SuperKEKB IR Upgrade Idea

IR superconducting magnets modification plan

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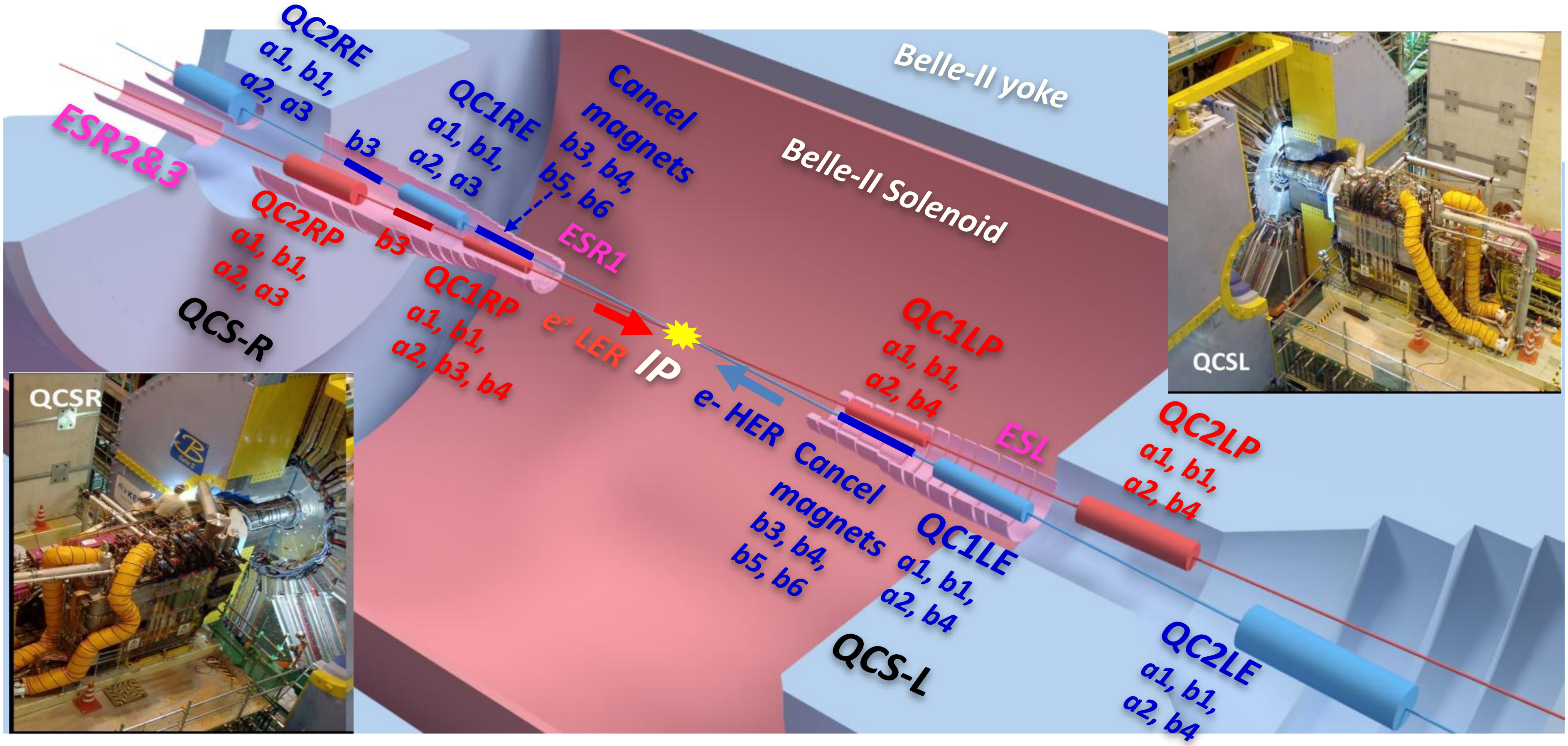
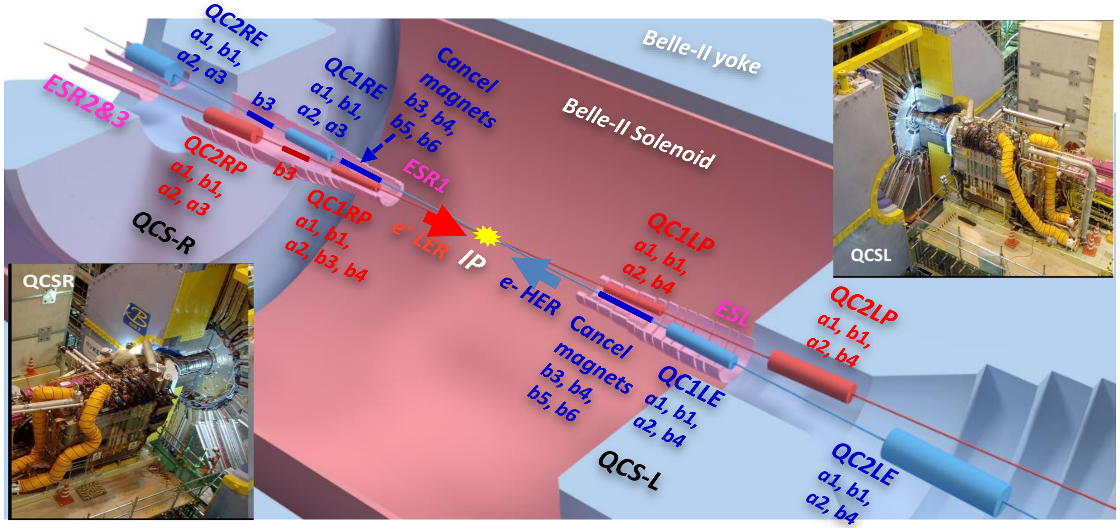
Superconducting magnet system



