Final Focus Quadrupole Magnet (QCS) for SuperKEKB

Norihito Ohuchi

1. QCS R&D Magnet
2. QCS Magnet-Cryostat

QCS R&D Magnet (QCS-R)

Requirement from beam optics

- Integral field strength ($\int G\,dl$)

  QCS-R = 11.988 (T/m)×m, QCS-L = 14.328 (T/m)×m

- Location of magnet center from IP

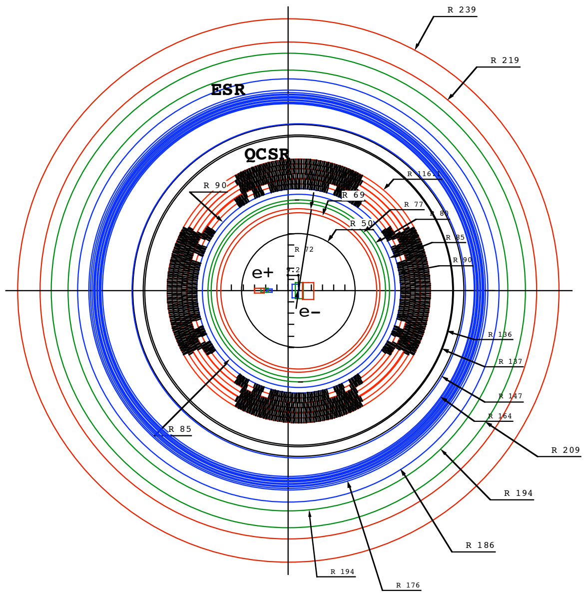
  QCS-R = 1163.3 mm, QCS-L = -969.4 mm

  The compensation solenoids, ESR and ESL, overlay the QCS magnets.

- Magnet position in the perpendicular plain to the Belle axis

  $(x, y)_{QCSR}$=(9.2, -0.3), $(x, y)_{QCSL}$=(21.2, 0.2)

  The axes of the compensation solenoids are coincident with the Belle axis.



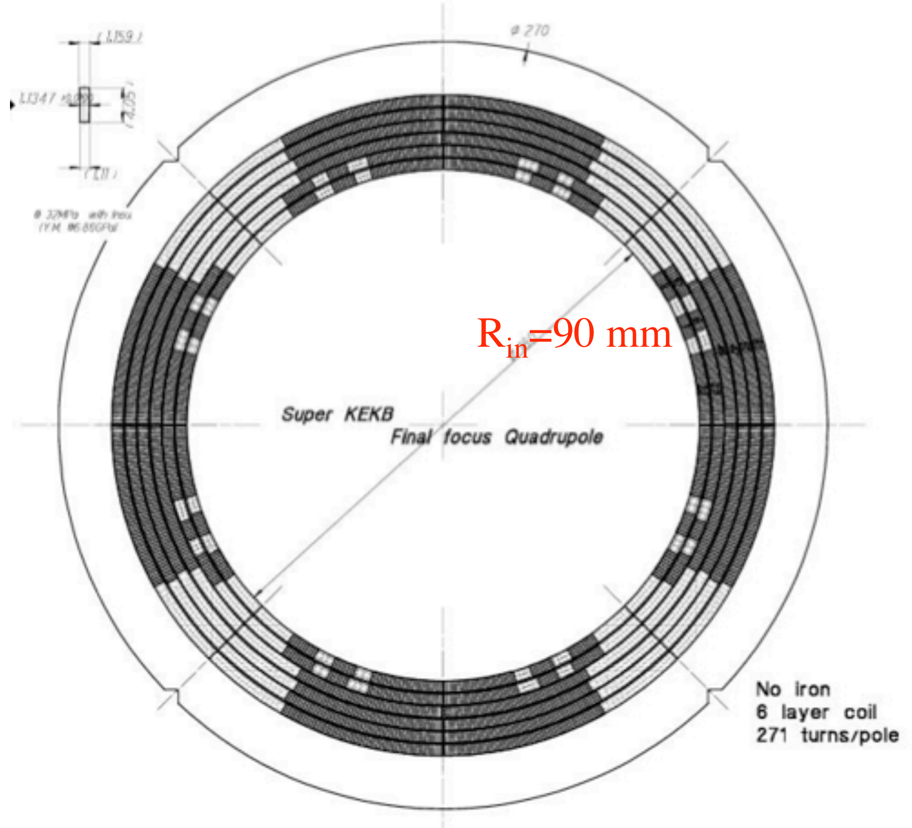
QCS R&D Magnet (QCS-R)

