Electron cloud effects in Cesr-TF and KEKB

K. Ohmi KEK

29 Feb 2008

LEPP, Cornell univ.

Contents

- History, electron cloud effect in KEK-PF
- Electron cloud build-up at KEKB
- Coupled bunch instability caused by electron cloud
- Single bunch instability caused by electron cloud
- Electron cloud effects in Cesr-TF

History

- Coupled-bunch instability had been observed at KEK-PF.
- Interpretation of the instability using photo-electron cloud model.
- Strange coupled bunch instability had been observed at CESR.
- The instability was observed at BEPC (China).
- Study of electron cloud effect for design of KEKB.
- Studies for PSR, LHC, SPS, SNS, JPARC, ILC …many machines.

Multi-bunch instability observed at KEK-PF

- KEK-PF is a 2nd generation light source operated by both of positron and electron beams. E=2.5 GeV L=186 m, Frf=500MHz.
- Instability was observed at multi-bunch operation of positron beam. N_{bunch}=200-300 for h=312.
- Very low threshold. I~15-20mA.
- The instability was not observed at electron beam operation.

- Had similar instability been observed at DORIS? Multi mode instability (197~ or 198~?)
- CESR, Electrons leak from Vacuum pump (J. Rogers et al.,).

Izawa et.al., Phys. Rev. Lett. 74, 5044 (1995).

BPM spectrum for V motion.

Electron 354 mA

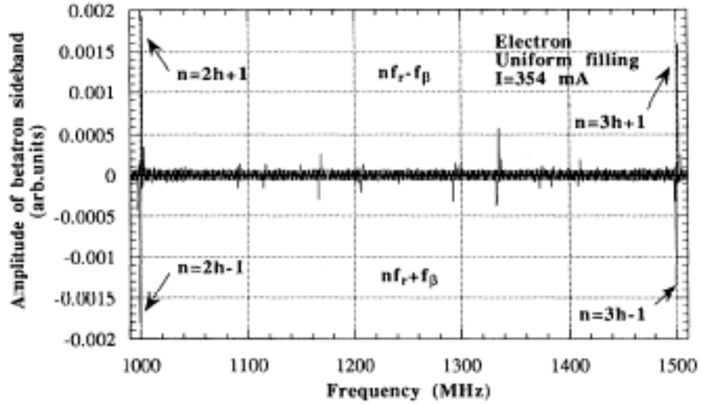


FIG. 1. Distribution of the betatron sidebands observed during electron multibunch operation with uniform filling.

Positron 324 mA & 240 mA

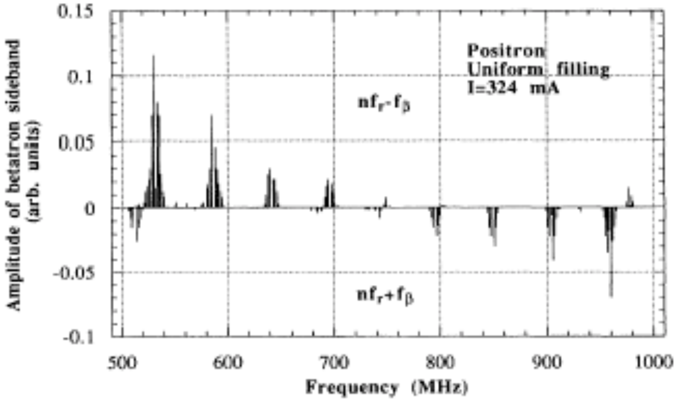


FIG. 2. Distribution of the betatron sidebands observed during positron multibunch operation with uniform filling.

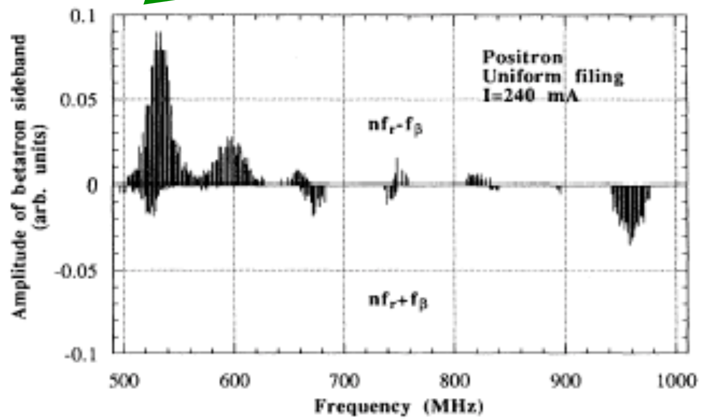


FIG. 3. Distribution of the betatron sidebands observed during positron multibunch operation with uniform filling. Only the stored current is different from Fig. 2.

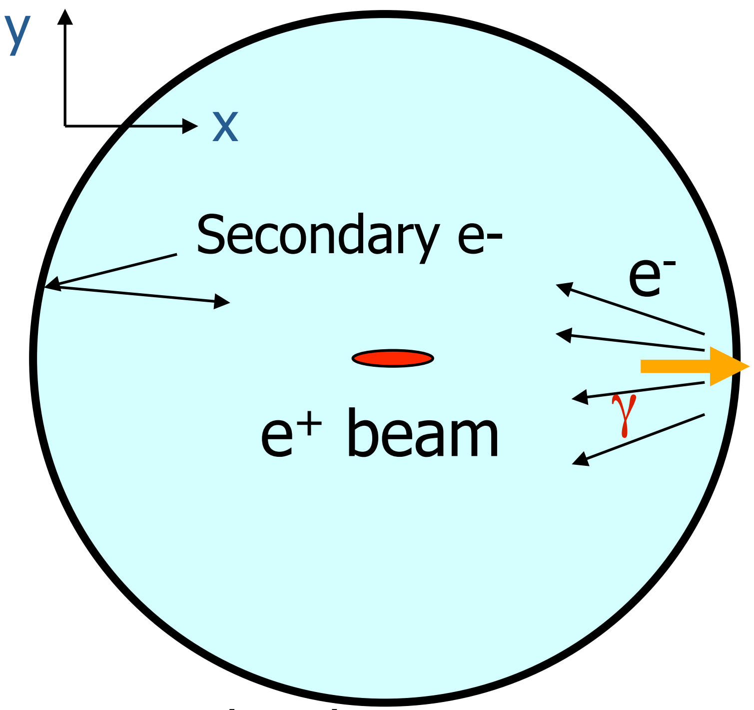
Interpretation of instability due to photo-electron cloud

- Positron beam emits synchrotron radiation.
- Electrons are produced at the chamber wall by photoemission. Production efficiency ~ $0.1e^-/\gamma$.
- Electrons are attracted and interacts with the positron beam, then absorbed at the chamber wall after several 10 ns. Secondary electrons are emitted according the circumferences.
- Electrons are supplied continuously for multi-bunch operation with a narrow spacing, therefore electron cloud are formed.
- A wake force is induced by the electron cloud, with the result that coupled bunch instability is caused.

K. Ohmi, Phys. Rev. Lett., 75, 1526 (1995).

First figure for electron cloud build-up

Model



Beam chamber

PRL,75,1526 (1995)

Recipes for electron cloud build-up are written in this paper.

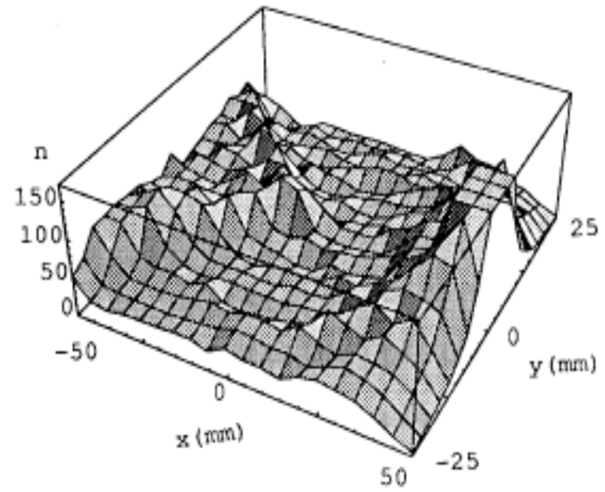


FIG. 2. A stationary distribution of photoelectrons with $\epsilon_0 =$ 5 eV.

direction, the practical density is given by multiplying 2×10^4 by the value from Fig. 2 in cm^{-3}. Typically, if we use 100, as in the figure, the density is 2×10^6 cm^{-3}. We consider the space-charge effect of the electron distribution. The electric field due to the peak distribution, which is a few hundreds in the figures, can be estimated to be ~100 V/m. The field from the beam is ~600 V/m at a distance of 1 cm from the beam center. Thus, when the electron motion is near the beam, the field of the beam is dominant.

Number of produced electrons

Number of photon emitted by a positron par unit meter.

$$Y_\gamma = \frac{5\pi}{\sqrt{3}} \frac{\alpha\gamma}{L}$$

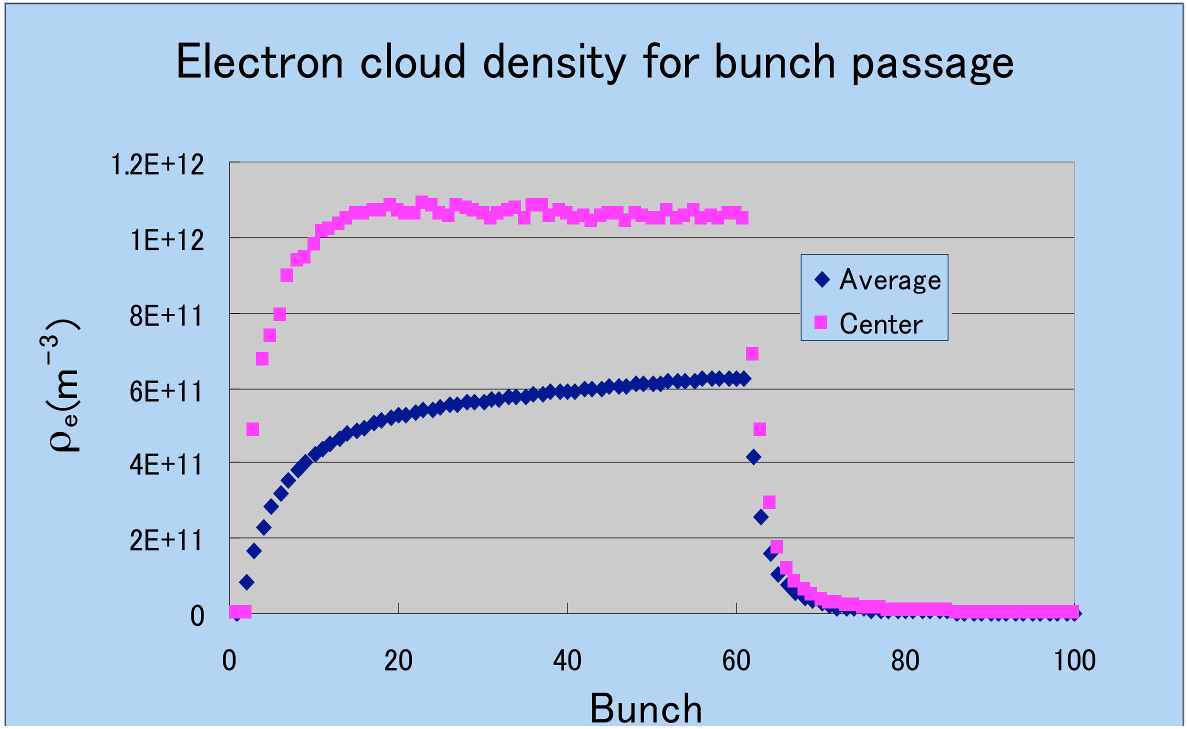
α : fine structure const=1/137

- KEKB-LER γ=6850 → Yγ=0.15/m
- KEK-PF =4892 → Yγ=1.7/m

- Bunch population
  $N_p=3.3\times10^{10}$ （KEKB-LER design 2.6A）
  $N_p=5\times10^{9}$ （KEK-PF 400mA)
- Quantum efficiency ($\eta=n_{p.e.}/n_\gamma$) 0.1
- Energy distribution 10±5 eV

- KEKB-LER $Y_{p.e.}=0.015$ e-/m.e+
- KEK-PF $Y_{p.e.}=0.17$ e-/m.e+ ,
- ionization 10^{-8} e-/m.e+ , proton loss(PSR) 4×10^{-6} e-/m.p

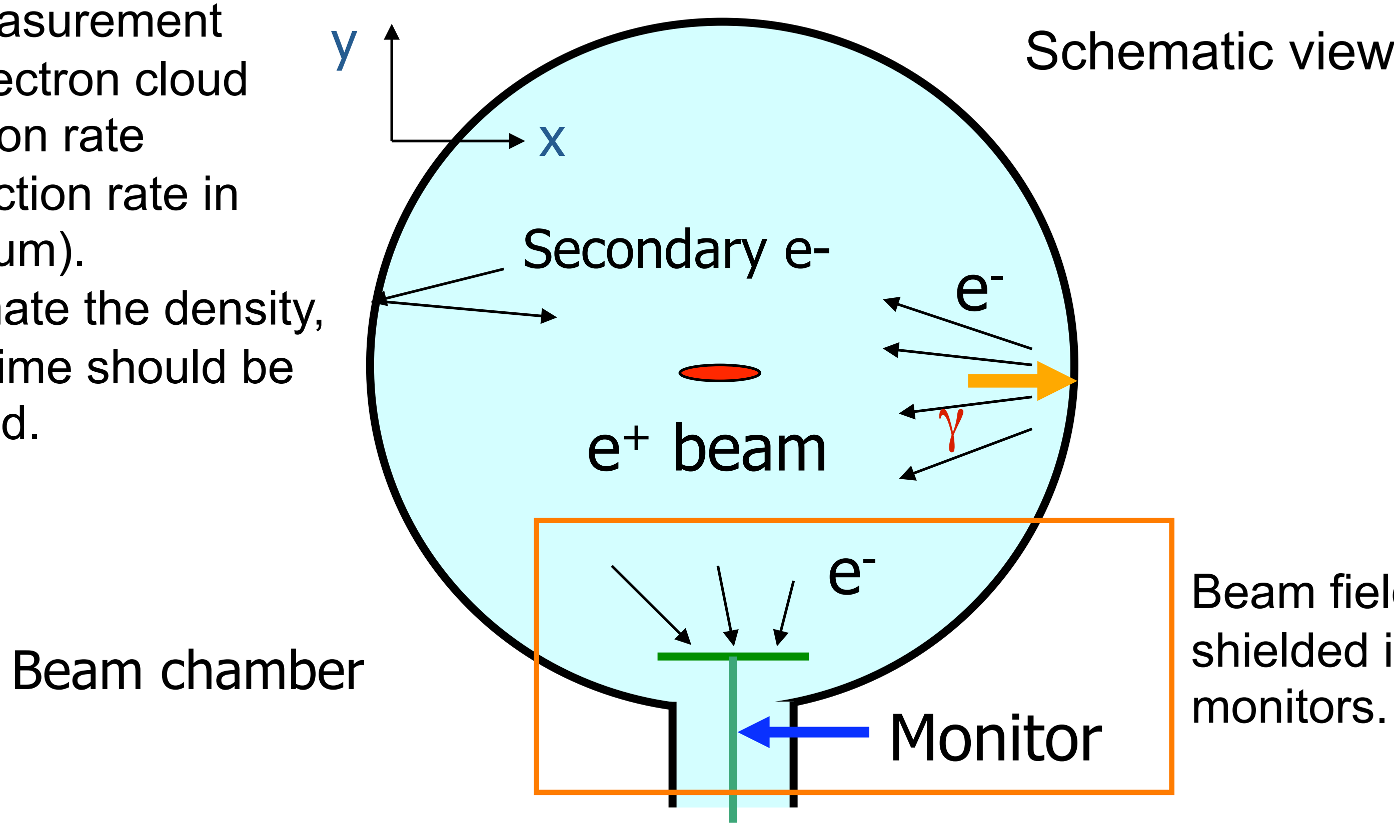
Electron cloud density given by simulation



60 bunches pass in every 8ns (KEKB).

Measurement of electron cloud (Y. Suetsugu, K. Kanazawa et.al.)

