Design of New IR Quads
(The 1^{st} consideration for the updated IR)

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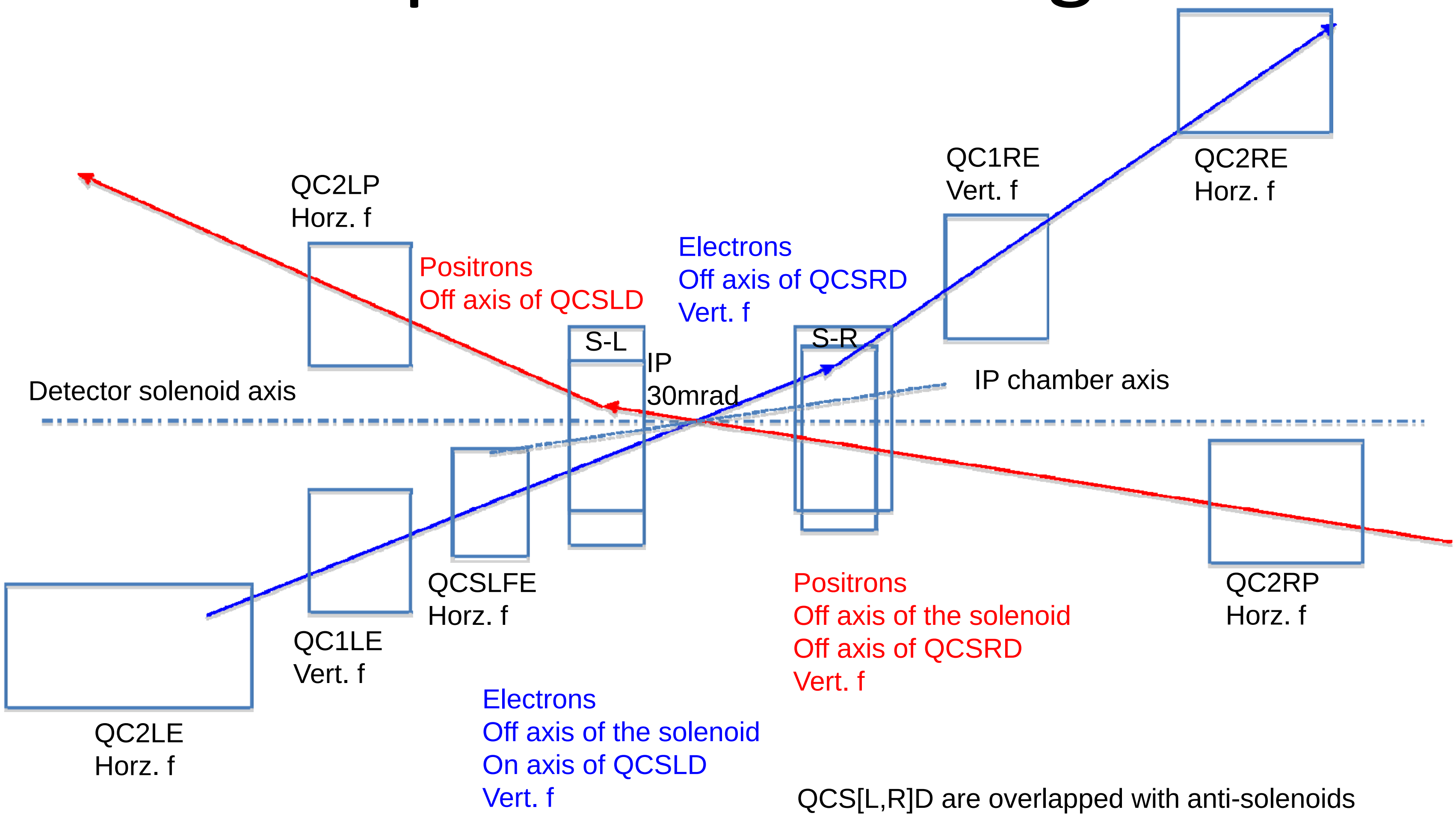
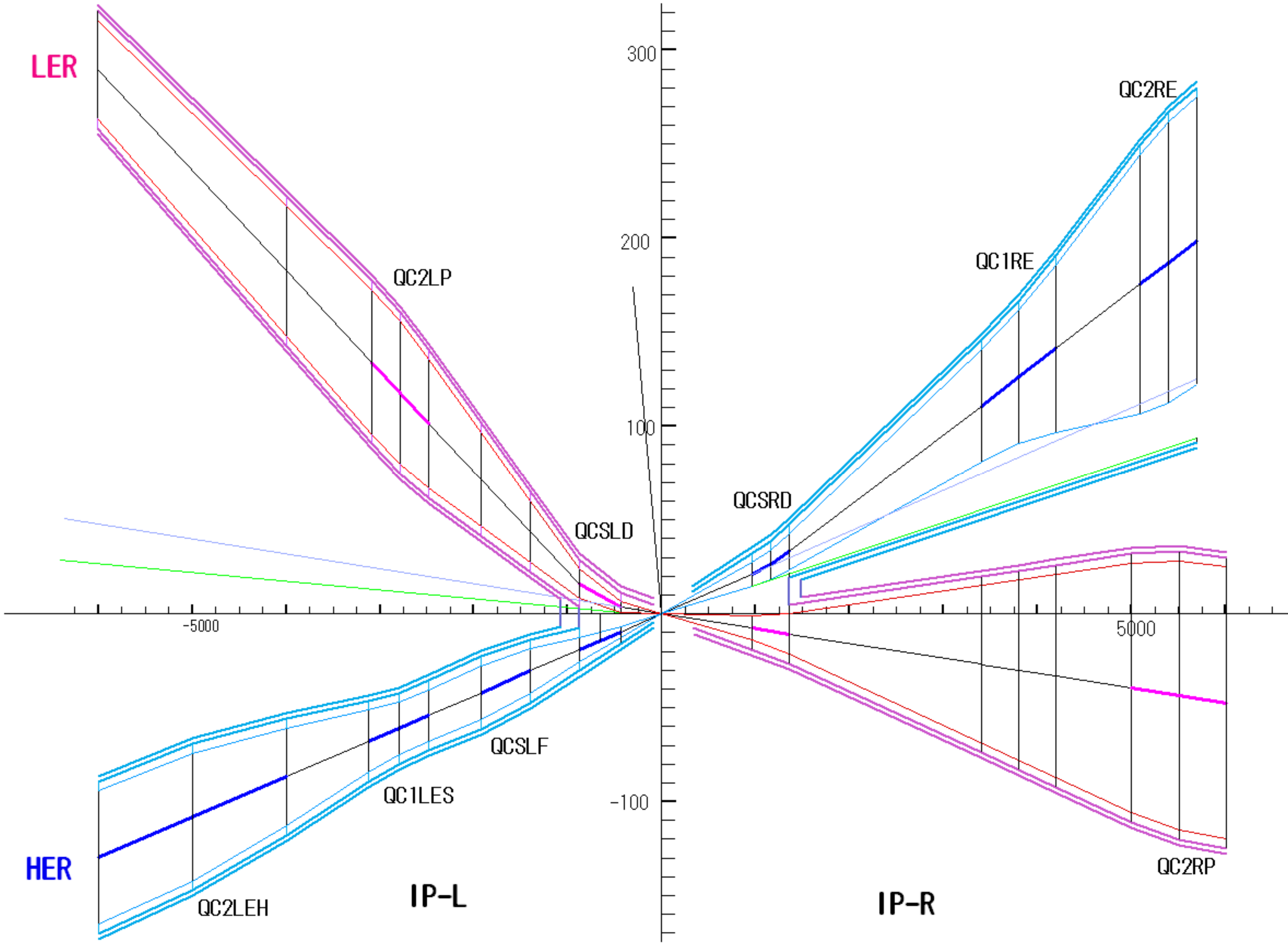
SuperKEKB IR Design



IR Beam Envelops based on the beam optics by Koiso



HER

QC2REH
17.49 T/m, 10.49 T
QC1RES
15.87 T/m, 12.69 T
QCSRD
36.38 T/m, 12.11 T
QCSLD
53.01 T/m, 23.33 T
QCSLF
44.34 T/m, 23.06 T
QC1LES
34.79 T/m, 22.27 T
QC2LEH
5.13 T/m, 10.26 T

