Beam-beam effects in High Energy LHC

K. Ohmi (KEK)

HE-LHC2010@Malta
14-16, Oct. 2010

Thanks to O. Dominguez and F. Zimmermann

HE-LHC

- E=16.5TeV
- Radiation damping time is 2h in the transverse emittance unit.

Updated parameter list for LHC energy upgrade at 33 TeV centre-of-mass energy

	nominal LHC	LHC energy upgrade
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40
beam half aperture [cm]	2.2 (x), 1.8 (y)	1.3
#bunches	2808	1404
bunch population [10^{11}]	1.15	1.29
initial transverse normalized emittance [μm]	3.75	3.75, 1.84
initial longitudinal emittance [eVs]	2.5	4.0
number of IPs contributing to tune shift	3	2
initial total beam-beam tune shift	0.01	0.01 (x & y)
maximum total beam-beam tune shift	0.01	0.01
RF voltage [MV]	16	32
rms bunch length [cm]	7.55	6.5
rms momentum spread [10^{-4}]	1.13	0.9
IP beta function [m]	0.55	1 (x), 0.43 (y)
initial rms IP spot size [μm]	16.7	14.6 (x), 6.3 (y)
full crossing angle [μrad]	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})
Piwinski angle	0.65	0.39
geometric luminosity loss from crossing	0.84	0.93
stored beam energy [MJ]	362	478.5
SR power per ring [kW]	3.6	62.3
dipole SR heat load dW/ds [W/m/aperture]	0.21	3.64
energy loss per turn [keV]	6.7	207.1
critical photon energy	44	576
longitudinal SR emittance damping time [h]	12.9	0.98
horizontal SR emittance damping time [h]	25.8	1.97
initial longitudinal IBS emittance rise time [h]	61	64
initial horizontal IBS emittance rise time [h]	80	80
initial vertical IBS emittance rise time [h] (κ=0.2)	~400	~400
note: IBS rise times > SR damping times		
events per crossing	19	76
initial luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0
beam lifetime [h]	46	12.6
integrated luminosity over 10 h [fb^{-1}]	0.3	0.5

Octavio Dominguez, Frank Zimmermann, 24 June 2010

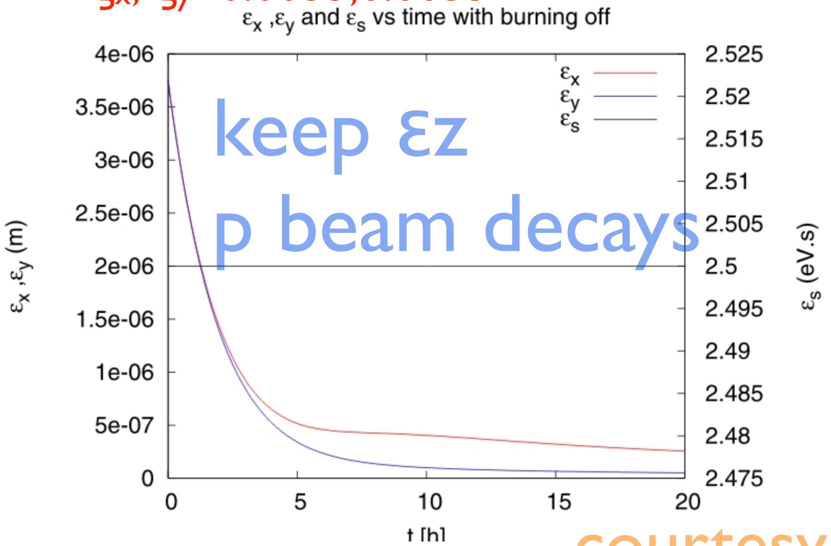
Introduction

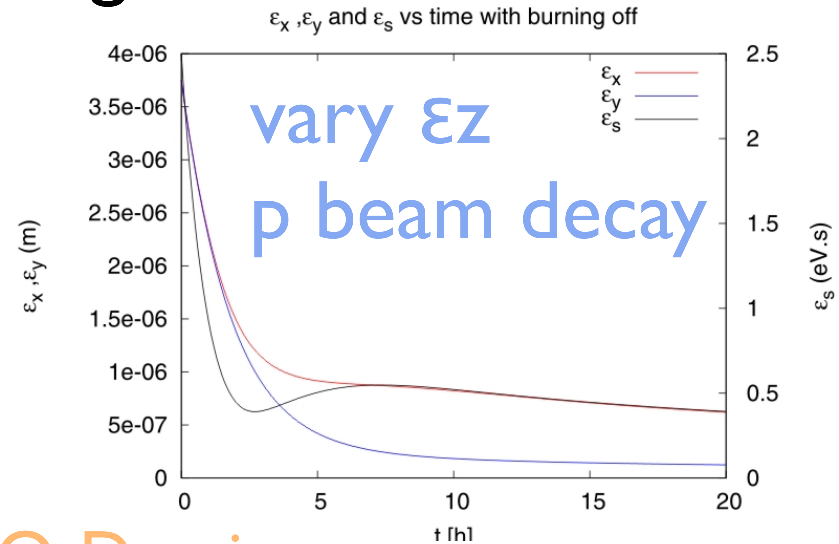
- Interplay of the synchrotron radiation, intra-beam scattering and beam-beam interaction.
- Coherent beam-beam effects in HE-LHC.
- Incoherent emittance growth in HE-LHC.
- Effects of IP optics parameters in the coherent and incoherent phenomena.

Beam size evolution with radiation damping and IBS

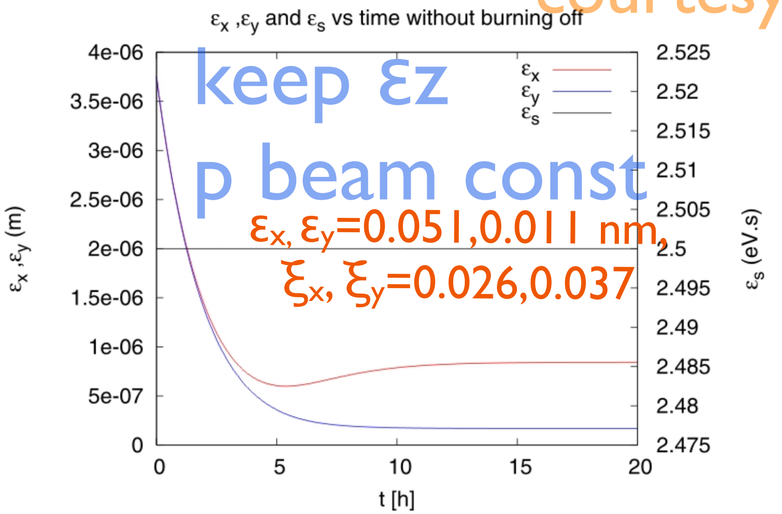
Initial
$\varepsilon_x, \varepsilon_y$=0.21, 0.10 nm,
ξ_x, ξ_y=0.0053,0.0053

