Collision Scheme in Upgrade and Super KEKB

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MAC2009 at KEKB

9-11 February, 2009

Introduction

- Limitation of the bunch length,
  Travel focus scheme
- present KEKB status
- Super Bunch scheme

Tentative Design Parameters

K. OIDE

		zero bunch current	design bunch current	
LER	sigz	5	6	mm
	sige	7.1	8.0	10^{-4}
LER neg. alpha	sigz	4.5	5.3	mm
	sige	7.1	8.5	10^{-4}
HER	sigz	3	3.6	mm
	sige	6.8	7.0	10^{-4}
HER neg. alpha	sigz	3	3.1	mm
	sige	6.8	7.7	10^{-4}

Luminosity optimization under the bunch length limit

- Using travel focus only in LER
- Different β, ε for two beams.
- Longer damping time of LER, 6000-8000(LER) and 4000 turns (HER).
- β_x=0.2m or 0.4m.

Waist control-I traveling focus

$$M_{TF} = e^{H_I} M_{headon} e^{-H_I}$$

$$H_I = \frac{a}{2} p_y^2 z$$

$$\bar{y} = y + \frac{\partial H_I}{\partial p_y} = y + a z p_y \qquad \bar{\delta} = \delta - \frac{\partial H_I}{\partial z} = \delta - \frac{a}{2} p_y^2$$

- Linear part for y. z is constant during collision.

$$\begin{pmatrix} \bar{\beta} & -\bar{\alpha} \\ -\bar{\alpha} & \bar{\gamma} \end{pmatrix} = T \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} T^t = \begin{pmatrix} \beta + \frac{a^2 z^2}{\beta} & \frac{az}{\beta} \\ \frac{az}{\beta} & \frac{1}{\beta} \end{pmatrix}$$

α=0

$$T = \begin{pmatrix} 1 & az \\ 0 & 1 \end{pmatrix}$$

- Minimum β is shifted at s=-az

How to configure the crab cavity and sextupoles

crab cavity

- Head on collision

$$M_{headon} = e^{\theta p_x z} M_{crs} e^{-\theta p_x z}$$

- Head on + travel focus

$$M_{TF} = e^{-\frac{1}{2} p_y^2 z} e^{\theta p_x z} M_{crs} e^{-\theta p_x z} e^{\frac{1}{2} p_y^2 z}$$

crab cavity

sextupole

- Actual Configuration

$$M_{TF} = e^{\frac{1}{2\theta} p_y^2 x} e^{\theta p_x z} e^{-\frac{1}{2\theta} p_y^2 x} M_{crs} e^{\frac{1}{2\theta} p_y^2 x} e^{-\theta p_x z} e^{-\frac{1}{2\theta} p_y^2 x}$$

$$= e^{\frac{1}{2\theta} p_y^2 x} e^{-\frac{1}{2\theta} p_y^2 (x+\theta z)} e^{\theta p_x z} M_{crs} e^{-\theta p_x z} e^{\frac{1}{2\theta} p_y^2 (x+\theta z)} e^{-\frac{1}{2\theta} p_y^2 x}$$

$$= e^{-\frac{1}{2} p_y^2 z} e^{p_x z} M_{crs} e^{-p_x z} e^{\frac{1}{2} p_y^2 z}$$

See H. Koiso's slide

Crabbing beam in sextupole

- Crabbing beam in sextupole can give the nonlinear component at IP
- Traveling waist is realized at IP.

$$H_I = \frac{a}{2} p_y^2 z$$

- At the sextupole position

$$z^* = \sqrt{\frac{\beta_x(s)}{\beta_x^*}} \theta x(s)$$

$$K_2 = \frac{1}{2} \frac{B'' L}{p/e} \approx \frac{1}{\theta} \frac{1}{\beta_y^* \beta_y} \sqrt{\frac{\beta_x^*}{\beta_x}}$$

K_2~30-50

- The same strength as the crab waist sextupole

Travel waist in the weak-strong model

- Reduction of z degree of freedom

$$\boldsymbol{x}(+0) = S\exp\left[- : \int_{-\Delta}^{\Delta} V_0^{-1}(s_i) H_{bb} V_0(s_i) ds_i : \right] \boldsymbol{x}(-0), \qquad s_i(z) = \frac{z - z_i}{2}$$

$$\begin{aligned} V_0(s) &\equiv V_0(s,0) = S\exp\left[- : \int_0^s H_0 ds : \right] \\ &= \prod_{i=\pm} \exp\left[- : \frac{p_{x,i}^2 + p_{y,i}^2}{2} s : \right], \end{aligned}$$

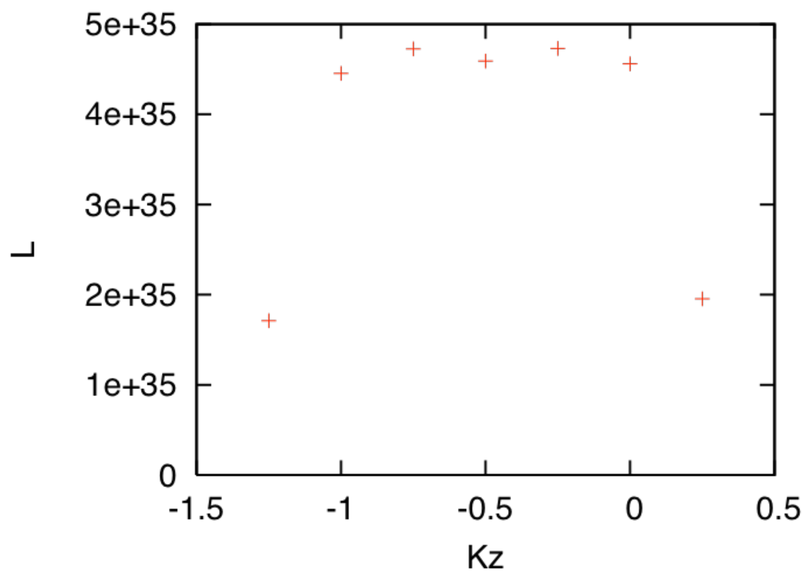
- Travel focus

$$\begin{aligned} \boldsymbol{x}(+0) &= e^{-H_I(z)} S\exp\left[- : \int_{-\Delta}^{\Delta} V_0^{-1}(s_i(z)) H_{bb} V_0(s_i(z)) ds_i : \right] e^{H_I(z)} \boldsymbol{x}(-0) \\ &\approx S\exp\left[- : \int_{-\Delta}^{\Delta} V_0^{-1}(z_i/2) H_{bb}(\boldsymbol{x}) V_0(z_i/2) ds_i : \right] \boldsymbol{x}(-0) \end{aligned}$$

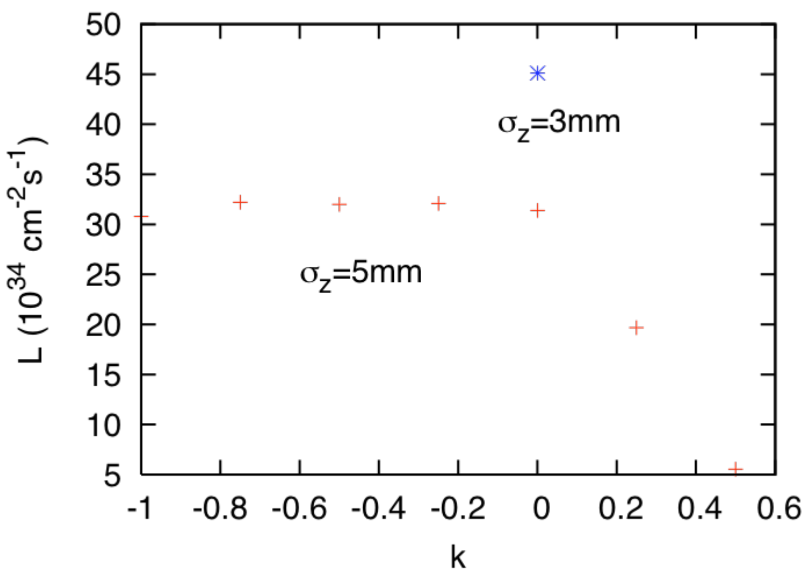
- This transformation does not include z.
- This beam-beam system is two degree of freedom (x-y).

Travel focusing results

- $\sigma_{z,HL}$=3mm, β_y=3mm, ε_x=18/24nm



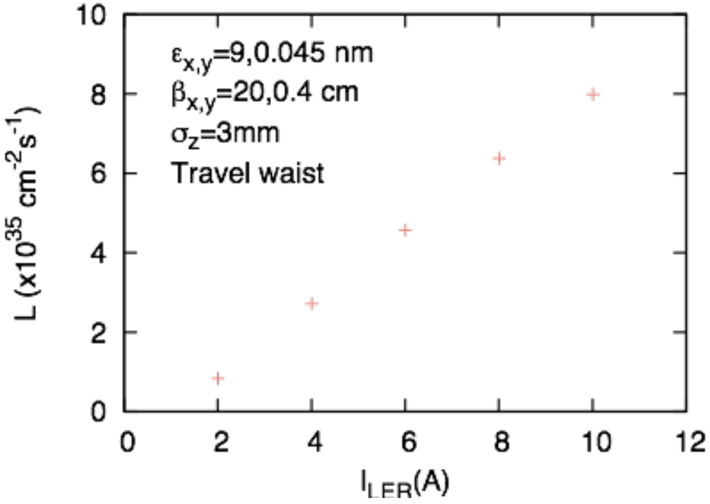
- $\sigma_{z,HL}$=5mm, β_y=3mm, ε_x=18/24nm

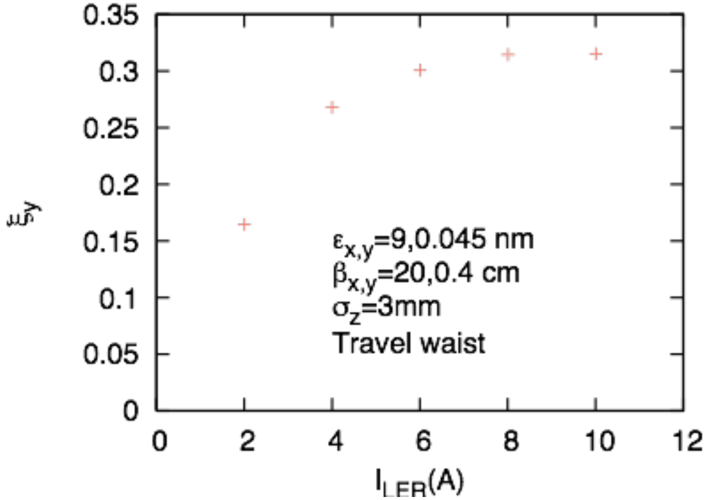


Travel focus gives a little luminosity increase, though the integrability of the beam-beam system improves. Life time is improved.

