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

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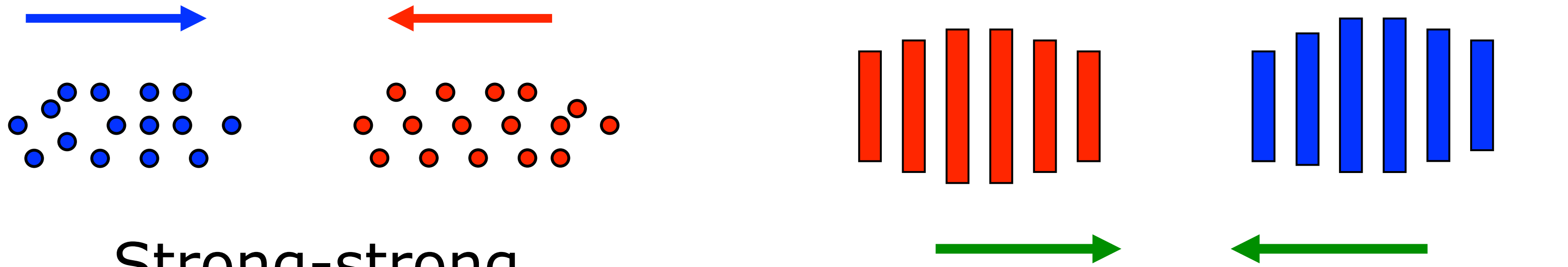
Parameters of LEP3 given by F. Zimmermann

	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	ξ_x/IP	0.09
#bunches/beam	4	ξ_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_ε	1.5	$\delta^{SR}{}_{rms}$ [%]	0.23
momentum comp. α_c [10^{-5}]	8.1	$\sigma^{SR}{}_{z,rms}$ [cm]	0.23
SR power/beam [MW]	50	L/IP[10^{32}cm^{-2}s^{-1}]	107
β^*_x [m]	0.2	number of IPs	2
β^*_y [cm]	0.1	Rad.Bhabha b.lifetime [min]	16
σ^*_x [µm]	71	Υ_{BS} [10^{-4}]	10
σ^*_y [µm]	0.32	n_γ/collision	0.60
hourglass F_{hg}	0.67	$\Delta\delta^{BS}$/collision [MeV]	33
$\Delta E^{SR}{}_{loss}$/turn [GeV]	6.99	$\Delta\delta^{BS}{}_{rms}$/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	ξ_x/IP	0.10
#bunches/beam	80	ξ_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_ε	1.0	δ^{SR}_{rms} [%]	0.15
momentum comp. α_c [10^{-5}]	1.0	$\sigma^{SR}_{z,rms}$ [cm]	0.17
SR power/beam [MW]	50	L/IP[10^{32}cm^{-2}s^{-1}]	490
β^*_x [m]	0.2	number of IPs	2
β^*_y [cm]	0.1	Rad.Bhabha b.lifetime [min]	32
σ^*_x [µm]	43	Υ_{BS} [10^{-4}]	15
σ^*_y [µm]	0.22	n_γ/collision	0.50
hourglass F_{hg}	0.75	$\Delta\delta^{BS}$/collision [MeV]	42
ΔE^{SR}_{loss}/turn [GeV]	2.1	$\Delta\delta^{BS}_{rms}$/collision [MeV]	65

3D beam-beam interaction



Strong-strong

- β_y=1mm, σ_z=2.3(LEP3)-1.7(TLEP-h)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.

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

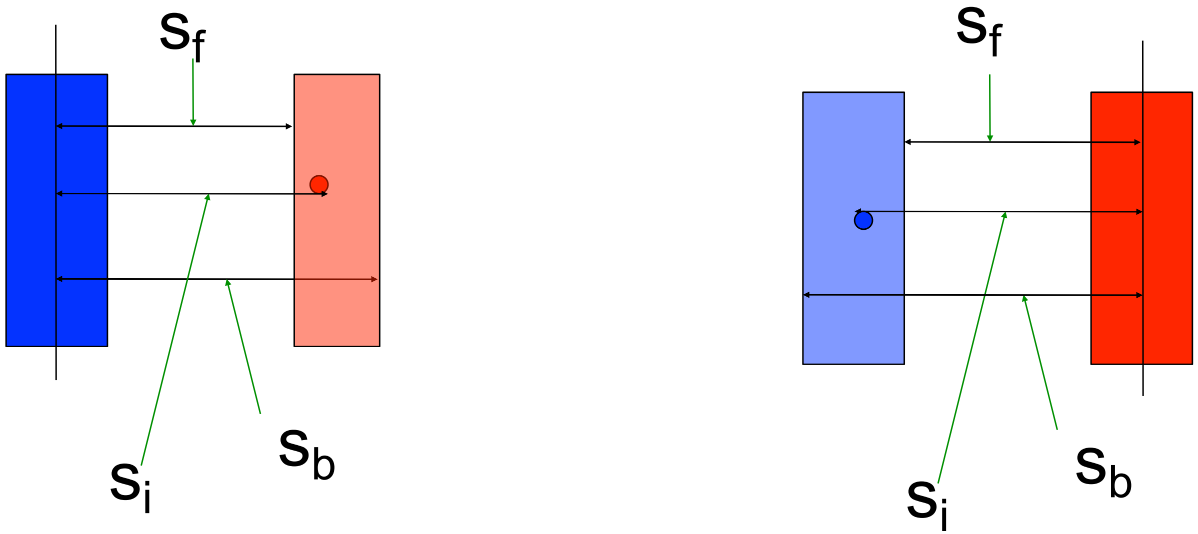
$$\prod_{j=1}^{N_{sl,+}} \exp\left[- : V_{0,-}^{-1}(s_{+,j})\phi_{+,j}(-, s_{+,j})V_{0,-}(s_{+,j})\Delta s :\right]$$

drift between slices

$$\begin{aligned} V_0(s) &\equiv V_0(s,0) = S \exp\left[- : \int_0^s H_0 ds :\right] \\ &= \prod_{i=\pm} \exp\left[- : \frac{p_{x,i}^2 + p_{y,i}^2}{2} s :\right], \end{aligned}$$

