I. Complex phenomenon of the beam-beam and the beam-electron cloud effects

II. Electron cloud effect in SuperKEKB

III. Electron cloud instability in DAΦNE

K.Ohmi KEK-IMSS

MAC2002, 26 Feb. 2001

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Complex phenomenon of the beam-beam and the beam-electron cloud effects

K.Ohmi (KEK)

MAC2002 , 26 Feb. 2002

Introduction

- Head-tail effect caused by beam-beam disruption

  E. Perevendentsev, A. Valishev, PR-ST-AB 4, 024403 (2001)

  K.Ohmi, A.Chao, SLAC theory group meeting, 24 Aug 2001

- Head-tail effect caused by electron cloud

  K.Ohmi, F.Zimmermann, PRL 85, 3821 (2000)

  K.Ohmi, F.Zimmermann, E.Perevedentsev, PR, E65, 16502 (2002)

- Complex phenomenon of above two effects

Complex phenomenon of two effects

- Complex phenomenon of (strong-strong) beam-beam and wake effects has been discussed by E. Perevendentsev, A. Valishev.
- This work is based on their idea.
- Another possibility (weak-strong beam-beam) is proposed by G.Rumolo, F. Zimmermann, K. Cornelis, and is also studied by K.Oide.

Beam-beam disruption

(two stream instability of beam-beam system)

- Linearized force of the beam-beam interaction between two rigid Gaussian beams

$$F_{y,\pm} = \frac{4\lambda_{\mp} r_e}{\gamma_{\pm}} \frac{c^2}{(\sigma_x + \sigma_y)\sigma_y} (y_{\pm} - y_{\mp}) \qquad \sigma_i = \sqrt{\sigma_{+,i}^2 + \sigma_{-,i}^2}$$

- A beam oscillates in a potential of another beam with an angular frequency

$$\omega_{\pm} = \left(\frac{4\lambda_{\mp} r_e}{\gamma_{\pm}} \frac{c^2}{(\sigma_x + \sigma_y)\sigma_y} \right)^{1/2} = \left(\frac{2\pi \xi_y c^2}{\sigma_z \beta_y} \right)^{1/2}$$

- Oscillation phase for one collision

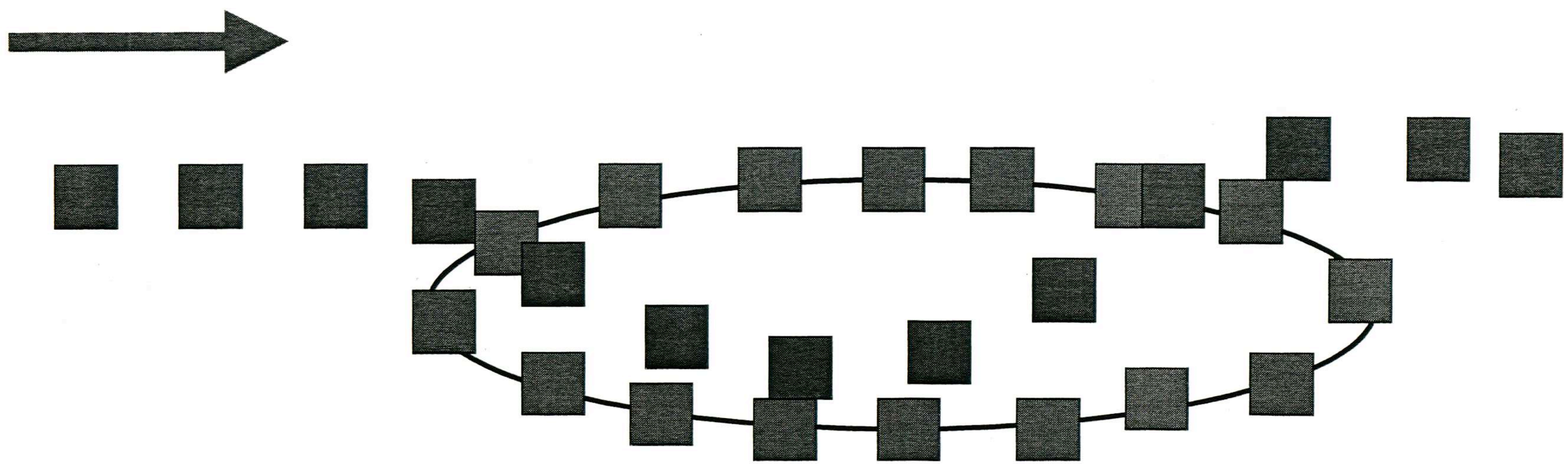
$$\phi = \omega \sigma_z / c = (2\pi \xi \sigma_z / \beta)^{1/2} = D^{1/2}$$

D:disruption parameter

Electron bunch --- one particle

Positron bunch --- a number of macro-particle

Trajectory of electron bunch in a positron bunch



Positron bunch

One-Two-particle model

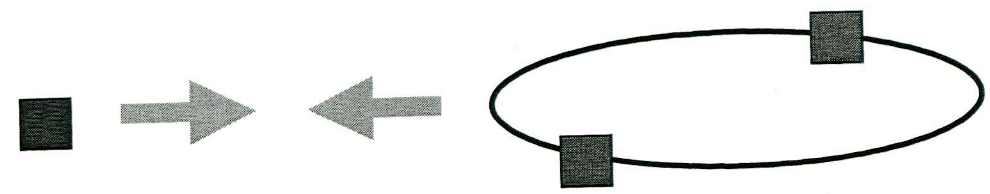
- KEKB

  $\xi = 0.08 \quad \sigma_z/\beta_y = 1 \quad \rightarrow \quad \phi = 0.7$
- Since ϕ is not small, two stream instability may be induced.
- For ϕ <1, two particle model can be applied.
- For simplicity, electron bunch is represented by single particle, while positron bunch by two particles. We call one-two particle model.

Beam-electron cloud interaction

- Electron oscillation phase $\phi_e = \omega_e \sigma_z / c$

  $\phi_e = 3$ for KEKB
- Two particle model for positron-electron cloud interaction is a little drastic approximation, but is not very nonsense because of $\phi_e = O(1)$.
- We approximate the interaction by a constant wake.



Electron Positron

- Two beams are represented by three (1+2) particles.

  $Y = (y_{1+}, p_{1+}, y_{2+}, p_{2+}, y_{-}, p_{-})^t$

  Note: the variables are normalized by β.

- Collision point

$$\Delta = \pm \frac{\sigma_z}{2} \sin\left(2\pi \nu_s s / L\right)$$

- One turn matrix $T_{rev}(\Delta) = B_{col}(\Delta) U$

- Collision of two beam (1-e and 2-e)

$$B_{1e}(\xi) = \begin{pmatrix} I_2 + b(2\xi) & 0 & -b(2\xi) \\ 0 & I & 0 \\ -b(\xi) & 0 & I_2 + b(\xi) \end{pmatrix}$$

$$B_{2e}(\xi) = \begin{pmatrix} I_2 & 0 & 0 \\ 0 & I_2 + b(2\xi) & -b(2\xi) \\ 0 & -b(\xi) & I_2 + b(\xi) \end{pmatrix}$$

$$b(\xi) = \begin{pmatrix} 0 & 0 \\ -\pi\xi & 0 \end{pmatrix} \qquad I_2 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Drift to the collision point from IP

$$D(\Delta) = \begin{pmatrix} d(\Delta) & 0 & 0 \\ 0 & d(\Delta) & 0 \\ 0 & 0 & d(-\Delta) \end{pmatrix} \qquad D_2(\Delta) = \begin{pmatrix} 1 & \Delta \\ 0 & 1 \end{pmatrix}$$

Transfer matrix of Collision

- 1st particle is head.

