Magnetic Alloy loaded cavities in J-PARC and CERN

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[1]J-PARC, [2]CERN

Proton Synchrotron Cavity

- For RF frequency sweep, ferrite-loaded cavity has been used.
- By large-current biasing, permeability of ferrite can be changed for resonant frequency sweep.

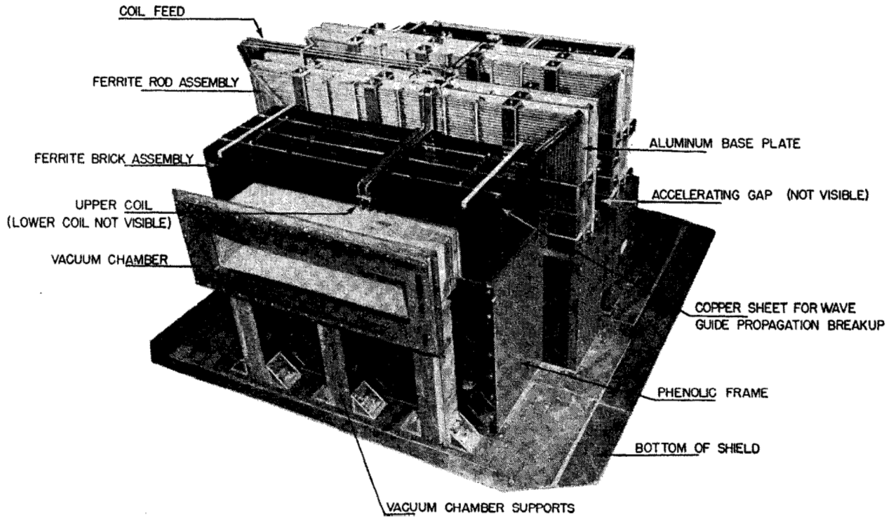
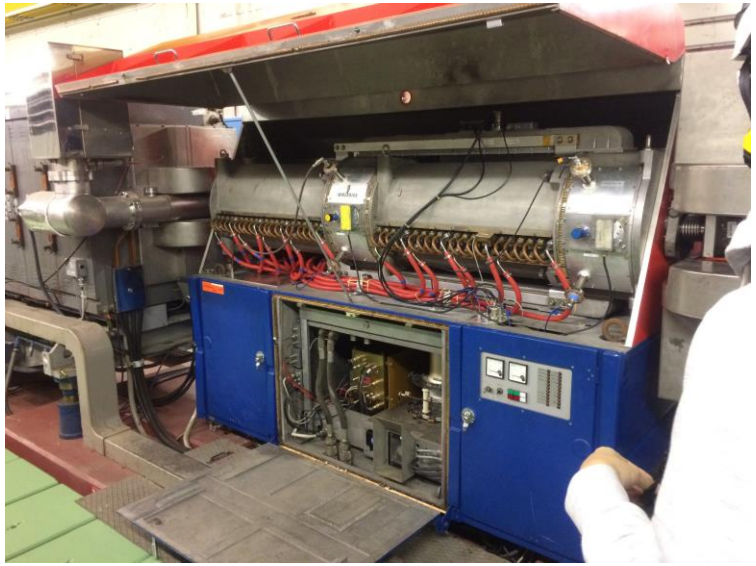


FIG. 1. Photograph of assembled ferrite core for Cosmotron accelerating unit.

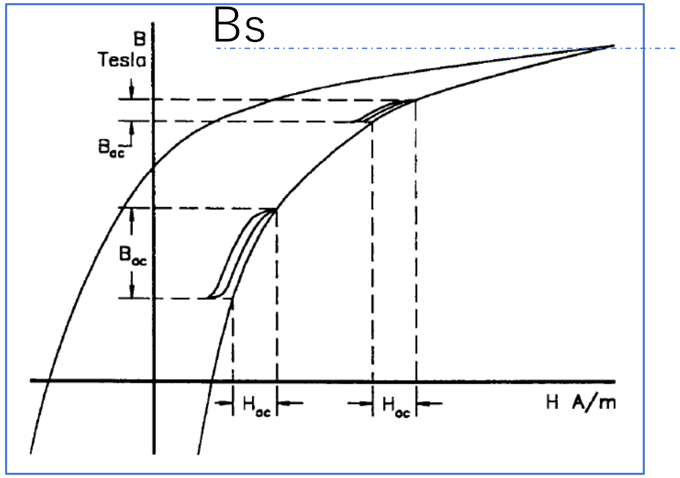
Cosmotron Cavity (weak focusing)
Review of Scientific Instruments
vol24 No.9, "Radio-Frequency System Part IV"



CERN PS cavity (strong focusing)

$Q = R/\omega L = \mu s'/\mu s'' \sim 100$

Ferrite cavity has narrow band



Bs~0.3 T ->
Limitation of RF voltage

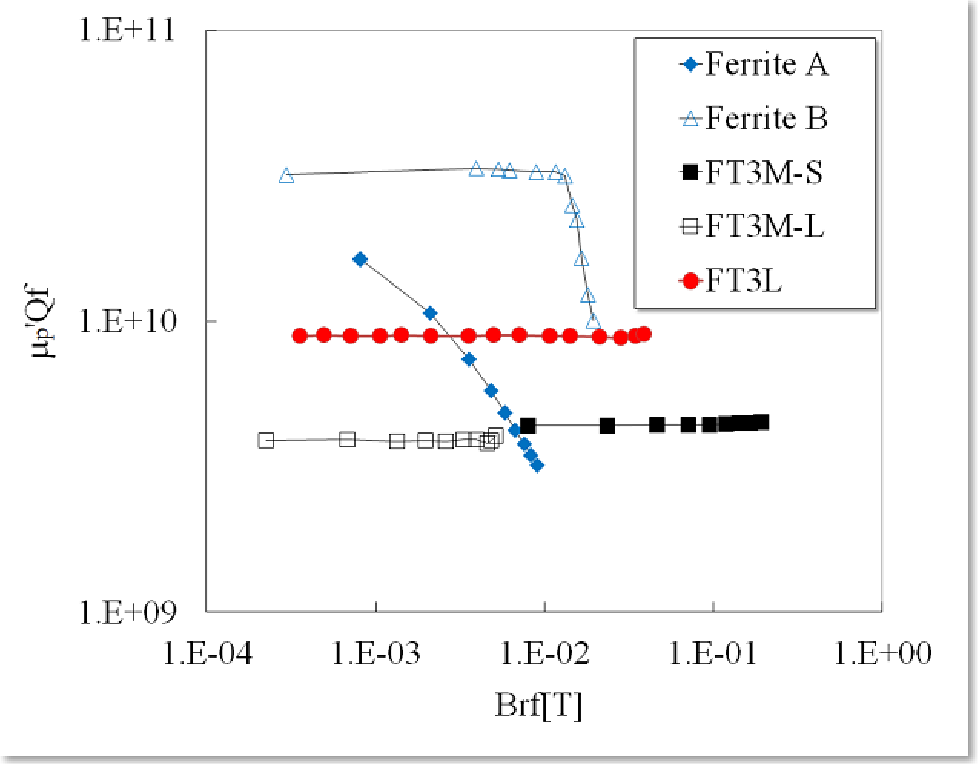
High Q => Low loss => Good Ferrite Cavity

