Double Quarter Wave Crab Cavity

– The Cryomodule, Cavity Assembly and Integration.

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on behalf of the DQWCC team

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Outline

- Cryomodule design requirements
- Cryo-system and Cryomodule description
- Cryo-module heat load estimates
- Cryomodule integration and unresolved issues
- Summary

Cryostat Design Requirements

Test environment	Safety valve set-point	Maximum allowable pressure (PS)	Test pressure (1.43xPS)
SM18 Test cryostat	1.5 bar±0.15* (abs)	1.5 bar (abs)	2.1 bar (abs)
SPS	1.8 bar±0.15* (abs)	1.8 bar (abs)	2.6 bar (abs)

A leak tightness check is to be done after all welds, surface treatments, and heat treatments to ensure the vacuum pressure to be better than $1 \cdot 10^{-10}$ mbar can be maintained.

For structural integrity during the cavity cool down cycle to 2 K in a vertical test cryostat, the bare cavity under vacuum must withstand an external pressure greater than 2.1 bar

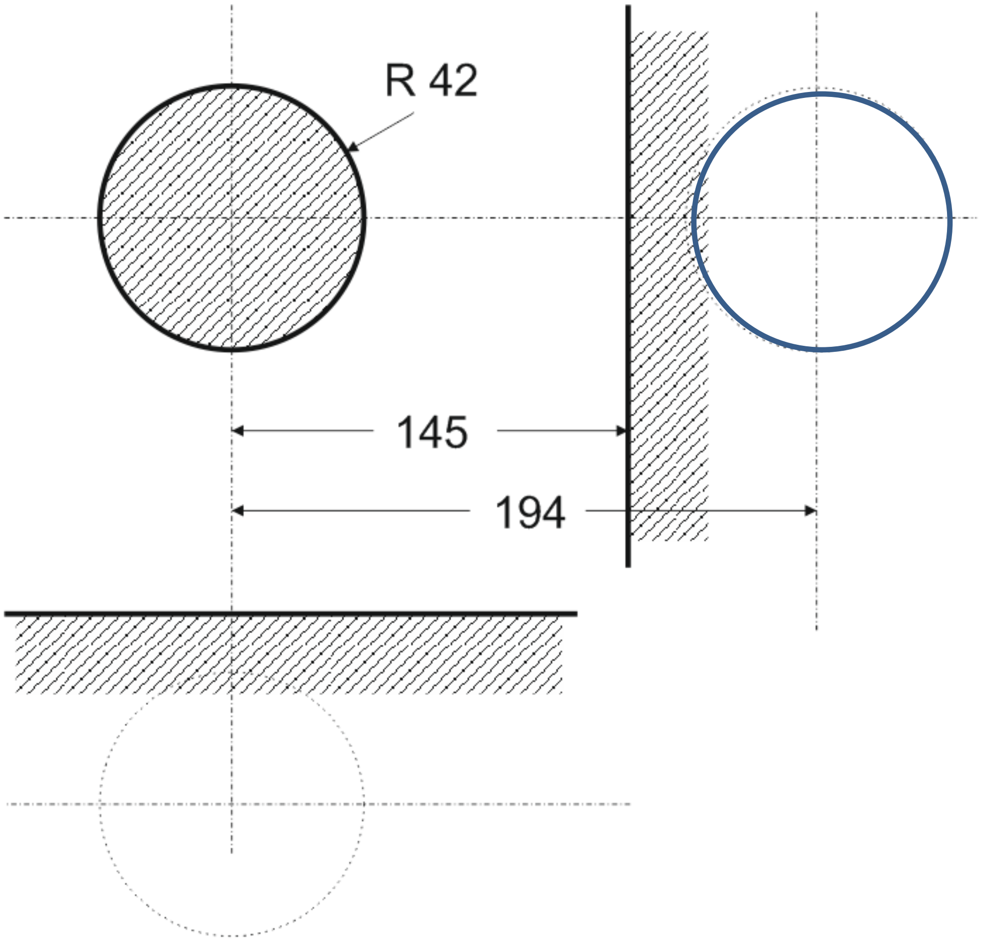
The baseline helium temperature used to cool the cavity is 2 K at a pressure of about 20 mbar (saturated superfluid helium).

Magnetic shielding in the cryostat around the cavity will reduce the external magnetic field on the outer surface of the cavity to below 1 μT field to achieve the desired quality factor of $Q = 1 \cdot 10^{10}$

Beam Tube Configuration

- In LHC The beam tube at both ends of the cavity must leave a clear radius of 42 mm. This will allow the transverse alignment of the cavity without reducing the aperture for the beam. A transverse distance of >145 mm between electric centre lines are kept clear for the passage of the 2nd beam tube.

- The cryomodule for the SPS test has two in line cavities but the cavities will have the 2nd beam tube is at a distance of 194 mm horizontally for both cases,



Cryomodule Geometric Tolerances

- Transverse rotation of the individual cavities inside the cryostat.
  - Cavity rotation in the x-y plane introduces a parasitic crossing angle in the non-crossing plane, thereby counter acting the crossing angle compensation as well as giving non-closure of the crab bump in the crossing plane. To limit this, it is required that the transverse rotation tolerance be 0.3° per cavity.
- Tilt of the cavity with respect to the longitudinal cryostat axis.
  - Cavity tilt with respect to the cryostat axis should be less than 1 mrad .
- Transverse displacement of cavities w.r.t each other inside a cryostat.
  - Intra-cavity alignment in the transverse plane with respect to the cryostat axis should not exceed the 0.7 mm tolerance set by the multipolar effects.
- Longitudinal displacement of cavities w.r.t each other inside a cryostat
  - Longitudinal displacement of the cavities from their nominal position is not crucial as deviation can be compensated by adjustments of the individual cavity set point voltages to account for changes in the optical functions. However, this displacement should be minimized to limit the cavity voltage imbalance to less than 0.1% of the nominal voltage, which is approximately 1-2 cm. Thus the longitudinal displacement tolerance is set at of the cavities 10mm.

