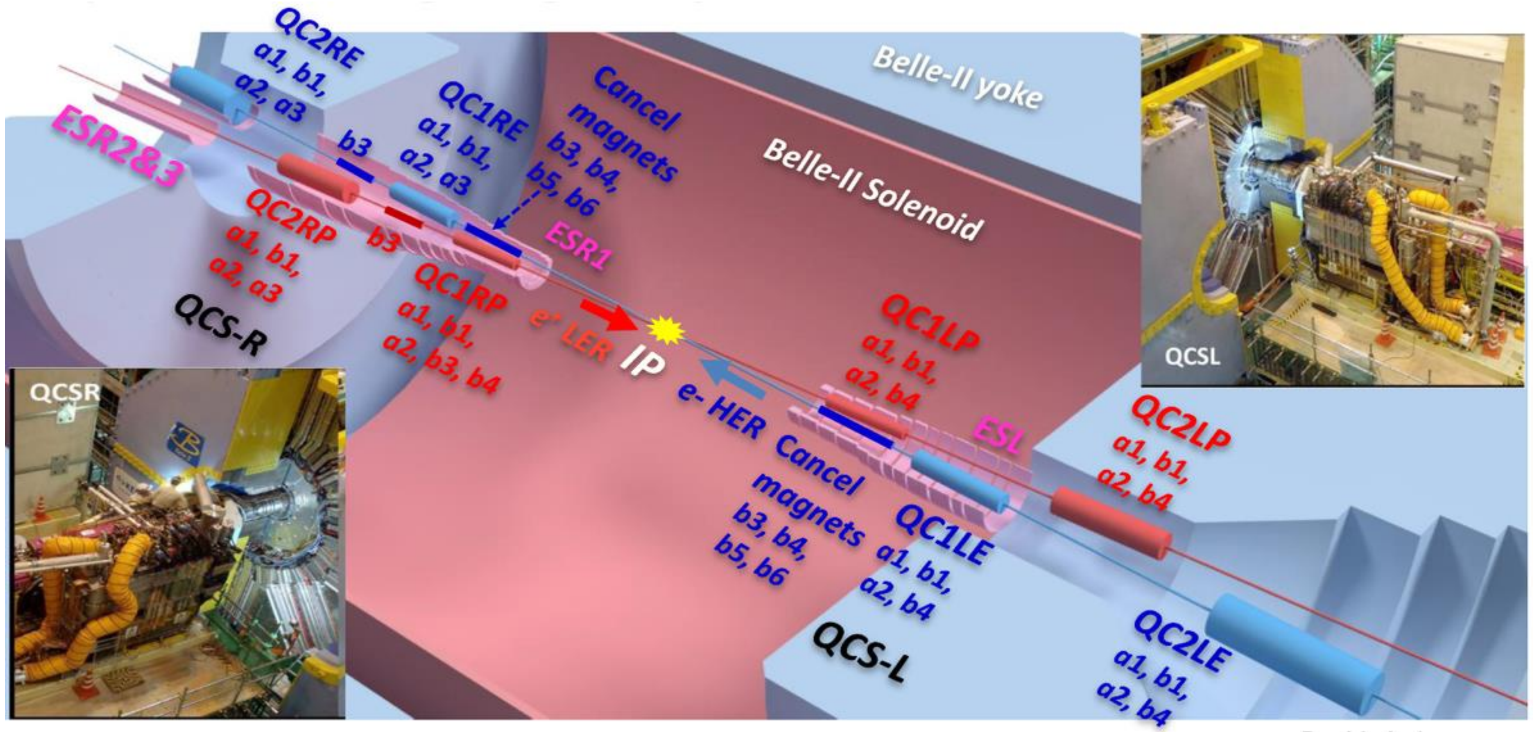
New QCS

Status report

Contents

1. Present IR and New IR

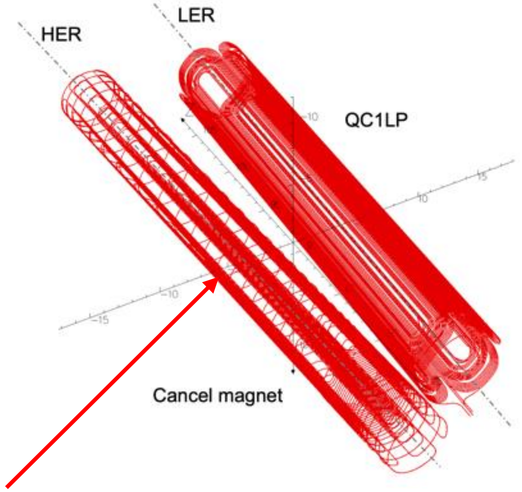
The HER and LER beamlines are installed @ a 41.5 mrad crossing angle to the detector solenoid axis



Compensation solenoid coils (ESL, ESR1, ESR2&3) are installed over both beamlines to compensate for the effect of the detector solenoid field (1.5T) on the beam.

55 superconducting magnets (NbTi)

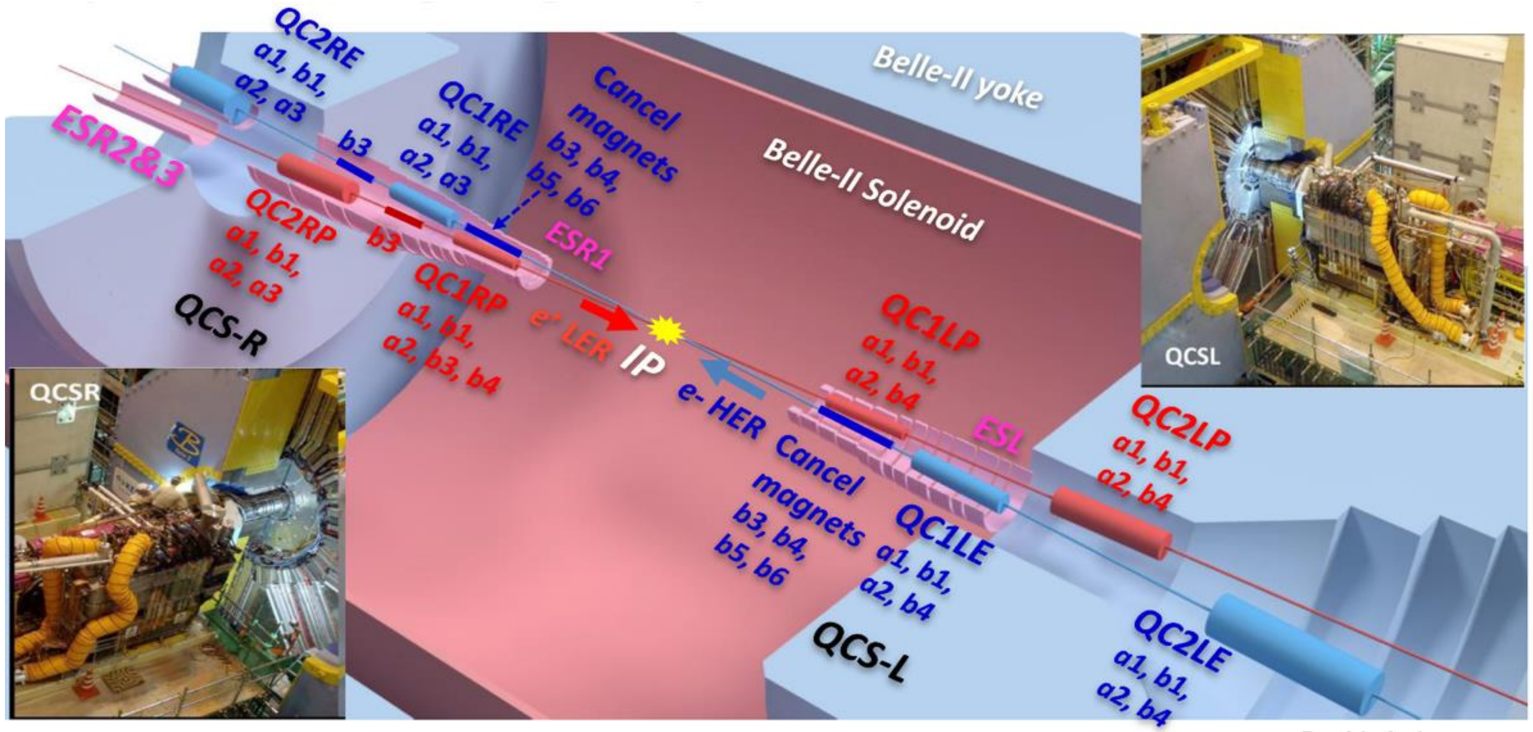
- 8 quadrupole magnets (QC1s, QC2s)
- 35 corrector magnets
- 8 magnets for canceling the leak field
- 4 compensation solenoid coils



