Crab cavity operation at KEKB

K. Ohmi for KEKB commissioning group

DAFNE-KEK meeting

11 December, 2008

Courtesy to Y. Funakoshi, H. Koiso and M. Tawada for many slides

Definition of the beam-beam parameter

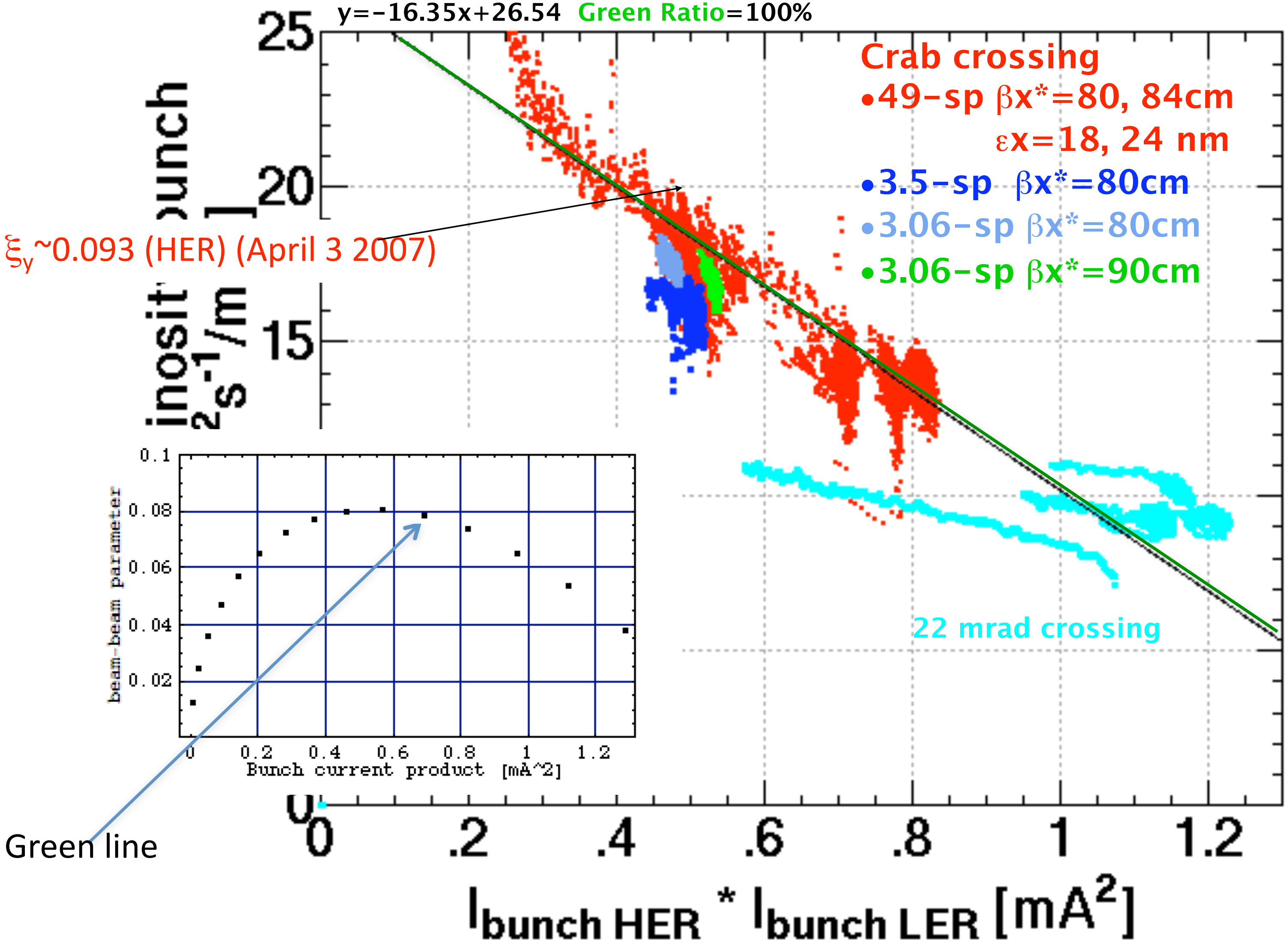
- Normalized luminosity

$$\xi_{n,\pm} = \frac{2r_e\beta_{y,\pm}L}{\gamma_\pm N_\pm f_{col}}$$

- Tune shift taken into account of the crossing angle and hour glass effects

$$\xi_\pm = \frac{2r_e\beta_{y,\pm}L}{\gamma_\pm N_\pm f_{col}}\frac{R_\xi}{R_L}$$

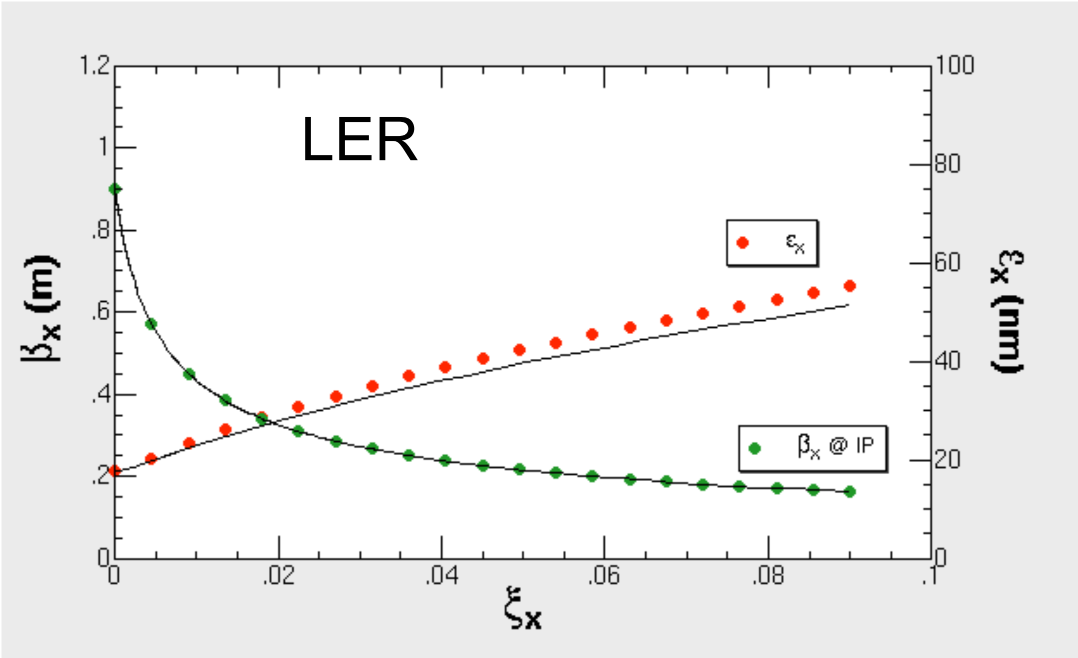
Specific Luminosity and beam-beam parameter
Before summer 2008



Machine parameters

	Nov. 2006 (w/o crab)		Mar. 2008 (with crab)		Units
	LER	HER	LER	HER	
Circumference	3016				m
Hor. emittance	18	24	18	24	nm
Beam current	1662	1340	1619	854	mA
# of bunches	1388+1		1584 + 1		
RF frequency	508.88				MHz
RF Voltage	8.0	15.0	8.0	13.0	MV
ν_s	-0.0246	-0.0226	-0.0246	-0.0204	
ν_x / ν_y	45.505/43.534	44.509/41.565	45.505/43.570	44.511/41.590	
β_x^* / β_y^*	59/0.65	56/0.59	90/0.59	90/0.59	cm
α (mom. compact.)	3.31 x 10^{-4}	3.38 x 10^{-4}	3.31 x 10^{-4}	3.38 x 10^{-4}	
ξ_x / ξ_y	0.117/0.105	0.070/0.056	0.091/0.094	0.100/0.090	
Beam life	110@1600	180@1340	118@1619	173@854	min.@mA
Luminosity	1.712		1.511		$10^{34}cm^{-2}s^{-1}$

Dynamic-β and dynamic emittance by beam-beam (calculation)



Y. Funakoshi

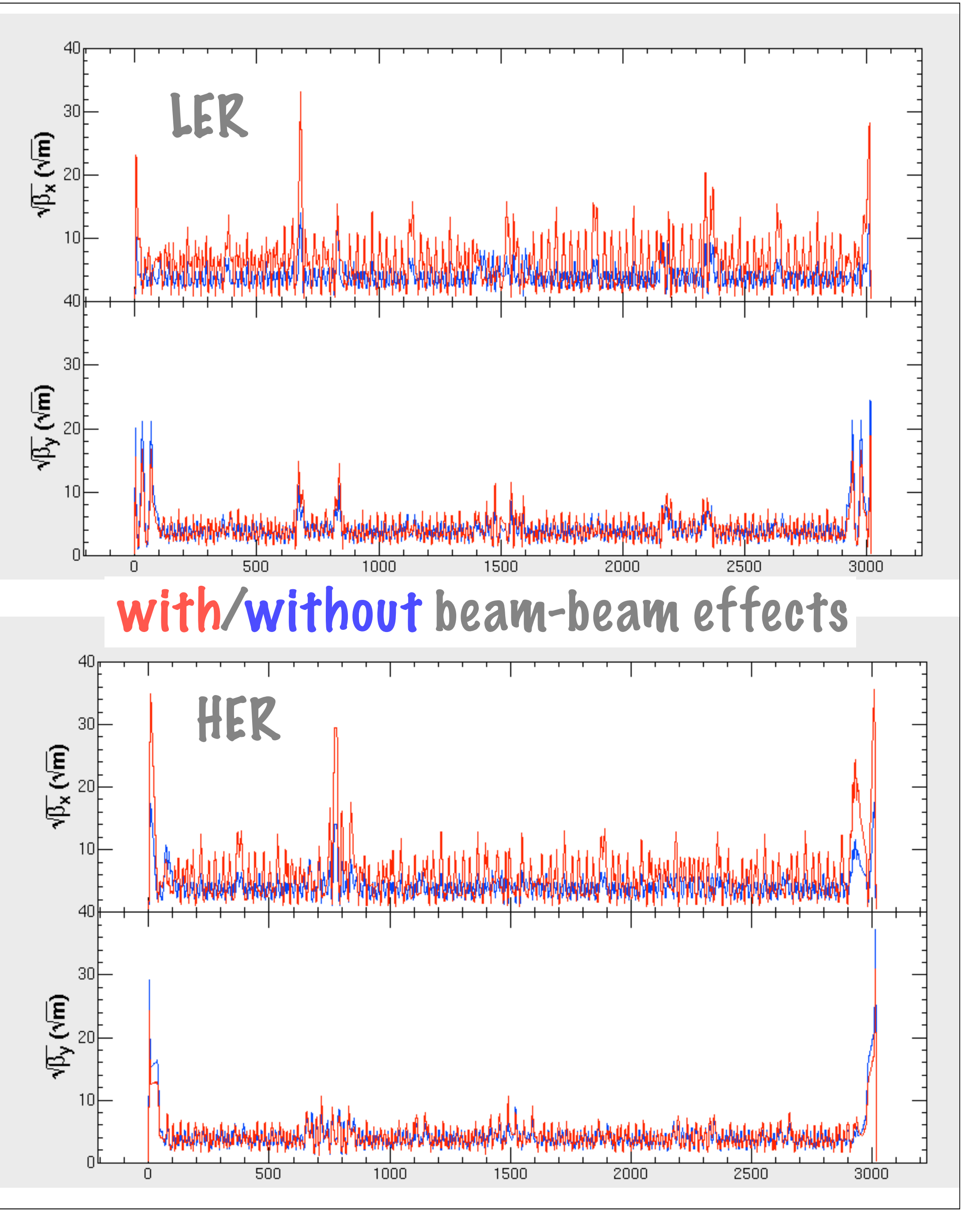
LER

ν_x	45.506
ν_y	43.57
β_x [m]	.9
β_y [m]	.0059
ξ_x max	.09
ξ_y max	.1

The focusing force of the beam-beam interaction not only squeezes the beam at the interaction point, but increases the emittance drastically.

