IR Magnets for Super KEKB

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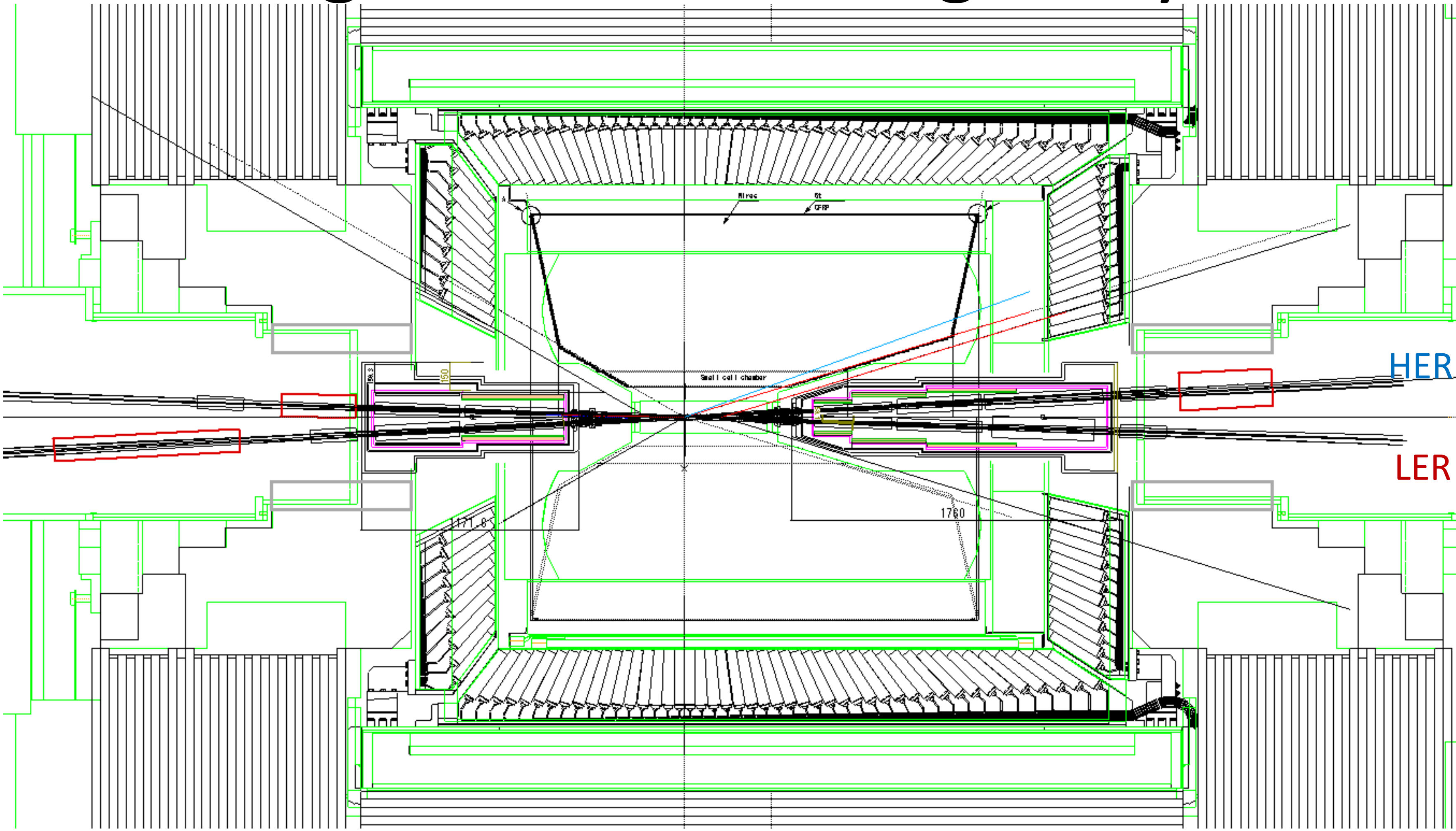
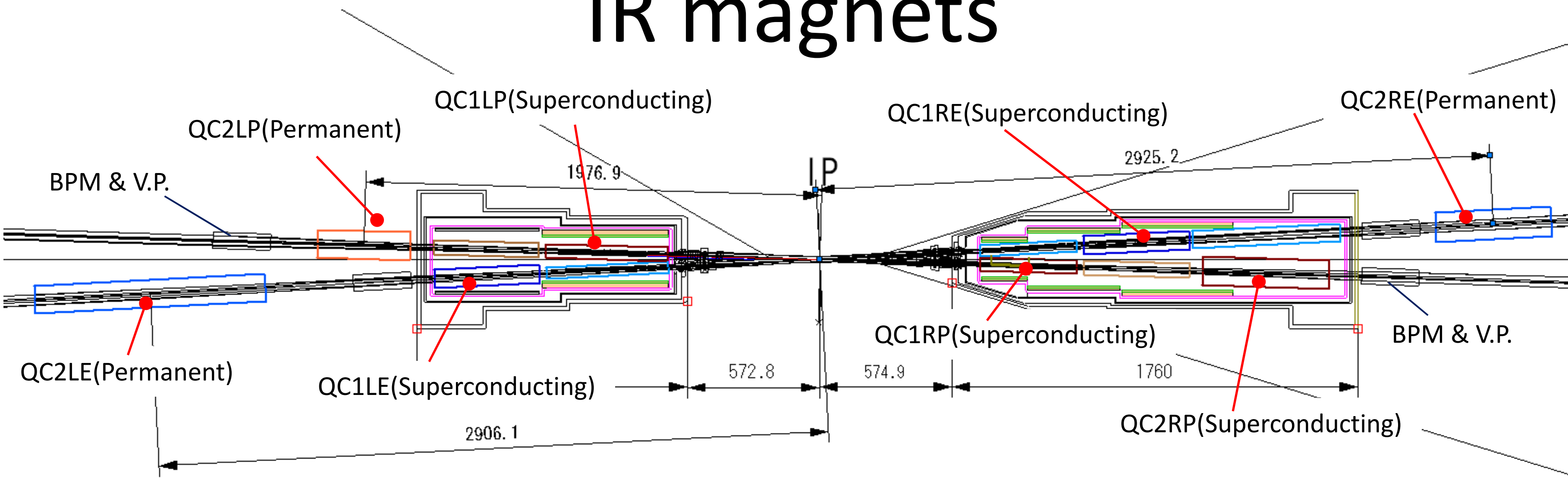
Configuration of IR magnet system



