



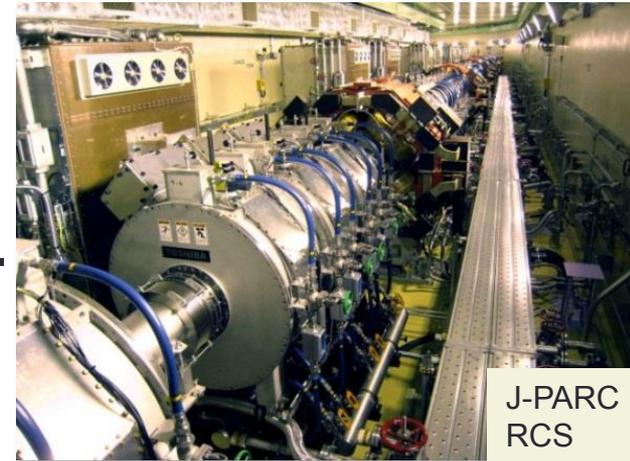
DEVELOPMENT OF HIGH GRADIENT RF SYSTEM FOR J-PARC UPGRADE

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Overview

- **J-PARC RCS (Rapid Cycling Synchrotron) delivers 500 kW beam to MLF (Material and Life Science Facility) and MR (Main Ring) 320 kW to T2K long baseline neutrino experiment.**
- Both RCS and MR adopt Magnetic Alloy (MA) loaded cavities for beam acceleration.
- **The upgrade project of J-PARC MR includes developments of higher gradient RF cavities and magnet power supplies for high repetition.**
- We have developed a new cavity using another Magnetic Alloy-Finemet FT3L. The cavity generates **two times higher voltage** than the present ones.
- We also developed **a mass production system** of the large FT3L cores for accelerator uses.
- **The cavity was installed and successfully operated up to $2E14$ ppp acceleration. Eight more cavities will be installed in this two years.**



Upgrade Scenario of J-PARC MR

J-PARC MR delivers 320 kW to T2K. In total, 10^{21} protons were delivered 2010-2015 March.

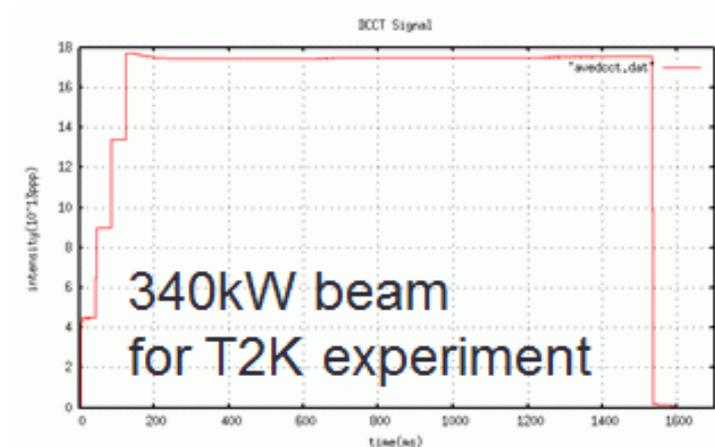
To deliver 750 kW to T2K experiment

- 1.3-sec operation of the MR instead of 2.48 sec repetition
 - Replacements of Magnet power supplies
 - New power supply buildings
 - Upgrade of injection/extraction kickers
 - **Upgrade of RF systems**
 - **Double RF voltage for acceleration (280 kV => 560 kV) by new higher field gradient cavities.**
 - New 2nd Harmonic RF systems

MR Run#	61
MR Shot#	718377 (2015/03/26 15:25:44)
NU Run#	610185
Event#	12464
Spill#	2958705
Deliv. p# (this J-PARC run)	1.1558e+20
Deliv. p# (2010/Jan/1-)	1.0000e+21

Memorial Shot !

**MR delivered
1E21 protons on
T2K target since
2010.**



DCCT signal

Power upgrade plan of MR

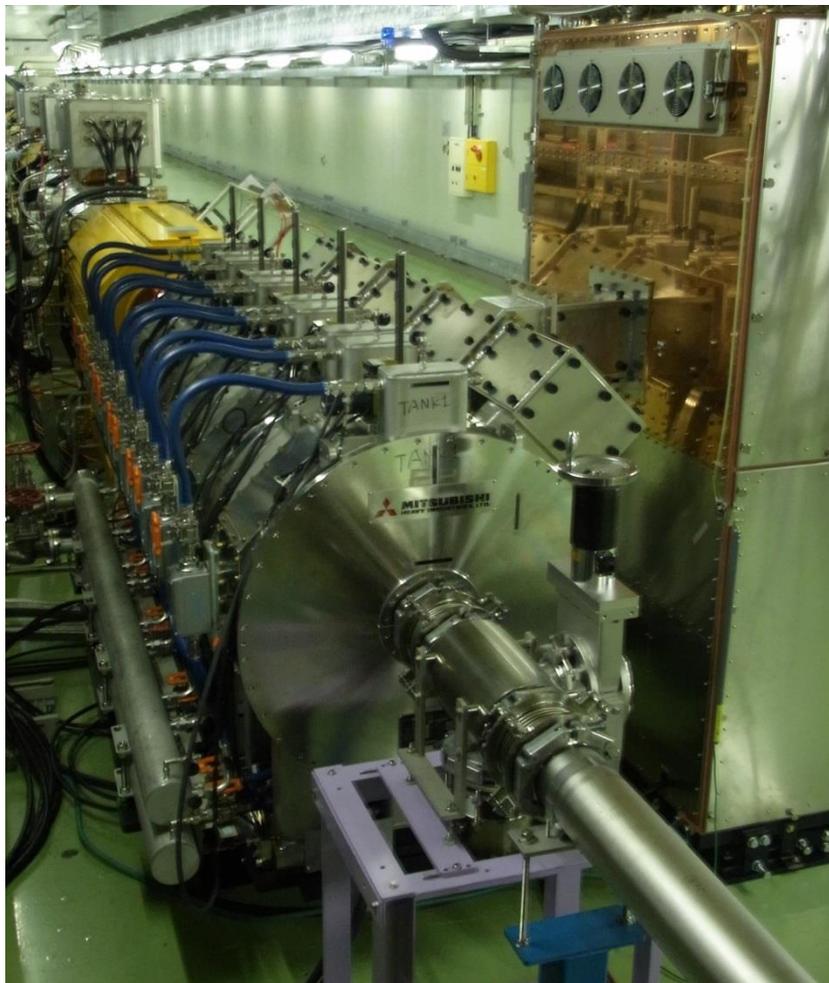
FX: The high rep. rate scheme is adopted to achieve the design beam intensity, 750 kW.

Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.

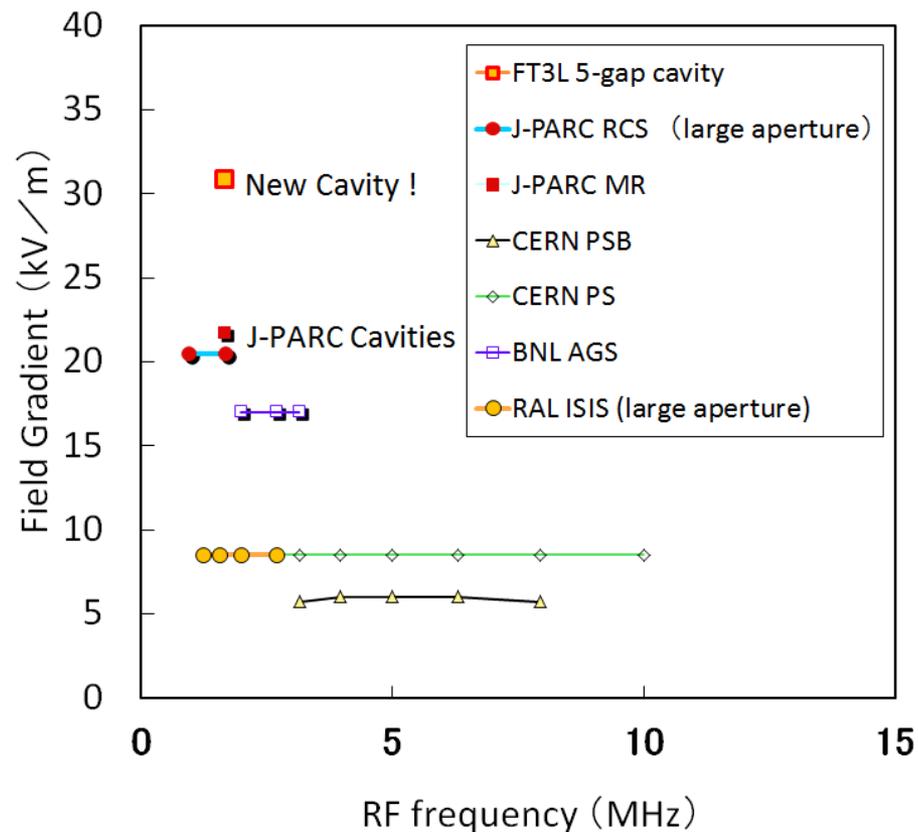
SX: After replacement of stainless steel ducts to titanium ducts to reduce residual radiation dose, 50 kW operation for users will be started. Beam power will be gradually increased toward 100 kW carefully watching the residual activity. Local shields will also be installed if necessary.

JFY	2014	2015	2016	2017	2018	2019
Event	Li. current 30 -> 50 mA		New power supply Buildings			
FX [kW] (study/trial)	240-320	>320	~400	>400	~750	>750
SX [kW] (study/trial)	-	24~50	>50	50~100	~100	100
Period of magnet PS	2.48 s				1.3 s	
New magnet PS	R&D	Low cost R&D		Mass production		
Present RF system						
High gradient rf system		Manufacture, installation & test				
Ring collimators	Back to JFY2012 (2kW)	Add. colli. C,D	Add. colli. E,F			
Injection system		Kicker PS improvement, Septa manufacture /test				
FX system		Kicker PS improvement, LF & HF septa manufacture /test				
SX collimator / Local shields			Local shields			
Ti ducts and SX devices with Ti chamber	Beam ducts	ESS				

New High Gradient RF system

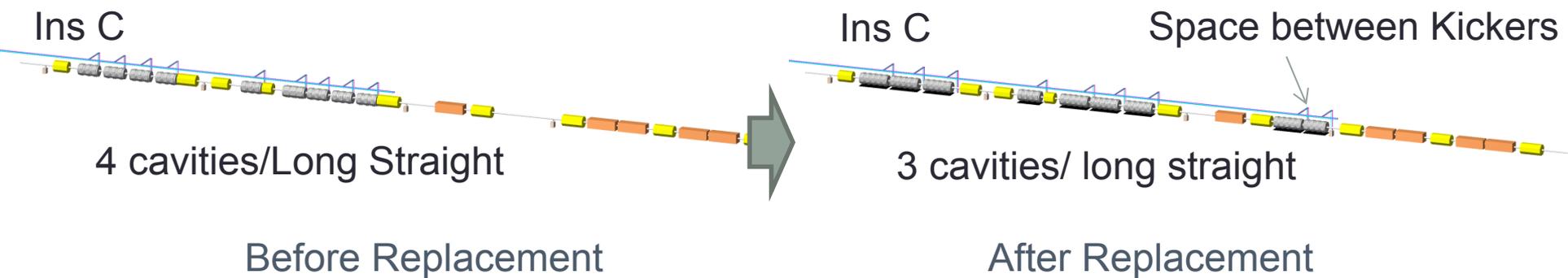


70 kV for operation (2 times higher)
80 kV for bench test before installation



New RF System using Finemet-FT3L in MR. Same amplifier, PS's can be used.

