Detailed Specification

Detailed Specification of the vacuum chambers, supporting frames and lifting table of the Cryogenic Stopping Cell of the Super-FRS

Document History

Version	Prepared/Checked by	Date	Comments
001	D. Amanbayev	27.03.2026	
002	D. Amanbayev	02.04.2026	Updated according to comments from S. Purushothaman
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Abstract

A cryogenic stopping cell (CSC) is a large, gas-filled cryogenic vacuum chamber system used to slow down and “thermalize” fast ion beams from fragment separator Super-FRS to low energies, so that they can be extracted and sent to precision experiments downstream. This document defines the requirements for the thermo-mechanical, vacuum physical, technical and metallurgical characteristics of the vacuum chambers and related components. The document also stipulates the requirements regarding the dimensions, the testing, and the inspection of the CSC.

This document covers components of the work package with PSP code 1.2.1.2.1, including vacuum chambers, supporting frames, and lifting table.

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1 Purpose and Classification of the Document

The purpose of this document is to specify the detailed technical requirements for the design, manufacturing, testing and delivery of the components of the Cryogenic Stopping Cell of the Super-FRS at FAIR. The document covers components of the NUSTAR work package with PSP code 1.2.1.2.1, including vacuum chambers, supporting frames, and lifting table.

- In this document, the GSI Helmholtzzentrum für Schwerionenforschung GmbH will be referred to as GSI or the Company, and the provider or commercial company will be referred to as the Contractor.
- This document is the most detailed document in the hierarchy of the project documentation for the cryogenic stopping cell and defines all rules, boundary conditions and information required for the planned technical realization of this system.
- General regulations and requirements are specified in the General Specifications, Technical Guidelines and/or Common Specifications. They are only referenced in the present document. The related documents are listed in Section 8.
- This document belongs to the Technical Part of the Contract. All commercial and organizational conditions are specified in the Commercial Part of the Contract. No legal or contractual conditions are treated in this document. All related information is given in the corresponding contract.
- This document is addressed to all people involved in the processes of
    - Engineering
    - Production planning and management
    - Quality assurance
    - Testing
- All definitions within this specification are valid for the cryogenic stopping cell and associated components within the context of the FAIR accelerator and experimental complex only and must NOT be applied for any other purpose than this.

Within this document, the basic and specific technological demands, functional properties and technical descriptions of the cryogenic stopping cell of the Super-FRS are specified. Together with all documents cited herein, this specification forms the basic set of information for the qualified design, construction, manufacturing and testing of the cryogenic stopping cell system.

2 Abbreviations, Terms, and Definitions

Table 1. Abbreviations and definitions

Abbreviation	Definition
CDR	Conceptual Design Report
CID	Component Identification Number
CSC	Cryogenic Stopping Cell
EDMS	Engineering Data Management Service
EPICS	Experimental Physics and Industrial Control System
FAIR	Facility for Antiproton and Ion Research
FAT	Factory Acceptance Test
FDR	Final Design Report
FEM	Finite Element Method
FRS	Fragment Separator
HRU	Helium Recovery Unit
PPS	Polyphenylene Sulfide
PVC	Polyvinyl chloride
RF	Radio-Frequency
RFQ	Radio-Frequency Quadrupole
RGA	Residual Gas Analyzer
SAT	Site Acceptance Test
TMP	Turbomolecular Pump
UHV	Ultra-High Vacuum

3 Scope of the Technical System

This document represents the Detailed Specification for the design, construction, and testing of the components of the Cryogenic Stopping Cell of the Super-FRS, including vacuum chambers, supporting frames, and lifting table. It defines the requirements for thermo-mechanical, vacuum-physical, and technical characteristics of the CSC. The document stipulates the requirements regarding the dimensions, the testing, and inspection of the CSC.

All the figures shown in the document are conceptual or schematic representations. The contractor is allowed to come up with their own design proposals considering the requirements and boundary conditions specified in Section 4.

3.1 System Overview

The following overview describes the complete CSC system, including components outside the scope of this tender. This context is provided to ensure the Contractor fully understands the operational environment and interface conditions relevant to the work. The contractual scope of supply is defined explicitly in Section 3.2.

A cryogenic stopping cell (CSC) is a large, gas-filled cryogenic vacuum chamber system used to slow down and "thermalize" fast ion beams from Super-FRS to low energies, so that they can be extracted and sent to precision experiments downstream.

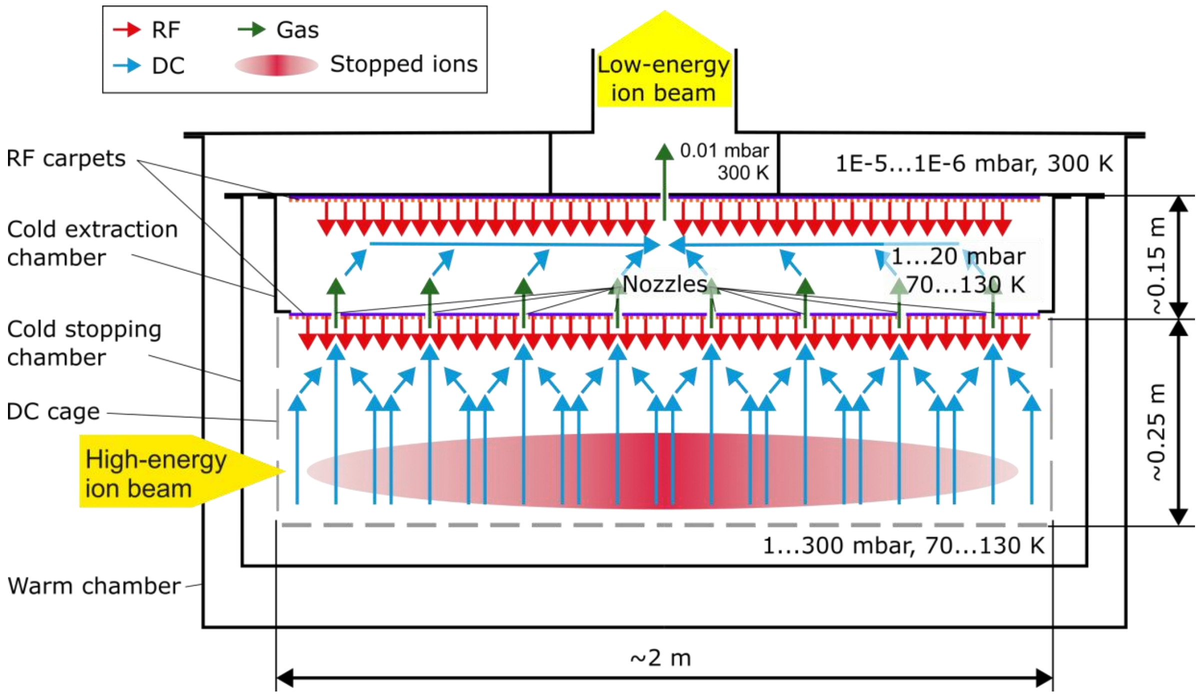

Figure 1. Schematic figure of the cryogenic stopping cell (CSC) of the Super-FRS.

The conceptual design of the CSC is shown schematically in Figure 1. The CSC consists of three main vacuum chambers. An outer warm chamber provides thermal insulation for the cold stopping and extraction chambers, that are at cryogenic temperature of 70 K. The cold stopping chamber contains a high-gas-density stopping region at the pressure of 1–300 mbar and the temperature of 70 K. The cold extraction chamber contains a low-gas-density extraction region at the pressure of 1–20 mbar and the temperature of 70 K and is pumped differentially. In idle, the system stays under ultra-high vacuum.

The ion beam enters the stopping region horizontally through two thin vacuum windows and is stopped in the helium stopping gas. Using electric DC fields, the stopped ions are transported in the orthogonal direction upwards to an array of RF carpets, which focuses the ions onto multiple intermediate extraction nozzles; here, the gas flow flushes the ions into the low-density extraction region. In the extraction region, the ions are collected and transported to the exit nozzle using an RF carpet. Behind the exit nozzle, the ions are further separated from the gas in an RFQ beam line and transported to experiments downstream of the CSC.

The digital mock-up views of the CSC are shown in Figure 2 and Figure 3. The CSC is mounted suspended in a holding frame. It must ensure that the height of beam axis is 2 meters (Figure 2). The warm chamber and the cold chambers are rectangular vacuum chambers. The top flange of the warm chamber (warm top flange) is connected to the frame. The body of the warm chamber is connected to the warm top flange. It must not be connected to the frame. The top flange of the cold chambers (cold top flange) is mounted suspended from the warm top flange. The cold extraction chamber and cold stopping chamber are connected to the same cold top flange. They must not be supported from the bottom and from the sides by the warm chamber. The electronic supplies (not part of this delivery) are mounted on the main frame of the CSC. The DC and RF electrode structures (not part of this delivery) are mounted inside the cold chambers.

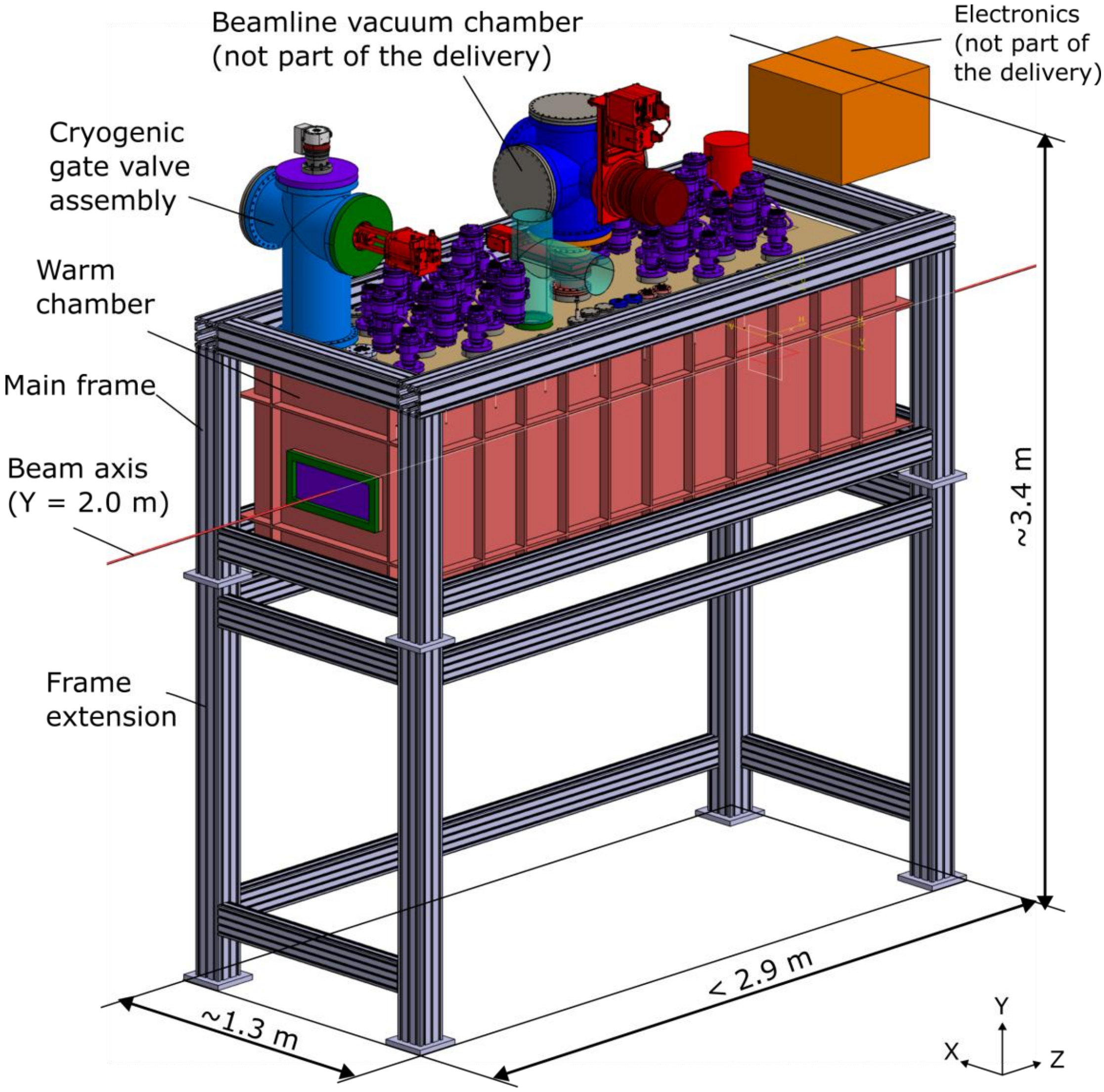

Figure 2. Digital mock-up of the CSC with the main subcomponents indicated.

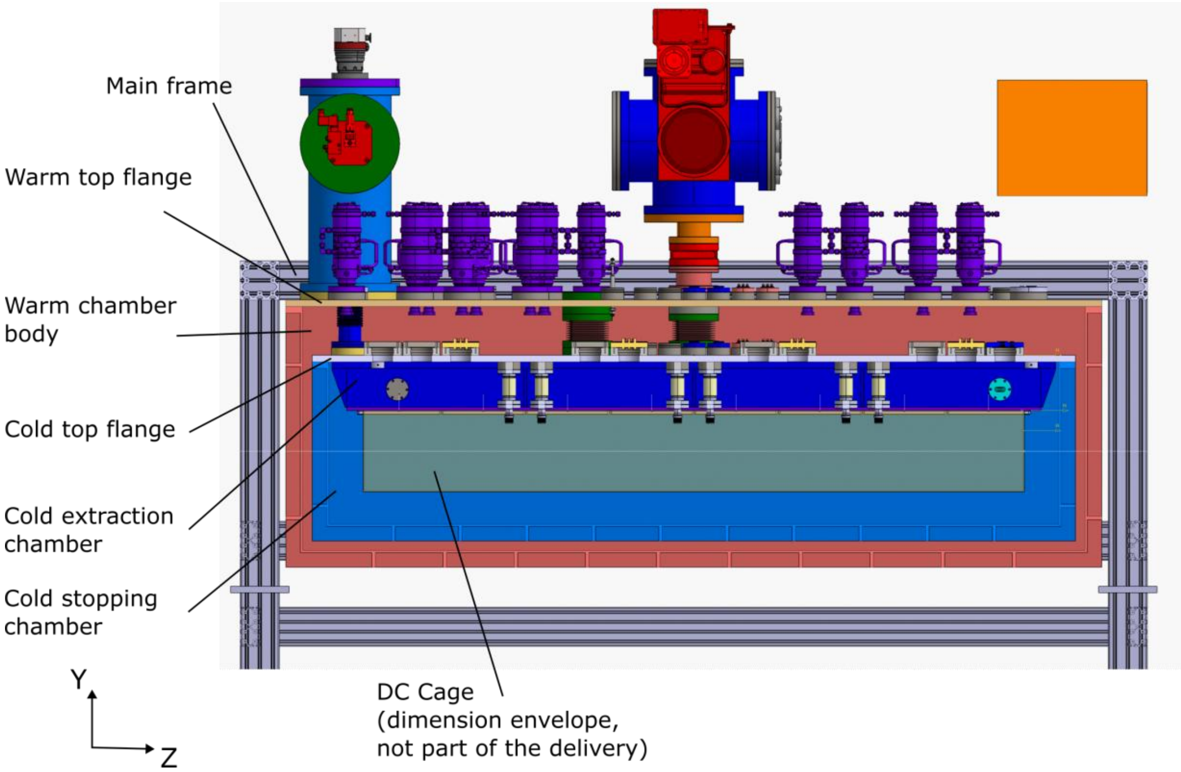

Figure 3. Section view of the CSC showing main flanges and vacuum chambers.

The warm chamber and cold chambers can be removed from the top flanges downwards in sequence using a lift table (scissor table), as shown in Figure 4. After maintenance has been performed, the outer chamber and the inner chamber are assembled in a reversed order. The lifting table will also be used to transport the assembled CSC across the facility.