  $B_{col} = D^{-1}(-\Delta)\, B_2 D(-\Delta)\, D^{-1}(\Delta)\, B_1\, D(\Delta)$
- 2nd particle is head.

  $B_{col} = D^{-1}(\Delta)\, B_1 D(\Delta)\, D^{-1}(-\Delta)\, B_2 D(-\Delta)$

Linear theory with constant wake

- Revolution matrix

$$U(\mu_+,\mu_-)=\begin{pmatrix} U_2(\mu_1) & 0 & 0 \\ V_2(W,\mu_2) & U_2(\mu_2) & 0 \\ 0 & 0 & U_2(\mu_-) \end{pmatrix} \qquad \Delta>0$$

$$U(\mu_+,\mu_-)=\begin{pmatrix} U_2(\mu_1) & V_2(W,\mu_1) & 0 \\ 0 & U_2(\mu_2) & 0 \\ 0 & 0 & U_2(\mu_-) \end{pmatrix} \qquad \Delta<0$$

$$U_2(\mu)=\begin{pmatrix} \cos\mu & \sin\mu \\ -\sin\mu & \cos\mu \end{pmatrix} \qquad V_2(W,\mu_2)=\begin{pmatrix} W/2\,\sin\mu_2 & -W/2\,\cos\mu_2 \\ W/2\,\cos\mu_2 & W/2\,\sin\mu_2 \end{pmatrix}$$

Chromatic phase

$$\mu_1 = \mu_+ + \mu_s \chi \sin \frac{\omega_s s}{c} \qquad \mu_2 = \mu_+ - \mu_s \chi \sin \frac{\omega_s s}{c}$$

$$\chi = \frac{2\pi Q' \sigma_z}{\alpha C} = \frac{Q' \sigma_\delta}{\nu_s}$$ Chromatic phase

Synchrotron motion

- We study eigen-value problem of single synchrotron period. The synchrotron tune is assumed to be 1/n.

  Note that the system is periodic.

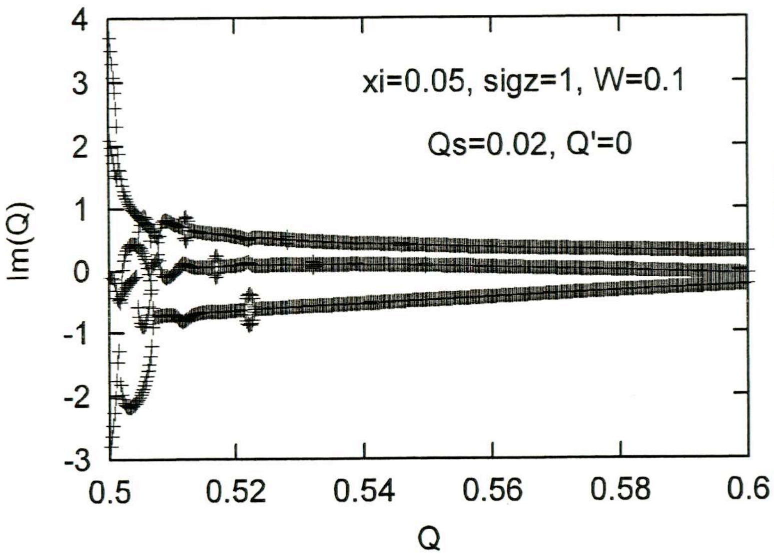
  The study was performed numerically.

$$T_{syn} = \prod_{i=1}^{n} T_{rev}(\Delta_i)$$

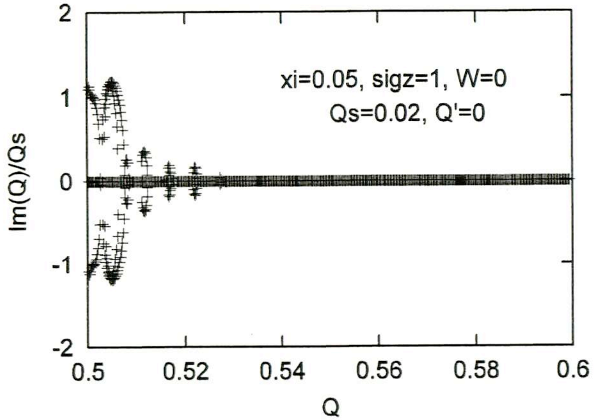
Results for two particle model

- Tune scan (both beam)

