RF acceleration of FFAG accelerators at KURRI

Tom Uesugi et al.

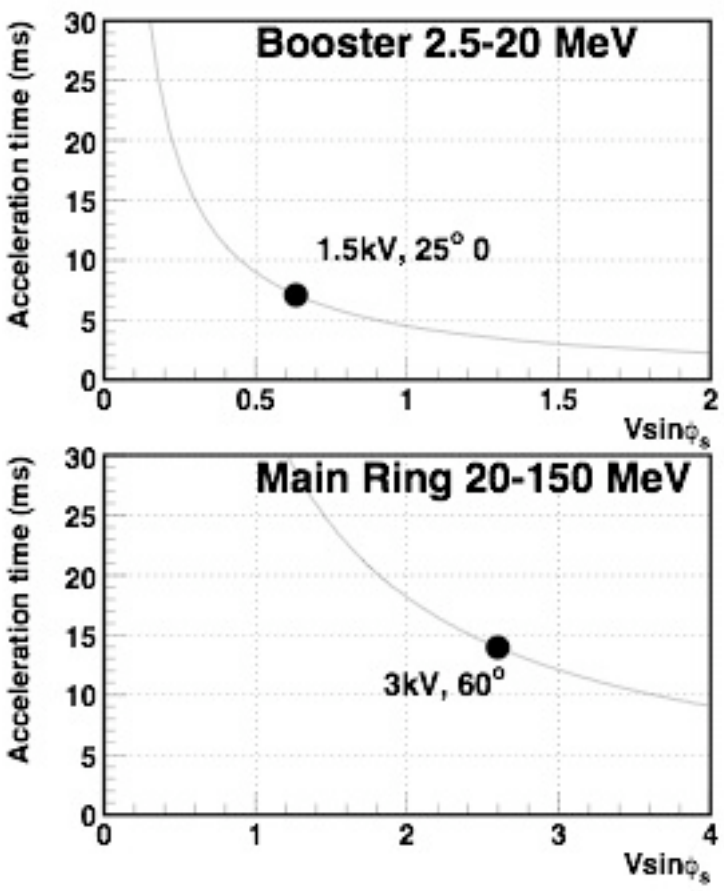
Designed parameters

Booster（ k=2.5, R0=1.42m ）
2.5 MeV~20 MeV

Voltage：1.5 kV
Freq. ：2.5∽5.5 MHz
Acc time：7ms

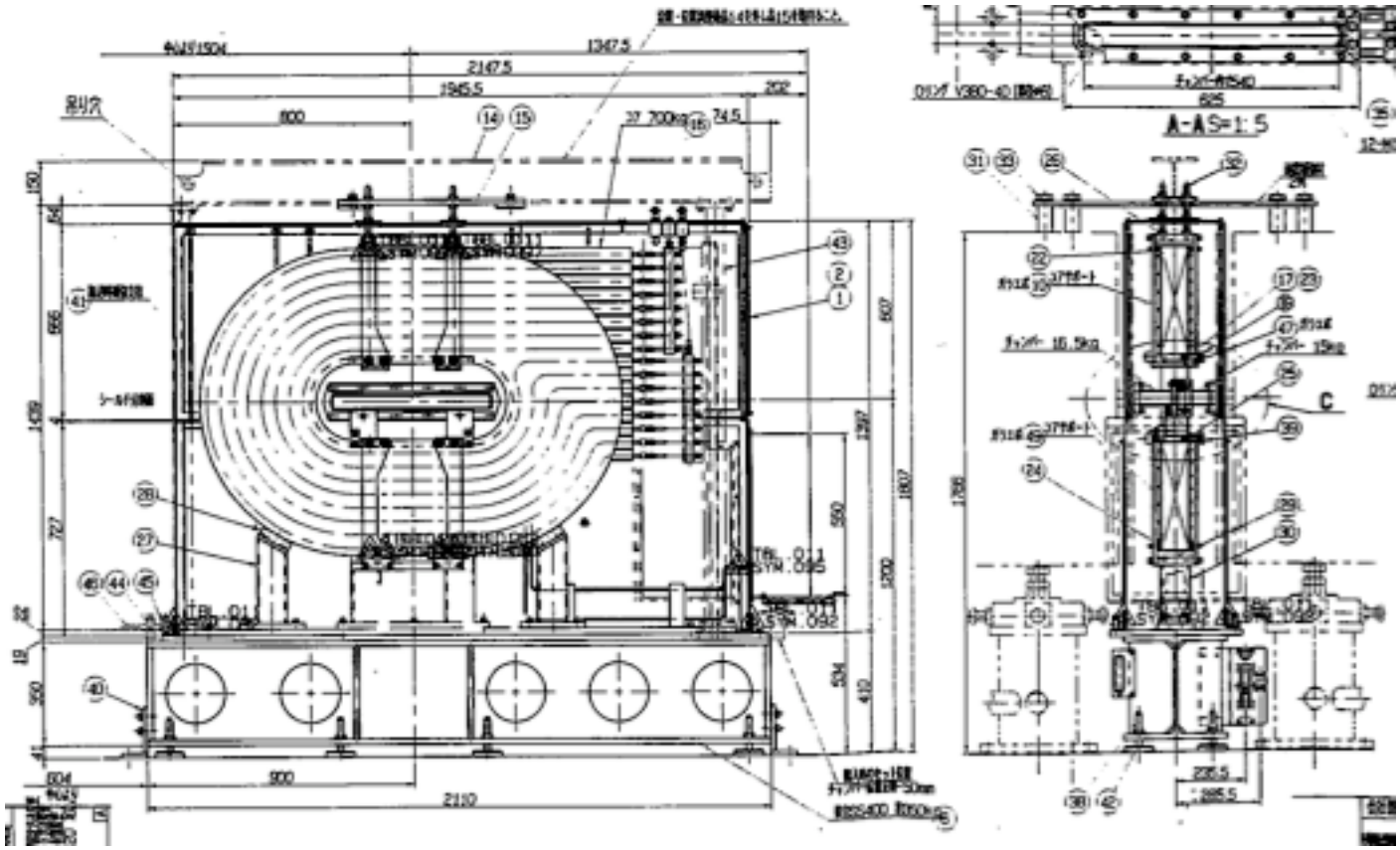
Main Ring（ k=7.5, R0=4.54m ）
20 MeV~150 MeV

