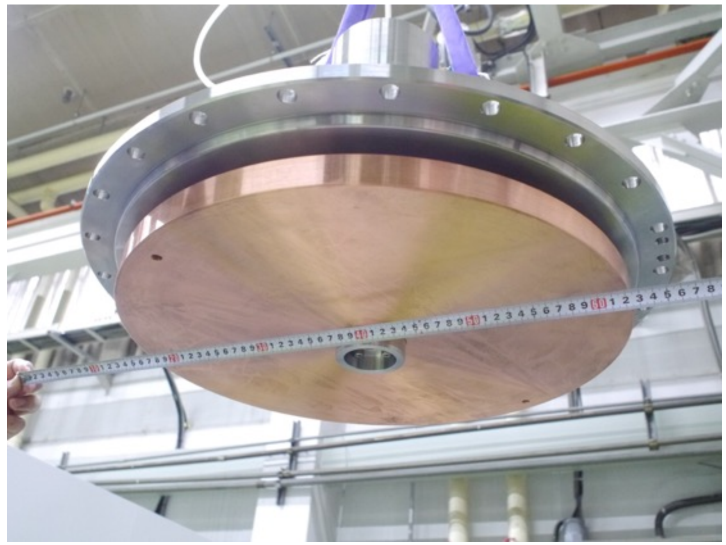
ILC E-Driven e+ Source

Hardware R&D of the Rotation Target and Rerated Areas in the last year



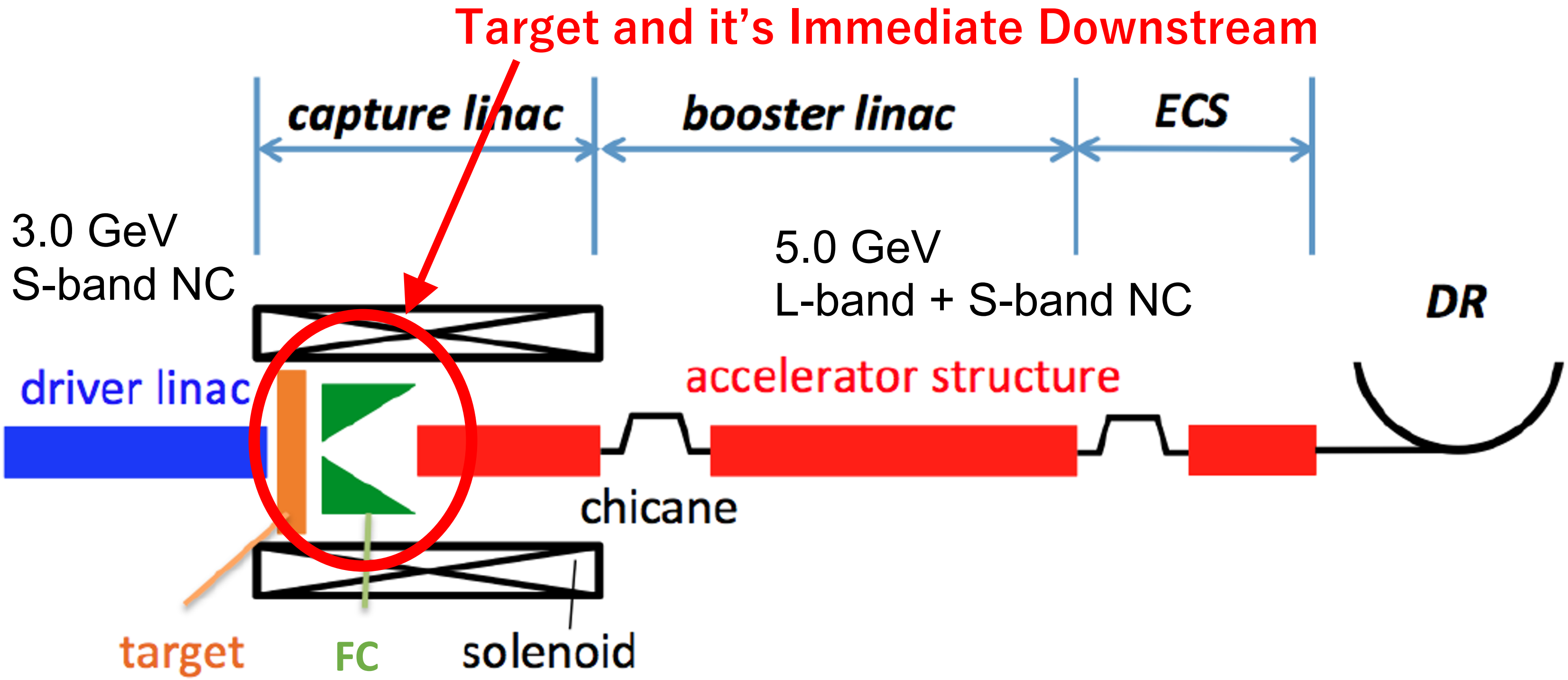
Works by Rigaku, Iwate Prefectural Industrial Technology Center,
Kondo Equipment Co., Ltd., Iwate Industry Promotion Center,
Iwate University/Tohoku University, Hiroshima University, Waseda University,
Metal Technology Co., Ltd., TOHOKU SEIMITSU CO., LTD., and KEK

17-January-2022

IDT WG2, Source Group, Fully Remote

presented by T. Omori (KEK)

E-driven ILC Positron Source

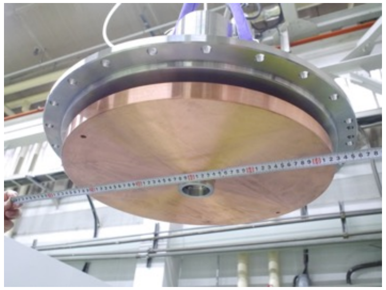


- 20 of 0.48us pulses are handled with NC linacs operated in 300Hz.
- 100 of 300 pulses are actually fired.

Today's Topics

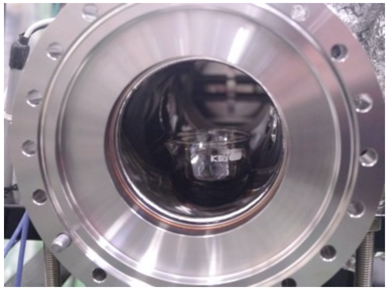
(1) Prototype #2 with Dummy Disk

The weight and the moment of the dummy disk is as same as the real target.
Vacuum test with rotation.



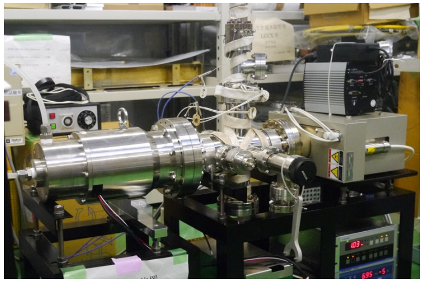
(2) Evaporation Pan Test

Put ferrofluid in an evaporation pan.
Then put the pan in a vacuum chamber and make residual gas analysis.



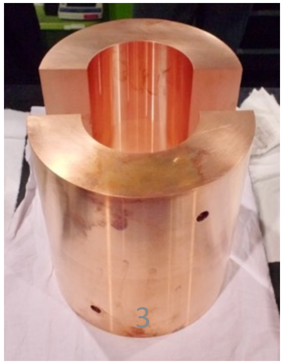
(3) Prototype #1 with Irradiated Ferrofluid.

Irradiated ferrofluid is used in the prototype #1.
Vacuum test with rotation.



(4) Cooling design of the immediate down stream of the target

The collimator, the flux concentrator, and the first accelerating tube and are in severe thermal environment. Cooling design and hardware test are on going.



(1) Vacuum test with Rotation

Prototype #2 with Dummy Disk

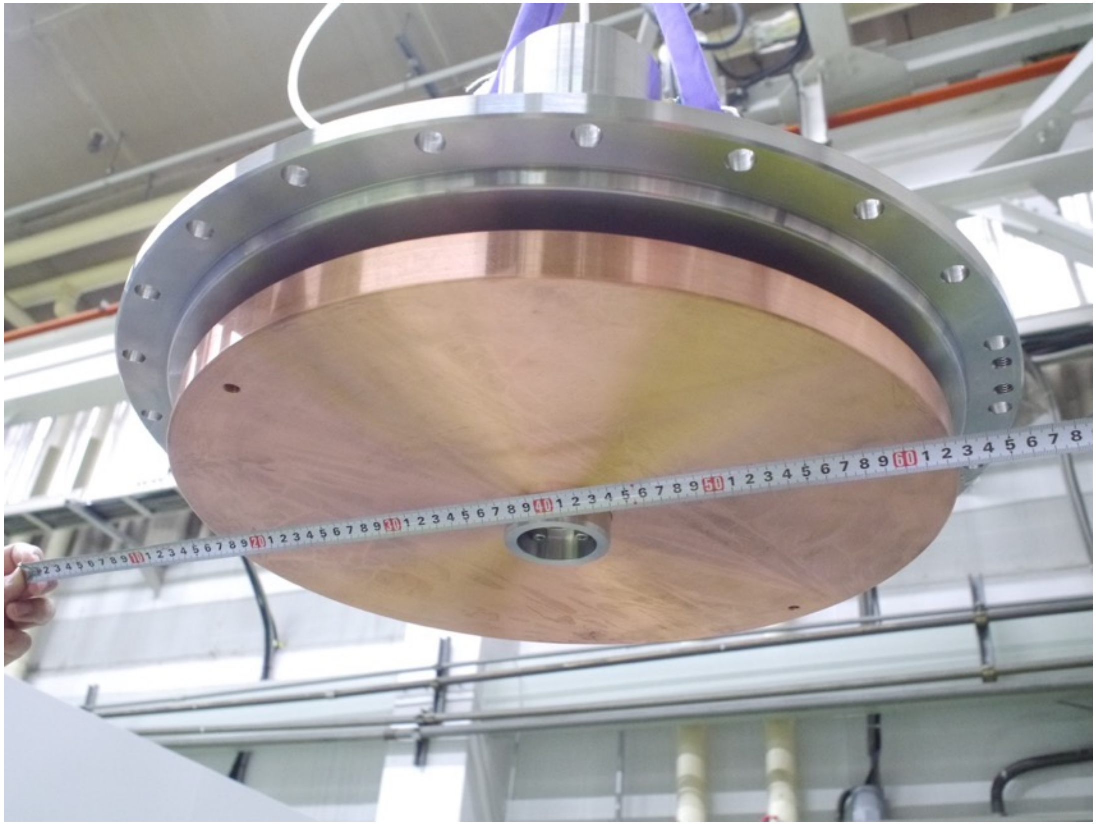
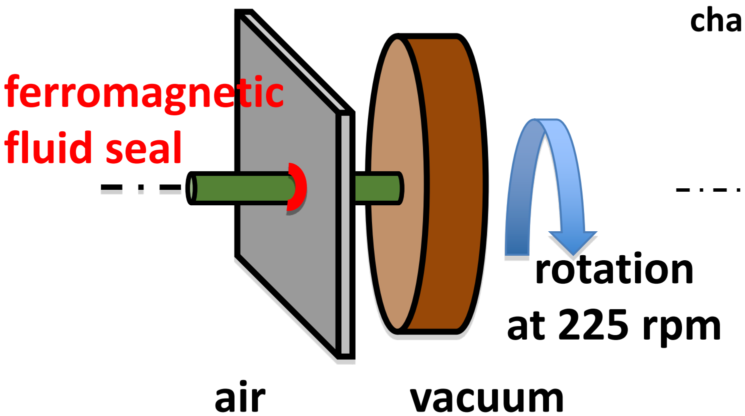


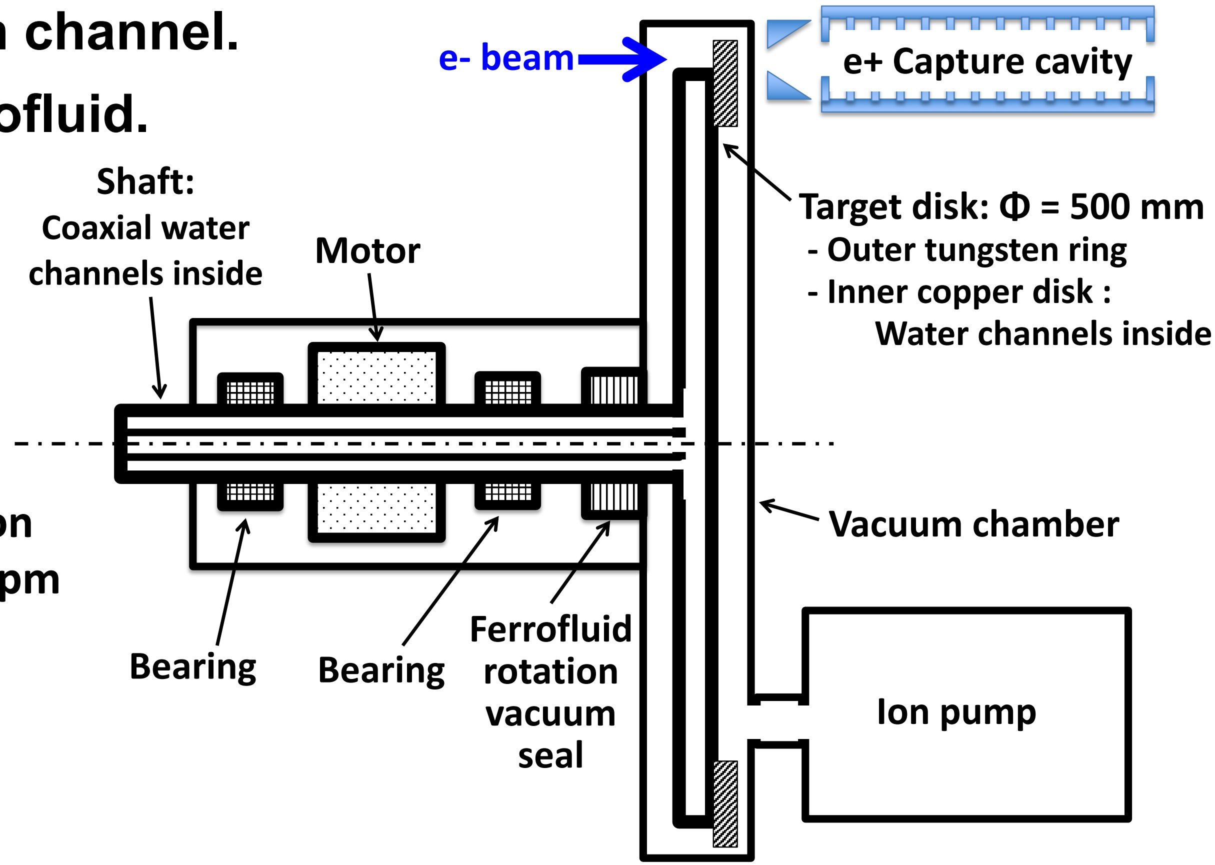
photo: Prototype #2 with Dummy Disk, at RIGAKU Workshop, Tokyo.

Rotation Target

- W-Re 16mm thick.
- 5 m/s tangential speed rotation (225 rpm, 0.5m diameter) in vacuum.
- Water cooling through channel.
- Vacuum seal with ferrofluid.




ferrofluid

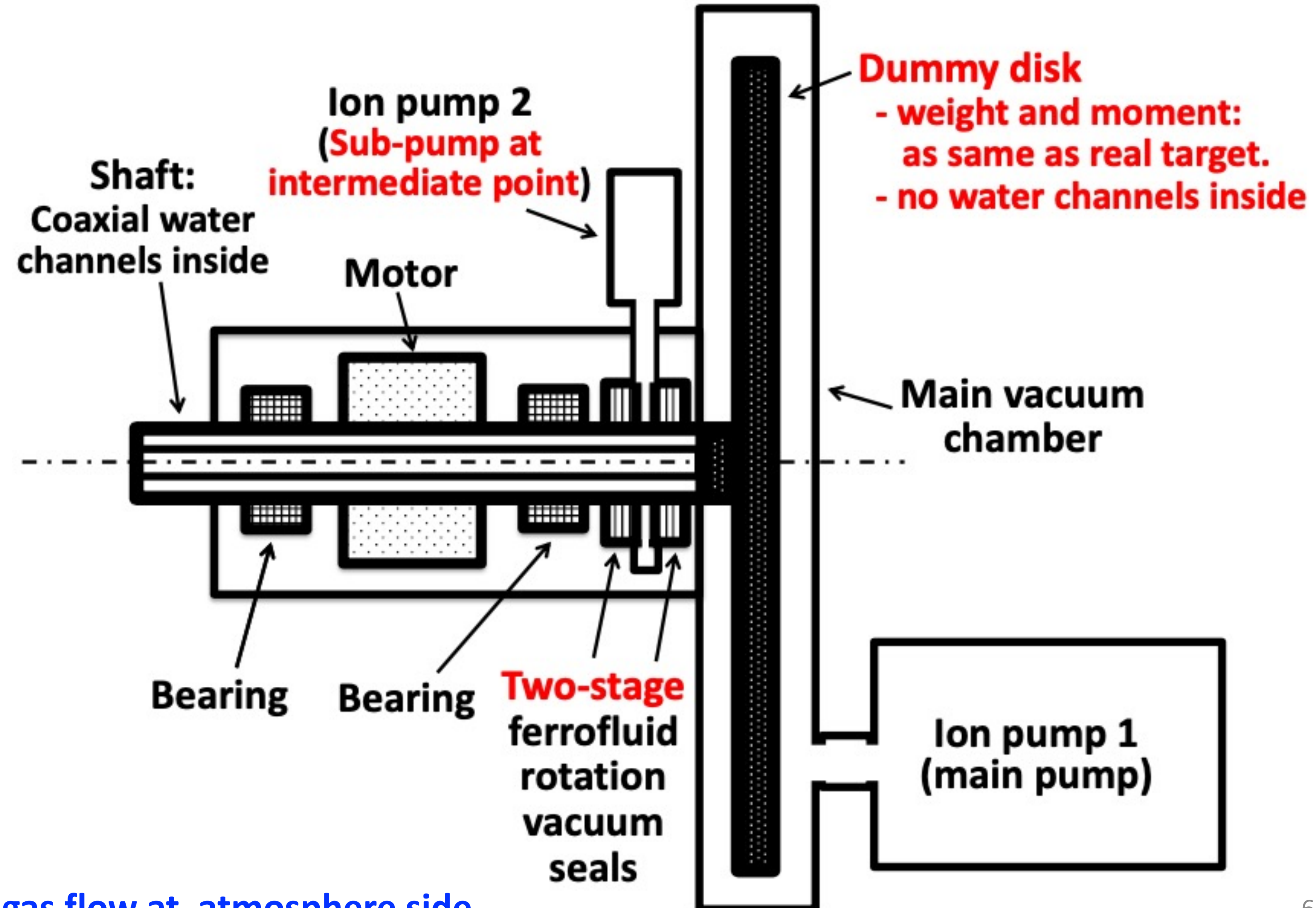


Hiroshima U., Waseda U., Rigaku, and KEK

Prototype #2 with Dummy Disk

Dummy Disk Added, February 2021.