3D symplectic integrator for slice-by-slice collision

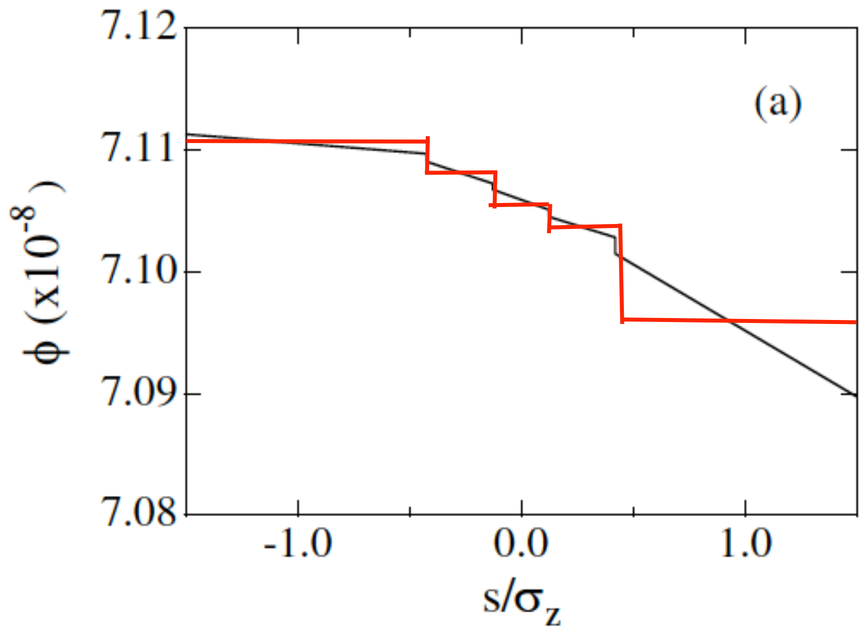
- Potential is calculated at s_f and s_b.
- Potential is interpolated to s_i between s_f and s_b.

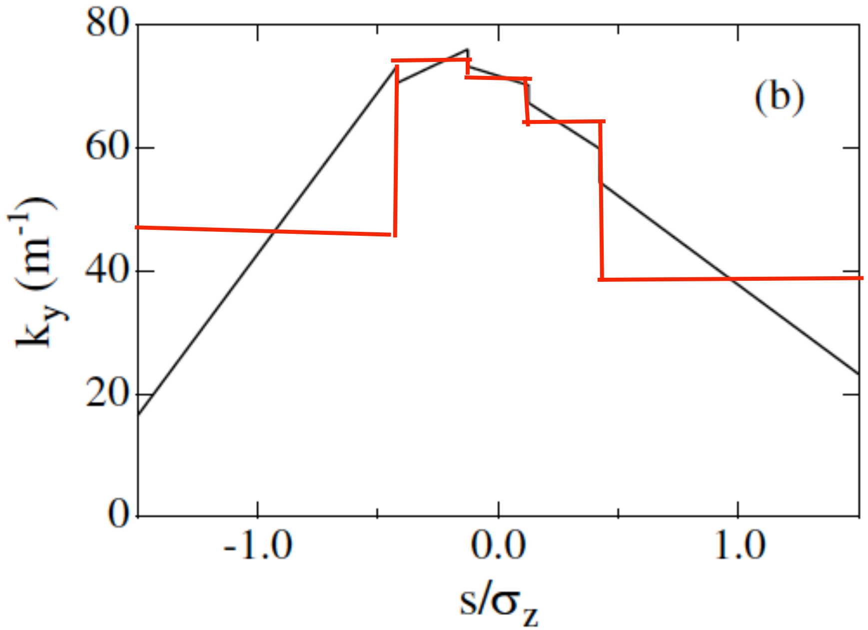


- Since the interaction depends on z, energy kick should be taken into account $d\phi/dz$.
- We repeat the same procedure exchanging particle and slice.

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

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





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

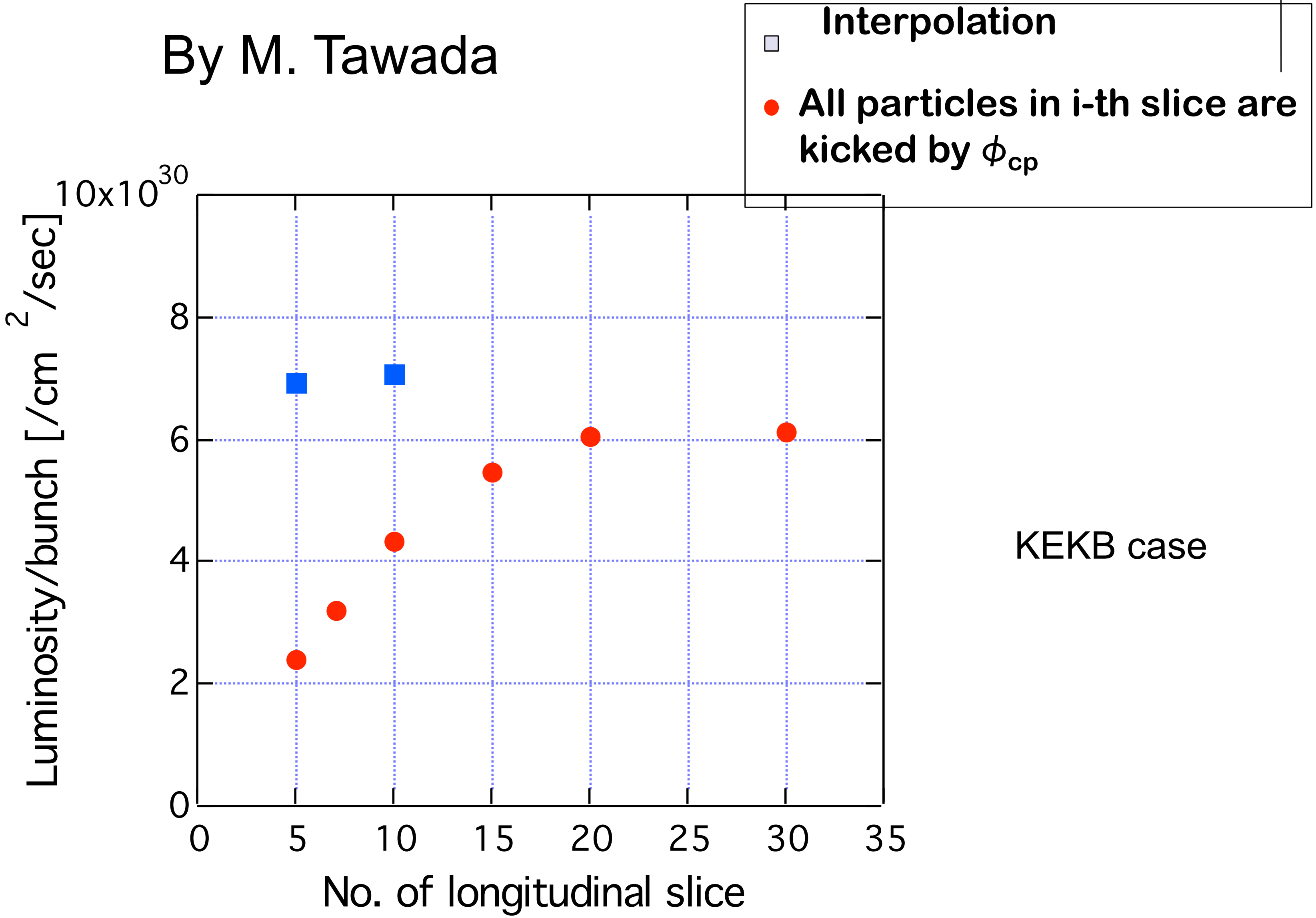
$$\phi_j(s) = \phi_j(s_b) + \frac{\phi_j(s_f) - \phi_j(s_b)}{s_f - s_b}(s - s_b)$$

