

MDI Engineering and Cryomodule Concept for FCCee

John T. Seeman (SLAC)

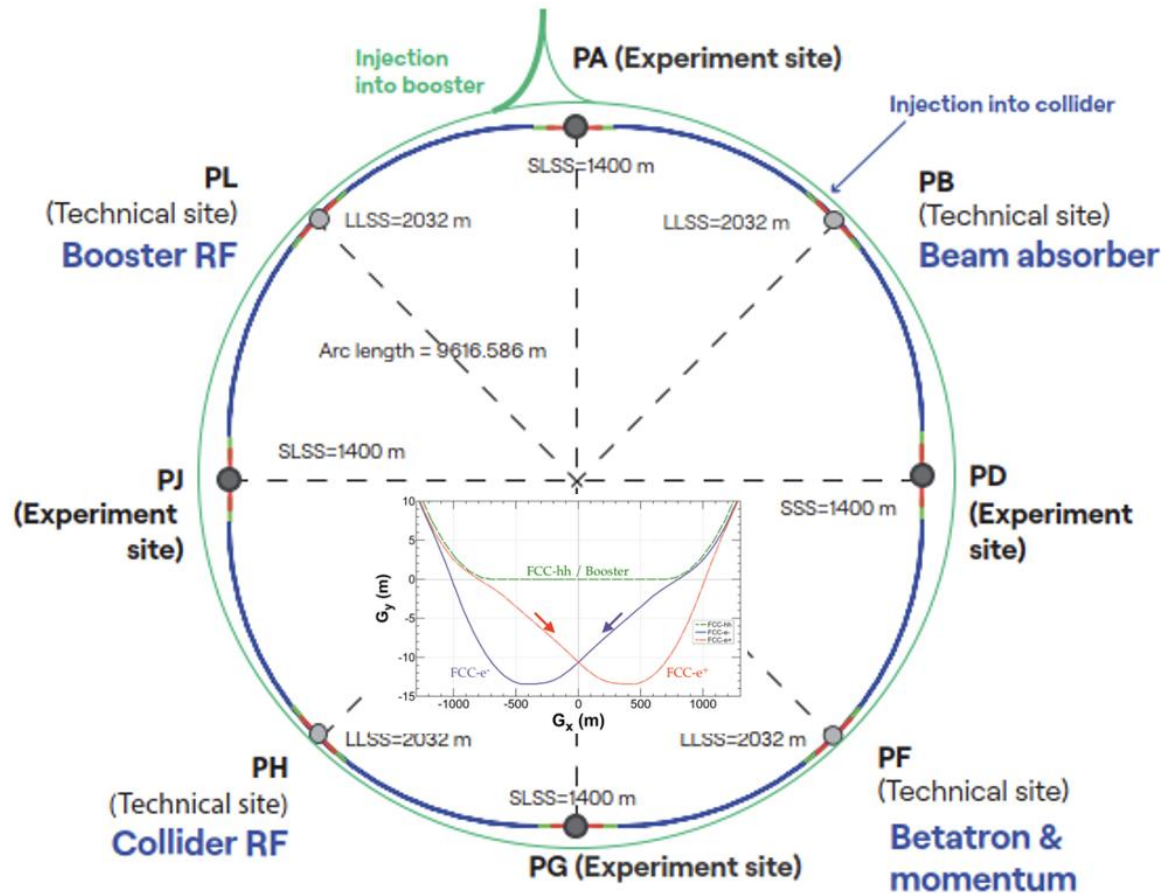
Sept 8, 2026

4th Annual Higgs Factory-Future Circular Collider Workshop at SLAC

Thank you for FCCee cryostat technical inputs/discussions:

SLAC

- A. O. Beltramello
- B. P. Borges de Sousa
- C. M. Boscolo
- D. A. Ciarna
- E. S. DeBarger
- F. D. Diyalov
- G. F. Franesini
- H. S. Gessner
- I. G. Iadarola
- J. G. Kerr
- K. M. Koratzinos
- L. T. Montagne
- M. A. Novokhatski
- N. K. Oide
- O. F. Palla
- P. B. Parker
- Q. L. Pollastrini
- R. P. Raimondi
- S. T. Raubenheimer
- T. K. Suguitan
- U. V. Teotia
- V. F. Zimmermann
- W. And others



FCCee IR is similar to the SuperKEKB with Cantilevered IR Cryostats

SLAC

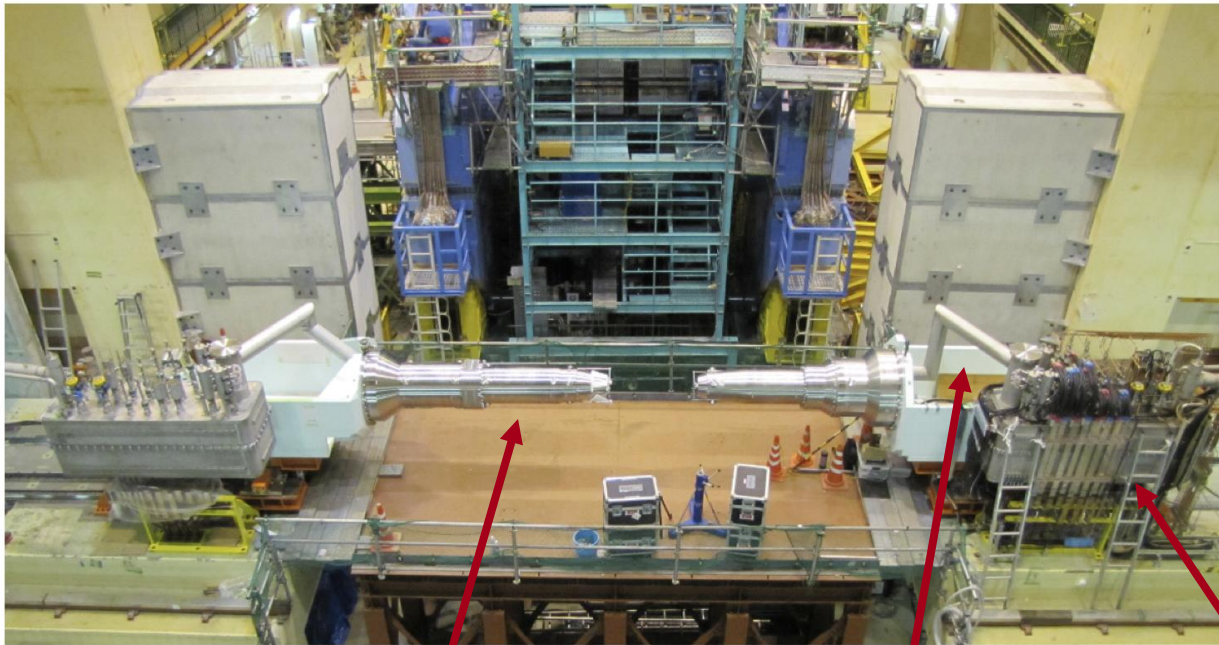


Figure 11: QCSL/R cryostats and Belle-II detector in IR.

IP Magnet Cryostat

QF2 mounted in
white support



Guide rails to remove
FF quadrupole cryostat

Cryogenic Junction Box

Near Term Work at SLAC on FCCee from HFCC

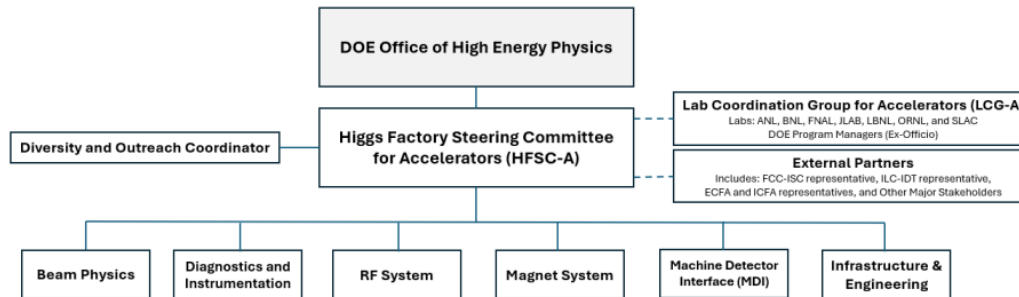


Figure 1: Organization of the U.S. Higgs Factory Coordination Consortium for Accelerators

HFSC-A members

- Drs. Tor Raubenheimer (SLAC)
- Dr. Steve Gourlay (FNAL)
- Dr. Matthias Liepe (Cornell University), and
- Dr. Jean-Luc Vay (LBNL)

HFSC-A grant: Cryostat Design Grant (J. Seeman, A. Novokhatski et al):

---Work on cryostat design: layout, reentrant welder, assembly, clearances, forces, beam pipe, HOMs, backgrounds, and heating. Will engage a Mechanical (Cryogenic) Engineer in July 2026.

HFSC-A grant: Beam-Beam Physics Grant: (S. Gessner, P. Kicsiny, et al)

---Beam-beam forces, quantum effects, speed-up calculations, code bench-marking, systematics of luminosity measurements. Work has started.

SLAC LDRD 2026: LumiCal Supports and Utilities Layout: (C. Vernieri, S. Gessner, L. Pollastrini) Layout, installation, tolerances.

FCc ee IR Solenoid Compensation Scheme (LCC)

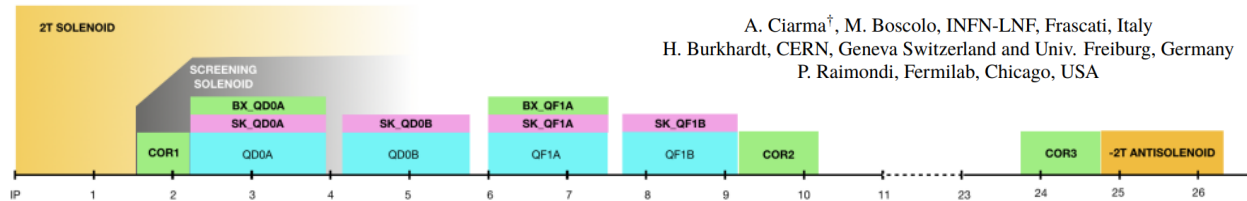


Figure 2: Layout of the standard solenoid compensation scheme for LCCO lattice v92.

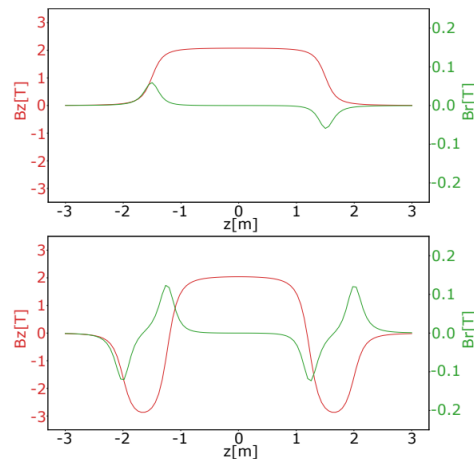


Figure 1: Longitudinal (red) and radial (green) magnetic fields along the 15mrad axis in the two compensation schemes (standard proposed here on the top, baseline on the bottom).

