Beam-beam effect in super-B

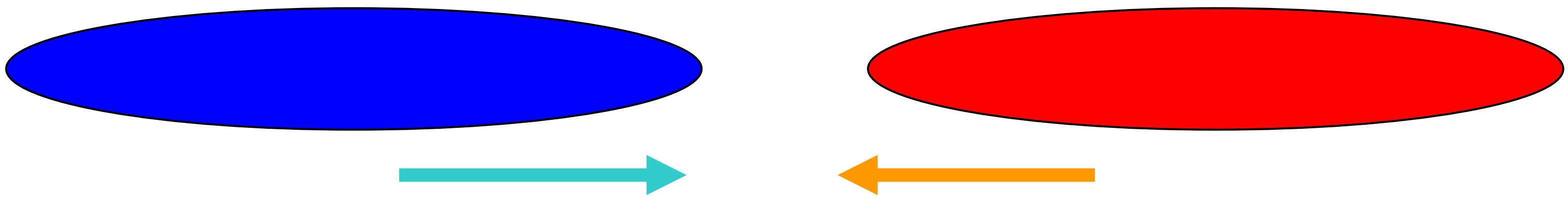
K. Ohmi

MAC2007 for KEKB,

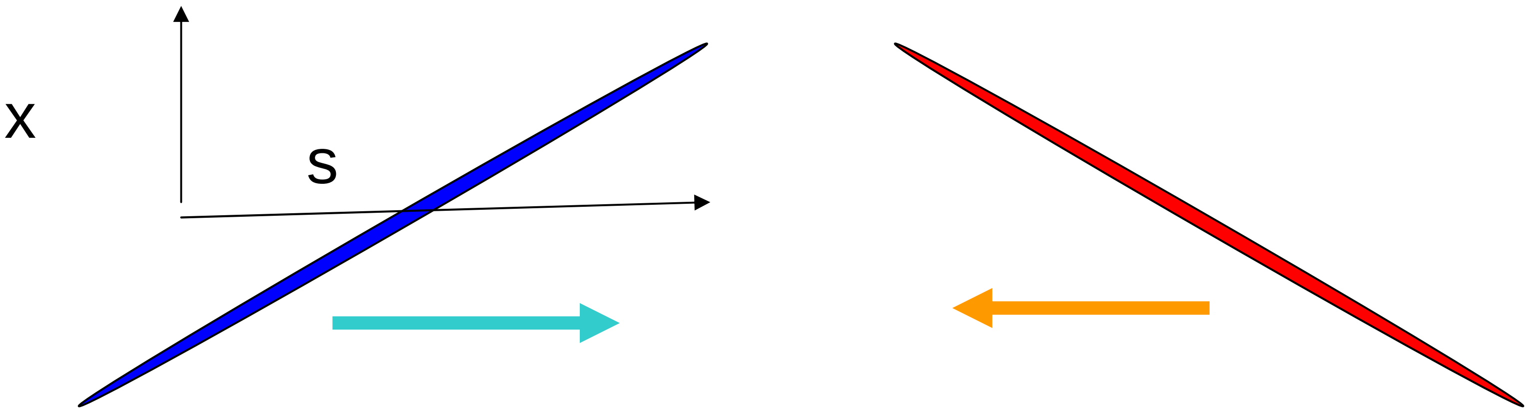
19-21, Mar. 2007

Two approach toward high luminosity

- High current, high beam-beam parameter.



- Low emittance, low beta, low current, so-called super bunch collision



Super B parameters

	SuperKEKB	Middle	SuperB (LNF/SLAC)
εx	9.00E-09	6.00E-09	0.8E-09
εy	4.50E-11	6.00E-11	2E-12
βx (mm)	200	50	9
βy (mm)	3	0.5	0.133
σz (mm)	3	6	6
νs	0.025	0.01	0.012/0.026
ne	5.50E+10	5.50E+10	1.9E+10
np	1.26E+11	1.27E+11	3.3E+10
$\theta/2$ (mrad)	0	15	25
ξx	0.397	0.022	
ξy	0.794->0.24	0.179	
Lum (W.S.)	8E+35	1.00E+36	1.00E+36
Lum (S.S.)	8.25E35	8-9E35	

Comparison of two approach

High curent $\frac{\sqrt{\varepsilon_x \beta_x}}{\theta \sigma_z} > 1$ or $\theta = 0$

$$L \sim \frac{N^2}{\sqrt{\varepsilon_x \beta_x \varepsilon_y \beta_y}}$$

$$\xi_x \sim \frac{N}{\varepsilon_x}$$

$$\xi_y \sim N \sqrt{\frac{\beta_y}{\varepsilon_x \beta_x \varepsilon_y}}$$

$$\beta_y > \sigma_z$$

θ: half crossing angle

Low emittance $\frac{\sqrt{\varepsilon_x \beta_x}}{\theta \sigma_z} < 1$

Overlap factor

$$L \sim \frac{N^2}{\sqrt{1+\theta^2}\sigma_z \sqrt{\varepsilon_y \beta_y}}$$

$$\xi_x \sim \frac{N}{\sqrt{1+\theta^2}\sigma_z} \sqrt{\frac{\beta_x}{\varepsilon_x}}$$

$$\xi_y \sim \frac{N}{\sqrt{1+\theta^2}\sigma_z} \sqrt{\frac{\beta_y}{\varepsilon_y}}$$

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

ξ_x is smaller due to cancellation of tune shift along bunch length

High current approach

$$L \sim \frac{N^2}{\sqrt{\varepsilon_x \beta_x \varepsilon_y \beta_y}}$$

$$\xi_x \sim \frac{N}{\varepsilon_x}$$

$$\xi_y \sim N\sqrt{\frac{\beta_y}{\varepsilon_x \beta_x \varepsilon_y}}$$

$$\beta_y > \sigma_z$$

Keep ε_x, β_x and $\sqrt{\frac{\beta_y}{\varepsilon_y}}$.

$$\varepsilon_y \beta_y \to 0$$

$$L \to \infty$$

$\beta_y > \sigma_z$ limits luminosity

- High current, Small coupling
- Choice of operating point

$$\nu_x \to +0.5 \quad \xi_y \to \infty \quad N \to \infty$$

θ=0

$$L \to \infty$$

Low emittance approach

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

$$\xi_x \sim \frac{N}{\theta\sigma_z}\sqrt{\frac{\beta_x}{\varepsilon_x}}$$

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

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

Keep $\sqrt{\frac{\beta_y}{\varepsilon_y}}$, $\sqrt{\frac{\beta_x}{\varepsilon_x}}$ and $\frac{\sqrt{\varepsilon_x\beta_x}}{\beta_y}$.

