# LHC-CC09, 3rd LHC Crab Cavity Workshop

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# Cryostat & Tuner Compatibility*

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*reported at PAC2009, TU5PFP034

# *Abstract*

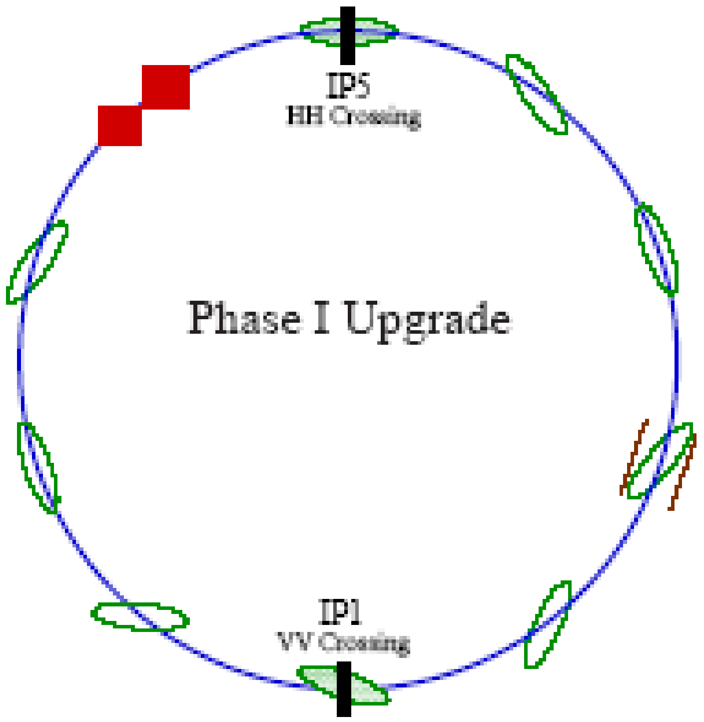
- The complex LHC crab cavity design and the beam-line configuration pose very tight constraints for the cryostat design.
- An initial assessment of the LHC main RF cryostat points to a new design both from the RF and engineering point of view.
- The cavity and tunnel constraints are discussed in detail and an initial cryostat design along with the cryogenic circuit is presented.

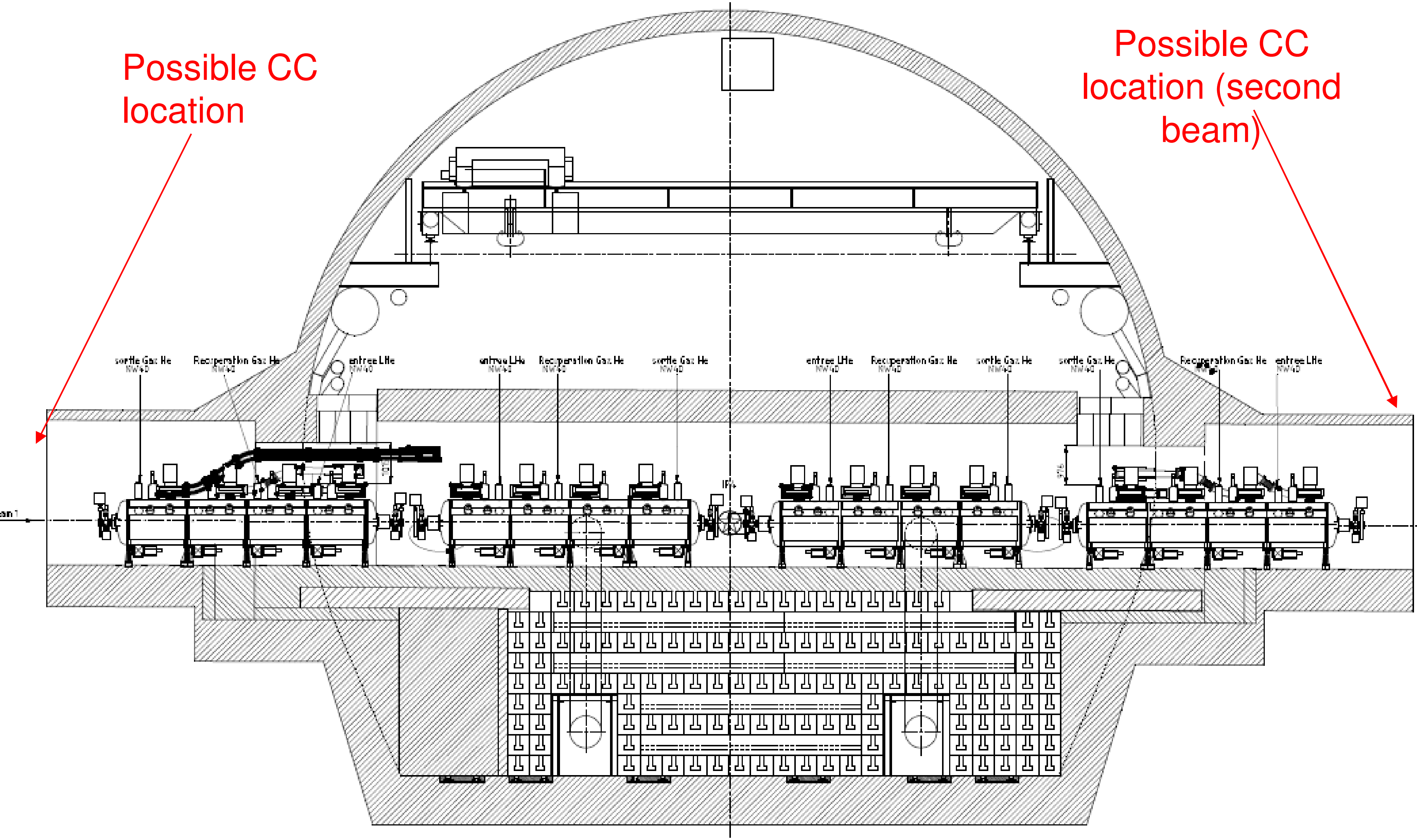
- A prototype crab cavity in the LHC is foreseen as the first important step to realize a full crab crossing scheme for the phase II IR upgrade of the LHC.

- At present only the IR4 region hosting the main RF station of the LHC, has a special horizontal dog-leg to separate the beam lines to 42 cm. Elsewhere the separation is 19 cm. Due to the typical size of the RF structures under consideration (800 MHz cavities), a global scheme in the IR4 section is the best choice for the prototype tests.

- The 800 MHz upper limit was chosen as the best compromise between the LHC bunch length and transverse dimensions of the cavity.

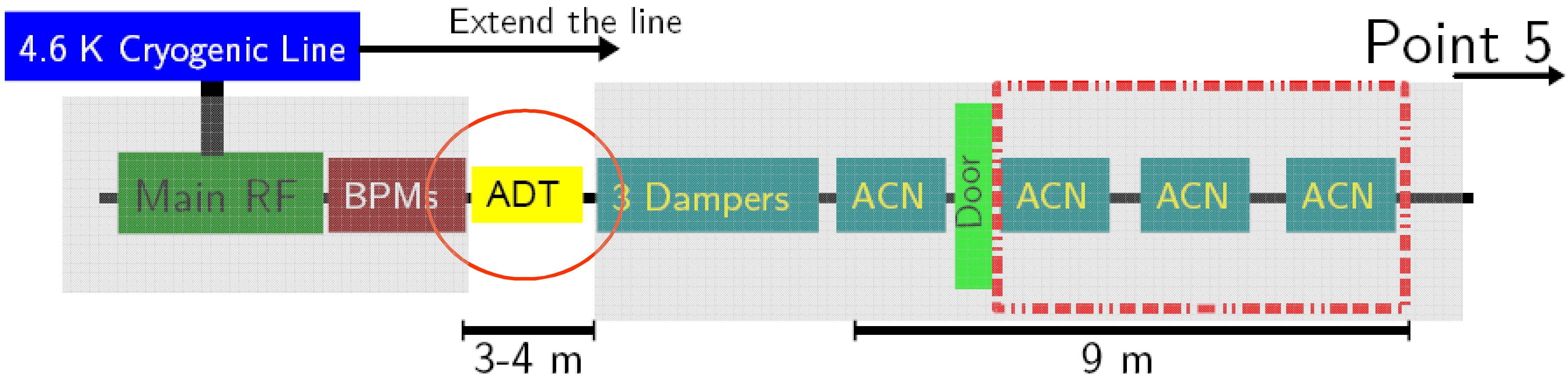
- In the dog-leg region 800 MHz superconducting cavities can be accommodated because elsewhere the beam line separation is too small.



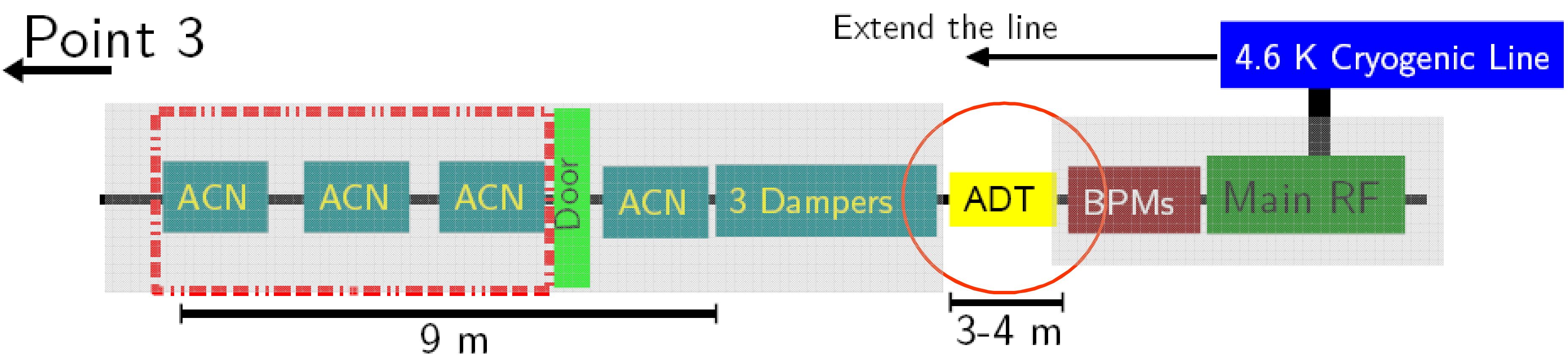



# LHC IP4 location (RF)

The present layout in the IR4 region and the anticipated location for the crab cryomodule near the ACN capture cavities:

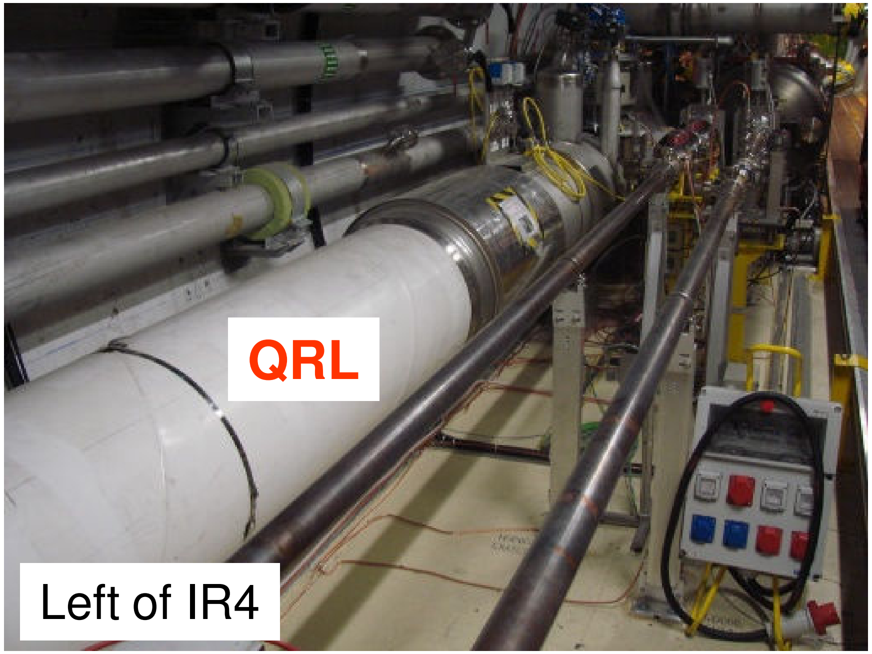


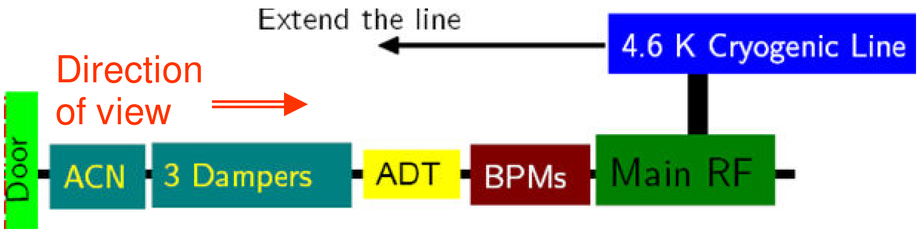

Max 3m longitudinally

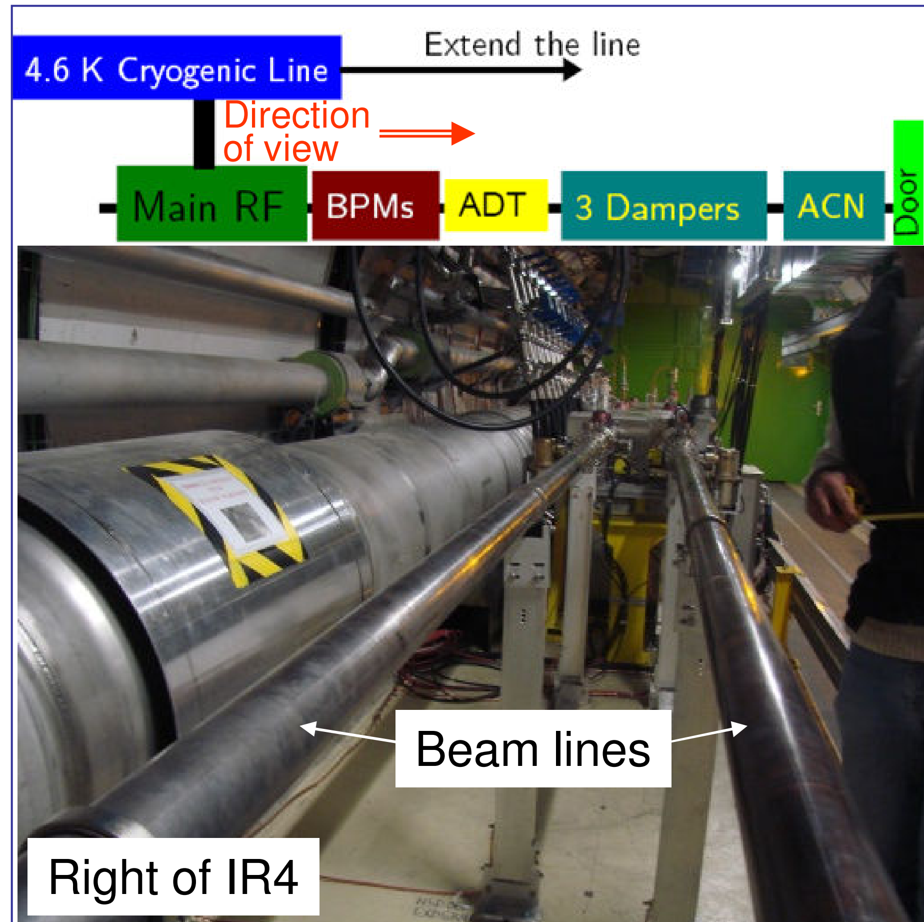


# ADT Reserved Damper

## Space 3-4 m




The Capture Cavity region is also under consideration.

- The cryostat has either to completely avoid the counter rotating beam or incorporate it (as in the LHC main RF).

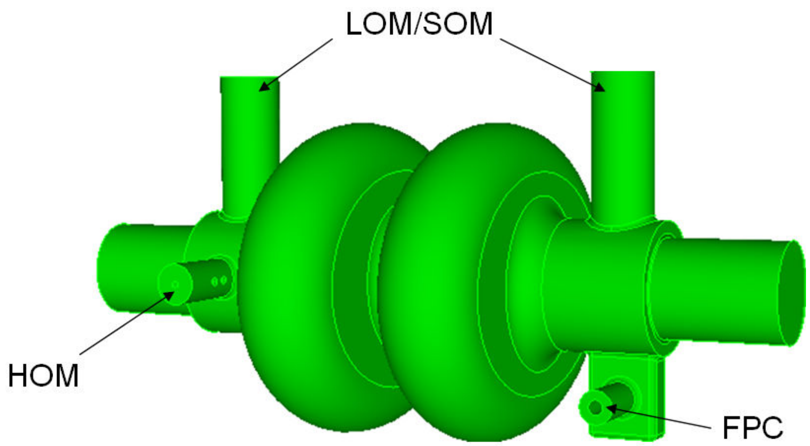
- But for the inside beam-line closest to large main cryogenic line,  the available radial space is only 42 cm.

- Therefore, cavities for both beam lines along with their helium vessels and magnetic shielding should be design to fit within the allowed region.

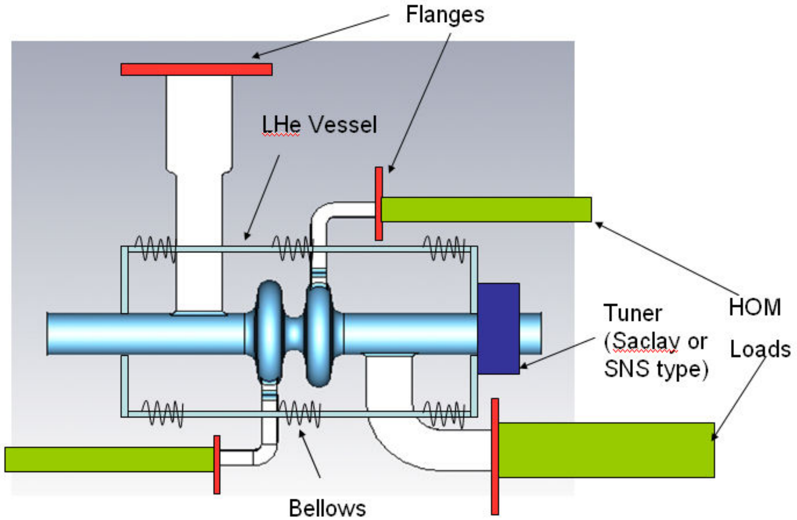
- It should be noted that the length of the cryostat should be relatively compact (3 m) to avoid longitudinal space constraints if the capture cavities are required for LHC operation.

- The only other location would be to fit the cavities within 3-4m space available for the spare damper assuming that it is not required for operation.

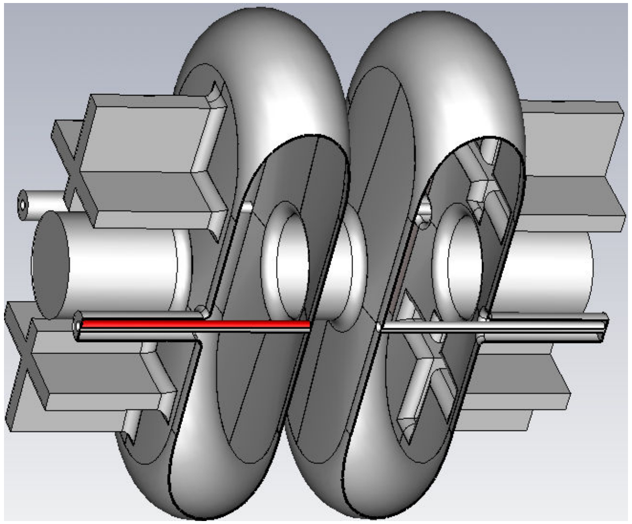
# Three Crab Cavity designs:




SLAC design with coaxial couplers

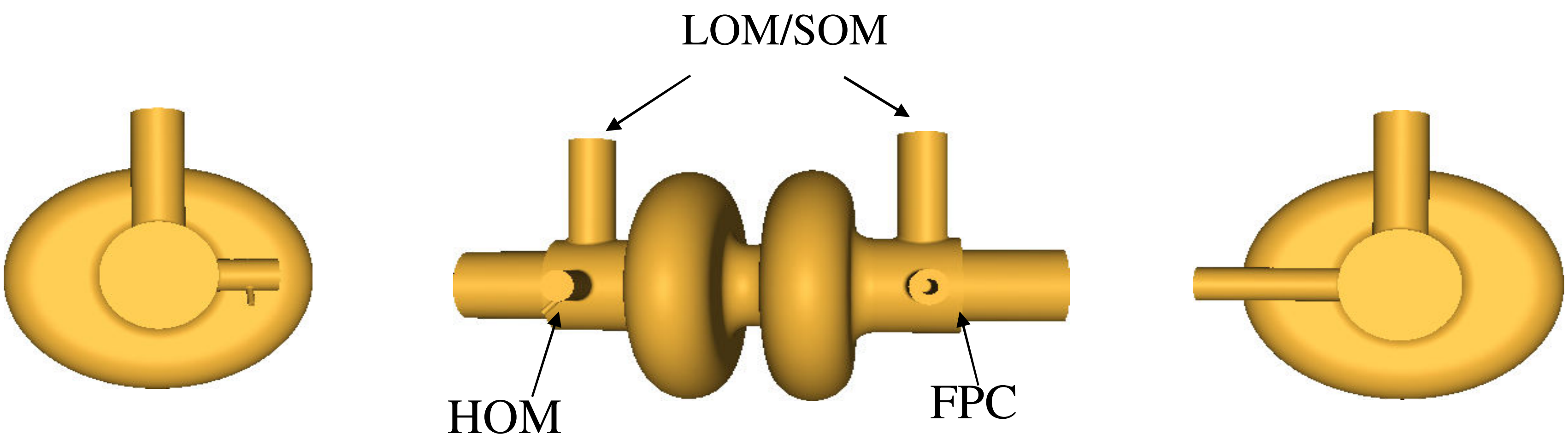



UK design with WG couplers



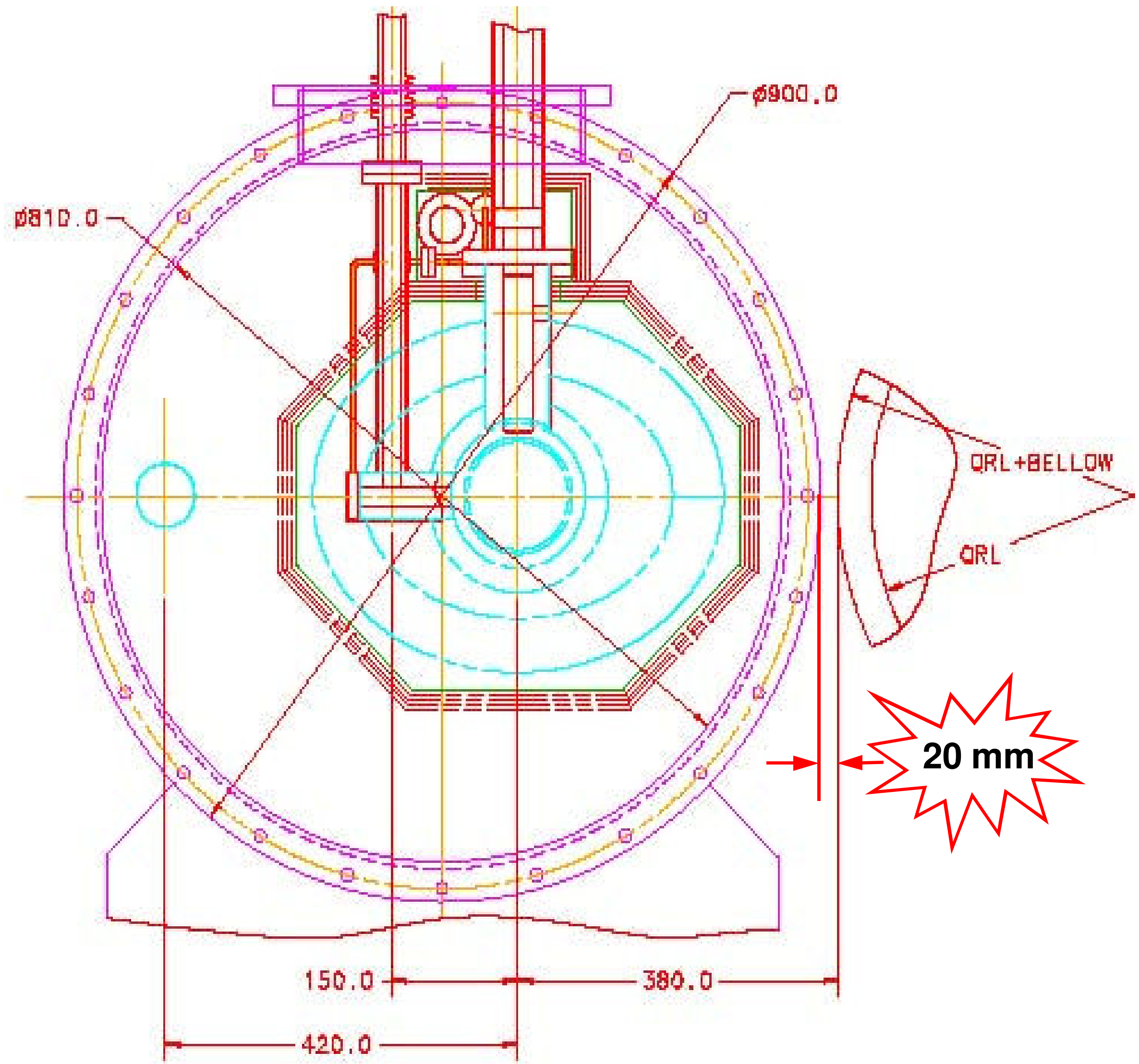
KEK design with coax and WG couplers

- Start conceptual design for SLAC CC
  - Geometrical constrains for basic SLAC CC design
  - Coupler constrains
  - Tuning