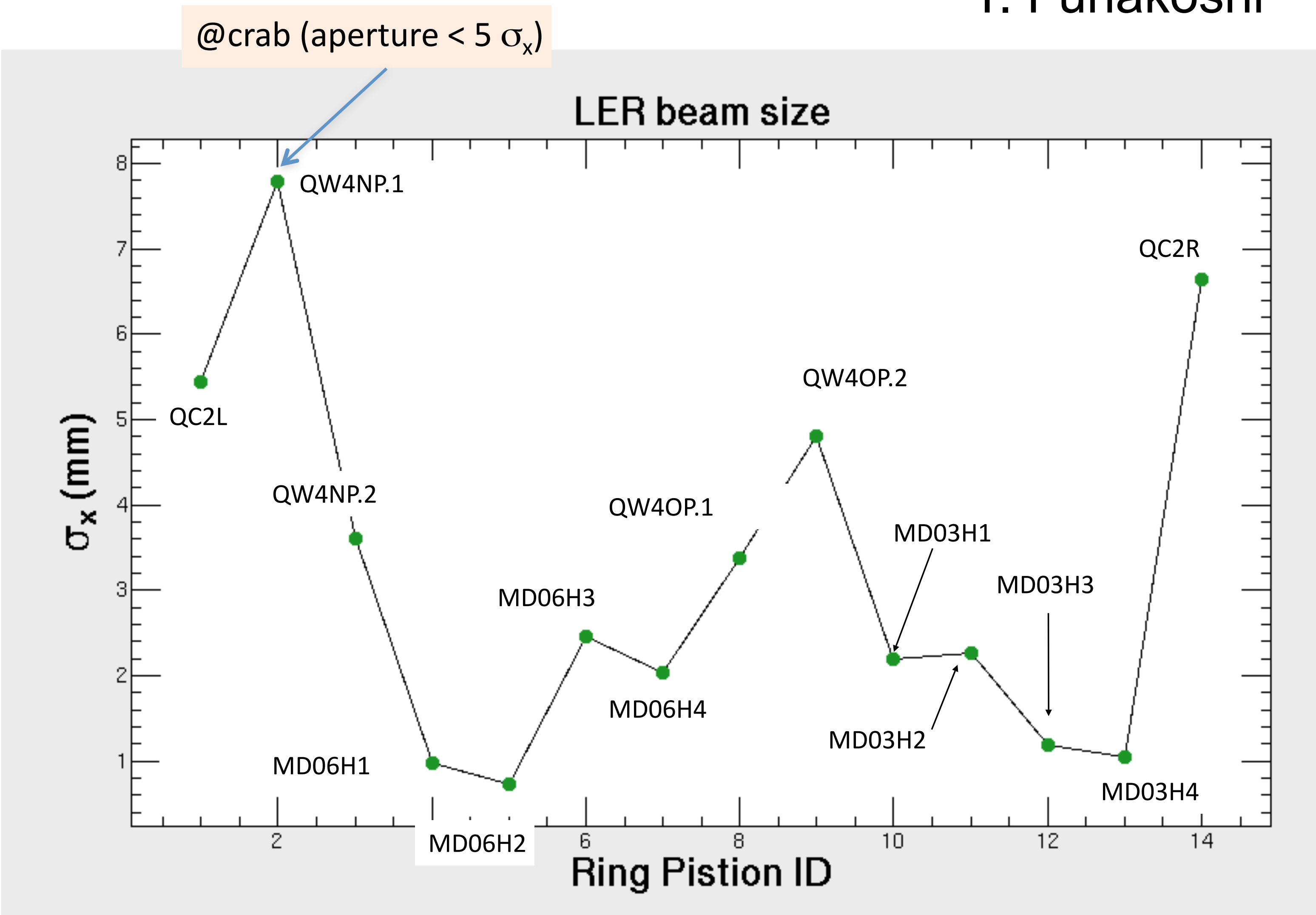
Deformation of β-function all around the ring due to beam-beam effect ("dynamic beta")

Y. Funakoshi



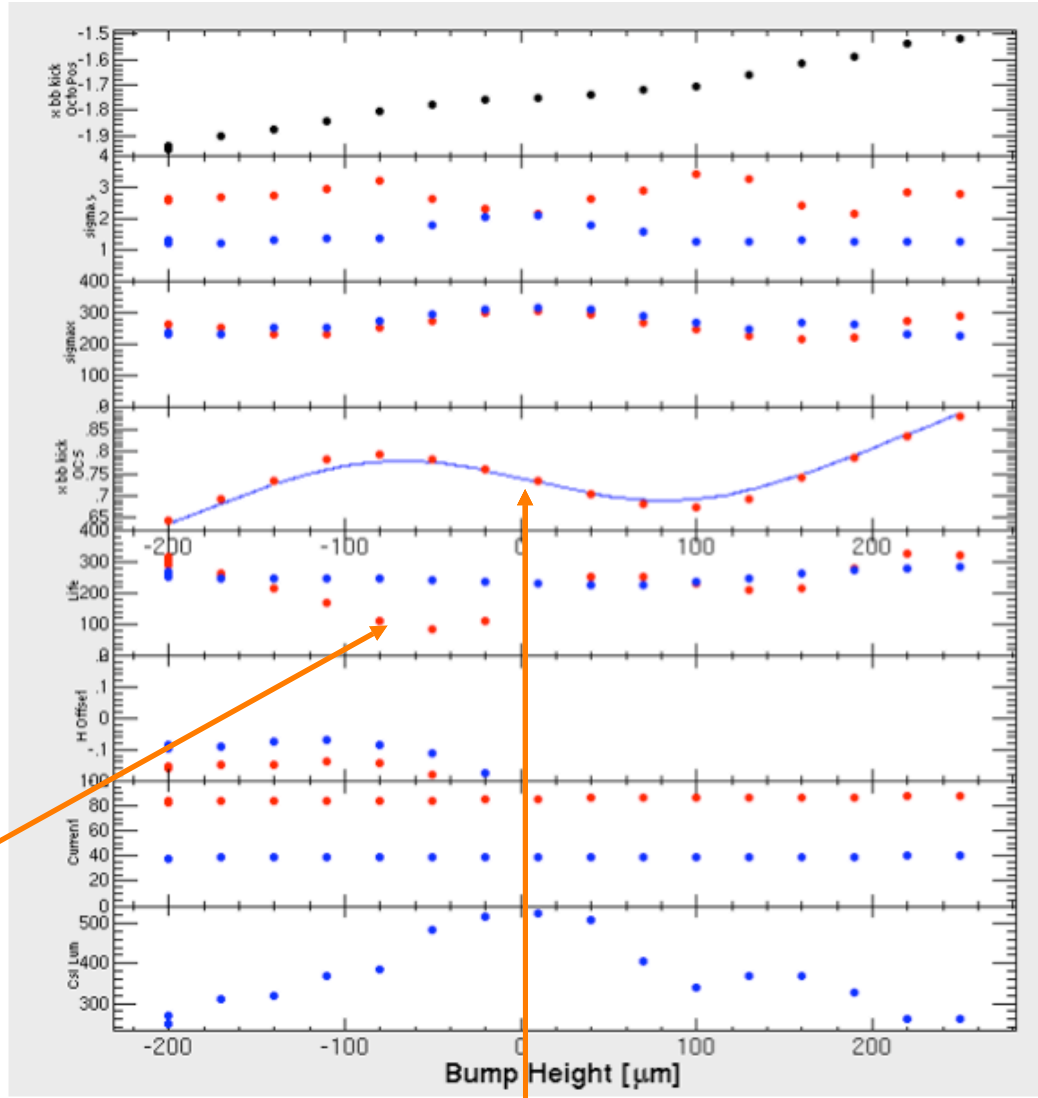
Beam size calculation with dynamic beam-beam effects

Y. Funakoshi



Mysterious lifetime asymmetry with respect to sign of hor. offset

- The (HER) beam current seems to be limited by the short life time of the LER beam.
- The (LER) beam lifetime is very asymmetric with respect to H offset.

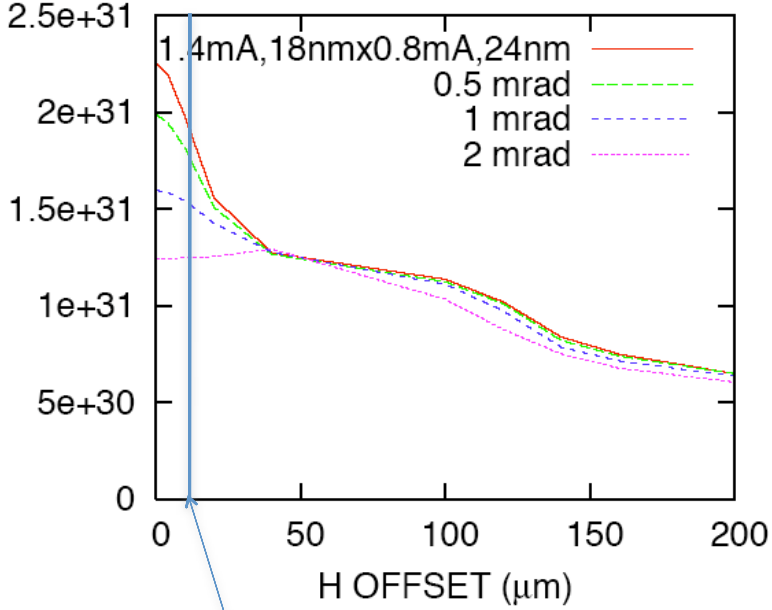


LER lifetime

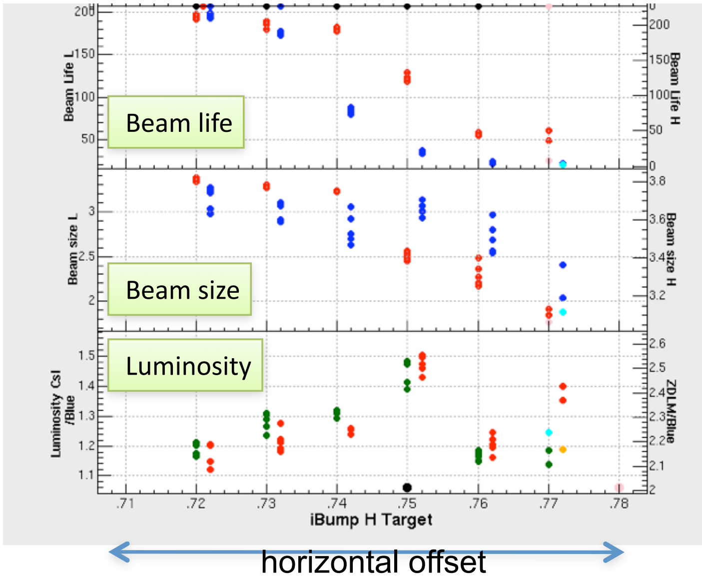
Collision center given by the beam-beam kick

Horizontal offset at IP and crossing angle

Beam-beam simulation

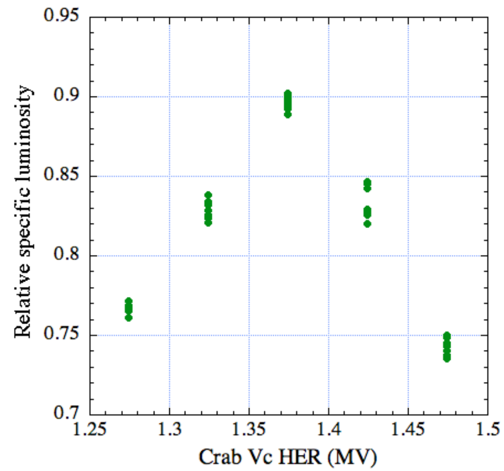


Horizontal offset scan:
experiment with relatively small beam current



- Luminosity boost by crab crossing disappears with 2 mrad crossing angle.
- Luminosity boost by crab crossing disappears with ~40 μm horizontal offset.
- Typical value of horizontal offset in physics experiment is ~15 μm, which is obtained by offset scan.
- This kind of offset depending on beam current can degrade the specific luminosity.
- Some luminosity boost by the crab crossing is actually observed by crab Vc scan.

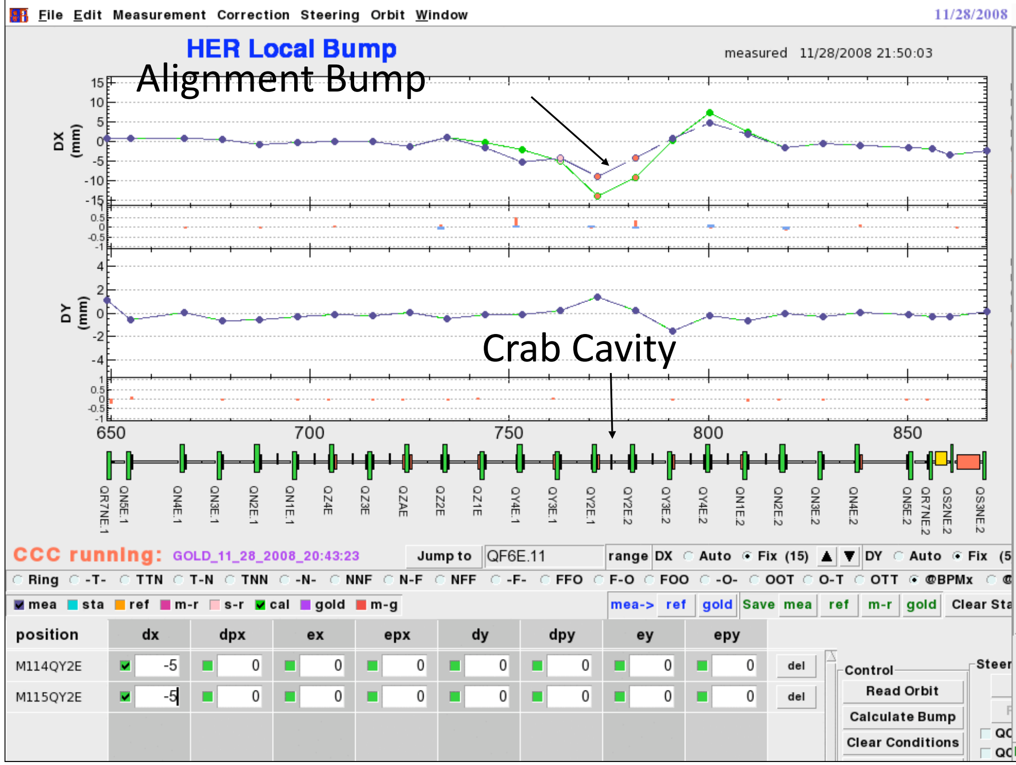
Crab Vc scan (experiment in physics run)

