KEKB operational experience with crab cavities

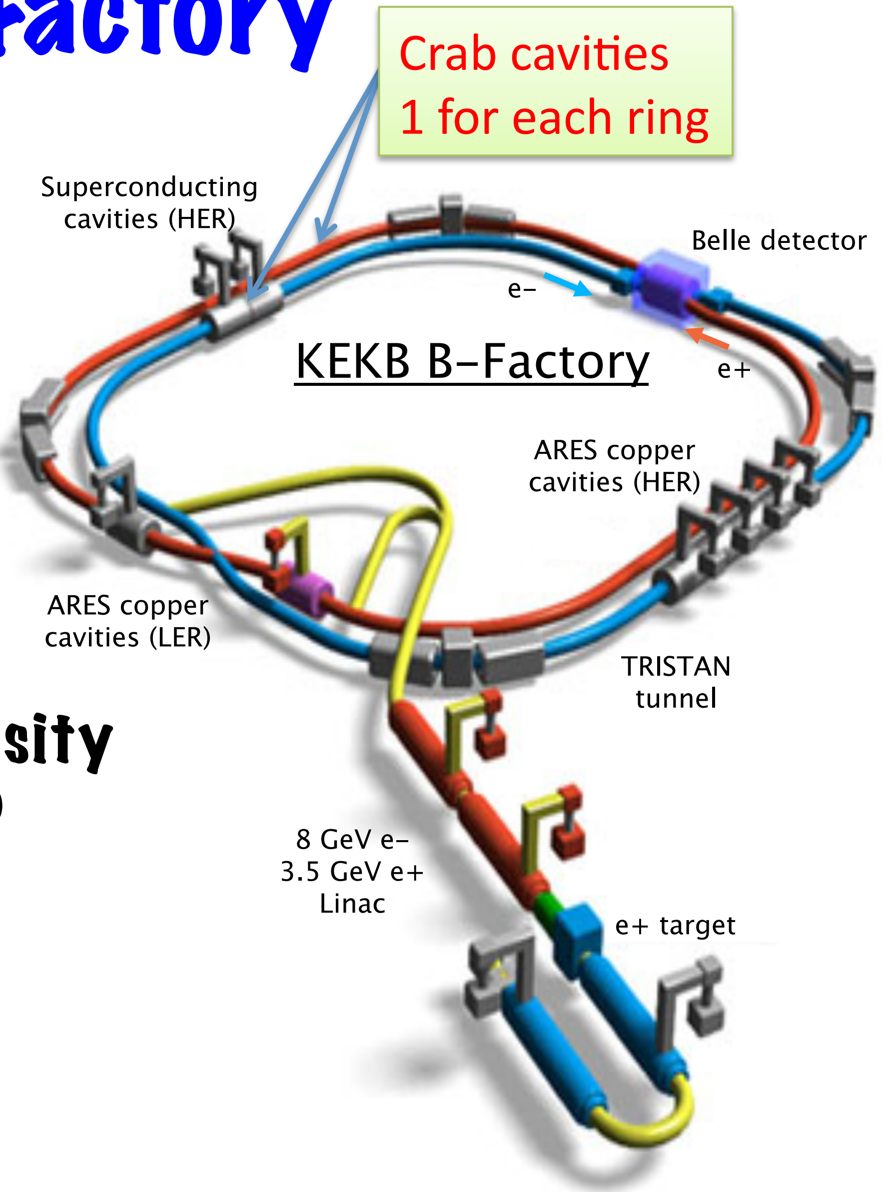
Y. Funakoshi
for the KEKB commissioning group

~~KEK-B~~

KEKB

What is KEKB?

KEKB B-Factory



♦World-highest Peak Luminosity

- $2.11 \times 10^{34} cm^{-2}s^{-1}$
- Twice as high as design value

♦World-highest Integrated Luminosity

- Total: $1040 fb^{-1}$ as of June 30th 2010

♦Crab crossing

♦Skew-sextupole magnets

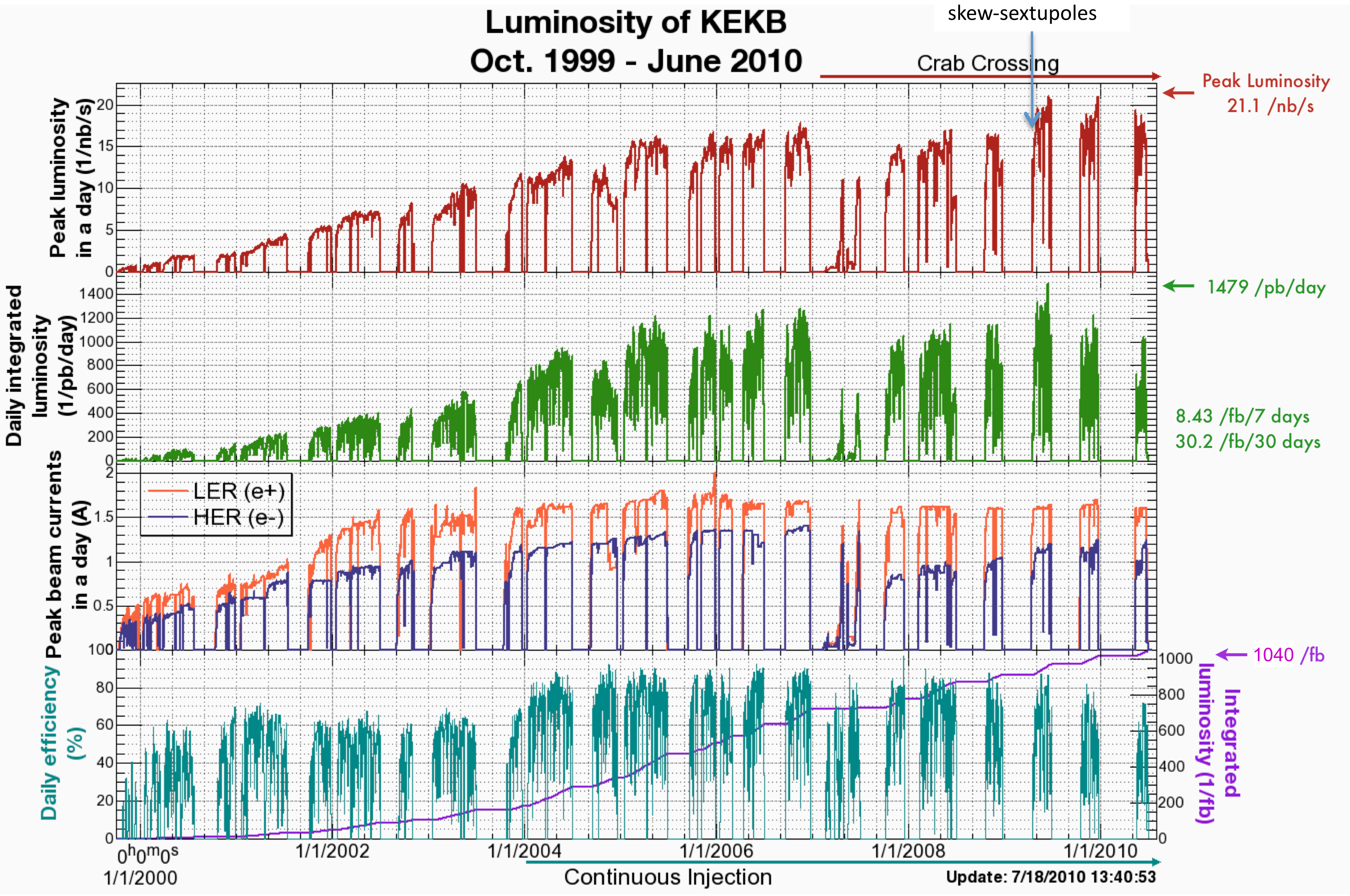
The KEKB operation was terminated at the end of June 2010 for the upgrade toward SuperKEKB.

Finally two crab cavities were installed in KEKB, one for each ring in January 2007

HER (e-, 8 GeV)

LER (e+, 3.5 GeV)

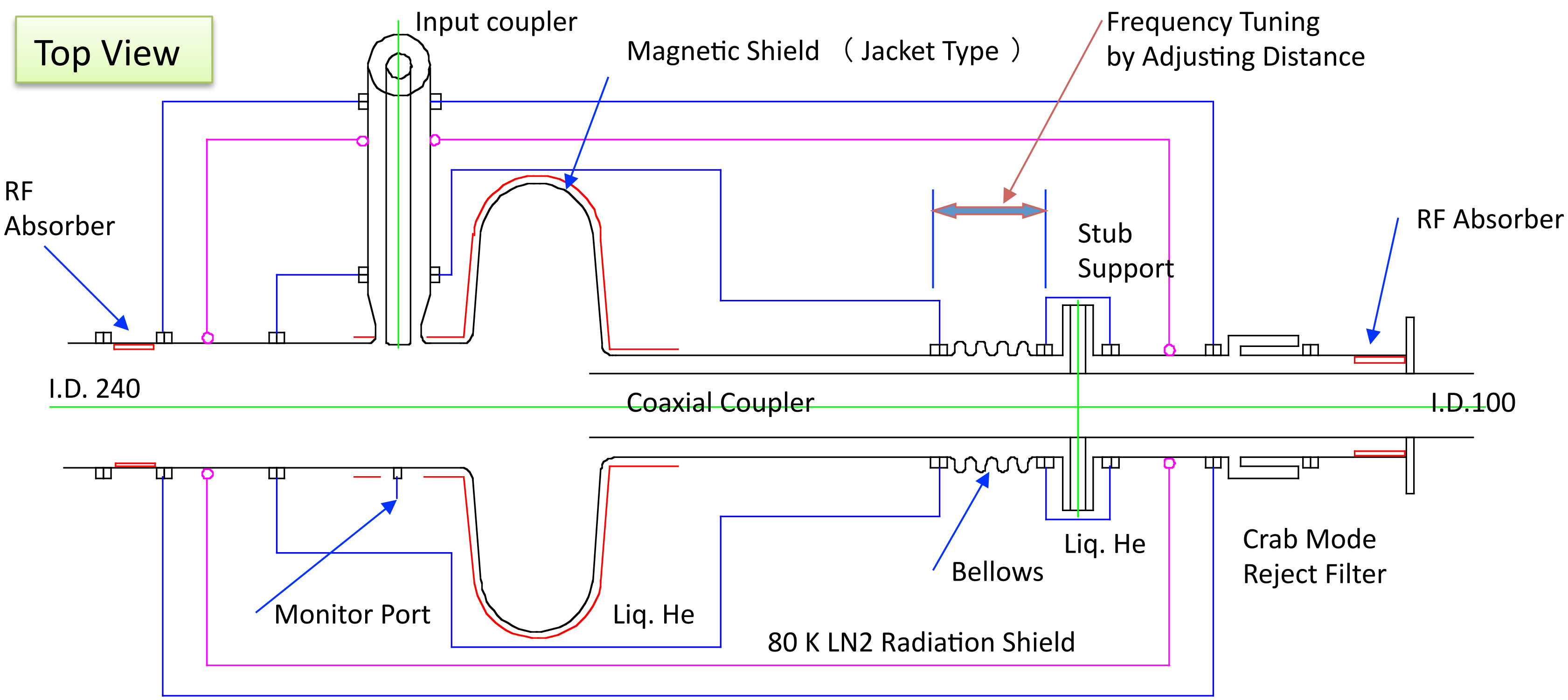
.....after 13 years' R&D from 1994



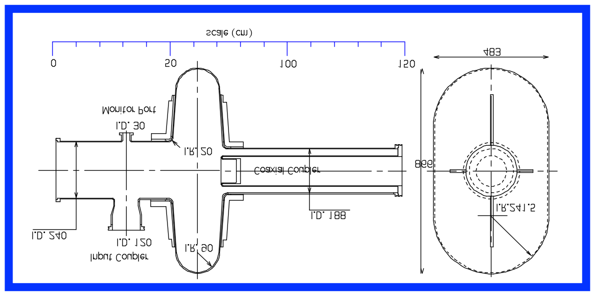
Luminosity of KEKB
Oct. 1999 - June 2010
skew-sextupoles
Crab Crossing
Peak Luminosity
21.1 /nb/s
1479 /pb/day
8.43 /fb/7 days
30.2 /fb/30 days
1040 /fb
Peak luminosity in a day (1/nb/s)
Daily integrated luminosity (1/pb/day)
Peak beam currents in a day (A)
LER (e+)
HER (e-)
Daily efficiency (%)
Integrated luminosity (1/fb)
1/1/2000
1/1/2002
1/1/2004
1/1/2006
1/1/2008
1/1/2010
Continuous Injection
Update: 7/18/2010 13:40:53

KEKB Crab Cavities

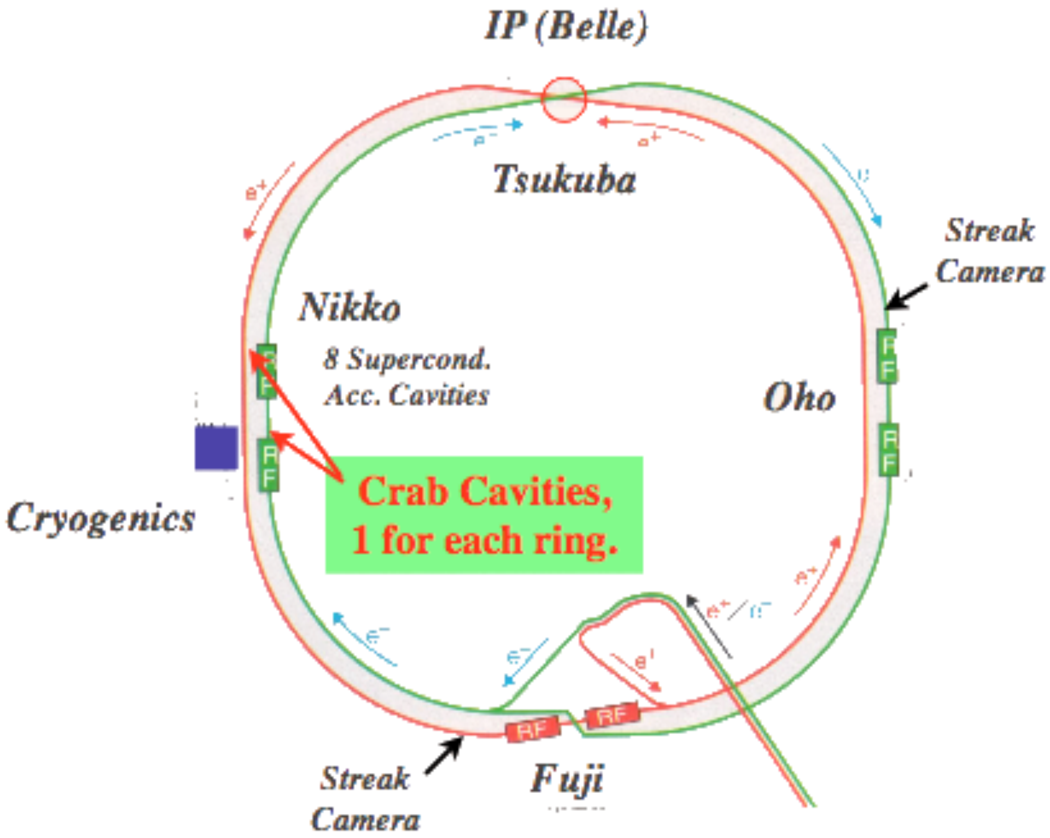
Structure of KEKB Crab Cavity



Crab mode: TM110: B_y on beam axis
Lower mode: TM010: dumped through coaxial coupler
Squashed cell shape to split TM110 modes



Single Crab Cavity scheme



Beams tilt all around the rings.
-> z-dependent horizontal closed orbit

Tilt at the IP:

$$\frac{\phi_x}{2} = \frac{\sqrt{\beta_x^C \beta_x^*}\cos\left(\pi\nu_x - \left|\Delta\psi_x^C\right|\right)}{2\sin\pi\nu_x}\frac{V_C\omega_{RF}}{Ec}$$

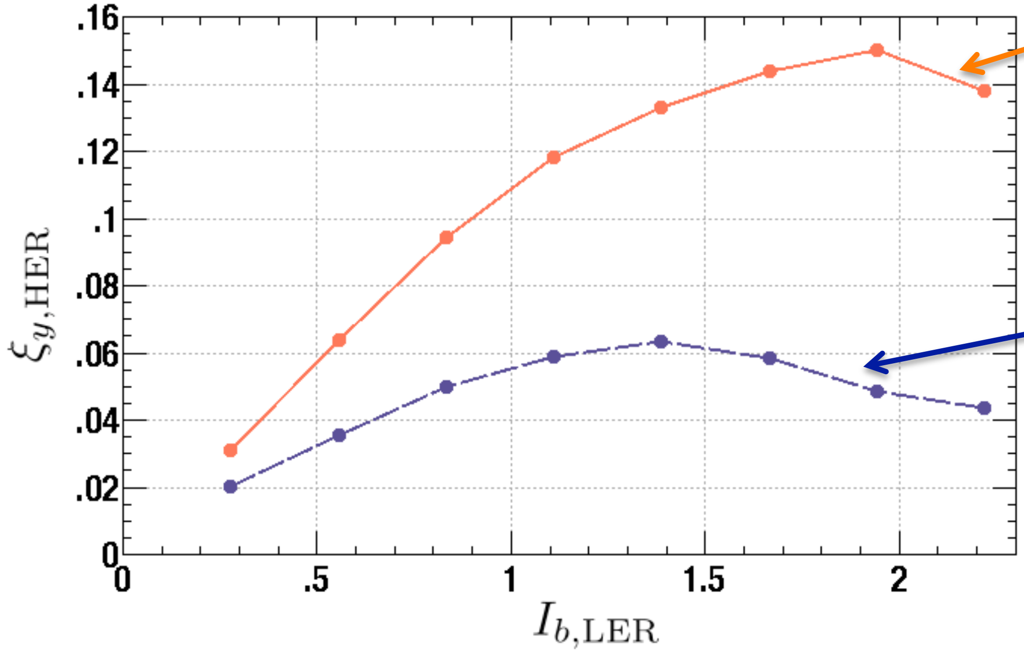
Ring	LER	HER	
ϕ_x	22		mrad
β_x^*	1.2	1.2	m
β_x^C	51	122	
ν_x	0.506	0.511	
$\Delta\psi_x/2\pi$	0.25	0.25	
V_C	0.97	1.45	MV
$\omega_{RF}/2\pi$	509		MHz

- 1 crab cavity per ring.
- Saves the cost of the cavity and cryogenics.