Voltage：3 kV
Freq. ：2.1∽4.7 MHz
Acc time：15ms

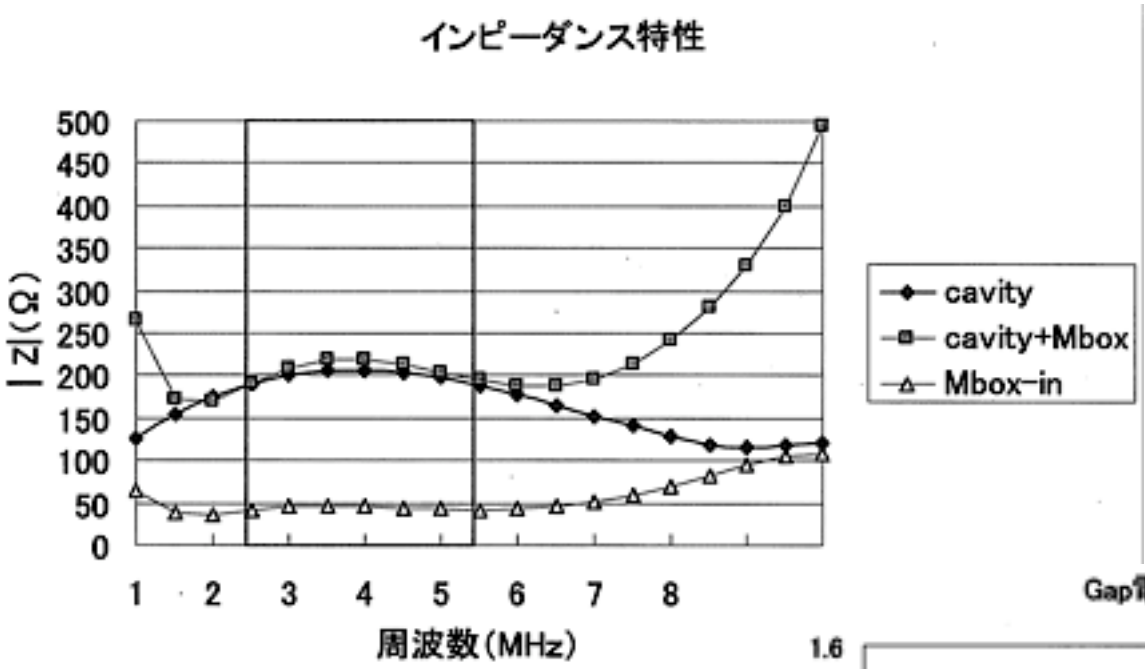


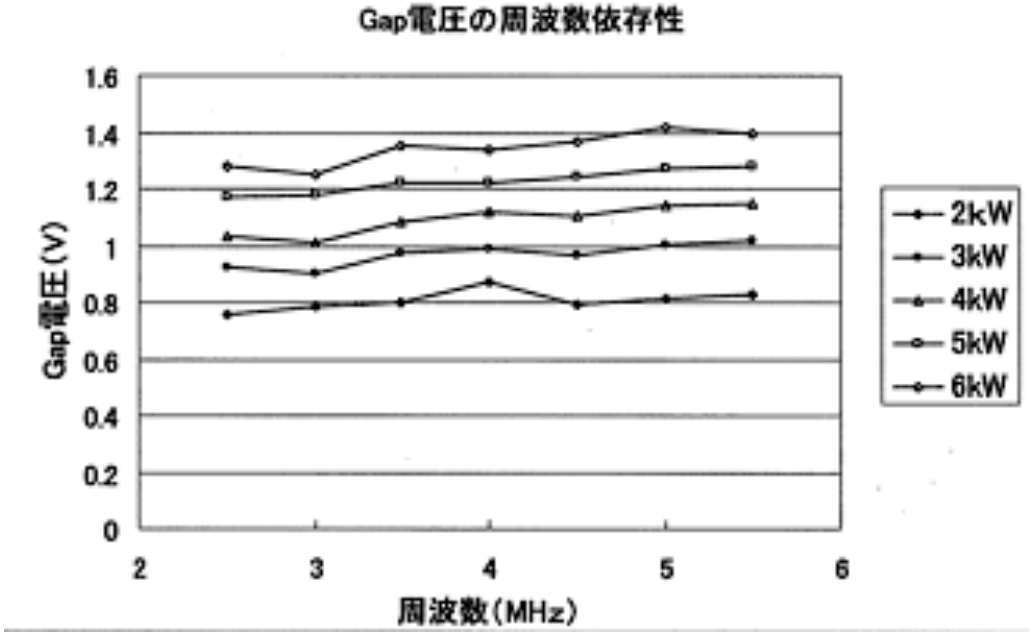
RF cavity of BOOSTER

- Amorphous、 water cooling
- ∽200Ω
- λ/4 resonator



Impedance


インピーダンス特性
500
450
400
350
300
250
200
150
100
50
0
|Z|(Ω)
1
2
3
4
5
6
7
8
周波数(MHz)
cavity
cavity+Mbox
Mbox-in


Gap電圧の周波数依存性
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Gap電圧(V)
2
3
4
5
6
周波数(MHz)
2kW
3kW
4kW
5kW
6kW

