IR Magnet System

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SLAC National Accelerator Laboratory
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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Topics covered

FCCee IR Status:

Magnets

Cryostats

Comparisons to SuperKEKB (ongoing)

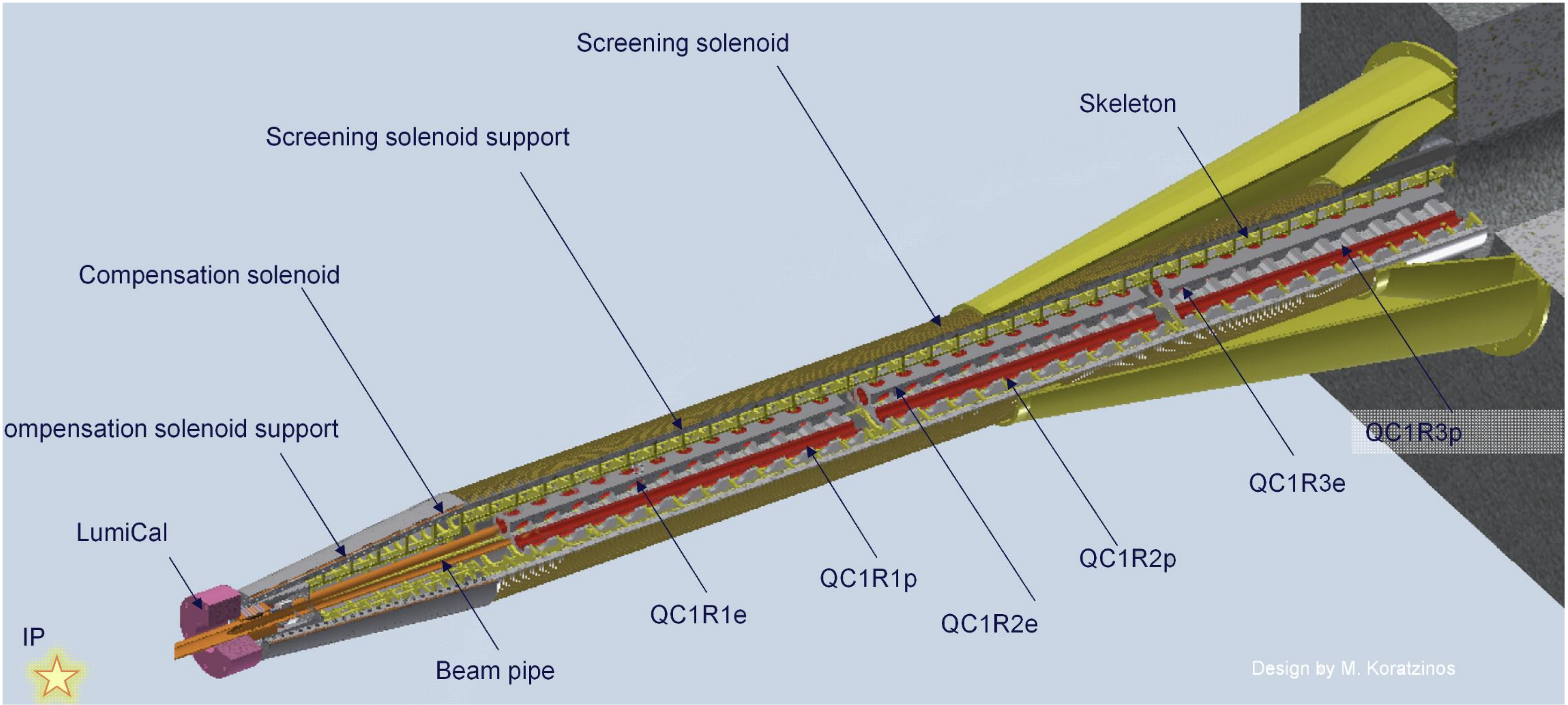
Comparisons to CEPC (TDR in December 2023)

Tasks for 2024-2025

Thank you for help from:

P. Borges de Sousa, M. Boscolo, S. DeBarger, A. Foussat, M. Koratzinos, A. Novokhatski, N. Ohuchi, B. Parker, P. Raimondi, M. Sullivan, F. Zimmermann, …

Nominal FCCee magnet raft and cryostat



(M. Koratzinos, …)

FCCee IR magnet longitudinal locations, lengths, and strengths (K. Oide)

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Present separation of QC1 to QC2 is 30 cm.
New Raimondi lattice has separation at 1.5 m.

quads	L (m)	s (near)	s (far)	B' @Z(T/m)	B' @tt(T/m)
QC2L2	1.25	-7.190225	-8.440225	14.714061	62.103023
QC2L1	1.25	-5.860225	-7.110225	16.568025	41.767626
QC1L3	1.25	-4.310225	-5.560225	-18.109897	-99.714408
QC1L2	1.25	-2.980225	-4.230225	-24.629491	-88.924038
QC1L1	0.7	-2.200225	-2.900225	-43.72333	-96.796669
QC1R1	0.7	2.200225	2.900225	-43.72333	-96.796669
QC1R2	1.25	2.980225	4.230225	-30.963853	-97.183137
QC1R3	1.25	4.310225	5.560225	-15.401024	-82.712171
QC2R1	1.25	5.860225	7.110225	41.716447	17.331058
QC2R2	1.25	7.190225	8.440225	2.96821	62.122116

Z: FCCee_z_575_nosol_5_bb.sad
tt: FCCee_t_572_nosol.sad

K. Oide
27 Sep 2023

K. Oide is available to discussion any needed changes. P. Raimondi's lattice has more space from QC1 to QC2.

Alternative IR Solenoid Compensation Scheme

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A. Ciarma†, M. Boscolo, INFN-LNF, Frascati, Italy
H. Burkhardt, CERN, Geneva Switzerland and Univ. Freiburg, Germany
P. Raimondi, Fermilab, Chicago, USA

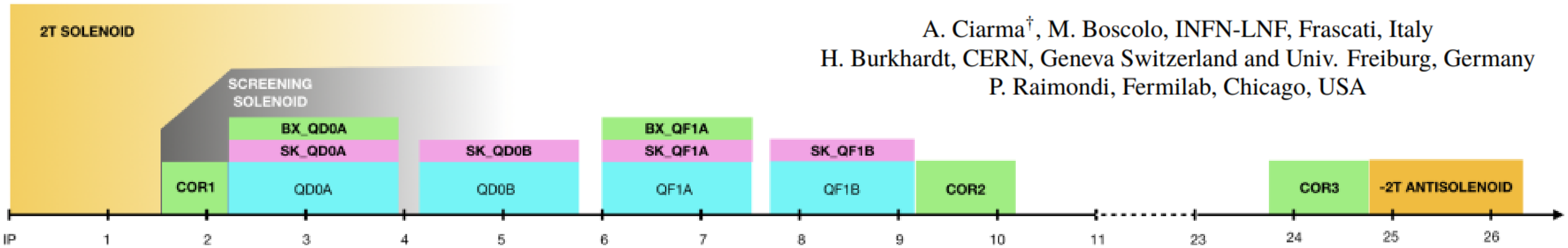


Figure 2: Layout of the standard solenoid compensation scheme for LCCO lattice v92.

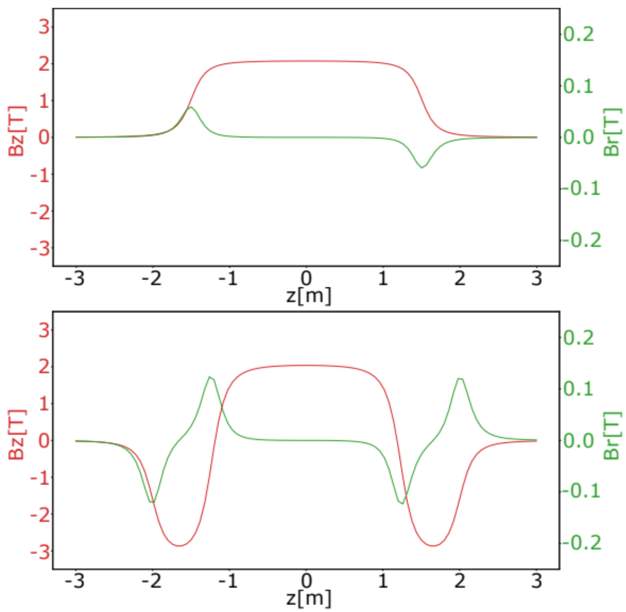


Figure 1: Longitudinal (red) and radial (green) magnetic fields along the 15 mrad axis in the two compensation schemes (standard proposed here on the top, baseline on the bottom).

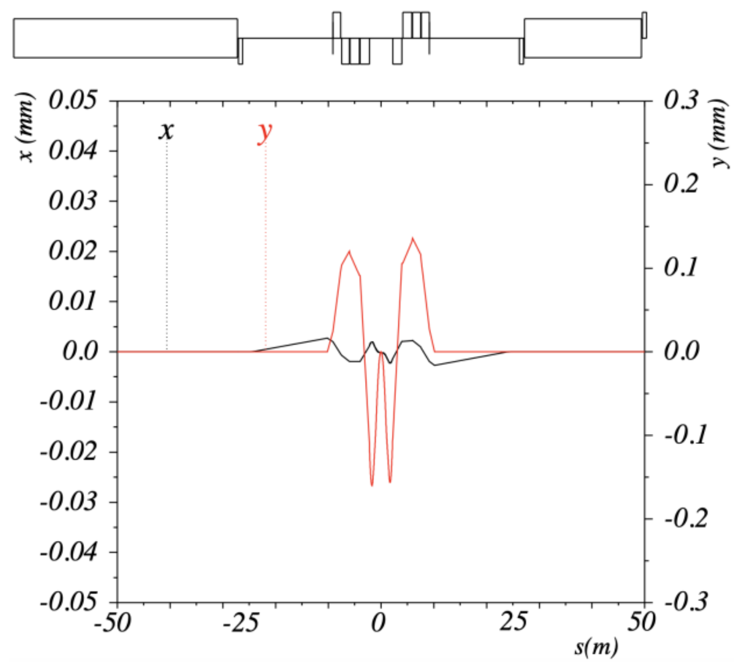


Figure 3: Horizontal and vertical orbit bumps.

