Beam-beam effects in crab crossing

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MAC 07-2

29 Nov.-5 Dec. 2007

Contents

- Simulation of knob scan
- Beam-beam halo with weak-strong simulation in SAD
- Emittance growth due to wake force with offset orbit and crabbing.
- Correlation of Life time and beam size. Touschek life time with beam-beam interaction.

Simulation of knob scan

M. Tawada

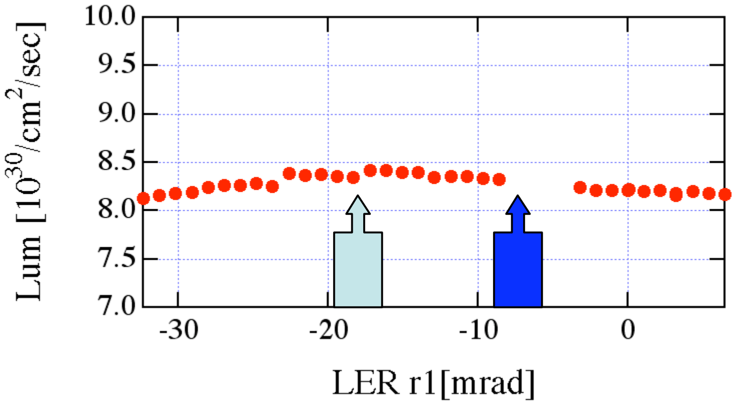
- Current 0.8/1.4 mA/bunch (HER/LER)
- ε_x = 24/18 nm (HER/LER) 1% coupling
- $\beta_{x/y}$ = 80/0.7 cm (both)
- $\nu_{x/y/z}$ = 0.511/0.580/0.025

Start from this initial Tilt and Dispersion error

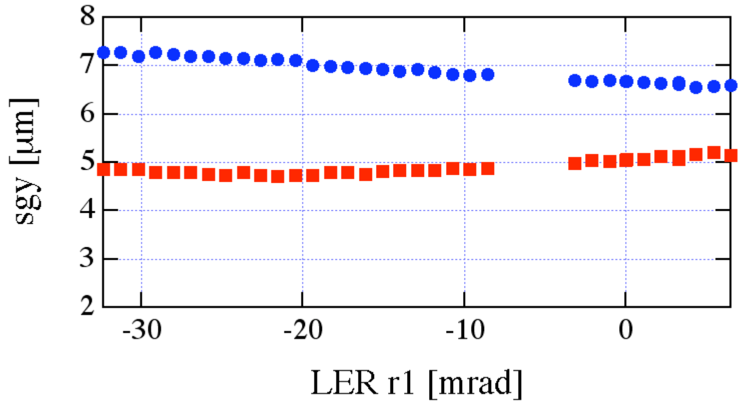
$L_0 = 8.3 \times 10^{30}$ $cm^{-2}s^{-1}$/bunch

	LER (1unit)	HER (1unit)
r1 (mrad)	-7.51 (3.17)	-2.44 (0.53)
r2 (mm)	1.24 (0.22)	-0.1 (0.43)
r3 (/km)	367 (59.38)	423 (48.72)
r4 (mrad)	-103.7 (25.02)	-230 (36.85)
ey (mm)	1.08 (0.36)	-1.68 (0.59)
eyp (mrad)	-55.0 (18.98)	61.8 (21.65)

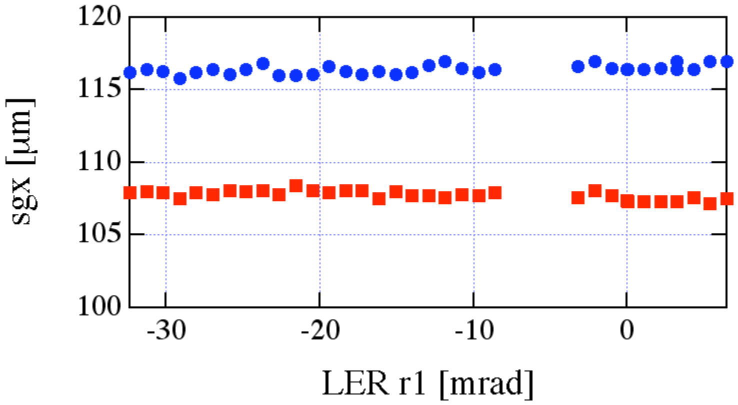
LER r1



Lum [10^{30}/cm^2/sec]
10.0
9.5
9.0
8.5
8.0
7.5
7.0
-30
-20
-10
0
LER r1[mrad]

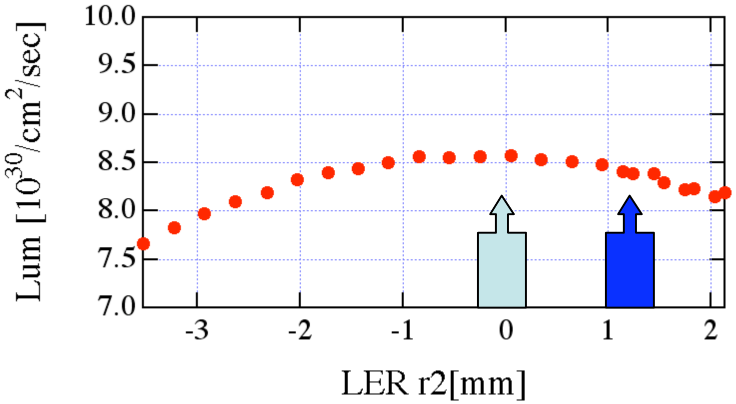


sgy [μm]
8
7
6
5
4
3
2
-30
-20
-10
0
LER r1 [mrad]

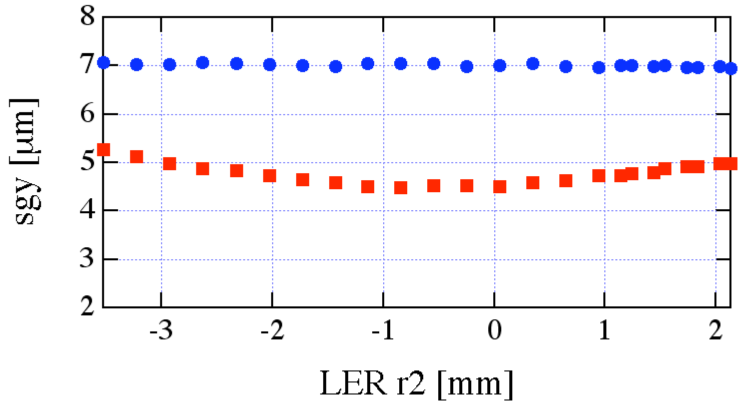


sgx [μm]
120
115
110
105
100
-30
-20
-10
0
LER r1 [mrad]

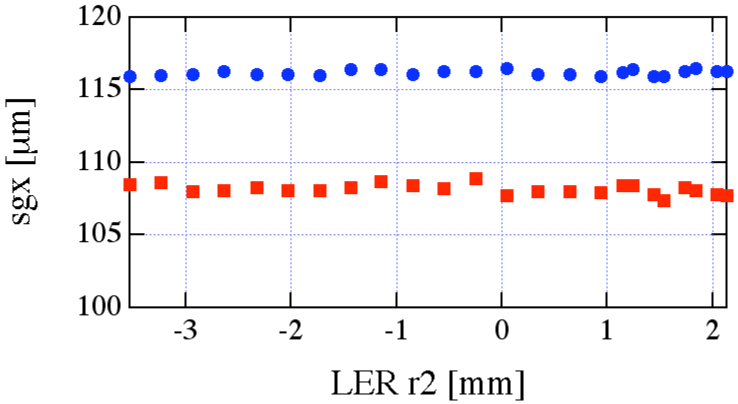
LER r2



10.0
9.5
9.0
8.5
8.0
7.5
7.0
Lum [10^30/cm^2/sec]
-3
-2
-1
0
1
2
LER r2[mm]

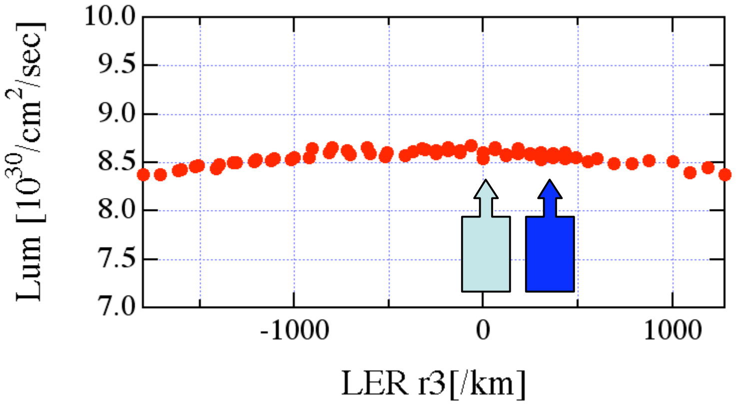


8
7
6
5
4
3
2
sgy [µm]
-3
-2
-1
0
1
2
LER r2 [mm]

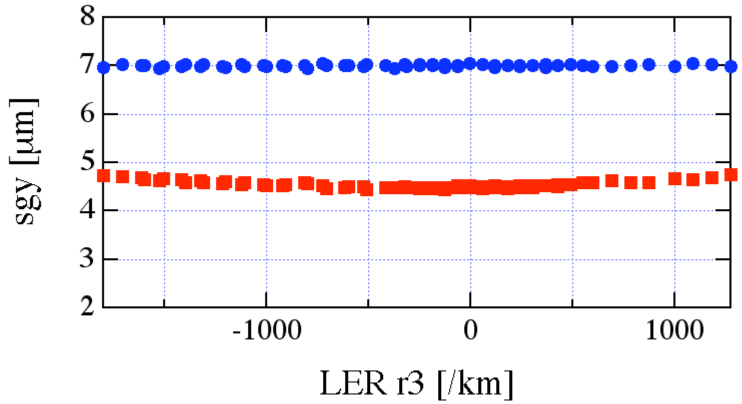


120
115
110
105
100
sgx [µm]
-3
-2
-1
0
1
2
LER r2 [mm]

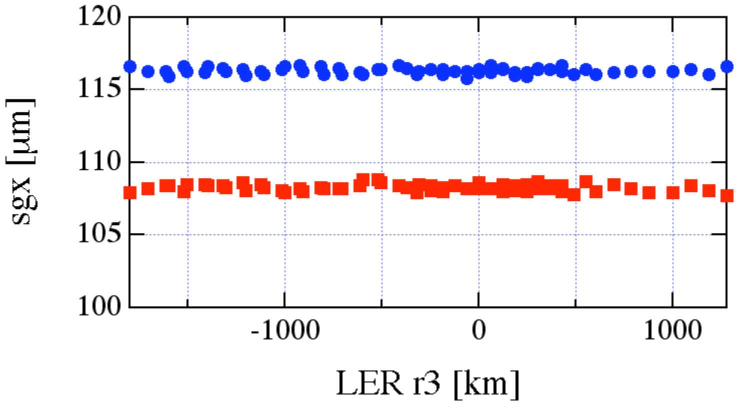
LER r3



Lum [10^30/cm^2/sec]
10.0
9.5
9.0
8.5
8.0
7.5
7.0
-1000
0
1000
LER r3[/km]

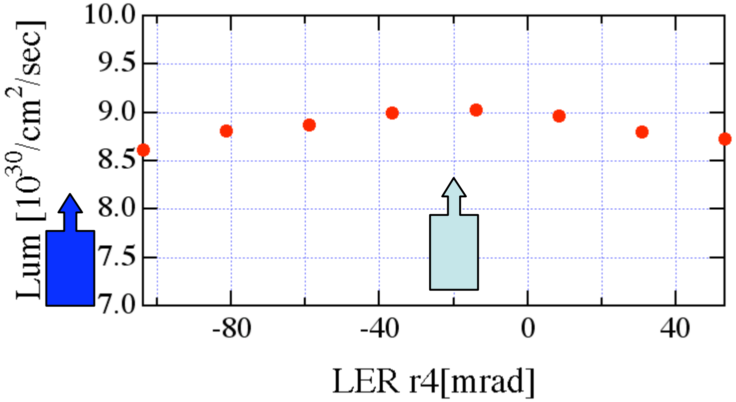


sgy [μm]
8
7
6
5
4
3
2
-1000
0
1000
LER r3 [/km]

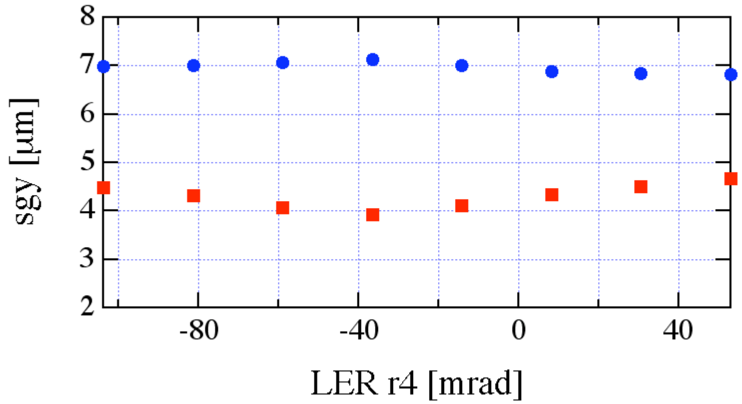


sgx [μm]
120
115
110
105
100
-1000
0
1000
LER r3 [km]

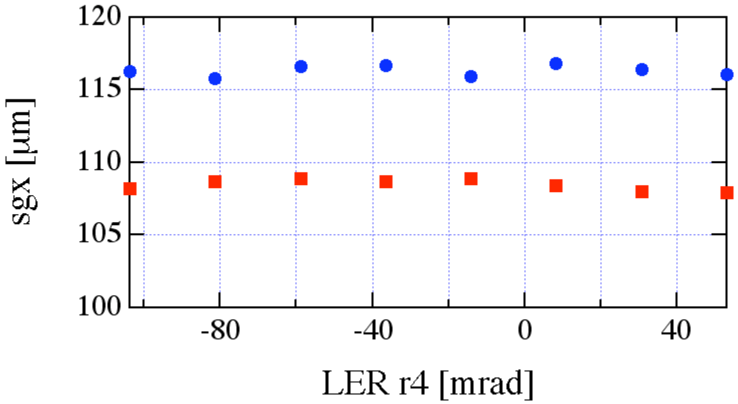
LER r4



10.0
9.5
9.0
8.5
8.0
7.5
7.0
Lum [10^{30}/cm^2/sec]
-80
-40
0
40
LER r4[mrad]

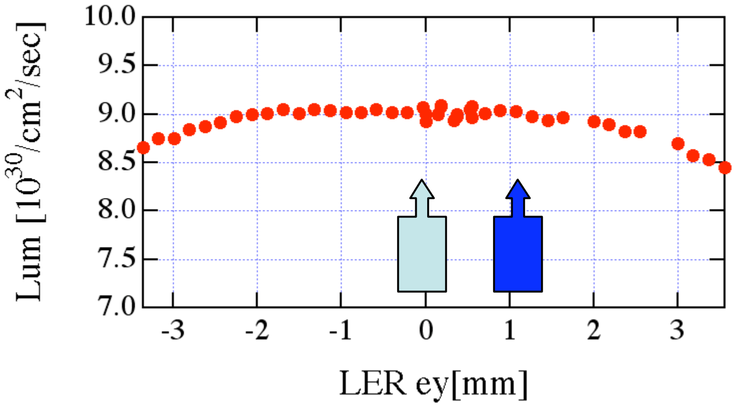


8
7
6
5
4
3
2
sgy [µm]
-80
-40
0
40
LER r4 [mrad]

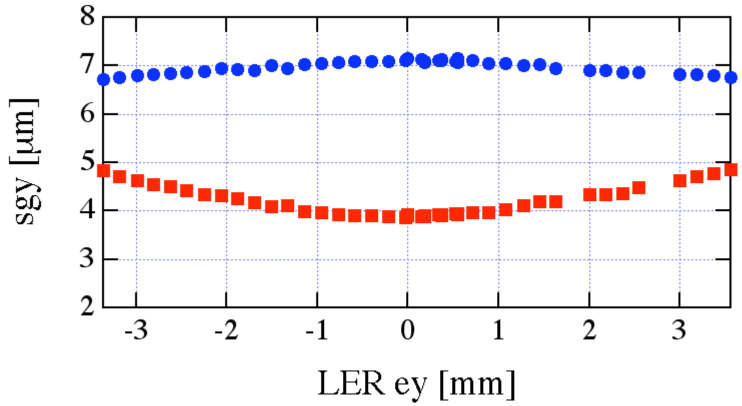


120
115
110
105
100
sgx [µm]
-80
-40
0
40
LER r4 [mrad]

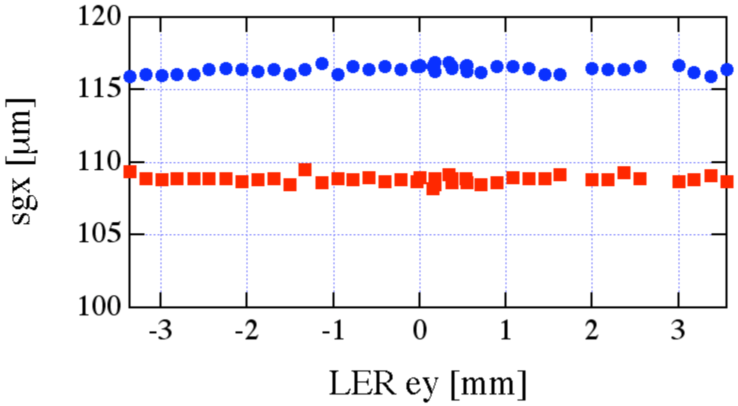
LER ey



Lum [10^30/cm^2/sec]
10.0
9.5
9.0
8.5
8.0
7.5
7.0
-3
-2
-1
0
1
2
3
LER ey[mm]

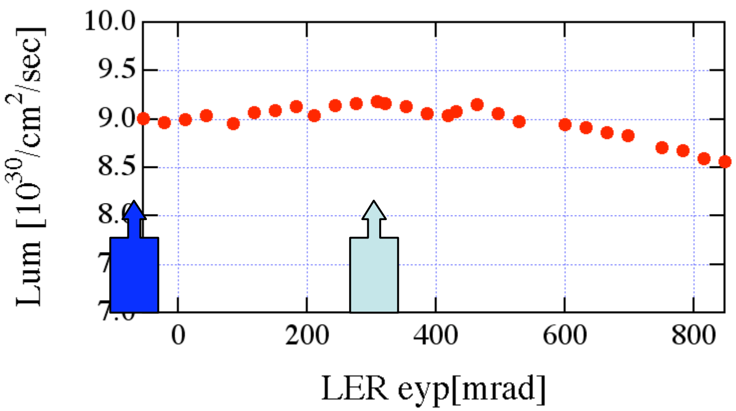


sgy [μm]
8
7
6
5
4
3
2
-3
-2
-1
0
1
2
3
LER ey [mm]

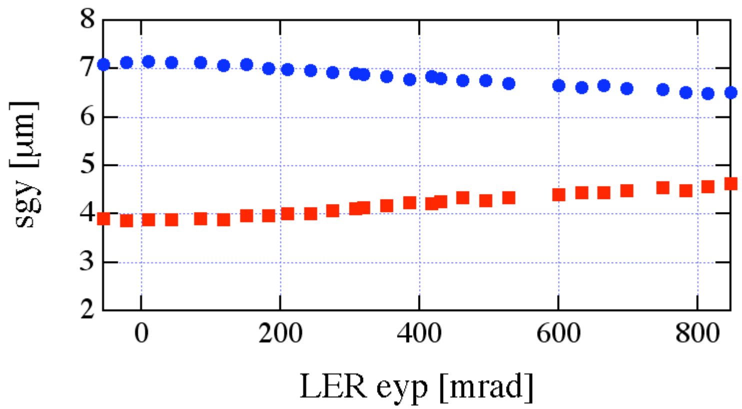


sgx [μm]
120
115
110
105
100
-3
-2
-1
0
1
2
3
LER ey [mm]