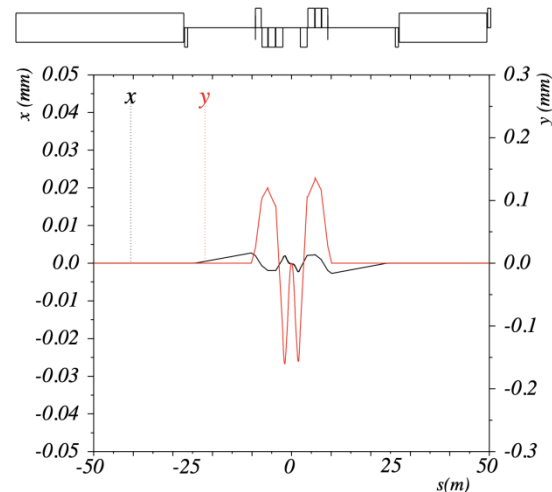


Figure 3: Horizontal and vertical orbit bumps.

P. Raimondi will soon provide a new IR lattice design for LCC (~Sept 2026).

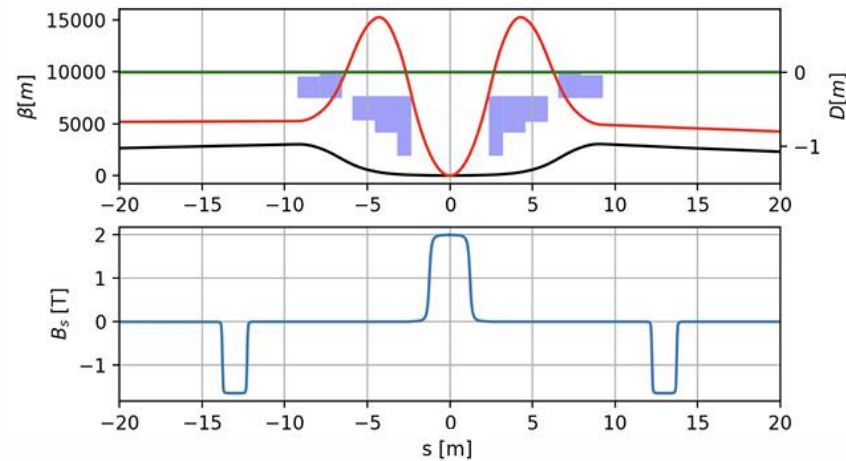
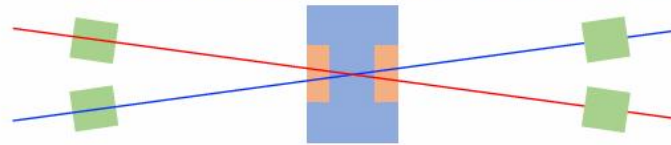
Ongoing study of Solenoid Compensation



Compensation scheme

There are **7 solenoids** at each IP

- 1 experiment solenoid (2 T)
- 2 screening solenoids inside (to cancel the field at the final focus quads)
- 2 x 2 compensation solenoids (to have zero net integrated field)



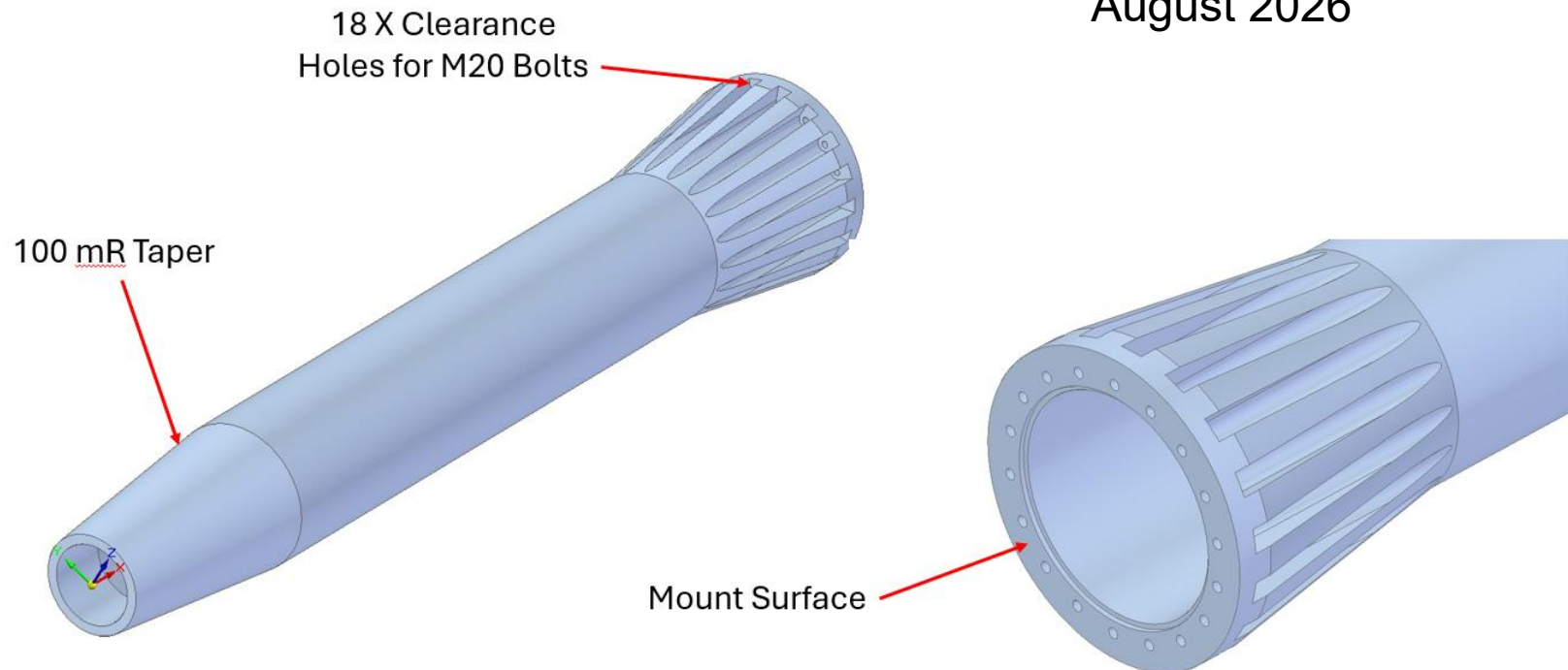
B. Parker, V. Teotia, G. Iadarola

Transitioning from detector field: 2T to 3T.

Cryostat Outer Vacuum Shell Model

Modeling by Kyle Suguitan

August 2026



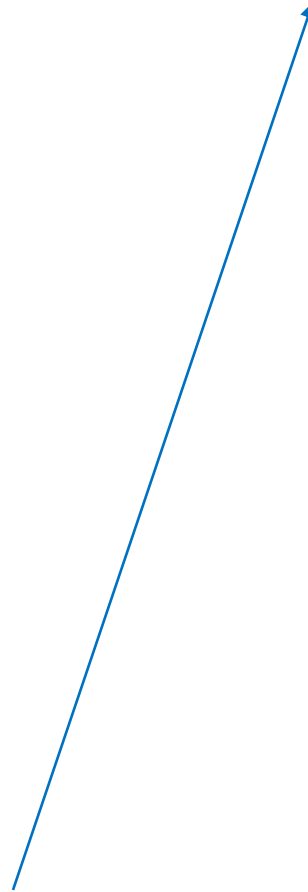
Funding: DOE HFSC-A grant in 2026.

T. Montagne, K. Suguitan, J. Seeman

IR cryostat component layers identified

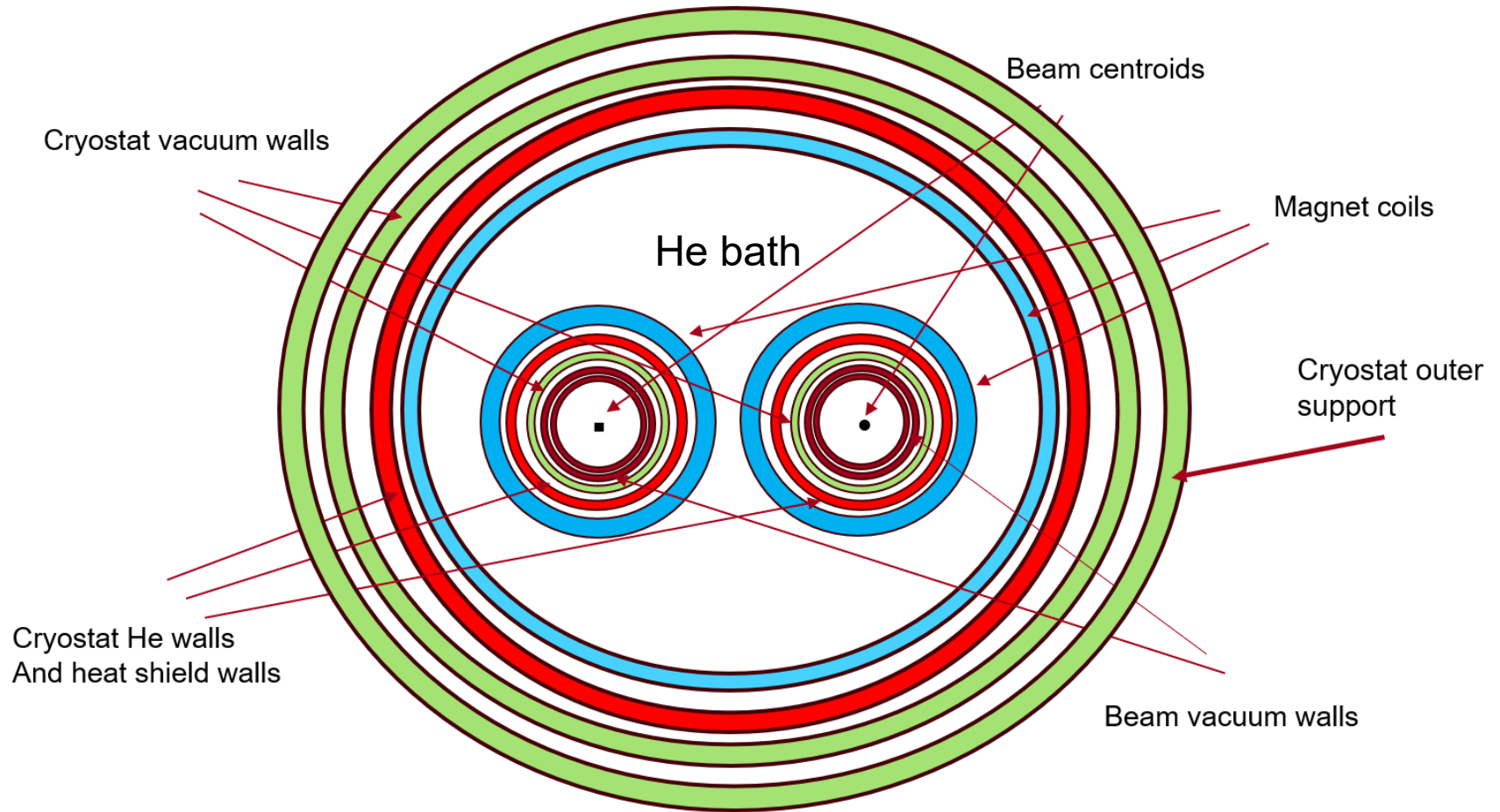
10	Solenoid axis line
11	
12	Support shim thickness
13	Trim coil thickness
14	Magnet coil thickness
15	Support shim thickness
16	He vessel thickness
17	Insulating vacuum thickness
18	Heat shield (~50K)
19	Insulating vacuum thickness
20	Vacuum vessel thickness
21	Air gap
22	Outer beam pipe thickness
23	Water cooling layer for pipe
24	Inner beam pipe thickness
25	Inner vacuum wall to beam
26	Beam center
27	Sum: solenoid axis to beam
28	
29	Beam location (15 mrad)