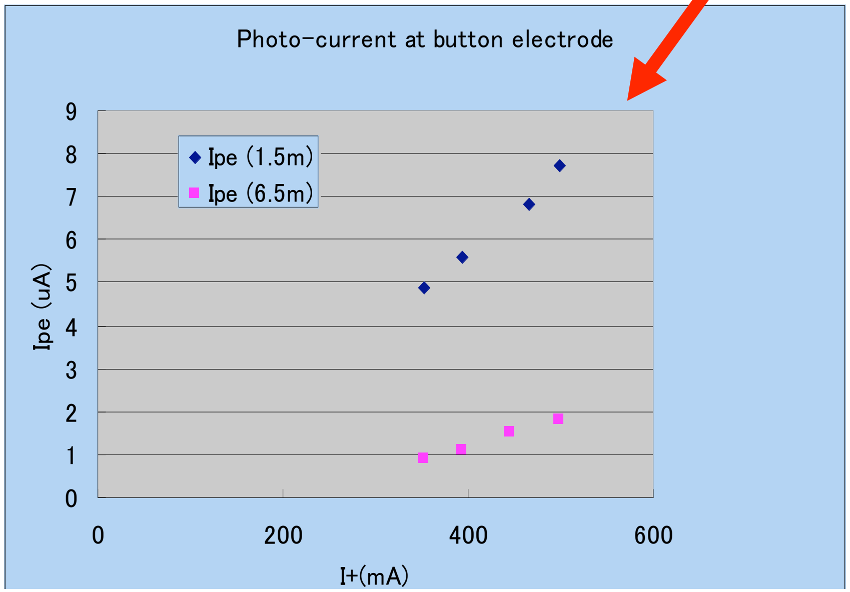
This measurement gives electron cloud absorption rate (=production rate in equilibrium).
To estimate the density, storing time should be multiplied.

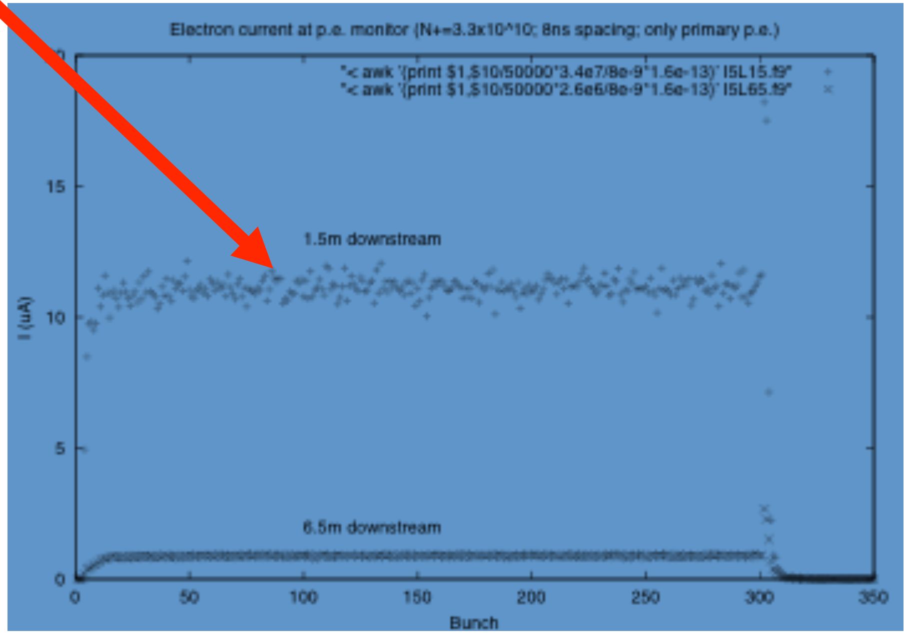


Beam field is shielded in actual monitors.

Experiment and simulation results

I_{pe}=10 μA at I_+=600 mA at 1.5 m down stream of Bend.

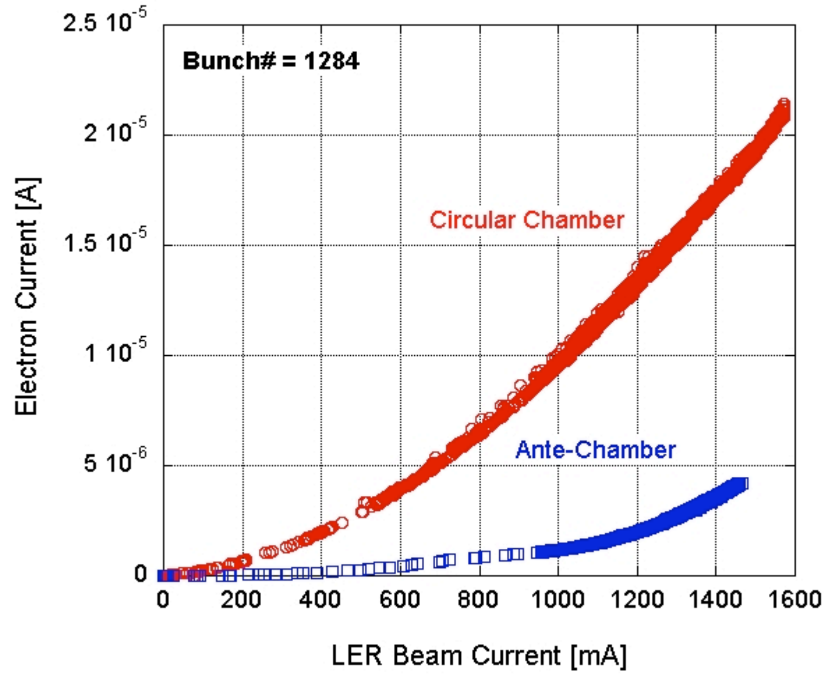




Recent measurement of electron cloud

(not recent but 200*)

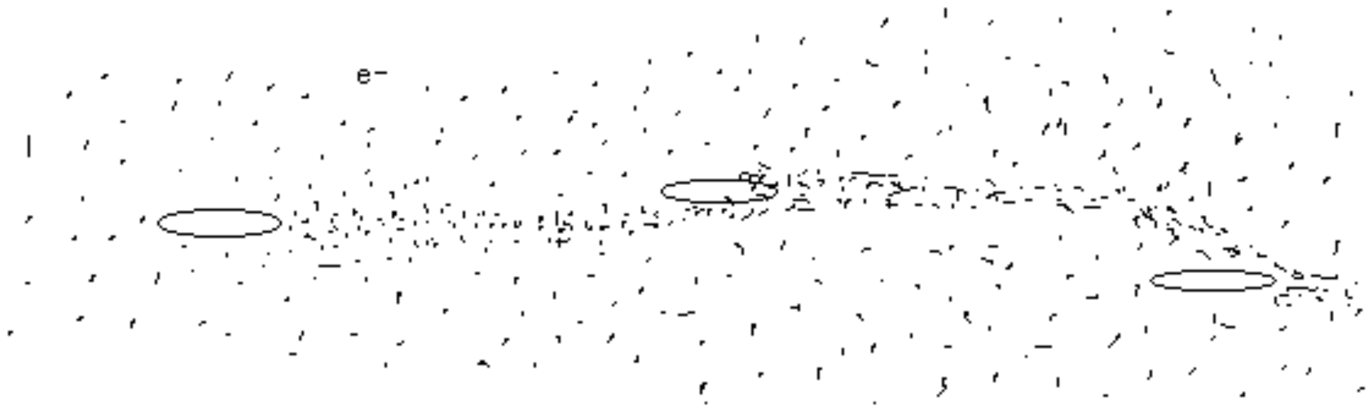
- Electron production rate increase as a function of the beam current. $I_e = k\, I_b^{1.8}$.
- Photoemission, . $I_e = k\, I_b$.
- Index, 0.8 , is due to multipactoring.



Y.Suetsugu, K. Kanazawa

ILC-DR 5GeV 400 mA

Coupled-bunch instability (CBI) caused by the electron cloud



- Wake field is induced by the electron cloud
- Coupled bunch instability due to the wake field causes beam loss.

Wake force and unstable mode for KEK-PF

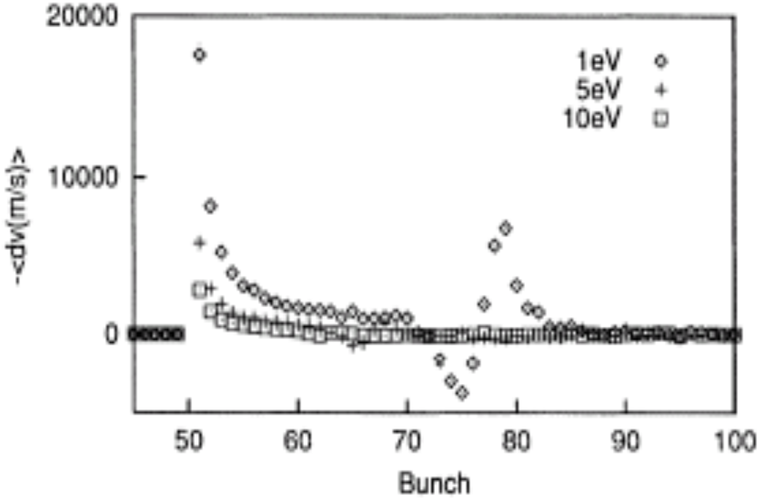


FIG. 3. Wake forces for each initial photoelectron energy. To obtain the wake, 10^6 virtual electrons in every bunch were used.

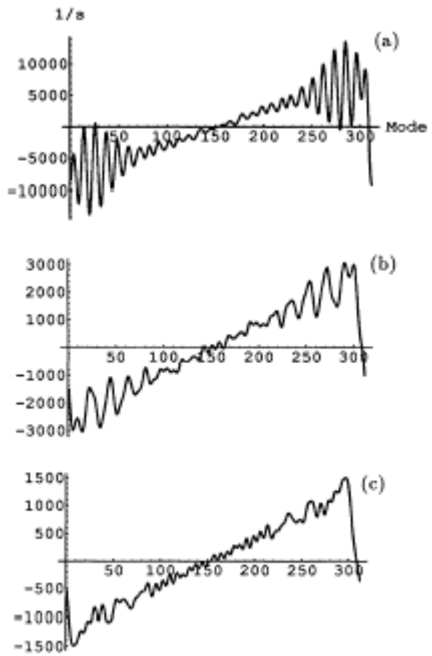


FIG. 4. Growth rates of the coupled-bunch instability. The positive values mean unstable modes. The wakes of 51 to 100 bunches in Fig. 3 were summed with Eq. (8). (a) $\epsilon_0 = 1$ eV. (b) $\epsilon_0 = 5$ eV. (c) $\epsilon_0 = 10$ eV.

Very fast growth of the coupled bunch instability was explained.

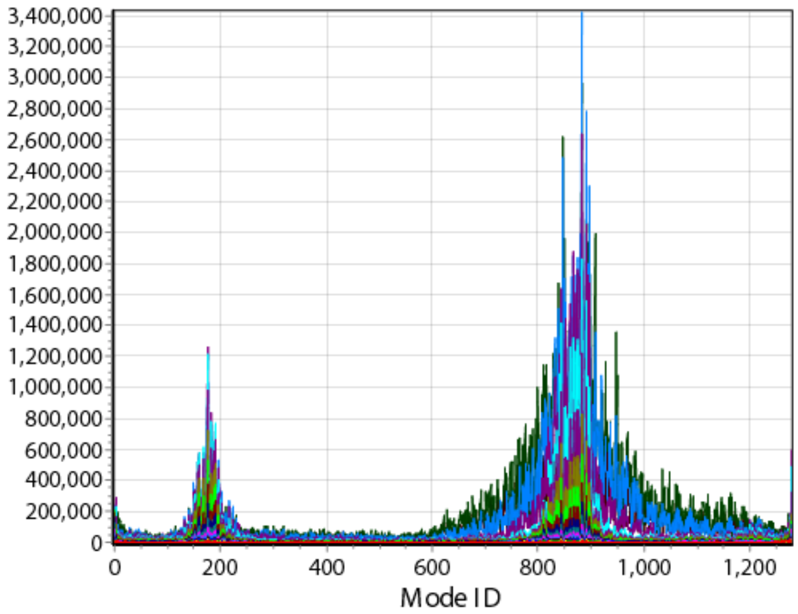
K.Ohmi, PRL,75,1526 (1995)

Measurement of the coupled bunch instability in KEKB

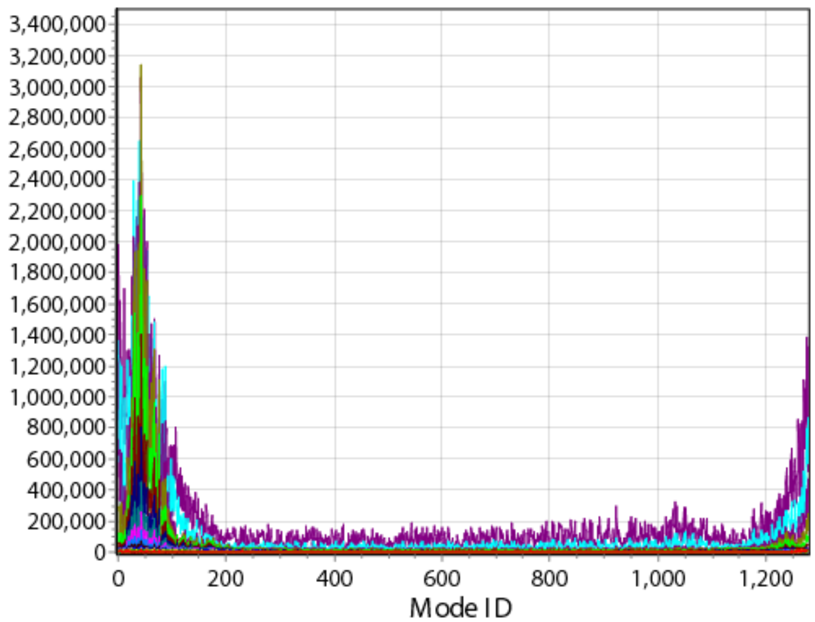
- Fast amplitude growth which causes beam loss has been observed.
- The mode spectrum of the instability depends on excitation of solenoid magnets.

M. Tobiyama et al., PRST-AB (2005)

Solenoid off



on (measurement)



Tracking

K.Ohmi, PRE55,7550 (1997)

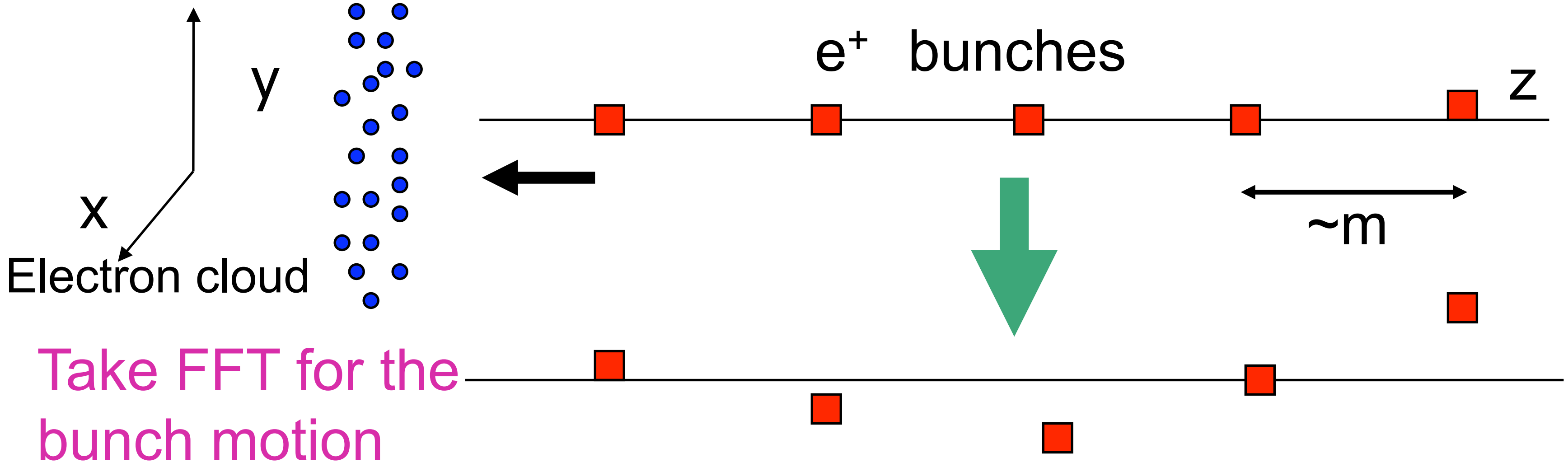
K.Ohmi, PAC97, pp1667.