Will any of these geometric requirements be attempted in the SPS cryomodule?

Cryo-system Heat load Estimates

Equipment	Heat load	Source of capacity
Service module	~2.5 W @ 4.5/2K ~30 W @ 80 K	Cold box -> 0.13 g/s LN2
Buffer tank	~1.5 W @ 4.5 K	Cold box -> 0.08 g/s
Transfer lines	~4 W @ 4.5 K	Cold box -> 0.21 g/s
Cryo module static	~14 W @ 2 K 223 W @ 80 K	Cold box -> 0.68 g/s LN2
Cryo module dynamic	~11 W @ 2K	Buffer -> 0.5 g/s
Total static:	~22 W	Cold box -> ~1.1 g/s

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Summary (assuming cold box capacity of 1.5 g/s):

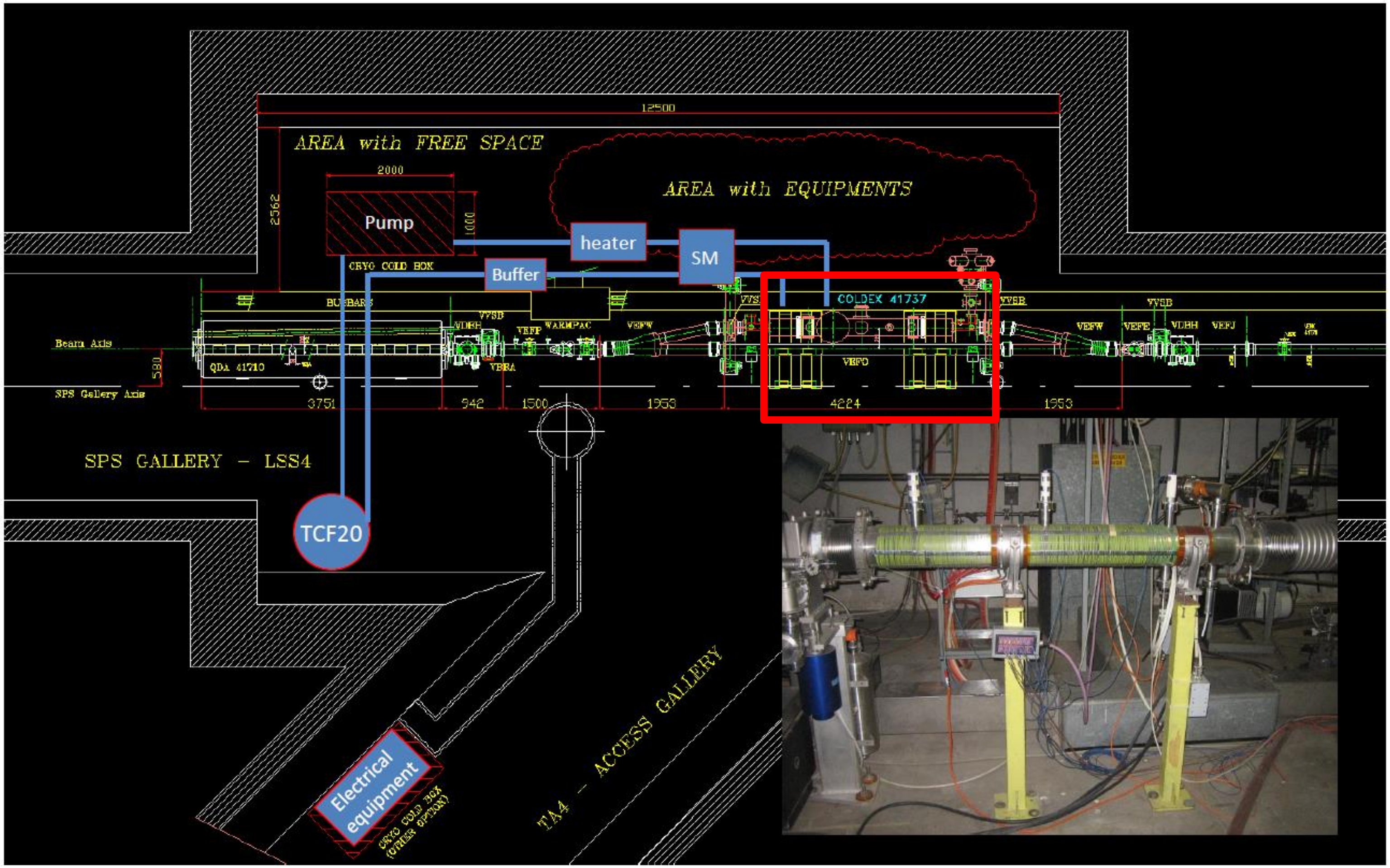
Total Static: 1.1 g/s -> calculated margin on the cold box is 0.4 g/s

Total Static + Dynamic = 1.6 > 1.5 g/s -> run without thee buffer is not possible

