

Study of the future SuperKEKB IR design upgrade for higher luminosity

S.Tanaka (KEK IPNS)

the 13th Joint Workshop of the France-Japan ([TYL/FJPPN](#)) and France-Korea ([FKPPN](#)) International associated Particle Physics Laboratories.

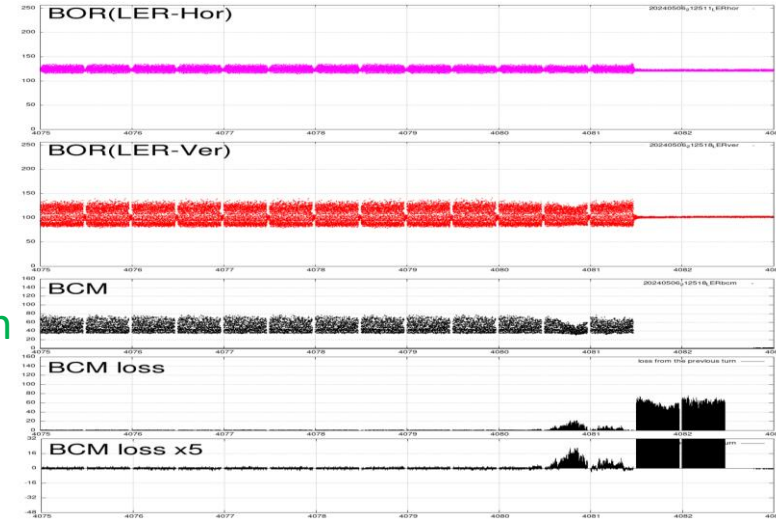
IJCLab BONIS Julien AUGUSTE Didier KOU Emi AUGUSTE Didier LE DIBERDER Francois MIZUK Roman PEINAUD Yann WINTER Marc	KEK IPNS SHUJI Tanaka AKIMASA Ishikawa (SVD) KATSURO Nakamura (SVD) KOJI Hara(SVD) TAKASHI Kohriki KANAZAWA Kenichi	U-Tokyo YOSHIYUKI Onuki(SVD) IPMU/U-Tokyo TAKEO Higuchi(SVD)
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Current SuperKEKB status

After the LS1, SuperKEKB/BelleII has restarted from this January.

We have several issues/problem on the beam operation

1. Sudden Beam Loss
2. Beam-Size Blowup due to Beam-Beam Interactions
3. Beam-Related Background
4. Injection Efficiency and Emittance Blowup in the Beam Transport Line
5. Difficulties to Keep Beam Orbit Stable (from Low Current to High Current)
6. Short Lifetime and Narrow Dynamic Aperture with Squeezing

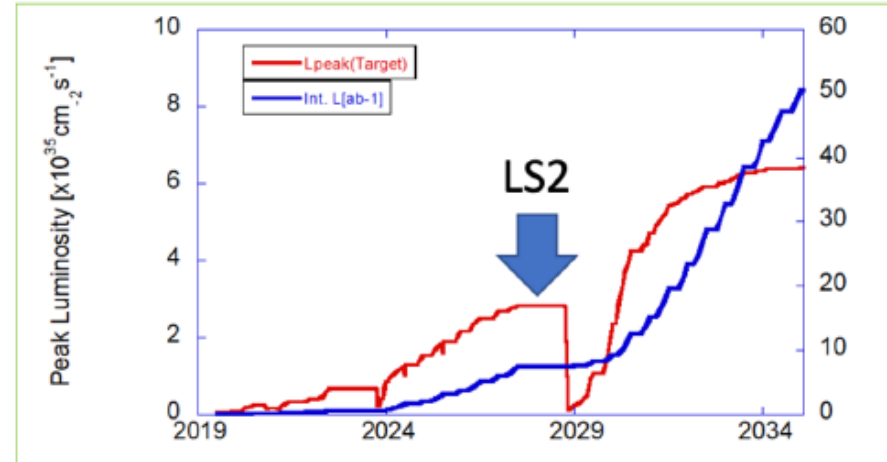
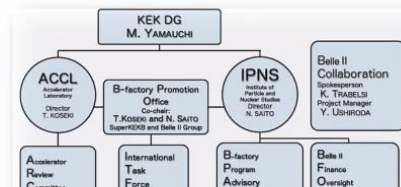
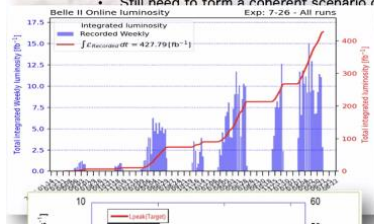


- Further upgrade program LS2 is under discussion

Belle II and Belle Overview

Exploration of New Physics with the World Highest Luminosity

- A Quest for More Luminosity
 - SuperKEKB achieved $4.7E34 \text{ cm}^{-2}/\text{s}$ in 2022.
 - KEKBx2.2; PEP-IIx3.8; Still need a factor > 10 improvement
 - Belle II Integrated Luminosity 428/fb ~ 41% of Belle's
 - Sensitivities started to exceed Belle thanks to better detector and analysis.
- Near+long term plan is being made with acc group
 - CDR studies for LS2 upgrades and beyond were reviewed at BPAC

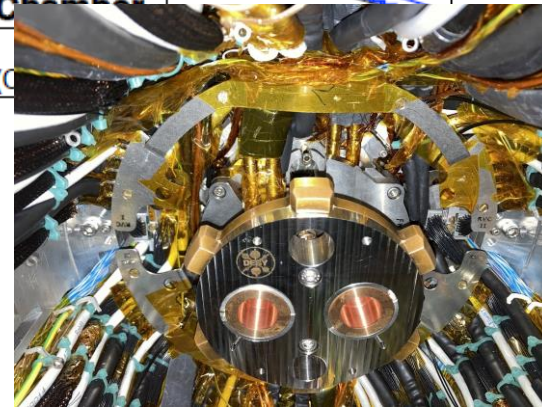
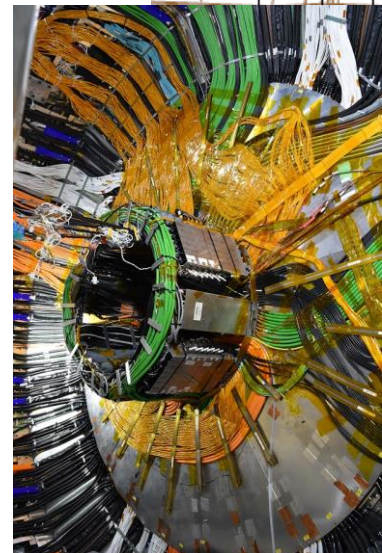
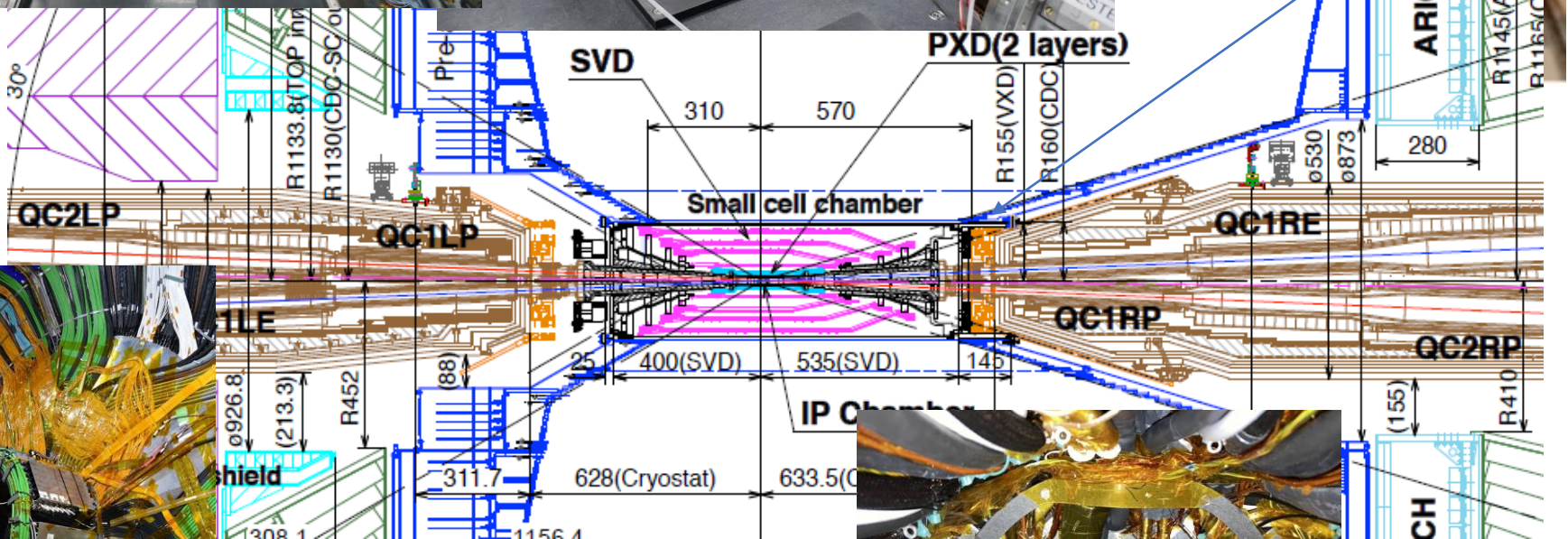
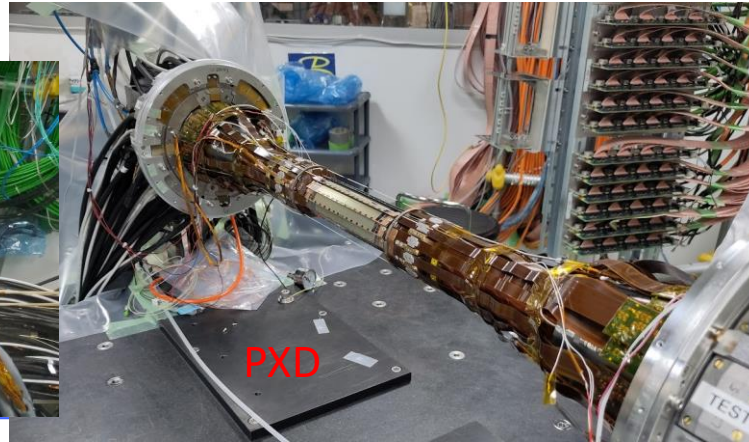
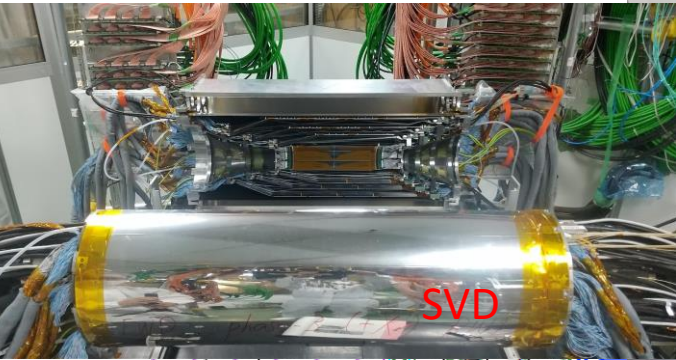


