

# Beam-beam simulations: dynamical effects and beam-beam limit for LEP3

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KEK-ACCEL  
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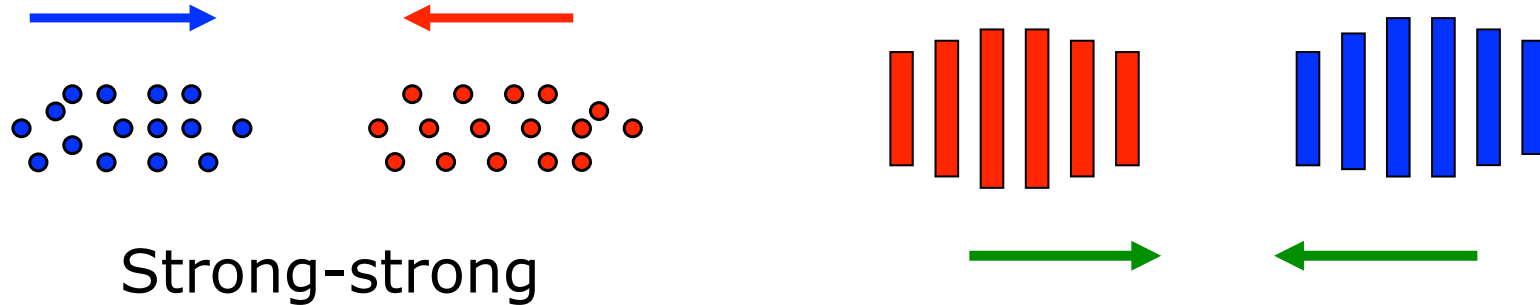
# Parameters of LEP3 given by F. Zimmermann

	LEP3		LEP3
beam energy $E_b$ [GeV]	120	$V_{RF,tot}$ [GV]	12.0
circumference [km]	26.7	$\delta_{max,RF}$ [%]	4.2
beam current [mA]	7.2	$\xi_x/IP$	0.09
#bunches/beam	4	$\xi_y/IP$	0.08
#e-/beam [ $10^{12}$ ]	4.0	$f_s$ [kHz]	3.91
horizontal emittance [nm]	25	$E_{acc}$ [MV/m]	20
vertical emittance [nm]	0.10	eff. RF length [m]	600
bending radius [km]	2.6	$f_{RF}$ [MHz]	1300
partition number $J_\epsilon$	1.5	$\delta_{rms}^{SR}$ [%]	0.23
momentum comp. $\alpha_c$ [ $10^{-5}$ ]	8.1	$\sigma_{z,rms}^{SR}$ [cm]	0.23
SR power/beam [MW]	50	$L/IP$ [ $10^{32}cm^{-2}s^{-1}$ ]	107
$\beta_x^*$ [m]	0.2	number of IPs	2
$\beta_y^*$ [cm]	0.1	Rad.Bhabha b.lifetime [min]	16
$\sigma_x^*$ [ $\mu m$ ]	71	$\Upsilon_{BS}$ [ $10^{-4}$ ]	10
$\sigma_y^*$ [ $\mu m$ ]	0.32	$n_\nu/collision$	0.60
hourglass $F_{hg}$	0.67	$\Delta\delta^{BS}/collision$ [MeV]	33
$\Delta E_{loss}^{SR}/turn$ [GeV]	6.99	$\Delta\delta_{rms}^{BS}/collision$ [MeV]	48

# Parameters of TLEP-H given by F. Zimmermann

	TLEP-H		TLEP-H
beam energy $E_b$ [GeV]	120	$V_{RF,tot}$ [GV]	6.0
circumference [km]	80	$\delta_{max,RF}$ [%]	9.4
beam current [mA]	24.3	$\xi_x/IP$	0.10
#bunches/beam	80	$\xi_y/IP$	0.10
#e-/beam [ $10^{12}$ ]	40.5	$f_s$ [kHz]	0.44
horizontal emittance [nm]	9.4	$E_{acc}$ [MV/m]	20
vertical emittance [nm]	0.05	eff. RF length [m]	300
bending radius [km]	9.0	$f_{RF}$ [MHz]	700
partition number $J_\epsilon$	1.0	$\delta_{rms}^{SR}$ [%]	0.15
momentum comp. $\alpha_c$ [ $10^{-5}$ ]	1.0	$\sigma_{z,rms}^{SR}$ [cm]	0.17
SR power/beam [MW]	50	$L/IP$ [ $10^{32}cm^{-2}s^{-1}$ ]	490
$\beta_x^*$ [m]	0.2	number of IPs	2
$\beta_y^*$ [cm]	0.1	Rad.Bhabha b.lifetime [min]	32
$\sigma_x^*$ [ $\mu m$ ]	43	$\Upsilon_{BS}$ [ $10^{-4}$ ]	15
$\sigma_y^*$ [ $\mu m$ ]	0.22	$n_\nu/collision$	0.50
hourglass $F_{hg}$	0.75	$\Delta\delta^{BS}/collision$ [MeV]	42
$\Delta E_{loss}^{SR}/turn$ [GeV]	2.1	$\Delta\delta_{rms}^{BS}/collision$ [MeV]	65

# 3D beam-beam interaction



- $\beta_y = 1 \text{ mm}$ ,  $\sigma_z = 2.3 \text{ (LEP3)} - 1.7 \text{ (TLEP-h)} \text{ mm}$ . For  $\sigma_z > \beta_y$ , the beam-beam force varies significantly along the bunch length.
- A bunch is divided into several slices which contain many macro-particles.
- Collision is calculated slice by slice.

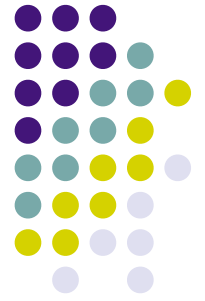
$$\prod_{i=1}^{N_{sl,-}} \exp \left[ - : V_{0,+}^{-1}(s_{-,i}) \phi_{-,i}(+, s_{-,i}) V_{0,+}(s_{-,i}) \Delta s : \right]$$

$$\prod_{j=1}^{N_{sl,+}} \exp \left[ - : V_{0,-}^{-1}(s_{+,j}) \phi_{+,j}(-, s_{+,j}) V_{0,-}(s_{+,j}) \Delta s : \right]$$

