Electron cloud effect for JLC damping ring

K.Ohmi, KEK

ECLOUD2002, 15-19, Apr. 2002

Parameters

- Energy E=1.98GeV
- Circumference L=395m
- Bunch population $N_+=0.75\times10^{10}$
- Bunch spacing $L_{sp}/c=1.4ns$
- Bunch train structure (72bunchx1.4ns+60ns)x4
- Total current $I_+ = 700mA$
- Emittance $\varepsilon_x = 7\times10^{-10}m$ $\varepsilon_y = 5\times10^{-12}$ m
- Bunch length $\sigma_z=5mm$

Electron cloud build-up

- Ante-chamber R=1cm
- In KEKB test ante-chamber, electron current 1/5 of cylindrical chamber was observed.
- Average Photoelectron yield $Y_{1\gamma}$=0.013 $e^-/(m.e^+)$ for Y_γ=0.65 γ/(m.e+).

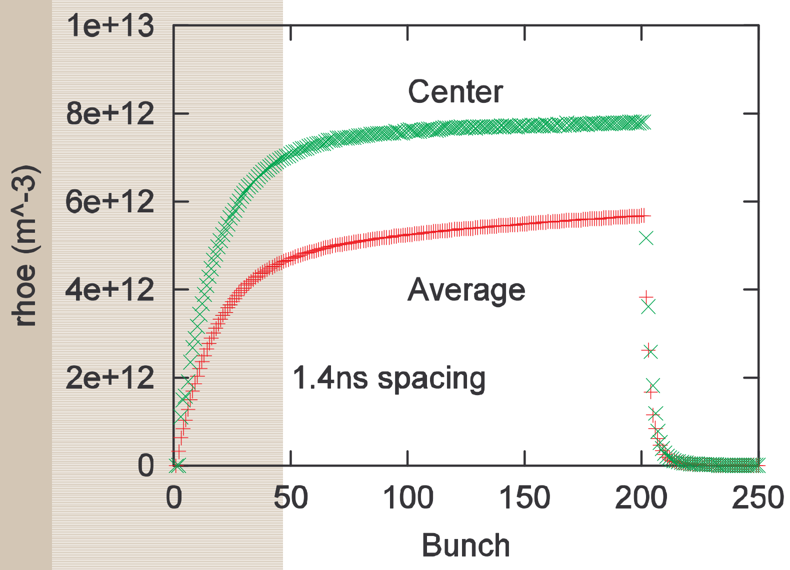
  (KEKB 0.015 $e^-/(m.e^+)$ for Y_γ=0.15 γ/(m.e+))
- Secondary Y_2=1.0 e/e
- The yield approximately corresponds to electron current at surface by

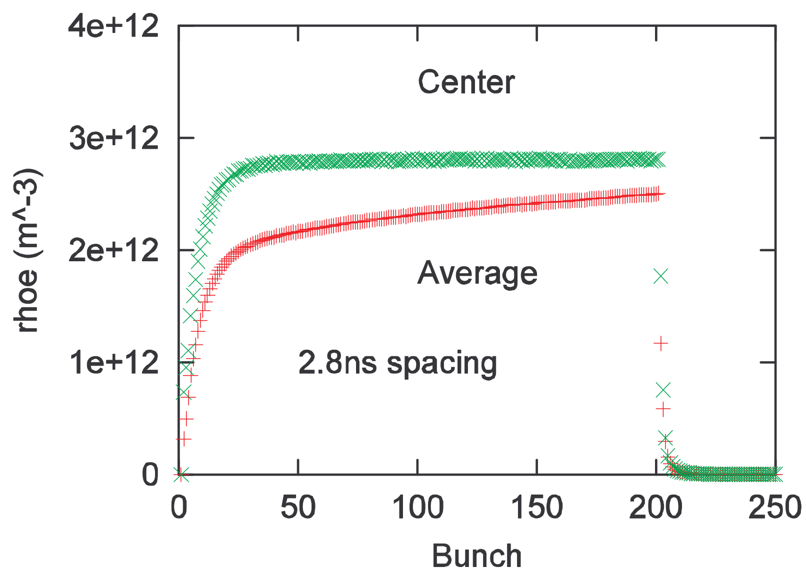
$$I_{ec}(\mathrm{A/m^2}) = Y_{1(+2)} N_p e\, f_{rep} / 2\pi R$$

Electron density

1.4ns

2.8ns





Instability caused by electron cloud

- Coupled bunch instability
- Single bunch instability

- We estimate these instabilities by the approximation with the wake force.

Coupled Bunch Instability caused by electron cloud

- Wake force is calculated a numerical method as follows,
- Equilibrium electron cloud.
- A (i-th) bunch Δy_i with a displacement passes through the cloud.
- Calculate kick $\Delta p_{y,j}$ of j-th bunch.