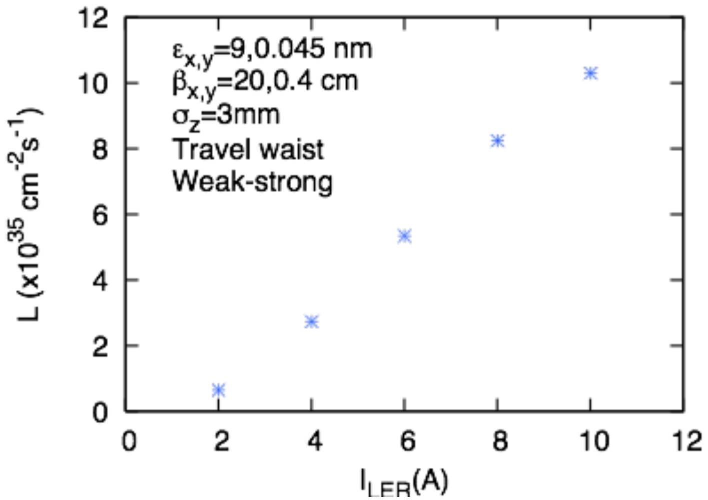
Extremely high beam-beam tune shift

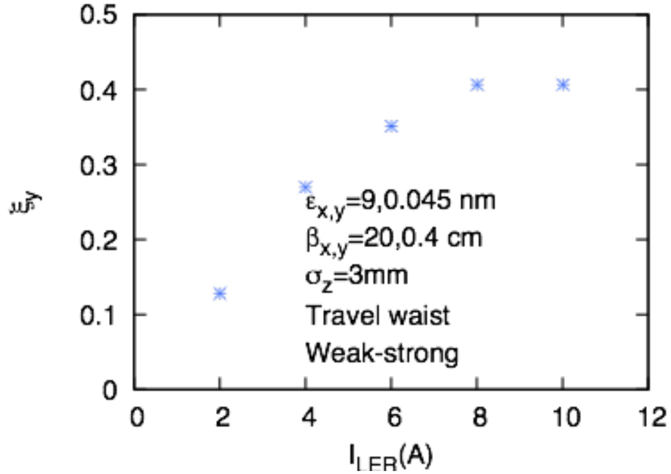
- Strong-strong $\xi \sim 0.3$





- weak-strong $\xi \sim 0.4$





Parameters -positive α-

β_x (m)	0.2	0.4
β_y (mm)	$6_H/3_L$	$6_H/3_L$
ε_x (nm)	12/20	12/20
τ/T_0	4000/8000	4000/8000
σ_z(mm)	3.5/6	3.5/6
L	5×10^{35}	$3\text{-}4\times10^{35}$

Parameters -negative α-

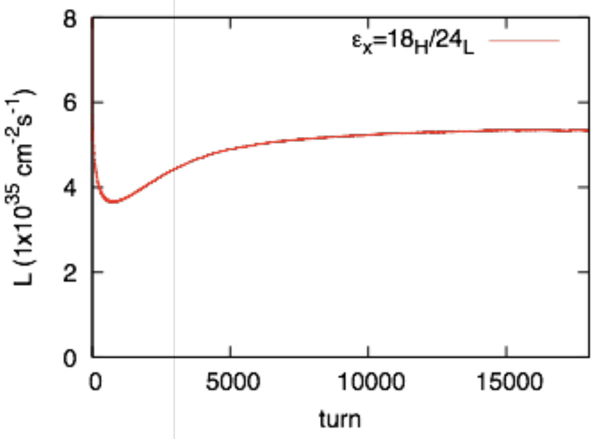
SuperKEKB machine parameters

SuperKEKB using traveling focus (only for LER) and negative α

		LER	HER	
Emittance	ε_x	24	18	nm
	ε_y	0.24	0.09	nm
Beta at IP	β_x*	20	20	cm
	β_y*	3	6	mm
Bunch length	σ_z	5	3	mm
Betatron tune	ν_x/ν_y	.505/.5905	.505/.5905	
Synchrotron tune	ν_s	0.025	0.025	
Beam current	I_+/I_-	9.4	4.1	A
#bunches/harmonic#	N_b/h	5018/5120		
Crossing angle	$2\phi_x$	30 → 0 (crab crossing)		mrad
Beam-beam*1	ξ_x	0.182	0.138	
	ξ_y	0.295	0.513	
Damping	T_x	6000	4000	turns
	T_y	6000	4000	turns
	T_e	3000	2000	turns
Luminosity	L	5.3×10^{35}		$cm^{-2}s^{-1}$

