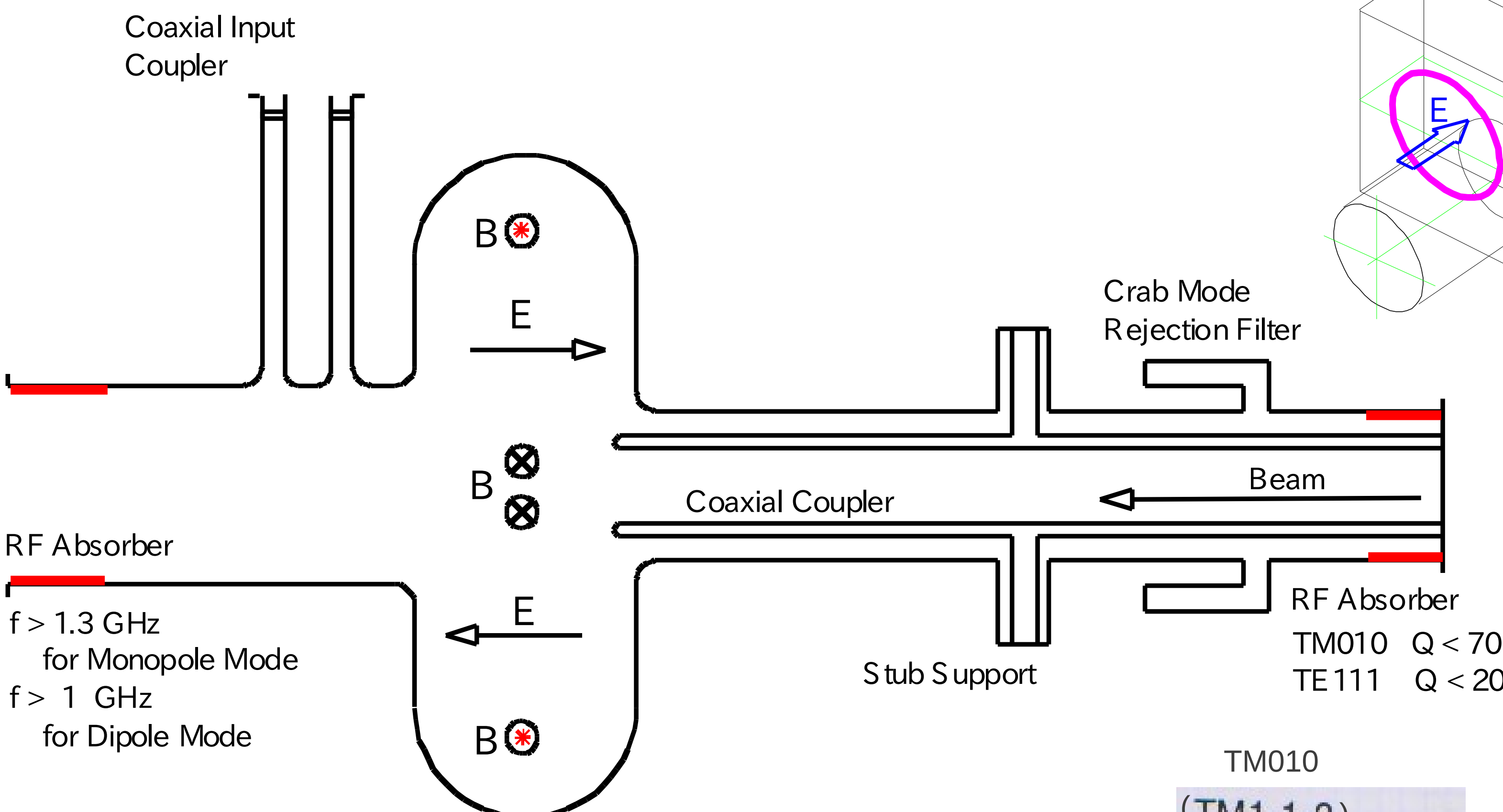
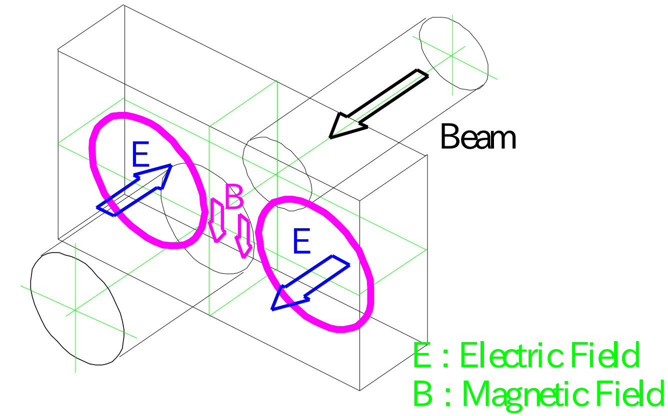
KEK Crab Cavity Experience

- Baseline design of the KEKB crab cavity
- Test results before installation.
- Beam test
  (beam spectrum, Gas absorption, Maintenance)
  (LLRF oscillation, Kick the mass center)

- Summary

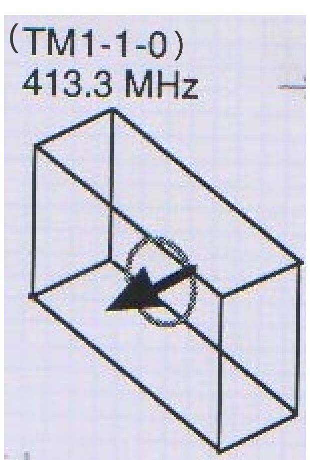
Baseline design of KEKB crab cavity



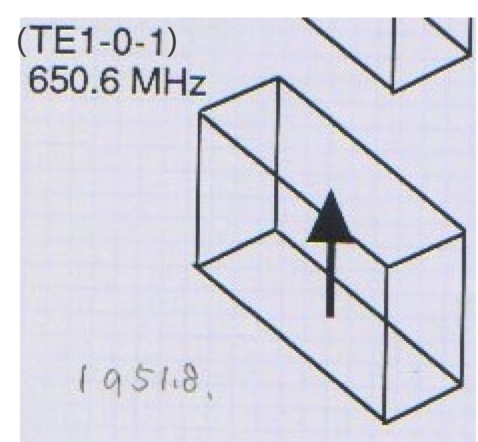


TM110
(TM210)
509MHz

TM010



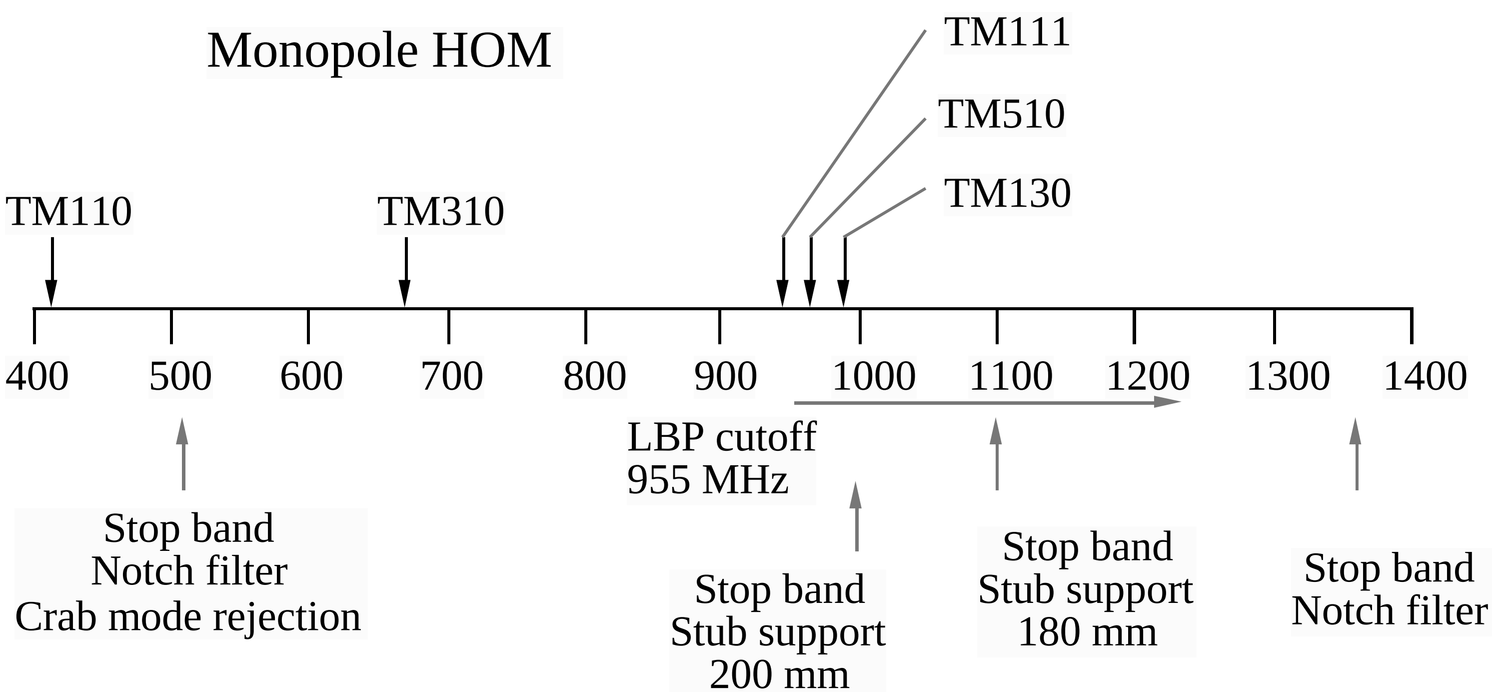
TE111



The baseline design of the KEKB crab cavity was developed by K.Akai at cornel univ in collaboration with cornel univ.

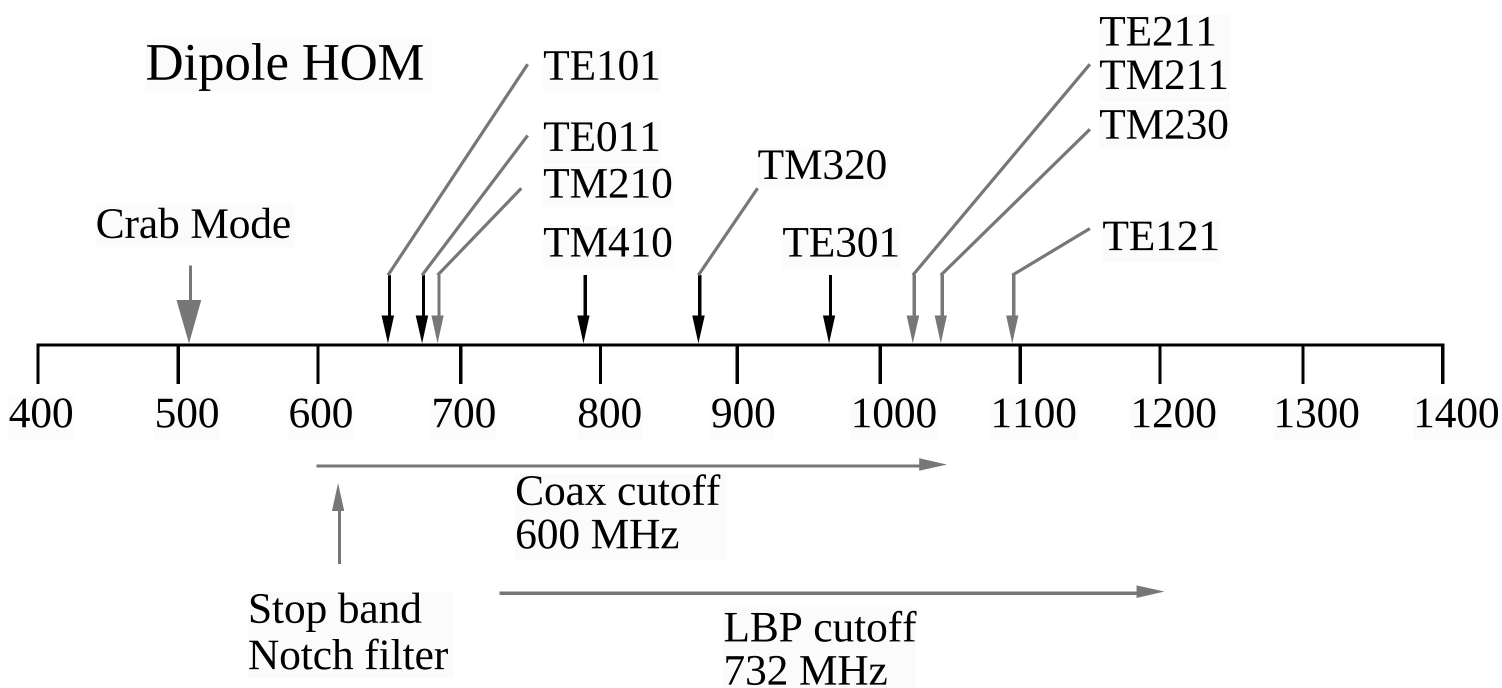
Mode identified Cylindrical coordinate
(Cartesian coordinate)

