Development of Single-Spoke Cavities for ADS at JAEA

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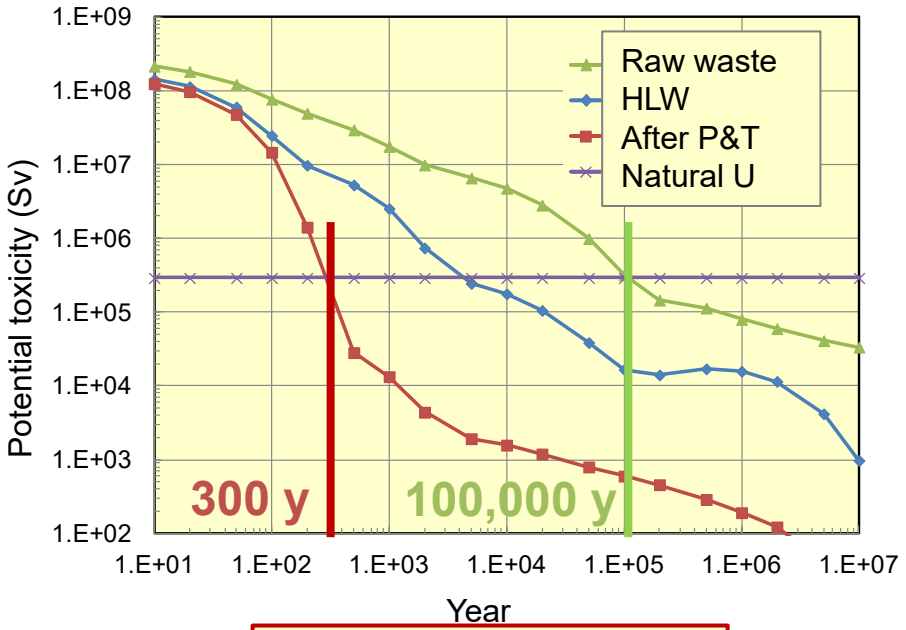
Contents

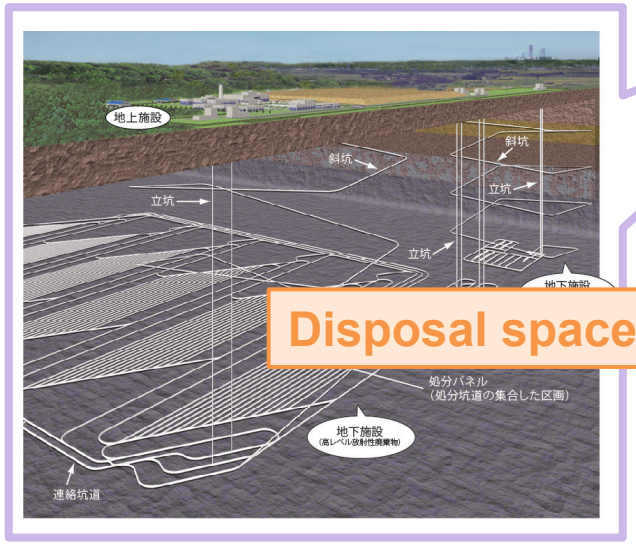
- ADS proposed by JAEA
- ADS linac overview.
- Prototyping of Spoke Cavity.
- Summary

Nuclear waste problem

- How to dispose nuclear waste is a common issue for all humanity.
- Japan's case
  - Already exiting 18,000 tons
  - If nuclear plant can restart,
    1,000 tons newly generated (/year/40 plants)
- If **Partitioning and Transmutation** effectively works...,

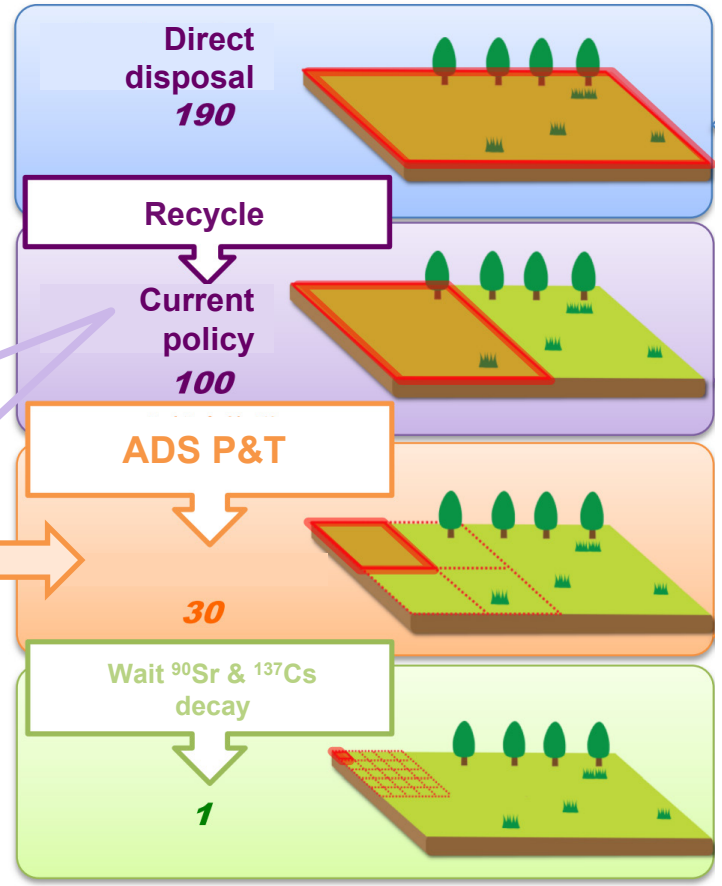


Toxic period 1/300



Current plan of geological disposal
https://www.numo.or.jp/
10 km^2 required

Disposal space 1/3



Aim of the JAEA Accelerator Driven transmutation System (ADS)

- Reduce
  - long-term toxicity of
  - disposal space for

  nuclear waste.
- MA transmutation is effective.
- Need ultimate neutron source ~10^{19} /s
  - J-PARC: 10^{17} /s

Actinides

Trans-Uranium Elements (TRU)

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
U-235	700,000,000	47	10 kg
U-238	4,500,000,000	45	930 kg

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
Pu-238	88	230	0.3 kg
Pu-239	24,000	250	6 kg
Pu-240	6,564	250	3 kg
Pu-241	14	4.8	1 kg

Pu: ~10 kg, 1%

Minor Actinides (MA)

Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
Np-237	2,140,000	110	0.6 kg
Am-241	432	200	0.4 kg
Am-243	7,370	200	0.2 kg
Cm-244	18	120	60 g

MA: ~1 kg, 0.1%

Fission Products (FP)

