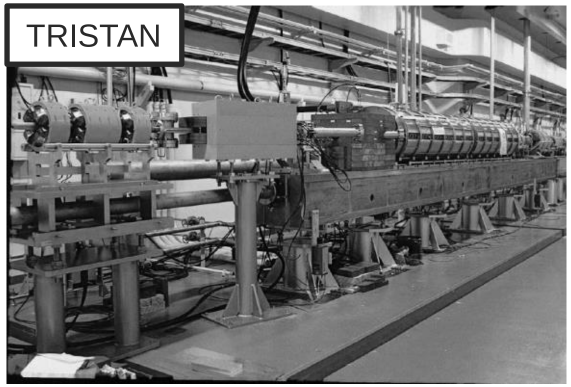
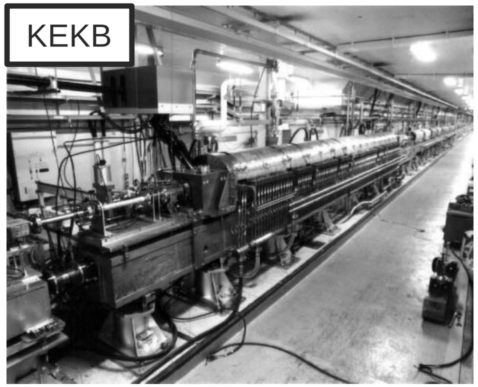
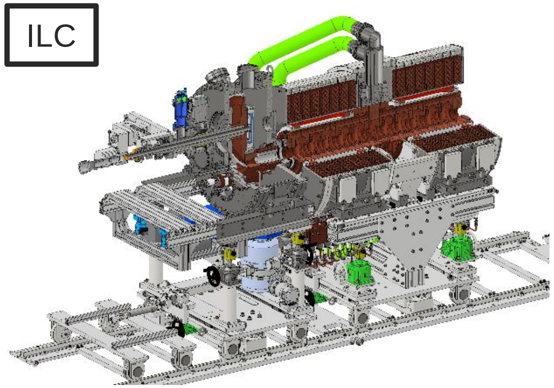
Positron source design and experiment for FCC, SuperKEKB and ILC

Y. Enomoto
On behalf of KEK iCASA positron group







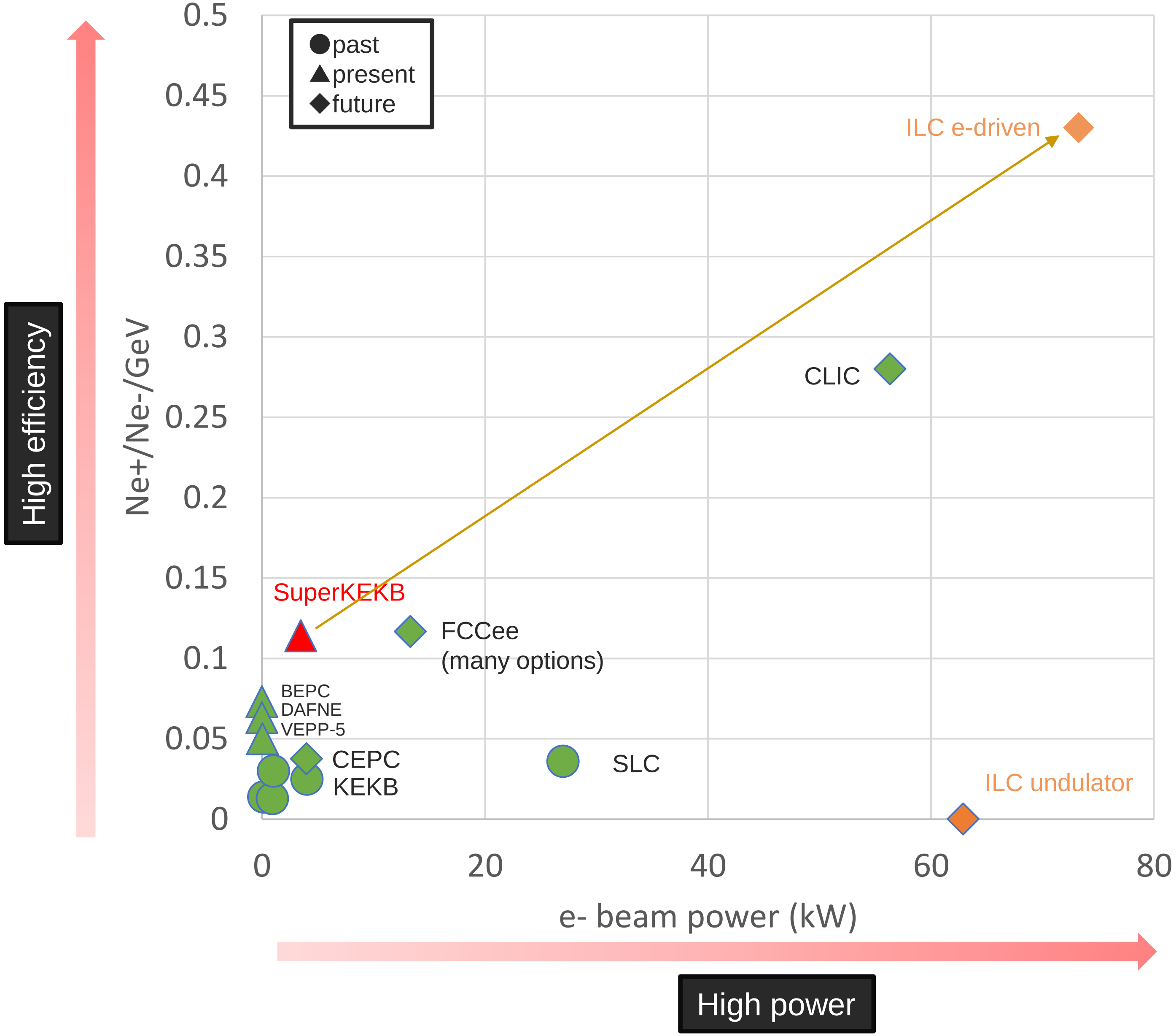
This work was supported by【MEXT Development of key element technologies to improve the performance of future accelerators Program】Japan Grant Number JPMXP1423812204.

Contents

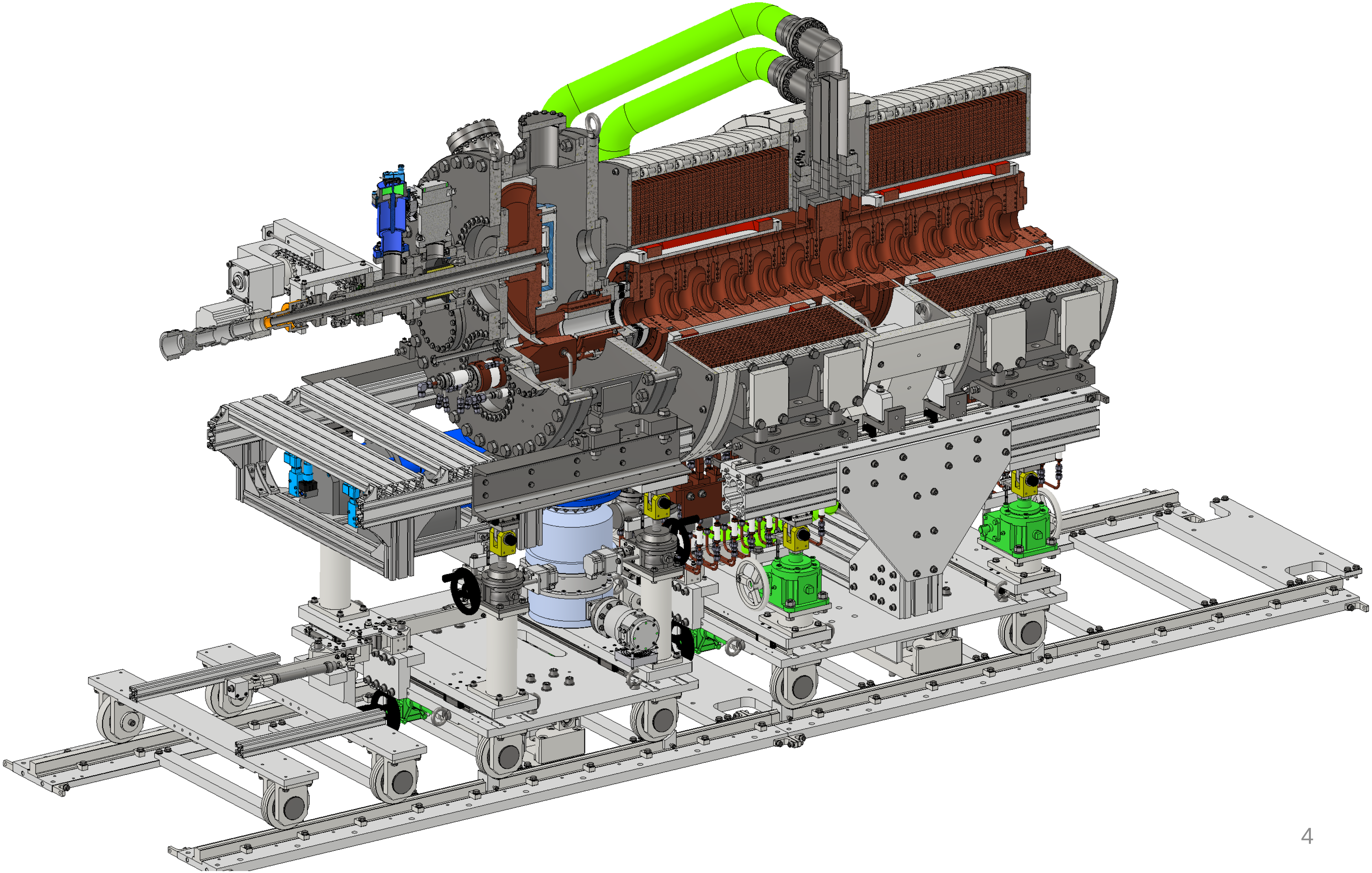
- Progress and status of the electron driven positron source for ILC
- Beam tuning study and operation experiences of SuperKEKB
- Collaboration with FCC

Comparison of positron sources

	SKEKB	ILC	FCC
e- energy	3.2 GeV	3 GeV	
e- charge/bunch	10 nC	3.7 nC	
Repetition	50 (25) Hz	5 Hz	
Num. bunches	2	1320 = (33+33) x 20	*Many options*
Total charge / s	1000 (500) nC	24667 nC	
Beam power on target	3.2	74	
yield	0.4	1.3	

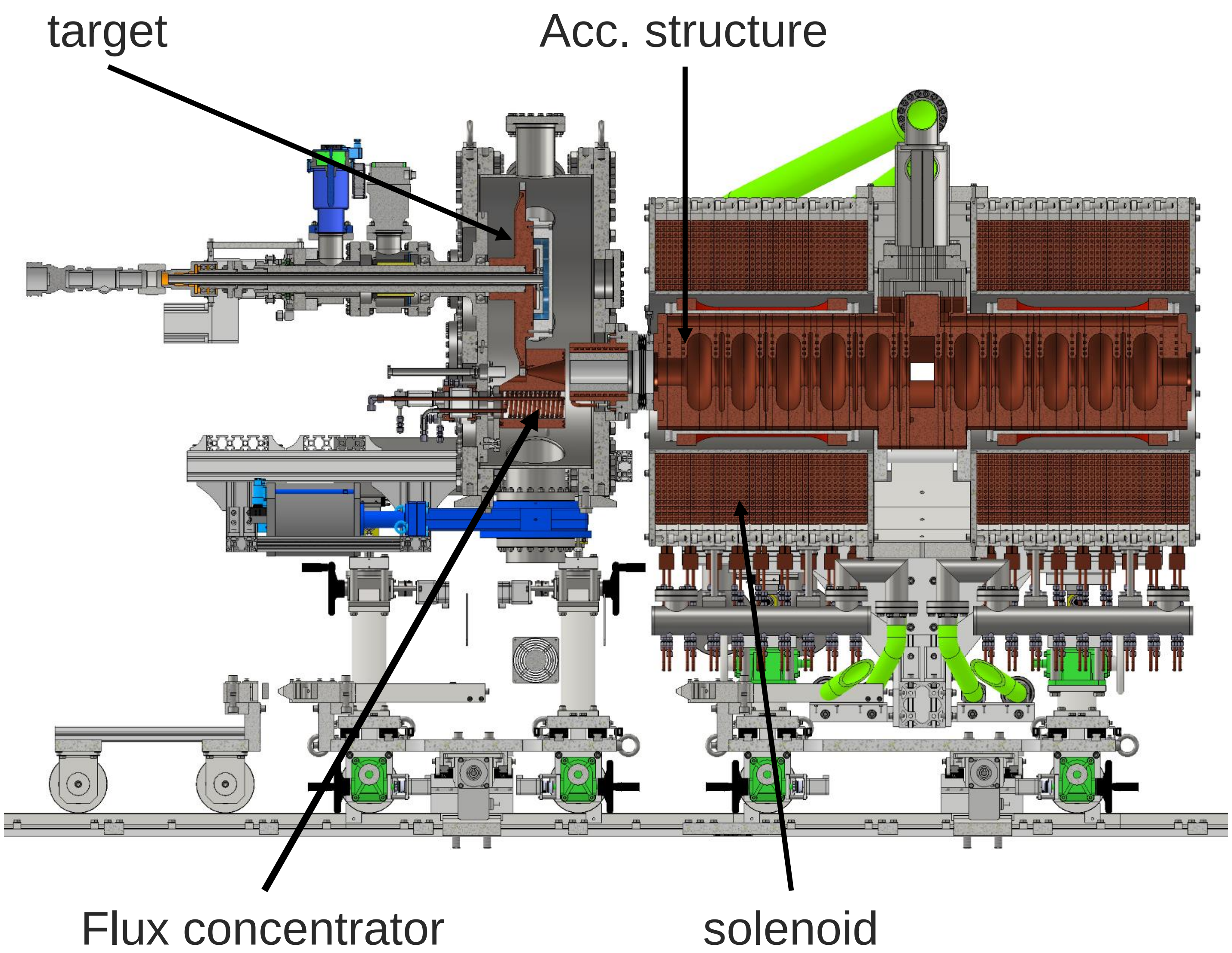


Progress and status of the electron driven positron source for ILC



Prototype to be built by JFY2027

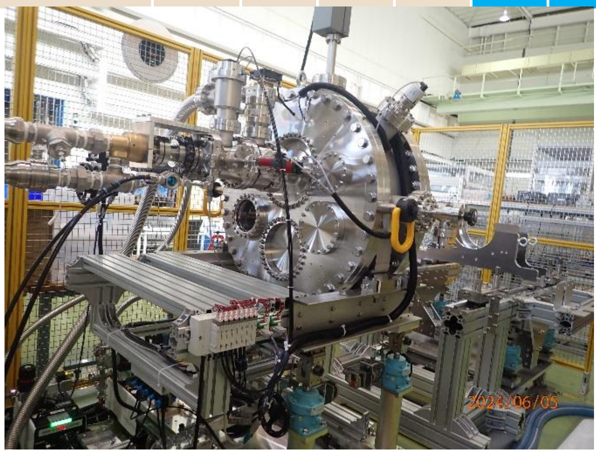
- Project started Sep. 2022
- Grant from MEXT during JFY2023 and JFY 2027
- Build prototype in KEK
- Prepare 3D model, drawings, EDR



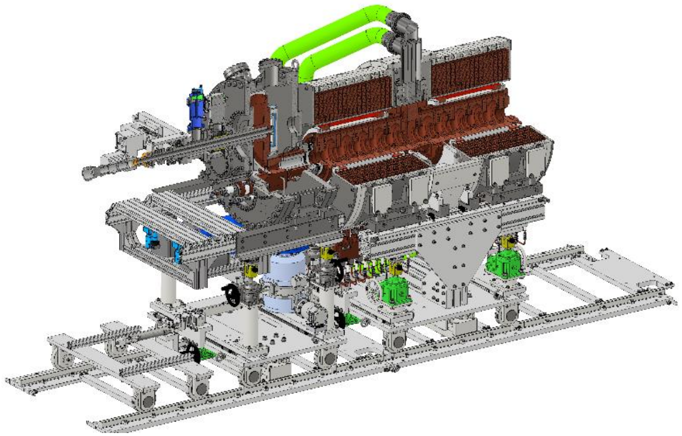
5 years-plan(as of 2024/3/28)

FY		2022		2023				2024				2025				2026				2027			
year			2023				2024				2025				2026				2027				
Quarter		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Test bench																							
High power test bench																							
W-Cu connection																							
Target unit	Rotation mechanis m																						
	Disk																						
FC base	1st unit																						
magnet	Solenoid																						
	Power supply																						
Chamber, vacuum, support																							
Acc. structure	1st unit																						
FC power supply																							