Motivations of our project

- The Belle II experiment using the SuperKEKB accelerator at KEK resumed operation **in January 2024** after equipment upgrades during **the Long Shutdown (LS1)** since 2022.
- In order to achieve the initial goal of 50 times the integral luminosity of KEKB, **we are considering renovating the Belle II detector and the Interaction Region during a second Long Shutdown (LS2) period.** Currently, the Superconducting Final Focus Magnet System (QCS) is being studied from the perspective of beam optics design and testing of magnet materials. And also, the detector group is developing several new sensor systems to be used as the next Vertex detector at the collision point. In this project, from the perspective of connecting these elements, we focused on examining how to install, assemble, and cool the sensors in the vertex detector around the collision point, and how to assemble the IP beam pipe (Beam pipe at collision point) and radiation shields. The aim is to create a more realistic mechanical design by comparing and examining several options.
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- A feature of SuperKEKB is that it incorporates a design called a **“Nano-beam scheme “in which two beams collide at a large beam crossing angle.** This design is now being adopted in future electron-positron colliders such **as the ILC and FCCee.** Therefore, this review of the IR is not limited to SuperKEKB's contribution alone.

SuperKEKB IR

Remote Vacuum connection



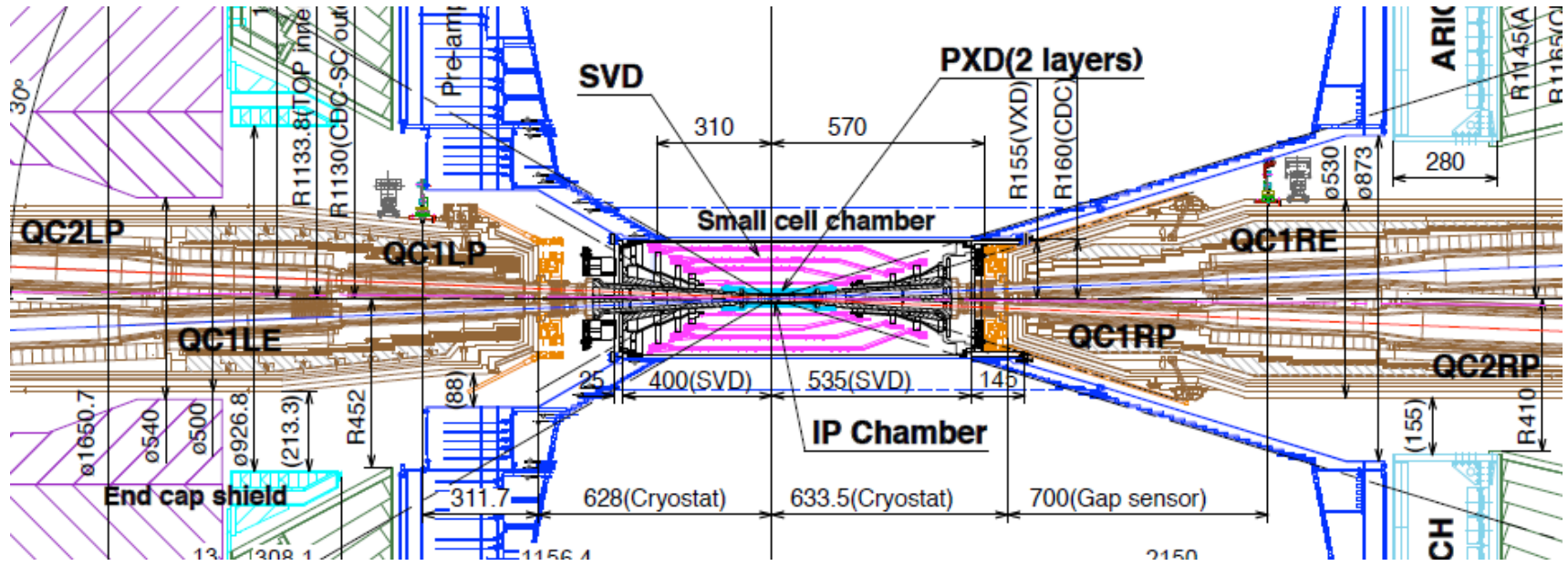
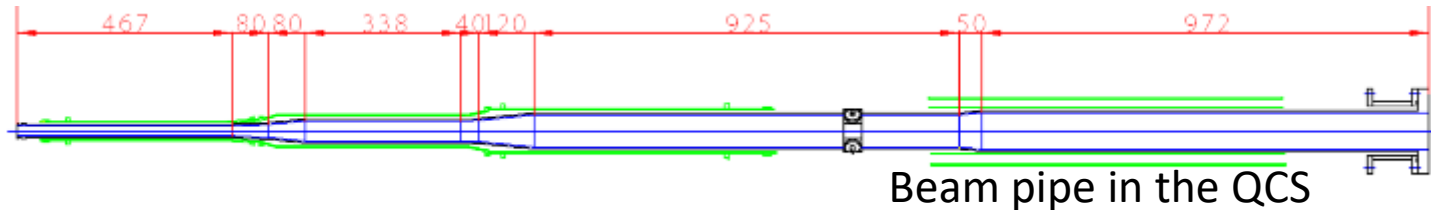
LS2 IR design conceptual discussion

1. Preparing IP BP+QCS+VXD integration concept
 1. **(Option 1)** Keeping borders btw. each component (minor modification):
 1. Modification within each allocated structure (i.e. QCS, VTX) can be possible
 2. Discussion on how to install the VXD sensor is necessary, but base integration steps will generally be maintained.
 2. **(Option 2)** Completely rebuild QCS and renovate VXD as well.
 1. The material, shape processing, and assembly of IP pipes and shields should be matched to Option 1 as much as possible.
 2. Either way, we haven't reached a realistic discussion yet.
2. **(Now we are here)** Listing options and related challenges and issues
3. If Realistic IR mechanics integration design concept was prepared
 - Listing service space requirements as next step
4. Final IR mechanics integration design

SuperKEKB IR design (option1)

- IP beam pipe + shields + VXD
- Bellows pipe (with BPM)
- RVC
- QCS beam pipe
- QCS magnets
- QCS cryostat
- CDC and more

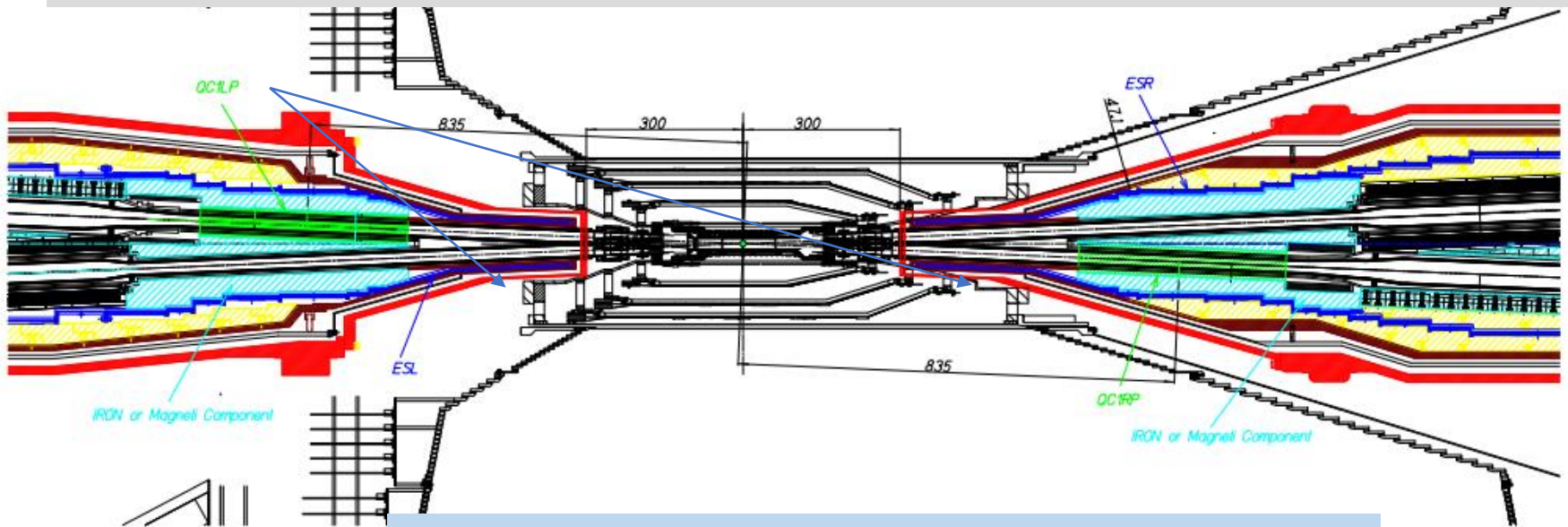
Related subjects
 Optics design
 BG simulation
 Component Alignment



