Review of MA Cavity

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KEK

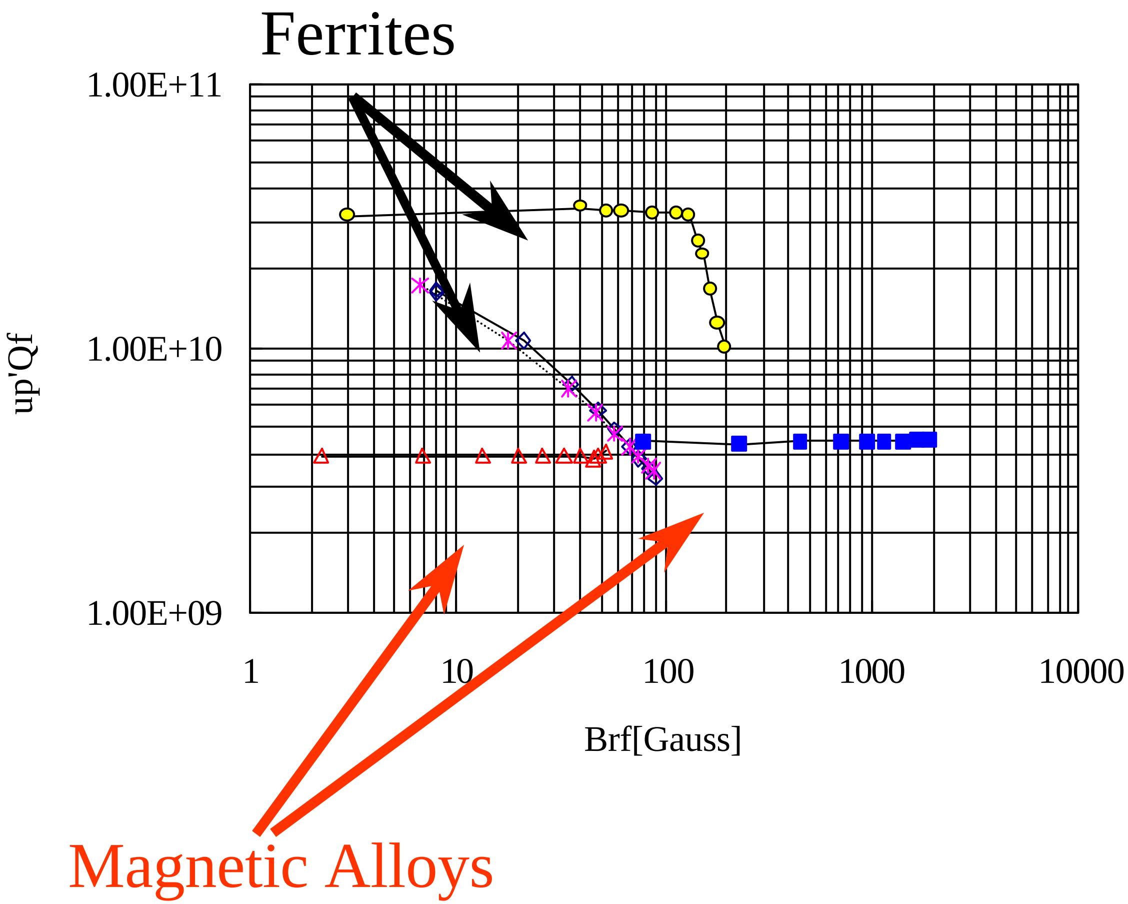
Contents

- Characteristics of Magnetic Alloy
- History of MA Cavity
  - 4 Generations
- Barrier Bucket
- Making of MA Cavity
- Unsolved Problems
- Summary

Magnetic Alloy (MA)

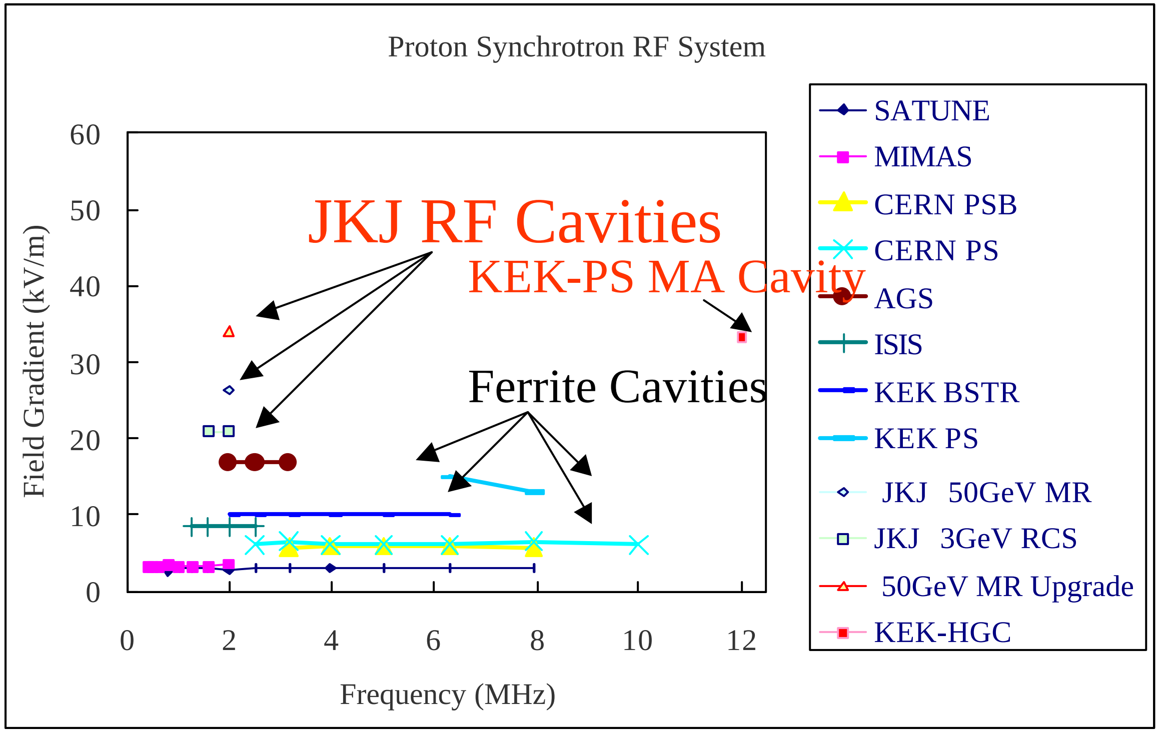
- Thin Tape , 18 μm
  - Large core(<4m)
  - Rectangular Shape is possible to make, Thickness -35mm (50mm in future)
- High Field Gradient
  - Voltage limit: Brf <Bsat. (1T) , Voltage per layer < 5 V
- High Curie Temperature
- Stable characteristics: Good for Beam Loading Compensation
- Large permeability(about 2000 at 5MHz)
- Original Q value is small(0.6).
- High Q is possible by cut core configuration

High Gradient



JKJ RF Cavities

Field Gradient of Cavities for Proton Synchrotrons



Why High Field Acceleration

3 GeV RCS

Fast cycling:25 Hz

Needs high voltage:450 kV

Number of Bunches: 2 by N-users

Low Frequency:0.9-1.7MHz

Circumference is limited.

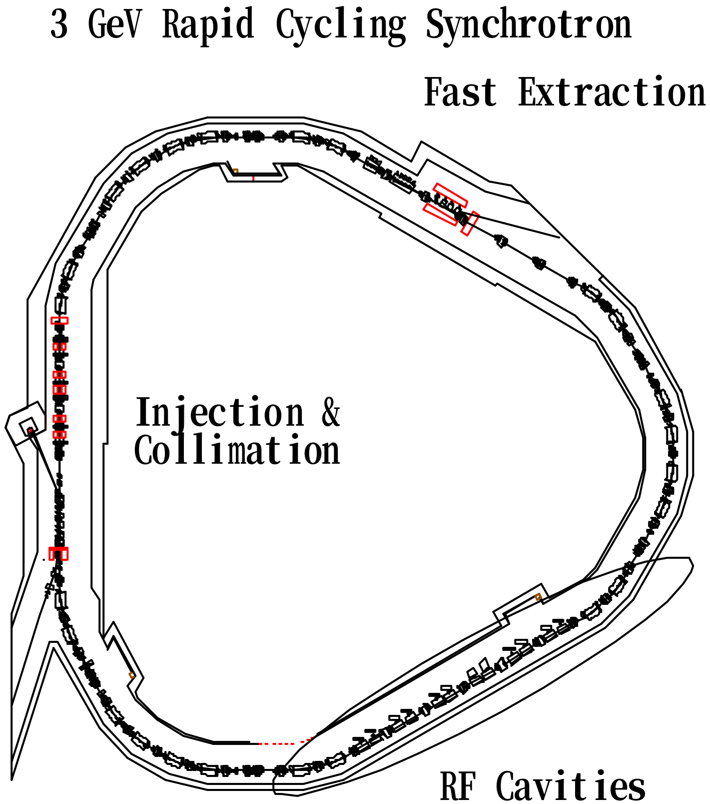
Needs spaces for extraction of 3 GeV beam with large beam size, injection and collimation.

