Overview of IR magnets and construction status

N. Ohuchi

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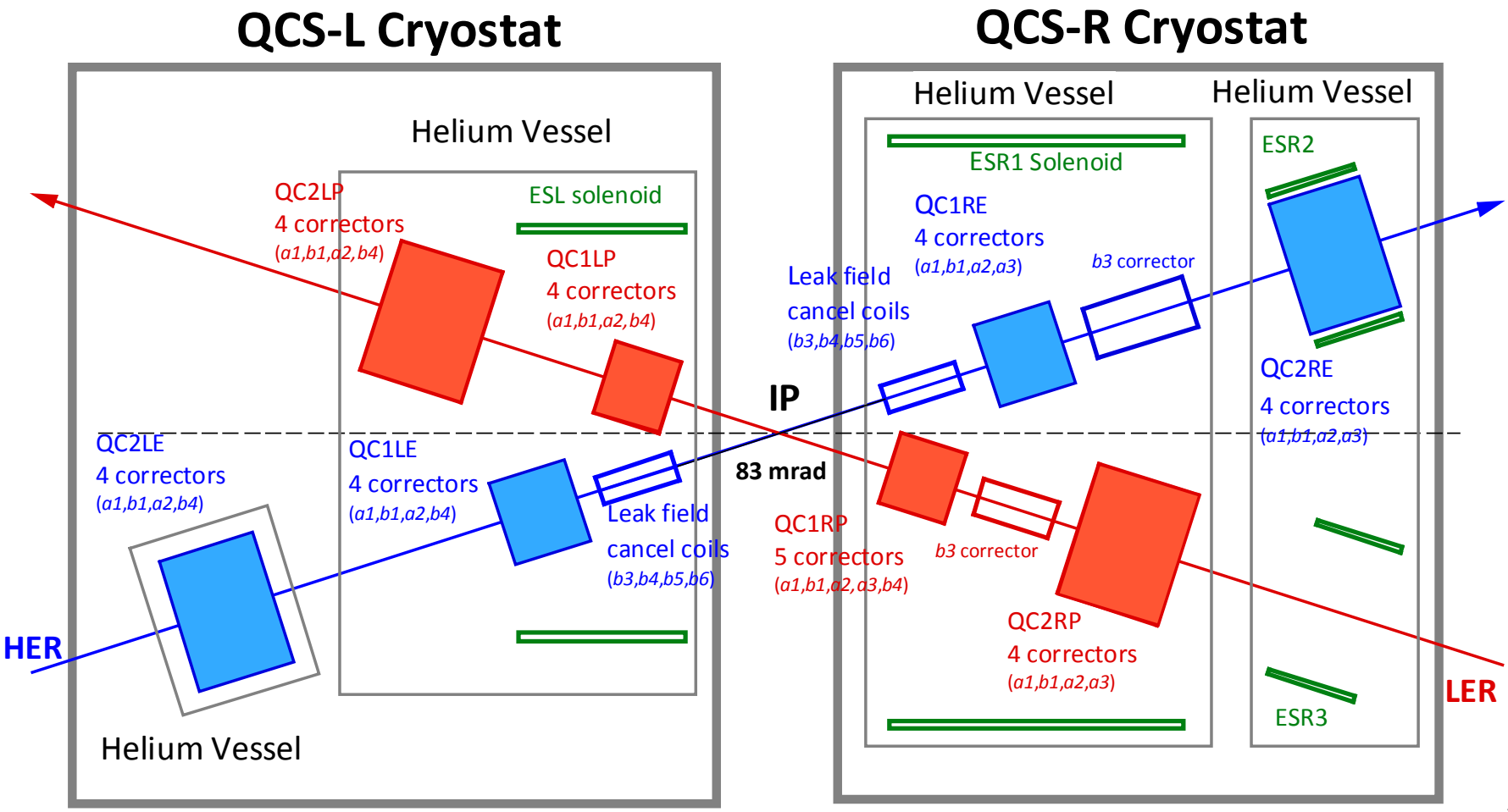
Overview of IR magnets



4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
16 SC correctors: a1, b1, a2, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
1 compensation solenoid

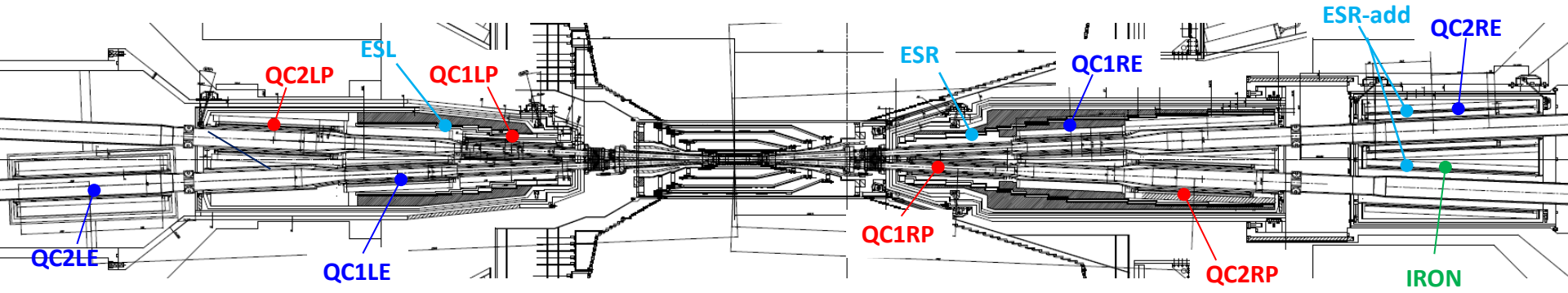
4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
19 SC correctors: a1, b1, a2, a3, b3, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
3 compensation solenoid

Overview of IR magnets

- Main quadrupoles [QC1, QC2]
  - Forming final beam focusing system with quadrupole doublets.
- Correctors [a_1, b_1, a_2, a_3, b_3, b_4]
  - a_1, b_1, a_2: magnetic alignment of the magnetic center and the mid-plane phase angle of main quadruple.
  - a_3, b_3: correction of sextupoles induced by magnet construction errors.
  - b_4:increasing the dynamic transverse aperture (increasing the Touschek life time).
- Compensation solenoid[ESR, ESL]
  - Canceling the integral solenoid field by the particle detector (Belle II).
  - By tuning the B_z' profile, the beam vertical emittance can be minimized.
  - The compensation solenoids are designed to be overlaid on the main quadrupoles and correctors.
  - ESR consists of three solenoid magnets of ESR1, ESR2 and ESR3.
- Leak field cancel coils [b_3, b_4 , b_5, b_6]
  - Canceling the leak field on the electron beam line from QC1P (collared magnet).
- Total number of the SC devices in two cryostats = 55

Overview of IR magnets

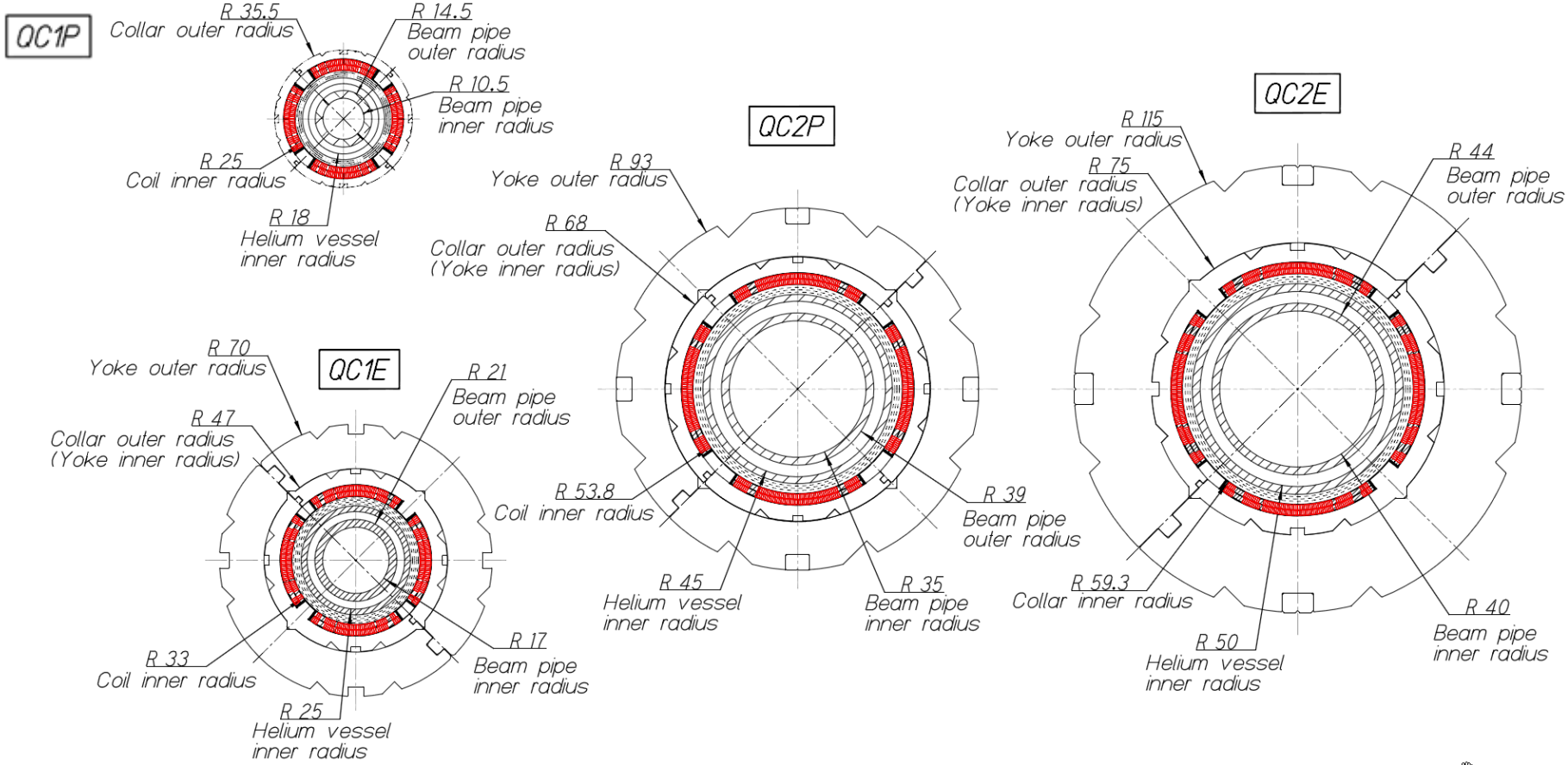
- Main quadrupoles [QC1, QC2]
  - QC1L(R)P, QC2L(R)P for the left (right) side cryostat to IP and for the position beam line.
  - QC1L(R)E, QC2L(R)E for the left (right) side cryostat to IP and for the electron beam line.



	Integral field gradient, (T/m)・m	Magnet type	Z pos. from IP, mm	θ, mrad	ΔX, mm	ΔY, mm
QC2RE	13.58 [32.41 T/m × 0.419m]	Iron Yoke	2925	0	-0.7	0
QC2RP	11.56 [26.28 × 0.410]	Permendur Yoke	1925	-2.114	0	-1.0
QC1RE	26.45 [70.89×0.373]	Permendur Yoke	1410	0	-0.7	0
QC1RP	22.98 [68.89×0.334]	No Yoke	935	7.204	0	-1.0
QC1LP	22.97 [68.94×0.334]	No Yoke	-935	-13.65	0	-1.5
QC1LE	26.94 [72.21×0.373]	Permendur Yoke	-1410	0	+0.7	0
QC2LP	11.50 [28.05 × 0.410]	Permendur Yoke	-1925	-3.725	0	-1.5
QC2LE	15.27 [28.44×0.537]	Iron Yoke	-2700	0	+0.7	0

Overview of IR magnets

- Cross section design of main quadrupoles [QC1, QC2]
  - The quadrupole magnets are designed with the two layer coils (double pane cake design).
  - In the early design, the smaller young modulus of the SC cable than the real cable were applied.
    - As the result, 10 units sextupole field by the assembly error of the magnet was induced.
    - All magnet cross sections were redesigned, and a_3 and b_3 correctors have been installed in the right cryostat.