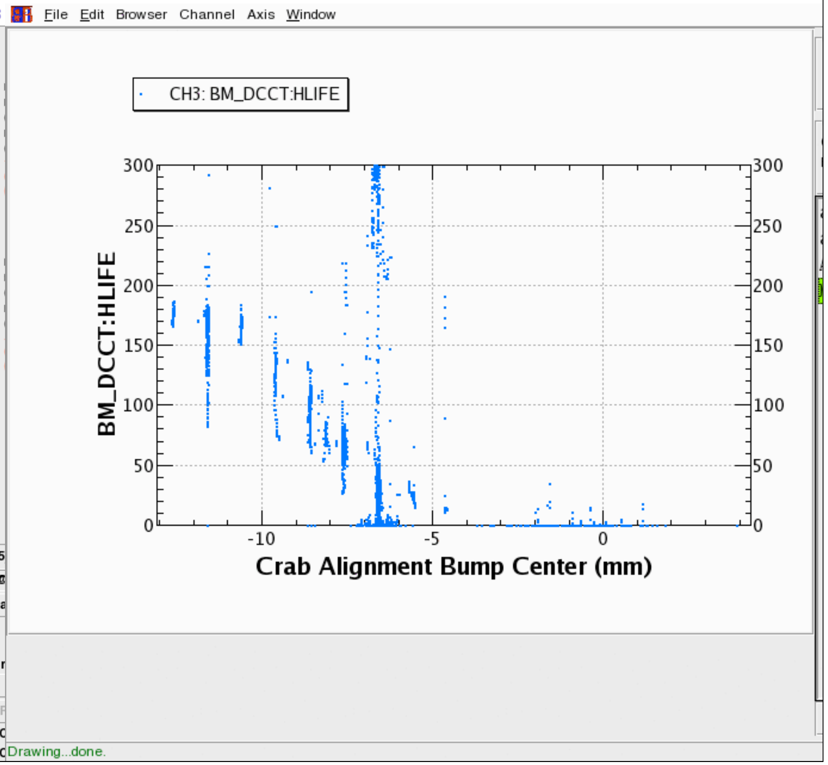


Comments

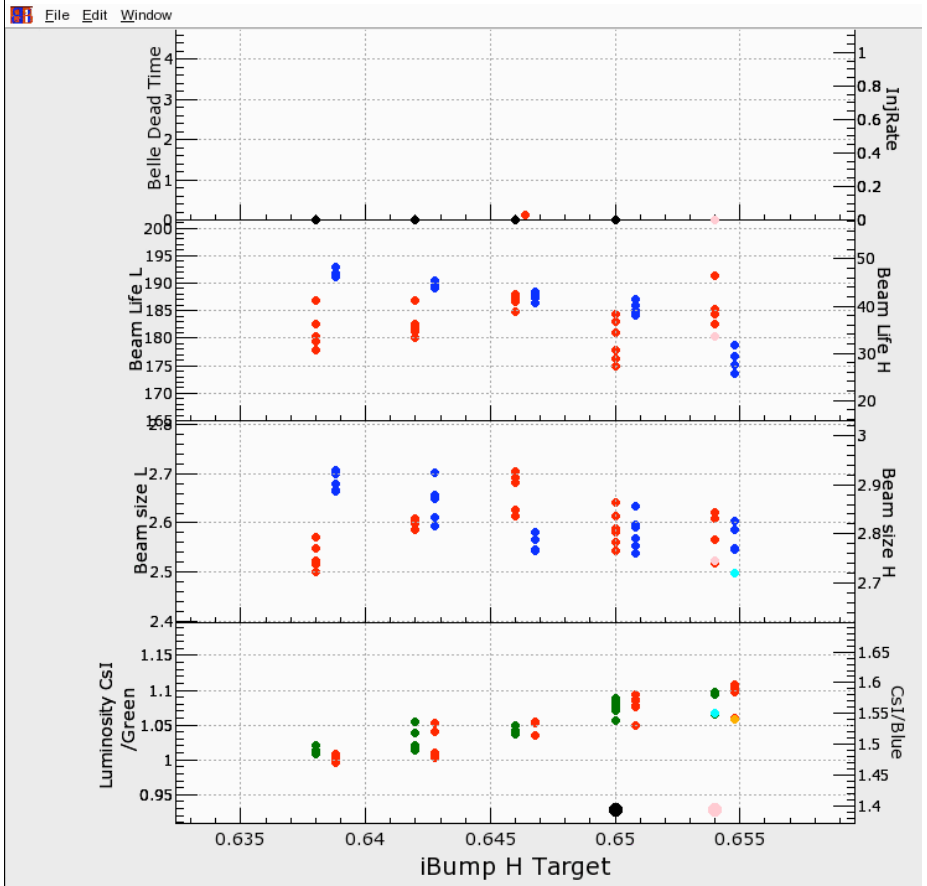
Shift report 11/28 by Flanagan

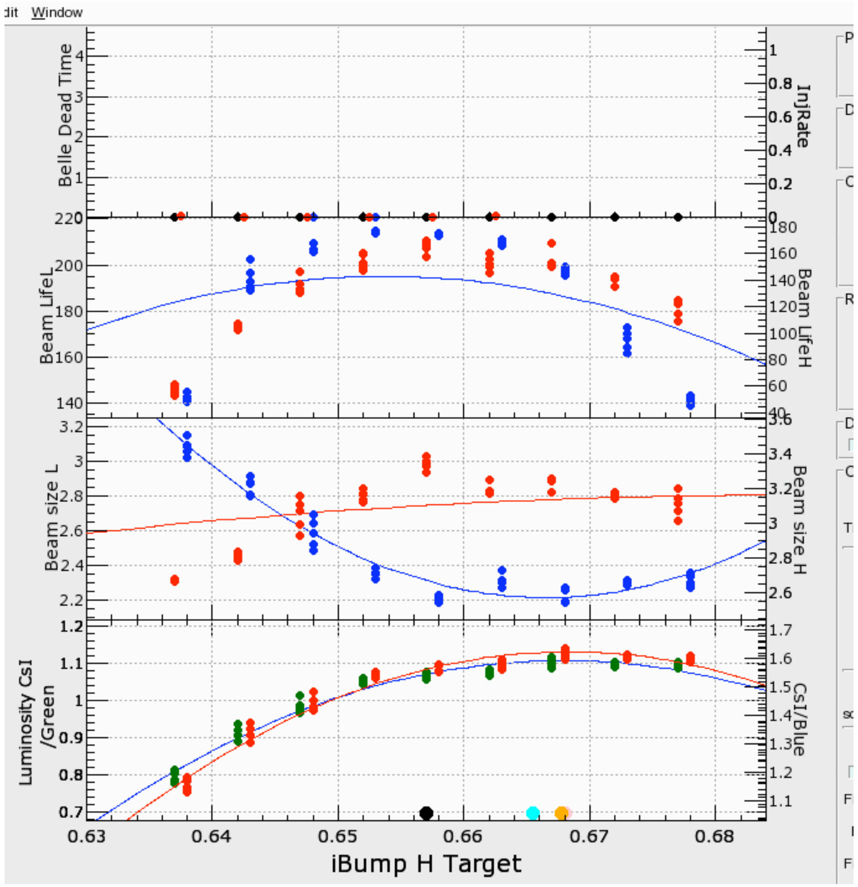
- After Crab On tuning, An orbit bump which escapes a mask near the crab cavity is scanned by Koiso, with the result that no effect on beam life.
  - 99bunches, 155/97 (L/H) mA
- HER Crab Alignment Bump was scanned.
  - org. position~ -6.5 mm, life time is longer for the bump -12mm.
- Horizontal beam-beam offset was scanned at the bump -6.5-5=11.5 mm.





Horizontal beam-beam offset scan





Crab bump org. -6mm
life time is short for higher luminosity region

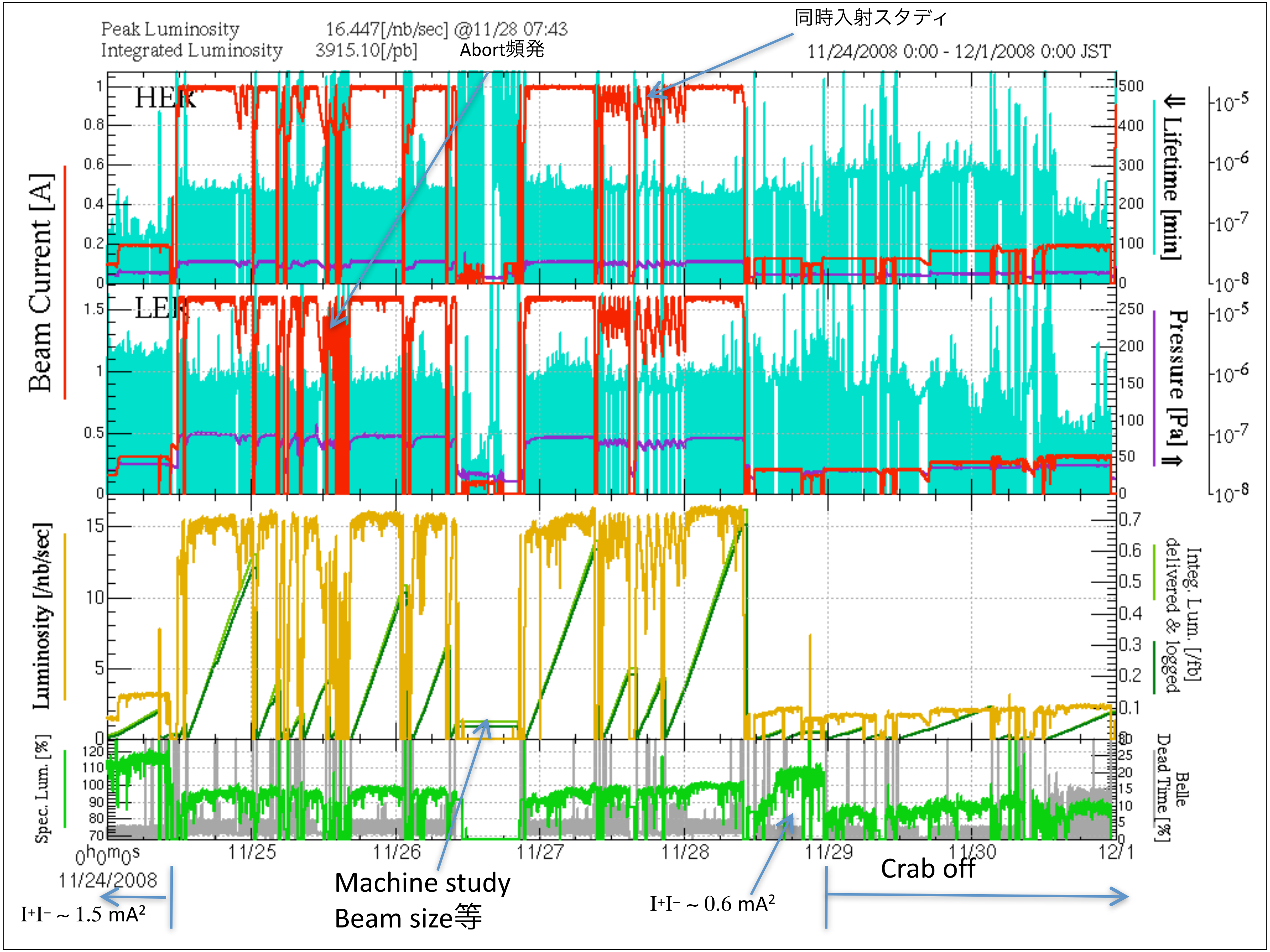
Crab bump -6.5-5=-11.5mm

Physical aperture issue near the HER Crab

- Physical aperture near the HER crab cavity seems to limit the beam life time at a bunch high current.
- The physical aperture seems to give the life time asymmetry for the horizontal beam-beam offset.

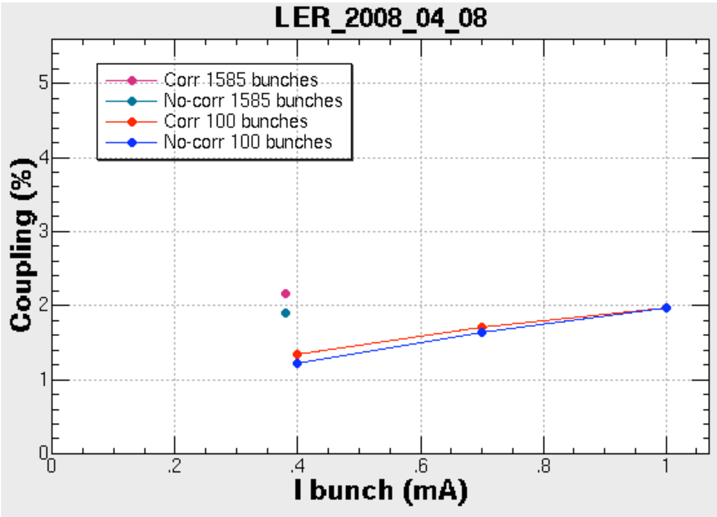
Operation status, Nov-Dec, 2008

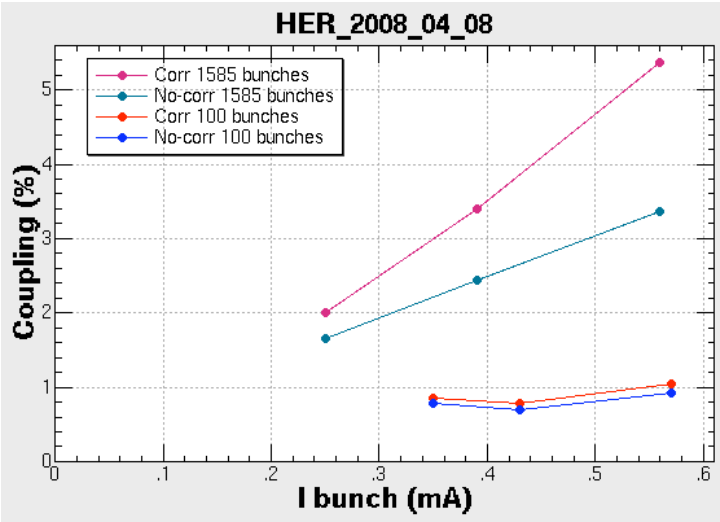
- Luminosity
  - Lpeak = 16.447 /nb/s (β_x^*= 1.5m)
  - Shift integrated luminosity record: 439.6 /pb/shift (Nov. 28 morning)
- Beam currents
  - LER: 1600mA, HER: 1000mA (or low bunch number)
- Optics
  - ε_x(LER)= 18nm, ε_x(HER)= 24nm
  - β_x^*(LER/HER)= 1.5m
- Tuning
  - As usual
- Machine study
  - Low bunch number: comparison of crab on and off
  - Beam size measurement
  - bunch phase along the train
  - Linac study for simultaneous injection

