KEKB instrumentation and tuning for crab cavity tuning

Y. Funakoshi
KEK

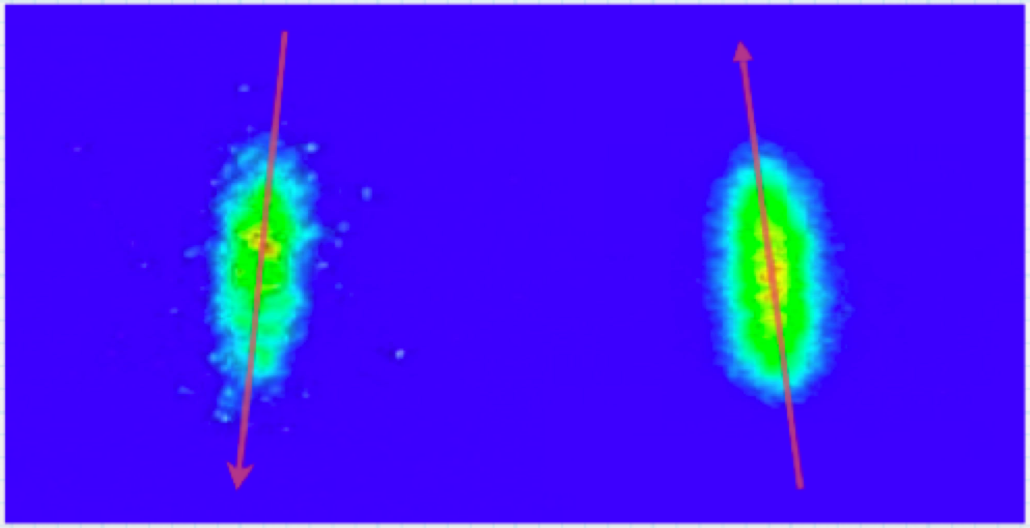
Evidence of crabbing motion (1): Streak camera