Adjustment of Stop Band for Monopole Modes



Y.Morita
(Mode identified by Cartesian coordinate)

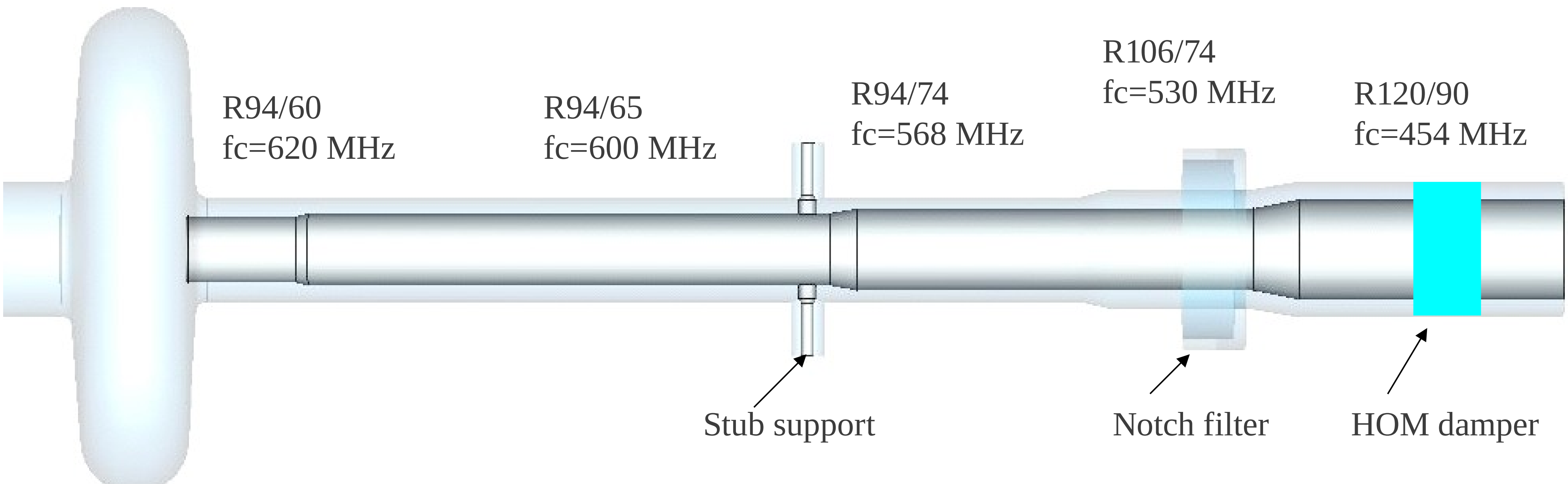
Adjustment of Stop Band for Dipole Modes



Y.Morita
(Mode identified by Cartesian coordinate)

Tapered coaxial coupler design

Coaxial coupler has several tapered sections.
Decrease cut-off frequency (fc) for TE-mode propagation.

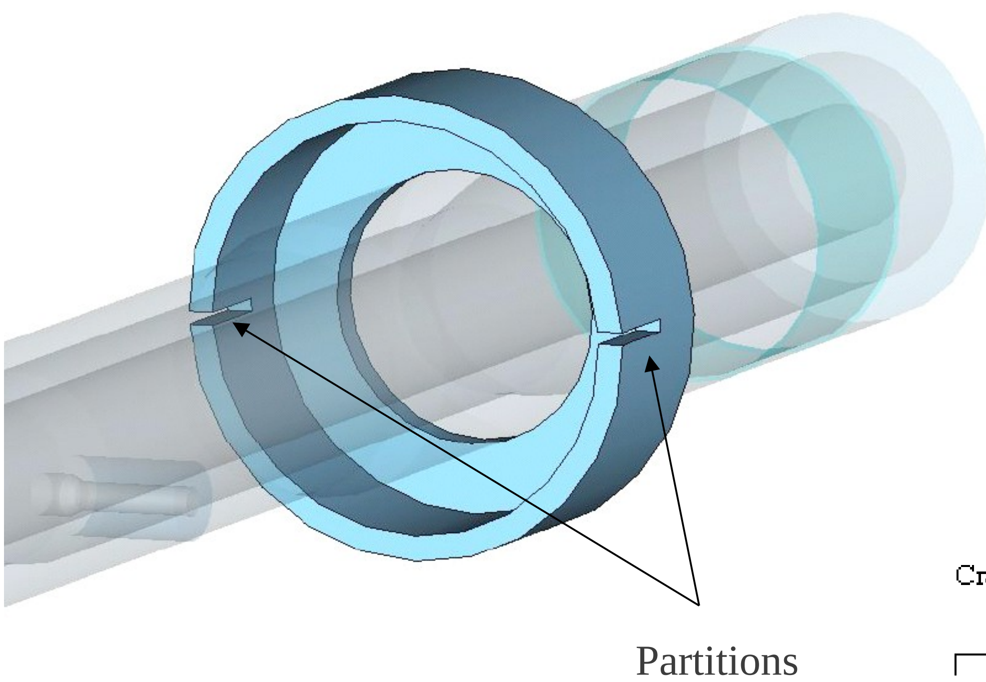


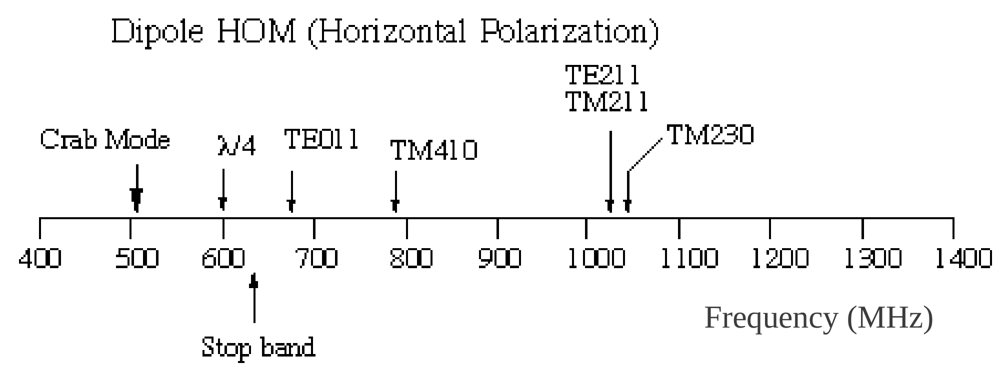
Y.Morita

Y.Morita
(Mode identified by Cartesian coordinate)

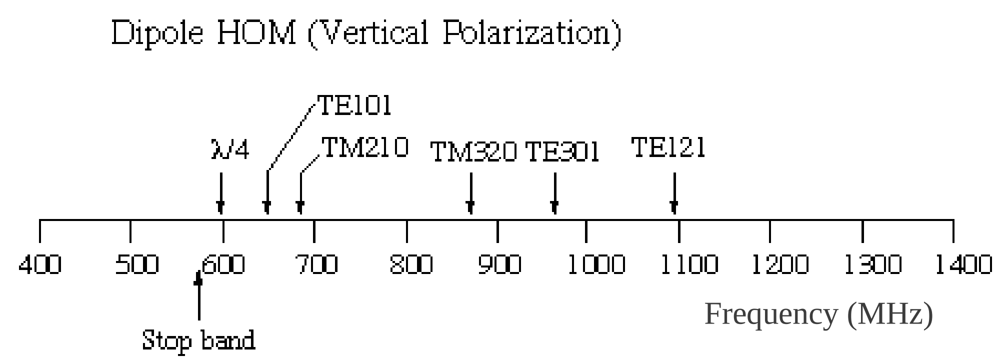
Stop band splitting design of the notch filter

Previous design has a stop band at 630 MHz for TE mode. This band is close to the TE-1/4λ mode.
Stop band splitting notch filter has partitions in mid-plane to separate stop bands for horizontally polarized TE mode (650 MHz) and vertically polarized one (570 MHz).