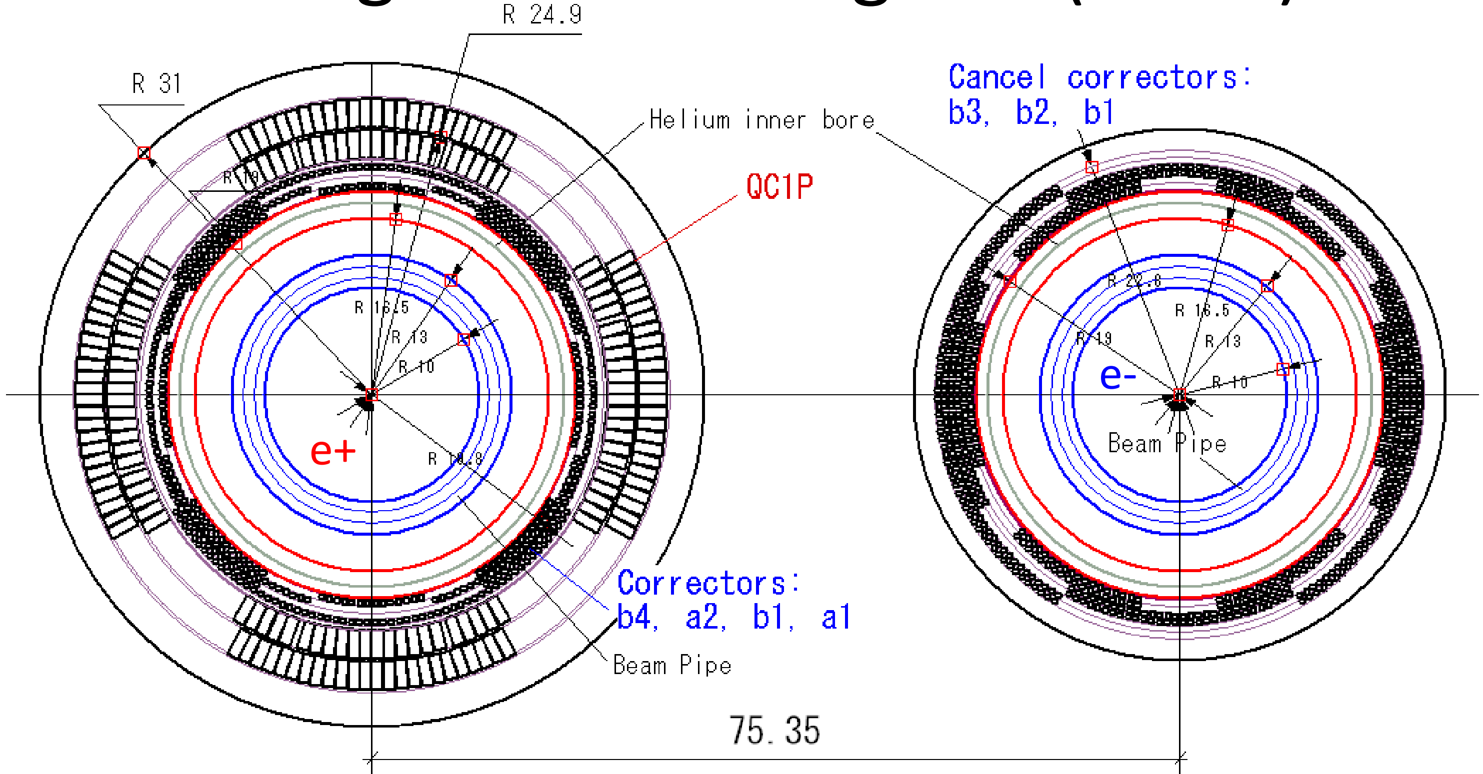
5 SC main qadrupoles (QC1RP, QC1RE, QC2RP, QC1LP, QC1LE)
3 permanent quadrupoles (QC2RE, QC2LP, QC2LE)
2 SC compensation solenoids
32 SC correction coils

IR magnets



	Integral field gradient, (T/m)・m	Position from IP, mm	Magnet type
QC2RE	12.91	2925.0	Permanent
QC2RP	10.92	1936.1	S.C.
QC1RE	26.22	1376.0	S.C.
QC1RP	22.43	908.1	S.C.
QC1LP	22.91	-922.1	S.C.
QC1LE	26.03	-1461.0	S.C.
QC2LP	10.96	-1977.1	Permanent
QC2LE	14.13	-2900.0	Permanent

Design of IR SC magnets (QC1P)



Magnet design (QC1RP and QC1LP)

Same design of the cross section for QC1RP and QC1LP

2 layer coils [double pancake type]

Designed SC cable [under development]

- Cable size : 2.5 mm in height, and 0.93 mm in width
- SC strand cable : ϕ 0.5 mm, 10 wires in the cable

SC correctors inside of the magnet bore

- b_4, a_2, b_1, a_1 from the inside
- Single layer coil

Beam pipe : warm tube, inner radius=10 mm

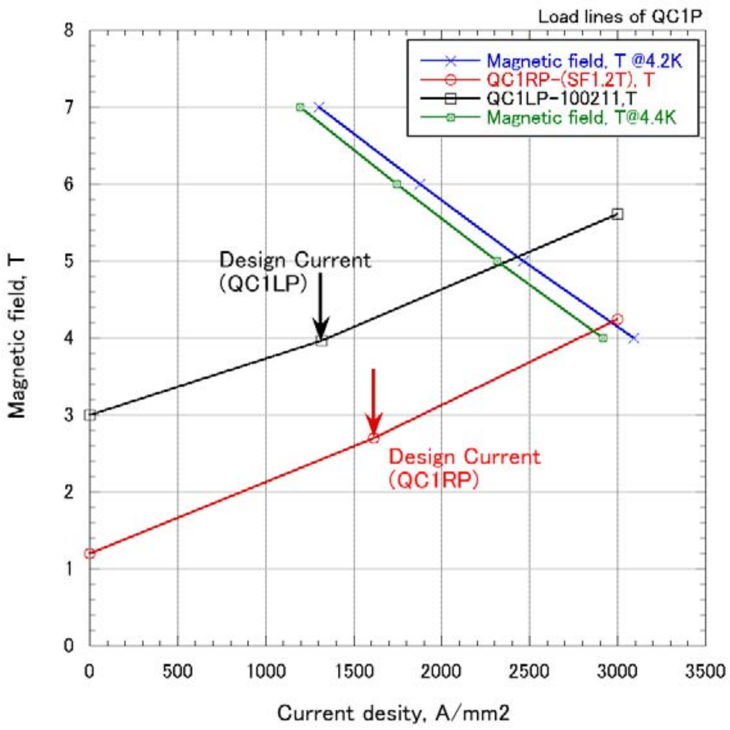
SC cancel correctors against the leak field from QC1P

- b_3, b_2, b_1 from the inside

Beam pipe : warm tube , inner radius=10 mm

Design parameters of QC1RP and QC1LP

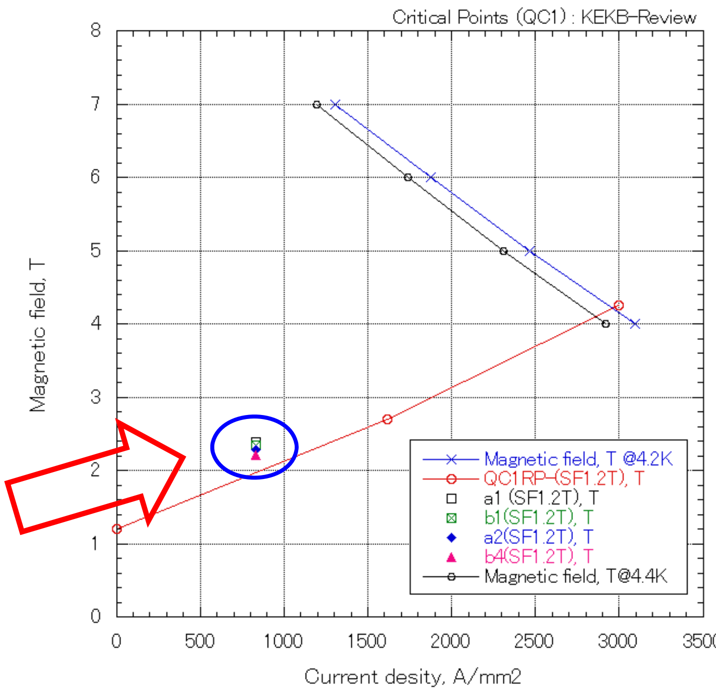
	QC1RP	QC1LP
Coil inner radius, mm	22.00	
Coil outer radius, mm	27.55	
Turns in one pole	11 (1st layer), 12 (2nd layer)	
Spec. of integral field, T	22.43	22.91
Field gradient, T/m	75.61	62.00
Effective magnetic length, m	0.2967	0.3695
Magnet current, A	1510.7	1232.3
Current density of the cable (SC area), A/mm^2	1615.8	1326.2
Magnetic field by Belle and comp. sol., T	1.2	3.0
Max. field in the coil without solenoid field, T	2.24	1.84
Max. field in the coil with solenoid field, T	2.70	3.98
Operating point with respect to B_c at 4.4 K	66%	80%
Error field at 1 cm (2D calculation)	$b_6 = -1.04 \times 10^{-4}$ $b_{10} = -1.60 \times 10^{-4}$ $b_{14} = 4.31 \times 10^{-6}$	