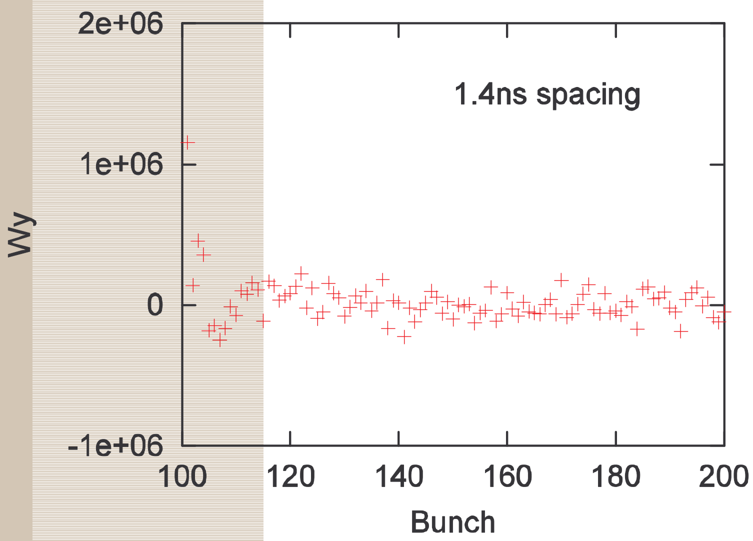
$$W(z_i - z_j) = \frac{\gamma}{N_p r_e} \frac{\Delta p_{y,j}}{\Delta y_i}$$

- Growth of the coupled bunch instability is estimated by

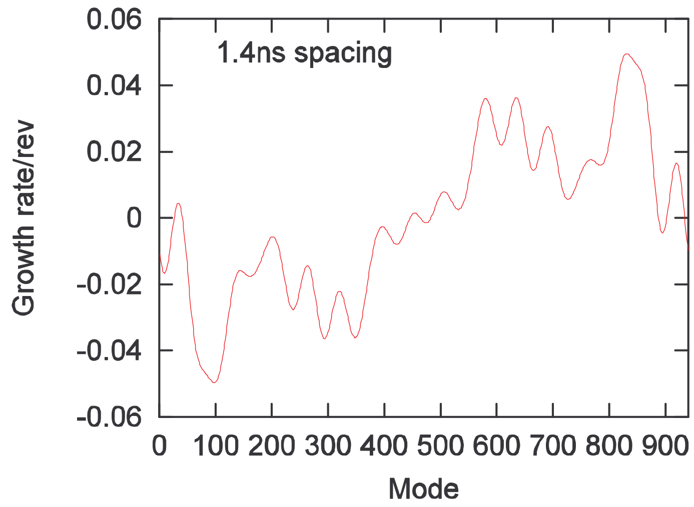
$$\Omega_m - \omega_\beta = \frac{N_\gamma r_e c}{2\gamma T_0 \omega_\beta} \sum_{n=1}^{n_0} W\left(\frac{n}{h} L\right) \exp\left(2\pi i n \frac{m + \nu_y}{h}\right)$$

Medium range Wake force and growth of CBI (Fill 1.4ns)

Wake force



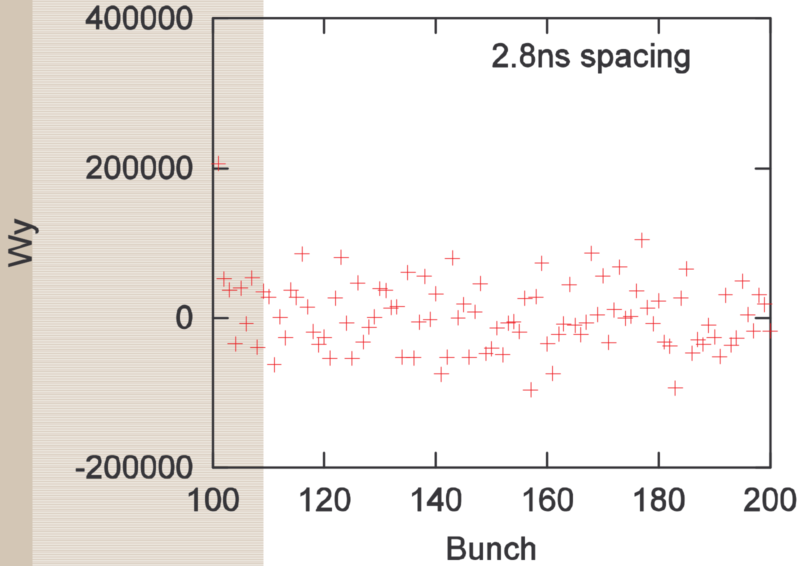
Mode stability



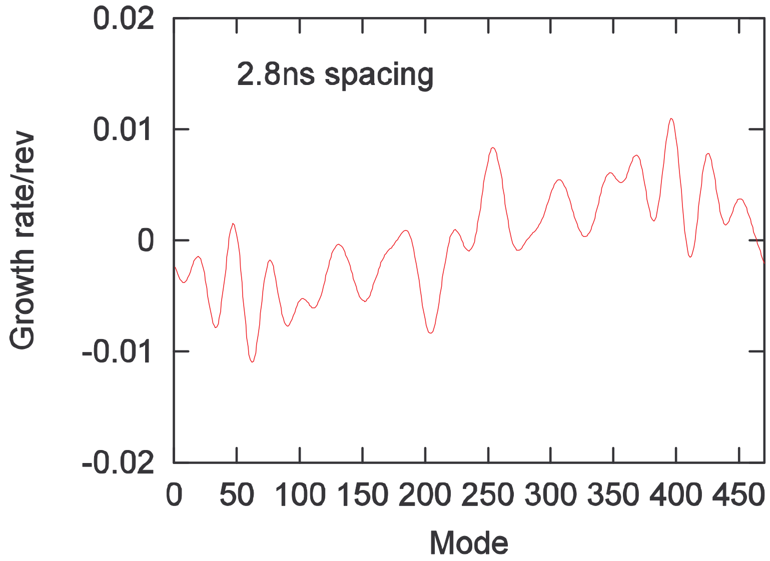
Growth time 20 turns 26μs

Medium range Wake force and growth of CBI (Fill 2.8ns)

