QCS upgrade plan

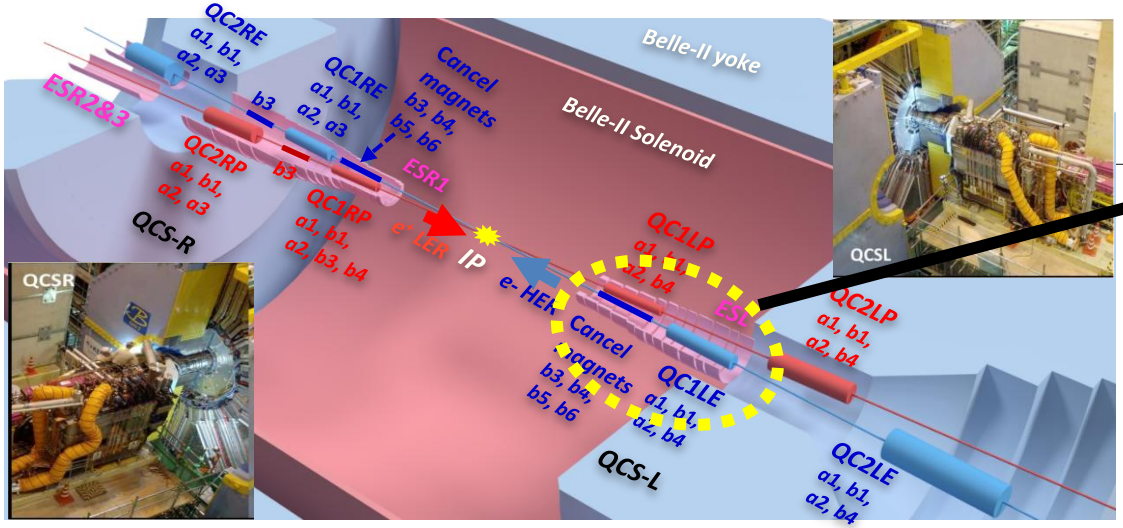
Outline

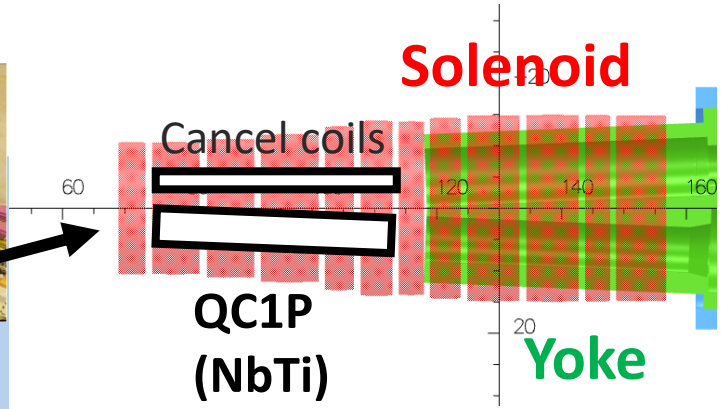
- ✓ Present QCS
- ✓ QCS upgrade plan
- ✓ Magnet R&D progress
- ✓ QCS upgrade schedule
- ✓ Summary

