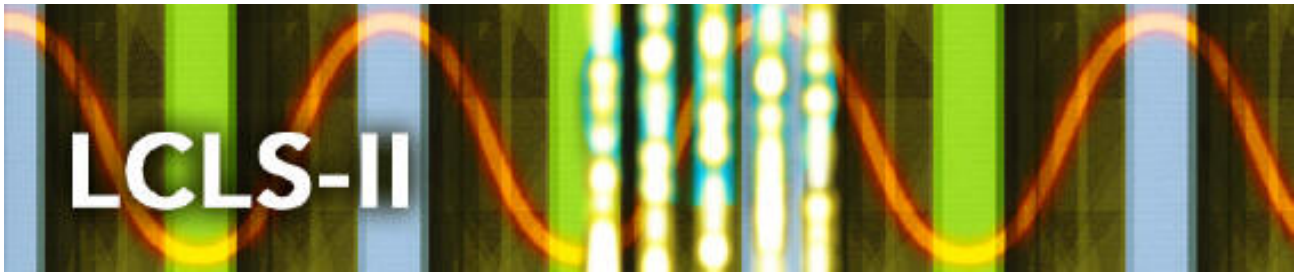

Cryomodule Interconnect Design

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U.S. DEPARTMENT OF ENERGY
Office of Science
Jefferson Lab
Fermilab
BERKELEY LAB
SLAC NATIONAL ACCELERATOR LABORATORY

Outline

1) Cryomodule interconnect overview
2) Requirements and challenges
3) Interconnect design
4) Installation quality control
5) Shipping configurations
6) Things-to-do upon module delivery

Additional information

1). Cryomodule Interconnect Overview

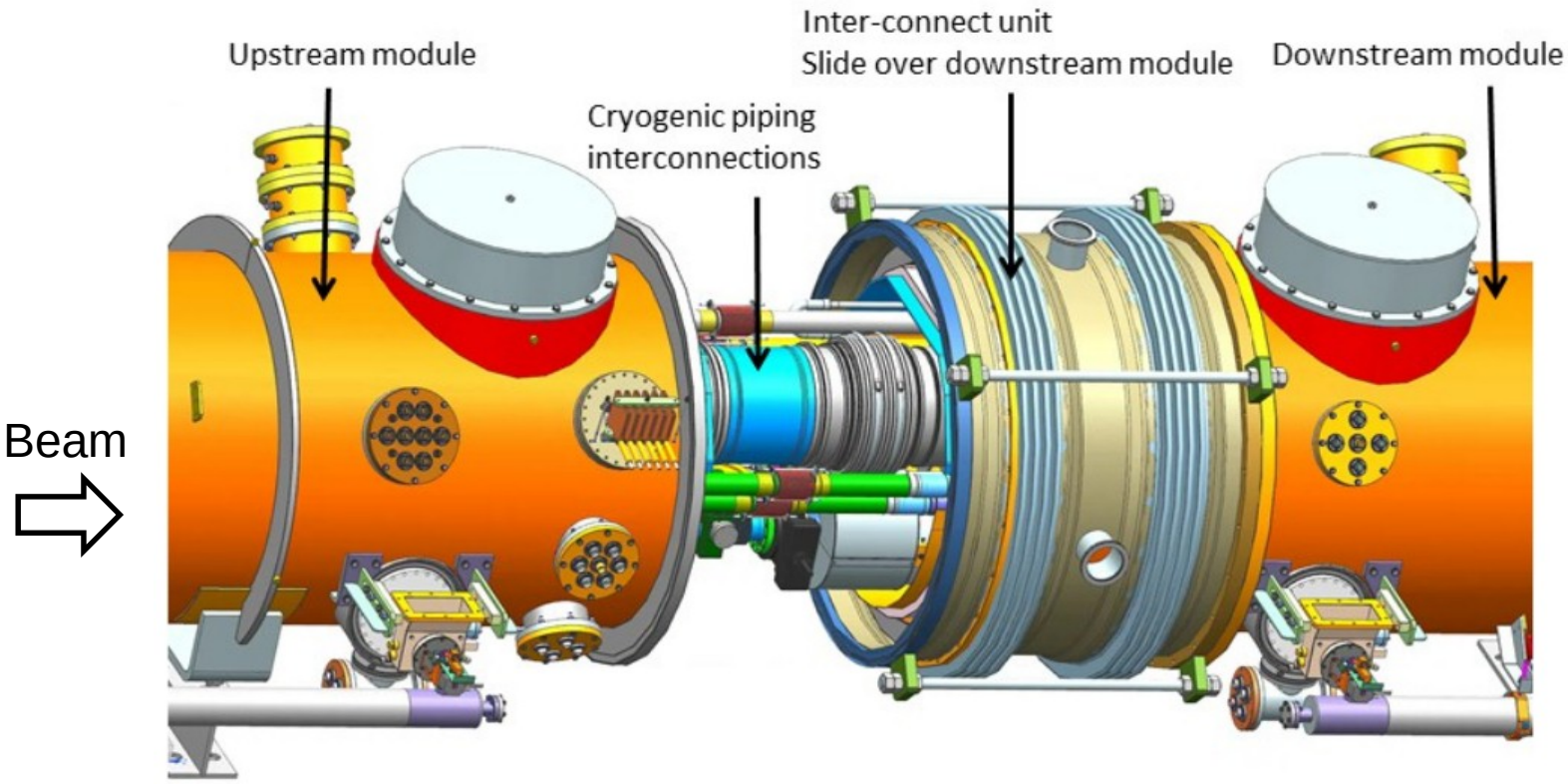
- Inter-module unit
- Module ends and inter-module kit (parts list)
- Module layers and interconnect joints
- LCLS-II tunnel

2). Interconnect Requirements and Challenges

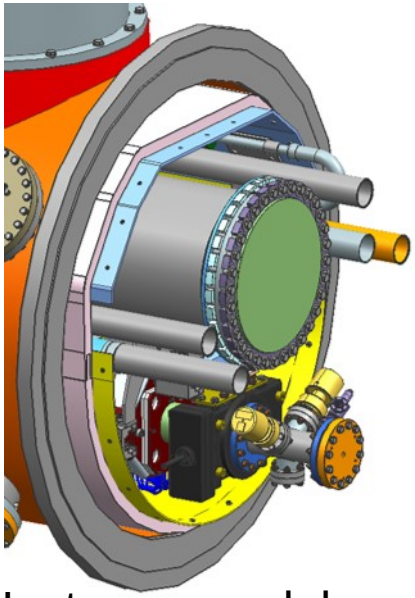
- Allowance for material differential thermal contractions
- *In-situ* welding & pressure piping code compliance
- Particle free UHV to preserve cavity cleanliness

Cryomodule Interconnect Overview

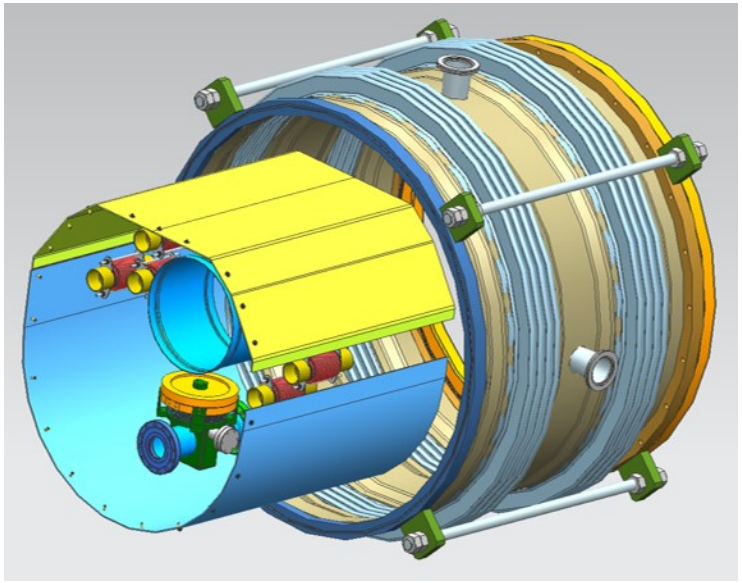
- A bellows inter-connect unit (850.0 mm) between two modules
- Outer shell of the inter-connect unit can slide over the vacuum vessel to allow space for welding of six cryogenic pipes *in-situ*



