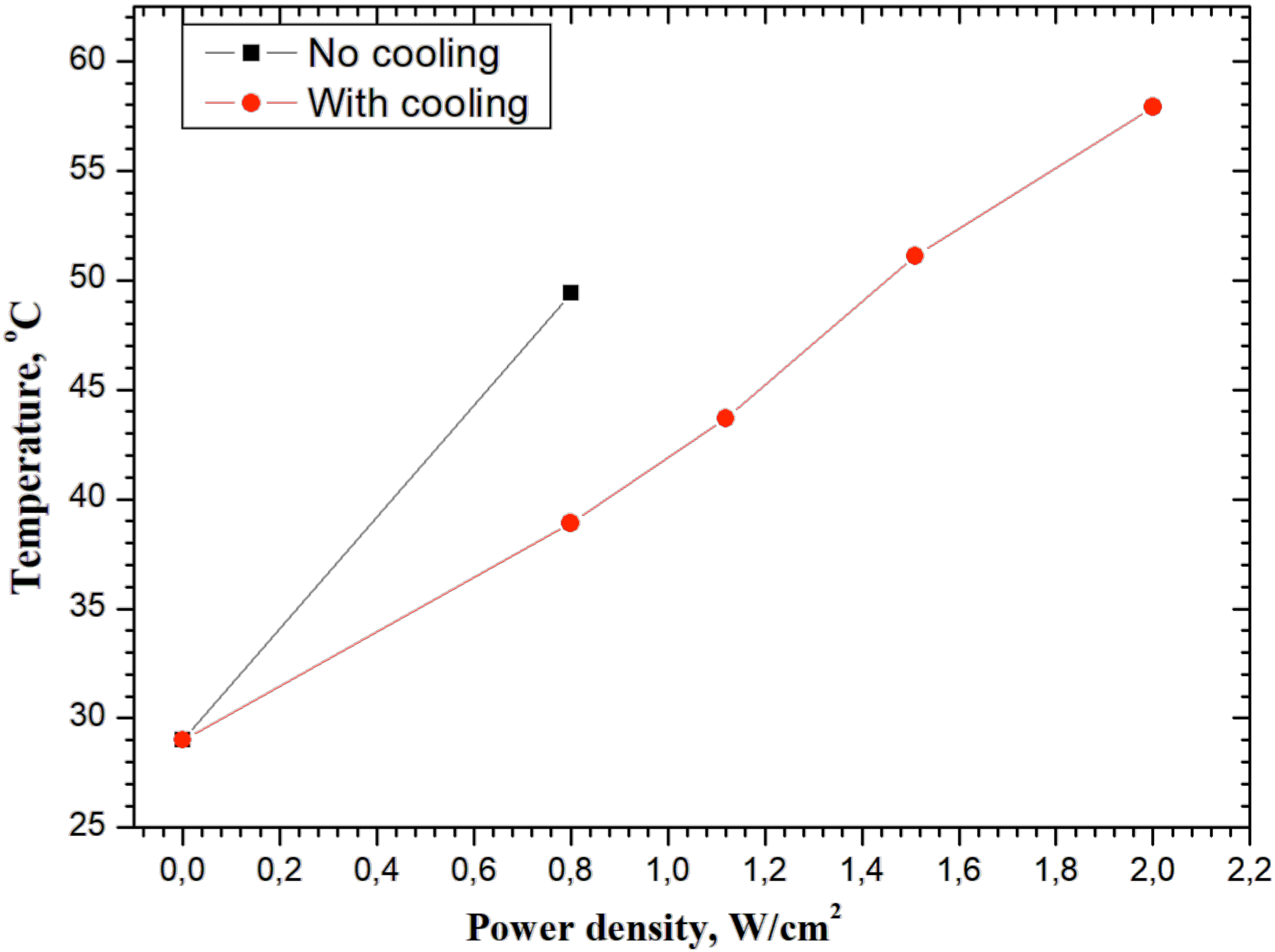
The heater power is 5.7 W.
The power density is 1.51 W/cm^2

The heater power is 7.5 W.
The power density is 2.0 W/cm^2

New cooling set-up for heat bridges for ALICE 3

3) Heating + cooling supply

Temperature on the Test panel vs. power density



New!

CTE compatibility for Si and CF -?
Large samples & Conceptual ideas for ALICE 3

ITS-3 pixel Layer 2 flat sensor 280x94 mm^2 as a possible solution for the future ALICE 3

Diagram of stitched sensors of Layer 2 module (horizontal and vertical dimensions are close to scale).[1]

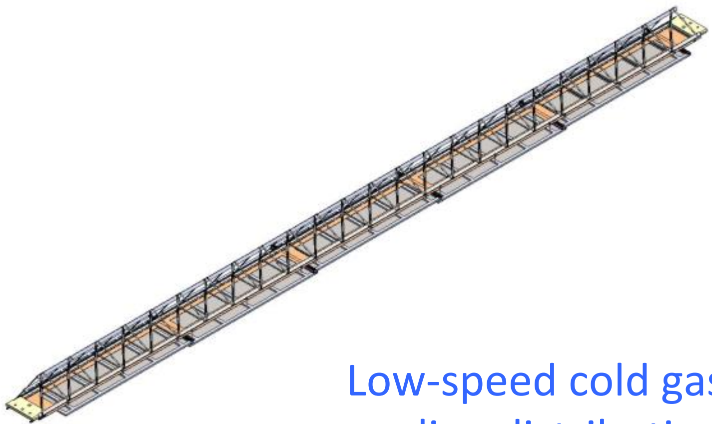
- We consider for the peripheral sensor area the underpressure liquid cooling as the feasible solution for power P_endcap : 750 - 1000 mW