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 IR

The HER and LER beamlines are installed @ a 41.5 mrad crossing angle to the detector solenoid axis



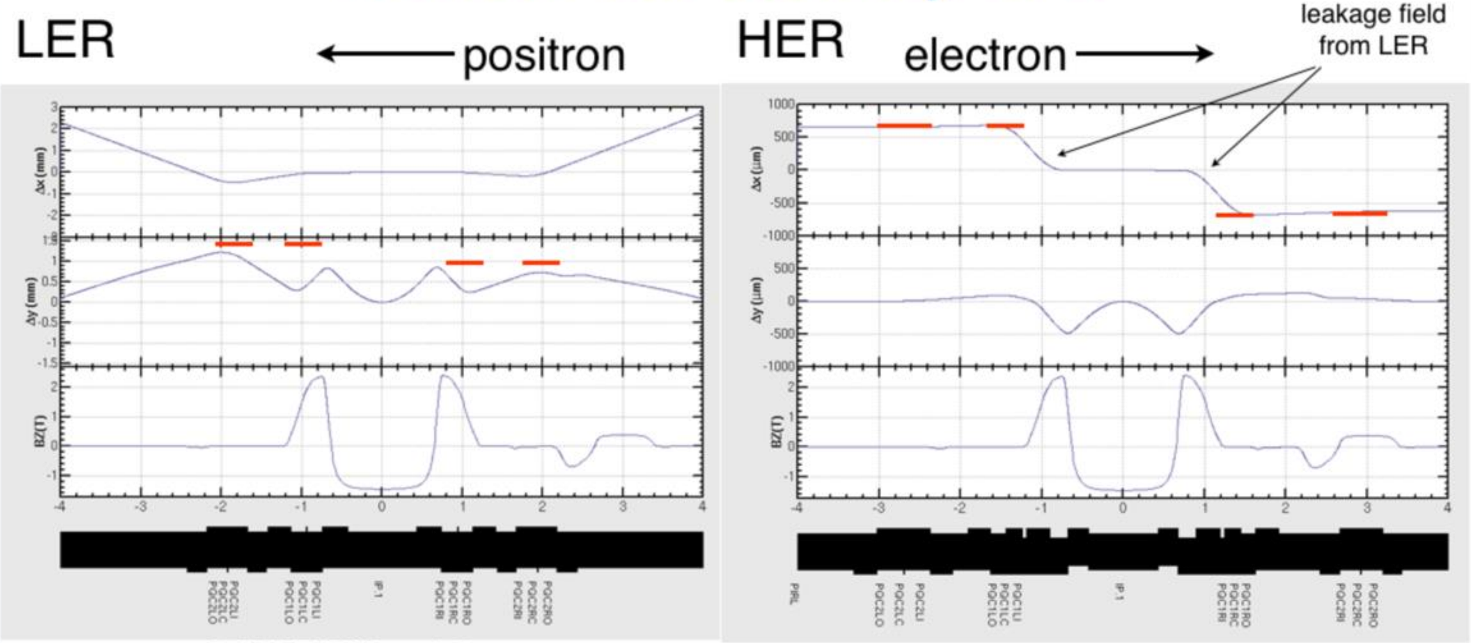
In present IR design, the quadrupole magnets are exposed to the detector solenoidal field.

- The global effect of the detector solenoid is compensated for by the compensation solenoid.
- The local rotation of the orbit plane due to the solenoid field, the QC1 magnet on the LER side is set to a rotation angle of 10 ~mrad.

- 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.

- HER, is subject to horizontal trajectory changes due to the leakage magnetic field from QC1P, and QC1E and QC2E have a ±700 μm horizontal offset.

Orbit in the vicinity of IP



QC2LP DY= +1.5 mm
QC1LP DY= +1.5 mm
QC1RP DY= +1.0 mm
QC2RP DY= +1.0 mm
(+y means downward)

QC2LE DX= +0.7 mm
QC1LE DX= +0.7 mm
QC1RE DX= -0.7 mm
QC2RE DX= -0.7 mm
(+x means outer of the ring)

QCS offset is adopted to reduce the field of dipole correctors.

3

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Large chromatic aberration arises from the present IR

- 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.

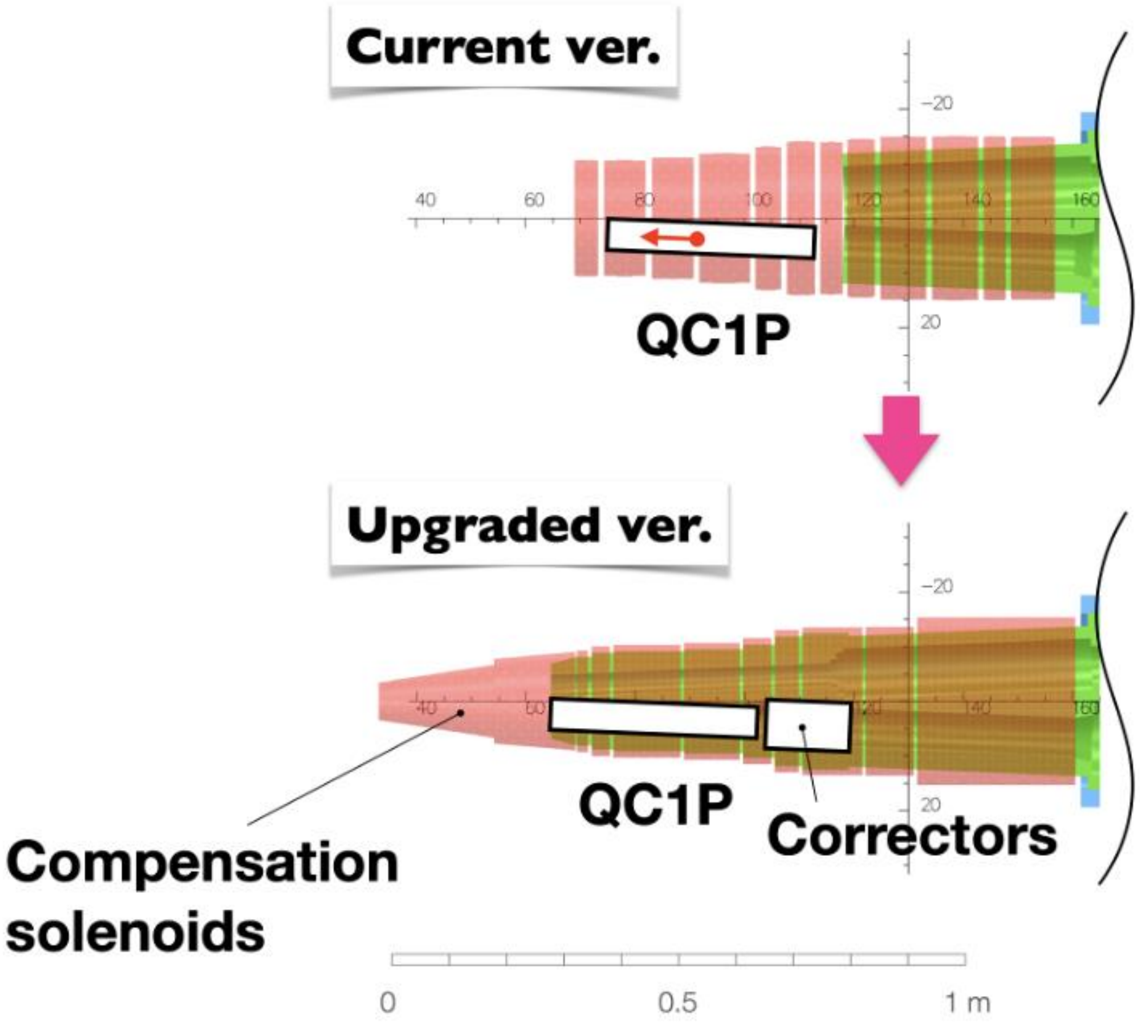
→Tilting sextupole magnets are used for chromatic x-y coupling correction