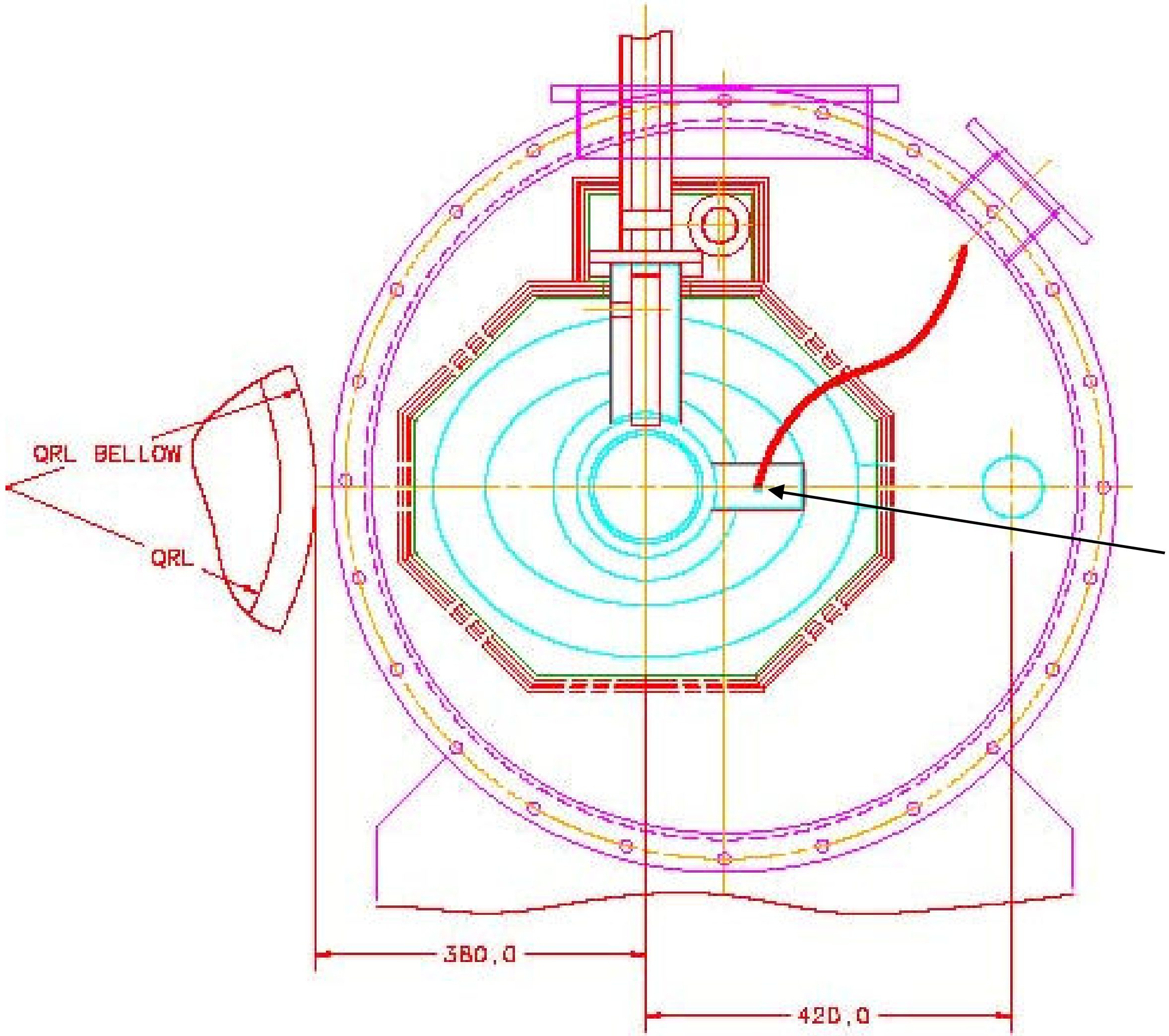

SLAC CC design with horizontal FPC

# Left of IR4, ADT (View from the Door)



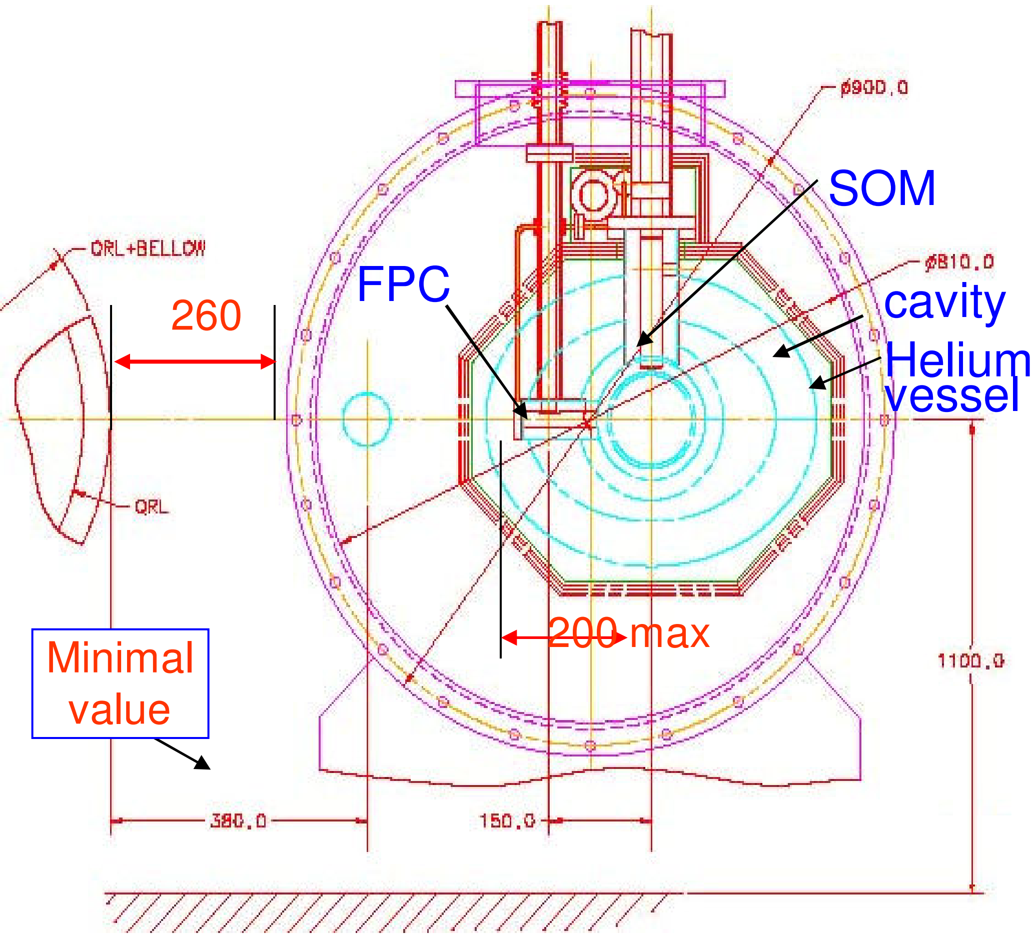

- Diameter of CM is ~ 900mm
- Very limited space between Helium vessel and cryostat wall (QRL position vs. beam)
- No way for horizontal main coupler output (limits from both sides).
- Design of the main coupler with vertical output is required. Horizontal part of the coupler is limited ( < 15cm)
- LOM and SOM couplers are already in vertical plane, HOM coupler is connected by cable
- Cavity position in the cryostat is asymmetric. It will probably complicate alignment, which is more severe than for accelerating cavity

# Left of IR4, ADT (View towards the Door)




- LOM (High power) and HOM coupler are in the same side of the cavity
- HOM coupler → cable connected, port location is not limited

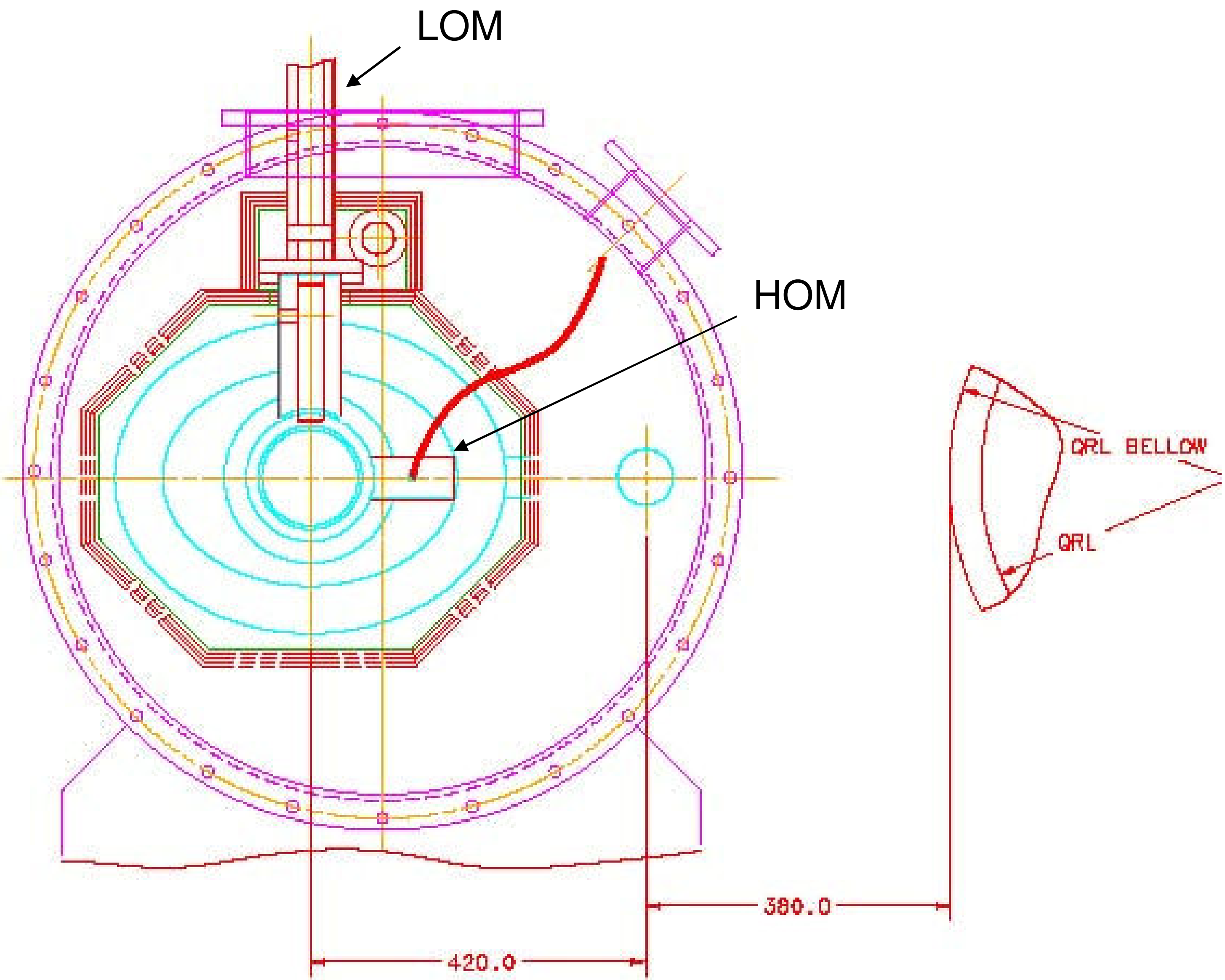
# Right of IR4, ADT (View towards the Door)