SC correctors on the inner bores of the QC1RP and QC1LP

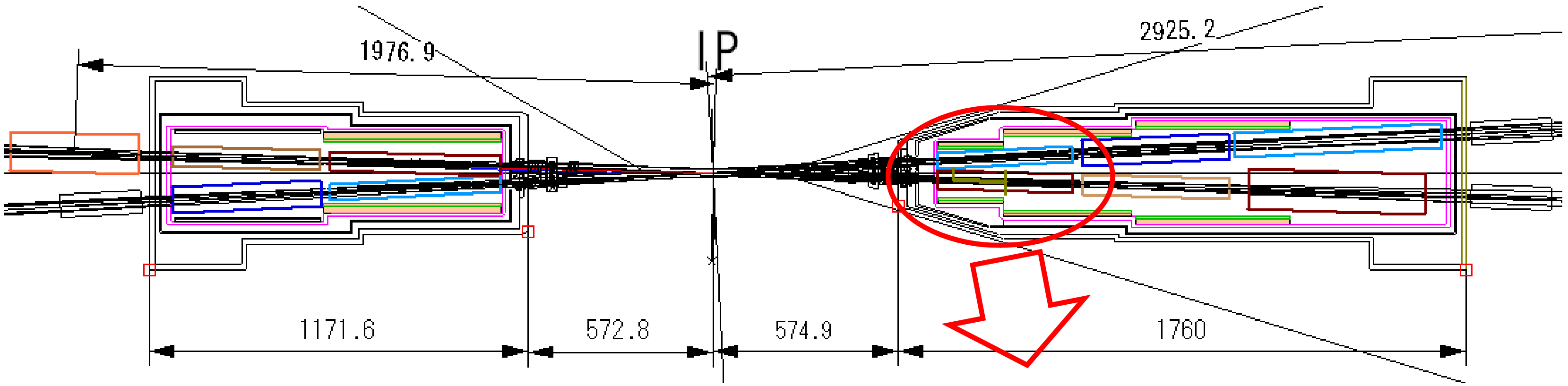
	b_4	a_2	b_1	a_1
Coil inner radius, mm	19.2	19.8	20.4	21.0
Coil outer radius, mm	19.8	20.4	21.0	21.6
Turns on one pole	7	14	30	30
Design current, A	50	50	50	50
Magnetic field at R=1cm	6438 T/m^3	2.298 T/m	0.048 T	0.047 T
Bias magnetic field by all magnets for QC1RP, T	2.20	2.29	2.34	2.39
Operating point with respect to J_c at 4.4 K	< 30 %	< 30 %	< 30 %	< 30 %
Capacity for magnetic alignment for QC1RP at R= 1 cm	NA	± 15.3 mrad	± 0.64 mm	± 0.62 mm

Operating points of SC correctors

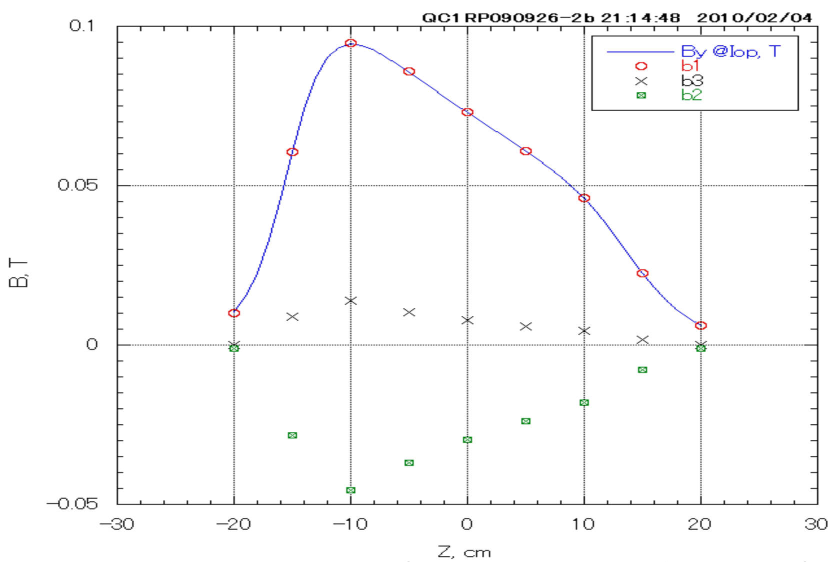


Cancel correctors for the leak field of QC1RP and QC1LP

- The SC quadrupoles are designed not to have iron yokes since they are installed in the Belle solenoid field.
- The leak magnetic fields of the main quadrupoles on the opposite beams are canceled with the SC correctors of b_1, b_2 and b_3.