The degree of correction depends on the measurement accuracy of optical parameters, reproducibility of magnetic fields, etc.

→IR that does not require such large optics correction

Y. Arimoto

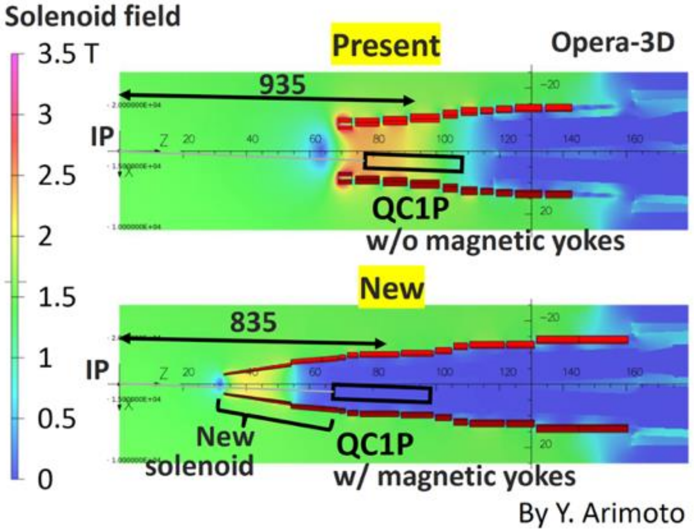
QCS-R and QCS-L



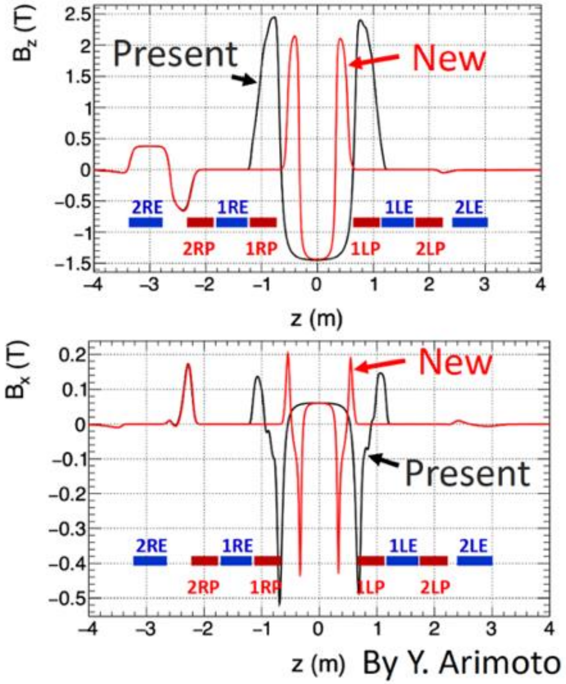
New IR

- Move QC1P closer to the IP by 100mm
  - Larger dynamic aperture
  - Longer beam lifetime
- Install a compensation solenoid coil between the IP and QC1P
  - 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
- To realize this, QC1P needs to be made with thin coils