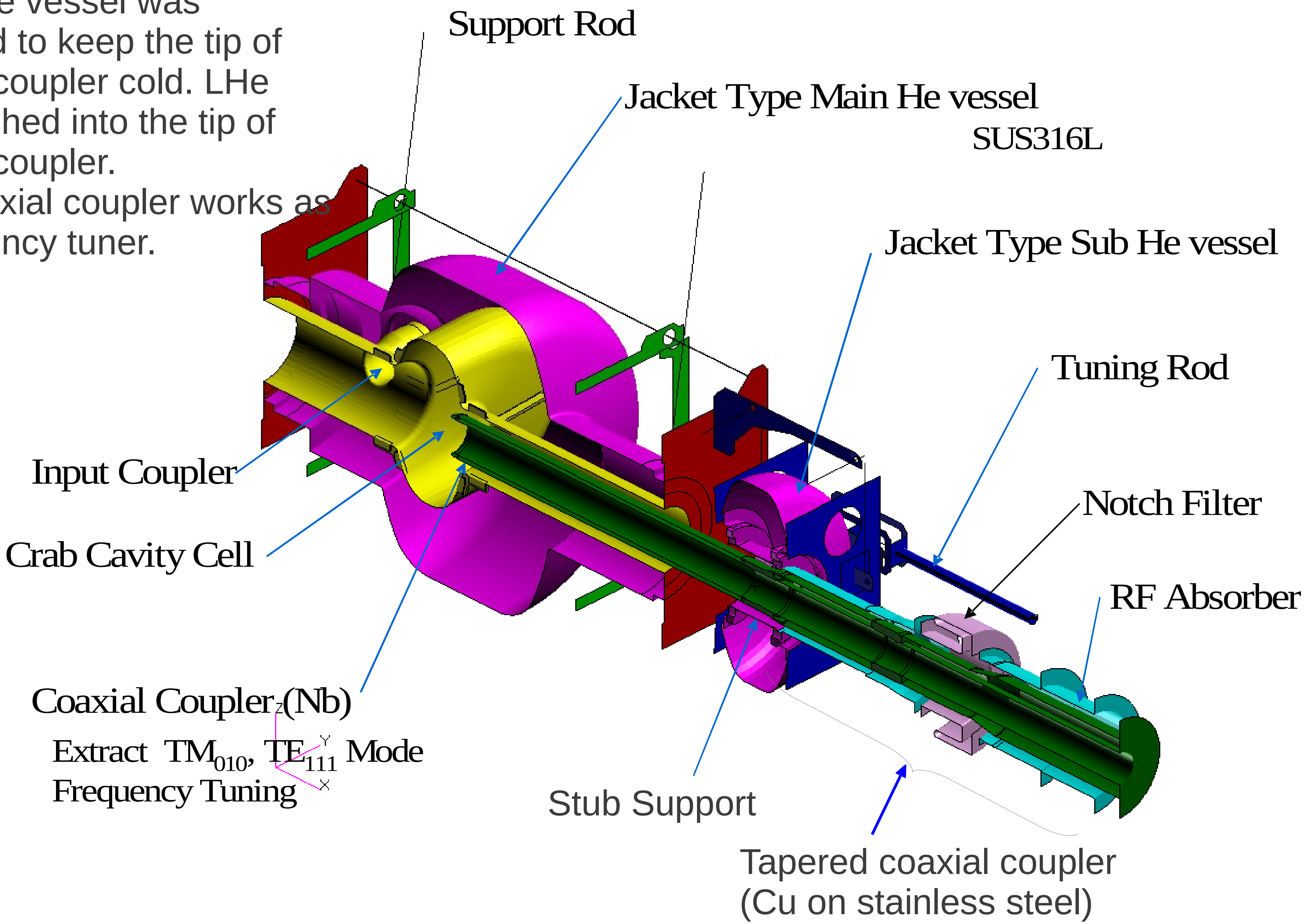


Stop band (H-V splitting)	
TEM	509 MHz
TE(H)	650 MHz
TE(V)	570 MHz



Actual design of KEKB crab cavity

A sub He vessel was attached to keep the tip of coaxial coupler cold. LHe was pushed into the tip of coaxial coupler.
The coaxial coupler works as a frequency tuner.

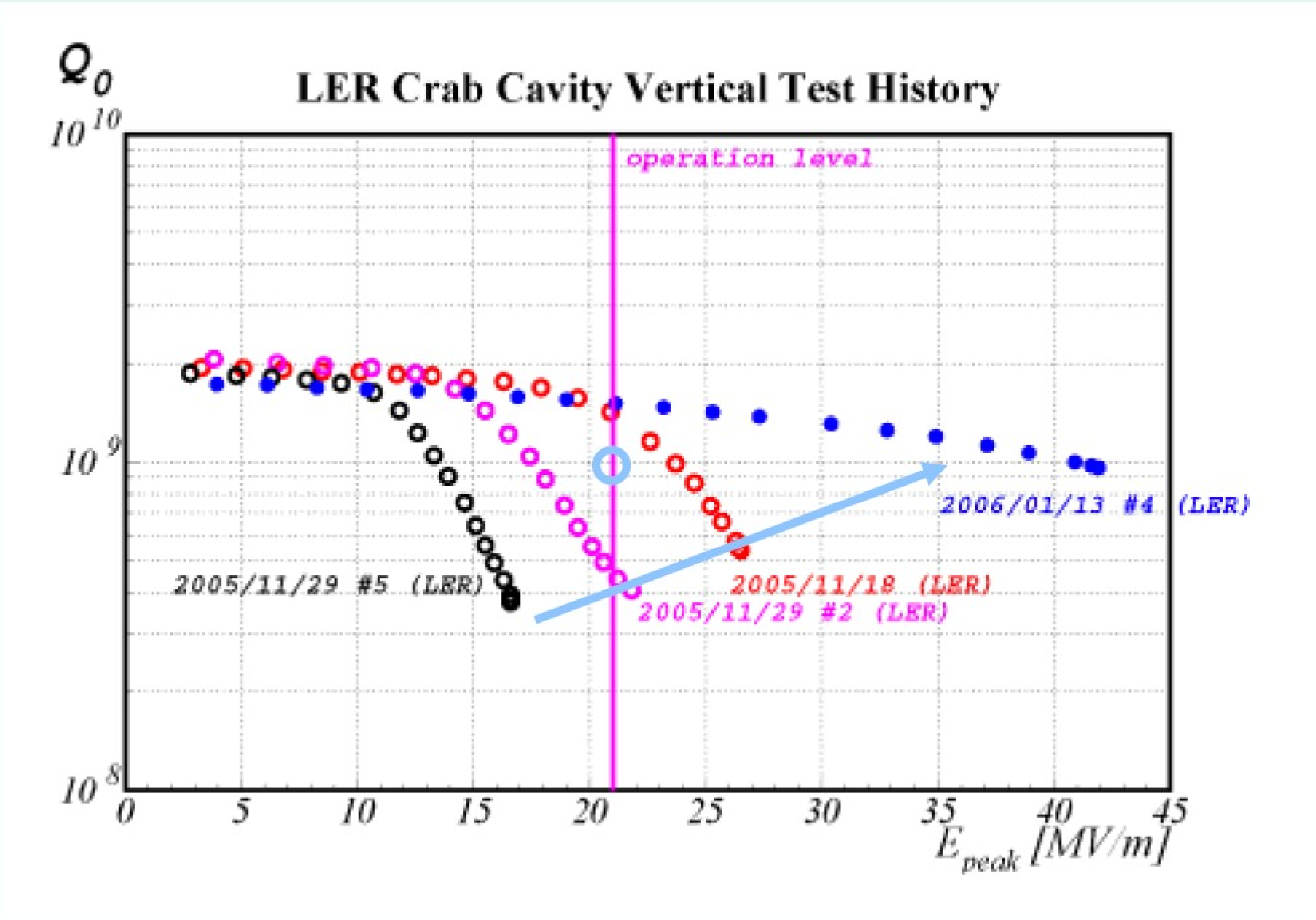


Surface treatment

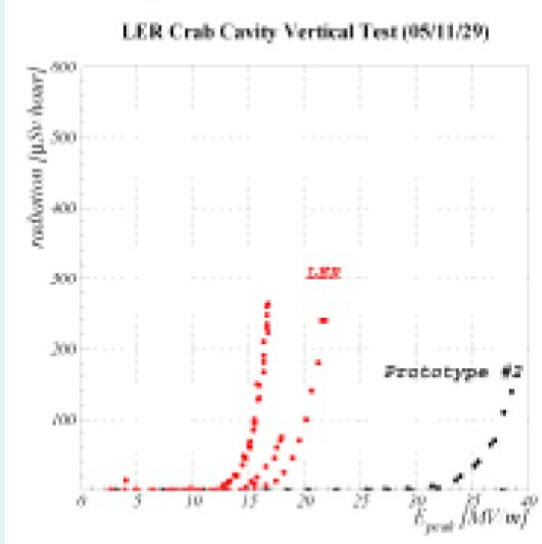
The surface treatment was adopted the standard procedure.
Almost tool and facility were available.   (tesla cavity, KEKB scc)

If the cavity property is below the required value,
The cavity go back to some phase.

Test Result   Crab Cavity #LER



X-Ray



Nov. 18   1st Test

↓

H.P.R.

↓

Nov. 29   2nd Test

Field Emission

EP2

A emitter
was found.

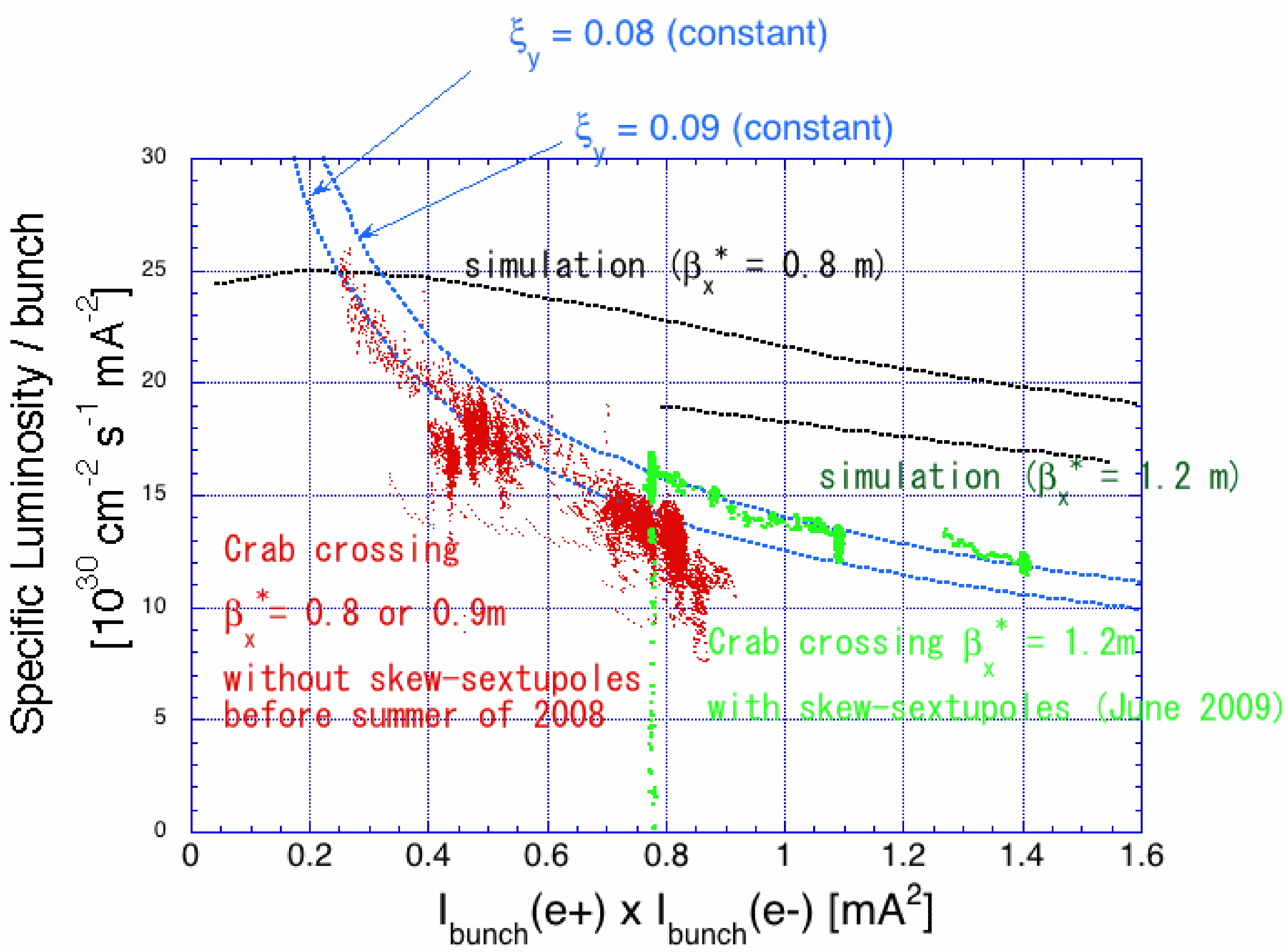
↓

Jan. 13 Test

Recovered !

