Compressed Baryonic Matter Experiment

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CBM-STS Thermal Demonstrator Mechanics and Lessons for STS Mechanics*

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Abstract

This technical note describes the cooling mechanics and its test with the Thermal Demonstrator for the Silicon Tracking System (STS) of CBM-FAIR. The demonstrator comprises three half-stations unlike eight full-stations as in the final STS, and is intended to investigate the STS operational conditions from thermal point-of-view. The details and chosen approaches or solutions for the different system components, such as the cooling elements, thermal enclosure, etc., are described. Moreover, the learnings are intended to play a key role in the integration procedure and component choices of the final STS.

*This version of the technical note is a prelude of the cooling mechanics for the CBM-STS Cooling Engineering Design Review (July 07, 2023) - `https://indico.gsi.de/event/17904/`

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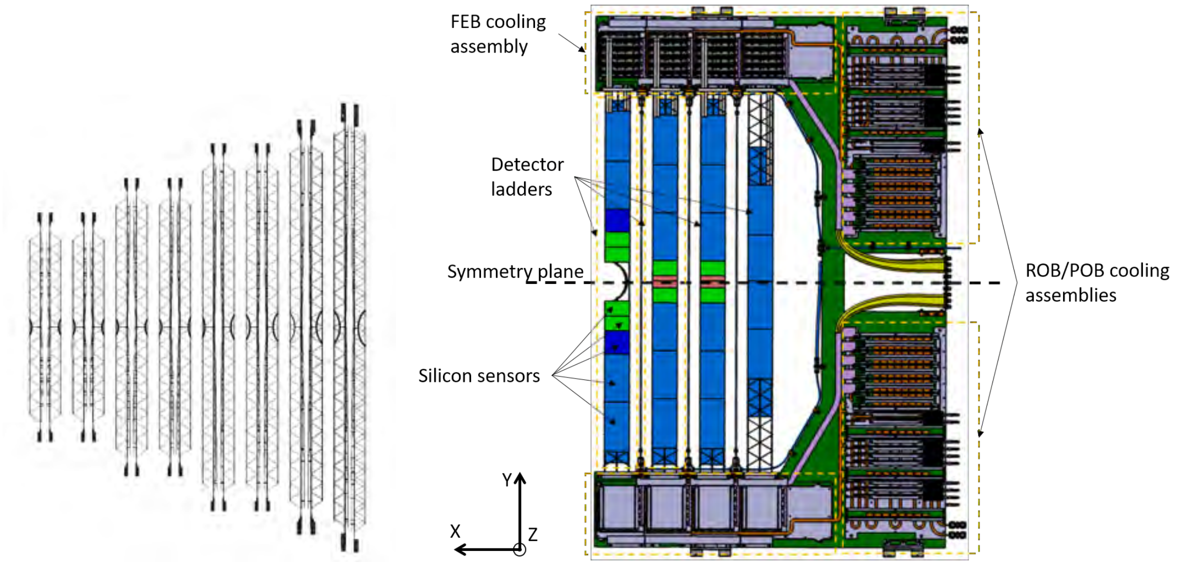
1 Introduction to CBM-STS (from Cooling Mechanics Point-of-View)

The Compressed Baryon Matter (CBM) experiment is designed as a fixed-target spectrometer with the Silicon Tracking System (STS) located in a superconducting dipole magnet being the primary tracking detector subsystem [1]. STS comprises eight tracking layers (hereafter referred to as *stations*) located 0.3 ... 1.0 m downstream of the target and has a collective active area of ≈ 4 m^2. The primary building block of STS is referred to as *module* which is composes of a double-sided silicon microstrip silicon sensors connected to the front-end electronics (FEEs) via ultra-light shielded microcables (see Fig. 1). The silicon sensors are mounted on carbon-fibre ladders and the FEEs are located outside the physics aperture of $\theta > 25°$ to ensure a low material budget of $0.3\% - 2\%$ X_0 per station (see Fig. 2).

Figure 1: STS Module comprising a double-sided silicon micro-strip sensor (left), ultra-thin microcables (middle) and a pair of front-end electronics boards (right)



(a) (b)

Figure 2: STS CAD Rendering. (a) Side-view showing eight tracking stations (only the active area comprising the silicon sensors mounted on carbon-fibre ladders). (b) Front-view showing one side of the STS C-frame. The silicon sensors (shown as red, green and blue rectangles) are mounted on carbon-fibre ladders, which are connected to the peripherally located infrastructure, such as electronics, readout and their respective cooling assemblies.

The silicon sensors are expected to be exposed to non-ionising fluence of up to $1 \times 10^{14} n_{eq}(1\,\mathrm{MeV})/\mathrm{cm}^2$ during the its entire operational lifetime. Therefore, the sensors are to be air-cooled to operate between 0 ... +10°C throughout detector operation to minimise the reverse annealing effects, maximise signal-to-noise ratio and keep the sensors away from thermal runaway [2]. The FEEs dissipate ≈ 25 W per module and altogether ≈ 40 kW, including the readout boards and other powering infrastructure, such as DC-DC converters. Since the FEEs are located only 20 ... 50 cm away from the silicon sensors, FEEs will be also kept at comparable temperatures to silicon sensors (0 ... +10°C) by using monophase 3M™ NOVEC™ 649 to minimise any residual heat exchange between the two heat sources. Given the sub-zero coolant temperatures required to neutralise the electronics power dissipation, the STS is placed inside a thermal enclosure. Further information on STS cooling concept and simulations is detailed in [3].

To experimentally verify the cooling concepts under realistic boundary conditions, a *Thermal Demonstrator* has been commissioned which also represents the possibility to establish the concepts of STS cooling mechanics. The thermal demonstrator consists of three STS-like half-stations with one "active" layer (FEE power dissipation of approx. 1 kW) sandwiched between two mechanically "passive" layers. The silicon heat resistors, representing silicon sensors, are air cooled by using impinging jets from carbon-fibre perforated tubes. The FEE cooling is achieved by using cooling elements with 3M™ NOVEC™ 649 as the coolant. The entire experimental setup is housed in a thermal enclosure made of carbon-fibre foam sandwich with actively cooled panels. Moreover, STS-like peripheral services, such as electronics and coolant feedthroughs, coolant manifold, valves and transfer lines are also tested. The CAD rendering of the STS demonstrator is shown in Fig. 3.

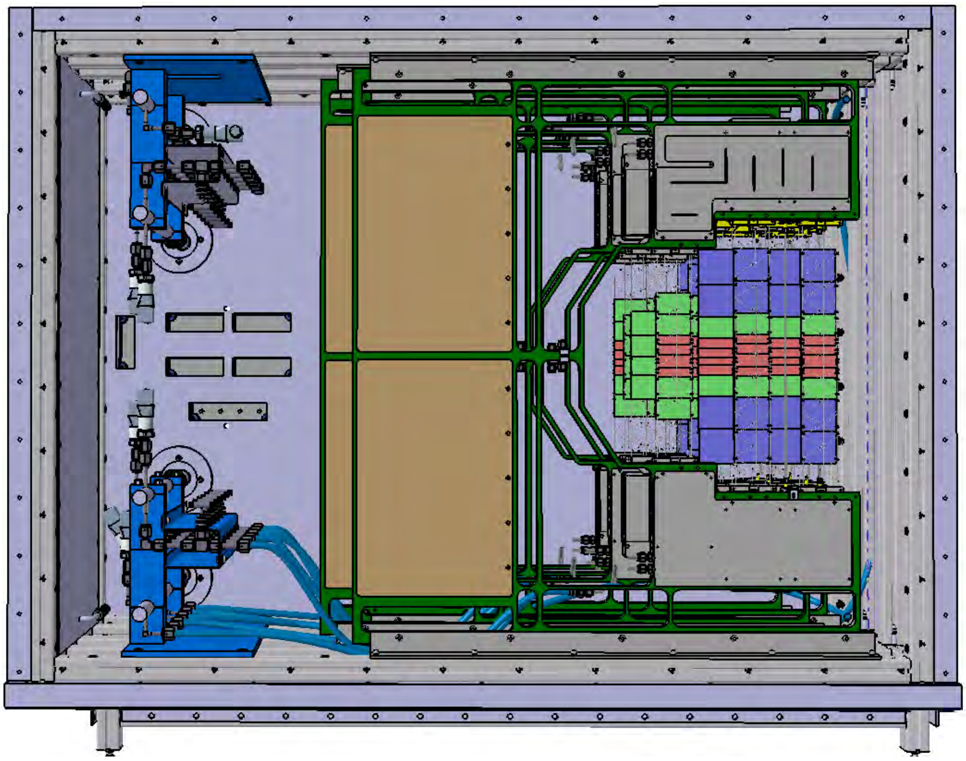


Figure 3: Overview of the thermal demonstrator from the opened back panel. On the left side of the box are the manifolds for the cooling liquid and on the right side the C-frame prototypes with realistic sensor modules and electronics as well as dummy sensor components. On the front side there are feedthroughs for the connection of the coolant, electronic cables and gas lines.

This technical note aims to describe the concept and experiences of the cooling mechanics developed for the thermal demonstrator. The note is structured to focus individually on different cooling sub-topics, i.e., sensor cooling (Sec. 2), FEE cooling (Sec. 3) and detector enclosure (Sec. 4). Moreover, the learnings from the respective sub-topics are also extrapolated to the final STS mechanics. These concepts, albeit in not its entirety, have been presented in the CBM-STS Mechanics Engineering Design Review (2021) [4], and this document represents a continuation of these efforts.