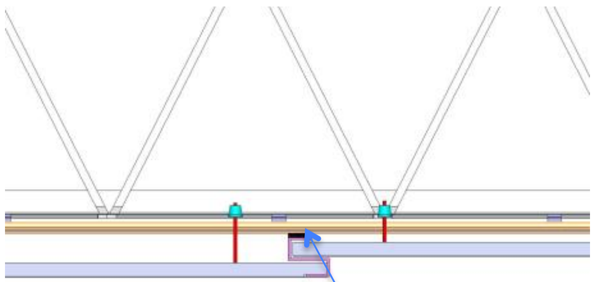
Low-speed cold gas is proposed to cool large area thin pixel sensors in order to minimize vibrations

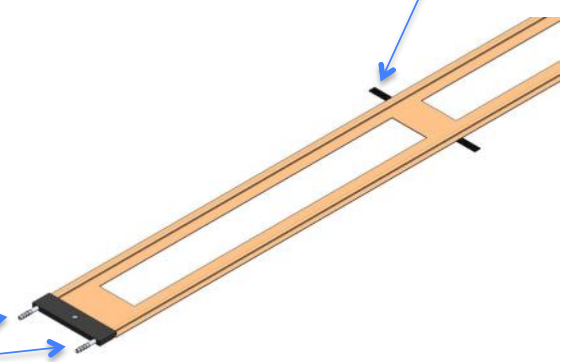
[1] ALICE-PUBLIC-2018-013

New!

Option 1: long ladders composed of 5x2800 mm length modules in tiles

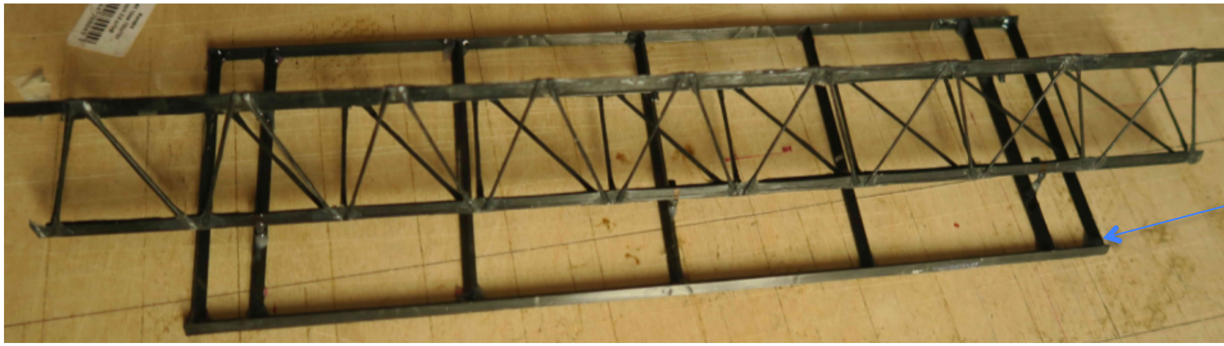


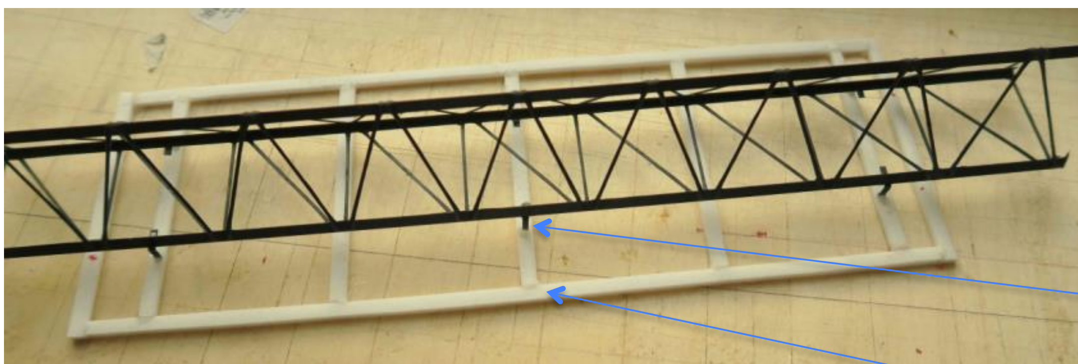


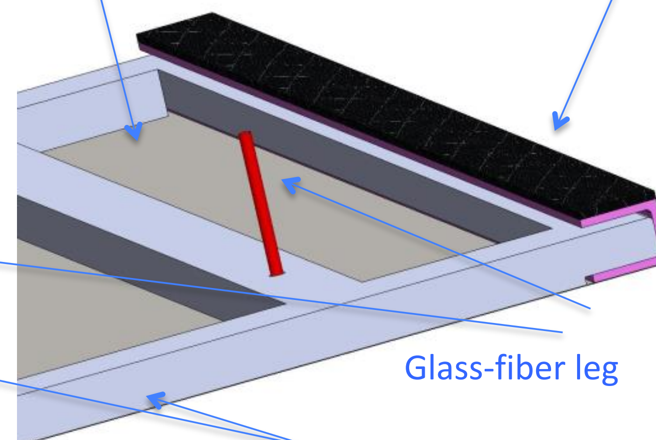


New!

Option 2: individual 2800 mm length module







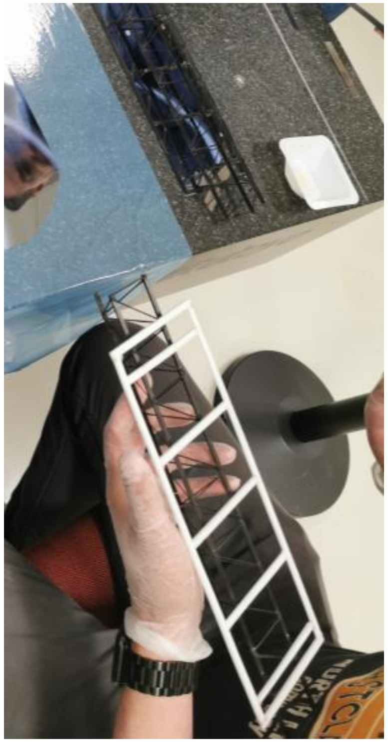
- To be tested at CERN in April together with Si-plates glued
- Thermomechanical stability limits?
- Vibrational (hopefully)