Dynamic (assuming 150 L buffer):
11 W -> 0.5 g/s -> 10.5 h of operation*

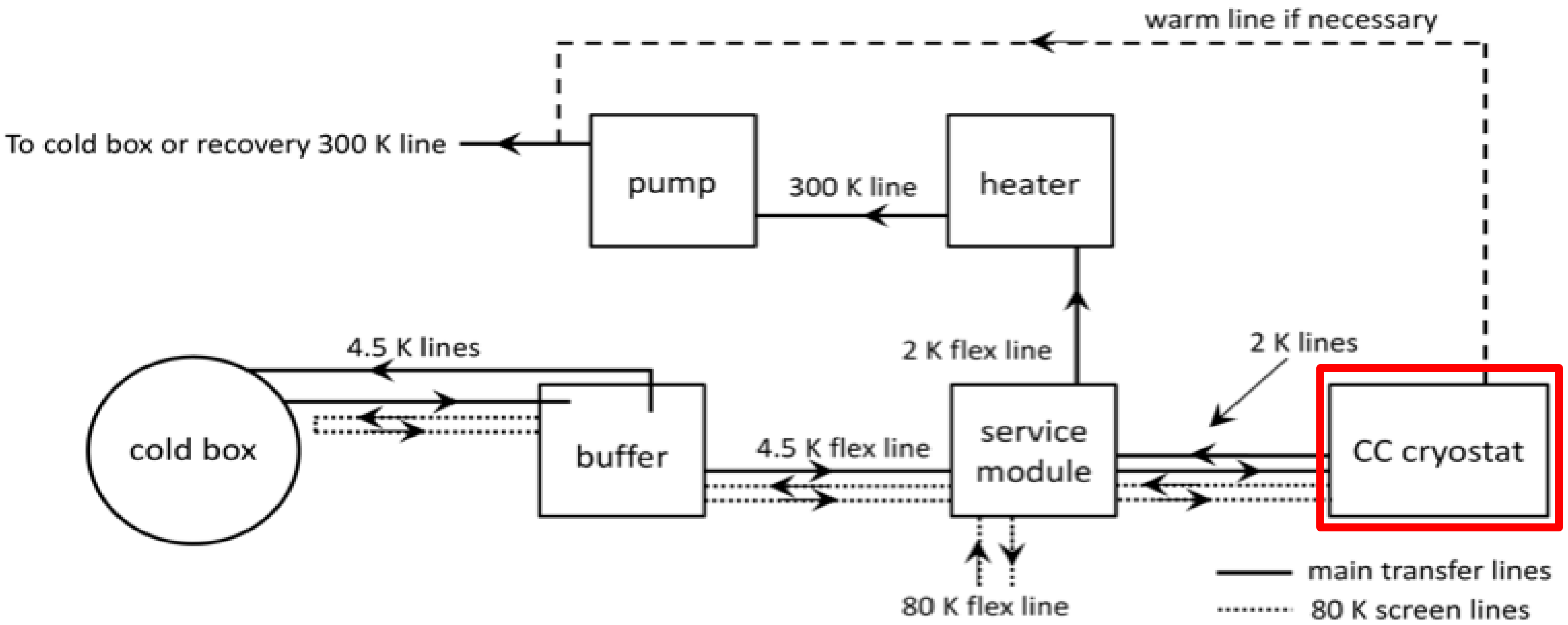
Filling of 150 L buffer with 0.4 g/s will take ~13 h

Cryostat system integration at the SPS



Cryogenic System

- Cryogenic infrastructure in SPS BA4, is currently limited 4.5 K cooling capacity, will be modernized and modified to provide cooling power at level of 2 K.
- The planned configuration of the helium distribution between TCF20 cold box and the cryostat will consist of cryogenic transfer lines, liquid helium buffer tank and service module equipped with sub-cooling heat exchanger and expansion valve.
- The return line of 2 K helium gas will go from the cryostat to service module to heater and then to the pumping unit, and then back to either the cold box or a He recovery line.

