Beam Dynamics Issue in Nano Beam Scheme

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SuperKEKB MAC

Feb. 7-9, 2011

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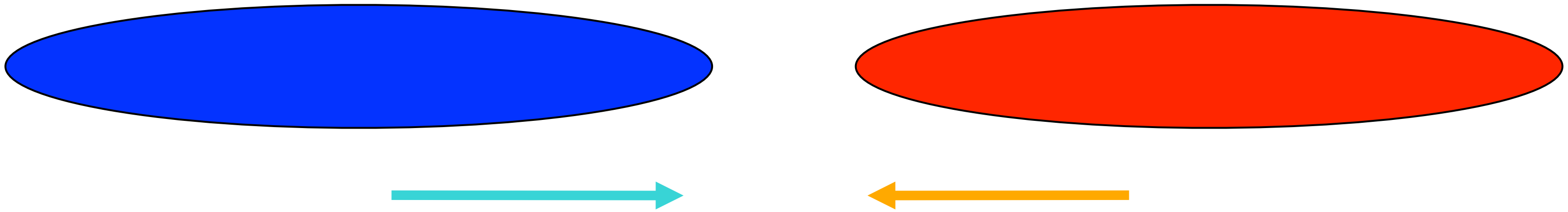
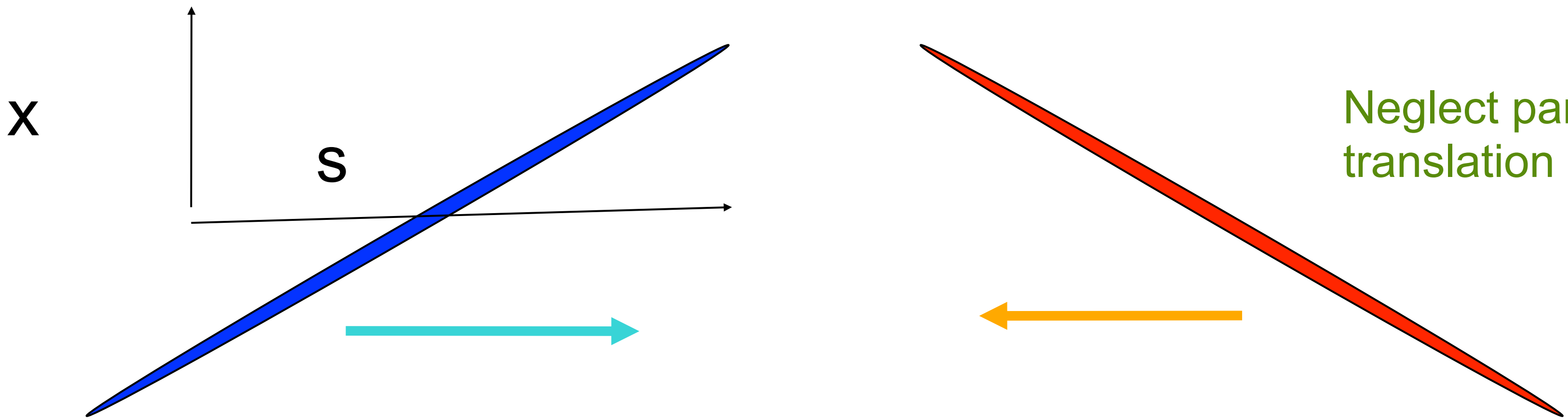
- Beam-beam effects
  - Nano-beam scheme
  - Synchro-beta effects
  - Tolerance for errors
- Electron cloud effects
- Transverse impedance issues

Nano-beam scheme

- KEKB with crab cavity targeted a high beam-beam parameter >0.1.



- SuperKEKB goes toward Low emittance, low beta, moderate beam-beam parameter <0.1



Neglect parallel translation to x

Low emittance approach

Φ: half crossing angle

$$\sigma_x/\phi < \sigma_z$$

$$\sigma_x/\phi < \beta_y$$

$$L \propto \frac{N^2}{\phi\sigma_z\sqrt{\varepsilon_y\beta_y}}$$

$$\xi_x \propto \frac{N\beta_x}{(\phi\sigma_z)^2}$$

$$\xi_y \propto \frac{N}{\phi\sigma_z}\sqrt{\frac{\beta_y}{\varepsilon_y}}$$

Keep $\sqrt{\frac{\beta_y}{\varepsilon_y}}$ and σ_x/β_y

Then take limit $\varepsilon_y\beta_y \to 0$

$$L \to \infty$$

- Bunch length is free.
- Small beta and small emittance are required.

Super KEKB

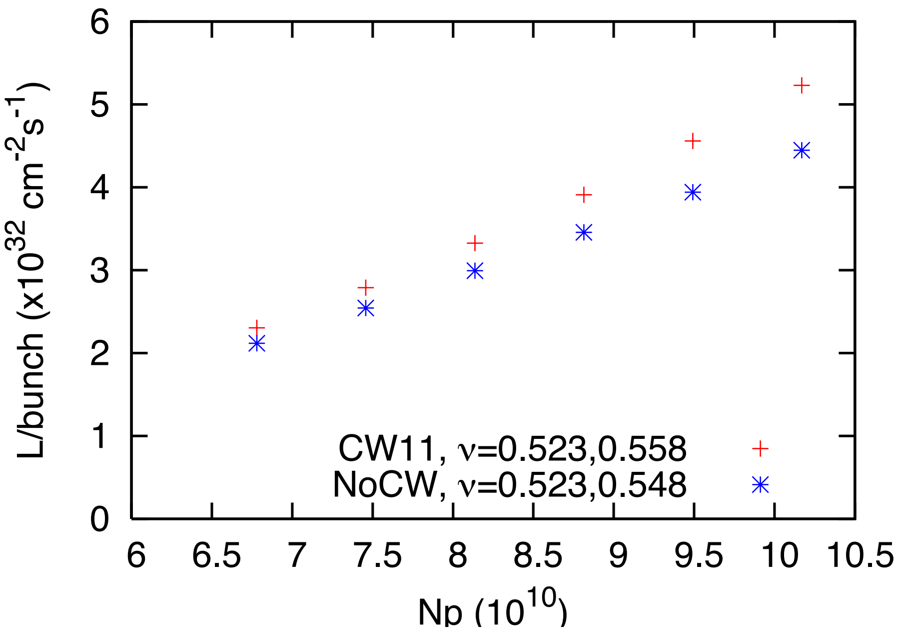
ε_x=3/5 nm, ε_y=3/5 pm

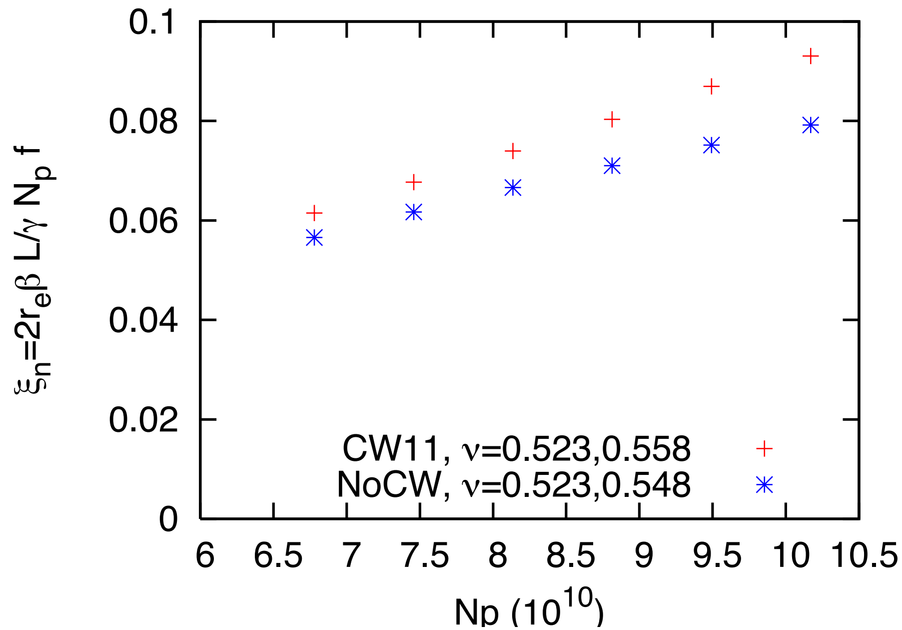
β_x=32/25 mm, β_y=0.3mm

Current dependence of L and ξ

given by a weak-strong simulation

- Nano beam collision is reliable for small $\xi<0.1$ without Crab Waist.
- The gain of CW remarkably appear higher beam-beam parameter.