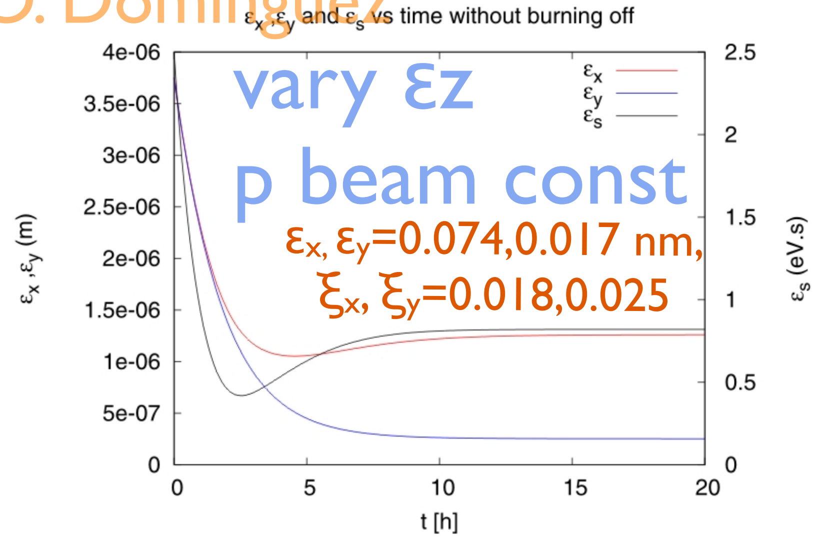
O. Dominguez and F. Zimmermann





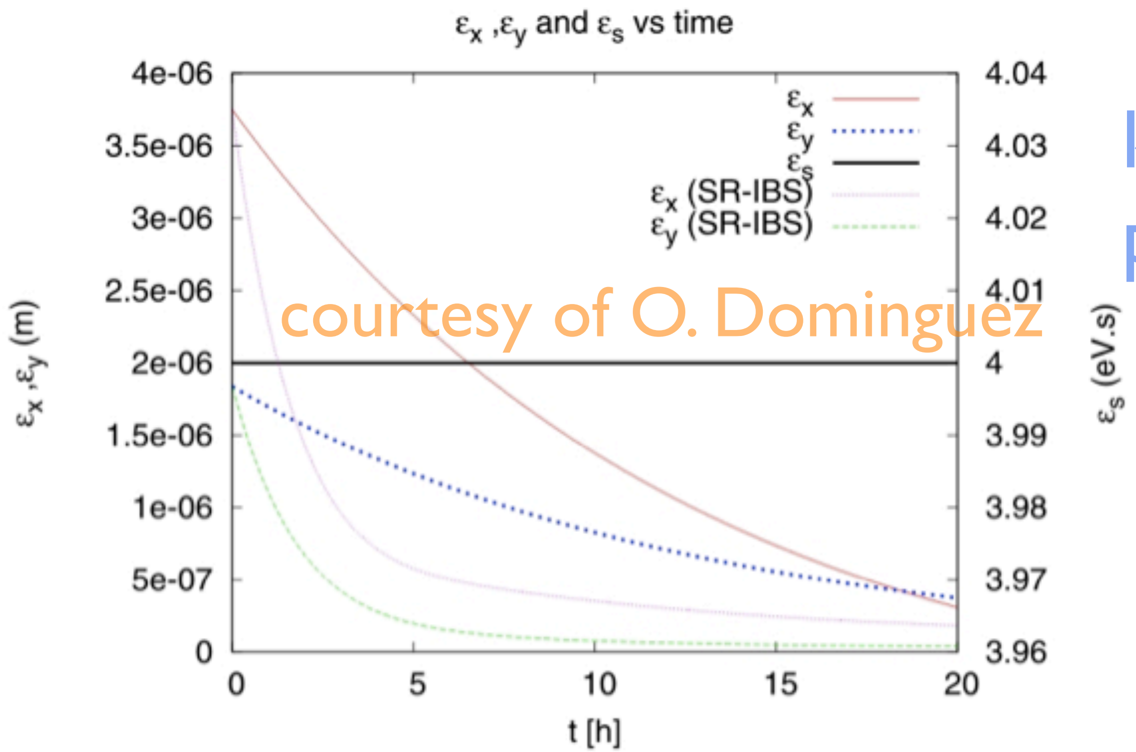
courtesy of O. Dominguez





Control transverse excitation

- Emittance is controllable by applying external fluctuation (kicker) with keeping the beam-beam parameter. Conservative case.
- We study higher beam-beam parameter utilizing the emittance radiation damping.



keep ε_z, ξ_x, ξ_y,
p beam decays

Coherent and incoherent effects of the beam-beam interaction

- Coherent effect is studied by the strong-strong simulation. Single IP and 2D sim.

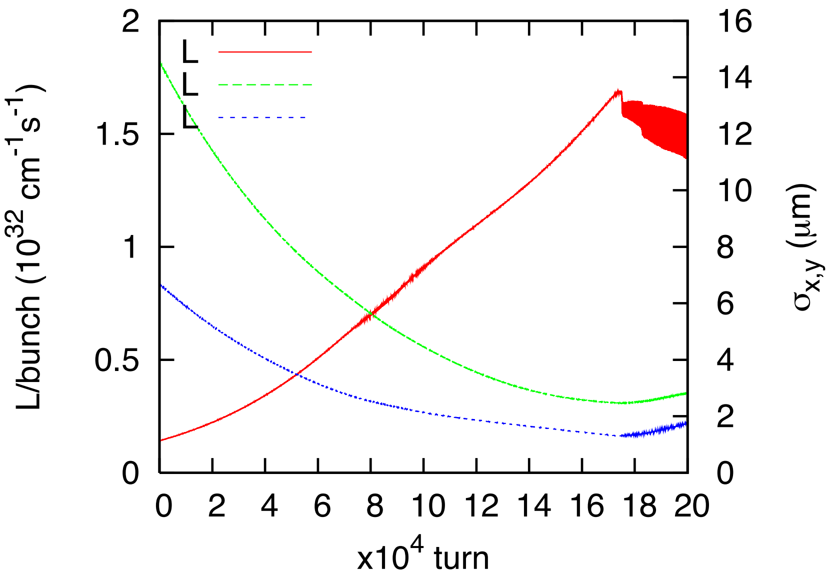
- Incoherent effect has been studied by the weak-strong simulation. Two IP, 3D sim., crossing angle are taken into account.

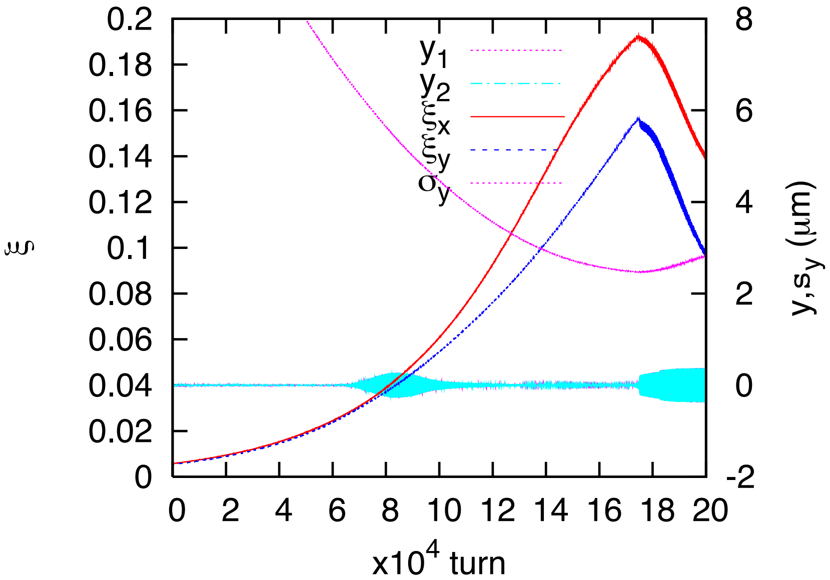
Study of coherent effect in HE-LHC

- Strong-strong simulation with a code BBSS. Single IP. Turn is regarded as collision occurrence for 2IP.
- Considering simulation time, the radiation damping time has to be chosen faster than actual value.
- Simulations are performed with 2000 and 200 times faster damping time.
- We expect that extrapolation gives information.