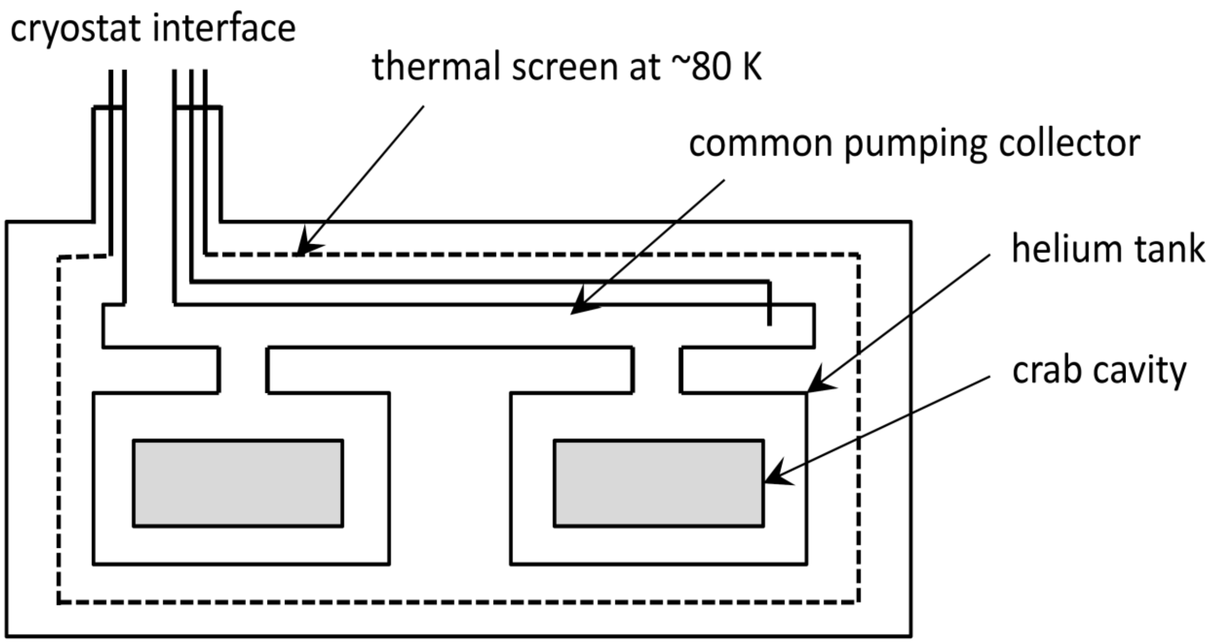


Summary of heat loaded on the Crab Cavities cryomodule for the SPS tests

HL per cryomodule		HL @2K [W]	HL @80K [W]	Comments
Static	Radiation (Cavity + Phase Sep. Cold surface + Thermal shield)	**0.2**	**6.8**	Rescaling from LHC: $0.1 W/m^2$@cold mass $1.7 W/m^2$@thermal shield
	CWT	**3.0**	**12.6**	1 heat interceptor not optimized
	Supporting system	**0.2**	**3.3**	HL@2K estimated from SPL
	RF couplers	2 x 2 = **4.0**	2 x 50 = **100**	For a tube thickness t = 3mm
	Cables & Instrumentation	**1.0**	**0**	Tentative
	Tuner	**0.2**	**0**	Not thermalized
	Other order modes	4x0.2 + 2x2 ~ **5.0**	**100**	Max losses found in ODU cryostat: 4 small HOMs (4x0.2W @2K estimated from SPL) + 2 "chimneys" HOM (2x2W @2K for a thickness of 3 mm and a length outside He bath of 340 mm); @80K: 4x? + 2x45W
Total Static		**13.6**	**222.7**	
Dynamic	Deflecting mode	**6.0**	**0**	Tentative
	Beam current	**0.5**	**0**	Tentative
	RF couplers	2 x 2 = **4.0**	2 x 5 = **10**	For a tube thickness t = 3mm ; P_{avg} = 100 kW
	Other order modes	**0.6**	**10**	for a P_{avg} = 100 kW; f = 1000 MHz; @2K chimneys: 2x0.1 + small HOM (estimated from SPL): 4x0.1@2K; @80K: 4x?+2x4
Total Dynamic		**11.1**	**20**	
Total losses		**24.7**	**242.7**	