drift between slices

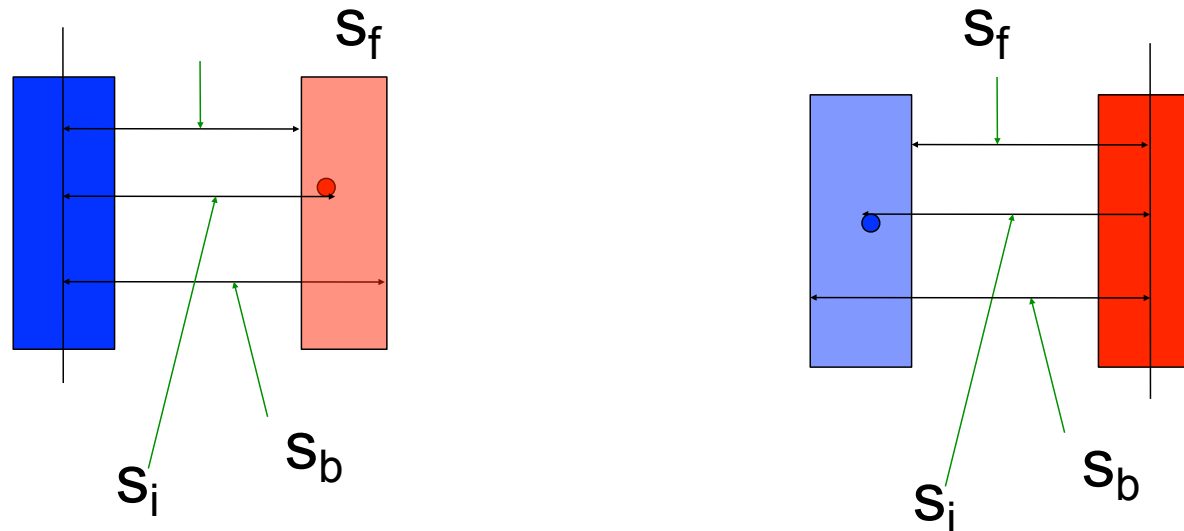
$$V_0(s) \equiv V_0(s, 0) = S \exp \left[ - : \int_0^s H_0 ds : \right]$$

$$= \prod_{i=\pm} \exp \left[ - : \frac{p_{x,i}^2 + p_{y,i}^2}{2} s : \right],$$



# 3D symplectic integrator for slice-by-slice collision

- Potential is calculated at  $s_f$  and  $s_b$ .
- Potential is interpolated to  $s_i$  between  $s_f$  and  $s_b$ .

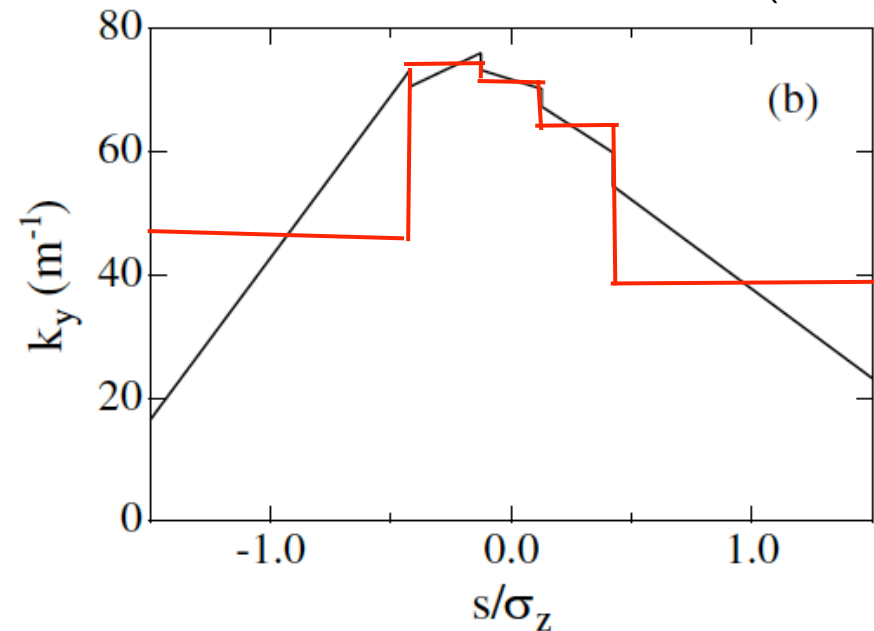
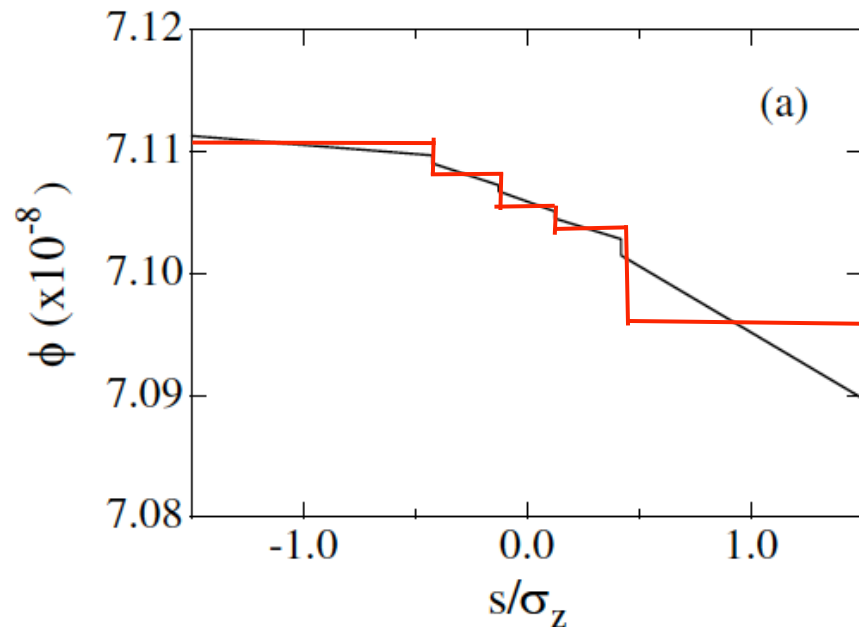


- Since the interaction depends on  $z$ , energy kick should be taken into account  $d\phi/dz$ .
- We repeat the same procedure exchanging particle and slice.

# Potential and linear kick of he slice-by-slice collision

KEKB case

K.Ohmi et al., PRST7,104401 (2004)



$$k_y = \partial^2 \phi(s) / \partial y^2 = \Delta p_y / \Delta x$$

$$\phi_j(s) = \phi_j(s_b) + \frac{\phi_j(s_f) - \phi_j(s_b)}{s_f - s_b} (s - s_b)$$