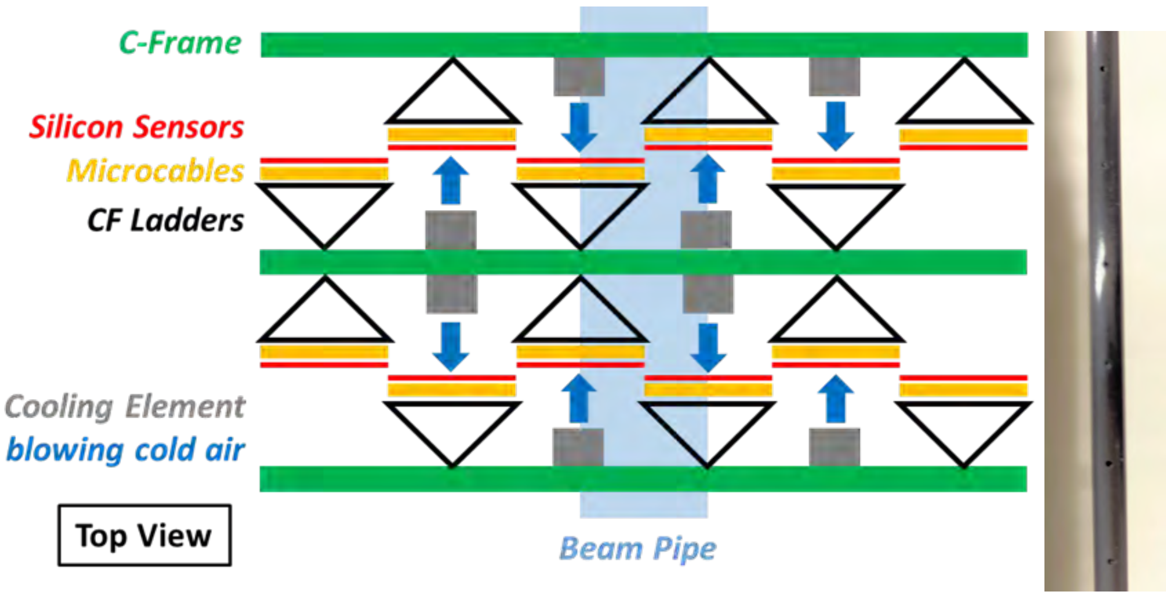
2 Silicon Sensor Cooling

2.1 Carbon-Fibre Perforated Tube's Geometry

Perforated carbon-fibre tubes are the cooling elements designed to neutralise the marginal power dissipated by the innermost sensors of the innermost ladders ($\Delta x = \Delta y \leq \pm$ 10 cm) of every STS station by adding minimal material budget in STS's physics acceptance. This is achieved by blowing air onto the exposed silicon sensor surface with the CF-tube attached to the opposite C-frame (see Fig. 4(a)). Further information on the rationale behind the design of these tubes is detailed in [3], with the typical values of the important geometric parameters listed in Tab. 1 Based on these parameters, commercially available CF tubes[1] have been used with the perforations drilled in house (see Fig. 4(b)).

Parameter	Value
Inner Diameter (D_0)	3.50 mm
Shell Thickness	0.75 mm
Material Budget (local; max. trajectory length = 3.57 cm)	1.25% x/X_0
Material Budget (averaged over sensor area)	0.06% x/X_0
Pitch (S)	14 mm
Length (L) per half	100 mm
Number of Holes (N) per half	8
Height (H) from the innermost sensor of a normal (central) ladder	12 mm (10.5 mm)

Table 1: Properties of the carbon-fibre based perforated tube. Since gas flow will enter from both sides of the tube, values for tube length and number of holes are quoted for half of the tube's actual length.



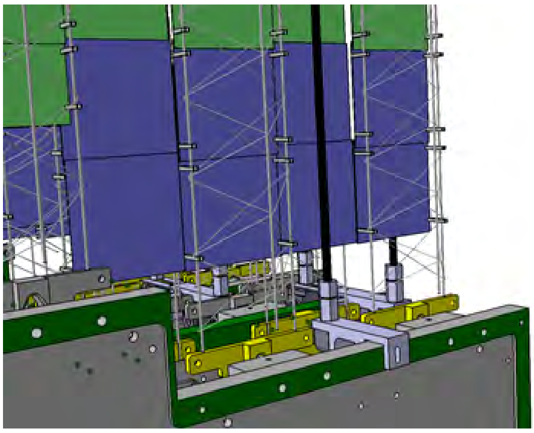
(a) (b)

Figure 4: (a) Conceptual representation of the silicon sensor cooling concept, with the cooling elements (perforated CF-tube) for a given ladder mounted on the neighbouring C-frame, and only the innermost ladders being cooled. (b) The CF-tube with perforations.

[1]Carbon Composite GbR; Article Number - PCT05035-1

2.2 Integration of Carbon-Fibre Perforated Tube

Given the non-standard dimensions of the CF-tube and the lack of integration space on the C-frame, special holders and connectors have been produced. For mounting the carbon tubes, 3D-printed holders were produced that allow the distance between the tubes and the sensor surface to be adjusted (see Fig. 5).

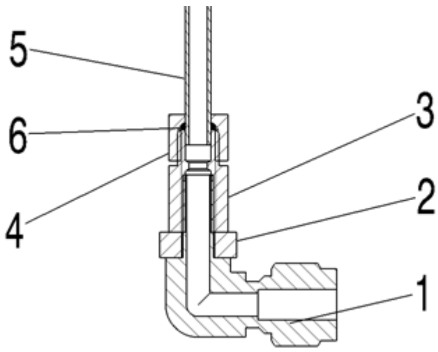


(a)

(b)

Figure 5: (a) CAD view of the custom holder used to align the CF-tube and integrate it onto the C-frame. (b) Corresponding photo of the adapter (shown in black; 3D printed part) as assembled on one of thermal demonstrator's C-frames.

To further connect the CF-tube to the global air distribution system, commercially available angle connector[2] was modified and screwed to a hexagon adapter that was customised to the tube's geometry (see Fig. 6(a)). The hexagon adapter consists of two parts: the lower part (item 3) is used for fastening to the C-frame mounting bracket or holder (item 2). The upper cap nut (item 4) and the O-ring (item 6) are used for fastening and sealing the carbon tube (item 5). When mounting, it is important to ensure that the perforations are correctly aligned). The assembled tube with the connector is shown in Fig. 6(b).



(a)

(b)

Figure 6: (a) Sectional view of the connection of gas line with the carbon tube for the sensor gas cooling. (b) The assembled CF-tube with custom connector. The details of the individual items and mounting concept in mentioned in the text.

[2]Swagelok Part Number - SS-6M0-2R-6M

These manufacturing and integration feasibility of these concepts have been experimentally tested in the thermal demonstrator. Furthermore, this also allowed to test the airflow distribution amongst several C-frames by using a distribution box based on dedicated rotameters[3]. This distribution box also contains a dedicated supply to maintain the low-humidity environment inside the thermal enclosure ensured by distributing perforated pneumatic hoses[4] throughout the enclosure's volume.

2.3 Extrapolation to final STS

The learnings about the sensor cooling mechanics from the thermal demonstrator have been successfully implemented in the CAD design of the final STS (see Fig. 7). This already provides a preliminary, yet concrete idea about the integration feasibility of these concepts on a higher and more complex mechanical structure.

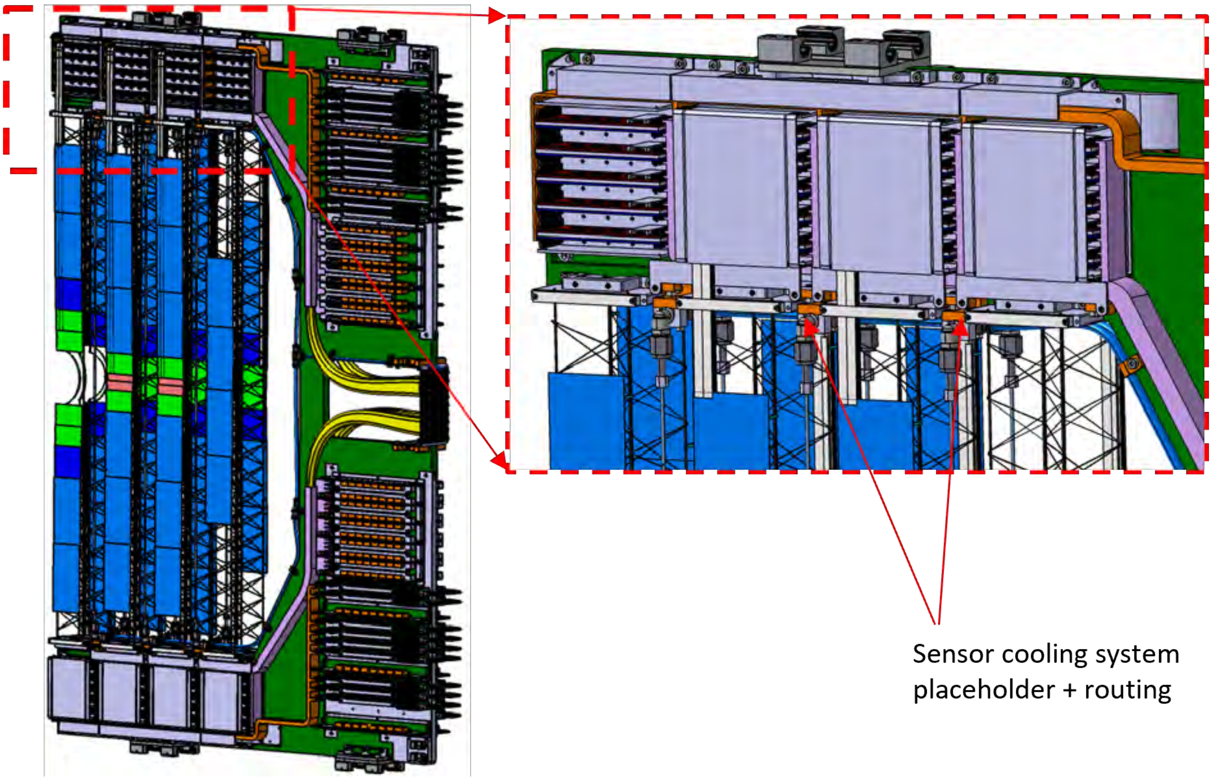


Figure 7: CAD rendering of the most densely assembled C-frame with all cooling and cabling services. The call-out on the right shows a zoomed-in representation of the sensor cooling implementation on this critical C-frame.

