Beam Dynamics
Beam-beam and electron cloud

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Machine parameters

2013/July/29	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.18×10^{-4}	4.53×10^{-4}		
σ_δ	$8.10(7.73) \times 10^{-4}$	$6.37(6.30) \times 10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6.0(5.0)	5(4.9)	mm	():zero current
ν_s	-0.0244	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.86	2.43	MeV	
$\tau_{x,y}/\tau_s$	43.2/21.6	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

From http://www-superkekb.kek.jp/index.html

Beam-beam effects in nano beam collision

- Simulation results of weak-strong simulation, BBWS, using linearized arc.
- Error tolerance for IR optics
- Realistic arc containing lattice nonlinearity.
- Space charge and beam-beam.

2. Beam-beam and luminosity: LER

➢ Lum. tune scan for LER (by BBWS: weak strong with linear arc)

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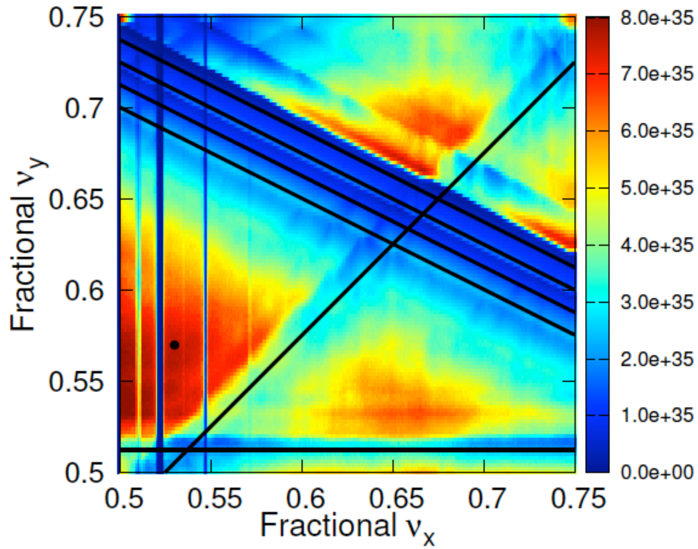
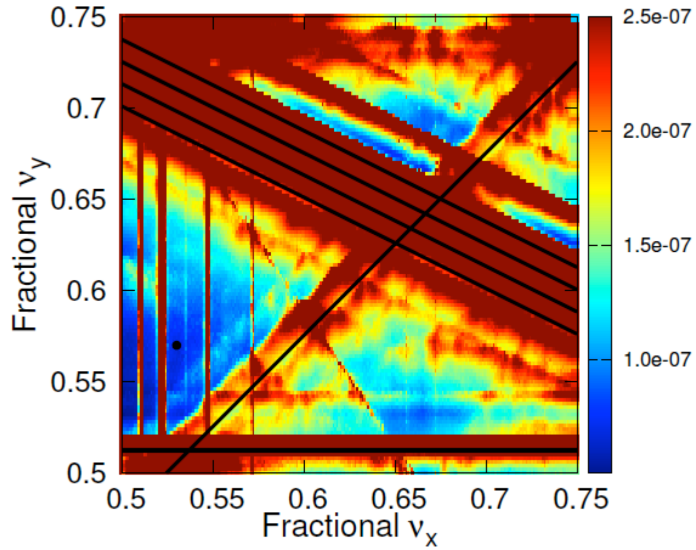
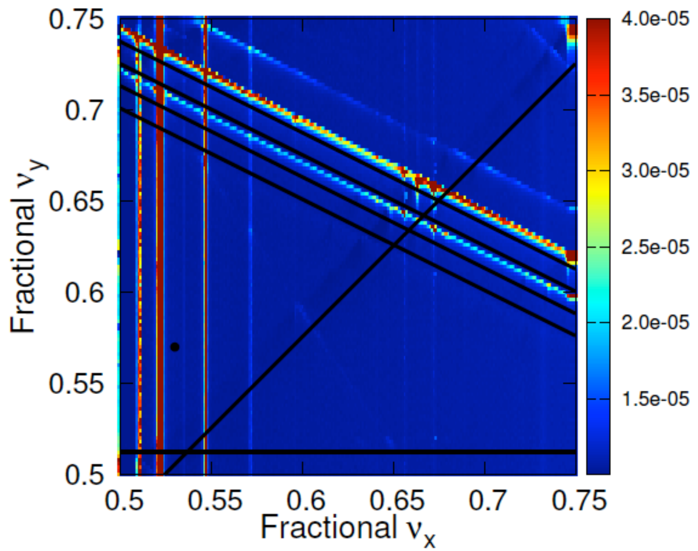




σ_y

σ_x



Choice of tune operating point

ν_x near half integer, keep away from synchrobeta resonance

ν_x ,ν_y=0.53,0.57

2. Beam-beam and luminosity: HER

➤ Lum. tune scan for HER (by BBWS: weak strong with linear arc)

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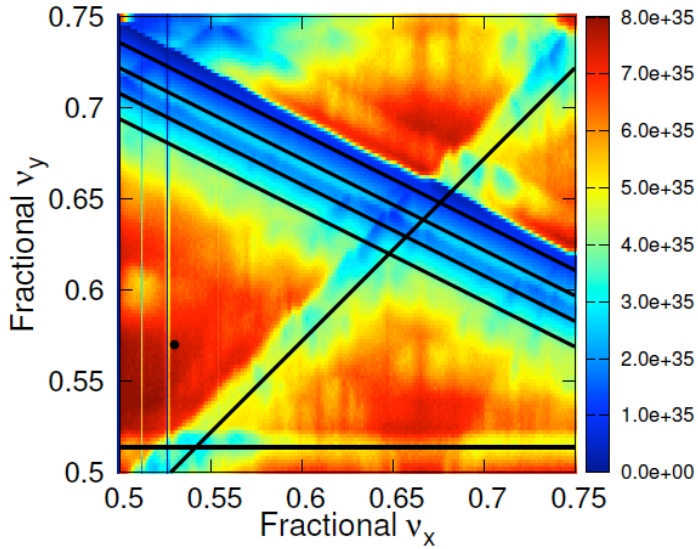
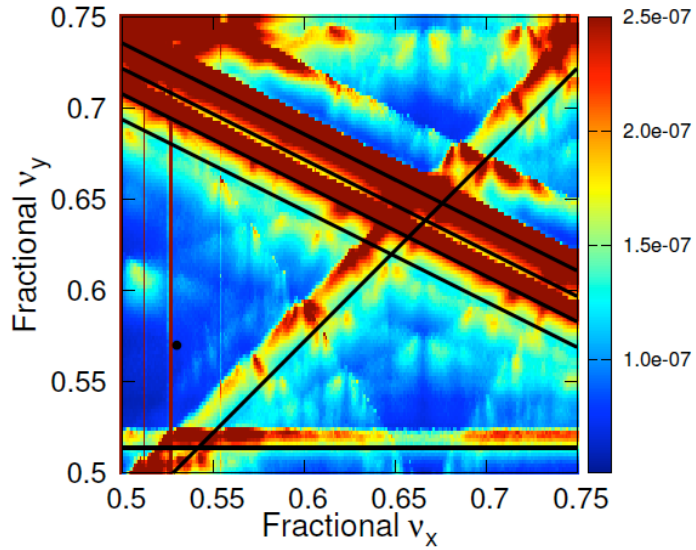
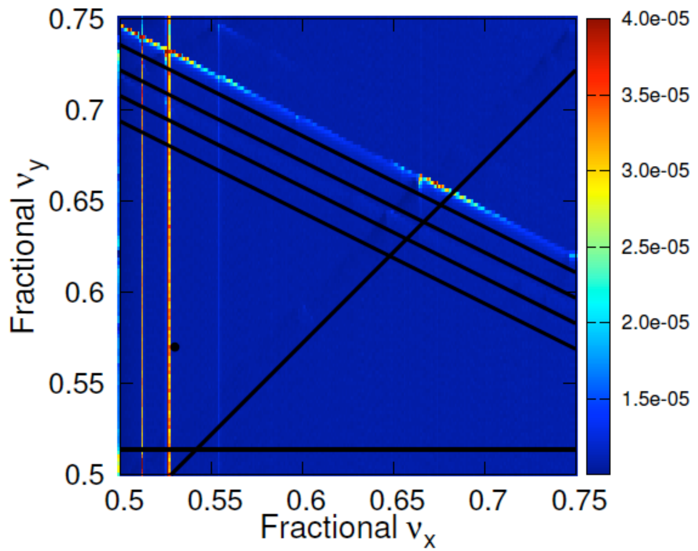




