2004/ Feb./17-KEKB Review

Superconducting Magnet for Super-KEKB

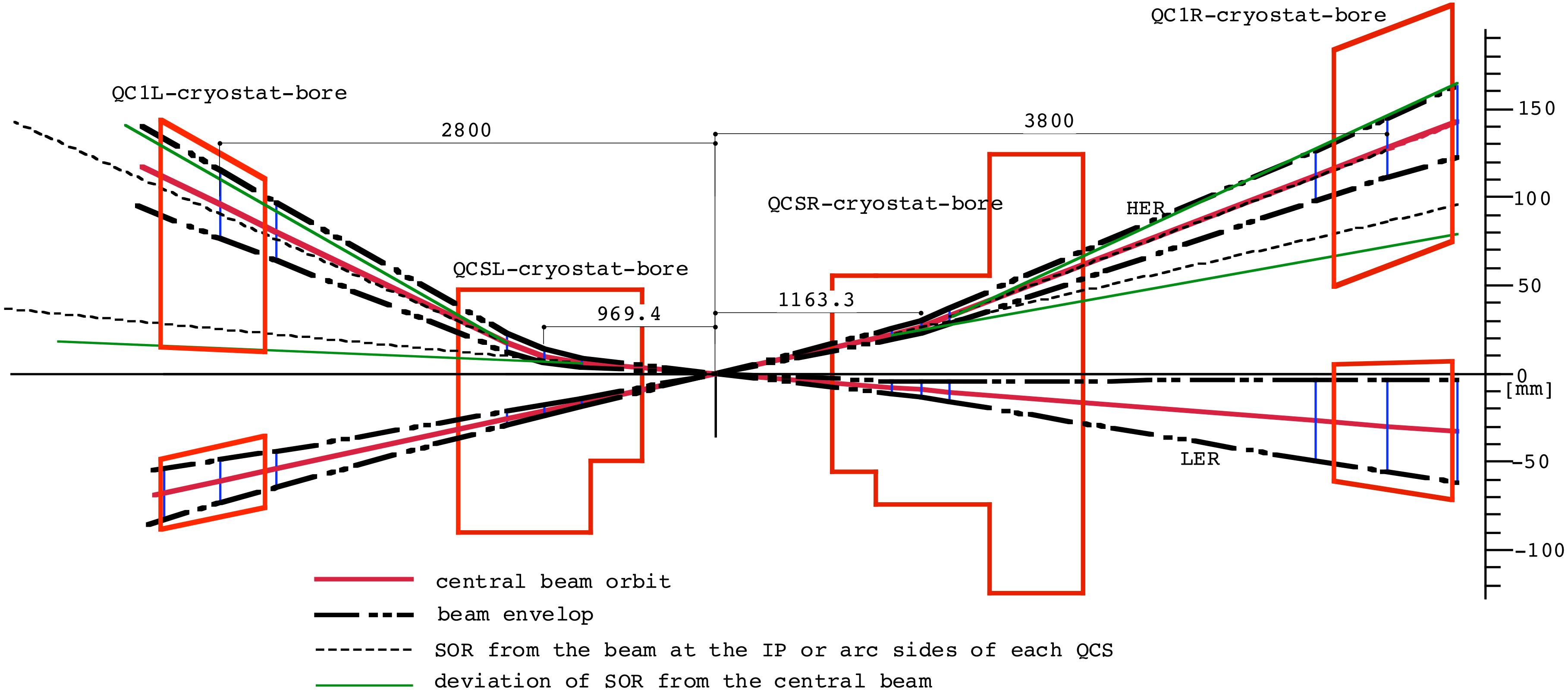
Norihito Ohuchi

(1) SC Magnets Design Constraints
(2) Final Focus Quadrupole (QCS)
(3) Compensation Solenoid (ES)
(4) Superconducting Special Magnets (QC1)
(5) Summary and Further Study for SC Magnets

(1) SC Magnets Design Constraints

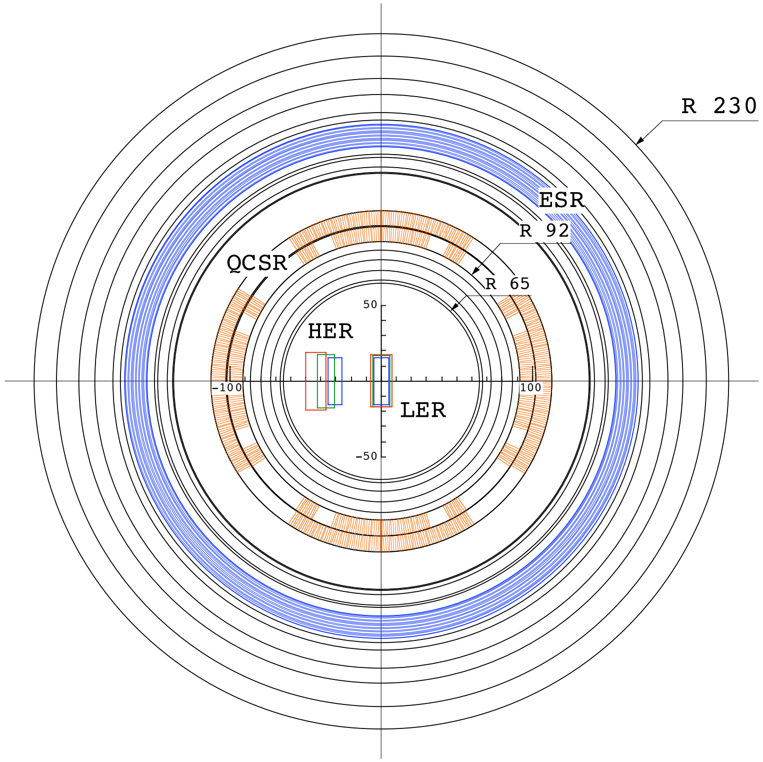
Magnet-cryostat design was performed under the following spatial constraints;

- Beam envelops (from the beam optics of X=30 mrad and βx=20cm by H. Koiso)
- Synchrotron light envelops (from the estimation by Y. Funakoshi)
- Boundary with Belle detector (same as the present system)