Solve both equations of beam and electrons simultaneously

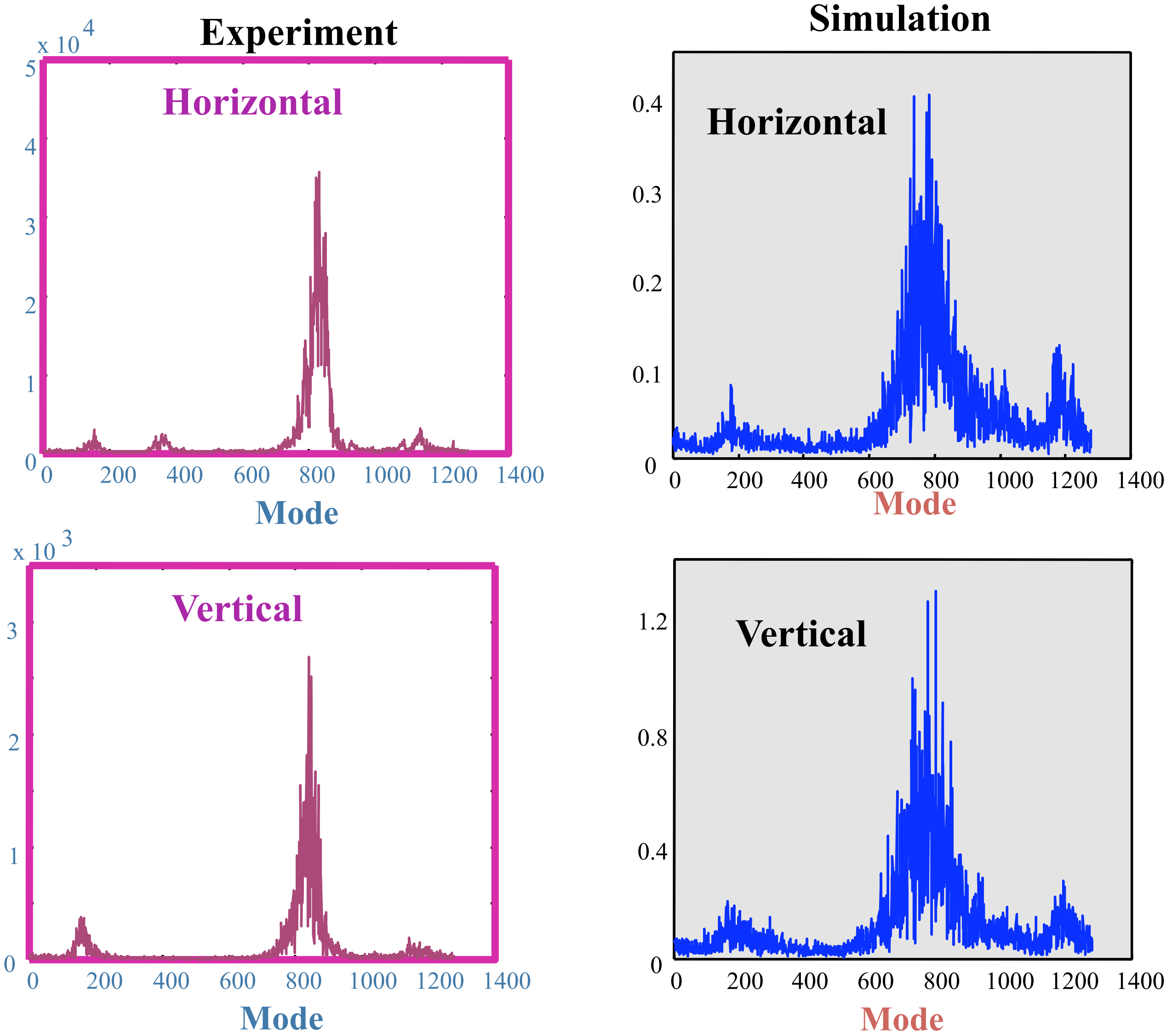
$$\frac{d^2\mathbf{x}_{+,a}}{ds^2} + K(s)\mathbf{x}_{+,a} = \frac{2r_e}{\gamma}\sum_{j=1}^{N_i}\mathbf{F}_G(\mathbf{x}_{+,a} - \mathbf{x}_{e,j};\sigma(s))\delta(s - s_j)$$

$$\frac{d^2\mathbf{x}_{e,a}}{dt^2} = \frac{e}{m}\frac{d\mathbf{x}_{e,a}}{dt}\times\mathbf{B} - 2N_p r_e c\sum_n\sum_{i=1}^{N_b}\mathbf{F}(\mathbf{x}_{e,a} - \mathbf{x}_{p,i})\delta(t - t_i(s_e + nL))$$

$$-r_e c^2\frac{\partial\phi(\mathbf{x}_{e,a})}{\partial\mathbf{x}_{e,a}} \qquad (2)$$



CBI mode spectra in KEKB Solenoid-Off



Bunches are filled every 4 bucket.

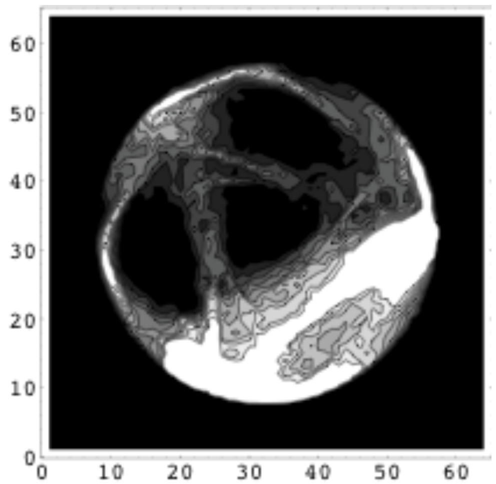
Su Su Win et al,(EC2002)

Effect of Solenoid magnet

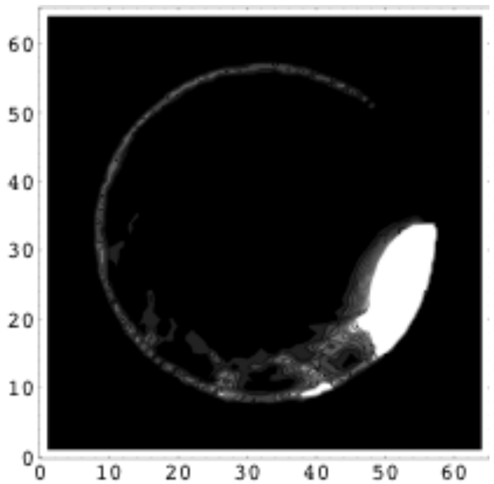
- Solenoid magnets suppress the electron cloud effect partially.
- We can observe electron cloud effect characterized by solenoid magnet.

- Cloud distribution (K. Ohmi, APAC98)

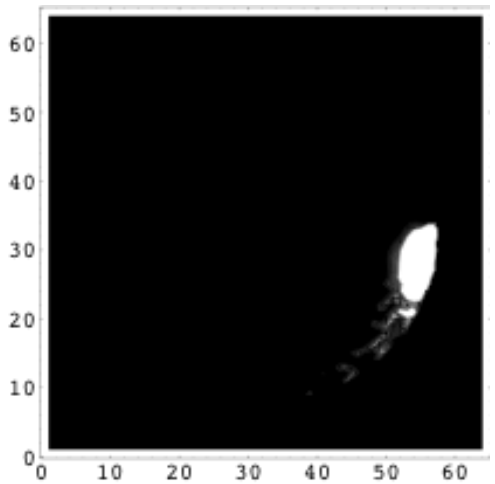
10 G



20 G



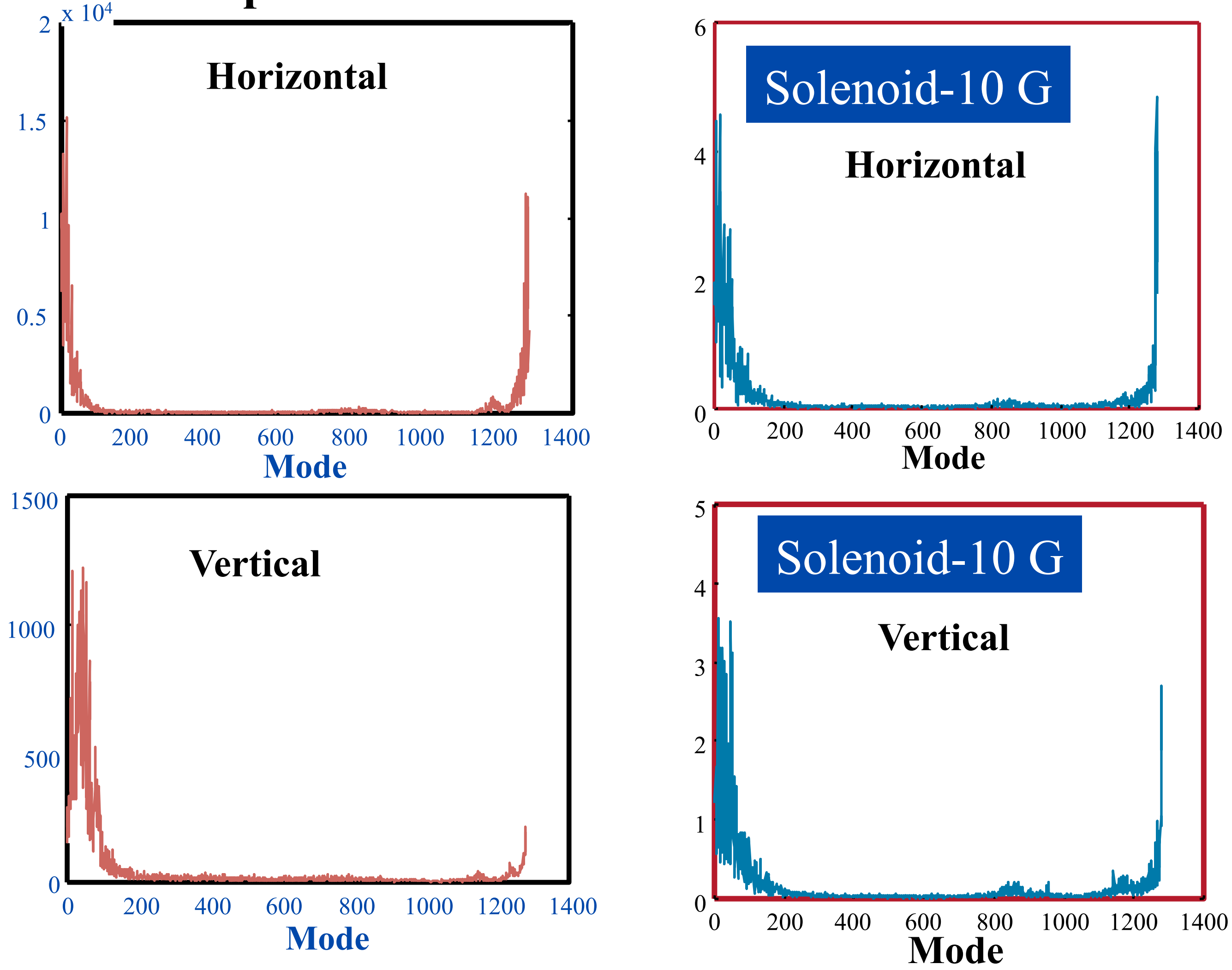
30 G



KEKB

Solenoid-ON

Experiment **Simulation**



Su Su Win et al., EC2002

Single bunch instability

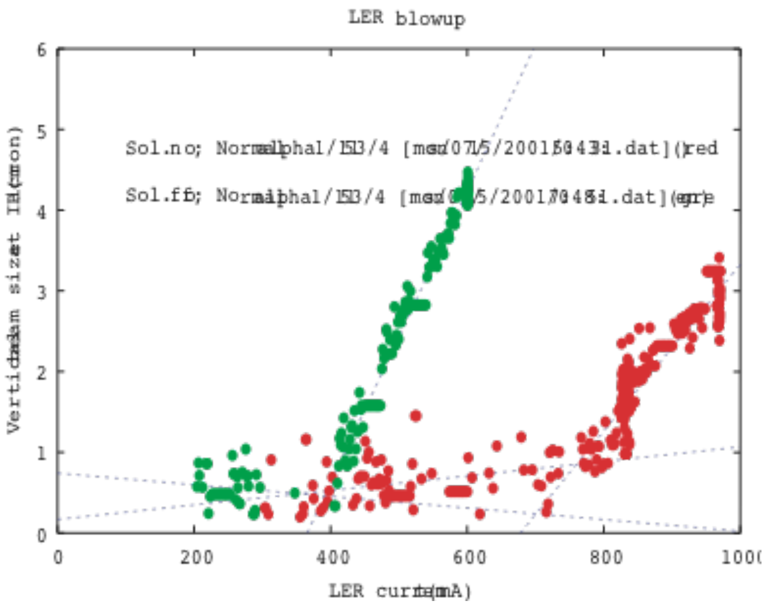
Vertical Beam size blow up of positron beam at commissioning of KEKB

- A beam-size blow-up has been observed above a threshold current. The threshold is given for total current.
- The blow-up was observed in multi-bunch operation, but was perhaps single bunch effect. Beam size was measured by putting a bunch with an arbitrary current in a bunch train.
- Luminosity is limited by the beam size blow-up.

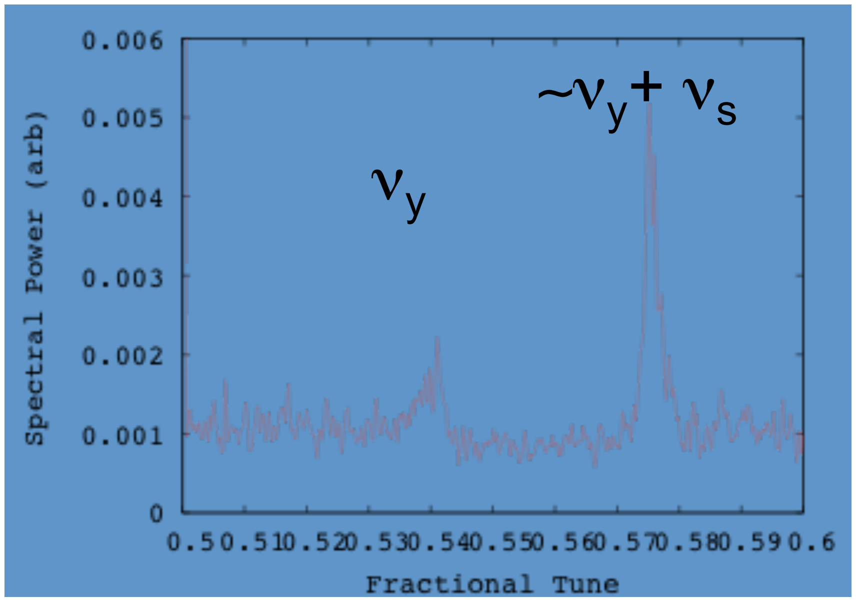
- Synchro-beta sideband induced by electron cloud head-tail instability was observed.

Measurements of the single bunch instability

- Beam size blow-up
- Synchro-beta sideband



Fukuma et al.