Cryomodule Interconnect Overview -- Module Ends & Inter-module Kit

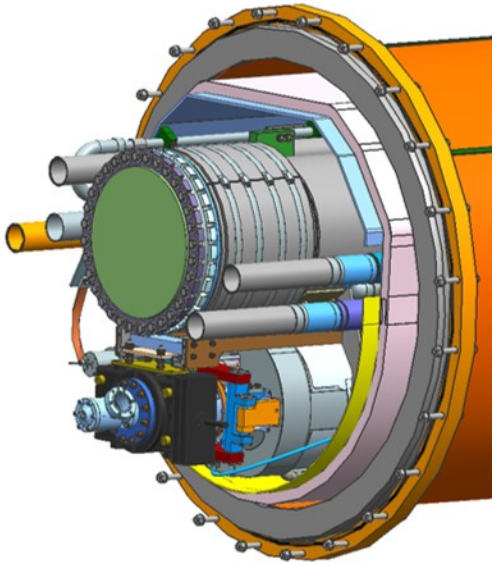


Upstream module



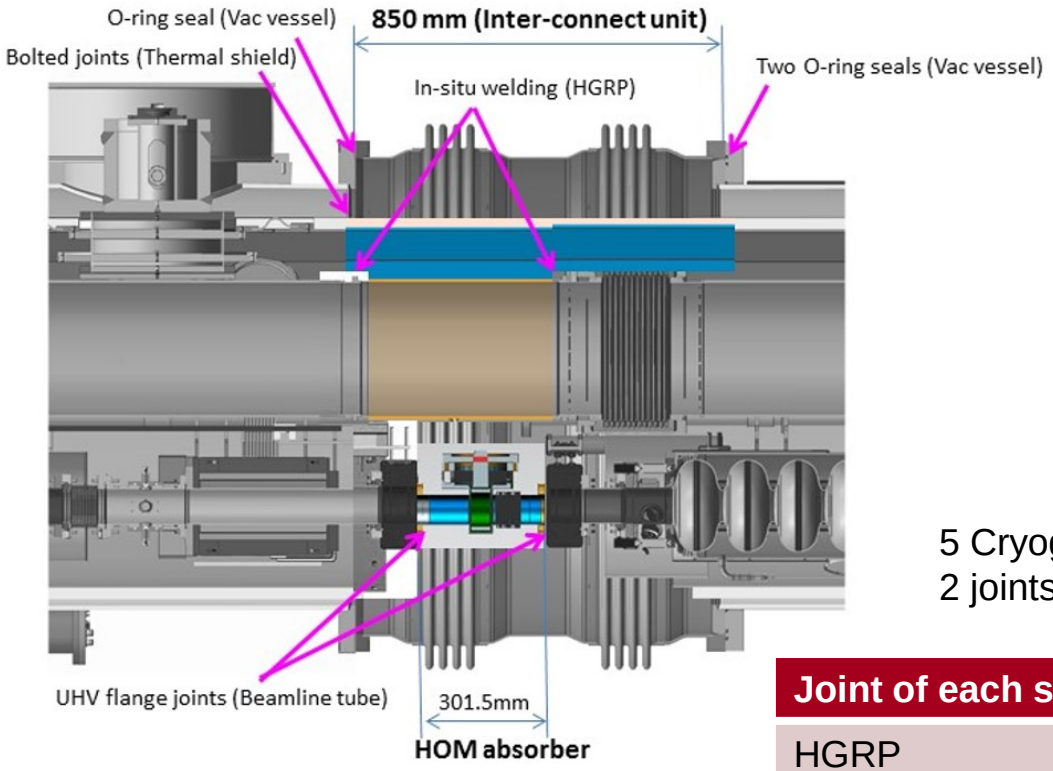
Inter-module kit

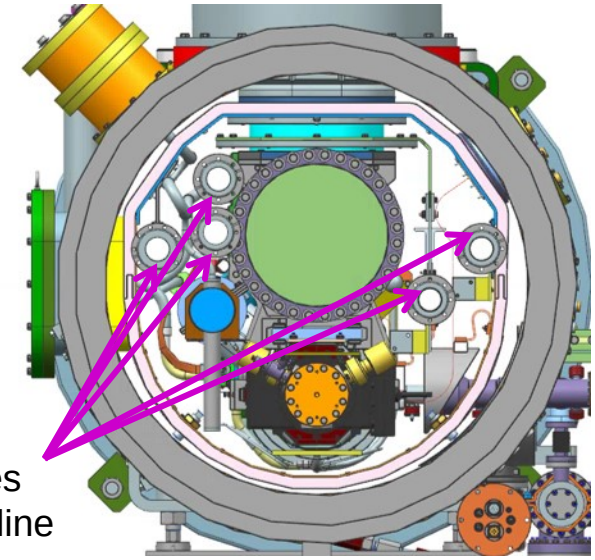
- Vacuum vessel inter-module bellows unit, F10009987, leak checked, but no blank flanges provided
- Thermal shield, F10038024 & F10038467
- HGRP, F10030193
- Bellows and spools for cryogenic pipes (Qty. 5), F10030695
- HOM absorber, F10017631
- MLI blankets (10 layers to 2K-8K components, 30 layers to 35-55K)
- Gaskets, fasteners, intercept straps



Downstream module

Cryomodule Interconnect Overview
-- Module Layers and Interconnect Joints



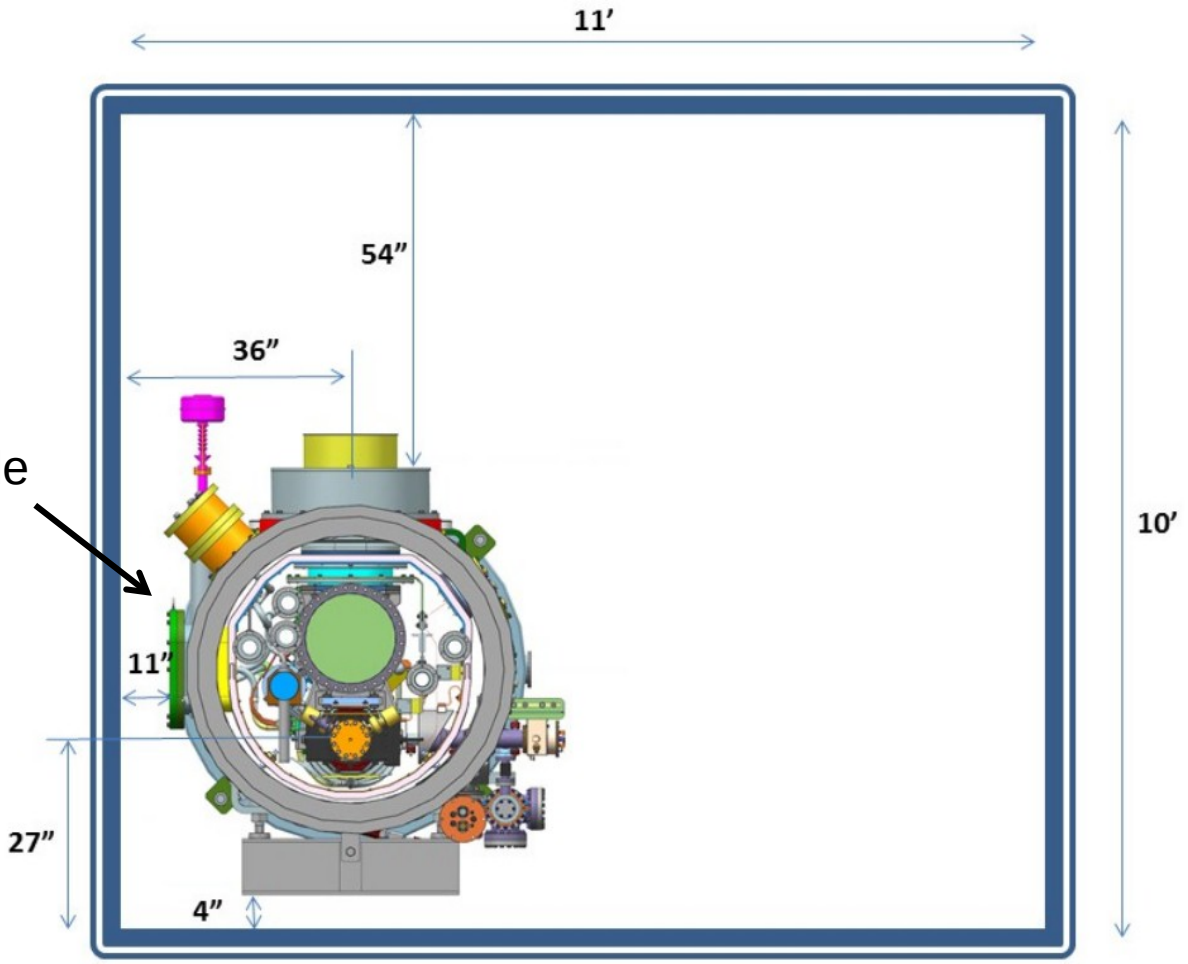


5 Cryogenic pipes
2 joints for each line

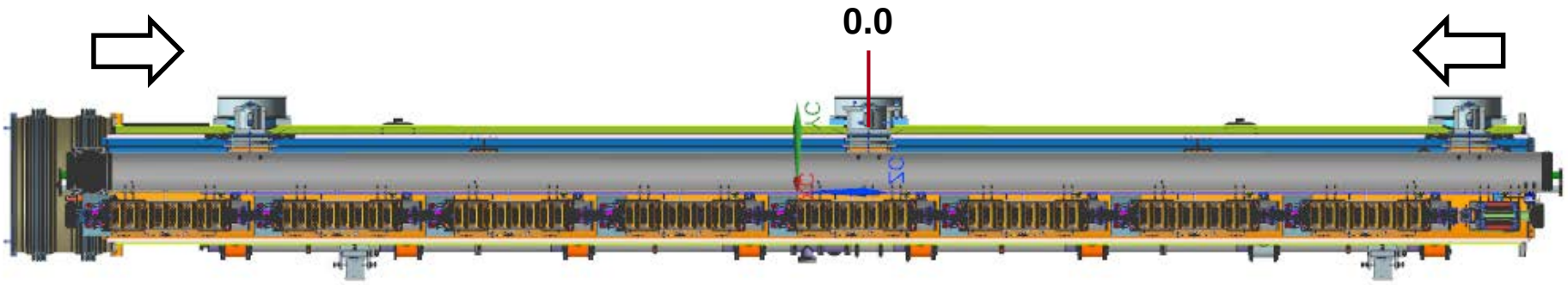
Joint of each sub-system	Type
HGRP	*In-situ* welding
Cryogenic pipes (5 lines)	*In-situ* welding
Beamline tube	Particle free UHV flange joints
Thermal shield	Good thermal conduction
Vacuum vessel	Vacuum O-ring flange joints