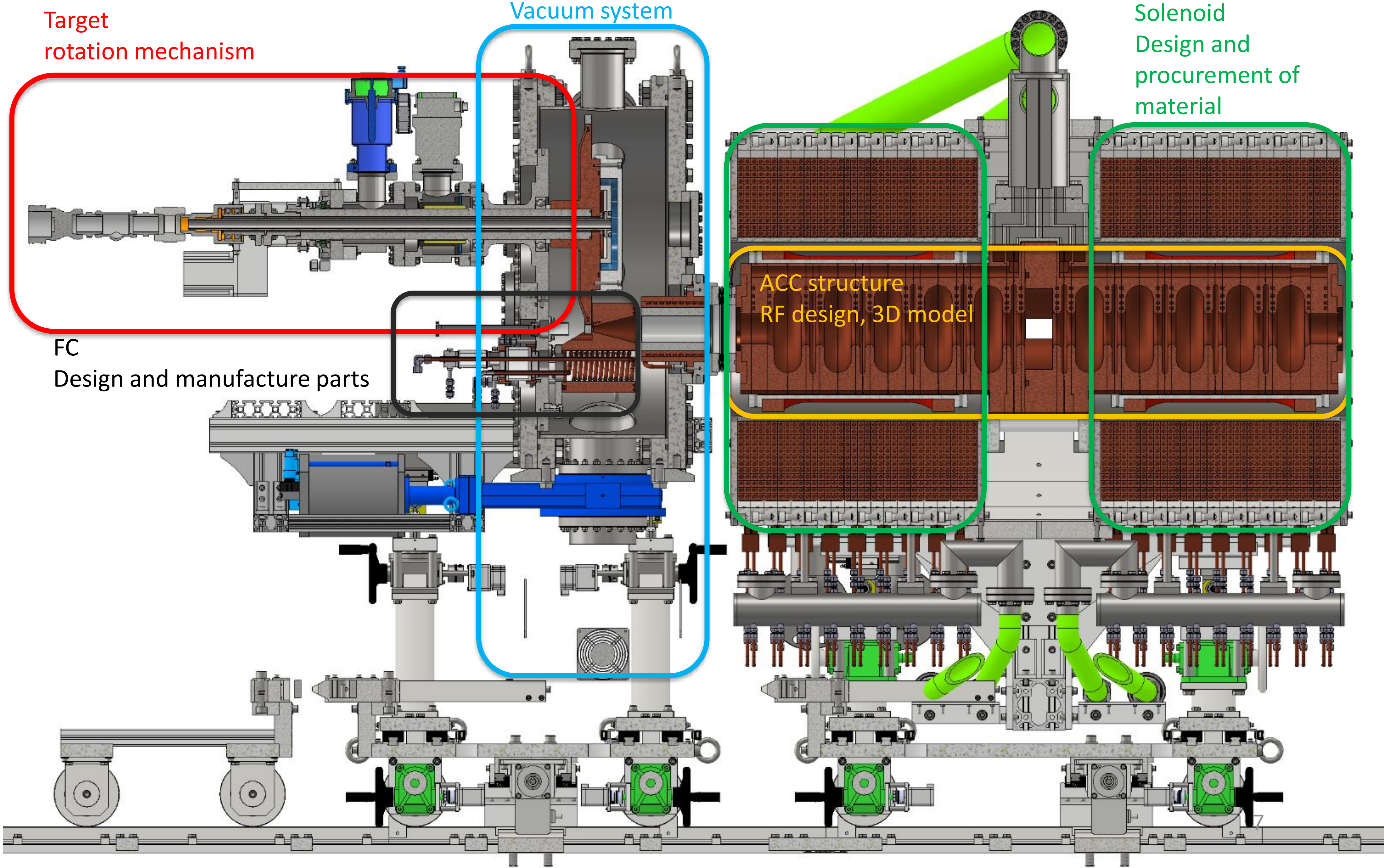
Design
Manufacuring
test



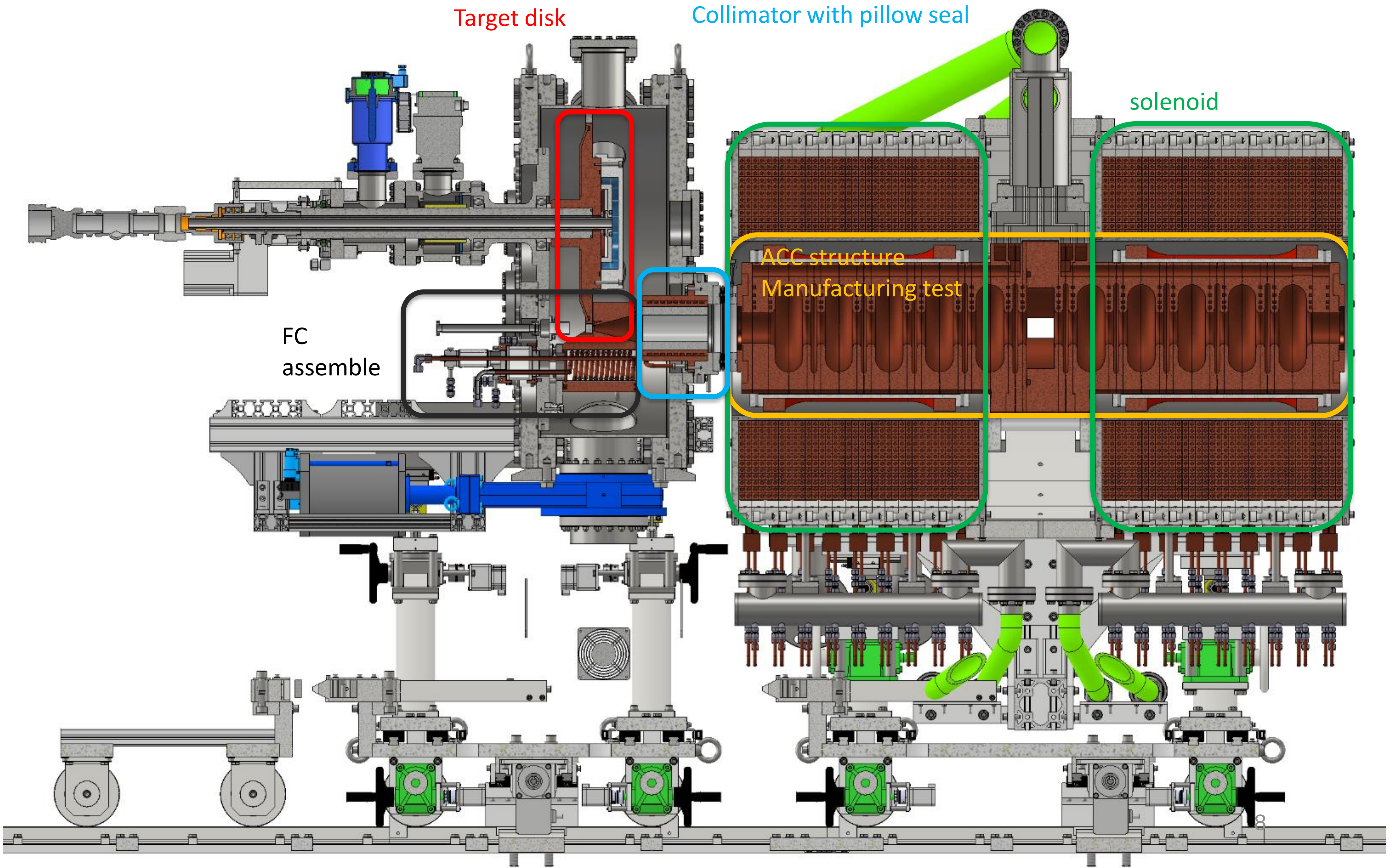
Now!



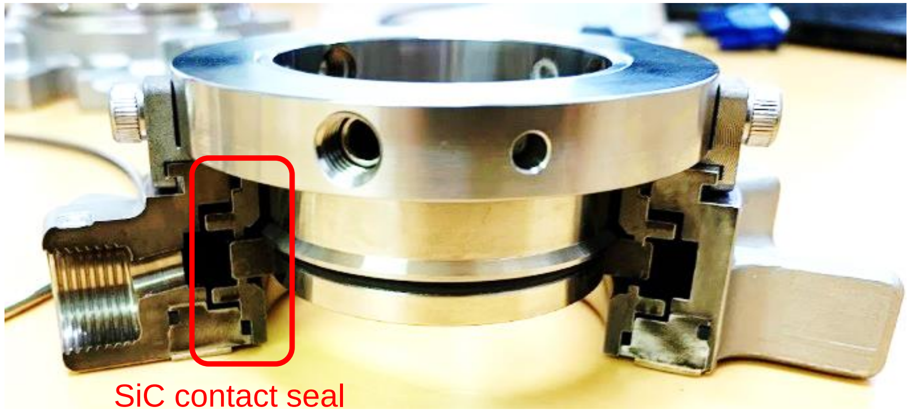
What we did in JFY2023

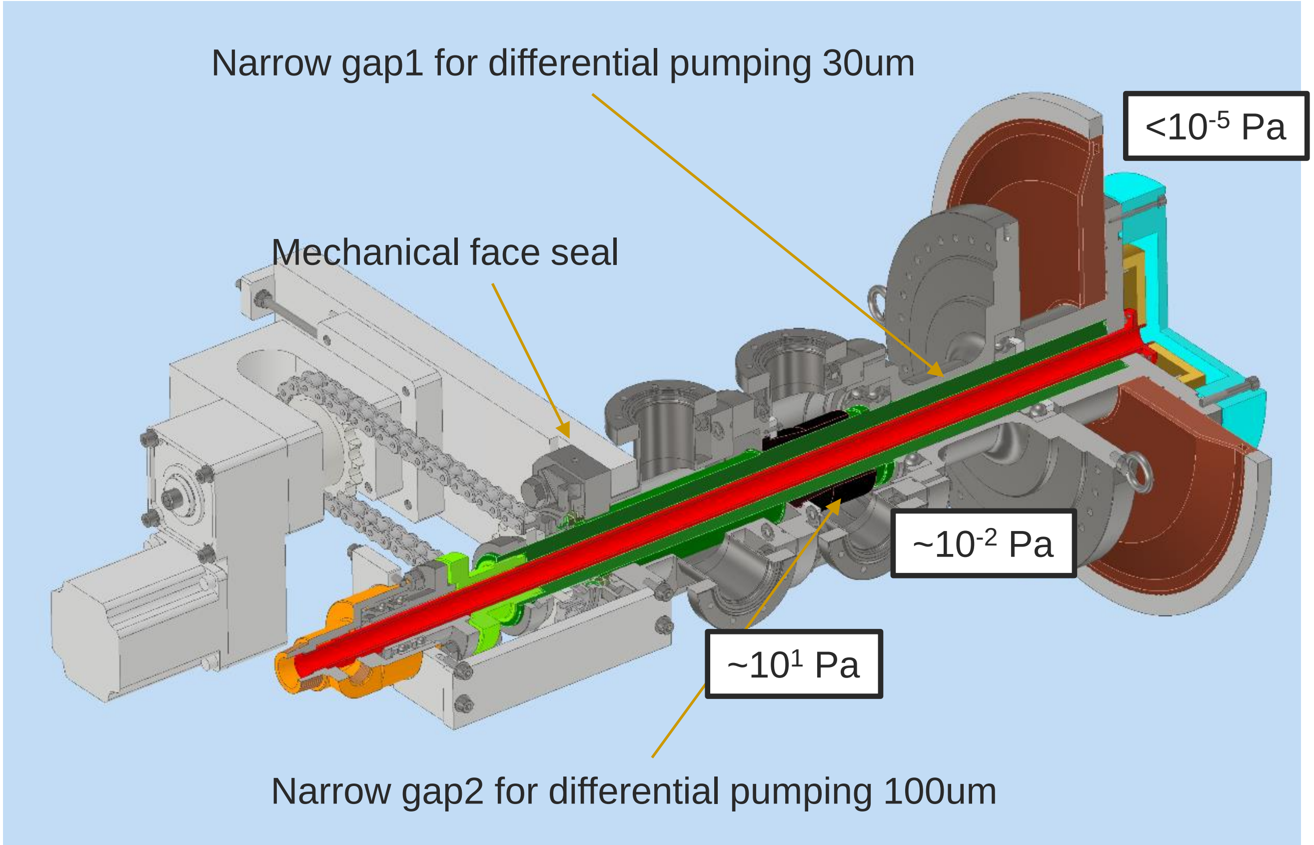


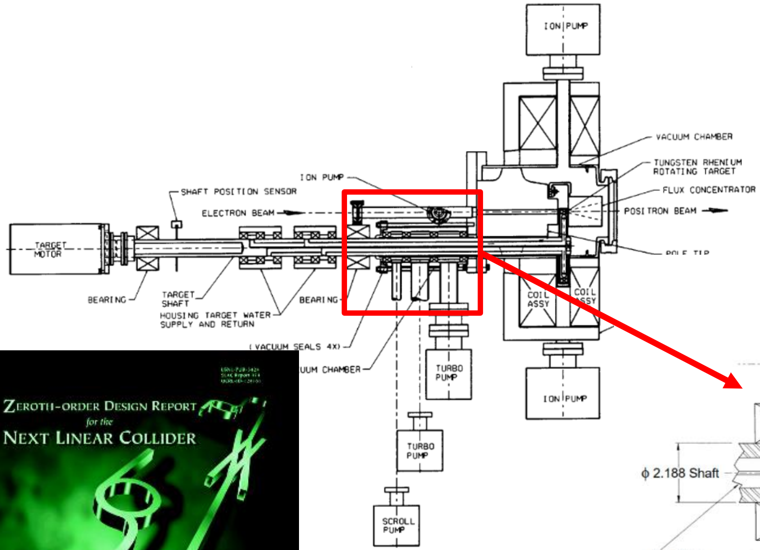
What we plan to do in JFY2024



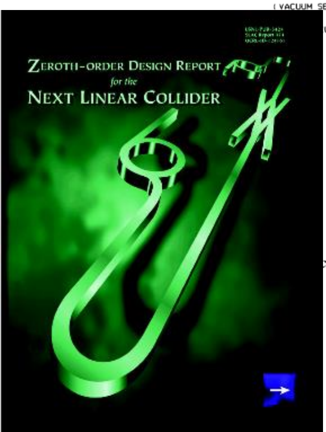
Rotating Target - concept







...hematic of the NLC positron target system.



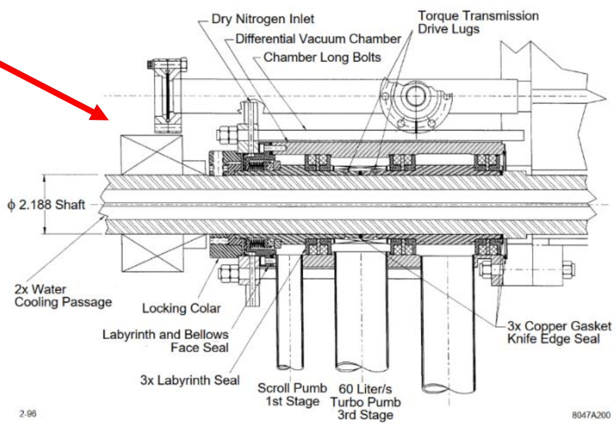
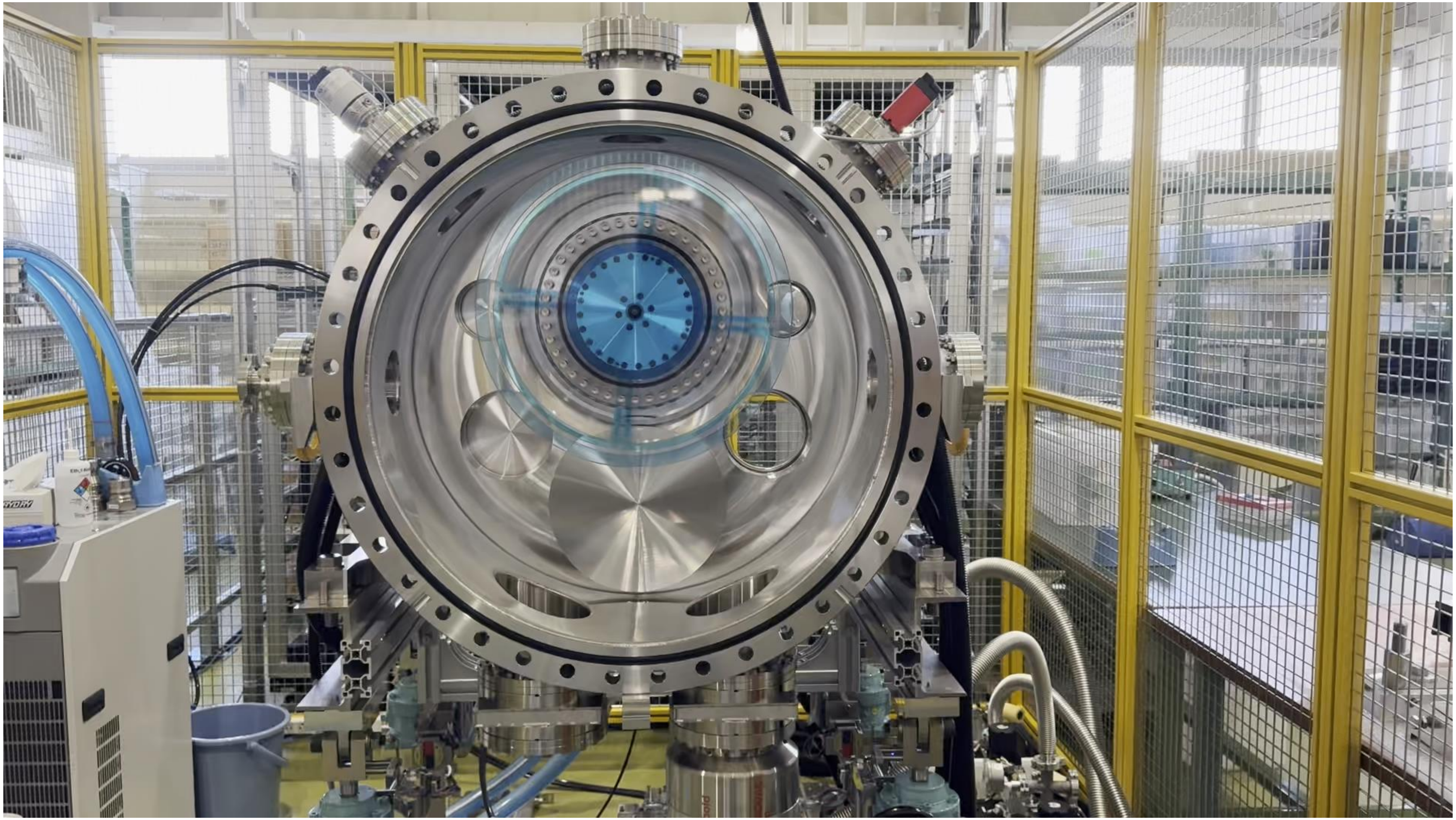


Figure 3-6. *NLC rotating target differential vacuum vacuum chamber and seals consept.*

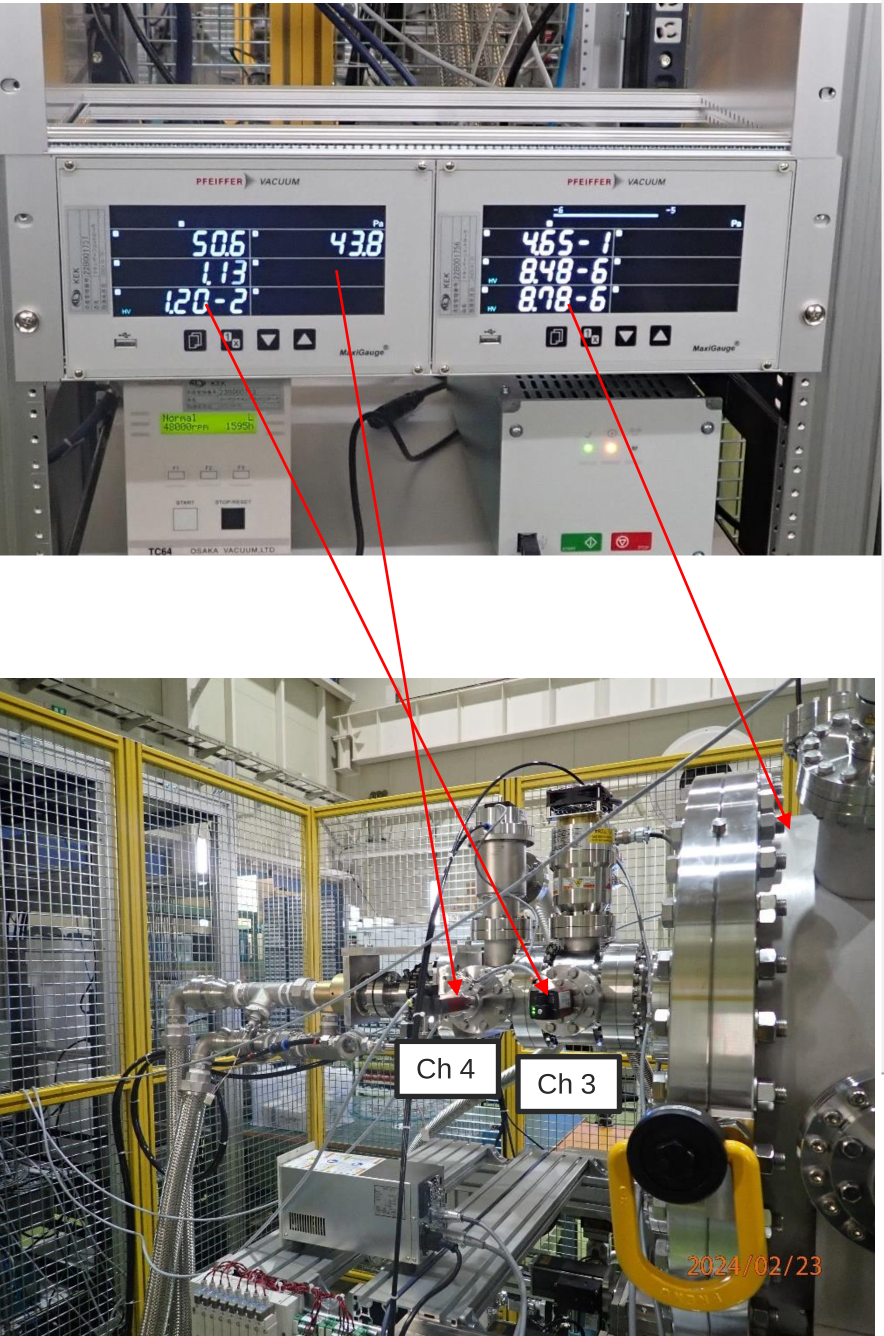
- Mechanical face seal and 2 stage differential pumping with very narrow gap (30 um, 100 um)
- Idea from design report of NLC