RF R&D in the mid-1990s

- In 1994, R&D started in Japan.
- Found that **nano-crystalline material,** Finemet®, might be used for cavity.

Loss ∝ μ QF. Low Q is OK if μ is large

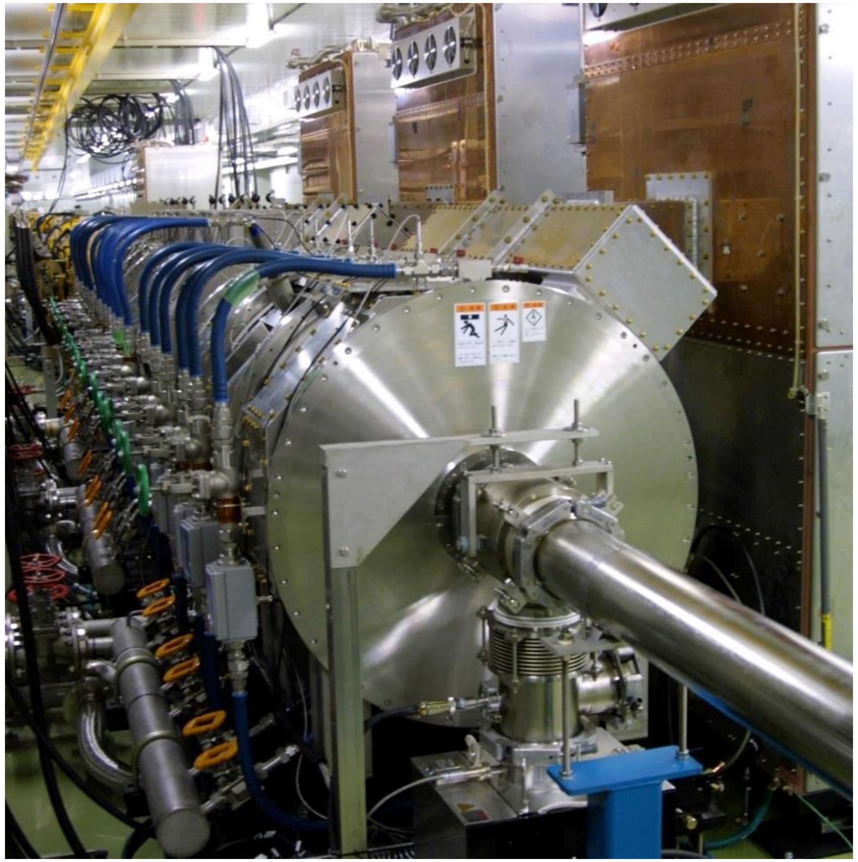
- Bs~1.2 T -> stable at high voltage
  -> High gradient
- Very large permeability
  -> wideband, no biasing
- In 1998, first acceleration test at HIMAC
  -> LEIR:Pb acceleration for LHC
  - HIMAC MA Cavity: direct water cooling