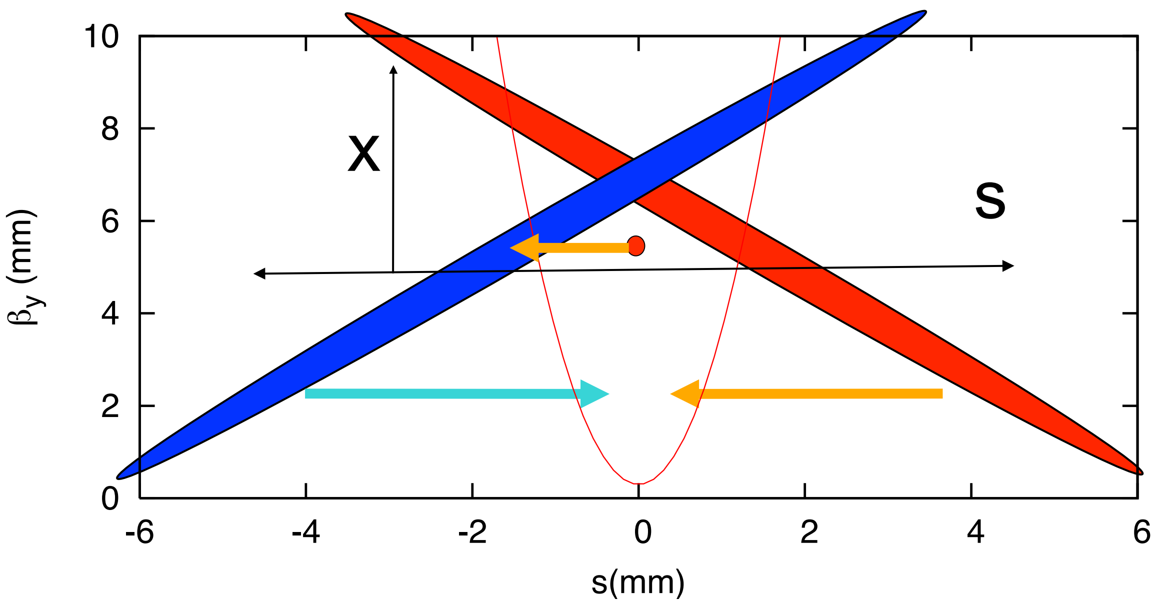
$\nu s=0.012$

Crab waist is base line of SuperB.
Beam particles collide with the other beam at their waist using sextupole magnets both side of IP.

Characteristics of the collision

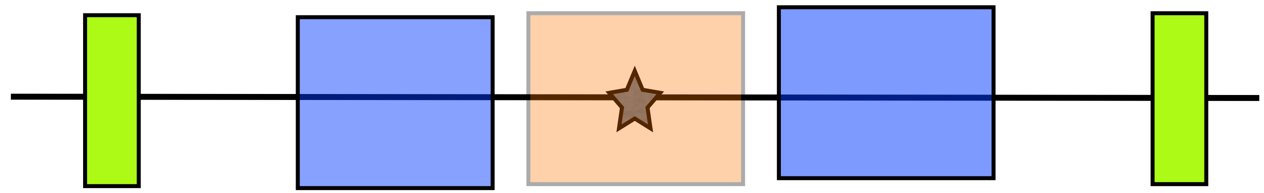
- βy is small only interaction area
  - Beam particles with a large horizontal amplitude collide high beta region
  - Issues on injection, collision offset, Touschek ....
  - Crab waist recovers the issues, but

Talk by Ohnishi, Iida



Neglect parallel translation to x

Crab waist and IR nonlinearity



$$\mathcal{M}_{IR} = e^{-axy^2} e^{-H_{Q's}} e^{-H_{Sol}} e^{-H_{BB}} e^{-H_{Sol}} e^{-H_{Q's}} e^{-axy^2}$$

$$\not\parallel$$

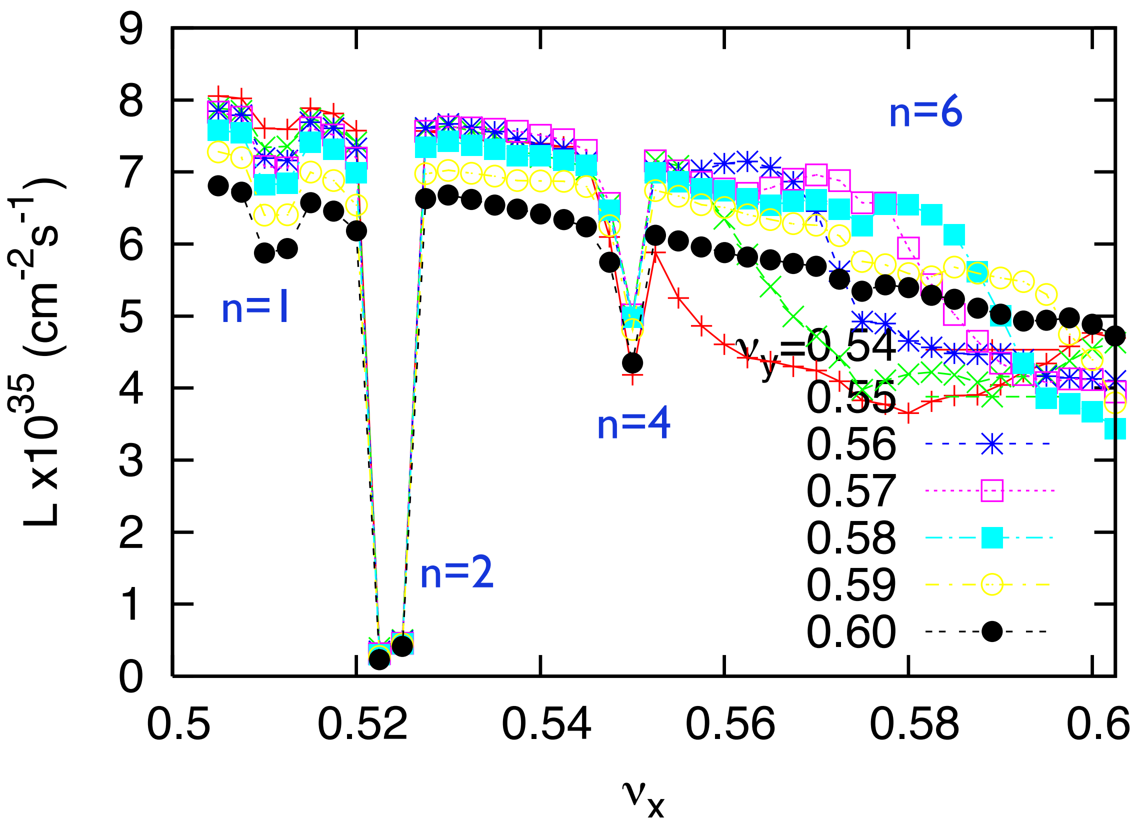
$$e^{-H_{Q's}} e^{-H_{Sol}} e^{-xp_y^2/2\phi} e^{-H_{BB}} e^{-xp_y^2/2\phi} e^{-H_{Sol}} e^{-H_{Q's}}$$

- Strong dynamic aperture degradation is seen by crab sextupole installation (H. Koiso).
- We do not know how to handle the nonlinear terms of Q's and Solenoid located at very high β.
- Crab waist is an option in (the) future for Super KEKB.