Wake force



Mode stability



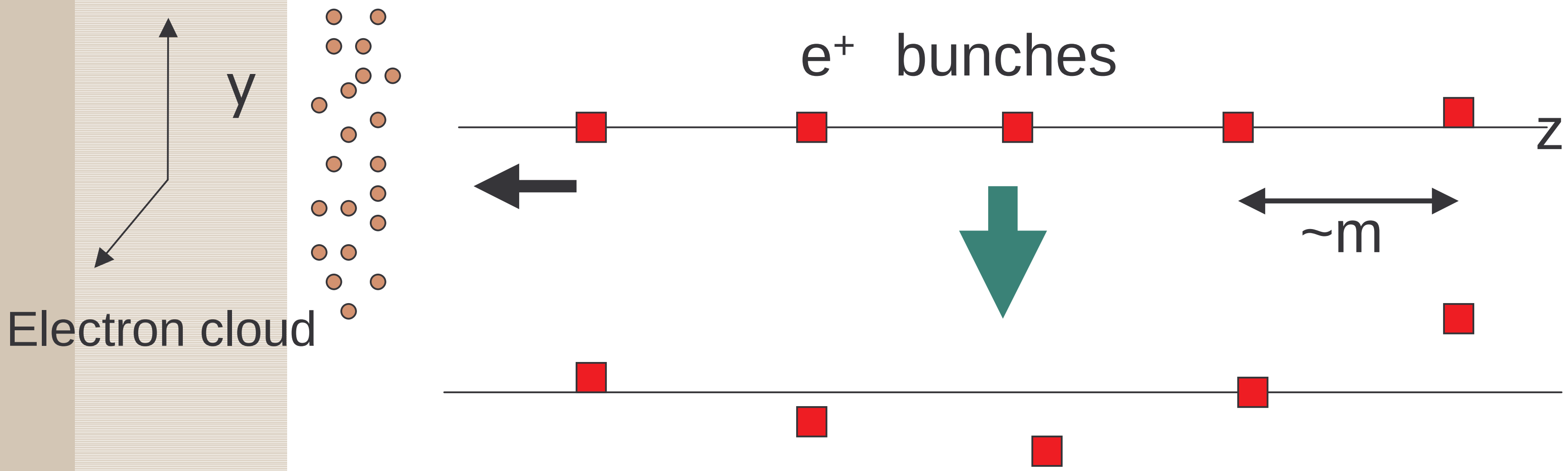
Growth time 100 turns 130μs

Tracking simulation

Solve both equations of beam and electrons simultaneously

$$\frac{d^2\mathbf{x}_{+,a}}{ds^2} + K(s)\mathbf{x}_{+,a} = \frac{2r_e}{\gamma}\sum_{j=1}^{N_i}\mathbf{F}_G(\mathbf{x}_{+,a} - \mathbf{x}_{e,j};\sigma(s))\delta(s - s_j)$$

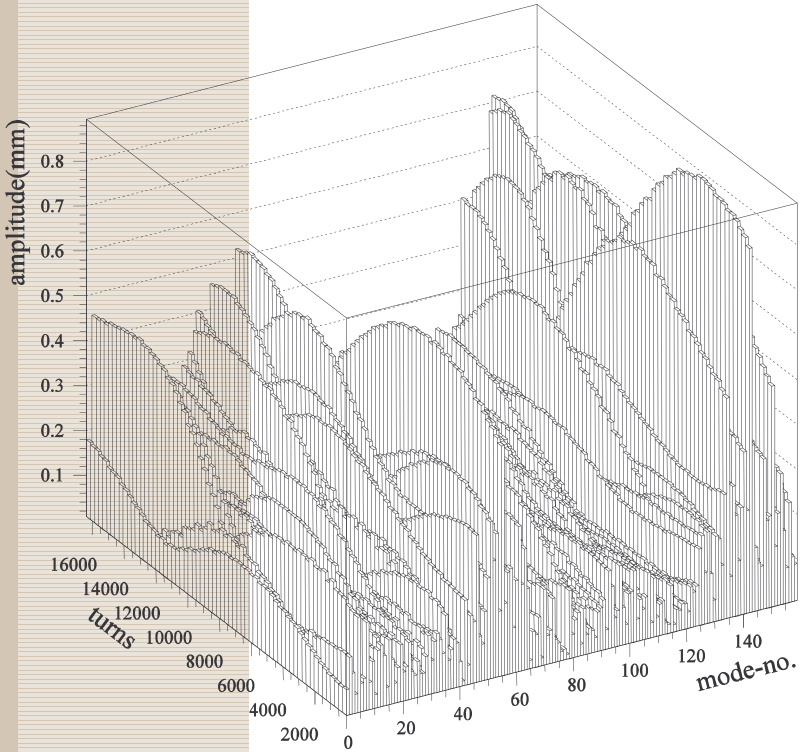
$$\frac{d^2\mathbf{x}_{e,j}}{dt^2} = 2N_+ r_e c^2 \mathbf{F}_G(\mathbf{x}_{e,j} - \mathbf{x}_{+,a};\sigma(s))\delta(t - t(s_{e,j})) - \frac{e}{m}\frac{\partial\phi}{\partial\mathbf{x}}$$