Motivation for Crab Cavities at KEKB

Beam-Beam Simulations

● Crab Crossing can boost the beam-beam parameter higher than 0.15 ! (K. Ohmi)

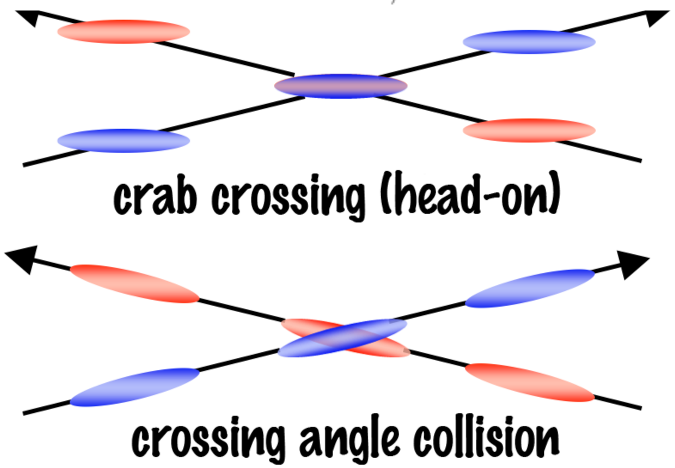


Head-on (crab)

Strong-strong beam-beam simulation

22mrad crossing angle

Head-on	}	→ ξ_y ~0.15
ν_x =.508		

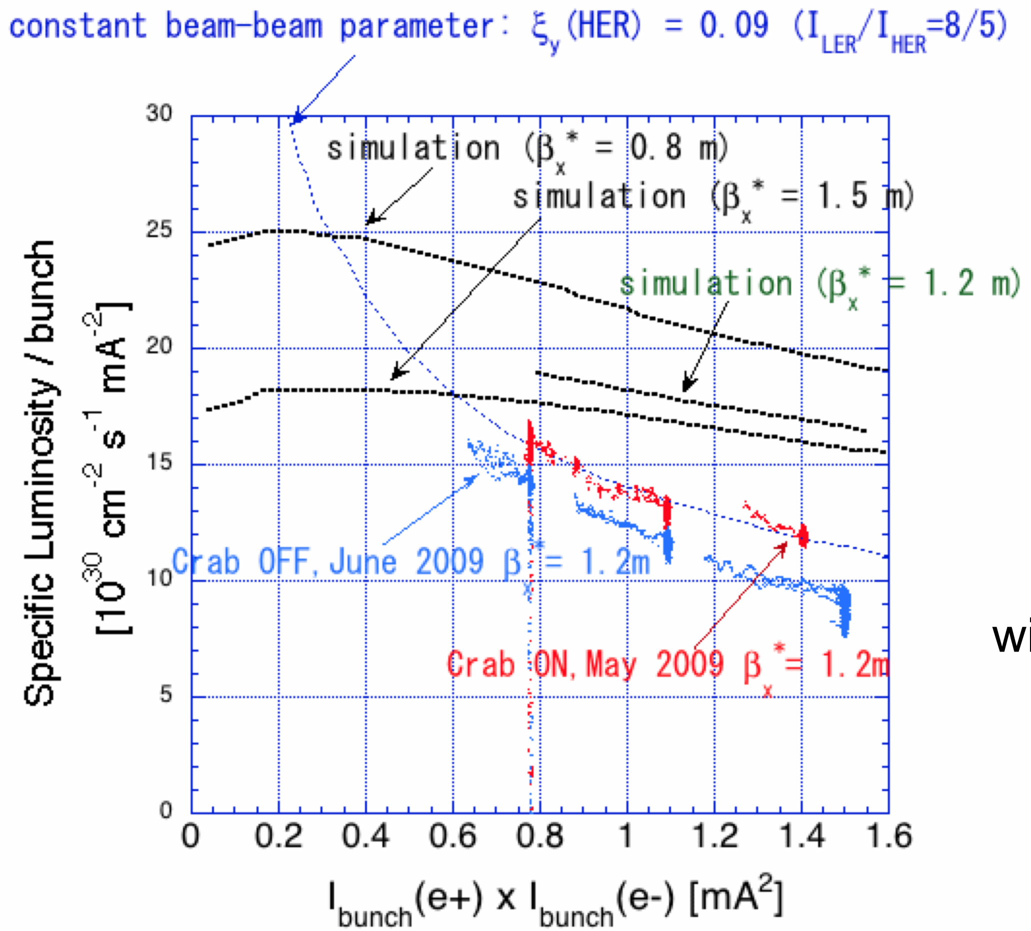


●After this simulation appeared, the development of crab cavities was revitalized.

With the crab crossing, the beam-beam parameter and then the luminosity would be doubled !!

Improvement of Luminosity with Crab Cavities

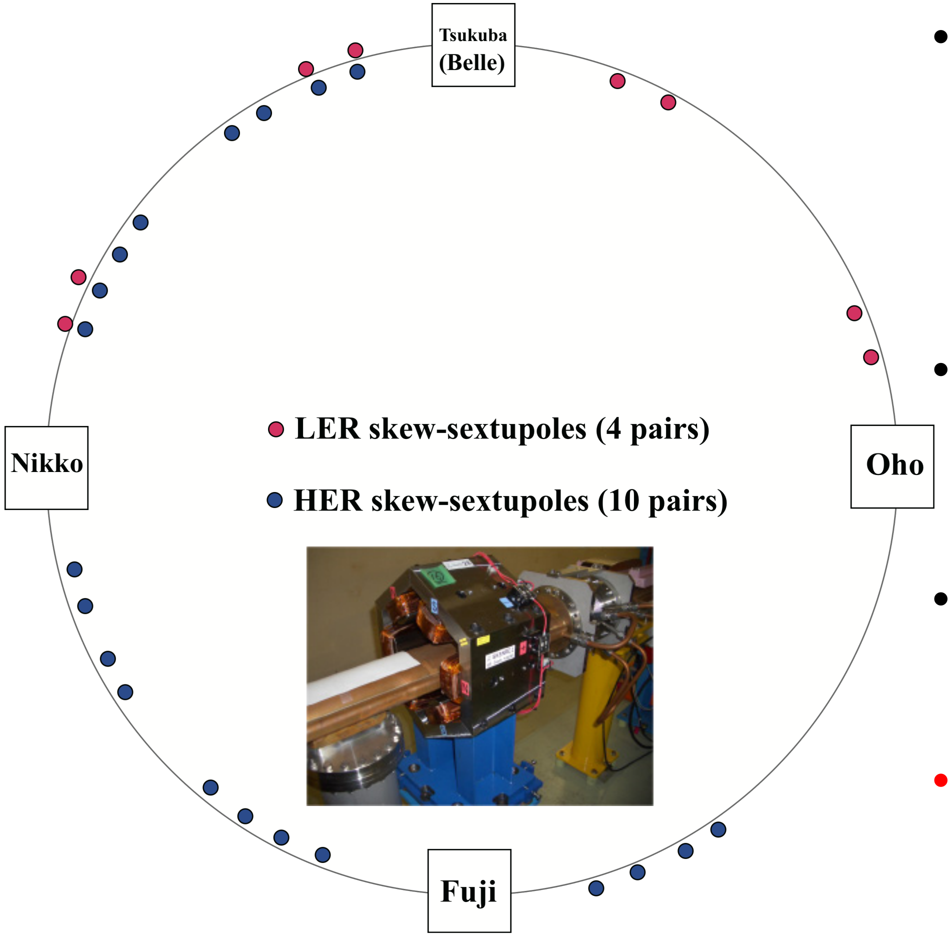
Specific luminosity (crab on/off)



with skew sextuples

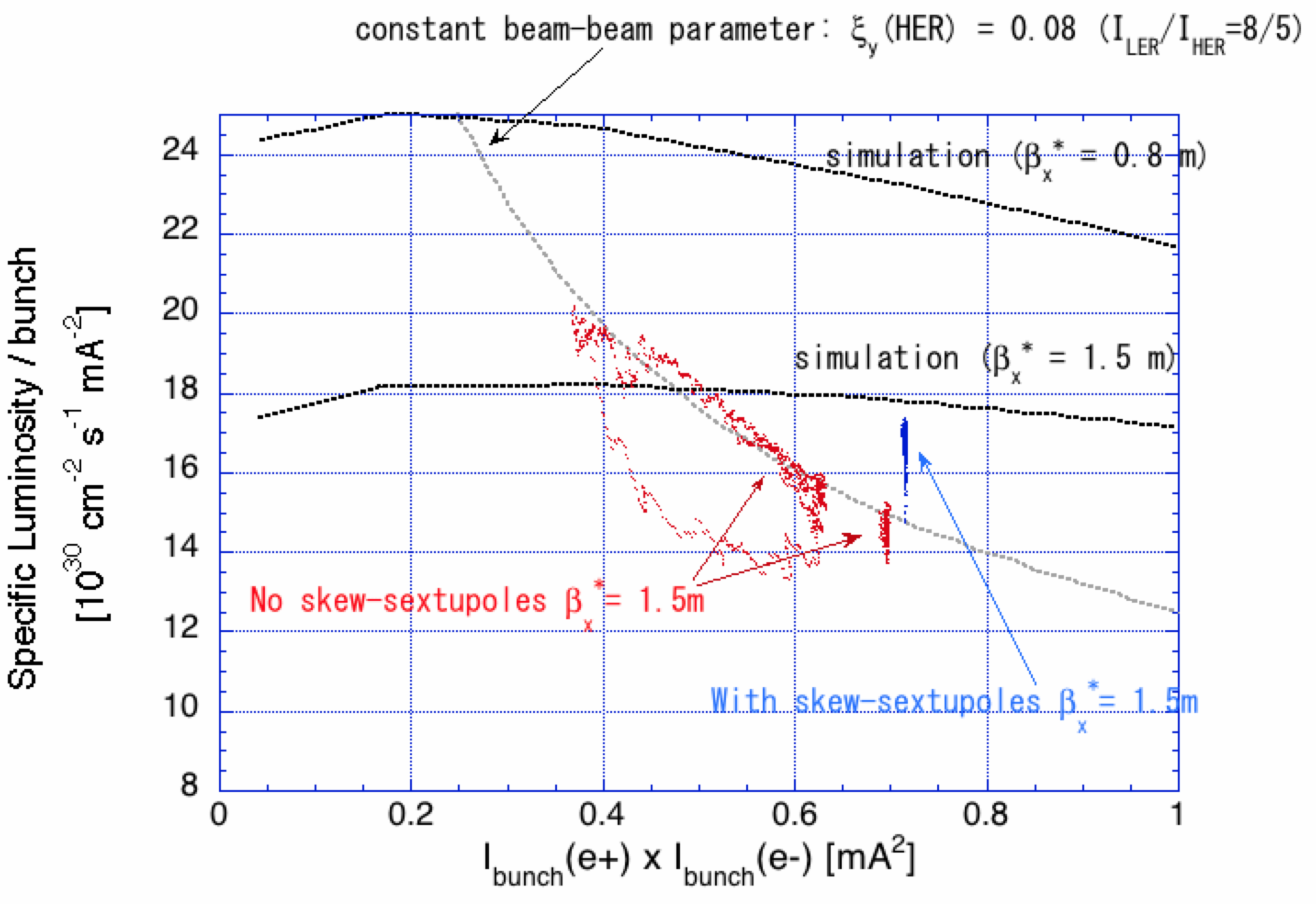
Luminosity improvement by crab cavities is about 20%.
Geometrical loss due to the crossing angle is about 11%.

Chromaticity of x-y coupling at IP

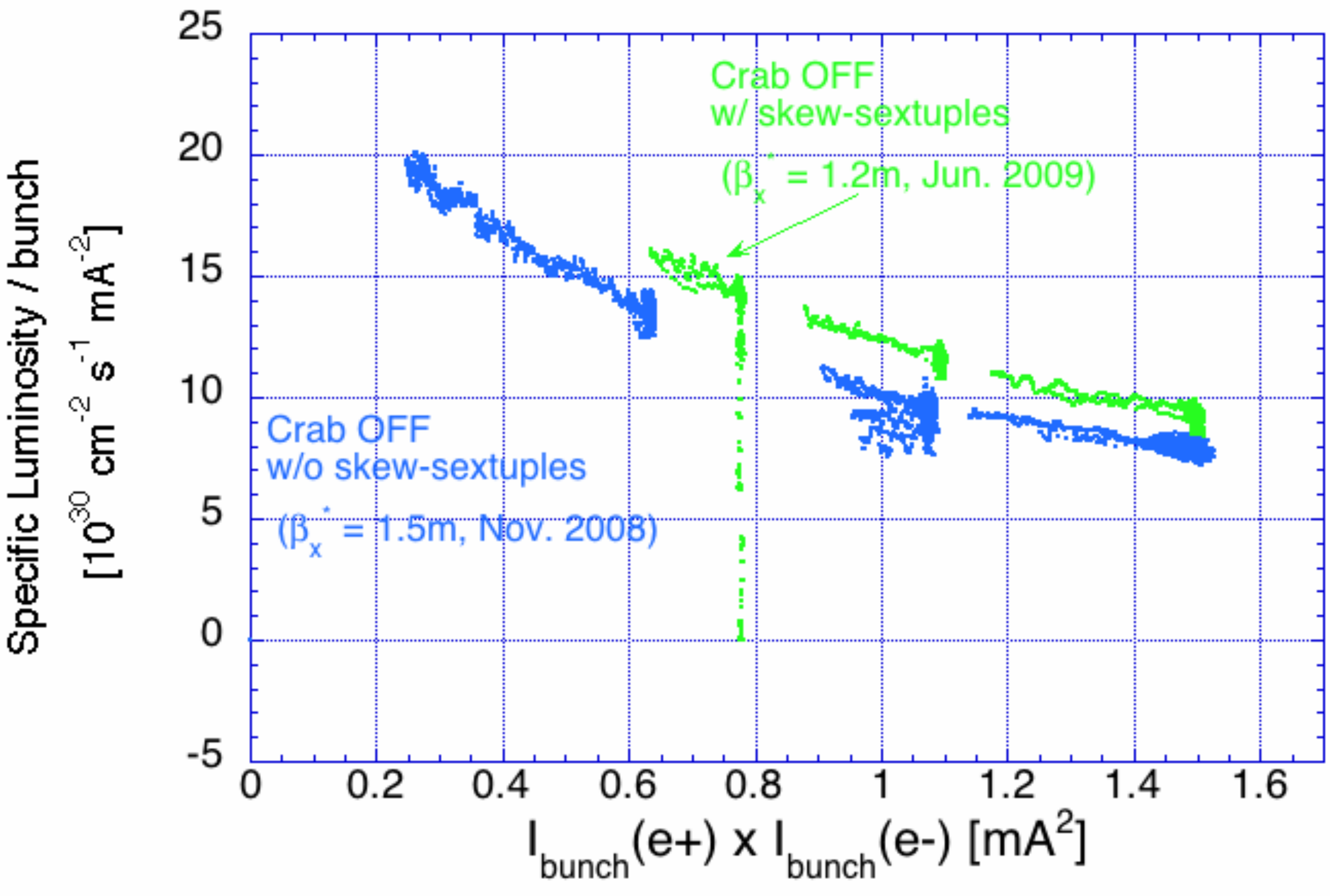


- Ohmi et al. showed that the linear chromaticity of x-y coupling parameters at IP could degrade the luminosity, if the residual values, which depend on machine errors, are large.
- To control the chromaticity, skew sextupole magnets were installed during winter shutdown 2009.
- The skew sextuples are very effective to increase the luminosity at KEKB.
- The gain of the luminosity by these magnets is ~15%.

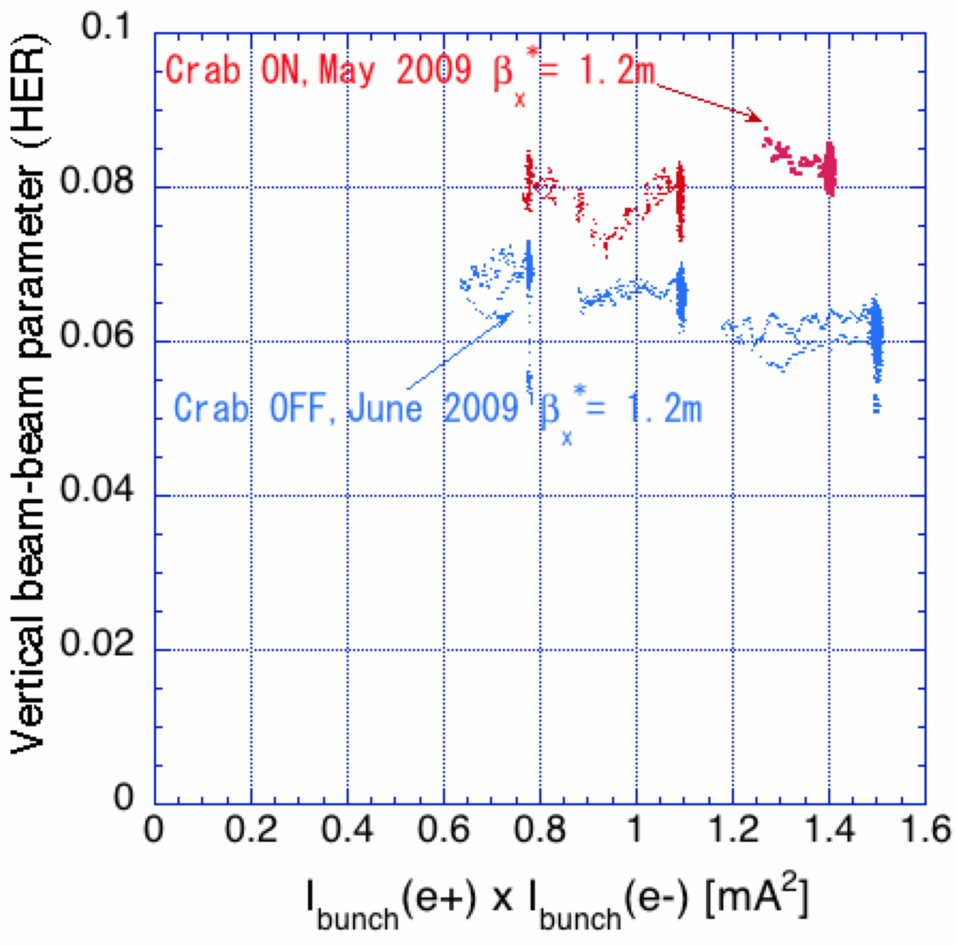
Effectiveness of skew-sextupole magnets (crab on)



Effectiveness of skew-sextupole magnets (crab off)



Beam-beam parameter (crab on/off)



	Crab on	Crab off
R_L	0.828	0.763
$R_{\xi y}$(HER)	1.15	0.993

Effectiveness of crab cavities

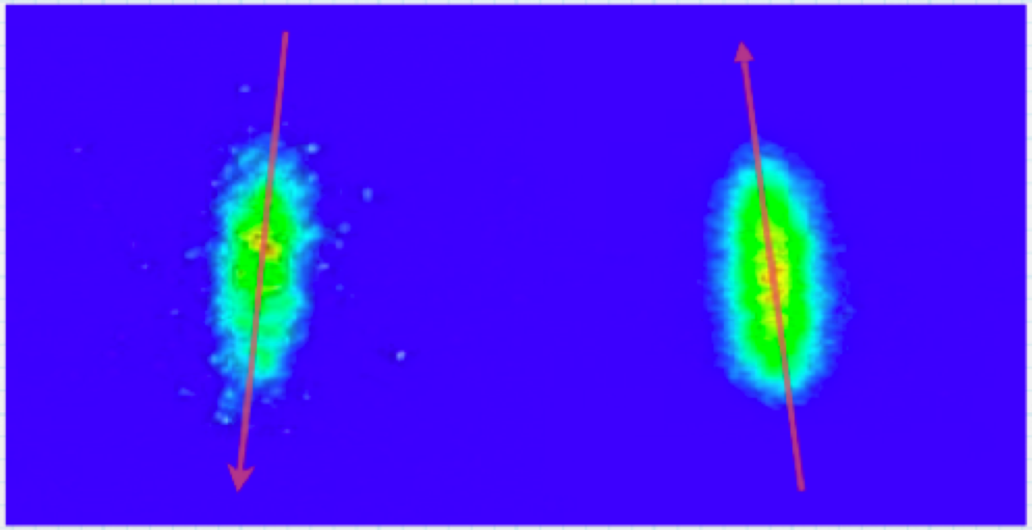
- The crab cavities at KEKB did work and brought the luminosity increase by ~20%.
- The highest luminosity with crab is 2.1 x 10^{34} $cm^{-2}s^{-1}$.
  - Skew-sextupoles
  - Increase of HER beam current by solving the physical aperture problem
- There still exists a large discrepancy between the luminosity achieved and the beam-beam simulation.
  - The simulation predicted that the luminosity would be doubled.
  - Side effects of large tuning knobs to compensate the machine errors?
  - We will have no opportunity to investigate the reason for this.