RF voltage upgrade



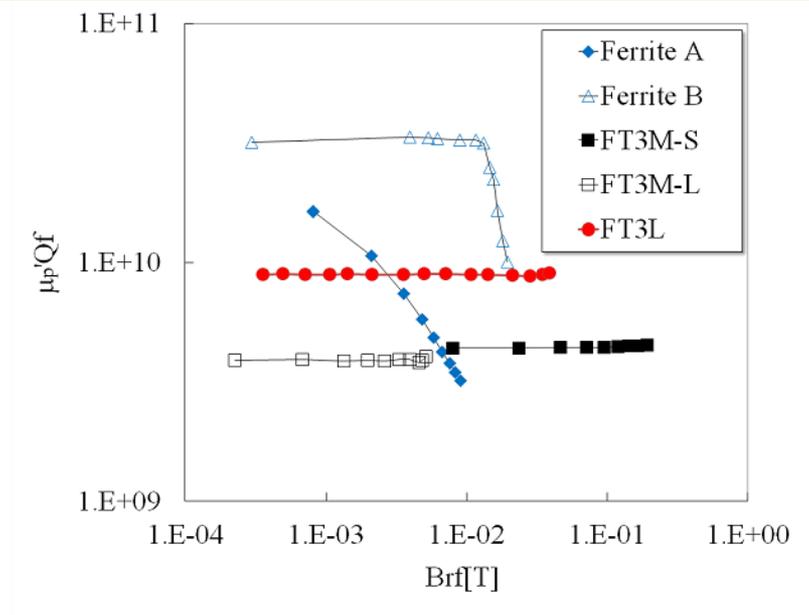
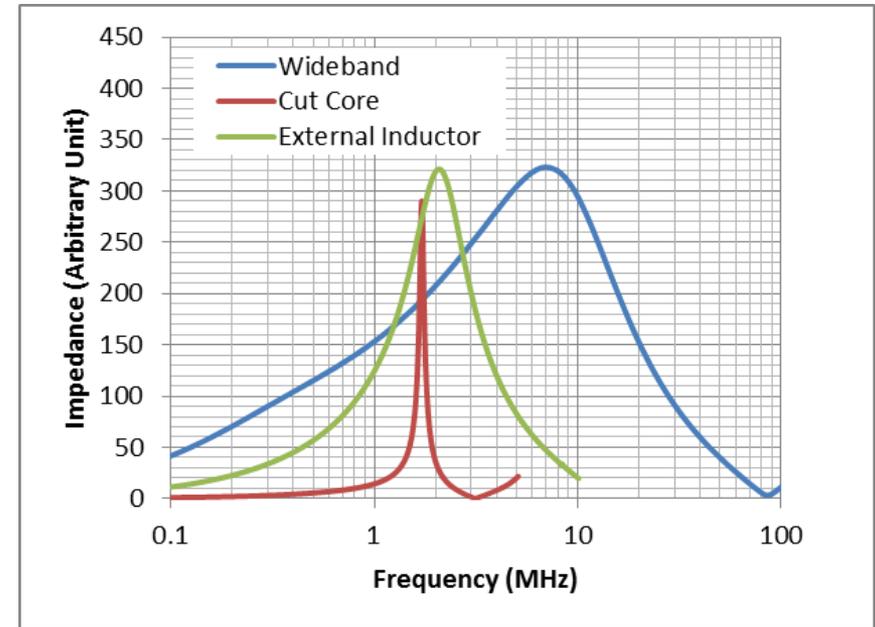
	2013	2014	2015	2016	2017	2018
Events	Li 400 MeV	Li 50mA				MR 1.3-sec operation
Present FT3M cavities	9	8	4	0	0	0
New FT3L Cavities	0	1	5	9	9	9
New FT3L 2 nd cavity	0	0	0	0	2	2
Available voltage	315 kV	355 kV	485 kV	602 kV	602 kV	602 kV
(2 nd Harmonic)	(35 kV)	(70 kV)	(70 kV)	(70 kV)	(70 kV)	80 kV
Number of cavity cells	27	29	36	43	43	43+8(2 nd)

Required voltage: 280 kV(~2017), 540 kV(2018~)

RF Cavity

Magnetic Alloy (MA) Cavity is:

- Wideband System
 - Acceleration w/o tuning
 - Also good for medical uses
 - Bandwidth can be controlled
 - Hybrid (external parallel inductor)
 - Cut Core configuration
- High Gradient
 - Constant shunt impedance at High voltage
 - High Curie Temperature