X. Wang

10 Feb. 2026

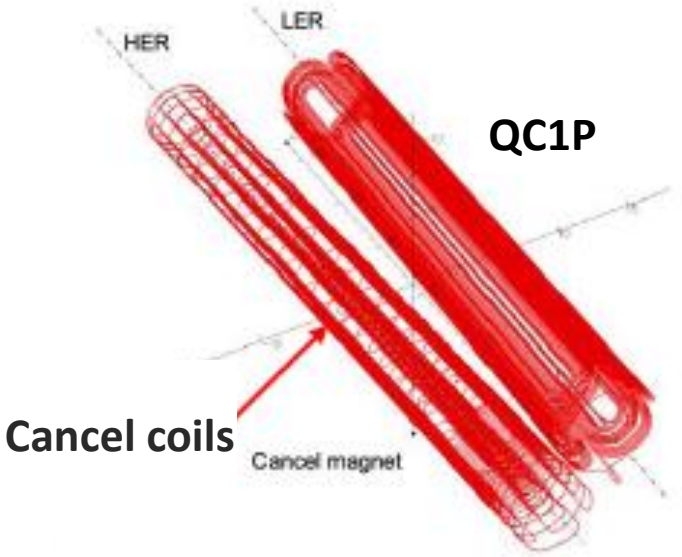
Present QCS



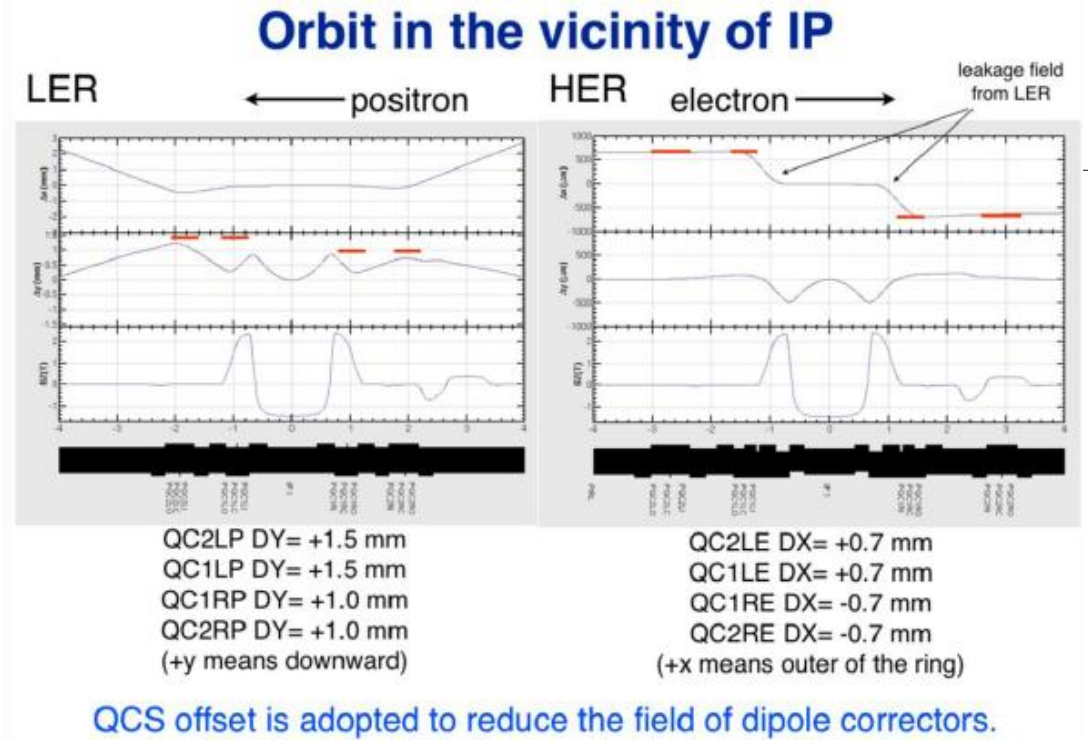


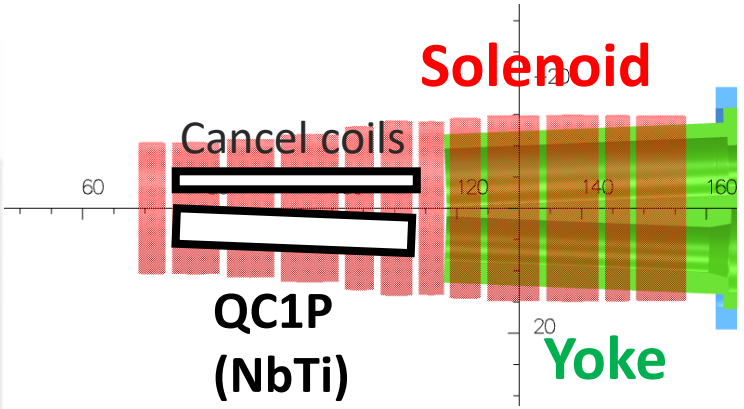
8 quadrupole magnets
35 corrector coils
8 cancel coils
4 compensation solenoids

- Compensating solenoid coils are installed over both beamlines to compensate for the effect of the detector solenoid field (1.5T) on the beam.
- To avoid leakage of the magnetic field to the opposite beamline, all magnets except QC1P are equipped with magnetic shields.
- Cancel coils are provided on the HER beamline to cancel out leak fields from QC1P (and the detector solenoid field), instead of a magnetic shield due to lack of separation space.



Present QCS



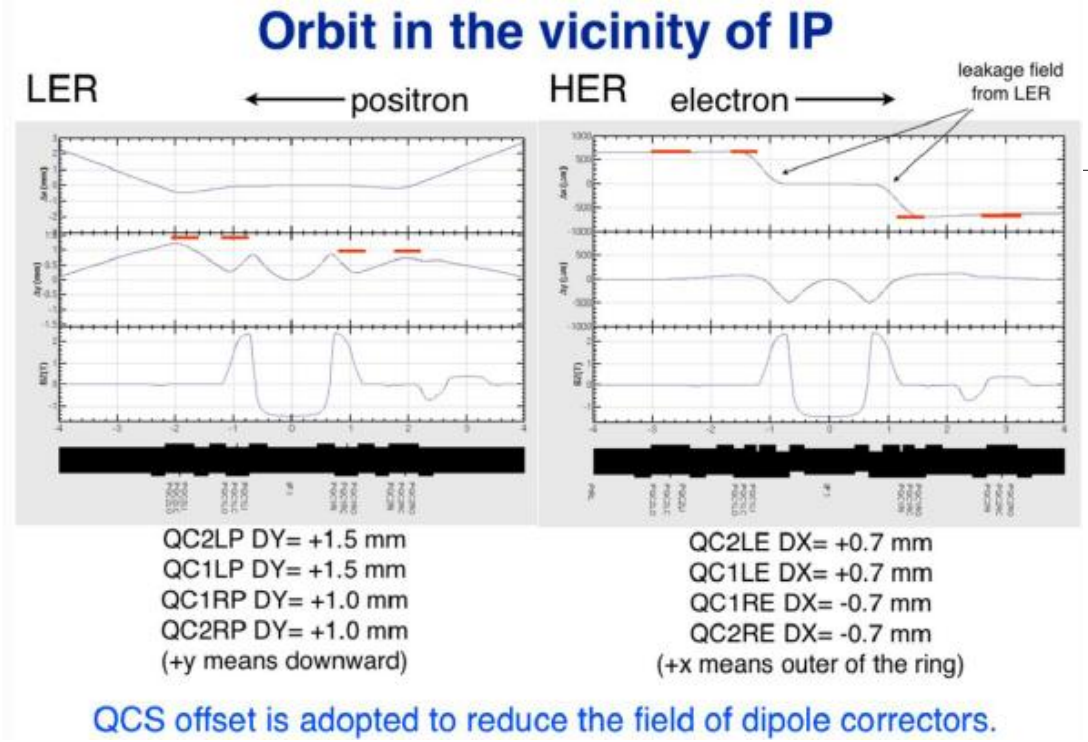


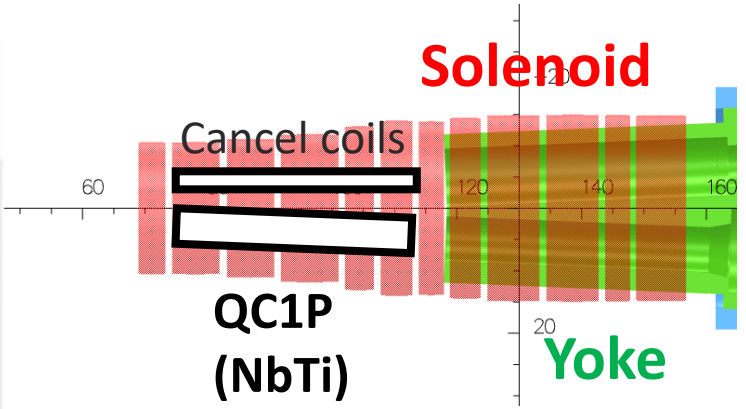
Magnet	Int. field T	Z m	Δx mm	Δy mm	Δθ mrad
QC1LP	22.96	−935	0.0	−1.5	−13.35
QC1RP	22.96	935	0.0	−1.0	7.204
QC2LP	11.48	−1925	0.0	−1.5	−3.725
QC2RP	11.54	1925	0.0	−1.0	−2.114
QC1LE	26.94	−1410	0.7	0.0	0.0
QC1RE	25.39	1410	−0.7	0.0	0.0
QC2LE	15.27	−2700	0.7	0.0	0.0
QC2RE	13.04	2925	−0.7	0.0	0.0

In present IR design, the quadrupole magnets are exposed to the solenoidal field.
The global effect of the detector solenoid is compensated for by the compensation solenoids.