Some Experience of Beam Operation with Crab Cavities

Evidence of Crabbing Motion (1): Streak Camera

- Observation with Streak Cameras (H. Ikeda et al, FRPMN035)

inside of
the rings



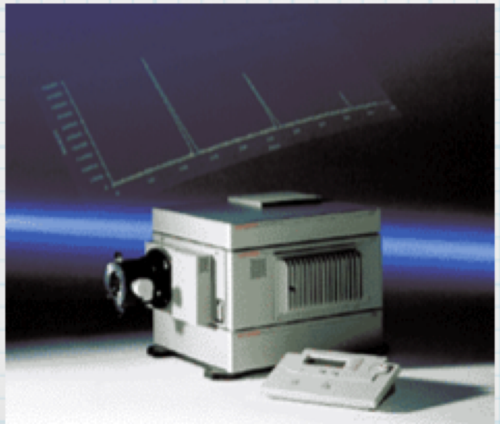
outside of
the rings

longitudinal

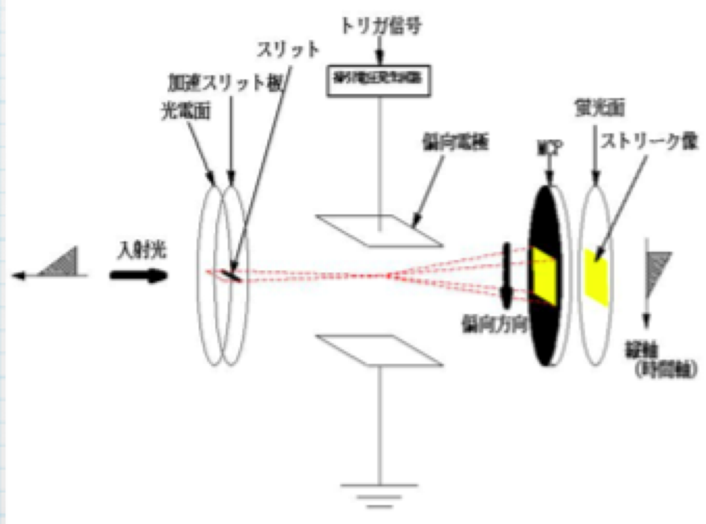
LER

HER

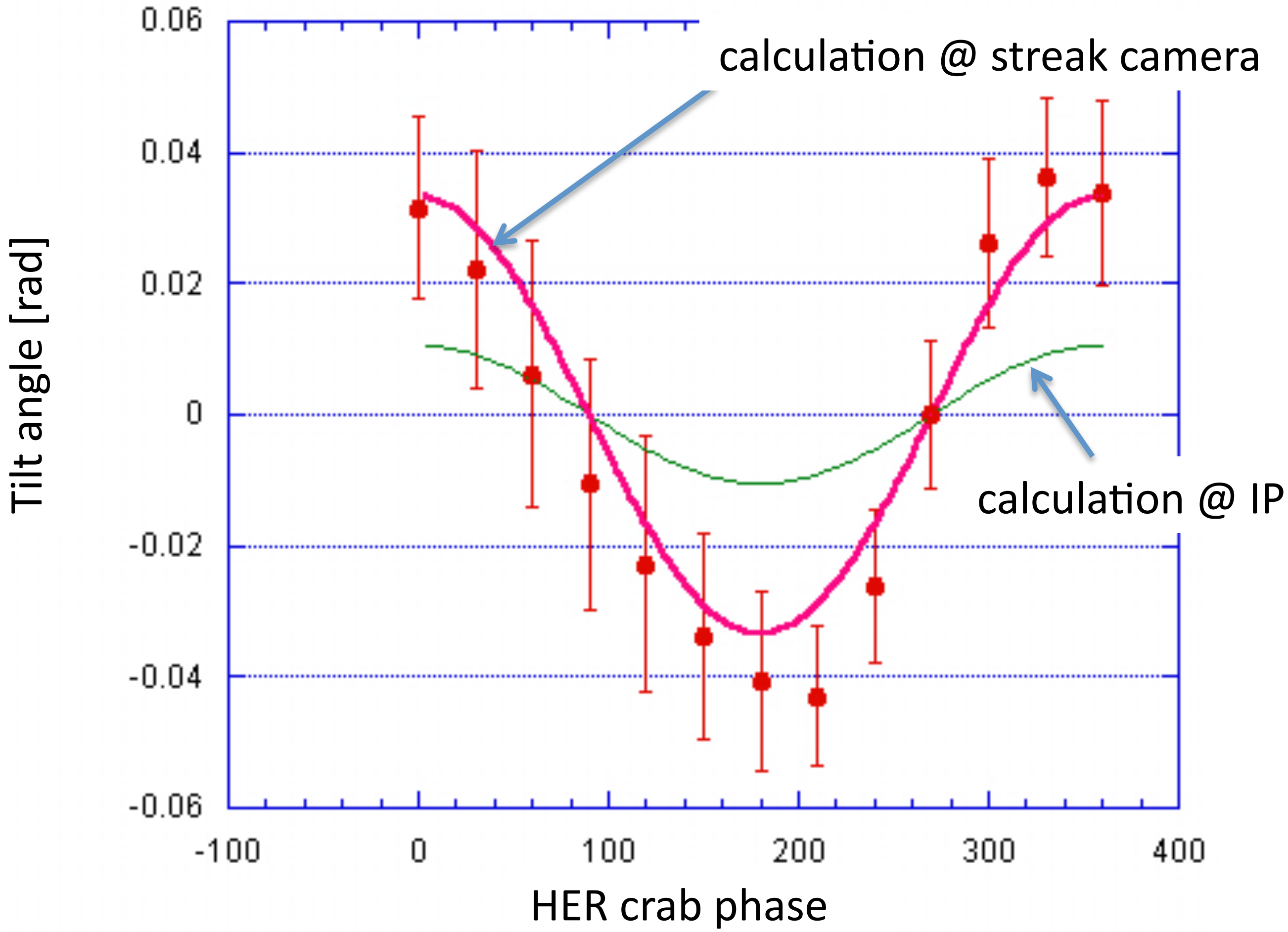
horizontal



The streak camera

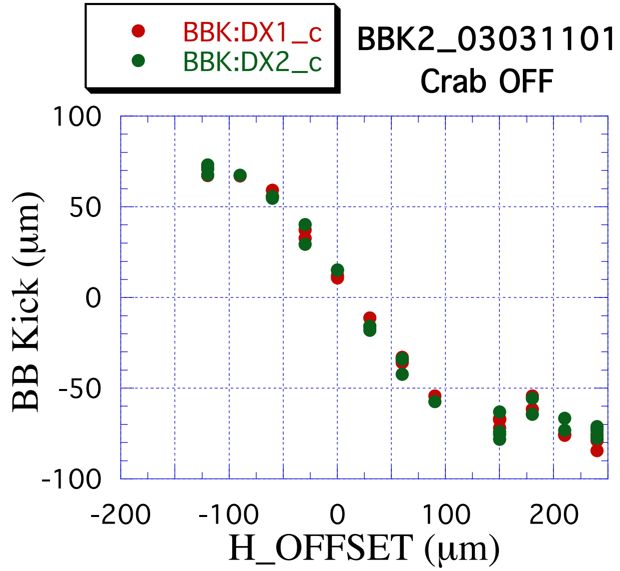


HER crabbing angle measurement and calculation



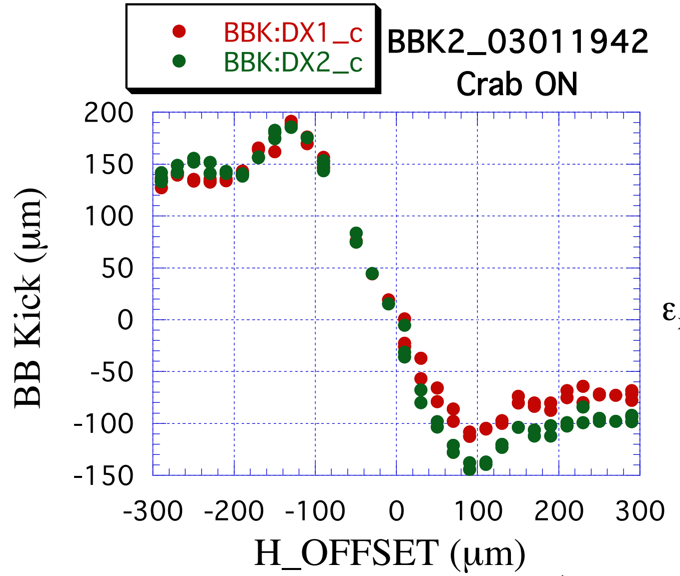
Evidence of Crabbing (2): Beam-Beam Deflection

Crab OFF



Bunch Current: 0.73/0.42 mA

Crab ON (Vc = 1.31/0.92 MV)



ε_x L/H=18/24 nm

Bunch Current: 0.64/0.47 mA

$\Sigma_{x\_x'=11}$=230 +/- 3 μm (OFF) → $\Sigma_{x\_x'=00}$=167 +/- 3 μm (ON)

- Horizontal effective size at IP reduces to 72% by the crab.

Ratio of Slope:

$$\frac{\left.\frac{\Delta k}{\Delta x}\right|_{x'=0}}{\left.\frac{\Delta k}{\Delta x}\right|_{x'=11}} = 2.14$$

- HER current was lost from 15 to 13.5 mA during scan.

T. Ieiri

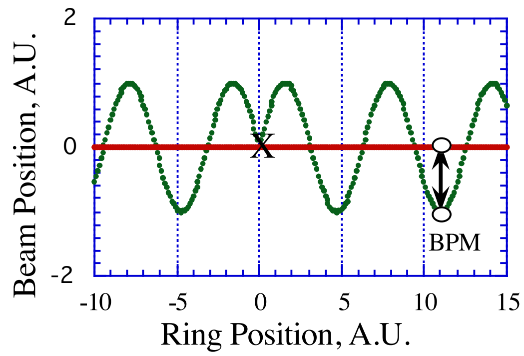
Method of Measurement of Beam-Beam Kick

- Beam-Position Change measured at a detector

$$\Delta X_{\det.} = \frac{\sqrt{\beta_{\det.}\beta_x^*}}{2sin(\pi\nu)}\theta_{b-b}\cos(\pi\nu - |\Delta\varphi_d|)$$

$$\Rightarrow \quad \Delta X_{\det.} \propto \theta_{b-b}$$

<COD>



- Beam-beam Kick (Rigid Gaussian)

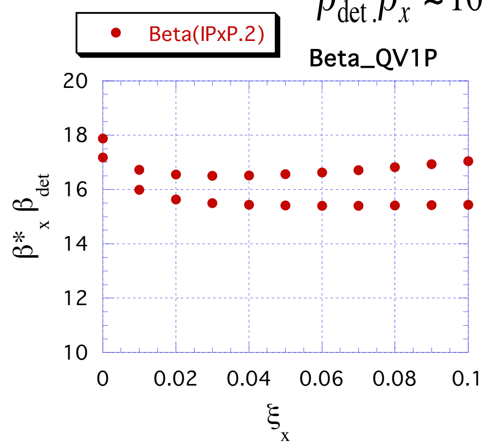
Δ_x: Horizontal Offset

$$\theta_{b-b} = \frac{-2r_eN_b}{\gamma}\Delta_x\int_0^\infty \frac{\exp(-\frac{\Delta_x^2}{(t+2\Sigma_x^2)})}{(t+2\Sigma_x^2)^{3/2}(t+2\Sigma_y^2)^{1/2}}dt \qquad \Delta_y = 0$$

$$\theta_{bb}^+ \approx \frac{-1.94\cdot r_eN^-}{\gamma^+}\frac{\Delta_x}{\Sigma_x^2} \quad \Rightarrow \quad \frac{\theta_{bb}^+}{\Delta_x} \propto \frac{N^-}{\Sigma_x^2} \qquad |\Delta_x| < \Sigma_x$$

<Dynamic Beta>

$\beta_{\det.}\beta_x^* \approx 16$



By Fukuma & Funakoshi

- Effective Horizontal Size at IP

$$\Sigma_x = \sqrt{(\sigma_x^+)^2 + (\sigma_x^-)^2}$$

Missing partner method:
Orbit difference of collision and non-collision bunches

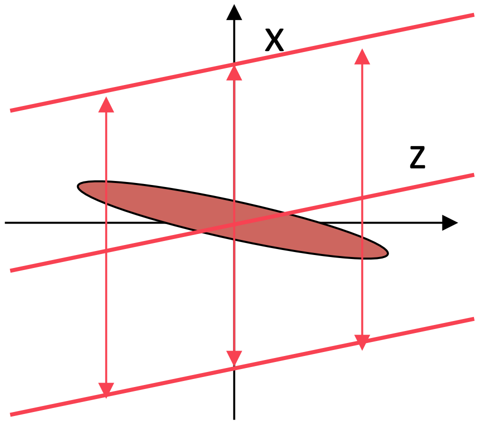
T. Ieiri

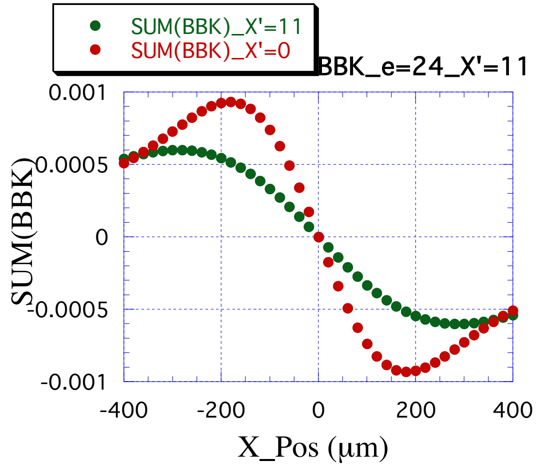
Calculation of Beam-Beam Kick with and without Crossing Angle

Use code “BBWS” by Ohmi

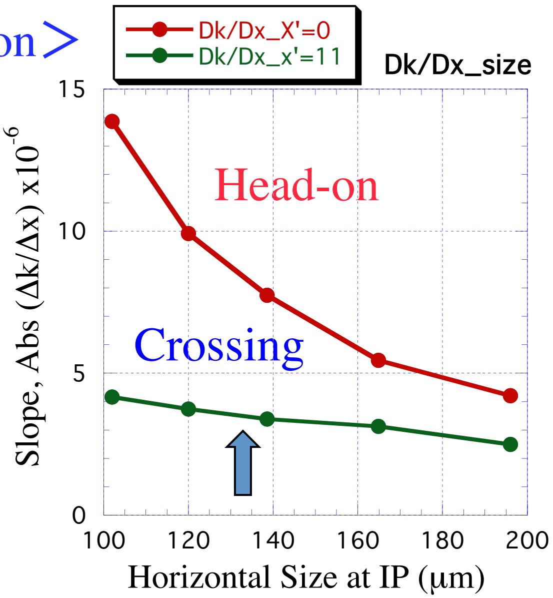
How to calculate the kick with an angle of 22 mrad

ε_x=24 nm





<Slope in Linear Region>



- A particle is horizontally moved and the kick data are summed up, including the longitudinal profile.

Result:

- The measurement is consistent with the calculation.