Assume 2000x faster damping time

200 times bigger excitation

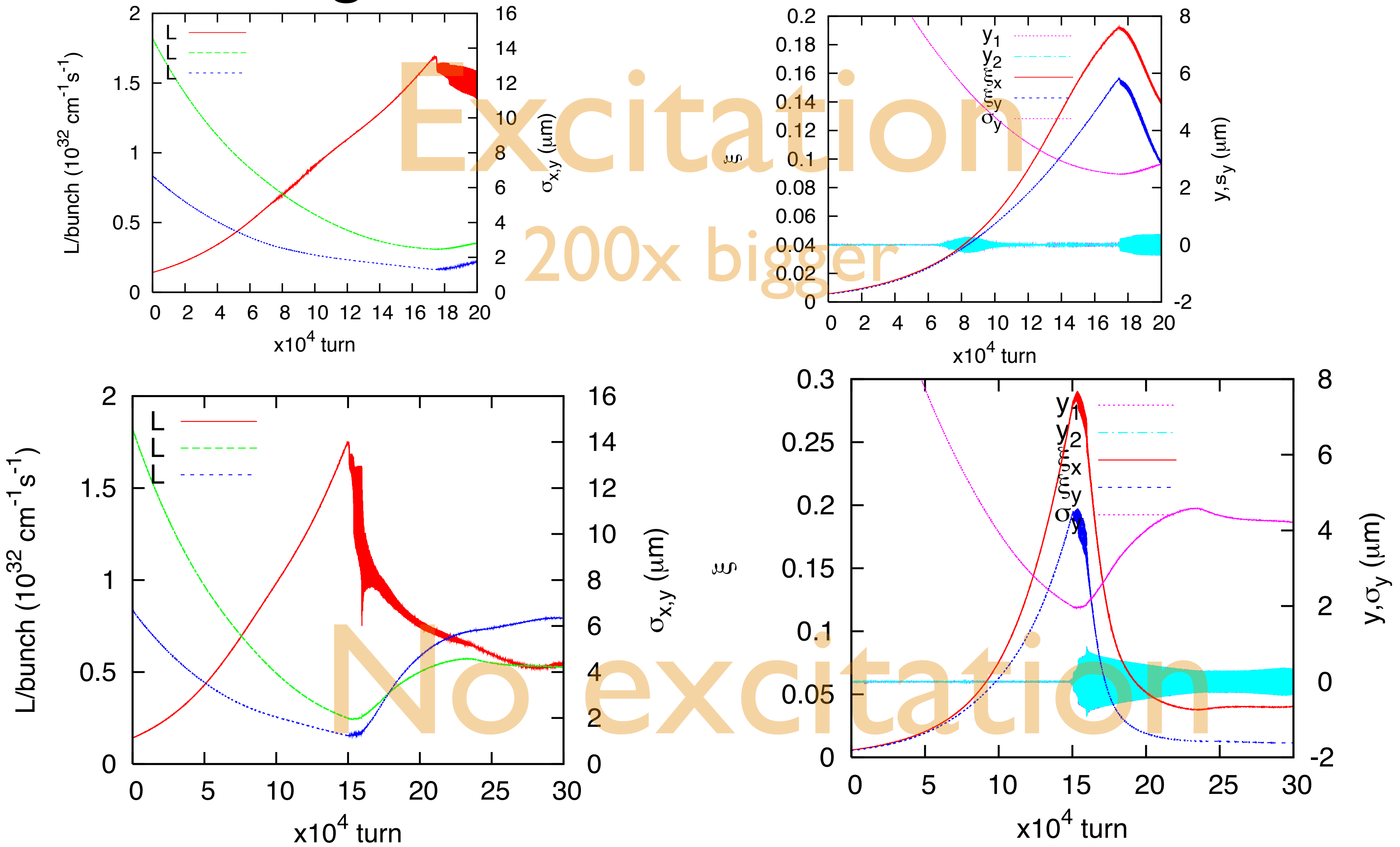




- Dipole oscillation limit the luminosity. The beam-beam parameter is very high ξ~0.15.
- The dipole oscillation was seen at ξ>0.05 in a flat beam such as lepton colliders for $\sigma_z << \beta_y$.

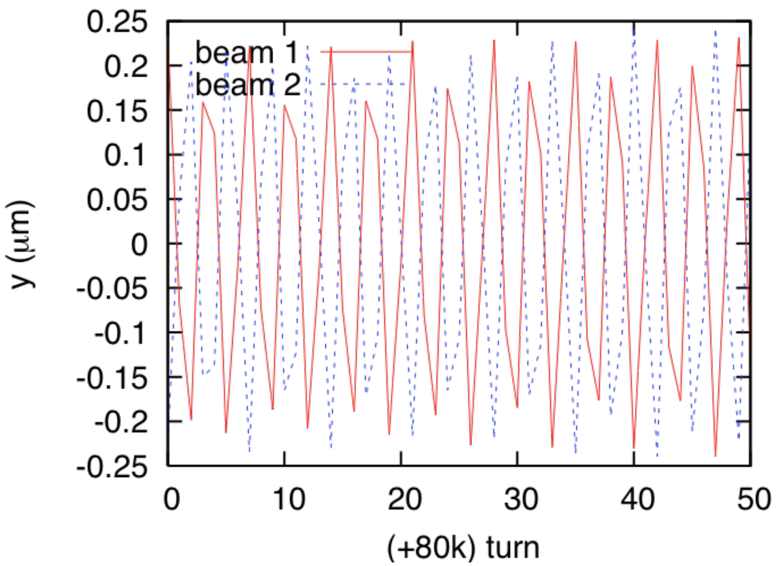
Excitation ON/OFF

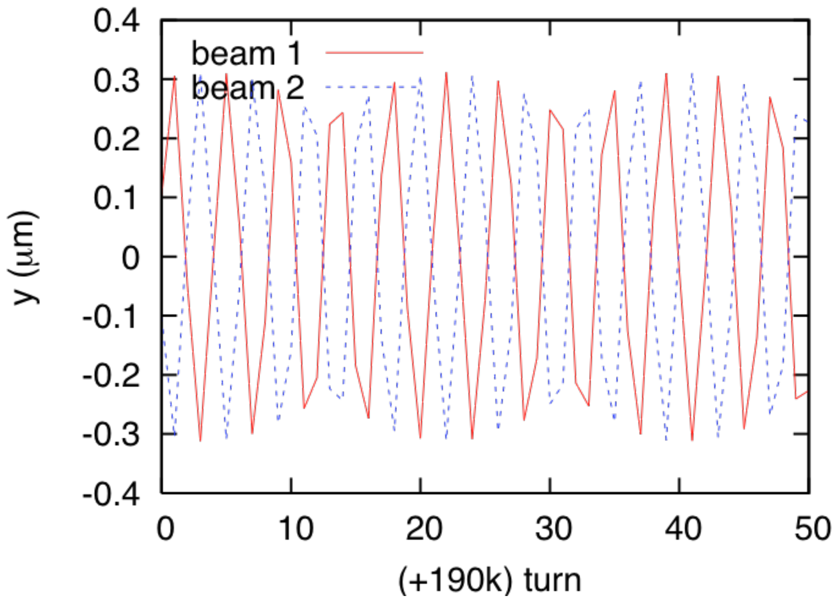
- No big difference.



