MAC2010
Feb. 16, 2010

Superconducting Cavity

Yoshiyuki MORITA

Outline

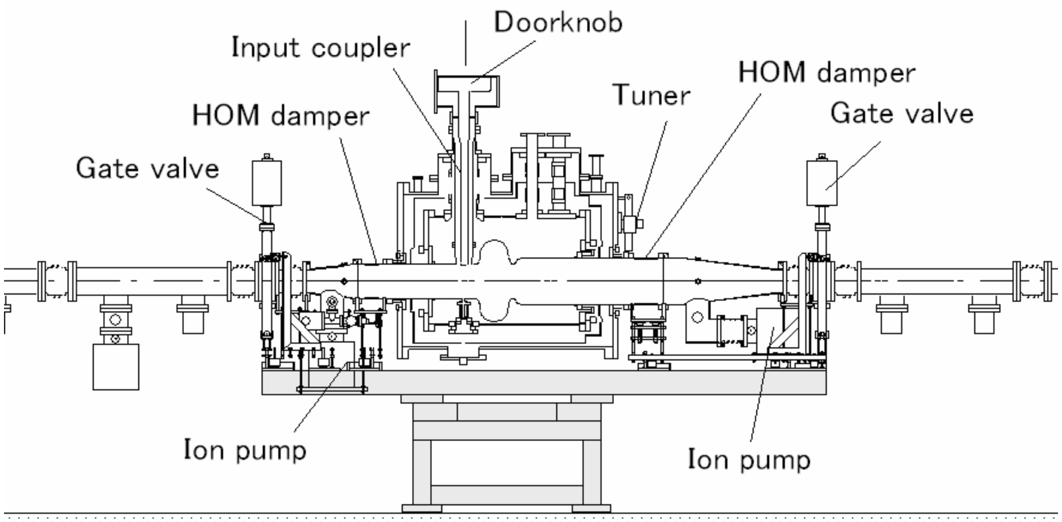
- R&D for Super-KEKB
  - KEKB superconducting cavities
  - Beam studies for reverse phase mode
    - Voltage and phase settings
      - Not to change the total voltage
    - Low current study
      - Synchrotron tune
      - Bunch length
      - Beam loading
    - High current study
      - Transient behavior at cavity trip
    - Luminosity run
      - Stability
  - HOM damper
  - Input coupler

KEKB superconducting cavity

A cross sectional view of the KEKB Superconducting Accelerating Cavity.
A 509 MHz single cell cavity with a large iris diameter of 220 mm has ferrite HOM absorbers on both sides and a coaxial-type power coupler. The cryomodules of 3700 mm in length are connected to the beam ducts of 150 mm in diameter.

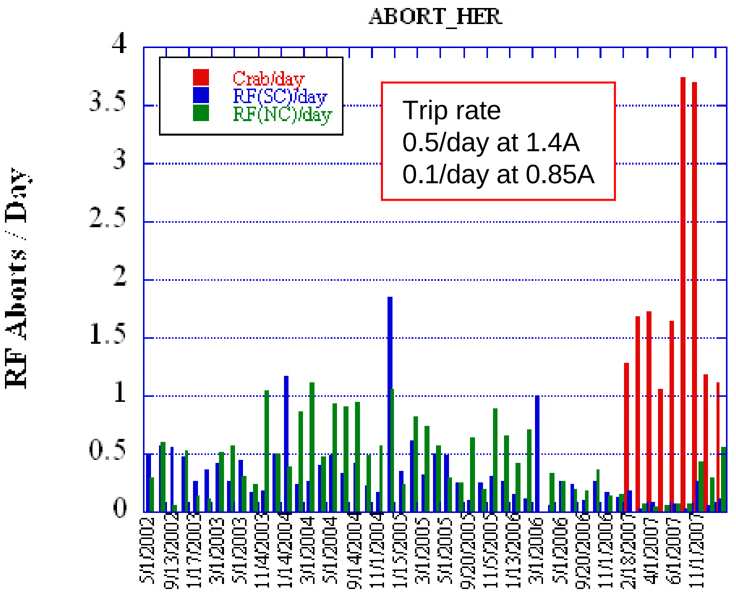
Designed and achieved parameters

Parameter	design	achieved	unit
Beam Current	1.1	1.4	A
Bunch charge	2	10	nC
RF voltage	1.5	1.2-2	MV/cav.
Beam loading	250	350-400	kW/cav.
HOM power	5	16	kW/cav.



Eight superconducting cavities in HER

Abort statistics @ HER



R&D for Super-KEKB
Reverse phase mode

Required total voltage: Lower than the present voltage

13-15 MV→6.7MV

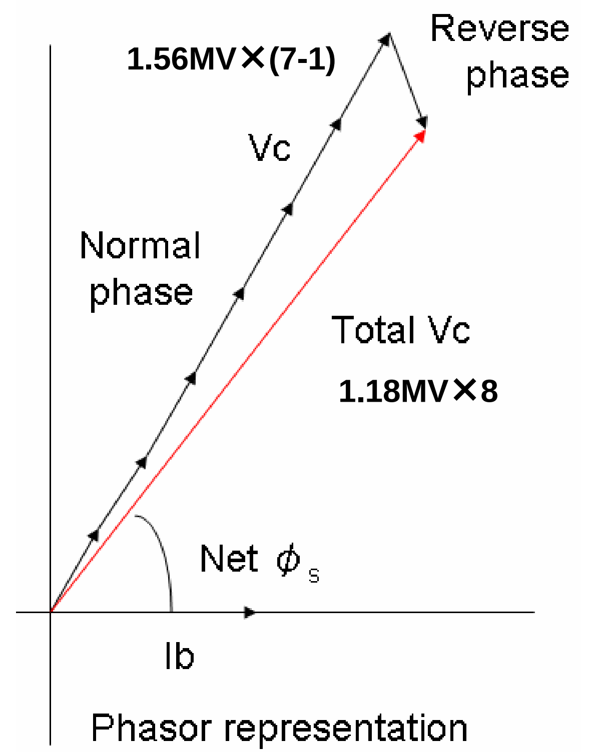
Required total beam power: Higher than the present one

5MW→7.7MW@2.6A

→ External Q must be modified (Qext=50,000 at present)

→ Input couplers must be exchanged

→ High risks for cavity contamination



New operation method proposed

Reverse phase mode

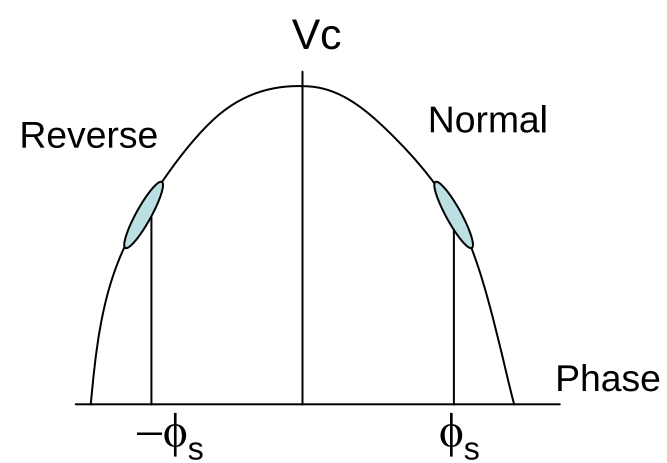
Synchronous phases of several cavities are reversed