29	Beam location (15 mrad)
30	
31	Beam center
32	Outer vacuum beam to wall
33	Inner beam pipe thickness
34	Water cooling layer for pipe
35	Outer beam pipe thickness
36	Air gap
37	Vacuum vessel thickness
38	Insulating vacuum thickness
39	Heat shield (~50K)
40	Insulating vacuum thickness
41	He vessel thickness
42	Support shim thickness
43	Magnet coil thickness
44	Trim coil thickness
45	Support shim thickness
46	Anti-solenoid support
47	Anti-solenoid coil thickness
48	Large spacer
49	Shim thickness
50	He vessel thickness
51	Insulating vacuum thickness
52	Vacuum vessel thickness
53	Copper shielding thickness
54	Support rod gap
55	External support thickness
56	Sum: beam center to outside
57	
58	Overall sum
59	
60	Dectector stay clear (100 mrad)



J. Seeman (~2025)

Transverse Schematic QC1 Cryostat Layers with Warm Beam Chambers

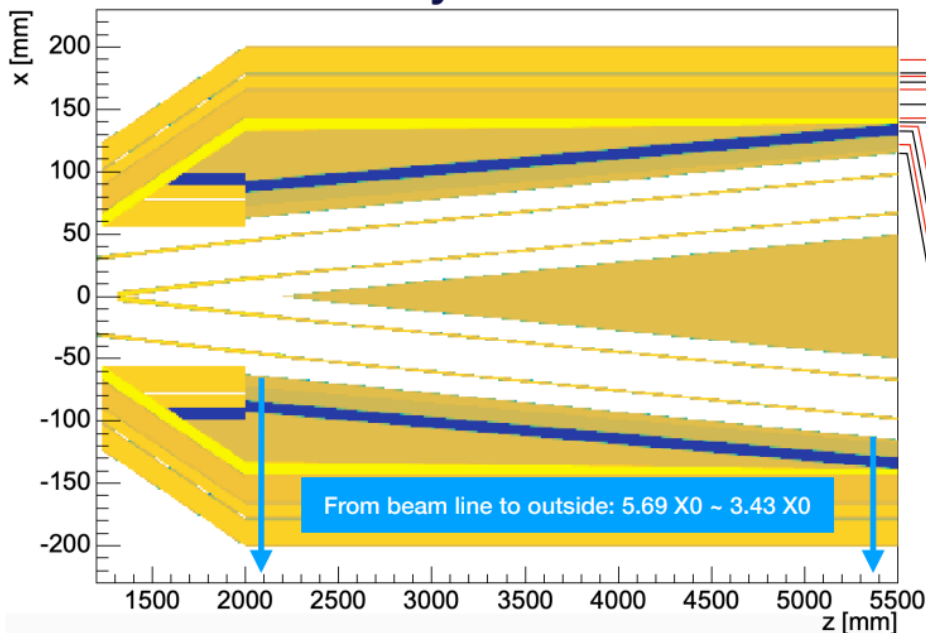


(J. Seeman ~2024)

More realistic cryostat model

<https://github.com/aciarma/k4geo/tree/cryostat#>

not for merge! branch intended for tests



20mm	Steel	Vacuum Vessel
1mm	Aluminum	Thermal Shield
2mm	Vacuum	Vacuum Gap
10mm	Steel	Helium Vessel
2mm	G10	Shim
20mm	Solenoid Mixture	Solenoid
2mm	G10	Shim
10mm to 4mm	Tungsten	Tungsten Shielding
40mm to 0mm	Aluminum	Aluminum Infill
10mm	Helium	Helium
11mm	G10	Shim
10mm to 1mm	Aluminum	Aluminum Infill

Reduced to 10 mm.

Studying if 10 mm He Vessel can hold 30 tons.

Vacuum vessel and two 1 mm beam pipes, etc, not listed here

Agreed Radial Buildup from the May 5 Meeting

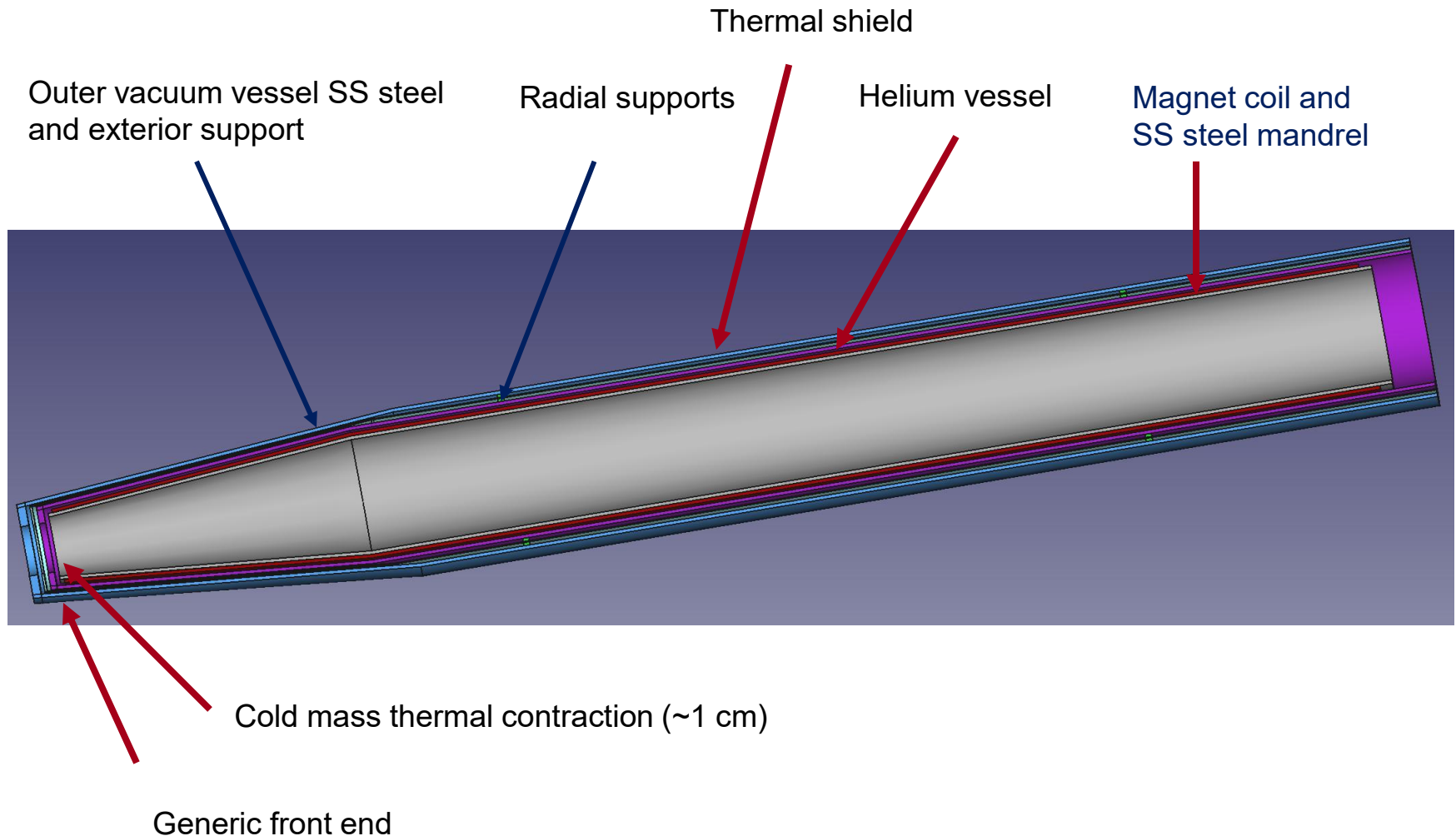
New Radial Build-up of Layers for QC1 Cryostat at 5.5 m

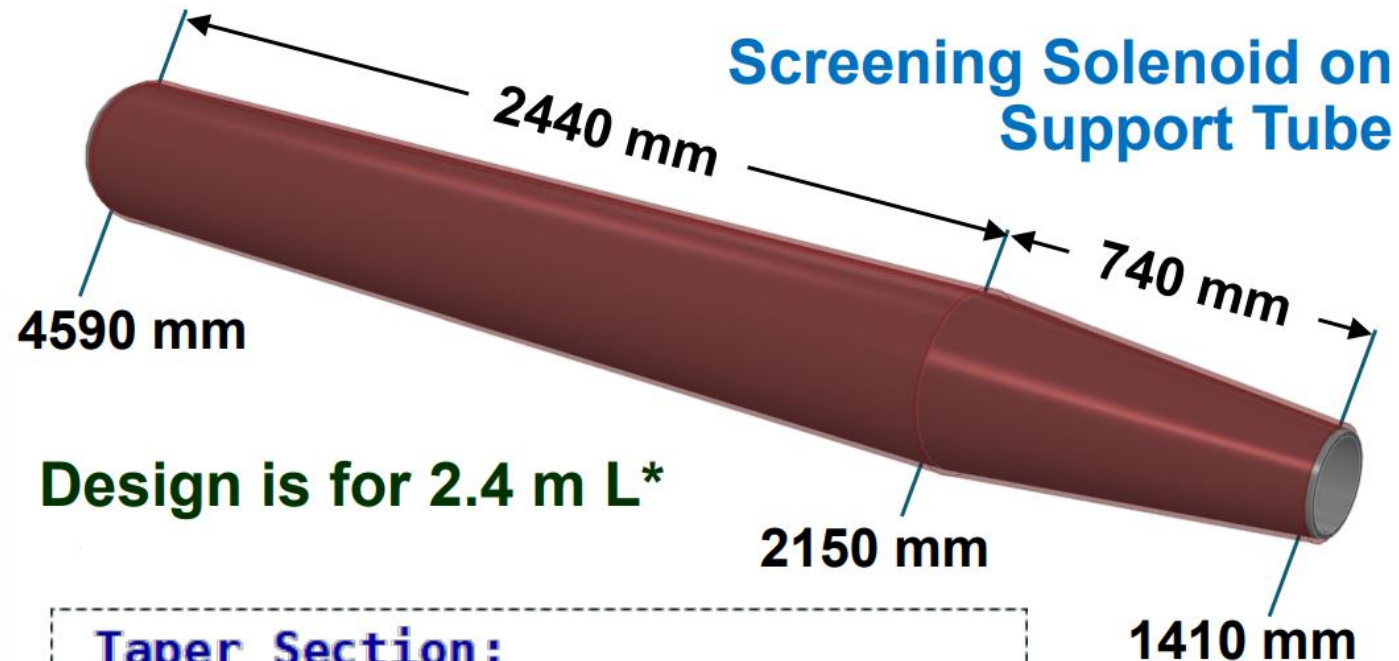
5-May-26

B. Parker, A. Ciarma, J. Seeman

Layer	Material	Name of Layer	Comments
Thickness (mm)			
10	Stainless steel	Radial force brackets	Outside to inside vacuum vessel. Too localized for background reduction
10	Stainless steel	Vacuum vessel	Outer transverse support for full cryostat.
9	Vacuum	Thermal gap	
3	Aluminum	Thermal shield	(1 or 2 mm?)
9	Vacuum	Thermal gap	
10	Stainless steel	Helium vessel	Must resist accidental helium expansion
6	Helium liquid	Helium coolant	1.9 K
10	NbTi and Cu	Solenoid coil	
10	Stainless steel	Solenoid coil support	Must transmit longitudinal solenoid forces to outboard end
1	Al/Fe/W	Background reduction	1 to 10 mm Trapezoidal shape to reduce backgrounds
5	Helium liquid	Helium coolant	1.9 K
83	Sum		