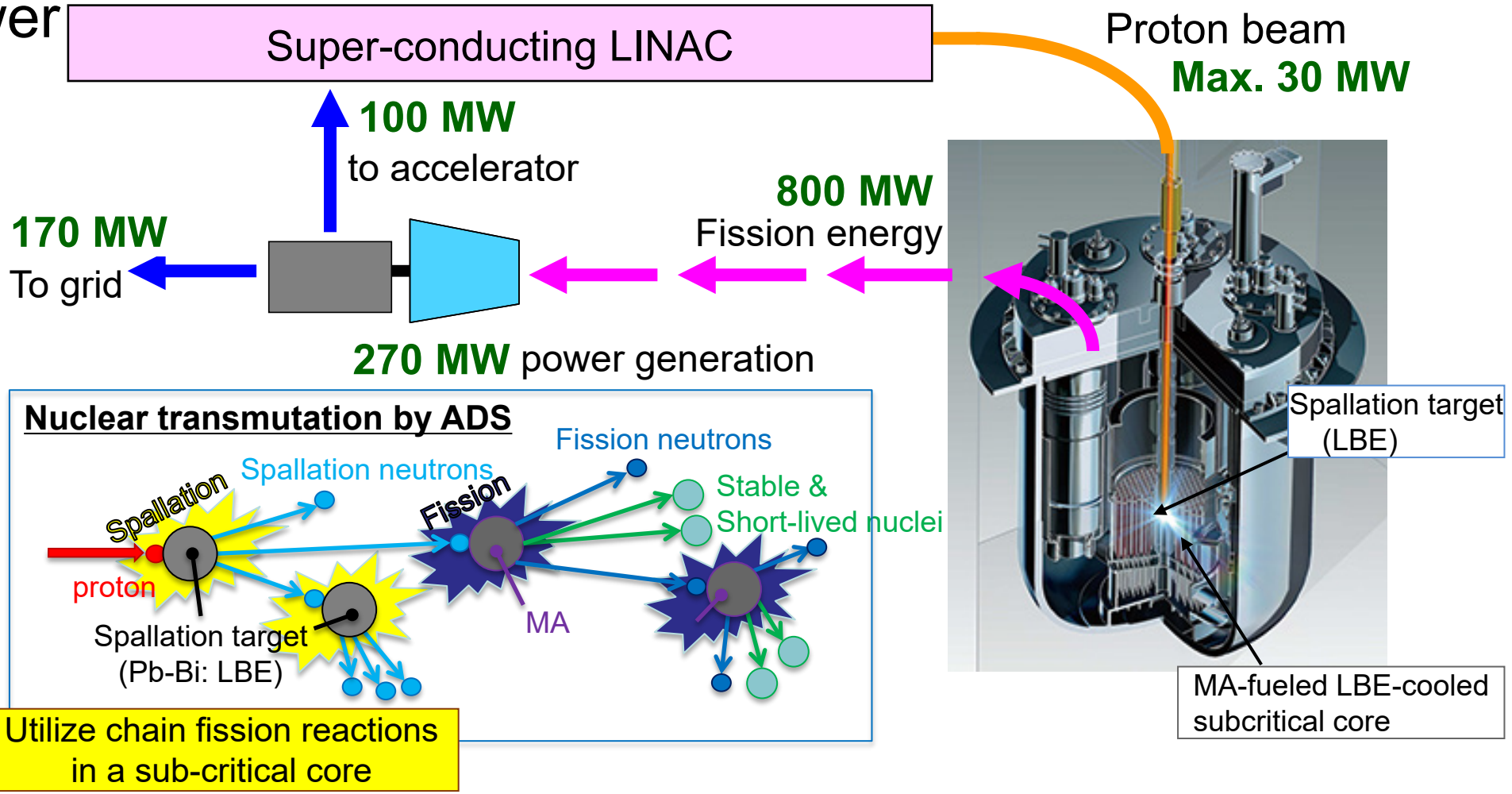
Nuclide	Half-life (years)	Dose conv. fac. (μSv/kBq)	Content (per 1 ton of SP)
Se-79	295,000	2.9	6 g
Sr-90	29	28	0.6 kg
Zr-93	1,530,000	1.1	1 kg
Tc-99	211,000	0.64	1 kg
Pd-107	6,500,000	0.037	0.3 kg
Sn-126	100,000	4.7	30 g
I-129	15,700,000	110	0.2 kg
Cs-135	2,300,000	2.0	0.5 kg
Cs-137	30	13	1.5 kg

Dose conversion factor:
An index that indicates the effects of ingestion of radionuclides into the human body.
Shown in absorbed dose (Sv) per radioactivity (Bq).

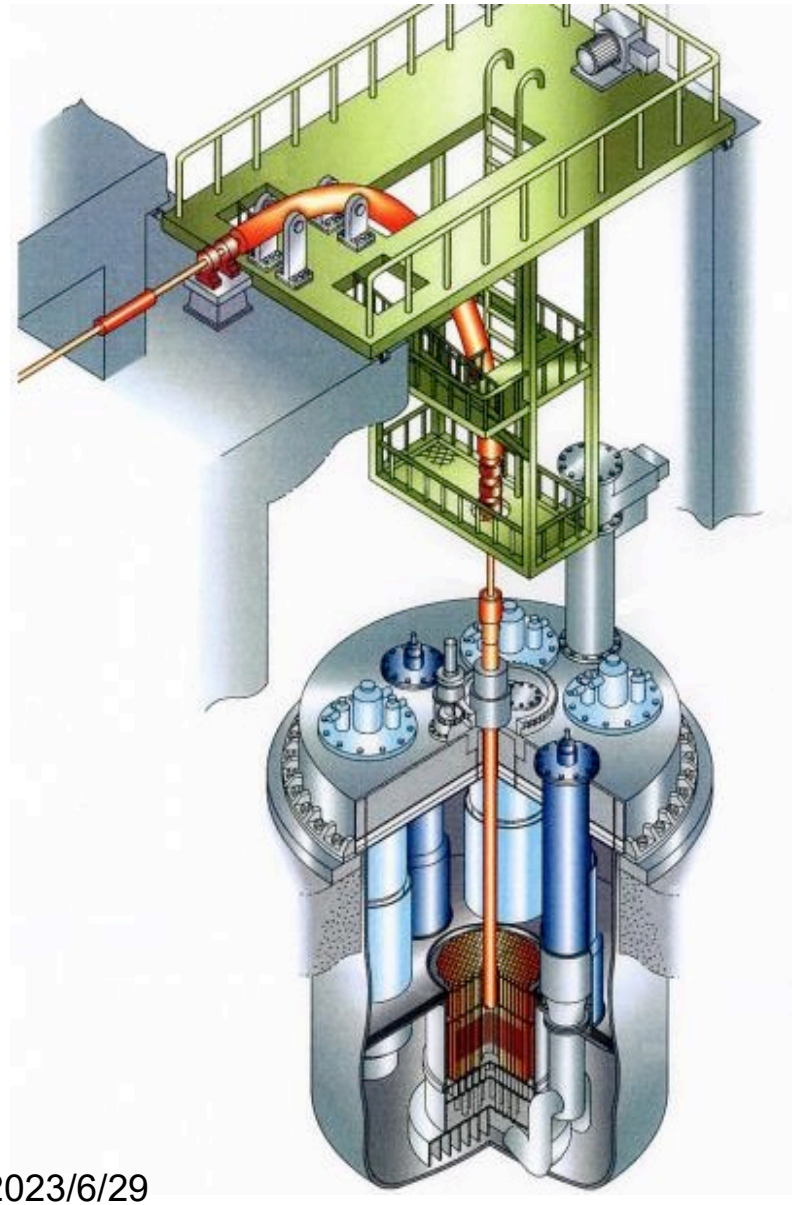
Major long-lived nuclide in 1 ton nuclear waste

High intensity proton accelerator + subcritical reactor = ADS

- Accelerator power 1 MW→30 MW
- Chain reaction x 30
- Total 100 gain from existing neutron source



ADS proposed by JAEA - LBE Target/Cooled Concept



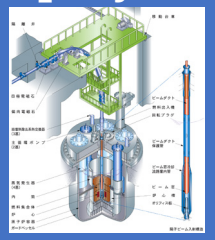
- Proton beam: 30 MW
- Spallation target: Pb-Bi eutectic (LBE)
- Coolant: LBE
- Subcriticality: $k_{eff} = 0.97$
- Thermal output: 800 MWt
- MA initial inventory: 2.5 t
- Transmutation rate: 10%MA / Year

  (=250 kg: MA from 10 units of LWR)

※The actual plant will be constructed by electric power companies under the responsibility of the emitter, by using the provided technology developed by JAEA.