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

inside of the rings

outside of the rings

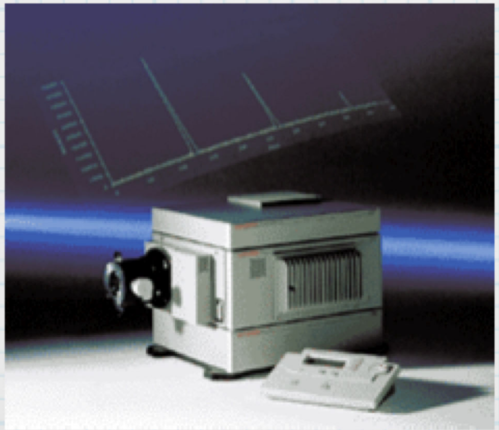
longitudinal



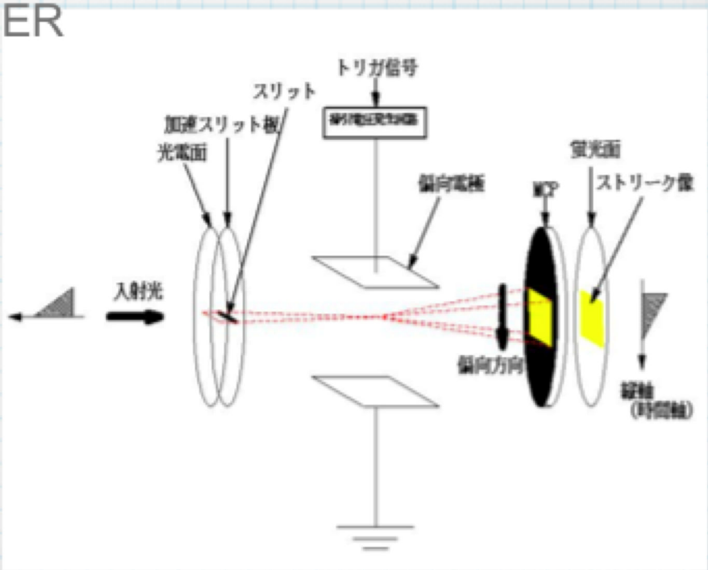
LER

HER

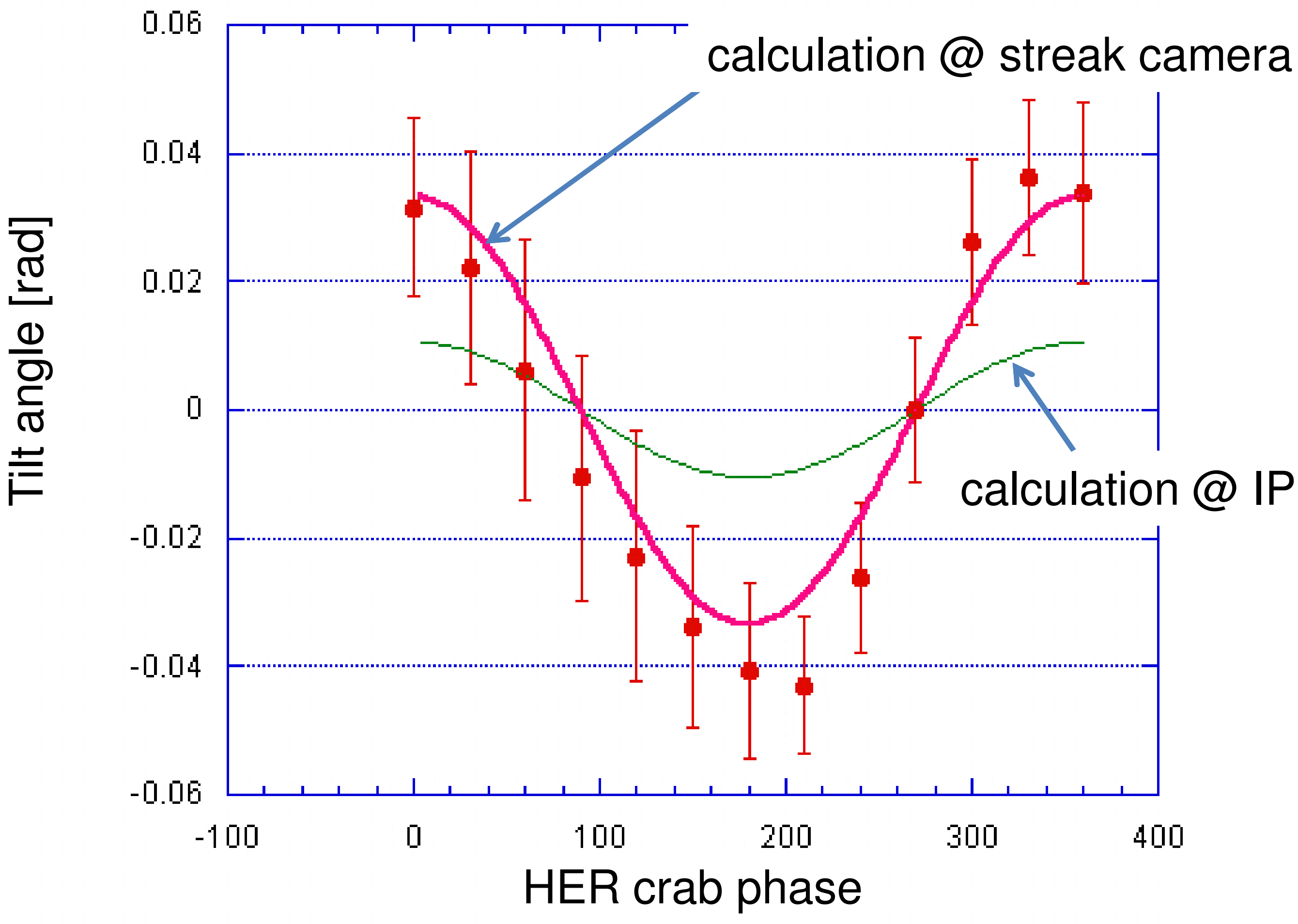
horizontal



The streak camera

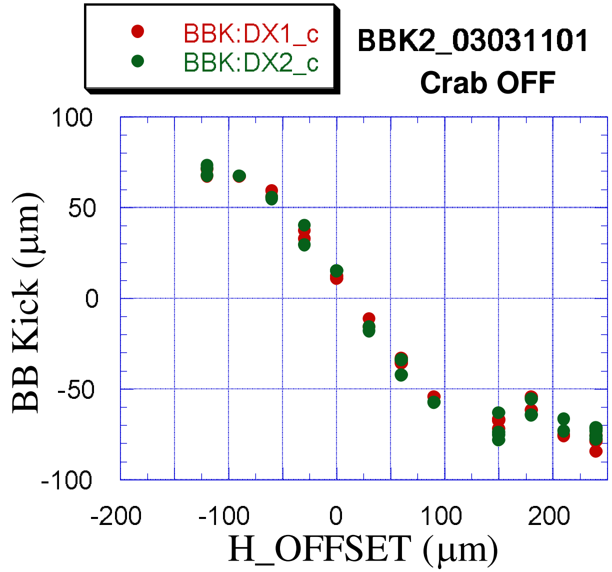


HER crabbing angle measurement and calculation



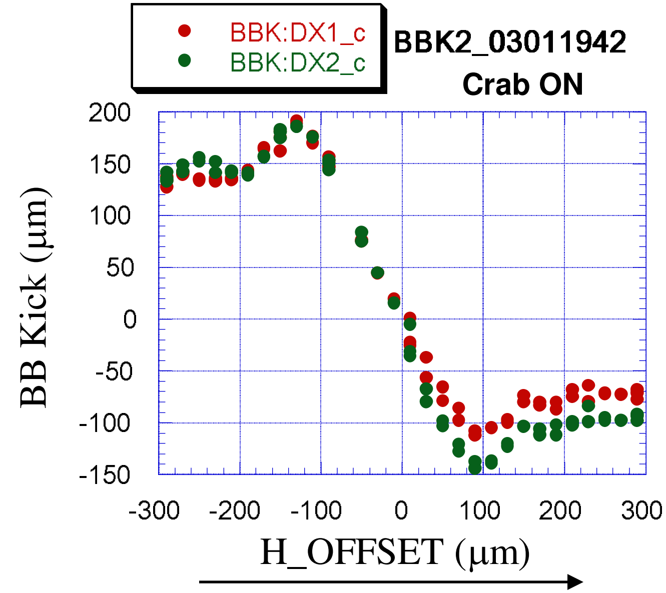
Evidence of crabbing (2): Beam-beam deflection

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:

$$\frac{\frac{\Delta k}{\Delta x_{x'=0}}}{\frac{\Delta k}{\Delta x_{x'=11}}} = 2.14$$

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

T. Ieiri

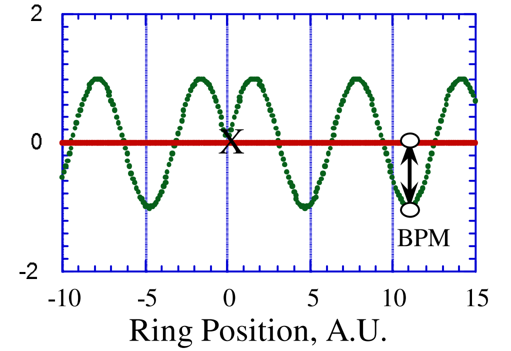
Method of measurement of beam-beam kick

- 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

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

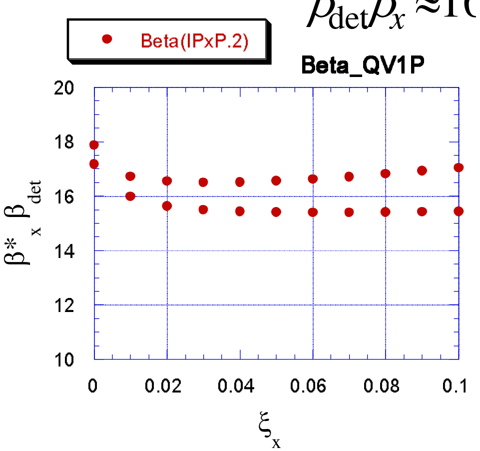
$$\Delta_y = 0$$

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

$$|\Delta_x| < \Sigma_x$$

<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

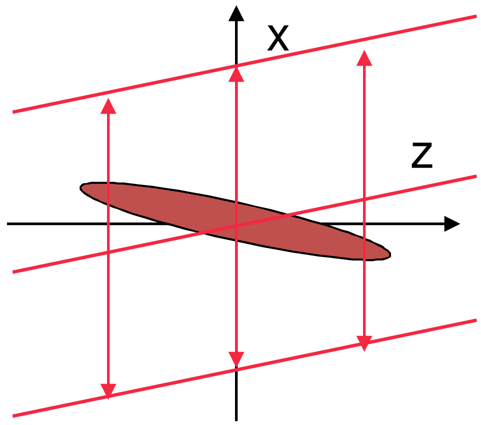
T. Ieiri

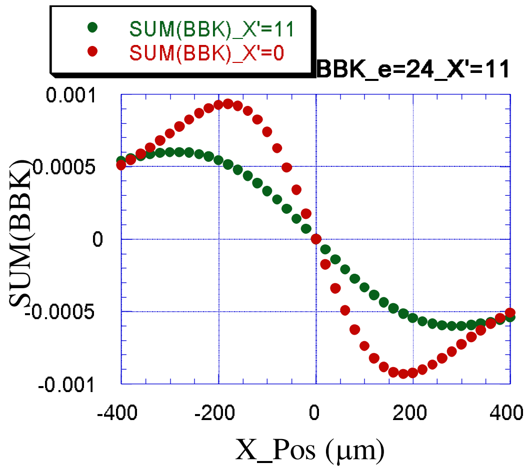
Calculation of Beam-Beam Kick with and without Crossing Angle

Use code "BBWS" by Ohmi

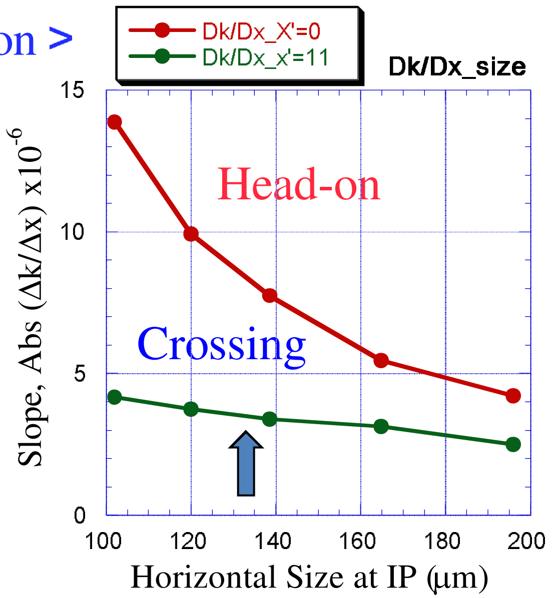
How to calculate the kick with an angle of 22 mrad

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:

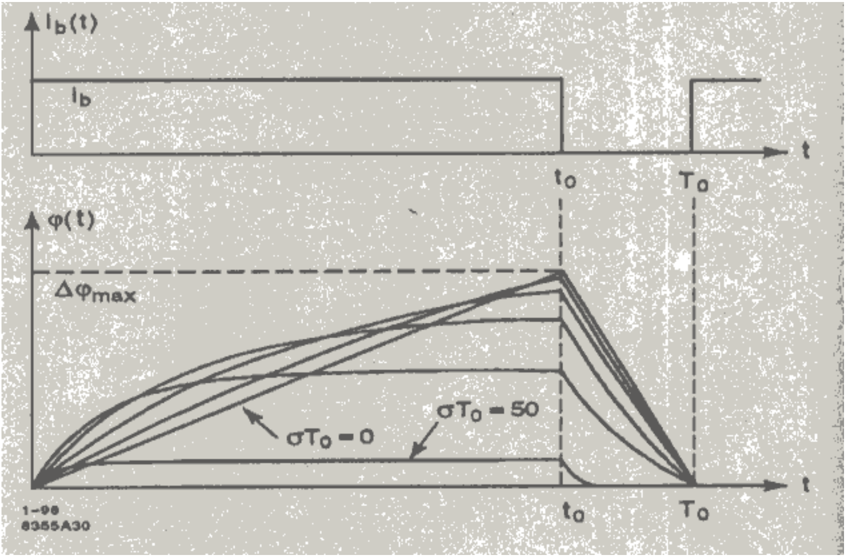
- The measurement is consistent with the calculation.

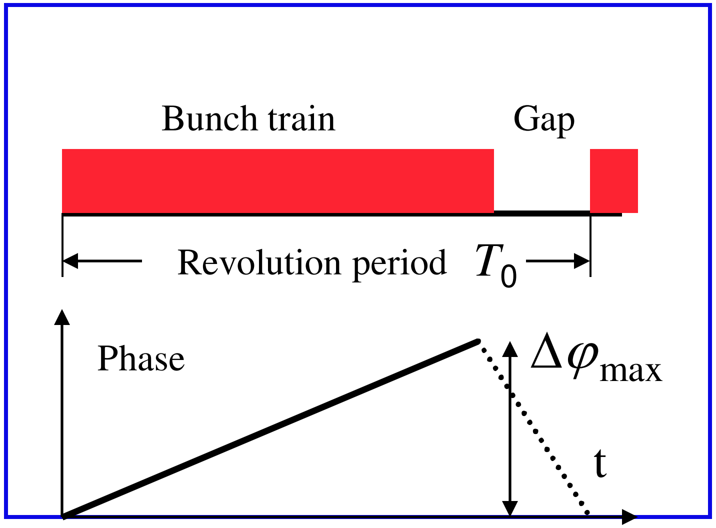
T. Ieiri

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





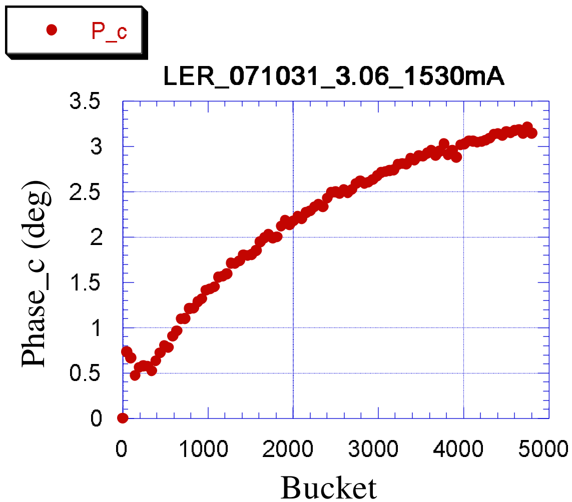
D. Boussard

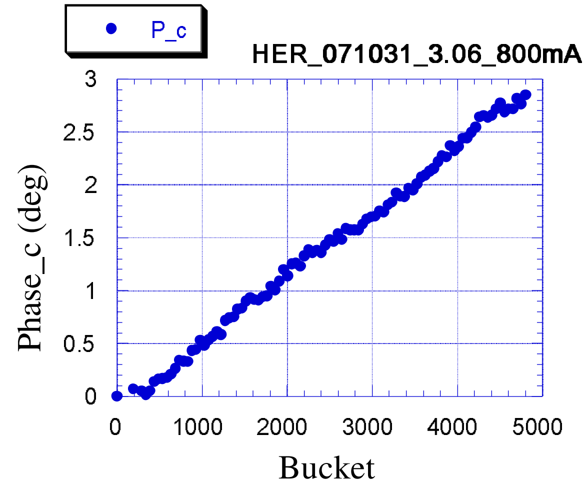
Phase and orbit shift along train with 3.06 spacing: Crab ON

LER / 1530mA

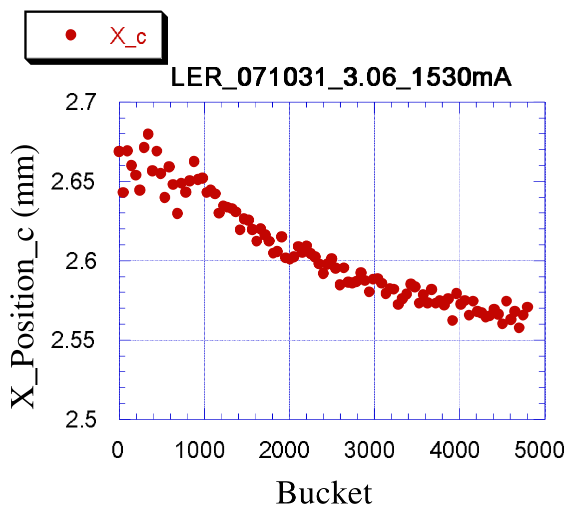
HER / 800mA

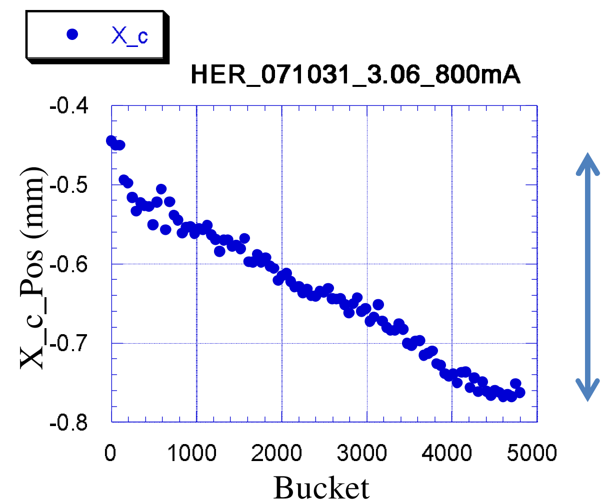
Z





X





$\sim 0.2\sigma_x$

N=1585

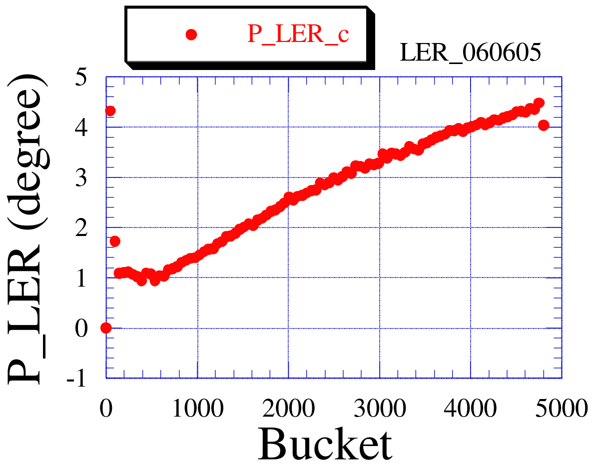
T. Ieiri

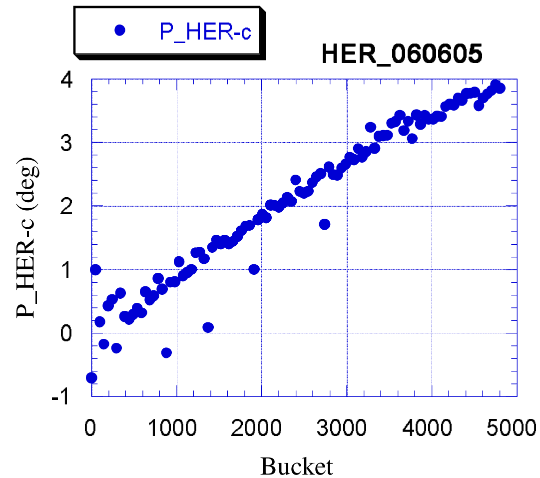
Phase and orbit shift along train with 3.06 spacing: Crab OFF

