HIGH GRADIENT MAGNETIC ALLOY CAVITIES FOR J-PARC UPGRADE

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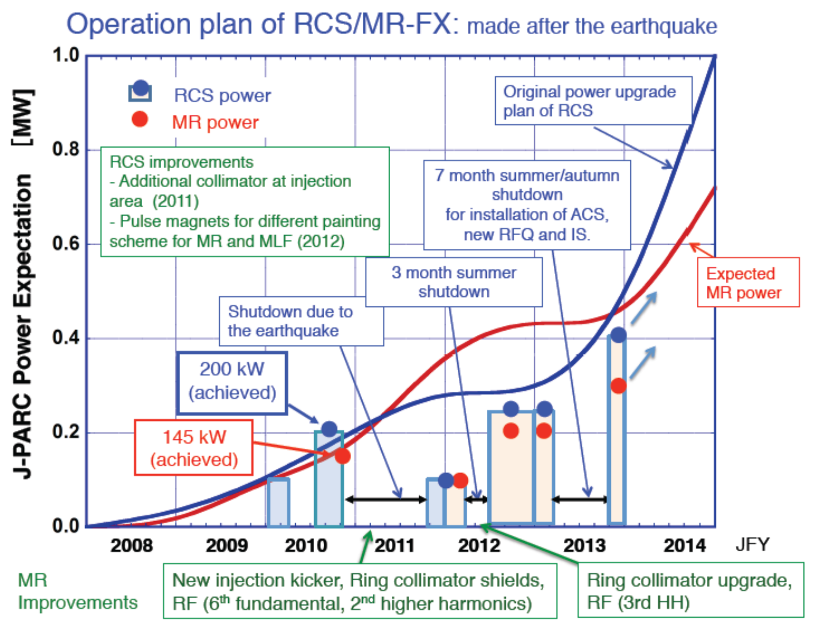
Contents

- Motivations to develop high gradient RF
- Development of high impedance core
- Next Steps
  - Plan of high power test
  - Design of high gradient cavity
- Summary

Upgrade Scenario of J-PARC

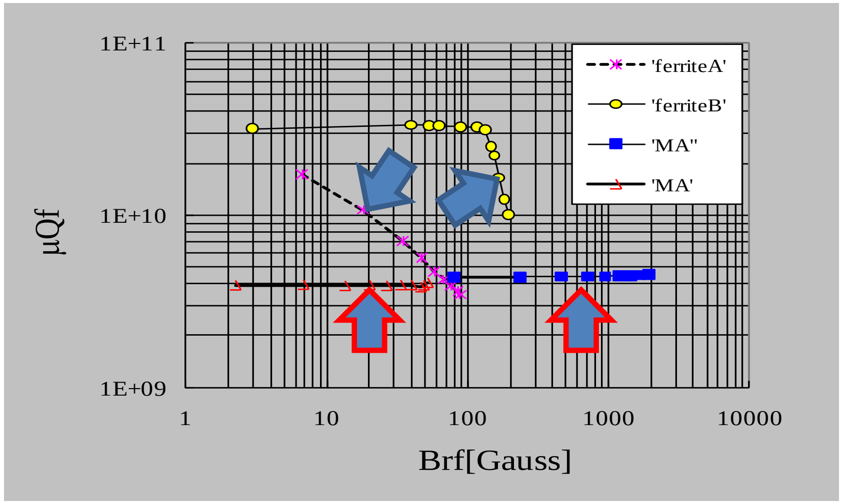
- Achieved to deliver;
  - 3 GeV 200 kW to MLF
  - 30 GeV 145 kW to FX(ν)
  - 30 GeV 5 kW to SX
- We use 11 MA (Magnetic Alloy) cavities for RCS, 6 for MR.
  - These cavities can generate higher field gradient than ferrite-loaded cavity.
- Machine stops by the earthquake. We plan to restart accelerator in this year.
- Key issues to increase beam power ,
  - RCS: Linac upgrade to 400 MeV
  - MR: Linac +RCS upgrade, intensity-up and rep. rate
- To increase rep. rate of MR, upgrade of RF system is required.
  - Rep. time: 3 sec -> 1.2 sec
  - RF Vol.: 210 kV -> 500 kV+200 kV (2nd)
  - # of cavity: 6 -> 12



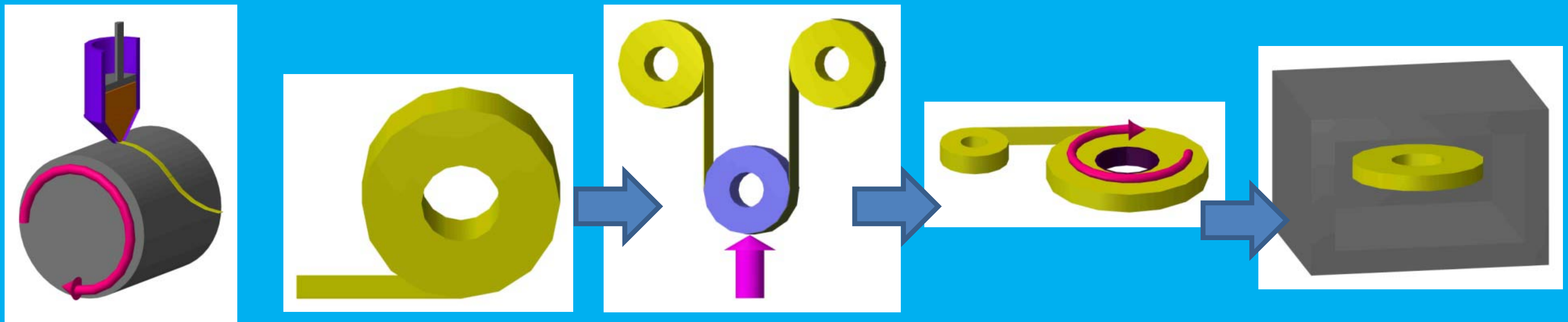
But, available spaces for RF are limited ! 12 systems. We need >50 % higher gradient compared to present MA cavity.