*1: ignore effects of traveling focus

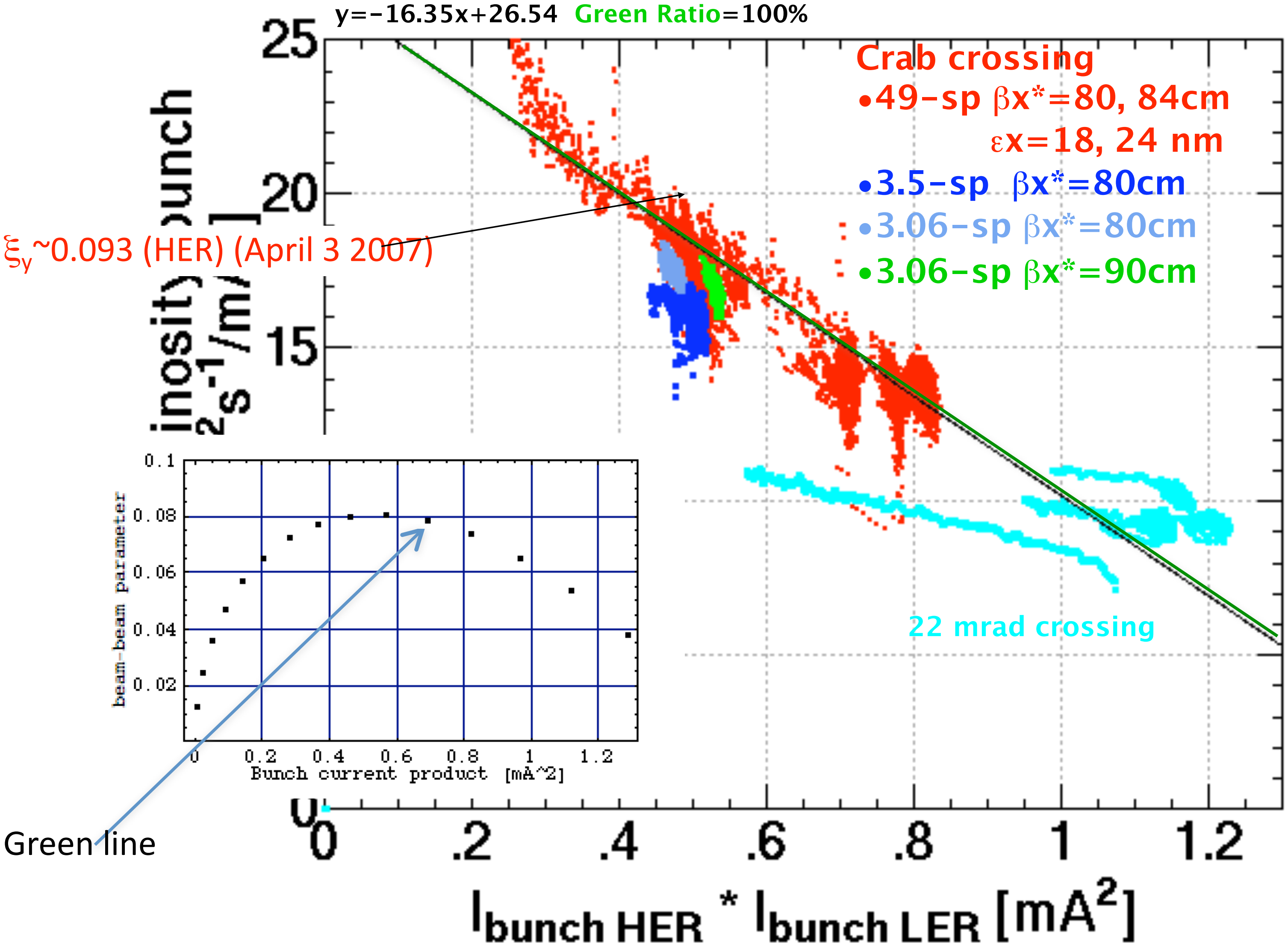
- Simulation



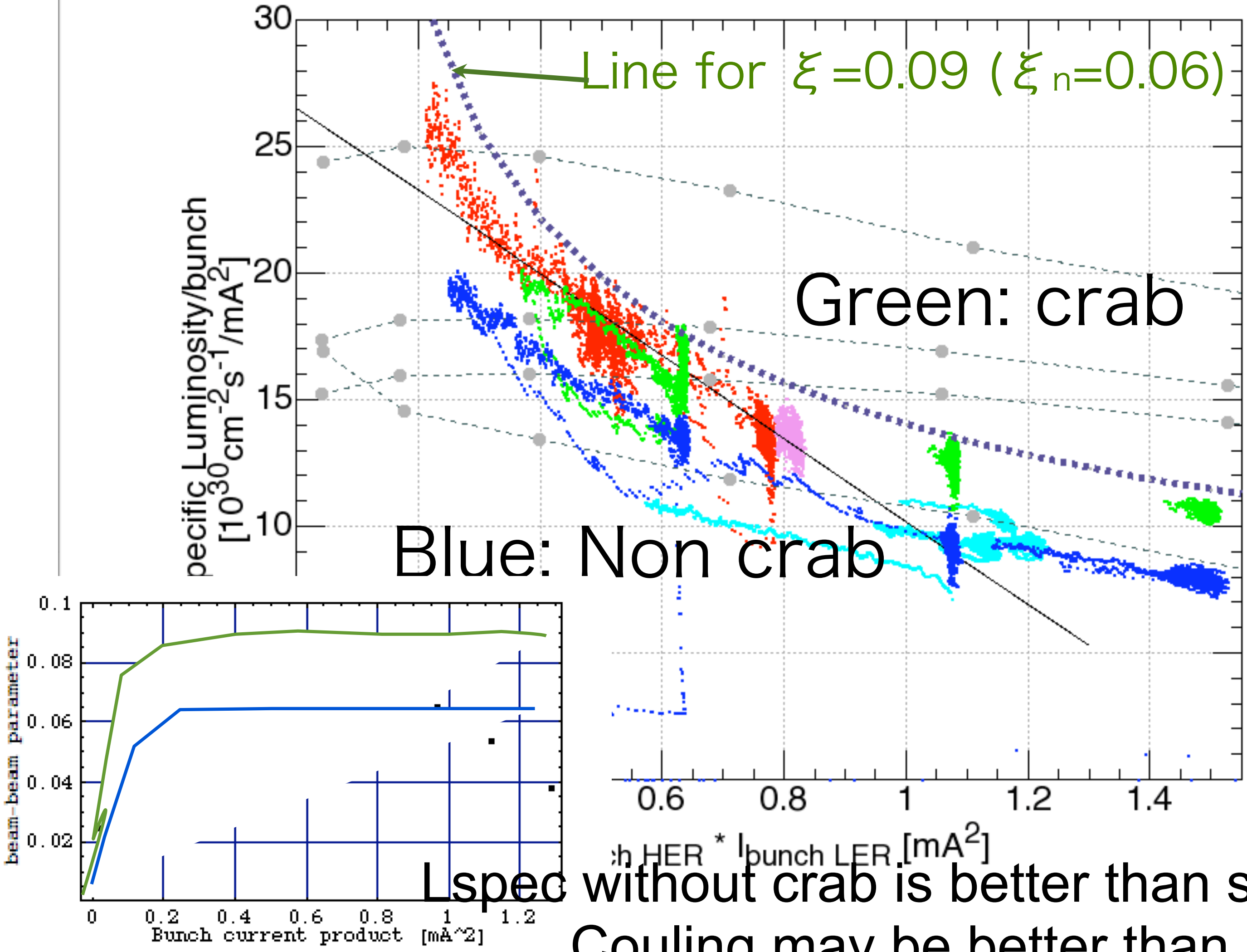
Present KEKB luminosity

- Life time issue is solved. Aperture limits the life time and also gave its asymmetry behavior. Y. Funakoshi et al.,
- The luminosity drop is reduced, and the luminosity behaves to keep a constant beam-beam parameter for changing current.
- The beam-beam parameter is around $\xi=0.09$($\xi_N=2r_e\beta L/\gamma Nf=0.06$).

Specific Luminosity and beam-beam parameter Before summer 2008

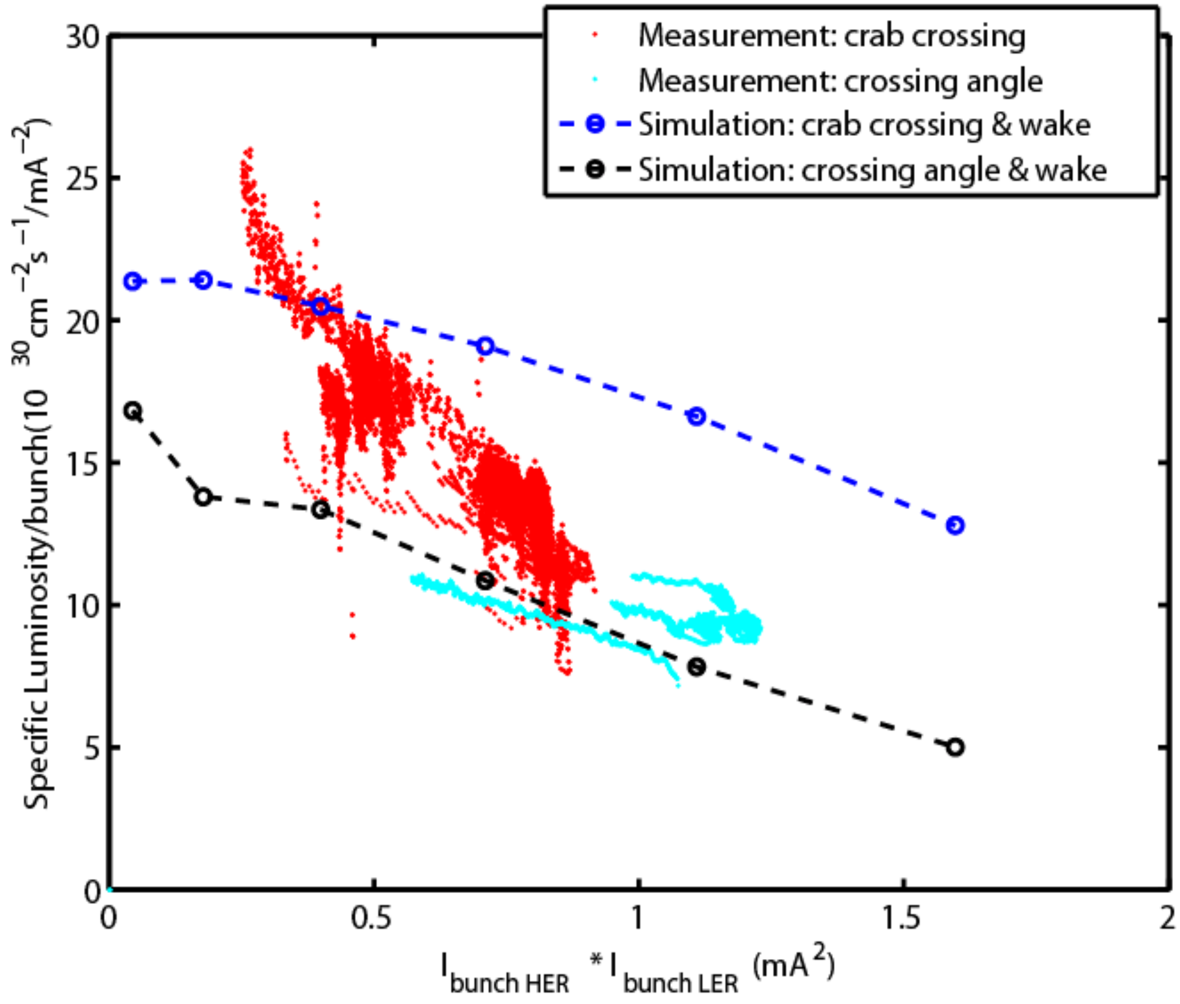


Specific luminosity for crab and non crab collision



Lspec without crab is better than simulation.
Couling may be better than 1%.

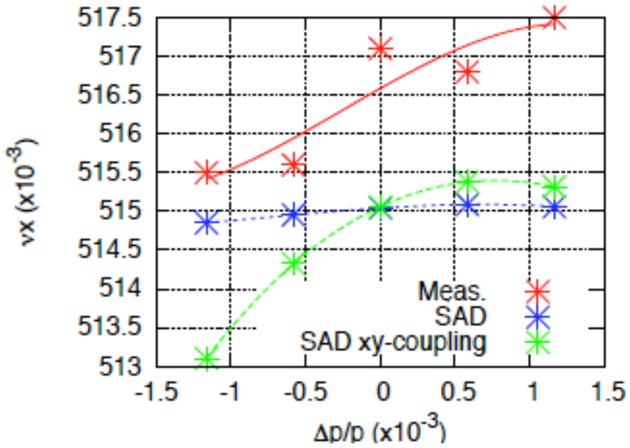
Specific Luminosity given by Y. Cai

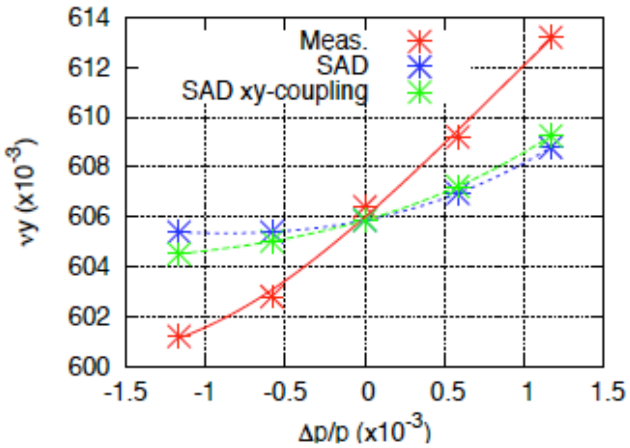


Nonlinear chromaticity measurement and estimation with SAD

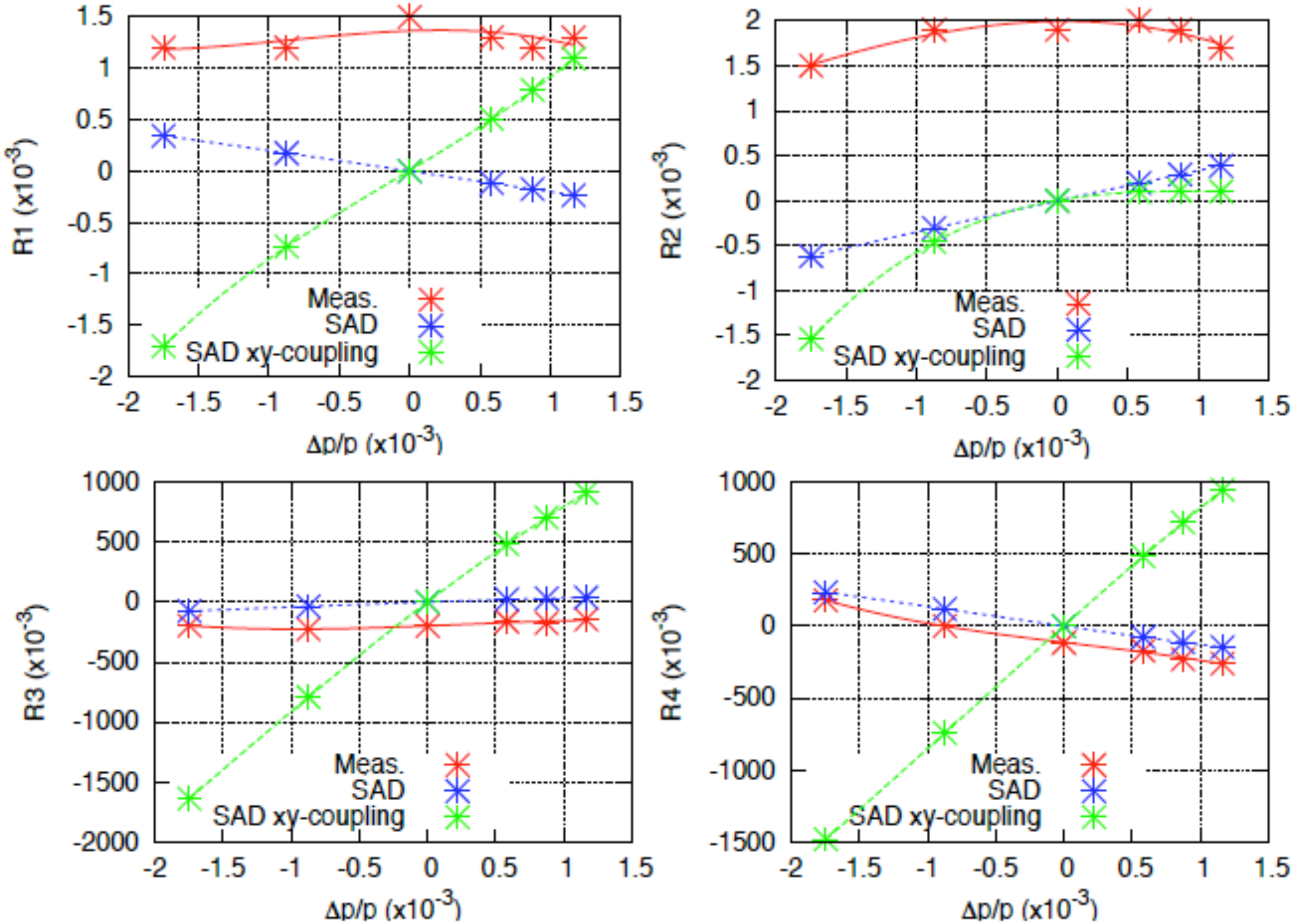
Figure fitted up to 3rd order

$$\nu_i = \nu_{i0} + \nu_{i1}\delta + \nu_{i2}\delta^2 + \nu_{i3}\delta^3$$





- SAD : no error
- SAD xy : 1% coupling with Vertical offset errors of sextupole.
- Measurement