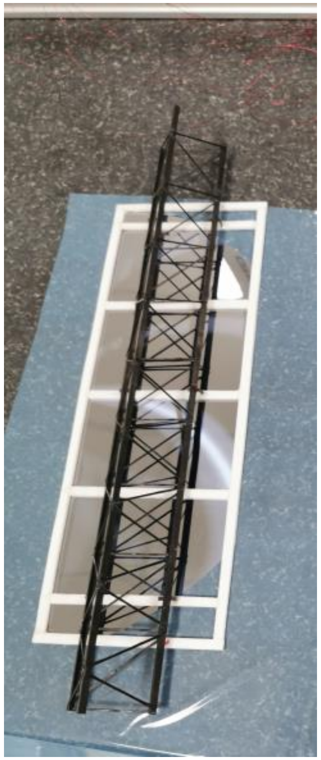
https://www.3accorematerials.com/en/markets-and-products/airex-foam

NB! Airex T92.80 alone CTE = (135 ± 10) 10-6 /K (!?)

New!

Option 2:
individual 2800 mm length module





1) Thin large area 280x94 mm^2 Si-plate is glued (Araldite) to the CF frame. In several dots of glue.

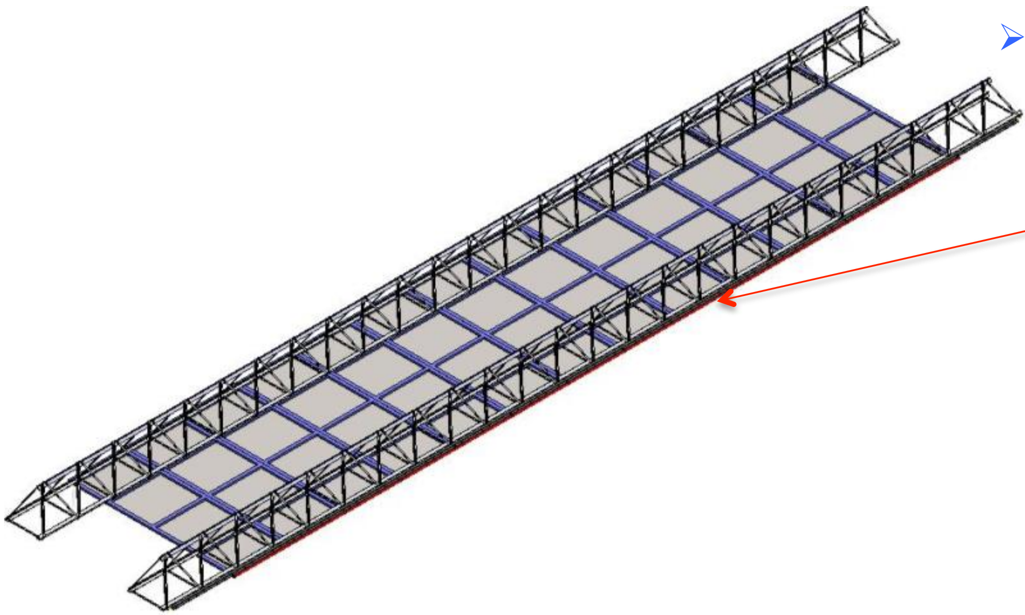
2) Thin large area 280x94 mm^2Si-plate is being glued (Araldite) to the AIREX® foam frame. Thin layer of glue.

3) AIREX® foam frame with large area Si-plate 15.04.2024

New!

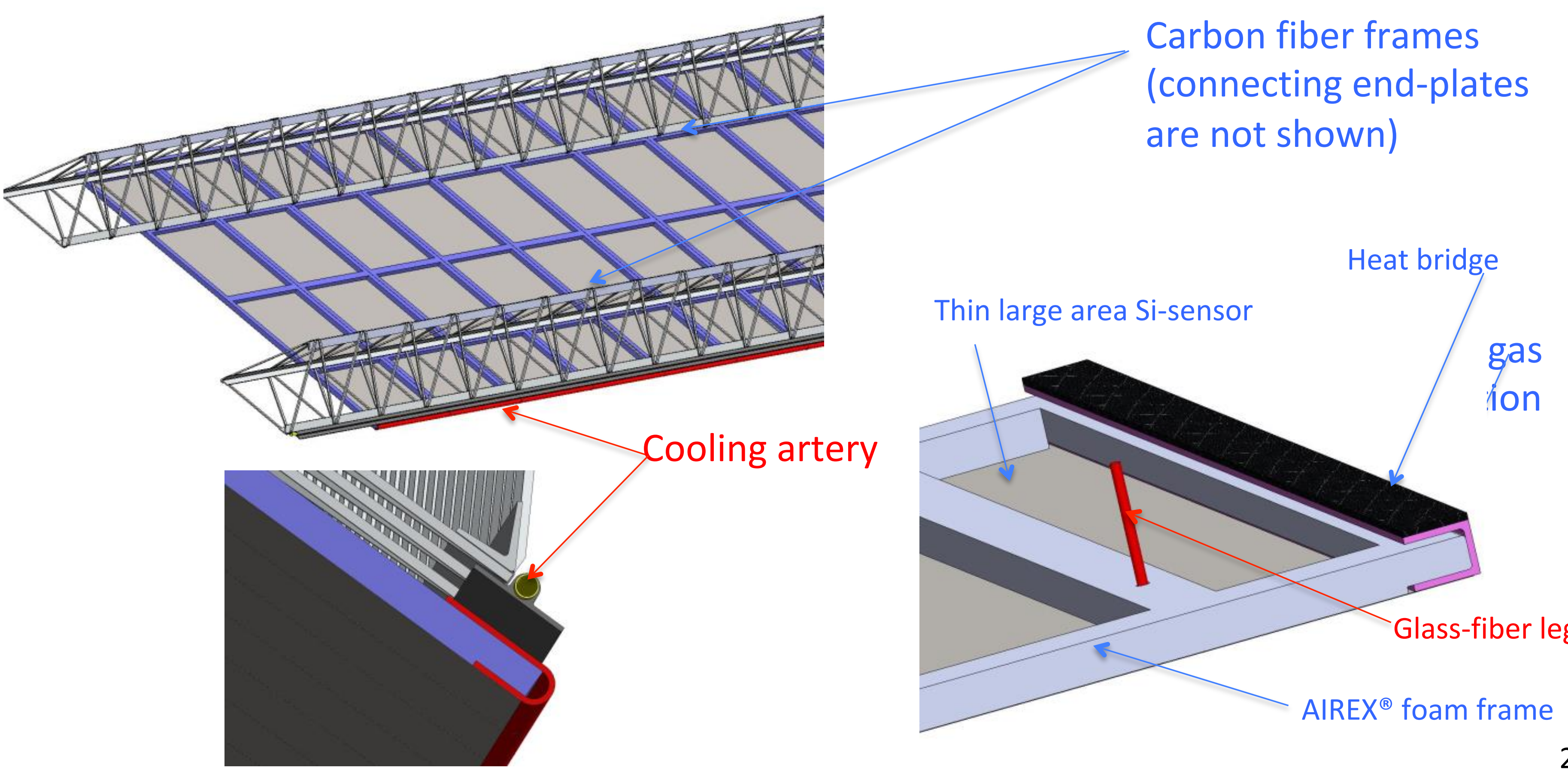
Option 3: perpendicular to cooling artery orientation of 2800 mm length modules