Dipole oscillation

- π mode





~80000 turn

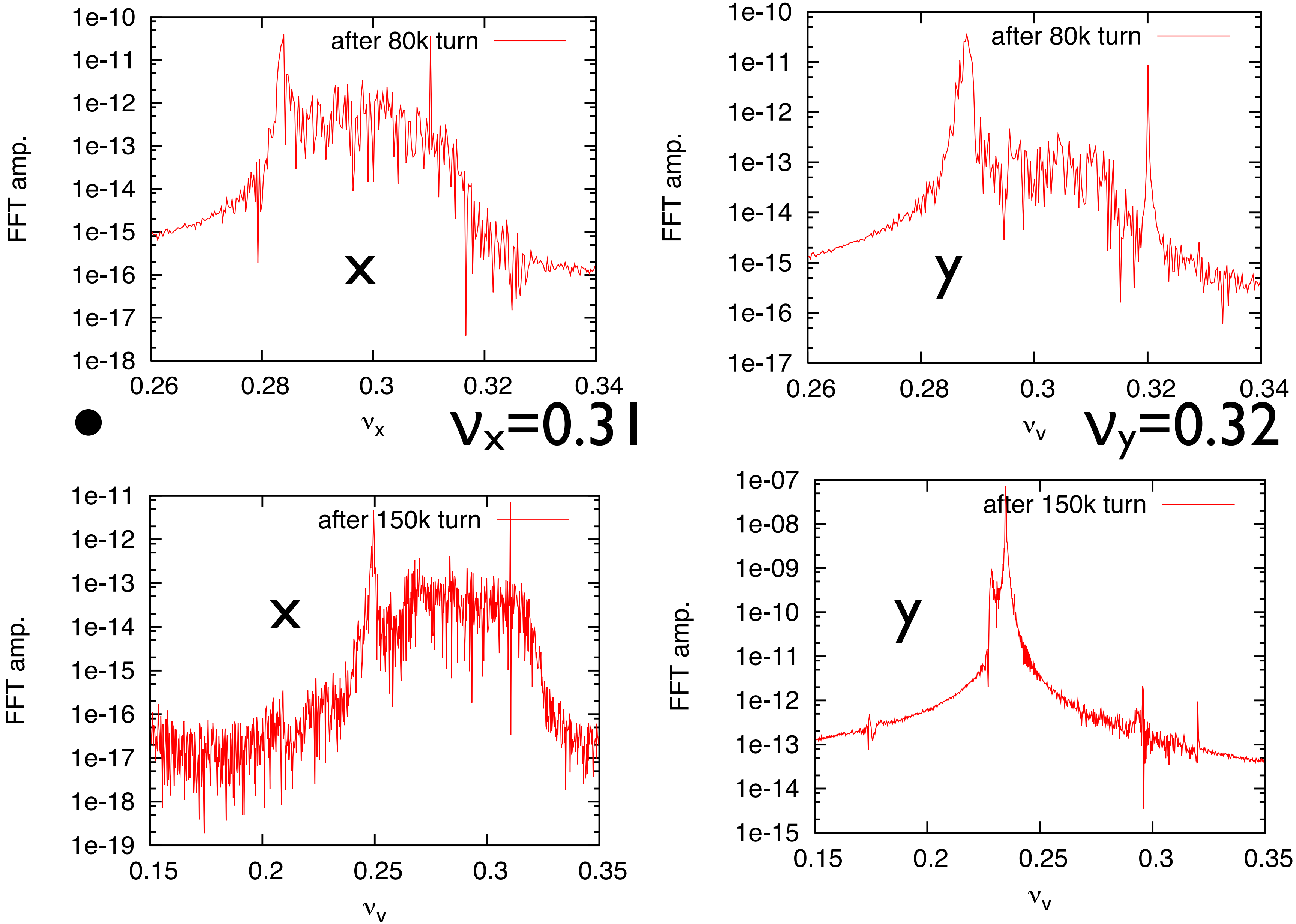
x2000=1.6x10⁸=4 hour

~190000 turn

x2000=3.8x10⁸=9 hour

Not realized by IBS

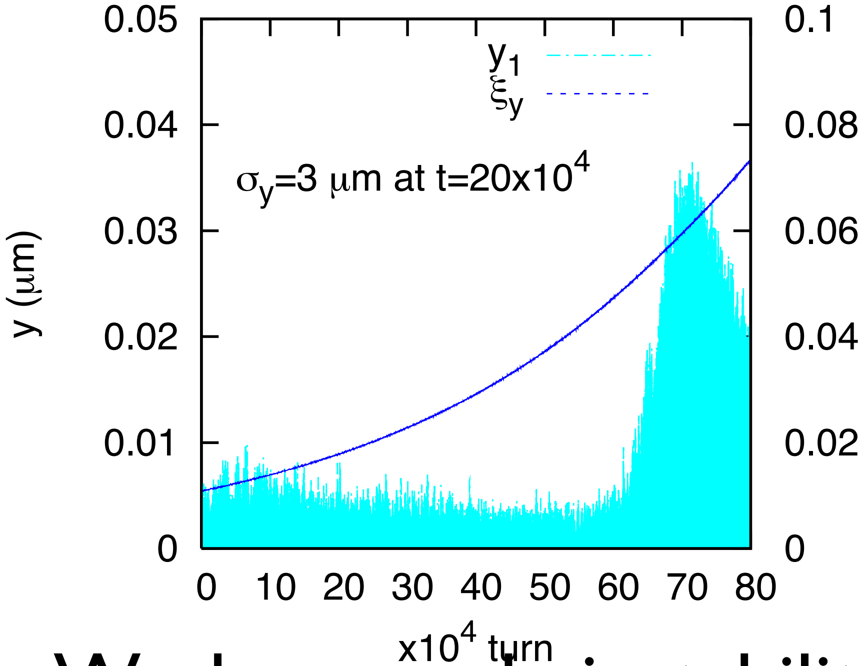
Fourier spectra for the instability



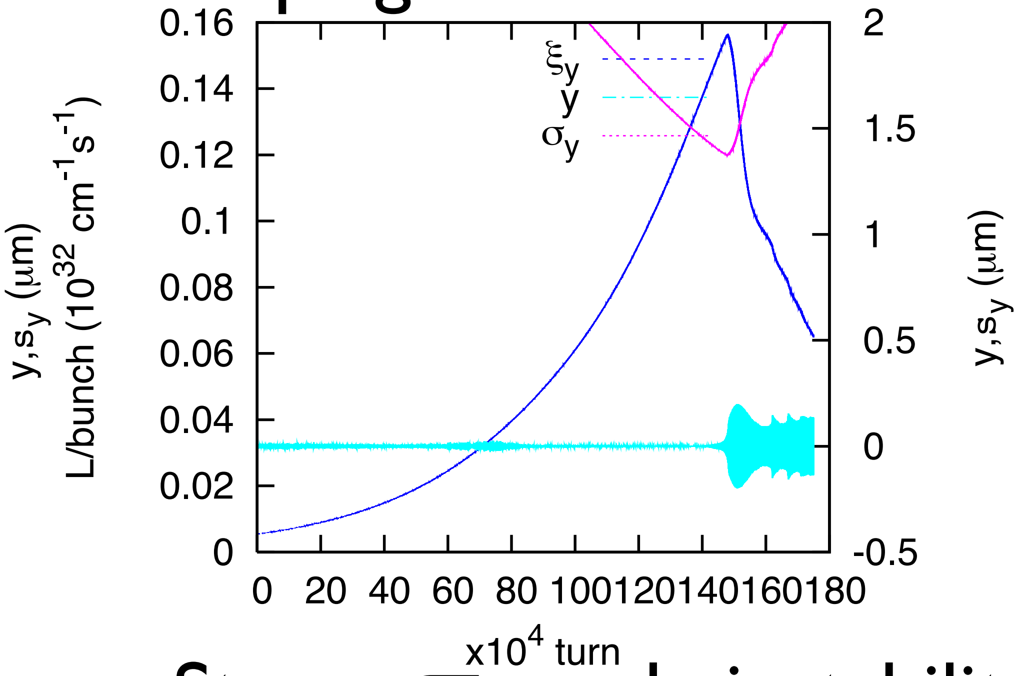
200x faster damping

20 times bigger excitation

- Excitation ON/OFF
- No remarkable difference. Coherent instability does not depend on the damping time.