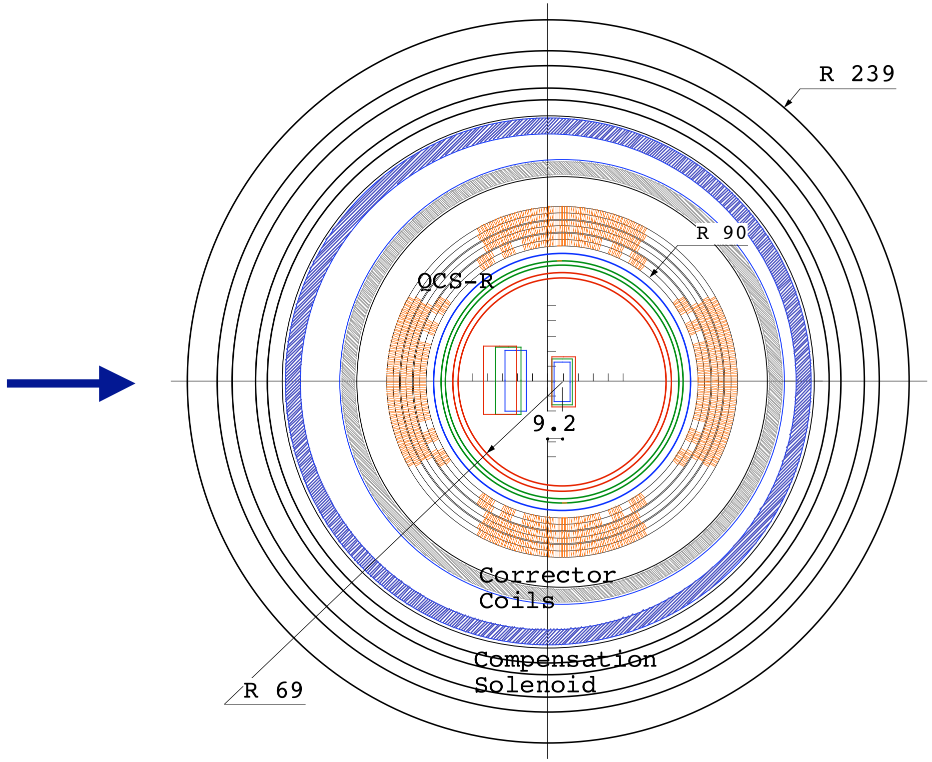


(2) Final Focus Quadrupole (QCS)

QCSR & ESR (viewed from IP)



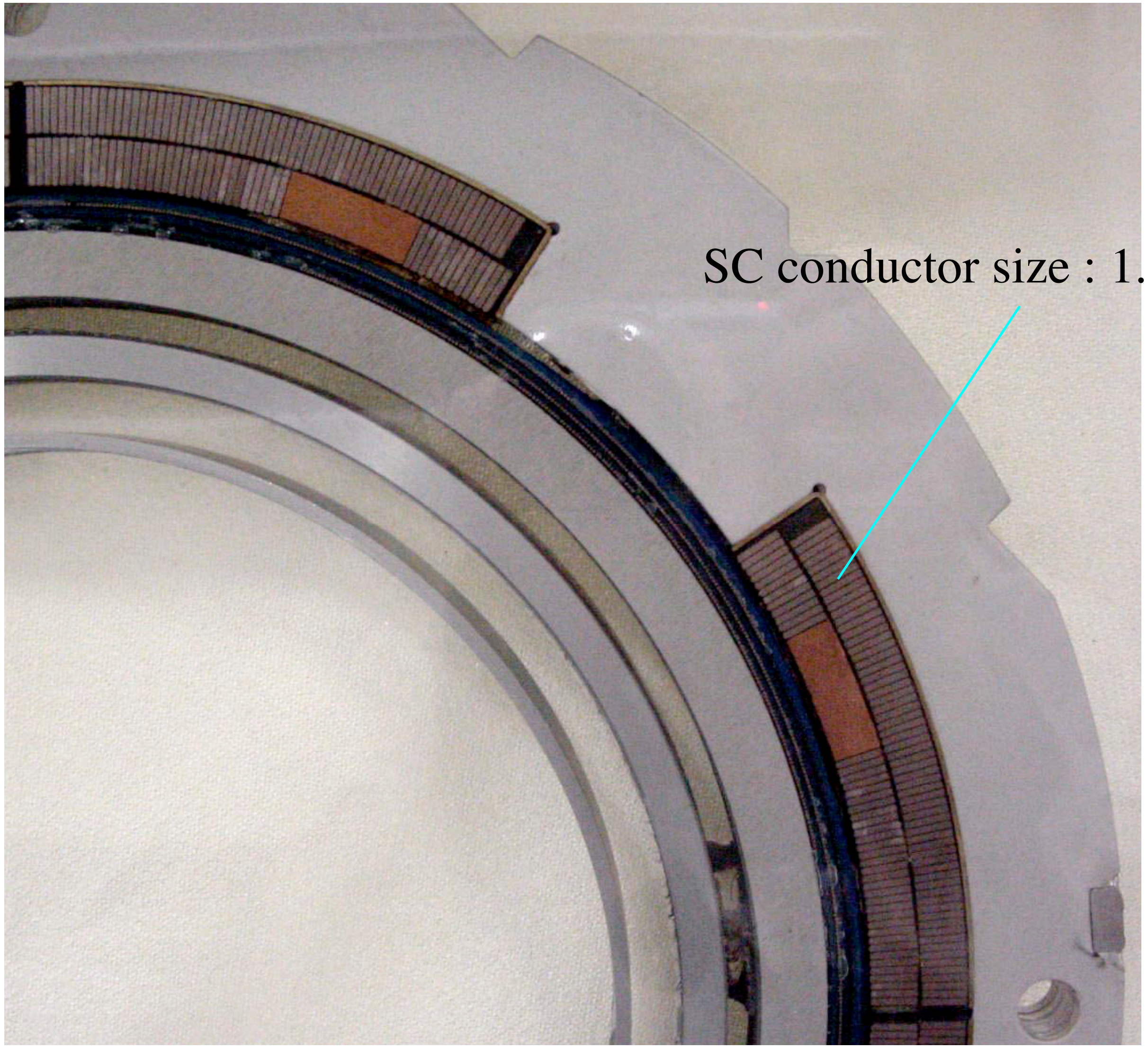
New Cross Section of QCSR & ESR



- 2 layer coil
- SC cable size : 1.1mm×10mm
- Design current : 3650 A for G=36 T/m
- Magnetic center shift w.r.t. the Belle axis
  QCSR = 0.0 mm, QCSL = 29.1mm