[3]Yokogawa Rotameter Type RAGL41
[4]Festo 6mm Pneumatic Tube

3 Front-End Electronics Cooling

3.1 Material Compatibility with 3M™ NOVEC™ 649

The crucial selection criteria for all components to be used in the front-end electronics cooling circuit (such as valves, connectors, hoses, sealants, etc.) is their compatibility with 3M™ NOVEC™ 649. This was based on prior research and operational experiences [5, 6], which are briefly summarised in Tab. 2.

Class of Materials	Substrates	Compatibility
Metals and Alloys	Al, Cu, Steel, SS, ...	OK
Rigid Polymers	PE, PP, PMMA, PC, GRP, PA, ...	OK
	PVC	Partially, as plasticizers can be extracted
Flexible Polymers	Silicone, PTFE	Partially due to low molecular weight extraction and/or swelling
	Polyurethene	OK
Elastomers	EPDM, Butyl, Nitril	OK, although plasticizer-free versions are preferred
Adhesives	Epoxies	OK
	Silicone	Generally not compatible
	Polyurethene	Partially, as specific tests required
	Acrylic Adhesives	Specific tests required

Table 2: Summary of compatibility of different materials with 3M™NOVEC™649 as shared by 3M and CERN-EN-CV department.

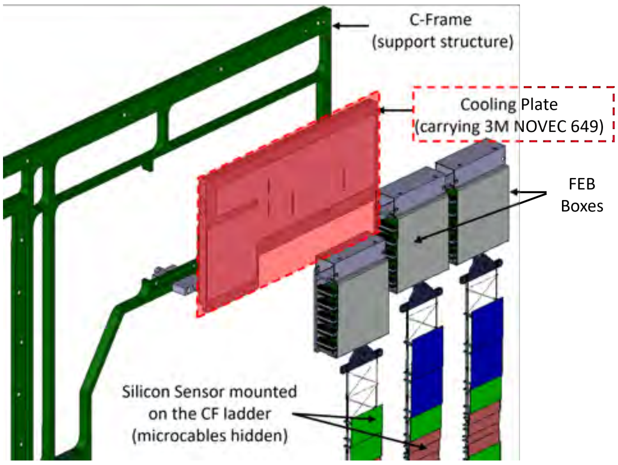
3.2 Cooling Plate

The STS front-end electronics are located outside STS's physics acceptance and dissipate ~ 40 kW in the detector volume of 3.5 m^3. This power is to be neutralised by cooling plates carrying 3M™ NOVEC™ 649 at temperatures down to -40°C with power dissipation per plate varying between $\approx$ 0.2-0.8 kW (see Fig. 8(a)). Please note that the power dissipation depends on the number of sensors and the corresponding electronics hosted on a given STS station. Moreover, the spacing between two adjacent C-frames limits the maximum cooling plate thickness to 12 mm.

The cooling plates are developed in close cooperation with Cool Tec[5], which uses 'Friction Stir Welding' technology for aluminium (AlMg3). This is a solid state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. This technology allows to flexibly mill fluid channels to enhance local heat transfer coefficient between the coolant and the cooling plate, thereby increasing the cooling performance (see Fig. 8(b)).

The performance of these cooling plates have been characterised, both in terms of their thermal and pressure performance. Detailed Computational Fluid Dynamics Simulations (CFD) simulations have been performed in SolidWorks™ to understand the cooling efficiency of these plates when the electronics power to be neutralised by them is the highest (see Fig. 9(a) and [**empty citation**] for more details). The bulging of the sample cooling plate under various pressures was measured with the STS ladder metrology setup [7], and was shown to be $\approx 100\mu m$ at maximum operational pressure of 5 bar(g) (see Fig. 9(b), 9(c)).

[5] Cool Tec Electronic GmbH, Germany, `www.cooltec.de`



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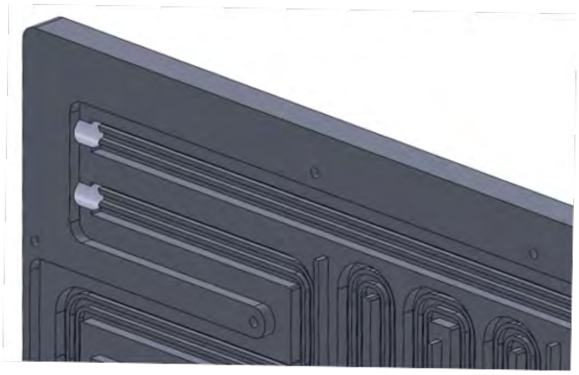
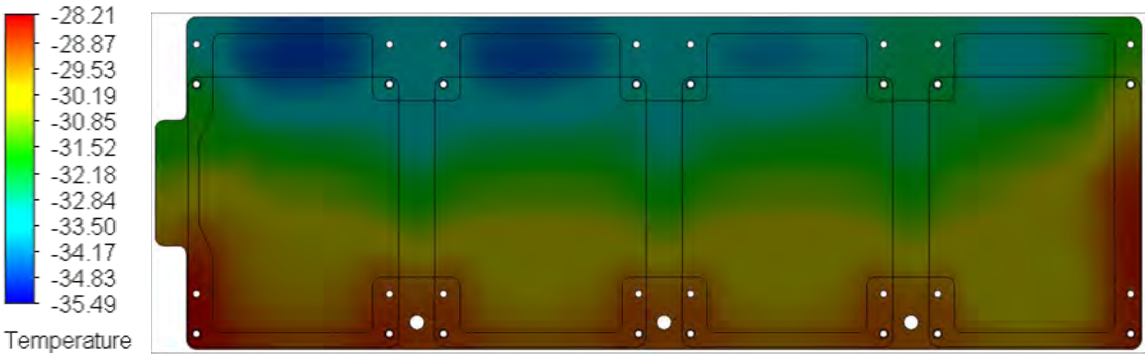


(b)

Figure 8: (a) Sectional view of the connection of gas line with the carbon tube for the sensor gas cooling. (b) The assembled CF-tube with custom connector. The details of the individual items and mounting concept in mentioned in the text.



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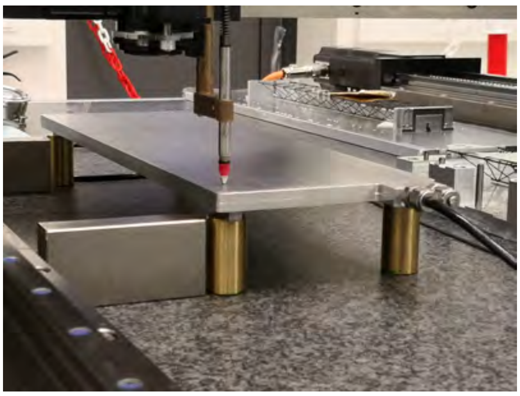

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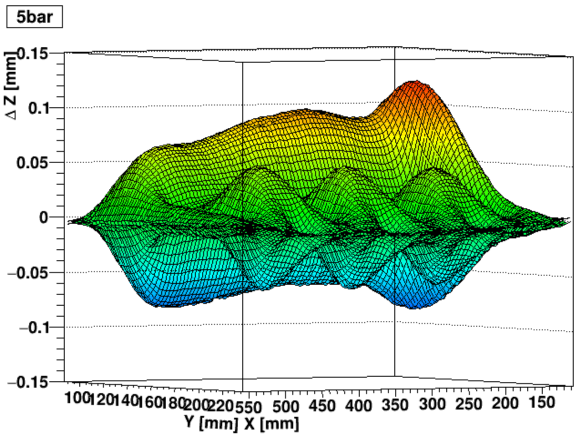


(c)

Figure 9: (a) CFD simulations for the FEB cooling plate with maximum power dissipation amongst all STS C-frames (800 W) cooled with 3M™ NOVEC™ 649 flowing at 3 litre/min and -40°C. (b) Metrology setup to measure cooling plate's bulging when kept under pressure. (c) Bulging measured across the plate's surface under pressure of 5 bar(g).

The low viscosity of 3M™ NOVEC™ 649 makes the connectors interfaces especially vulnerable to leakages which could manifest over STS's lifetime. In light of this issue and the limited material compatibility of 3M™ NOVEC™ 649, the baseline option for all connector interfaces is Swagelok® VCR® connector[6] providing metal-to-metal sealing. Due to the limited options on the threaded connections provided by Cool Tec on the cooling plate, a similar metal-to-metal sealing ensured by Swagelok® RS-Fittings[7] with copper gaskets. Based on these boundary conditions, cooling plates for the thermal demonstrator have been assembled and their leak tightness successfully tested up to 7 bar(g) (see Fig. 10).

