LS2: Next Long shutdown

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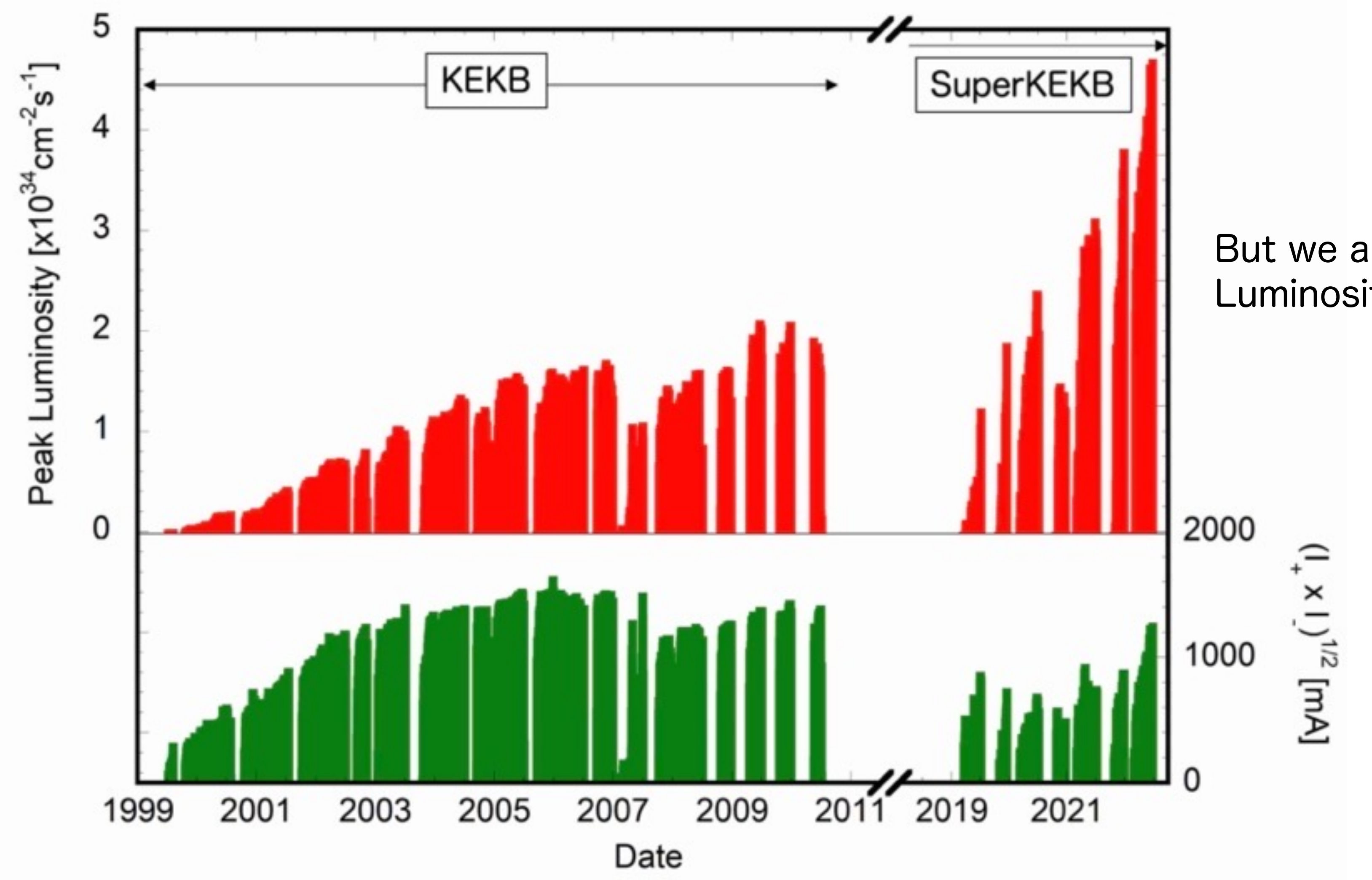
SuperKEKB can provide
higher luminosity with lower beam current than KEKB→ “nano-beam” SuperKEKB is a “eco” “sustainable” machine



But we are a luminosity frontier machine
Luminosity increase is our 1st mission

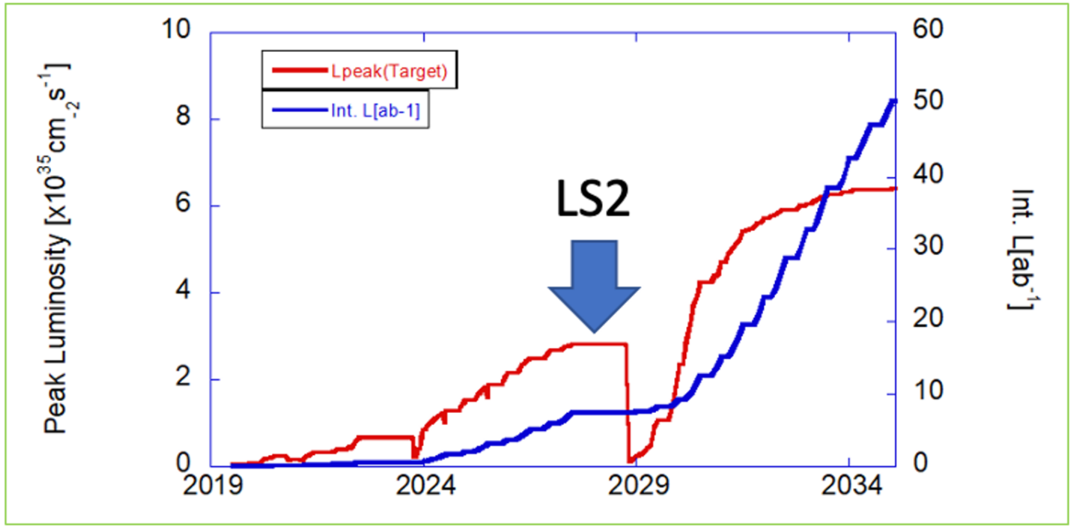
If to go for LS2 or not depends on
- how SuperKEKB performs
- MEXT evaluation sometime ~ 2026.

1. Introduction

- We need another long shutdown (LS2) to improve the machine performance beyond $\sim 2\times10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and toward the target peak luminosity of $6\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

- It probably requires
  a. modifications of the IR
  b. an upgrade of the injection complex.

And more



- The modifications must be effective enough that there is a gain of a factor of ~2 at least (depending on the length of the shutdown) in peak luminosity.

2. Main Ring (IR)

Three scenarios are under consideration.

1. Moderate scale modification around 2027 (more than 1 year shutdown):
   - New QC1 with larger physical aperture, installed closer to the IP for larger dynamic aperture, keeping the boundary as is.
     - R&D work on Nb_3Sn quadrupole magnet is necessary.
     - Evaluate the impact of modifications on machine performance by 2025 at the latest.
2. Larger scale modification, in addition to 1:
   - New anti-solenoid configuration, which probably requires detector modifications.
     - Optical evaluation of the anti-solenoid field profile and coil design needed.
     - R&D work on Nb_3Sn thin solenoid is necessary.
     - New cryostats and a cryogenic system for anti-solenoid coils need to be designed and fabricated.
3. Much Larger scale modification sometime later (~203x)
   - New ideas to be sought for, by the ITF, for example.