- The local rotation of the orbit plane due to the solenoid field, the quadrupole magnets on the LER side is set to a rotation angle of 10 mrad or more.
- The LER, where the vertical orbit is greatly meandering due to the detector solenoid and compensation solenoid. The vertical offset of QC1P and QC2P is set to 1.0, 1.5mm.
- The HER is subject to horizontal trajectory changes due to the leakage magnetic field from QC1P, and QC1E and QC2E have a ±700μm horizontal offset.

Present QCS





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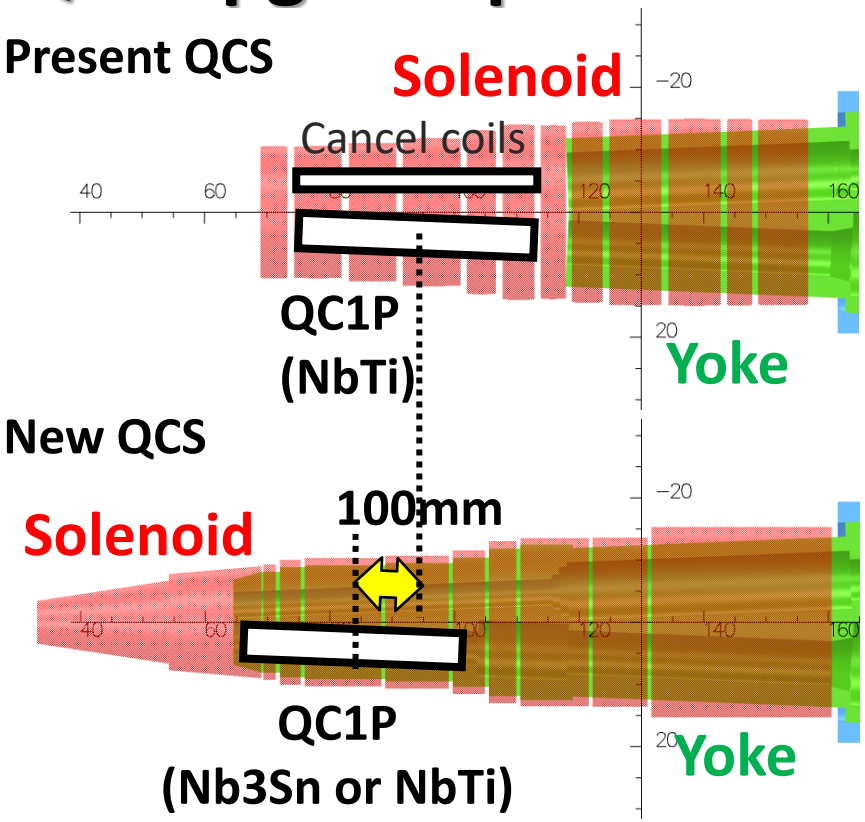
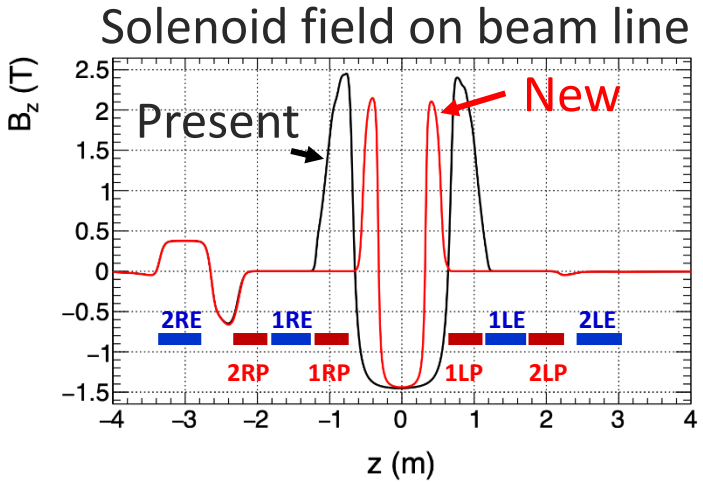
Large chromatic aberration arises from the present QCS.

- Chromatic x-y coupling correction is required for both HER and LER.
- LER chromatic x-y coupling is larger than in HER because the solenoid magnetic field between IP and QC1P is not canceled.
- Tilting sextupole magnets are used for chromatic x-y coupling correction.

QCS upgrade plan





A compensation solenoid is added in front of QC1P on the IP side.
The QC1P is covered by the yoke.

⇒ Much smaller chromatic x-y coupling
⇒ Reduction in the emittance growth from the IR
⇒ Straight orbit through the IP
⇒ No need to place QC magnets with offsets/rolls
⇒ No need for the 8 cancel coils

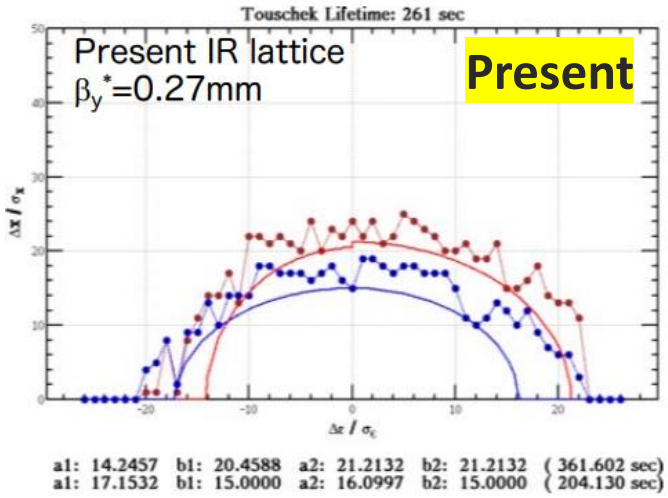
The QC1P can be installed in its current position or placed closer to the IP by 100mm.