Magnetic Alloy

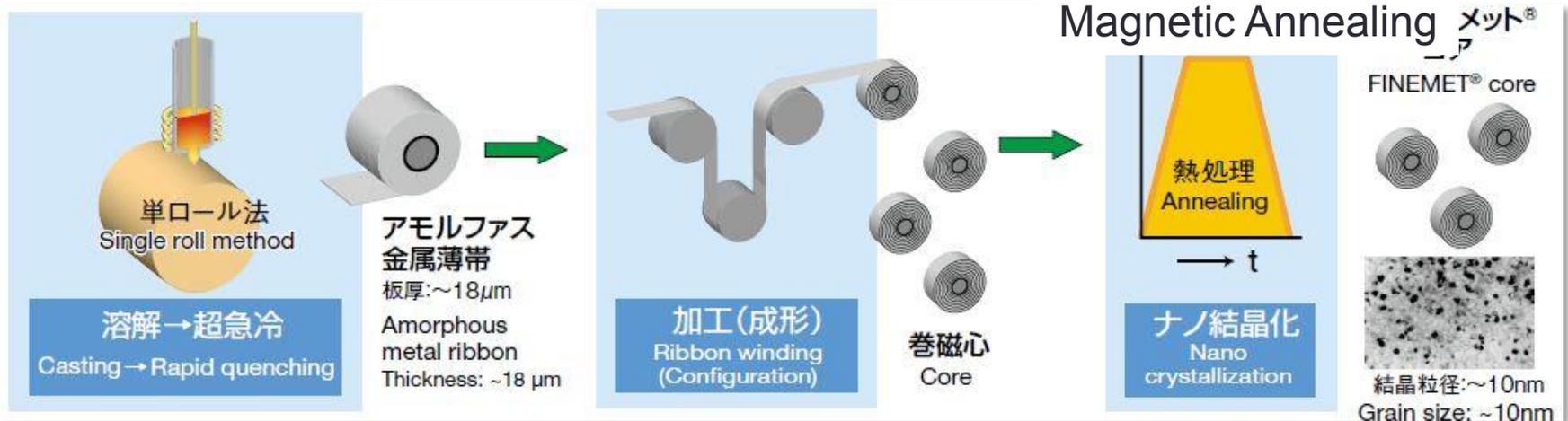
Magnetic Alloy

- Amorphous, Finemet (nano-crystalline), etc
- Thin metal ribbon (18 μ m \rightarrow 13 μ m) with high permeability
 - Not Ferrite
- Ring Core Shape is formed of ribbon.



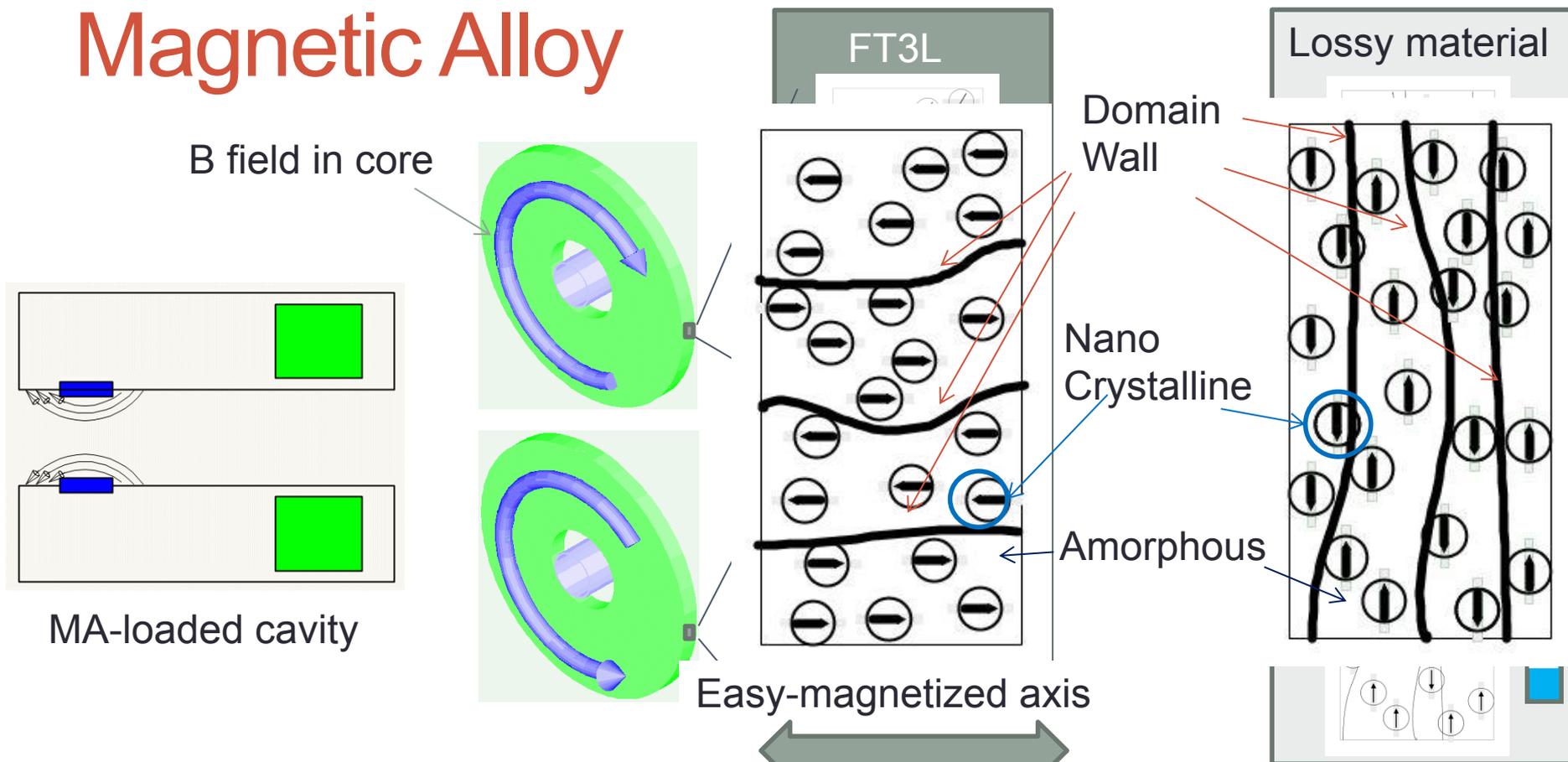
← 800 mm →

- First MA (amorphous) cavity: MIMAS in Saclay, France
- We started R&D from '95 for high intensity proton accelerators.