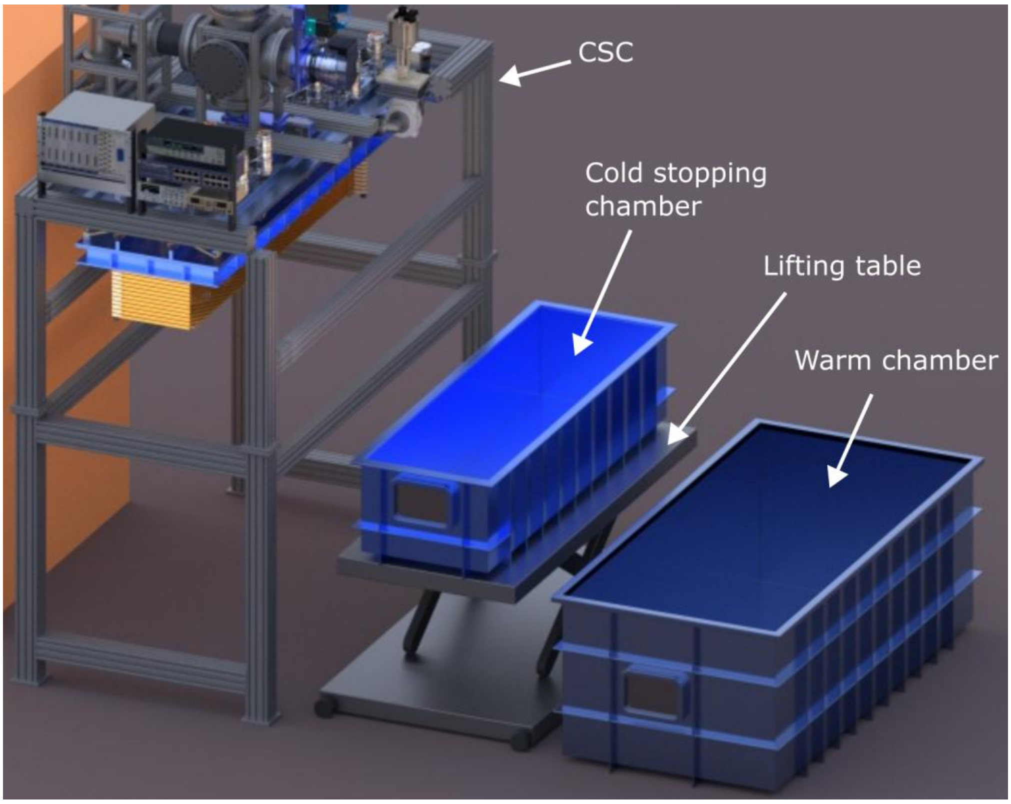

Figure 4. Schematic view of partially disassembled CSC. Warm chamber and cold stopping chamber dismounted from the corresponding flanges using lifting table.

The cold extraction chamber and cold stopping chamber are separated from each other by a Cold Separation Plate, described in detail in Section 4.3.10.

3.2 Scope of Delivery

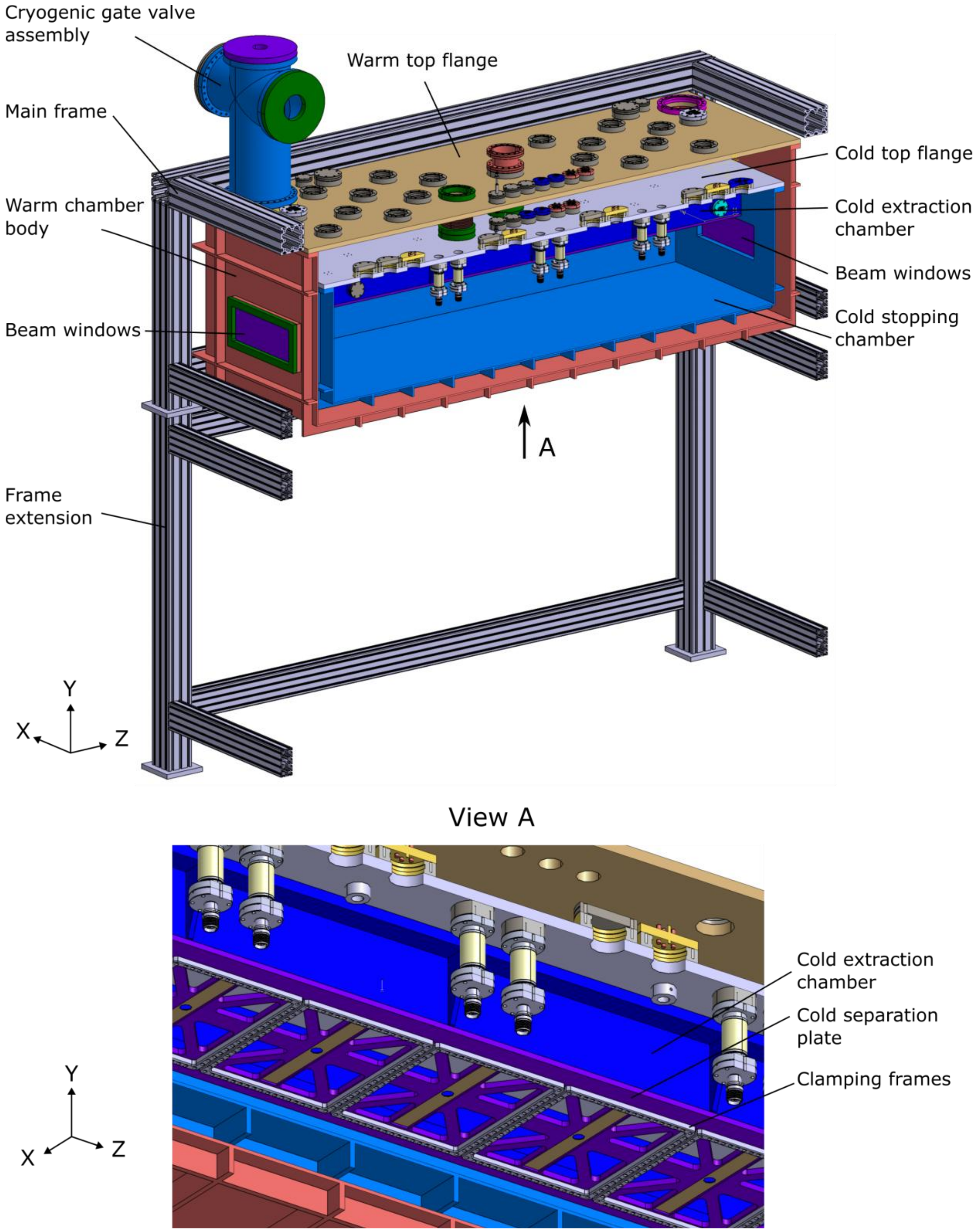

Figure 5. Section view of the CSC showing components in the scope of this delivery. Blind flanges, adaptor flanges, bellows, electrical feedthroughs, overpressure protection valves, security valves and associated gaskets are not labeled. Copper braids, pressure and temperature sensors, baking system, lifting table, and lifting and transport gear are not shown.

The delivery must include:

- Warm chamber body
- Warm top flange
- Cold extraction chamber
- Cold stopping chamber
- Cold top flange
- Cold separation plate
- Clamping frames
- Suspension system for vacuum chambers
- Cryogenic gate valve assembly
- Blind flanges, adaptor flanges, bellows and associated gaskets
- Electrical feedthroughs
- Overpressure protection valves, security valves
- Copper braids for connecting cryocoolers to cold top flange.
- Beam windows
- Heating/baking system
- Temperature sensors and readout
- Pressure measurement in cold stopping chamber
- Main frame
- Frame extension
- Lifting table
- Lifting and transport gear
- Design and finite element analysis (FEA) of the vacuum chambers and their support frames, according to stability and dimensioning criteria.
- Thermo-mechanical calculations for relevant operating scenarios (cool-down, warm-up, normal operation, bake-out conditions). The results shall demonstrate sufficient cooling capacity, acceptable temperature gradients, and allowable thermal stresses in all components of the cryogenic system and shall be documented.
- 3D-model, manufacturing drawings including complete set of drawing for tools, process control plan, test plan and time schedule for design, production and delivery (see the FAIR General Specifications F-GS-F-01e [1]).
- Further documentation according to Section 7 of the General Specification.

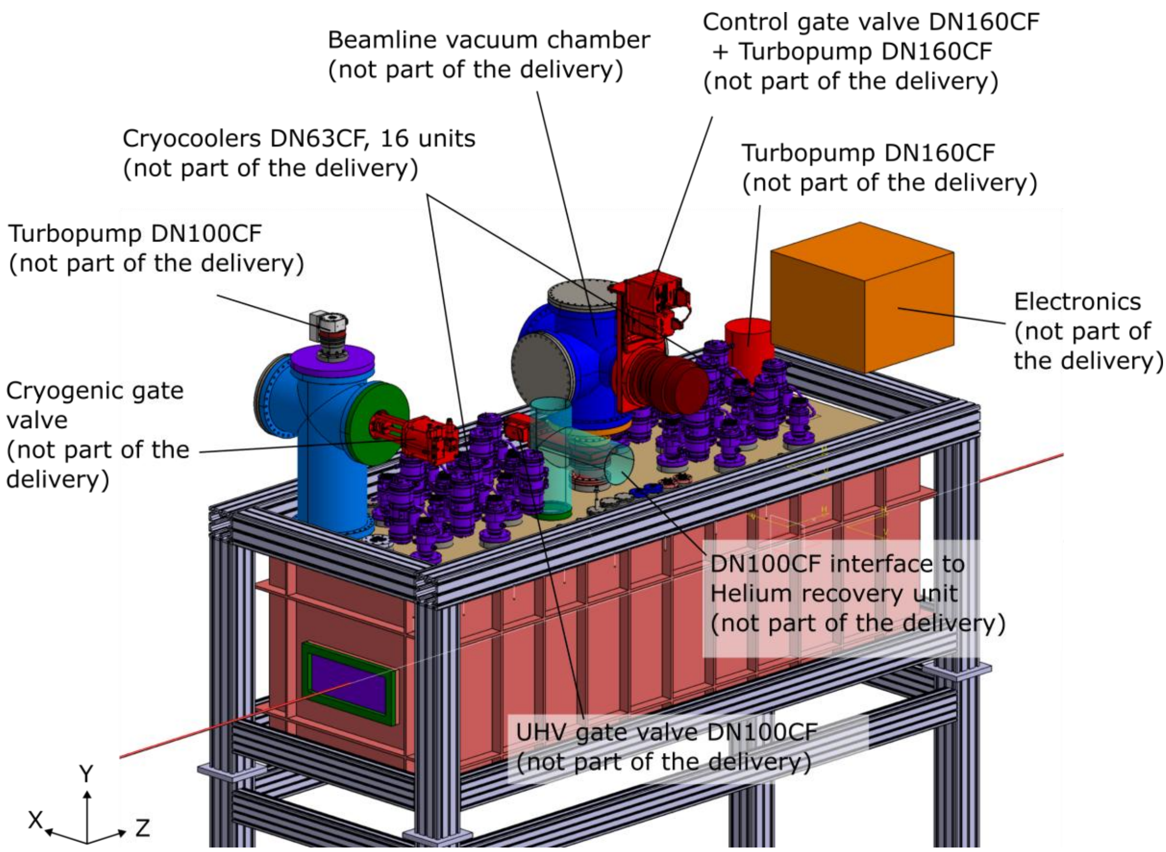

*Figure 6. Section view of the CSC showing components that are **not** in the scope of this delivery.*

Figure 6 shows components of the CSC that the delivery must **not** include:

- Cryocoolers DN63CF
- Turbopump DN100CF
- Cryogenic gate valve
- Control gate valve DN160CF
- Turbopump DN160CF
- UHV gate valve DN100CF
- Electronics to drive DC and RF components
- Beamline vacuum chamber
- RF Carpets
- DC cage
- Control system

3.3 Spare Parts

The delivery must include spare parts including:

- Four spare beam entrance windows
- Twenty spare metal gaskets for sealing of cold extraction chamber
- Twenty spare metal gaskets for sealing of cold stopping chamber
- Ten spare gaskets for sealing of warm chamber

4 System Specification

4.1 Technical Requirements for System Components

- The outer dimensions of the complete system must be a length of under 2.9 m, a width of 1.3 m, and a height of 3.4 m, as indicated in Figure 2.
- Warm and cold vacuum chambers, the corresponding top flanges and cold separation plate shall be made of aluminum alloy. Preferred alloy is Aluminum 6061-T6.
- The dimensions of vacuum chambers are defined in Table 2. Dimensions outline the inner volume. Wall thickness and flanges are not considered.
- All internal surfaces of the cold stopping and extraction chambers shall be electropolished or mechanically polished. The purpose of this surface treatment is to reduce surface outgassing, minimize particle generation, and maintain high gas purity within the cryogenic stopping cell.
- The stability of the chambers shall be proven by the Contractor with FEM analysis. The wall thickness of the vacuum chambers shall be decided by the Contractor considering the structural stability of the chambers and the available space. The FEM analysis shall consider load scenarios indicated in Table 3.
- External reinforcement ribs may be considered to increase stiffness of vacuum chambers and flanges.
- All welding seams shall be done by a certified welder. All weld joints shall be of full-penetration type. The joint design shall exclude any trapped volumes that may give rise to virtual leaks. Internal welds shall be used wherever practicable. External welds shall only be permitted where internal welding is not technically feasible, and their use shall be documented and subject to approval by the Company.
- The weld quality class for the cold vacuum chambers and flanges shall be weld class B according to ISO 10042.
- The weld quality class for the warm vacuum chambers shall be weld class C or better according to ISO 10042.
- The weld quality class for the main frame and frame extension shall be weld class C or better.
- The cold extraction chamber and the cold stopping chamber shall be sealed using metal gaskets to ensure ultra-high vacuum integrity under cryogenic conditions. The sealing design shall ensure direct flange-to-flange contact between the mating components. This is strictly required for efficient conductive cooling from the cold top flange to the bodies of the cold extraction and cold stopping chambers.
- The sealing surfaces and flange geometry must be designed to withstand at least 50 assembly cycles with minimal risk of wear or degradation. The Contractor shall propose a sealing solution (such as, but not limited to, diamond-profile metallic seals) that allows for relatively simple and localized repair of the sealing surfaces in the event of minor scratching or damage. Sealing concepts that require the complete replacement of a vacuum chamber or extensive remachining due to minor damage to the sealing edge are not acceptable for these primary rectangular flanges.

- Warm chamber shall be sealed with elastomer gaskets.
- The cold top flange, including attached cold extraction chamber, cold stopping chamber, all flanges and mounted components, shall be mounted in a suspended configuration from the top flange of the warm chamber (warm top flange). The suspension system shall support the full weight of the cold chamber assembly exclusively and shall not require any additional supports during normal operation.
- Warm top flange and cold top flange shall be interfaced with flanges and ports specified in Section 4.3.
- Aluminum chambers shall be interfaced with standard stainless steel CF flanges (governed by ISO 3669) and components using specialized bimetallic flanges.
- The main frame and frame extension shall ensure that the central axis of the vacuum chamber beam entrance ports is positioned at a height of 2000 mm (+0 mm / -10 mm) relative to the floor level. The design shall incorporate provisions for height adjustment within +50 mm and -50 mm.
- The frame extension shall incorporate adjustable base plates or feet compatible with the Company's facility floor alignment plates (to be specified later). The Contractor shall design these interfaces to match the provided geometric and dimensional details, which will be supplied during the detailed design review phase.
- The mass of the assembled system excluding the lifting table shall stay under 3 tons.
- The Contractor shall affix CE marking to all supplied equipment in accordance with applicable EU Directives, including provision of the complete Technical File and signed EU Declaration of Conformity.

Table 2.Technical requirements for warm and cold vacuum chambers. Dimensions outline the inner volume. Wall thickness and top flanges are not considered.

Component	**Dimension, mm** **Length x Width x Height**	**Material**
Warm chamber	2400 x 900 x 750	Aluminum (preferably 6061-T6)
Cold stopping chamber	2250 x 750 x 500	Aluminum (preferably 6061-T6)
Cold extraction chamber	2130 x 360 x 150	Aluminum (preferably 6061-T6)
Cold Separation Plate	2130 x 360 x 10	Aluminum (preferably 6061-T6)

The final values for all dimensions and their tolerances given in these specifications are subject to the final design. The final design and the production drawings are the responsibility of the contractor.

Table 3. Load scenarios for FEM analysis of stability of vacuum chambers. Absolute pressures are assumed.

Scenario	**Pressure**			
	Warm chamber	**Cold stopping chamber**	**Cold extraction chamber**	**Ambient**
1	Vacuum	Vacuum		1 bar
2	Vacuum	1 bar		1 bar
3	1 bar	Vacuum		1 bar
4	1 bar	1bar	Vacuum	1 bar

4.2 Functional requirements (Parameter list)

This section defines the functional requirements of the system in terms of the measurable performance parameters and boundary conditions to be met by the Contractor. The corresponding parameter list is provided in *Table 4*.

