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Fermilab Engineering Document
LCLS-II 3.9GHz Cryomodule Mechanical Design
ED0004081, Rev. 0

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On behalf of the Cryomodule design team

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1. Introduction

This document gives a summary of the design considerations and documentations of the LCLS-II 3.9 GHz cryomodule, with the focus being on the mechanical and thermal design. It is assumed that the reader is familiar with the design of the 1.3 GHz cryomodule and understands the technical terminologies used here. The PDF files linked here are for quick references only. Please see the associated reference documents in Teamcenter or Slacspace for the most current information.

Thirty-five 1.3 GHz cryomodules and two 3.9 GHz cryomodules will be connected to form four linac sections (L0, L1, L2, and L3) which are separated by three warm beamline sections (LH, BC1, and BC2), shown in Fig. 1.1. The two 3.9 GHz cryomodules, CMH1 and CMH2, will be installed in the L1 section, shown in Fig. 1.2.

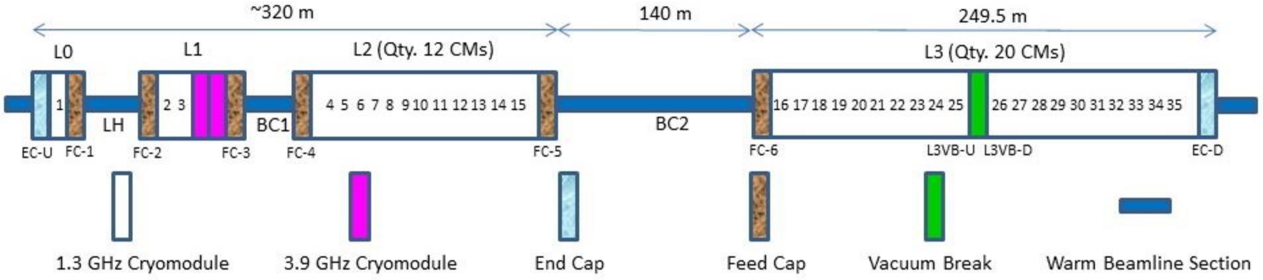


Figure 1.1: Linac with cryomodules in sections

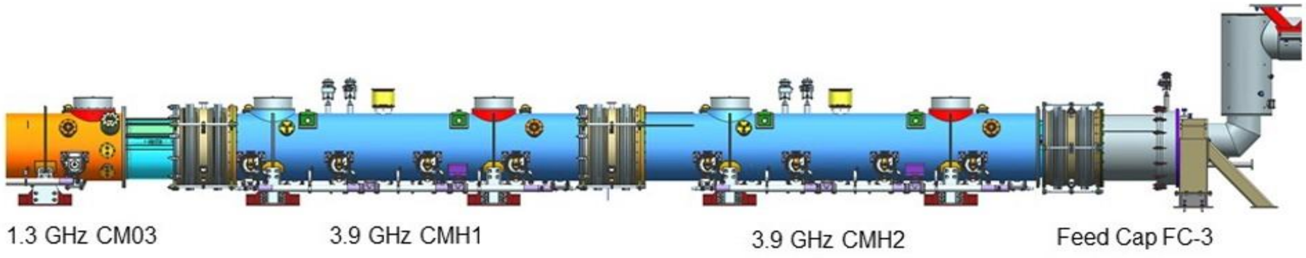


Figure 1.2: Two 3.9 GHz cryomodules located in linac subsection L1

Most of the features on the 3.9 GHz cryomodule are identical or similar to those of the 1.3 GHz cryomodule. The module interconnect unit is standard for both cryomodules. Listed in Table 1.1 are two other documents describing cryomodule features that are not covered here.

Table 1.1: Engineering documents about the 1.3 GHz cryomodule and module interconnect unit mechanical design

Document No.	Description
LCLSII-4.5-EN-0566 (ED0004361)	1.3 GHz cryomodule mechanical design
LCLSII-4.5-EN-0710 (ED0002593)	Cryomodule interconnect design and installation

2. 3.9 GHz cryomodule general description

The 3.9 GHz cryomodule design is based on the design first developed at Fermilab for the FLASH ACC39 module now in operation at DESY, and incorporates the design refinements from the similar cryomodules built for the European XFEL. The functional requirements and the overall structural design of this cryomodule are similar to those for the LCLS-II 1.3 GHz cryomodule.

Each 3.9 GHz cryomodule houses eight 3.9 GHz 9-cells superconducting cavities, operated in CW mode at 2 K. These 3.9 GHz cavities with a specified Q_0 of 2.0 x 10^9 will each provide an energy gain of 13.4 MV/m. The cryomodule installed "slot length" is 6.5545 m, and the overall dimensions of the cryomodule are shown in Fig. 2.1.

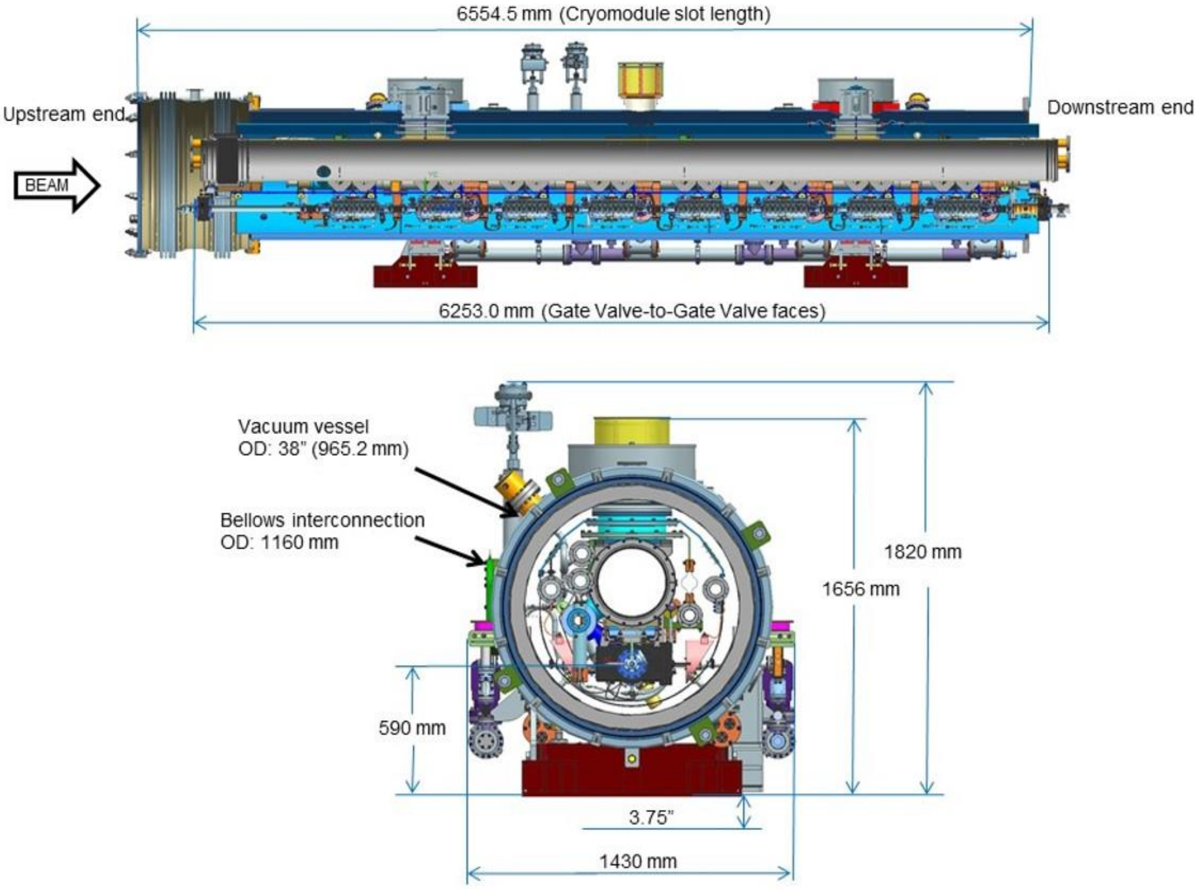


Figure 2.1: Overall dimensions of the 3.9 GHz cryomodule

The parameters, functional requirements, technical specification and the top assembly drawing of the 3.9 GHz cryomodule are listed in Table 2.1.

Table 2.1: Top level documents on the 3.9 GHz cryomodule design

Document No.	Description
LCLSII-4.1-PR-0097	3.9 GHz cryomodule physics requirements
LCLSII-4.1-FR-0096	3.9 GHz cryomodule functional requirements
LCLSII-4.5-ES-0879	3.9 GHz cryomodule technical description
F10014857	3.9 GHz prototype cryomodule top assembly drawing

The overall structural of the 3.9 GHz cryomodule is shown in Fig. 2.2. The cavity beamline string is suspended under the HGRP with hangers, and the HGRP is suspended by two support posts. The adjustable suspension brackets of the cold mass support posts allow the precision alignment of the beamline string with regard to the vacuum vessel fiducials. The vacuum vessel provides the insulating vacuum to reduce gas convection, and thermally isolates the cold-mass from the room temperature. Between the vacuum vessel and the cold-mass, the 40 K thermal shield with 30 layers of MLI blankets effectively suppress the thermal radiation to the cold-mass. Cryogenic pipes provide cooling to the cavities and thermal shield, and thermal intercepts to various cold-mass components. The cavities will be cooled by 2 K saturated liquid helium fed by the 2-phase supply line. The HGRP returns the evaporated gas to the cryogenic plants. Table 2.2 lists the materials, sizes and weights of major components of the module. The total weight of the 3.9 GHz cryomodule is about 5.3 Tons.