Overview of IR magnets

- Correctors
  - From space constraint, the SC correctors were designed inside of the quadrupole bores .
  - The SC correctors were designed and directly wound on the support bobbin (helium inner vessel) by BNL under the US-Japan research collaboration
    - Direct winding method
    - Multi-layer coil [maximum layer=4 by limiting with the gap distance between the main quadrupole magnet and the helium inner vessel]
    - Some correctors were assembled on the outer surface of the main quadrupole magnets.
  - Each corrector is excited by the individual bipolar power supply.

QCSL

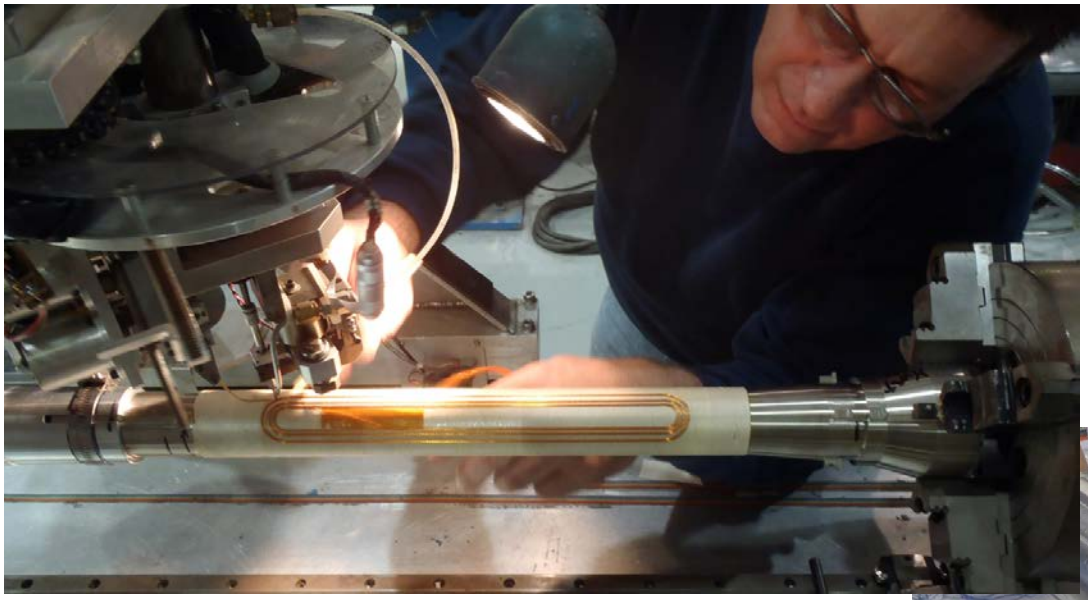
Main Quadrupole	Corrector
QC1LP	a_1, b_1, a_2, b_4
QC2LP	a_1, b_1, a_2, b_4
QC1LE	a_1, b_1, a_2, b_4
QC2LE	a_1, b_1, a_2, b_4

QCSR

Main Quadrupole	Corrector
QC1RP	a_1, b_1, a_2, a_3, b_4
QC2RP	a_1, b_1, a_2, a_3
QC1RE	a_1, b_1, a_2, a_3
QC2RE	a_1, b_1, a_2, a_3
Between QC1RP and QC2RP	b_3
Between QC1RE and QC2RE	b_3

Overview of IR magnets

- Direct winding SC Corrector by BNL

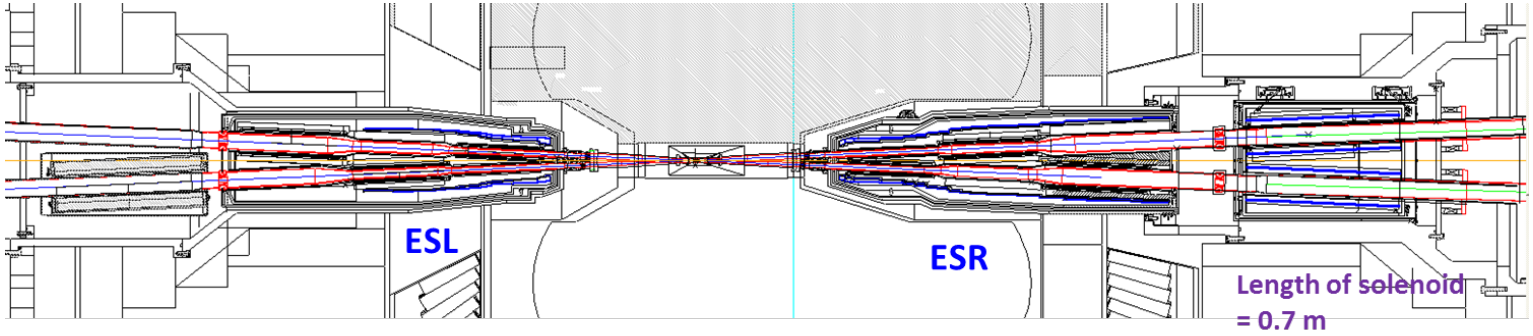


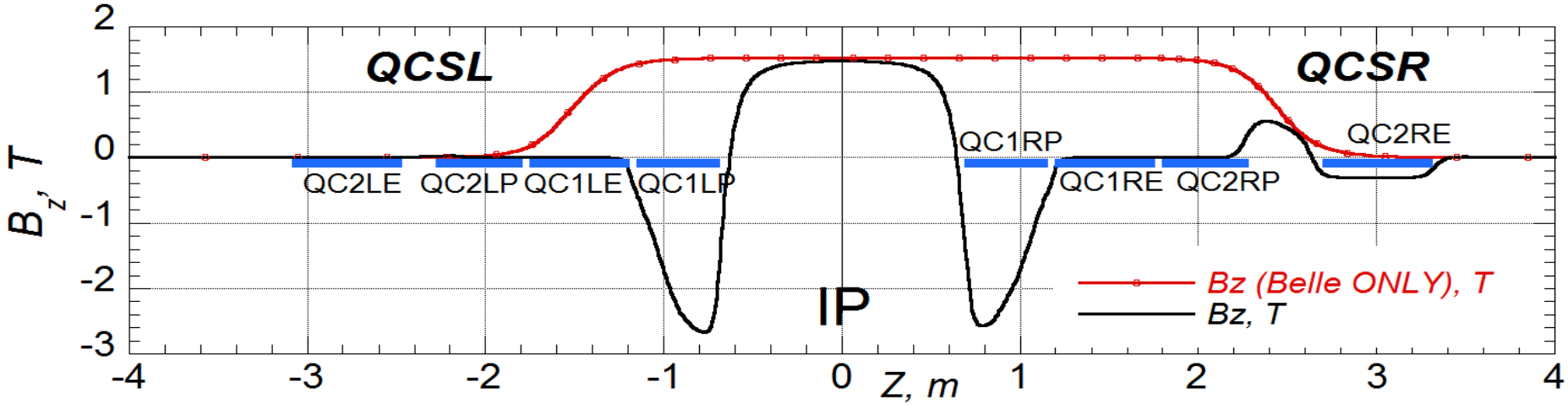
a_1 corrector winding for QC1LP @BNL

Assembly of QC2LE and correctors

Overview of IR magnets

- Compensation solenoids [ESL, ESR1, ESR2 and ESR3]





- In the left cryostat, one solenoid (12 small solenoids) is overlaid on QC1LP and QC1LE.
- In the right cryostat, the 1st solenoid (15 small solenoids) is overlaid on QC1RP, QC1RE and QC2RP.
  - The 2nd and 3rd solenoids on the each beam line in the QC2RE vessel.

Overview of IR magnets

- Compensation solenoids [ESL, ESR1]

ESL consists of 12 coils:
Magnet length= 914 mm
Maximum field at 403 A= 3.53 T
Stored Energy= 118 kJ

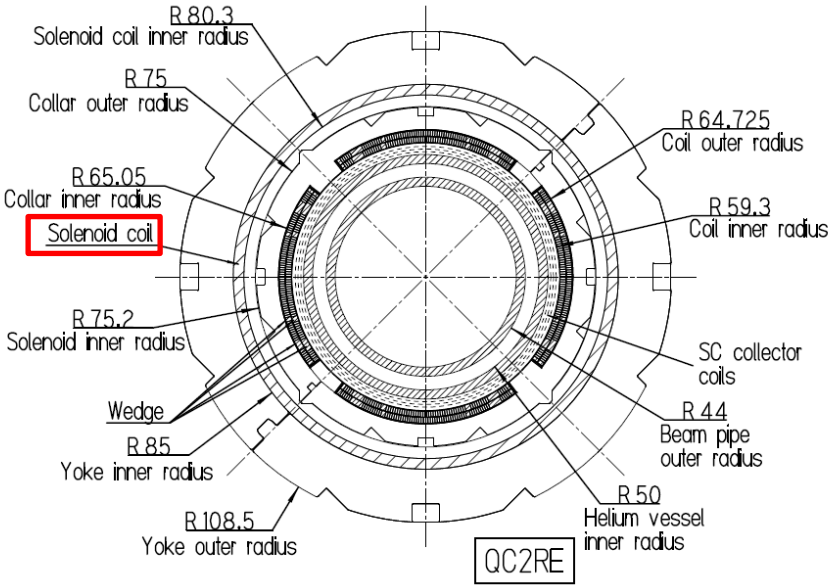
ESR1 consists of 15 coils:
Magnet length= 1575 mm
Maximum field at 450 A=3.19 T
Stored Energy= 244 kJ

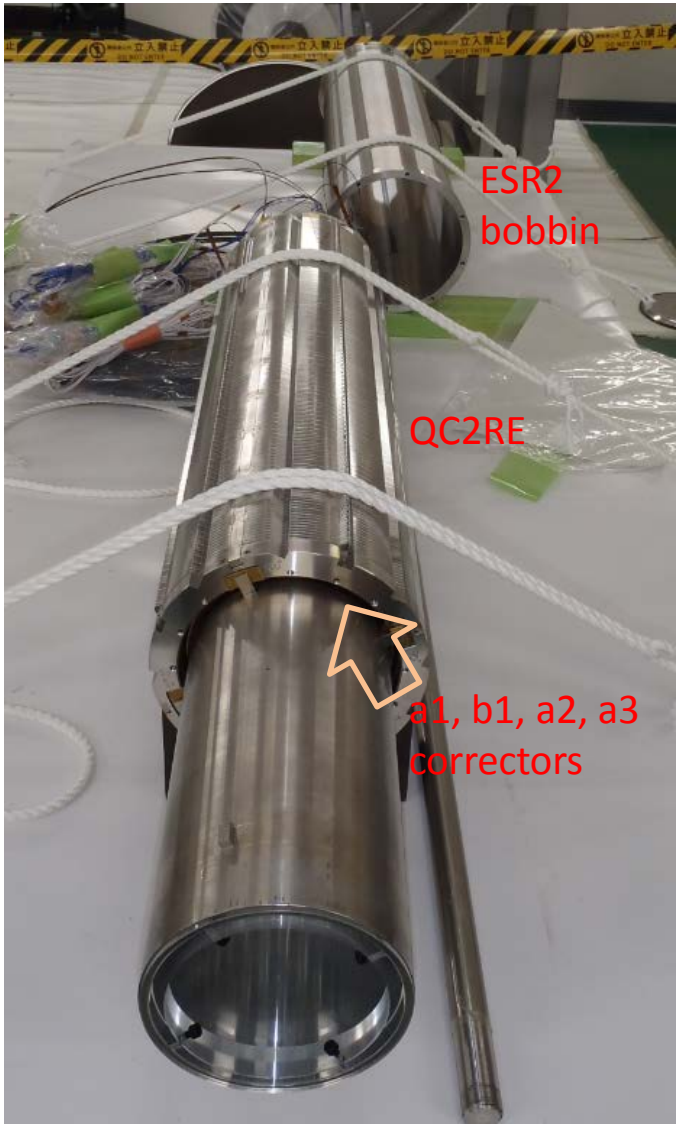
The quench protection system is reported by **X. Wang**.