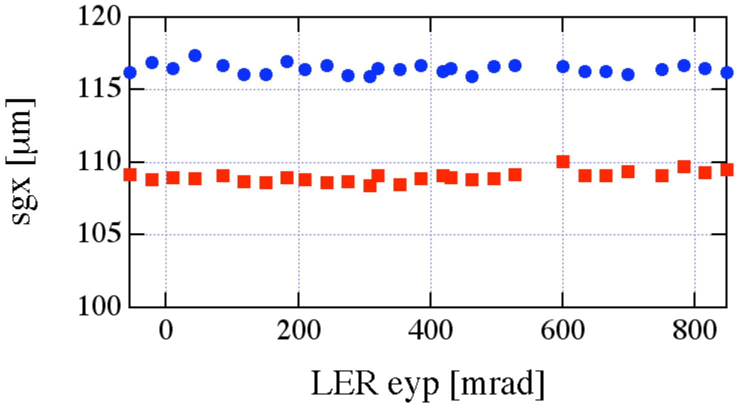
LER eyp



Lum [10^30/cm^2/sec]
10.0
9.5
9.0
8.5
0
200
400
600
800
LER eyp[mrad]

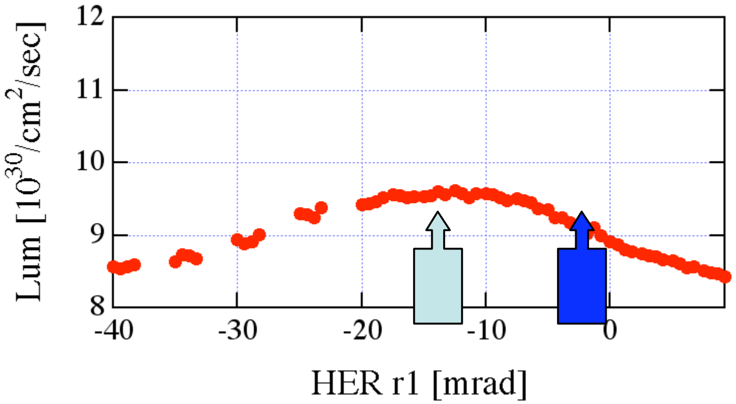


sgy [µm]
8
7
6
5
4
3
2
0
200
400
600
800
LER eyp [mrad]

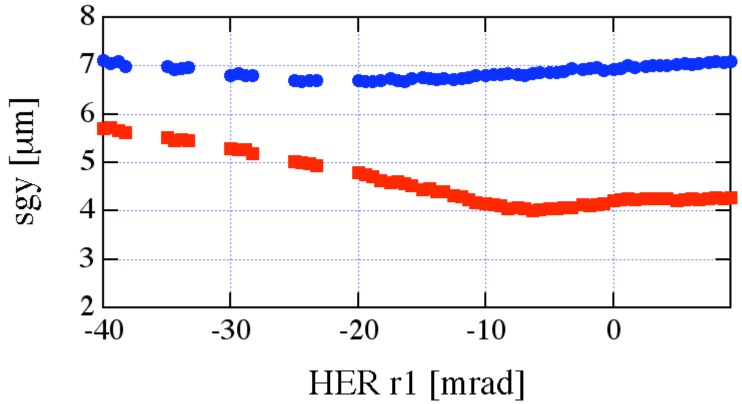


sgx [µm]
120
115
110
105
100
0
200
400
600
800
LER eyp [mrad]

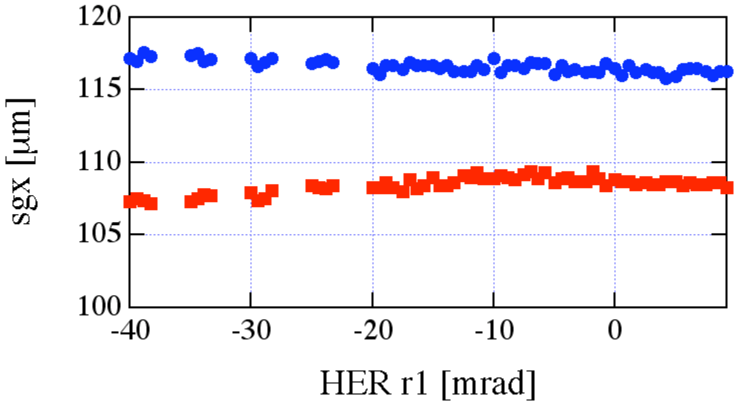
HER r1



Lum [10^{30}/cm^2/sec]
12
11
10
9
8
-40
-30
-20
-10
0
HER r1 [mrad]

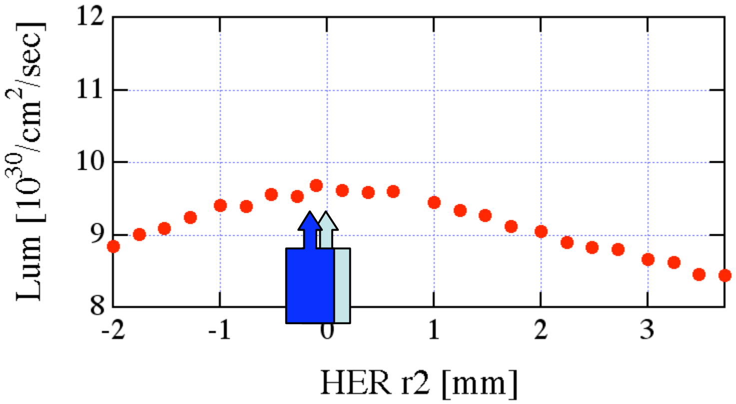


sgy [μm]
8
7
6
5
4
3
2
-40
-30
-20
-10
0
HER r1 [mrad]

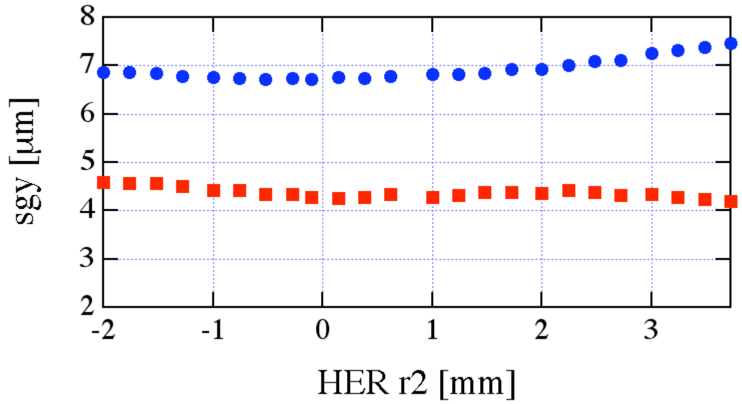


sgx [μm]
120
115
110
105
100
-40
-30
-20
-10
0
HER r1 [mrad]

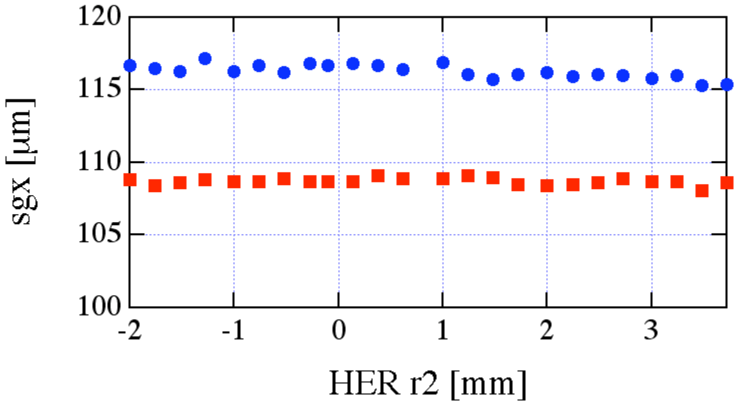
HER r2



Lum [10^{30}/cm^2/sec]
12
11
10
9
8
-2
-1
0
1
2
3
HER r2 [mm]

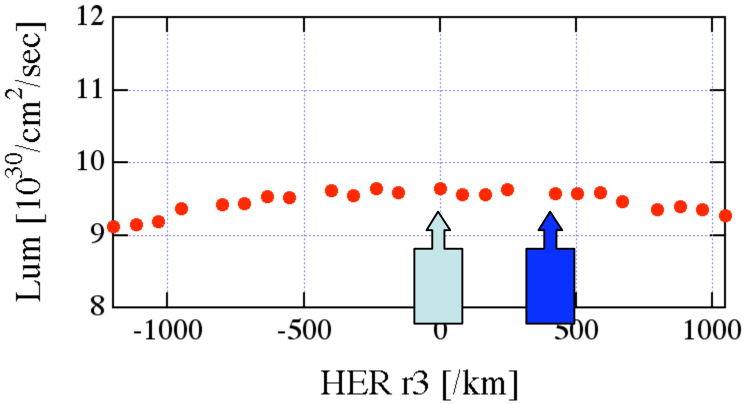


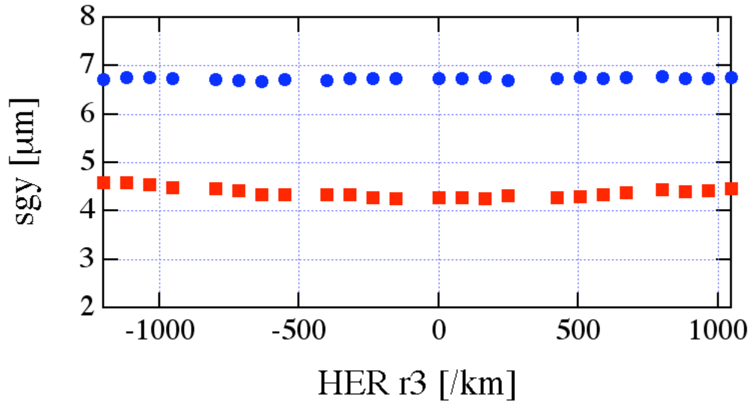
sgy [μm]
8
7
6
5
4
3
2
-2
-1
0
1
2
3
HER r2 [mm]

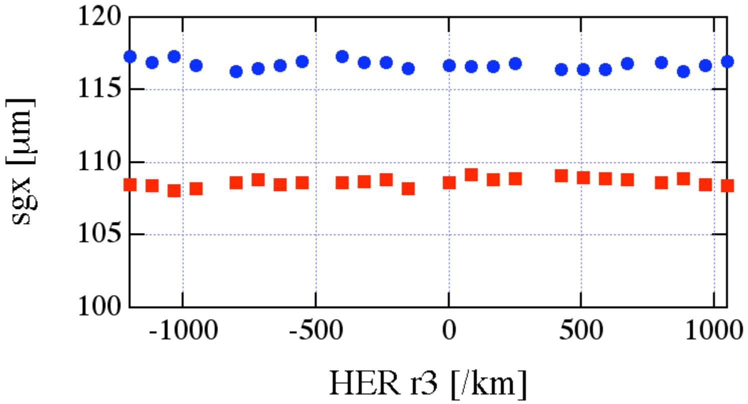


sgx [μm]
120
115
110
105
100
-2
-1
0
1
2
3
HER r2 [mm]

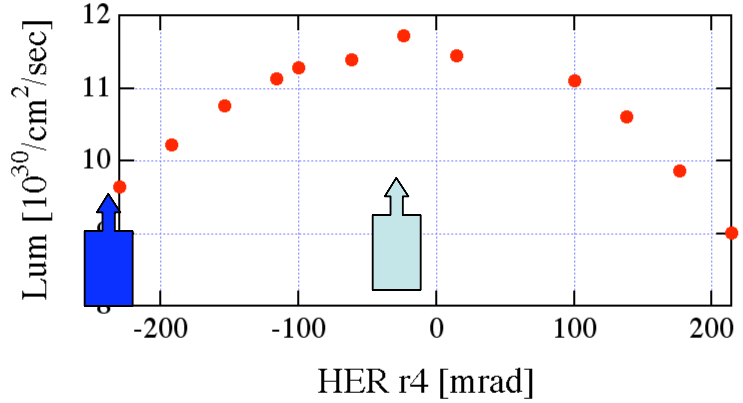
HER r3

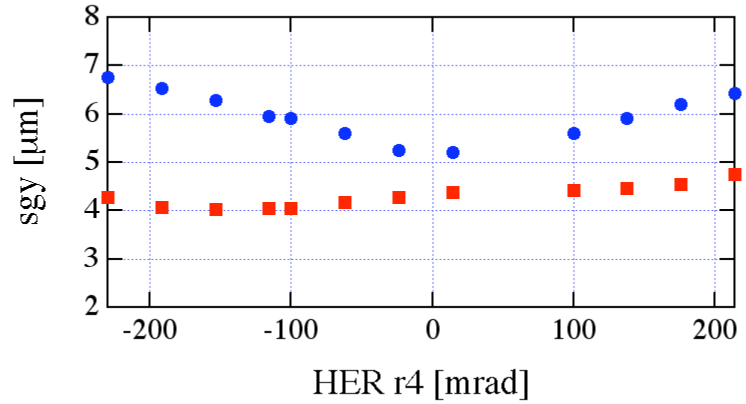

Lum [10^{30}/cm^2/sec]
12
11
10
9
8
-1000
-500
0
500
1000
HER r3 [/km]

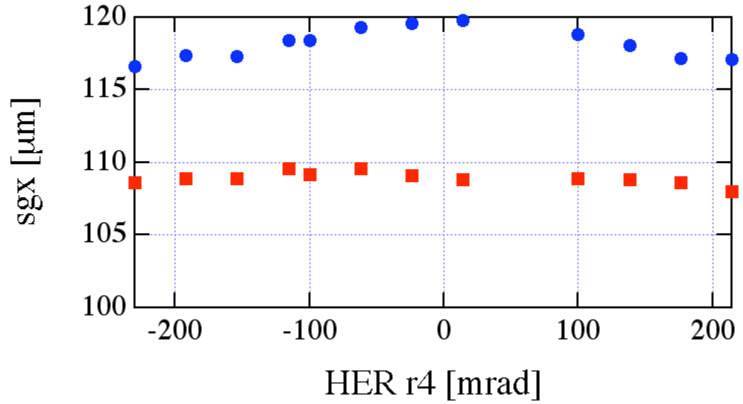

sgy [μm]
8
7
6
5
4
3
2
-1000
-500
0
500
1000
HER r3 [/km]


sgx [μm]
120
115
110
105
100
-1000
-500
0
500
1000
HER r3 [/km]

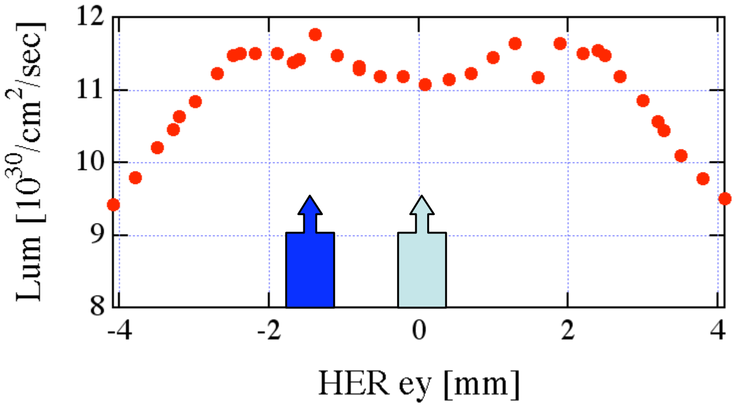
HER r4


Lum [10^30/cm^2/sec]
12
11
10
-200
-100
0
100
200
HER r4 [mrad]

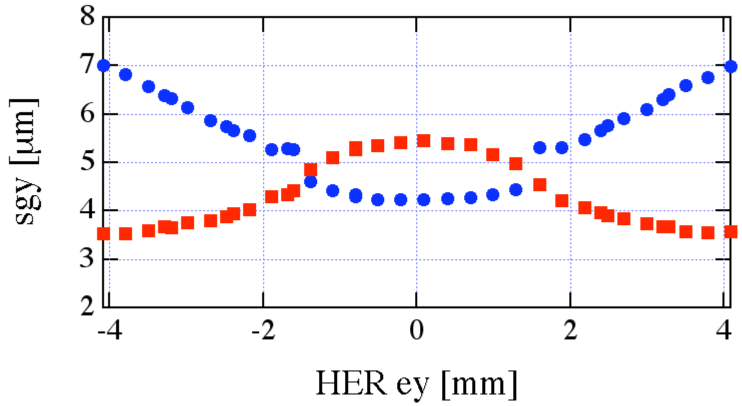

sgy [µm]
8
7
6
5
4
3
2
-200
-100
0
100
200
HER r4 [mrad]


sgx [µm]
120
115
110
105
100
-200
-100
0
100
200
HER r4 [mrad]

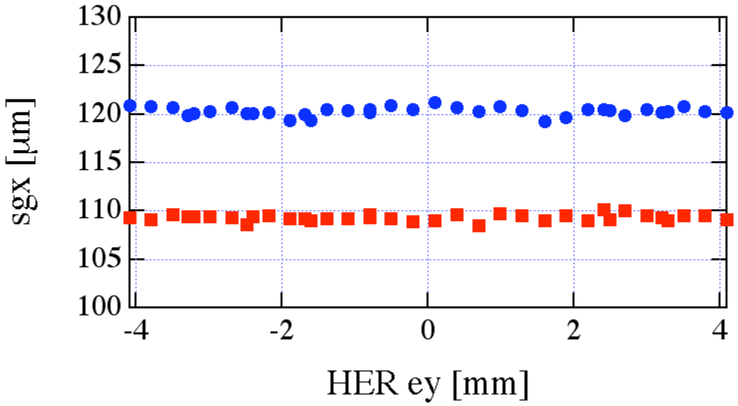
HER ey



12
11
10
9
8
-4
-2
0
2
4
Lum [10^30/cm^2/sec]
HER ey [mm]

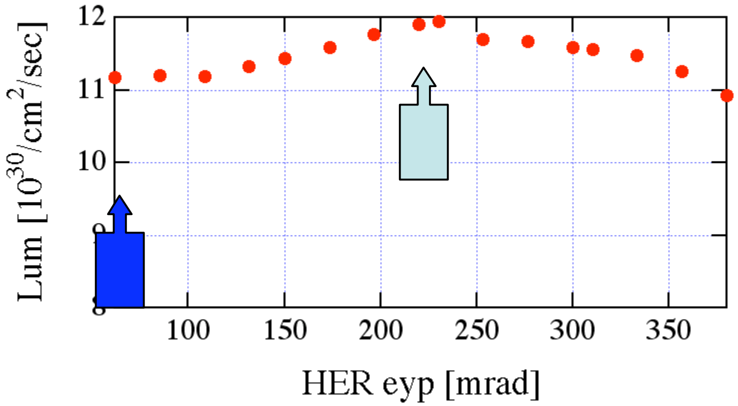


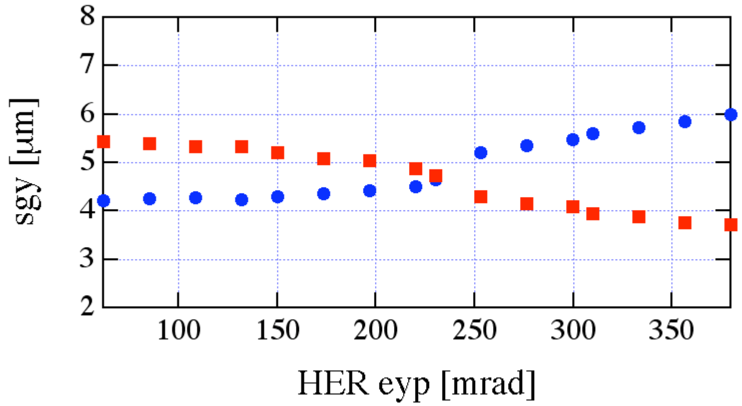
8
7
6
5
4
3
2
-4
-2
0
2
4
sgy [µm]
HER ey [mm]

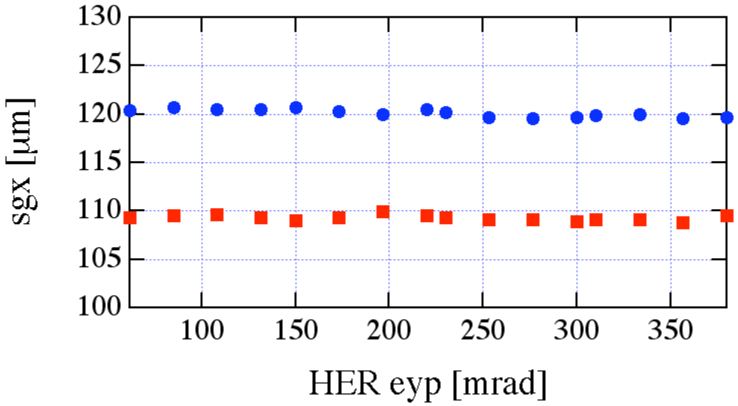


130
125
120
115
110
105
100
-4
-2
0
2
4
sgx [µm]
HER ey [mm]

HER η_y'







This may have two peak at η_y'=-200.

