Status of Q1 to D1 cryostat design, interconnects and cold mass interfaces

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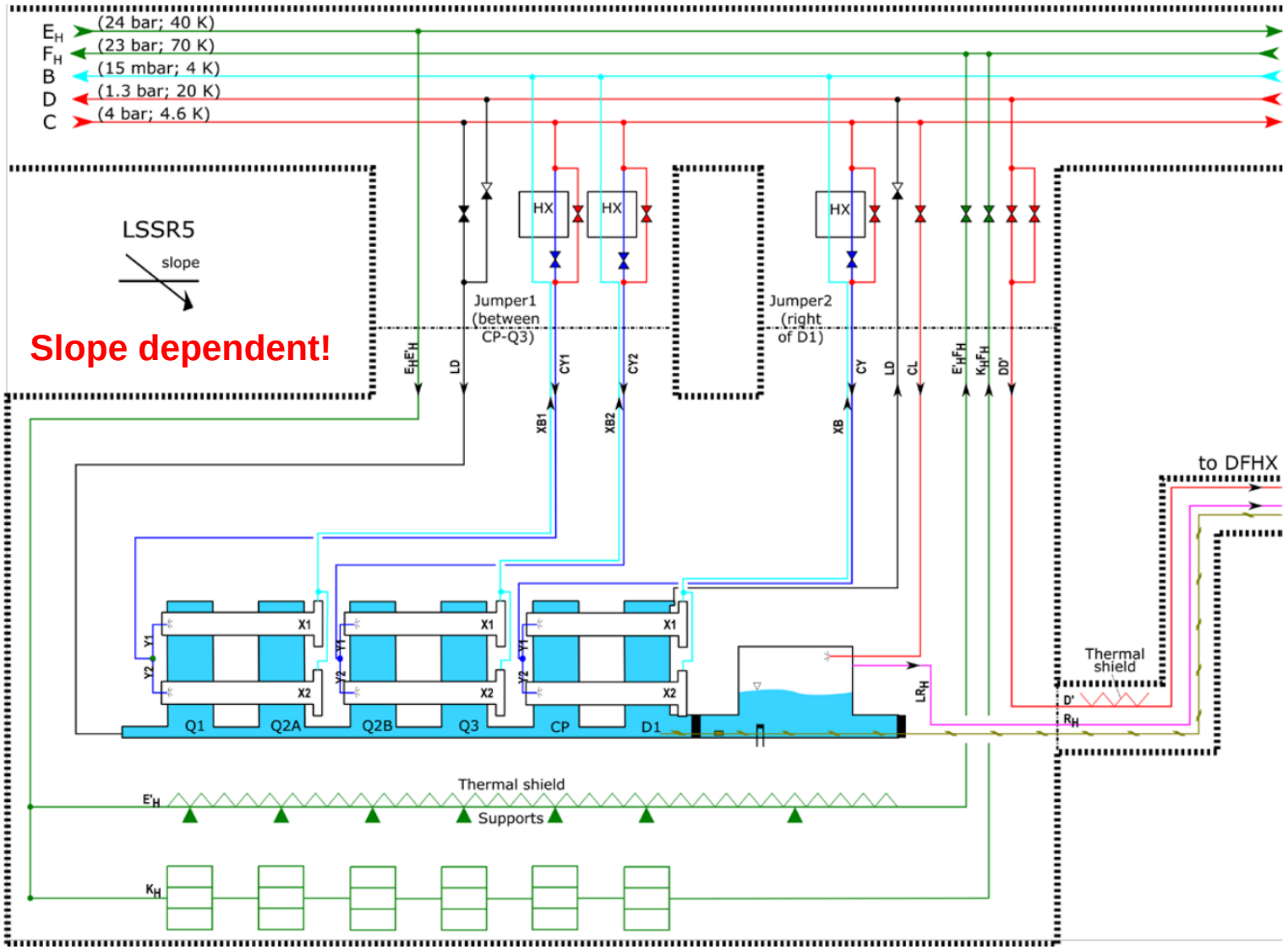
6th HL-LHC Collaboration meeting, 14-16 Nov. 2016

A concept of cryostat and cold mass that…

- **Fits in the tunnel** (same width as other LHC cryostats) and encloses all the cryogenic piping running along the string, including phase separators.
- Interconnects based on all welded seals (LHC solution), including space required for **cutting and welding** machines.
- Minimises work in the **tunnel**, by design.
- Corrector busbars, trims and CLIQ circuit cables may be routed on **auxiliary lines** along the cryostat.
- **Cold mass supports** based on LHC dipole and SSS concept. Sledge on rails cryostating principle.
- **Isostatic support** of the cryo-assembly, designed to accomodate pressure end loads (vacuum and quench) and allow remote alignment.
- Aims at **alignment stability** requirements comparable to those of the LHC SSS.
- Minimises the number of component and assembly **variants**.

Based on preliminary cryo flowscheme (WP9)



https://edms.cern.ch/document/1710017/0.3

and size estimations (WP9)

Minimum Pipe Inner Diameters [mm]

	Nominal Operation		Cool Down		Magnet Quench		For HL-LHC Design		Used on LHC
Identifier	$d(L_{min})$	$d(L_{max})$	$d(L_{min})$	$d(L_{max})$	$d(L_{min})$	$d(L_{max})$	$d(L_{min})$	$d(L_{max})$	d
E_HE_H'	17	24	11	11	-	-	17	24	15.2
LD [J1]	-	-	50	50	tbd	tbd	50	50	50
XB1	71	100	-	-	-	-	71	100	70
CY1	12	12	-	-	-	-	12	12	10
XB2	71	100	-	-	-	-	71	100	70
CY2	12	12	-	-	-	-	12	12	10
XB	58	73	-	-	-	-	58	73	70
CY	12	12	-	-	-	-	12	12	10
LD [J2]	-	-	50	50	tbd	tbd	50	50	50
CL	8	10	8	8	-	-	8	10	20
E'_HF_H	12	15	13	13	-	-	13	15	15.2
K_HF_H	17	21	-	-	-	-	17	21	10
DD'	tbd	tbd	tbd	tbd	-	-	tbd	tbd	-
E'_H	12	-	9	-	-	-	12	-	-
K_H	8 *	-	-	-	-	-	8 *	-	-

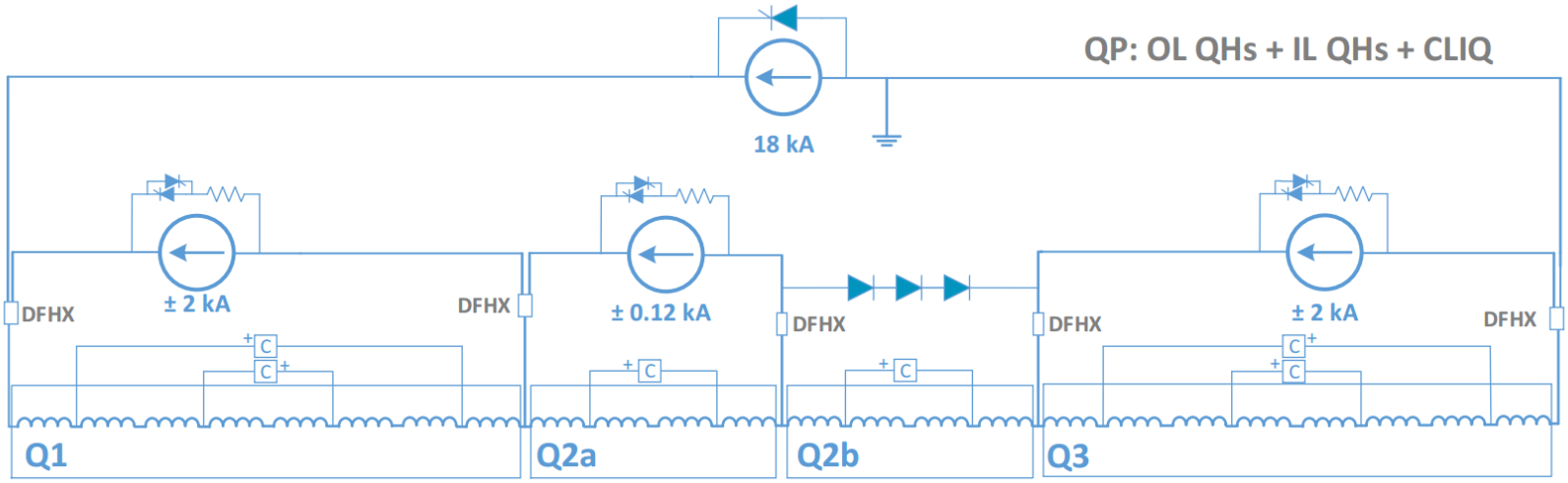
Integration inside the cryostat is driven by the **Ø100 mm** pumping lines And…

- Free longitudinal cross section for HeII: **150 cm²** (100 cm² btw. CP and D1)
- Size of phase separators: **12.5 L** for Q1 to Q3; 5.5 L for CP and D1

https://edms.cern.ch/document/1710017/0.3
Heat loads: https://edms.cern.ch/document/1610730/1.1
Static heat loads: https://edms.cern.ch/document/1690235/0.1

Referring to present circuit for busbar routing

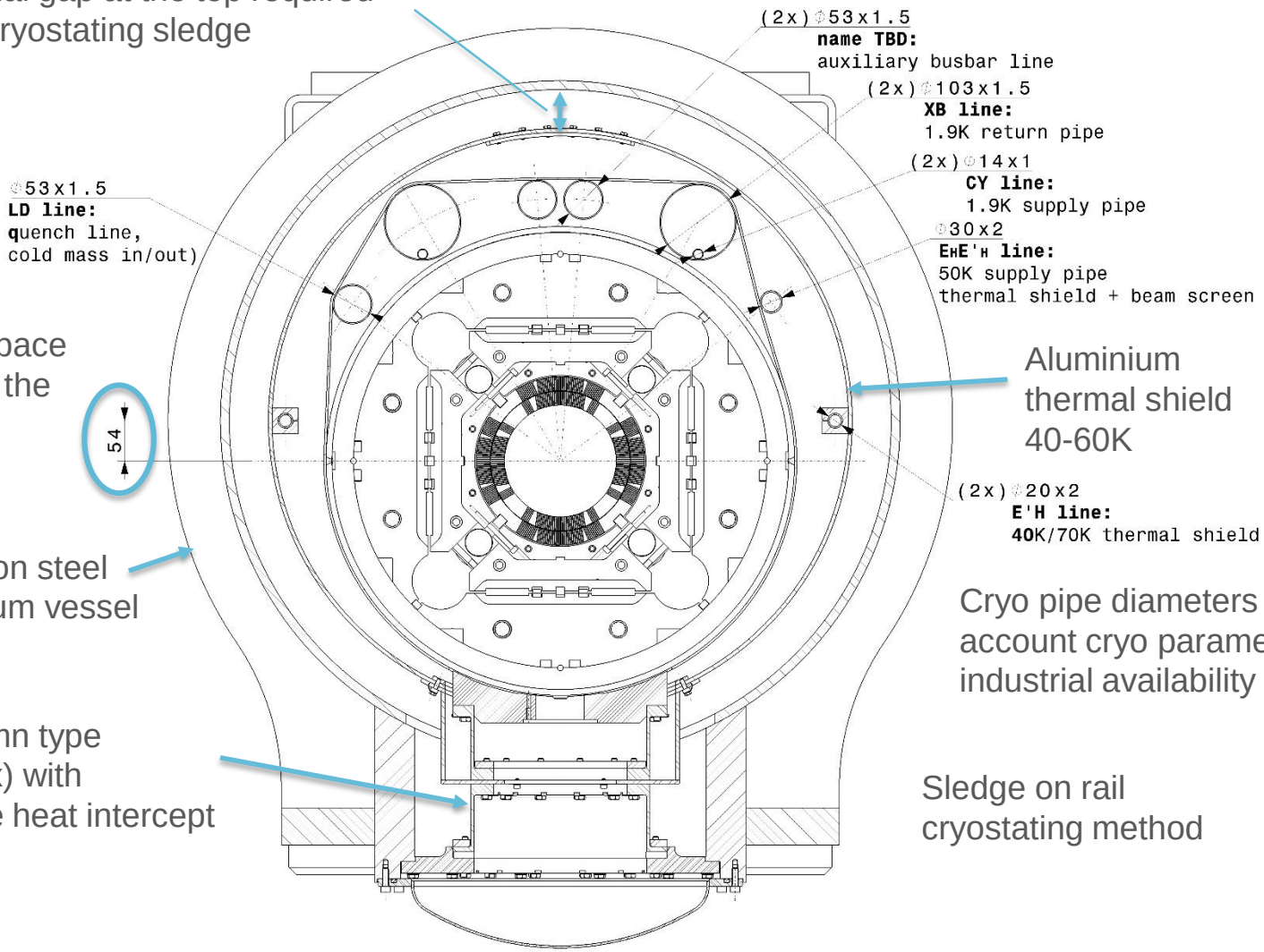
As of October 2016



The approach being to route the larger and stiffer 18 kA busbars inside the cold masses and the remaining in auxiliary lines