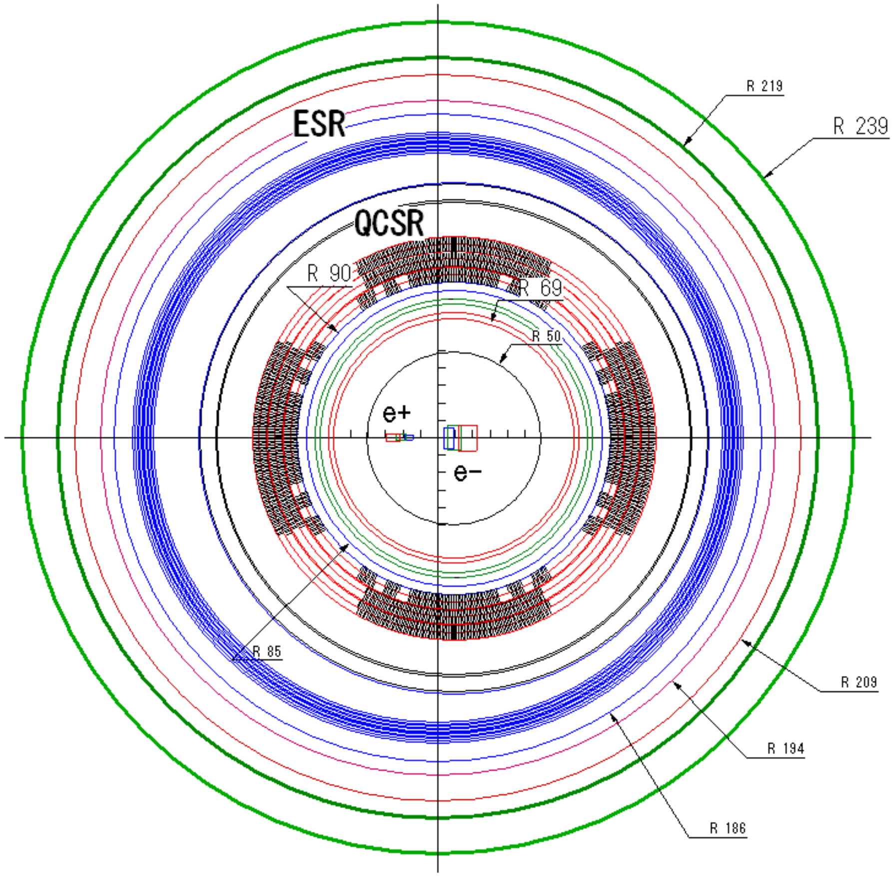
LER

QC2RP
3.06 T/m, 3.10 T
QCSRD
36.38 T/m, 12.11 T
QCSLD
53.01 T/m, 23.33 T
QC2LP
10.58 T/m, 6.49 T

The space for the magnet design is defined by the area of 5 σ of beam size + 5 mm for the design margin of beam pipe + 3mm thickness of beam pipe.

Final focus quadrupole (QCSRD and QCSLD)

- QCSRD

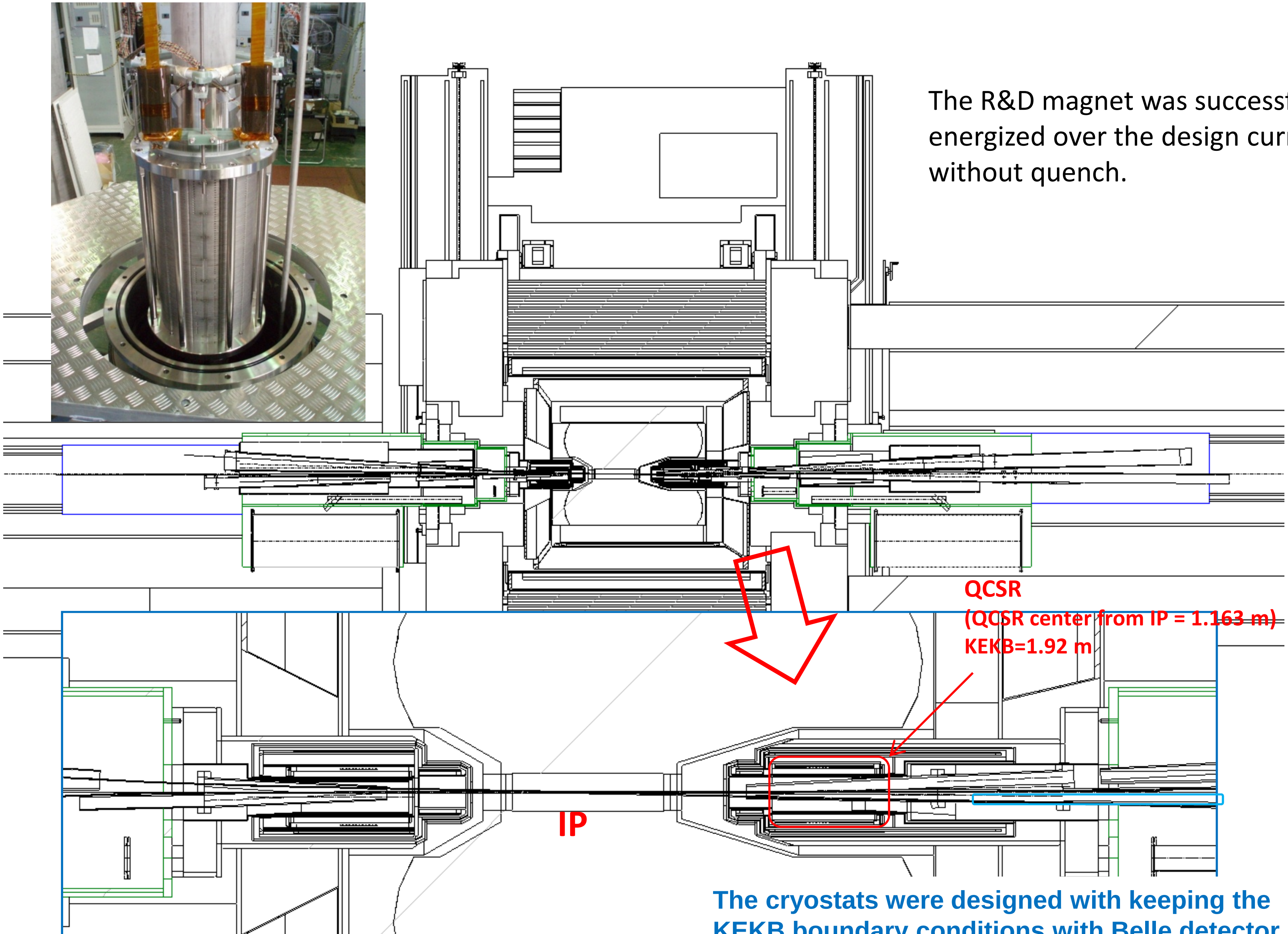


Cross section of QCSRD

Design parameters of QCSRD

- 6 layer coils (3-double pane cake coils)
- Inner coil radius : 90.0 mm
- Outer coil radius : 116.8 mm
- Cable size : 1.1 mm × 4.1 mm
  - 1.1 mm × 7.0 mm (KEKB)
- Number of turns : 271 in one pole
  - 1st layer = 38, 2nd layer = 39
  - 3rd layer = 46, 4th layer = 47
  - 5th layer = 50, 6th layer = 51
- Field gradient : 40.49 T/m
- Magnet current : 1197.6 A
- Magnetic length : 0.299m
- Inductance : 69.98 mH
- Stored energy : 49.3 kJ
- Operation temperature : 4.5 K
- Operation point w.r.t. SC limit : 76%
- Magnet bore : room temp.