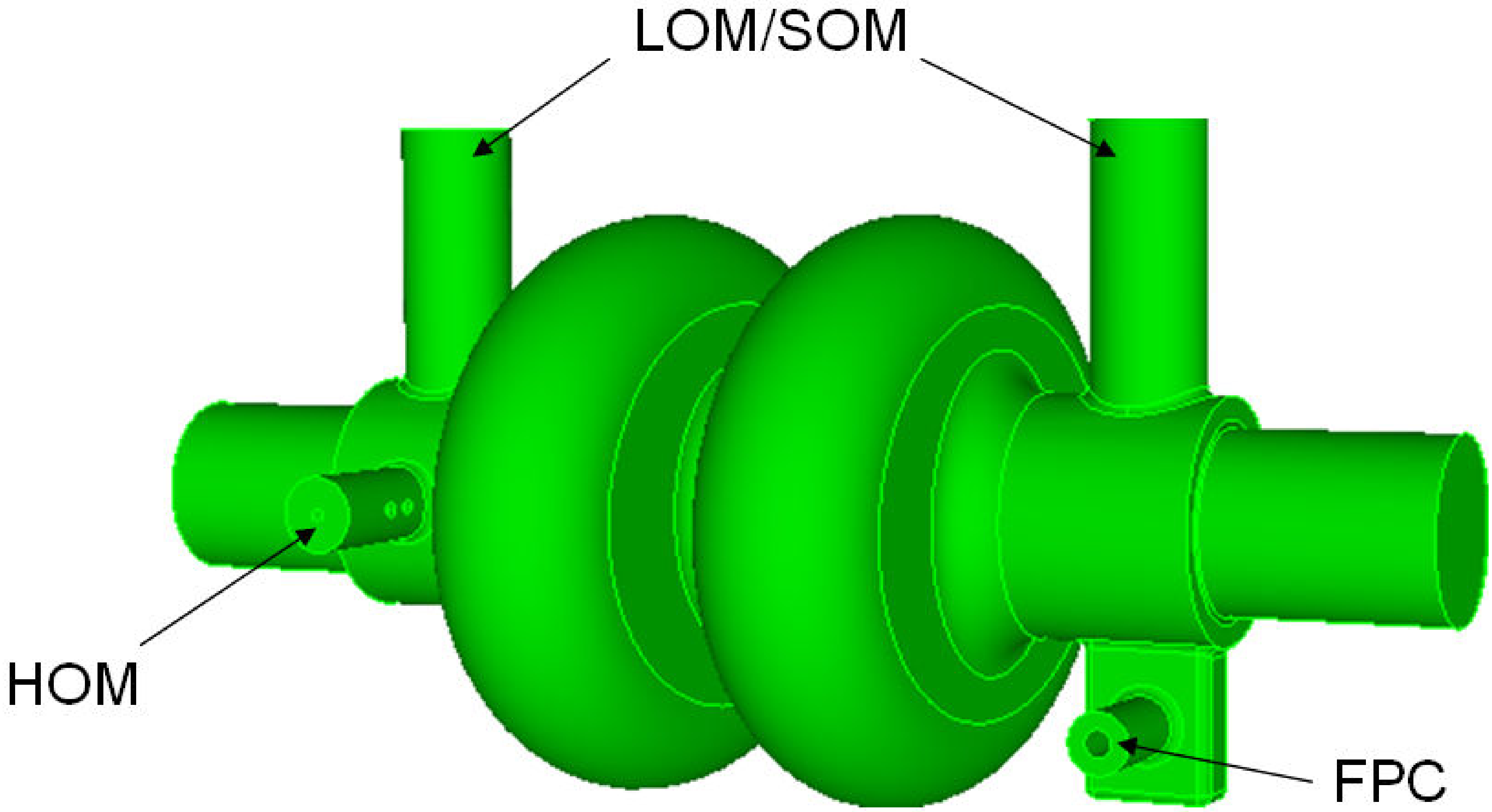



- In this location more room from left side (If needed)

- Placement of any horizontally oriented couplers is not possible due to the limited space available between beam-lines and QRL. Therefore, a design of the main power coupler which is nominally oriented in the horizontal plane requires a vertical output. Horizontal length of the coupler is limited to 150 mm. From aisle side it is limited by transportation needs.

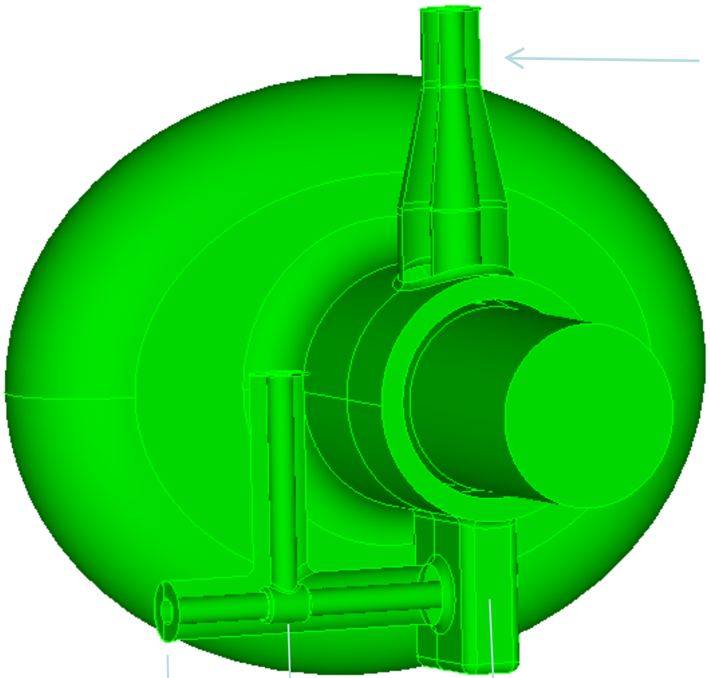
# Right of IR4, ADT (View from the Door)






SLAC new design of the FPC

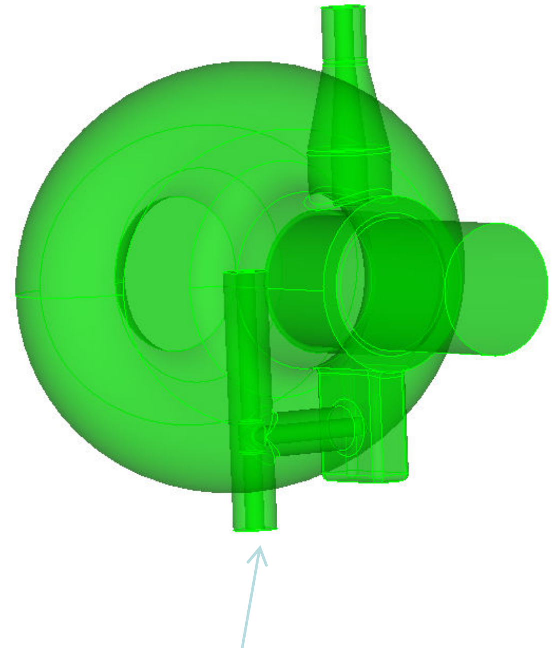
The LOM and SOM couplers for this cavity design are already in vertical plane, and the HOM coupler is connected by a flexible cable to the output port.



LOM/SOM Tapered to:
Outer radius: 20 mm
Inner radius: 8.7 mm
(damping ok)

Vertical coax from the beam center:
130 mm, larger is fine

Matching stub:
80-100mm

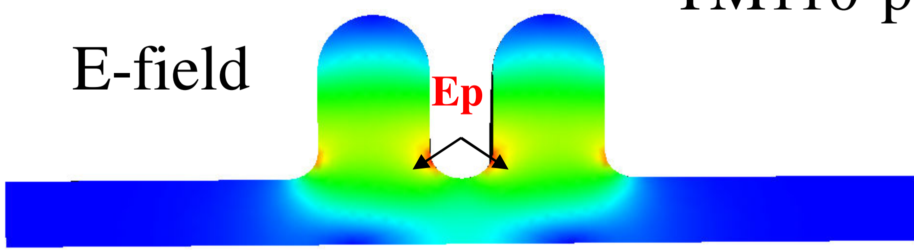


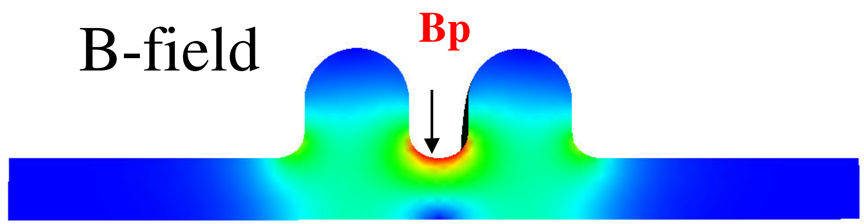
The matching stub can also be in the vertical direction, if found to be more advantageous

FPC coax dimension:
- Outer radius: 20mm
- Inner radius: 8.7 mm
- Power is 20-30kW CW SW (Qext ~ 2.6e6)
- We need cooling in the inner conductor

# 800MHz Crab Cavity RF Parameters

TM110-pi mode




| | |
|---|---|
| Frequency | 800MHz |
| (R/Q)_T | 117Ohm/cavity |
| Deflecting Voltage $V_T$ | 2.5MV |
| Deflecting Gradient Ekick | 6.67MV/m |
| Epeak | 24.72MV/m |
| Bpeak | 82.75mT |
| Mode separation (Opt.-SOM) | 89MHz |

TESLA TDR cavity peak fields for comparison
(Eacc: 37-47MV/m)
Epeak: 70-90MV/m
Bpeak: 150-190mT

SLAC NATIONAL ACCELERATOR LABORATORY

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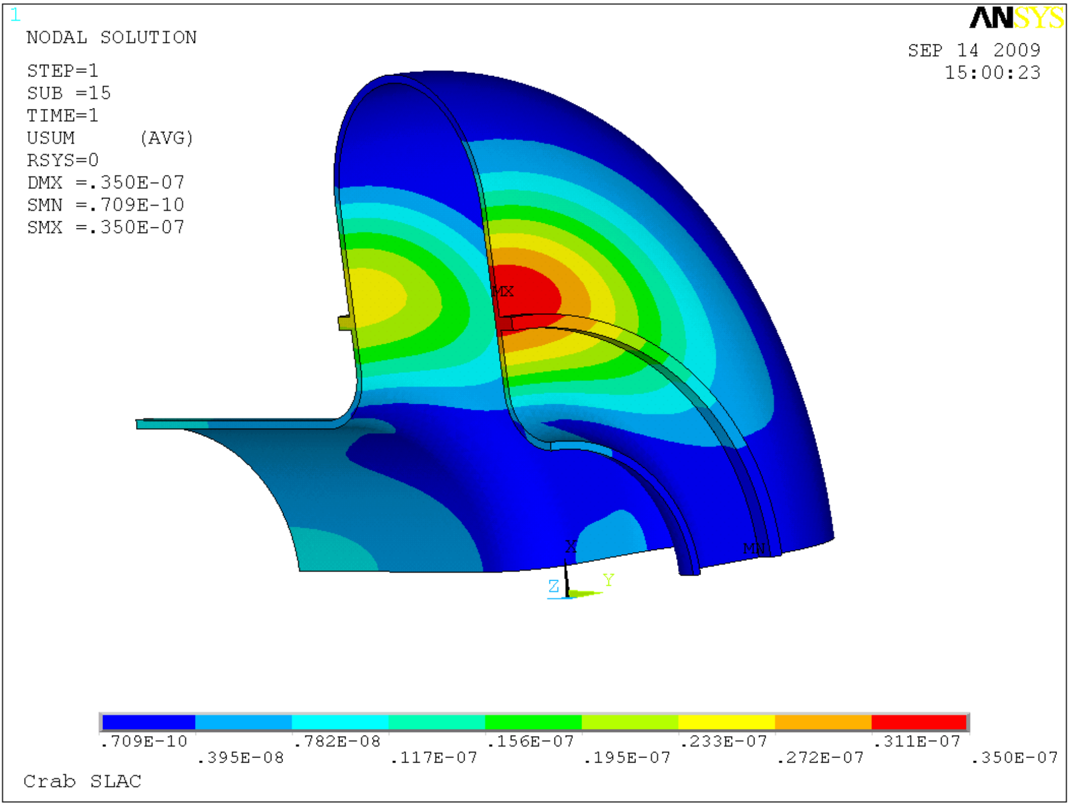



•Displacement (in m) of crab cavity due to Lorentz forces.

•Wall thickness 4mm,

•Frequency shift

without a stiffing ring is 66 Hz/MV,

with the ring is 51 Hz/MV.

•Fields are normalized on 1J stored energy.