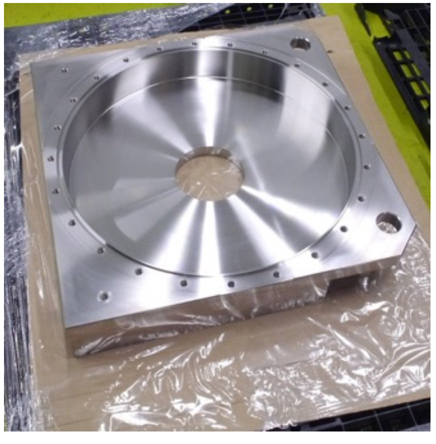
Vacuum Test with Rotation Started from April 2021.

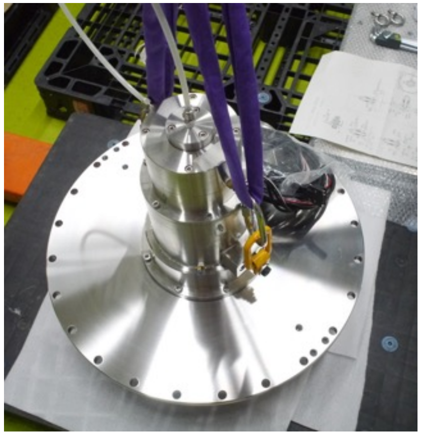


Dry N2 gas flow at atmosphere side

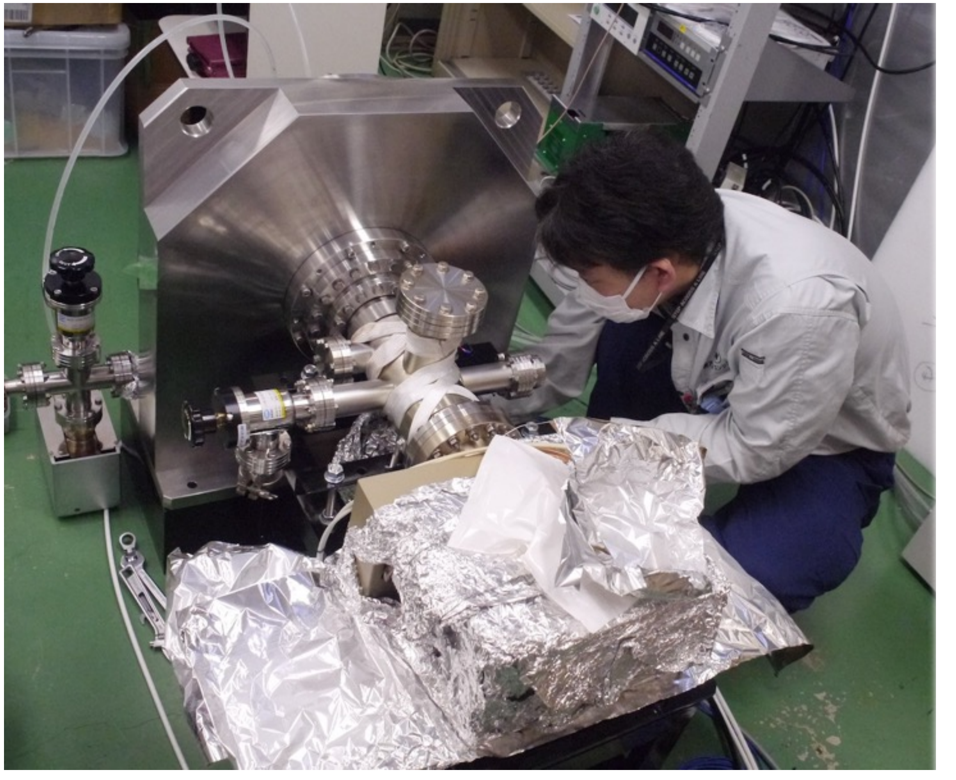
We added the dummy target disk.

Fabrication at RIGAKU workshop
Jan. 2021





Assembling at KEK
Feb.-Mar. 2021

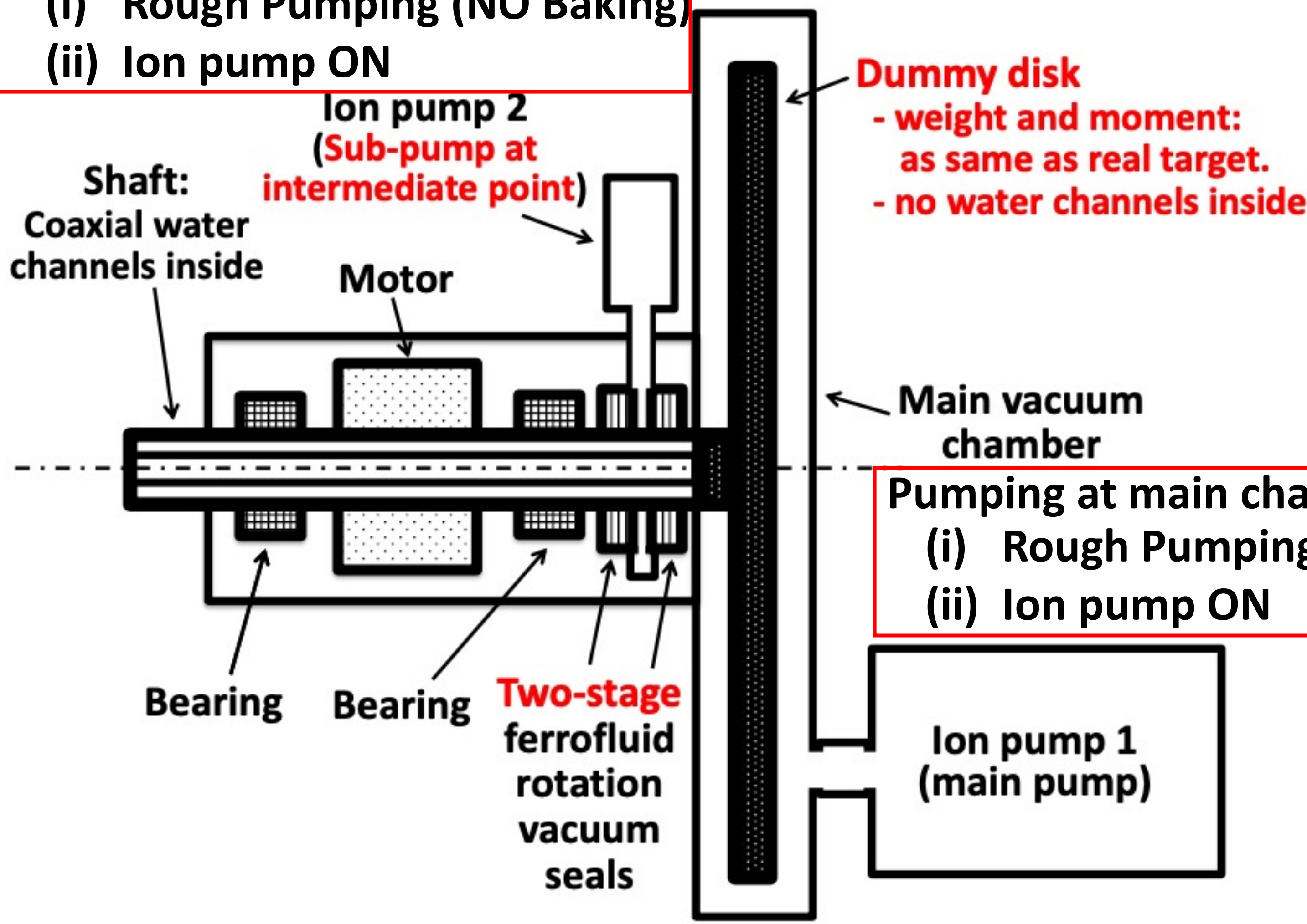


Prototype #2 with Dummy Disk Experimental Procedures

Make pumping at both main chamber and intermediate point from the beginning.

Pumping at intermediate point

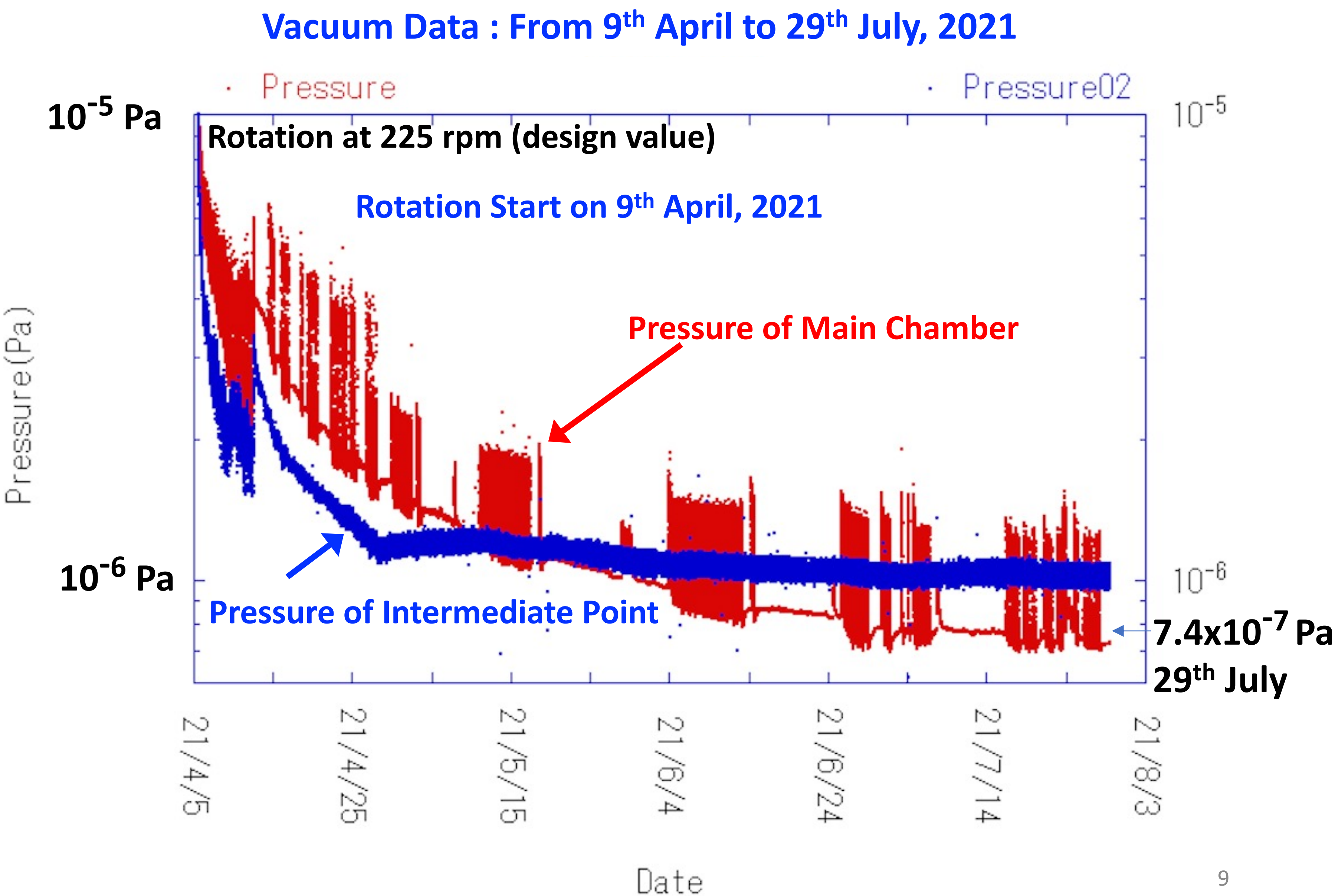
(i) Rough Pumping (NO Baking)
(ii) Ion pump ON