Magnet parameters

- 6 layer coils (3-double pane cake coils)
- Inner coil radius : 90.0 mm
- Outer coil radius : 116.8 mm
- Cable size : 1.1mm × 4.1mm
- 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 : 40.124 T/m
- Magnet current : 1186.7 A
- Magnetic length : 0.299 m
- Inductance : 69.98 mH
- Stored energy : 49.3 kJ



→ S.C. coil temperature rise< 60 K

Normal transition (Quench)

QCS R&D Magnet (QCS-R)

Magnetic field calculation (field quality)

QCS R&D Magnet (QCS-R)

- Multipole components in 2-D calculation (magnet cross section) @ R_{ref} = 50 mm

  b_2=10000, b_6=0.12, b_{10}=-0.04, b_{14}=0.12

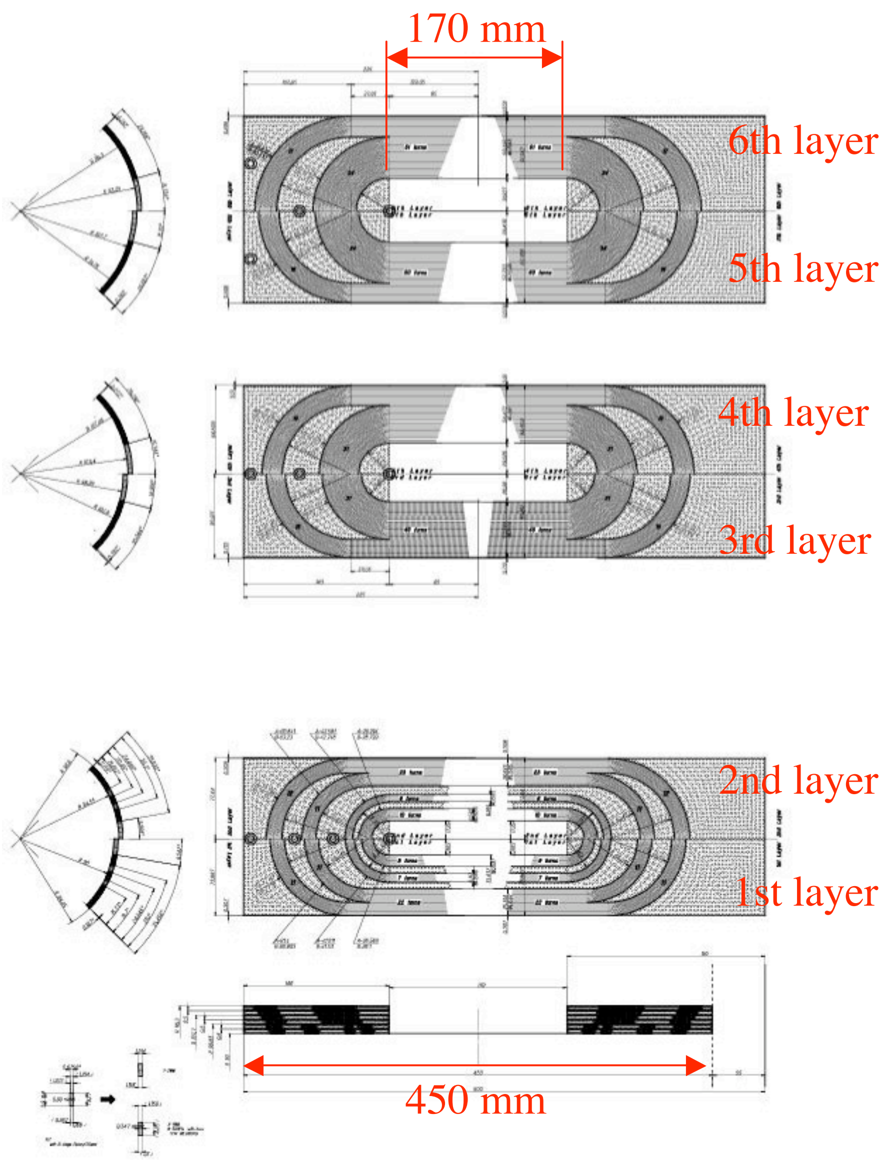
- Integral multipole components (including magnet ends) @ R_{ref} = 50 mm

  $\int b_2 dl$=10000, $\int b_6 dl$=-0.04, $\int b_{10} dl$=0.46, $\int b_{14} dl$=0.02

QCS-L

- Integral multipole components (Length of the magnet straight section=228.3mm) @ R_{ref} = 50 mm