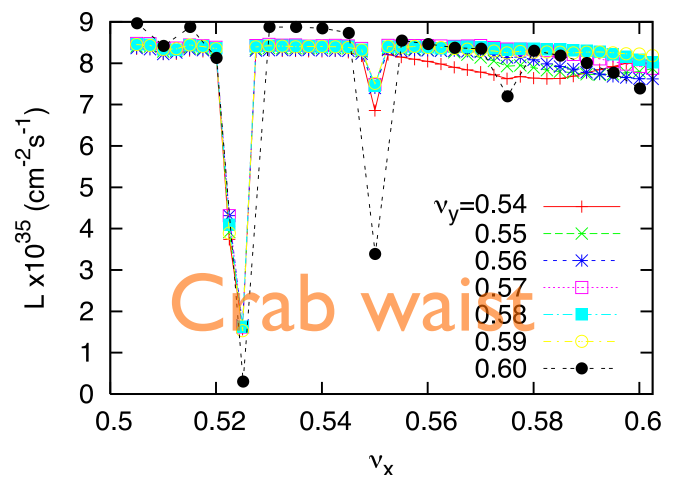
Study of synchro-beta resonance

- Tune scan shows strong synchro-beta resonances.
- Beam-beam interaction contains x^2z^2 terms, which gives the synchro-beta effects.
- Weak-strong and strong-strong simulations are performed to study the effects.

Luminosity in tune space given by weak strong simulation

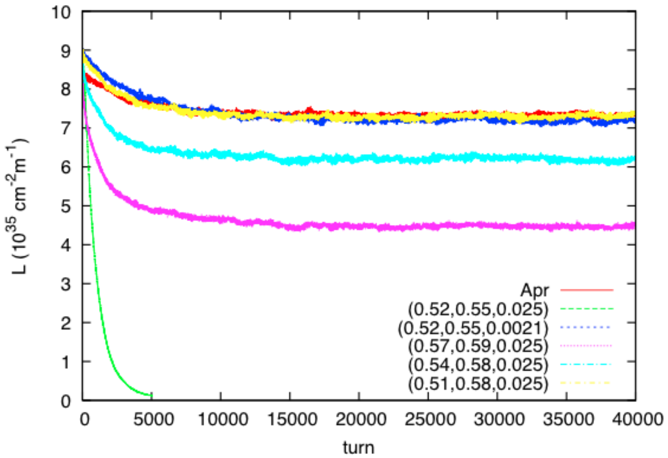


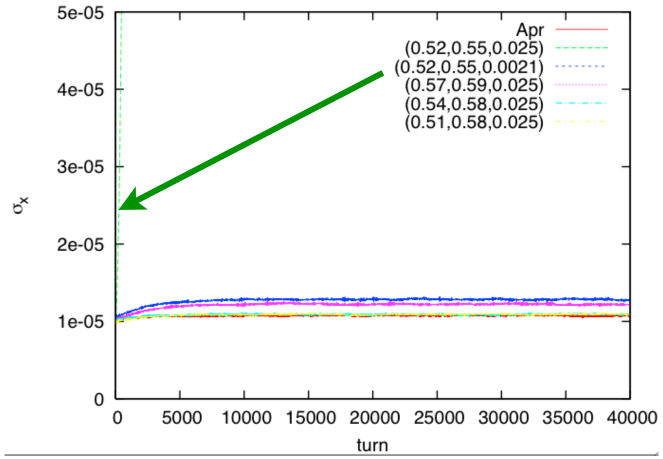
- $2\nu_x - n\nu_s = int$
- Very strong resonances are seen.

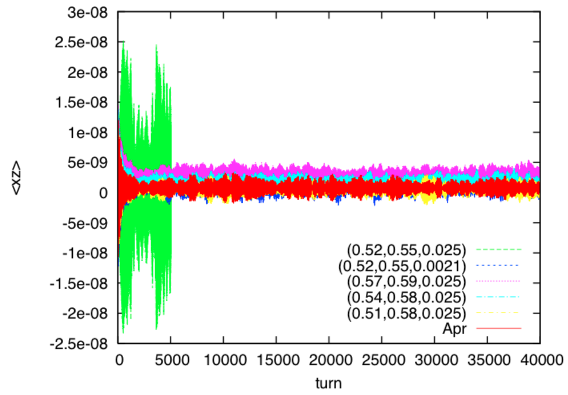


Tune near half integer is better.