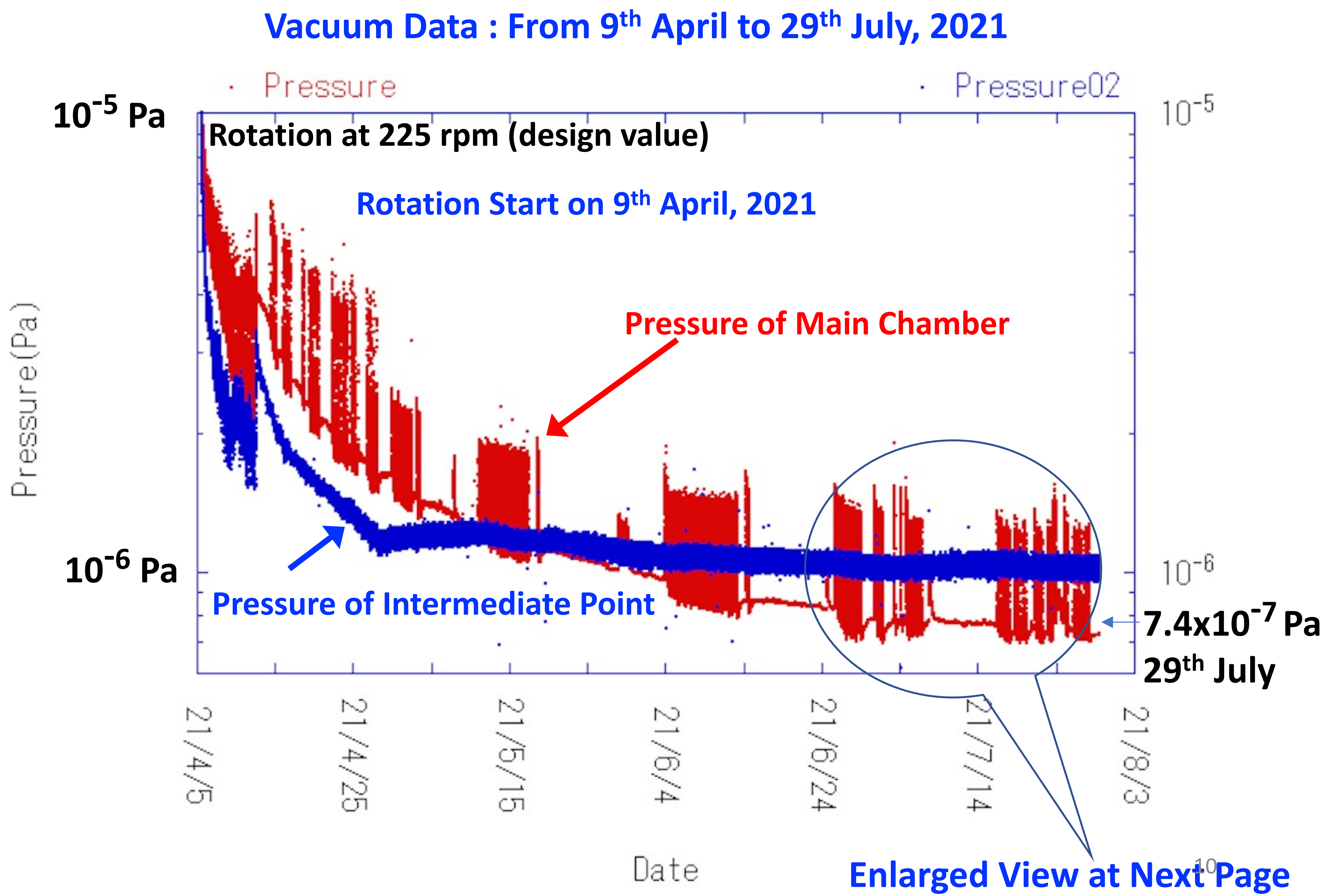
Pumping at main chamber

(i) Rough Pumping + Baking
(ii) Ion pump ON

Prototype #2 with Dummy Disk

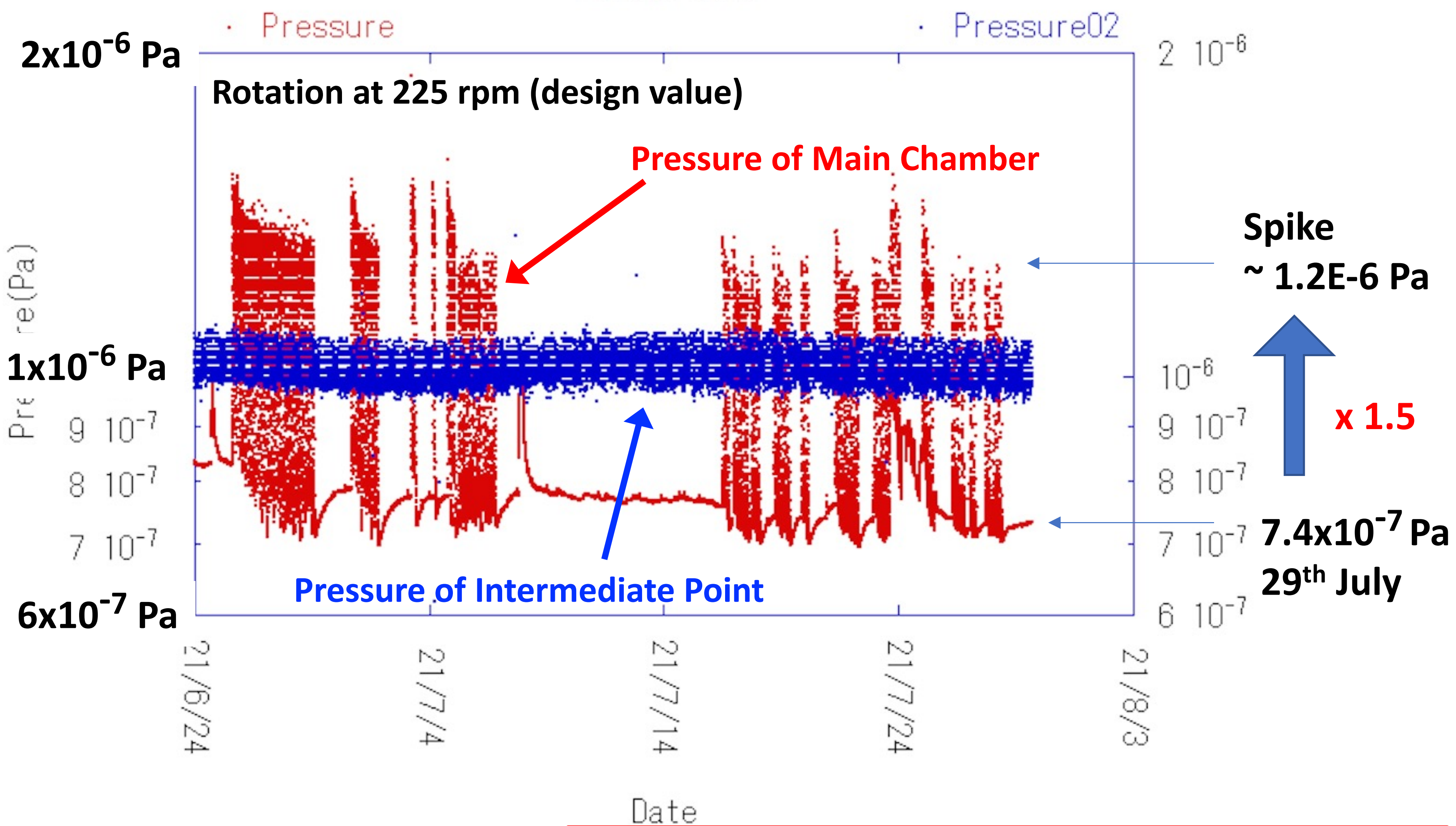


Prototype #2 with Dummy Disk



Prototype #2 with Dummy Disk

Vacuum Data, Enlarged Plot : From 24th July to 29th July, 2021



- We achieved $7x10^{-7}$ Pa with dummy disk.
- Spike appears again. But height is small (x1.5).

(2) Evaporation Pan Test

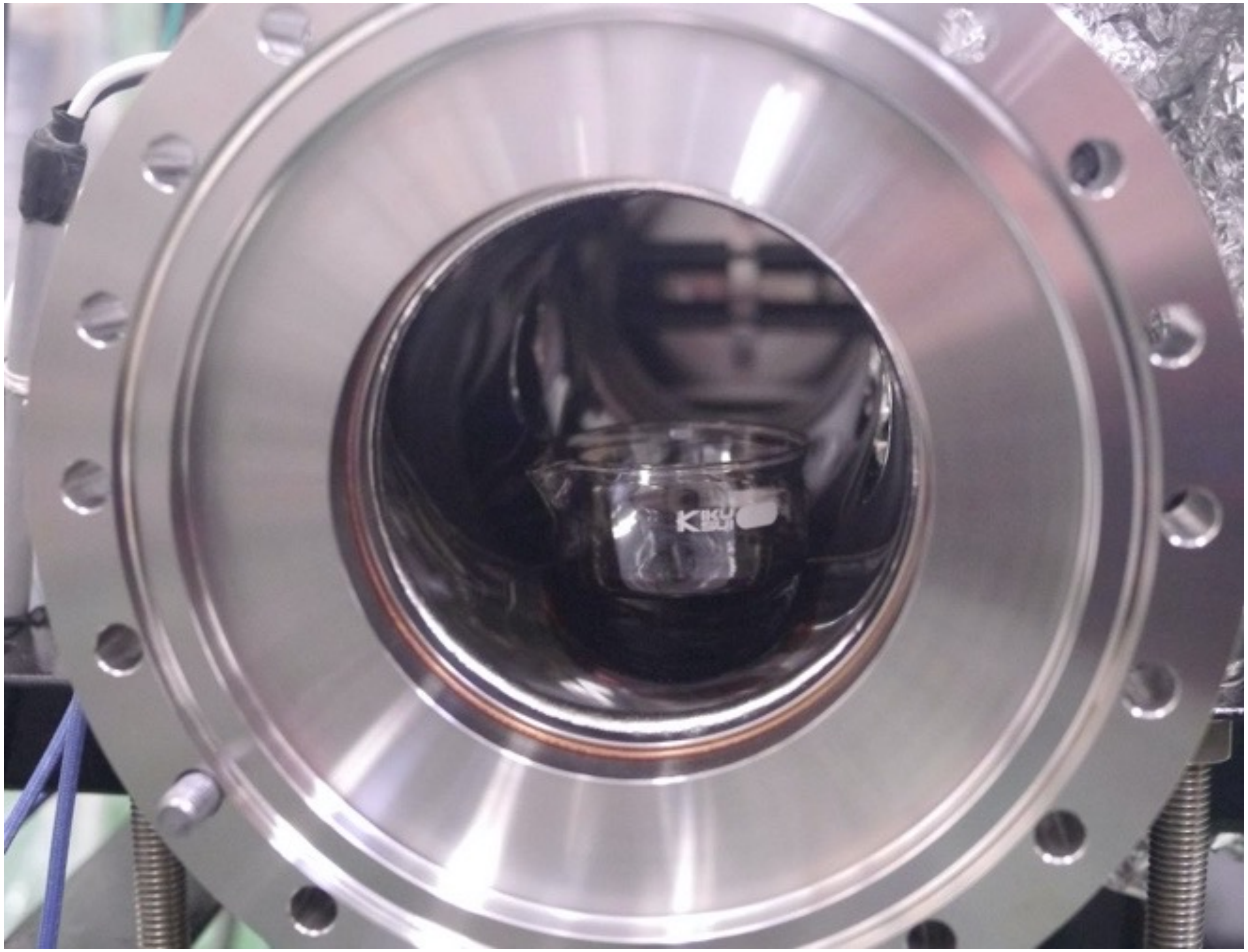


photo: Evaporation pan in the vacuum chamber at KEK, Tsukuba.

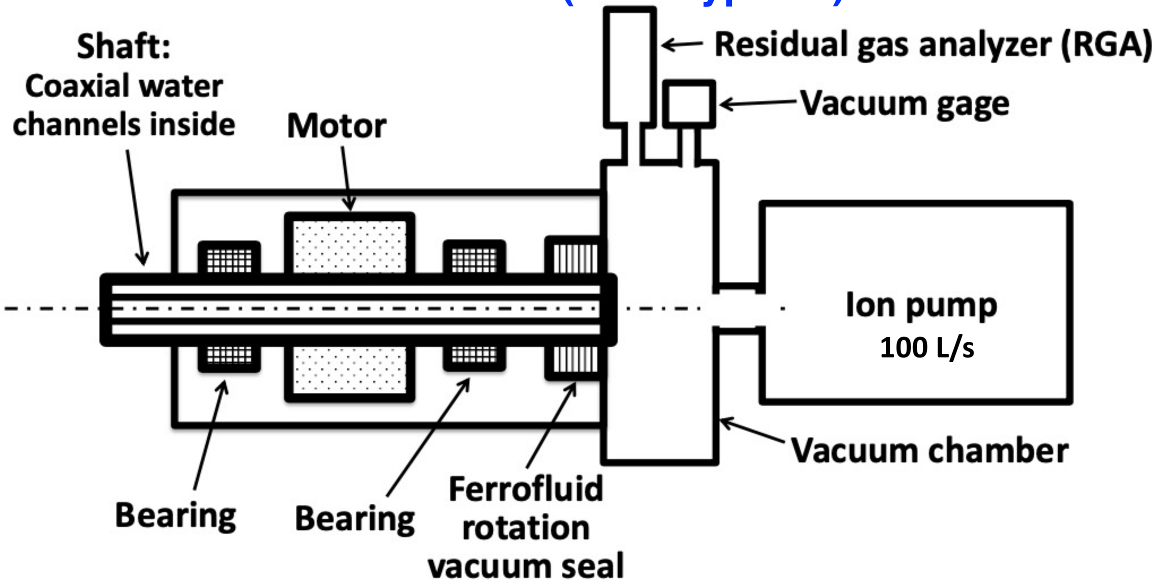
Evaporation Pan Test

Aim.

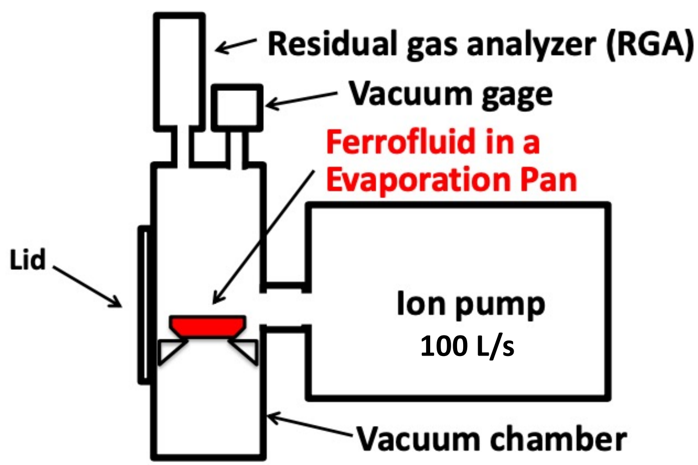
Assuming that the polymer of the ferrofluid decomposes into small molecules (CH-based molecules), determine the upper limit of the amount that will be come out as gas.

CAUTION:
We do NOT claim that the polymer of the ferrofluid decomposes into small molecules.

* Vacuum Test with Rotation (Prototype #1)

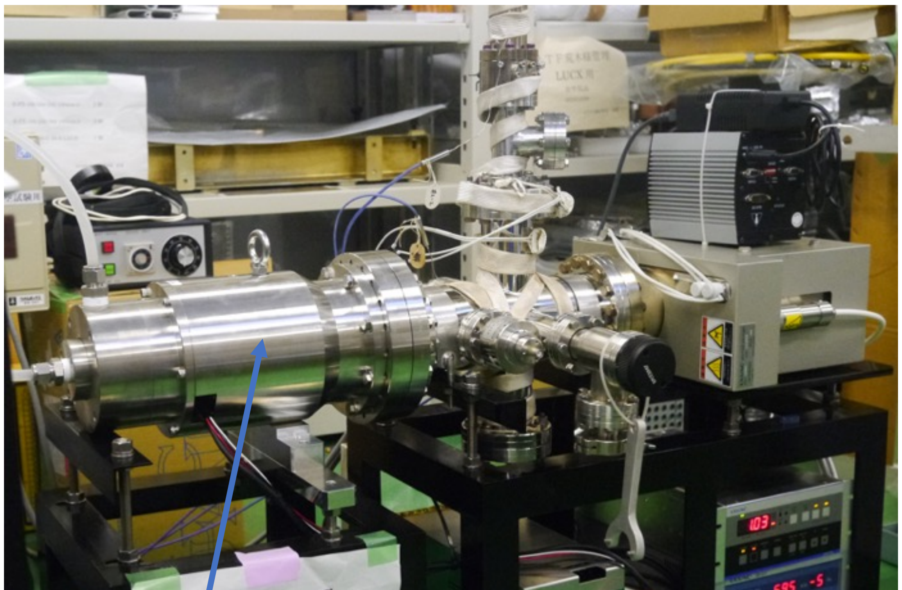


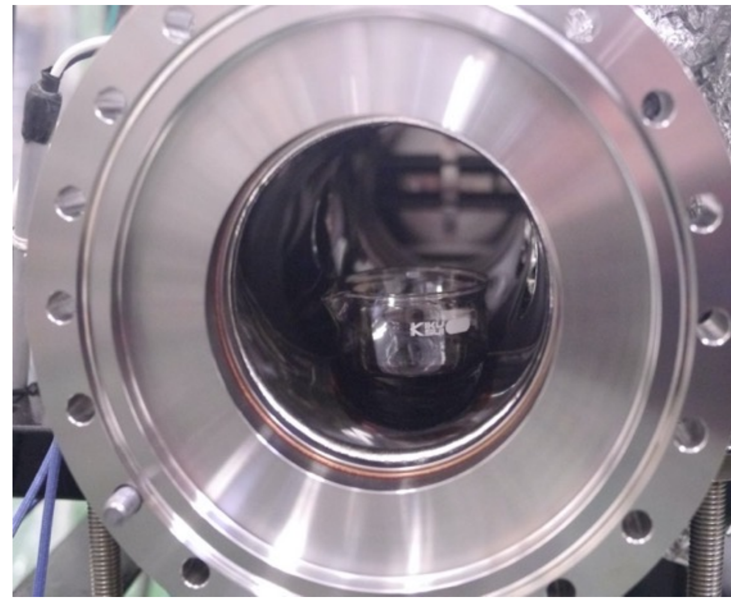
* Evaporation Pan Test



Evaporation Pan Test

(1) Put ferrofluid in an evaporating pan. (2) Put the pan in a vacuum chamber. (3) Close the vessel with a lid. (4) Rough pumping without baking (reason of NOT baking: to protect the ferrofluid). (5) Then turn on ion pump.

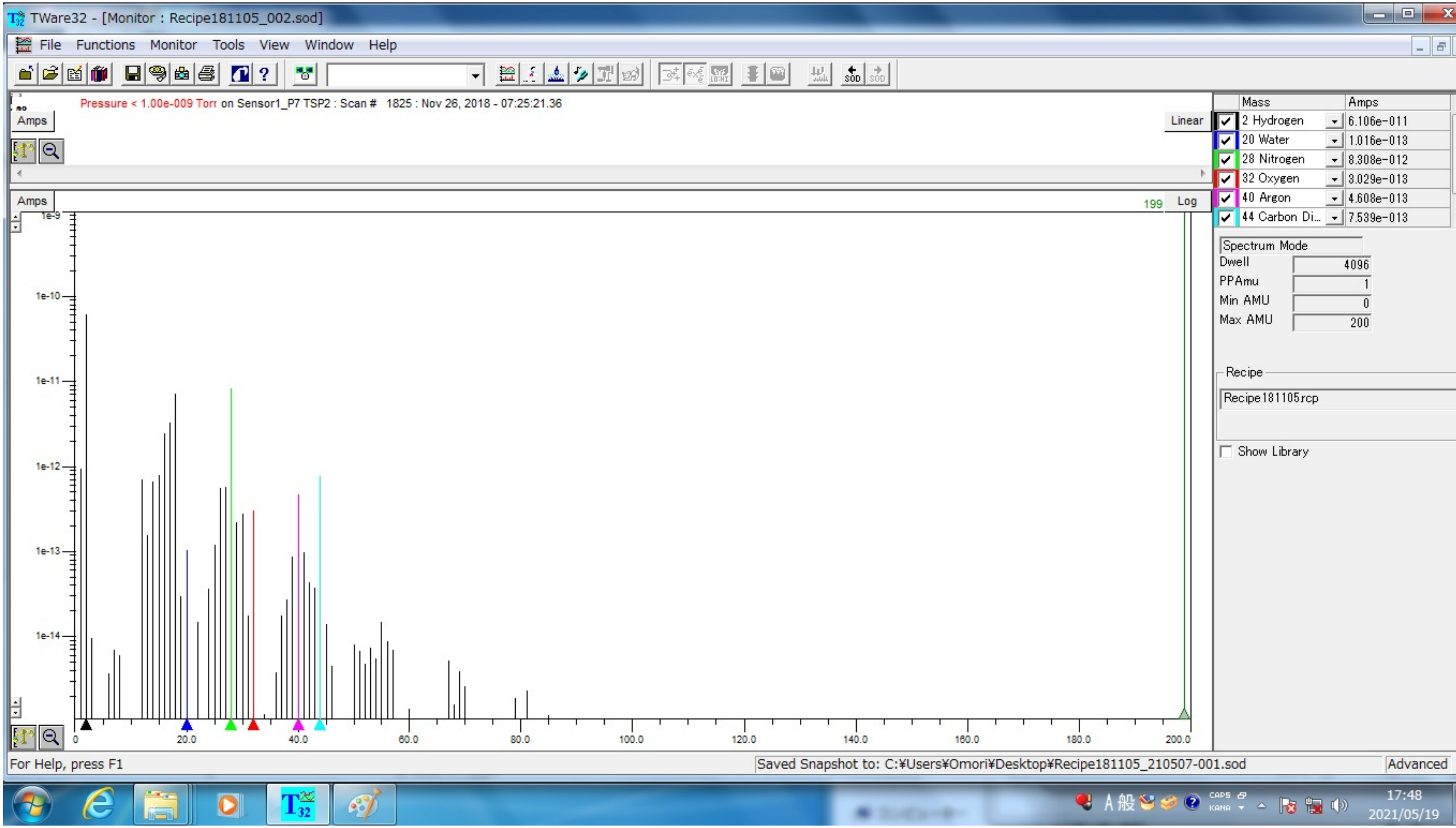




Detach prototype#1 from the test bench, then put ferrofluid in a vacuum chamber.