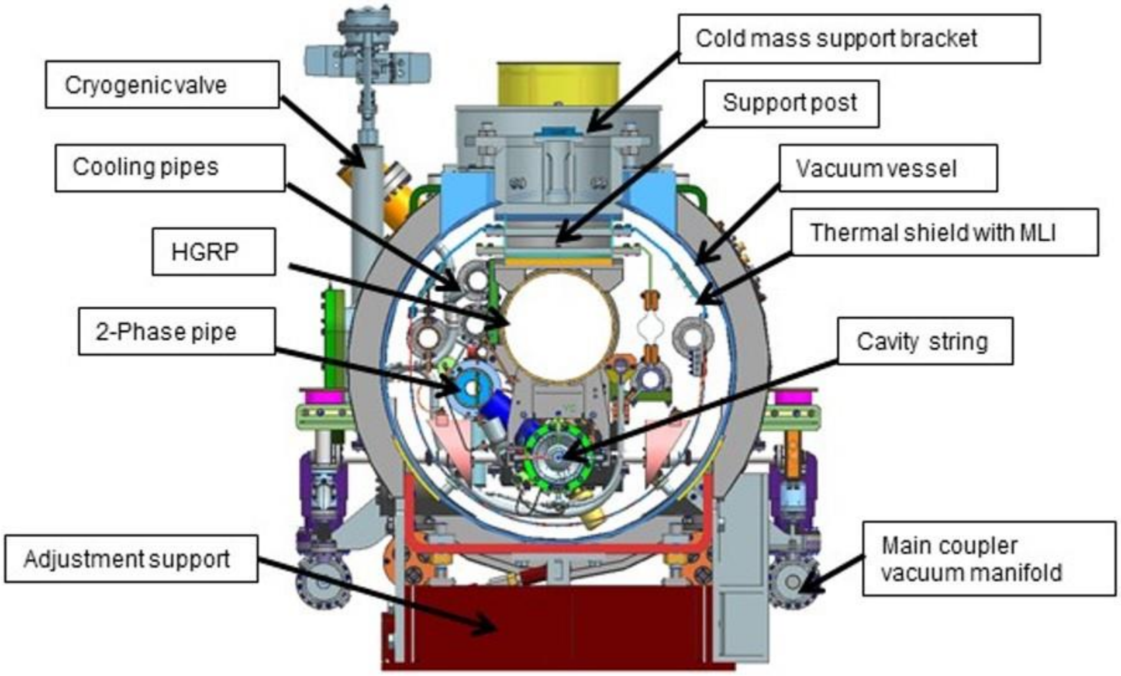


Figure 2.2: Cross-section of the LCLS-II 3.9 GHz cryomodule showing its major sub-assemblies

Table 2.2: Material and size of module major components

Components	Material	Weight, kg
Vacuum vessel	Carbon steel A516 GR. 60, Φ965.2 mm, 9.5 mm wall	2400
HGRP	Stainless steel 316L, Φ312 mm, 6 mm wall	400
Support posts and brackets	G10 fiberglass tube, Φ300 mm, 2.2 mm wall, SS/Al	170 x 2
Thermal shield	Aluminum 1050, 6.35 mm/3.175 mm sheets	400
Cryogenic manifolds	Stainless steel 316L or Aluminum 6061-T6	150
Cavity beamline string and supports	Nb/Ti/SS	450
Stands	Stainless steel	375 x 2
Main coupler vacuum manifold	Stainless steel	80 x 2
Instrumentation flanges/cables, hardware, miscellaneous items	miscellaneous	250
Total		5300

The major external features on the cryomodule are shown in Fig. 2.3. The designs of these features are identical to those on the 1.3 GHz module, except the couplers are on both sides of the module. The names and locations of all the external features that are welded on the vacuum vessel are identified in the vacuum vessel weldment drawing F10014858.

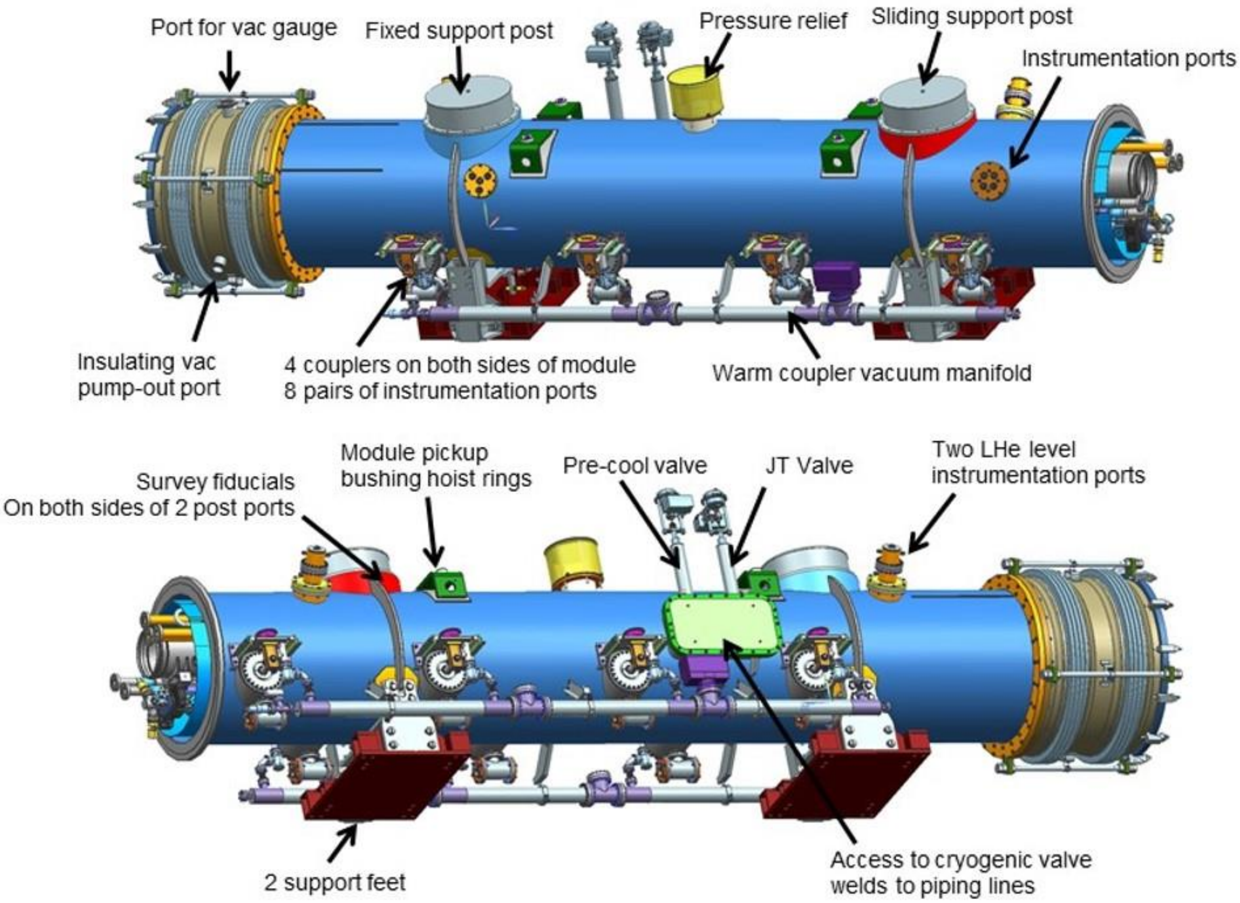


Figure 2.3: 3.9 GHz Cryomodule external features

3. 3.9 GHz cryomodule cold mass

The cold mass is a core component to provide support, alignment, cooling and thermal insulation for the superconducting RF cavities. It includes the following sub-systems, shown in Fig. 3.1

- Cavity string
- Helium gas return pipe (HGRP) and low temperature cryogenic pipes
- Two sets of support posts with suspension bracket
- 50 K thermal shield and high temperature cryogenic pipes
- Multi-layer insulation (MLI)

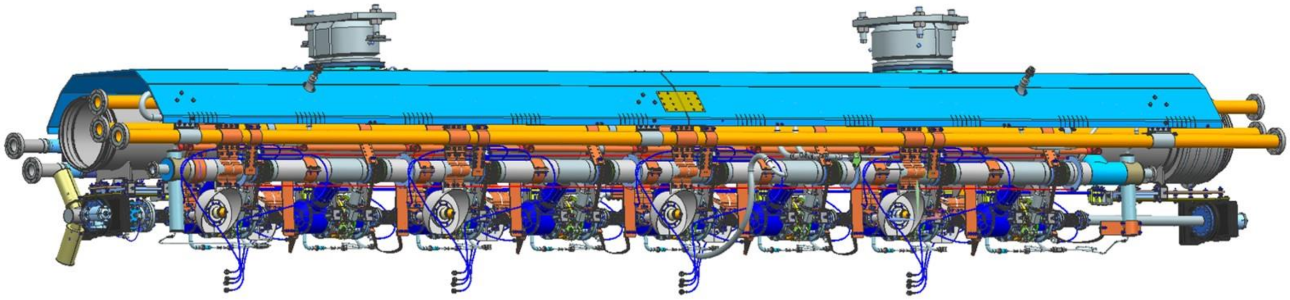


Figure 3.1: 3.9 GHz cryomodule cold mass (with thermal shield lower sheet suppressed)

The diameter and interfaces at each end of the 3.9 GHz cryomodule are identical to the 1.3 GHz cryomodules for contiguous interconnection with an identical inter-module unit. The cryomodule uses an identical support scheme and cooling scheme with closed two-phase and cool-down pipes, JT valve and cool-down valve, pipe sizes, thermal shielding, and interconnects. The drawings of the module major components are listed in Table 3.1.

Table 3.1: Drawings of cryomodule major sub-assemblies

Drawing No.	Description of sub-assembly	References
F10014812	Cavity beamline string assembly, at warm	
F10014858	Vacuum vessel weldment	ED0004908, FEA engineering document
F10014819	Cold mass sub-assembly	
F10014820	Cold mass upper sub-assembly	
F10014821	HGRP assembly	
F10014979 F10056145	Thermal shield upper sub-assembly Thermal shield lower sub-assembly	
F10058455	Main coupler vacuum manifold	

3.1 Cavity beamline string

The beamline string in each cryomodule consists of eight RF cavities. Compared to the 1.3 GHz cryomodule, there is no focusing and steering magnet package but the space is retained in case a magnet package is desired in the future. There is a beam position monitor (BPM) at the downstream end. The beamline terminates at each end with an all-metal gate valve. The beamline aperture is Φ38 mm. Between the gate valve and the end of the cavity string, there is a flange reducer to provide a transition from Φ38 mm to Φ78 mm. The overall length between the two gate valves flange faces is 6253.0 mm. A beamline higher-order-mode absorber (BLA) is located in the cold beamline interconnect between the two 3.9 GHz cryomodules. There is no BLA at the downstream end of the second 3.9 GHz cryomodule CMH2. The beamline components are shown in Fig. 3.2 and listed in Table 3.2.