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

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

Convergence for the slice number

By M. Tawada



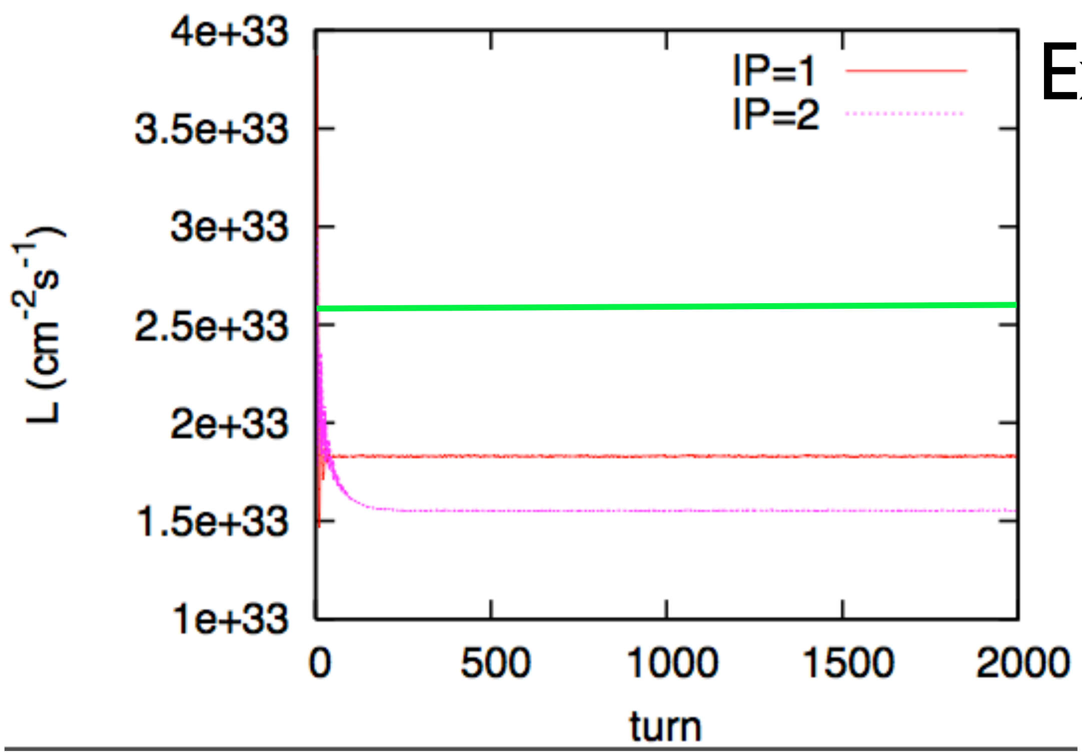
KEKB case

Simulation

- Radiation damping rate
  - LEP3 τ_{xy}/T_0=0.036, τ_s/T_0=0.043
  - TLEP-H τ_{xy}/T_0=0.013, τ_s/T_0=0.00875
- Track particles 1000 turns (2000 turns for half ring), >10x T_0/τ_{xy}.
- Target luminosity per collision
  - LEP3 L=2.675x10^{33} cm^{-2}s^{-1}
  - TLEP-H L=6.125x10^{32} cm^{-2}s^{-1}
- N_{macrop}=1,000,000 n_{zslice}=16

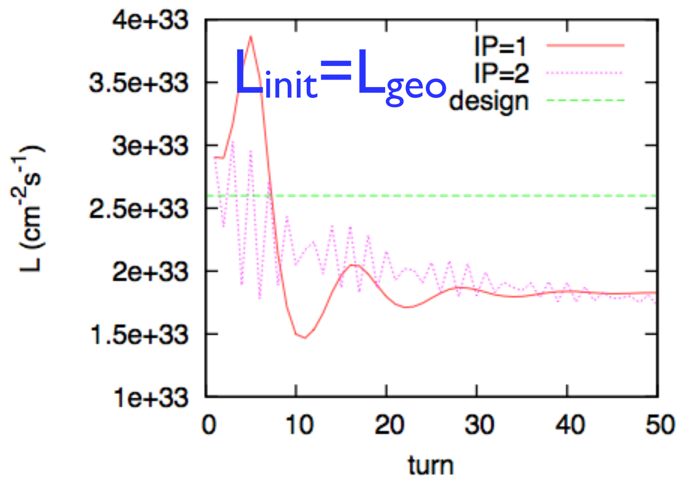
Simulation I (first trial)

- ν_x=0.52, ν_y=0.58
- Comparison between IP=1 and 2.