Overview of IR magnets

- Compensation solenoids [ESR2, ESR3]

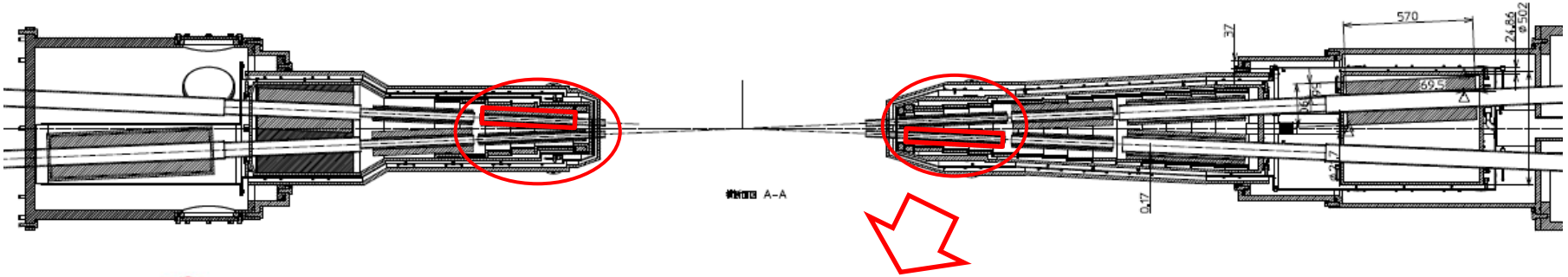
ESR3 for LER beam line

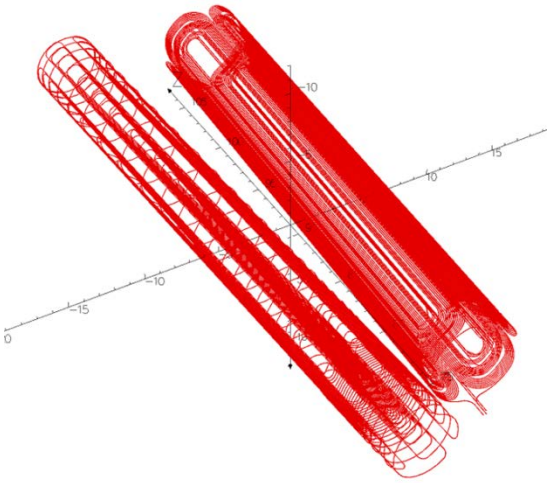


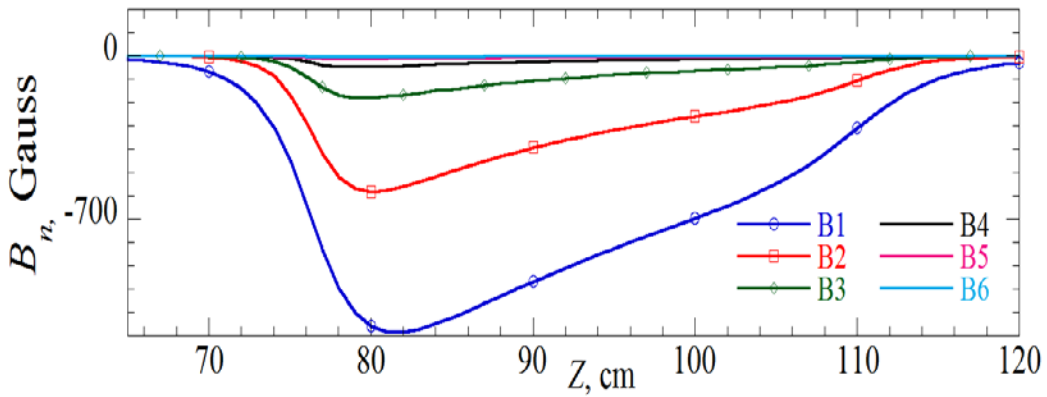


Overview of IR magnets

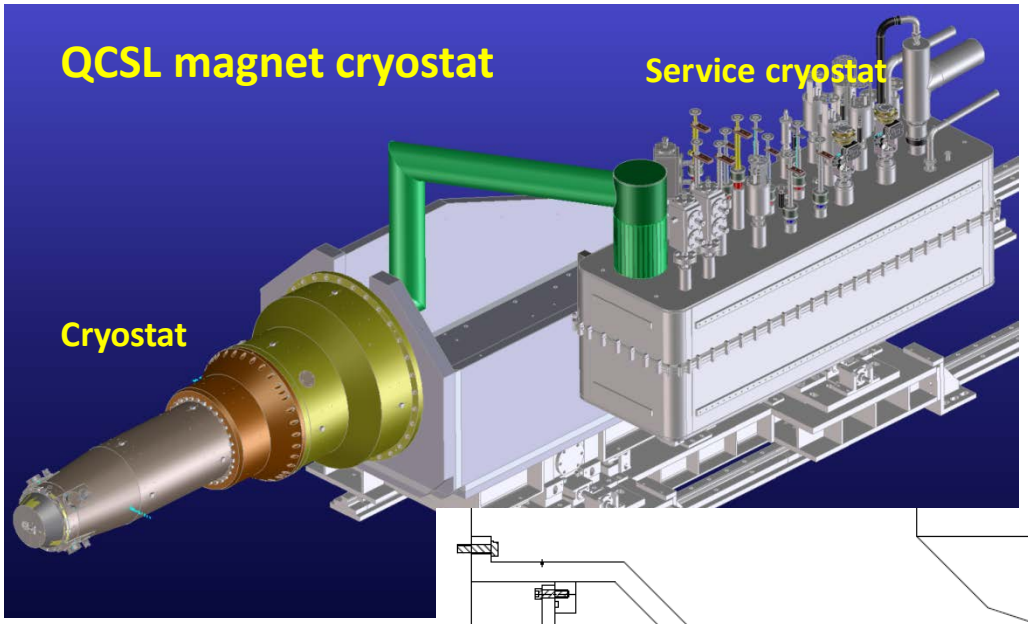
- QC1P leak field cancel magnets
  - QC1P for the e+ beam line is non-iron magnet and the e- beam line is very close to QC1P. The leak fields from QC1P go through the e- beam line.
  - ***B_3, B_4, B_5*** and ***B_6*** components of the leak fields are designed to be canceled with the SC cancel magnets.
  - By rolling QC1P in design and lower level of the QC1P axis than HER beam line, skew field components are induced. The cancel magnets are rotated to cancel the skew components in design.
  - B_1 and B_2 components are not canceled, and they are included in the optics calculation.



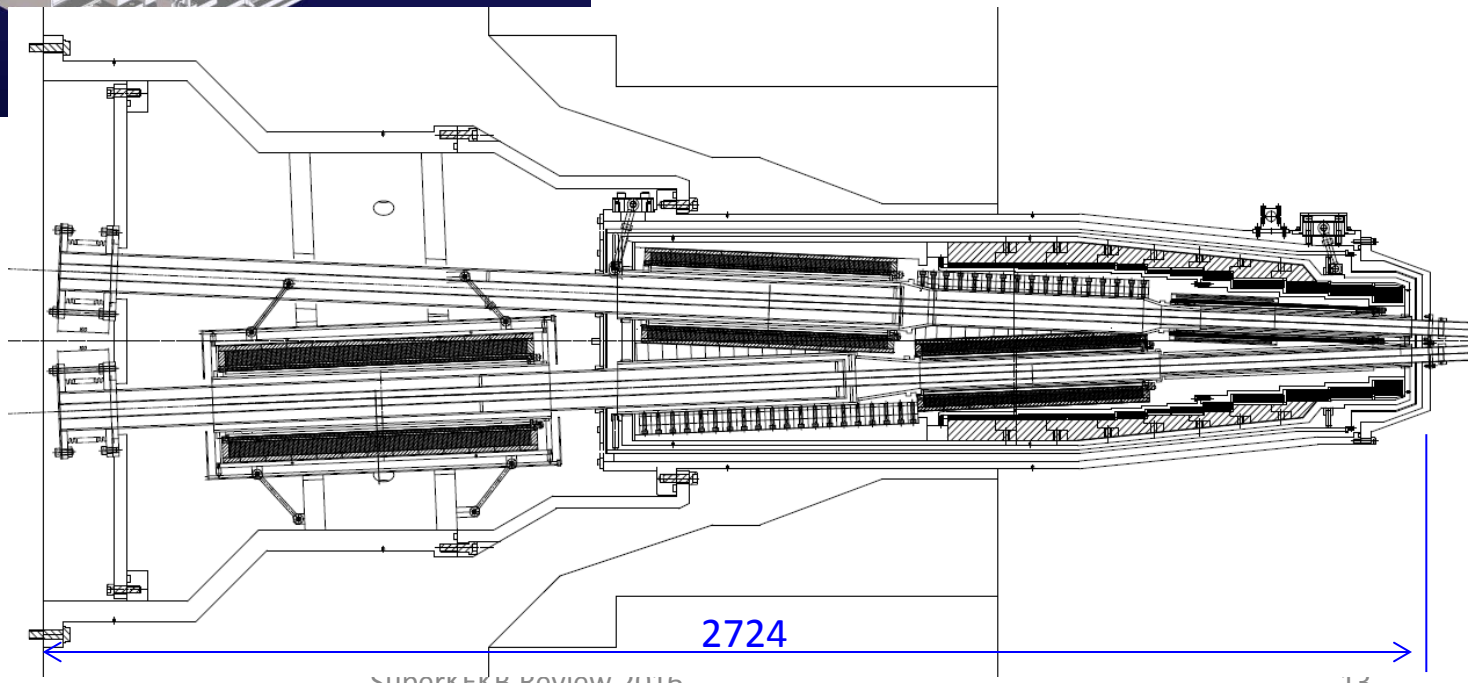




Production of magnets and cryostats



Cross section of QCSL magnet cryostat

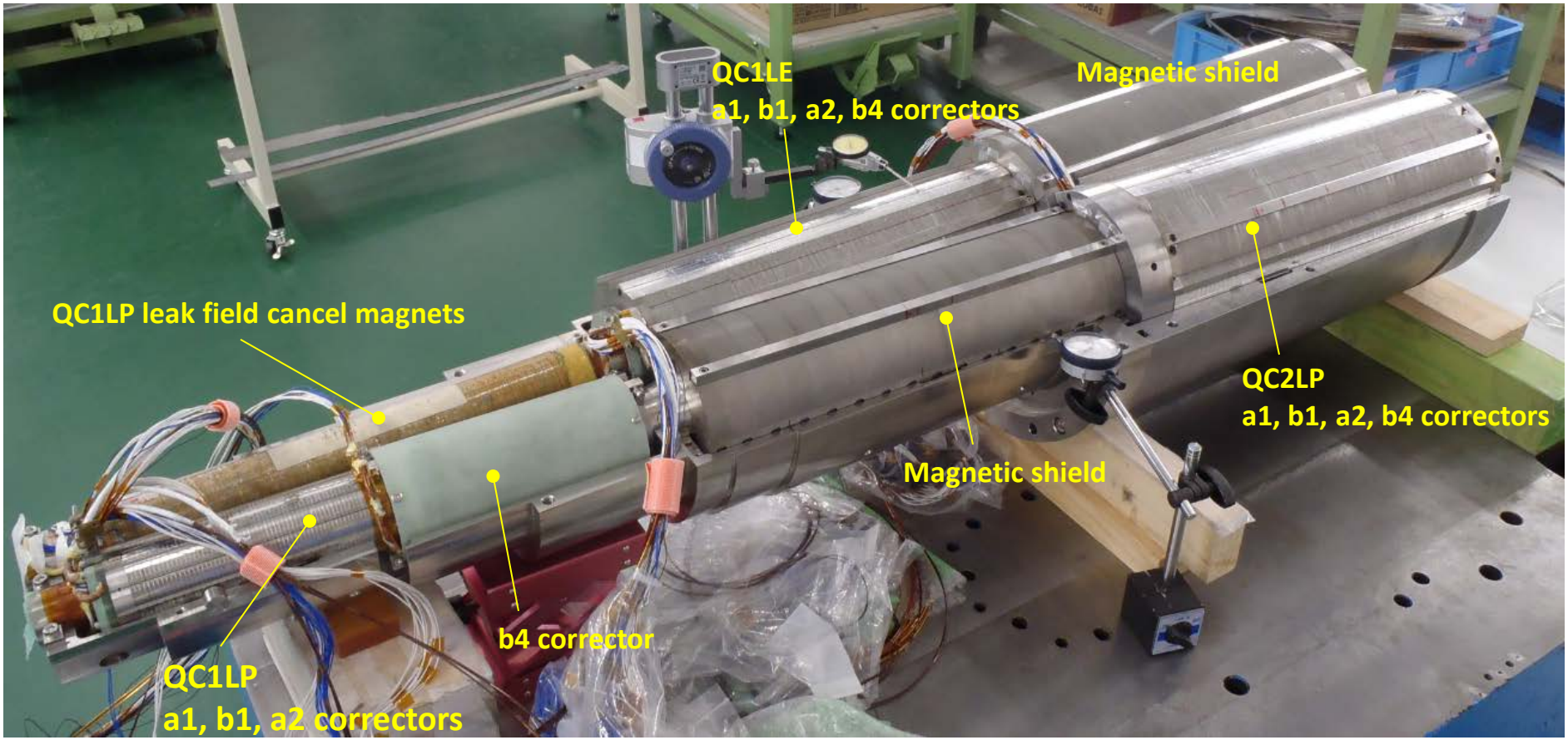


Production of magnets and cryostats

- SC magnets
  - 8 main quadrupole magnets: completed
  - 35 correctors: completed
  - 8 leak field cancel magnets: completed
  - 4 compensation solenoids: 3 solenoids are completed.
    - ESR2 for e- beam line will be completed in July.
- Magnet-cryostats
  - QCSL magnet cryostat was completed, and delivered to KEK at Dec. 25, 2015.
    - Constructing the QCSL cryostat started at Nov. 2014, and the cryostat was expected to be delivered to KEK in March 2015.
    - During assembly, several electrical troubles happened.
    - Field measurements are now on going.
  - QCSR magnet cryostat is now being built.
    - The QCSR cryostat will be delivered in November.