R1 (x10-3)
Δp/p (x10-3)
Meas.
SAD
SAD xy-coupling
R2 (x10-3)
Δp/p (x10-3)
Meas.
SAD
SAD xy-coupling
R3 (x10-3)
Δp/p (x10-3)
Meas.
SAD
SAD xy-coupling
R4 (x10-3)
Δp/p (x10-3)
Meas.
SAD
SAD xy-coupling

Chromaticity

Meas.

$$\begin{pmatrix} \nu x \\ \nu y \end{pmatrix} = \begin{pmatrix} 44.5 \\ 41.6 \end{pmatrix} + \begin{pmatrix} 1.09 \\ 5.61 \end{pmatrix} \delta + \begin{pmatrix} -126 \\ 842 \end{pmatrix} \delta^2 + \begin{pmatrix} -1.69 \times 10^5 \\ -3.37 \times 10^5 \end{pmatrix} \delta^3$$

SAD

$$\begin{pmatrix} \nu x \\ \nu y \end{pmatrix} = \begin{pmatrix} 44.5 \\ 41.6 \end{pmatrix} + \begin{pmatrix} 0.126 \\ 1.29 \end{pmatrix} \delta + \begin{pmatrix} -64.6 \\ 898 \end{pmatrix} \delta^2 + \begin{pmatrix} -2.7 \times 10^4 \\ 1.22 \times 10^5 \end{pmatrix} \delta^3$$

SAD xy

$$\begin{pmatrix} \nu x \\ \nu y \end{pmatrix} = \begin{pmatrix} 44.5 \\ 41.6 \end{pmatrix} + \begin{pmatrix} 0.892 \\ 1.84 \end{pmatrix} \delta + \begin{pmatrix} -627 \\ 749 \end{pmatrix} \delta^2 + \begin{pmatrix} 4.41 \times 10^4 \\ 1.45 \times 10^5 \end{pmatrix} \delta^3$$

Meas.

$$\begin{pmatrix} \alpha x \\ \beta x \\ \alpha y \\ \beta y \end{pmatrix} = \begin{pmatrix} -0.411 \\ 0.924 \\ -0.136 \\ 0.00621 \end{pmatrix} + \begin{pmatrix} 18 \\ -99.8 \\ 340 \\ -0.843 \end{pmatrix} \delta + \begin{pmatrix} -4.4 \times 10^4 \\ 5240 \\ -5250 \\ -31.8 \end{pmatrix} \delta^2 + \begin{pmatrix} 2.31 \times 10^7 \\ 8.19 \times 10^7 \\ -2.14 \times 10^8 \\ 6.9 \times 10^5 \end{pmatrix} \delta^3$$

SAD

$$\begin{pmatrix} \alpha x \\ \beta x \\ \alpha y \\ \beta y \end{pmatrix} = \begin{pmatrix} 1.7 \times 10^{-5} \\ 0.9 \\ -8.88 \times 10^{-6} \\ 0.0059 \end{pmatrix} + \begin{pmatrix} -16.9 \\ -27.1 \\ -9.01 \\ 0.0682 \end{pmatrix} \delta + \begin{pmatrix} -2.43 \times 10^4 \\ -2.06 \times 10^4 \\ -5207 \\ 60 \end{pmatrix} \delta^2 + \begin{pmatrix} -1.22 \times 10^6 \\ 6.76 \times 10^5 \\ 1.03 \times 10^6 \\ 9240 \end{pmatrix} \delta^3$$

SAD xy

$$\begin{pmatrix} \alpha x \\ \beta x \\ \alpha y \\ \beta y \end{pmatrix} = \begin{pmatrix} -0.0766 \\ 1 \\ -0.00565 \\ 0.00602 \end{pmatrix} + \begin{pmatrix} 27.9 \\ -48.3 \\ -3.8 \\ 0.0812 \end{pmatrix} \delta + \begin{pmatrix} -6.68 \times 10^4 \\ -4707 \\ -6224 \\ 61.1 \end{pmatrix} \delta^2 + \begin{pmatrix} 6.61 \times 10^6 \\ -5.65 \times 10^6 \\ 1.05 \times 10^6 \\ 7915 \end{pmatrix} \delta^3$$

Meas.

$$\begin{pmatrix} r1 \\ r2 \\ r3 \\ r4 \end{pmatrix} = \begin{pmatrix} 0.00136 \\ 0.002 \\ -0.198 \\ -0.114 \end{pmatrix} + \begin{pmatrix} 0.0495 \\ 0.019 \\ 45.7 \\ -114 \end{pmatrix} \delta + \begin{pmatrix} -99.5 \\ -182 \\ 7860 \\ 4440 \end{pmatrix} \delta^2 + \begin{pmatrix} -3.94 \times 10^4 \\ -1.95 \times 10^4 \\ -1.09 \times 10^7 \\ -1.52 \times 10^7 \end{pmatrix} \delta^3$$

SAD

$$\begin{pmatrix} r1 \\ r2 \\ r3 \\ r4 \end{pmatrix} = \begin{pmatrix} 1.44 \times 10^{-8} \\ -5.66 \times 10^{-7} \\ 2.84 \times 10^{-5} \\ -0.00015 \end{pmatrix} + \begin{pmatrix} -0.2 \\ 0.342 \\ 38.8 \\ -134 \end{pmatrix} \delta + \begin{pmatrix} -0.894 \\ -6.41 \\ -3469 \\ 4156 \end{pmatrix} \delta^2 + \begin{pmatrix} 1578 \\ -601 \\ -6.34 \times 10^5 \\ 2.3 \times 10^6 \end{pmatrix} \delta^3$$

SAD xy

$$\begin{pmatrix} r1 \\ r2 \\ r3 \\ r4 \end{pmatrix} = \begin{pmatrix} 5.55 \times 10^{-6} \\ 3.37 \times 10^{-6} \\ 0.000817 \\ 0.00126 \end{pmatrix} + \begin{pmatrix} 0.82 \\ 0.275 \\ 864 \\ 843 \end{pmatrix} \delta + \begin{pmatrix} 24 \\ -235 \\ -5.91 \times 10^4 \\ -1.74 \times 10^4 \end{pmatrix} \delta^2 + \begin{pmatrix} 6.55 \times 10^4 \\ 6.4 \times 10^4 \\ -9.5 \times 10^6 \\ -8.18 \times 10^6 \end{pmatrix} \delta^3$$

Symplectic expression of the chromaticity

- Hamiltonian which gives the chromaticity is obtained and is used in the beam-beam simulation.

- 10xn coefficients are determined from 10xn chromaticities.

Y. Seimiya at al.

$$(\nu_{x,n}, \beta_{x,n}, \alpha_{x,n}, \nu_{y,n}, \beta_{y,n}, \alpha_{y,n}, r_{i,n})$$

$$\downarrow$$

$$H = \sum_{n=1} (a_n x^2 + b_n x\bar{p}_x + c_n \bar{p}_x^2 + u_n y^2 + v_n y\bar{p}_y + w_n \bar{p}_y^2 + d_n xy + e_n x\bar{p}_y + f_n \bar{p}_x y + g_n \bar{p}_x \bar{p}_y)\delta^n$$

Beam size scan simulation without BB (ν_y=0.58)

D. Zhou et al.

- SAD no error

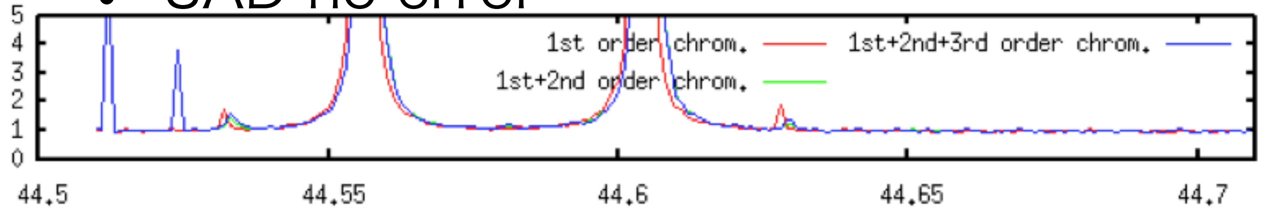


Fig. 2-b The same as Fig. 2-a, but different y scale

- SAD 1% coupling with with Vertical offset errors of sextupole.