- 6 layer coil
- SC cable size : 1.1mm×4.1mm
- Design current : 1134 A for G=36 T/m
- Magnetic center shift w.r.t. the Belle axis
  QCSR = 9.2 mm, QCSL = 21.2mm

KEKB-QCS-cross-section



SC conductor size : 1.1mm × 7.0mm (KEKB-QCS)

↓

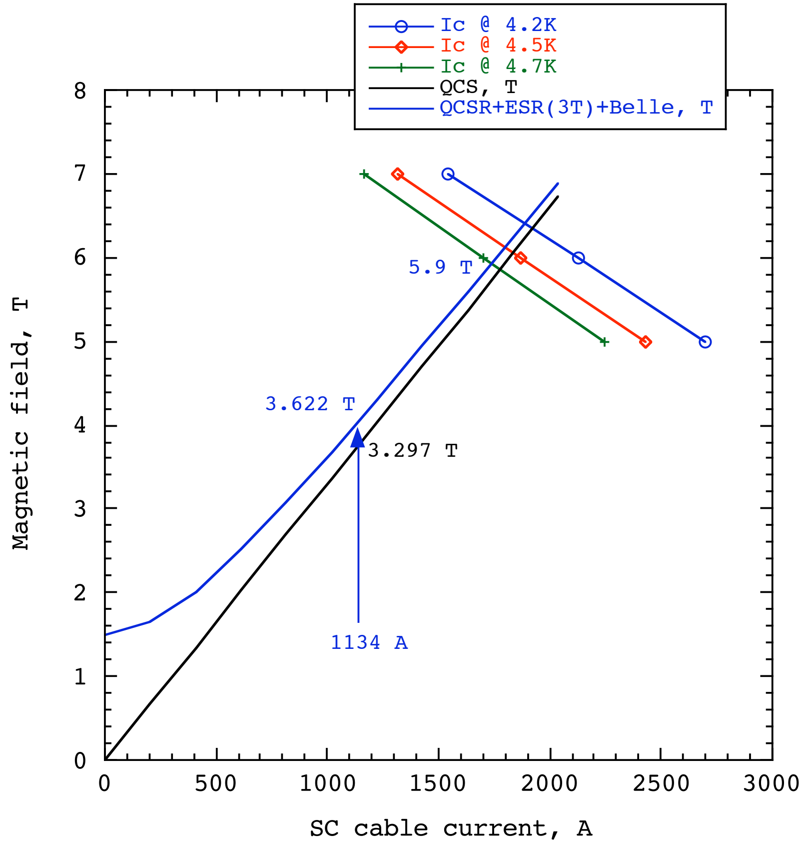
1.1mm × 10.0mm
(old design)

↓

1.1mm × 4.1mm
(new design)

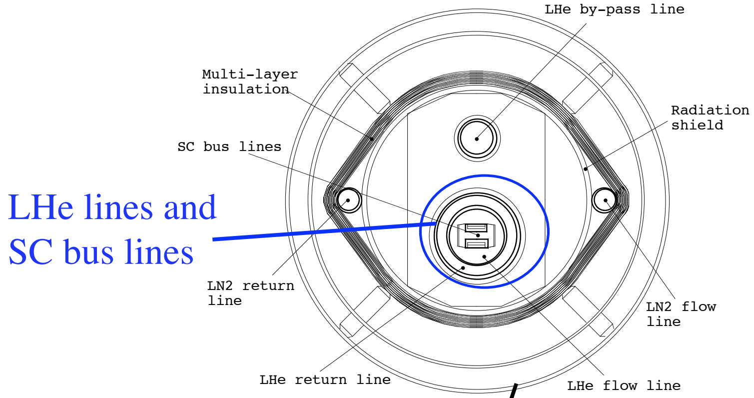
Parameters of **New QCS Design**

1. 6 layer coils (3-double pane cake coils)
2. Inner radius : 90 mm
3. Cable size : 1.1mm(W), 4.1mm (H)
4. Field gradient =36 T/m @1134A
5. Max. field in the coil = 3.74 T
6. Effective magnetic length
   - QCSR = 0.333 m
   - QCSL = 0.398 m
7. Inductance
   - QCSR = 77.94 mH
   - QCSL = 93.16 mH
8. Stored Energy @1134A
   - QCSR = 50.09 kJ
   - QCSL = 59.87 kJ
9. I_{op}/I_c = 68 % @ 4.7 K
10. Field quality (@ r=55mm)
    b_2=10000, b_6=0.16, b_{10}=0.61, b_{14}=0.43



QCS load line with ESR and Belle fields.
The plotted results are calculated by the two dimensional model.

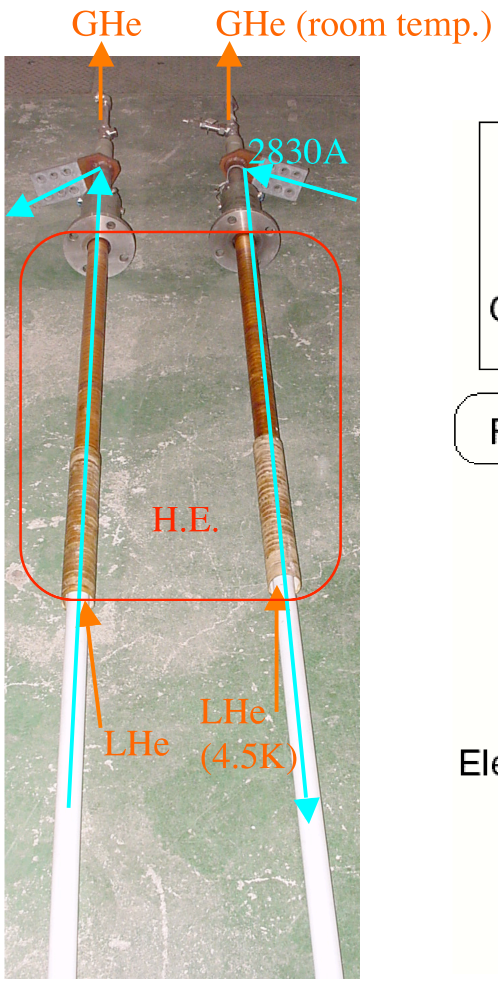
Effect of New Designed QCS on the cryogenic system