Cryomodule Interconnect Overview
LCLS-II Tunnel

Tight space on wall side



Interconnect Requirements and Challenges
-- Allowance for Material Differential Thermal Contractions



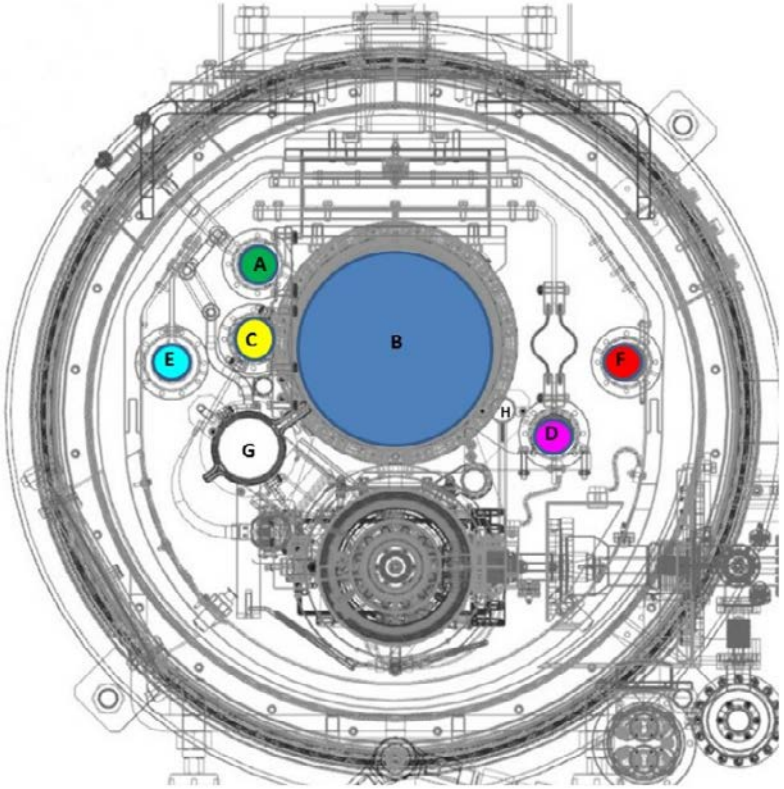
- Cold-mass and all the cryogenic pipes are fixed in position at the central post
  - When cold, these components will contract in length vs. vacuum vessel

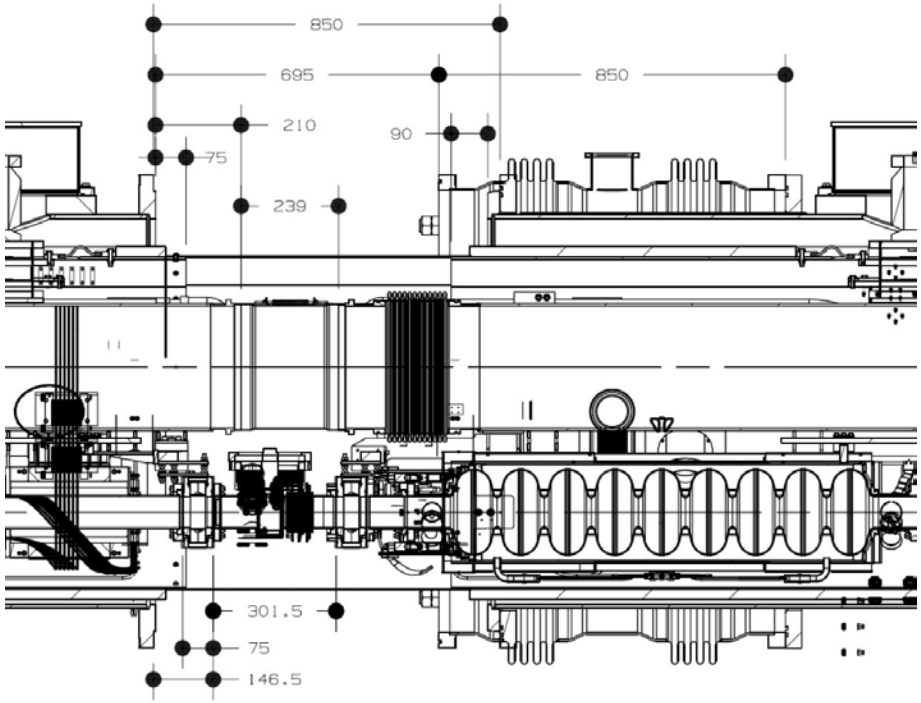
- Interconnect bellows on cryogenic pipes
  - to mechanically decouple the modules and allow for thermal contraction or expansion during thermal cycling

Component	Material	Temperature	ΔL/L	ΔL at inter-connection
HGRP, cryogenic circuits	SS	300K – 2K	0.319%	37.5 mm
Thermal shield, 55K extruded pipe	Al 6061-T6	300K – 40K	0.350%	40.0 mm

Interconnect Requirements and Challenges
-- *In-situ* Welding & Pressure Piping Code Compliance

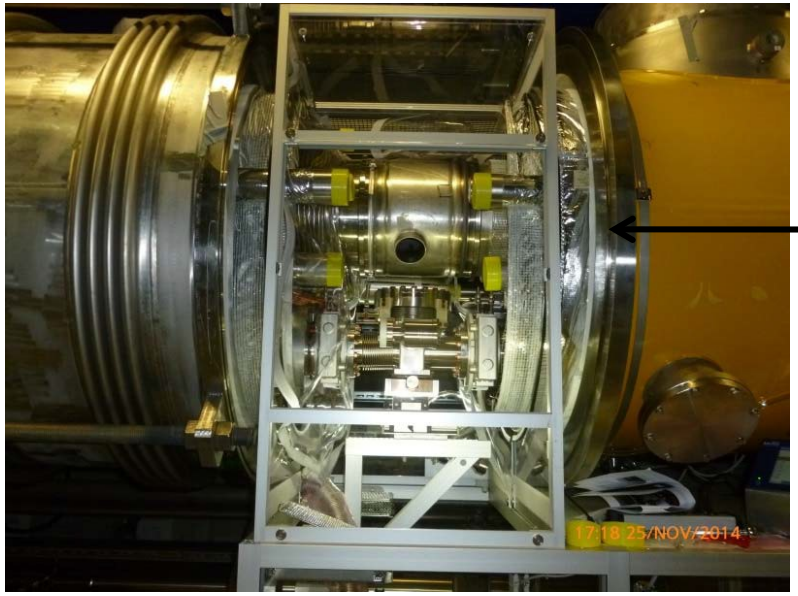
- Space for welding is very tight
- Leak checking for a long string
- Pressure testing (or X-ray inspection) for full penetration welding





Interconnect Requirements and Challenges -- Particle Free UHV to Preserve Cavity Cleanliness

- Beamline vacuum needs to preserve particle cleanliness of the cavity surfaces
- When making beamline connections between the modules, similar cleaning and assembly procedures as those performed for the cavities in the particle free clean rooms should be applied
- A portable softwall cleanroom (class 10) is required

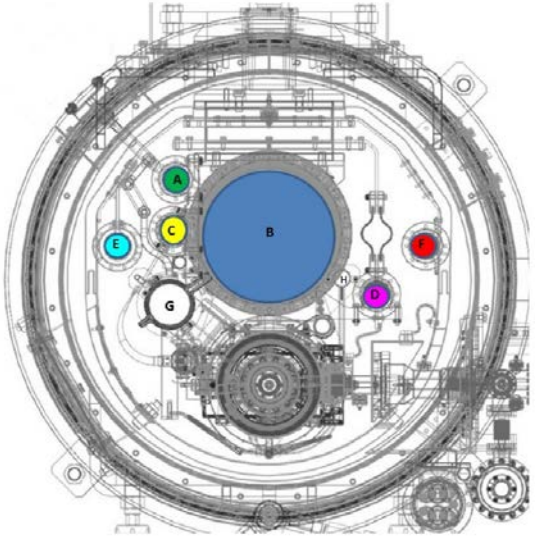


Portable clean room used at XFEL

3). Cryomodule Interconnect Design

- Interconnect pipe dimensions and X-Y coordinates
- HGRP interconnect
- Cryogenic pipes interconnect
- HOM absorber – beamline inter-module unit
- Thermal shield interconnect
- Vacuum vessel interconnect