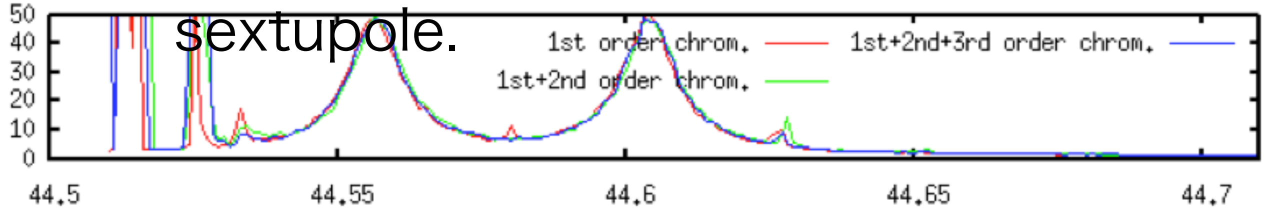


Fig. 4-a Emity/Emity0 with different set of chromaticicities

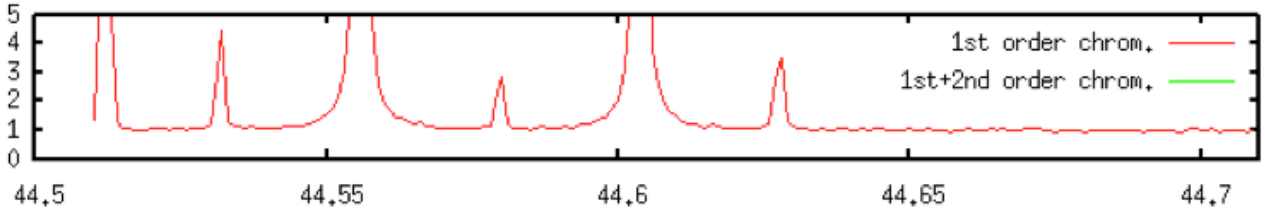
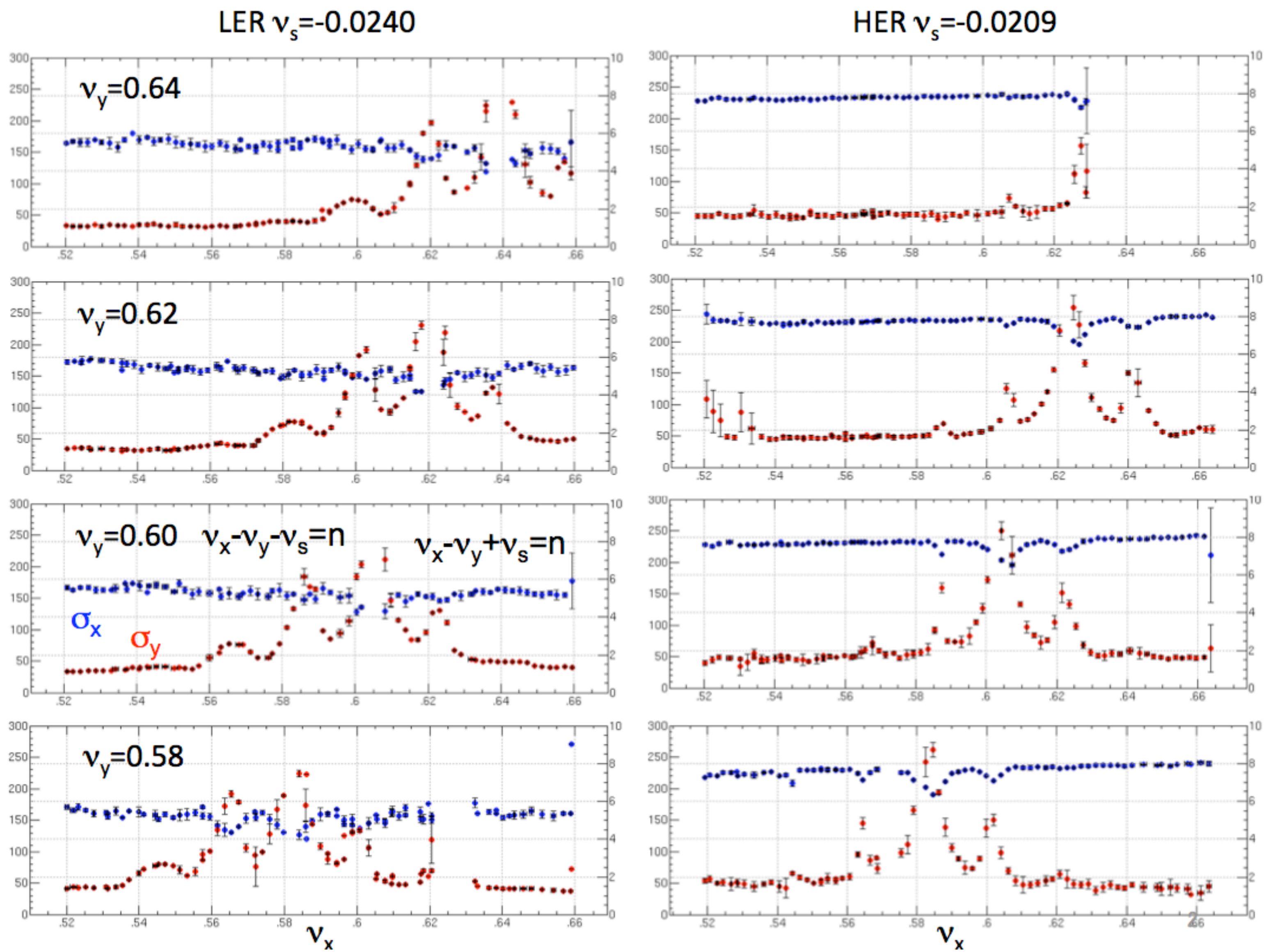


Fig. 6-b The same as Fig. 6-a, but different y scale

Measured beam size scan (Y. Ohnishi et al.,)



Beam size and luminosity simulation under the presence of the chromaticity

D. Zhou et al.

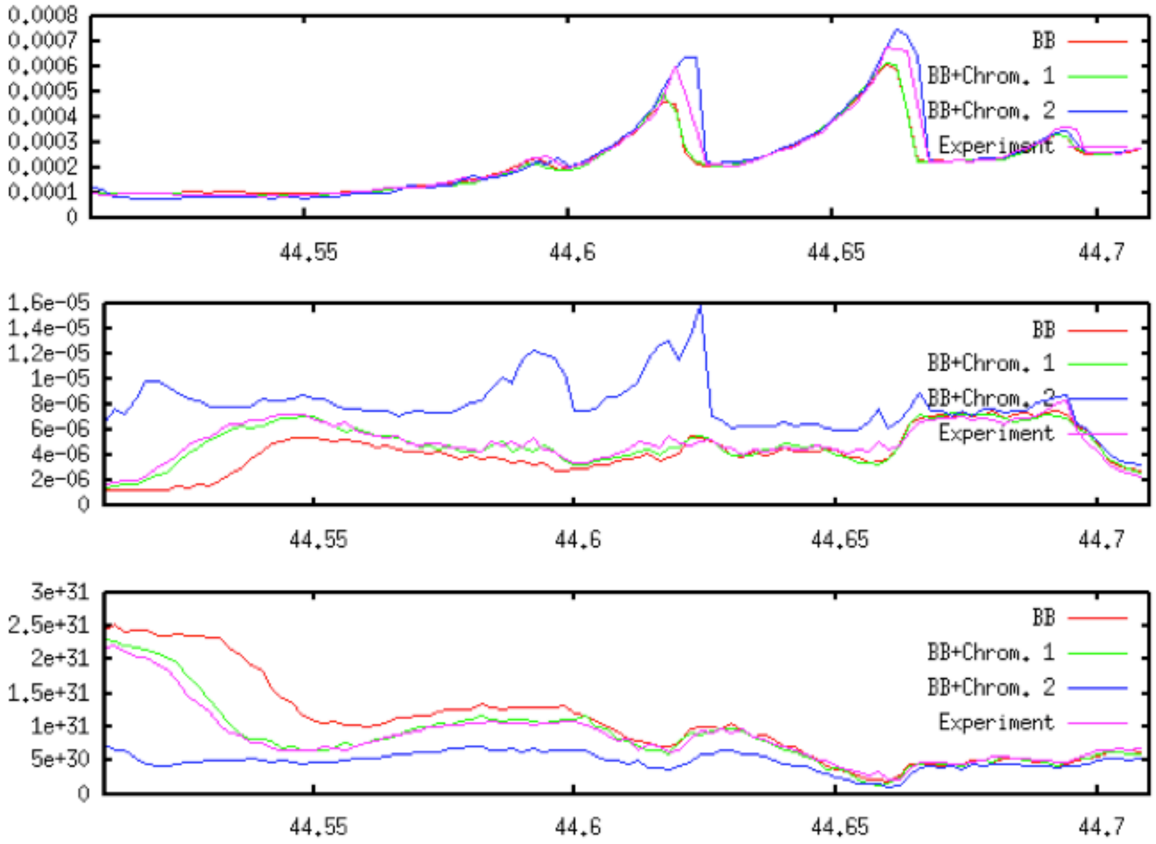


Fig. 13 Hor. Beam size (up), Vertical Beam size (middle), and Luminosity (down) at different settings of chromaticities with vertical tune Nuy=41.58 (BB: only beam-beam added, BB+Chrom. 1: 2008-10-27-sad file, BB+Chrom. 2: 2008-10-27-SAD_xy file, Experiment: measured chromaticities)

R chromaticity scan simulation

D. Zhou et al.

Meas.

$$\begin{pmatrix} r1 \\ r2 \\ r3 \\ r4 \end{pmatrix} = \begin{pmatrix} 0.00136 \\ 0.002 \\ -0.198 \\ -0.114 \end{pmatrix} + \begin{pmatrix} 0.0495 \\ 0.019 \\ 45.7 \\ -114 \end{pmatrix} \delta + \cdots$$

SAD

$$\begin{pmatrix} r1 \\ r2 \\ r3 \\ r4 \end{pmatrix} = \begin{pmatrix} 1.44\times10^{-8} \\ -5.66\times10^{-7} \\ 2.84\times10^{-5} \\ -0.00015 \end{pmatrix} + \begin{pmatrix} -0.2 \\ 0.342 \\ 38.8 \\ -134 \end{pmatrix} \delta + \cdots$$

SAD xy

$$\begin{pmatrix} r1 \\ r2 \\ r3 \\ r4 \end{pmatrix} = \begin{pmatrix} 5.55\times10^{-6} \\ 3.37\times10^{-6} \\ 0.000817 \\ 0.00126 \end{pmatrix} + \begin{pmatrix} 0.82 \\ 0.275 \\ 864 \\ 843 \end{pmatrix} \delta + \cdots$$

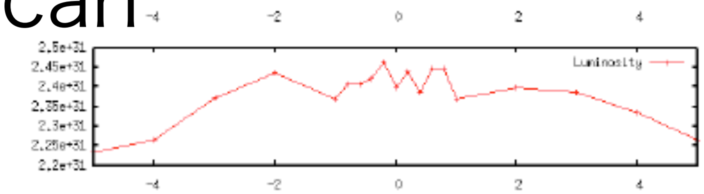


Fig.5 Horizontal beam size, Vertical beam size and Luminosity vs. $dR1/d\delta$

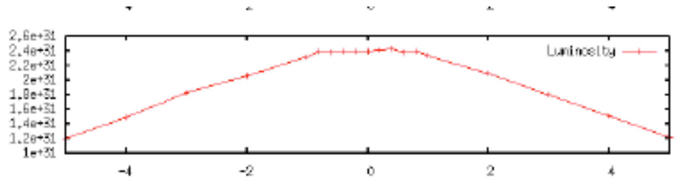


Fig.6 Horizontal beam size, Vertical beam size and Luminosity vs. $dR2/d\delta$

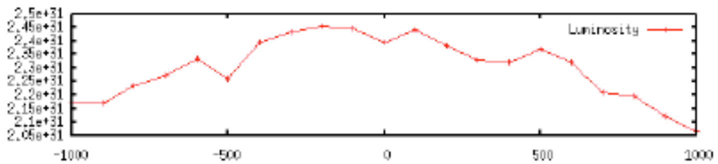


Fig.7 Horizontal beam size, Vertical beam size and Luminosity vs. $dR3/d\delta$

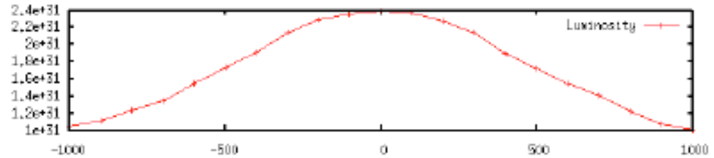


Fig.8 Horizontal beam size, Vertical beam size and Luminosity vs. $dR4/d\delta$

Summary for the present operation

- Life time issue is solved. The beam-beam parameter is the highest in the world except LEP.
- Luminosity can be achieved 2x10^{34} soon, but still lower than our expectation.
- Linear X-Y coupling and dispersion errors does not seem to be well controlled.
- Their chromatic effect is next subject.
- Skew sextupole magnets placed at dispersive section can control the chromaticity, and is installed this shutdown.
- The very high beam-beam parameter seems to be hard to realize.
- Crab cavity works well, thus we continue the tuning of the parameters with taking the data.
- It may be the time to study another possibilities.

