Document Approval: **Date Approved**

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Revision History

Revision	Date Released	Description of Change
R0	6/2/2015	Original Release.

Table of Contents

Login info to access FNAL documents linked in this docu: “User “**lcls2module**” /Psw ”**module1.3GHz**”
FNAL web page gives a summary of documents related to the module mechanical interfaces

1 Scope

An XFEL-style cryomodule modified for continuous-wave operation was selected for the LCLS-II linac. This document specifies the external interfaces of the cryomodules for connection during installation in the SLAC tunnel. It covers the external features and locations of the physical interfaces on the cryomodule such as module support and alignment, cryogenic piping, FPC with its waveguide, and instrumentation connectors. It describes the requirements and procedures for making inter-module connections, and the requirements of vacuum systems. The focus is the mechanical interfaces. Detailed descriptions of each system are covered in Sections 4 to 9, with links to reference documents for additional information.

Many other "interfaces" such as cryogenic requirements, RF power, controls, etc., are outside the scope of this document. The functional requirements of the 1.3 GHz Superconducting RF Cryomodule LCLSII-4.5-FR-0053 includes the statement of the exclusions of the cryomodule work.

The revision R0 of this document refers to the two prototype cryomodules; known differences with respect to the production cryomodules are indicated in Section 10.

2 Definitions

Term	Definition
SLAC	SLAC National Accelerator Laboratory
FNAL	Fermi National Accelerator Laboratory
LCLS-II	Linac Coherent Light Source upgrade
XFEL	X-ray Free Electron Laser, an SRF linac under construction at DESY which includes TESLA-style cryomodules
CM	Cryomodule
Cold-mass	An ensemble of components to which a stable cryogenic environment needs to be guaranteed. It includes the beamline string, 40 K thermal shield, cryogen piping and support posts
HGRP	Helium Gas Return Pipe, the 300 mm diameter helium pipe which also serves as the structural backbone of the cold-mass
MLI	Multi-Layer Insulation, aluminized mylar wrapped in layers alternately with a conductively insulating material
FPC	Fundamental RF power coupler
HOM	Higher order mode
UHV	Ultra high vacuum
CCG	Cold cathode gauge
MFC PS	Mass flow control pumping station
GV	Gate valve
RAV	Right angle valve

3 Introduction

The major external features and locations of physical interfaces on the cryomodule are shown in Figure 3.1. It has mounts, flanges, and ports for support posts, FPCs, instrumentations, safety relief, tuner access, vacuum pump-out and gauge, power to the magnet current leads, and cryogenic valves. The names and locations of all the external features that are welded on the vacuum vessel are identified in the vacuum vessel weldment drawing F10026610.

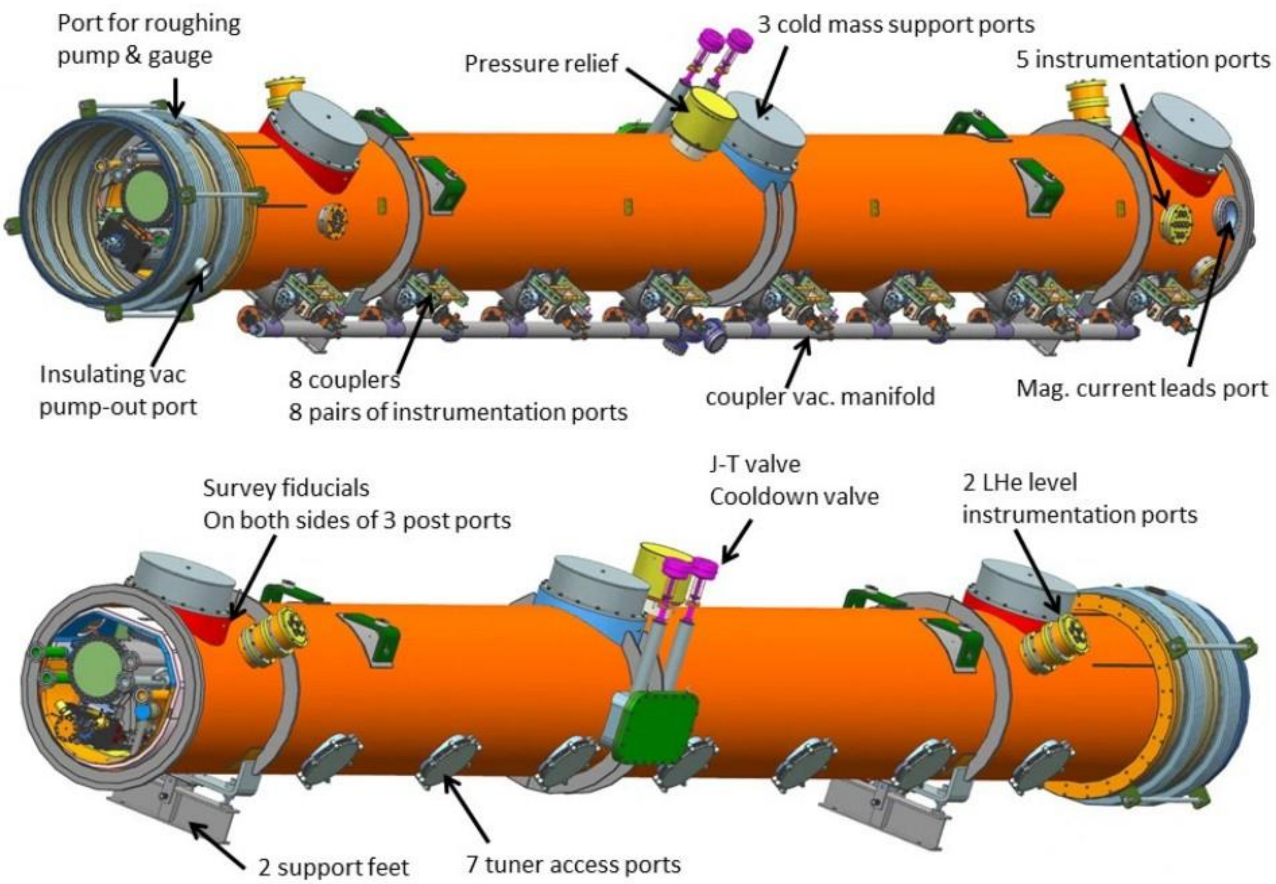


Figure 3.1: Prototype cryomodule and its major external physical interfaces

The cryomodule consists of several complex sub-assemblies. The top assembly drawing is F10009945, in which the names and positions of all the sub-assemblies are identified. The cross-section of the cryomodule is shown in Figure 3.2, and the drawings of its major sub-assemblies are listed in Table 3.1. The cavity beamline string is suspended under the HGRP by three support posts. The post is an assembly of a low thermal conduction G10 fiberglass pipe and four stages of shrink-fit aluminum and stainless steel discs and rings. The adjustable suspension brackets of the posts allow the precision alignment of the beamline string with regard to the vacuum vessel fiducials. The vacuum vessel supports the weight of the cold-mass, 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 cavity 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.

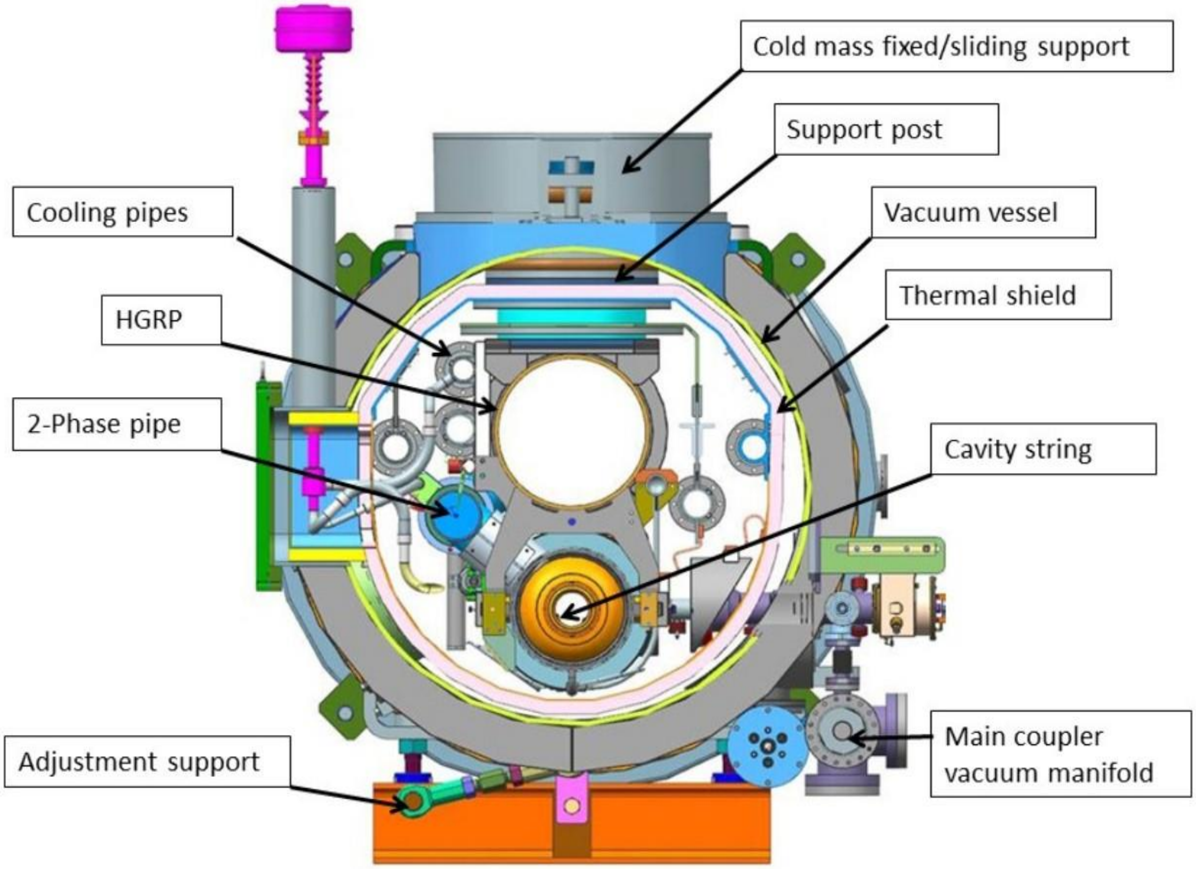


Figure 3.2: Cross-section of the cryomodule showing its major sub-assemblies

Table 3.1: Drawings of cryomodule major sub-assemblies

Drawing number	Description of sub-assembly
F10009887	Cavity string assm, which includes cavities, FPRs, tuners, magnets, beam position monitor, GVs, etc.
F10026609	Vacuum vessel weldment
F10023305	HGRP assm
F10017606	Thermal shield upper assm
F10017613	Thermal shield lower assm
F10028131	Cold mass support post assm
F10008909	Cold mass fixed support assm
F10008910	Cold mass sliding support assm
F10037597	Adjustment support assm
F10010017	Main coupler warm vacuum manifold assm
F10025738	2-phase pipe assm

Figure 3.3 shows the overall dimensions of the cryomodule. The face-to-face distance of the GV flange at both ends of the beamline string is 11918.9 mm. There will be a HOM absorber with a length of 301.5 mm between two modules. Including the gap for two beamline tube flange joints, the installed “slot length” of the cryomodule is 12222.0 mm, which is defined in the SCRF 1.3 GHz Cryomodule physics requirements document LCLSII-4.1-PR-0146-R0.

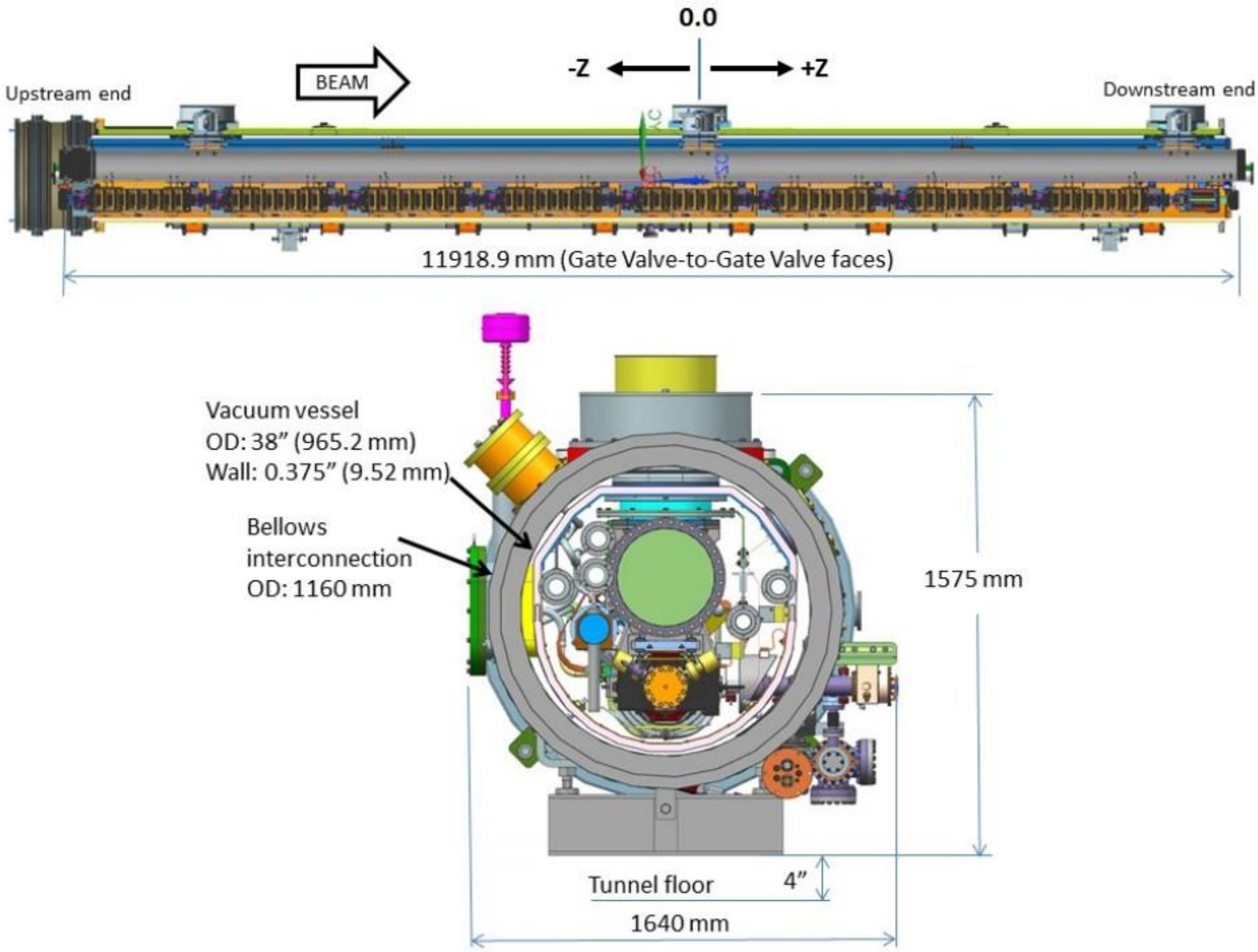


Figure 3.3: Overall dimensions of the cryomodule. Cryomodule coordinates are measured from the central cold-mass support.

