Tolerance for Beam-beam and ecloud

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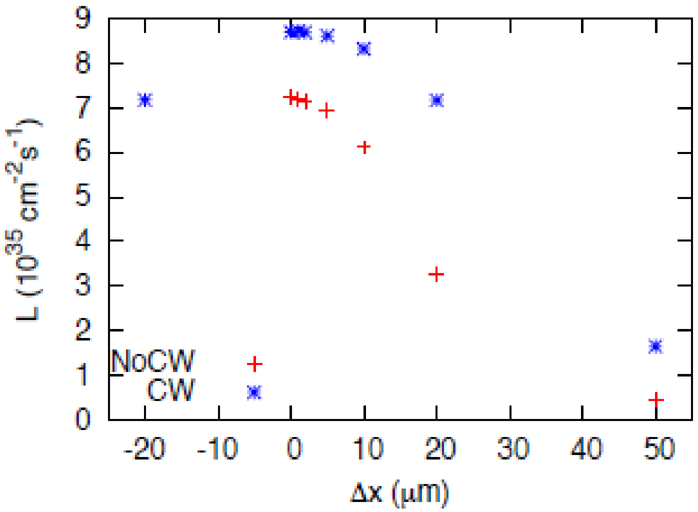
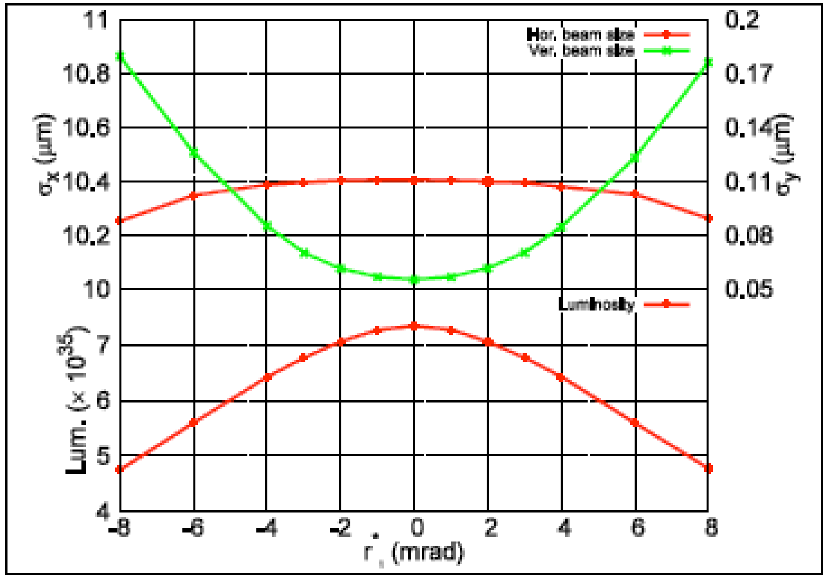
Tolerance of IR errors for Beam-beam interactions

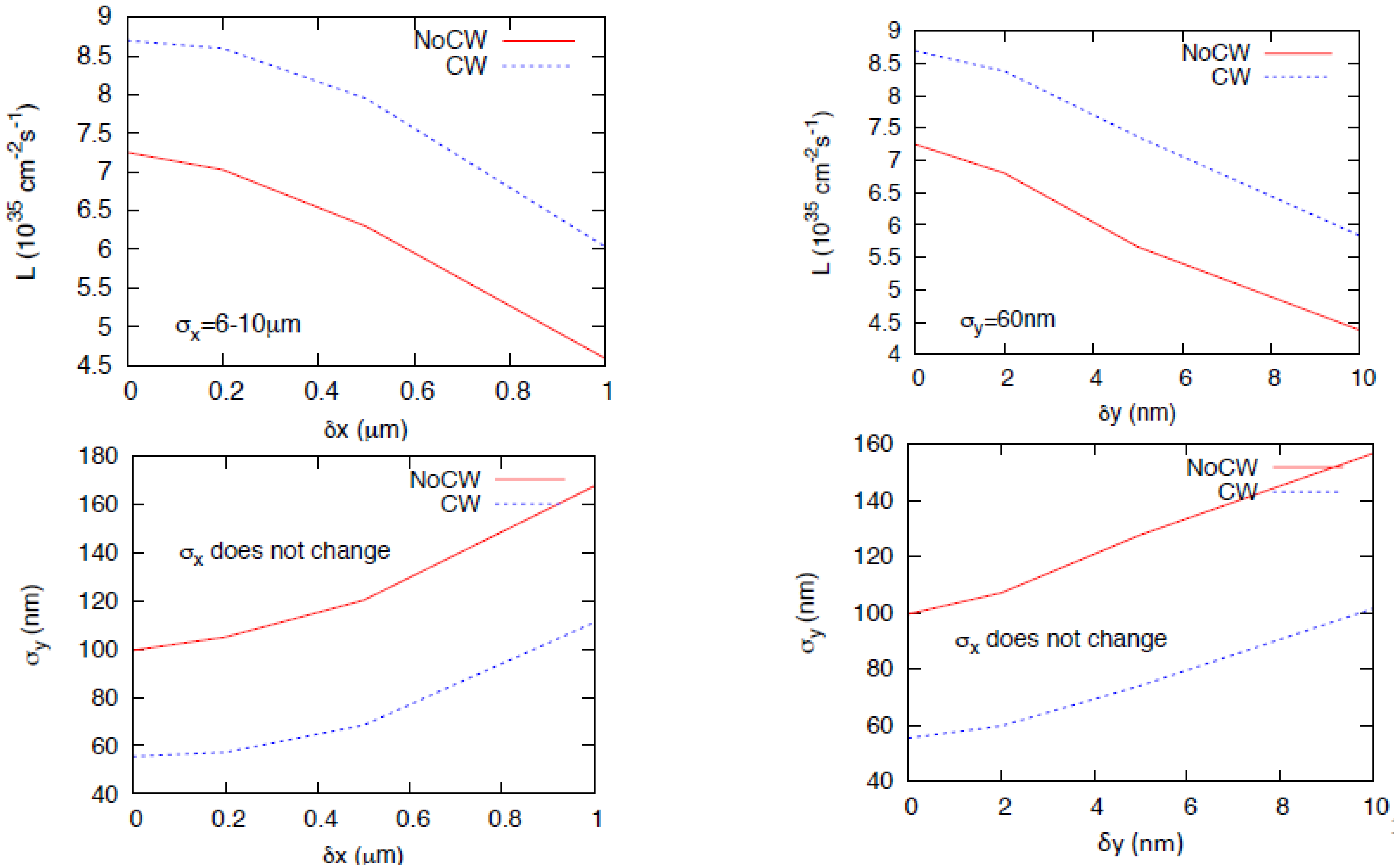
- Weak-strong simulation is used for the parameter scan.
- Examples, x-offset and r1*.