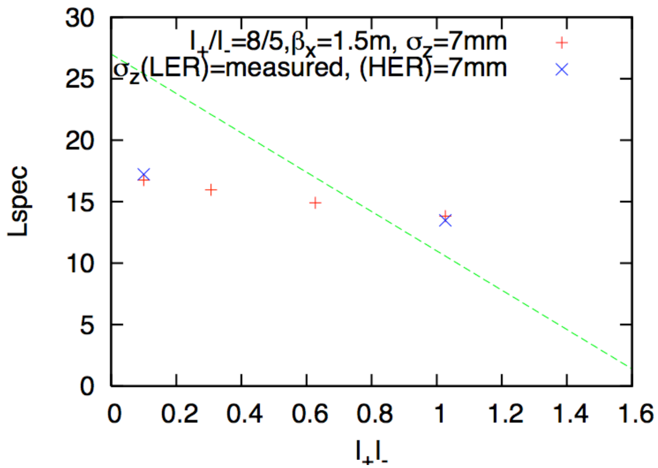


Peak Luminosity 16.447[/nb/sec] @11/28 07:43
Integrated Luminosity 3915.10[/pb]
Abort頻発
同時入射スタディ
11/24/2008 0:00 - 12/1/2008 0:00 JST
HER
LER
Beam Current [A]
⇓ Lifetime [min]
Pressure [Pa] ⇑
Luminosity [/nb/sec]
Integ. Lum. [/fb] delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
0h0m0s 11/24/2008
11/25
11/26
11/27
11/28
11/29
11/30
12/1
Crab off
Machine study
Beam size等
I+I- ~ 1.5 mA²
I+I- ~ 0.6 mA²

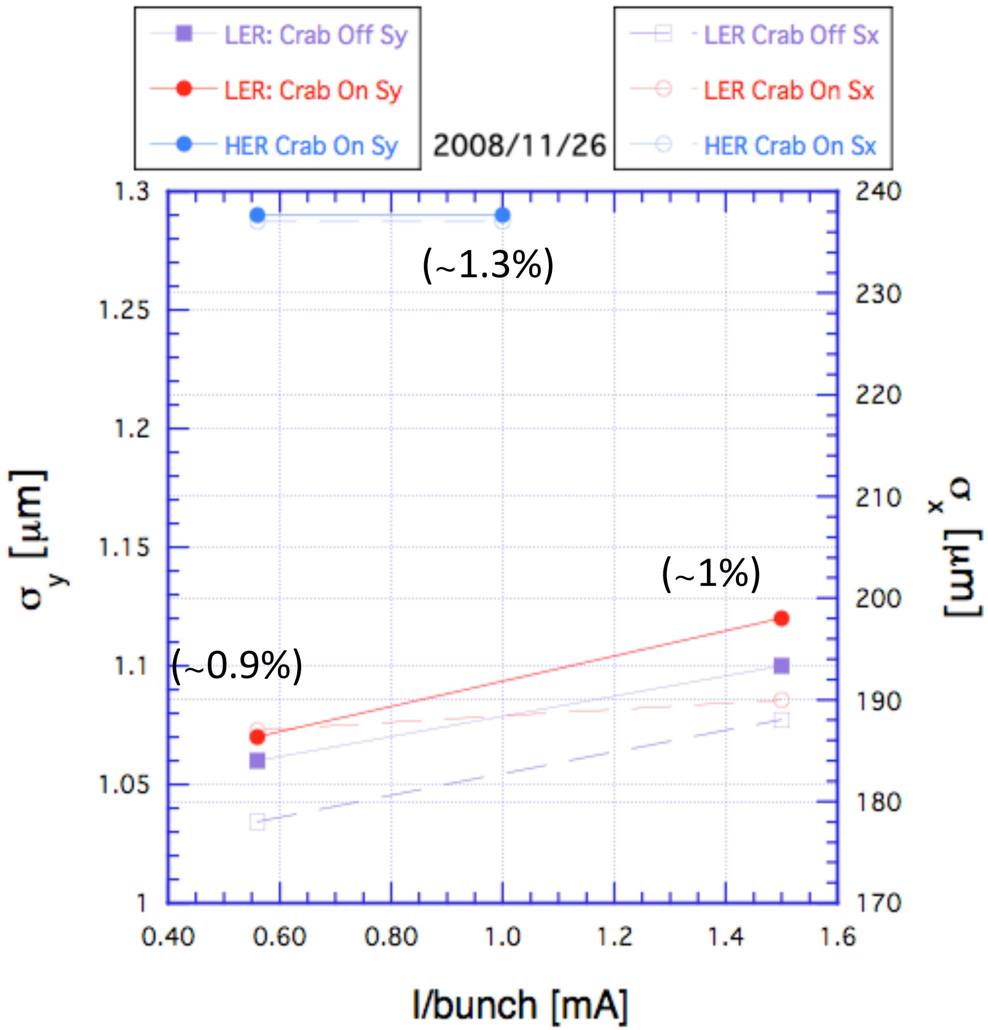
Energy dependence of vertical emittance in LER?





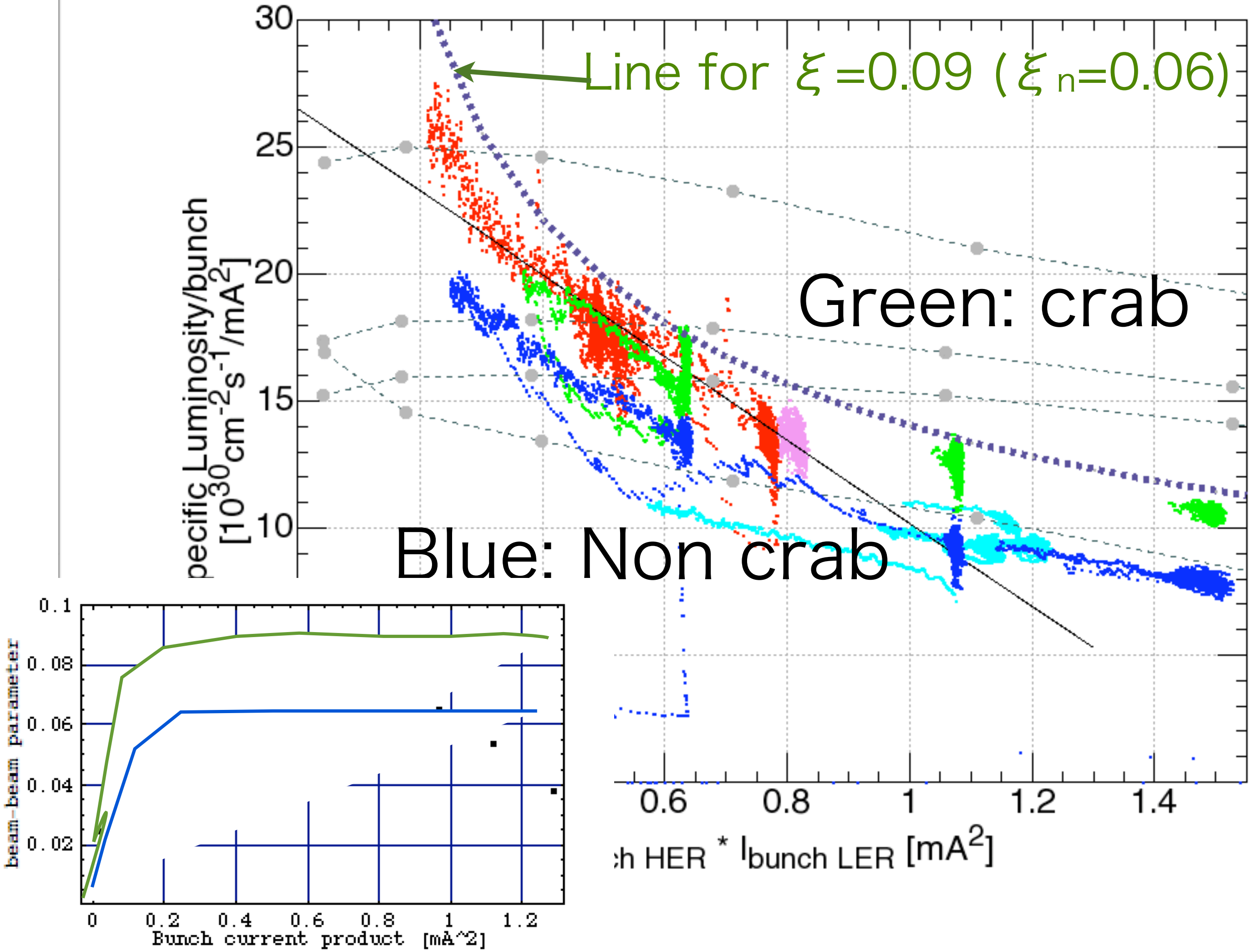


Vertical beam size little depend on the bunch current



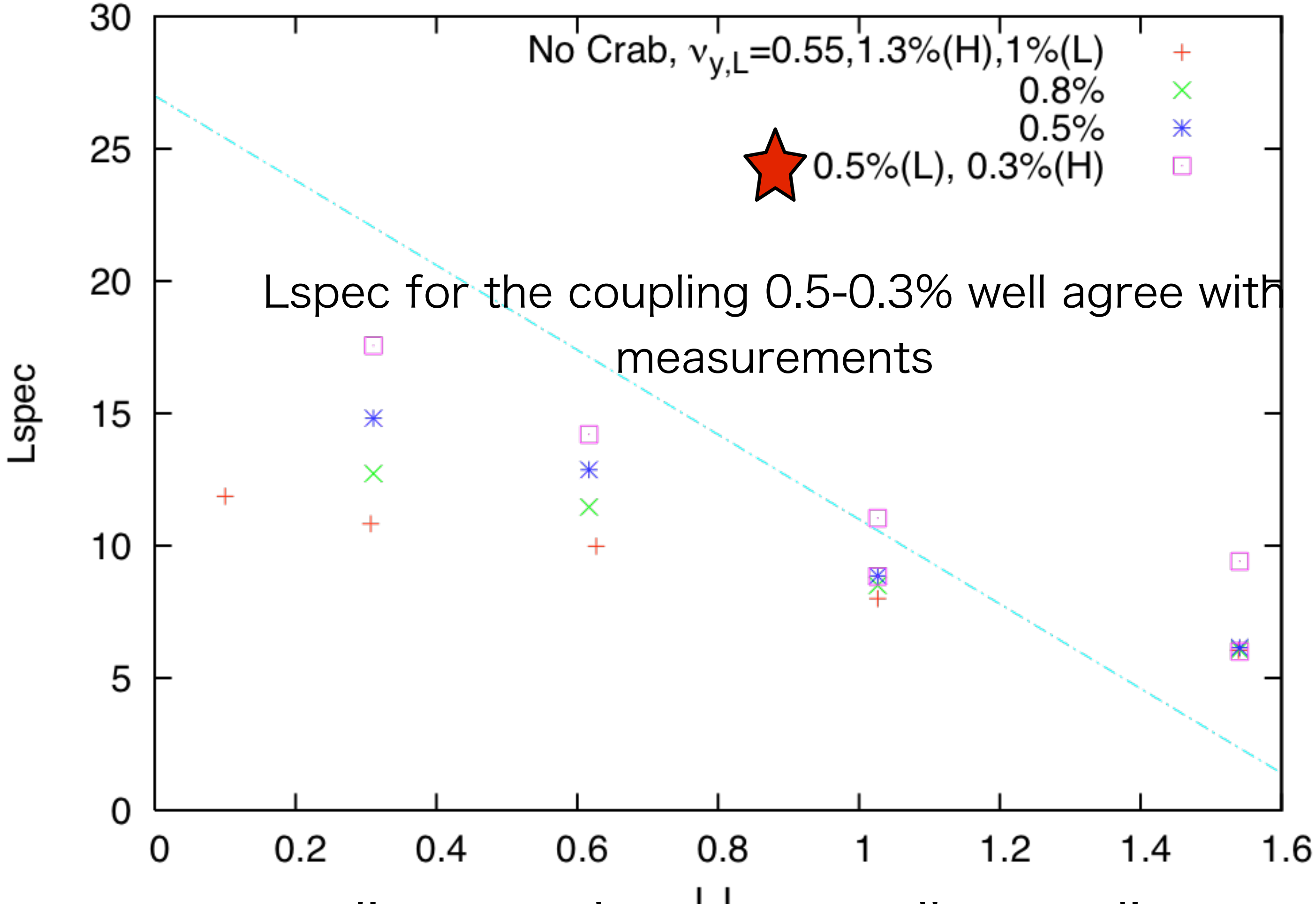
by Iida

Specific luminosity for crab and non crab collision



K. Ohmi

Specific luminosity simulation



x-y coupling may be very small to realize the luminosity behavior for non crab.

