Recent Progress on the Development of a High Gradient RF System using High Impedance Magnetic Alloys, FT3L

Chihiro Ohmori, Keigo Hara, Katsushi Hasegawa,
Makoto Toda, Masahito Yoshii-KEK/J-PARC
Masahiro Nomura, Alexander Schnase†, Taihei Shimada,
Fumihiko Tamura, Masanobu Yamamoto-JAEA/J-PARC

Overview

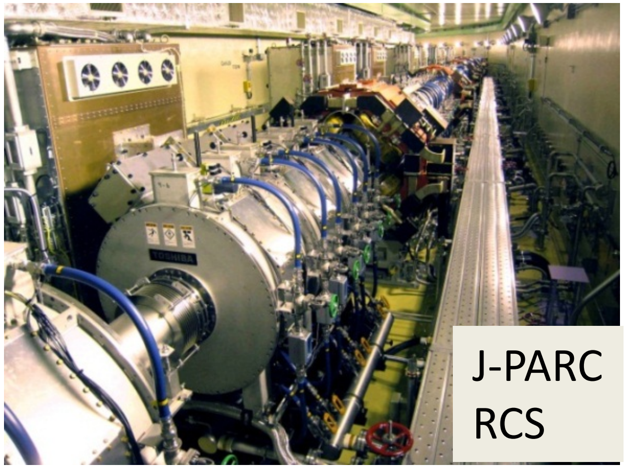
J-PARC RCS and MR adopt

Magnetic Alloy (MA) loaded cavities for beam acceleration.

An upgrade project of J-PARC MR (Main Ring) includes developments of high gradient RF cavities and magnet power supplies for high repetition rate.

High impedance magnetic alloy, FT3L, is the key component for the upgrade.

Recent progress of the developments: test results of FT3L-loaded cavity and improvement of FT3L ring core will be reported.



Introduction

Magnetic Alloy

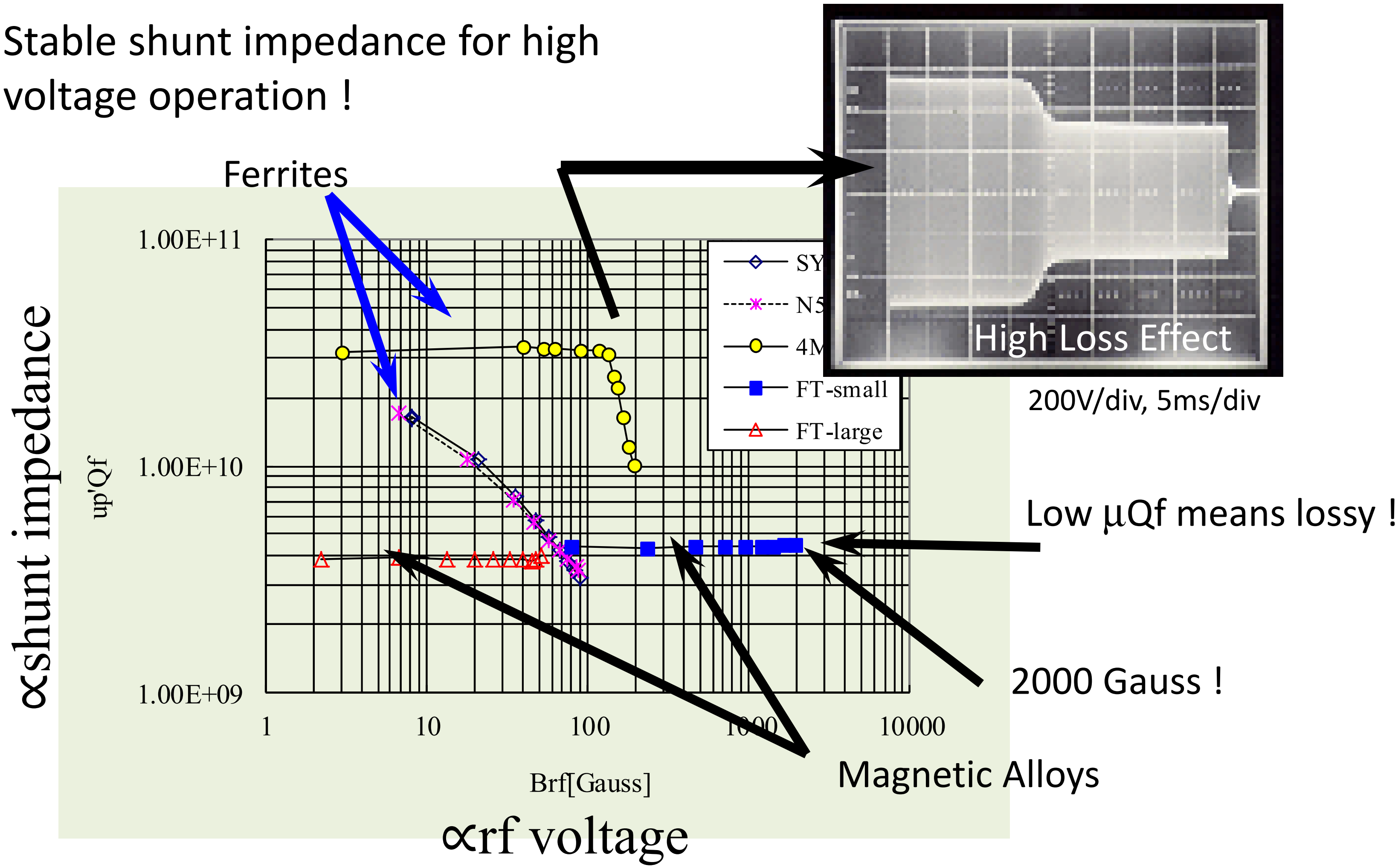
- Amorphous, Finemet, etc
  - Thin metal ribbon (18μm) with high permeability
  - Not Ferrite
- Ring Core Shape is formed of ribbon.
  - First MA cavity: MIMAS in Saclay, France
  - We started R&D from '95 for high intensity proton accelerators.

Magnetic Alloy (MA) Cavity is:

- Wideband System
  - Acceleration w/o tuning
  - Also good for medical uses
- High Gradient
  - Constant shunt impedance
  - High Curie Temperature

Characteristics of MA

Stable shunt impedance for high voltage operation !