The total RF voltage is kept as low as the required value

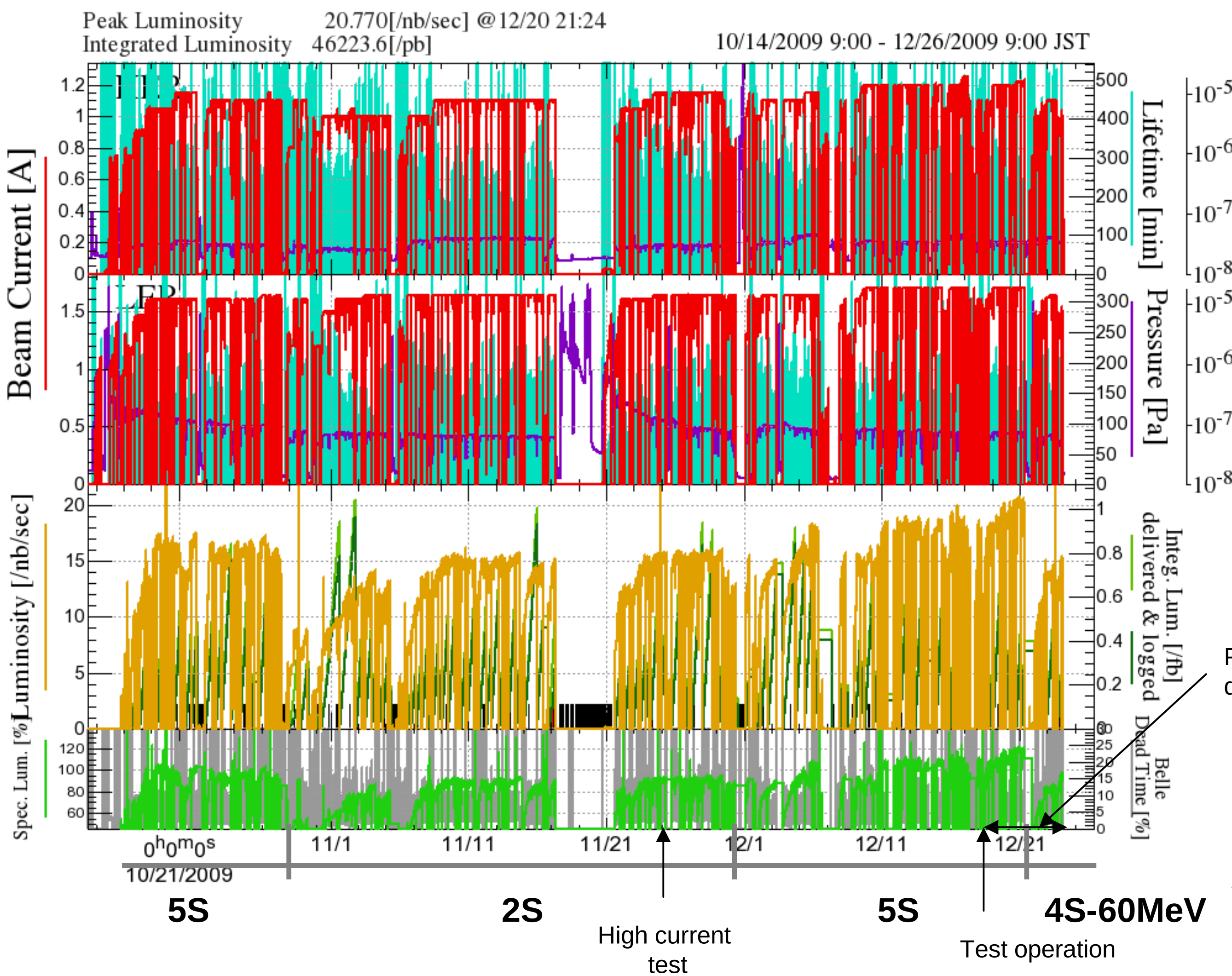
→ Each cavity can have high voltage

→ Each cavity can share equal beam loading

→ No need for Qext modification

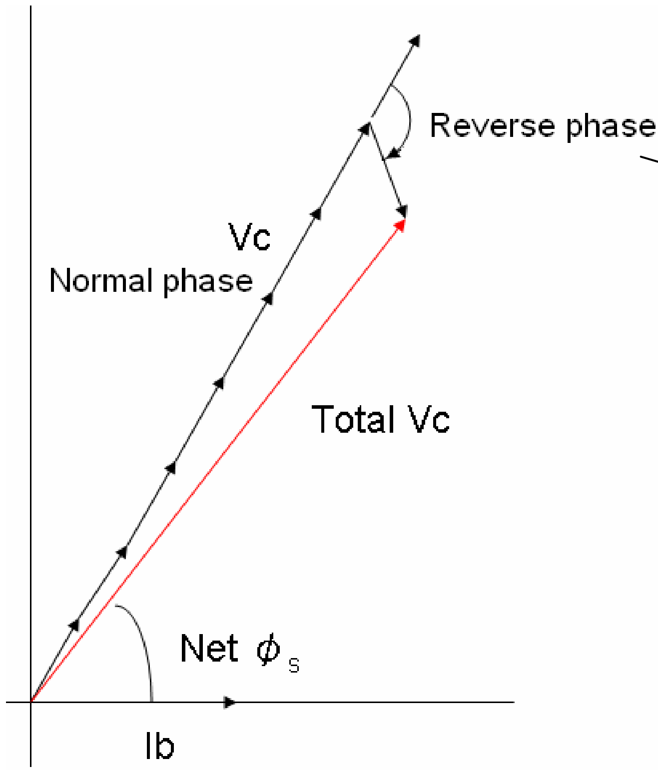


Beam studies and test operation

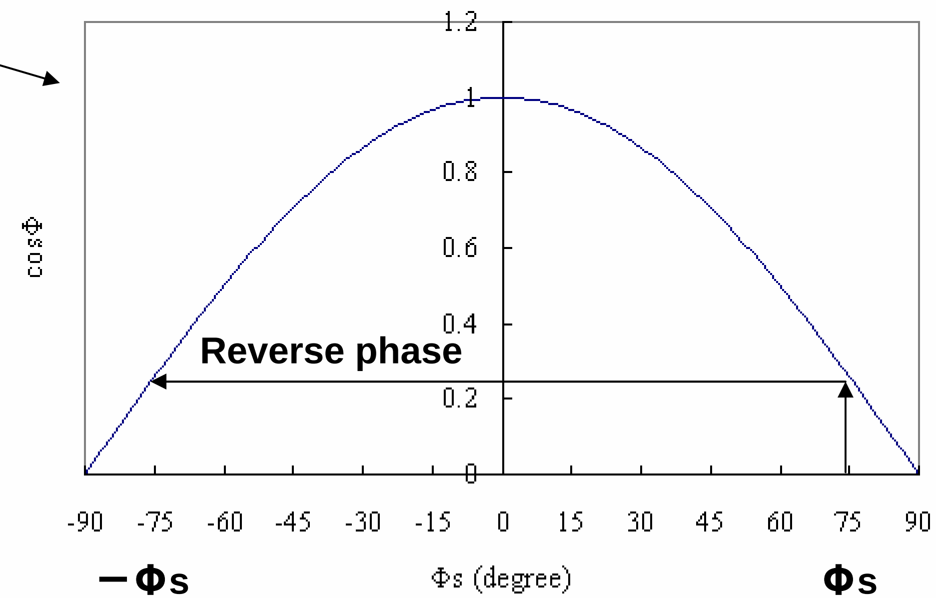


Date	Beam Study
June 26	Low current study @ 150 mA Synchrotron tune Bunch length Beam loading
Nov. 25	High current study up to 930 mA
Dec. 18	High current study up to 1 A
Dec. 18-24	Test operation