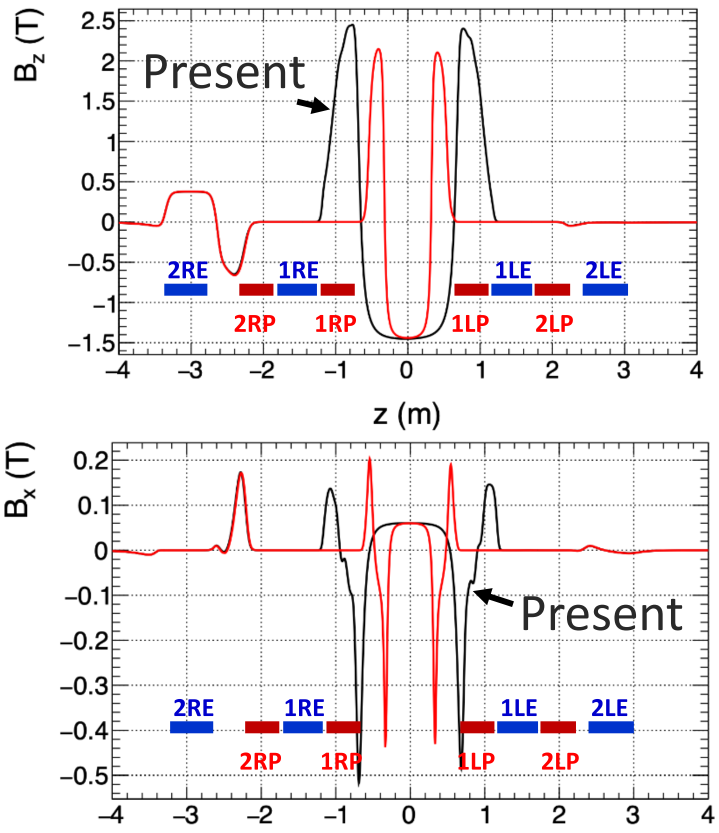
By Y. Arimoto

55 superconducting magnets
- 8 quadrupole magnets (QC1s, QC2s) for focusing or defocusing beams
- 35 corrector magnets for tuning beams
- 8 magnets for canceling the leak field from the quadrupole magnets
- 4 solenoids for canceling the detector solenoid field of 1.5 T

Superconducting magnet system



Solenoid field on beam line



By Y. Arimoto

In present IR design, the quadrupole magnets are exposed to the solenoidal field.

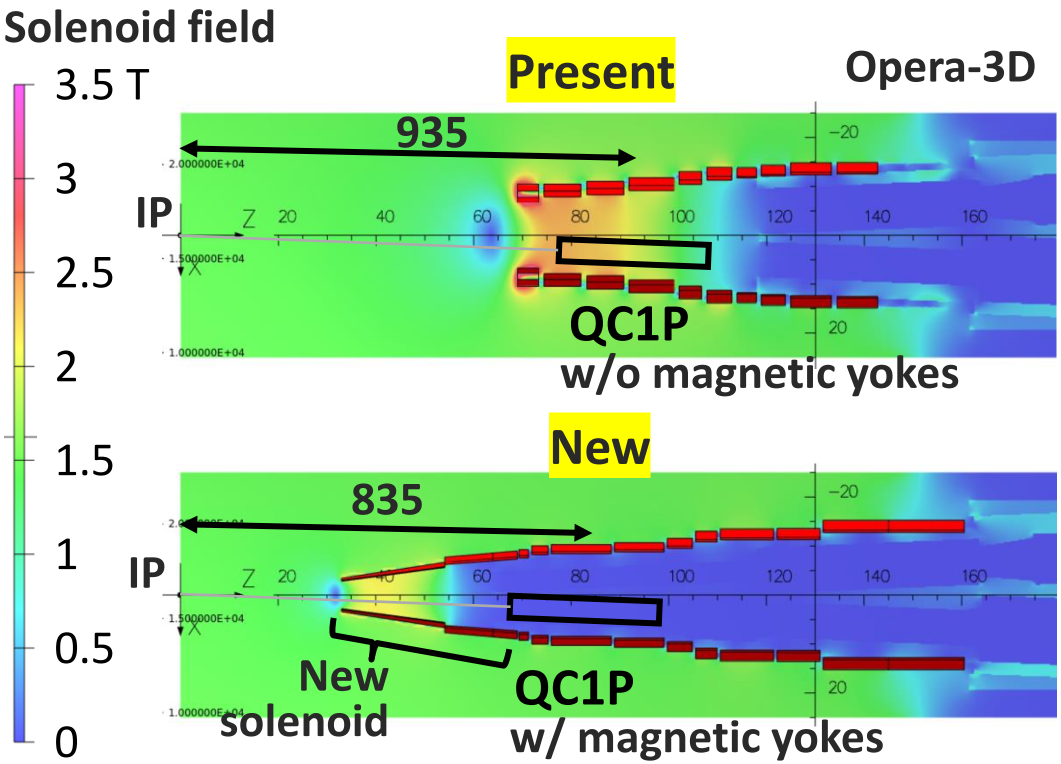
To cancel the chromatic X–Y coupling and minimize vertical emittance, the quadrupole magnets require vertical offsets, rotations, and horizontal offsets.

Magnet	Int. field	Z	Δx	Δy	$\Delta\theta$
	T	m	mm	mm	mrad
QC1LP	22.96	−935	0.0	−1.5	−13.35
QC1RP	22.96	935	0.0	−1.0	7.204
QC2LP	11.48	−1925	0.0	−1.5	−3.725
QC2RP	11.54	1925	0.0	−1.0	−2.114
QC1LE	26.94	−1410	0.7	0.0	0.0
QC1RE	25.39	1410	−0.7	0.0	0.0
QC2LE	15.27	−2700	0.7	0.0	0.0
QC2RE	13.04	2925	−0.7	0.0	0.0

We aim to redesign a simple IR with no solenoid field overlap.