From the catalog of Hitachi Metal Ltd.

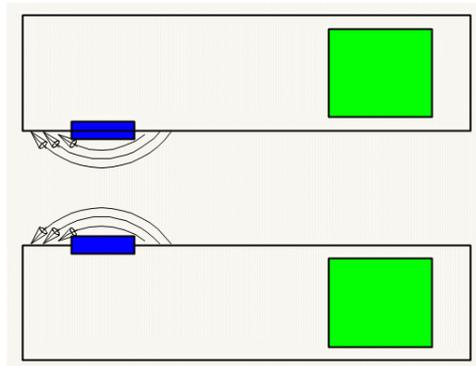
Magnetic Alloy



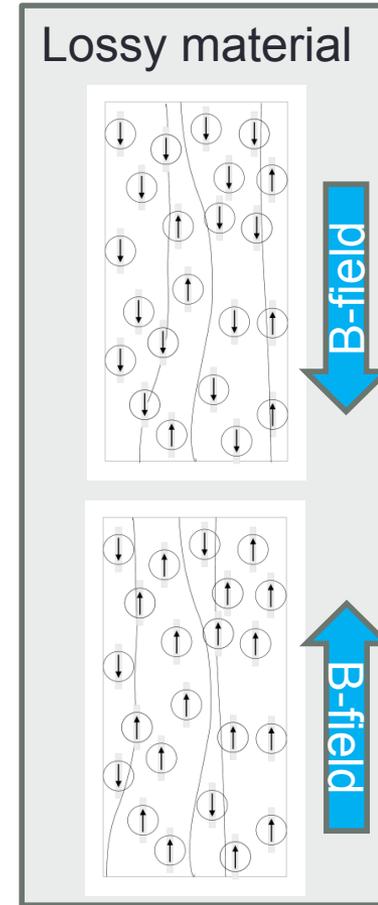
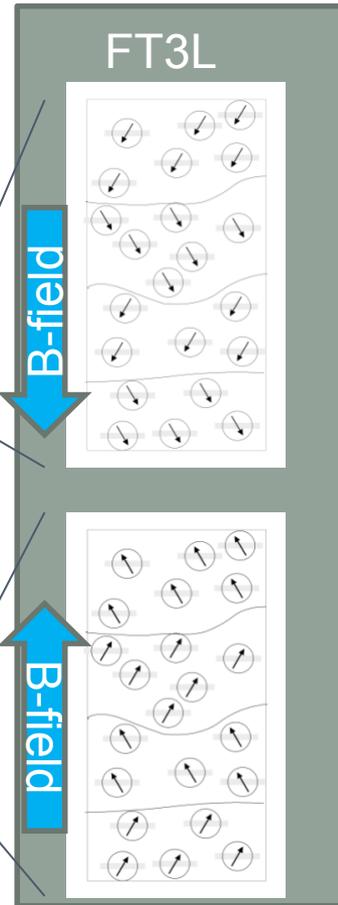
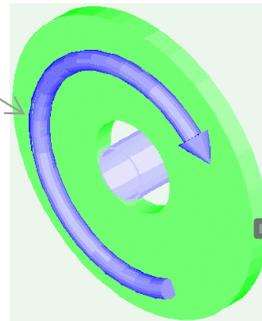
- Magnetic annealing make domain wall perpendicular to RF field. Normal annealing makes domain wall random directions (mixture of \parallel and \perp).
- Main Cause of Loss in MA core is "Domain Wall Displacement". FT3L does not have it because the domain wall is perpendicular to RF field.

Magnetic Alloy

B field in core



MA-loaded cavity



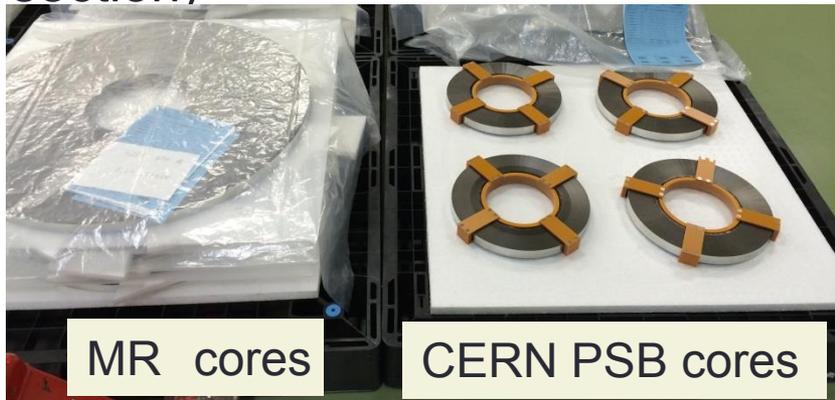
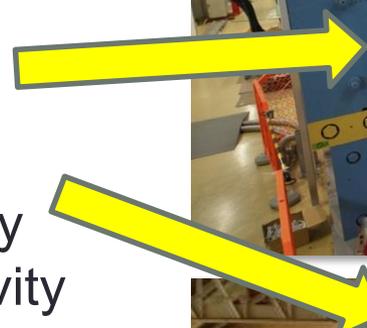
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FT3L production

- We need FT3L cores for cavities. But, cores (>10 cm) were not available.
 - 1m X 1m size Oven with magnetic field !

Our solution is DIY !