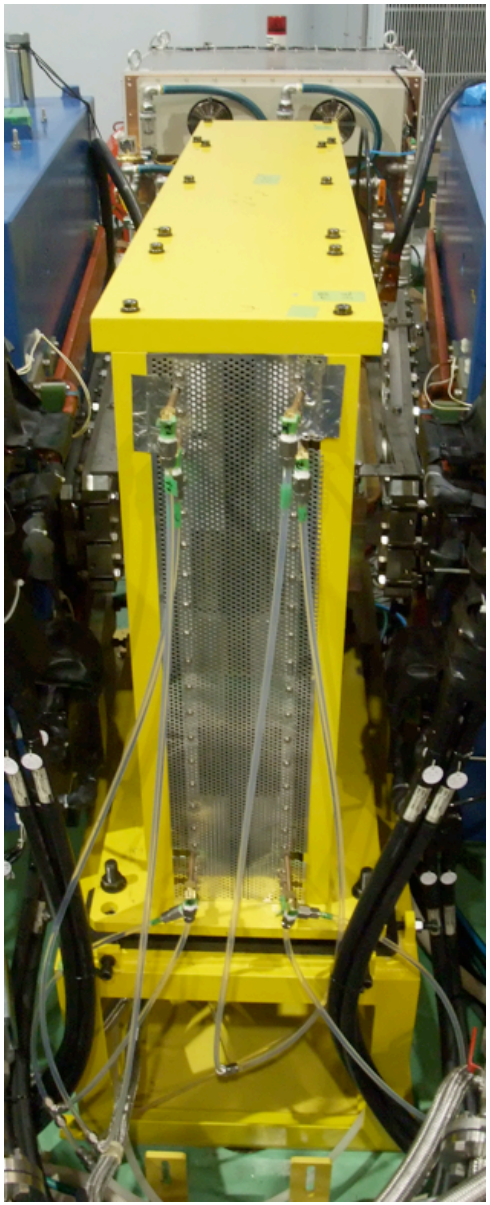
Amplfier

- Thamway T145-6845A
  2.5 - 5.5MHz 6 kW

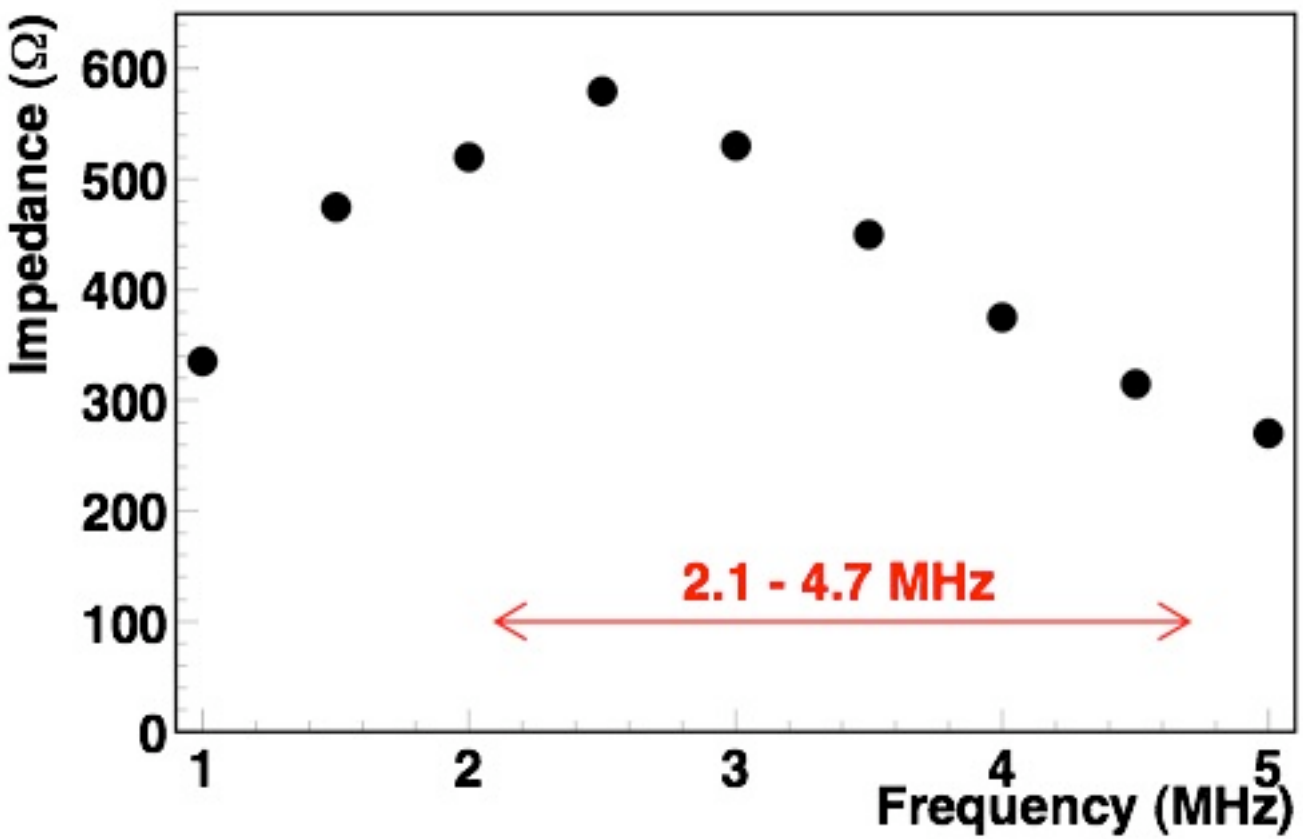
RF cavity of MAIN RING

＝ from KEK

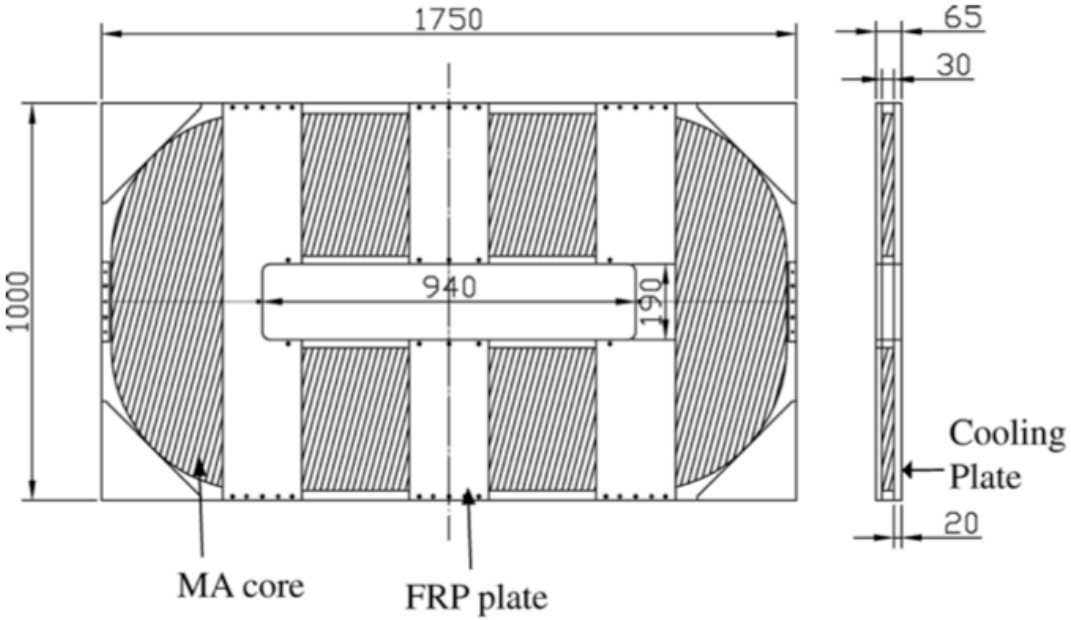
- Magnetic Alloy（FT-3M） x 2
- 500 ~ 600 ohm
- Water cooling ＋ air-cooling
- Magnetic shield
- COD correction magnets