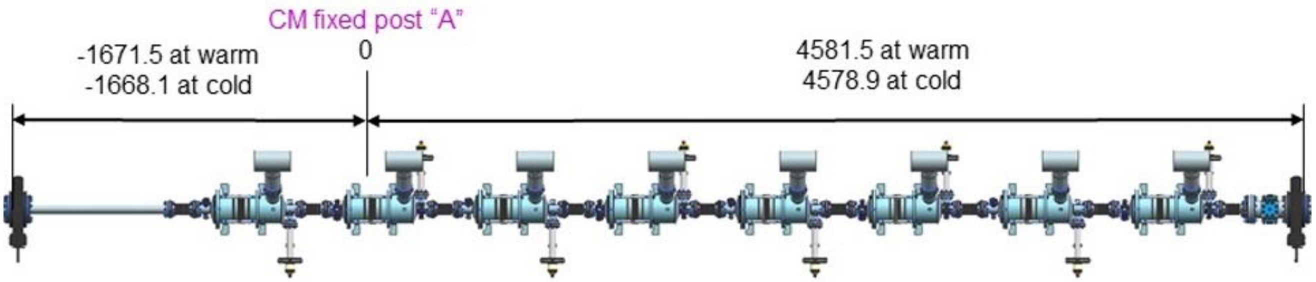


Figure 3.2: 3.9 GHz cryomodule beamline string

Table 3.2: Drawings of the beamline components (starting from upstream end)

Drawing No.	Description of Component	
F10023441	Beamline upstream end flange adapter (for transport)	
VAT P/N 780456EA	All metal gate valve with RF liners, QTY.2	
F10025858	Beamline upstream weldment spool	
F10054536	Beamline string bellows weldment, QTY. 9	
F10048855 cavity-A (even) F10048856 cavity-B (odd)	3.9GHz dressed cavity	
	F10048752	3.9 GHz RF cavity assembly
	F10048833	3.9 GHz cavity helium tank weldment
	F10048846	3.9 GHz cavity helium tank adapter ring
	F10060013	3.9 GHz cavity inner magnetic shield
	F10051979	3.9 GHz cavity HOM antenna feedthrough
	F10053939	3.9 GHz cavity field probe
F10002532	Flange reducer, 78 mm to 38 mm	
F10023160	Cold beam position monitor	
F10051111	Beamline downstream end transport spool (for transport)	
XFEL_004542_0000	HOM absorber	
F10026202	Beamline flange joint gasket	

In order to minimize transverse kicks, input couplers are located on either side of the cryomodules, with cavity pairs oriented as shown in Fig. 3.3. The cavity-to-cavity slot length at cold is 634.2 mm, (8+ 0.25) x lambda.

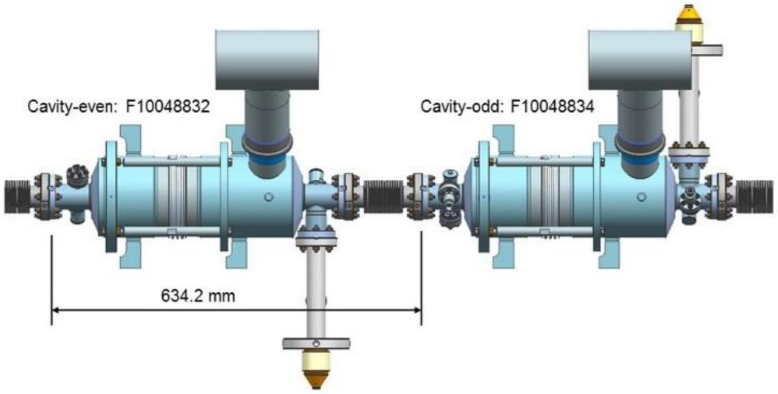


Figure 3.3: 3.9 GHz cryomodule cavity pair

The beam pipe and bellows are copper-plated so as to reduce heating due to HOMs and evanescent fundamental mode fields. Active control of the cavity resonant frequency is provided by a blade tuner that is stacked with a pair of piezo tuners. Access to the tuner mechanism is not provided by cryomodule ports as in 1.3 GHz cryomodules. Each RF cavity is independently powered through a fundamental power coupler which is connected via air-filled waveguide to a solid-state amplifier at 3.9 GHz. Each coupler has flexible bellows on both inner and outer conductor that can provide variable Qext by adjusting antenna penetration into a cavity.

3.2 Support system of cold mass and cavity

The beam-line string is suspended under the HGRP, which acts as the beamline backbone and is supported by two support posts to the vacuum vessel, with the upstream post fixed while the downstream post is slide-able. The cavity helium vessel is anchored to an invar rod via a clamp, shown in Fig. 3.4. The C-shaped needle clamps holding the helium vessel lugs have the bearing structures to allow beamline frictionless movement with respect to the HGRP during thermal cycling.

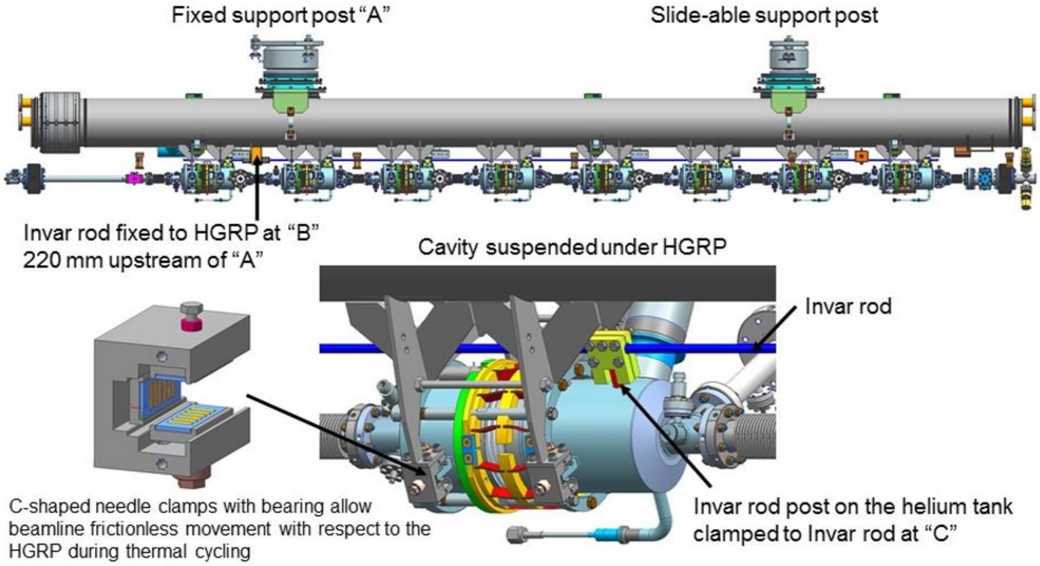


Figure 3.4: Support system of cavity helium tank to the HGRP and invar rod

3.3 Beamline element positions at warm and at cold

The cavity position at warm is stated in the drawing of beamline string F10014812.

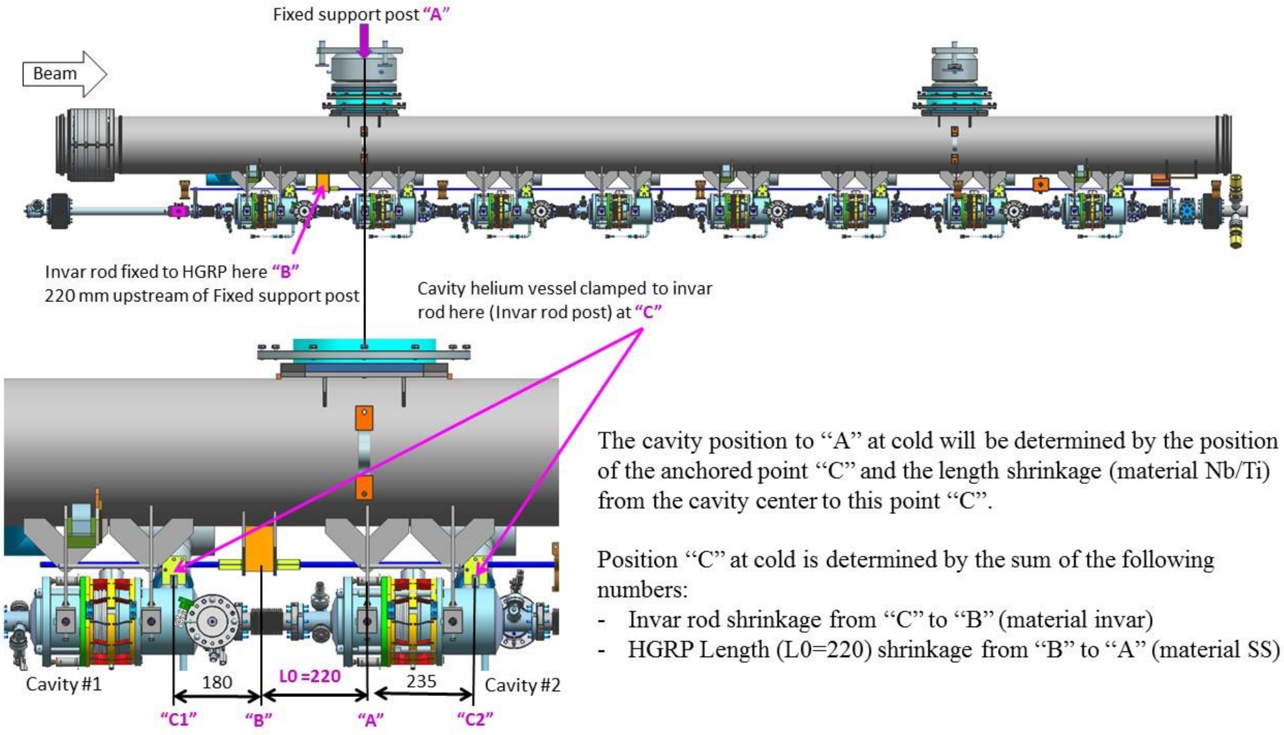
The cavity position at cold will be determined by the position of the anchored point at the invar rod post and the length shrinkage from the cavity center to this point. Shown in Fig. 3.5, there are three reference locations, “A”, “B”, and “C”, which we will use for determining the cavity positions at cold.

- “A”, location of cryomodule fixed support post;
- “B”, location of the invar rod fixed to the HGRP; due to the supports of cavity #2 being under the module fixed support post, “B” is offset by 220 mm upstream to “A”;
- “C”, location of the anchored point of the cavity helium vessel to the invar rod.

The position of cavity center with regard to “A” at cold will be determined by the position of “C” and the length shrinkage (material Nb/Ti) from the cavity center to “C”.