σ_y

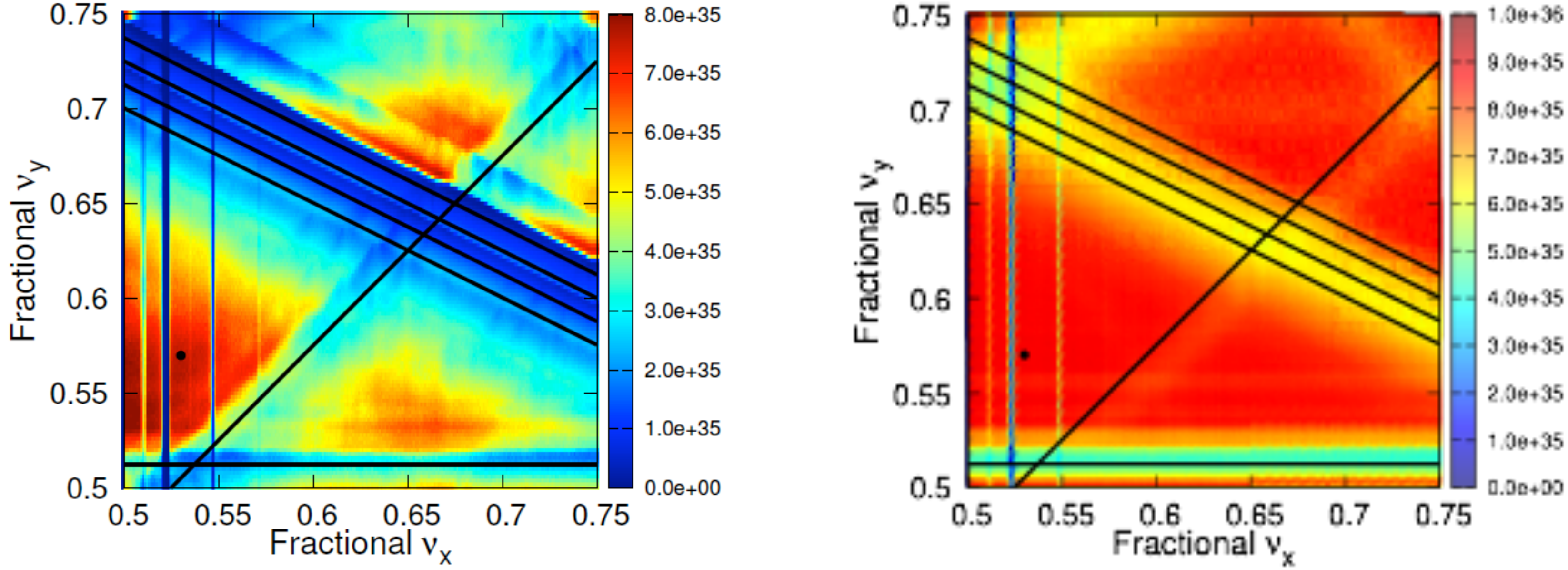
σ_x



σ_z

2. Beam-beam and luminosity: LER

➤ Lum. scan w/o and w/ crab waist for LER (by BBWS)



$$H_I^* = \pm \frac{1}{2\theta_h} x p_y^2$$

The crab waist is very powerful.
Degradation of dynamic aperture is inevitable, because nonlinearity between IP and crab waist sextupole is not transparent.

IR error tolerance

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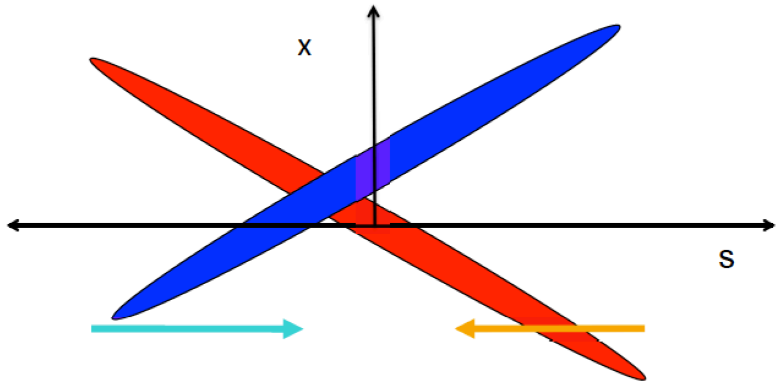
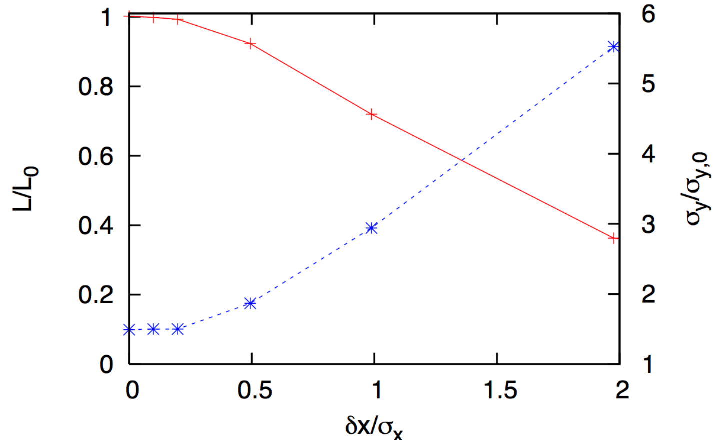
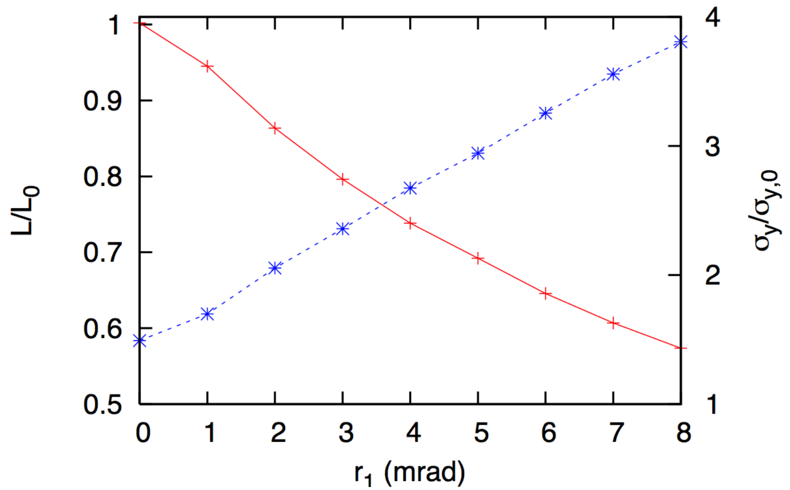