Transverse: Outer Shell (Solenoids) Cryostat Layout (B. Parker, V. Teotia, May 2026)





Design is for 2.4 m L*

Taper Section:

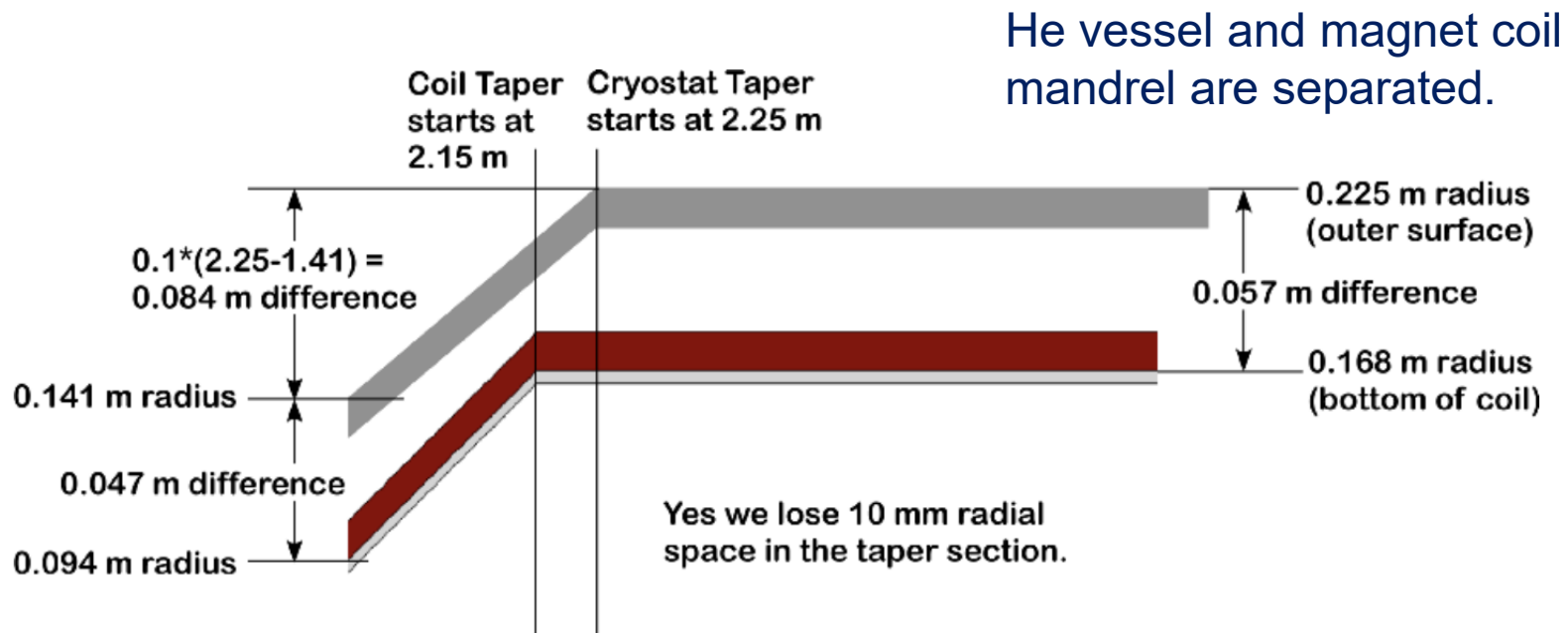
R_{in} goes from 94 to 168 mm

R_{ou} goes from 104 to 178 mm

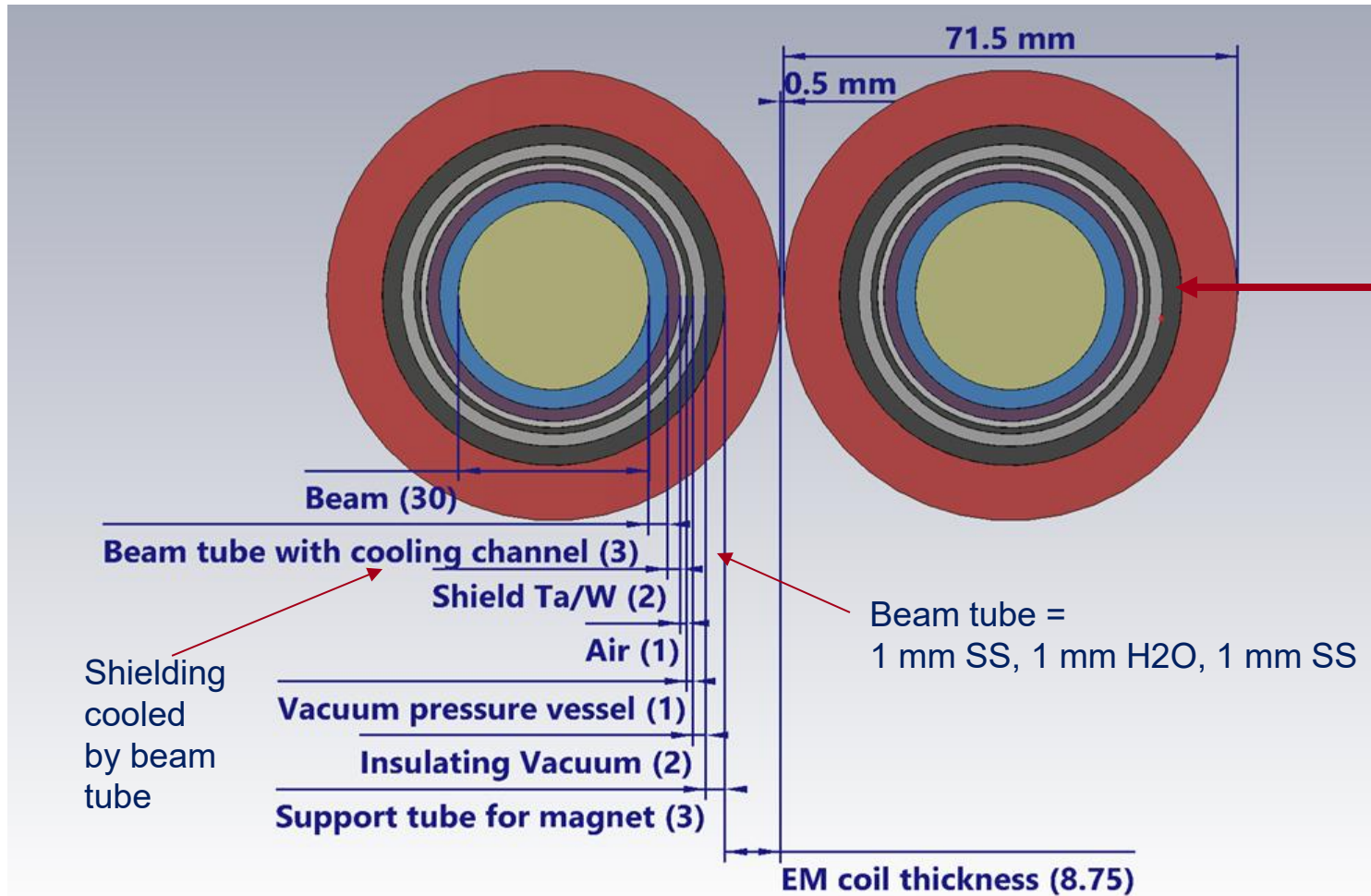
Thickness is now 10 mm

Slope = $(168-94)/740 = 0.1$ rad

Radial taper dimensions for screening-solenoids



Radial Layout in the Front of full QC1A (March 2026)



Here the magnet coil mandrel is, also, the helium vessel

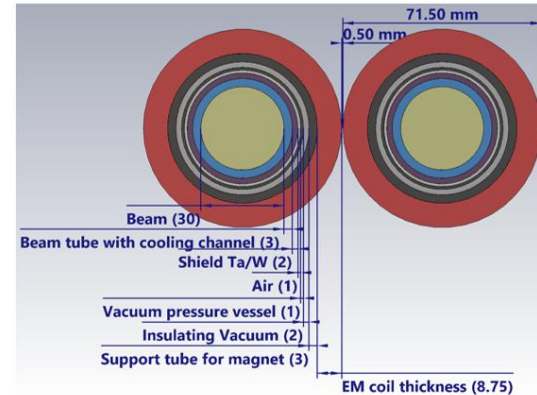
Now all layers fit due to
a) $L^* = 2.4$ m
b) Direct wind SC magnets on helium vessel.

$$L^* = 2.4 \text{ m}$$

Internal dimensions near inboard end of QC1A

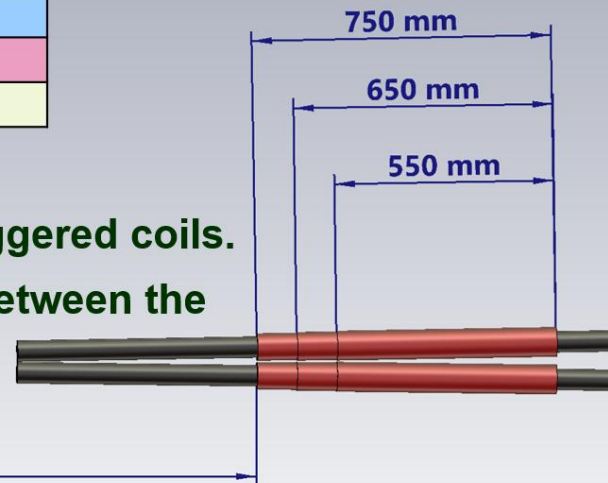
QC1: Cross section at $L^*=2.4$ meter & coil layout

Corrector space 2
Corrector space 1
Skew Quadrupole corrector : Double Helical
Main quadrupole : Double helical
Main quadrupoles : Serpentine
Main quadrupoles : Serpentine (750 mm)
Main quadrupole : Double helical (750 mm)
Skew Quadrupole corrector : Double Helical (750 mm)
Corrector space 1 (650 mm)
Corrector space 2 (550 mm)



Possible Future Options:

1. Reduce L^* below 2.4 m with staggered coils.
2. Can easily reduce dead space between the coil sections (use same tube).



B. Parker,
V. Teotia,
...

Longitudinal length build up from IP to end of QC1C.