Beam noise

- Turn by turn noise without correlation in turns.



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=60 nm

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

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

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

$$U = \frac{\sqrt{3} r_e \beta_y}{\gamma \nu_s \omega_e \sigma_z/c} \frac{|Z_\perp(\omega_e)|}{Z_0} = \frac{\sqrt{3} r_e \beta_y}{\gamma \nu_s \omega_e \sigma_z/c} \frac{KQ}{4\pi} \frac{\lambda_e}{\lambda_p} \frac{L}{\sigma_y(\sigma_x+\sigma_y)}$$

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

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

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.
- $\omega_e\sigma_z/c$~12-20 for SuperKEKB.
- We use $K=\omega_e\sigma_z/c$ and $Q_{nl}=7$ for analytical estimation.

Parameters

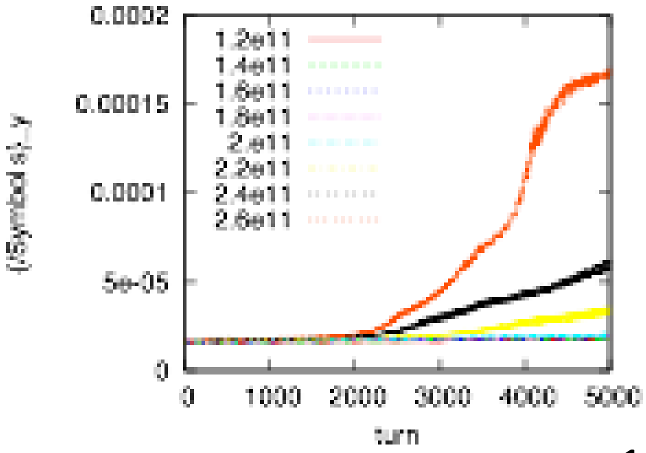
Table 1: Basic parameters of the positron rings

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 simulation in 2010



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- Simulation ρ_{th}=2.1x10^{11} m^{-3}.(ν_s=0.012)
  ρ_{th}=4.5x10^{11} m^{-3}.(ν_s=0.025)
- Analytic ρ_{th}=2.7x10^{11} m^{-3}.(ν_s=0.025)
- **Target ρ_e~1x10^{11} m^{-3}**
- Take care of high β section. Effects are enhanced.

$$\frac{1}{L}\oint \rho_e \beta_y ds = 10 \times 10^{11}\, m^{-1} \quad or \;\; 45 \times 10^{11}\, m^{-1}$$

Electron cloud instability in high beta lattice

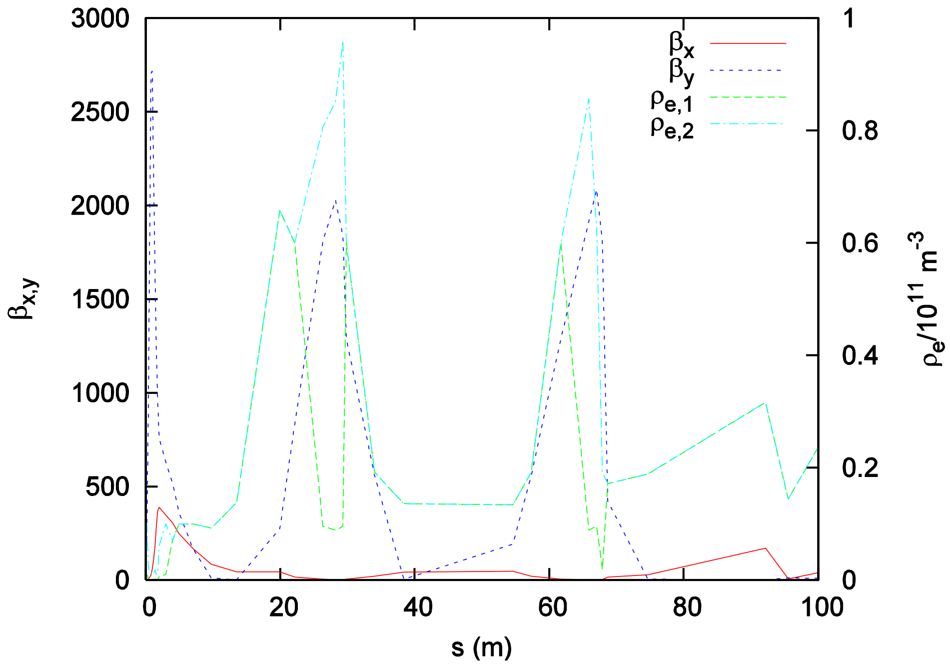
- Realistic electron cloud distribution was given by Suetsugu et al.
- The wake effect to beam is stronger for large β_y.
- IR beta is huge, β_y=2000-3000m. Beam size is large , electron frequency is slow.