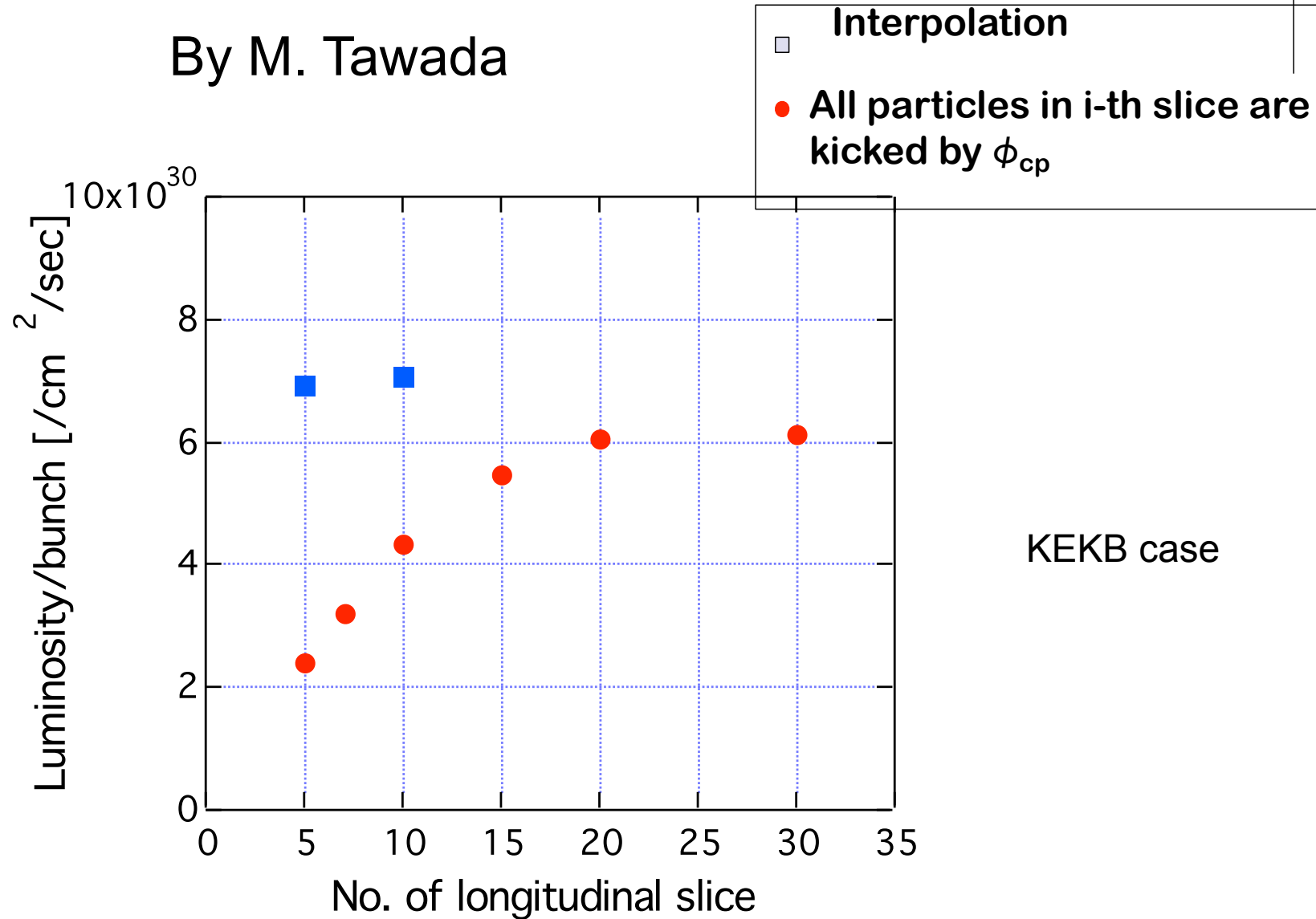
$$\phi_j(s) = \phi_j(s_c)$$

- potential is interpolated.
- potential at center of slice, BAD method



# Convergence for the slice number

By M. Tawada

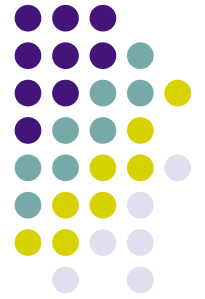




# Simulation

- Radiation damping rate
  - LEP3  $\tau_{xy}/T_0=0.036$ ,  $\tau_s/T_0=0.043$
  - TLEP-H  $\tau_{xy}/T_0=0.013$ ,  $\tau_s/T_0=0.00875$
- Track particles 1000 turns (2000 turns for half ring),  $>10x T_0/\tau_{xy}$ .
- Target luminosity per collision
  - LEP3  $L=2.675 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
  - TLEP-H  $L=6.125 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- $N_{\text{macrop}}=1,000,000$   $n_{\text{zslice}}=16$



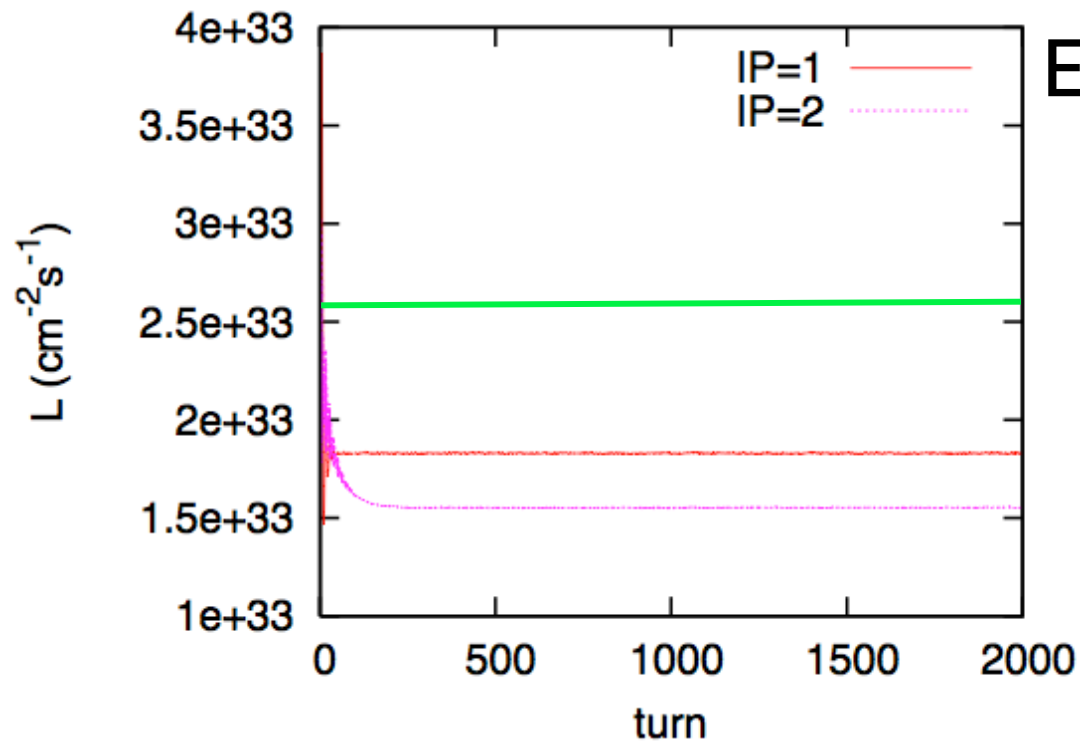


# Choice of operating point

- $(\nu_x, \nu_y) = (0.51, 0.55-0.59)$  is the best for dynamic beta in horizontal and integrability in vertical in every e<sup>+</sup>e<sup>-</sup> colliders with single IP.
- $(\nu_x, \nu_y) = (0.02, 0.10-0.18)$  for 2IP. The horizontal tune may not be acceptable.
- Luminosity dependence in tune space is shown in this presentation. (No strategy for optimization now.)

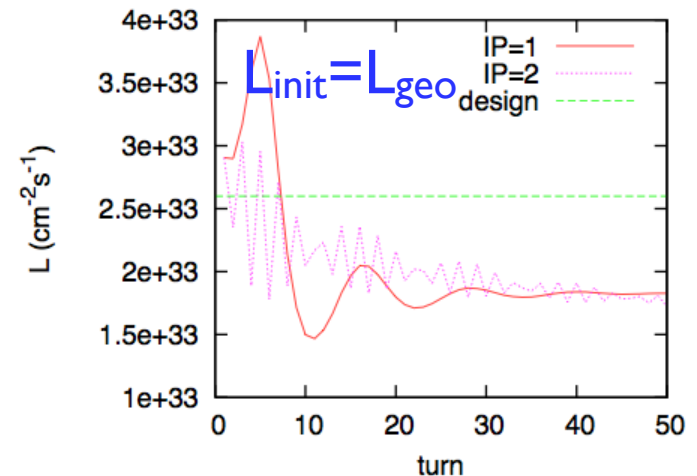
# Simulation I (first trial)

- $v_x=0.52, v_y=0.58$
- Comparison between IP=1 and 2.