$$\varepsilon_y\beta_y \to 0$$

$$L \to \infty$$

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

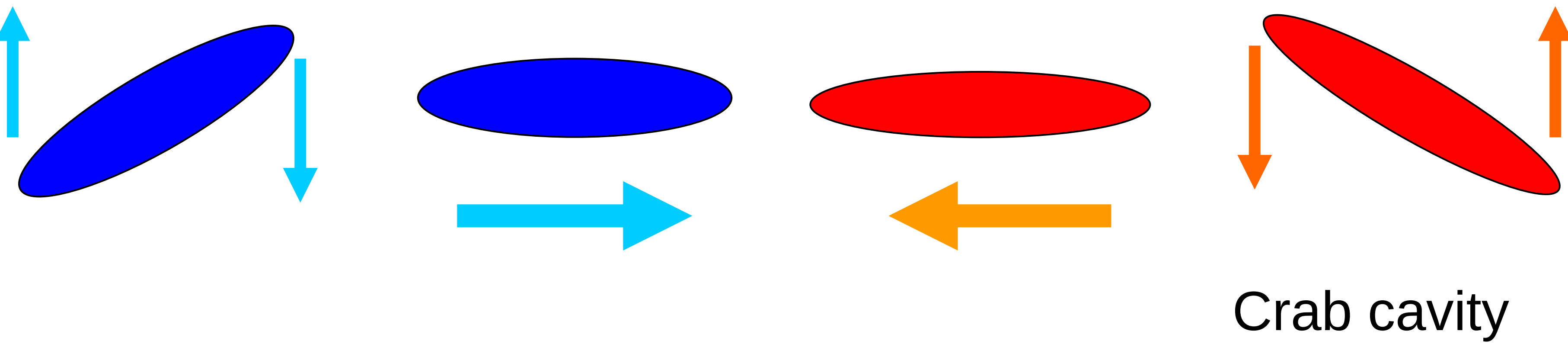
High current approach

- Reinforce RF system to store high current.
- Operation cost due to the high current.
- Heating of hardware, chamber, mask ....
- High beam-beam parameter with head-on collision: high nonlinear system.
- Sensitive for noise and error due to high beam-beam parameter.
- Limit of bunch length, instability and coherent synchrotron radiation.

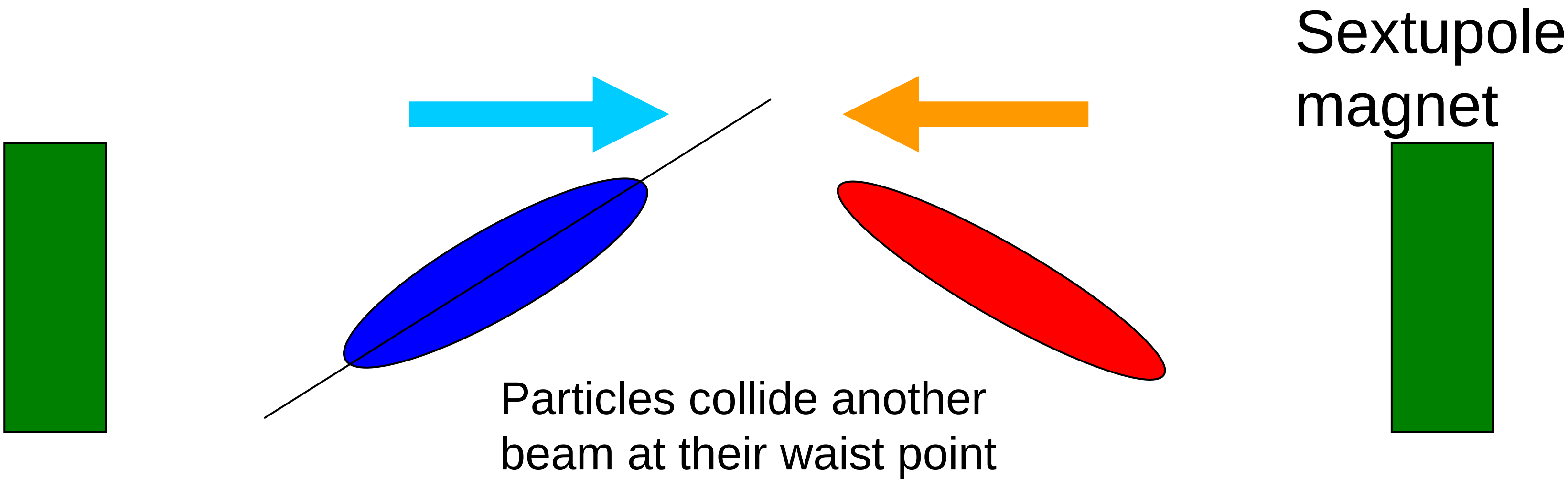
Low emittance approach

- Low emittance, magnet system should be reinforced.
- Low beta, the strongly focused IR, may be limit dynamic aperture.
- Single turn or multi turn injection. Multi-turn injection requires wide dynamic aperture, while single turn injection requires a high speed kicker (~2ns). A low emittance damping ring and high precision injection are required.
- High sensitivity due to the very low emittance.
- The main ring is similar to ILC damping ring equip with the final focus system of ILC.

- Crab crossing



- Crab waist



Super B with high current approach

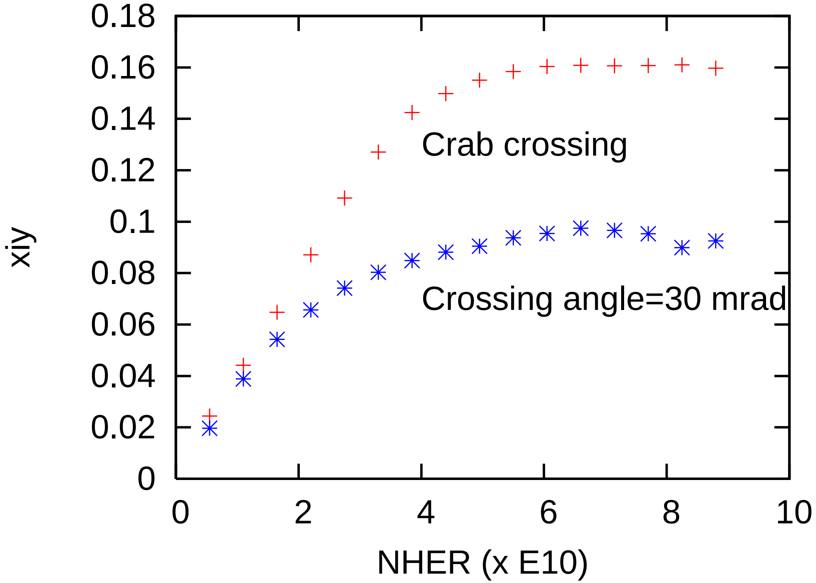
	SuperKEKB	Middle	SuperB (LNF/SLAC)
εx	9.00E-09	6.00E-09	0.8E-09
εy	4.50E-11	6.00E-11	2E-12
βx (mm)	200	50	9
βy (mm)	3	0.5	0.133
σz (mm)	3	6	6
νs	0.025	0.01	0.012/0.026
ne	5.50E+10	5.50E+10	1.9E+10
np	1.26E+11	1.27E+11	3.3E+10
θ/2 (mrad)	0	15	25
ξx	0.397	0.022	
ξy	0.794->0.24	0.179	
Lum (W.S.)	8E+35	1.00E+36	1.00E+36
Lum (S.S.)	8.25E35	8-9E35	