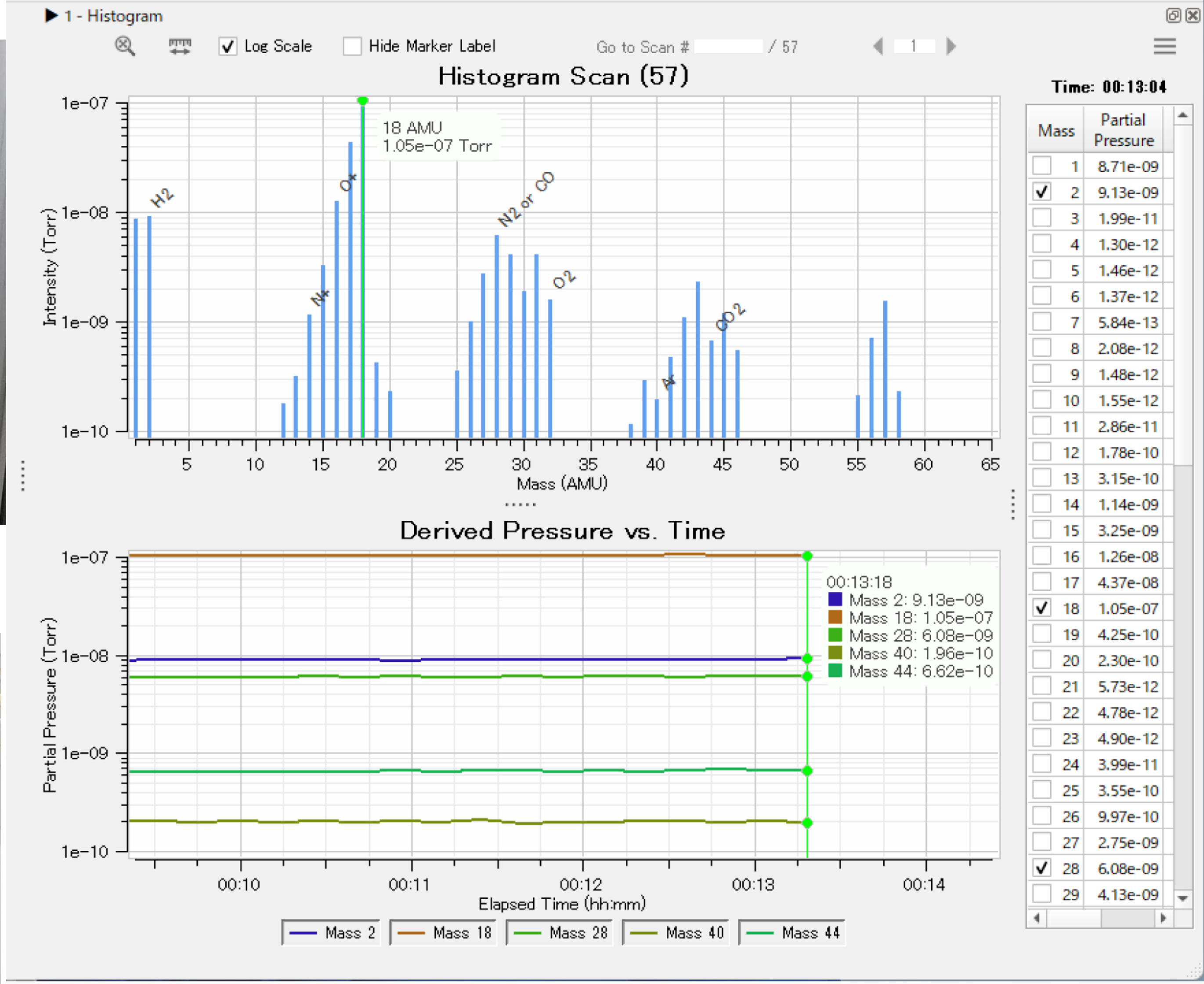
Rotating target - Rotation test with dummy disk



Cooling Water is flowing
Rotation speed is slower than design value

Rotating target Vacuum test w target

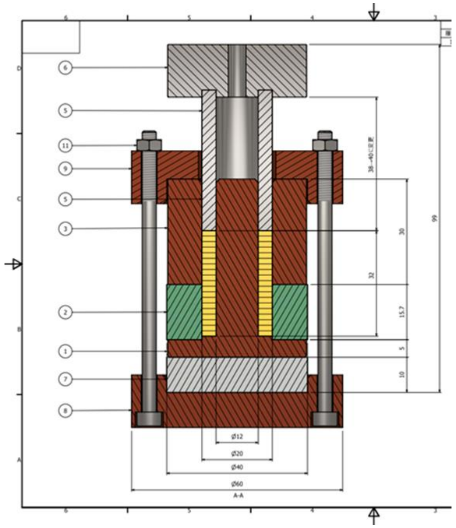




No significant pressure rise during rotation
Differential pumping works as designed

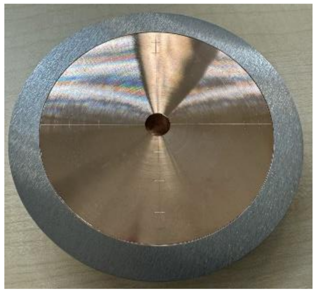
Rotating target - Bonding test of W-Cu

- W-Cu bonding is one of a challenge
  - Very different properties, melting point, thermal expansion…
- Bonding test by Φ40 and Φ100 W rings
  - Final disk size is Φ500
- Tested boding method
  - SPS(Toho)
    - Not good result till now
  - HIP(MTC)
    - Ongoing
  - Pressed fit with Li-Nitrogen (KEK)
    - Use this method for 1st prototype(Φ500)
    - Detail thermo-mechanical simulation to optimize interference and disk size



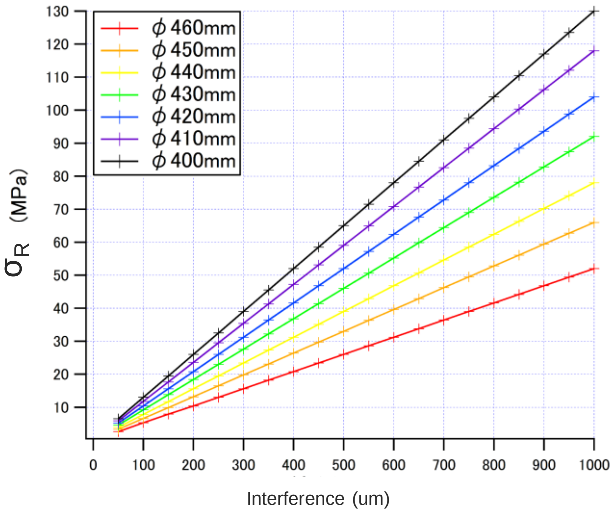


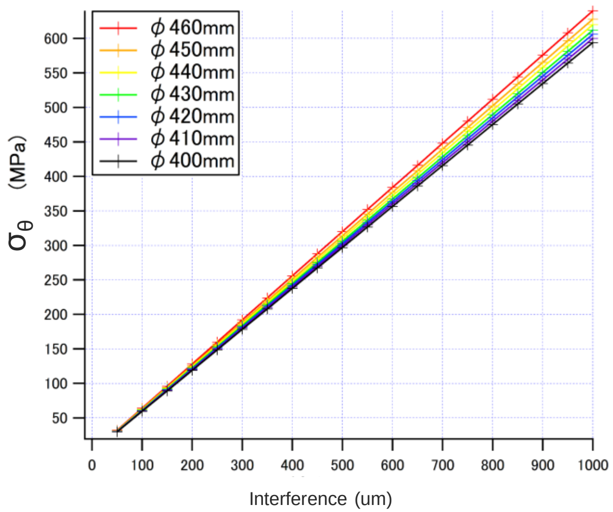


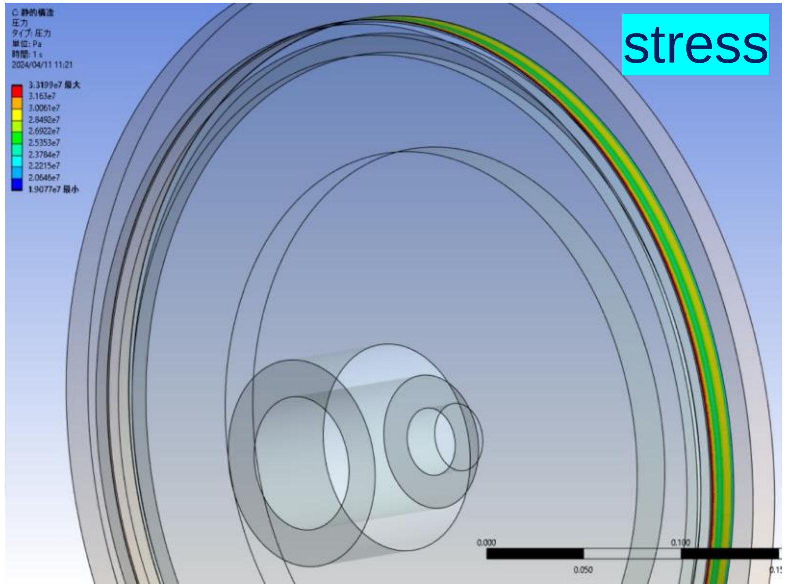


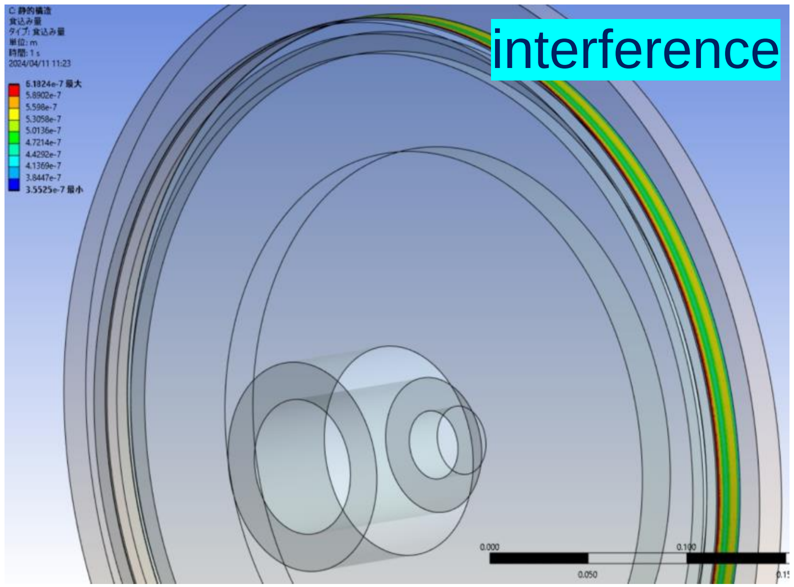
Rotating target – thermomechanical simulation

- Ansys Contact simulation by Y. Morikawa
- Parameter
  - Diameter of W ring / Cu disk
  - Diameter of cooling water pass
  - Initial interference









Thermal contact is dependent on σ_R
Larger interference → larger σ_R
thicker W ring → higher stiffness → larger σ_R

$$k_{TE} = \frac{1}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2}} \frac{p_m}{H_{min}} + \frac{\lambda_f}{\delta_1 + \delta_2}\left(1 - \frac{p_m}{H_{min}}\right) \quad \text{(Tachibana's equation)}$$

$P_m = \sigma_R$: surface pressure

Rotating target – thermomechanical simulation

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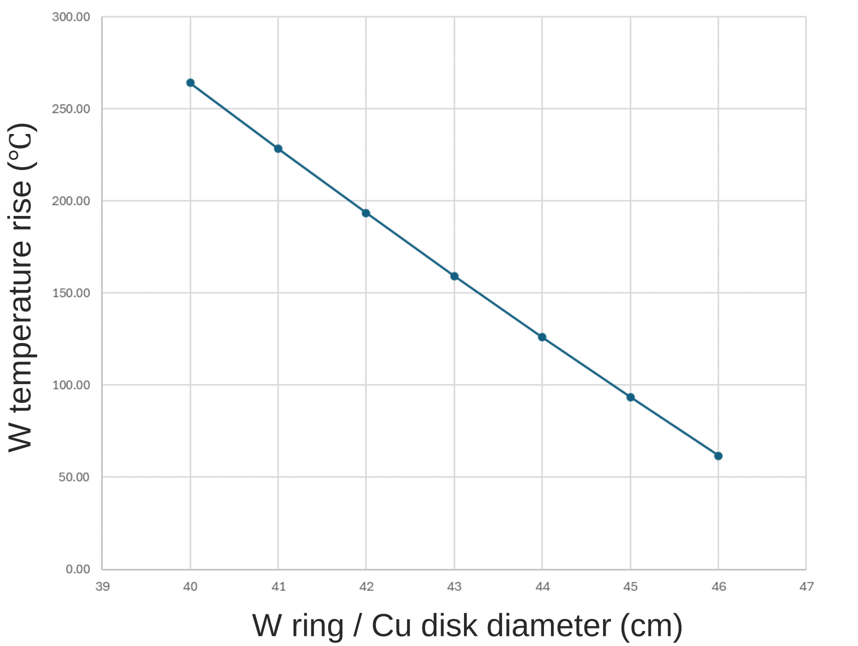
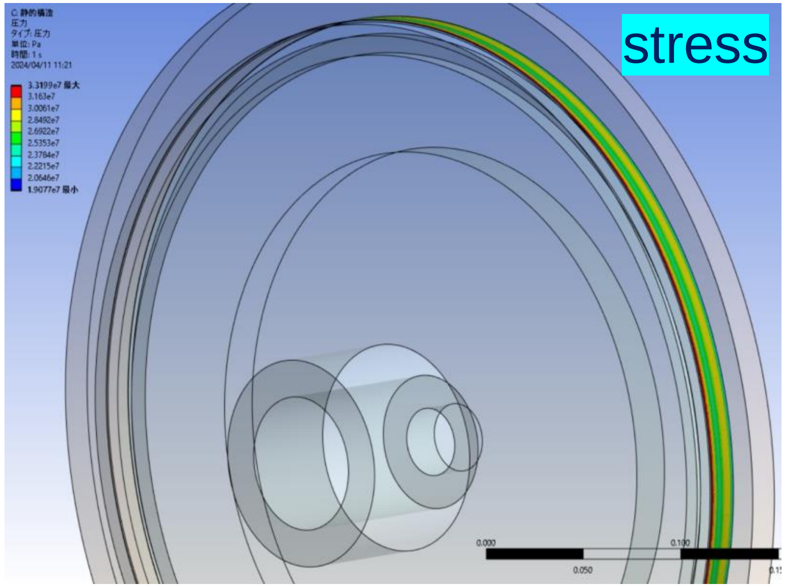
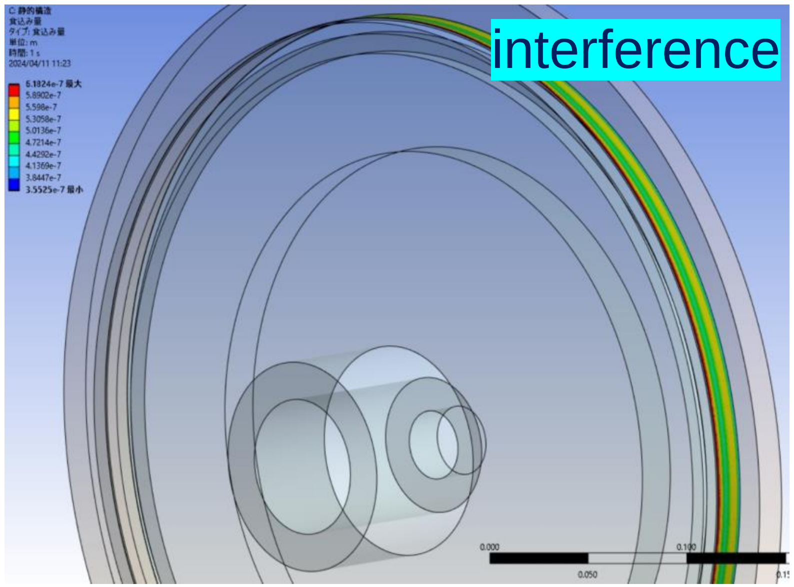


Thicker W ring → higher temperature rise
→ larger thermal expansion → smaller σ_R