  $\int b_2 dl$=10000, $\int b_6 dl$=-0.02, $\int b_{10} dl$=0.38, $\int b_{14} dl$=0.04



QCS R&D Magnet (QCS-R)

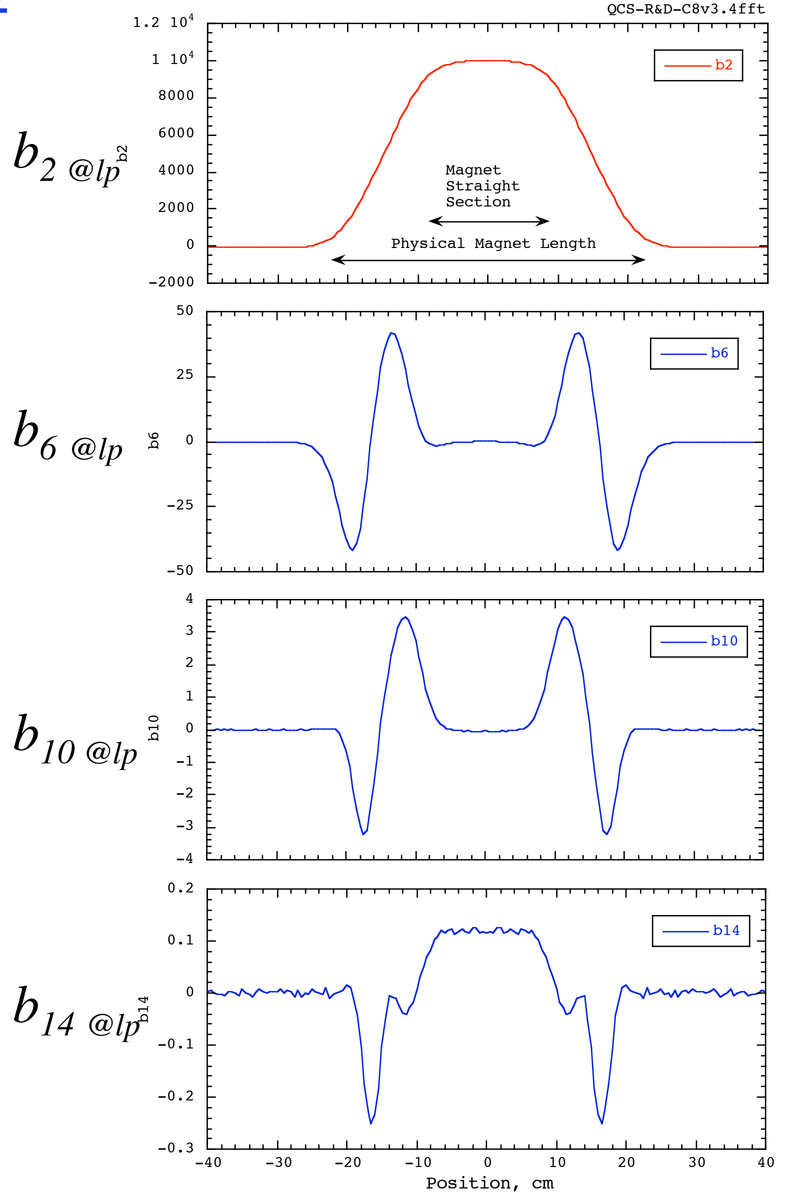
Field profile along beam line

- Calculated integral b_6, b_{10}, b_{14}
  $\int b_6 dl$ = -0.04, $\int b_{10} dl$=0.46, $\int b_{14} dl$=0.02

- Peak of $b_{6\ @lp}$, $b_{10\ @lp}$, $b_{14\ @lp}$

	Max.	Min.
$b_{6\ @lp}$	41.8	-41.6
$b_{10\ @lp}$	3.48	-3.23
$b_{14\ @lp}$	0.126	-0.252

$b_{n@lp}=(B_{n\ @lp}/B_{2@\text{mag-center}})\times 10000$



QCS R&D Magnet (QCS-R)