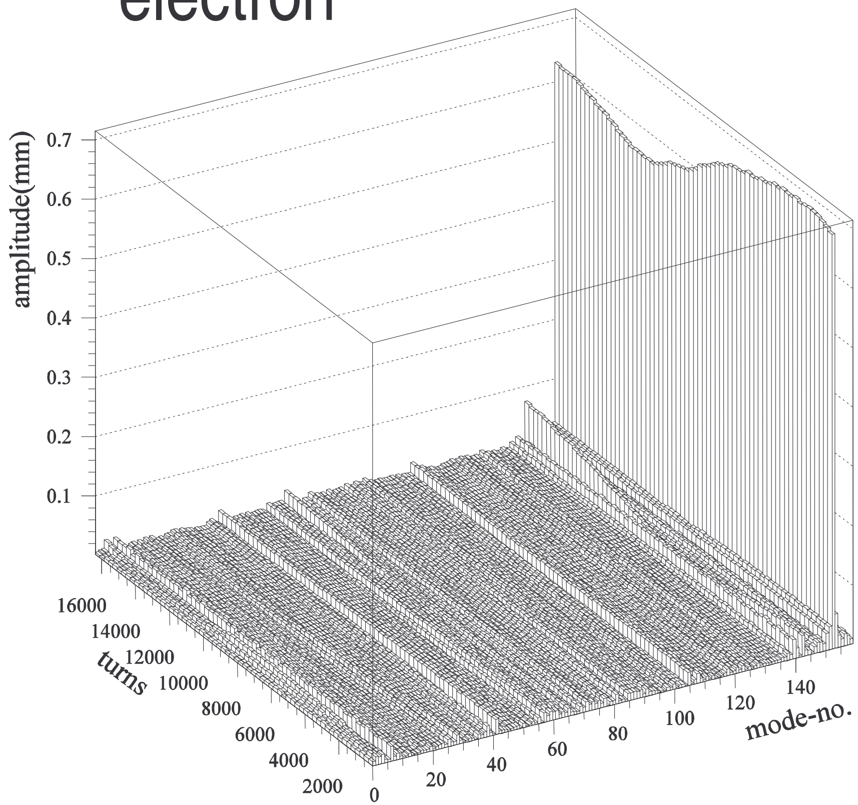
Coupled bunch instability in other rings