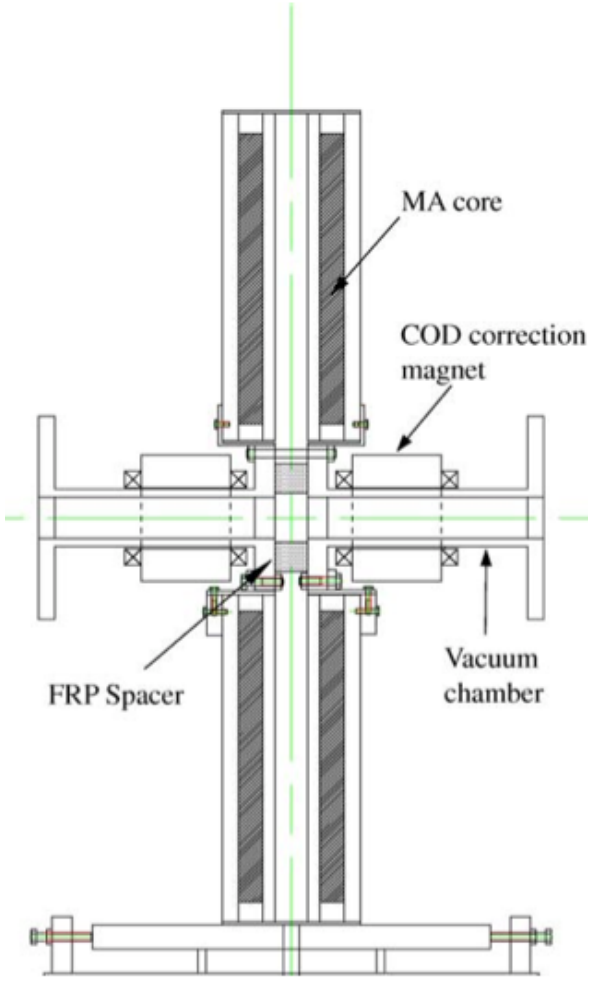


Impedance


Impedance (Ω)
600
500
400
300
200
100
0
1
2
3
4
5
Frequency (MHz)
2.1 - 4.7 MHz

Designed picture

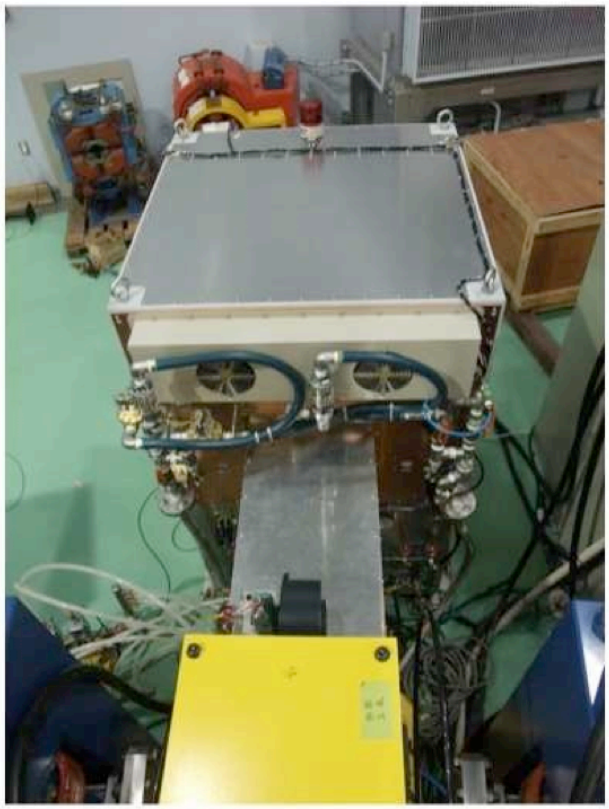




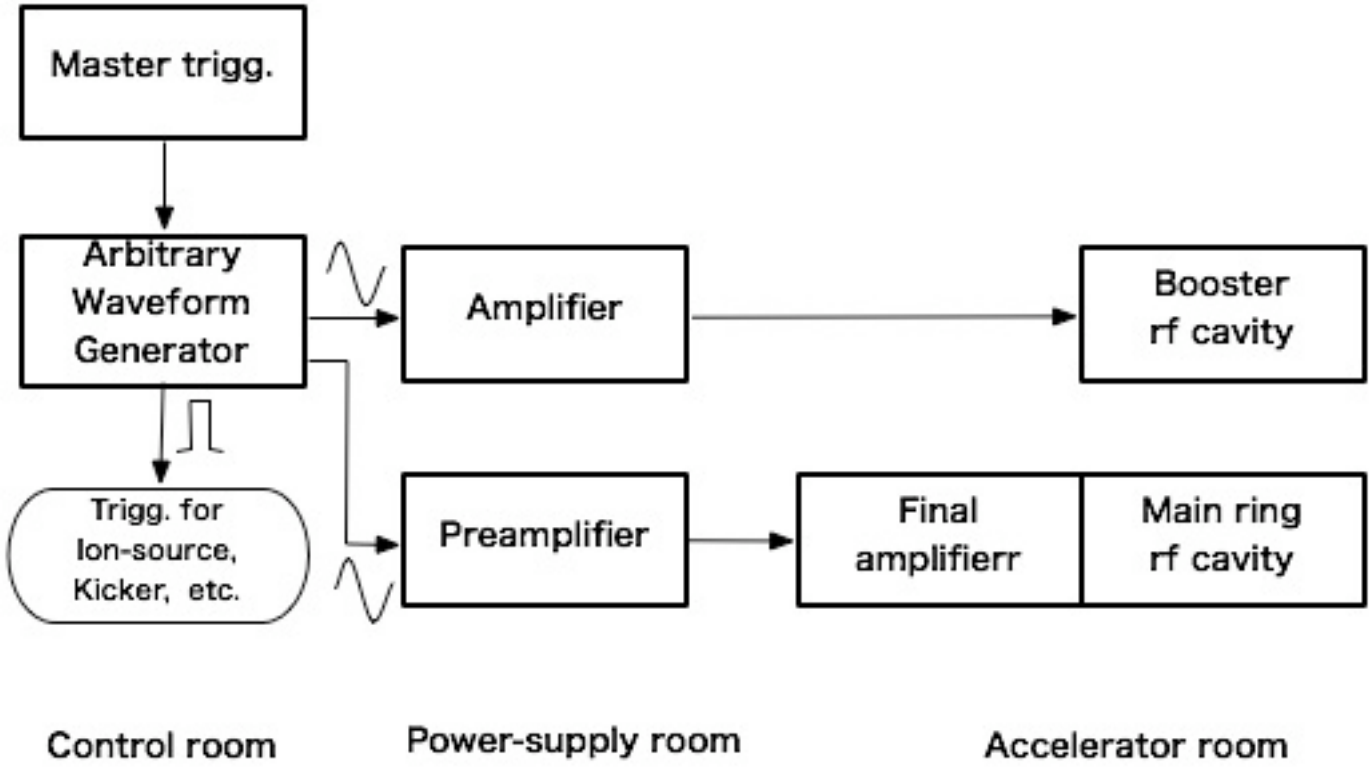
Power amplifier

Thamway　T145-6544C　2.1-4.7MHz　3kW

55kW（4CW25000B×2　1.5 ~ 5.0 MHz



Schematic diagram



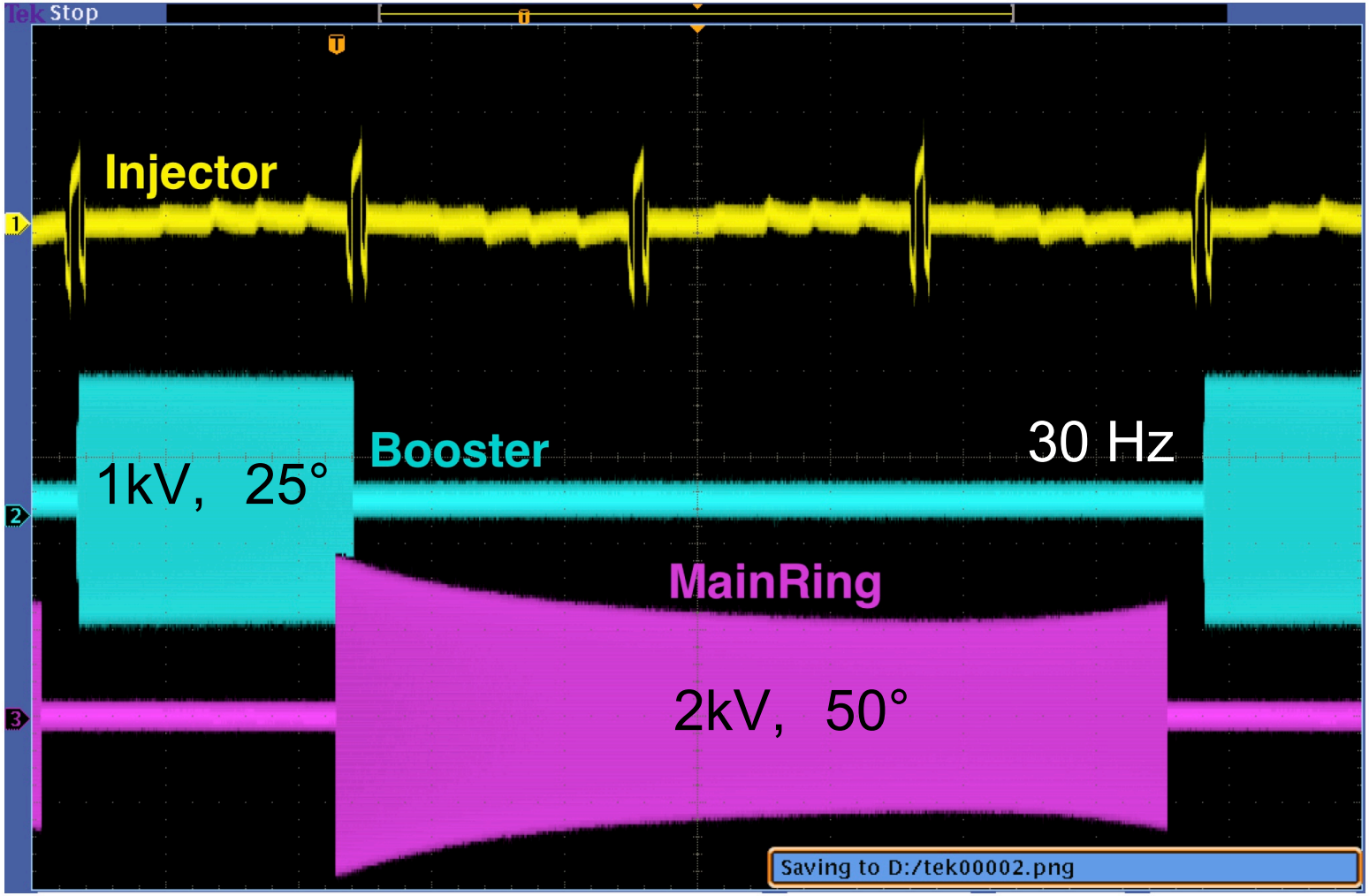
- No tuning-loop
- No ΔR、Δφ feedback
  Timing jitter ~ several ns