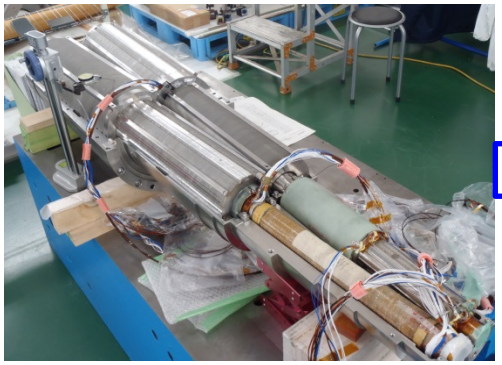
Production of magnets and cryostats

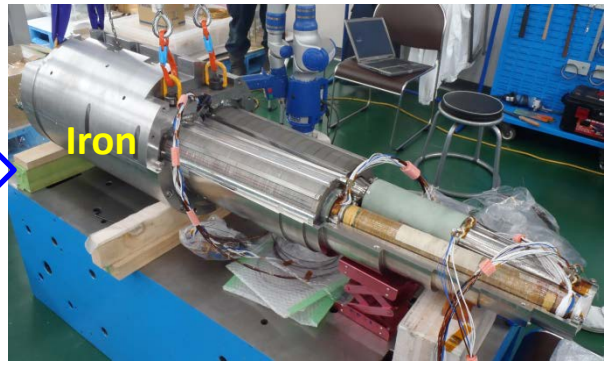
Assembly of the QC1LP, QC2LP, QC1LE, correctors and QC1LP leak field cancel magnets (Front cold mass of QCSL)



Production of magnets and cryostats

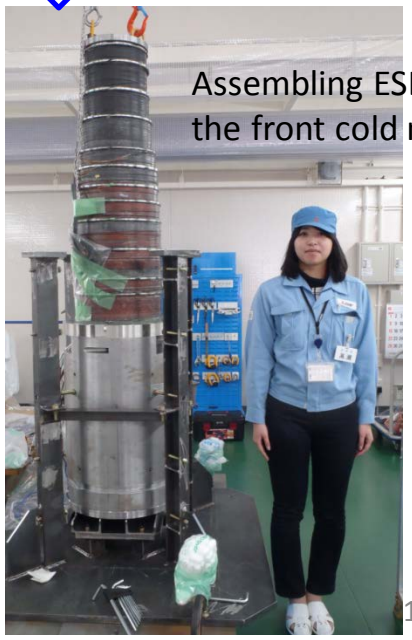
Assembly of the front cold mass of QCSL



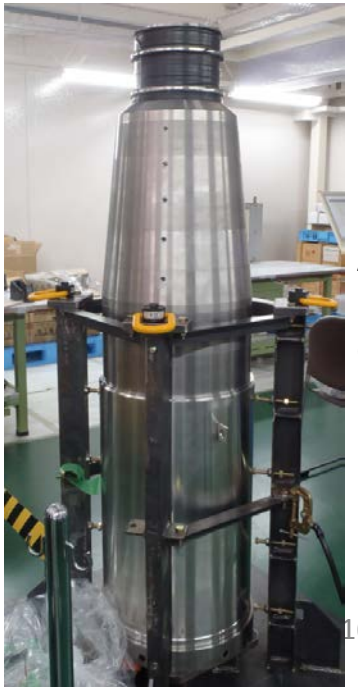


Fixing the magnets with the support components

Measurement of quadrupole alignment in the cold mass with the stationary harmonic coil at room temperature



Assembling ESL on the front cold mass



Assembling the radiation shield of W alloy on ESL

Covering the cold mass with the helium vessel and welding the vessels

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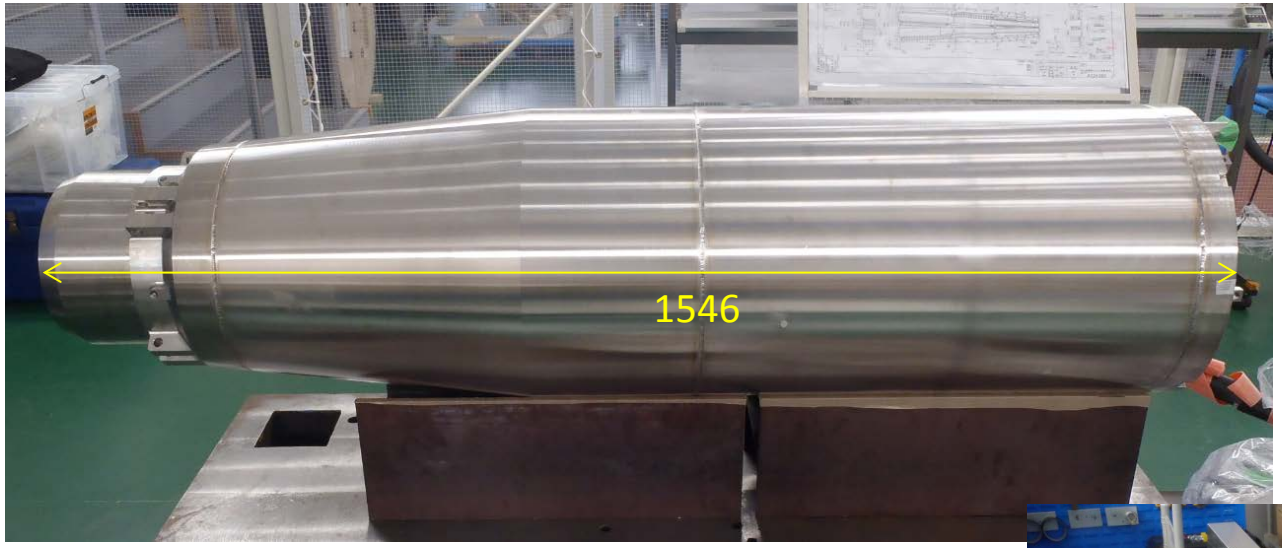
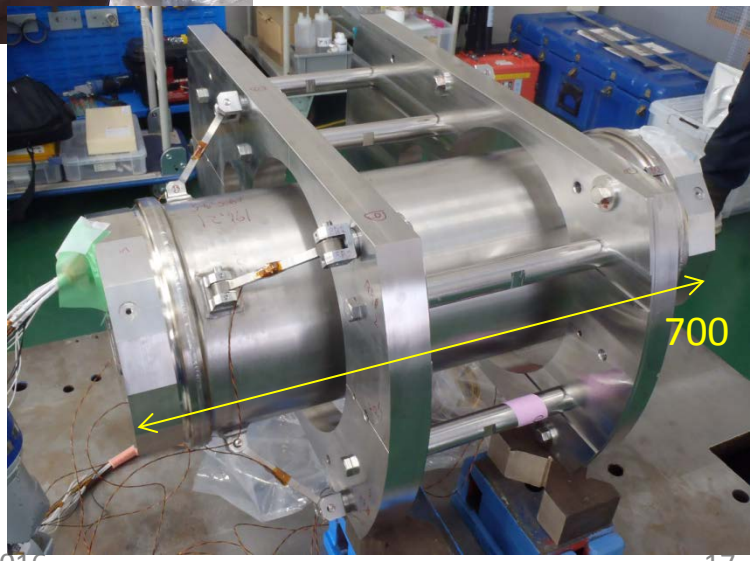
Production of magnets and cryostats

Front and rear cold masses of QCSL



Front cold mass

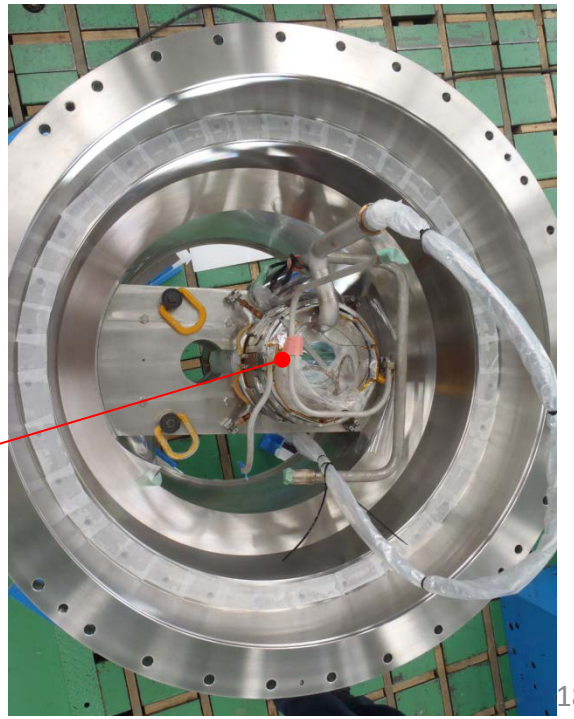


Rear cold mass
(QC2LE)

Production of magnets and cryostats

Assembling the cold masses into the QCSL cryostat

Front cold mass



Rear cold mass
(QC2LE)

Production of magnets and cryostats

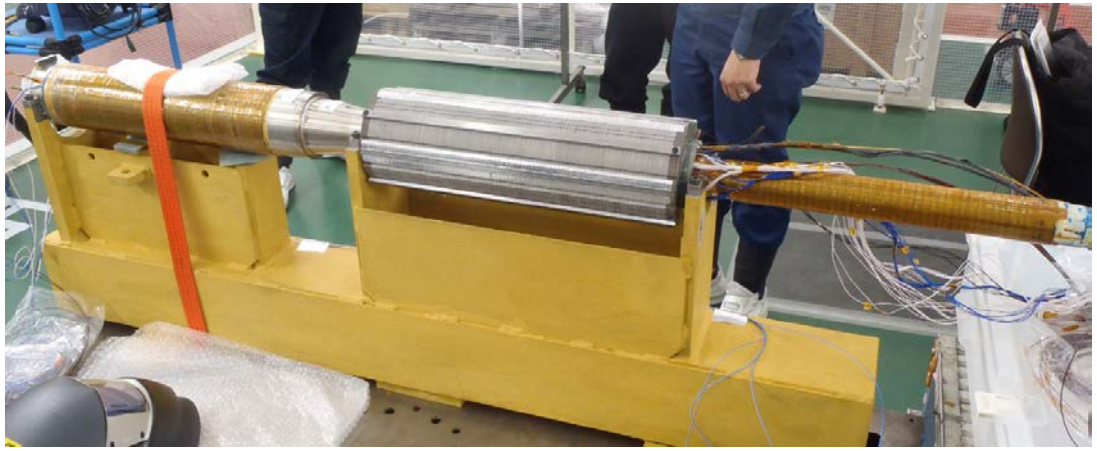
- Troubles : Electrical insulation damages during assembly of the QCSL cryostat
  - Voltage signal cables in the pipes by welding heat
    - Replacement of cables and pipes
  - ESL solenoid coil
    - The SC cable insulation was damaged by the edge of the radiation shield.
    - The cold mass was disassembled to find the damaged position.
  - ESL SC cable and voltage signal cables in the service cryostat
    - The cables were damaged by the edge of the SUS plate as the shield to welding heat.