NbTi→Nb_3Sn cable

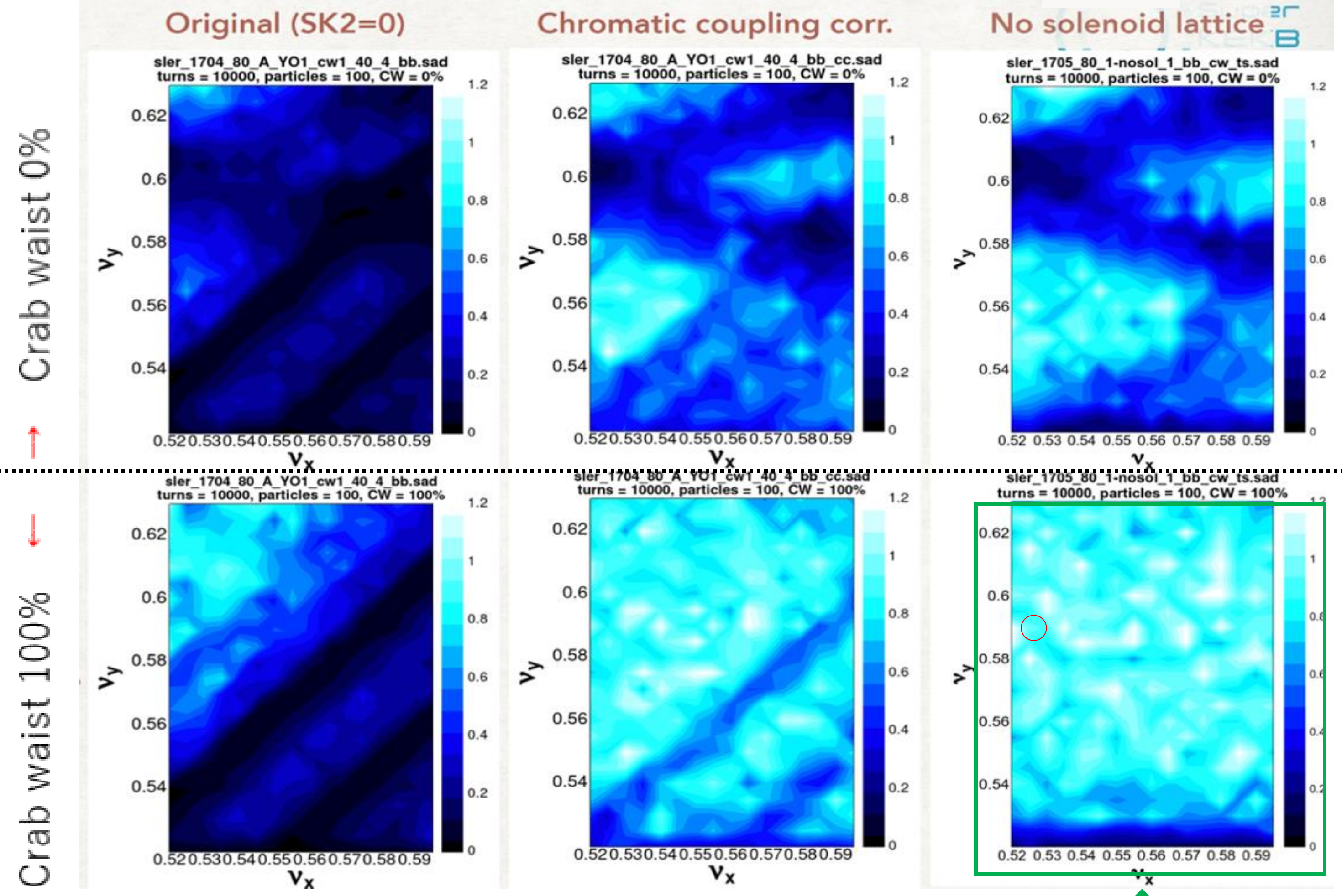


Solenoid field on beam line



Specific luminosity

K. Oide

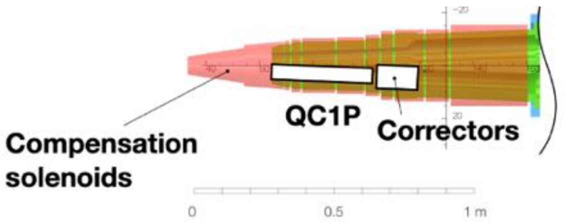


Aiming for this

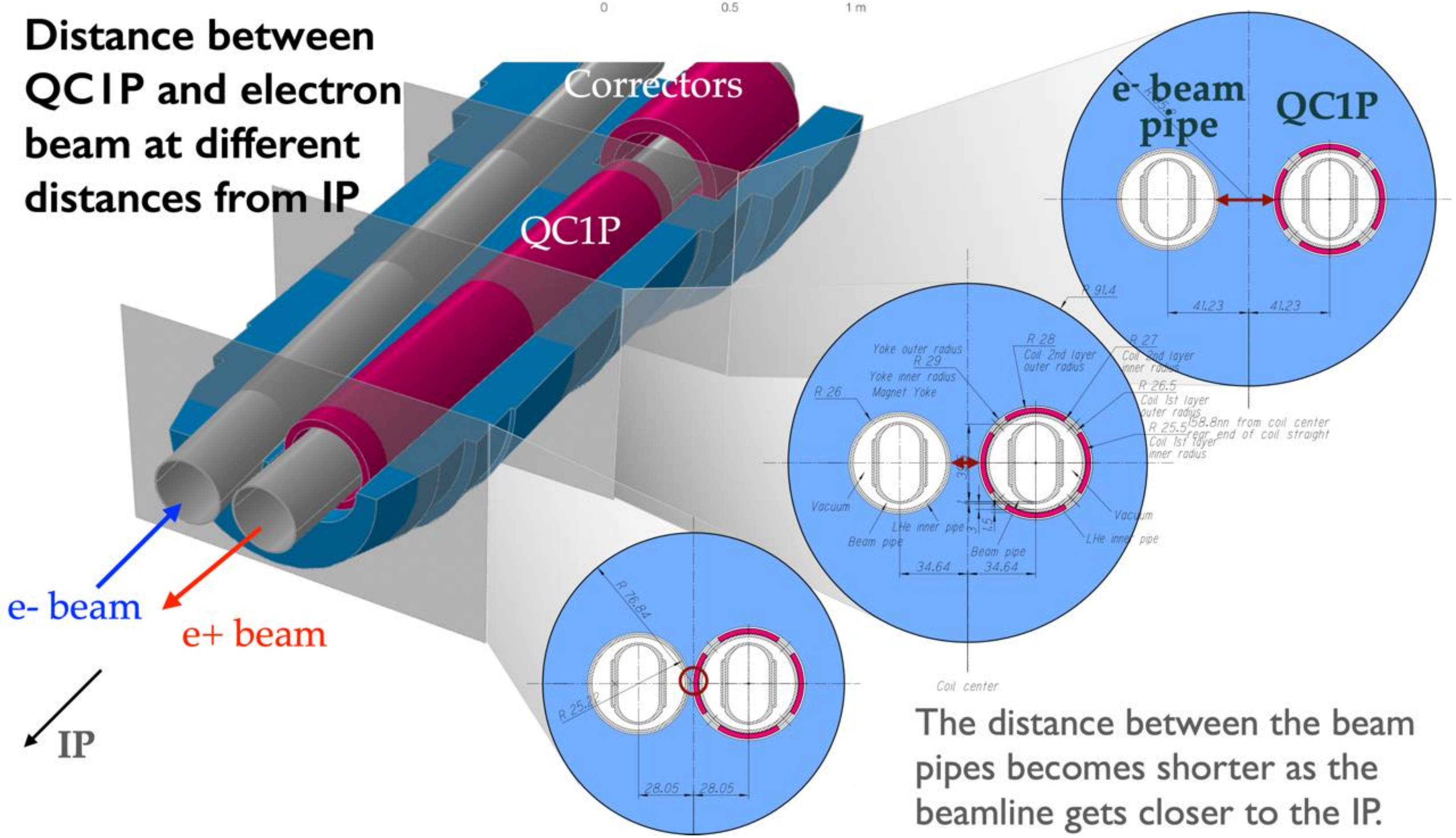
Peak luminosity 5.1 x10^{34} ($cm^{-2}s^{-1}$), Dec. 27, Owl, 2024

Tunes (x/y)	44.525 / 46.589	45.531 / 43.599

New IR



Distance between QC1P and electron beam at different distances from IP



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

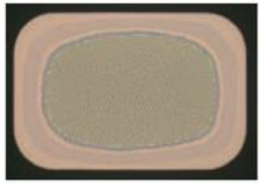
Y. Arimoto @ARC Dec. 2024

Requirements for the conductor

- Limited space
  - Thin coil
  - Large packing factor
  - Higher current density
- Against quench
  - Larger temperature margin
- Flux creep
  - Smaller filament size