➢ **SuperKEKB-wide effort needs to be made to establish a reliable model through extensive machine studies after LS1.**

1. Improvement in Touschek lifetime expected.

2. Improvement in Touschek lifetime and chromatic x-y coupling reduction and emittance growth suppression are expected.

3. No constraint, can include redesign of the crossing angle, extensive beamline modifications and so on.
This will take a lot longer time and need a lot more manpower to evaluate.

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BPAC Feb.19, 2023 4

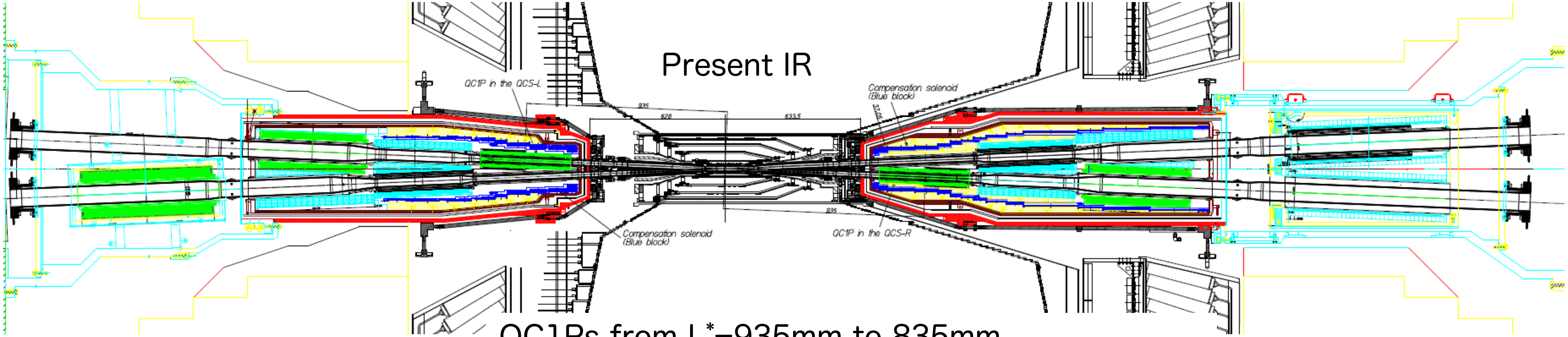
- Magnet configuration
- Current distribution

⇅

- Optics evaluation using 3D magnetic field profile

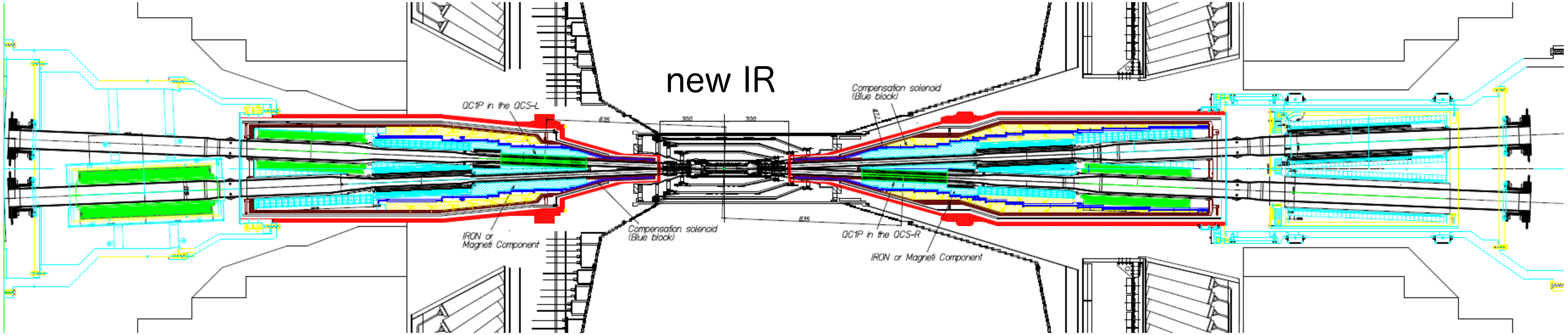
1.BPAC 2023
•Strategy
•Progress since 2022

Present IR

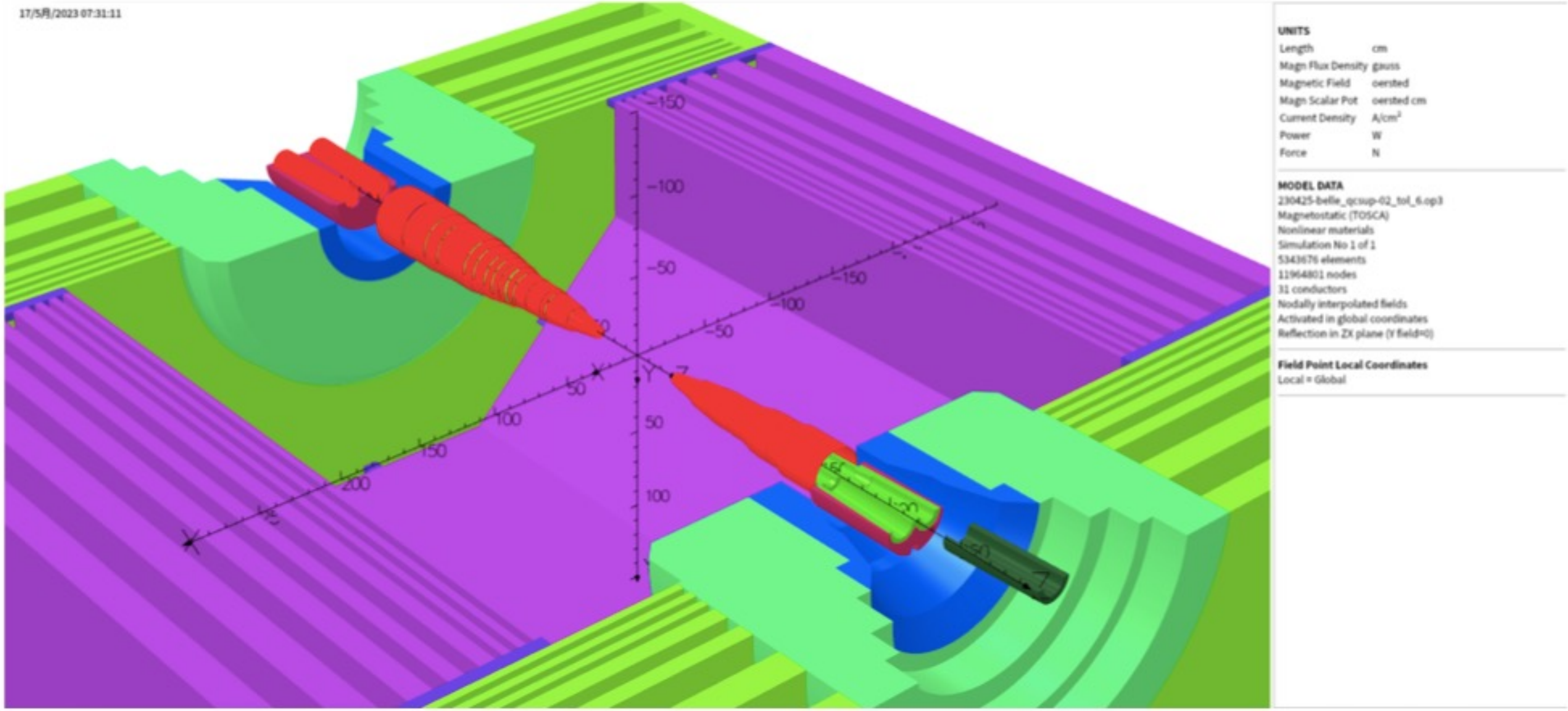


QC1Ps from L*=935mm to 835mm
Cover QC1Ps with the magnetic yoke
Install new solenoid coils between IP and QC1Ps