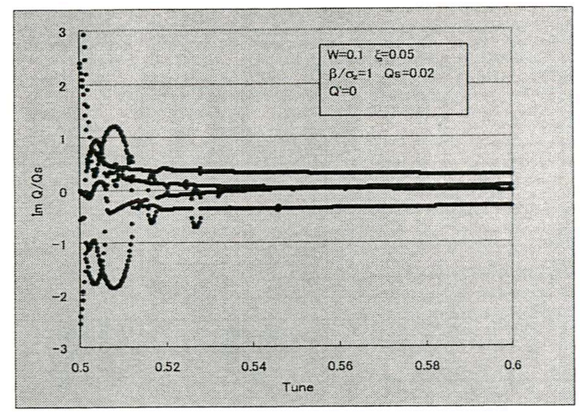
One-two



W=0



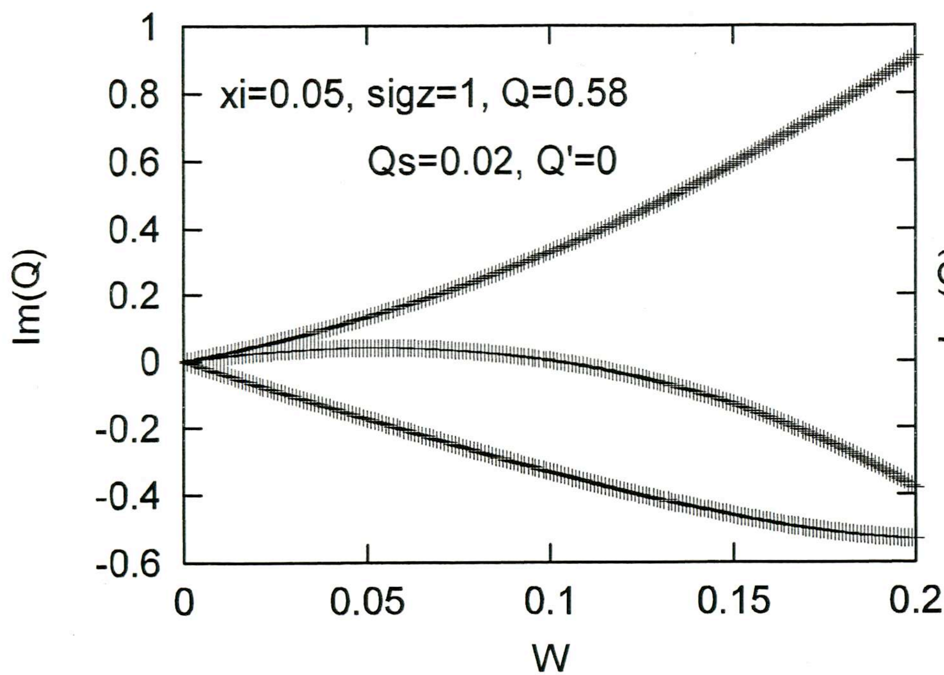
Two-two

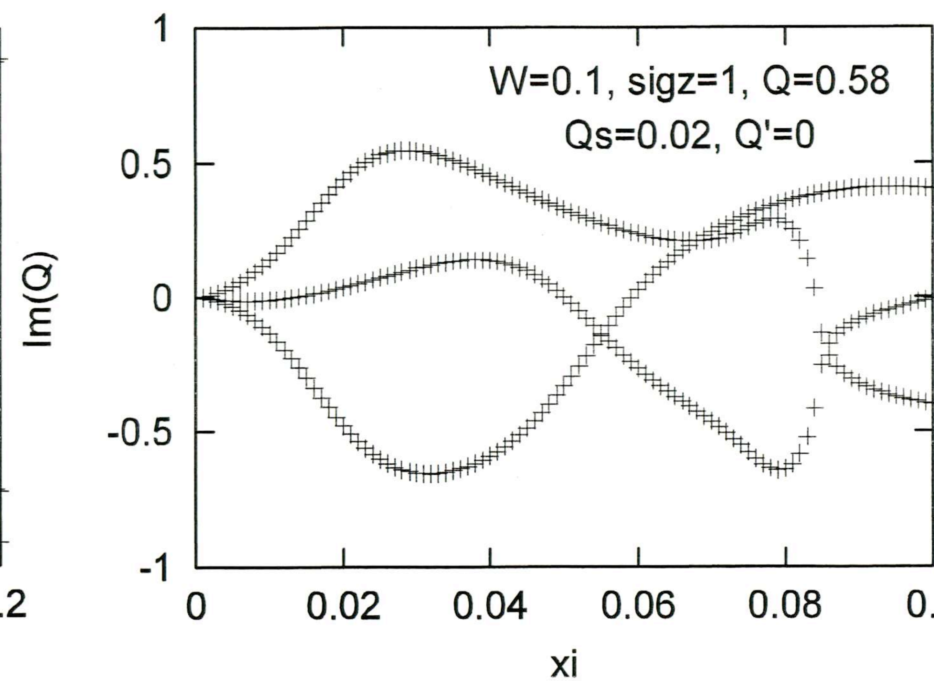


Imaginary tune was obtained for all bare tune area.

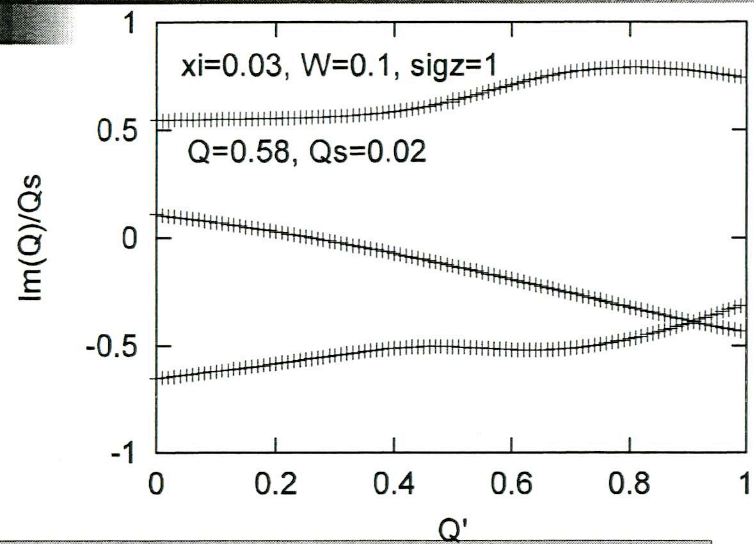
Real tune was not merged. Normal head-tail?

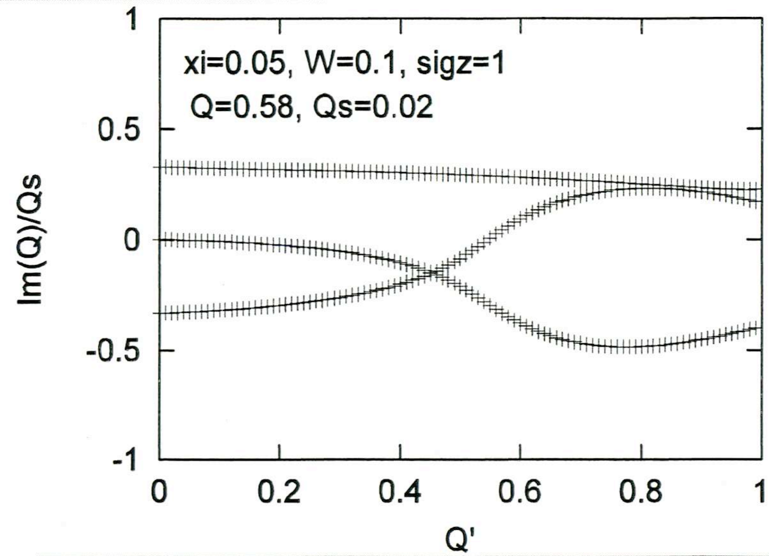
Wake and beam-beam strength

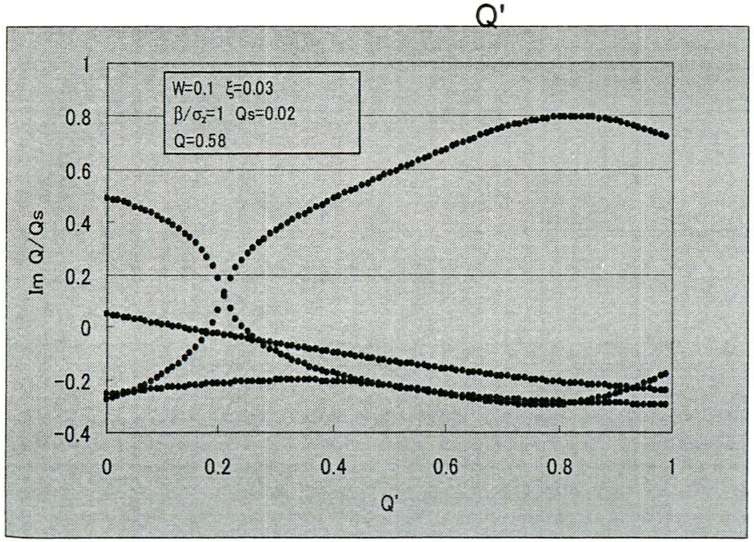


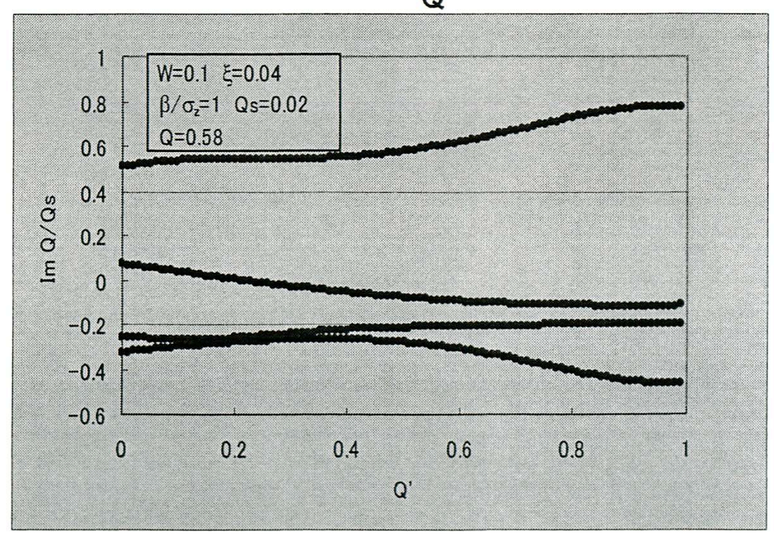


Chromaticity









Extensions of the model

- Arbitrary ν_s. Comment by Oide.