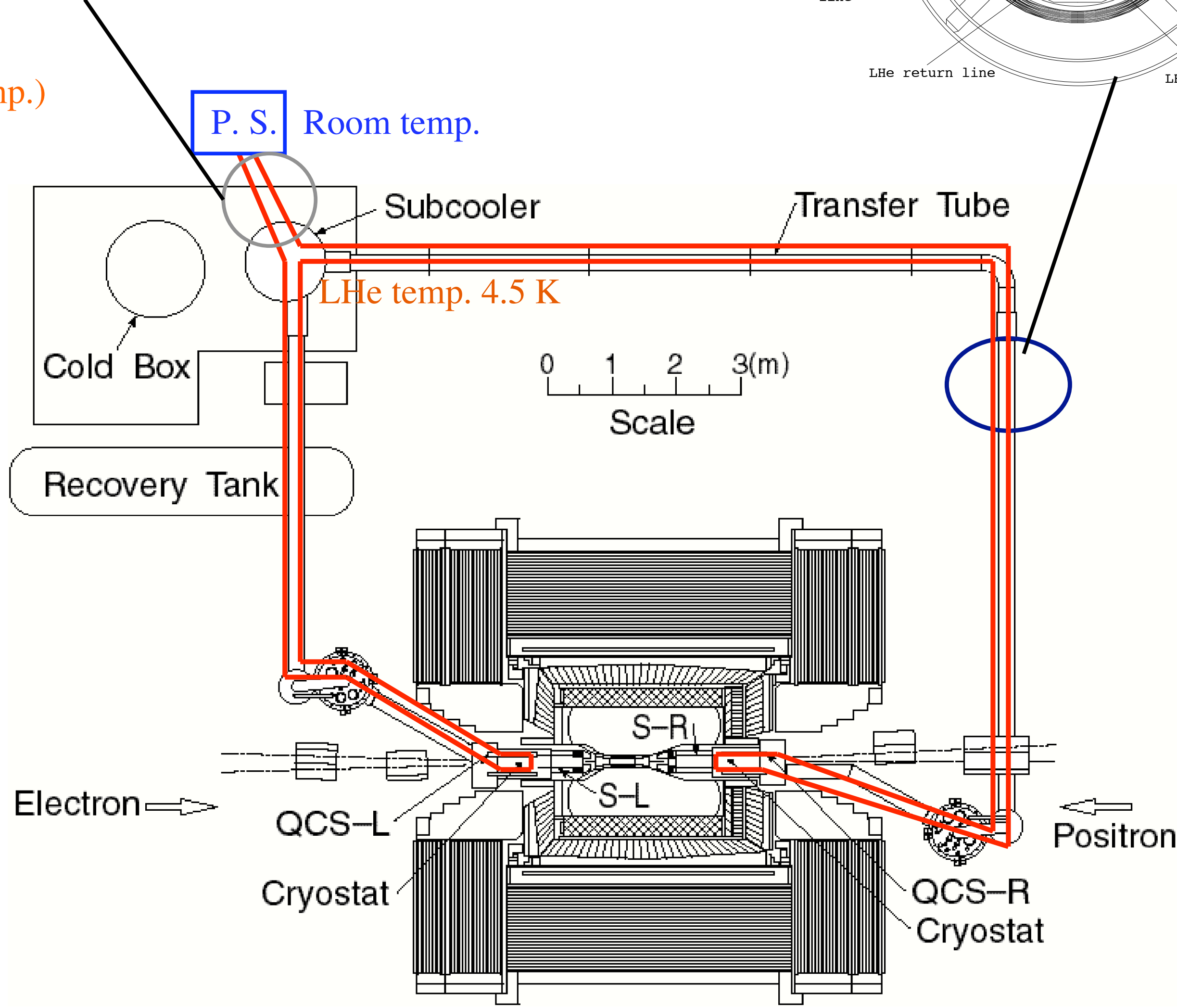


Current Leads

(Physically, the environments at LHe temp. and room temp. connect by these current leads.)