Expect L_{geo}~2.675x10^{33}

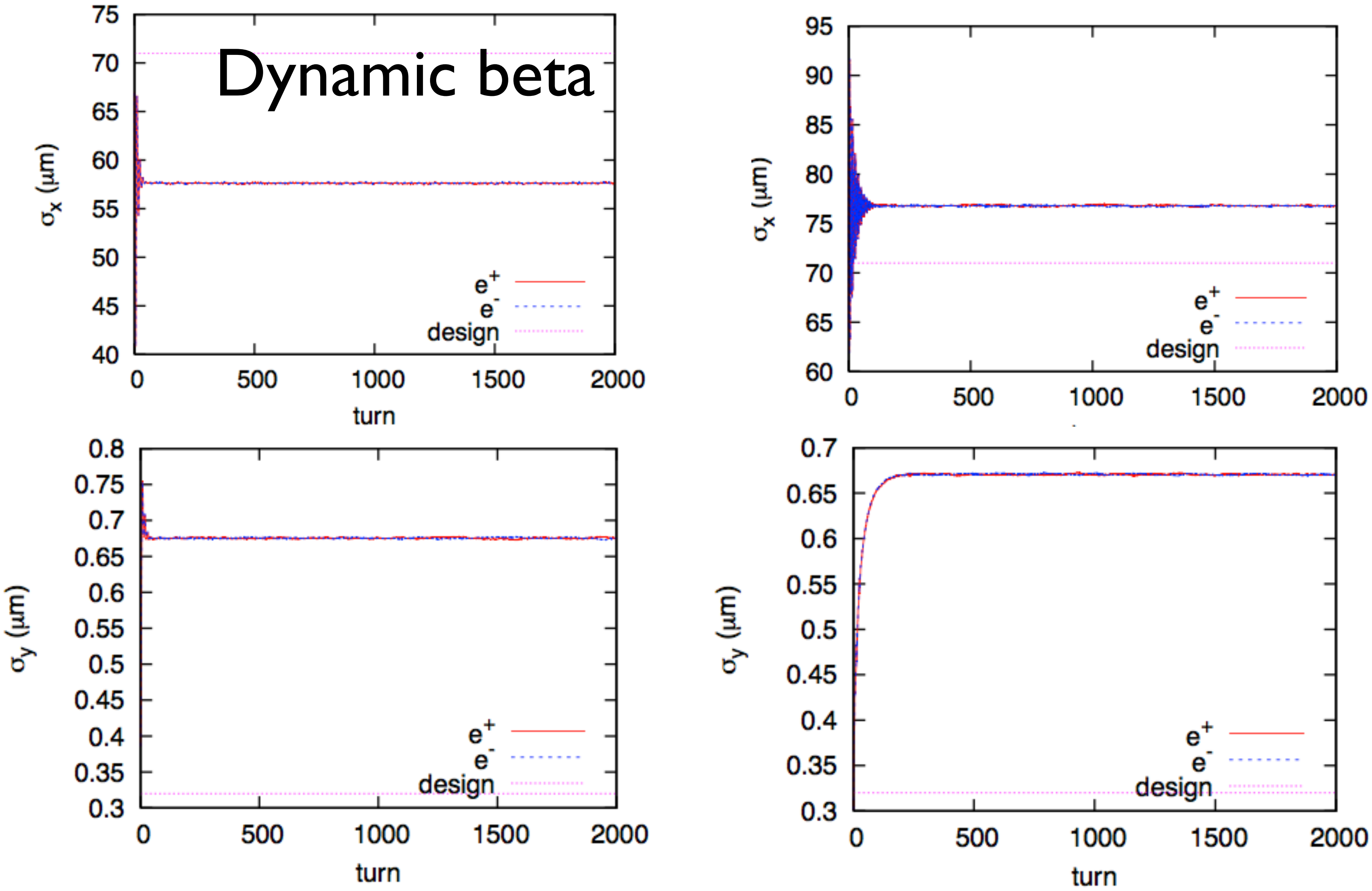
Short term behavior



Beam size

ν_x=0.52, ν_y=0.58

IP=1 IP=2



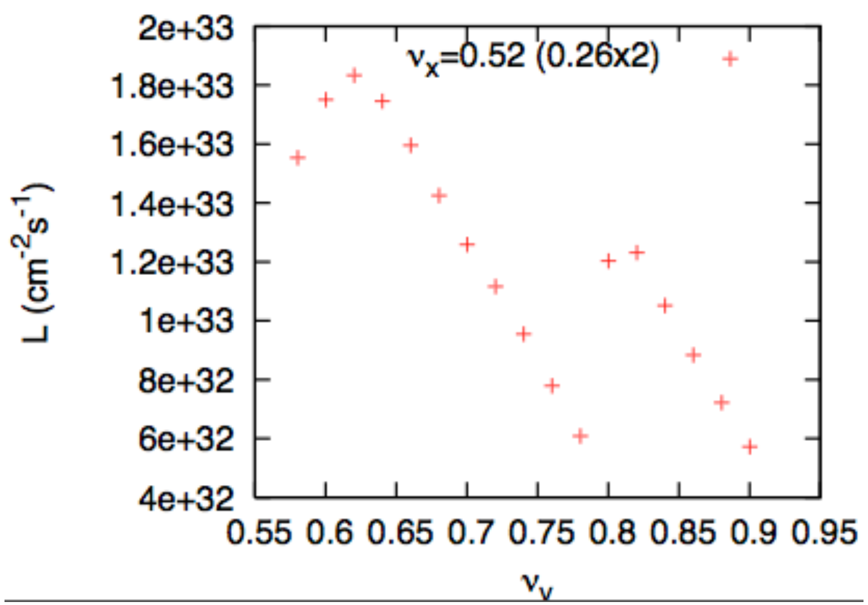
First impression of the simulation results

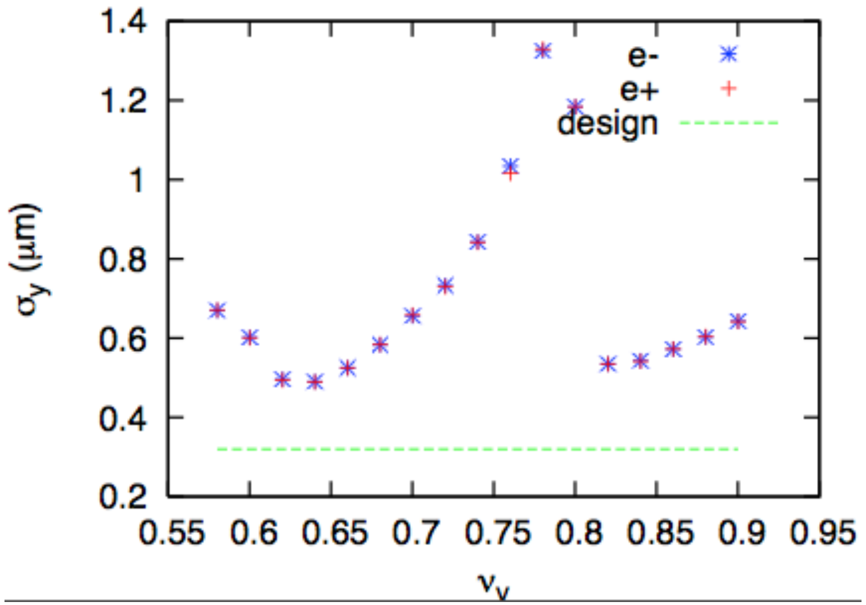
- Dynamic beta works well for IP=1 in this operating point, (0.52,0.58), but does not for IP=2. This is reasonable result.
- Luminosity for IP=1 is not very good. Usually this operating point showed higher luminosity than target one in KEKB.
- Vertical beam size increases in short time.
- Large synchrotron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

Systematic study: Tune scan

- IP=2, ν_x=0.52, scan ν_y
- Head-tail type of coherent motion appear ν_y>0.8.
- Incoherent ν_y~0.75 ?