Beam-beam Interaction and crossing angle

- Beam-beam interaction as a transformation of dynamical variable.

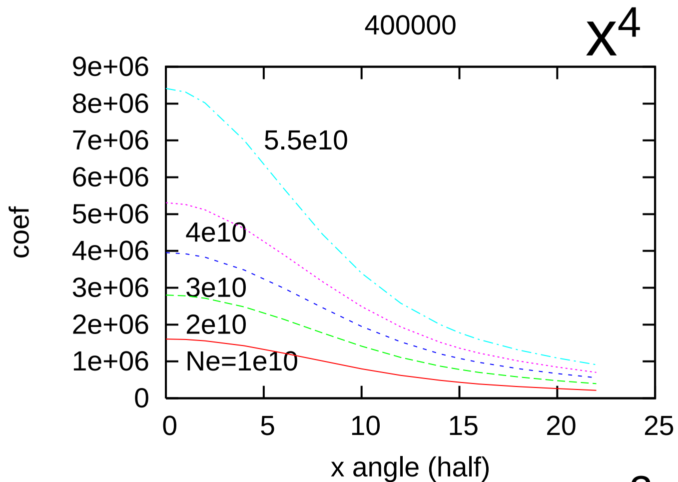
$$\mathbf{X} = \exp\left(-:(U_3 + U_4 + ...):\right)\mathbf{x}_0$$

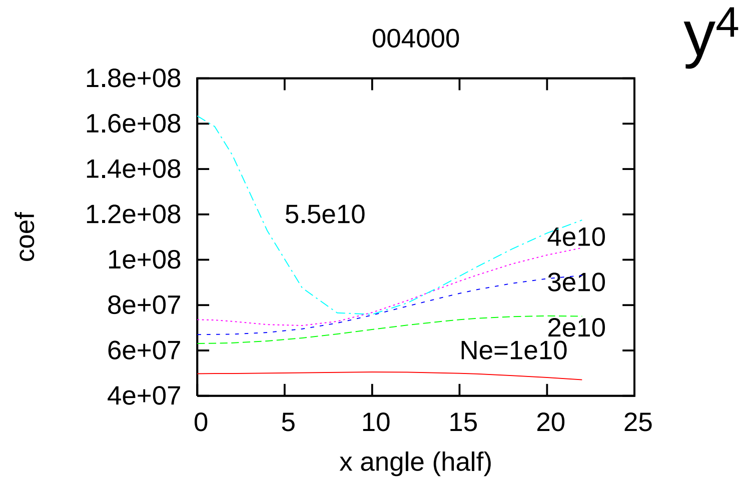
- x^4 , y^4 term decrease but another coupling term increases for crossing angle. A kind of symmetry breaking degrade luminosity performance.

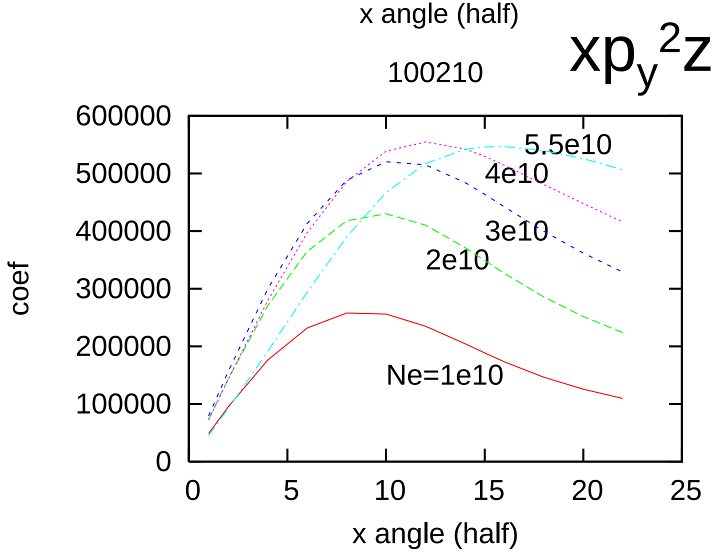


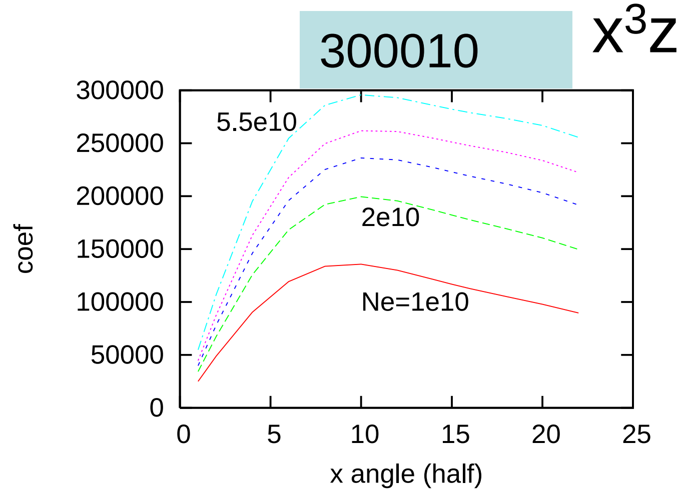
4-th order Coefficients due to crossing angle

- Coefficient of $U_4(x,y,z)$.