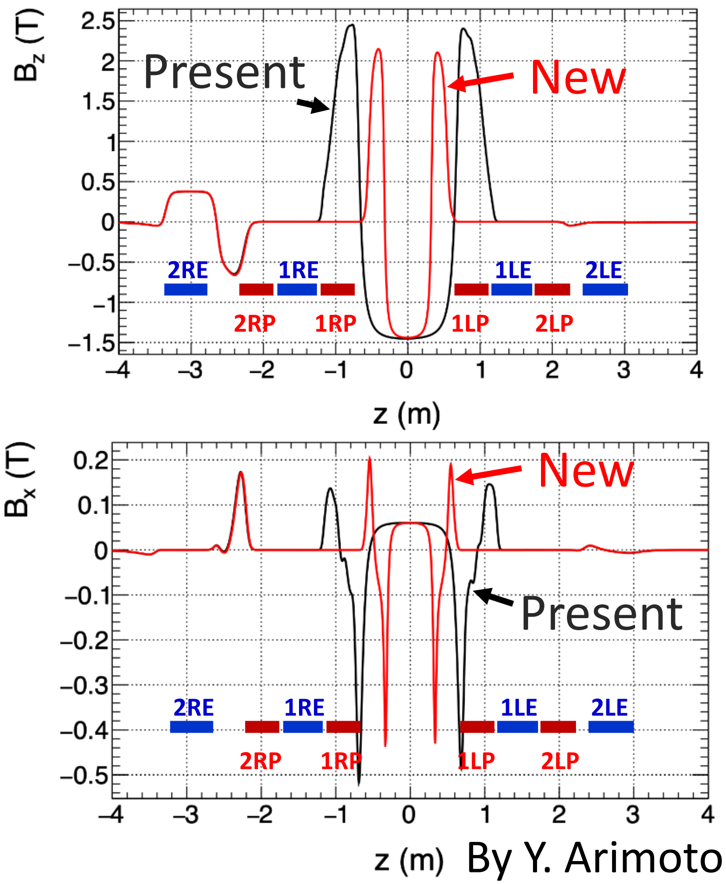
N. Ohuchi et al., DOI:10.1016aj.nima.2021.165930

Design concepts of new IR



By Y. Arimoto

Solenoid field on beam line



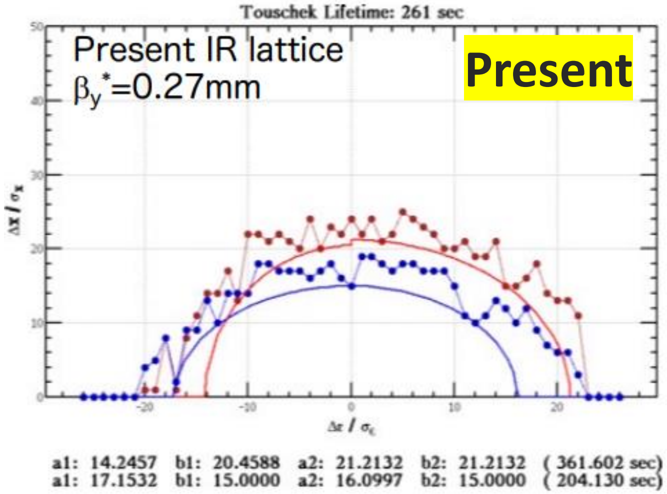
By Y. Arimoto

- Separating QC1P from the solenoid field by adding a new compensation solenoid.
  To cancel chromatic X–Y coupling and minimize vertical emittance.
- Moving QC1P closer to the IP by 100 mm.
  To enlarge dynamic aperture of LER and extend Touschek lifetime.

Comparison of present and new IR designs

Preliminary optics evaluation

The dynamic aperture was improved and the Touschek lifetime increased from 261 s to 424 s.



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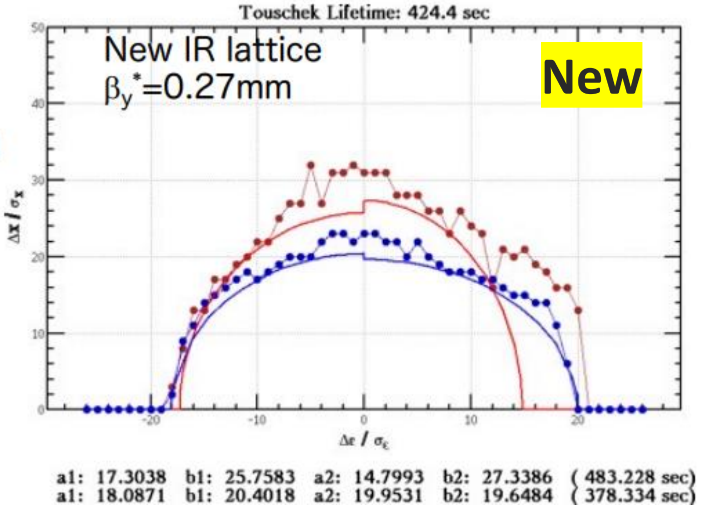
a1:  14.2457   b1:  20.4588   a2:  21.2132   b2:  21.2132   ( 361.602 sec)
a1:  17.1532   b1:  15.0000   a2:  16.0997   b2:  15.0000   ( 204.130 sec)
```

Touschek lifetime from ~260 s to ~420 s.