FCCee IR SC CCT magnet QC1 tests (Fall 2023) (M. Koratzinos …)

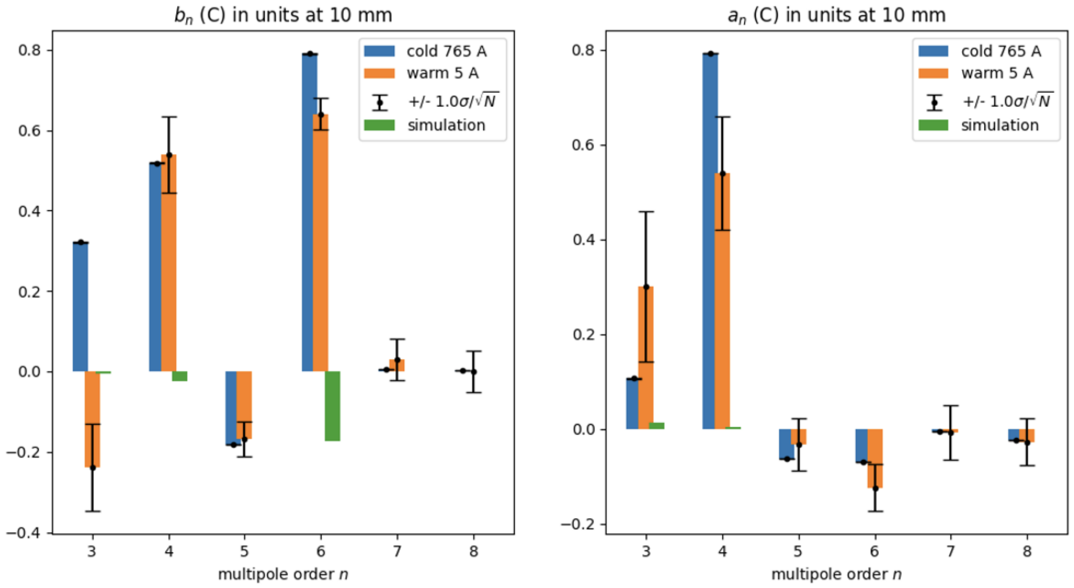
The test at SM18

- Cryostat supporting 1.9K superfluid helium
- Training campaign
- Measurement of splice resistance
- Measurement of quenchback
- Measurement of RRR

M. Koratzinos

Field quality - cold

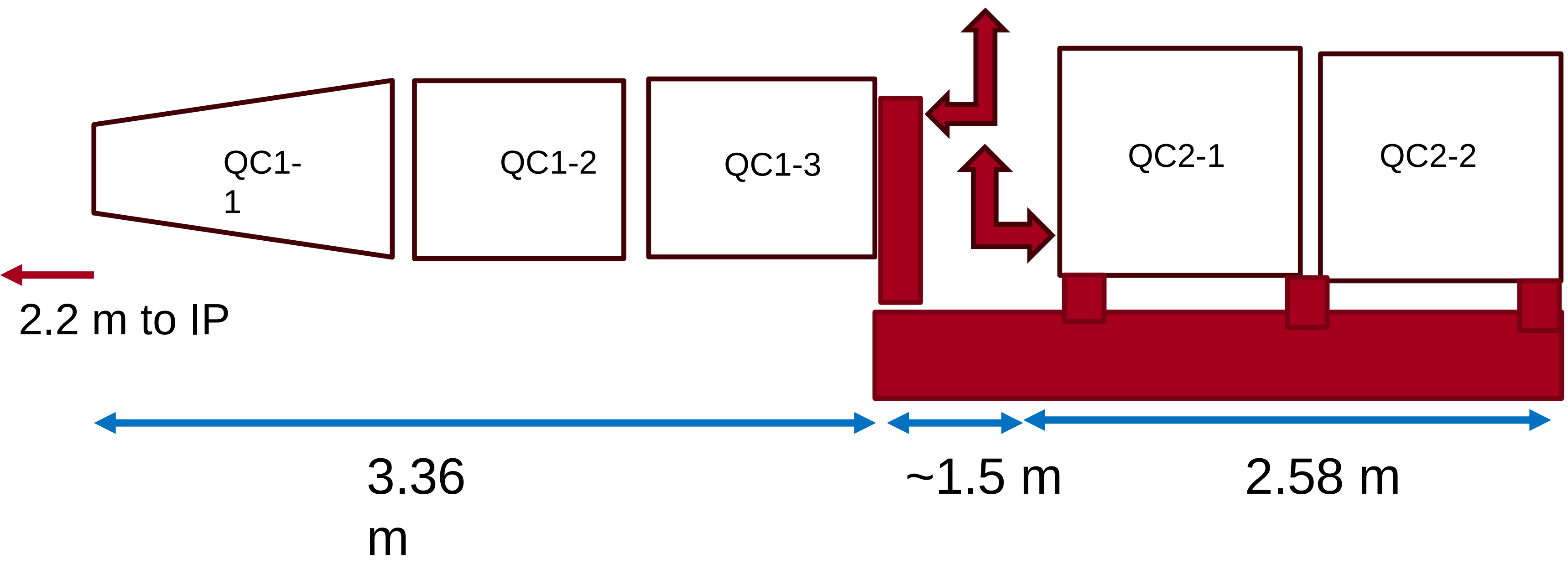
- Work under way, but already <1unit for all multipoles
- We did not do the same trick during cold measurements
- The 'warm' measurements below come from the unrotated data



FCCee IR Cryostat (preferred option):

IR QC1 and QC2 in different cryostats but one integrated raft (not to scale)

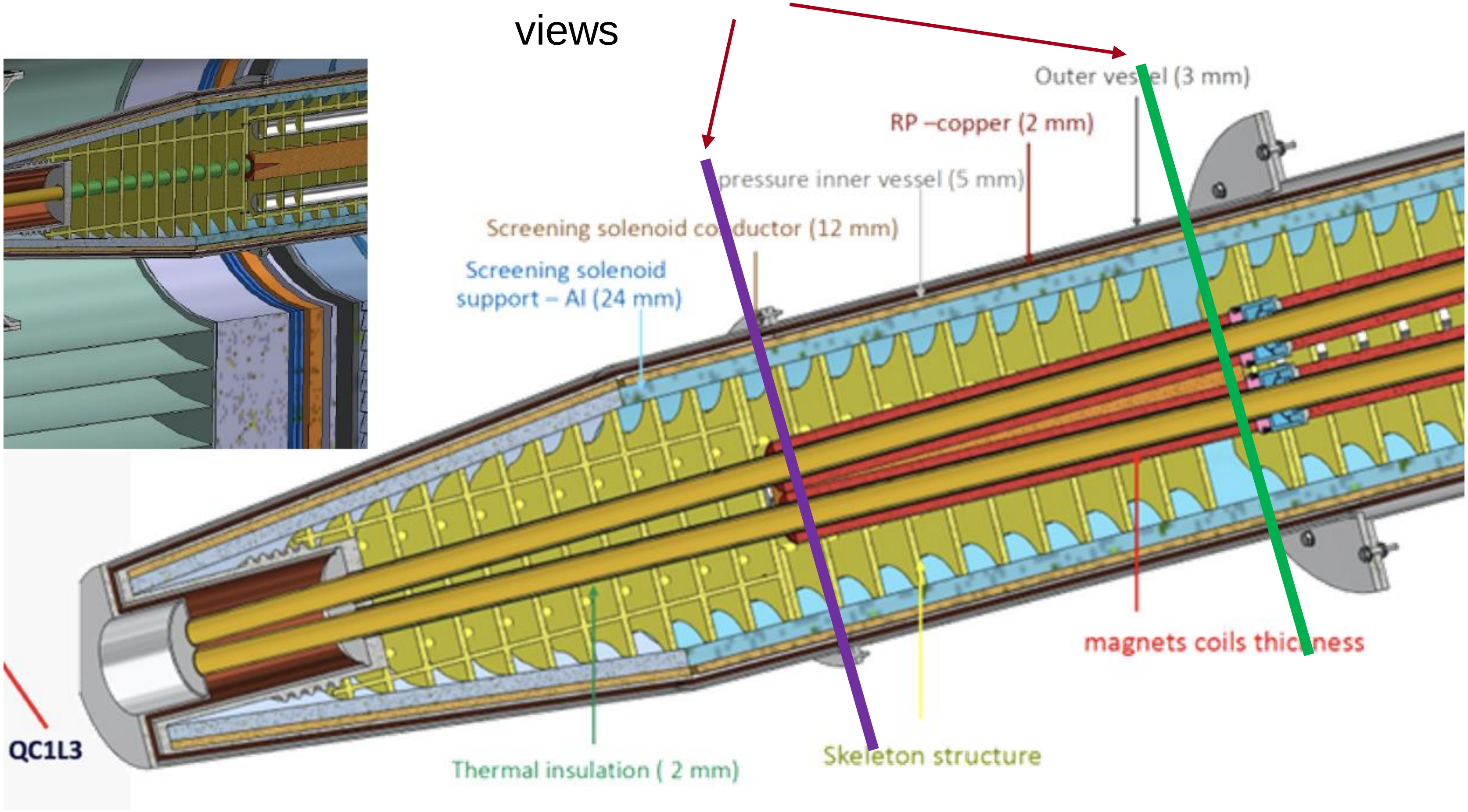
Need to make space for cryogens, leads, and cantilever supports.



Needed functions for the space between QC1 and QC2

1) Beam pipes (cold vs warm)
2) e+ and e- BPMs (radial space)
3) Cantilevered supports (many forces)
4) Detector shielding near beam pipe (backgrounds and magnet quenches)
5) Vibration mitigation and control (orbit control)
6) Two cryostat end caps, cryogenic ports, disconnects (cryogen flow, heat load)
7) Magnet leads (warm to cold)
8) Alignment (internal positioning, remote)
9) Instrumentation (what to measure and how)
10) Remote operation flange controls and access (design, safe operation)
11) Vacuum disconnects (locations)
12) Assembly strategy (order of installation)
13) Cool down radial differential movements ($\Delta r/r$ ~3x10^-3, 0.5 mm movements)
14) Cables (routes, numbers)