Production of magnets and cryostats

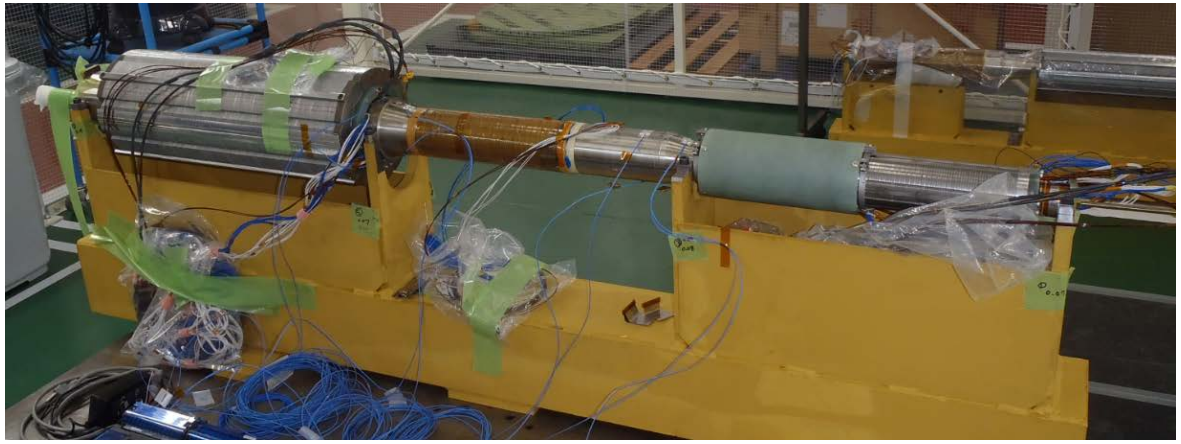
The QCSL magnet cryostat was delivered to KEK at Dec. 25, 2015.

Production of magnets and cryostats

Assembly status of the QCSR magnet cryostat



QC1RE, QC1RP leak field cancel magnets and correctors



QC1RP, QC2RP and correctors

Tests and construction schedule

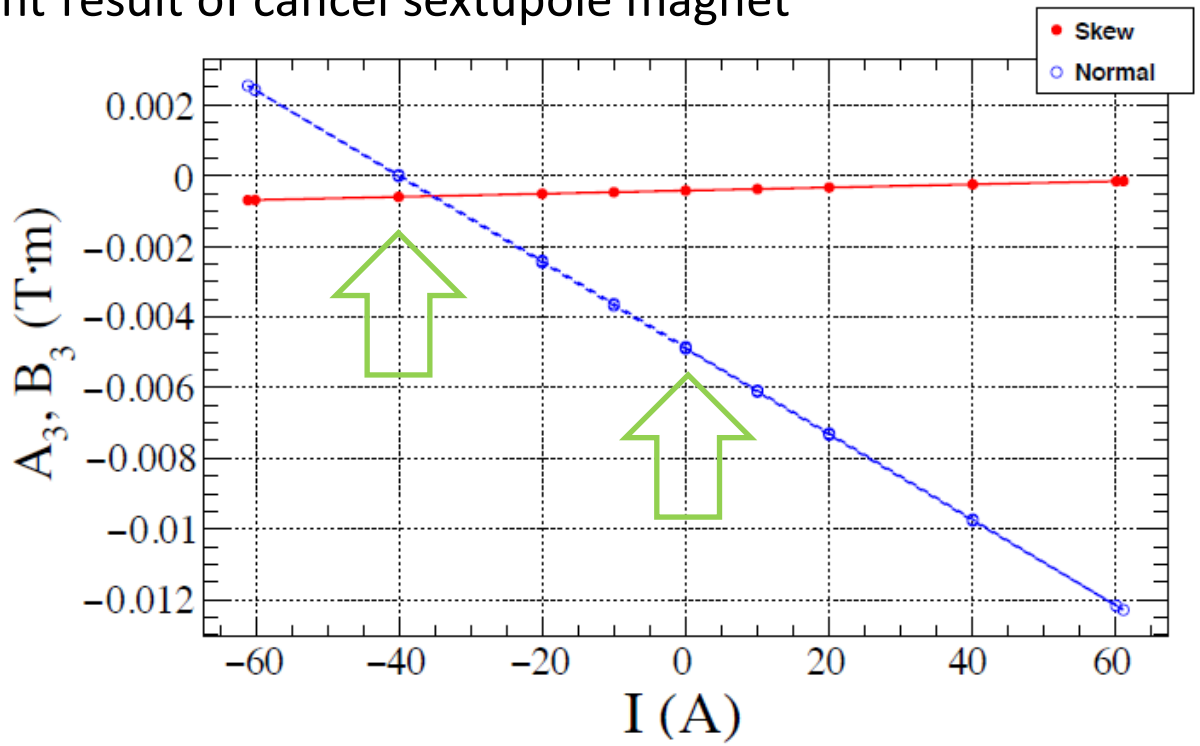
- The QCSL magnet cryostat is being tested in the **experimental laboratory** from Feb. 19th, 2016.
  - Cool down test
    - Measurement of the temperature profile in the cryostat
    - Heat load measurements of the cryostat
    - Results of the cold test is reported by **Z. Zong**.
  - Excitation test
    - Excitation of all magnets in the single and combined modes
  - Field measurements by harmonic coils
    - Integral field measurements and field profile measurements by two type of harmonic coils
    - For different inner radius of quadrupole magnets, harmonic coils of three different radii are prepared.
  - Quadrupole axis and mid-plane angle by single stretched wire (SSW)
    - Measurements have been performed with FNAL colleagues under US-Japan research collaboration.
  - Solenoid field measurement by 3D Hall probe
    - The measurement system is being prepared, and the measurement will be performed in last half of this month.

Production of magnets and cryostats

- Problem :
  - QC1LP leak field cancel magnets compensate the normal and skew field components of C_3, C_4, C_5 and C_6 in design.
    - a_3, a_4, a_5 and a_6 were not cancelled while the normal components were well cancelled.

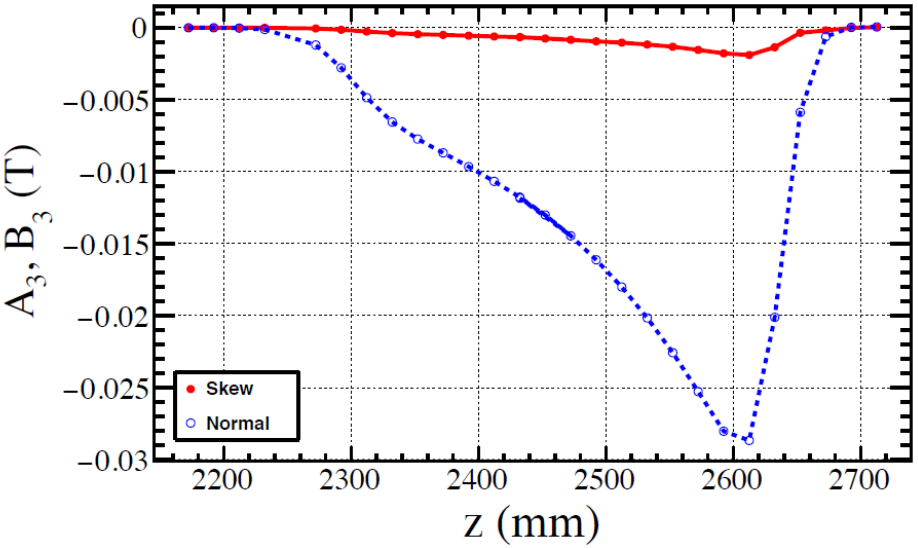
Integral field measurement result of cancel sextupole magnet

Measured radius = 12 mm

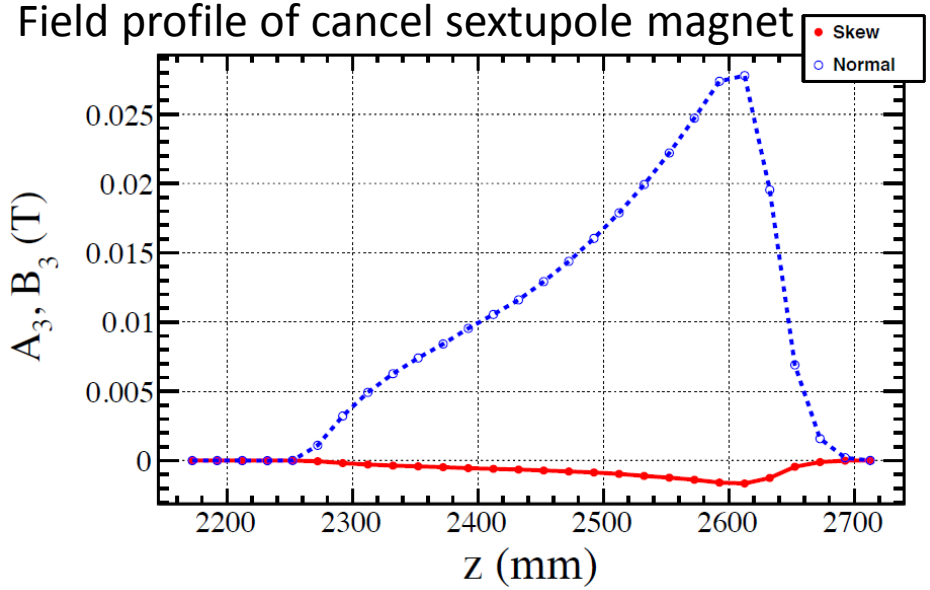


Production of magnets and cryostats

Field profile of leak field by QC1LP



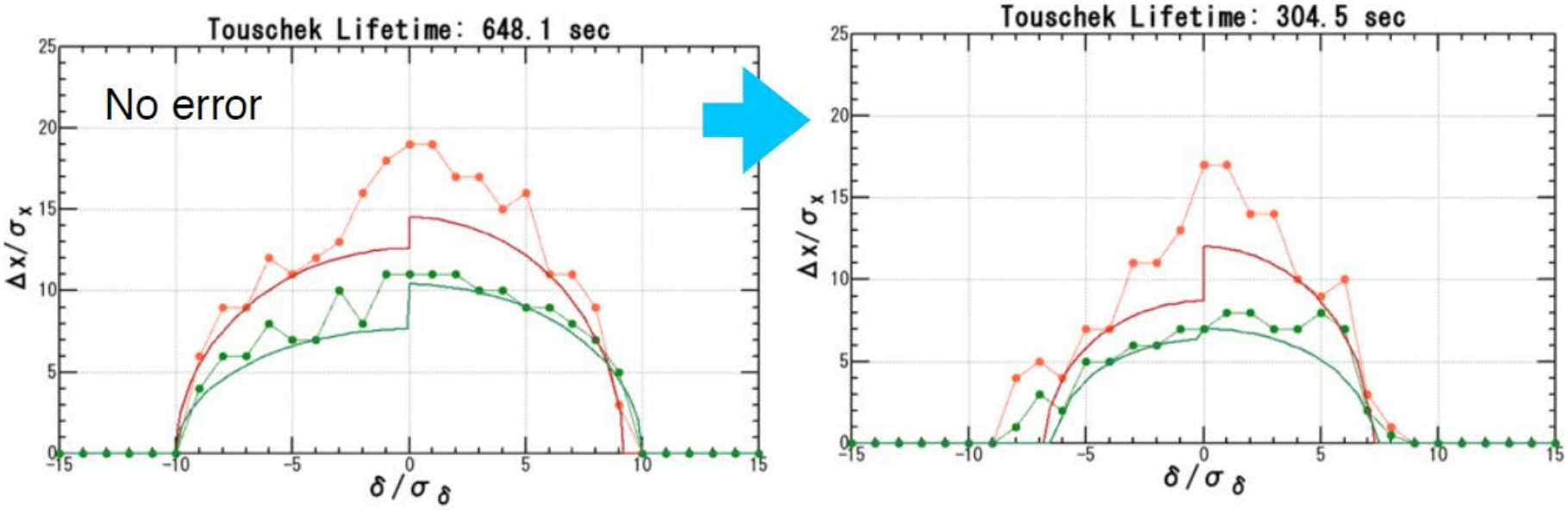
Field profile of cancel sextupole magnet



- Field profile measurements
  - Measurements were performed by the 20 mm long harmonic coil.
  - b_3 by the cancel magnet has the opposite sign to b_3 of the leak field by QC1LP.
  - a_3 by the cancel magnet has the same sign to a_3 of the leak field by QC1LP.