1	IR Cryostat Component Longitudinal Positions			J. Seeman May 10, 2026
2		Preliminary	Preliminary	
3	Longitudinal Component	Start distance	End Distance	Component
4		From IR	from IR	Length
5		(mm)	(mm)	(mm)
6	Collision point	0	0	Starting point
7	Vertex chamber	0	155	AlMeMet
8	100 mrad line crosses vertex chmbr	100	100	100 mrad line
9	Vertex chamber end assembly	0	155	Coolant inlet and exit
10	Divergent chamber to LumiCal	115	1074	AlBeMet? Not to end of Divergent Chamber
11	LumiCal	1074	1190	W Tungsten sandwich
12	BPM module and utility gap	1190	1240	4 buttons
13	Bellows module	1240	1280	Elliptical shape
14	Chamber before remote flange	1280	1380	
15	Y Chamber tip start before Remote Flg	1280	1280	0
16	First half Remote Flange	1380	1410	30
17	Second half Remote Flange	1410	1440	30
18	Chmbr remote flange to pipe flange	1440	1596	156
19	Pipe flange	1596	1630	34
20	Distance flange to cryo vacuum vessel	1630	1640	10
21	Cryo vacuum vessel	1640	1655	15
22	Cryo vacuum gap	1640	1645	5
23	Cryo thermo shield	1645	1648	3
24	Cryo vacuum gap	1648	1663	15
25	Cryo He vessel	1663	1688	25
26	Cryo He vessel bellows (warm)	1688	1718	30
27	Mandrel from He bellows to magnet(cold)	1718	2200	482
28	Cryo Quad QC1R0, BC0.1	2200	2350	150
29	Mandrel longitudinal quad gap	2350	2400	50
30	Cryo Quad QC1R1	2400	3150	750
31	Mandrel longitudinal quad gap	3150	3250	100
32	Cryo Quad QC1R2	3250	4500	1250
33	Mandrel longitudinal quad gap	4500	4600	100
34	Cryo Quad QC1r3	4600	5850	1250
35	Mandrel gap to He vessel end plate	5850	5930	80
36	He vessel end plate	5930	5970	40
37	Gap He vessel to thermal shield	5970	5975	5
38	Thermal shield	5980	5985	5
39	Gap from thermal shield to vacuum vessel	5985	5990	5
40	Pressure vessel thickness	5990	6030	40

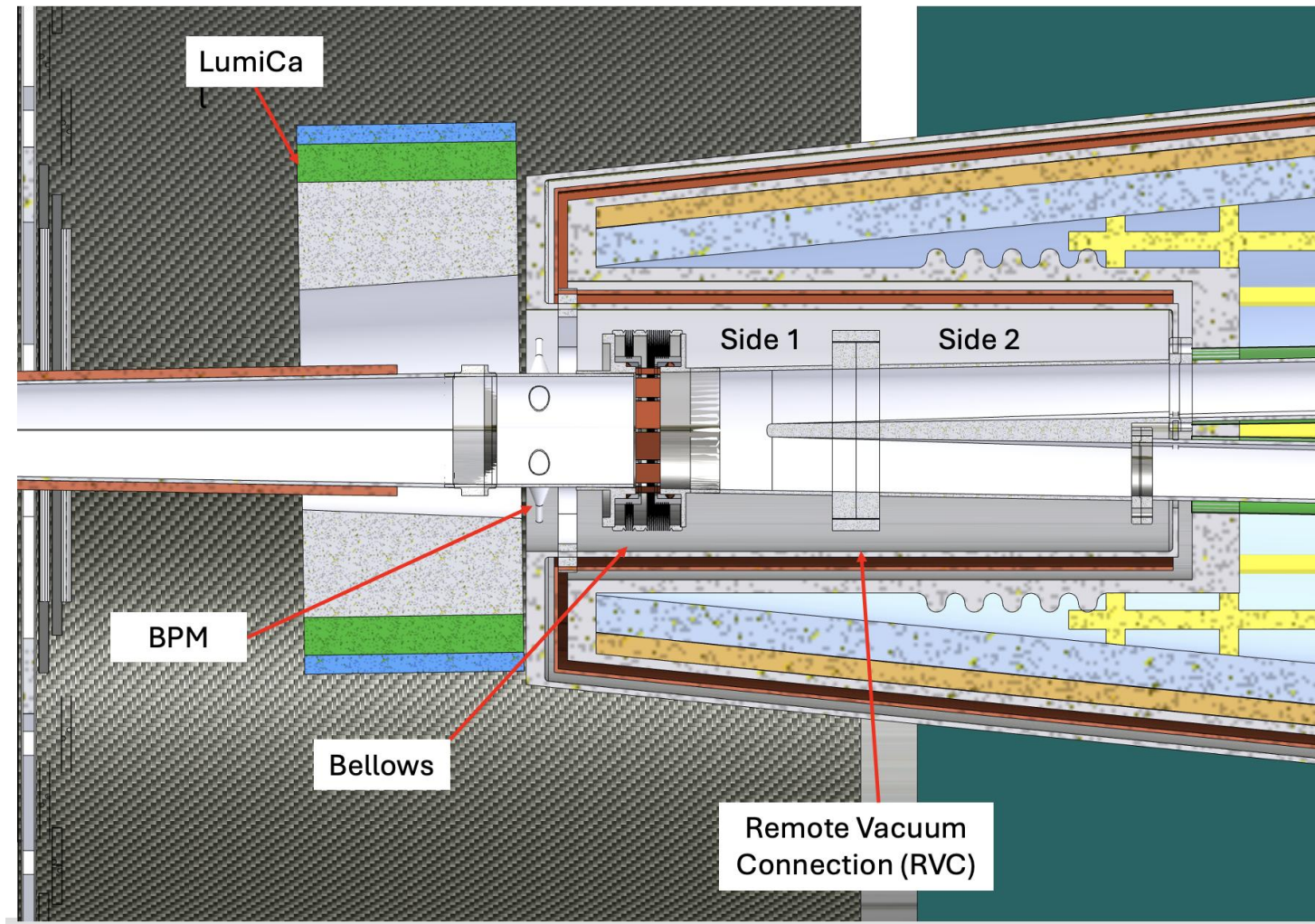
November 2025

Detector beam pipes



Present FCCee IR magnet cryostat (Francesco Franesini)

SLAC



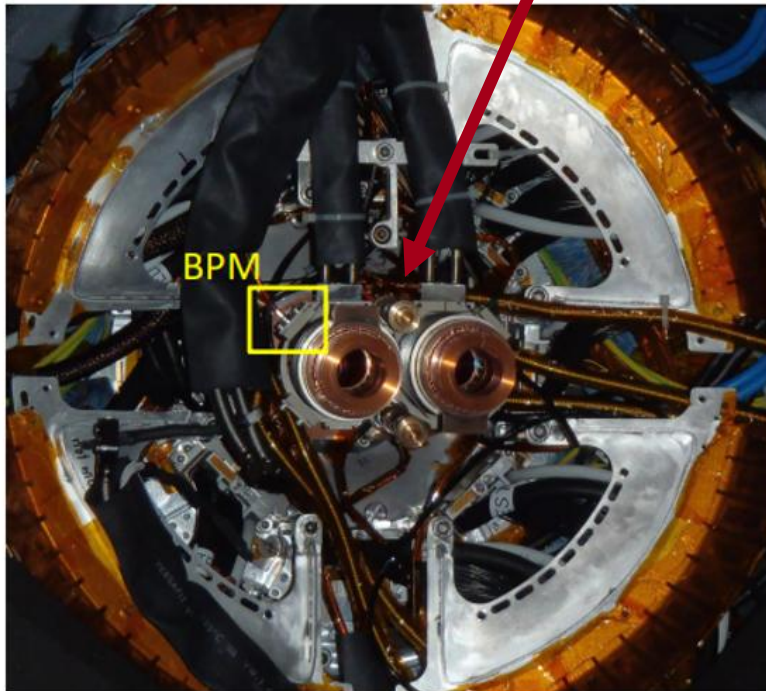
Circa ~2024

Remote Flange at SuperKEKB (before pipe merger)

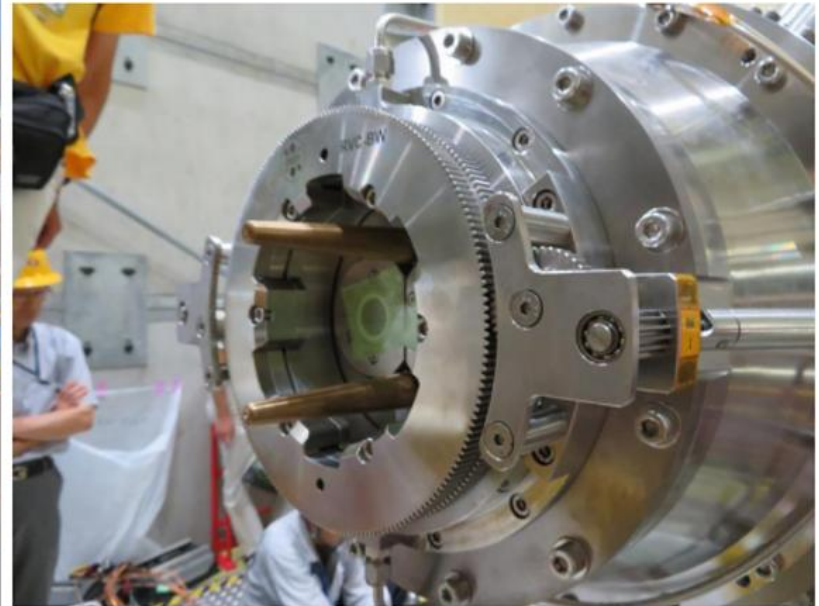


How the in-board BPM, bellows and magic flange are positioned and supported, overall alignment, vibration control, etc.

Dual bores



DESY design

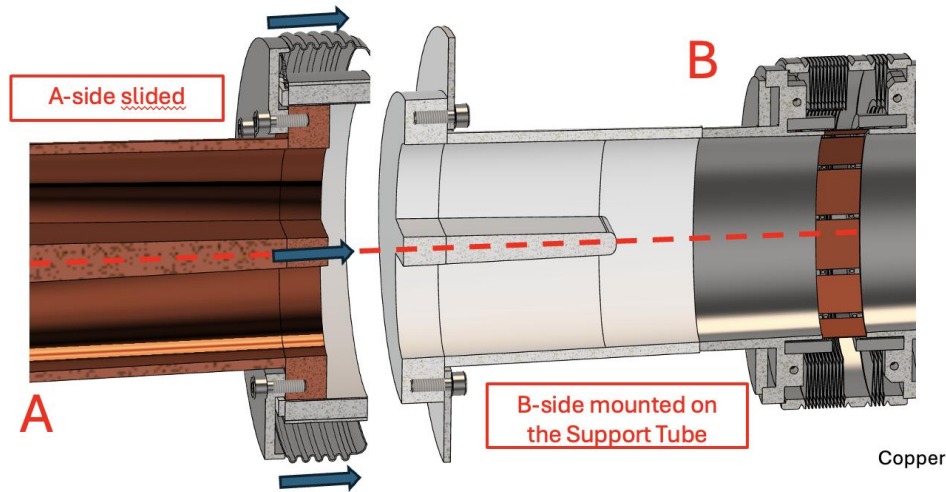


(M. Tobiyama et al)

Concept for FCC Remote Flange: Shape Memory Alloy

SLAC

A **shape memory alloy (SMA)** is a material that can recover a large pseudoplastic deformation through heating. This process can be **reversible using two-way shape memory alloy**, this material can switch between **two different shape simply by heating and cooling**. In this way is possible to create a connection dismantlable between two parts.