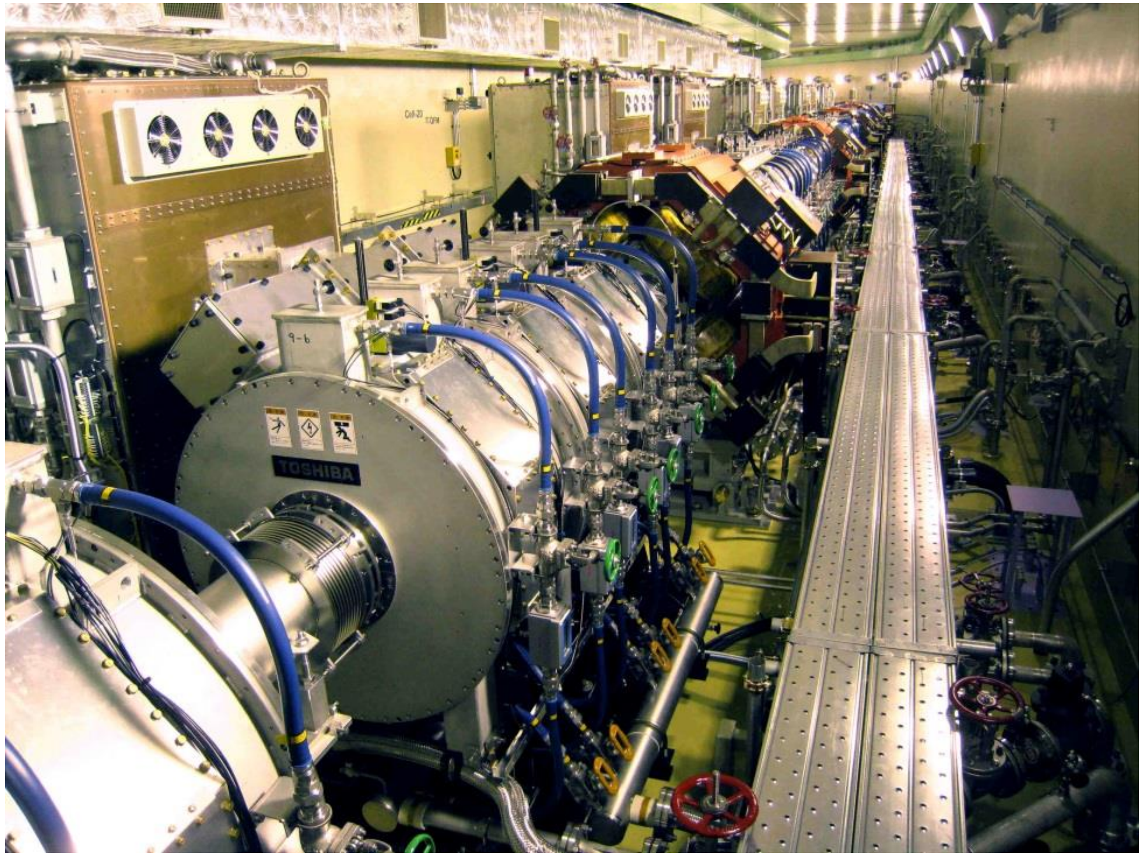


stable at high voltage

J-PARC

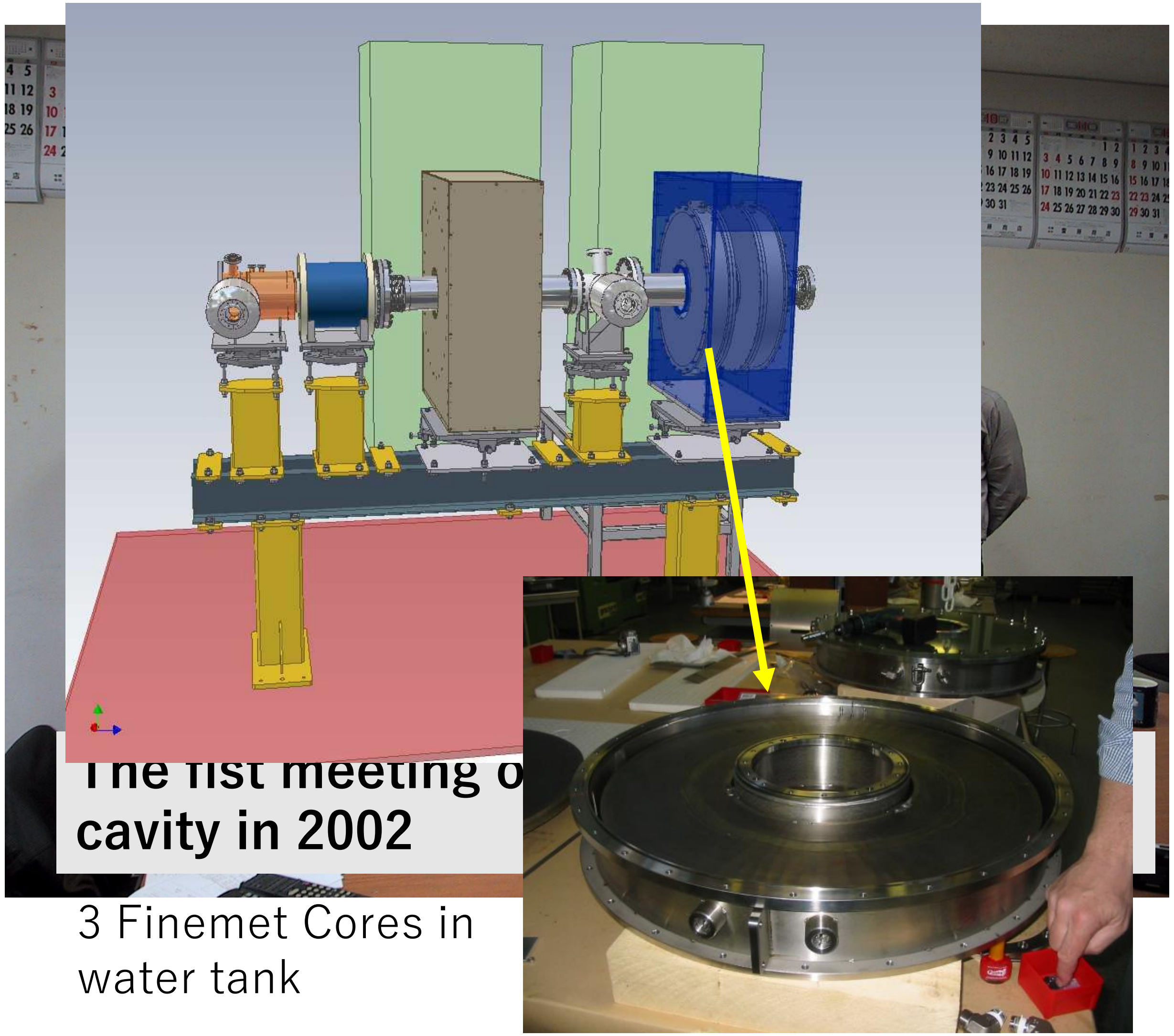
- Main Ring and RCS(Rapid Cycling Synchrotron) adopted Magnetic Alloy cavities (2007~)





Low Energy Ion Ring (LEIR) Cavities

LEIR has been delivering Pb ion for LHC, successfully.