Rotating target – thermomechanical simulation

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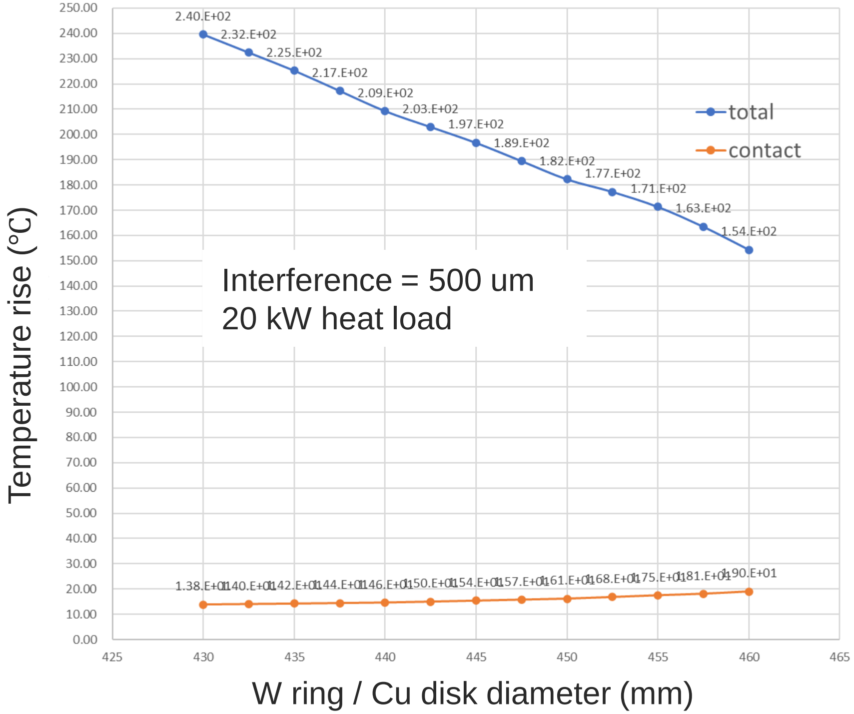
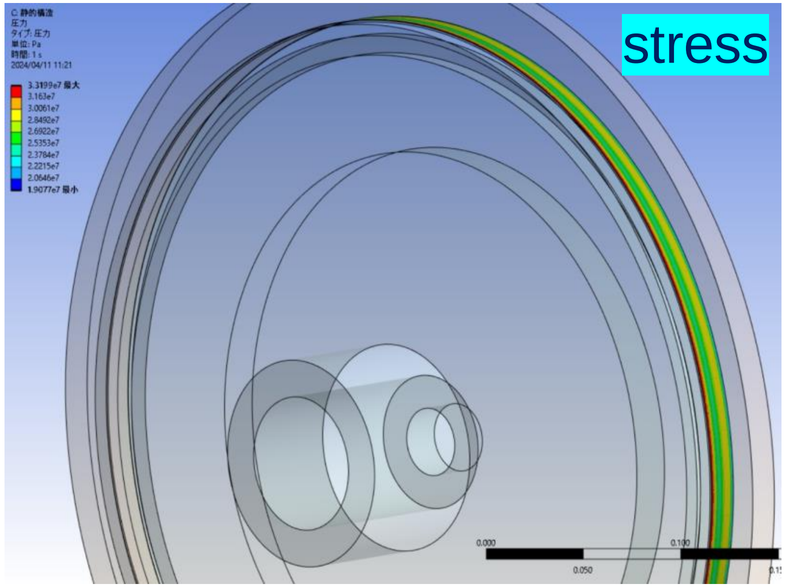
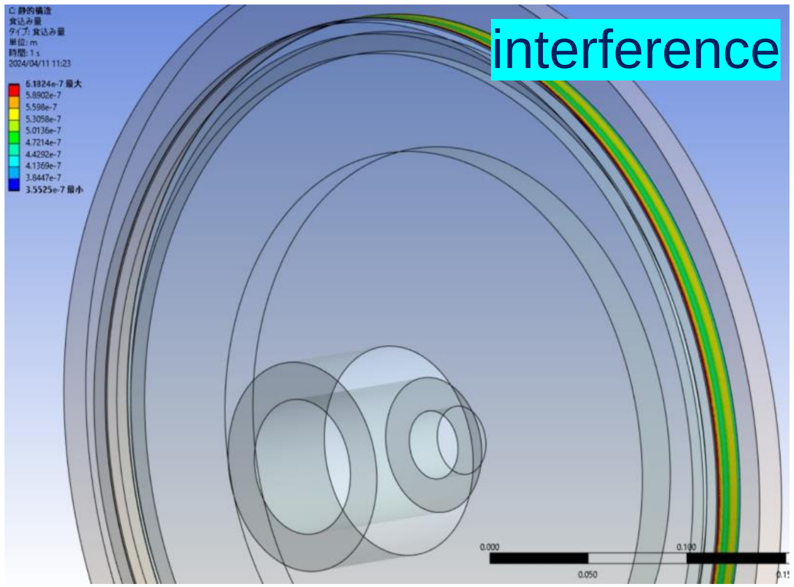
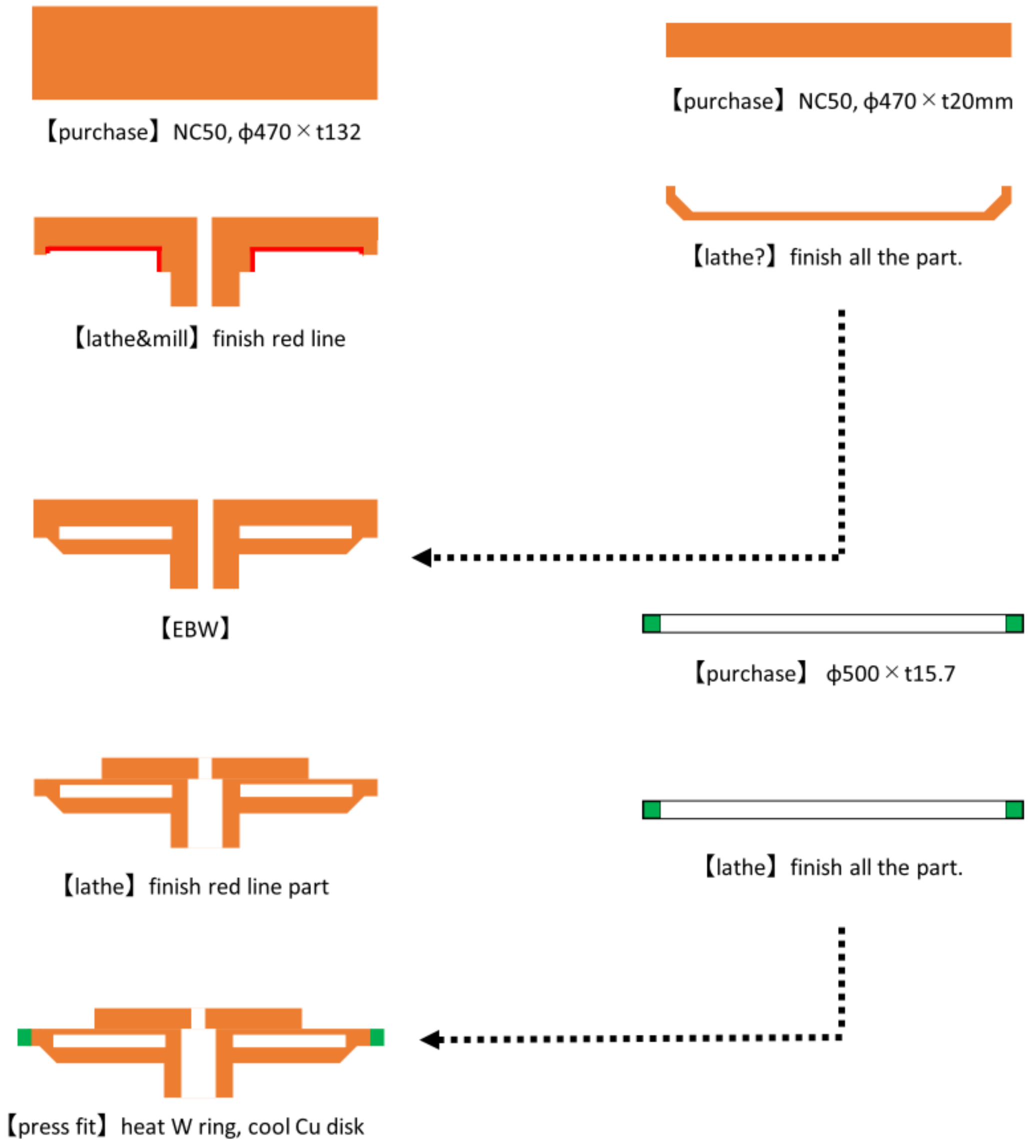


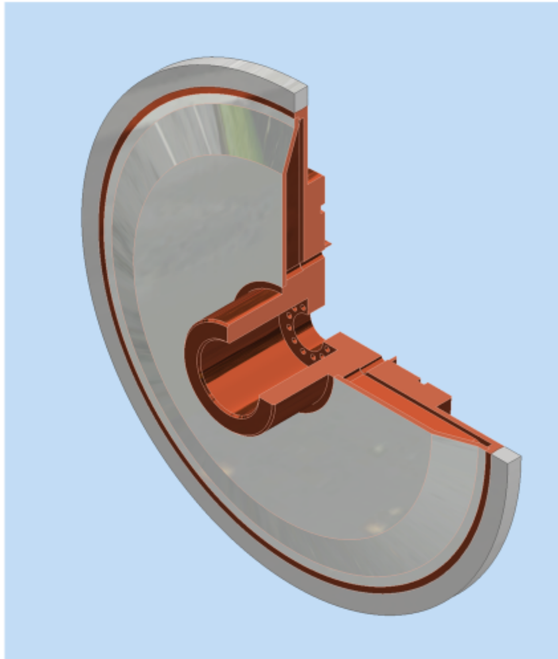
W ring / Cu disk diameter dependence of
Temperature rise @ contact << total temperature rise
→highest cooling layout is better





Rotating target –target disk prototyping





- 【Purchase】: Cu alloy (NC50) delivered
- 【lathe & mill】~June
- 【EBW】~July
- 【lathe】~August
- 【Press fit】with W ring ~ September

FC - concept

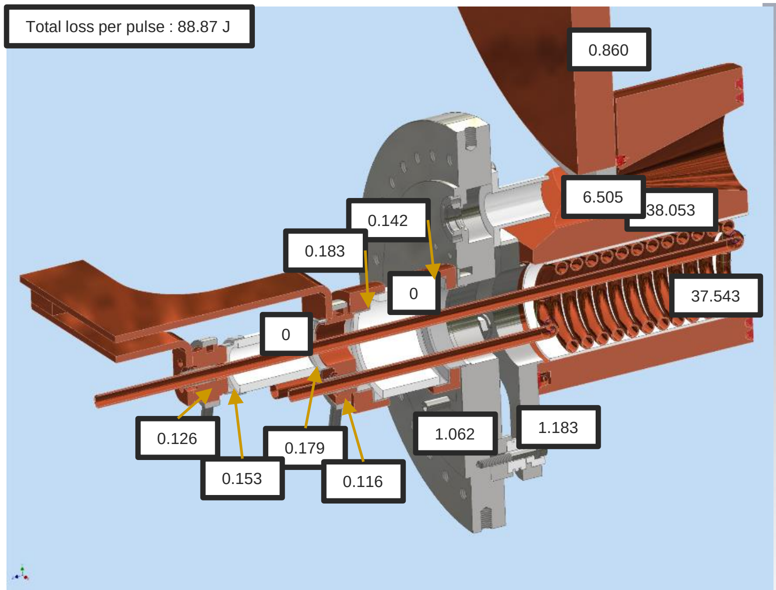
- Basic design and concept are the same as ones used in the previous project, SLC and SuperKEKB
- Engineering design to satisfy requirement, especially cooling mechanism is important
  - Simulation using CST
    - Method was established and validated through the design of FC for SuperKEKB
    - Cooling water path design
    - Heat resistant materials
      - CuCr (SH-1)
- High power pulsed power supply
  - Energy recovery type might be necessary to satisfy requirements
    - Design JFY2024
    - Prototype JFY2025 and 2026

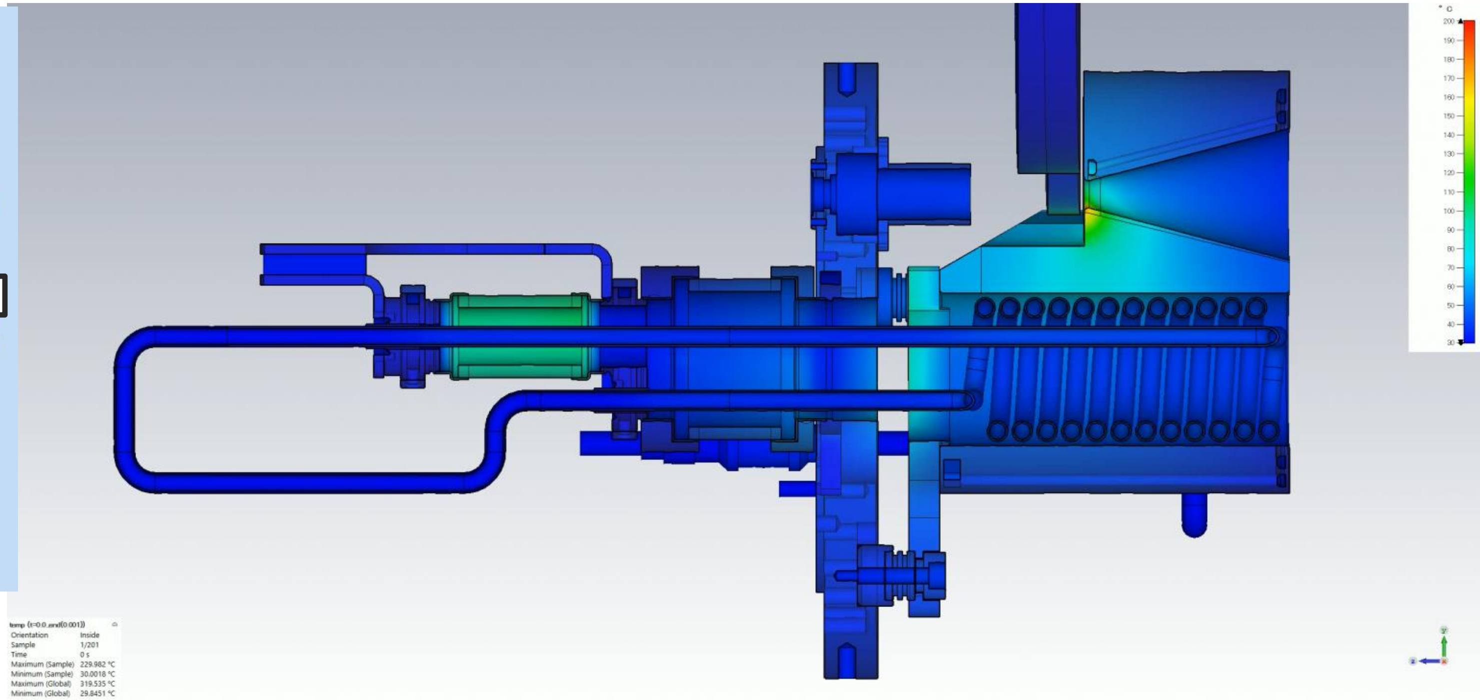
	SKEKB	ILC
voltage (kV)	20	20
current (kA)	12	35
repetition (Hz)	50	100 (300)
Pulse width (us)	6	11 （5-1-5）
Aperture (mm), diameter	7	12
Peak magnetic field (T)	3.5	5
Peak power (MW)	240	700
Average power (kW)	12	128
Ohmic loss (kW)	0.8	9

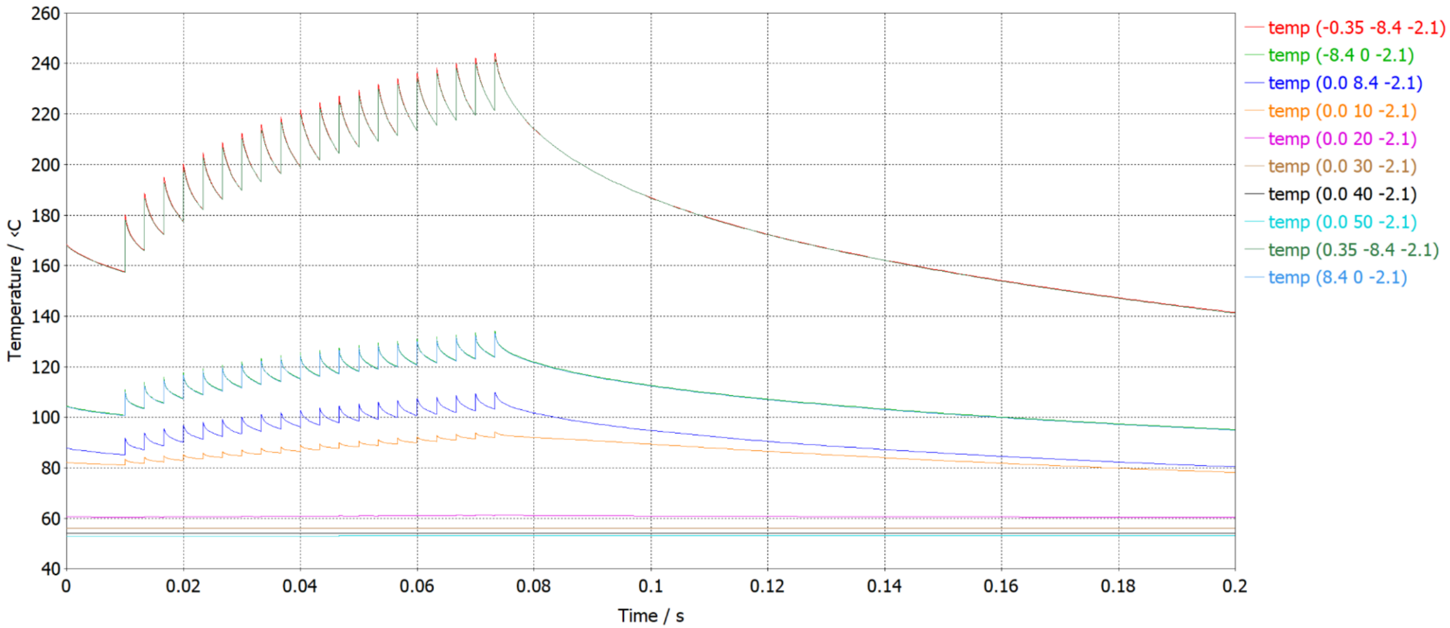
ILC ～ 10 x SuperKEKB in power

- Requirements for material of FC
  - High yield strength at high temperature
  - High thermal and electrical conductivity
  - Weldable by EBW
  - Available ～200 x 200 x 200