Voltage and phase settings



How to set $-\Phi$



How to set V and Φ

$$V_c \cos\phi_s = \frac{8}{8} V_c' \cos\phi_s'$$

$$V_c \sin\phi_s = \frac{6}{8} V_c' \sin\phi_s'$$

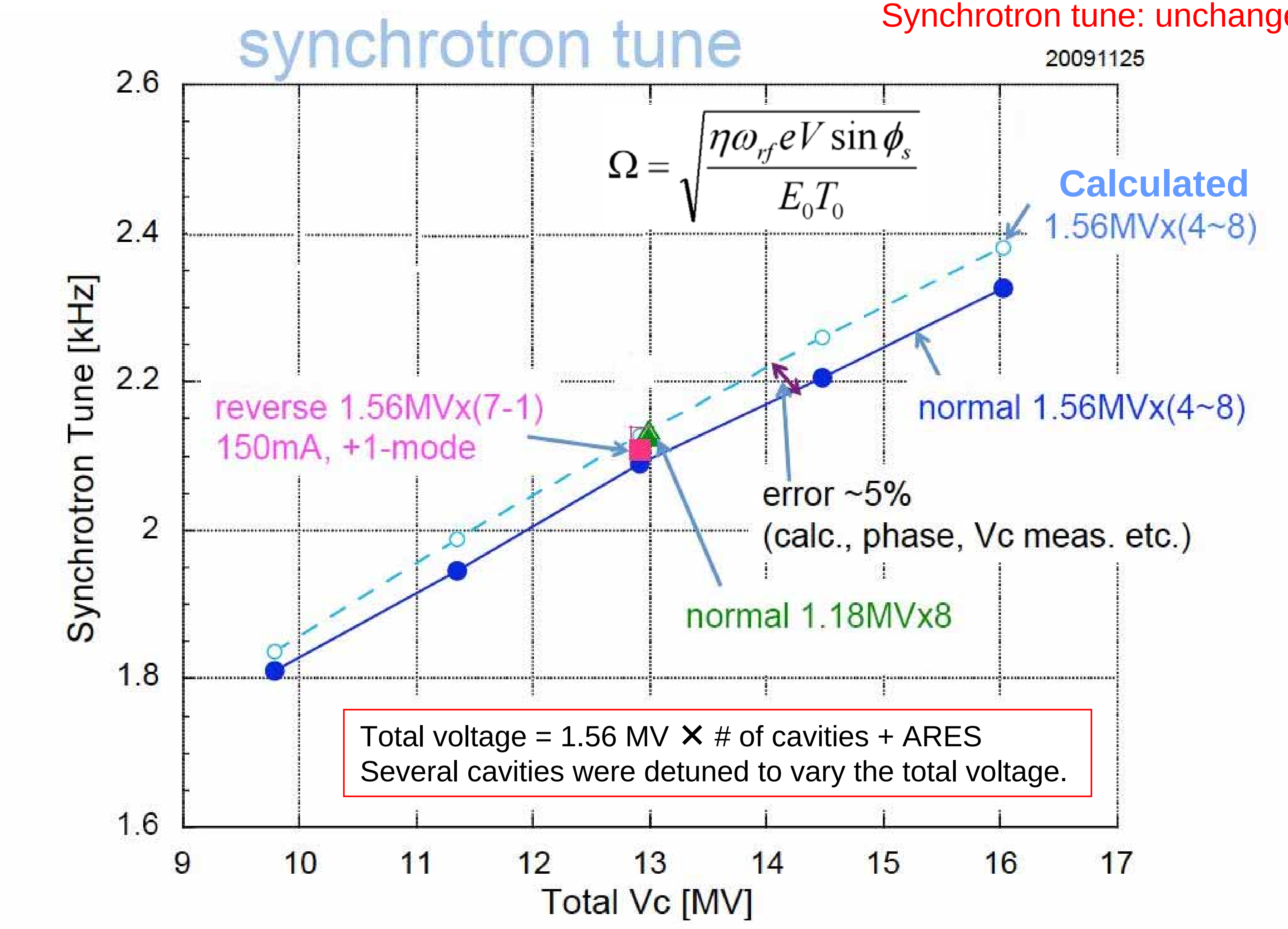
$$V_c' : 1.18 \rightarrow 1.56 MV$$

$$\phi_s' \rightarrow \phi_s + 3.1^o$$

$$\phi_s' \rightarrow -(\phi_s + 3.1^o)$$

date	energy	phase shift	Φs
2009/6/26	4S	165.2	82.6
2009/11/25	2S	168.2	84.1
2009/12/18	5S	161.7	80.8
2009/12/21	4S off res	164.7	82.3