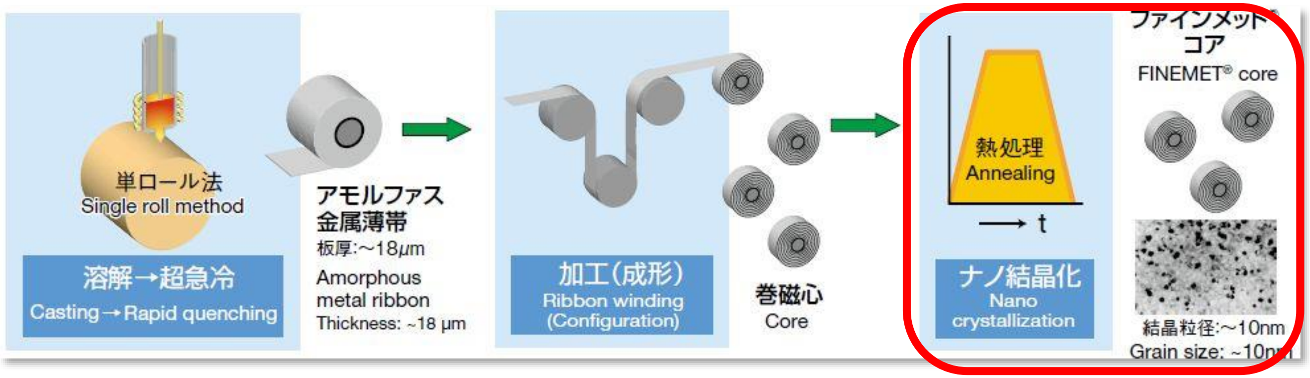


3 Finemet Cores in water tank

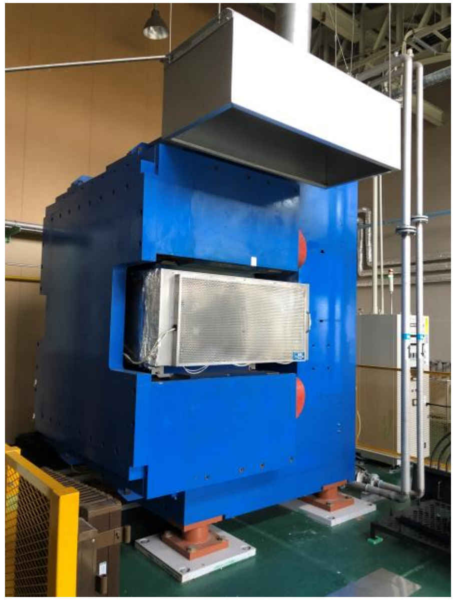
Please see LEIR MA cavity.

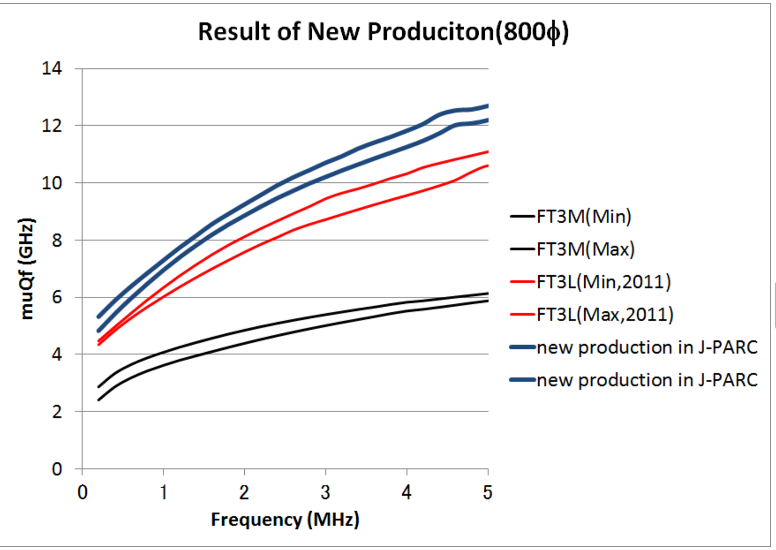
Improvement of core by magnetic-annealing

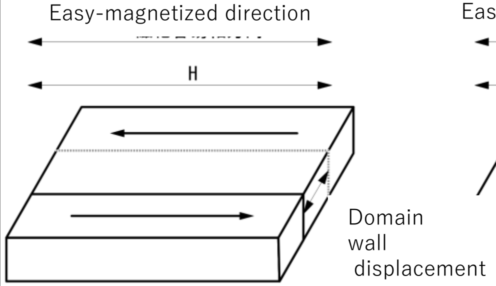
- Magnetic-annealing & thin ribbon improved cavity impedance.
- Pushed replacement of ferrite cav.



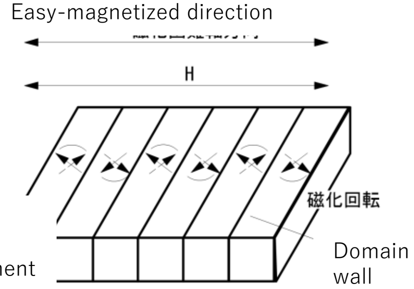
Mag. Annealing oven



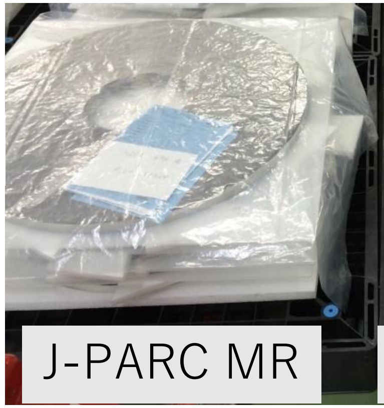


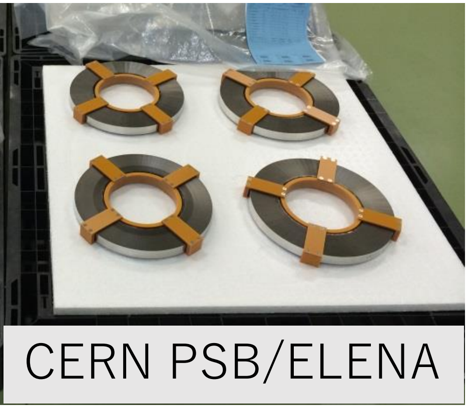


H-type
Surge Blocks
ITER NBI



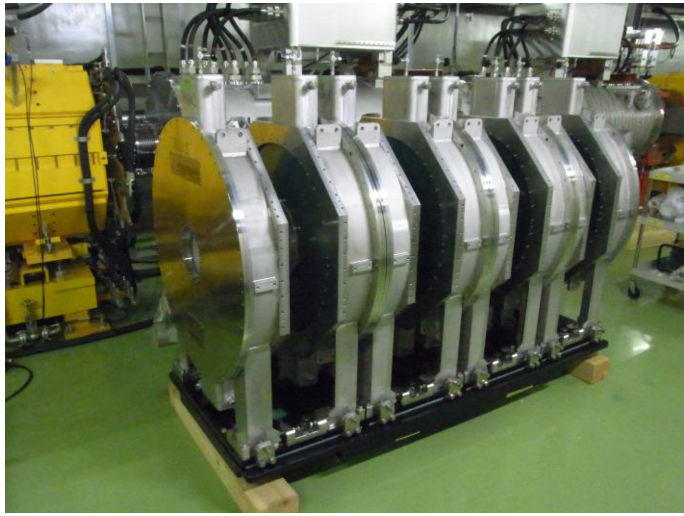
L-type
FT3L cores
Cavity applications
Transformers





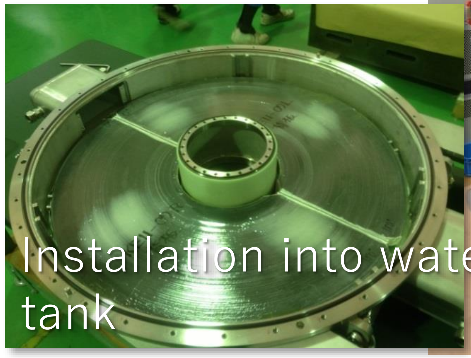
FT3L cores (Mag.-annealed)

- J-PARC Main Ring RF upgrade (~300kV -> 600 kV)
- CERN PSB RF upgrade (ferrite -> MA cavities)
- MedAustron RF cavity
- CERN PS damper cavity
- CERN ELENA deceleration cavity
- CERN AD cavity
- J-PARC RCS RF upgrade (push-pull -> **single-ended**)



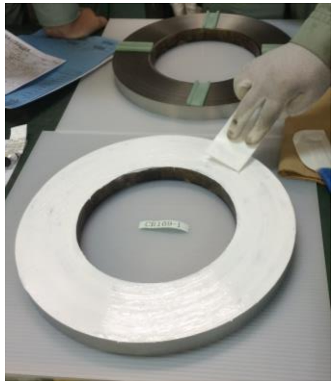
Many applications and different specifications!