Position “C” at cold is determined by the sum of the following numbers:

- Invar rod shrinkage from “C” to “B” (material invar)
- HGRP shrinkage from “B” to “A”: 0.67 mm.



The cavity position to “A” at cold will be determined by the position of the anchored point “C” and the length shrinkage (material Nb/Ti) from the cavity center to this point “C”.

Position “C” at cold is determined by the sum of the following numbers:

- Invar rod shrinkage from “C” to “B” (material invar)
- HGRP Length (L0=220) shrinkage from “B” to “A” (material SS)

Figure 3.5: Reference points “A”, “B”, and “C” for determining the cavity positions at cold

The thermal contraction rate of various materials in the cavity support system is listed in Table 3.3. Table 3.4 lists the “C” position change at cold. Table 3.5 lists the length shrinkage of the beamline components. Fig. 3.6 shows the length labels used in Table 3.5. The beamline upstream bellows spool is supported to the invar rod on the upstream end, while the beamline downstream bellows spool is supported to the invar rod downstream end. Table 3.6 gives the summary of the beamline elements positions at warm as well as at cold, with respect to the cryomodule fixed support post, position “A”.

Table 3.3: Thermal contraction rate of various materials in the module.

Component	Material	Temperature	ΔL/L
HGRP	SS	300K – 2K	0.306%
Cavity	Nb/Ti	300K – 2K	0.152%
Invar rod	Invar	300K – 2K	0.0536%

Table 3.4: Invar rod post (anchored point of each cavity) position “C” change at cold

Invar rod post #, “C”	“C” to “B” at warm	Position change “C” to “B” at cold	Position change “C” to “A” at cold
Cavity 1, C1	-180.3	0.10	0.77
Cavity 2, C2	454.2	-0.24	0.43
Cavity 3, C3	1088.7	-0.58	0.09
Cavity 4, C4	1723.2	-0.92	-0.25
Cavity 5, C5	2357.7	-1.26	-0.59
Cavity 6, C6	2992.2	-1.61	-0.93
Cavity 7, C7	3626.7	-1.95	-1.27
Cavity 8, C8	4261.2	-2.29	-1.61

Table 3.5: Beamline components length shrinkage

Label	Description	Material	length	length shrinkage at cold
L1	US GV face to invar rod US end	SS	755	2.31
L2	US bellows support to "C"	Invar	516	0.28
L3	Cavity Center to "C"	Ti/Nb	122	0.19
L4	Invar rod DS end to "C8"	Invar	267	0.14
L5	Invar rod DS end to BPM center	SS	108	0.33
L6	Invar rod DS end to DS GV face	SS	273	0.84
	HOM absorber center to DS flange face	SS	139	0.43

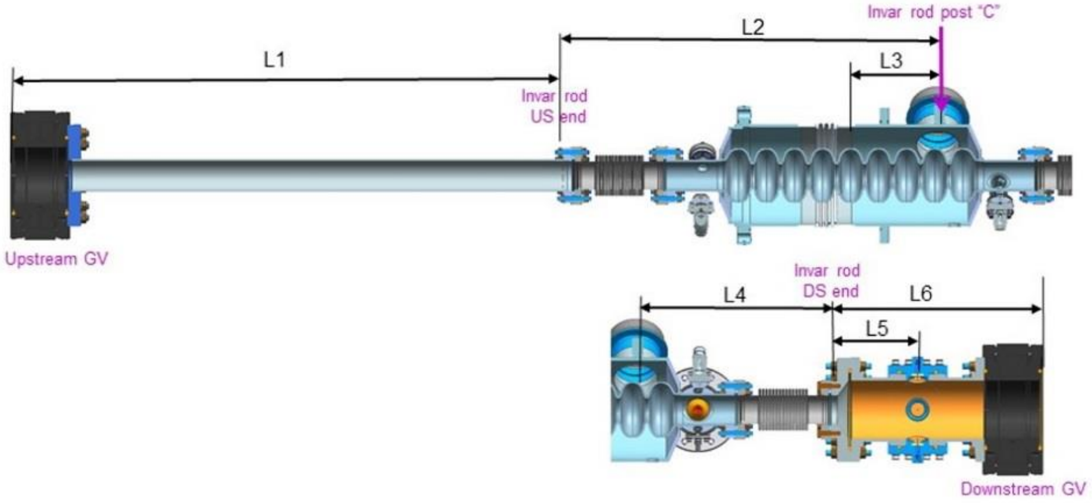


Figure 3.6: Length of the beamline components as labeled in Table 3.5

Table 3.6: Beamline element center position at warm and at cold, with respect to "A"

Beamline components	Position at warm	Cavity-to-cavity at warm	position change at cold	Position at cold	Cavity-to-cavity at cold
US GV flange face	-1671.5		3.36	-1668.14	
Cavity 1 center	-522.5		0.96	-521.54	
Fixed post "A"	0.0		0.00	0.0	
Cavity 2 center	112.0	634.5	0.62	112.62	634.2
Cavity 3 center	746.5	634.5	0.28	746.78	634.2
Cavity 4 center	1381.0	634.5	-0.07	1380.93	634.2
Cavity 5 center	2015.5	634.5	-0.41	2015.09	634.2
Cavity 6 center	2650.0	634.5	-0.75	2649.25	634.2
Cavity 7 center	3284.5	634.5	-1.09	3283.41	634.2
Cavity 8 center	3919.0	634.5	-1.43	3917.57	634.2
BPM center	4416.5		-2.09	4414.41	
DS GV flange face	4581.5		-2.59	4578.91	
GV-to-GV flange faces		6253.0			6247.05
HOM absorber center	4744.0		3.79	4747.79	
HOM absorber length		301.5			307.5
Cryomodule slot length		6554.5			6554.5

The total longitudinal shrinkage of the beamline will be 6 mm when cold. The bellows on the HOM absorber will accommodate this motion.

3.4 Studies on cavity helium tank chimney size

The maximum dynamic heat load per cavity is estimated to be 24 W, which in turn determines a chimney inner diameter. Due to various constraints, shown in Fig. 3.7, the chimney into helium vessel is limited to a 60.2 mm inner diameter which could handle a 29.8 W heat load. This gives a 25% heat transport margin. In order to increase the heat transport margin, careful studies were performed to explore the options in the design.

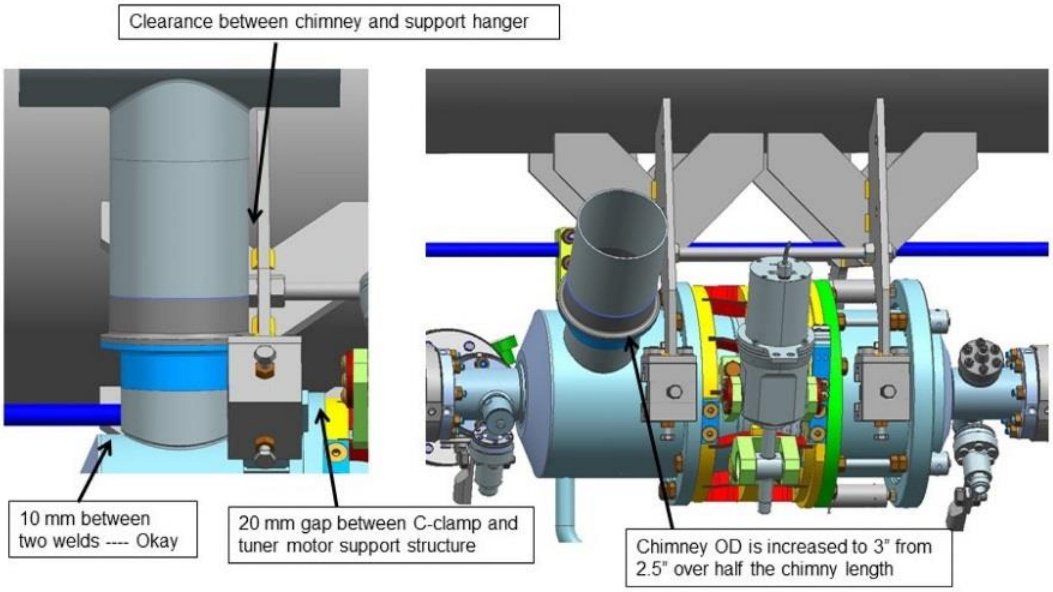


Figure 3.7: Clearances at room temperature among the parts around helium vessel chimney

With a design incorporating the chimney size step up in diameter at Ti-SS transition, shown in Fig. 3.8, the heat transport capacity could be increased to 36 W, a 20% increase. LCLSII-4.5-EN-0843 describes analysis of heat transport from the cavity out of the helium vessel.

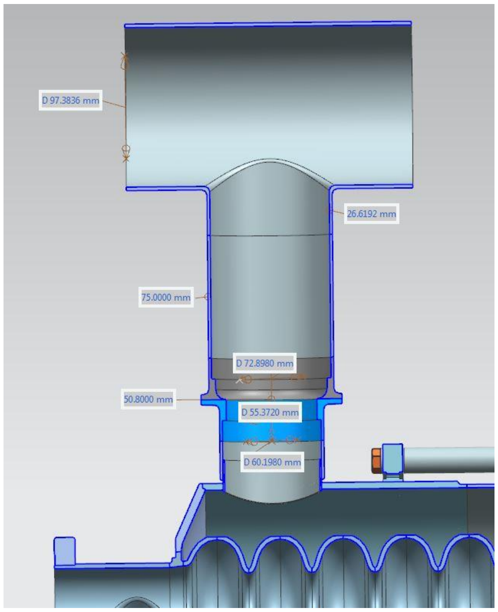


Figure 3.8: Chimney size step up in diameter at the Ti-SS transition

3.5 Cryogenic piping

The 3.9 GHz cryomodule uses an identical cooling scheme of the 1.3 GHz cryomodule, with the same pipe sizes and positions, shown in Fig. 3.9 and Fig. 3.10, and described in Table 3.7. Table 3.8 lists the parameters of the cryogenic pipes.