•Stiffing ring dimensions:

Width: 6 mm;

Height: 10 mm;

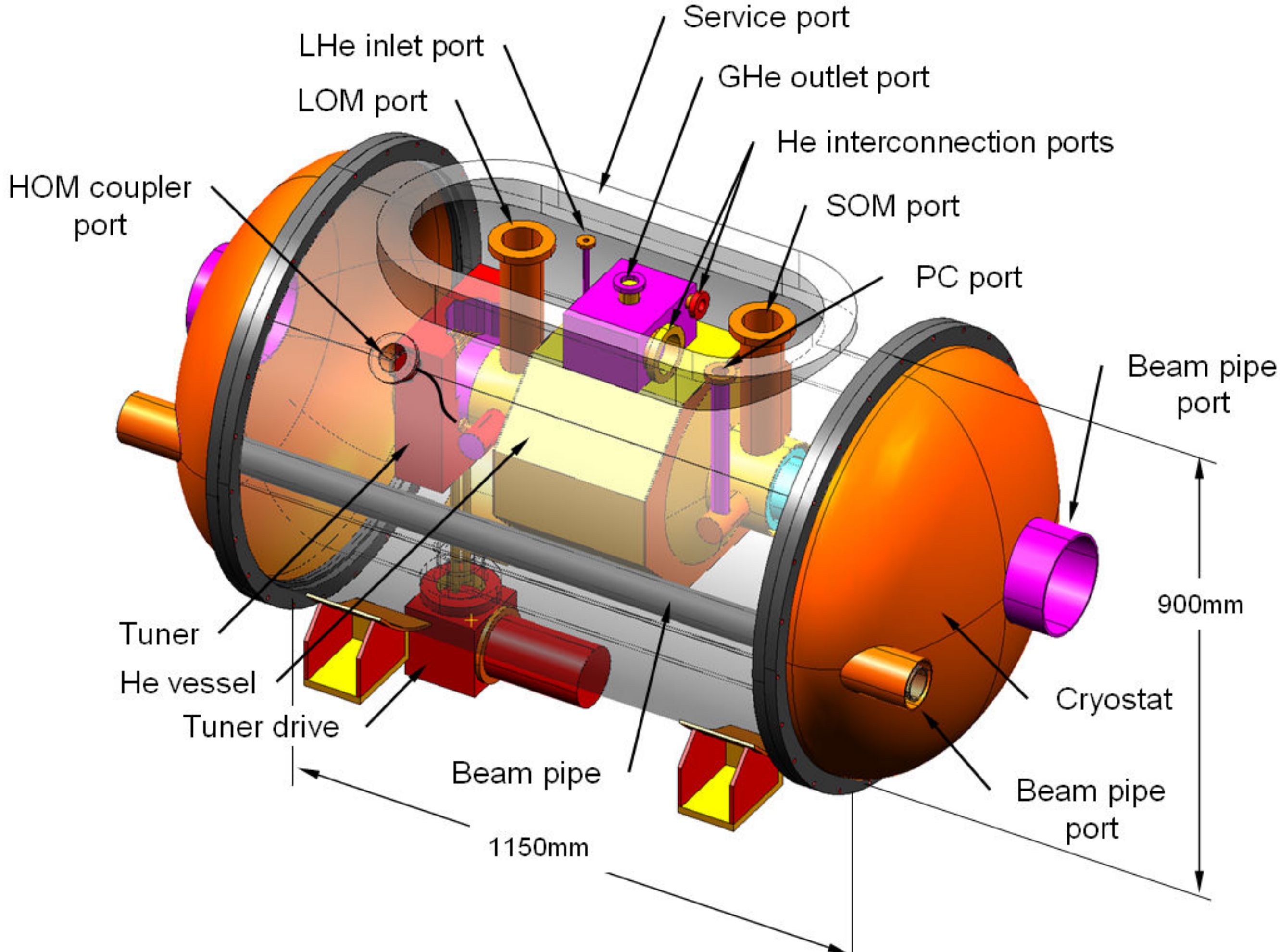
Radius: 127 mm (optimal).

**Stiffing Rings:**

- **Improve detuning curve**
- **Raise the structure resonate frequencies**
- **Increase require tuner forces**
- **Do not eliminate need for fast tuner**

- During the first test, a two-cell cavity for each beam is anticipated to provide a transverse kick of 2.5 MV.
- The cryostat design must satisfy the environment limitations for the both beam-lines.

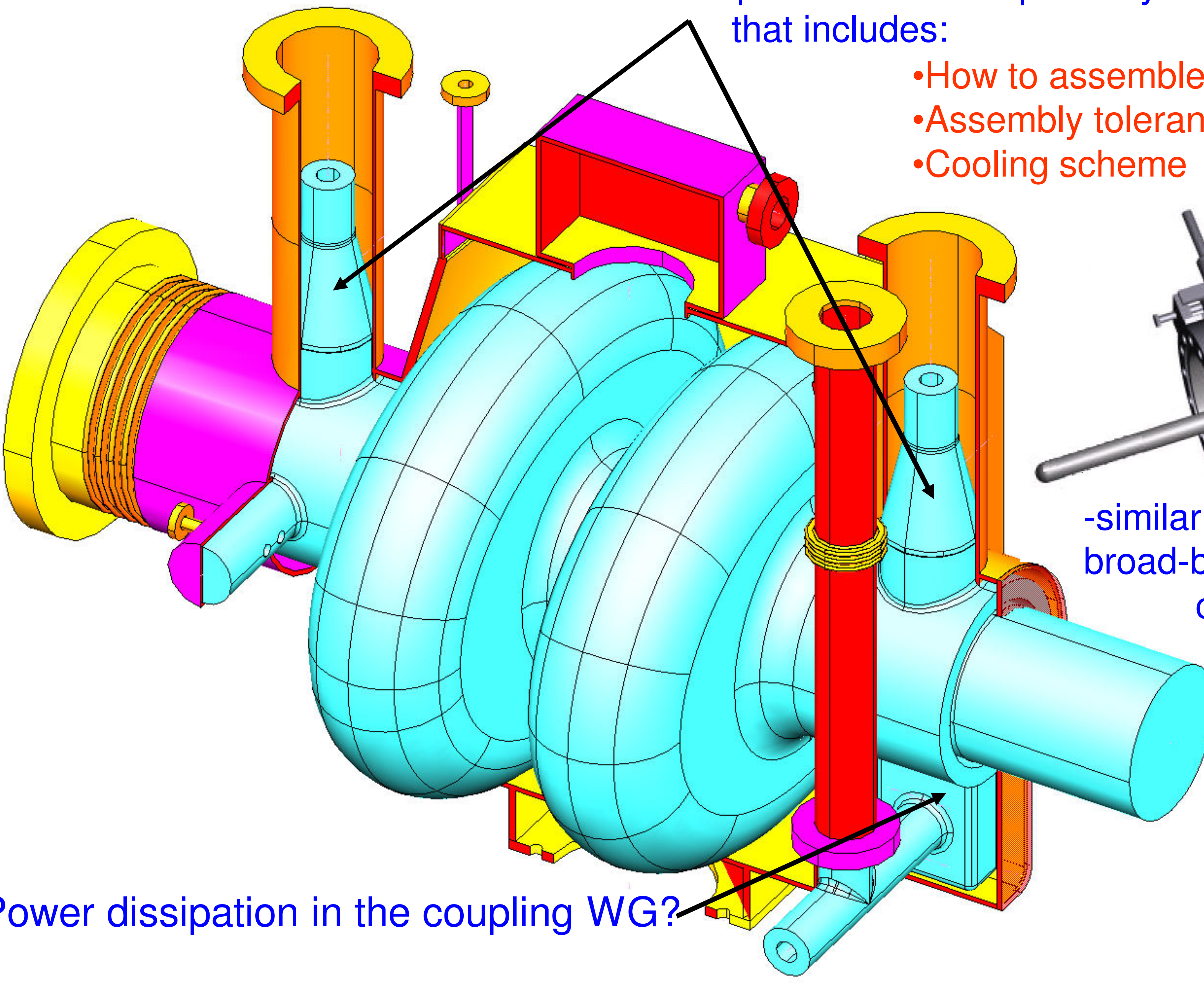
- The cryostat should have a modular structure similar to cavities of the LHC main RF system. This allows for additional cavities to be installed if a higher kick voltage is deemed necessary.
- Thus, the helium box contains interconnection ports for the second cavity.
- A service port is suggested for the He inlet/outlet ports as well as for the RF couplers (main, LOM and SOM).

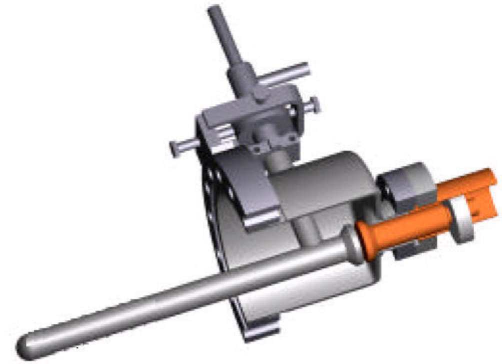



Schematic of the LHC Crab Cavity cryostat. The outer diameter (900 mm) is constrained by the limited space between Helium vessel and cryogenic line.  The length is 1150mm.

Realistic concept of the all the couplers is required for the complete cryostat design that includes:

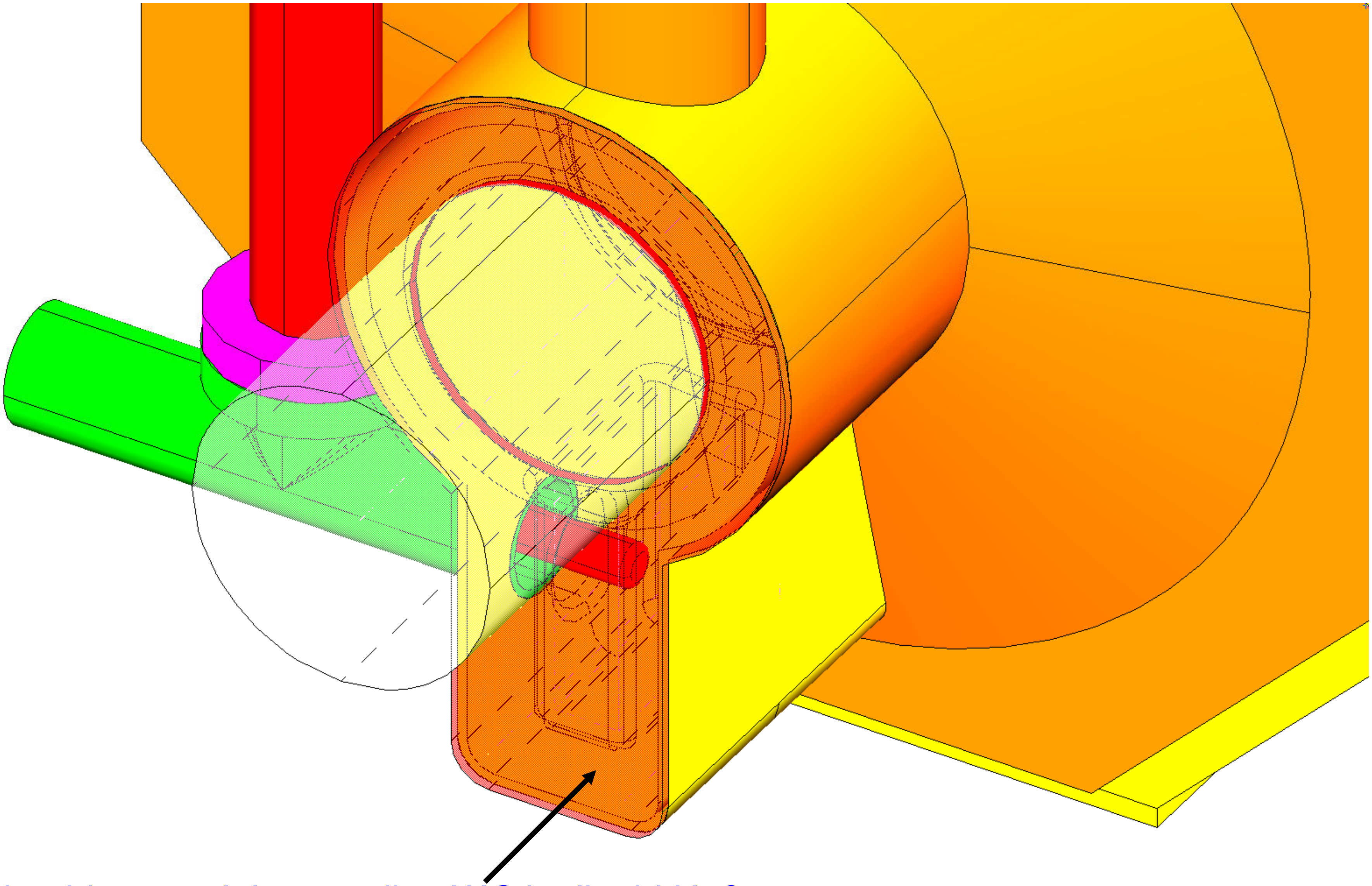
- How to assemble
- Assembly tolerances
- Cooling scheme





-similar to CERN broad-band HOM coupler.