Expect  $L_{\text{geo}} \sim 2.675 \times 10^{33}$

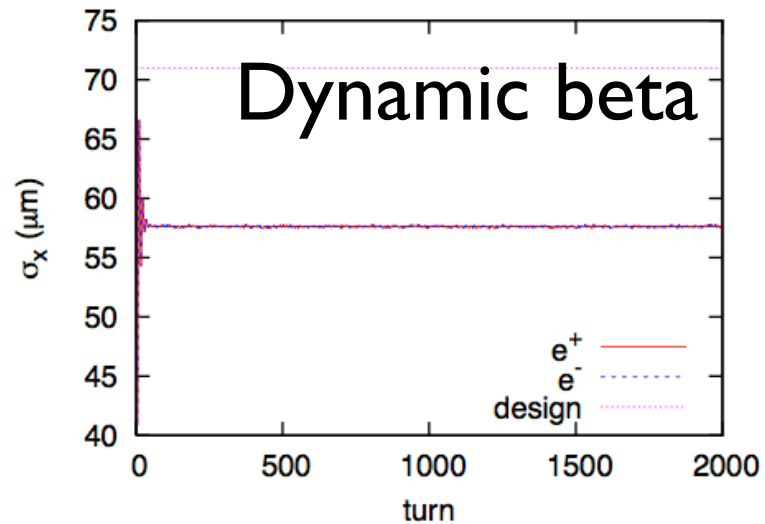
## Short term behavior



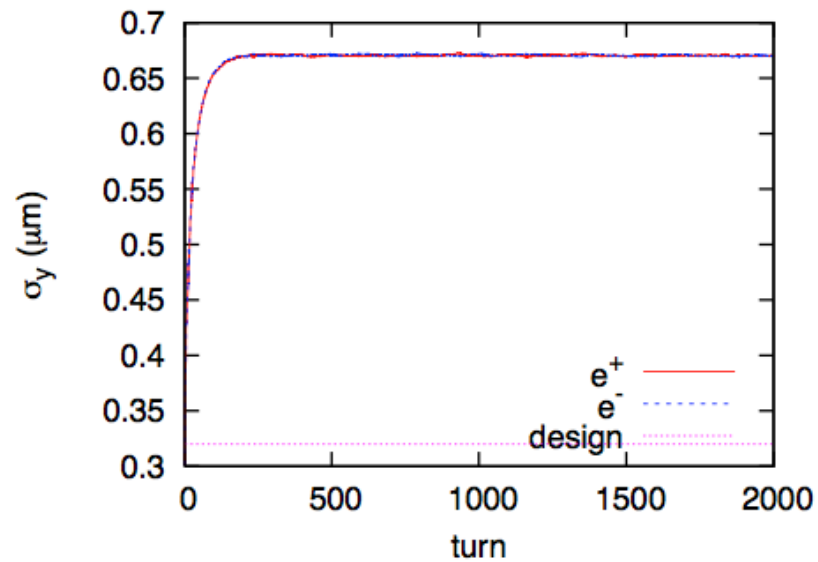
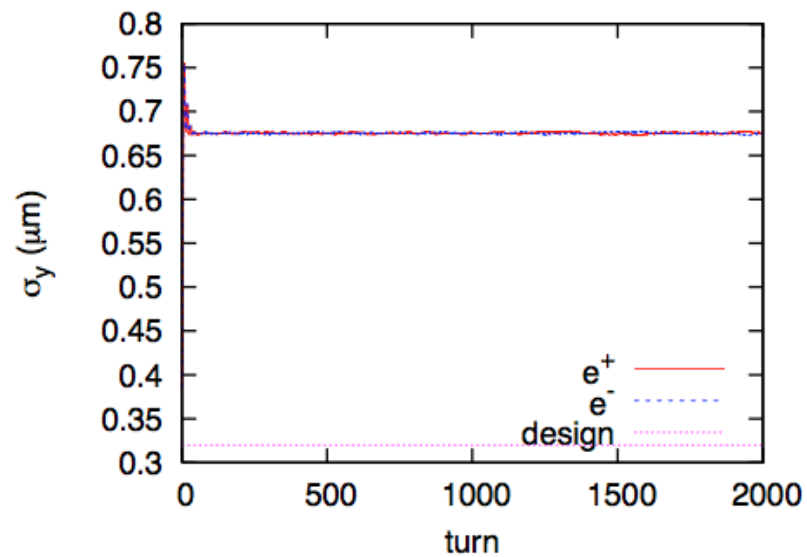
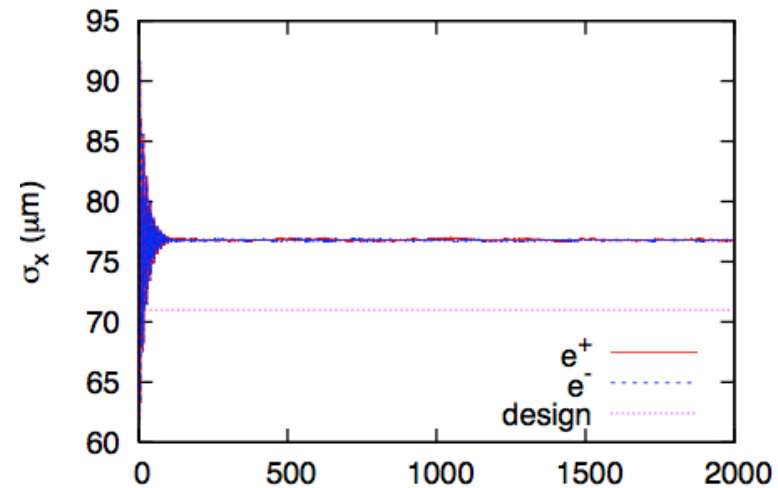
# Beam size