L_{geo}~2.675x10^{33}

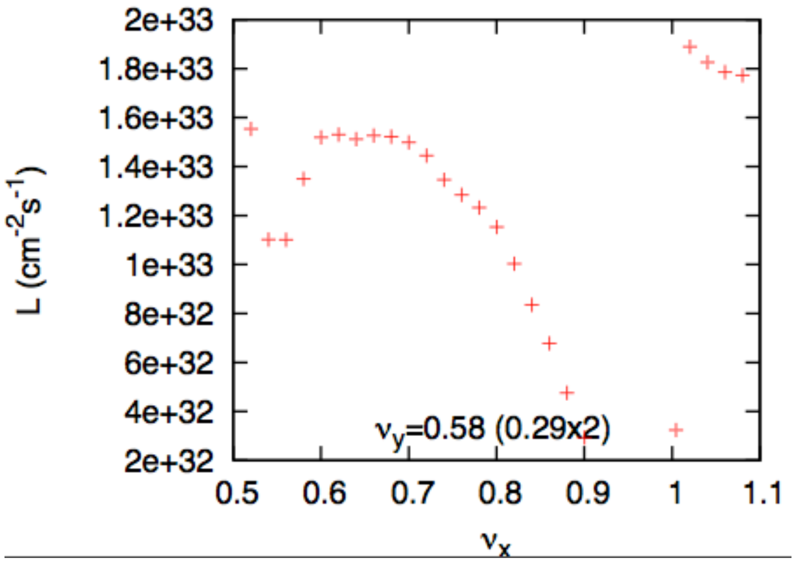




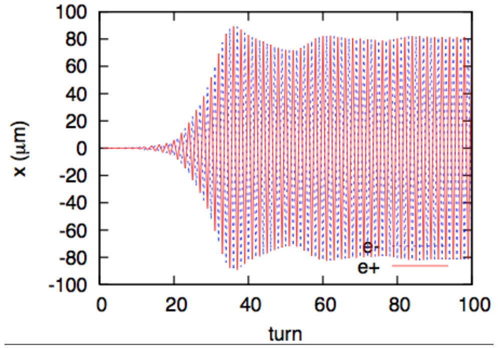
Tune scan II

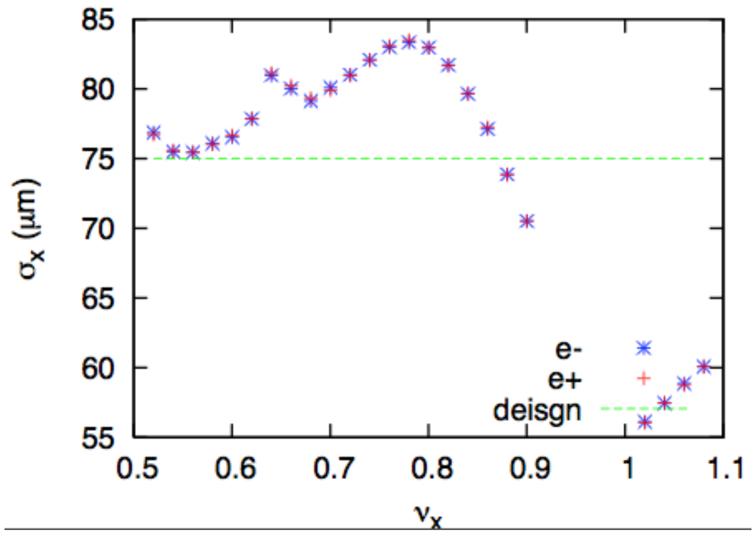
- IP=2, ν_y =0.58 (0.29x2), scan ν_x

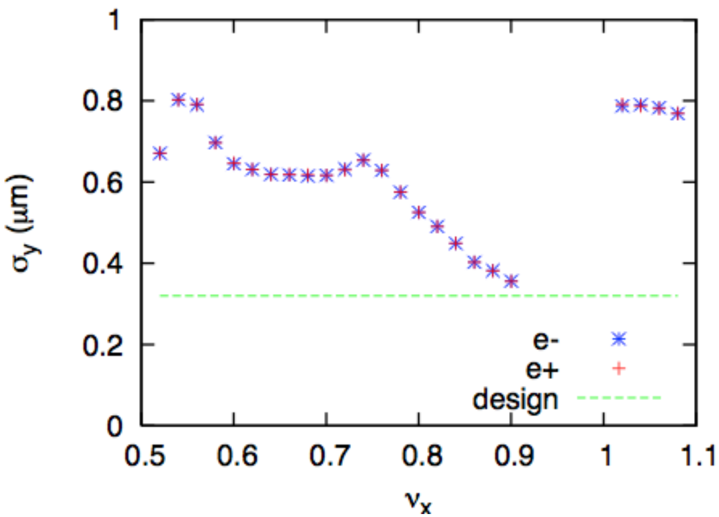
L_{geo}~2.675x10[33]