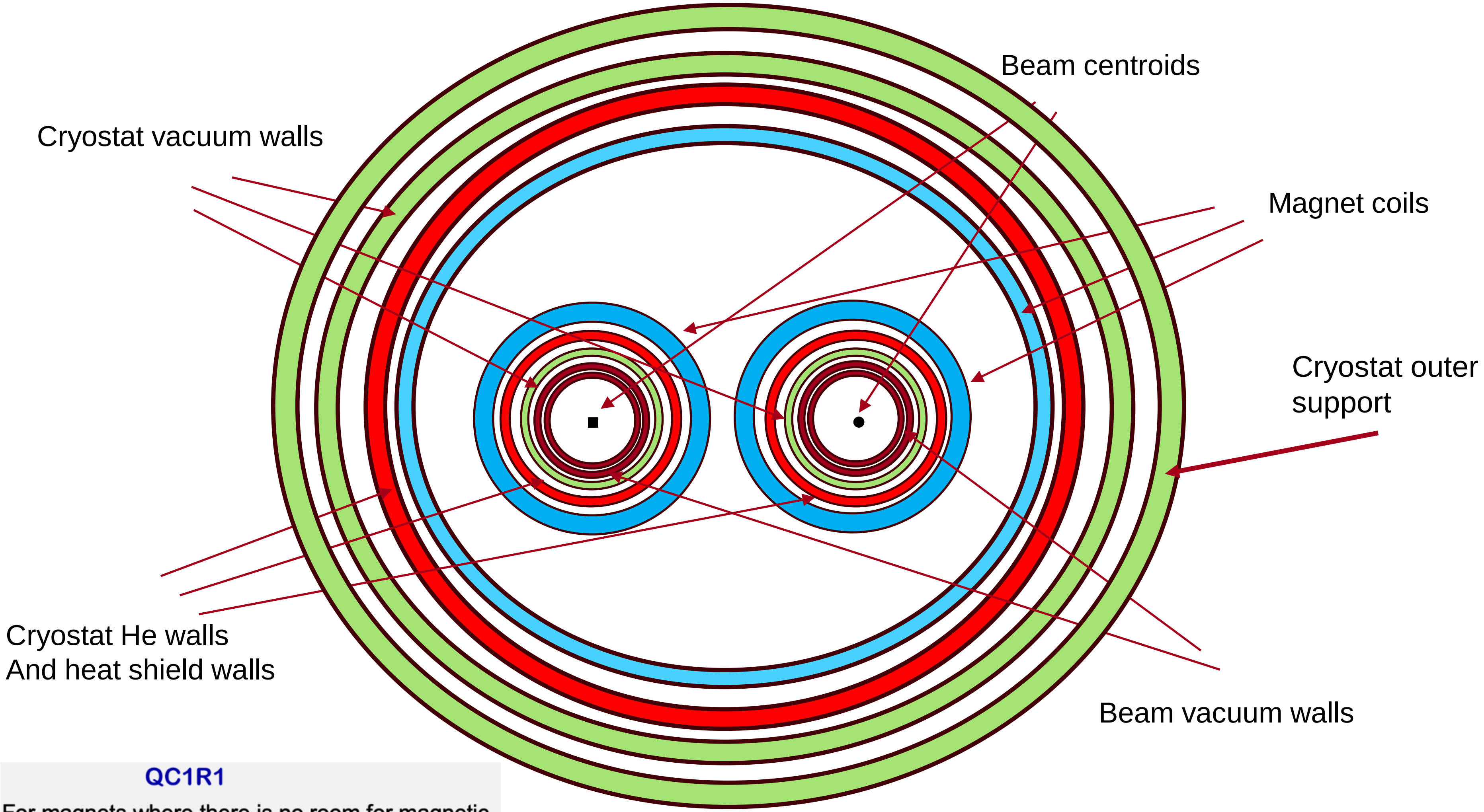
Some cryo-stat dimensions



M. Koratzinos, M. Boscolo

IR Magnet Cross Section View (front and end of each magnet)

Showing separated heat shield and vacuum vessel.



QC1R1

For magnets where there is no room for magnetic yoke material between the coils, the only practical solution is to use flexibility of CCT (double helical) to make local compensation of the magnetic cross talk between side-by-side quadrupole apertures.

J. Seeman November 2023

Tentative radial build for the QC1 assembly

Option I – common He space for all magnets

Presently **all dimensions are arbitrary** and for illustration of the cryostat structure only!

Common He space for both screening solenoid and quadrupoles

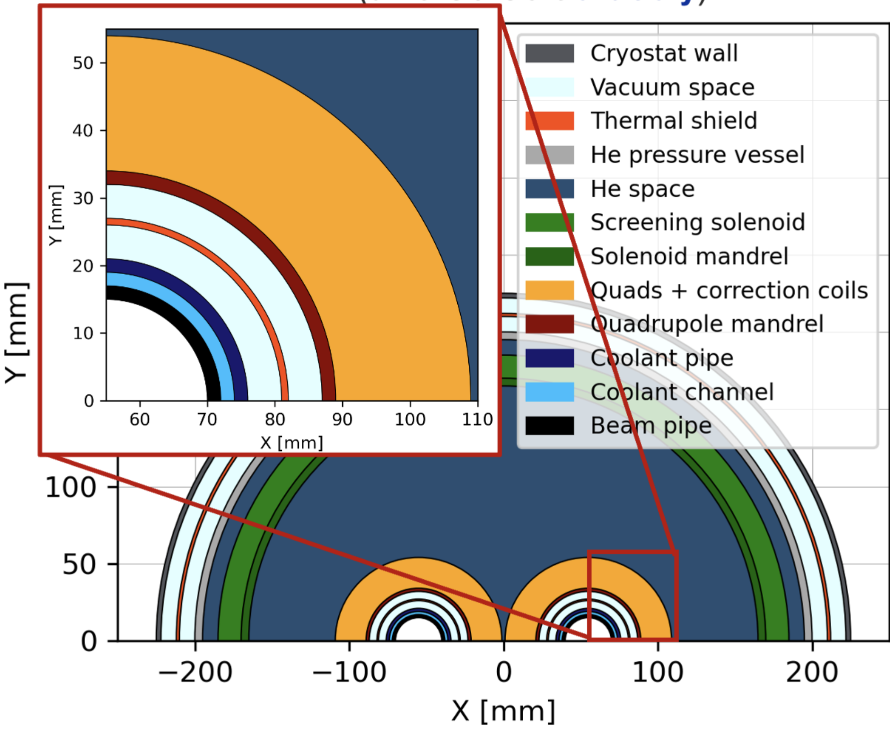
Annular space (5+1+5=11 mm) reserved between beam pipe assembly and quadrupole mandrel **for vacuum insulation + thermal shield**

“Quadrupole mandrel” is also He pressure vessel inner boundary

Screening solenoid supported by mandrel that can be perforated for He passage

Vacuum insulation + **thermal shield** between cold mass and cryostat vessel

Proposed x-section of QC1 cryostat at arbitrary length (dimensions are **arbitrary**)



IR cryostat component dimensions

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)**

Radial distances from Detector Solenoid axis to Beam axis for QC1A/B

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1	**FCCee IR Transverse Magnet and Chamber Dimensions**							
2	7-Jun-24		J. Seeman					
3	All dimensions are in mm.							
4		CS1	CS1		CS1	CS1	CS1	CS1
5	Magnet and location:	QC1L1	QC1L1		QC1L1	QC1L1	QC1L2	QC1L2
6		Inner	Inner		Inner	Outer	Inner	Outer
7	Numbers from:	**MK1**	**MK2**		**JSee**	**JSee**	**JSee**	**JSee**
8								
9	Z Location	2200	2200		2200	2900	2980	4230
10								
11	**Detector solenoid central axis line**	0	0		0	0	0	0
12								
13	Support shim/space thickness	1	0		1	12	13	32
14	Trim coil thickness	0	0		2	2	2	2
15	Magnet coil thickness	12	12		12	12	12	2
16	Support shim thickness	0	0		1	1	1	1
17	He vessel thickness	0.5	1		2	2	2	2
18	Insulating vacuum thickness #2	1.5	2		1.5	1.5	1.5	1.5
19	Thermal shield (50 k)	0	0		0.5	0.5	0.5	0.5
20	Insulating vacuum thickness #1	0	0		1.5	1.5	1.5	1.5
21	Vacuum vessel thickness	1	1		2	2	2	2
22	Air gap	0	0		1.5	1.5	1.5	1.5
23	Outer beam pipe thickness	0	0		1	1	1	1
24	Water cooling layer for pipe	1	1		1	1	1	1
25	Inner beam pipe thickness	1	1		1.5	1.5	1.5	1.5
26	Inner vacuum wall to beam	15	15		15	15	15	15
27	**Sum: Det solenoid axis to beam center**	33	33		43.5	54.5	55.5	64.5
28								
29	**Beam location (15 mrad)**	33	33		33	43.5	44.7	63.45

Radial distances from beam location to outer cryostat wall at QC1A/B

SLAC

29	**Beam location (15 mrad)**	33	33		33	43.5	44.7	63.45
30								
31	Outer vacuum beam to wall	15	15		15	15	15	15
32	Inner beam pipe thickness	1	1		1.5	1.5	1.5	1.5
33	Water cooling layer for pipe	1	1		1	1	1	1
34	Outer beam pipe thickness	0	0		1	1	1	1
35	Air gap	0	0		1.5	1.5	1.5	1.5
36	Vacuum vessel thickness	1	1		2	2	2	2
37	Insulating vacuum thickness #2	0	0		1.5	1.5	1.5	1.5
38	Thermal shield (50 k)	0	0		0.5	0.5	0.5	0.5
39	Insulating vacuum thickness #1	1.5	2		1.5	1.5	1.5	1.5
40	He vessel thickness	0.5	1		2	2	2	2
41	Support shim thickness	0	0		1	1	1	1
42	Magnet coil thickness	12	12		12	12	12	12
43	Trim coil thickness	0	0		2	2	2	2
44	Support shim thickness	1	0		5	5	5	5
45	Skeleton support thickness	121	121		66	55	48	39
46	Anti-solenoid support	10	10		20	20	20	20
47	Anti-solenoid coil thickness	10	10		15	15	15	15
48	Shim thickness	0	0		2	2	2	2
49	He vessel thickness	2	2		5	5	5	5
50	Insulating vacuum thickness	4	4		4	4	4	4
51	Vacuum vessel thickness	5	5		5	5	5	5
52	Allowed outer rod support connector	0	0		10	10	10	10
53	Copper shielding thickness	2	2		2	2	2	2
54	**Sum: beam center to outside**	187	187		176.5	165.5	158.5	149.5
55								
56	**Overall sum (Det axis to outer wall)**	220	220		220	220	214	214
57								
58	**Dectector stay clear (100 mrad)**	220	220		220	290	298	423