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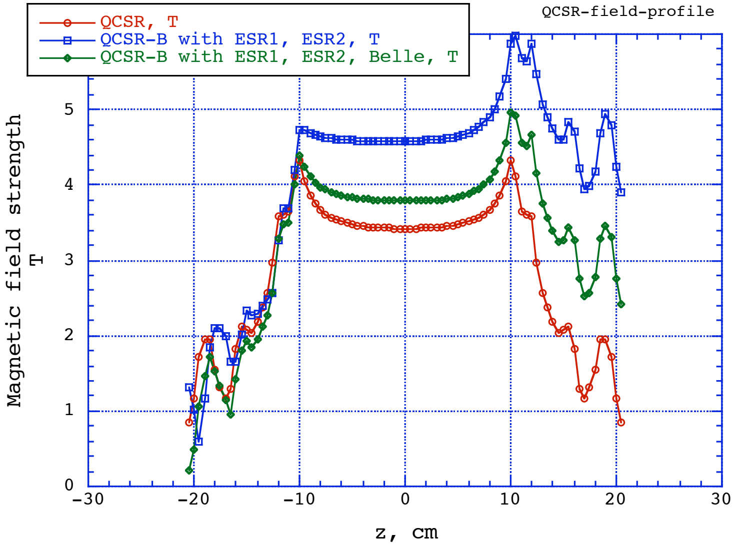
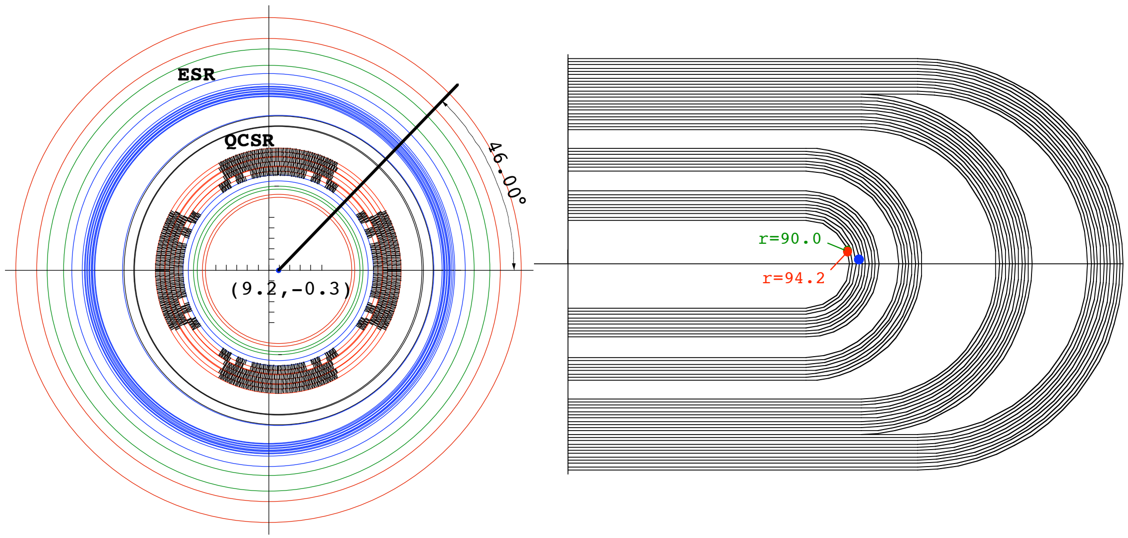
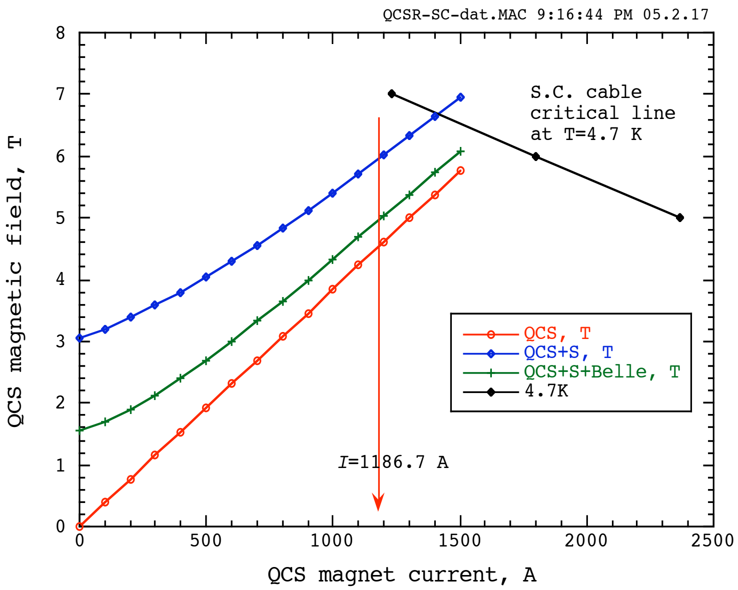
Max. field in the coil