Standard cryostat cross section

Radial gap at the top required for cryostating sledge



Offset creates space for piping inside the cryostat

Aluminium thermal shield 40-60K

Carbon steel vacuum vessel

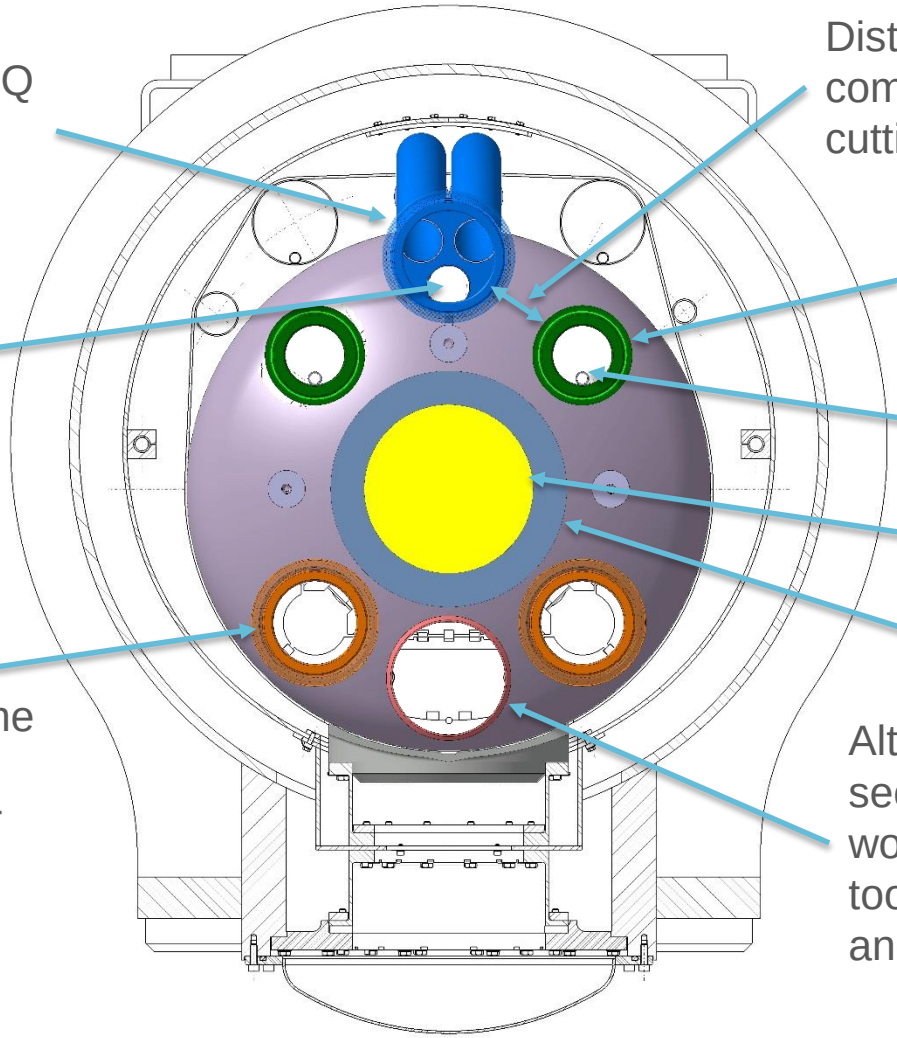
Cryo pipe diameters take into account cryo parameters and industrial availability

GFRE column type supports (3x) with intermediate heat intercept

Sledge on rail cryostating method

More details on drawing: LHCQQX__0001

Cold mass interfaces



Trim+Correctors / CLIQ
or
Trim / Correctors

18 kA busbars

HeII cross section
2x75 cm^2 located the
at same radius as
the heat exchanger

Distance between lines
compatible with existing
cutting machines

Heat exchangers (2x)

HeII inlet

Beam line

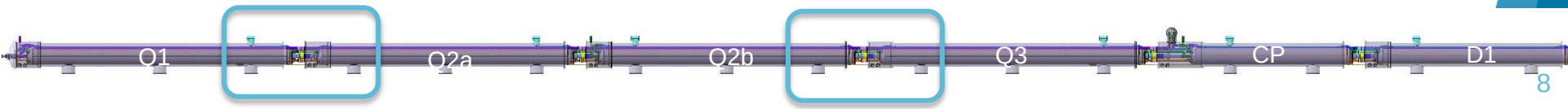
Beam screen
bellows

Alternative: HeII cross
section 150 cm^2. Less
work in the tunnel but
too close to beam line
and large (rigid) bellows!

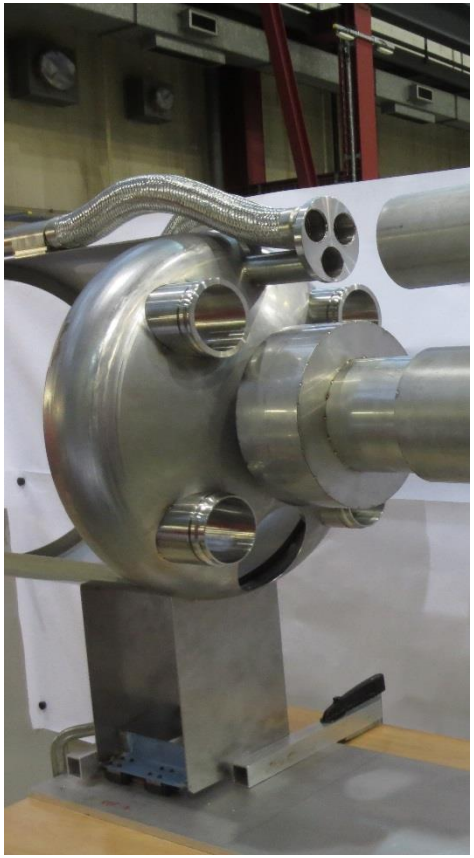
More details on drawing: LHCQQX__0001

The simplest magnet interconnect config.
(Q1/Q2a or Q2b/Q3 or CP/D1)

Splice box
Universal expansion joints for lower interc forces



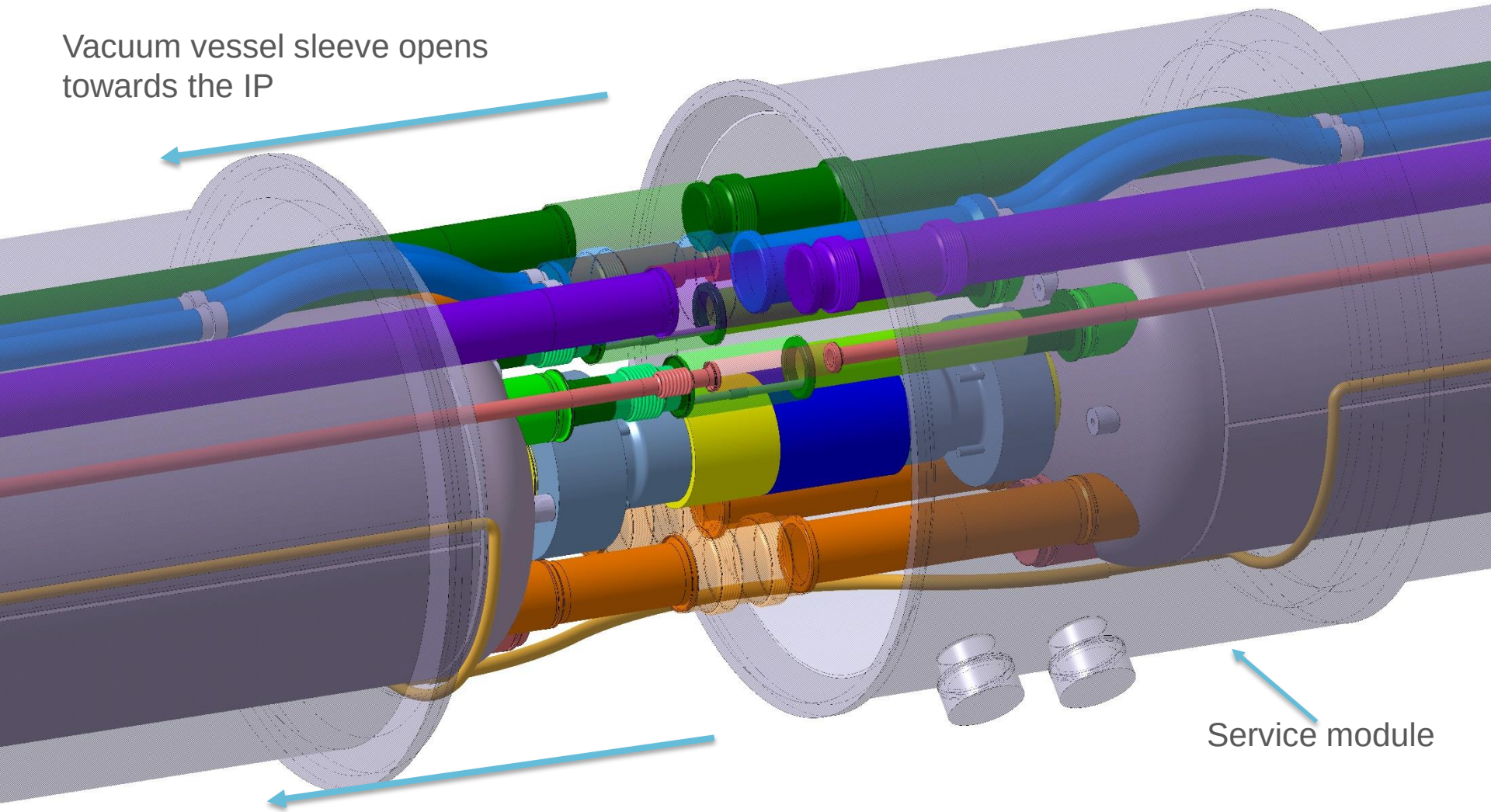
Full scale mockup being built

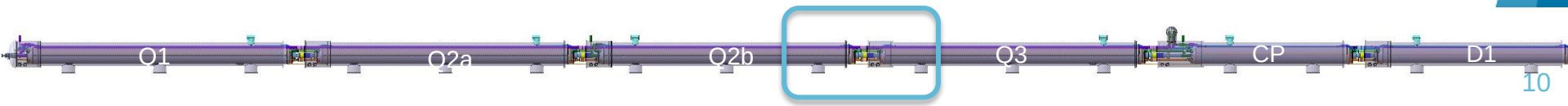


- Busbar splices and routing
- Welding clearances
- Envelope for cutting tools

Complete interconnect

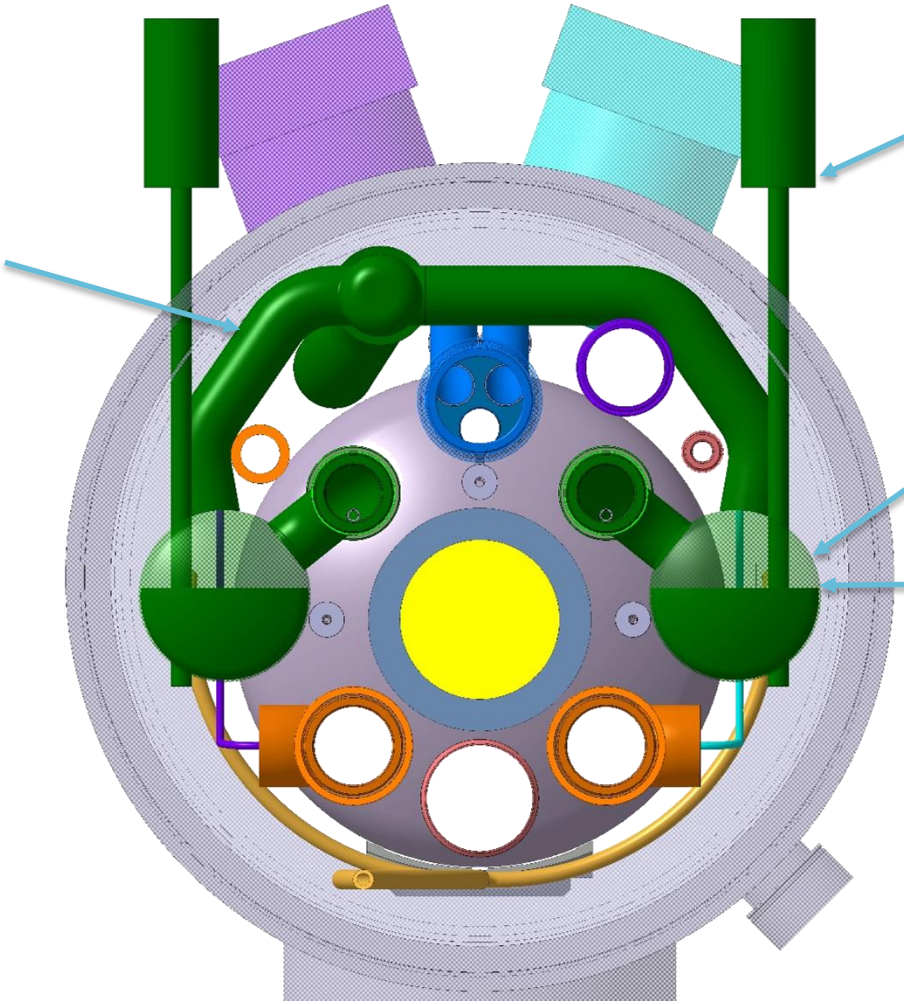
Vacuum vessel sleeve opens towards the IP