```
a1:  17.3038   b1:  25.7583   a2:  14.7993   b2:  27.3386   ( 483.228 sec)
a1:  18.0871   b1:  20.4018   a2:  19.9531   b2:  19.6484   ( 378.334 sec)
```

The chromatic X–Y coupling parameters became a few orders of magnitude smaller.

	L*(mm)	$\partial R1/\partial\delta$	$\partial R2/\partial\delta$	$\partial R3/\partial\delta$	$\partial R4/\partial\delta$
Present	935	-8.9×10^{-3}	$+4.0\times10^{-3}$	$-5.0\times10^{+1}$	$+2.9\times10^{+1}$
New	835	$+2.3\times10^{-5}$	-6.0×10^{-6}	-4.4×10^{-2}	$+5.5\times10^{-3}$

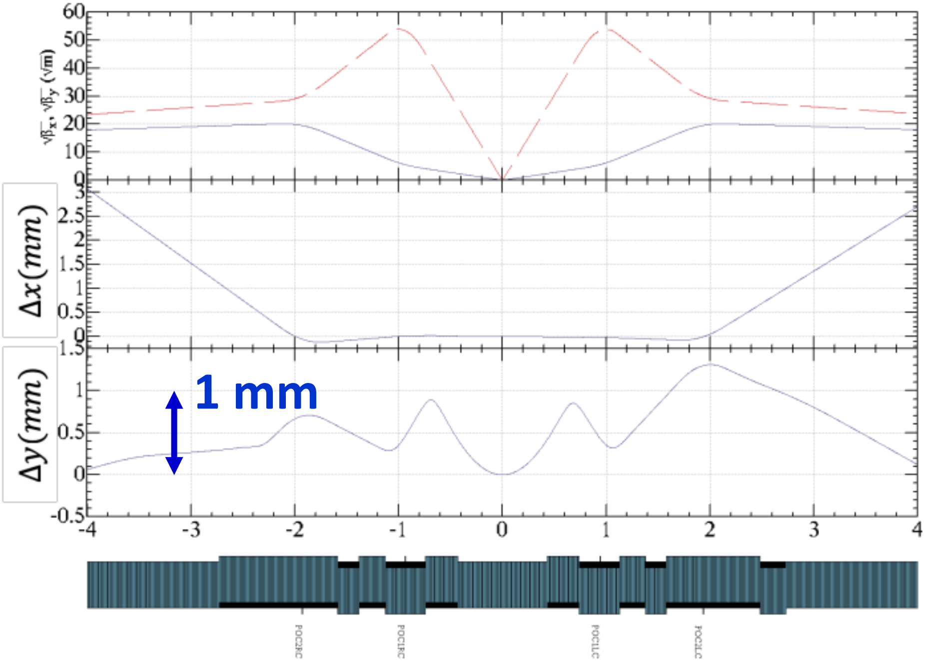
By A. Morita

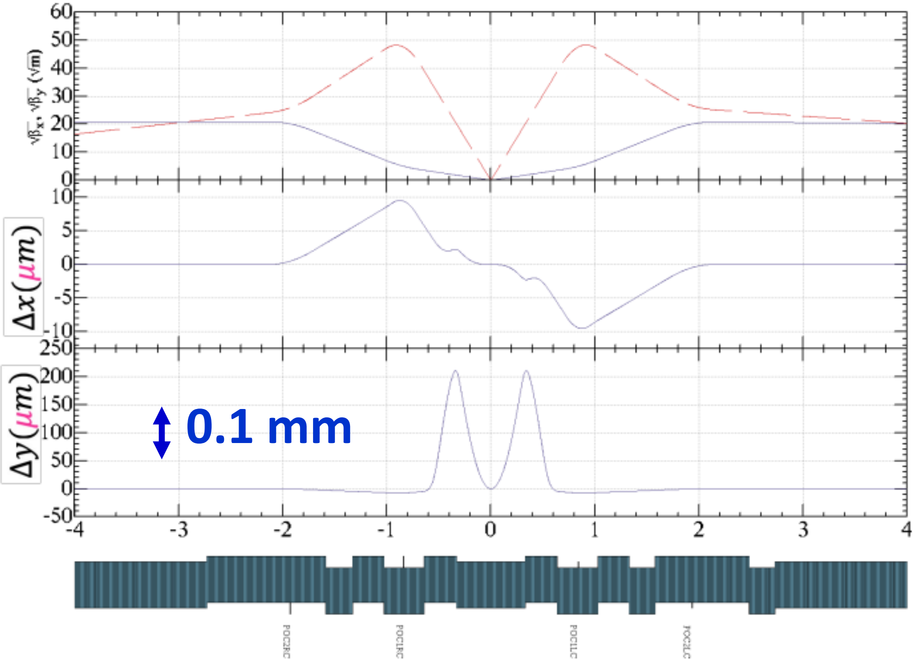
Comparison of present and new IR designs

Preliminary optics evaluation

The orbit displacement with new IR lattice is ~10 um at QC1s, while it is about 1 mm with the present lattice.

The vertical emittance from the new IR was calculated to be 14 fm, which is negligible.

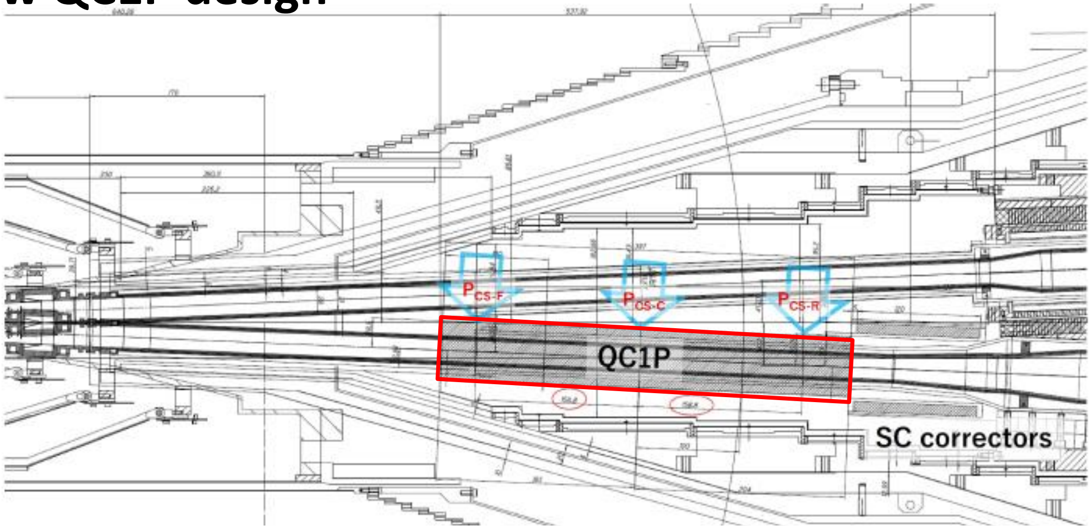

Present IR


New IR

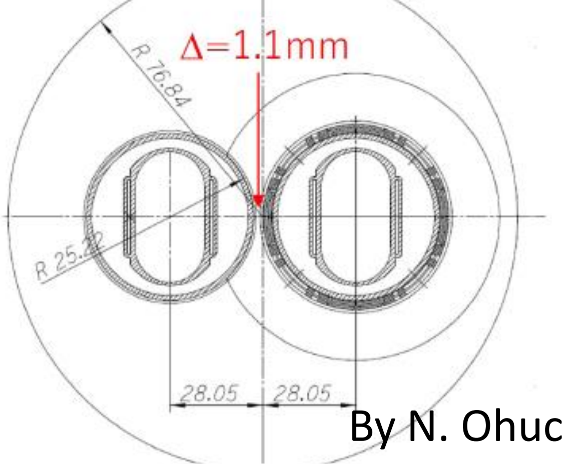
By A. Morita

Comparison of present and new IR designs

New QC1P design



IP side cross section



By N. Ohuchi

QC1P parameters	Present	New
Distance between the IP and the magnet center $L*$ (mm)	935	835