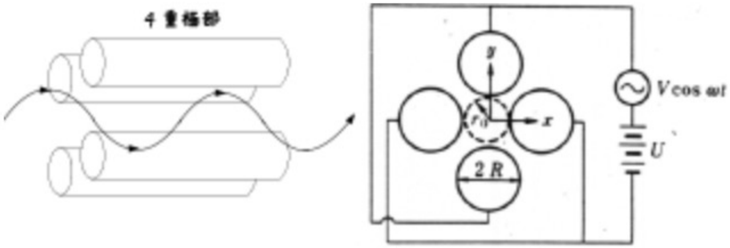
Evaporation Pan Test

Residual Gas Analysis after 22 days of pumping by Ion pump.



Residual Gas Analyser

Principle



Mass Pattern

電子衝撃による気体の電離および解離の研究

I. クラッキング・パターンの安定度，電離確率，
および電離能率曲線（その1）

早 川 晃 雄*・杉 浦 俊 男**

(1955 年 7 月 22 日 受理)

第 1 表　クラッキング・パターンの安定度
（電子加速電圧，100 V； 全電子電流，200 μA； イオン加速電圧. 1300V）

試料	M/e	イオン	クラッキング・パターン（平均値）	平均偏差	同，%	測定回数
	13.3	A^{+++}	0.041			
	20	A^{++}	12.54	0.23	1.8	
A	36	$^{36}A^{+}$	0.308			41
	38	$^{38}A^{+}$	0.061			
	40	A^{+}	100	—	—	
	14	$N^{+}(N_2^{++})$	17.3	0.31	1.8	
N_2	28	N_2^{+}	100	—	—	19
	29	$^{15}NN^{+}$	0.75			
	16	O^{+}	28.2	0.47	1.6	
O_2	32	O_2^{+}	100	—	—	7
	34	$^{16}OO^{+}$	0.41			
H_2	1	H^{+}	2.82	0.04	1.4	16
	2	H_2^{+}	100	—	—	

Summary of Analysis

Mass Number	Results of Measurement (Amps.)	Molecule Assignment						
		H_2	CH_4	H_2O	N_2 + CO	O_2	CO_2	Unknown
1	9.51e-13	9.51e-13	0	0	0	0	0	0
2	6.11e-11	6.11e-11	2.46e-14	0	0	0	0	0
12	7.17e-13	0	8.12e-14	0	0	0	6.53e-14	5.67e-13 (*)
14	6.69e-13	0	1.61e-13	0	0	0	0	5.08e-13 (*)
15	8.09e-13	0	8.09e-13	0	0	0	0	0
16	2.48e-12	0	9.45e-13	0	0	8.54e-14	7.24e-14	1.38e-12 (*)
17	3.33e-12	0	1.04e-14	1.54e-12	0	0	0	1.79e-12 (*)
18	7.27e-12	0	0	7.27e-12	0	0	0	0
22	1.50e-14	0	0	0	0	0	1.43e-14	0
28	8.31e-12	0	0	0	8.24e-12	0	7.39e-14	0
29	2.22e-13	0	0	0	2.22e-13	0	0	0
32	3.03e-13	0	0	0	0	3.03e-13	0	0
34	0	0	0	0	0	0	0	0
44	7.54e-13	0	0	0	0	0	7.54e-13	0
45	1.42e-15	0	0	0		0	1.42e-15	0
Amps. of each molecule	–	6.21e-11	2.03e-12	8.81e-12	8.46e-12	3.88e-13	9.81e-13	4.25e-12
Sum of others	8.46e-13(**)	–	–	–	–	–	–	–

A sort of simultaneous linear equations, but not complete.

Evaporation Pan Test

Summary of Analysis

*** RGA Current of Each Molecule (Amps.)**

H_2	6.21e-11
CH_4	2.03e-12
H_2O	8.81e-12
N_2+CO	8.46e-12
O_2	3.88e-13
CO_2	9.81e-13

In order to be on the safe side in the following discussions, the XCH classification was established.

XCH Identified as CH_4 + Unkowns(*) of Mass(12)(14)(16)(17) + Sum of Others (**)

XCH 7.12e-12

*** Total RGA Current**

8.973e-11

*** Total Pressure (Measured by Ionization Gauge)**

9.27e-7 Pa

Evaporation Pan Test

Analyze Residual Gas after 22 days of pumping by Ion pump.

note: All pressures are shown in nitrogen equivalent.

Total Pressure	9.27e-7 Pa

Partial Pressure

H_2	6.41e-7 Pa
XCH	7.36e-8 Pa
H_2O	9.25e-8 Pa
N_2+CO	8.74e-8 Pa
O_2	4.01e-9 Pa
CO_2	1.01e-8 Pa

What is XCH

- **In order to be on the safe side in the following discussions, the XCH classification was established.**
- **XCH: Identified as CH4, plus unknown components including other hydrocarbons and unknown components arising from analysis (including errors).**
- **XCH is an estimate of the upper limit of hydrocarbon molecules from a pragmatic point of view.**

Evaporation Pan Test

Surface Area of Evaporation Pan $7 \times 10^{-4}\ m^2$ (Diameter of Evaporation Pan = 3 cm)
Ion Pump Capacity 100 L/s ($=100 \times 10^{-3}\ m^3/sec$)

"Evaporation" Rate per Unit Area of XCH determined by Evaporation Pan Test

$$(7.36e\text{-}8\ Pa) \times (100 \times 10^{-3}\ m^3/sec) / (7 \times 10^{-4} m^2)$$

$$= (7.36e\text{-}9\ Pa\ m^3/sec) / (7 \times 10^{-4} m^2)$$

$$= 1.1e\text{-}5\ Pa\ m/sec$$

In the real target, ferrofluid is a ring which diameter is 3 cm and width is 100 micron, if you see it from the vacuum chamber.

The surface area of it: $3.14 \times 0.3\ m \times 100 \times 10^{-6}\ m = 1 \times 10^{-5}\ m^2$

XCH "Evaporation" Rate in the Real Target.

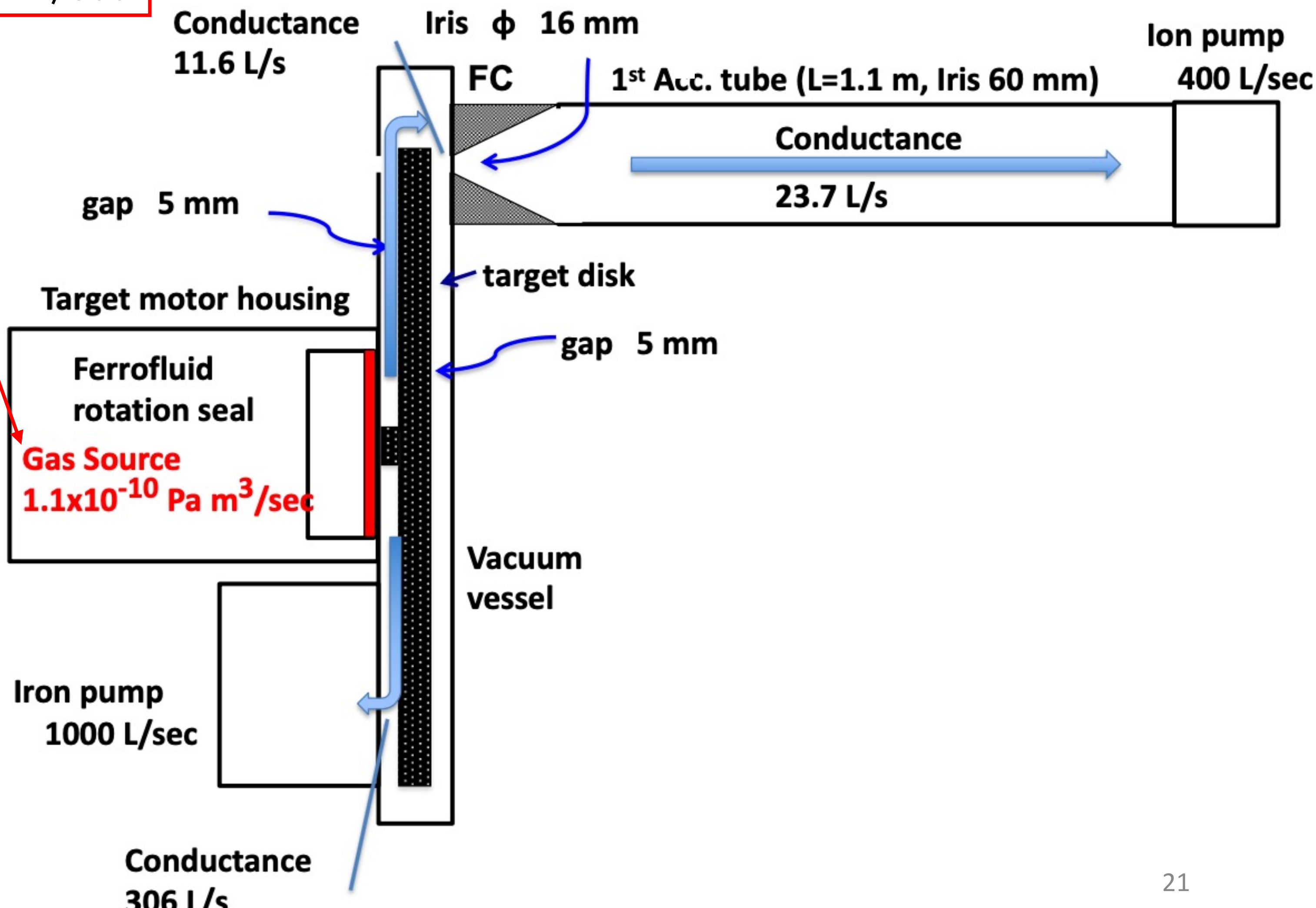
$$1.1e\text{-}10\ Pa\ m^3/sec$$

Evaporation Pan Test

Model to Calculate XCH Partial Pressure at Acc. Tube

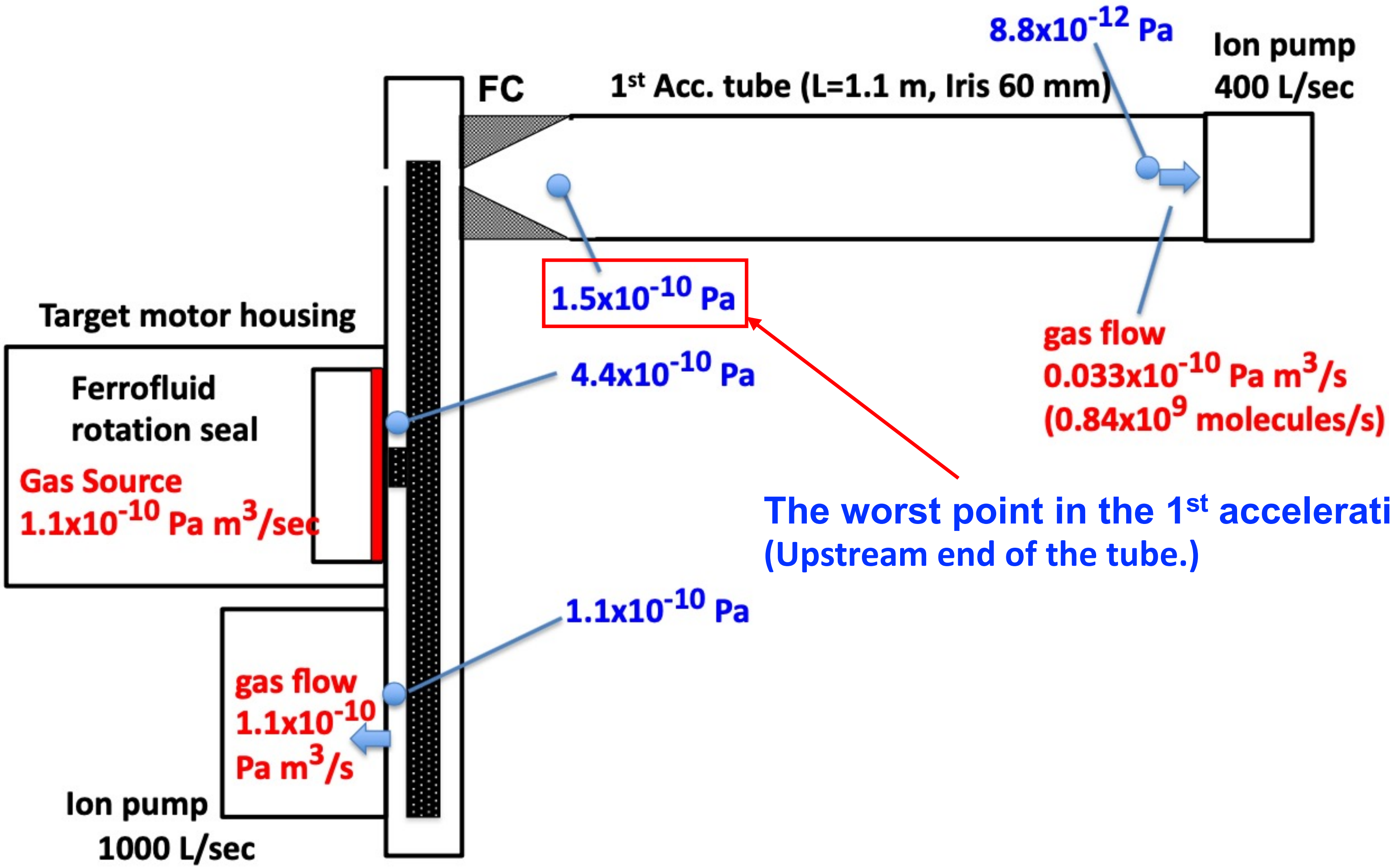
XCH "Evaporation" Rate in the Real Target.

1.1e-10 Pa m³/sec



Evaporation Pan Test

Results of the Model Calculation
XCH Partial Pressure at Various Points.



The worst point in the 1st accelerating tube.
(Upstream end of the tube.)

Upper limit of CH-based gas at upstream end of the accelerating tube: 1.5×10^{-10} Pa.
We judge it is reasonably safe, according to the past experiences.

(3) Vacuum test with Rotation

Prototype #1 with Irradiated Ferrofluid

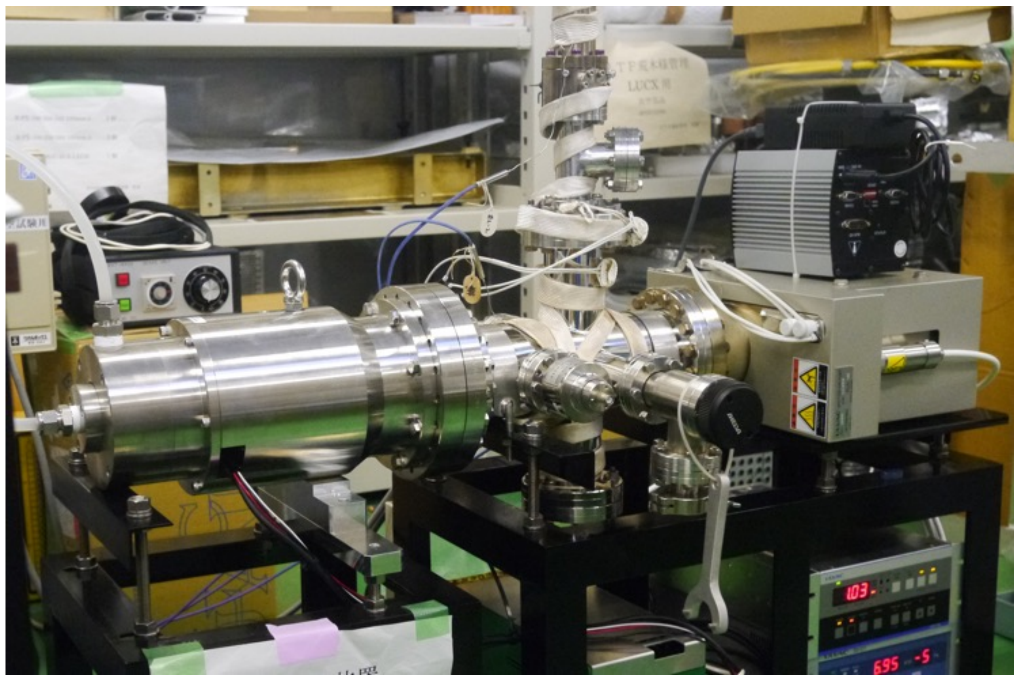
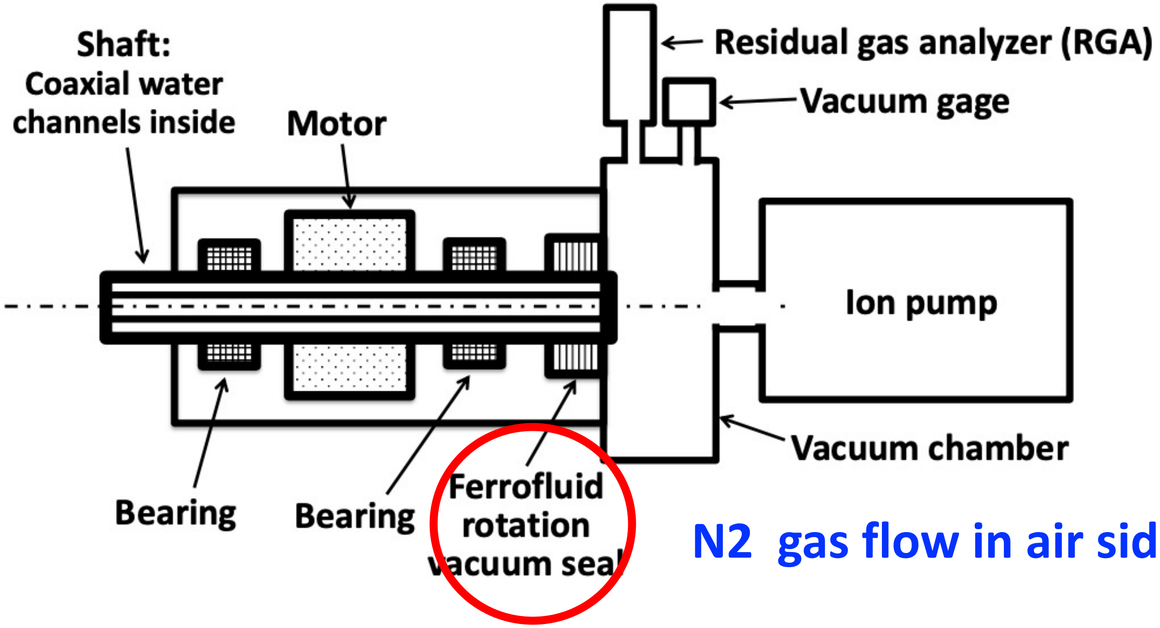