50 GeV MR

Needs high voltage: 280-600 kV

Needs space for 2nd Harmonic system

Like 3 GeV RCS



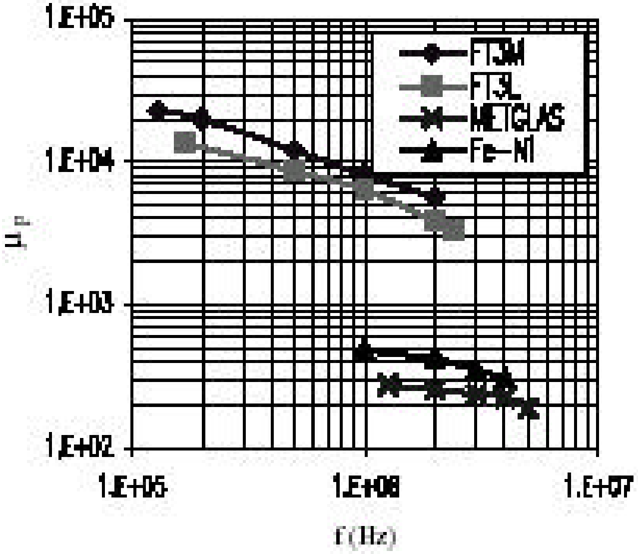
Large Permeability and Low Q

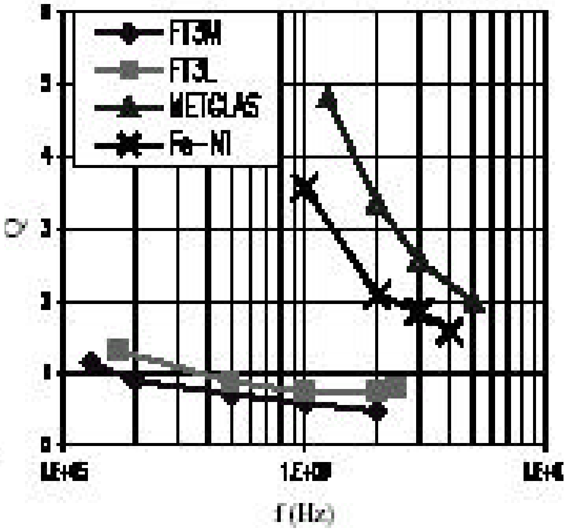
- Advantage
  - Shunt Impedance is high.
  - Wide Band System
    - Acceleration w/o Tuning System(Cost & Stability)
    - Bunch Manipulation (Barrier, Dual H and SawTooth)
    - Easy to compensate beam loading(Feed Forward)
- Disadvantage
  - Number of harmonics to be compensate.

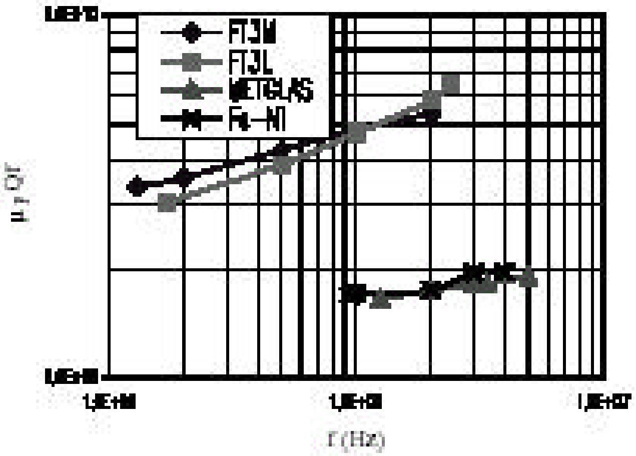
Cut Core and High Q

- Loss (Shunt Impedance) is not reduced.
- Inductance is reduced.
- Advantages
  - Reduce Harmonic to be compensated.
  - Minimize Bandwidth to cover the RF frequency.
  - Still easy to compensate Beam Loading
- Disadvantages
  - Need Another System for manipulation.
- JKJ-RCS System(Q=2-3)
  - Still Dual Harmonic by single system is possible
- JKJ-50 GeV MR : Q~10

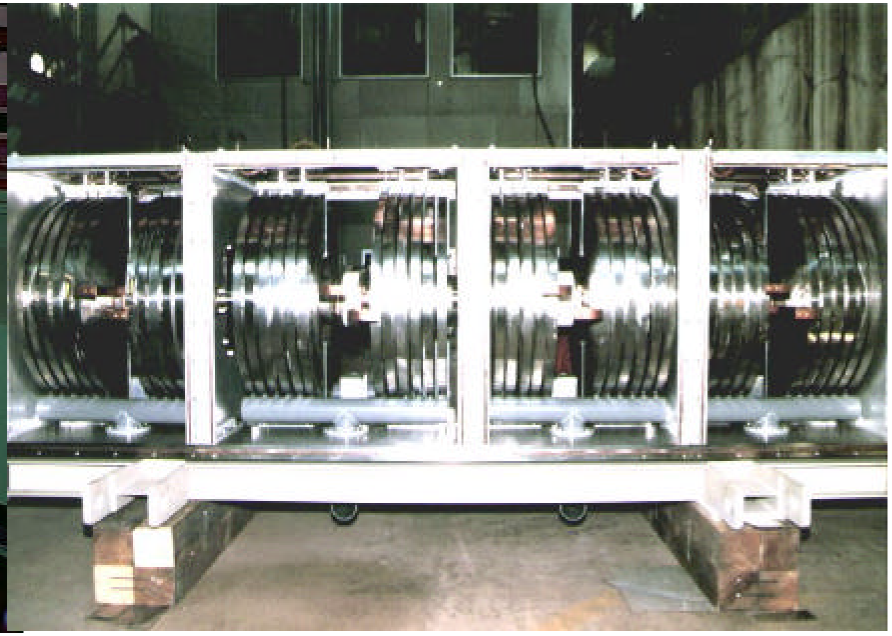
Other MAs


FT3M
FT3L
METGLAS
Fe-Ni
1.E+05
1.E+04
1.E+03
1.E+02
μ p
1.E+05
1.E+06
1.E+07
f (Hz)


FT3M
FT3L
METGLAS
Fe-Ni
Q
f (Hz)

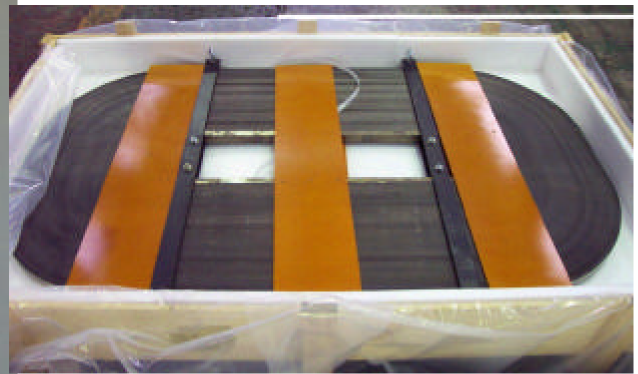

FT3M
FT3L
METGLAS
Fe-Ni
f (Hz)

History of MA Cavity



First Generation :
Wide Band and Air Cooling
Barrier Bucket Cavity installed in AGS (US-Japan Collaboration)
2.6m, 40kV, 6% duty, driven by 30kW tubes

PoP FFAG Cavity

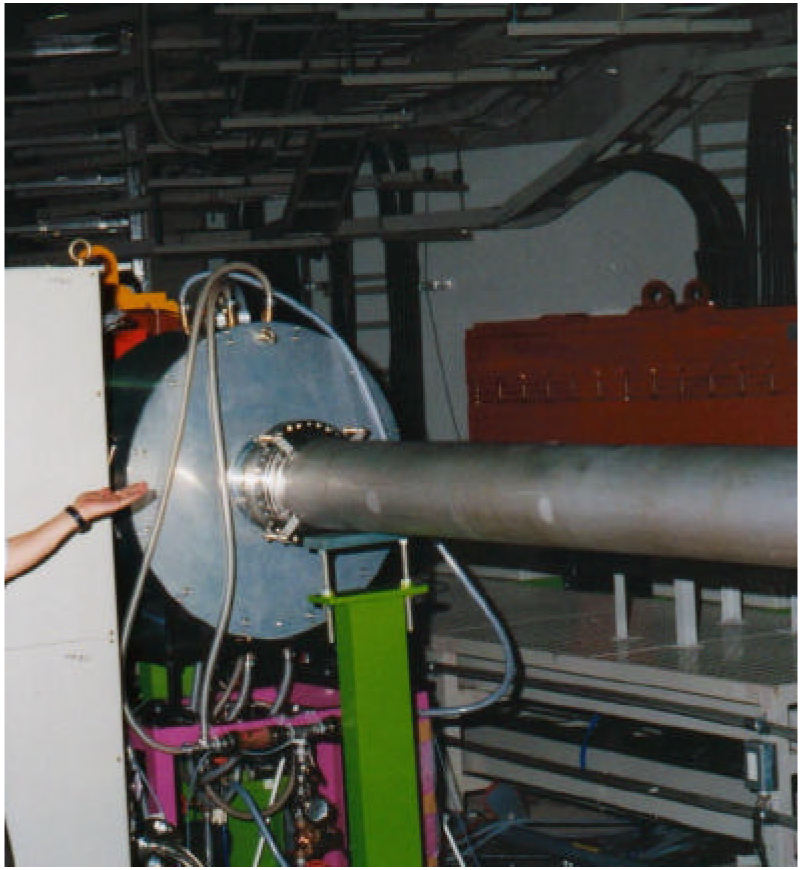


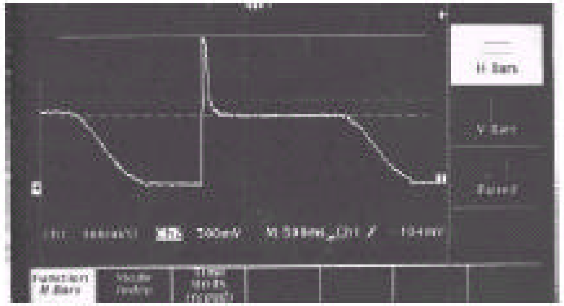
Proton beam was successfully accelerated.
And two medical Synchrotrons are using same type

The Second Generation:
Wide Band and Water Cooling

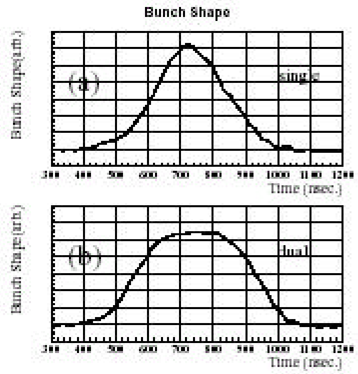
HIMAC Cavity: 50cm, 20kV, water cooling driven by 150kW tubes

5kV, CW, driven by 30kW tubes.