$$T_{syn} = T_{rev}(\sigma_z / 2)^{\frac{1}{2\nu_s}} T_{rev}(-\sigma_z / 2)^{\frac{1}{2\nu_s}}$$

$1/2\nu_s$ is not integer

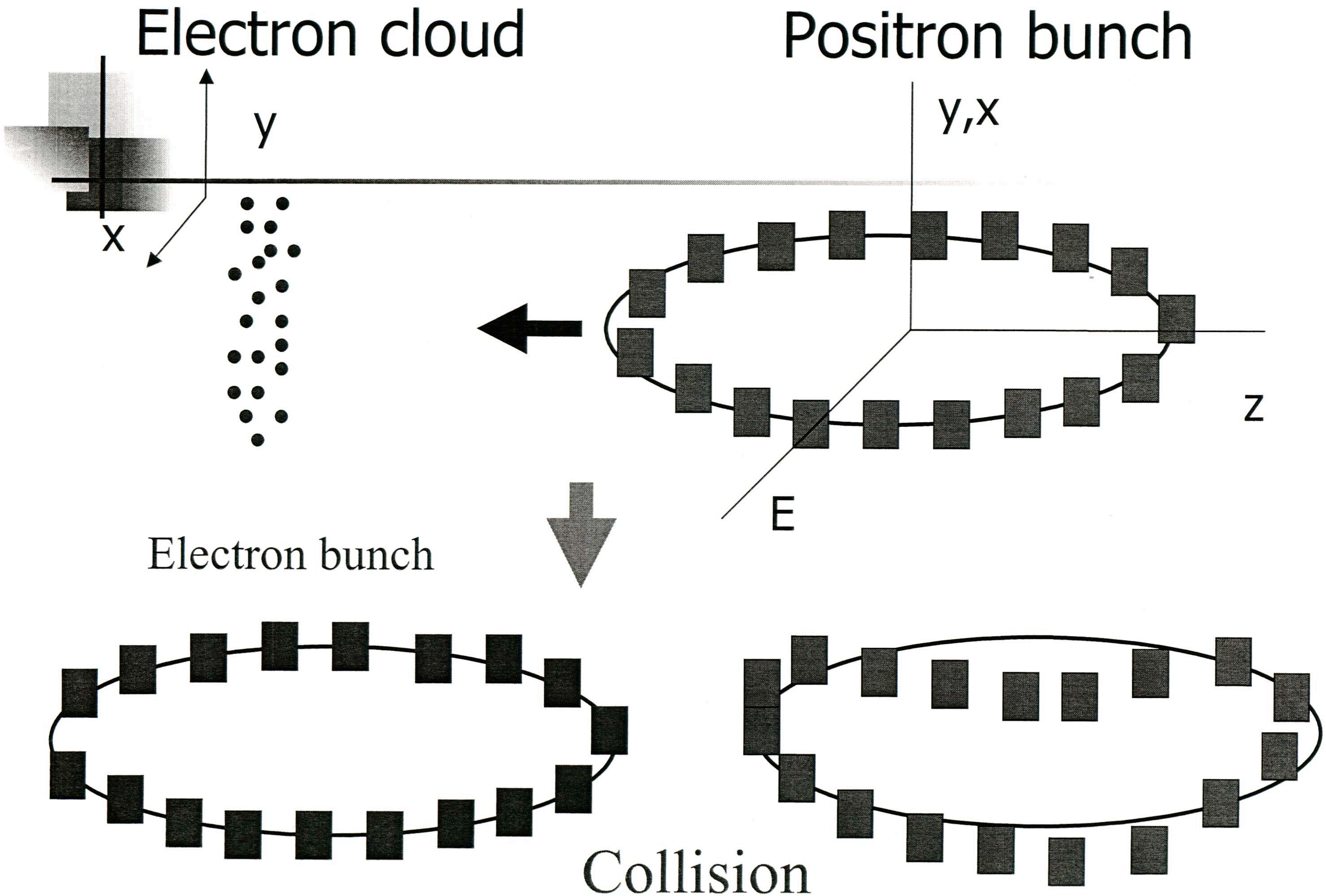
- Two-two particle model with the same synchrotron tune.

Similar results were obtained.

- Further extensions are done by numerical simulations.

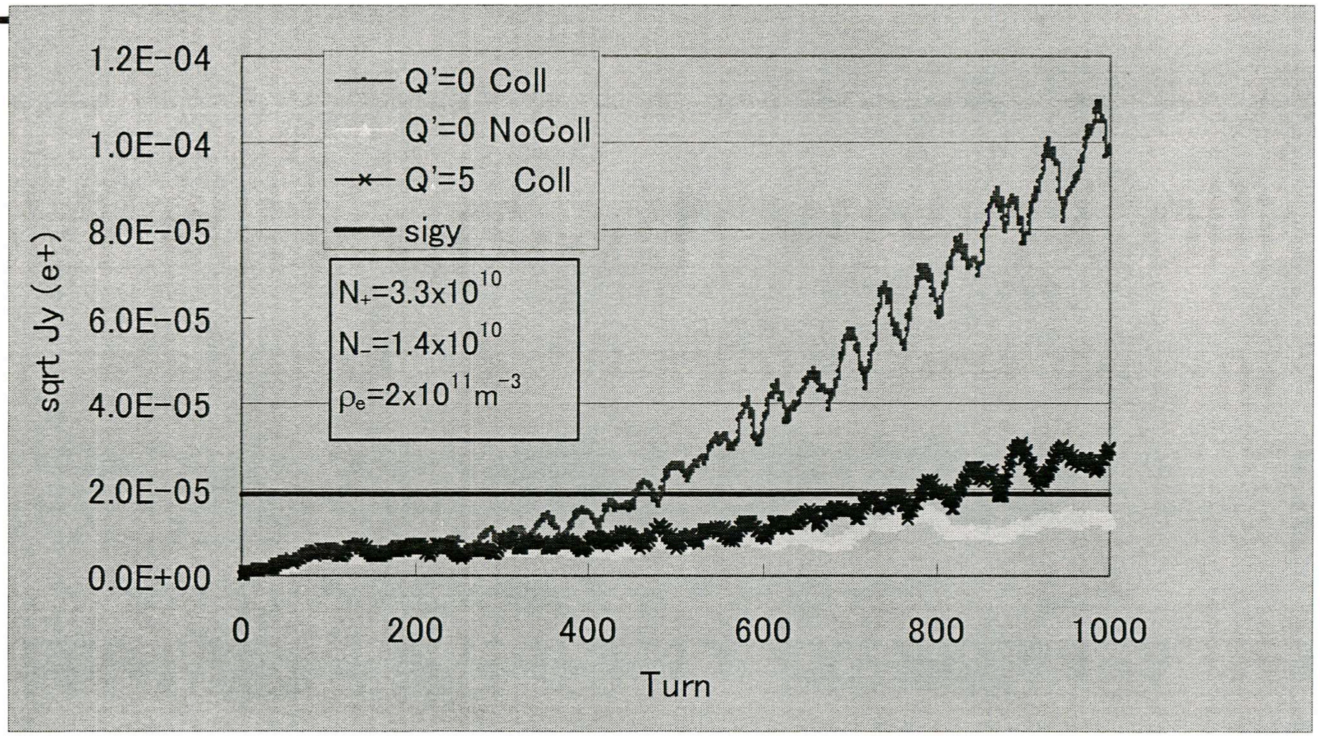
Simulation using Gaussian model

- Both beams are presented by macro-particles on the z-p_z phase space. The macro-particles have rigid Gaussian charge distribution in the transverse plane.
- Electron cloud is represented by a lot of point-like macro-particles.
- Electron cloud is set at one position of the ring. (Should be set more positions with different betatron phase in more sophisticated simulation.)