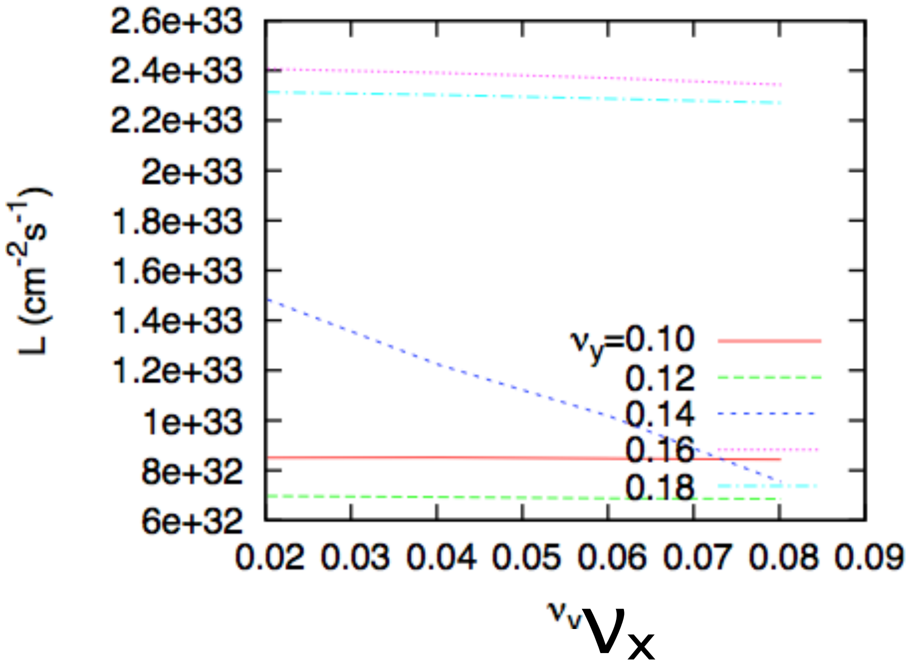
Coherent motion appears at ν_y>0.8





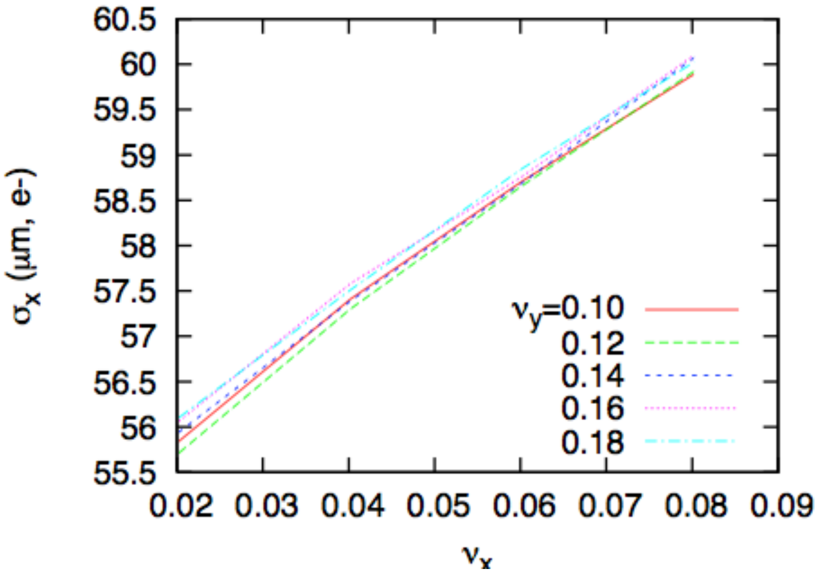


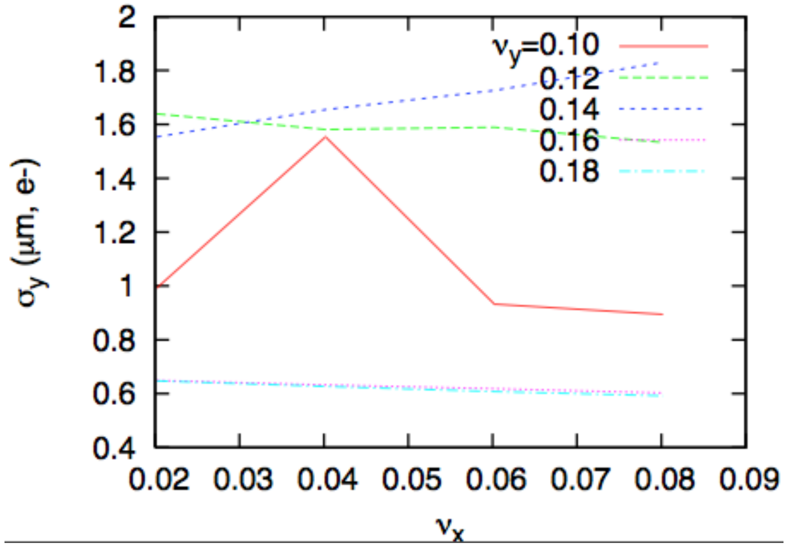
Slight upper of integer



L_{geo}~2.675×10^{33}

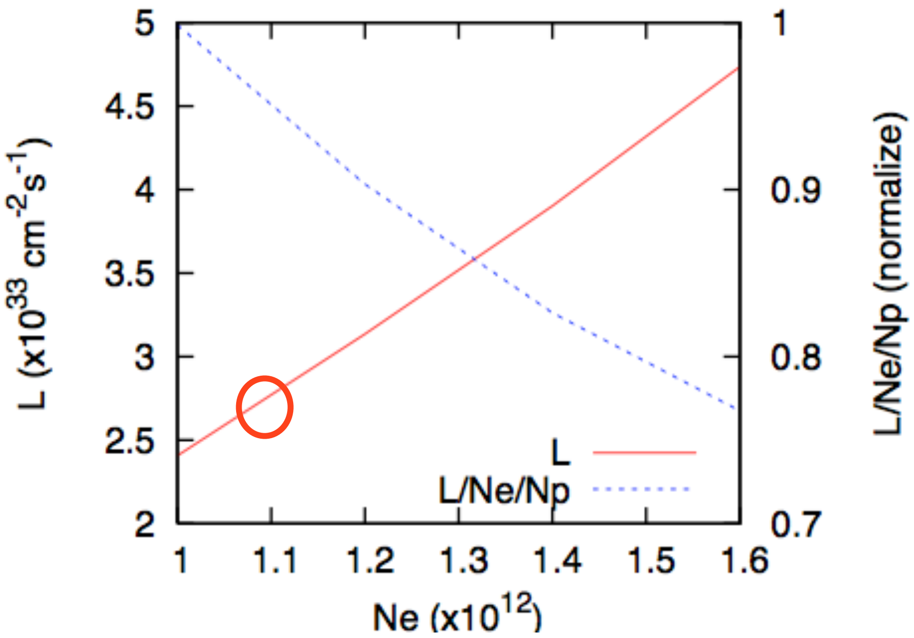
- Best Luminosity, but lower than deisgn.