Table 4. Functional requirements

Parameter	**Value**
Operating temperature	70–130 K
Bake-out temperature	380 K
Cool-down time	100 K in < 24 hours 70 K in < 48 hours
Integral leak rate for cold vacuum chambers	$\leq 1 \times 10^{-9}$ mbar·L/s
Integral leak rate for warm vacuum chambers	$\leq 1 \times 10^{-7}$ mbar·L/s
Operating pressure in cold stopping chamber	300 mbar (helium at 70 K)
Maximum allowable pressure in the cold stopping chamber	1050 mbar (absolute)
Maximum allowable pressure in the warm stopping chamber	1050 mbar (absolute)

Thermal functional requirements assume cooling power of 480 Watts provided by sixteen cryocoolers CryoTel® DS30 (not part of this delivery). Technical specifications of the CryoTel® DS30 cryocoolers will be provided by the Company.

The system design shall ensure that the gas pressure in the cold extraction chamber never exceeds the pressure in the cold stopping chamber under any operating or fault conditions. To guarantee this, the Contractor shall incorporate a pressure-relief or one-way valve system between the two chambers. This equalization valve shall automatically open to vent gas from the extraction chamber to the stopping chamber in the event of a reverse pressure gradient, thereby protecting the internal components (such as the RF carpets and separation plate) from mechanical damage. The valve mechanism must be compatible with operation and ultra-high vacuum conditions listed in Table 4, and shall not introduce virtual leaks or particulate contamination.

4.3 Interfaces

All connections for media (pumping, cooling, helium gas) and for the electrical components are made through the top flange of the warm chamber. The connections are shown schematically in Figure 7 and are specified in this section.

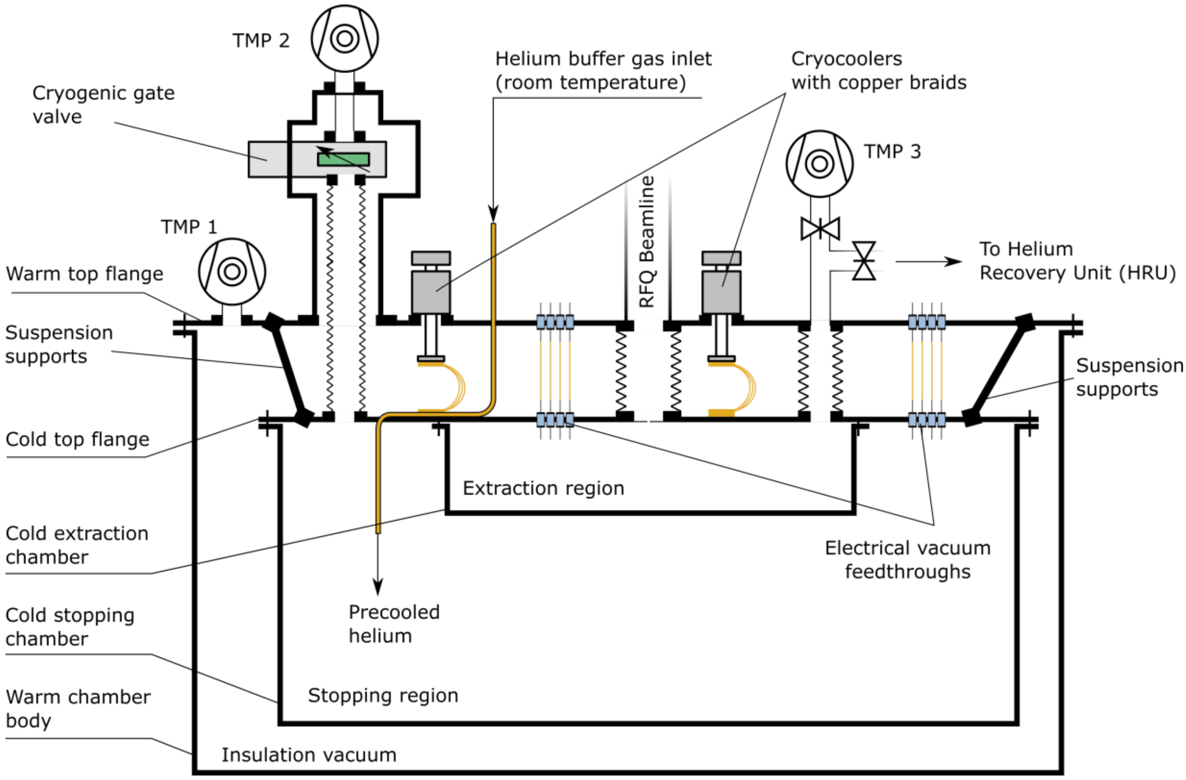

Figure 7. Schematic figure illustrating the connections of the CSC.

The cooling system of the CSC is based on electrically driven cryo-coolers. The cryo-coolers are mounted on the top flange of the warm chamber and connected to the top flange of the cold chambers using flexible copper braids. The helium stopping gas is fed into the CSC at room temperature; pre-cooling occurs in loops of the gas line that are in thermal contact with the top flange of the cold chambers. A turbomolecular pump TMP 1 is used for evacuating the warm chamber. The stopping and the extraction regions of the cold chambers are evacuated using turbomolecular pumps TMP2 and TMP3 respectively. For normal operation with stopping gas in the CSC, the extraction region is connected to the Helium Recovery Unit (HRU, not part of this delivery) for pumping. The pumping ports are connected to the vacuum chambers by flexible bellows.

4.3.1 Pumping ports

Figure 8 and Figure 10 illustrate conceptual arrangement of the pumping ports and their interfaces. The Contractor shall design the pumping ports in accordance with these concepts and the boundary conditions defined in this specification

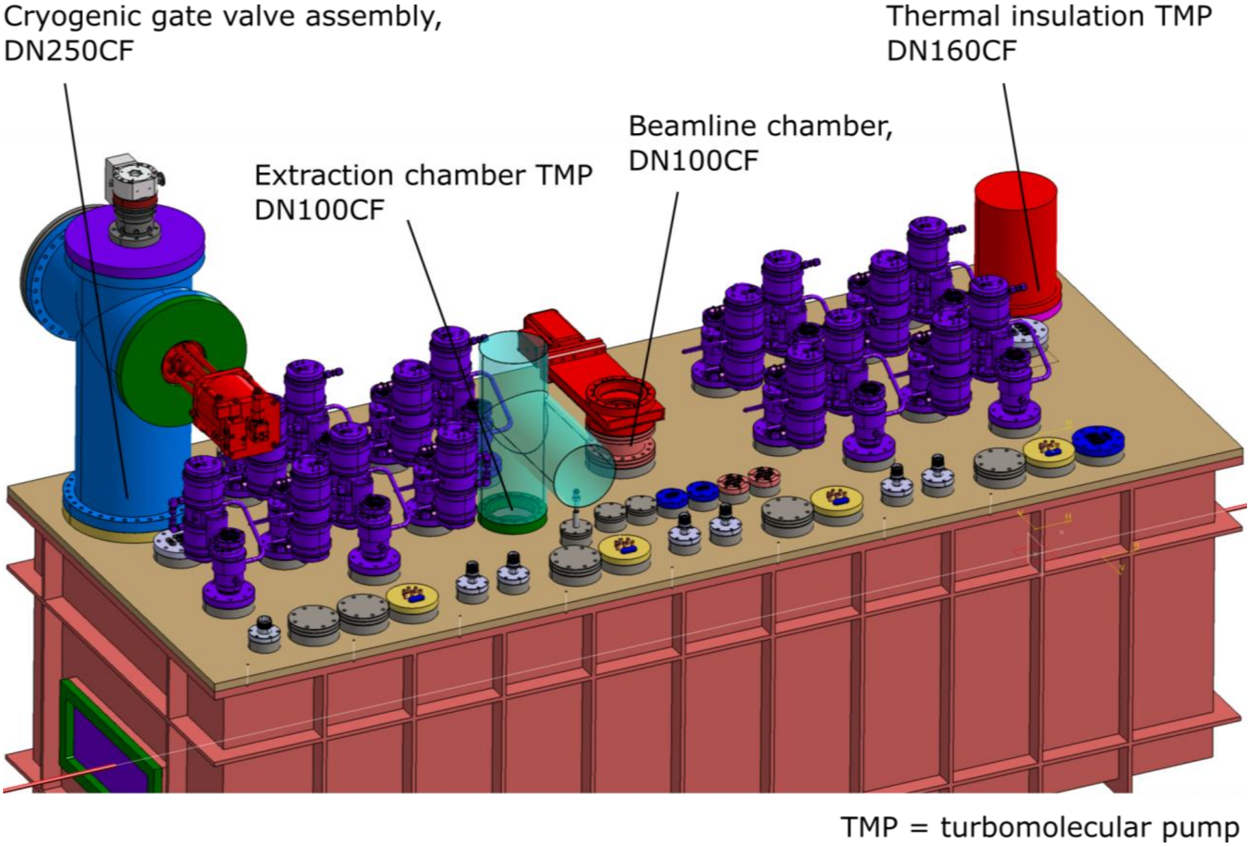

Figure 8. Pumping ports of the warm chamber top flange

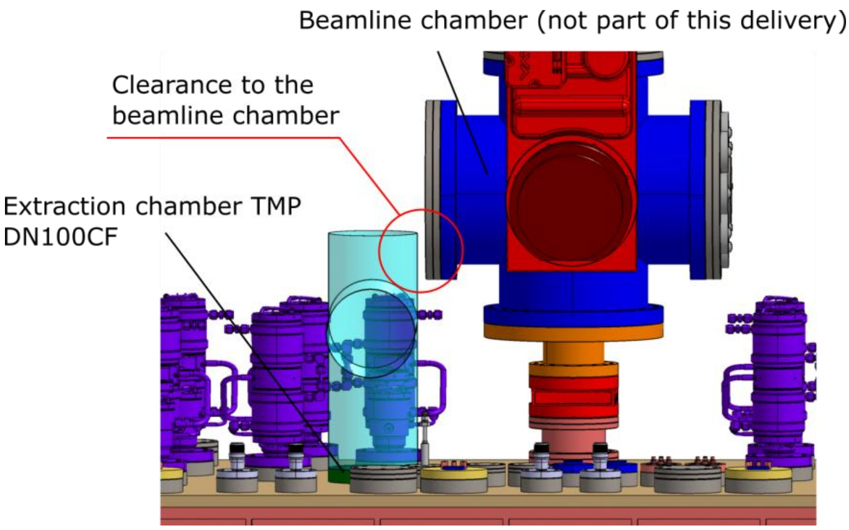

Figure 9. Position of extraction chamber TMP port shall ensure clearance to the beamline chamber

Positioning of the extraction chamber TMP port on the warm top flange shall ensure clearance to the beamline chamber as indicated by the opaque cyan region in Figure 9.

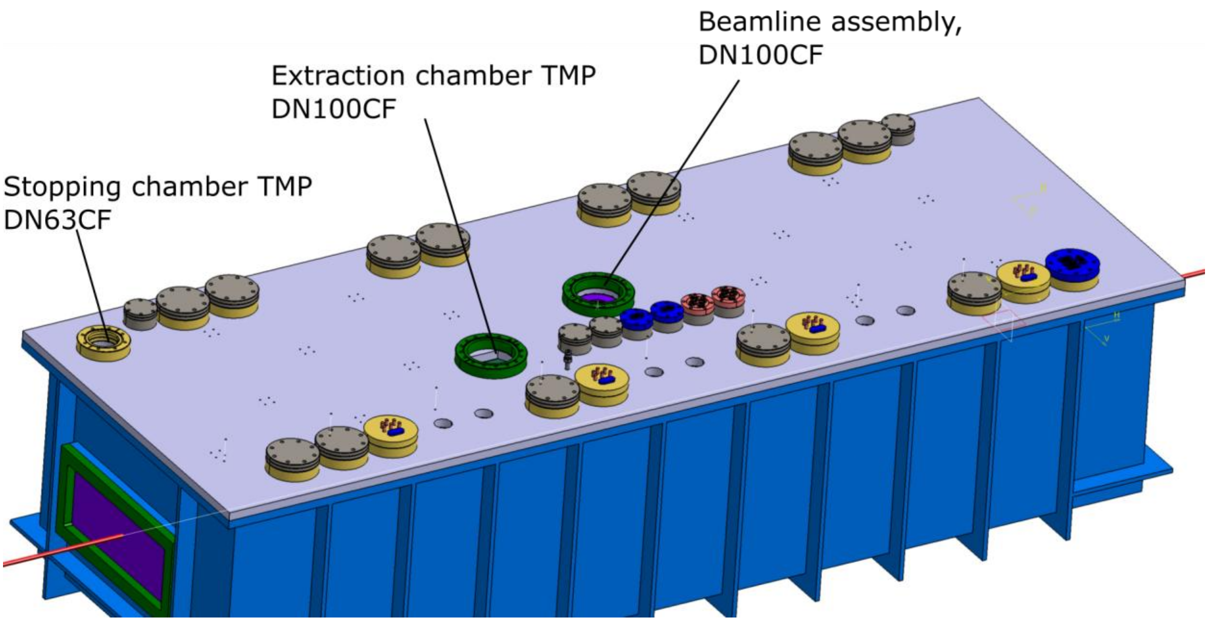

Figure 10. Pumping ports of the cold chambers top flange

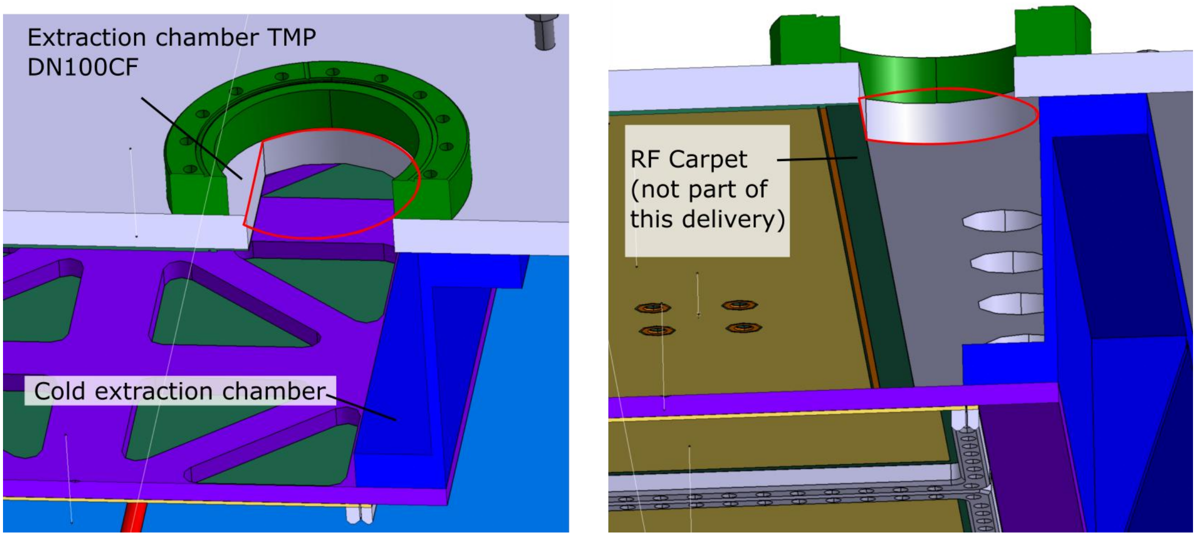

Figure 11. Non-circular shape of the pumping port of the cold extraction chamber

The pumping port of the extraction chamber, as shown in Figure 11, shall be designed such that sufficient continuous installation area for the RF carpet is ensured. A circular port geometry is preferred where this can be achieved without compromising the available RF carpet mounting area. Where a circular geometry conflicts with the required RF carpet installation space, a non-circular port geometry shall be used.