What is Magnetic Alloy (MA) ?

- In J-PARC, we use nano-crystalline Fe-based soft magnetic material, not amorphous.
- It has two advantages
  - Higher saturation field -> higher RF voltage, higher field gradient
  - Wide band (low Q) -> frequency sweep w/o tuning, simplifying LLRF



Production Procedure of MA



Casting & fast quenching → **Amorphous ribbons** → **SiO2 coating for acc. use** → **Making a large-size core** → **Annealing (Crystallization)**

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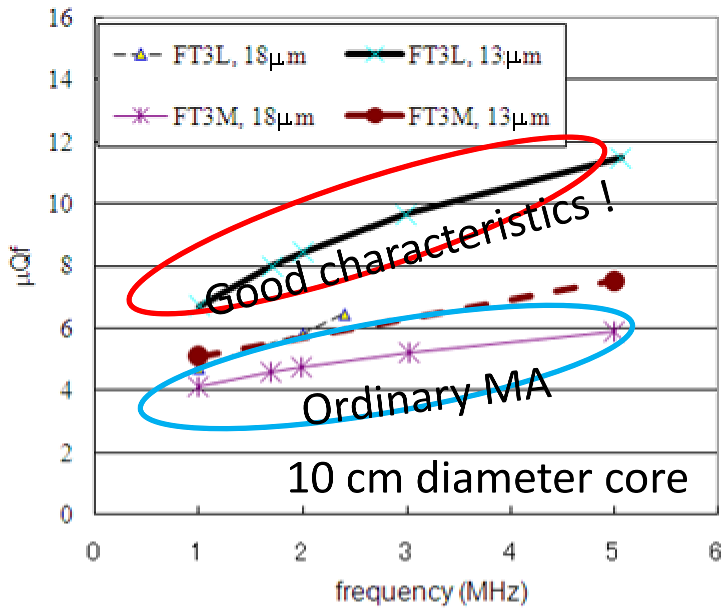
Improvements of Magnetic Alloy

Characteristic of MA depends on

- Material
  - Mixture of nano-crystalline and amorphous
  - Behavior of nano-crystalline
  - Magnetically stable axis (easy magnetized axis) vs. RF flux
- Thickness
  - Core is formed by winding thin ribbon.
  - Thinner ribbon reduces the eddy current loss
- Packing factor
  - Usually 70 %
  - Space between ribbons.
- Insulation
  - To reduce eddy current loss

If easy-magnetized axis of crystalline is perpendicular to RF flux,

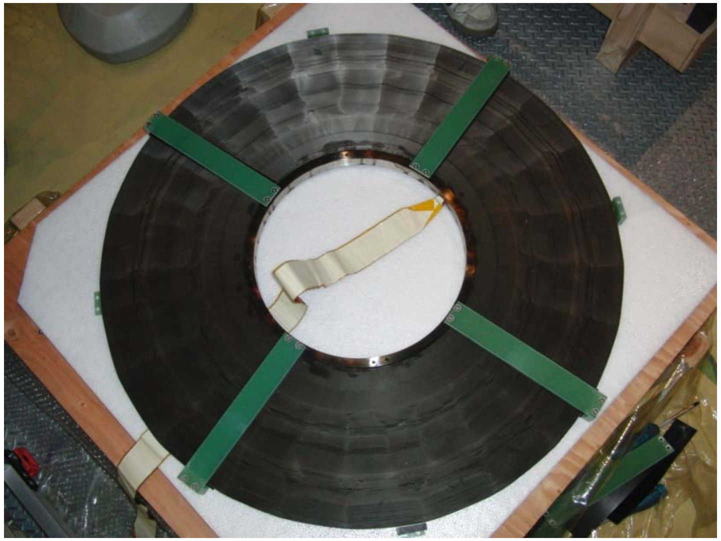


If easy-magnetized axis of crystalline is parallel to RF flux, it is bad for RF use.

Problem : There was no place to make a large-size high-impedance core. It was not sure if large core has same characteristics (Size Effects).

Development of High Impedance Core

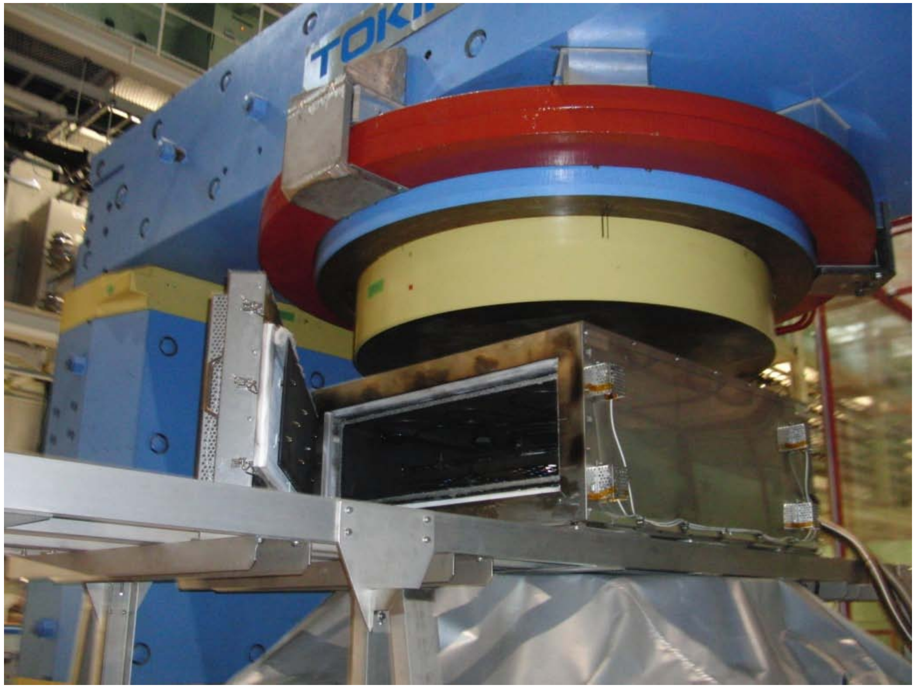
If no place to make large-size core, DIY.