Input file of Arbitrary Waveform Generator

Example

```
          . . .
a4=1.2e-4*1e12
a5=-2.1e-6*1e15
PHIs=-55./360.
DeltaFai=0.5

'******** Initial blank
size=(T1-T2)*clock
"tmp1.wfm" = 0.

'******** flatbase
size=T2*clock
"tmp2.wfm"=sin(2.*pi*(C0*time+DeltaFai))

'******** acceleration
size=T3*clock
dphi=C0*T2+DeltaFai+PHIs
"tmp3.wfm"=(0.4+0.6*6./(a0+a1*time+a2*time^2+a3*time^3+a4*time^4+a5*time^5))
*sin(2.*pi*(C0*time+C1*time^2+C2*time^3+C3*time^4+C4*time^5+C5*time^6+C6*time^7+dphi))

'******** final blank
size=T4*clock
"tmp4.wfm"=0.

"tmp5.wfm" = join("tmp1.wfm","tmp2.wfm")
"tmp6.wfm" =join("tmp3.wfm","tmp4.wfm")
"090106_06.wfm" = join("tmp5.wfm","tmp6.wfm")
```

Input RF signals



Booster

(1) Flatbase (constant frequency) injection
Capture by saw-tooth rf,
longitudinal matching by phase rotation

(2) Phase jump for accelerating bucket,
without smoothing

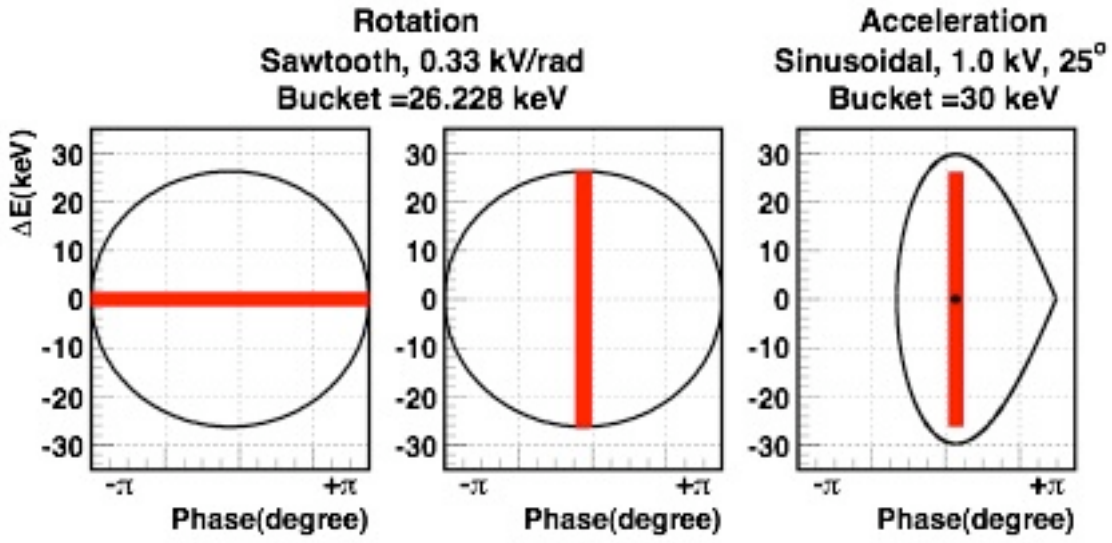
(3) Constant voltage (1kV) and synchronous phase (25deg)

(4) No flattop; Output beam energy is determined by
the timing of extraction kicker

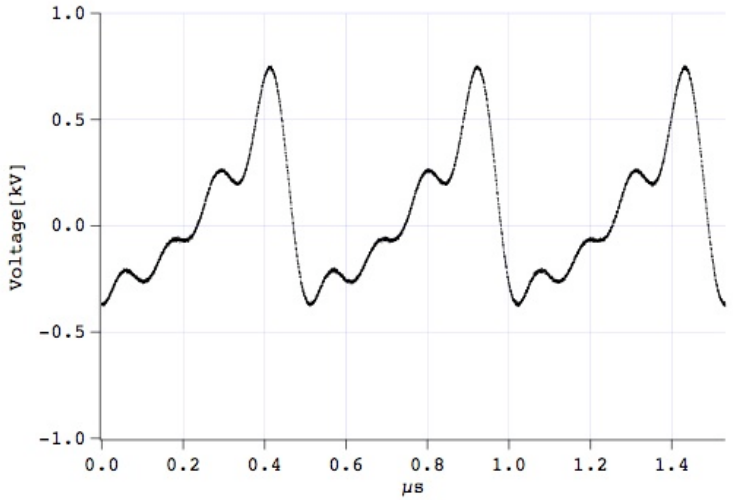
Longitudinal matching by phase rotation

H. Horii et al., FFAG07J, Osaka (2007).

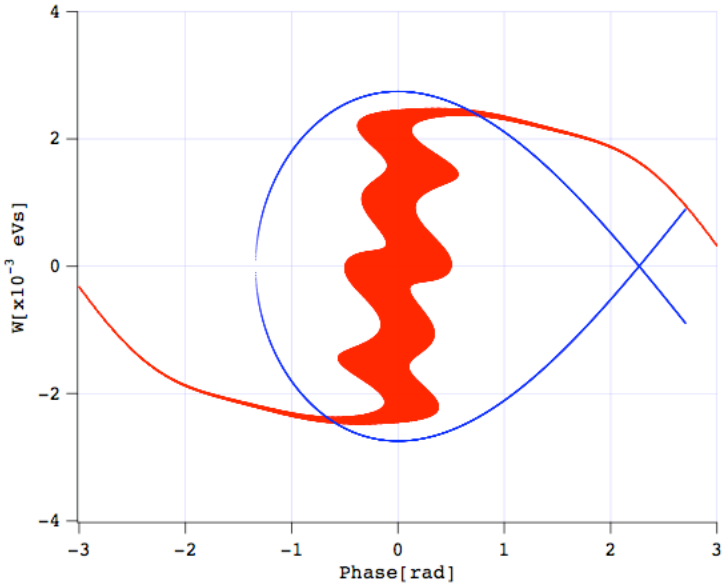
- Coasting beam is injected in the booster.
- Adiabatic capture is not available
  in such a rapid cycling accelerator.
- Matching is done after 1/4 synchrotron oscillations.
- Linear (saw-tooth) rf is used to minimize filamentation.