(possible) PFD for He II cooling

Adapted from HL-LHC D2 magnet

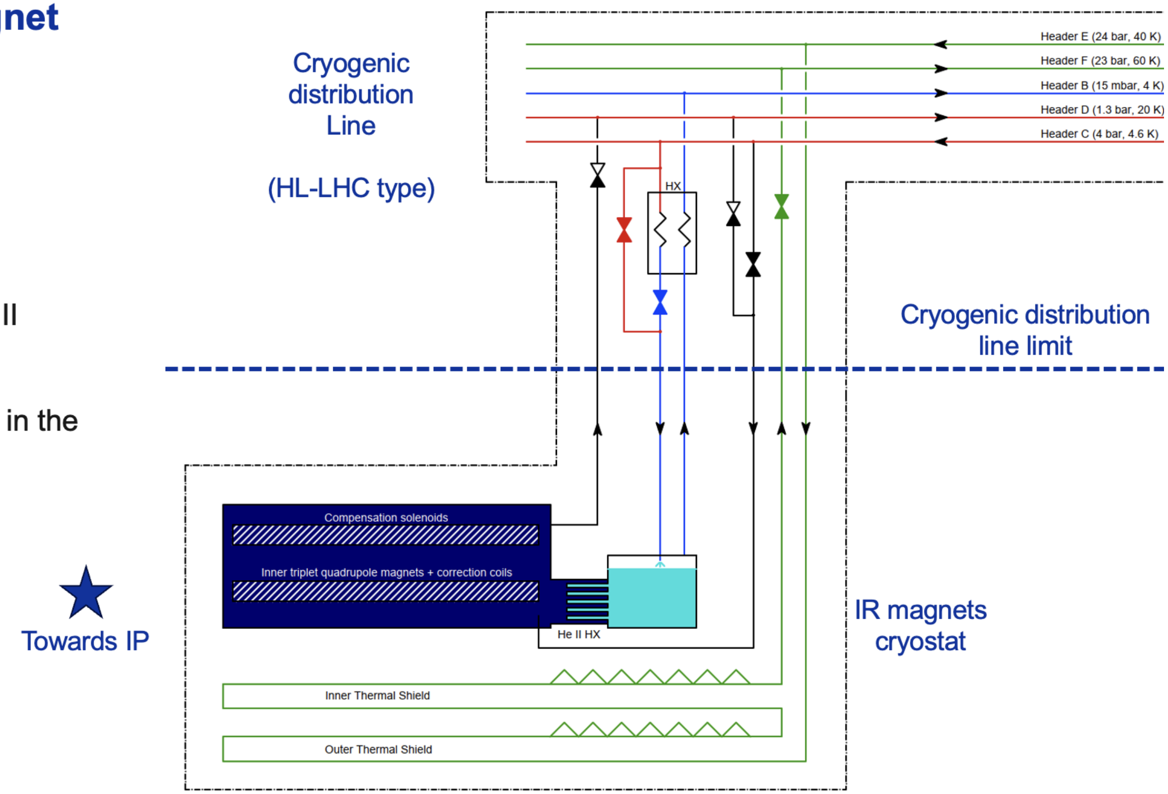
Shown:

- Cryogenic distribution line (top)
- Jumper connection (middle)
- IR magnets (bottom)

Considered inner triplets cooled via He II pressurised/He II saturated HEX

Considered solenoids and quadrupoles in the same bath

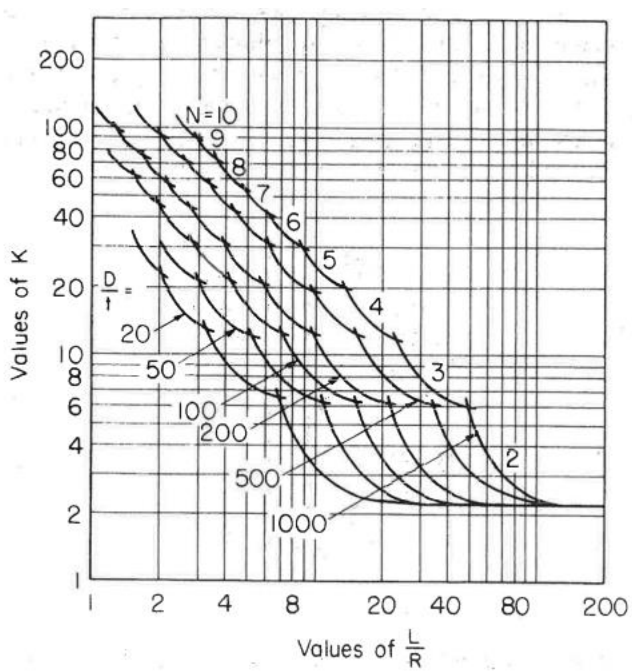
Thermal shields can use a 40 K – 60 K circuit as in HL-LHC or could potentially be cooled by conduction only from the jumper into the magnet cryostat (shown)



Inner He vessel in cryostat may crush if quench or vacuum loss

Example at SLAC of thin-walled water chamber:

Water pump pulled ~1 Bar pressure on water tank at SLAC causing it to crush.



Radial external pressure with fixed edges.

Options to make the QC1/QC2 radial and longitudinal space issues more conservative

A) Keep layout as in present optical lattice and present cryostat design

Beam pipe "welded" into cryostat as the inner wall. (Solve vacuum design issues)
Likely increases the cryogenic heat load.

B) Keep the IP crossing angle the same and move magnets outward (~0.8 m)

Move QC1 away from IP about 0.8 m. (2.2 m to 3.0m)

Move QC2 away from IP about (0.8 +1.2 =) 2.0 m. (5.86 m to 7.86 m)

Minimum betay* increases a little.

C) Increase full crossing angle from 30 mrad to 40 mrad:

Move QC1 away from IP about 0.03 m. (2.2 m to 2.23 m) (add a Lumi-Cal gap)

Move QC2 away from IP about (0.03 +1.2 =) 1.23 m. (5.86 m to 7.09 m)

Quadrupole strengths are reduced. Minimum betax* increases. Luminosity the same.

Beam line components move transversely in the tunnel for both beams.

Wider tunnel in some locations.

D) Reduce the field overhead in the SC magnet design (presently ~30%).

Saves radial space at QC1A/B/C.

Reduces the magnet reliability.

E) Find radial space for background heavy metal shield (~5 mm) between beam chamber and magnet → New design

SuperKEKB IR Cryostats

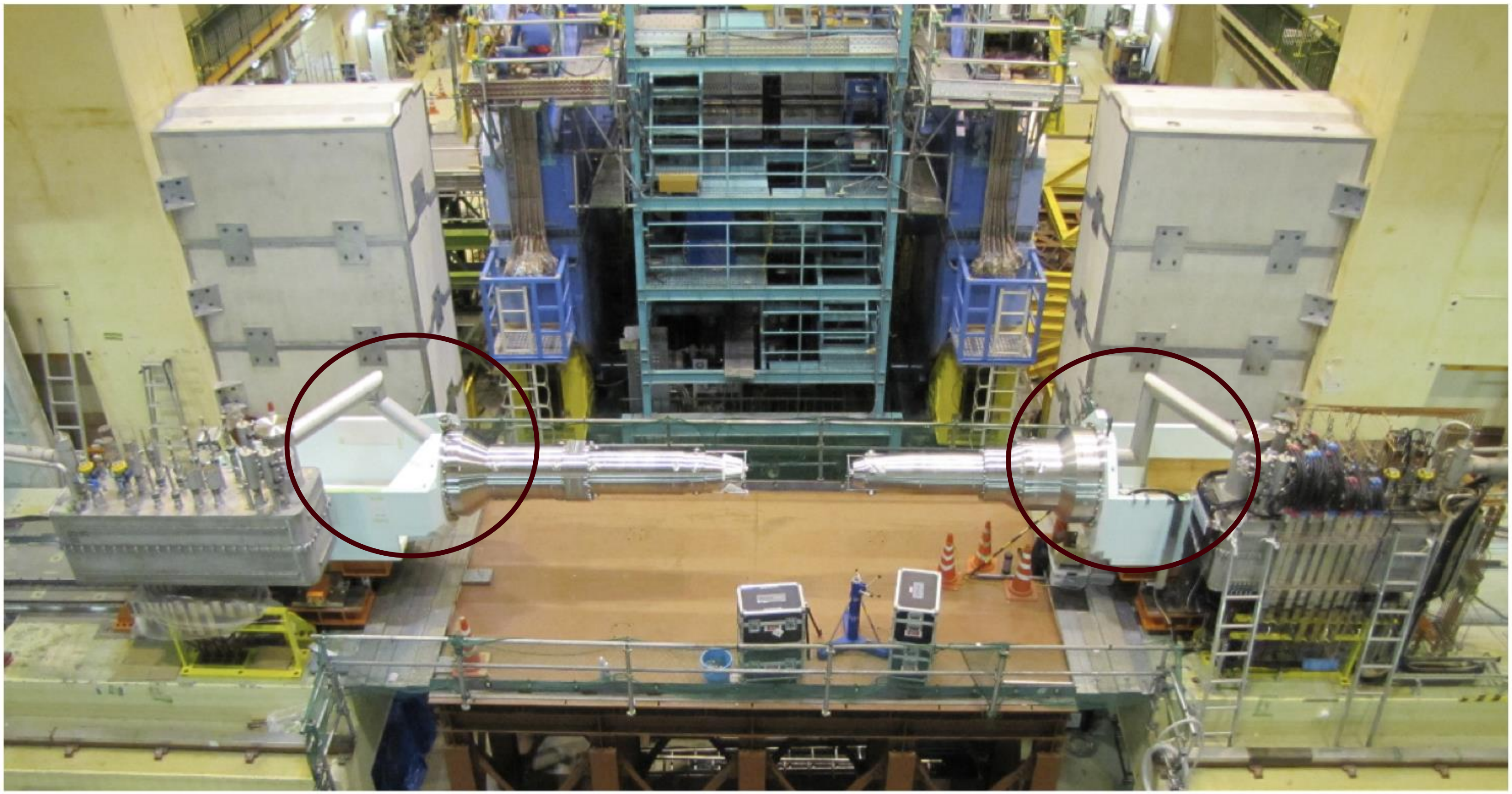
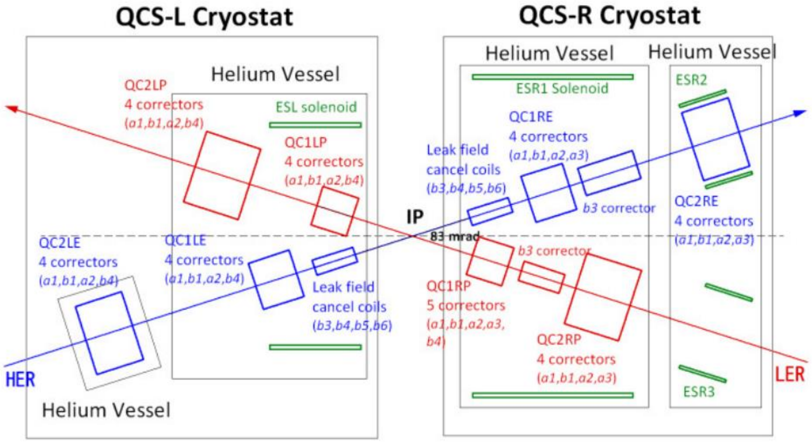


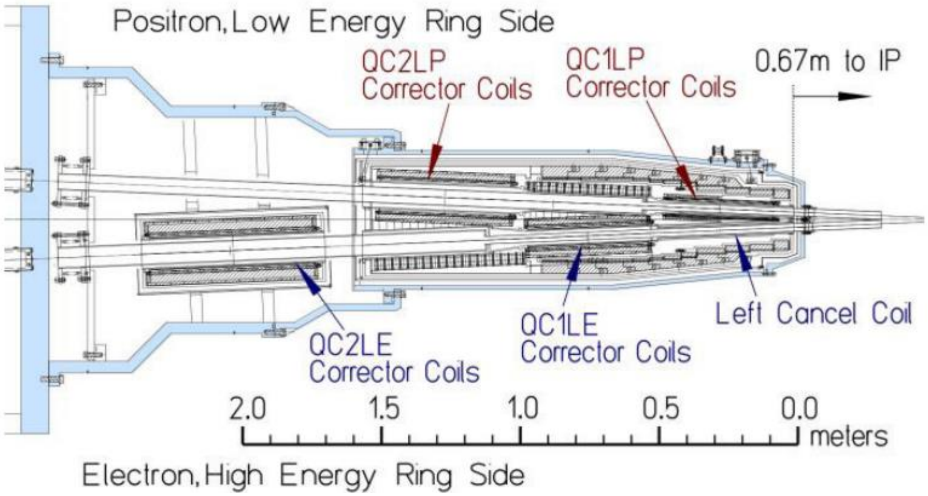
Figure 11: QCSL/R cryostats and Belle-II detector in IR.