- Support: 2 carbon fiber frames are rigidly connected (end-plates are not shown)
- AIREX® foam frames with Si-sensors are mounted side-by side



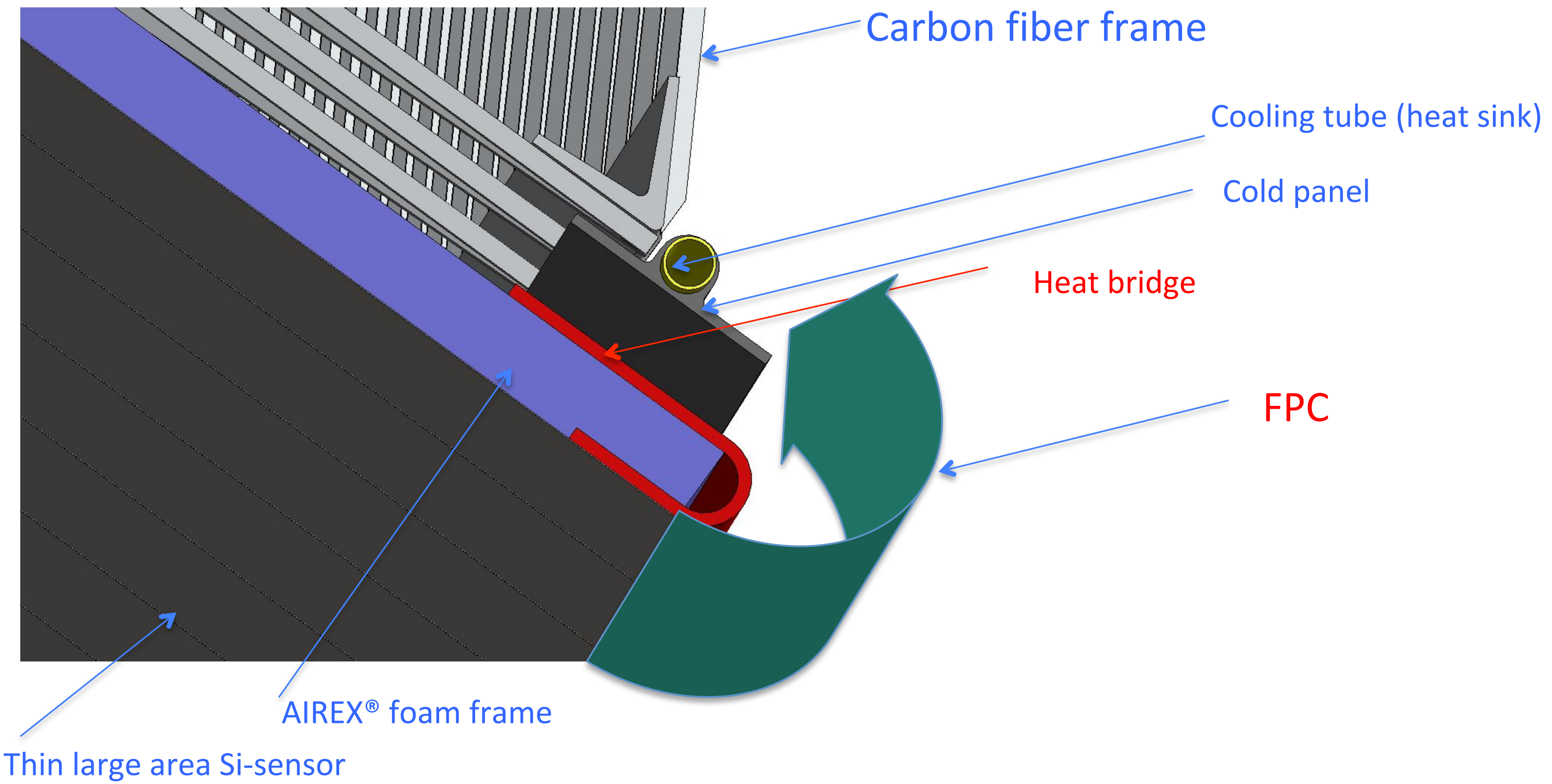
New!

Option 3: perpendicular orientation of 2800 mm length modules



New!