new IR



3Dモデル全体



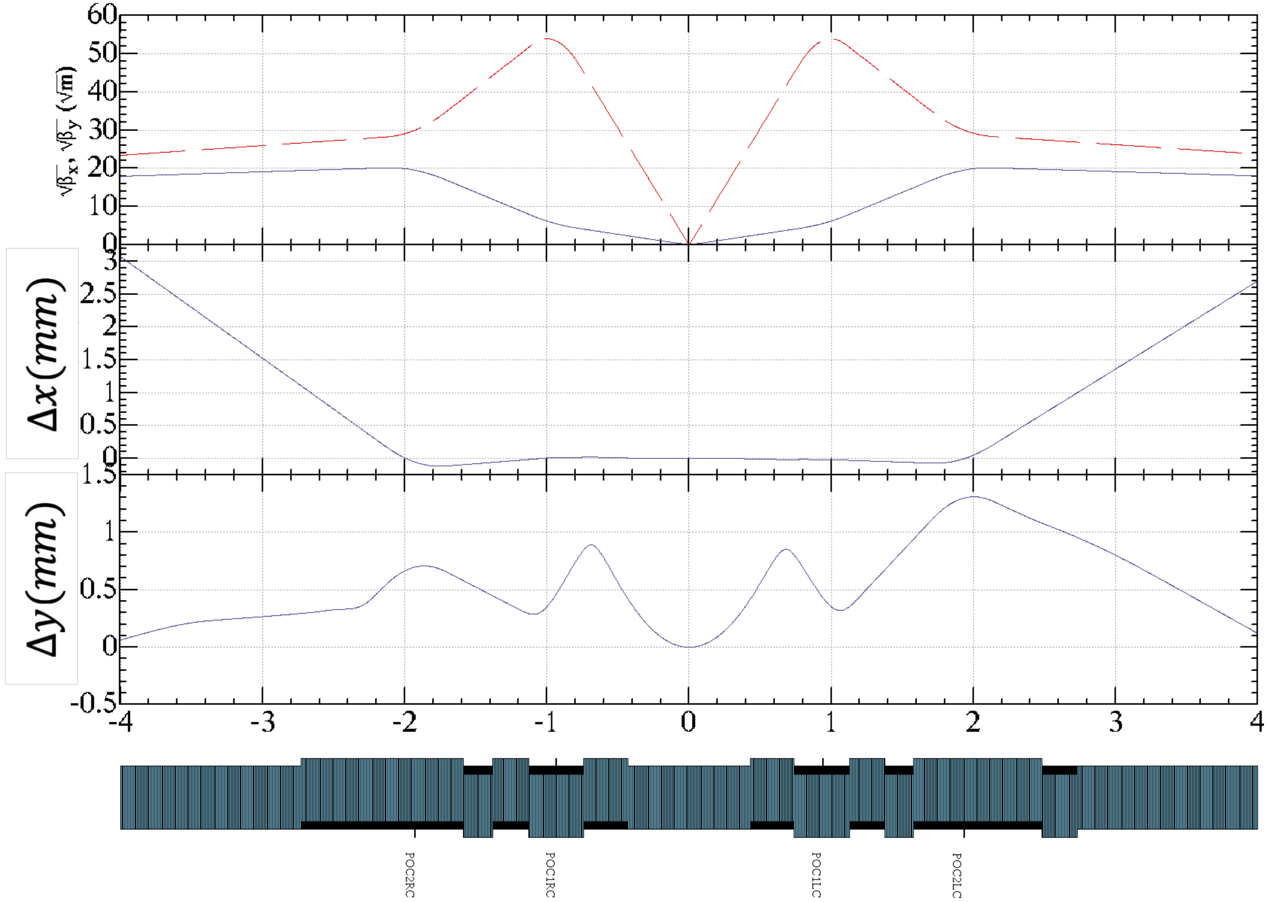
3D field calculation carried out by Y. Arimoto
& the data were given to the optics G.