Horizontal size and <xz>



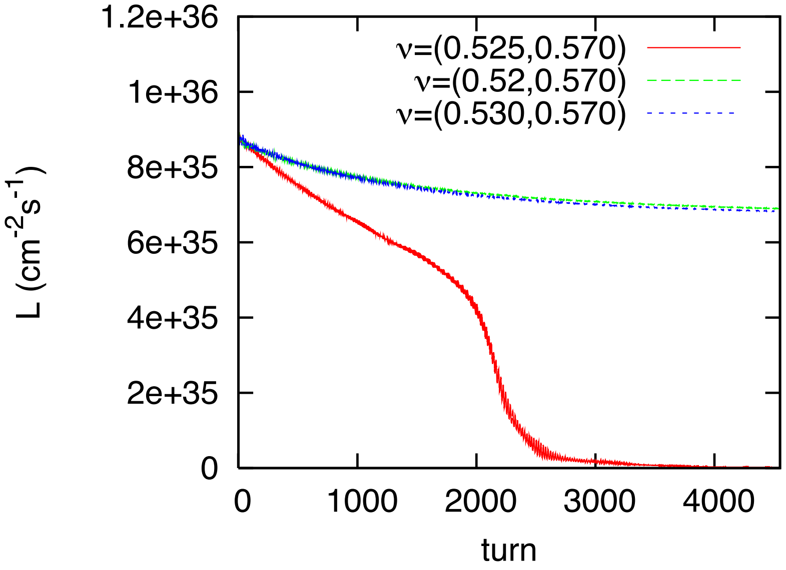


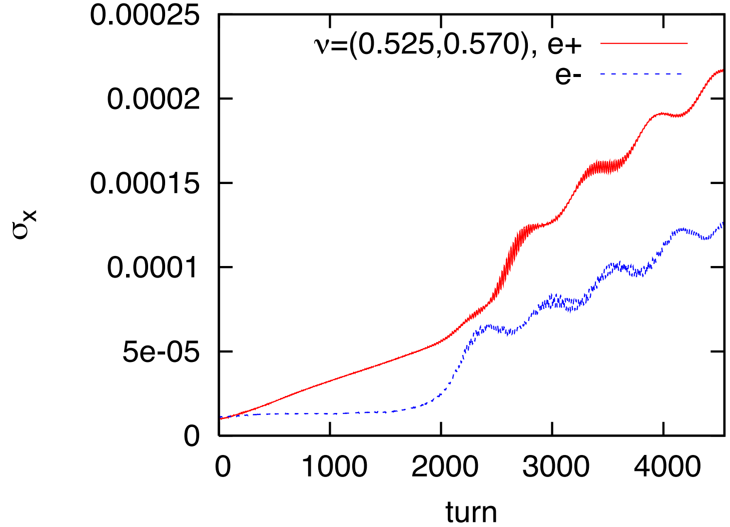


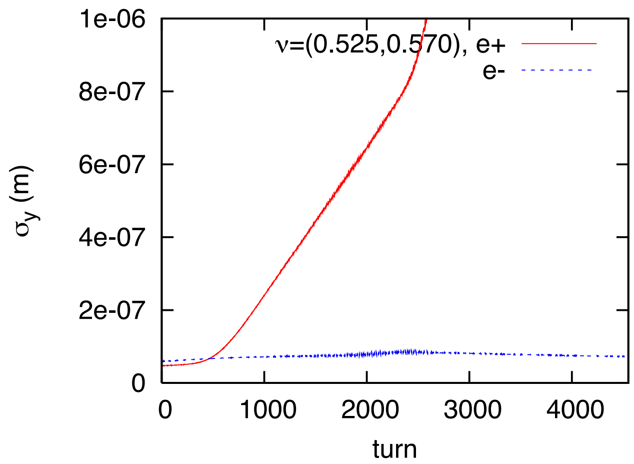
- σx and <xz> behave harmful at the resonance tune.
- Synchro-beta resonance. Increasing horizontal beam size enhances vertical hour glass.

Strong-strong beam-beam simulation

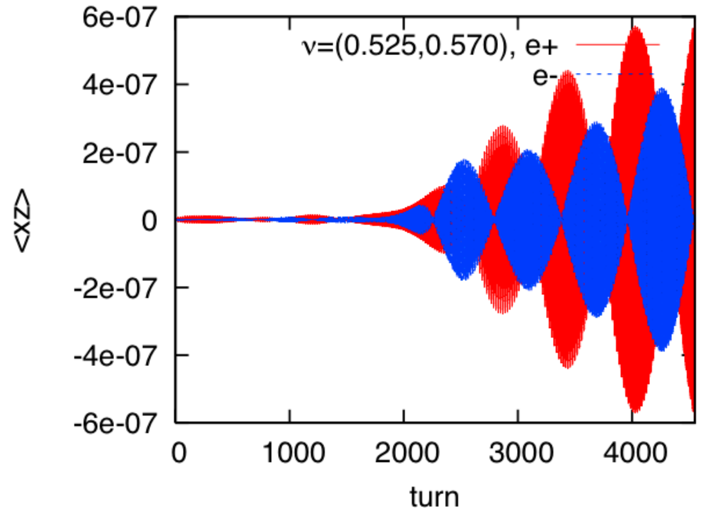
- Coherent instability should be studied by strong-strong model

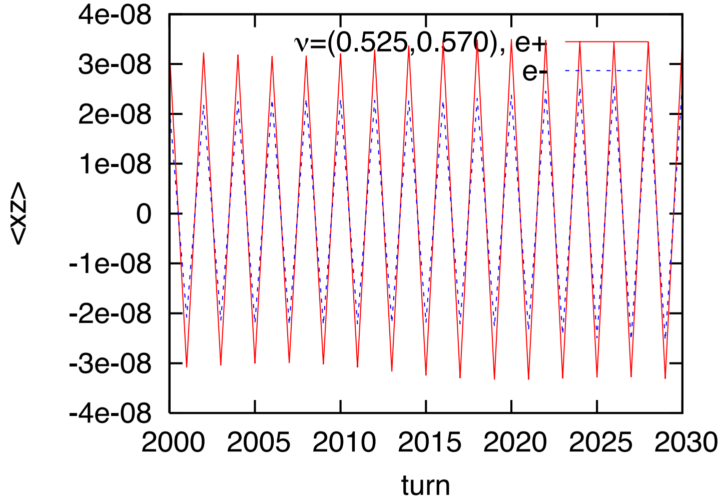




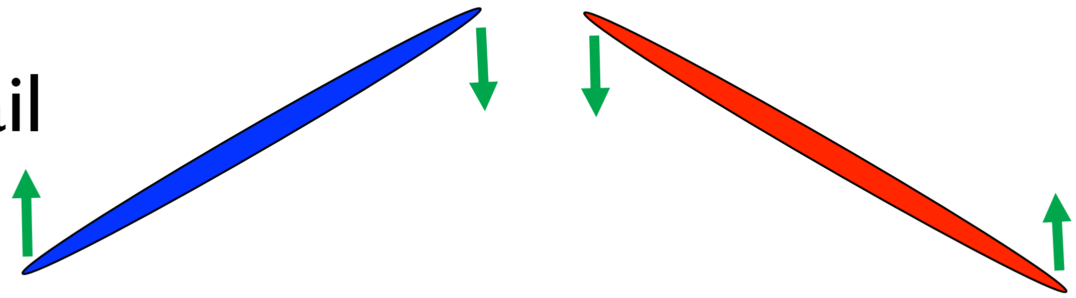


Coherent beam-beam motion on the s-β resonance





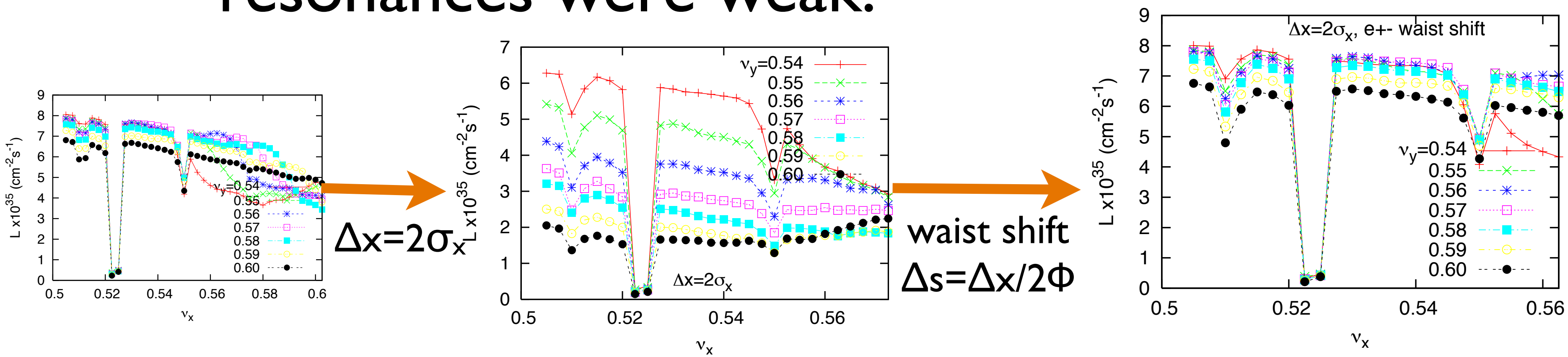
- $2\nu_x - 2\nu_s = \text{int}$
- Coherent head-tail mode



Tune scan and Synchro-beta resonances

- Though some resonances degrades luminosity, reliable tune area is a sufficient space.

- When a horizontal offset exists, resonances $2\nu_x-(2n-1)\nu_s$ can appear. The odd order resonances were weak.