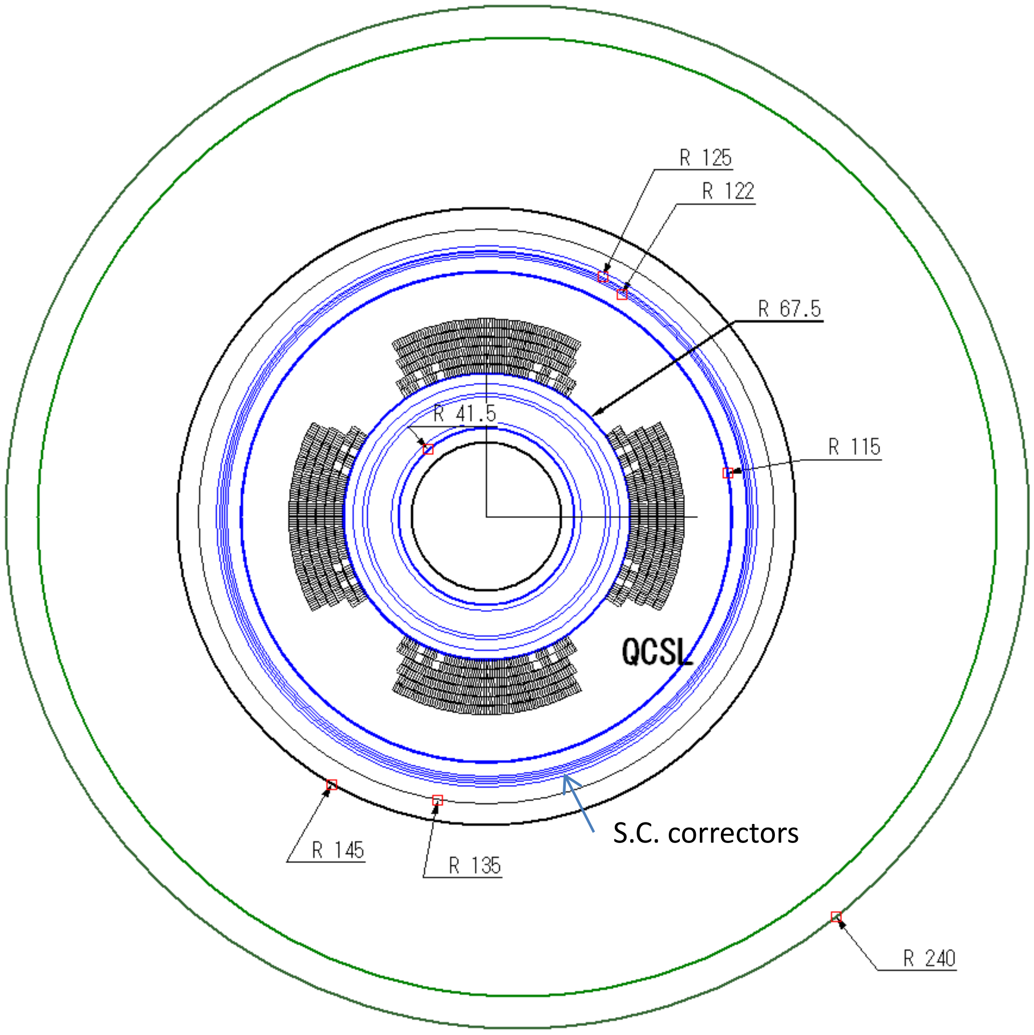
QCSRD R&D Magnet and Cryostat Design



The R&D magnet was successfully energized over the design current without quench.

The cryostats were designed with keeping the KEKB boundary conditions with Belle detector.

QCSLD cooled at 1.9 K



Cross section of magnet cryostat

Design parameters of QCSLD

- 6 layer coils
- Inner coil radius : 67.5 mm
- Outer coil radius : 92.7 mm
- Cable size : 1.1 mm × 4.1 mm
  - Cu ratio = 1.3
- Number of turns : 208 in one pole

  1st layer = 29, 2nd layer = 31
  3rd layer = 35, 4th layer = 37
  5th layer = 37, 6th layer = 39
- *G* by 2D cross section : 121.1 T/m
- Magnet current : 2834.8 A
- Magnetic length : 192.6 mm
- Estimated physical magnet length: 435 mm
- Operation temperature : 1.9 K
- Max. field in the magnet : 7.62 T
  - (without Belle and compensation solenoid fields)
- Operation point w.r.t. SC limit : 74%
- Magnet bore : room temp.

Cable performance at 1.9 K for QCSLD

NbTi

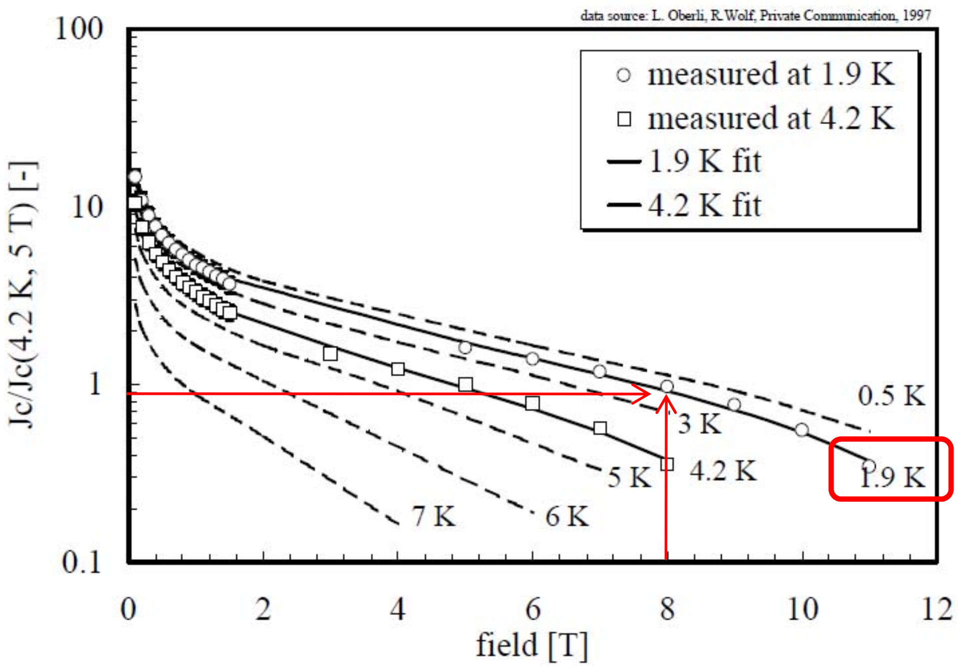


Fig. 7. Field dependence of the normalized $J_c(B,T) / J_c$ (5 T, 4.2 K) for a typical LHC strand [13]-[14], measured at 1.9 and 4.2 K. The fit to the data is shown (solid lines) together with curves generated for different temperatures (dashed lines).

From LHC-Project Report 358

NbTi cable for QCSRD

I_c = 3495 A @ 5T and 4.2 K
Cu ratio = 1.8
Cable size = 1.1 mm × 4.1 mm

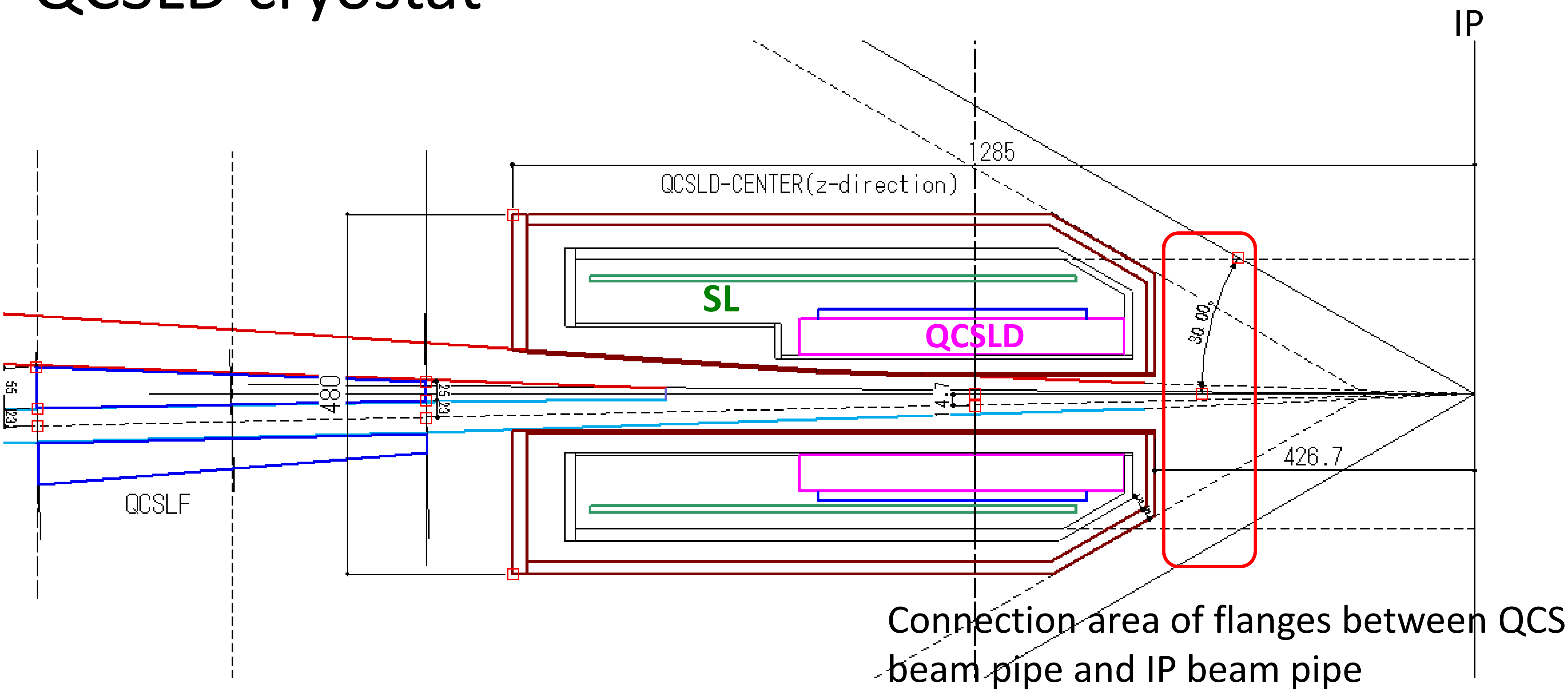
By decreasing temperature from 4.2 K to 1.9 K