Phase separators and pumping lines

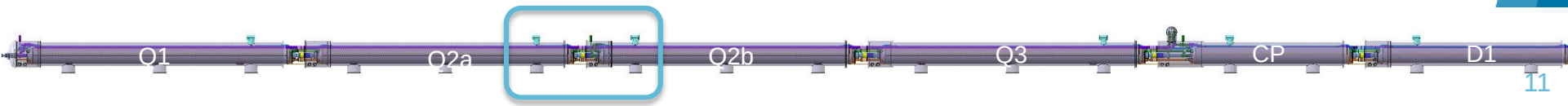
Pumping manifold requires locally enlarged diameter: service module



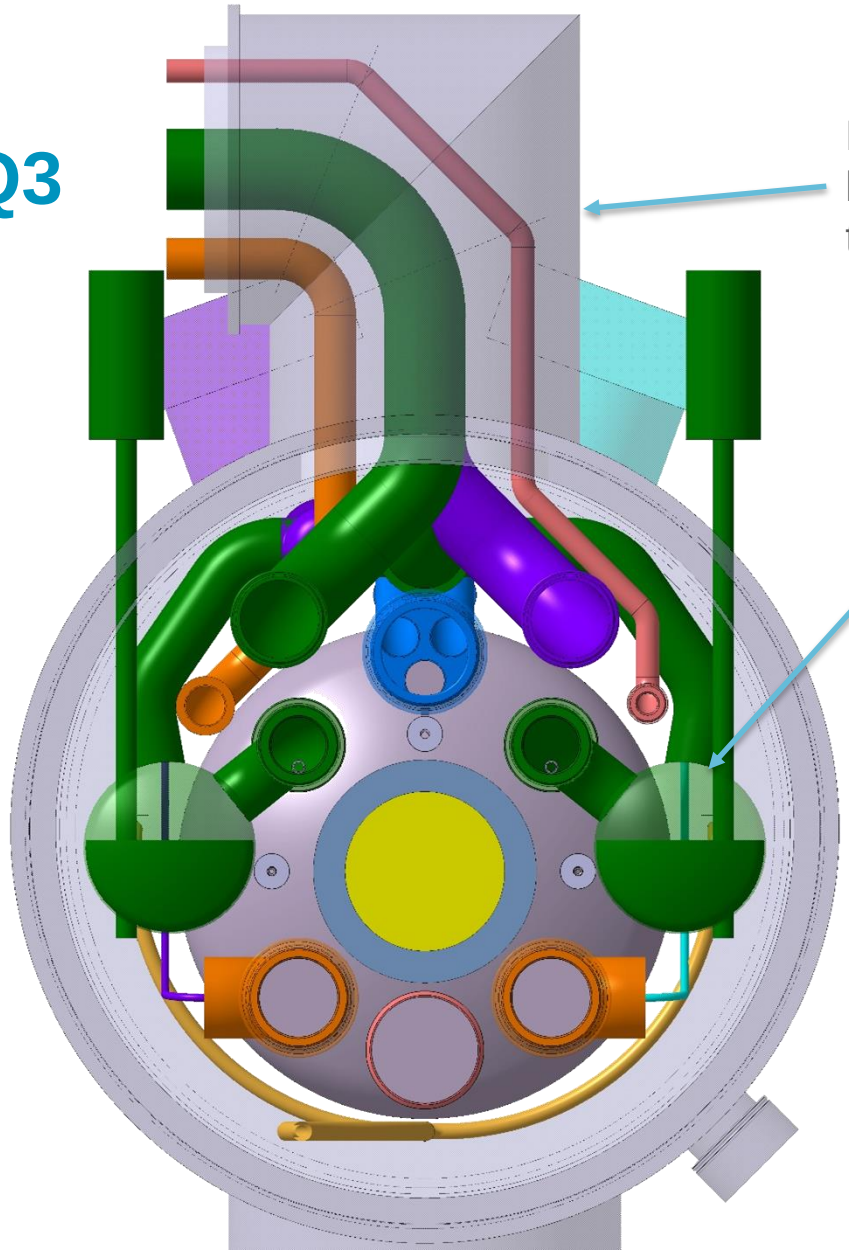
Reservation for level gauge (if needed)

Lower than heat exchanger

2x 6.5 L of liquid volume

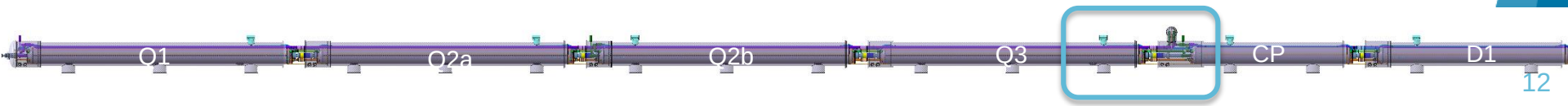


Jumper between Q3 and CP



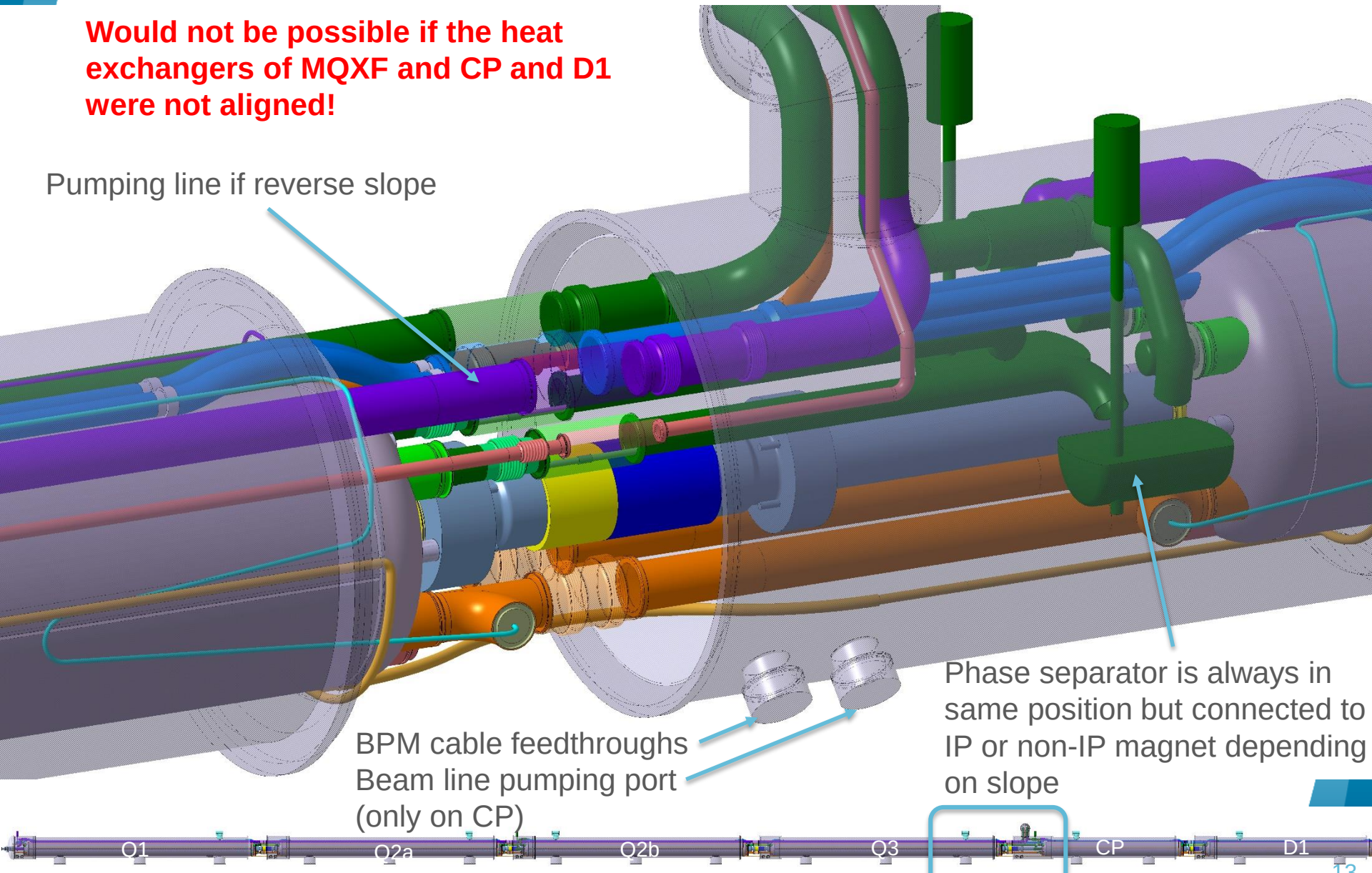
Larger diameter and height than today in the LHC

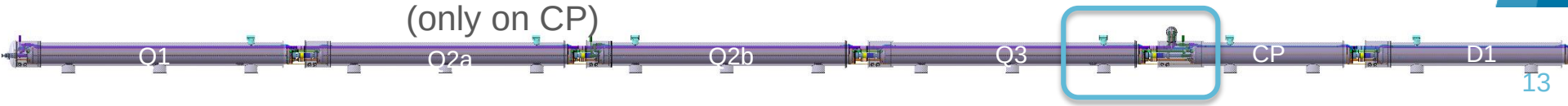
Standardised position of phase sepatators and pumping manifold