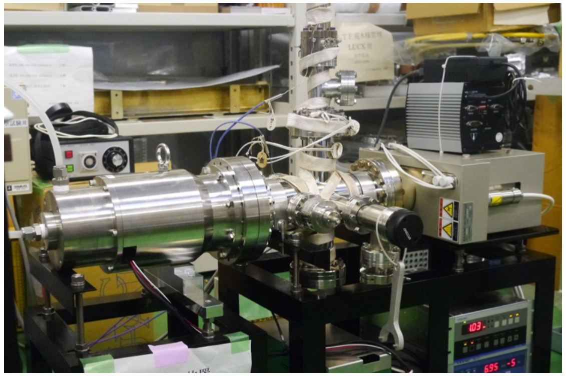
photo: Prototype #1

Prototype #1 with
4.7 MGy irradiated ferrofluid.



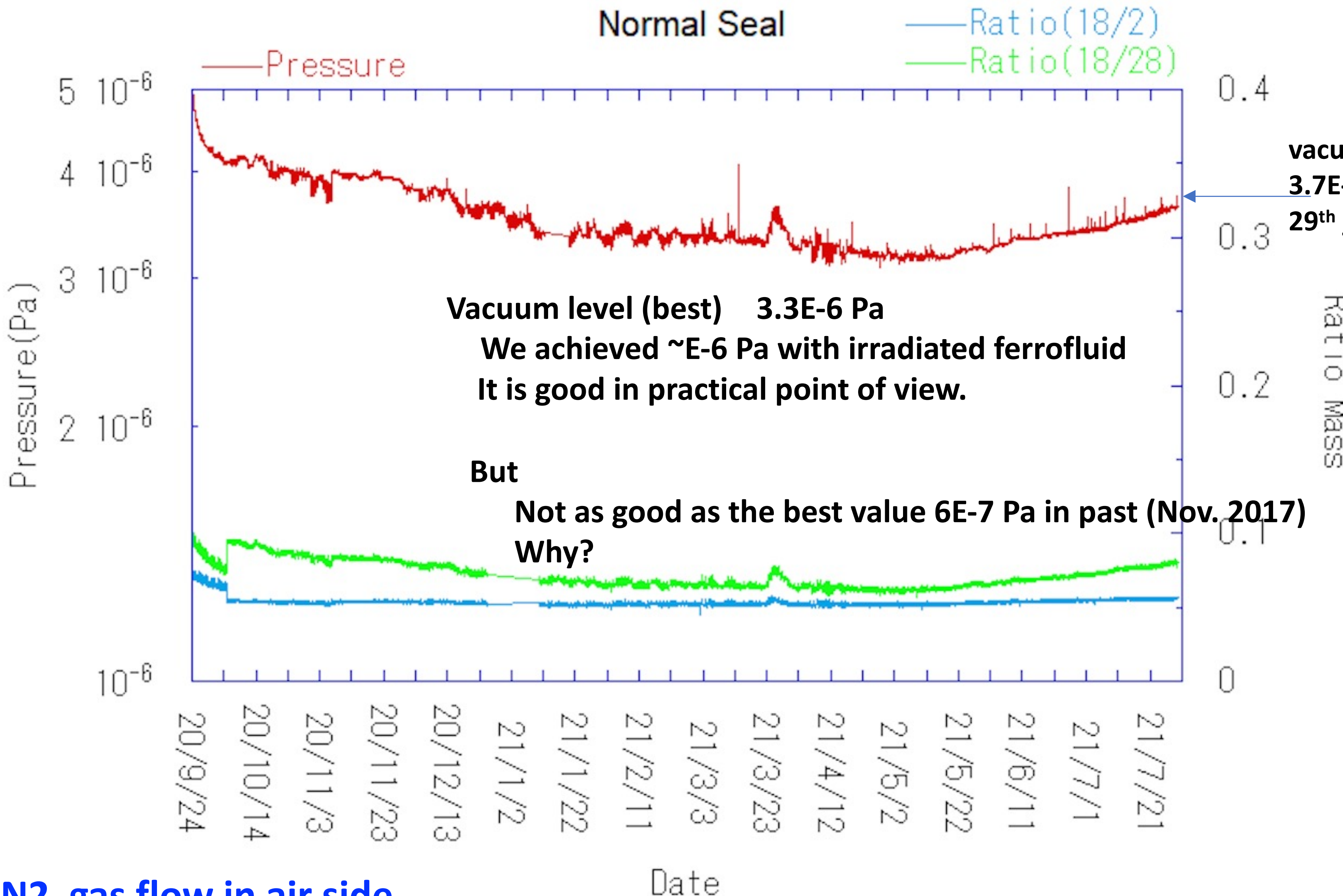
N2 gas flow in air side

Replace to 4.7 MGy irradiated
ferrofluid (ILC 2600 bunch x 3 years)



Prototype #1 with 4.7 MGy irradiated ferrofluid

September 2020 to July 2021



vacuum level 3.7E-6 Pa 29th july

Vacuum level (best) 3.3E-6 Pa

We achieved ~E-6 Pa with irradiated ferrofluid

It is good in practical point of view.

But

Not as good as the best value 6E-7 Pa in past (Nov. 2017)

Why?

N2 gas flow in air side

Prototype #1 with 4.7 MGy irradiated ferrofluid

September 2020 to July 2021

Vacuum level 3.3E-6 Pa

We achieved ~E-6 Pa with irradiated ferrofluid

It is good in practical point of view.

But

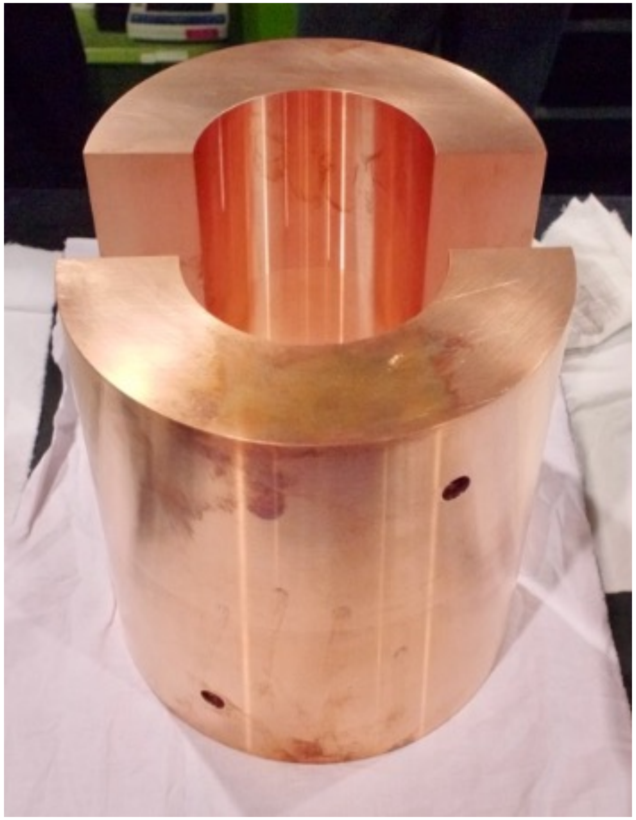
Not as good as the best value 6E-7 Pa in past (Nov. 2017)

Why?

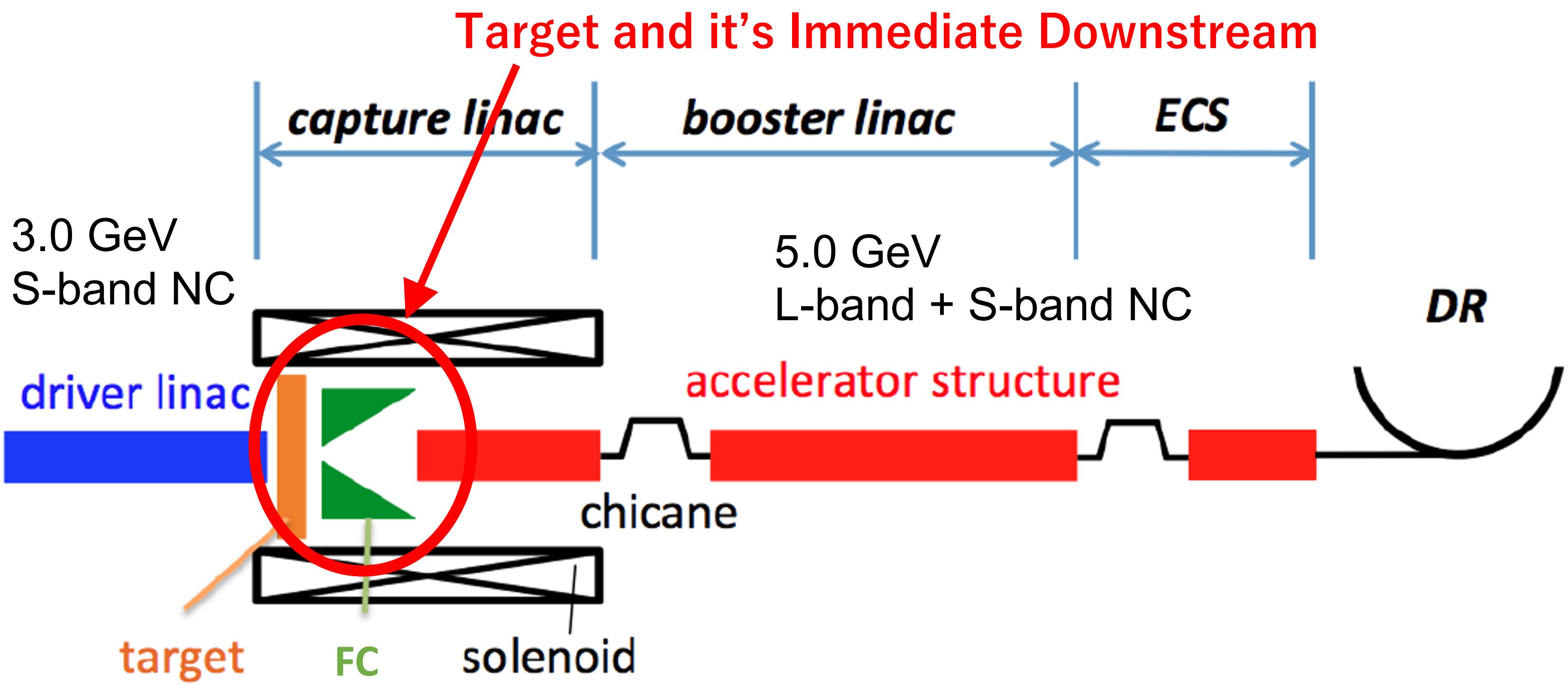
Why?

- **Irradiated fluid?**
- **Ion pump is aged?**
- **Humidity in air side of body is high (10 - 20%) ?**
- **Other reason？**

(4) Cooling design of Immediate Downstream of Target



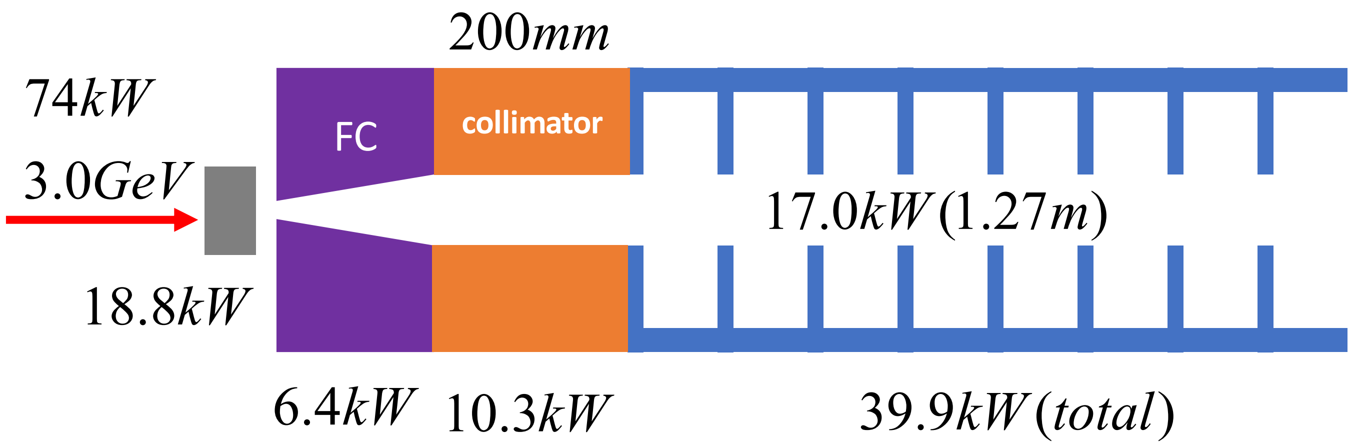
E-driven ILC Positron Source



- 20 of 0.48us pulses are handled with NC linacs operated in 300Hz.
- 100 of 300 pulses are actually fired.

Heat Load at Target and it's Immediate Downstream

note : Each number is subject to reevaluate and is possibly changed.



Target	$18.8kW$
collimator	$10.3kW$
Flux Concentrator	$6.4kW(beam)+14kW(ohmic)$ $\mathrm{PEDD=9J/g(1320bunch)=0.4kW/cm^3}$
Capture Linac	$39.9kW(total)$ $3.32kW(RF)$ per $9Cell(tube)$ $17.0kW(beam)+3.32kW(RF)$ in $first$ $9Cell$

What to do

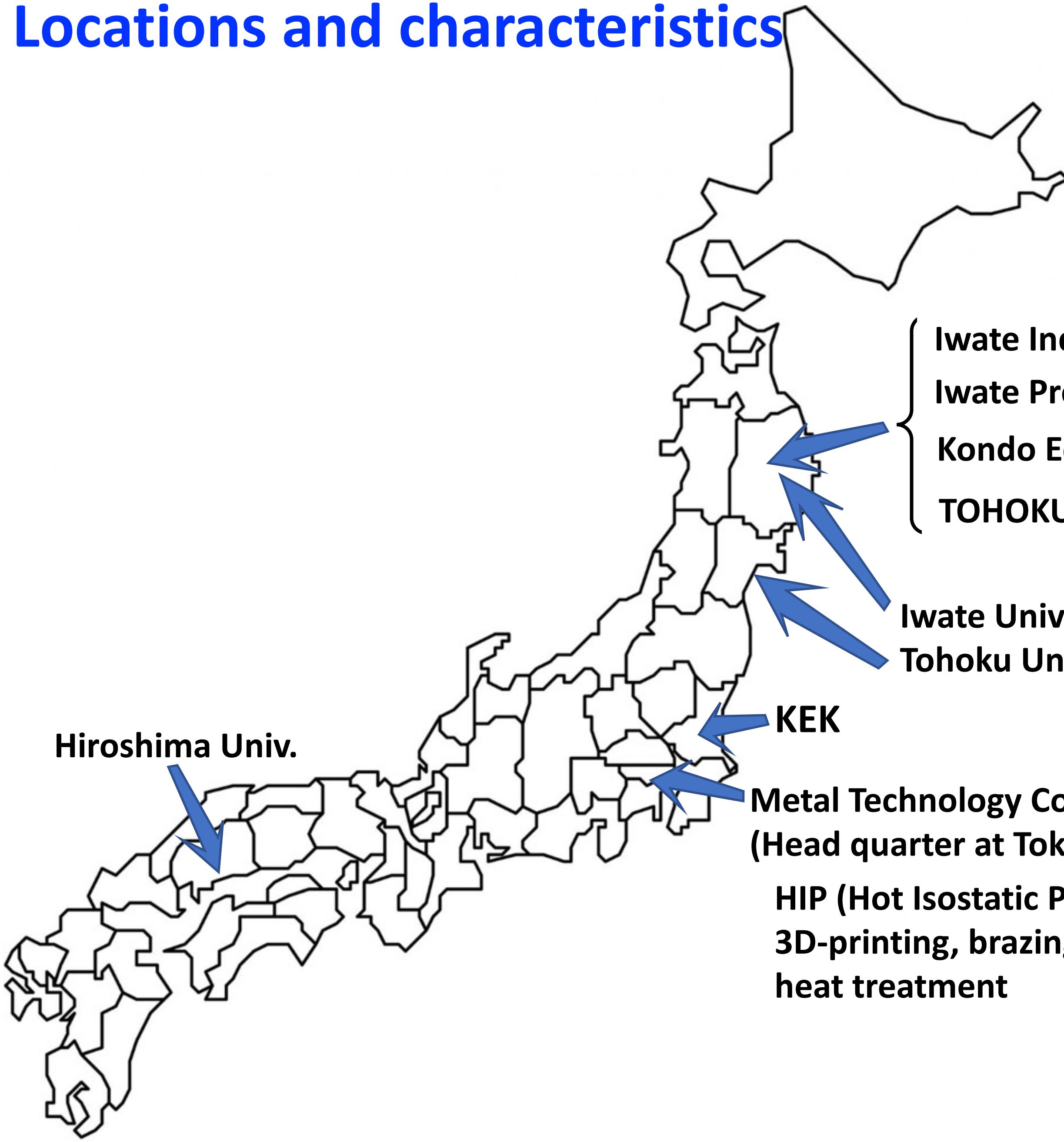
The collimator, the flux concentrator, and the first accelerating tube are located at immediate downstream of the target. They are directly hit by the electromagnetic shower and are in severe thermal environment.