LER/1640mA

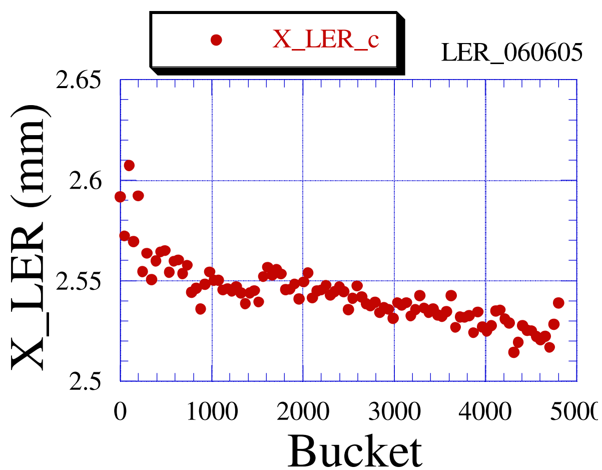
HER/1260mA

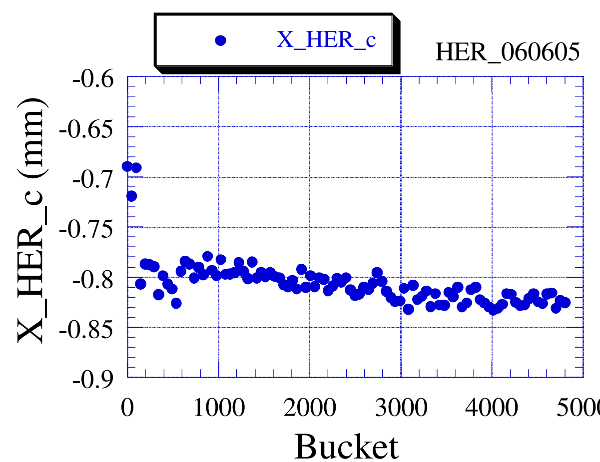
Z





X





N=1585

T. Ieiri

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.

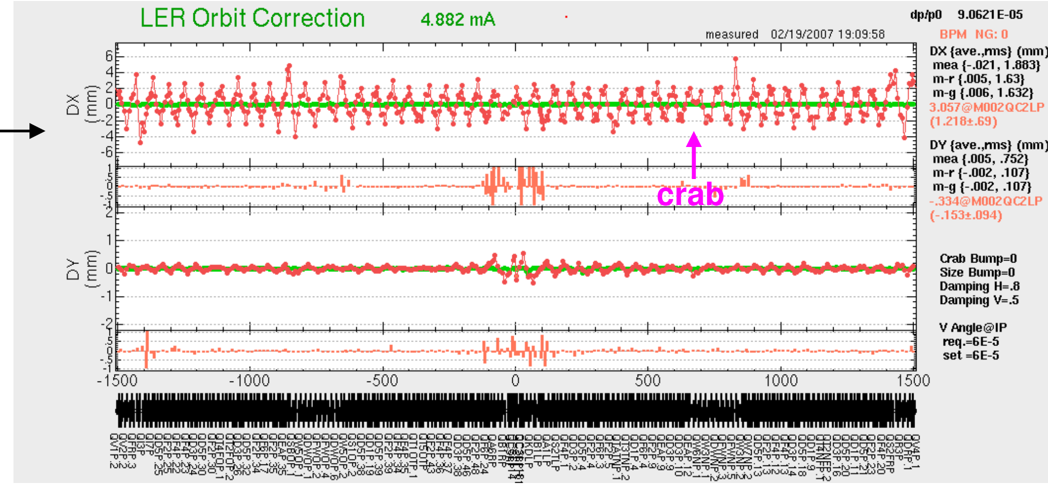
Crab system Adjustment

- Crabbing voltage
  - Calibrated from klystron output power and the loaded Q value.
  - The measurement to adjust the phase using beam (below) also gives an independent calibration of the voltage.
  - Both are in good agreement within a few percent.
- Crabbing phase
  - The reference phase is searched to minimize the beam orbit difference between the crabbing on and off, so that the bunch center is not kicked by the crabbing 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 (see yesterday's talk).
- 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.

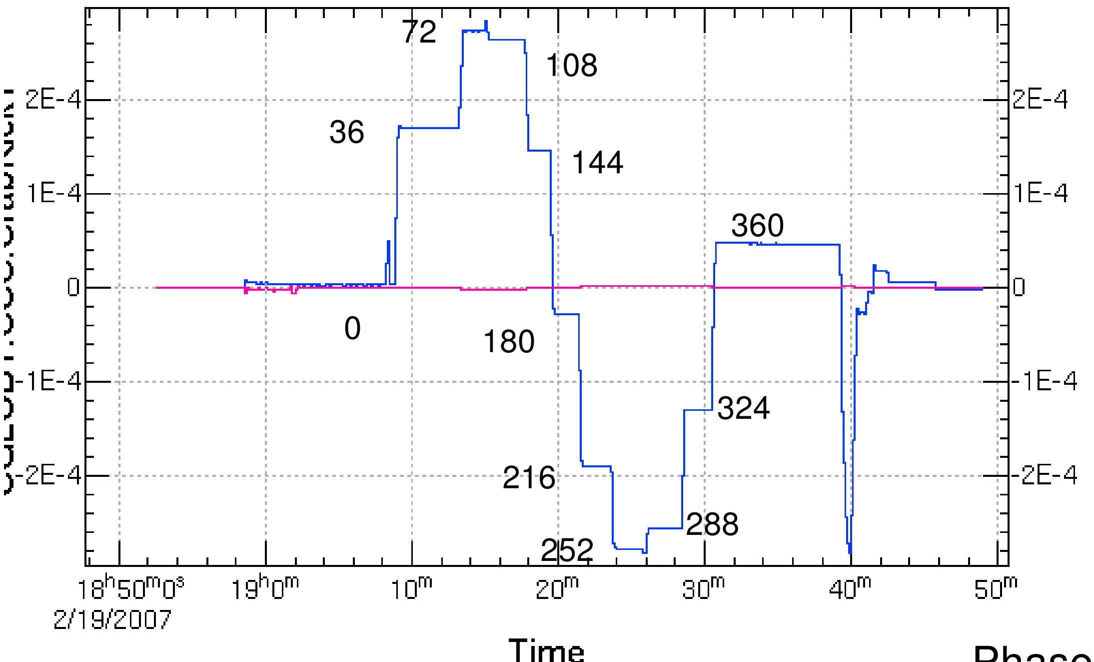
H. Koiso, A. Morita

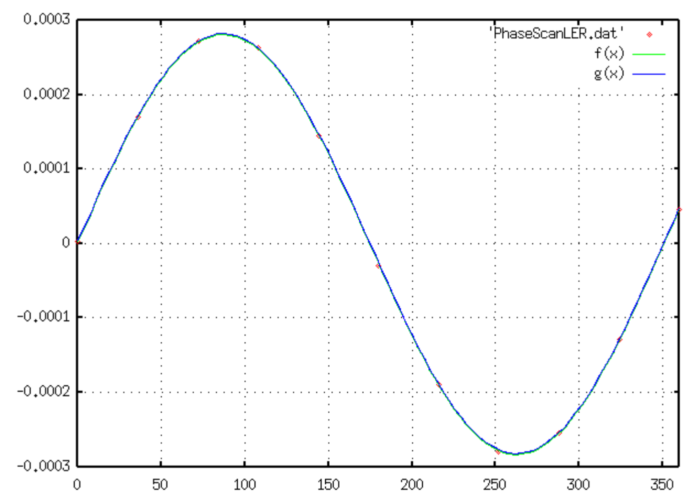
Crab Phase Scan (LER)