Profile of the leak field of QC1RP on the e- beam line

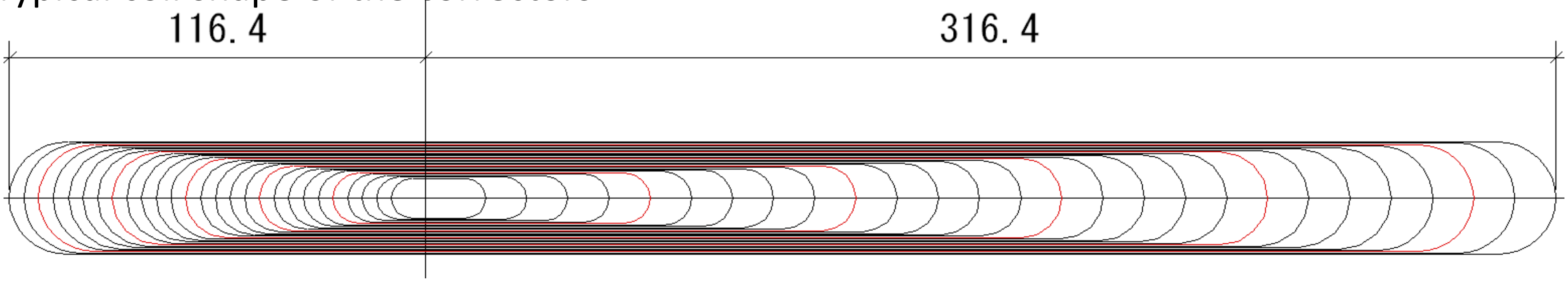


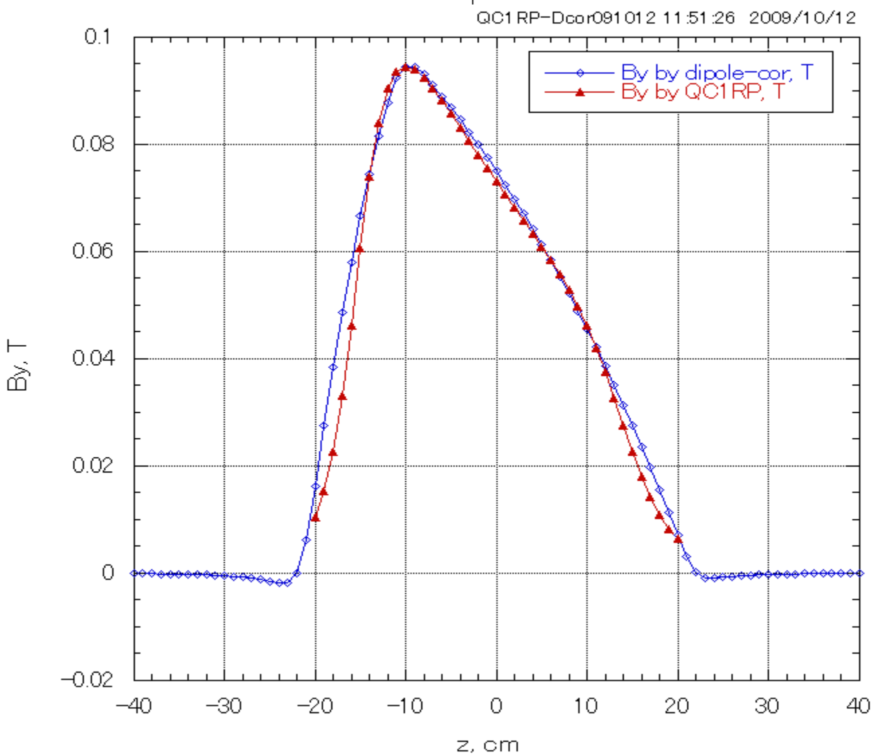
Position of Z=0 corresponds to the center of QC1RP.

- The magnetic fields at r=1cm of the e- beam line are expanded by Fourier transformation, and the leak field components are studied.
- The main components are B_1, B_2 and B_3, and the leak field of QC1RP can be cancelled with these correctors under the level of 10 gauss.

Design of the cancel correctors

Typical coil shape of the correctors





The field profiles of the B_y component of the leak field and the dipole component by the corrector.

Coil design

- The wire positions in the coil ends are designed to have the field profile of the leak field of the quadrupoles.
- 2 layer coils [double pancake type]
- No SC wire connection between the coils
- Designed superconductor [wire]

  Wire size : ϕ 0.4mm (bare)

  ϕ 0.46mm (with insulation)

  Cu ratio : 1.1

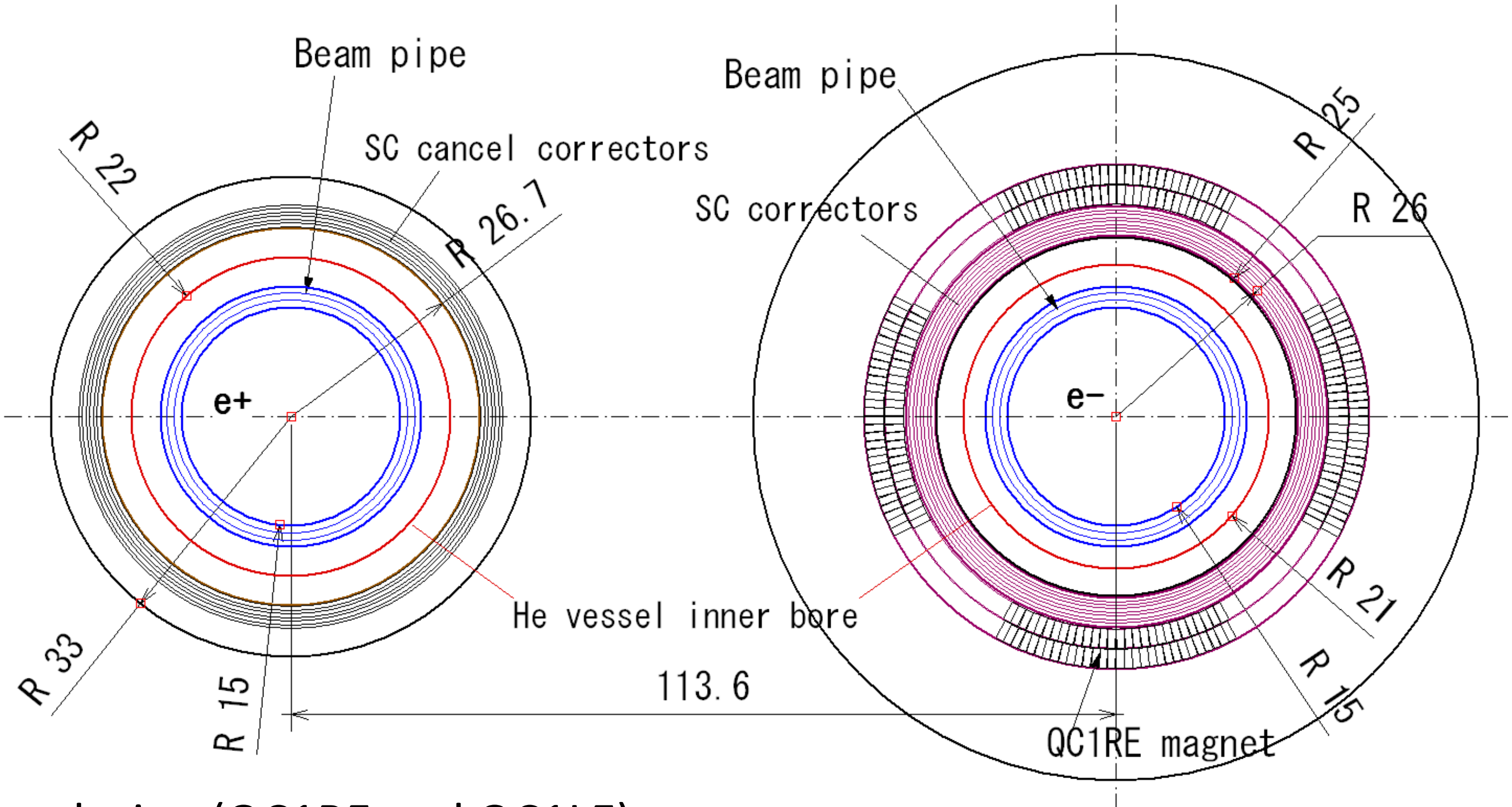
Design parameters of the correctors in the cross section for QC1RP

	b_3	b_2	b_1
Coil inner radius, mm	19.5	20.5	21.5
Coil outer radius, mm	20.5	21.5	22.5
Turns on one pole	22	34	72
Design current, A	50	50	50
Magnetic field at R=1cm	273.3 T/m^2	5.10 T/m	0.108 T
Bias magnetic field by Belle and compensation solenoids, T	1.2	1.2	1.2
Operating point with respect to J_c at 4.4 K	< 30 %	< 30 %	< 30 %

The quadrupole field by the b_2 corrector can cancel this component in the leak field.