K.Hosoyama

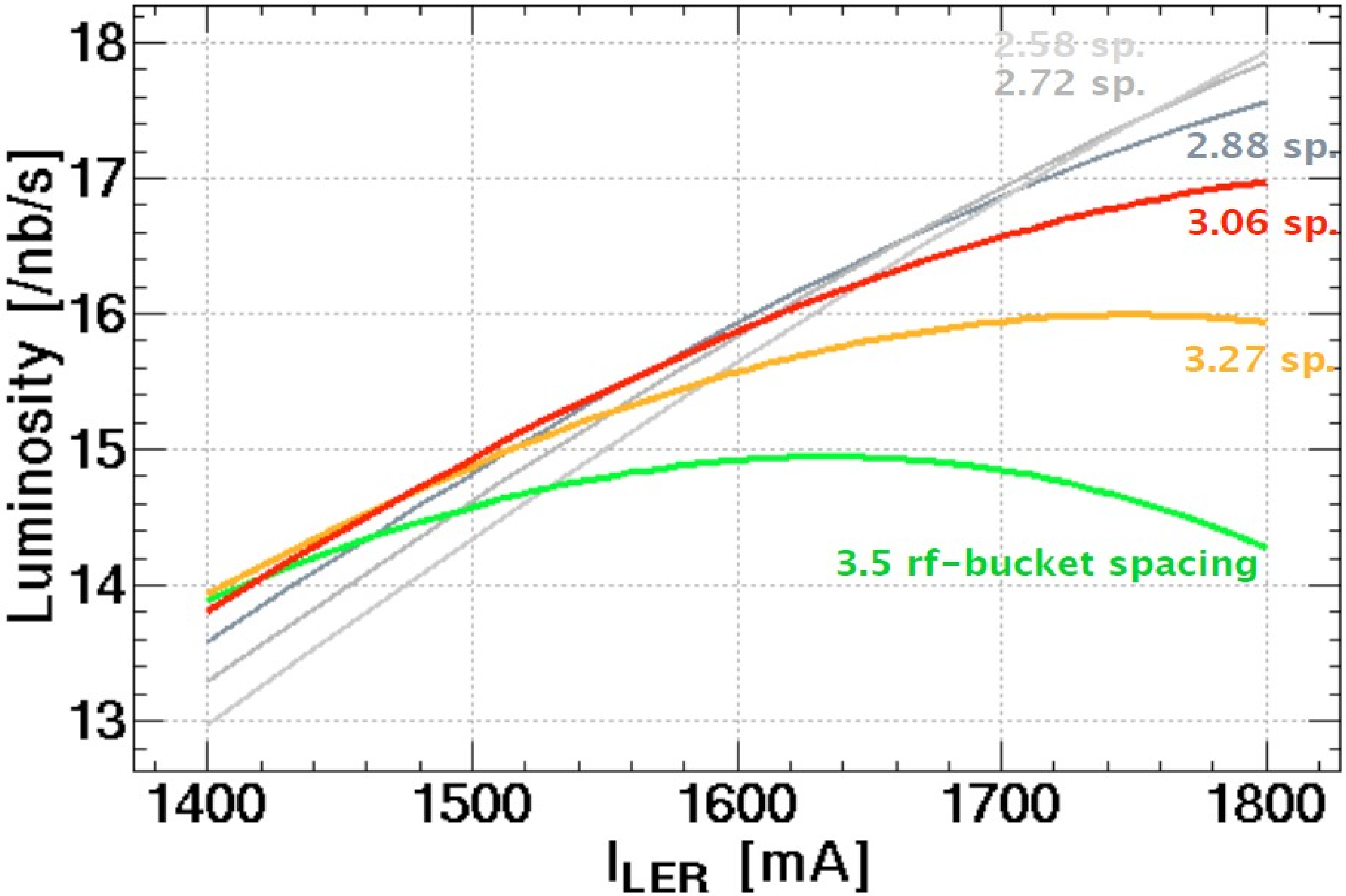
Specific luminosity with fewer number of bunches (200 bunches/beam)



Bunch number optimization

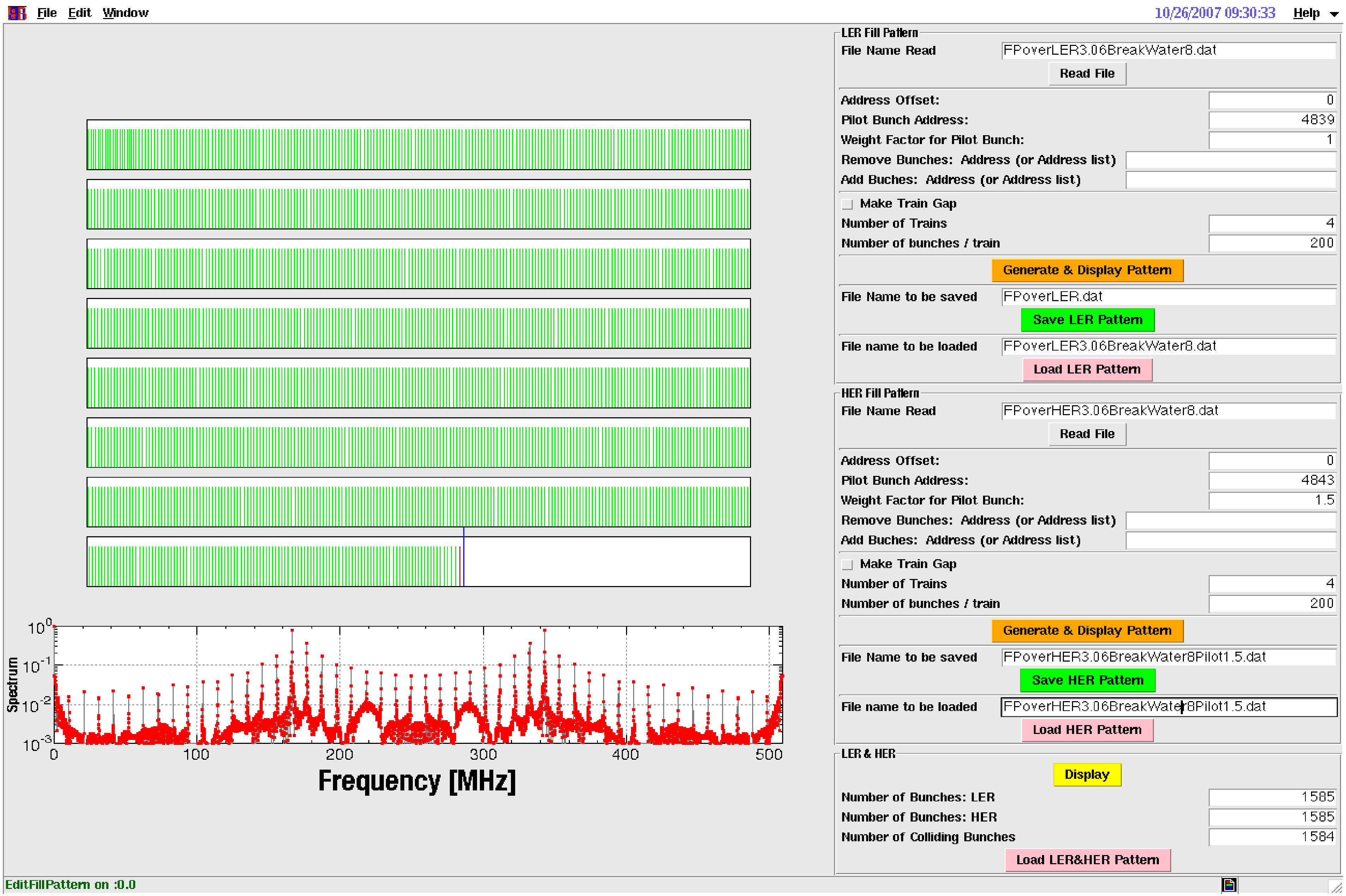
To make higher luminosity, the bunch number was optimized.
3.5 rf-bucket spacing was ordinary bunch pattern before install the crab cavities.

To change the fill pattern was required to make high luminosity.