MA(FT3L) core for RCS
(O.D. 85cm)

- We need;
  - Large-size oven to anneal
  - Large dipole magnet to install oven
- High energy experiment uses large-size magnets. “Rental” Magnet for proof-of-principle.
- In June and July after the earthquake, large size MA(FT3L) cores with high impedance were produced in J-PARC.

Production System of Large Core

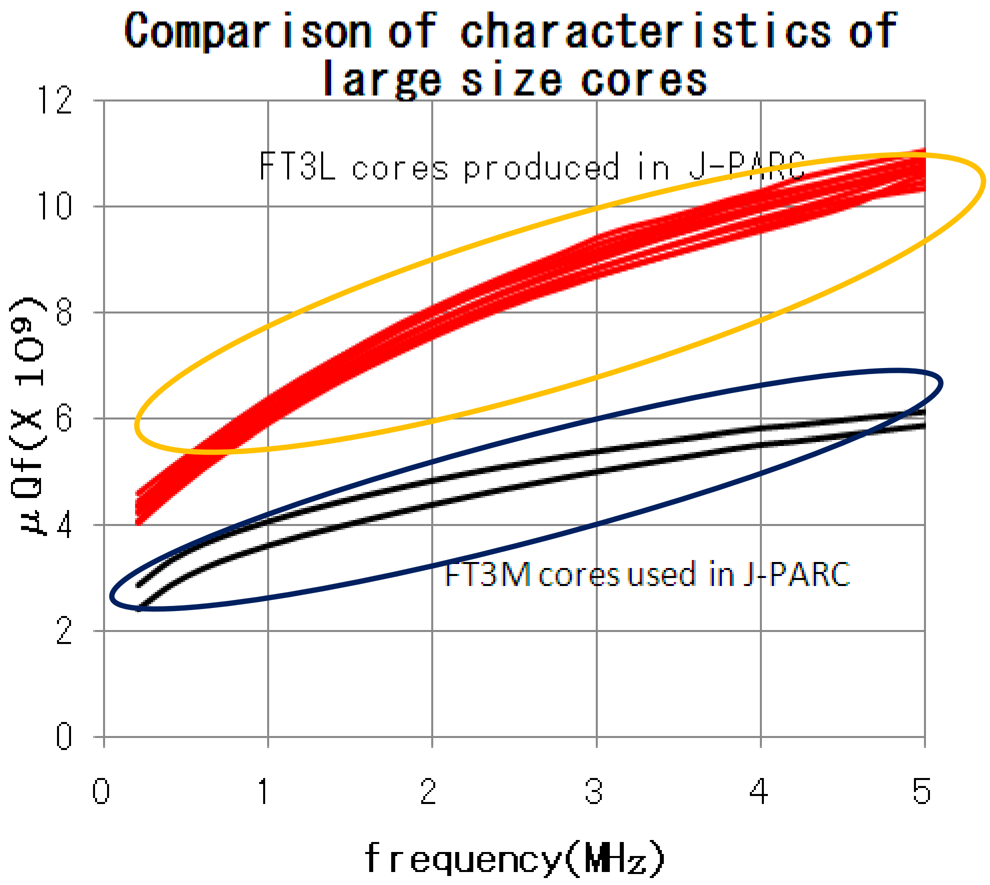


- Cores were produced using old cyclotron Magnet in J-PARC hadron experiment Hall.
- 12 MA(FT3L) cores were produced in June and July (one core/ day)

First annealed MA(FT3L) Core for MR and support frame

The area was controlled for safety

Characteristics of high impedance core



μQf is given by core impedance divided by a core form factor.