The modules will be installed in the SLAC tunnel (10 feet height x 11 feet width) with the coupler ports facing the aisle and the center of the beam tube approximately 36” from the wall and 27” from the floor. The bottom of support unit will be 4’’ (maximum) from the tunnel floor, shown in Figure 3.4. SLAC will install two surveyed plates into the tunnel floor for each cryomodule to a precision relative to the beamline that will allow final module alignment using the adjustable support stand.

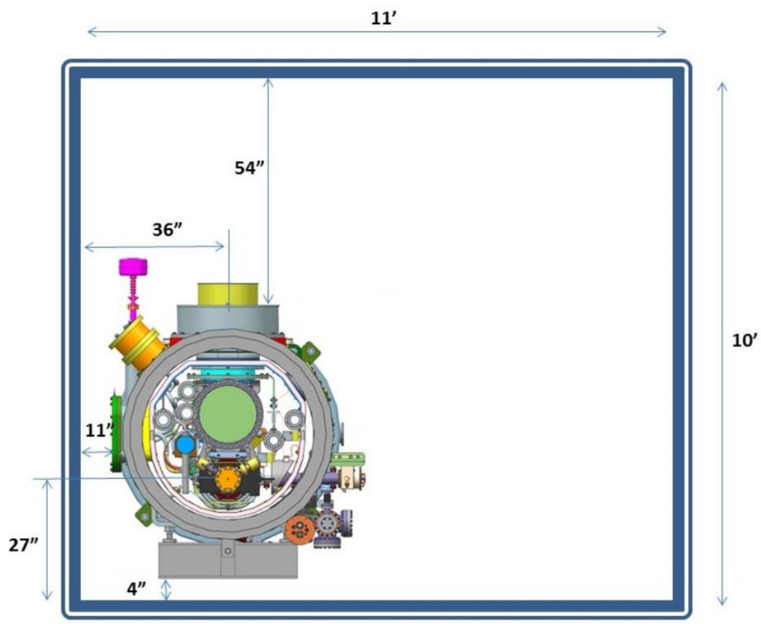


Figure 3.4: SLAC tunnel with 1.3 GHz cryomodule

Thirty-five 1.3 GHz cryomodules and two 3.9 GHz cryomodules will be connected to form four linac segments (L0, L1, L2, and L3) which are separated by three warm beamline sections (LH, BC1, and BC2) for the laser heater and bunch compressors, shown in Figure 3.5.

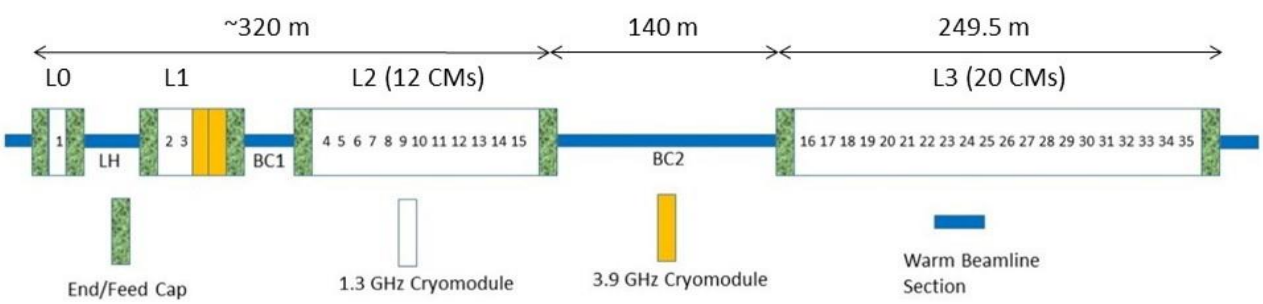


Figure 3.5: Linac with cryomodules in sections

A bellows inter-connect unit with a length of 850.0 mm is to be installed between adjacent cryomodules, shown in Figure 3.6. The connections of each subsystem have their distinct requirements:

- Welding for HGRP and cryogenic piping lines, in a tight space;
- UHV flange joints for beamline tubes, follow the particle free vacuum practice;
- Good thermal conduction at the thermal shield joints;
- Vacuum O-ring flange joints to the insulating vacuum vessel.

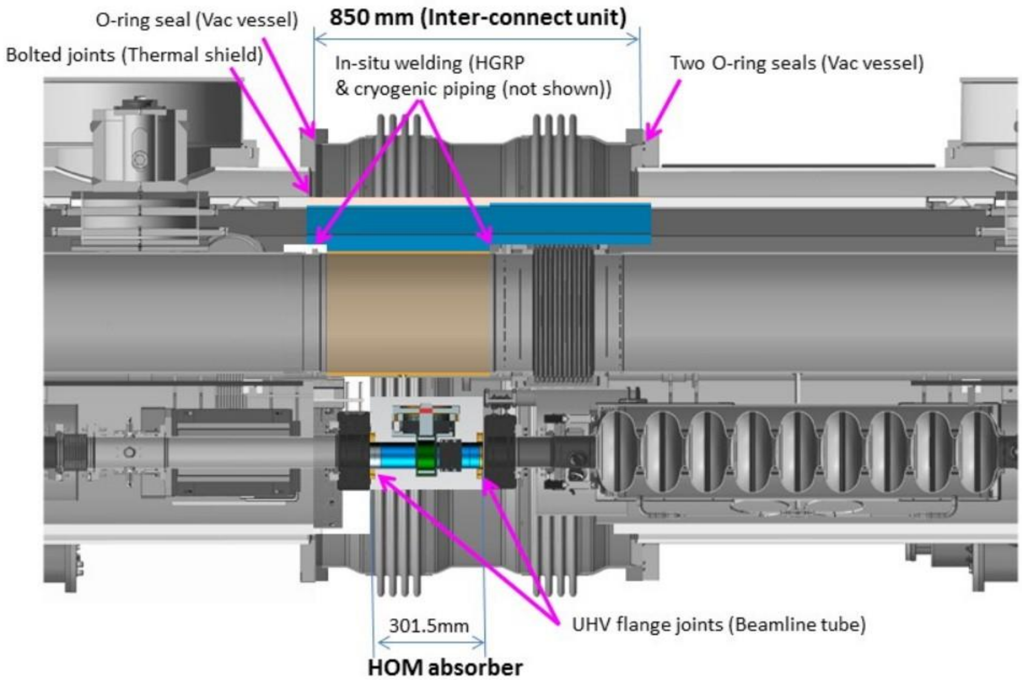


Figure 3.6: Central cross-section showing inter-module connections

The outer shell of the inter-connect unit can slide over the vacuum vessel to allow space for welding of six cryogenic pipes *in-situ*; bellows are used to mechanically decouple the modules and allow for thermal contraction or expansion during thermal cycling, shown in Figure 3.7. The bellows also serve to accommodate the welding procedure.

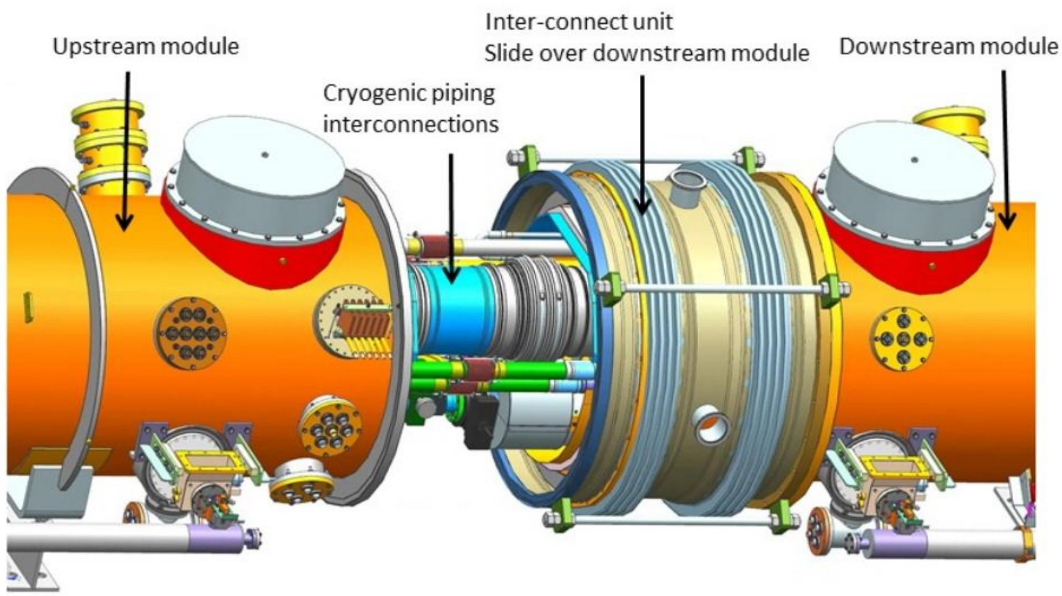


Figure 3.7: Inter-module cryogenic piping connections

There are eight FPC ports on the vacuum vessel. The warm sides of the FPCs are connected by a vacuum manifold, and each coupler module has instrumentation flanges and a waveguide support system, shown in Figure 3.8.

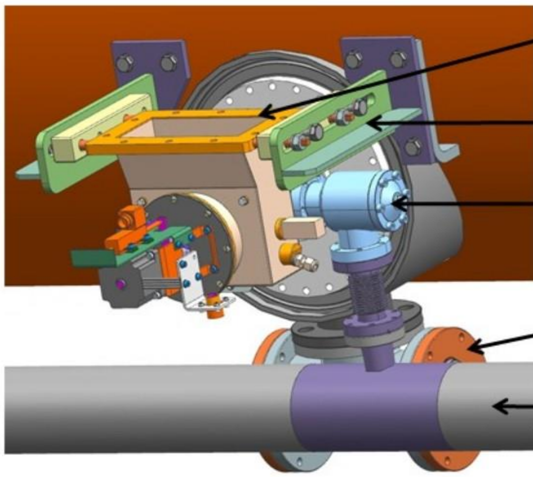


Figure 3.8: Instrumentation port and RF power coupler with its support system

The instrumentation wires and cables of the cryomodule are extracted from the module using flanges with vacuum tight electrical connectors. The prototype cryomodule instrumentation sensors are listed here: RF signals (field probe, HOMs), temperature sensors, heaters, quench voltage taps, electron pickups, magnetic field sensors, helium liquid level sensors and pressure transducers, magnets current leads, tuner piezo actuators, stepper motors, and tuner step motor limit switches. Production cryomodules will have fewer instrumentation sensors.

On the cryomodule, there is a pressure relief port to protect the module from over-pressurization, cryogenic valves for cavity helium tank liquid level control and cool-down flow rate control, and tuner access ports.

The module has three distinct vacuum spaces: insulating vacuum, beamline (cavity) vacuum, and a vacuum space on the warm side of the cold window of the FPCs, shown in Figure 3.9. For each linac section, the cryomodules share the same insulating vacuum space. There will be a vacuum break in the middle of section L3, so as to minimize the impact of loss of vacuum accidents and for leak checking a long linac string. Each individual cryomodule has its own warm coupler vacuum manifold which is shared among its eight FPCs on the warm side of the cold window.

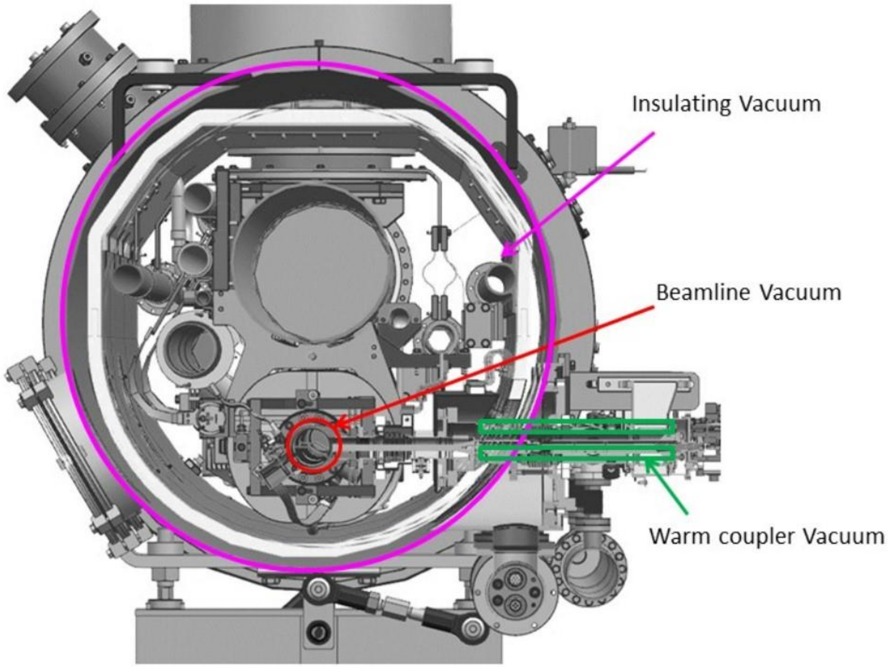


Figure 3.9: Vacuum subsystems of the cryomodule

4 Module Support and Alignment

There are two adjustment supports per module, located 4150.0 mm on each side of the center cold mass support port, 8300.0 mm apart. The support stand is a non-magnetic weldment with a w-beam type construction. The bottom (bearing) flange has a width of 7.5 inches and a length of 30 inches. The embedded stainless steel plate will be surveyed and anchored (with four Hilti anchors (Φ1" x 15" grade-8 rods using Hilti HIT-RE 500-SD adhesive) to the tunnel floor by SLAC at a fixed elevation offset to the beamline center line. A second plate is attached to the embedded plate using six ¾" – 10 bolts. In addition, a pair of seismic restraints are used to secure each stand after the alignment is complete. The mechanism of the module positional adjustment and the support attachment to the floor is shown in Figure 4.1. The stand has ±0.5" adjustability in vertical, transverse and longitudinal directions.

The engineering drawing of the module attachment to the tunnel floor is F10037597. The drawings of the detailed support unit components are listed in Table 4.1.

The fully assembled supports should be painted to protect against corrosion in tunnel. Care should be taken to protect the painting during transportation and rigging.