1.BPAC 2023
•Strategy
•Progress since 2022

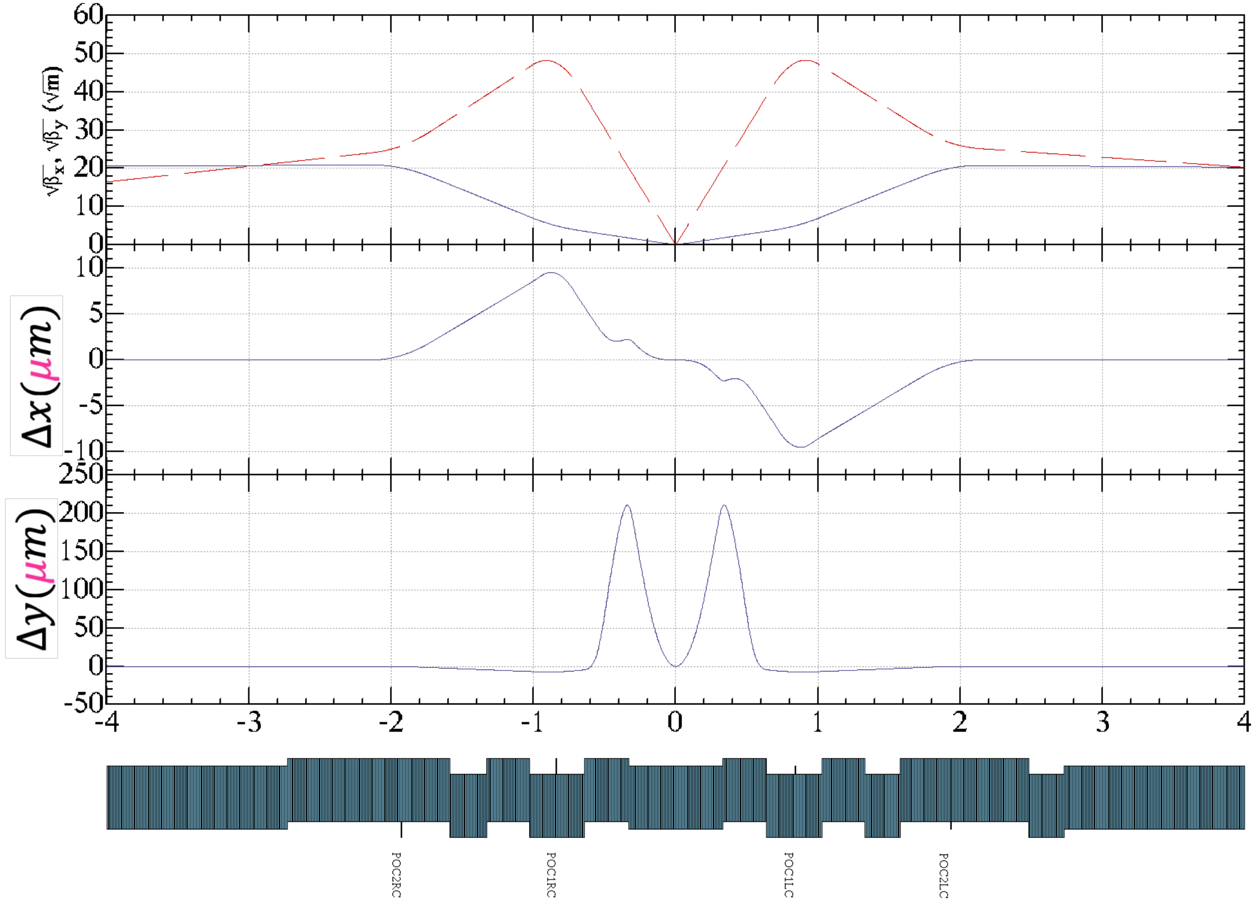
By A. Morita

IR orbit, straighter with New IR

Present IR



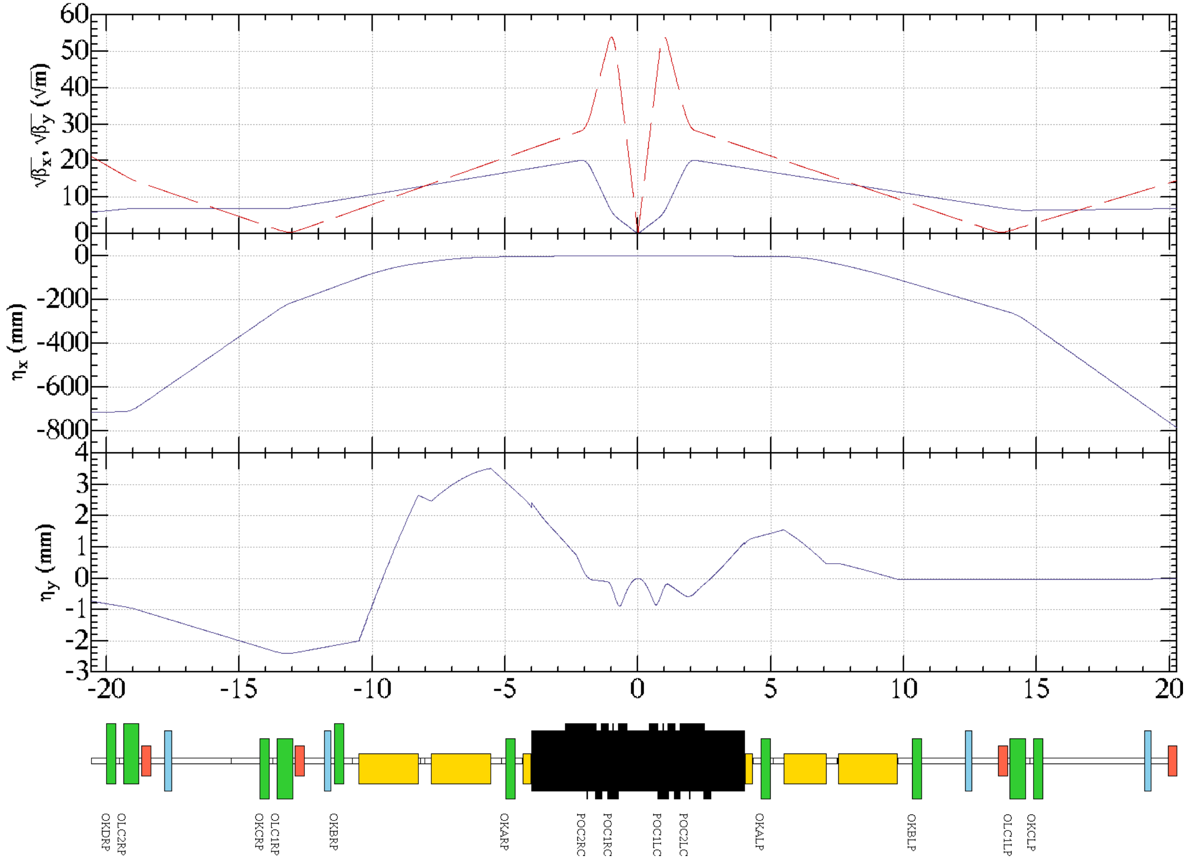
New IR



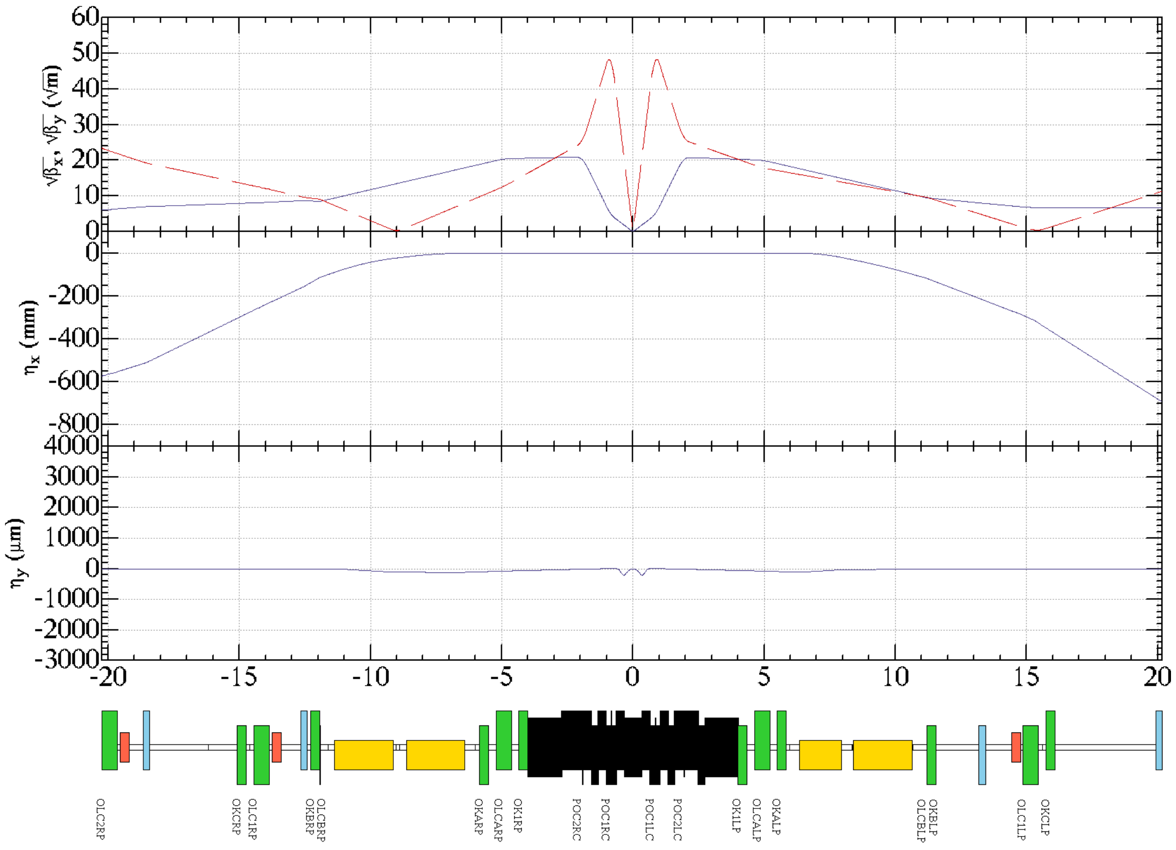
IR dispersion

By A. Morita

Present IR

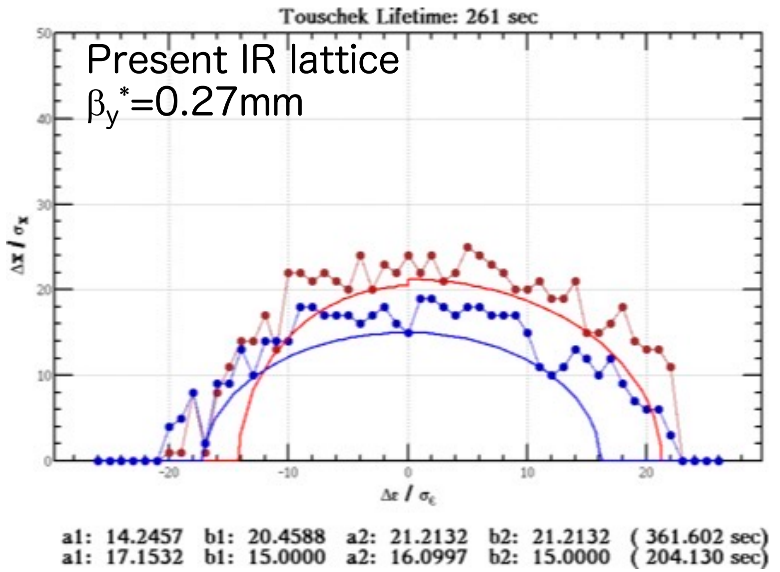


New IR

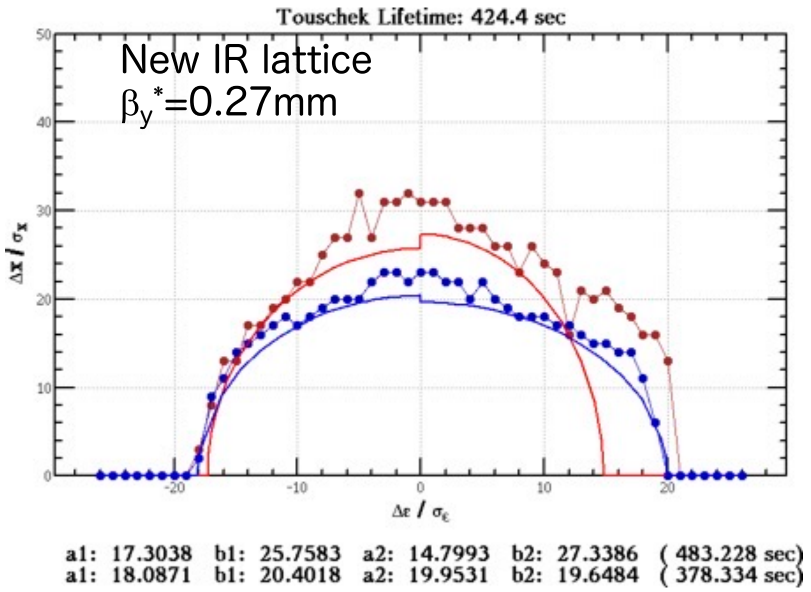