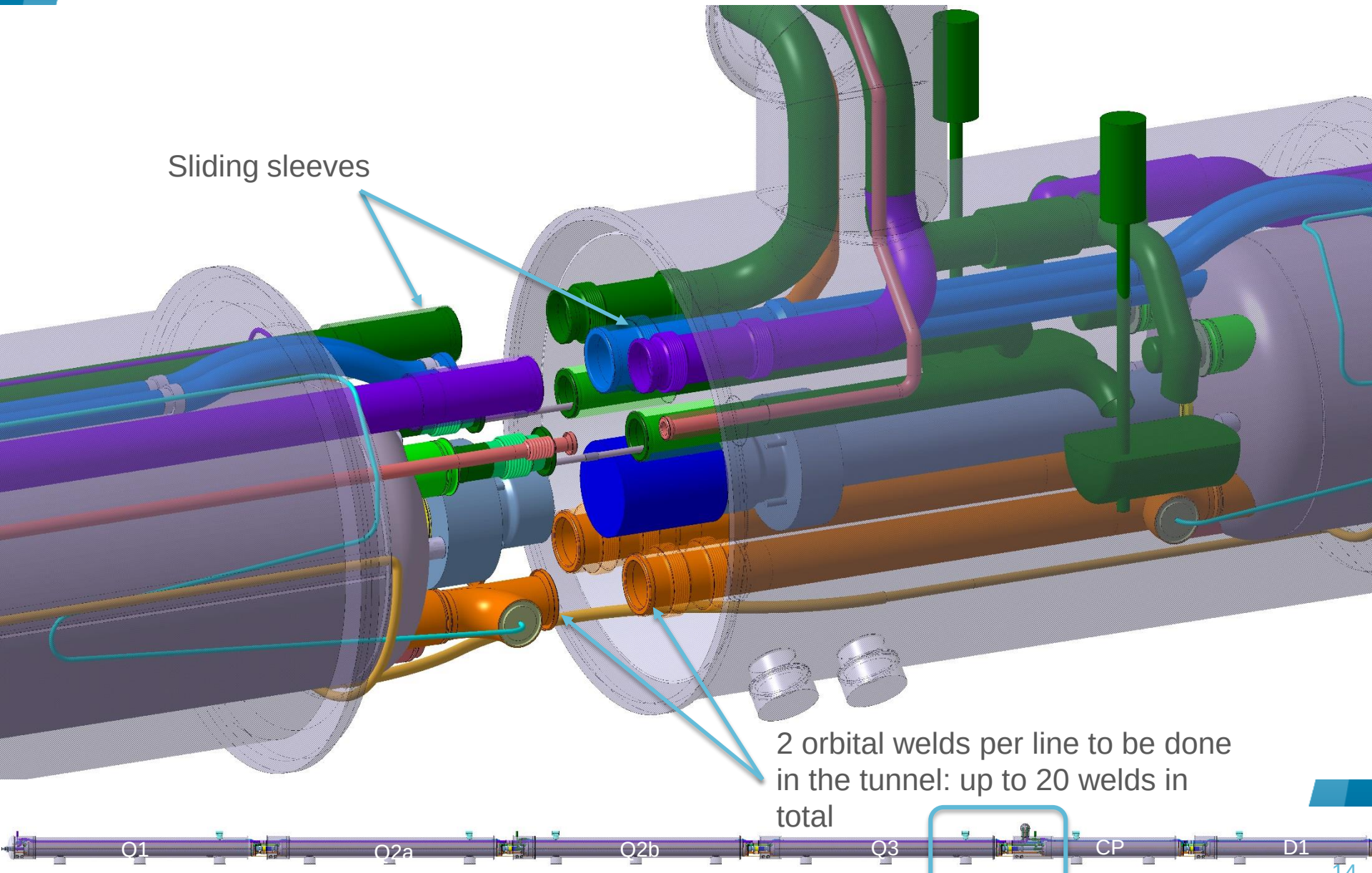
Interconnect and service module Q3-CP

Would not be possible if the heat exchangers of MQXF and CP and D1 were not aligned!



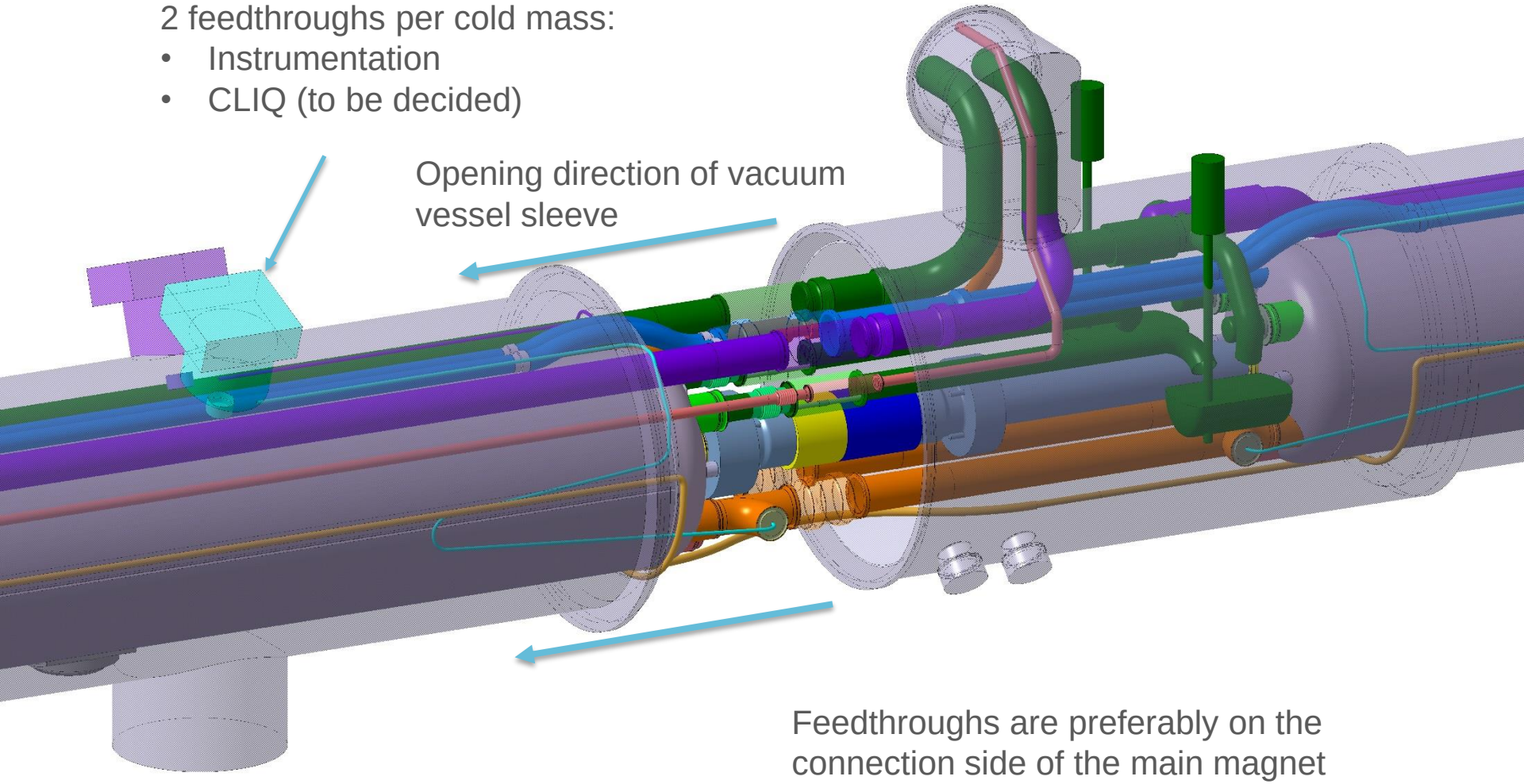


Before interconnecting

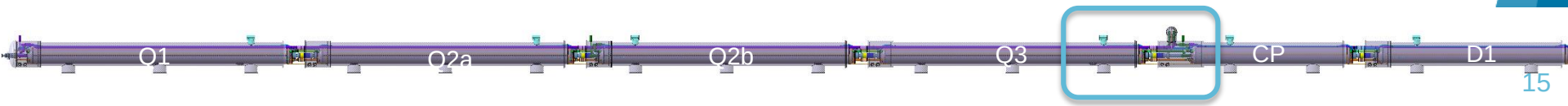


2 feedthroughs per cold mass:

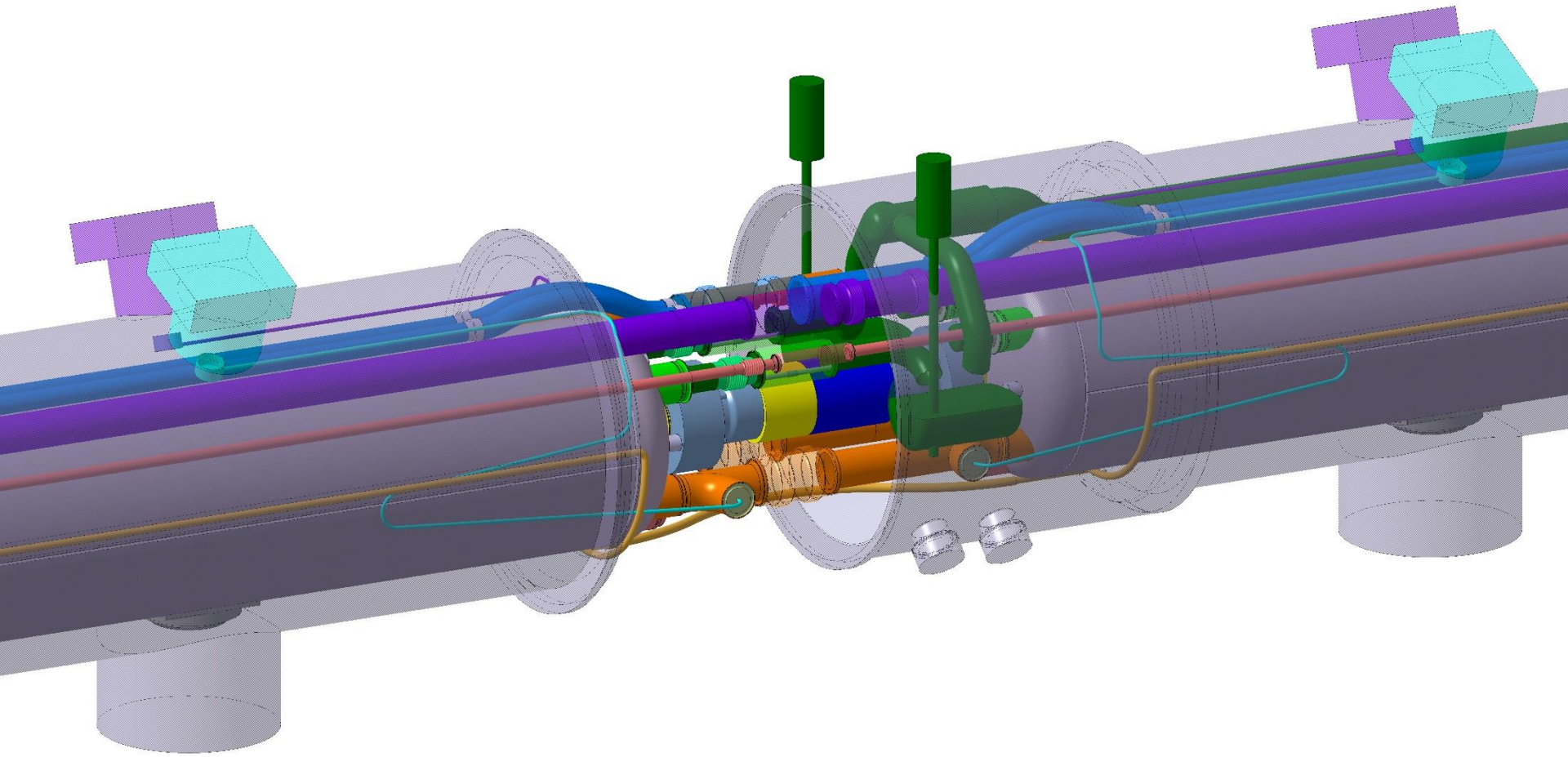
- Instrumentation
- CLIQ (to be decided)