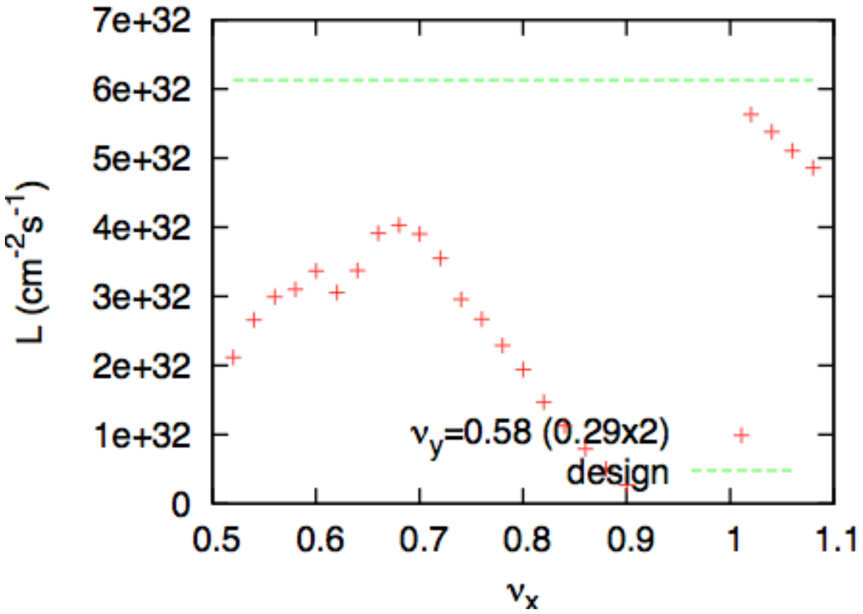
Bunch population and specific luminosity

- $L=2.6\times10^{33}$ $cm^{-2}s^{-1}$ is achieved at $Ne=1.1\times10^{12}$.