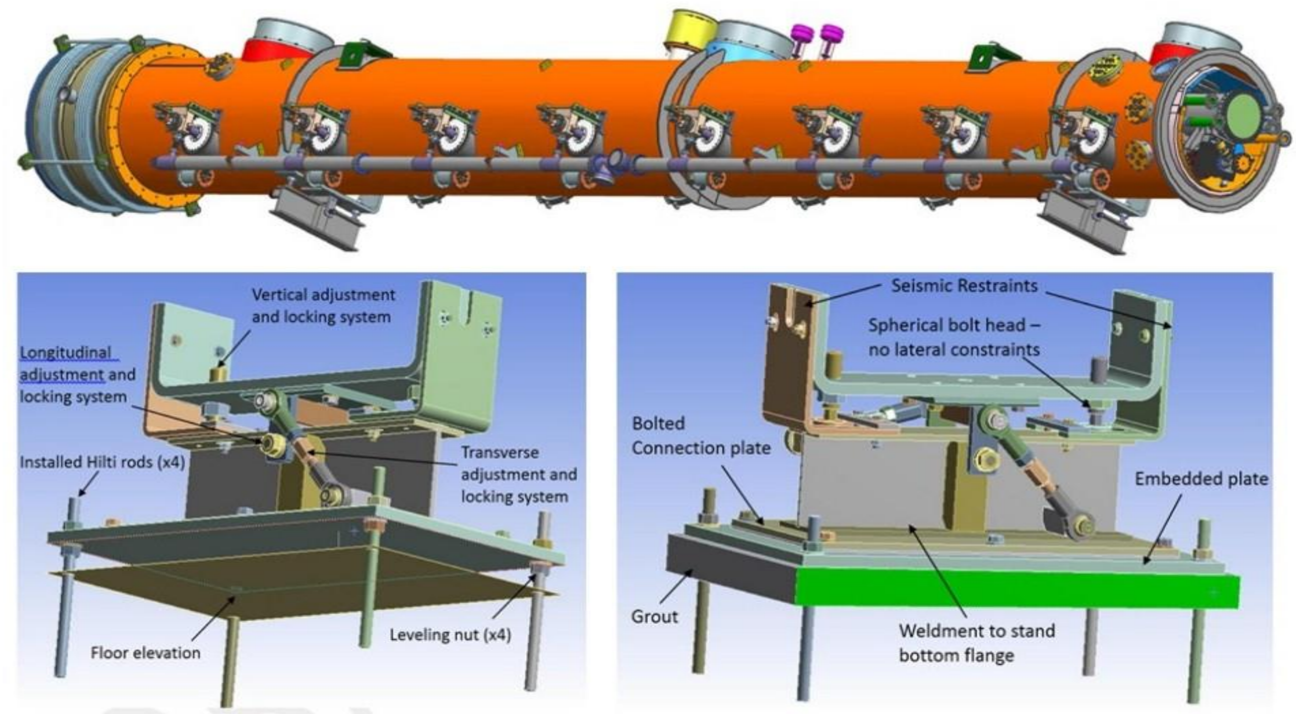


Figure 4.1: Cryomodule adjustable support unit and its attachment to the tunnel floor

Table 4.1: Drawings of the support unit

Drawing No.	Description
F10037597	LCLS-II cryomodule support assembly
F10037684	LCLS-II cryomodule adjustable support
F10036755	LCLS-II cryomodule adjustment plate weldment

Application of viscoelastic pads are required to minimize misalignment during local tremors. FNAL document ED0002673 provides a complete list of assembly, weldment and associated drawings, with a description of stand function, adjustment and securing after alignment. It also gives installation instructions for the embedded plate attachment to the tunnel floor using Hilti adhesive anchors, grout epoxy and stand-to-plate torque specification.

There are ten survey ball tooling fiducials on the vacuum vessel, shown in Figure 4.2, for the module alignment in the tunnel. On the GV body of both ends of the beamline string there are four alignment fiducials, installed with hot glue, which serve to measure the beamline string position relative to the support posts on the vacuum vessel before and after shipment. It is extremely important to remove these fiducials (magnetic) after the alignment checks at SLAC prior to cryomodule installation in the tunnel.

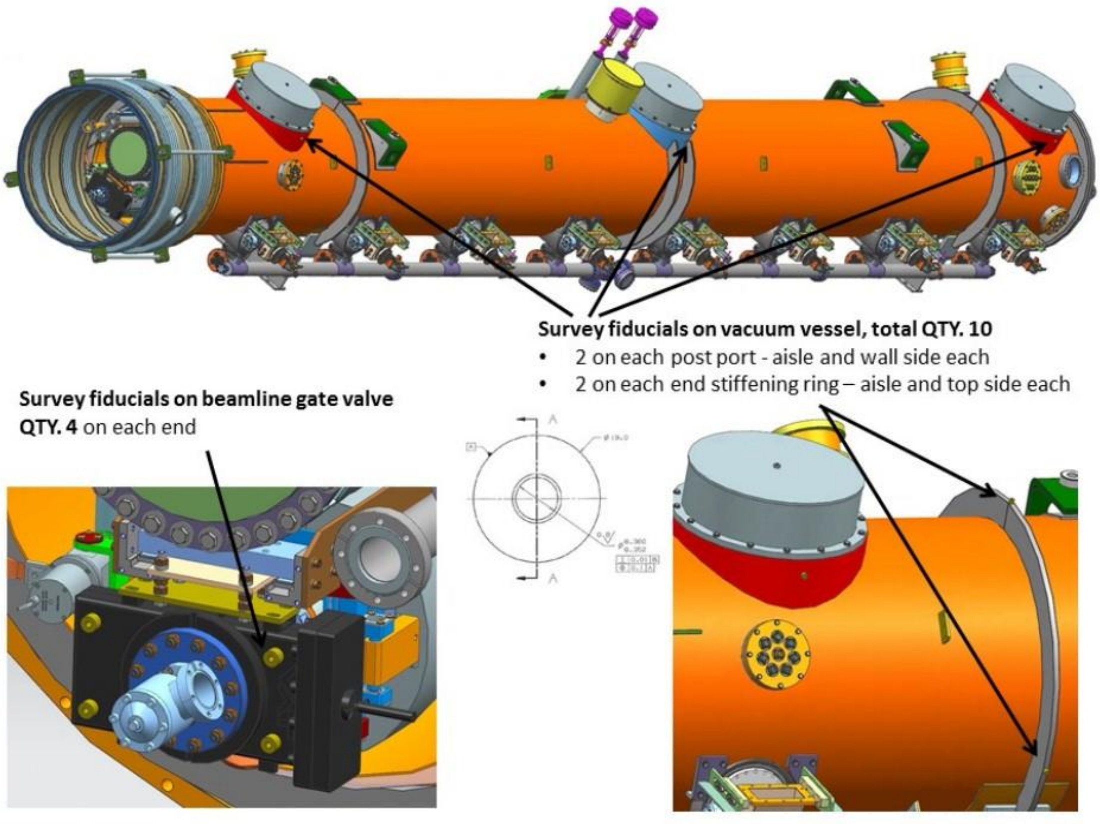


Figure 4.2: Survey fiducials on vacuum vessel and on gate valves of beamline string

The cold-mass fiducials are transferred from support posts (F10028131) to the external references on the vacuum vessel during the assembly process at partner labs. The cold-mass position adjustment system (central support F10008909, sliding support F10008910), shown in Figure 4.3, is in the insulating vacuum space and is locked before shipment.

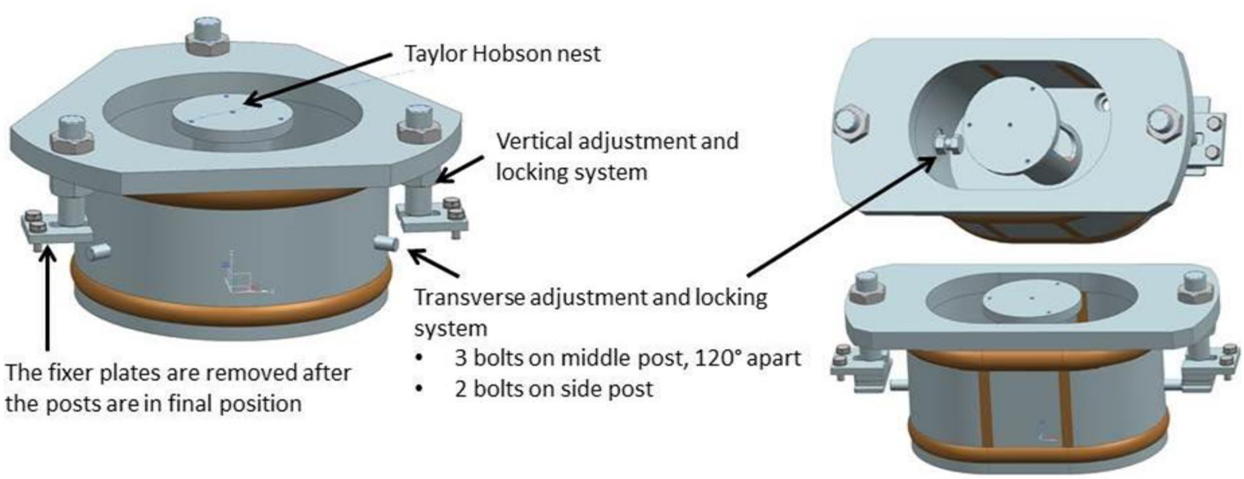


Figure 4.3: Cold-mass position adjustment structure (enclosed in insulating vacuum space)

The final alignment of the cryomodule in the SLAC tunnel needs to be done using the 10 external survey fiducials on the vacuum vessel with a laser tracker.

5 Module Inter-connections

At the module inter-connection, connections of two adjacent modules need to be made *in-situ*, shown in Figure 5.1. The inter-connection drawing is F10010875, which gives dimensions of the space in the inter-connect area.

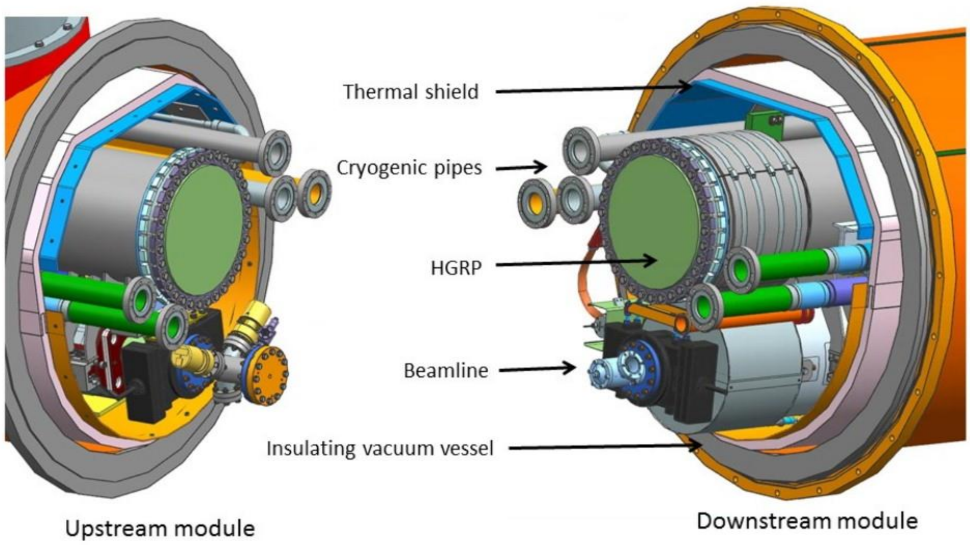


Figure 5.1: Ends of two adjacent modules before being connected through inter-connect unit

The space for making the inter-connect joints is very tight. It requires careful planning of the assembly sequences. The sequence would be in the following order, same as the way that has been developed at XFEL: welding of HGRP, beamline connection, welding of cryogenic pipes, thermal shield connection, and closing of the vacuum vessel, shown in Figure 5.2. The exact sequence might change after additional studies and developments are done. The detailed inter-connect step-by-step assembling procedures are described in FNAL engineering document ED0002593. It includes pre-assembly preparations, assembly sequences, quality control and check-list before closing out the inter-connect unit.

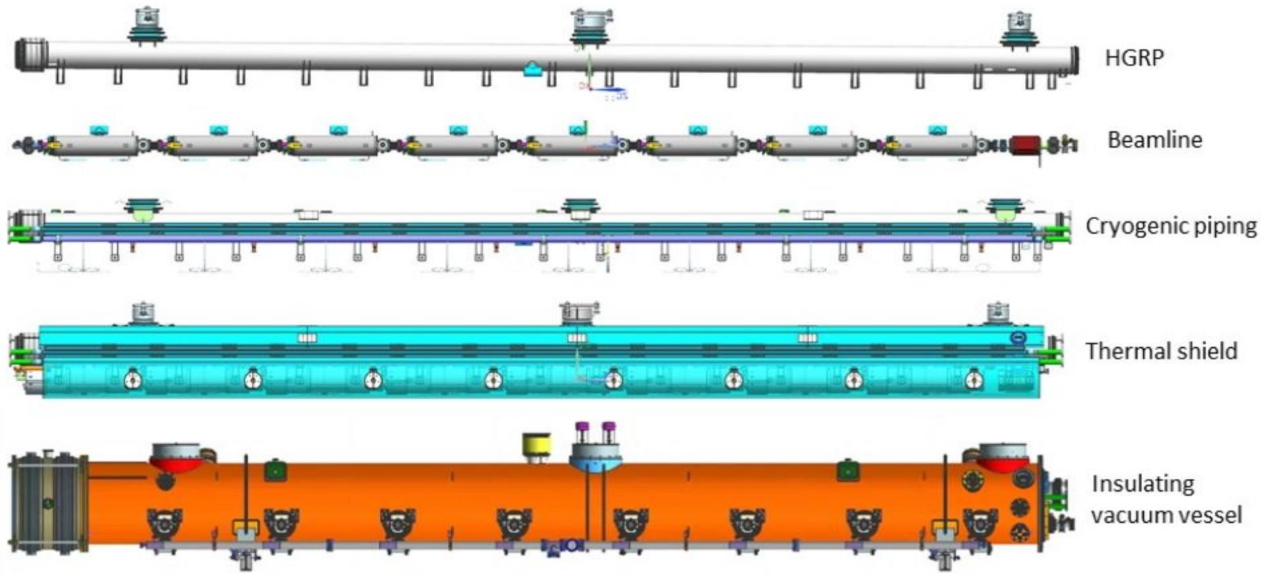


Figure 5.2: Layers that need to be inter-connected between the modules

The inter-connections for the warm-cold end caps, which cryogenically terminate a cryomodule linac string at both ends, are covered in Cryogenic Distribution System interface control document LCLSII-4.9-IC-0058-R0.

5.1 Requirements and preparations for making module inter-connections

The cold-mass and all the cryogenic pipes are fixed in position at the central post of the module and slide-able at the ends. When cold, these components will contract in length with respect to the vacuum vessel. Therefore, during installation when making inter-connections, particular attention should be given to ensure sufficient expansion capacity of the bellows or sufficient overlapping length of the thermal shield. The differential thermal contraction/expansion among the interfacing components of different materials during the thermal cycling are shown in Table 5.1.

Table 5.1: Thermal contraction rate of various materials in the module.

Component	Material	Temperature	ΔL/L	ΔL at inter-connection
HGRP, cryogenic circuits	SS	300K – 2K	0.319%	37.5 mm
Thermal shield	Al 1050	300K – 40K	0.350%	40 mm

The warm and cold dimensional details of the major components inside the cryomodule are described in the master spreadsheet FNAL document ED0001152. The cavity helium vessel is supported on an Invar rod with a low friction sliding structure against the HGRP thermal contraction, shown in Figure 5.3.