By A. Morita

1. LER DA



Touschek lifetime from ~260 s to ~420 s.

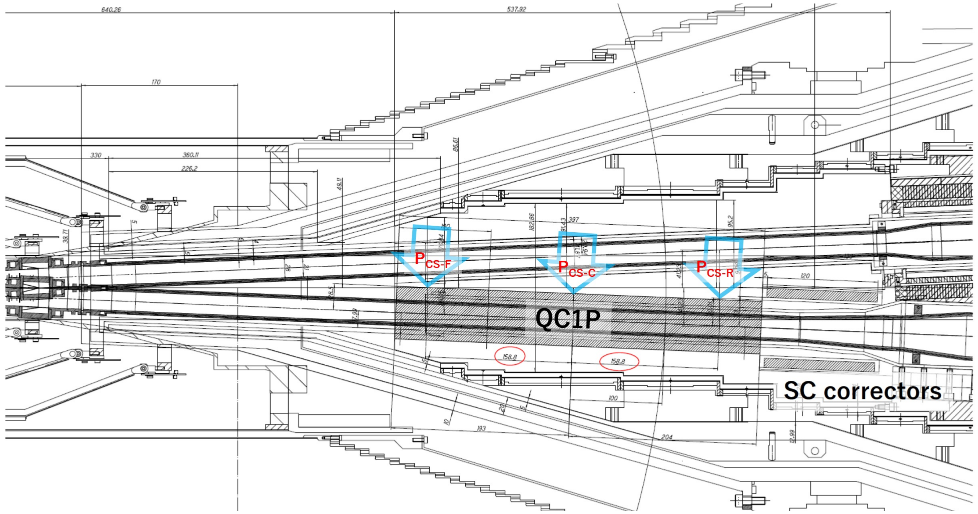


2. Chromatic coupling improves significantly,

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

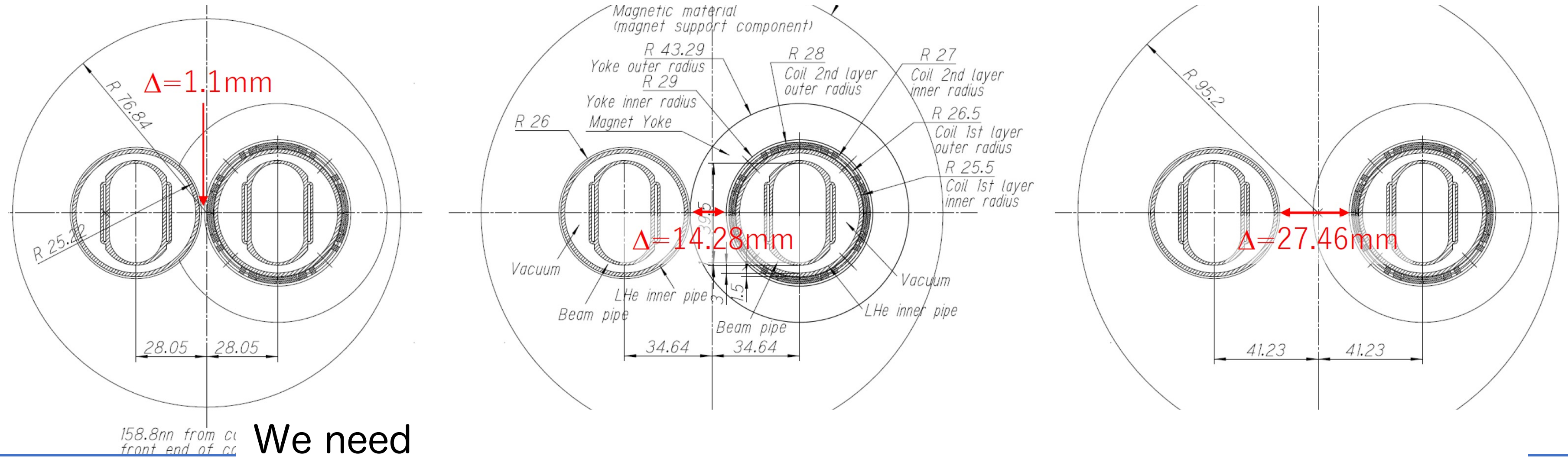
3. Emittance growth arises from IR is reduced to several tens of femtometer.