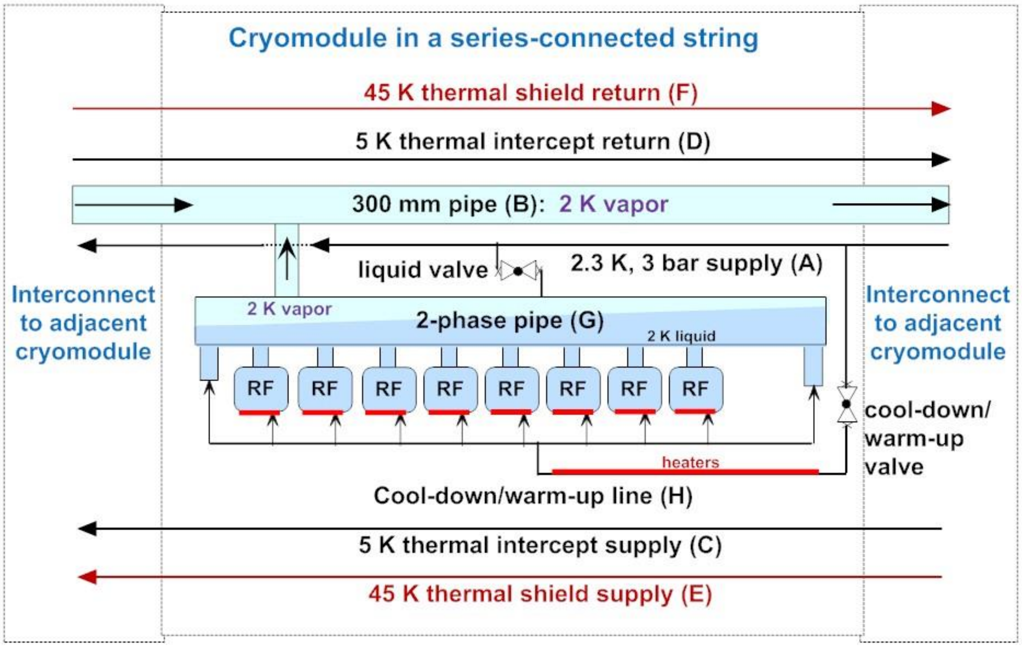


Figure 3.9: 3.9 GHz cryomodule cryogen flow schematic

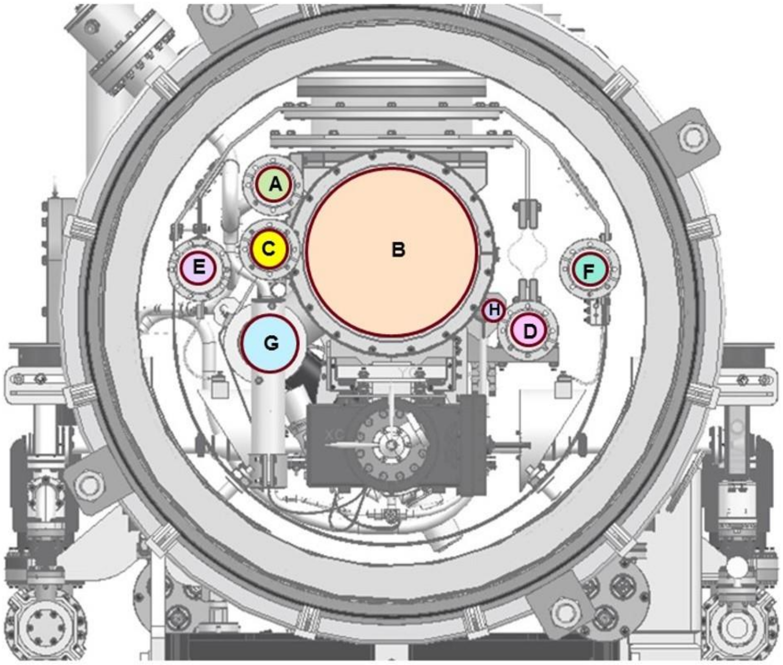


Figure 3.10: Cryogenic pipe positions and labels

Table 3.7: Cryogenic circuits in the cryomodule

Circuit	Lines	Description
2 K piping	Lines A (supply) through G (two-phase pipe) to B (return)	Provides 2K liquid helium to the cavities with a valve for liquid supply in each module. The RF cavities are maintained within the 1.8 K to 2.1 K range by means of a stagnant bath of saturated liquid helium
Cool-down /warm-up	Lines A (supply) through H and then G (two-phase pipe) to B (return)	A cool-down/warm-up valve and closed-ended piping for cool-down /warm-up of individual module, to provide high thermal gradient during cool-down through 9.2 K transition temperature to minimize flux trapping
5 K piping	Lines C to D	A helium circuit in the temperature range of 5 K to 8 K, provides a low temperature thermal intercept for the support posts, RF power coupler, and instrumentation wires
45 K piping	Lines E to F	A helium circuit in the temperature range of 35 K to 55 K, provides conductive thermal intercepts to the thermal radiation shield, and to tuner piezo actuator wires and housing, RF power coupler, HOM absorbers, cryogenic valves, and instrumentation wires

Table 3.8: Parameters of cryogenic pipes

Line	Description	Coordinates (X, Y) [mm]	Operating pressure [bar]	Design Pressure [bar]
A	2.2 K supply	219, 125.5	3.0	20.0
B	HGRP	0, 0	0.031	2.05 warm/ 4.0 cold
C	4.5 K supply	225.5, 6.5	3.0	20.0
D	5.5 K return	-252, -144.0	2.8	20.0
E	35 K supply	355, -31.0	3.7	20.0
F	55 K return	-367, -30.2	2.7	20.0
G	2 K-2 phase		0.031	2.05 warm/ 4.10 cold
H	Cool-down/warm-up		3	20

The cavities will be cooled by 2 K saturated liquid helium fed by the 2-phase supply line. Heat from the outside surface of the RF cavity, and heat entering via conduction from the beam pipe at the RF cavity ends, is carried through stagnant saturated Helium II to the liquid helium surface in the 2-phase pipe via superfluid heat transport. The HGRP returns the evaporated gas to the cryogenic plants, shown in Fig. 3.11.

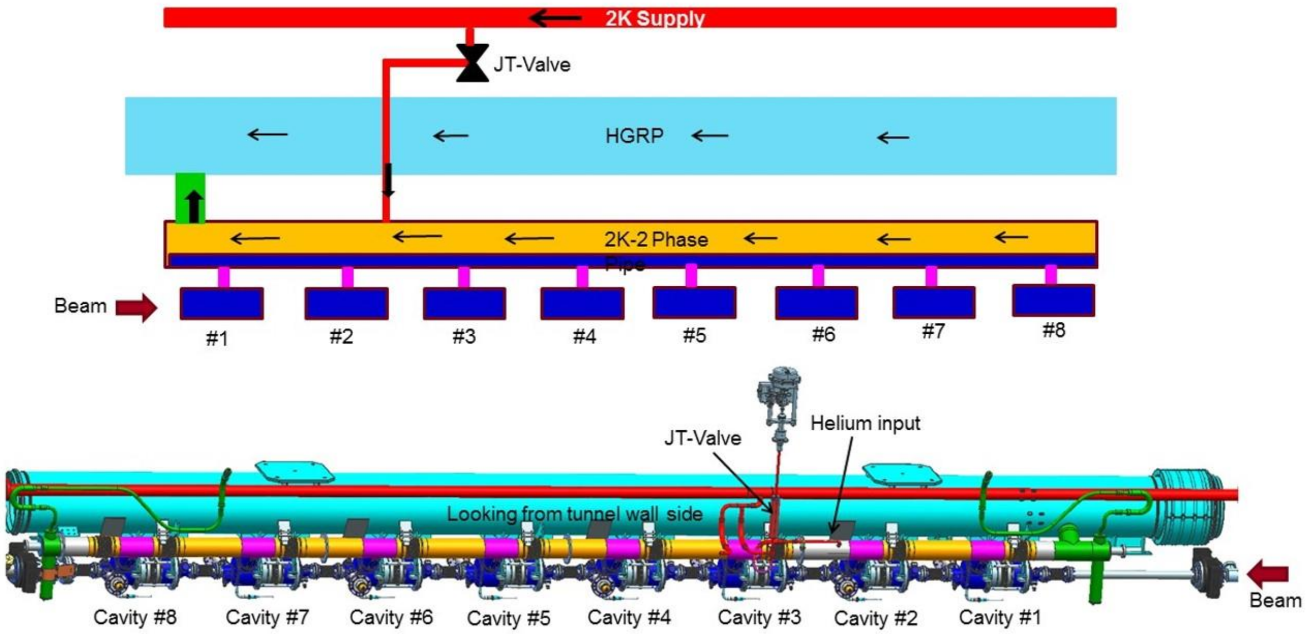


Figure 3.11: 2 K cryogenic piping (upper: flow scheme; lower: model with matching colors)

The liquid helium levels in the 2-phase pipe with the LCLS-II tunnel slope ~0.5% is shown in Fig. 3.12.

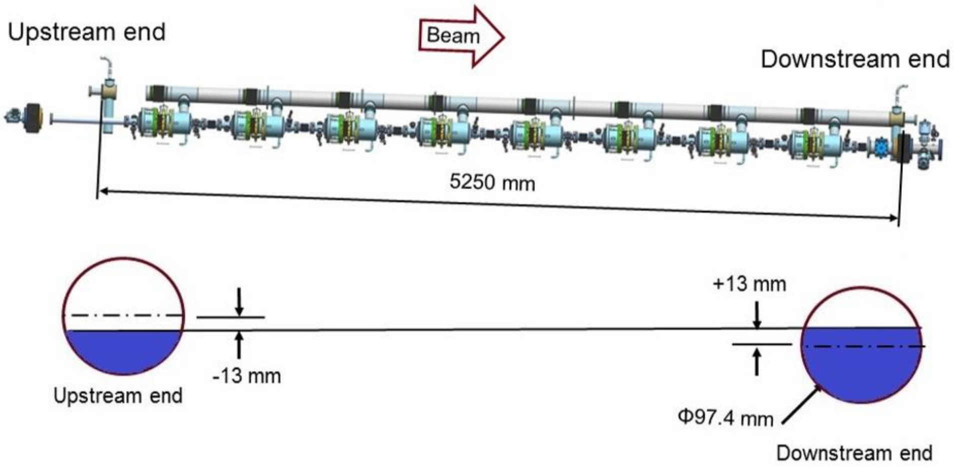


Figure 3.12: Liquid helium levels in the 2-phase pipe with the LCLS-II tunnel slope ~0.5%

3.6 50 K thermal shield

The thermal shield upper section, shown in Fig. 3.13, supports the weight of the whole shield and two high temperature cryogenic pipes, Line E and Line F. The shield is made from aluminum AL 1100-H12 sheets of ¼" thickness. It consists of two sections, joined together and then welded to a long extruded pipe, Line F. To avoid the thermally induced mechanical stresses or material deformations during welding or cool-down process, finger-slits are made to the joints at the cooling pipe attachments. It is important to ensure a good thermal contact joint, as the cooling of the entire shield will be through the helium gas in the extruded pipe. The connection plates are used to assemble the two shield sheets prior to welding and serve as templates for drilling holes for the rivets. Indium foils are used for the thermal braids installation, with the procedure specified in Fermilab document ED0004287, to ensure a good thermal path between the thermal strap connectors and the component surface. Loctite type 242 (blue) is used for all fasteners threads, to ensure the bolted connections will not loosen due to thermal cycling or shipping vibrations.