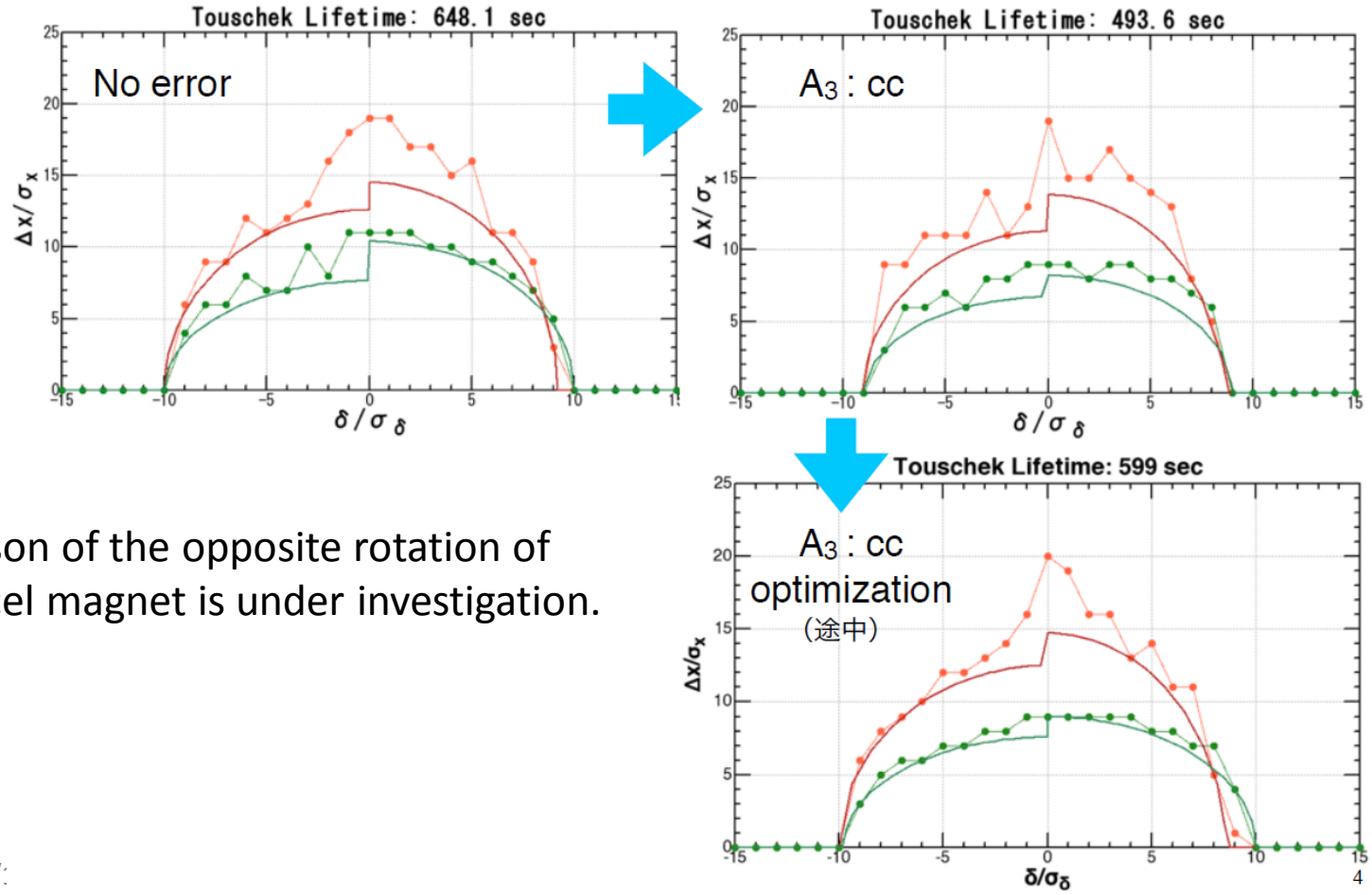
Production of magnets and cryostats

- Impact of a_3 to e- beam
  - In case of no a_3 on the e- beam line, Touschek life time is 648.1 sec.
  - With measured a_3, Touschek life time is reduced to 304.5 sec.



Production of magnets and cryostats

- When the sextupole cancel magnet in QCSR has the same problem
  - Reduction of Touschek life time is less than the only one side.
  - By optimization, the life time is recovered to 599 sec.



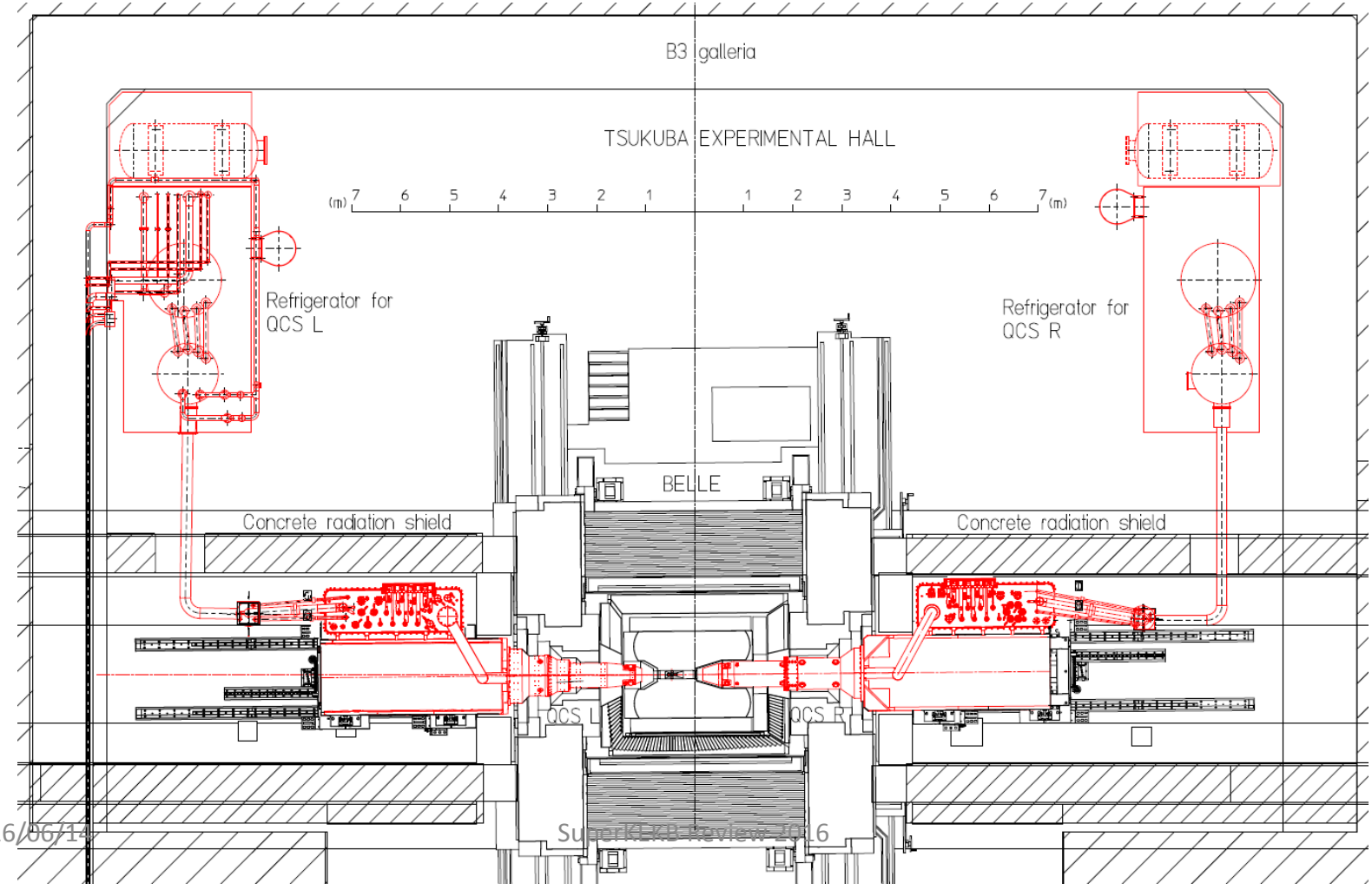
The reason of the opposite rotation of the cancel magnet is under investigation.

Tests and construction schedule

- **Major works after Phase-1 commissioning operation to Phase-2**
  - Completion of QCSR magnet cryostat
    - Assembly of cold mass
    - Field measurements at room temperature
  - Construction of the two cryogenic systems
    - The cooling power of the refrigerator for QCSL was measured at 2014.
      - **Connection between the cryogenic system and the QCSL cryostat**
    - The refrigerator for QCSR was kept in a separate building from 25 years ago after shutting TRISTAN down.
      - **The refrigerator was moved to the IR in the Tsukuba experimental hall.**
      - **Building the cryogenic system with completion of the QCSR cryostat.**
  - Tests and measurements in the Tsukuba IR
    - Tuning the operations of two cryogenic systems and cooling two cryostats down to 4K.
    - Excitation tests of 55 SC magnets
    - Field measurements of 55 magnets on the beam lines.
      - **Field quality by harmonic coils**
      - **Magnet alignment by single stretched wire (SSW) under the research collaboration with FNAL**
      - **Field profile along the beam lines by Hall probe**

Tests and construction schedule

- Construction of final focus magnet system in SuperKEKB IR
  - The magnet-cryostats have the individual cold box.
  - Construction and process tuning of the two cryogenic system are performed in series.



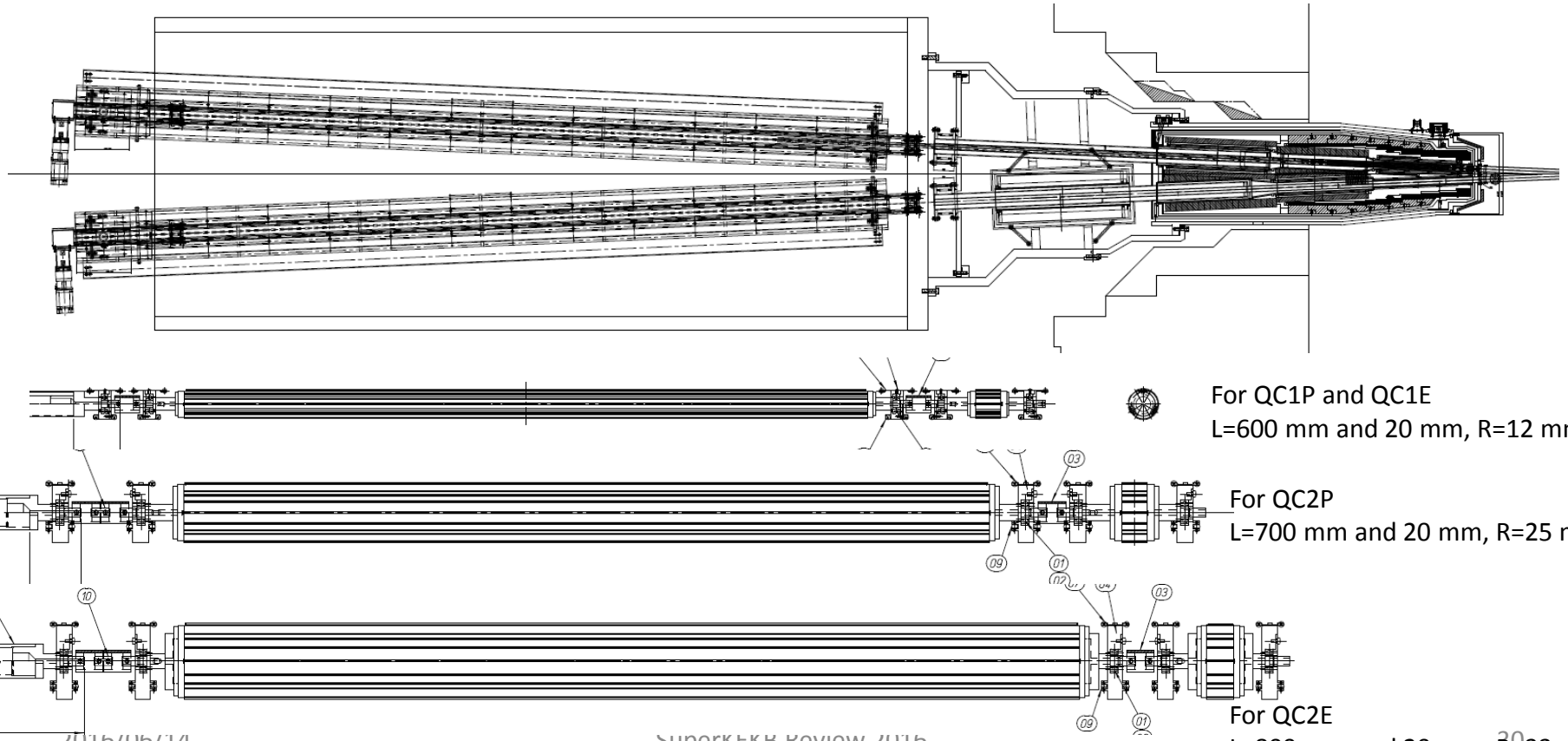
Construction Schedule

Construction status of cryogenics

He compressor for QCSR
Relocated from Oho exp. hall to the new comp. building in Tsukuba exp. hall.