Required integrated field GL_eff (T)	23	25.75
Required field gradient G (T/m)	67.88	76.01
Distance between the coil & HER helium vessel (mm)	10.8	1.1

New QC1P requires a 12% increase in the field strength if the magnetic length is maintained.
The new design has very little space on the IP side.

⇨ We need to design a coil that is thinner than the present QC1P.
The superconducting wire needs a non-Cu current density higher than 3000 A/mm2 .

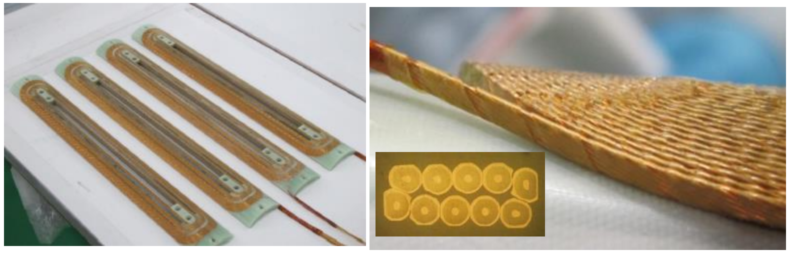
New QC1P magnet

Selection of superconducting wires

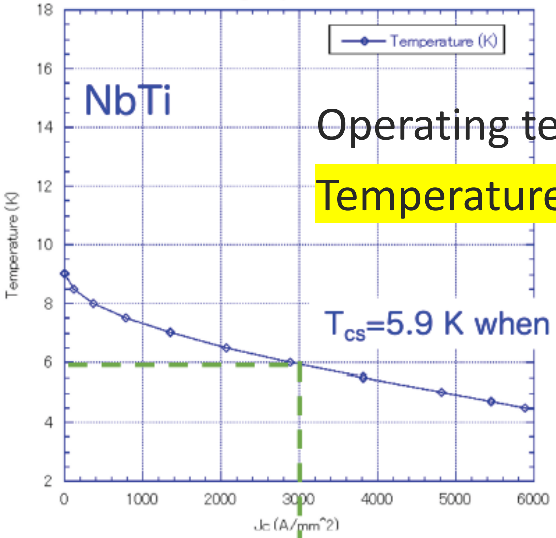
For the new QC1P, we chose Nb3Sn wire because of its large temperature margin.

NbTi wire (Present QC1P)

Diameter : 0.498 mm
Filament size: 7.4 um



Present QC1P coil ΔT : ~2 K



Operating temperature : 4.7 K

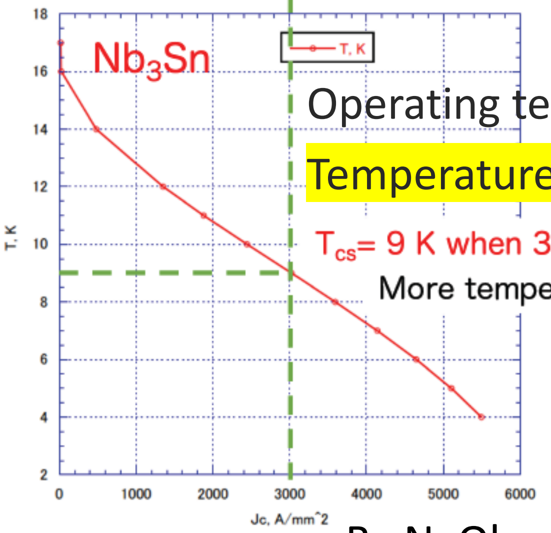
Temperature margin ΔT : ~1 K

T_{cs}=5.9 K when 3000A/mm²

Nb3Sn wire

1.13 mm x 1.7 mm
Filament size: 3.2 um

Sugimoto, etc. , Furukawa Electric Review, No. 55 2024



Operating temperature : 4.7 K

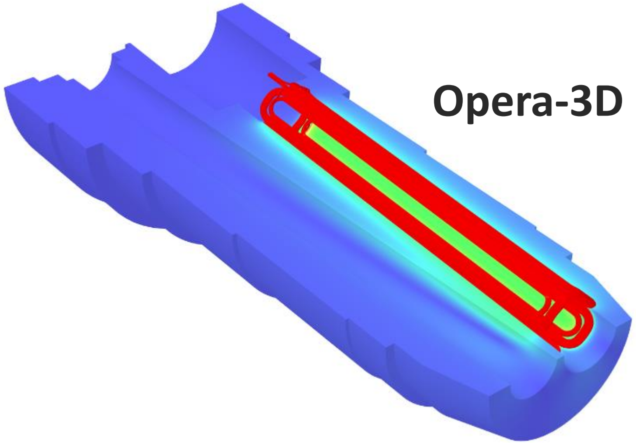
Temperature margin ΔT : ~4 K

T_{cs}= 9 K when 3000A/mm²
More temperature margin

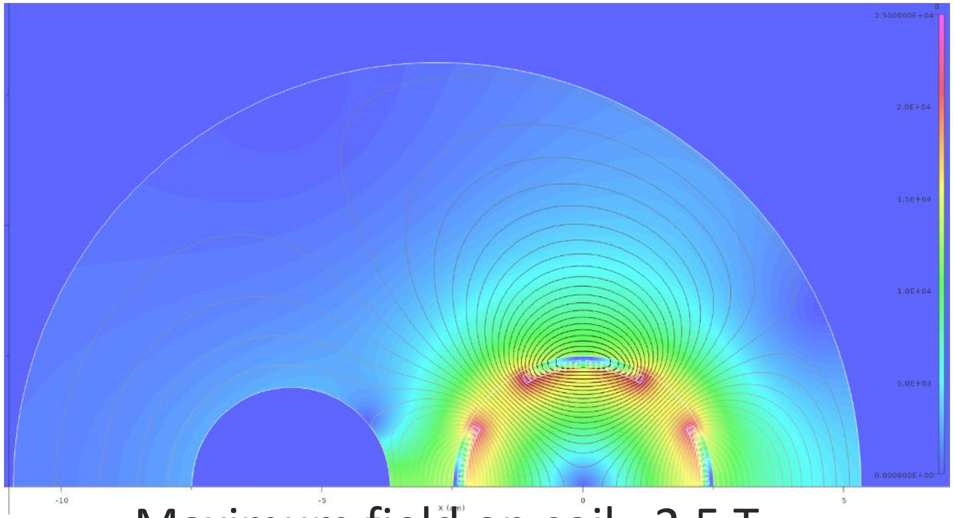