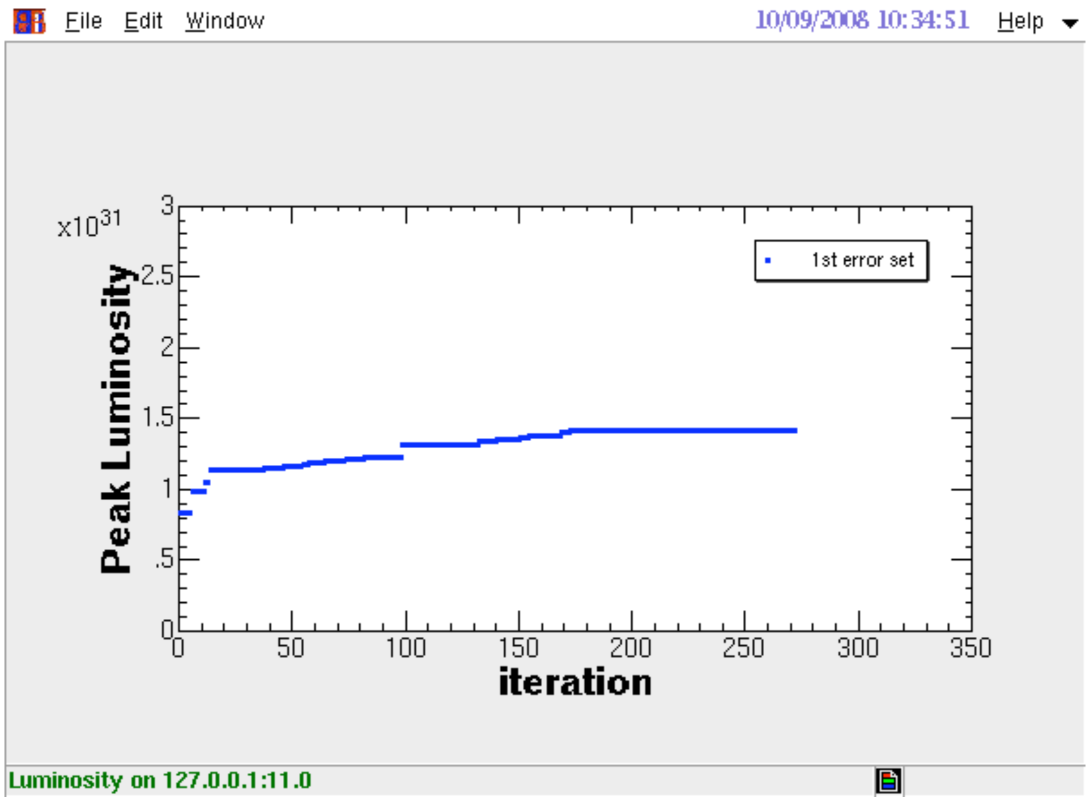
Knob scan simulation by M. Tawada
Tilt & Dispersion (12 parameters)

- Current 0.8/1.4 mA/bunch (HER/LER)
- ε_x = 24/18 nm (HER/LER) 1% coupling
- $\beta_{x/y}$ = 80/0.7 cm
- $\nu_{x/y}$ = 0.511/0.580
- L/bunch=24E30 w/o error, L=3.6e34 for 1500 bunch

Start from this initial Tilt and Dispersion error

	LER (1unit)	HER (1unit)
r1 (mrad)	15.71 (3.17)	-3.16 (0.53)
r2 (mm)	-1.34 (0.22)	-1.97 (0.43)
r3 (/km)	-341 (59.38)	374 (48.72)
r4 (mrad)	-149 (25.02)	215 (36.85)
ey (mm)	-1.91 (0.36)	2.17 (0.59)
eyp (mrad)	-62.6 (18.98)	94.4 (21.65)

Downhill Simplex method



L/bunch=1.42e31, L_{tot}=2.1e34 for 1500 bunch.

After Downhill Simplex method
L/bunch=14.2x10^{30}, L_{ideal}/bunch=24x10^{30}

	LER (1unit)	HER (1unit)
r1 (mrad)	-24.94 (3.17)	-22.377 (0.53)
r2 (mm)	-1.51 (0.22)	-1.73 (0.43)
r3 (/km)	-651 (59.38)	1176 (48.72)
r4 (mrad)	-21.3 (25.02)	-20.9 (36.85)
ey (mm)	-0.314 (0.36)	-0.114 (0.59)
eyp (mrad)	-25.3 (18.98)	-1.455 (21.65)

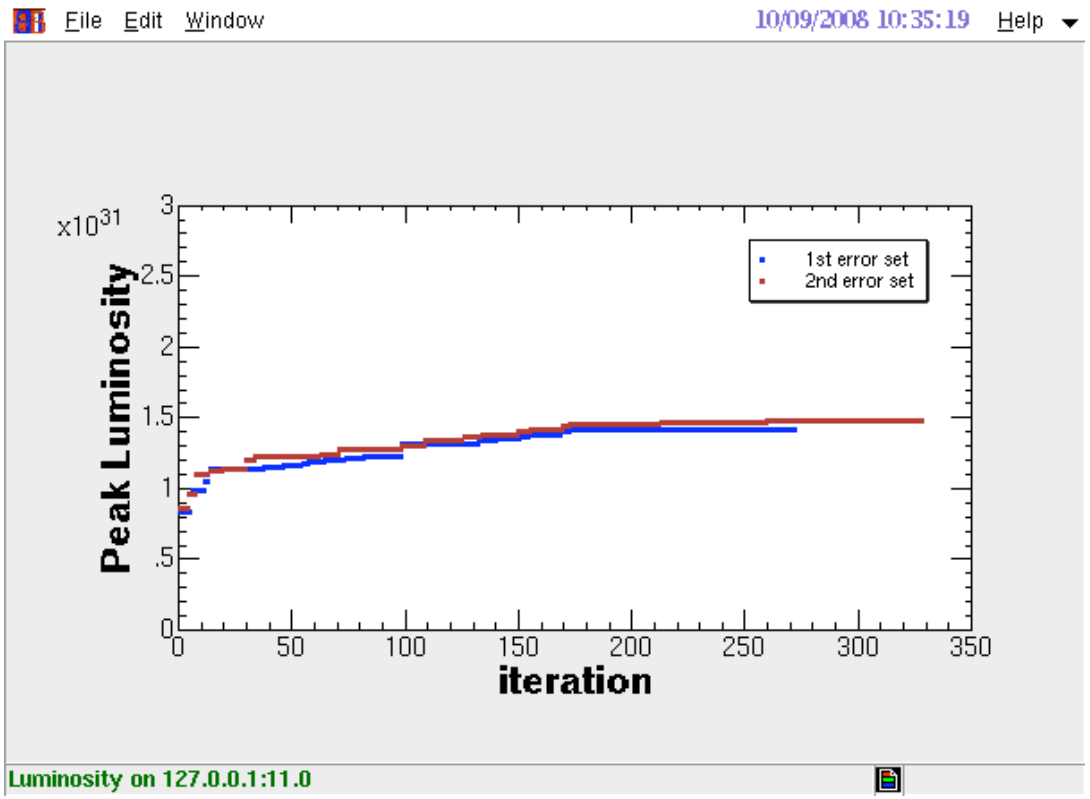
2nd error set (Start from this initial Tilt and Dispersion error)

	LER (1unit)	HER (1unit)
r1 (mrad)	-12.5 (3.17)	2.5 (0.53)
r2 (mm)	0.8 (0.22)	-2.0 (0.43)
r3 (/km)	-300 (59.38)	-250 (48.72)
r4 (mrad)	100 (25.02)	-180 (36.85)
ey (mm)	-1.5 (0.36)	-2.8 (0.59)
eyp (mrad)	80 (18.98)	-80.0 (21.65)

2nd error set (Downhill Simplex method)
L/bunch=14.8x10^{30}, L_{ideal}/bunch=24x10^{30}

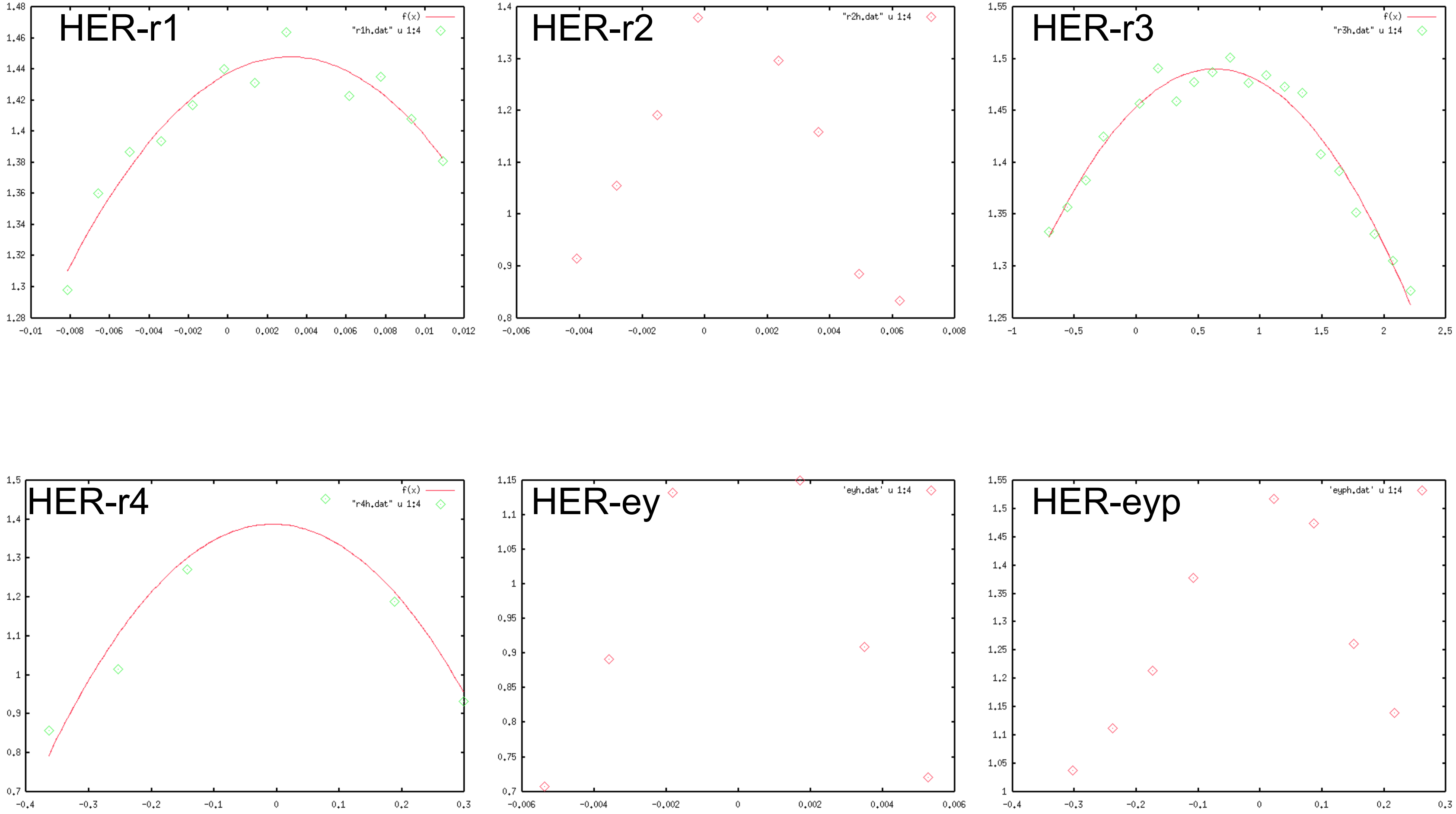
	LER (1unit)	HER (1unit)
r1 (mrad)	4.74 (3.17)	4.55 (0.53)
r2 (mm)	0.99 (0.22)	1.06 (0.43)
r3 (/km)	-956 (59.38)	-119 (48.72)
r4 (mrad)	9.17 (25.02)	-32.60 (36.85)
ey (mm)	-0.055 (0.36)	-0.063 (0.59)
eyp (mrad)	19.85 (18.98)	-43.59 (21.65)

Downhill Simplex method (1st, 2nd)
L/bunch=14.2, 14.8E30
(L/bunch=24E30 w/o error)

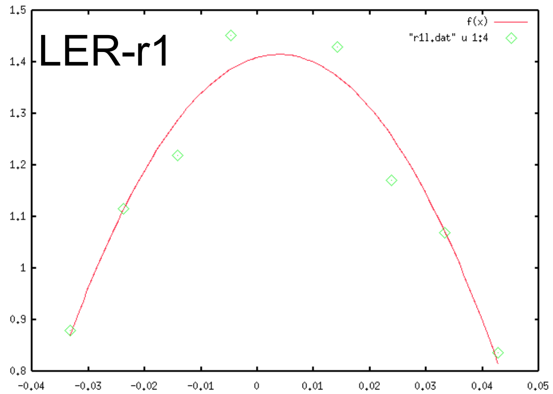


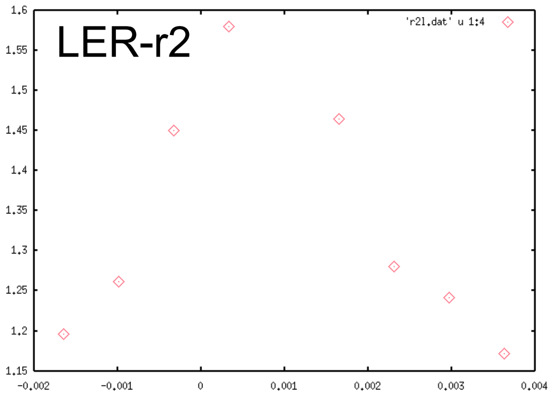
manual knob scan after downhill simplex

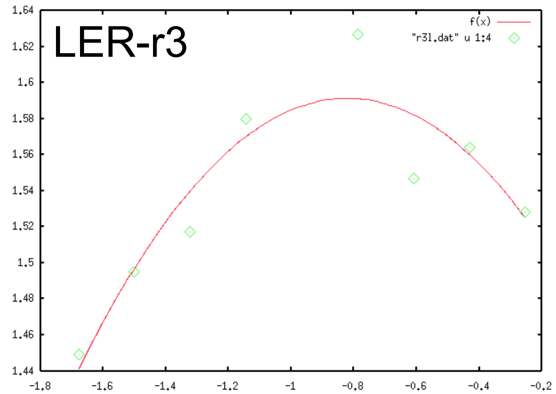
2nd error set

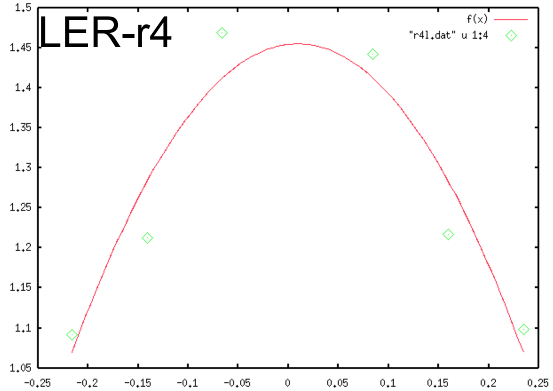


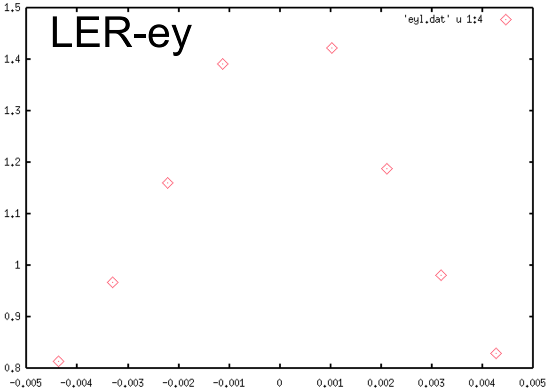
manual knob scan after downhill simplex
2nd error set