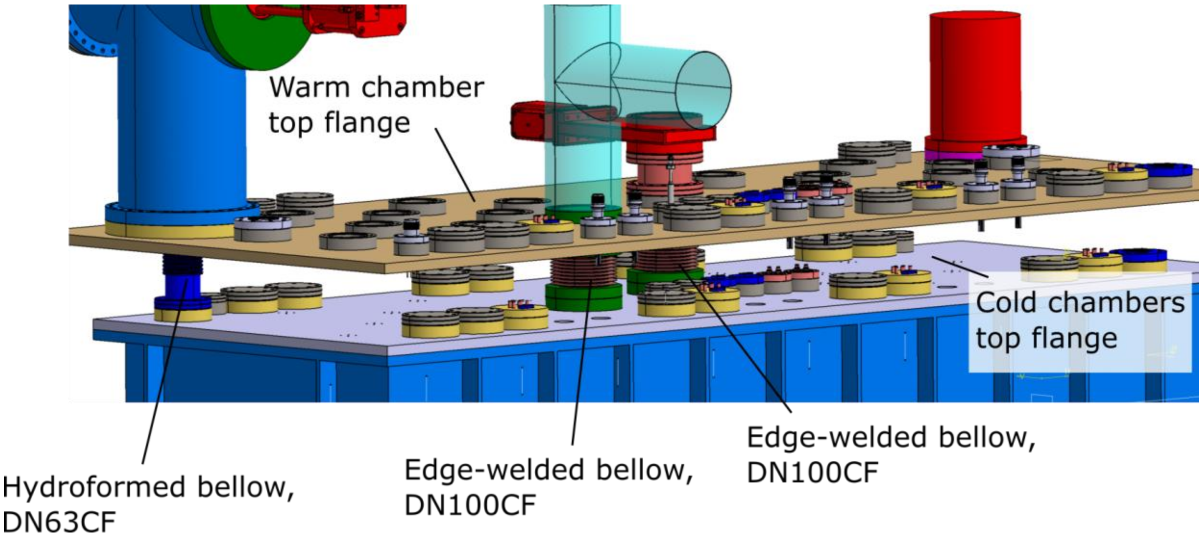

Figure 12. Pumping ports interface between warm top flange and cold top flange

The extraction chamber TMP port and the beamline assembly port on the warm top flange shall be interfaced with the corresponding ports on the cold top flange via edge-welded bellows as shown in Figure 12.

The stopping chamber TMP port on the cold top flange shall be interfaced with the cryogenic gate valve assembly shown in Figure 29.

The thermal-insulation TMP port on the warm top flange shall have no interface with the cold top flange.

4.3.2 Ports and thermal links for cryocoolers

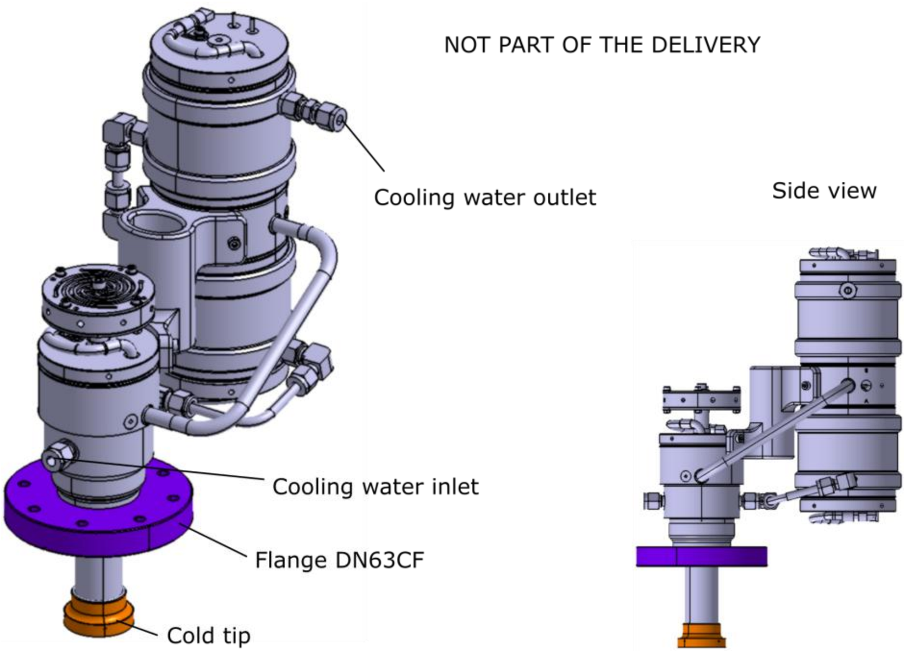

Figure 13. Components of a cryocooler. Cryocoolers are not part of this delivery.

The cryocoolers are the main components of the cryogenic system that provides the cooling power required to remove the thermal load from the system and to cool the cold chamber assembly to the specified operating temperature.

The cryocoolers are not part of the Contractor's scope of delivery. Their specification is provided solely to define the design boundary conditions for the vacuum chambers and associated interfaces. The 3D model, technical specifications and drawings of the cryocoolers will be provided. Components of a cryocooler are shown in Figure 13.

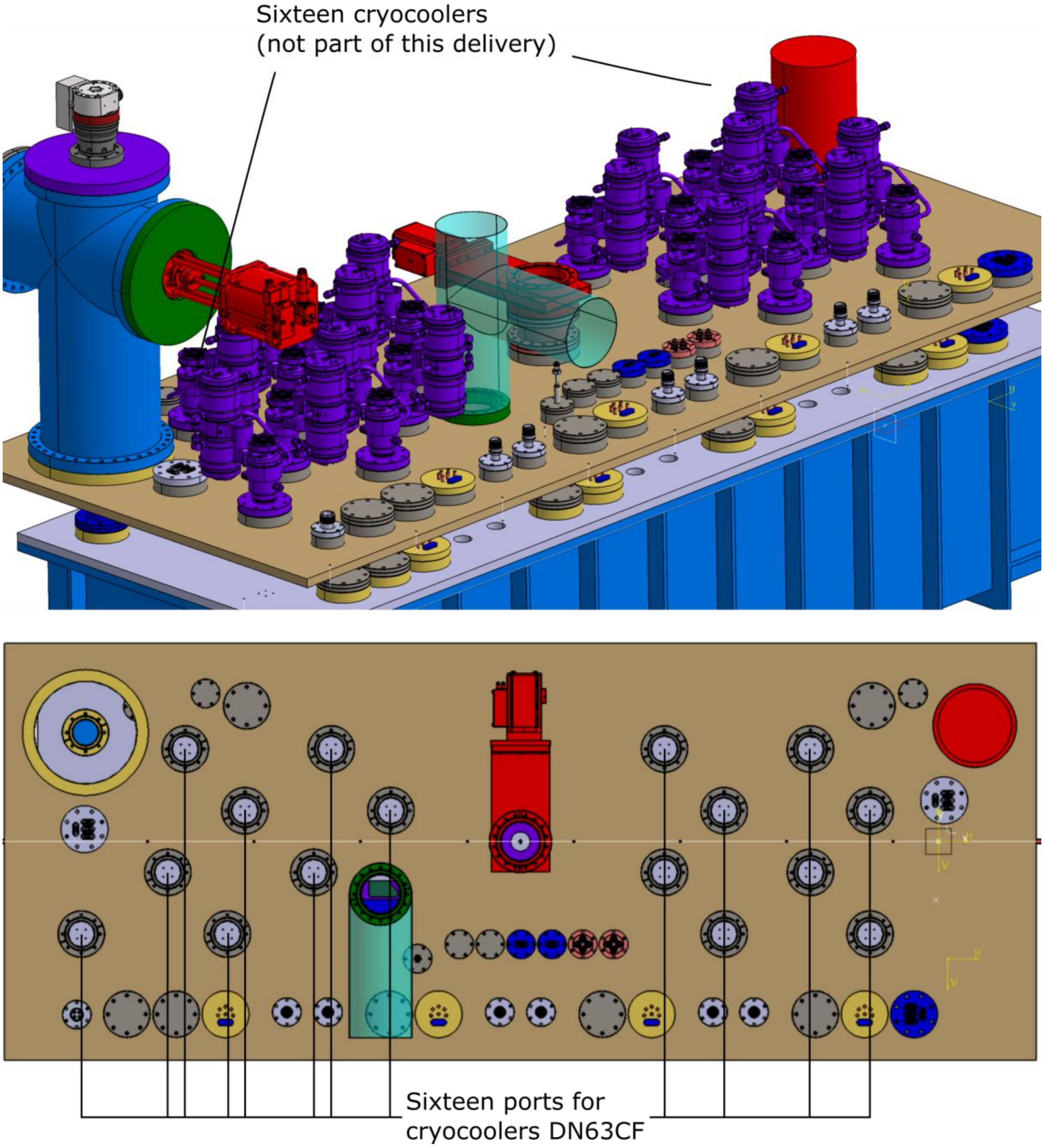

Figure 14. Sixteen cryocoolers and their corresponding ports with DN63CF flanges on the top warm flange.

A total of sixteen cryocoolers shall be foreseen (Figure 14). Each cryocooler shall be mounted with its DN63CF flange to the warm top flange and thermally linked with its cold tip to the top cold flange. The cold tips of the cryocoolers shall be connected to the top cold flange by means of flexible copper braids.

The screw hole pattern of the cold tip is shown in Figure 15. **The top cold flange shall include the corresponding interface and attachment points required for the connection of the flexible copper braids.**

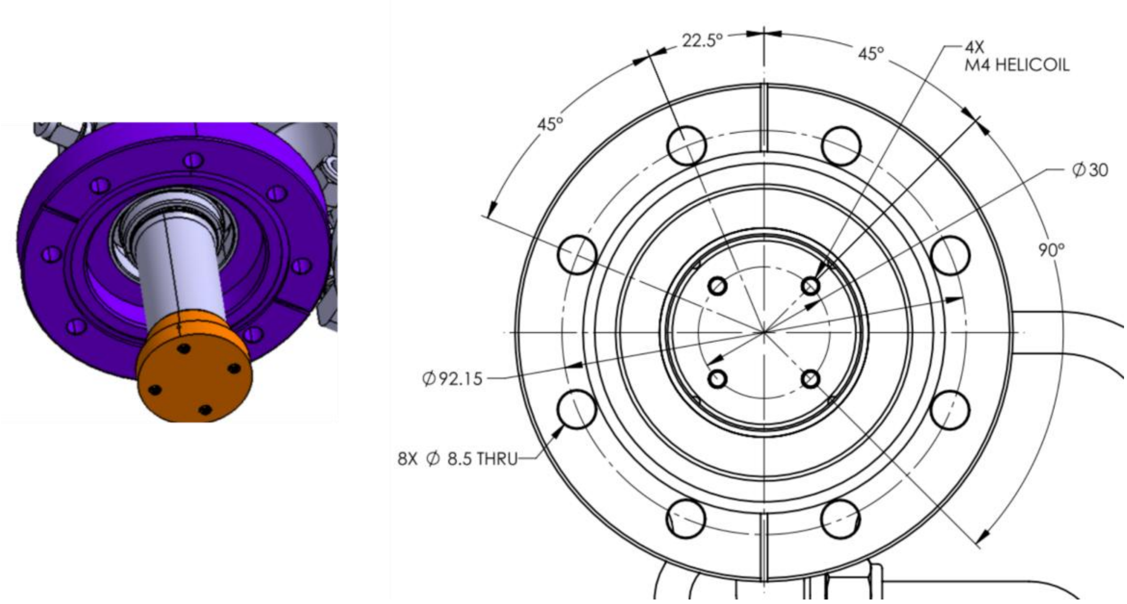

Figure 15. Screw hole pattern at the cold tip of the cryocooler.

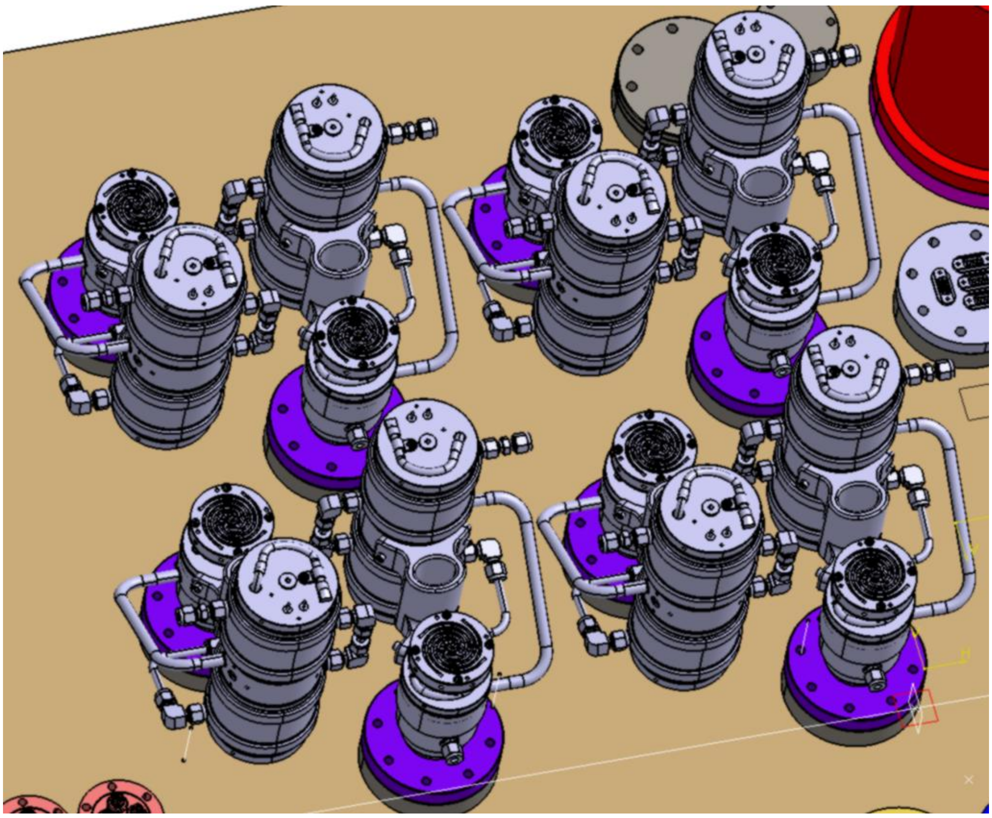

Figure 16. Possible arrangement of cryocoolers

The arrangement and spacing of the cryocoolers on the warm top flange shall ensure sufficient clearance for the cooling-water connections and their installation.

The checkerboard arrangement shown in Figure 16 illustrates the requirement for a uniform distribution of cooling power across the top cold flange and for a compact arrangement of the cryocoolers without collision or interference of the cooling-water connections. Alternative arrangements may be proposed by the Contractor.

4.3.3 Bake-out system

The CSC shall be bakeable to the bake-out temperature specified in Section 4.2 prior to cool-down to achieve optimum cleanliness of the stopping cell. The heating solution shall also allow for a fast warming-up of the CSC for maintenance. Preferably, the heating shall be attached directly to the cold top flange, utilizing conductive heat transfer to warm the entire cold chamber assembly.

The heating system and its control logic shall ensure that temperature gradients across the vacuum chambers and flanges remain within safe limits to prevent permanent mechanical deformation or excessive stress on the seals.

The Contractor shall verify the proposed heating concept via thermal calculations.

4.3.4 Beam windows

The front and rear outer faces of the warm chamber and of the cold stopping chamber shall be provided with ports for the installation of beam window assemblies.

A beam window is a rectangular metal foil with the width of 400 mm, height of 150 mm and thickness of approx. 100 micrometers fixed onto a metal mounting flange. Conceptual design and location of beam windows is shown in Figure 17.