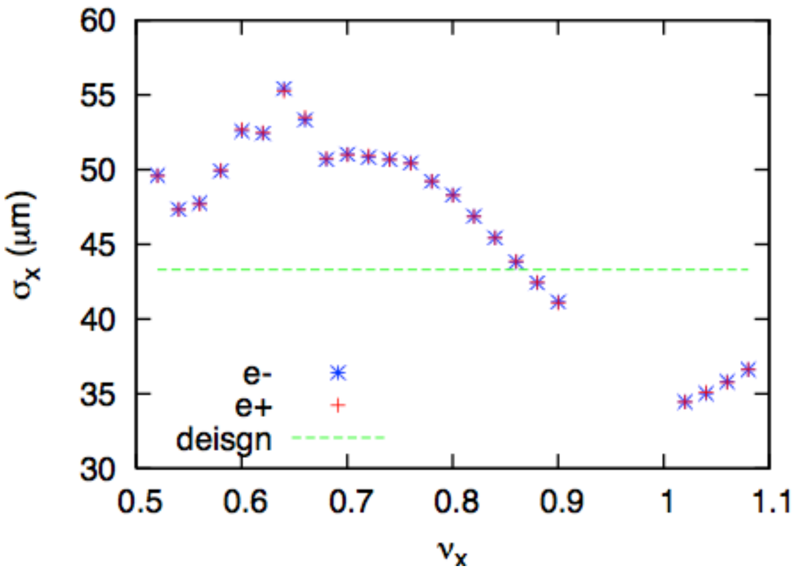


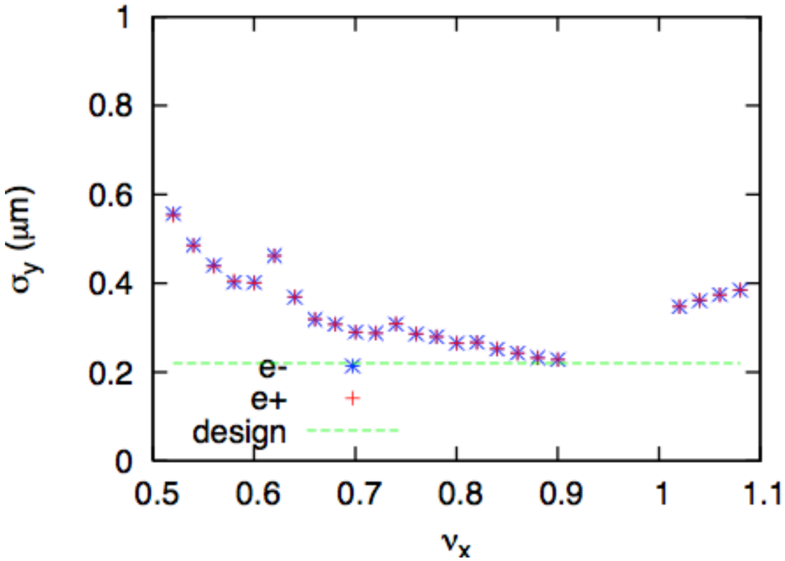
$L_{geo}\sim2.675\times10^{33}$

TLEP-H

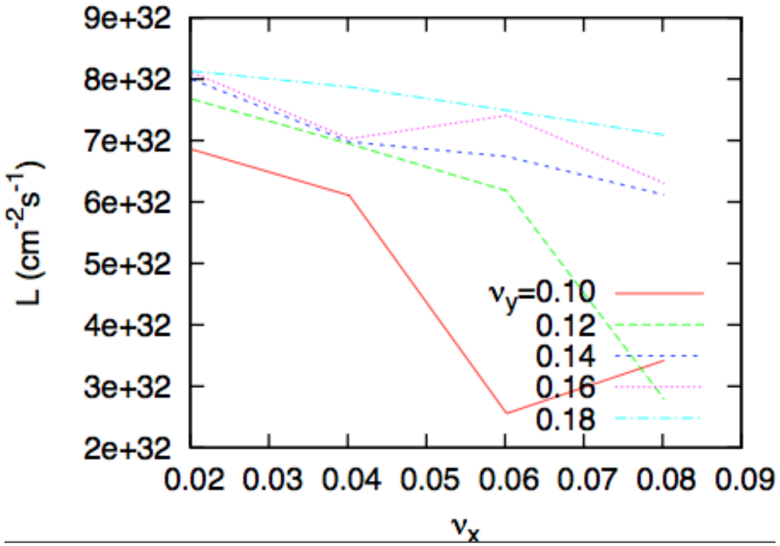


- ν_y =0.58 (0.29x2), scan ν_x

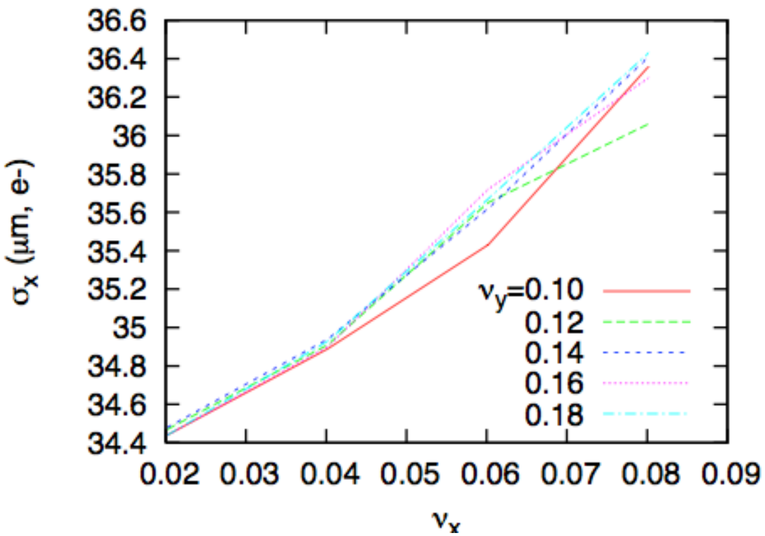


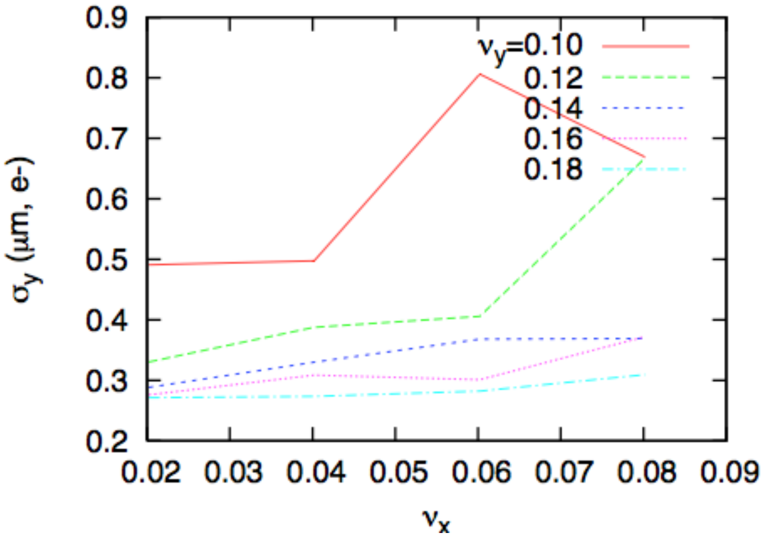


TLEP-H



- Design luminosity 6.1×10^{32} is reachable.
- Better result than LEP3.
- ν_s is lower than LEP3.

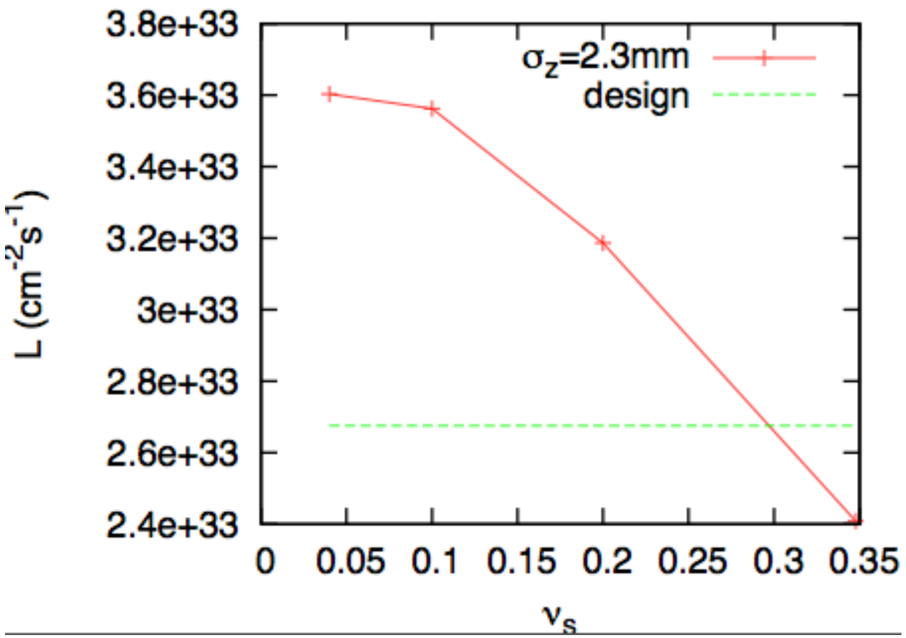


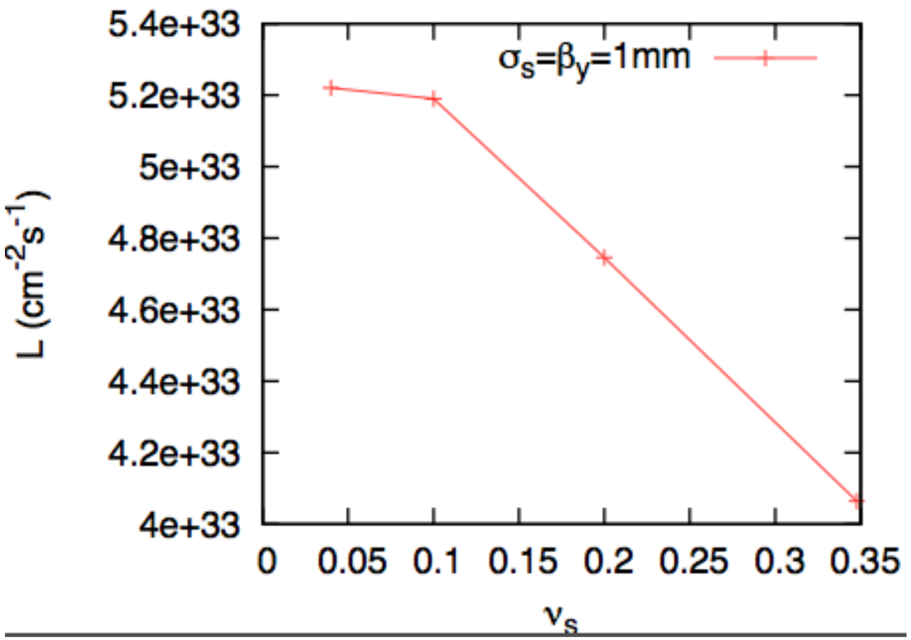


Synchrotron tune (LEP3)

- Luminosity degradation at large synchrotron tune is seen.

- ν_x=0.02, ν_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.

Choice of operating point

- (ν_x,ν_y)=(0.51, 0.55-0.59) is the best for dynamic beta in horizontal and integrability in vertical in every e+e- colliders with single IP.
- (ν_x,ν_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.)