Electron cloud
Positron bunch
y
x
y,x
z
E
Electron bunch
Collision

Instability growth w/wo Collision

- $I_+=0.53$mA $I_-=0.22$mA first design val.

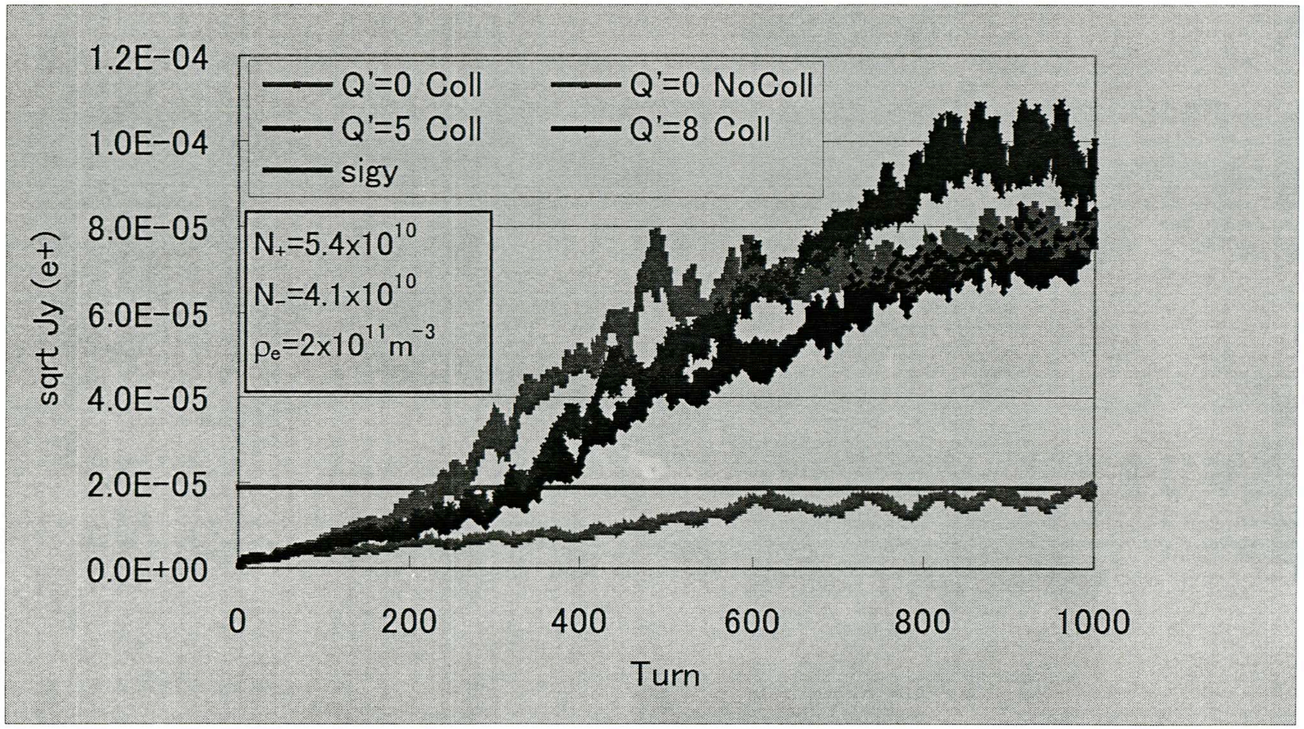


- Growth was obtained below the strong-head-tail threshold.

  $\rho_e=2\times10^{11}m^{-3}$ for $\rho_{th}\sim5\times10^{11}m^{-3}$

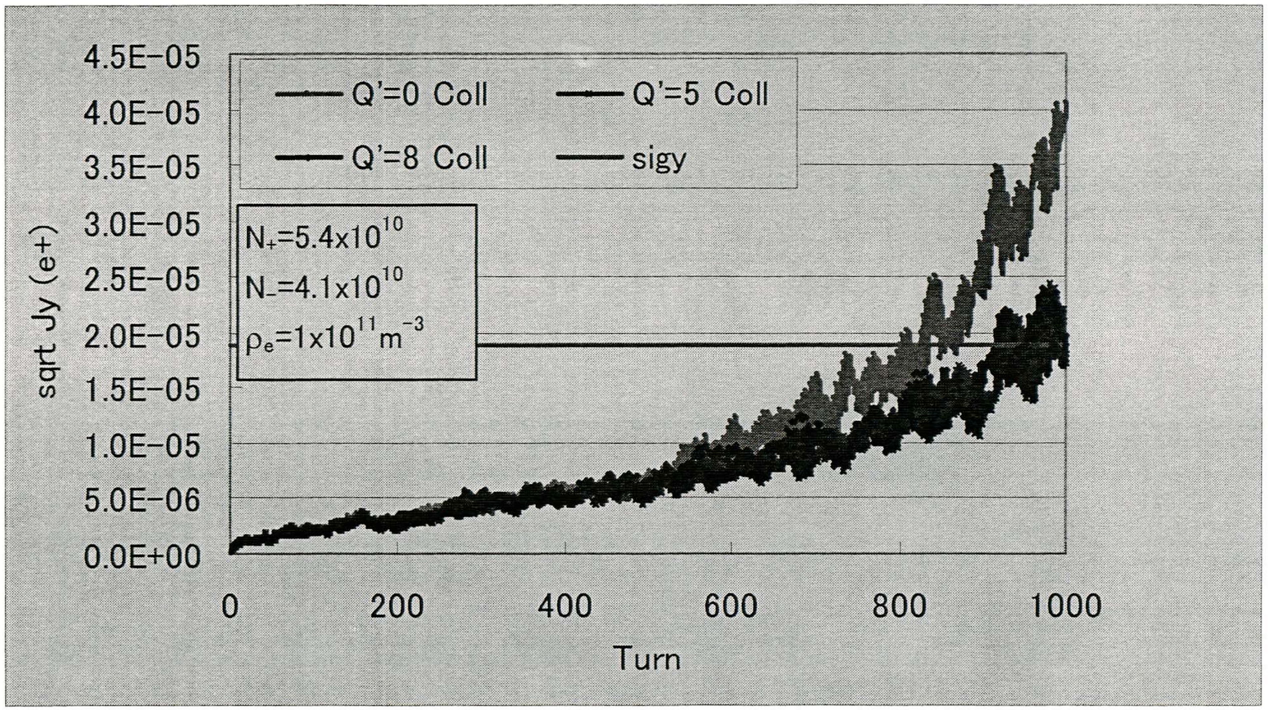
- Chromaticity works suppression of the instability.

- $I_+=0.86mA$ $I_-=0.66mA$ present operation.