Moving QC1P closer to the IP by 100mm

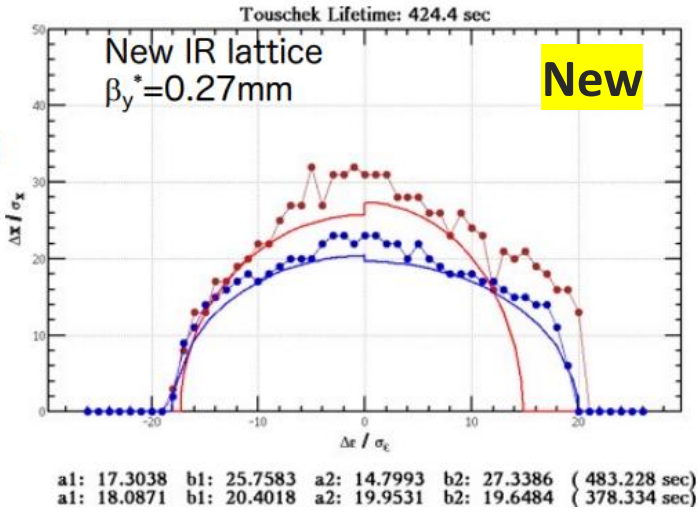
⇒ Larger dynamic aperture
⇒ Longer beam lifetime

Comparison of present and new IR designs

The dynamic aperture is expected to be improved.
By relocating the QC1P 100mm closer to the IP, Touschek lifetime increases from 261 seconds to 424 seconds.



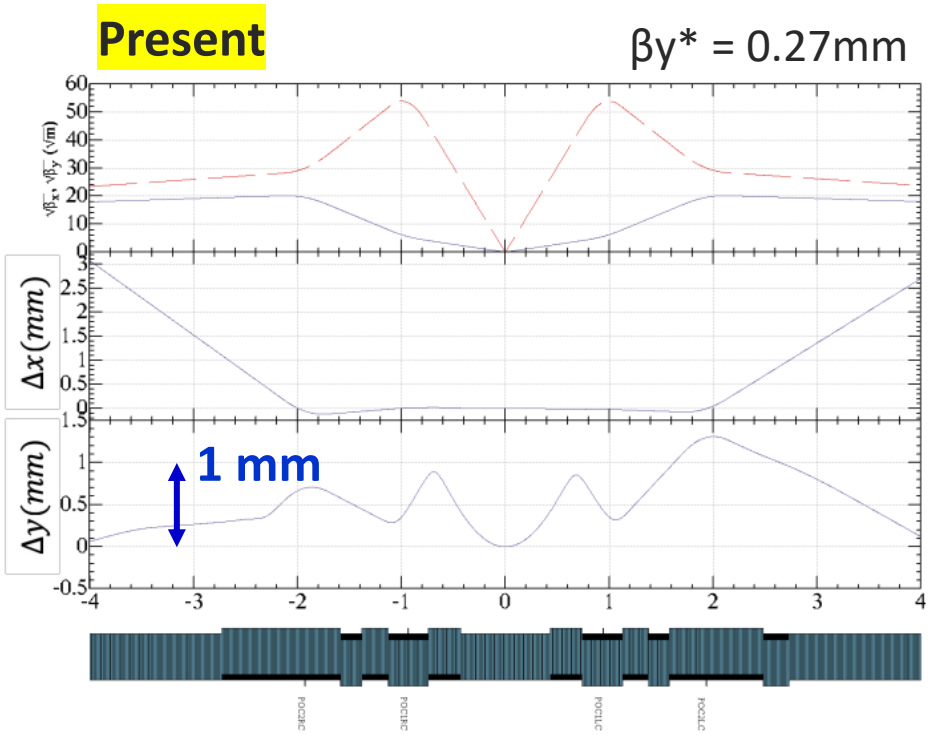
Touschek lifetime from ~260 s to ~420 s.

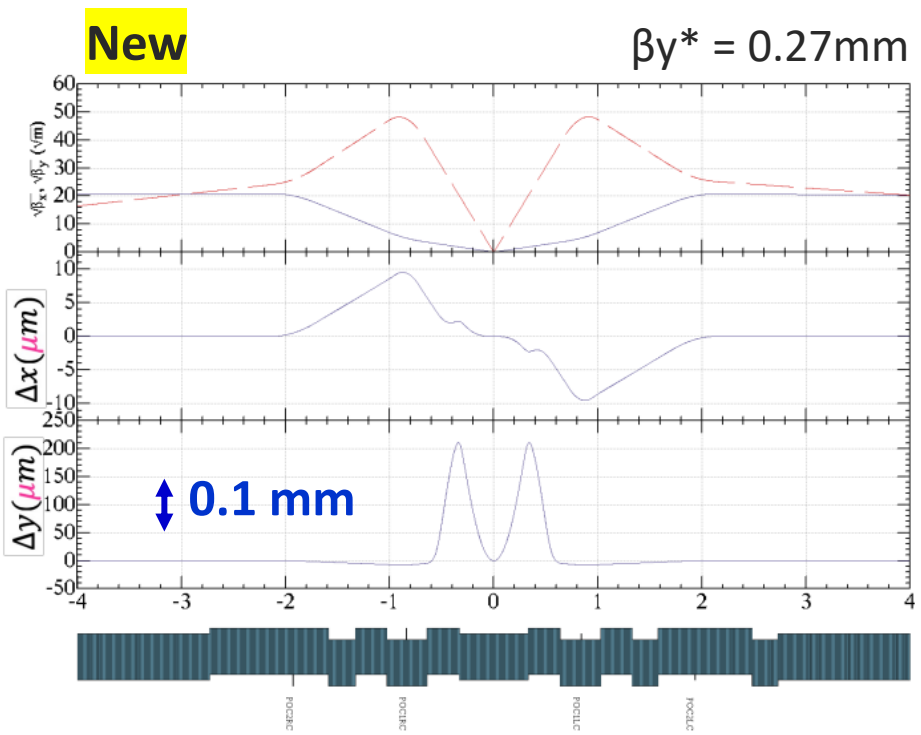


The chromatic X–Y coupling parameters becomes a few orders of magnitude smaller.

	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}	$+5.5\times10^{-3}$

Comparison of present and new IR designs





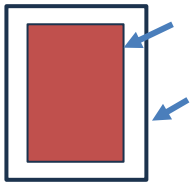
- The orbit displacement with new IR lattice is ~10 um at QC1s, while it is about 1 mm with the present lattice.
- The vertical emittance from the new IR was calculated to be 14 fm, which is negligible.