LS2 IR design (Option2)

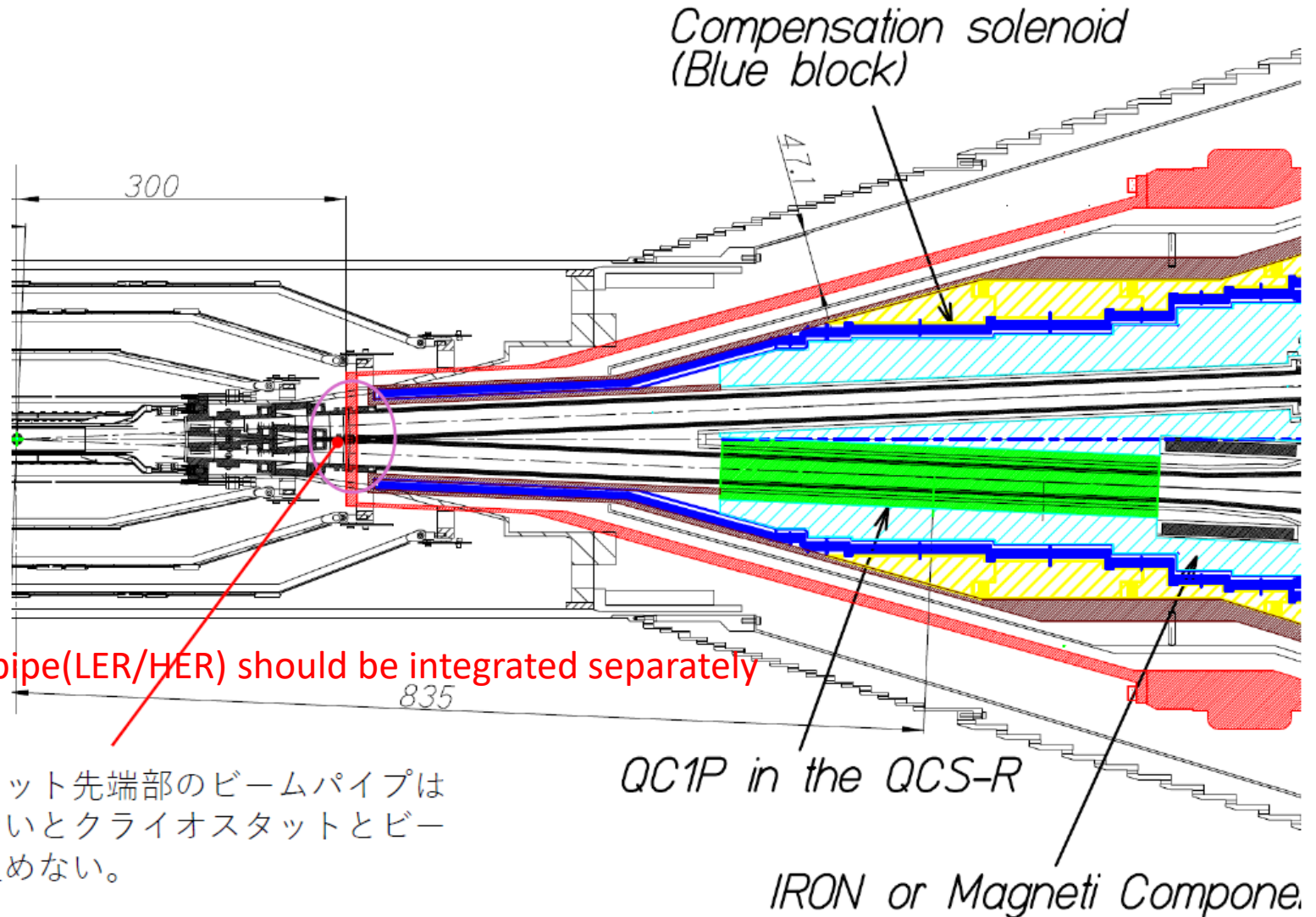
New Cryostat

For the higher luminosity: New QCS design was proposed (optics and QCS group)
Belle Solenoid field should be canceled for the beam focusing and orbit control
This cancel coil is currently overlapped with QC1 (last focus magnet)
Cancel solenoid locates near to the IP for higher luminosity design



QCS outer structure design is still under discussion.
(The size might be increased after the detailed checks)

New QCS concept proposal(option2)



Issue on the new QCS design

- 1, How to connect (with vacuum seal)
- 2, Alignment
- 3, Cooling (Pipes, sensors)
- 4, mechanical stress (thermal. Earthquakes)
- 5, BG shields
- 6, Physics data quality
- 7, Service space



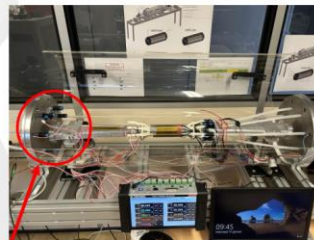
iVTX cooling



Outlet position influence :

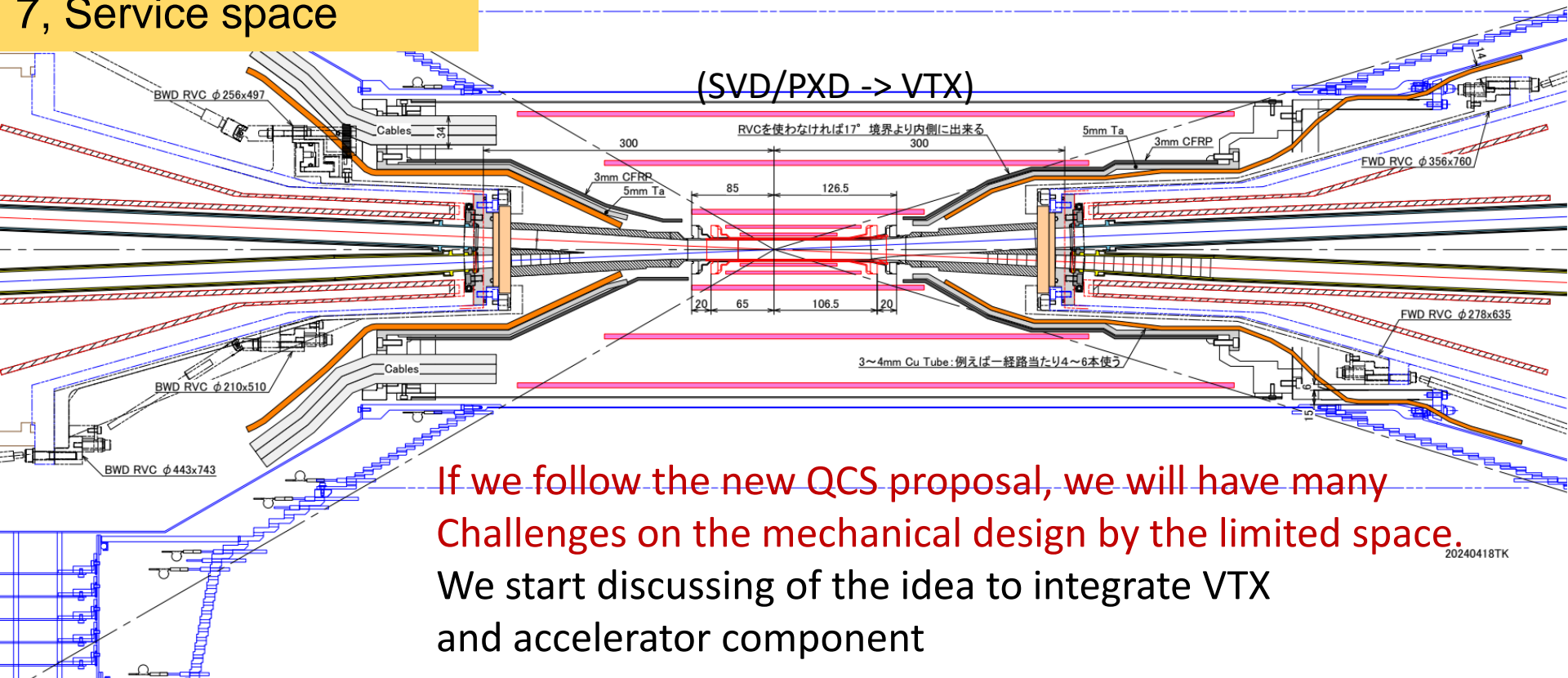


Air Outlet by iVTX support



Air outlet On opposite Flange / inlet support
Less space used by air service inside the VXD volume