By N. Ohuchi



Parameter	Current IR optics	New IR optics
L* (mm)	935 →	835
Distance between the coil & HER helium vessel (mm)	10.8 →	1.1
Required integrated field GL_{eff} (T)	23 →	25.75
Required field gradient G(T/m)	67.88	76.01

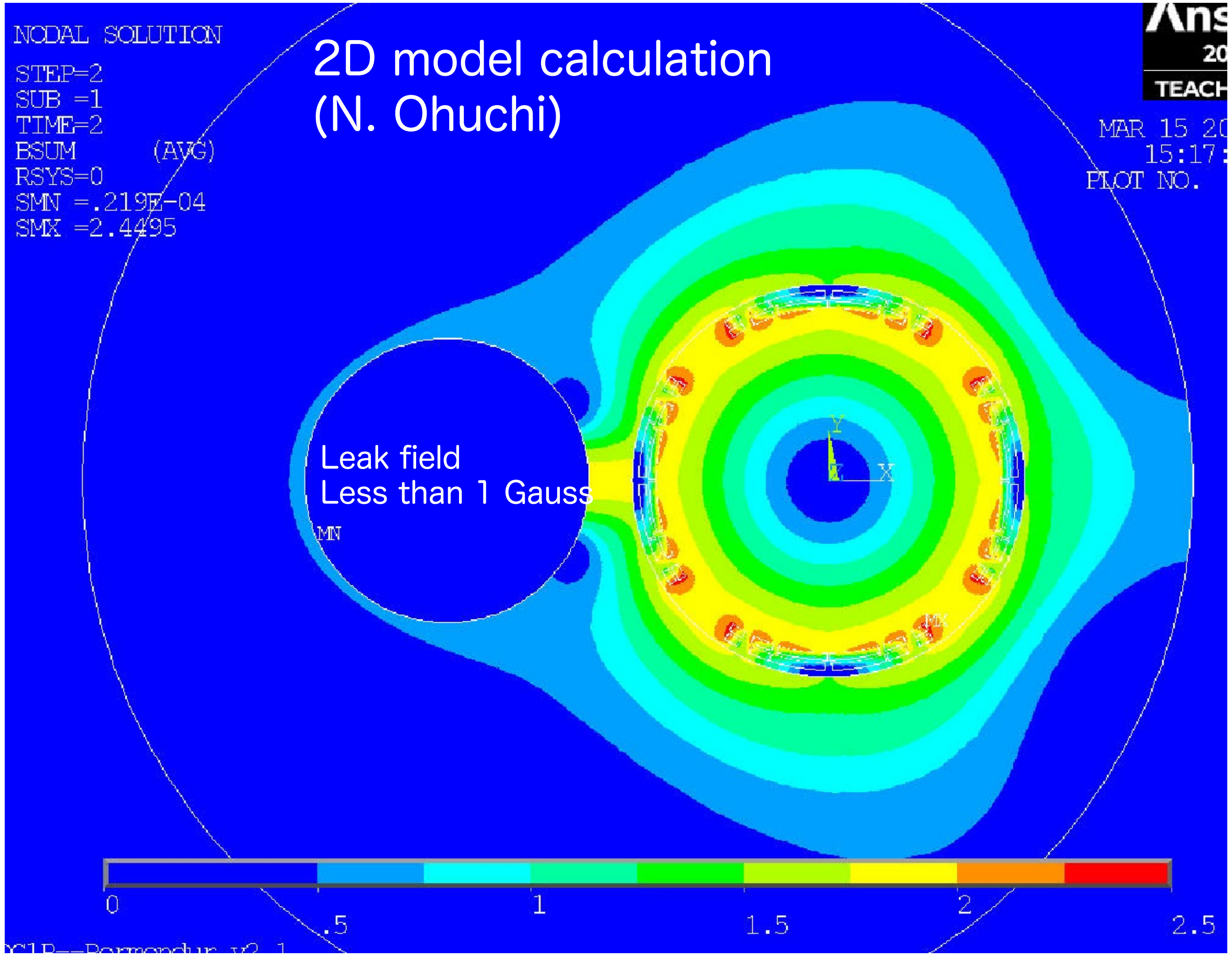
Cross sectional view along the LER beam line, if we scale the current NbTi QC1P



We need
- Thinner coil
- Superconducting wire that can withstand higher current density (from 1630A/mm^2 to >3000A/mm^2, beyond NbTi)

→ Nb_3Sn magnet

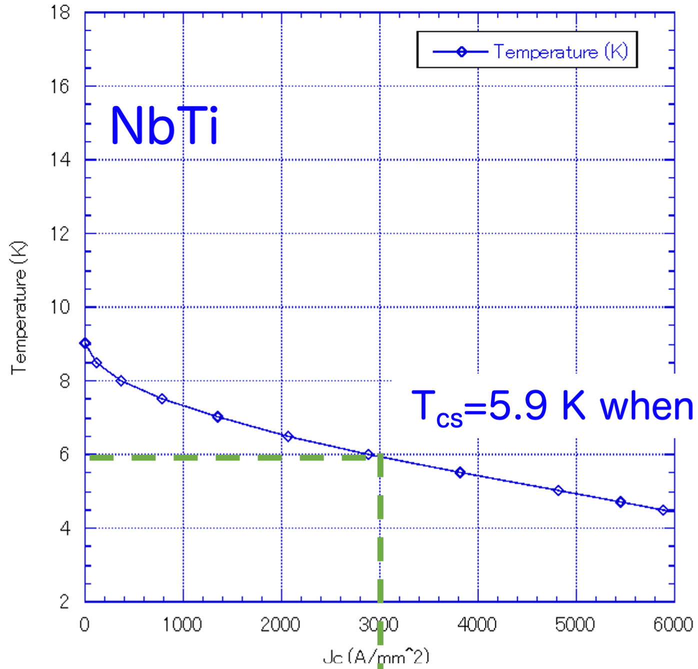
Current sharing temperature @2.5T By N. Ohuchi