Horizontal orbit by crab kick



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

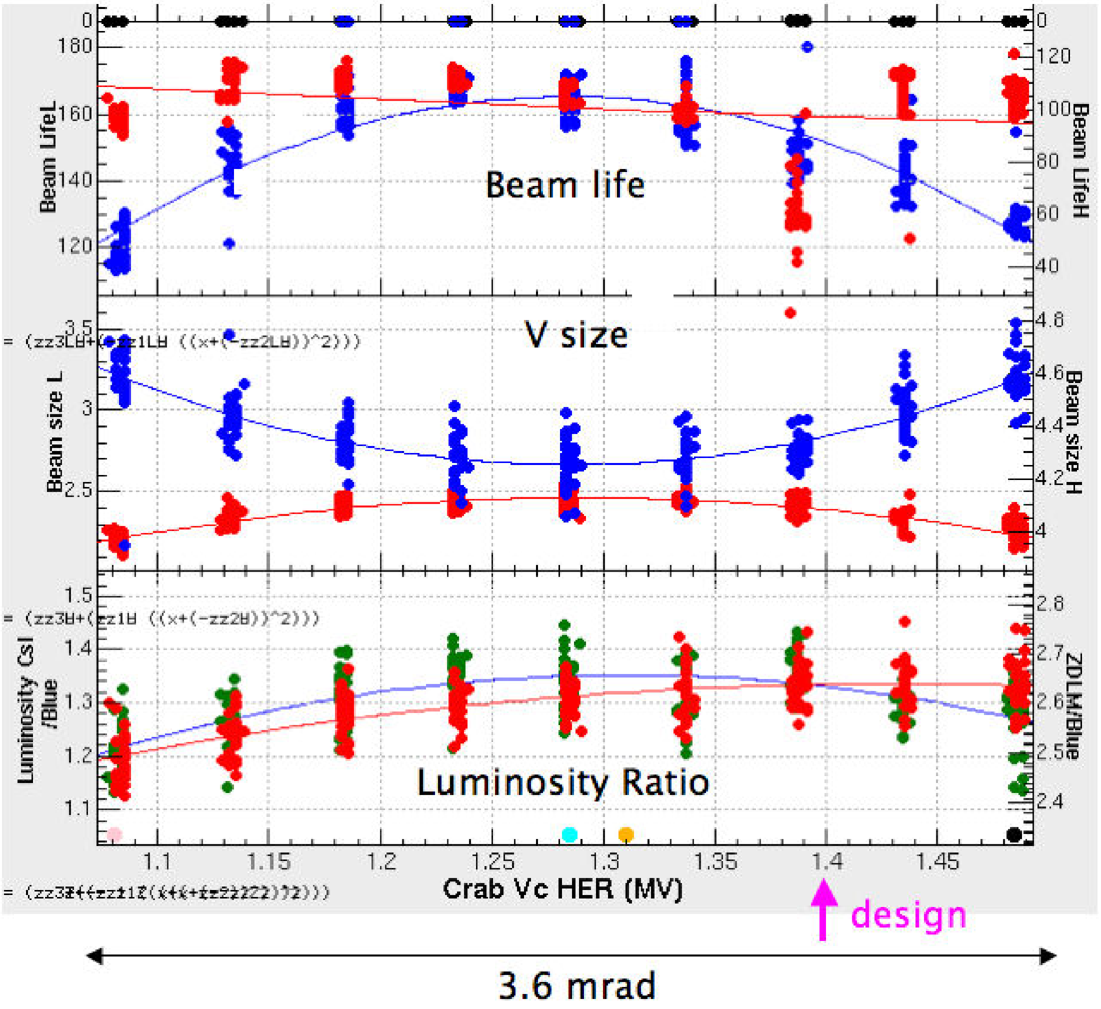




Phase 0 : 174.8 deg.
Vcrab set:1.0MV, estimated: 0.987MV

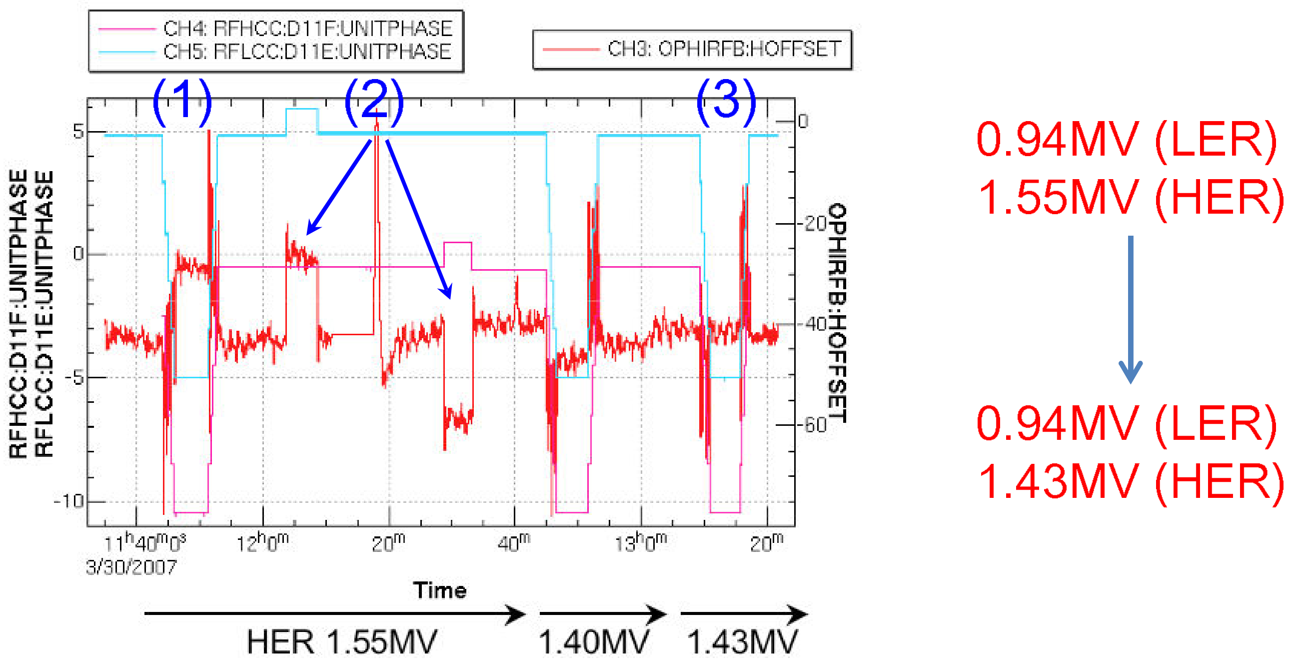
agree very well

An example of crab Vc scan

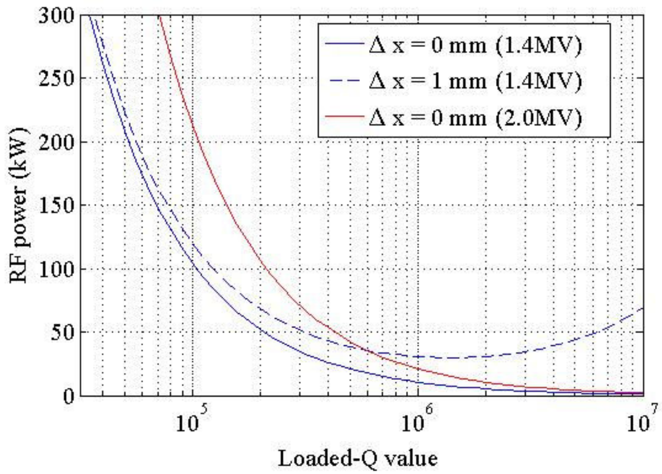


Crab phase vs Horizontal beam-beam kick

- 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)。



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.