By N. Ohuchi

New QC1P magnet

Preliminary field evaluation

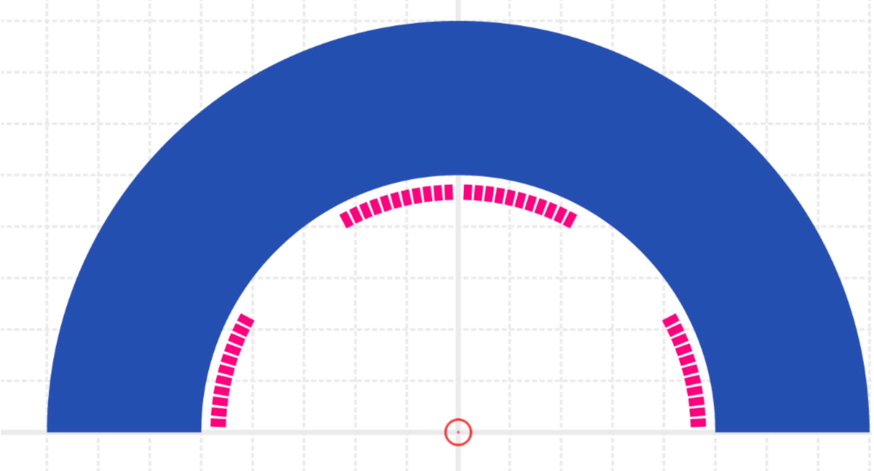


Cos 2θ magnet with a yoke



Maximum field on coil : 2.5 T

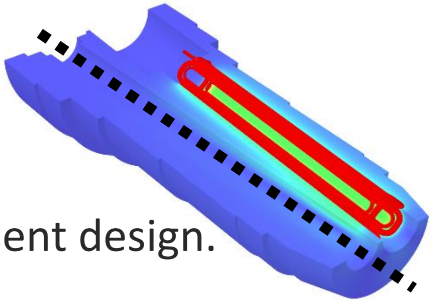
New QC1P parameters	Design value
Field gradient G (T/m)	80
Integrated field GL_eff (T)	26.7
Effective length (mm)	334
Current (A)	1680
Non-Cu J (A/mm2)	3000
Coil inner radius (mm)	22.5
Coil thickness (mm)	<2



Coil and yoke cross section

By Y. Arimoto

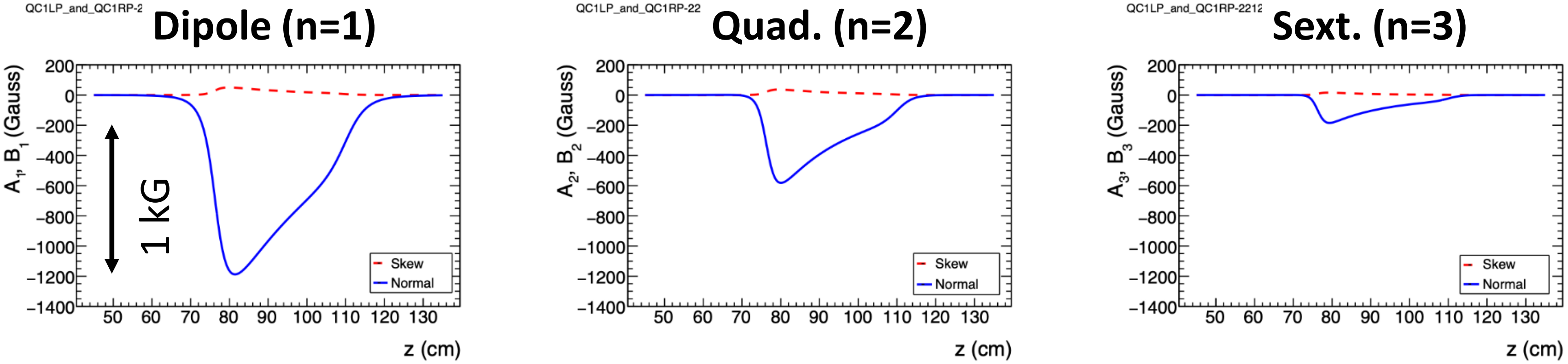
New QC1P magnet



Leak field evaluation

Correctors and cancel coils are used for the field correction of the present design.
We can minimize the leak field with the new QC1P.

Present QC1P (I=1626 A, R_{ref} = 10 mm)

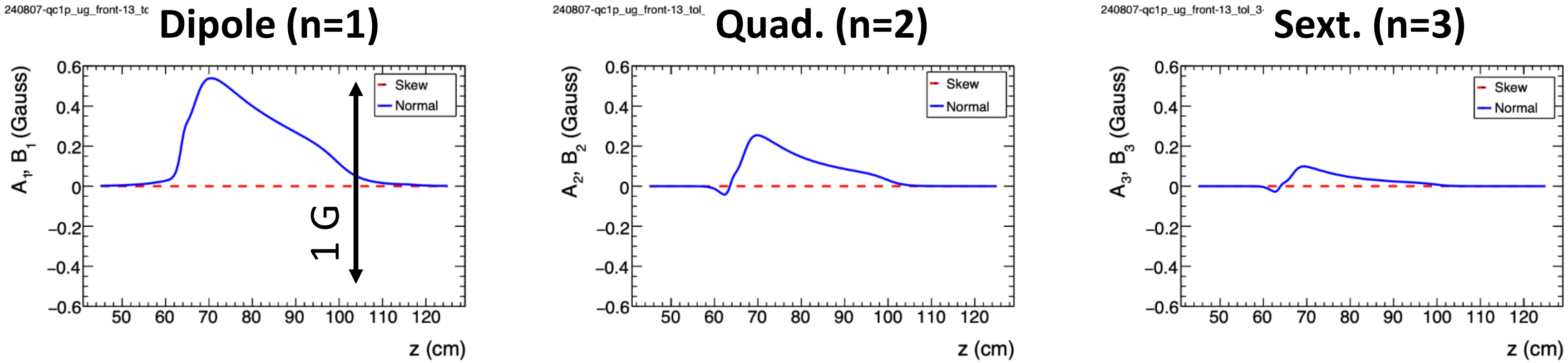


Dipole (n=1)

Quad. (n=2)

Sext. (n=3)

New QC1P (I=1704 A, R_{ref} = 10 mm)



Dipole (n=1)

Quad. (n=2)

Sext. (n=3)

By Y. Arimoto

Technical issues and recent progress

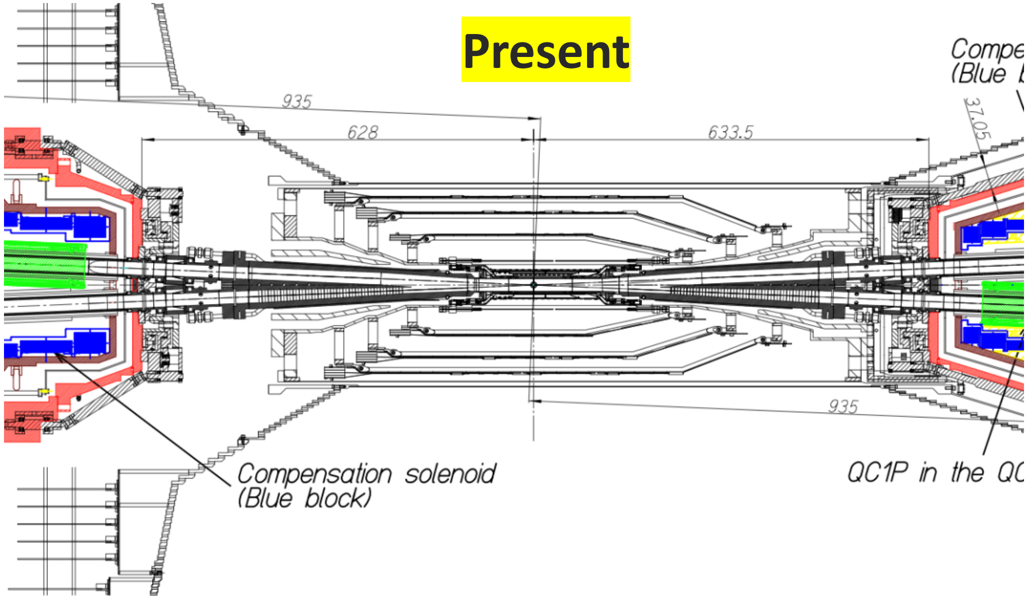
Modifications in the IR region

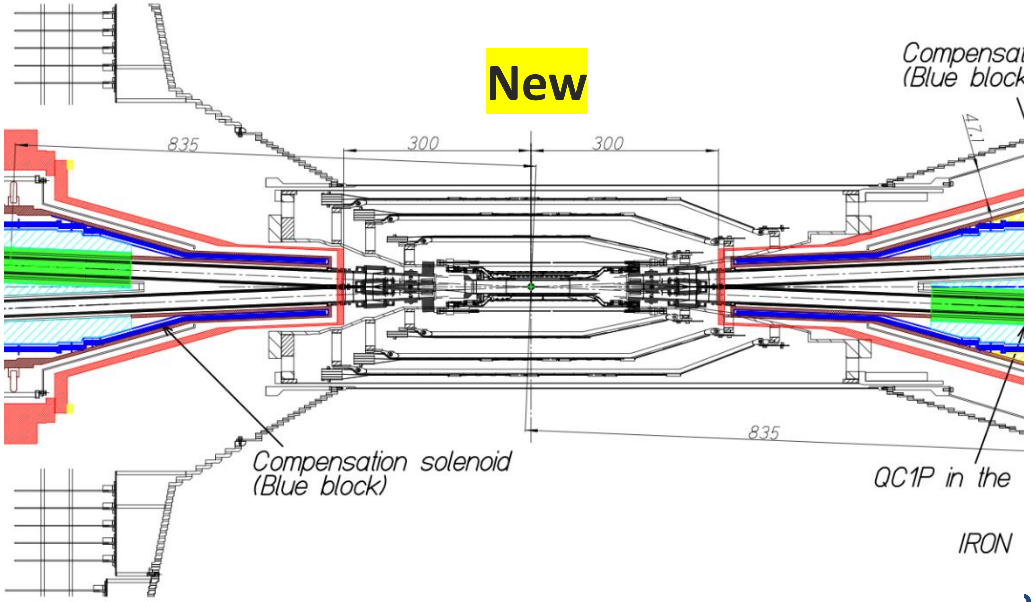
Some parts of the cryostat and Belle II detector interfere on the forward side.