Summary of IR error tolerance

	SuperKEKB	KEKB
dx/σ_x (static)	0.8	-
dy/σ_y (static)	0.8	0.4
dx/σ_x (fast)	0.08	-
dy/σ_y (fast)	0.09	0.025
ds	0.07 mm	2 mm
r_1	3.0 mrad	2.1 mrad
r_2	0.1 mm	0.4 mm
r_3	10 m^{-1}	0.35 m^{-1}
r_4	0.4 rad	0.07 rad
$dr_1/d\delta$	2.1	6.1
$dr_2/d\delta$	0.074 m	2.5
$dr_3/d\delta$	8400 m^{-1}	1100 m^{-1}
$dr_4/d\delta$	290	440
η_y	31 μm	500 μm
η'_y	0.23	0.6

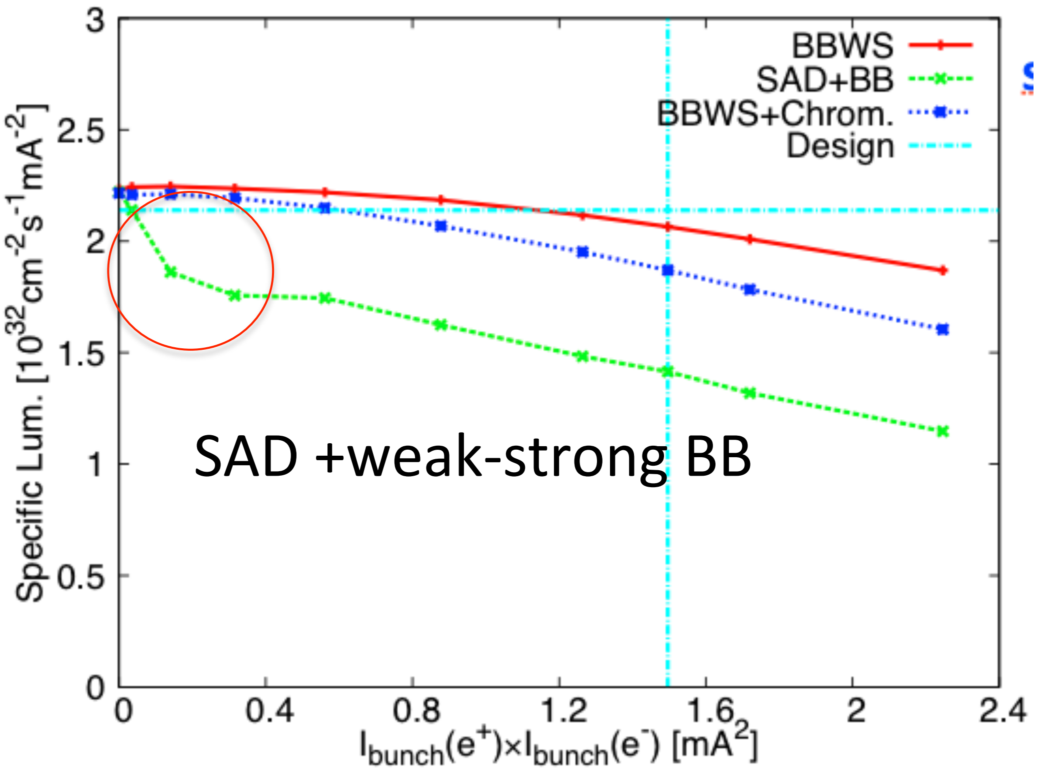
Beam-beam interaction in the realistic lattice

- Weak-strong beam-beam simulation using SAD.

- Crosscheck is began using other codes, Acceleraticum (Levichev,Piminov), BMAD(Sagan), SCTR (K.O.).

Weak-strong Simulation for LER lattice

- Even low current, luminosity loss ~20% is seen.
- 30% loss at the design current.
- Chromatic effect can not explain the lum. Loss.