- This quadrupole field can be used as the defocusing field for the e- beam in the right side of IP.
- In the left side, it can work as the focusing field.
- Integral field of B_2 in the leak field = 0.98 (T/m)• m
  - Sum of the B_2 fields in the leak field and by the corrector corresponds to 7.6% of the field by QC1RE.

Design of QC1E



Magnet design (QC1RE and QC1LE)

Same design of the cross section for QC1RP and QC1LP

2 layer coils [double pancake type]

Designed SC cable : same as the QC1P

SC correctors inside of the magnet bore

b_4, a_2, b_1, a_1 from the inside

2 layer coils [double pancake type]

Beam pipe : warm tube, inner radius=15 mm

SC cancel correctors against the leak field from QC1E

b_3, b_2, b_1 from the inside

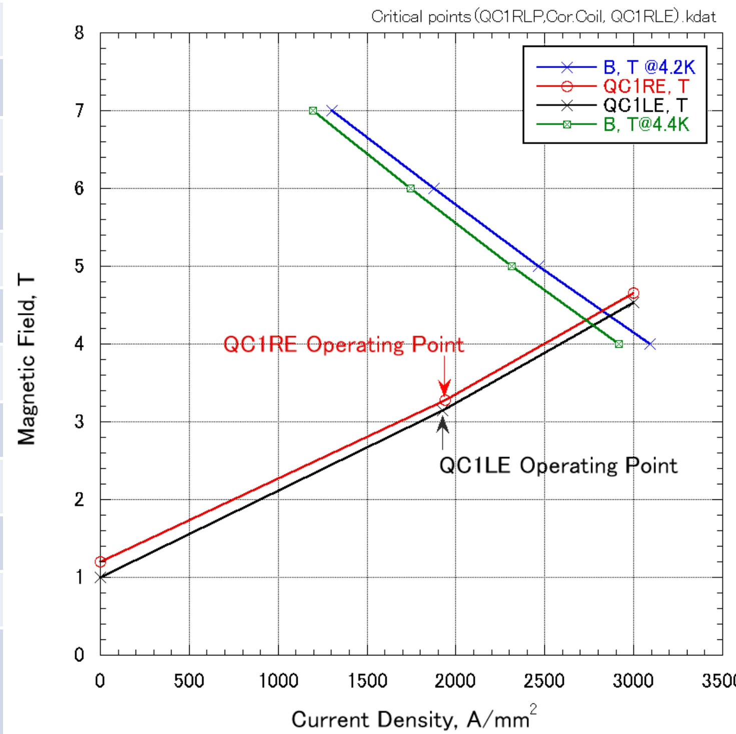
2 layer coils [double pancake type]

Beam pipe : warm tube , inner radius=15 mm

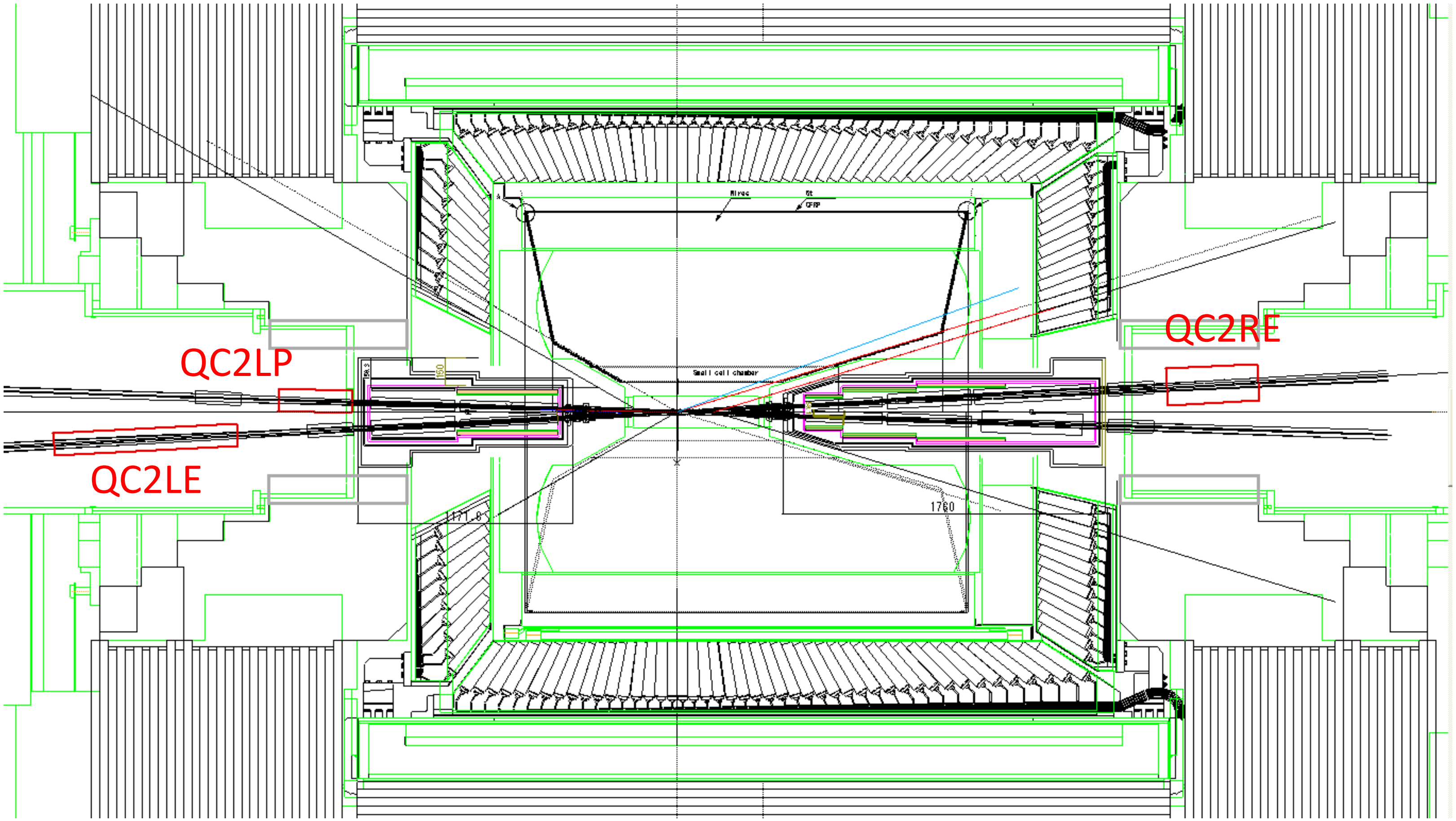
Design parameters of QC1RE and QC1LE

	QC1RE	QC1LE
Coil inner radius, mm	28.25	
Coil outer radius, mm	33.80	
Turns in one pole	14 (1st layer), 15 (2nd layer)	
Spec. of integral field, T	26.22	26.03
Field gradient, T/m	72.91	72.38
Effective magnetic length, m	0.3596	0.3596
Magnet current, A	1814.6	1801.4
Current density of the cable (SC area), A/mm^2	1940.7	1926.6
Magnetic field by Belle and comp. sol., T	1.2	1.0
Max. field in the coil without solenoid field, T	2.89	2.87
Max. field in the coil with solenoid field, T	3.28	3.15
Operating point with respect to B_c at 4.4 K	76%	75%
Error field at 1 cm (2D calculation)	$b_6 = 1.15 \times 10^{-4}$ $b_{10} = -0.27 \times 10^{-4}$ $b_{14} = 0.23 \times 10^{-6}$	

Load lines of QC1RE and QC1LE



Design of IR permanent magnets (QC2RE, QC2LP, QC2LE)



- QC2RE, QC2LP and QC2LE locate out of the inner area of Belle detector.