Option 3: perpendicular to cooling artery orientation of 2800 mm length modules

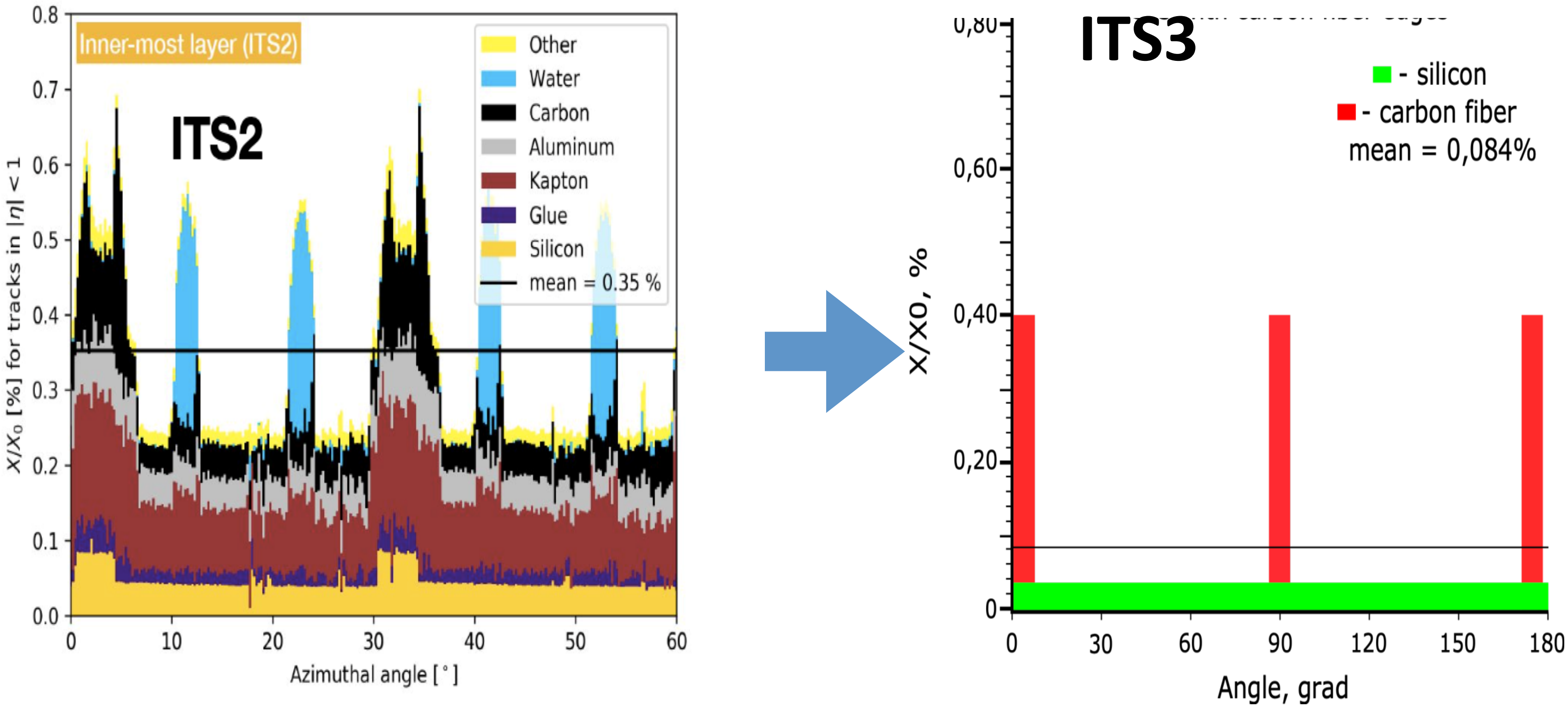


Conclusions

- **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 cold gas cooling mock-ups**
- **The ultra lightweight self-supported mechanics for ALICE ITS-3 modules is based on the ITS 1 and ITS 2 carbon fiber ALICE technology**
- **Concept: 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.**
- **ALICE Internal Technical Note is being prepared.**

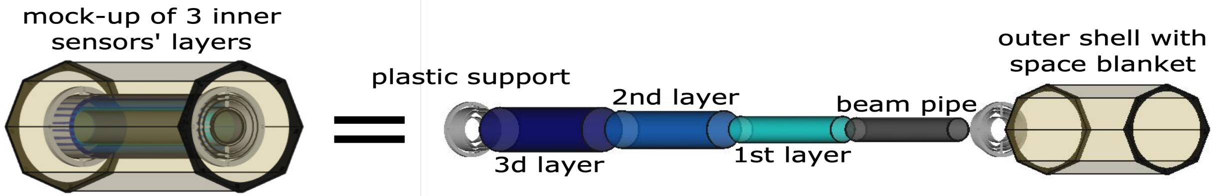
BACK-UP SLIDES

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

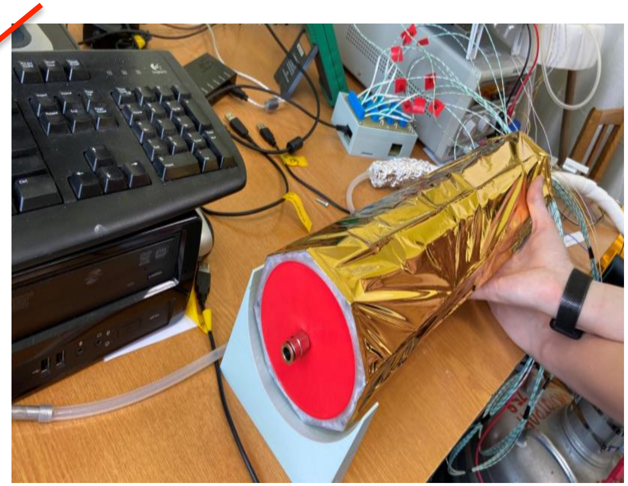


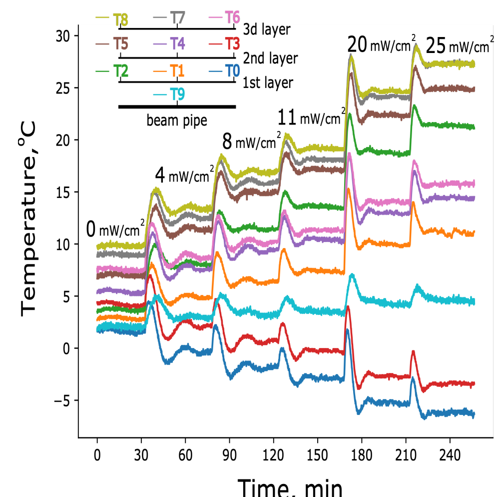
- ➢Red spikes in the right are due to the CF longerons (Note different scale in X axis)
- ➢The thickness of CF V-shaped longerons might be decreased by applying the high stiffness, high tensile strength and low weight THORNEL X1100 or TORAYCA® T1100G (Tensile Strength ~7,000 Mpa)