Cooling test setup



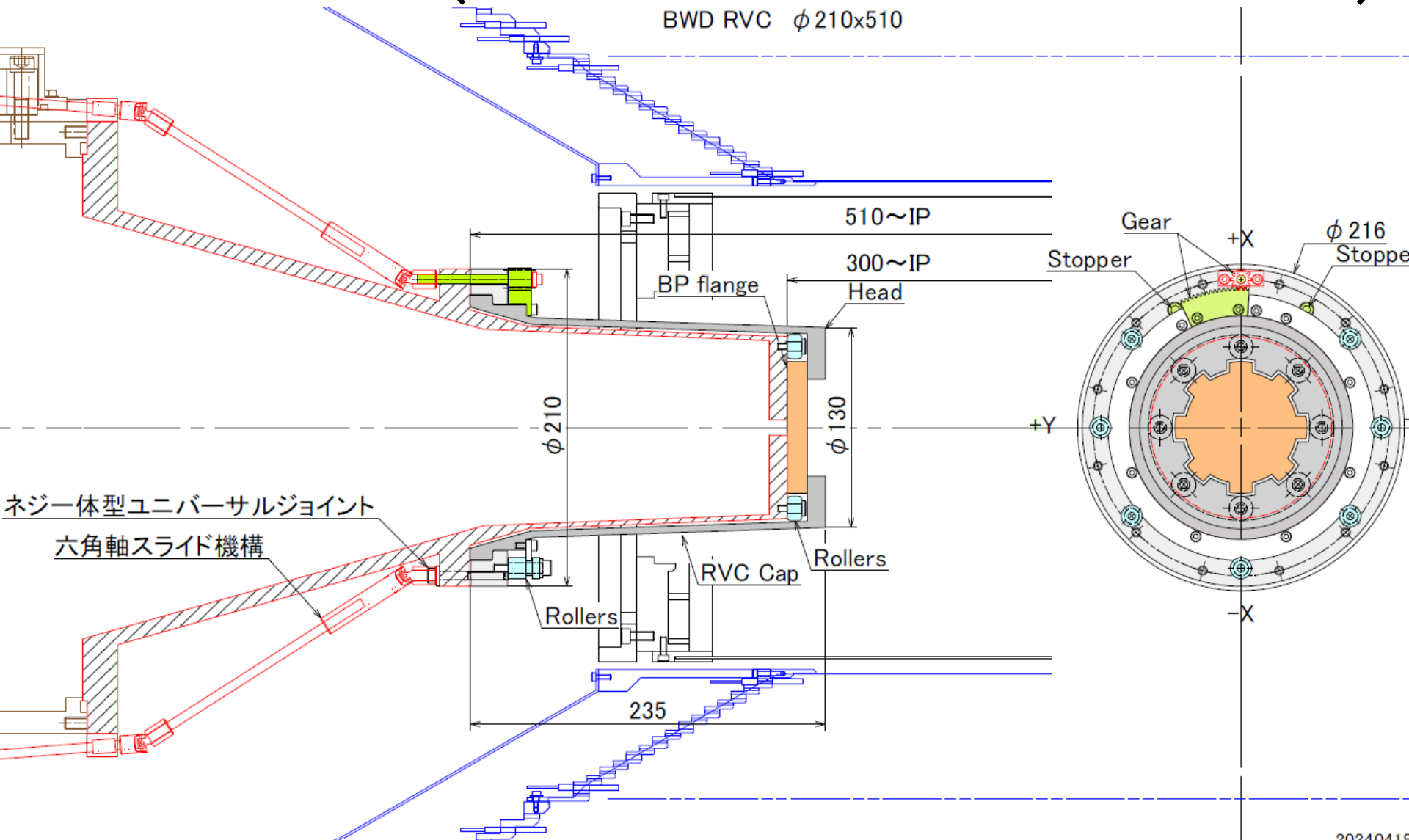
If we follow the new QCS proposal, we will have many Challenges on the mechanical design by the limited space.

We start discussing of the idea to integrate VTX and accelerator component

R&D subjects on LS2 IR discussion

- R&D can be split into development sub-groups for the components
 - VTX (sensor development and system development),
 - Readout, Ladder design, cooling, position allocation and so on
 - IP beam pipe (KEK-Belle),
 - BG shields, cooling , sensor mount space, Production test
 - QCS(QCS group, vacuum group),
 - Cryostat design (mechanical simulation)
 - QCS Beam pipe integration with QCS structure
 - Beam pipe design (SR ridge and using Ta but SUS316L currently)
 - bellows pipe(vacuum group)
 - New design for smaller space?
 - BPM (monitor group),
 - New BPM development is necessary?
 - If the space allocation is defined, this activity will start.
 - BPM should be near to IP.
 - RVC (KEK-Belle), Beam pipe remoteconnection
 - (FWD)/BWD new RVC design to fit the space
 - VXD integration(KEK Belle and machine group)
 - VXD integration steps and listing issues
 - And more (VTX installation or ...)

BWD RVC(remote vacuum connection)



An idea of beam pipe remote connection mechanics. Some tests with mock are mandatory.

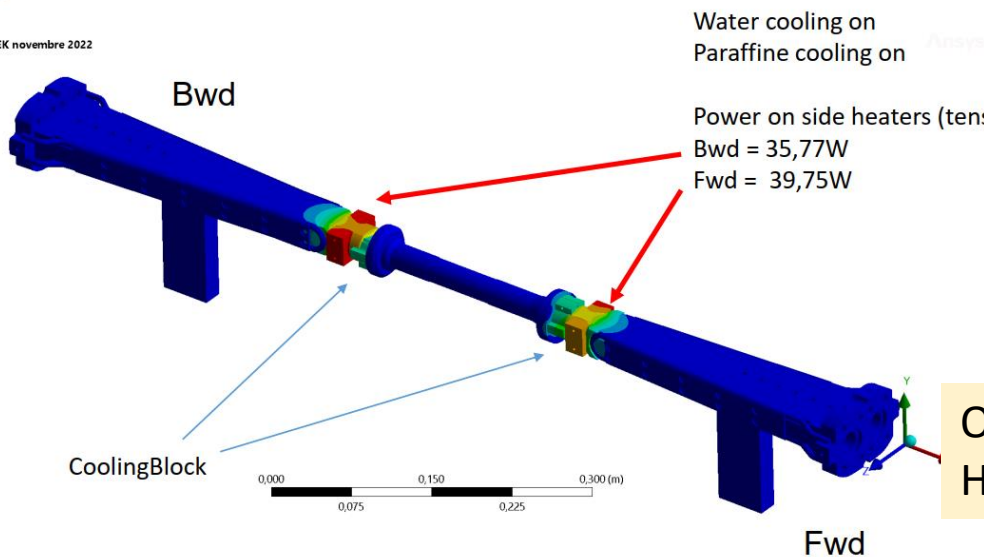
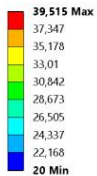
Plan of this year activities

- This year's program contains two concrete tasks:
 1. **IP beam pipe cooling monitoring:** During the past years, we have been investigating the efficiency of the current IP beam pipe cooling system. What have been achieved so far are i) estimate of heat load due to the wall loss and the synchrotron radiation, ii) thermal simulation based on the estimate 1), iii) test of the water and paraffins cooling that is currently applied, using the phase II beam pipe. And now that the Run 3 has started, we are going to test the three items above with the data which will be taken by the newly installed thermal sensors. **This data will help us to modify our models in the simulation and will allow us to make a more precise prediction, which will be a very important input for the operations of the the SuperKEKB accelerator as well as Belle II detector**
 2. **Launching a new France-Japan working group to discuss the future upgrade mechanics.** Now that the SuperKEKB is reaching to the first milestone luminosity, 10^{35} , the accelerator group will soon be able to start the upgrade discussion. As the IR(Interaction Region) mechanics including the one for vertex detector is closely related to the accelerator upgrade, it is timely to create such working group including experts of mechanics. Our new team covers a wide range of subjects, from the assembly of the IR mechanics, vertex detector (sensors, services, thermal management) as well as physics. For this first year, we will organise regular online meetings to set up a strong collaboration between France and Japan on these subjects.



IP thermal test @ KEK

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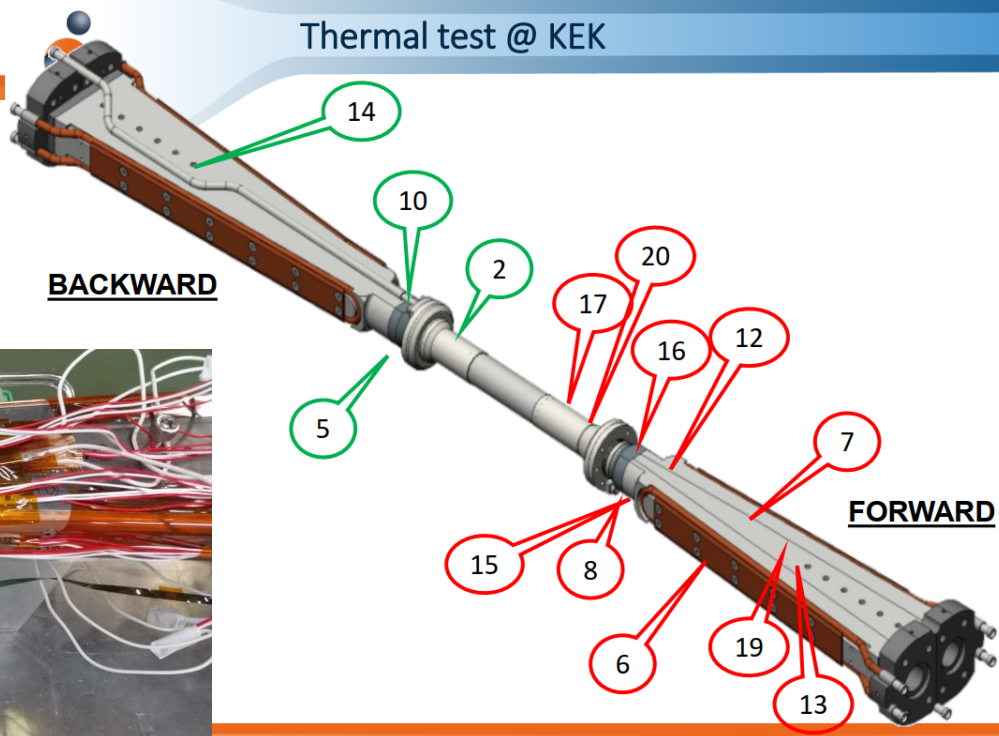