Simulation result

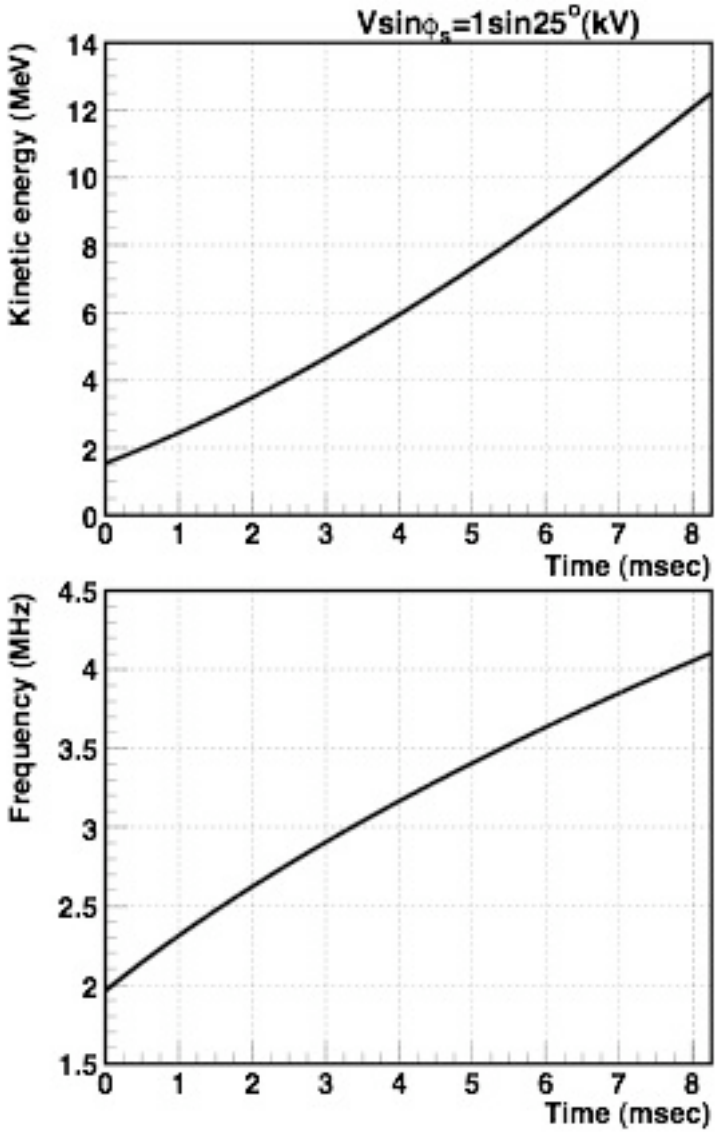


Saw-tooth rf waveform
which was obtained experimentally



Simulation results
(0.1% dp/p of injected beam was assumed)

Acceleration at constant Phi-s



Eini	1.54 MeV
Fini	1962 kHz
Field index	2.5
Voltage	1kV
Phi-s	25°

Eext	12.5 MeV
after	8.247 ms accel.

Main Ring

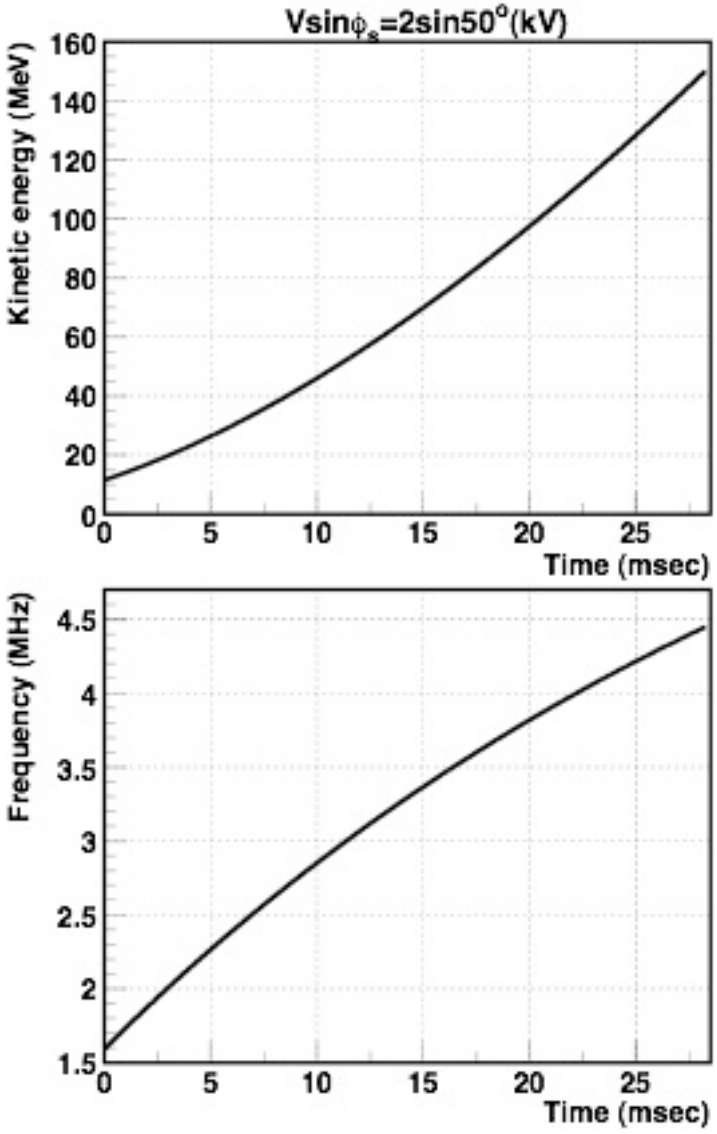
(1) Flatbase (constant frequency) injection

(2) Phase jump for accelerating bucket,
without smoothing

(3) Constant voltage (2kV) and synchronous phase (50deg)

(4) No flattop; Output beam energy is determined by
the timing of extraction kicker

Acceleration at constant Phi-s



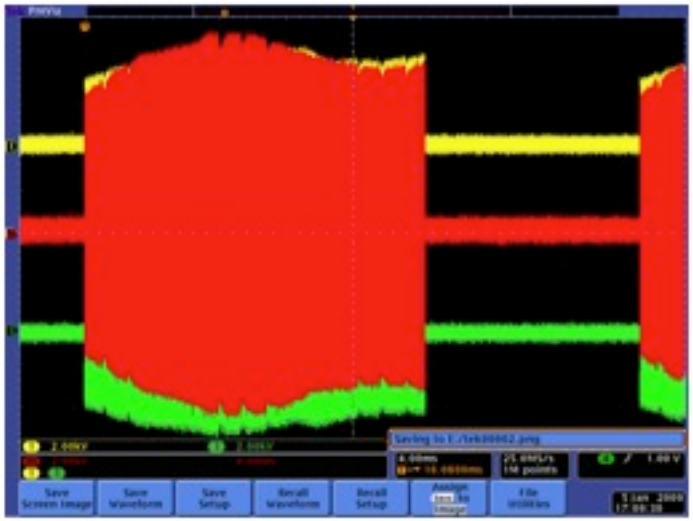
Eini	11.57 MeV
Fini	1591.84 kHz
Field index	7.6
Voltage	2kV
Phi-s	50deg