- QCSR, operated independently
  - Max. field in the coil = 4.56 T @1186.7A
  - I_{op} / I_c =72.6%
- QCSR, operated with ESR
  - Max. field in the coil = 5.97 T @1186.7A
  - I_{op} / I_c =83.6%
- QCSR, operated with ESR and Belle
  - Max. field in the coil = 4.99 T @1186.7A
  - I_{op} / I_c =75.1%

Field Profile along the magnet length
at r= 90 mm, θ= 46 degree







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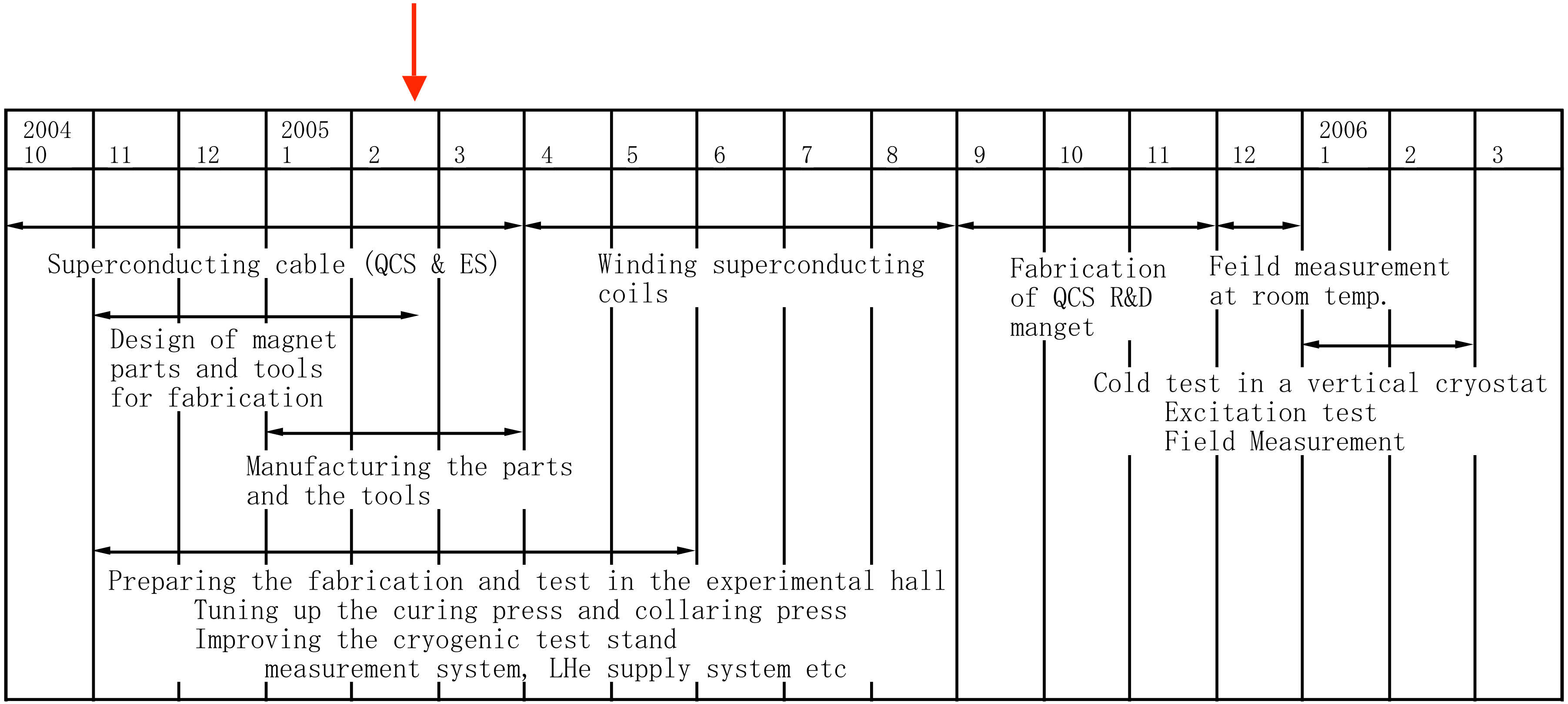
QCS R&D Magnet (QCS-R)

Construction schedule



QCS R&D Magnet (QCS-R)