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

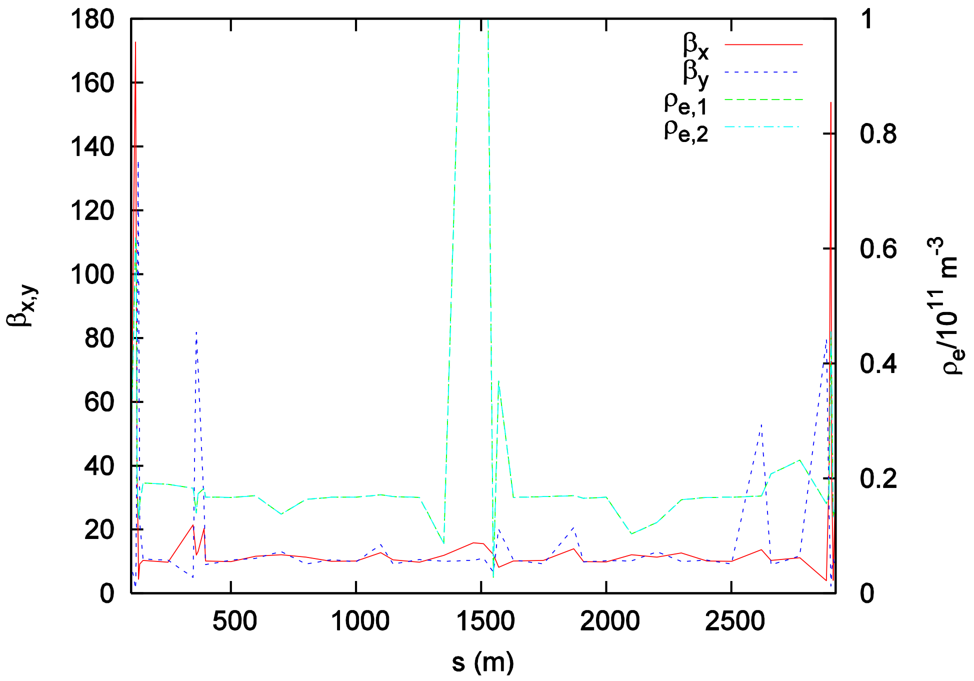
- Unstable mode depends on $\omega_e\sigma_z/c$, and the spread reduces Q factor of the electron cloud wake.
- The estimation using $\oint \rho_e \beta_y ds$ is inaccurate.
- PEHTS simulation using s dependent grid Poisson solver have been performed.