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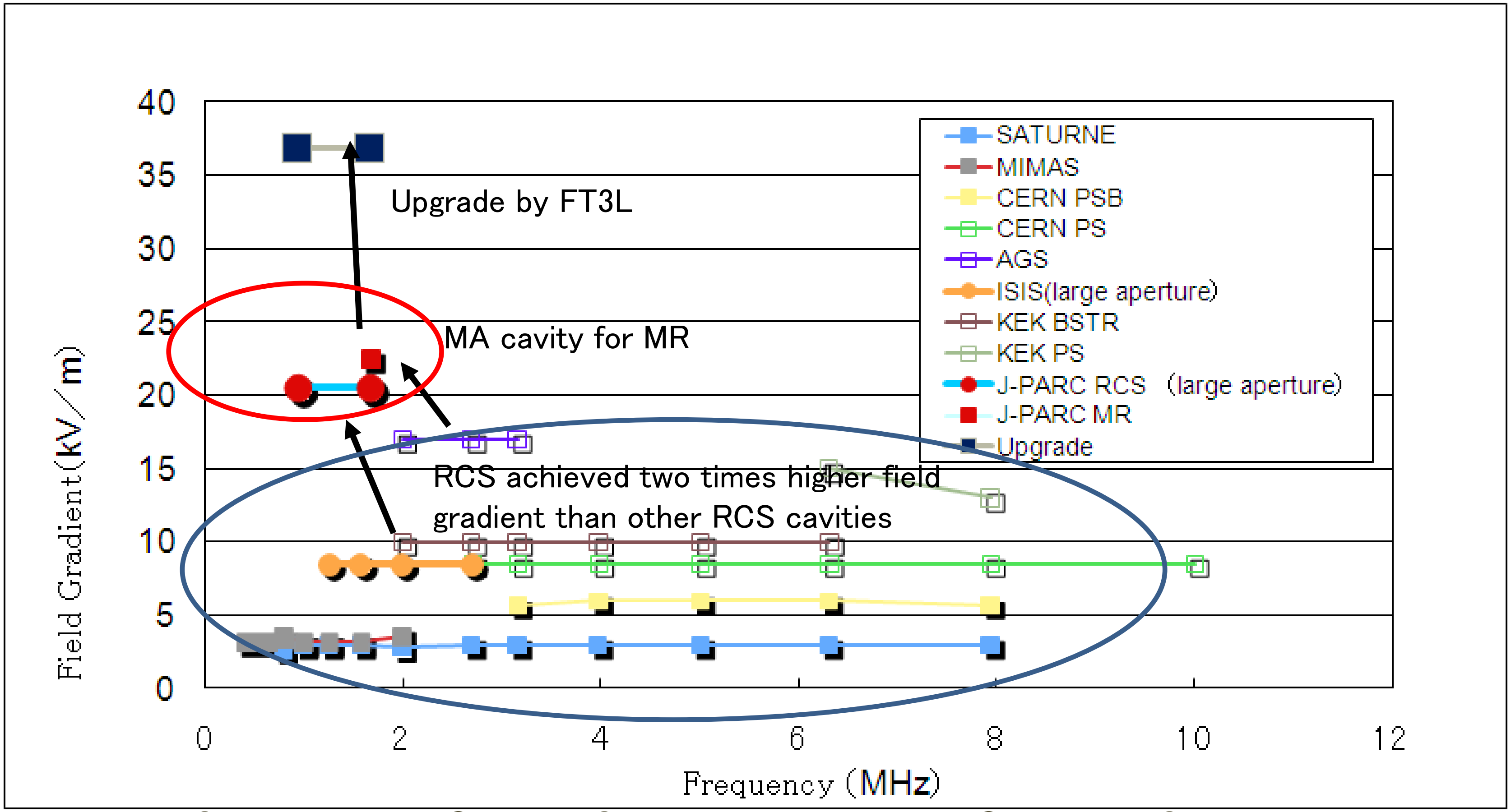
Next Step

- High Power Test of Cores.
  - FT3L cores will be processed for cut core configuration
  - Cores will be installed in a present cavity for high power test
- Engineering Design of High Gradient Cavity
  - 3 Gaps to 4 Gaps
  - Core thickness from 35 mm to 25 mm
  - Re-design cavity to fit thinner cores
- Mass production scenario
- To understand mechanism

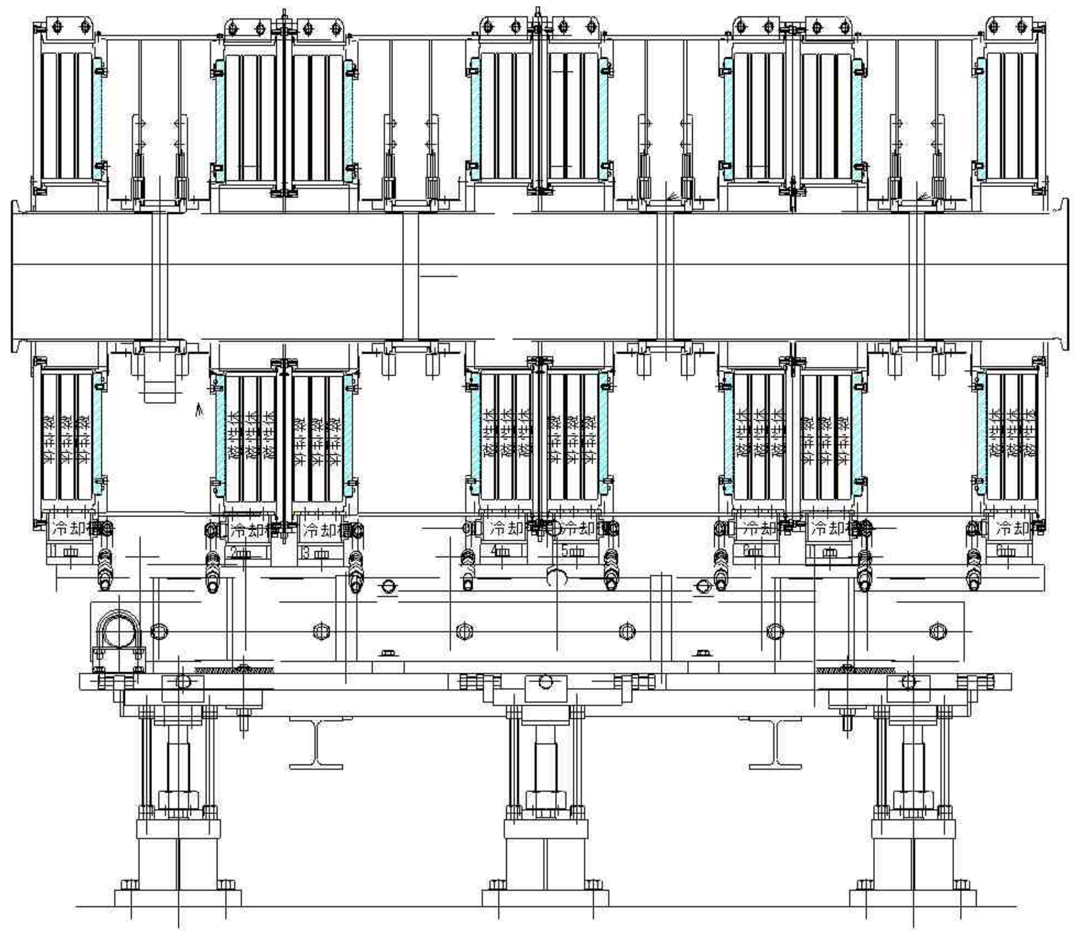
Field Gradient of RF Cavity for Proton/ion acceleration