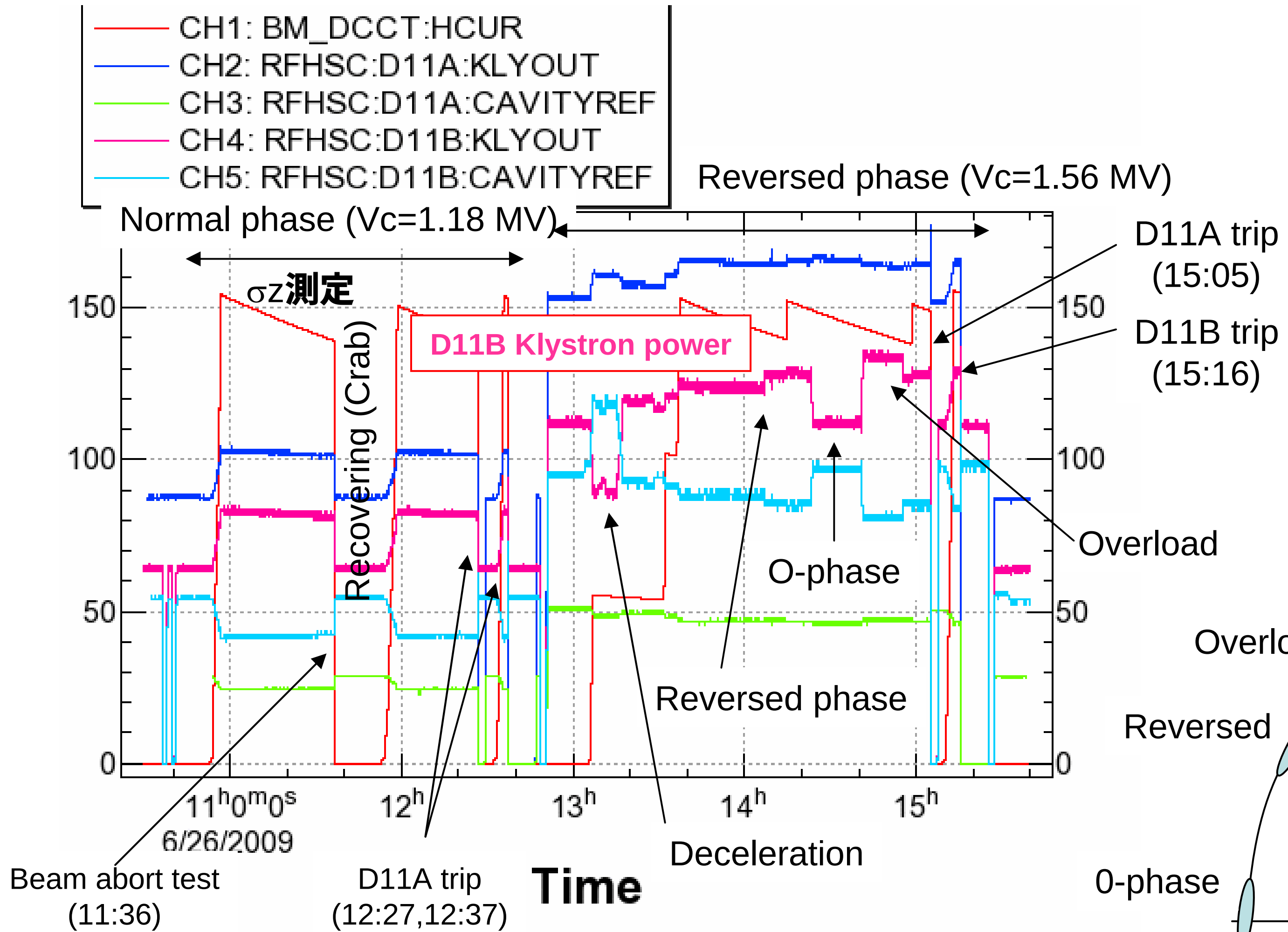
Synchrotron tune: unchanged

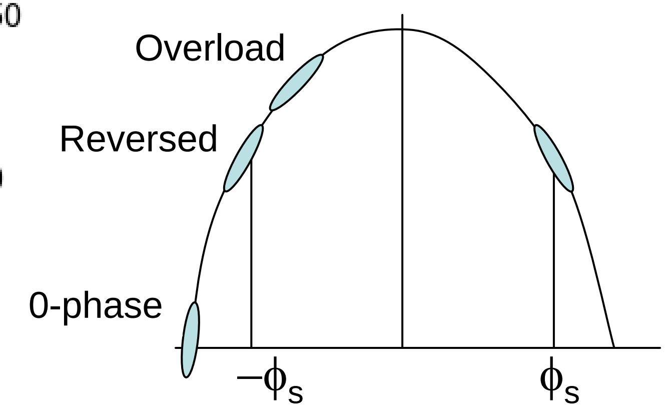


Total voltage = 1.56 MV ✕ # of cavities + ARES
Several cavities were detuned to vary the total voltage.

Beam loading

Beam loading of the reverse phase cavity can be controlled.