Beta function and estimated cloud density

IR

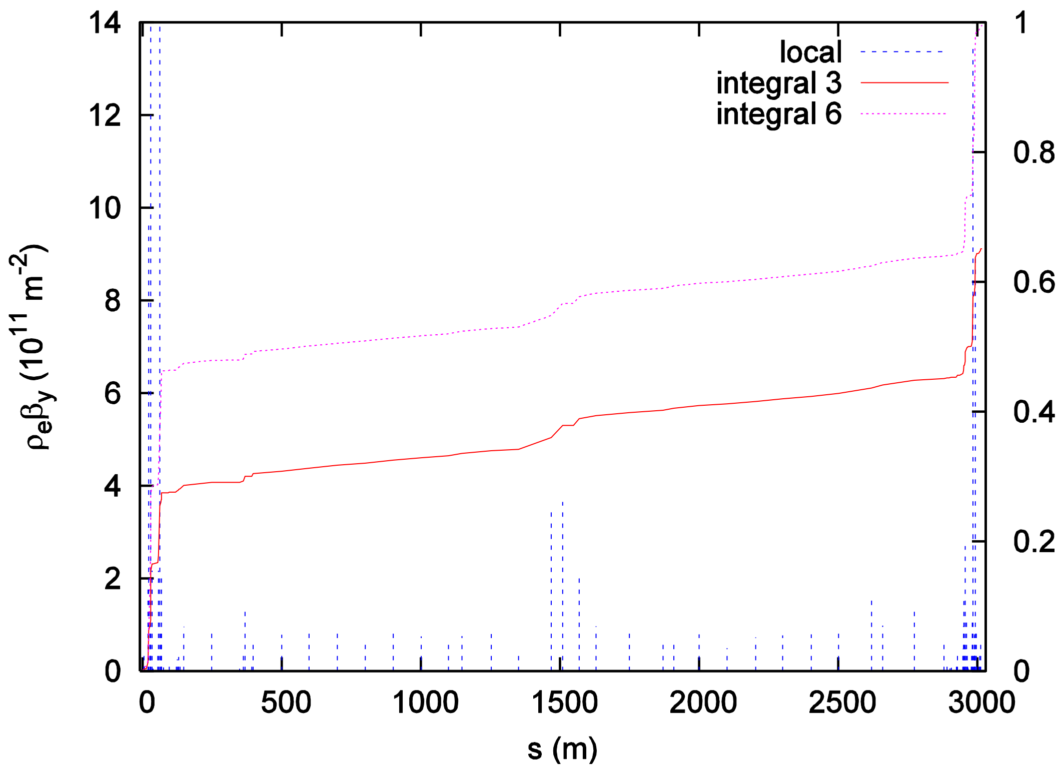


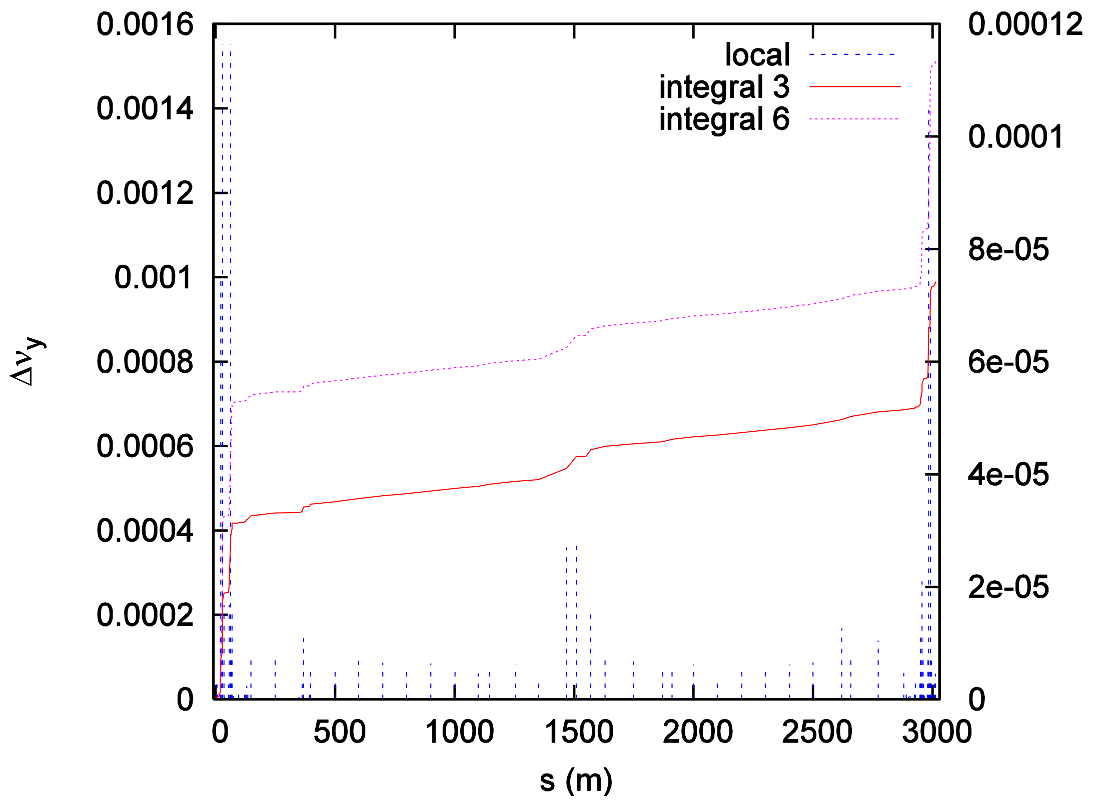
whole ring



Two cases of cloud densities, model 3; green and model6; cyan curves. (Suetsugu)