Cryomodule Interconnect Design -- Interconnect Pipe Summary



- Pipe X-Y coordinates are same as those in XFEL module
  - XFEL drawing: DESY 0_06_8205_0_000 (module 3 plus, 10/4/06)
  - LCLS-II drawing: F10009945
  - Welding heads/toolings used on XFEL should work for LCLS-II module
- LCLS-II module has more space than XFEL module
  - No 5 K thermal shield
  - 2-phase pipe and warm-up/cool-down pipes are closed in each module
- At interconnect region, welding will be SS-SS tubes of identical sizes for all five pipes A,C,D,E,and F
  - Pipes D & F are Al pipes with SS-Al transitions

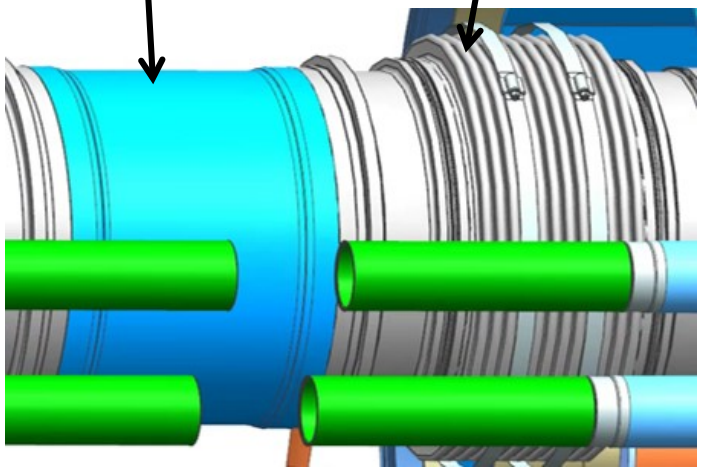
Pipes	Drawing #	Description	Material & size	Coordinates (X, Y) [mm]	Operating pressure [bar]	Design Pressure [bar]
B	F10023305	HGRP	SS316L, 300 ID/312 OD [mm]	0, 0	0.031	2.0 warm 4.0 cold
A	F10015253	2.2 K supply	SS316L, 2” SCH10	219, 125.5	3.0	20.0
C	F10015251	4.5 K supply		225.5, 6.5	3.0	20.0
D	F10030805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

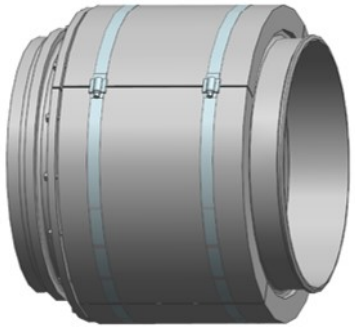
Cryomodule Interconnect Design -- HGRP Interconnect

- A stainless steel pipe is to be welded between the adjacent HGRPs

HGRP bellows unit on downstream module

HGRP inter-connect pipe
(F10030193)



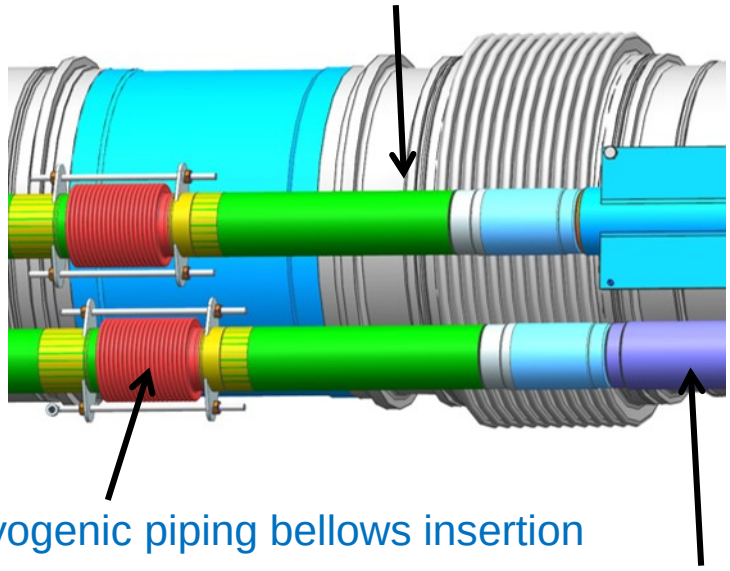


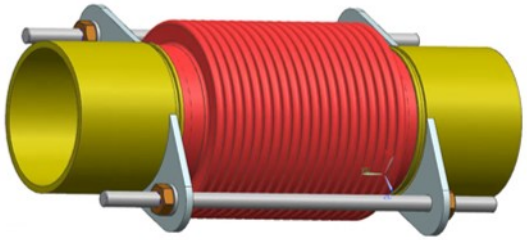
Bellows restraining clamps for protection during handling and welding

- will be removed after inter-connect welding
- Made out of four Al quarter-rings (F10023885)

Cryomodule Interconnect Design
-- Cryogenic Pipes Interconnect

- A stainless steel bellows insertion is to be welded between the adjacent pipes





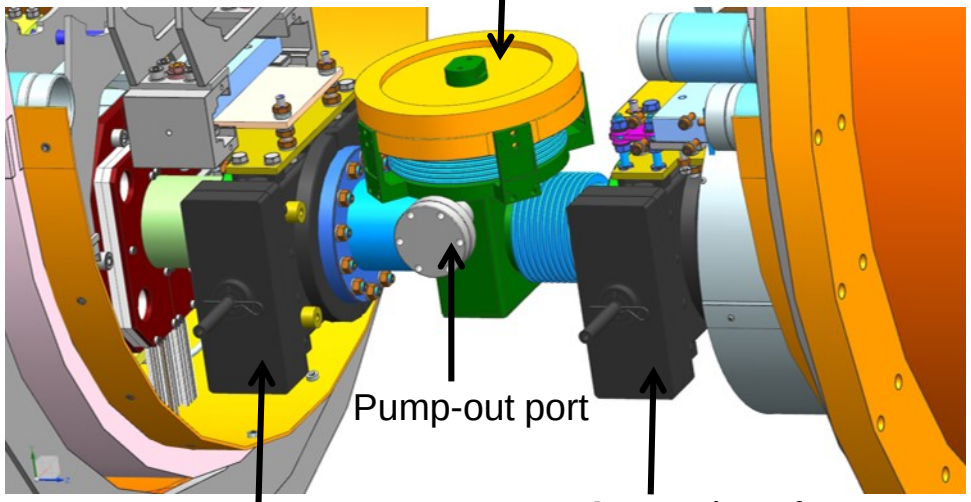
Bellows insertion

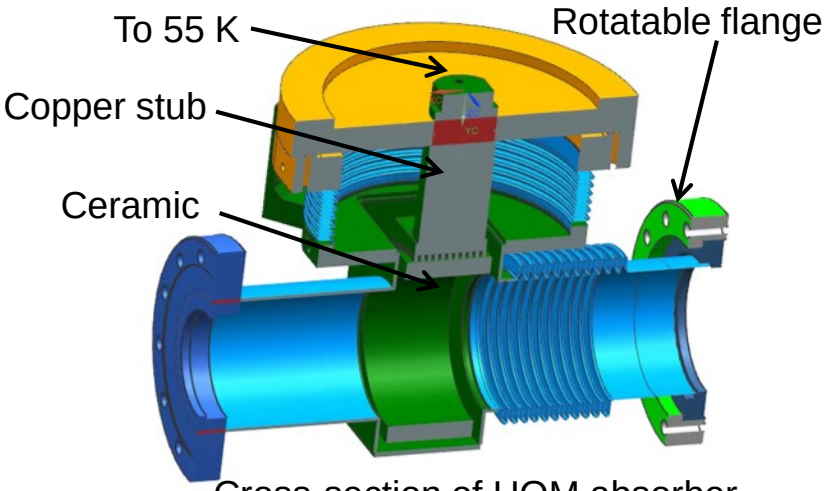
- Face-to-face length of pipe ends: 200.6mm
- (F10030695)
- Axial shift: ±30mm, lateral shift: ±5mm
- Angular: ±1°

- Bellows will be compressed at installation and is expected to expand at cold

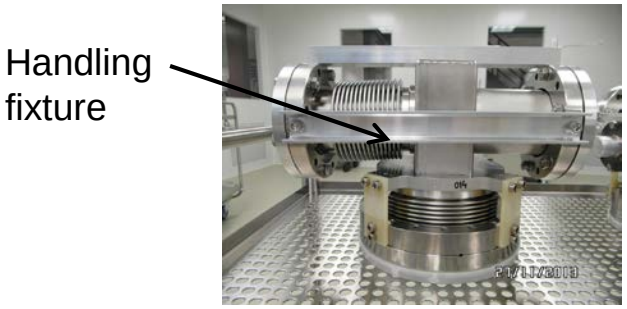
Cryomodule Interconnect Design
-- HOM Absorber – Beamline Inter-module Unit

- Beamline terminates at each end with an all-metal GV
- A HOM absorber between the modules
- Pump-out port allows pump-down and leak-check of this interconnect section before it is valved in to the cavity strings