BEPC mode spectra by Single Path Beam Position Monitor

Positron

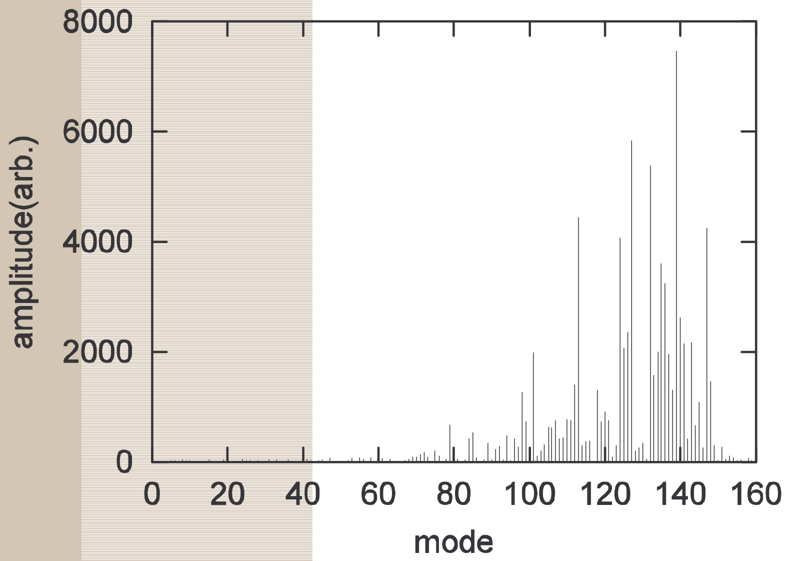


electron

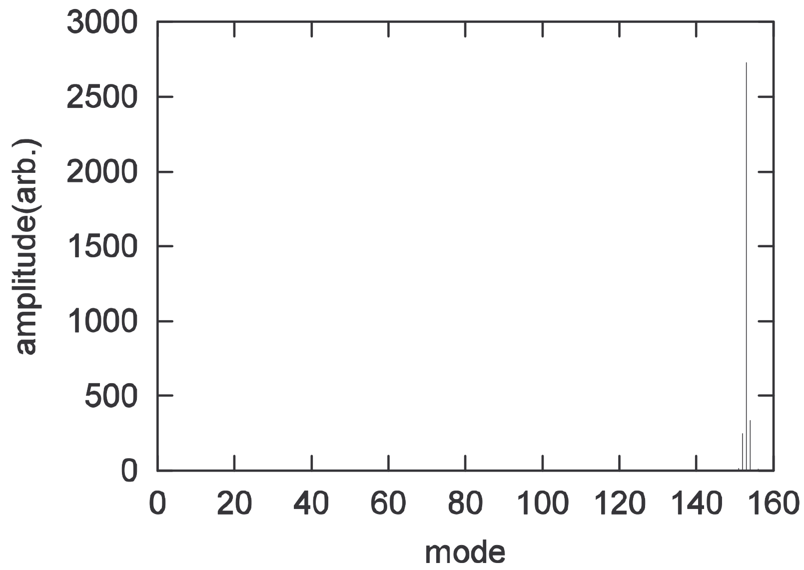


BEPC mode spectra by tracking simulation

Positron



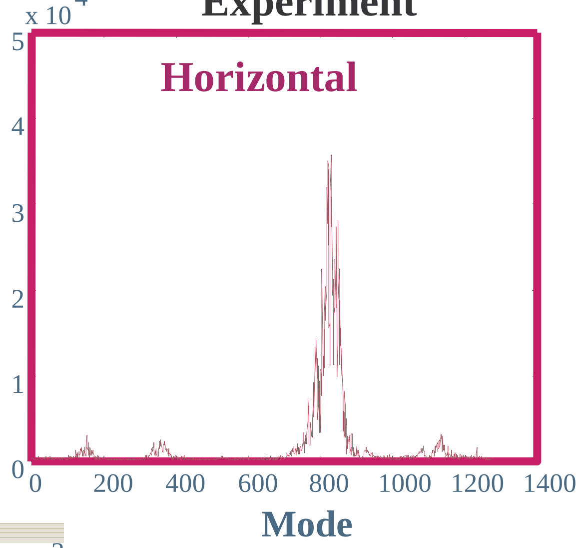
electron

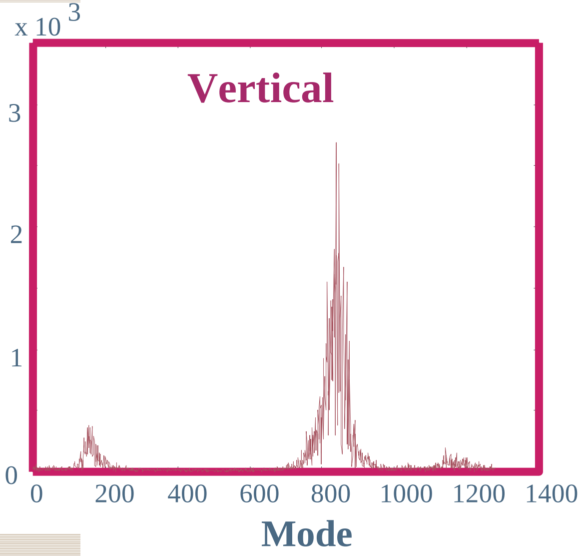


Solenoid-Off

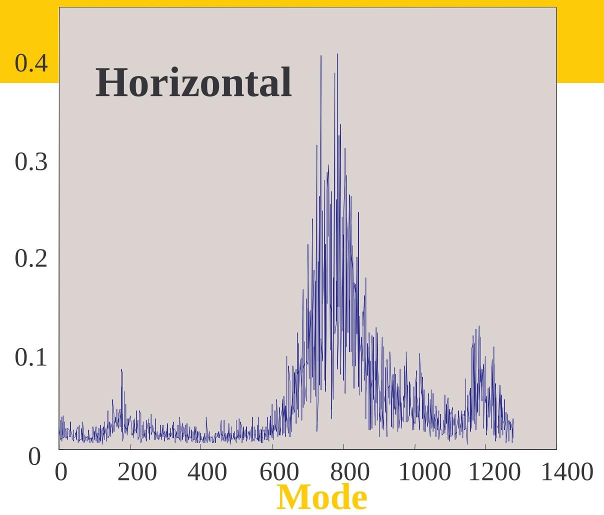
KEKB

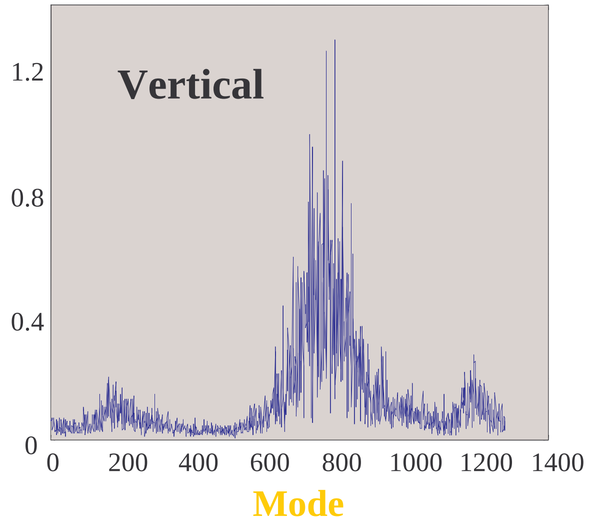
Experiment





Simulation



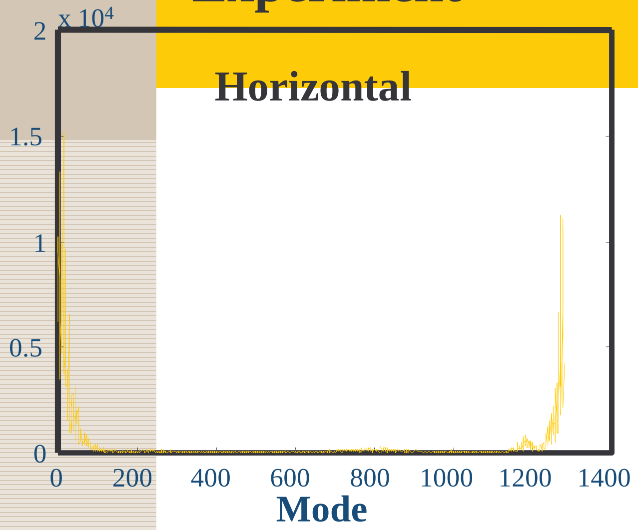


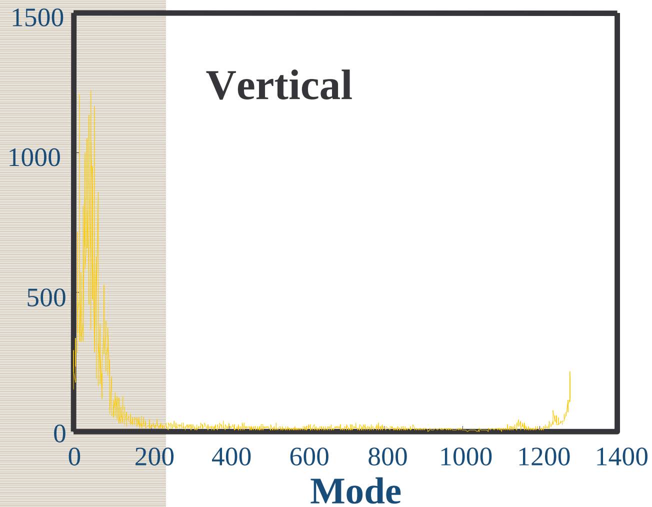
By Su Su Win

Solenoid-ON

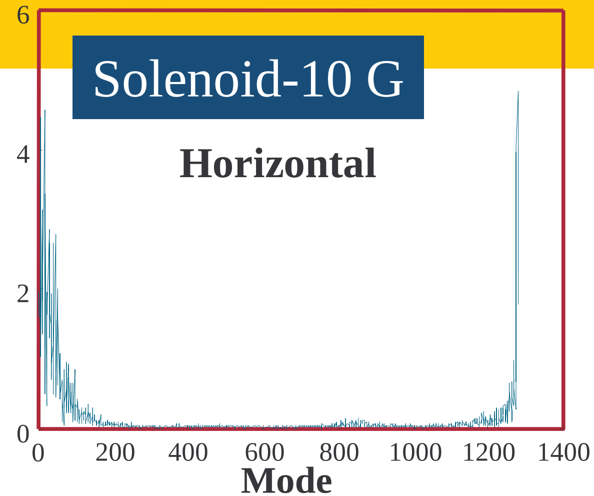
KEKB

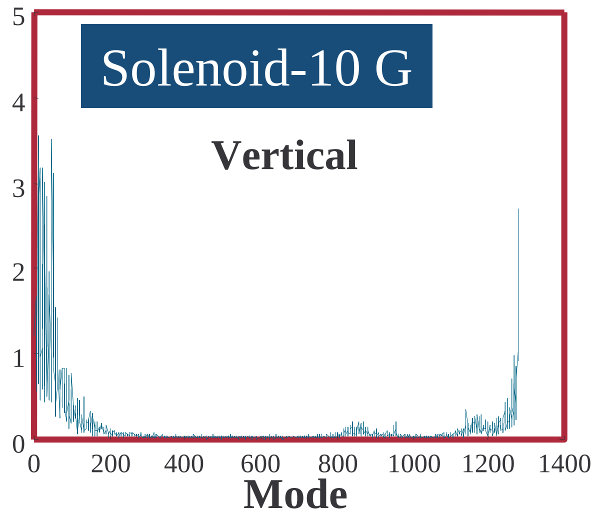