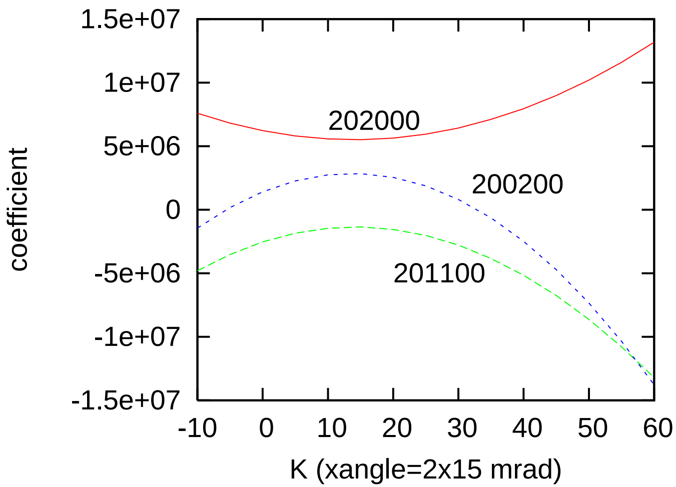
Crab waist

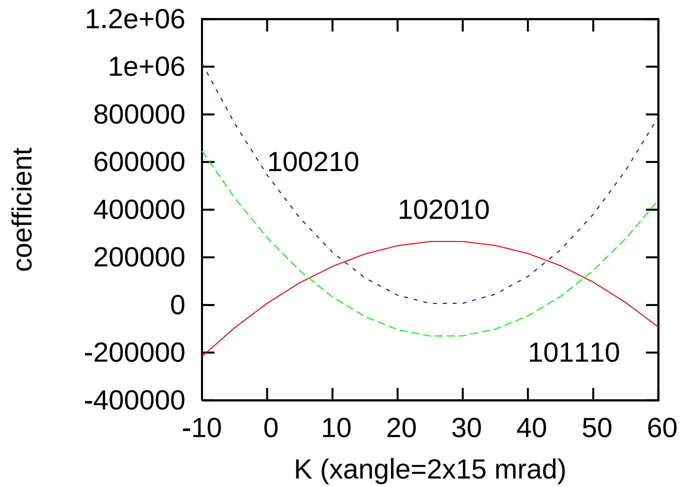
- Add sextupole magnets at both side of collision point for finite crossing collsion.
- Effective potential is expressed as follows,

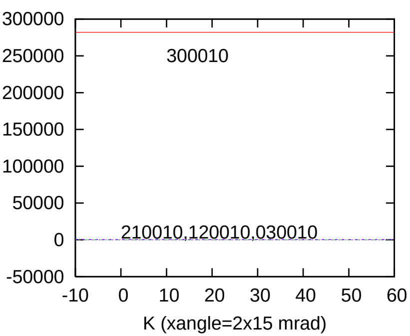
$$U(x,y,z)\delta(s-s^*)+Kxp_y^2\delta(s-s^*-\varepsilon)-Kxp_y^2\delta(s-s^*+\varepsilon)$$

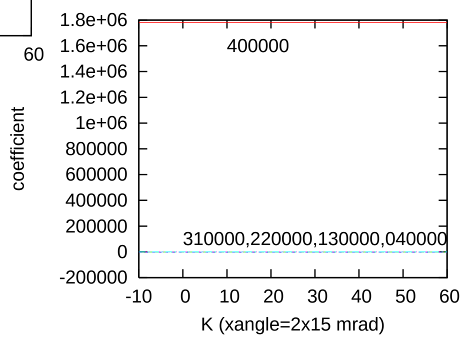
Put sextupole magnets both side of the collision point at the vertical betatron phase difference, $\pi(2n+1)/2$ and horizontal $m\pi$.

4-th order Coefficients as a function of crab sextupole strength,





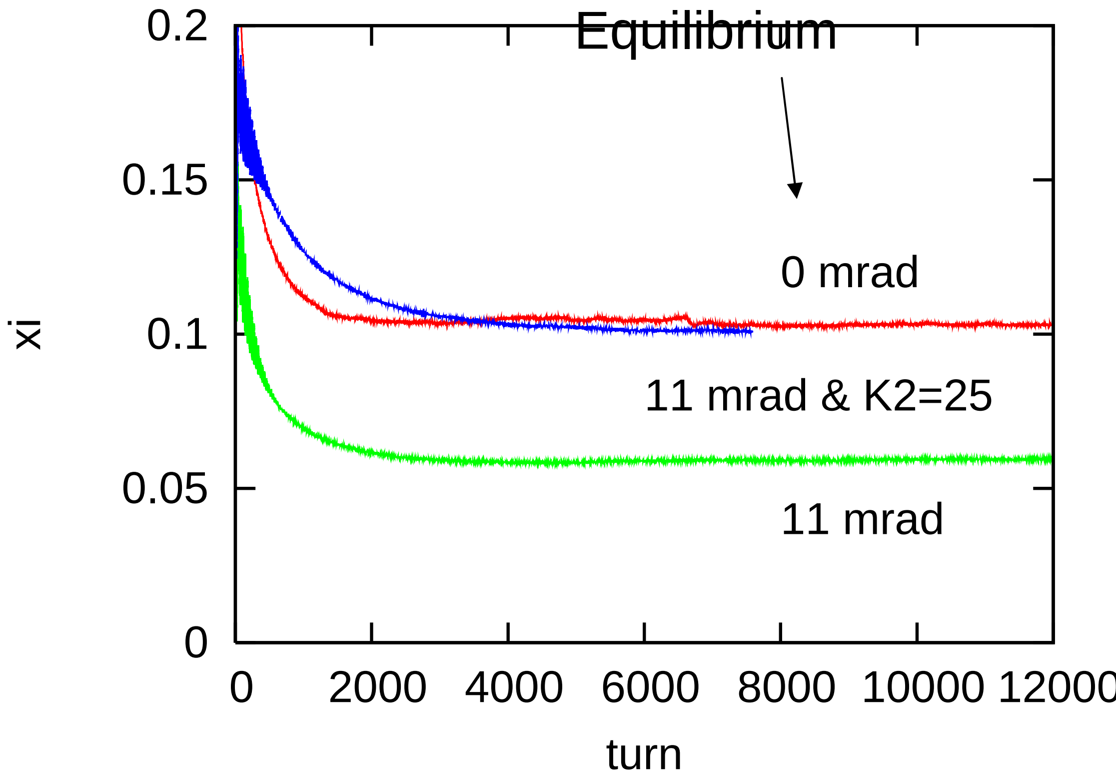




- $H=K \times p_y^2/2$, theoretical optimum, K=1/xangle.
- Clear structure- 220,121
- Flat for sextupole strength- 400, 301, 040

- Crab waist sextupoles cancel some coupling terms induced by crossing angle, while keep the synchro-betatron terms.
- $H=25 \times p_y^2$. Luminosity for crab waist is comparable with that of crab crossing for a parameter range.