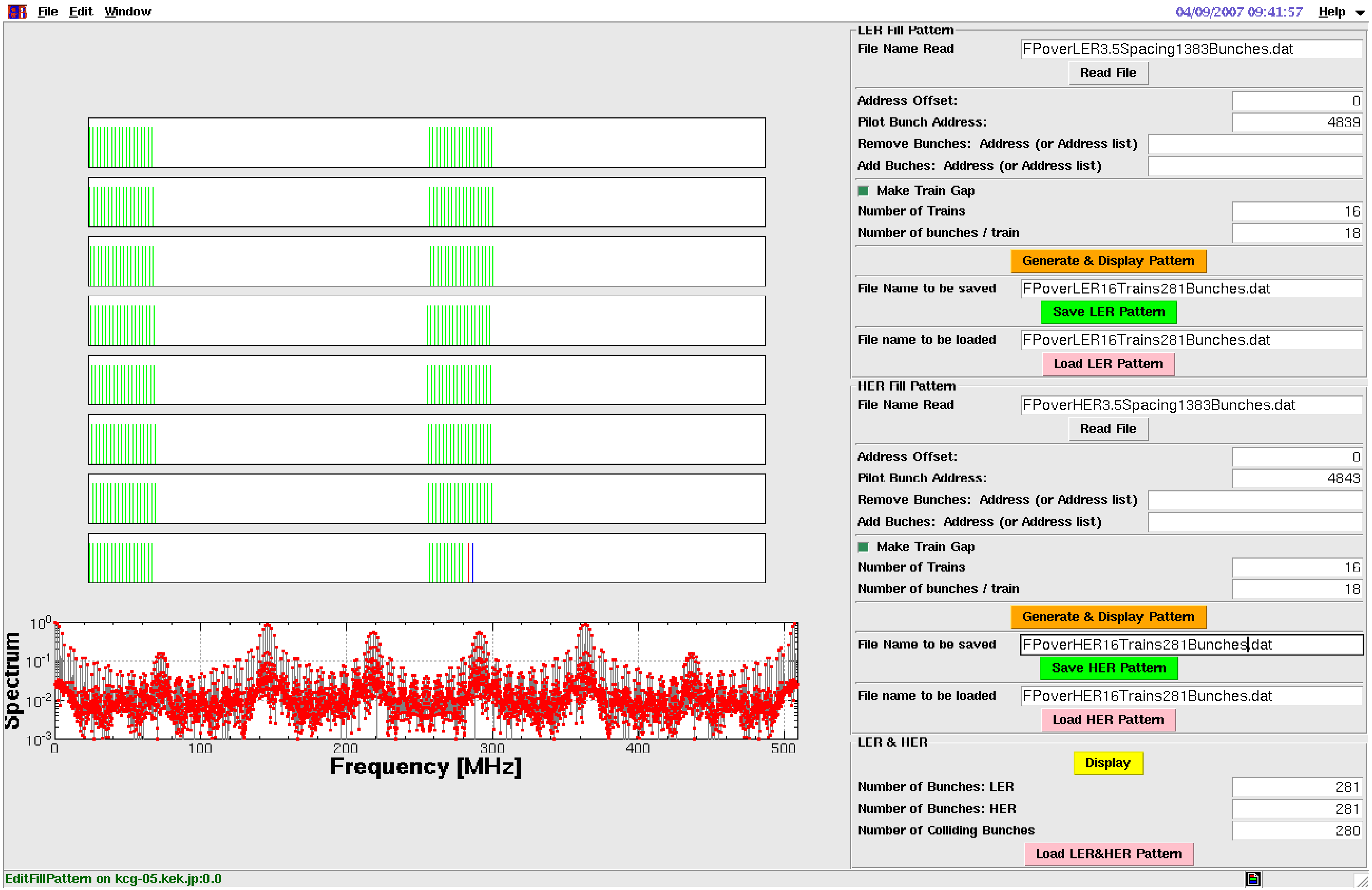


Beam spectrum of 3.5 rf-backet spacing

Beam spectrum of 3.06 rf-backet spacing



Beam spectrum of special pattern for machine study



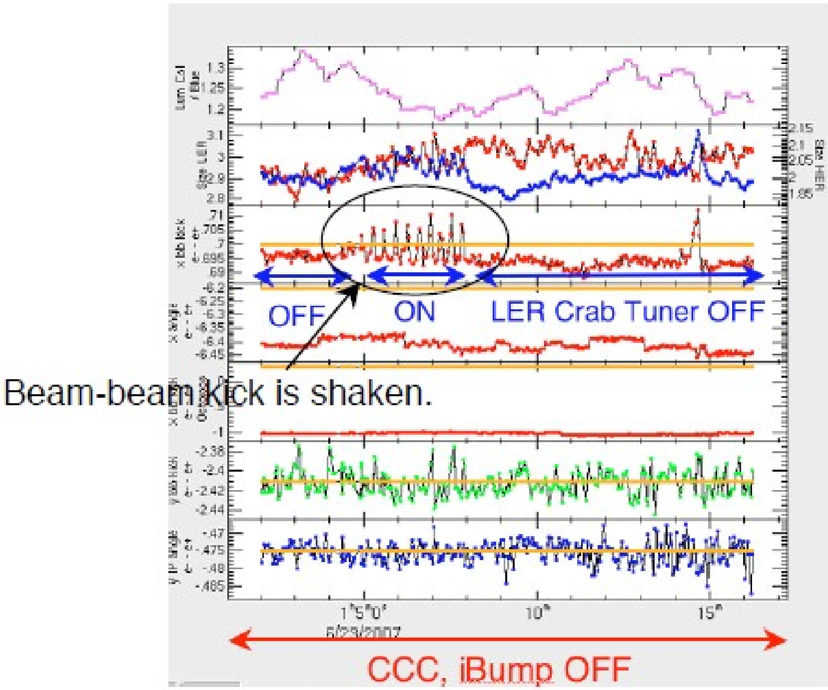
Beam spectrum

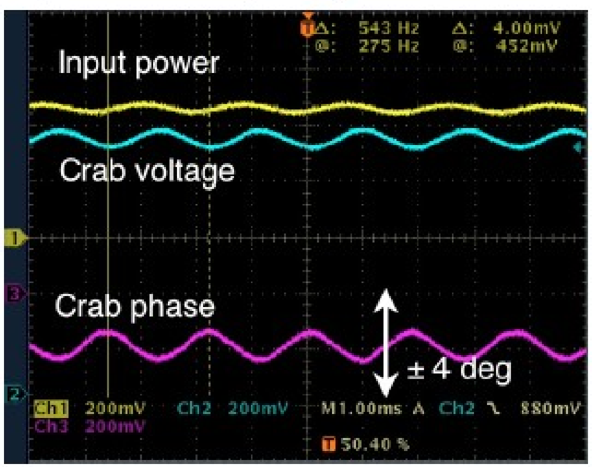
- The cavity vacuum was deteriorated, and the frequency of the cavity break down was increased just after change the fill pattern.
- If some specific mode was excited, the cavity vacuum was deteriorated even the cavity was detuned.

Maintenance

- Regular maintenance day was held every 2 weeks.
- If break down occur frequently, aging (commissioning) work was required. Sometimes additional aging was done at first year.
- If additional aging was not sufficiently effective, Cavity warm up was done to remove absorbed gases. (The cavities were warmed up twice in first 2 months)

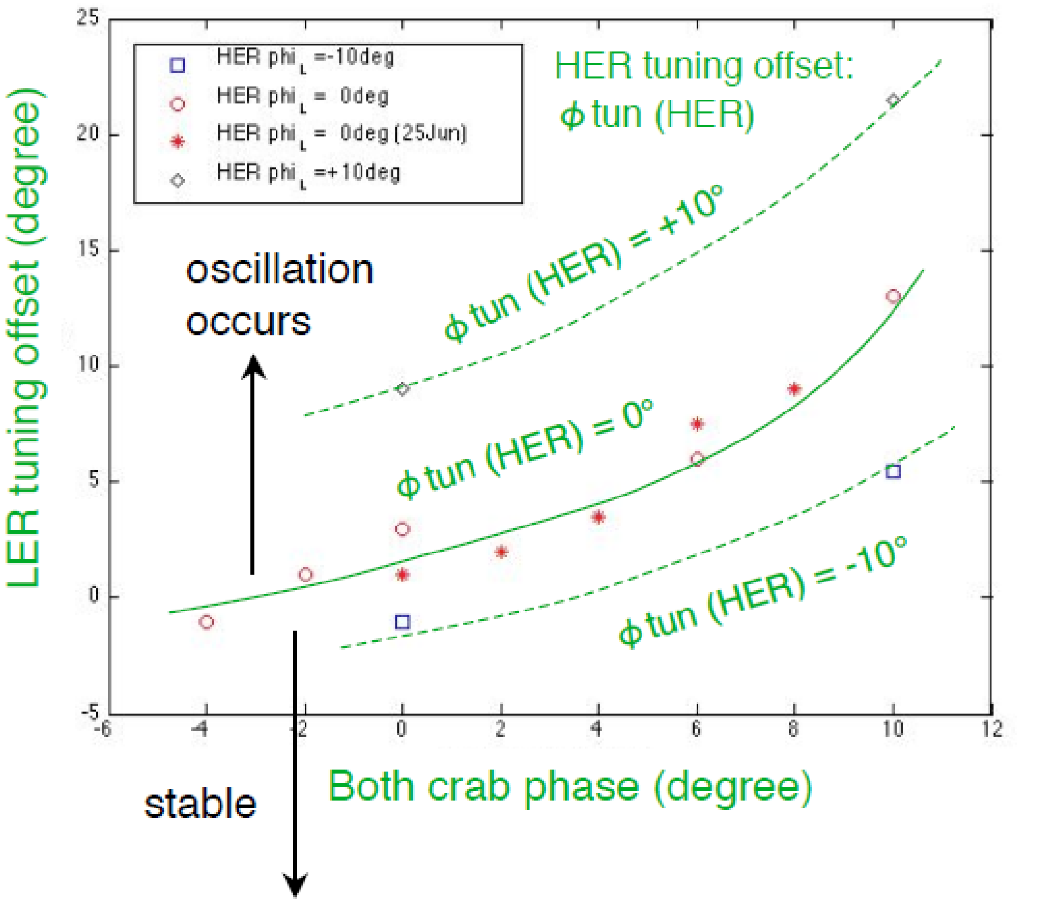
Oscillation of high-current crabbing beams





- A large-amplitude oscillation was observed in high-current crab-crossing operation in June.
  - It caused unstable collision, short beam life time and luminosity degradation.
  - Crab amplitude and phase were modulated at 540 Hz. Horizontal oscillation of beams was also observed at the same frequency.
  - None of the beam orbit feedback systems is responsible, since their time constants are 1 to 20 sec, much slower than the oscillation.
  - The oscillation occurred when the LER tuning phase migrated to the positive side. This gave us a hint to understand the phenomena.

A remedy for the oscillation was found



Dependence on the crab phase and tuning phase.
Beam current was 1150 mA (LER) and 620 mA (HER).

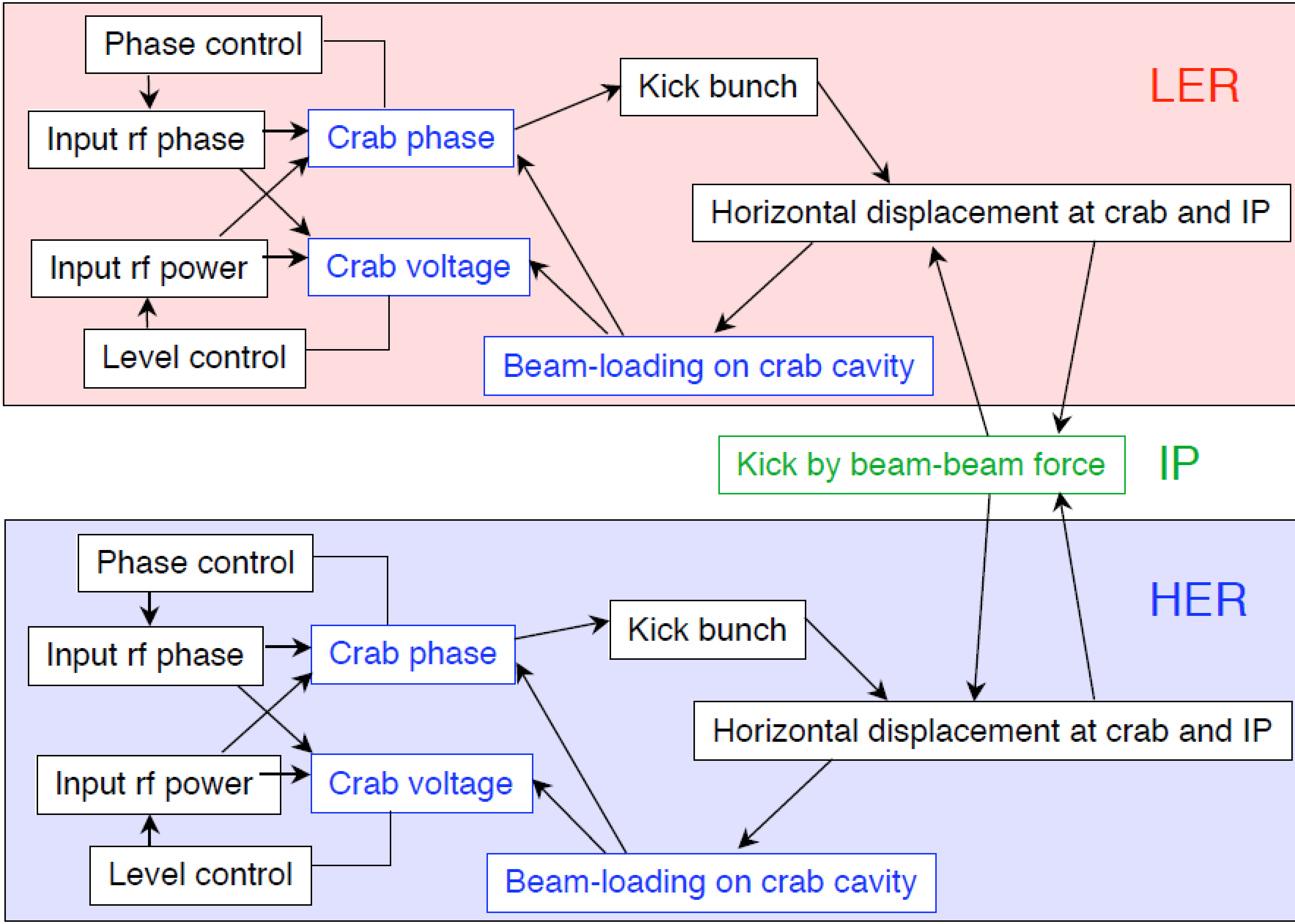
Observations at a machine study

- The oscillation occurred only with high-current colliding beams: it never occurred with a single beam, even at a high current.
- Both beams oscillates coherently.
- The threshold for the oscillation is dependent on the crab phase and tuning phase (see left).

Cause and remedy

- We concluded that the oscillation is caused by beam loading on crab cavities together with beam-beam force at the IP (see, next slide).
- We found that it can be avoided by shifting the crabbing phase by +10° and controlling the tuning offset angle appropriately.