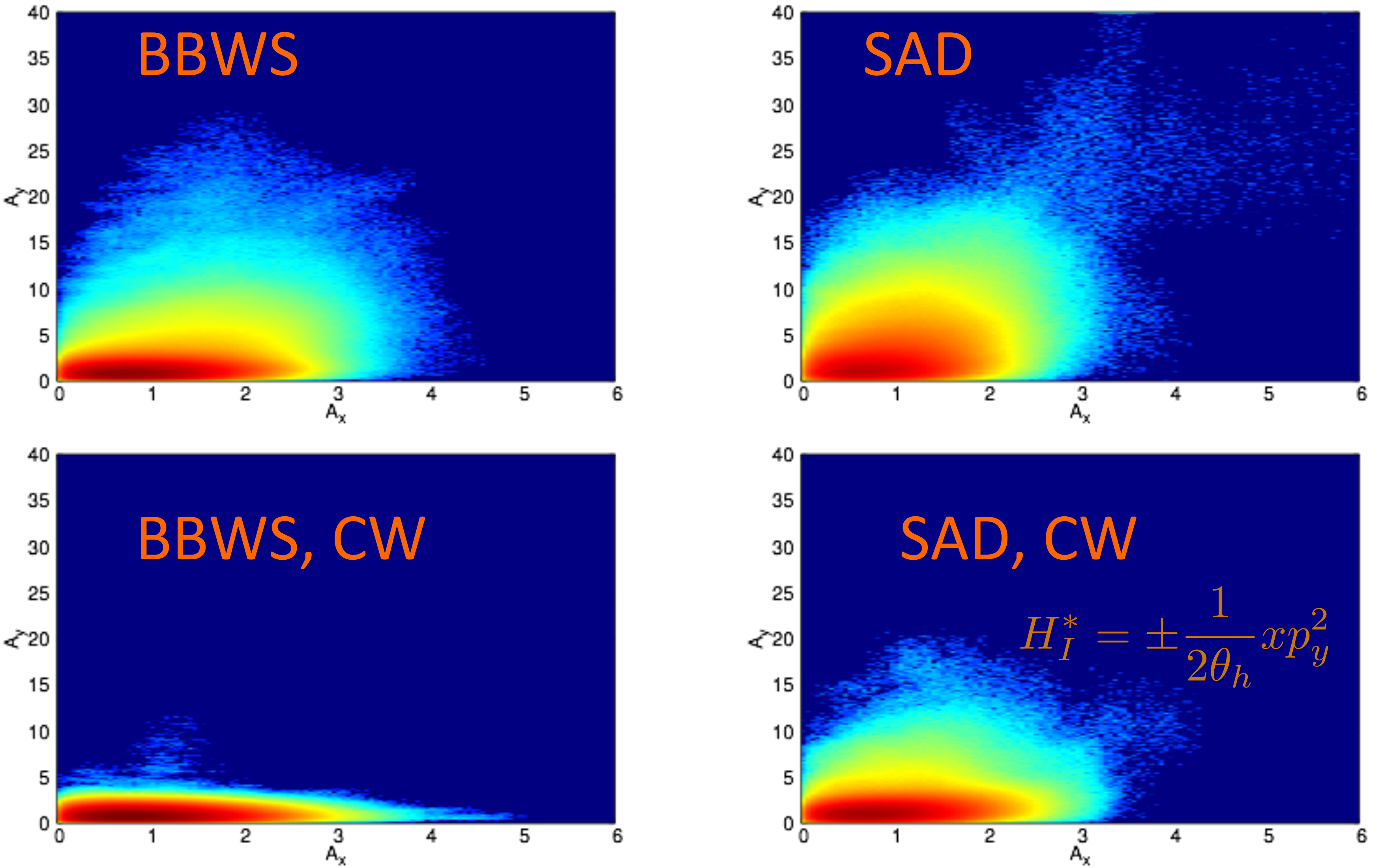


sler_1684

Beam tail distribution LER, A=J/ε

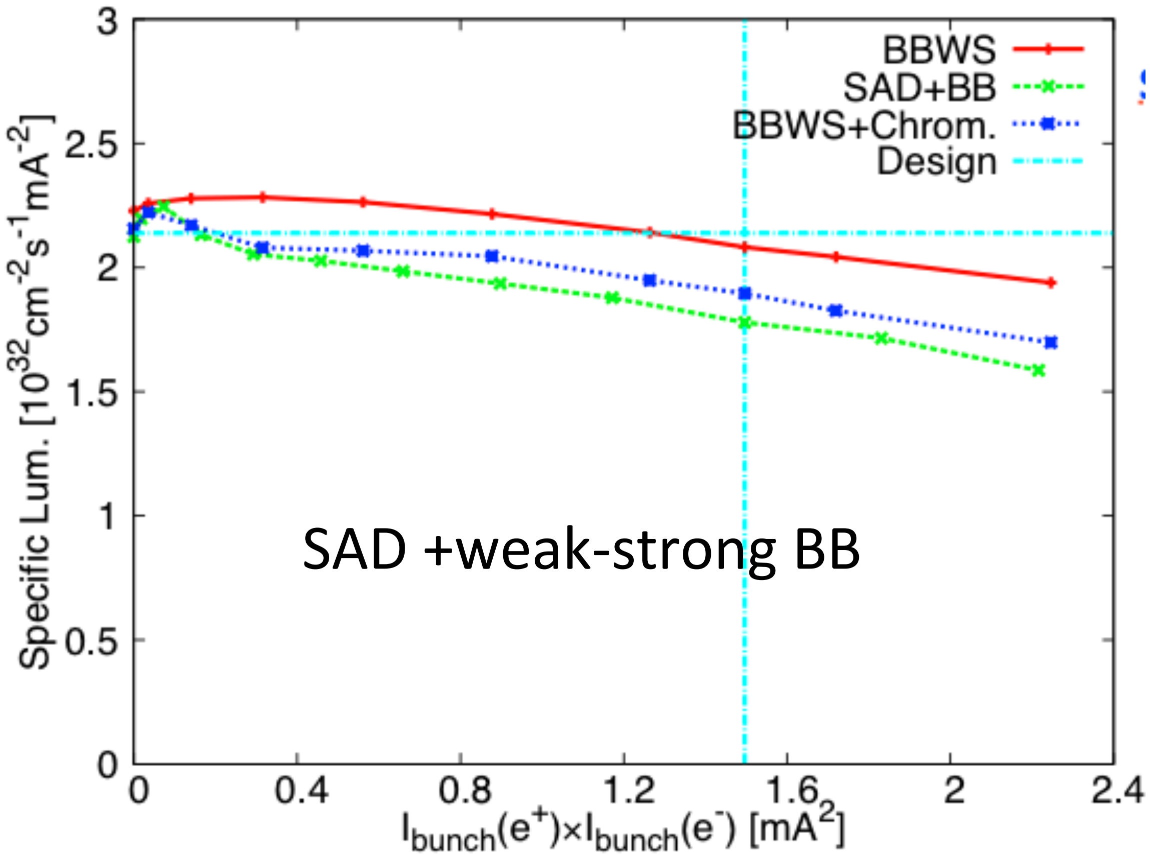
- Ne=6.53×10^{10},

SAD +weak-strong BB



Weak-strong Simulation for HER

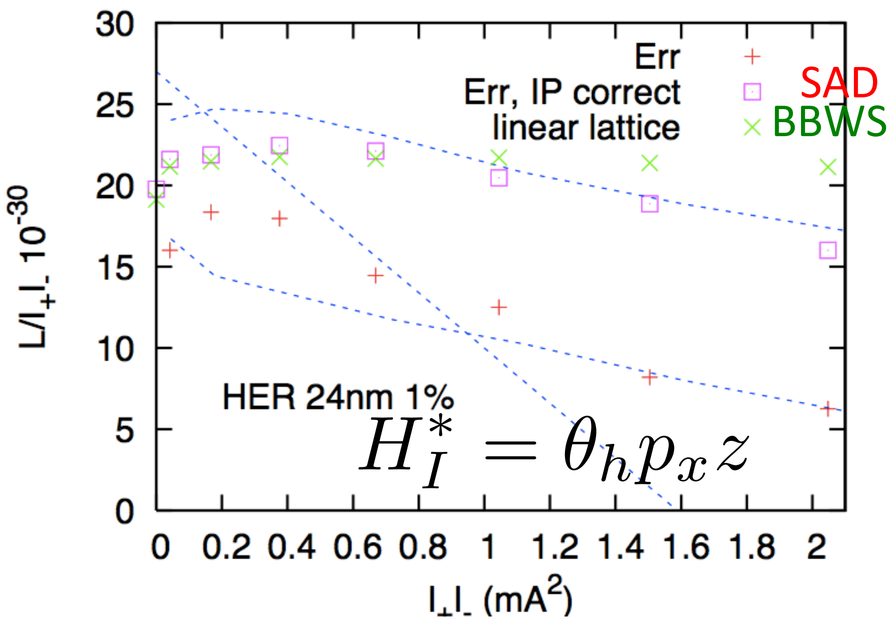
- ➤ No remarkable luminosity loss is seen (~10%).
- ➤ The lum. loss is mainly due to chromatic effect