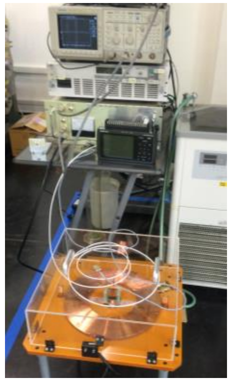
Assembly of FT3L cavity

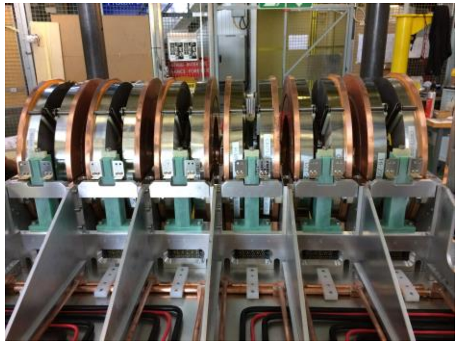


Direct water cooling

Indirect cooling







Over 20 yrs effort on MA cavities

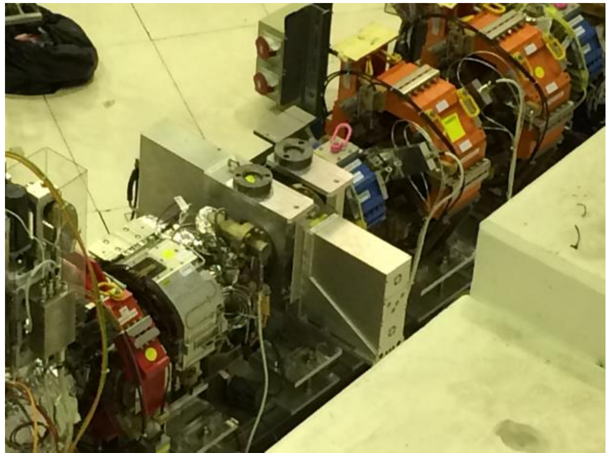
Table 1: Magnetic Alloy Cavities

Facilities	Rings	Number of Cavities	Cell per Cavity	Total Voltage	Q-value	Cooling	Core	O.D. of core	Purposes
CERN	LEIR	2	1	8 kV	<1	Direct	FT3M	67 cm	Acc., 2nd
	PSB	3 × 4	2 ×6	24 kV	<1	Indirect	FT3L	33 cm	Acc.,2nd, 3rd blow-up
	PS	1	5	5 kV	<1	Indirect	FT3L	33 cm	damper, barrier RF
	ELENA	1	1	500 V	<1	Indirect	FT3L	33 cm	Decel.
	AD	1	5	4 kV	<1	Indirect	FT3L	33 cm	Decel.
J-PARC	RCS*	11	3	396 kV	~2.3	Direct	FT3M	85 cm	Acc.,2nd
		1	4	36 kV	~2.5	Direct	FT3L	85 cm	Acc.,2nd
	MR*	8	4	448 kV	~20	Direct	FT3L	80 cm	Acc.
		1	4	55 kV	~10	Direct	FT3L	80 cm	2nd
		1	4	55 kV	~10	Direct	FT3M	80 cm	2nd

FT3M and FT3L are the name of cores which were annealed without and with magnetic field.

* Sep. 2023,- RF system upgrades are ongoing at J-PARC.

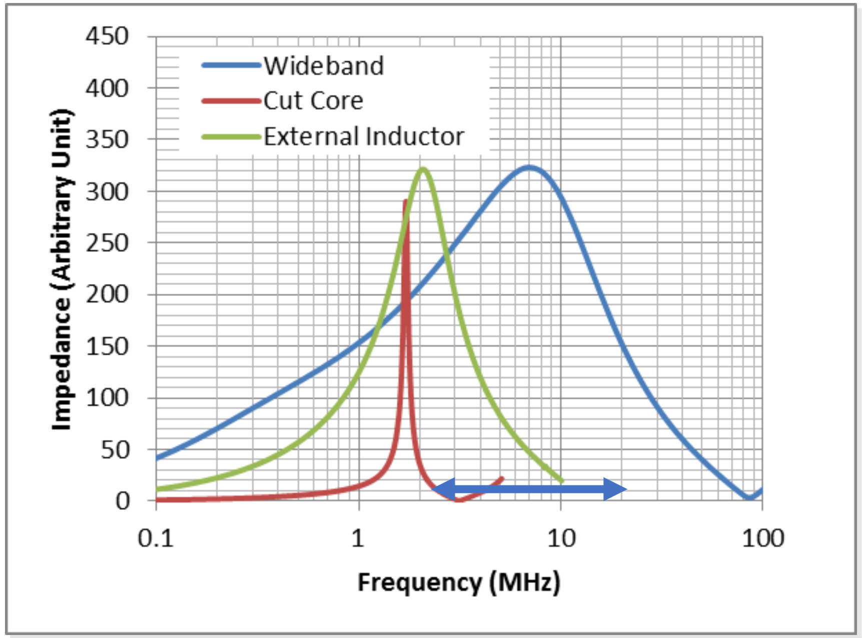
for 1.3 MW beam operation!