Cooling test at KEK FEM analysis for the Heating estimation

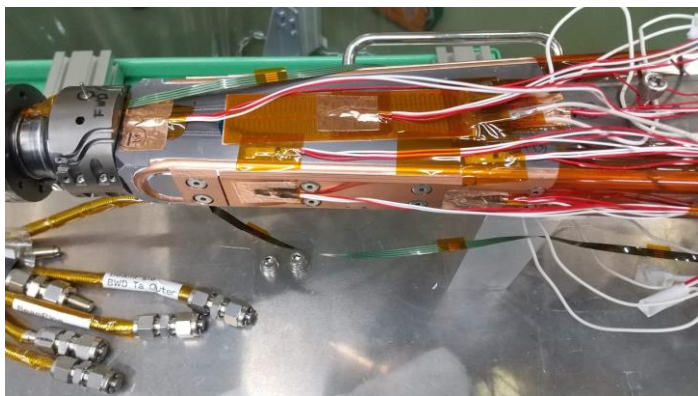
Our expectation by the study
 Heating area is localized (hotspot)

24 novembre 2022

Thermal test @ KEK



#	Designation
1	-----
2	On beampipe LEFTSIDE
3	H.S
4	Ambiant Temp
5	IP Temp Sensor DOWN LEFT SIDE
6	Side position
7	Beside heater
8	Paraffine pipe IN
9	WATER IN CENTRALE
10	IP Temp Sensor TOP LEFT SIDE
11	WATER OUT 2 RIGHT SIDE (arrière)
12	Beside Mount Block
13	Behind heater
14	Top LEFT SIDE
15	IP Temp Sensor DOWN
16	IP Temp Sensor TOP
17	Be pipe RIGHTSIDE
18	WATER OUT 1 LEFT SIDE (avant)
19	Behind heater (cable kapton)
20	On side heater

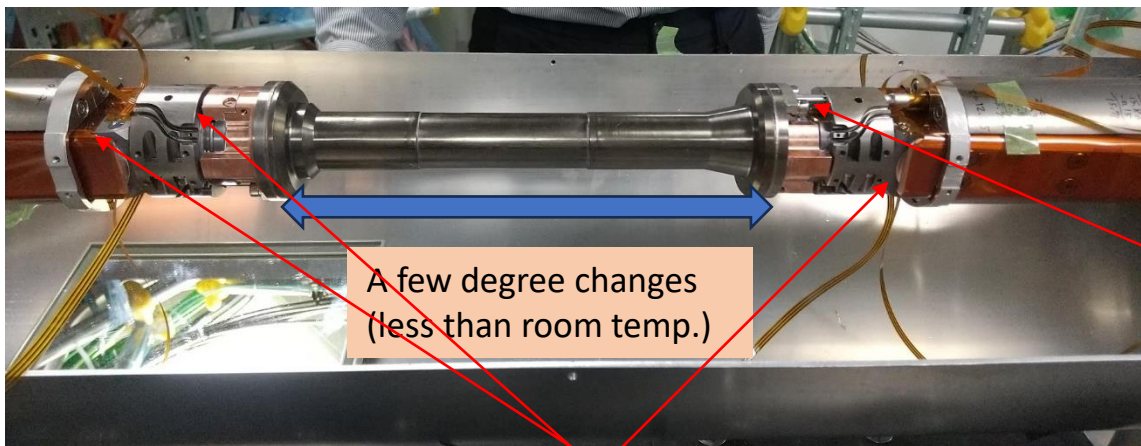


24 novembre 2022

J. Bonis- Y. Peinaud – D. Auguste

LER/HER=1000/800 mA

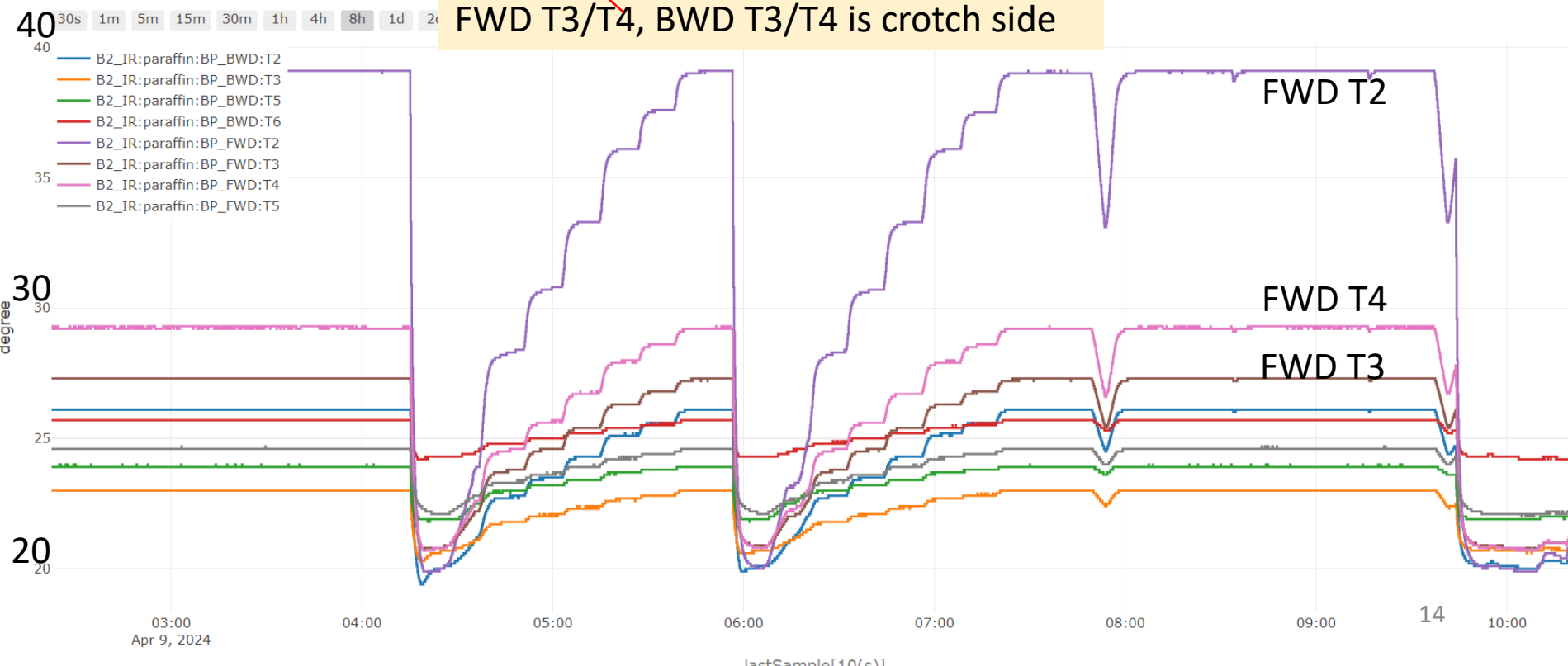
- FWD T2 is hot spot (~39 degrees) :



We confirmed the hotspot at FWD

Hot spot (FWD T2)
The same as phase 3 run

FWD T3/T4, BWD T3/T4 is crotch side



Summary

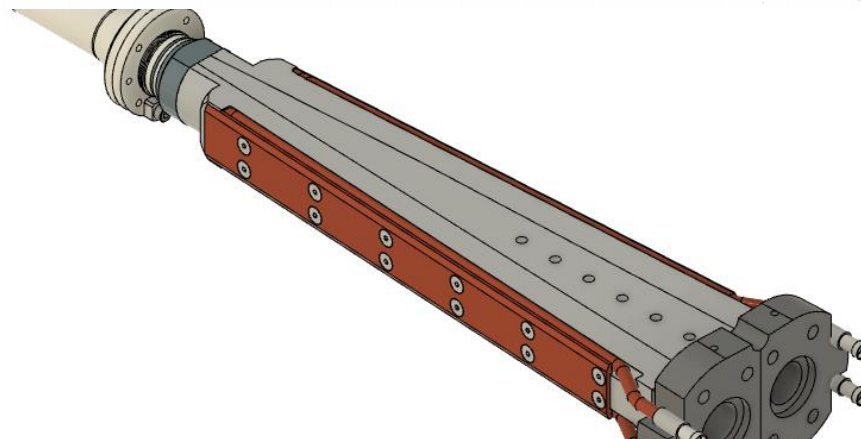
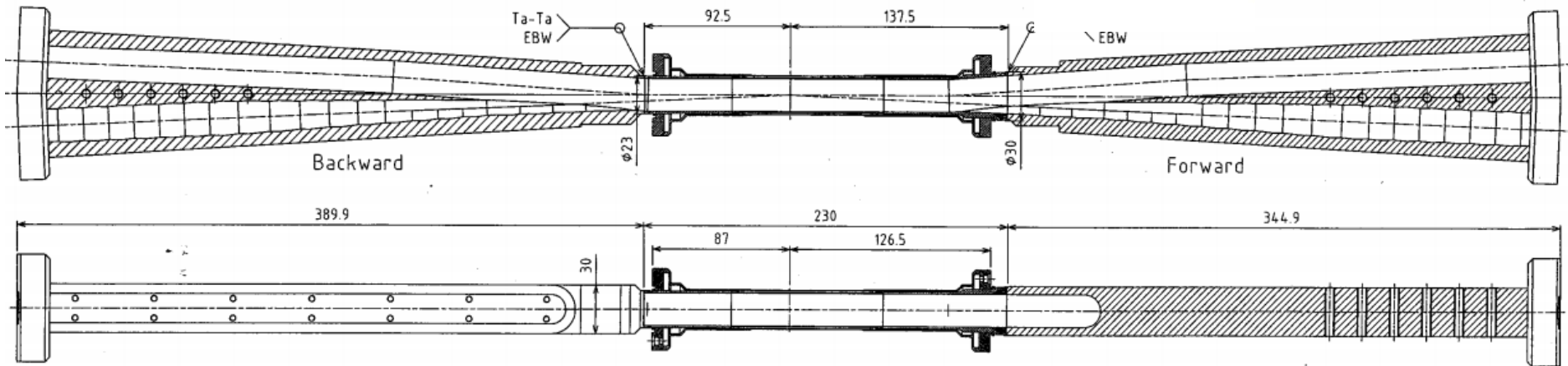
- In order to achieve the initial goal of 50 times the integral luminosity of KEKB, we are considering renovating the Belle II detector and the Interaction Region during a second Long Shutdown (LS2) period.
- Currently there are two scenarios:
 1. **(Option 1)** Keeping borders btw. each component (minor modification):
 2. **(Option 2)** Completely rebuild QCS and renovate VXD as well.
- KEK with U-tokyo and IJClab will have a joint group to discuss IR and next generation of VXD mechanics

backup

IP pipe heating

IP beam pipe heating is caused by HOM, wall current and SR (SRB, SRQ)