Magnet parameters of QC2RE, QC2LP and QC2LE

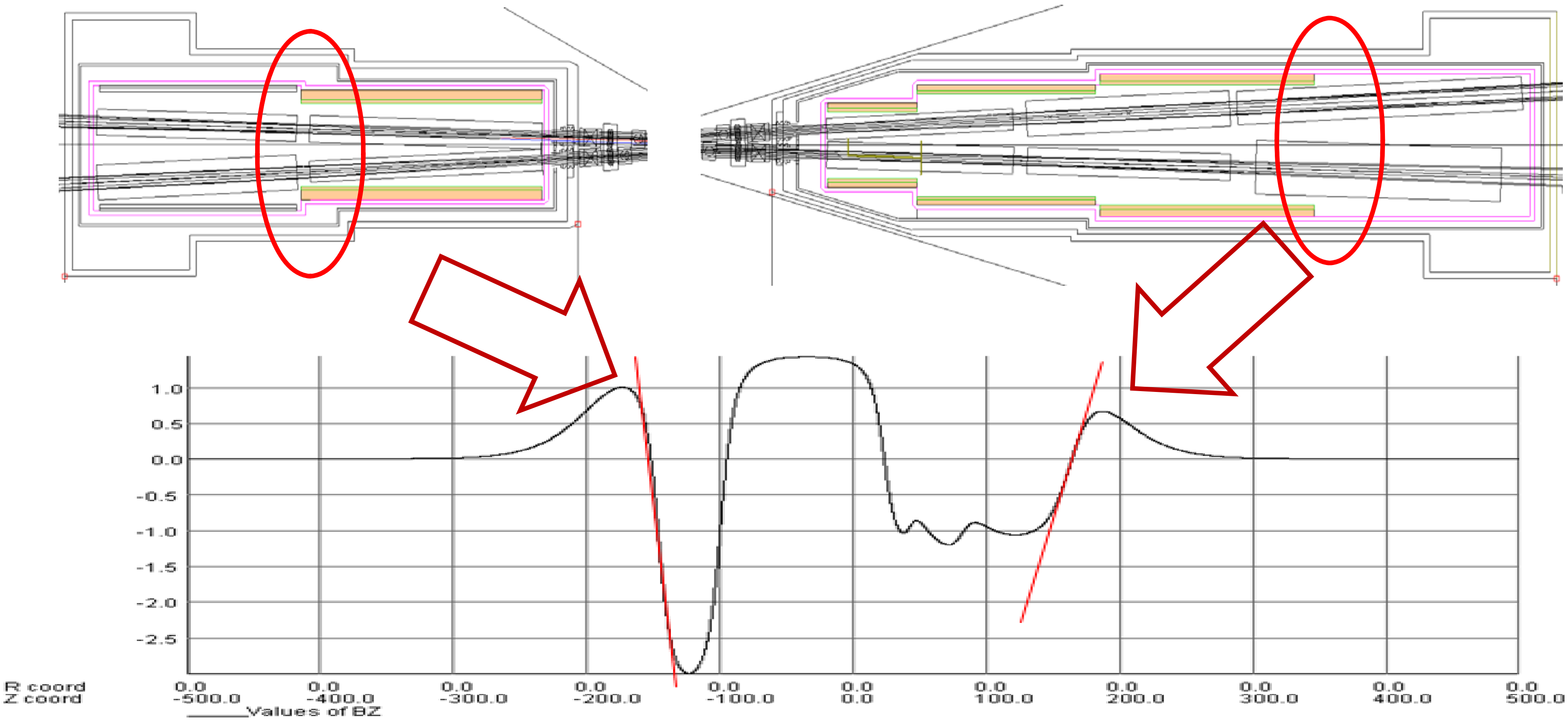
	Int. field gradient, (T/m)m	Magnet length, m	Required field gradient, T/m	Beam pipe outer radius, m	Field at coil inner radius, T
QC2RE	12.91	0.6	21.52	0.04	0.86
QC2LP	10.96	0.45	24.36	0.035	0.85
QC2LE	14.13	1.0	14.13	0.04	0.57

- Requirement of installation of BPMs and vacuum pumps as close to IP as possible.
  - BPMs and vacuum pump can be installed out of the cryostats.
- Small disturbance on the field profile of the solenoid fringe field

⇩

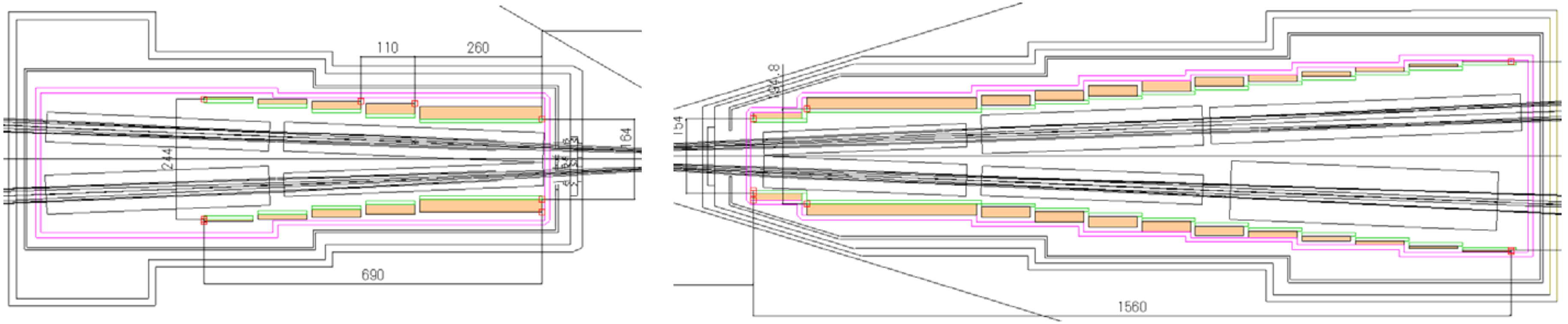
- Permanent magnet for QC2RE, QC2LP and QC2LE is considered.
- The remnant field of Samarium-cobalt (SmCo) is 1.04~1.12 T.
  - This material is available for these permanent magnets.
  - The corrector coils for these permanent magnets will be installed in case of insufficient field stability due to temperature and radiation, and the necessity of the field change at energy scan.