SuperBunch-crab waist option

- We have some difficulties to go the scheme with keeping the present luminosity.
- To increase the luminosity step by step, β_x at IP should be reduced, with keeping ε_x. Because the present ξ_x, which is >0.1, should be decrease first.
- Low β_x had been tried a long ago. In present KEKB, β_x<0.5m seems to be difficult to inject the beam, though dynamic β may affect.
- We should try low β_x at another tune operating point far from 0.5 again.

SuperBunch/Micro-beta approach

- Decrease β_x and β_y with keeping $(\varepsilon_x \beta_x)^{1/2}/\beta_y$
- $\xi_y \sim (\beta_y / \varepsilon_y)^{1/2}$, $\xi_x \sim \beta_x$
- $L \sim N/(\beta_y)^{1/2}$

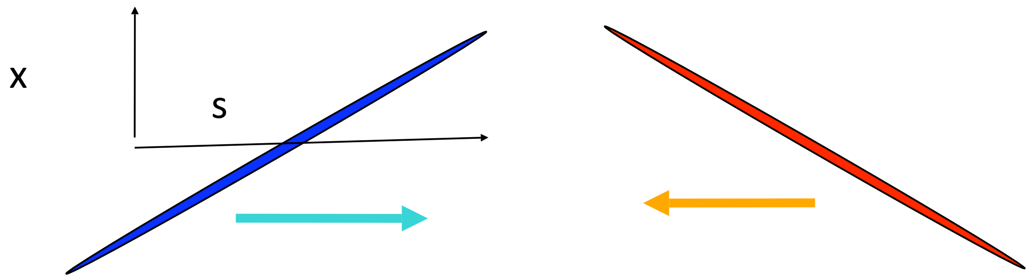
$$\frac{\sqrt{\varepsilon_x \beta_x}}{\theta_h \sigma_z} < 1$$

$$L \sim \frac{N^2}{\theta_h \sigma_z \sqrt{\varepsilon_y \beta_y}} \sim \frac{N\xi_y}{\beta_y}$$

$$\xi_x \sim \frac{N\beta_x}{\theta_h^2 \sigma_z^2}$$

$$\xi_y \sim \frac{N}{\theta_h \sigma_z}\sqrt{\frac{\beta_y}{\varepsilon_y}}$$

$$\beta_y > \frac{\sqrt{\varepsilon_x \beta_x}}{\theta_h}$$



parameters of several cases (5000 bunches)

	Super KEKB	Normal ε	LER low-ε	L/H low-ε	KEKB test
εx (nm)	$18_H/24_L$	10/10	1/10	1/1	18/18
εy(nm)	0.09/0.24	0.1	0.01/0.04	0.01/0.01	0.18/0.18
βx (mm)	200	10/10	10/10	10	50
βy (mm)	6/3	0.6/0.6	0.8/0.2	0.2	3
σz (mm)	3.5/6	6	6	6	6
φσz/σx	0.0	9	28/9	28	2.2
ne	5.25×10^{10}	2.2×10^{10}	2.2×10^{10}	2.2×10^{10}	1.75×10^{10}
np	$12. \times 10^{10}$	3.3×10^{10}	3.3×10^{10}	3.3×10^{10}	4×10^{10}
φ/2 (mrad)	0	15	15	15	11
ξν,x	0.397	0.0017	0.0018	0.0018	0.0108
ξν,y	0.3	0.047/0.031	0.035/0.11	0.09	0.069
Lum (W.S.)	5×10^{35}	1×10^{35}	2×10^{35}	5×10^{35}	4×10^{34}
Lum (S.S.)	5×10^{35}				

Strong-strong simulation for the super Bunch scheme

- Slice longitudinal direction, 150 slices for $\phi\sigma_z/\sigma_x$= 15-25.
- Collisions of 150x150 times were calculated for one revolution. The i-th and j-th slices collides at $s_{ij}= (z_i-z_j)/2$.
- Two type of the strong-strong simulation
  - Gaussian approximation
  - PIC solver, but Gaussian approximation is used for $\phi s_{ij}/\sigma_x>2.5$ (preliminary).

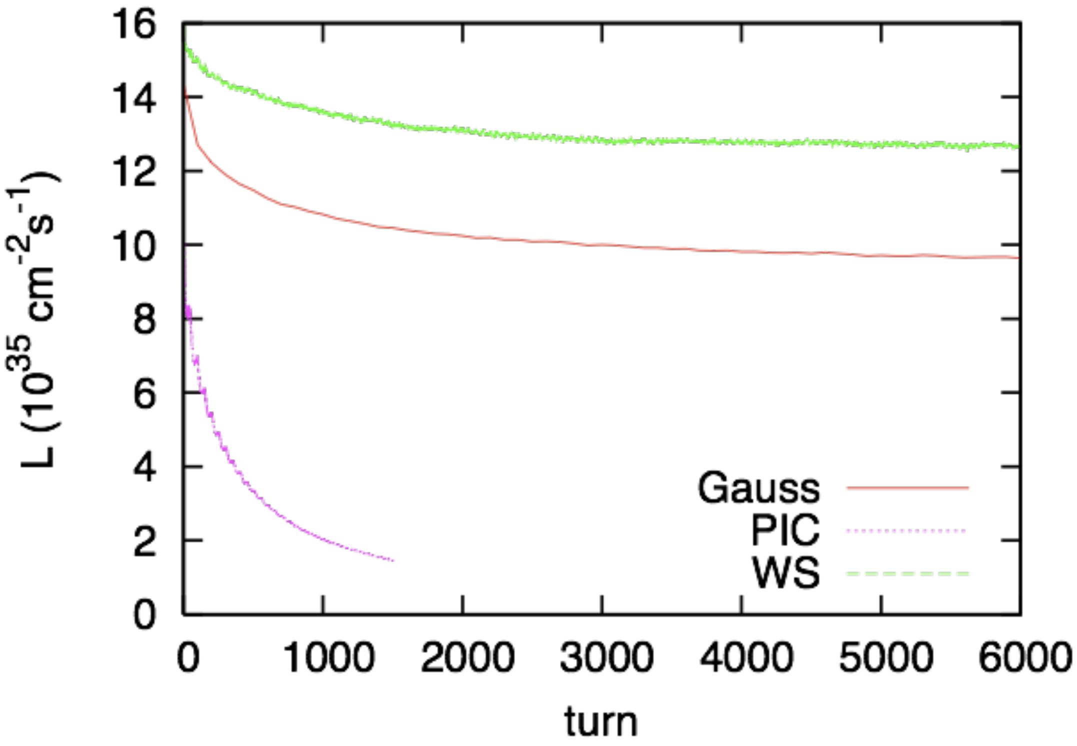
Super B (Italy)

	HER	LER
Circumference	3016	
Energy	7	4
$\varepsilon_x/\varepsilon_y$	$1.6\text{x}10^{-9}/4\text{x}10^{-12}$	$2.8\text{x}10^{-9}/7\text{x}10^{-12}$
σ_z	0.006	0.006
β_x/β_y	0.02/0.00039	0.035/0.00022
$N_\pm$	$5.52\text{x}10^{10}$	$5.52\text{x}10^{10}$
$\nu_x/\nu_y/\nu_s$	0.57/0.60/0.01	0.57/0.60/0.01
ϕ ($\phi\sigma_z/\sigma_x$)	0.024(25)	-15

- M. Biagini et al.

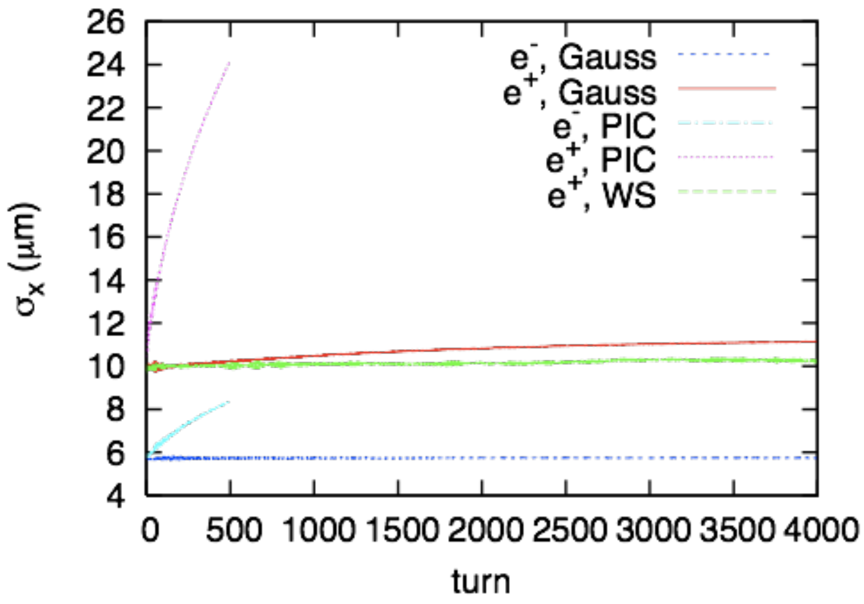
Luminosity

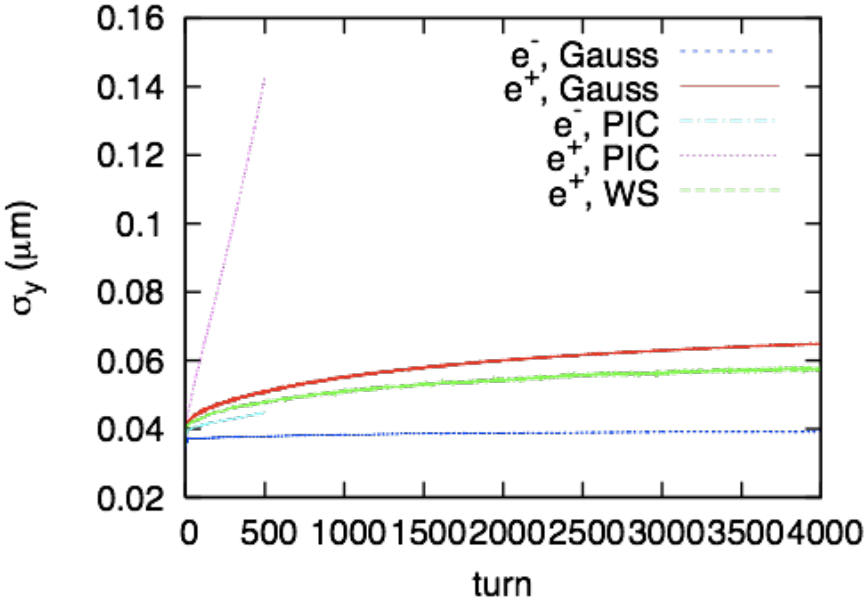
- Gaussian approximation
- PIC simulation, which is the first trial,showed a low luminosity now. Numerical errors are doubted. Revised simulation is on going.