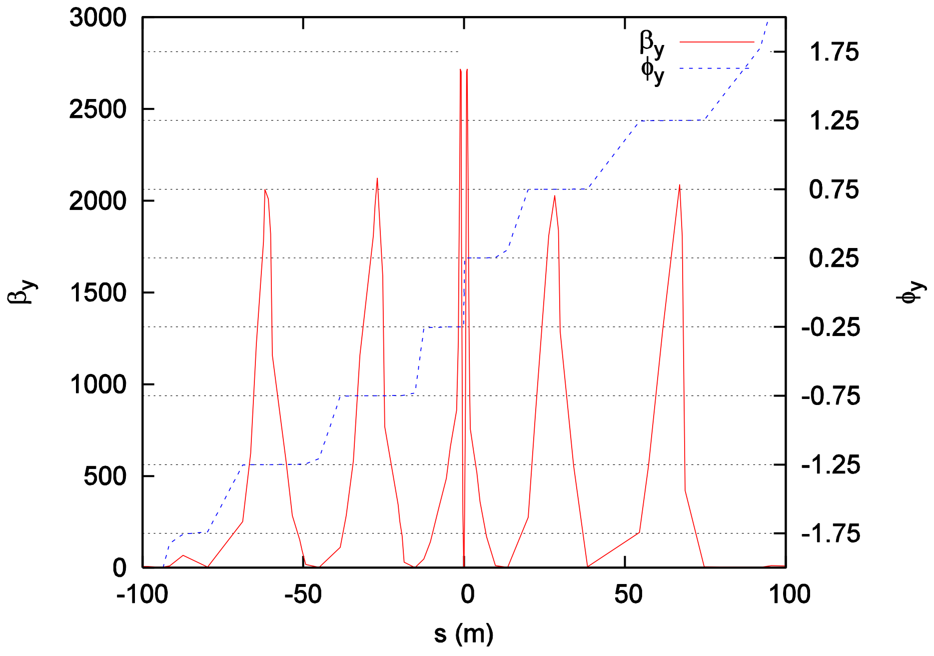
Tune shift contribution

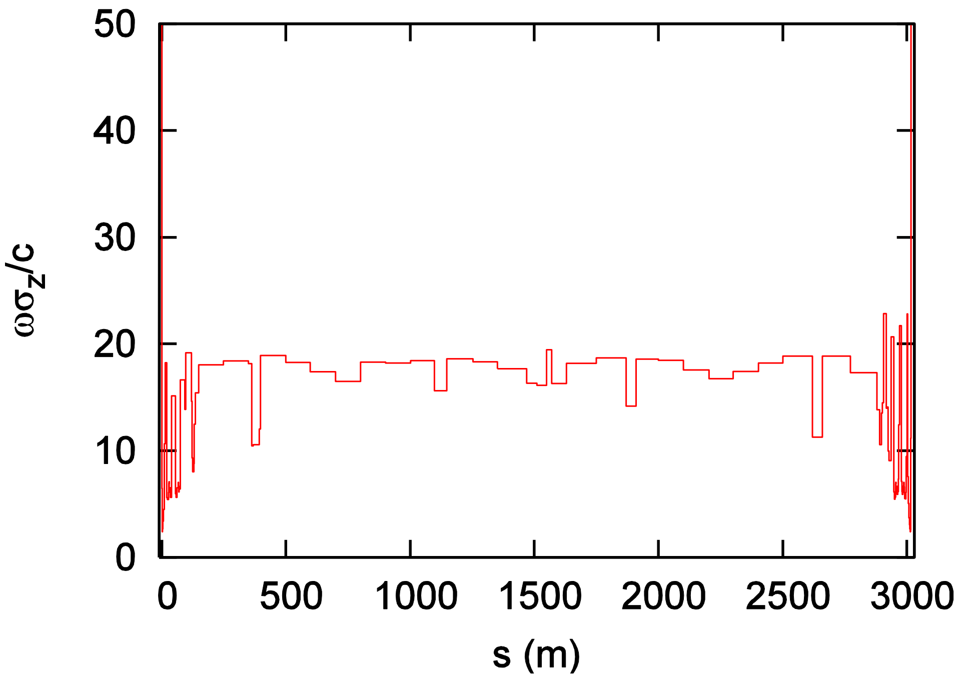




- Tune shift and $\rho_e\beta_y$ near IR (-70<s<70m) are dominant.
- Design $\frac{1}{L}\oint \rho_e\beta_y ds = 10 - 14 \times 10^{11}\ m^{-1}$

Betatron tune and electron frequency variations

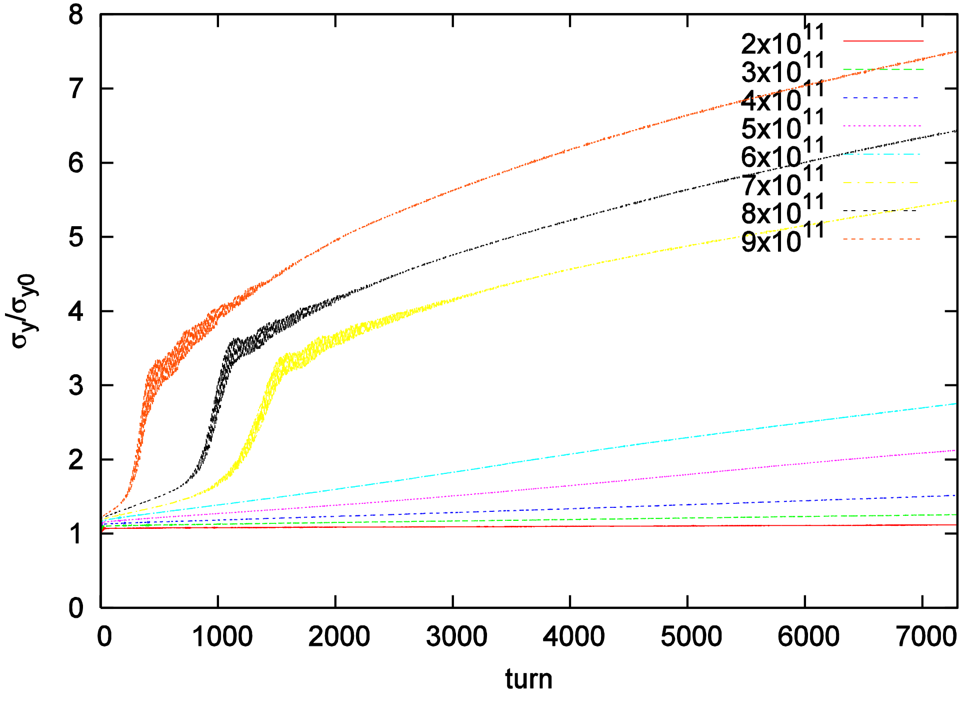




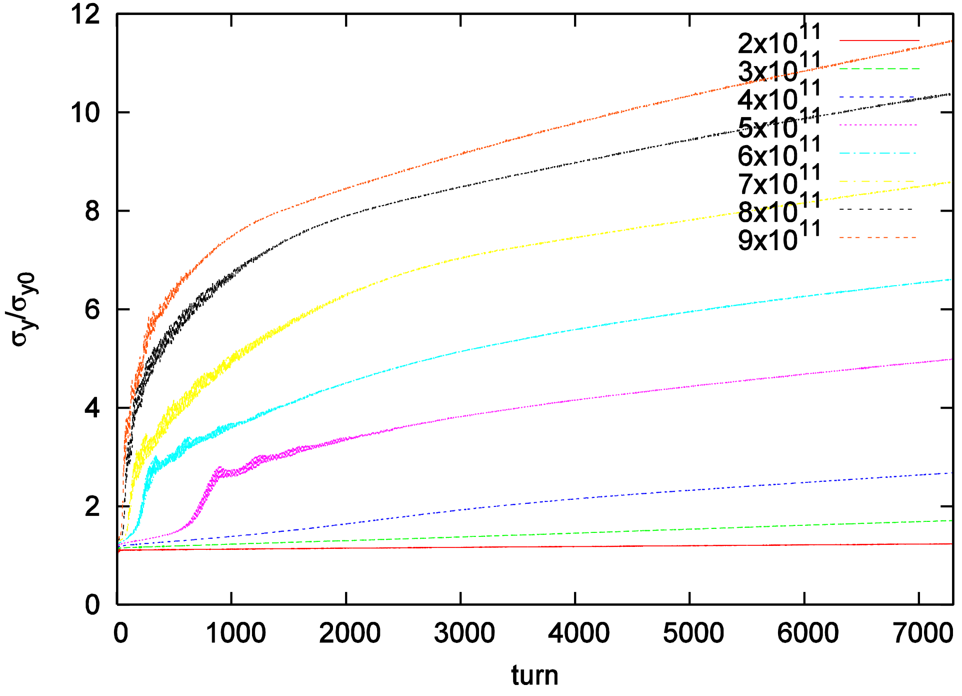
- High beta section separate the betatron phase difference π. Nonlinear force with even parity is coherently accumulated.
- $\omega_e\sigma_z/c$ is very high near IP. The area is narrow and low beta, neglect.