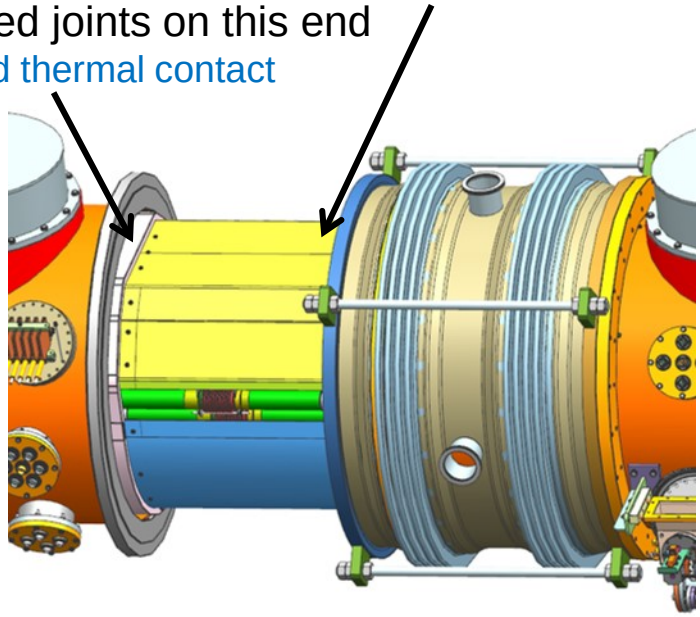
Cross-section of HOM absorber (F10017631, 301.5 mm long)

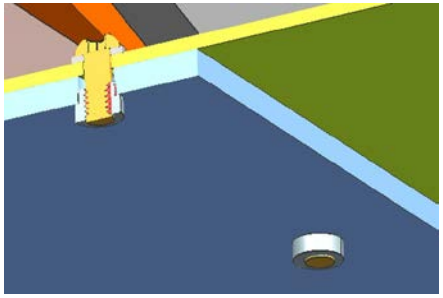


Cryomodule Interconnect Design -- Thermal Shield Interconnect

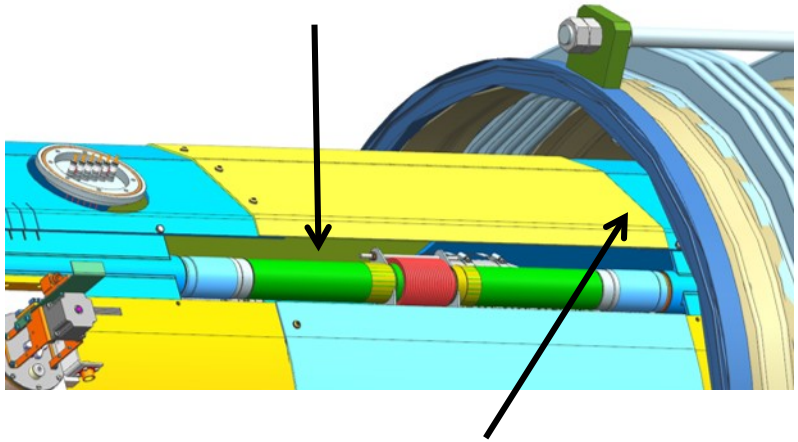
Thermal shield inter-connect sheets
(F10038024 & F10038467)

Bolted joints on this end
Good thermal contact





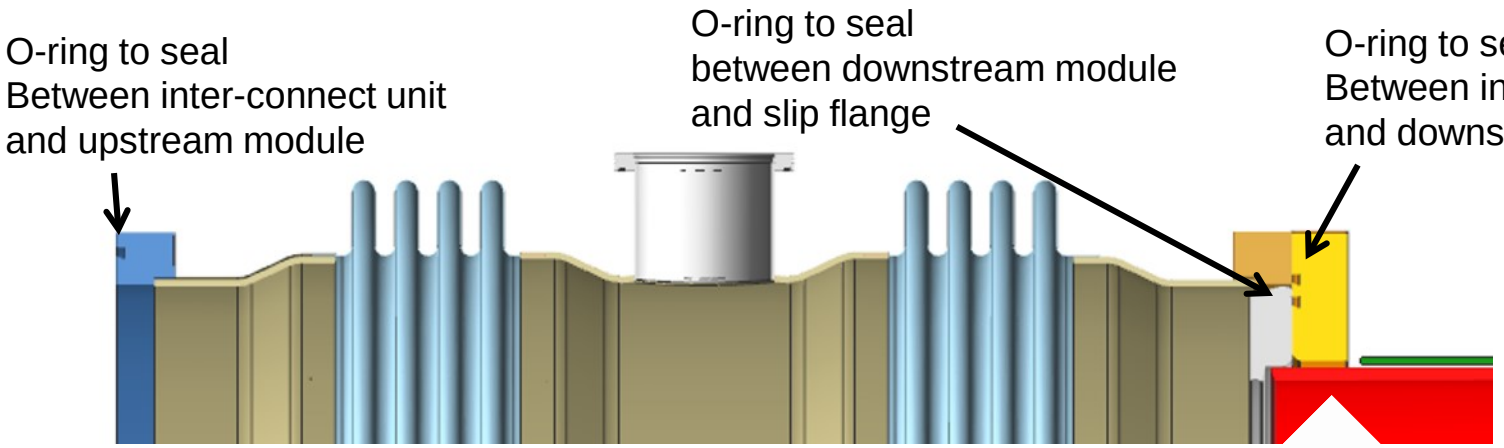
Discontinuity of direct thermal connection from 55 K cooling line

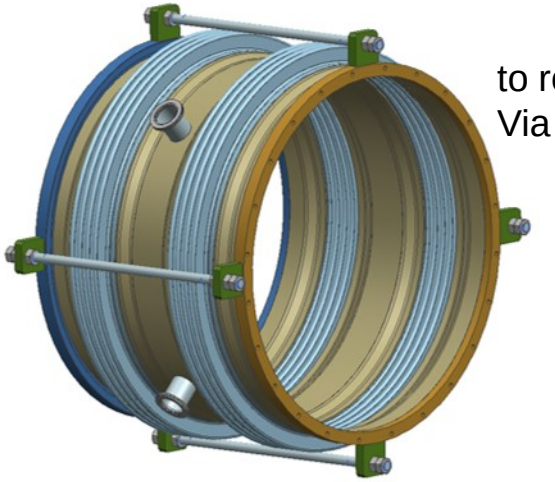


This end slides over the thermal shield of the downstream module
(50 mm overlap)

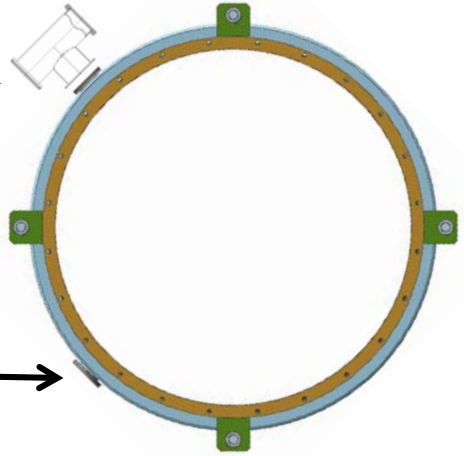
Cryomodule Interconnect Design -- Vacuum Vessel Interconnect

- Three O-ring seals (EPDM material for the seal) to complete the connection between inter-connect unit and cryomodules