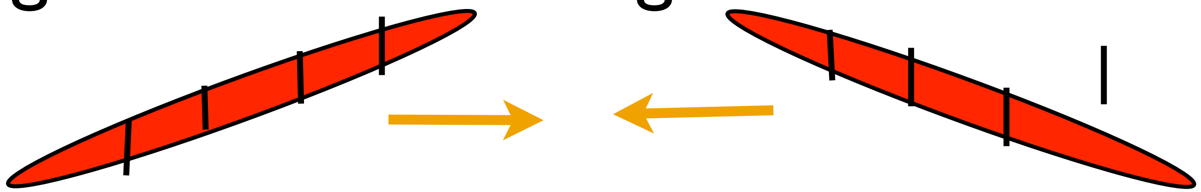
Weak π-mode instability at $8\text{x}10^5$ turn~4hour.



Strong π-mode instability at $15\text{x}10^5$ turn~8 hour

Incoherent emittance growth

- 2 IP, phase difference π (pessimistic case)
- crossing angle, 5 slices along z.
- Turning off the radiation damping, luminosity degradation is investigated.

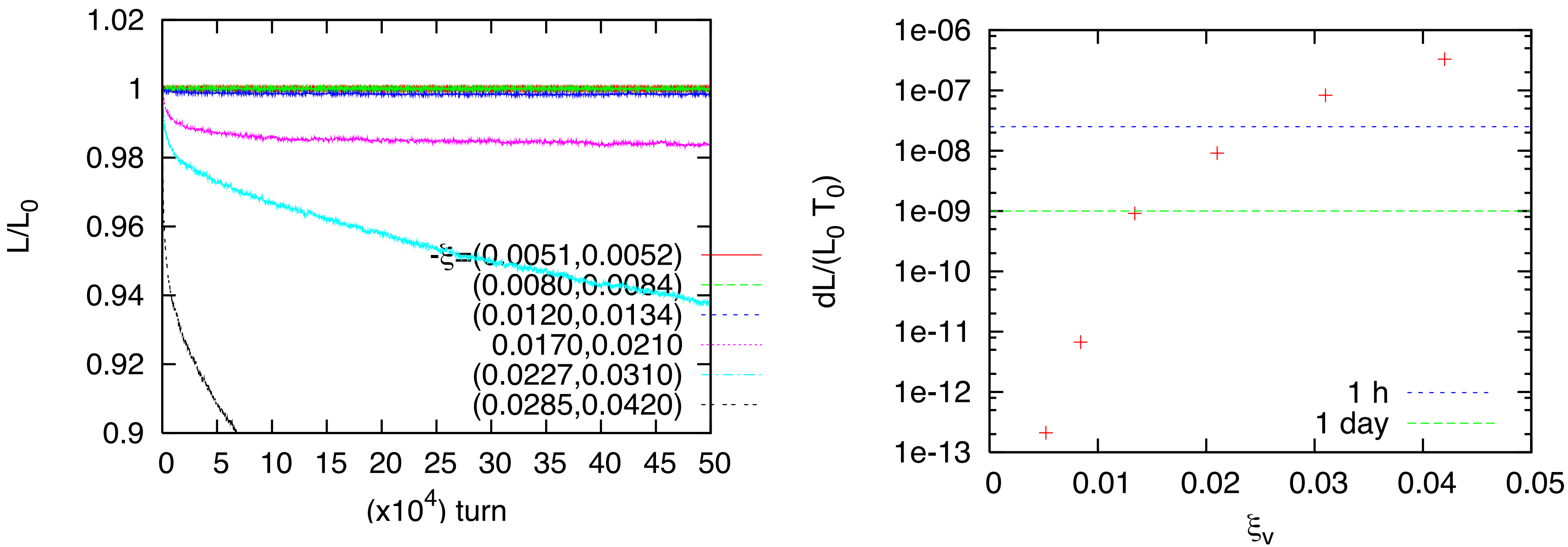


t (h)	ε_x (nm)	ε_y (nm)	ξ_x (/IP)	ξ_y (/IP)
0	0.21	0.1	0.0051	0.0052
1	0.13	0.062	0.0080	0.0084
2	0.076	0.037	0.012	0.013
3	0.046	0.022	0.017	0.021
4	0.027	0.014	0.023	0.031
5	0.016	0.0097	0.029	0.042

Study 6 cases, which are t=0-5 hour after the injection without IBS.

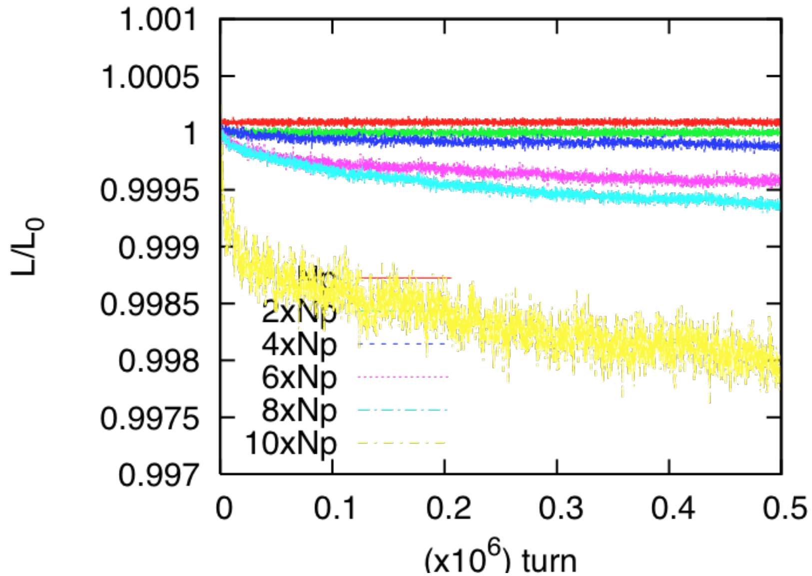
Luminosity degradation due to incoherent emittance growth

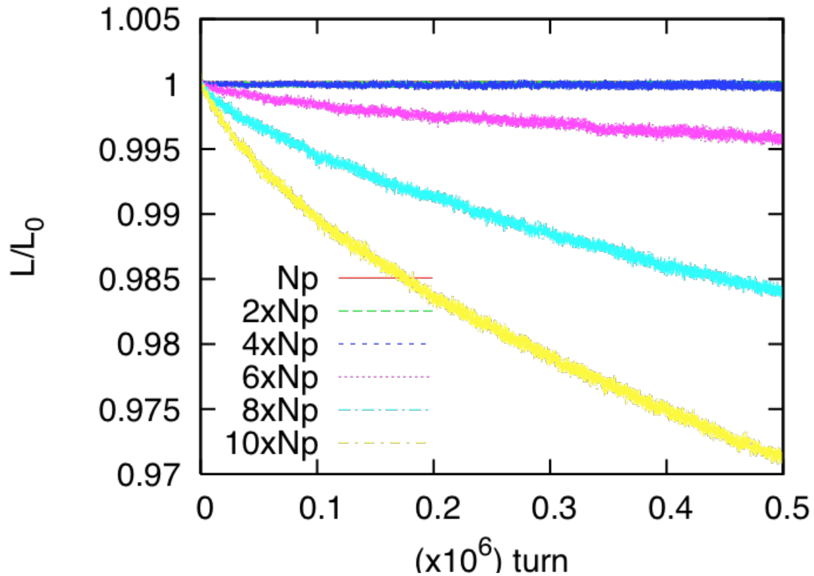
- The beam-beam parameter is 0.0134/IP for 1 day and 0.025/IP for 1 hour life time.
- This result can be also applied for the present LHC.