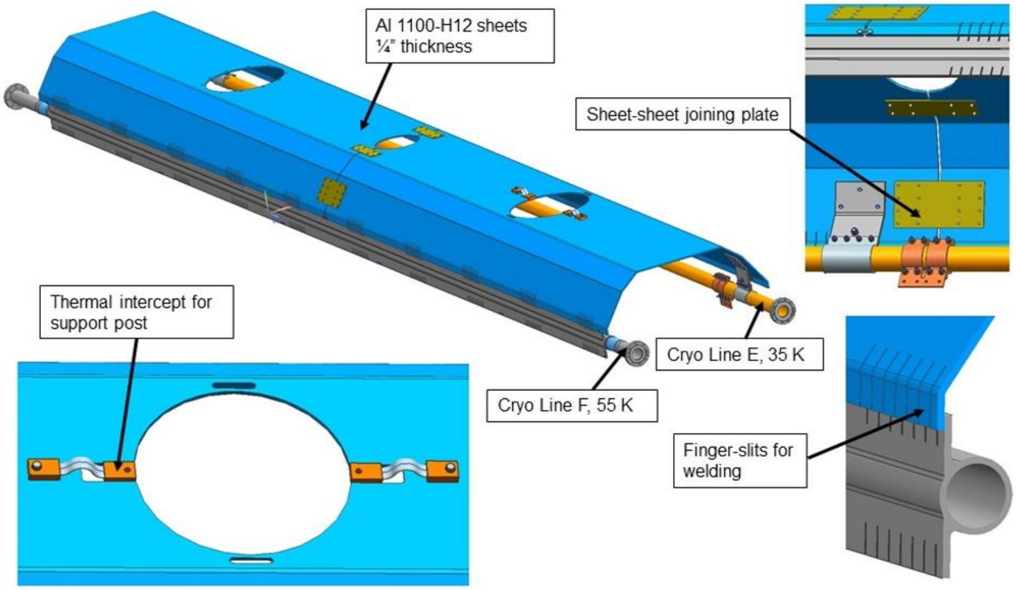


Figure 3.13: Thermal shield upper-assembly

The thermal shield lower section is made from aluminum AL 1100-H12 sheet of 1/8" thickness. It consists of five sections, with the butt joint held with two pairs of connection tabs between them, shown in Fig. 3.14.

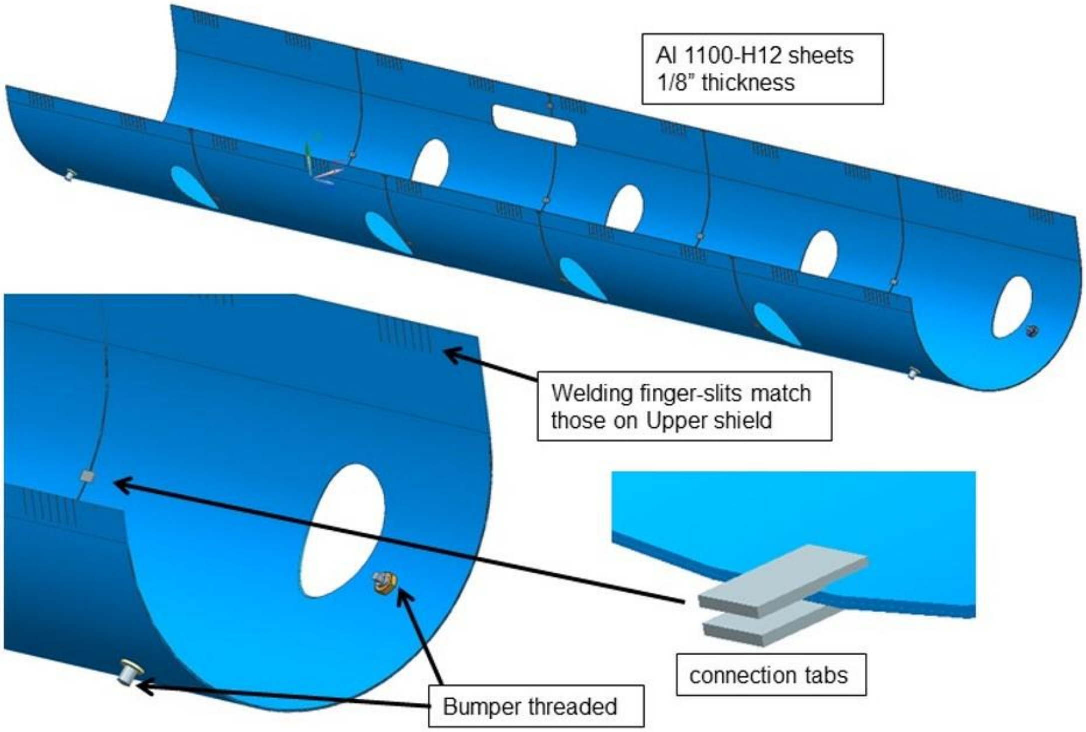


Figure 3.14: Thermal shield lower-assembly

3.7 Thermal intercepts

Thermal intercepts are used for various components (Support posts, RF power coupler, HOM absorbers, and instrumentation wires) to the 5K and 50 K temperatures, respectively, shown in Fig. 3.15.

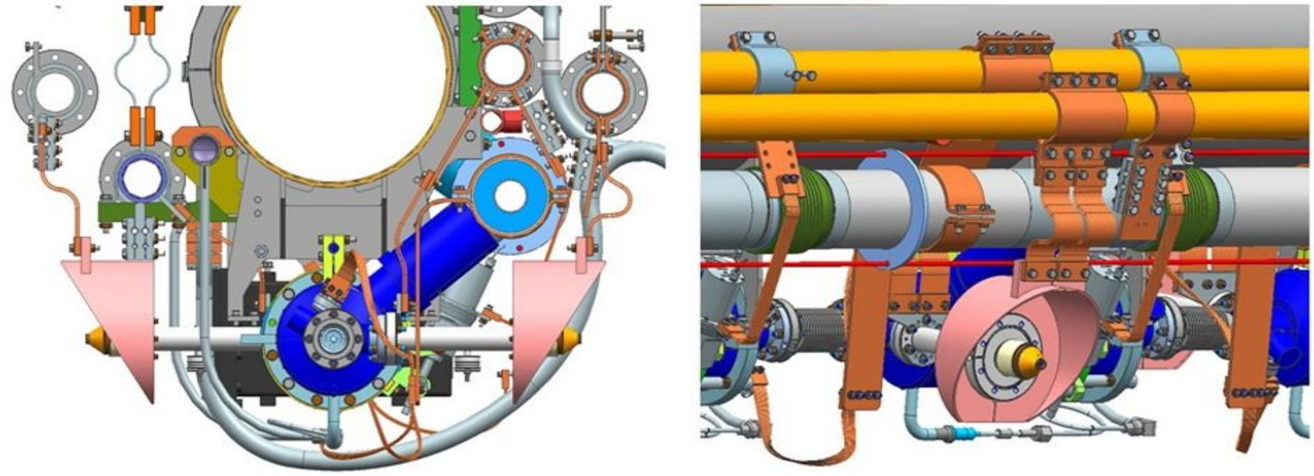


Figure 3.15: Thermal intercepts for various components

In order to better accommodate the coupler intercepts on the wall side of the cryomodule, cooling Line C and E material is changed to aluminum, compared to the corresponding stainless steel pipes in the 1.3 GHz cryomodule.

4. 3.9 GHz cryomodule external features

The 3.9 GHz cryomodule ends are identical to those in the 1.3 GHz cryomodule. The module interconnect unit is identical to the one used for the 1.3 GHz cryomodule as well.

4.1 Vacuum vessel

The vacuum vessel provides the insulating vacuum to the cold mass and the RF cavities. The majority of the material of the vacuum vessel is carbon steel (A516 Grade 60) with the flanges that use O-ring seals made of stainless steel 304L or 316L. The vacuum vessel is 5.7345 m long and 0.965 m [38”] in diameter. There are ports for support posts, input RF power couplers, tuner access, instrumentation, and safety relief, shown in Fig. 4.1.

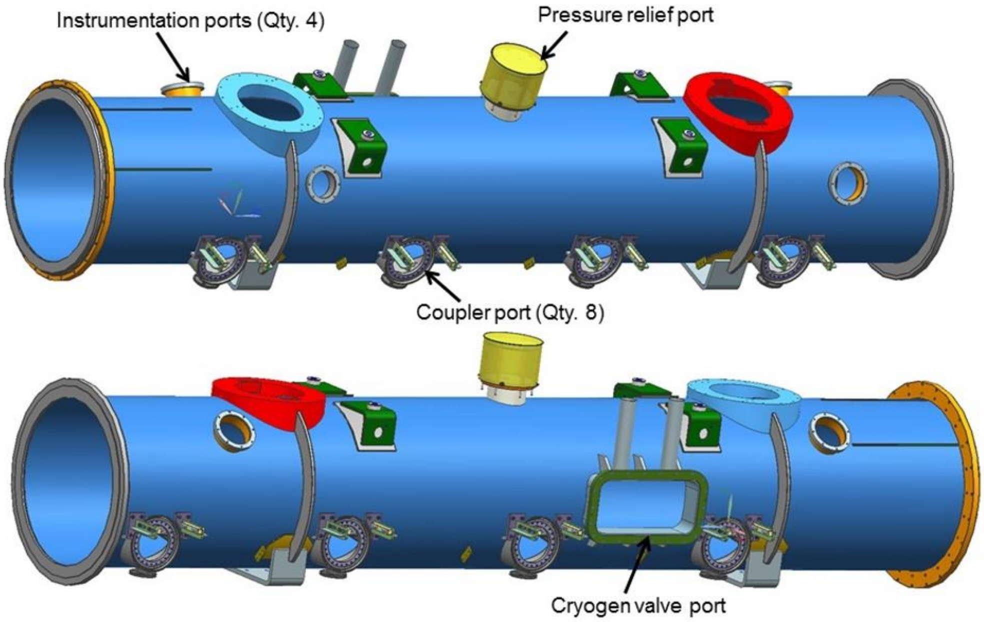


Figure 4.1: 3.9 GHz Cryomodule vacuum vessel

Static structural analysis was performed to evaluate the vacuum vessel mechanical stresses and deformations under the cold mass weight of 3 Ton. The FEA model setup and the analysis results are summarized in engineering document ED0004908. Equivalent stresses on the vessel under vacuum are shown in Fig. 4.2. It was concluded that the vessel will be safe under two scenarios: module in air and under vacuum.