This support system results in a longitudinal motion of beamline end from the module center less than 3 mm when cold. The bellows on the HOM absorber will accommodate this motion.

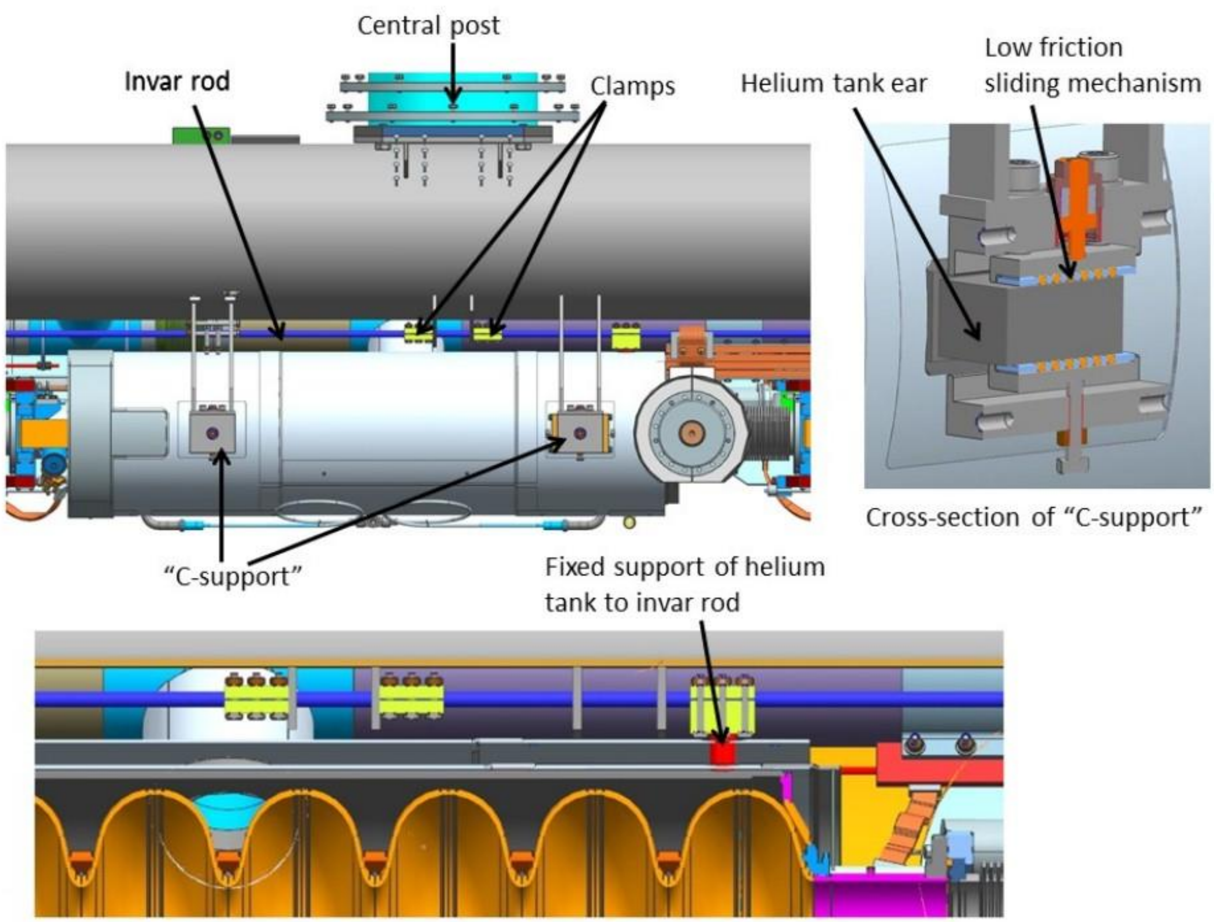


Figure 5.3: Low friction support system of cavity helium tank to the HGRP and invar rod

Shown in Figure 5.4, the HGRP (line B) and five cryogenic pipes (lines A, C, D, E and F), marked in different colors, need to be welded at the inter-module connections. The remaining two piping lines, the 2-phase pipe line G and warm-up/cool-down line H, are closed off in each cryomodule so they don't require inter-module welding.

Table 5.2 lists the sizes and coordinates of these pipes. The positions of these cryogenic pipes are same as those in the FNAL CM2 cryomodule, in order to match the pipe positions on the feed cap/end cap of the FNAL test stand.

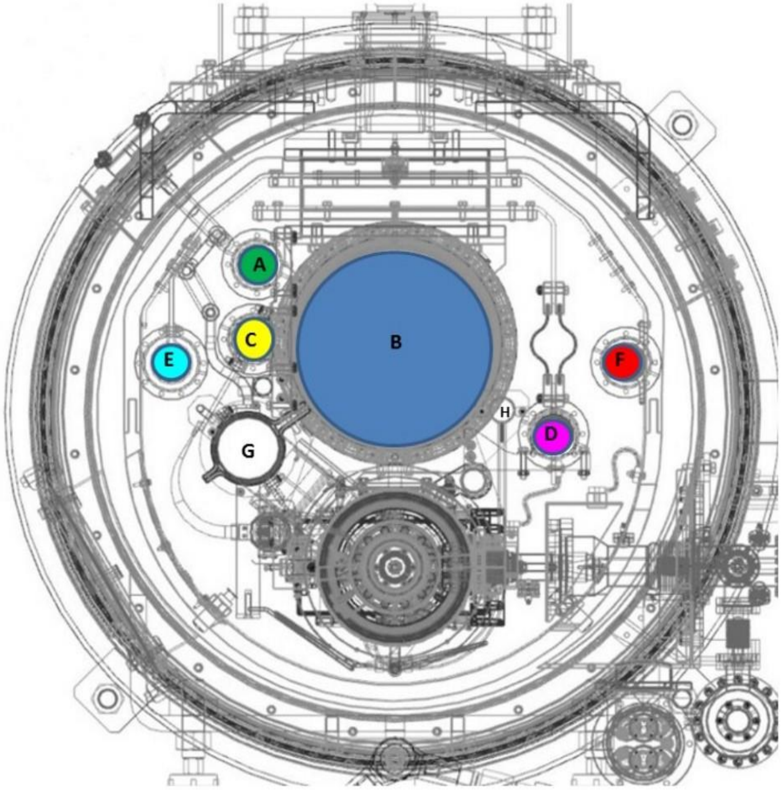


Figure 5.4: Cryomodule cross section, with the cryogenic pipes requiring welding at the inter-module connections highlighted in colors

Table 5.2: Sizes, coordinates, operating pressures and design pressures [LCLSII-2.5-FR-0053] of pipes used in interconnecting region

Pipes	Drawing #	Description	Material & size	Coordinates (X, Y) [mm]	Operating pressure [bar]	Design Pressure [bar]
B	F10023305	HGRP	SS316L, 300 ID/312 OD [mm]	0, 0	0.031	2.0 warm 4.0 cold
A	F10015253	2.2 K supply	SS316L, 2″ SCH10	219, 125.5	3.0	20.0
C	F10015251	4.5 K supply	SS316L, 2″ SCH10	225.5, 6.5	3.0	20.0
D	F10030805	5.5 K return	SS316L, 2″ SCH10	-252, -144.0	2.8	20.0
E	F10009981	35 K supply	SS316L, 2″ SCH10	355, -31.0	3.7	20.0
F	F10014771	55 K return	SS316L, 2″ SCH10	-367, -30.2	2.7	20.0

For easy interconnect welding, tolerances on these coordinates should be ±2.0 mm. In order to obtain a good quality of welding, the tube ends must be aligned well, with the general requirement of a gap less than 5 percent of the wall thickness. The actual (as-built module) X-Y locations of each pipe with respect to design locations will be measured and provided by partner labs for each cryomodule.

A certified welder and qualified welding procedure are required for all the welds, follow B31.3 Code rules. The welding will be performed with an automatic orbital welding machine, with a custom-made tractor welding head for the HGRP line and a standard closed welding head for other pipes. These automatic welding machines will provide an argon gas environment to the outside of the pipes for welding. It is also required to have an argon gas purge inside the pipes for the welding. The flow rates and pressures of the boiled off liquid argon gas (from a dewar) will be provided in the interconnect welding procedures document ED0002593.

All electrical connectors on the module should be properly shorted before each welding operation. When the cryomodule is idle and is not being worked on for interconnect assemblies, a continuous flow of clean dry air purge should be kept for the insulating vacuum space, to prevent degradation of the lubricant used on tuner components and to keep the MLI material dry. After welding, leak checking and pressure testing (or X-ray test) should be performed. The joint for beamline inter-connection should follow the particle free vacuum procedure. Thermal anchors and MLI's should be installed before closing out the insulating vacuum vessel.

5.2 HGRP inter-connection

At the module inter-connection, a stainless steel pipe with custom fit length will be welded between the adjacent HGRPs. On the upstream end of each HGRP there is a bellows unit, part of the cryomodule assembly, with a clamp made out of four quarter aluminum rings for protection during handling, shown in Figure 5.5. A custom-made water cooled welding head with an automatic welding filler supply, which is similar to the one that developed at XFEL, will be used. After welding, the clamp needs to be removed.

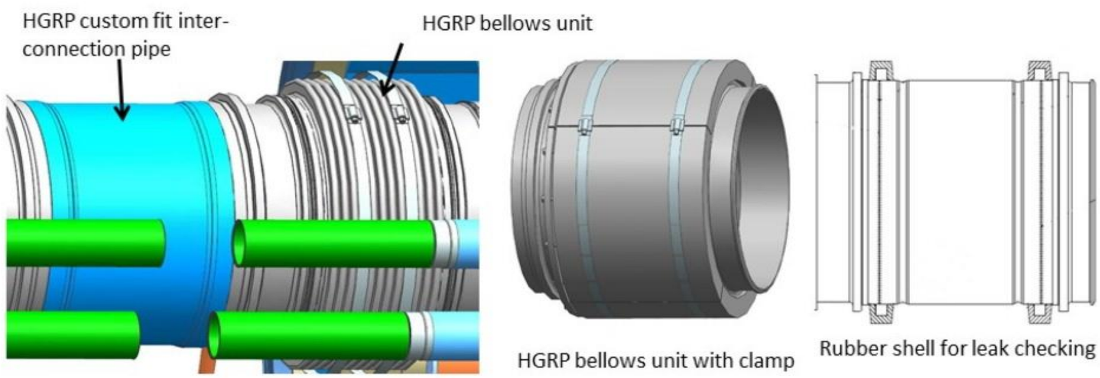


Figure 5.5: HGRP inter-connection, and fixtures for handling and leak checking

The drawing of the bellows assembly with the clamps is in the set of HGRP drawings F10023305. The drawing of the HGRP interconnect pipe is F10030193.

For leak checking the welds, a rubber shell will be used to pump externally at the weld area for a reverse leak check. Filling the cryo pipes internally with helium and reverse leak checking will help to avoid filling the tunnel with helium or increasing the helium background.

5.3 Beamline tube inter-connection

The beamline terminates at each end of the cryomodule with an all-metal GV. At the beamline tube inter-connection, there is a HOM absorber, shown in Figure 5.6, for providing higher order modes power dissipation. The HOM absorber has a length of 301.5 mm, and it has a rotatable flange at the downstream end. The pump-out port is a 2-3/4" CF flange. The drawing of the cavity beamline string is F10009887, and the drawing of HOM absorber assembly is F10017631.

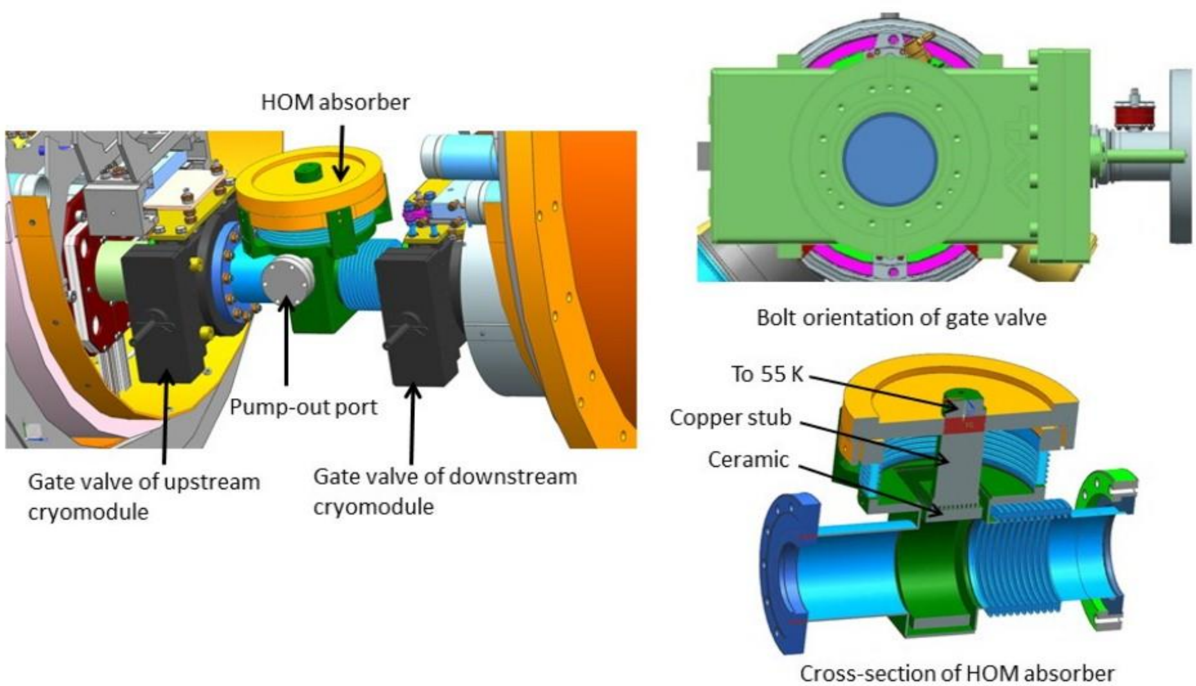


Figure 5.6: HOM absorber to be mounted as a beamline tube inter-connection, and adjacent GV orientation

Prior to installation in the linac string, the beamline vacuum of each module will be under vacuum. At each end of the beamline string, there is a short spool connected to the GV. The downstream GV is open to the beamline vacuum monitoring spool which contains two vacuum gauges, while the upstream GV will be closed, shown in Figure 5.7.