Eext		100 MeV
	after	20.4 ms accel.
		150 MeV
	after	28.3ms

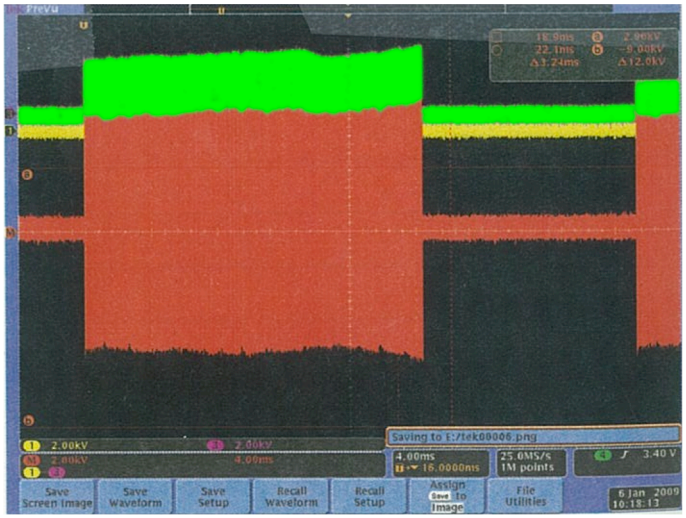
Amplitude modulation to compensate cavity impedance

Gap voltage must be flat in order to keep Phi-s constant.

- Gap voltage depends on f and df/dt.
-Iteration :
  Gapvoltage measurement,
    and AM pattern edit



→



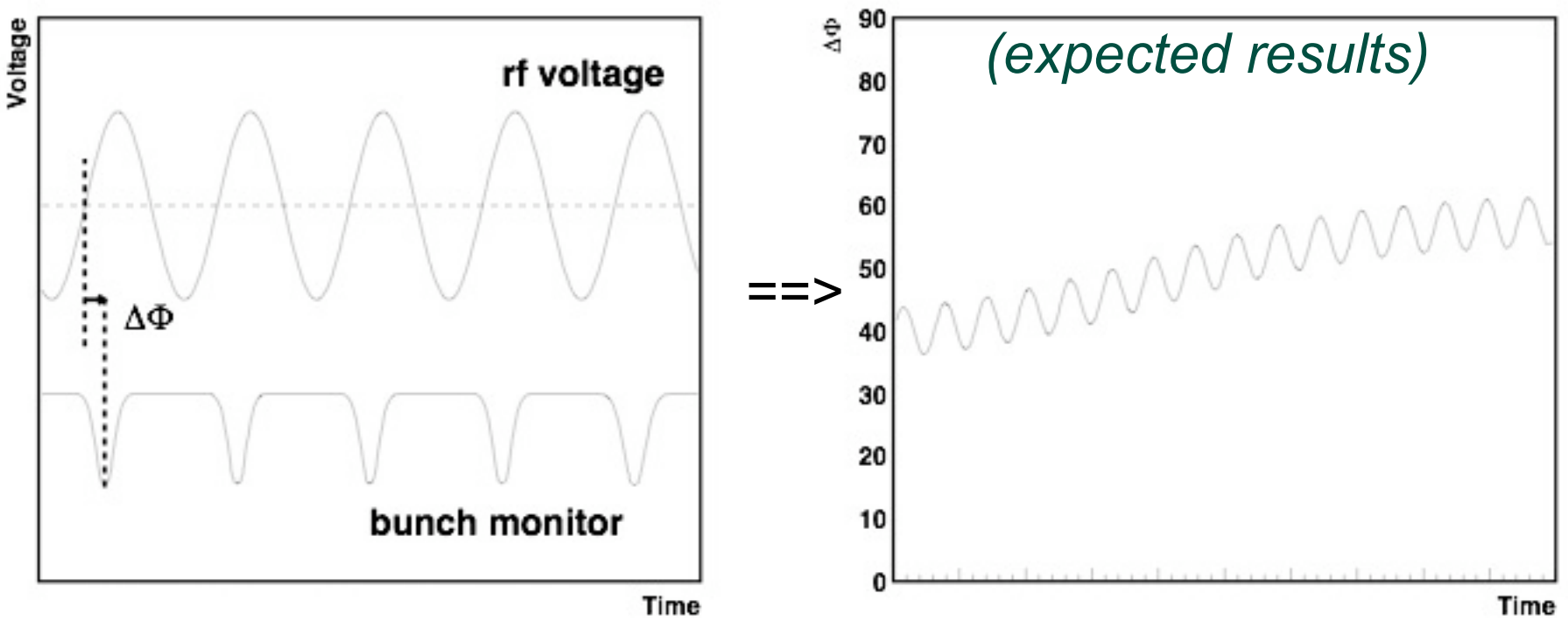
Before correction（red）

After correction（red）

Measurement of PHI-s

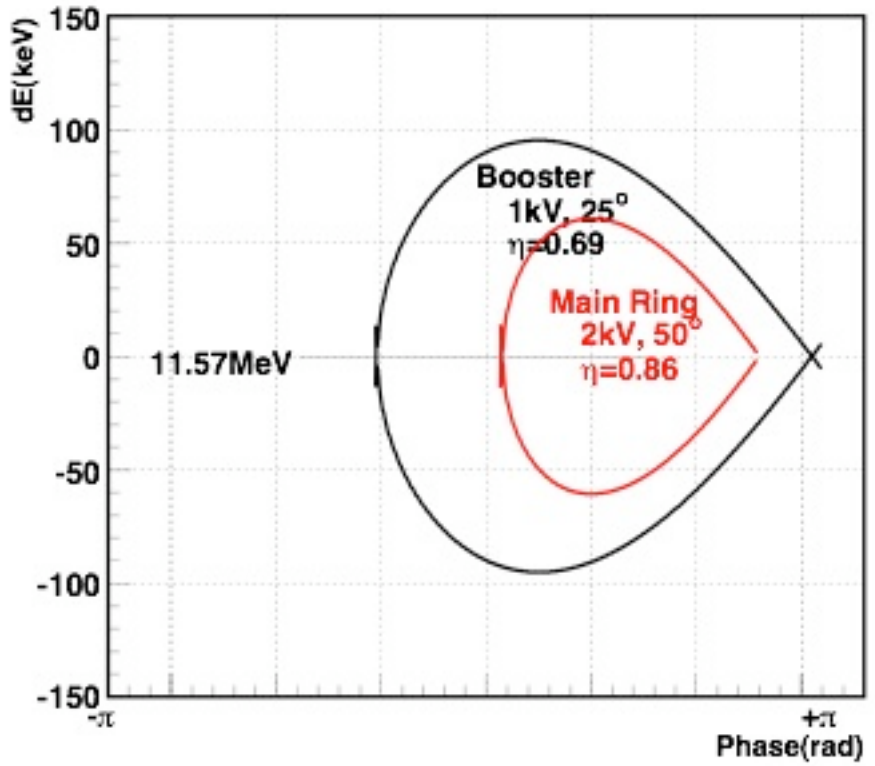
Is tried by

H. Imazu et al. (in tomorrow session!)



Bucket-to-bucket maching between Booster and Mainring

- Bucket size in the MR at Einj is smaller than that in the Booster at Eext (Figure)