Cold gas 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)





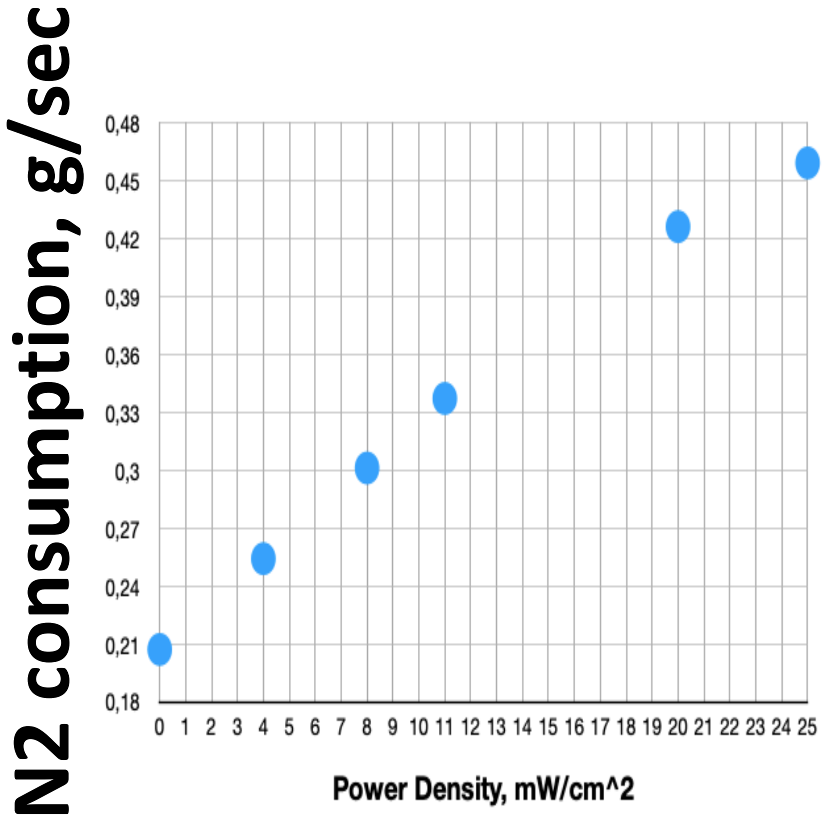
ITS-upgrade WP5 meeting, 10 May 2022
https://indico.cern.ch/event/1158834/

- Encouraging results with fiberglass+wire heaters cylinder layers mock-up
- **Temperature<25 °C for all heat loads**
- **Speed of N_2 gas flow ~0**

3 layers

blowing from one side

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



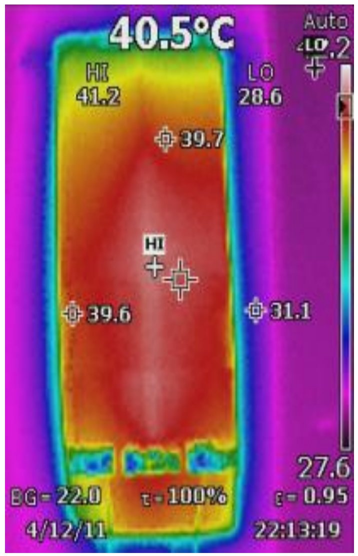
- at 25 mW/cm^2 the nitrogen consumption is ~1653g/hour

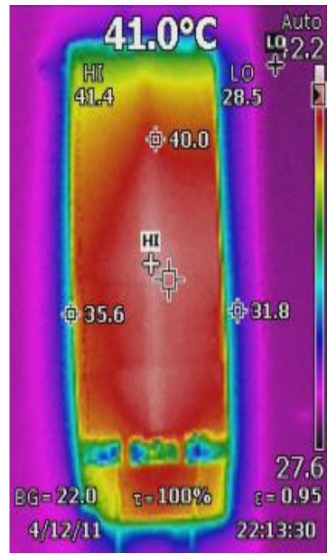
ITS-upgrade WP5 meeting, 10 May 2022, 16:00 → 17:35 Europe/Zurich
https://indico.cern.ch/event/1158834/

35

Test sample No.2 for non-uniform heat loads:

temperature maps under power density on the flat heater (board) of 20 mW/cm2 (total power 800 mW) and longitudinal heaters power density of 120 mW/cm^2 (total power 245 mW).