Effect of crossing angle

- 2 IP
- ξ=0.0034/IP for Np.





zero crossing angle $\theta_H \sigma_z / \sigma_x = 0.6$

Luminosity degradation without crossing angle is very small.

Tentative result for HE-LHC

- A weak coherent instability arises at ξ~0.03, but disappear for further turn evolutions.
- A strong coherent instability arises at ξ~0.15 and degrade the luminosity. This condition is not realized by IBS.
- Incoherent growth is dominant compare than the coherent instability.
- Incoherent growth time is 0.0134/IP for 1 day and 0.025/IP for 1 hour life time. It is possible to be ~0.02/IP considering radiation damping time 2 h.
- Since the geometrical beam-beam parameter limit of IBS is 0.03/IP, the beam size should be controlled to be 0.02/IP using an external noise.

x-y coupling for HE-LHC beam beam performance

- x-y coupling affects the beam-beam performance essentially in KEKB. It is effect of beam-beam dynamics, but not that of geometric.
- How x-y coupling affects LHC performance.
- Model with 2000 time faster damping to study coherent instability.
- Weak strong simulation to study incoherent growth.

x-y coupling at IP

- Parametrization of x-y coupling

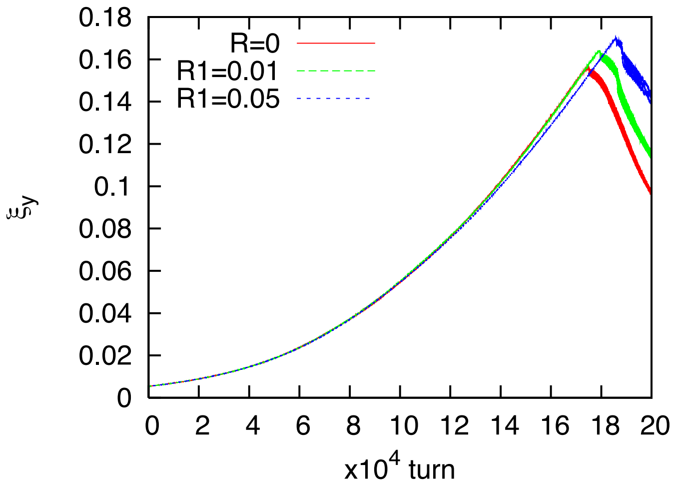
$$\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = RB \begin{pmatrix} X \\ X' \\ Y \\ Y' \end{pmatrix} \qquad R = \begin{pmatrix} r_0 & 0 & r_4 & -r_2 \\ 0 & r_0 & -r_3 & r_1 \\ -r_1 & -r_2 & r_0 & 0 \\ -r_3 & -r_4 & 0 & r_0 \end{pmatrix}$$

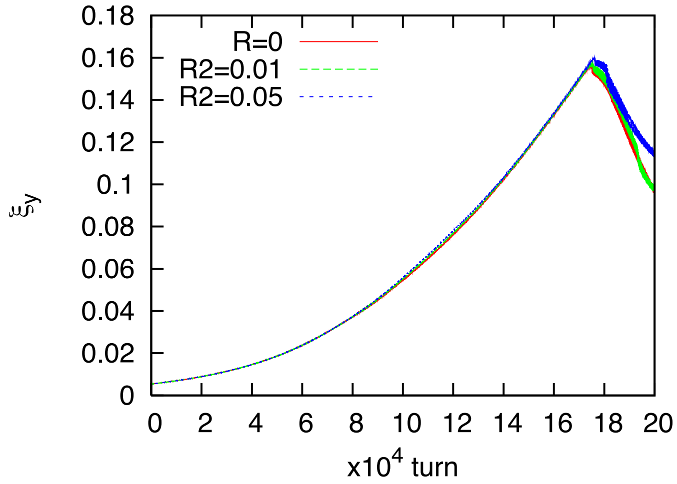
$$B = \begin{pmatrix} \sqrt{\beta_x} & 0 & 0 & 0 \\ -\alpha_x/\sqrt{\beta_x} & 1/\sqrt{\beta_x} & 0 & 0 \\ 0 & 0 & \sqrt{\beta_y} & 0 \\ 0 & 0 & -\alpha_y/\sqrt{\beta_y} & 1/\sqrt{\beta_y} \end{pmatrix}$$

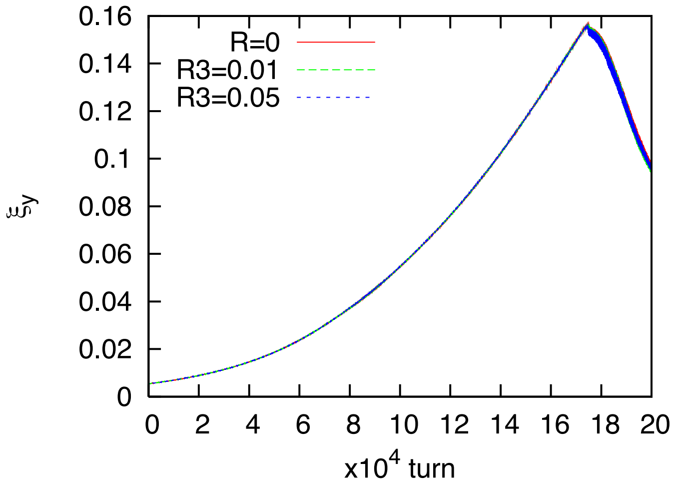
- r_i's are a kind of Twiss parameter. They are function of s.
- Horizontal beam-beam kick induces vertical kick.

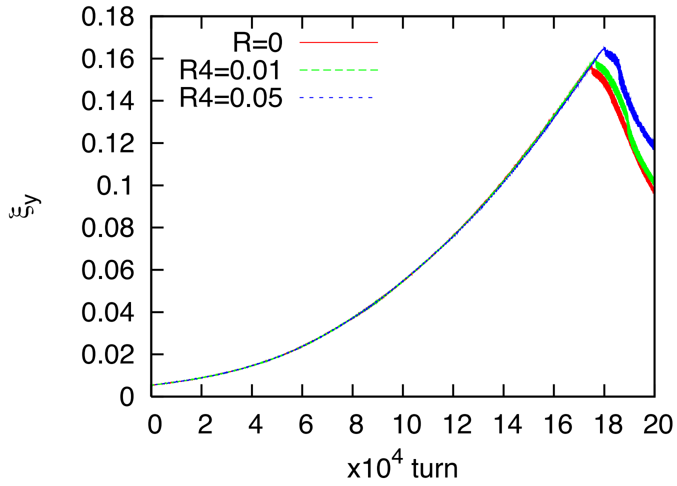
Effect of x-y coupling in coherent instability