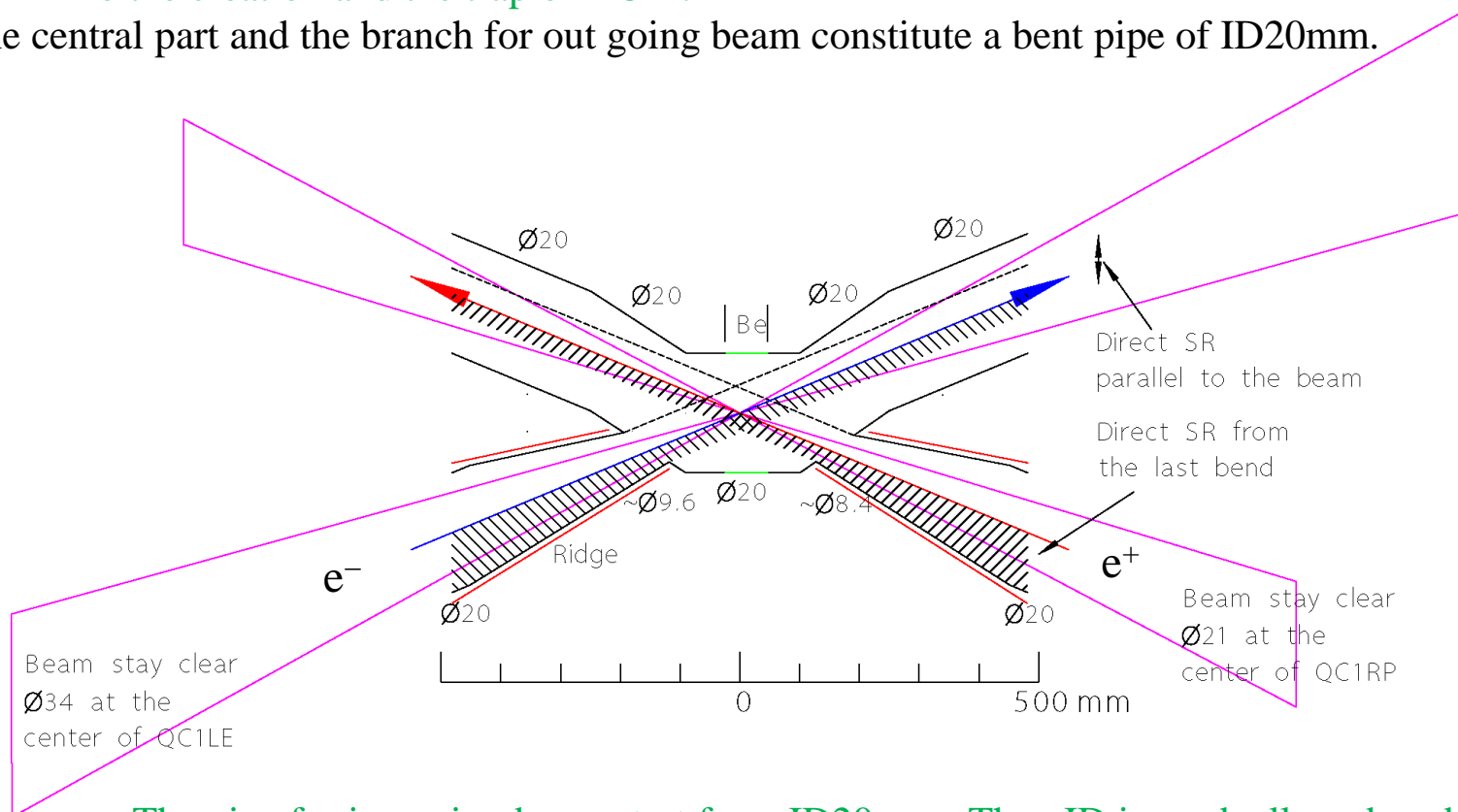
HOM is occurred by cavity shape in the pipe



4. IP Chamber

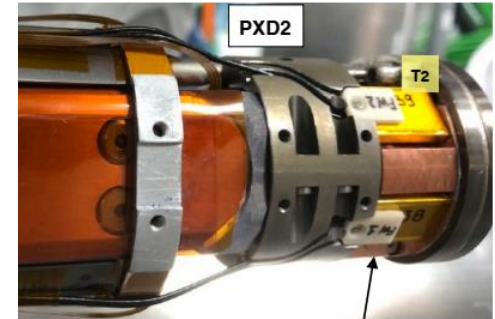
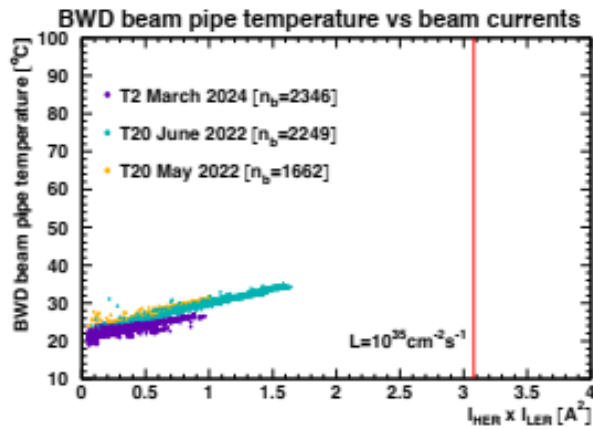
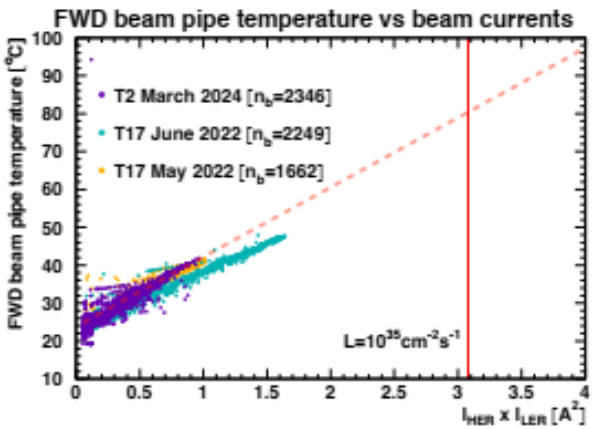
(1) Design principle of the inner shape

- Minimize the creation and the trap of HOM.
- The central part and the branch for out going beam constitute a bent pipe of ID20mm.

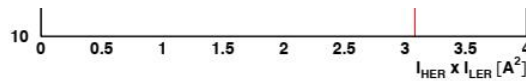
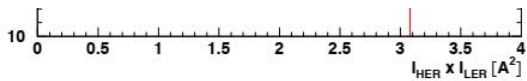


- The pipe for incoming beam start from ID20 mm. Then ID is gradually reduced to about 9 mm to stop direct SR.
- The inner surface of a pipe for incoming beam has ridges to prevent scattered light from hitting the central part.

Correlation of Temperature Increase with Beam Currents 2022 vs 2024

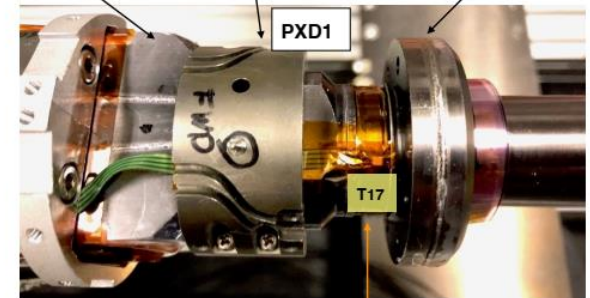


New cooling block (FWD and BWD)