The boundary of the detector must be determined to proceed with the discussion of the IR installation method.

We have started a study group on hardware assembly and installation for IR modifications.

- Magnet group
- Monitor group
- Vacuum group
- Belle II group
- other


Present


New

Technical issues and recent progress

Modifications of QC1P magnet

Nb3Sn wires are brittle and sensitive to strain, and their superconducting properties may change significantly with strain and heat treatment processes.

Manufacturing tolerances in coils and magnets have a significant effect on the field quality.

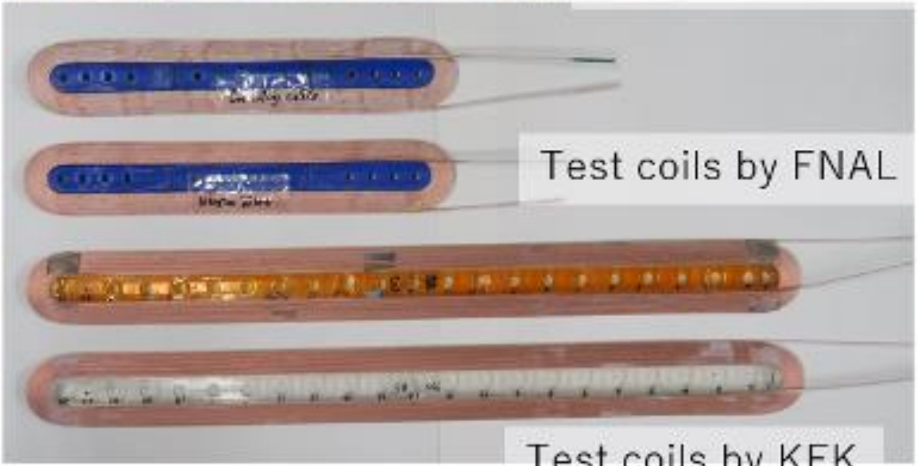
We focus on feasibility testing to determine whether QC1 can be fabricated using Nb3Sn wire.

Research collaboration with FNAL and Furukawa Electric Co., Ltd. And KEK has started.

- Wire test
- Coil winding test
- Quench protection study

etc.

Jigs for winding coil in KEK



Test coils by FNAL

Test coils by KEK

QC1P development schedule

	JFY 2024				JFY 2025				JFY2026				JFY2027			
Design of mirror magnet	🟩	🟩	🟩	🟩												
Procurement of Nb$_3$Sn conductor	🟩	🟩	🟩													
Production of mirror magnet				🟩	🟩	🟩										
Cold test of mirror magnet							🟩									
Design of prototype quad							🟩	🟩								
Production of prototype quad								🟩	🟩	🟩	🟩	🟩	🟩	🟩		
Cold test of prototype quad															🟩	
Final magnet design															🟩	🟩

A series of coil tests are planned over the next few years.

We aim to design and manufacture a prototype magnet starting at the end of JFY2025.

- Excitation tests
- Magnetic field measurements

Summary

- The new IR optics idea was evaluated using a 3D magnetic field profile.
  Longer lifetime is expected.
  Beams go straight through the IP, through the center of the quads.
  Chromatic x-y coupling becomes a lot smaller.
    Luminosity degradation, which arises from IR nonlinearity and beam-beam effects, may be recovered. Further simulation work is necessary.
  Emittance growth from the new IR is expected to become much smaller.

- QC1P and the new compensation solenoid coil must be designed in a more compact manner, which requires the use of Nb3Sn wire.

- Research and development on Nb3Sn magnets is essential for realizing the IR upgrade idea.

- Regular meetings started, to discuss IR hardware assembly and installation issues.
- R&D with KEK Cryogenics Science Center, FNAL and Furukawa Electric Co., Ltd. has begun.