to roughing pump/vacuum gauge
Via right-angle valves



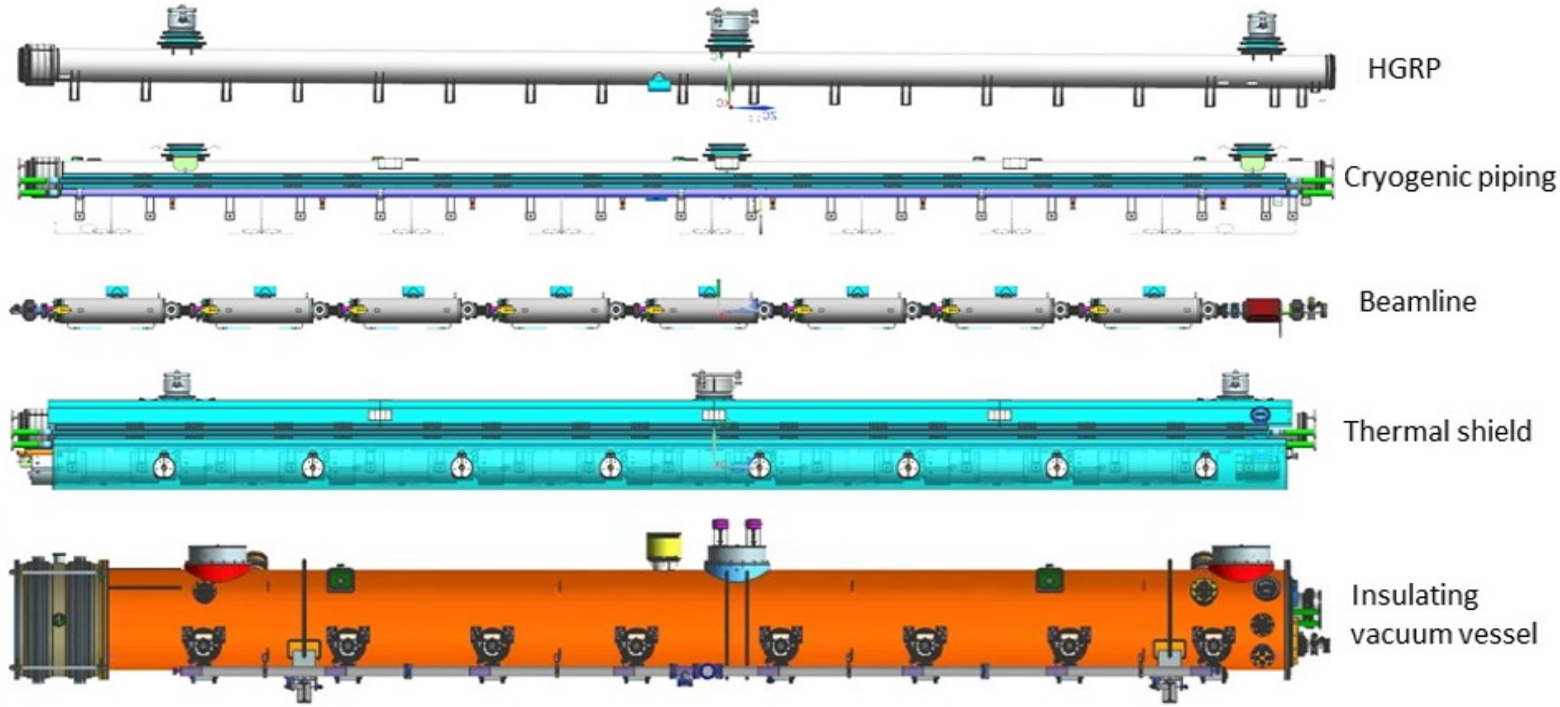
to turbo pump station
Via a gate valve

4). Installation Quality Control

- Assembly sequence
- Pre-assembly preparations and tools/fixtures
- Cryogenic lines pipe welding
- Cryogenic lines leak checking
- Cryogenic lines pressure testing
- Particle free UHV practice
- Close-out of the cryomodule

Installation Quality Control
-- Assembly Sequence

- Follow the assembly sequence that has been developed at XFEL:
  - welding of HGRP
  - welding of cryogenic pipes
  - beamline connection
  - thermal shield connection
  - Closing-out of vacuum vessel



Installation Quality Control
-- Pre-assembly Preparations and Tools/Fixtures

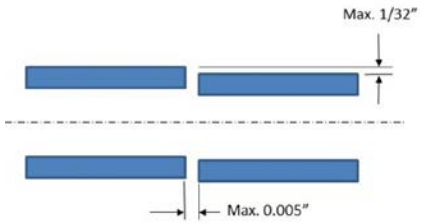
- Keep MLI and the insulating vacuum space dry
  - Fermilab suggests: a continuous boiled off nitrogen gas (or dry air if ODH concern) purge for insulating vacuum space during storage and preparation for installation
  - Dry air purge is required to prevent degradation of the lubricant used on tuner components
  - XFEL uses shower caps and desiccants
- All electrical connectors should be properly shorted before welding operation

  Connector shorting checklist will be created according to the instrumentation list

Sub-system	Tools and fixtures
HGRP inter-connect	Bellows restraint unit Rubber shell for leak checking
Cryogenic pipe inter-connect	Bellows restraint unit Aluminum jacket for leak checking
Beamline inter-connect	Portable clean room (ISO 4, Class 10) HOM absorber bellows restraint unit HOM absorber assembly lifting fixture Holder for gaskets (particle free cleaned, individually wrapped) Assembly hardware
Thermal shield inter-connect	
Vacuum vessel inter-connect	

Installation Quality Control
-- Cryogenic Lines Pipe Welding

- For 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

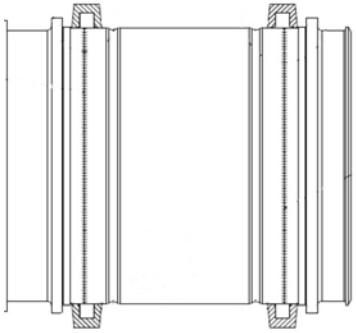


- The actual (as built module) X-Y locations of each pipe will provided by partner labs for each cryomodule
- Mis-alignments of the pipes could be accommodated by the joining bellows
  quite flexible with an axial shift of +/- 30 mm and a lateral shift of +/-5 mm
- A certified welder and qualified welding procedure is required
- Using 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
- An boiled off argon gas environment Inside & outside of the pipes for welding

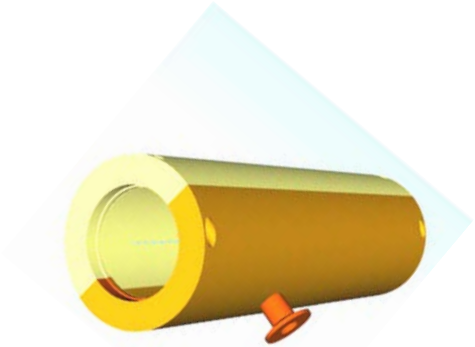
Installation Quality Control
-- Cryogenic Lines Leak Checking

- XFEL uses the clam shell for reverse leak checking the welds
  - Filling the cryo pipes internally with helium (pressure no more than 0.5 bar gauge) will help to avoid filling the tunnel with helium and helps to get a better minimum detectable leak rate
  - Helium contaminated cryo pipes from testing will not be easy to pump down and leak check with good MDL in a short time frame
  - However, if there is a leak, it is impossible to pinpoint the leak with this method

- No leak shall be detectable on the most sensitive scale of the leak detector with a minimum sensitivity of 2×10^{-9} mbar × liter/sec



XFEL Rubber shell for leak checking HGRP weld



XFEL Aluminum jacket for leak checking cryogenic pipes

Installation Quality Control
-- Cryogenic Lines Pressure Testing or X-rays

- To comply with pressure piping code, post welding test: pressure tests or X-ray inspection

- For XFEL module: X-ray inspection all lines
- For LCLS-II module: X-ray inspection HGRP or wait to do pressure test after insulating space is under vacuum
  - Even though the HGRP was pressure tested during fabrication to 6 bar, SLAC cannot pressure this pipe to 6 bar post interconnect welding, because it shares the common helium circuit with the SRF cavities.
  - When the beamline of the cavities is under vacuum(Pbeam=0 bar abs), as CM received at SLAC, the HGRP cannot be pressurized to 2.3 bar differential (3.3 bar ABS) unless insulating vacuum is pumped down. If not, the cavities frequency will be disturbed permanently

- All other 5 cryogenic pipes can be pressure tested, with filtered nitrogen gas from a dewar for 30 min, with the test pressure: 1.1 x MAWP

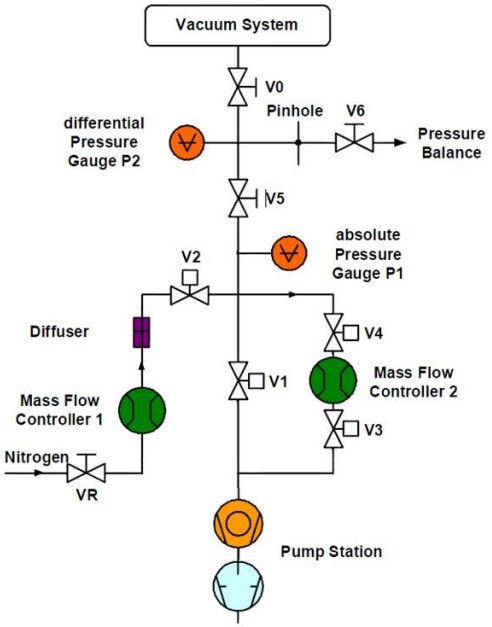
Pipes	Description	Operating pressure [bar]	Design Pressure [bar]
B	HGRP	0.031	2.0 warm, 4.0 cold
A	2.2 K supply	3.0	20.0
C	4.5 K supply	3.0	20.0
D	5.5 K return	2.8	20.0
E	35 K supply	3.7	20.0
F	55 K return	2.7	20.0

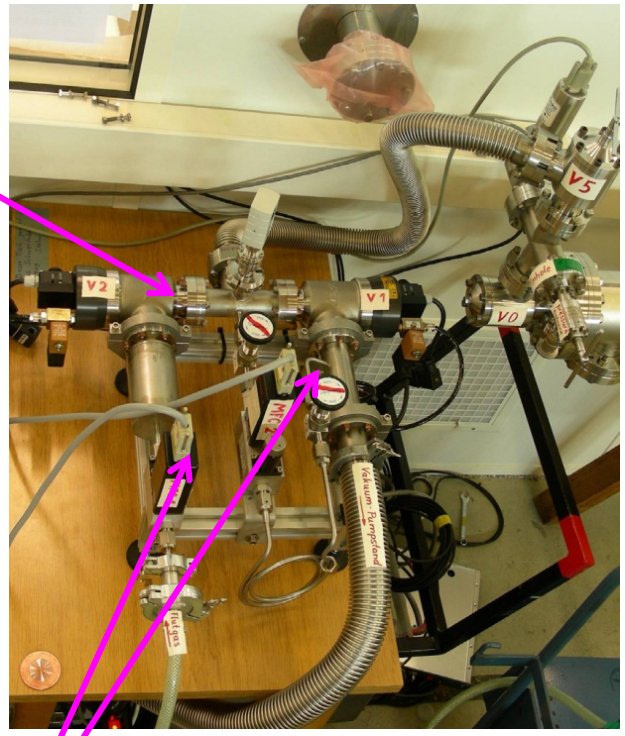
Installation Quality Control
-- Particle Free UHV Pumping/Venting Practice