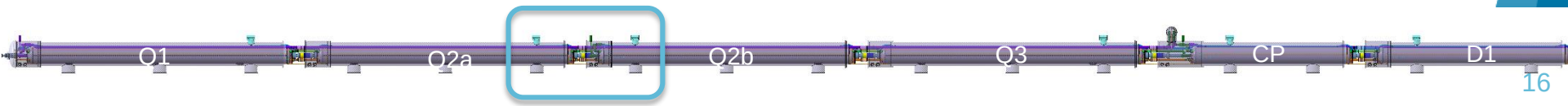


Feedthroughs are preferably on the connection side of the main magnet



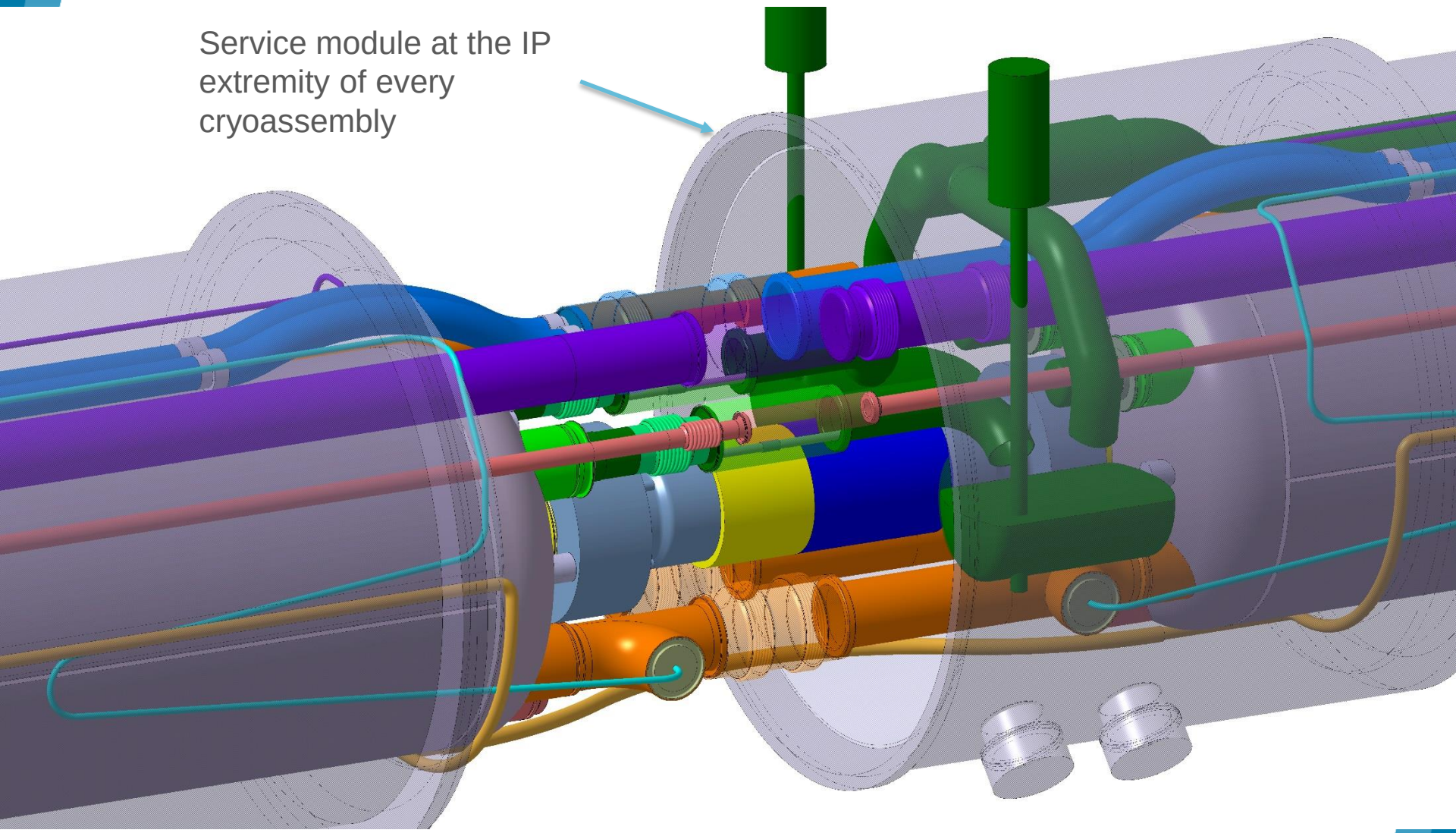
Q2a/Q2b: both are connection side

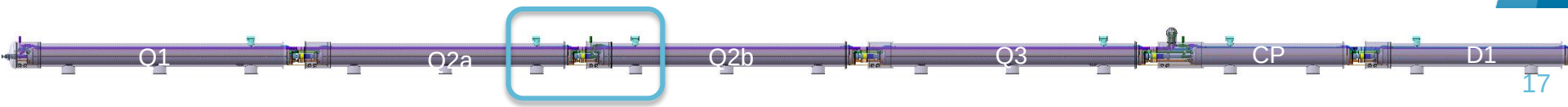




The most compact interconnect

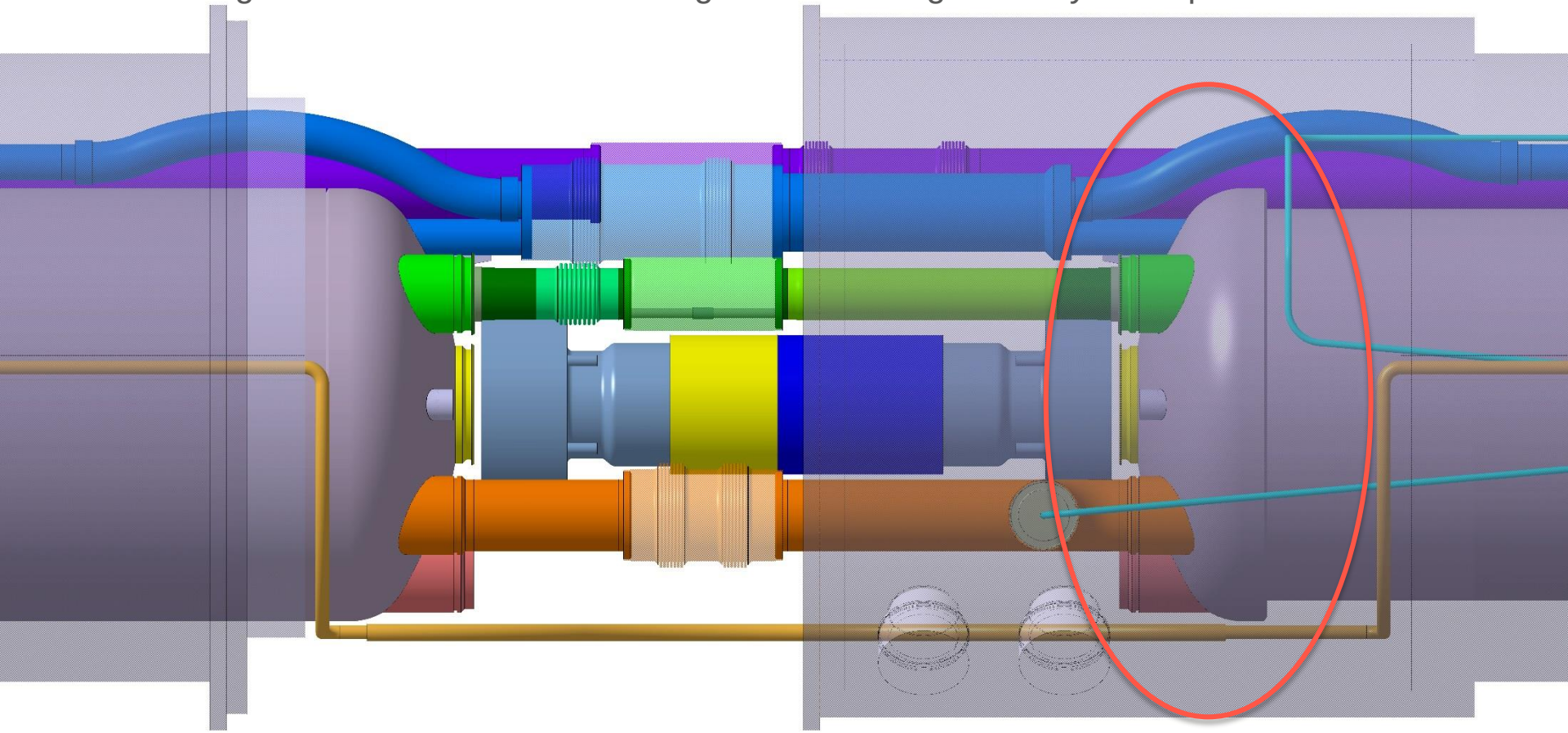
Service module at the IP extremity of every cryoassembly



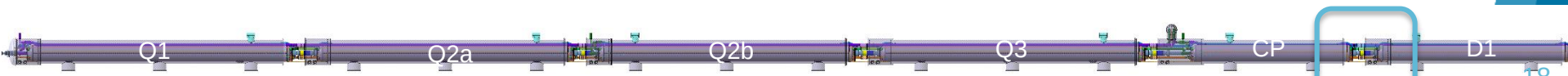


CP to D1

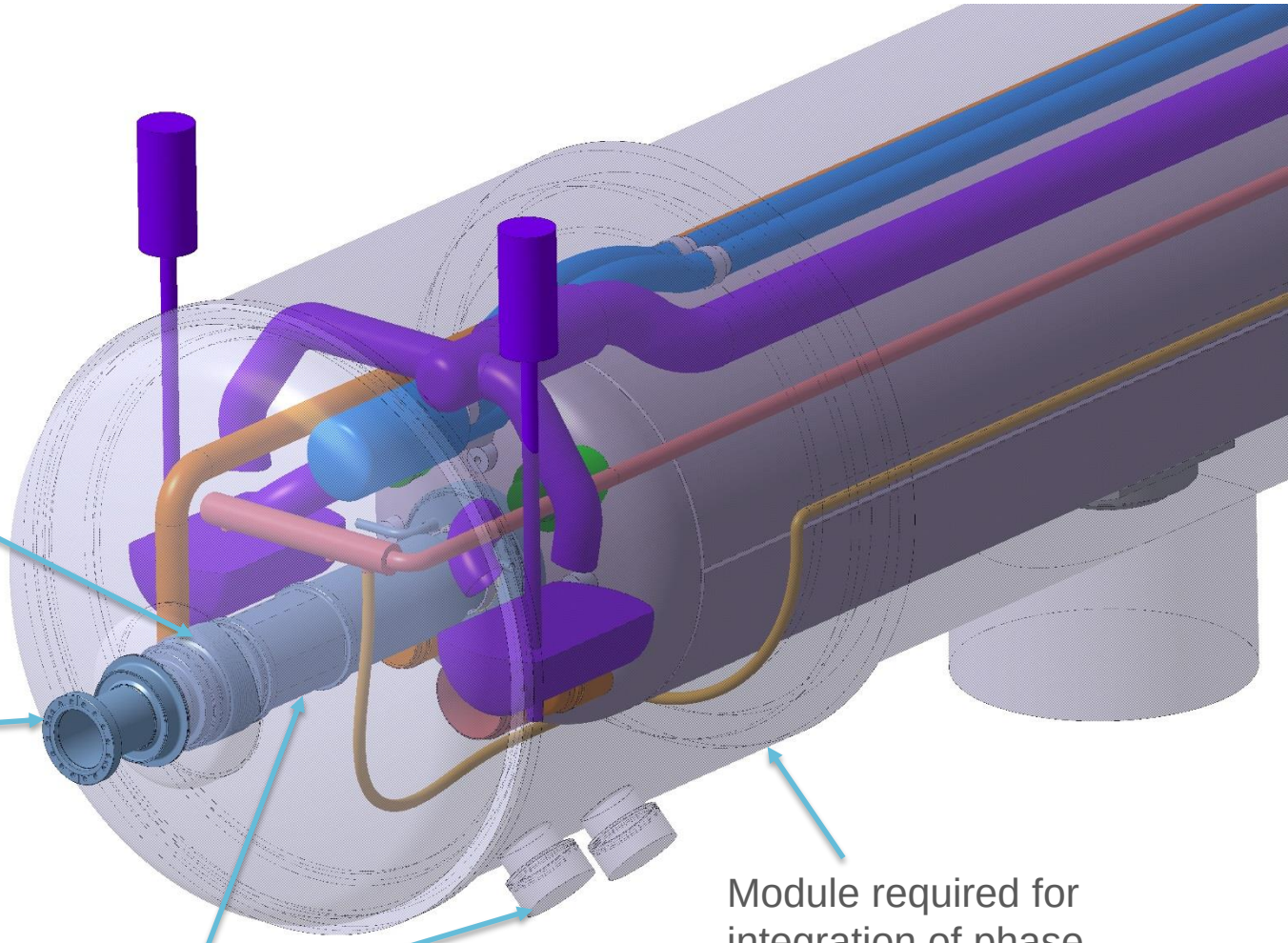
D1 cold mass diameter is 570 mm. The heat exchangers and HeII lines will be close to the edge – End covers of same design as other magnets may be required