KEKB-QCS current leads

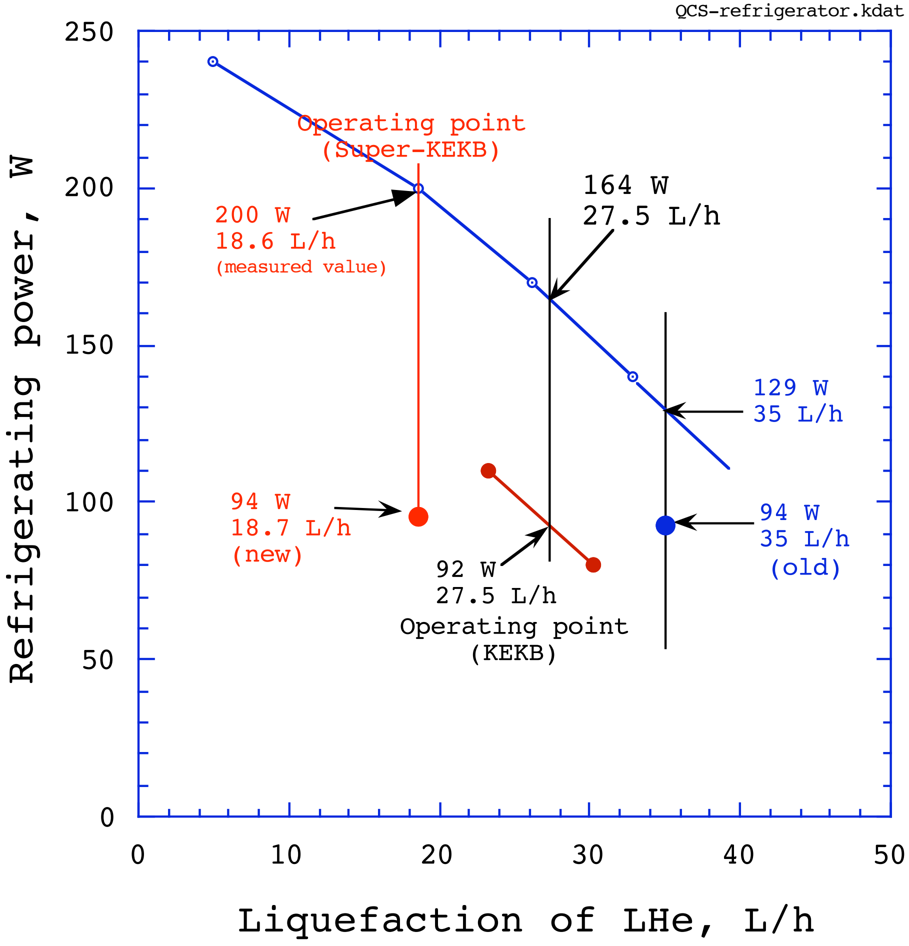




Heat load of the cryogenic system

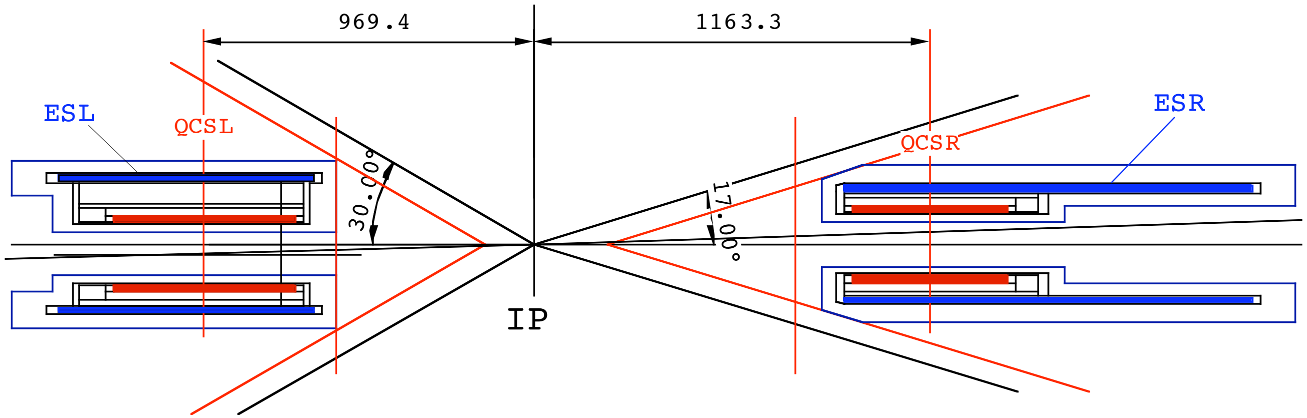
	KEKB	Super-KEKB
Current leads		
QCS	15 L/h	5.7 L/h new (22 L/h) old
ES	8.5 L/h	9 L/h
Correctors	4 L/h	4 L/h
Cryostat	22 W	24 W
Transfer line	70 W	70 W
Total	27.5 L/h +92 W	18.7 L/h +94 W (35 L/h +94 W)
Refrigerator	27.5 L/h +164 W	18.7 L/h +199.6 W (35 L/h +129 W)
Margin	72 W	105.6 W ← (35 W)

Cooling capacity of QCS refrigerator



(3) Compensation Solenoid (ES)

ES and QCS configuration (old design)



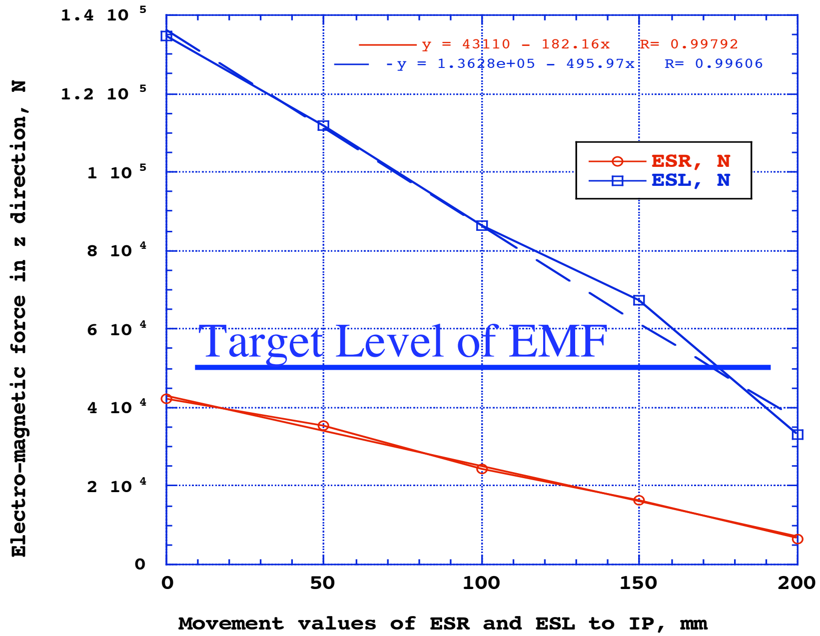
Electromagnetic Force :

- ESR 42288 N (4.3 tons)

  KEKB-ESR : 7050.5 N (0.7 tons)
- ESL -134820 N (13.8 tons)

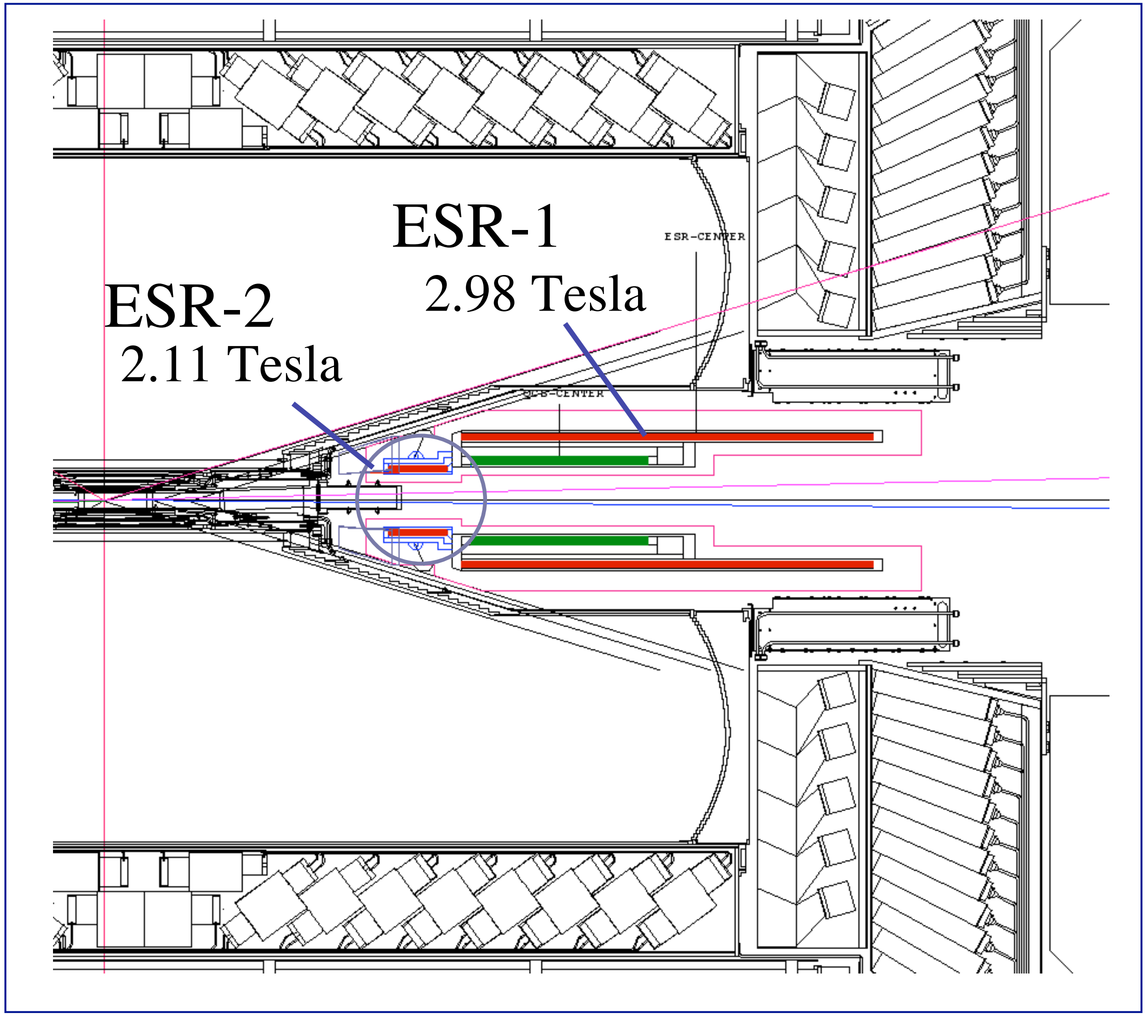
  KEKB-ESL : -23505 N (2.4 tons)