- XFEL design
  - Prevent particles from entering the vacuum system or moving in the system
  - Allows automatic pump-down/venting

Diffuser

- ❑ Filters particles > 3 nm , w/ SS filter
- ❑ Allows gas flow in 360 ˚
- ❑ Gas flow uniformly





Beamline pump port

Mass Flow Controller

- ❑ soft start, aperture increased as pressure decreased
- ❑ w/ particle filter; Charcoal filter if use a N2 gas bottle

Installation Quality Control
-- Close-out of the Cryomodule

- MLI blankets are installed
  - 10 layers on 2K-8K components
  - 30 layers on 35K-55K parts
  - MLI staggering scheme (a zigzag order) shall be finalized
- Intercept straps are installed
  - HOM absorber to 55K pipe
- Continuity of thermal insulation must be ensured in the inter-connection regions
  - Good thermal contact at inter-connection joints
- Make three O-ring joints
  - Light apiezon grease is permitted
  - Confirm all tools, scrap, and spurious materials are out of the insulating vacuum space
- Leak check new flange joints

5). Shipping Configurations

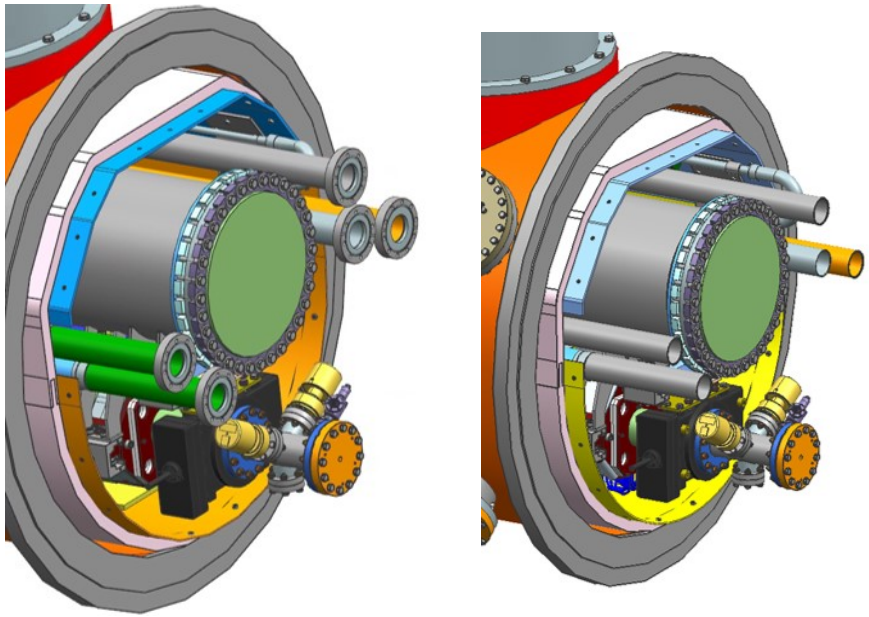
- Ends of cryogenic pipes
- Ends of beamline tube
- Insulating Vacuum

6). Things-to-do Upon Module Delivery

- Insulating Vacuum
- Beamline Vacuum

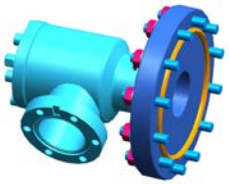
Shipping Configurations
-- Ends of Cryogenic Pipes

- On-going discussions on whether or not the flanges should be cut off at PLs
  - It takes one hour to cut one end at XFEL
  - Tube ends need good fitting
  - Needs orbital pipe cutter(3 sets vs. 1 set at SLAC, may need to re-do end finishing)
  - Flanges provide shipping protection
  - Current shipping fixture is designed with flanges on



Shipping Configurations
-- Ends of Beamline Tube (Curtis Baffes)

- After the cryomodule testing is completed at partner labs, transportation tees with vacuum devices will be installed at each end of the beamline



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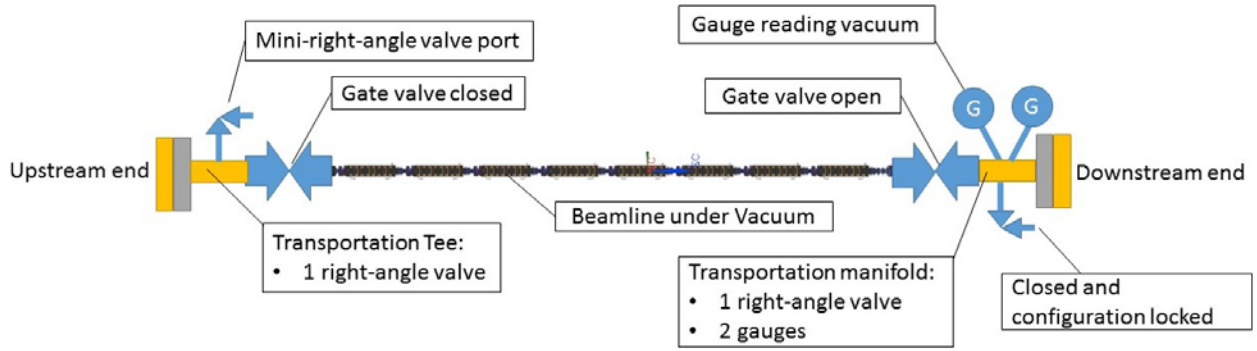
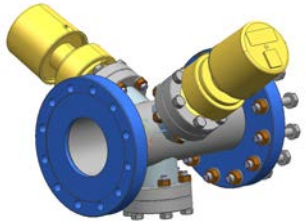
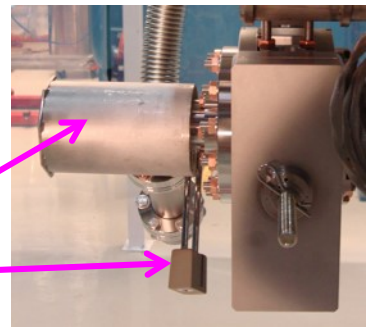




(F10031763)

- The beamline will be shipped under vacuum, with the vacuum gauges powered on but no active pumping during shipment

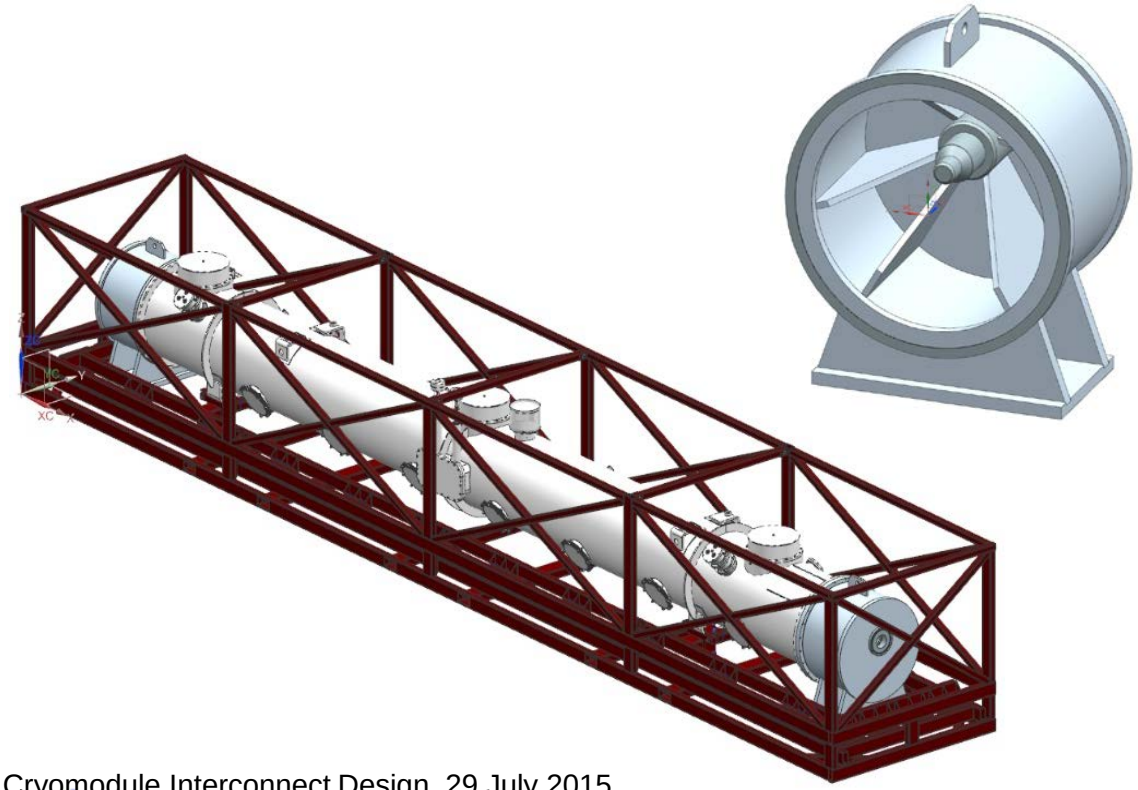
- The downstream GV is open to the spool which contains two vacuum gauges, while the upstream GV will be closed