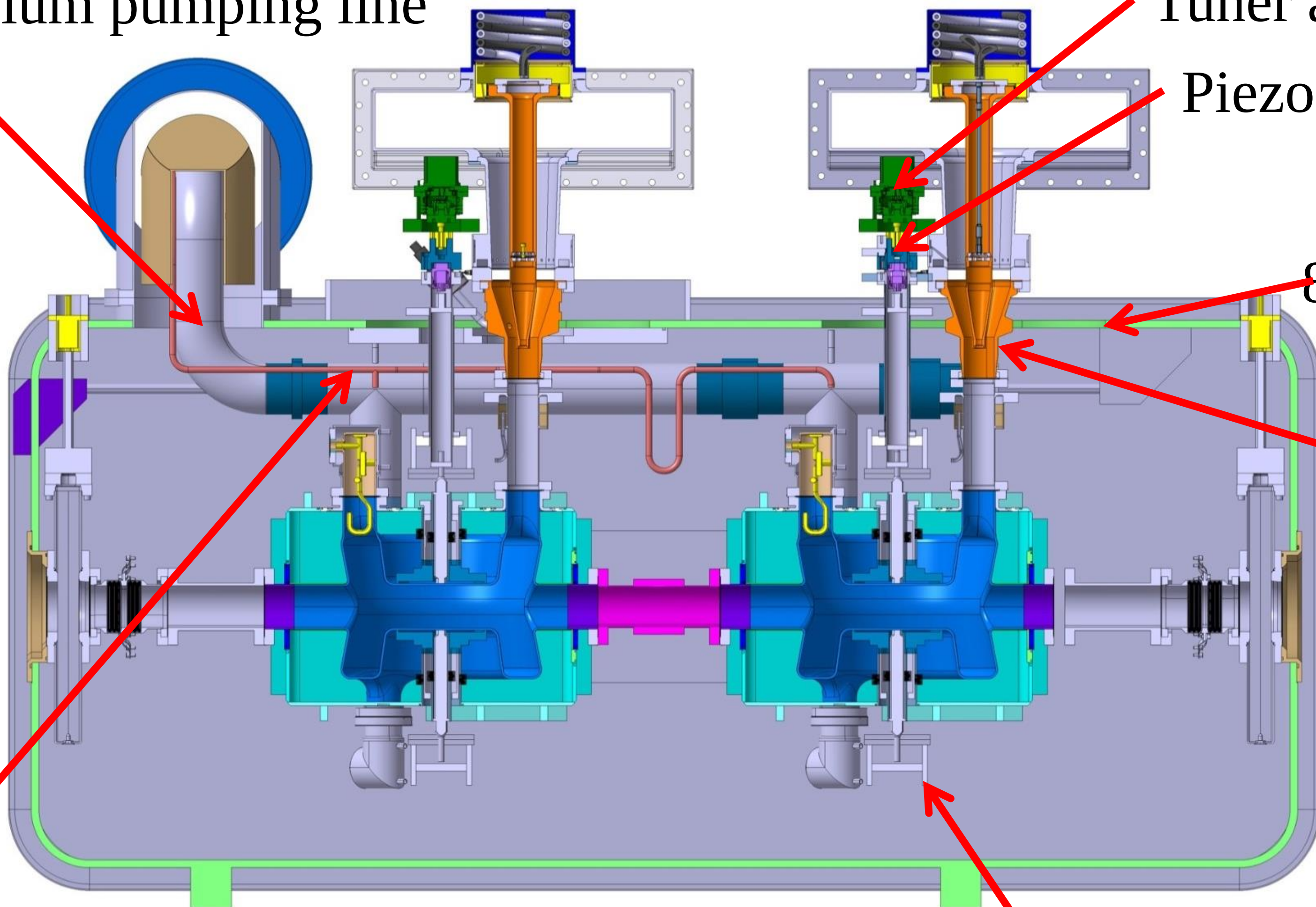
Crab Cavity Cryomodule Concept

- The cryostat interface will consist of four lines: 2 K supply, 2 K pumping, 80 K inlet and 80 K outlet (a warm recovery line can be added and connected with low pressure if necessary) lines, and the basic scheme of the cryostat circuits is presented



- The helium tanks for two cavities will be separate but have a common pumping collector.
- The pumping collector is the only hydraulic link between the two helium tanks so that under quench conditions the cavities are only indirectly coupled.