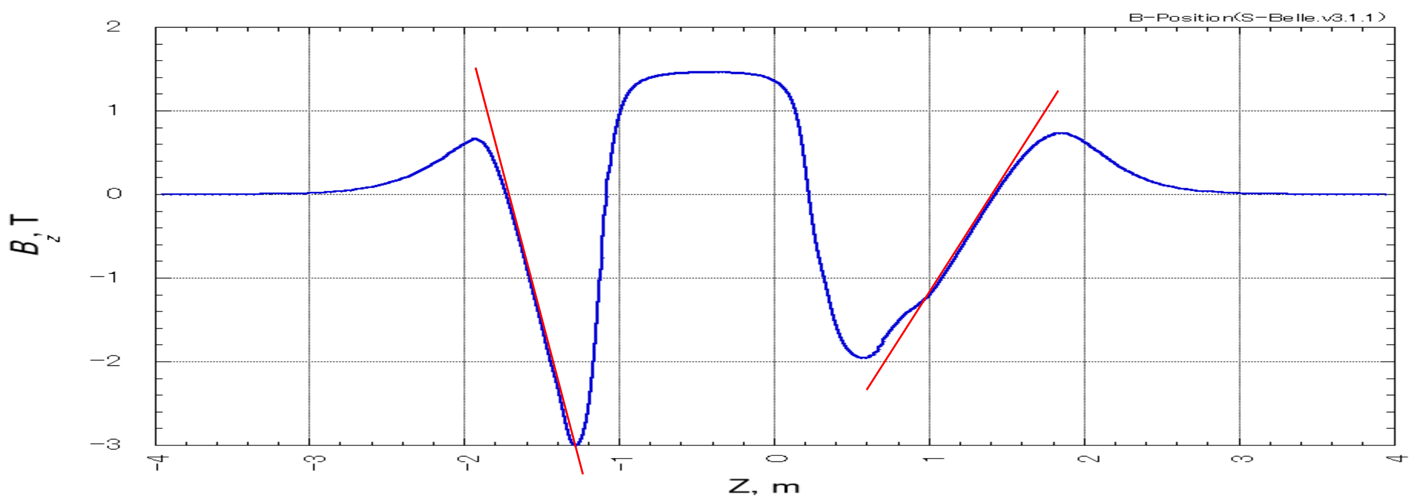
Compensation solenoids, ESR and ESL



- Design of compensation solenoids
  - The axes of the compensation solenoids consist with the Belle solenoid axis.
  - The solenoids encircle the QC1RP, QC1RE, QC1LP, a part of QC2RP and correctors.
- From the recent beam simulation, the fringe fields by the compensation solenoids increase the beam emittance.

Proposed new compensation solenoids



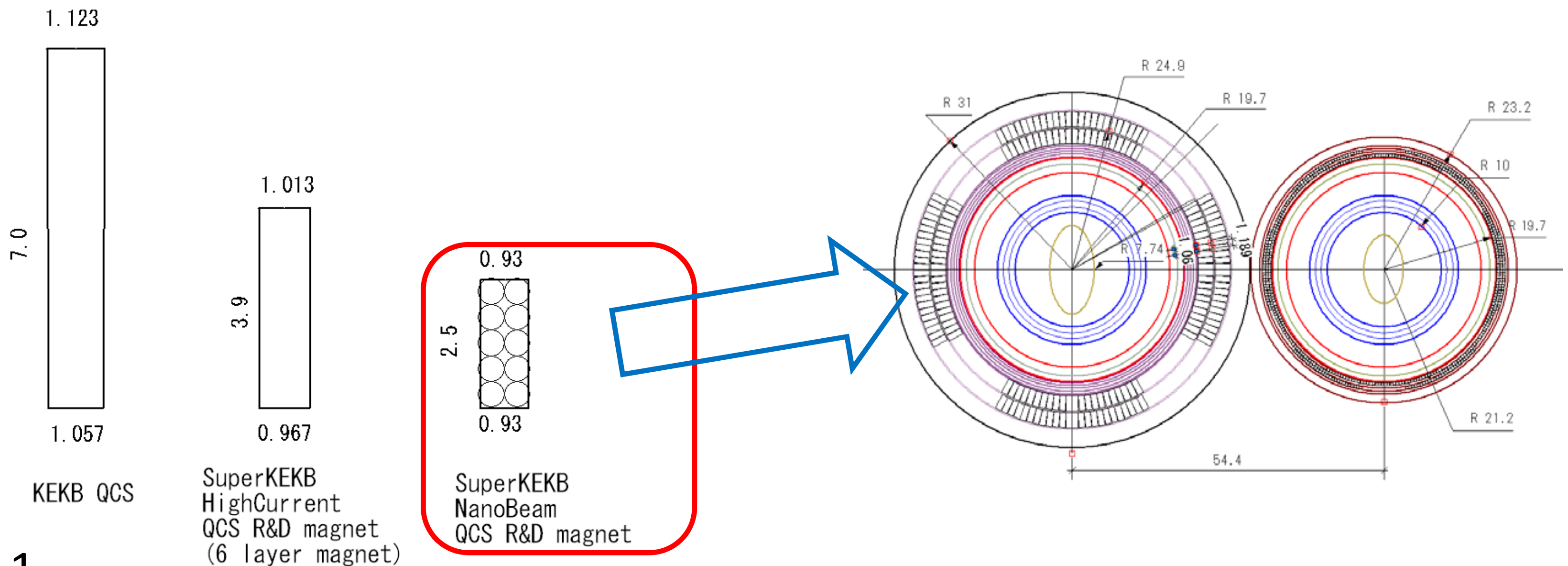


- Design of compensation solenoids
  - The solenoids are designed to be segmented into small coil pieces.
  - The coil pieces have decreased turns gradually along the distance from IP.
  - The electro-magnetic forces on the ESR and ESL are 31.2 kN and -26.2 kN, respectively.
- The field changes of the solenoid field are managed to be a half of the previous design.
- The field profile will be included in the beam simulation and studied soon.

R&D and progress

1. Small cross section SC cable for QC1
2. QC1RP R&D magnet
3. Permanent quadrupole development
4. Multi-current leads for correctors
   - One set of assembly of eight conductors for 4 correctors is designed and manufactured. The cold test will be performed in April.
5. Power supply for IR magnets
   - The power supply for the QC1 is now being constructed.
   - The target stability of the transport current is less than 20 ppm/24 hours.
   - The performance of the power supply with QC1RP R&D magnet will be measured in Dec. 2010.