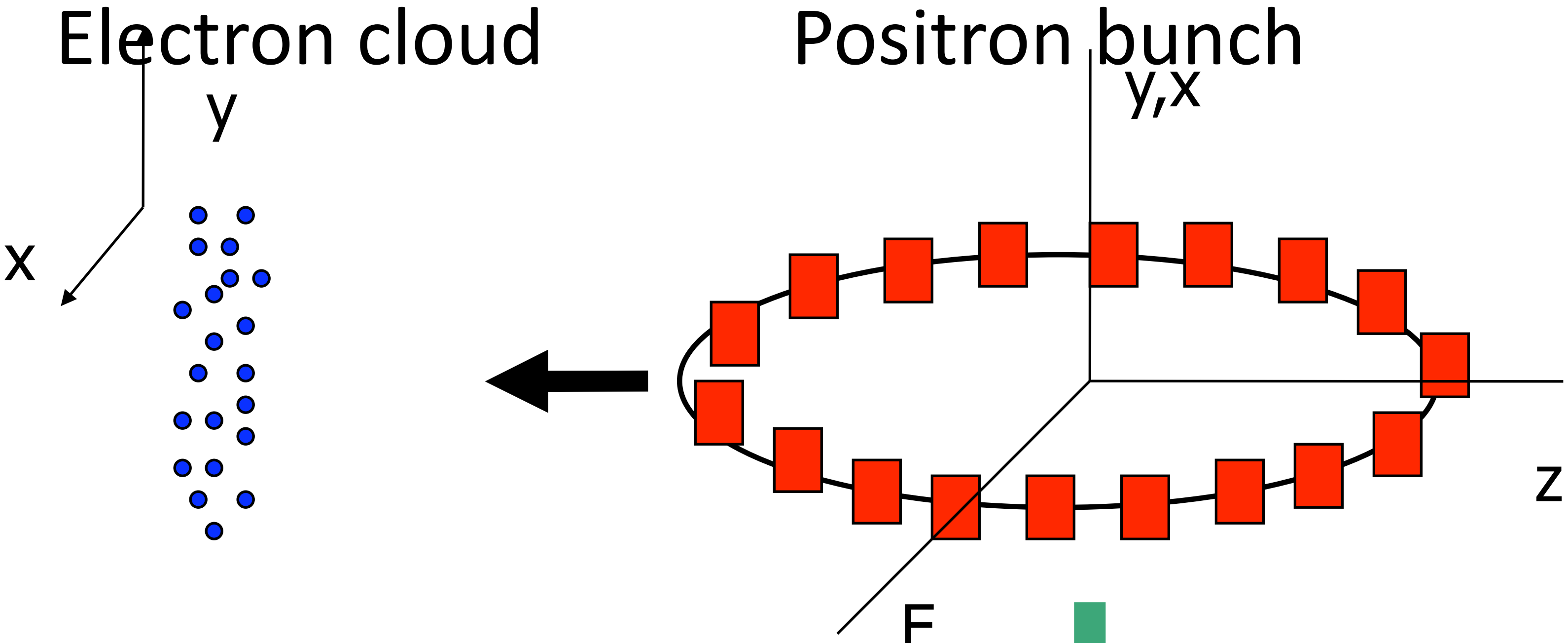


J. Flanagan et al.

Head-tail instability model

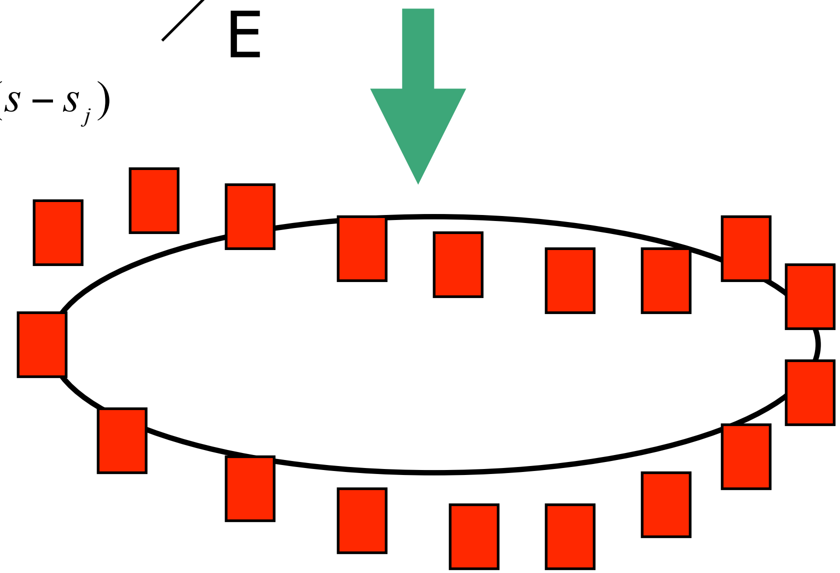
- Simulation using Gaussian model, the same method as the study for CBI.
- Wake field approach, the same as CBI.
- PIC simulation (like beam-beam strong-strong)

Simulation using Gaussian micro-bunch model

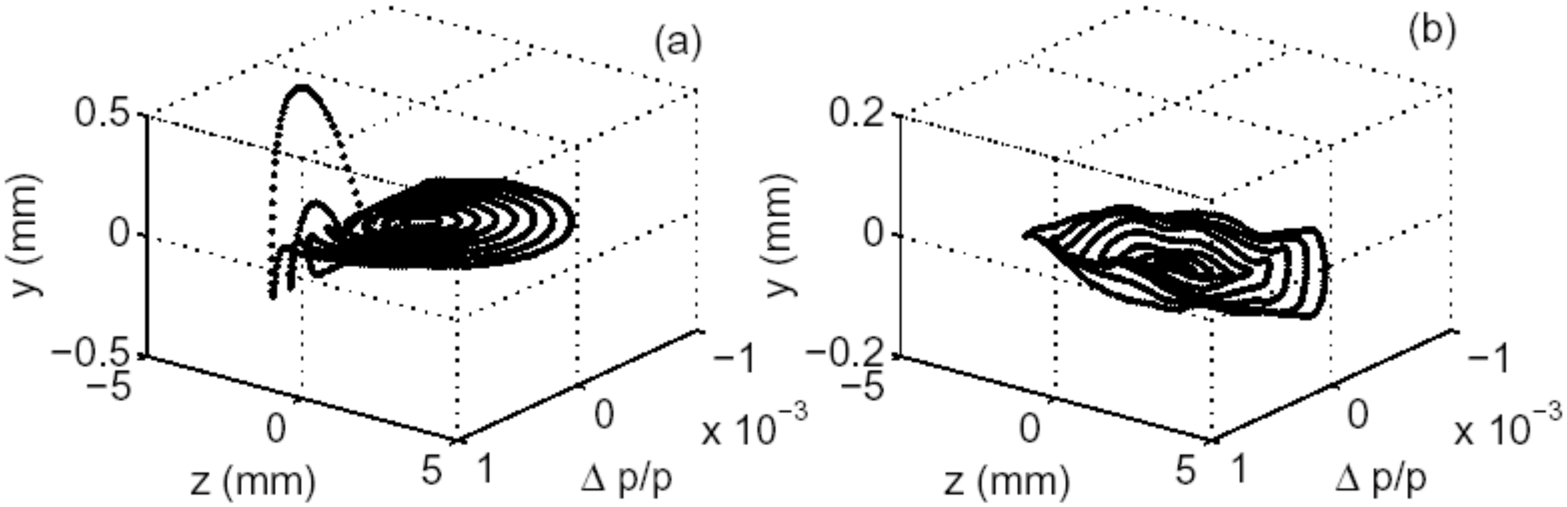


$$\frac{d^2\mathbf{x}_{+,a}}{ds^2} + K(s)\mathbf{x}_{+,a} = \frac{2r_e}{\gamma}\sum_{j=1}^{N_i}\mathbf{F}_G(\mathbf{x}_{+,a}-\mathbf{x}_{e,j};\sigma(s))\delta(s-s_j)$$

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



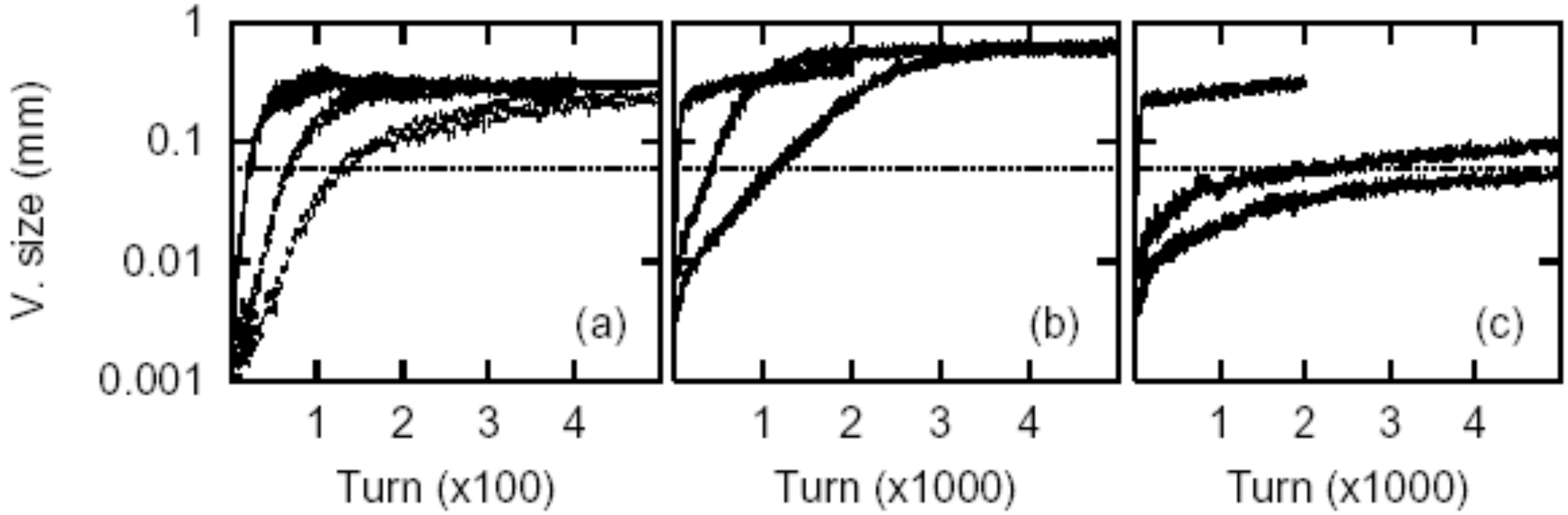
- Bunch head-tail motion w/wo synchrotron motion.



Vertical amplitude of the macro-particles in the longitudinal phase space are plotted. Multi-airbag model (z-δ) is used to visualize in these figures.

K. Ohmi, F. Zimmermann, PRL85, 3821 (2000).

Head-tail and strong head-tail instability



ρ_e=2x10^{11} , 4x10^{11}, 10x10^{11} m^{-3}

- Unstable for Positive chromaticity --- head-tail
- Unstable for ρ_e= 10x10^{11} m^{-3} irrelevant to chromaticity --- strong head-tail

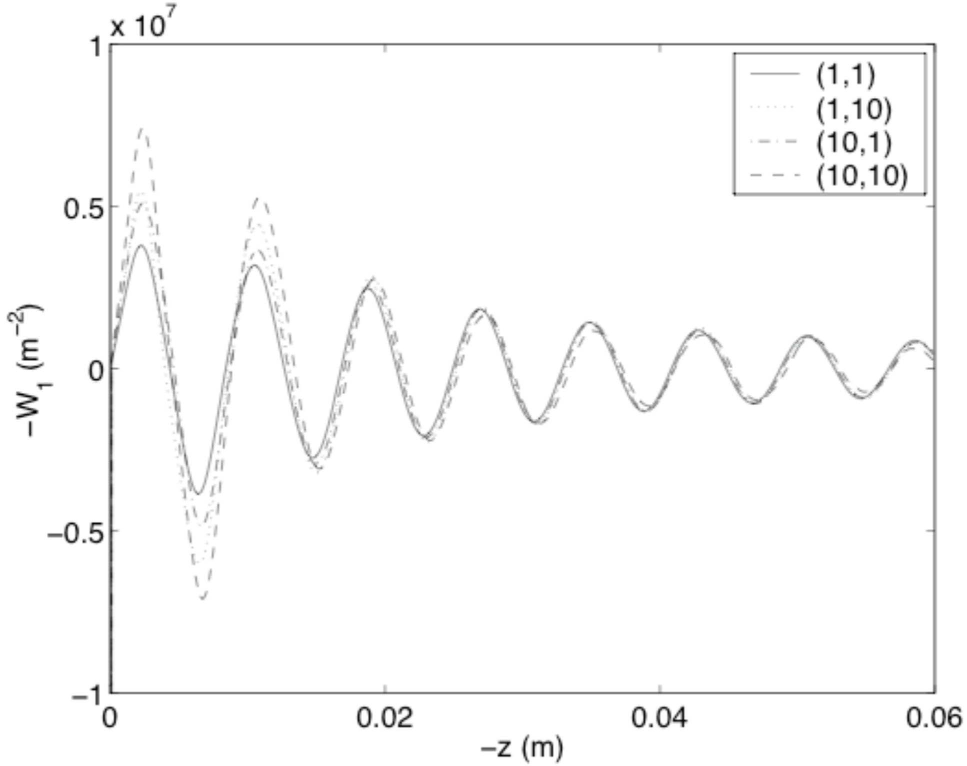
Wake field approach

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

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

K=1 for Linearized model. K~2-3 for the numerical calculation.

Vertical wake field given by the numerical method

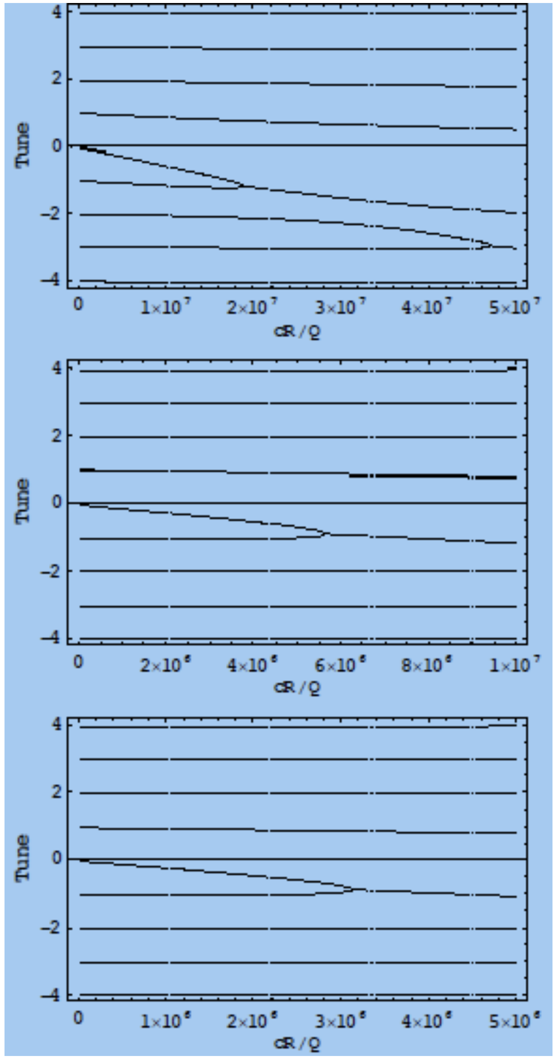


Q=5~10

- (1,1) is consistent with the analytical calculation.
- (10,10) is twice larger than (1,1).
- Instability threshold is calculated by the wake force.

K. Ohmi, F. Zimmermann, E. Perevedentsev, PRE65,016502 (2001)

Threshold of strong head-tail instability



- Mode coupling theory

  Threshold : ρ_e=1-2x10^{12}m^{-3}

- Coasting beam model

$$\rho_{e,th} = \frac{2\gamma\nu_s\,\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L}$$

Q=min(Q_{nl}, $\omega_e\sigma_z$/c)

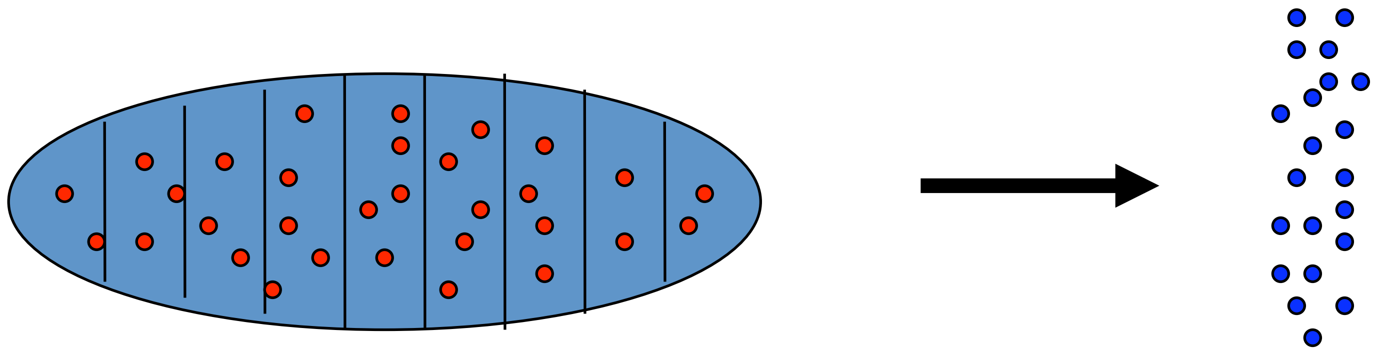
$$\omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}$$

  Threshold : ρ_e=5x10^{11}m^{-3}

- Coasting beam model is better coincident with simulation.