The conductor can transfer the current of 0.9 × I_c @ 5T and 4.2 K

I_c = 3145.5 A @ 8T and 1.9 K

Cu ratio = 1.3
I_c = 4253 A @ 8T and 1.9 K

QCSLD cryostat

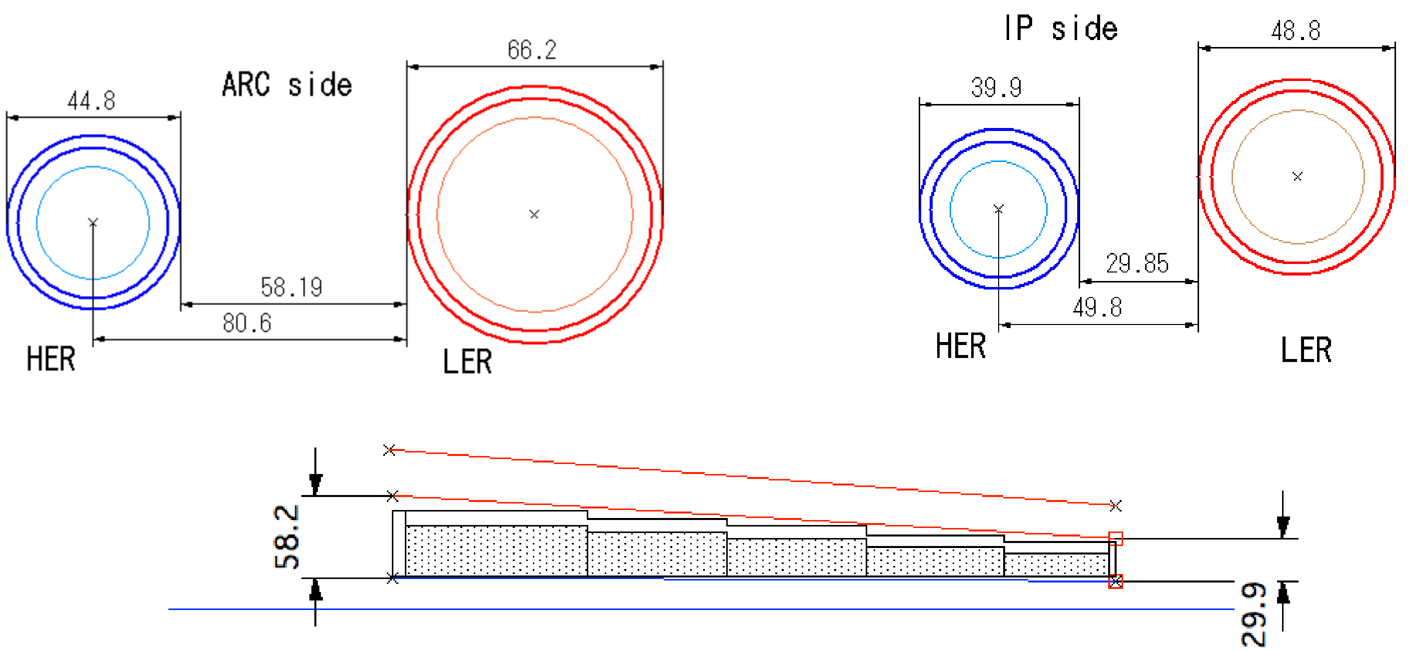


The connection between the QCS beam pipe and the IP beam pipe are very difficult.

- In the left side of IP, the QCS cryostat is considered to be inserted into Belle detector with connecting to IP beam pipe and holding SVD and the beam pipe.
- The QCS cryostat bore works as the beam pipe (warm bore).

QCSLF (Permanent magnet)

Distances between two beams are assumed to be 29.85mm (IP side), 58.2mm(Arc side).