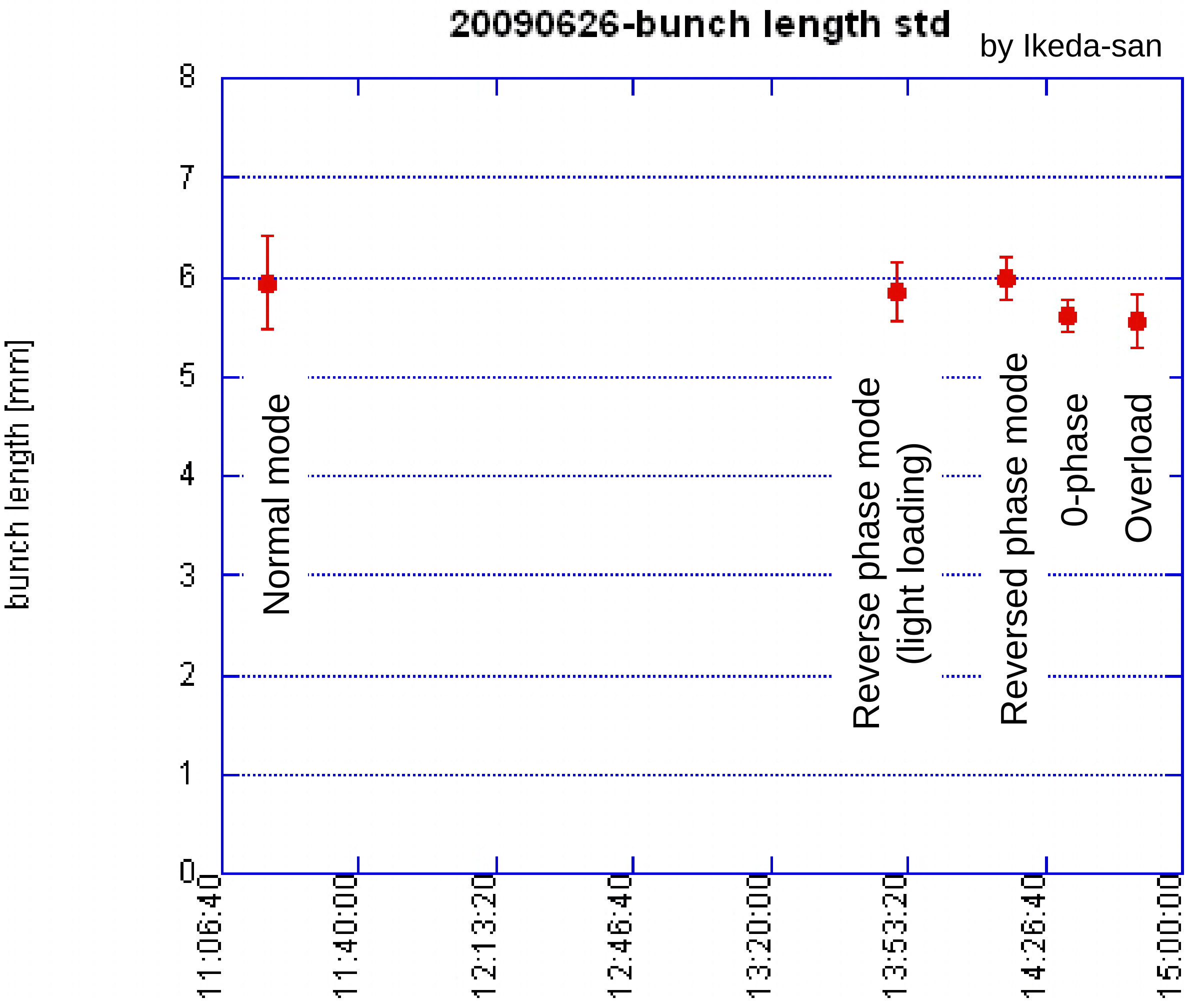




Bunch length

Bunch length: unchanged

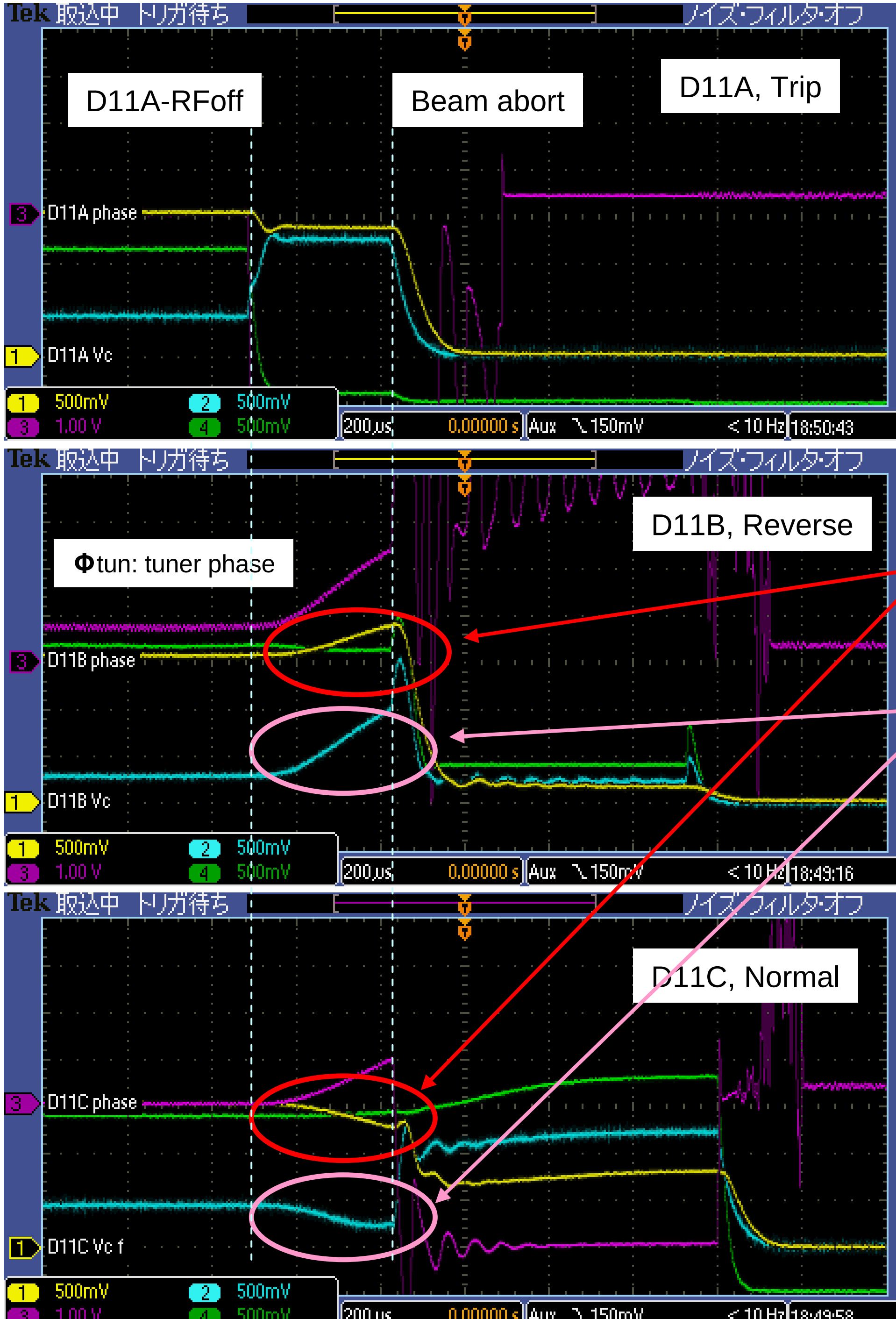
$$\sigma_z = \frac{c\eta\sigma_\varepsilon}{\Omega E_0}$$



2009/11/25 by Flanagan-san
@ 150 mA

Forward phase	6.74 +/- 0.01
Reverse phase	6.71 +/- 0.01

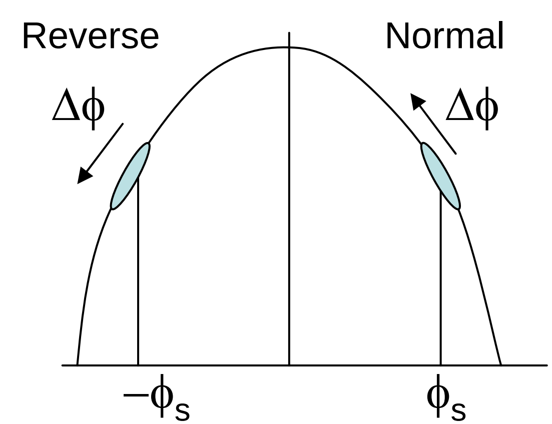
Pin, Pr, Vc, ϕtun variations at D11A trip
Beam current：1A