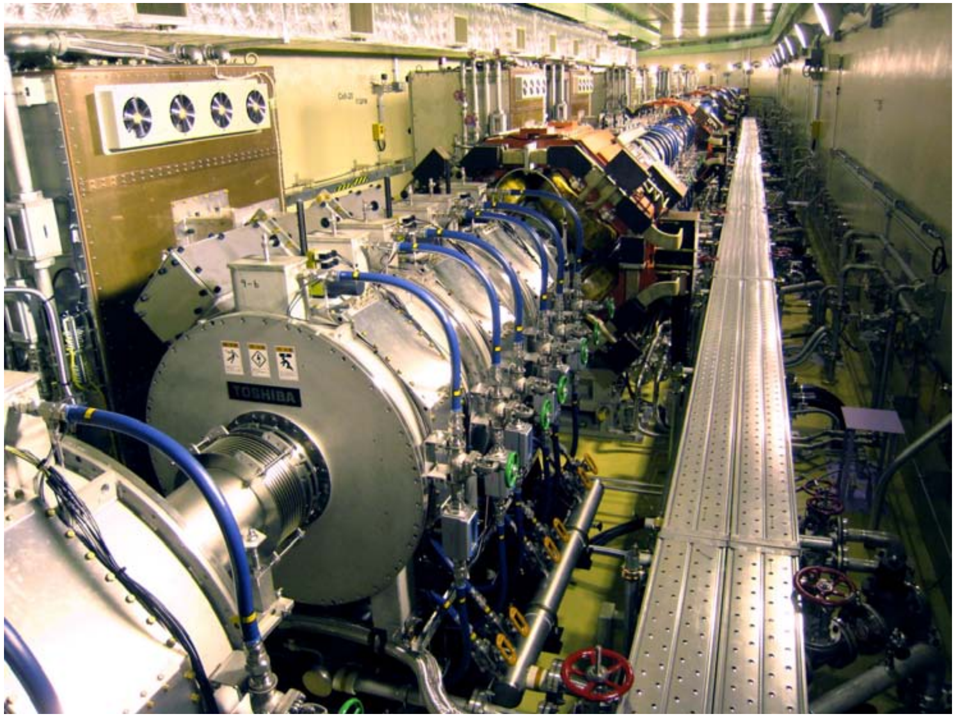
Development of FT3L large-size cores for accelerators will help to develop and improve other proton/ion rings.

Cavity Upgrade Scenario

- Core thickness: 35 mm->25mm
- Impedance is 40 % higher
- Present 3 Cell-cavity->4 Cell
- Direct water cooling
  - Flexible cooling scheme.

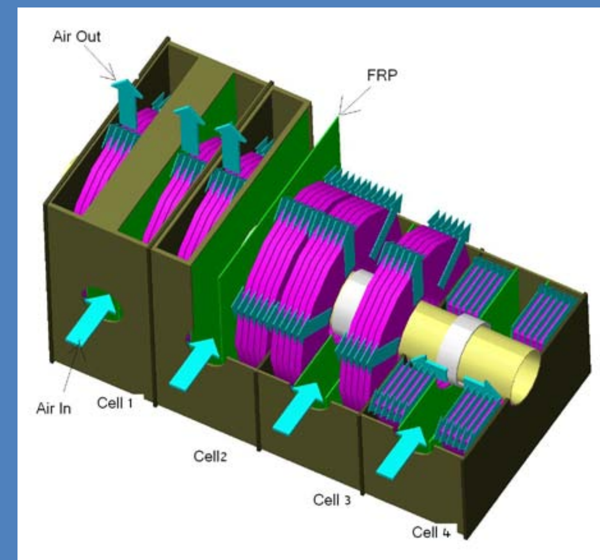


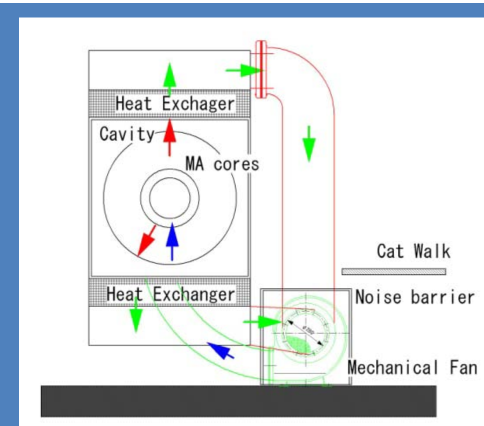
Alternative design of RCS Cavities



- Direct water cooling scheme is used for J-PARC RF.
- Alternative design using forced air cooling becomes possible by high impedance cores. “Air cooling” cavity also fits present space.