Nb_3Sn

Example of commercial conductor



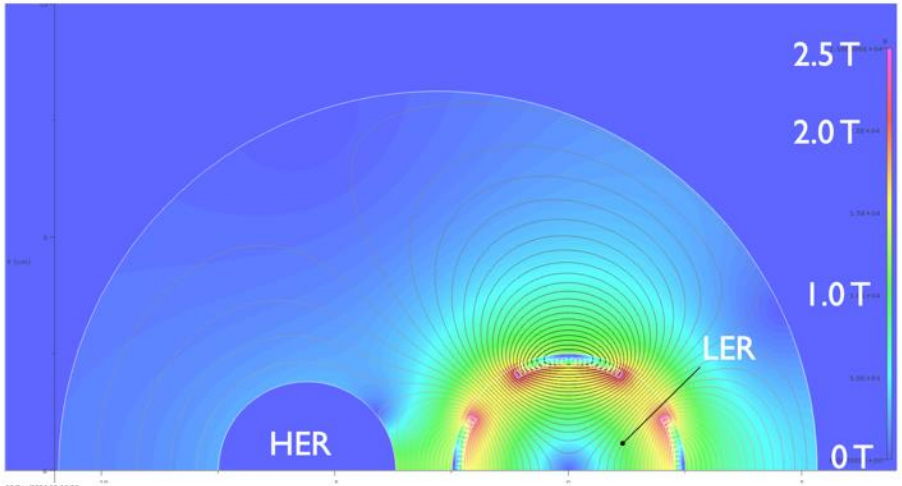
1.13 mm x 1.7 mm →0.8 mm x 1.5 mm

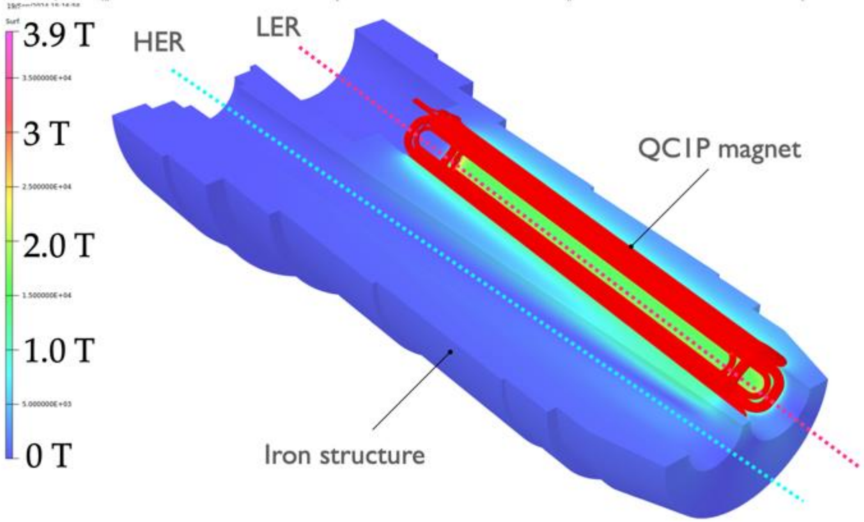
Filament size: 3.2 μm → $2.3\mu m$

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

Magnet and iron structure

- QC1P is located in iron structure.
- The iron structure has functions as follows,
  - Increase field gradient,
  - Shield a leak field to HER
  - Shield the Belle II solenoid field with combination of the compensation solenoids
  - Reduce a peak B-field at conductor





Parameters of upgrade QC1P

Parameters	Values
G: B-Field Gradient	80 T/m
GL: G-Integral	26.7 T
L: Effective length	334 mm
Current	1680 A
J (Non-Cu)	< 3000 A/mm^2
Inner radius of coil	22.5 mm
Coil thickness	< 2 mm
T_c@B=2.5 T	> 8.7 K*
Relative multipole error	< 1x10^{-4}

* Assuming temperature margin of 4 K at operating temperature of 4.7 K

- The present HER beam line is "protected" from the QC1P leak field, by the cancel coils instead of iron shield.
- New configuration keeps the leak field small, no need for the cancel coils.

Why we need R&D on Nb_3Sn QC1 magnet

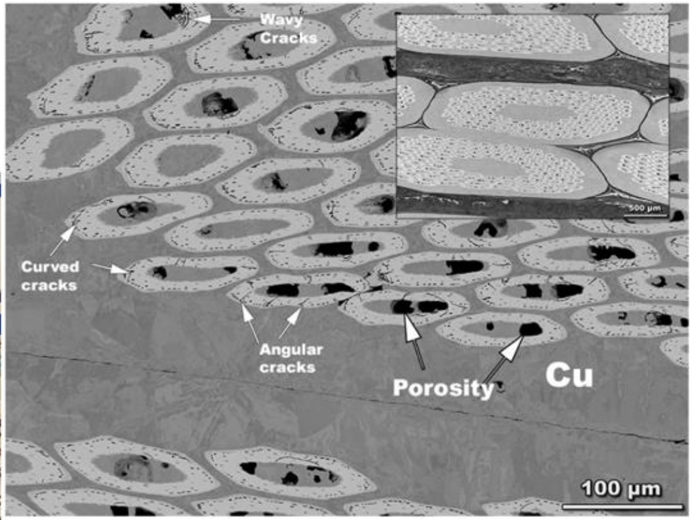
HiLumi News: 7.2-m-long niobium–tin quadrupole magnet manufactured at CERN reaches nominal current for the first time

The 7.2-metre-long version of this vital HL-LHC component reached nominal current plus an operational margin corresponding to a coil peak field of 11.5 T at 1.9 K during a test in SM18

25 JANUARY, 2023

The MQXFBP3 magnet after the test, during assembly with the nested dipole orbit corrector. (Image: CERN)

https://home.cern/news/news/accelerators/hilumi-news-72-m-long-niobium-tin-quadrupole-magnet-manufactured-cern



Metallographic analysis of 11 T dipole coils for High Luminosity-Large Hadron Collider (HL-LHC)

To cite this article: Shreyas Balachandran *et al* 2021 *Supercond. Sci. Technol.* **34** 025001

Our QC1P faces similar challenges as large HiLumi magnets.
On the other hand, quite different challenges.

- Much smaller than any other Nb_3Sn accelerator magnets. Handling of such brittle cable is tougher for small coils.
- Operating in the lower magnetic field environment than LHC.
- QC1P filament size < 5 μm, much smaller than LHC filament (~50 μm).
  - To prevent quenches from flux jump and to reduce long-term field drift.

2. QC1P R&D Progress

This work is supported by KEK and also by
U.S.-Japan Science and Technology Cooperation
Program in High Energy Physics

- Practice winding with CuNi cable done.
- Nb_3Sn conductor delivered in February.
- First test winding with Nb_3Sn just finished (on Feb.28th)
  - Some measurements will follow

Next slide

- Preparing to measure mechanical property of Nb_3Sn conductor, time dependence of magnetization at KEK
- Quench protection design is underway (KEK cryogenic center)

The shape and size of each jig has reasons, and experience is important in its design.

In fact, the shape of the one jig piece was fine-tuned based on FNAL engineer's opinion, and things went well.

QC1P R&D progress

New!

Nb_3Sn cable delivered to KEK, 1st test coil wound on Feb.28, 2025

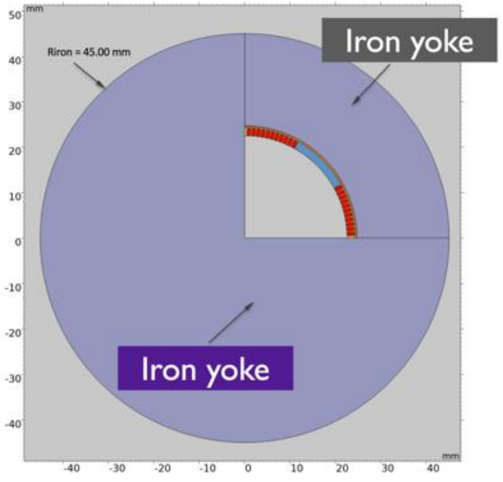
HiLumi Nb_3Sn 7.2 m dipole

Schedule

Y. Arimoto @ARC Dec. 2024

	JFY 2024	JFY 2025	JFY2026	JFY2027
Design of mirror magnet				
Procurement of Nb_3Sn conductor		Review		
Production of mirror magnet		Review		
Cold test of mirror magnet			Review	
Design of prototype quad				
Production of prototype quad				Review
Cold test of prototype quad				
Final magnet design*				