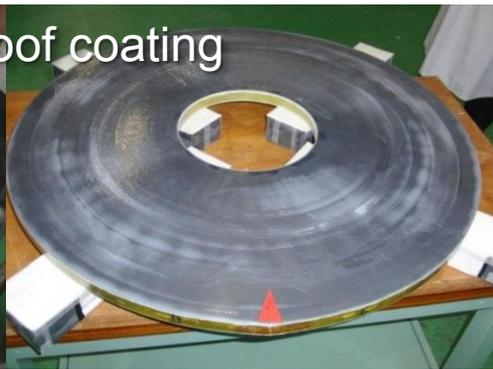
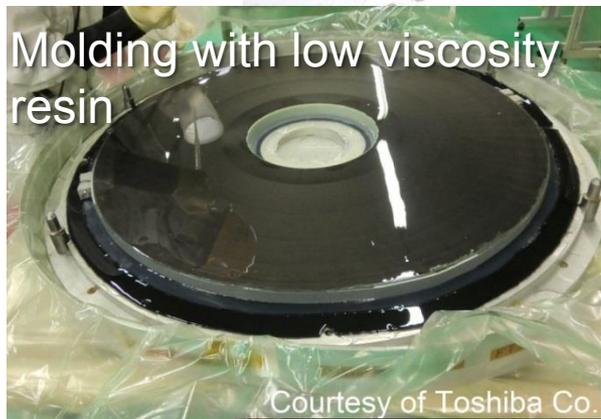
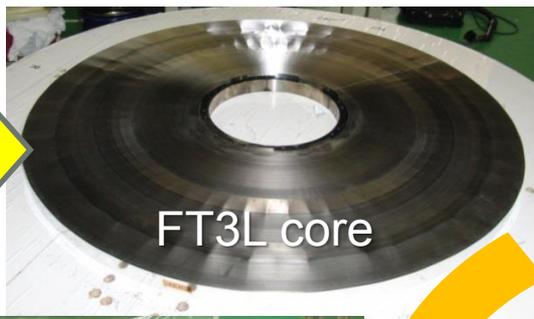
- 2009: Oven with good thermal distribution
- 2010-2011: PoP production test
- 2012 Mass production test
- 2013 Mass production in company
- 2014 Assembling of first FT3L cavity and installation in Insertion C (RF section)



MR cores

CERN PSB cores

Assembly of FT3L cavity



Power test

High power test in 2014

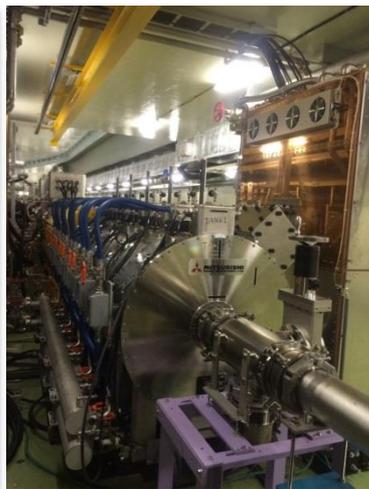


Our RF lab. in J-PARC was closed after the earthquake in 2011. It restarted in the last summer!

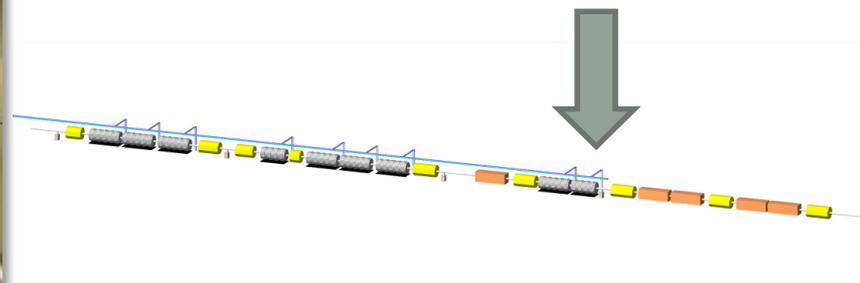
2 sets of power test

- Test 1 in Summer
 - 5-cell set up
 - 720 H, 16 kV/cell (**80 kV/cav.**)
- Test 2 in Fall
 - 3-cell are used
 - 370 H, 16 kV/cell(80 kV/cav.)
 - 110 H with **53 % higher power** than expected machine operation
 - Some different core support schemes were tested.

Installation of 1st cavity



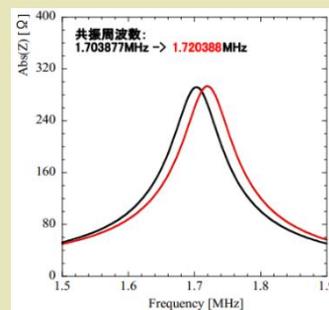
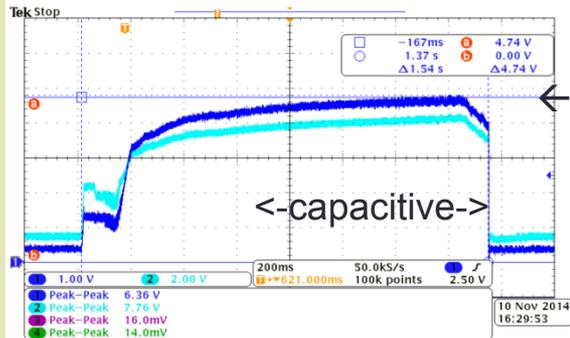
The first Cavity was installed as #9.