$$v_x=0.52, v_y=0.58$$

IP=1



IP=2



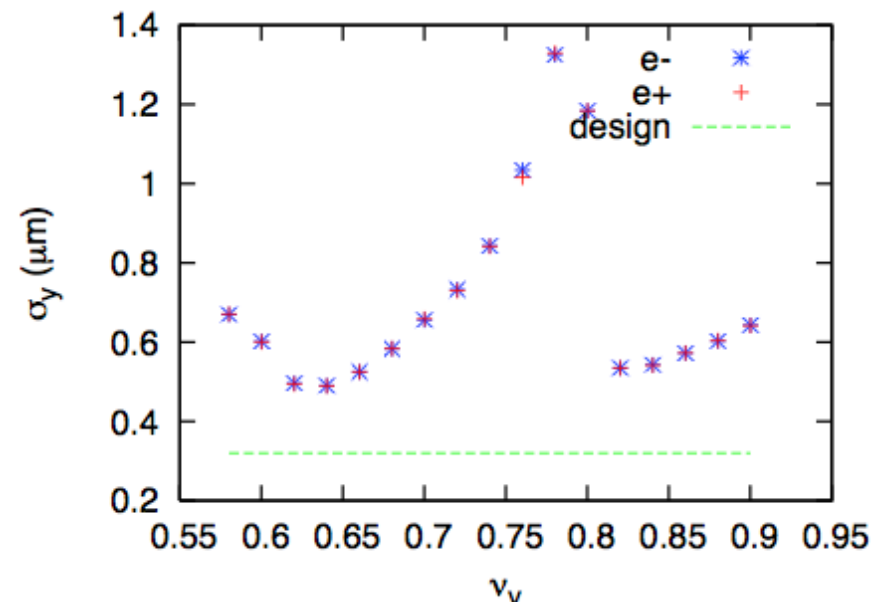
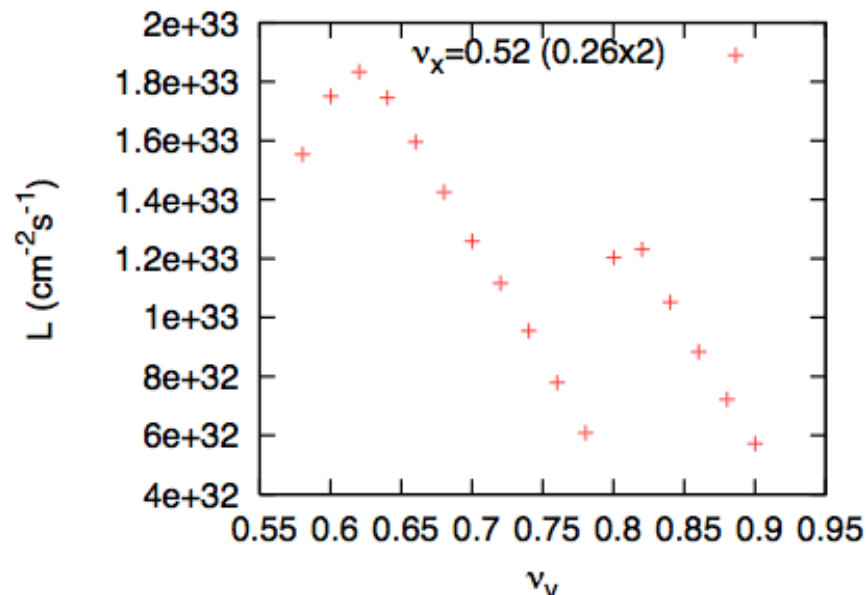
# First impression of the simulation results

- Dynamic beta works well for IP=1 in this operating point, (0.52,0.58), but does not for IP=2. This is reasonable result.
- Luminosity for IP=1 is not very good. Usually this operating point showed higher luminosity than target one in KEKB.
- Vertical beam size increases in short time.
- Hourglass or large synchrotron tune may affect.

# Systematic study: Tune scan

- IP=2,  $v_x=0.52$ , scan  $v_y$
- Head-tail type of coherent motion appear  $v_y > 0.8$ .
- Incoherent  $v_y \sim 0.75$  ?

$$L_{\text{geo}} \sim 2.675 \times 10^{33}$$

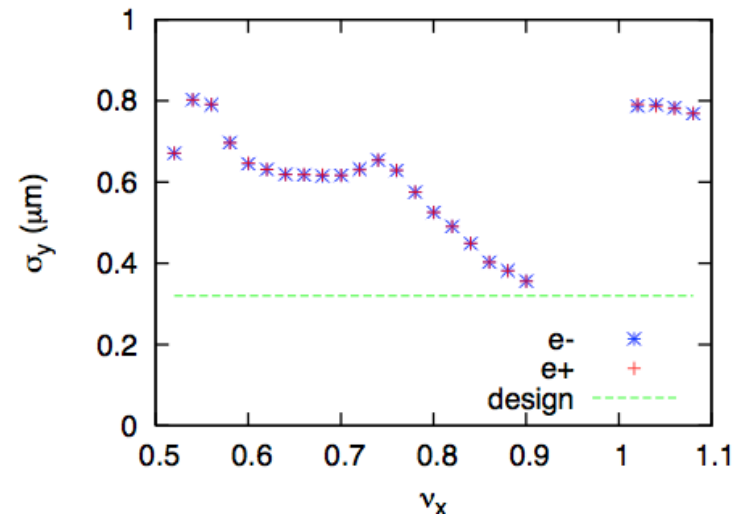
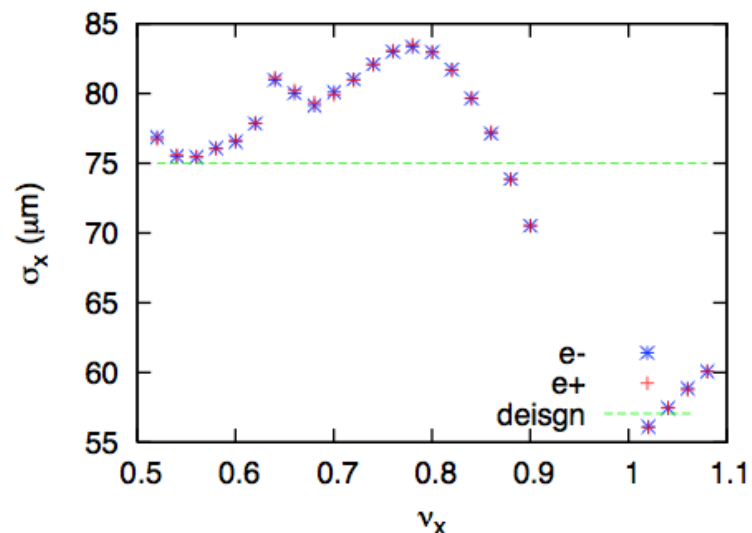
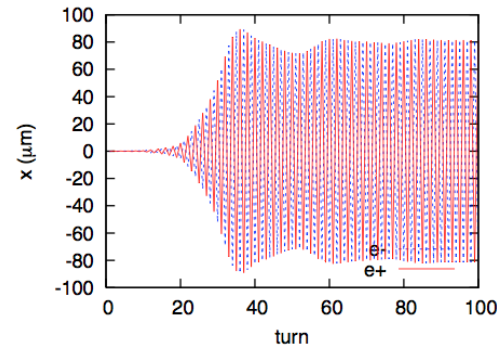
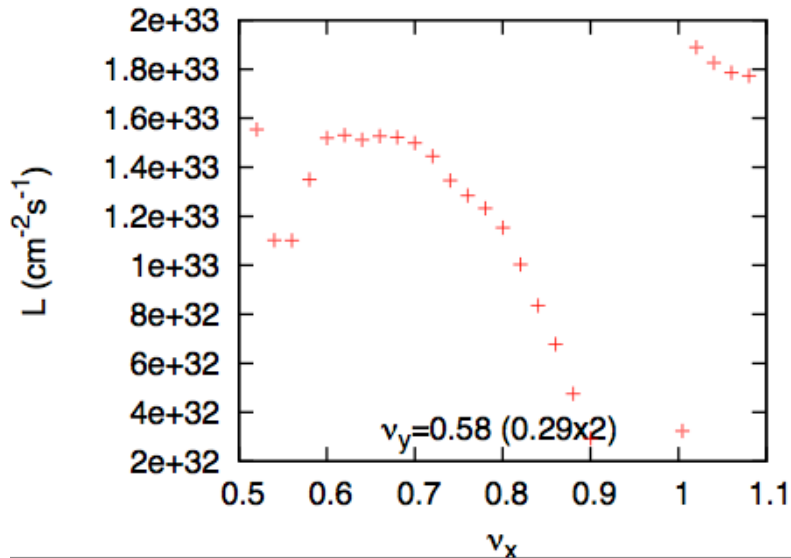