Experiment





Simulation





By Su Su Win

Single bunch instability caused by electron cloud

- The single bunch instability is analyzed by wake field method and tracking simulation.

Wake field

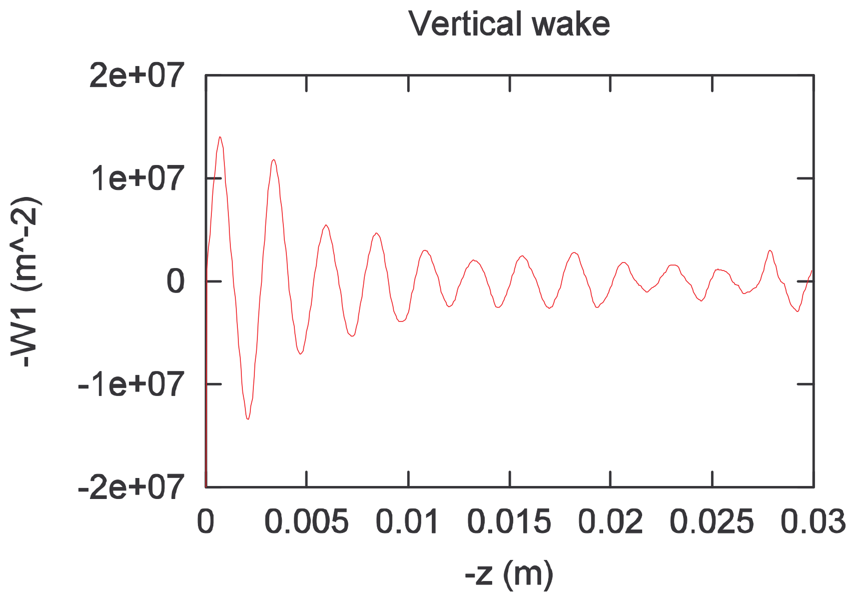
- Linearized model.
- Numerical calculation including nonlinearity.
(Similar way to the calculation of the multi-bunch wake field)

Short range wake field induced by electron cloud

Short range wake for coasting beam

Analytical solution with
a simplified linear theory

$$W = K\frac{\lambda_e}{\lambda_p}\frac{L}{(\sigma_x+\sigma_y)\sigma_y}\frac{\omega_e}{c}\sin\left(\frac{\omega_e}{c}z\right)$$