The flux concentrator and the first accelerating tube also generate heat by themselves.

We are going to solve the "Cooling design of Immediate Down Stream of Target" by Industry, Local Government, and Academia cooperation.

Iwate Prefectural Industrial Technology Center,
Kondo Equipment Co. Ltd., Iwate Industry Promotion Center,
Iwate University/Tohoku University, Hiroshima University,
Metal Technology Co. Ltd., TOHOKU SEIMITSU CO. LTD., and KEK

Participating companies / organizations
Locations and characteristics



HIP (Hot Isostatic Pressing),
3D-printing, brazing, welding,
heat treatment

Participating companies / organizations Locations and characteristics

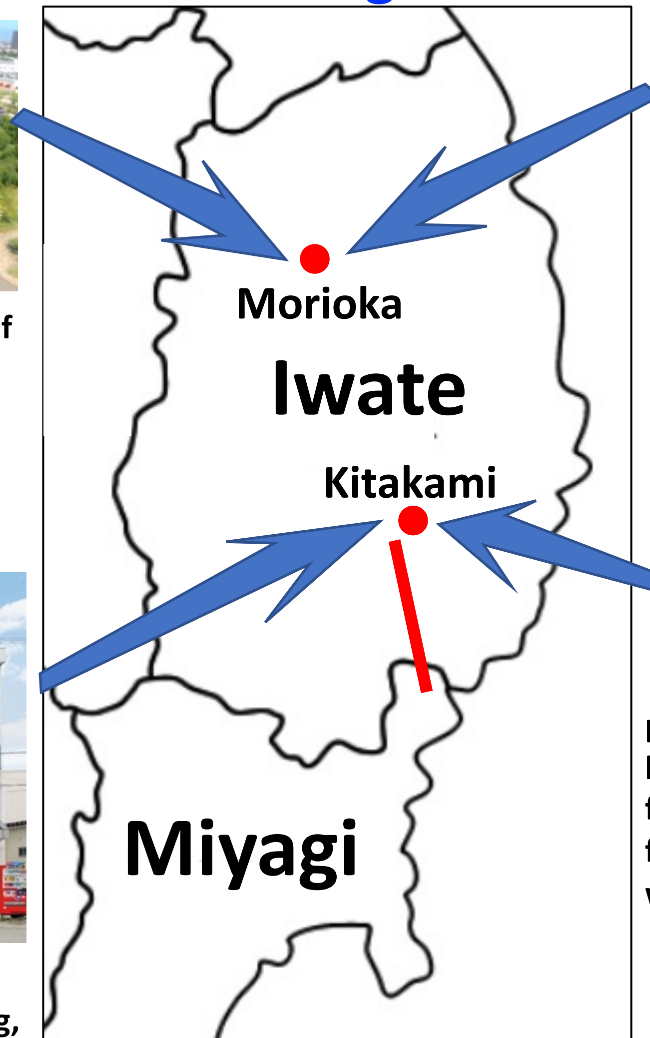
Iwate Prefectural Industrial Technology Center (地独)

“Contribute to the community" in terms of both industrial promotion and solving prefectural government issues. Provide technical support to companies.

TOHOKU SEIMITSU

Bonding methods (welding, diffusion bonding, vacuum brazing, friction welding, Spark Plasma Sintering,,,,)

Iwate: enlarged view



Iwate Industry Promotion Center (公財)

To support promotion of industry in Iwate, cooperating with the government, Iwate prefectural government, Commerce-and-industry organizations, and research institutes.

Kondo Equipment Co., Ltd.

piping in general, air conditioning systems, heating and cooling systems, sanitary facilities, fire extinguishing systems, piping for large plants, prefabrication piping system with 3D-laser-measurement with 3D-CAD

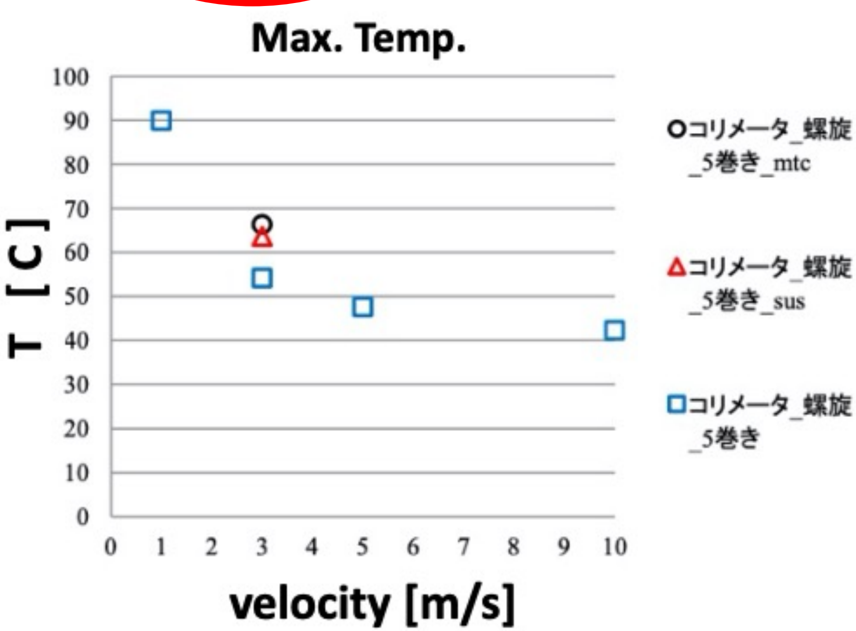
National Stadium

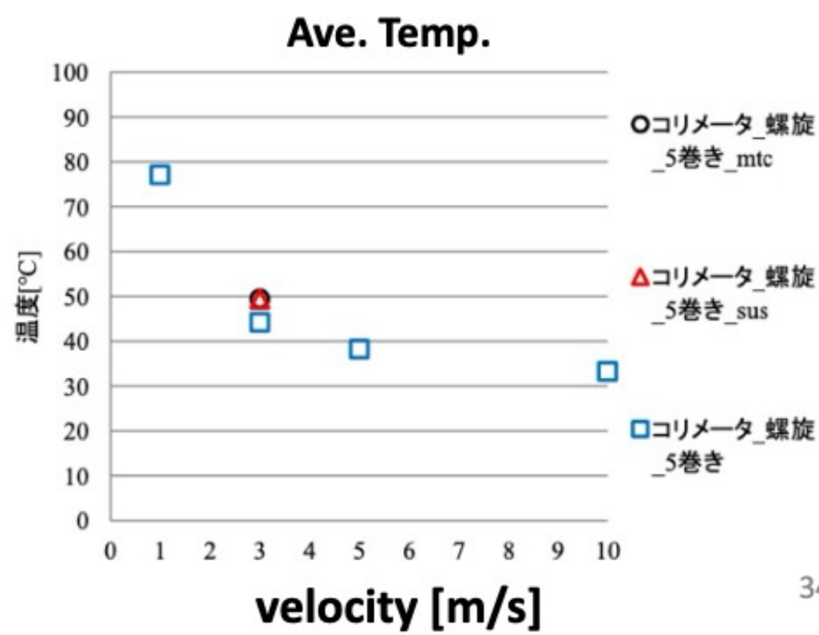
TOHOKU SRF

Collimator : an example of ongoing studies

Collimator : an example of ongoing studies

note : Collimator is a passive device. Heat is generated by EM shower alone.

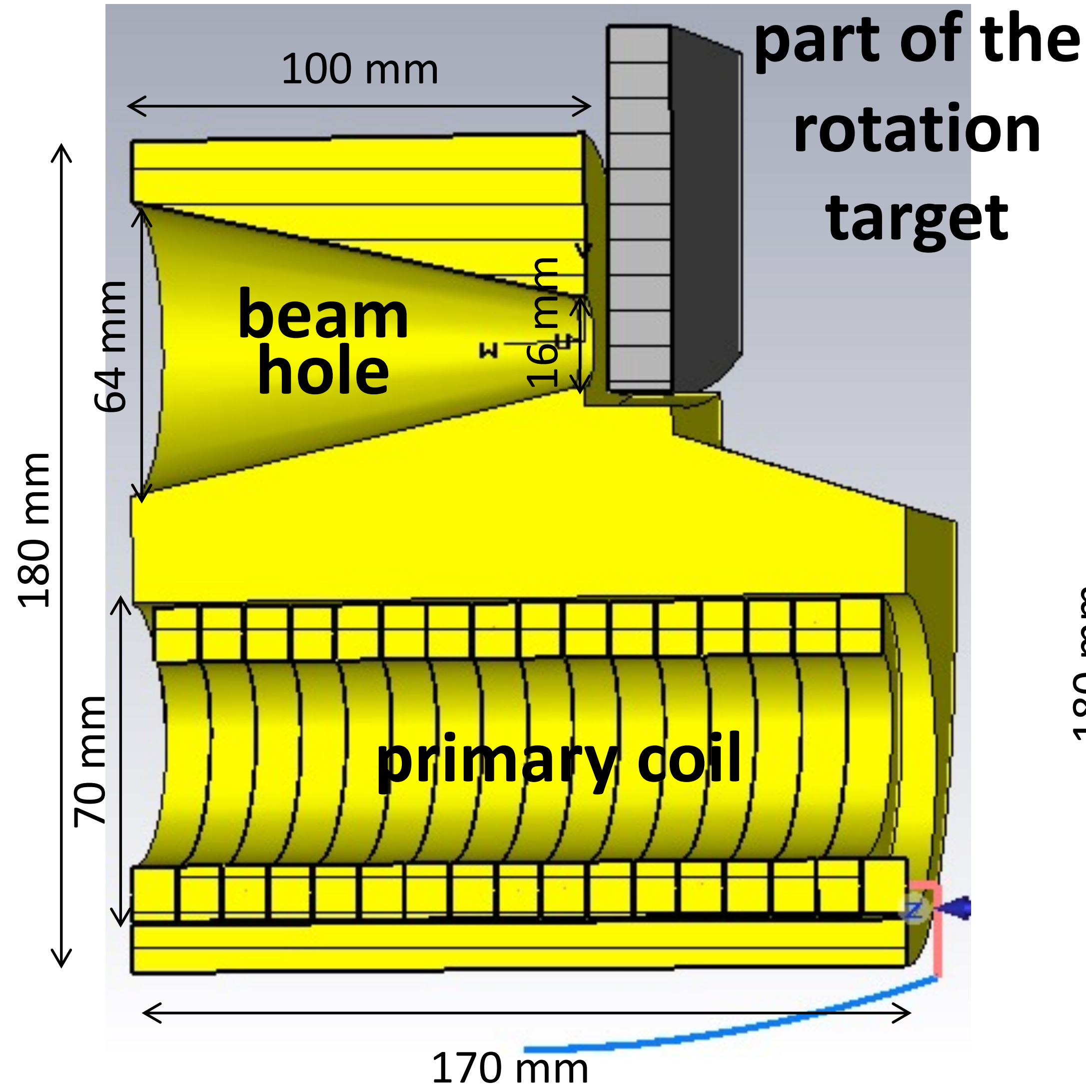


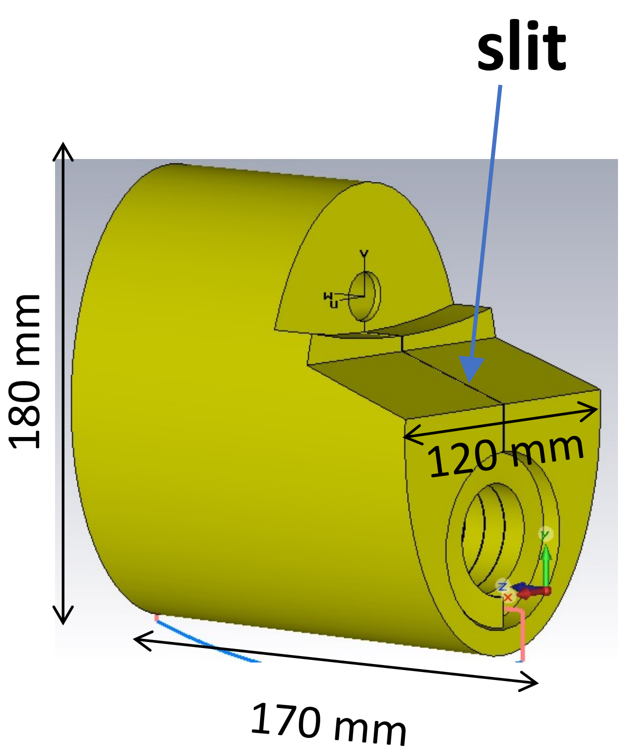


FC : an example of ongoing studies

Single turn FC D16 mm

Pavel MARTYSHKIN et al.
Budker INP 2016-2
KEK Preprint 2015-65





FC : example of ongoing study

note : Heat both by EM shower and by ohmic loss are considered in the study.

3D-printing model

velocity	2	5	m/s
Max Temp.	75	60	℃
Ave. Temp.	49	37	℃

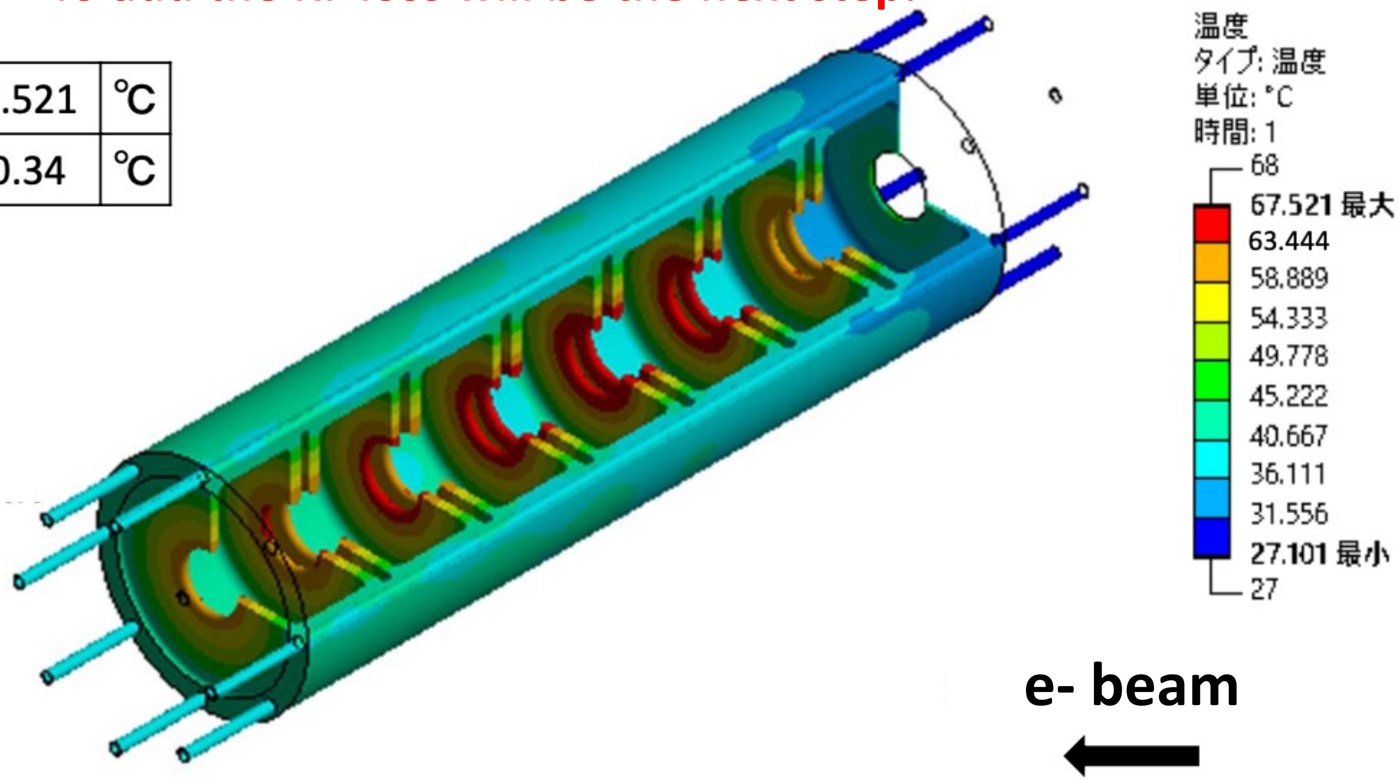
Modular Design model (3 modules)