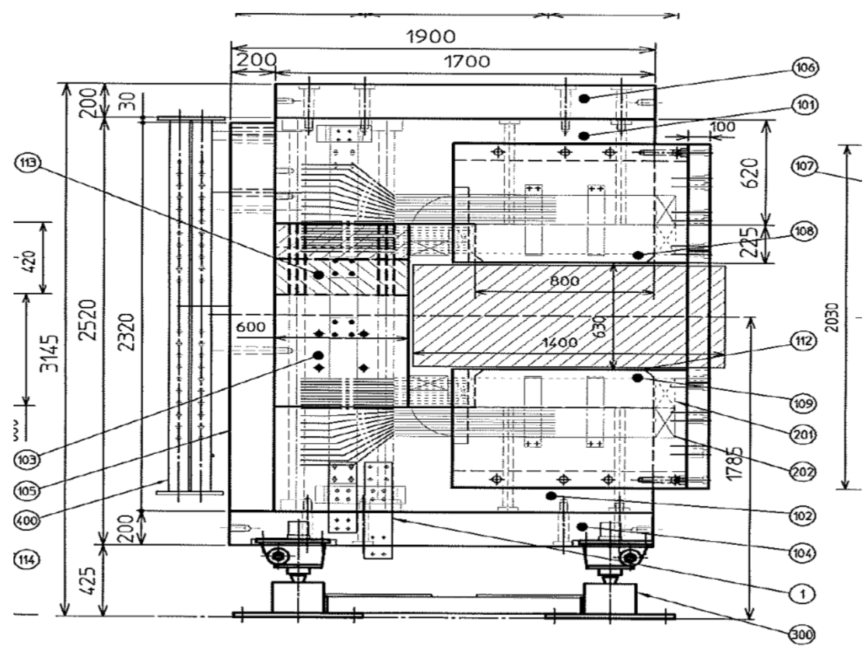
Air cooling scheme





Scenario for mass production

- “Rental” Period of Cyclotron Magnet ended!
  - Production system was disassembled.
- Another magnet has been arrived to KEK.
- Magnet will be modified and mass production system will be assembled in J-PARC next FY to fit J-PARC upgrade scenario.

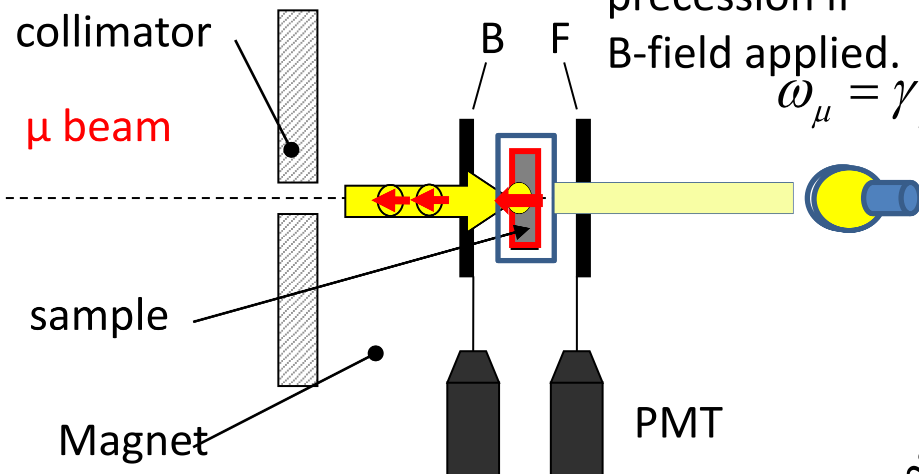


μSR (muon spin rotation, relaxation, resonance)

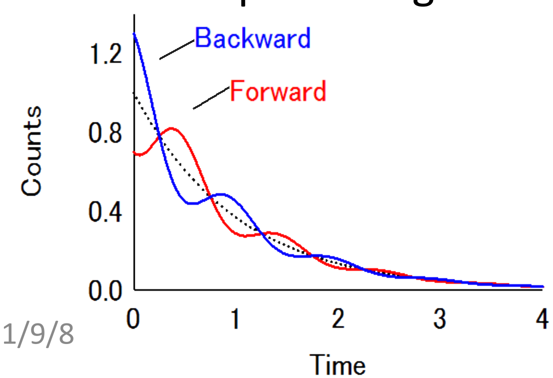
<u>Spectrometer</u>

Muon makes precession if B-field applied.