# Tune scan II

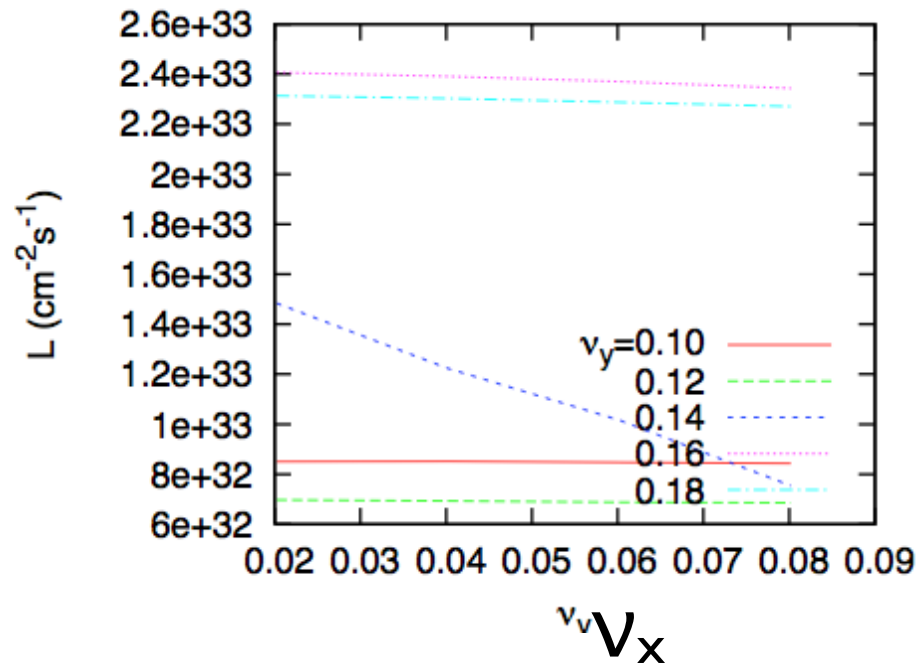
- IP=2,  $\nu_y = 0.58$  ( $0.29 \times 2$ ), scan  $\nu_x$

$$L_{\text{geo}} \sim 2.675 \times 10^{33}$$

Coherent motion appears at  $\nu_y > 0.8$

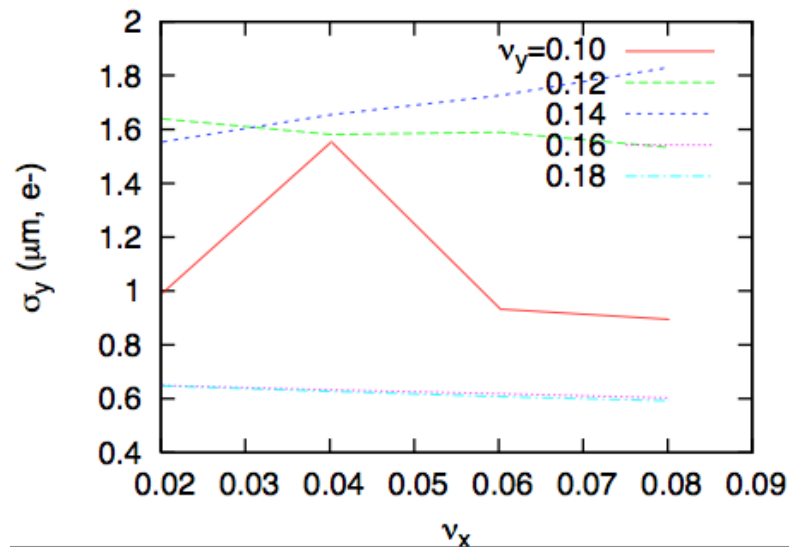
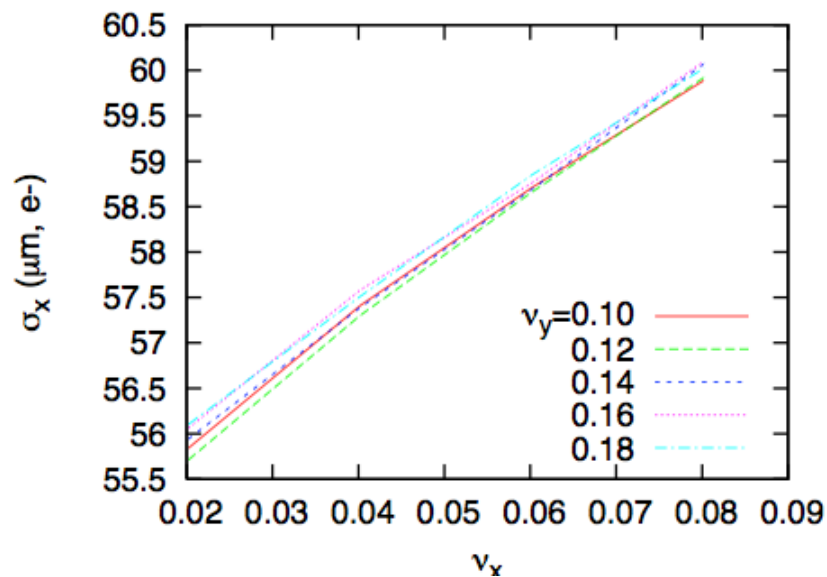


# Slight upper of integer



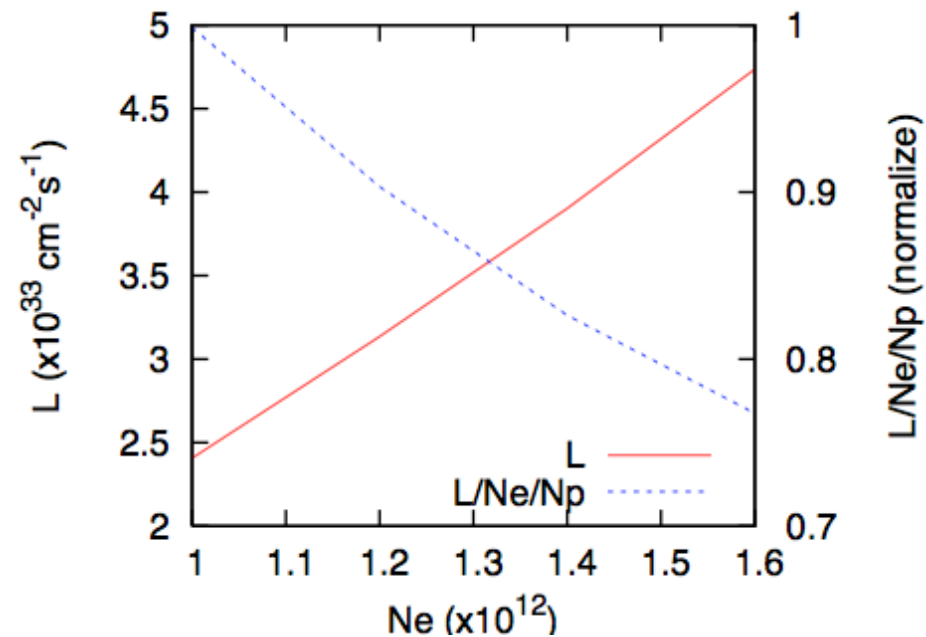
$$L_{\text{geo}} \sim 2.675 \times 10^{33}$$

- Best Luminosity, but lower than deisgn.