★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.

- 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.

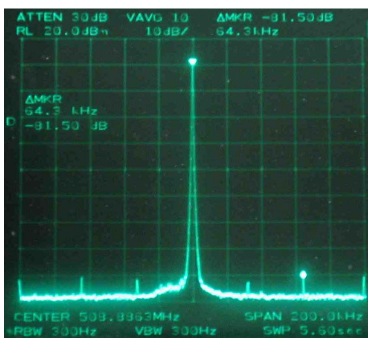
Table 1: Parameters for the crab crossing for KEKB.

	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

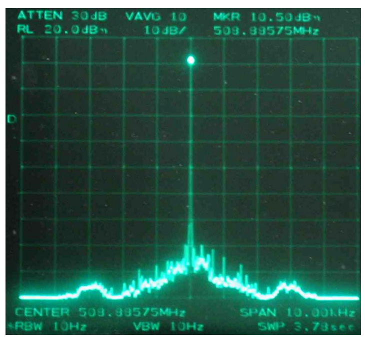
Phase stability

- 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.

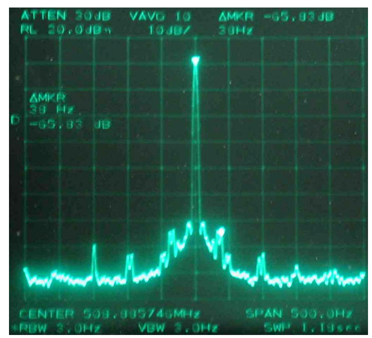
According to b-b simulation by Ohmi-san, allowed phase error for N-turn correlation is $0.1\times\sqrt{N}$ (degree).



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

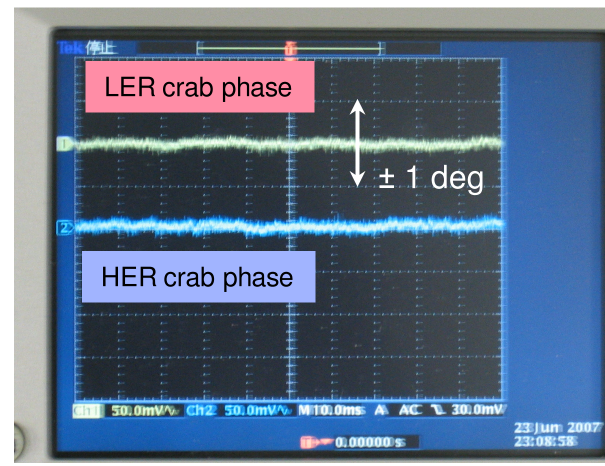


Span 10 kHz



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

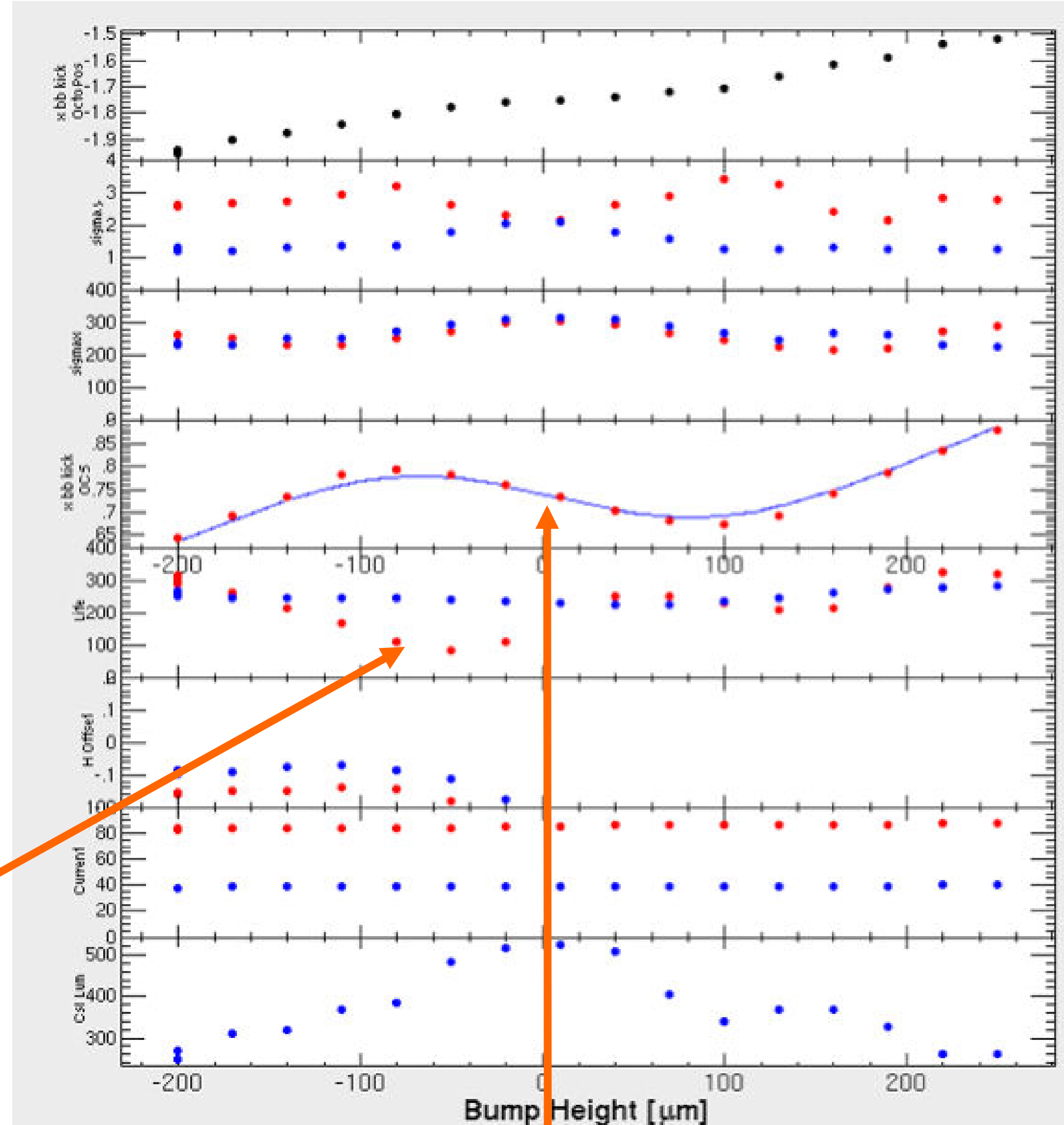
Spectrum around the crabbing mode measured at a pick up port of the LER crab cavity. Beam current was between 450 and 600 mA.



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

Horizontal offset scan

- The (HER) beam current seems to be limited by the short life time of the LER beam.