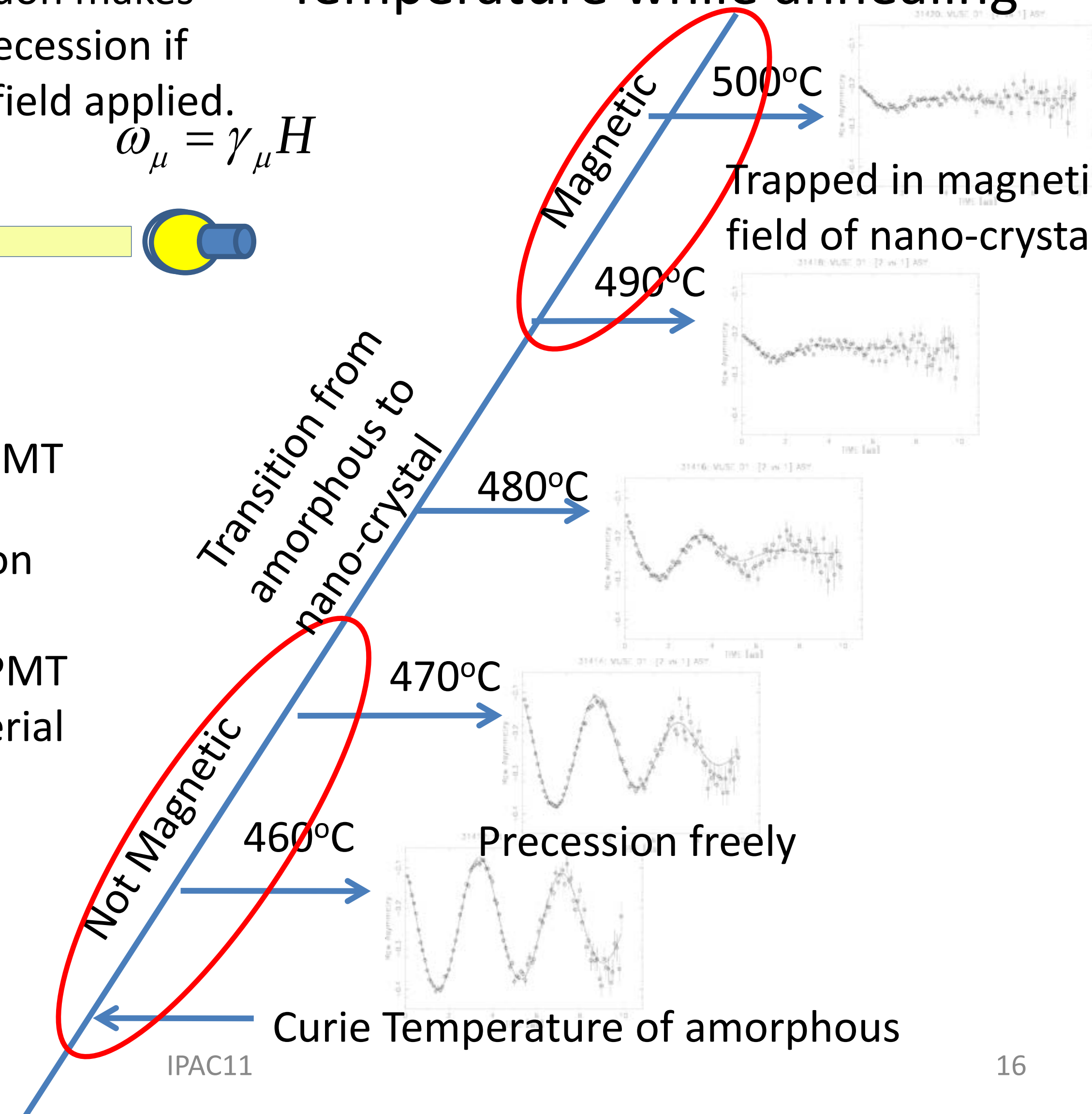
$$\omega_\mu = \gamma_\mu H$$



As the direction of decayed positron depends on muon spin, forward/backward asymmetry of PMT indicates muon spin in target material