# Bunch population and specific luminosity

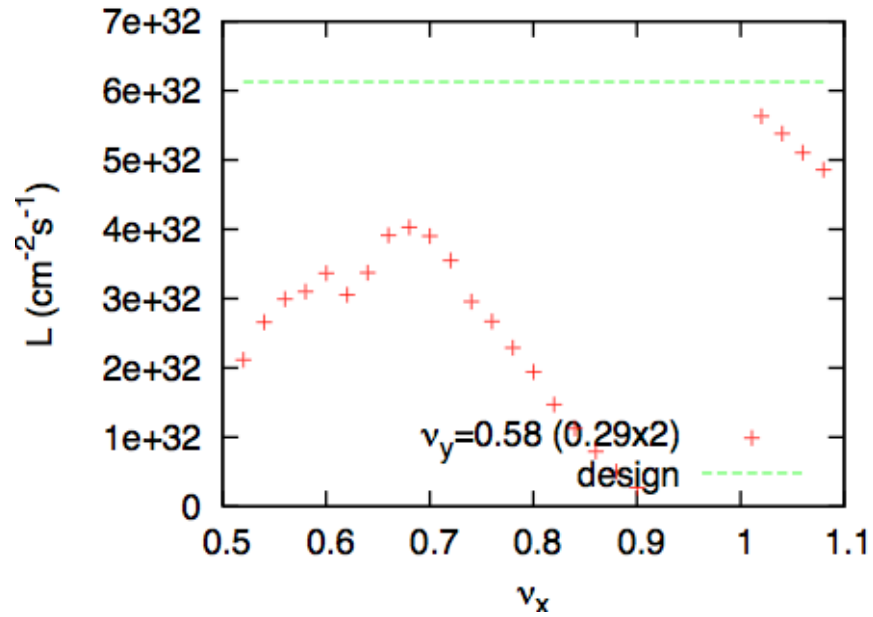
- $L=2.6 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$  is achieved at  $N_e=1.1 \times 10^{12}$ .



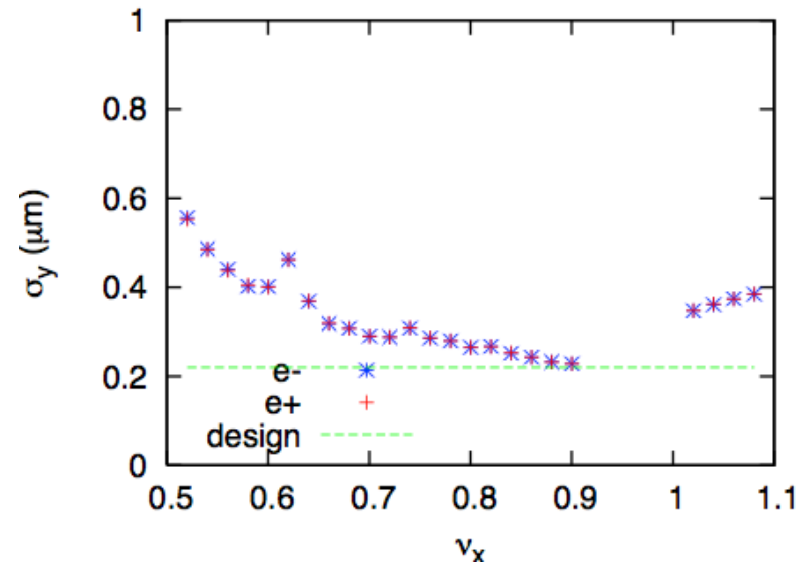
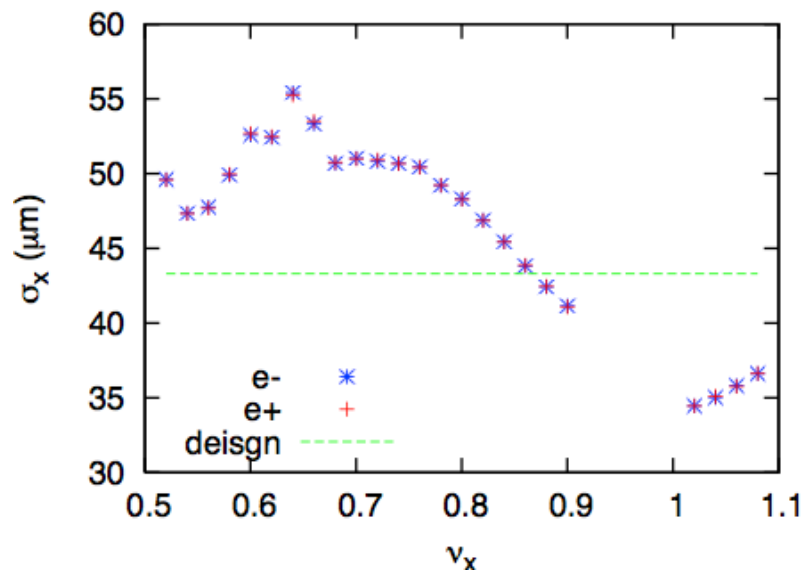
$$L_{\text{geo}} \sim 2.675 \times 10^{33}$$