Possible mechanism of the oscillation



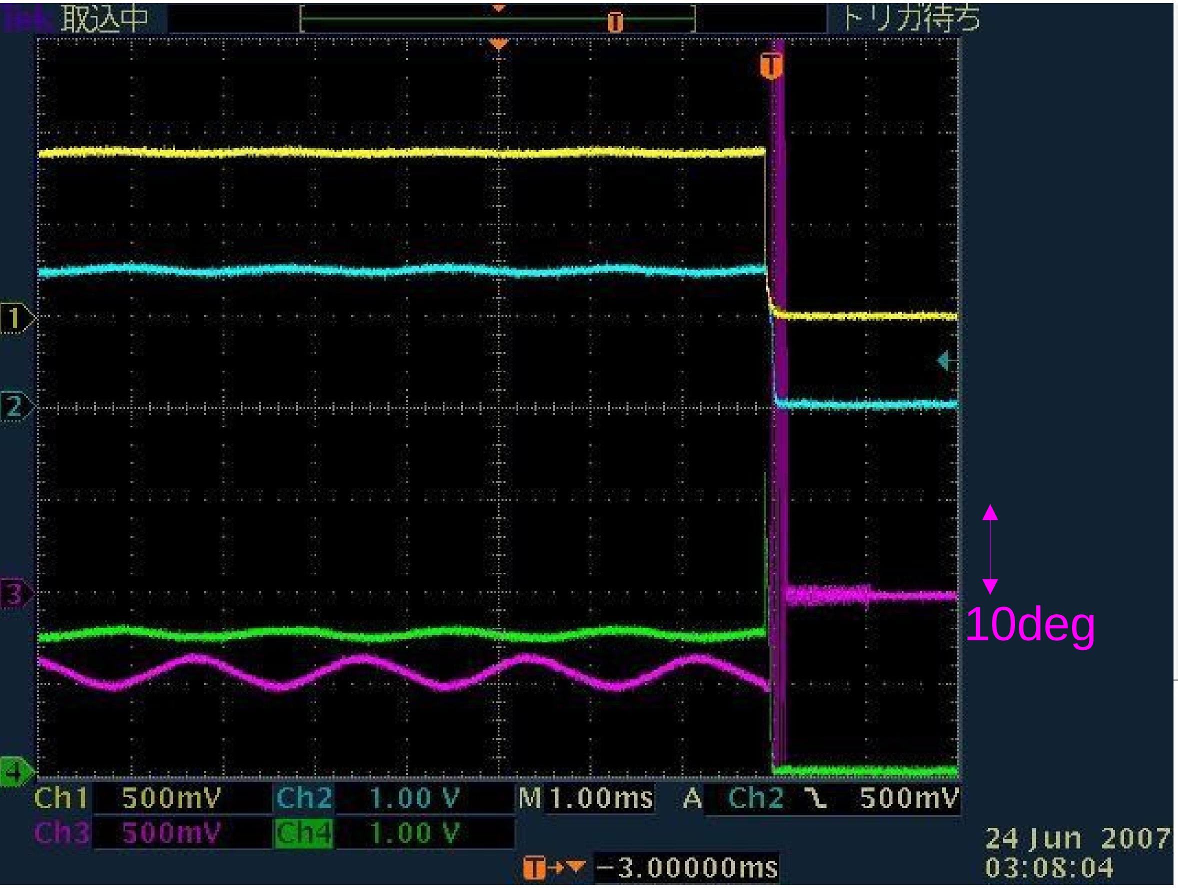
Reachable kick voltage

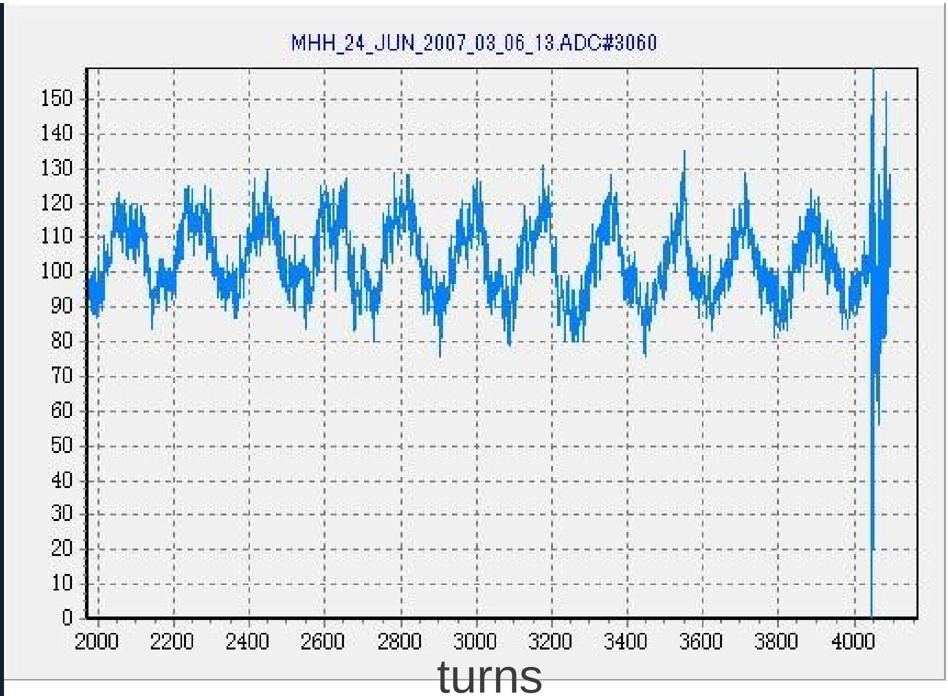
	HER	LER	
Vertical test	2.0	2.8	Limited by RF power supply.
	↓	↓	
Horizontal test	1.8	1.9	
	↓	↓	
Just after install	1.4	1.45	
		↓	
After 1 mounth	↓	1.0	LER Voltage suddenly dropped after a big quench.
		↓	
After 3 years	1.7	1.3	LER Voltage gradually recovered.

Uncontrolled RF kicks beam mass center.

- Accidental beam turbulence was observed by bunch by bunch feedback system.
- Slow phase error makes COD.
- Fast phase error makes free oscillation.

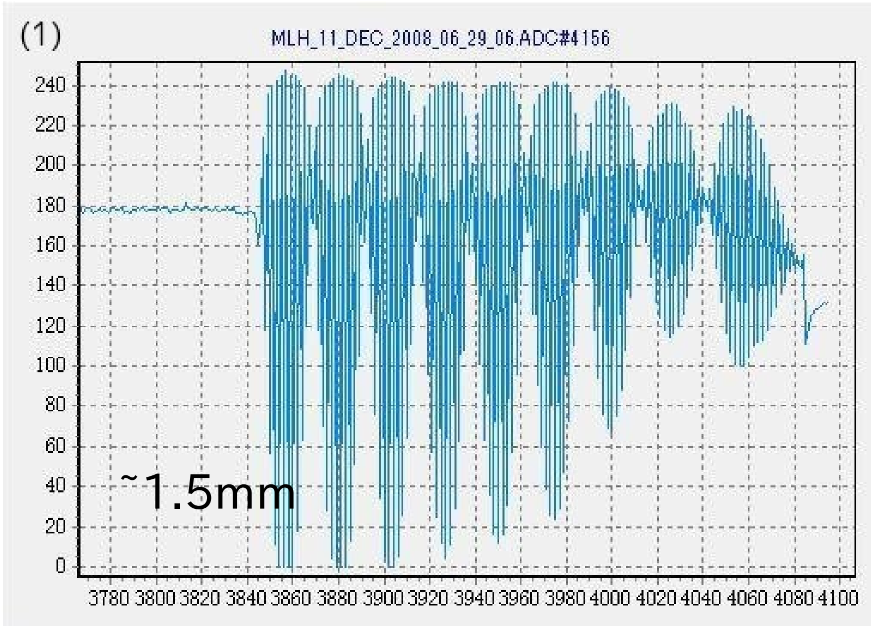
Yellow :Klystron output power
Blue :Pick up power(∝Vc2)
Purple :Cavity phase
Green :Beam current

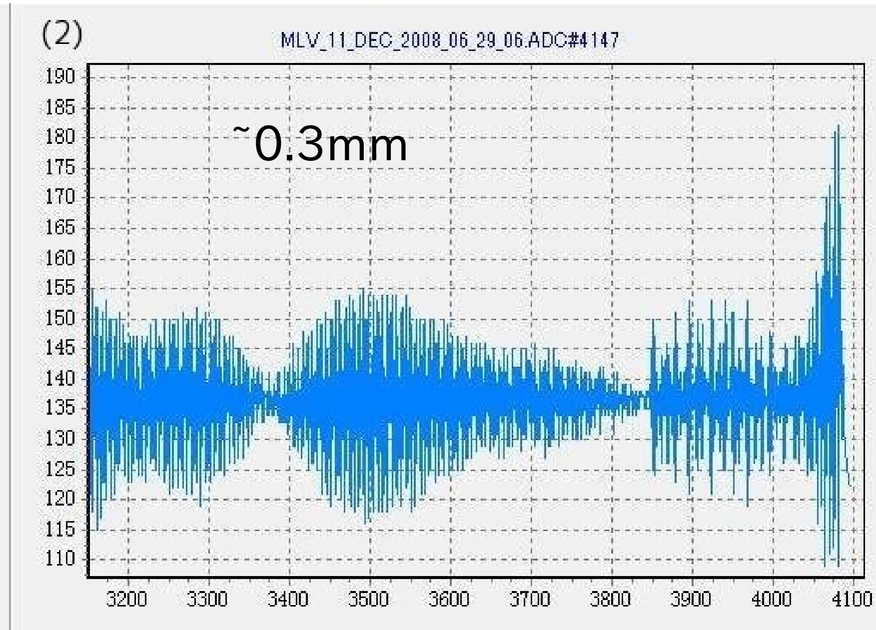


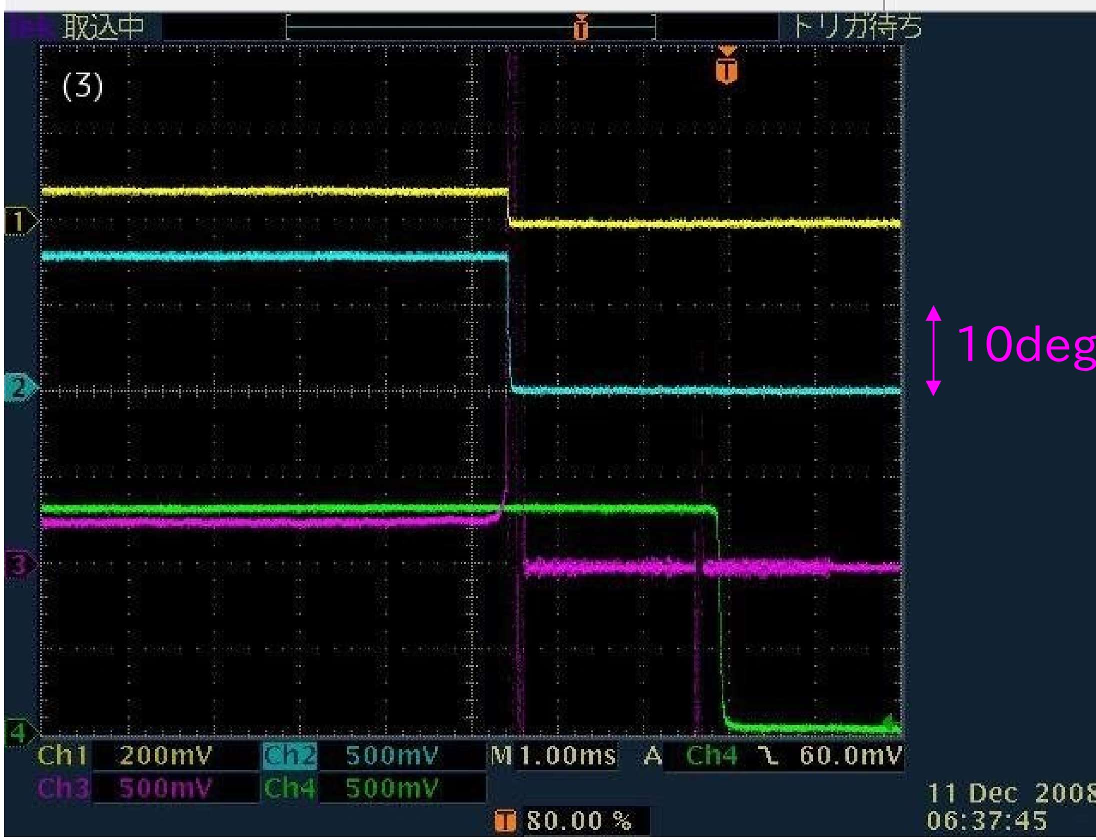


When LLRF feedback was oscillated, corresponding displacement was observed.