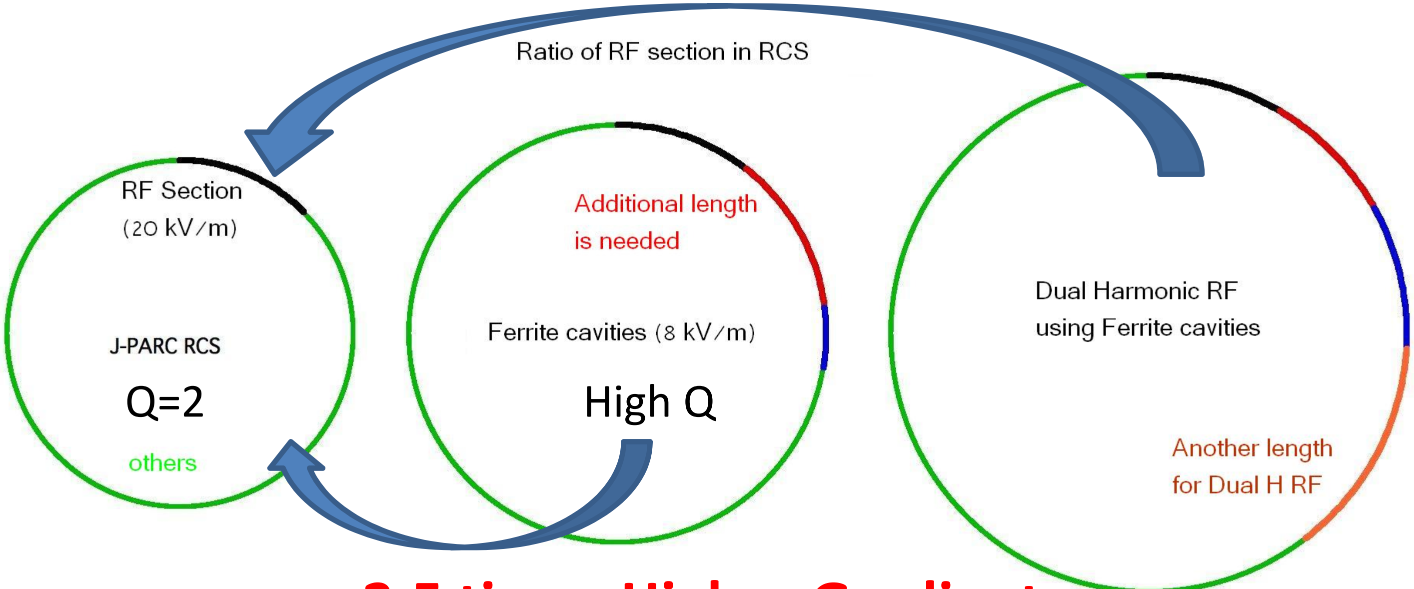


200V/div, 5ms/div

Wideband & high gradient cavity

Especially for Rapid Cycling Synchrotron which should be compact, the high gradient and wideband cavity reduced the accelerator size.

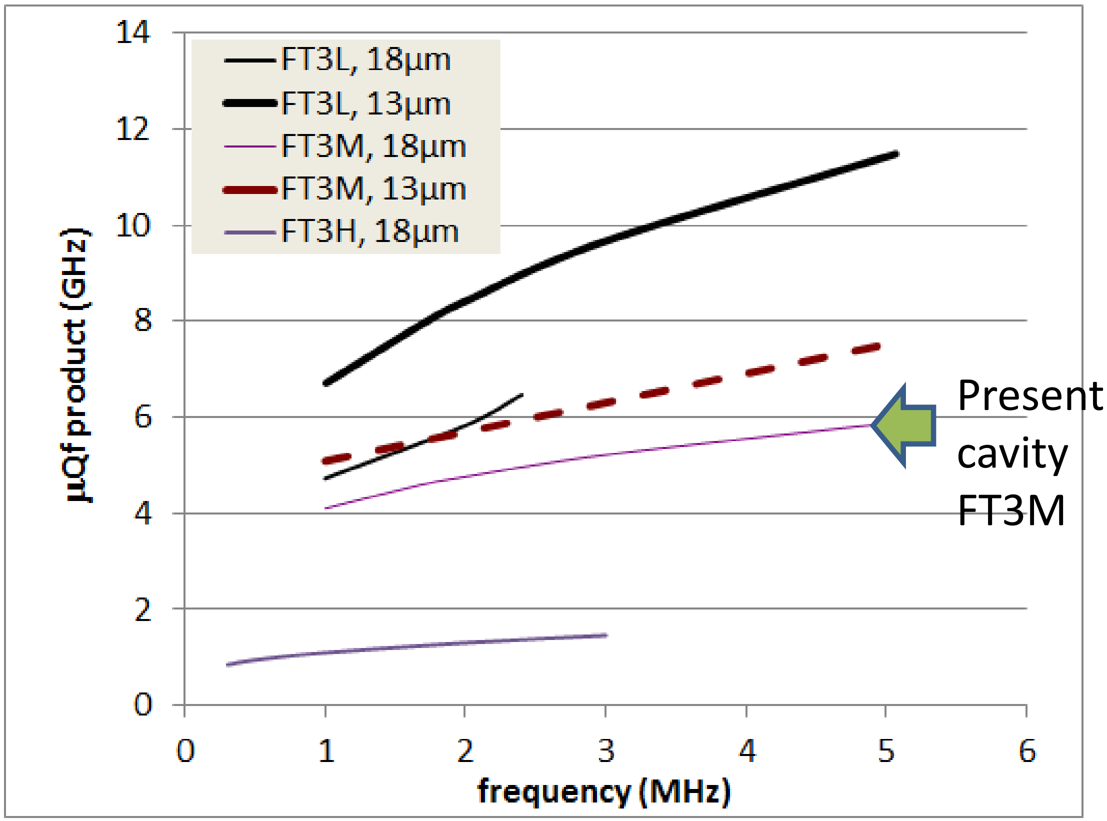
Wideband for dual Harmoncs



2.5 times Higher Gradient

For MR upgrade, higher gradient cavity for high rep. rate (~ 1Hz) is necessary as space is limited.

To obtain higher field gradient, need to reduce power loss in core



$\mu Qf \propto shunt\ impedance$

Power Loss depends on

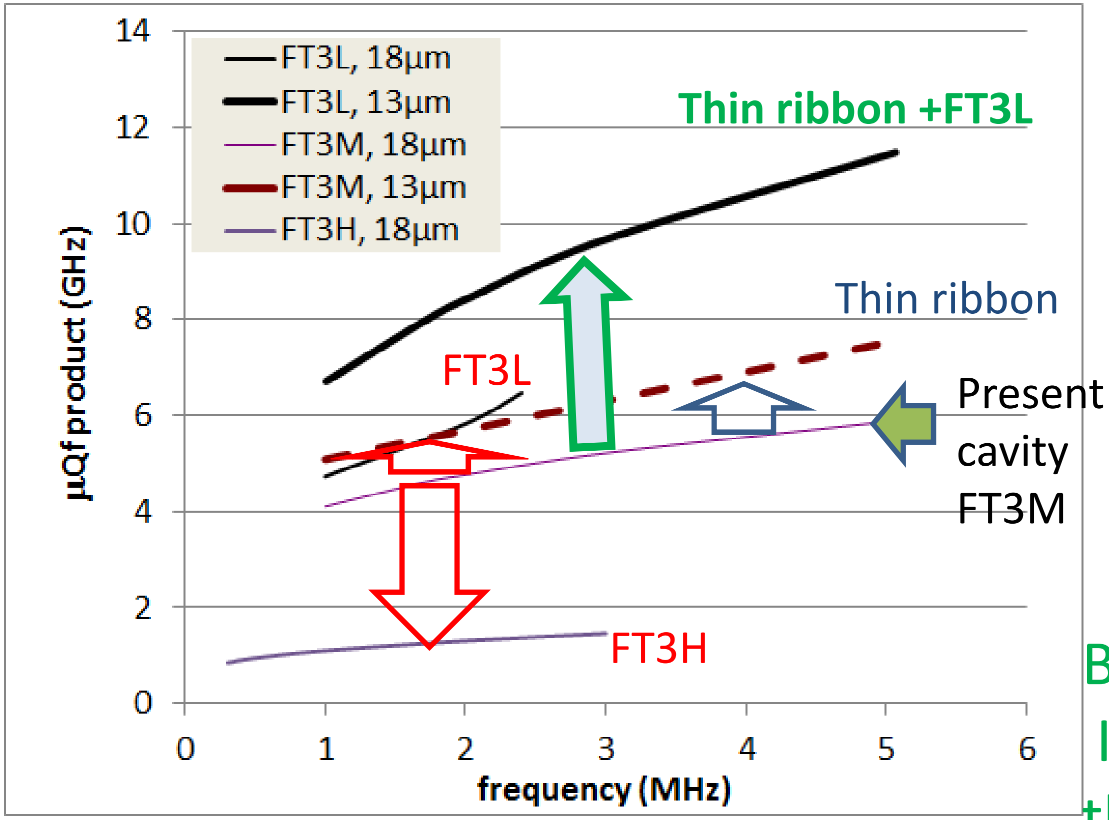
$$\text{Power Loss} \propto \frac{1}{R_{Hysterisis}} + \frac{1}{R_{Eddy}}$$