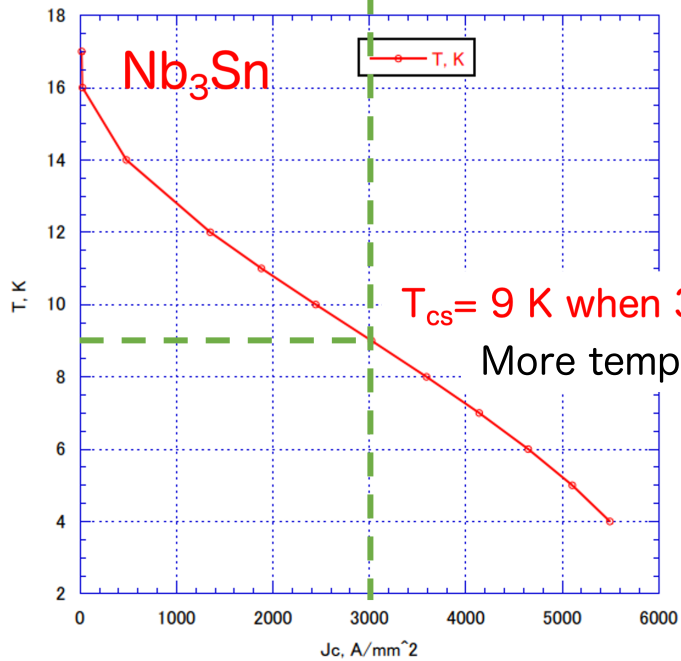
Field gradient = 80T/m

Current density in Nb_3Sn is 3112 A/mm^2

B_{max} in the coil ~ 2.5 T



T_{cs}=5.9 K when 3000A/mm^2



T_{cs}= 9 K when 3000A/mm^2

More temperature margin

Nb_3Sn accelerator magnets at CERN

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

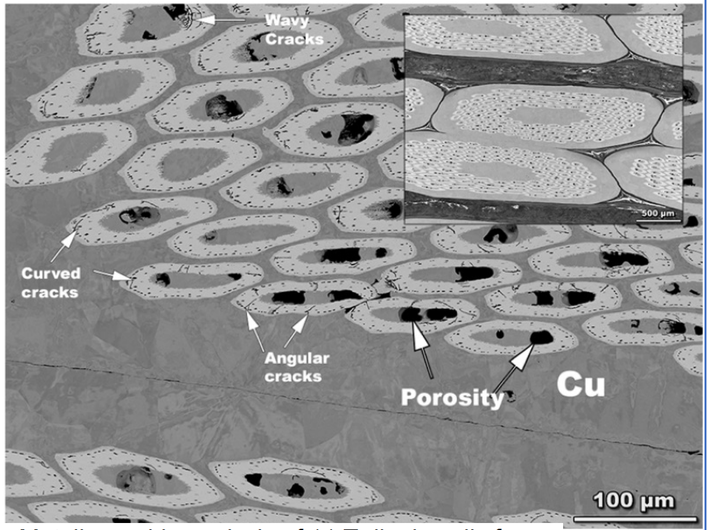
The 7.2-metre-long version of this vital HL-LHC component reached nominal current plus an operational margin corresponding to a coil peak field of 11.5 T at 1.9 K during a test in SM18

25 JANUARY, 2023

Another success for the HL-LHC magnet programme: after the successful endurance test of a 4.2-metre-long niobium–tin quadrupole magnet in the United States in spring 2022, the HL-LHC quadrupole's longer version proved its worth later in the year. "MQXFBP3", the third full-length quadrupole prototype to be tested at SM18, reached nominal current plus an operational margin in September–October 2022, confirming the success of the niobium–tin technology for superconducting magnets.

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 face similar challenges and, on the other hand, quite different challenges.

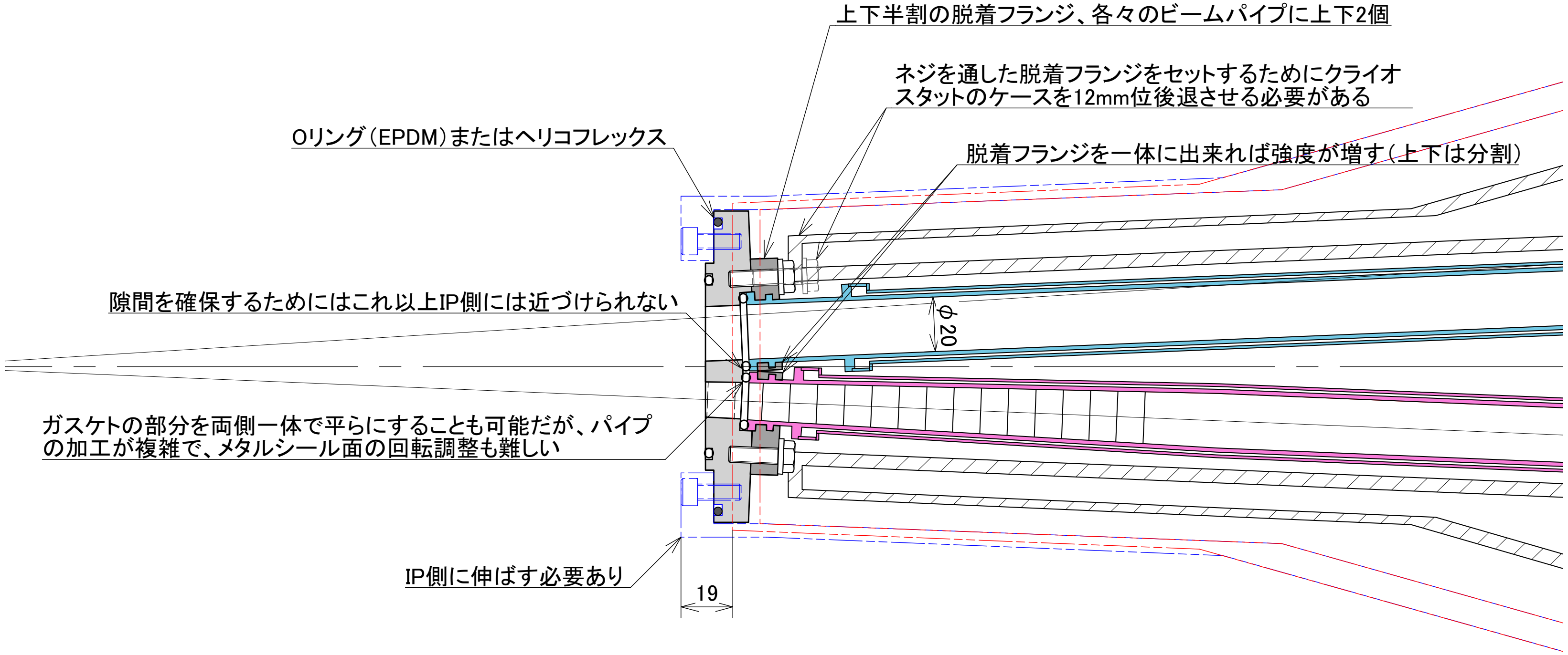
Much smaller any other Nb3Sn accelerator magnets in the world.
Making a small magnet with such brittle wire.
Operating in the lower magnetic field environment than LHC.
QC1P filament size < 5 μm , much smaller than LHC filament (~50 μm).
→ →To prevent quenches from flux jump and to reduce long-term drift.

R&D required

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

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

・Front PlateをFront Capから分離して、Front Capが無い状態でBeam Pipeを接続する。
・脱着フランジとQCSのコイルケースが干渉するので、コイルケースを後退させる必要あり～12mm
・Front Cap先端をIP側に伸ばす必要あり～20mm



An example of topics being discussed

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

Some Furukawa technologies are
subject to Non-Disclosure Agreement (NDA)

- Coils were test wound with the sample wire we sent @ FNAL.

- We made an application for U.S.-Japan Science and Technology Cooperation Program in High Energy Physics.