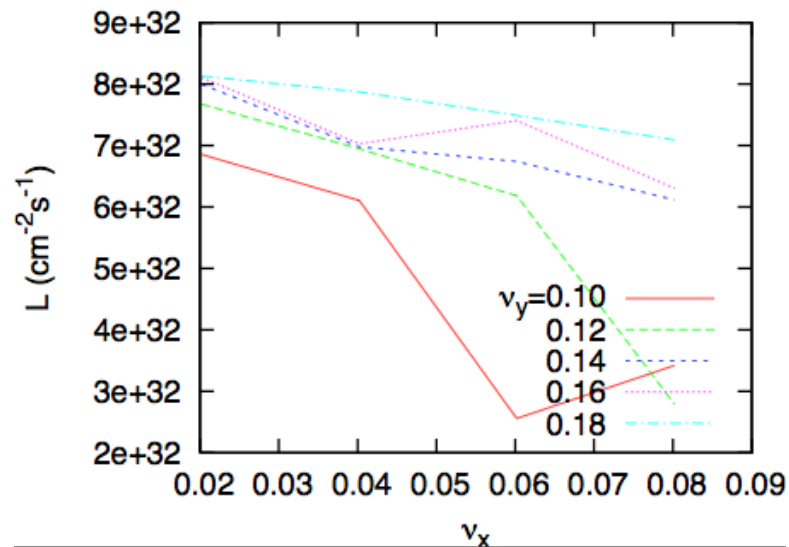
# TLEP-H



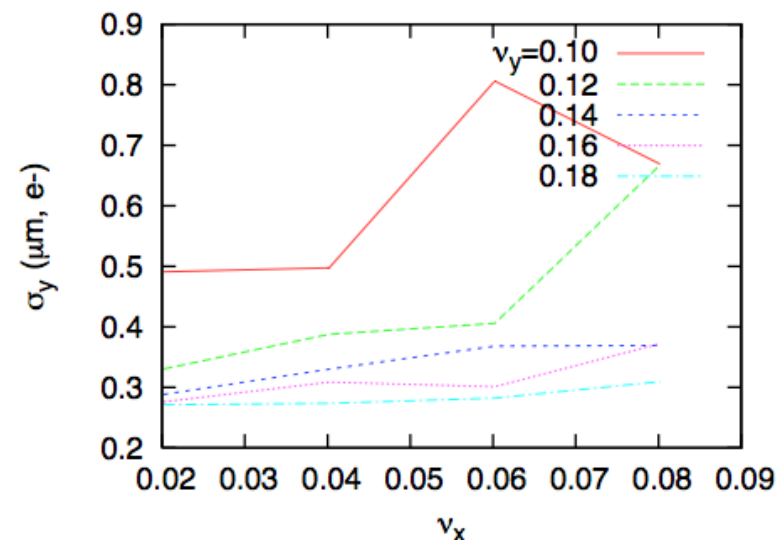
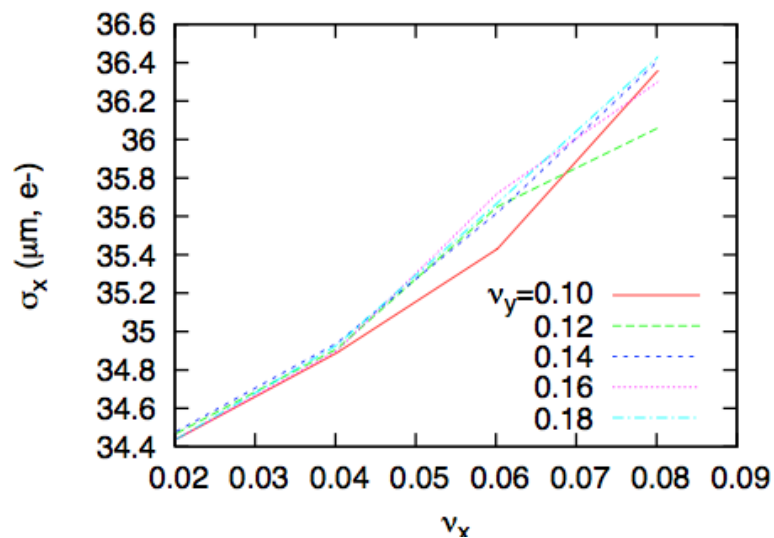
- $v_y = 0.58$  ( $0.29 \times 2$ ), scan  $v_x$



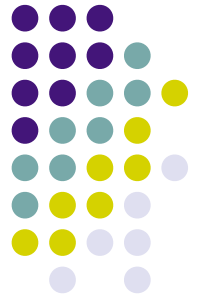
# TLEP-H



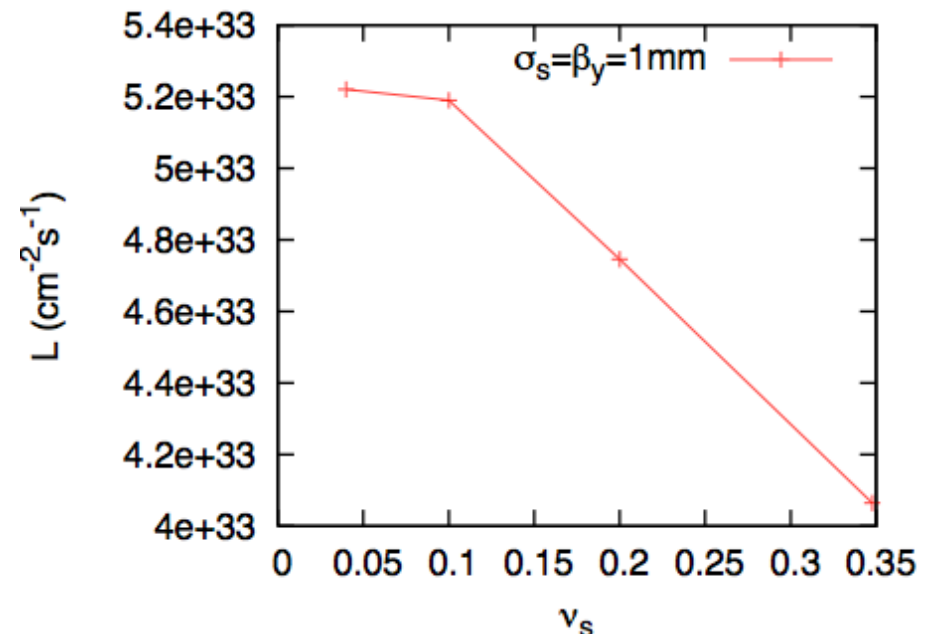
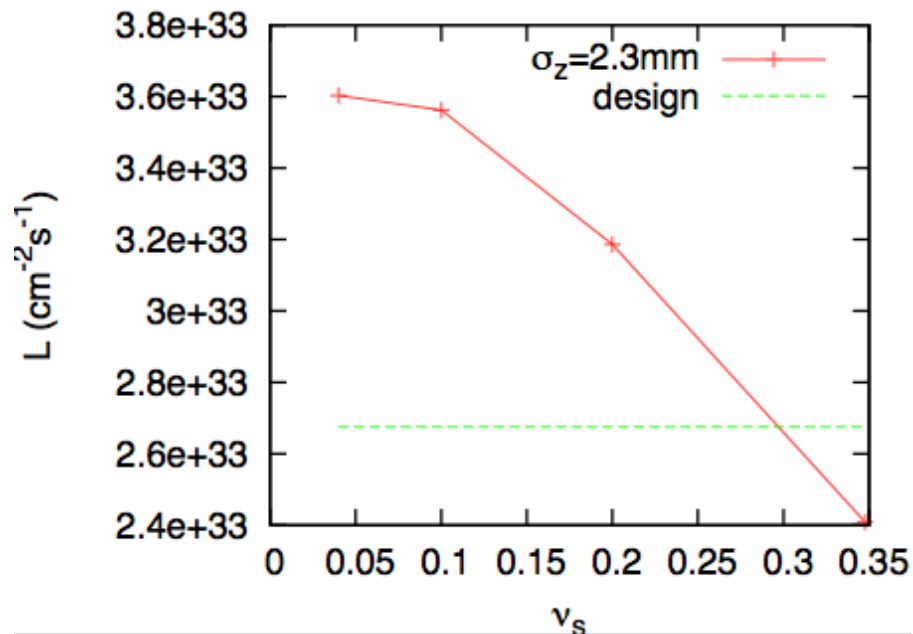
- Design luminosity  $6.1 \times 10^{32}$  is reachable.
- Better result than LEP3.
- $v_s$  is lower than LEP3.



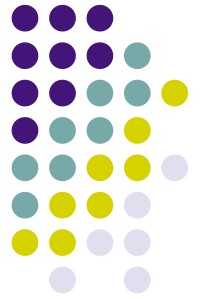
# Synchrotron tune (LEP3)



- Luminosity degradation at large synchrotron tune is seen.
- $\nu_x=0.02, \nu_y=0.19$  IP=2



# Summary



- Beam-beam simulations has been performed for LEP3 and TLEP-H.
- Rough tune scan was done.
- To achieve the design luminosity in LEP3, 10% more bunch population is necessary at least. TLEP-H can achieve the design.
- The large synchrotron tune degrades the luminosity performance.
  - The treatment of synchrotron motion and z dependence of the beam-beam force should be checked.