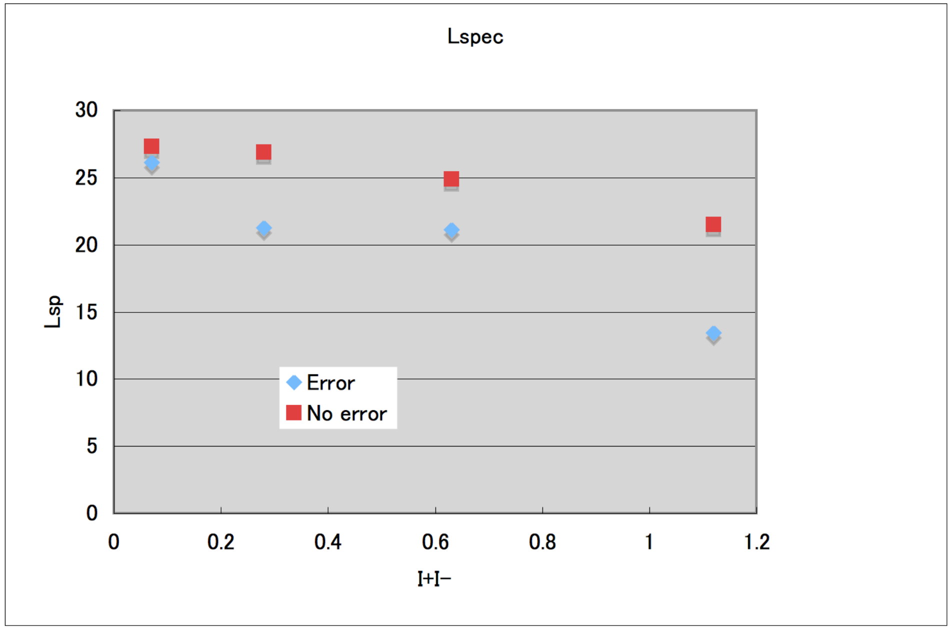
After 1 cycle, Tilt, Dispersion error

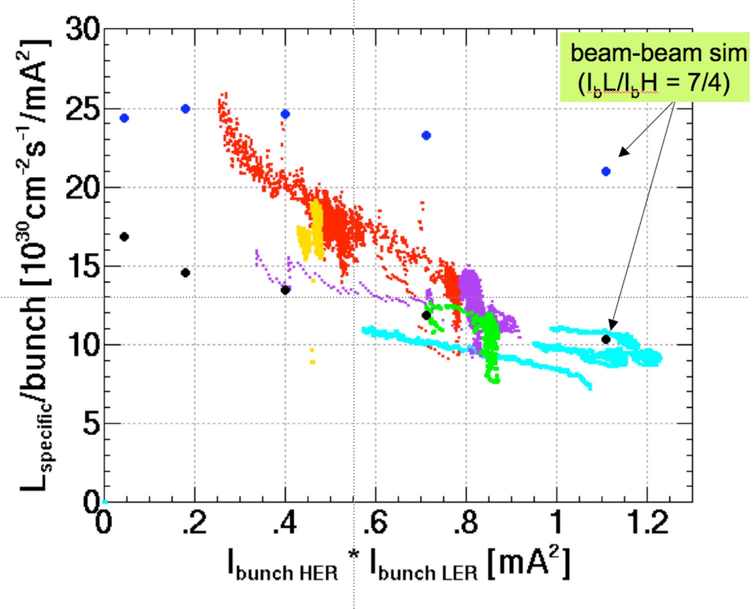
$L_1 = 12.2 \times 10^{30}\ cm^{-2}s^{-1}$/bunch

	LER (1unit)	HER (1unit)
r1 (mrad)	-17.23 (3.17)	-12.5 (0.53)
r2 (mm)	0.0 (0.22)	0.0 (0.43)
r3 (/km)	0.0 (59.38)	0.0 (48.72)
r4 (mrad)	-20 (25.02)	0.0 (36.85)
ey (mm)	0.0 (0.36)	0.0 (0.59)
eyp (mrad)	300 (18.98)	230 (21.65)

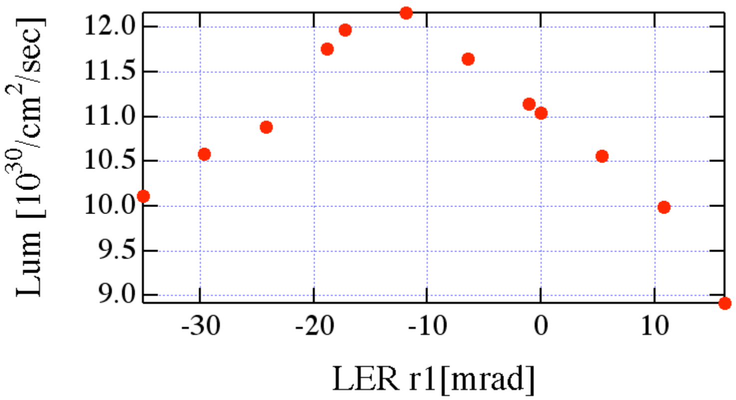
Current dependence at this condition (after 1-st cycle)

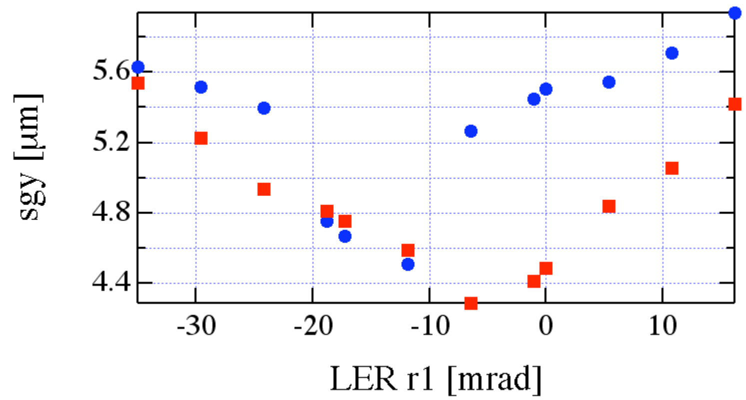
- Luminosity degradation is remarkable at high current.

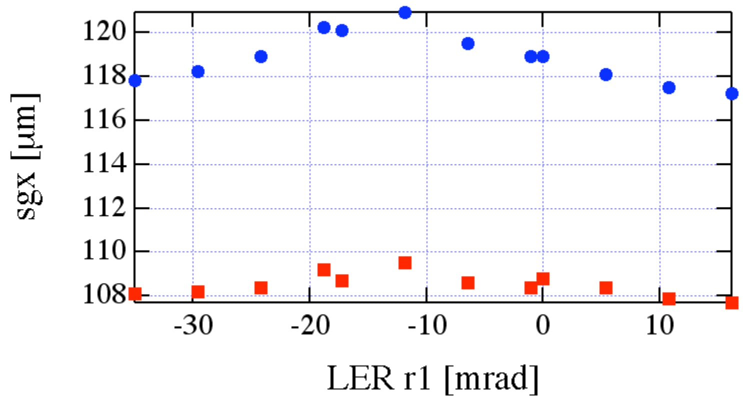




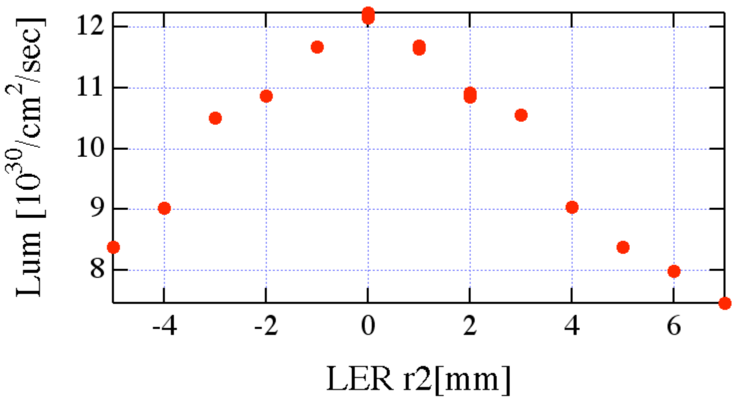
LER r1-2 (means 2nd cycle)



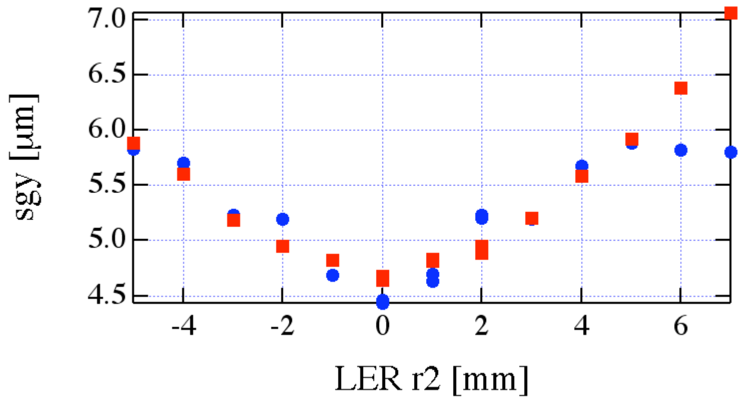




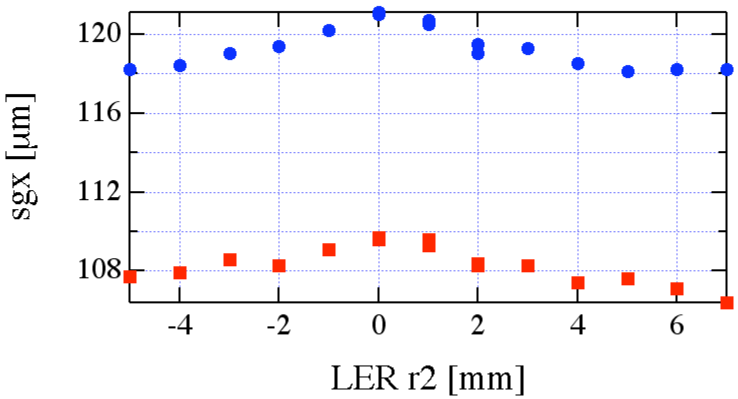
LER r2-2



Lum [10^{30}/cm^2/sec]
12
11
10
9
8
-4
-2
0
2
4
6
LER r2[mm]

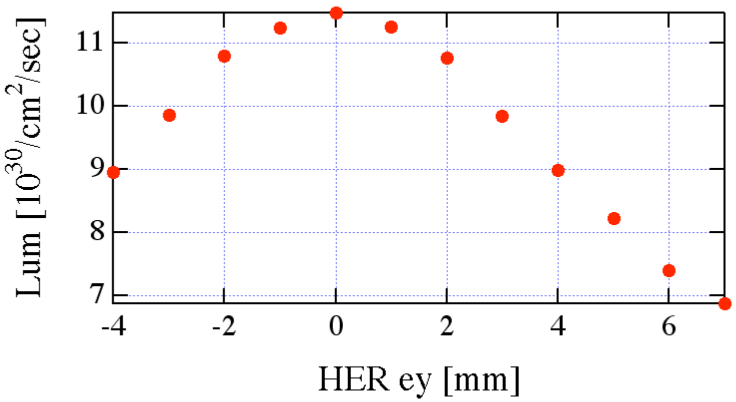


sgy [μm]
7.0
6.5
6.0
5.5
5.0
4.5
-4
-2
0
2
4
6
LER r2 [mm]

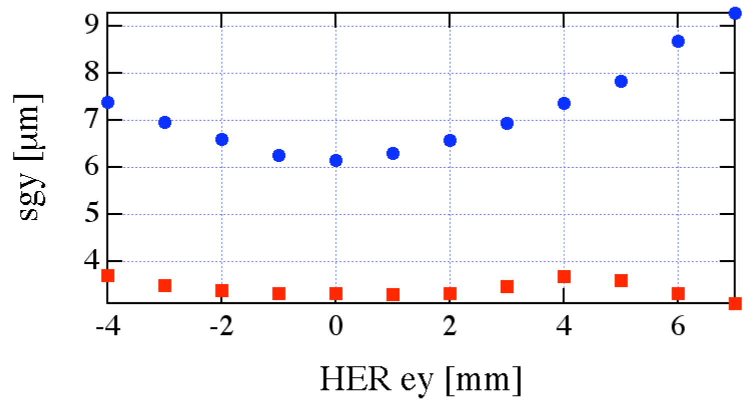


sgx [μm]
120
116
112
108
-4
-2
0
2
4
6
LER r2 [mm]

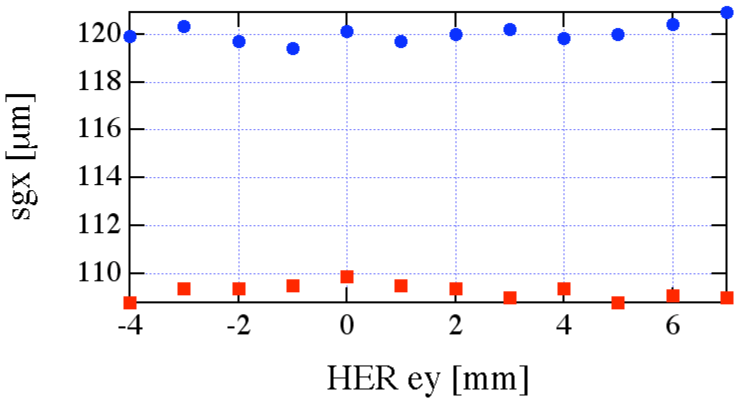
HER ey-2



Lum [10^{30}/cm^2/sec]
11
10
9
8
7
-4
-2
0
2
4
6
HER ey [mm]

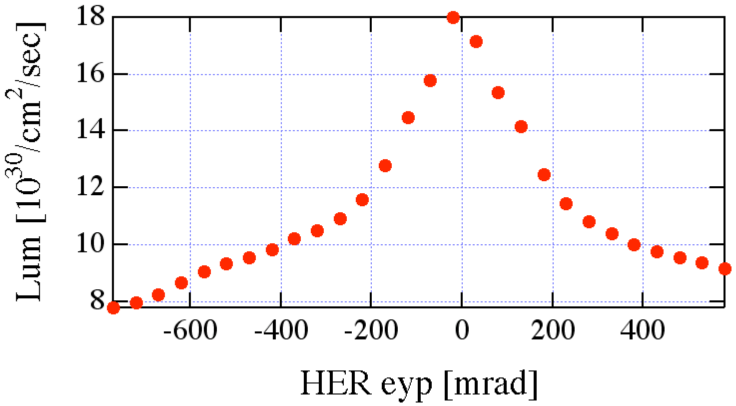


sgy [μm]
9
8
7
6
5
4
-4
-2
0
2
4
6
HER ey [mm]

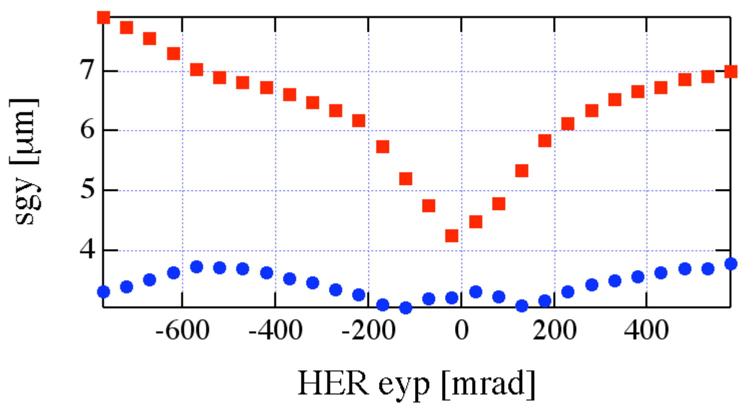


sgx [μm]
120
118
116
114
112
110
-4
-2
0
2
4
6
HER ey [mm]

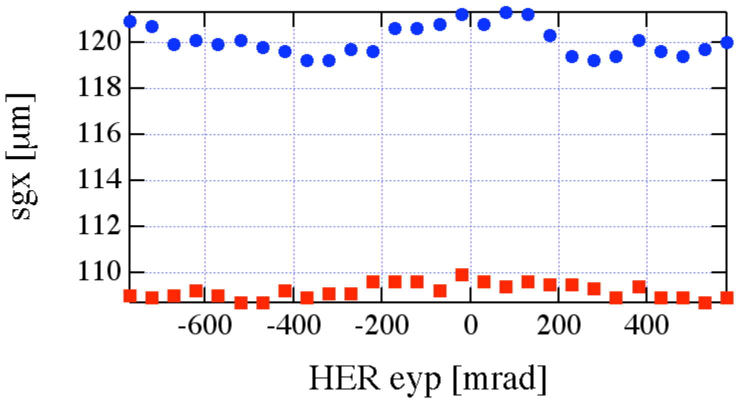
HER eyp-2



Lum [10^30/cm^2/sec]
18
16
14
12
10
8
-600 -400 -200 0 200 400
HER eyp [mrad]



sgy [μm]
7
6
5
4
-600 -400 -200 0 200 400
HER eyp [mrad]



sgx [μm]
120
118
116
114
112
110
-600 -400 -200 0 200 400
HER eyp [mrad]