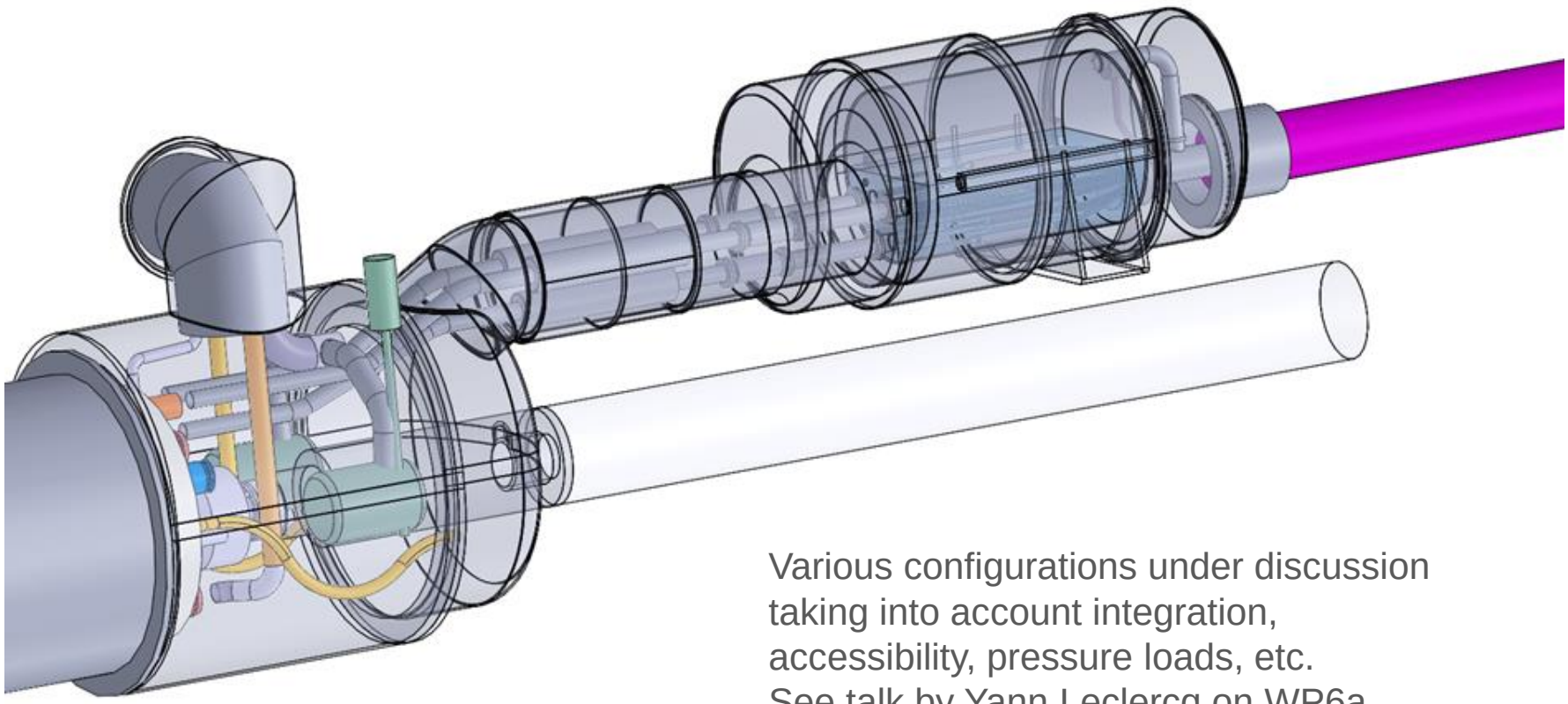
Similar to what exists today in LHC SSS



Q1 IP end


RF bellows inside cryostat
Cold to warm transition
BPM
Module required for integration of phase separators and pumping line

D1-DFX extremity (non-IP side)



Various configurations under discussion taking into account integration, accessibility, pressure loads, etc.
See talk by Yann Leclercq on WP6a

Ex. in this configuration the vacuum force is taken by the D1 vacuum vessel and its supports. Q1 support scheme may be used.

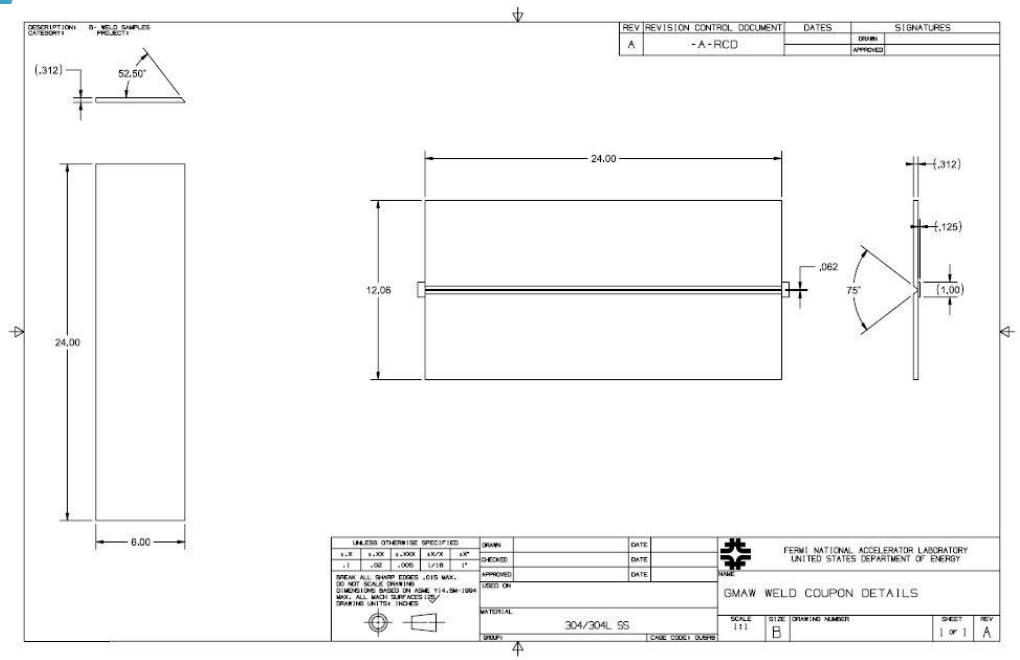
This is probably not the last iteration…

- **Pressure drop** calculations must now be updated taking into account proposed diameters, bends, bellows, etc.
- We need to design the **bellows** in order to evaluate the distances available for tooling and estimate **interconnect forces**.
- Some interconnect lines will need **stiffening supports**.
- CAD is not enough for the design of interconnects - we build **mockups**.
- Finding a solution for the busbar routing and splicing is very much related to the **circuit and busbar** characteristics.
- Very compact interconnects – intervention time and accessibility will be a challenge when minimising **radiation doses** to personnel.
- There will be opportunities for improvement - let's give ourselves some more time before agreeing on the **cold mass interfaces**.

MQXFS1c – shell design validation

- In the short model program the plan is to verify the shell design by using MQXFS1c
- Goal for the test of MQXFS1c:
  - Verify the welding procedure
    - X-ray examination of the weld
    - Leak check
    - Stress measurement and analysis using strain gauges
  - Quench test of the magnet – no mechanical induced degradation
    - Interference between the shell and coil will be controlled
- The test is planned to be performed in February-March, 2017 using Fermilab's VMTF

Weld Test Results



	Before Welding	First Pass	Final Pass
Width @ A	12.04” (305.8 mm)	11.970” (304.0 mm)	11.965” (303.9 mm)
Width @ B	12.06” (306.3 mm)	12.000” (304.8 mm)	11.960” (303.8 mm)
Width @ C	12.05” (306.1 mm)	12.026” (305.5 mm)	12.000” (304.8 mm)

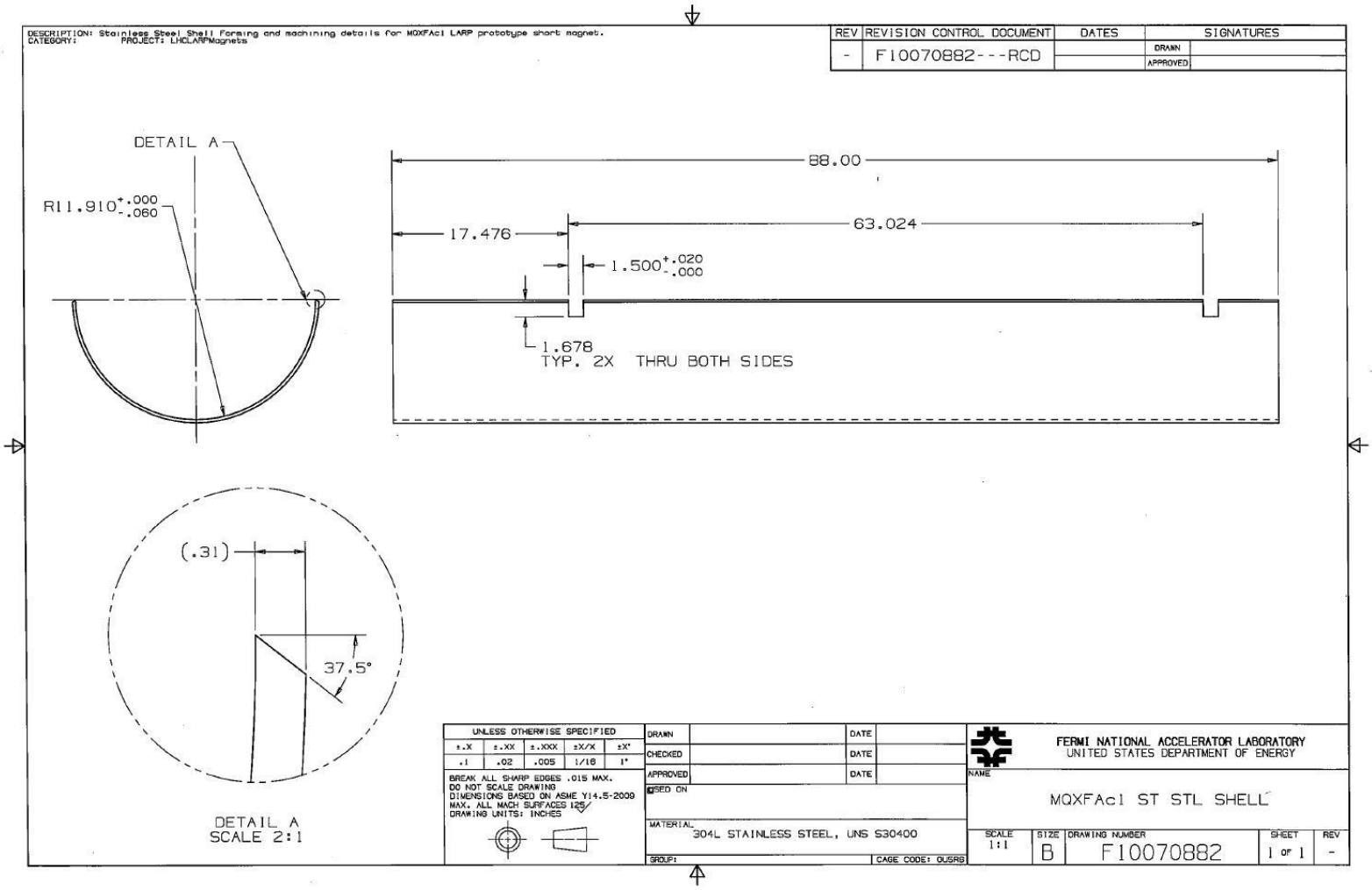
Welding Sample:

- Material 304 St Stl 5/16” (8 mm) thk.
- Procedure - Gas Metal Arc Welding (GMAW) in DC Pulse mode
- 3 passes (1 root & 2 cover)
- Filler Wire used: .035” Dia. 308LSi
- Travel speeds:
  - 1st: 8.75 IPM (222 mm/m)
  - 2nd: 10.50 IPM (267 mm/m)
  - 3rd : 11.25 IPM (286 mm/m