Serious problem on the mechanical design of the cryostats



Electromagnetic force as a function of the ESR and ESL positions.

ESR, QCSR and cryostat



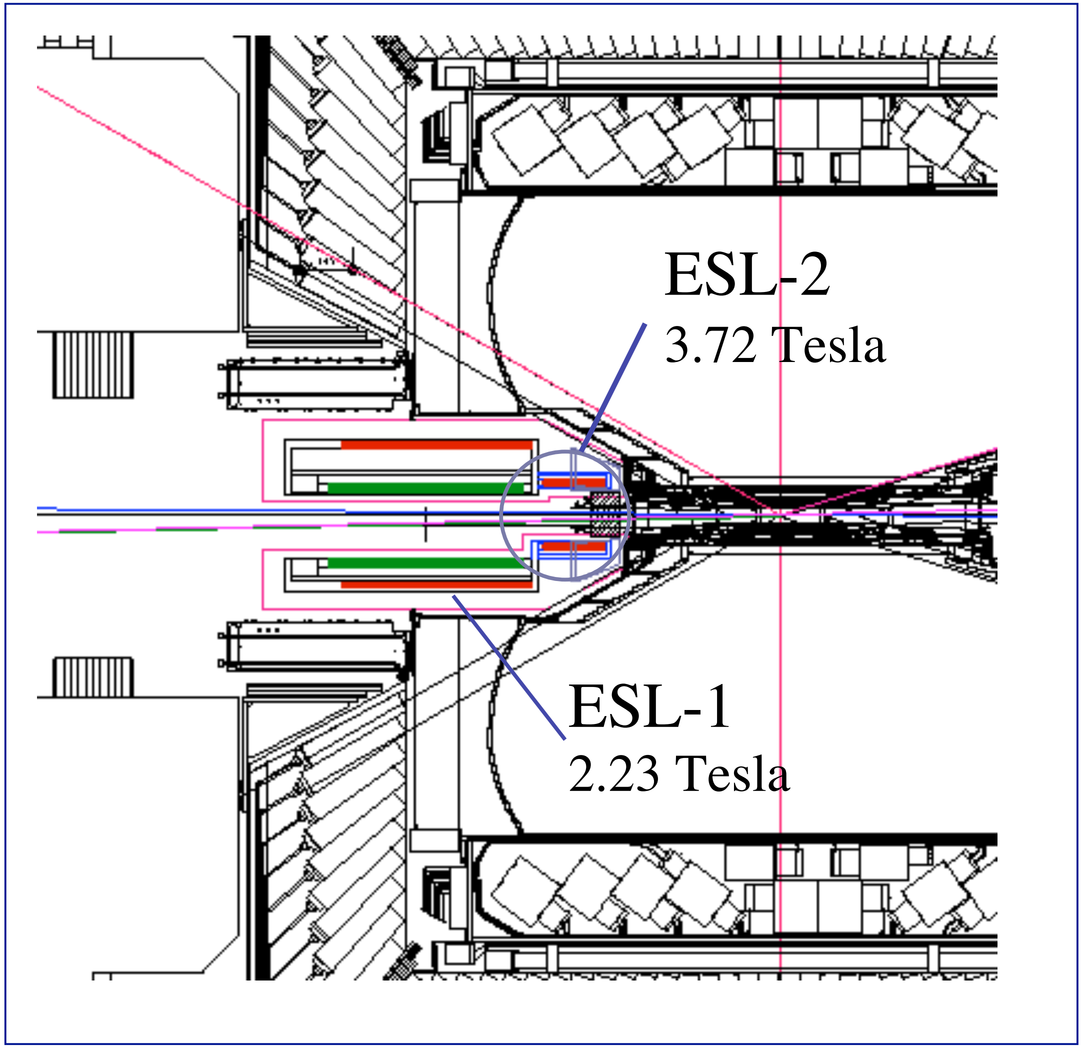
ESR Parameters

	ESR-1	ESR-2
Central field w.o. Belle field, T	2.98	2.11
Max. field w.o. Belle field, T	3.00	2.45
Current *Iop*, A	619	619
Iop / *Ic*, %	51	47
Coil		
Inner radius, mm	155	77
Outer radius, mm	165.2	87.2
Length, mm	1050	150

Electro-magnetic force
4.2×10^4N —> 2.2×10^4N
(0.7×10^4N for KEKB)