History of JAEA-ADS and J-PARC

1988 Omega project launched



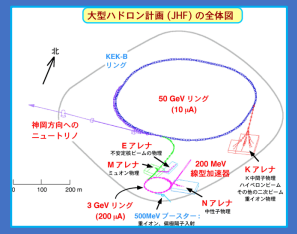
ADS Conceptual design

JAERI (JAEA) project

NSP included

KEK project

JHP start



JHF start jointed

2001 J-PARC start

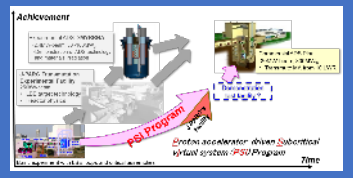
Concentrated on J-PARC construction

2009 User operation start

2011 Great e. Japan earthquake (severe accident of F1 plant)

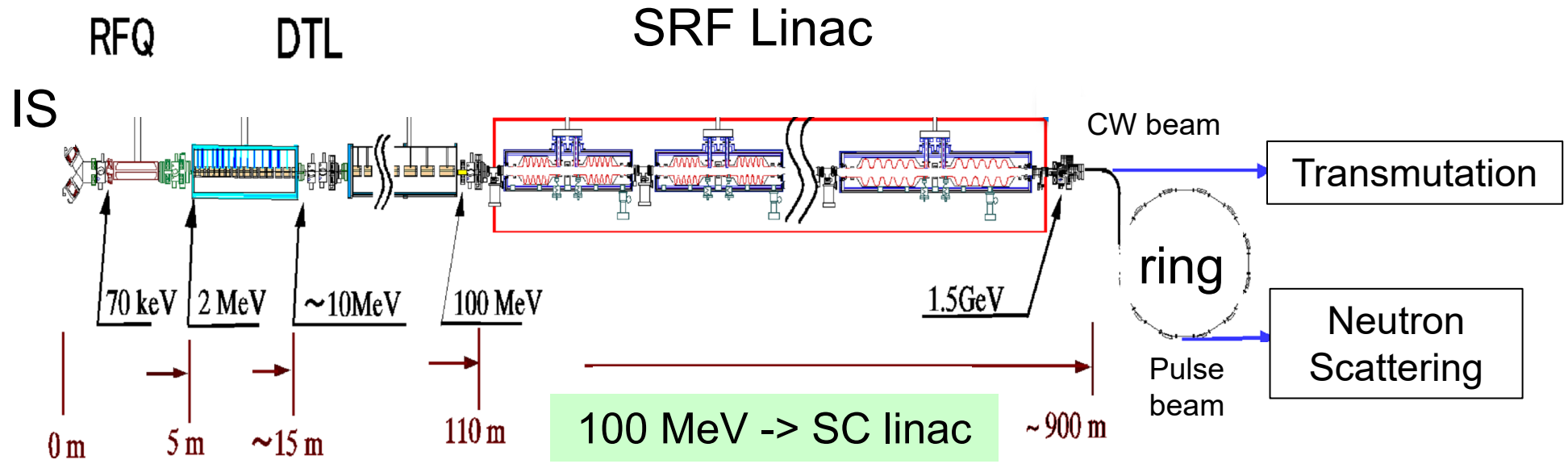
Funding for TEF got smaller and smaller

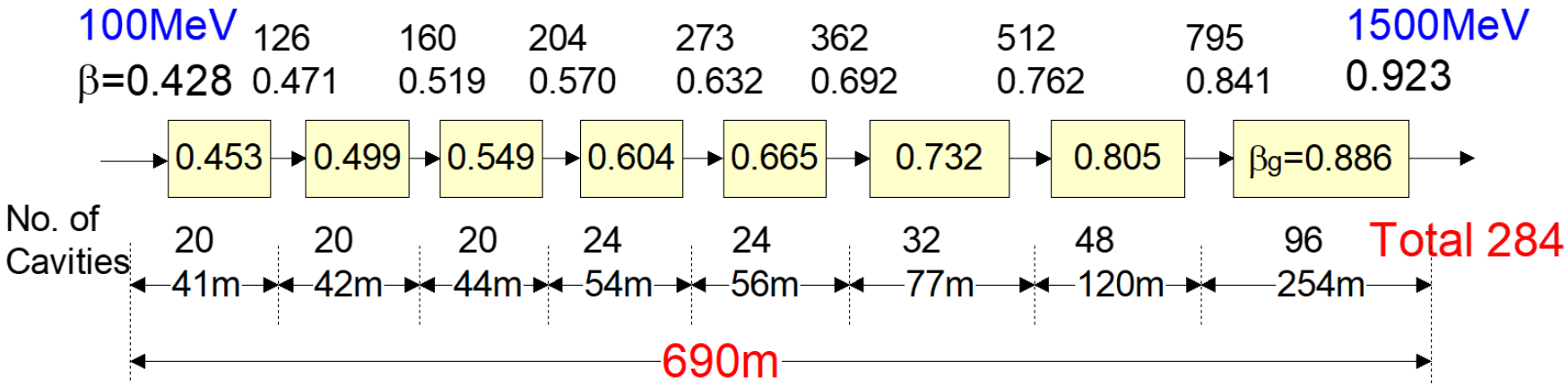
2019 Reconsidering strategy



10th anniversary

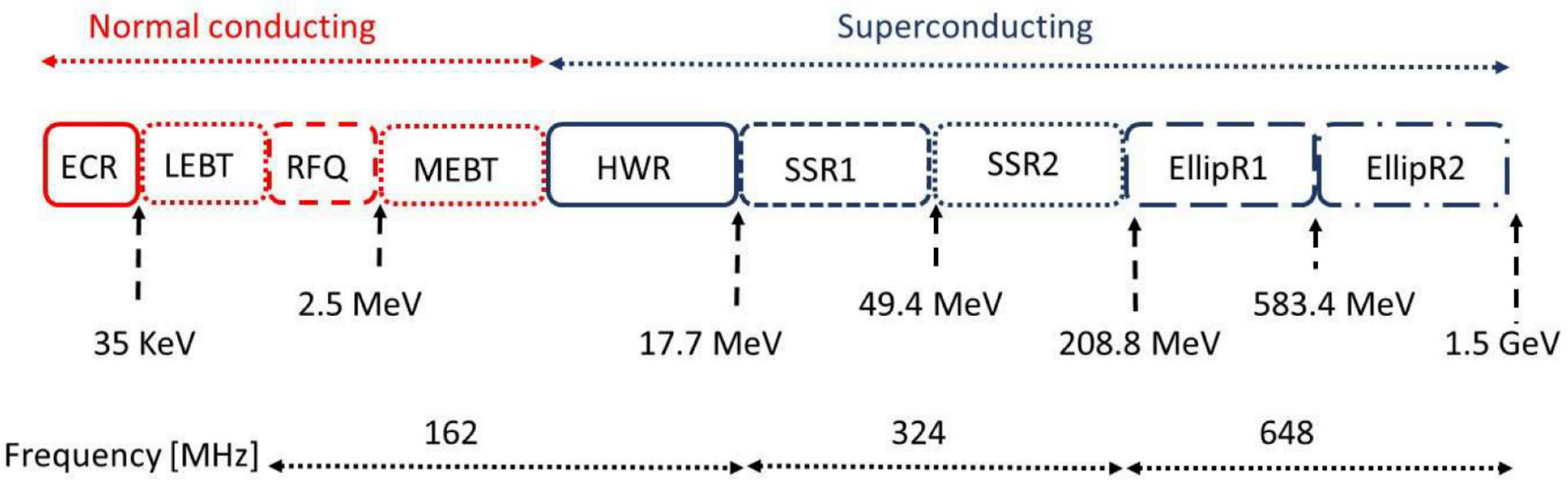
Neutron Science Project (NSP) at JAERI





N. Ouchi et al., SRF97, A02
M. Mizumoto et al, LINAC98, TU1004
N. Akaoka et al., SRF99, WEP020

Overview of the JAEA-ADS linac



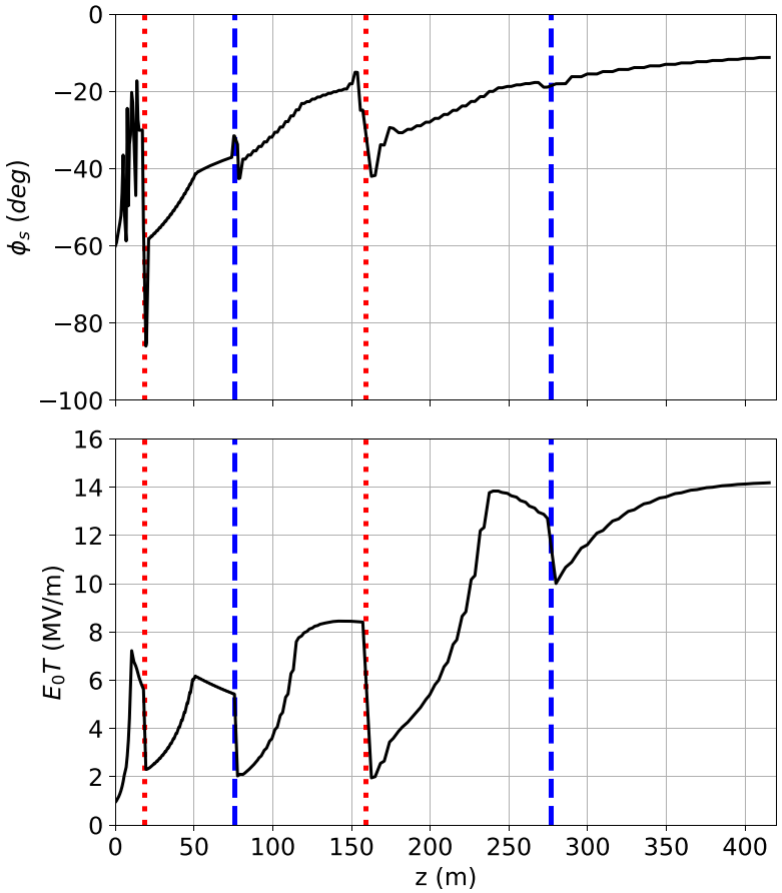
Parameters for JAEA ADS linac	
Energy	1.5 GeV
Current	20 mA
Duty	100% (CW)
Power	30 MW

Trip / year [H. Takei et. al, J. Nucl. Sci. Technol. 49, 384 (2012)]	
$0 < \tau < 10$ s	20,000
10 s $< \tau <$ 5 m	2,000
$\tau >$ 5 m	42