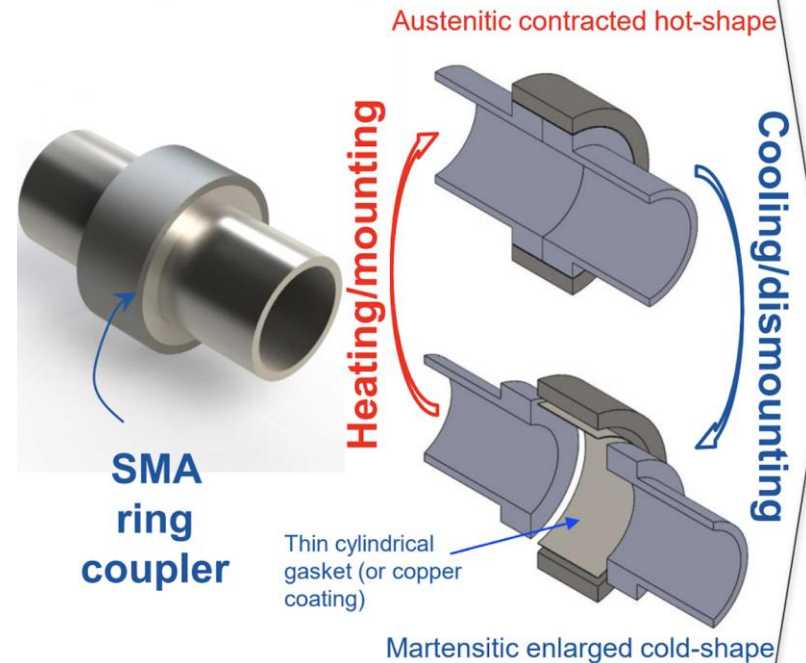


In progress:

- **Positioning system design** (in order to reach the tolerances needed for the gasket mounting)
- **Dismounting system** (cooling system for SMA ring expansion + easy gasket removal)

Complex sealing surface and alignment

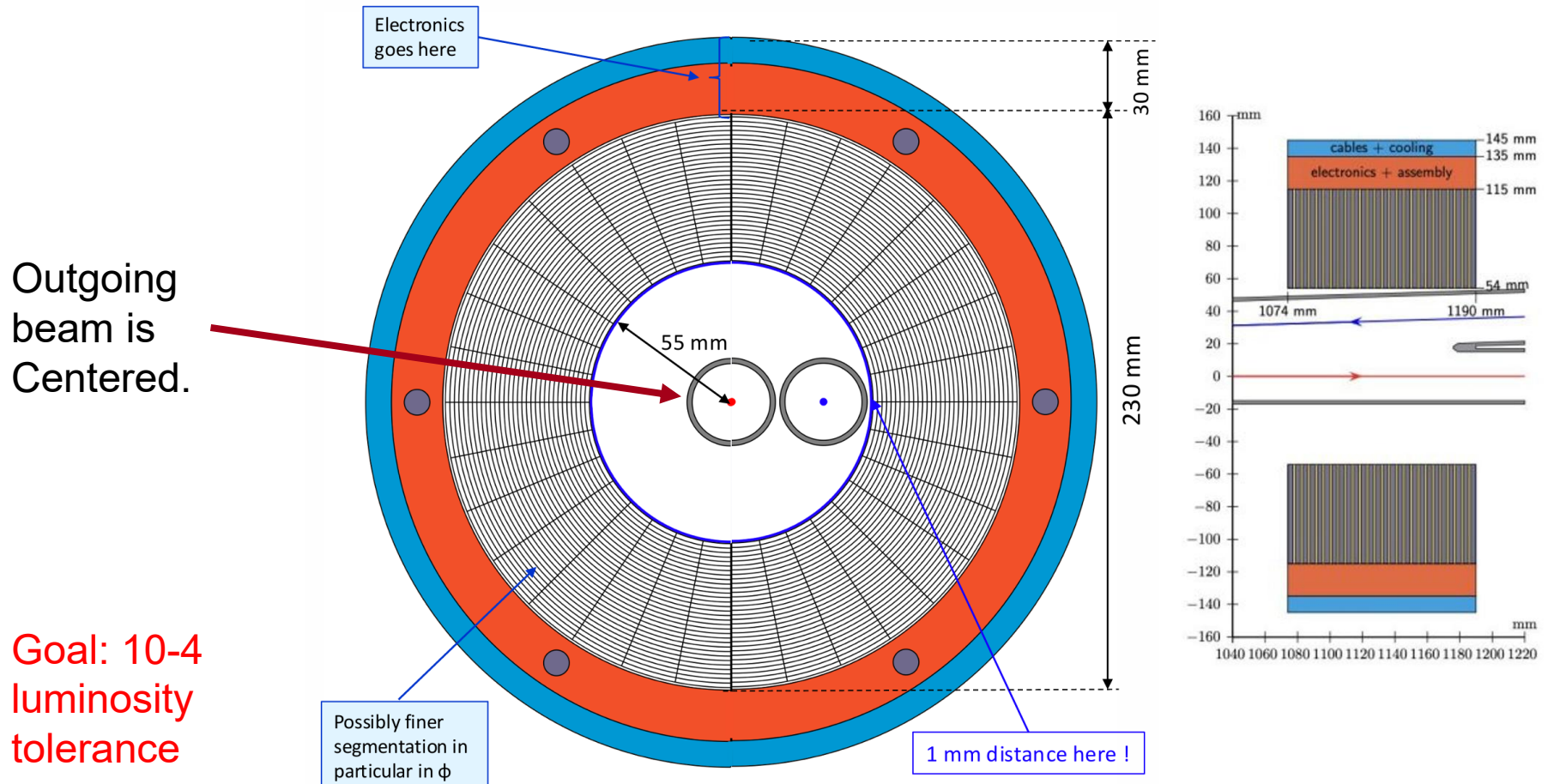
Shape memory alloy couplers



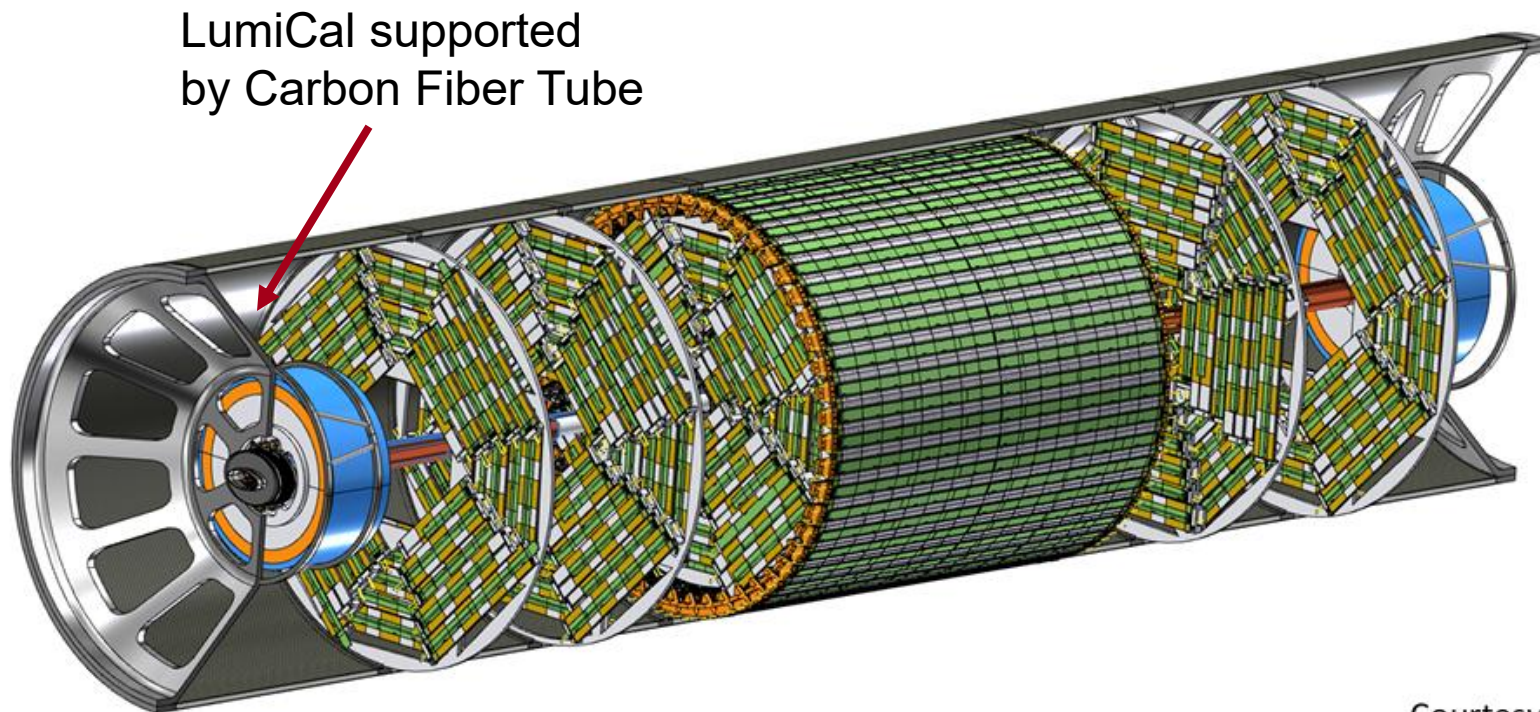
F. Niccoli, F. Fransesini ~2024

LumiCal Dimensions

LumiCal bore allows accelerator bellows and remote vacuum flange to pass.