Beam size

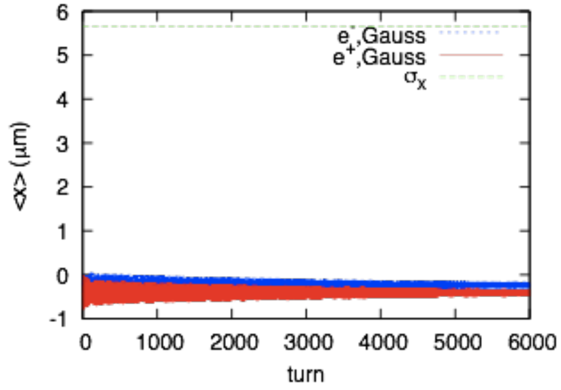
- The beam sizes given by Gaussian approximation agree with those by the weak-strong simulation.
- Strange behavior in PIC model.

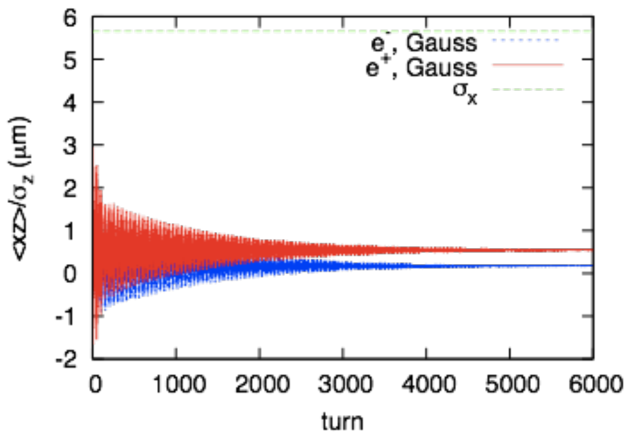


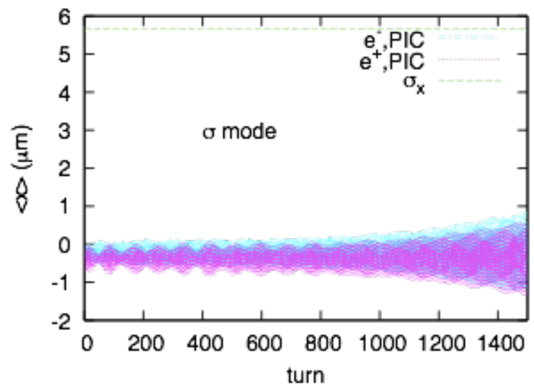


Coherent motion in Gaussian model

- Coherent motion is seen at the early stage maybe due to a miss-match, but damp in a few radiation damping time.



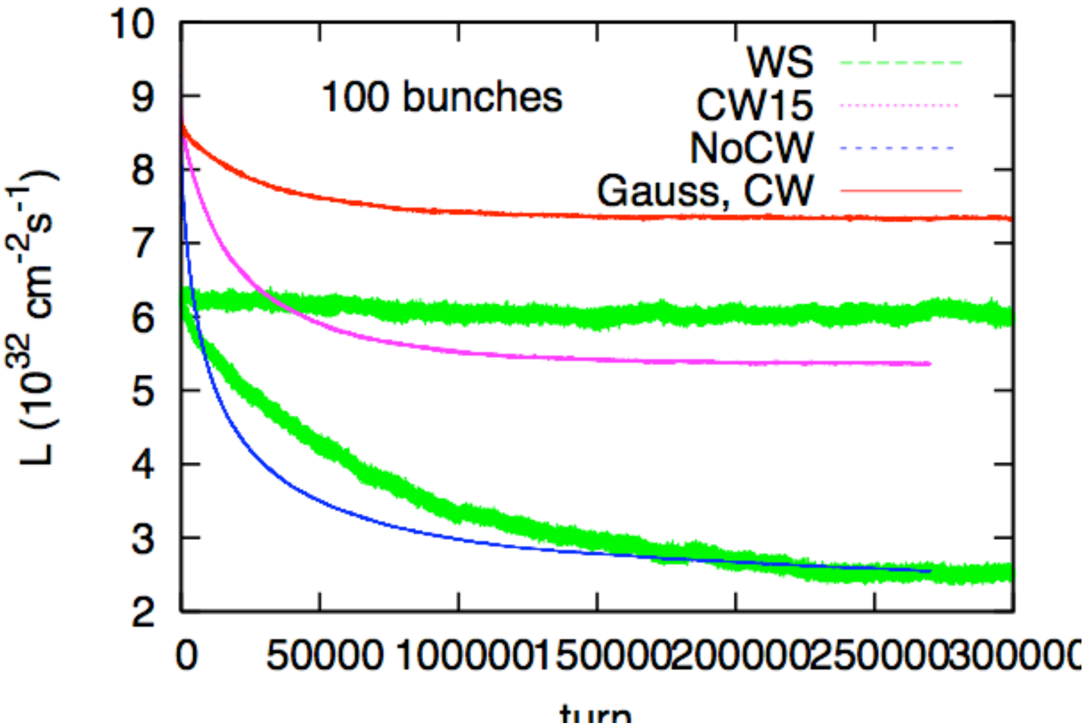




Growth of a coherent motion is seen, but a numerical error is doubted.

DAFNE

- Measured luminosity=4.5×10^{32} $cm^{-2}s^{-1}$.



Summary

- Super KEKB design with crab cavity. Beam-beam performance is $L=5\times10^{35}cm^{-2}s^{-1}$ for β_x=0.2m. It degrade 20-30% for β_x=0.4m.
- A steady effort should be continued with the crab cavity operation.
- Every trials to increase the luminosity should be performed in KEKB. Travel focus is combined scheme of crab cavity and crab waist.
- To study the superbunch-crab waist scheme with keeping or improving the present performance, low β_x operation (~5-10cm) should be tried.

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
τx/T	110000	110000	4000	4000	31900	0
ξv+=2 re β L/γ N f	0.0210	0.0315	0.0861	0.0802	0.0073	0.0561
ξv−=2 re β L/γ 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

Near the half integer tune in Horizontal

- Transformation

$$x_{n+1} = \left(1 - \frac{\mu_x^2}{2}\right) x_n + \beta_x \mu_x p_{x,n}$$

$$p_{x,n+1} = -\mu_x x_n + \left(1 - \frac{\mu_x^2}{2}\right) p_{x,n} - F_x(x_{n+1}, y_{n+1})$$

$$x(n) = (-1)^n x_n$$

$$\mu_x = 2\pi(\nu_x - 0.5)$$

$$F(-x, y) = -F(x, y)$$

$$F_x(x, y) = F_x(x, 0) + \cancel{\left.\frac{\partial F_x}{\partial y}\right|_{y=0} y + \frac{1}{2} \left.\frac{\partial^2 F_x}{\partial y^2}\right|_{y=0} y^2}$$

$$\left.\frac{\partial F_x}{\partial y}\right|_{y=0} = 0 \qquad \frac{1}{2} \left.\frac{\partial^2 F_x}{\partial y^2}\right|_{y=0} y^2 \approx F_x(x, y) \times \frac{\sigma_y}{\sigma_x}$$

Vertical motion

- Vertical map

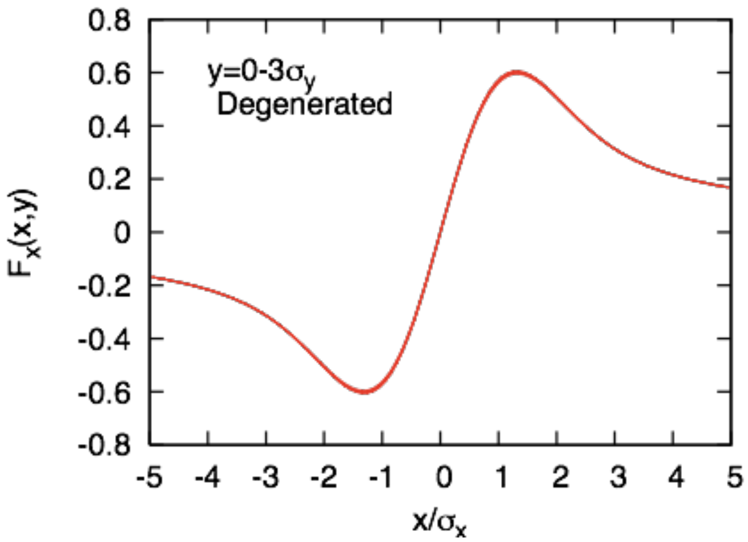
$$y(n+1) = \cos\mu_y y(n) + \beta_y \sin\mu_y p_y(n)$$

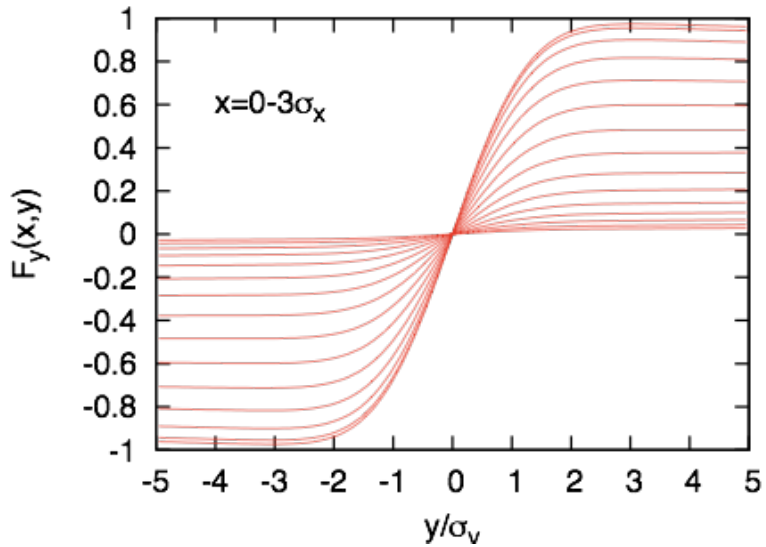
$$p_y(n+1) = -\frac{1}{\beta_y}\sin\mu_y y(n) + \cos\mu_y p_y(n) - F_y(x(n+1), y(n+1))$$

$$F_y(\bar{x}+x_r, y) = F_y(\bar{x}, y) + \frac{1}{2}\left.\frac{\partial^2 F_y}{\partial x^2}\right|_{x=\bar{x}} \langle x_r^2 \rangle + \ldots$$

- F_y fluctuates due to
- If horizontal motion is chaotic, stochasticity of the vertical motion increases, with the result that emittance growth is enhanced.