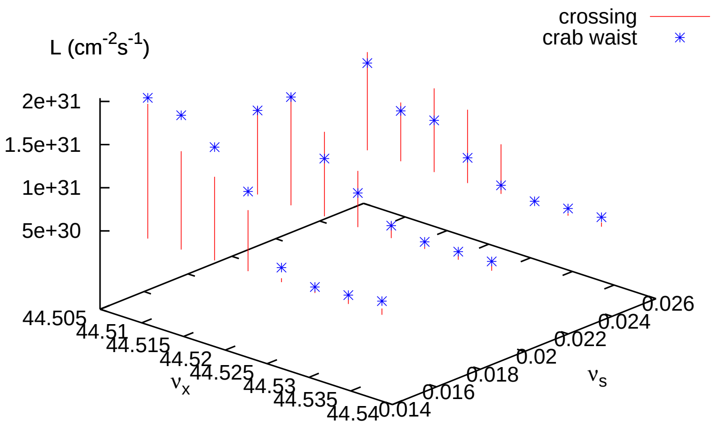
Luminosities for crab crossing and crab waist is not always same.

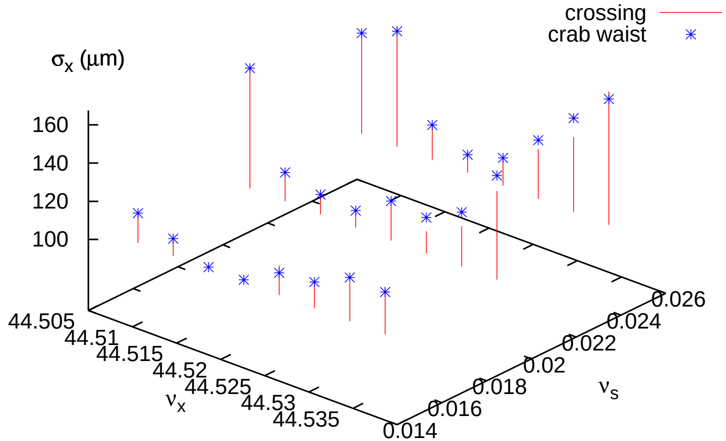


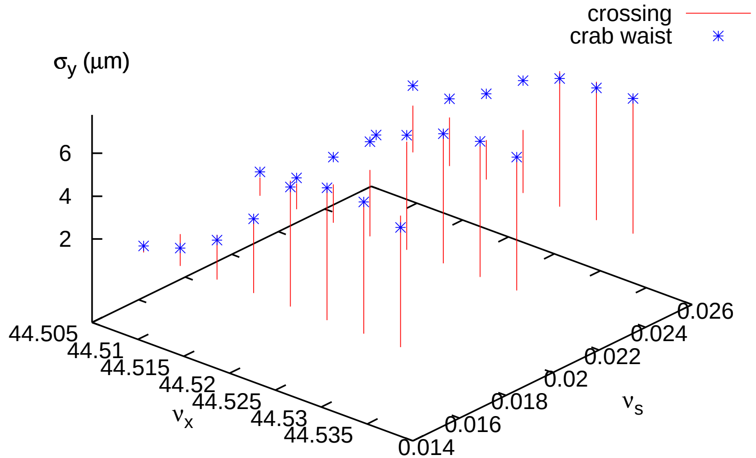
$\nu_s=0.016$

Tune scan, ν_x-ν_s

- Efficient region of the Crab waist scheme is not wide.
- Low ν_s.
- High ν_x degrades the performance independent of crab waist. Synchro-beta dominant.

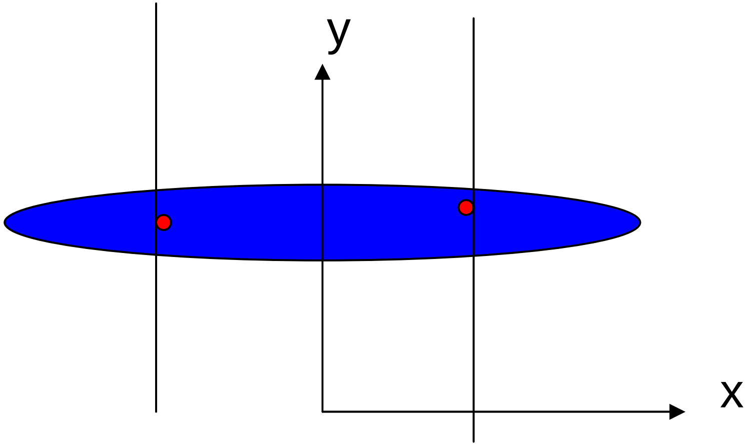






Horizontal tune half integer ν_x=0.5

- Particles interact with fixed beam at x and –x mutually. The phase space structure in y-p_y at x is the same as that at -x, because of symmetry of the fixed beam.
- System is one dimension, beam-beam tune shift is 0.5
- KEKB tries to realize a high luminosity with this technique.
- A high precision tuning is required.



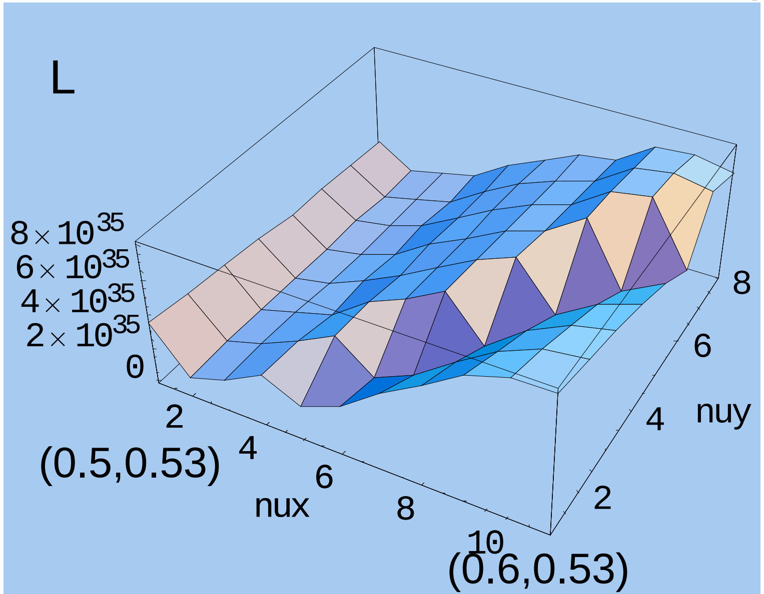
For crab waist at low emittance

- Synchro-beta transformation term as x^3z, which is induced by crossing angle and is not cancelled by the crab sextupole, disturbs luminosity performance near the half integer tune.
- In KEKB low emittance operation, a beam-beam instability has been observed.
- Operation strategy is completely different from the present one.