Hysteresis loss

and

Eddy current loss

To obtain higher field gradient, need to reduce power loss in core



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Power Loss depends on

$$\text{Power Loss} \propto \frac{1}{R_{Hysterisis}} + \frac{1}{R_{Eddy}}$$

Hysteresis loss

Improvements of material

and

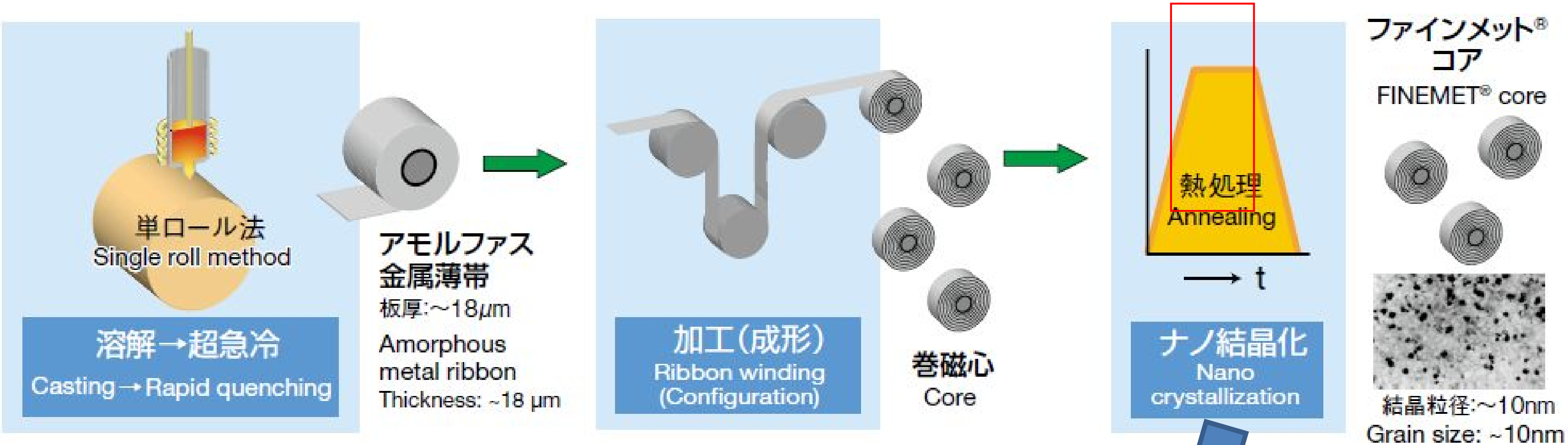
Eddy current loss

Thinner ribbon

Both

Improvements of material and thickness of ribbon

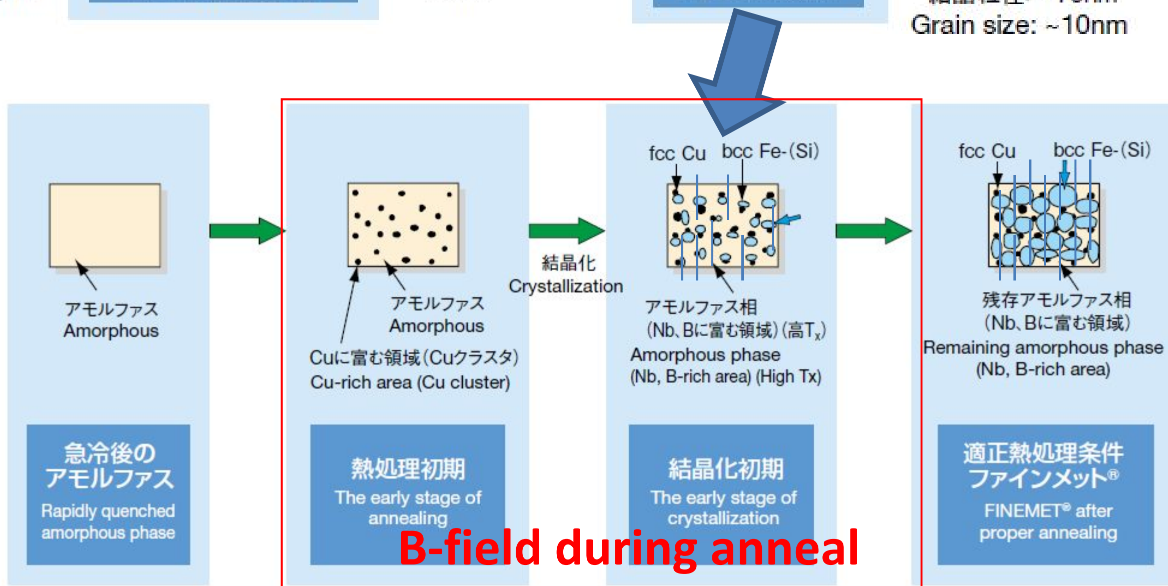
FT3L



FT3M: w/o B-field
(now we are using)

FT3L,3H: with B-field

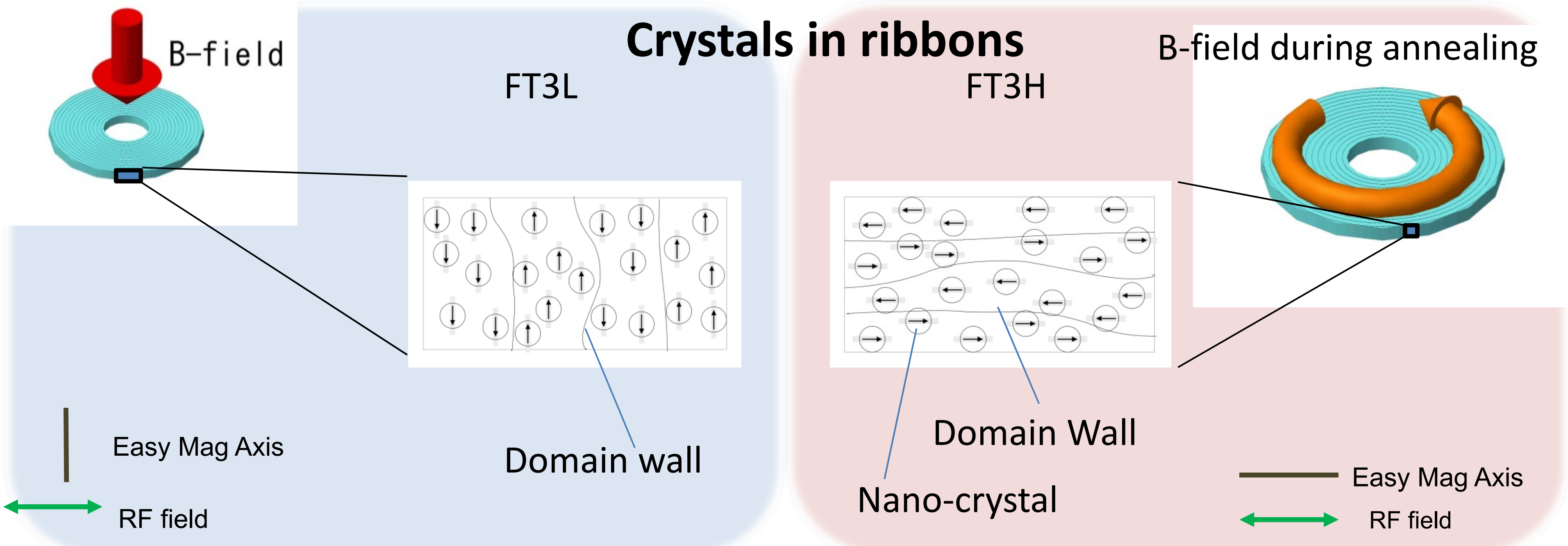
Axis of easy magnetization is aligned.



from the catalog of Hitachi Metal Co.