T. Ieiri

K. Akai

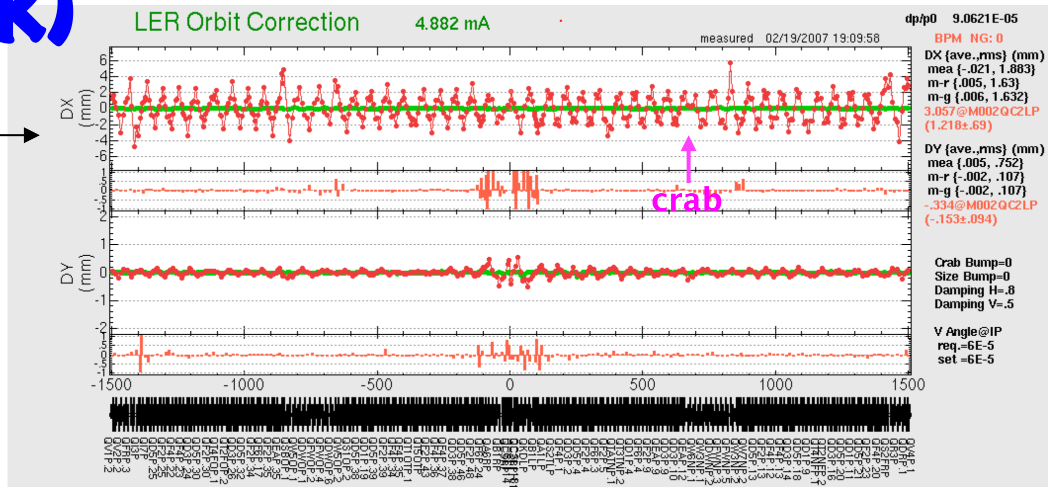
Crab system Adjustment

- Crab voltage
  - Calibrated from klystron output power and the loaded Q value.
  - The measurement to adjust the phase using beam also gives an independent calibration of the voltage.
  - Both are in good agreement within a few percent.
  - In addition, a crab voltage scan is done to maximize the luminosity in the luminosity run.
- Crab phase
  - The reference phase is searched to minimize the beam orbit difference between the crab on and off, so that the bunch center is not kicked by the crab voltage.
  - In the high-current operation, the phase is shifted by 10 degrees from the reference phase to cure the oscillation observed at high-current crab collision.
- Field center in the cavity
  - Searched by measuring the amplitude of the crabbing mode excited by a beam when the cavity was detuned. A local bump orbit was set to adjust the beam orbit on the cavity axis.

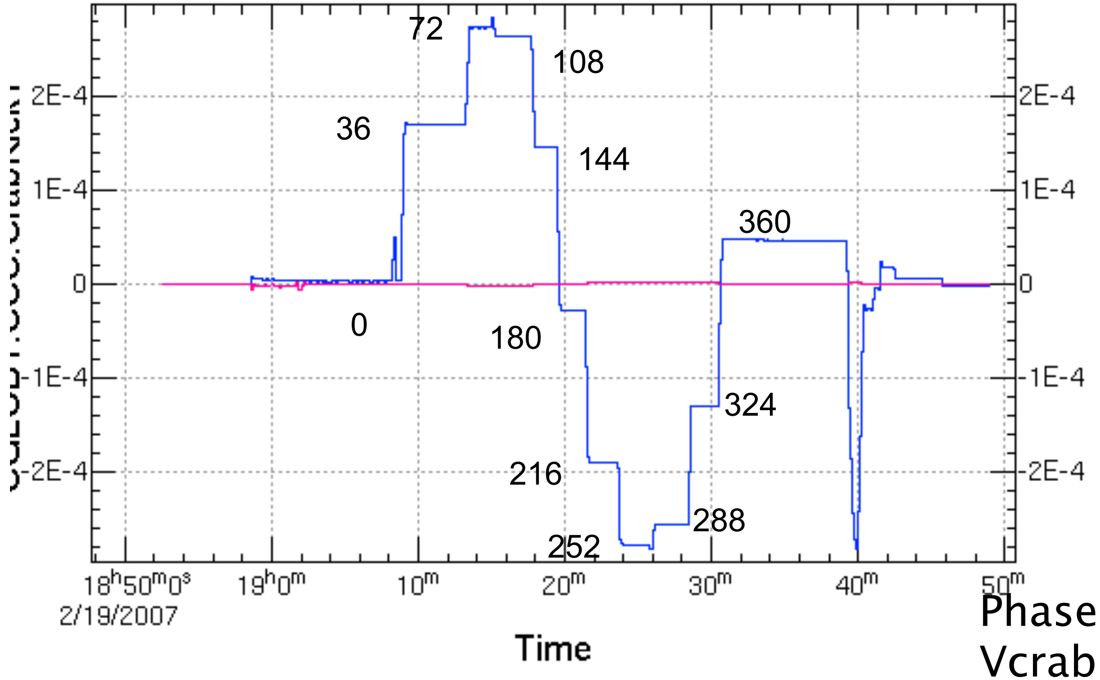
Crab Phase Scan (LER)

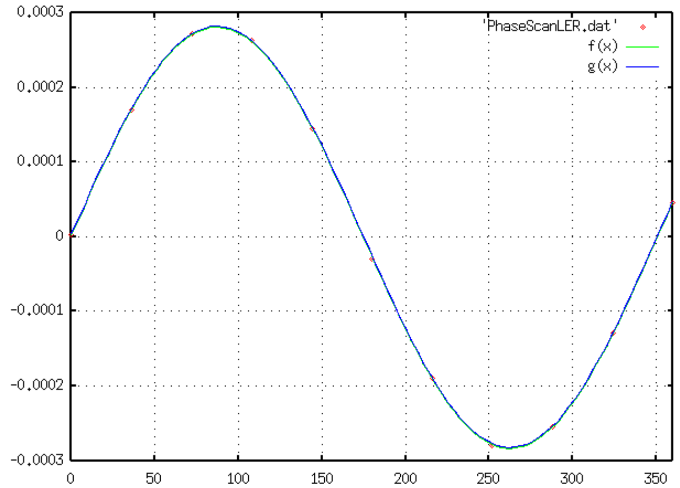
H. Koiso, A. Morita

Horizontal orbit by crab kick



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





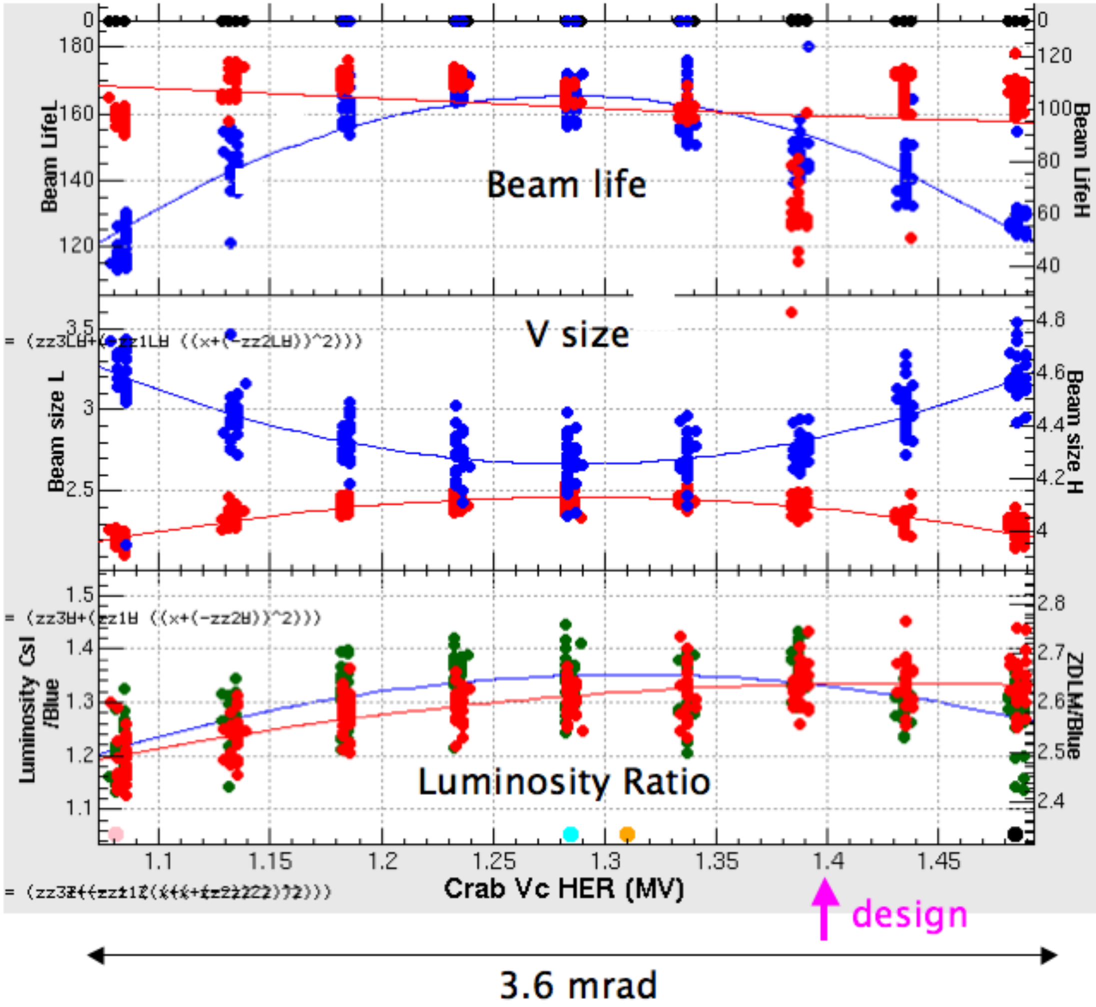
Phase 0 : 174.8 deg.

Vcrab set:1.0MV, estimated: 0.987MV

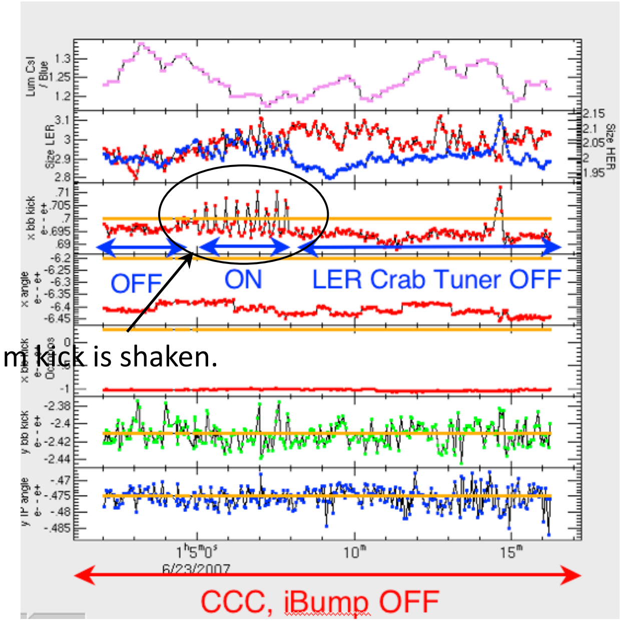
agree very well

To find the zero-cross point of crab Vc, the crab phase scan is done.

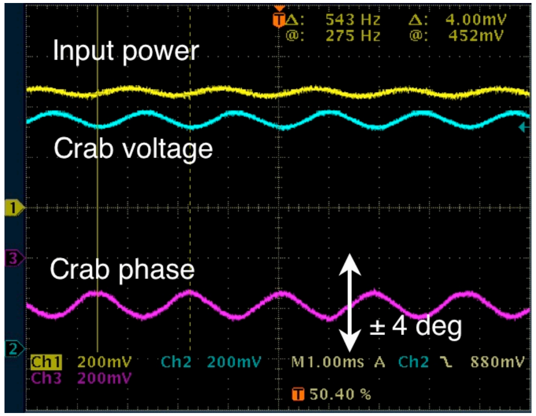
An example of crab Vc scan



Oscillation of High-current Crabbing Beams



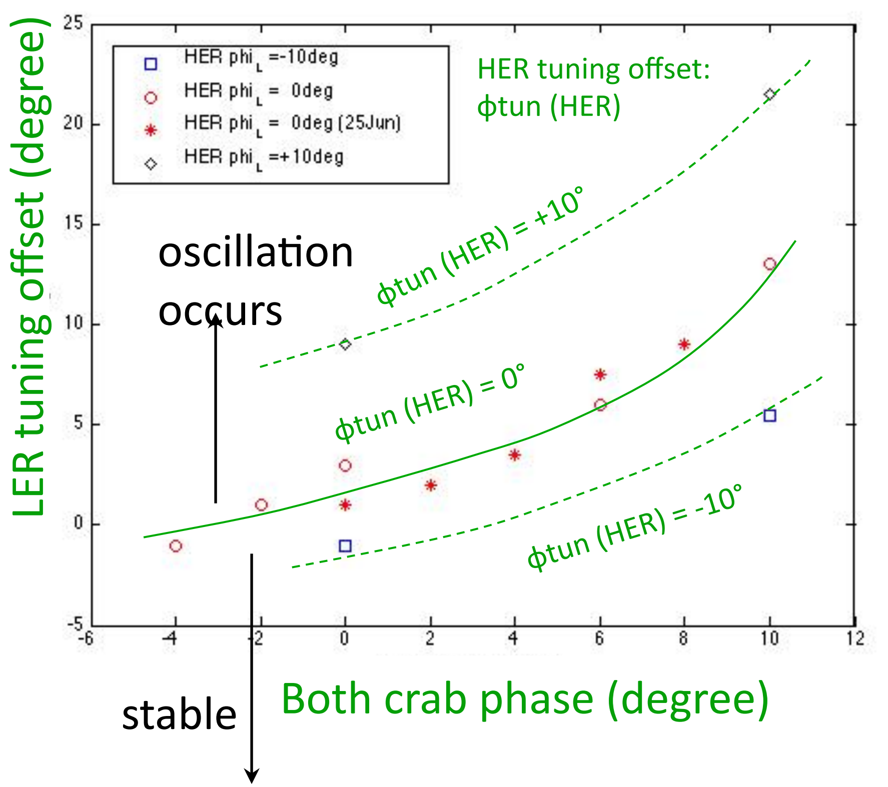
Beam-beam kick is shaken.



- A large-amplitude oscillation was observed in high-current crab-crossing operation in June 2007.
  - It caused unstable collision, short beam lifetime and luminosity degradation.
  - The crab voltage and phase were modulated at ~540 Hz. A 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.

K. Akai

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).

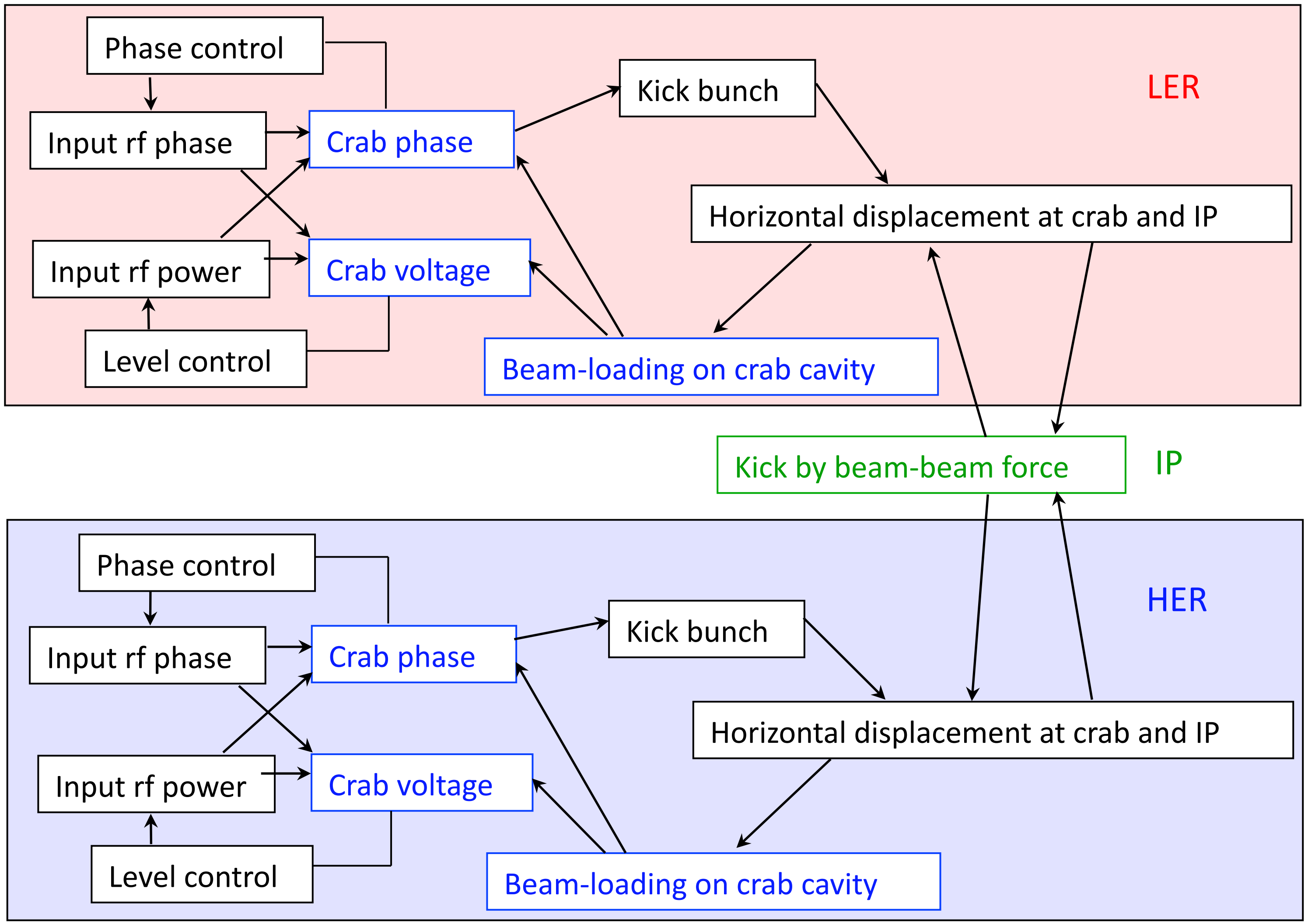
Observations at a machine study

- 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

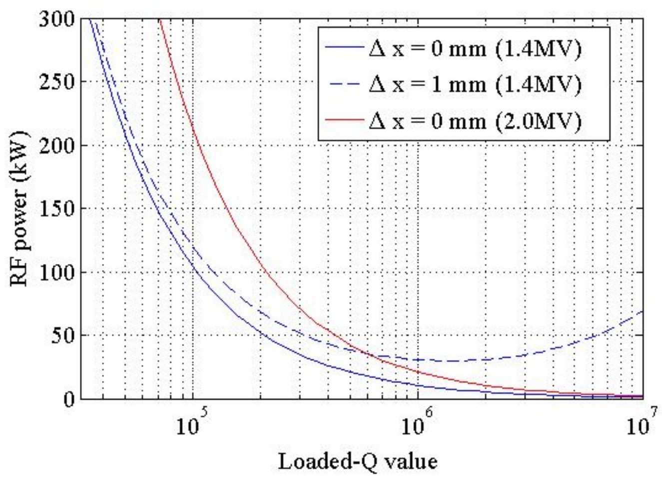
- We concluded that the oscillation is caused by beam loading on crab cavities together with beam-beam force at the IP (see, next slide).
- We found that it can be avoided by shifting the crabbing phase by +10° and controlling the tuning offset angle appropriately.