Central Chamber with IDEA Detector Components



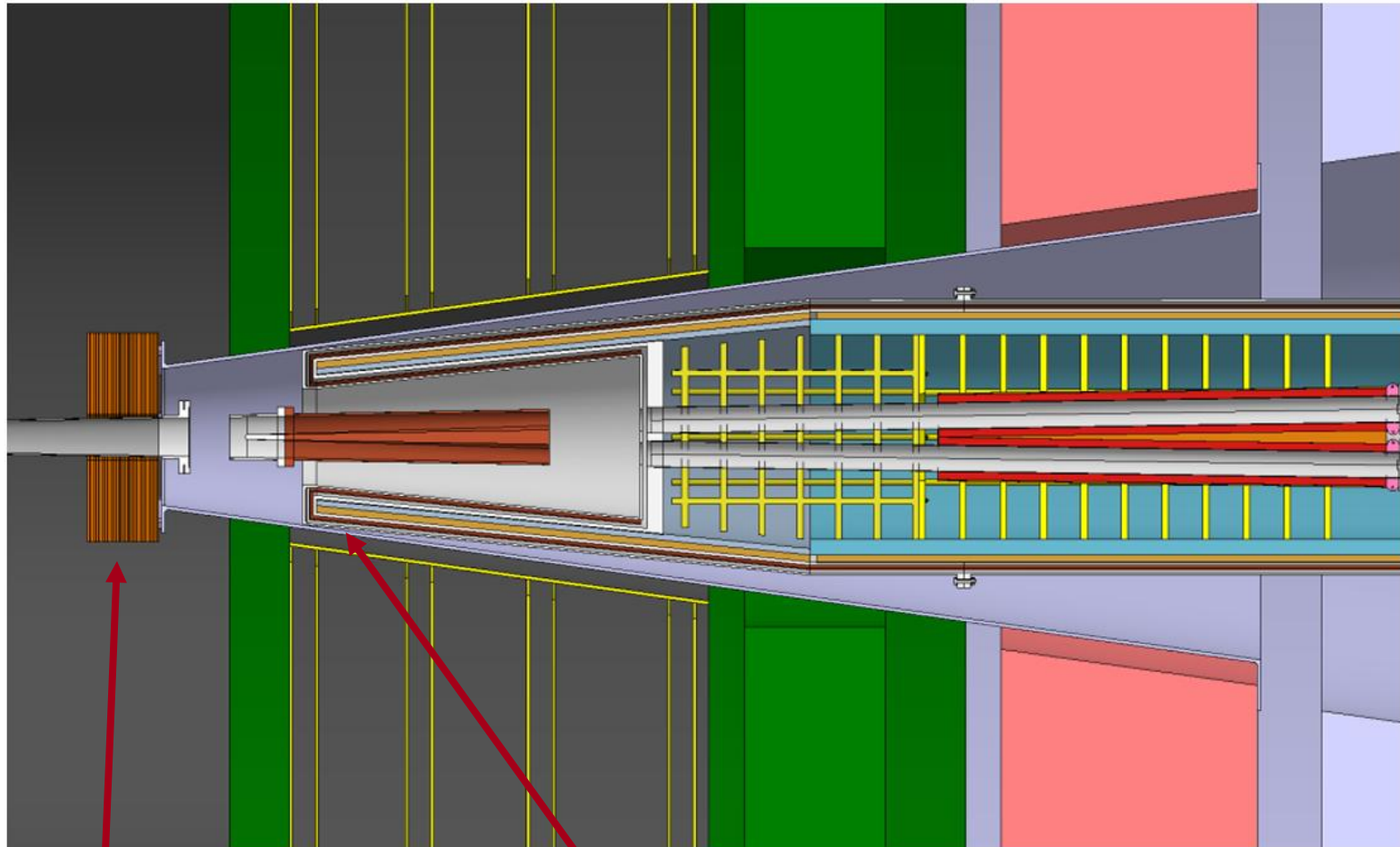
Courtesy F. Palla

LumiCal support concept for the ALFA Detector

SLAC

Where does moving detector endcap start?

End LumiCal support ↓



LumiCal bore too small?

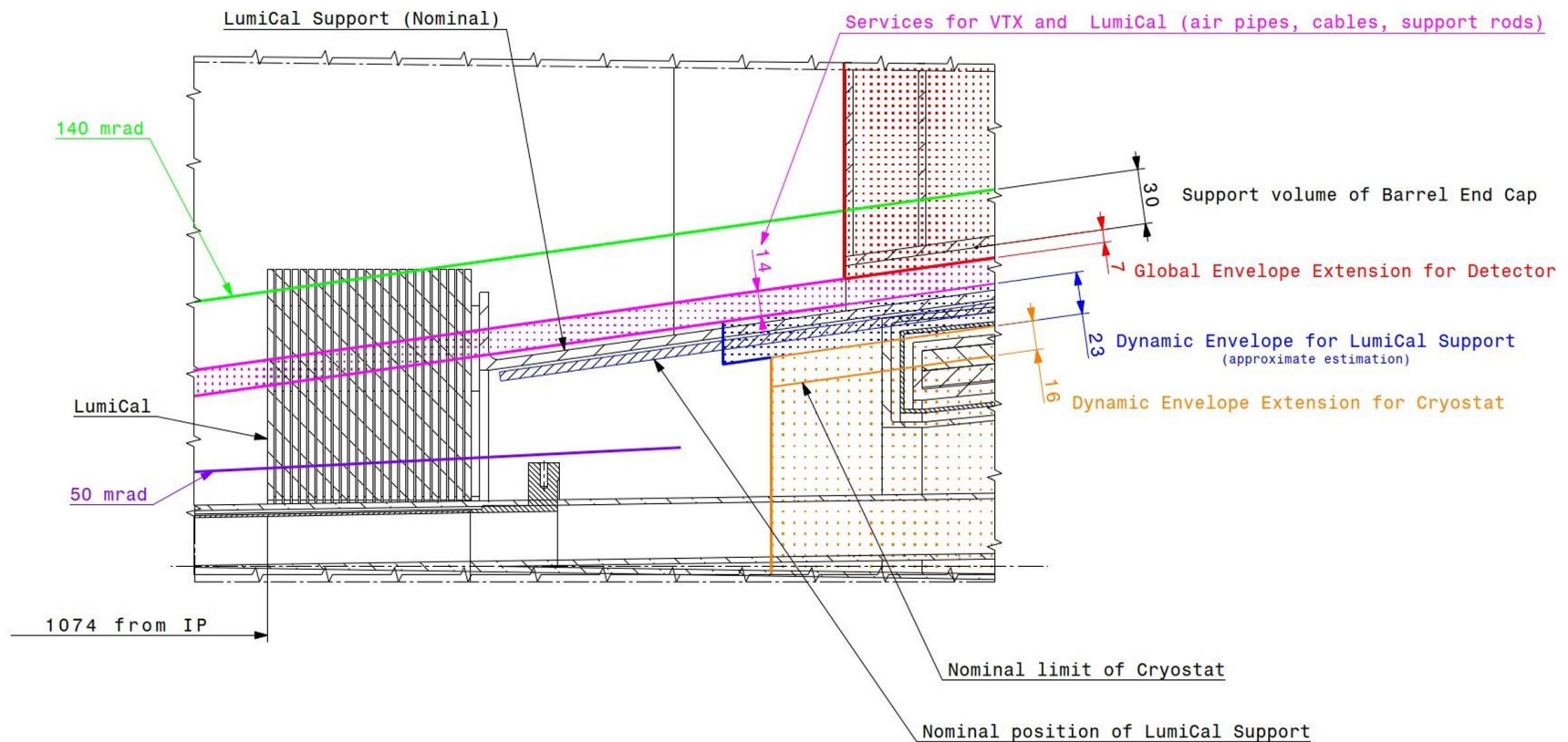
Need space for
cryostat utilities

G-G Kerr, O. Beltramello

Interface between the Magnet Cryostat and ALFA Utilities

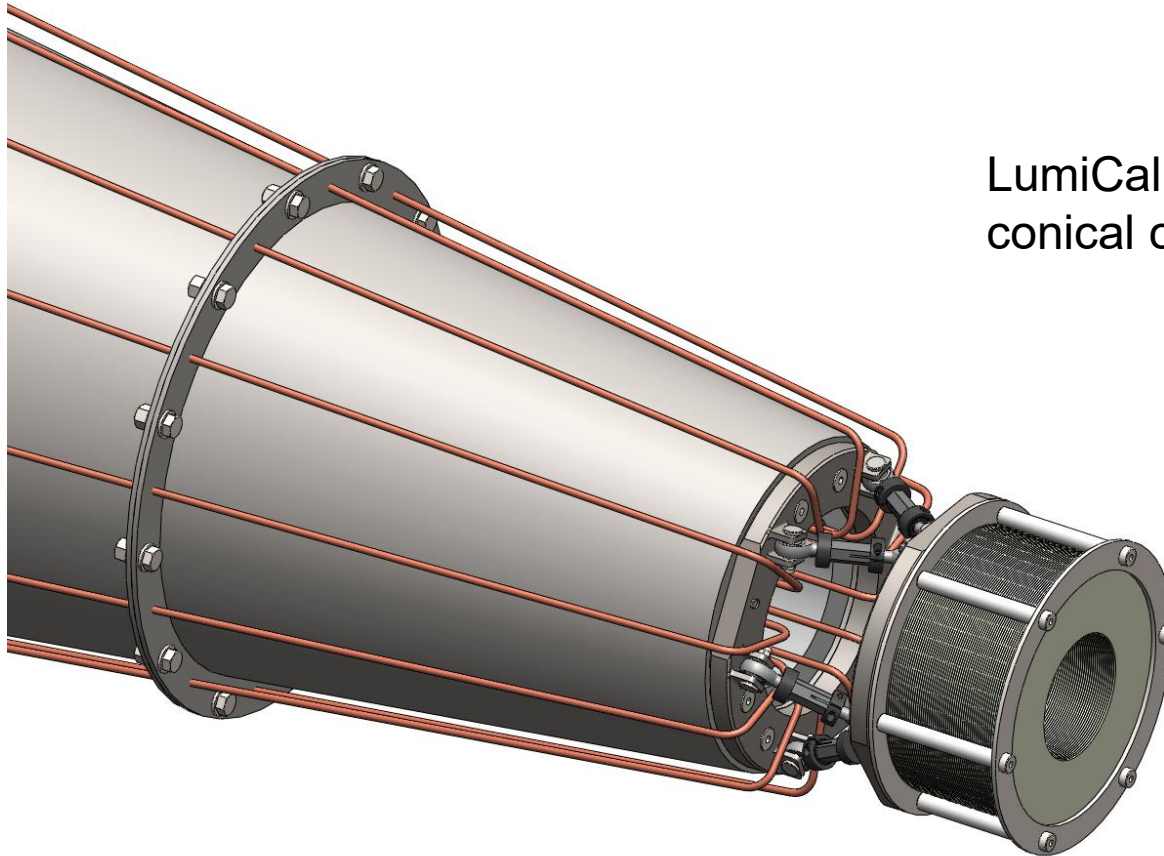
In development

Current situation between the detector envelope and the environment for ALFA detector



D. Diyalov, O. Beltamello

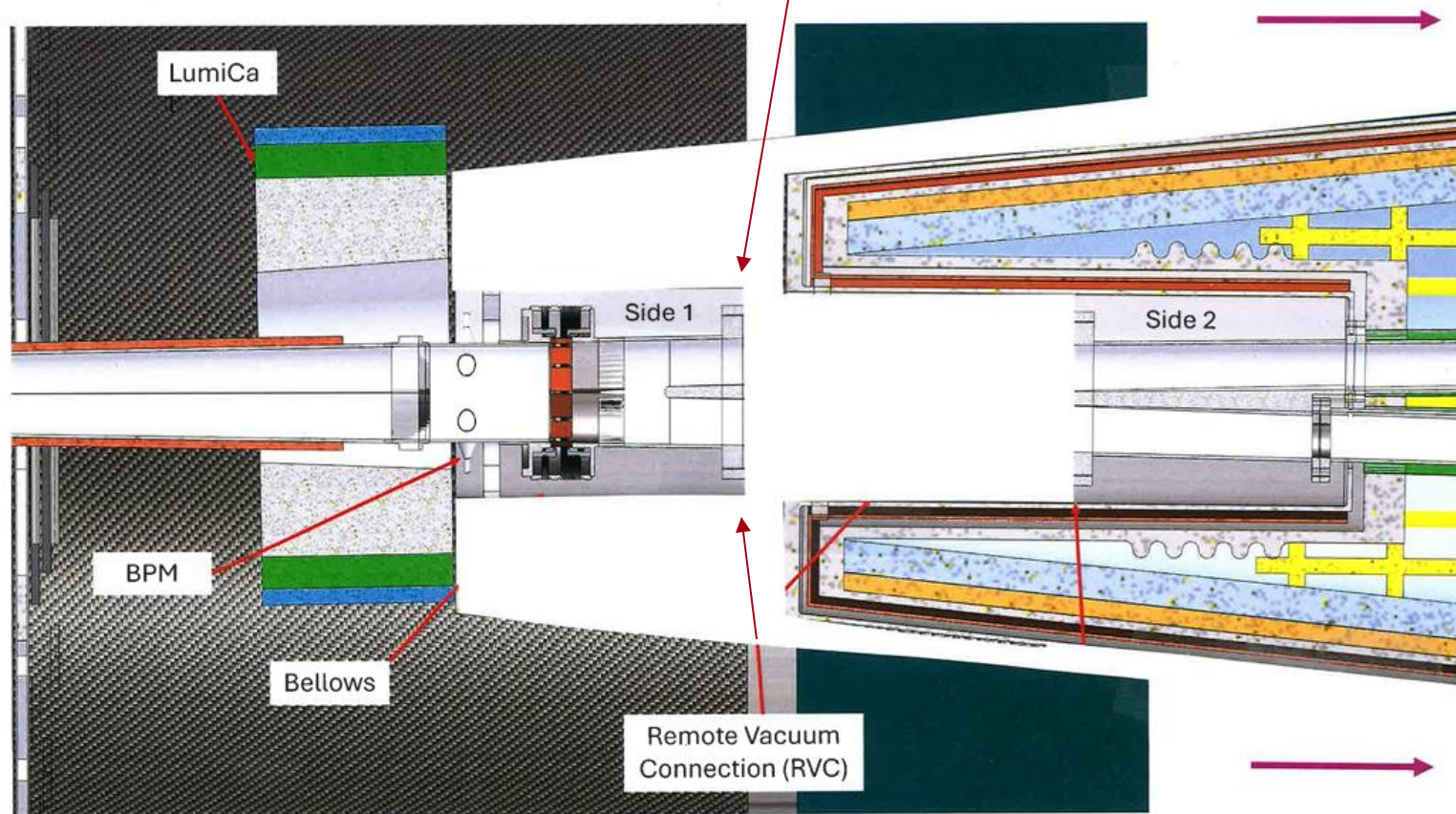
LumiCal Support and Utilities (SLAC)