Shell Design

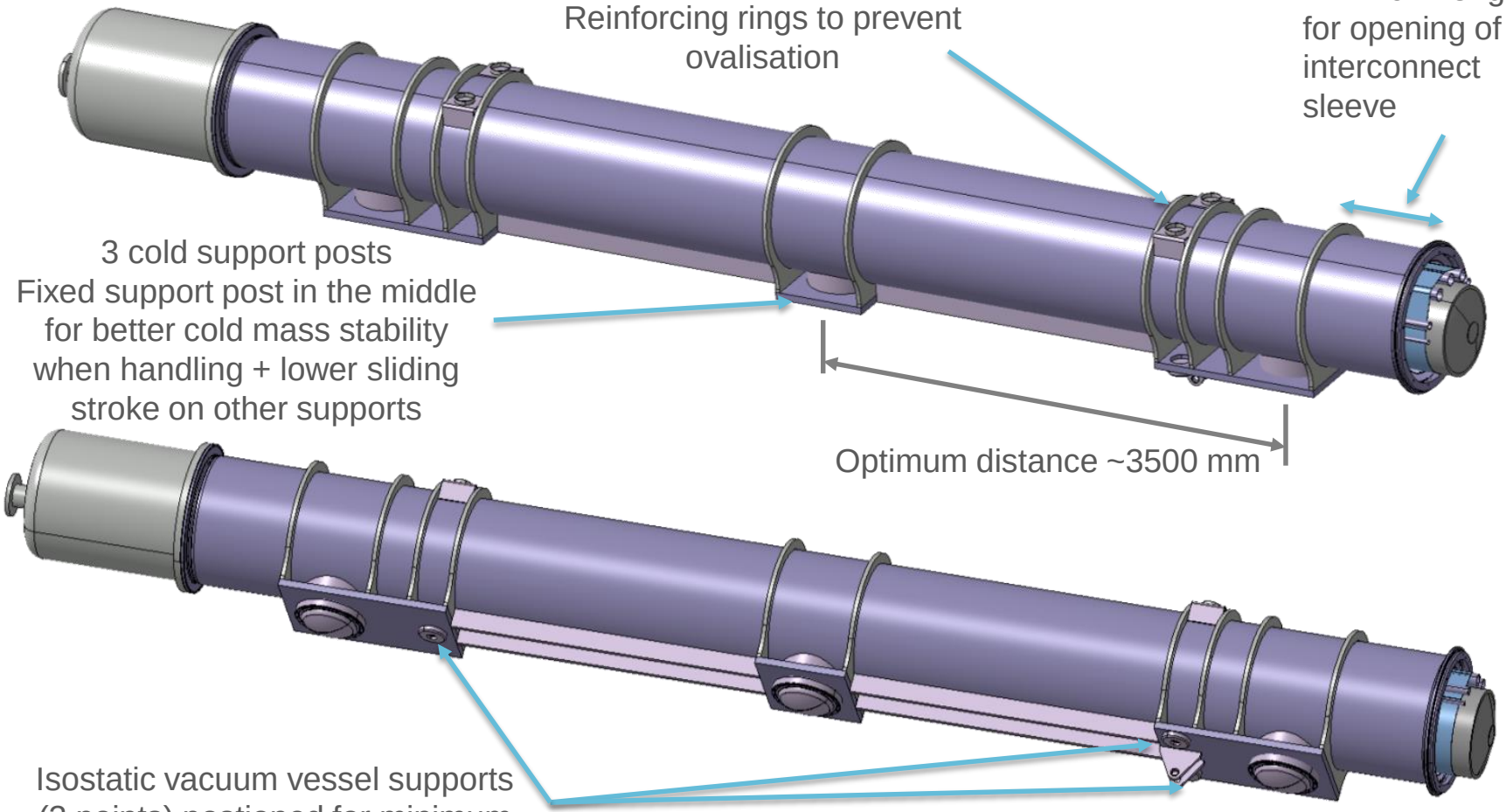
- Stress requirements on the Shell
  - Maximum 100 MPa
  - No Minimum contact required.
- Tolerances based on stress requirements and weld test results
  - With SS skin RT modulus of 198 Gpa, a +/-2.3 mm circumferential tolerance will equal a +/-37MPa variation in shell pre-stress (Heng Pan, LBNL).
  - Fermi experimental Shrinkage=0.200” (5.1 mm)
  - Set Shell Circumference +0.11” (2.8 mm) for an interference fit of 0.09”(2.3 mm). At +2.3 mm, assume Max pre-stress = 74MPa & still touching at -2.3 mm.

Shell Design



Thank you for your attention!

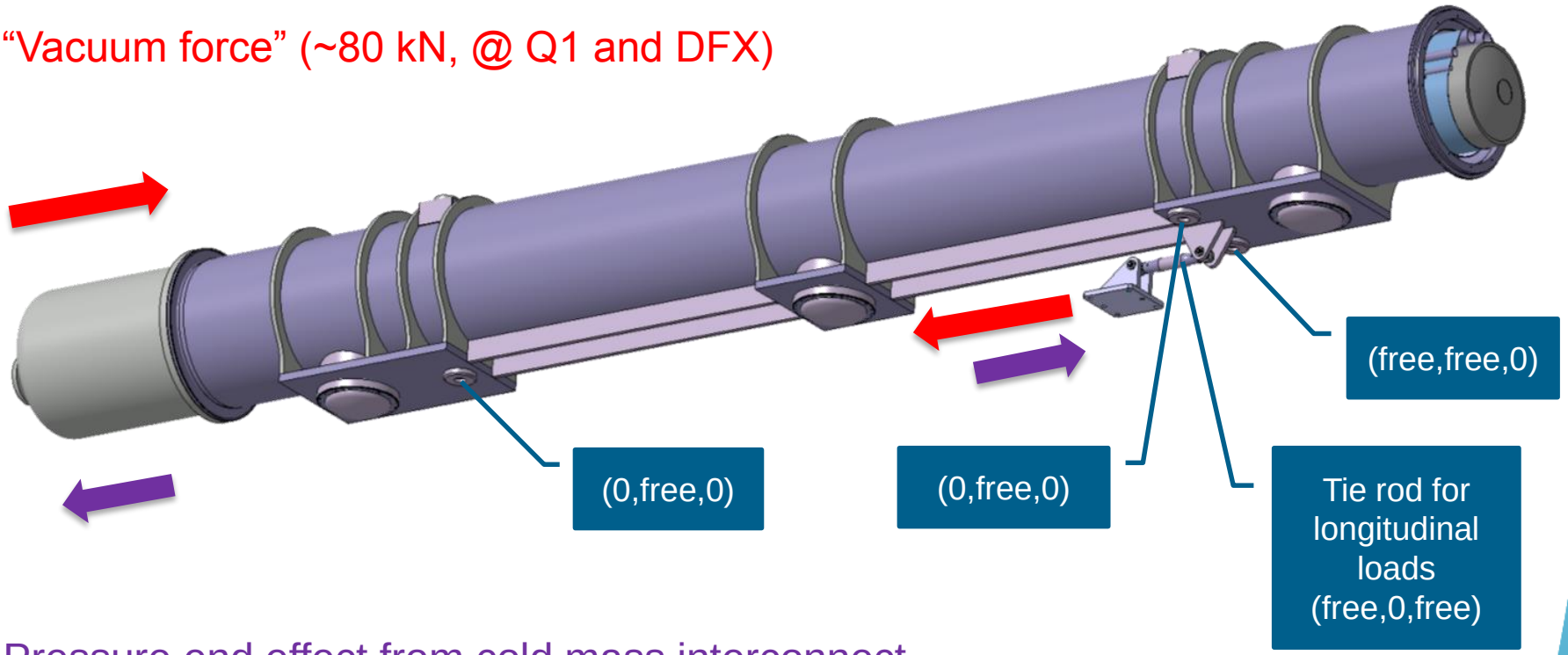
Vacuum vessel



- Low carbon steel certified resilience down to -50 ºC for pressure applications
- Flanges from 304L forged rings

Dealing with vacuum and pressure end loads

“Vacuum force” (~80 kN, @ Q1 and DFX)



Pressure end effect from cold mass interconnect (depends on interconnect design)

Static heat loads in the cryostat

Table 1 – Total heat loads on the 64 m long Q1 to DFX continuous cryostat.

Source of heat loads	Heat load to the cryogenic circuit [W]	
	1.9 K	40-70 K
Radiation to thermal shield	-	205.5
Radiation to cold mass	8.10	
Support posts	8.42	131.0
Cold to warm transitions	-	20.0
BPM cables	-	9.8
Instrumentation feedthroughs	5.46	-
Beamscreen to cold mass	TBD	-
Other	TBD	TBD
TOTAL (Preliminary)	**21.98**	**366.3**

https://edms.cern.ch/document/1690235/0.1

Mateusz Sozin

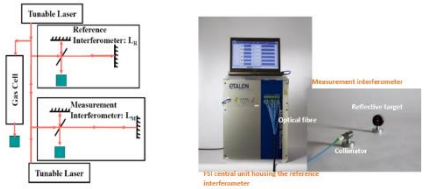
Cold mass position monitoring

Cold mass monitoring

- Objective: integrate an alignment system to monitor the position of cold mass inside the MQXF cryostats (T°<3K, high level of radiations >1MGy, technical vacuum)
- Strategy:
  - Use of Frequency Scanning Interferometry (FSI), absolute distance measurement
  - Adapt the solution under validation for the crab cavities

Remainder – FSI

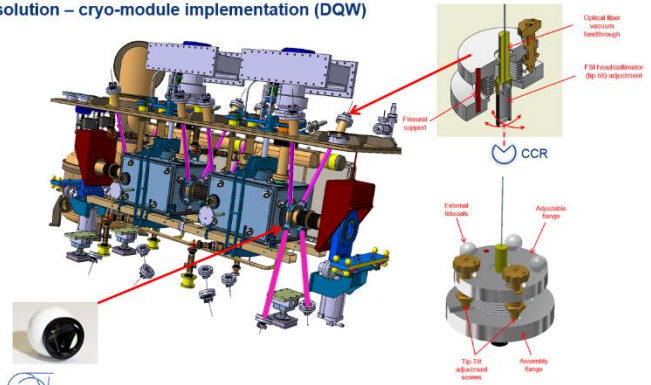
FSI solution – absolute interferometric distance measurement



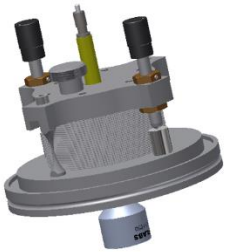
- Absolute distance measurement
- 8 channels expandable to 100
- Uncertainty (95%) = 0.5 µm/m
- Traceable
- Measurement distance: 0.2 – 20 m
- Fibre length – up to several hundreds meters

FSI position monitoring – crab cavity example

FSI solution – cryo-module implementation (DQW)



Crab-cavity FSI feedthrough – technical details



Cryostat side – FSI head:

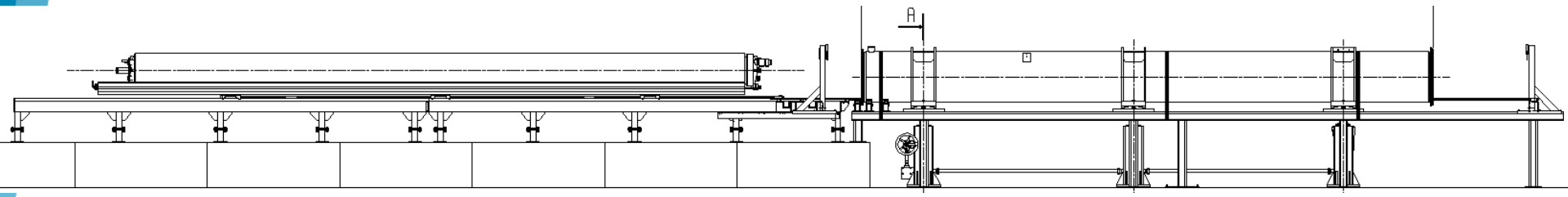
- Prototype UHV-ISO-K DN63 flange
- Laser beam diameter 8mm
- Thermal shield hole – diameter 30mm
- Transversal movement range +/- 3.5mm (the optics have to be optimized for triplets use – longitudinal contraction of ~20mm)