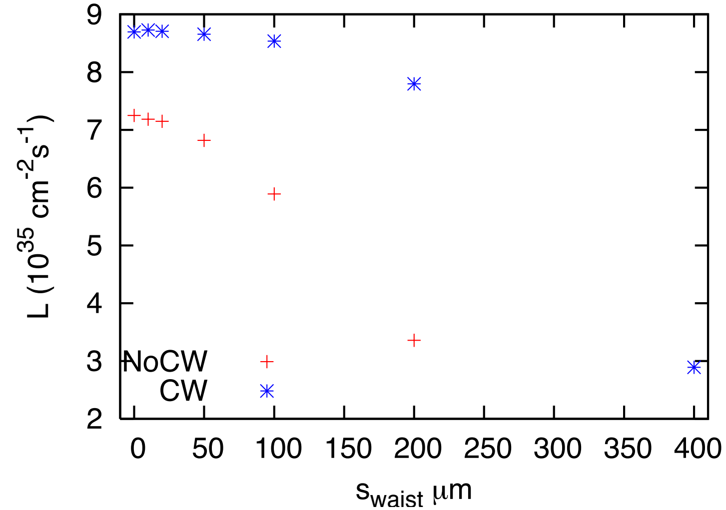
Coupling-dispersion error tolerance

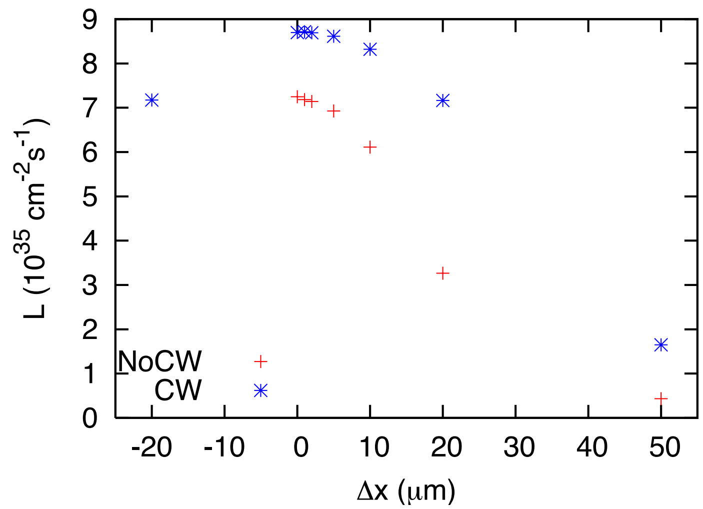
- Collision offset
- x-y coupling at the collision point
- dispersion at the collision point
- Their chromaticity

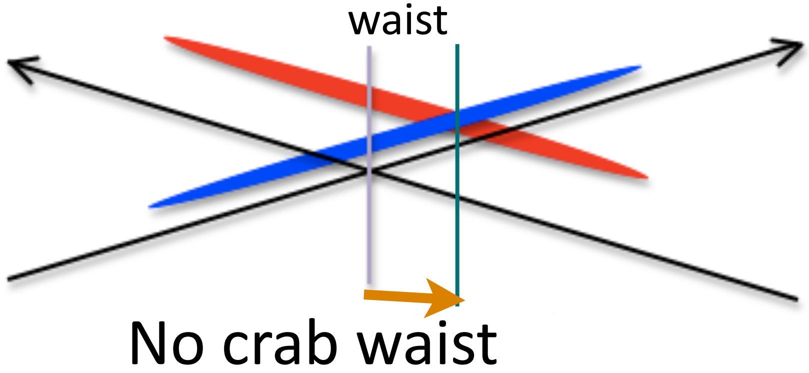
- Correction of these errors are essential to achieve the high performance in KEKB. It should be important also in SuperKEKB.

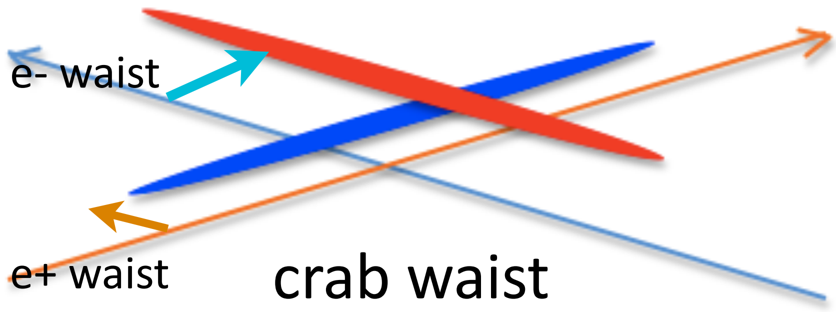
Tolerance of collision condition Horizontal collision offset and waist

- Horizontal offset and waist are related to each other.
- The cross point of the waist is only one in x-z plane for the crab waist scheme.