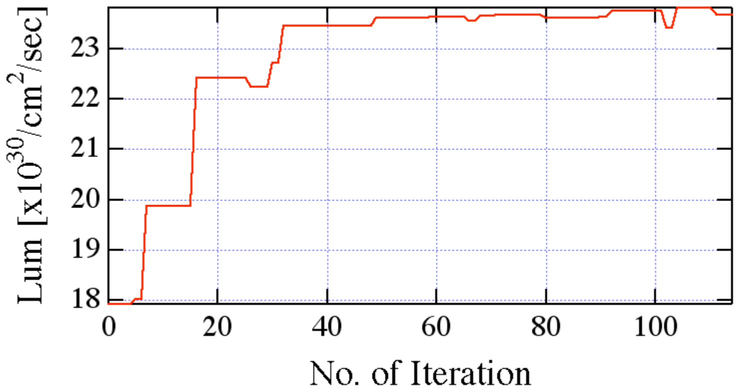
Tilt, Dispersion error after 2nd cycle

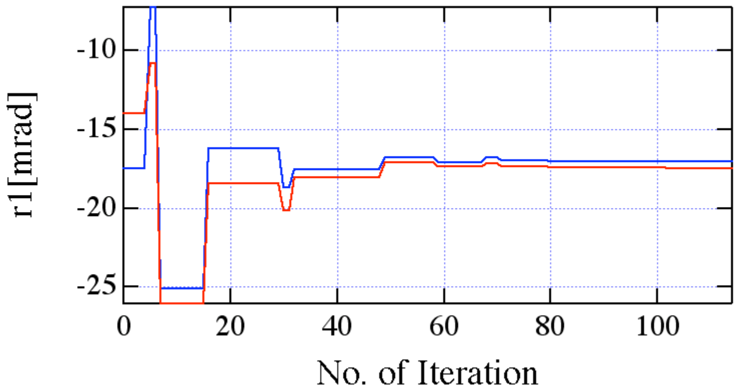
L_2=18.0x10^{30} $cm^{-2}s^{-1}$/bunch

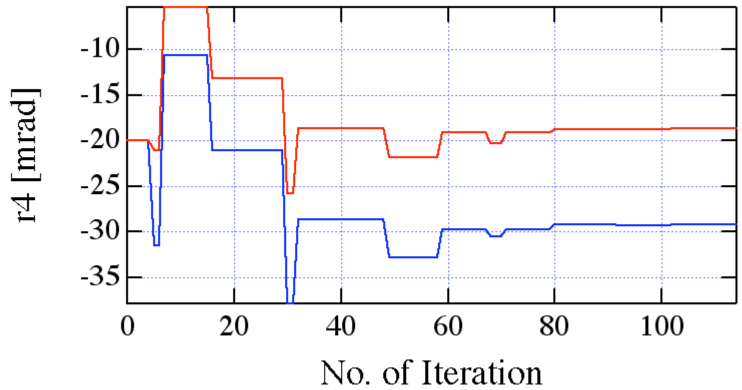
	LER (1unit)	HER (1unit)
r1 (mrad)	-14 (3.17)	-17.5 (0.53)
r2 (mm)	0.0 (0.22)	0.0 (0.43)
r3 (/km)	0.0 (59.38)	0.0 (48.72)
r4 (mrad)	-35 (25.02)	-10.0 (36.85)
ey (mm)	0.0 (0.36)	0.0 (0.59)
eyp (mrad)	0 (18.98)	0 (21.65)

DownhillSimplex after 2nd cycle with HER_r1,HER_r4,LER_r1, LER_r4

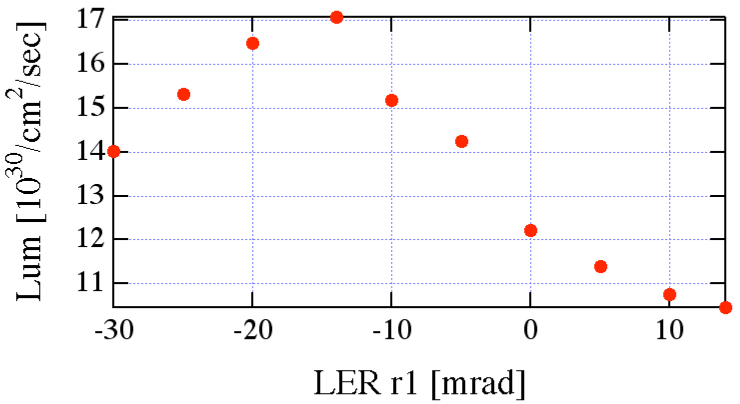
$L_{3,simp}=23.7\text{x}10^{30}\ \text{cm}^{-2}\text{s}^{-1}/\text{bunch}$

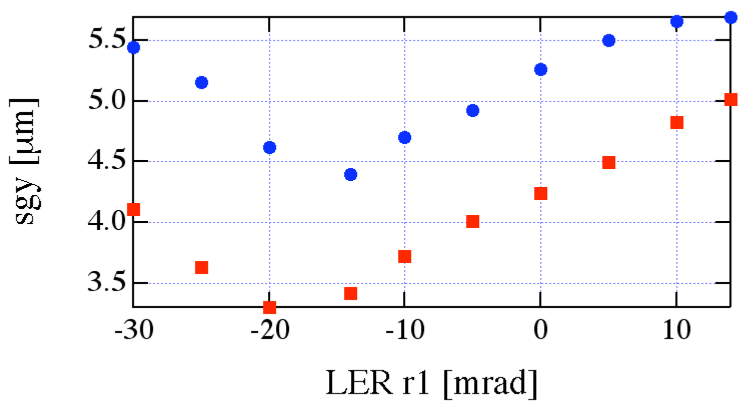


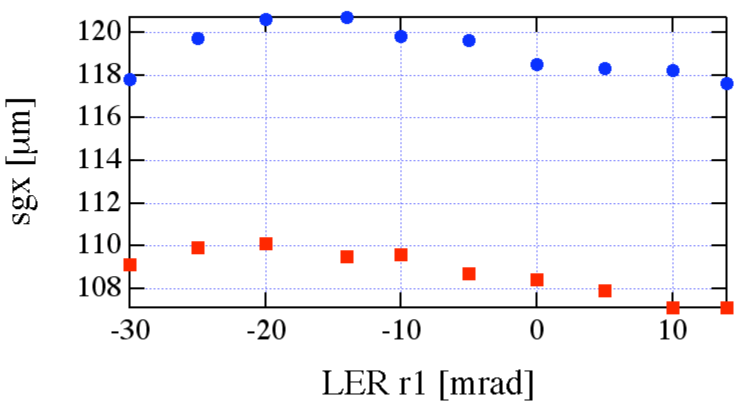




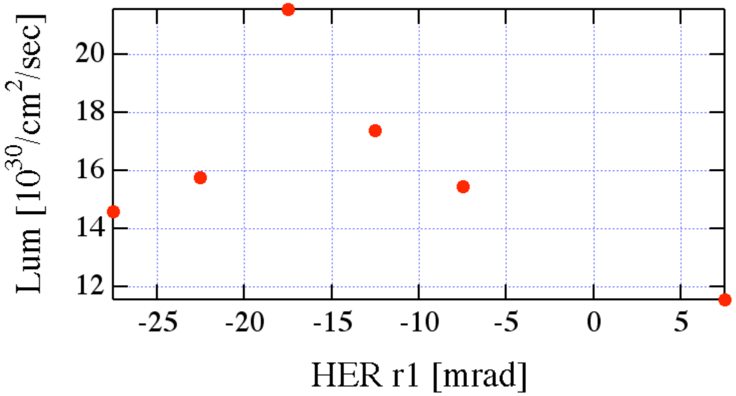
3rd regular scan with only r1,r4 after 2nd scan



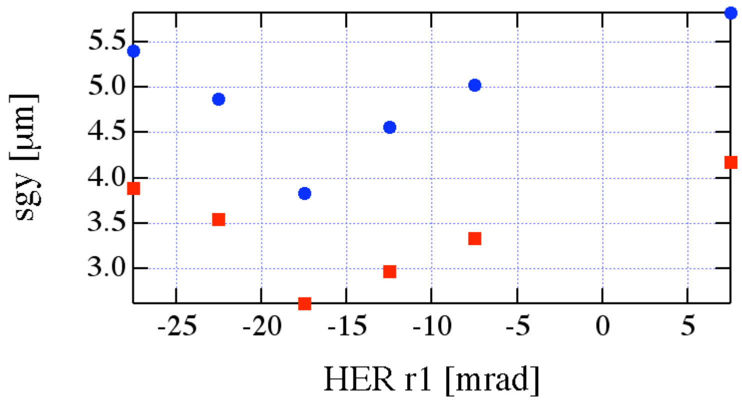




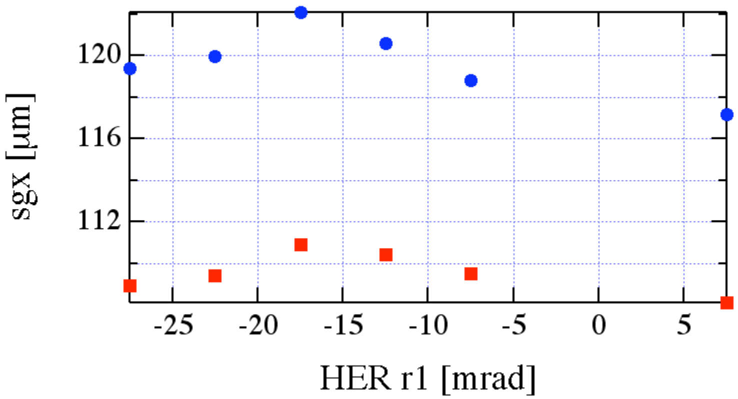
HER r1-3



Lum [10^{30}/cm^2/sec]
20
18
16
14
12
-25 -20 -15 -10 -5 0 5
HER r1 [mrad]

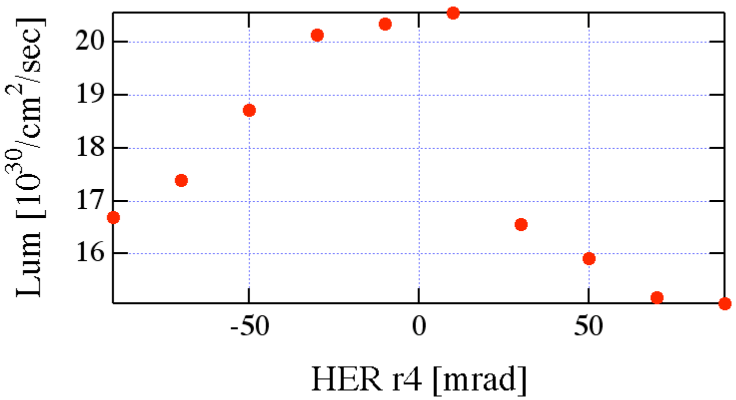


sgy [μm]
5.5
5.0
4.5
4.0
3.5
3.0
-25 -20 -15 -10 -5 0 5
HER r1 [mrad]

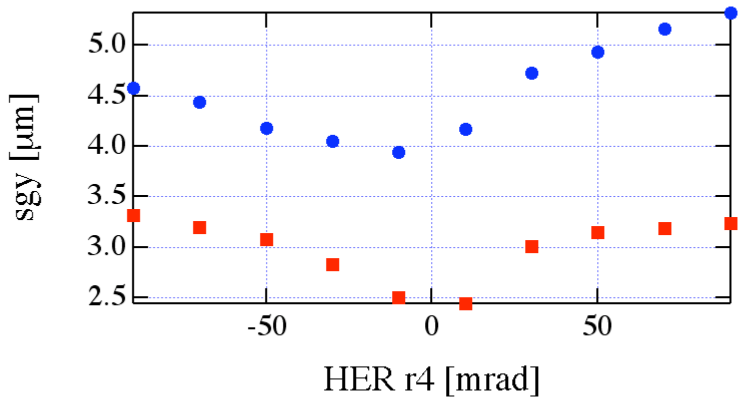


sgx [μm]
120
116
112
-25 -20 -15 -10 -5 0 5
HER r1 [mrad]

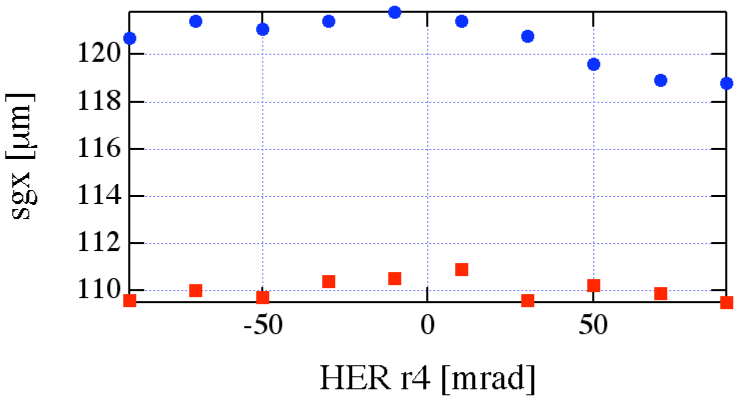
HER r4-3



Lum [10^{30}/cm^2/sec]
20
19
18
17
16
-50
0
50
HER r4 [mrad]



sgy [μm]
5.0
4.5
4.0
3.5
3.0
2.5
-50
0
50
HER r4 [mrad]



sgx [μm]
120
118
116
114
112
110
-50
0
50
HER r4 [mrad]

Tilt, Dispersion error after 3rd scan

$L_{3,regular}$=21.5x10^{30} $cm^{-2}s^{-1}$/bunch

	LER (1unit)	HER (1unit)
r1 (mrad)	-16 (3.17)	-17.5 (0.53)
r2 (mm)	0.0 (0.22)	0.0 (0.43)
r3 (/km)	0.0 (59.38)	0.0 (48.72)
r4 (mrad)	-20 (25.02)	10.0 (36.85)
ey (mm)	0.0 (0.36)	0.0 (0.59)
eyp (mrad)	0 (18.98)	0 (21.65)

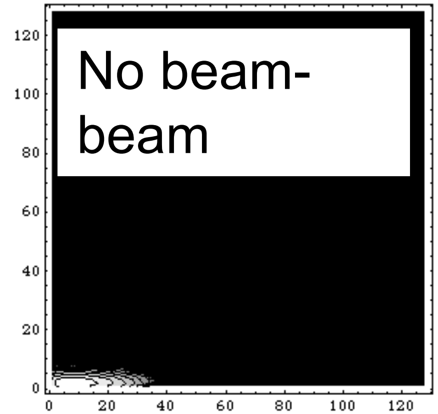
Summary for knob scan simulation

- R1 and R4 mean rotation of real and momentum space, respectively.
- R1(L)=R4(L)=R1(H)=R4(H) (others=0) means simple rotation of both beam should result no luminosity degradation.
- R1-R4 was not resolved and dispersion was mislead due to error each other in 1st cycle.
- Dispersion error was corrected, and R1-R4 tend to coincide for both ring at 2nd cycle.
- Tolerance of R4 is rough than that of R1.
- Regular scan does not seem to have problem.
- Simplex method also gave high luminosity.

Halo simulation using Gaussian weak-strong model

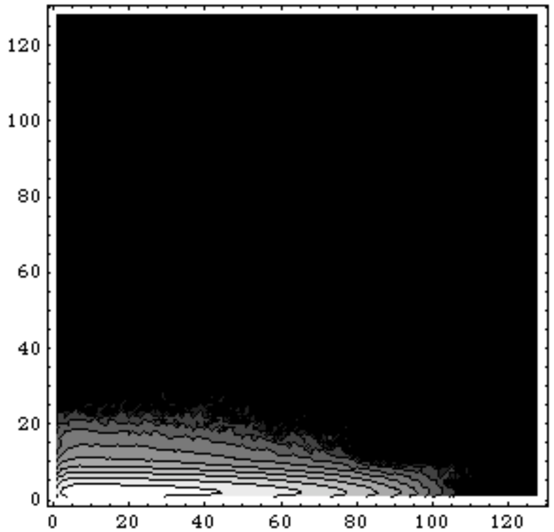
- Long term simulation with a small number of particles.
- 10 particles and 10^7 turns for linear arc model.
- 10 particles and 10^6 turns for SAD model.
- Aperture H ~30 σ_x, V ~75σ_y (Ax~12 μm Ay~1 μm).

Simple arc transformation using matrix trans.

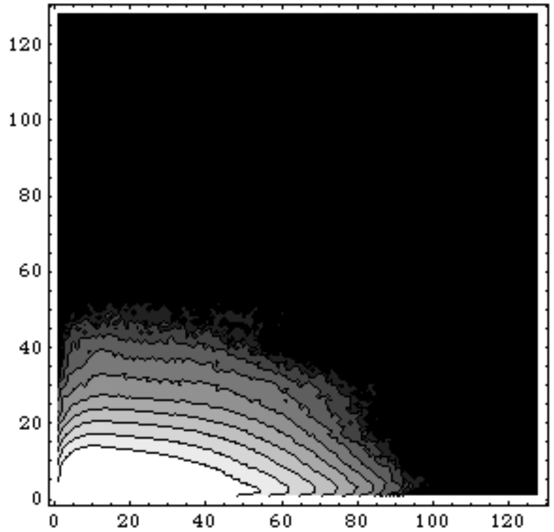


H-axis 0-12.8σ_x (0.1σ_x/unit)
V-axis 0-64σ_y (0.5σ_y/unit)

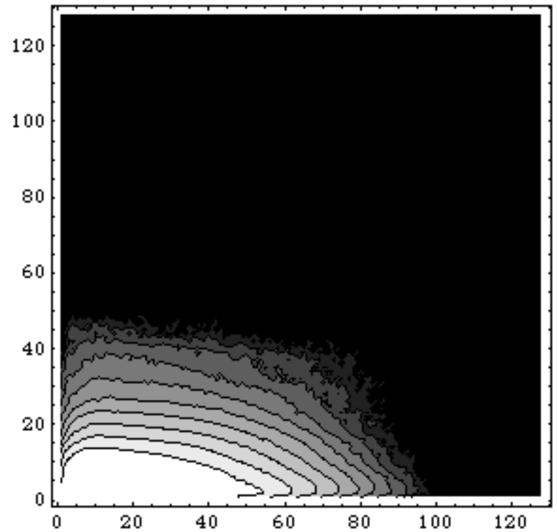
Contour plot with log scale



0 μm



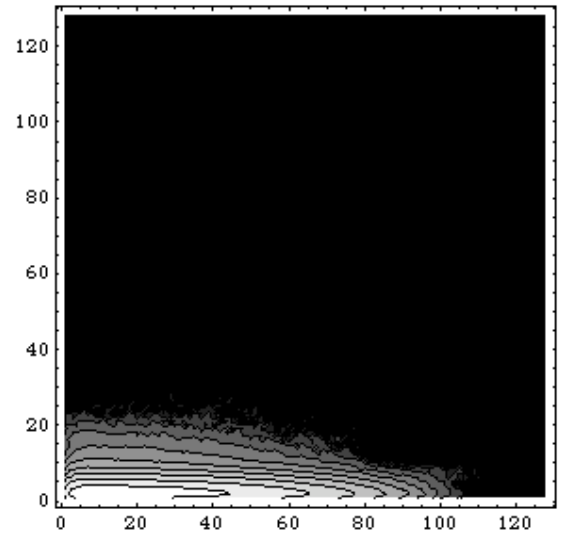
+100 μm



-100 μm

Symmetric for Horizontal offset

The hor. and ver. halo do not matter.