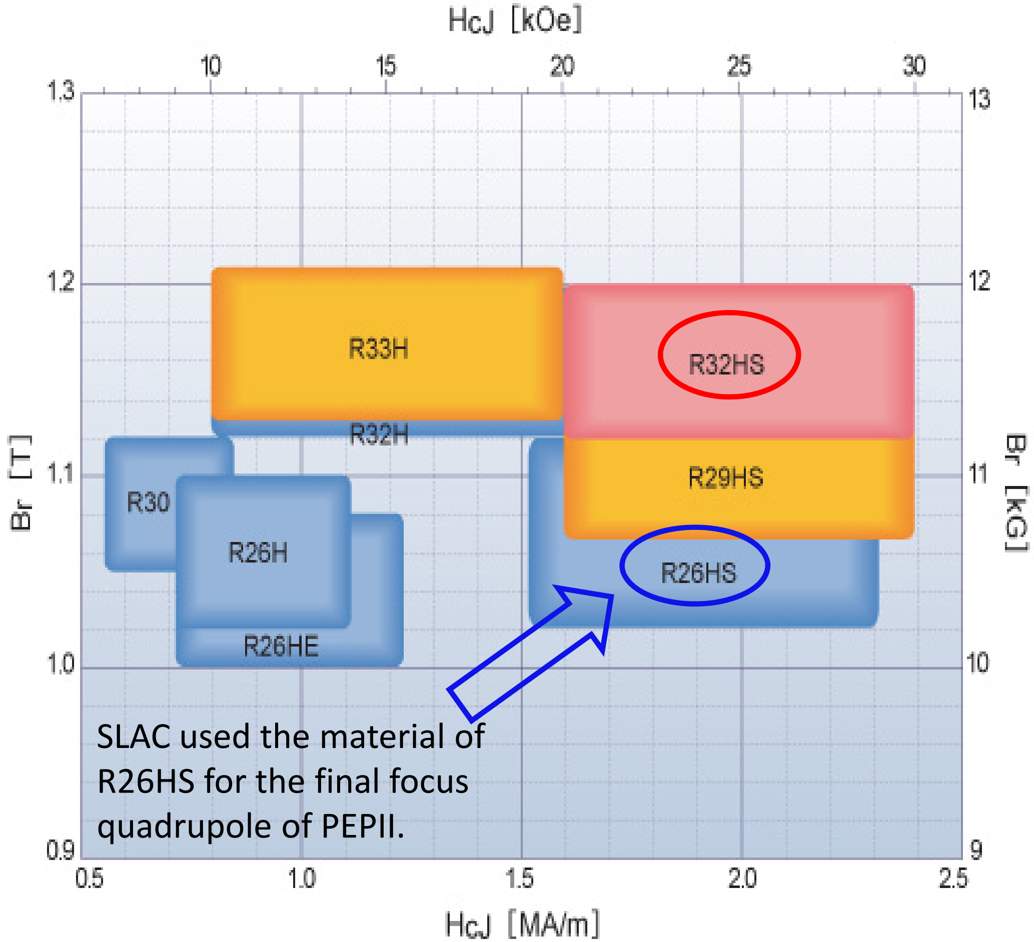


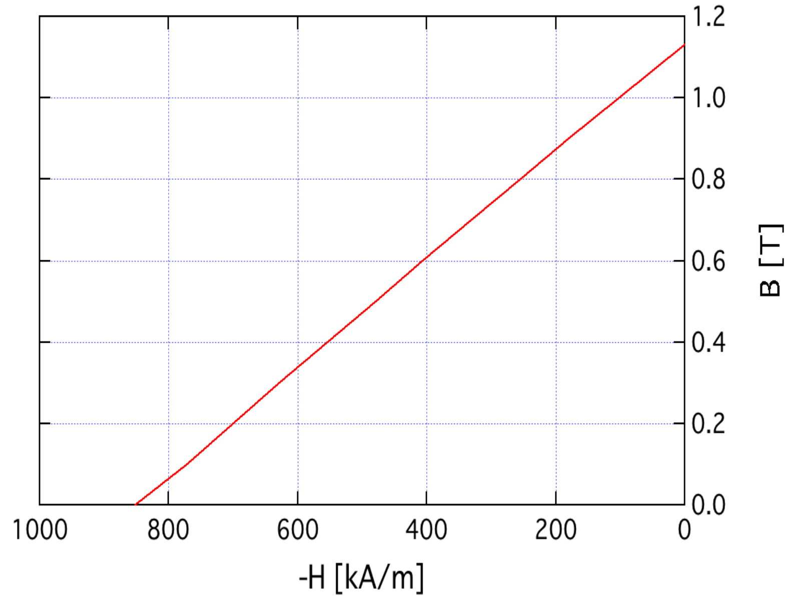
- Magnet bore= 23 mm
- Outer radius of the magnet
  - IP side = 35 mm, magnet center = 50 mm, Arc side = 65 mm
  - Total magnet length = 520 mm

Magnetic Design of QCSLF

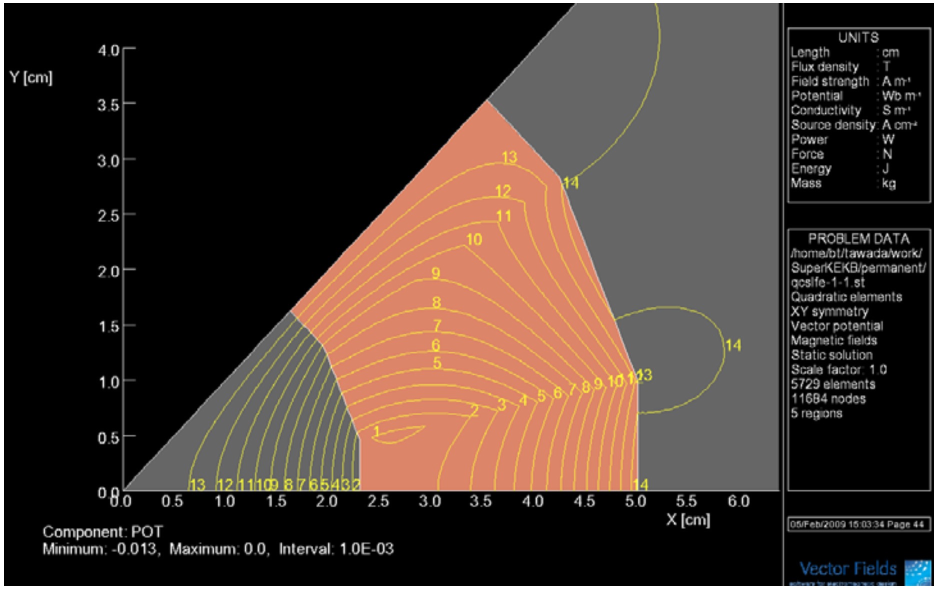
R32HS (SmCo) by Shin-Etsu chemical Co., Ltd is used for the field calculation of QCSLF.