Mechanism

- FT3M : Annealed w/o B-field. ->
  Easy-magnetized axes of crystal are distributed randomly.
- FT3L,3H : Annealed with B-field -> Axis will be aligned.
  - FT3H : Lossy (only 1/4 of FT3M impedance)
  - FT3L＝FT3M－FT3H (removed "lossy" crystal from FT3M)



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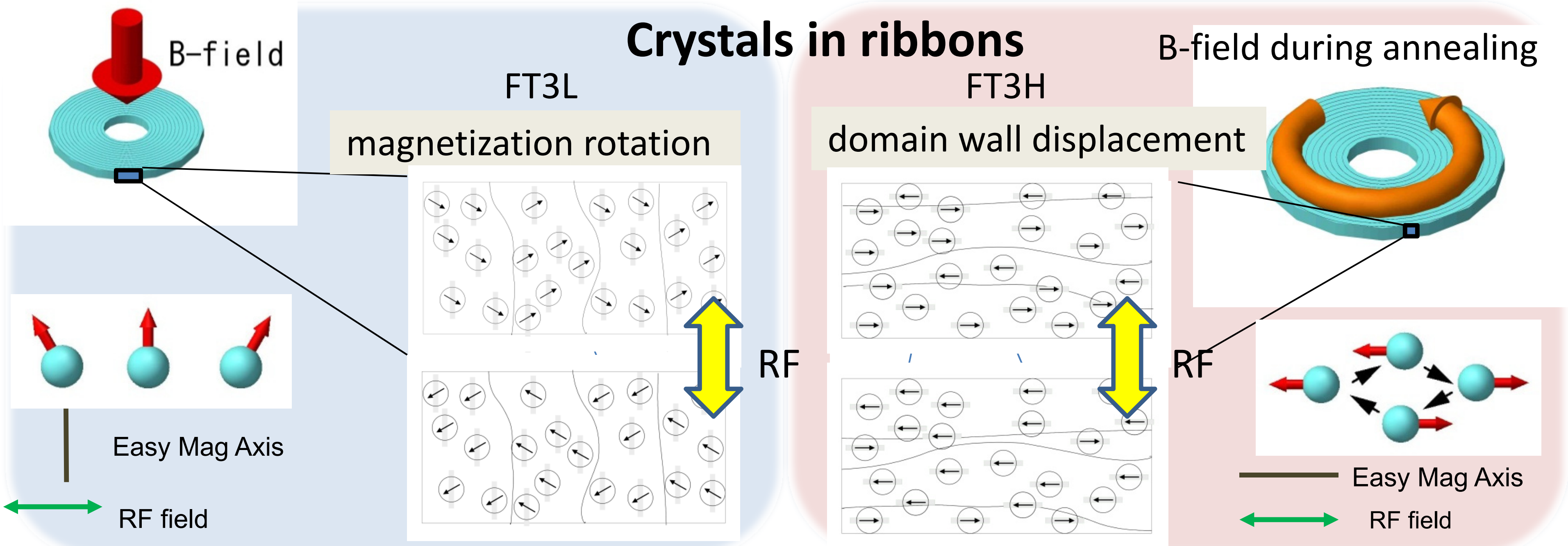
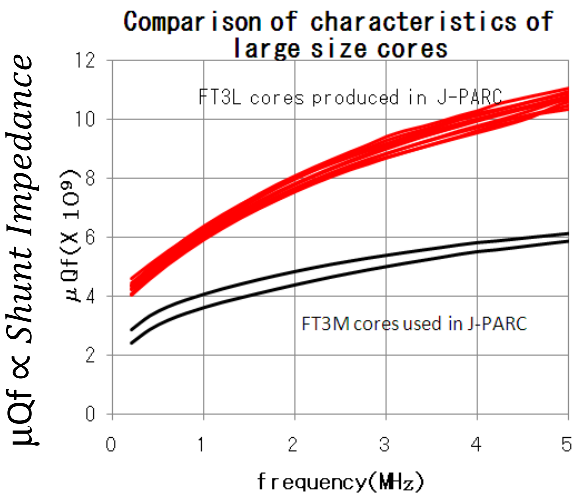


Test FT3L core production in J-PARC

FT3L looked a solution for J-PARC upgrade. But…
There was not a large system to make FT3L core for J-PARC.
And there was a risk to make a large core.

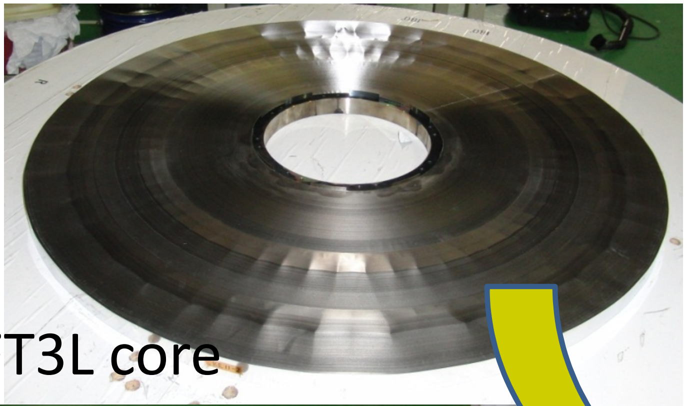
DIY scenario:
A large oven was installed in "FM magnet".
All FT3L cores show high μQf.