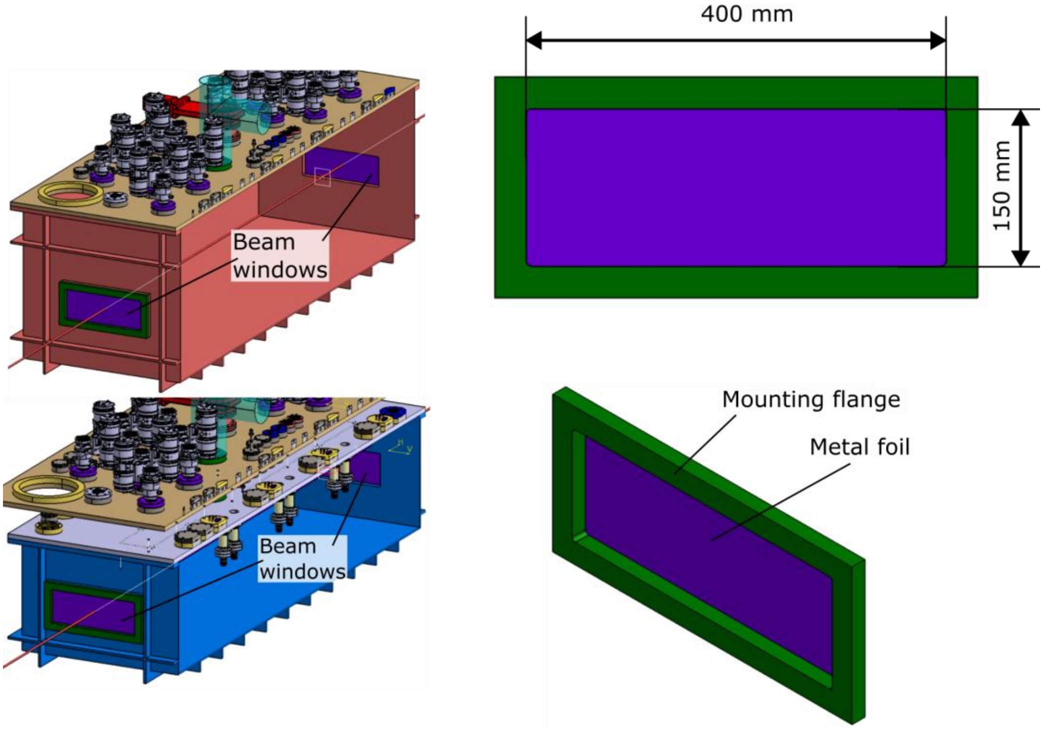

Figure 17. Conceptual design and location of beam windows

The beam window foil and the corresponding mounting flange shall be made of titanium. The preferred material is titanium Grade 5 (Ti-6Al-4V). The mounting flange shall include a suitably rounded edge radius in the contact area with the foil to prevent damage to or to the tearing of the beam window. The Contractor shall propose the beam window design solution and shall demonstrate by calculation and, if required, by test that the beam window assembly can withstand a pressure difference of 1050 mbar.

If required to ensure the mechanical integrity of the beam window, a support grid may be incorporated into the design. Any support grid should be designed such that it does not obscure the central area of 150 mm x 100 mm.

If the Contractor considers an increase in foil thickness necessary, this shall be subject to prior agreement by the Company.

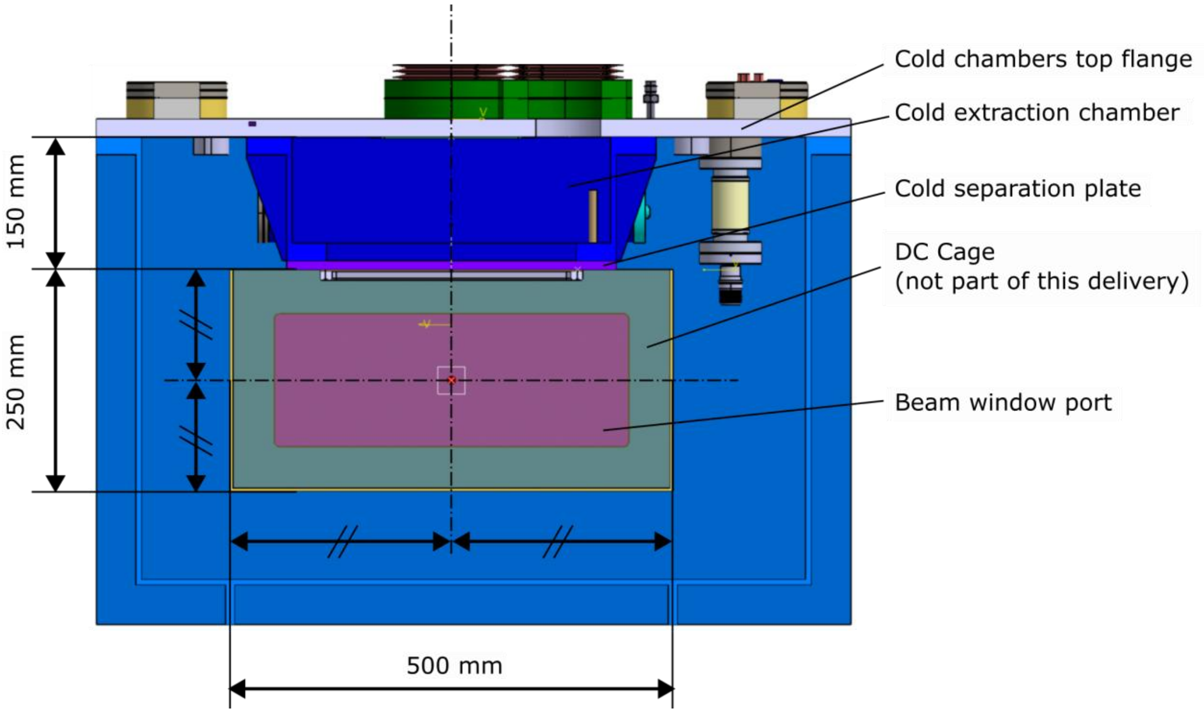

Figure 18. Positioning of beam window ports

The beam window ports shall be arranged symmetrically with respect to the DC cage. The position of the DC cage shall be defined such that its upper boundary is located 150 mm below the top flange of the cold chamber and coincides with the boundary of the cold separation plate. The dimensions of the DC cage shall be 500 mm x 250 mm (width x height).

4.3.5 Electrical feedthroughs

Electrical feedthroughs provide electrical interfaces for components installed inside the vacuum chambers while maintaining vacuum integrity and electrical insulation across the chamber boundary. All feedthroughs shall be suitable for operation over the full temperature and pressure range specified in Section 4.2. Feedthroughs offered by Accu-Glass Products, Inc. and Allectra GmbH are considered suitable reference solutions; equivalent products may be proposed by the Contractor.

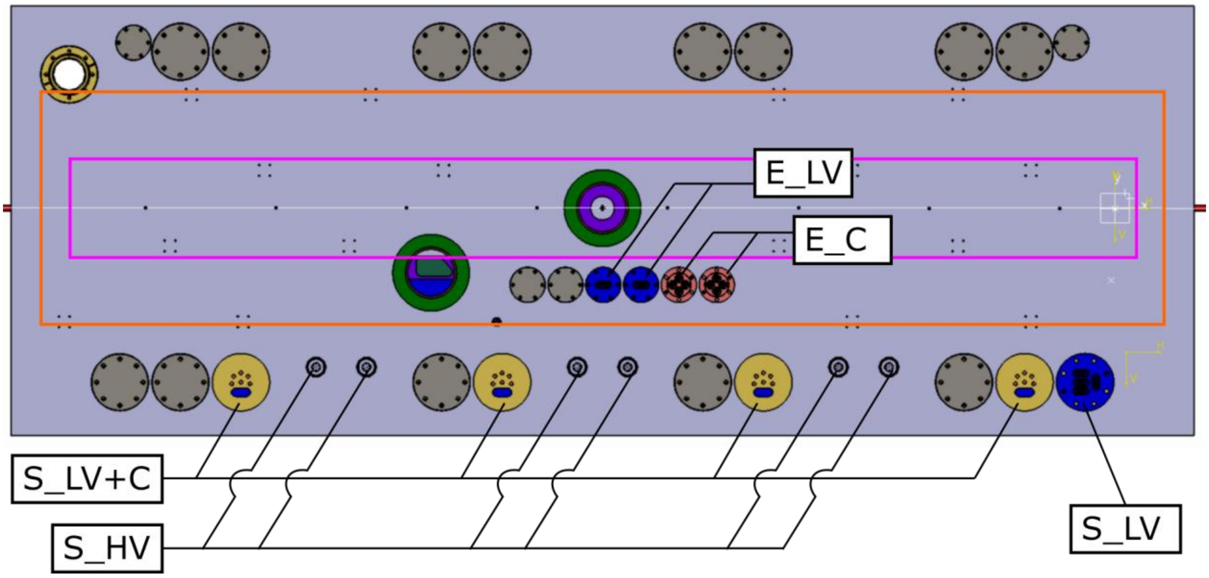

Figure 19. Electrical feedthroughs at the cold chambers top flange

Figure 19 shows arrangement of electrical feedthroughs at the top flange of cold chambers. Orange line indicates the boundary of the extraction region. Electrical feedthroughs for components of the extraction region shall not be routed through the stopping region, and feedthroughs for components of the stopping region shall not be routed through the extraction region.

Feedthroughs of the extraction region shall not overlap the extraction RF carpet mounting area. Purple line indicates the corresponding boundary.

The details about electrical feedthroughs of cold chambers are listed in Table 5.

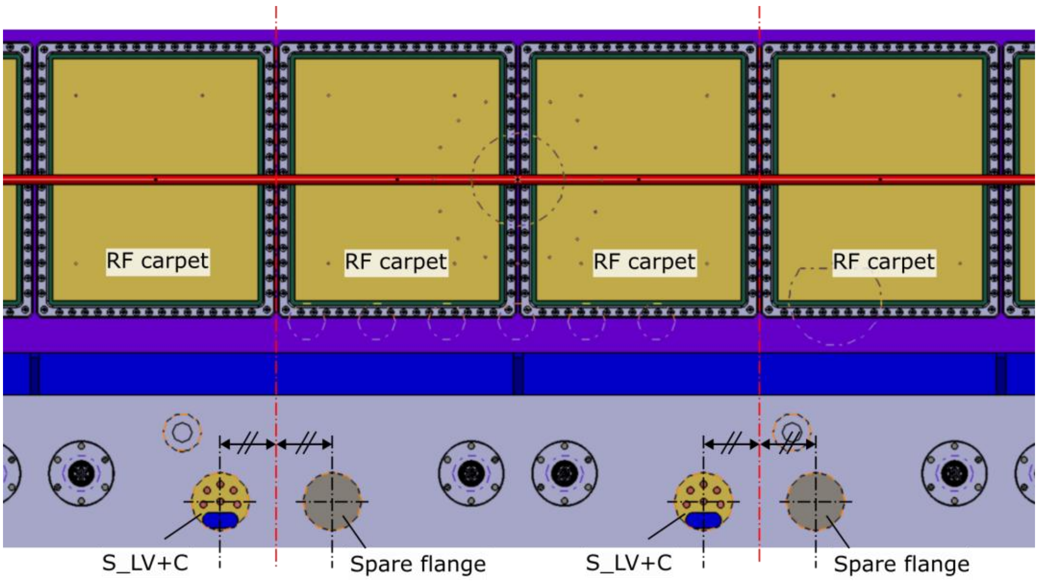

Figure 20. Arrangement of S_LV+C feedthrough with respect to RF carpets

One pair consisting of an S_LV+C feedthrough and the adjacent spare flange shall be arranged symmetrically with respect to the centers of the RF carpets (Figure 20) to achieve short and approximately equal cable lengths. This arrangement assumes that one such feedthrough supplies two RF carpets. A corresponding pair of spare DN63CF flanges shall be provided on the opposite side with respect to the beam axis.

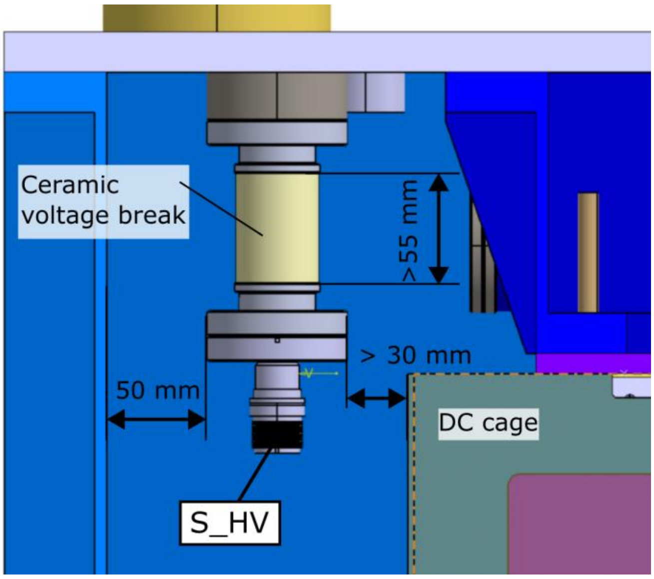

Figure 21. Section view of the S_HV feedthrough assembly inside the cold stopping chmaber

The S_HV feedthrough shall be placed at a sufficient distance from the walls of the cold stopping chamber and from the DC cage such that operation at 5 kV in helium at 200 mbar is possible without electrical discharge. The feedthrough assembly shall be electrically decoupled from the cold top flange so that it can be floated up to 5 kV. This may be realized, for example, by means of ceramic voltage breaks, provided that their dimensions and insulation properties are sufficient to prevent electrical discharge between the floated and grounded ends. Figure 21 illustrates the assumed design solution and the corresponding distances as the basis for the design concept. Alternative solutions may be proposed by the Contractor, provided that compliance with all specified requirements is demonstrated.

Table 5. List of electrical feedthroughs of the cold chambers top flange

Code	Description	Feedthrough type	Q-ty	Flange	Purpose
E_LV	Extraction region, low voltage	9-pin D-Sub	2	DN40CF	DC of extraction RF Carpet
E_C	Extraction region, coaxial	4-pin SMA	2	DN40CF	RF (~3 MHz) of extraction RF Carpet
S_LV+C	Stopping region, low voltage + coaxial	Custom (15-pin D-Sub + 6-pin SMA)	4	DN63CF	DC + RF (~10 MHz) of stopping RF carpets
S_HV	Stopping region, high voltage	7-pin (Allectra 267-075HV12K-7-C40)	6	DN40CF	DC (5 kV) for DC cage
S_LV	Stopping region, low voltage	4x9-pin D-Sub	1	DN63CF	Temperature and pressure sensors readout, DC (<200 V) inputs

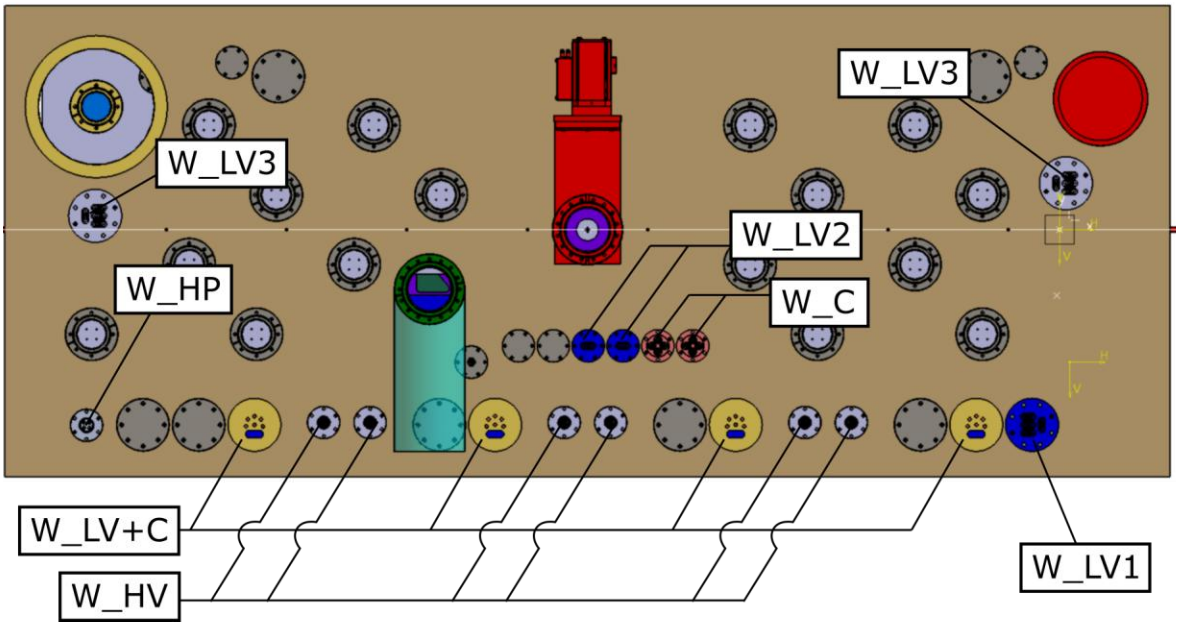

Figure 22. Electrical feedthroughs at the warm chamber top flange

The arrangement of electrical feedthroughs at the top flange of warm chamber is shown in Figure 22 and Table 6.