Magnet R&D progress

Compensation solenoid

Preliminary design using the present NbTi wire

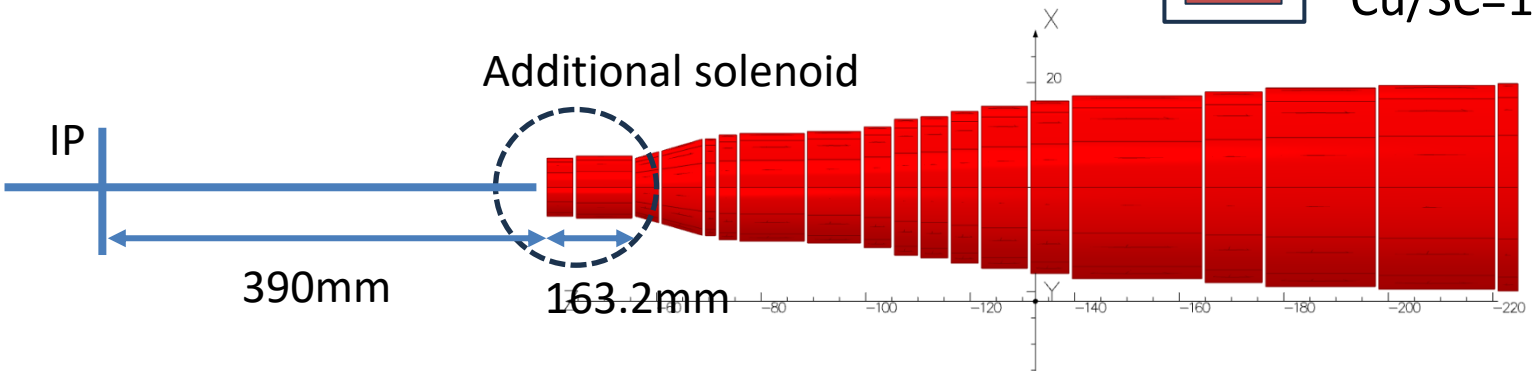
NbTi wire

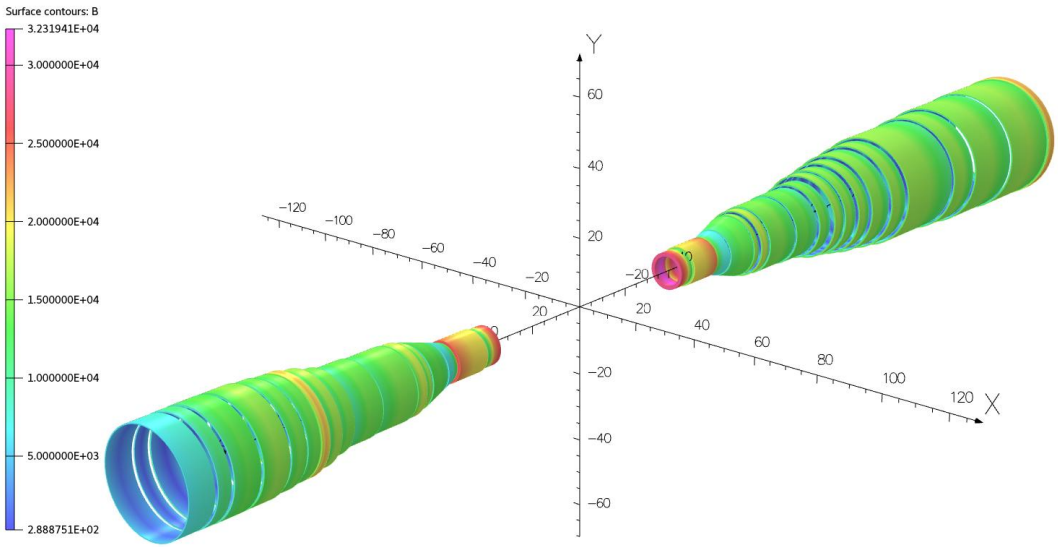


0.932 × 1.384mm

1.025 × 1.487mm

Cu/SC=1.7



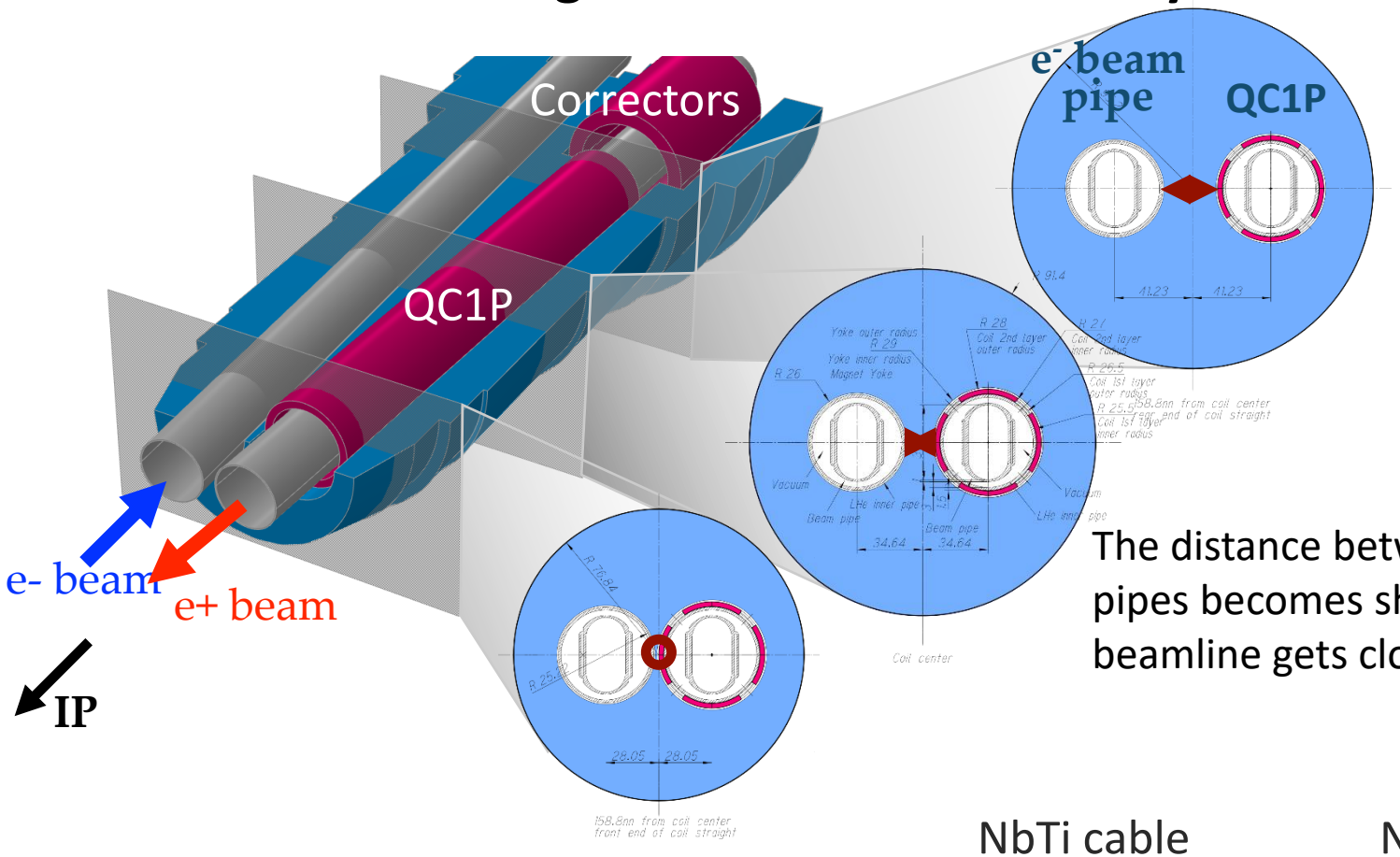


	Present ESL/ESR1	Additional solenoid (Front side)
Iop (A)	390/450	600
J (A/mm2)	257/296	395
Bmax (T) on coil	3.5/3.1	3.3
Load line ratio	0.56	0.60

Magnet R&D progress

QC1P

Moving QC1P closer to the IP by 100mm

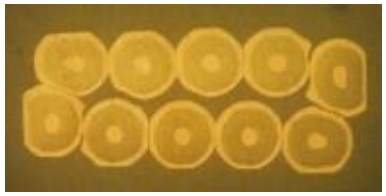


The distance between the beam pipes becomes shorter as the beamline gets closer to the IP.

The space on the IP side is limited.