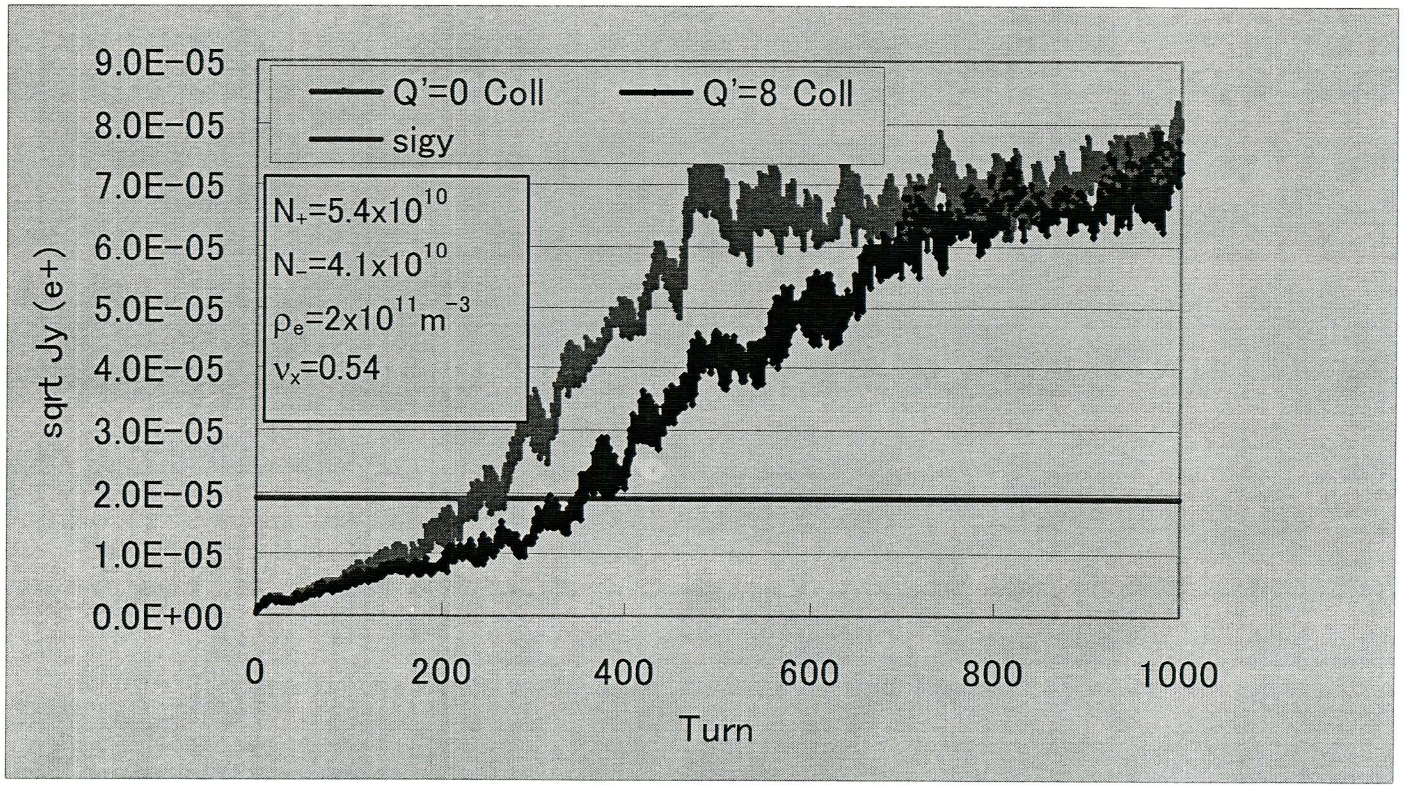
Chromaticity does not work suppression of the instability.

- I_+=0.86mA I_-=0.66mA present operation.



For lower cloud density $\rho_e=1x10^{11}m^{-3}$, the behavior does not change, though the growth become slower.

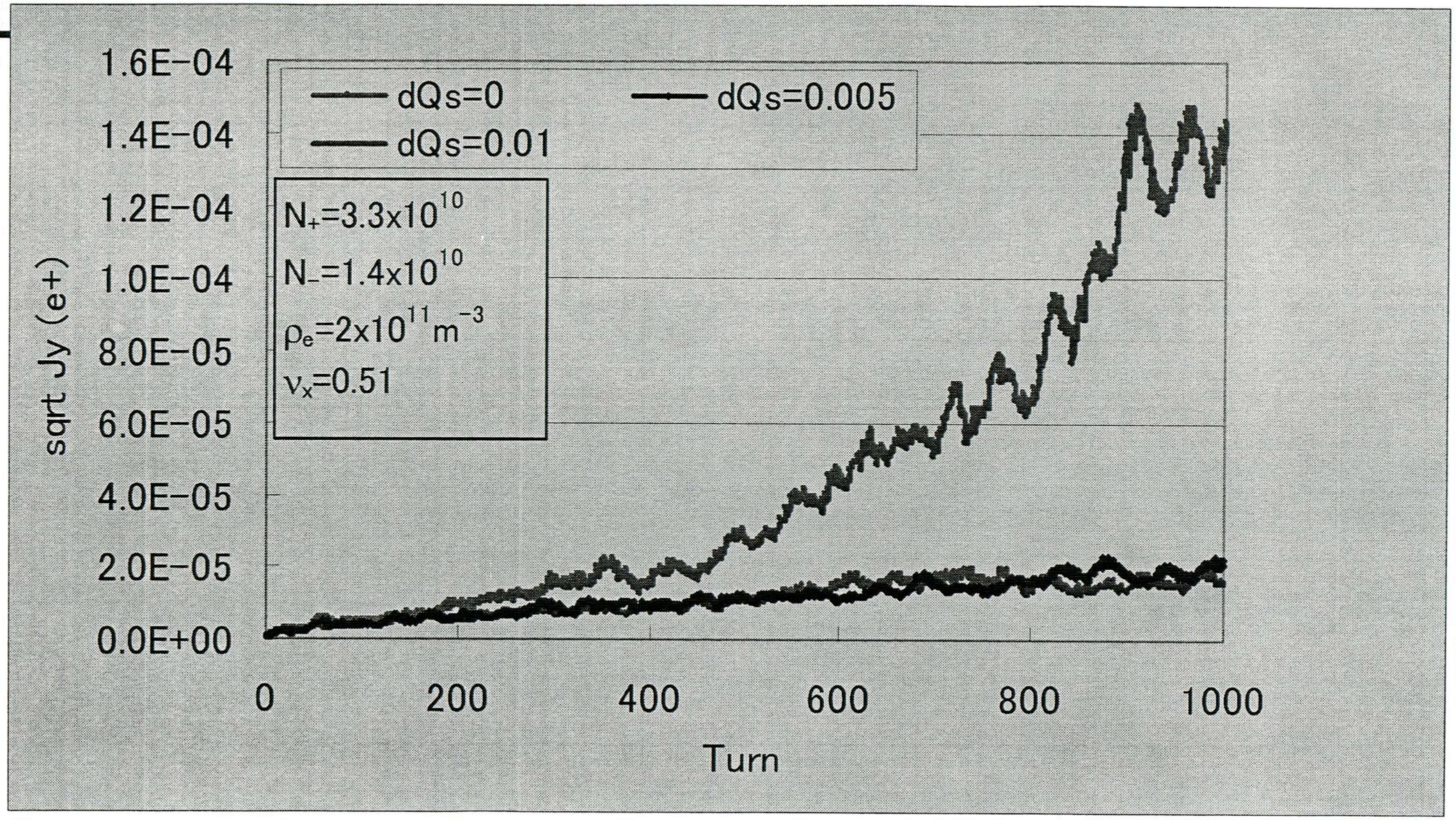
- The results do not depend on,
  - ν_x=0.51 -> 0.54
  - ν_s (HER) = 0.02 -> 0.03