300 Ton Magnet was used for the test !

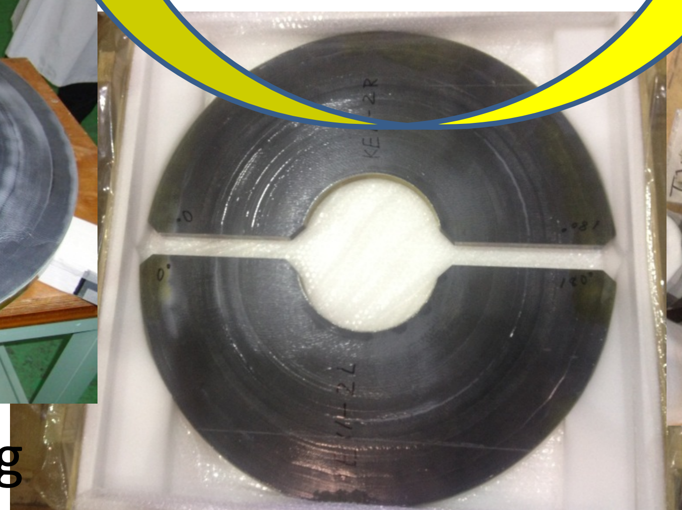
Reported in IPAC11

Assembly of FT3L cell

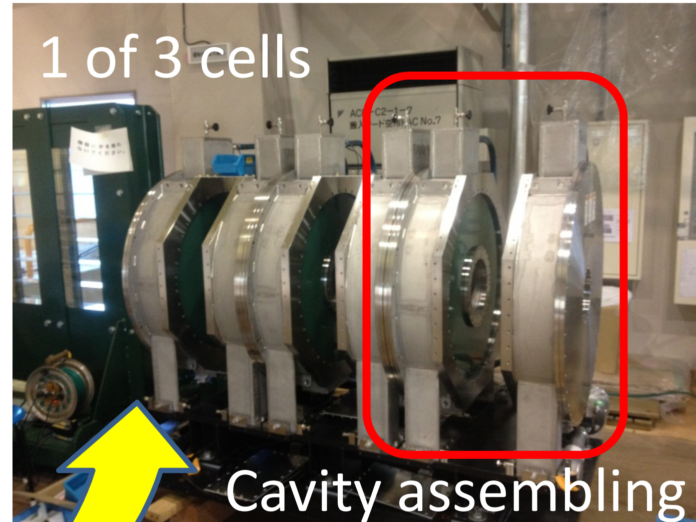


FT3L core

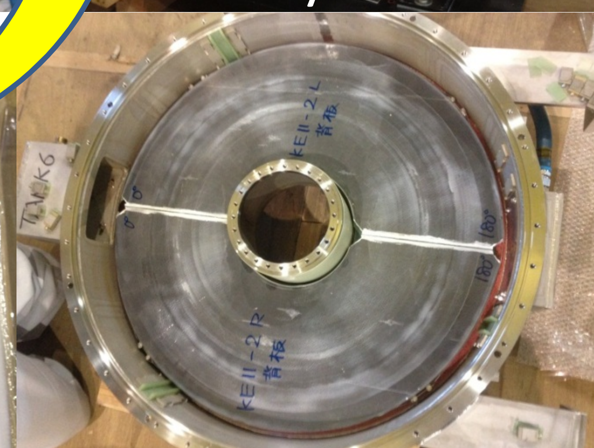
Water-proof coating



Cutting & Polishing (Q=26)

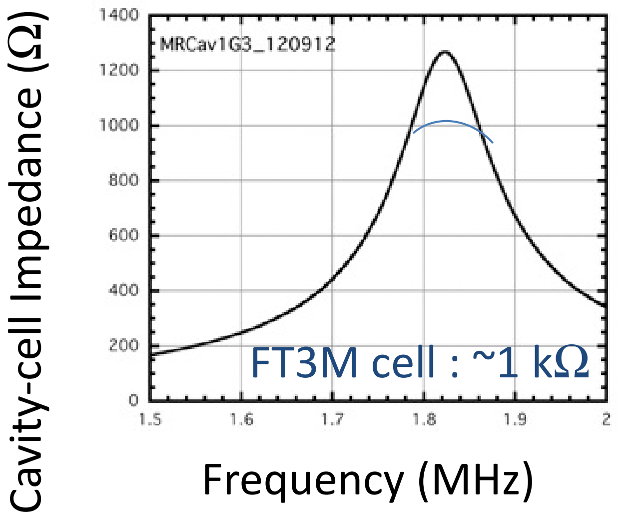


Cavity assembling



Installation into water tank

FT3L cavity under Operation



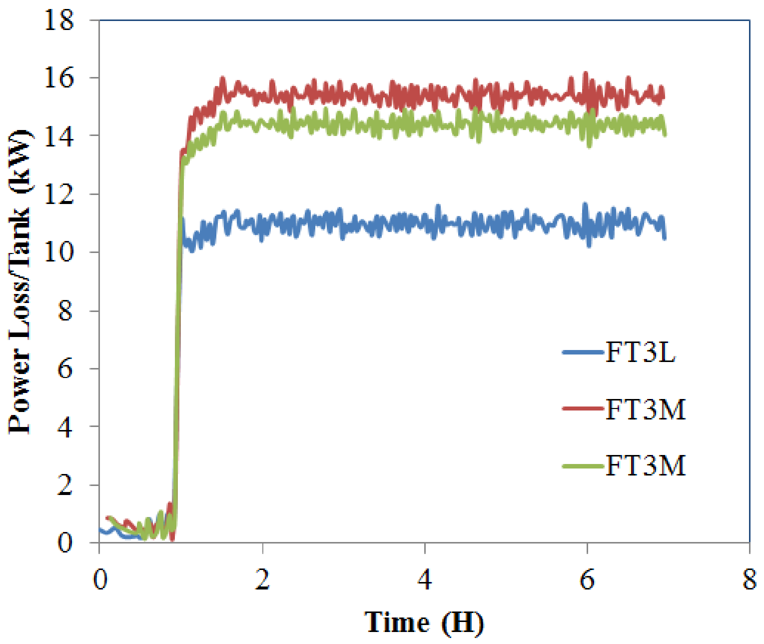
6 FT3L cores were installed in a cavity.

Higher impedance

Low Power consumption

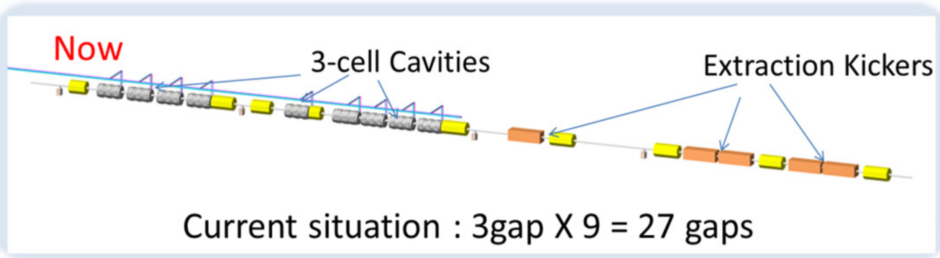
(Small temp. rise of cooling water)

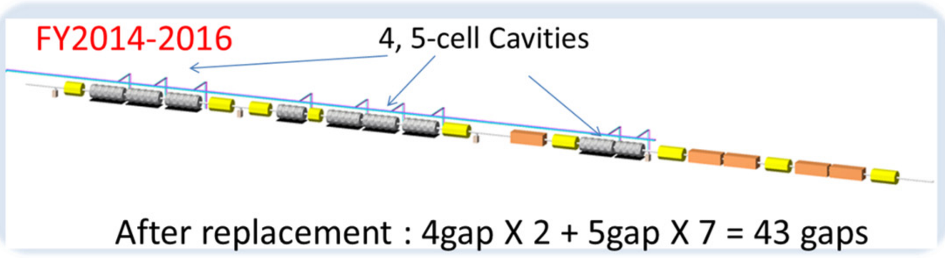
Stable high-power operation after installation in 2012



Upgrade Scenario of J-PARC Cavities

- FT3L cavities fit to our requirements - 1 Hz operation of J-PARC MR needs ~2 times larger voltage (450 kV and 2nd Harmonic RF).
  - All (9) RF stations will be replaced with FT3L systems.
    - More cavity cells & higher voltage
    - Need about 280 MA cores ! Too many for DIY.
  - We need the mass-production scenario – Assembling of FT3L core production system & lending it to a company.