Mirror magnet



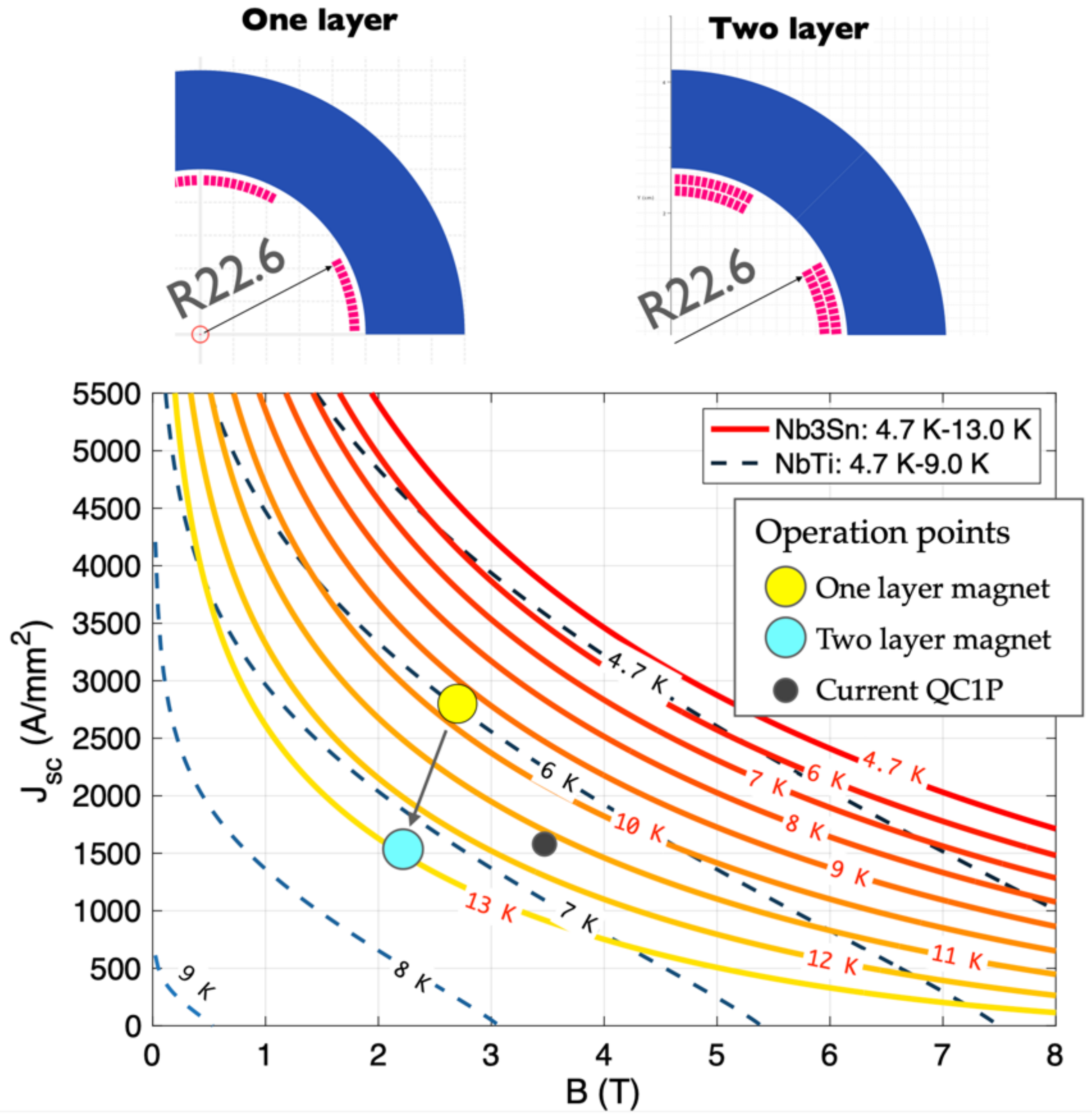
by Vadim Kashikhin (FNAL)

Mirror magnet

- Design work is underway, with single layer configuration.
- Mechanical, thermal, magnetic properties will be checked.

Two-layer option

Y. Arimoto@ARC



Nb3Sn 1 layer →2 layer
- Lower current density
- Larger temperature margin
- Better control of higher order multipoles

No experiences with such thin Nb_3Sn coil manufacture

Insulation during heat treatment and epoxy impregnation issues need to be solved.

	New QC1P		New QC1P		Present QC1P
	Nb_3Sn		NbTi		
# of layer	1	2	1	2	2
Temp. margin	4K	8K	1K	2.5K	2K

NbTi cable becomes a candidate
- No major technical problems
- We have experiences
- Temp. margin not that much larger than the present QC1P.

3. Summary

3. Summary

- The present and new IR design, compared.
- QC1P R&D progress is presented.
    - First test coil with Nb_3Sn
- Schedule up to fabrication of a mirror magnet is presented.
- Continue to develop QC1P with Nb_3Sn cables.

Note: IR upgrade is just one of many items, such as

- Injector upgrade
- Injection efficiency and stability improvement
- Emittance blowup suppression in the BT
- Higher stored beam currents (additional RF)
- others

backup

Parameter comparison
SuperKEKB↔FCCee

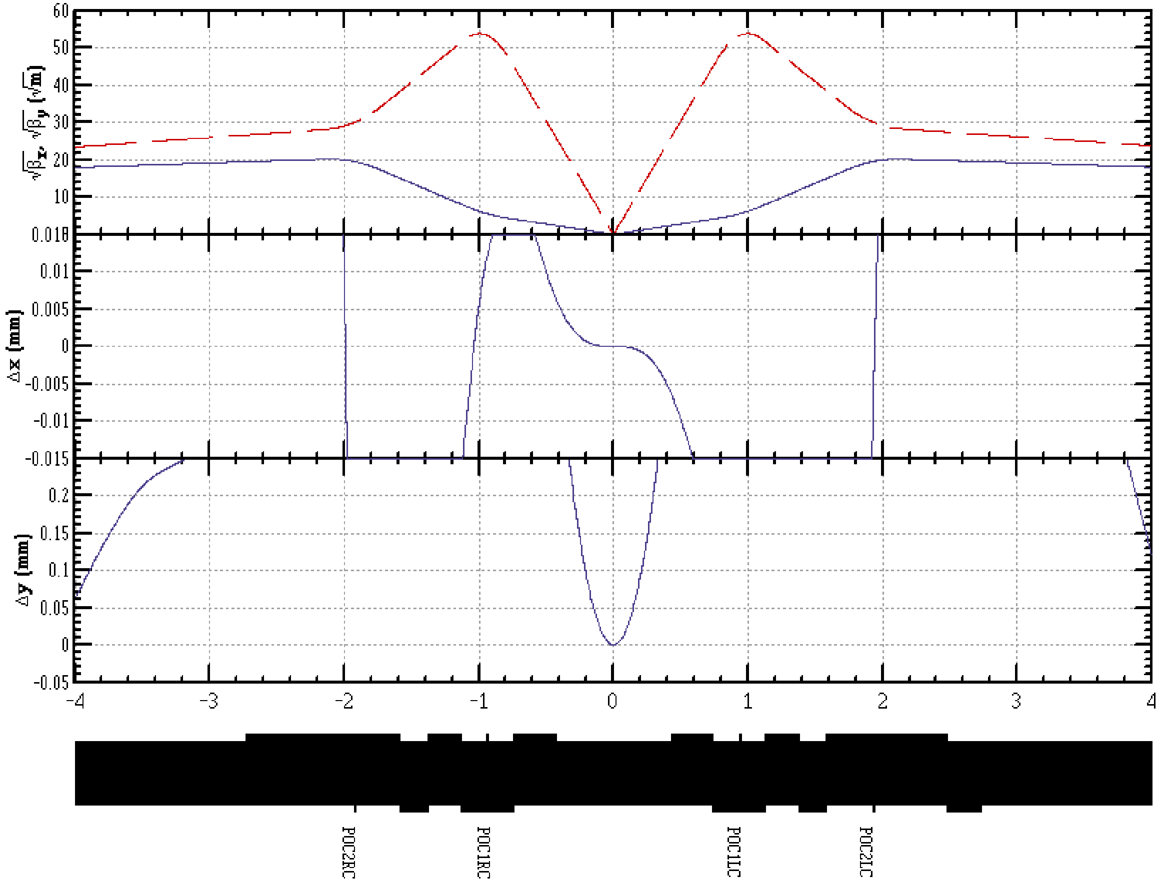
	SuperKEKB#	FCCee (Z)##
Circumference (km)	3.016	97.756
Solenoid field at IP (T)	1.5	2.0
Beam energy (GeV)	4.0(e^+)/7.0(e^-)	45.6/45.6
Full crossing angle at IP (mrad)	83	30
Horizontal emittance ϵ_x (nm)	3.2/4.6	0.27
Vertical emittance ϵ_y (pm)	8.6/12.9	1.0
Horizontal beta β_x (mm)	32/25	150
Vertical beta β_y (mm)	0.27/0.3	0.8