There are two options for LTS materials:

- NbTi cable or wire
- Nb3Sn wire

NbTi cable

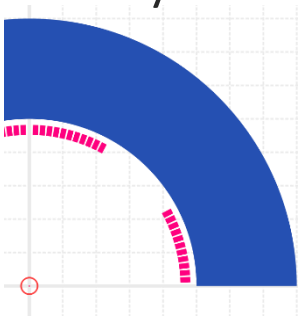


Nb3Sn wire

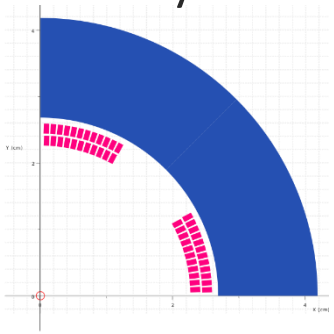
Magnet R&D progress

QC1P

One layer coil

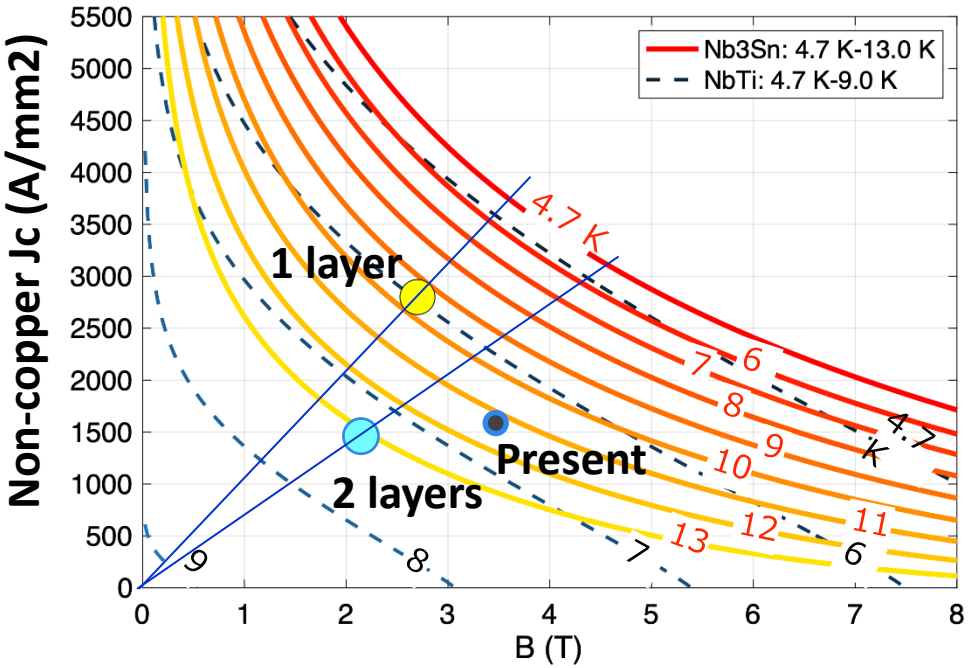


Two layers coil



	Nb3Sn		NbTi	
100mm closer to IP	yes	yes	yes	no (Present)
# of layer	1	2	2	2
Temp. margin	4K	8K	2.5K	2K
Bmax on coil	2.8T	2.2T	2.2T	3.5T
Load line ratio	0.80	0.50	0.51	0.58

Top = 4.7 K



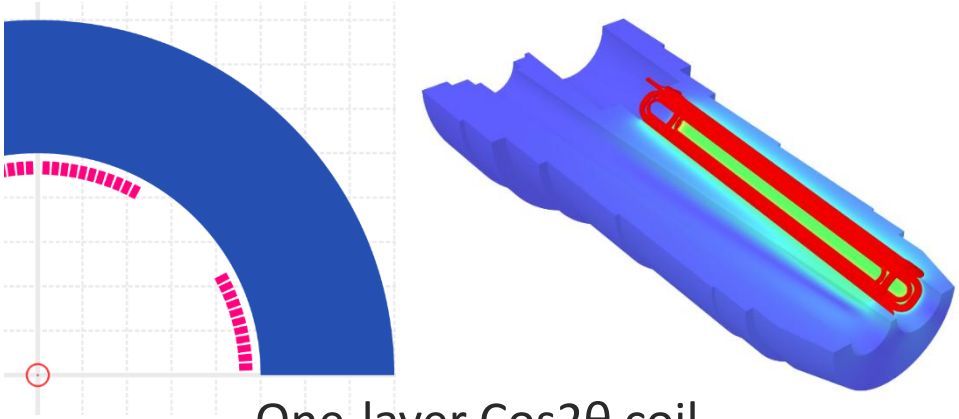
Not only Nb3Sn but also NbTi has been considered for the QC1P coils. The Nb3Sn coil offers a higher temperature margin.