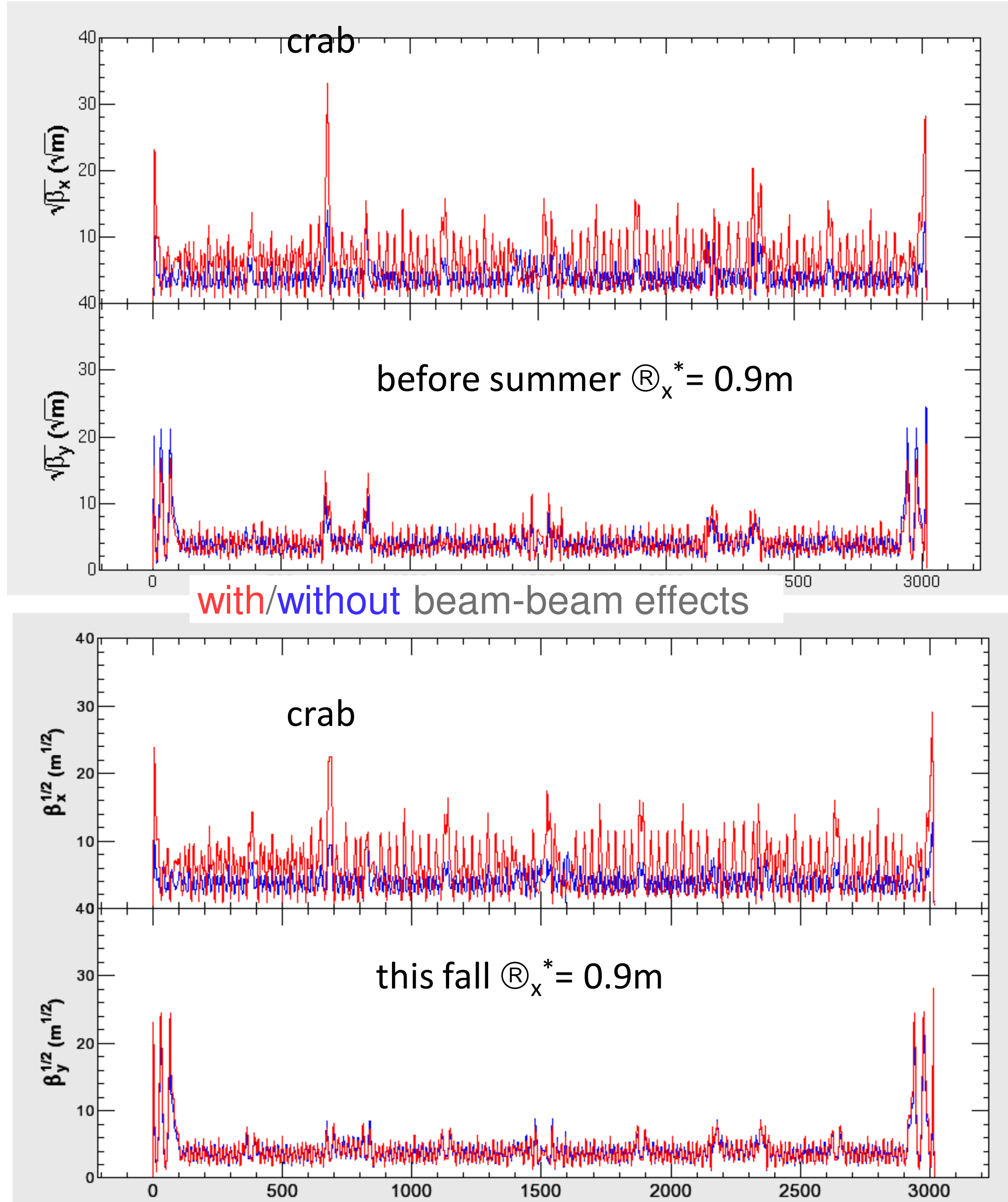


LER lifetime

Collision center given by the beam-beam kick

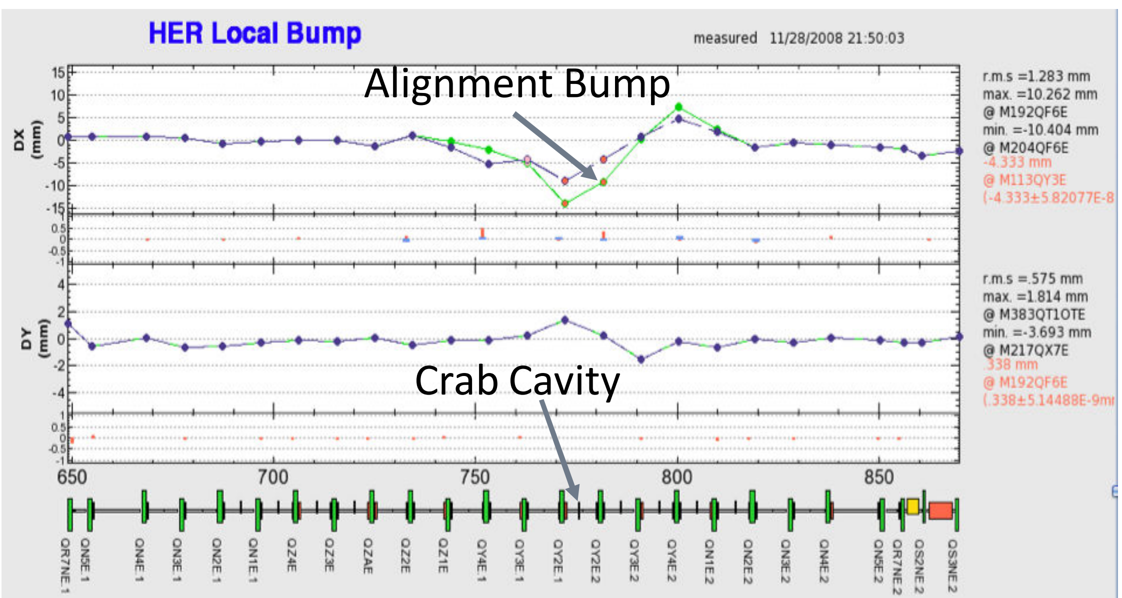
- **The (LER) beam lifetime is very asymmetric with respect to H offset.**