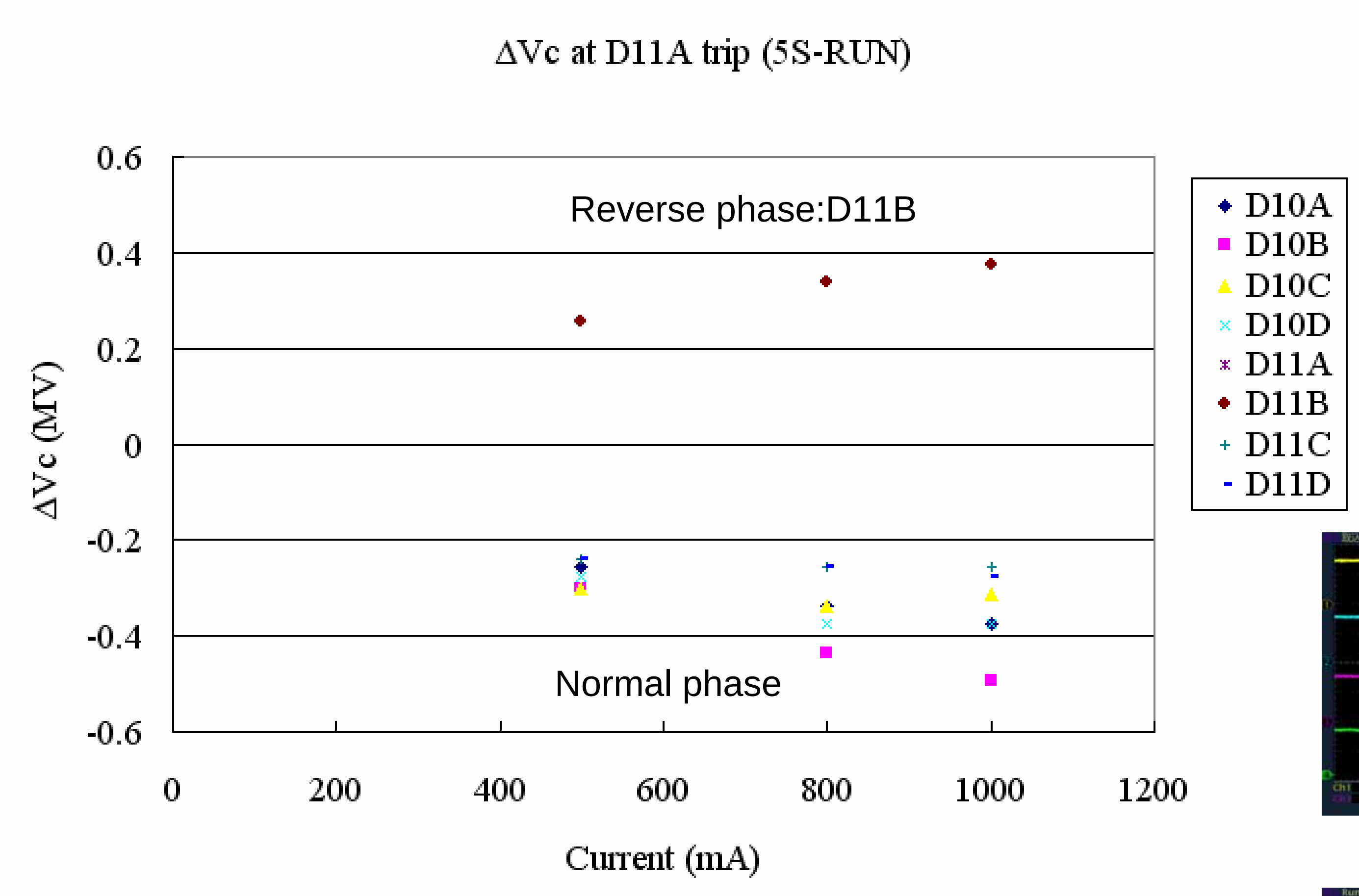
Voltage:Vc

Reflected power: Pr

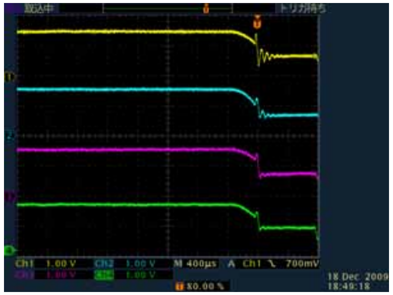
Vc: D11B:increased
D11C:decreased
Pr: D11B:increased
D11C:decreased
Φtun ~30 deg.
Pin: not significantly changed



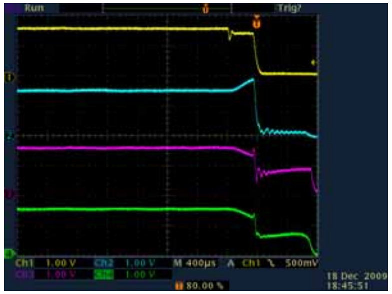
ΔVc at D11A trip (5S-RUN)



Abort LOG D10



Abort LOG D11

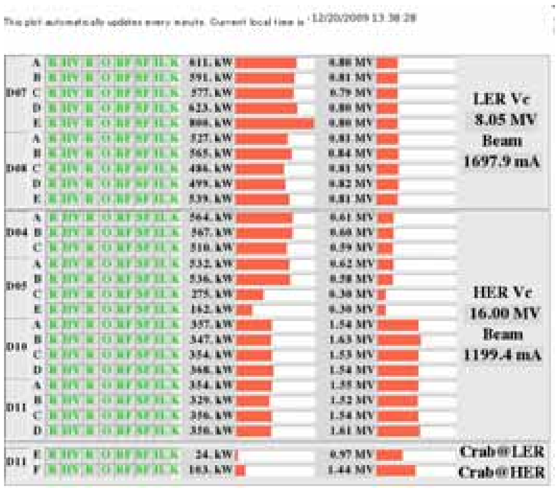


Voltage variation at D11A trip
The reversed cavity increased the voltage.
Other normal phase cavities decreased voltages.

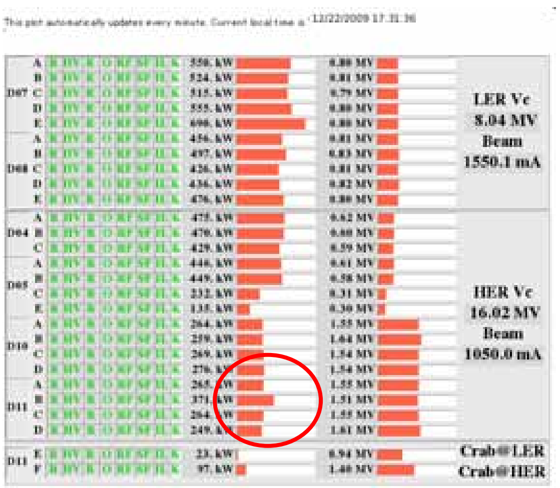
Luminosity RUN

- Luminosity RUN with reverse phase operation
  - Dec. 18 to 24
  - Stably operated
    - No beam abort caused by the cavity trip
    - Beam current: 1200 mA
    - RF power delivered to beam: ~300kW/caviyty
  - Energy change from 5S to 4S(off resonance)
    - D11B: Overload due to beam phase change
    - Phase adjustment

Klystron powers at 5S-RUN@1200mA

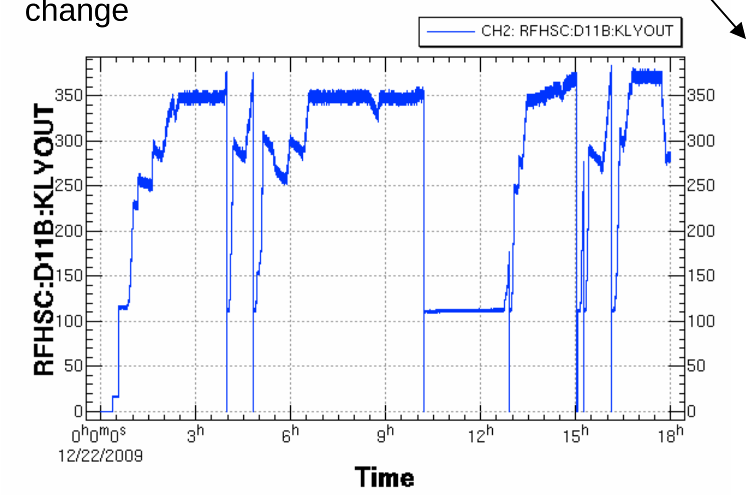


At 4S-RUN



Overload

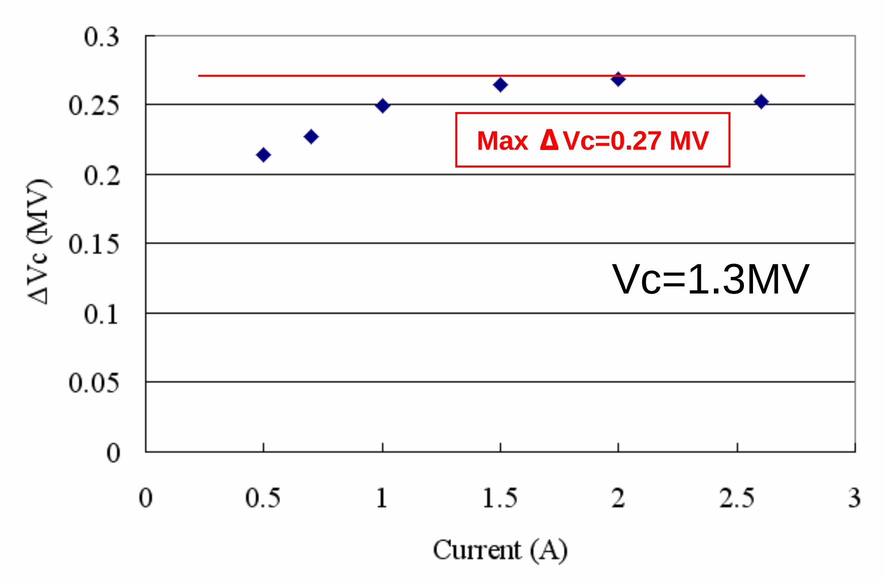
Klystron power >350 kW due to beam phase change



Reverse phase operation in Super-KEKB

Voltage and phase settings

State	# of cavities	Beam Current	Vc	Φs	Beam power	Detune
Normal	5	2.6 A	1.3 MV	±83°	400 kW	47 kHz
Reverse	3					



The tuner phase variation was assumed (30 deg./A).
The maximum voltage variation is +0.27 MV at a beam current of 2A.
This variation is acceptable for the superconducting cavities.