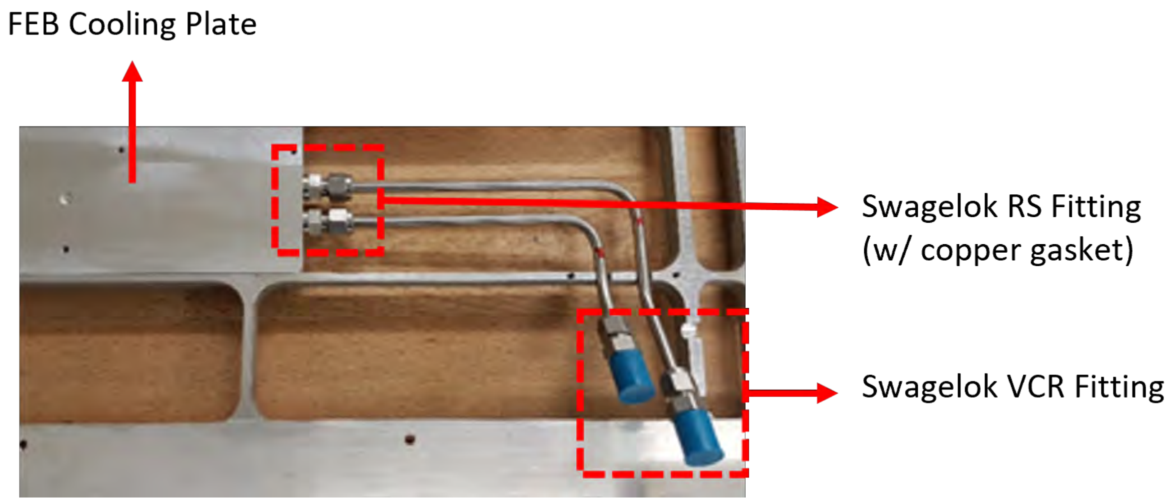


Figure 10: Cooling plate for front-end electronics boards (FEBs) assembled with metal-to-metal seal based connectors.

3.3 On-Detector Distribution Manifold

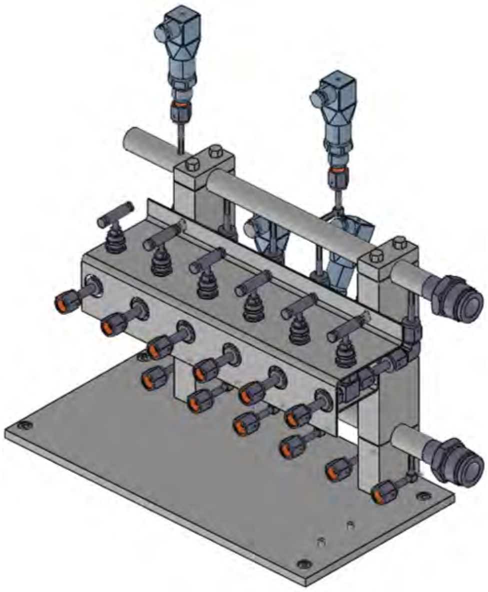
The distribution manifold located inside the STS thermal enclosure is designed to passively distribute the desired flowrate from the cooling plant to a given set of cooling plates on the C-Frame. It comprises of the main distribution tube and individual branches along with their respective control valves on the return branches.

Individual branches are made from 1/4 in. stainless steel flexible hoses, and can also help dampen the vibrations carried by the coolant from the cooling system's components. Swagelok® FJ-series metal hose[8] is the chosen option because of its high pressure rating, Swagelok® VCR end-connection availability, low bending radius (2.54 cm) and low weight (0.16 kg/m). The fine flow regulation is provided by the Swagelok® NR-series needle valve[9], where components are rated down to -53°C and are available with 3M™ NOVEC™ 649 compatible materials (UHMWPE, PEEK, Grafoil).

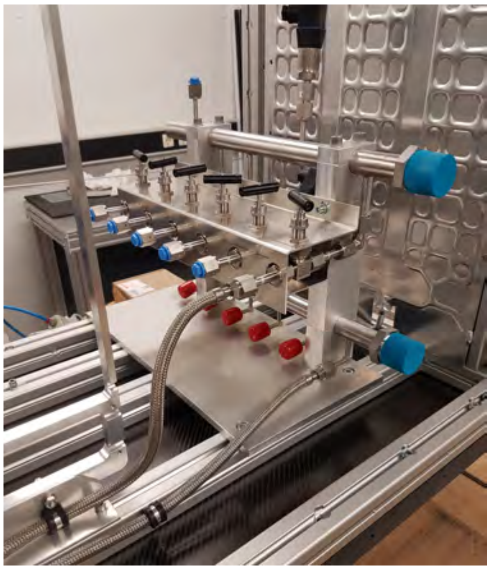
Based on these concepts, two sample manifolds for the thermal demonstrator have been produced in cooperation with the local Swagelok subsidiary[10] (see Fig. 11(a), 11(b)). In addition, there are connections for temperature and pressure measurement in the supply and return lines. Please note that the temperature and pressure sensors in the sample manifold won't be included in the final STS's manifolds because of their unsuitability in radiation and magnetic environment. The

[6] Swagelok® VCR® Catalogue - www.swagelok.com/downloads/webcatalogs/en/ms-01-24.pdf
[7] Swagelok® Gaugeable Tube and Adapter Fittings Catalogue - www.swagelok.com/downloads/webcatalogs/en/MS-01-140.pdf
[8] Swagelok® Hose and Flexible Tubing Catalogue - www.swagelok.com/downloads/webcatalogs/en/MS-01-180.pdf
[9] Swagelok® Needle Valve Catalogue - www.swagelok.com/downloads/webcatalogs/en/MS-01-168.pdf
[10] Swagelok® Stuttgart - B.E.S.T. Fluidsysteme GmbH, Germany - www.stuttgart.swagelok.solutions

manifold has a total of six connections, four of which are used for FEB cooling, and another connection is for the side cooling plates, which serve as condensate traps (see Fig. 11(c) for the P&ID). The last port is a spare and is not connected. The main ports are connected to the insulated hoses of the cooling system, which are routed through dedicated feedthroughs (more information on the condensate traps and feedthroughs in Sec. ??).



(a)



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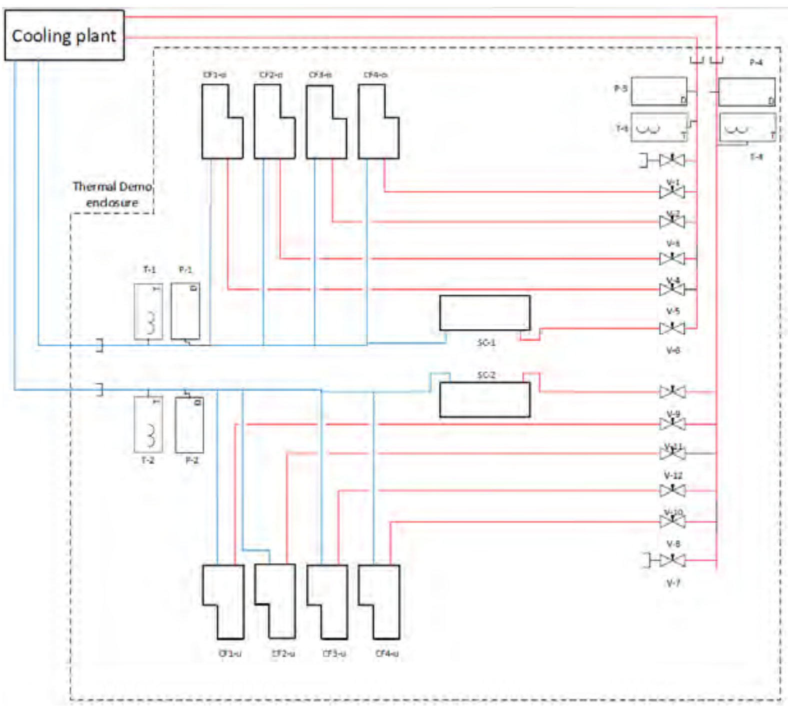


(c)

Figure 11: (a,b) CAD rendering and produced sample of the 3M™ NOVEC™ 649 distribution manifold. For the thermal demonstrator, one unit is used for the top and one for the bottom. (c) Concept for the cooling circuit of the demonstrator with eight FEB cold plates and two cold plates as condensate traps.

3.4 Extrapolation to final STS

Based on thermal demonstrator's findings about the structure and manufacturing process of the FEE's cooling elements, various versions of similar cooling plates have been designed and implemented in the CAD drawings of the final STS. This also includes the metal-to-metal seal connectors oriented in the way that they could be connected to their respective distribution manifold. Due to variability of the number of sensors, and thereby the electronics on different detector stations, two major variants of the FEB cooling blocks are required. FEB Cooling block 3 is designed for max. 6 FEB Boxes (3 per side) and FEB Cooling block 4 for max. 8 FEB Boxes (4 per side). For the assembly and integration purposes, a vertical and horizontal pointing directions of the hydraulic connectors to the outside (see Fig. 12).