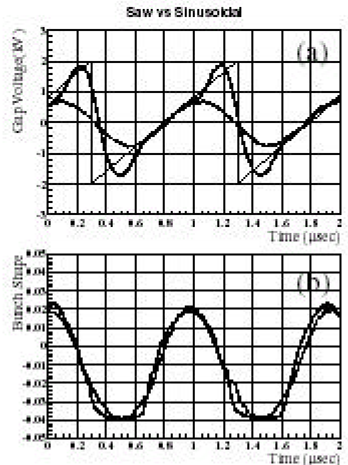




Beam Acceleration

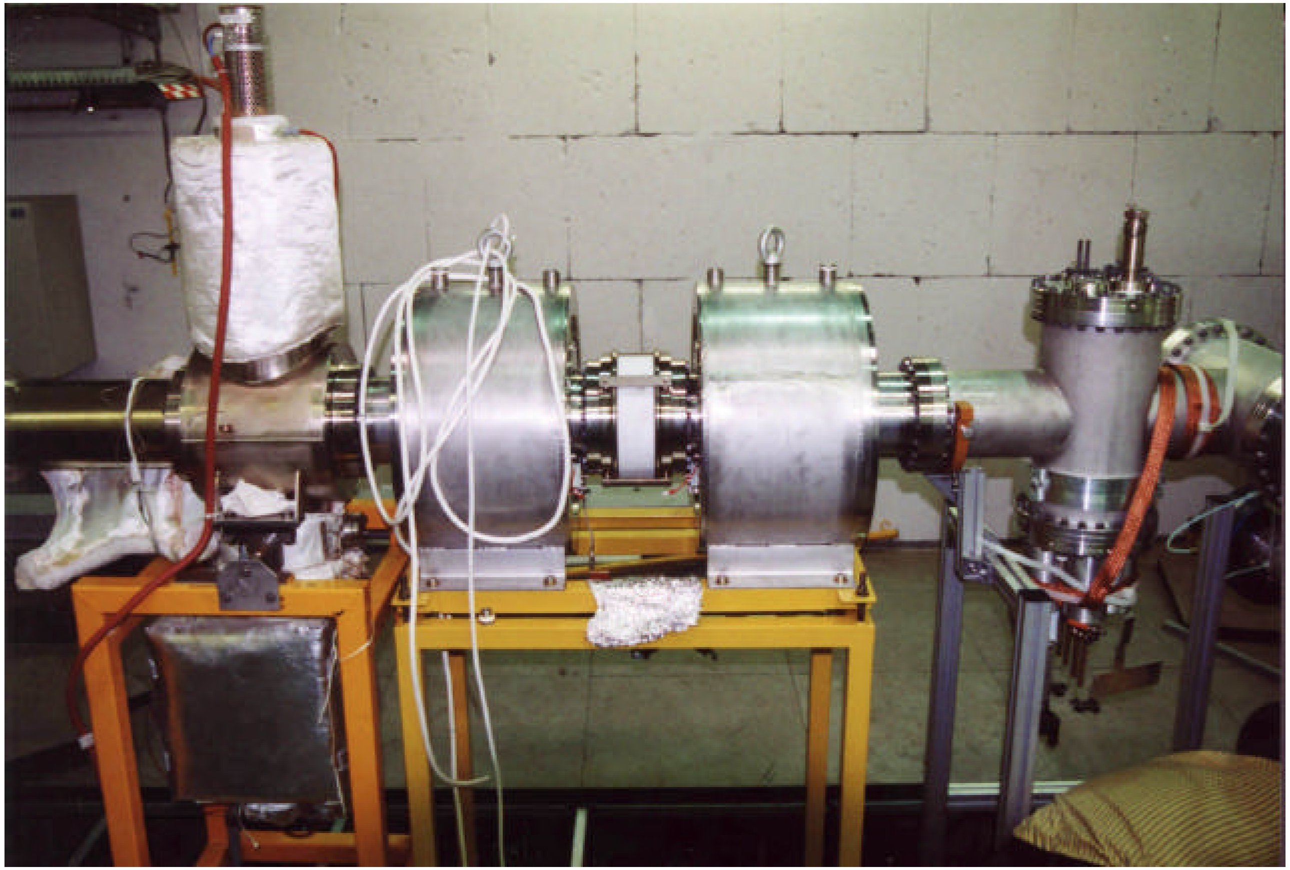


Dual H Cavity



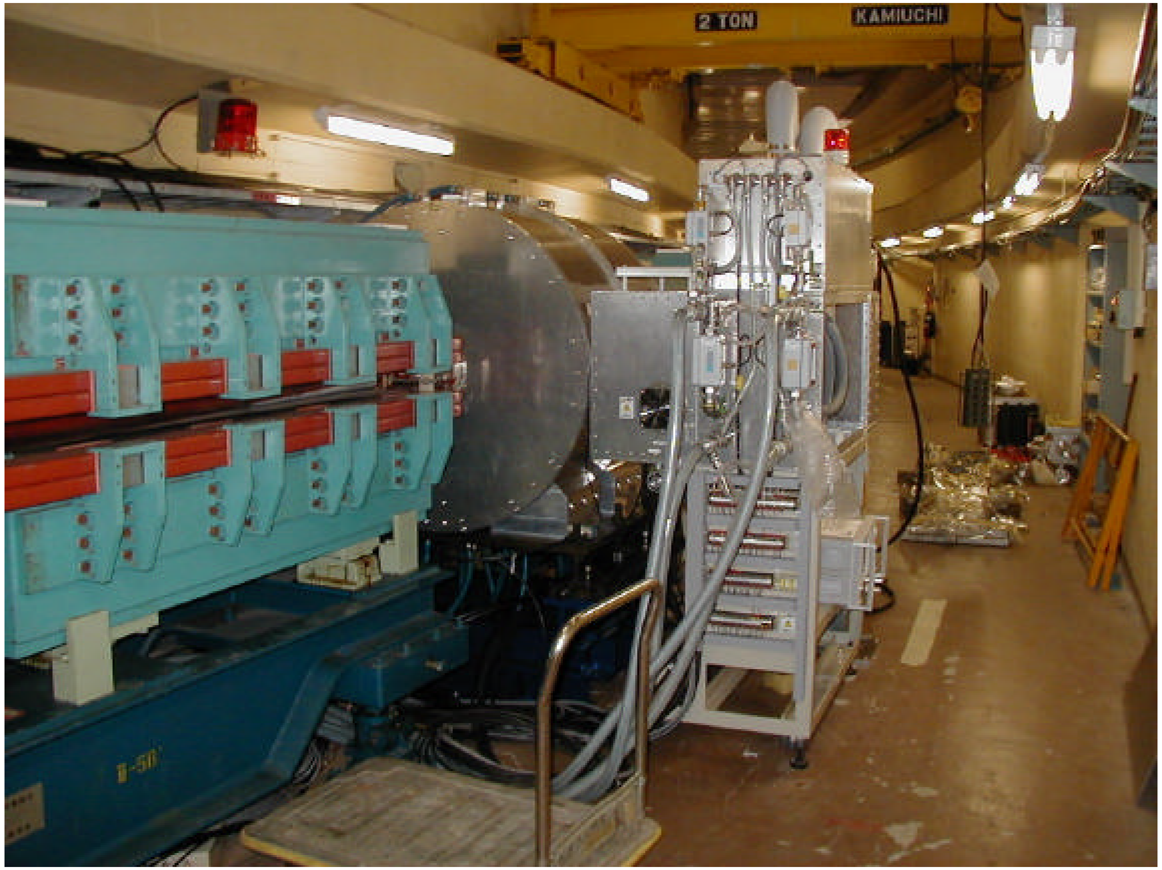
Saw Tooth RF

The Second Generation:
Wide Band and Water Cooling
COSY Cavity:



From A. Schnase

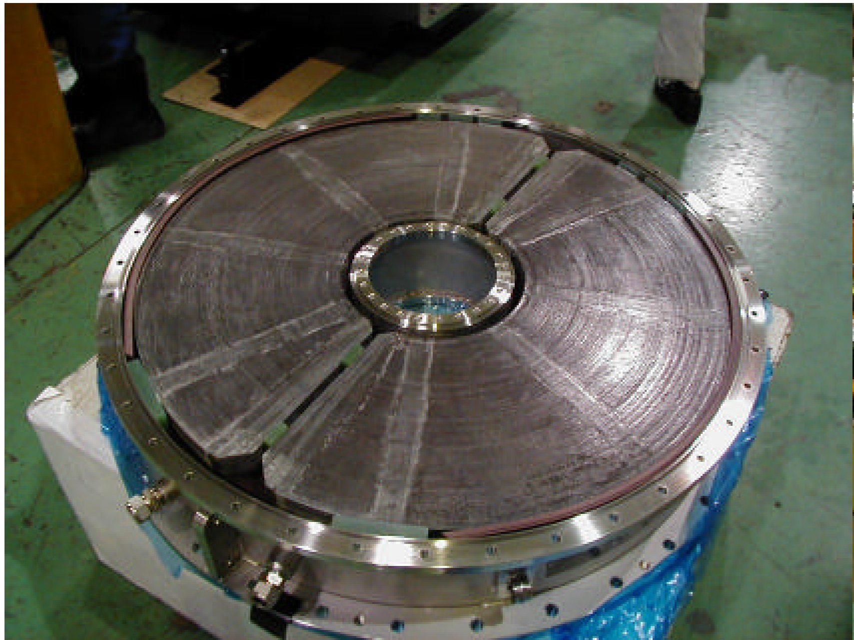
The Third Generation:
Narrow Band and Direct Water (or Coolant) Cooling
KEK-PS MA Cavity: 90cm, 30kV, Cut Core, Fluorinate Cooling



The Third Generation:

JKJ RF Cavity(Direct Cooling Type): 1.7m, 60kV, Cut Core

Water cooling, driven by 600kW tubes

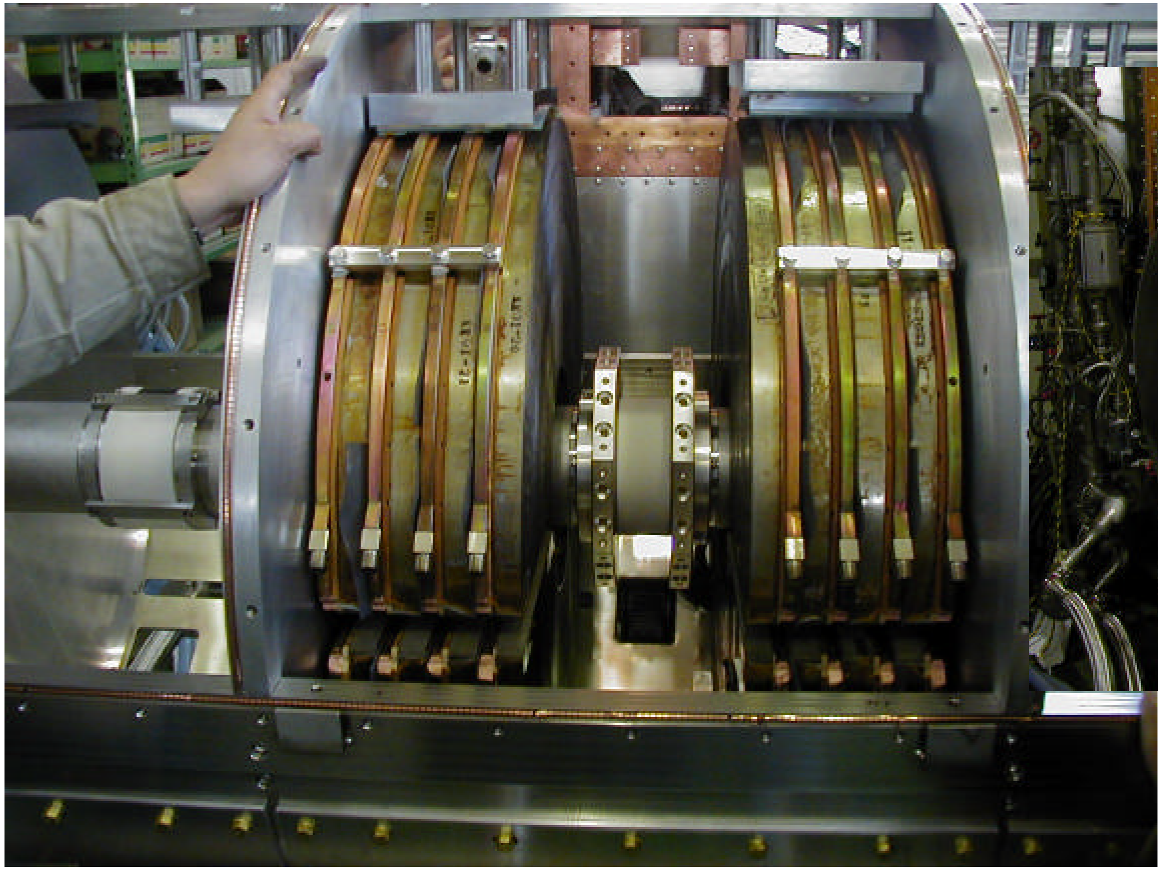


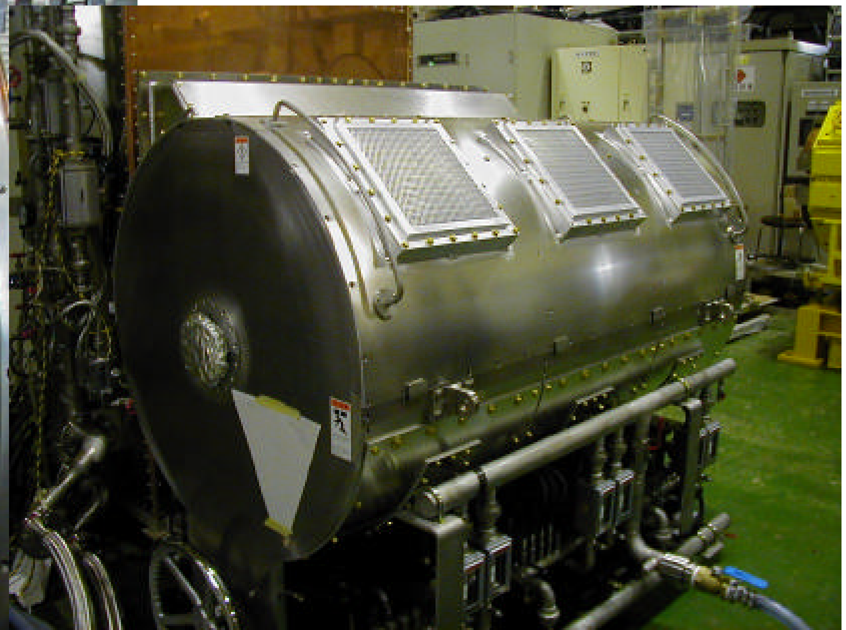
The Fourth Generation

Narrow Band and Indirect Cooling

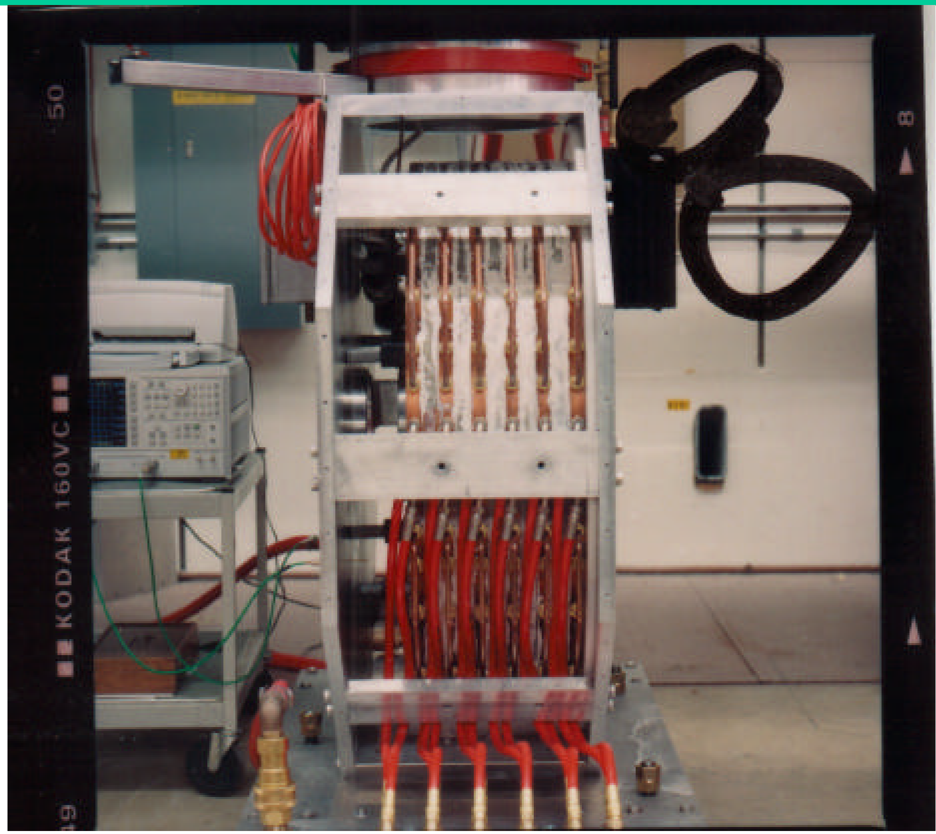
JKJ RF Cavity(Indirect Cooling Type): 1.7m, 60kV, Cut Core