B. Yee-Rendon et al., doi:10.1103/PhysRevAccelBeams.24.120101

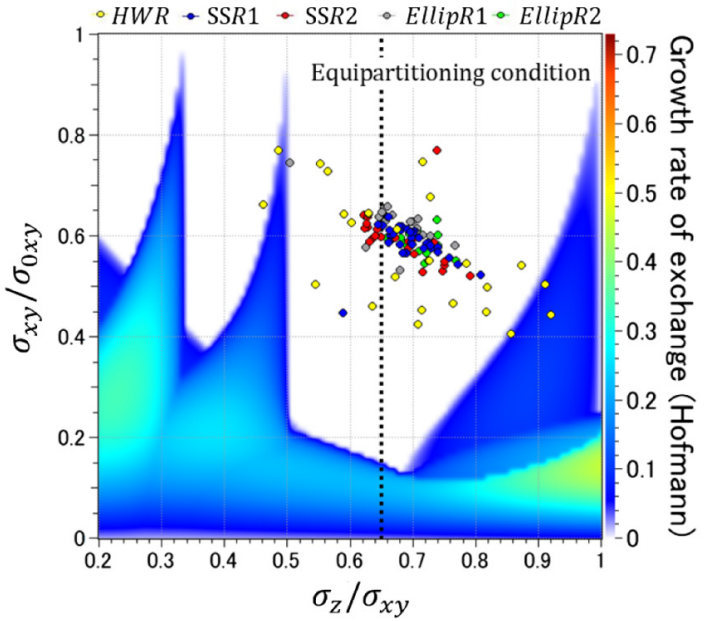
JAEA-ADS linac design

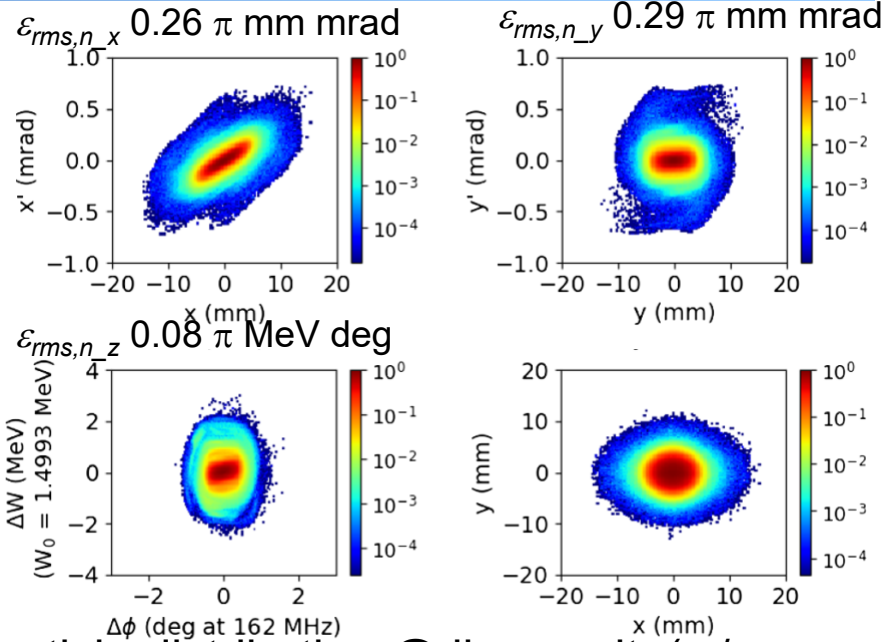
Maximize E_{acc}, (E_{pk}<30 MV/m) keeping long. acceptance



Total length 416 m

Equipartitioning is fully implemented

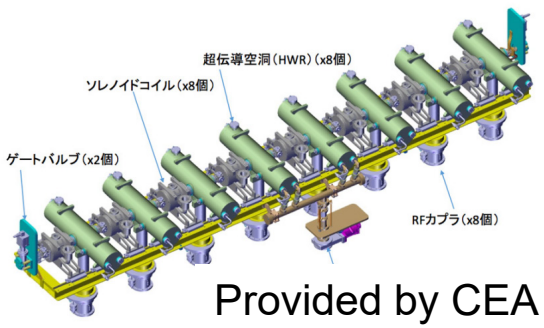




Particle distribution @ linac exit (w/o errors)

	HWR	SSR1	SSR2	Ellips1	Ellips2	total
f_0 (MHz)	162	324		648		
β_g	0.08	0.16	0.43	0.68	0.89	
max. E_{acc} (MeV/m)	7	7	8	14	14	
# of cavities	25	66	72	60	70	293
# of cryomodules	3	33	24	20	14	94

Why prototyping spoke cavity?

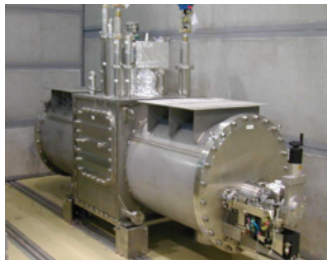


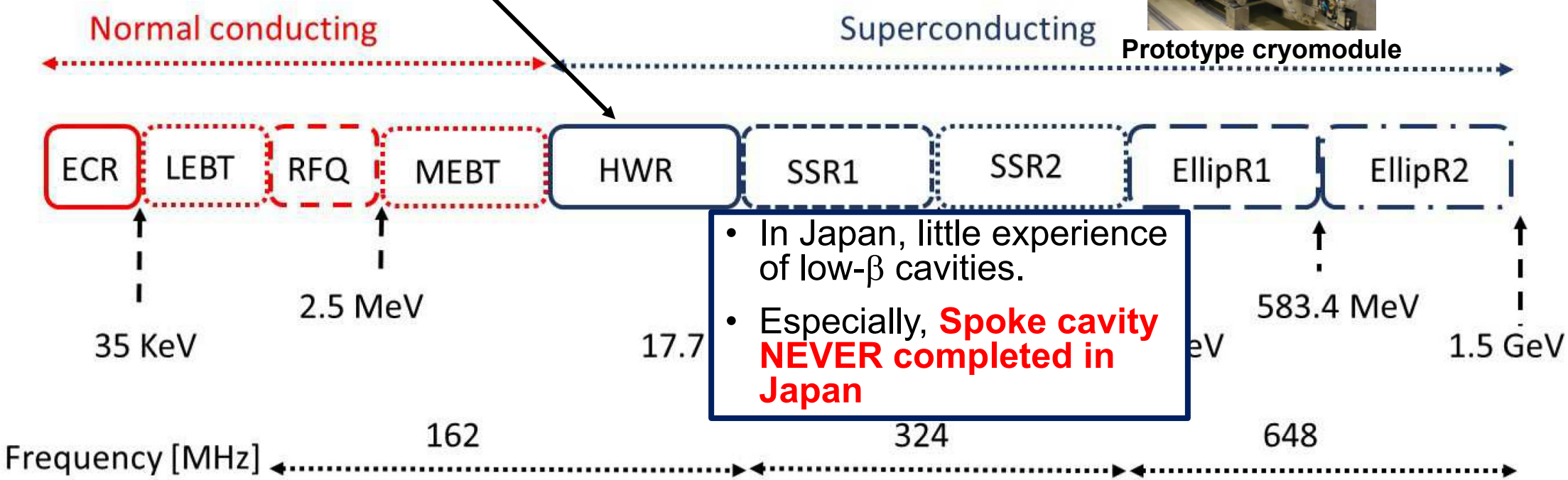
Provided by CEA

- LIPAc HWR will start @ QST Rokkasyo.
- We hope share operation experience.


Prototype elliptical cavity

- Experience of elliptical cavity at JAEA and KEK…


Prototype cryomodule

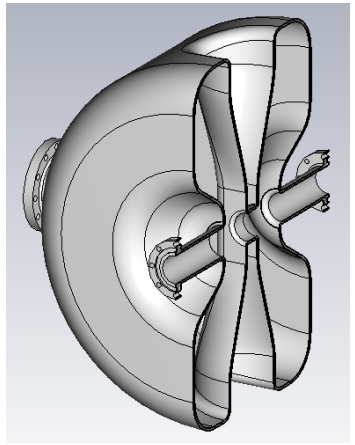


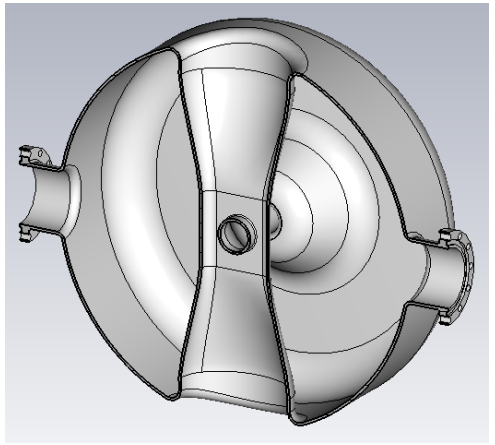
- In Japan, little experience of low-β cavities.
- Especially, **Spoke cavity NEVER completed in Japan**

Performance evaluation of our own technology, feedback to ADS design is significantly important