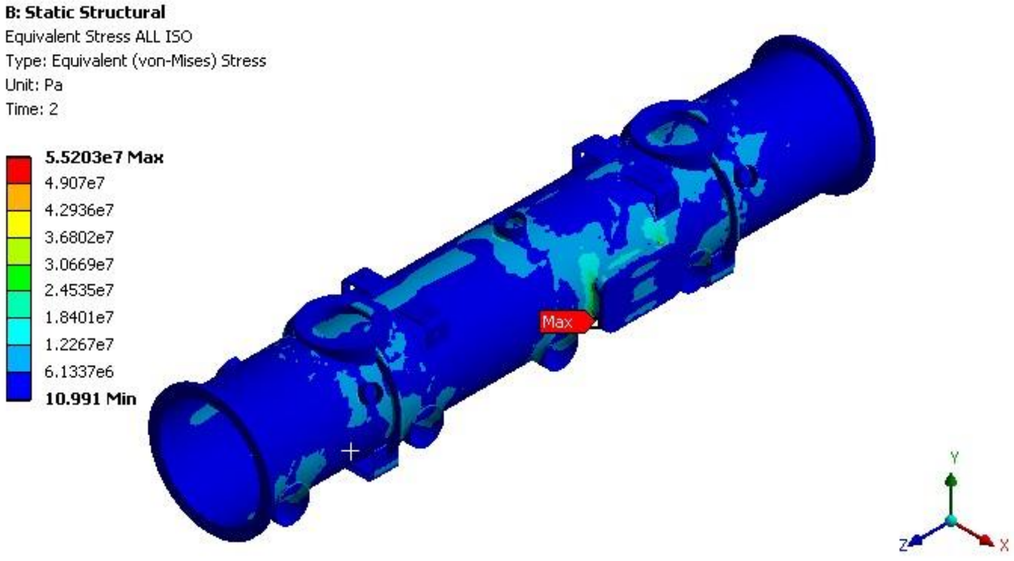


Figure 4.2: Equivalent stresses on the vessel under vacuum

The exterior surfaces will be painted with NAL Blue (RGB: 0, 76, 151, Hex: #004C97, CMYK: 100, 53, 2, 16, PMS: 2945C 2945U).

4.2 Coupler, waveguide supports, and coupler vacuum manifolds

There are eight FPC ports alternating between aisle and back wall, as shown in Fig. 4.3. They are aligned concentric to the couplers at cold, in an interval of 634.2 mm, which is the cavity-to-cavity spacing at cold. The port positions are slightly offset with respect to the coupler at installation at room temperature, listed in Table 4.1. The bellows on both inner and outer conductor in each coupler will accommodate this offset.

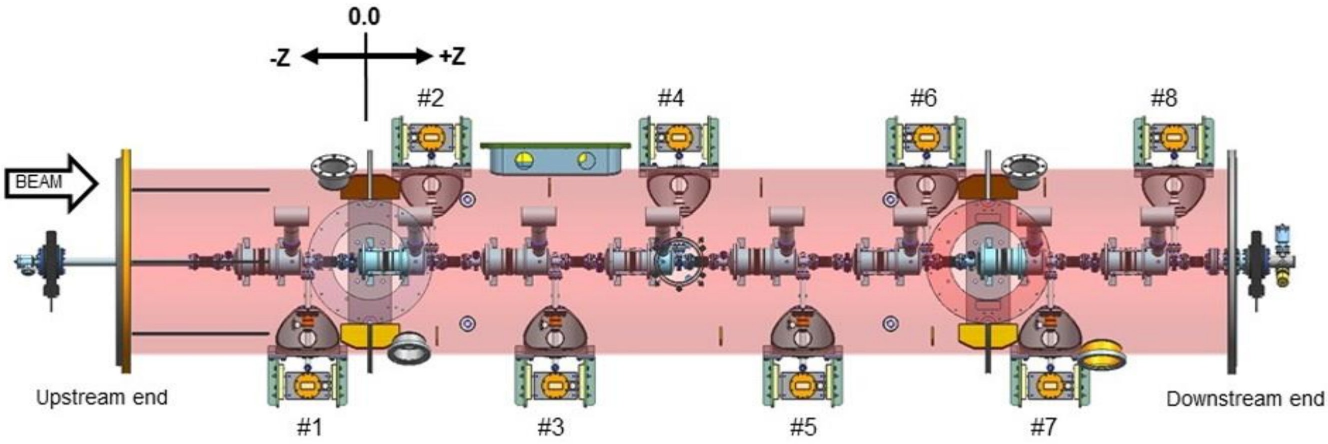


Figure 4.3: Location of the couplers

Table 4.1: Coupler position offset at installation

	Coupler at warm F10014812	Coupler port /coupler at cold F10014858	Offset at installation
Cavity 1	-319.5	-318.9	0.6
Fixed post	0.0	0.0	0.0
Cavity 2	315.0	315.3	0.3
Cavity 3	949.5	949.5	0
Cavity 4	1584.0	1583.6	-0.4
Cavity 5	2218.5	2217.8	-0.7
Cavity 6	2853.0	2851.9	-1.1
Cavity 7	3487.5	3486.1	-1.4
Cavity 8	4122.0	4120.3	-1.7

During RF operations, there may be vacuum activity in the warm coupler space, releasing gases from the waveguide. This space is connected to the coupler vacuum manifold which is shared by the eight couplers.

On each side of the module, there is a vacuum manifold (F10058455) connected to the coupler warm vacuum space, shown in Fig. 4.4. The warm coupler vacuum manifolds are on both sides of the module.

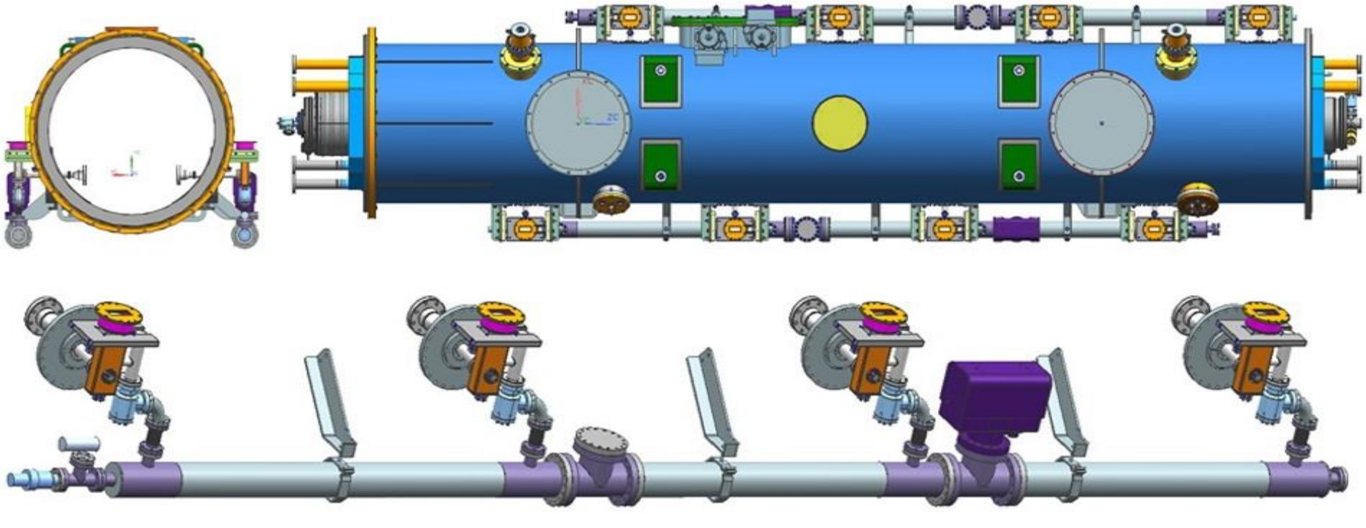


Figure 4.4: Cryomodule warm coupler vacuum manifold

The drawing of the main coupler warm assembly is F10052974, and its specification is ED0005767. In the waveguide pill box, an alumina window provides a separation of the vacuum from the air-filled waveguide space, shown in Fig. 4.5.

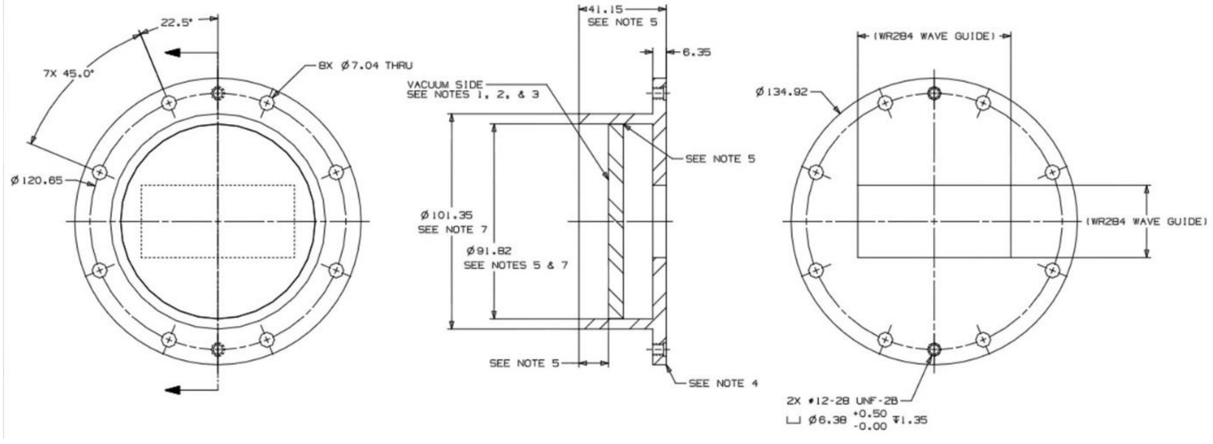


Figure 4.5: Coupler waveguide pill box

4.3 Instrumentation Connectors

The instrumentation arrangement is similar to the 1.3 GHz module except for the flanges for the magnets, shown in Fig. 4.6.