Summary of the reverse mode study

- Feasibility studies for reverse phase operation
  - Voltage and phase settings：Yes we can!
  - Synchrotron tune： unchanged
  - Bunch length: unchanged
  - Beam loading: well controlled
  - Beam acceleration: very stable
  - At cavity RF trips
    - No uncontrollable behavior observed
    - Positive voltage variation but acceptable
  - Luminosity RUN for five days
    - No beam abort caused by the cavity trip
    - Beam current of 1200 mA stored with beam power of 300 kW

We conclude reverse phase operation for Super-KEKB is possible !

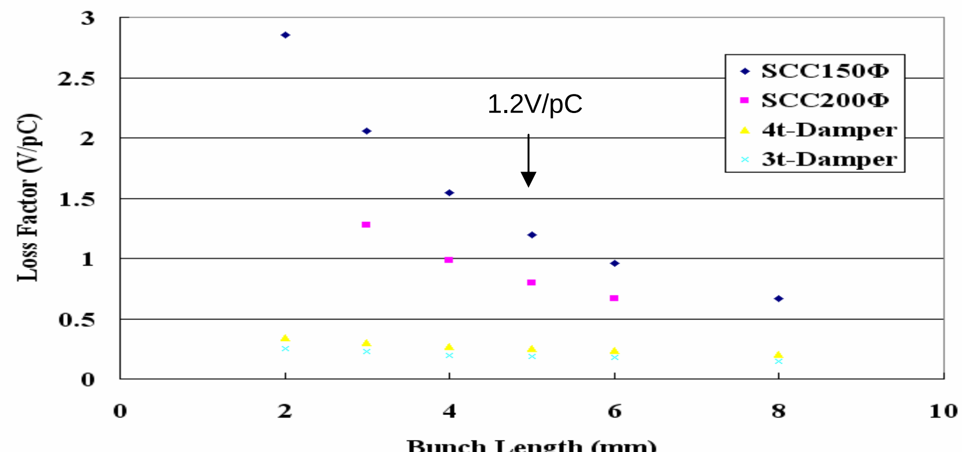
Expected HOM powers in the Super-KEKB

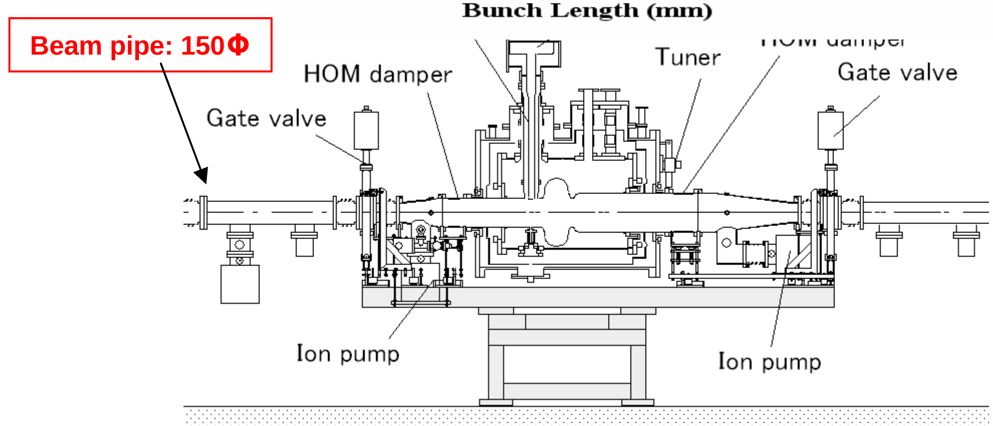
HOM dampers for high power application

- Expected HOM powers
  - at 2 A, 19 kW+ damper loss (8 kW)
  - at 2.6 A, 32 kW+ damper loss (13 kW)

Parameters of Super-KEKB for HER
Maximum current: 2.6A ←1.4A
Bunch length: 5 mm ←6-7mm
# of bunches: 2500 ←1600

Beam current	SBP load	LBP load
(A)	(kW)	(kW)
2	12	15
2.6	20	26



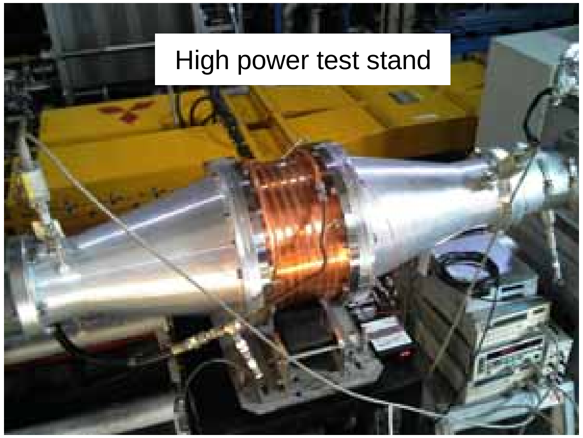


We have to develop HOM dampers for higher currents than 2 A !

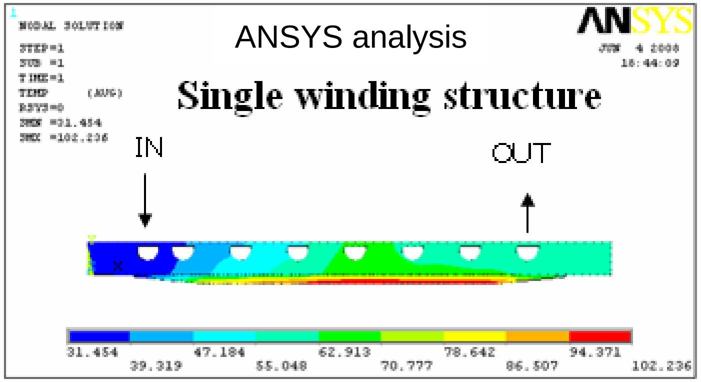
Development of new dampers for high current application

In order to reduce outgas of the HIPped ferrite material, surface temperature of the ferrite has to be suppressed. HOM damper design was modified.

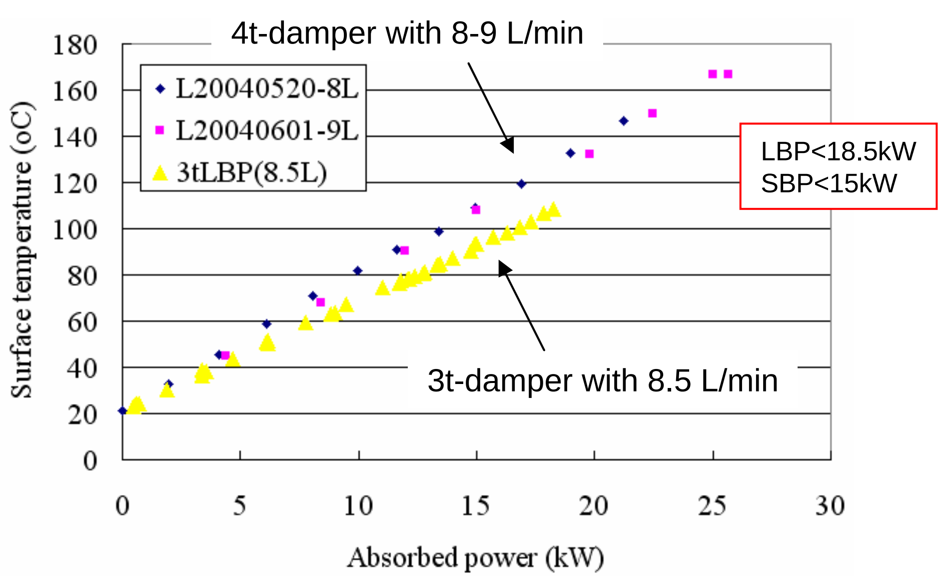
- Reduce thickness of the ferrite material form 4t to 3t.
- Make a double winding structure of the cooling channel.