Table 6. List of electrical feedthroughs of the warm chamber top flange

Code	Description	Feedthrough type	Q-ty	Flange	Purpose
W_LV1	Warm chamber, low voltage	4x9-pin D-Sub	1	DN63CF	Temperature and pressure sensors readout, LV DC (<200 V) inputs
W_LV2	Warm chamber, low voltage	9-pin D-Sub	2	DN40CF	DC of extraction RF Carpet
W_LV3	Warm chamber, low voltage	4x9-pin D-Sub	2	DN63CF	Temperature sensors of cryocoolers
W_C	Warm chamber, coaxial	4-pin SMA	2	DN40CF	RF (~3 MHz) of extraction RF Carpet
W_LV+C	Warm chamber, low voltage + coaxial	Custom (15-pin D-Sub + 6-pin SMA)	4	DN63CF	DC + RF (~10 MHz) of stopping RF carpets
W_HV	Warm chamber, high voltage	7-pin (Allectra 267-075HV12K-7-C40)	6	DN40CF	HV DC (5 kV) for DC cage
W_HP	Warm chamber, high power	--	1	DN40CF	Heating elements for bake-out

The electrical feedthroughs between the top flanges of the warm and cold chambers shall be wired in accordance with the allocation specified in

Table 7.

Table 7. Wiring allocation of electrical feedthroughs between the warm and cold top flanges

Warm chamber top flange	Cold chamber top flange	Purpose
W_LV1	S_LV	Temperature and pressure sensors readout, LV DC inputs
W_LV2	E_LV	DC of extraction RF Carpet
W_LV3	--	Temperature sensors of cryocoolers
W_C	E_C	RF (~3 MHz) of extraction RF Carpet
W_LV+C	S_LV+C	DC + RF (~10 MHz) of stopping RF carpets
W_HV	S_HV	HV DC (5 kV) for DC cage
W_HP	--	Heating elements for bake-out

Coaxial cables shall be routed and thermally anchored to minimize their heat input into the cryogenic system. The Contractor shall propose the corresponding technical solution and demonstrate its suitability.

4.3.6 Gas feedthroughs

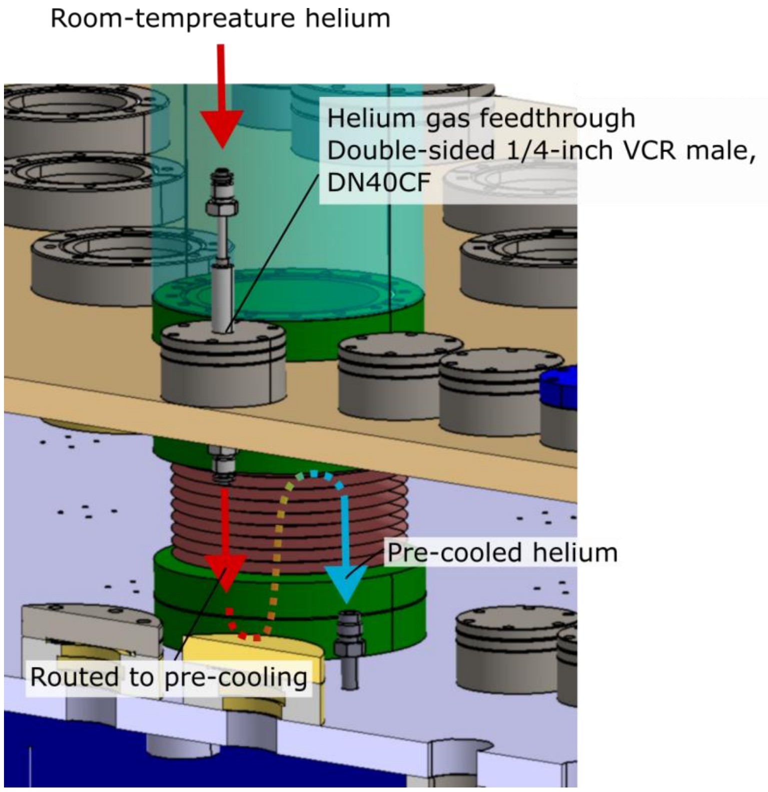

Figure 23. Schematic illustration of gas feedthroughs

Helium gas shall be supplied to the system at room temperature through a double-sided 1/4-inch VCR male feedthrough mounted on a DN40CF flange. From there, the gas shall pass through a pre-cooling system before entering the cold stopping chamber via the cold top flange (Figure 23. Schematic illustration of gas feedthroughs).

The pre-cooling system shall eliminate hot spots on the cold top flange, ensuring the maximum temperature above the stopping region remains below 90 K and above the extraction region remains below 130 K during nominal operation (helium gas at 70 K). Design of the pre-cooling system is the responsibility of the Contractor. As an example, the pre-cooling system may consist of a pipe, channel, or equivalent gas line that is thermally linked to the cold top flange, the cryocoolers, or the copper braids. The Contractor shall demonstrate by calculation the thermal performance of the proposed pre-cooling system design.

4.3.7 Pressure measurement in cold stopping chamber

The system shall be equipped with a pressure measurement assembly capable of providing a continuous and reliable pressure readout directly from the cold stopping chamber. The output signal of this pressure measurement will be utilized by the control system within an active feedback loop to dynamically regulate the gas pressure inside the cold chamber. The Contractor shall design and propose the complete technical solution for this pressure measurement, including the sensor type, mounting location, routing, and necessary feedthroughs. The proposed solution shall be fully compatible with the operating conditions, as defined in Section 4.2.

The output signal of the sensor will be used in the control system in the feedback loop to regulate the pressure in the cold chamber.

The Contractor shall demonstrate that the chosen implementation minimizes heat input into the cryogenic system and maintains the required ultra-high vacuum integrity.

4.3.8 Spare ports

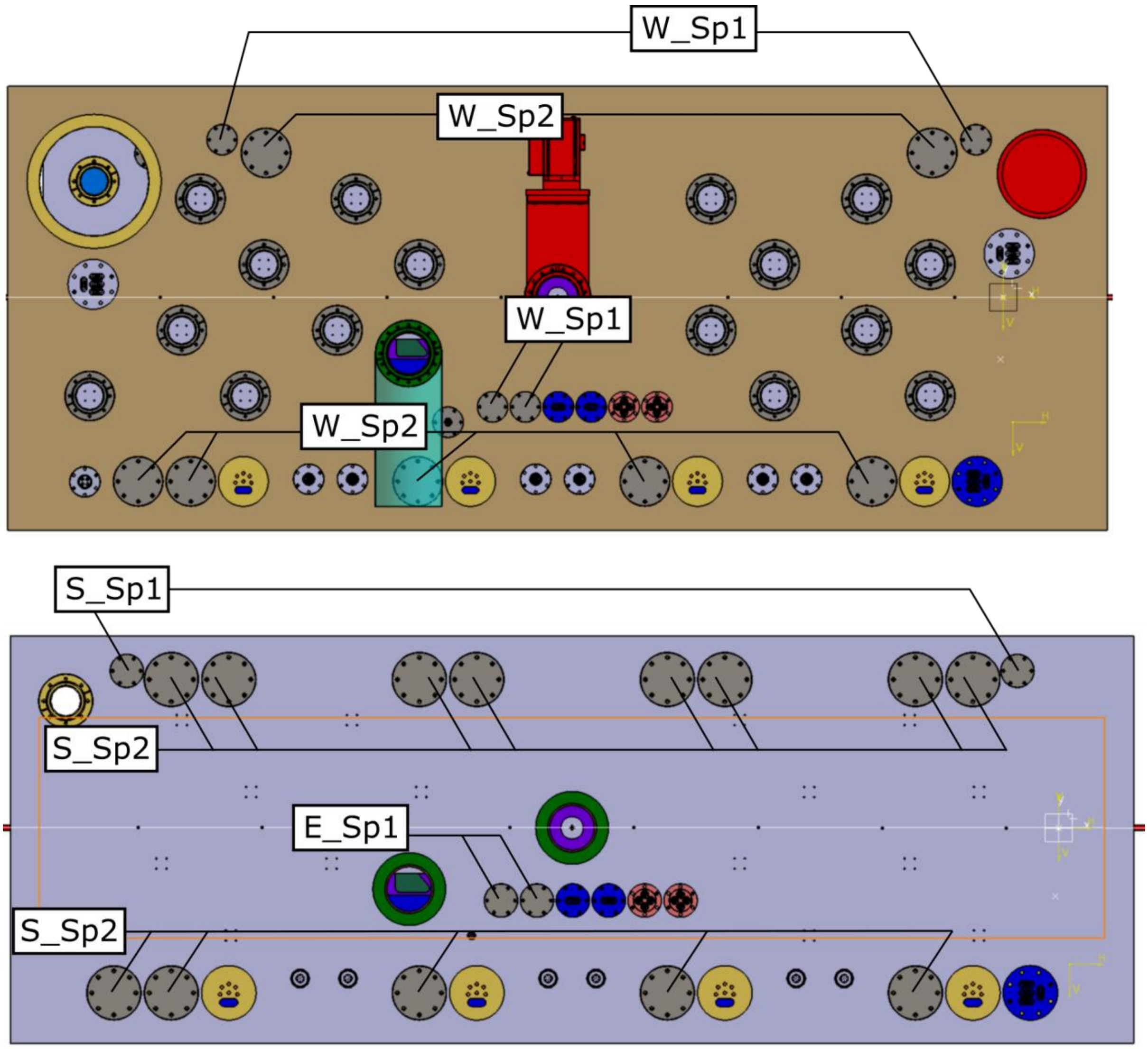

Figure 24. Spare ports at the top warm and cold flanges.

The ports for the spare flanges designated in Figure 24 as "W_Sp…", "E_Sp1", and "S_Sp…" shall be designed and positioned in accordance with the same constraints and requirements as defined for their corresponding active flanges ("W_...", "E_...", and "S_...") in Section 4.3.5.

4.3.9 Mounting points for DC cage in stopping region

The inner side of the top cold flange shall be equipped with mounting interfaces (ports or attachment points) for the structural suspension of the DC cage assembly.

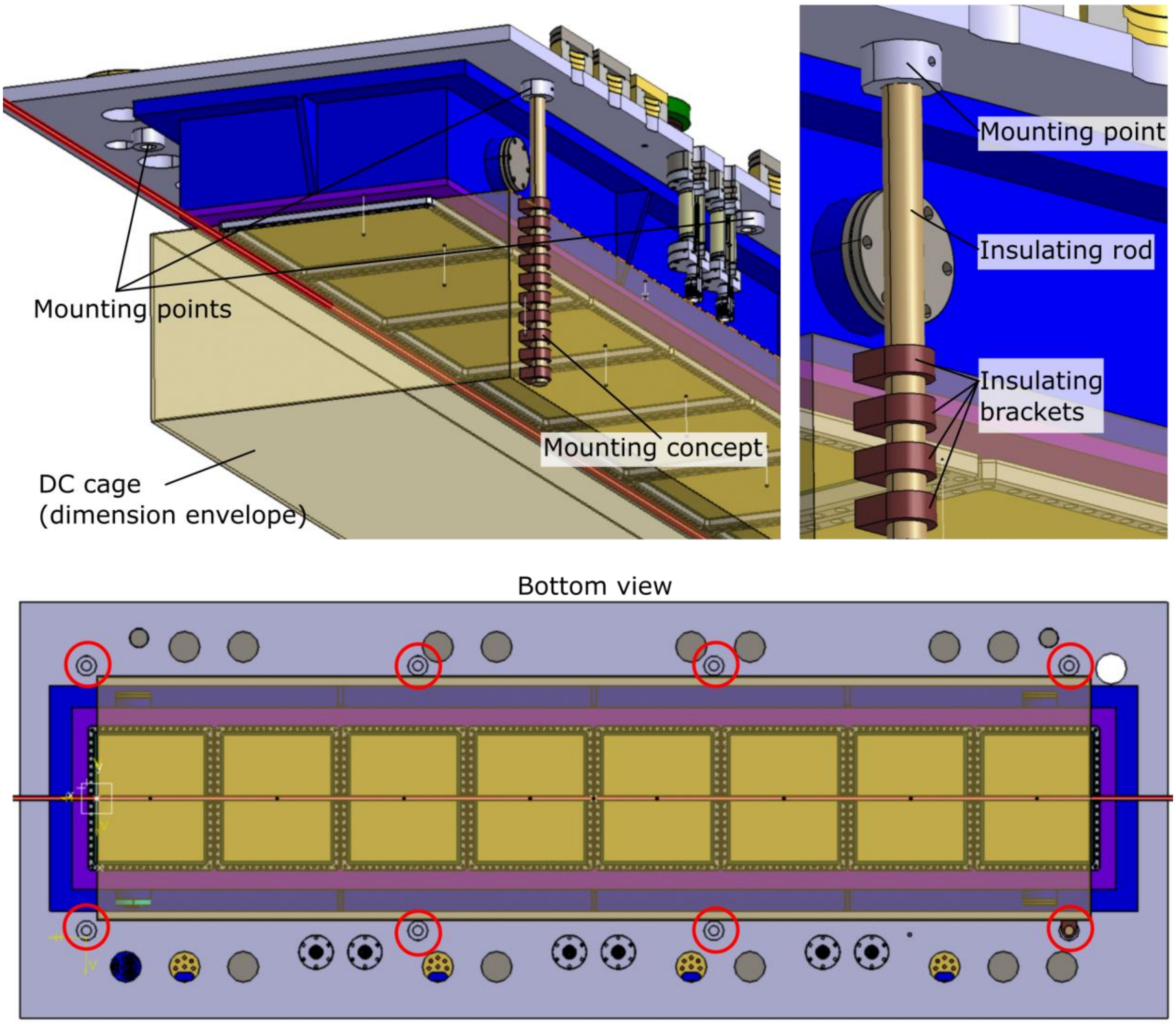

Figure 25. Conceptual layout of mounting points for the DC cage assembly in the stopping region

The design and technical realization of these mounting interfaces are the responsibility of the Contractor. To support this design process, the conceptual layout of the DC cage assembly is illustrated in Figure 25 and described below.

The DC cage electrodes consist of stainless steel metal strips. These individual strips are attached to a set of main vertical insulating rods via insulating brackets. It is assumed that polyphenylene sulfide (PPS) will be used as the insulating material for both the rods and the brackets. The brackets electrically insulate the metal strip electrodes from one another, while the main rods insulate the entire DC cage assembly from the grounded top cold flange. As shown in the bottom view of Figure 25, the conceptual mounting points surround the perimeter of the DC cage, where the rods are inserted and mechanically locked.

The mounting interfaces on the top cold flange shall be designed to safely bear the mechanical load of the DC cage assembly, which has an estimated weight of 60 kg.

The Contractor shall ensure that the final design of the mounting interfaces provides sufficient mechanical stability to locate the DC cage with a positional tolerance of ±1 mm relative to its nominal position defined by the cold top flange and the beam axis.

4.3.10 Cold separation plate

A cold separation plate shall be provided. This plate serves as the structural mount for the RF carpets. Together with RF carpets, the cold separation plate acts as a physical pumping barrier between the stopping and extraction regions (Figure 26).

The cold separation plate shall be dismountable to allow for maintenance and component replacement. The mechanical interface between the plate and the chamber shall be designed to ensure direct metal-to-metal (flange-to-flange) contact, guaranteeing well-defined alignment and optimal thermal conduction.

The RF carpets will be mounted to the cold separation plate and mechanically pressed into position using dedicated Clamping Frames. The Clamping Frames shall be fastened using M4 screws. The Contractor shall machine the corresponding M4 blind threaded holes into the cold separation plate to accommodate this fastening method.

The vacuum seal between the cold separation plate and the RF carpets shall be achieved using indium wire. The Contractor shall design and machine the corresponding sealing grooves into the cold separation plate to ensure a reliable, leak-tight indium seal under cryogenic conditions.

The actual RF carpets are not part of the Contractor's scope of delivery (see Section 3.2).

The Contractor shall provide two sets of dummy plates for the nozzle positions:

One set featuring a central orifice with a diameter of 0.4 mm to simulate the flow conductance of the actual nozzles during testing.

One set consisting of blank (solid) plates with no orifices, to be used for vacuum leak testing and complete isolation of the chambers."

For conducting vacuum and performance tests, the Contractor shall manufacture and supply two sets of metallic dummy plates matching the outer geometry of the RF carpets. In Set A, each dummy plate shall feature a central orifice with a diameter of 0.4 mm to simulate the flow conductance of the actual nozzles. In Set B, the dummy plates are blank solid plates with no orifices, to be used for vacuum leak testing and complete isolation of the chambers.