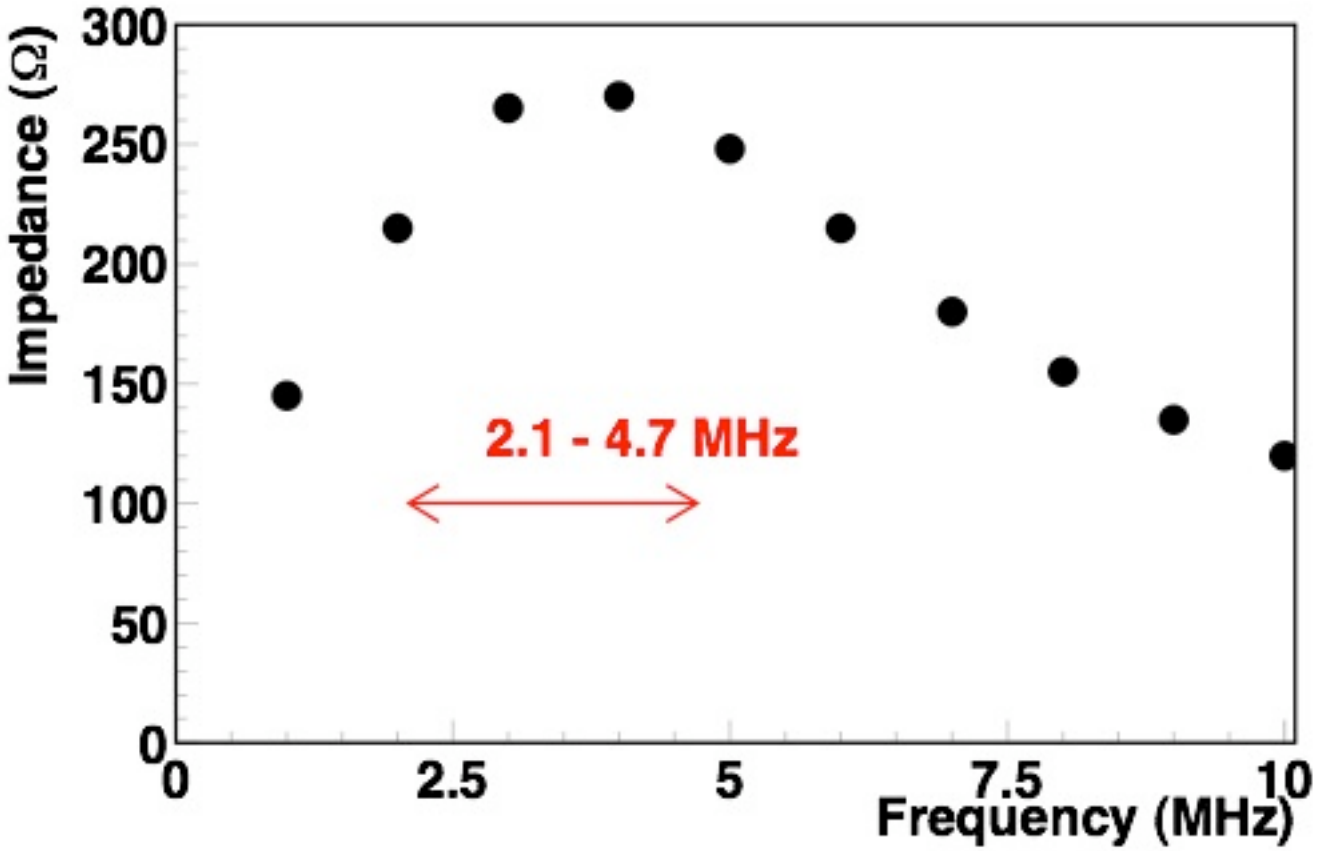
Future: upgrading

We have another RF cavity for MAIN RING

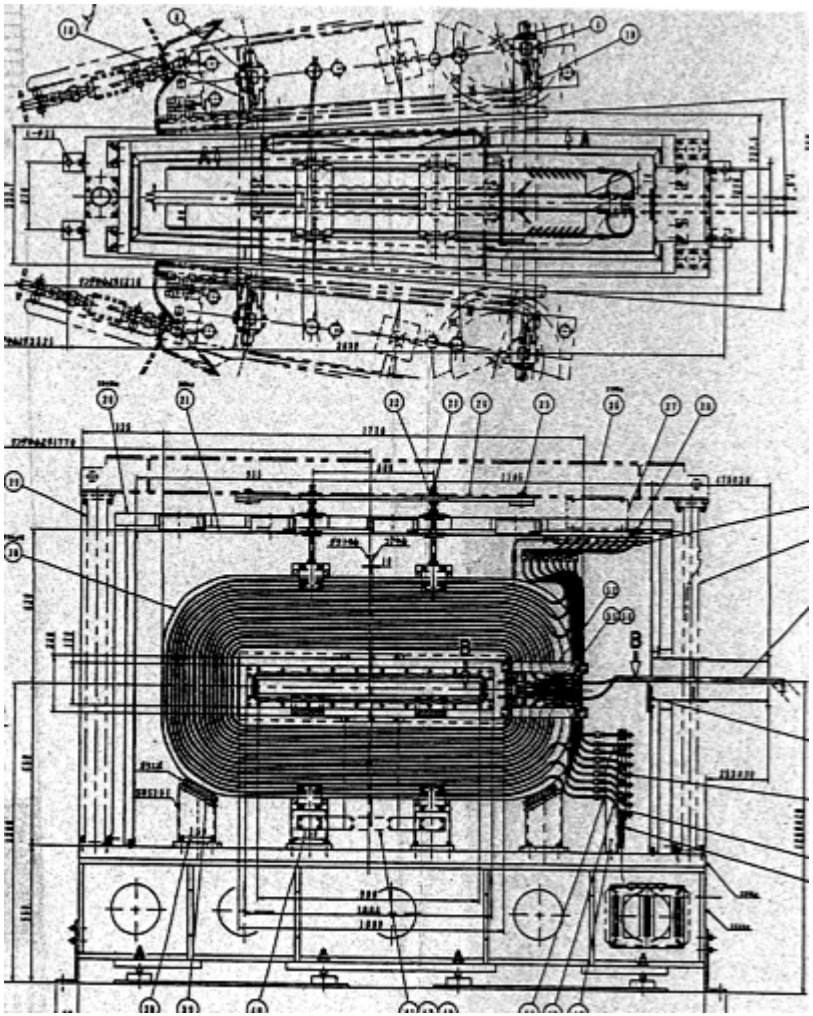
This cavity, originally installed in the main ring, was replaced by another cavity (next slide) later, because of the thickness.

- Amorphous core X 2
- ~ 250 ohm
- Water cooling（one-side）
- Magnetic shield
- COD correction magnets

Impedance


Impedance (Ω)
300
250
200
150
100
50
0
0
2.5
5
7.5
10
Frequency (MHz)
2.1 - 4.7 MHz

Designed



→ シールド含めた厚み
230mmと広く、
これが大きなCOD 源となる
おそれがあるため、
現在は使用していない。

→ COD補正磁極を増強することで、
将来的に補助RFとして使用する
可能性あり。

Summary

	Booster	Main Ring
Operation	Phase rotation injection, Constant PHI-s(25deg), Up to 11.57 Mev in 8.247 ms	Flatbase injection, Constant PHI-s(50deg), Up to 100 MeV in 20.4ms (150MeV in 28.3ms)
Issue	Nothing	Relatively low bucket area (compared with booster)
Cure		- Increase rf voltage (at least capture stage) - Increasing PHI-s in the booster.