Tests and construction schedule

- Measurements of harmonic coils in **SuperKEKB IR**
  - One unit of measurement system has two harmonic coils.
  - The harmonic coils are moved by the mover, the movement is measured by the digital scaler.
  - **Two sets of the mover system are prepared for shortening the measurement period.**
  - The harmonic coil measurement is reported by **Y. Arimoto**.



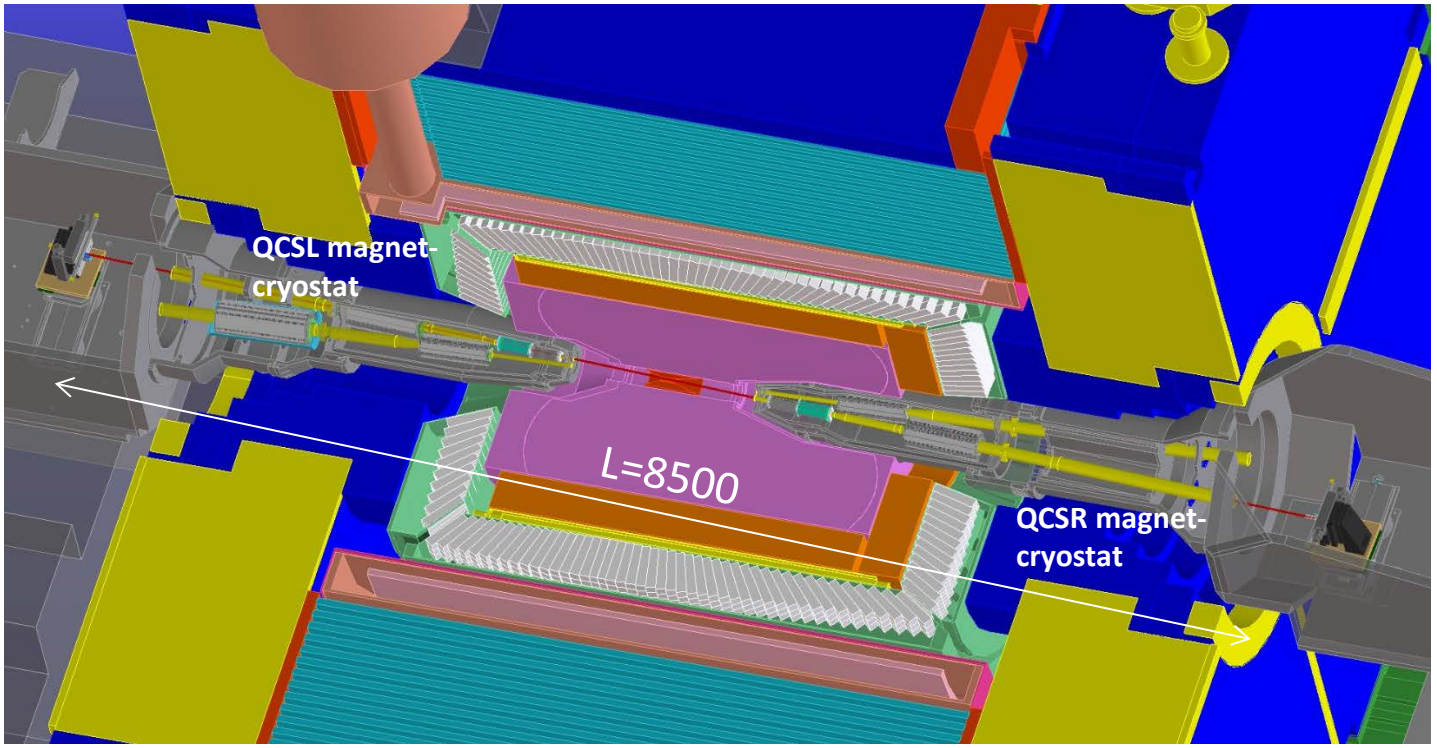
For QC1P and QC1E
L=600 mm and 20 mm, R=12 mm

For QC2P
L=700 mm and 20 mm, R=25 mm

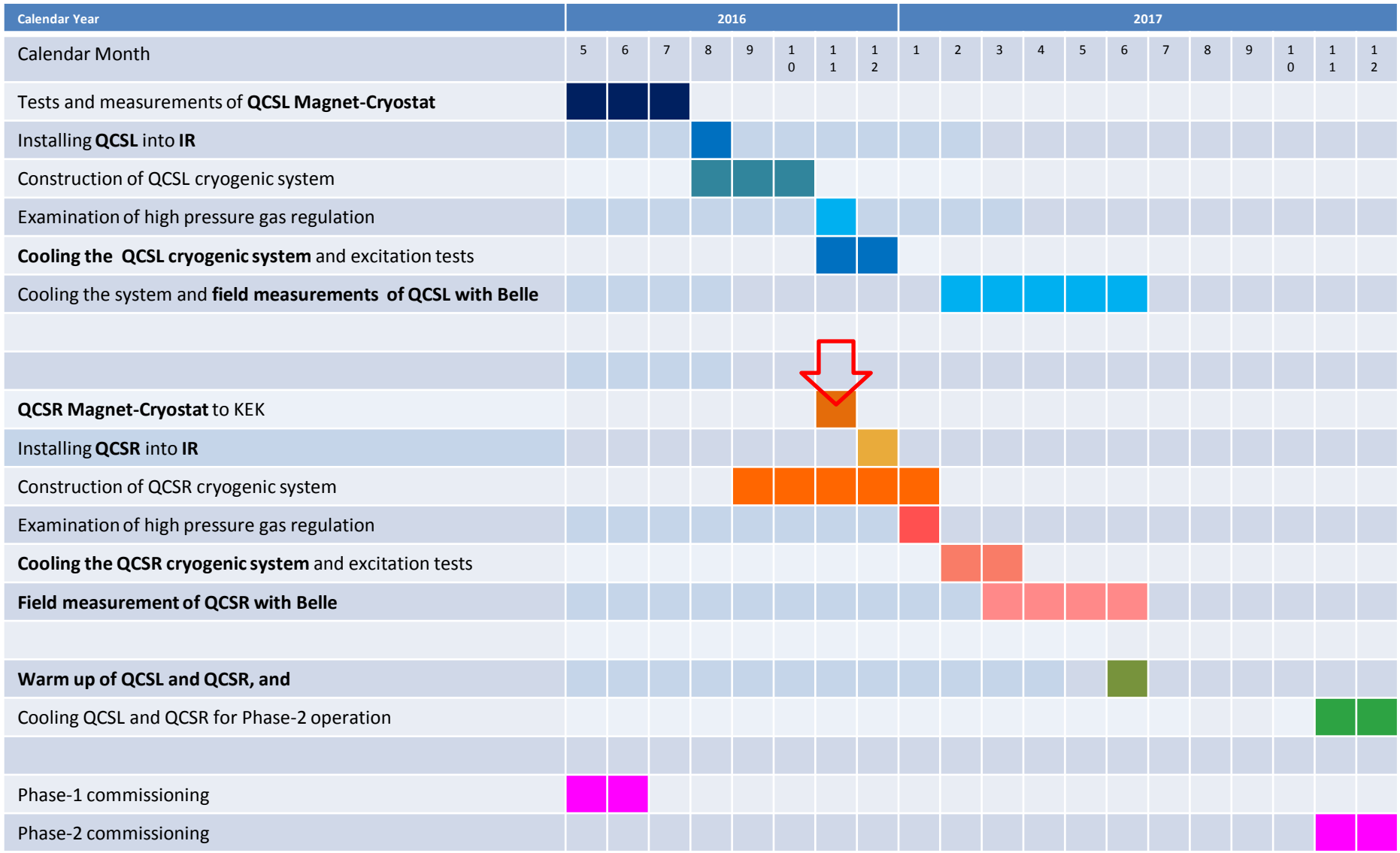
For QC2E
L=800 mm and 20 mm, R=33 mm

Tests and construction schedule

- SSW measurements in **SuperKEKB IR**
  - The wire is stretched along the beam line which goes through IP.
  - Two magnet-cryostats of QCSL/R are aligned to the beam lines with the targets of the cryostats.
  - The SSW system directly measures the quadrupole field centers and angles with respect to the beam lines with the precision of ±0.1 mm.
  - SSW measurement is reported by **H. Iinuma**.



Construction Schedule



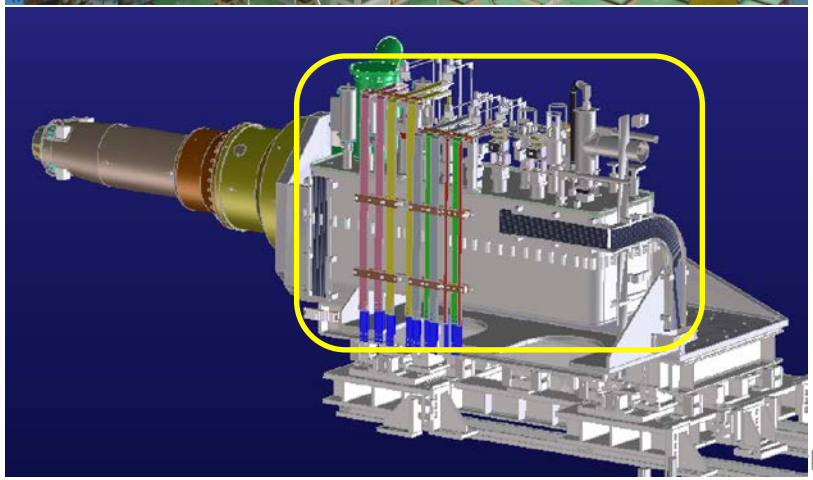
Summary

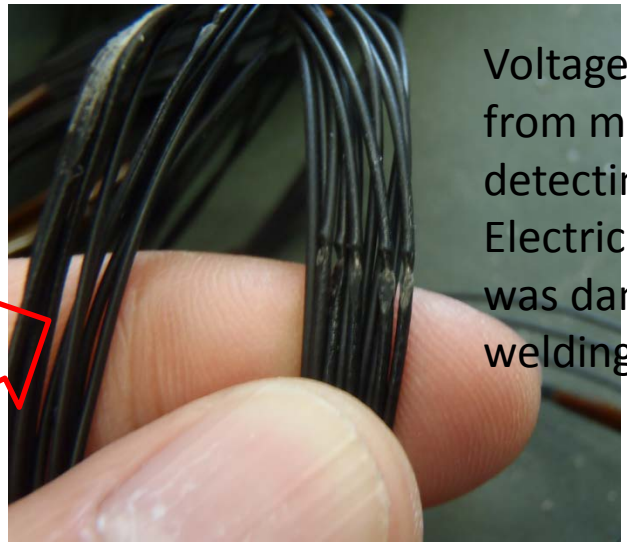
- QCSL magnet cryostat was delivered to KEK at Dec. 25, 2015.
  - The cold test of the cryostat started from Feb. 19, 2016, and the field measurements are going on.
  - From the field measurements, it turns out that the QC1LP leak field cancel magnets have wrong rotation.
    - The reason of the wrong rotation is under investigation.
- QCSR magnet cryostat is expected to be delivered to KEK in November 2016.
- Tons of work for completing the final focus system will be done until June 2017.