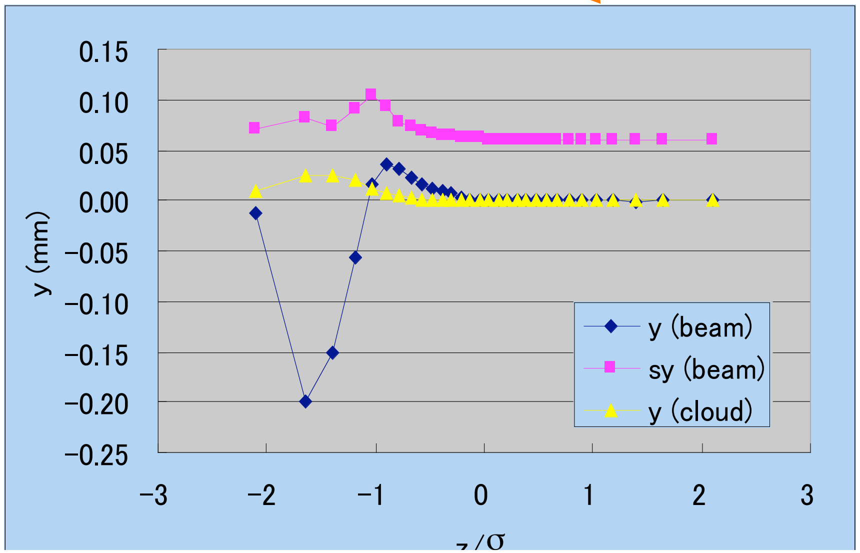
Simulation with Particle In Cell method

- Electron clouds are put at several positions in a ring.
- Beam-could interaction is calculated by solving 2 dimensional Poisson equation on the transverse plane.
- A bunch is sliced into 20-30 pieces along the length.

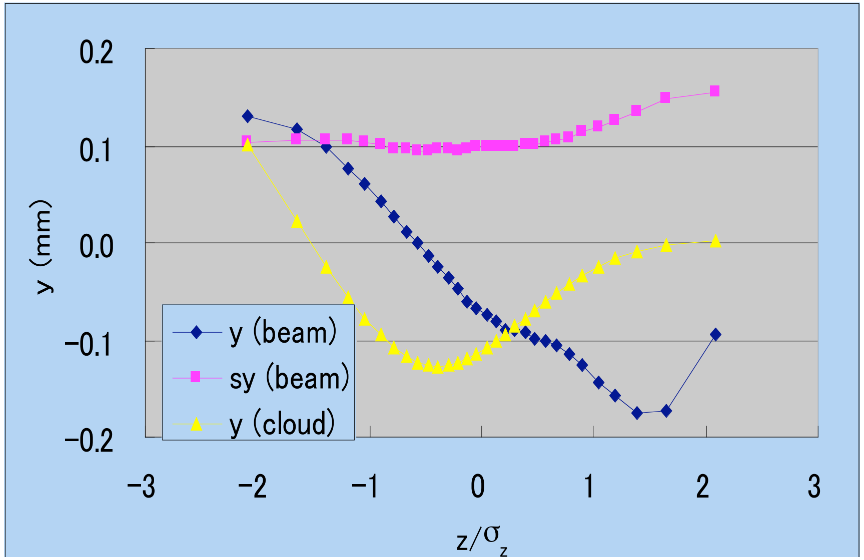


PIC simulation

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



BBU



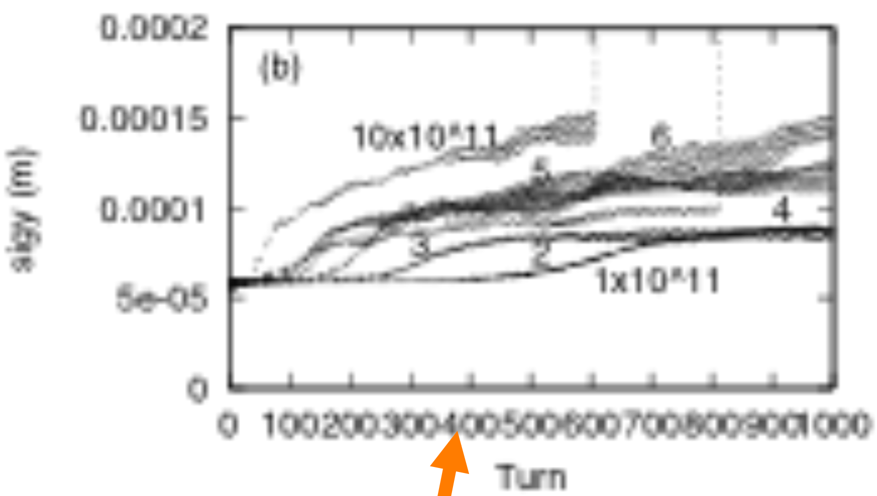
Head-tail motion

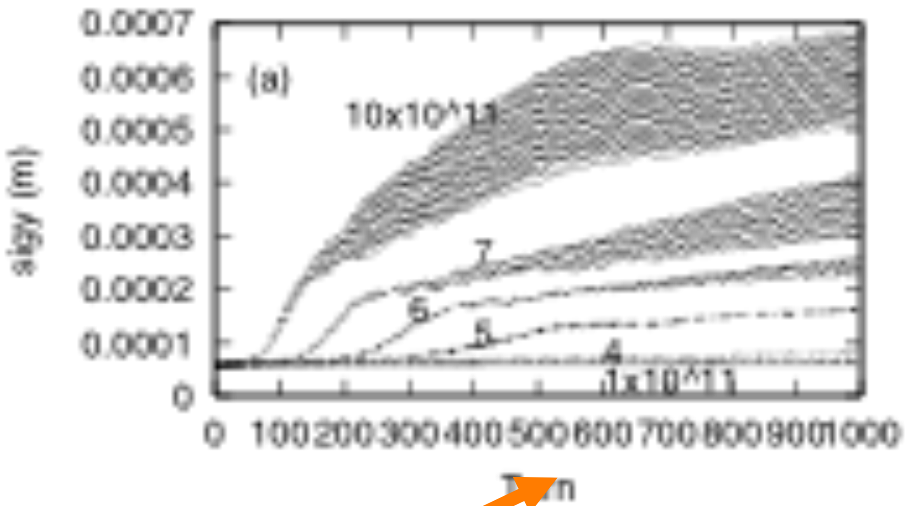
Pink: size along bunch length

yellow: <y> of cloud

Dark blue: <y> of bunch

Threshold behavior





- ν_s=0 no threshold, ν_s>0 clear threshold.
- $\rho_{e,th}=5\text{x}10^{11}\text{m}^{-3}$
- The cloud density is consistent with that predicted by the measurement of electron current.
- This beam size blow-up can be understood as strong head-tail instability caused by electron cloud.

Solenoid winding in KEKB ring

(0) C-yoke permanent magnets are attached in the arc section of ~800m

(1) Solenoids are wound in the arc section of 800m (Sep. 2000).

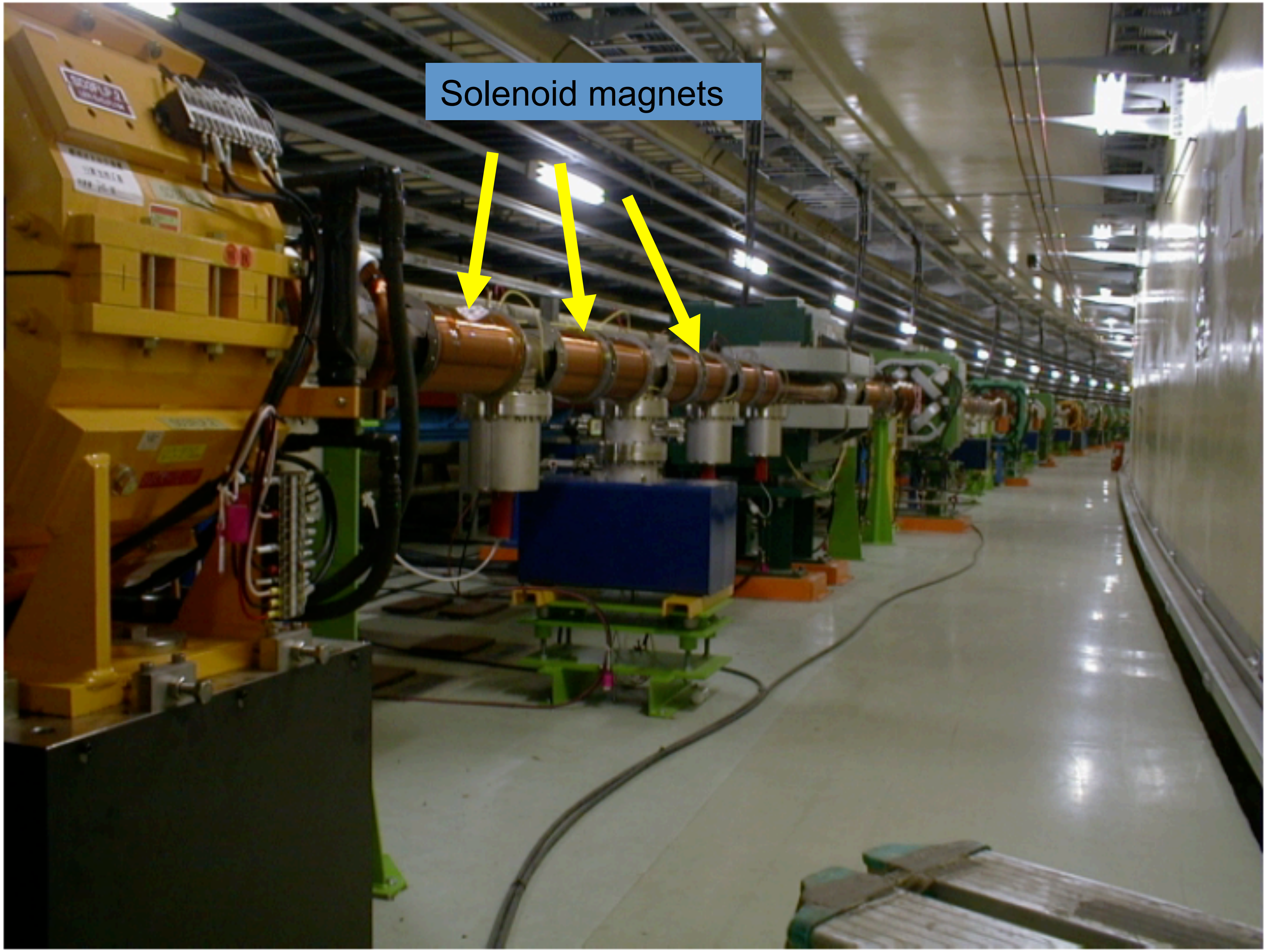
(2) Solenoids are wound additionally in the arc section of 500m (Jan. 2001).

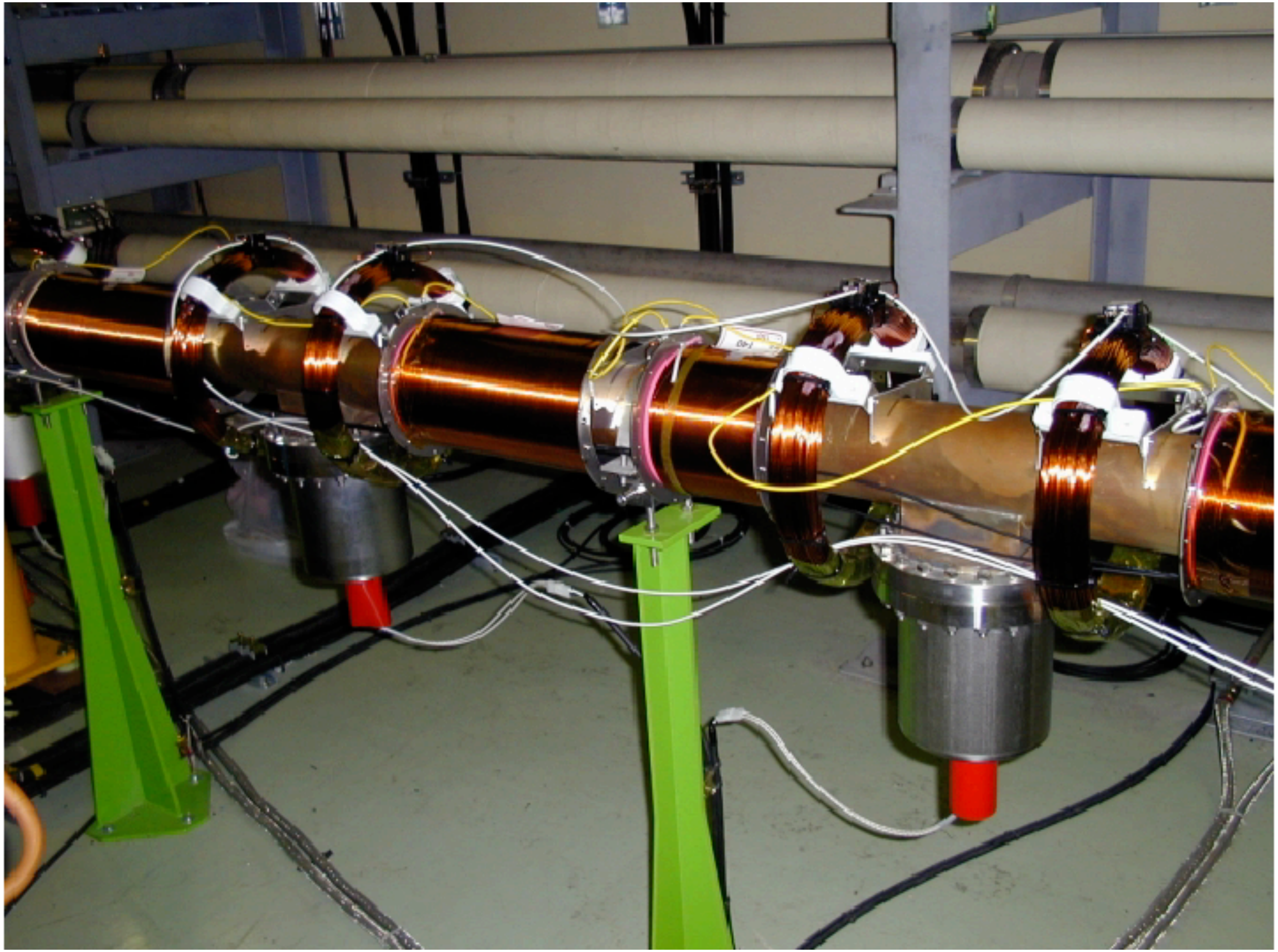
(3) Solenoids are wound in the straight section of *100m (Apr. 2001).

(4) Add solenoids even in short free space (August 2001).

(5) 95 % of drift space is covered (~2005).

(6) Solenoid in ¼ of quadrupole magnets (2005)

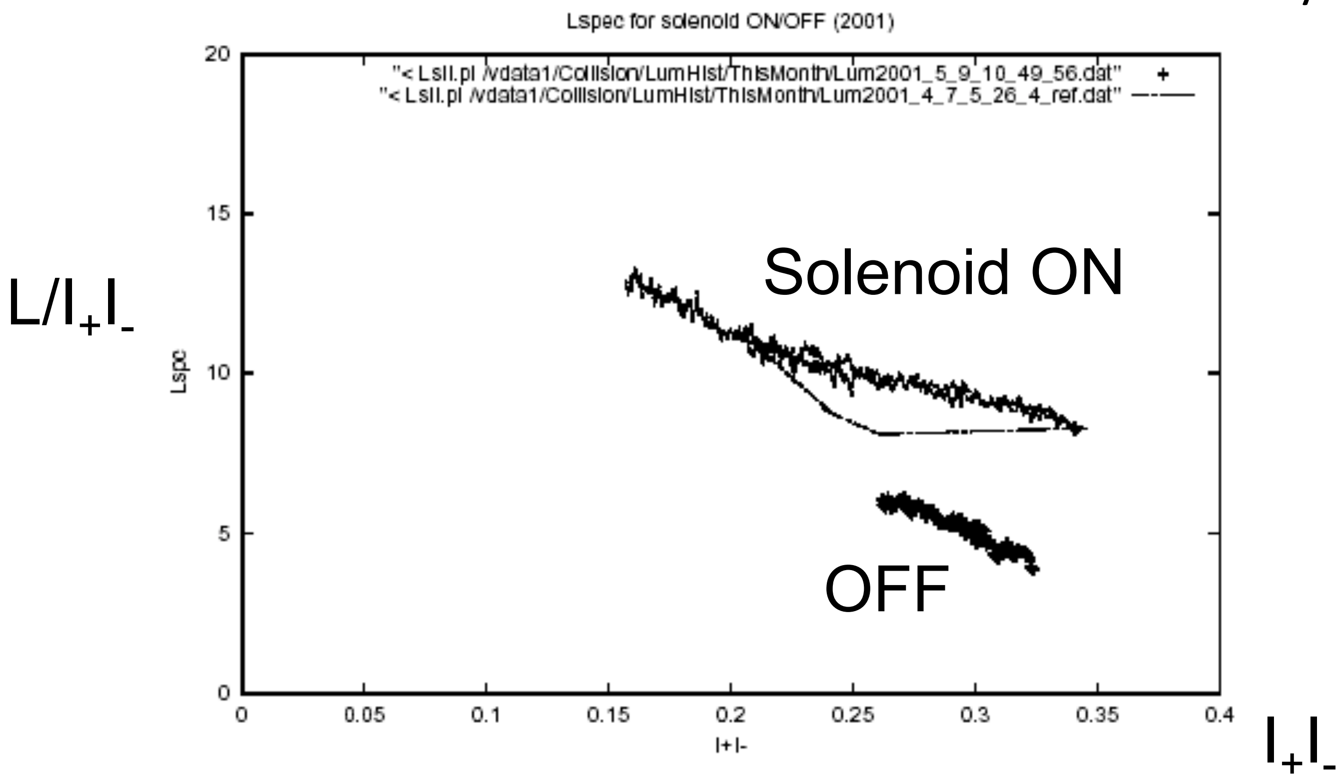

Solenoid magnets



Luminosity for Solenoids ON/OFF

- When solenoids turn off, stored current is limited to a lower value than usual operation due to beam loss (coupled bunch instability).
- Luminosity is quite low (~half).