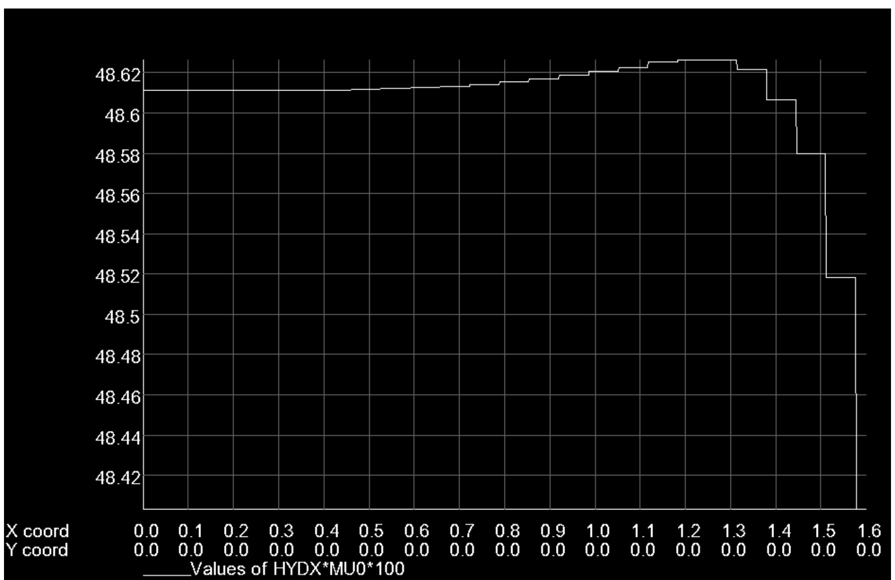
- Br = 1.13 T





Field calculation of QCSLF





At the magnet center

- R_{in} = 23mm, R_{out} = 50mm
- Field gradient = 48.61 T/m

IP side

- R_{in} = 23mm, R_{out} = 35 mm
- Field gradient = 30.61 T/m

Arc side

- R_{in} = 23mm, R_{out} = 65 mm
- Field gradient = 58.15 T/m

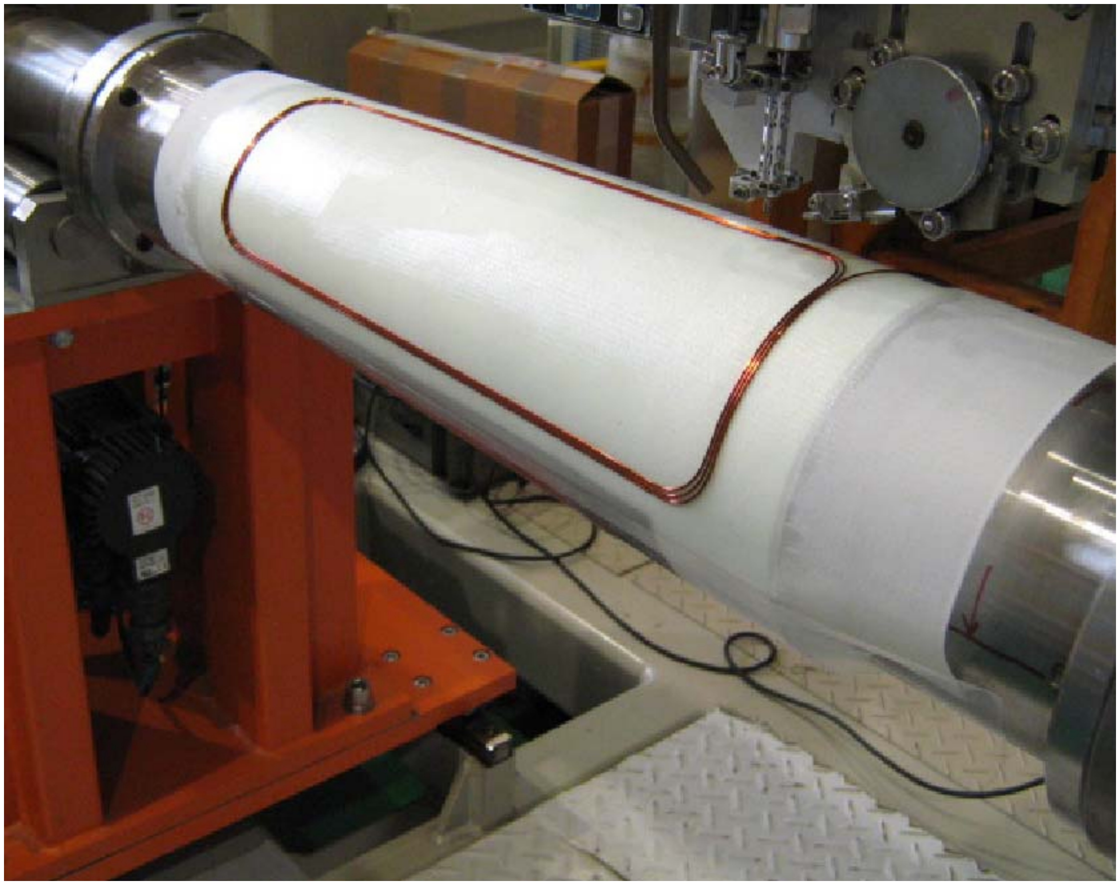
Average = 45.79 T/m

Requirement of QCSLF from beam optics

- 44.34 T/m, 23.06 T

QC1RE, QC2RE & QC2RP

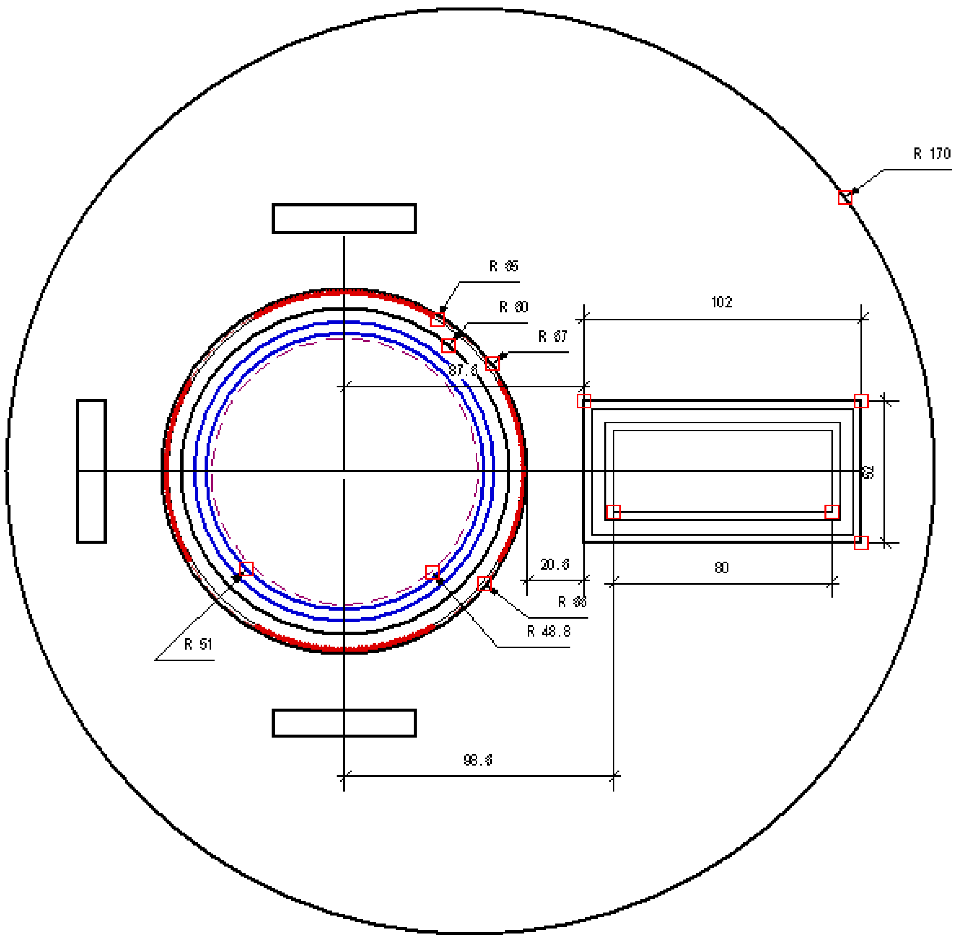
- The magnets are designed by the S.C. wiring technique.
- The magnets are in shape of a circular truncated cone in order not to be exposed to the SR light from QCSRD.



R&D of winding of S.C. wire on the QC1RE bobbin in shape of the circular truncated cone.

Diameter of S.C. wire = 0.781mm

QC1RE magnet design

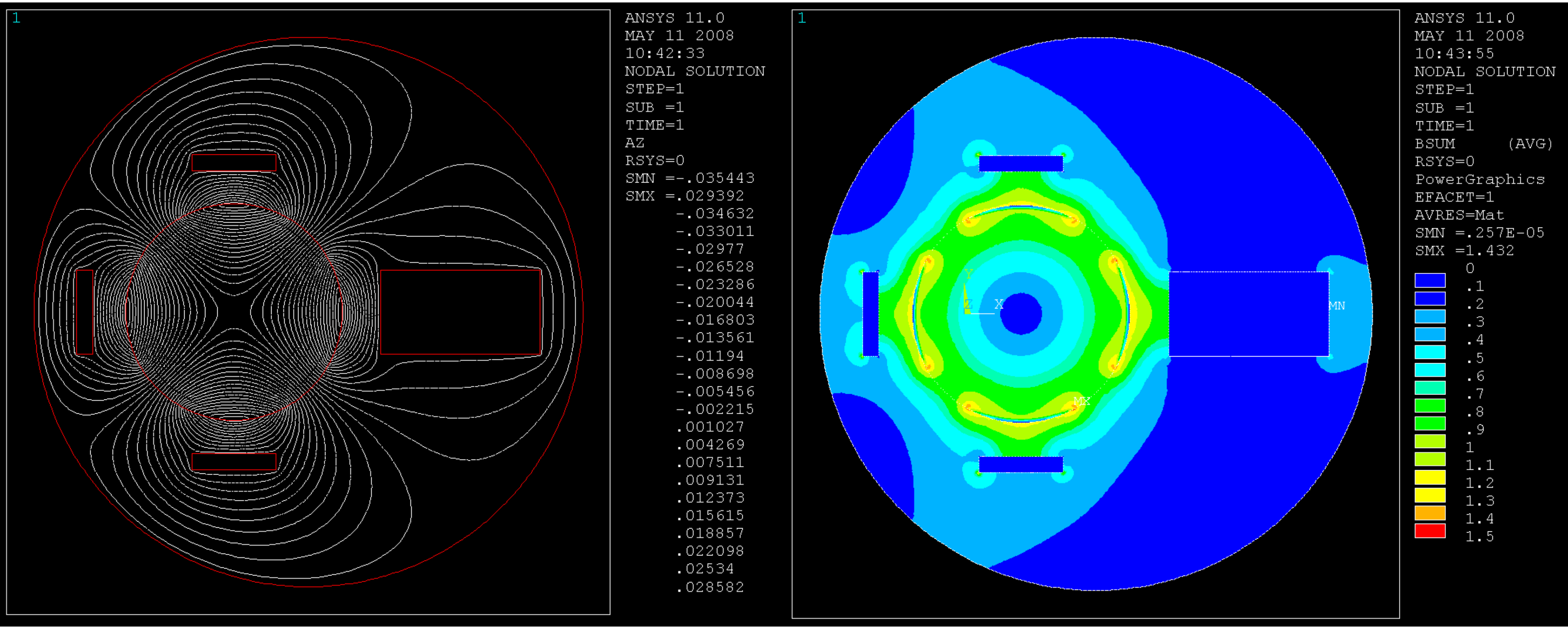


Cross section design of QC1RE at IP side
The cryostat bore functions as a beam pipe, and it is cooled at 80 K by LN_2.