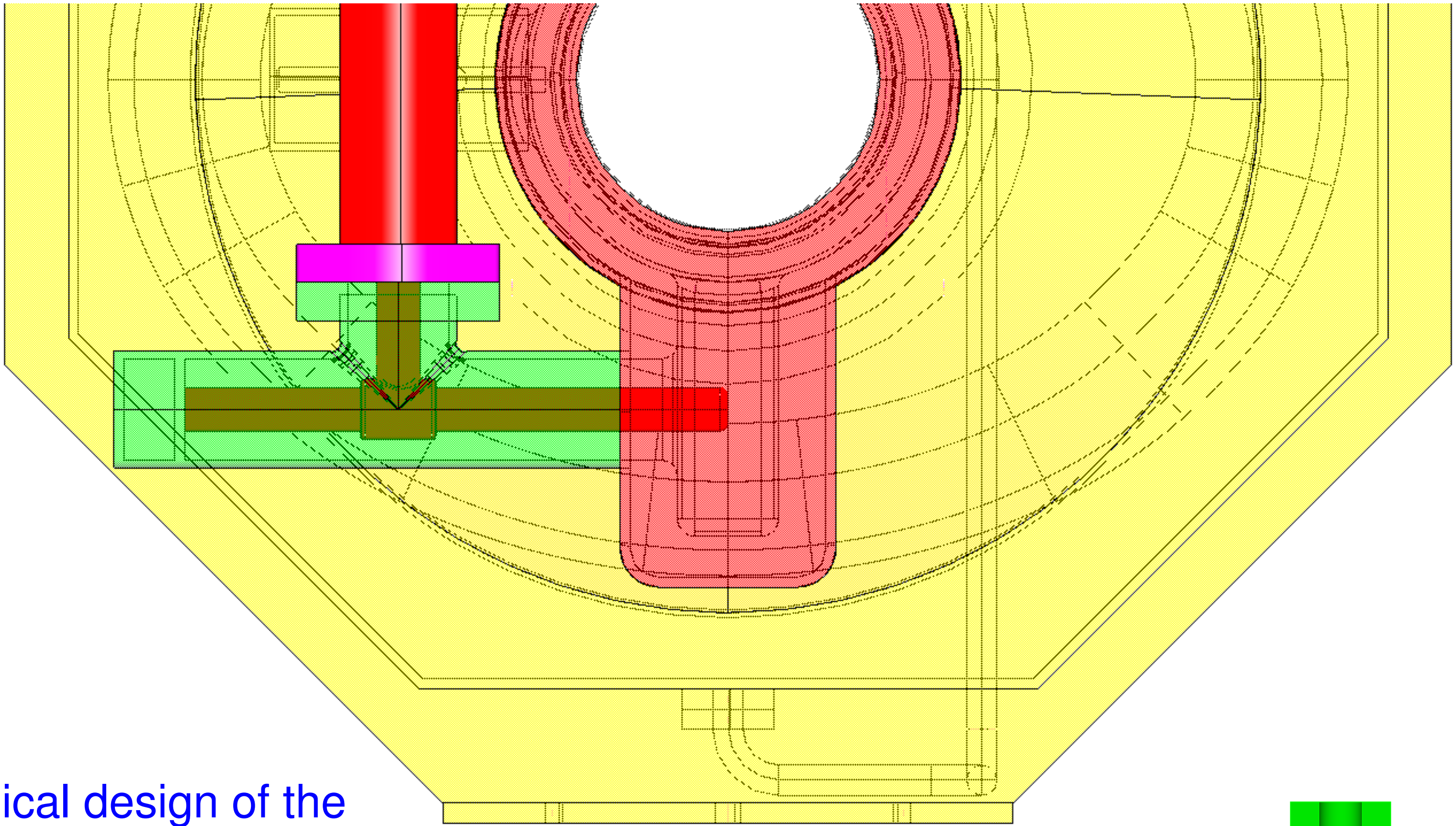
Power dissipation in the coupling WG?



Should we cool the coupling WG by liquid He?

New SLAC design of vertical FPC with the T-connection like in KEK Tristan-type ERL coupler :

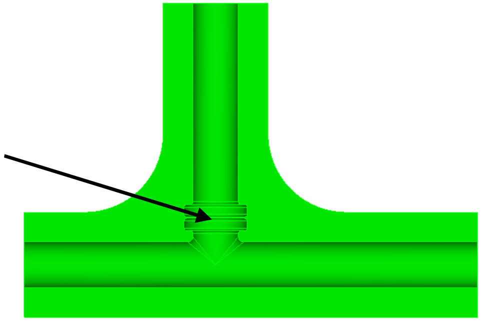
Do we need adjustable power coupler ?



Mechanical design of the cooled FPC is necessary:

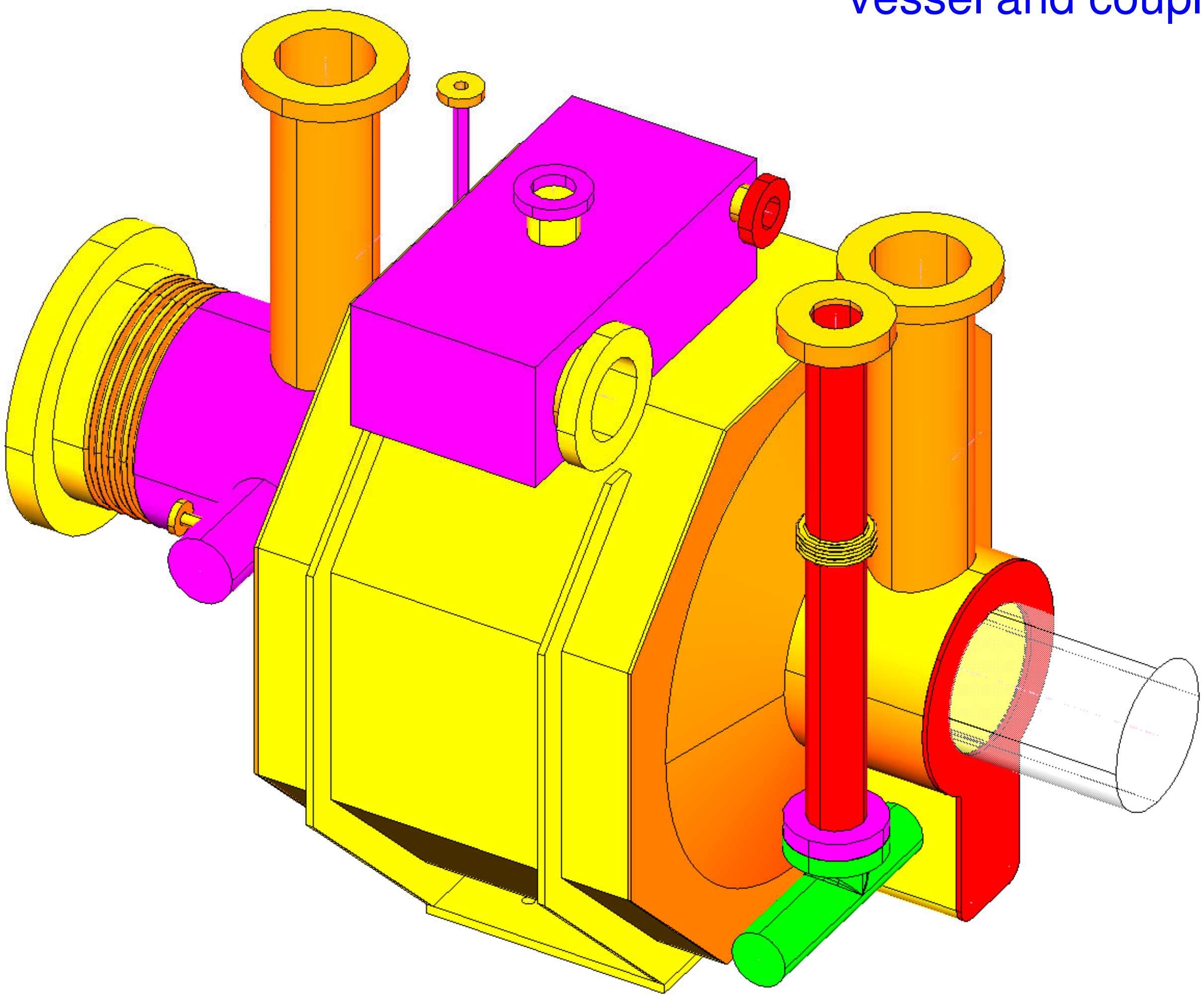
- How to assemble
- Assembly tolerances
- Cooling scheme

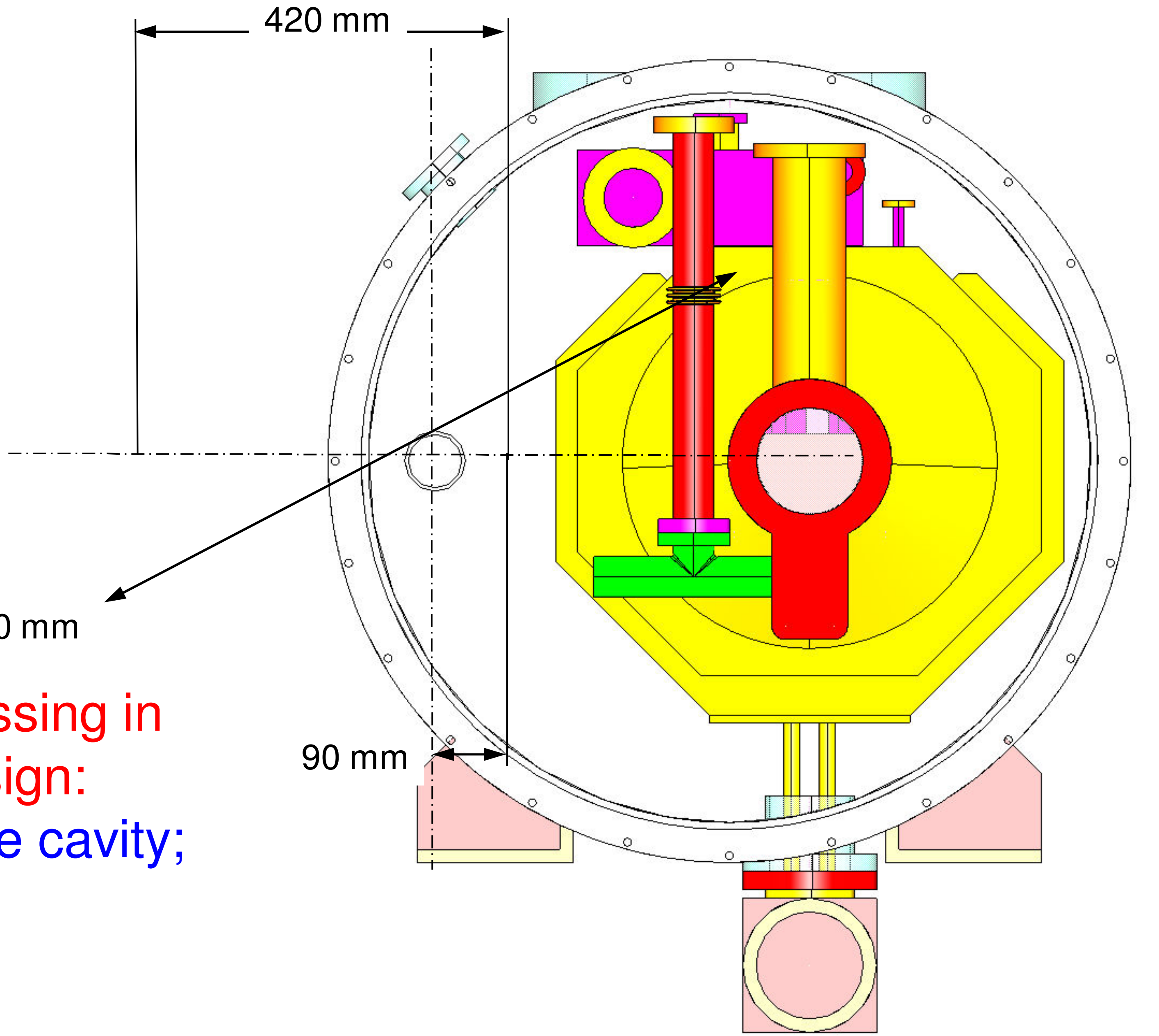
SLAC version with capacitive coupling



- The He vessel design is necessary together with the cavity mechanical design.

- Mechanical analysis (stress, forces, deformation) of the cavity including helium vessel and couplers has to be performed.

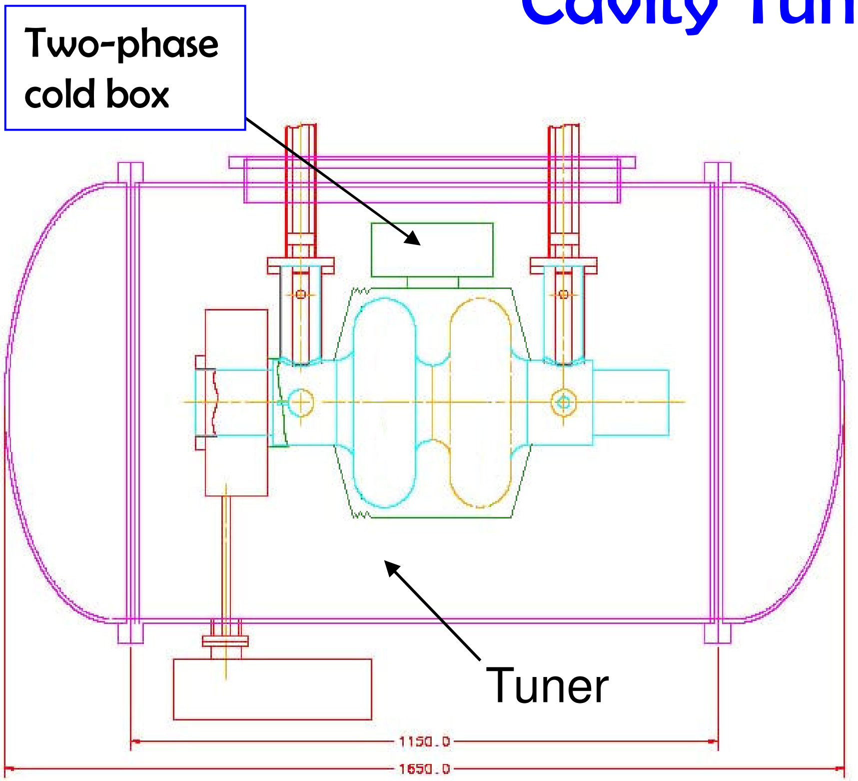


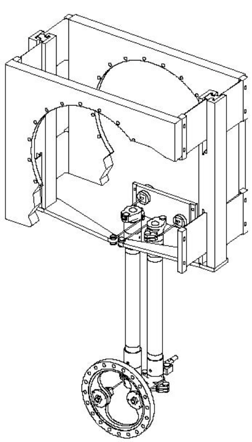


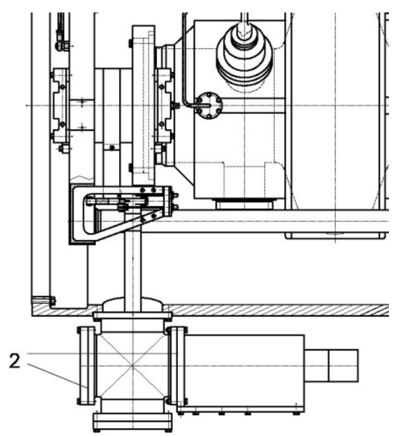

What is still missing in conceptual design:

- Supports for the cavity;
- Alignment;
- Shielding.