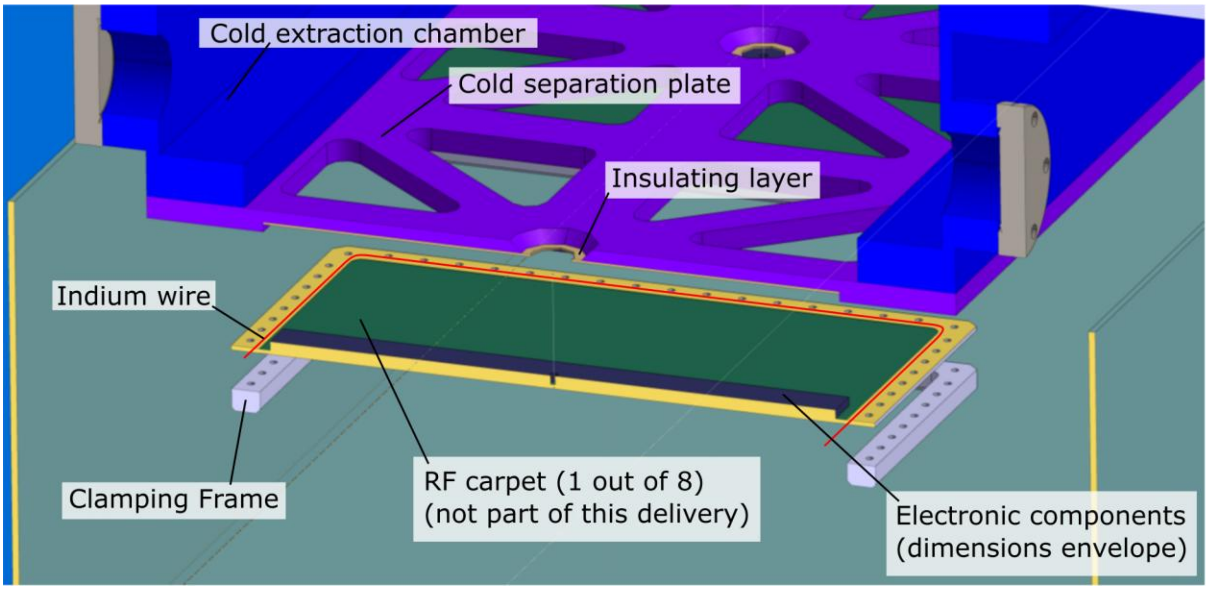

Figure 26. Assembly of cold separation plate, cold extraction chamber and RF carpet

The cold separation plate shall feature exactly eight gas through holes (extraction nozzles). These holes shall be designed as conical holes; the specific inner and outer diameters of these nozzles are fixed and shall be manufactured in accordance with the provided concept in Figure 27.

The Contractor shall determine the final thickness of the cold separation plate based on mechanical calculations. The thickness shall be sufficient to ensure structural integrity and to maintain a flat sealing surface against the operating pressure difference and clamping forces.

The design of the plate shall incorporate pockets or recesses where structurally permissible, in order to minimize the total cold mass and reduce the cryogenic heat load.

The mounting arrangement shall include suitable insulating layers to electrically isolate and protect the electronic components on the back side of the RF carpets from the grounded cold separation plate.

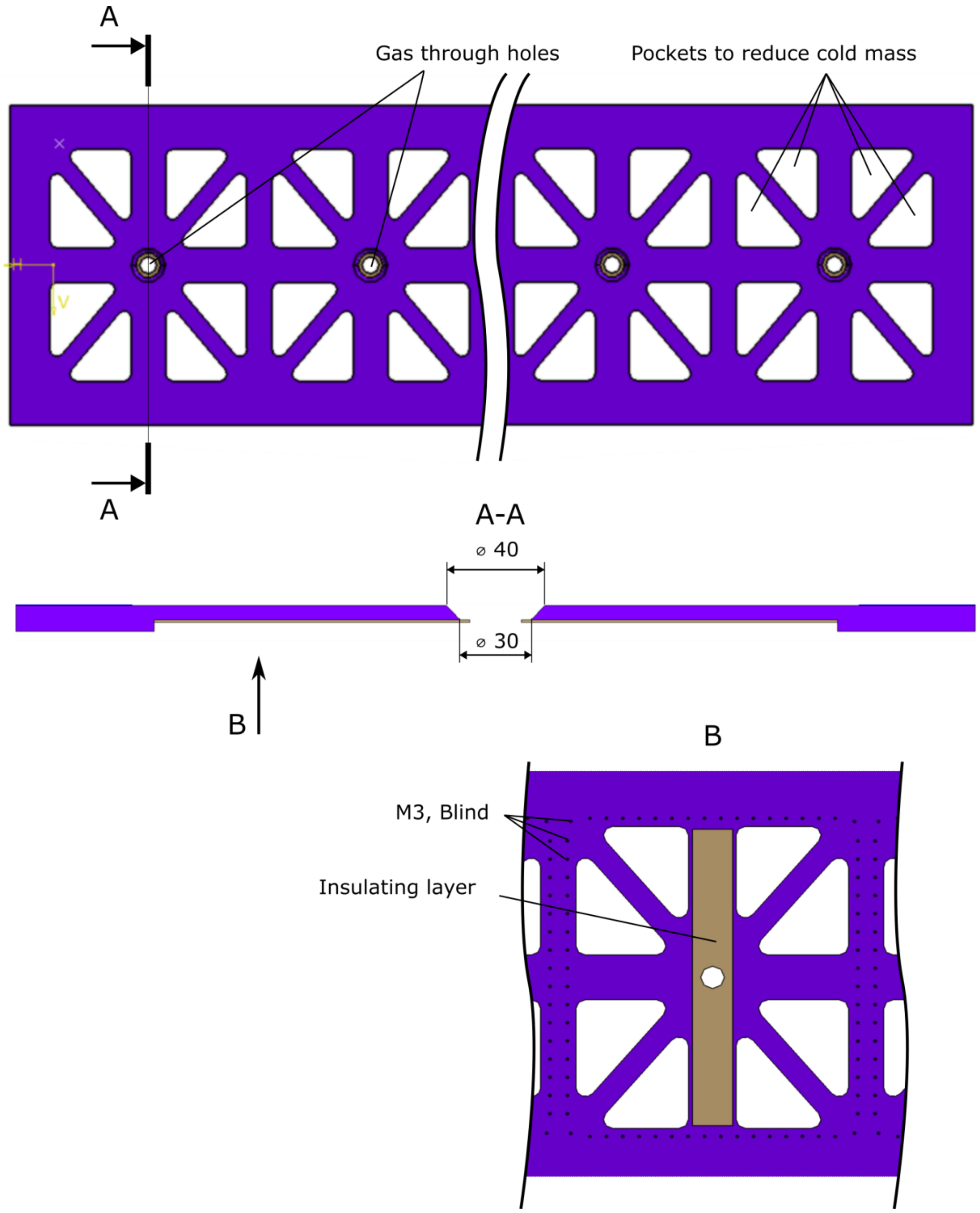

Figure 27. Conceptual design of cold separation plate. Top view, section view A-A, bottom view B.

4.3.11 Mounting points for electrodes in cold extraction chamber

In the extraction chamber, a set of electrode plates will be installed to create a DC electric field that guides ions upwards. These DC electrodes will be structurally supported by the bottom flange of the cold extraction chamber.

The electrodes will be electrically isolated from the chamber using insulating rods and stand-offs. It is assumed that polyphenylene sulfide (PPS) rods with a diameter of 10 mm will be utilized for this purpose.

To accommodate the mounting of these rods, the inner side of the bottom flange of the cold extraction chamber shall be provided with threaded blind holes (Figure 28). The Contractor shall machine these blind holes assuming an M8 thread size, ensuring they do not compromise the vacuum integrity or mechanical strength of the bottom flange. The Contractor shall determine the exact locations, quantity, and required depth of these threaded blind holes during the detailed design phase. The arrangement shall ensure sufficient mechanical stability for the electrode assembly while avoiding interference with other internal components or structural features. The proposed hole pattern and dimensions shall be submitted to the Company for review and approval prior to manufacturing.

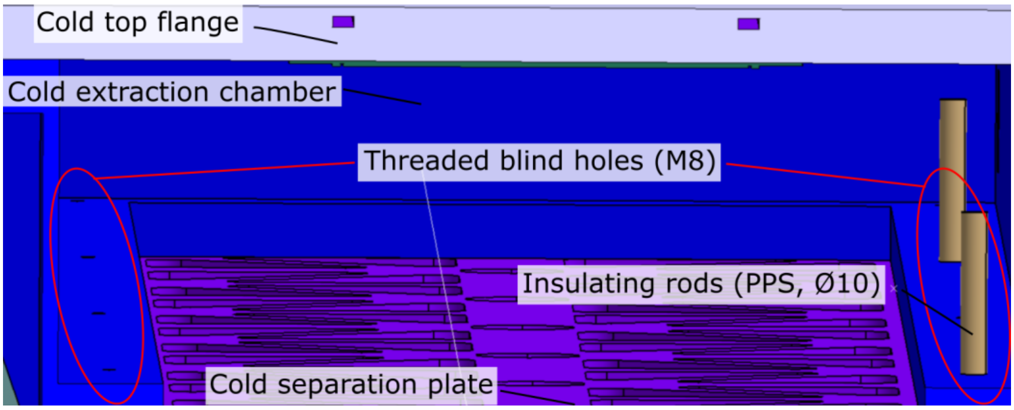

Figure 28. Conceptual layout of mounting points for the electrodes in the extraction region

4.3.12 Cryogenic gate valve assembly

For normal operation, the pumping port to the stopping region needs to be closed (TMP2 in Figure 7). This is done using a cryogenic gate valve DN63CF. The cryogenic gate valve consists of two parts: valve body and actuator. As shown in Figure 29, the valve body is installed inside the thermal insulation vacuum and is sealed so that the connection point for the actuator is on the air side.

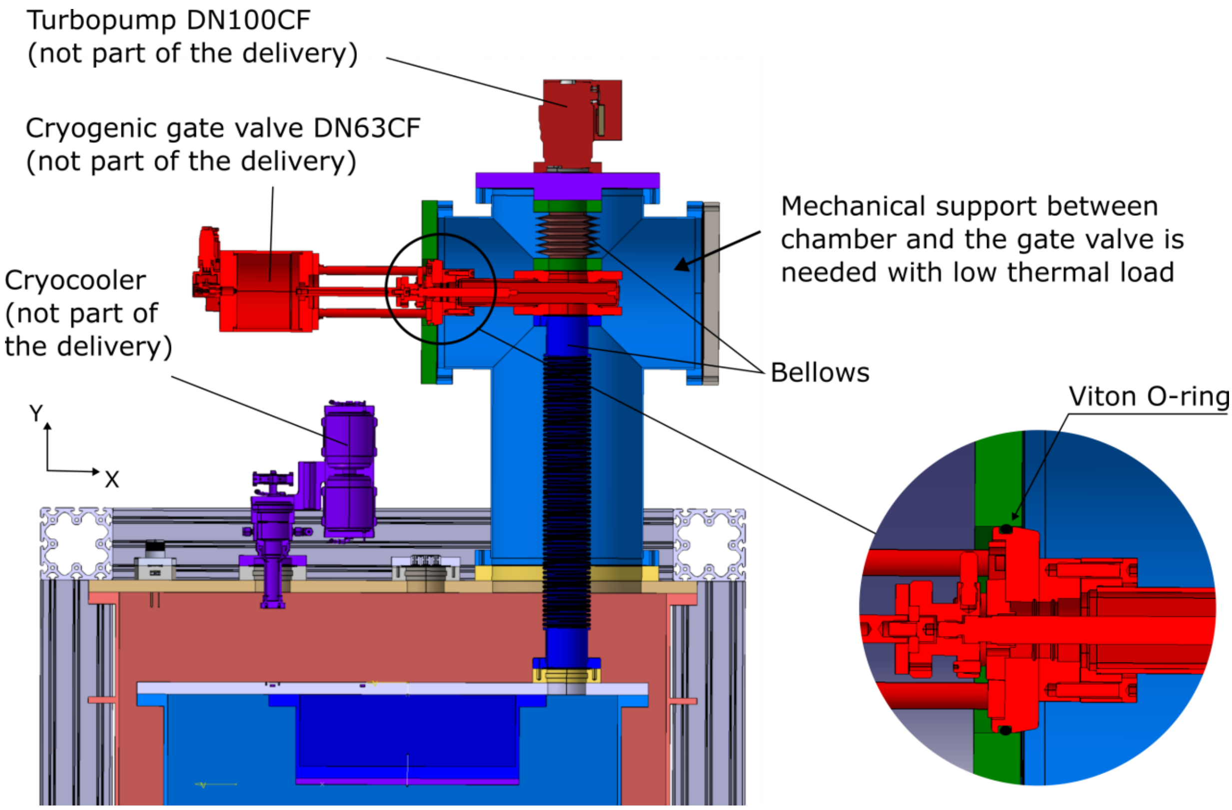

Figure 29. Section view of the Cryogenic Gate Valve Assembly.

The cryogenic gate valve itself is excluded from the Contractor's scope of delivery (Section 3.2). The Company will provide the 3D model of the valve to enable the Contractor to design the corresponding mechanical and vacuum interfaces. The assembly connecting the cold stopping chamber to TMP2 shall be designed according to the component specifications below.

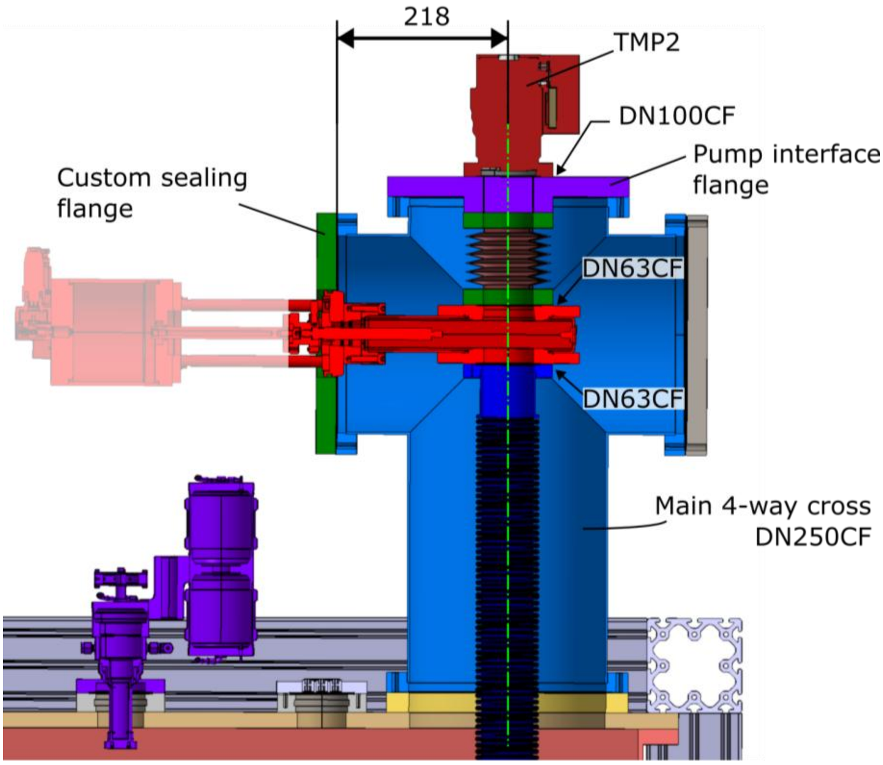

Figure 30. Cryogenic Gate Valve Assembly components.

4.3.12.1 Main 4-way cross assembly

A custom 4-way cross based on DN250CF flanges shall be provided as the primary vacuum enclosure for the cryogenic gate valve assembly.

The horizontal "arm" of the 4-way cross to which the cryogenic gate valve connects shall have a custom length of 218 mm, measured from the central vertical axis of the cross to the sealing face of the flange.

The vertical height of the bottom "arm" of the 4-way cross shall be designed by the Contractor to ensure sufficient clearance between the cross assembly and the adjacent cryo-coolers.

4.3.12.2 Gate valve mechanical support

The cryogenic gate valve shall be mechanically supported by the main 4-way cross structure. The support design shall minimize cryogenic heat load and must allow for simple, straightforward removal of the cryogenic gate valve for maintenance purposes. The complete design of this internal support system is the responsibility of the Contractor.

4.3.12.3 Custom sealing flange

A custom flange (shown in green in Figure 30) shall be provided to seal the body of the cryogenic gate valve inside the vacuum chamber. The sealing mechanism between the valve body and this flange shall utilize a static radial piston seal. The geometrical parameters and tolerances of the port in this flange will be provided by the Company.