Possible mechanism of the oscillation



K. Akai

Orbit Control and Feedback near Crab Cavities



Dependence of RF power on the loaded Q value and a horizontal beam orbit for a beam current of 2 A.

- We have chosen Q_L=1~2 x10^5 for a good compromise.
  - This value is suitable for operating the system with a possible error of ΔX=1mm, and
  - A high power source of 200 kW is sufficient for conditioning the cavity up to 2 MV.

Typical parameters for the crab crossing.

Table 1: Parameters for the crab crossing for KEKB.

	LER	HER	unit
Beam energy	3.5	8.0	GeV
Beam current	1.7	1.35	A
RF frequency	508.9		MHz
Crossing angle	± 11		mrad
$\beta_{x,IP}$	80	80	cm
$\beta_{x,crab}$	80	170	m
V_{kick}	0.9	1.45	MV
Loaded-Q	2.0×10^5	1.6×10^5	
RF power for V_{kick}	23	90	kW

★Orbit feedback around crab cavities

Only horizontal orbit feedback is considered.

◆4 horizontal steering magnets to make an offset bump for each ring

◆4BPM to monitor the offset at the crab cavity.
⇒2 upstream (entrance) BPMs and 2 downstream (exit)

System speed (design) <~1 Hz.

◆We found that the orbit is stable enough.

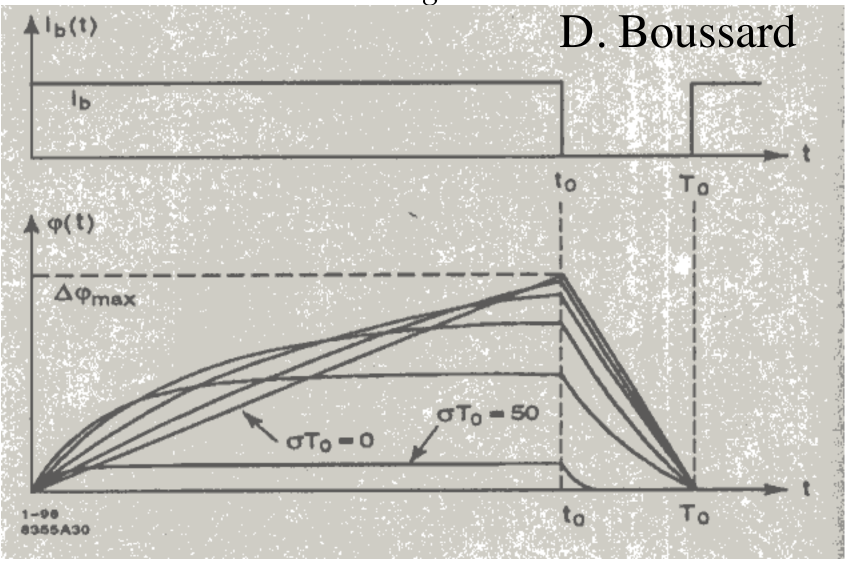
Usually, we do not need the orbit feedback.

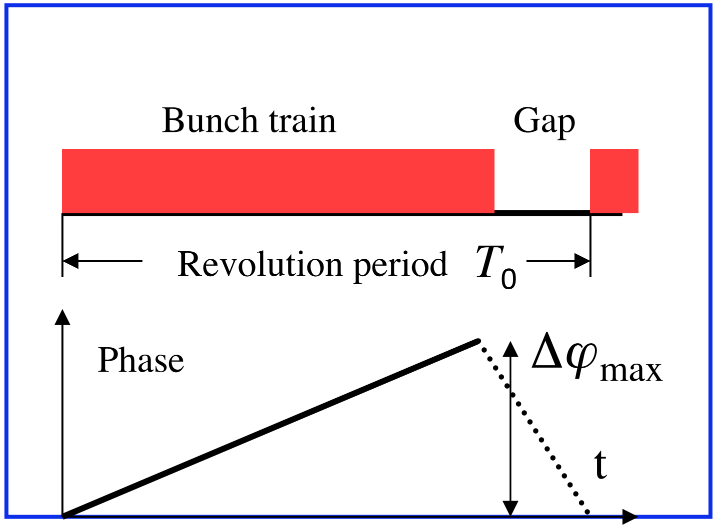
Effect of Transient Beam Loading

$$\Delta\varphi_{max} = \frac{R\omega_{rf}}{2QV_c}\bar{I}_b(T_0 - t_0) = \frac{R\omega_{rf}}{2QV_c}\bar{I}_b\Delta T_g$$

t_0 : length of bunch train

ΔT_g: Gap length





T. Ieiri

- The beam gap transient brings phase differences for bunches in the bunch train.
- Due to this, each bunch sees a different crab phase and then a different H-COD.
- In the KEKB case, this COD difference amounts to about $0.2\sigma_x$ at the IP.
- Fortunately, the effects of the two beams cancel each other and so almost no luminosity degradation is brought by this effect.

Measurement on Phase and Orbit Shift along Train

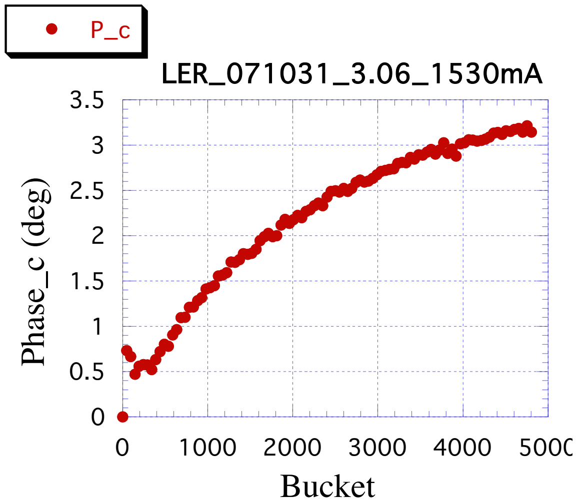
3.06 bucket spacing

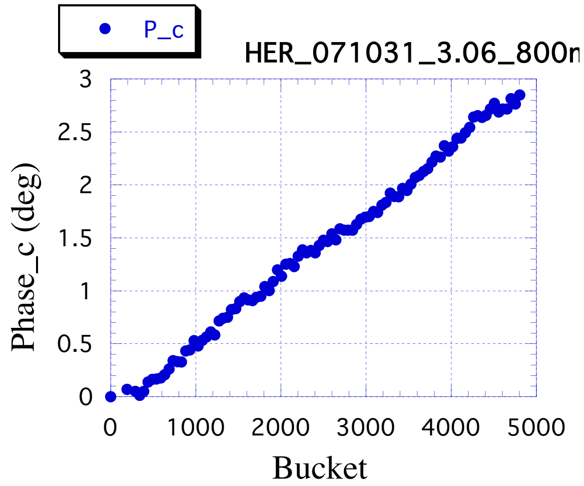
Crab ON

LER / 1530mA

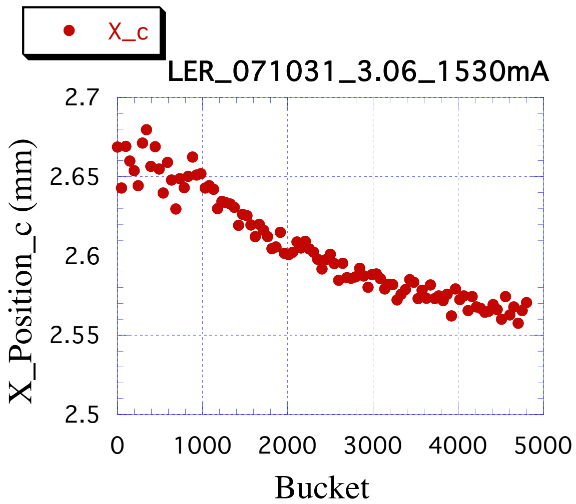
HER / 800mA

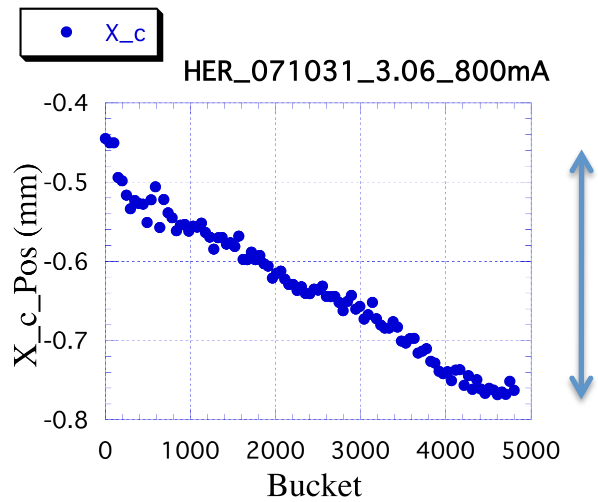
Z





X





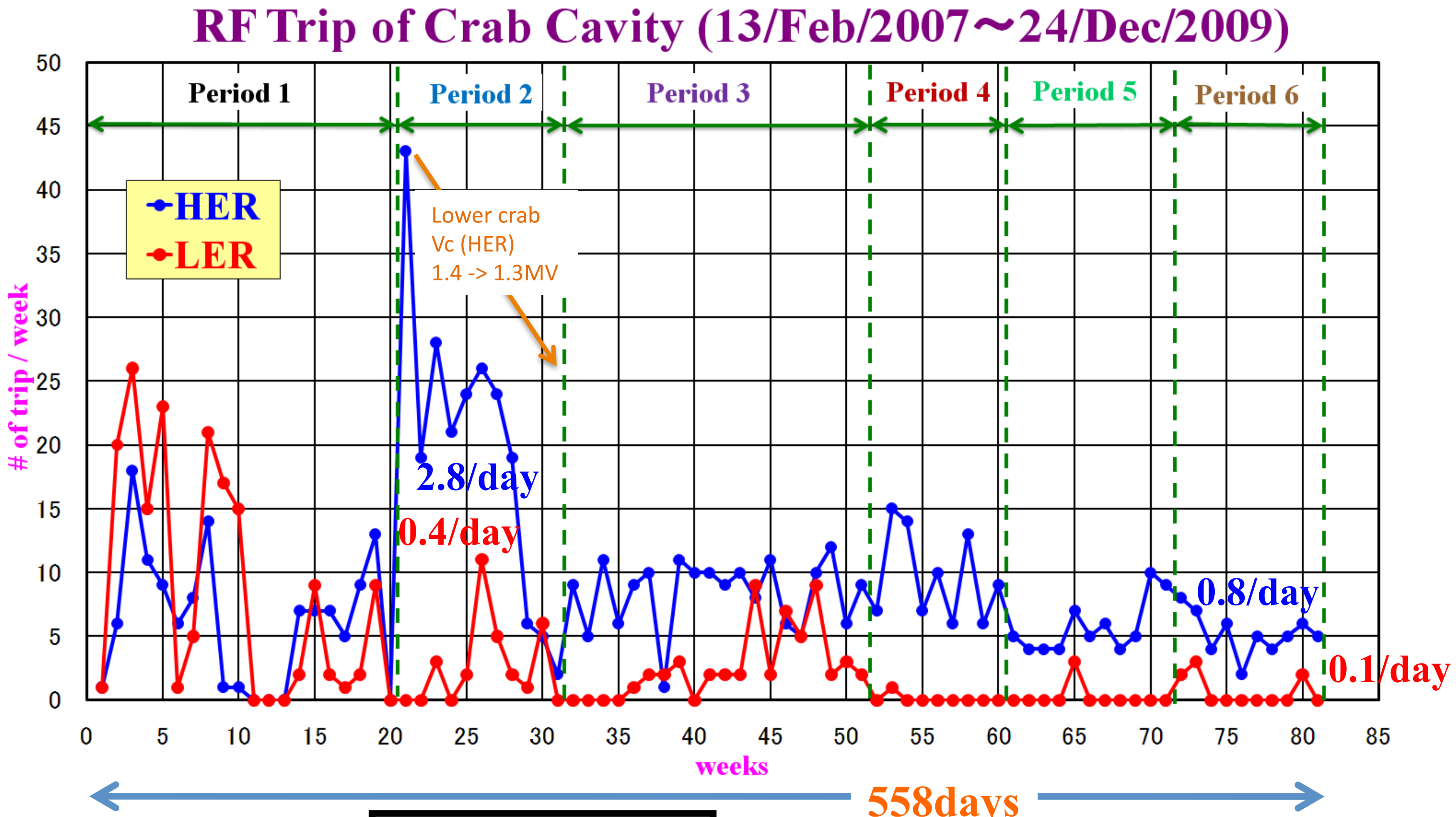
$\sim 0.2\sigma_x$

N=1585

T. Ieiri

RF Trips of Crab Cavities

Period 1 : Feb/2007~Jun/2007, Period 2 : Oct/2007~Dec/2007, Period 3 : Feb/208~Jun/2008
Period 4 : Oct/2008~Dec/2008, Period 5 : Apr/2009~Jun/2009, Period 6 : Oct/2009~Dec/2009



Total average

HER : 1.3/day
LER : 0.5/day

RF trip of LER Crab was very small last year.

Y. Yamamoto

Crab Cavity I/L System

Breakdown detector

RF output from pickup probes

Vacuum

Temperature

Arc sensor

He pressure/level

Flow rate of cooling water

→ Crab RF Off → Beam abort

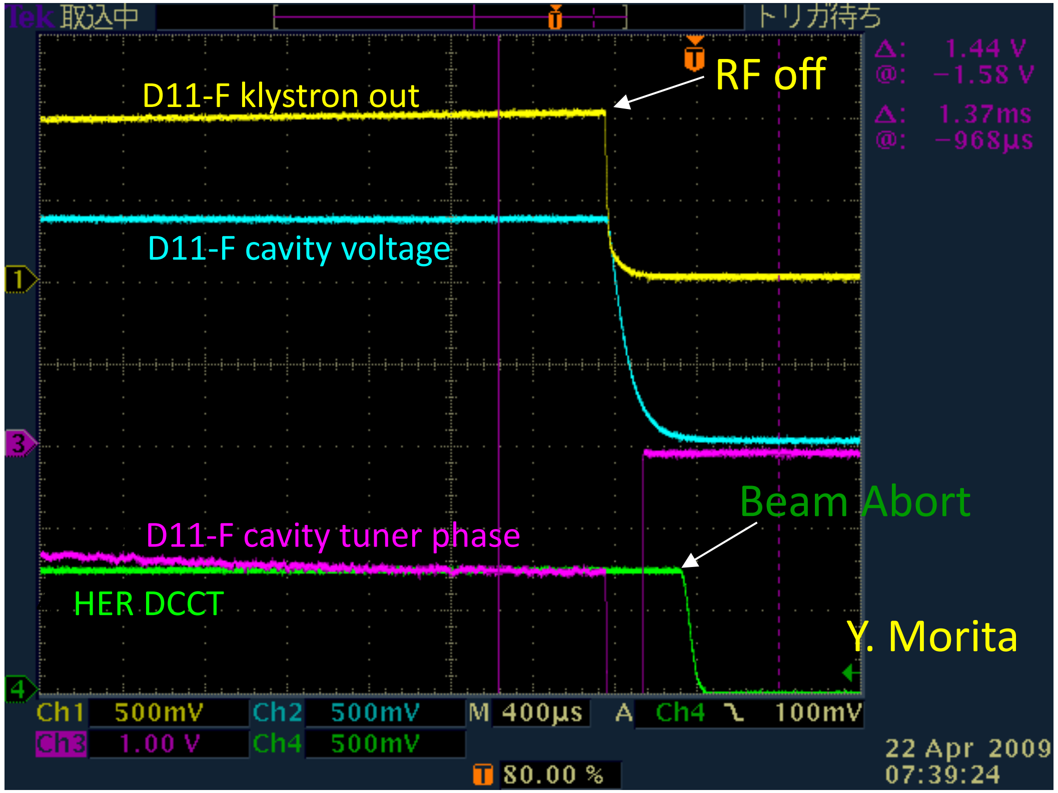
Breakdown detector judges whether P_{kly}, V_C and φ_{crab} (only V_C for LER) are normal, or not.
If not, Crab RF is switched off.
This is the most frequent cause of Crab RF trip.

Several pickup probes are attached for monitoring the transmit power and the RF output at coaxial beam pipe.

Whenever Crab RF is switched off, the beam is aborted coincidently, because of safety.

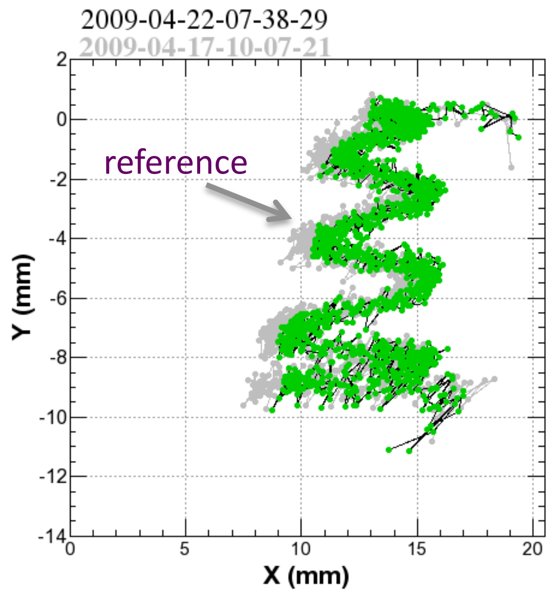
Y. Yamamoto

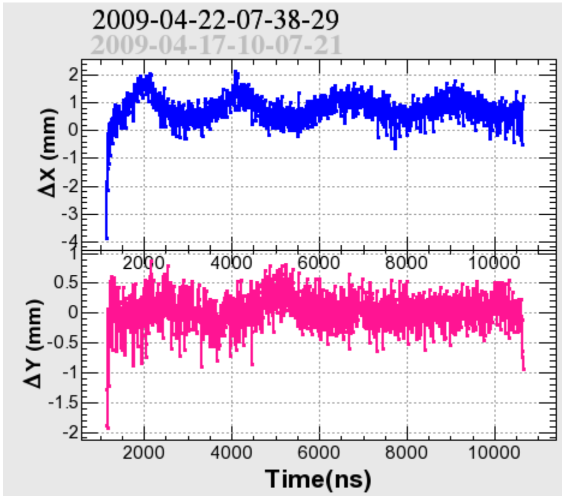
What happens in case of Crab RF Trip?