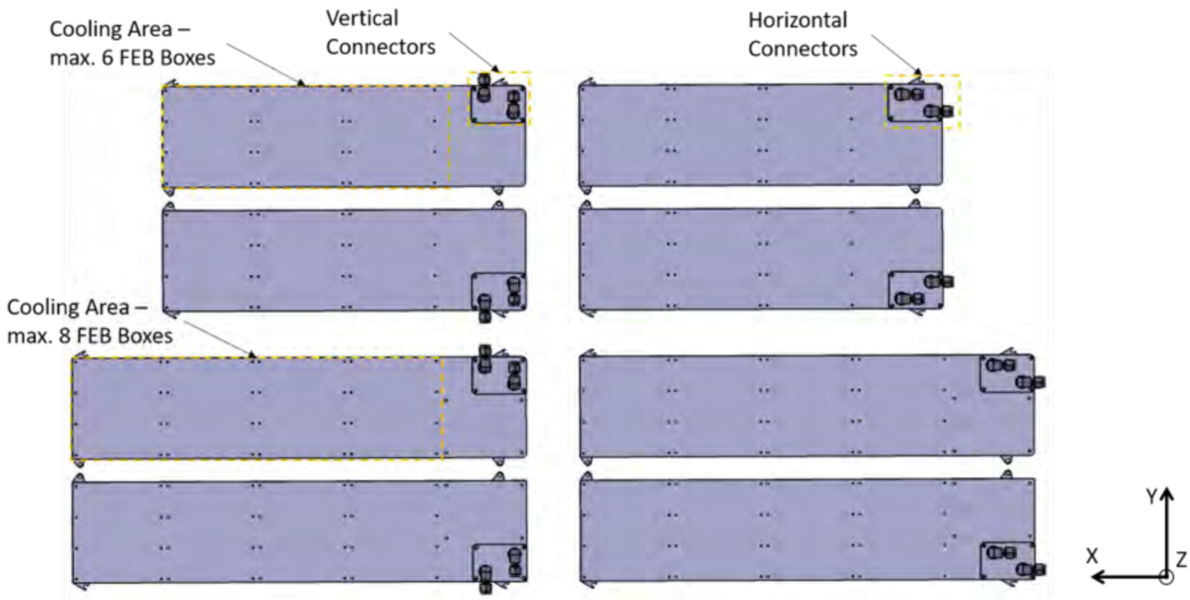


Figure 12: CAD rendering of different versions of FEB Cooling Blocks for the final STS.

4 Detector Enclosure

4.1 General Requirements

The requirements on the detector enclosure are threefold: (i) thermal, (ii) electromagnetic, and (iii) mechanical. Due to sub-zero operating conditions of the STS, it will be hosted inside a thermal enclosure to avoid any outside heat and humidity from entering the STS environment. Moreover, the enclosure will also act as an electromagnetic enclosure to shield and minimise any noise pick by STS's electronics. Mechanically, the enclosure must be rigid enough to host ≈2000 kg of weight with minimum deformations, yet lightweight enough to not introduce minimal additional material budget. A more detailed list of general requirements for detector enclosure are as follows:

- Thermal Insulation
- Shielding against thermal radiation
- Mechanical stability of the bottom plate
- Minimal material budget for back plate
- Fixture of beam pipe back plate
- Fixture of target/MVD box front plate
- Feedhthroughs in the front plate
- Cryo trap on the side plate
- Gas tightness
- Mounting options for the various components, such as rail system, etc.

Given the convoluted and complex nature of the detector enclosure, this document only addresses possible solutions to the thermal aspects under realistic mechanical boundary conditions and their implementation with the thermal demonstrator (addressed in subsequent subsections).

4.2 Thermal Demonstrator's Enclosure

The general concept of the detector enclosure's insulation panel fulfilling the aforementioned thermal requirements is illustrated in Fig. 13. Primarily, the insulation panel comprises of CF-foam sandwich which is further sandwiched in aluminised polyimide foils for thermal shielding. Additionally, the inner side of the enclosure's side panel includes thin cooling plates as the coldest spot in the enclosure to safely host any condensation outside the electronics area and provide additional cooling of the STS environment. Please note that other panels of the enclosure can't host similar cooling plates due to either material budget or space constraints.

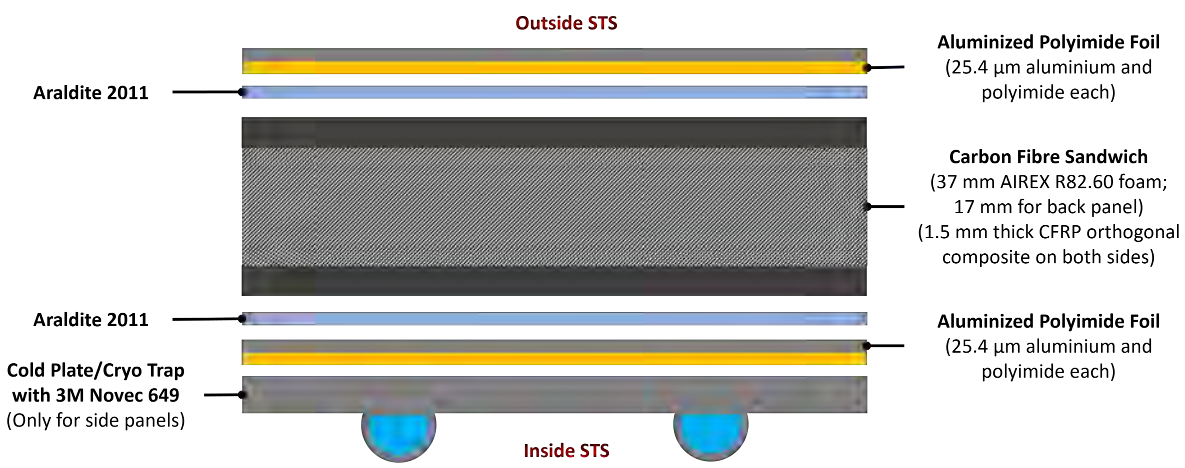
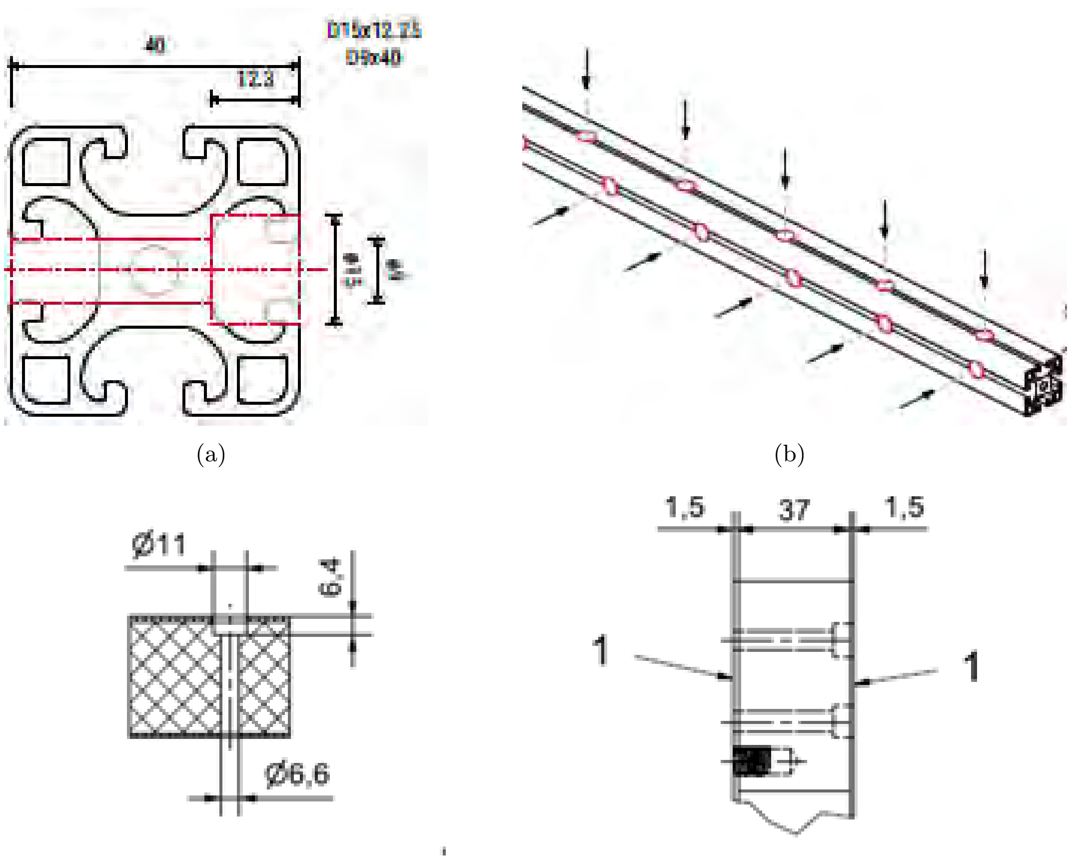


Figure 13: Cross-sectional schematic of the insulation panel.

4.2.1 CF-Foam Sandwich Insulation Panels and Mainframe

The CF-foam sandwich panels are manufactured in cooperation with CarbonVision[11]. The core thermally insulating material of the panel consists of AIREX® R82.60[12] which is 37 mm thick (17 mm thick for back panel to reduce the material budget in STS's physics acceptance). AIREX® R82.60 is a polyetherimide structural foam which is stiff, formable, has good adhesive bonding, provides sufficient thermal insulation (k = 0.031 ... 0.039 W/m·K), low density (ρ = 60 kg/m^3), radiation hard and has been successfully used by several trackers based at CERN-LHC [8, 9]. The foam is sandwiched between 1.5 mm thick carbon cover sheets consisting of a fabric pre-preg on the outer layers and a unidirectional pre-preg on the inner layers. The orientation of the inner layers is rotated alternately by 90° and aligned parallel to the edge of the panel until a layer thickness per panel of 1.5mm has been achieved.