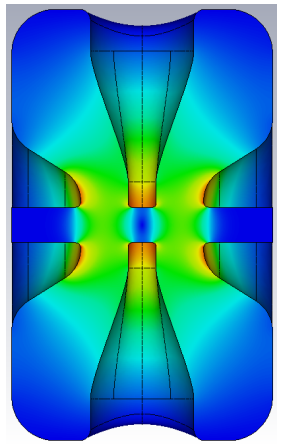
Prototype spoke cavity for the JAEA-ADS linac

ECR | LEBT | RFQ | MEBT | HWR | SSR1 | SSR2 | EllipR1 | EllipR2

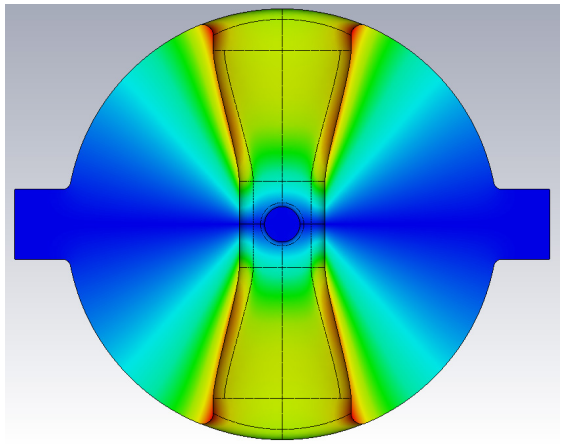


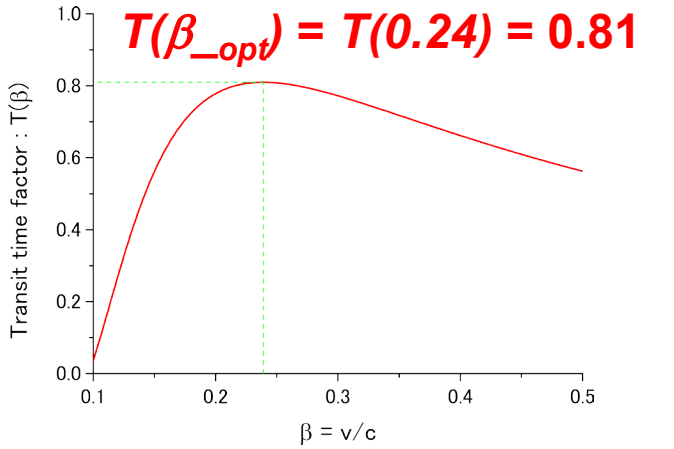


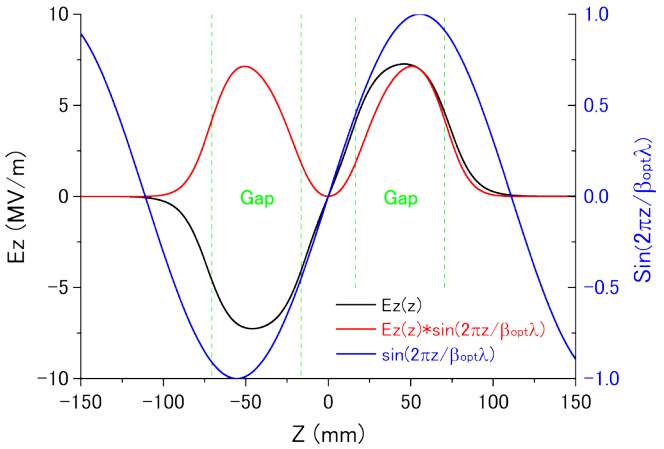
E-field



H-field







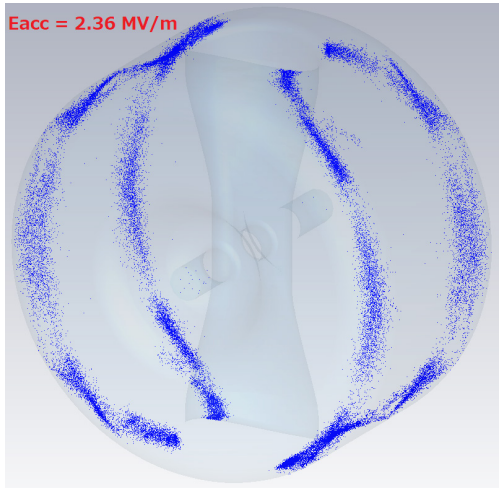
Design parameters

f_0	324 MHz
β_g	0.188
β_{opt}	0.24
Beam aperture	40 mm
Cavity diameter	~ 500 mm
Cavity length	300 mm
L_{eff}	222 mm
G	90 Ω
$T(\beta_{opt})$	0.81
R_{sh}/Q_0	240 Ω
E_{peak}/E_{acc}	4.1
B_{peak}/E_{acc}	7.1 mT/(MV/m)

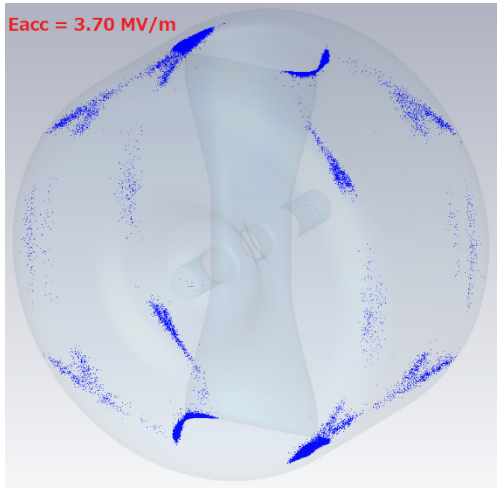
Target Q_0 5x10^9 @ E_{acc} = 8 MV/m

J. Tamura et. al., doi.org/10.7566/JPSCP.33.011049

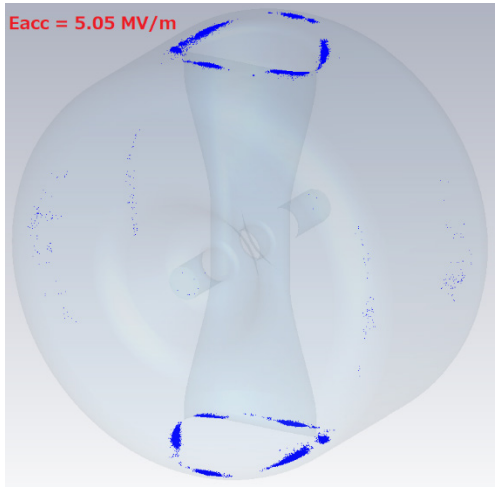
Multipactor analysis



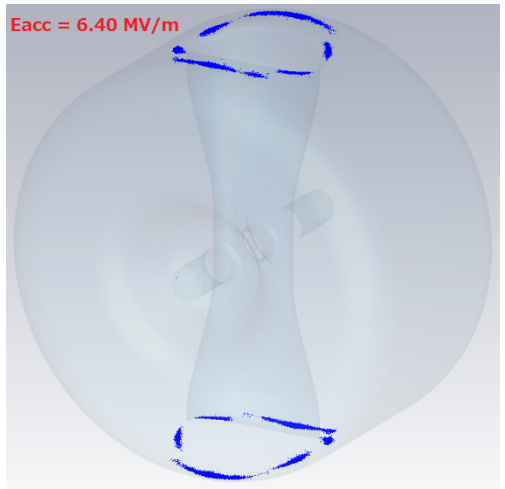
E_{acc} = 2.36 MV/m



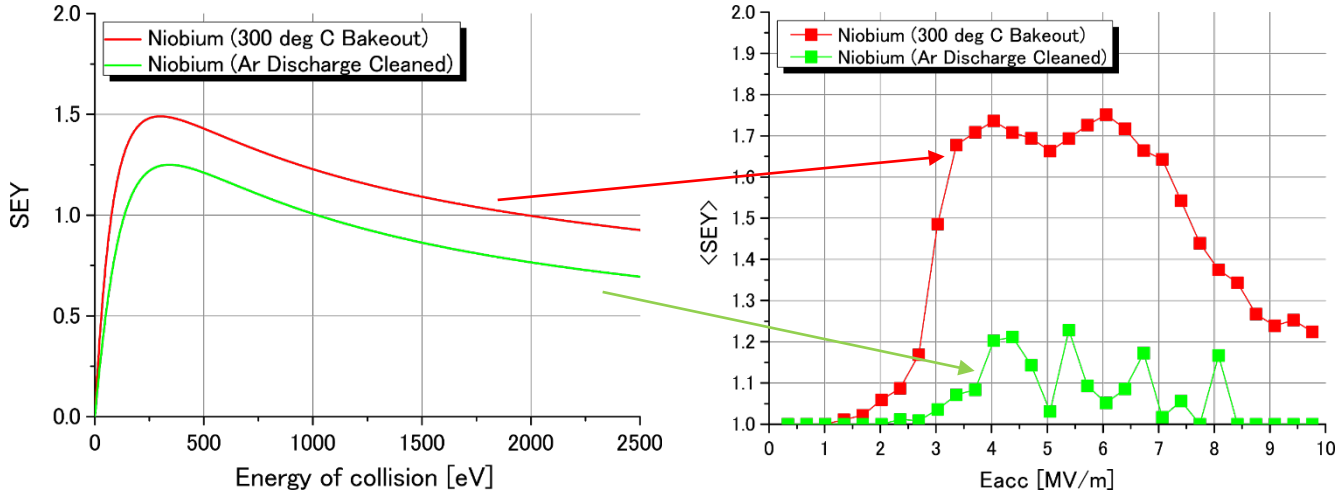
E_{acc} = 3.70 MV/m



E_{acc} = 5.06 MV/m



E_{acc} = 6.40 MV/m



Assumed Secondary Emission Yield

- Possible multipactor regions were confirmed.
- Careful inspection and care are needed for these regions in fabrication.