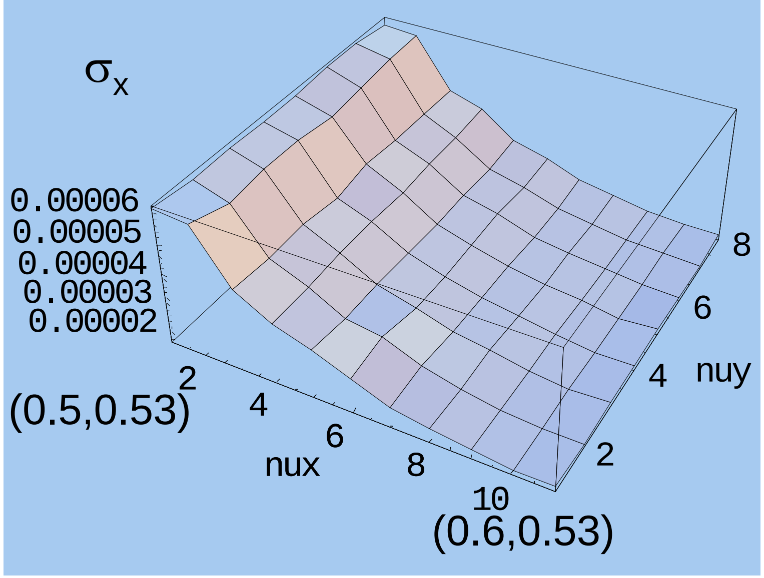
Super B with meddle parameter

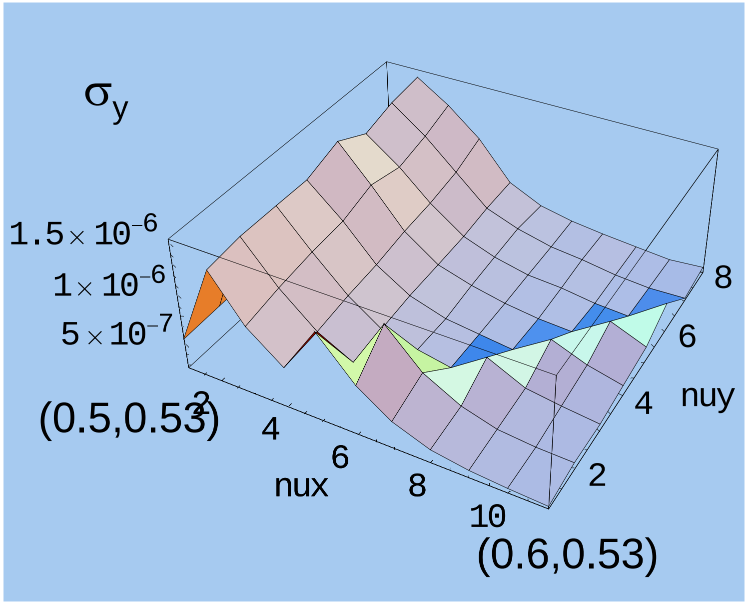
	SuperKEKB	Middle	SuperB (LNF/SLAC)
εx	9.00E-09	6.00E-09	0.8E-09
εy	4.50E-11	6.00E-11	2E-12
βx (mm)	200	50	9
βy (mm)	3	0.5	0.133
σz (mm)	3	6	6
νs	0.025	0.01	0.012/0.026
ne	5.50E+10	5.50E+10	1.9E+10
np	1.26E+11	1.27E+11	3.3E+10
θ/2 (mrad)	0	15	25
ξx	0.397	0.022	
ξy	0.794->0.24	0.179	
Lum (W.S.)	8E+35	1.00E+36	1.00E+36
Lum (S.S.)	8.25E35	8-9E35	

Strong strong simulation results for the middle case, high current & low β

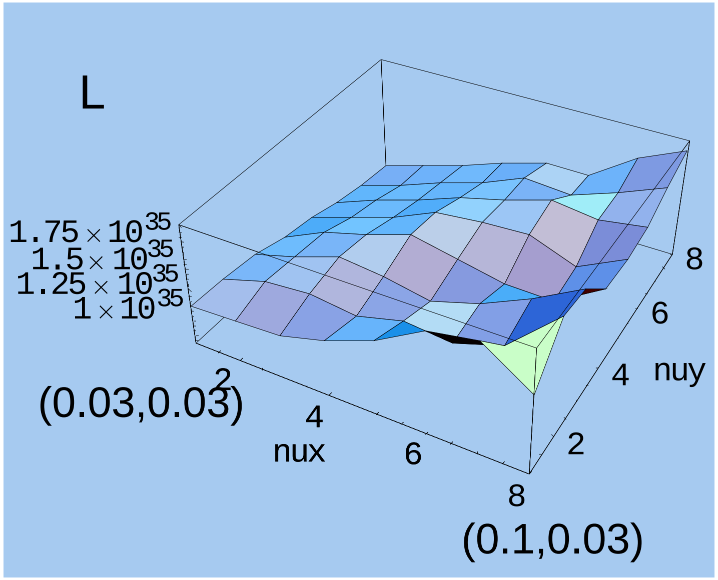


- Crab waist option of Super KEKB, longitudinal slice, Nslice=20, 1000 turn.
- Scan area
- $0.503<\nu_x<0.603$
- $0.53<\nu_y<0.6$
- 0.01 step