A mainframe assembled from aluminium item© profiles is made to support sandwich panels and the test components, such C-frames and 3M™ NOVEC™ 649 distribution manifolds. For the assembly of frames and sandwich panels, flat countersinks have been drilled into the frame profiles on two sides that must always point outwards (see Fig. 14, 16(a) for drawings and details). This allows sufficient independence between different assembly stages of the thermal demonstrator and enables flexible adaptation of test structures, if needed.



(a) (b)

(c)

Figure 14: (a,b) Drawing of the mechanical adjustment on the aluminum item© frame for mounting the eventual mainframe and carbon box. (c) Drawing section of the screw holes and threaded sets in the carbon plates for mounting and other connections.

[11] CarbonVision GmbH, Germany - `www.carbonvision.de`

[12] AIREX® R82.60 Technical Information - `https://www.3accorematerials.com/en/markets-and-products/airex-foam/airex`

To integrate and seal the panels together onto the supporting mainframe, HELICOIL® threaded inserts with blind holes were used inside the sandwich panels. As a time- and money-saving solution, polyamide rims are embedded along the edges of the panels and feedthrough cutouts for better stability of the screw connection, while still maintaining sufficient thermal insulation (see Fig. 15). The first assembly test with the CarbonVision sandwich panels onto the item© mainframe is shown in Fig. 16(b). Further in-house steps on completing these panels for eventual thermal demonstrator application are described in subsequent sub-subsections.

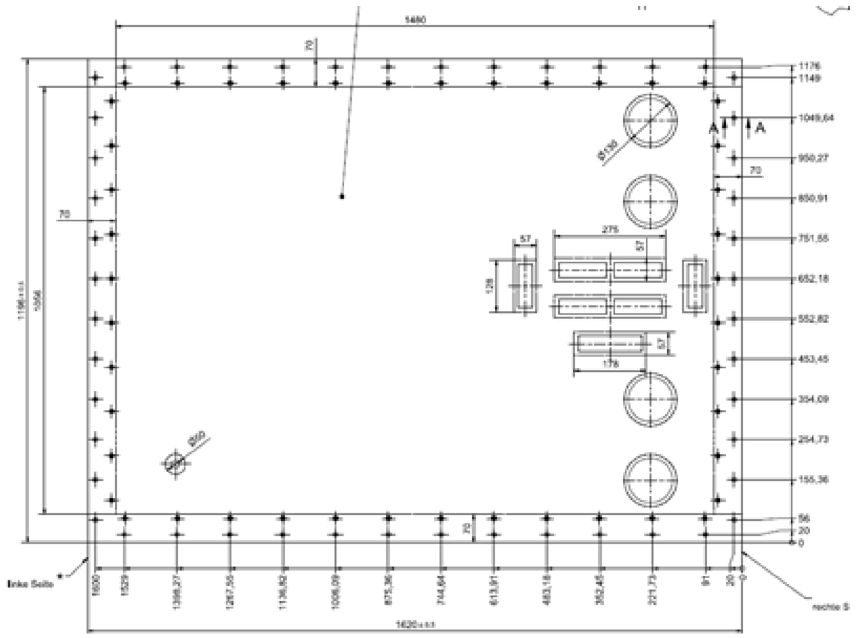
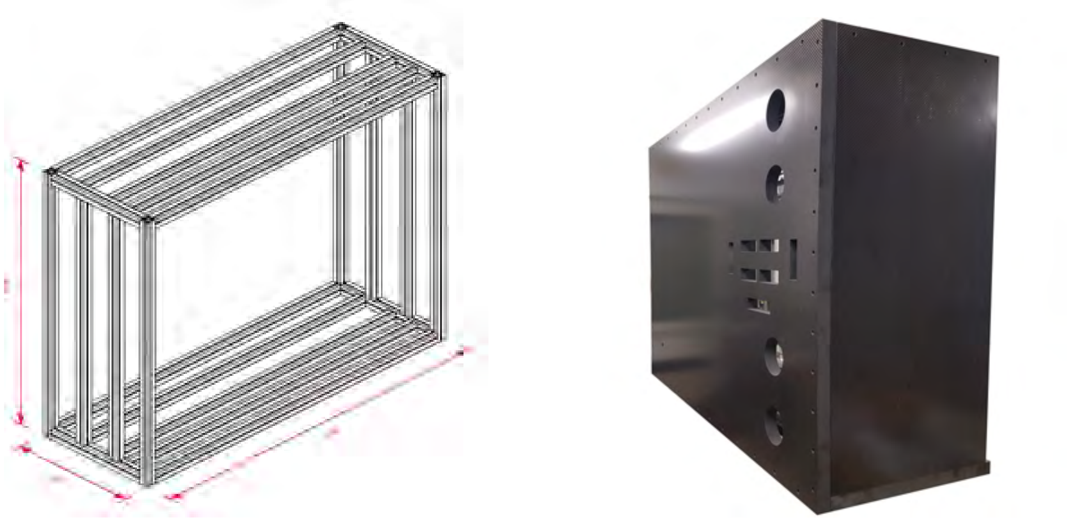


Figure 15: Drawing of the front panel with the polyamide frames inserted around the perimeter to ensure the strength of the screw connection.

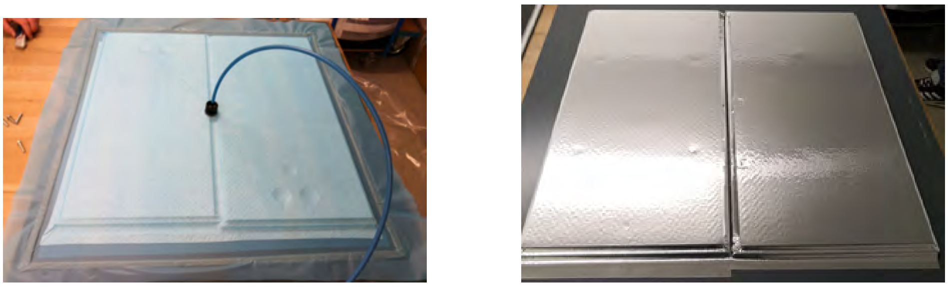


(a) (b)

Figure 16: (a) Mainframe made of aluminum item© profiles for mounting the internal components and sandwich panels. (b) Thermal enclosure made from integrating CarbonVision sandwich panels onto ©mainframe.

4.2.2 Gluing of Sandwich Panels with Aluminised Polyimide Foils

The sandwich panels are further glued with aluminised polyimide foils ($25.4\mu m + 25.4\mu m$) from CGS Tape[13] to provide thermal and electrical shielding. Upon applying the spray adhesive, light pressure was applied to further improve the contact between the foil and sandwich panels. Please note that in line with other LHC experiments' trackers' experiences [9, 10, 11, 12, 13], subsequent panel assemblies will be vacuum bagged with these foils by using ARALDITE®2011 for a longer-lasting and reliable adhesive bond. The proof-of-principle of the in-house vacuum bagging process with smaller sandwich panels was satisfactorily shown (see Fig. 17).

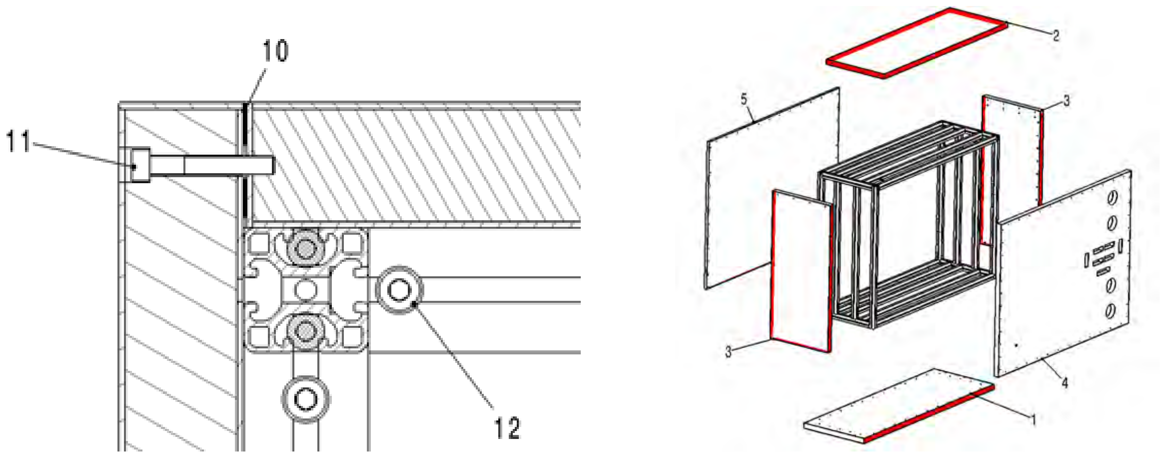


(a) (b)

Figure 17: In-house vacuum bagging for gluing aluminised polyimide foils to sandwich panels.

4.2.3 Sealing of the Thermal Demonstrator's Enclosure

The aluminium-polyimide glued sandwich panels are integrated onto mainframe by applying two parallel rows of commercially available EPDM[14] sealing tape (dimensions 10x2 mm) between the contact surfaces. The resulting enclosure and mainframe have a sealing gap of 1 mm (see Fig. 18(a)). As shown in Fig. 18(b), the sealing gaskets can be applied during the assembly of items 1-4. The rear wall (item 5) must remain open for further assembly of the feedthroughs and test parts. Please note that only one EPDM sealing row was used for the back plate to avoid deformation of the plate during assembly due to the plate's reduced thickness.