Vertical emittance growth caused by the electron cloud fast head-tail instability

Model 3: green in p.9



Model 6: cyan in p.9



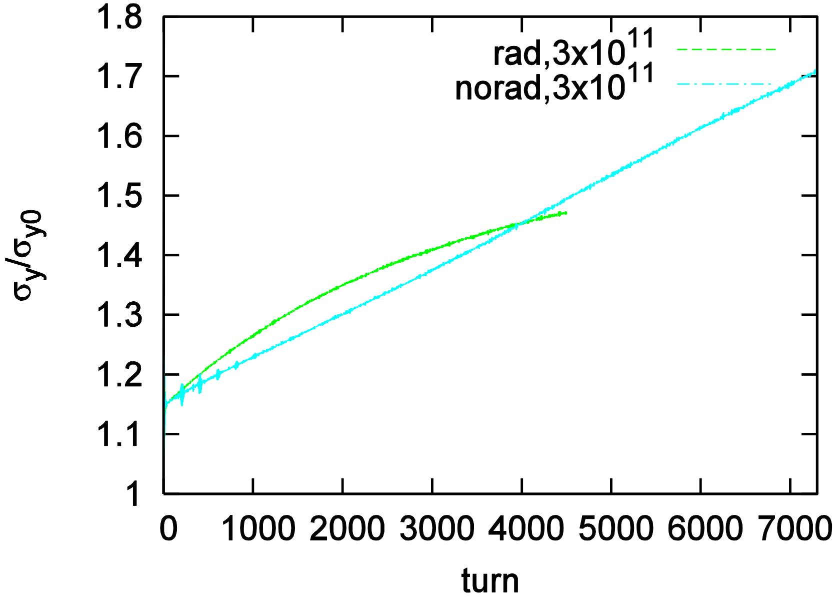
$\rho_{e,th}$=6xdesign

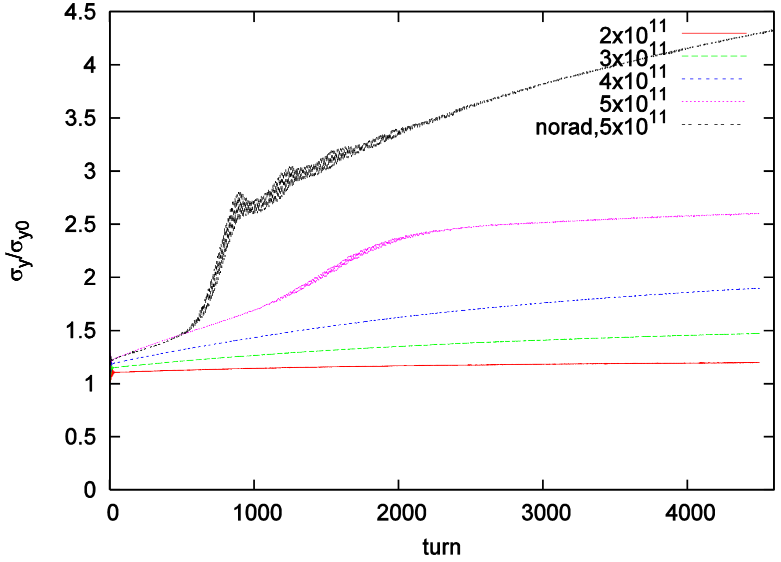
$$\frac{1}{L}\oint \rho_e \beta_y ds = 60 \times 10^{11}\ m^{-1}$$