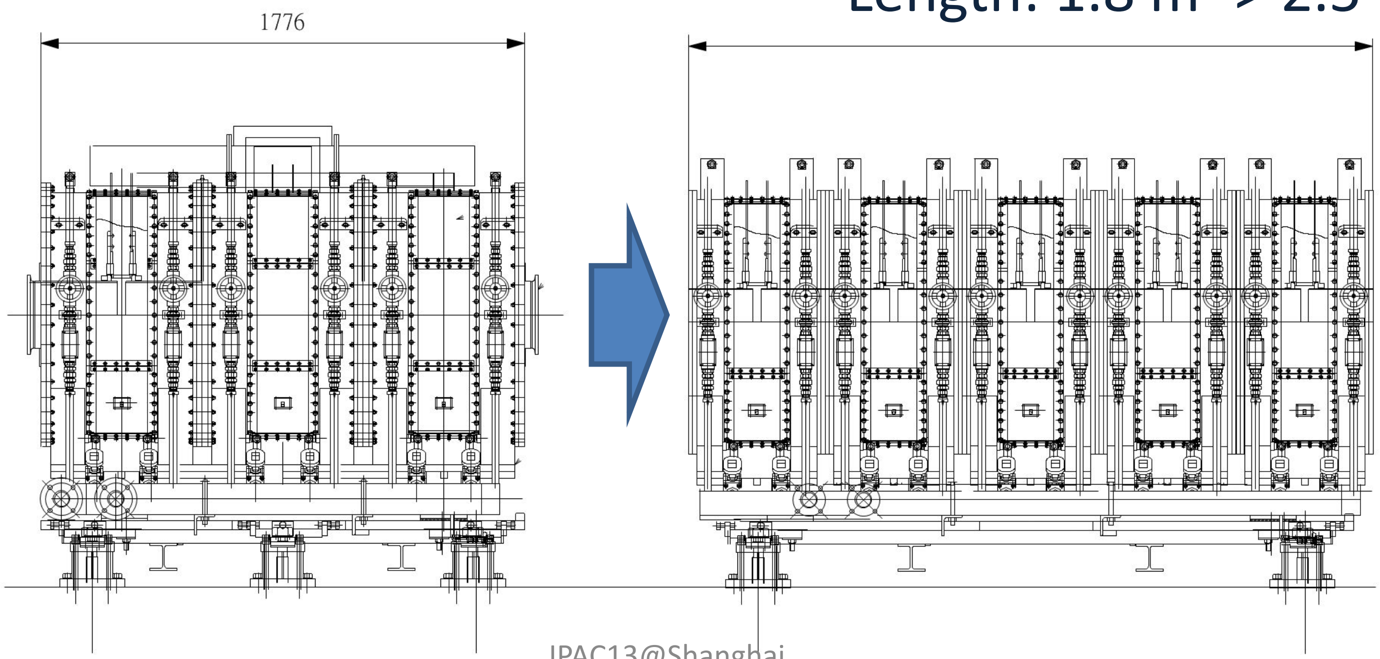




Design of FT3L cavity

Production starts from FY2013.
Same amplifier and power supply
Direct water cooling will be used.
Max. Voltage: 45 kV => 75 kV
Operation: 34 kV => 67.5 kV

Length: 1.8 m -> 2.5 m

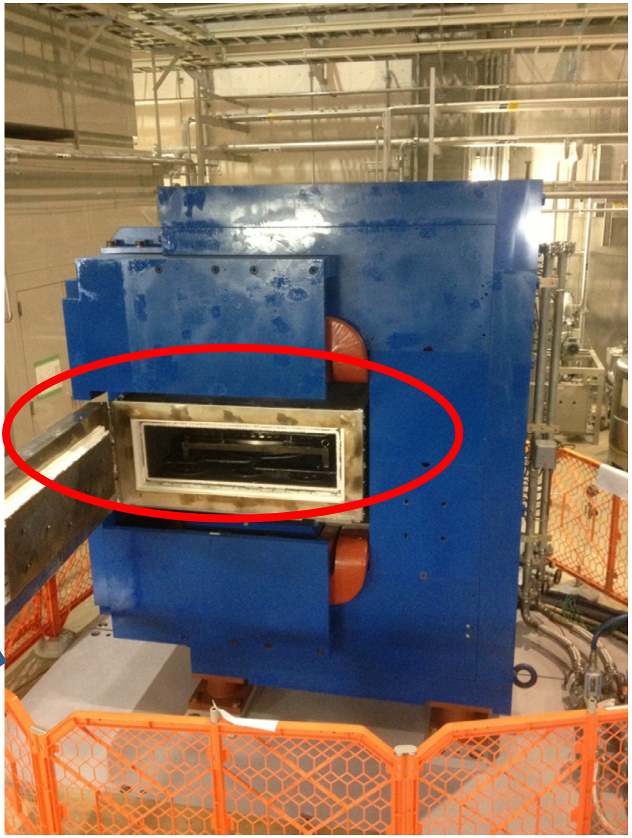


FT3L Production using "Kappa" magnet

- "Kappa" magnet was originally used for nuclear experiment in KEK PS.
- Modified for our purpose.