Water cooling, driven by 600kW tubes



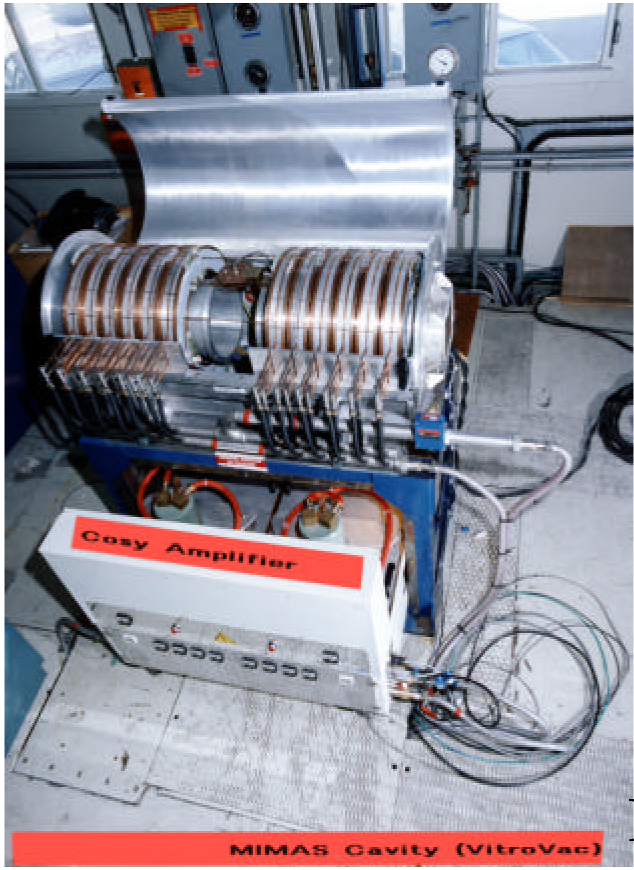


The Fourth Generation
Narrow Band and Indirect Cooling
FNAL MA Cavity (US-Japan Collaboration)



From Wildman, FNAL

The 0th Generation
Wide Band and Indirect Cooling (?)



From A. Schnase

Barrier Bucket Experiments

- Two Barrier Cavities for Experiment
  - Ferrite and MA cavities
- Each cavity generates single sine wave of 40 kV at rep. rate of 351 kHz.
- Five bunches from Booster were accumulated and 3×10^{13} was stored w/o loss. Barrier bunch was generated.
- Longitudinal Emittance Growth by factor of 3 was observed. It was caused by Mismatch, mainly.
- Beam Loading on MA cavity was compensated.
- Beam Loading on Ferrite Cavity and overshooting Voltage of MA Cavity disturbed smooth debunching. After BB experiment at AGS, the overshooting problem was solved by adding H=1 and 2 voltage.

Barrier Bucket Experiment

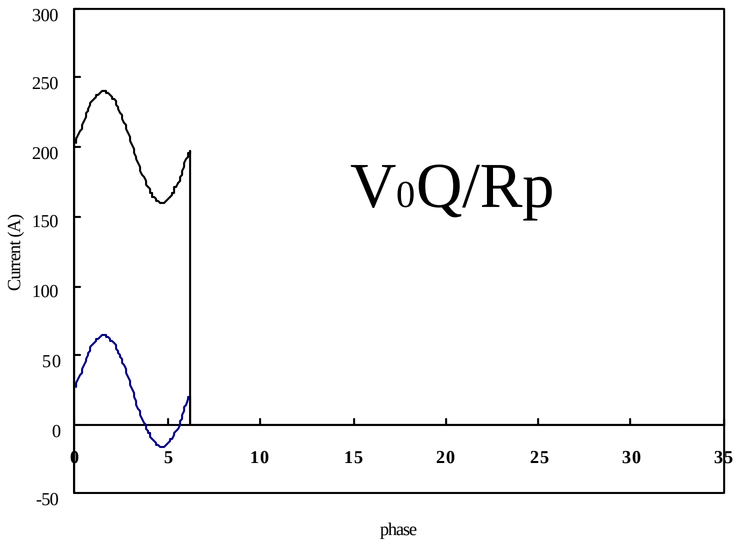
- Use two cavities:
  - KEK MA-loaded cavity (2.6m, 2X30kW tubes) KEK made for this experiment
  - AGS ferrite cavity (2.6m, driven by 600kW tube) .

$$V(t) = \begin{cases} V_0 \sin wt, & if\ 0 < wt < 2p \\ 0, & otherwise \end{cases}$$

$$I(t) = \frac{V(t)}{R} + \frac{1}{L}\int_0^t V(t')dt' + C\frac{dV(t)}{dt}$$

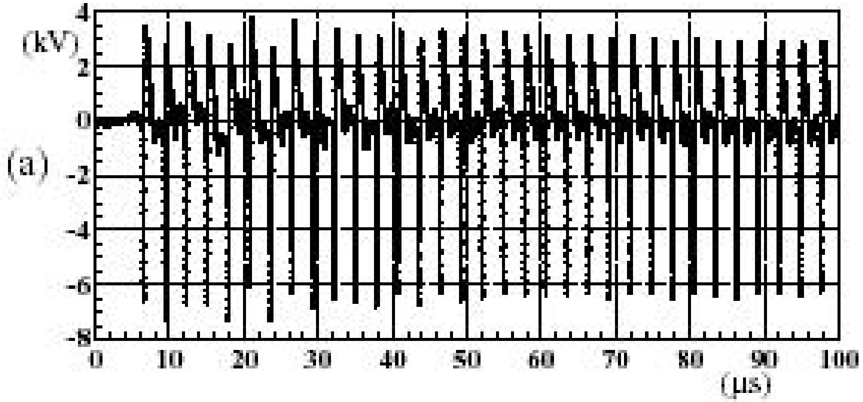
$$= \begin{cases} \frac{V_0}{wL} + \frac{V_0}{R_P}\sin wt + V_0 \cos wt(wC - \frac{1}{wL}), & if\ 0 < wt < 2p \\ 0, & otherwise, \end{cases}$$

$$= \begin{cases} \frac{V_0}{R_P}(Q + \sin wt) + V_0 \cos wt(wC - \frac{1}{wL}), & if\ 0 < wt < 2p \\ 0, & otherwise, \end{cases}$$