For comparison: SuperKEKB IR SC Magnet System

Norihito Ohuchi (2013): “IR SC magnet system is the most important and complicated hardware in SuperKEKB.”

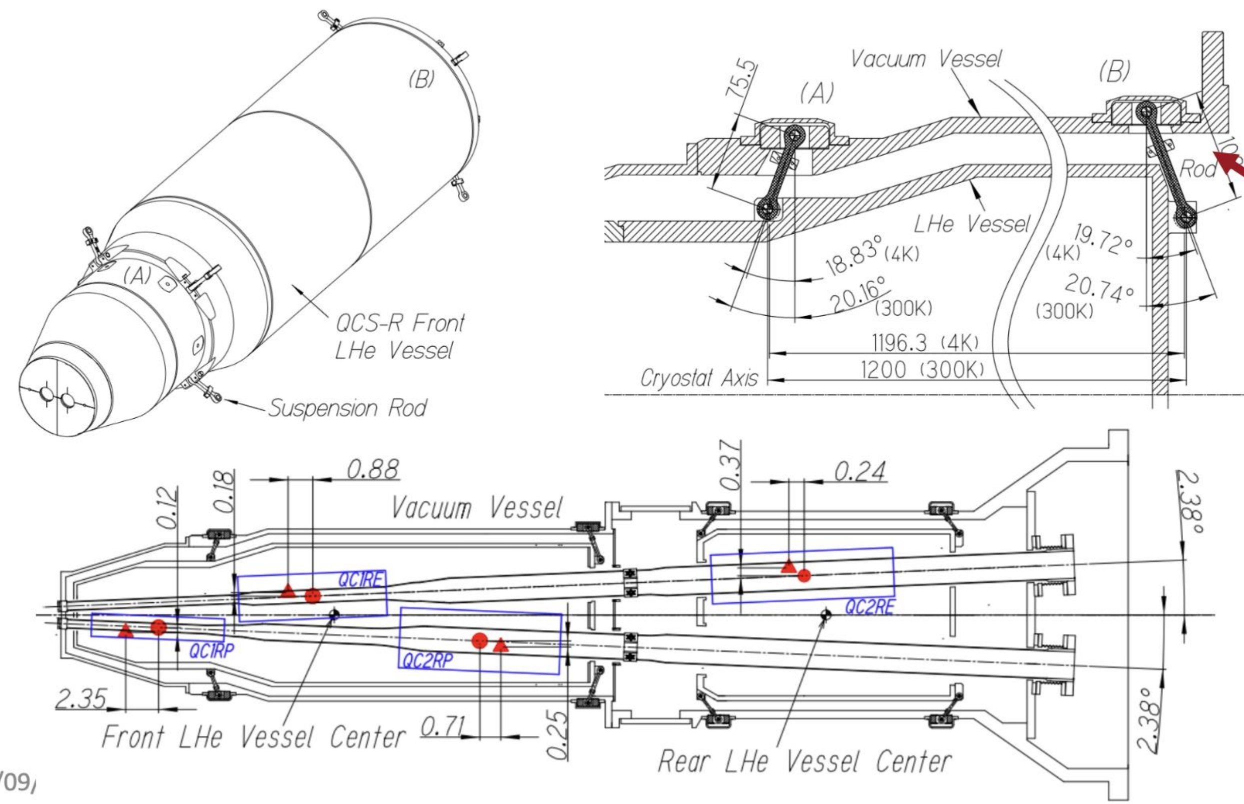
SuperKEKB IR SC magnets:
- 8 quadrupoles, 4 solenoids, 43 correctors





SuperKEKB IR Cryostat

Magnets are mechanically supported by the cryostat components in the helium vessel.
Helium vessels are supported by the rods (Ti alloy) from vacuum vessel.



Vacuum tight joints

2023/09/

Eight rods per cryostat

(N. Ohuchi)

CEPC IR magnets and cryostats (Dec 2023)

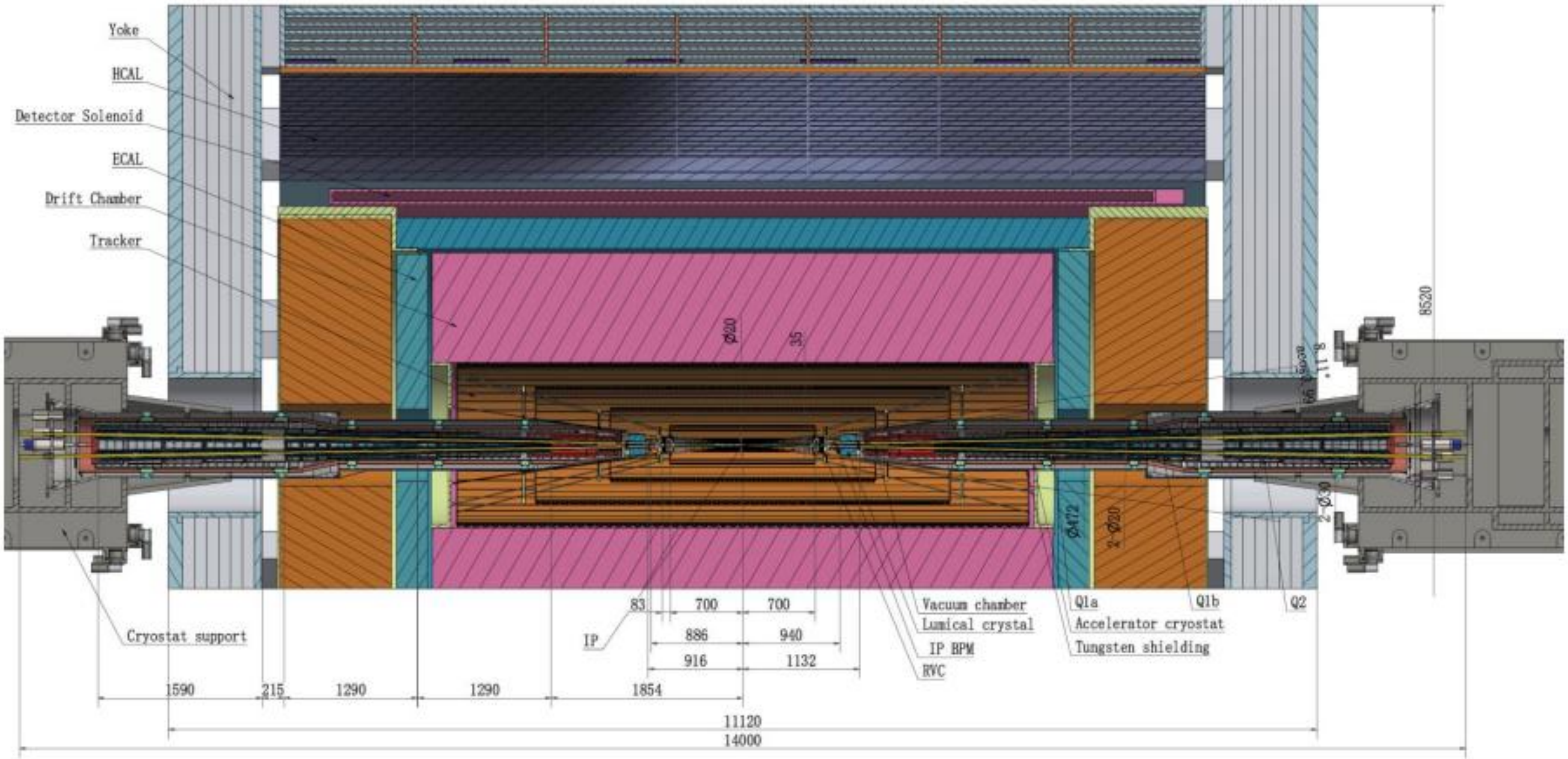


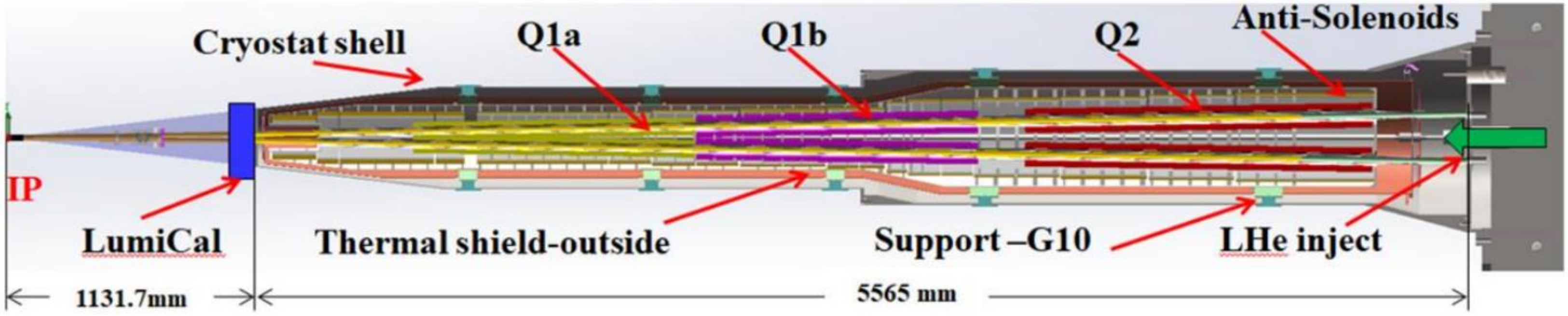
Fig 4.2.6.1: CEPC MDI layout.