- 1-layer Nb3Sn coil
- 2-layers Nb3Sn coil
  Lower current density
  Higher temperature margin
- 2-layers NbTi coil
  Present position or closer to IP

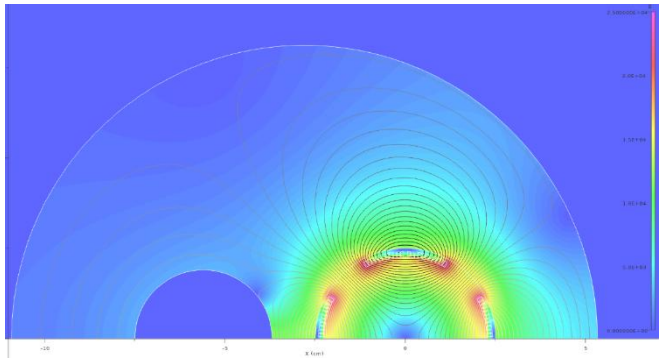
Magnet R&D progress

QC1P

Field profile of a 1-layer configuration



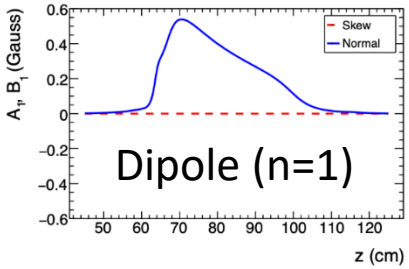
One-layer Cos2θ coil

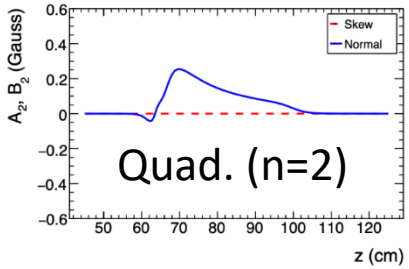


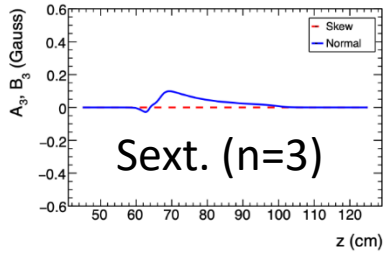
Maximum field on coil : 2.5 T

Parameters	Values
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

Leak field on HER





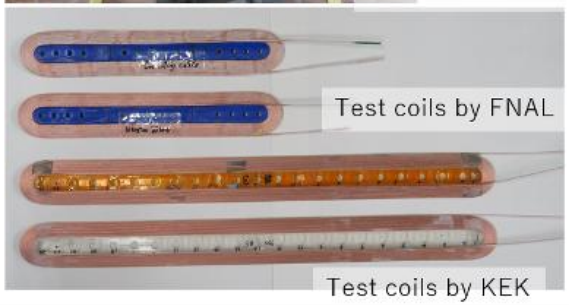


New configuration keeps the leak field small, no need for the cancel coils.