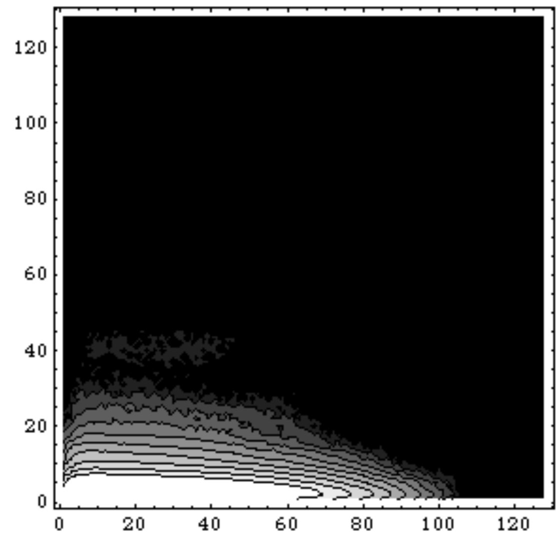


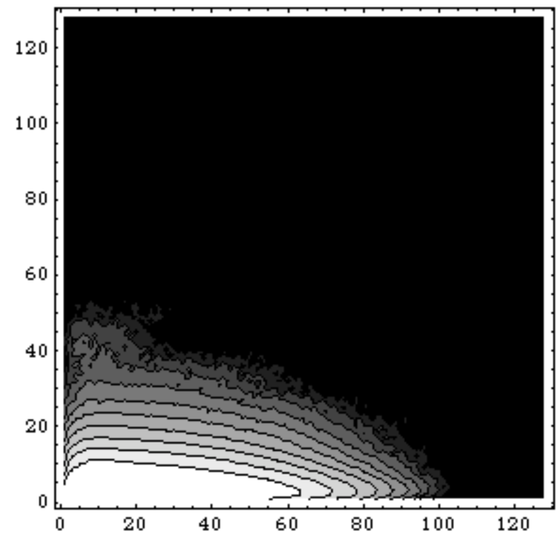
0 μm

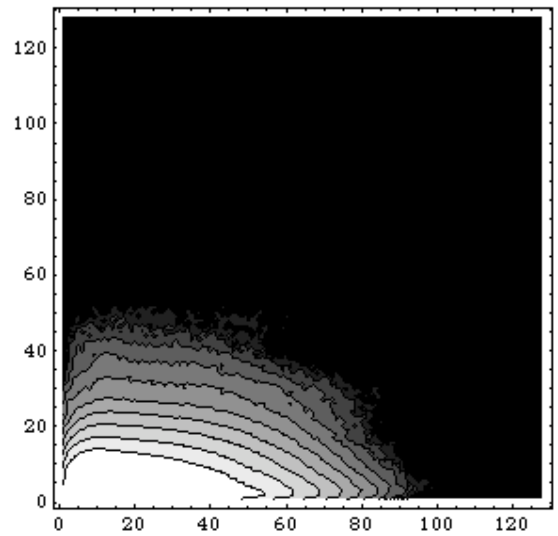
Horizontal offset induces vertical halo

H-axis 0-12.8σ_x (0.1σ_x/unit)
V-axis 0-64σ_y (0.5σ_y/unit)
Contour plot with log scale

20 μm 50 μm 100 μm





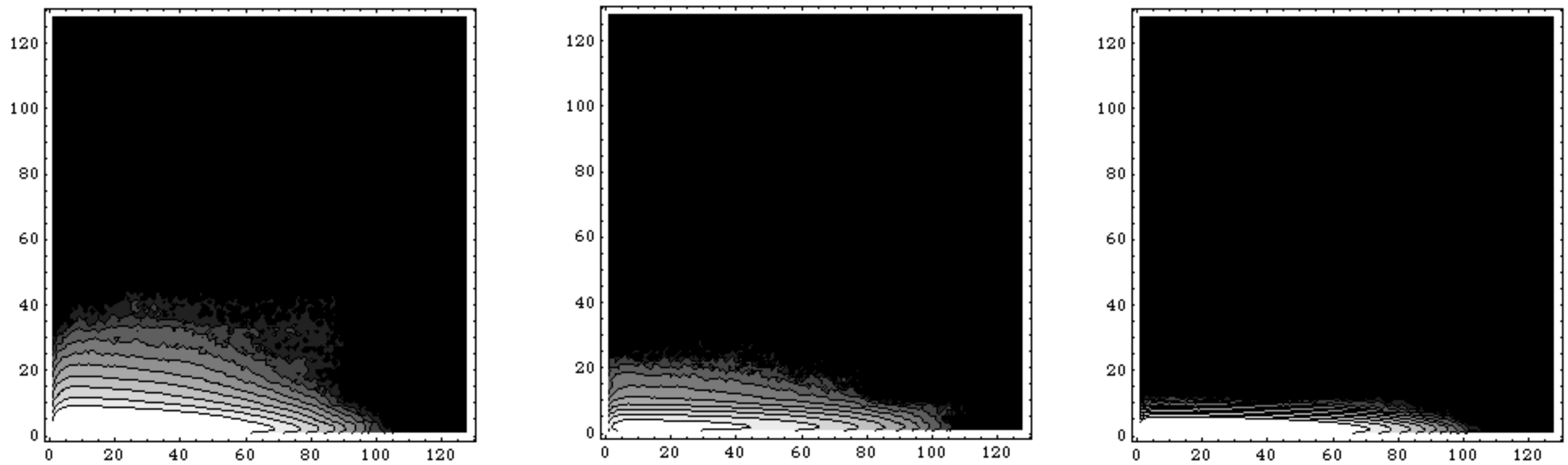


iSize works for vertical halo

Experiments showed iSize did not work for life time improvement.

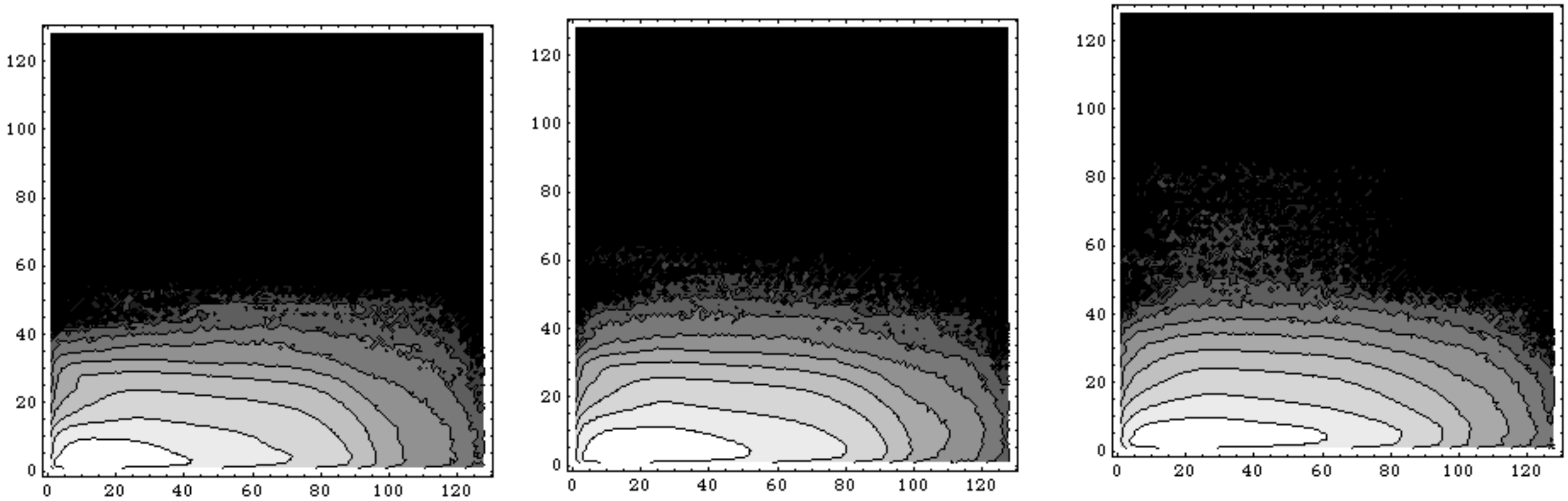
The vertical halo does not matter.

ε_y 0.6×10^{-10} 1.8×10^{-10} 5.4×10^{-10}



H-axis 0-12.8σ_x (0.1σ_x/unit) V-axis 0-64σ_y (0.5σ_y/unit)

Crossing collision with 11 mrad



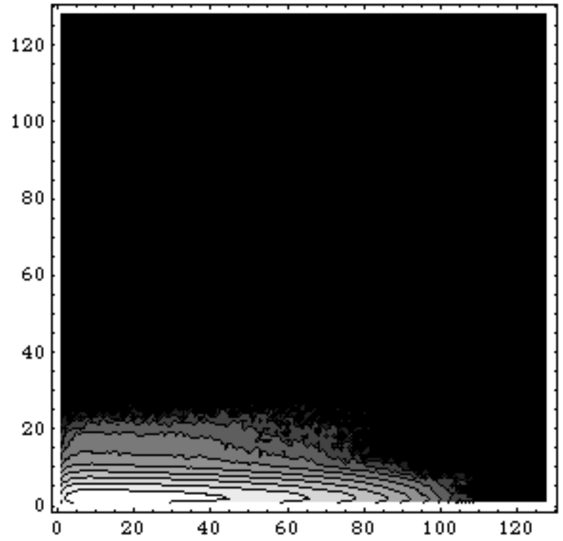
Hoffset 0 μm 50 μm 100 μm

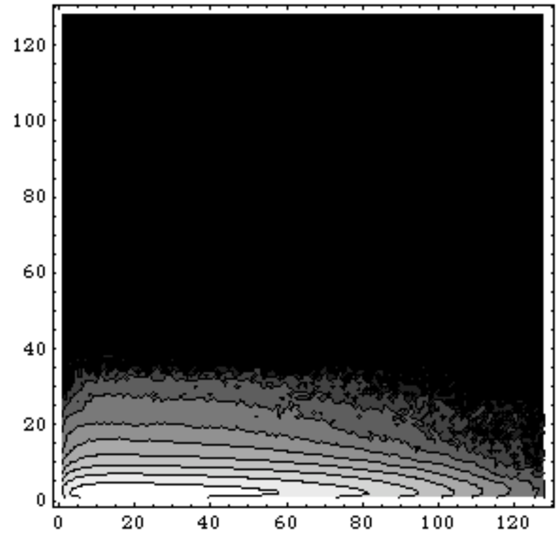
No asymmetry appeared for H offset

H-axis 0-12.8σ_x (0.1σ_x/unit) V-axis 0-64σ_y (0.5σ_y/unit)

Effect of noise

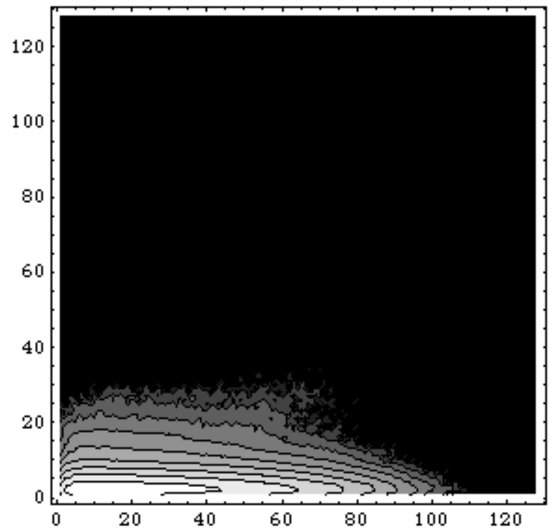
- Fast horizontal turn by turn noise, 2 μm and 10 μm

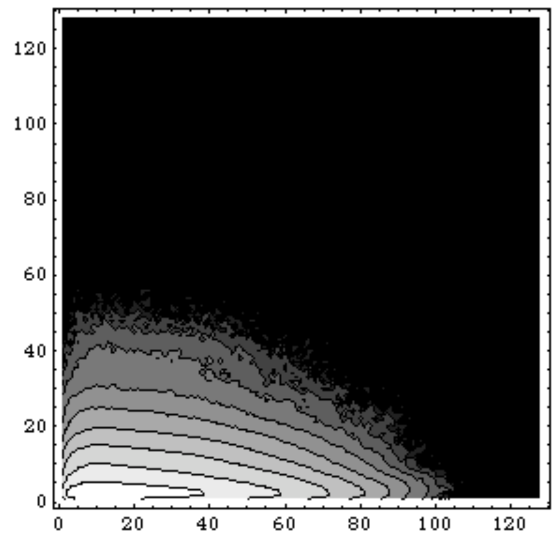




- Slow horizontal noise ~30 Hz 20 μm and 100 μm

- No strong effect



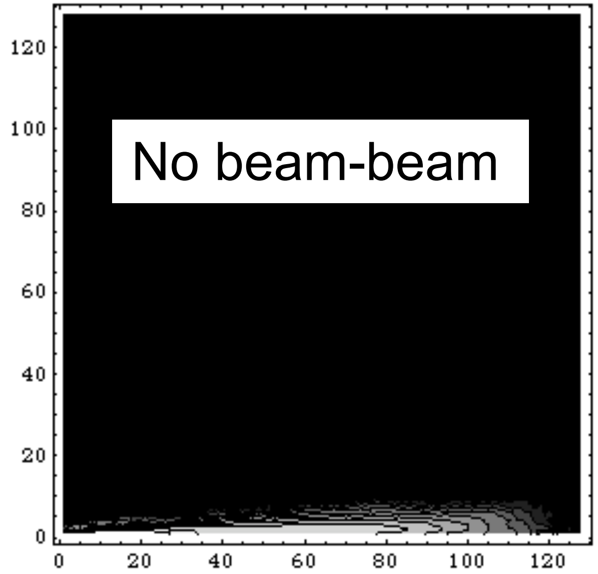


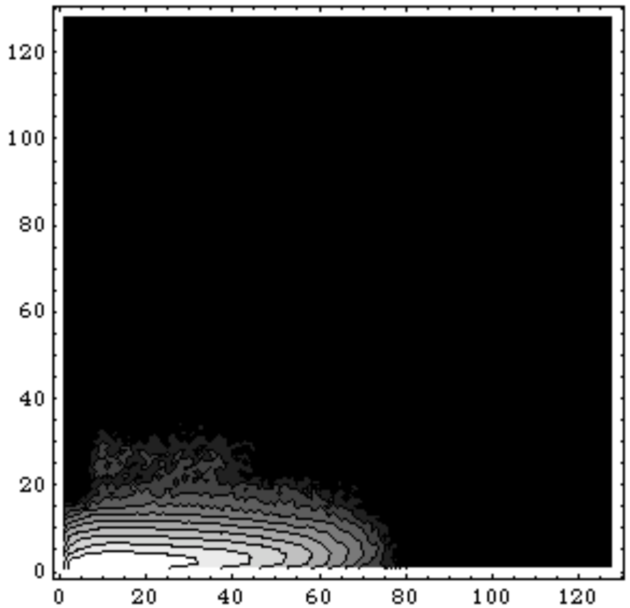
SAD tracking

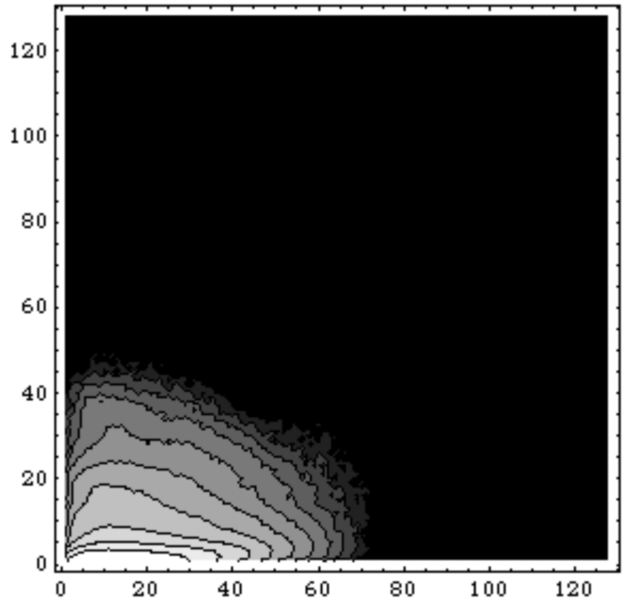
- Simple model did not explain experiments, short life time, its asymmetry for H offset, iSize did not help us.
- Lattice nonlinearity may affect KEKB performance more than our guess.
- Beam-beam code based on weak-strong model installed in SAD (1994) is revived.

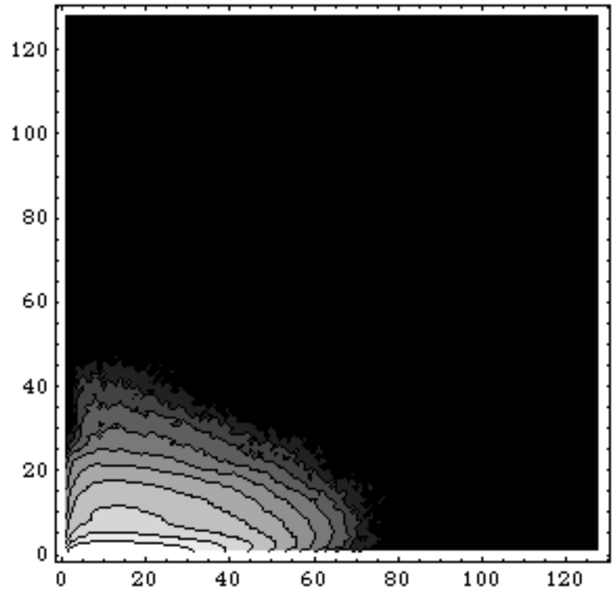
HER

H-axis 0-12.8σ_x ($0.1\sigma_x$/unit)
V-axis 0-64σ_y ($0.5\sigma_y$/unit)







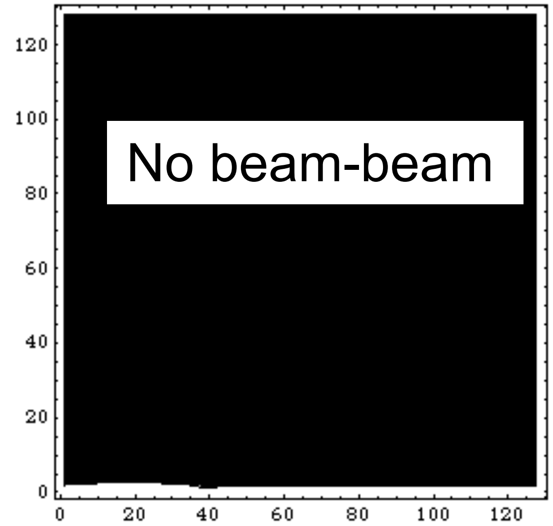


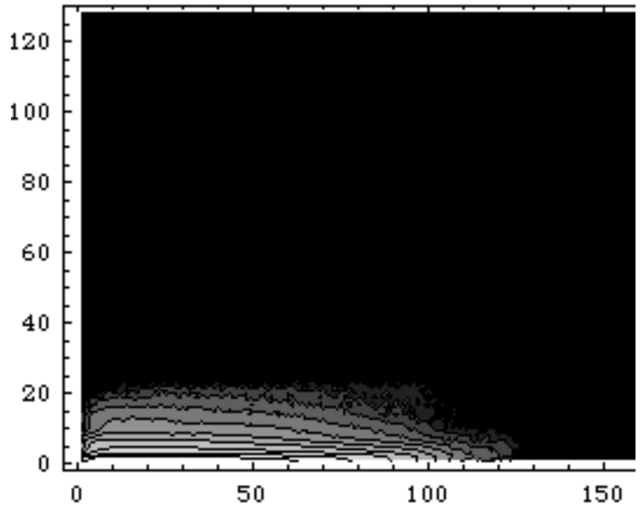
0 μm   +100 μm   -100 μm

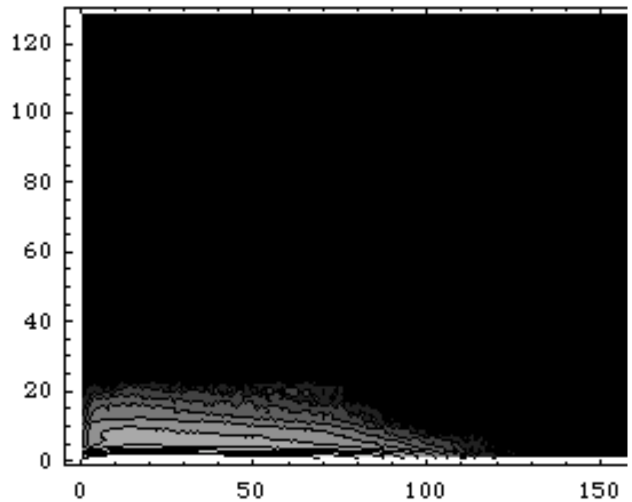
No remarkable asymmetry. No beam-beam case was worst.