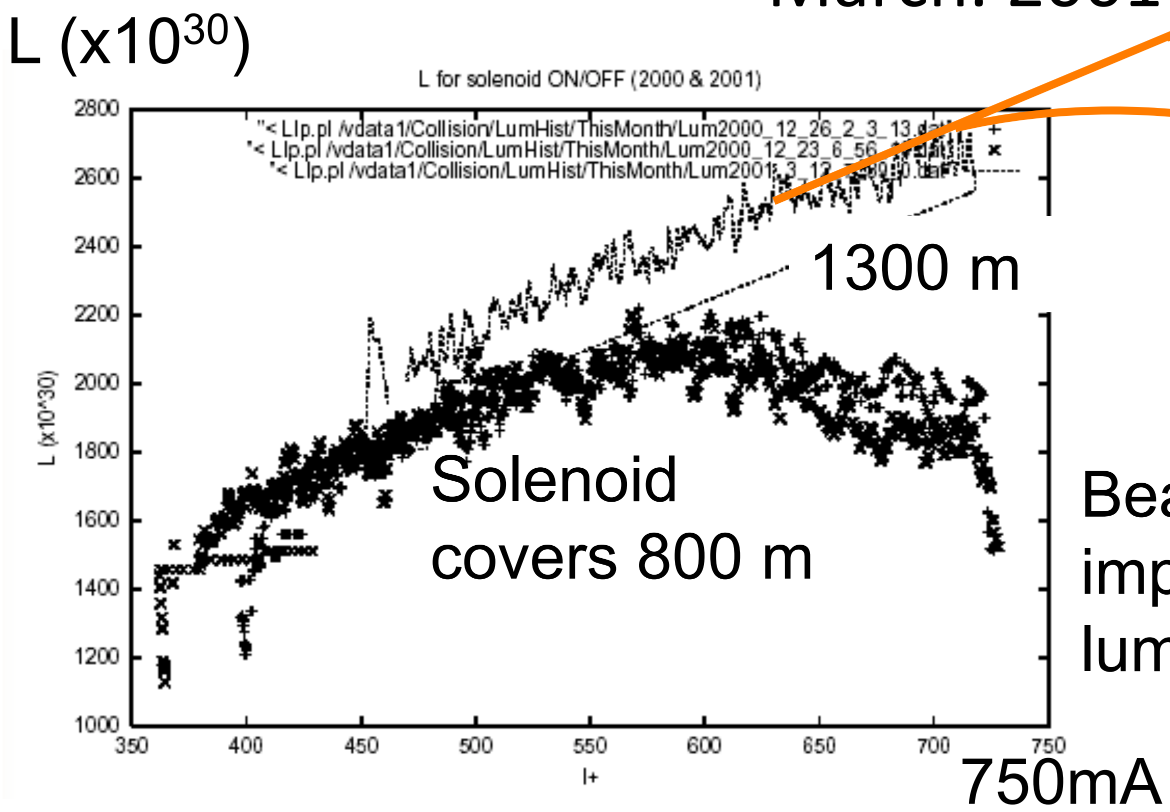
Specific Luminosity for Solenoid ON/OFF (measurement at May.2001)



Effect of additional solenoid

Typical luminosity behavior at Dec. 2000 and March. 2001

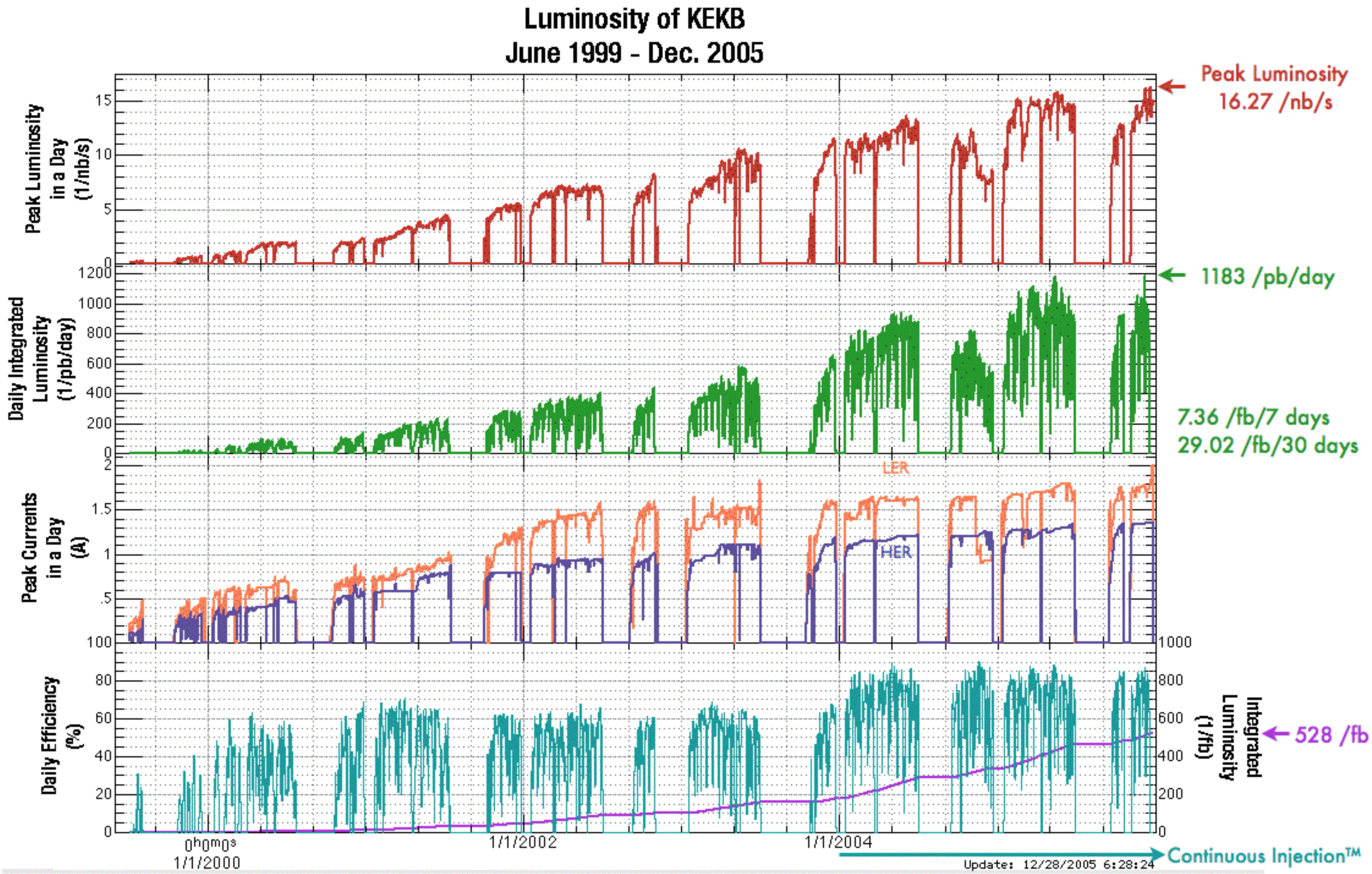
Longer and longer



Beam-beam tuning also improves the luminosity.

- Adding solenoid, positron current with peak luminosity increases.
- Now peak luminosity is given at around 1600-1800 mA.

Luminosity history of KEKB

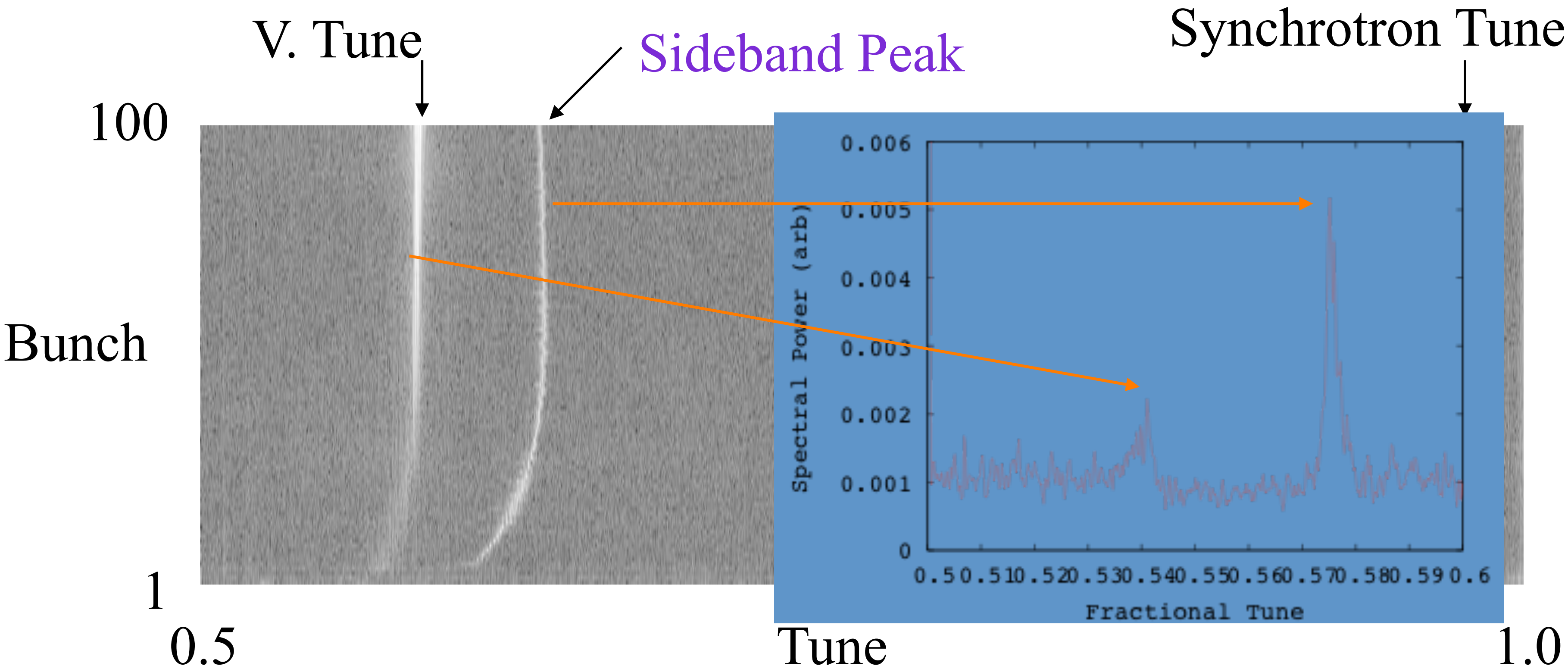


Measurement of synchro-beta sideband - evidence for head-tail instability

- If the beam size blow-up is due to head-tail instability, a synchro-betatron sideband should be observed above the instability threshold.
- The sideband spectra was observed with a bunch oscillation recorder.
- The threshold was consistent with simulations.

- The sideband appear near $\sim\nu_y+\nu_s$, while simulation gives $\sim\nu_y-\nu_s$, like ordinary strong head-tail instability.

Fourier power spectrum of BPM data



- LER single beam, 4 trains, 100 bunches per train, 4 rf bucket spacing
- Solenoids off: beam size increased from 60 μm ->283 μm at 400 mA
- Vertical feedback gain lowered
  - This brings out the vertical tune without external excitationBunch Spacing vs Spec. Lum.Luminosity-bunch current-sideband experiment
- Measure as a function of bunch current.

J. Flanagan et al., PRL94, 054801 (2005)

- Sideband is measured for noncolliding bunch.

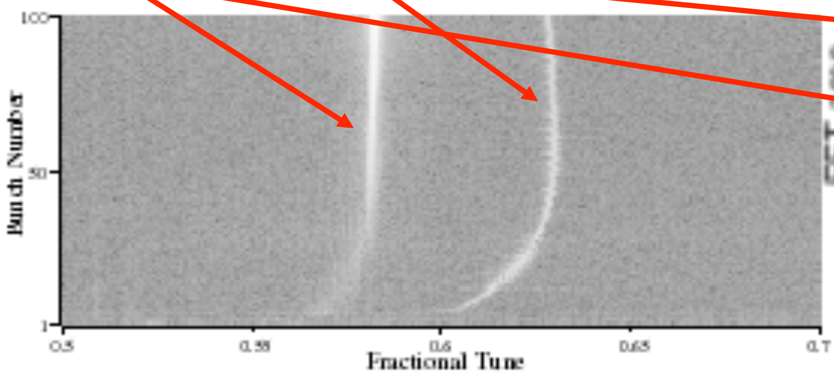
Electron cloud induced head-tail instability

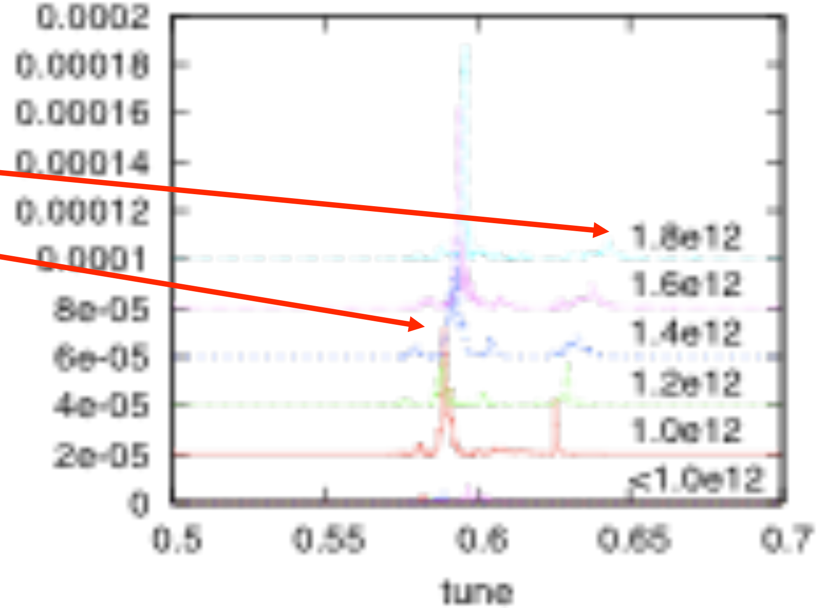
- E. Benedetto, K. Ohmi, J. Flanagan
- Measurement at KEKB

Simulation (PEHTS)
HEADTAIL gives
similar results

Betatron sideband

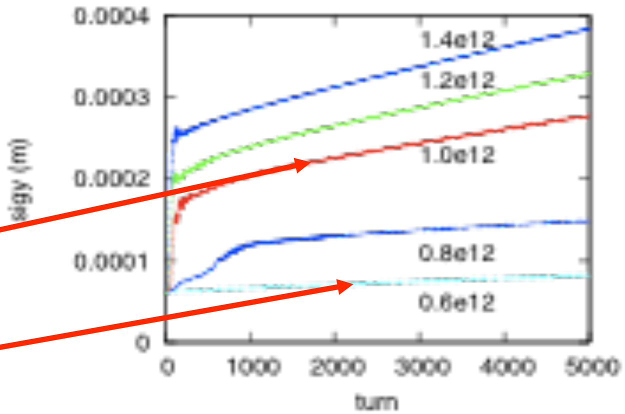
Tail of train





Head of train

FIG. 1. Two-dimensional plot of vertical bunch spectrum versus bunch number. The horizontal axis is the fractional tune, from 0.5 on the left edge to 0.7 on the right edge. The vertical axis is the bunch number in the train, from 1 on the bottom edge to 100 on the top edge. The bunches in the train are spaced 4-rf buckets (about 8 ns) apart. The bright, curved line on the left is the vertical betatron tune, made visible by reducing the bunch-by-bunch feedback gain by 6 dB from the level usually used for stable operation. The line on the right is the sideband.