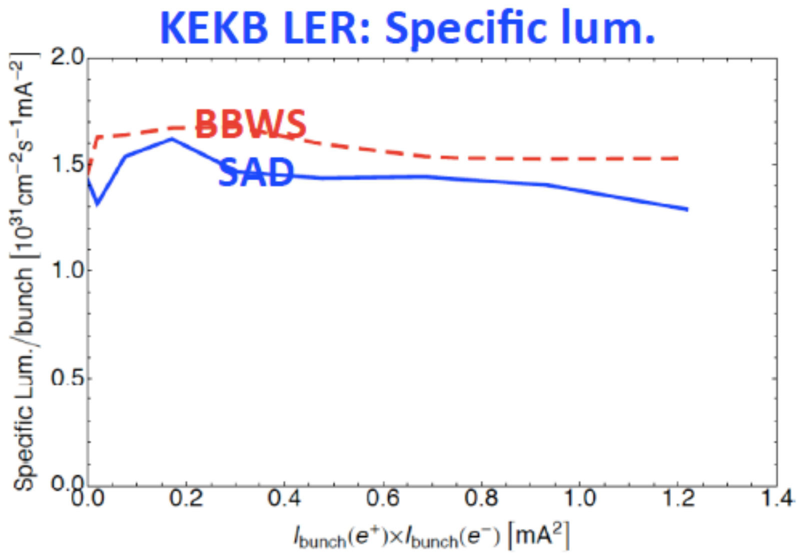
sher_5755

Other experiences on beam-beam in realistic lattice

KEKB crab, EPAC08



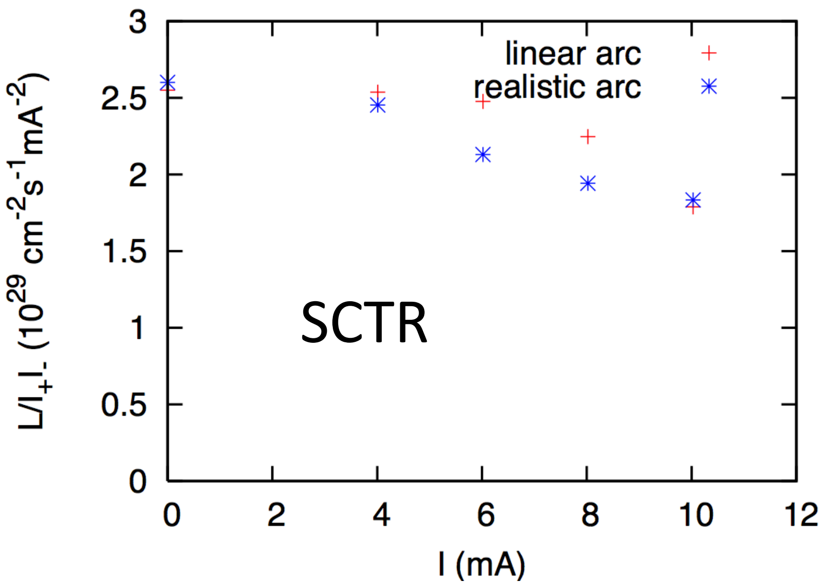
No crab

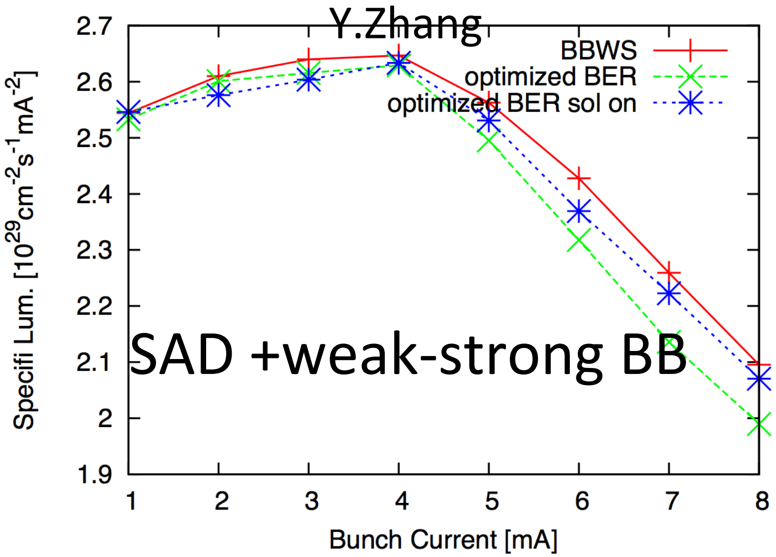


- No clear degradation due to lattice nonlinearity is seen in KEKB, except high beam-beam parameter.

BEPC-II

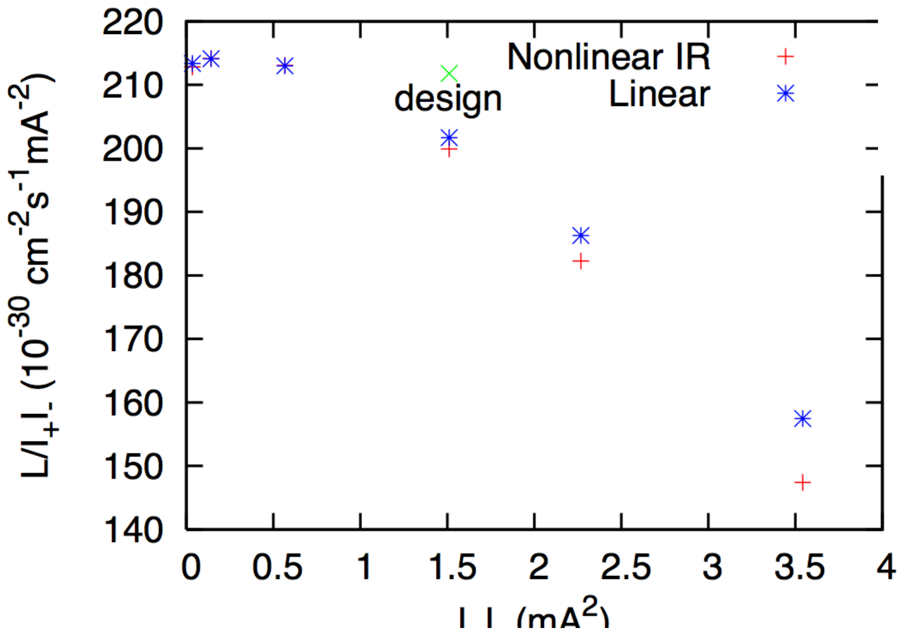
- SCTR code showed 15% loss at 6 & 8 mA.
- SAD does not show clear difference

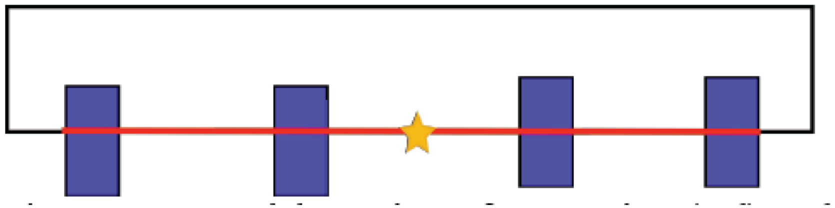




SuperKEKB

- Simplified IR model for SuperKEKB

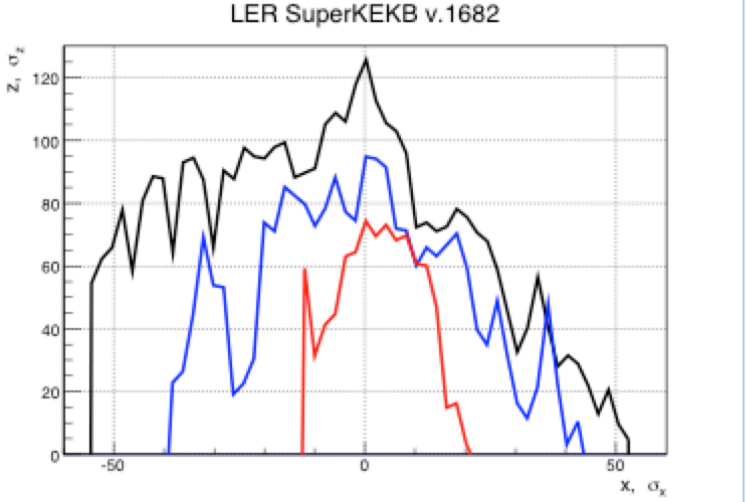


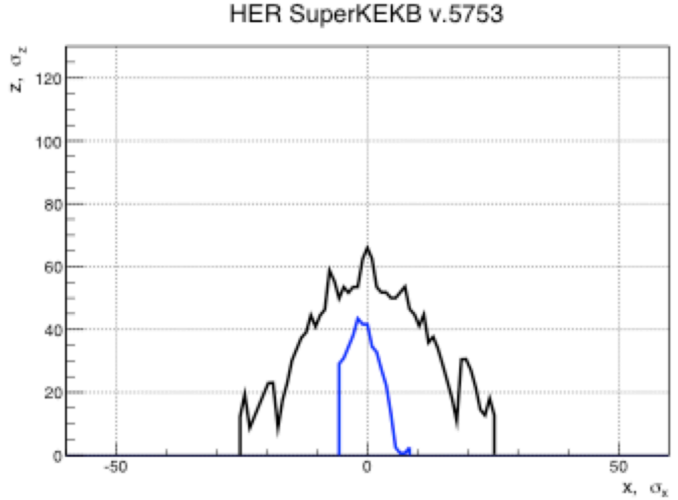


Status of Acceleraticum (Piminov)

Tab. 1. The main parameters (for zero current).