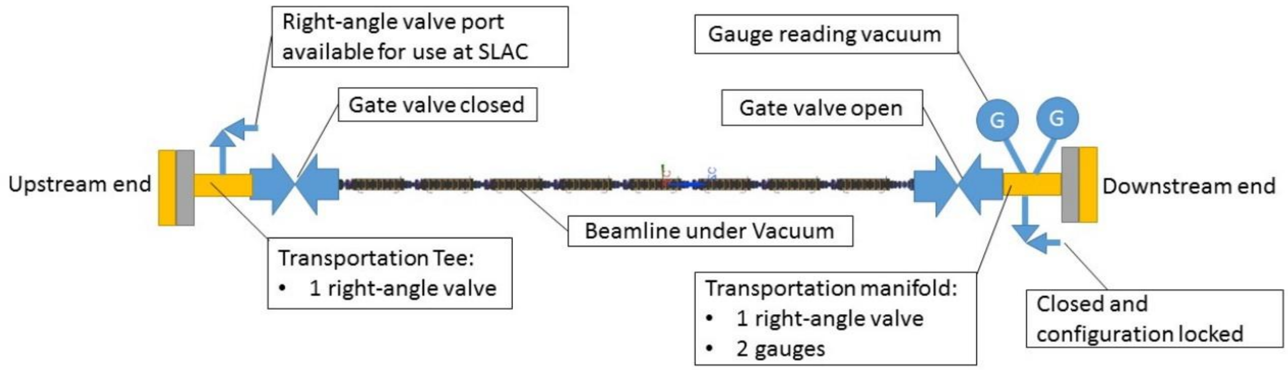


Figure 5.7 Beamline end arrangements prior to installation

A softwall portable cleanroom (Class 10, IS0 4) must be used for making the beamline inter-connections. It is required to strictly follow the particle free UHV practice, which is discussed in Section 9.2, for making the joints and pumping down the system. It is required that the particle counts of the air flowing in the particle free space have the following values per cubic foot per minute: <10 (0.3 µm), <5 (0.5 µm), and zero of 1.0 µm and larger. Extreme care must be taken in the critical envelope 1 foot x 1 foot x 1 foot around the joint.

Given a small clearance from the beamline to either the tunnel floor or to the HGRP, an air filter below or above the beamline would be very close to the critical surfaces. Therefore, the only viable laminar flow is horizontal, with the filter installed behind the beamline. The pump station should be equipped with oil free pumps, mass flow controllers and diffusers to avoid strong turbulence of the gas flow.

Make sure that both GVs are closed on adjacent cryomodules before starting beamline interconnect work. After the connections are made, pump down and leak check this newly assembled beamline interconnect space, and make sure that it is under vacuum and leak tight before opening the GVs to the cavity string vacuum space. Special care (slowly open) is given when opening the GVs.

Thermal anchors should be installed on the HOM absorber (copper stud and instrumentation wires) from 55K return line.

5.4 Cryogenic piping inter-connections

In addition to the HGRP, there are five cryogenic pipes that need to be welded *in-situ*, with bellows insertions. Assemblies with bellows and supporting rods are shown in Figure 5.8. Prior to welding, the flanges need to be cut off with an orbital pipe cutter. It is extremely important that the cutting is done carefully to provide a square, burr free and deformation-free butt weld joint, which is important for obtaining a high quality of welding. The orbital welding requires a gap no more than 0.005” for a butt weld joint of 2” Schedule 10 pipes (with a 0.109” wall thickness).

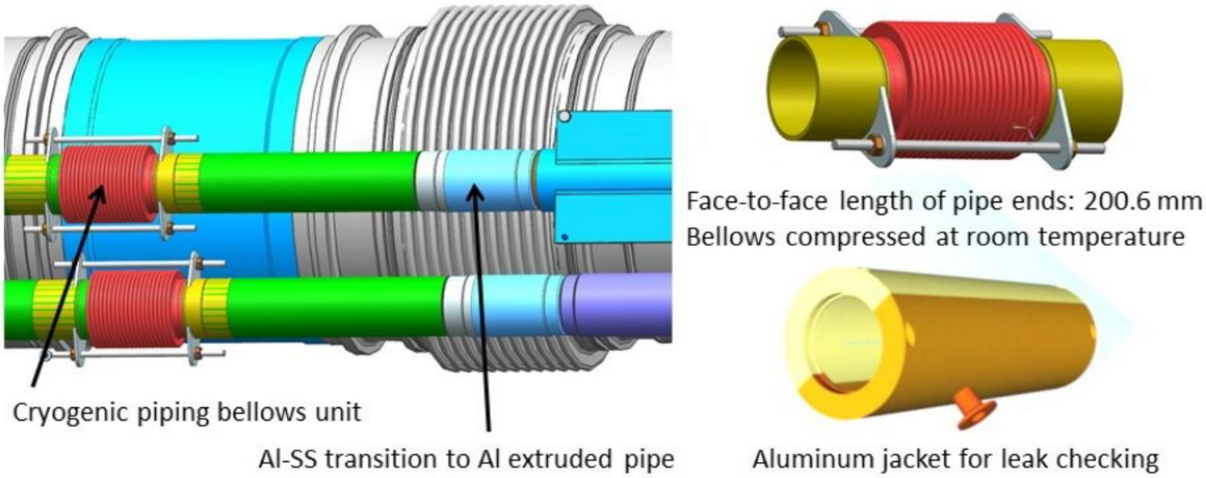


Figure 5.8: Cryogenic piping inter-connections, and fixtures for handling and leak checking

The bellows should be compressed at room temperature and is expected to expand at cold. On aluminum piping lines D and F, there will be Al-SS transitions already on the module, therefore all inter-connect joints will be SS-SS welding of 2” (Schedule 10) pipes. It is assumed that the welding of these cryogenic lines could be performed with a standard closed welding head, as is the case for the XFEL module connections. The welding is done without filler material, and the welding sequence will be in the following order: pipe C, A, E, D, and F. The drawing of the bellows insertion assembly is F10030695.

For leak checking the welds, an aluminum jacket will be used to pump externally the welds area for a reverse leak check. Filling the cryogenic pipes internally with helium and reverse leak checking will help to avoid filling the tunnel with helium or increasing the helium background.

After the welding of all the cryogenic pipes, pressure tests need to be performed. Especially, HGRP pressure test is the most critical pressure test because when this pipe is pressurized, the helium circuit of the cavities are pressurized at the same time. Details of the pressure test setups and parameters will be discussed in the module interconnect assembly procedure document ED0002593.

Ten layers of MLI blankets need to be installed on all 2K-8K components.

5.5 Thermal shield inter-connection

The continuity of the thermal insulation must be ensured in the inter-connection regions. This section is thermally connected to the thermal shield on one end to the upstream module with fasteners, the same way as those done to the joints of thermal shield sheets inside the module. The other end slides over the thermal shield of the downstream module. Since the cooling of the thermal shield is through conduction from the 55 K extruded pipe, and there is a discontinuity of the direct thermal path from this pipe to the inter-connection unit thermal shield, a good thermal contact should be ensured at the upstream inter-connection joints, shown in Figure 5.9. After the connections are made, 30 layers of MLI blankets need to be installed.

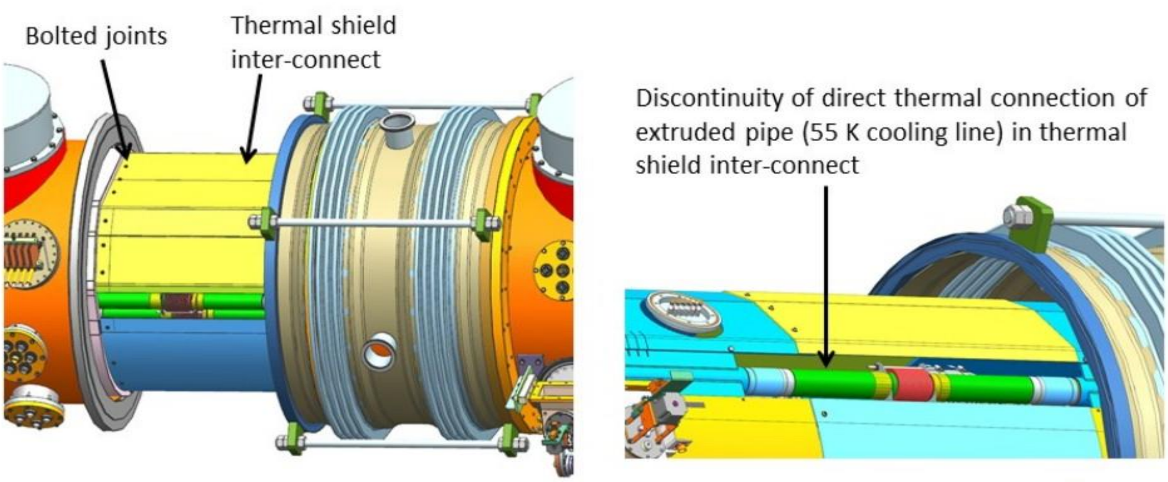


Figure 5.9: Thermal shield inter-connection

The drawing of the thermal shield interconnect sheets are F10038024 (upper) and F10038467 (lower).

5.6 Vacuum vessel inter-connection

There are 3 O-ring seals (EPDM material for the seal) in the cryomodule inter-connection vacuum vessel flanges to complete the connection between inter-connect unit and cryomodules, as shown in Figure 5.10.

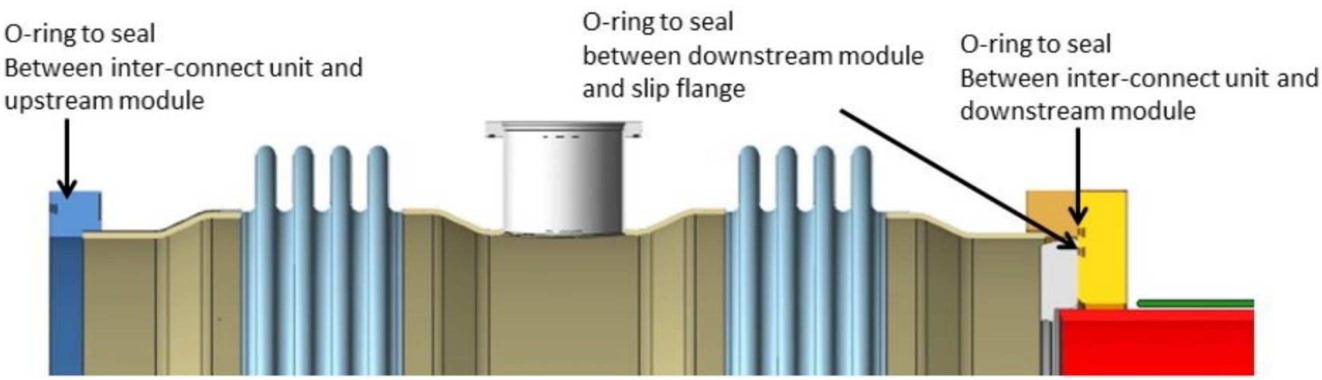


Figure 5.10: Vacuum vessel inter-connection joints

The drawing of the module interconnect unit assembly is F10008897. The overall length of this flexible inter-connect unit is 850 mm. The four support rods will permanently stay loosely in position after the connection is made.

6 Coupler and Waveguide Supports

There are eight FPC ports in an interval of 1383.6 mm, as shown in Figure 6.1 and their locations are listed in Table 6.1.

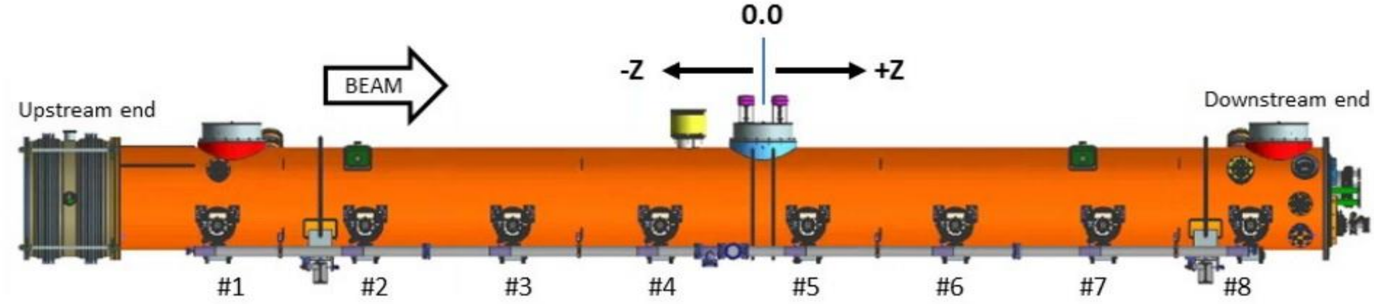


Figure 6.1: Location of the couplers

Table 6.1: Locations of the coupler ports (Z=0, central support post)

Coupler #	Z
Coupler 1	-5113.0
Coupler 2	-3729.4
Coupler 3	-2345.8
Coupler 4	-962.2
Coupler 5	421.4
Coupler 6	1805
Coupler 7	3188.6
Coupler 8	4572.2

Details of the coupler mechanical interfaces are described in LCLSII-4.5-IC-0237-R0. It includes the information on waveguide support brackets and bars, VAT RAV, bellows flex coupling, pumping manifold, temperature sensor, IR detector and electron pick up. The drawing of the waveguide port flange is in the set of warm coupler assembly drawings F10027886. The distance of the flange to the center of the vacuum vessel is 119.1 mm vertically and 581.3 mm in the horizontal direction, shown in Figure 6.2.

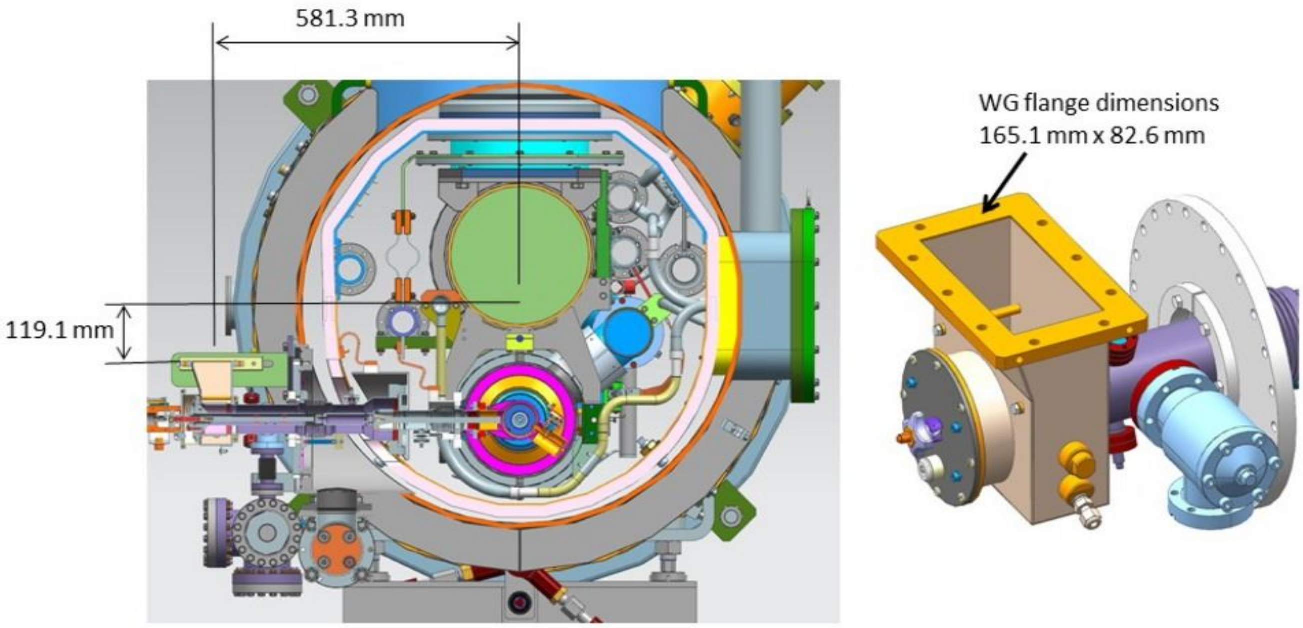


Figure 6.2: External interfaces of the coupler and waveguide support brackets

After the cryomodule testing is done at partner labs, motorized coupler tuners will be replaced with manual tuners (knobs) prior to shipment. The warm coupler vacuum manifold is described in Section 9.4.