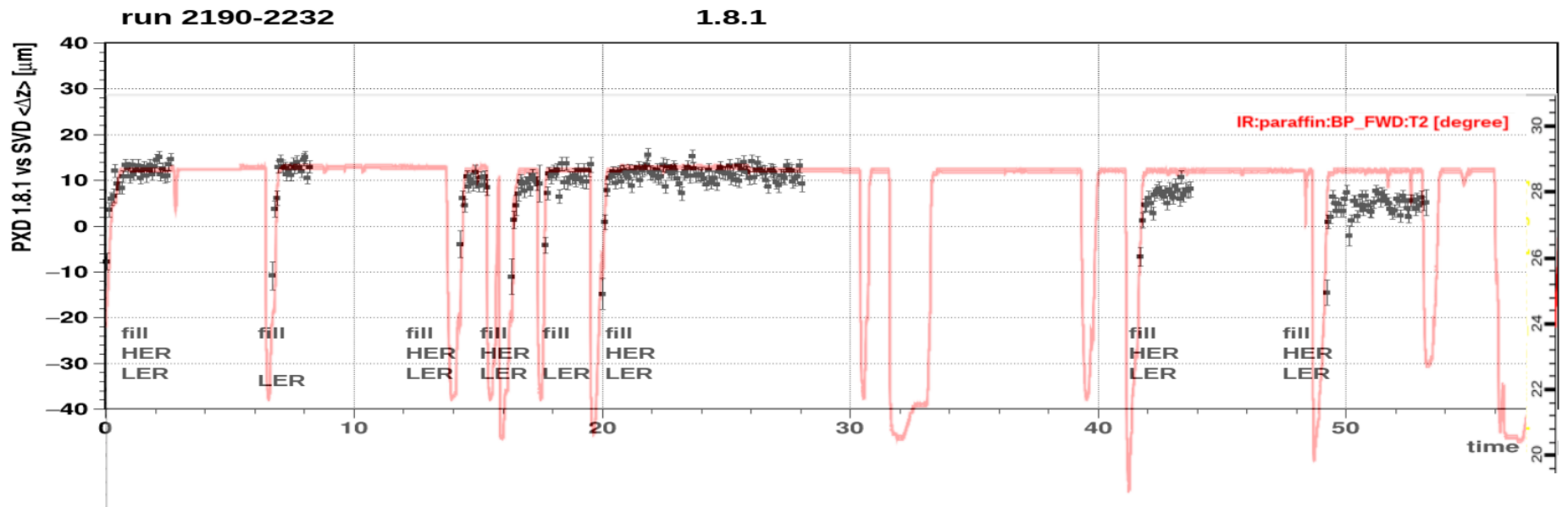
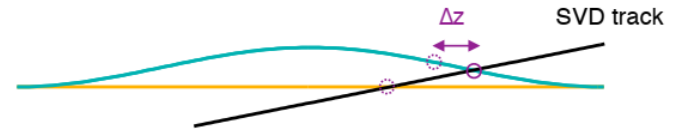


- Expectations from beam related heat sources
 - Higher Order Mode (HOM) $P_{HOM} \propto q_{bunch}^2 / \Delta t_{bunch} = I_{beam}^2 \Delta t_{bunch} \propto I_{beam}^2 / n_{bunch}$
 - Wall current $W_L / L \propto q_{bunch} I_{beam} / \sigma_z \propto I_{beam}^2 / (n_{bunch} \sigma_z)$
 - Synchrotron radiation $P_{SR} \propto E_{beam}^4 I_{beam}$
- Empirically find best correlation of temperature with beam current product
 - only weak dependence on n_{bunch}
- Different behaviour between FWD and BWD compared to 2022
 - BWD: lower temperature level and reduced rate of increase → new cooling seems to help
 - FWD: steeper temperature rise with beam currents in 2024

Crotch part water cooling PXD mount block IP chamber paraffine cooling



L1 Ladder Bowing in March 2024

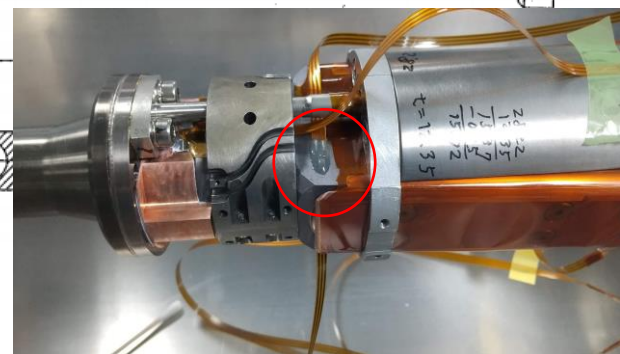
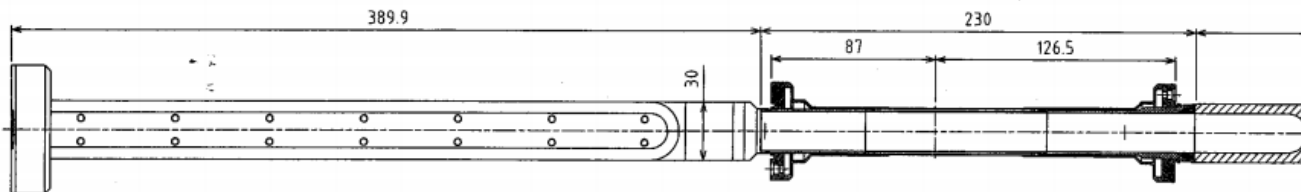
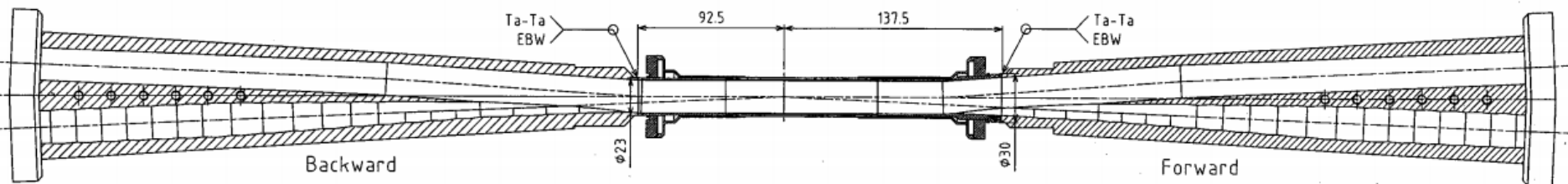
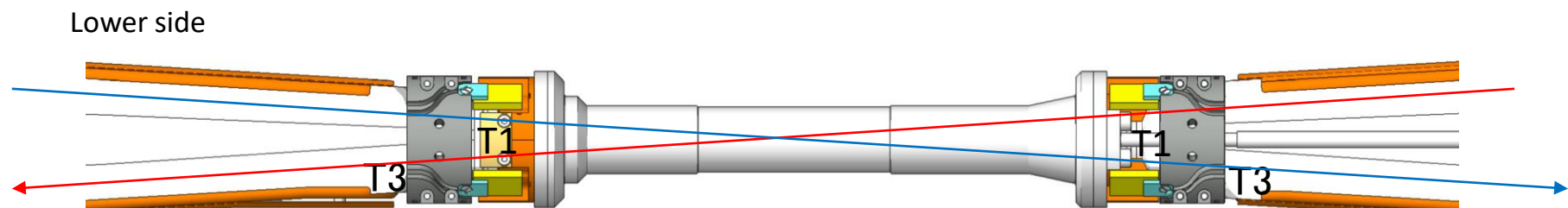
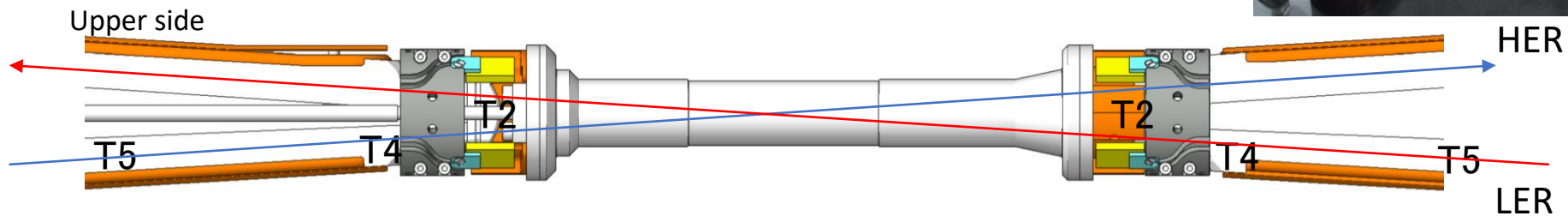