# Cavity Tuning Concepts

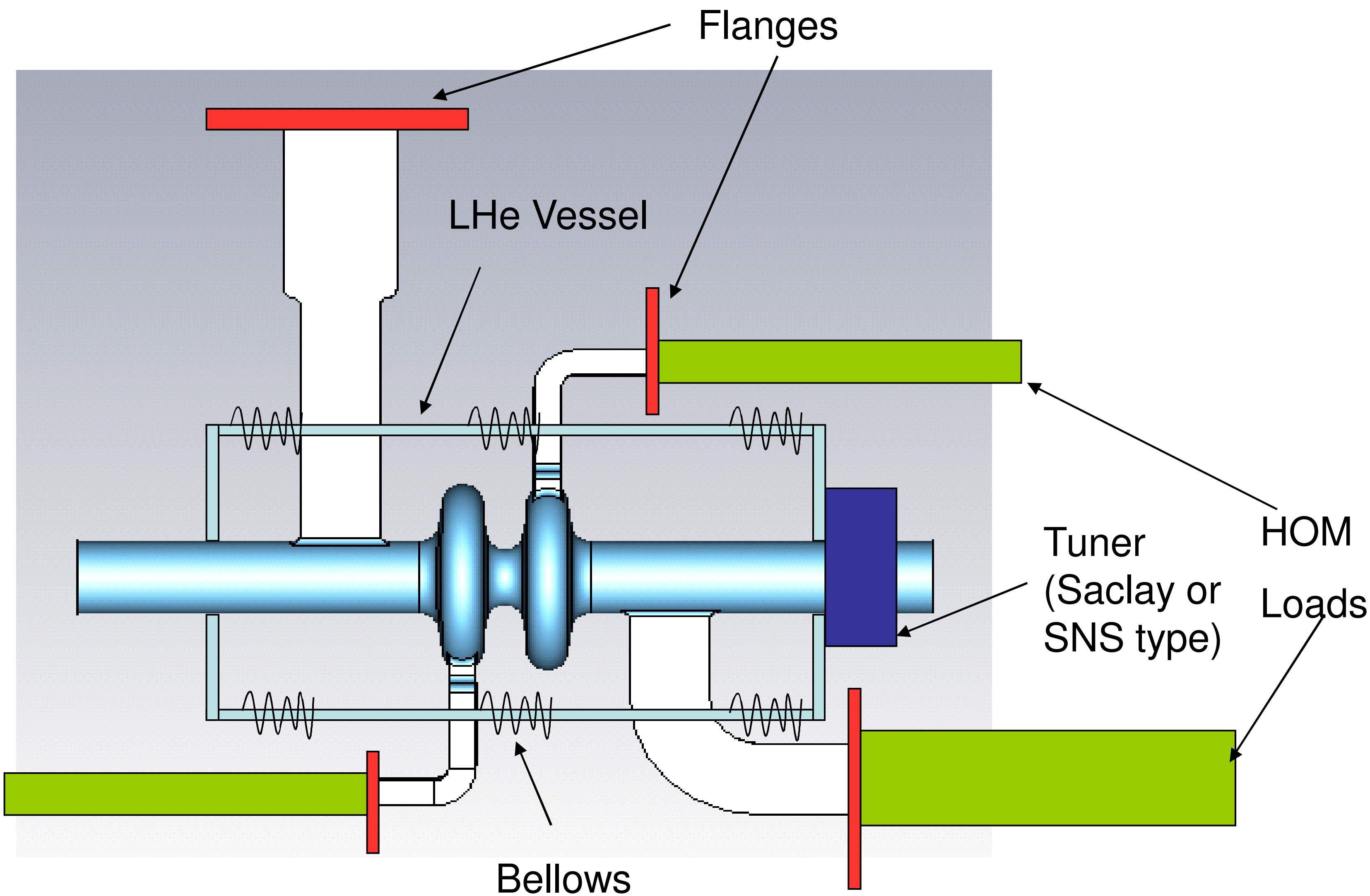


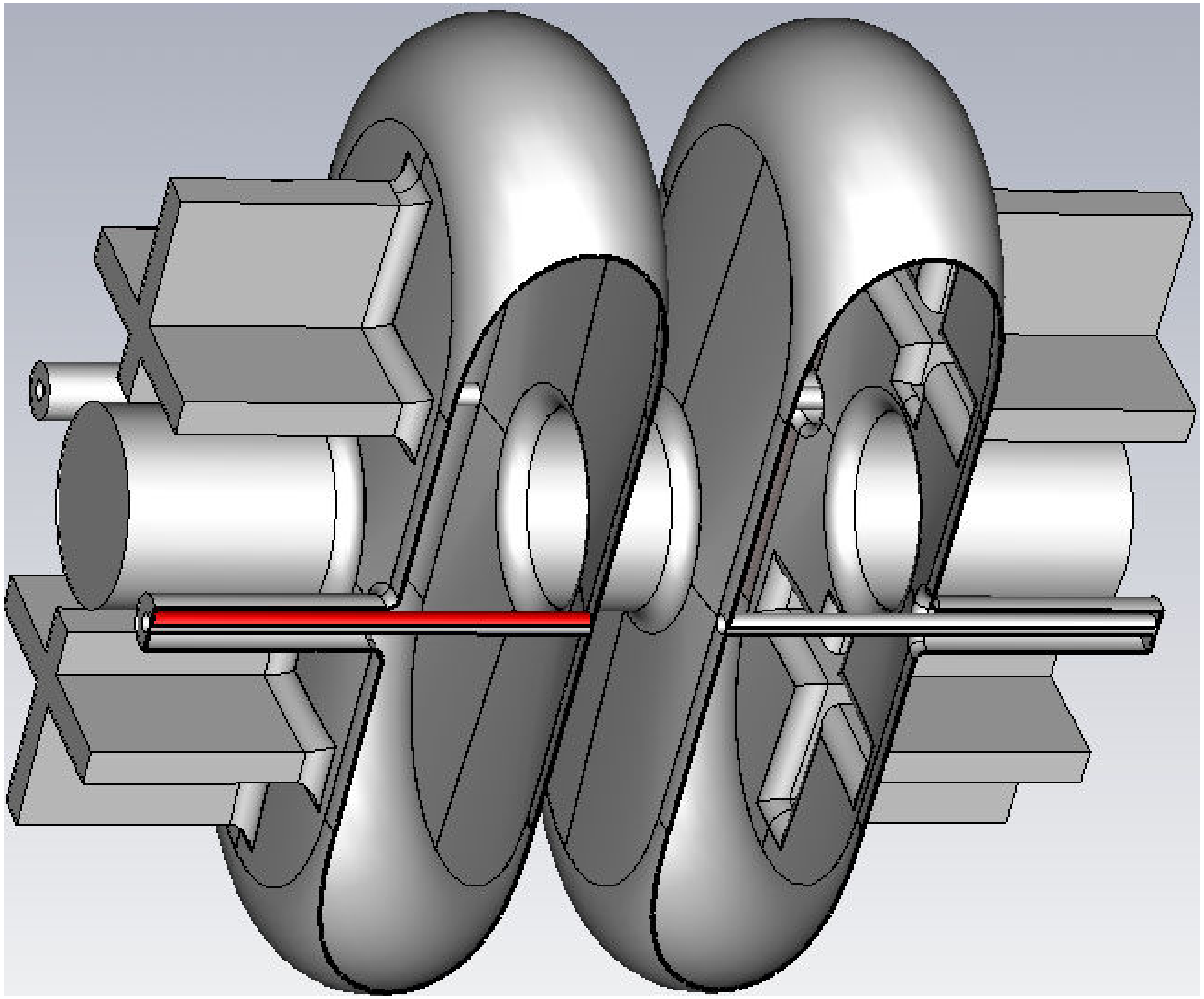


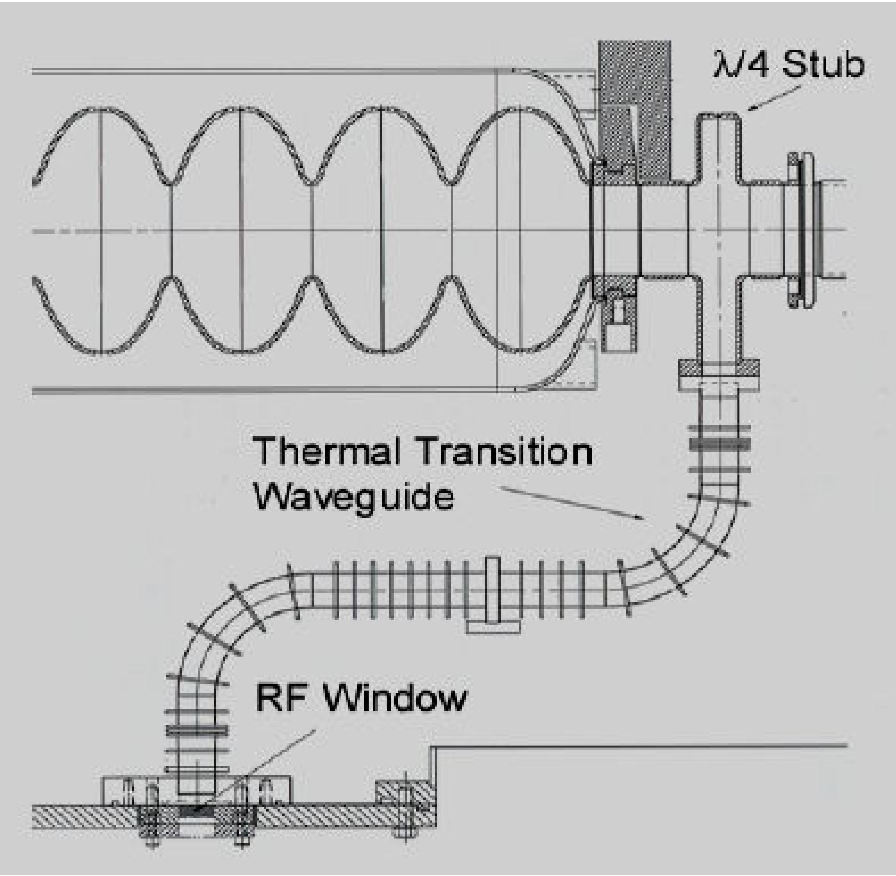

- Try to use CERN design with minimum modifications.
- Tuning range should be clarified: 10-100 kHz?
- Specifications for the cavity not defined (forces, deformations of each cavity, field stability, etc …)
- Mechanical analysis (stress, forces and deformation) of the cavity tuning. Analysis should include helium vessel and couplers.
- Helium vessel is part of cavity design, not part of cryostat design (but they should be matched)

# UK version of the Crab Cavity - waveguide approach:

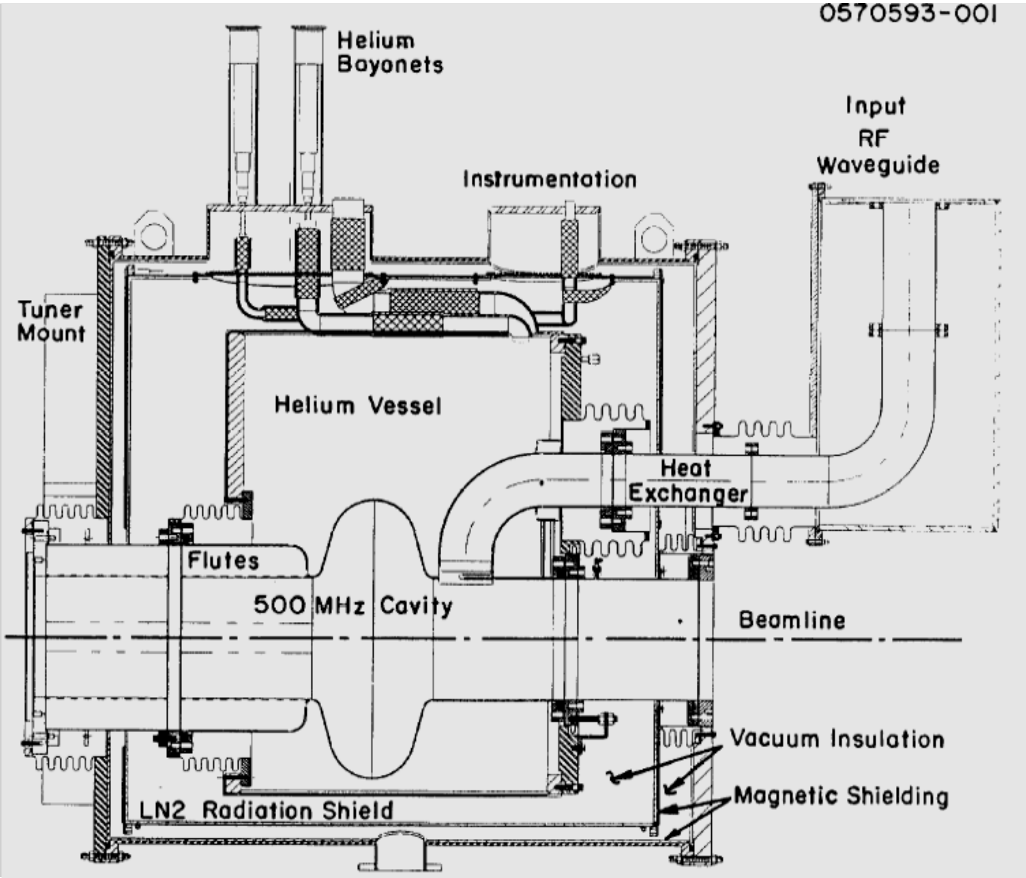


# KEK design with coax and WG couplers






CEBAF




CESR

Main concern: dimension constrains. Waveguide scheme may require an extra space for thermal transition waveguide (CEBAF), or heat exchanger (CESR).