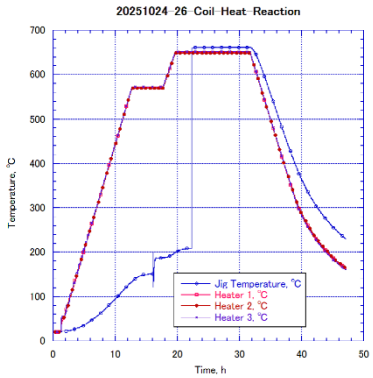
Magnet R&D progress

Prototype Nb3Sn coil

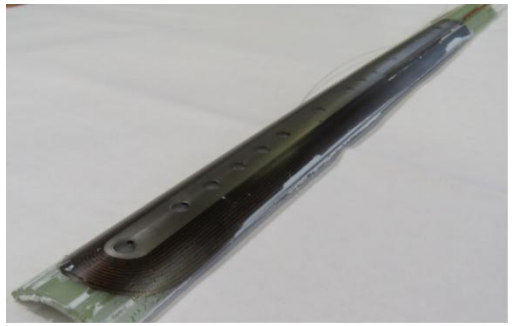
Winding

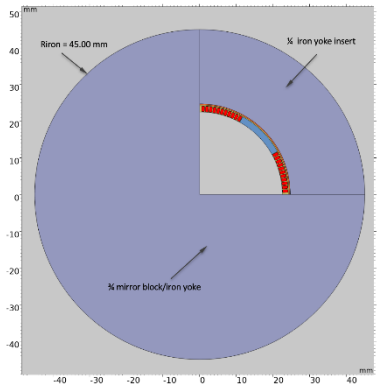


Heat-reaction



Splice and Epoxy impregnation

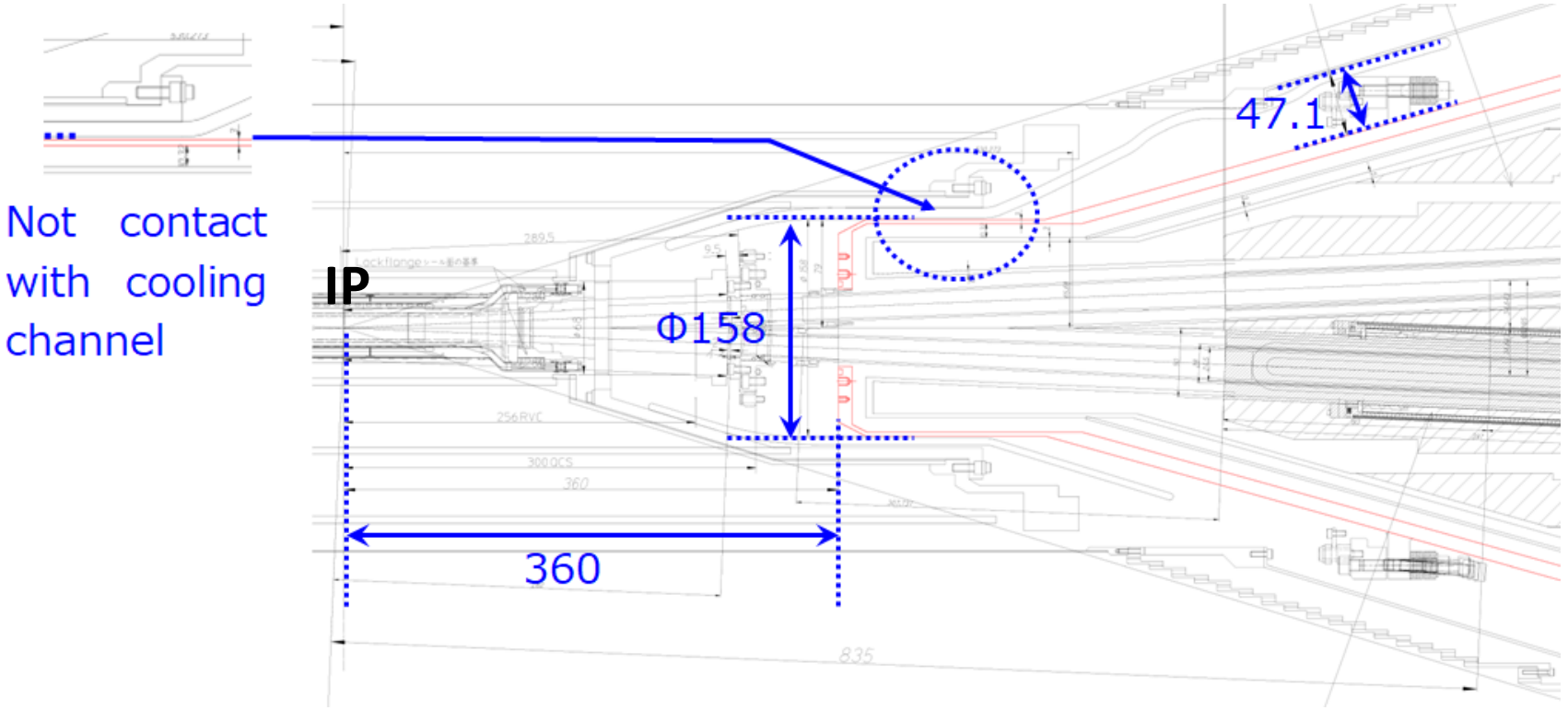




Next work

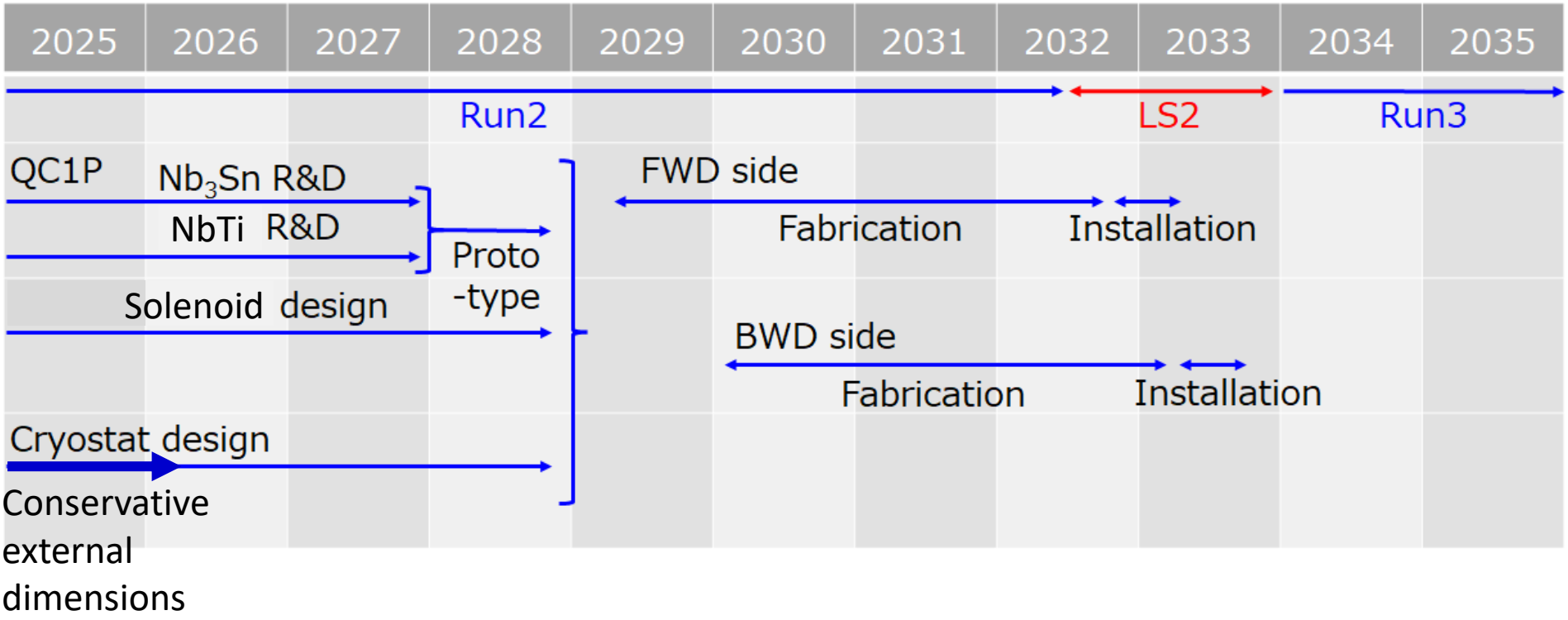
- Construction of mirror magnet and excitation test

Conservative external dimensions of QCS cryostat



- IR optimization requires modifications to the Belle II detector, focusing on the QCS–Belle II interface.
- Monthly technical meetings with Belle II members are ongoing.
- The conservative design assumes that the compensation solenoid will be added in front of the QC1P and that the QC1P will be 100 mm closer to the IP.

QCS upgrade schedule



- This is a tentative schedule.
- The QCS upgrade plan will be finalized by the end of fiscal year 2027.

Summary

Present QCS

- The quadrupole magnets are exposed to the solenoidal field. The global effect of the detector solenoid is compensated for by the compensation solenoids. The quadrupole magnets on the LER side have a rotation, The QC1P and QC2P have a vertical offset, and the QC1E and QC2E have a horizontal offset.

QCS upgrade plan

- A compensation solenoid is added in front of QC1P on the IP side. The QC1P is covered by the yoke.
  ⇒ Much smaller chromatic x-y coupling, reduction in the emittance growth from the IR, straight orbit through the IP, no need to place QC magnets with offsets/rolls, and no need for the 8 cancel coils.
- Moving QC1P closer to the IP by 100mm
  ⇒ Larger dynamic aperture and longer beam lifetime
- Preliminary design of the compensation solenoid and QC1P is presented.
- Prototype Nb3Sn coil R&D is underway.
  The next step is to make a mirror magnet and perform the excitation test.
- The QCS upgrade plan will be finalized by the end of fiscal year 2027.