- $cR/Q = 1.4\times10^{7}\ m^{-2}\ (0.94\times10^{7}\ m^{-2})$
- $\omega_e =$ $(5.5\times10^{11}\ s^{-1})$

Threshold of fast head-tail instability

- Bounce frequency of electrons in the positron beam potential

  $\omega_e \sigma_z / c = 9.5$ (V)>>1 2.6 (H)>1

- Coasting beam model
- Stability criteria

$$U = \frac{\sqrt{3}\lambda_p r_0 \beta}{\nu_s \gamma \omega_e \sigma_z / c} \frac{|Z_\perp(\omega_e)|}{Z_0} = 1$$

Threshold cloud density of some positron rings

	KEKB	DAFNE	PEPII	JLC DR
E (GeV)	3.5	0.55	3.1	1.98
L (m)	3016	97.7	2000	395
Np	3.30E+10	4.00E+10	6.00E+10	7.50E+09
$\omega \sigma z/c$	2.5	3.2	3.8	9.1
νs	0.018	0.012	0.02	0.02
σx (μm)	420	2000	800	84
σy (μm)	60	63	80	7.1
σz (mm)	4	24	12	5
Z(ρ=10^12)	1088	193	1236	826
ρth	5.60E+11	1.64E+12	8.04E+11	2.56E+12

Equation of motion for Gaussian model

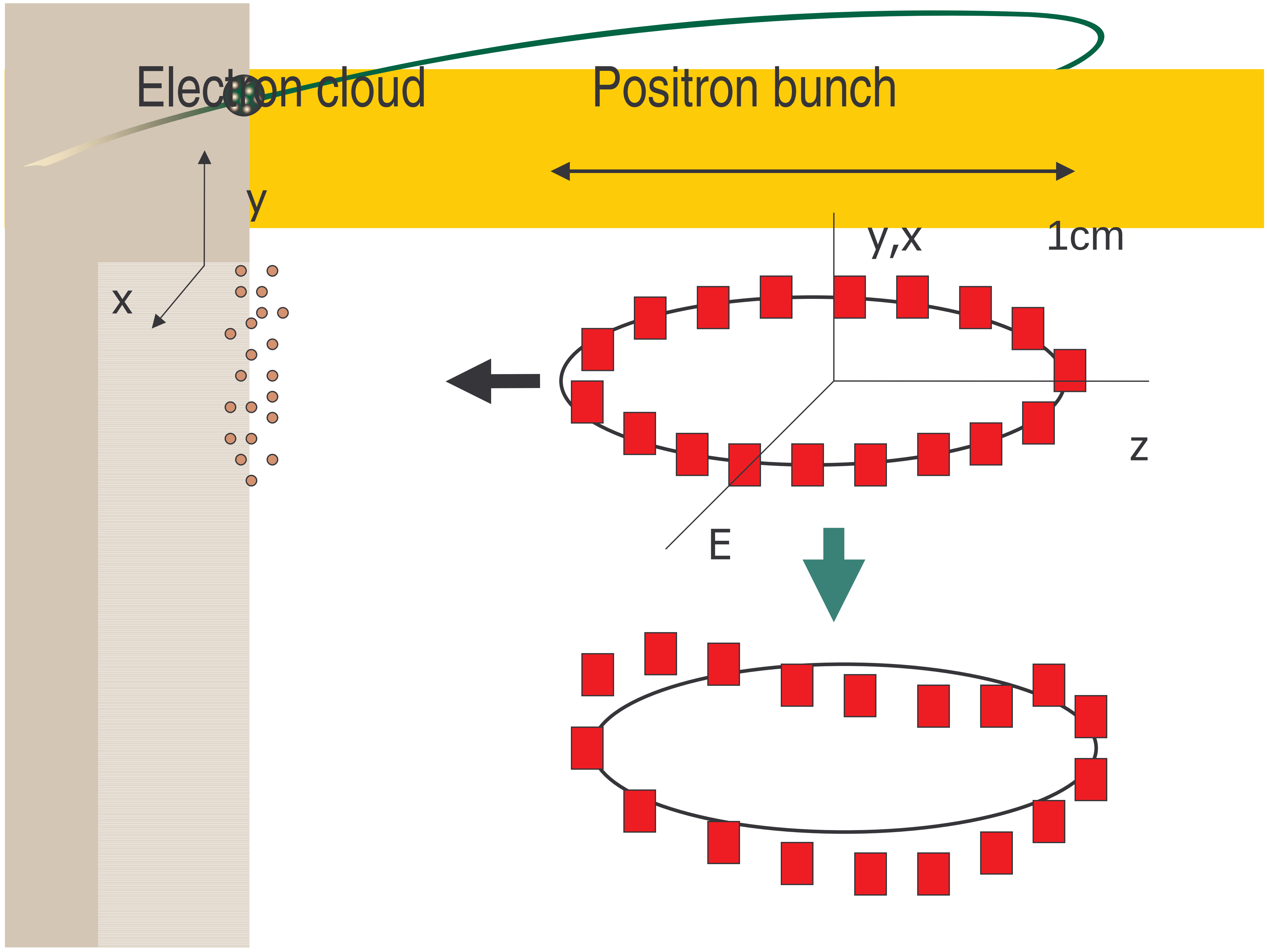
- Macro-particles with fixed transverse Gaussian size (distributed in the longitudinal phase space).
- Macro-electrons in transverse plane.

$$\frac{d^2\mathbf{x}_{+,a}}{ds^2} + K(s)\mathbf{x}_{+,a} = \frac{2r_e}{\gamma}\sum_{j=1}^{N_i}\mathbf{F}_G(\mathbf{x}_{+,a} - \mathbf{x}_{e,j};\sigma(s))\delta(s - s_j)$$

$$\frac{d^2\mathbf{x}_{e,j}}{dt^2} = 2N_+ r_e c^2 \mathbf{F}_G(\mathbf{x}_{e,j} - \mathbf{x}_{+,a};\sigma(s))\delta(t - t(s_{+,a}))$$

The same equation as CBI except of the time scale (s~1cm).