Beam displacement corresponding phase error was observed.







In this case, the beam was not aborted after turn off the RF.
After turned off the RF power for crab cavity, a horizontal oscillation was started. And it seems decaying.
Finally, the beam was aborted due to discharge caused by the beam induced field. The beam survived for 2msec after turned off the RF.

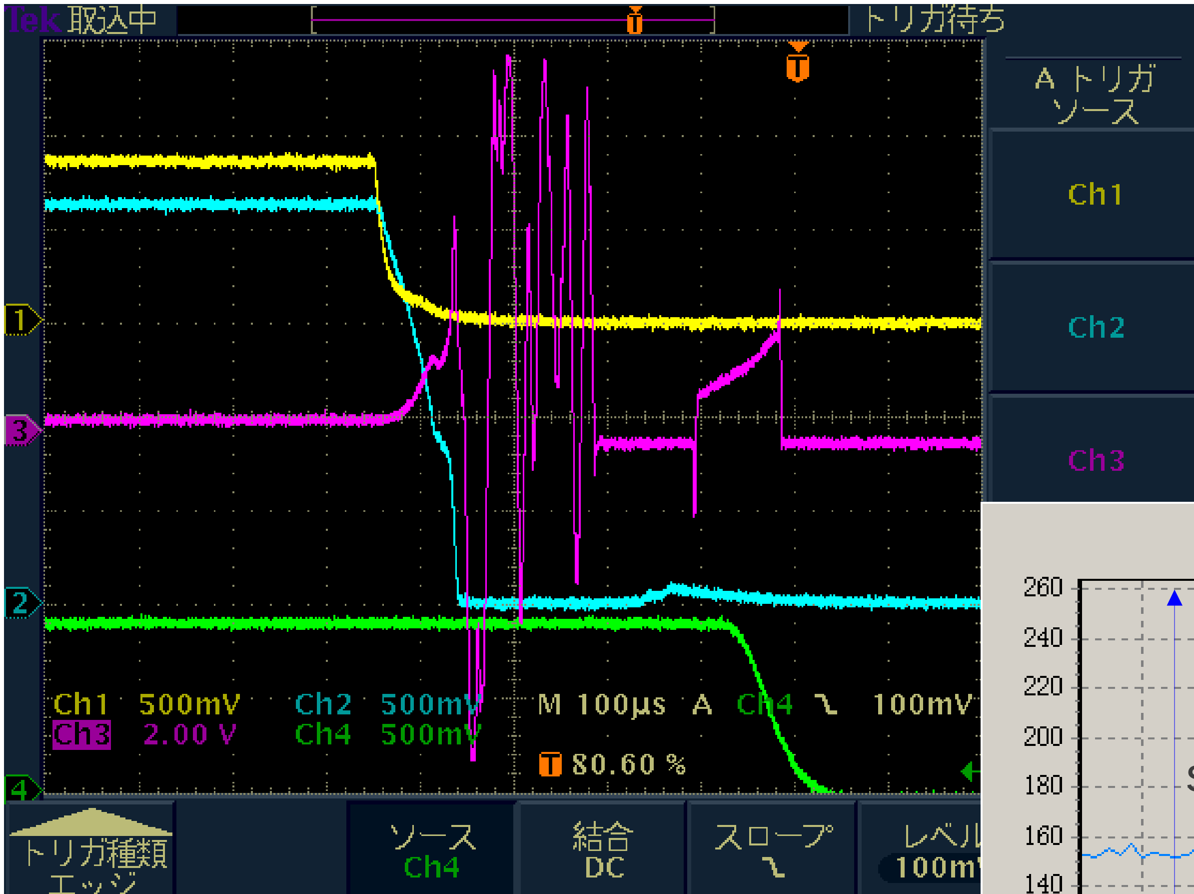
Yellow	:Klystron output power
Blue	:Pick up power(∝Vc2)
Purple	:Cavity phase
Green	:Beam current

Yellow :Klystron output power
Blue :Pick up power(∝Vc2)
Purple :Cavity phase
Green :Beam current

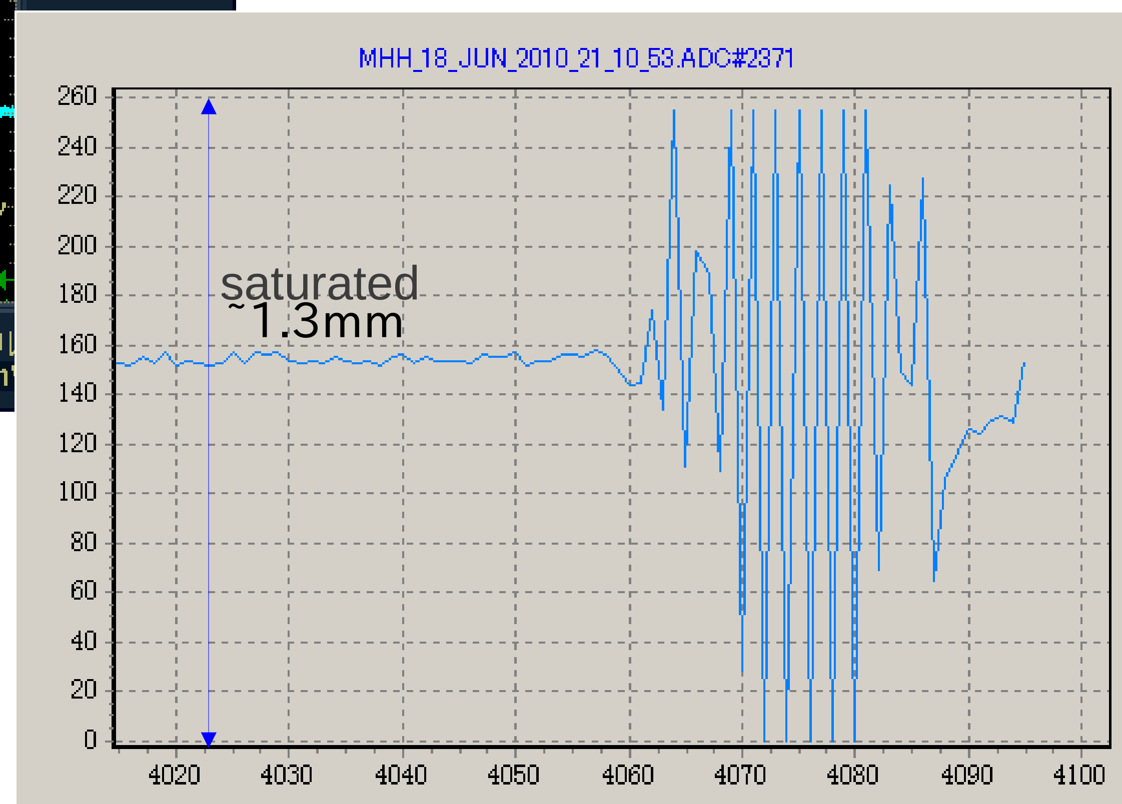
The LER beam was aborted by intentional abort request.

The expected decay time of stored energy was 65 μsec.
(130 μsec for cavity voltage)

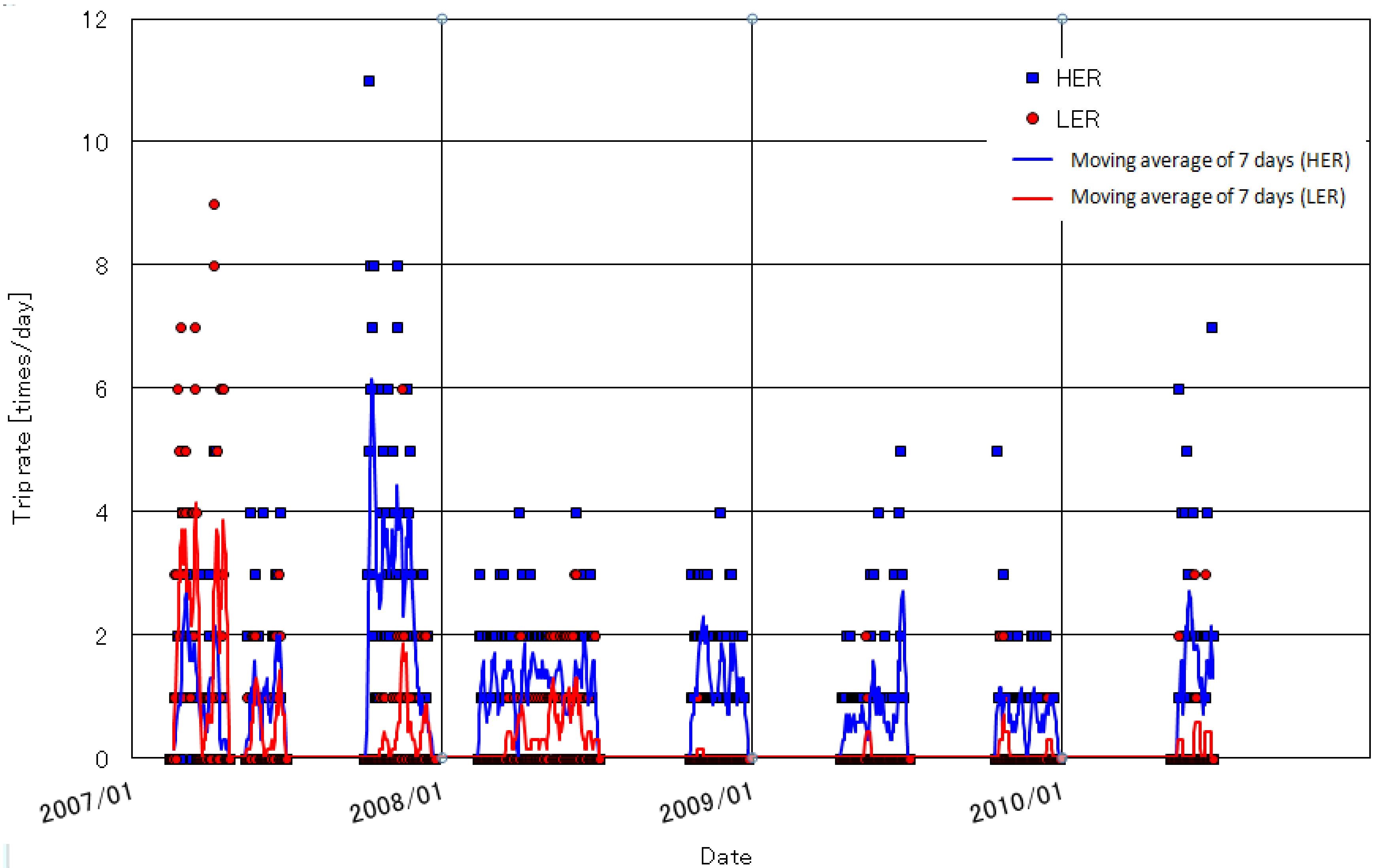
To stop the RF power makes turbulence.