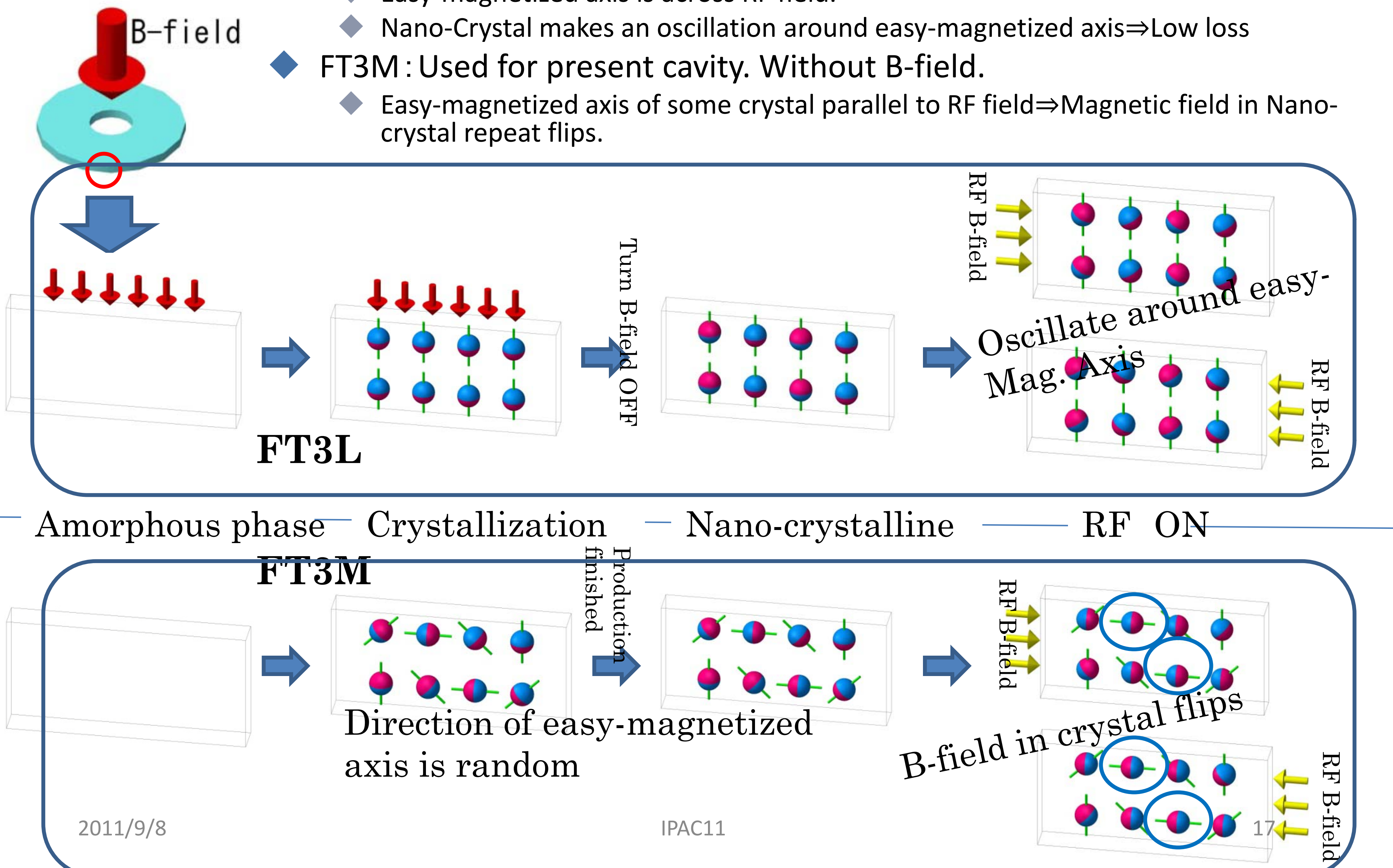


Temperature while annealing



Mechanism of High Impedance

- FT3L: Annealed in B-field ⇒Easy-magnetized axis is aligned
  - Easy-magnetized axis is across RF field.
  - Nano-Crystal makes an oscillation around easy-magnetized axis⇒Low loss
- FT3M: Used for present cavity. Without B-field.
  - Easy-magnetized axis of some crystal parallel to RF field⇒Magnetic field in Nano-crystal repeat flips.



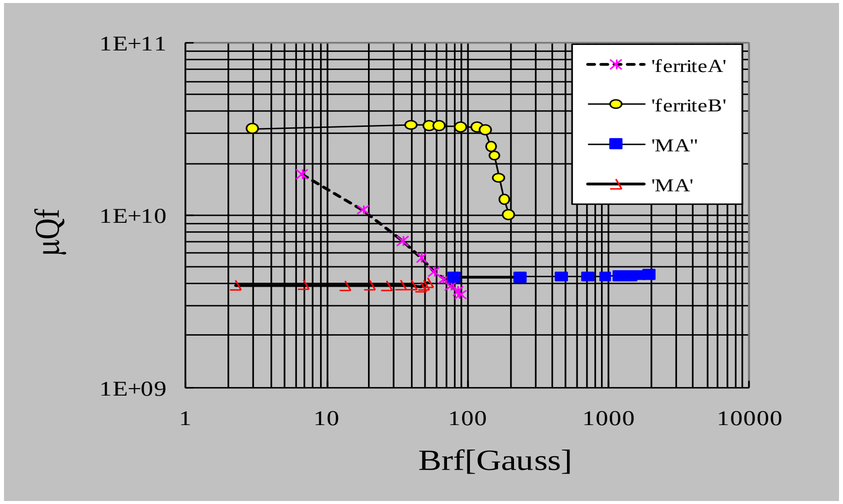
Summary

- We successfully made large-size high-impedance MA(FT3L) cores for RF cavities.
- Using these cores, a higher gradient cavity is designed.
- High gradient cavity is necessary to achieve design intensity of J-PARC. We will use 6 old and 6 FT3L cavities for 1.2 sec MR cycle. Replacement of 1-2 old cavities of RCS will be helpful for 1 MW.
- These high impedance cores might be also useful to upgrade other proton machines and/or to built new compact accelerators.

Limitation of RF voltage

In Proton machine,

- RF voltage is limited by characteristics of magnetic material loaded in cavity.
- For a ferrite-loaded cavity, saturation of magnetic cores and heat loss were the main problems.
- For a Magnetic Alloy-loaded cavity, heat loss is the main problem.



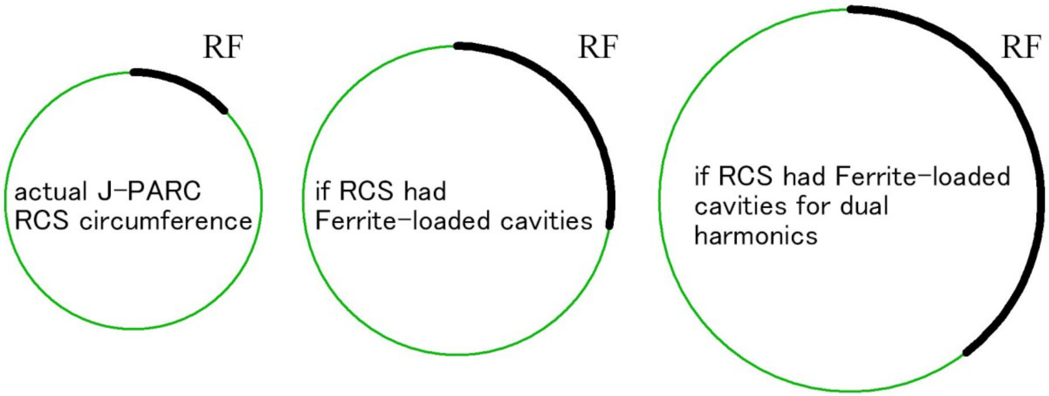
Using MA cavity, RCS becomes compact !

For high-rep. MR,

high-gradient

MA cavity can solve shortage of space.

Length ratio for RF stations in an accelerator



To increase RF voltage, improvement of material is effective !