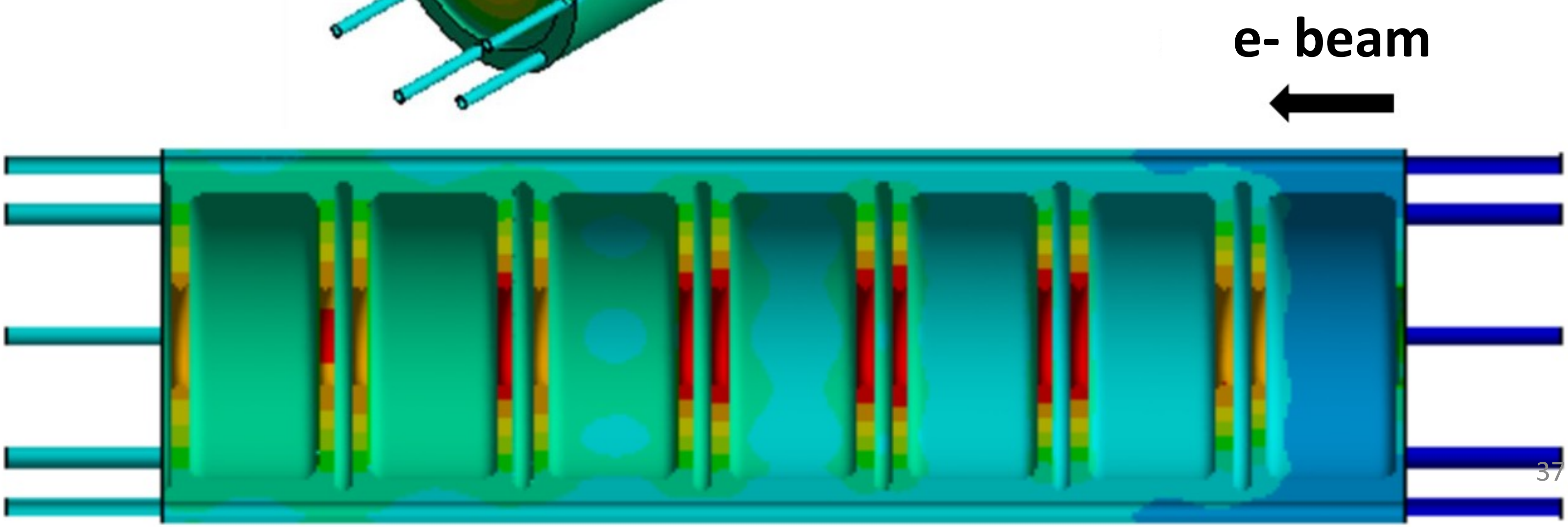
velocity	2	5	m/s
Max Temp.	77	65	℃
Ave. Temp.	46	38	℃

Capture Cavity (the first acc. tube): an example of ongoing studies

note : Heat only by EM-shower is considered in the study.
To add the RF loss will be the next step.

Max Temp.	67.521	℃
Ave. Temp.	40.34	℃





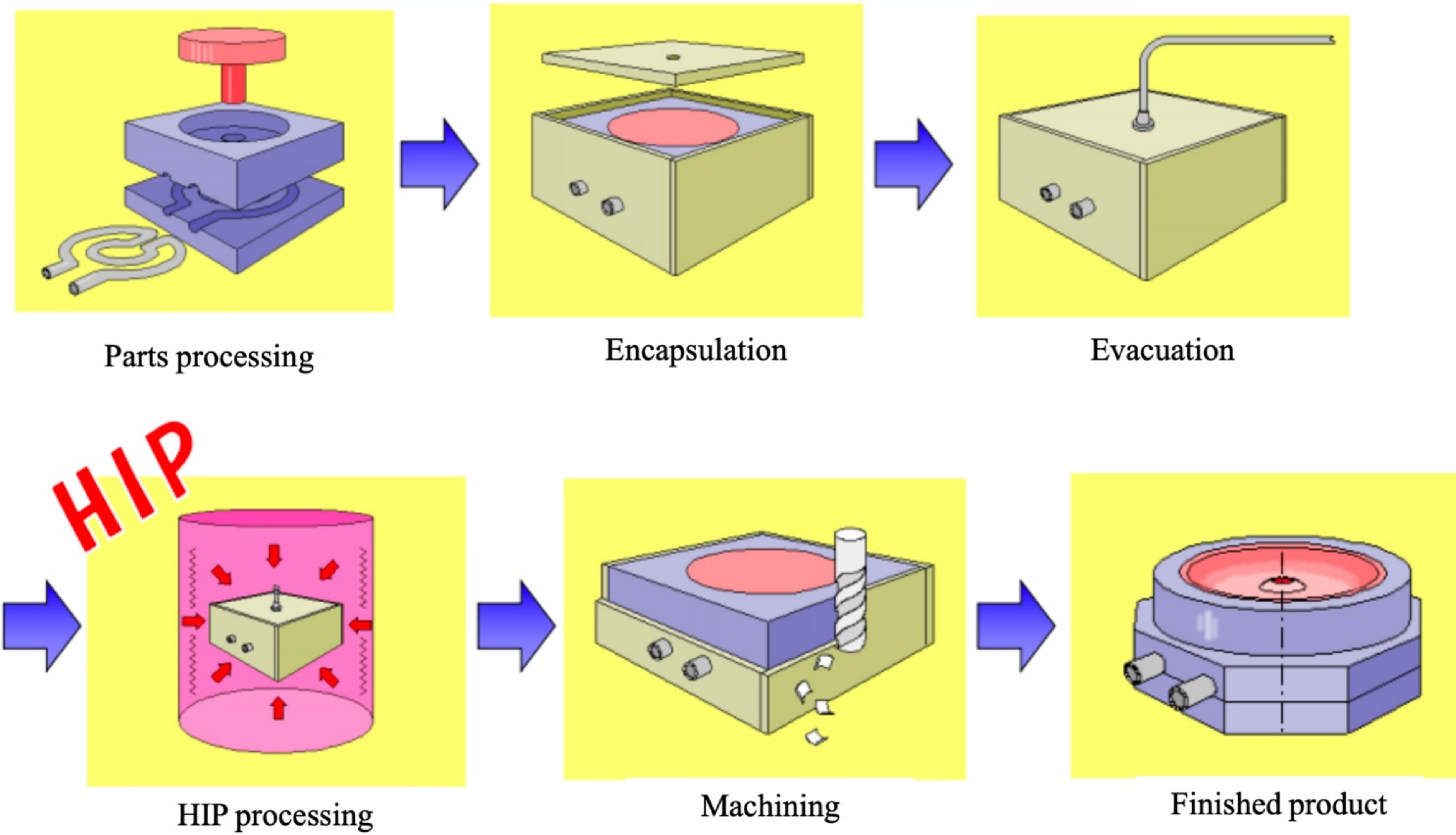
We made a mock-up of the collimator by Hot Isostatic Pressing (HIP)

We made a mock-up of the collimator by HIP

A 7 kW heater will be used to give heat at inner surface

The heater was made budget of Iwate Univ.

Encapsulated parts are bonded by HIP process



Diffusion Bonding by HIP

MTC

◆ Hot Isostatic Pressing(HIP)

Diffusion bonding, which was difficult with the conventional method, is possible in an environment of high temperature and high pressure (1000 kg / cm2 = over 98 MPa).

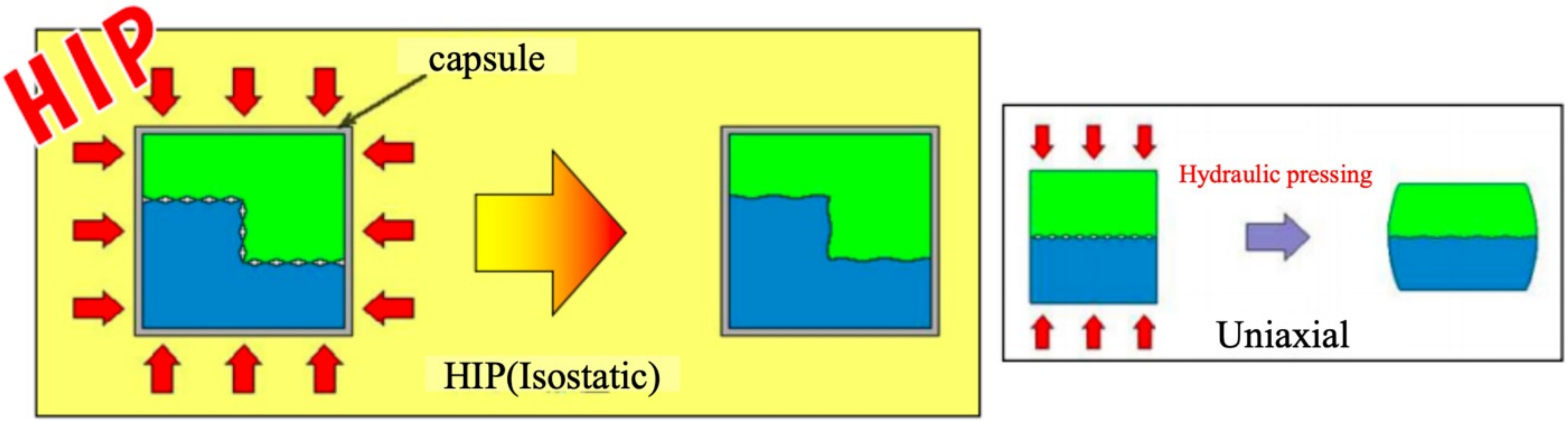


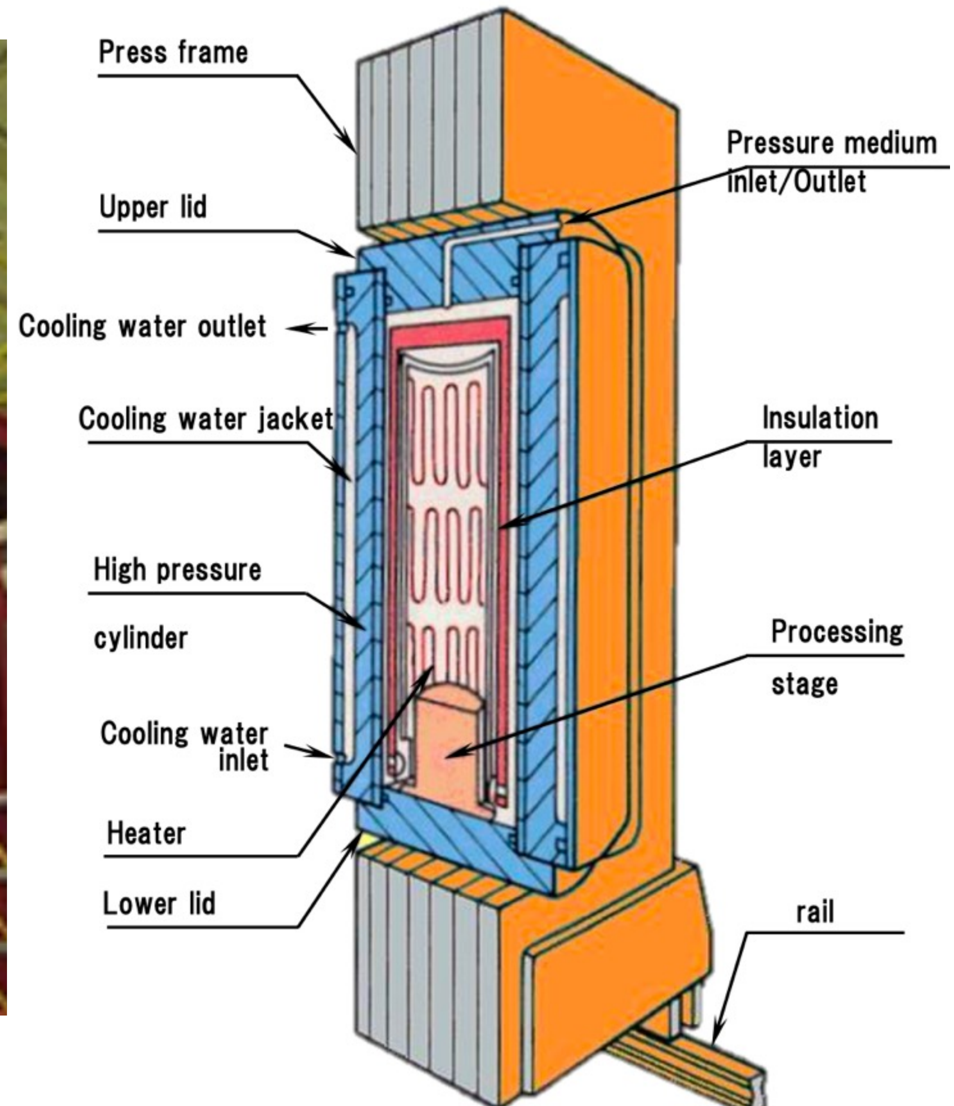
Image diagrams of Isostatic and Uniaxial pressing

- Diffusion bonding of Dissimilar metals(Cu-SUS, Ti-SUS, Cu-carbon steel)
- Bonding for all surface directions (Isostatic)
- Three-dimensional shape (No remarkable deformation in one direction)
- High temperature strength without brazing material.

金属技研・長澤氏 ILCX 2021 スライド

HIP machine in Metal Technology Co.