20090422 7:38 HER Vc abort

Beam positions of aborted beam





Typical example when HER Crab RF trips.

HER beam current: 750 mA

We abort the beam and switch-off the crab RF in case of crab RF trip.

In some cases, the beam is kicked more largely by the crab after RF trip and before RF off.

One of my colleagues (Nakanishi) are studying the transient behavior of the beam.

BEAM BEHAVIOR DUE TO CRAB CAVITY BREAKDOWN

K.Nakanishi*, Y.Funakoshi, M.Tobiyama, KEK, Tsukuba, Japan

Abstract

Crab cavities were installed in KEKB in 2007. The function of the cavity is to tilt the bunch of the beam in the longitudinal direction. But if the RF phase gets out of control, the cavity kicks the beam like a steering magnet. To avoid this unwanted kick, the RF phase must be controlled well. In the beam operation, some disturbances may occur such as a discharge, a quench, etc. When such disturbances occur, it is very difficult to control the RF phase precisely. We can't trust measured RF phase at that time. In KEKB, beam is aborted quickly when a disturbance is detected. Beam behavior before detecting the disturbances has been investigated.

voltage caused by the phase offset is compensated by steering magnets. The revolution periods of the beam for both rings are 10 μsec. The decay times of the cavity voltage are much longer than the revolution periods of the beams. The beam abort timing and the behavior of the crab cavity voltage are shown in Figure 2, when the crab cavity RF system makes an abort signal. It shows that the cavity voltage is turned off in about 100 μsec, and after a 200 μsec further delay, the beam is dumped.

Table 1: Typical values of related machine parameters of KEKB

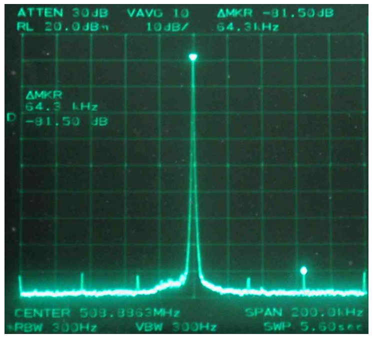
Ring	LER	HER	unit
β^*	80	80	cm

RF phase shifts 50 degree in 50 *μsec after the RF stop*

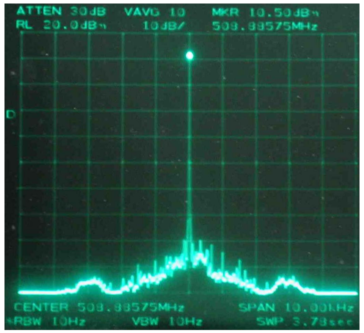
Phase stability

- Spectrum of pick up signal is consistent with phase detector data.
- Phase fluctuation faster than 1 kHz is less than ± 0.01°, and slow fluctuation from ten to several hundreds of hertz is about ± 0.1°.
- They are much less than the allowed phase error obtained from the beam-beam simulations for the crabbing beams in KEKB.

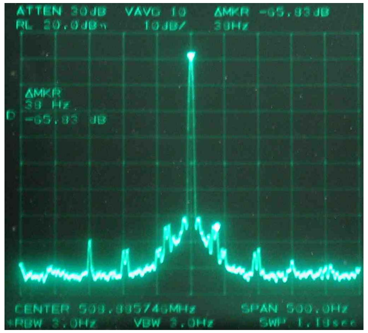
According to b-b simulation by Ohmi-san, allowed phase error for N-turn correlation is 0.1×√N (degree).



Span 200 kHz
Sideband peaks at 32kHz and 64kHz.

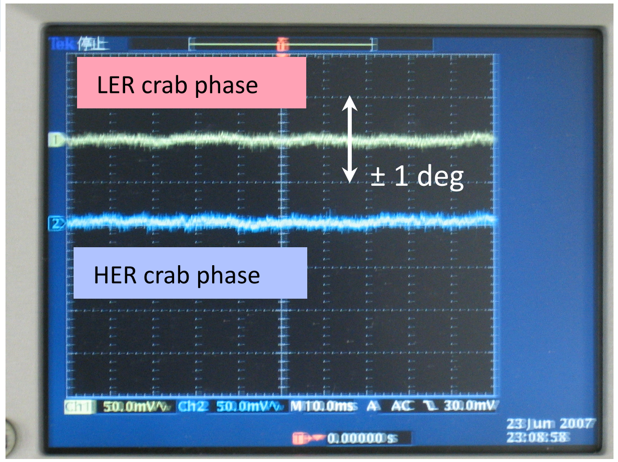


Span 10 kHz



Span 500 Hz
Sideband peaks at 32, 37, 46, 50, 100 Hz.

Spectrum around the crabbing mode measured at a pick up port of the LER crab cavity. Beam current was between 450 and 600 mA.



Phase detector signal. Beam current was 385mA (HER) and 600 mA (LER).

K. Akai

Measurements or experiences on impedance related issues

- The following measurements were done before and after the installation of crab cavities (by T. Ieiri).
  - Bunch current dependence of coherent tune shift
  - Loss factor
  - Bunch lengthening as function of the bunch current
- No significant difference was observed on these measurements between before and after crab.
- We once observed a coupled bunch instability due to the crabbing mode. However, this was due to wrong setting of the detuning frequency.
- As for the HOMs or LOMs, we have no experience that they induced any coupled bunch instability.

CAVITY VOLTAGE DROP OF LER CRAB

Cavity voltage of LER Crab was better than HER at horizontal test.
But, after installation to beam line, it dropped gradually.
And, it dropped suddenly from 1.3 to 1.0MV in Mar/17/2007.

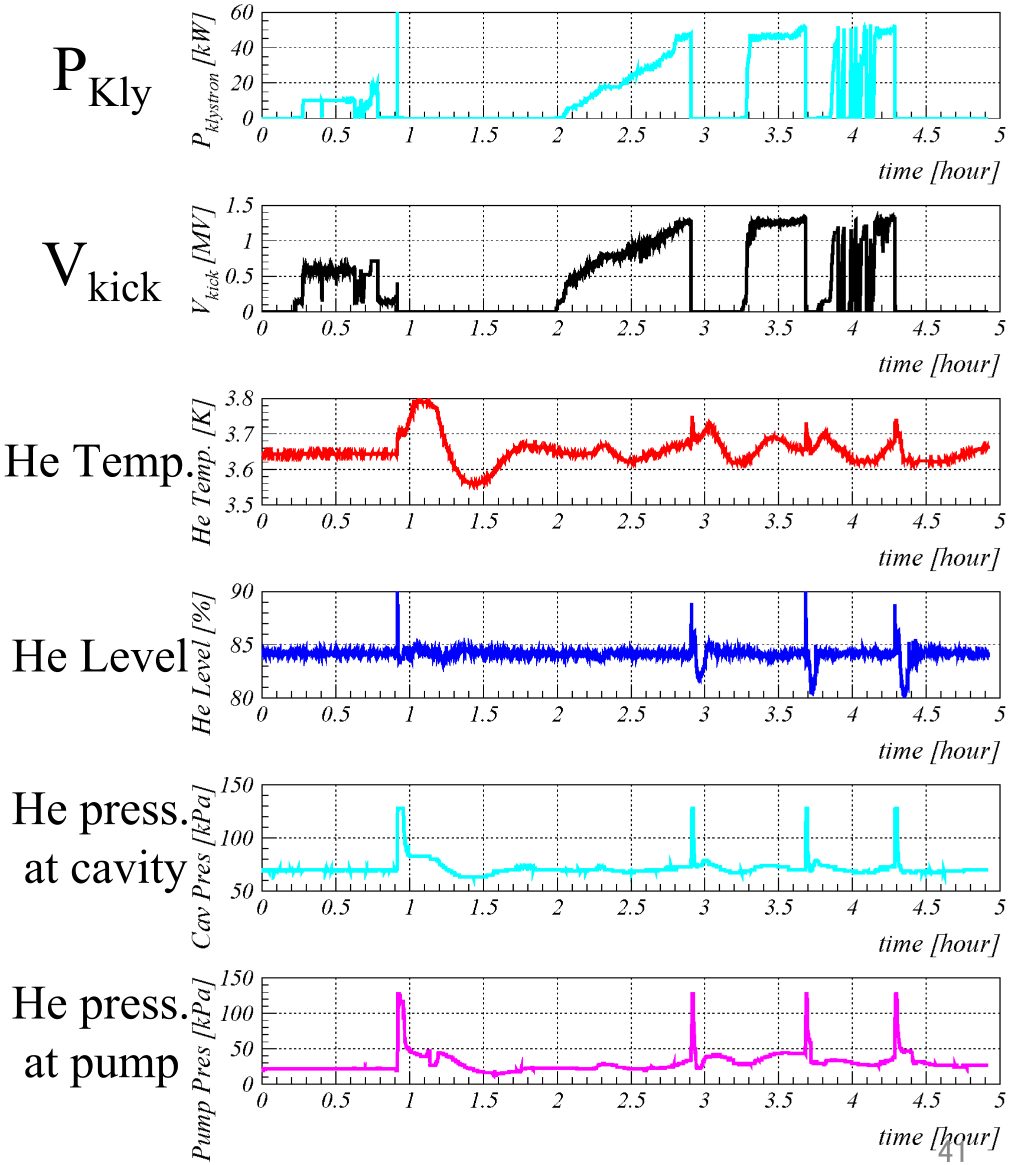
	Date	Cavity voltage [MV]	Comment
	Dec/2006	1.9	horizontal test
	Feb/19/2007	1.5	at beginning of beam commissioning
	Feb/22/2007	1.3	maintenance day
black day	Mar/17/2007	1.3 → 1.0	suddenly dropped
	Mar/23/2007	1.1	after thermal cycle
	May/22/2008	1.2	slightly recovered
	Jun/30/2008	1.3	after pulse conditioning
	Dec/18/2009	1.3	not more recovered

We hope cavity voltage of LER Crab is more recovered!
For example, at lower temperature, it can be operated?

Y. Yomamoto

LOWER TEMPERATURE OPERATION

Commissioning for LER Crab Cavity ('09/4/6)



Hosoyama-san's group tried lower temperature operation than 4.2K.

First trial was done in autumn/2008.
It failed due to unexpected oil reduction of pumping system.

Second trial was done in spring/2009.
Lower temperature operation was successful!
The operation was stable around 3.6K.

But, performance of LER Crab cavity was not recovered.

Y. Yomamoto

SuperKEKB

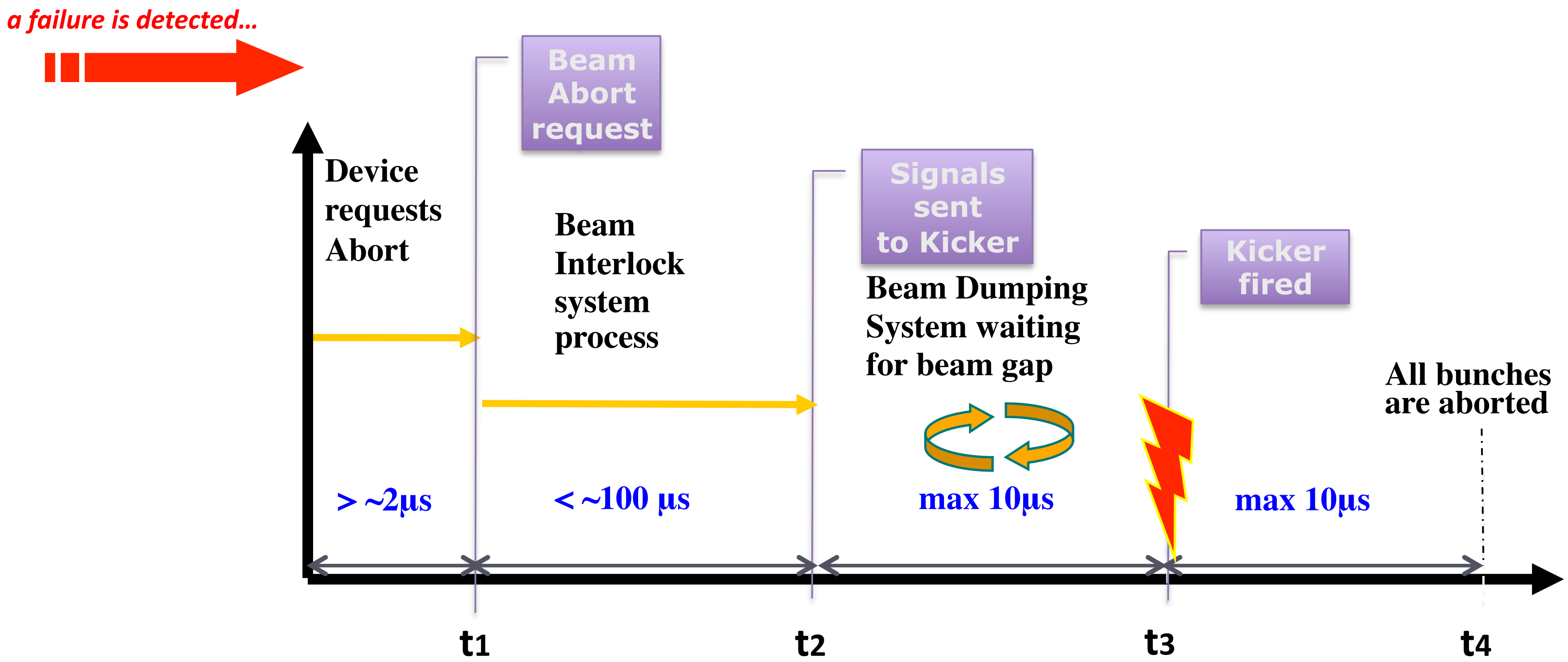
- We have decided to change the design concept of SuperKEKB from the high-current scheme to the Nano-Beam scheme (Italian scheme).
  - No crab cavities will be needed for SuperKEKB with the Nano-Beam scheme.

Summary

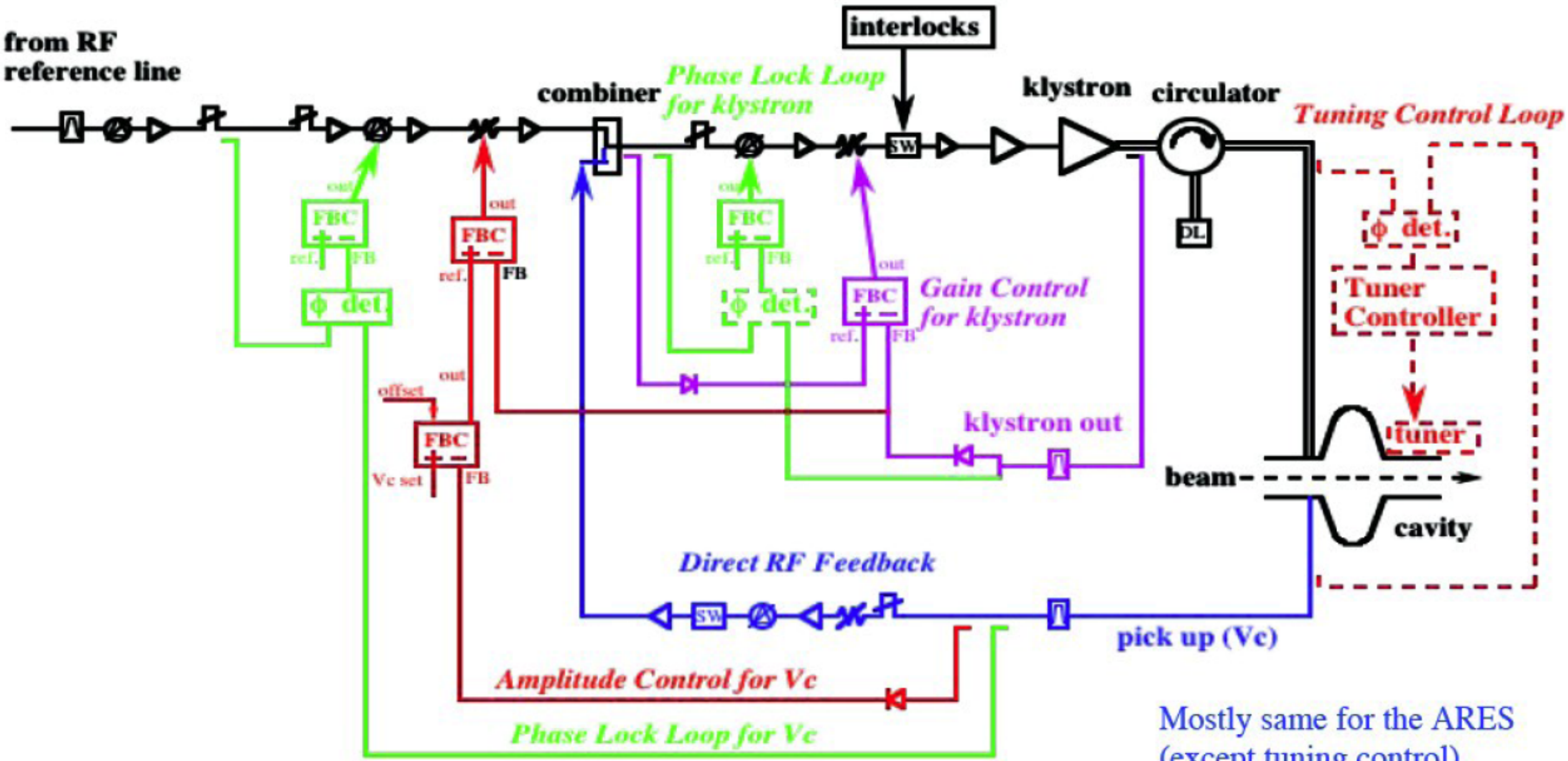
- The crab cavities at KEKB have been working much more stably than the initial expectation.
- They have been used in usual physics run.
- The crab cavities at KEKB did work in the sense that the luminosity gain with the crab cavities is much larger than the geometrical loss due to the crossing angle.
- There still exists a large discrepancy between the beam-beam simulation and the experiment with the crab crossing.
- We have 3-year's experiences of the beam operation with crab cavities and hope that these experiences are useful for other laboratory .
- The KEKB operation was terminated at the end of June 2010 for the upgrade toward SuperKEKB.