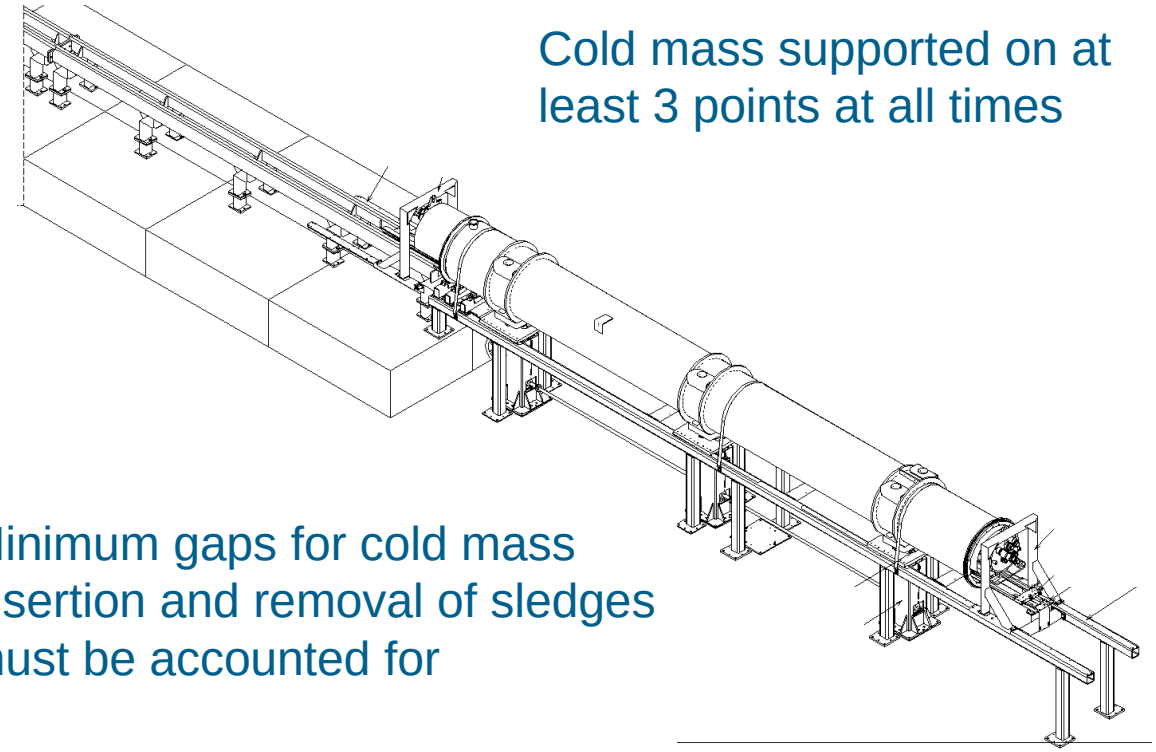
Cold mass side:

- Ball mounted reflector

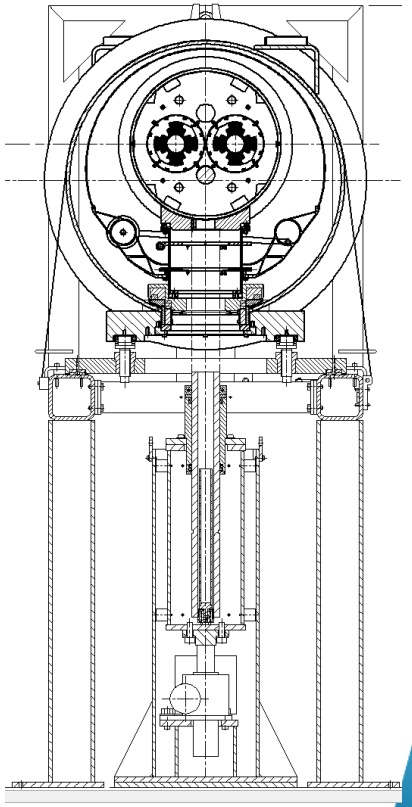
Cryostating tooling: sledge on rails

The principle currently used in dipoles and long SSS





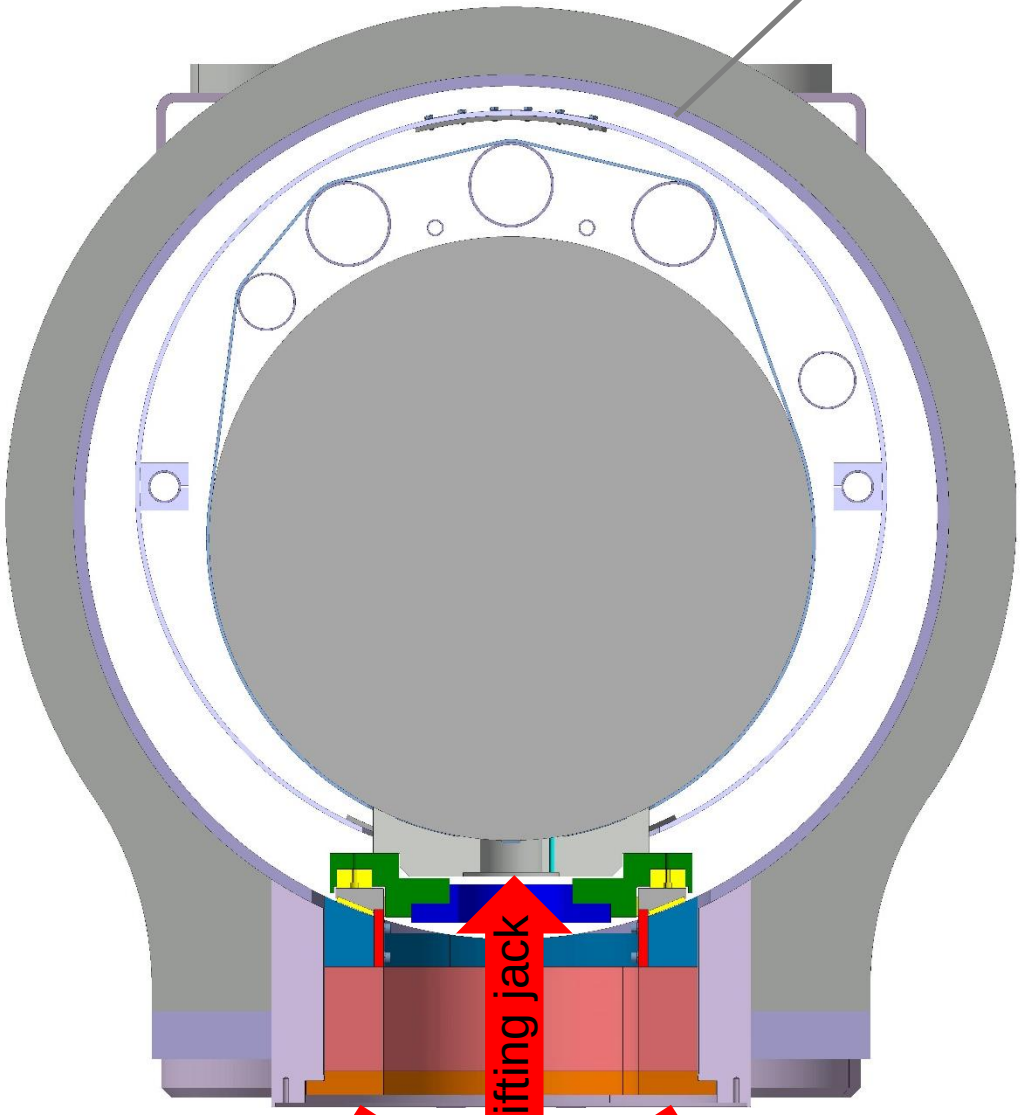
Cold mass supported on at least 3 points at all times

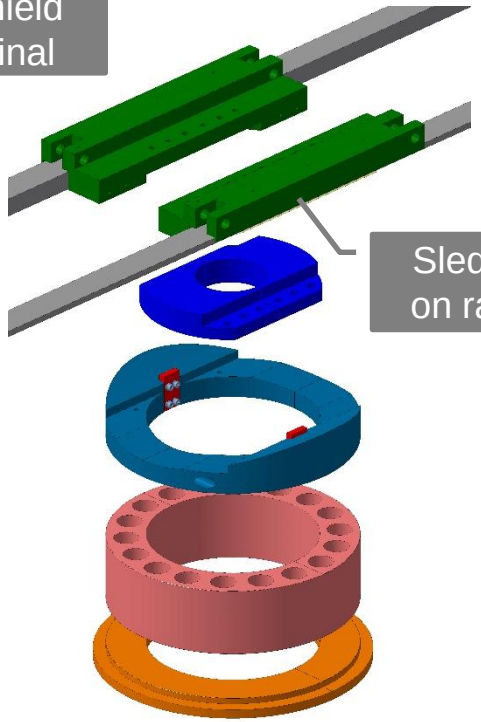


Minimum gaps for cold mass insertion and removal of sledges must be accounted for

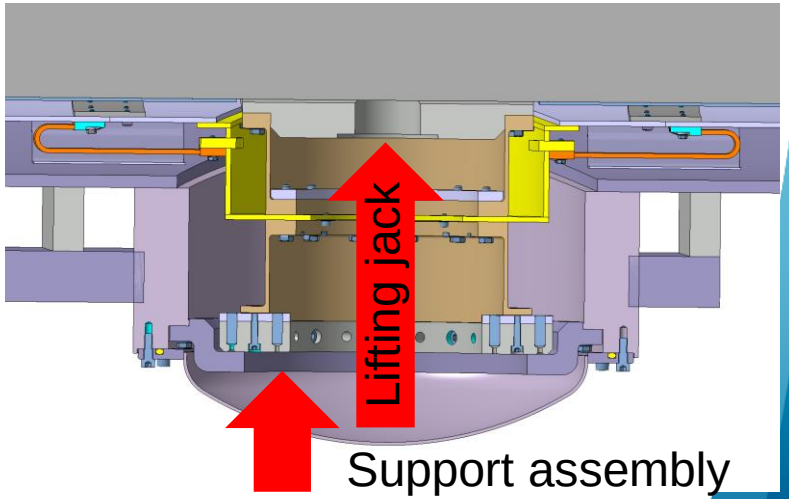
Cryostating tooling

Cold mass+shield lifted wrt nominal





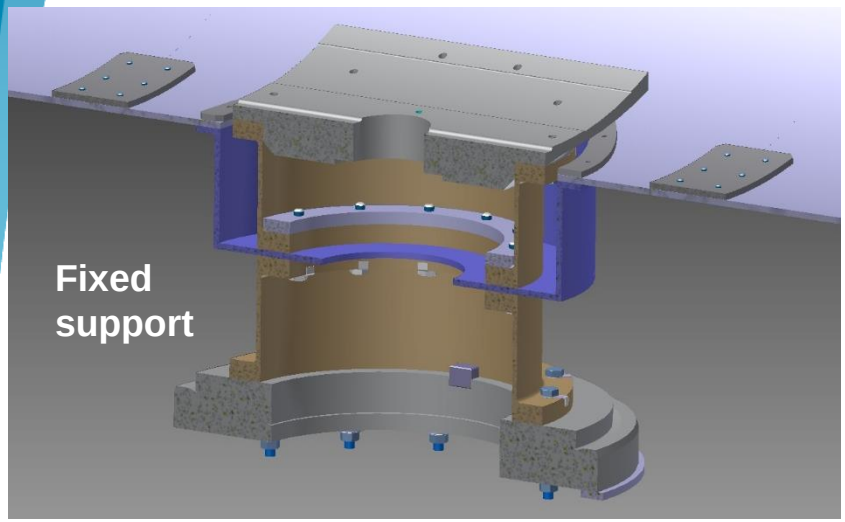
Sledge on rails

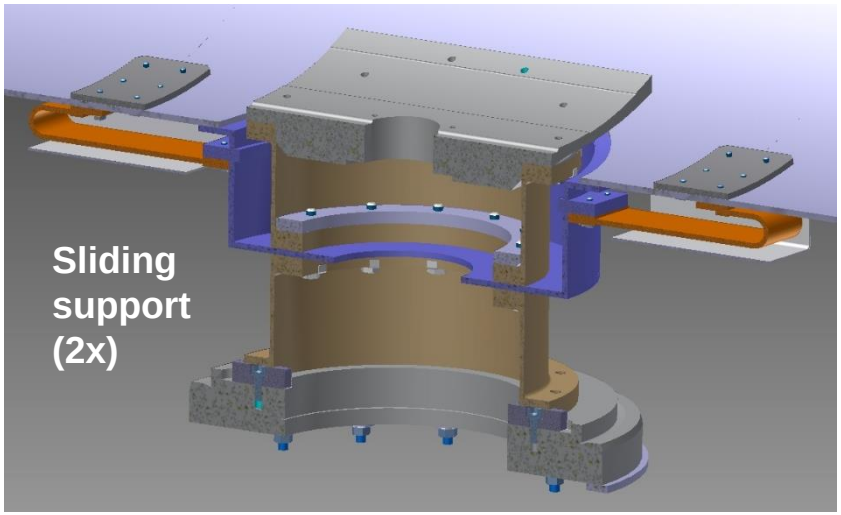


Support assembly

Tooling removal

Cold mass support posts





- **Two-part** GFRE column
- Aluminium **heat intercept** plate (perfect heat intercept)
- **Fixed support** in the centre of cold mass rigidly connects the cold mass to vacuum vessel
- **Sliding support** bolted to the cold mass and sliding on vacuum vessel
- Bolted assembly using invar washers and lock tab washers to ensure **preload maintained** at cold
- **Thermal shield** is supported by the heat intercept plates, thus without additional heat load
- **Thermalization straps** on sliding support for independent movement between cold mass and thermal shield