In this case, RF power was stopped manually.
RF input coupler exposed big traveling wave RF power at that time, and it caused discharge phenomena.



RF trip rate of crab cavities

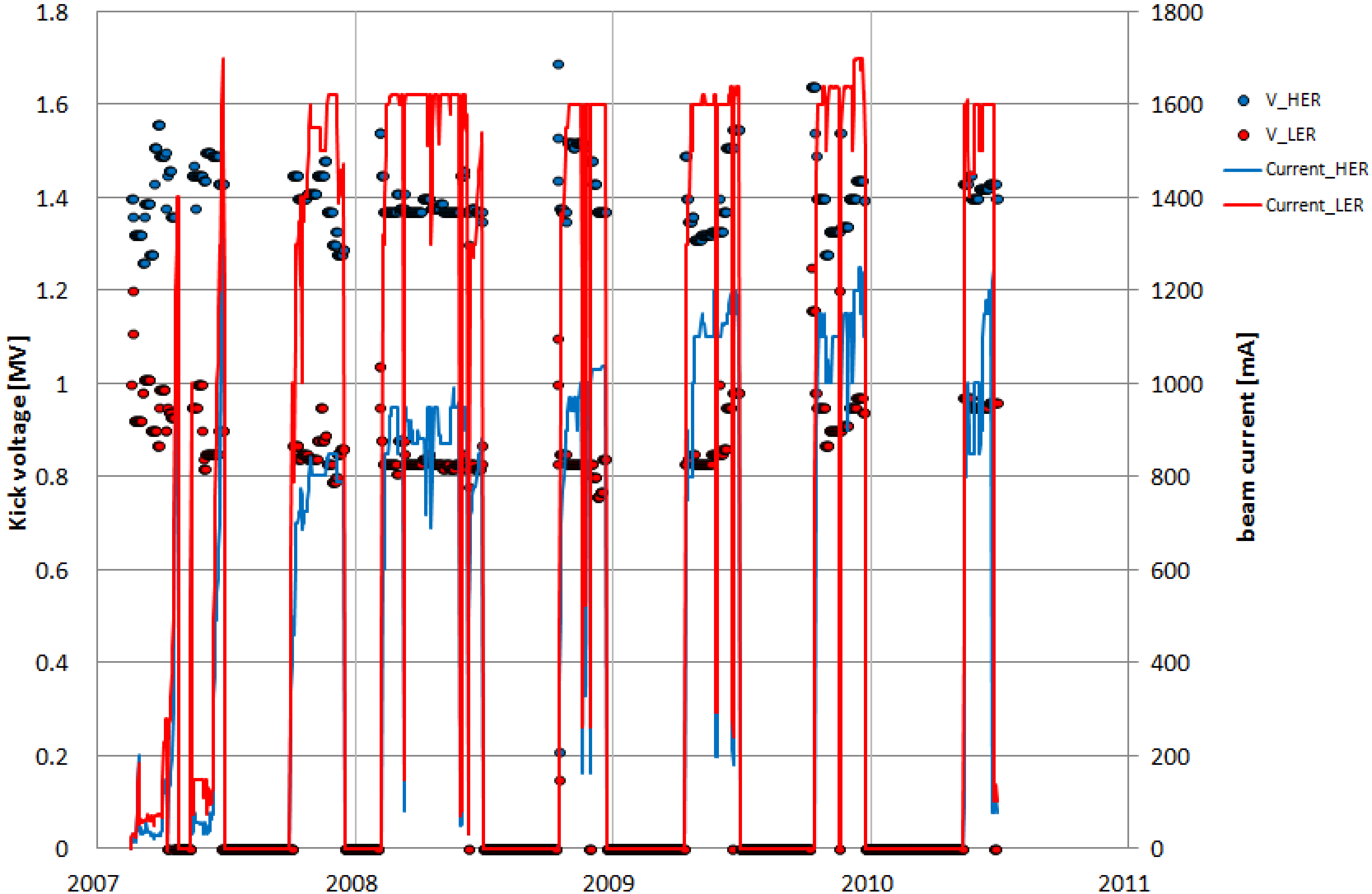


The averages of the RF trip rate during whole operation period were 1.3 and 0.5 per day for HER and for LER respectively.

Summary

- In KEKB, Crabing mode is not the lowest mode. The lowest mode and higher order mode(HOM) dumping was required. It makes the cavity system complicated.
- The KEKB crab cavity system have many parasitic mode (i.e. HOM related coaxial coupler that is the lowest mode and higher order mode dumper and frequency tuner). HOM was sometimes excited by beams. It deteriorated the vacuum and cause some discharge phenomena.
- When reachable voltage was dropped, removing the absorbed gases was effective by regular aging effort or system warming up.
- An oscillation of RF feedback system was observed at high beam current operation. It was made by interaction of RF control system through the beam-beam force. It could be suppressed by adjusting cavity control parameter (i.e. tuning offset and crabing phase).
- Crabing phase error makes COD.
- When the crab cavity RF turns off, uncontrolled RF may be caused free oscillation.
- RF trip rate of crab cavity was decreased day by day.

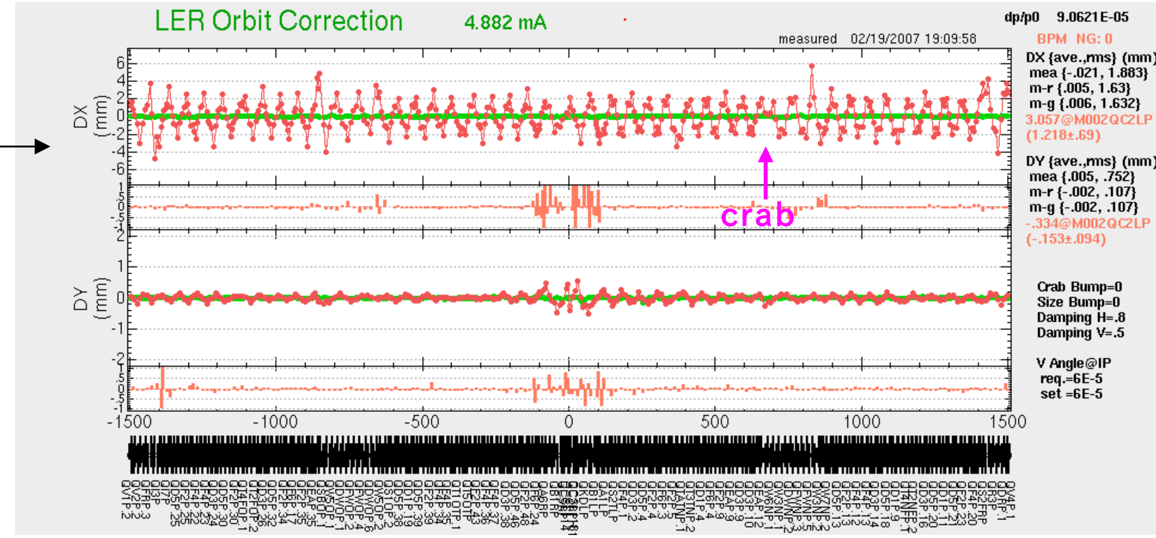
Operating condition of crab cavity



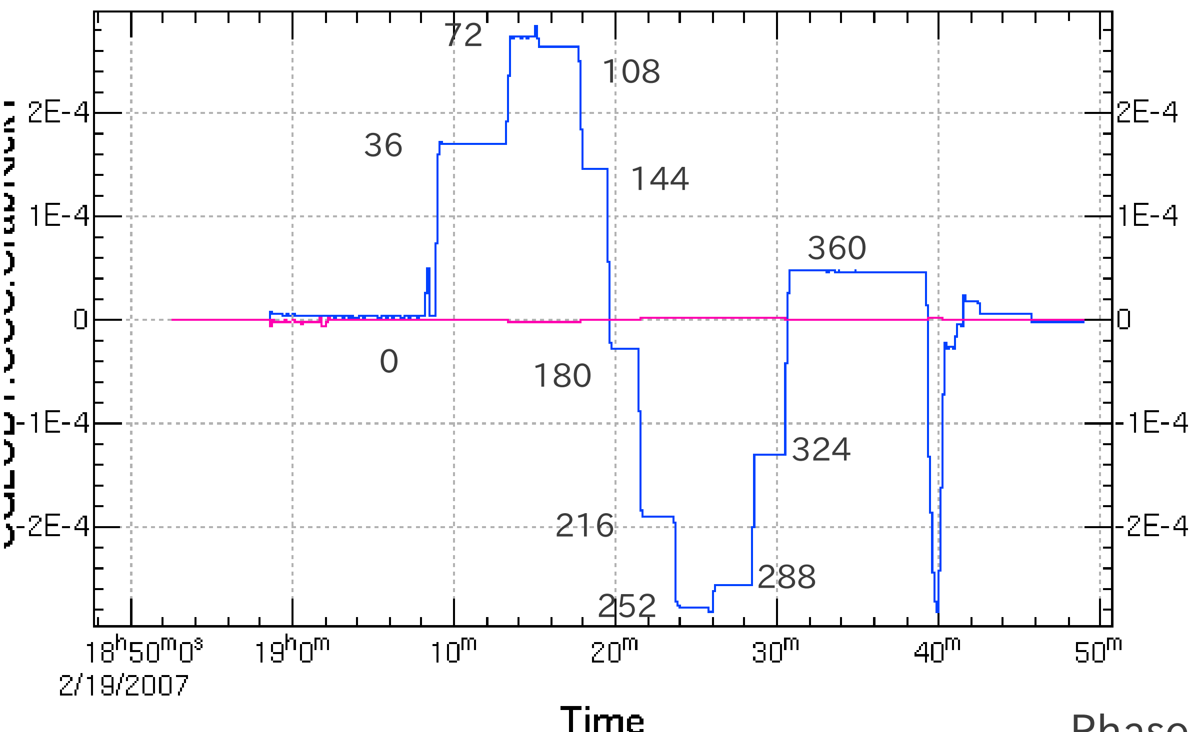
Crab Phase Scan (LER)

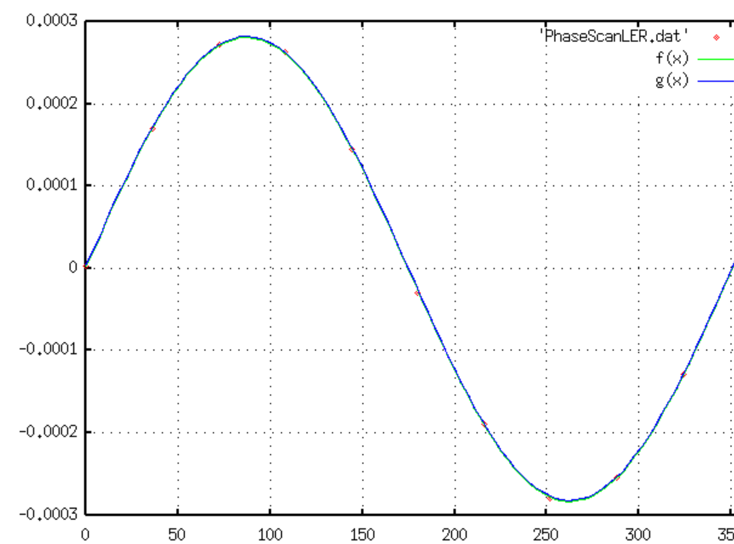
H. Koiso, A. Morita

Horizontal orbit by crab kick



Horizontal kick by crab cavity (rad)
(Estimated from orbits around the ring)





Phase 0 : 174.8 deg.
Vcrab set:1.0MV, estimated: 0.987MV
agree very well