- No remarkable effect for x-y coupling

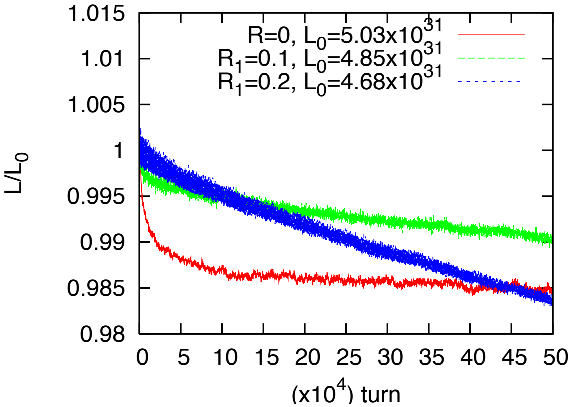


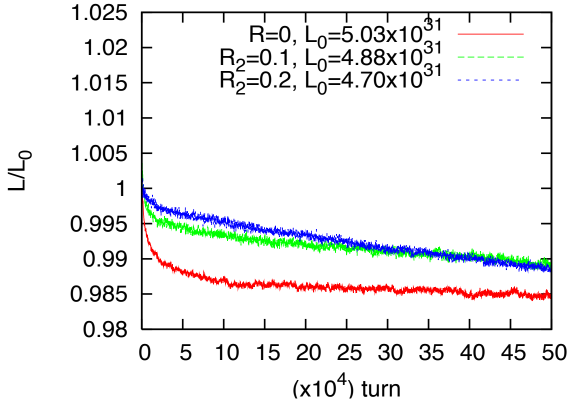


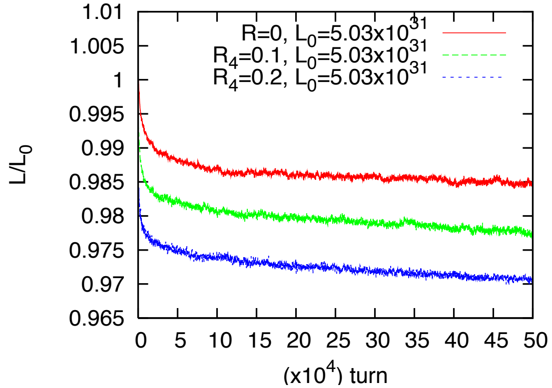


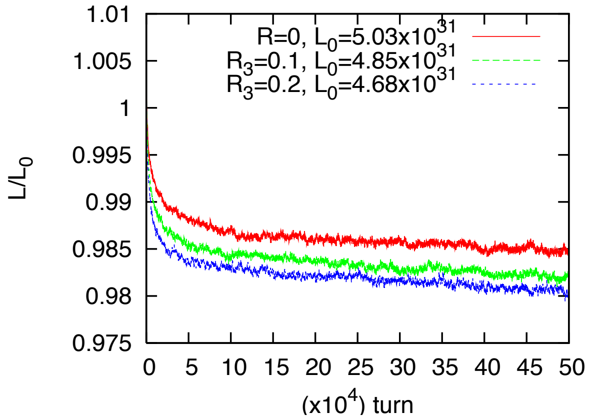


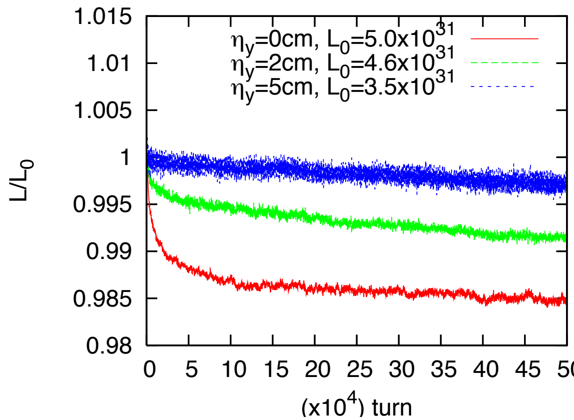
Effect of x-y coupling for incoherent emittance growth











- ξ/IP=(0.017,0.021)
- Clear degradation is seen only for R1,R2=0.2.
- The sensitivity is 10^2-10^3 looser.

Summary

- Coherent instabilities are seen in the simulation, but does not seem serious.
- Incoherent emittance growth is weak for the design beam-beam parameter.
- Higher beam-beam parameter $\xi_{tot}>0.03$ is possible in the simulation.
- IP optics error did not affect the beam-beam performance, different from KEKB. The reason may be due to the round beam.
- External noises should be taken care.
- Effect of nonlinear optics should be studied.

Beam-beam limit in proton colliders
Study of beam noise, PAC07

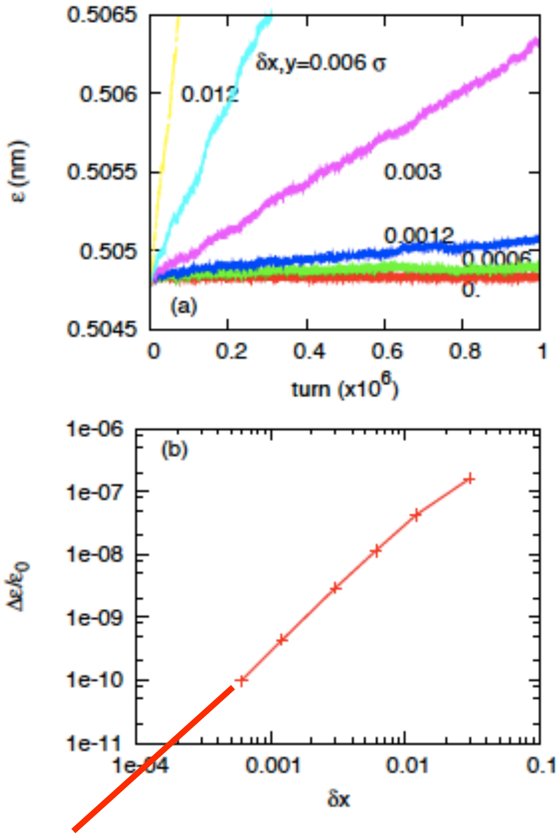


Figure 1: Emittance growth due to noise given by a weak-strong simulation. Plots (a) and (b) depict the evolution of emittance for various noise amplitude and their emittance growth rate, respectively.

Saturation is due to the macro-particle statistics 10^6

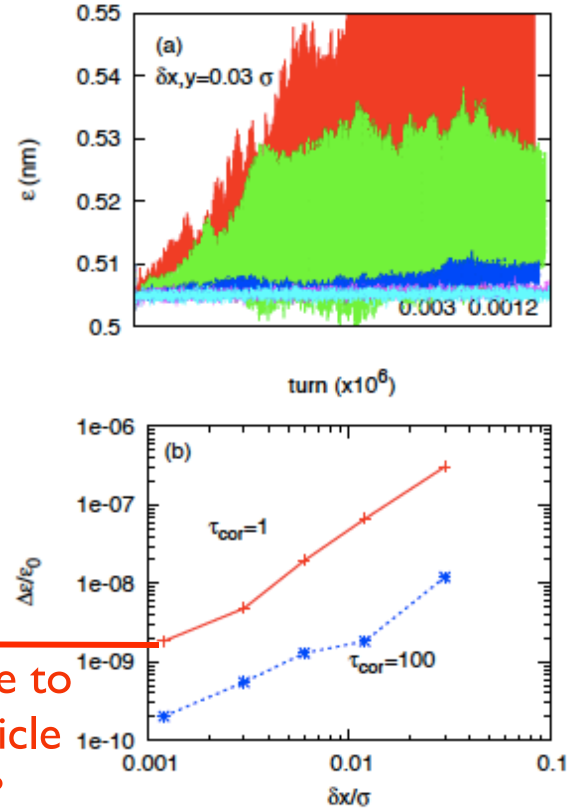


Figure 2: Emittance growth due to the fluctuation given by the strong-strong simulation. t_{cor} is the correlation time (in turns) of the fluctuation.

Beam-beam limit in proton colliders
Strong-strong or weak-strong, EPAC08

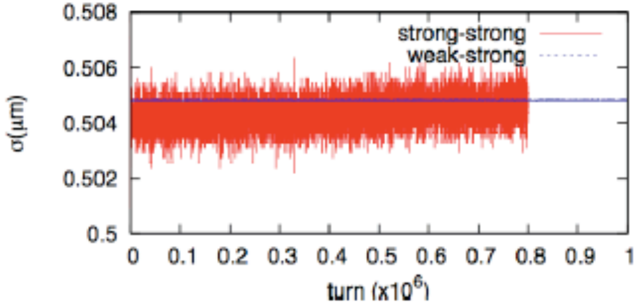


Figure 1: Emittance growth in weak-strong (blue) and strong-strong (red) simulations.