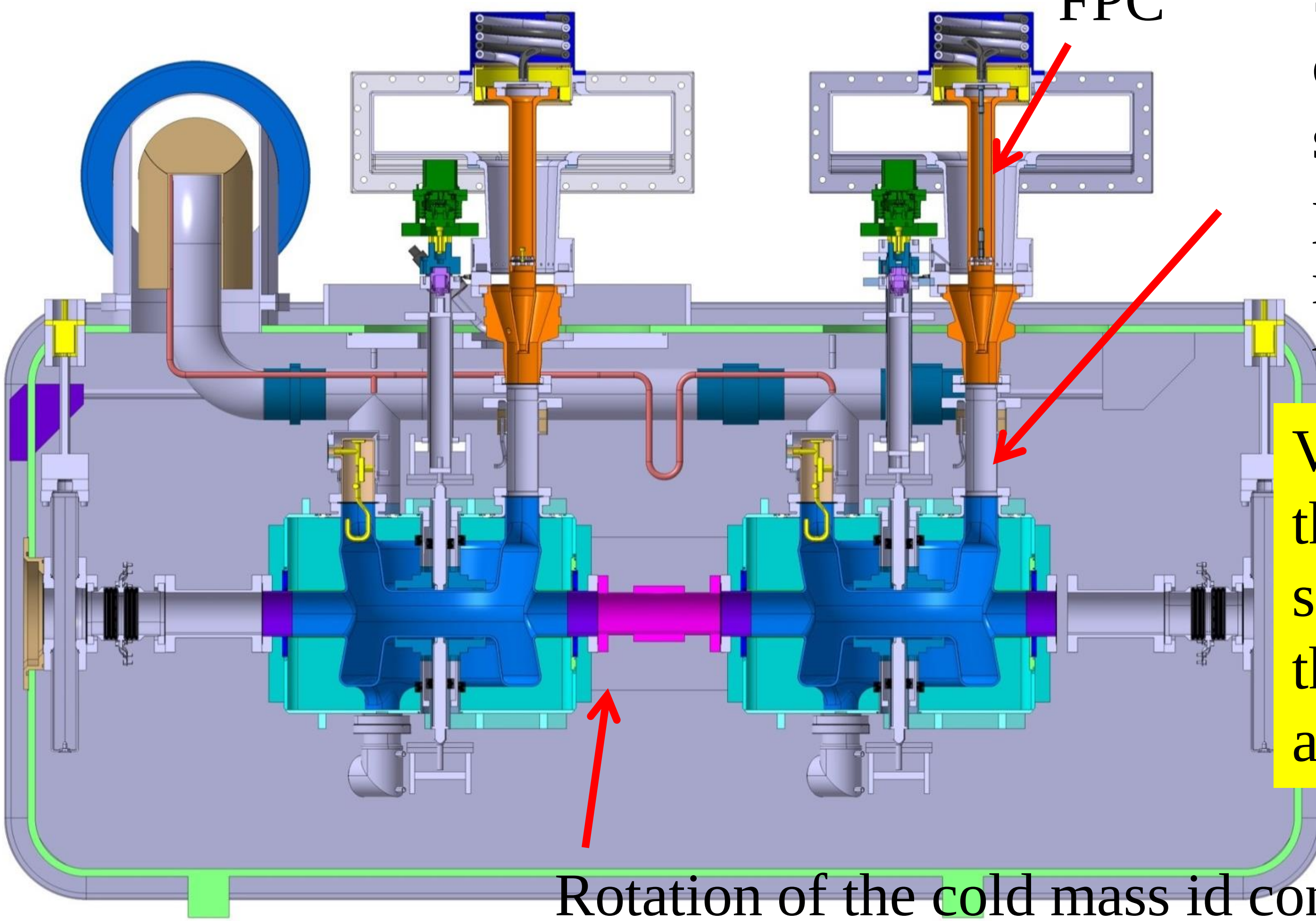
Crab Cavity Cryomodule



BNL Cryomodule

Crab Cavity Cold Mass Support

FPC



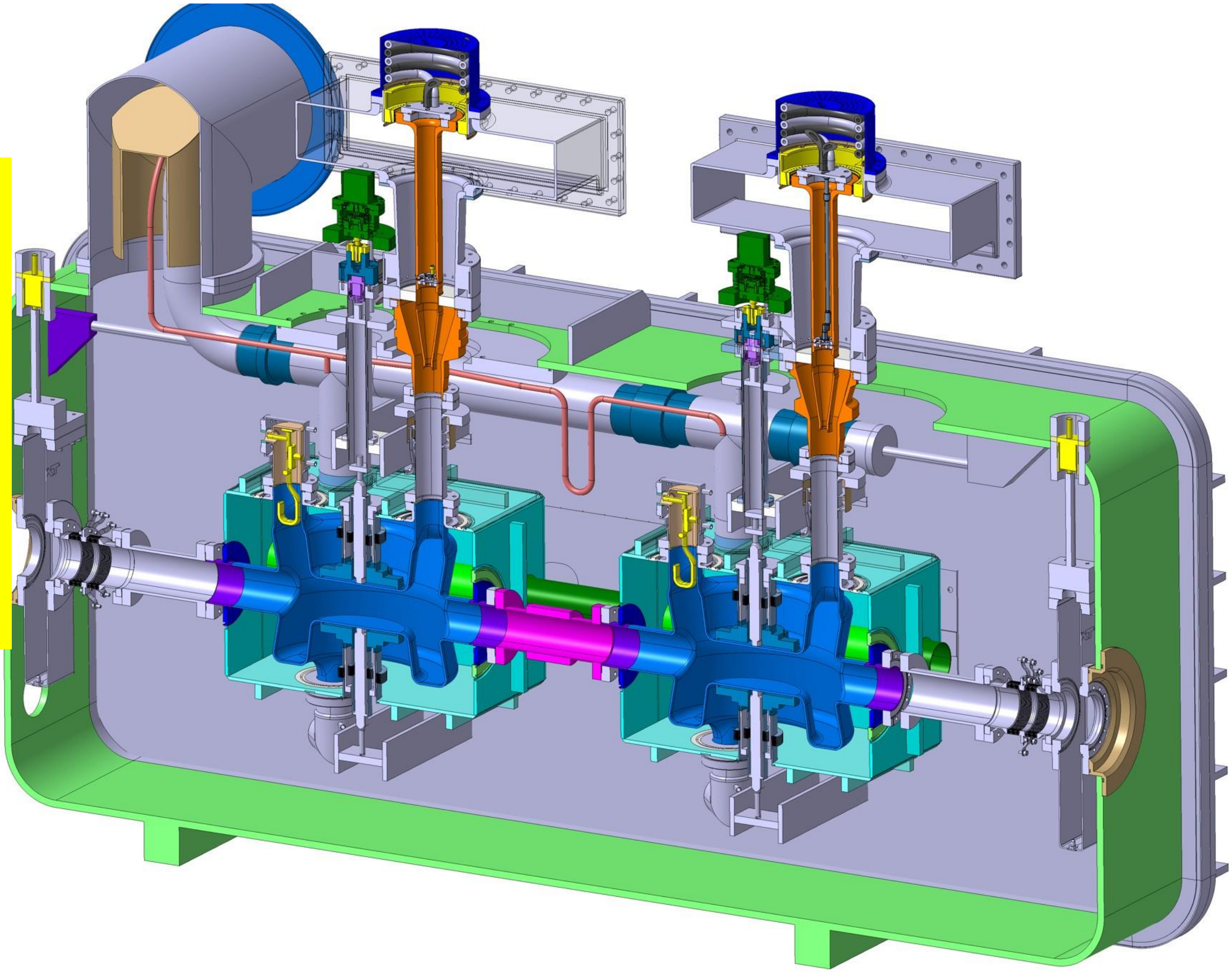
Support for the cold mass is supported primarily by the rigid connection to the FPC

View of analysis that shows that the support from only the FPC is acceptable

Rotation of the cold mass id constrained by rigid plate attached between the two cold masses