The same may be needed for both UK and KEK designs.

# General requirements:

- The cavity needs two cleaned, RF compensated valves at its ends to protect the cavity SC surface during transport and machine vacuum manipulations. During installation and removal of cavities, breaking part of the machine vacuum should be avoided. Hence also the latter has be confined by two opposing similar valves.
- The cavity vacuum has to allow the connection of a pumping stand used before and during cool-down and removed during machine operation, supplanted by a permanent ion sputter or similar pump. The vacuum tank will need a working permanently to compensate for micro-leaks through port seals in the cryostat.
- The cryostat and cavity should be equipped with LHC standard seals, cryogenic connections, cable connectors and gauges (pressure, LHe-level, temperatures) for compatibility reasons.
- Also CERN safety rules have to be respected concerning pressure vessel regulations for He and vacuum tank, rupture disks, relieve valves as well as electric power installation for European 230/400 V, 50 Hz with Swiss electrical outlets.

- The cryostat has to be transported from ground level to its intended location.
- It needs to be equipped with stable fix-points for transport, especially for lowering in the shaft. In the tunnel it should either fit standard CERN transport equipment or have its autonomous system.
- Concerning weight and longitudinal dimensions there should be no true limitation when comparing to the LHC magnets.
- Transversely protruding objects (e.g. couplers) have to be limited such that they do not represent an obstacle during transport nor, once installed, penetrate into the LHC transport zone.
- A zone for the surveyors’ work in the area should be respected.

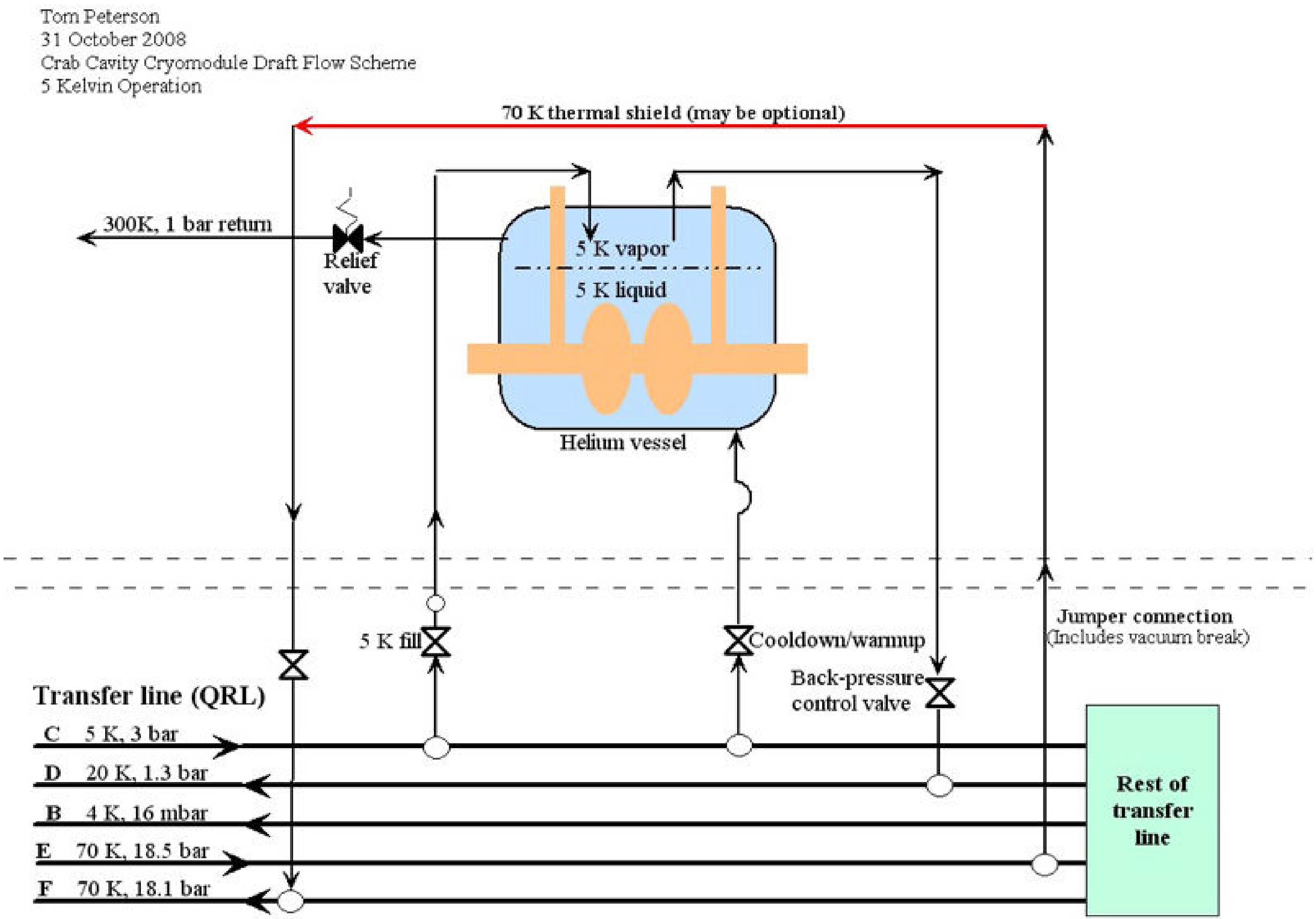
# CRYOGENIC CIRCUIT

- It is anticipated that a 4.5 K helium jumper supply similar to the main RF has to be installed from the QRL near the crab cavity installation.

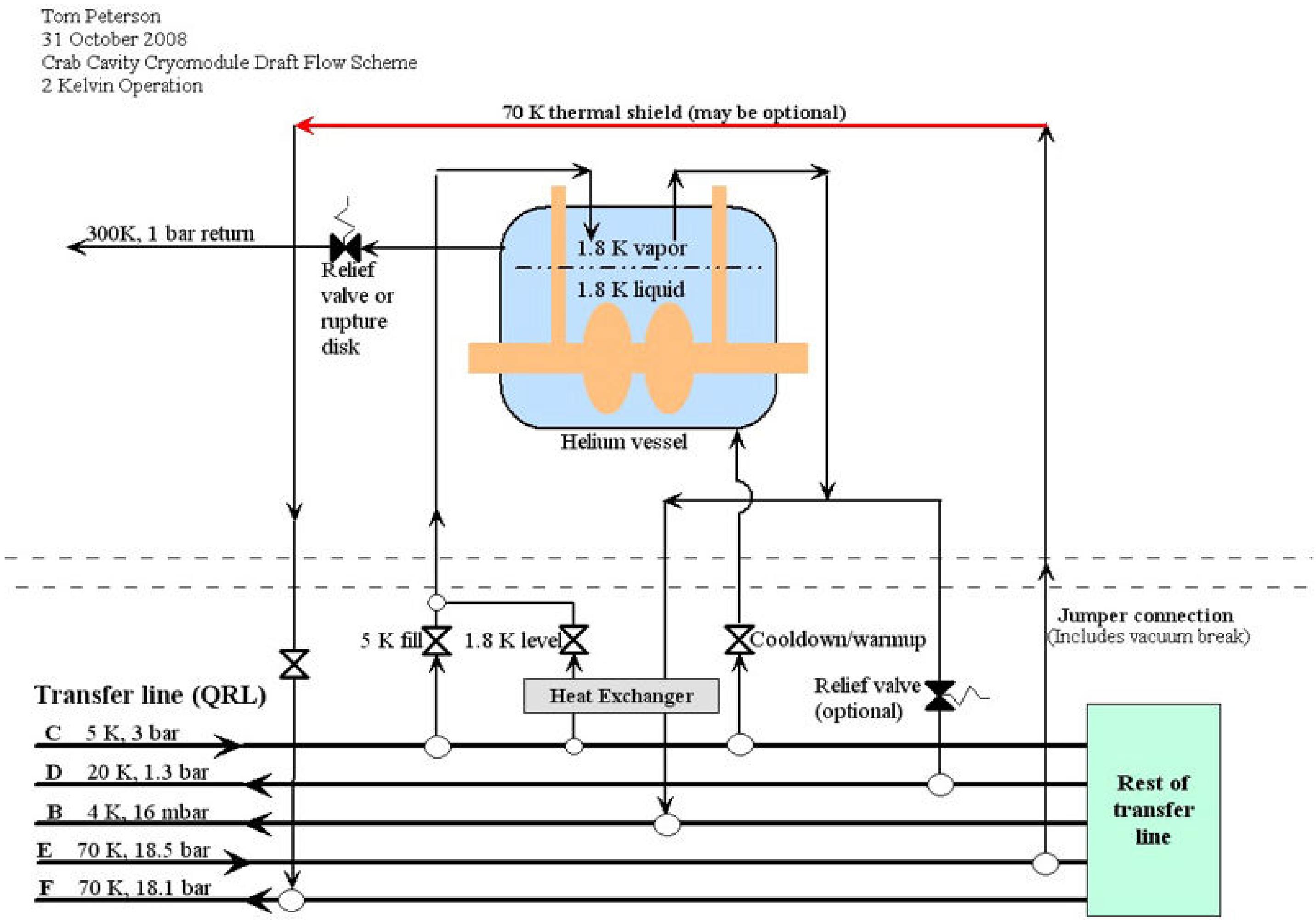
- Disadvantages from operating at 4.5 K:
  - higher losses,
  - microphonics from boiling helium
  - lower operating gradients

  which need to be evaluated.

- If the evaluation mandates a 2 K operation, the cryostat will be equipped with heat exchanger to pump it 2K and equip with proper thermal shielding.




4.5 K cryogenic circuit envisioned from the crab cryomodule with corresponding relief valves and a return line to 20 K at 1.3 bar. A similar circuit exists for 1.8 K operation where 5 K helium at 3 bar is used in a similar concept as the superconducting magnets to generate saturated helium. A relief valve and rupture at 300 K or optionally at 20 k is required to avoid pressurizing the helium vessel.


Tom Peterson
31 October 2008
Crab Cavity Cryomodule Draft Flow Scheme
2 Kelvin Operation
70 K thermal shield (may be optional)
300K, 1 bar return
Relief valve or rupture disk
1.8 K vapor
1.8 K liquid
Helium vessel
5 K fill
1.8 K level
Cooldown/warmup
Heat Exchanger
Relief valve (optional)
Jumper connection
(Includes vacuum break)
Transfer line (QRL)
C 5 K, 3 bar
D 20 K, 1.3 bar
B 4 K, 16 mbar
E 70 K, 18.5 bar
F 70 K, 18.1 bar
Rest of transfer line

1.8 K option.

# Summary:

- The work on the cryostat mechanical design is started;
- The details of the cryostat position and distances to the critical elements of the environment are to be clarified;
- Working closely with RF designers to finalize the cavity and coupler dimensions to advance the cryostat design to the next phase :
  - Specification (cooling, tuning, forces, etc…) and mechanical/alignment tolerances;
  - Mechanical design of the cavity including Helium vessel;
  - Real EM and mechanical design of the couplers (FPC, LOM, SOM. HOM) - cooling, supports, assembly.

Deflecting cavity for the Project-X: LHC CC cavity ideas were used .