LumiCal support design with conical connection.

Removal of the SC Magnet Cryostat: Utilities and Supports?

Supports and Alignment?

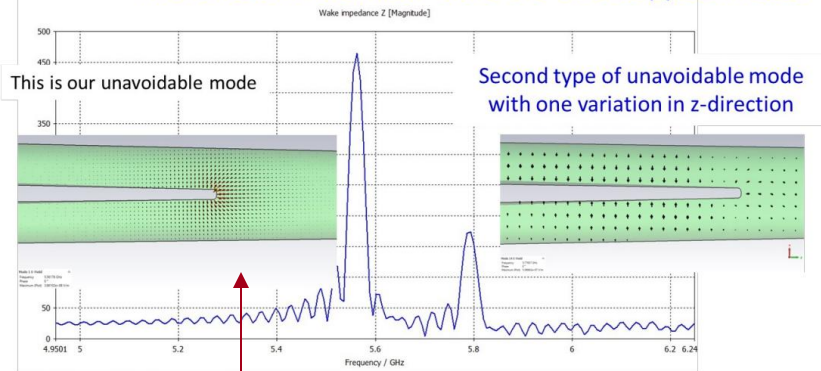


Needs “rails” for support and alignment!

Vacuum Chamber Higher Order Modes (HOMs) (A. Novokhatski Jan 2026)

SLAC

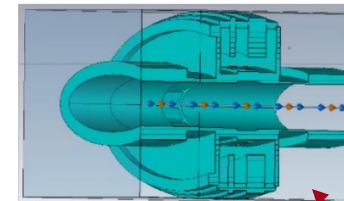
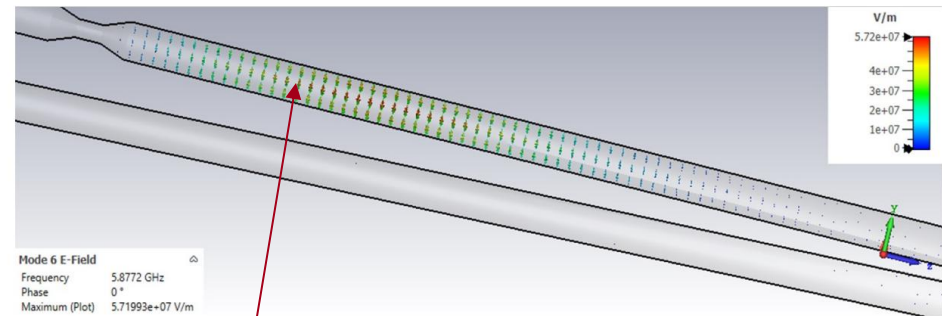
In the new IR chamber there are two trapped modes



Second trapped modes is due to lengthening the mutual pipe

Two trapped modes leading to heating in Y chamber

An additional trapped mode due to the elliptical mask



Trapped mode between SR mask and IP

Beam heating in IP bellows by small HOMs

Total Beam Heating in IR (A. Novokhatski Jan 2026)

Some IR HOM beam power travels down the beam chambers away from the IR.
Some IR HOM beam power is absorbed in the IR chambers, shown in table below.

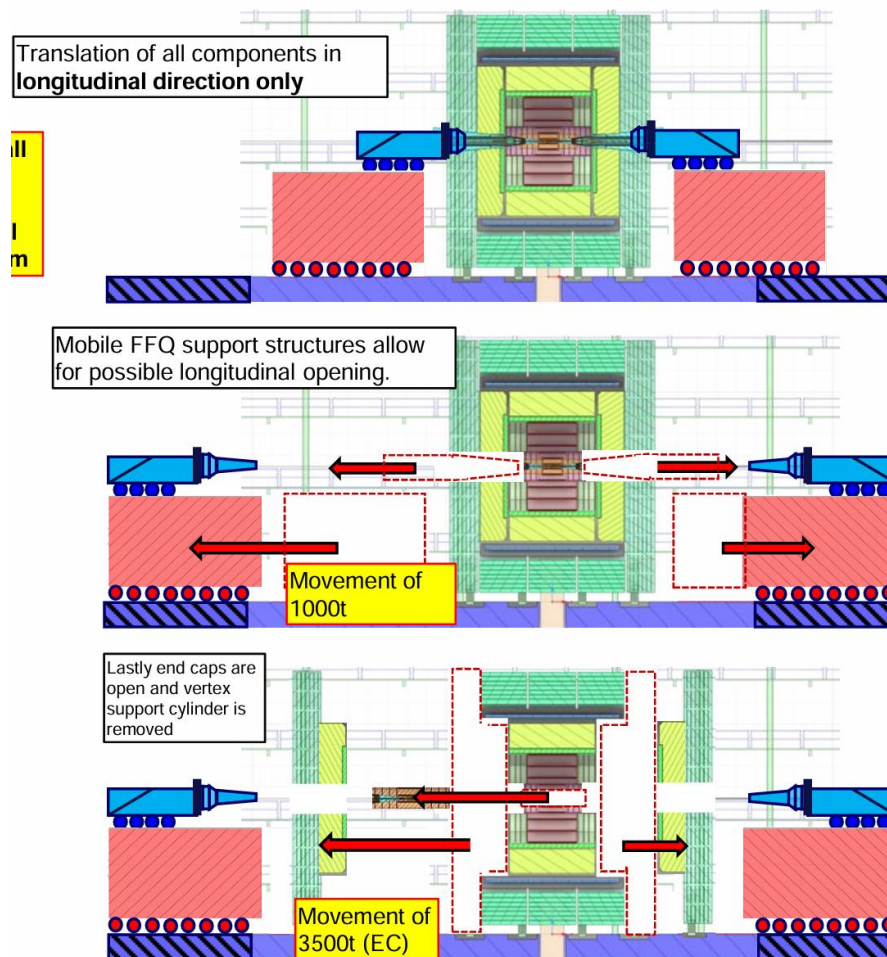
Parameter	Z	WW	H(ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [A]	1.292	0.135	0.0268	0.0051
number of bunches/beam	11200	1856	300	60
rms bunch length [mm]	15.20	5.40	5.59	2.33
Circumference [m]	90658.82	90658.82	90658.82	90658.82
average bunch spacing [ns]	28.20	170.20	1052.95	5264.74
Energy beam power loss in IR [W]	3274.69	671.50	157.22	76.61



All IR chambers must be water cooled (only allow ~1 cm gap in cooling).

Magnet Cryostat in the Detector Cavern

Longitudinal opening scenario (side view)



Detector endcap is removed longitudinally after magnet cryostat is removed.

Estimated Calendar Time required to remove and replace magnet cryomodules during CERN Year End Technical Stops YETS

13			
14		Time duration	Time duration
15	Cryostat removal /reinstall task	One IR side	Eight IR sides
16		(hours)	(hours)
17	Accelerator IR Removal		
18	Beam measurements of ending beam/accel status	2	4
19	Mechanical survey meas'ts in operating condition	10	20
20	Vacuum vent Raft1 Q1 and secure	4	8
21	Vacuum vent Raft2 Q2 and secure	4	8
22	Vacuum vent Raft3 and secure	4	8
23	Cryo warm up Raft 1+Raft 2+junction boxes+secure	24	48
24	Disconnect remote flange	2	4
25	Electrically disconnect Raft 1+secure cables	8	16
26	Electrically disconnect Raft 2+secure cables	8	16
27	Electrically disconnect Raft 3+secure cables	8	16
28	Crane out and store Raft 3	8	16
29	Crane out and store Raft 2	8	16
30	Roll out and secure Raft 1	8	16
31	Roll out Raft 4 sub-base and secure	4	8
32			
33	Total time (hours) ready to move detector end-cap	102	204
34	Total time (Days)	12.75	25.5
35			
36	Accelerator IR Reinstallation		
37	Roll in Raft 4 sub-base and secure	4	8
38	Roll in and secure Raft 1	16	32
39	Survey and align Raft 1	16	32
40	Reconnect remote flange	4	8
41	Crane in and secure Raft 2	8	16
42	Survey and align Raft 2	12	24
43	Crane in and secure Raft 3	12	24
44	Survey and align Raft 3	8	16
45	Electrically reconnect Raft 1 and verify	16	32
46	Electrically reconnect Raft 2 and verify	16	32
47	Electrically reconnect Raft 3 and verify	6	12
48	Vacuum pump down Raft1 Q1 and secure beam pipe	8	16
49	Vacuum pump down Raft2 Q2 and secure beam pipe	6	12
50	Vacuum pump down Raft3 and secure beam pipe	4	8
51	Cryo cool down Raft2 Q2 and junction box+secure	16	32
52	Cryo cool down Raft1 Q1 and junction box+secure	16	32
53	Beam measurements & fix beam/accel conditions	16	32
54			
55	Total time (hours) to restore after detector end cap	184	368
56	Total time (days)	23	46
57			
58	Overall total days (8 hrs/day)	35.75	71.5

J. Seeman June 2026

Assumed shared crews.

36 days for 1
detector endcap

72 days for 8
detector endcaps

Forward cryostat tasks

- Identify near-IR differences between detectors (~ 5) relative to their cryostats.
- Finalize screening solenoid specifications.
- Specify all cryostat beamline magnet correctors.
- Determine cryostat front-end (reentrant) components (inboard of 2.4 m).
- Develop concepts for support of beamline components, LumiCal, and VTX.
- Define utility pathways between cryostat and the detector fiducial volume.
- Collect safety requirements (pressure & He vessels, earthquakes, assembly)

Thank you for your participation.

END
FIN
FINE
ENDE
LOPPUA