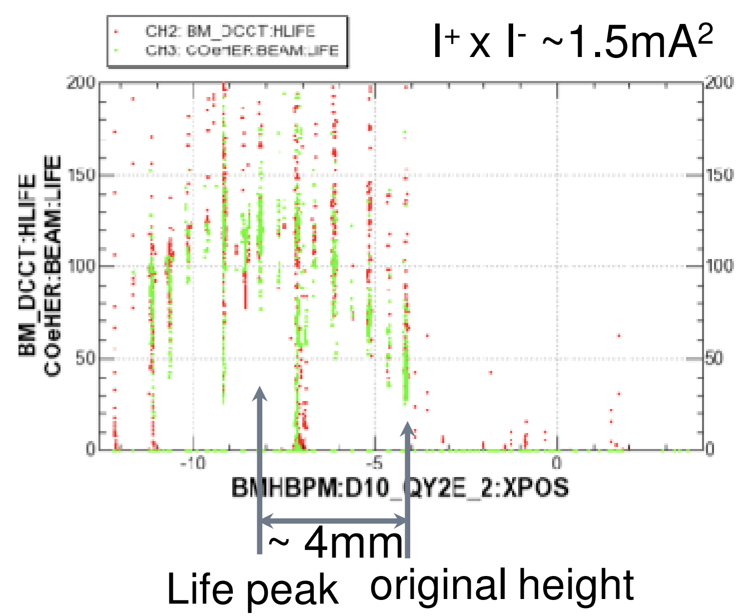
Beta's with dynamic beam-beam effect



Aperture survey around HER crab

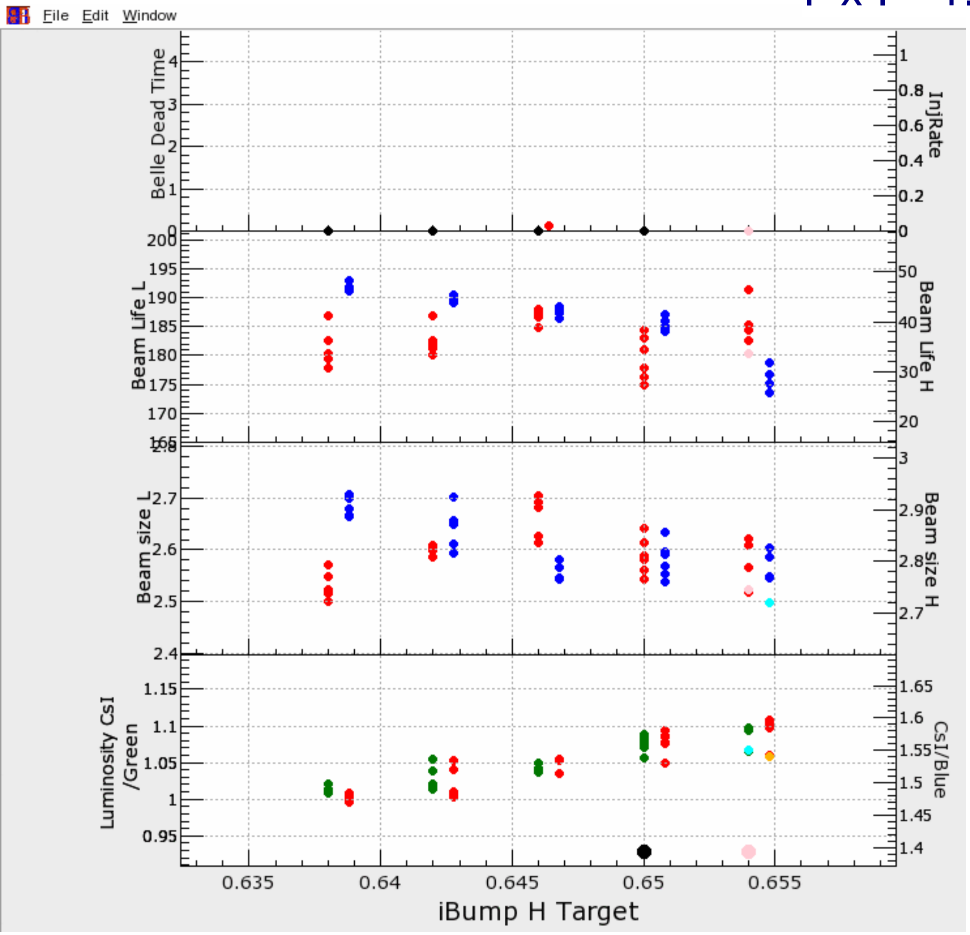
- Scan of HER Crab Alignment Bump
  - Original bump height: ~-6.5 mm necessary to minimize the beam loading
  - Higher bumps made the lifetime longer (peak at a bump with Δx = ~ -4mm).
- Mis-alignment of HER crab cavity?
  - After the machine was shutdown, we actually found a mis-alignment of the HER crab cavity which is consistent with the original bump height.
  - Necessity of the additional 4mm bump is still a mystery.

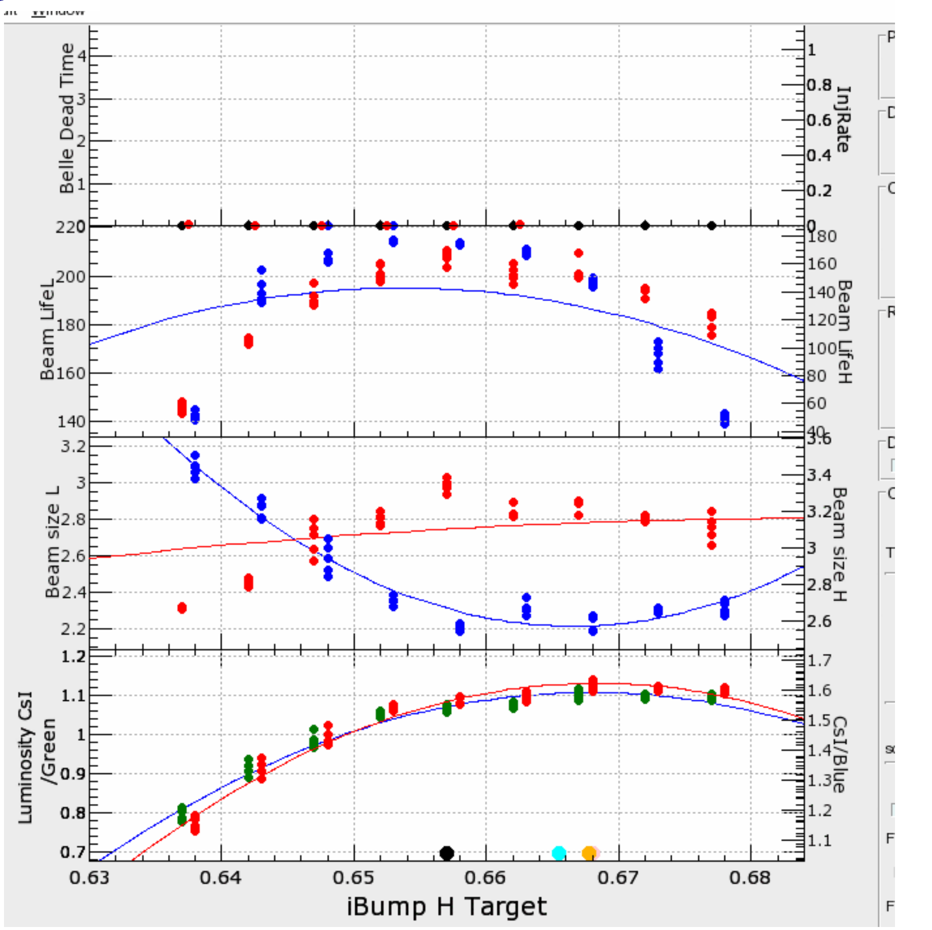




Horizontal offset target scan

$I^+ \times I^- \sim 1.5mA^2$





Original crab bump
Could not go to the right direction.

crab bump -5mm
in addition to original crab bump

Physical aperture around the crab is responsible to the short beam lifetime and restricted the luminosity.

Summary

- The crabbing motion of the beam with a single crab cavity scheme has been confirmed by the streak camera measurement.
- Effective head-on collision was confirmed by the measurement of the beam-beam deflection.
- The synchronous phase shifts along the train from the transient beam loading have some size at KEKB. However, their impact on the luminosity is very small owing to the cancelation of the effect between the two rings.
- We have observed almost no harmful effects due to the crab cavities or the single crab cavity scheme (global crab cavity scheme) from the viewpoint of the beam dynamics.
  - Dynamic aperture, synchro-betatron resonance (yesterday's talk)
  - Bunch current dependent tune shift, loss parameter, bunch lengthening, coupled bunch instabiity

Summary [cont'd]

- Crab Vc is determined so as to maximize the luminosity in the real beam tuning situation at KEKB.
- The phase errors of the crab cavities are much less than the allowed level of the errors obtained from the beam-beam simulations.
- At KEKB, the dynamic beam-beam effects (emittance enlargement and the beta-beating) are very important, since the horizontal tune is very close to the half-integer. Due to this problem, physical aperture around the crab cavity limited the ring acceptance. After solving this problem, we could increase the bunch current (of HER) and the luminosity.
- In autumn this year, we will operate KEKB for about 2 months. There is possibility that it will be the final opportunity to operate the crab cavities at KEKB.