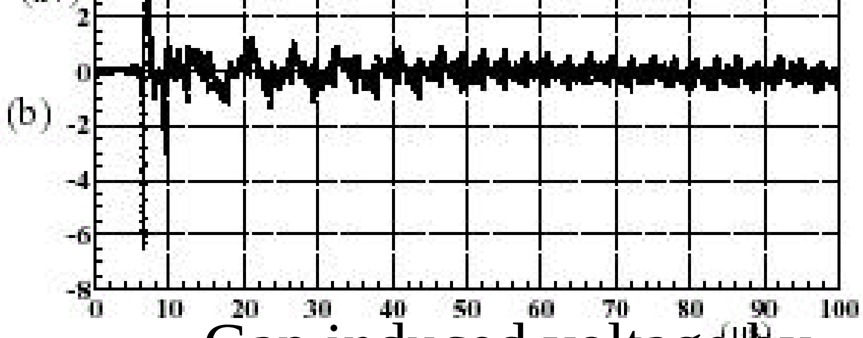


Barrier Bucket Experiment

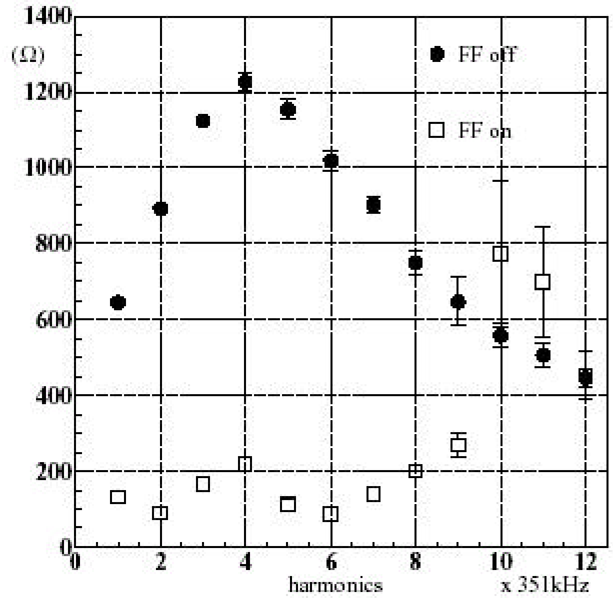
W/o FF



With FF

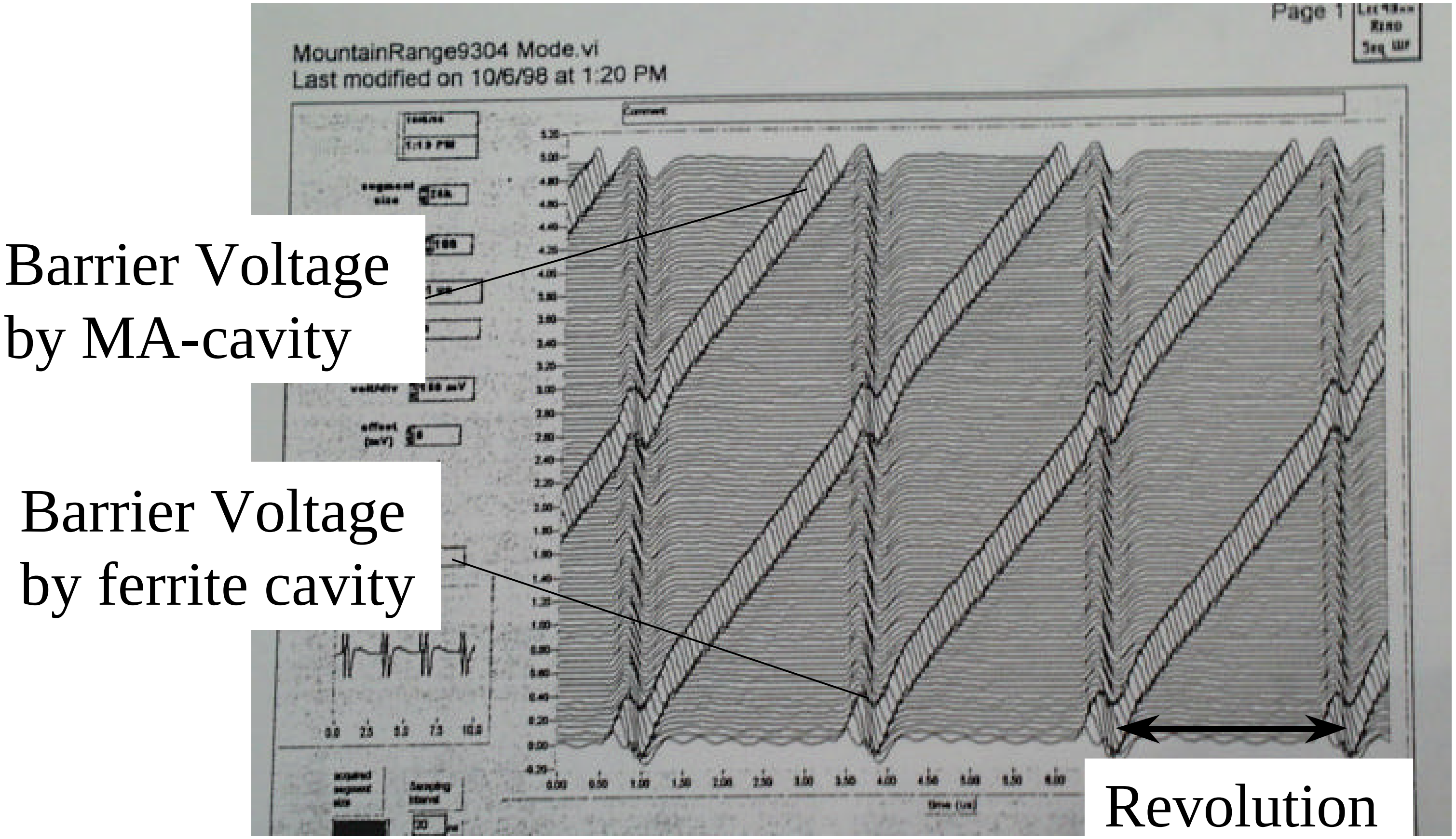


Gap induced voltage by
8X10[12] proton per bunch



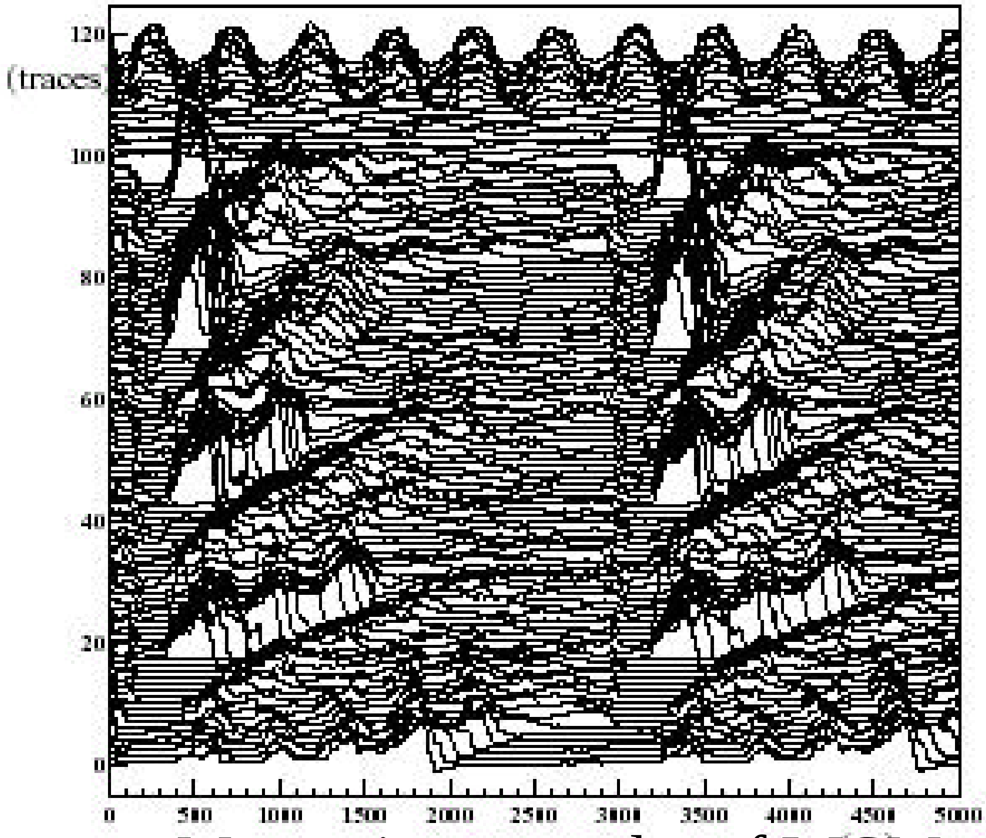
FFT results

Barrier Bucket Experiment

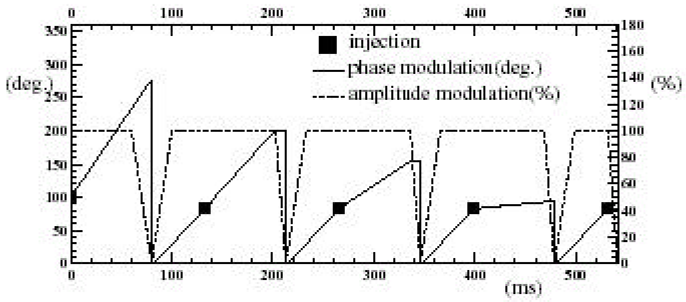


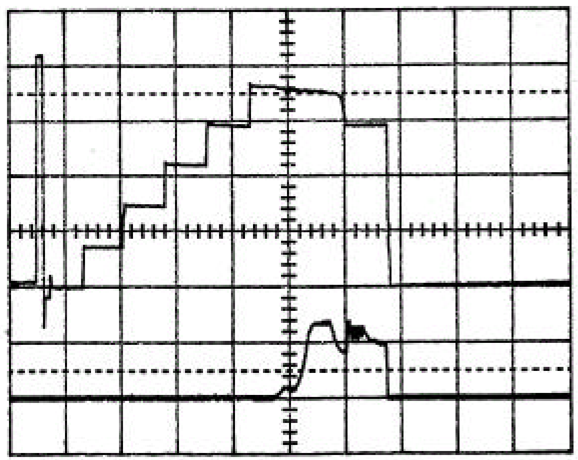
MA cavity was used for Moving Barrier because of adiabatic turn-on/off

Barrier Bucket Experiment



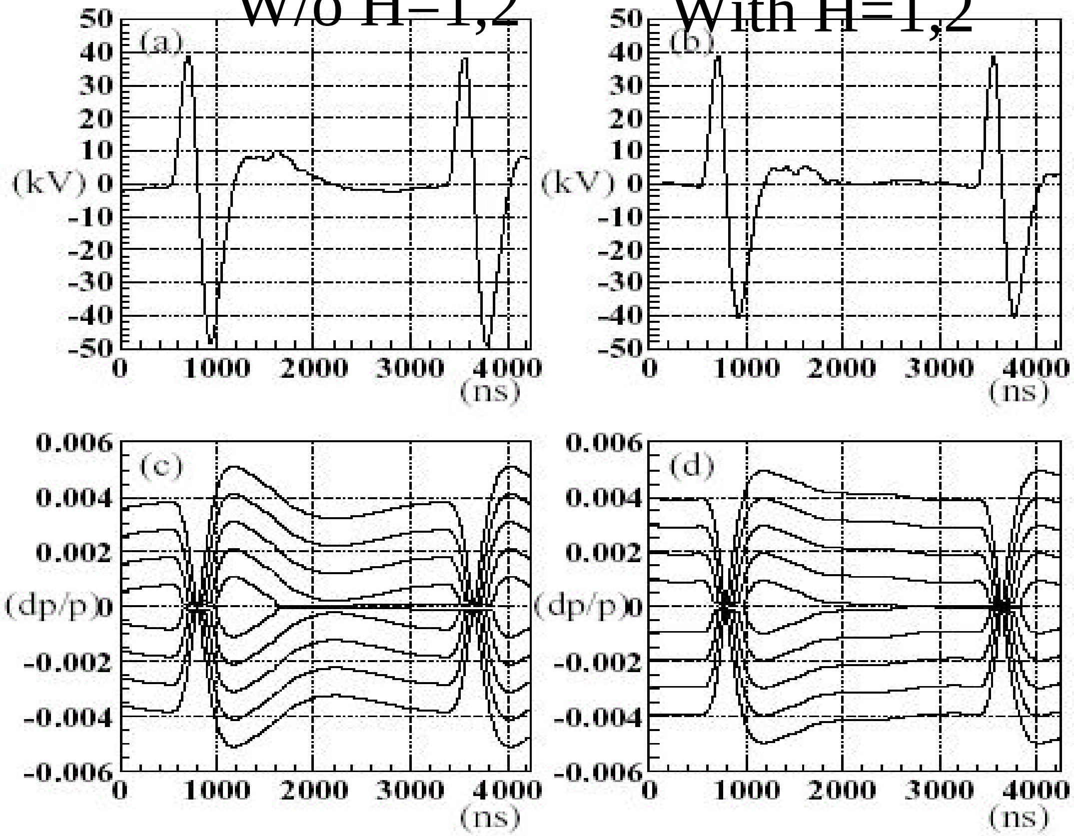
Mountain range plot of WCM
Interval of trace is 5.8 ms