55 tons

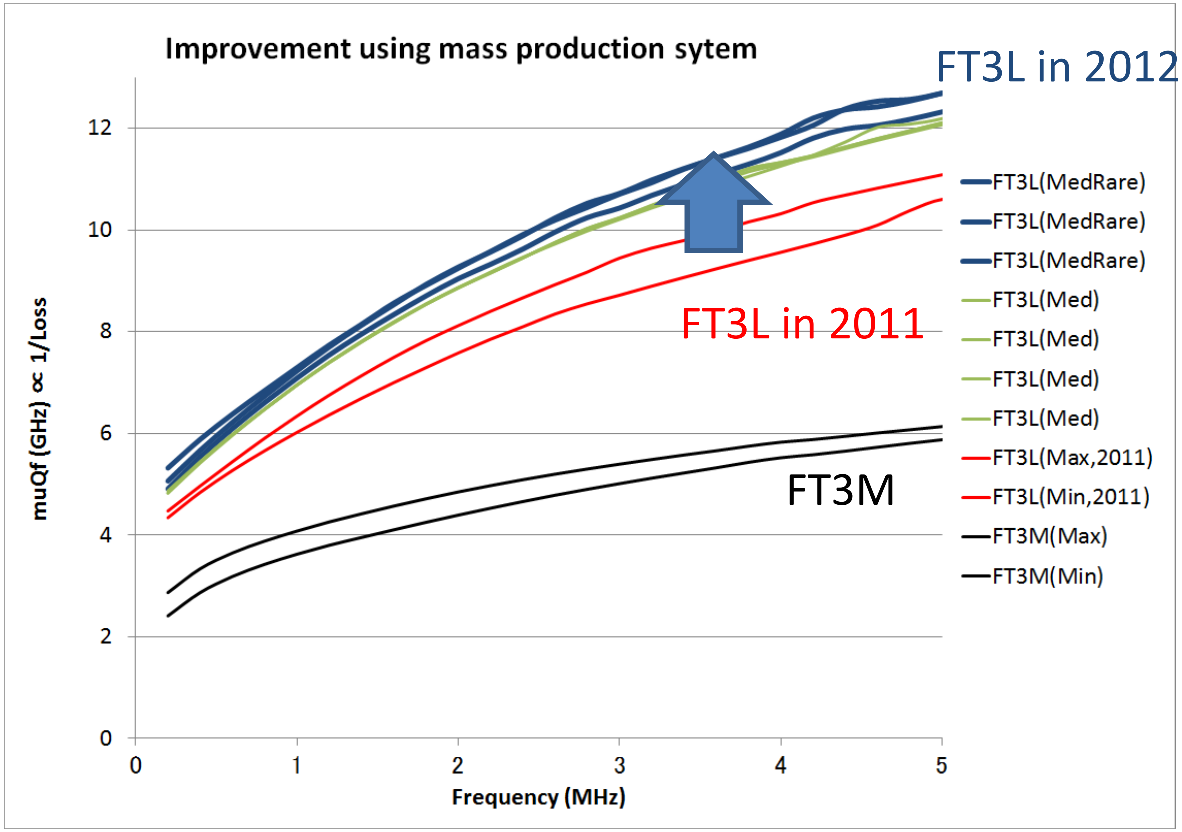
Enlarged aperture for oven



65 tons

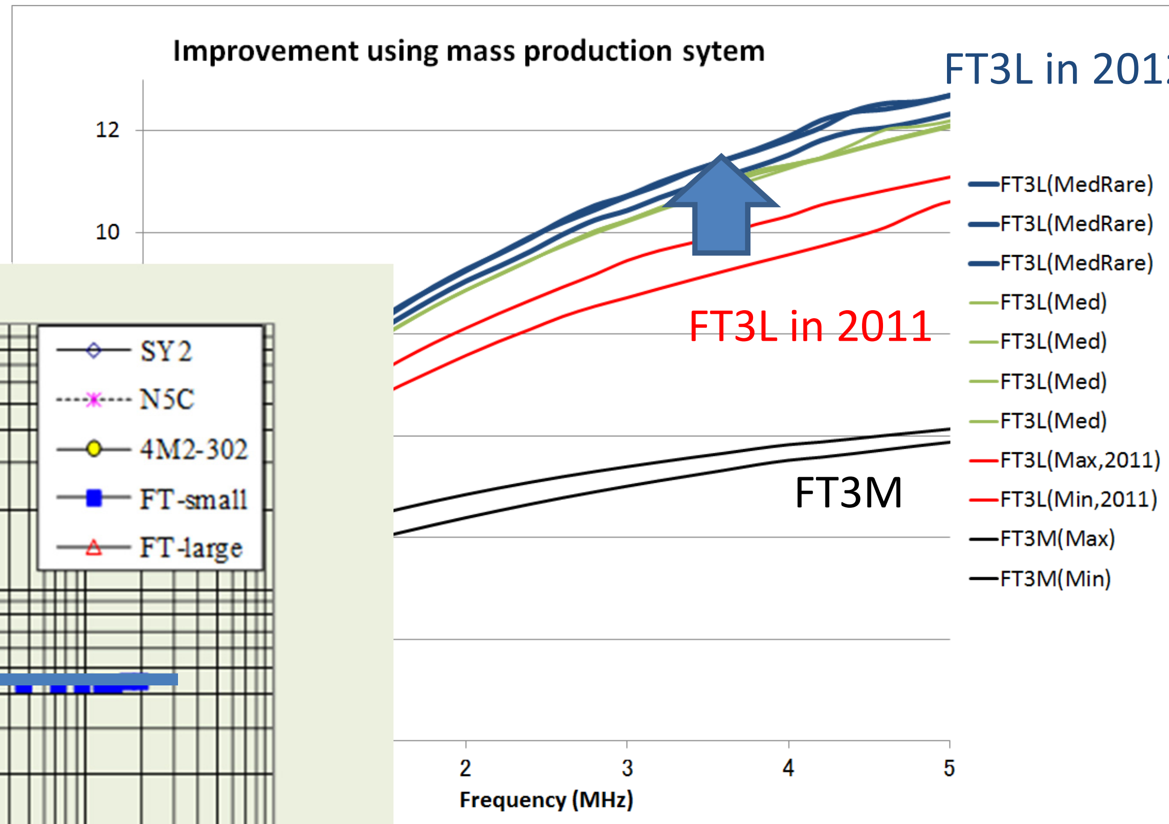
Moving to Company, now

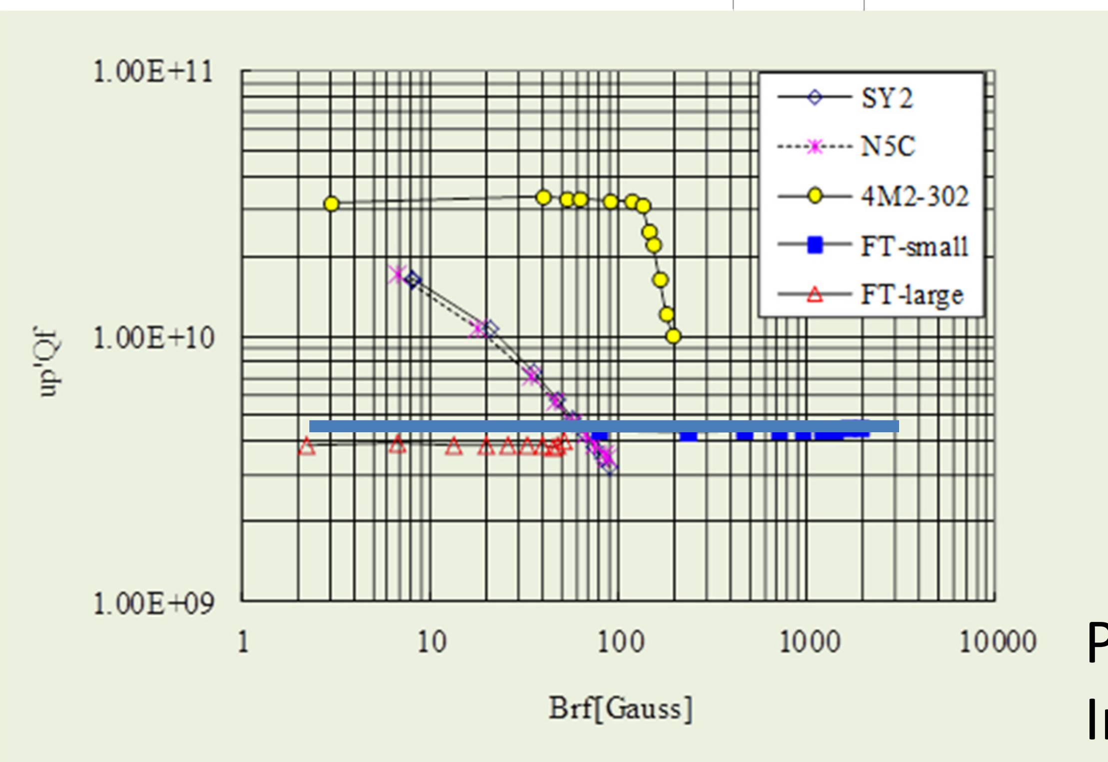
Recent Improvements



Packing factor(10 %)
Improvement of material(>5 %)

Recent Improvements



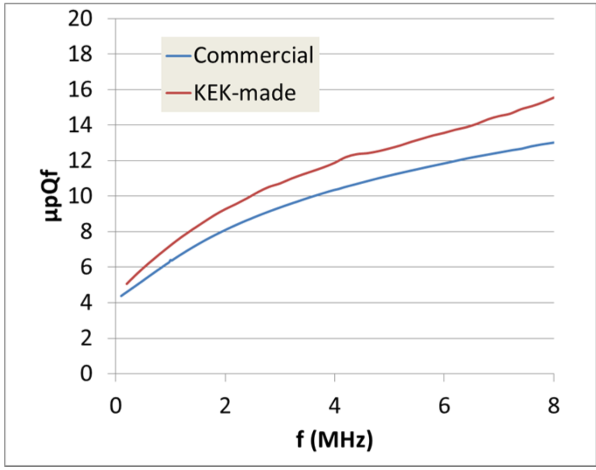


Packing factor(10 %)

Improvement of material(>5 %)

Further Improvements

- KEK-made is better than company-made, although small size core should be usually better.



Very good ! But, how ?