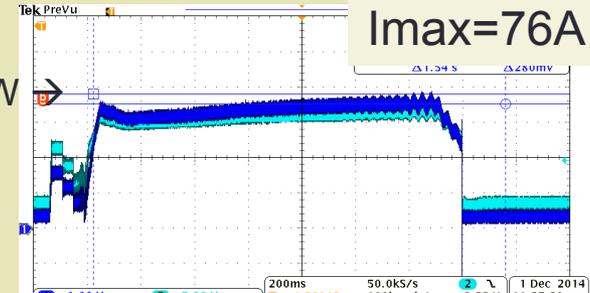
Cavity cell impedance is >30% higher than present ones, and >10% better than FT3L 1-cell cavity using PoP cores of 2011 production.
Q-value (23.3) is several % higher than we planned(21-22).

Cavity Tuning and Anode Current

Anode current =96A!



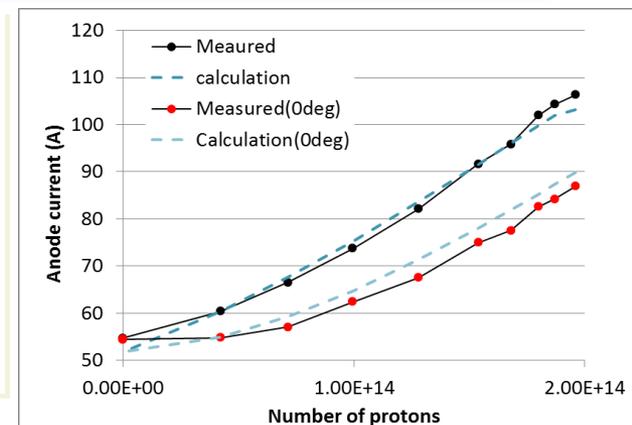
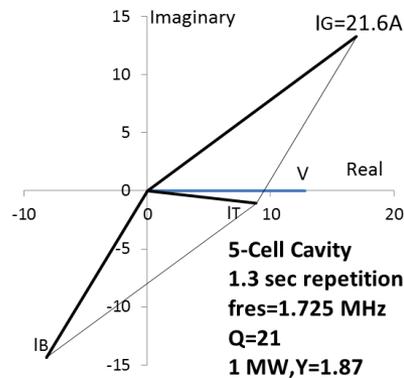
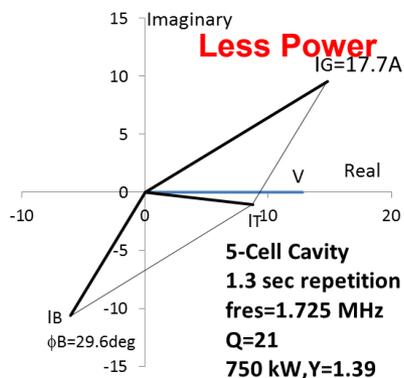
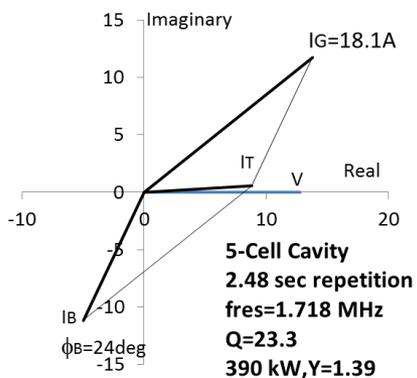
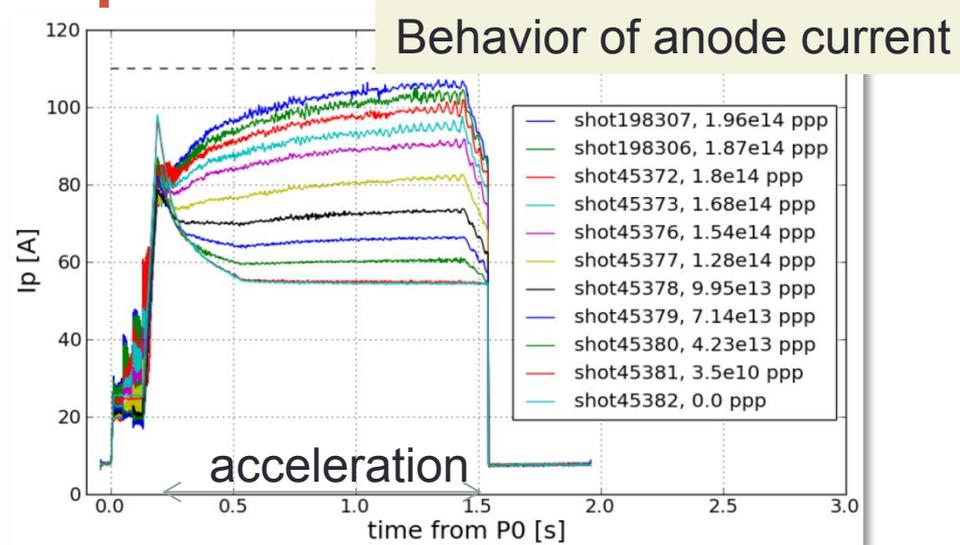
250kW →



Cavity should be inductive!

High Power Beam Operation

- **2E14 protons have been accelerated!**
- Behaviors of power consumption can be understood by the phasor diagram analysis on the beam loading.
- For 1.3-sec. operation of the MR, cavity will be tuned at an optimum value (Q-value=20~22).