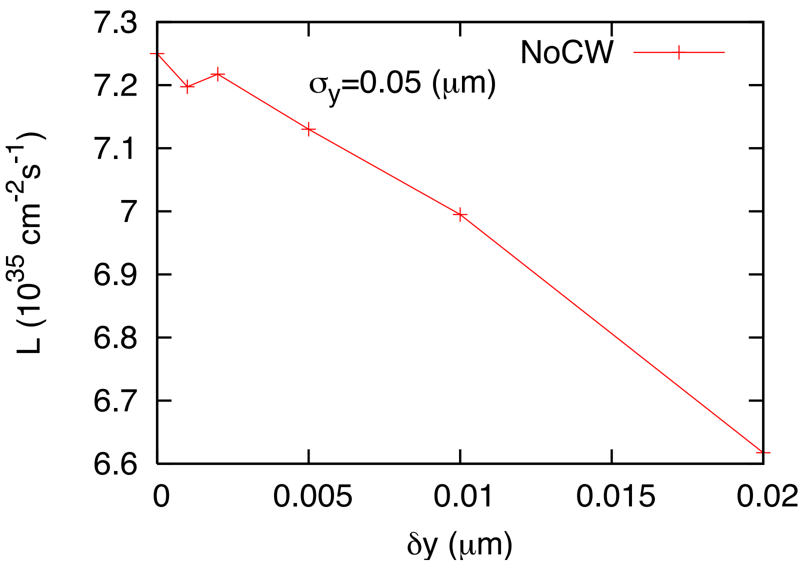


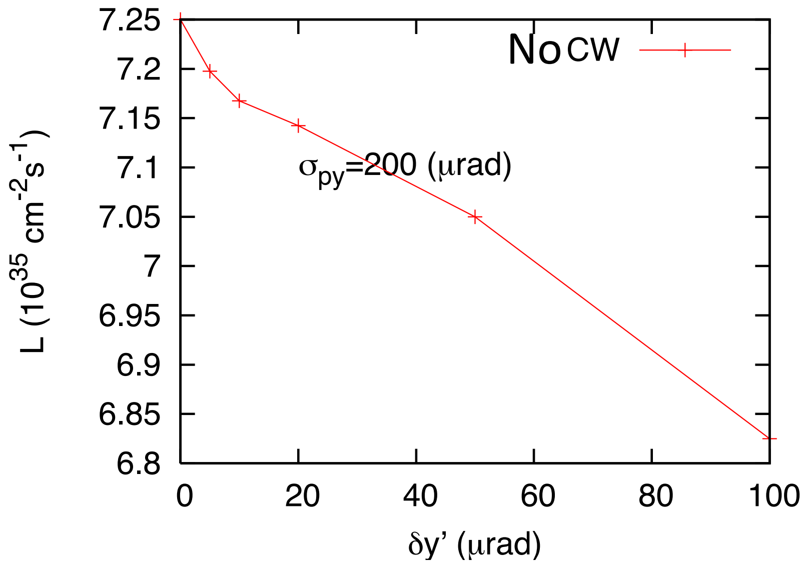




Vertical offset

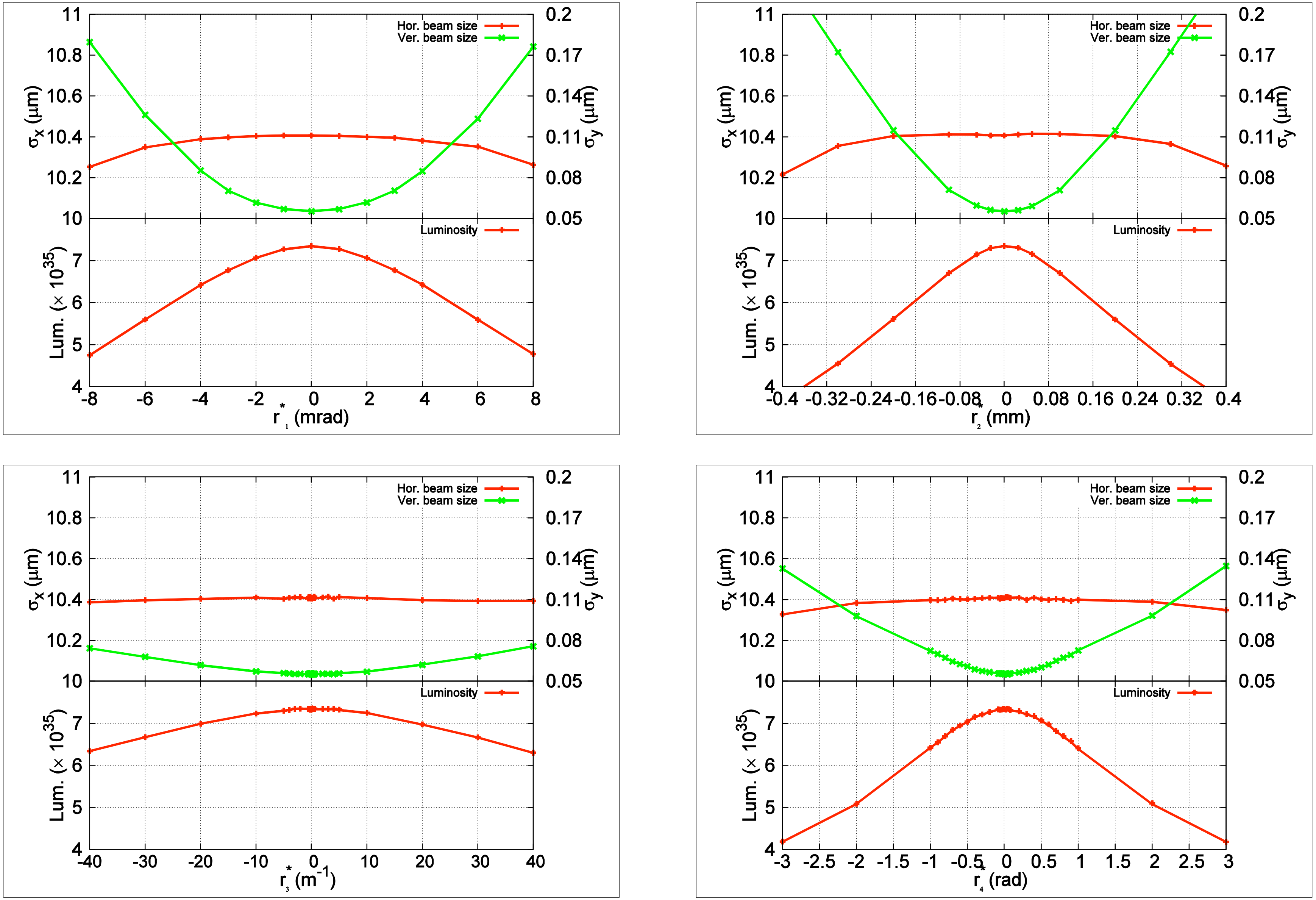
- tolerance ~$0.5\sigma_y$ (20%)
- $0.2\sigma_y$=0.01μm (5%)