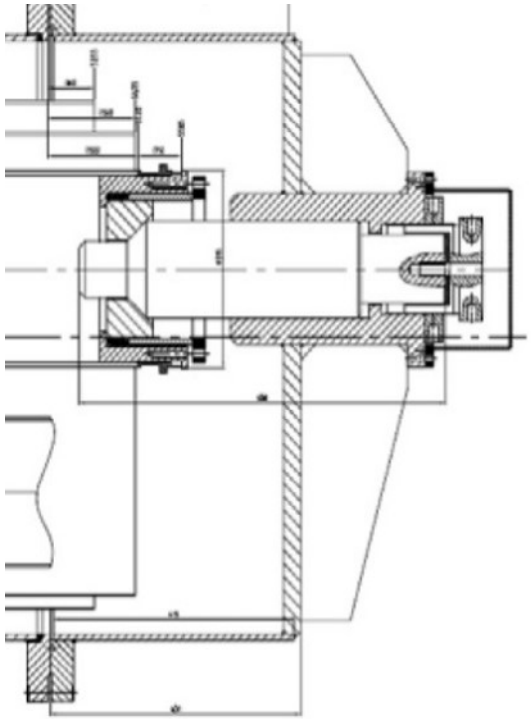


Shipping Configurations (Mike McGee) -- Insulating Vacuum

- Insulating vacuum space will be backfilled with boiled off nitrogen to 5 psig (20 psia) positive pressure for shipping

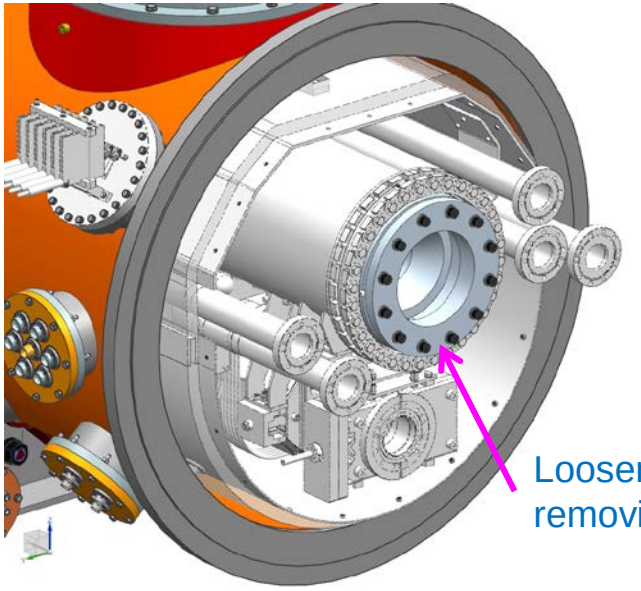
- End caps to keep and withstand the positive nitrogen pressure inside the vessel, as well as to support the HGRP at the ends





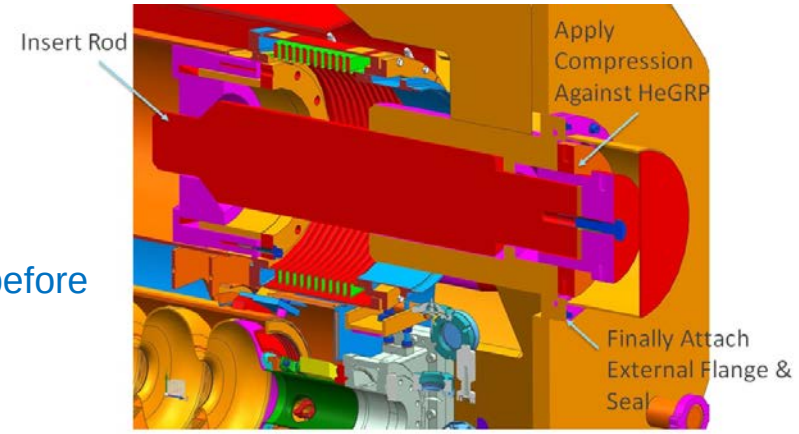
Things-to-do Upon Module Delivery -- Insulating Vacuum (Mike McGee)

- Shipping end caps need to be removed and returned to partner labs



Loosen all screws first before removing the assembly

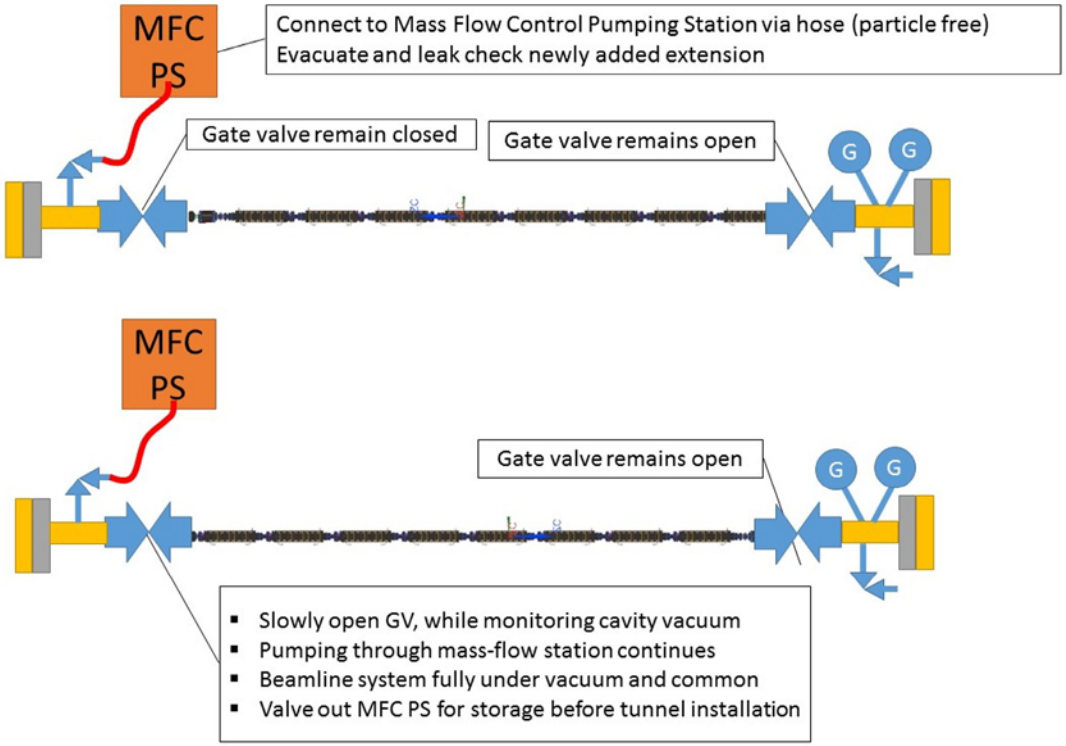
- Ten bolts hold and expand the swage feature within the HGRP end
- Insert rod is secured externally after attaching the cap



- Keep MLI and the insulating vacuum space dry
  - Fermilab suggests: module purge caps should be installed to allow continuous boiled off nitrogen gas (or dry air) purge for insulating vacuum space during storage and preparation for installation
  - Nitrogen gas purge is required to prevent degradation of the lubricant used on tuner components
  - XFEL uses shower caps and desiccants

Things-to-do Upon Module Delivery -- Beamline Vacuum (Curtis Baffes)

- Number of the valve open-and-close cycles of the beamline vacuum should be minimized
  - to prevent particles from being introduced into the cavity region
- In case a pump-down is needed during the storage, follow the steps below:



Additional Information

- web page shared with SLAC

https://web.fnal.gov/project/lcls2_cryomodule/SitePages/Module%20interconnection.aspx

- Inter-connect assembly general procedure ED0002593

Module interconnection

This page gives a general guidance about making the cryomodule inter-connections in the linac tunnel at SLAC during module installation. It includes the requirements, pre-assembly preparations, assembly sequence and step-by-step procedures, quality control, and things-to-do before closing out the inter-connection unit.

General information	Linac layout and module inter-connections	
	Requirements and challenges of making inter-connections	
Pre-assembly preparations	Assembly parts list	
	List of tools and fixtures	
	Connector shorting list	
	Keeping MLI material dry	
Quality control	Pipe welding	XFEL piping coordinates
	Fermilab in-process weld examination form	LCLS-II module piping coordinates (sh. 2)
		XFEL piping bellows specifications
		Orbital welder used at XFEL (100% standard)
		Orbital welding steps at XFEL
		Custom-made welding tractor (w 90% std)
	Particle free vacuum practice	
	Leak checking	
	Fermilab pressure vessel testing manual	
	Fermilab pressure vessel testing form	
Step-by-step procedures	Assembly sequence	
	1). Welding of HGRP interconnection	
	2). Welding of cryogenic pipe interconnection	
	3). Beamline interconnection	
	4). Thermal shield interconnection	
	5). Vacuum vessel interconnection	

Fermilab Engineering Specification

LCLS-II 1.3GHz Cryomodule Inter-connection Assembly Procedure

ED0002593, Rev. -

Rev.	Date	Description	Originated By	Checked By	Approved By
-	May 4, 2015	Draft	*Yun He*		