FC – thermal simulation



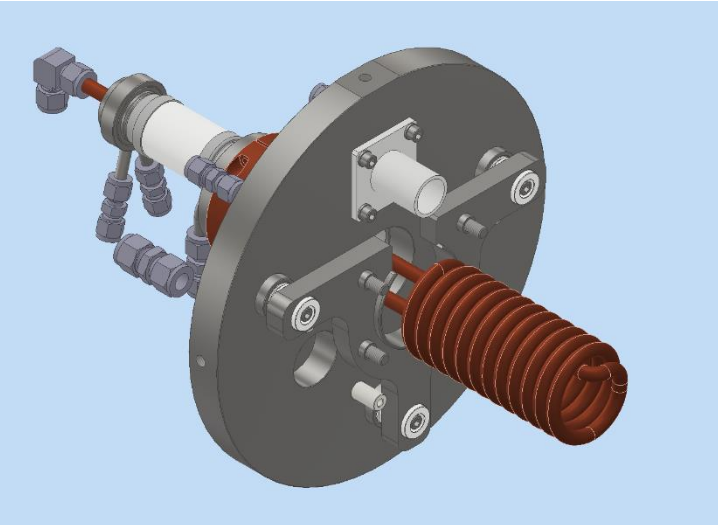




FC – prototyping

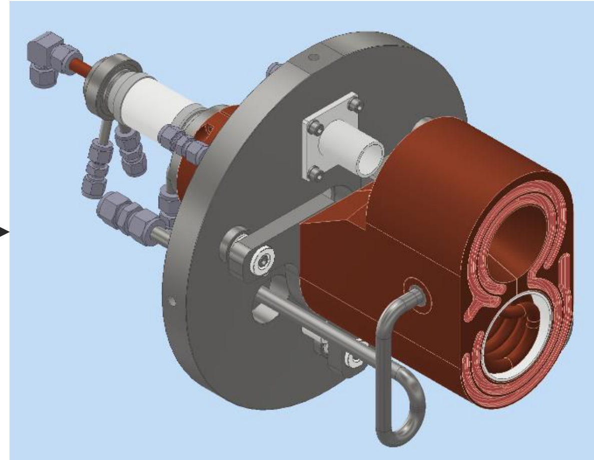
FY2023

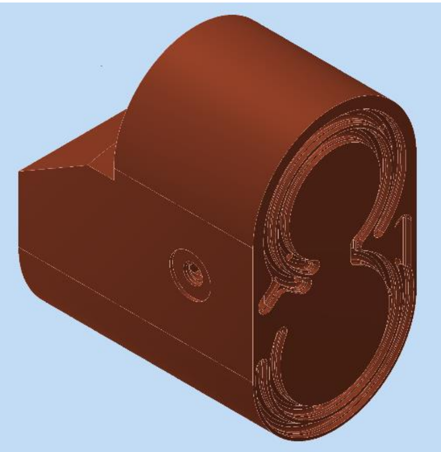
FY2024



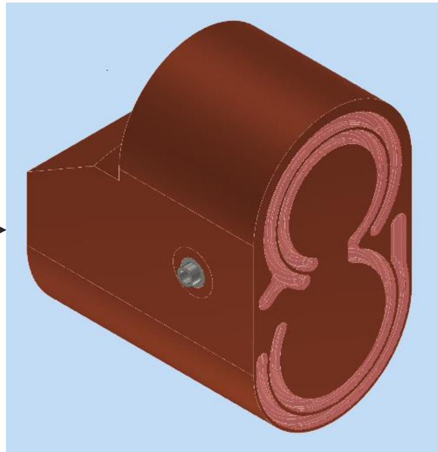
Parts(delivered)
- feedthrough
- flange, support
- piping
- electrode
- bolt, pin, bush
- coil

Welding & assembly

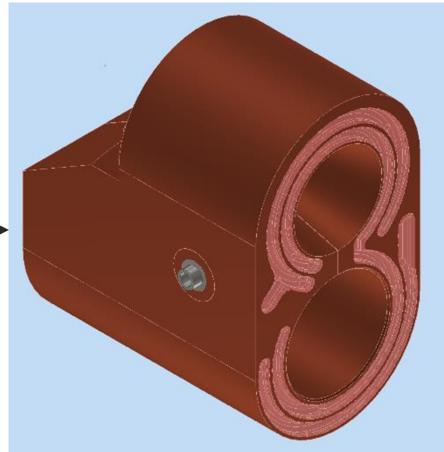




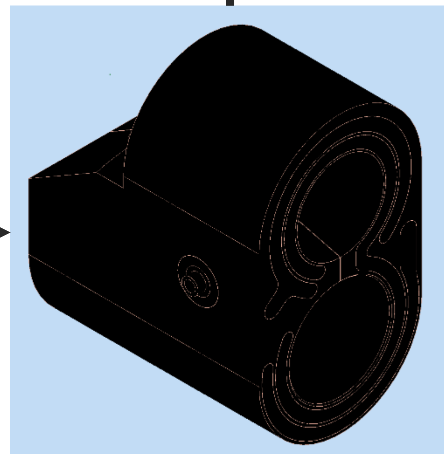
Machining done



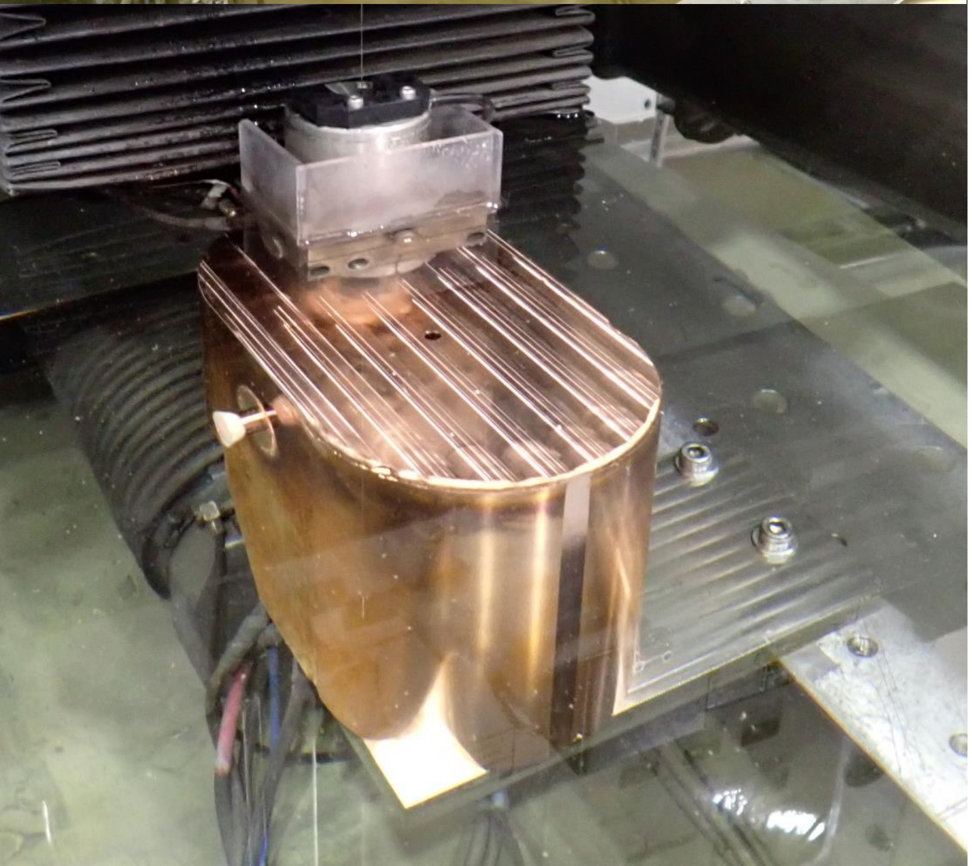
EBW done

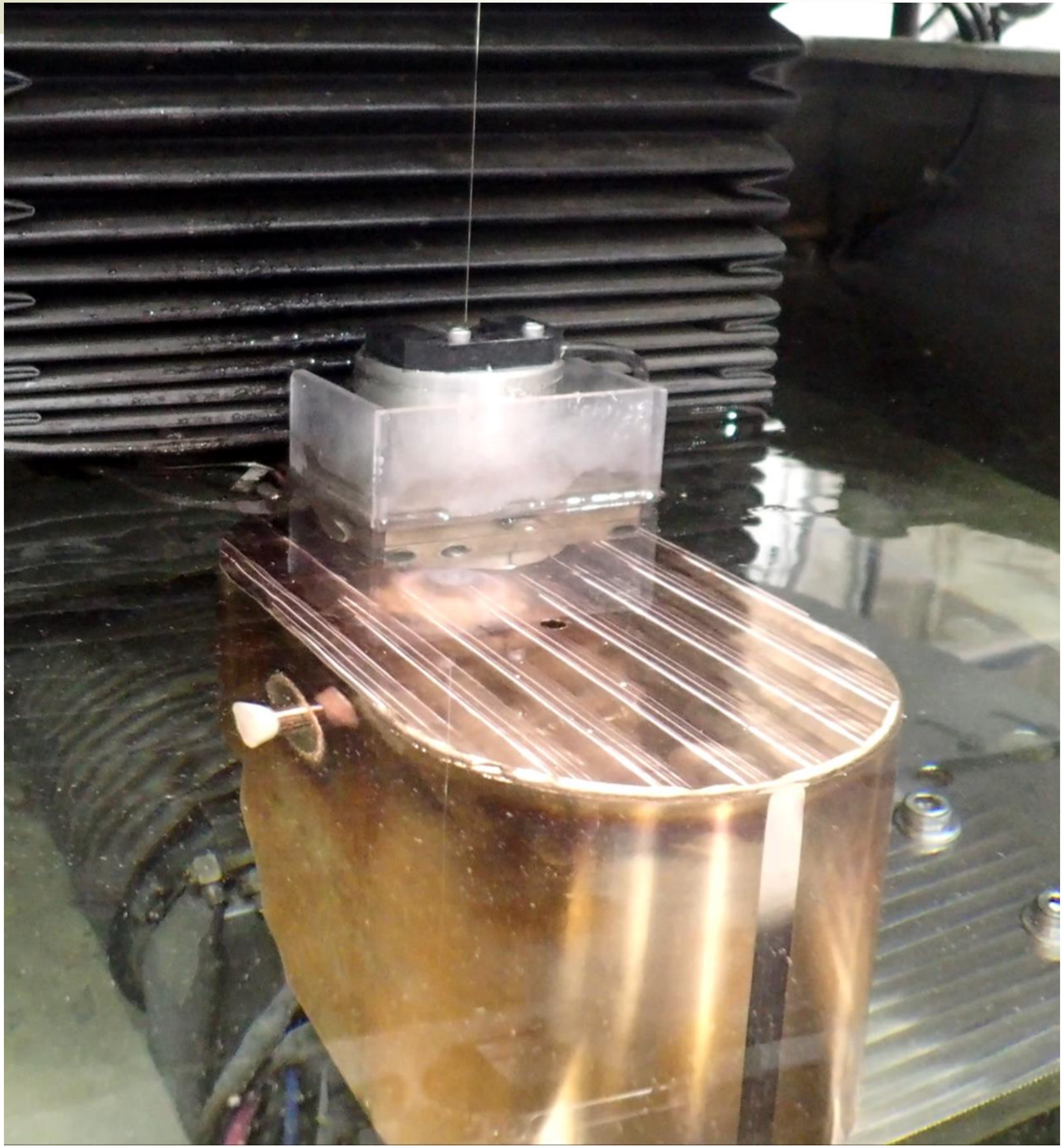


Secondary working
Milling & EDM
done



CP
Black plating
Cleaning
In progress ~6/28





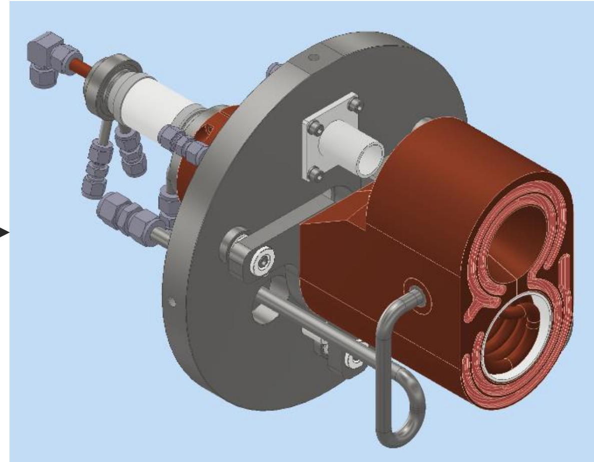
FC – prototyping

FY2023

FY2024

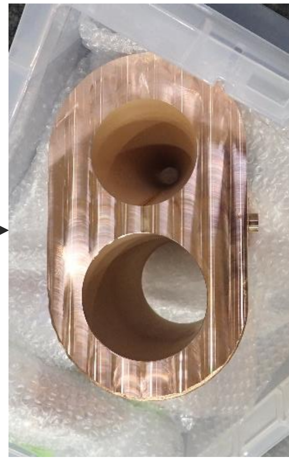
Parts(delivered)
- feedthrough
- flange, support
- piping
- electrode
- bolt, pin, bush
- coil

Welding & assembly ~August

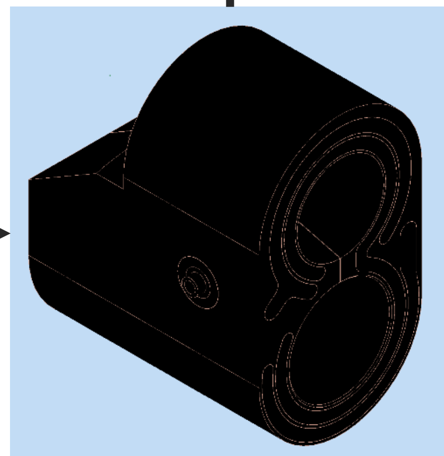


Machining done

EBW done



Secondary working
Milling & EDM
done



CP
Black plating
Cleaning
In progress ~6/28

Acc. Structure - concept

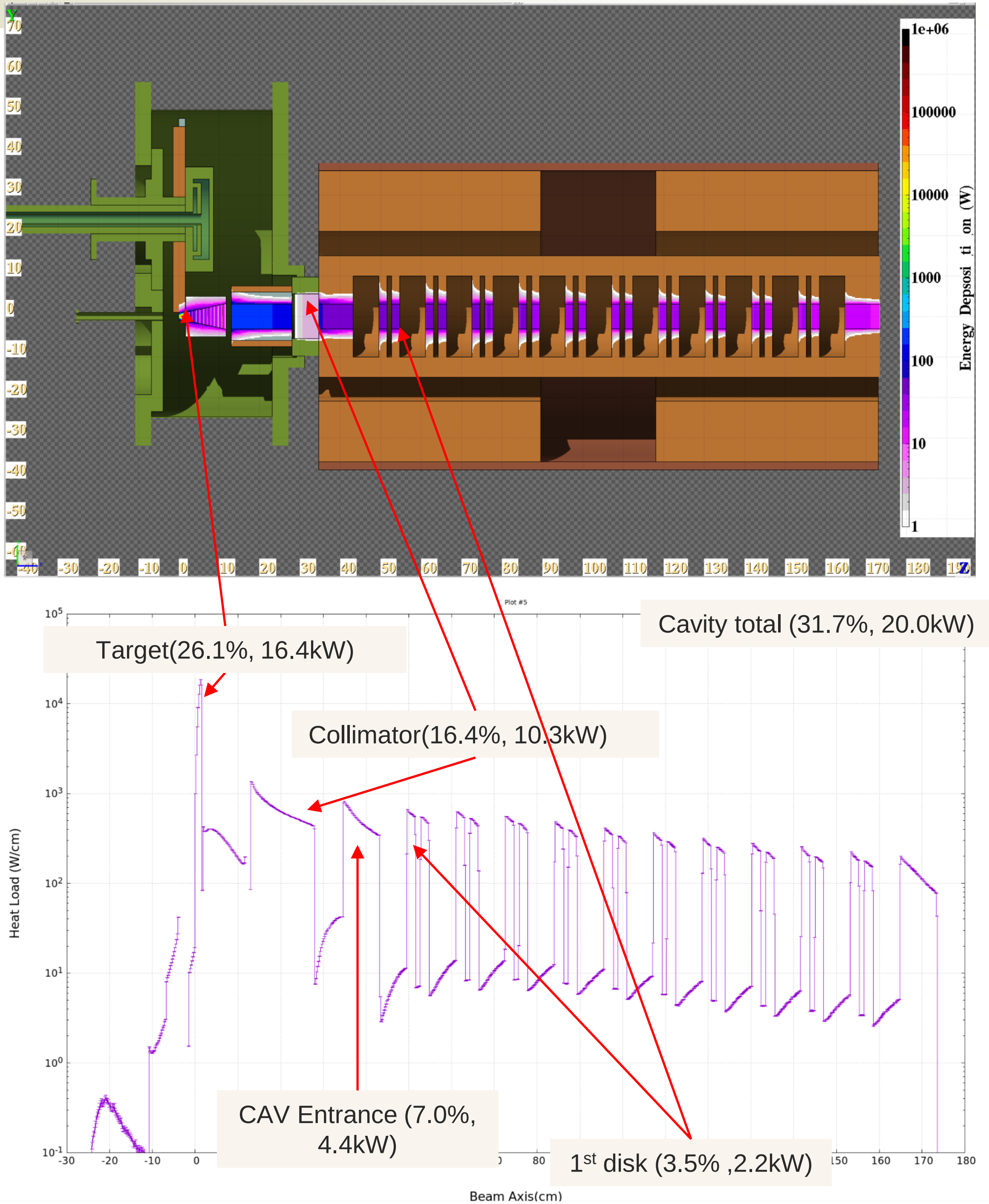
Challenges

- **Beam loading compensation**
  - High beam current : > 0.6A
  - Multi bunch operation
- **Powerful cooling system is required.**
  - Very high heat load due to electromagnetic shower from the target
- **Remote beam flange connection**
  - High activation by shower from the target and the connection point is surrounded by solenoid coils

Design Policy

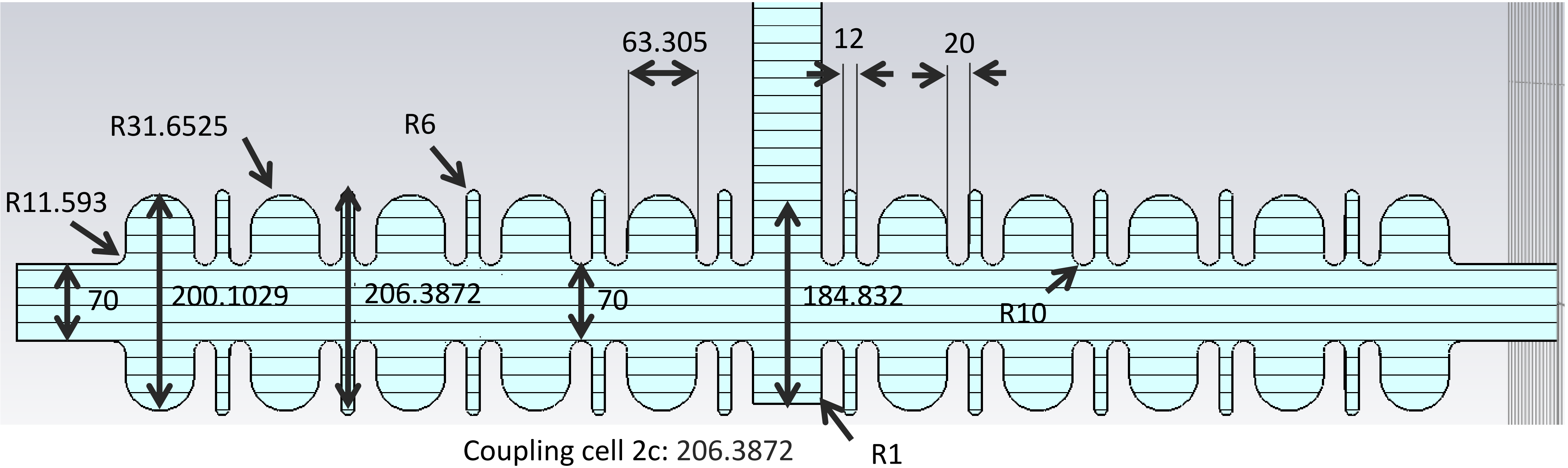
- **High group velocity**
- **Large coupling β**
- **Water channel in the**

APS cavity with a bi-periodic structure that operates in the π/2 mode, which maximizes the group velocity.