Cavity parts fabrication 2020

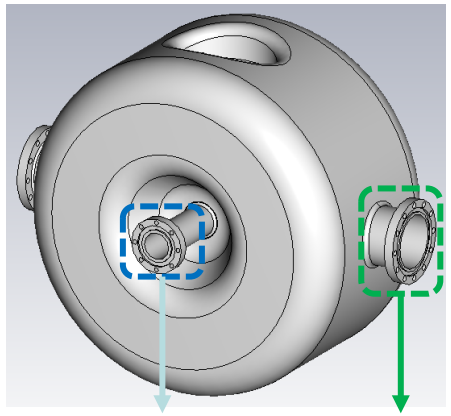
Machined from Nb blocks

End drift-tubes (EDTs)

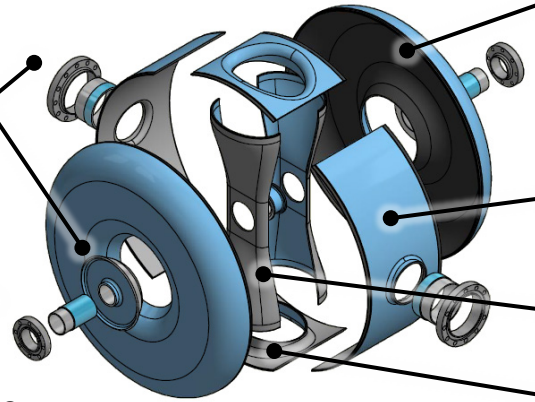
Machined from Nb-Ti blocks

Beam port flanges

RF port flanges

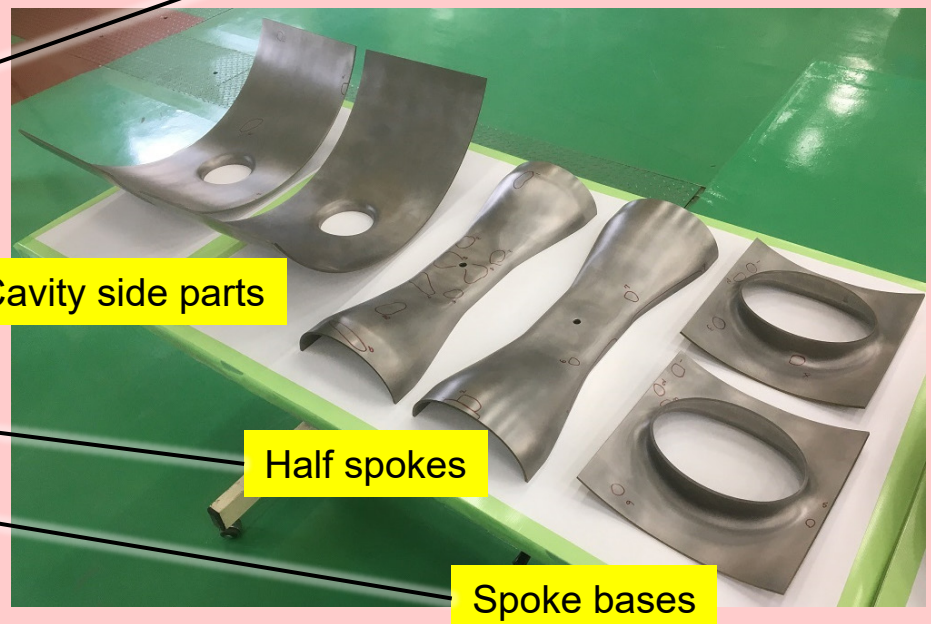


Beam port RF port



Press formed from Nb sheets (3.5 mm t)

End plates



Cavity side parts

Half spokes

Spoke bases

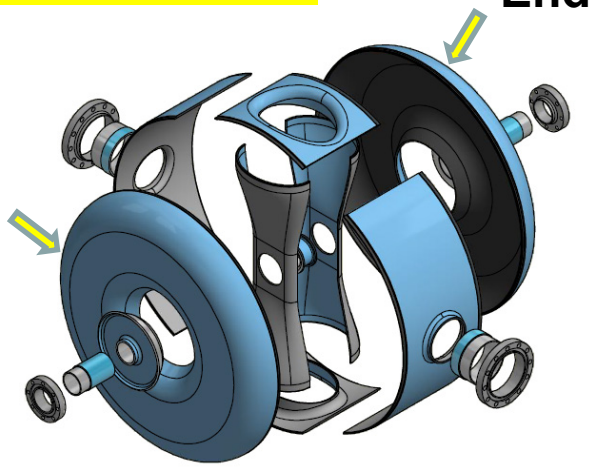
- Fabrication started from 2020
- All materials are provided by Tokyo Denkai.
  - Nb sheets, Ingots (for DTs), Nb-Ti ingots (for flanges)
- RRR of delivered pure Nb material > 300

Example of the press-forming (end plates case)

Before press

Pressed

Trimmed

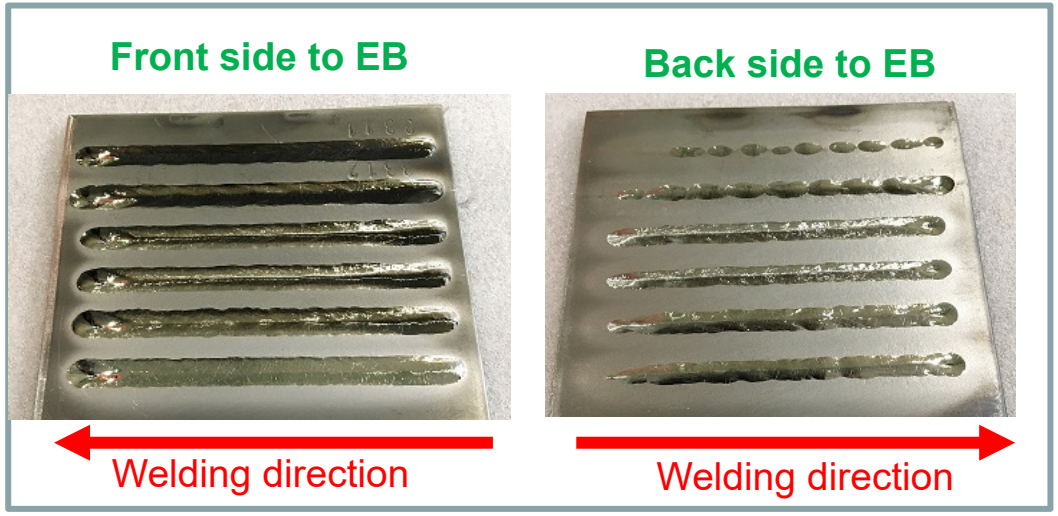


- Main parts were made by plastic deforming process, press forming using dice, or bending.