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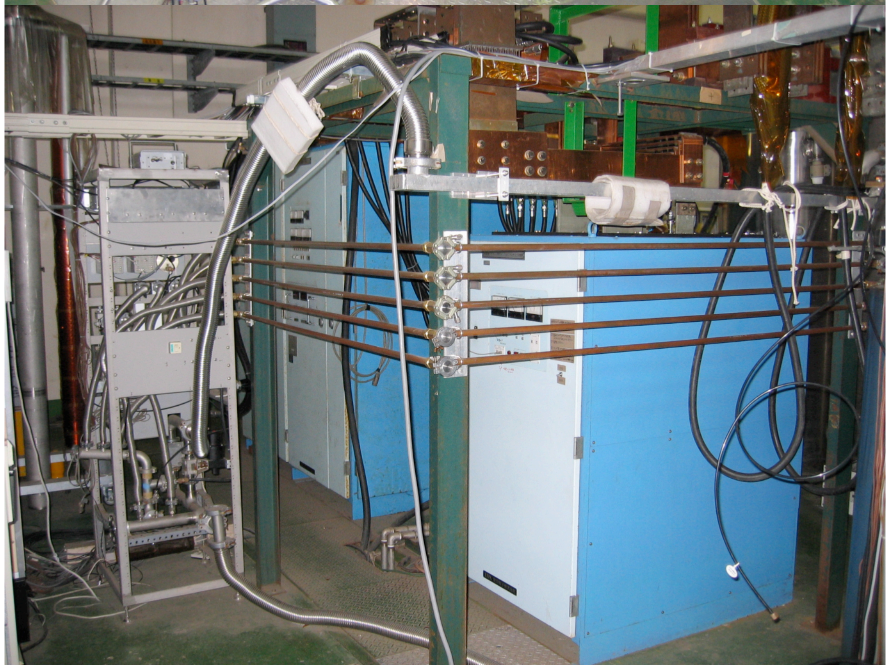

QCS Magnet Cryostat

- Requirement from the Belle group
  - Redesigning cryostat configuration to reduce the Rad. Bhabha BG

    pointed by M. Sallivan in 6th HLWS, 2004

    reported by O. Tajima in this meeting

    Introducing the heavy metal (Tungsten alloy) as one of the magnet structural materials.

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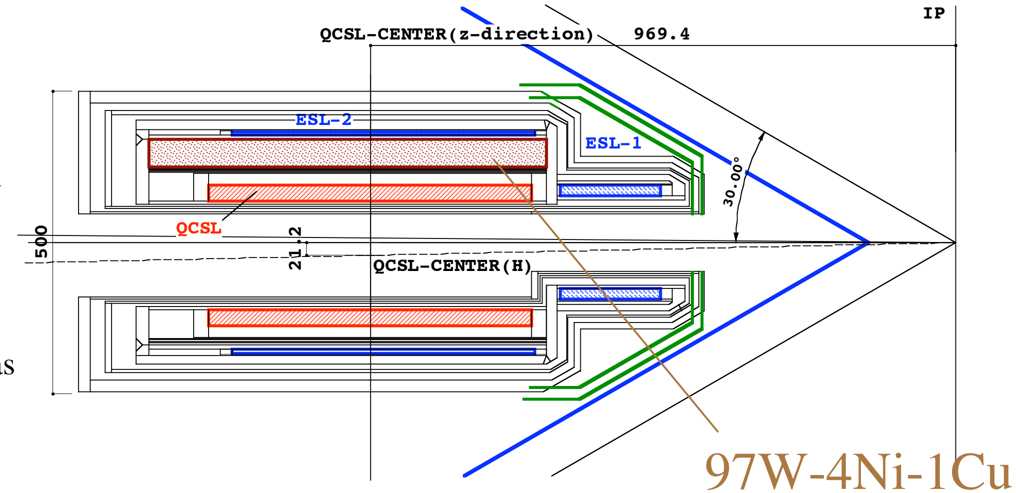
    Necessary to modify the support system of the liquid helium vessel



  - Increasing the space between the detector and the cryostat for wiring the cables