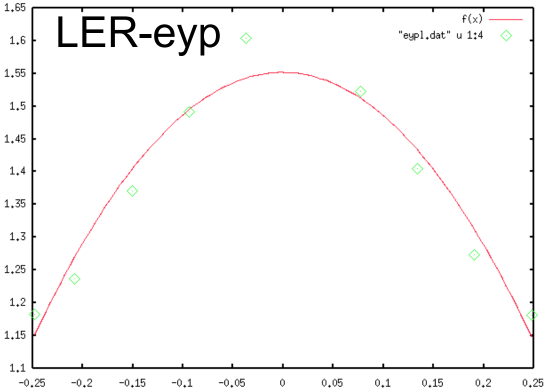












manual knob scan after downhill simplex (2nd error set)

	LER (1unit)	HER (1unit)
r1 (mrad)	3.77 (3.17)	3.13 (0.53)
r2 (mm)	0.99 (0.22)	0.714 (0.43)
r3 (/km)	-821 (59.38)	-631 (48.72)
r4 (mrad)	9.14 (25.02)	-6.32 (36.85)
ey (mm)	0.0 (0.36)	0.0 (0.59)
eyp (mrad)	-0.565 (18.98)	7.0 (21.65)

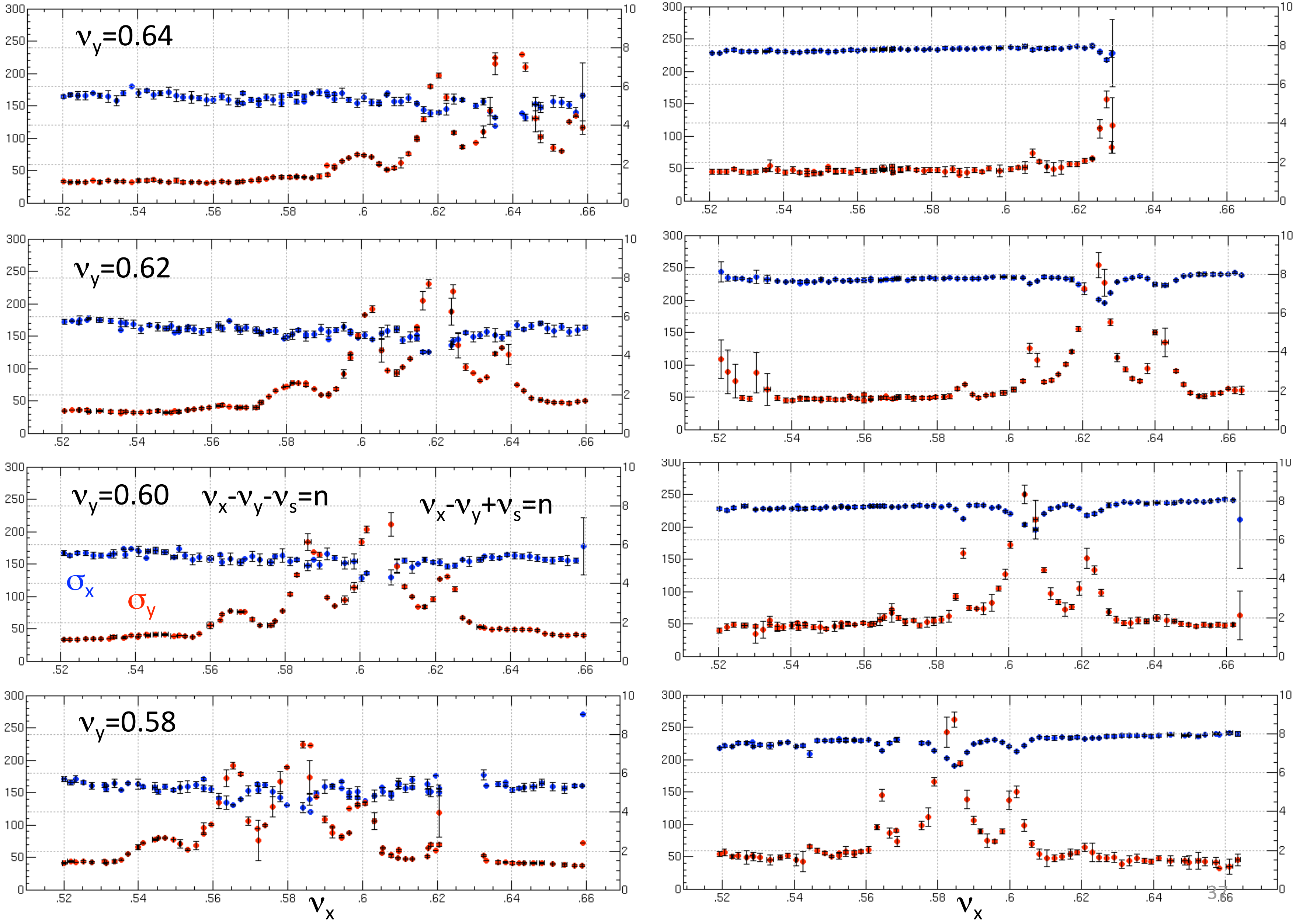
Summary for knob scan simulation

- A knob simulation is performed with Downhill Simplex and manual scan.
- Answer is 0 for every parameter, or R1(L)=R4(L)=R1(H) =R4(H).
- Initial error was 4 or 5 unit of the operation knob.
- The luminosity is achieved 60 % of ideal simulation after the Downhill Simplex optimization. Some knobs become larger value than initial values due to the optimization.
- A manual scan after the Simplex optimization gives little gain.

Synchro-beta resonance and nonlinear chromaticity

- Tune scan for the beam size was performed.
- Linear resonances and their synchro-beta side-band was seen.
- Nonlinear chromaticity has been studied by Y. Seimiya and D. Zhou.

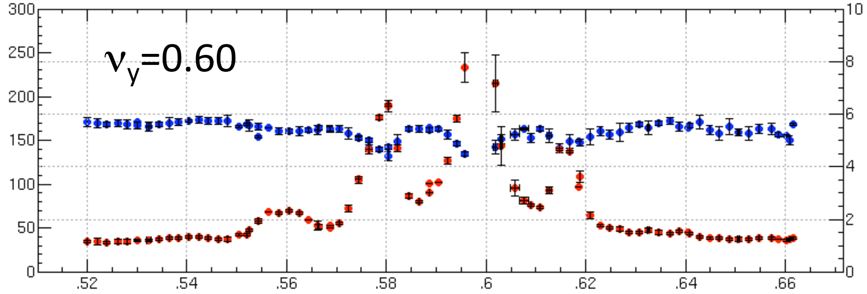
LER ν_s=-0.0240 Y. Ohnishi, K. Ohmi HER ν_s=-0.0209