Head-tail regime

Incoherent regime

Feedback does not suppress the sideband

- Bunch by bunch feedback suppress only betatron amplitude.

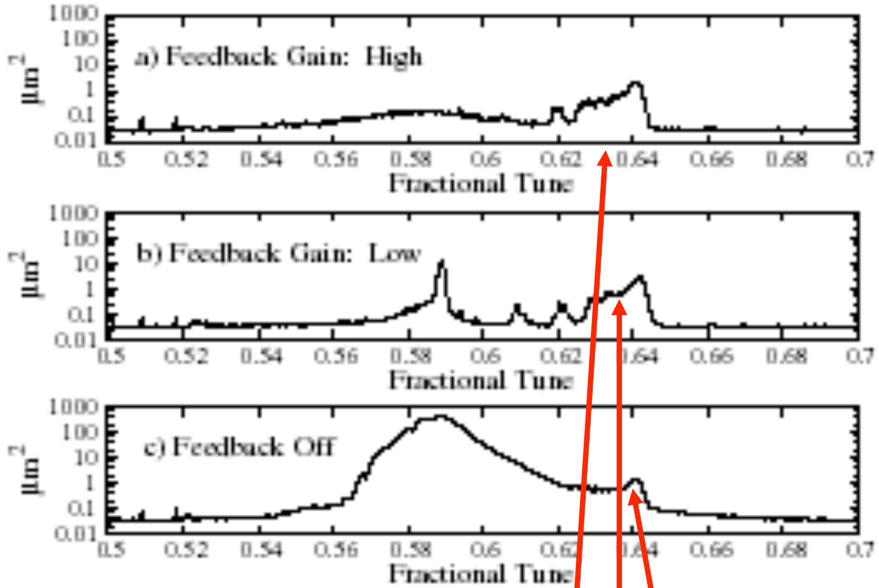
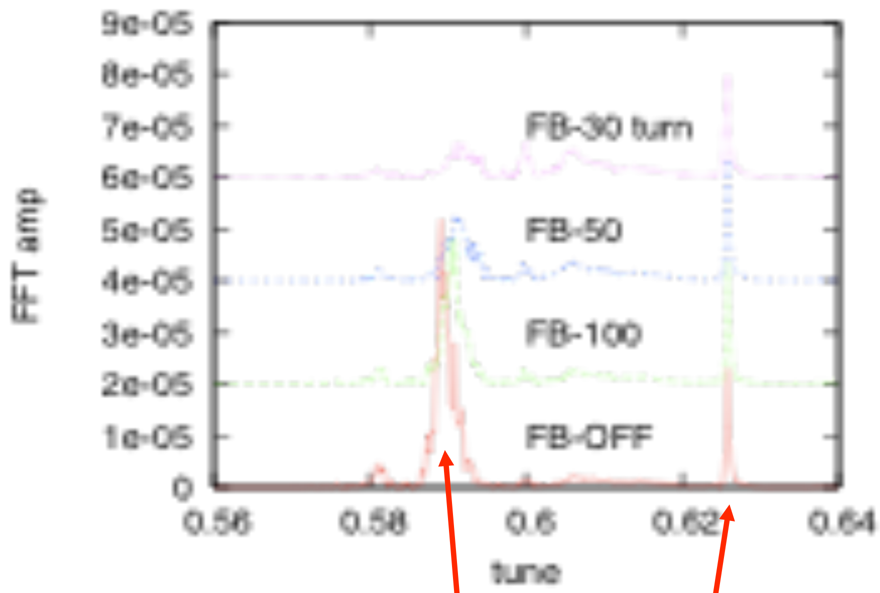


FIG. 2. Averaged spectra of all bunches with the feedback gain (a) high, (b) low, and (c) set to zero. The vertical betatron peak is visible at 0.588, and the sideband peak can be seen around 0.64.



Betatron sideband

Simulation (PEHTS)

Sideband signal is Integrated over the train

Electron cloud effect in CESR, CesrTF and KEKB-lowε

- Tune shift measurement and electron build-up.
- Coupled bunch instability
- Single bunch instability

- Incoherent emittance growth

Number of produced electrons

Number of photon emitted by a positron par unit bending angle.

$$\frac{dY_{pe}}{d\theta} = \frac{5}{2\sqrt{3}}\alpha\gamma \times 0.1(/\mathrm{rad})$$

Quantum eff.=0.1

- CESR 5GeV γ=10000 → Y_{pe}=0.086/m, Ec=3 keV
- Cesr-TF 2GeV (arc) =4000 → Y_{pe}=0.034/m, Ec=100 eV

- Bunch population
  $N_p = 2 \times 10^{10}$
- electrons created by a bunch passage in a meter
  $N_p x Y_{pe} = 1.7 \times 10^9$ (5GeV) 6.8×10^8 (2GeV)

If electrons are accumulated 5 times,

- electron line density (m^{-1}) 8.5×10^9 (5GeV), 3.4×10^9 (2GeV)
- volume density(m^{-3}) 1.7×10^{12} , 6.8×10^{11}
- Corresponding Tune shift 0.0037, 0.0037 (7.4e-4/bunch)
- Beam line density $N_p/4.2 = 4.8 \times 10^9$

Tune shift

- 2nd order moment ($\langle x_e^2 \rangle_c$, $\langle y_e^2 \rangle_c$) of electron cloud distribution gives tune shift., where $\langle x^2 \rangle_c = \langle x - \langle x \rangle \rangle^2$.

$$\mathbf{E} = \frac{\rho e}{\varepsilon_0}\left(\frac{ax}{1+a}\hat{\mathbf{x}} + \frac{y}{1+a}\hat{\mathbf{y}}\right)$$

$$(\Delta\nu_x, \Delta\nu_y) = \frac{r_e}{\gamma}\left(\oint \frac{\rho a}{1+a}\beta_x ds, \oint \frac{\rho}{1+a}\beta_y ds\right)$$

$$a \equiv \left\langle y_e^2 \right\rangle_c \Big/ \left\langle x_e^2 \right\rangle_c$$

$$\Delta\nu_x + \Delta\nu_y = \frac{r_e}{\gamma}\oint \rho_e \beta ds \qquad \text{if } \beta_x \sim \beta_y$$

Tune shift at KEKB

(... ings of Ecloud07)

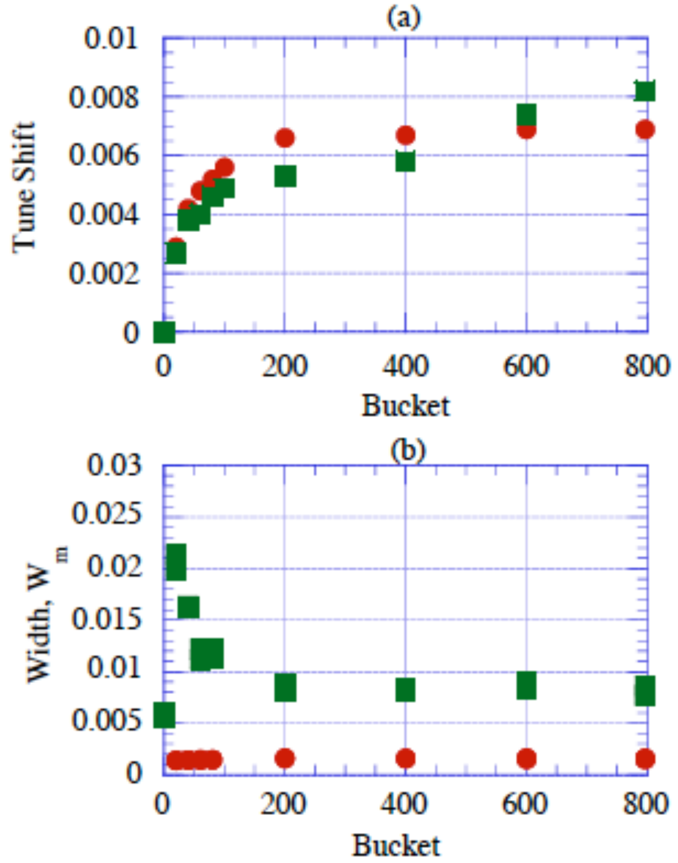


Figure 4: Tune shift (a) and spectrum width (b) along a train. The red dots (horizontal) and green squares (vertical) are measured at a bunch current of 0.5 mA. The tune of the head bunch of the train is used as the reference.

Without solenoid

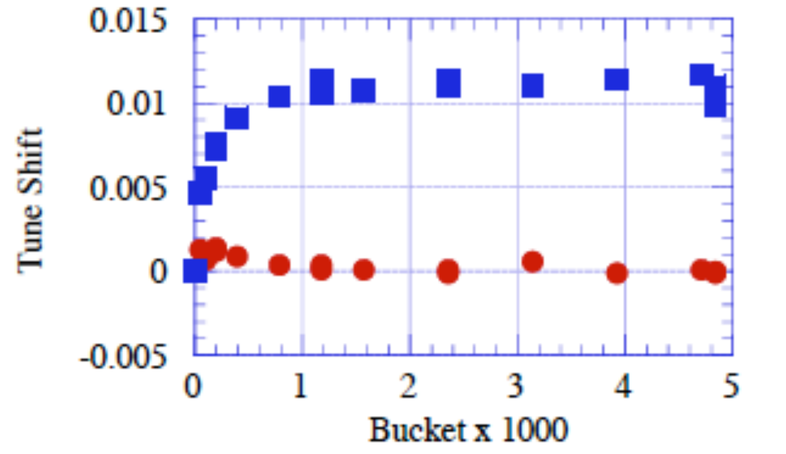


Figure 11: Horizontal (red dots) and vertical (blue squares) tune-shifts along the bunch-train. The bunch current is 1.0 mA with an average spacing of 7 ns.

With solenoid

- Both showed similar density because of $\nu_x+\nu_y$=0.015 and 0.012

Tune shift at CESR

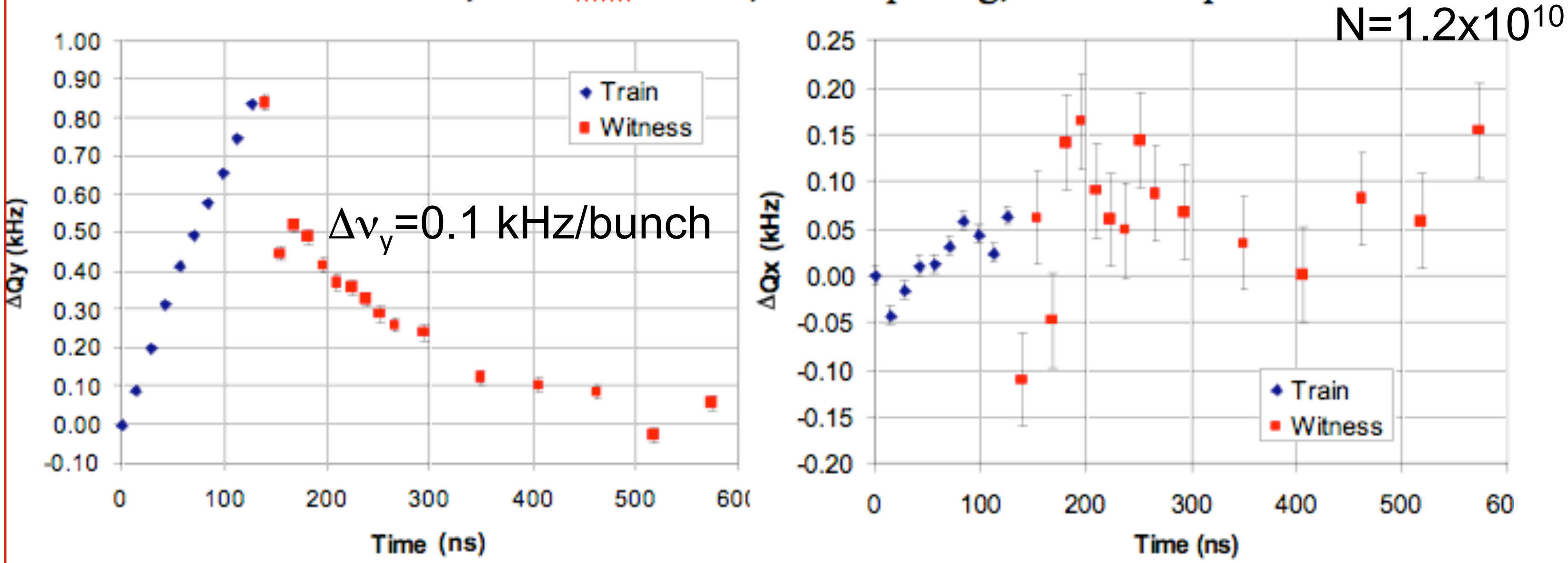
$$\Delta\nu_x + \Delta\nu_y = \frac{r_e}{\gamma}\oint \rho_e \beta ds$$

Cornell University
Laboratory for Elementary-Particle Physics

Witness Bunch Studies – e^+ Vertical Tune Shift

- Initial train of 10 bunches ⇨ generate EC
- Measure tune shift and beamsize for witness bunches at various spacings
- Bunch-by-bunch, turn-by-turn beam position monitor

Positron Beam, 0.75 mA/bunch, 14 ns spacing, 1.9 GeV Operation



Error bars represent scatter observed during a sequence of measurements

1 kHz ⇨ $\Delta\nu$=0.0026
$\rho_e \sim 1.5 \times 10^{11}\ m^{-3}$
Ohmi, etal, APAC01, p.445