4.3.12.4 Pump interface flange

A custom top flange (shown in purple in Figure 30) shall be provided to seal the upper port of the 4-way cross. This component shall be a DN250CF blank flange modified to feature a central pumping port. The port shall be equipped with CF sealing surfaces on both the air side (external) and the vacuum side (internal). The external (air side) interface of the central port shall be a DN100CF flange, dedicated to the connection of turbomolecular pump TMP2. The internal (vacuum side) interface of the central port shall be connected to the DN63CF cryogenic gate valve. This internal connection shall be realized by means of an edge-welded bellows to accommodate thermal contraction and mechanical tolerances.

4.3.13 Main frame, frame extension and handling interfaces

The complete support structure for the Cryogenic Stopping Cell (CSC) shall consist of two primary assemblies: a main frame and a frame extension (Figure 31).

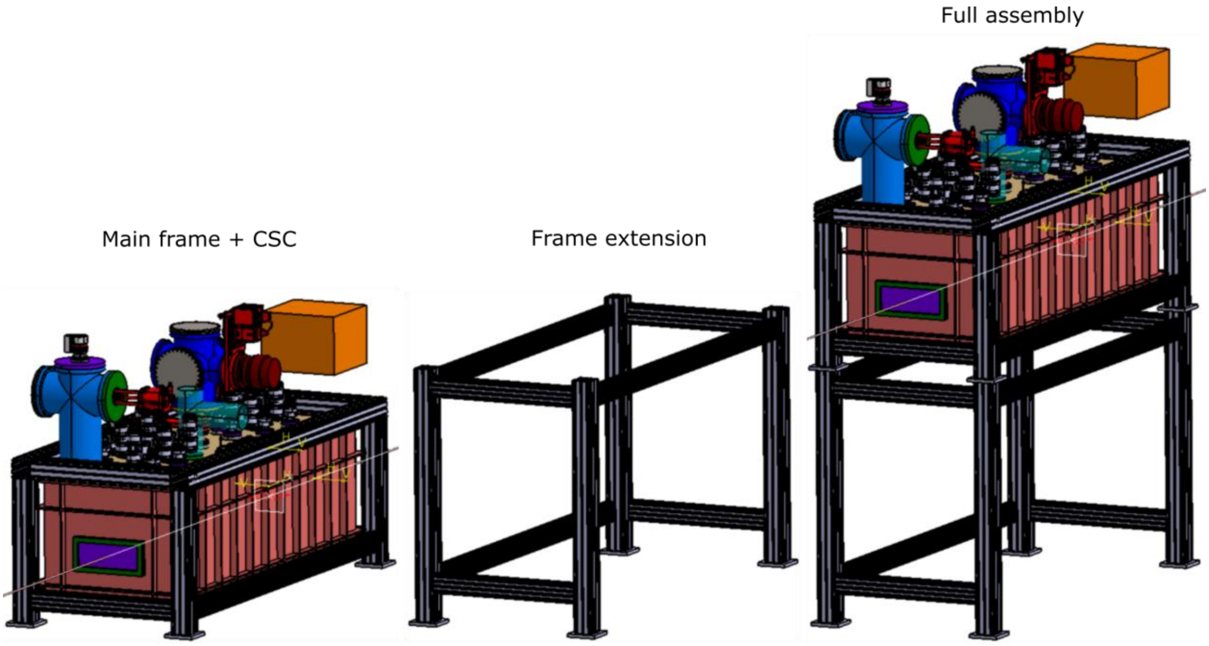

Figure 31. Conceptual illustration of the main frame, frame extension and fully assembled system

4.3.13.1 Structural integration

The warm top flange of the CSC shall be rigidly attached to the main frame, serving as the sole structural suspension point for the entire vacuum chamber assembly. The warm vacuum chamber shall hang freely from the warm top flange and must not be directly attached to, or supported by, any part of the frame structure in normal operation.

The system shall be designed such that the main frame (carrying the CSC) can be mechanically separated and decoupled from the frame extension.

4.3.14 Transport and Handling

The integrated assembly of the main frame (with the CSC) and the frame extension shall be designed for safe transport and handling in all directions, including free rotation, via wheels, overhead crane, and lifting table (see Figure 4). The CSC is assumed to be transported vented at room temperature; solutions enabling transport in evacuated state are encouraged.

When separated, the frame extension alone shall also be fully transportable via wheels, overhead crane, and lifting table.

The detailed design of all transport and handling interfaces, including structural feet, heavy-duty caster wheels, crane lifting lugs/hooks, and mechanical interfaces for the lifting table is the sole responsibility of the Contractor. The Contractor shall demonstrate that these handling interfaces comply with safety standards and are adequately rated for the total weight and center of gravity of the respective assemblies.

For transport, installation, or handling, temporary additional supports or restraint elements may be provided to limit the motion of the cold chamber within the warm chamber and to protect the suspension system and surrounding components from transport-induced loads.

The final design and the production drawings are the responsibility of the Contractor. Contractor shall use the information in Section 4.4 to define the boundary conditions for the components and interfaces described above.

4.4 System Environment and Infrastructure

Note: The control system of the CSC is outside the scope of this tender. The following information is provided solely as context for the selection of electronic components and sensors.

All active components and instrumentation (e.g., turbomolecular pumps, valves, pressure sensors, temperature sensors, power supplies, and voltage read-outs, etc.) will be integrated into the central control system of the CSC. The control architecture will be a slow-control system based on EPICS (Experimental Physics and Industrial Control System). Where applicable, the Contractor should propose sensors and components with interfaces compatible with standard EPICS integration.

All temperature sensors shall be fully compatible with, and readable by, Lake Shore Cryotronics temperature monitors and controllers without the need for additional signal conditioning or calibration conversion.

Pressure transmitters manufactured by MKS Instruments are strongly preferred.

5 Procedure

This chapter presents the procedure to realize the specified system in more detail in accordance with the FAIR General Specifications F-GS-F-01e [1].

5.1 Design Phase

The design phase contains the conceptual design phase which ends with a conceptual design review (CDR) and the final design phase which ends with the final design review (FDR).

During the design phase the vacuum chambers will be drawn in detail and checked by the Company. The phase ends with a released design review which induces the start of the next phase.

5.1.1 Conceptual Design Phase (CDR)

In a startup phase, the Contractor will work out a design of the CSC based on the documents provided by the Company. During this phase, there will be a close contact between the Contractor and the Company. The co-operation will be underlined by written engineering sheets/replies.

The documents for the conceptual design will follow the rules of the Construction Guidelines (see the FAIR Technical guidelines listed in Section 8) and must contain:

- Written conceptual design report (CDR)
- The design of the CSC and 3D model
- A thermo-mechanical analysis, i.e., a stress, cool-down, bake-out analysis by using, for example, FEM simulations
- Specified requirements of the interfaces, see Section 4.3.
- Draft of production and delivery process plan
- Draft of technical risk and hazard analysis according to EN ISO 12100
- Welding procedures
- Detailed description of test procedures, especially how the non-standard flanges are closed.
- Draft of acceptance test protocols

The Company will study this report and asks for clarification or further details if necessary. After the Company has given approval to the conceptual design, the Contractor has to ensure the compatibility of all components according to the requirements.

5.1.2 Final Design Phase (FDR)

The final design report (FDR) has to be detailed on an engineering level which allows starting the production immediately. The final design documentation must include at least:

- The final 3D model and the entire set of production drawing (2D)
- Complete specification of all interfaces
- Statement about the measurable maximum dimensions and weight of components (with and without packaging) prior to the final assembly
- Released production and delivery process plan.
- Released technical risk and hazard analysis according to EN ISO 12100.

- Released acceptance test protocols.
- List of the necessary manufacturing and test equipment
- Released handling instructions/operation manual.
- Installation instructions

The production phase shall start after the approval and release of the FDR.

2D drawings shall be made following the FAIR Technical Guideline F-TG-B-04e_KRL_20130228 [2]. All 2D drawings must be approved by the Company. Work started before release of drawings will be refused and cost will have to be carried by the manufacturer. This release process does not absolve the Contractor from design responsibility.

5.2 Production

The production will follow the released process and control plan and allows the Company to attend at specified stopping points.

Mechanical designs shall follow the rules of Component Reference by the FAIR Technical Guideline F-TG-ZT-3.75e [3]. All the vacuum chambers shall be labelled with a unique number, called Component IDentification (CID) following the FAIR Technical Guideline F-TG-B-0.5e [4]. This number has to be durably affixed to the component. This could be done by etching or engraving. In addition, CID must be affixed in a machine-readable format, i.e. a 2D-barcode as well.
In addition, all chambers shall be labelled with a metal tag containing a QR code. The tags and the CID numbers will be supplied by the Company.
The production phase ends with an approval of the factory acceptance tests which will be accompanied by the Company. In case major deviations occur that require rework, this rework must be agreed upon with Company in advance.

5.3 Surface properties and cleanliness

The manufacturer has to guarantee that:

- All parts and if necessary, all required tools during all stages of manufacturing and assembly have the required cleanliness for vacuum components.
- The vacuum surfaces must be smooth, i.e., free of scratches, holes or oxidation. Visible surface defects have to be removed only by methods accepted by the Company like scraping or wheel grinding without any grease, oil or other lubricants. Also, for the sealing surfaces of the flat flanges special protection measure should be taken.
- All mechanical cold working operations must exclude the use of heavy organic lubricants.
- Due to the sensitivity of the knife-edges for scratches or dents, they have to be protected during the whole manufacturing process with a lid. The lids must only be removed, if worked on the flange directly.
- Plastic materials, especially PVC, are not allowed in contact with the vacuum surfaces neither as packaging nor as covers.

5.4 Cleaning

The manufacturer has to perform surface treatment and cleaning of all surfaces facing the vacuum. During all stages of manufacturing, it is necessary to avoid any surface contamination. One has to pay attention that the inner chamber surface remains totally free of greasy and oily substances. These surfaces must be absolutely free of contaminants, must not display any traces of corrosion, oxidation or temper colors. Acidic or caustic liquids with subsequent neutralization treatment may not be used.

6 Quality Assurance, Tests and Acceptance

6.1 Quality Assurance system of the Contractor

Herein, all the measures shall be described in detail or referenced, which ensures that the present specifications will be fulfilled. The complete Quality Acceptance process is written down in the FAIR General Specifications, F-GS-F-01e [1].

The Contractor installs a quality assurance system which allows following quality planning, quality steering, quality measurement and quality improvement. A regular exchange of information exchange between the Contractor and Company is necessary.

For details see the FAIR General Specifications, F-GS-F-01e [1].

6.2 Factory Acceptance Test (FAT)

The appointment for the Factory Acceptance Test (FAT) has to be announced to the Company at least 30 days ahead so that the presence of the Company representatives can be guaranteed. The Contractor provides all tools which are necessary for the acceptance test procedure. After the release of the factory acceptance test reports by the Company the distribution can take place. All FAT tests shall be carefully recorded in protocols. All test documentation shall be submitted to Company.

6.2.1 Mechanical Acceptance test

The Contractor is requested to carry out a Mechanical acceptance test according to the FAIR Technical Guideline F-TG-V-7.1e [5]. All vacuum chambers must have the required dimensions and surface quality. The check will be done at the manufacturer site. The measurement protocols to be delivered to Company.

The final cleaning of the vacuum component must be done after the mechanical inspection because it includes the check of the vacuum surfaces. If a re-work is necessary after the mechanical inspection, the required tolerances have to be proved again.

6.2.2 Vacuum Acceptance Test

The proof of aptitude of the vacuum chambers has to be done in a dedicated vacuum test setup of the manufacturer. Inspection and testing shall be performed by using properly calibrated equipment. Only dry (oil-free) pumping combinations are allowed for vacuum inspection. The test procedure is described in detail in FAIR Technical Guideline F-TG-V-7.2e [6].

- The outgassing rate of the vacuum chamber has to be measured.
- Leak tests shall be performed for the chambers with a calibrated He-leak detector. The Contractor shall provide a proposal for a leak test procedure with a complete setup, all pumps and the measurement equipment documented in detail.
- The residual gas composition and pump down curve shall be recorded and documented in the acceptance test protocol. Acceptance criteria is outlined in FAIR Technical Guideline F-TG-V-7.2e [6]. In addition, an outgassing rate measurement and RGA spectra of the rubber seals, which will be used for acceptance test of focal plane chambers, should be carried out and document before the first acceptance tests of the focal plane chambers. This will allow distinguishing hydro-carbon contamination from the chamber and the rubber seals, if present.

- The ultimate pressure reached is not binding, but <1E-6 mbar is recommended for the measurements.

The Company could provide an acceptance certificate (see the FAIR Technical Guideline F-TG-V-7.15e [7]), where all measurements and tests have to be documented, if desired.

6.3 Site Acceptance Test (SAT)

The SAT Part A test repeats the FAT tests of all components in order to assure the wanted performance also after the transport to the Company's site. The Contractor will assist in performing the SAT Part A.

The SAT Part B tests cooling-down with Company's cryocoolers and helium gas supply, verifying thermal performance.

If the SAT fails it will be the responsibility of the Contractor to arrange any necessary repair. In the case of return to the manufacturer premises, the full set of Factory Acceptance Tests (FAT) detailed in Section 6.2 must be repeated before delivery.

6.4 Packaging and Transport

The shipping and packaging of vacuum components has to follow to the FAIR Technical Guideline F-TG-V-9.1e [8]. The CSC has to be packed without contamination and damaging during packaging. Stable transport boxes for all vacuum chambers are necessary.

7 Documentation

All documentation generated under the Contract shall be handed over to the Company and shall become the property of the Company. Documentation shall be prepared in accordance with Chapter 6 of the FAIR General Specifications F-GS-F-01e [1].

- Manufacturing drawings used for production (as-built condition).
- Risk and hazard analysis covering assembly, transport, installation, and commissioning activities
- Declaration of Conformity and related CE documentation.
- Maintenance and operational instructions (manual) delivered in both German and English.
- User manual delivered in both German and English.
- Material test certificates in accordance with DIN EN ISO 10204 (3.1 / 2.2 as applicable).
- Certificates of welding personnel.
- 3D CAD model in .stp or CATIA file formats according to the FAIR Technical Guideline F-TG-B-04e_KRL_20130228 [2]. The data exchange guidelines are given in the FAIR Technical Guideline Data Exchange F-TG-B-02e-DARL_T1-v3_0 [9].
- FAT documentation.
- SAT documentation.

8 Related Documents

8.1 List of 3D models provided by the company:

- Conceptual design of the CSC as part of the Super-FRS Ion Catcher setup:
  “26K_SUPERFRS_ION_CATCHER_000_000_00.stp”
- Cryocooler:
  “8-19-2021 GSI layout.STEP”
- Cryogenic gate valve:
  “14K_021_010_00_A_170_00_VAT_VENTIL_868061_AllCATPart.stp”

8.2 References

This is a list of the FAIR Technical Guidelines and General Specifications to be applied in the design and of the basic documentations to be considered. The related documents are used as references in the present document. Mandatory specifications are marked with “MANDATORY” or they are only “RECOMMENDED”. All documents are available on the EDMS system of FAIR.

[1] "MANDATORY. FAIR General Specification, F-GS-PMO-en, EDMS 1365092".

[2] "RECOMMENDED. FAIR Technical Guideline F-TG-MDS-en-KRL, Design Guideline, EDMS 1229367".

[3] RECOMMENDED. FAIR Technical Guideline F-TG-ZT-3.75e, Component Reference, EDMS 1467107.

[4] "RECOMMENDED. FAIR Technical Guideline F-TG-B-0.5e, Permanent Labelling and Tagging of Components, EDMS 1229368".

[5] "RECOMMENDED. FAIR Technical Guideline F-TG-V-7.1e, Mechanical Acceptance Test for Beam Vacuum Components, EDMS 1172905".

[6] "RECOMMENDED. FAIR Technical Guideline F-TG-V-7.2e, Vacuum Properties Acceptance Test without Bake-out, EDMS 1172906".

[7] "RECOMMENDED. FAIR Technical Guideline F-TG-V-7.15e, Record for Factory Acceptance Test (FAT) of Vacuum, EDMS 1172908.".

[8] "RECOMMENDED. FAIR Technical Guideline F-TG-V-9.1e, Transport and Packaging of Vacuum Components, EDMS 1172926".

[9] "RECOMMENDED. FAIR Technical Guideline F-TG-B-02e-DARL_T1-v3_0, Data Exchange, EDMS 1229366".

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