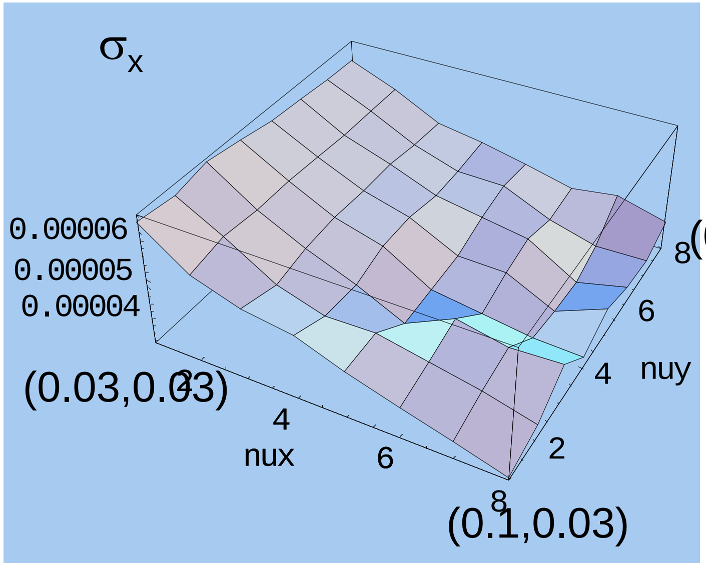


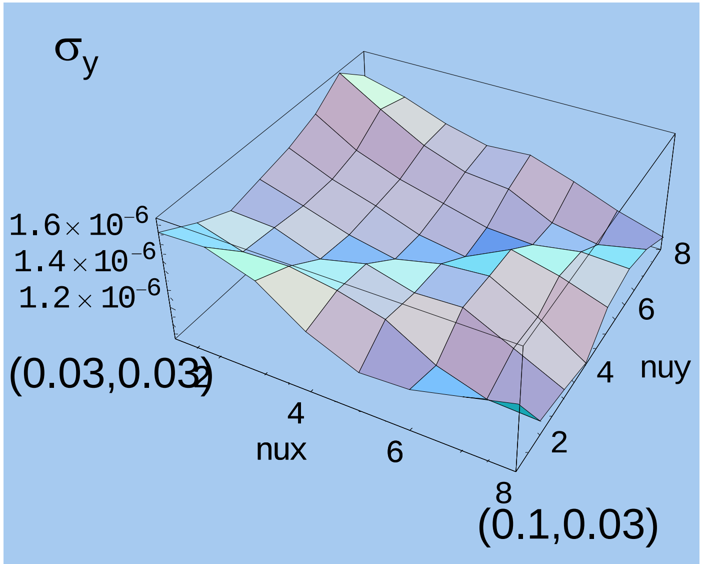


Near integer tune: high current & low β

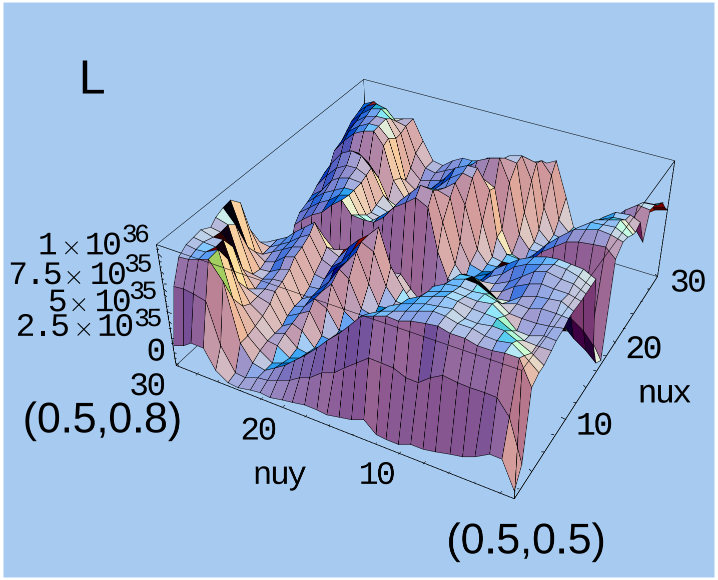


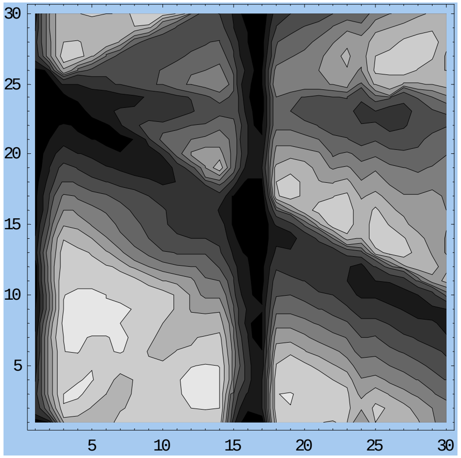
- $0.033<\nu_x<0.103$
- $0.03<\nu_y<0.1$
- 0.01 step
- Lum. is better at higher tunes in both, but still low.





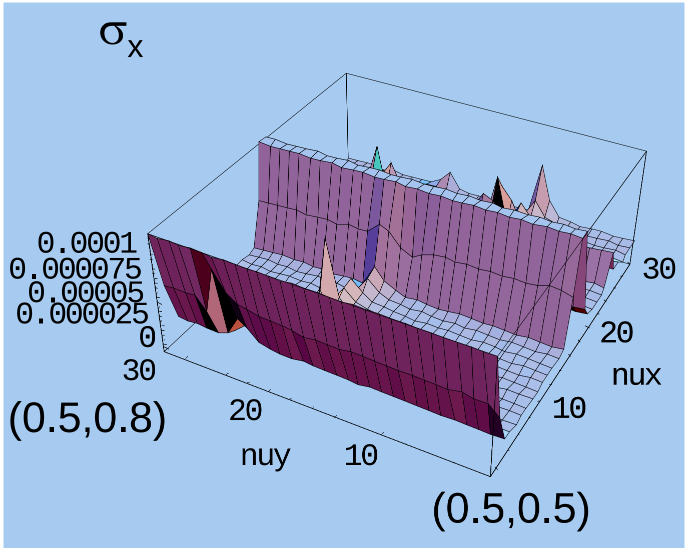
Weak strong simulation results for the middle case, high current & low β

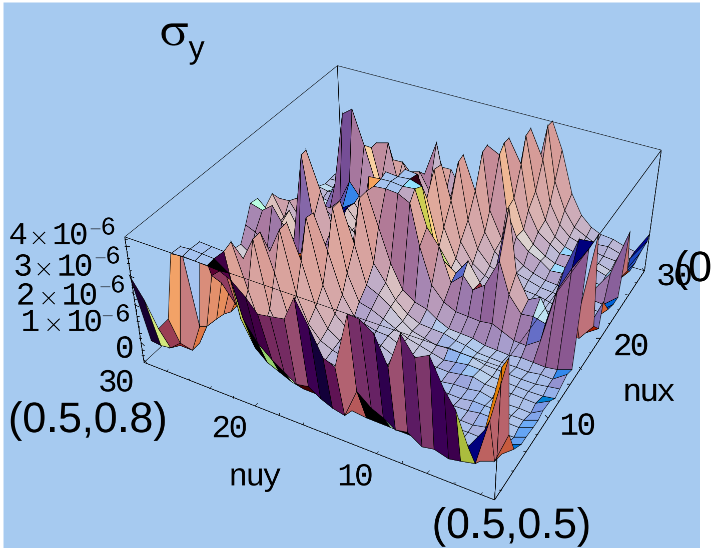




- Crab waist option of SuperKEKB
- $0.503<\nu_x<0.803$
- $0.503<\nu_y<0.803$
- 0.01 step

- Stopband is narrower in the weak-strong simulation. Note that the horizontal size of one beam is fixed.