7 Instrumentation Connectors

The instrumentation wires and cables of the cryomodule are extracted from the module using flanges with vacuum tight electrical connectors. These flanges are O-ring sealed to the ports on the vacuum vessel. The prototype cryomodule instrumentation sensors are listed here: RF signals (field probe, HOMs), temperature sensors, heaters, quench voltage taps, electron pickups, magnetic field sensors, helium liquid level sensors and pressure transducers, magnets current leads, tuner piezo actuators, stepper motors, and tuner step motor limit switches.

There are four instrumentation feedthrough ports on the vacuum vessel and a pair of flanges located under each coupler port, plus two ports dedicated for helium vessel, and one port for magnet current leads, shown in Figure 7.1.

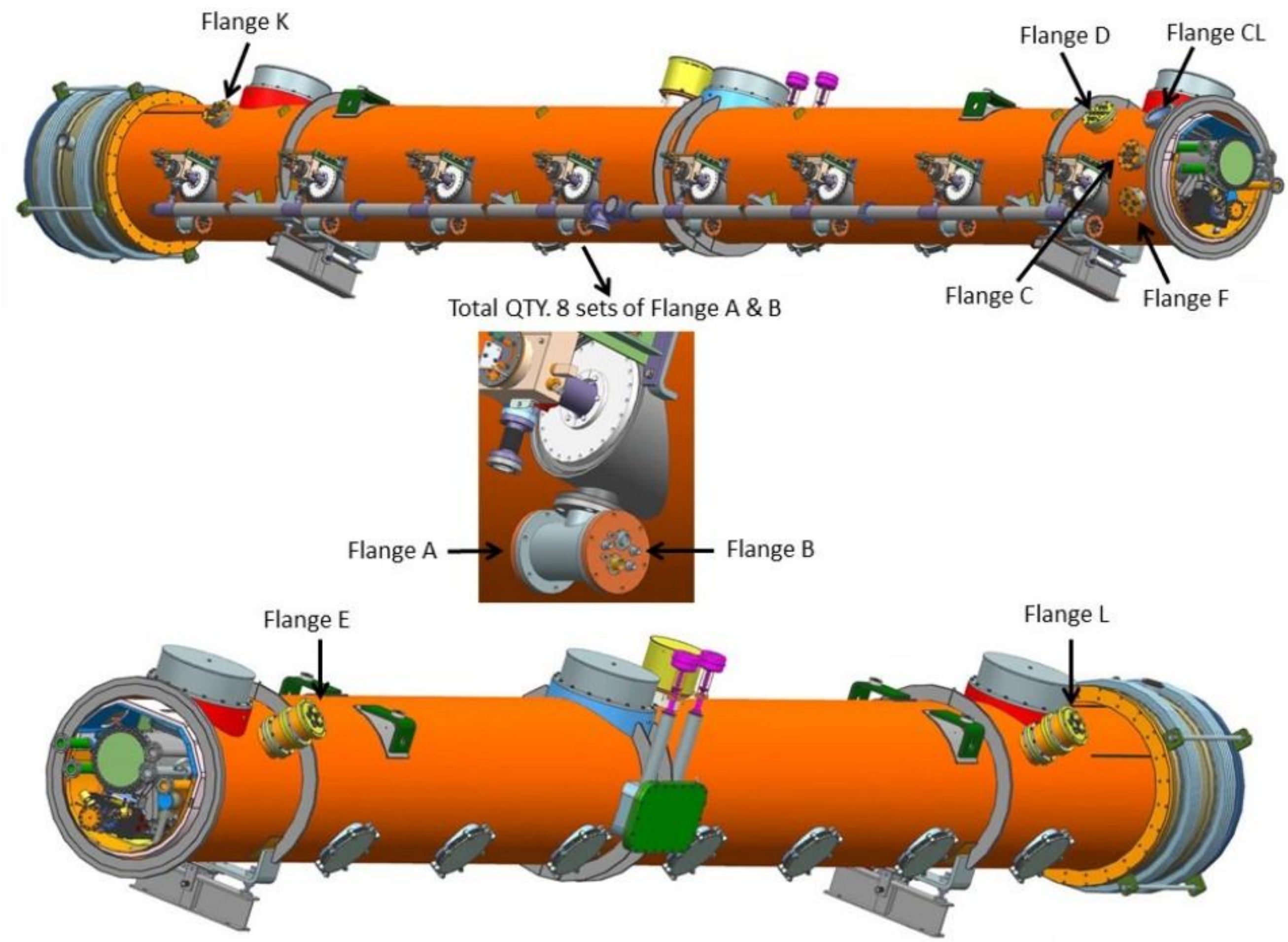


Figure 7.1: Instrumentation feedthrough flanges

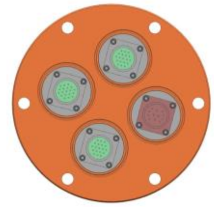
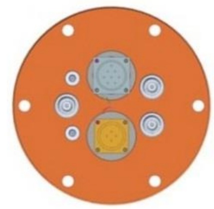
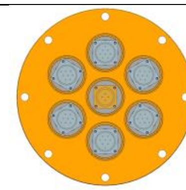
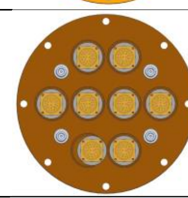
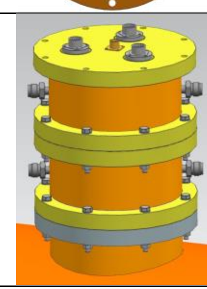
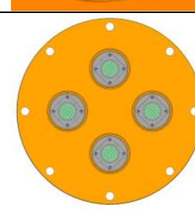
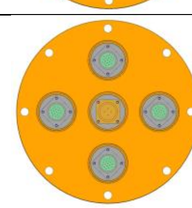
The documents on instrumentations are listed in Table 7.1. These documents describe feedthrough assignments, connector types and sensor descriptions on instrumentation flanges, as well as information on the interfaces outside the cryomodule instrumentation flanges, such as couplers, vacuum systems and cryogenic valves, etc.

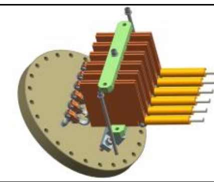
Table 7.1: Instrumentation documents for prototype cryomodule

Document #	Description
ED0002454	Prototype Cryomodule Instrumentation List
F10022915	Prototype module P&ID
ED0002638	P&ID (instrumentation) tag name list

Based on the document ED0002454, a summary of the sensor assignments and connector types of the flanges on the prototype cryomodule is shown in Table 7.2.

Table 7.2: Instrumentation flanges with the assigned sensors for prototype cryomodule

Flange Label Drawing #	Sensor assignments and connector types		Connector placement
Flange A F10022659	Tuner piezo actuators	12-pin DT02H-14-12PN	
	Stepper motor/coupler platinum RTDs	19-pin DT02H-14-19PN	
	Helium vessel/Beam tube/Magnetic shield Cernox RTDs	19-pin DT02H-14-19PN	
	HOM coupler Cernox RTDs	19-pin DT02H-14-19PN	
Flange B F10022657	Step motor, Tuner limit switches	8-pin DT02H-16-8PN	
	Cavity/HOM field probes	N-Type, H+S 34-N-50-0-3/133NE, QTY. 3	
	coupler electron pick-ups	SMA-Type, H+S 34_SMA-50-0-3/111NE, QTY. 2	
	Helium vessel heaters	4-pin 8673-14B-4PN-SP-M121	
Flange C F10037010	Magnets voltage taps	8-pin DT02H-16-8PN, QTY. 3	
	Magnets heater	4-pin 8673-14B-4PN-SP-M121	
	Magnets power lead voltage taps	8-pin DT02H-16-8PN, QTY. 3	
Flange D F10036970	BPM pick-ups	N-Type, H+S 34-N-50-0-3/133NE, QTY. 4	
	magnetic sensors	26-pin DT02H-16-26PN, QTY. 8	
Flange E & L F10037261 F10037263	Helium vessel liquid level sensors, heater	6-pin DT02H-10-6PN, QTY. 1	
	Cavity helium pressure sensors	VCR 8 Male pressure tap	
	Helium vessel temperature sensors	19-pin DT02H-14-19PN, QTY. 2	
	magnetic sensors	19-pin DT02H-14-19PN, QTY. 1	
Flange F F10037075	Magnet temperature sensors	19-pin DT02H-14-19PN	
	Magnet lead temperature sensors	19-pin DT02H-14-19PN, QTY. 3	
Flange K F10037077	Cool-down Cernox RTDs	19-pin DT02H-14-19PN, QTY. 4	
	Heaters on helium cool-down	4-pin 8673-14B-4PN-SP-M121	

Flange CL F10022642	Magnets current leads	

Here we present the prototype cryomodule instrumentation interfaces. Because of the level of detail and longer time needed, instrumentation details are being separately developed for the production cryomodules, and future revisions of this document or a separate interface control document will capture details.

8 Pressure Relief, Tuner Access, Cryogenic Valve Ports and Pickup Bushing Hoist Rings

This section describes the remaining external features that are not covered in Sections 4-7. They are shown in Figure 8.1 and listed in Table 8.1.

Table 8.1: Drawings of several external features on the cryomodule

Document #	Description
F10023631	Module pickup bushing hoist rings
F10030619	Pressure relief port
F10026618	Cryogenic valve port
F10026614	Tuner access port

The design and locations of these components can be found in the set of drawings of the vacuum vessel F10026609. The locations of tuner ports are listed in Table 8.2.

Table 8.2: Locations of the tuner access ports (Z=0, central support post, positive number means downstream, as shown in Figure 5.1)

Tuner port #	Z
Tuner port 1	-4929.0
Tuner port 2	-3546.0
Tuner port 3	-2162.0
Tuner port 4	-779.0
Tuner port 5	605.0
Tuner port 6	1989.0
Tuner port 7	3372.0

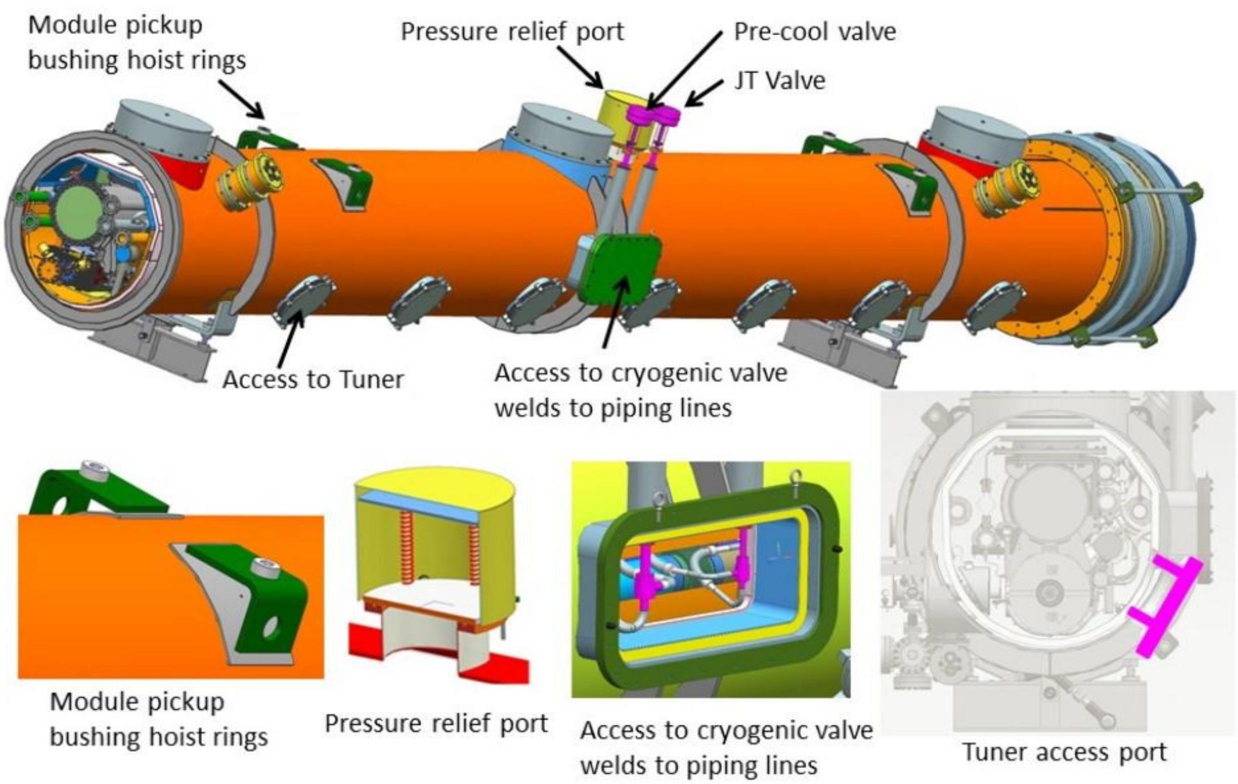


Figure 8.1: Locations and detailed views of module pickup bushing hoist rings, pressure relief port, cryogenic valve port, and tuner access port

The module weighs about 8 Ton. The four pickup bushing hoist rings mounted on the upper surface are 6800.0 mm and 640.0 mm apart in the module longitudinal and transverse directions, respectively. The lifting fixtures are described in FNAL document ED0002675.

The insulating vacuum is protected from over-pressurization by means of a spring-loaded lift plate, which is located on top of the vacuum vessel. The opening has a 213.5 mm inner diameter. Provisions are provided to allow free passage of the gas out past thermal shield and MLI to the lift plate. There will be two reliefs on the L0 standalone cryomodule, and one relief per module on the rest of the modules. The calculations of the cryomodule vacuum vessel venting are described in FNAL document ED0002396. For the first cryomodule, in addition to the additional pressure relief, there are other unique features, which will be covered in other documents. All cryogenic process circuits are pressure relieved by the cryogenic distribution system, and beamline vacuum is relieved by the SLAC accelerator system. Both of these are outside the cryomodule work.

There are two cryogenic valves on the wall side of the module, one JT valve (DN6 x 600 mm from Weka) for liquid level control and the other cool-down/warm-up valve (DN15 x 600 mm from Weka) for optimal cool-down flow rate control. In case there is a leak on these two lines, the welds of these two valves to the cooling lines can be accessed from the O-ring sealed port of the size 670.0 mm x 320.0

mm. If it becomes necessary to replace the cryogenic valve, the actuator is removable. The length of the valve is 1 m, and without the actuator it is 0.8 m. Therefore a 0.8 meter clearance is needed on the top of the cryogenic valves.