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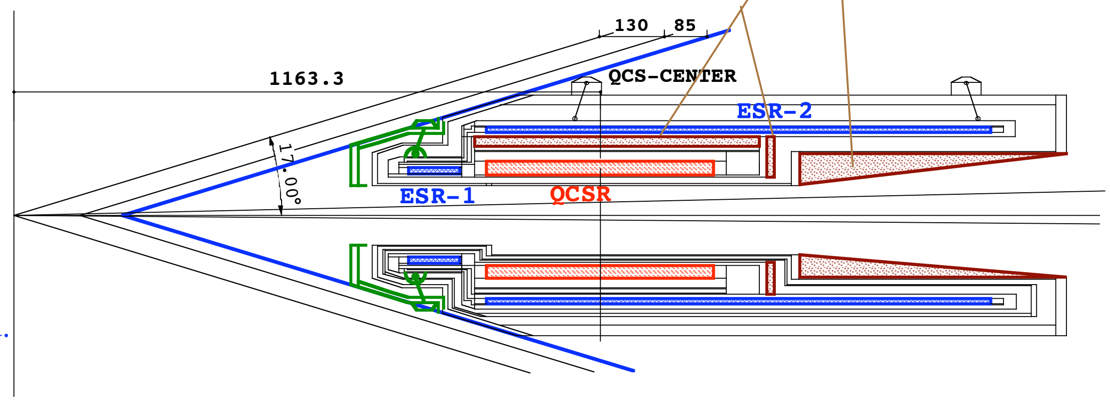
    ESR and ESL solenoids were calculated again, and the fronts of the cryostats were re-designed.

    The created space in radial direction :

    25 mm for ESR

    38 mm for ESL



QCS Magnet-Cryostat

- Tungsten alloy (97W-4Ni-1Cu)
  - Density = 18.5 g/cm^3, Non-magnetic material.
- Weight of the components in the magnet-cryostat

	Right, kg	Left, kg
Helium Vessel	234	202
QCS	135	157
ES	90	48
Correctors	33	44
B.G. shield (97W-4Ni-1Cu)	116	145
Total	608	596

- EMF induced by the interaction with the Belle detector and the ES-magnets
  - $EMF_{ESR} = 2.2\times10^4$ N , $EMF_{ESL} = 4.8\times10^4$ N

QCS Magnet-Cryostat

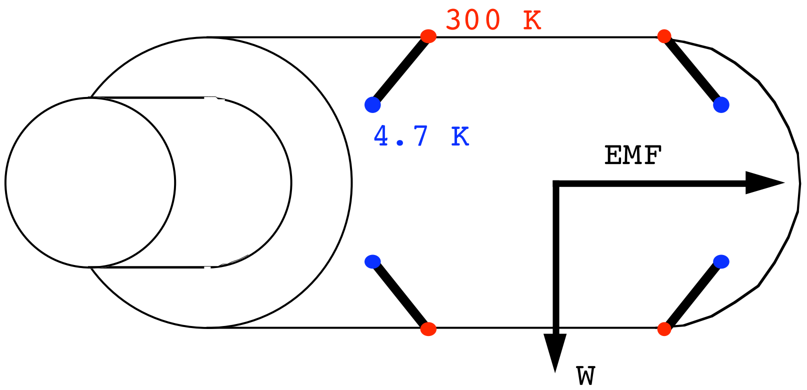
Design of the support system

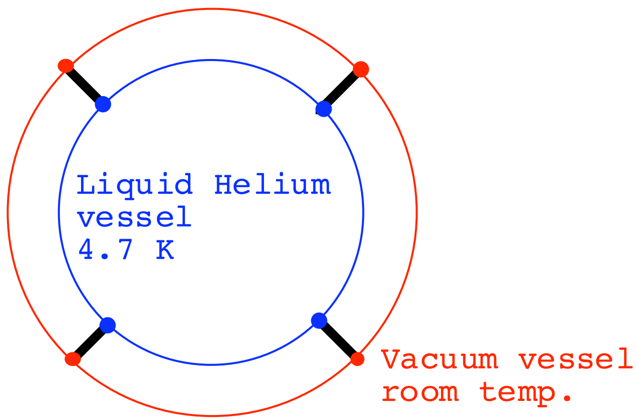
- The liquid helium vessel is supported with eight rods.
  - The material of the rod is a titanium alloy (Ti-6Al-4V, ELI).

    The titanium alloy has half thermal conductivity of the stainless steel from 77 K to 300 K.

    The yield strength of the titanium alloy is 1.5 times larger than that of the SUS316LN at 300 K.

- The rods are designed to stand EMF and *G*.
- They are designed not to change the center of QCS against the thermal contraction by cool-down.
- The heat load via these support rods must be within the refrigerator capacity.