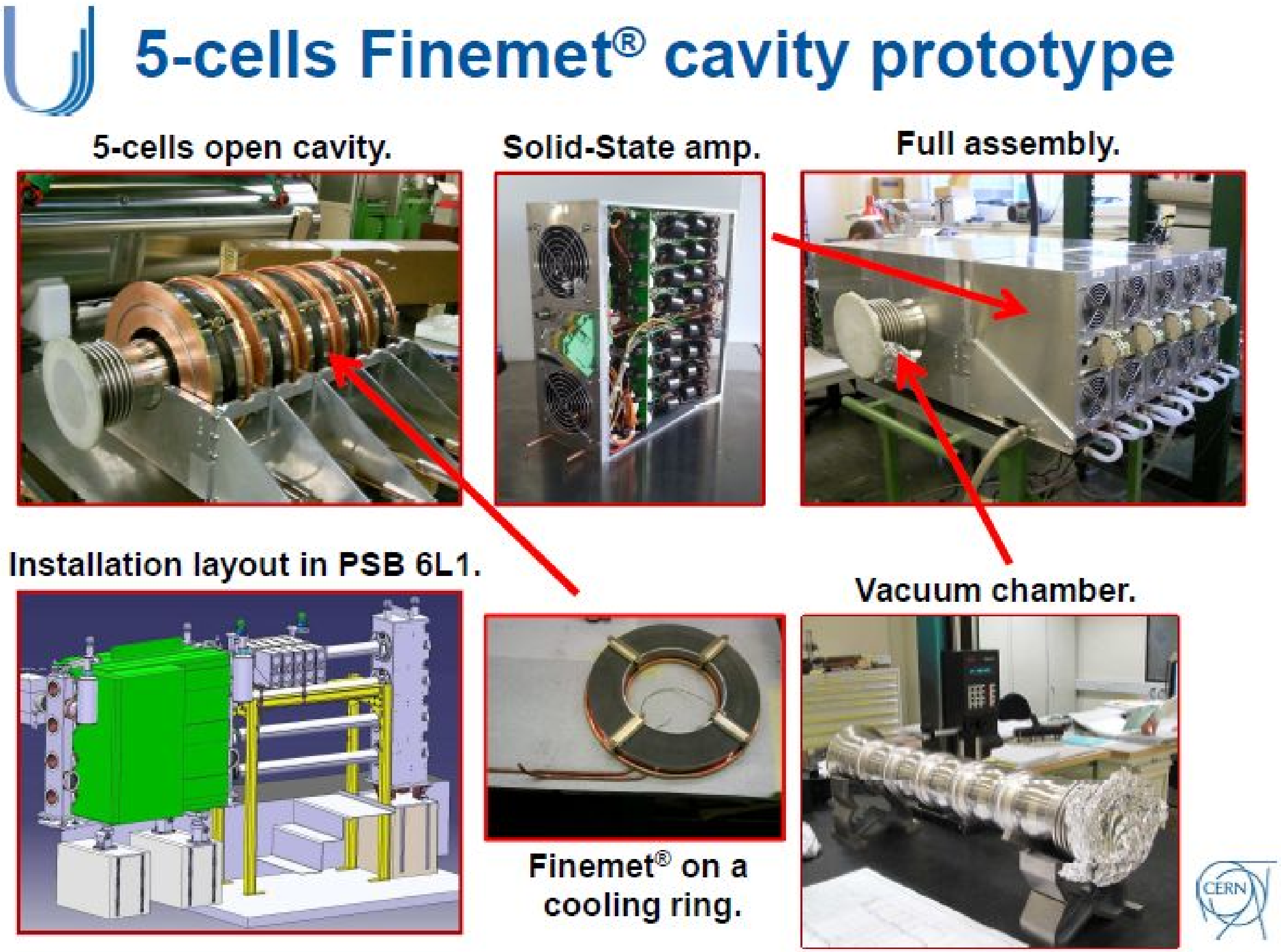
- BH-curve measurements + investigations suggest
  - Accidentally, we chose an (almost) optimized temperature and magnetic field pattern for our purpose to use a few MHz region.

  We may still have some possibilities for improvements.

- And, of course, thinner ribbon.

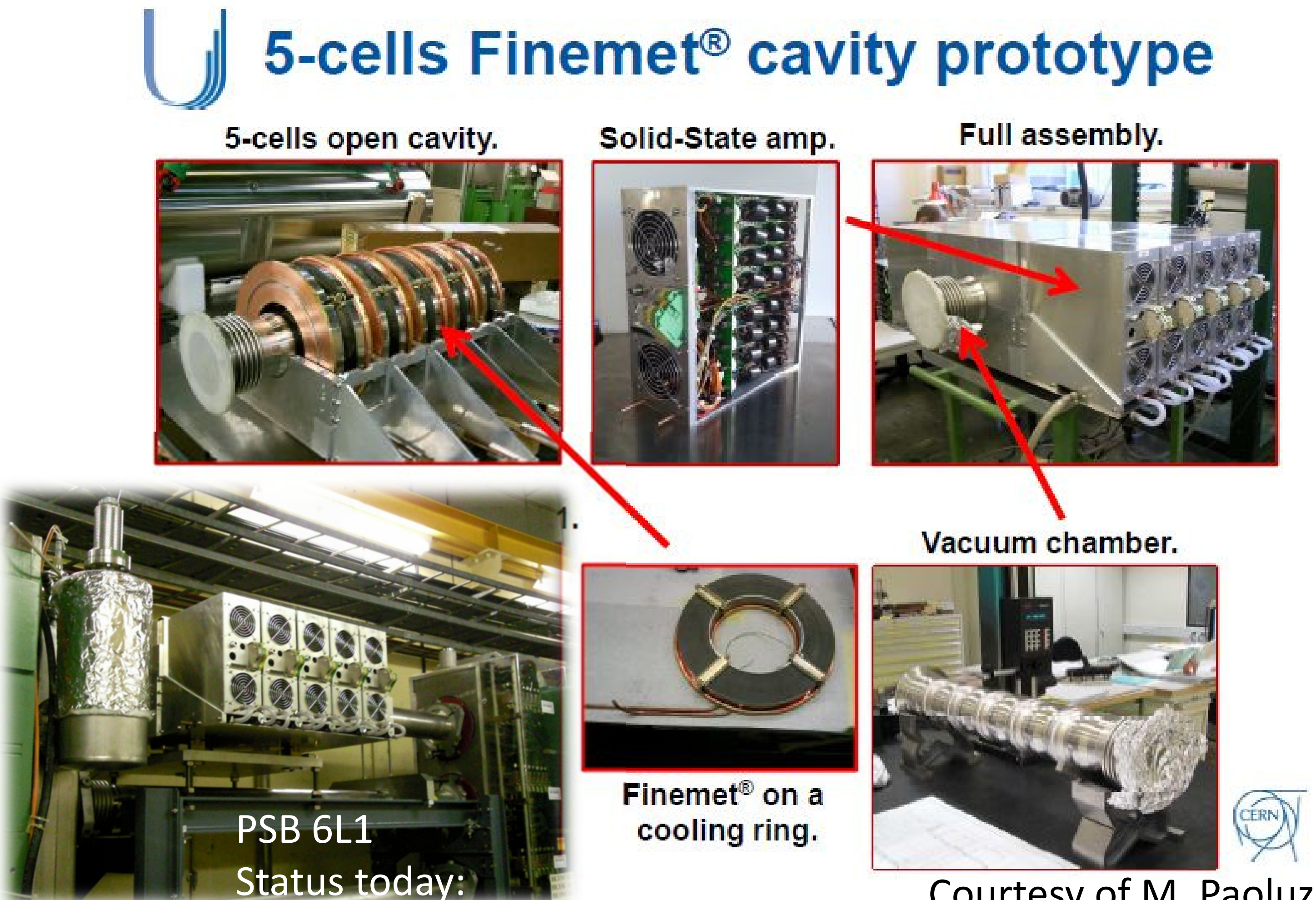
$$\text{Loss} \propto \frac{1}{R_{Hysterisis(material)}} + \frac{1}{R_{Eddy(thickness)}}$$

FT3L cavities for other accelerators : ~LHC injector upgrade~



Courtesy of M. Paoluzzi WEPEA065

FT3L cavities for other accelerators : ~LHC injector upgrade~



Courtesy of M. Paoluzzi WEPEA065

Summary

- FT3L cavity was installed in 2012 and has been used for operation of MR.
  – Low power loss and stable operation
- Replacement of all J-PARC MR cavities is planned in 2014-2016 for 1-Hz operation of MR.
  – Replacements of RCS cavities are also considered.
- New FT3L cavities will double the RF voltage per system.
- FT3L cavity technique will be also applicable for other accelerators: LHC Injector Upgrade & Med-Austron.

Posters : TUPME019,WEPEA019, WEPEA020, WEPFI021, WEPFI022