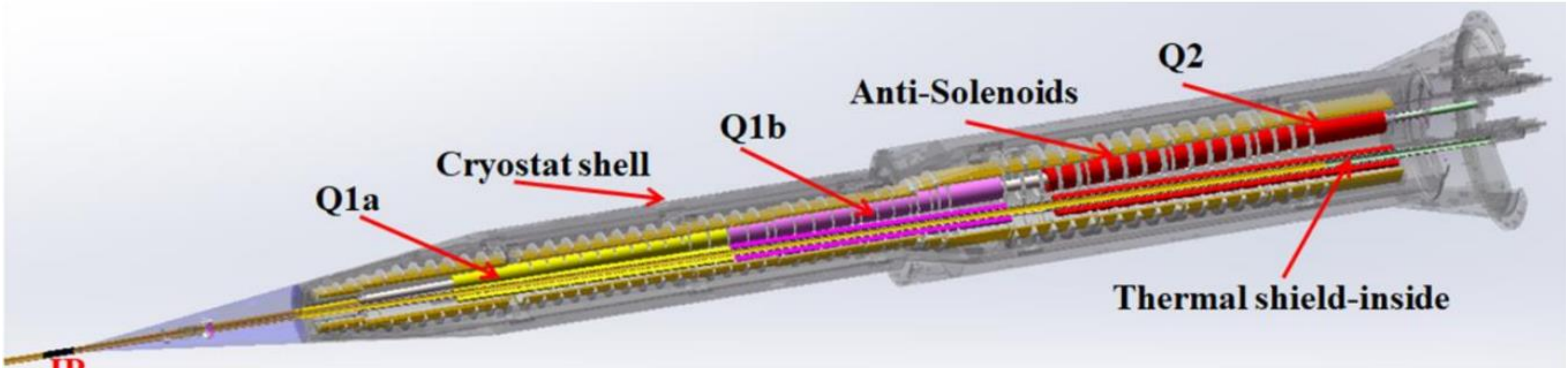
CEPC IR magnet specifications (Dec 2023)

Table 4.2.1.2: The length and strength of the final quadrupoles for the compatible modes.

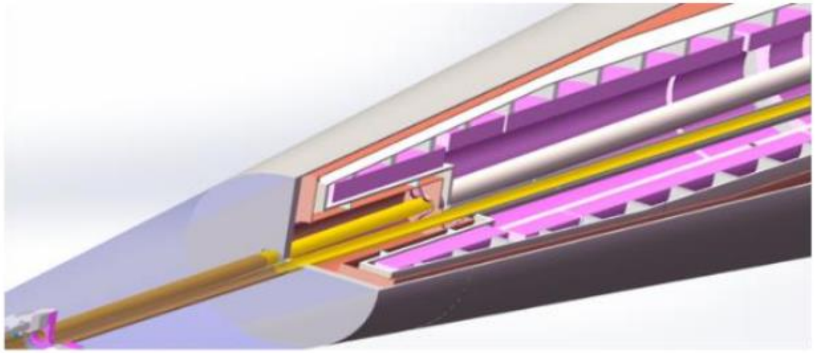
Quadrupole	L [m]	Distance from IP [m]	Strength [T/m]			
			$t\bar{t}$	Higgs	W	Z
Q1AIRU	1.21	1.9	-141	-141	-94	-110
Q1BIRU	1.21	3.19	-59	-85	-56	+65
Q2IRU	1.5	4.7	-51	+95	+63	0
Q3IRU	3	7.2	+40	0	0	0
Q1AIRD	1.21	-1.9	-142	-142	-95	-110
Q1BIRD	1.21	-3.19	-64	-85	-57	+65
Q2IRD	1.5	-4.7	-47	+96	+64	0
Q3IRD	3	-7.2	+40	0	0	0

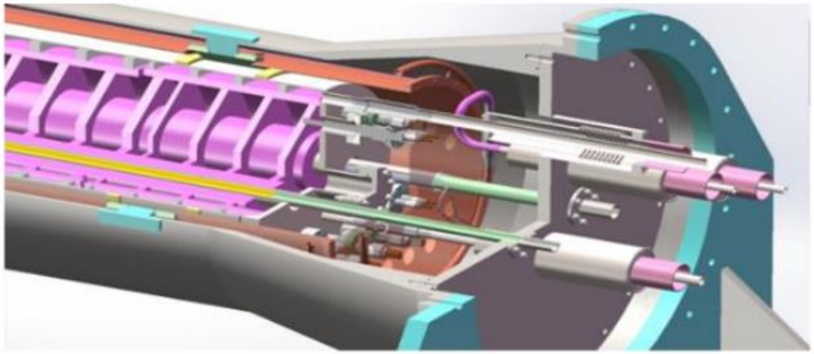
CEPC IR 6.8 m cryostat (Dec 2023)





CEPC IR cryostat details (Dec 2023)





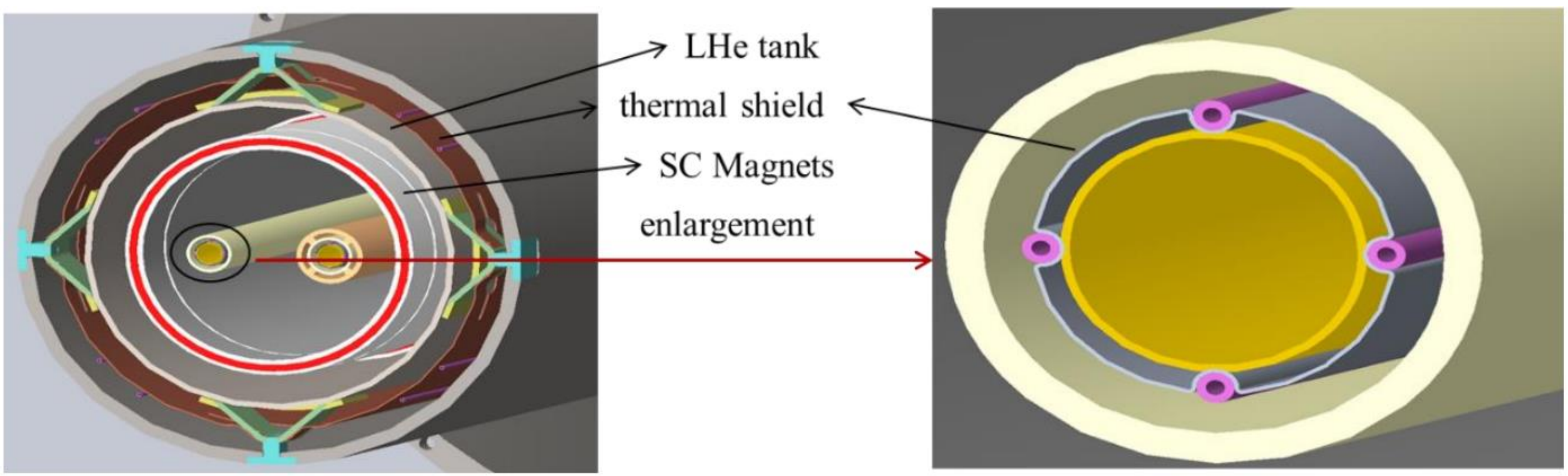
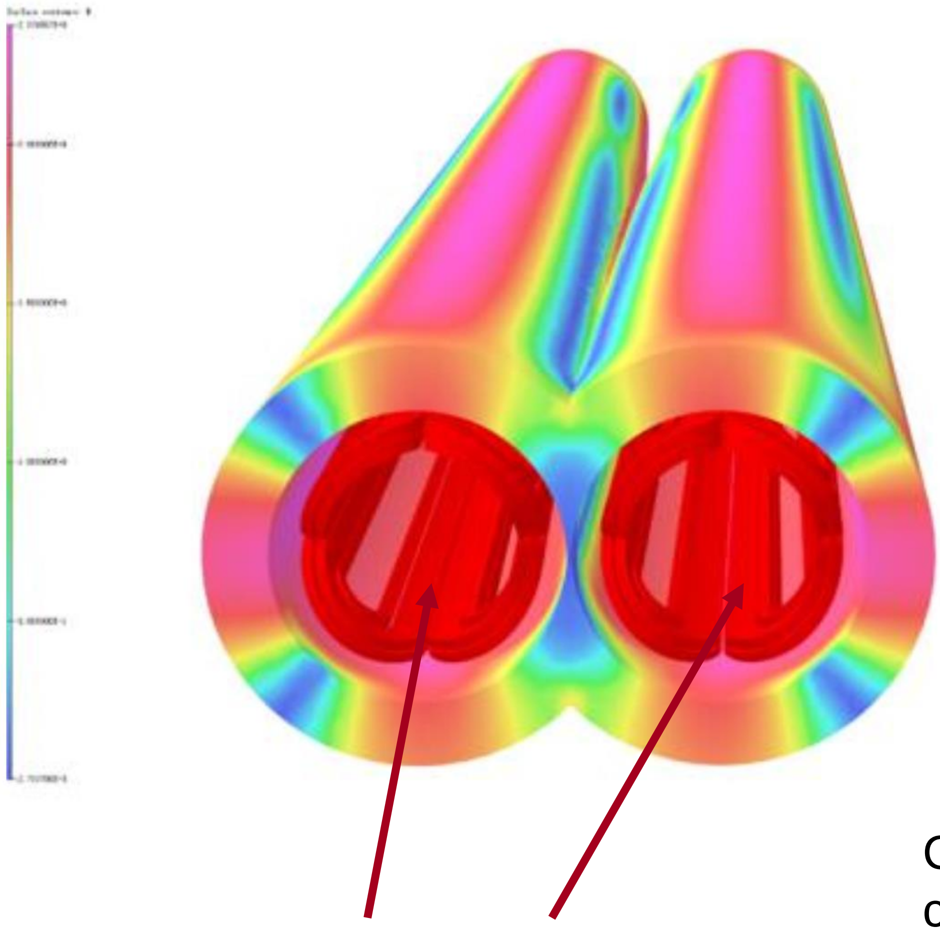


Figure 7.1.36: Mechanical design of the MDI cryostat.

CEPC: Iron shields around QC1a for cross-beam field reduction



Beam apertures

CCT magnets
can be built with
with compensation.
Needs verification.