Heat load via support rods in cryostat
3.4 W(KEKB) —> 3.5 W

ESL, QCSL and cryostat



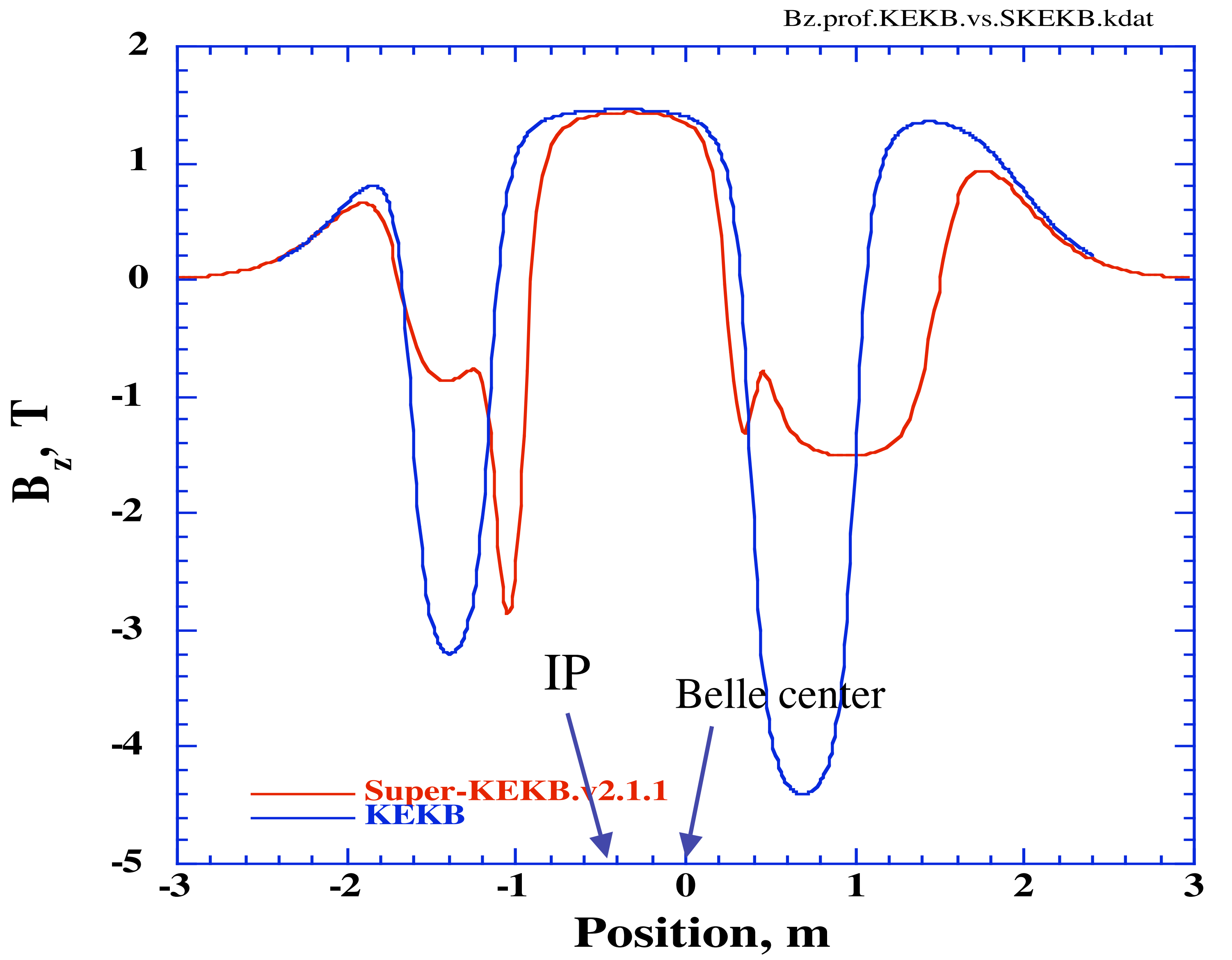
ESL Parameters

	ESL-1	ESL-2
Central field w.o. Belle field, T	2.23	3.72
Max. field w.o. Belle field, T	2.59	4.14
Current *Iop*, A	615	615
Iop / *Ic*, %	48	63
Coil		
Inner radius, mm	185	77
Outer radius, mm	194	93.9
Length, mm	519	175

Electro-magnetic force
13.5×10^4N —> 4.8×10^4N
(2.4×10^4N for KEKB)