Cavity Bandwidth

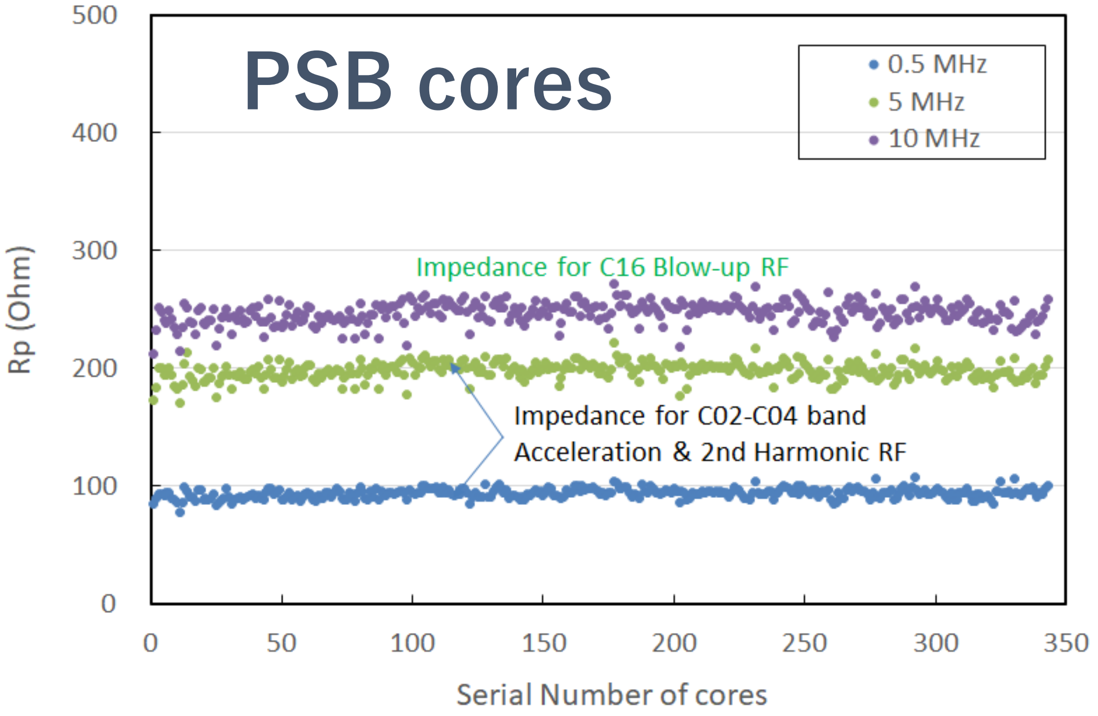
- F. Pedersen pointed out to increase Q for high intensity applications when we started MA cavity R&D.

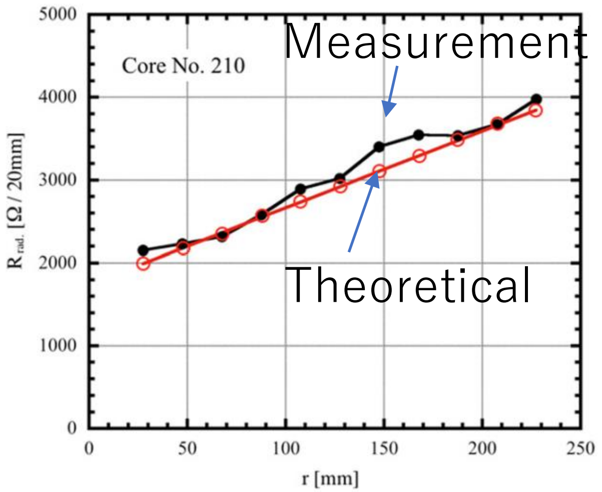
Cavity Impedance

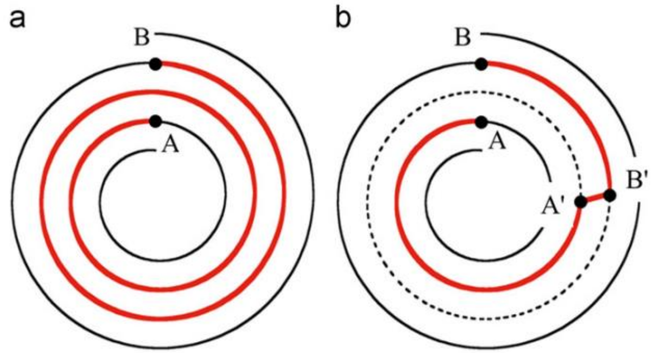


- J-PARC Main Ring adopted a cut-core scheme to achieve Q~20
- RCS adopted an external inductor to achieve Q~2
- Now, RCS adopts single-end cavity of Q~2.5
- Multi-harmonic compensation by digital LLRF is useful for beam loading.

Production of cores



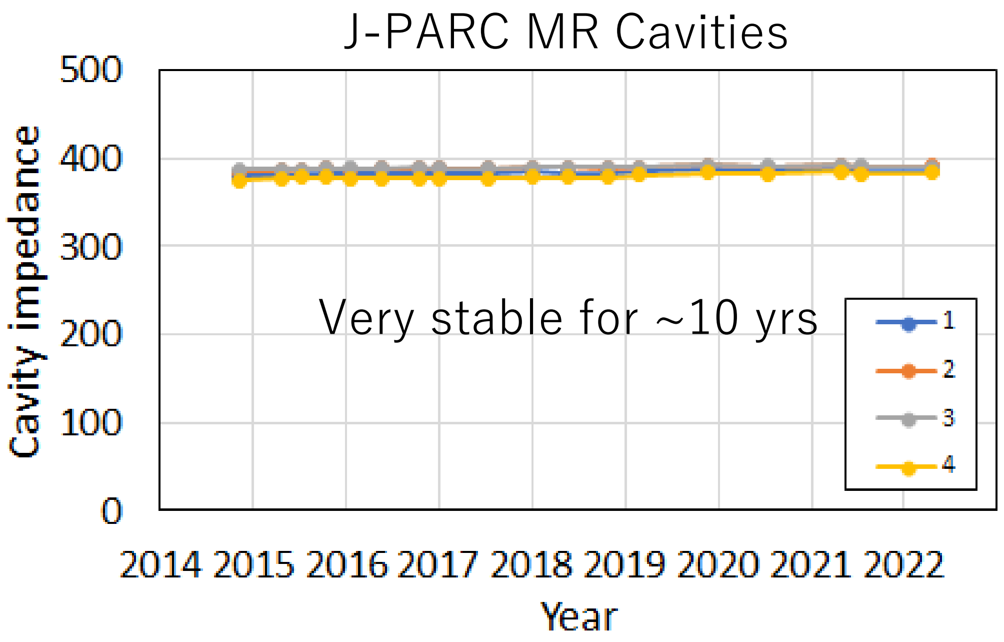




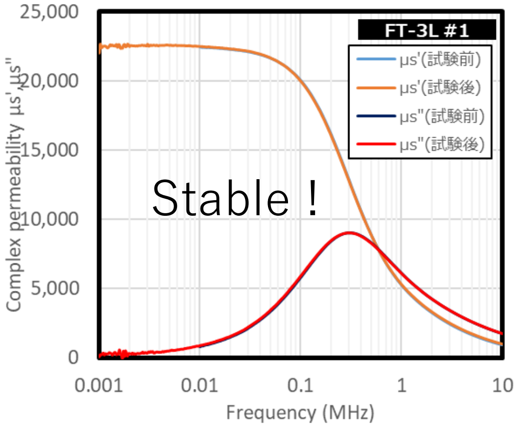
- Stable quality of cores through the production.
  - Good magnetic characteristics
  - Good insulation of ribbons