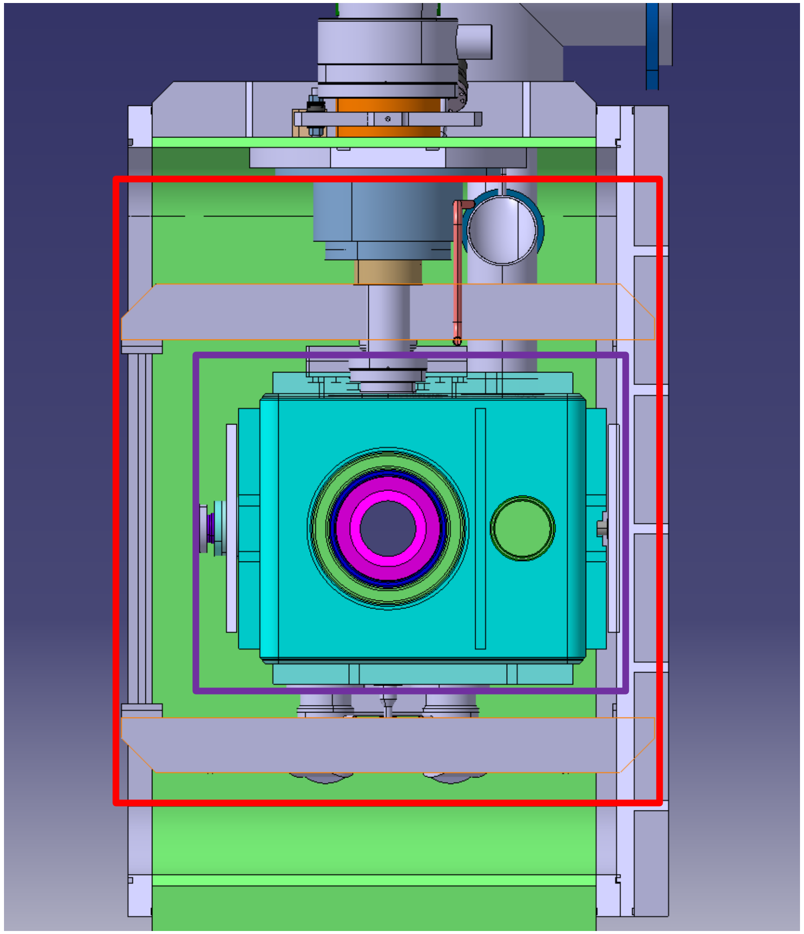
BNL Cavity Cryomodule

Better View of structural support or plate that holds the two cavities together.

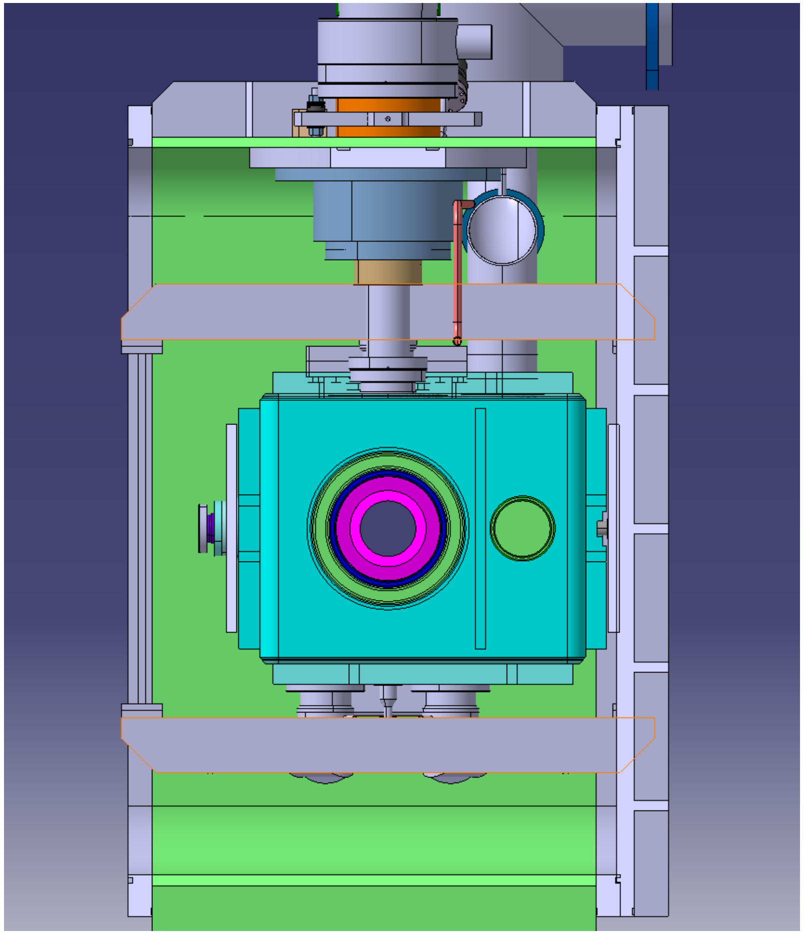


Interference between cavity reaction frame and vacuum vessel

Design of magnetic shielding and it's interface with the cavity and reaction frame.