Spare slides

Beam Abort Delays



Low-level RF for KEKB Superconducting cavity



Mostly same for the ARES
(except tuning control).

D. Zhou, K. Ohmi, Y. Seimiya, Y. Ohnishi

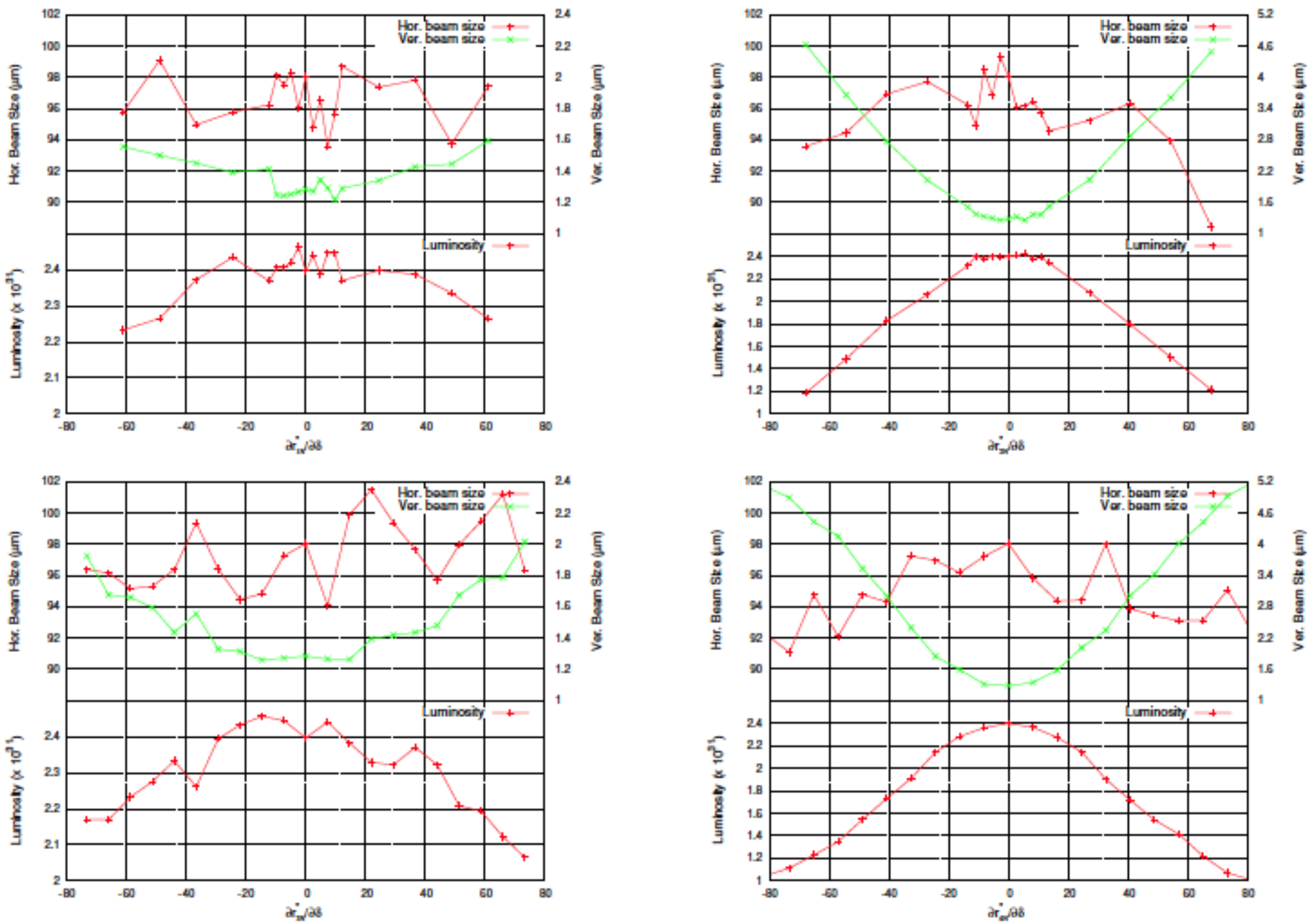


Figure 8: Scan of first order chromaticity of coupling parameters at IP (Top left: $\partial r^*_{1N}/\partial\delta$, Top right: $\partial r^*_{2N}/\partial\delta$, Bottom left: $\partial r^*_{3N}/\partial\delta$, Bottom right: $\partial r^*_{4N}/\partial\delta$)

$$\begin{pmatrix} r^*_{1N} & r^*_{2N} \\ r^*_{3N} & r^*_{4N} \end{pmatrix} = \begin{pmatrix} R^*_1\sqrt{\beta^*_x/\beta^*_y} & R^*_2/\sqrt{\beta^*_x\beta^*_y} \\ R^*_3\sqrt{\beta^*_x\beta^*_y} & R^*_4\sqrt{\beta^*_y/\beta^*_x} \end{pmatrix}$$

Definition of x-y coupling parameters (SAD notation)

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = T \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix}$$

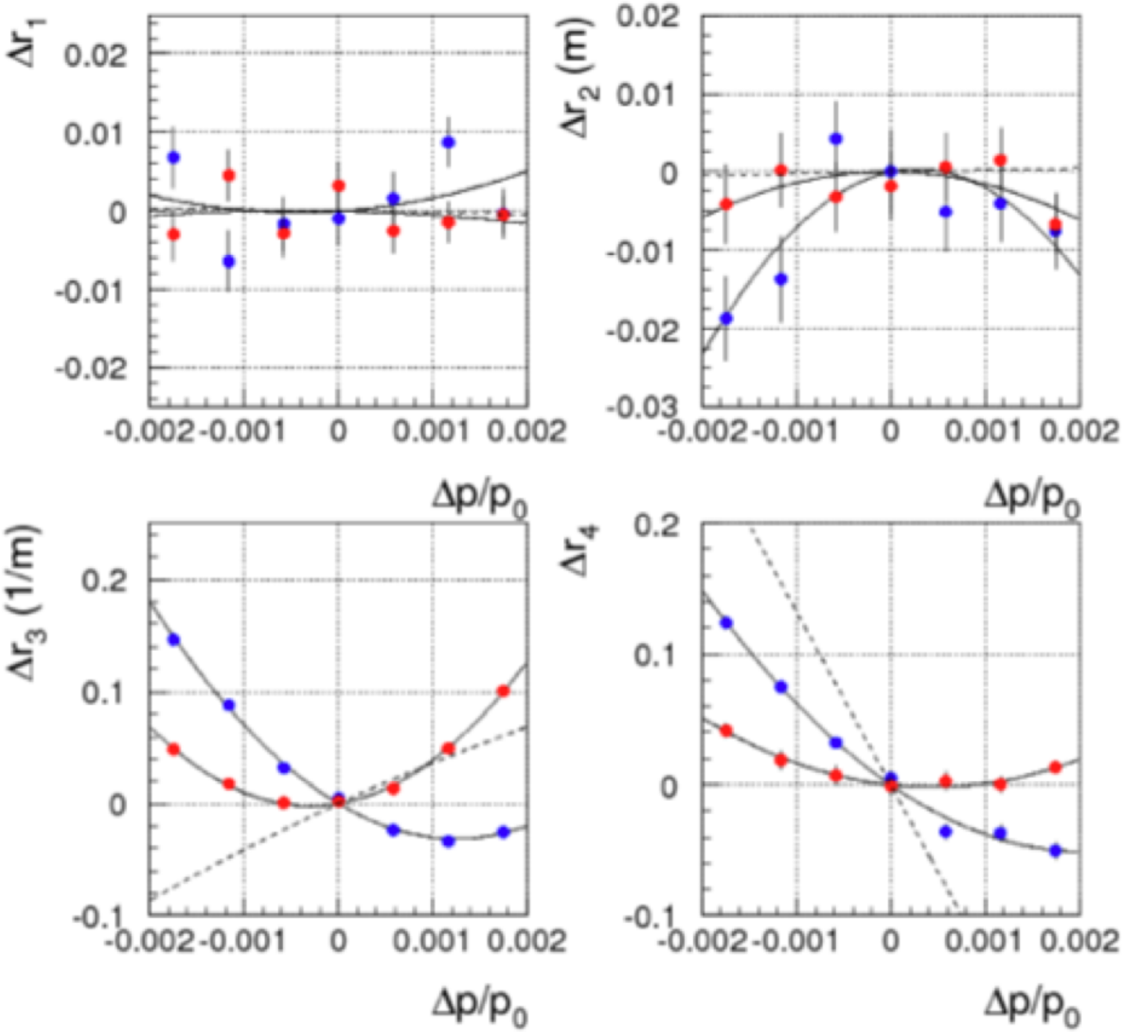
$$T(s) = \begin{pmatrix} \mu I & SR^t S \\ R & \mu I \end{pmatrix} = \begin{pmatrix} \mu & 0 & -R_4 & R_2 \\ 0 & \mu & R_3 & -R_1 \\ R_1 & R_2 & \mu & 0 \\ R_3 & R_4 & 0 & \mu \end{pmatrix}$$

$$S = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}, \quad \mu^2 + \det R = 1$$

Normal (decoupled) coordinate

Usual coordinate

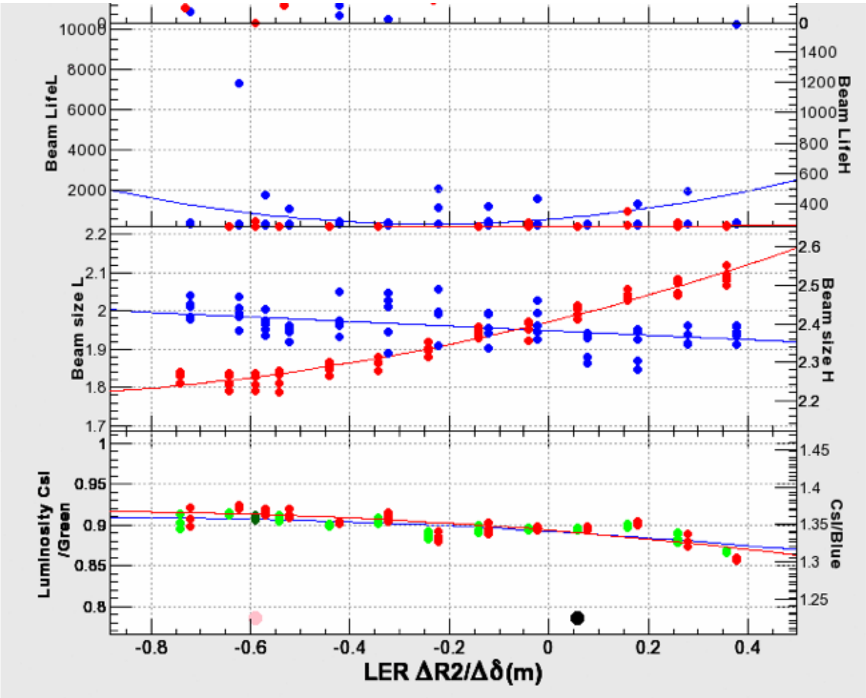
Measurement on chromaticity of x-y coupling at IP (HER)

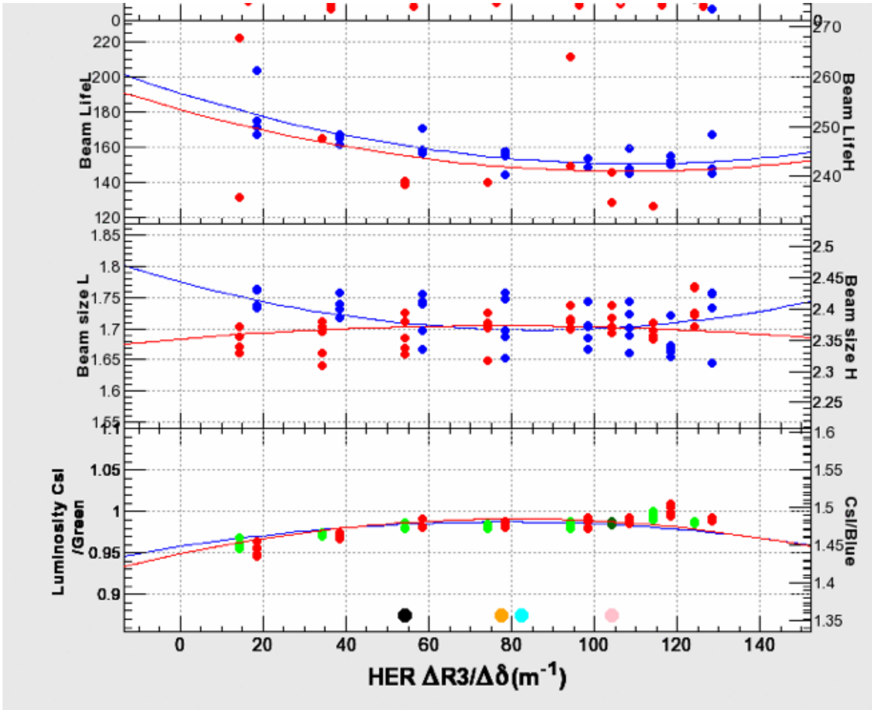


blue: without skew-sextuples

red: with skew-sextuples

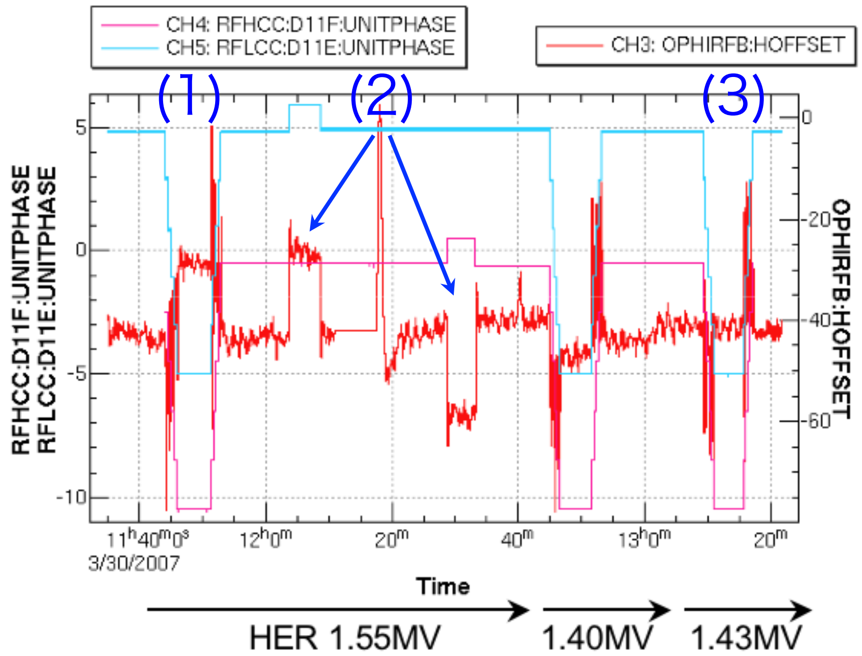
Examples of R-chromaticity scan





Crab phase vs Horizontal beam-beam kick

- Balance of crab kick strength between HER and LER can be tested by measuring the horizontal offset with the same amount of the crab phase shifts.
  - Crab phase of LER and HER were changed by10°: The horizontal offset at IP (beam-beam kick) changed by15μm. (1) 。(ideally zero)
  - Change LER phase only by1° or HER only by1° brought offsets of 16~19μm.(2) 。(calculated value from crabbing angle is18μm.)
- When we changed HER crab Vc from 1.55 to 1.43MV, the horizontal offset did not change with the same 10° phase change.(3)。



0.94MV (LER)
1.55MV (HER)

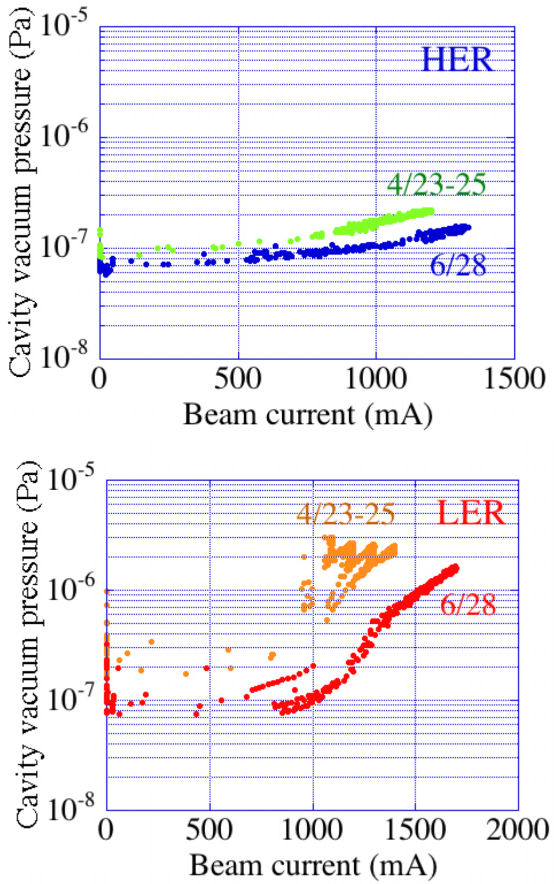
↓

0.94MV (LER)
1.43MV (HER)

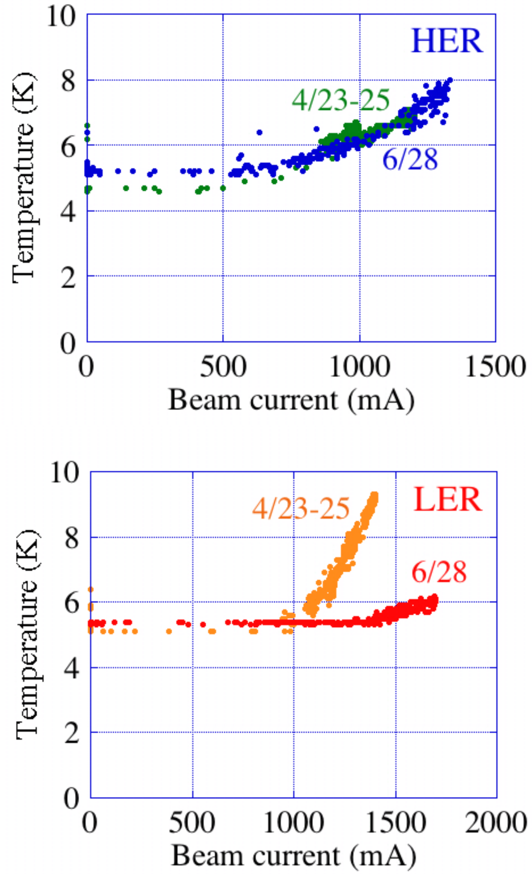
High beam current operation with crab detuned

- Machine time
  - We tried twice (April and June 2007).
- Beam currents
  - We stored the same beam currents as before crab.
    - LER: 1700mA, HER: 1350mA
  - Achieved luminosity
    - 11.16 /nb/s（16.4 /nb/s before cab）no enough time for tuning
- Crab situation (No serious problems were found.)
  - No crab trips
  - Heating of coaxial parts (LER, HER)
    - Temperature alarm -> We could manage to reinforce the cooling power.
  - HER LBP HOM absorber temperature alarm
    - Only alarm -> Reinforcement of cooling power afterward.
  - Coupled bunch instability due to crab mode
    - Detuning frequency was wrong. -> Re-tuning of detuning frequency.