QC1RE design parameters

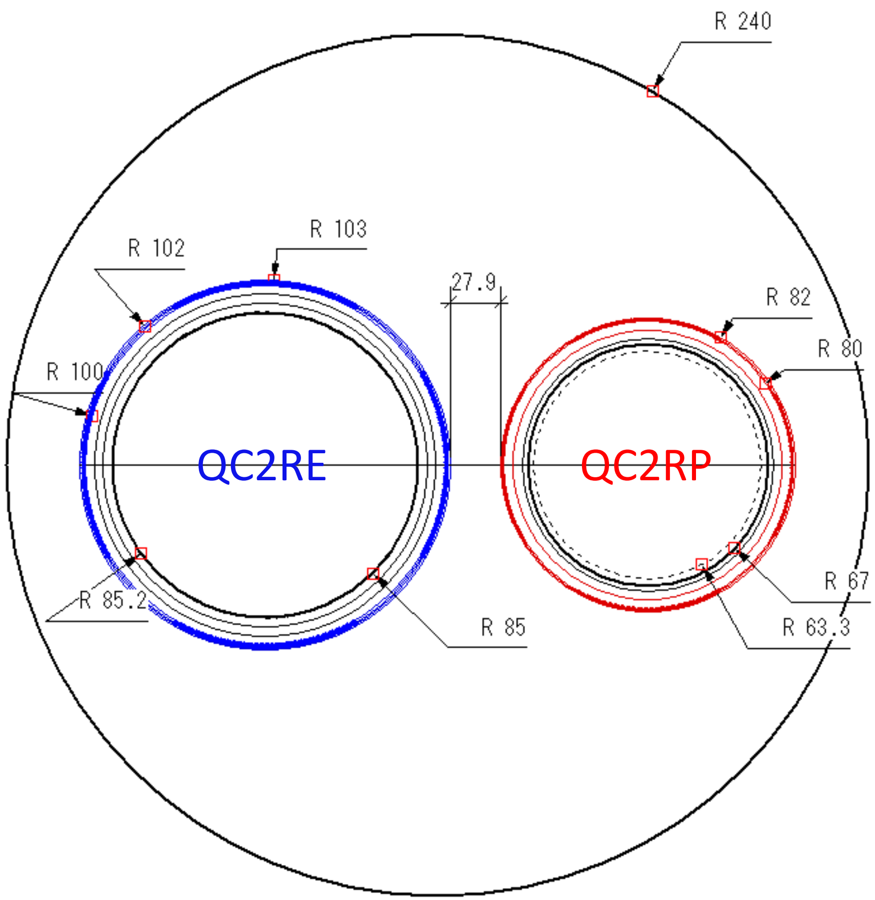
- Average field gradient = 12T/m
- Effective magnetic length = 0.75m
- Inner radius of beam pipe bore = 51mm
  - Beam pipe temperature=80K
- Inner radius of LHe vessel bore =60mm
- Coil(Circular Truncated Cone)
  - 2 layer coils by S.C. wire
  - R_{in} of the coil=65mm (IP side)
  - R_{in} of the coil＝73.6mm (magnet center)
  - Turns/pole＝34
- Outer radius of Iron Yoke = 170mm
- Required field gradient at IP side
  - G_{IP}= 12×（73.6/65）^{2}＝15.39T/m

QC1RE magnetic field calculation



- Design current of the magnet = 384.7 A
- Field gradient = 15.39 T/m
- Current density of S.C. wire = 733.8 A/mm^2
  - Cu/NbTi = 1.4, current density at NbTi = 1761.2 A/mm^2
- Maximum field in the coil =1.432T
- Leak field at the positron area ＜0.2Gauss

QC2RE & QC2RP magnet design



Cross section design of QC2RE and QC2RP at IP side. The cryostat bores function as beam pipes, and they are cooled at 80 K by LN_2.

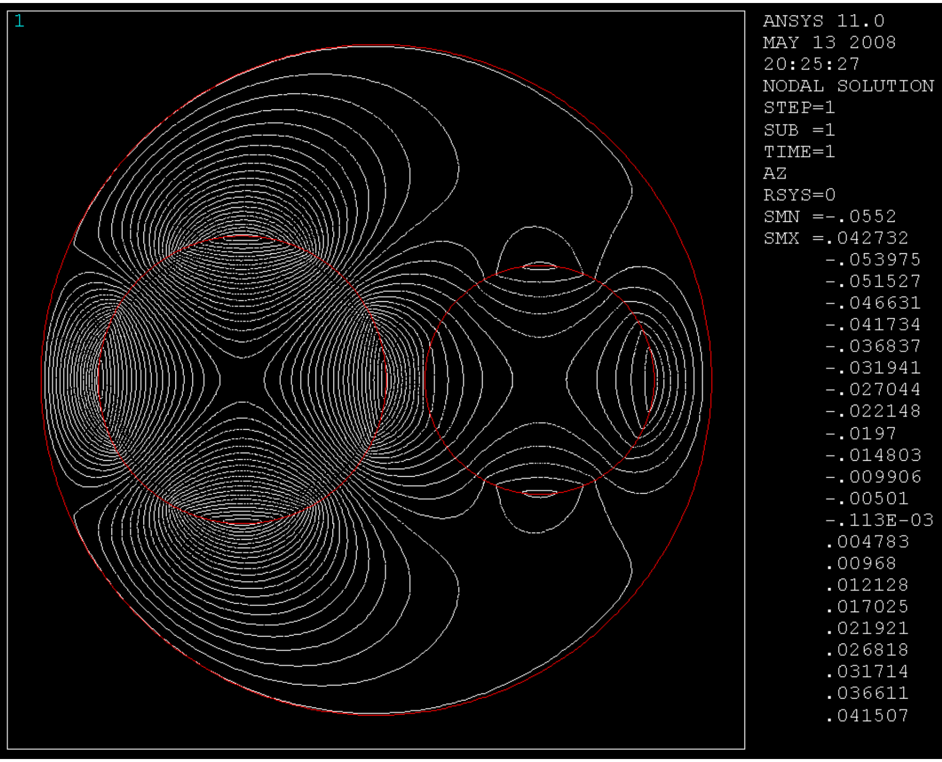
QC2RE design parameters

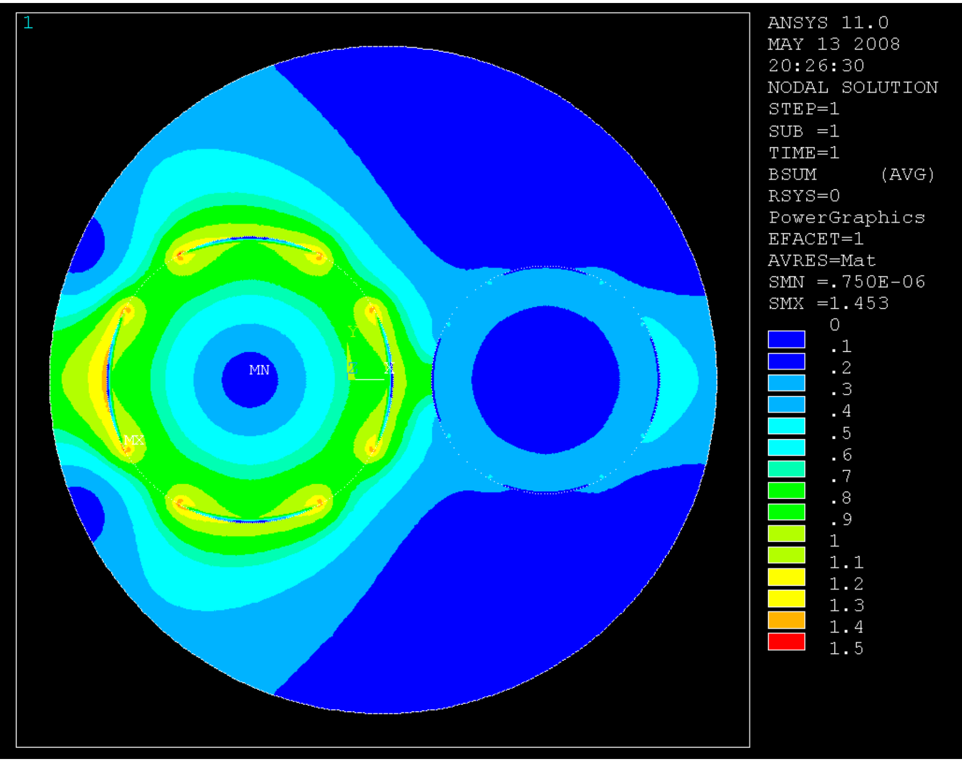
- Average field gradient = 8.8 T/m
- Effective magnetic length = 0.8 m
- Inner radius of beam pipe bore = 85 mm (T=80K)
- Inner radius of LHe vessel bore =95 mm
- Coil (Circular Truncated Cone)
  - 2 layer coils by S.C. wire
  - R_{in} of the coil=100 mm (IP side)
  - R_{in} of the coil＝106.5 mm (magnet center)
  - Turns/pole＝ 52× 2
- Outer radius of Iron Yoke = 240mm
- Required field gradient at IP side
  - G_{IP}= 8.8×（106.5/100）^{2}＝9.98T/m

QC2RP design parameters

- Average field gradient = 3.4 T/m
- Effective magnetic length = 1.0 m
- Inner radius of beam pipe bore = 67 mm (T=80K)
- Inner radius of LHe vessel bore =75 mm
- Coil (Circular Truncated Cone)
  - 1 layer coil by S.C. wire
  - R_{in} of the coil=80 mm (IP side)
  - R_{in} of the coil＝85 mm (magnet center)
  - Turns/pole＝ 42
- Required field gradient at IP side
  - G_{IP}= 3.4 ×（85/80）^{2}＝3.86T/m