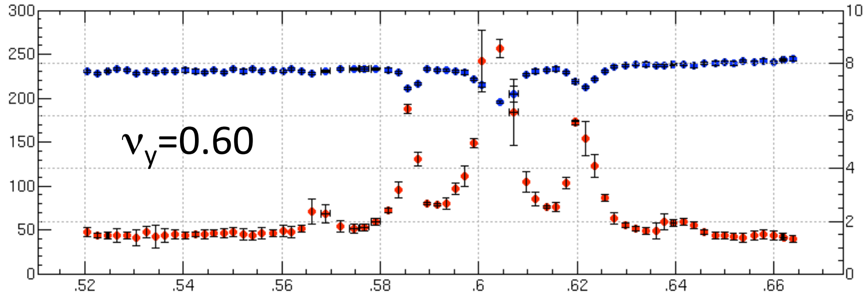


LER

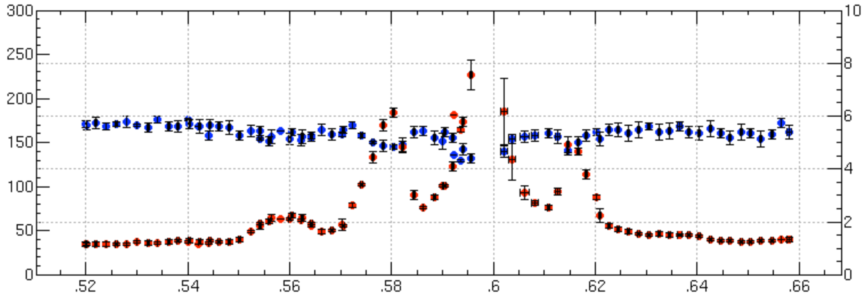
HER

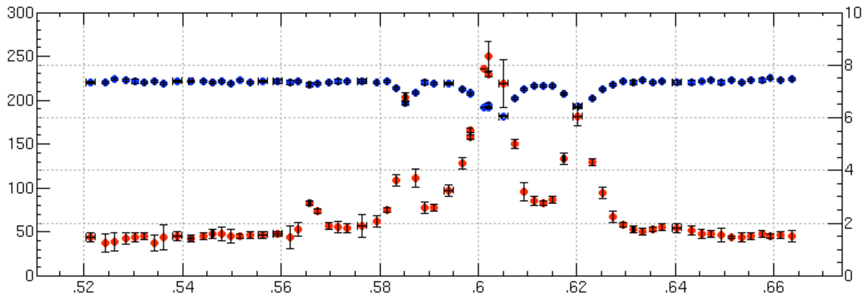
Knob = 0 / CRAB ON



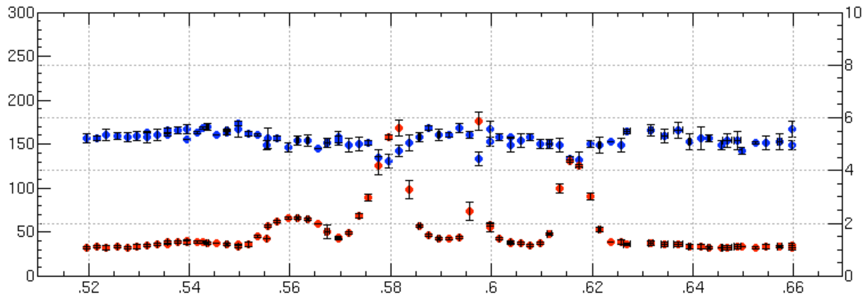


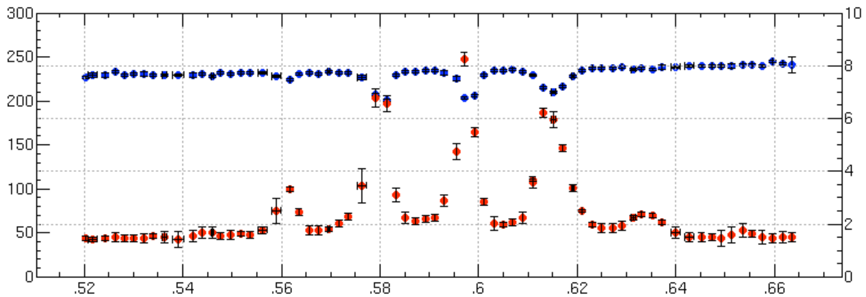
Knob = 0 / CRAB OFF





After optics correction Knob = 0 / CRAB ON



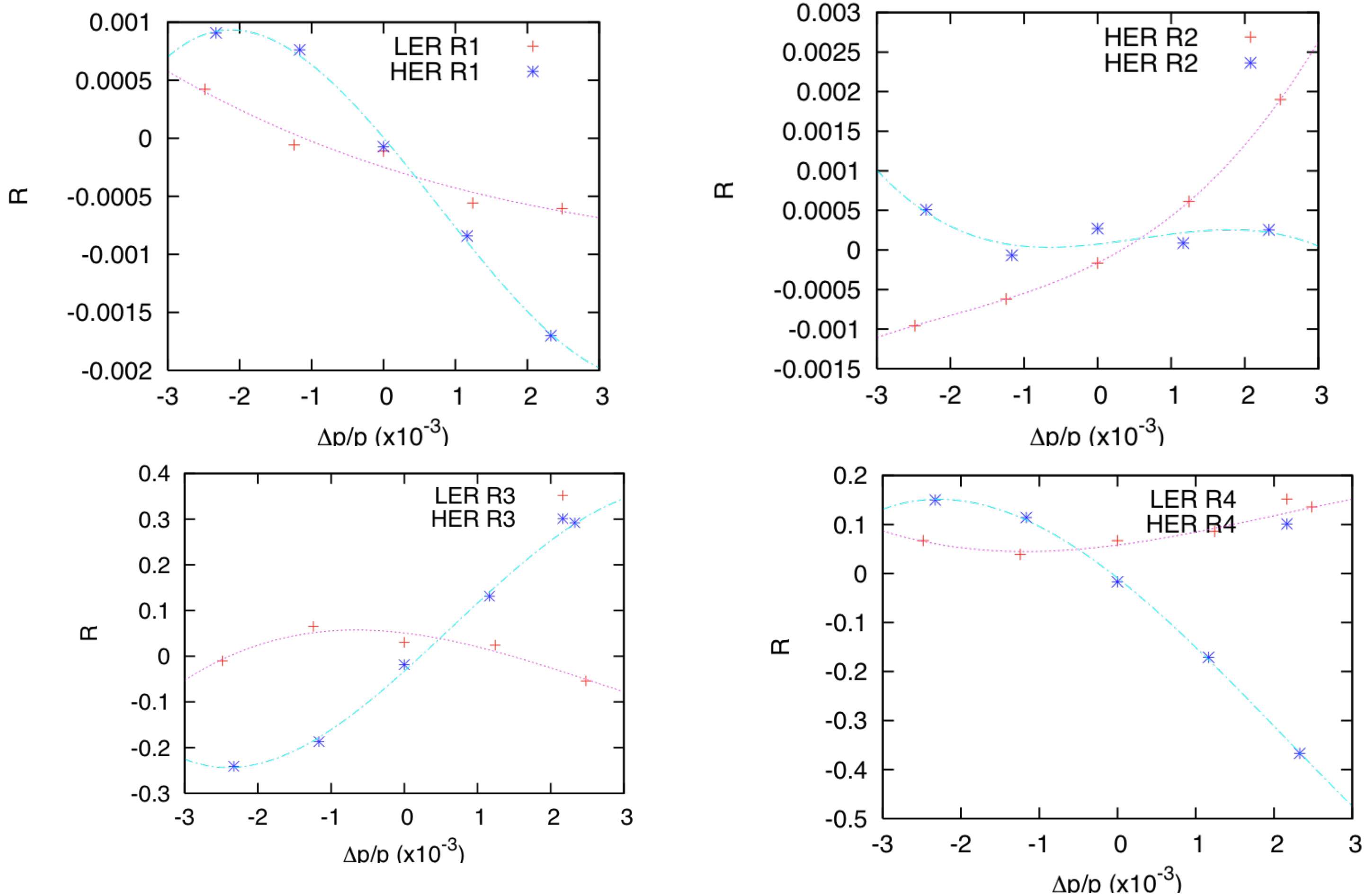


ν_x ν_x

Coupling chromaticity can cause the resonance lines
Measurement of off momentum R

Y. Seimiya, K. Ohmi, H. Koiso, K. Oide

$$R_i(\delta) = R_{i0} + R_{i1}\delta + R_{i2}\delta^2 + R_{i3}\delta^3$$



Linear R chromaticity correction with Skew sextupoles

$$X = \frac{x}{\sqrt{\beta_x^*}} \qquad P_X = \frac{\alpha_x^* x + \beta_x^* p_x}{\sqrt{\beta_x^*}}$$

$$k_x = \frac{\beta_x \beta_y^{1/2} K_2}{6} \qquad k_y = \frac{\beta_y^{3/2} K_2}{6}$$

$$J_X = \frac{X^2 + P_X^2}{2} = \frac{\gamma x^2 + 2\alpha_x x p_x + \beta_x p_x^2}{2}$$

$$\exp(-:F_3:)\exp(-:\mu J:) = \exp(-:\phi J:)\exp(-:k_x X^2 Y + k_y Y^3:)\exp(-:(\mu-\phi)J:)$$

$$= \exp(-:\phi J:)\exp(-:k_x X^2 Y + k_y Y^3:)\exp(+:\phi J:)\exp(-:\mu J:)$$

$$= \exp(-:k_x(X\cos\phi_x + P_X\sin\phi_x)^2(Y\cos\phi_y + P_Y\sin\phi_y) + k_y(Y\cos\phi + P_Y\sin\phi)^3 + :)\exp(-:\mu J:)$$

$$H_I \approx \oint \left[\left\{ k_x X\cos\phi_x + P_X\sin\phi_x + \frac{\eta_x}{\sqrt{\beta_x^*}}\delta \right\}^2 (Y\cos\phi_y + P_Y\sin\phi_y) + k_y(Y\cos\phi + P_Y\sin\phi)^3 \right] ds$$

$$\phi = \phi^* - \phi(s)$$

$$H_I \approx \oint \left[\left\{ k_x X \cos\phi_x + P_X \sin\phi_x + \frac{\eta_x}{\sqrt{\beta_x^*}} \delta \right\}^2 (Y\cos\phi_y + P_Y \sin\phi_y) + k_y (Y\cos\phi + P_Y \sin\phi)^3 \right] ds$$

$$X = \frac{x}{\sqrt{\beta_x^*}} \qquad P_X = \frac{\alpha_x^* x + \beta_x^* p_x}{\sqrt{\beta_x^*}} \qquad k_x = \frac{\beta_x \beta_y^{1/2} K_2}{6}$$

$$H_I \approx \oint \frac{\beta_x \sqrt{\beta_y} K_2}{3} \left[\left(\frac{\cos\phi_x + \alpha_x^* \sin\phi_x}{\sqrt{\beta_x^*}} x + \sqrt{\beta_x^*} \sin\phi_x p_x \right) \left(\frac{\cos\phi_y + \alpha_y^* \sin\phi_y}{\sqrt{\beta_y^*}} y + \sqrt{\beta_y^*} \sin\phi_y p_y \right) \frac{\eta_x}{\sqrt{\beta_x^*}} \delta \right] ds$$

$$d_1 = \oint \frac{K_2}{3} \frac{\beta_x \sqrt{\beta_y}}{\beta_x^* \sqrt{\beta_y^*}} \left(\cos\phi_x + \alpha_x^* \sin\phi_x \right) \left(\cos\phi_y + \alpha_y^* \sin\phi_y \right) \eta_x ds = 21.72$$

$$e_1 = \oint \frac{K_2}{3} \frac{\beta_x \sqrt{\beta_y \beta_y^*}}{\beta_x^*} \left(\cos\phi_x + \alpha_x^* \sin\phi_x \right) \sin\phi_y \eta_x ds = 0.0540$$

$$f_1 = \oint \frac{K_2}{3} \frac{\beta_x \sqrt{\beta_y}}{\sqrt{\beta_y^*}} \sin\phi_x \left(\cos\phi_y + \alpha_y^* \sin\phi_y \right) \eta_x ds = -35.89$$

$$g_1 = \oint \frac{\beta_x \sqrt{\beta_y \beta_y^*} K_2}{3} \sin\phi_x \sin\phi_y \eta_x ds = -0.14$$

Other studies for lattice nonlinearity

- Estimation of crab waist sextupole component at IP.
- The two sextupole magnets pair are set 180 degree phase advance, thus no nonlinear components are induced in ideal lattice.
- The nonlinear components are induced by errors.
- The nonlinear component are estimated by measurement of beta function and phase, which deviate from design values.

- XY^2: $$\sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_2}{6}\left(\frac{1}{2}\cos\phi_{x,i}+\frac{1}{4}\cos\left(\phi_{x,i}-2\phi_{y,i}\right)+\frac{1}{4}\cos\left(\phi_{x,i}+2\phi_{y,i}\right)\right)$$
- XP_Y^2: $$\sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_2}{6}\left(\frac{1}{2}\cos\phi_{x,i}-\frac{1}{4}\cos\left(\phi_{x,i}-2\phi_{y,i}\right)-\frac{1}{4}\cos\left(\phi_{x,i}+2\phi_{y,i}\right)\right)$$
- XYP_Y: $$\sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_2}{6}\left(\frac{1}{2}\sin\left(\phi_{x,i}-2\phi_{y,i}\right)-\frac{1}{2}\sin\left(\phi_{x,i}+2\phi_{y,i}\right)\right)$$
- P_XY^2: $$\sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_2}{6}\left(-\frac{1}{2}\sin\phi_{x,i}-\frac{1}{4}\sin\left(\phi_{x,i}-2\phi_{y,i}\right)-\frac{1}{4}\sin\left(\phi_{x,i}+2\phi_{y,i}\right)\right)$$
- $P_XP_Y^2$: $$\sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_2}{6}\left(-\frac{1}{2}\sin\phi_{x,i}+\frac{1}{4}\sin\left(\phi_{x,i}-2\phi_{y,i}\right)+\frac{1}{4}\sin\left(\phi_{x,i}+2\phi_{y,i}\right)\right)$$
- P_XYP_Y: $$\sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_2}{6}\left(\frac{1}{2}\cos\left(\phi_{x,i}-2\phi_{y,i}\right)-\frac{1}{2}\cos\left(\phi_{x,i}+2\phi_{y,i}\right)\right)$$

2006/12/27 Y. Ohnishi

LER

These values are very small to affect the beam-beam performance

Evaluate from beta function measurement

X^3

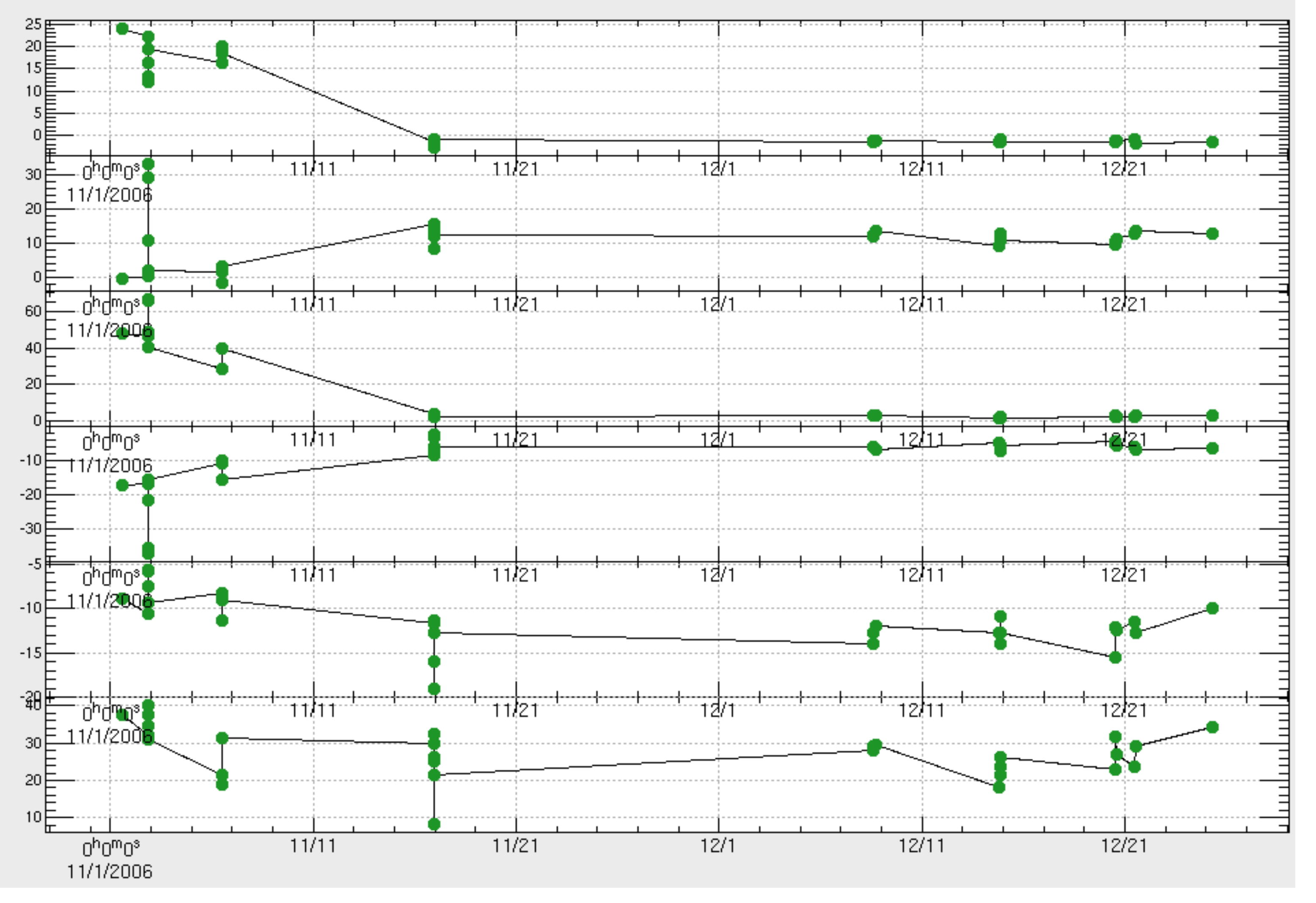
X^2P_X

XP_X^2

P_X^3

XY^2

XP_Y^2



Tilt due to the transverse wake force

- Measured by Ieiri.

$$\left(\frac{d\nu_x}{dI}\right)_{I=0} = -\frac{r_e W_0}{8e\gamma\omega_0}\beta$$