Parameters	LER		HER		Units
	wo FF	w FF	wo FF	w FF	
Energy, E	4.000		7.007		GeV
Circumference, L	3.01631				km
H tune, ν_x	44.529872	44. 528621	45.529934	45. 529659	
V tune, ν_z	42.563915	44. 568009	42.570035	43. 563408	
Hor delta tune*), $\Delta\nu_x$	$-1.28\cdot10^{-4}$	$1.38\cdot10^{-3}$	$6.61\cdot10^{-5}$	$3.41\cdot10^{-4}$	
Ver delta tune*), $\Delta\nu_z$	$-1.30\cdot10^{-4}$	$1.99\cdot10^{-3}$	$3.52\cdot10^{-5}$	$6.59\cdot10^{-3}$	
Synchrotron tune, ν_s	0.022026	0.024424	0.027398	0.027934	
Hor natural chrom**), ξ_x	-55.2	-116	-75.4	-171	
Ver natural chrom**), ξ_z	-78.9	-804	-65.5	-1528	
Hor total chrom, ξ_x	0.76	-0.4	1.17	5.4	
Ver total chrom, ξ_z	1.65	6.7	1.08	4.1	
Compaction factor, α	$2.583\cdot10^{-4}$	$3.170\cdot10^{-4}$	$4.335\cdot10^{-4}$	$4.505\cdot10^{-4}$	
Energy losses, U_0	2.08	2.08	2.5	2.5	MeV
Hor damping time, τ_x	38.7		56.5		ms
Ver damping time, τ_z	38.7		56.5		ms
Long damping time, τ_s	19.4		28.2		ms
Hor emittance, ε_x	2.14		4.48		nm·rad
Energy spread, $\sigma_{\Delta E/E}$	$8.036\cdot10^{-4}$		$6.42\cdot10^{-4}$		
Bunch length, σ_s	0.45		0.49		cm

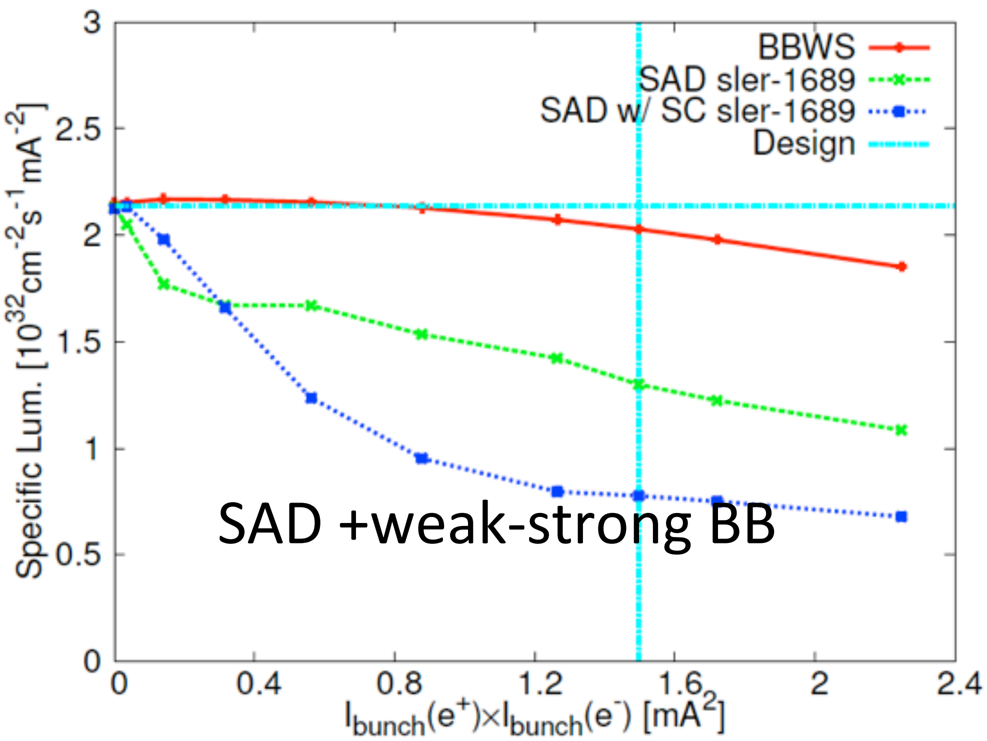




(black) – ΔE/E=0, (blue) – ΔE/E=0.5%, (red) – ΔE/E=1%

Space charge: LER

- ➤ Weak-strong model for space charge
- ➤ "Strong" beam: Emittance growth due to IBS included
- ➤ Remarkable luminosity loss is seen (65%).



Electron cloud instability

- Threshold of single bunch instability using simple model, constant beta, resonator wake.

- Threshold of single bunch instability using realistic lattice and cloud density.
- Incoherent emittance growth due to electron cloud located at the high beta section.

Threshold of single bunch instablity

- Constant beta model, resonator wake.

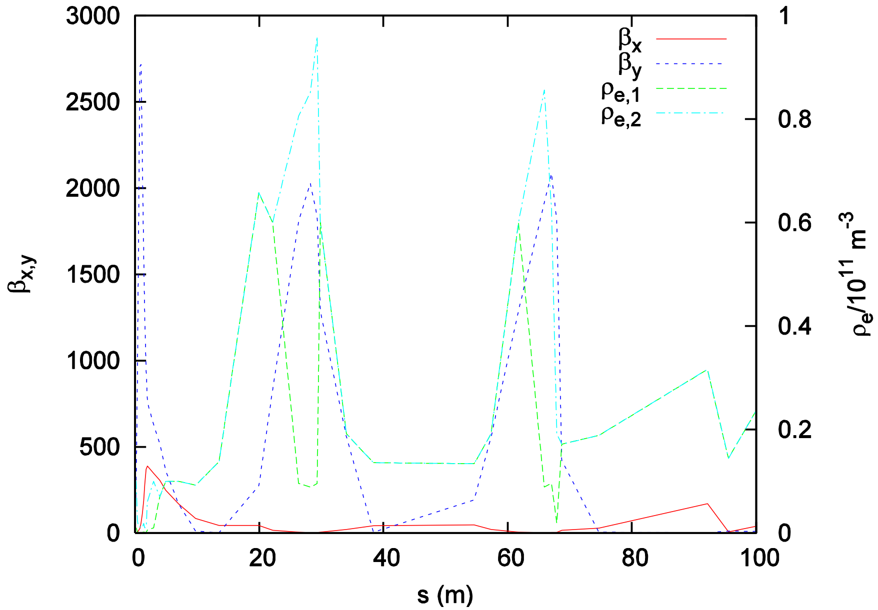
Lattice		KEKB	Cesr-TA	PETRA-III	SuperKEKB	Super B
Circumference	L (m)	3,016	768	2304	3016	1260
Energy	E (GeV)	3.5	2-5	6	4.0	6.7
Bunch population	$N_+(10^{10})$	8	2	0.5	9	5
Beam current	I_+ (A)	1.7	-	0.1	3.6	1.9
Emittance	ε_x(nm)	18	2.3	1	3.2	2
	ε_y(nm)	0.18	0.023	0.01	0.01	0.005
Momentum compaction	$\alpha(10^{-4})$	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