Back up

Production of magnets and cryostats

- Voltage signal cables in the pipes by welding heat



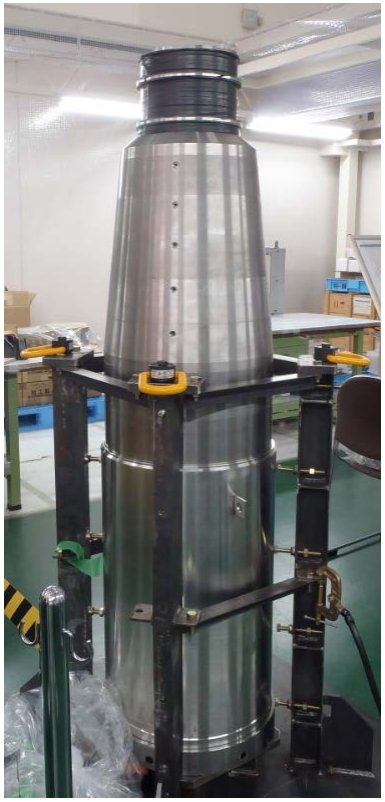


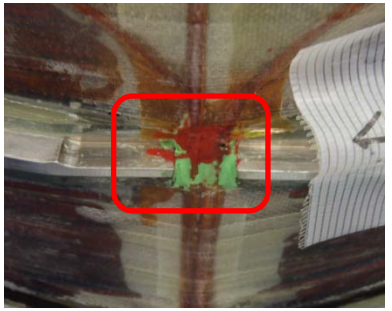
Voltage signal cables from magnets for detecting quench: Electrical insulation was damaged by welding heat.

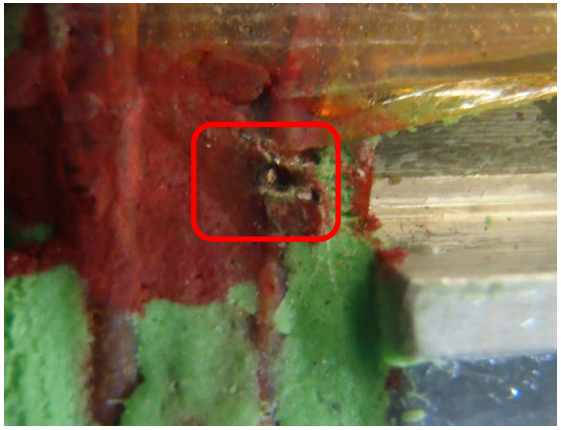
Insulation was melted and bonded to the inner surface of the pipe.

Production of magnets and cryostats

- The position was specified when the tungsten radiation shields were dismounted from the ESL.
- It was considered that the electrical insulation was damaged by the edge of the tungsten radiation shield during assembly to the ESL.

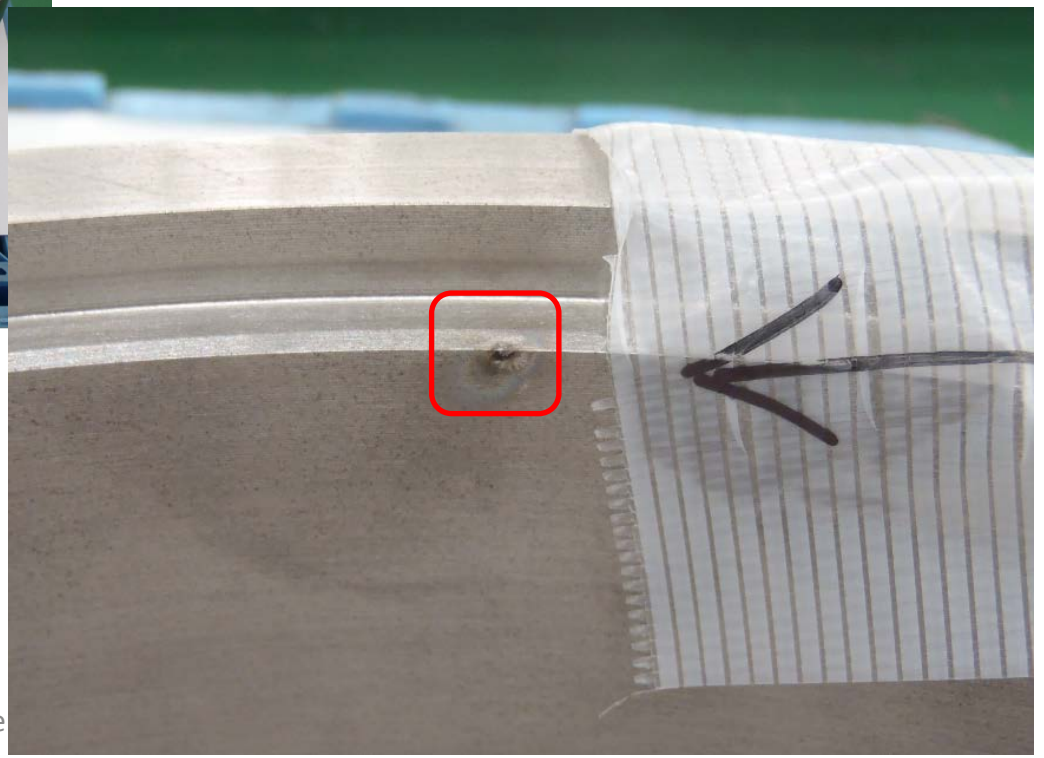






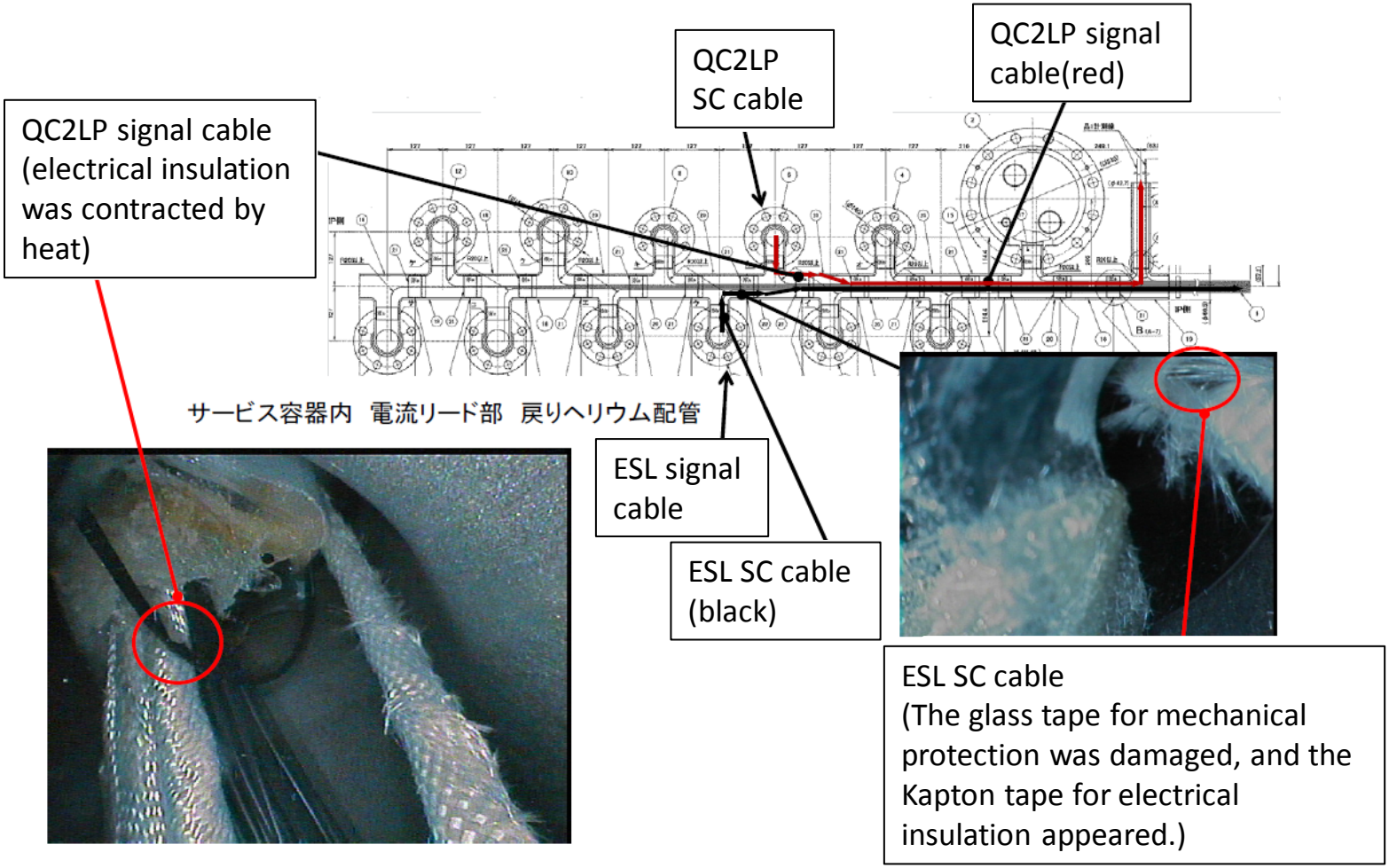
Production of magnets and cryostats

Tungsten radiation shield



Production of magnets and cryostats

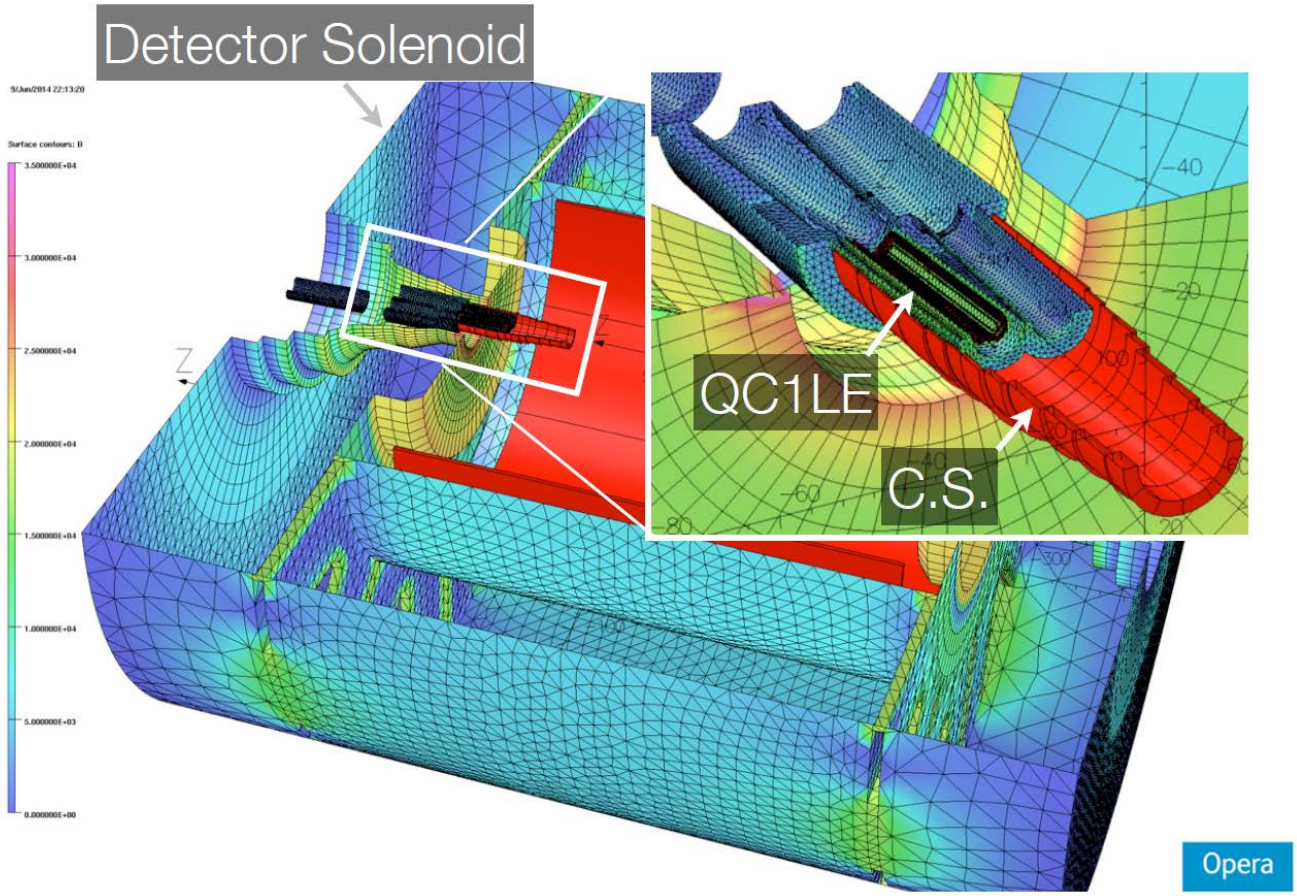
Electrical earth fault for the ESL SC cable and the voltage signal



Field calculation by 3D model

IR 3D model : all magnets with the corrector magnets are included.

- The calculation model is now being refined by Y. Arimoto.



By Y. Arimoto