#J. Particle Accelerator Society of Japan, Vol. 15, No. 4, 2018

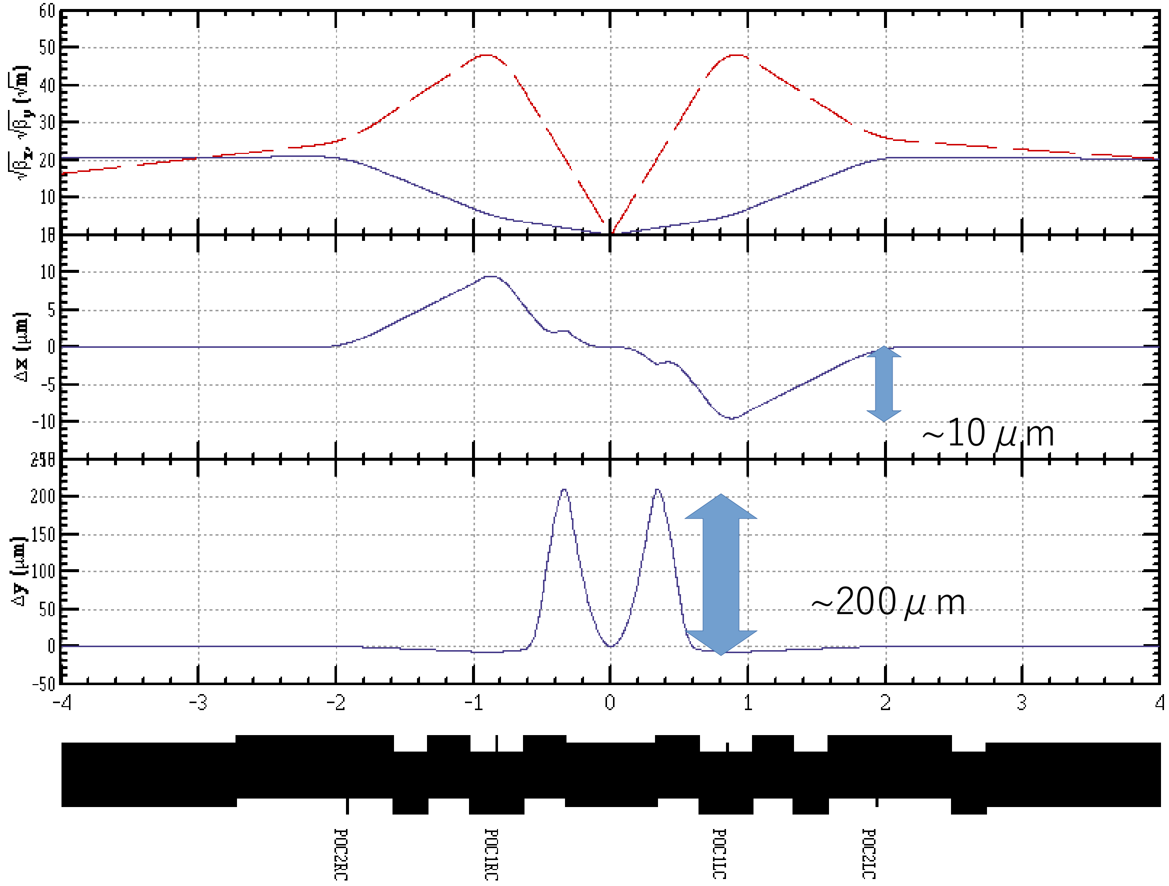
##Lepton Collider (FCC-ee) Baseline V1.0 Parameters (30 June 2020)
https://twiki.cern.ch/twiki/bin/view/FCC/FCCeeParameters_CDRBaseline-1_0

IR Orbit comparison

When set to the same scale



"sler_1704"
The current IR (design lattice)



"V21-r0g0"
New IR

A. Morita

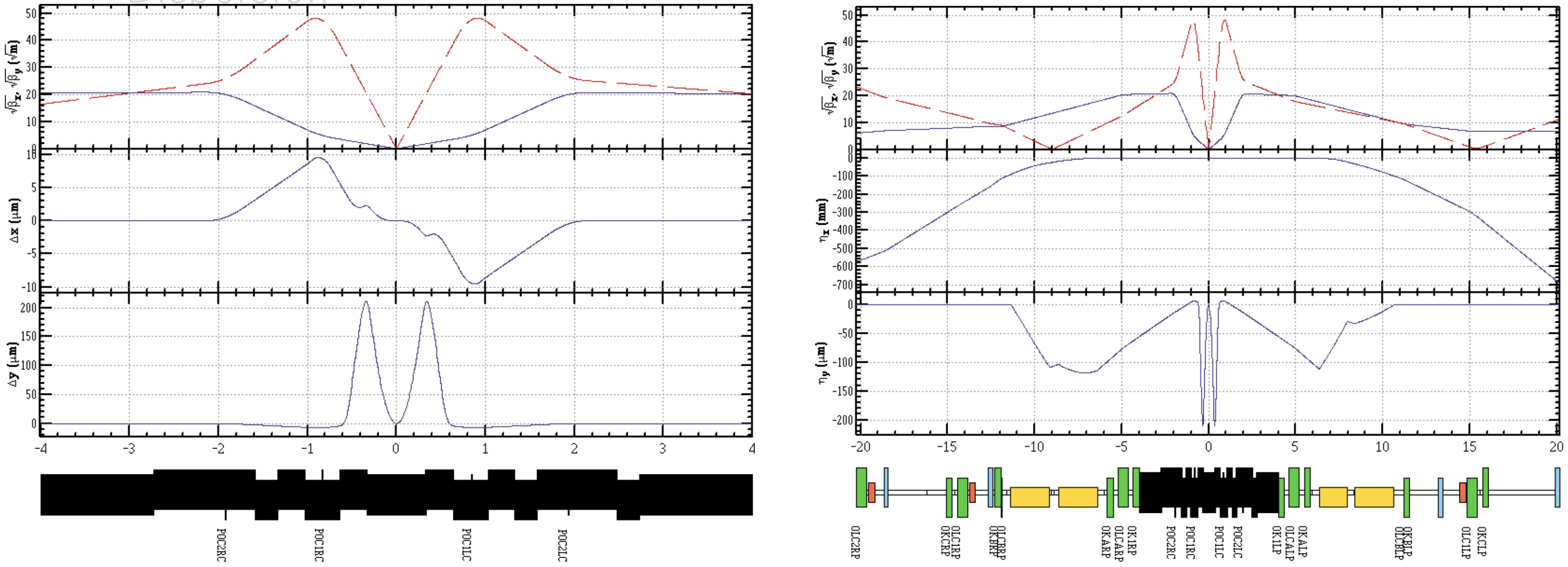
- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

	Lattice	回転六極	∂R1/∂δ	∂R2/∂δ	∂R3/∂δ	∂R4/∂δ
935 mm	sler_1704	ON	-8.888×10^{-3}	$+4.012\times10^{-3}$	$-4.963\times10^{+1}$	+2.939
	sler_1704	OFF	-2.274	-1.011×10^{-2}	$-4.226\times10^{+2}$	$-6.058\times10^{+2}$
835 mm	V21-r0g0	ON	$+2.318\times10^{-5}$	-5.991×10^{-6}	-4.390×10^{-2}	$+5.509\times10^{-3}$
	V21-r0g0	OFF	$+1.059\times10^{-1}$	$+2.835\times10^{-4}$	+8.145	$+2.571\times10^{+1}$