Comparisons of IR features for FCCee, CEPC, ILC, SuperKEKB

Machine		FCCee	CEPC	ILC	SuperKEKB
Crossing-angle	mrad	30	33	14	83
L*	m	2.2	1.9	3.5	0.935
L* x Cross-angle	mm	66	63	49	78
Vertical β_y* at IP	mm	0.7-1.6	0.9-2.7	0.4	0.3
Detector soln field	T	2/3	3	3.5/5	1.5
Detector stay clear	mrad	100	118/141	90	350/436
He temperature	K	1.9	4.2	4.5	4.5
QC1s side-by-side		Yes	Yes	No	No

Suggested focus topics for FCCee MDI and IR magnets for 2024-2025

SLAC

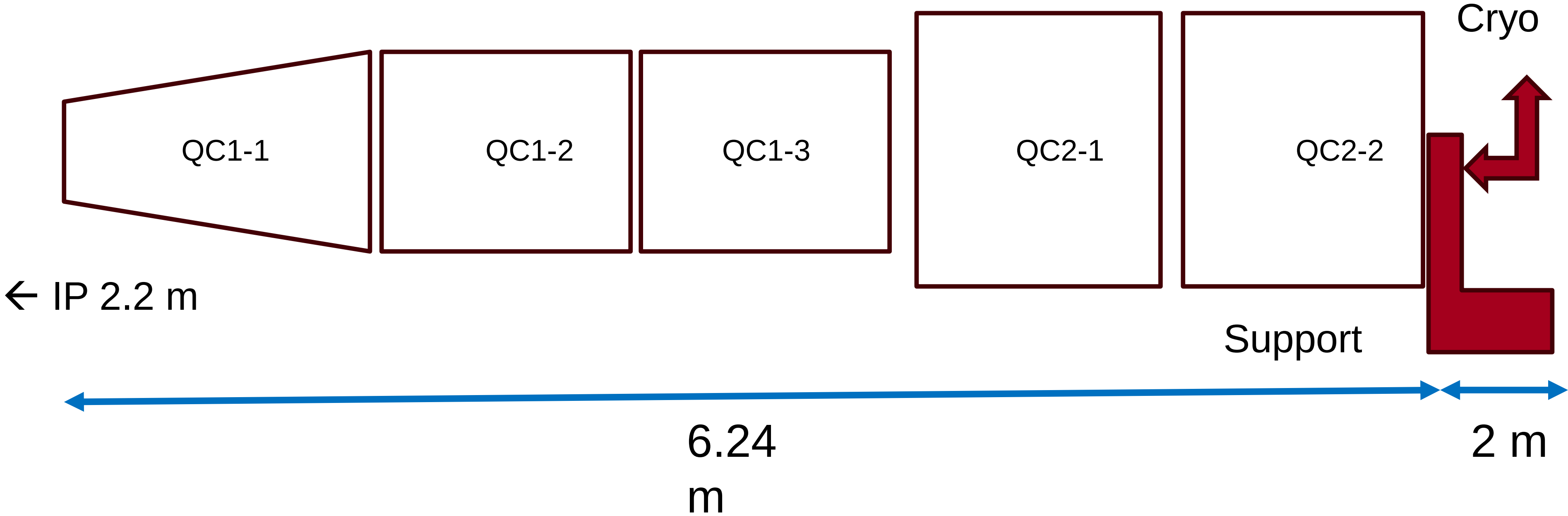
1) Add inner background shielding: W, Ta, or Cu inside magnets in cryostat (Δr?)
2) Resolve new IR lattice vs present: QC1,QC2 placement and anti-solenoids
3) Make initial cryostat design (4 or 7 m) by cryogenic/mechanical engineer(s)
4) Answer if IR magnets need higher-order trim coils
5) Confirm 100 mrad detector-accelerator cone angle
6) IR BPMs and other diagnostics
7) Full list of magnet, vacuum, and cryogenic specifications
8) Converge on background mask geometry
9) Make initial layout of magnet/cryogenic splice box
10) Construct a left and right CCT magnet pair for QC1 and test
11) Carry out warm test of CCT quadrupole for reduced left-right field cross-talk
12) Design remote vacuum flanges (need 6 flanges with 2 designs)
13) Radial differential movements during cool down

Thank you for your attention!

Again, thanks to many people for their inputs!

Second option: IR QC1 and QC2 in one cryostat and raft (not to scale).

CEPC has adopted this option (Dec 2023).



Overall SuperKEKB IR Layout

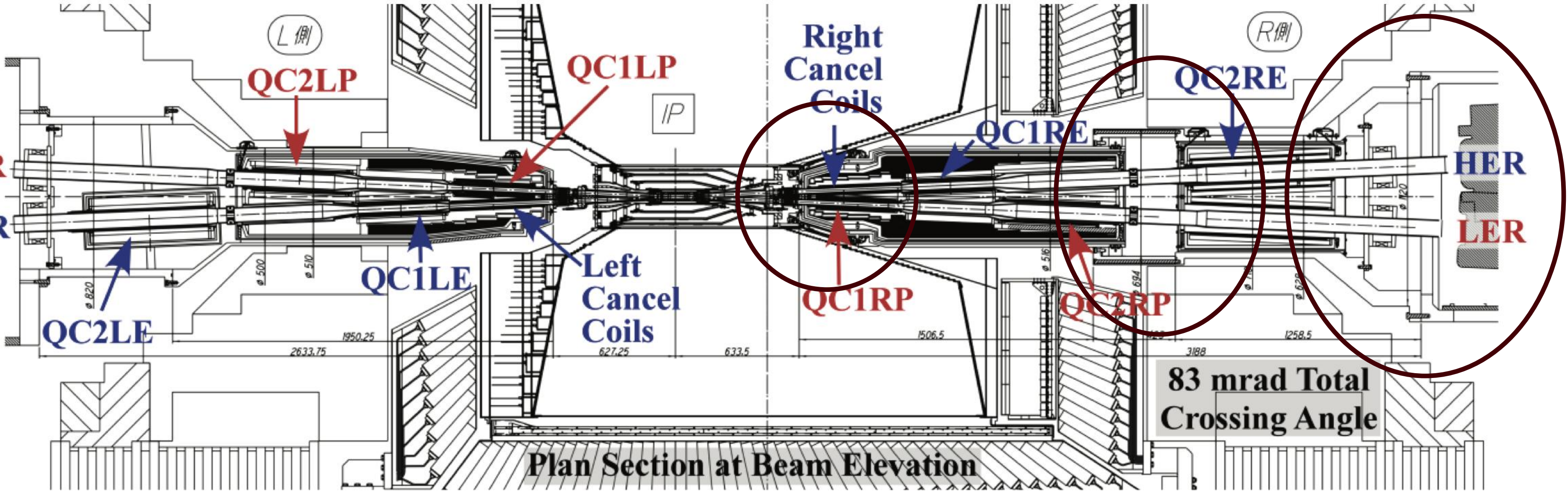
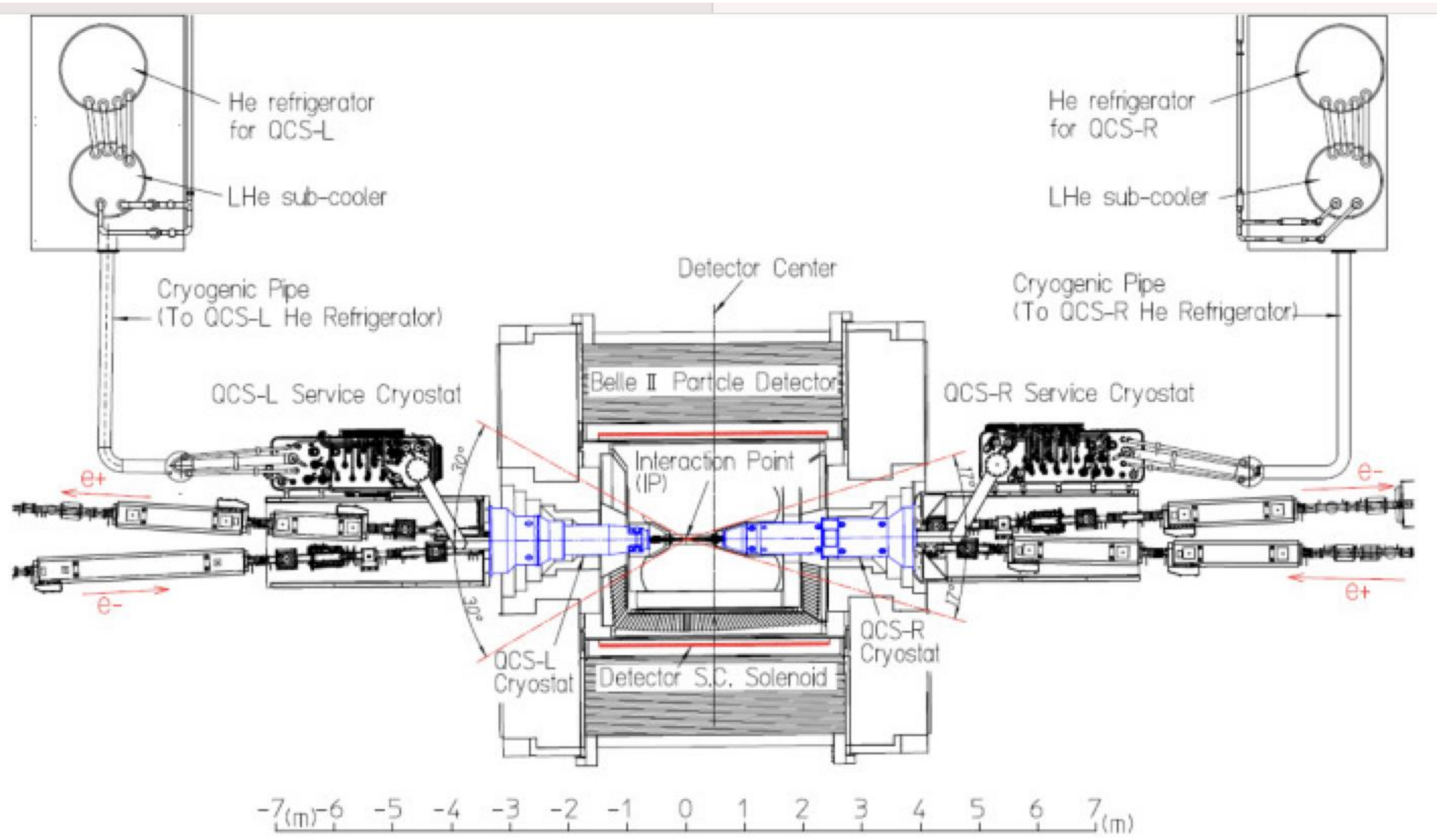