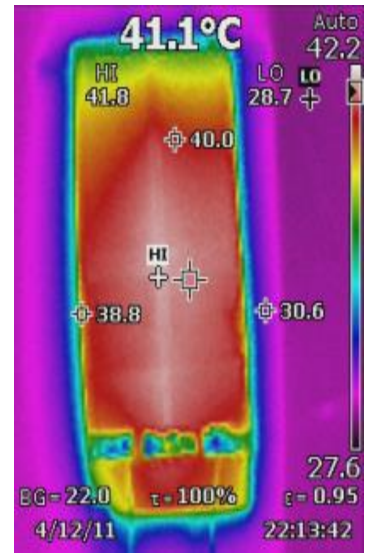
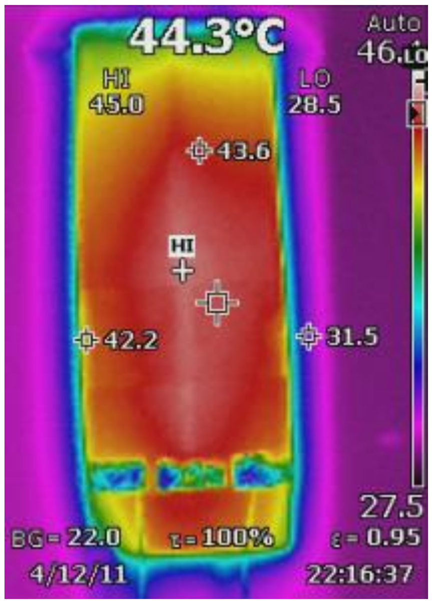
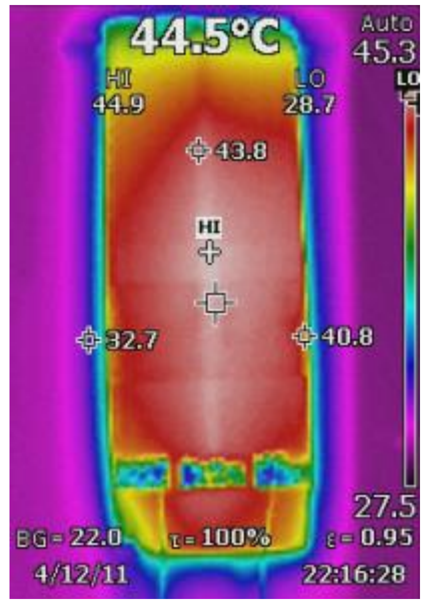


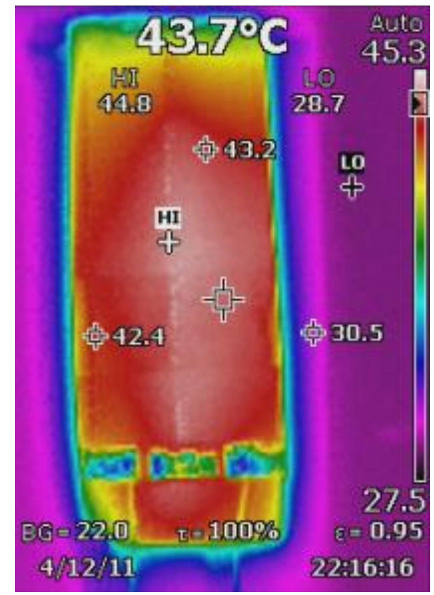
Figure 28 shows thermal imaging images of a silicon wafer at a power on the flat heater (board) of 20 mW/cm2 (total power 800 mW), while at the longitudinal heaters 120 mW/cm2 (total power 245 mW). To assess possible local heating in the area of the longitudinal heaters, the power on them was doubled.

Test sample No.2 for non-uniform heat loads: temperature maps under

power density on the flat heater (board) of 25 mW/cm2 (total power 1000 mW), longitudinal heaters power density of 120 mW/cm^2 (total power 245 mW).







.

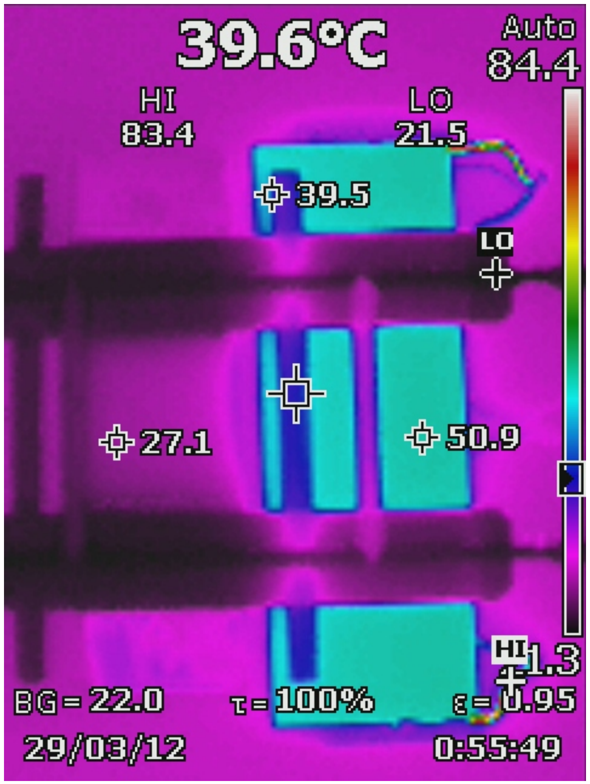
- Conclusion: non-uniform (localized) thermal loads are averaged due to the high thermal conductivity of silicon

New cooling set-up for heat bridges for ALICE 3

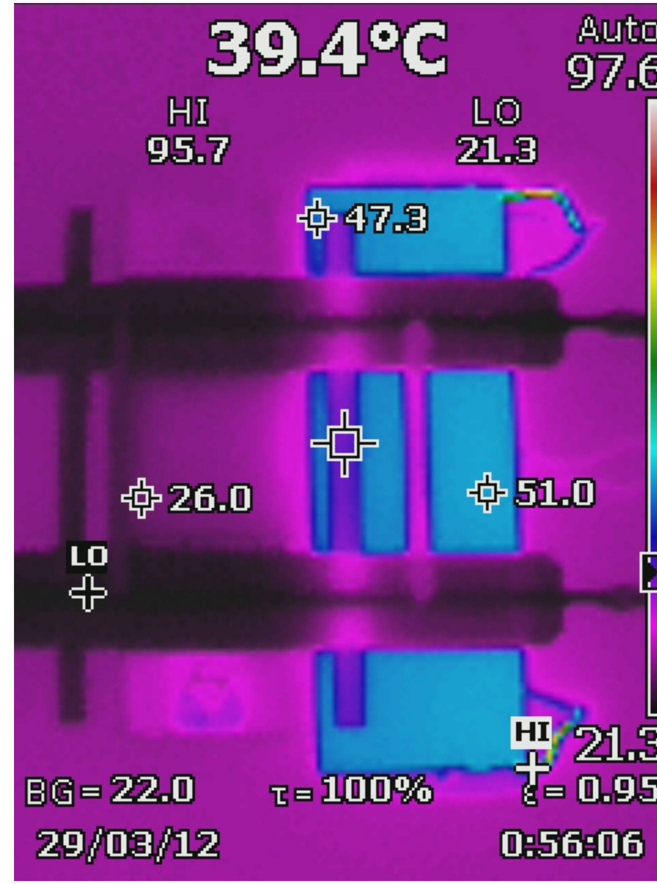
TESTS:

3) Heating + cooling supply

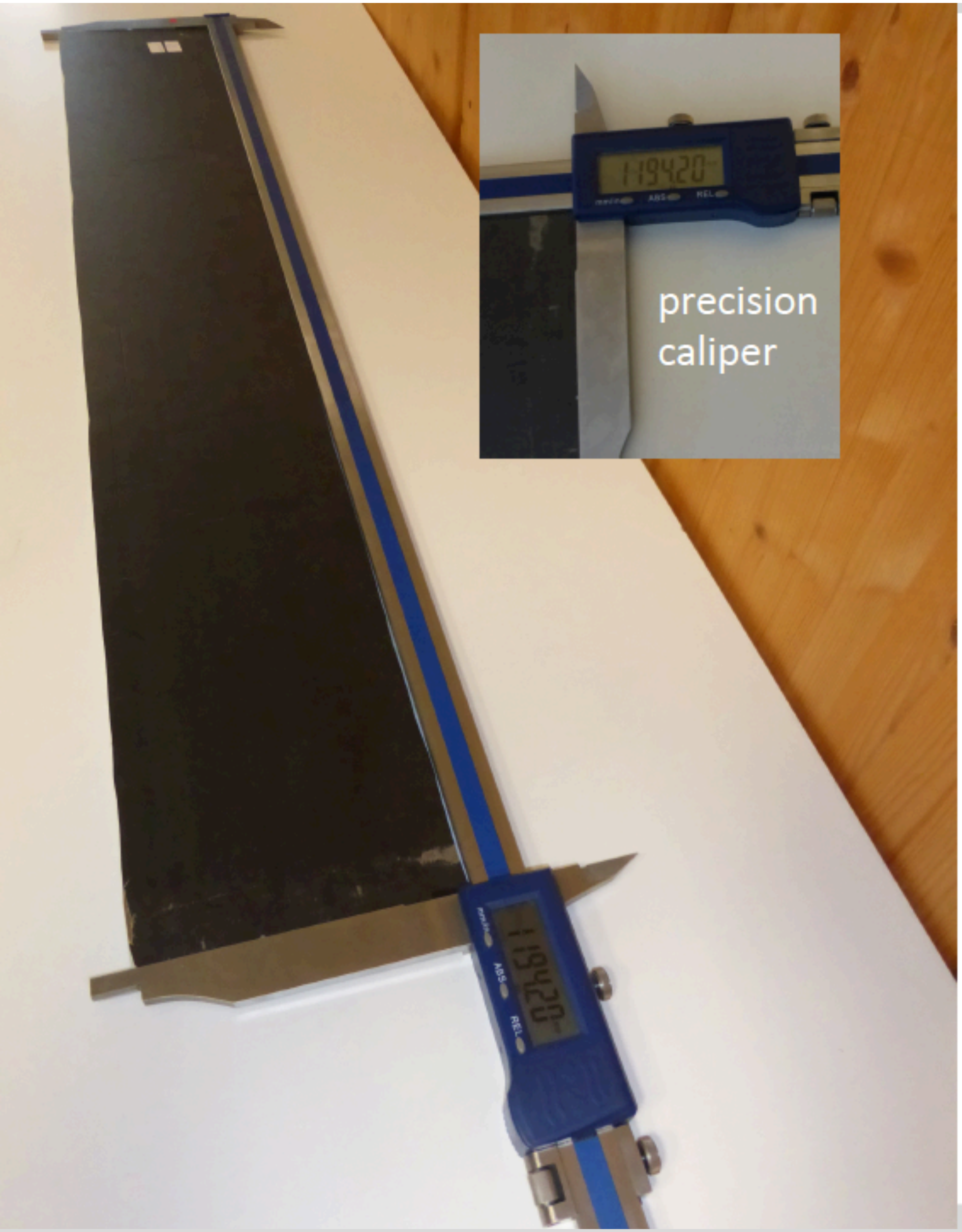
Temperature measurements on the thermal brige



20 sec



The heater power is 5.7 W.
The power density is 1.51 W/cm^2



CTE measurements (120 cm long pieces dT=22-(-18)=40 ^{0}C)

Sandwich:

9 mm Airex T92.80
(T92=PET foam, 80=80 kg/m^3)

Carbon fiber skins (0-90^o)
2x50 μm Granoc E70

CTE = (4 ± 1) 10^{-6} /K
(matches very well silicon)

Airex T92.80 alone
CTE = (135 ± 10) 10^{-6} /K

Granoc alone (NFG info)
CTE = (-0.2 ± 0.2) 10^{-6} /K

Conclusions-1

- We started in SPb the thermomechanical tests of CTE compatibilty for available CF composite structures and Si plates.
- When heated 20-120 ^{o}C, flat silicon plate bends almost linearly from 200 microns to 1000 microns
- Cooling process indicates some Hysteresis 20-120 ^{o}C.
- Important: Si plate with 8 cm distance between gluing points does not break in these temperature variations 20-120 ^{o}C!
- Near future plans include:
  - ✓ Si+CF rib CTE compatibility test
  - ✓ cold gas cooling tests for non-uniform + uniform power generation (using current ALICE specifications)