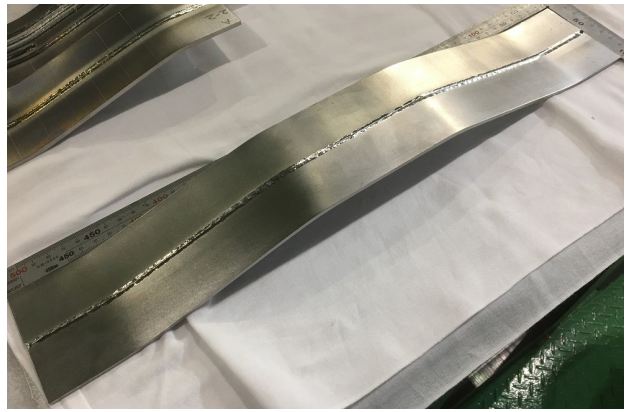
Electron beam welding (EBW)

Vertical EB machine

https://www.kuroki.co.jp/kogyo/our_business/ebw.html



Taper section of spoke



RF-port pipe

RF-port flange

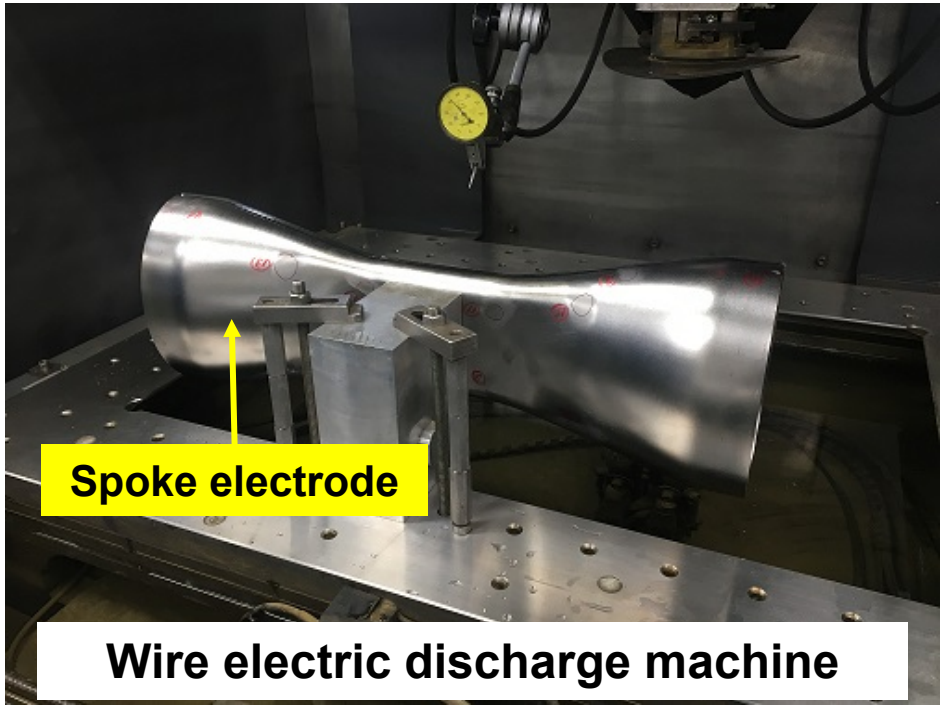
- EBW process started from 2021
- Prior to the actual EBW, conditions were surveyed for every EBW parts using TP.

Spoke assemble 2021

EBW

Inside

Trim
both ends

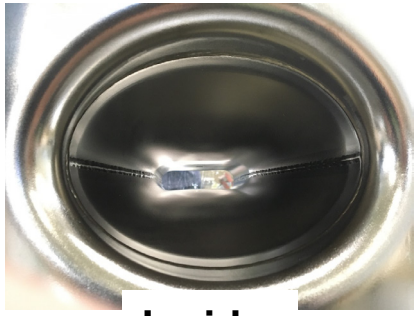


- Each tip to be welded was CPed (~10 μm) just before EBW.

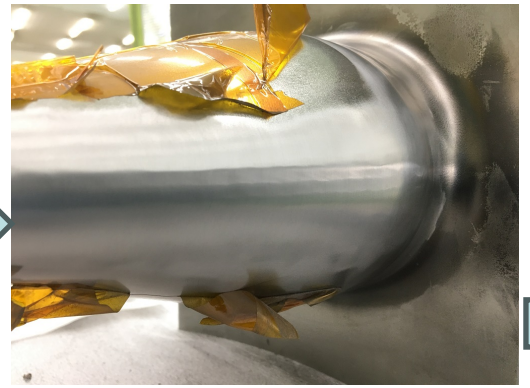
Spoke assemble cont.

Spoke

EBW

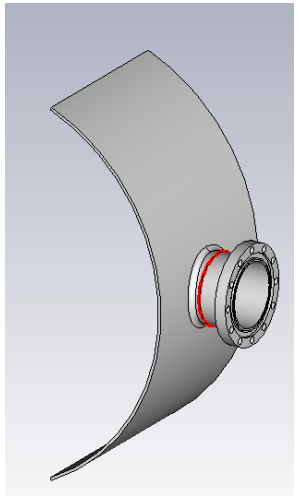


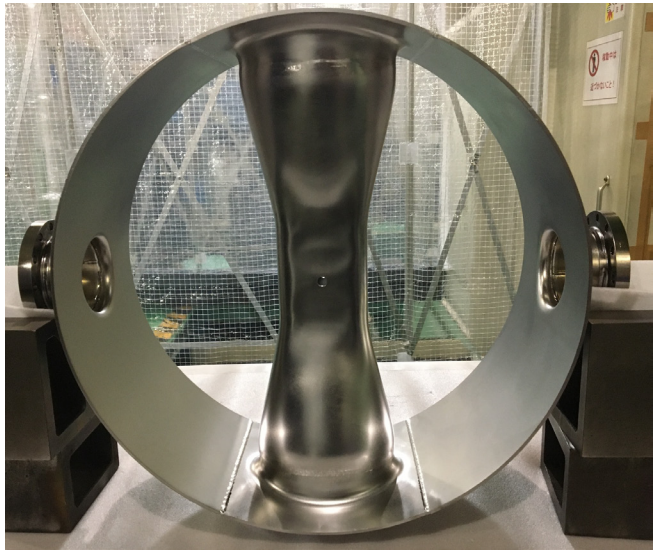
Inside



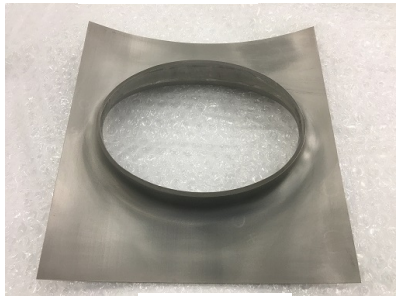
Mechanically polished to smooth edge due to dimension mismatch btw. Spoke and Base

EBW



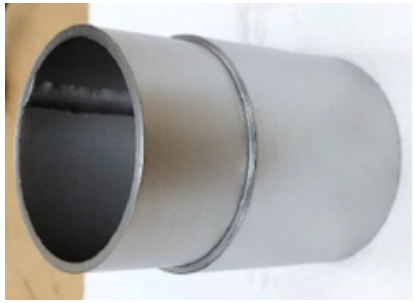


Finished!