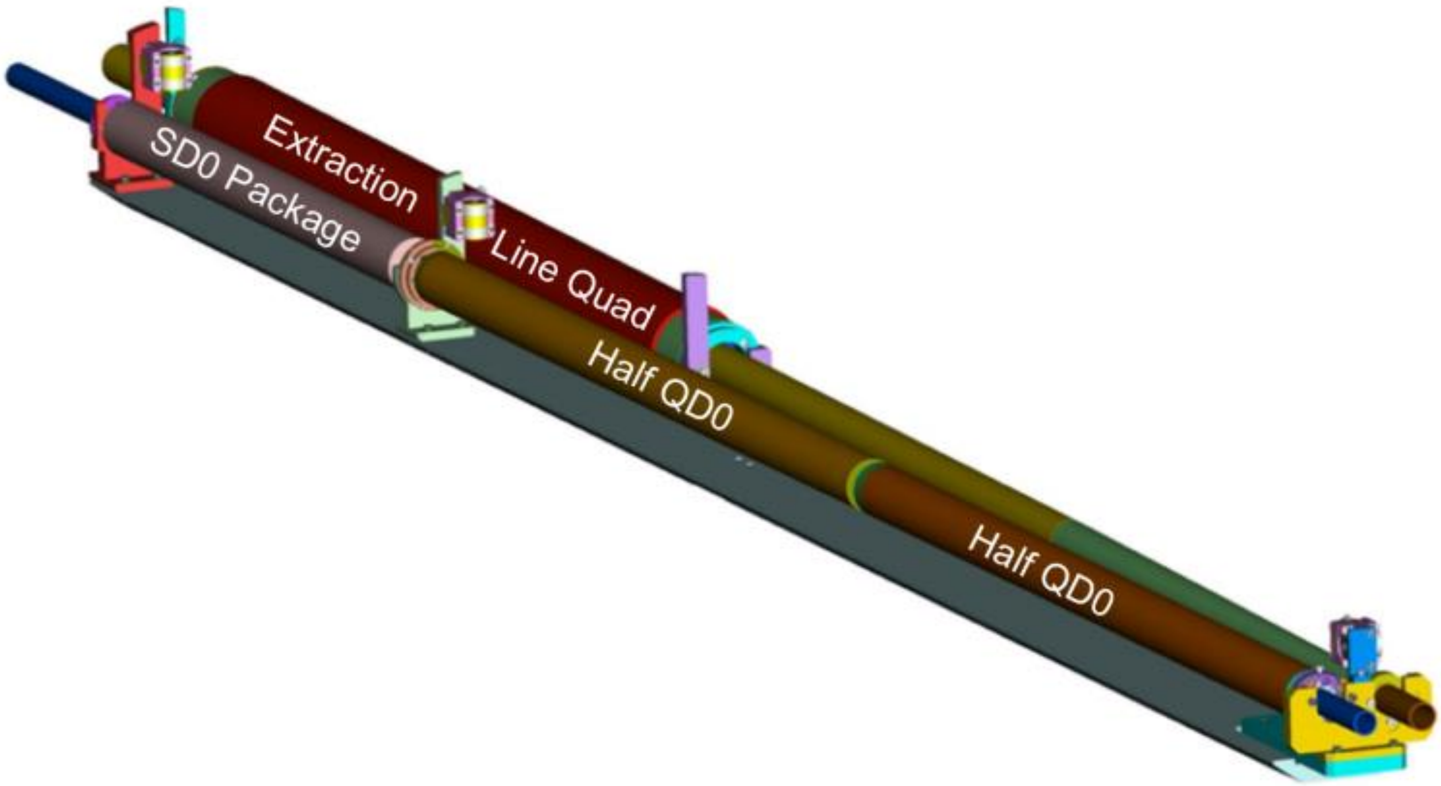
Figure 1:. SuperKEKB IR layout inside Belle-II with high energy, e^-, (HER) and low energy, e^+, (LER) rings indicated.

KEKB Cryo-plant Layout

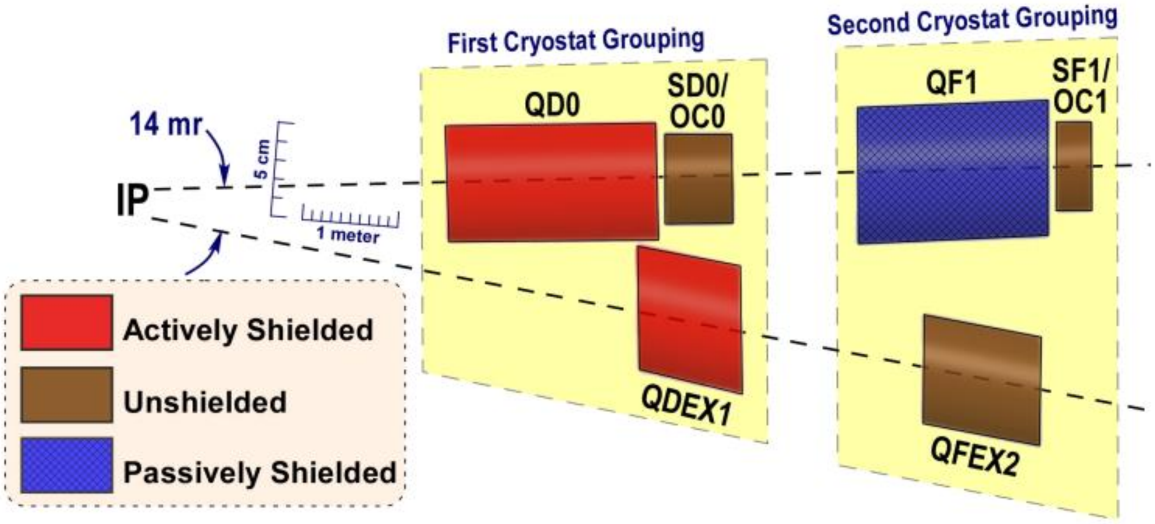


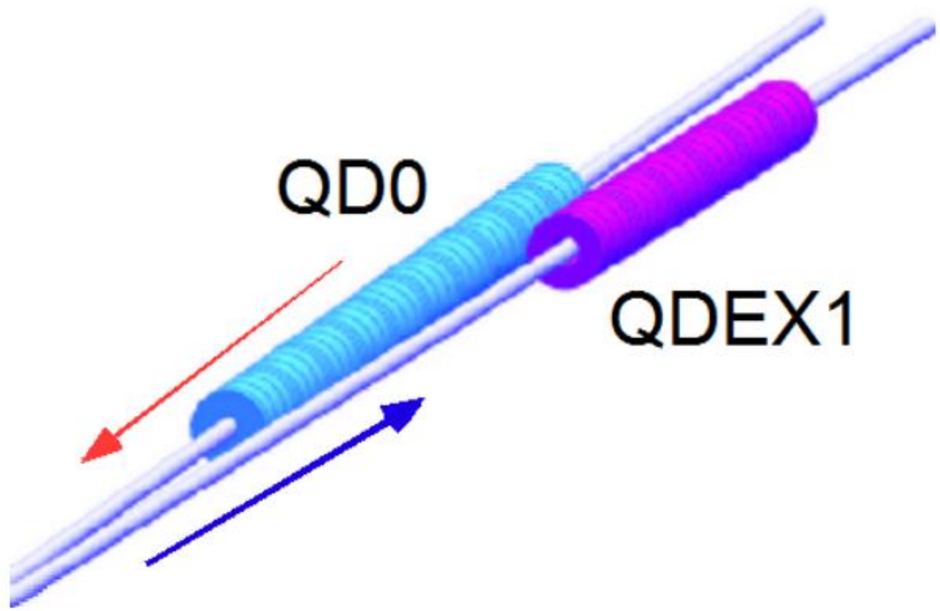
ILC IR magnets (2013)

Figure 8.8
Engineering model of the detector-mounted final-focus magnets [173]. The QD0 magnet is split into two coils to allow for energy flexibility.



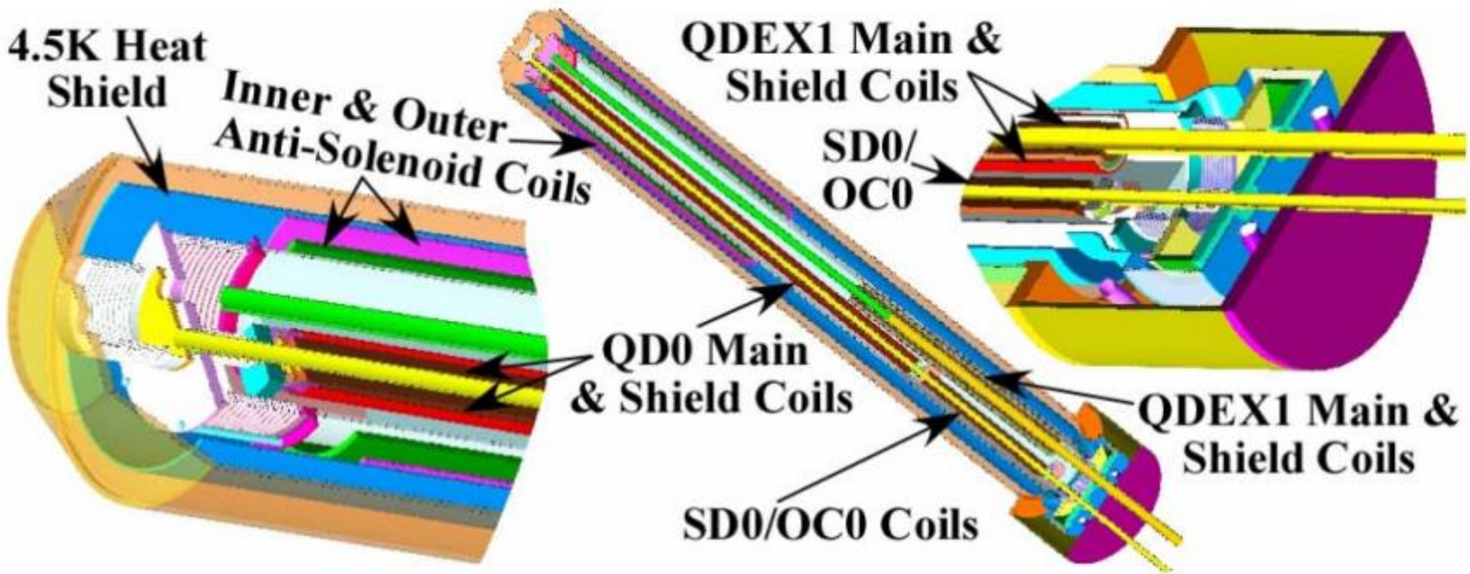
ILC IR magnet locations (2013)





ILC cryostat details (B. Parker et al)

Proceedings of PAC07, Albuquerque, New Mexico, USA THPMS091



The QD0 Magnet Grouping shown with a Force Neutral Anti-Solenoid in a QD0 Common Cryostat.