$dL/L(SS)=10^{-9}$/turn

$dL/L(WS)=10^{-14}$/turn

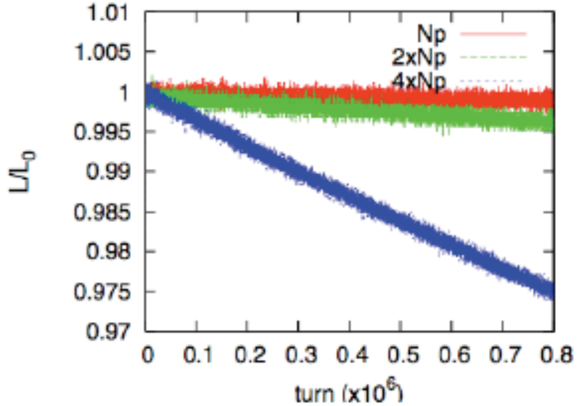


Figure 2: Luminosity decrement given by the strong-strong simulation for nominal, twice, and four times bunch populations in LHC.

This growth, which is worse than that of W.S, is fake. The weak-strong simulation is more feasible thane the strong-strong one.

Beam-beam limit in proton colliders
Strong-strong or weak-strong, EPAC08

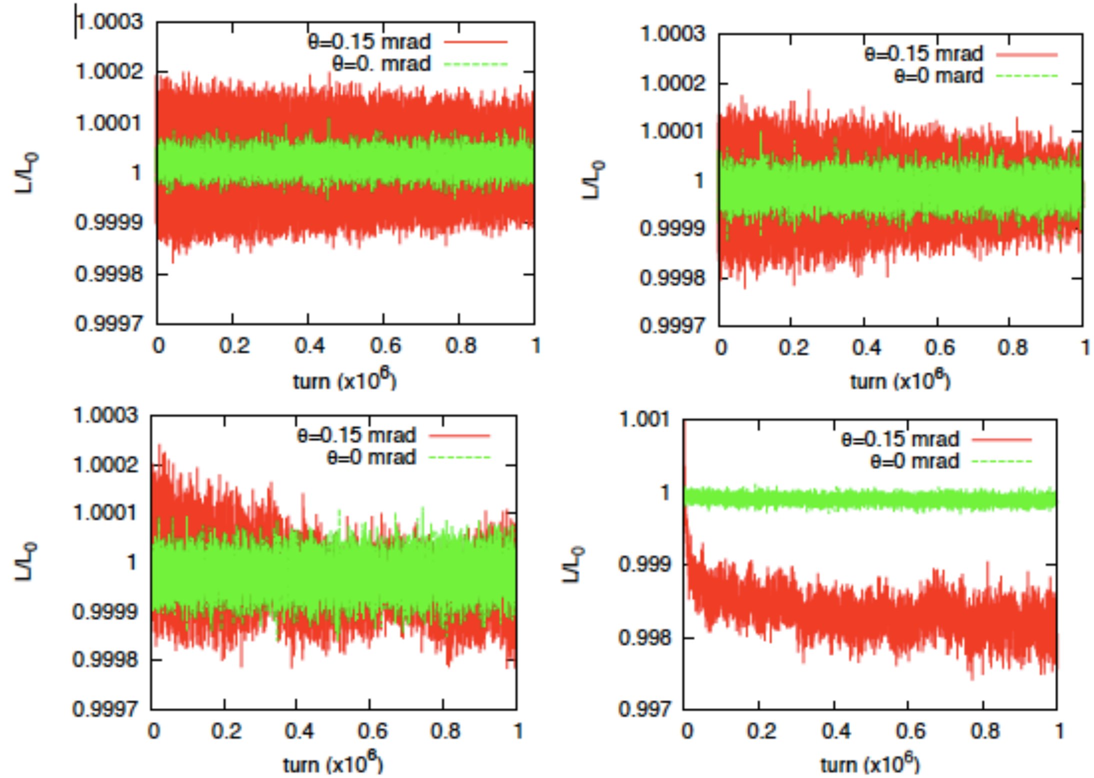
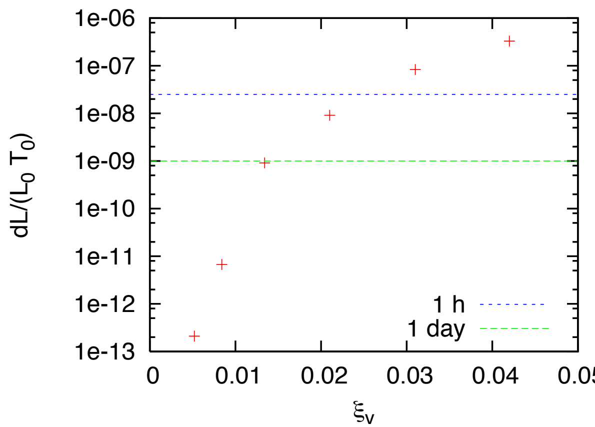
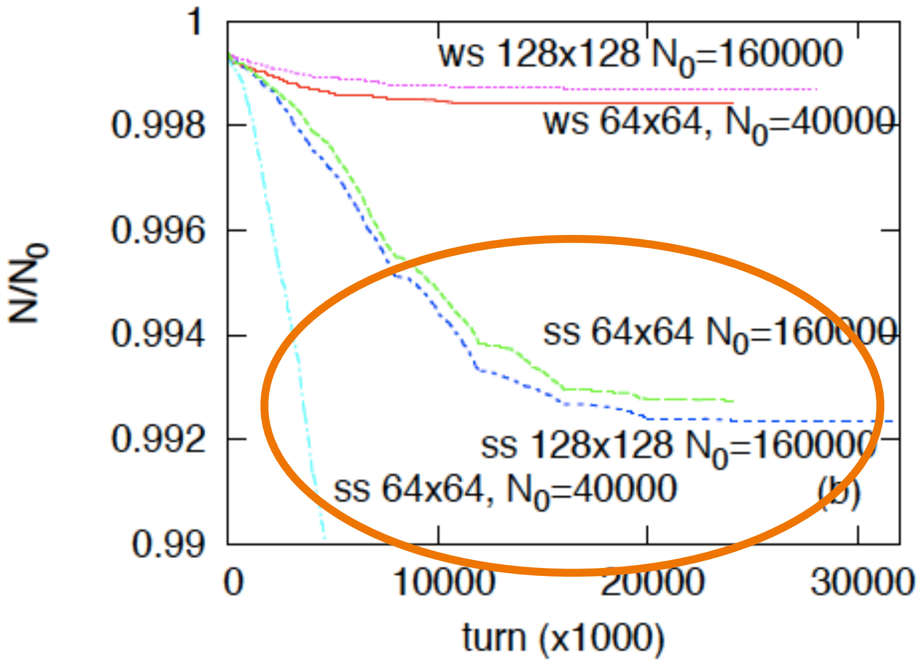


Figure 6: Luminosity decrement at the nominal LHC collision for the bunch populations, N_p=1.15x10^{11} (nominal), 2xN_p, 4xN_p and 6xN_p. Two lines plot luminosity evolution with crossing angle 0.15 mrad and 0 mrad.



Fake beam loss in Space charge simulation for J-PARC (PAC07)

- PIC simulation like S.S. beam-beam or frozen.



W.S with realistic beam distribution (NonGaussian)

These losses should be fake too.

The numerical noise in electron machines < radiation excitation. S.S is feasible.

Thank you for your attention