(a) (b)

Figure 18: (a) Connection between sandwich plates, mainframe and EPDM sealing (pos. 10). (b) Exploded view of the box with frame and the sealing surfaces (marked in red).

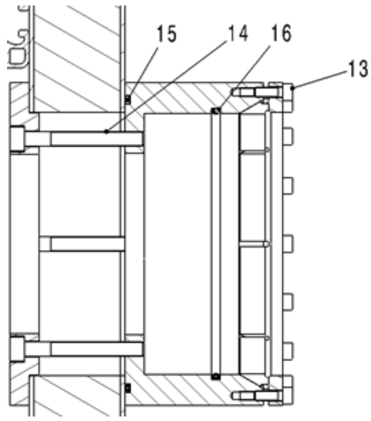
[13] Creative Global Services (CGS), Canada - `www.cgstape.com`
[14] Ethylene Propylene Diene Monomer rubber

4.2.4 Feedthroughs

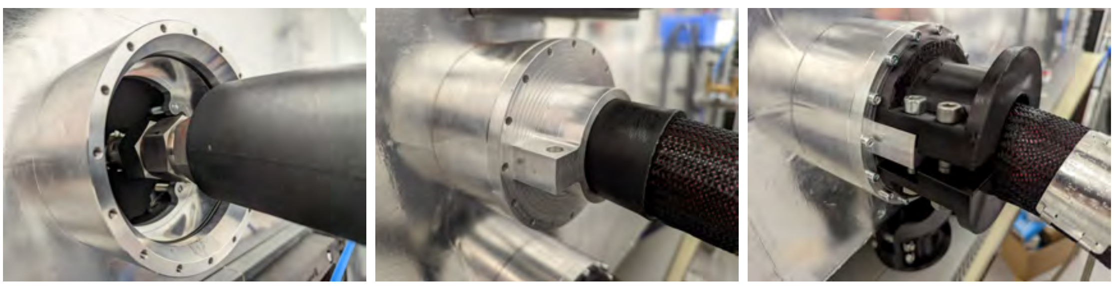
The integration and testing procedure of STS, along with STS's operating conditions mandates the following requirements on service penetrations or feedthroughs. Based on the these requirements, feedthrough concepts have been developed and tested for both, the cold-bulky 3M™ NOVEC™ 649 lines and numerous yet thinner cables.

- modular and reusable concept to ensure accessibility to all services
- minimise any moisture ingression inside STS enclosure's dry environment
- thermally isolating to minimise heat transfer into STS enclosure's cold environment
- minimise the feedthrough area on the enclosure's front panel

(a) 3M™ NOVEC™ 649 Lines: The transport lines carrying 3M™ NOVEC™ 649 and the distribution are connected through a custom-designed feedthrough assembly, which is thermally insulating, leak-tight and removable (concept shown in Fig. 19(a)). The feedthrough is fastened to the front sandwich panel with counter-plates. The feedthrough for the cooling line first screwed to the front panel, making sure that the O-ring (item 15) is correctly seated to achieve sufficient gas tightness. The cooling line can then be fed through and connected to the manifold; an O-ring (item 16) ensures radial gas tightness of the cooling lines. The cooling lines are fixed with a clamping ring (item 13). Any cavities and heat-conducting surfaces are insulated with EPDM foam after the cooling line has been installed. The feedthrough's use is flexible and can be used with both, Demaco Vacuum Insulated Transfer Lines[15] and JULABO Insulated Metal Tubing[16]. The subsequent assembly adapterd for the JULABO lines is shown in Fig. 19(b)-19(d).



(a)



(b) (c) (d)

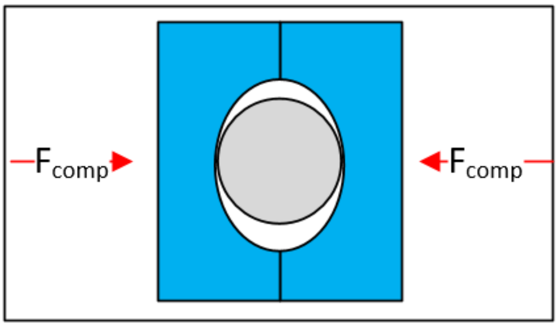
Figure 19: (a) Sectional view of the feedthroughs for the 3M™ NOVEC™ 649 lines. (b) The feedthrough assembly process for the Julabo transfer lines as used in the thermal demonstrator.

[15]Demaco Vacuum Insulated Transfer Lines (VIP) - `https://demaco-cryogenics.com/products/vacuum-insulated-transfer-`

[16]JULABO GmbH, Germany - `www.julabo.com`

(b) Cables and Gas Lines: Roxtec EzEntry™ cable entry seals[17] are commercially available feedthrough concept for the cables and gas transfer lines (see Fig. 20(a)). The sealing glands provide IP 66/67 protection and are available to fit different cable/tube diameters. The assembled panels can either be directly mounted on the front panel or via an adapter plate and counter plates (as in the thermal demonstrator). Due to the imperfect contact between some of the cable/tubes and the sealing glands, leakages were observed (see Fig. 20(b)). So, the assembled sealing glands were further encapsulated with a removable sealant putty[18] (see Fig. 20(c)).

(a)



(b)

(c)

Figure 20: (a) Feedthrough (Roxtec EzEntry™ 16) for cables and gas lines. (b) Gas leakage of the sealing elements in the installed state when the cable is too small. The blue rubber element is compressed laterally, creating a gap between the cable and the rubber element in the opposite direction to the direction of compression. (c) Roxtec EzEntry™ feedthroughs with further encapsulation (transparent sealant; Sylmasta Pack & Seal Electrical Sealant Putty) to enhance the leak-tight of the assembly.

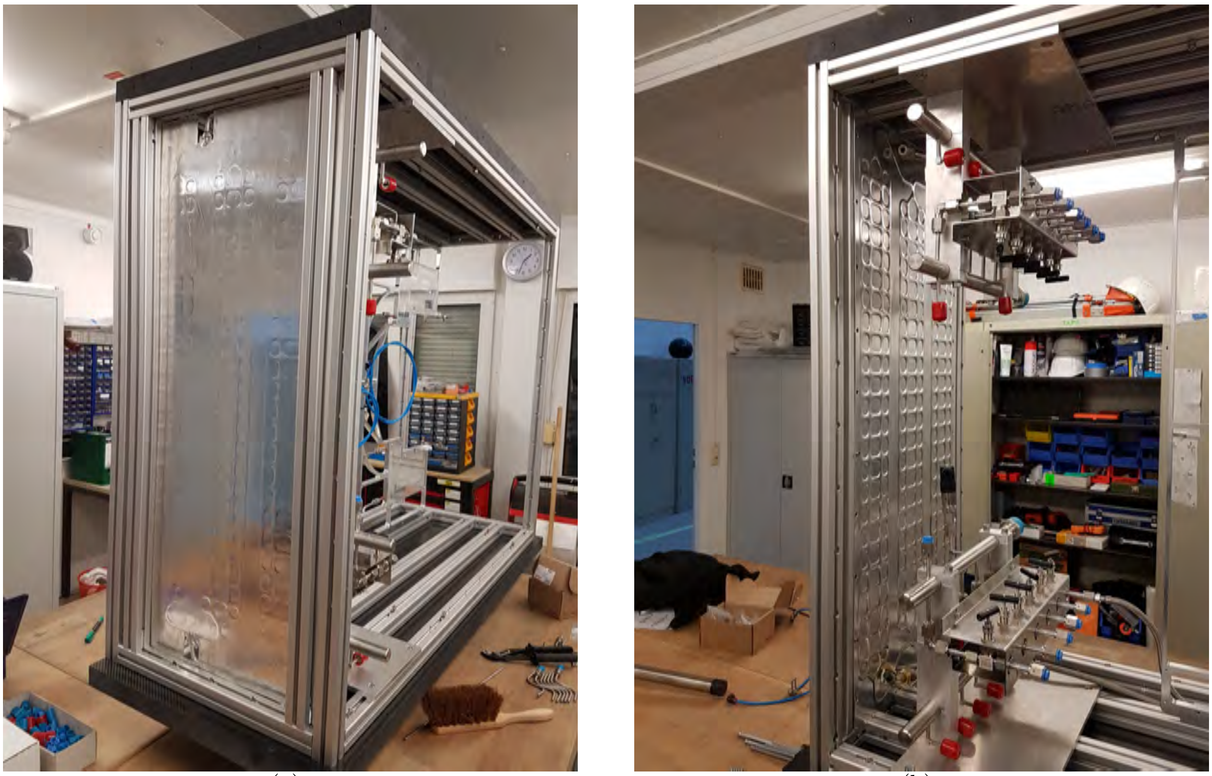
[17] Roxtec EzEntry™ - `www.roxtec.com/en/products/solutions/roxtec-ezentry`
[18] Sylmasta Pack & Seal Electrical Sealant Putty - `https://sylmasta.com/product/pack-seal/`

4.2.5 Cryo Trap/Side-Wall Cooling

The side panels of the enclosure are equipped with cold plates (see Fig. 13) to serve three crucial purposes: (i) compensate for panel's thin insulation by minimising the net heat coming inside the enclosure, (ii) provide more environment cooling by removing residual power dissipation from peripherally located cables, (iii) act as a cryo-trap in an accidental event of drop of the dew point in the enclosure and avoid condensation on the critical electronics.