Acc. Structure - RF design

RF design finished using CST and Superfish by M. Fukuda

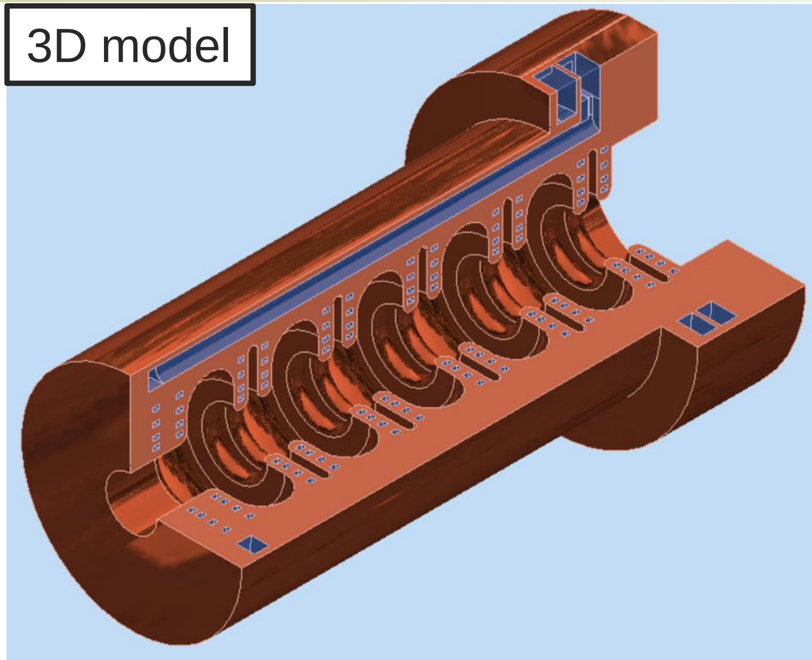


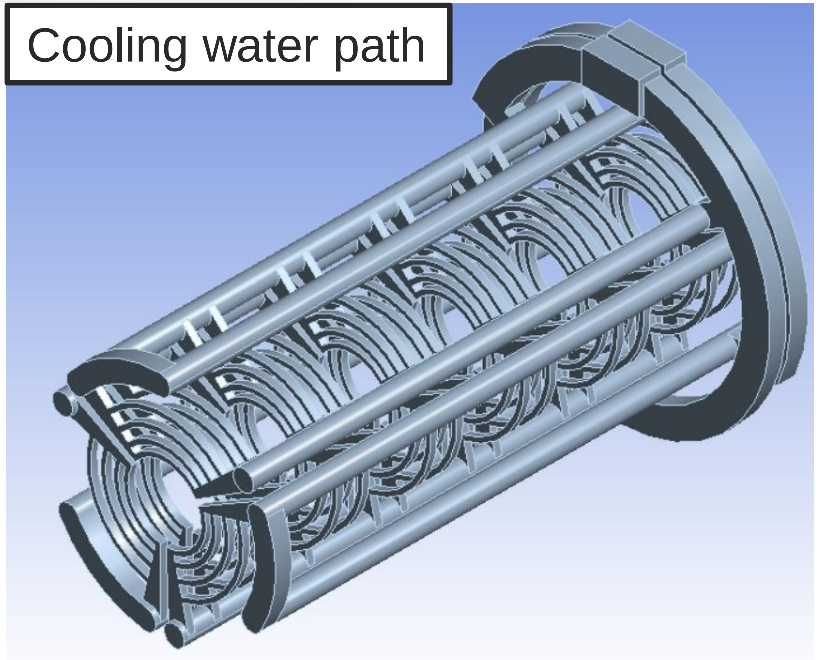
Prameters	value	Prameters	value
Resonant frequency (11π/21) [MHz]	1300	Q0	22806
Eacc [MV/m] (*1)	6.5	Qext	4513
Vacc [MV] (*1)	8.2	QL	3801
Ez max [MV/m] (*1)	13.6	Coupling β	5.05
Rsh [MOhm/m]	35.0	RF loss [1/W]	0.25
Transit-time factor (T)	0.78	RF loss (ave)[W] (*1) (*2)	625
Effective Rsh [MOhm/m] (Rsh*T*T)	21.3	Kilpatrick limit [MV/m] @ 1300MHz	32
Cavity length [m]	1.268	Max. Surface E-field [MV/m] (*1)	20 0.6 kilpatrick
Filling time [us]	1		

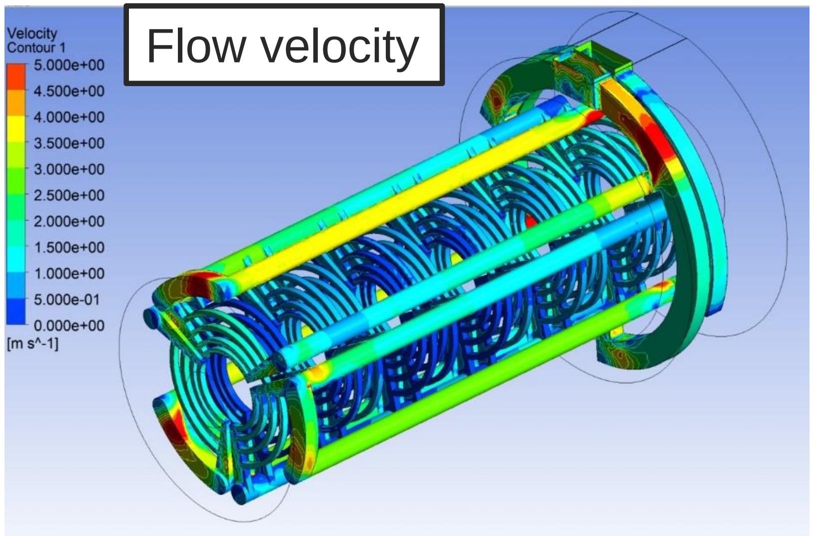
(*1) RF input power: 10MW (peak)
(*2) Pulse width 2.5us, Rep.Rate 100Hz

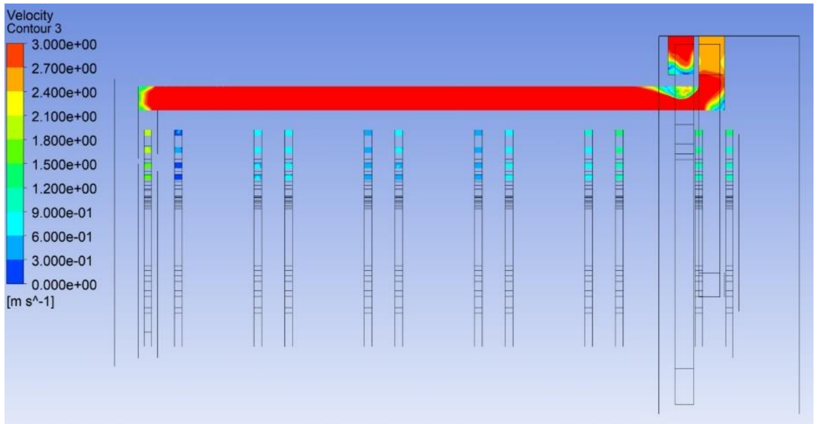
Acc. Structure - cooling design

- CFD simulation using ANSYS





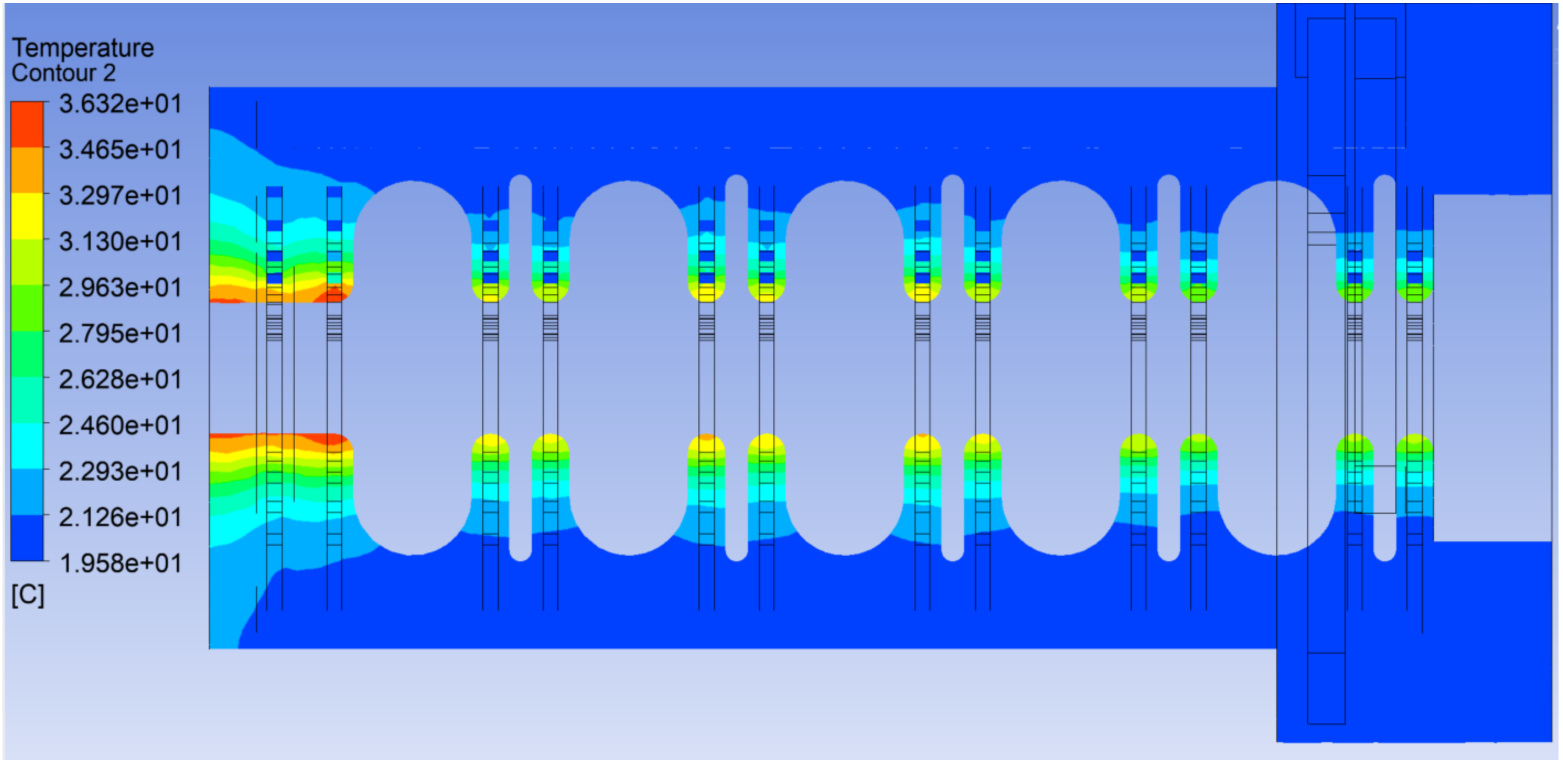




Flow velocity

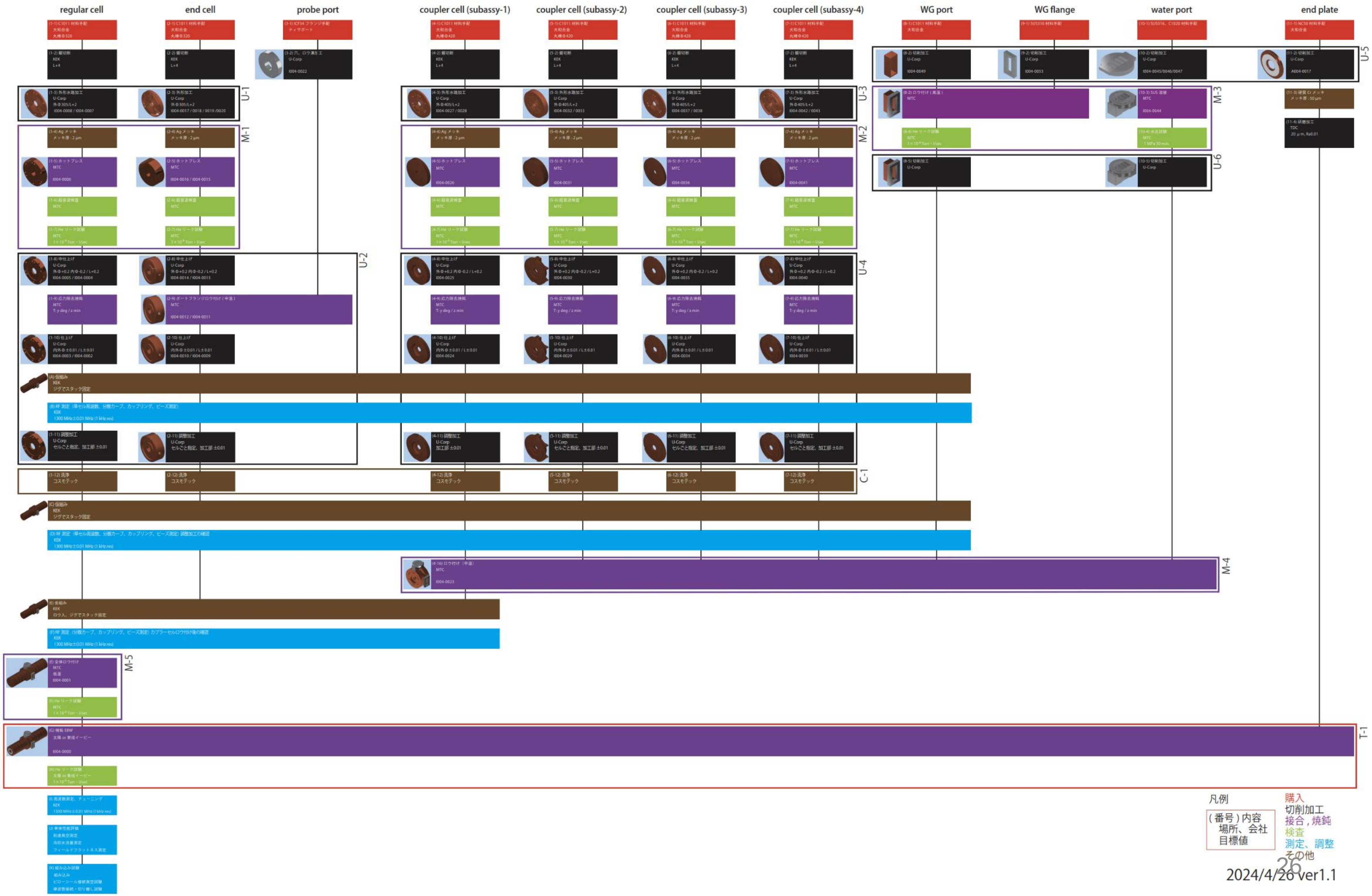
Acc. Structure - cooling design

・rough simulation with Φ90 uniform heat load (2.0e7 W/m3) = 1kW / 1 iris
・temperature rise ～10℃



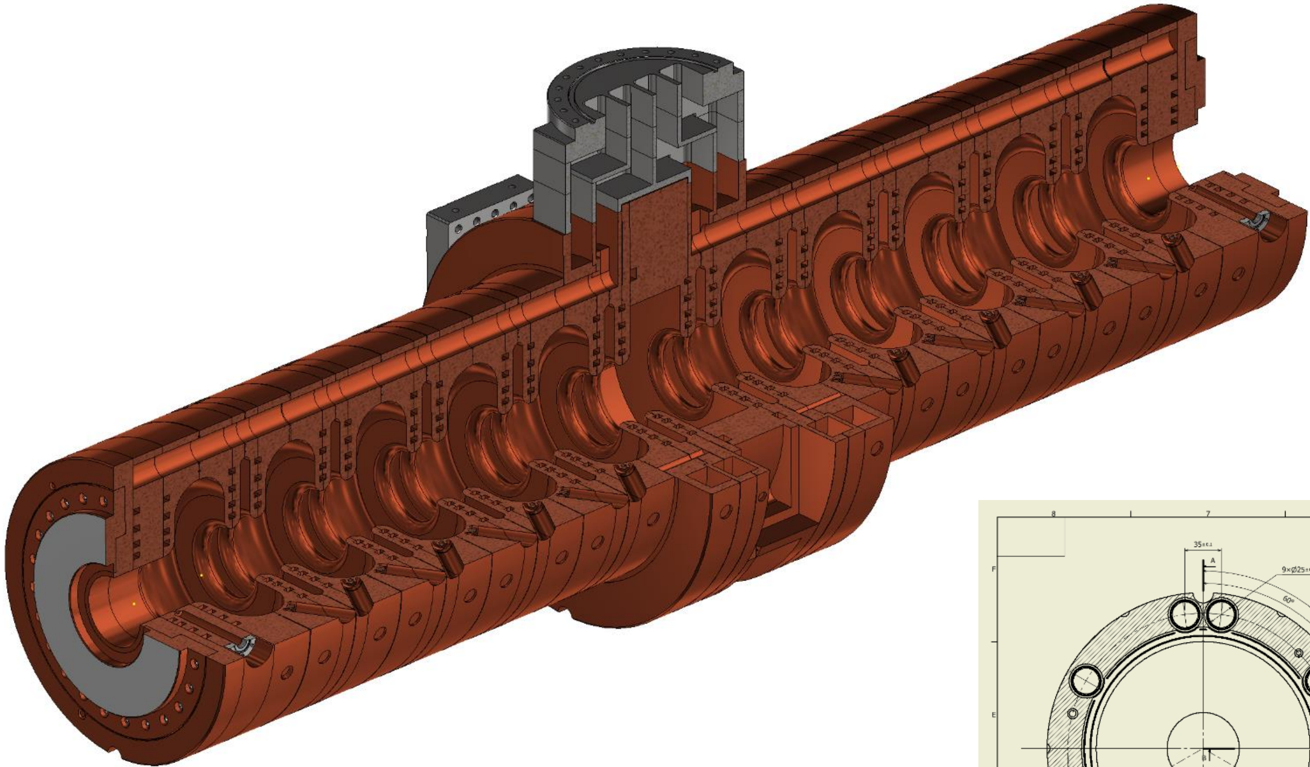
- Thermal simulation using ANSYS by Y. MorikawaS
- Export deformed shape and import it to RF simulation
  - Check shift of resonant frequency