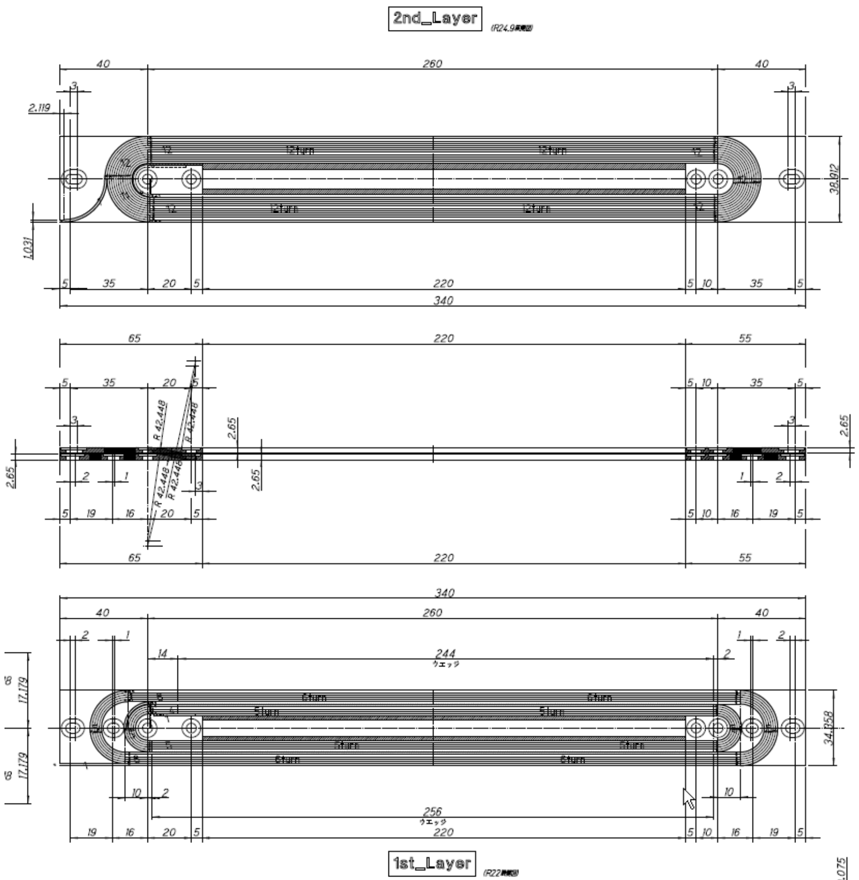
Small cross section SC cable for QC1

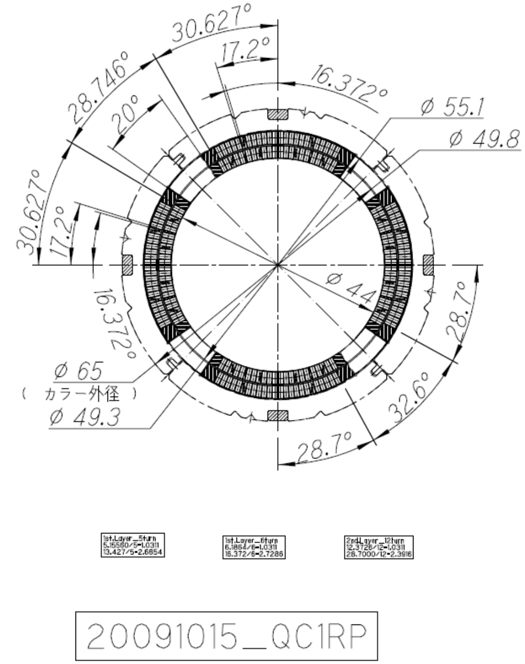


- STEP-1
  - Construction of dummy cable with Cu strand [Flat Cable] : completed.
    - Strand dia.=0.5mm, cable size=2.5mm × 0.93mm, strand number=10, cable length=10m
- STEP-2a
  - R&D of SC cable with NbTi strand[Flat Cable] : now under development up to March 2010.
    - Strand dia.=0.5mm, cable size=2.5mm × 0.93m, strand number=10, cable length=10m × 2
    - Cu/SC ratio=2.0, I_c=125A at 6T and 4.2K, Insulation ①12.5μm(T) × 3mm(W) , ② 25.0μm(T) × 3mm(W)
- STEP-2b
  - R&D of SC cable with NbTi strand [keystoned cable] : R&D will start from April 2010.
- STEP-3
  - Construction of the SC cable for QC1RP magnet : scheduled date of completion is September 2010.
    - Strand dia.=0.5mm, Cu/SC ratio=1.1, cable size=2.5mm × 0.93m, strand number=10, cable length=200m

R&D of QC1RP

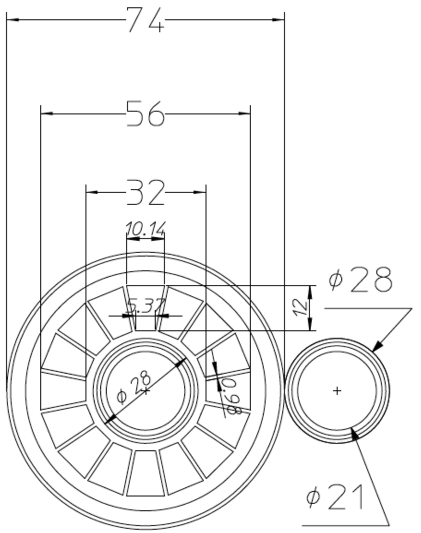
QC1RP R&D magnet construction drawings

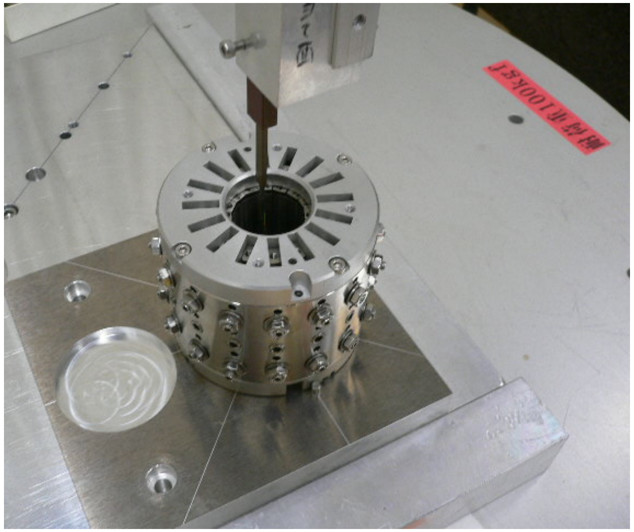


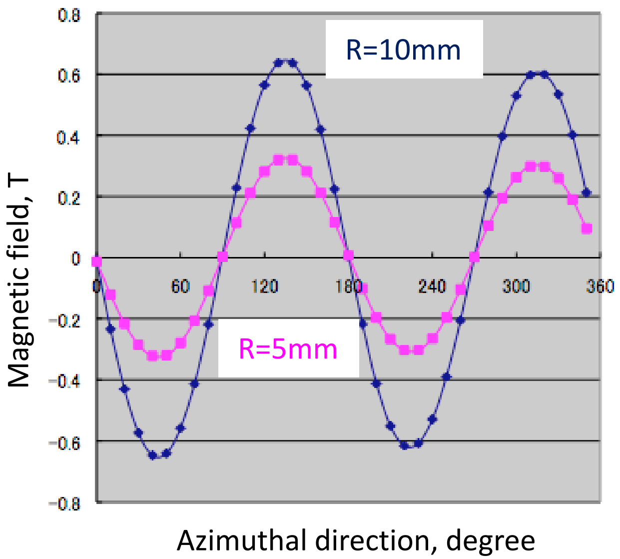


- The design of tools for the QC1RP R&D magnet is now completed.
- Manufacturing the tools of the magnet will be completed in March 2010.
- The SC corrector coils for QC1RP will be developed in the September 2010.
  - The superconducting wire for correctors has been already manufactured.
  - The cable diameter is 0.4 mm, and the Cu/SC ratio is 2.0.

Permanent magnet development







- The permanent R&D magnet was constructed.
  - The magnet was designed for QC1.
  - The length of the magnet is 50 mm.
- The material was SmCo [R26HS: Shin-Etsu Chemical Co., Ltd.].
- The magnetic field of the R&D magnet was measured.
  - The measured field gradient was 63.7 T/m.
  - The remnant field of the material was calculated to be 1.019 T at the coil inner radius of 16 mm.
- The precise field measurement system of the harmonic coil and the position tuning machine of the pieces of the permanent magnet will be prepared until this summer.
  - Error field of this permanent magnet will be measured and improved by the system.

Construction schedule of IR magnets