For this purpose, aluminium cooling plates manufactured by Rubanox[19] by using Roll-Bond technology are used, which allows to minimise the thickness down to 3 mm. The plates are mechanically mounted on the mainframe and hydraulically connected to the 3M™ NOVEC™ 649 distribution manifolds (see Fig. 21). Clamp connections and VCR adapter fittings were used for the connection. Care must be taken to ensure a damage-free surface at the cold plate connections so that a proper seal is achieved. Cooling tests without gas cooling have shown that in the event of condensation forming in the box, a large proportion of the condensation adheres to the side cooling plates.

Please note that no dedicated simulations were done to optimise the channel geometry for these samples since they are foreseen as an initial proof-of-concept. Subsequent versions will be based on thermal demonstrator's experience and detailed thermal modelling.

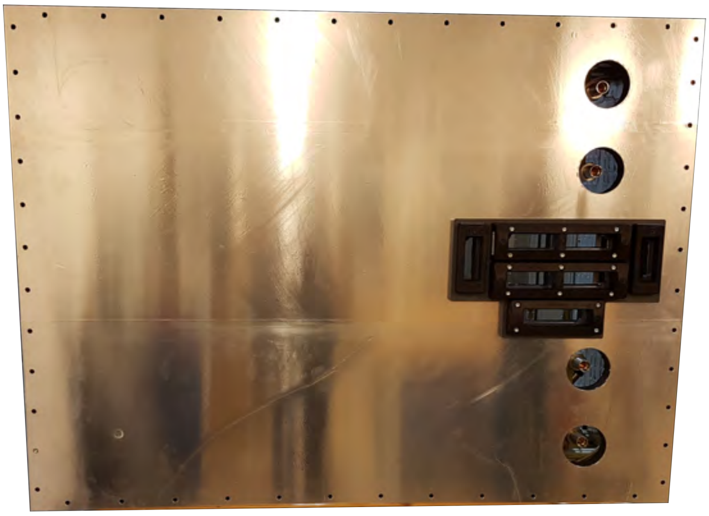


(a) (b)

Figure 21: Side-wall cooling plate (a) mounted onto the thermal demonstrator's mainframe, and (b) connected to the 3M™ NOVEC™ 649 distribution manifold.

[19] Rubanox Italia srl, Italy, www.rubanox.com

Based on the concept described in this section, the finally assembled enclosure for the thermal demonstrator is shown in Fig. 22.



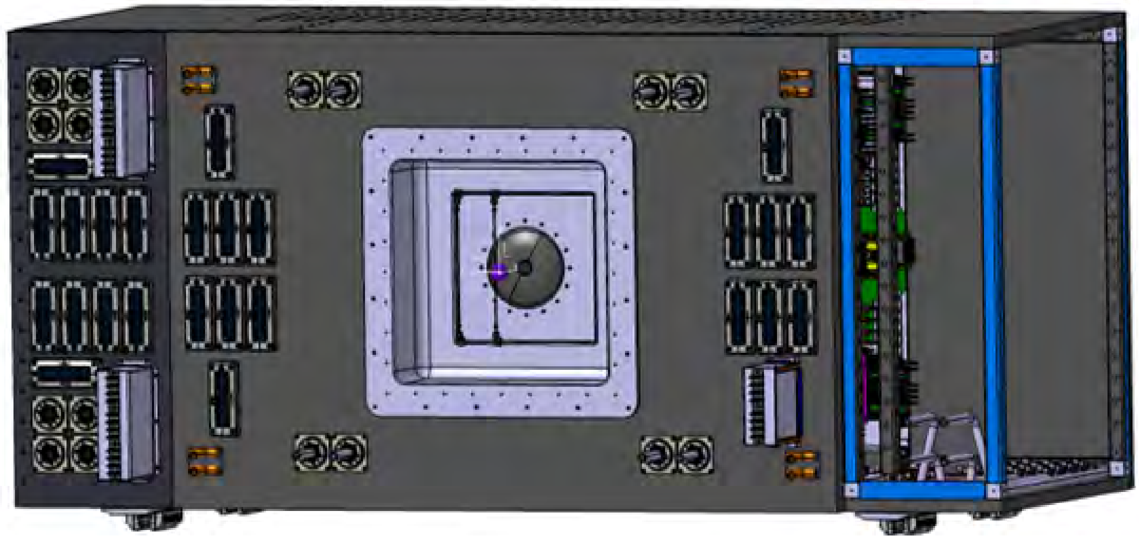
(a)

(b)

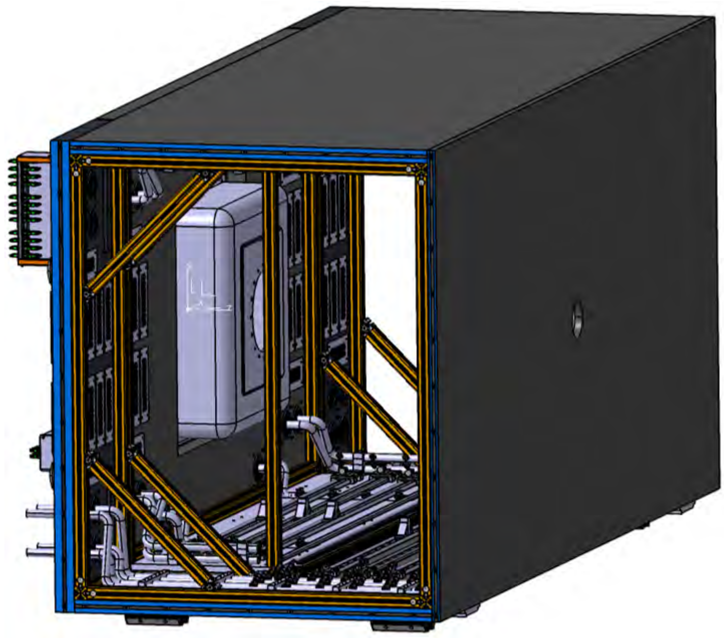
Figure 22: Carbon fibre reinforced sandwich box with foam core and aluminium profile frame for C-Frame assembly. (a) Front side with feed-through for the supply lines. (b) Opened rear side with C-frames and manifold before mounting the sensor components and electronics.

4.3 Extrapolation to final STS

Since the final STS enclosure is a much more complex object than the thermal demonstrator's enclosure, making direct extrapolations is difficult. Therefore, only the applicability of individual has been implemented in the final STS CAD drawings. These include the addition of Roxtec EzEntry™ feedthroughs for cables, thickness of carbon-fibre foam sandwich panels and use of the mainframe to support these panels to make an enclosure. This implementation for the final STS is shown in Fig. 23.



(a)



(b)

Figure 23: CAD renderings of the STS enclosure. (a) Front view of the STS enclosure showing Roxtec EzEntry™ feedthroughs for cables. (a) Side view of the STS enclosure (with panel removed) showing the mainframe structure (in orange) to support the sandwich panels.

5 Observation and Outlook

Due to the current ongoing tests on the demonstrator, not all tests to validate the behaviour of the design could be carried out yet. The observations that have occurred so far during the assembly and the first test and possible further steps are described below.

- **Assembly Process:** The high complexity of the C-frames and the large number of connection interfaces for electronics and cooling have shown that a detailed assembly plan and nomenclature of the C-frames with attached parts in the correct arrangement is essential to achieve a production distributed over several assembly stations, as it is no longer possible to adjust the C-frames after they have been assembled in the detector due to the density and required precision of the components. As a remedy, protocols for quality assurance of the C-frames are suitable, in which the number, alignment and functionality of the components are systematically checked.
- **Cooling Plates Concept:** The cooling plates for FEB cooling are well suited for both concepts. In the subsequent production of variants, care must be taken to ensure the appropriate choice of tolerances for the C-frame cut-out and the cooling plates in order to avoid manual reworking during assembly. In the concept with the friction-welded cooling plate, it was not possible to use a metal sealing washer due to the highly reduced thickness of the plate. A hardening thread seal provided sufficient sealing, but for the later assembly, the use of products that might be subject to ageing processes in the area that is difficult to maintain is not desirable. In the new concept of the cooling plates, the suitable sealing surface is taken into account.
- **Enclosure and Feedthroughs:** When mounting the back panel, it has been shown that the smaller thickness (due to material budget) and the force required to compress the seal cause deformation due to uneven contact pressure. This results in the screws not being able to be fitted in the lower area due to the orientation of the holes. This has shown that in the design of the back panel, the assembly forces due to the compression of the gasket is a critical factor. With the demonstrator, the problem could be solved by drilling out the screw holes on the lower side 3/10 mm and reducing the sealing surface. By tightening the screws evenly, the deformation was reduced and the assembly of the screws was possible. Since the feedthrough cannot be mounted gas-tight, further sealing with a silicone putty was able to visibly reduce the leakage of gas at the feedthrough. For another reason, the required leakage rate of 1.125×10^{-3} mbar·m^3/s could not be achieved and is greater than expected by a factor of 80. The value was chosen/estimated in such a way that in case of cooling failure, the box would keep the humidity low long enough to exclude condensation on the electronics. The position of the main leak could not yet be determined and must be further investigated, as well as an evaluation of the required value is necessary based on the ongoing tests in the demonstrator. The high deviation of the achieved leakage rate of 0.1 mbar·m^3/s leads to the assumption that the blind holes for the threaded inserts of the screw connection in the sandwich plates are permeable.

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