CBI (s~1m)

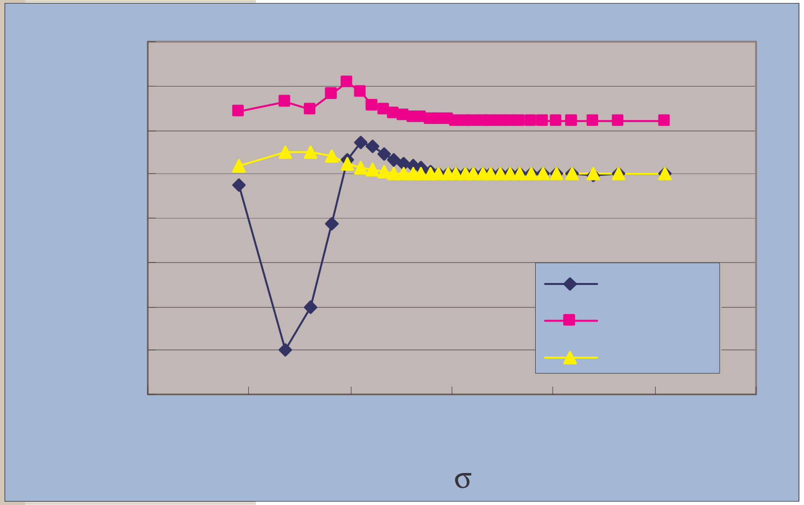


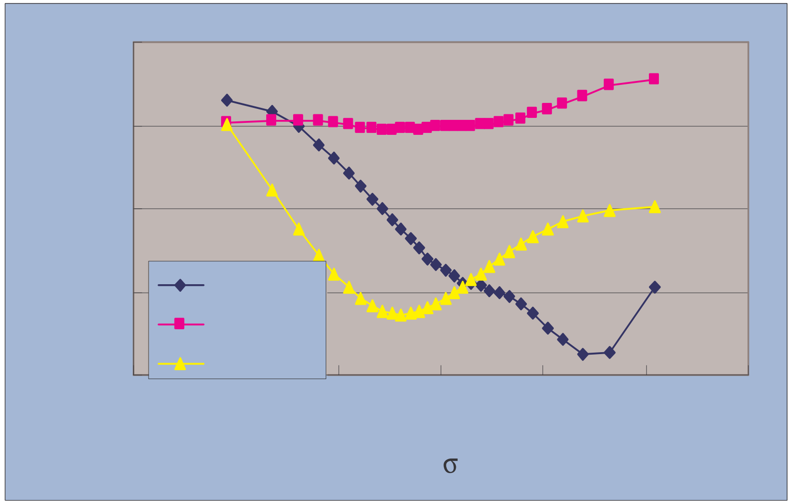
Electron cloud
Positron bunch
y
x
y,x
1cm
z
E

PIC simulation

- Transverse mesh. 2D electric field calculation for electrons and positron bunch.
- A bunch was sliced into 20-30 in the longitudinal direction.

Snap shot of beam shape for ν_s=0 and ν_s>0





KEKB

Summary

- We assume primary electron yield $Y_{1\gamma}$=0.013 $e^-/(m.e^+)$ for JLC damping ring. This value is 1/5 of the direct photoelectron yield, that was measured in KEKB test ante-chamber (I~1A).
- Electron cloud densities are 8×10^{12} m^{-3} and 3×10^{12} m^{-3} for 1.4 and 2.8ns spacing, respectively.
- The growth of coupled bunch instability is 20 turn (26μs) and 100 turn (130μs) for 1.4 and 2.8ns spacing, respectively.
- The growth of 20 turn is serious, but 100 turn can be recovered by bunch by bunch feedback.

Summary (cont.)

- The threshold cloud density of the fast head-tail instability is 2.5×10^{12} m^{-3} for ν_s=0.02.
- The wake approximation neglects some effects: nonlinearity, pinching of electrons… A simulation should be performed to confirm the results.
- We need a factor 3 reduction further for the electron production yield: $Y_{1(+2)}$=0.004 $e^-/(m.e^+)$.
- This value corresponds electron current of 5μA/cm^2 at the chamber surface R=1cm for beam current I=800mA.
- It is not impossible to achieve the value.

Summary cont.

Following studies for LC should be done,

- Design of beam chamber. Electron current should be measured in a positron storage ring. (I_+=0.8A, I_{ec}=1μA for R=5cm at Y_γ=0.65 γ/(m.e+)), as is done by Harkay et.al.(APS), Macek et.al. (PSR) and Kanazawa et.al.(KEK),
- ATF positron storage with a high current (~800mA).

,if we make progress in LC project with a normal conducting scheme.