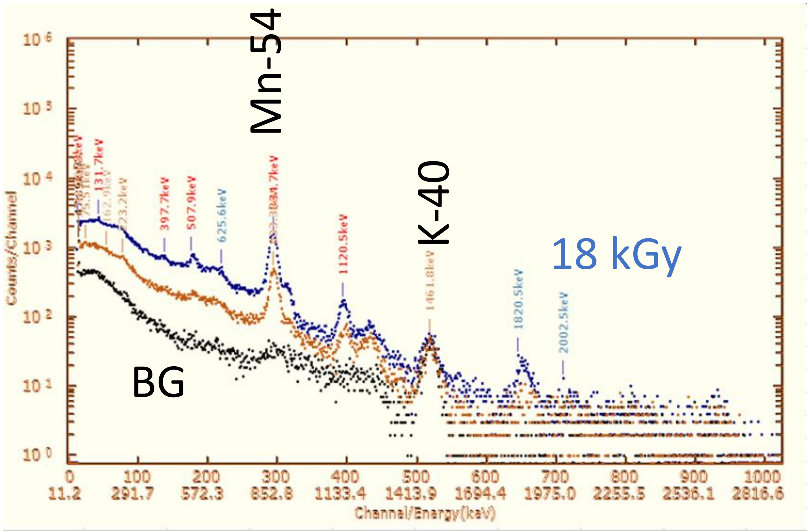
Stabilities

- J-PARC Cavity Impedance
  - Regular measurement using same calibration tool.



- Radiation hardness
  - 18 kGy + 2E14 n/cm2

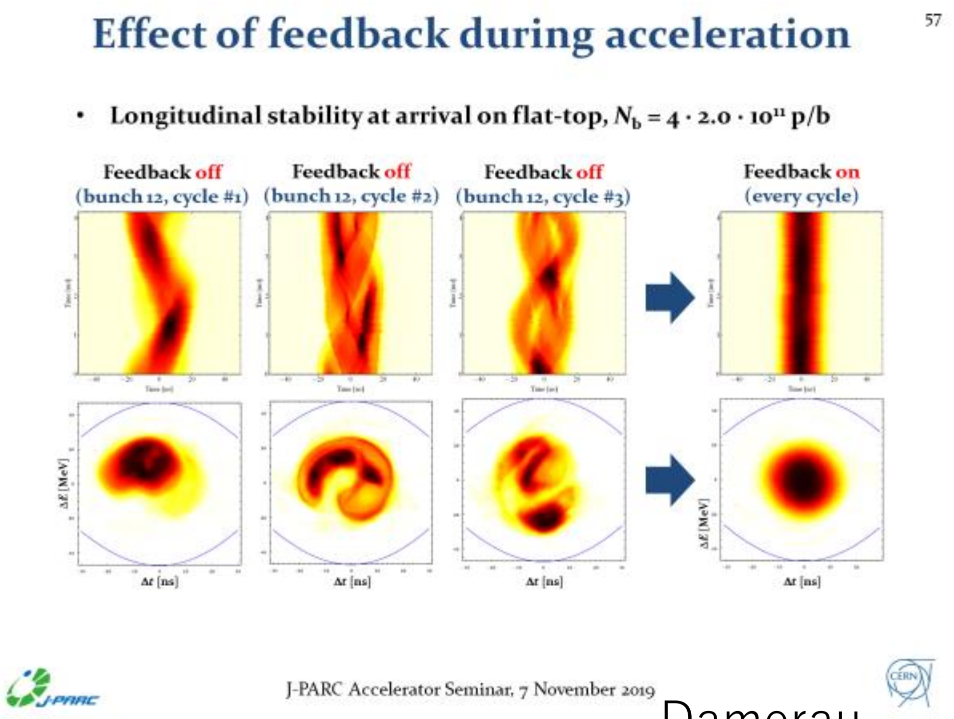




Coupled bunch instability

Multi-harmonic feedback is useful for wideband cavity system.

- CERN
  - cured by Damper system
- J-PARC
  - cured by multi-harmonic feedback



Damerau

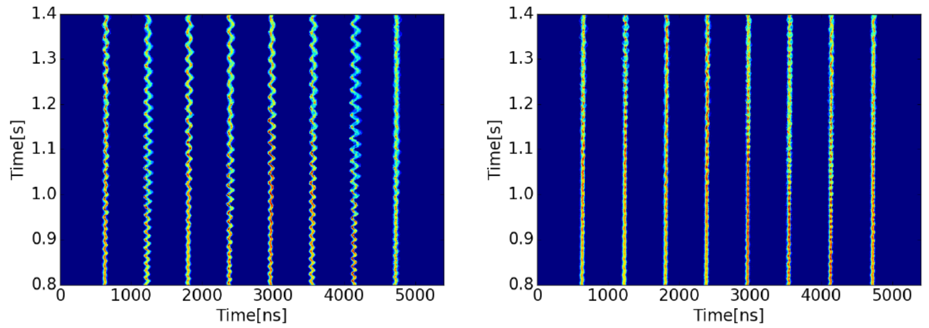


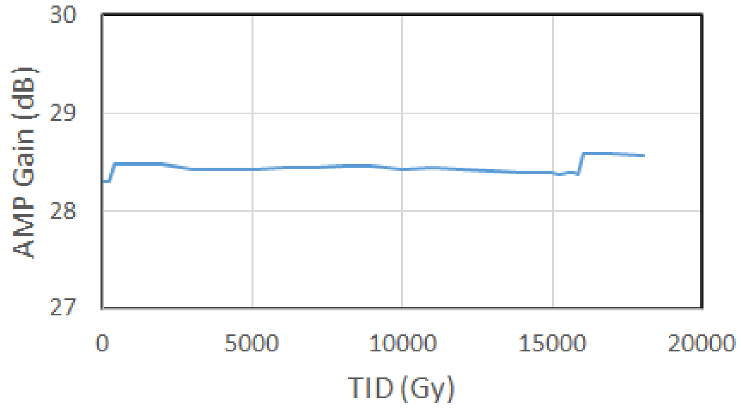
Figure 8: The mountain plot for the fast extraction in the J-PARC MR with the beam power of 480 kW (Left: with RF feedforward method for h=8.10. Right:Voltage vector feedback for h=8,10.).