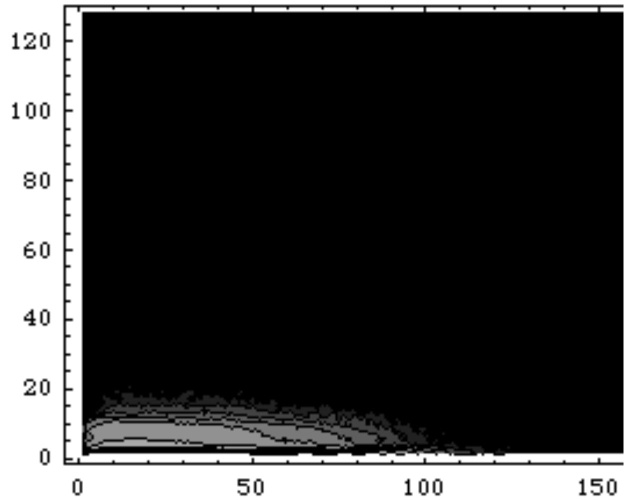
LER

H-axis $0.1\sigma_x$/unit
V-axis $0.5\sigma_y$/unit





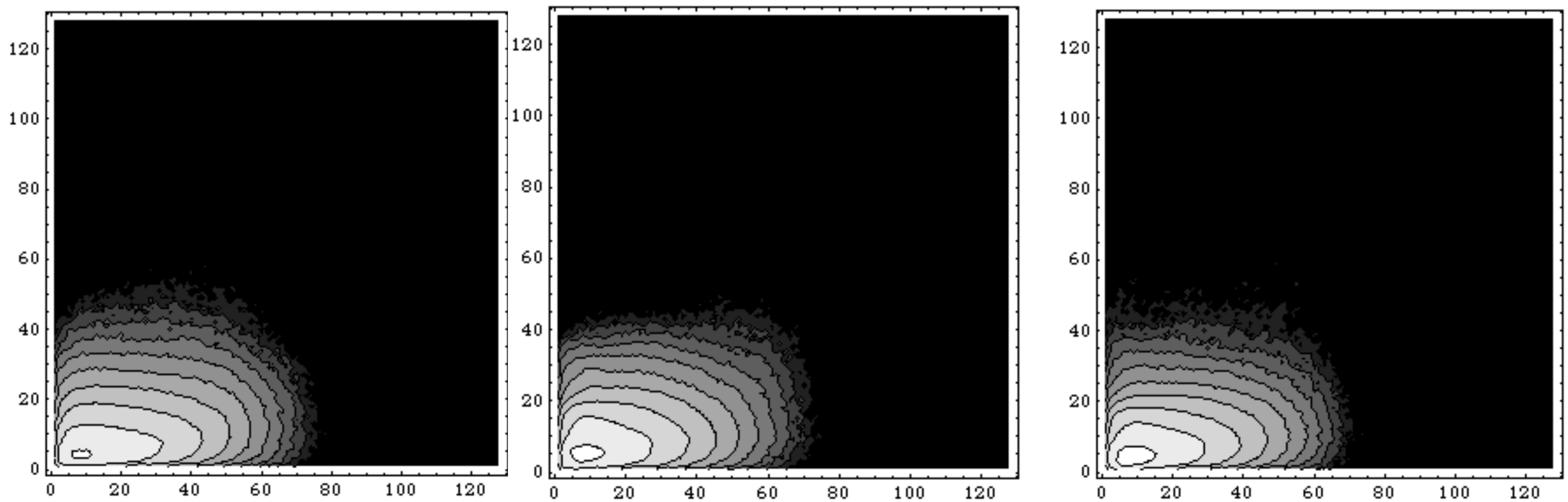




0 μm　　　+100 μm　　　-100 μm

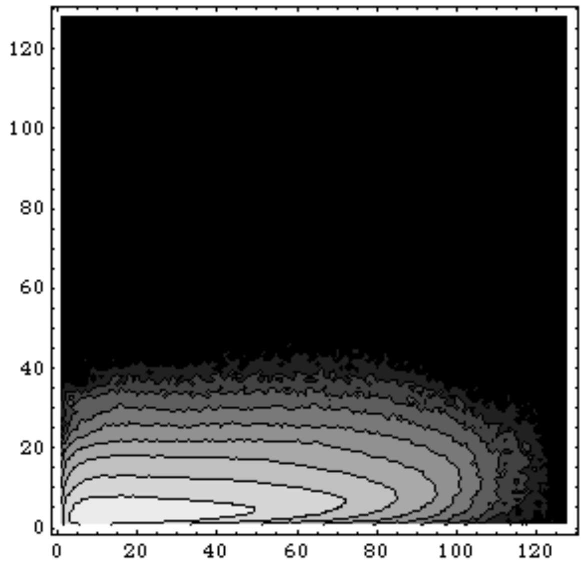
- Asymmetry is seen in vertical tail.
- No beam-beam is no problem

HER with errors correspond to 1% ε_y

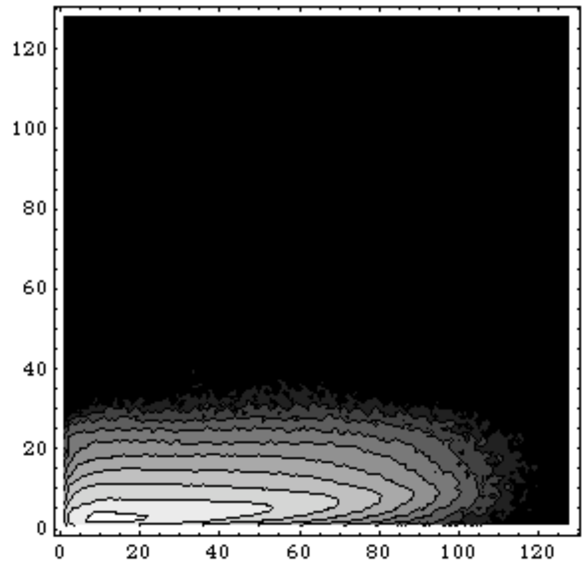


0 μm +100 μm -100 μm

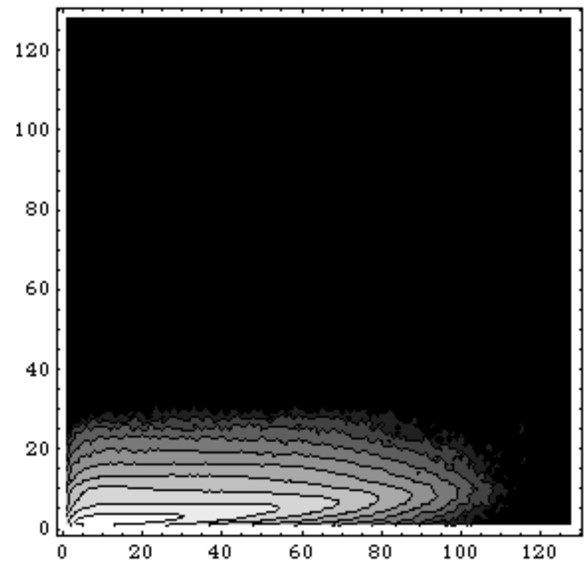
LER with errors correspond to 1% ε_y



0 μm



+100 μm



-100 μm

Summary of halo simulation

- Simulation for halo formation is performed with a weak-strong simulation based on Gaussian model.
- The halo did not seem to affect the beam Life time.
- Life time symmetry was not seen.
- Non Gaussian model will be tried, if this type of halo could limit the luminosity in KEKB.

Emittance growth due to wake force with offset orbit and crabbing

- Beam with crab angle along the ring experiences z dependent kick due to wake field, with the result that it can be distorted to banana shape.
- When the center of the transverse wake deviate, similar dipole kick is induced, with the result that the beam can be distorted to banana shape.
- The vertical distortion is serious because of the small size.

Tilt due to the transverse wake force (Ikeda)

- Measured by Ieiri.

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

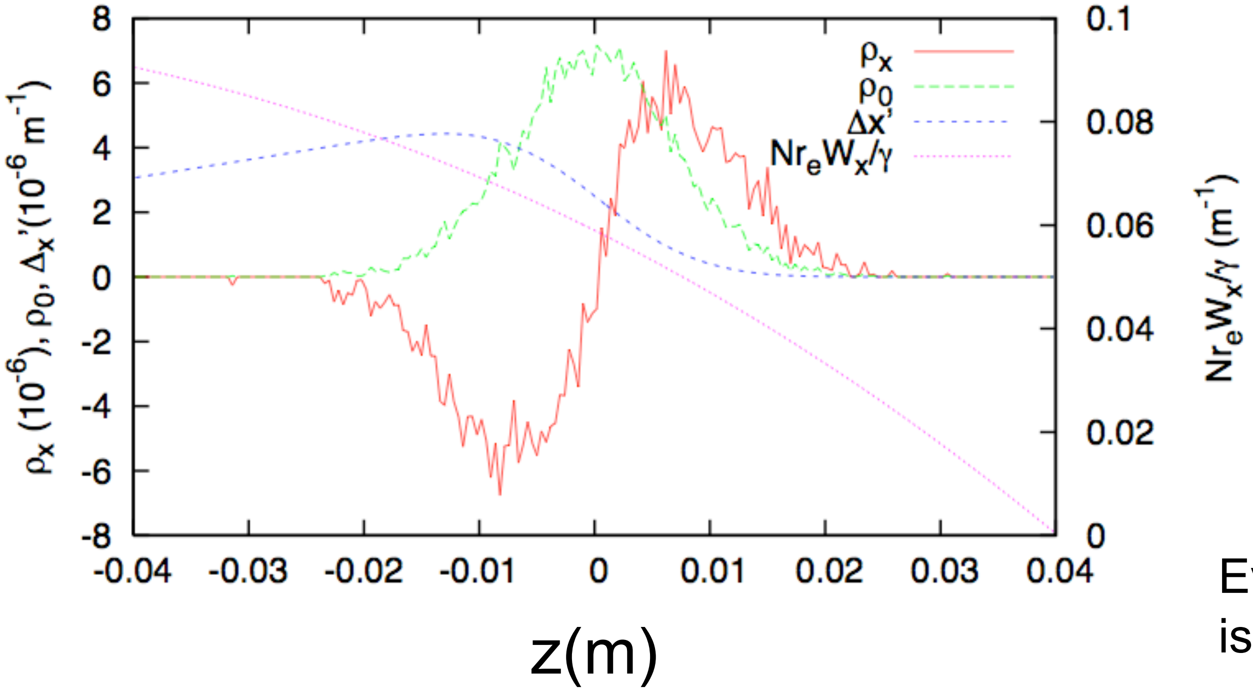
$$W_0 = \left(\frac{d\nu_x}{dI}\right)_{I=0} \frac{8e\gamma\omega_0}{r_e\beta}$$

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

$$= 1.7\times 10^6 \mathrm{m}^{-2}$$

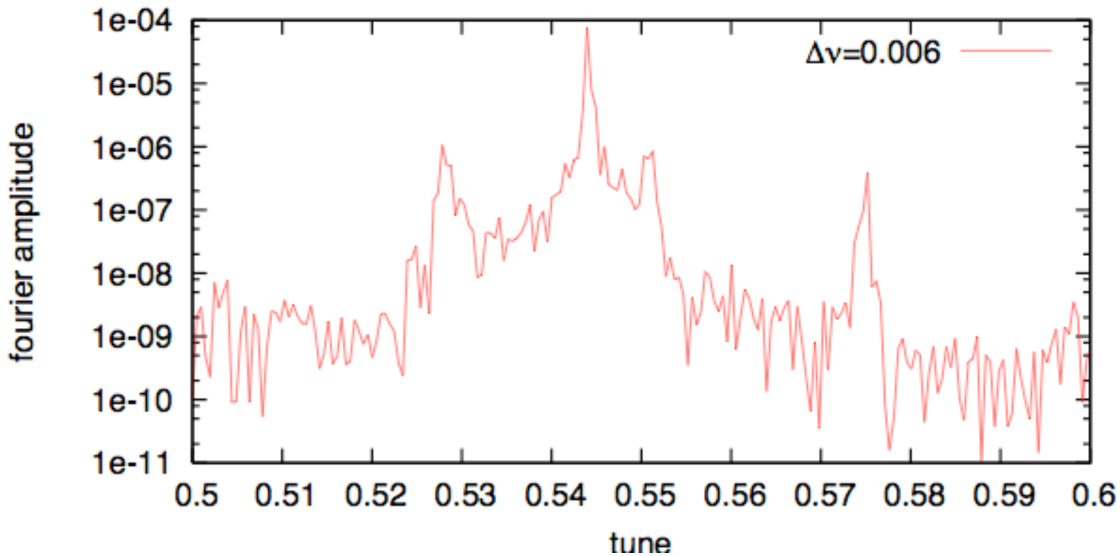
$$\Delta x_2' = \frac{N r_e W_0}{\gamma}\sigma_x = 7.5\times 10^{-6}$$

$$\Delta x_{crab}' = \frac{eV'}{E}\sigma_z = \frac{eV_0}{E}\frac{\omega_{rf}\sigma_z}{c} = 1.25\times 10^{-4}$$



*wake z=0~-0.08

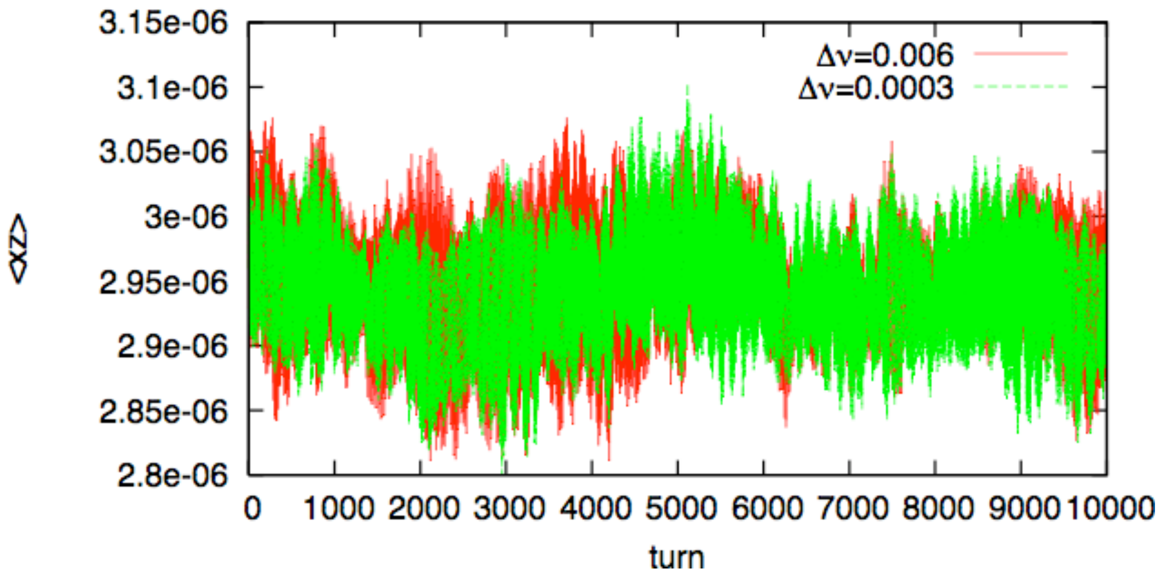
Even Δν=0.006, the kick is 1/30 of crab kick



ν_x=0.55

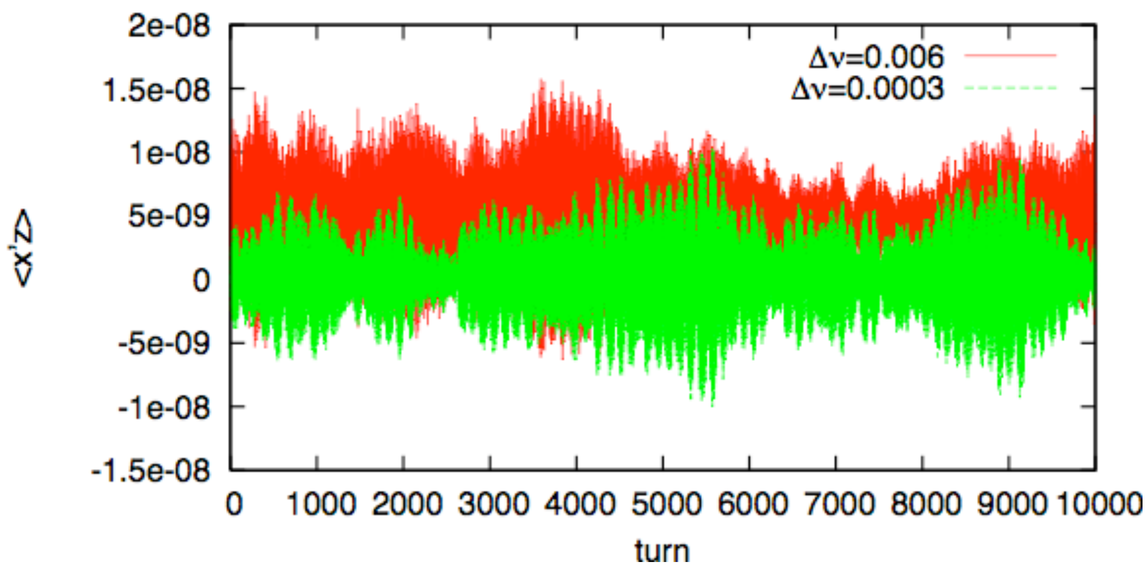
Spectrum by simulation with this condition

$$\Delta x'_{crab} = \frac{eV'}{E}\sigma_z = \frac{eV_0}{E}\frac{\omega_{rf}\sigma_z}{c} = 1.25\times 10^{-4}$$



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.