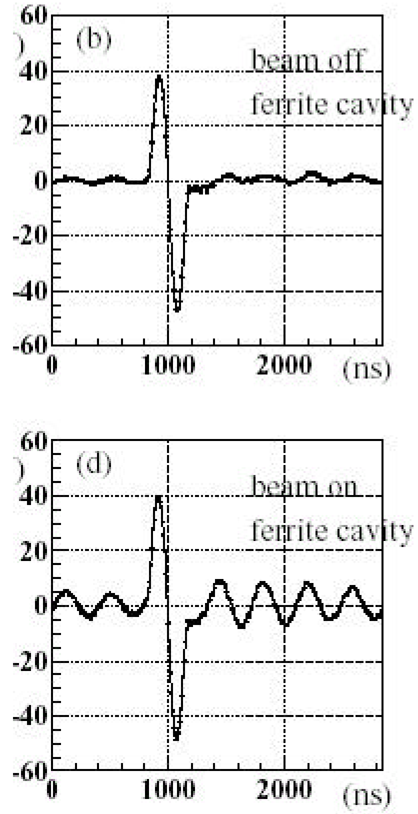


Barrier Bucket Experiment

W/o H=1,2 With H=1,2



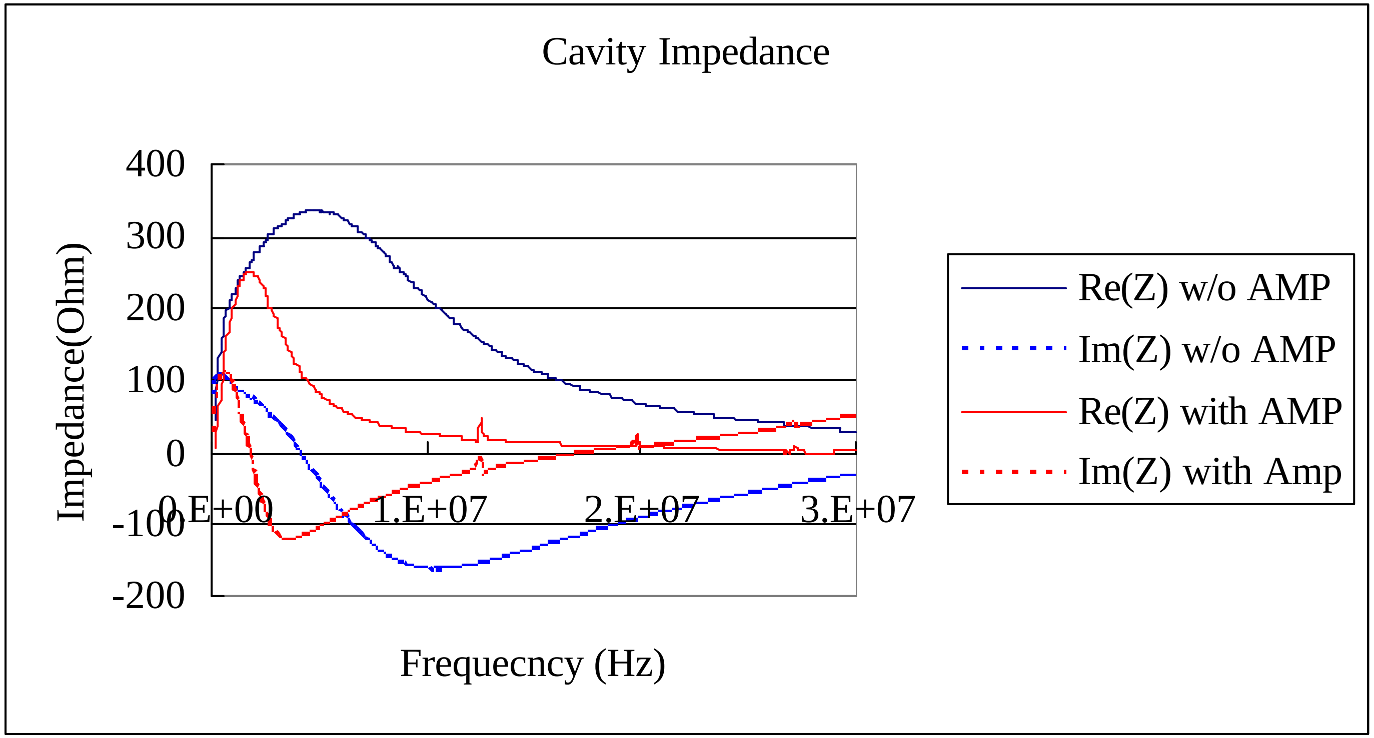
Overshooting Problem



Beam Loading on Ferrite Cavity

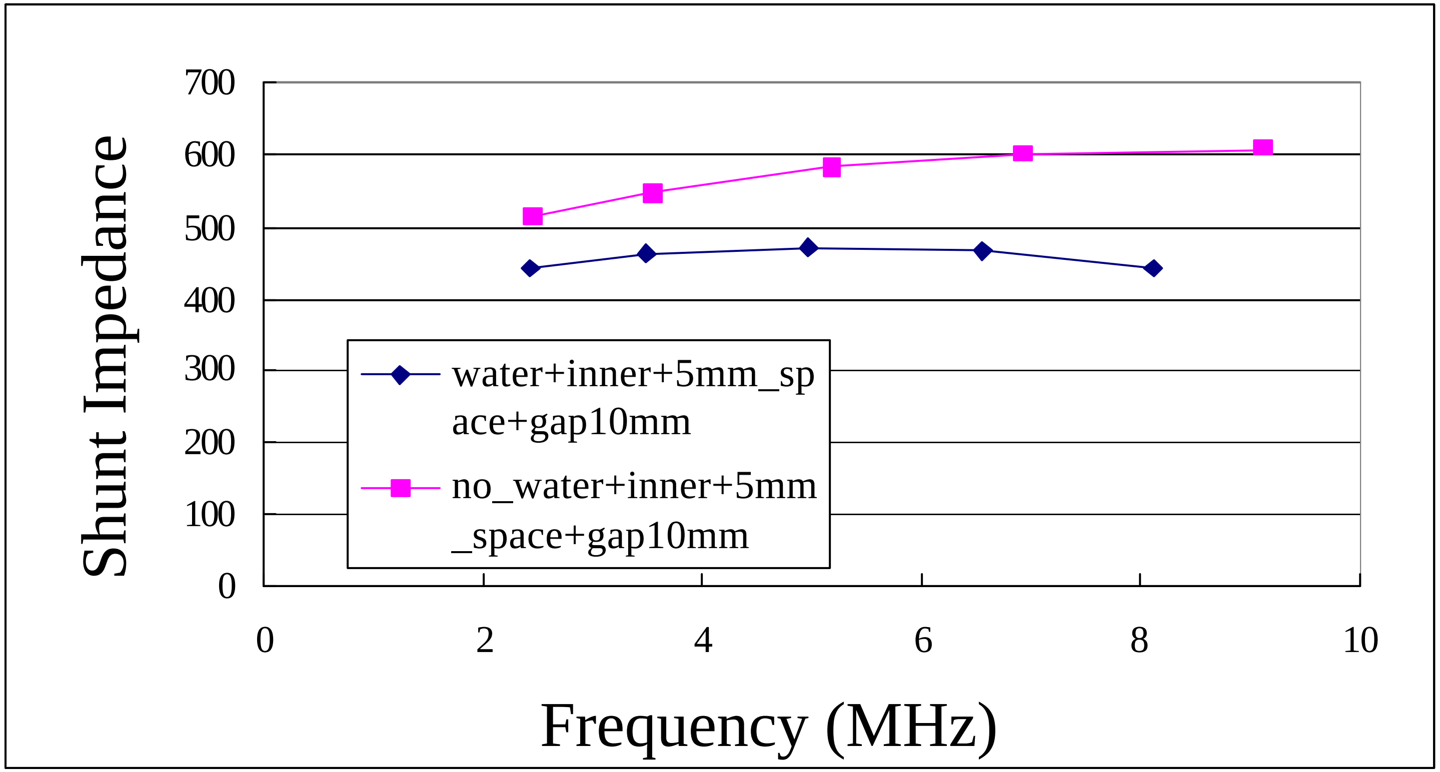
Making of MA Cavity

Wideband Cavity: Capacitance Effect.