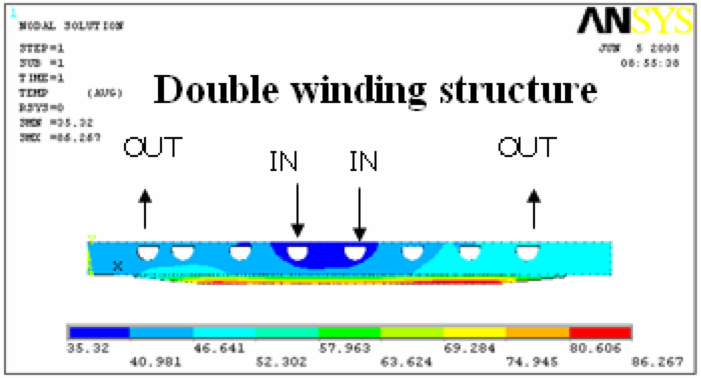


HOM dampers with a ferrite thickness of 3 mm were made and tested. Temperature rise was reduced by 25%. A double winding structure is expected to further reduce the temperature rise by 15 %. Dampers of this type are being fabricated. With those modifications, the LBP dampers can absorb 26 kW with surface temperature less than 120 ℃.



Absorbed power vs. surface temperature

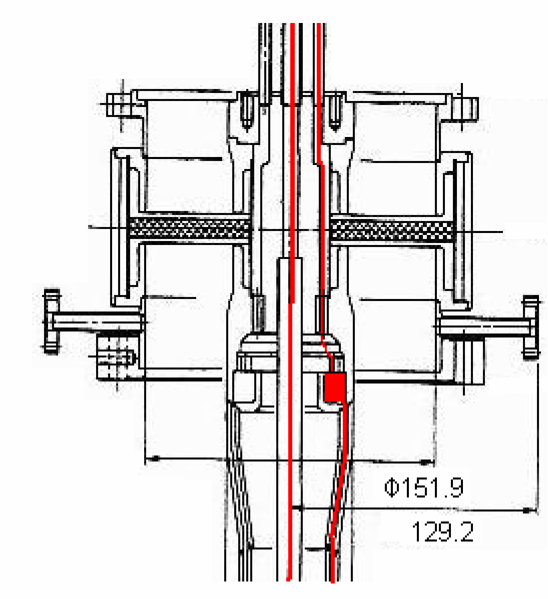


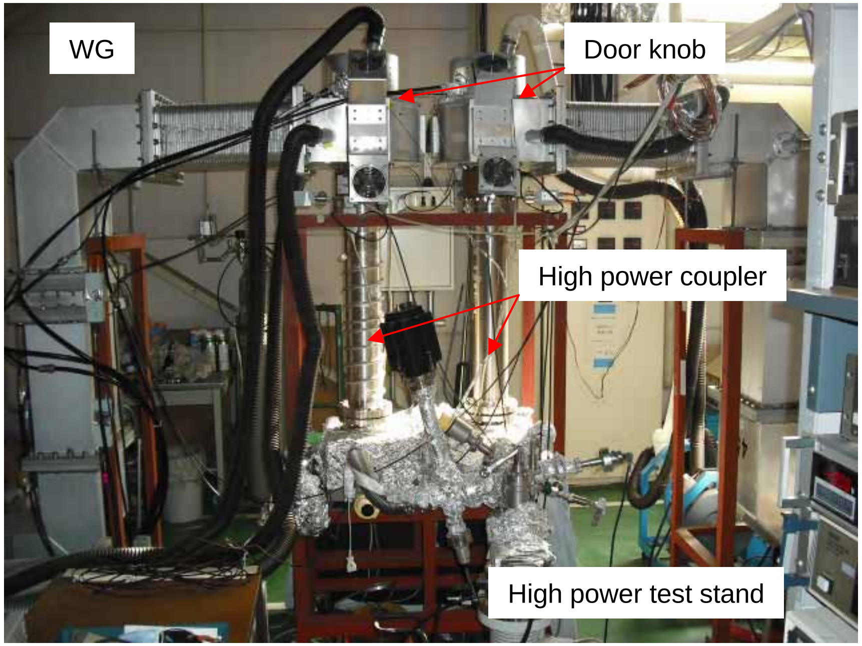


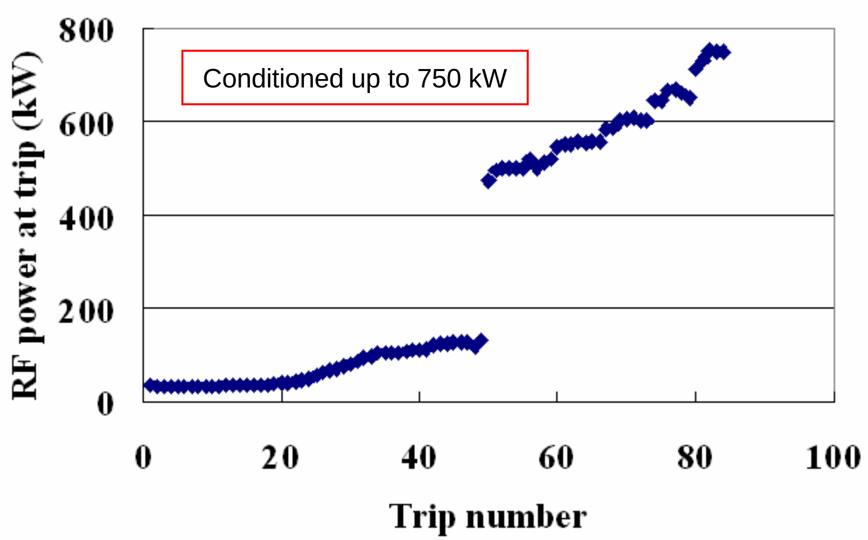
Development of input couplers for higher beam loadings

Although the present input couplers satisfy RF power requirements for Super-KEKB, it is desirable to continue to develop couplers for high RF power application.

New KEKB high power coupler.
This coupler has a single cooling water path to increase cooling capacity and also to reduce fabrication cost. A coupler of this type has been fabricated and RF tested up to 750 kW.







Summary

- Feasibility studies for the reverse mode were conducted
- We conclude the reverse phase mode can be applied for the Super-KEKB
- A modified HOM dampers were designed for high power applications.
  - Reduce ferrite thickness from 4 mm to 3 mm
  - Make double winding structure
  - Applied for higher currents than 2A
- We continue to develop input couplers for high power application.