High current: improvements in June

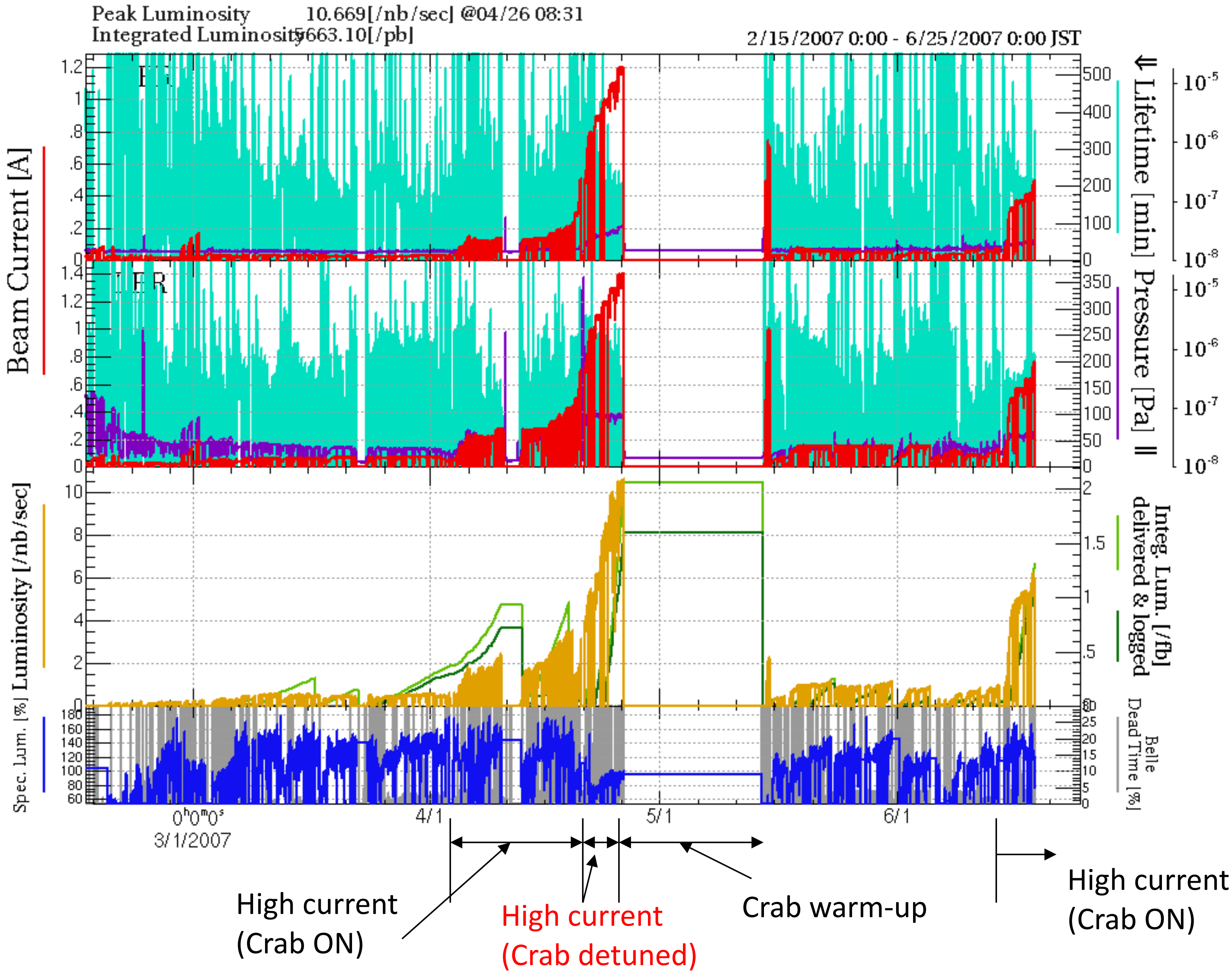


Vacuum pressure in the cavity before and after the warm up.

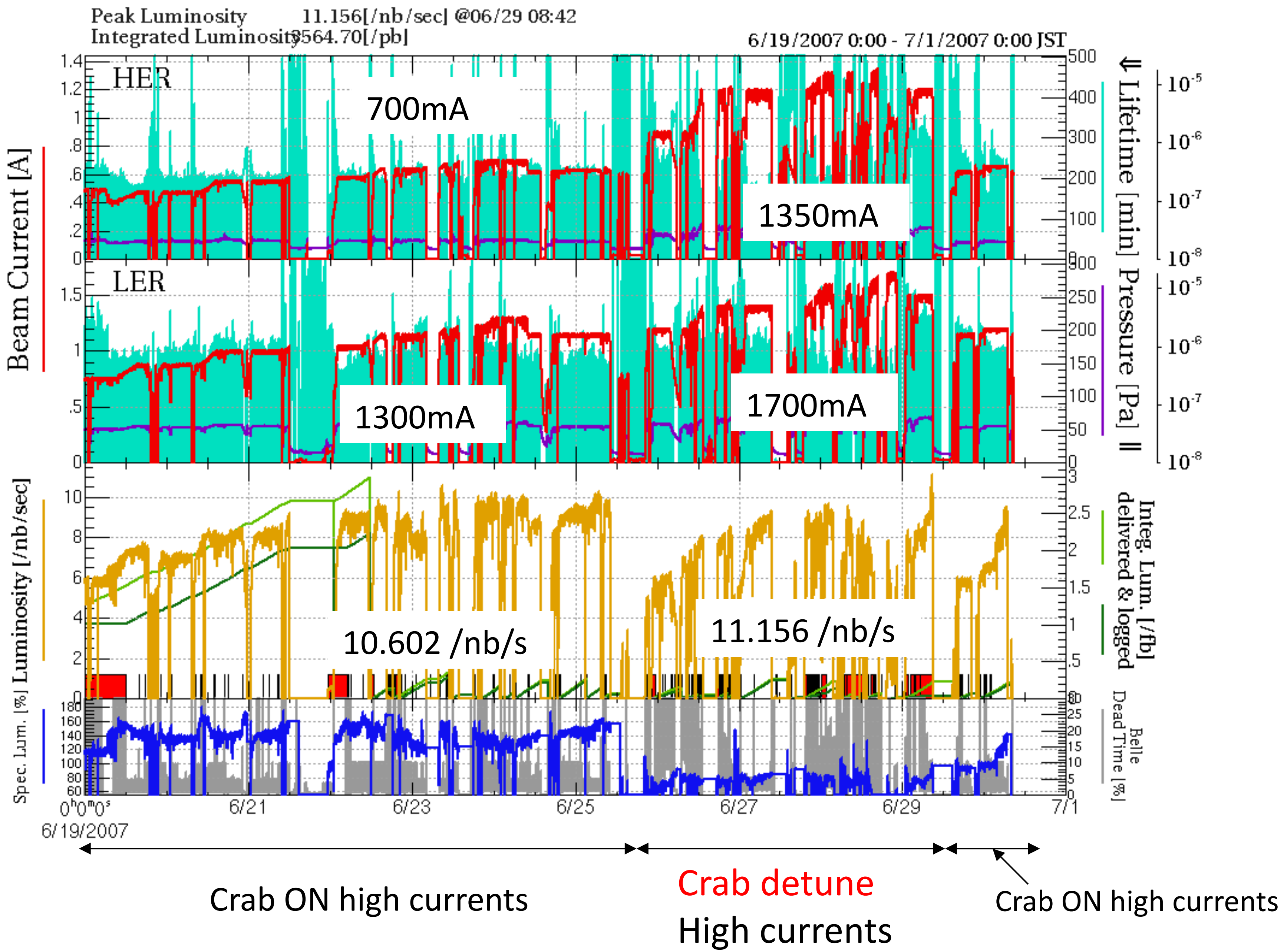


Temperature at the inner conductor of the coax before and after the reinforcement of the cooling power of the LER cavity.

K. Akai



Peak Luminosity 10.669[/nb/sec] @04/26 08:31
Integrated Luminosity 5663.10[/pb]
2/15/2007 0:00 - 6/25/2007 0:00 JST
HER
LER
Beam Current [A]
Lifetime [min]
Pressure [Pa]
Luminosity [/nb/sec]
Integ. Lum. [/fb] delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
3/1/2007
4/1
5/1
6/1
High current (Crab ON)
High current (Crab detuned)
Crab warm-up
High current (Crab ON)



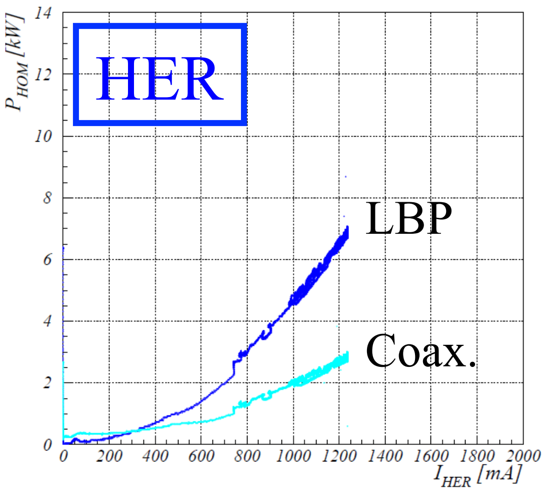
Peak Luminosity 11.156[/nb/sec] @06/29 08:42
Integrated Luminosity3564.70[/pb]
6/19/2007 0:00 - 7/1/2007 0:00 JST
HER
LER
700mA
1350mA
1300mA
1700mA
10.602 /nb/s
11.156 /nb/s
Beam Current [A]
Luminosity [/nb/sec]
Spec. Lum. [%]
⇐ Lifetime [min]
Pressure [Pa] ⇒
Integ. Lum. [/fb] delivered & logged
Belle Dead Time [%]
6/19/2007
6/21
6/23
6/25
6/27
6/29
7/1
Crab ON high currents
Crab detune
High currents
Crab ON high currents

HOM LOAD AT HOM DAMPERS

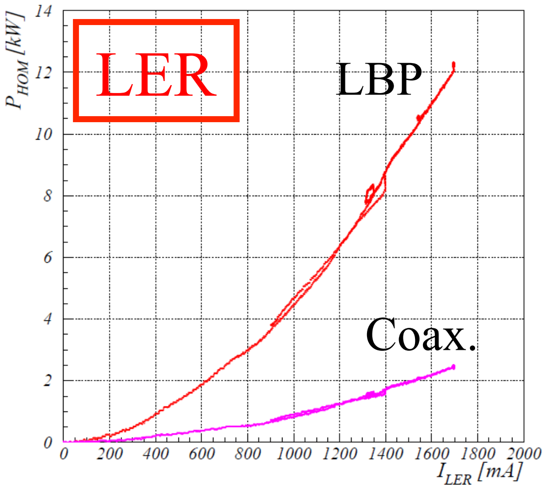
- Crab cavity has two ferrite HOM dampers.
- There are two SiC dampers at downstream of LER Crab cavity.
  - They are also effective for damping HOM load generated in Crab cavity.
- SiC2 damper was introduced for reduction of HOM load absorbed at SiC1.

	Load (kW)	T_{max} (°C)	Flow (ℓ/min)	k (V/pC)
HER 1250 mA				
Coaxial	3.0	34.0	5.0	0.28
LBP	6.9	40.0	7.0	0.74
LER 1700 mA				
Coaxial	2.5	31.3	5.0	0.13
LBP	12.4	47.2	7.5	0.68
SiC1	13.0	39.1	13.0	0.72
SiC2	12.2	41.5	10.3	0.66

Commissioning for HER Crab Cavity ('09/12/16)



Commissioning for LER Crab Cavity ('09/12/16)



Y. Morita

CRAB VOLTAGE SCANNING

Date	LER [MV]	HER [MV]
Feb/29/2008	0.83 → 0.88	1.37 → 1.41
Mar/4/2008	0.88 → 0.88	1.37 → 1.38
Apr/5/2008	0.83 → 0.84	1.38 → 1.39
Apr/15/2008	0.84 → 0.85	1.39 → 1.40
Apr/25/2008	0.83 → 0.83	–
Jun/4/2008	0.83 → 0.85	1.45 → 1.46
Jun/18/2008	0.83 → 0.83	–
Oct/26/2008	0.85 → 0.83	1.37 → 1.34
Nov/22/2008	0.83 → 0.81	1.50 → 1.48
Dec/18/2008	0.81 → 0.84	–
Apr/26/2009	0.85 → 0.83	1.35 → 1.32
May/20/2009	0.83 → 0.85	1.32 → 1.33
Jun/6/2009	0.85 → 0.86	1.33 → 1.37
Jun/18/2009	0.95 → 0.98	1.50 → 1.55
Nov/2/2009	0.87 → 0.90	1.29 → 1.34
Dec/12/2009	0.95 → 0.97	1.40 → 1.45

Voltage scanning is sometimes carried out as part of beam tuning for higher luminosity.

During this operation, RF trip of Crab cavity occurs frequently.

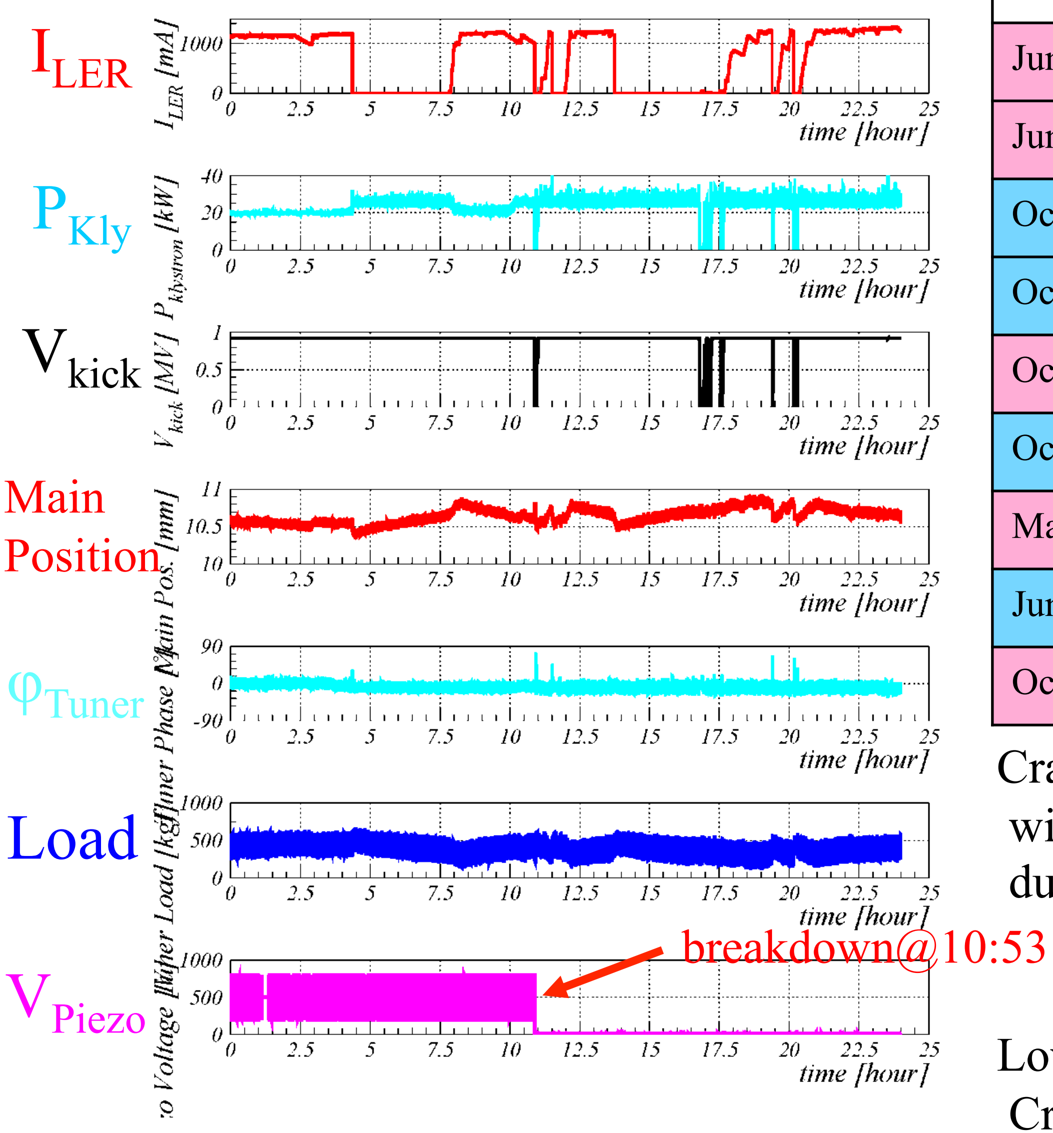
Very careful operation is necessary!

When Crab RF is switched off, RF conditioning is sometimes done at local control room.

← **Max. operation voltage**

PIEZO ACTUATOR BREAKDOWN

Commissioning for LER Crab Cavity ('07/6/23)



Date	Cavity	Comment
Jun/9/2007	LER	At RF recovery
Jun/23/2007	LER	At beam abort with RF trip
Oct/1/2007	HER	At RF recovery
Oct/4/2007	HER	At RF trip
Oct/16/2007	LER	At RF recovery
Oct/15/2008	HER	At RF trip
May/15/2009	LER	At beam abort with RF trip
Jun/11/2009	HER	At beam abort with RF trip
Oct/25/2009	LER	At beam abort with RF trip

Crab cavities have been operated without Piezo actuator during most of beam commissioning.

Not significant!

Low level feedback system can control Crab cavity without Piezo.