Acc. Structure - manufacturing process

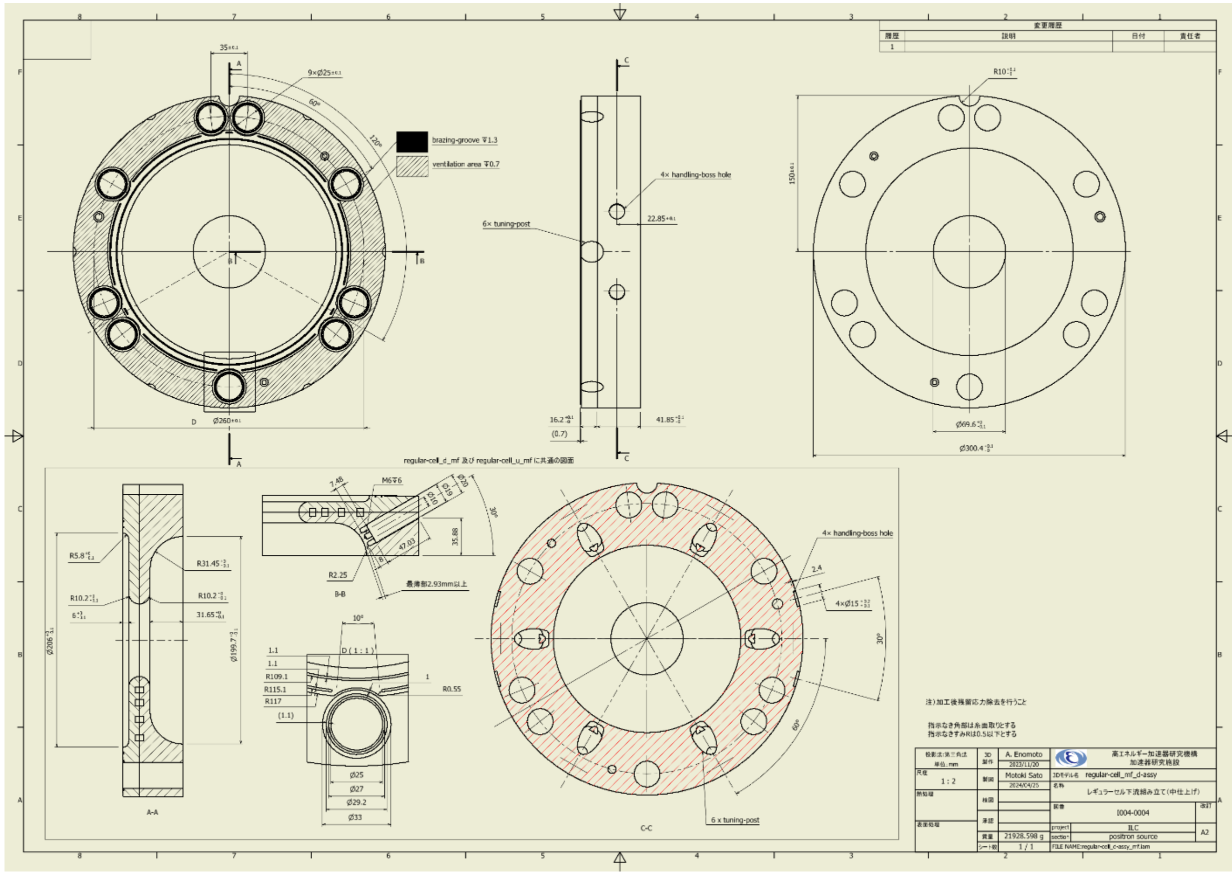


2024/4/26 ver1.1

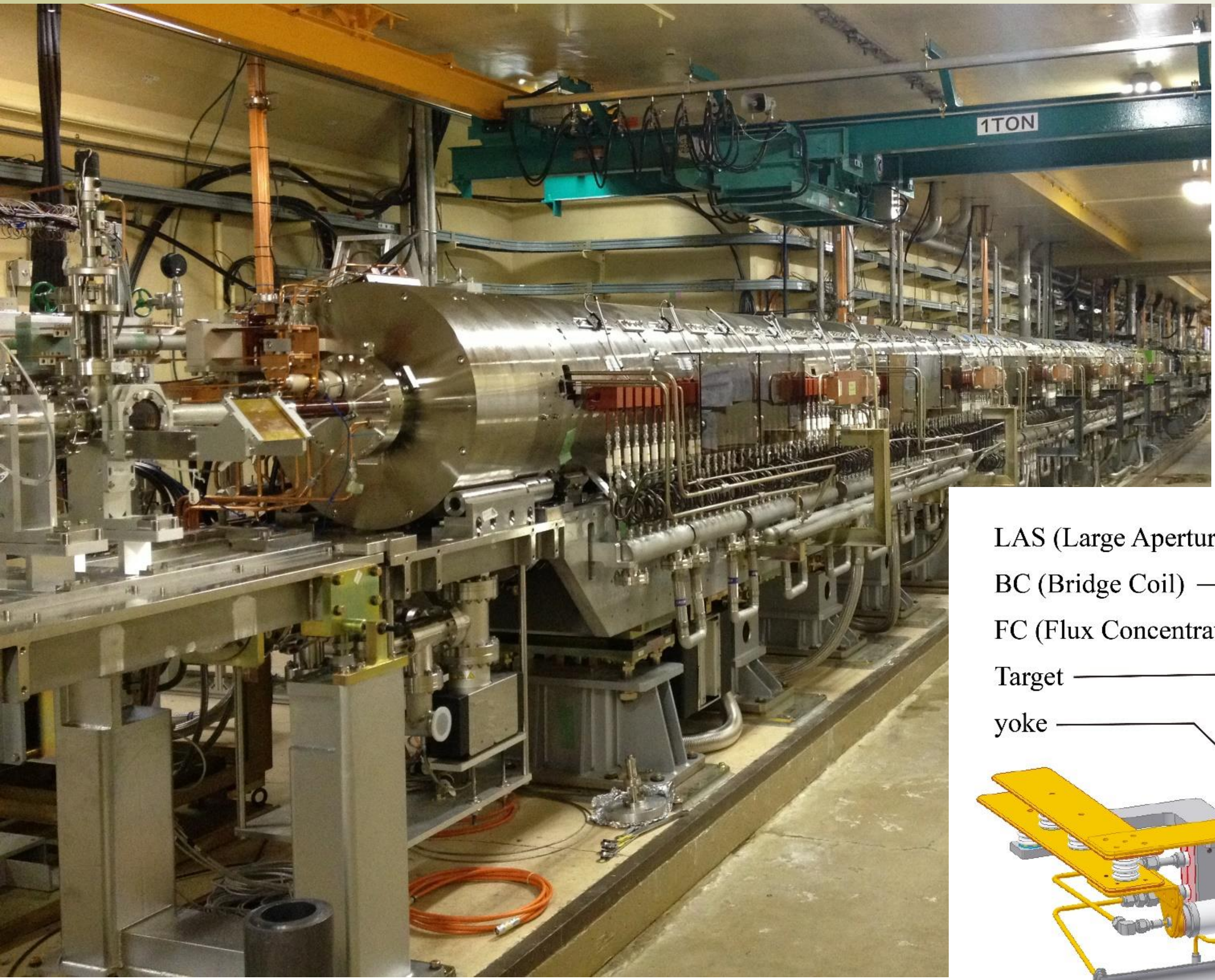
Acc. Structure - prototyping

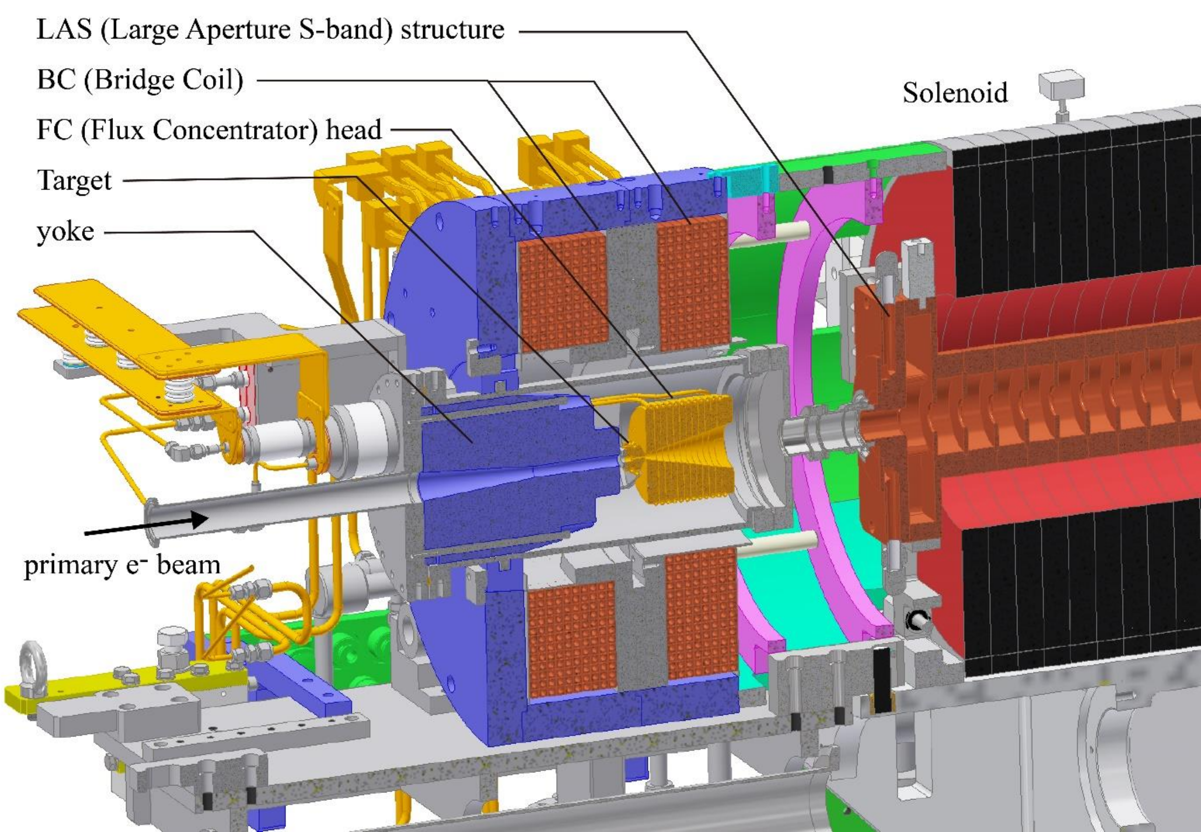


- 3D model is ready by A. Enomoto
- 2D drawings are 50% ready by M. Sato
- Material (C1011) has delivered
- Machining and hot press bonding test started



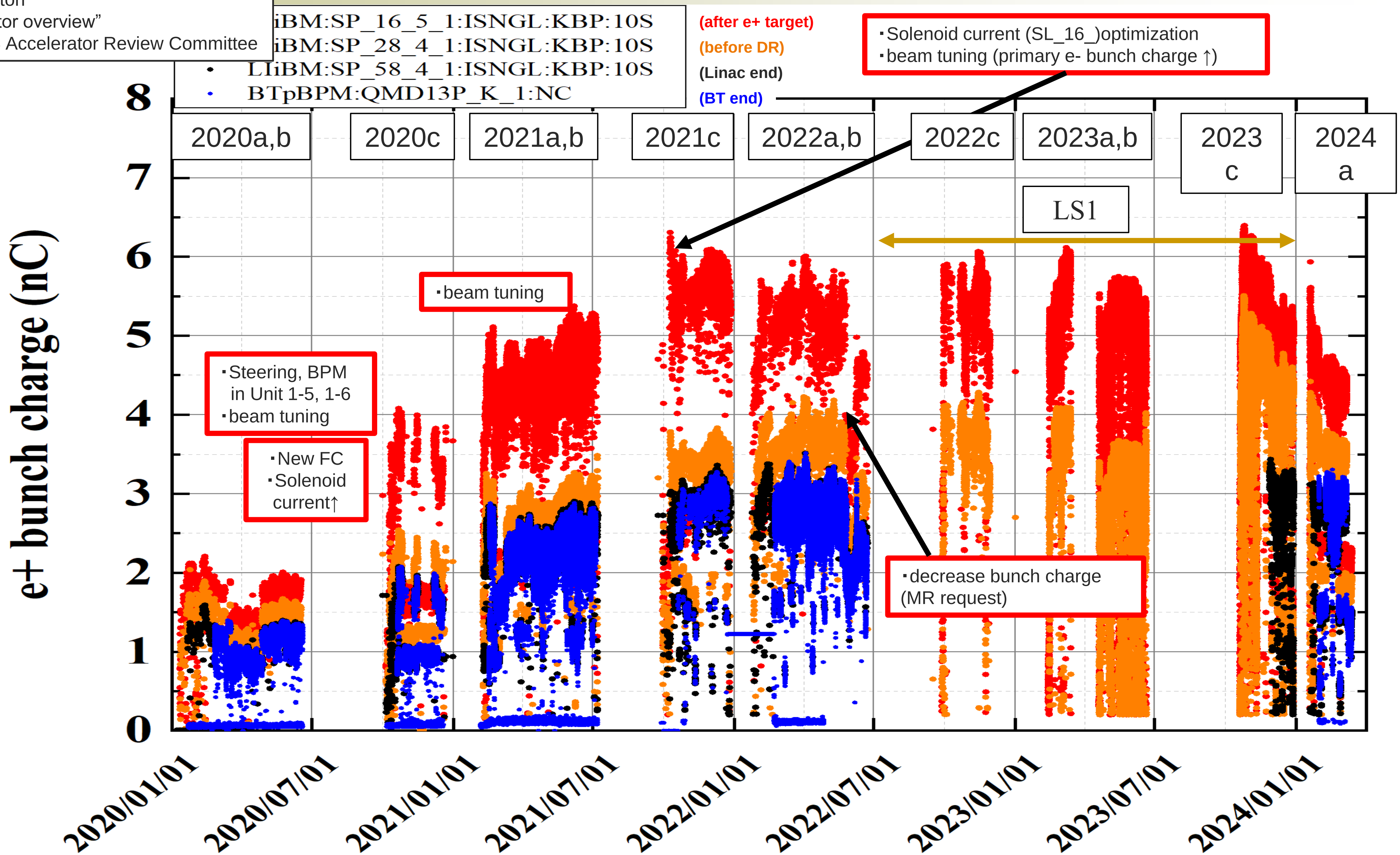
Beam tuning study and operation experiences of SuperKEKB





History of positron charge from 2020 to 2024

M. Satoh
“Injector overview”
KEKB Accelerator Review Committee



Present status and issues

M. Satoh
"Injector overview"
KEKB Accelerator Review Committee

- e+ bunch charge is almost achieved (final target: 4 nC)
  - 3.5 nC at linac end and BT
  - Machine learning based automatic tuning can help to increase the e+ bunch charge at the entrance of DR (up to around 5.5 nC).
  - Measured e+ production efficiency (65%) is comparable to the simulation result (60%).
  - Flux concentrator operation has been very stable.

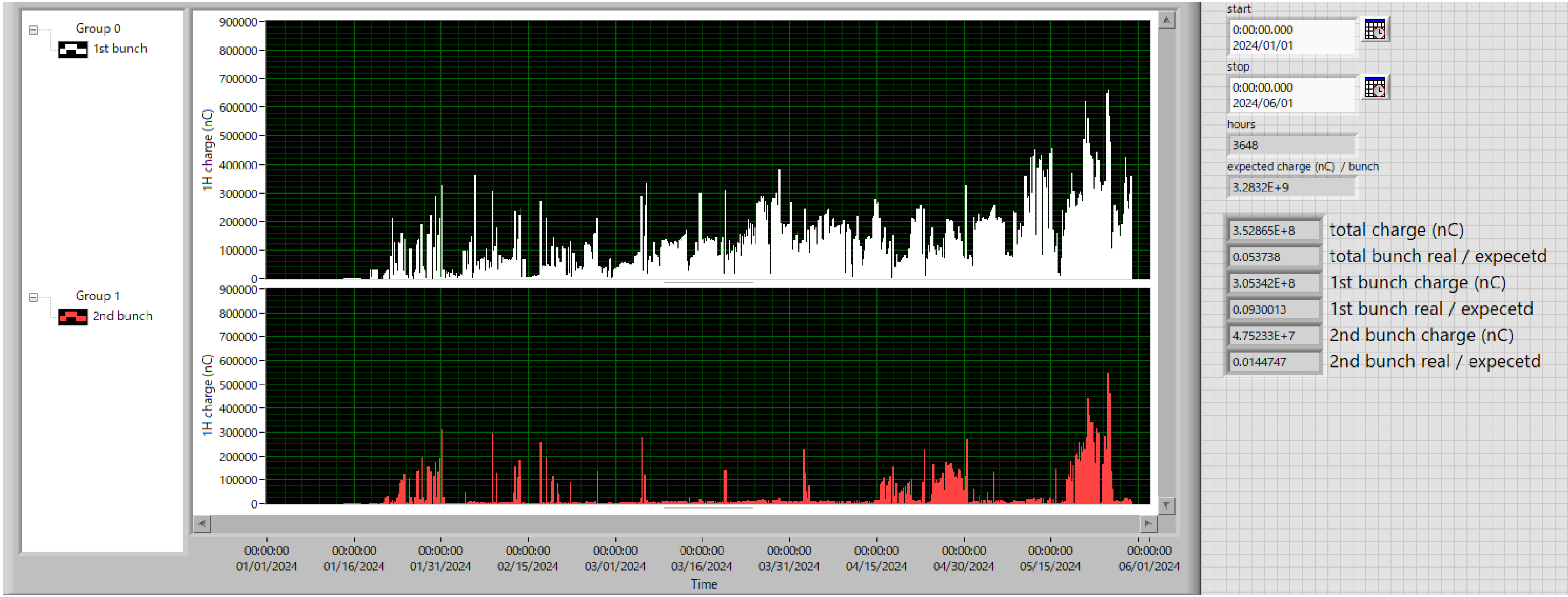
- Issue
  - Emittance at linac end and BT1 (before Arc1) are almost satisfied the final goal.
  - However, emittance at BT2 is increased. It could be caused by some magnetic errors.
  - Horizontal emittance after DR is larger than design value. Low emittance DR optics will be tested after LS1.

e+ emittance

Measured $\varepsilon_{nx,nxy}$ (3 nC) : 103.5/4.7 μm (at BT1)