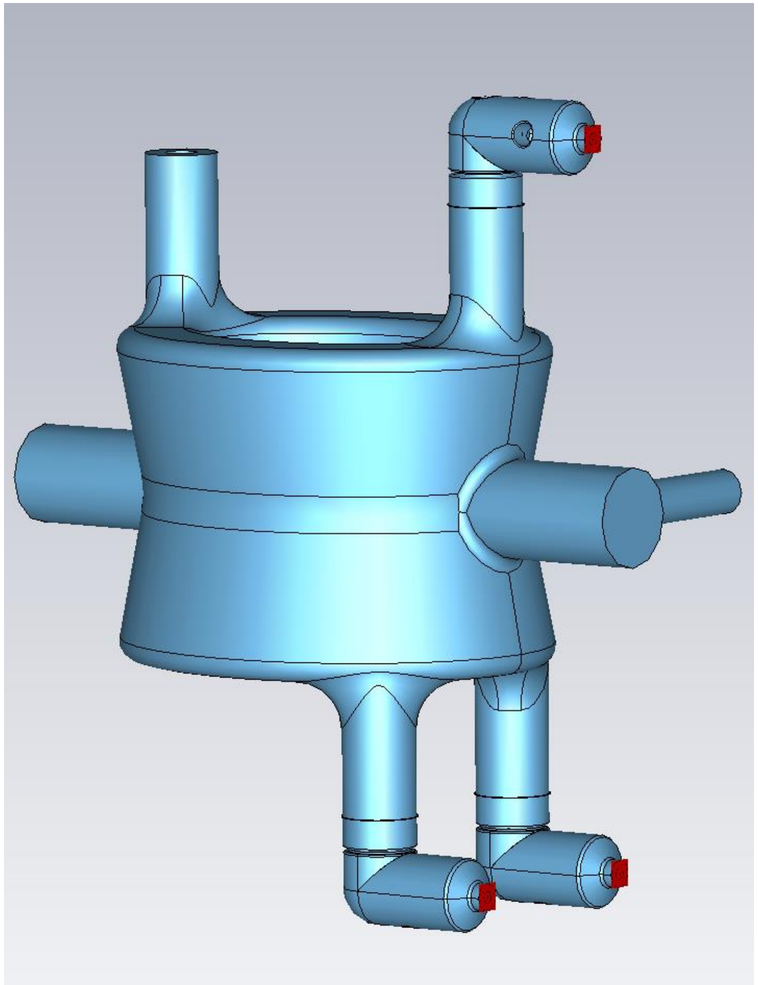
Cryomodule vacuum vessel design



- Interferences between cavity helium vessel and the cryostat wall

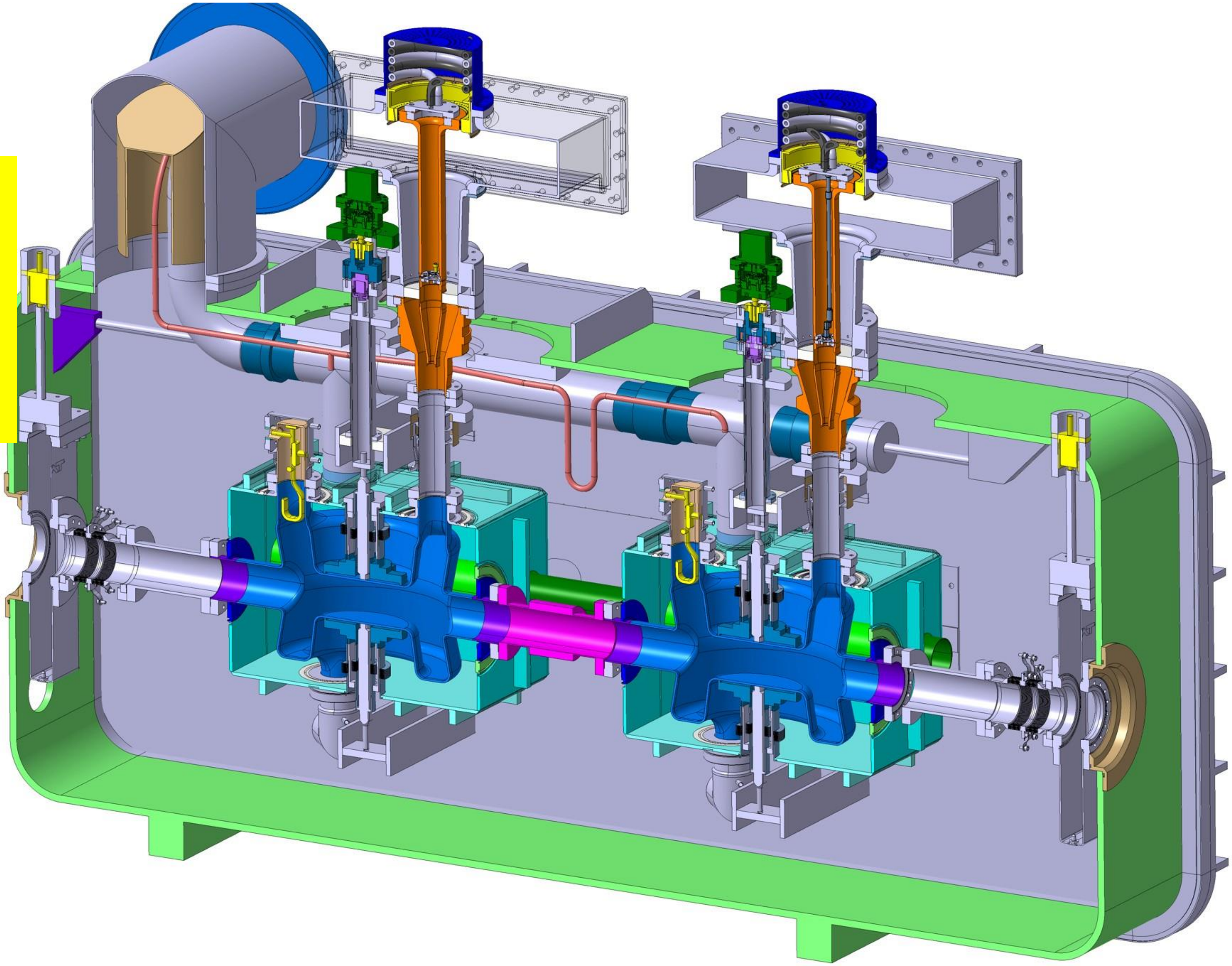
HOM System: Integration

- View of how the new HOM coupler appears in the Cryomodule



BNL Cavity Cryomodule

A few slides showing the installation procedure.



Cryomodule Summary

Heat Load Estimates