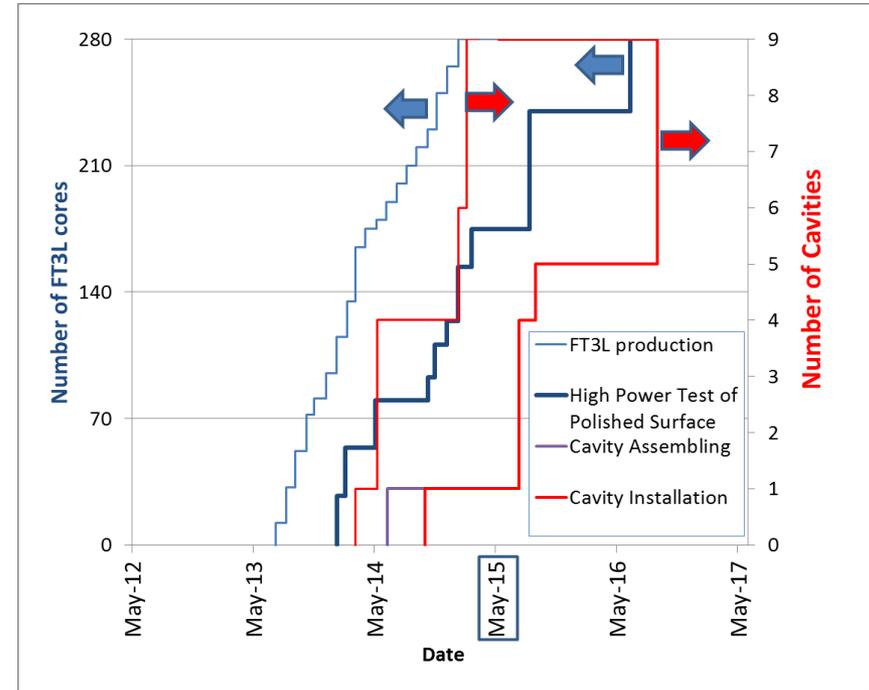


#9 cavity
2E14 protons
Q=23.3

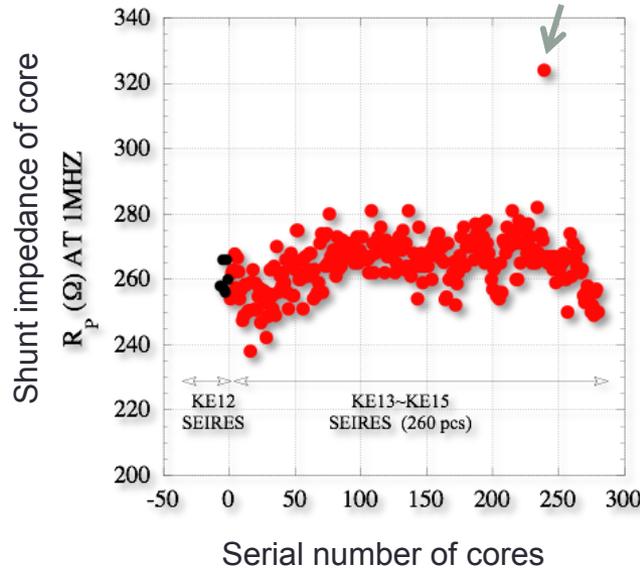
next cavities with optimum tuning
2E14 protons 2.7E14 protons
750 kW 1MW (need upgrade)

Mass Production

- Mass productions of FT3L cores and cavity shroud are finished.
- Manufacturing of cut cores are continuing.
- 4 cavities will be installed in this summer.
- Last 4 will be in 2016.



#239 shows a new record!
But, we don't know why.

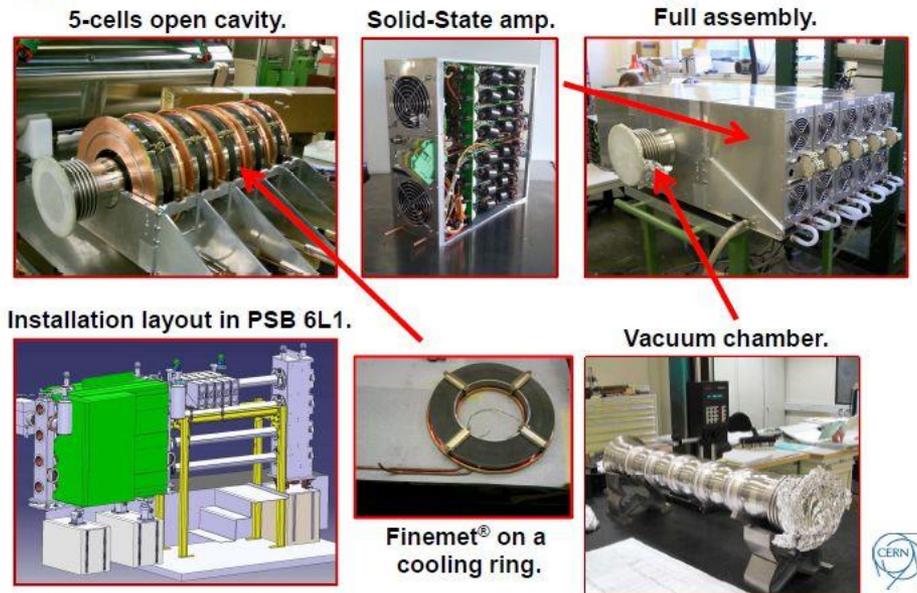


Contributions to other accelerators

- High Impedance FT3L is (or will be) also used for :
 - CERN PSB
 - PS Damper cavity
 - ELENA (\bar{P} deceleration)
 - MedAustron (Medical use)
 - KHIMA (Medical use)



5-cells Finemet® cavity prototype



Courtesy of M. Paoluzzi. WEPHA015

Summary

- Mass production of FT3L cavities have been started for J-PARC MR 750 kW upgrade.
- The first FT3L 5-cell cavity has been installed and used for beam operation up to $2E14$ ppp acceleration.
- 8 more cavities will be installed in this two years.
- FT3L will be used for other accelerators.

Thank you !