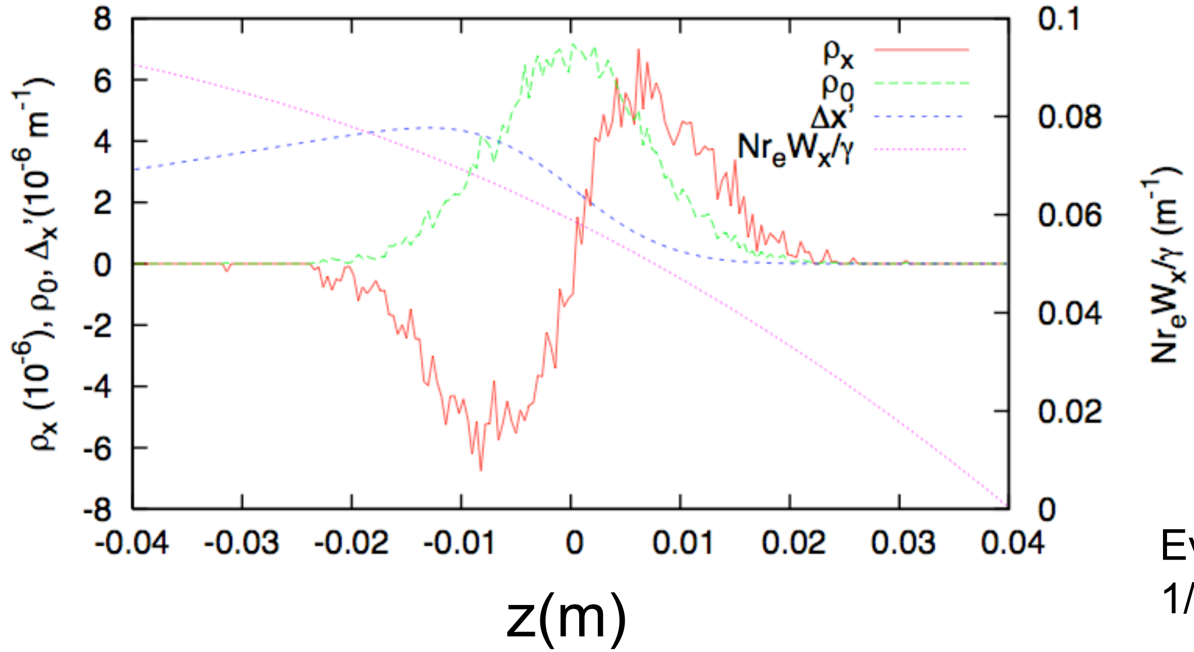
$$W_0 = \left(\frac{d\nu_x}{dI}\right)_{I=0} \frac{8e\gamma\omega_0}{r_e\beta}$$

$$\left(\frac{d\nu_x}{dI}\right)_{I=0} = 4A^{-1}$$

$$= 1.7\times10^6\mathrm{m}^{-2}$$

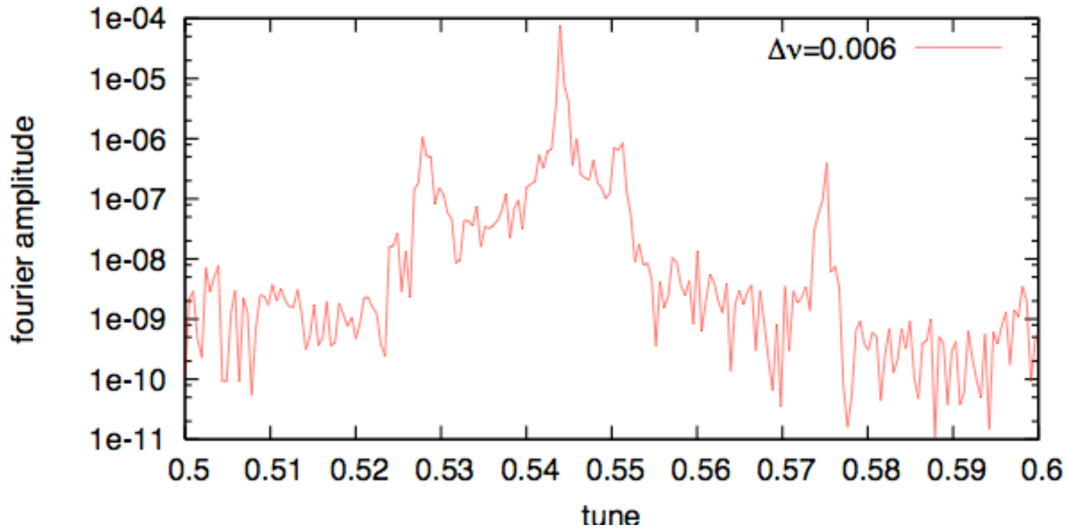
$$\Delta x'_2 = \frac{N r_e W_0}{\gamma}\sigma_x = 7.5\times10^{-6}$$

$$\Delta x'_{crab} = \frac{eV'}{E}\sigma_z = \frac{eV_0}{E}\frac{\omega_{rf}\sigma_z}{c} = 1.25\times10^{-4}$$



*wake z=0~-0.08

Even $\Delta\nu$=0.006, the kick is 1/30 of crab kick

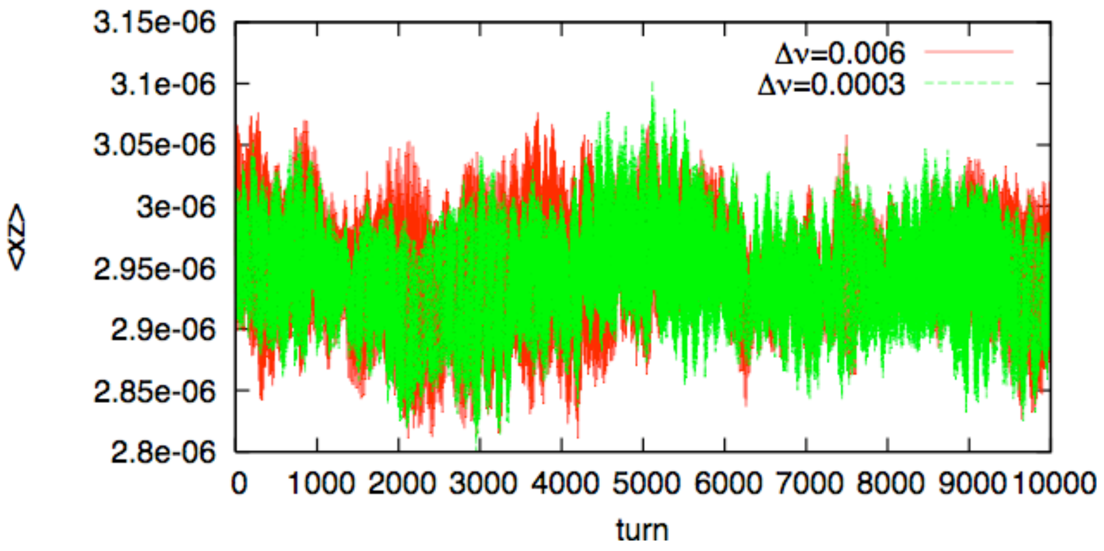


ν_x=0.55

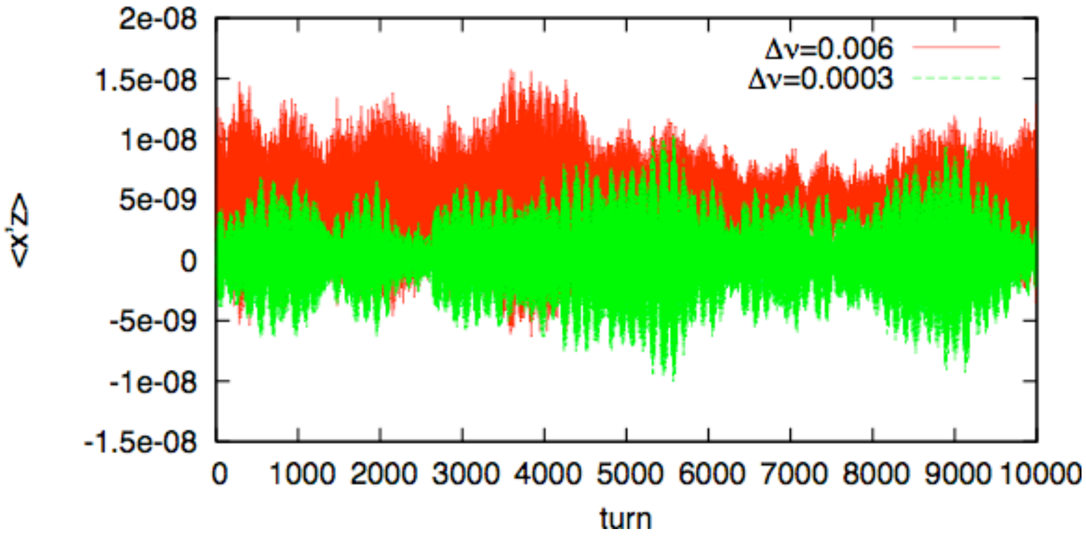
Spectrum by simulation with this condition

$$\Delta x'_{crab} = \frac{eV'}{E}\sigma_z = \frac{eV_0}{E}\frac{\omega_{rf}\sigma_z}{c} = 1.25\times10^{-4}$$

Change of equilibrium distribution



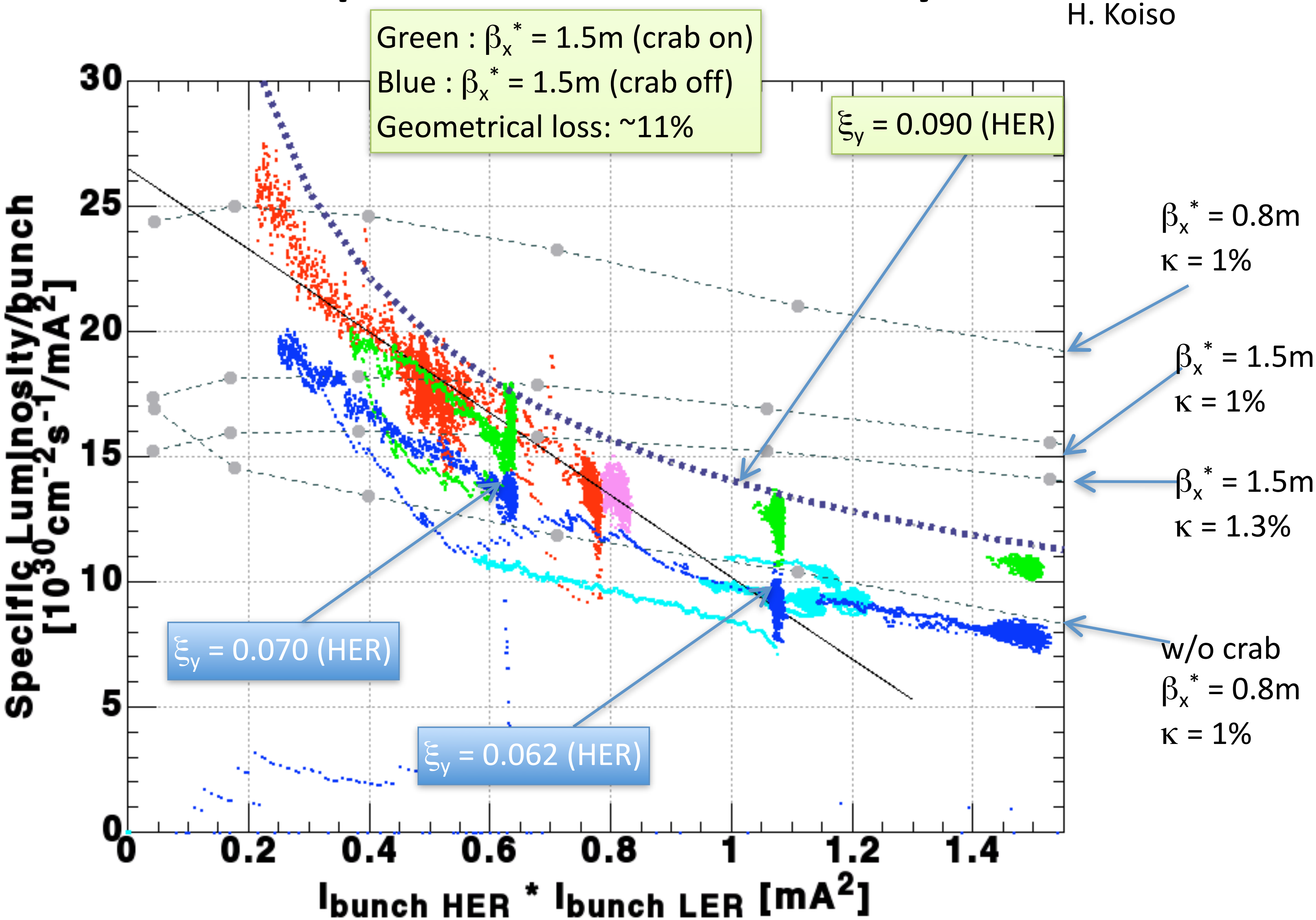
- <xz> does not change.
- <x'z> change a little $\sigma_{x'}\sigma_z/30$.



The wake effect of x-z tilt beam is weak.

Specific luminosity

H. Koiso



Beam-beam parameters for e+e- colliders

	DAFNE	DAFNE	KEKB	KEKB	BEPC-II	CESR
	before	2008.12.10	2008.11.21	2008.11.21	2008.3.20	2001.2 Rice
C	97	97	3016	3016	240	768.4
N bunch	110	105	199	1585	90	45
I+ (mA)	1.1	1.106	0.262	1.600	0.500	0.350
N+	2.02E+10	2.13E+10	8.27E+10	6.34E+10	2.78E+10	1.24E+11
E+	0.51	0.51	3.5	3.5	1.89	5.29
I−	1.5	1.431	0.162	0.970	0.500	0.350
N−	2.75E+10	2.75E+10	5.11E+10	3.84E+10	2.78E+10	1.24E+11
E−	0.51	0.51	8	8	1.89	5.29
εx	3.40E−07	2.50E−07	1.80E−08	1.80E−08	1.44E−07	2.05E−07
εy	1.70E−09	1.25E−09	9.00E−11	9.00E−11	1.44E−09	2.05E−09
βx	1.7	0.26	1.5	1.5	1.00E+00	0.9381
βy	0.017	0.0095	0.0059	0.0059	1.50E−02	0.018
$\tau x/T$	110000	110000	4000	4000	31900	0
$\xi n+=2\ re\ \beta\ L/\gamma\ N\ f$	0.0210	0.0315	0.0861	0.0802	0.0073	0.0561
$\xi n-=2\ re\ \beta\ L/\gamma\ N\ f$	0.0154	0.0243	0.0609	0.0579	0.0073	0.0561
L (measure)	1.5E+32	4.05E+32	2.90E+33	1.65E+34	1E+32	1.25E+33