There are seven tuner access ports to allow access to the tuner motor, drive mechanism, and piezos without pulling the cavity string out of the module. They are O-ring sealed flanges of 300 mm in diameter, facing the tunnel wall.

9 Module Vacuum Systems

This section describes the requirements and mechanical interfaces of the module vacuum systems. The instrumentation information of the vacuum systems is covered in other documents listed in Table 7.1. As shown in Figure 3.9, the module has three distinct vacuum spaces: beamline (cavity) vacuum, insulating vacuum, and a vacuum space on the warm side of the cold window of the couplers.

9.1 Requirements and devices of vacuum systems

Compared to storage ring type light sources, here the beam particles pass through the straight linac only once. Therefore the requirement of beamline vacuum pressure with respect to losses due to scattering on the residual gas are relaxed. Effects like emittance growth, fast ion instabilities or dynamic pressure increase due to synchrotron radiation are negligible. As specified for XFEL, an average pressure of 7.5×10^{-8} Torr is acceptable. However, particles can act as field emitters and thus limit the performance of the cavities, therefore particle free practice should be applied to the beamline vacuum system.

The insulating vacuum serves to minimize convective heat transfer to the cavity helium vessel and heat conduction through residual gas to the MLIs. For this purpose, a pressure of less than 1.0×10^{-4} Torr is required for the insulating vacuum space.

During RF operations, there may be vacuum activity in the space between the coupler cold and warm windows, and there will be gases being released from the waveguide. This space is kept under vacuum which is separate from the cavity vacuum, named as warm coupler vacuum space. This design enables complete closure of the cavity in the clean room by mounting the coupler up to the first window, thus preventing any contamination of the cavity RF surface during subsequent assembly of the module.

Table 9.1 lists the requirements and vacuum devices of the three vacuum spaces.

Table 9.1: Requirements and devices of the cryomodule vacuum subsystems

		Beamline vacuum (read at ends of each linac section)	Insulating vacuum	Warm coupler vacuum
Pressure (Torr)	**At cold**	1.0×10^{-10}	1.0×10^{-6}	1.0×10^{-9}
	prior to cool-down	1.0×10^{-8}	1.0×10^{-4}	1.0×10^{-7}
Characteristics		Particle free pump-down/venting	Large water in MLI	Outgassing during RF operation
Pumps	**Roughing**	Turbo backed by a Dry Scroll, w/ particle free setup	Roots Blower, then Turbo backed by a Dry Scroll	Turbo backed by a Dry Scroll
	In operation	Ion pump	Cryo pumping by cold surfaces; Turbo backed by a Dry Scroll, in case of a leak	75S TiTan ion pump with DI elements + 6" CF with side mounted TSP, SAFECONN feedthrough, with heater kit
Gauges	**Cold cathode gauge**	Inverted magnetron, LEMO connectors, 2.75" CFF, MKS #104220008		
	Convection gauge	2.75" CFF, MKS #103170024SH		
All-metal right angle valve		DN-40 CF-R, manual actuator, hexagon head, VAT #54132-GE02		
Gauge controller		Configured to operate 2 CC gauges and 2 convection gauges, all output LOG scale, MKS #937B-US-CCCCCT-NA		

As noted in Table 9.1, the beamline vacuum pressure prior to cool-down is read at the ends of each linac section. It is assumed that the pressure in the middle of each linac section is higher than 1.0×10^{-8} Torr. But it will be in the range of $10^{-9} \sim 10^{-10}$ Torr at cold, lower than the linac operation requirement.

The vacuum devices that are installed on the cryomodule are provided by partner labs. The models and connectors of these vacuum devices are compatible with the SLAC control system, as specified in SLAC vacuum controls engineering specifications LCLSII-2.7-ES-0344-R0. SLAC provides all the controller/cables of the vacuum devices, and the standard interface point is at the device's connector.

9.2 Beamline vacuum system

The beamline vacuum in the cryomodule consists of eight cavities connected to each other via copper-coated bellows, a beam pipe inside the superconducting quadrupole, a beam position monitor, and a module interconnection including beamline HOM absorber and pumping port. These are assembled in a class 10 (IS0 4) clean room and closed off by all-metal GVs at both ends. The quadrupole beam pipe and BPM are also copper-coated to reduce heating from propagating wakefields excited by the beam. Vacuum sealing is provided by aluminum gaskets between NbTi and stainless steel flanges.

In addition to standard UHV requirements, the beamline vacuum needs to preserve the particle cleanliness of the cavity surfaces. Similar cleaning and assembly procedures as those performed for the cavities in the particle free clean rooms should be applied to the beamline connections between the modules. For this purpose a portable softwall cleanroom (class 10) and strict adherence to the particle free UHV assembly protocols are required. In addition, strong gas condensation from neighboring room temperature sections onto the cold surfaces needs to be avoided. The beamline particle free length is specified in LCLSII-4.1-EN-0337.

In order to avoid any particle transport inside the beamline vacuum into the cavity areas, special care must be given to pump down and venting procedures. The pump station should be equipped with oil free pumps, mass flow controllers and diffusers to avoid strong turbulence of the gas flow, and to provide particle filters to clean the dry nitrogen for venting. A set-up developed for XFEL particle free pump down and venting is shown in Figure 9.1.

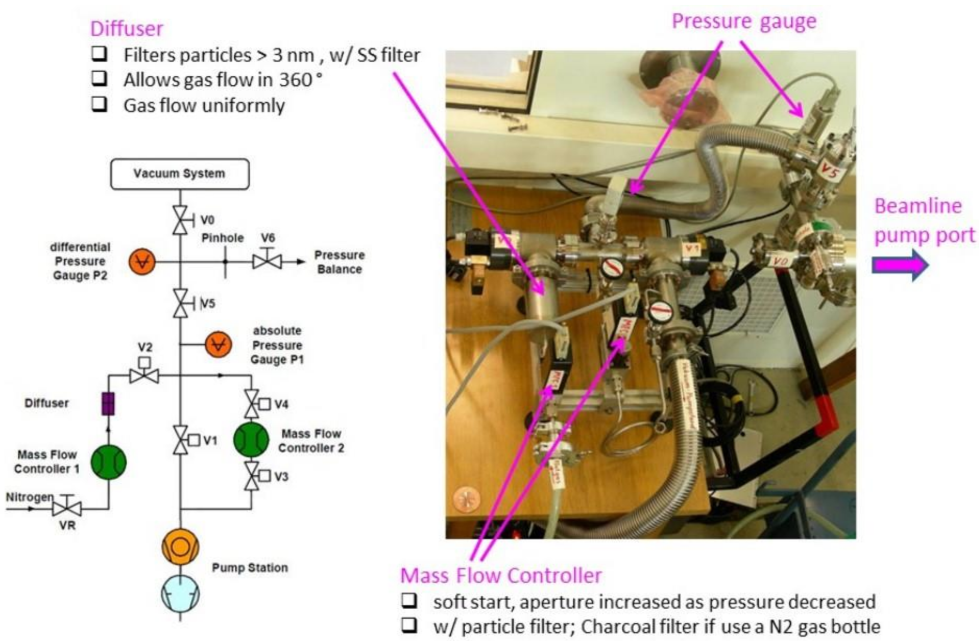


Figure 9.1: XFEL set-up for particle free pump down and venting

A mass flow controller allows a soft start of pumping by adjusting the gas flow with a variable diaphragm. It has an intrinsic particle filter on the side of the incoming flux. The diffuser has a membrane that allows gas flow in 360° and it has a stainless steel filter to prevent particles larger than 3 nm entering the system. Thus turbulences in the gas flow are largely reduced and large amounts of gas can flow through in a uniform manner, limiting the disturbance of particles in the system. This set-up and the operation procedures are adopted by FNAL for the ASTA beamline vacuum system.

The beamline vacuum subsystem includes two pump stations, provided by SLAC in the final installation, one at each end of the linac section. Each station contains an ion pump and a CCG. This is a setup used by XFEL, with pumping by ion pumps at a distance of 140 m when the system is at room temperature, while the pumps mainly act as pressure sensors when the cold masses are at cold. A fast shutter next to the last cold section, provided by SLAC, should protect the sensitive part of the beamline vacuum space in case of a sudden vacuum break in the room temperature sections.

9.3 Insulating vacuum system

Two 4” ports with ISO 100 KF flanges located on the module inter-connect unit serve for pumping and vacuum monitoring. The inter-connect unit is shipped to SLAC with blank-off flanges on these two 4” ports. Recommended vacuum devices arrangement is shown in Figure 9.2, and the suggested vacuum pump down procedure is the following. For initial pump-down, a roughing pump line with a Roots Blower and a cold trap will be used. Pumping will be through a turbo-molecular pump which is backed by a Dry Scroll pump. The turbo pump will be directly connected to a GV on the side 4” port. As stated in Section 5.6, the drawing of this inter-connect unit is F10008897.

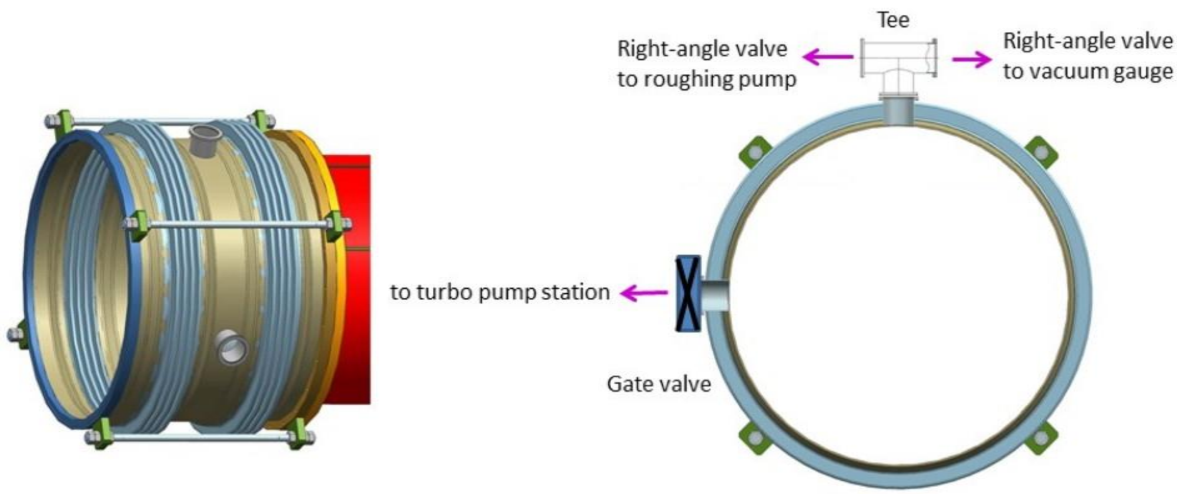


Figure 9.2: Cryomodule insulating vacuum subsystem

There is an opening with baffle on the thermal shield inter-connect unit, to allow free path of pumping to the space inside the shield. Several backfills with dry air will effectively purge the water in the MLIs. The turbo pump will be turned on once the pressure reaches 10^{-2} Torr range. When the pressure reaches 10^{-4} Torr range and leak check is completed, the cool-down could be started. The turbo pump will be left on until the cool down process is complete. Once at 2K, a rate-of-rise test can be performed to determine if the system is stable with turbo pumps off.

Gauges need to be installed on isolation RAVs, so that they can be replaced without requiring the string to be warmed to room temperature and vented if a gauge is faulty. In linac strings with multiple cryomodules, CCG and Pirani gauges are installed on alternate inter-connect units, to monitor the pressure when cold or during pumping down, respectively.

In case there is a helium leak into the insulating vacuum space, a turbo-molecular pump rated at 50 l/sec helium backed by a diaphragm roughing pump rated 15 l/min would provide sufficient pumping to maintain insulating vacuum with leaks up to 1.0 x 10^{-4} Torr-l/s. This setup is used by SNS.

9.4 Warm coupler vacuum system

The warm coupler vacuum space is pumped through a RAV to a vacuum manifold, which is tucked under the coupler, shown in Figure 9.3 and Figure 9.4.

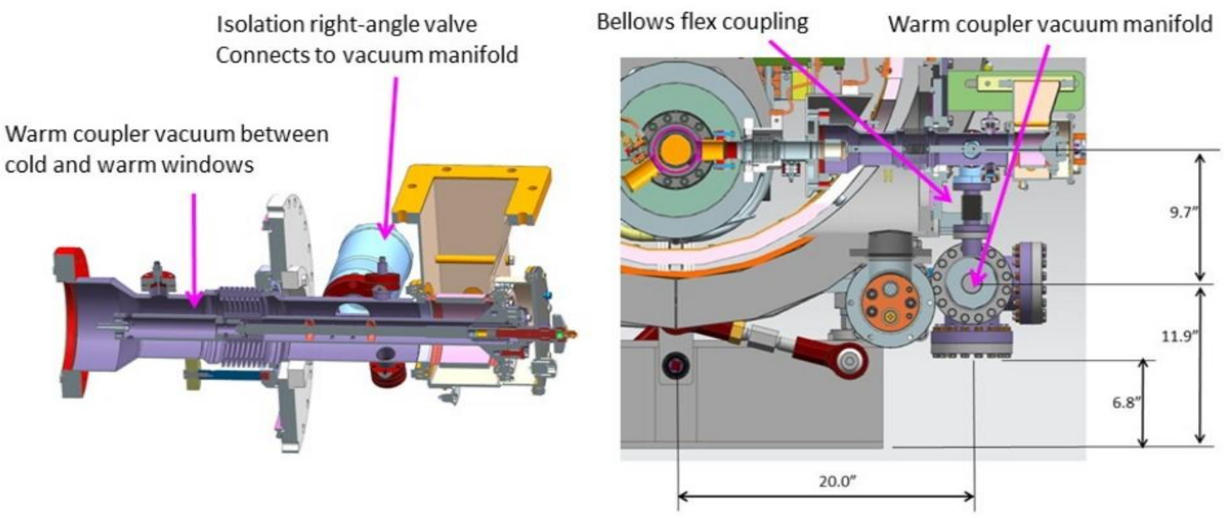


Figure 9.3: Cryomodule warm coupler vacuum space

The manifold is equipped with a 75 l/s ion pump and a titanium sublimation pump. The sublimation pump is in the XFEL design, but the pump activation has never been needed for FNAL CM1 and CM2 cryomodules. The mechanical interfaces of coupler to the vacuum manifold are described in LCLSII-4.5-IC-0237-R0. It includes the information on the pumps, RAV and the hardware for assembly.