QC2RE & QC2RP magnetic field calculation

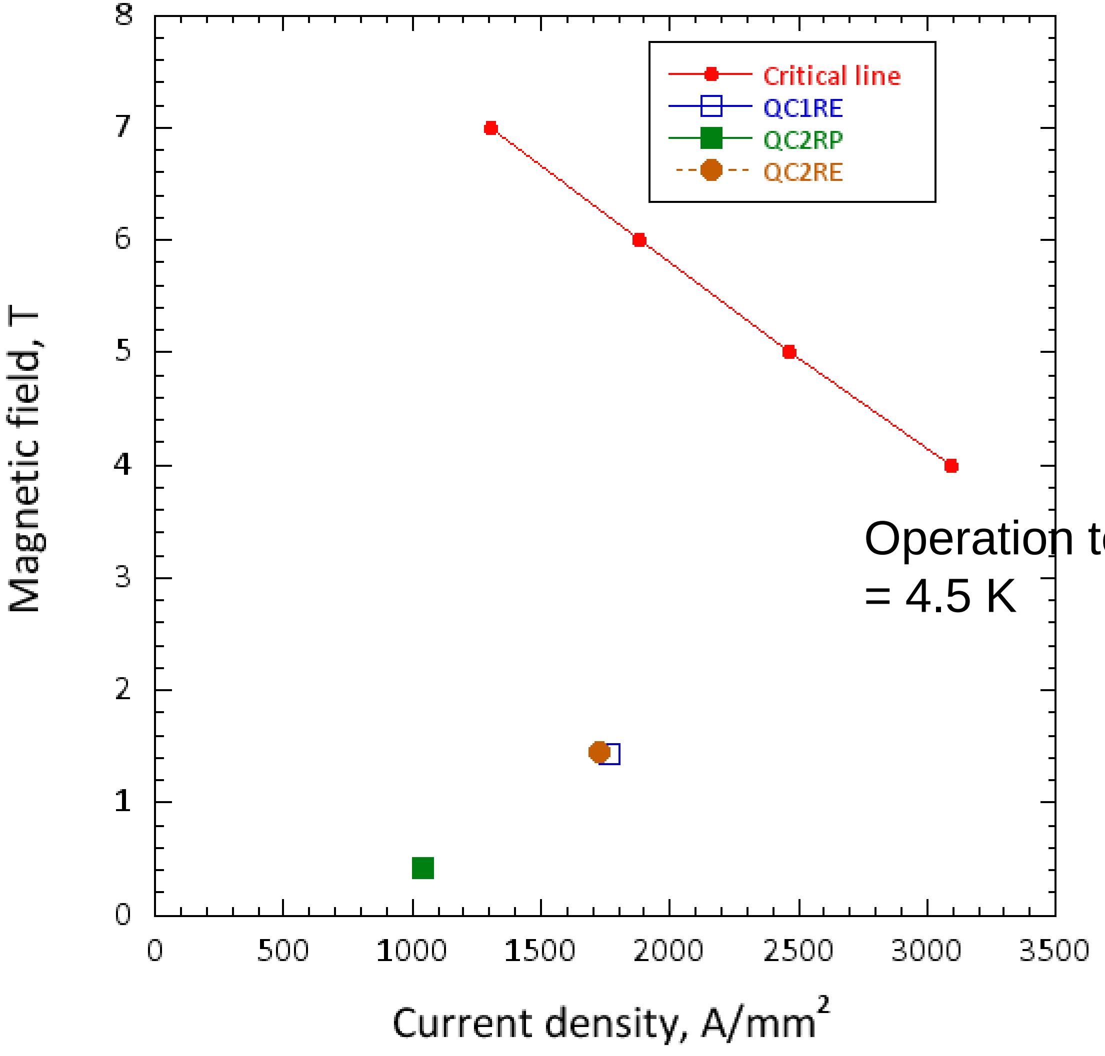




QC2RE
- Design magnet current = 377.5 A
- Field gradient = 9.98 T/m
- Current density of S.C. wire = 720.1 A/mm^2
  - Cu/NbTi = 1.4, current density at NbTi = 1728.2 A/mm^2
- Maximum field in the coil =1.453T

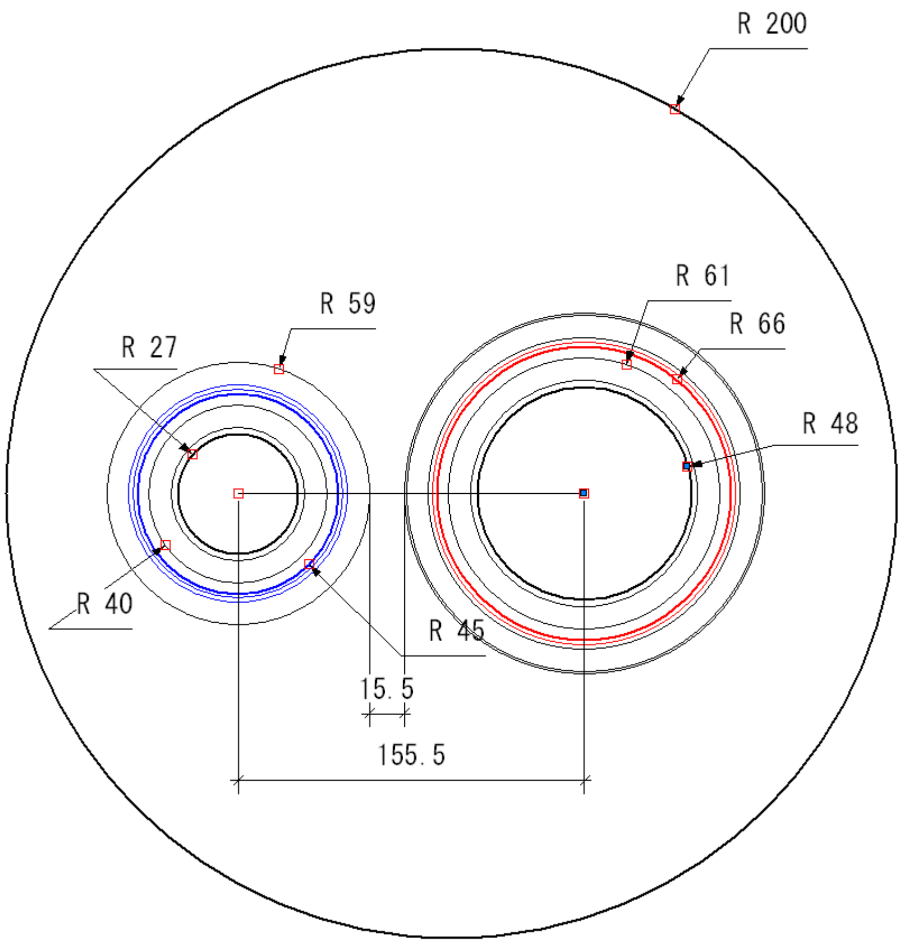
QC2RP
- Design magnet current = 227.2 A
- Field gradient = 3.86 T/m
- Current density of S.C. wire = 433.4 A/mm^2
  - Cu/NbTi = 1.4, current density at NbTi = 1040.1 A/mm^2
- Maximum field in the coil =0.425 T

Operation condition for QC1RE, QC2RP, QC2RE



Operation temperature
= 4.5 K

QC1LE & QC2LP (preliminary calculation)



Magnet cross section

QC1LE [34.79 T/m, 22.27 T]

- Coil inner radius = 45 mm
- Coil outer radius = 49 mm
- Iron Yoke inner radius = 59 mm
- Current density in the coil = 421.5 A/mm^2
  - Cu ratio = 1.5; J = 1054 A/mm^2
- G = 34.8 T/m
- Magnetic field in the coil = 1.6 T

QC2LP [10.58 T/m, 6.49 T]

- Coil inner radius = 66 mm
- Coil outer radius = 67 mm
- Iron Yoke inner radius = 69 mm
- Magnet parameters close to QC1RE

Summary

- For the updated IR beam optics, various types of quadrupoles are designed including the permanent magnet for QC1LE.
- QCSLD is designed to be operated at 1.9K, and the magnetic calculation with the compensation solenoid is necessary in order to confirm the operation margin.
- The circular truncated cone shape quadrupoles are proposed for QC1RE, QC2RE and QC2RP.
- These magnets need R&D in order to confirm the electric and magnetic performances.