Making of MA Cavity

Narrow Band and Direct Water Cooling Cavity

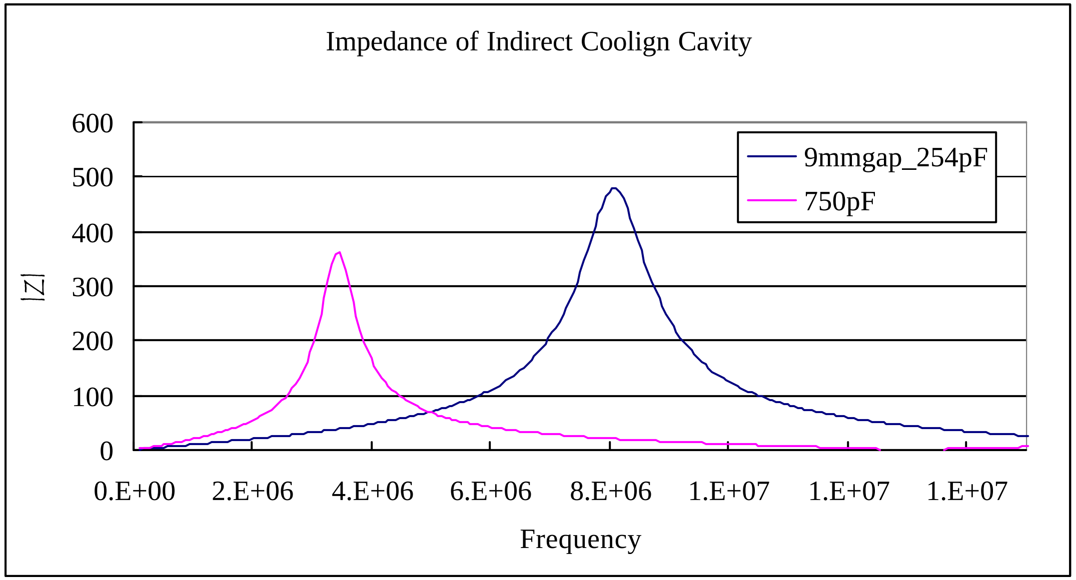


Cavity Impedance: 3 X 80cmO.D X 3.5 cm core

For 12 MHz Cavity in KEK-PS, Fluorinate Coolant is used.

Making of MA Cavity

Narrow Band and Indirect Water Cooling Cavity
with Insulators (5mm thickness and 2-4 W/mK)



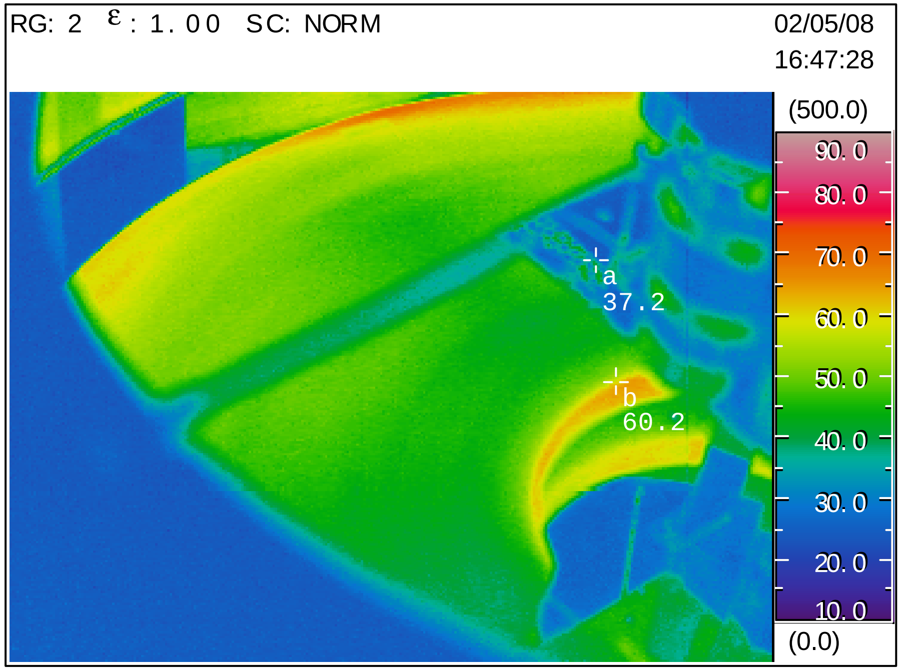
Cavity Impedance: 3 X 67cmOD X 2.5 cm Core
High Impedance at Low and High Frequency.

Making of MA Cavity

- Cavity Impedance
  - No Cut, Direct Water Cooling : OK, tube capacitance
  - Cut, Direct Water Cooling : OK up to several MHz
  - Cut, Indirect Water Cooling : OK
  - Cut Direct Cooling with Coolant: OK
- Cooling Efficiency
  - Direct Water Cooling:Very Good > 12 kW/core
  - Indirect Water Cooling : Good > 5kW/core

Making of MA Cavity

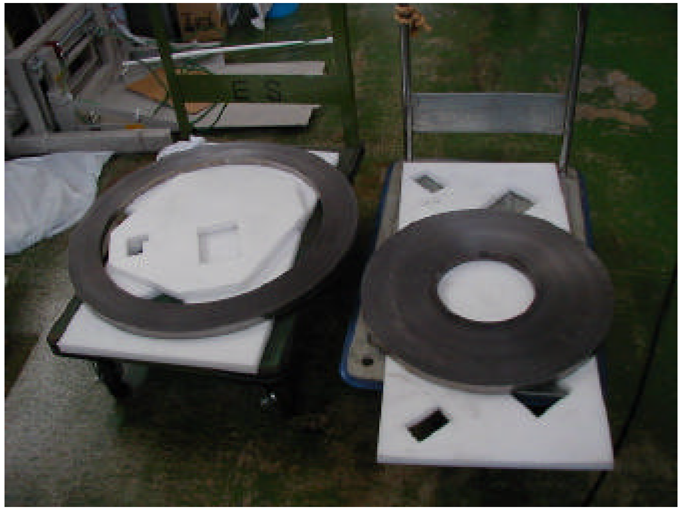
- Power Loss Distribution in Core
  - –Low Q : Loss at Gap, Few % of cores has very localized loss.
  - –High Q : Loss at Outer side because of inhomogenity of core. Outer has better characteristics.



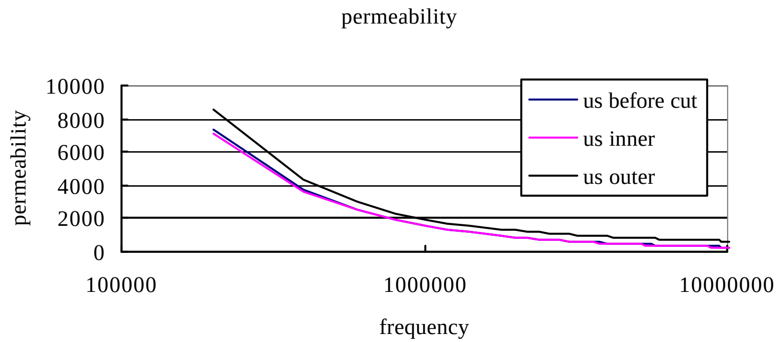
Unsolved Problems

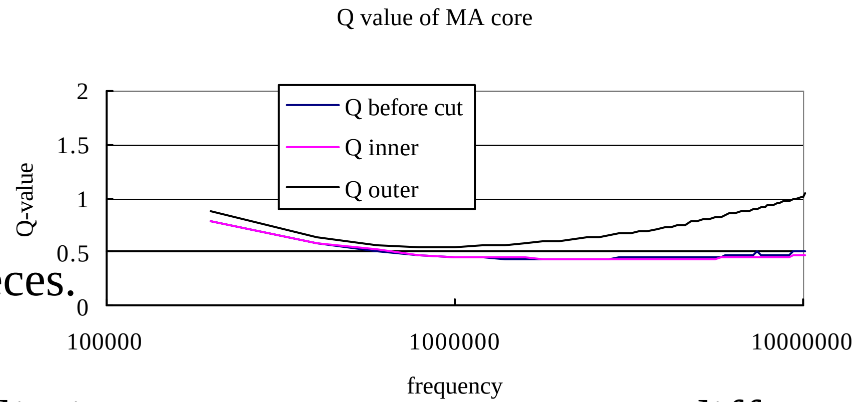
- Impedance reduction mechanism in Direct Water Cooling Cavity. Measurements are difficult because cores are in Water.
- Distribution of Loss in case of High Q cut core.

Localized Heat Loss



“Onion Cut” cuts a core into two pieces.
Before cut:80cmOD.24.5cmID
Inner:60cmOD,24.5cmID
Outer:80cmOD,62cmID





Preliminary measurements suggest difference of characteristics for inner and outer parts. This may be another cause of localized loss.

Summary

- We developed 4 different types of MA cavity
- For J-PARC(used be called JKJ or JHF), Direct (or Indirect) Water Cooling Cavity with Cut Cores
- Barrier Cavity: No Cut Core Cavity@ few MHz (or Small Gap Cut Core @ several MHz)
- For Bunch Rotation: Small Gap Cut Core or No Cut Core Cavity because of Saw Tooth RF
- For High Frequency (>several MHz) Cavity : Indirect Cooling Cut Core Cavity
- For Medical accelerator and Low Energy FFAG : No Cut Core Cavity
- Papers : http://hadron.kek.jp/member/chihiro/papers.html