~10 μ m shift in z

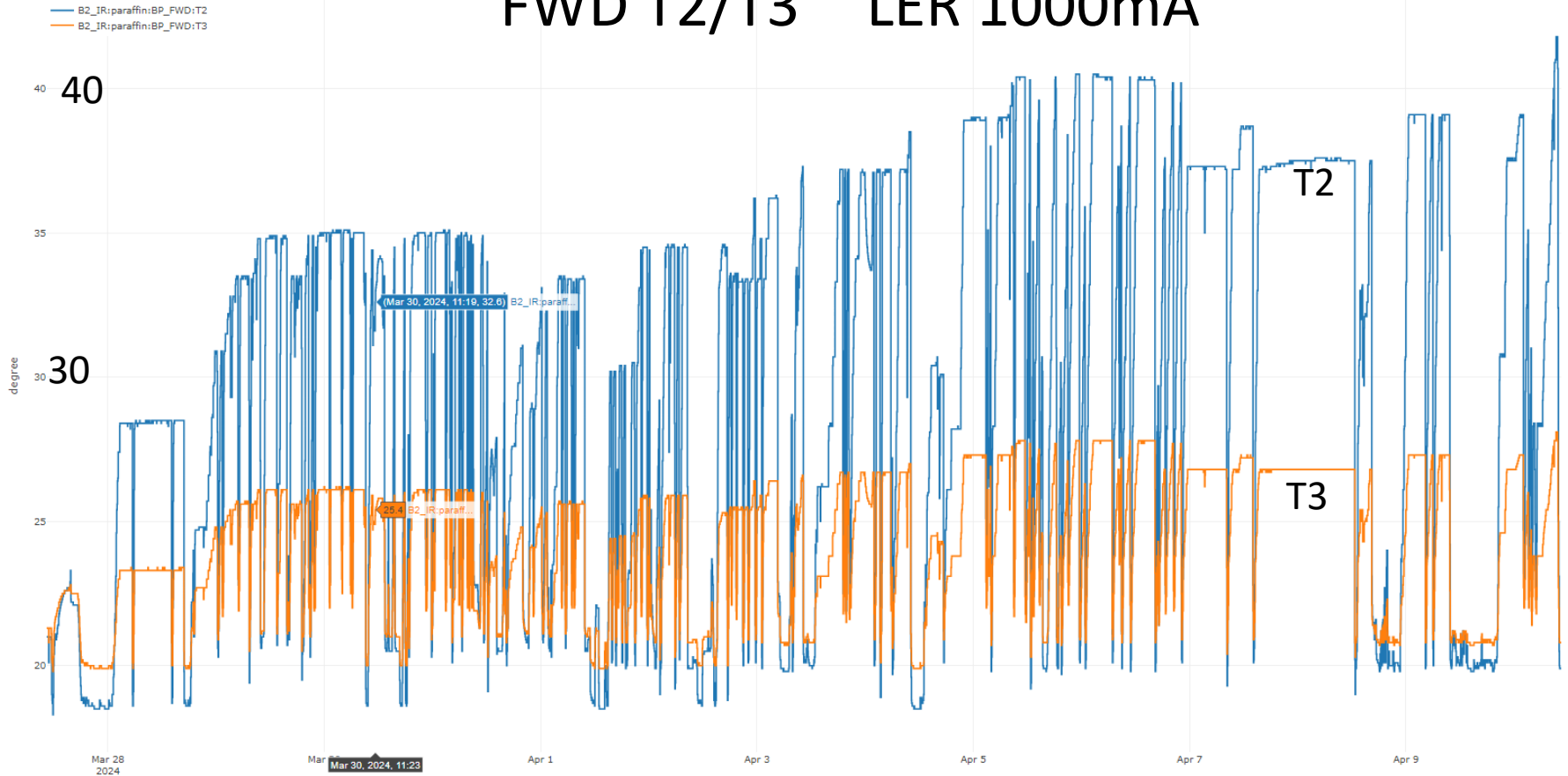
BP temp. sensors

BWD

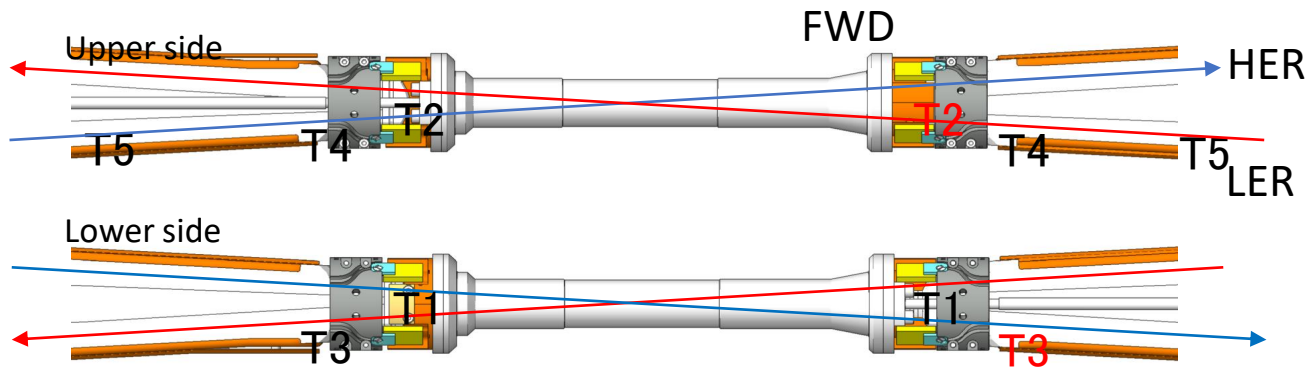
FWD



FWD T2/T3 LER 1000mA

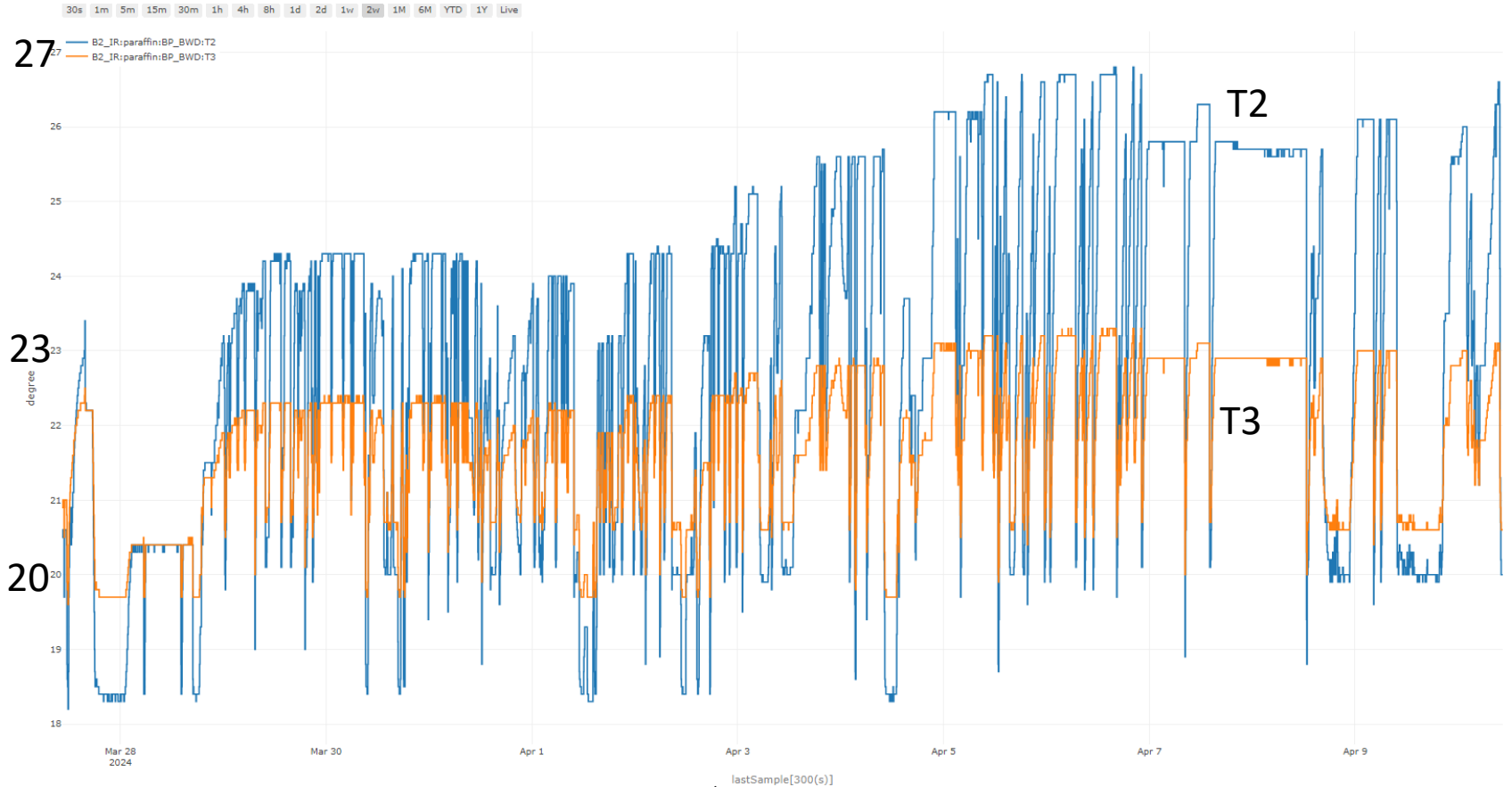


FWD T2(IP side from PXD mount block) is higher than FWD T3(QCS side)

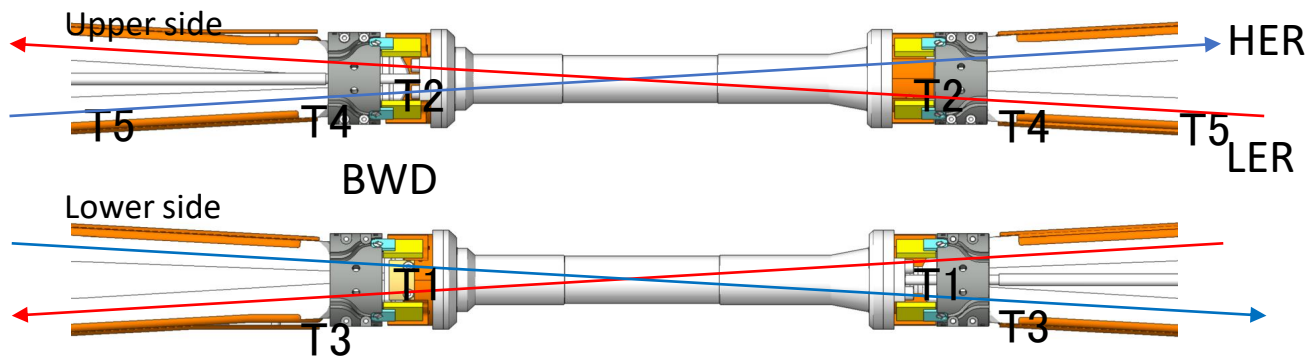


BWD T2/T3 LER 1000mA

EPICS Archiver Appliance Viewer



BWD T2(IP side from PXD mount block) is higher than BWD T3(QCS side)



Rough deformation estimation

LER 800mA						
2024/3/25						
material	location	Length	Thermal expansion coefficient	Temp. at Beam off	Temp at Beam On	Displacement(um)
Be	IP	80	12.4	23.5	25	1.488
Ti	IP	140	8.4	23.5	25	1.764
Ta	IP BWD	30	6.4	18	25	1.344
Ta	IP FWD	30	6.4	20	34	2.688
					Sum	7.284

LER 1000mA						
2024/4/10						
material	location	Length	Thermal expansion coefficient(^10-6)	Temp. at Beam off	Temp at Beam On	Displacement(um)
Be	IP	80	12.4	23.5	26	2.48
Ti	IP	140	8.4	23.5	26	2.94
Ta	IP BWD	30	6.4	18	27	1.728
Ta	IP FWD	30	6.4	20	40	3.84
					Sum	10.988

Current observation

- BWD side heating is no issue(very small).
- FWD side heating should be mitigate
 - This heating seems basically by SRQ
 - Only a mitigation option is shorter IP pipe for future higher beam current.
 - Silicon sensor should not be attached if it is sensitive to the temperature, because it is very difficult to predict hotspots.