Chromatic coupling improves with new IR (QC1P@835mm)

A. Morita

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion



```
Design momentum        P0 = 4.0000000 GeV Revolution freq.      f0 = 99333.385 Hz
Energy loss per turn U0 = 1.7605072 MV  Effective voltage     Vc = 9.4123078 MV
Equilibrium position dz = 17.641387 mm  Momentum compact. alpha = 3.2061E-4
Orbit dilation          dl = 8.5922670 mm  Effective harmonic #  h = 5122.9481
Bucket height       dV/P0 =  .0256922

  Imag.tune: 0.0000000           0.0000000           0.0000000
  Real tune:-0.4669097          -0.4300851          -0.0245815

    Damping per one revolution:
          X : -2.200631E-04    Y : -2.200379E-04    Z : -4.399110E-04
    Damping time (sec):
          X :  4.574646E-02    Y :  4.575170E-02    Z :  2.288442E-02
    Tune shift due to radiation:
          X :  2.714858E-06    Y :  3.562791E-06    Z :  8.049892E-07
    Damping partition number:
          X :    1.0003        Y :    1.0002        Z :    1.9996

Emittance X               = 1.90575E-9 m   Emittance Y              = 1.1393E-14 m
Emittance Z               = 3.54412E-6 m   Energy spread            = 7.53011E-4
Bunch length              = 4.70673080 mm  Beam tilt                = -4.8121E-9 rad
Beam size xi              =  .00780495 mm  Beam size eta            = 1.75297E-6 mm
```

Contribution from
the new IR is several tens of femtometer

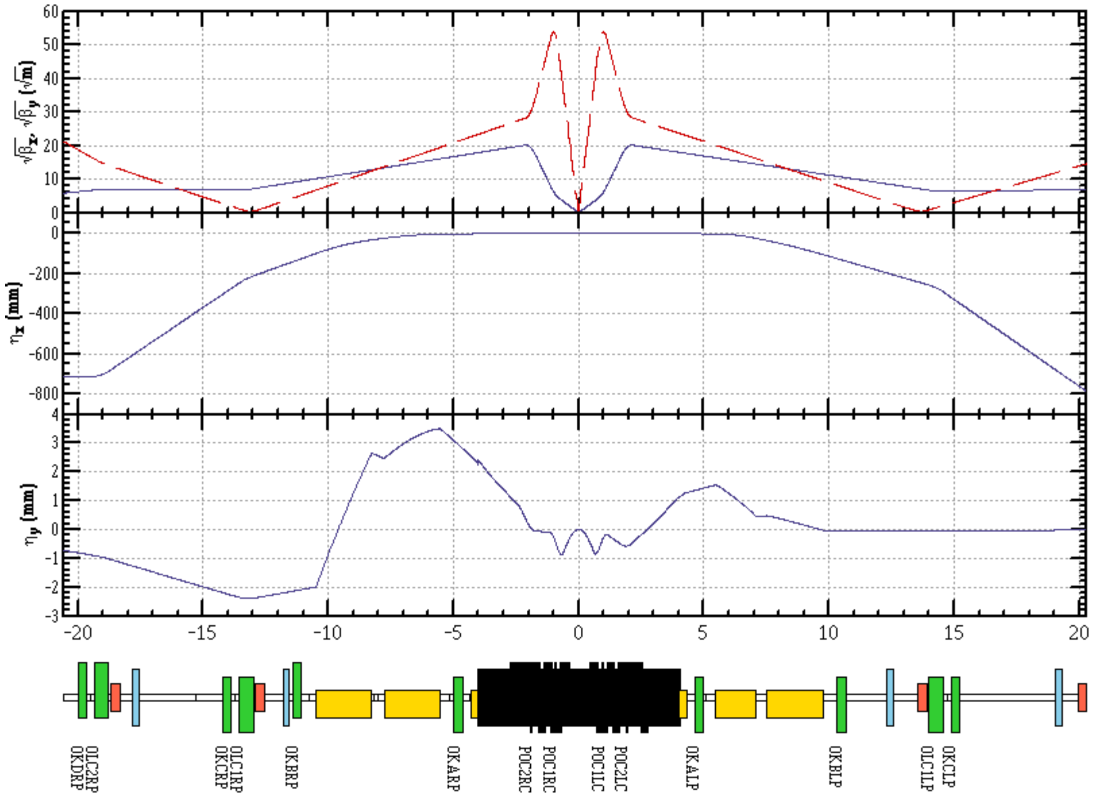
A. Morita

- Items to consider
  - Dynamic aperture, Touschek lifetime
  - Chromatic Coupling
  - Vertical emittance
  - Dispersion

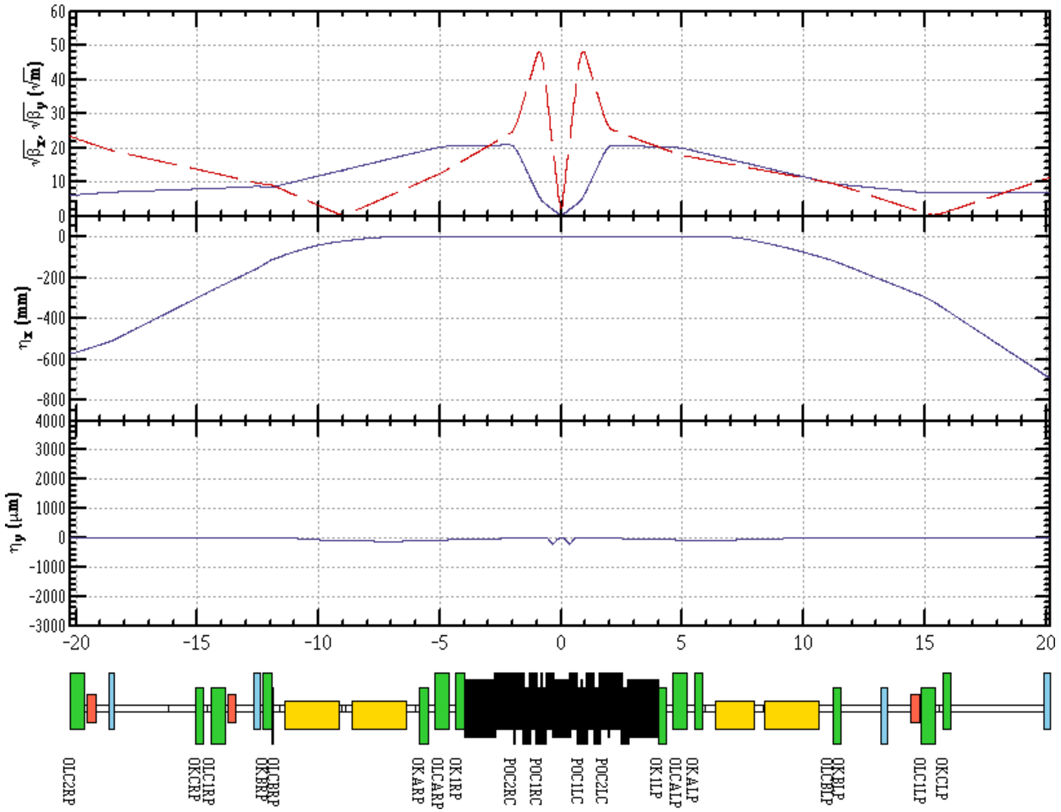
From UWG meeting Oct.26, 2023

IR dispersion comparison

When set to the same scale



“sler_1704”
The current IR (design lattice)



“V21-r0g0”
New IR

A. Morita