Asymmetric wake

- Assume beam off set shifts 1mm.

$$\Delta p_y = \frac{Nr_e}{\gamma}\int_z^{\infty} W_{1y}(z-z')\rho_1(z')dz'$$

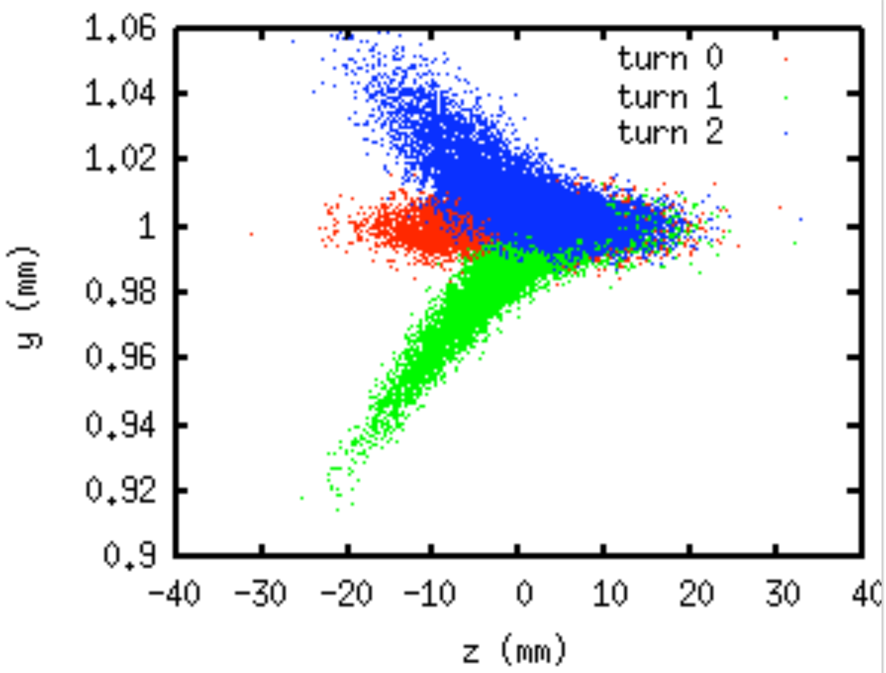
$$\rho_1(z') = \delta y \rho_0(z')$$

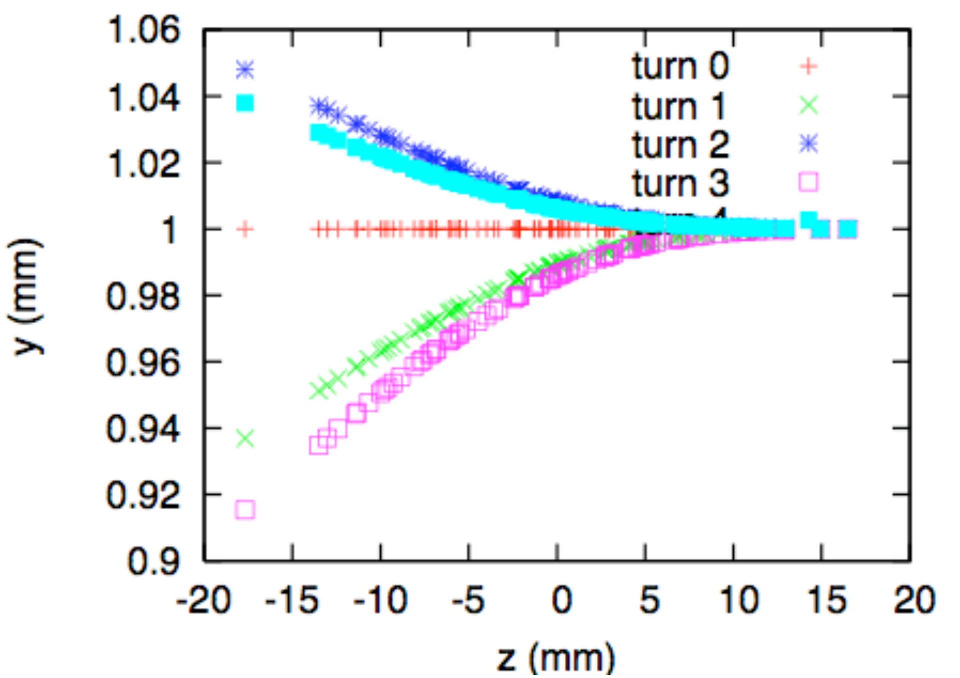
$$\rho_0(z) = \frac{1}{\sqrt{2\pi}\sigma_z}\exp\left(-\frac{z^2}{2\sigma_z^2}\right)$$

$$\Delta p_y \approx \frac{Nr_e}{\gamma}\frac{W_1\delta y}{\sigma_z}\mathrm{Erfc}\left(\frac{\mathrm{z}}{\sqrt{2\pi}\sigma_z}\right)$$

Check the code

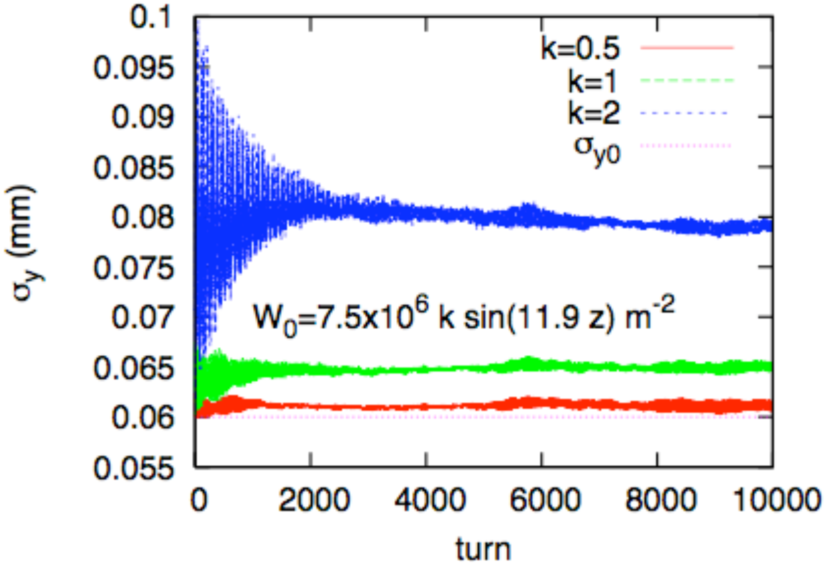
- Motion of first 2 turns was consistent with analytic estimate.
- Obtain an equilibrium distribution for radiation damping and excitation.

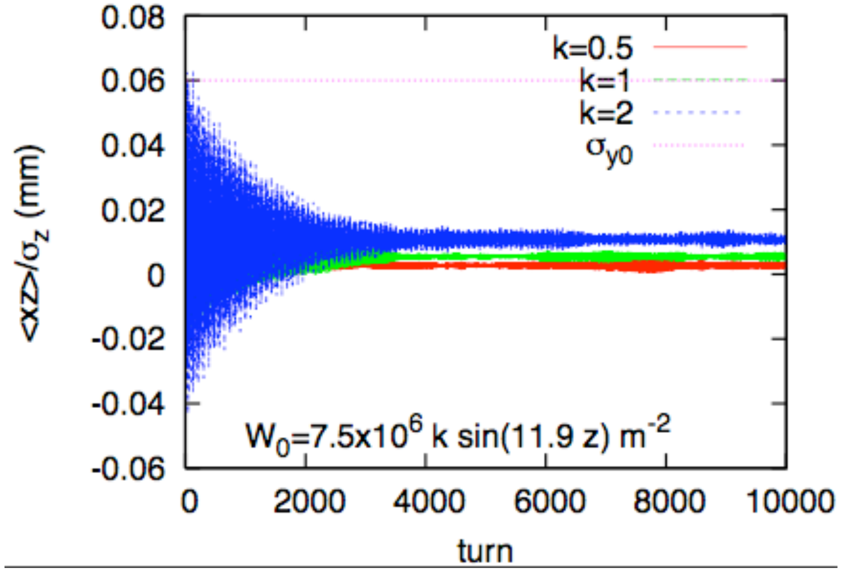




Beam size and y-z tilt

- They oscillate initial stage, but arrive at an equilibrium
- Emittance is large compare than tilt.

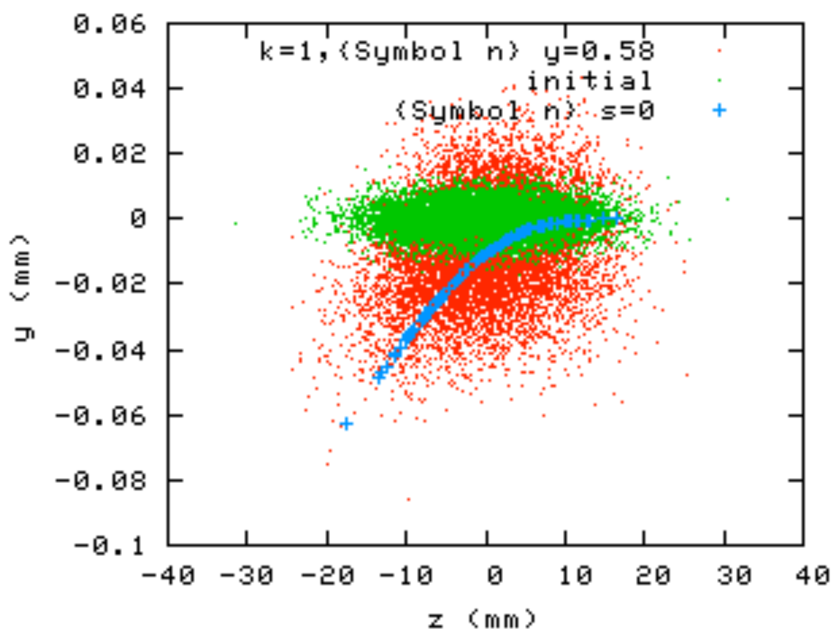


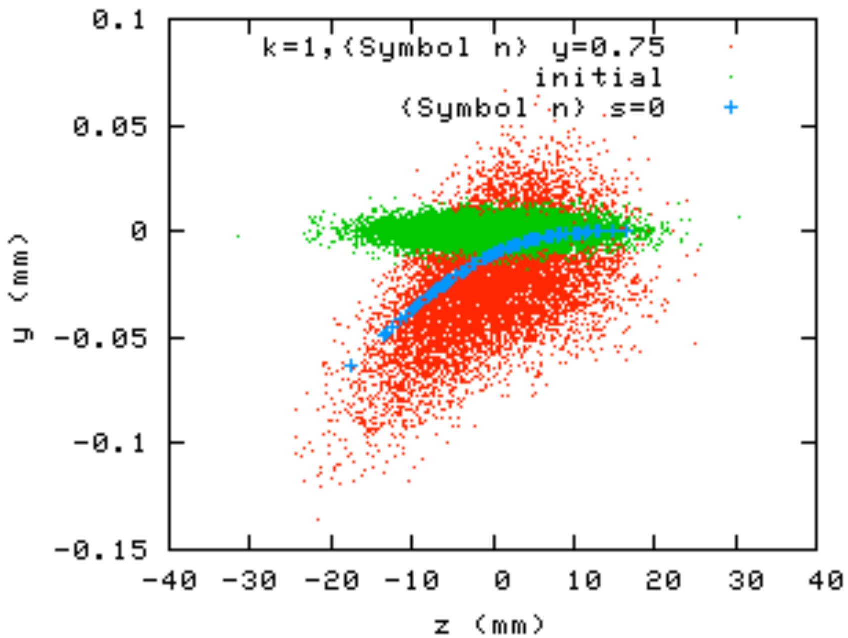


* $W=W_0k$

** Threshold of strong head-tail instability, k=3

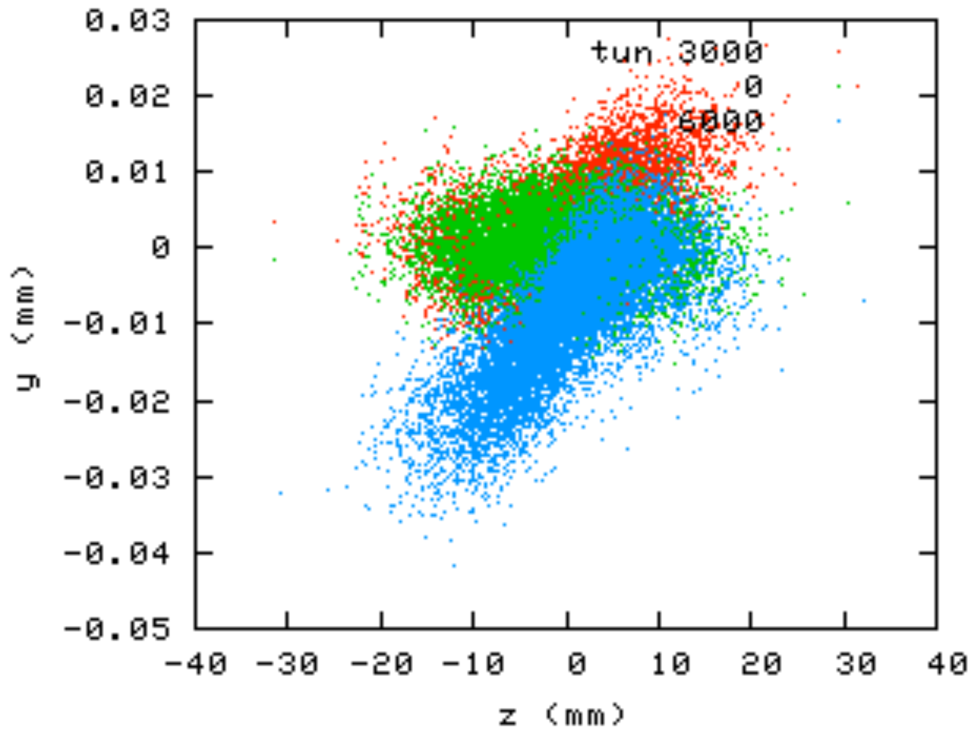
- Emittance (phase space volume) increases.
- Equilibrium shape depends on ν_y.





Radiation damping/excitation off

- Beam oscillates with banana shape, but its size does not increase.



Summary of wake effect for crabbing beam

- Asymmetry of 1mm is perhaps pessimistic.
- It does not seem to be big issue in present KEKB, though it depends on the asymmetry amplitude.
- The effect is more serious for Low emittance ring.
- What is the mechanism of the emittance growth? A kind of anomalous emittance growth.

Correlation of life time and beam size (emittance)

- We made effort to realize a small beam size to get high luminosity. The small beam size seems to give a short life time in many cases.
- We can not achieve high luminosity due to the short life time.
- The life time is related to asymmetry in the horizontal offset.

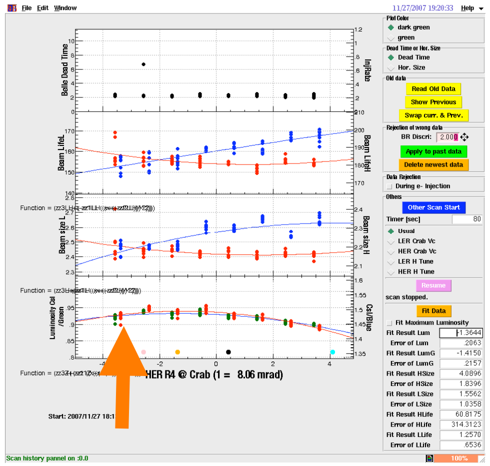
- Large angle scattering can be a reason for the beam-beam limit.
- Ohnishi had showed dynamic aperture shrink due to the beam-beam force.

iSize scan ~ V emittance scan

HER/LER V size vs. life

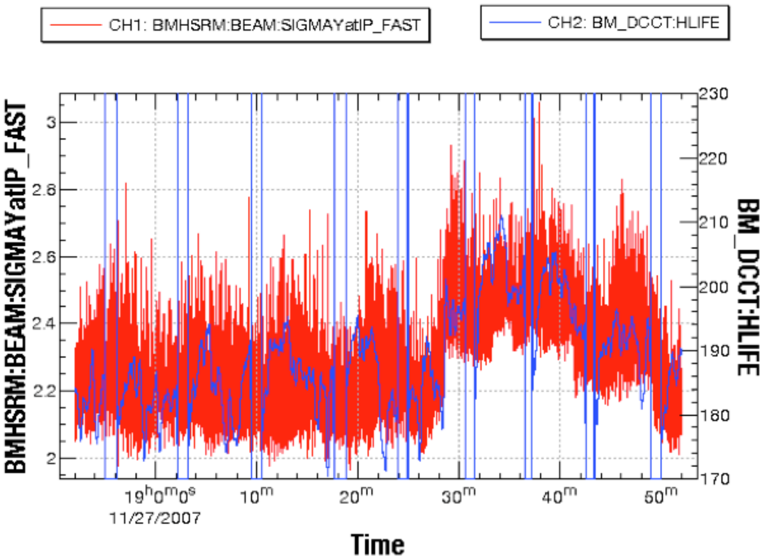
HER iSize bump 0.4 -> 0 mm

Short life time at small size for iSize scan. LER, which respond HER, also have the same feature.

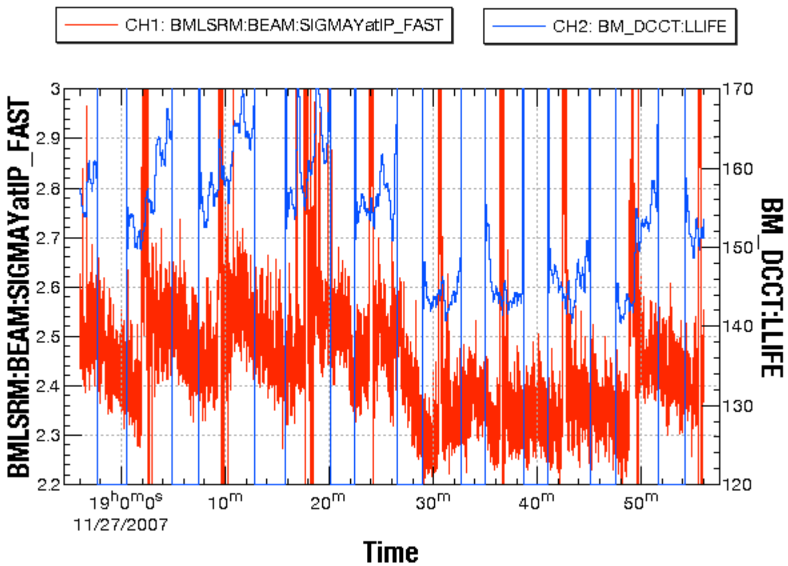


Short life time at small size for R4crab scan.