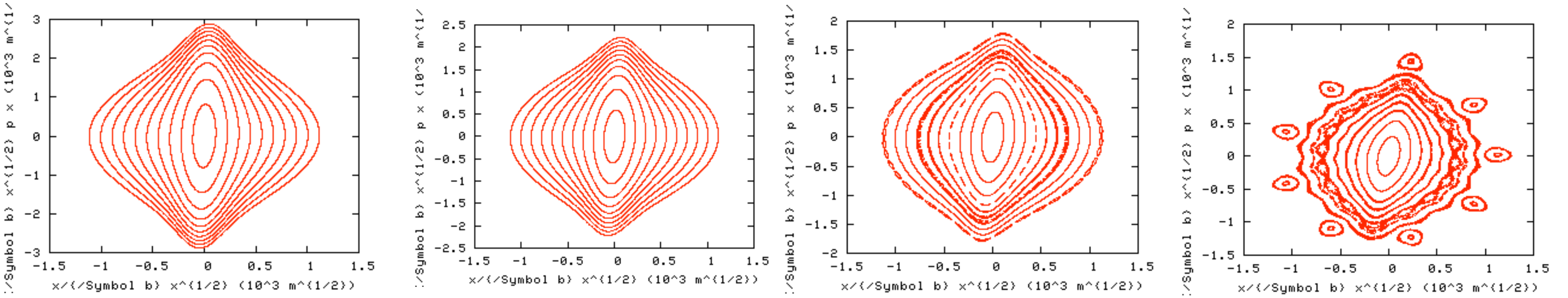
- Beam-beam force for a flat beam, $\sigma_x/\sigma_y=100$.



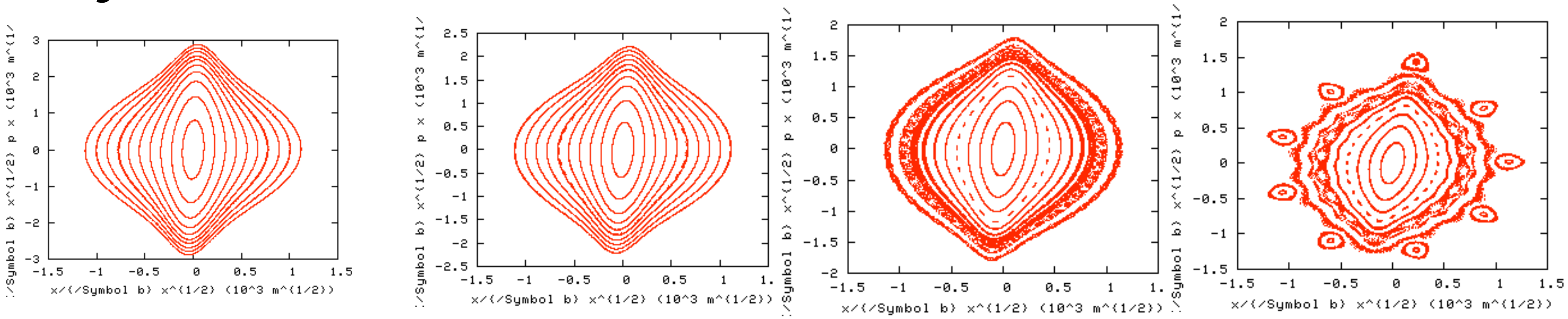


Horizontal motion

- y=0 μm
- 0.505 0.510 0.520 0.550



- y=2 μm

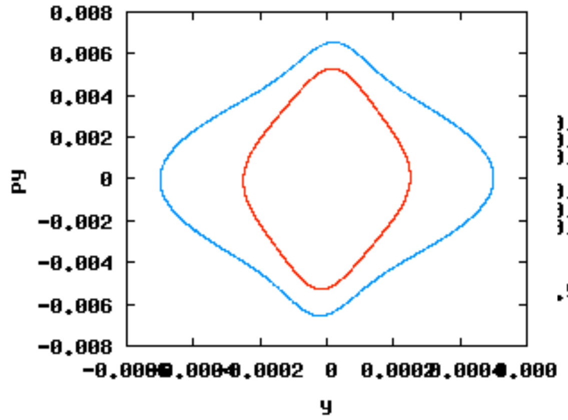


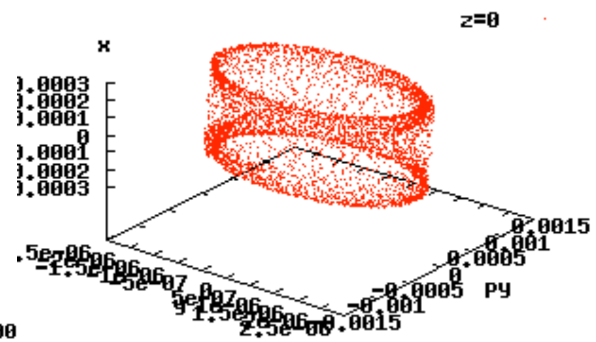
- The figures are roughly independent of y.

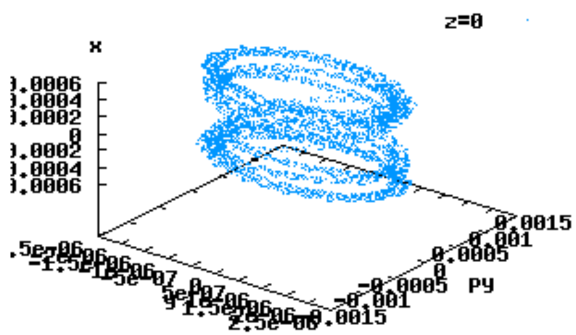
ν_x=0.505

- X motion is clearly solved at ν_x=0.505.
- Y motion is bound on surface. No emittance growth.

x-p_x | y-p_y-x | y-p_y-x



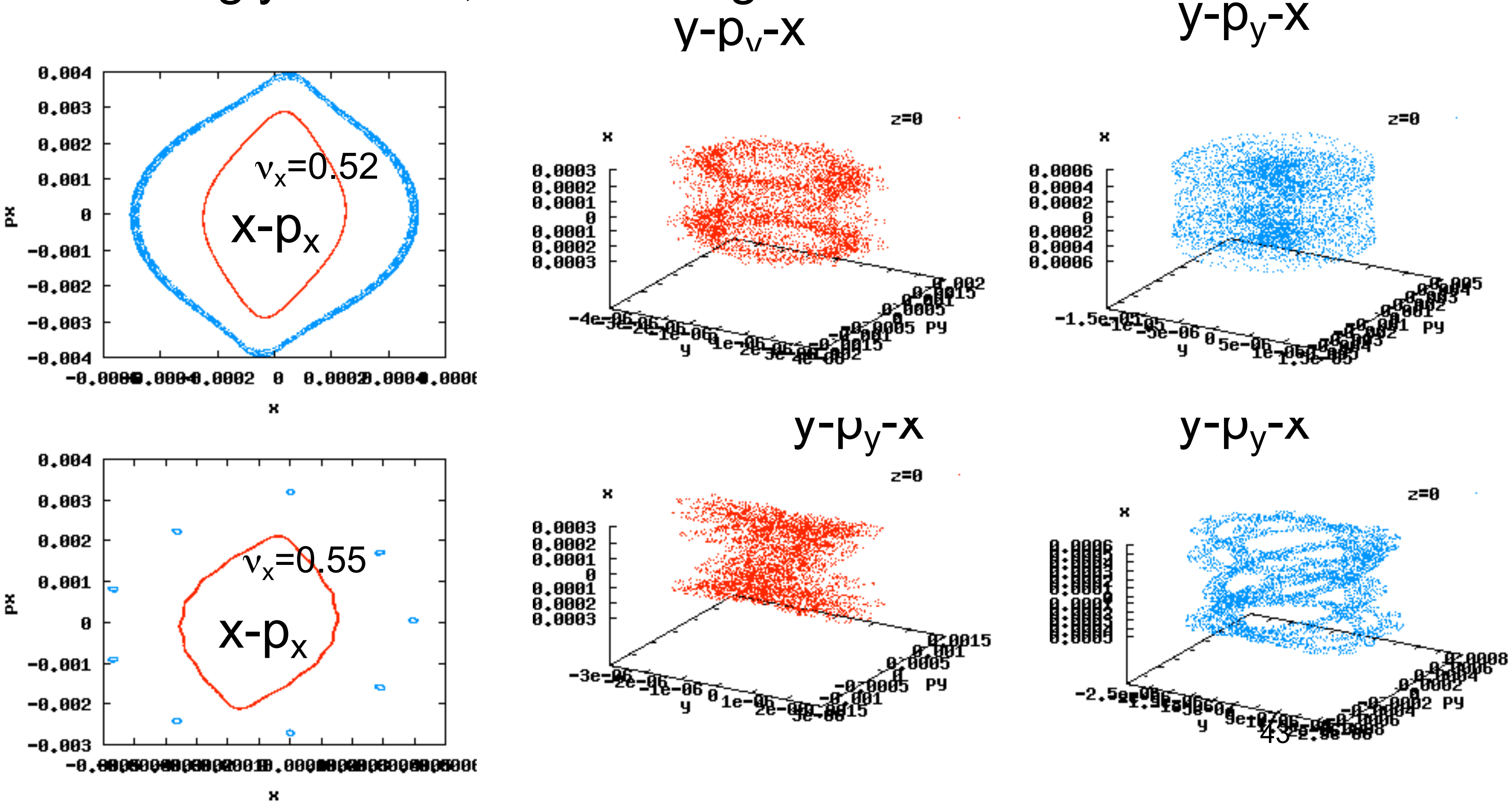




Horizontal tune near the half integer is better for luminosity.

ν_x=0.55 and 0.6

- When ν_x=0.55, 0.6, x motion is chaotic. y motion is strongly chaotic, emittance growth.



x-y coupling, ν_x=0.505

- R1=3.17e-3, R2=-0.22e-3, R3=0.059, R4=0.025 (1 unit of KEKB knob scan)