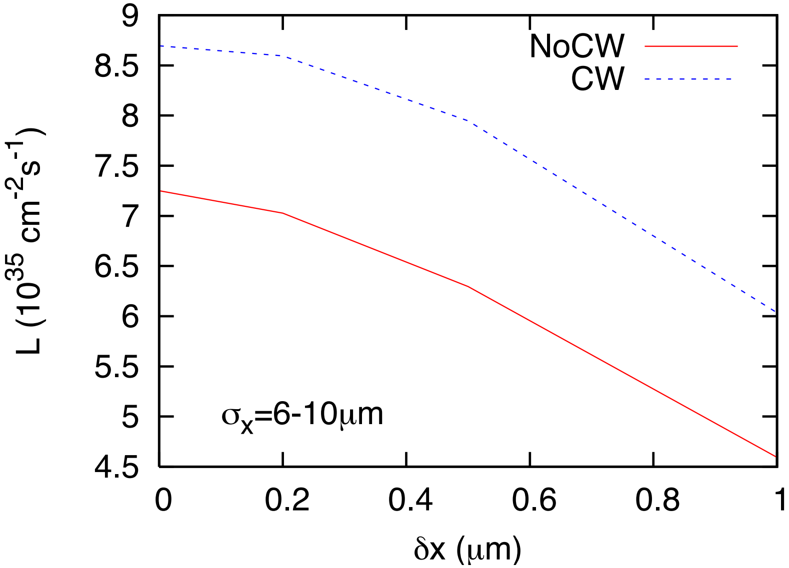
X-Y coupling w/ crab waist

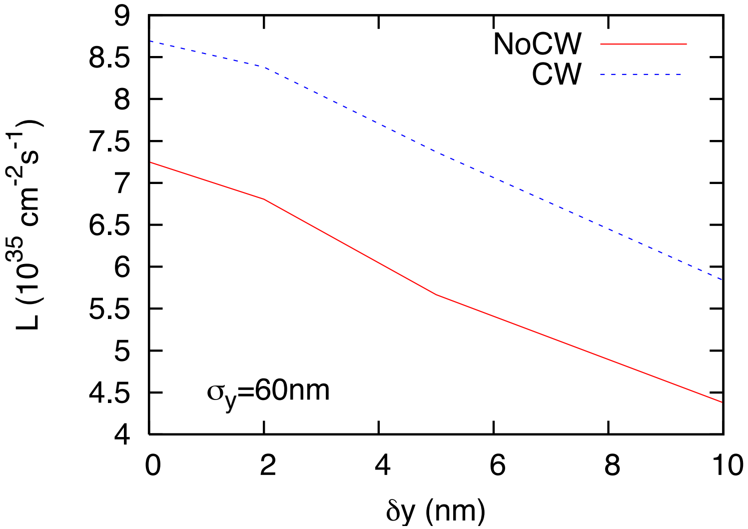
- D. Zhou & K. Ohmi

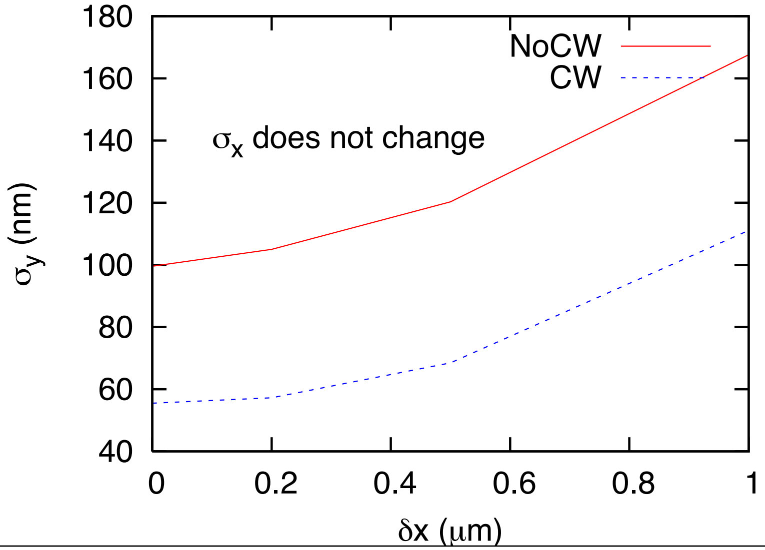


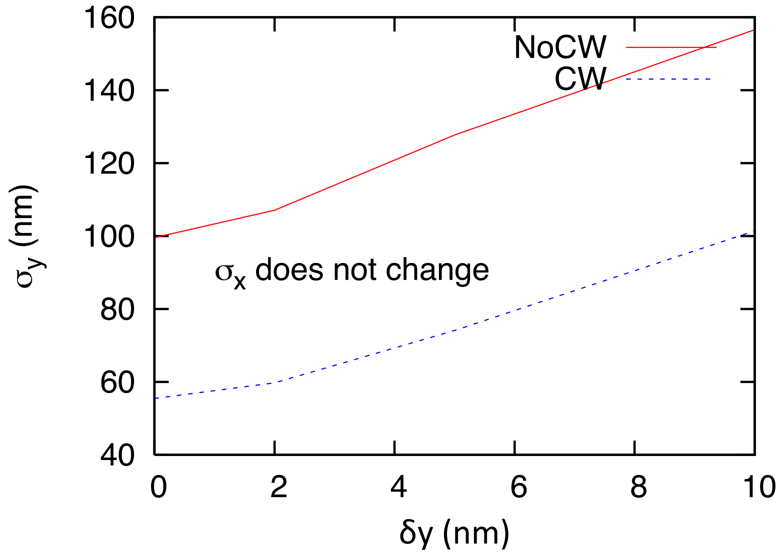
Beam noise

- Turn by turn noise









Summary – tolerance for parameters with 20% luminosity degradation

Parameter	w/ crab waist	w/o crab waist
r_1^* (mrad)	±5.3	±3.5
r_2^* (mm)	±0.18	±0.13
r_3^* (m^{-1})	±44	±15
r_4^* (rad)	±1.4	±0.4
$\partial r_1^* / \partial\delta$ (rad)	±2.4	±2.1
$\partial r_2^* / \partial\delta$ (m)	±0.086	±0.074
$\partial r_3^* / \partial\delta$ (m^{-1})	$\pm 1.0\times 10^4$	±8400
$\partial r_4^* / \partial\delta$ (rad)	±400	±290
η_y^* (μm)	±62	±31
$\eta_y'^*$	±0.73	±0.23
Δx (μm) collision offset	10	10
Δs (μm) waist error	100	100
Δy,Δy’(μm,μrad) collision offset	0.02 (100)	
δx (μm) turn by turn noise	0.5	0.5
δy (nm)	4	4

The degradation is roughly quadratic

σx=6-10μm σy=50 nm

Electron cloud instability

- $\omega_e \sigma_z / c$ is very high in low emittance rings.

- Single bunch instability
- Coupled bunch instability

Threshold of the strong head-tail instability (Balance of growth and Landau damping)

- Stability condition for $\omega_e\sigma_z/c>1$

$$\omega_e=\sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}$$

$$U=\frac{\sqrt{3}\lambda_p r_0\beta}{\nu_s\;\gamma\;\omega_e\sigma_z/c}\frac{\left|Z_\perp(\omega_e)\right|}{Z_0}=\frac{\sqrt{3}\lambda_p r_0\beta}{\nu_s\;\gamma\;\omega_e\sigma_z/c}\frac{KQ}{4\pi}\frac{\lambda_e}{\lambda_p}\frac{L}{\sigma_y(\sigma_x+\sigma_y)}=1$$

- Since $\rho_e=\lambda_e/2\pi\sigma_x\sigma_y$,

$$\rho_{e,th}=\frac{2\gamma\nu_s\,\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L}$$

Origin of Landau damping is momentum compaction

$$\nu_s\sigma_z=\alpha\sigma_\delta L$$

- $Q=\min(Q_{nl},\,\omega_e\sigma_z/c)$
- Q_{nl}=10 in this presentation, depending on the nonlinear interaction.
- K characterizes cloud size effect and pinching.

Parameters

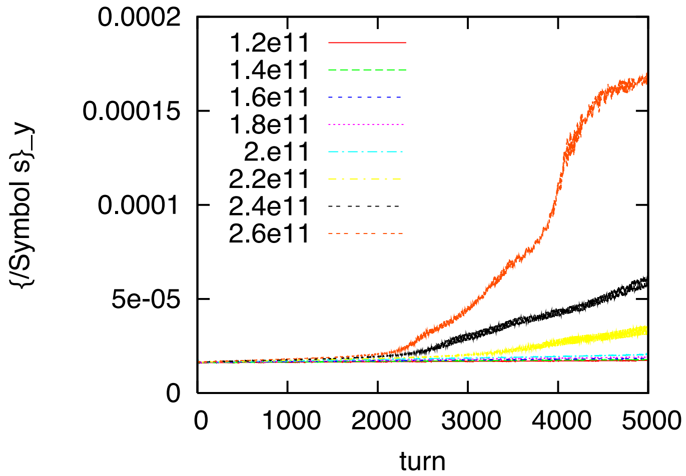
Table 1: Basic parameters of the positron rings

Lattice		KEKB	Cesr-TA	PETRA-III	SuperKEKB	Super B
Circumference	L (m)	3,016	768	2304	3016	1260
Energy	E (GeV)	3.5	2-5	6	4.0	6.7
Bunch population	$N_+(10^{10})$	8	2	0.5	9	5
Beam current	I_+ (A)	1.7	-	0.1	3.6	1.9
Emittance	ε_x(nm)	18	2.3	1	3.2	2
	ε_y(nm)	0.18	0.023	0.01	0.01	0.005
Momentum compaction	$\alpha(10^{-4})$	3.4	68	12.2	3.5	
Bunch length	σ_z(mm)	6	6.8	12	6	5
RMS energy spread	$\sigma_E/E(10^{-3})$	0.73	0.8		0.8	0.64
Synchrotron tune	ν_s	0.025	0.067	0.049	0.0256	0.0126
Damping time	τ_x(ms)	40	56.4	16	43	26

Table 2: Threshold of the B factories positron rings and others

		KEKB (no sol.)	KEKB (50 G sol.)	Cesr-TA	PETRA-III	SuperKEKB	SuperB
Bunch population	$N_+(10^{10})$	3	8	2		8	5
Beam current	I_+ (A)	0.5	1.7	-	0.1	3.6	1.9
Bunch spacing	ℓ_{sp}(ns)	8	7	4-14	8	4	4
Electron frequency	$\omega_e/2\pi$(GHz)	28	40	43	35	150	175
Phase angle	$\omega_e\sigma_z/c$	3.6	5.9	11.0	8.8	18.8	18.3
Threshold	ρ_e (10^{12} m^{-3})	0.63	0.38	1.7	1.2	0.27	0.54