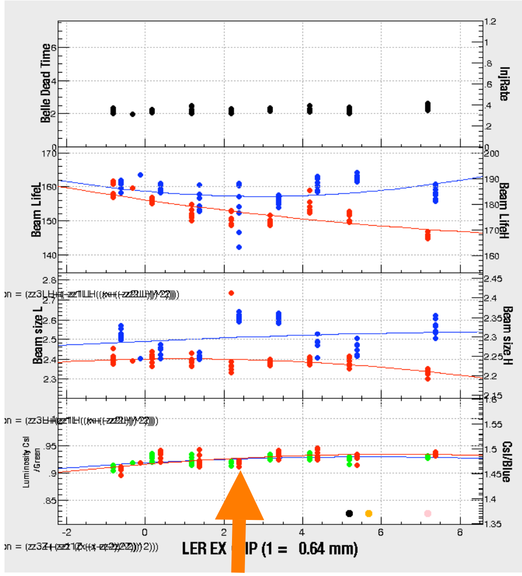
HER



LER

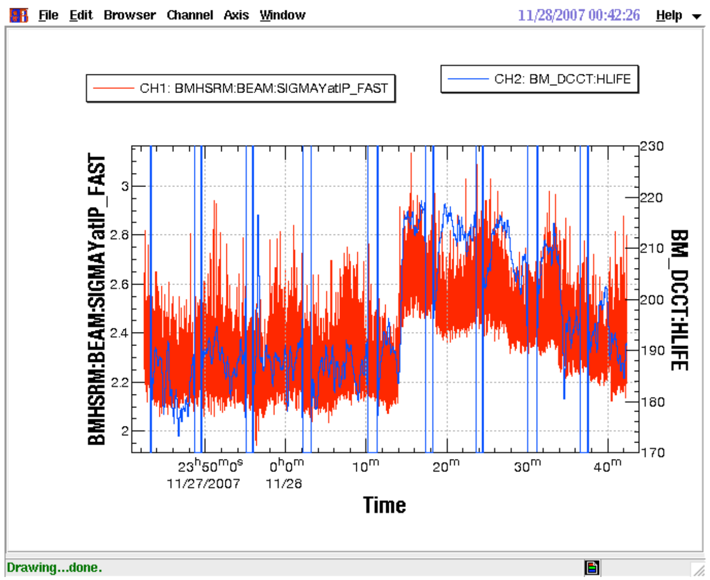


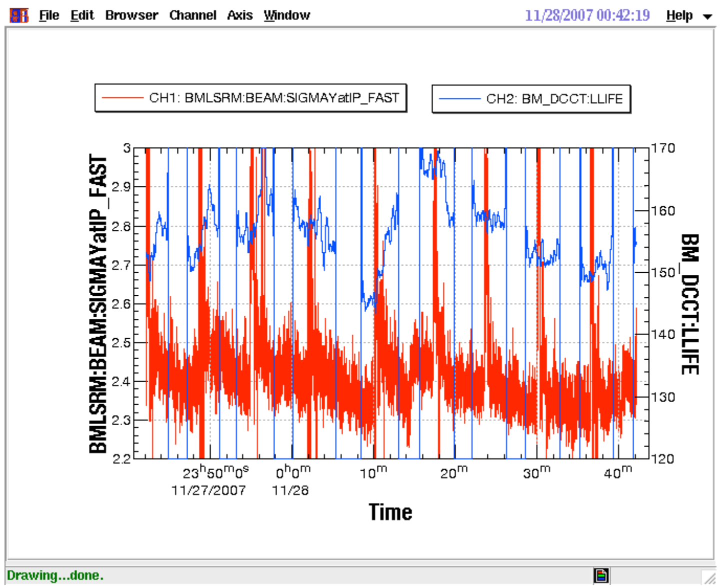
HER/LER V size vs. life - II
HER iSize bump 0.4 -> 0 mm



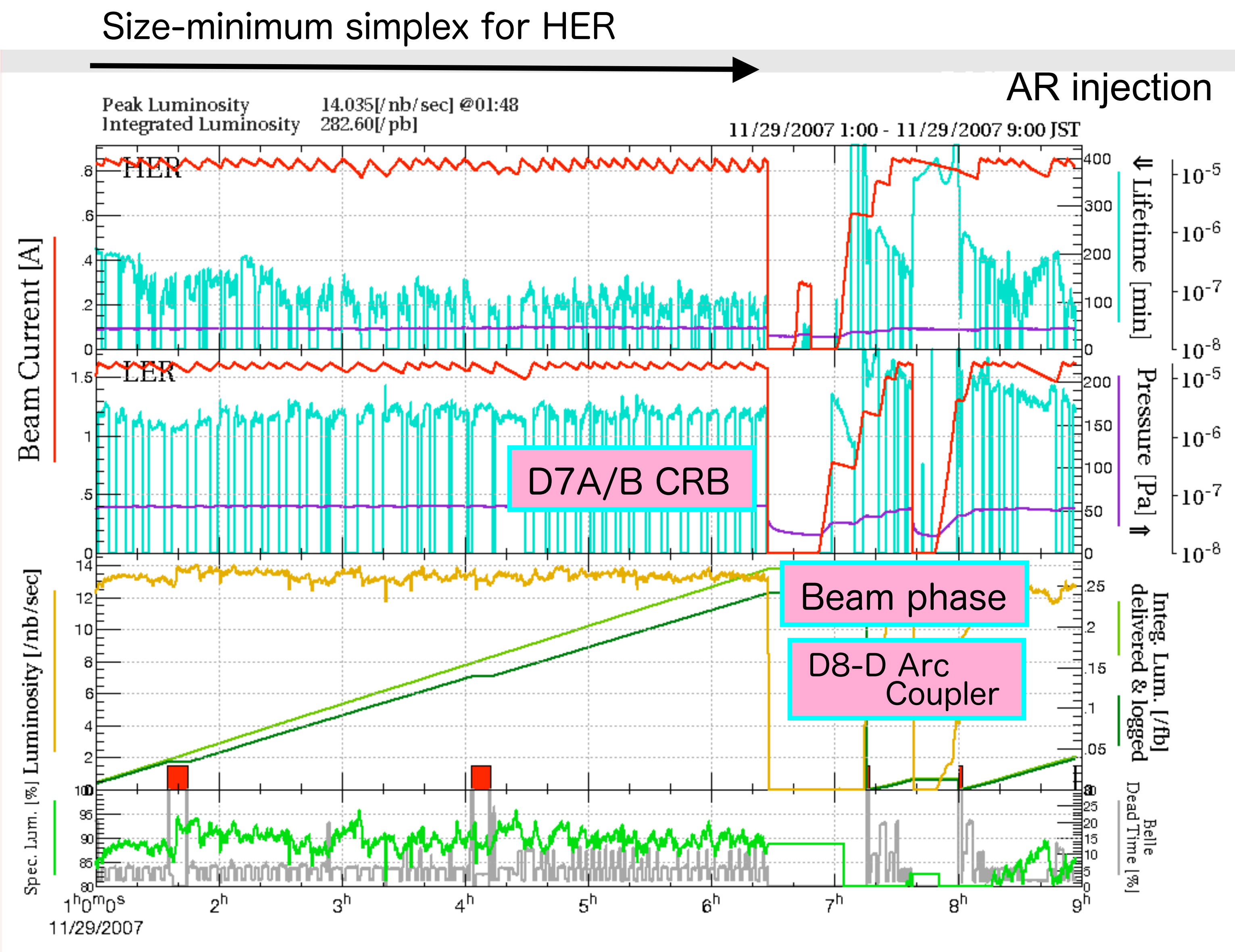
Short life time at small size for iSize scan.

Short life time at large beam size LER η_x



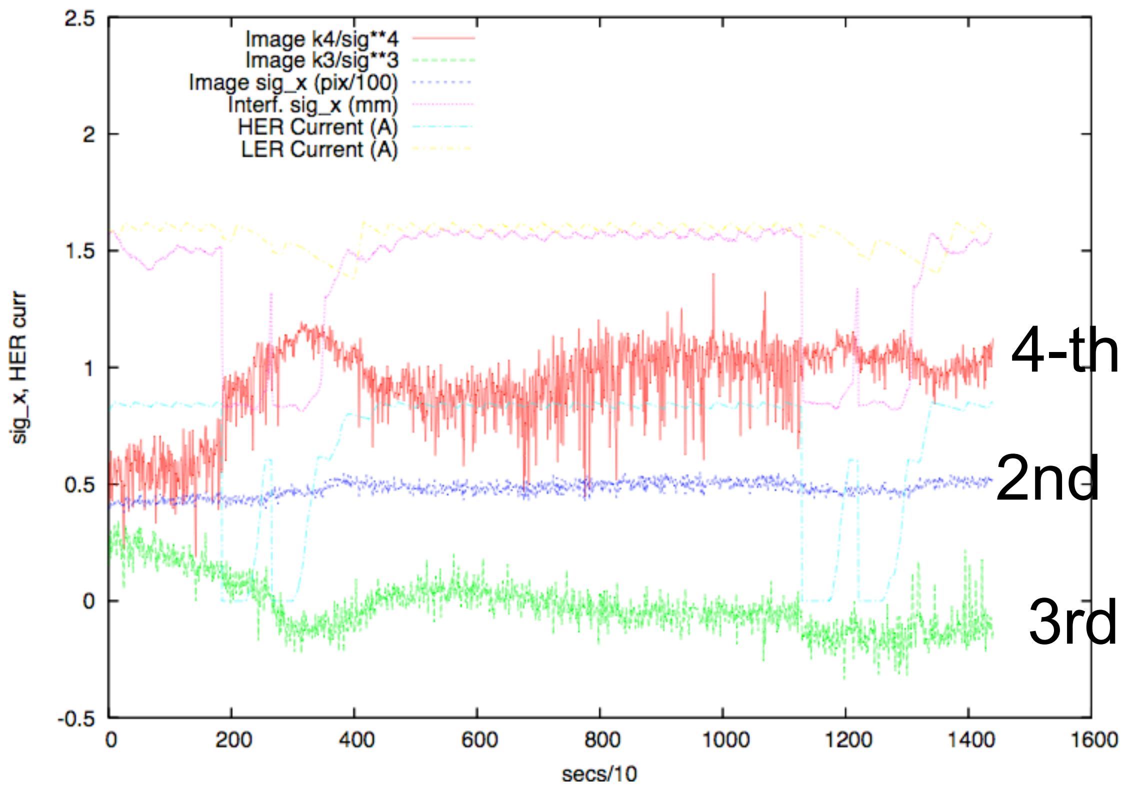


Shift Summary 29Nov day shift



Measurement higher order moment of Horizontal beam distribution

J. Flanagan



Pure emittance iSize bump

N. Iida & H. Koiso

- Present iSize bump gives dispersion whole of ring, even IP.
- Pure emittance bump without dispersion at IP will be tried to study the correlation of the beam life and emittance.

Intrabeam scattering

- Cross-section of e-e scattering

$$\frac{d\sigma}{d\Omega} = \frac{4r_e^2}{\gamma^2 p_\perp^4}\left[\frac{4}{\left(1-\sin^2\theta\cos^2\varphi\right)^2} - \frac{3}{1-\sin^2\theta\cos^2\varphi}\right]$$

- Touschek life

$$\frac{1}{\boldsymbol{\tau}} = 2N\int d\Omega \int d\mathbf{x}_1 \int d\mathbf{x}_2 A(\mathbf{x}_1,\mathbf{x}_2,\theta,\varphi)\frac{d\sigma}{d\Omega}v_\perp \psi(\mathbf{x}_1)\psi(\mathbf{x}_2)$$

$$\int d\mathbf{x}\psi(\mathbf{x}) = 1$$

- A=1 or 0 for outside/inside of aperture.

Longitudinal kick due to a large angle scattering

- Longitudinal component of the kick is enhanced by the relativistic factor, γ.
- Betatron oscillation is induced by the longitudinal kick via dispersion.
- Transverse component of the kick is neglected.
- The cross-section is integrated for φ .
- Aperture is function of p_t and φ.

$$\frac{d\sigma}{d\theta} = \frac{8\pi r_e^2}{\gamma^2 p_\perp^4}\left[\frac{2}{\cos^3\theta} - \frac{1}{\cos\theta}\right]\sin\theta$$

$$A(\mathbf{x}_1, \mathbf{x}_2, \theta, \varphi) = A(p_\perp, \theta)$$

Touschek life, integration

- Trivial integrations are performed. ($x_1=x_2,y_1=y_2,z_1=z_2$)

$$\frac{1}{\tau}=2N\int d\theta\int d\mathbf{p}_1\int d\mathbf{p}_2 A(p_\perp,\theta,\varphi)\frac{d\sigma}{d\theta}v_\perp\rho_P(\mathbf{p}_1)\rho_P(\mathbf{p}_2)$$

$$=2N\int d\mathbf{r}\rho(\mathbf{r})^2\boxed{\int d\theta\int d\mathbf{p}A(p_\perp,\theta)\frac{d\sigma(p_\perp,\theta)}{d\theta}cp_\perp\rho_P(\mathbf{p})}$$

- This integral is performed for particles out of aperture. Generally θ is integrated from 0 to $\delta_{bucket}/\gamma p_t$; A=1 for $\theta < \delta_{bucket}/\gamma p_t$, otherwise A=0.
- We integrate it for all phase space variable with considering aperture for all directions.

Numerical integration

- Outside of the aperture area, $A(p_t,\theta)$, is found by SAD.

$$\frac{1}{\tau} = \frac{32N\pi c r_e^2}{\gamma^2}\int d\mathbf{r}\rho(\mathbf{r})^2\int d\mathbf{p}\int_0^1 d\cos\theta A(p_\perp,\theta)\frac{1}{p_\perp^3}\left[\frac{2}{\cos^3\theta}-\frac{1}{\cos\theta}\right]\rho_P(\mathbf{p})$$

$$= \frac{32N\pi c r_e^2}{\gamma^3}\int d\mathbf{r}\rho(\mathbf{r})^2\int d\mathbf{p}\int_0^{\gamma p_\perp} d\Delta\delta A(p_\perp,\Delta\delta)\frac{1}{p_\perp^4}\left[\frac{2\gamma^3 p_\perp^3}{\Delta\delta^3}-\frac{\gamma p_\perp}{\Delta\delta}\right]\rho_P(\mathbf{p})$$

- Monte Carlo integration with realistic events.

$$\Delta\delta = \gamma p_\perp \cos\theta$$

$$\Delta x = \eta_x \Delta\delta$$

$$\Delta p_x = \eta'_x \Delta\delta$$

$$\int d\mathbf{r}\rho(\mathbf{r})^2 \approx \frac{1}{V}$$

V: Volume of the beam. The exact value is possible to calculate numerically.

Monte Carlo integration

- Distribution of **p** is realistic one (ρ_p).

$$\rho_p(\mathbf{p}) = \sum_{i=1}^{n} \delta(\mathbf{p} - \mathbf{p}_i)$$

- Uniform distribution for $\Delta\delta<\delta_{bucket}$. The integral $\Delta\delta>\delta_{bucket}$ is given.

$$f(\delta) = \sum_{i=1}^{n} \delta(\Delta\delta - \Delta\delta_i)$$

$$\frac{1}{\tau} = \frac{32N\pi c r_e^2}{\gamma^3 V} \frac{\Delta\delta_{bucket}}{n} \sum_{i=1}^{n} A(p_{\perp,i}, \Delta\delta_i) \frac{1}{p_{\perp,i}^4} \left[\frac{2\gamma^3 p_{\perp,i}^3}{\Delta\delta_i^3} - \frac{\gamma p_{\perp,i}}{\Delta\delta_i} \right]$$

$$p_\perp > \frac{\Delta\delta}{\gamma}$$

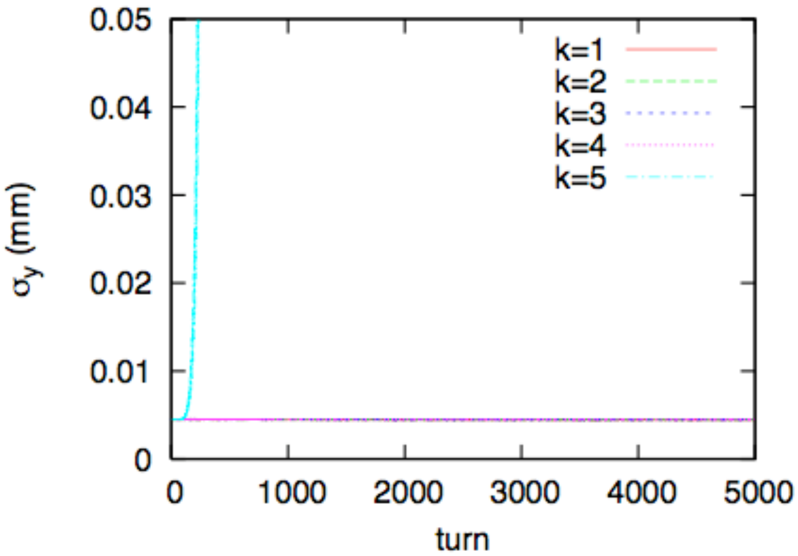
Life time estimation

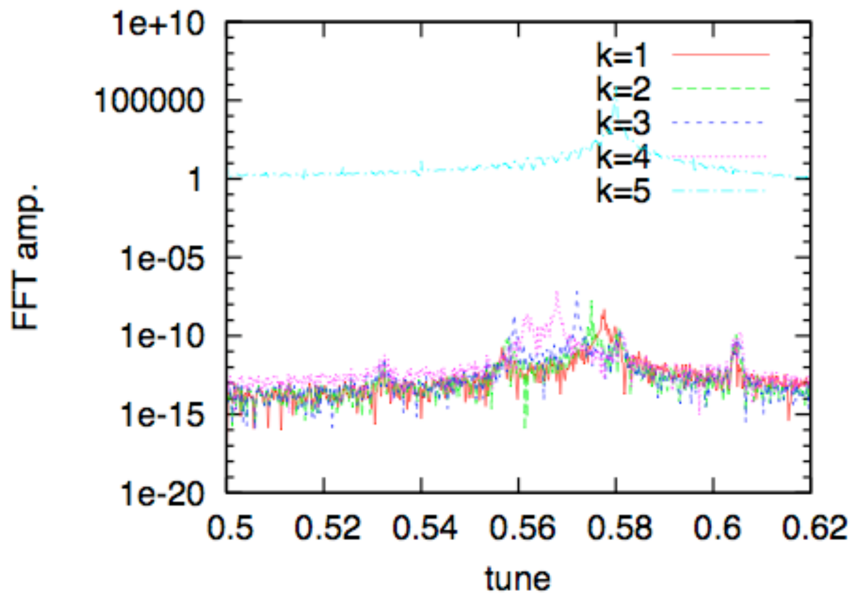
- The life time estimation is under progress.
- A preliminary result did not show asymmetry of the life time. Consistent with Ohnishi’s result.

How do we solve?

Low emittance parameter

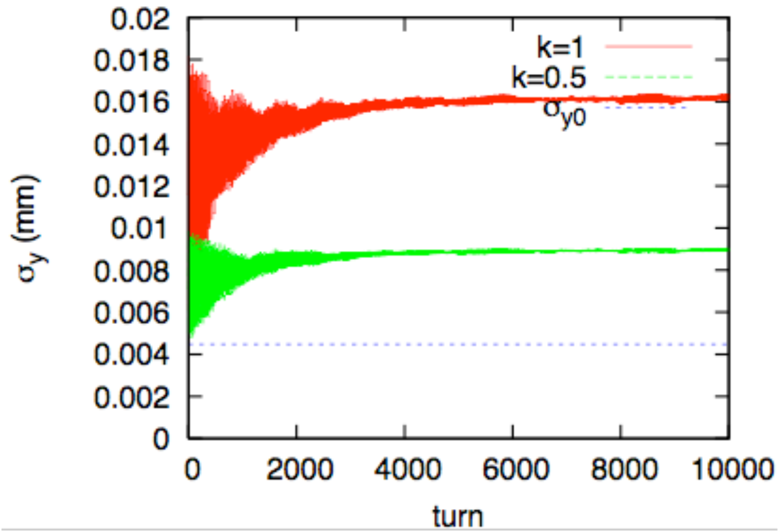
- This effect does not depend on design emittance.
- SuperBは低電流なのでthreholdはk=5

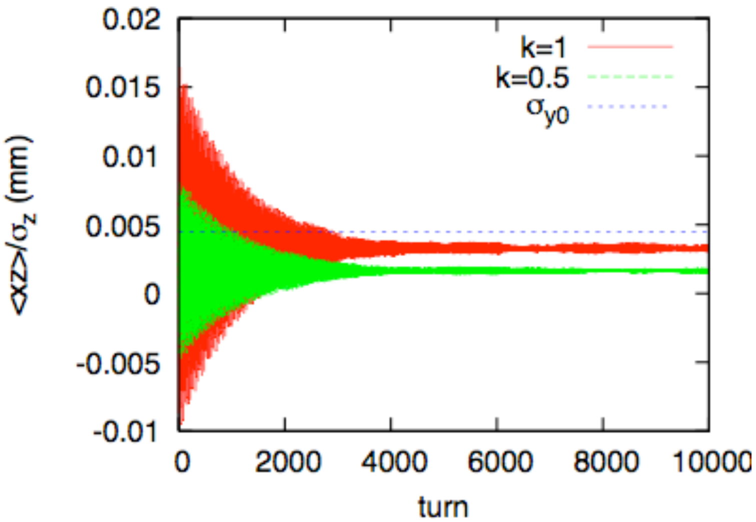




Beam size and tilt

- A large emittance growth





Tune dependence