Synchrotron tune spread

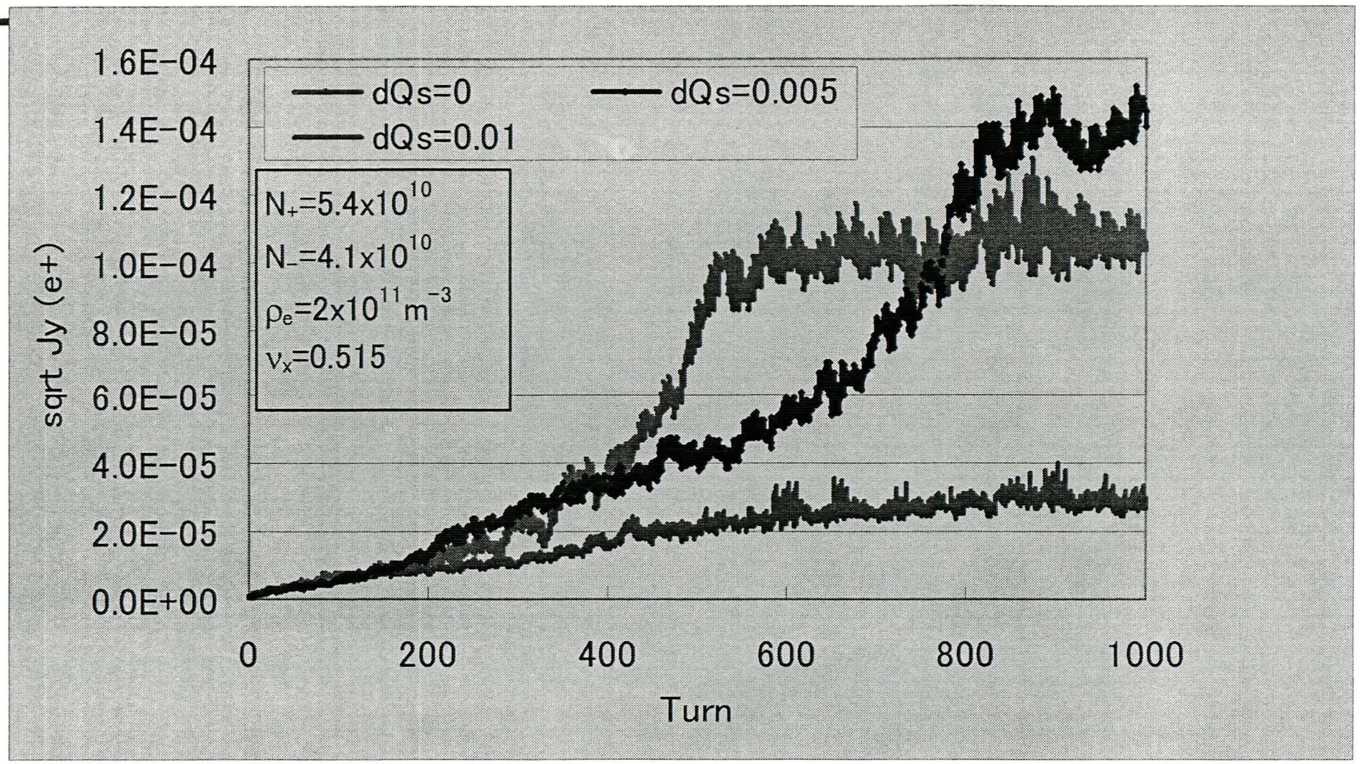
- This instability may be a kind of ordinarily head-tail effect, but not strong head-tail effect.
- If so, synchrotron tune spread affects the instability.

Effect of synchrotron tune spread



Synchrotron tune spread suppresses the instability.

- For Higher beam-beam parameter



For higher beam-beam parameters, more tune spread is required.

Summary

- Complex phenomena of beam-beam and beam-electron cloud were studied by using a linear theory and a simulation with Gaussian approximation.
- Below the each threshold of beam-beam and beam-cloud, an instability occurs due to their complex effect.
- The complex phenomena should exist.

Electron cloud for Super KEKB
(Ante-chamber)

Measurement using button monitors (by Kanazawa, Suetsugu et.al.)

- Electron production rate λ_e, which is defined as the number of electron produced by a bunch in a mater, are predicted by measuring electron current of button monitors.
- I_e $\mu A/m^2$ means

$$\lambda_e(m^{-1}) = 2\pi R I_e t_b / e$$

if electrons hit the chamber uniformly, where R and t_b are radius of chamber and bunch spacing.

- For example, $I_b = 1\ \mu A/cm^2$, $R = 5cm$ and $t_b = 8ns$ correspond to $\lambda_e = 1.6 \times 10^8\ m^{-1}$.
- The average electron cloud density is predicted by

$$\rho_e(\mathrm{m}^{-3}) = \frac{\lambda_e}{\pi R^2} \frac{t_e}{t_b}$$

t_e: electron traveling time in the chamber

=electron build-up time

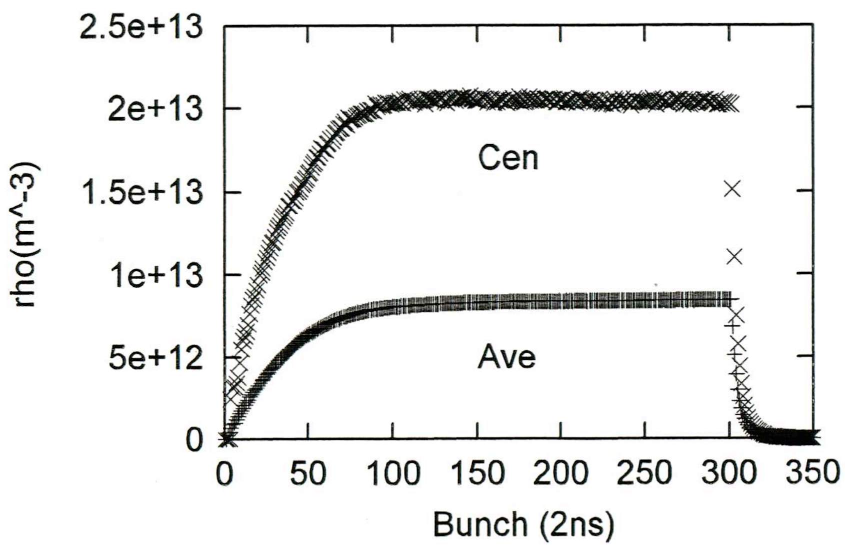
Measurement of electron current for test ante-chambers

- $I_+ \sim 1A$, the current for ante-chamber was typically 1/5 of that for normal Cu chamber.
- This value includes that due to secondary electrons.
- The current for the normal chamber was consistent with that due to primary photo-production $\lambda_e = 0.1\lambda_\gamma$.