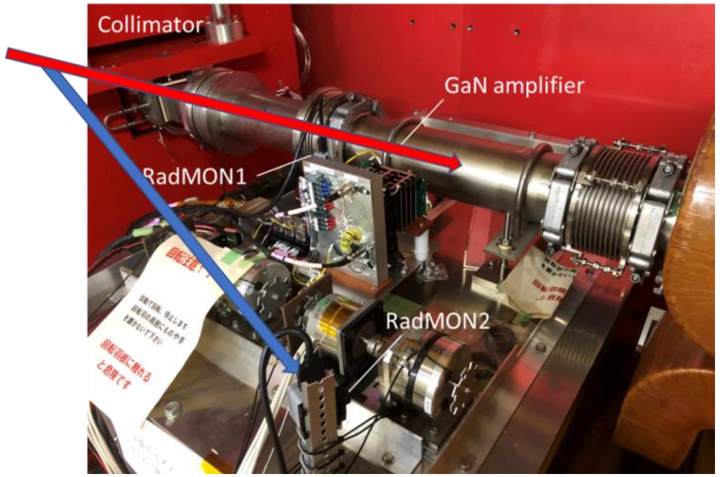
Sugiyama

Future prospects

- Cavity application
  - 40 MHz Landau cavity
    - Test bench moved to KEK from CERN
    - Use of higher impedance cores of 10 um thickness
  - Inductive adder for $\bar{p}$ deceleration
  - Medical synchrotrons
  - Medical FFA, Proton FFA

- Other collaboration items
  - GaN amplifiers to improve feedback gain of PS fast feedback system

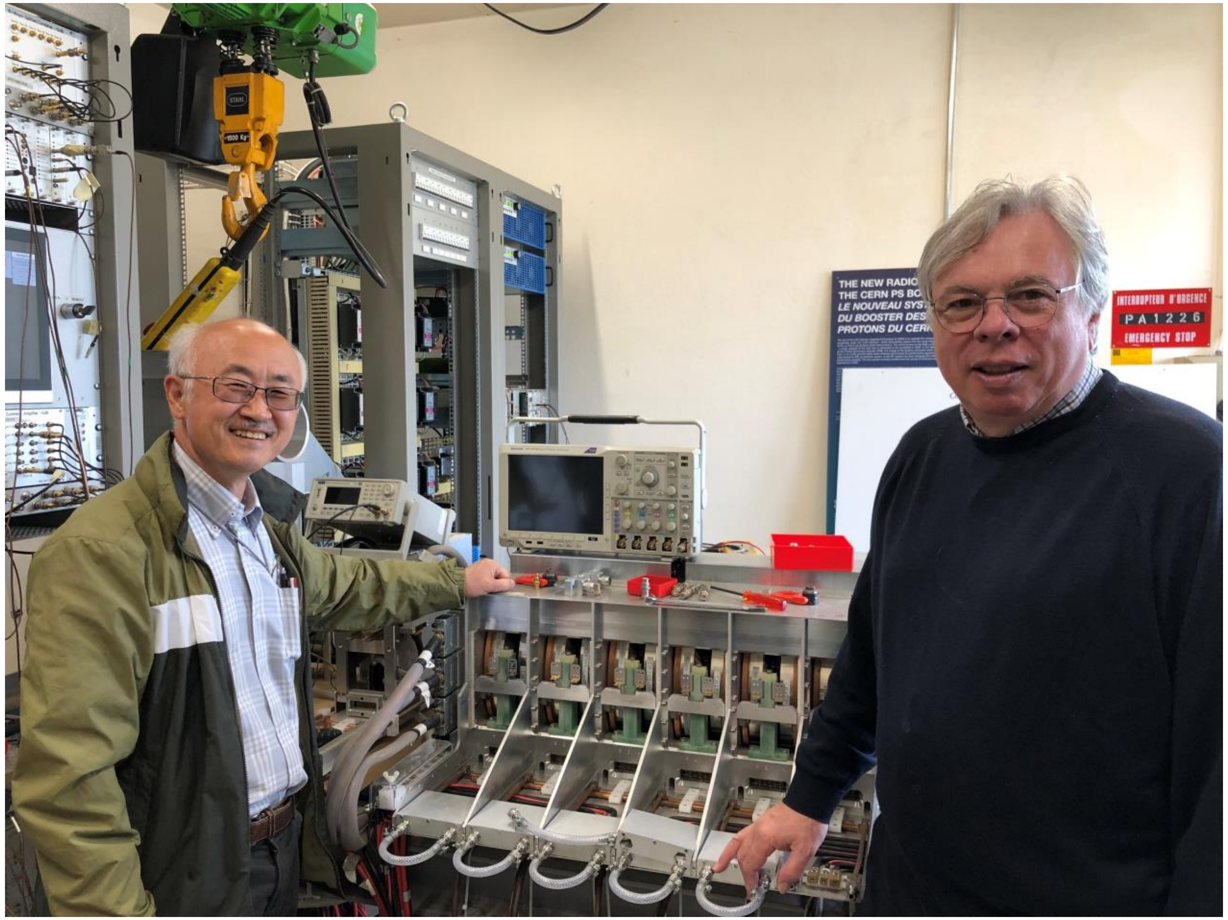




Summary

- Magnetic alloy cavities are used in several accelerators worldwide.
  - CERN cavity design using a small cell structure driven by solid-state amplifier became a universal design applied to many interesting applications including beam deceleration, instability damping, barrier bucket, and emittance control.
  - J-PARC chose the direct water cooling to achieve high-field gradient for high intensity beam acceleration.

>20 years collaboration



Thank you for your attention !