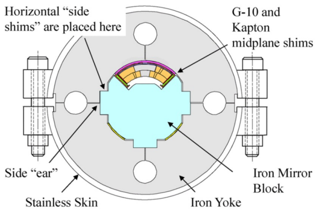
- We are planning to train students under International Leading Research （科研費：国際先導研究).

Before heat treatment

Presented by N. Ohuchi
@IR upgrade mini workshop Jan.27, 2024

1	Where	Japanese FY	JFY24	JFY25	JFY26
2		Month	April M J J A S O N D J F M	April M J J A S O N D J F M	April M J J A S O N D J F M
3		tasks/quarter	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
8	FNAL	1 Mirror and preliminary (prototype) magnet designs			
9	FNAL	2 Quench protection study/design			
10	KEK+FNAL	3 Tooling design/fabrication/procurement			
11	KEK	4 Nb3Sn cable procurement and production			
12	KEK	5 Practice winding			
13	KEK	6 First coil winding			
14	FNAL	7 First coil reaction + impregnation			
15	FNAL	8 Fabrication of the mirror magnet			
16	KEK	9 Testing of the mirror magnet (performance, analysi			
17	ALL	10 Results/Discussion/Decisions			
18	KEK	11 Winding of five prototype coils			
19	FNAL	12 Reaction + impregnantion of five prototype coils			
20	FNAL	13 Assembly of a prototype quadrupole magnet			
21	KEK	14 Testing of the prototype quadrupole magnet			
22	ALL	15 Results/Discussion/Decisions			
23	FNAL	16 Final magnet design			

Perform a step-by-step, careful evaluation.



"mirror" HQM (Nb_3Sn) for LHC upgrade

- Mirror and prototype magnet design.
- Making the Nb3Sn cable specification and production.
- Construction of the mirror magnet.
- Excitation test of the magnet.

- Construction of the prototype magnet.
- Excitation test of the magnet.
- Magnetic field measurements of the magnet.

- Final magnet design.

Depends largely on budget and manpower

- Injection is another very important factor for luminosity performance.

From M. Satoh for BPAC Feb,2023

- **Injector upgrade plan after LS1**
  - e- ECS installation in the current e- BT line
  - New e- BT line construction in PF-AR BT tunnel
    - To mitigate emittance growth due to ISR and CSR effect
  - Replacement of vacuum duct with the narrower one to mitigate CSR effect
  - Modification of SY3 dump line for the pulse-by-pulse beam diagnostics (2024)

- Installation of additional high-power klystrons for storing higher beam current.
- Renewal and maintenance of aging components.
- If new breakthrough found during the 2024 run, then they will be considered.
  - Some can be done before the next long shutdown, during the summer/winter shutdown.

New BT line for HER (Kikuchi)

- New BT line for the HER has been proposed, that envisages ease of the CSR/ISR emittance growth.
- New line share the tunnel in part with PF-AR transport line.
- If we preserve the current BT e- line and can switch the beam pulse-by-pulse, the current line could be used for beam diagnosis.

M. Tawanda, the 26th KEKB ARC, 2022

Chiral Belle

Slide from Z. Zhanguo
U.S.-Japan Science and Technology Cooperation Program in High Energy Physics.

R&D Proposal for Chiral Belle for Polarization Physics at SuperKEKB

Top-level objective (as Stage 4: Operation) for Chiral Belle for Polarization Physics

- To install two spin rotator units on both sides of the SuperKEKB IR
- To add polarized electron gun to inject freshly polarized electron beam
- Polarization measurement for the accelerator and detector operation

3 stages for R&D

Stage 1 (Design)

Polarized electron source
Design, fabricate, install and operate for lifetime study; R&D on longer lifetime photocathode

Spin rotator units
Conceptual and technical design

Stage 2 (Fabrication)

Polarized electron source
Incorporate longer-lifetime photocathode; Maintain performance and availability for HER machine studies

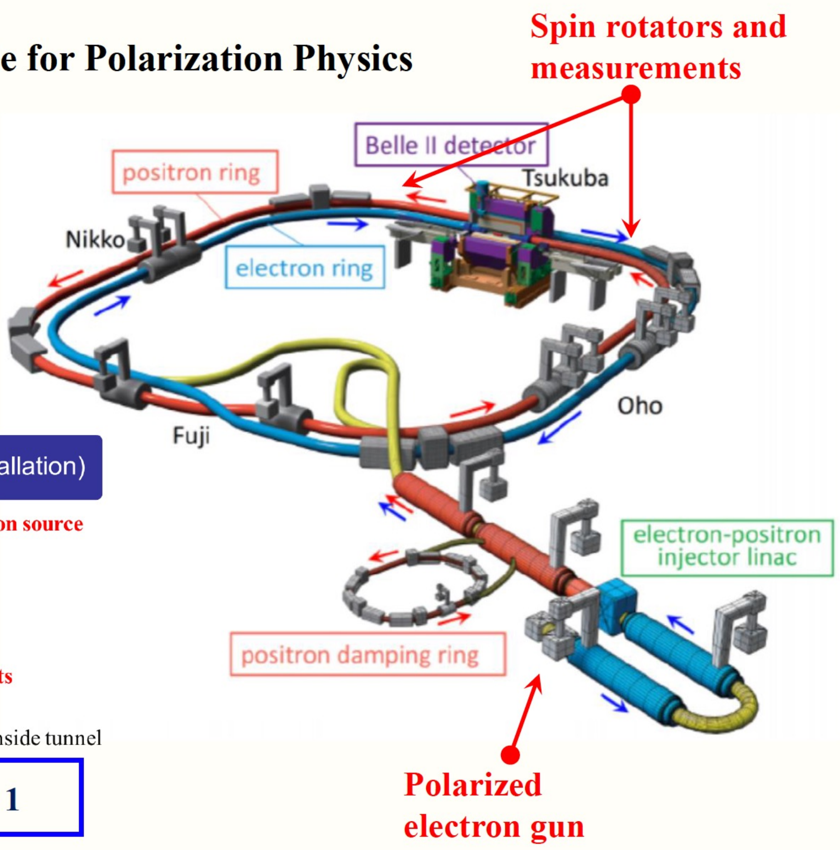
Spin rotator units
Fabrication and cryogenic testing in lab

Stage 3 (Installation)

Polarized electron source
Same as Stage 2

Spin rotator units
Installation, and commissioning inside tunnel

This R&D proposal: team assembled for the R&D of Stage 1



Status

- Simulation work are being carried out by people outside of SuperKEKB.
- Our priority is improving luminosity performance.
- No budget has been allocated from the SuperKEKB LINAC side.
- The first meeting between Chiral Belle and the SuperKEKB LINAC team (Ego-san) was held last December.

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.

→ Very simple IR
→ To realize this, Nb_3Sn magnets are needed.

- Regular meetings started, to discuss IR hardware assembly and installation issues.

- We believe that establishing the technology to make compact magnets using the Nb_3Sn superconducting wire will be useful not only for SuperKEKB IR upgrade but also for future accelerators and accelerator application.

We ask for your support

- R&D with KEK Cryogenics Science Center, FNAL and Furukawa Electric Co., Ltd. has begun.

Luminosity strategy

- Efforts will be made to establish a reliable model through extensive machine studies during 2024 run to understand the discrepancies between the simulation and the machine.
  - The path to higher luminosity will become clearer.