		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

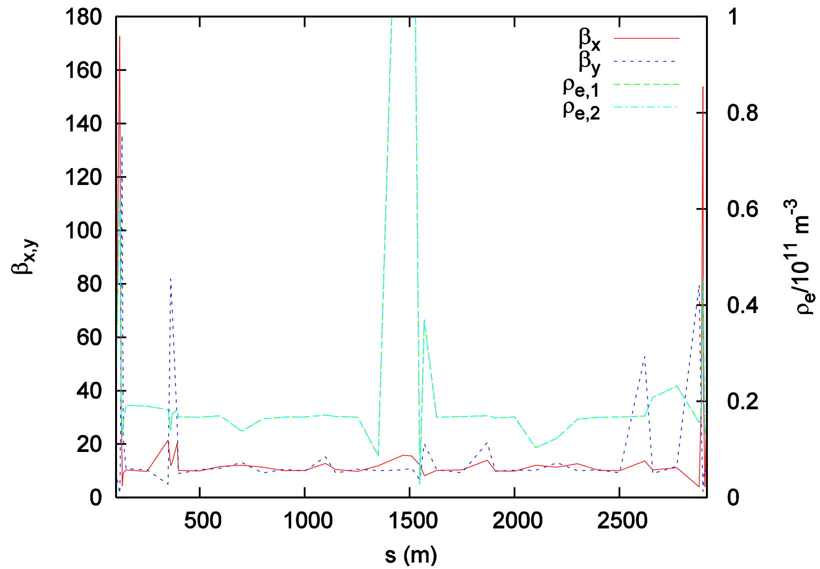
Electron cloud effects in realistic lattice and electron distribution

Beta function and estimated cloud density

IR

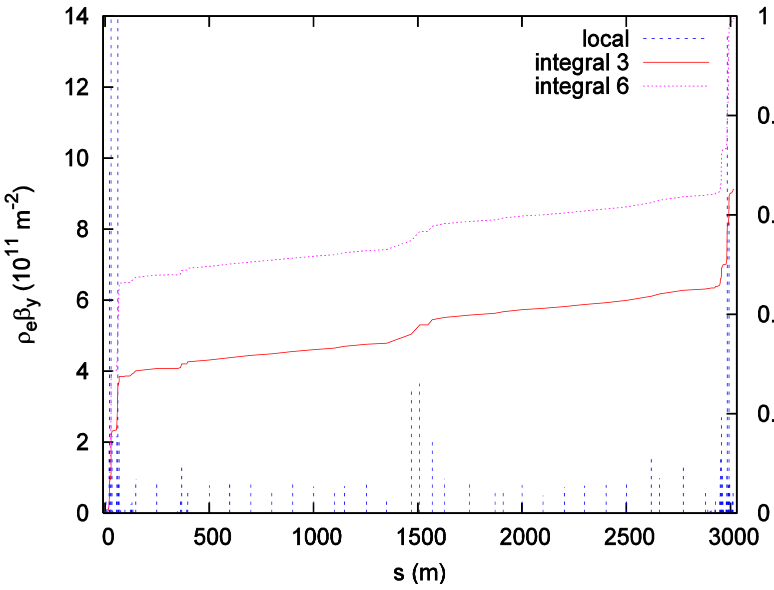


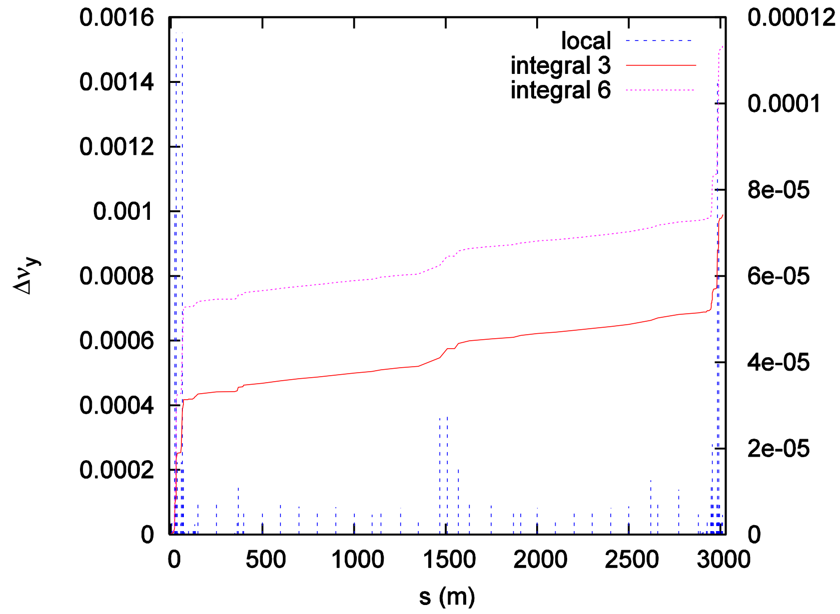
whole ring



Two cases of cloud densities, case 1; green (low density in high β Q) and model 2; cyan (high density in high β Q) curves. (Suetsugu)