Heat load via support rods in cryostat
3.2W(KEKB) —> 4.5W

B_z profile along the Belle axis

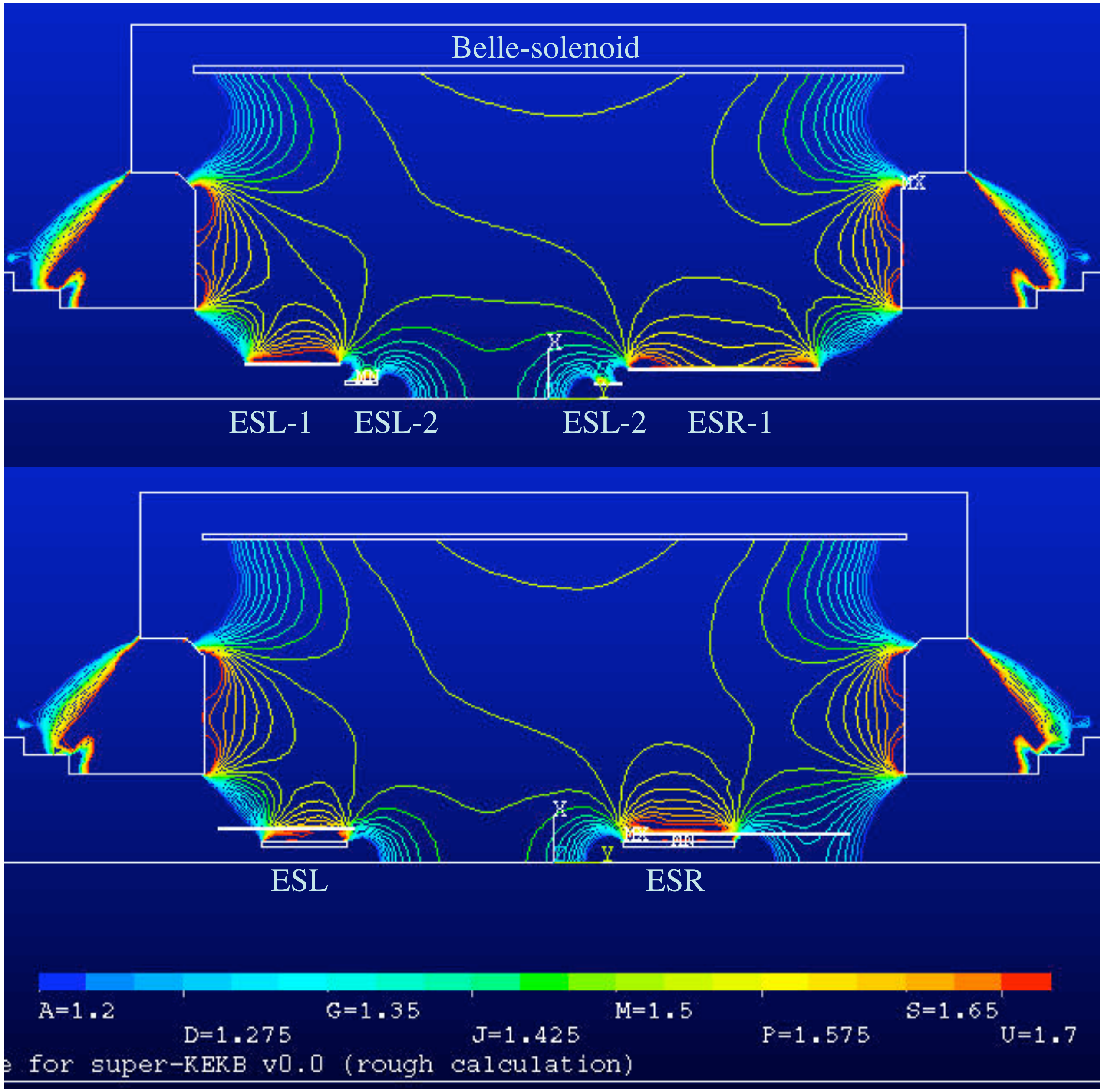


Solenoid field distortion in the Belle detector

Contour plots: 1.2 T < B_z <1.7 T

Super KEKB

KEKB

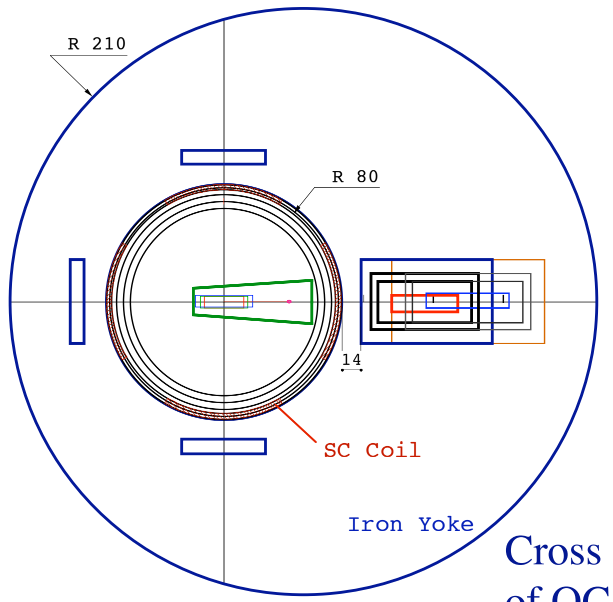


(4) Superconducting Special Magnets (QC1)

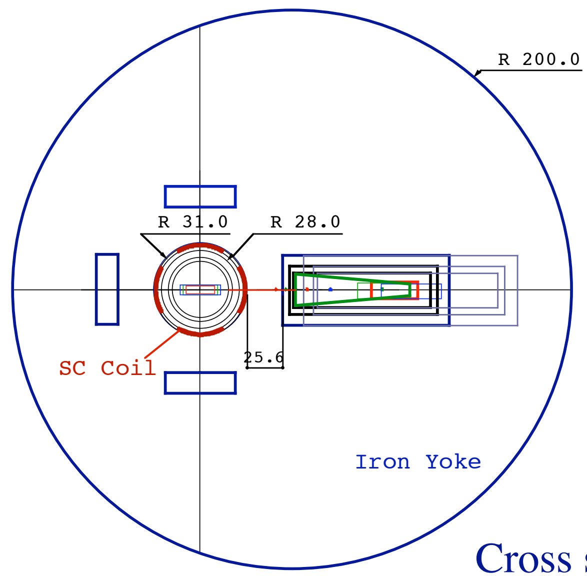
Parameters of QC1R and QC1L

	QC1R	QC1L
Coil	2-layer	1-layer
Coil inner radius, mm	80.0	31.0
Coil outer radius, mm	84.0	33.0
Yoke outer radius, mm	210	200
Field gradient, T/m	34.0	42.9
Eff. mag. Length, m	0.266	0.232
Current *Iop*, A	1319	1319
Max. field, T	3.28	1.62
Iop / Ic, %	73	59
Leak field on LER beam, Gauss	< 20	< 1.5
SC cable	1.1mm × 1.9mm	

(solid composite of rectangular cross section)



Cross section of QC1R



Cross section of QC1L

(5) Summary and Further Study for SC Magnets

Summary

- QCS
  - New magnet cross section
    - ✓ 6 layer coil (3 double pancake coils)
    - ✓ Magnet current 1134 A for G=36 T/m
    - ✓ Estimated margin of refrigerator=105.6 W (KEKB:72 W)
    - ✓ Field quality by 2 dim. cross section @R_{ref}=55mm

      b_2=10000, b_6=0.16, b_{10}=0.61, b_{14}=0.43
- ES
  - Compensation solenoid-> two solenoids for each side
    - ✓ EMF

      ESR=2.2 × 10^4N, ESL=4.8 × 10^4N

      (KEKB: ESR=0.7 × 10^4N, ESL=2.4 × 10^4N)
- QC1
  - Rough calculation of the 2-D cross section
    - ✓ *G*=34 T/m, $L_{eff.}$=0.266 m, leak field on LER beam<20 Gauss for QC1R
    - ✓ *G*=42.9 T/m, $L_{eff.}$=0.232 m, leak field on LER beam<1.5 Gauss for QC1L

Further study for the SC magnets

- 3-D magnetic field calculation for the all SC magnet

  ✓ Field quality of the whole magnet with coil and magnet ends
  ✓ Maximum magnetic field of each magnet under the combined operation of all magnets
  ✓ Electromagnetic force calculation between the magnets
  ✓ Quench analysis

- Design of the cryostats and vacuum chambers

  ✓ Mechanical and thermal design of the cryostats
  ✓ Interference between the cryostats and vacuum chambers