SuperKEKB



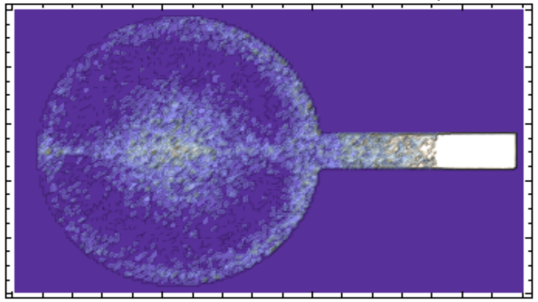
Y. Susaki, K. Ohmi, IPAC10

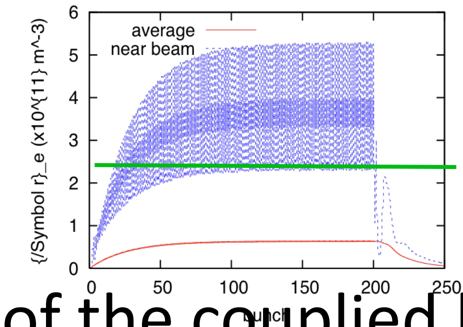
- Simulation ρ_{th}=2.1x10^{11} m^{-3}.(ν_s=0.012)
- Analytic ρ_{th}=2.7x10^{11} m^{-3}.
- **Target ρ_e~1x10^{11} m^{-3}**
- Take care of high β section. Effects are enhanced.

$$\oint \rho_e \beta_y ds/L = 10^{11} \times 10 \text{ m}^{-2}$$

Estimation of cloud density and coupled bunch instability

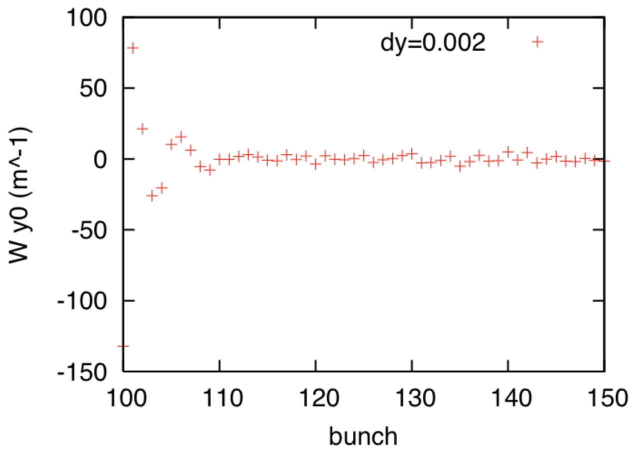
- Ante-chamber, $\delta_{2,max}$=1.2 without special structure like groove

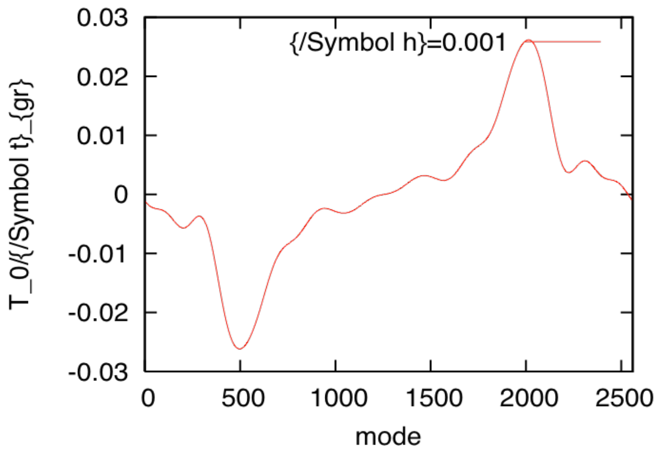




ρ_e=2.2x10^{11} m^{-3}

- Wake field and growth rate of the couplied bunch instability.





Growth time is 40 turns. It should be suppressed at ρ_e=1x10^{11} m^{-3}.

- Suetsugu-san estimates the density based on measurements and is designing the chamber to achieve density.

Fast head-tail instability due to mask impedance

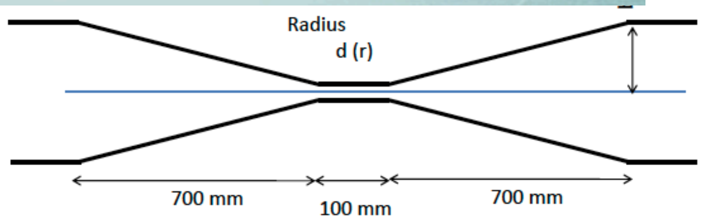
- Y. Suetsugu & D. Zhou

Estimated TMCI threshold

Component	Number of item	Average β_x/β_y (m)[1]	Kicker factor per item $k_{\perp x}/k_{\perp y}$ (V/pC/m)[2]	I_{th} (mA)
ARES cavity	18	19.5/31.8	1.1/1.2	210/120
BPM	440	16.6/23.4	$(6.7/5.7)\times10^{-3}$	1620/1360
Stripline kicker	1	29.4/15.2	2.5/2.5	1110/2140
Vertical mask[5]	4	12.3/14.7	3.9/1010	424/1.4
			?/104[3]	?/13.3
			?/1257[4]	?/1.1
Horizontal mask[6]	4	24.3/5.7	83.2/3.5	10.1/1020
			19/?[3]	44.1/?
Bellows	1000	10/11	0.026/0.055	313/135

Gdfidl
2D round model
rectangular cross sec.

V mask



d=2mm$^{\Phi}$

Beam tilt due to the impedance

$$\Delta y(z) = \sqrt{\beta_y \beta_y^*} \Delta y'(z) = \sqrt{\beta^*} \sum_i \sqrt{\beta_y(i)} y_0(i) \frac{1}{eE} \int_0^\infty \rho(z' + z) W_{y1}(z') dz'$$

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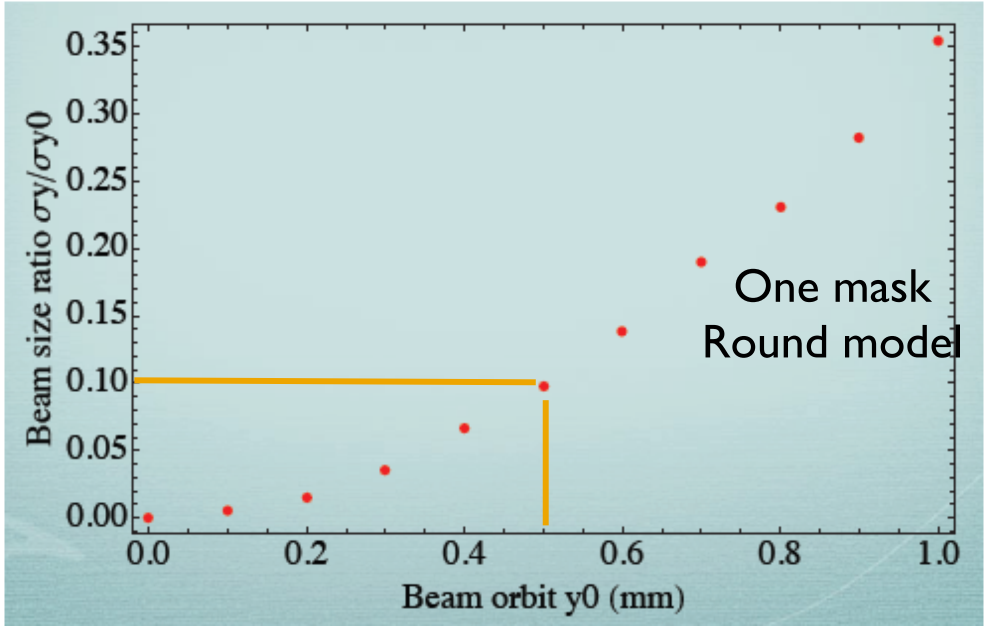

- Round model impedance: 1/10 of instability threshold.
- For the case of the impedance corresponding the instability threshold, tolerance of the orbit shift is 0.05 mm for 10% beam size increase.

Summary

- Tune scan and synchro-beta resonance for the beam-beam performance is done. Reliable tune area was a sufficient space.
- The tolerance for optics errors at IP was determined.
- Target electron cloud density to avoid instabilities was determined.
- Mask estimation and design will be updated.