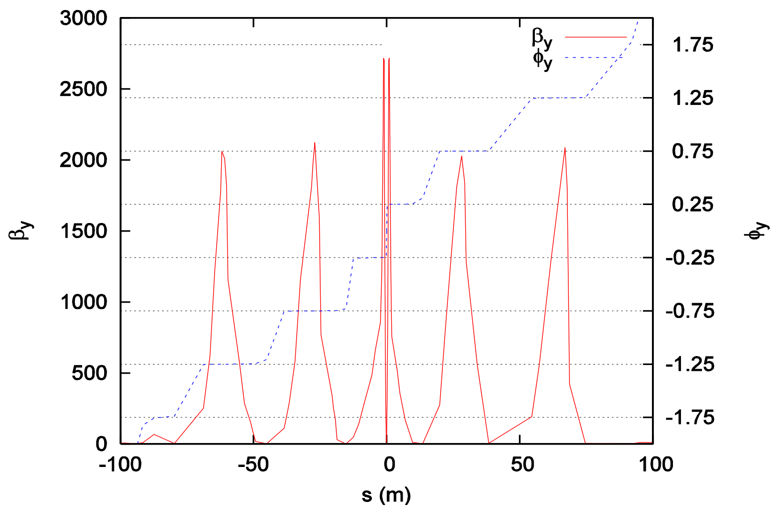
Tune shift contribution

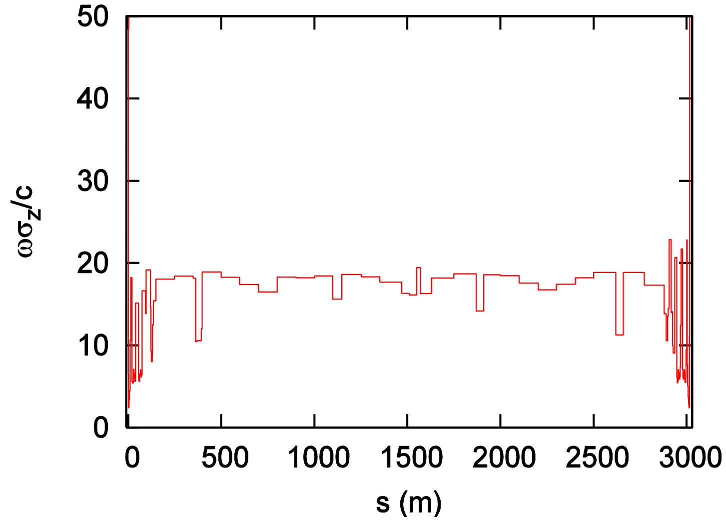




- Tune shift and $\rho_e\beta_y$ near IR (-70<s<70m) are dominant.
- Design

Betatron tune and electron frequency variations

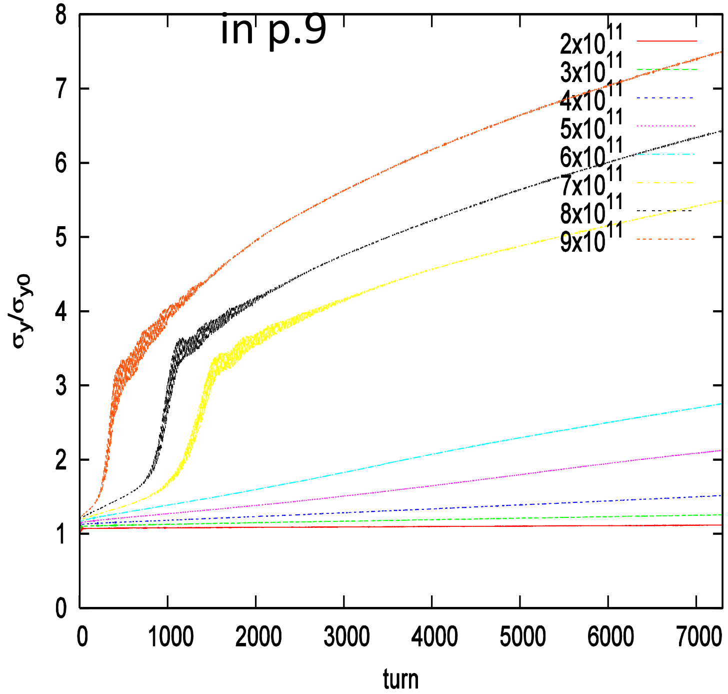




- High beta section separate the betatron phase difference π. Nonlinear force with even parity is coherently accumulated.
- $\omega_e\sigma_z/c$ is very high near IP. The area is narrow and low beta, neglect.

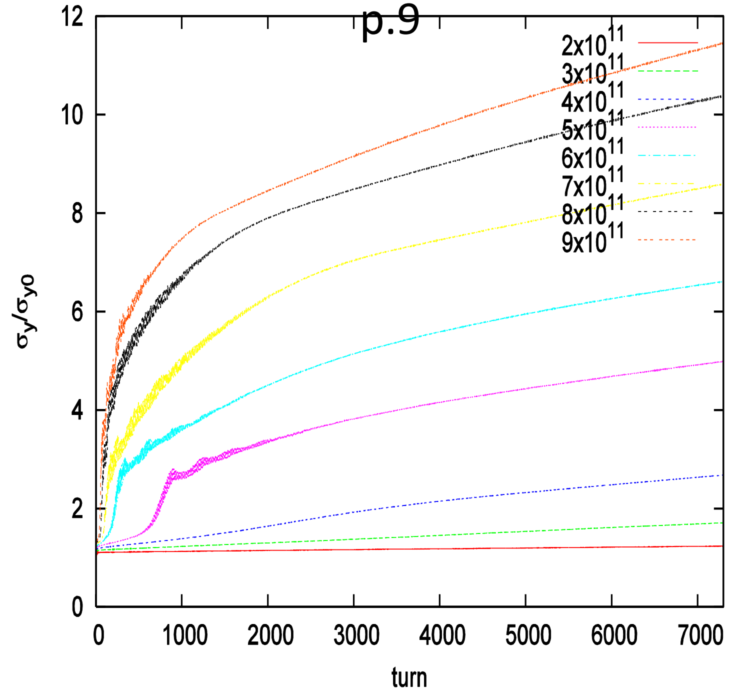
Vertical emittance growth caused by the electron cloud fast head-tail instability

Model 1: green in p.9



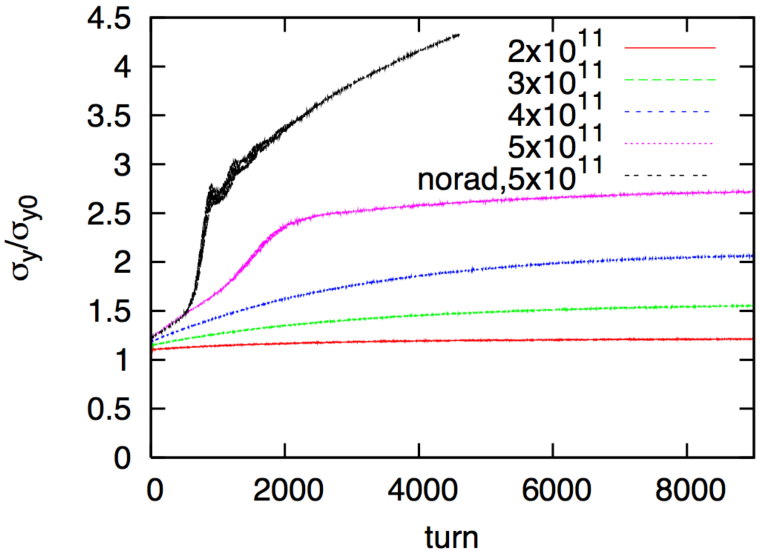
$\rho_{e,th}$=6xdesign

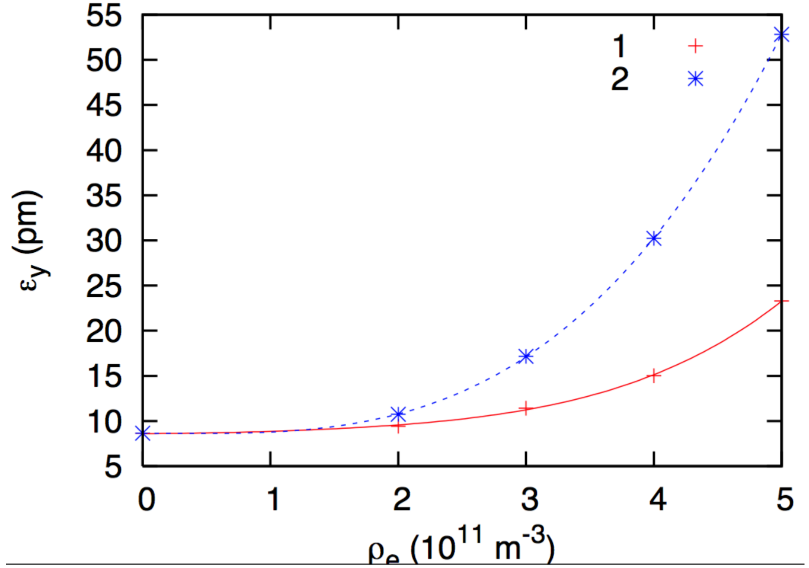
Model 2: cyan in p.9



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

Radiation damping and excitation





- Equilibrium emittance is 1.5xε_{design} for ρ_e=3x design, 1.2ε_{design} for ρ_e=2x in the case 2.
- The effect is 1/3 in the case 1 (high density in high β Q).
- Radiation damping suppress the coherent instability at ρ_e=4-5x design (black to magenta).

Summary I

- Beam-beam effect in realistic Lattice has been studied using weak-strong & SAD.
- Clear luminosity loss (30%) has been seen.
- In KEKB, BEPC, the loss is small.
- Crosscheck is began using several codes. Understanding of mechanism will be performed.
- Further loss (60-70%) is seen in taking account of space charge. Crosscheck and understanding will be performed.

Summary II

- Electron cloud in high beta section near IR is dominate for instability and emittance growth.
- The effects become visible at the cloud density twice higher than the design.