$\rho_{e,th}$=4xdesign

$$64 \times 10^{11}\ m^{-1}$$

Radiation damping and excitation



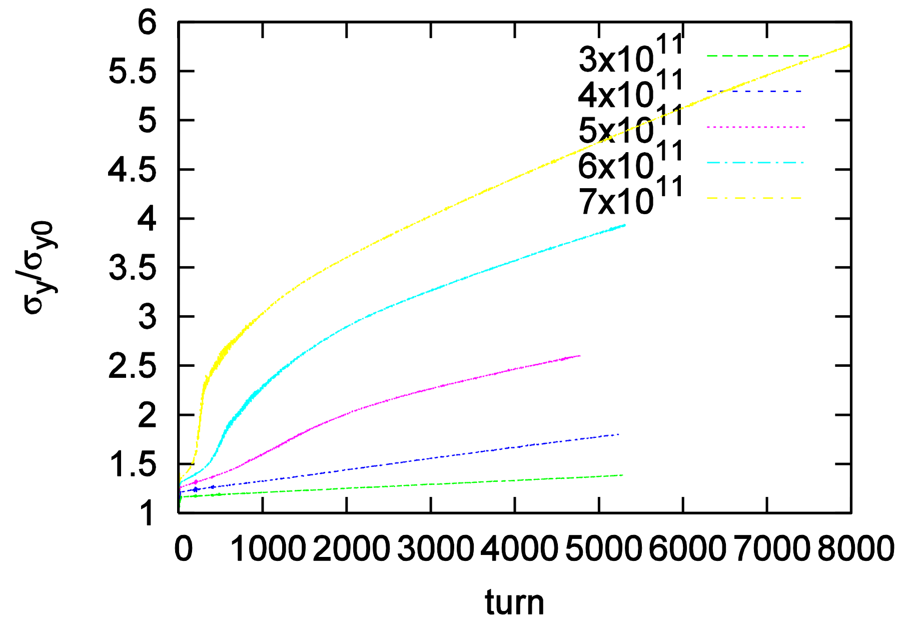


- Equilibrium emittance is 1.5xε_{design} for ρ_e=3x design, 1.2ε_{design} for ρ_e=2x.

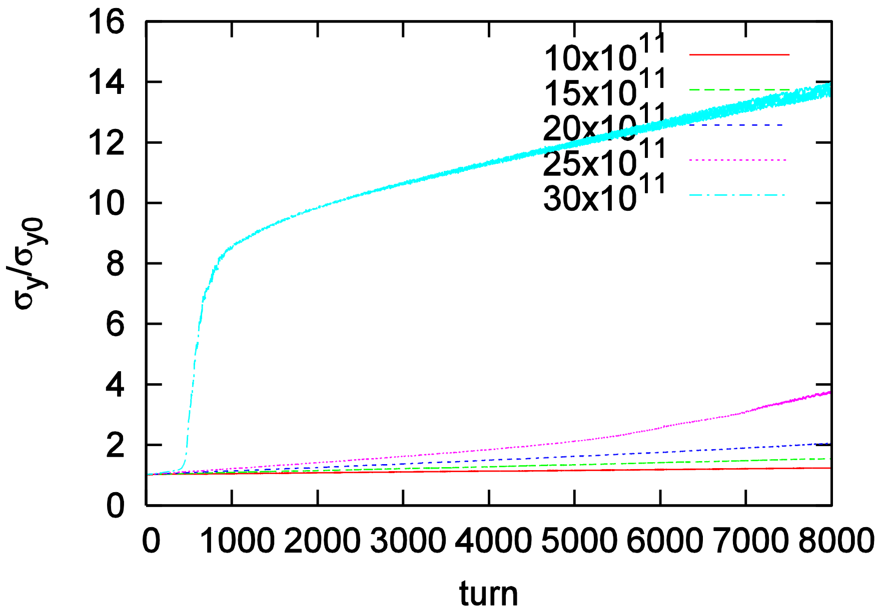
$$\frac{1}{L}\oint \rho_e \beta_y ds = 42 - 28 \times 10^{11}\, m^{-1}$$

- Radiation damping somewhat suppress the coherent instability at ρ_e=4-5x design (black to magenta).

Which cloud is dominant, in IR or Arc.



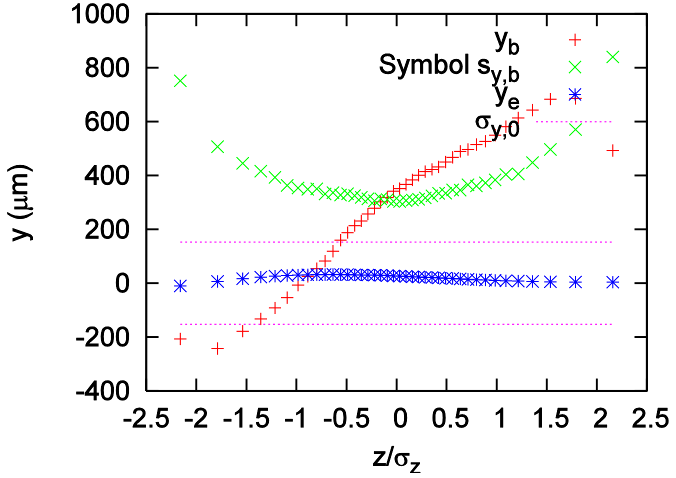
Electrons only near IR



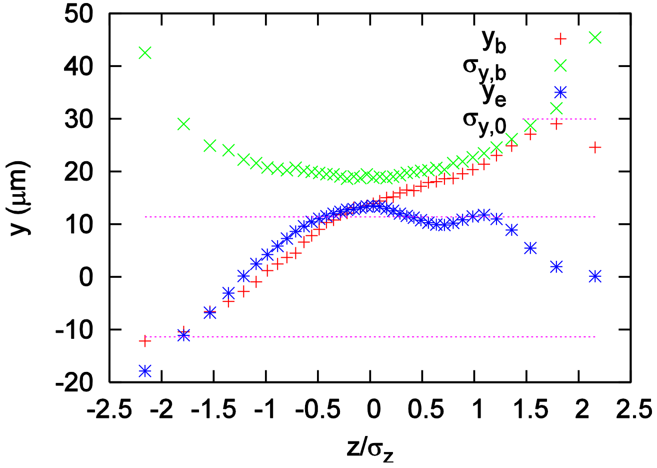
Electrons only in ARC

- Electrons near IR is dominant.
- It means that the incoherent emittance growth is evaluated correctly.