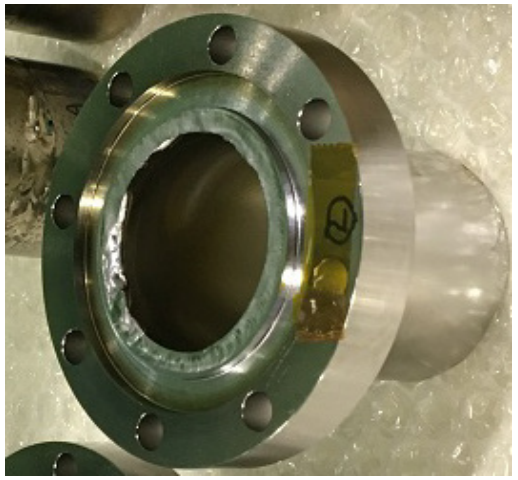


Base

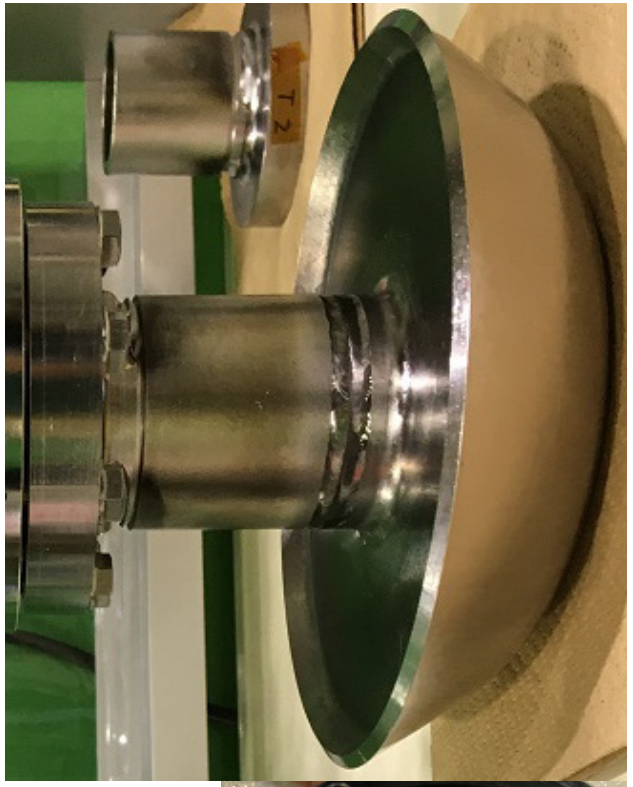
Beam port assemble 2022



EBW

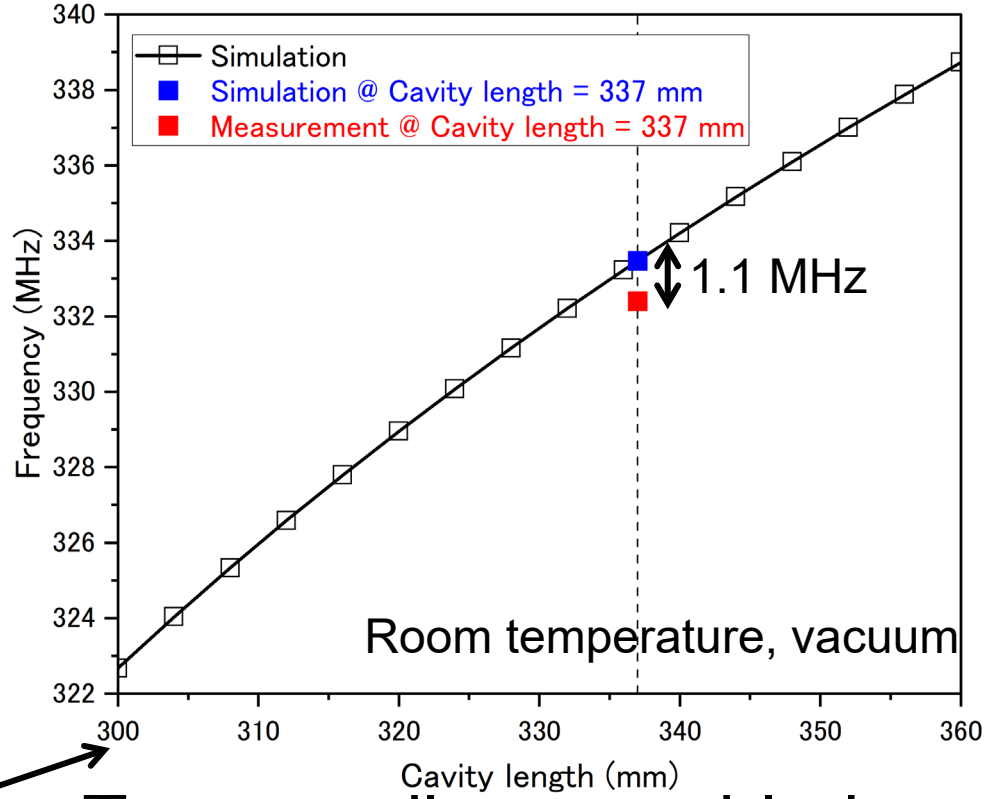


EBW



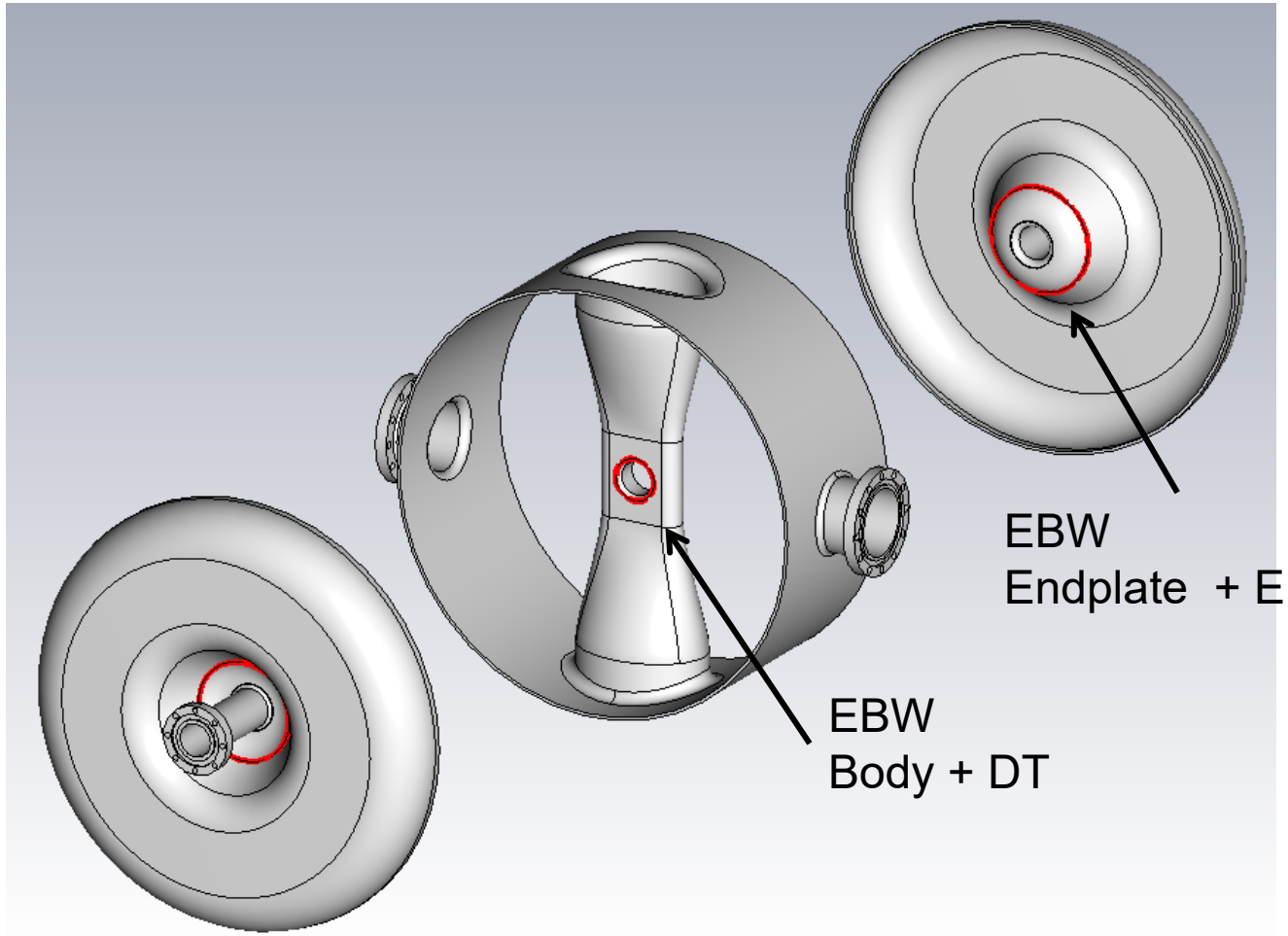
Inside = vacuum side

Frequency check



- Temporarily assembled and check frequency
- Well within tunable range in final assembly.

Next to do...

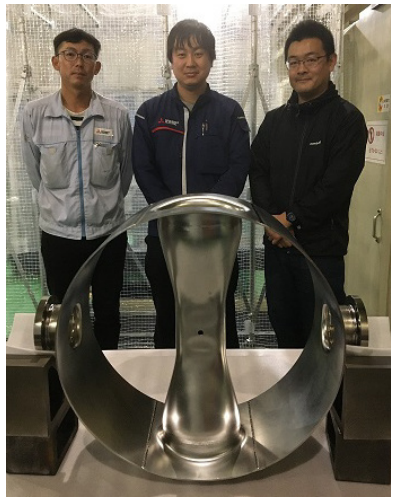


- EBW
  - End plate + EDT
  - Body + DT
- Frequency tuning
  - Iteration
- Final EBW
- BCP
- HPR
- Baking
- VT (First goal of this project)

Summary

- At JAEA, we are proceeding ADS development.
- Reference linac design has been established and prototyping of SSR is underway.
- We will conduct vertical test soon.

Special thanks to



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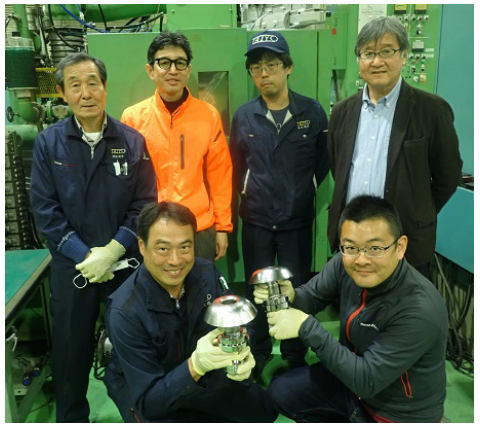

Taiyo EB Tech, Inc..