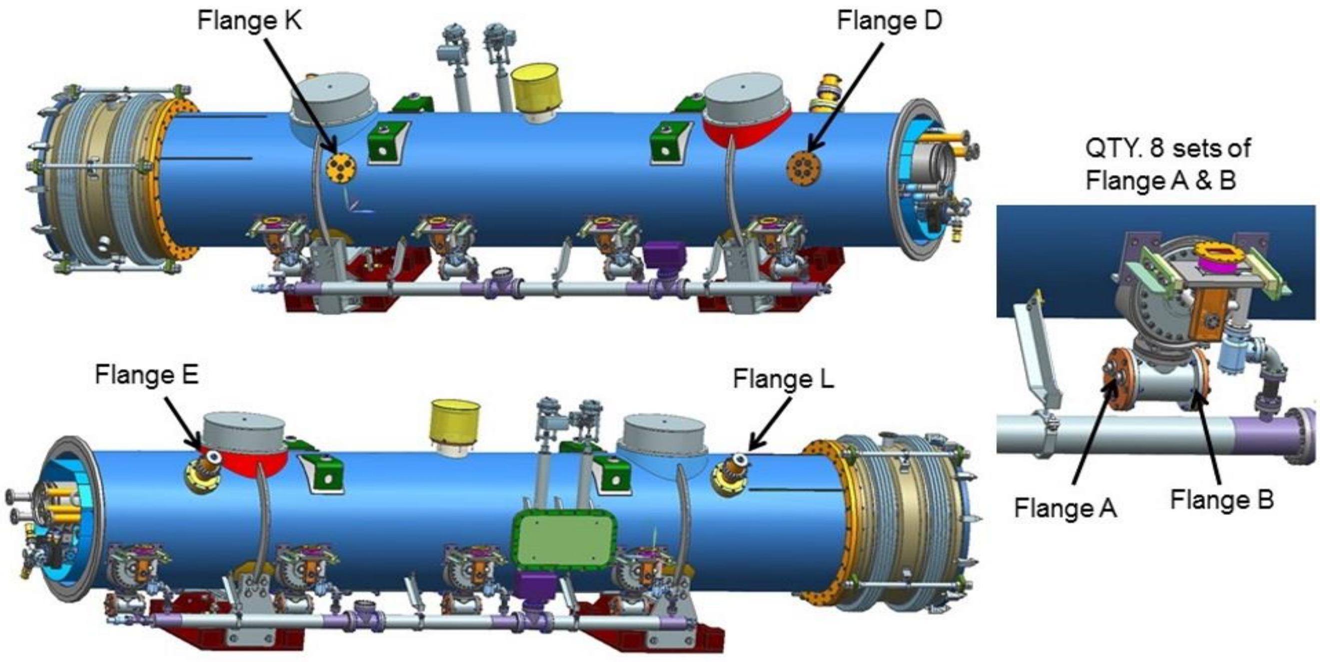


Figure 4.6: Instrumentation feedthrough flanges mounted on the vacuum vessel

The latest information on instrumentation specification, procedures, drawings, test results, checkouts, installation pictures, and calibrations can be found at this Fermilab web site. Table 4.2 gives a set of specifications about the instrumentation, connectors and cables.

Table 4.2: Instrumentation specifications

Document #	Description
ED0005772	3.9 GHz cryomodule instrumentation list
LCLSII-4.5-ES-0415	Cryomodule instrumentation specification
LCLSII-4.5-ES-0414	Cryomodule coaxial cable and connectors specification
LCLSII-4.5-ES-0416	Cryomodule multipin connectors specification
LCLSII-4.5-ES-0417	Cryomodule wire specification

5. 3.9 GHz Cryomodule sub-assemblies that are identical to those in the 1.3 GHz cryomodule

Table 5.1: 3.9 GHz Cryomodule sub-assemblies that identical to those in the 1.3 GHz cryomodule

Sub-assemblies identical to those in the 1.3 GHz cryomodule			
Drawing No.	**Description of sub-assembly**	Ref. in ED0004361	References
F10028131	Cold mass support post assembly	Section 3.3	ED0002026, Post assembly procedure ED0002383, Post traction test specification ES314512, G10 tube material specification ED0004389, Post thermal structural analysis
F10008909 F10008910	Cold mass fixed support assembly		
F10059214, F10059215, F10059219, F10059221, F10059222, F10059224	Instrumentation flanges A, B, D, E, L, and K	Section 4.3	Fermilab web site
Sub-assemblies with minor changes to those in the 1.3 GHz cryomodule			
MLI	Shorter by 5666 mm	Section 3.8	MLI specification
F10071095	Material cut-off near instrumentation flange A & B	Section 5.2	

6. Cryomodules comparison

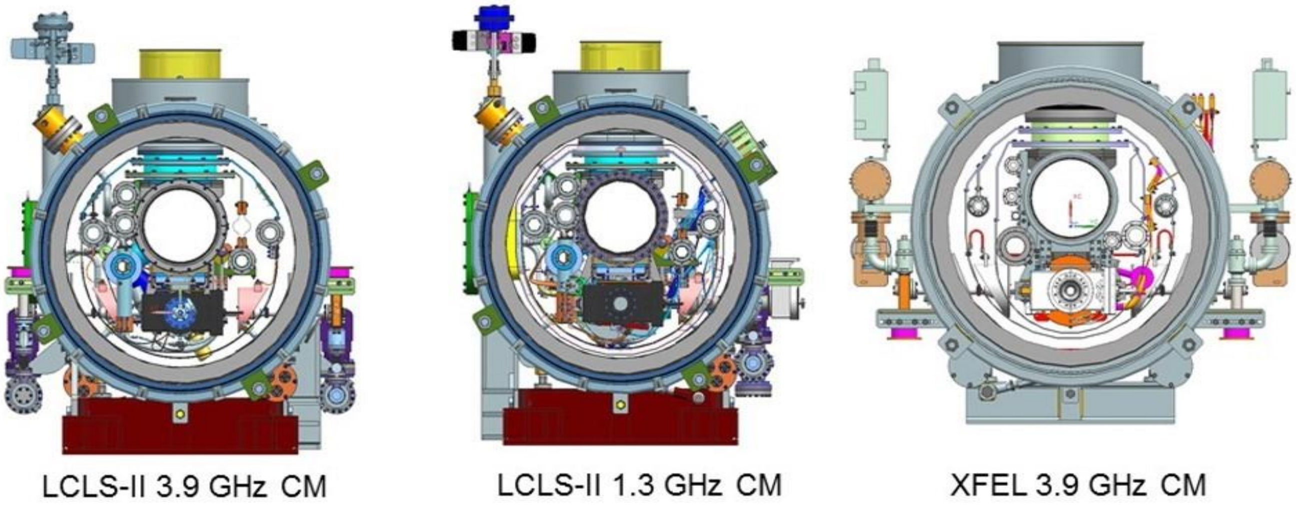
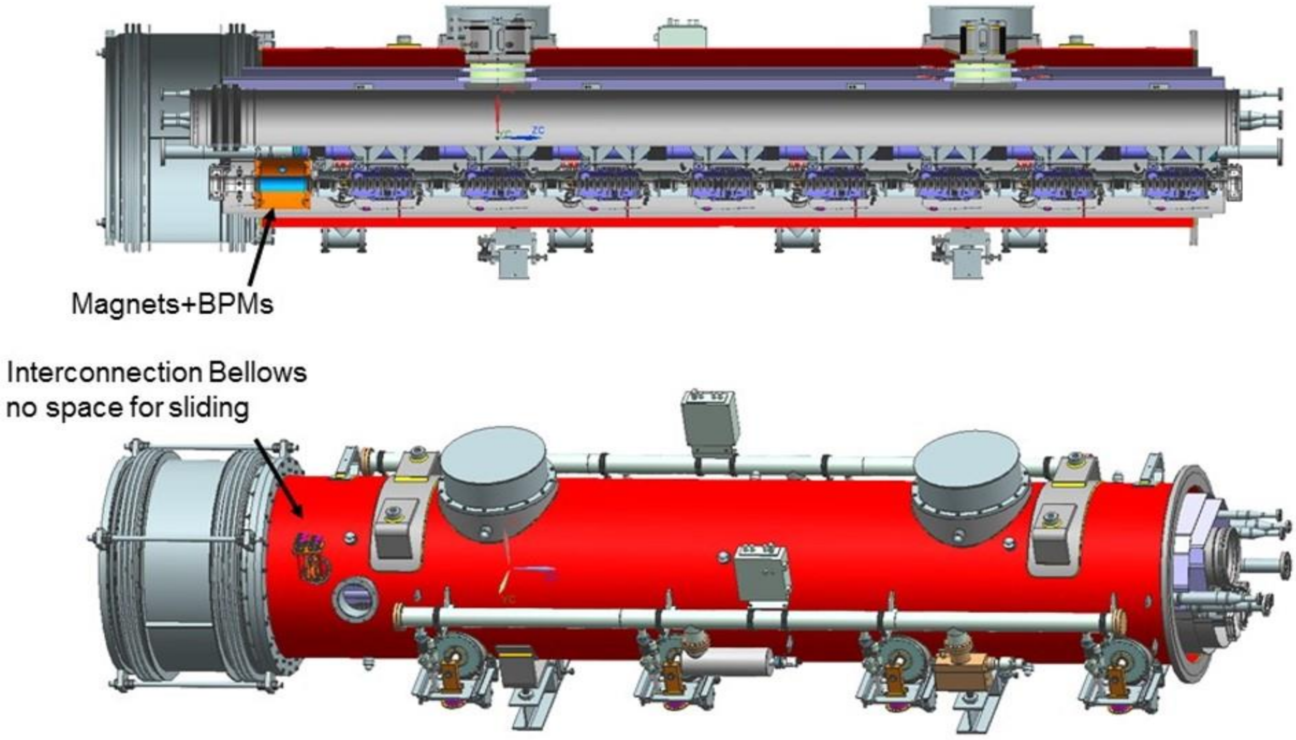

LCLS-II 3.9 GHz CM
LCLS-II 1.3 GHz CM
XFEL 3.9 GHz CM

Figure 6.1: Comparison of cross-sectional view of the cryomodules



Magnets+BPMs

Interconnection Bellows no space for sliding

Figure 6.2: XFEL 3.9 GHz cryomodule