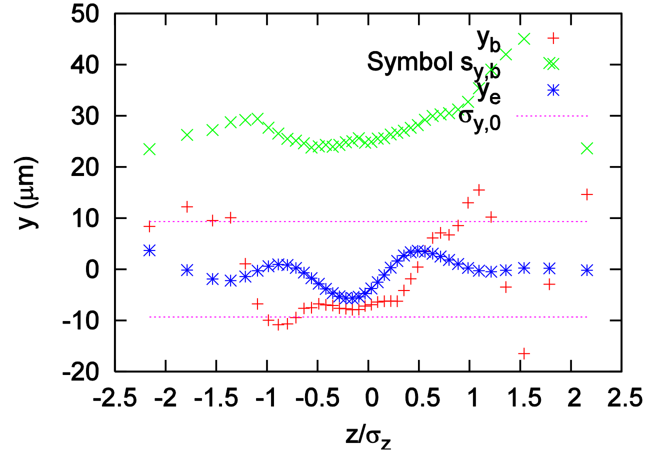
Bunch/electron motion in the instability



Slow cloud motion (blue) at β_y=2000m



Fast cloud motion at β_y=10m



Instability due to electrons only in ARC.

Fast cloud motion (blue) and higher mode instability (red)

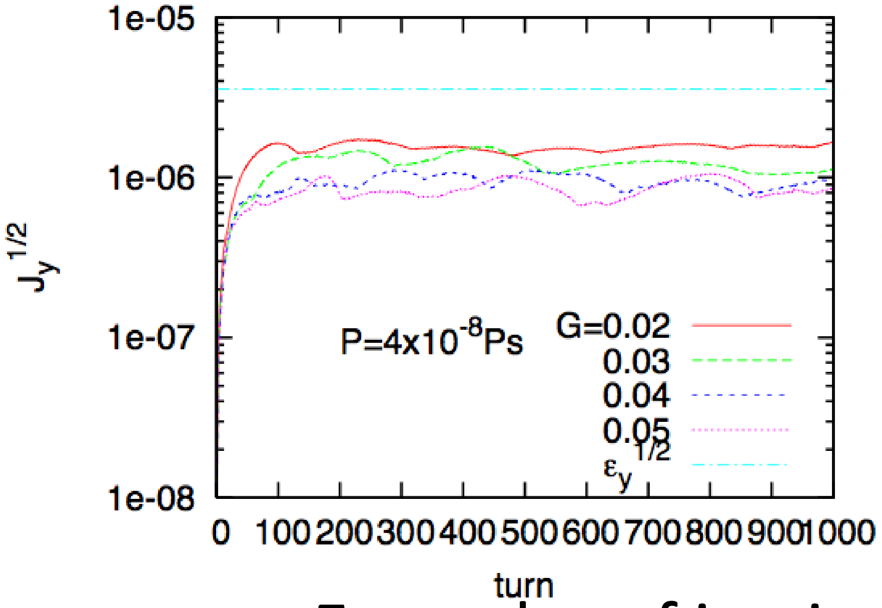
Summary

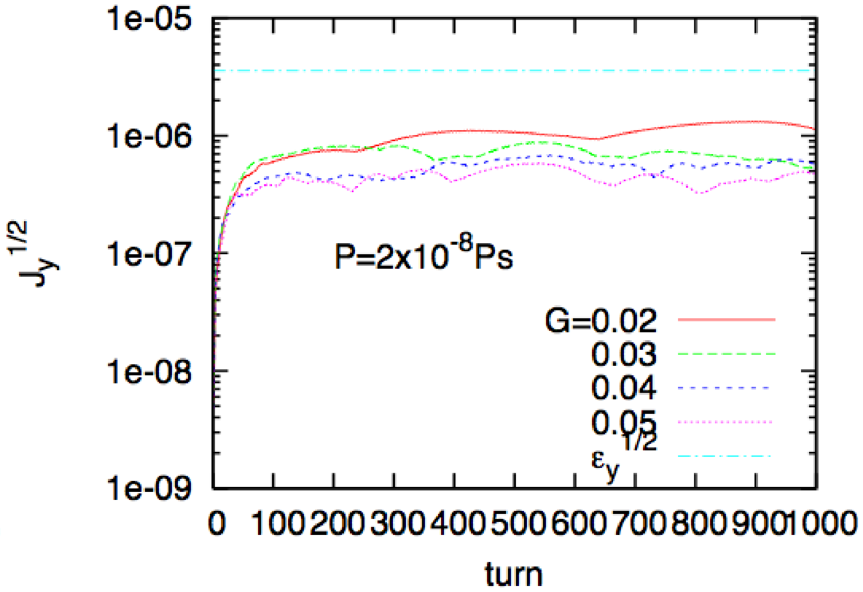
- IP optics tolerance for beam-beam interaction is presented.
- Simple estimation for electron cloud fast head-tail instability is presented.
- Detailed electron distribution along the ring is taken into account.
- Electrons in high beta section is dominant.
- The threshold is $\frac{1}{L}\oint \rho_e \beta_y ds = 60 \times 10^{11}\ m^{-1}$
- Incoherent emittance growth is visible around $\frac{1}{L}\oint \rho_e \beta_y ds = 20 \times 10^{11}\ m^{-1}$
- Design $\frac{1}{L}\oint \rho_e \beta_y ds = 10 - 14 \times 10^{11}\ m^{-1}$

Ion instability

- Turn-by-turn noise due to ion instability.
- Coupled bunch instability with very high growth rate.
- Feedback system suppresses the instability.
- Residual dipole motion as a turn by turn noise may degrade the beam-beam performance.

Instability growth with bunch-by-bunch feed back





- Examples of ion instability growth
- Bunch train length of Nb=2500 with spacing=4ns.

Ion frequency and growth contribution