Goal: $\varepsilon_{nx,nxy}$ (4 nC) : 100/15 (H/V) μm

DPA and total charge on the target



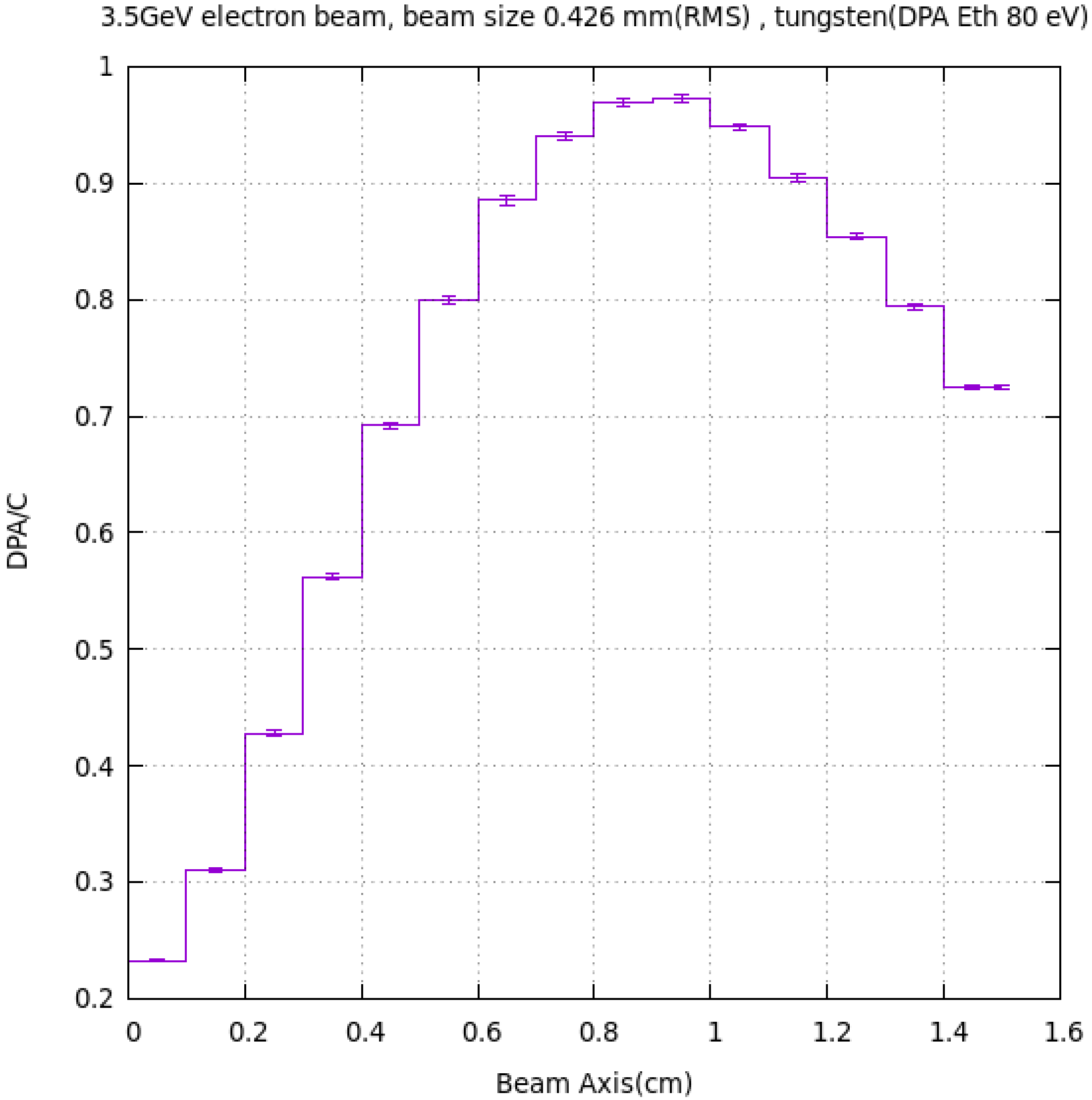
	Expected	achieved	ratio
Total	6.57 C	0.353 C	5.37%
1st bunch	3.28 C	0.305 C	9.30%
2nd bunch	3.28 C	0.0475 C	1.45%

5 month = 3648 hours
= 1/1 2024 ~ 6/1 2024

10 nC x 25 Hz x 3600 sec =
900,000 nC (0.9 mC) / hour / bunch @25 Hz

There has been no problem on the target
Care must be taken to evaluate any parameters, especially DPA
Real dose is about 5% of full power operation

DPA and total charge on the target

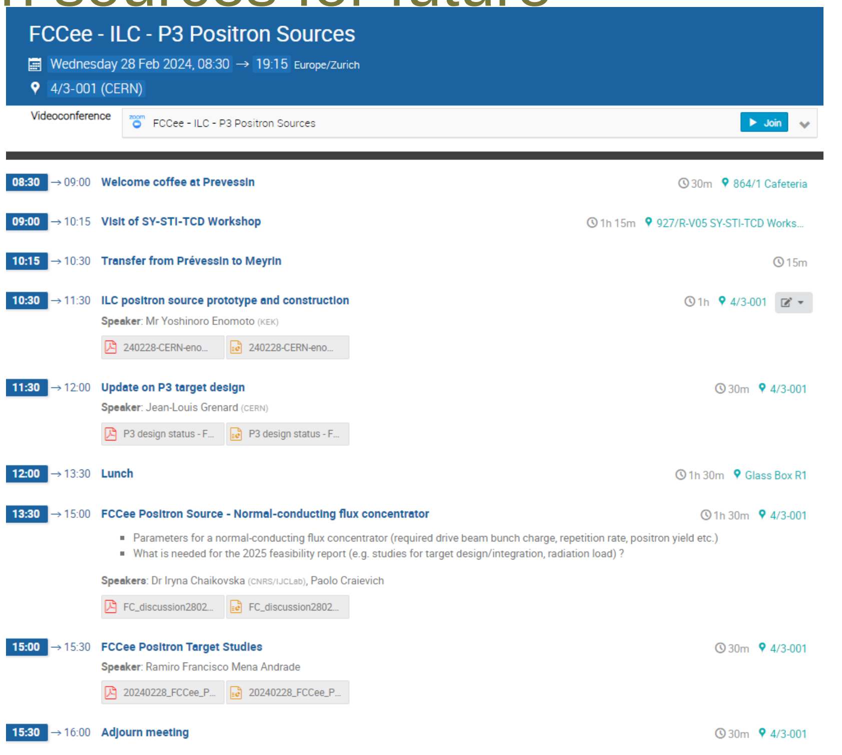


Simulated by Y. Morikawa

- Expected total charge on the target is 1 C / year
  - Assuming present operation condition
- DPA is ~ 1 at the maximum area
- 4 years has passed since the installation of present target
- No significant degradation of positron yield or other effect observed
  - Limited evaluation method

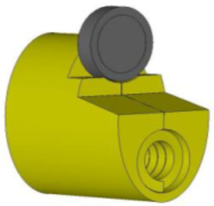
Collaboration with FCC

- French group (LAL, IJCLab) and KEK has long history of collaboration on the positron source
  - Since 1980s
- FJPPN(France Japan particle physics network)
  - 2018 - 2022 : High Intensity Positron Sources for Circular Colliders (SuperKEKB, FCC-ee)
  - 2023- : tart-to-end simulation of positron sources for future colliders
- One day meeting at CERN
  - Feb. 2024
  - Very effective and practical discussion

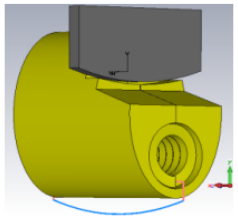


Combined simulation of SuperKEKB/ILC and FCC

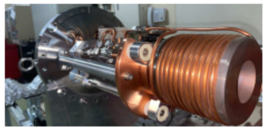
Positron capture: Flux Concentrator (FC) as a matching device



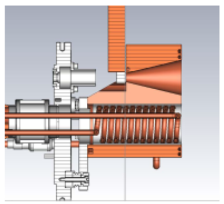
Originally designed by BINP for the FCC-ee (P. Martyshkin)
=> FC:FCC-BINP
Dropped as no info and further studies are available



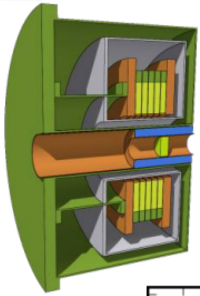
Originally designed by BINP for the ILC (P. Martyshkin) => FC:ILC-BINP
Dropped as no info and further studies are available



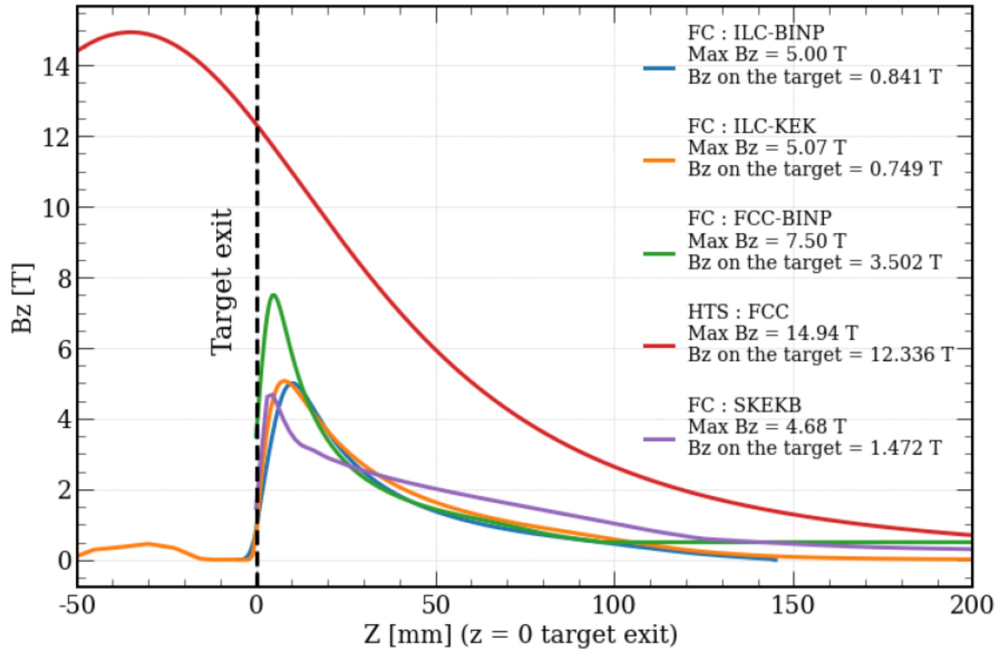
Originally designed by KEK for the SuperKEKB => FC:SKEKB-KEK
Under consideration



Designed by KEK for the ILC (Y. Enomoto) => FC:ILC-KEK
Assumed for the FCC-ee

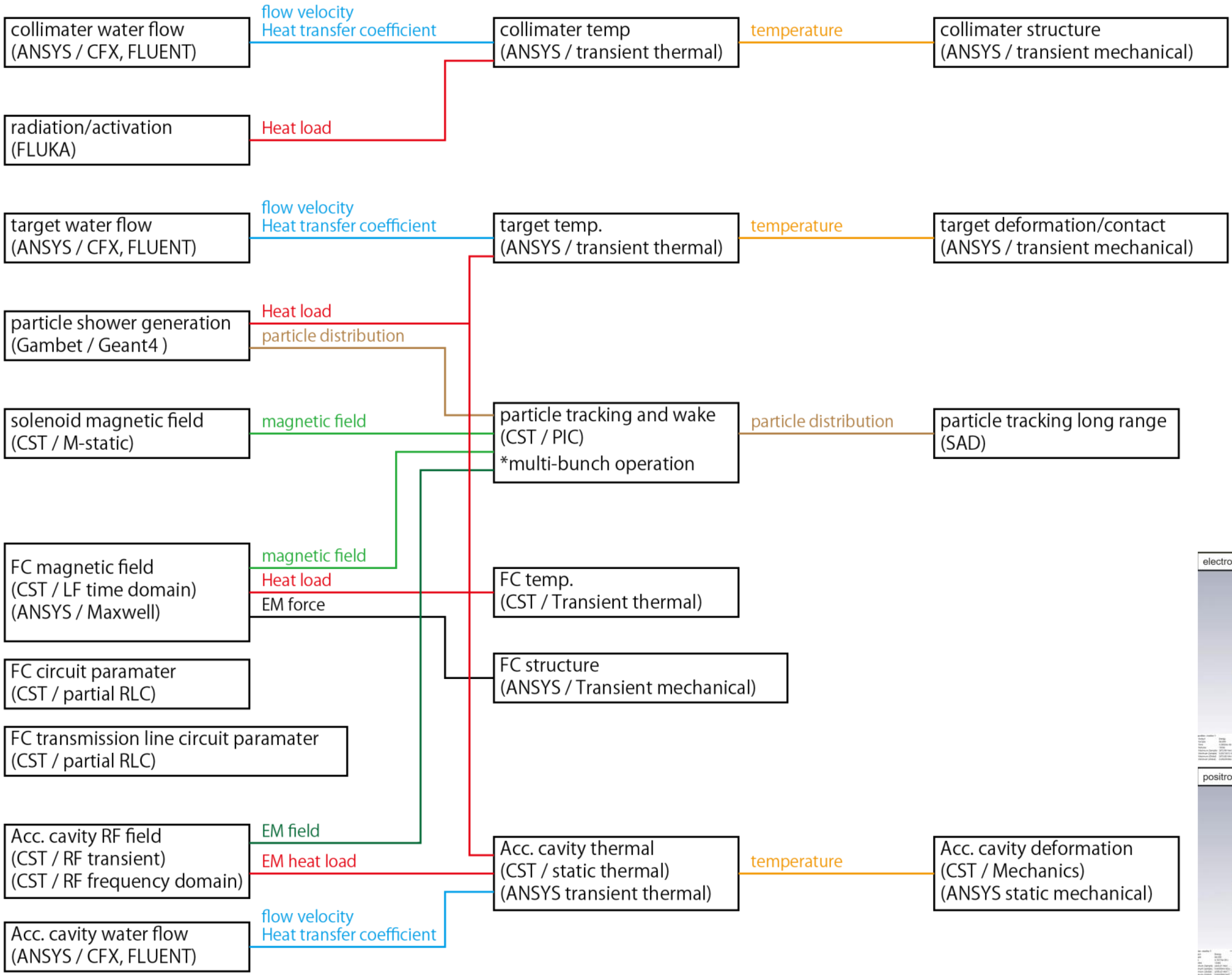


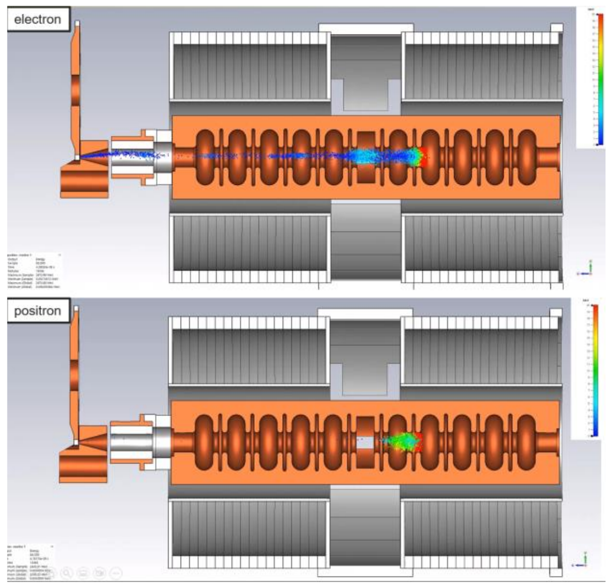
High-Temperature Superconducting (HTS) solenoid designed by PSI => HTS:FCC
(submitted to mid-term review)



Base-line design of positron source for FCC is based on HTC
Star-to-end simulation has been actively done recently
Reliable and robust FC option is now under consideration

Simulation flow of positron source





Experiment at KEK

- To validate simulation method, support from experimental data is important
- SuperKEKB is the only machine which can provide such opportunity
- French group visit KEK in Nov./Dec. in 2023 and joined experimental study
  - Similar work was done successfully in 2022 and results were analyzed and presented at IPAC’23
- To summarize the work, paper is in preparation

Presented at IPAC’23

UPDATE ON THE FCC-ee POSITRON SOURCE DESIGN STUDIES*

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B. Auchmann, P. Craievich, M. Duda, J. Kosse, M. Schaer, R. Zennaro, Paul Scherrer Institut, Villigen PSI, Switzerland
A. Bacci, M. Rossetti, INFN, Milano, Lombardia, Italy
Y. Enomoto, High Energy Accelerator Research Organization (KEK), Japan
P. Martyshkin
[1]also at KACST, Riyadh, Saudi Arabia
[2]also at NSC Kharkiv Institute of Physics and Technology, Ukraine

BENCHMARKING THE FCC-ee POSITRON SOURCE SIMULATION TOOLS USING THE SUPERKEKB RESULTS *

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[1]also at KACST, Riyadh, Saudi Arabia
Y. Zhao, A. Latina, CERN, Geneva, Switzerland
Y. Enomoto, F. Miyahara, High Energy Accelerator Research Organization (KEK) Japan
V. Mytrochenko, NSC Kharkiv Institute of Physics and Technology, Ukraine

Paper is in preparation

Modeling of the positron sources: an experiment-based benchmarking

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Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

F. Miyahara, T. Kamitani, Y. Enomoto
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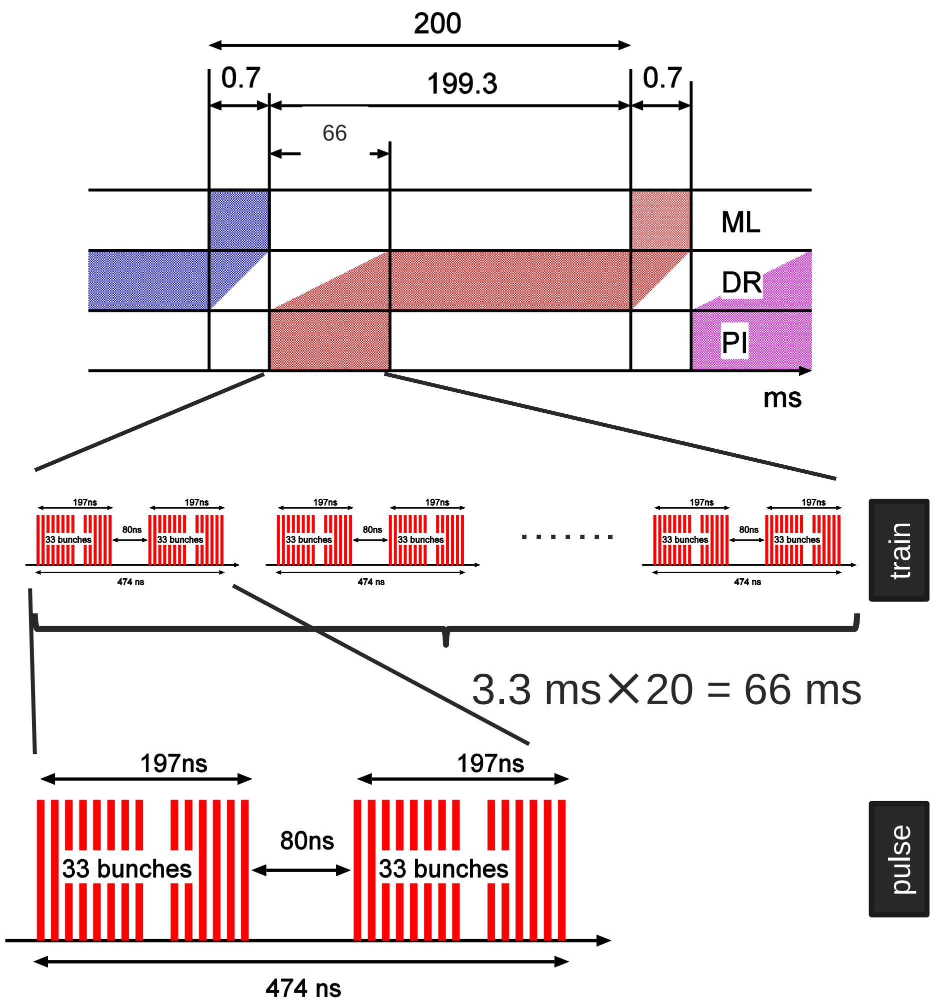
(Dated: May 19, 2024)

Summary

- ILC
  - Design and prototyping
- SuperKEKB
  - Stable operation
- Collaboration
  - Share the model, simulation and experimental results, operation experiences, cost estimation …

Bunch structure of ILC e-driven positron source

M. Kuriki, OHO seminar 2021



- Create positron for 66 ms
- Store them in the DR for 199.3 ms
- Extract them to main linac for 0.7 ms
- 20 pulse / train
- 66 bunch / pulse
- 1320 bunch / train
- Repetition 5 Hz