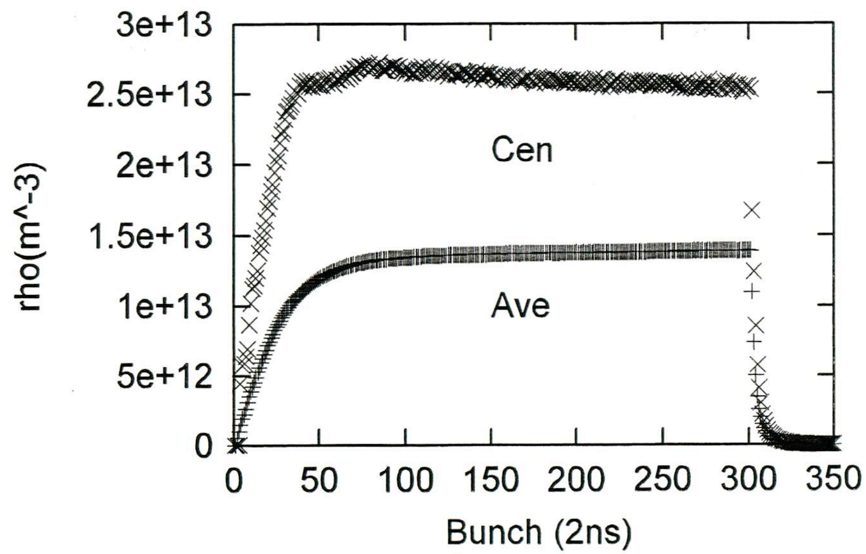
Electron density by simulation

3.5GeV	8GeV
$\lambda_e = 5x10^8\ m^{-1}$	$1.1x10^9\ m^{-1}$

KEKB design

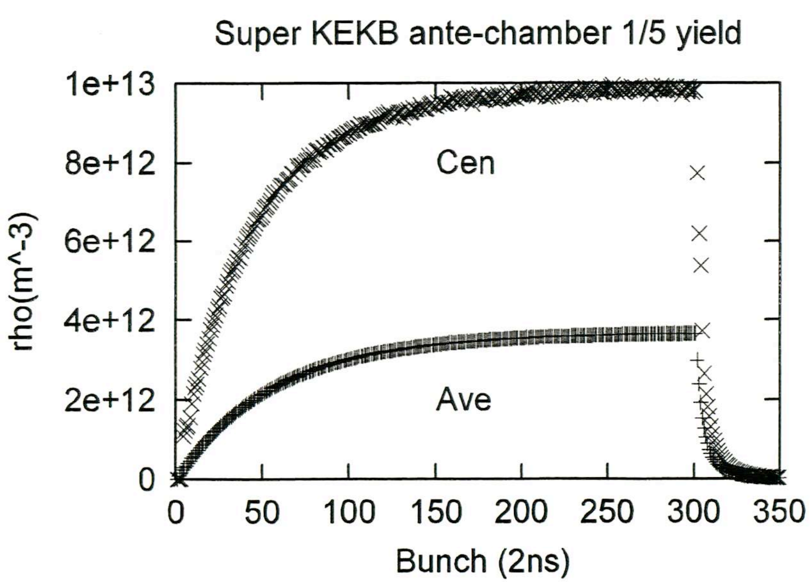


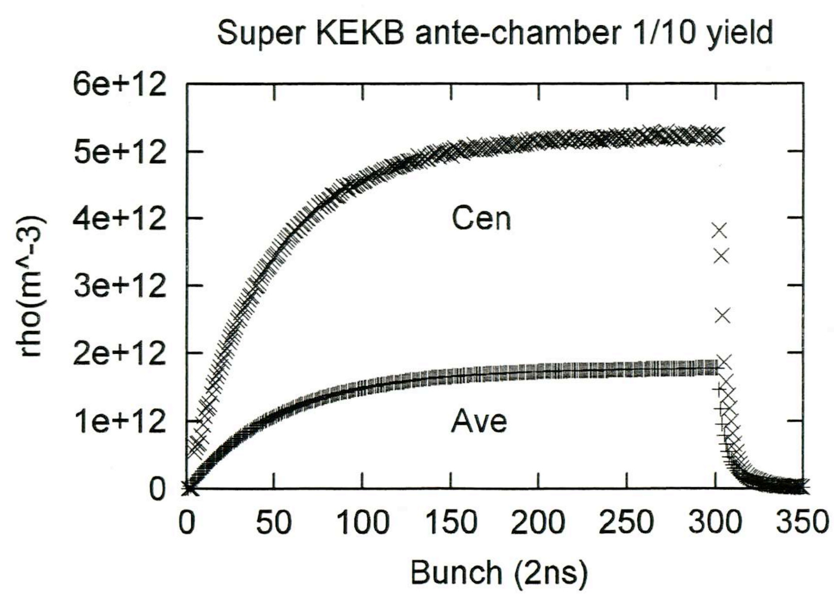
Super KEKB cyl-chamber



	3.5GeV	8GeV
$\rho_{e,av}$	$=0.9x10^{13}\ m^{-1}$	$1.4x10^{13}\ m^{-1}$
$\rho_{e,cen}$	$=2x10^{13}\ m^{-1}$	$2.5x10^{13}\ m^{-1}$

$\lambda_e = 2.2 \times 10^8\ m^{-1}$ $1.1 \times 10^8\ m^{-1}$





$\rho_{e,av} = 4 \times 10^{12}\ m^{-1}$ $2 \times 10^{12}\ m^{-1}$

$\rho_{e,cen} = 1 \times 10^{13}\ m^{-1}$ $5 \times 10^{12}\ m^{-1}$

Threshold

- Threshold density is estimated to be $\rho_{e,cen} = 1.1\text{x}10^{12}\text{m}^{-3}$ by the wake field method.
- Target value of $\lambda_e = 0.2\text{x}10^{8}\text{m}^{-1}$.

  (Primary yield ($N_e = 0.1N_\gamma$) $1.1\text{x}10^{9}\ \text{m}^{-1}$ of cylindrical chamber)

Electron cloud instability in DAΦNE

K. Ohmi, KEK

DAFNE-KEKB meeting

20 Feb 2002

Effective wake and impedance

$$W(z) = c\frac{R_S}{Q}\frac{\omega_e}{\varpi}\exp\left(\frac{\alpha}{c}z\right)\sin\left(\frac{\varpi}{c}z\right)$$

$$c\frac{R_S}{Q} = \frac{\lambda_e}{\lambda_p}\frac{L}{(\sigma_x+\sigma_y)\sigma_y}\frac{\omega_e}{c}$$

λ_e:line density of electron cloud at center ($2\pi\sigma_x\sigma_y\rho_e$)

λ_e:positron line density ($N_p/(2\sigma_z)$)

$$Z(\omega) = \frac{c}{\omega}\frac{R_S}{1+iQ\left(\frac{\omega_e}{\omega}-\frac{\omega}{\omega_e}\right)}$$

Beam Stability

- Long bunch $\omega_e \sigma_z / c > 1$

  coasting beam model

$$U = \frac{\sqrt{3}\lambda_p r_e \beta c}{4\pi\gamma\nu_s\left(\omega_e\sigma_z / c\right)} Z\left(\omega_e\right) = 1$$

- Short bunch $\omega_e \sigma_z / c < 1$

  two particle model, mode coupling theory

DAΦNE

Long bunch approximation

- $\rho_{th}=5\times10^{11}m^{-3}$ for KEKB $\omega_e\sigma_z/c\sim2.7$

  Q=3.4 (determined by ρ_{th})
- $\rho_{th}=16\times10^{11}m^{-3}$ for DAΦNE $\omega_e\sigma_z/c\sim3.3$

Electron density

- KEKB

  Production $\lambda_e = 5\text{x}10^8 m^{-1}$

  Bunch period 8ns

  Traveling time of e^- 80ns

  Cross-section of chamber $0.01 m^{-2}$

  Electron density $5\text{x}10^{11} m^{-3}$

- DAΦNE (1A)

Production $\lambda_e = 2.4 \times 10^9 m^{-1}$

ante-chamber (Al) $4.8 \times 10^8 m^{-1}$

Bunch period 6ns

Traveling time of e^- 80ns

Cross-section of chamber $0.01 m^{-2}$

Electron density $6.4 \times 10^{11} m^{-3}$

Note: In KEKB test antechamber, electron current was reduced to be 1/5 (Cu)

Summary

- The present operating current of DAΦNE (1A) may be less than the threshold of electron cloud instability.