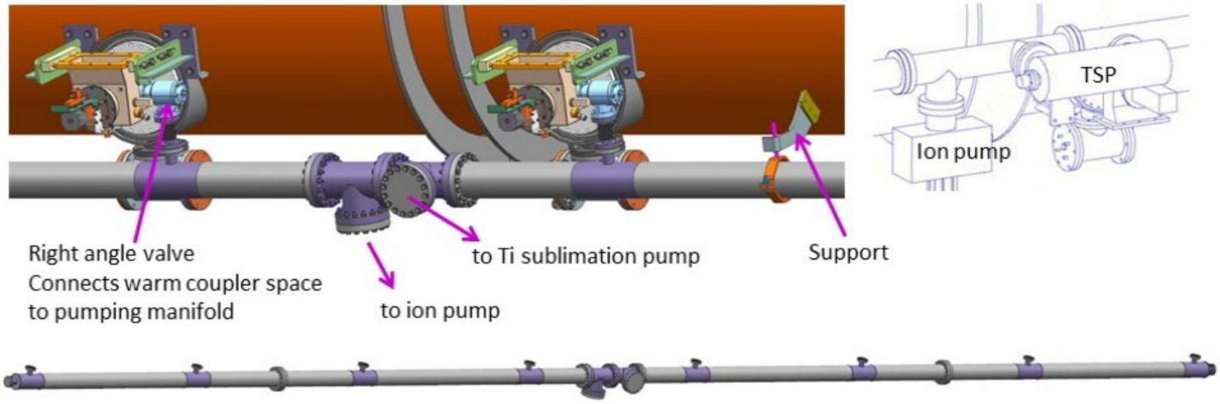


Figure 9.4: Cryomodule warm coupler vacuum subsystem

The isolation RAV on each coupler serves to isolate the individual warm end coupler from the rest of the couplers or the manifold during the process of assembling, leak checking or troubleshooting on the following occasions:

- During the cryomodule assembly process, when each warm end coupler is installed, leak checked, and backfilled with boiled off nitrogen, the isolation valve can be closed, thus protecting the coupler internal plating from moisture and contamination while the other couplers are being assembled; then the pumping manifold is assembled, leak checked and finally all vacuum spaces of the warm couplers are connected together;
- If there is a leak, it will be easier to diagnose with the capability of isolating each warm end coupler individually;
- It allows to isolate a leaking warm end coupler, to fix the leak problem without disturbing the vacuum and room temp processing for other seven couplers;
- It allows to isolate the warm couplers in case the pump or gauge on the vacuum manifold needs to be replaced;

However, because this isolation manual valve does not have position indicators to be connected to the linac control system, it could pose potential issues if it is accidently closed:

- It could not prevent RF from being provided to a coupler which is isolated from the warm coupler vacuum manifold;
- There would be an isolated vacuum volume without gauging;
- There could be over pressurization upon warming up if there is a leak into the isolated warm coupler vacuum space and there is gas condensed on the cold end of the coupler.

Therefore, administrative controls of locking these isolation valves open are essential. It could be done through a mechanical locking mechanism, shown in Figure 9.5. It was used for the RAVs at each end of the cavity string of the FNAL CM2 module during transportation, and it will also be used on the beamline ends of the LCLS-II cryomodules for shipment.

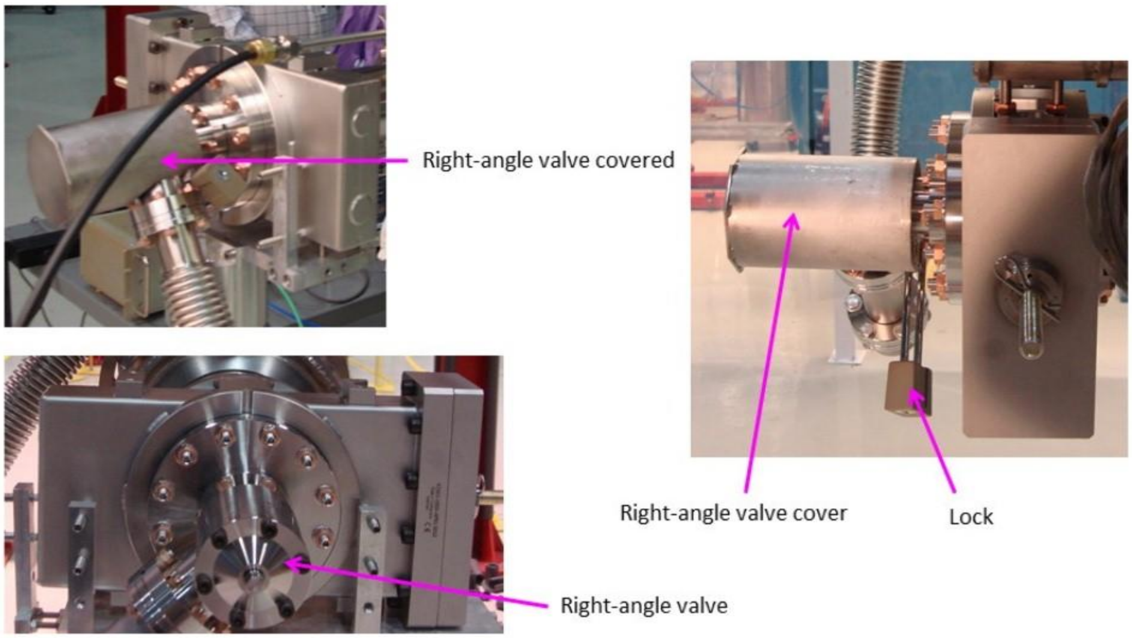


Figure 9.5: mechanical locking mechanism of the right angle valve

9.5 Vacuum configurations pre-shipment and things-to-do post-shipment

The components of bellows inter-connect unit and the module supports will be shipped in separate boxes from the main module package. The module insulating vacuum space will be backfilled with boiled off nitrogen to 5 psig (20 psia) positive pressure for shipping. The module will have end caps to keep and withstand the positive nitrogen pressure inside the vessel, as well as to support the HGRP at the ends during shipment.

After the cryomodule testing is completed at partner labs, transportation tees with vacuum devices will be installed at each end of the beamline if they are not on the system prior to testing. An MFC PS will be connected to prepare for beamline shipping configuration, with the procedure shown in Figure 9.6. The principle of this configuration is to limit cycles to sensitive components: particle generator (GVs) and particle transporter (venting cycles). The beamline will be then under UHV when the cryomodule is removed from the test stand.

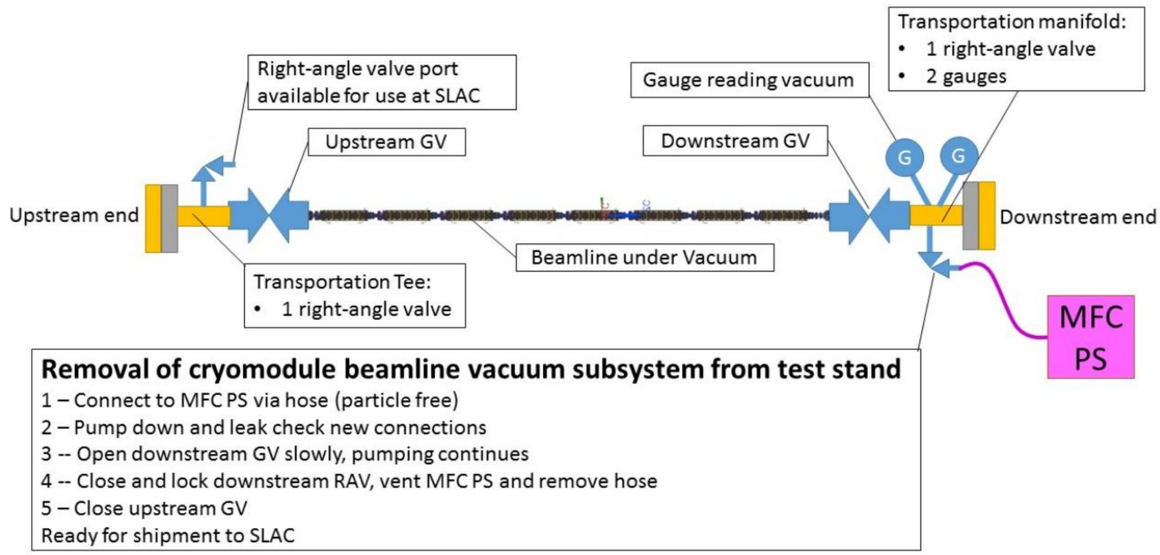


Figure 9.6: Removal procedure of cryomodule beamline vacuum subsystem from partner lab test stand

The beamline will be shipped under vacuum, with the vacuum monitoring system on but no active pumping during shipment. At each end of the beamline string, there is a short spool connected to the GV. The downstream GV is open to the spool which contains two vacuum gauges, while the upstream GV will be closed. The downstream RAV will be locked with the same mechanical locking mechanism shown in Figure 9.5. The RAV on the upstream spool is available for use at SLAC if pump down of the beamline string is needed.

The coupler vacuum system will be shipped under vacuum, with the RAV on each coupler open and locked to the warm section of coupler. There will be a CCG gauge and a Pirani gauge on one end and a RAV on the other end of this vacuum manifold, shown in Figure 9.7. The shipping support system will accommodate supports for the pumps.

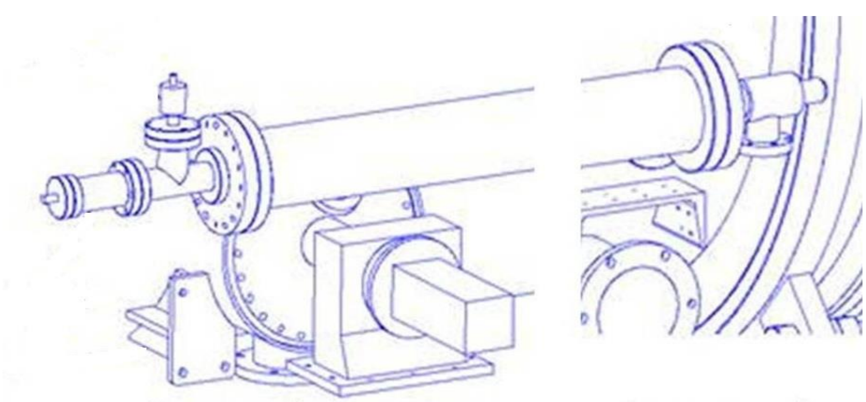


Figure 9.7: Coupler vacuum manifold end arrangements for module shipping

The cryomodule transport system consists of a base structural steel (truss) frame and an internal isolation fixture. The isolation fixture is supported by the base frame through a series of helical (wire rope) shock dampers. In FNAL document ED0002675, it describes the transportation design for all transport phases; local to FNAL site during assembly and testing, over-the-road from FNAL to SLAC and unloading with staging into the LCLS-II tunnel. Necessary lifting fixtures, support equipment and instrumentation are also described.

It is extremely important to remove the eight fiducials (magnetic) on the GV of each end of the beamline string after the alignment checks at SLAC prior to cryomodule installation in the tunnel.

As a general particle free practice, the number of the valve open-and-close cycles of the beamline vacuum should be minimized in order to prevent particles from being introduced into the cavity region. The beamline will not have active pumping during the shipment, nor during the storage. However, if the pressure reaches 7.5 x 10^{-2} Torr, particle transport inside the beamline vacuum space is possible, then a particle free UHV pumping system is required to pump down and leak check the beamline vacuum space. For this purpose, the RAV on the upstream spool is available for use at SLAC. Before opening the GV a leak check should be performed for the new connection joints. The GV should be opened slowly while monitoring pressure in the beamline.

The shipping end cap of the vacuum vessel will need to be removed upon receipt and returned to partner labs for future shipments. The module purge caps should be then installed to allow continuous dry air purge for insulating vacuum space during storage and preparation for installation. Dry air purge is required to prevent degradation of the lubricant used on tuner components and to keep MLI and the insulating vacuum space dry.

10 Differences Between Prototype and Production Modules

The differences between the prototype and production cryomodule external interfaces are listed in Table 10.1. Elimination of the tuner access ports for production modules is under consideration. Details on the production module interfaces, as they differ from those of the prototype module, will be provided in future revisions of this document or a separate interface control document.

Table 10.1: Differences between the prototype and production cryomodule external interfaces

	Prototype Module	Production Module
Access ports for tuner	Yes	Most likely, Yes
Temperature sensors	Cernox RTD	Silicon Diode
Instrumentation	More sensors for cavity, magnetic shield	A reduced set, to be determined

Wong, Theresa

From:	Yun He <yunhe@fnal.gov>
Sent:	Friday, May 01, 2015 7:12 AM
To:	Wong, Theresa
Subject:	RE: NEED APPROVAL - ICD "1.3 GHz Cryomodule External Physical Interfaces" (LCLSII-4.5-IC-0372-R0)

Hello Theresa,

I approve the document 1.3 GHz Cryomodule External Physical Interfaces, LCLSII-4.5-IC-0372-R0.

Regards,
Yun

From: Wong, Theresa
Sent: Tuesday, April 28, 2015 10:57 AM
To: Yun He; 'ginsburg@fnal.gov'; Ross, Marc C.; Chan, Jose Quim; Schultz, David C.
Cc: Marsh, Darren S.; Wong, Theresa; Hays, Greg; 'jncorlett@lbl.gov'; 'tommy@fnal.gov'
Subject: NEED APPROVAL - ICD "1.3 GHz Cryomodule External Physical Interfaces" (LCLSII-4.5-IC-0372-R0)

Dear All,

ICD "1.3 GHz Cryomodule External Physical Interfaces" is being prepared for release. Please stop by my desk (B052, 215A.46) to sign your approval of the document. If off-site, please send me your approval by email.

Attached is an electronic version for your review.

Thanks,

Theresa Wong
LCLS-II Project Administrator
SLAC National Accelerator Laboratory
2575 Sand Hill Rd MS 52
Menlo Park, CA 94025
T: (650) 926-4077
F: (650) 926-5368

Wong, Theresa

From: Camille M Ginsburg <ginsburg@fnal.gov>
Sent: Friday, May 01, 2015 1:10 PM
To: Wong, Theresa
Subject: RE: NEED APPROVAL - ICD "1.3 GHz Cryomodule External Physical Interfaces" (LCLSII-4.5-IC-0372-R0)

Dear Theresa,

I approve.

Thanks,
Camille

From: Wong, Theresa [wongt@slac.stanford.edu]
Sent: Thursday, April 30, 2015 17:49
To: Camille M Ginsburg
Subject: FW: NEED APPROVAL - ICD "1.3 GHz Cryomodule External Physical Interfaces" (LCLSII-4.5-IC-0372-R0)

Hi Camille,

Please send me your approval for ICD "1.3 GHz Cryomodule External Physical Interfaces".

Thanks,
Theresa

From: Wong, Theresa
Sent: Tuesday, April 28, 2015 10:57 AM
To: Yun He; 'ginsburg@fnal.gov'; Ross, Marc C.; Chan, Jose Quim; Schultz, David C.
Cc: Marsh, Darren S.; Wong, Theresa; Hays, Greg; 'jncorlett@lbl.gov'; 'tommy@fnal.gov'
Subject: NEED APPROVAL - ICD "1.3 GHz Cryomodule External Physical Interfaces" (LCLSII-4.5-IC-0372-R0)

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Thanks,

Theresa Wong
LCLS-II Project Administrator
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