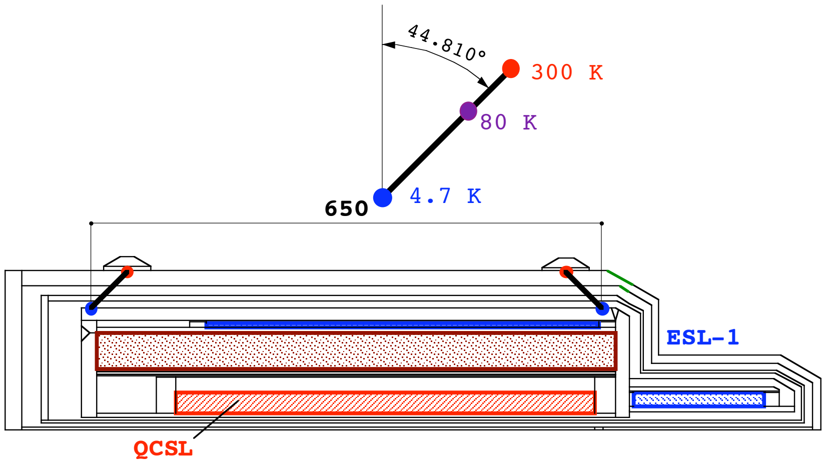


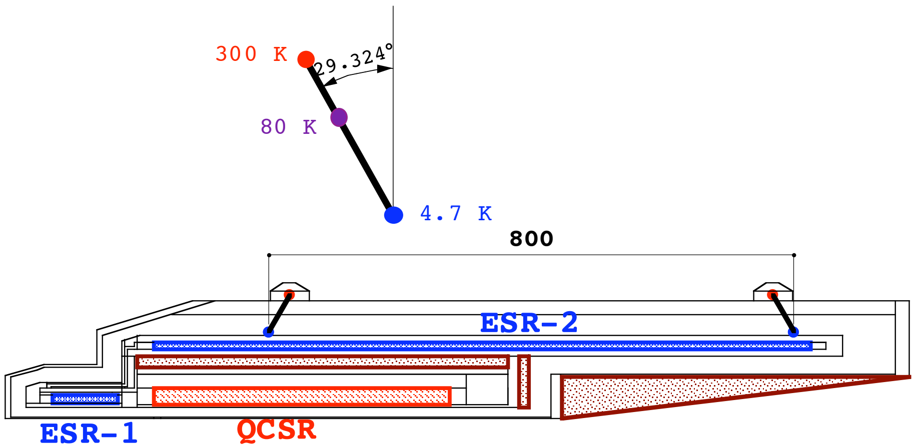


QCS Magnet-Cryostat

Modified support system

	Left	Right
Rod diameter, mm	7	6
Rod length, mm	65	65
Distance between rods, mm	650	800
Max. force through one rod, N	1.16×10^4	8.19×10^3
Stress, N/mm^2	306	290
Allowable tensile stress at R.T., N/mm^2	400	400
Heat load via one rod, W	0.24	0.18
Total heat load (eight rods), W	1.92	1.44





QCS Magnet-Cryostat

ESR-1 and ESL-1 parameters

ESR-1

	Previous design	Present design
Inner radius, mm	82.3	82.3
Outer radius, mm	91.1	95.5
Coil length, mm	150	100
Winding, turns × layer	75 × 8	50 × 12
Max. field without Belle, T	3.27	4.26 (75.3% @ 4.7K)
Max. field with Belle, T	2.14	2.76 (62.8% @ 4.7K)
Magnet current, A	619	647.2

ESL-1

	Previous design	Present design
Inner radius, mm	77	77
Outer radius, mm	92.4	94.6
Coil length, mm	166	166
Winding, turns × layer	83 × 14	83 × 16
Max. field without Belle, T	4.98	5.83 (92.4% @ 4.7K)
Max. field with Belle, T	3.49	4.33 (80.0% @ 4.7K)
Magnet current, A	619	656.2

Summary

- The 3-D field calculation of the QCS R&D magnet has been completed.
  - Integral multipole components (including magnet ends) @ R_{ref} = 50 mm

    $\int b_2 dl$=10000, $\int b_6 dl$=-0.04, $\int b_{10} dl$=0.46, $\int b_{14} dl$=0.02

- The designs of the magnet components and the tools for construction are almost completed. They will have been machined until the end of this March.

- For shielding the Rad. Bhabha BG, application of the heavy metal was studied as the material of the magnet components in the cryostat. The heavy metal does not have a large effect on the cryostat design at LHe temperature.

- In order to make space for wiring the cables from the detector, the fronts of the cryostats and the compensation solenoids, ESR-1 and ESL-1, were re-designed.

3-D calculation results with the Belle field

	QCSR	QCSL	ESR-1	ESR-2	ESL-1	ESL-2
I_{op}, A	1186.7	1186.7	647.2	647.2	656.2	656.2
Max. field, T	4.99	4.77	2.76	2.61	4.33	2.93
I_{op} / I_c, %	75	74	63	60	80	56