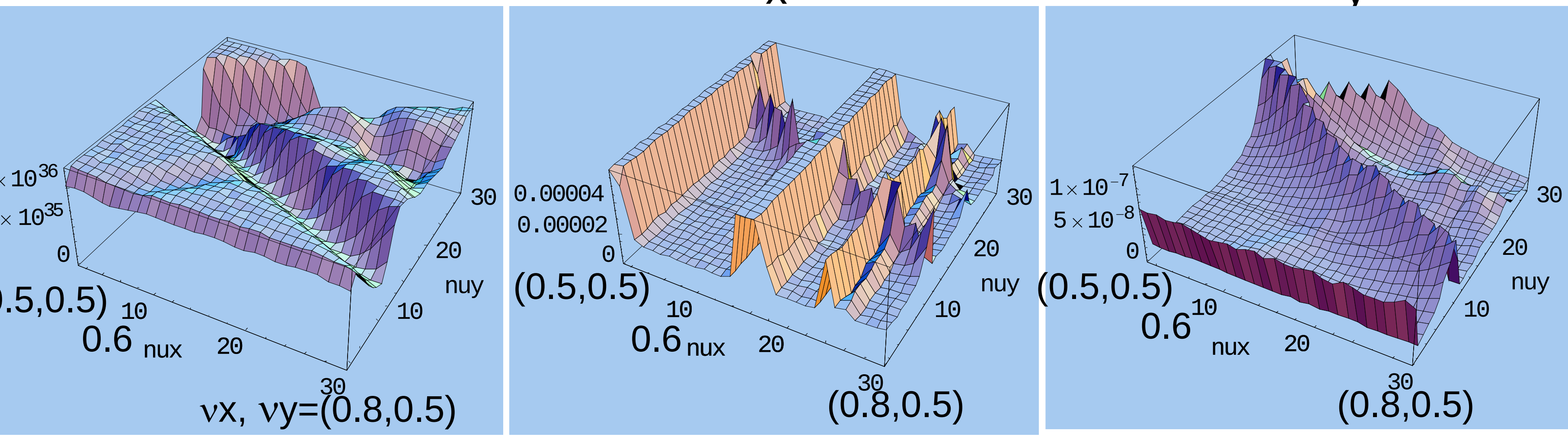
Super B with low ε and low β

	SuperKEKB	Middle	SuperB (LNF/SLAC)
εx	9.00E-09	6.00E-09	0.8E-09
εy	4.50E-11	6.00E-11	2E-12
βx (mm)	200	50	9
βy (mm)	3	0.5	0.133
σz (mm)	3	6	6
νs	0.025	0.01	0.012/0.026
ne	5.50E+10	5.50E+10	1.9E+10
np	1.26E+11	1.27E+11	3.3E+10
θ/2 (mrad)	0	15	25
ξx	0.397	0.022	
ξy	0.794->0.24	0.179	
Lum (W.S.)	8E+35	1.00E+36	1.00E+36
Lum (S.S.)	8.25E35	8-9E35	

Weak-strong simulation for low ε and low β (LNF/SLAC)

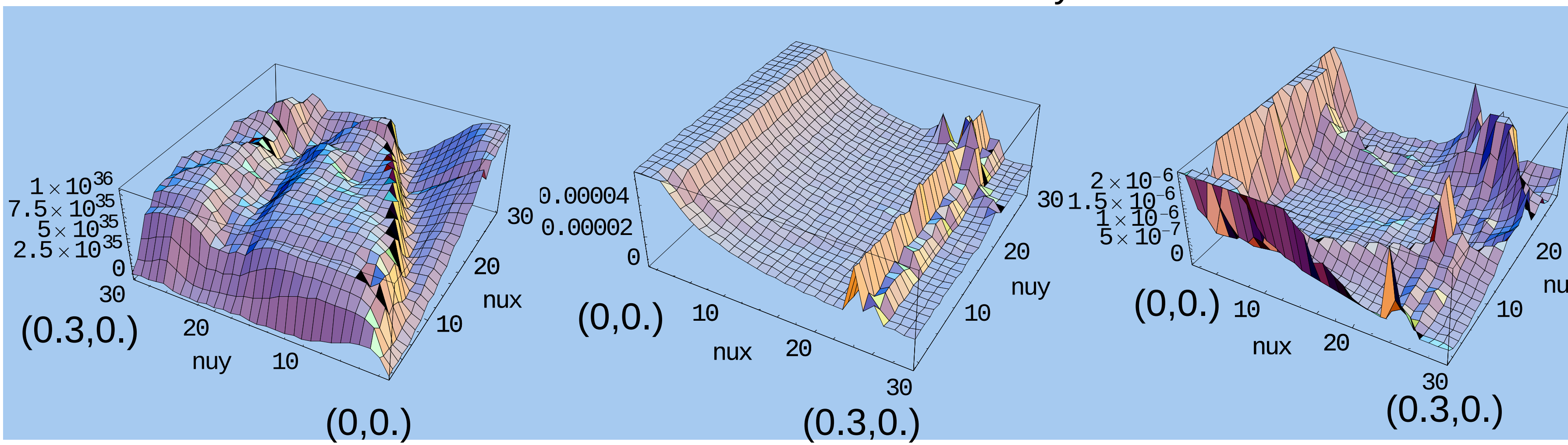
- Longitudinal slice, Nslice=200
- $0.503<\nu_x<0.803$, $0.503<\nu_y<0.803$, 0.01 step

L σ_x σ_y



- 0. 03<ν_x<0.303, 0.03<ν_y<0.303, 0.01 step
- Wide region with horizontal blow-up near ν_x~0. Similar as strong-strong.

L σ_x σ_y



Strong-strong simulation for the low ε and low β design is difficult, because a bunch should be sliced too much pieces in the longitudinal.

Stopband width in the strong-strong simulation may be the interesting issue for the collision scheme.

Summary

- The crab crossing is being studied in KEKB now.
- We understand how accurate tuning we can and have to do in KEKB.
- The crab waist scheme will be studied in DAFNE and KEKB in the near future.
- Synchro-betatron stop-band in the crab waist scheme, which is remarkable in the strong-strong simulation, is important issue. The low tune shift may help the stopband width.
- It is difficult to simulate the low ε and low β parameter with the strong-strong method now.
- We have to have a solution of dynamic aperture and injection scheme in the low emittance scheme.
- It becomes clear how and which way we choose gradually (soon).