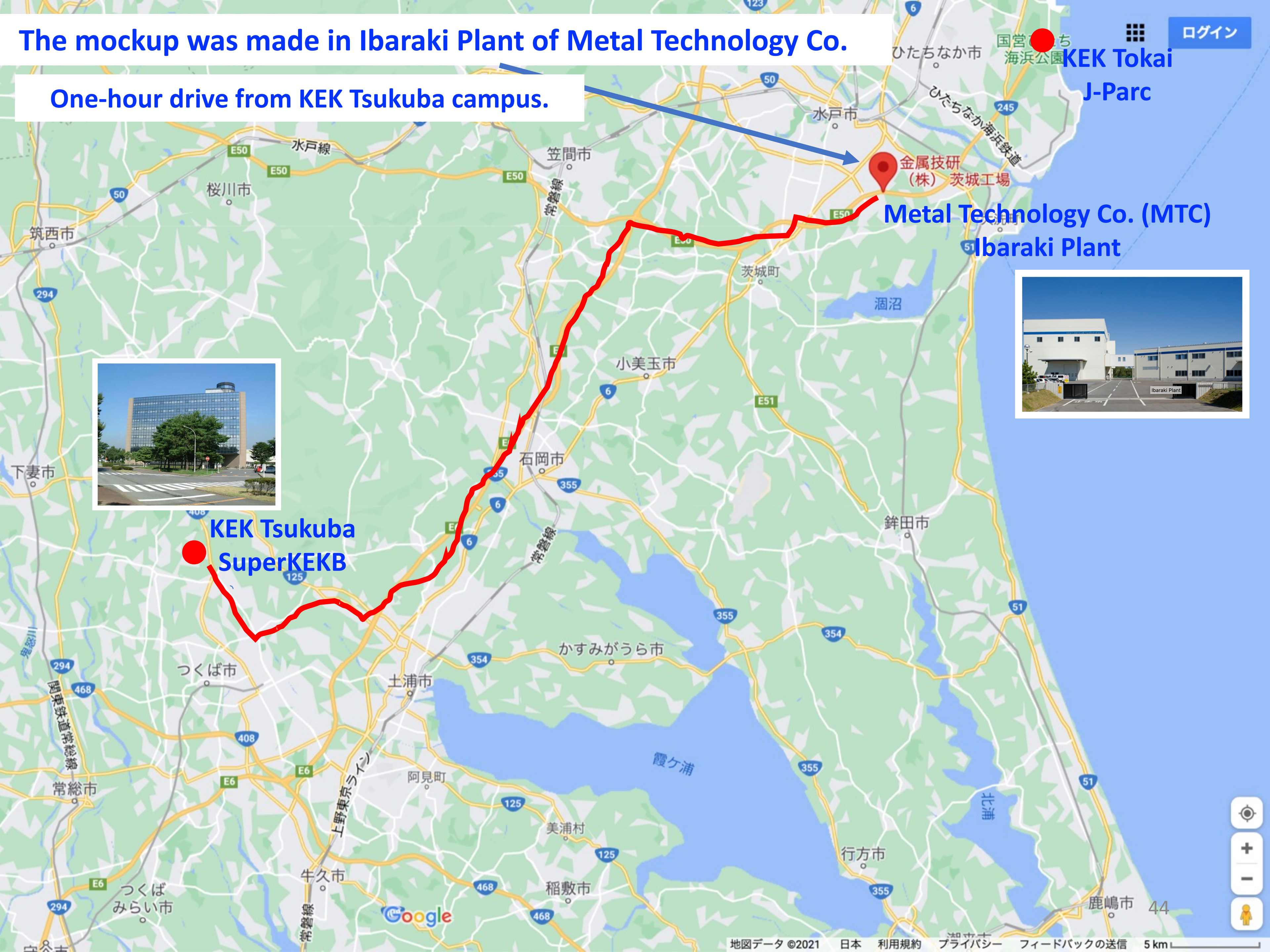
写真は金属技研 HP より借用



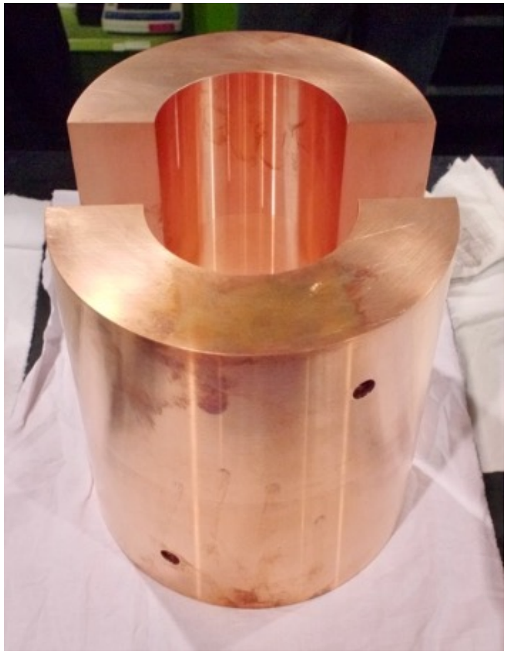
図は金属技研・長澤氏
ILCX 2021 スライドより借用

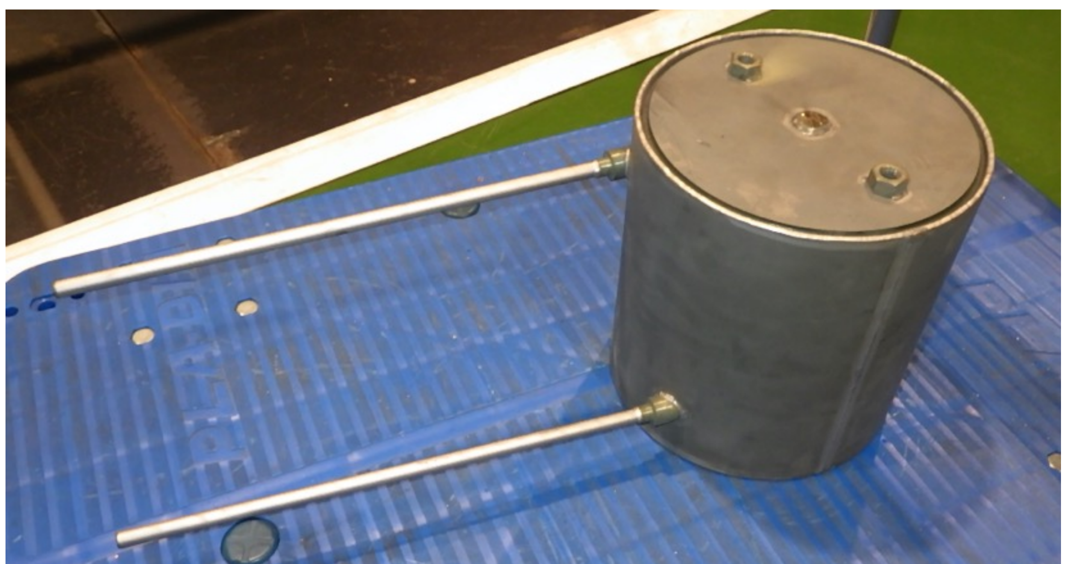
The mockup was made in Ibaraki Plant of Metal Technology Co.

One-hour drive from KEK Tsukuba campus.

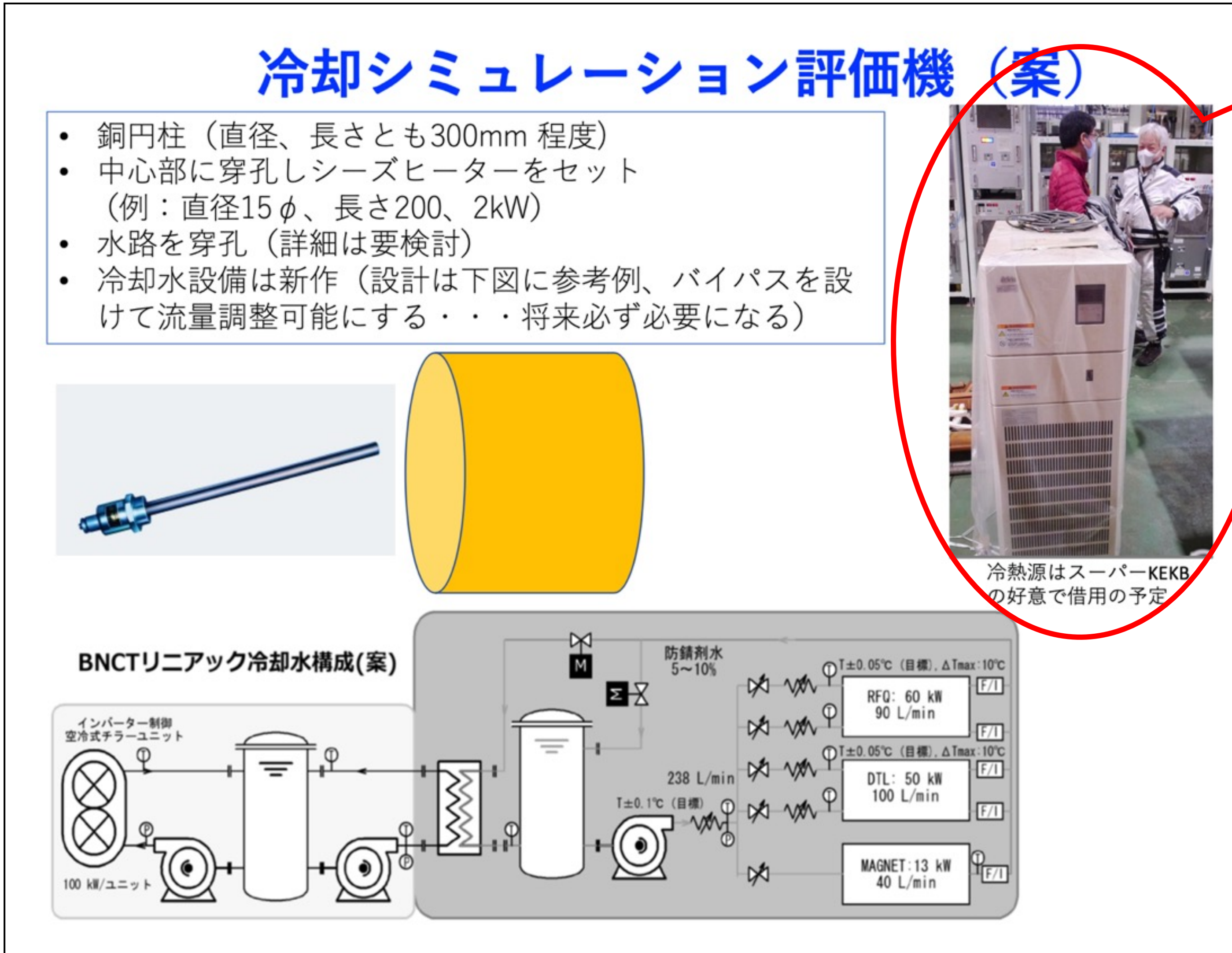


The Mockup under construction in Ibaraki Plant of Metal Technology Co.





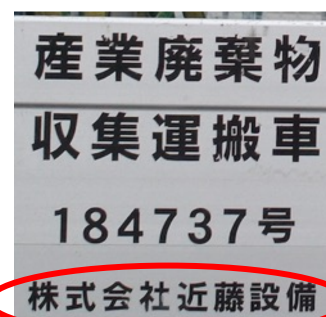
Preparation of the cooling test by the mock-up.



Chiller unit once used for KEKB.

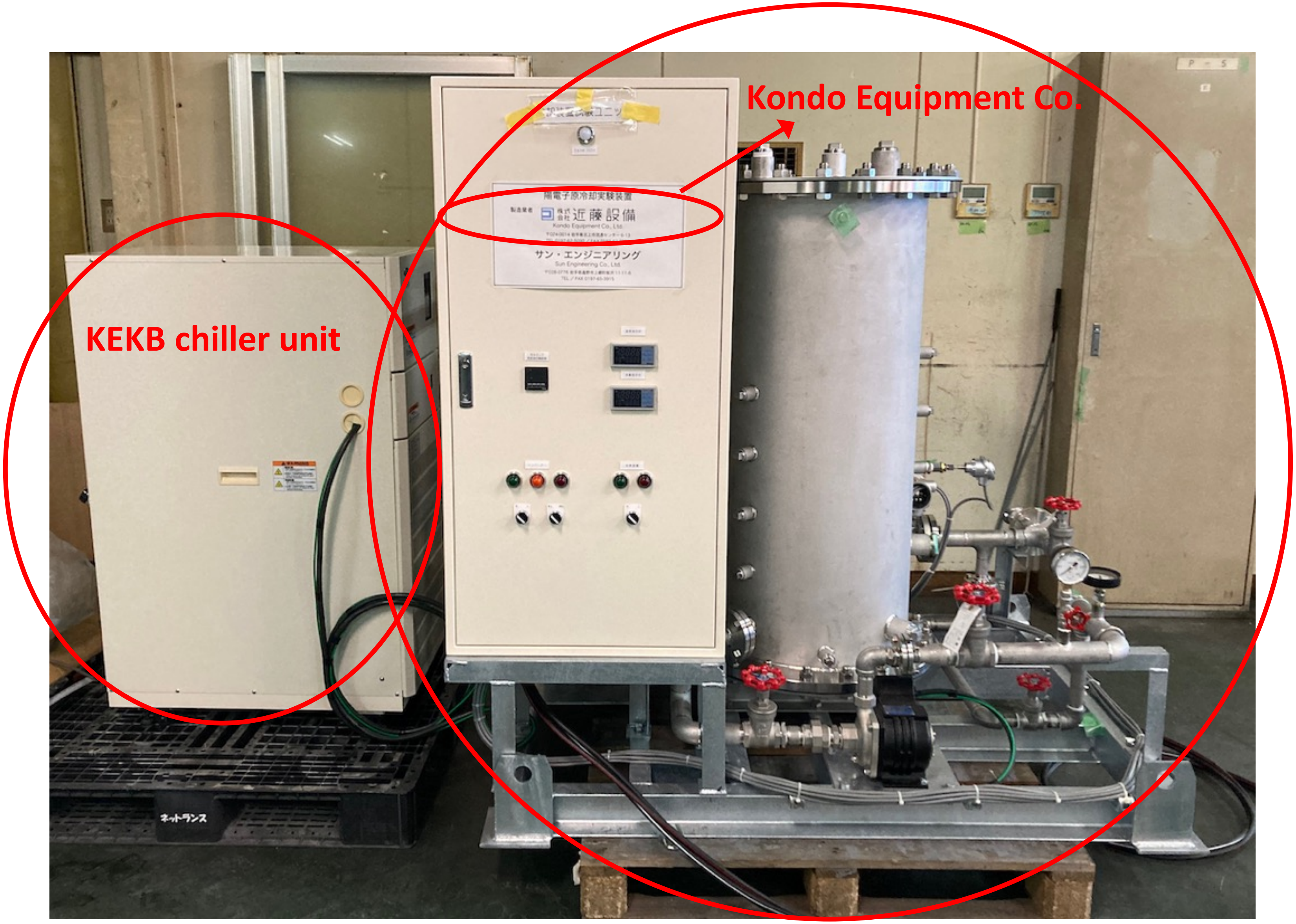
Courtesy of SuperKEKB accelerator team.

On December 6th, the chiller unit was transported to Iwate by a truck of Kondo Equipment Co.

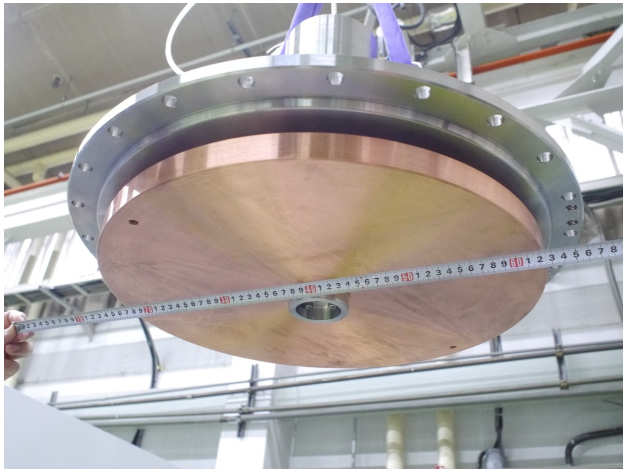


Kondo Equipment Co.

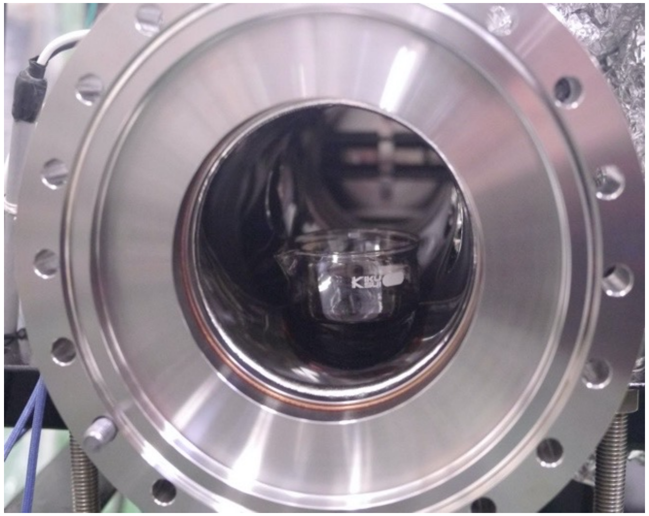
Cooling System constructed in Kondo Equipment Co.



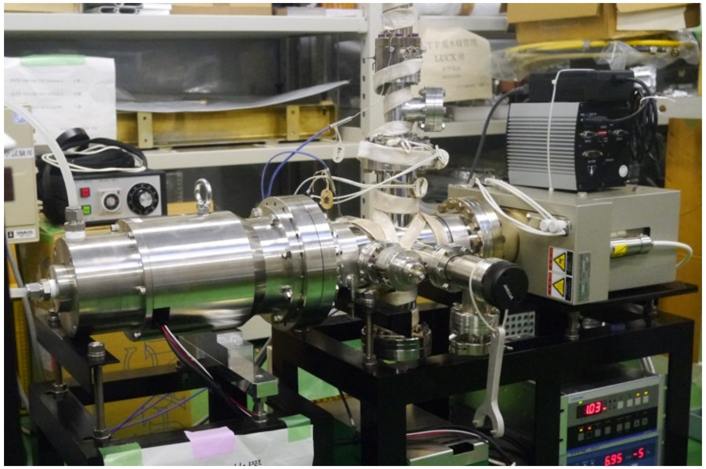
Summary



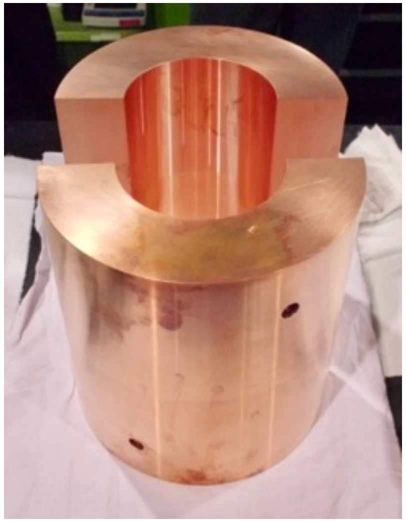
Prototype #2 with Dummy Disk



Evaporation Pan Test



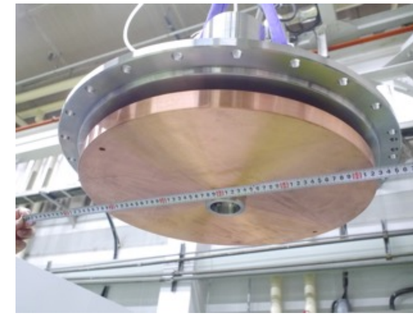
Prototype #1 with Irradiated Ferrofluid



Cooling design of downstream of the Target

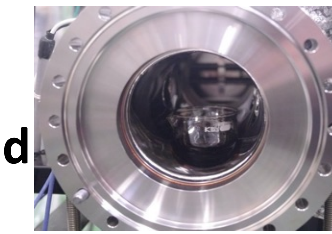
Summary

1. Prototype #2 with Dummy Disk: Vacuum test with Rotation



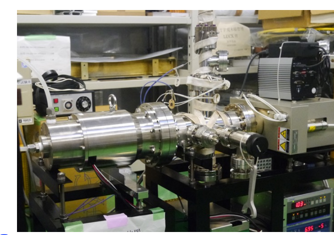
- We added the dummy disk on the prototype #2.
- We achieved 7×10^{-7} Pa with dummy disk.
- Spike appears again. But the height is small (x1.5).

2. Evaporation Pan Test



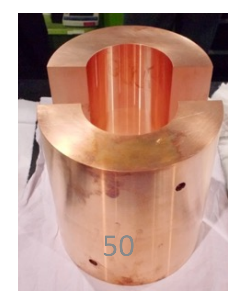
- Put ferrofluid in an evaporating pan and put it in the vacuum chamber.
- From the residual gas analysis data, the upper limit of the CH-based gas in the 1st accelerator tube is estimated to be 1.5×10^{-10} Pa.

3. Prototype #1 with Irradiated Ferrofluid: Vacuum test with Rotation



- 4.7 MGy irradiated ferrofluid is used in the prototype #1.
- We achieved 3.3×10^{-6} Pa. A good vacuum.

4. Cooling Design of Immediate Downstream of the Target



- The collimator, the flux concentrator, and the first accelerating tube are located at the immediate downstream of the target, and are in severe thermal environment. Cooling design and hardware test are on going.