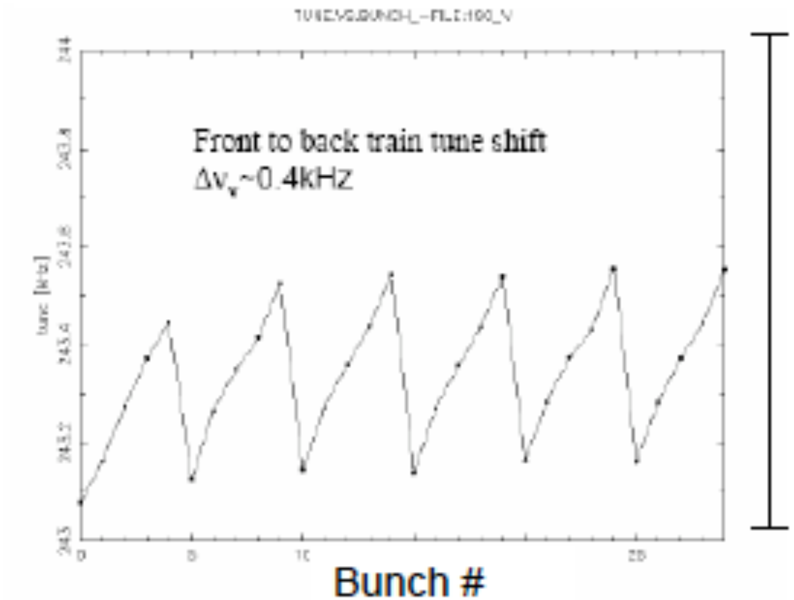
β=30m

Preliminary

Tune shift for 5.3 GeV in CESR

- 5.3 GeV 5 bunch (D. Rice, Sep 06)
- Tune shift is similar as that for 1.9 GeV.
- Cloud density is linear for γ.
- Sign of photoelectron dominant

vertical tune vs. bunch, I = 1 mA



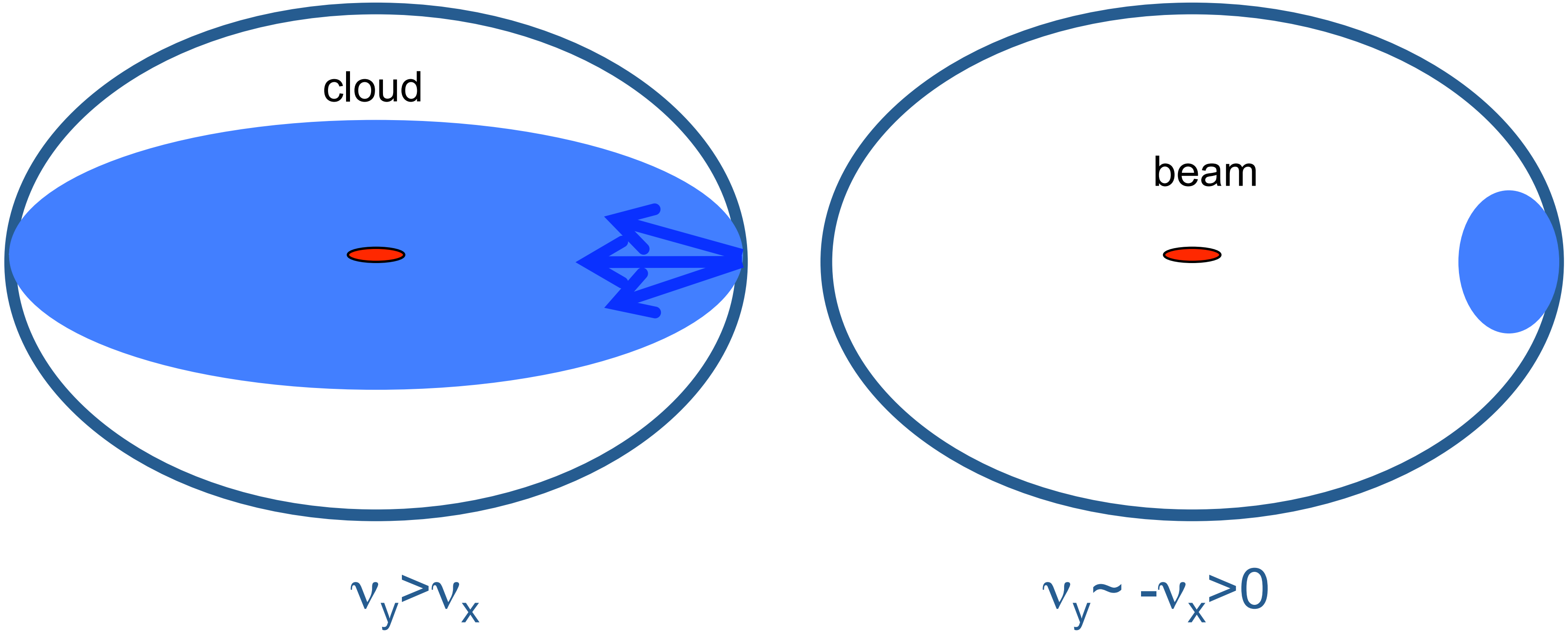
1 kHz

$\Delta\nu_y$=0.1 kHz/bunch

Measured tune shift is 1/3 of the simple estimation

- Maybe reasonable considering magnetic field
- Electron distribution depends on magnetic filed

Straight section | Magnetic field section

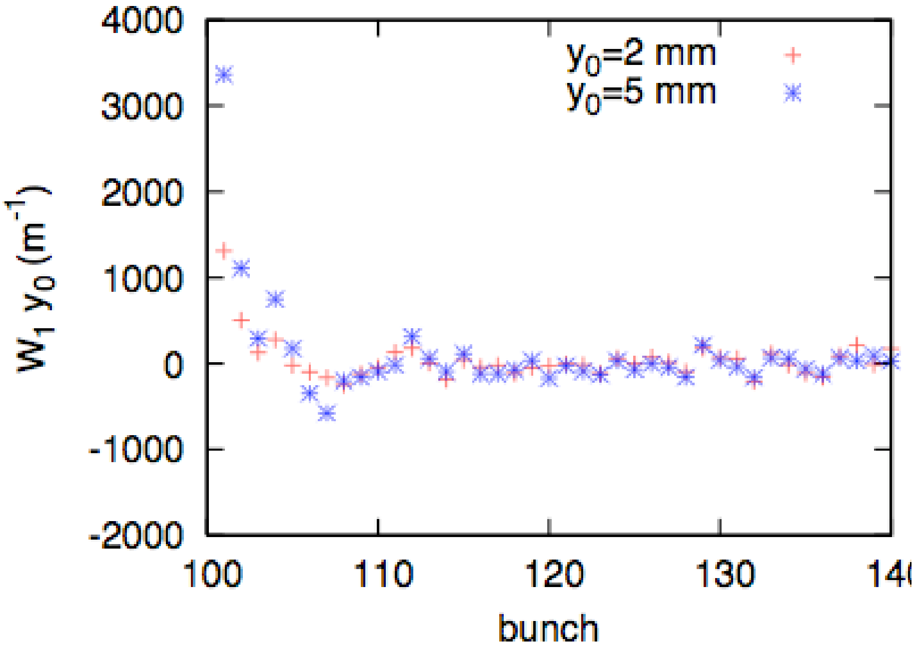


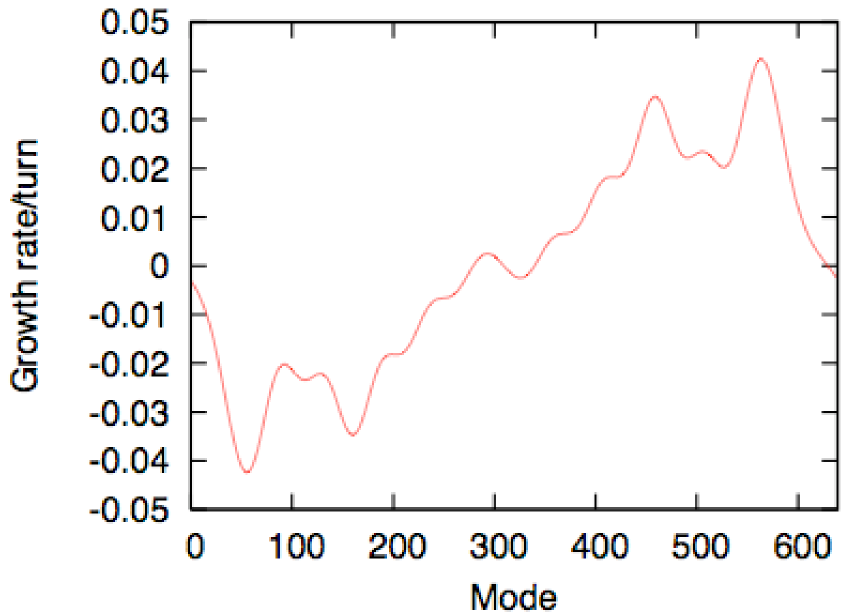
Wiggler section

- 1.3m (1m effective)x12, 2.1T, θ_{tot}=3.78 rad.
- $N_{pe,tot}$=15.9x2x10^{10}=3.2x10^{11} (5.2x10^{11} in arc).
- If the electrons localized in 20 m (for example), electrons are accumulated by N_{pe}=2.6x10^{10} $m^{-1}bunch^{-1}$.
- Beam line density N_p/4.2=4.8x10^9 m^{-1}.
- Electron production and buildup are suppressed by the space charge (neutralization) limit.
- Arc is dominant for the electron cloud tune shift and instabilities in CESR.

Coupled bunch instability

- $Np = 1 \times 10^{10}$, 4 ns spacing.
- Growth time ~25 turn, 64 μsec.





- Since tune shift is 1/3 of the estimation, the growth may be also 1/3.

Threshold of the strong head-tail instability (Balance of growth and Landau damping)

- Stability condition for $\omega_e\sigma_z/c>1$

$$U=\frac{\sqrt{3}\lambda_p r_0\beta}{\nu_s\ \ \gamma\ \ \omega_e\sigma_z/c}\frac{\left|Z_\perp(\omega_e)\right|}{Z_0}=\frac{\sqrt{3}\lambda_p r_0\beta}{\nu_s\ \ \gamma\ \ \omega_e\sigma_z/c}\frac{KQ}{4\pi}\frac{\lambda_e}{\lambda_p}\frac{L}{\sigma_y(\sigma_x+\sigma_y)}=1$$

- Since $\rho_e=\lambda_e/2\pi\sigma_x\sigma_y$,

$$\rho_{e,th}=\frac{2\gamma\nu_s\,\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L}$$

Origin of Landau damping is momentum compaction

- $Q=\min(Q_{nl},\ \omega_e\sigma_z/c)$ $Q_{nl}=7$ is used.
- K characterizes cloud size effect and pinching.
- $\omega_e\sigma_z/c$~12-15 for damping rings.
- We use $K=\omega_e\sigma_z/c$ and $Q_{nl}=7$ for analytical estimation.

Threshold for various rings

	KEKB	KEKB	KEKB-DRt	CesrTF	ILC-OCS	PEPII
L	3016	3016	3016	768.44	6695	2200
gamma	6849	6849	4501	3914	9785	6067
Np	3.30E+10	7.60E+10	2.00E+10	2.00E+10	2.00E+10	8.00E+10
ex	1.80E-08	1.80E-08	1.50E-09	2.30E-09	5.60E-10	4.80E-08
bx	10	10	10	10	30	10
ey	2.16E-10	2.16E-10	6.00E-12	5.00E-12	2.00E-12	1.50E-09
by	10	10	10	10	30	10
sigx	4.24E-04	4.24E-04	1.22E-04	1.52E-04	1.30E-04	6.93E-04
sigy	4.65E-05	4.65E-05	7.75E-06	7.07E-06	7.75E-06	1.22E-04
sigz	0.006	0.007	0.009	0.009	0.006	0.012
nus	0.024	0.024	0.011	0.098	0.067	0.025
Q	3.6	5.9	7	7	7	3.7
omegae	1.79E+11	2.51E+11	5.29E+11	5.01E+11	6.31E+11	9.20E+10
phasee	3.6	5.9	15.9	15.0	12.6	3.7
K	3.6	5.9	15.9	15.0	12.6	3.7
rhoeth	6.25E+11	3.81E+11	9.60E+10	2.92E+12	1.91E+11	7.67E+11

Tune shift at the threshold

	KEKB	KEKB	KEKB-DRt	CesrTF	ILC-OCS	PEPII
L	3016	3016	3016	768.44	6695	2200
gamma	6849	6849	4501	3914	9785	6067
Np	3.30E+10	7.60E+10	2.00E+10	2.00E+10	2.00E+10	8.00E+10
rhoeth	6.25E+11	3.81E+11	1.22E+11	4.76E+12	1.91E+11	7.67E+11
dnx+y@th	0.0078	0.0047	0.0023	0.0263	0.0111	0.0078
DampT-xy	40	40	75	56.4	26	40
DampR-xy	2.51E-04	2.51E-04	1.34E-04	4.54E-05	8.58E-04	1.83E-04

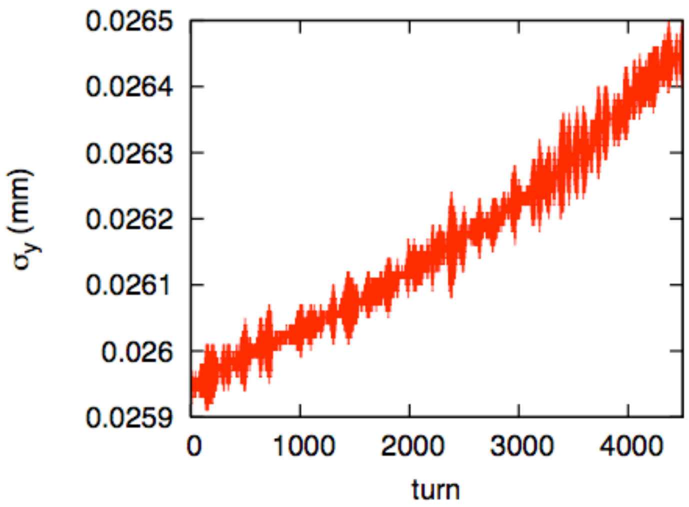
Incoherent emittance growth

- Mechanism: Nonlinear diffusion related to resonances and chaos
- The diffusion rate and the radiation damping time

- For an incoherent effect, beam size measurement without current dependence is necessary.
- It seems to be difficult in present KEKB tool.

Incoherent emittance growth below the threshold of the fast head-tail at KEKB-lowe and OCS

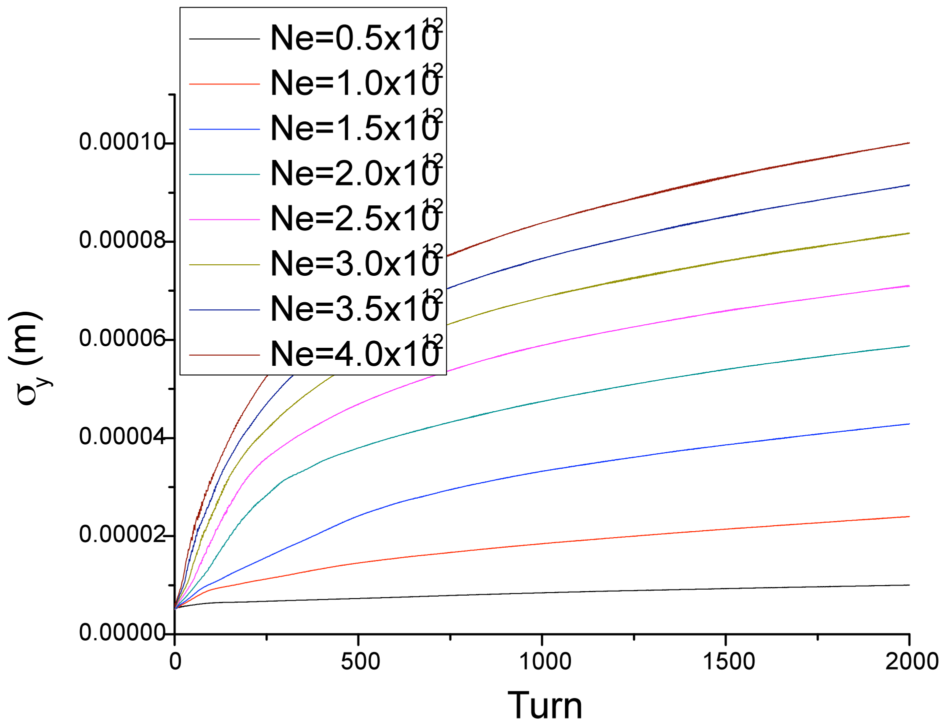
- OCS arc lattice is used for KEKB.
- $\rho_e = 3\text{x}10^{10}\ m^{-3}$ ($\rho_{e,th} = 1\text{x}10^{11}\ m^{-3}$)



- $\Delta\sigma_y/\sigma_y = 5.7\text{x}10^{-6} << 1/\tau_y = 2.5\text{x}10^{-4}$
- Incoherent effect was negligible for KEKB in this condition.

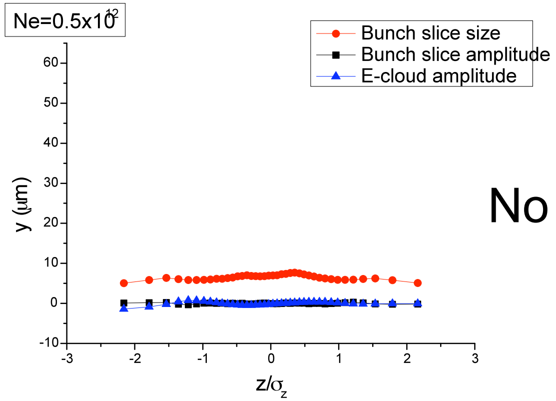
Incoherent emittance growth at Cesr-TF

- For high $\nu_s(\alpha)$ ring, coherent instability is strongly suppressed. Incoherent effect may be enhanced relatively.
- CESR (ν_s =0.098, α=6.4x10^{-3})
- The incoherent growth is faster than radiation damping time at ρ_e=1x10^{12} m^{-3}.

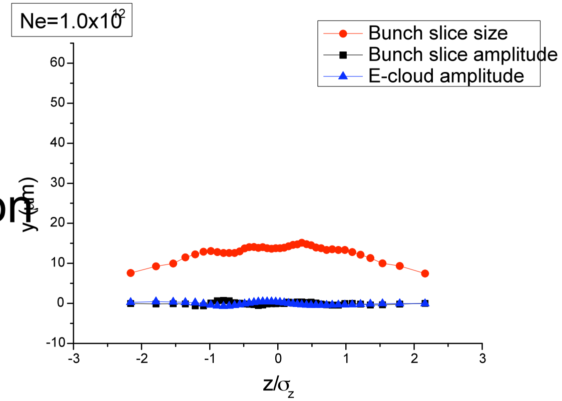


By H. Jin

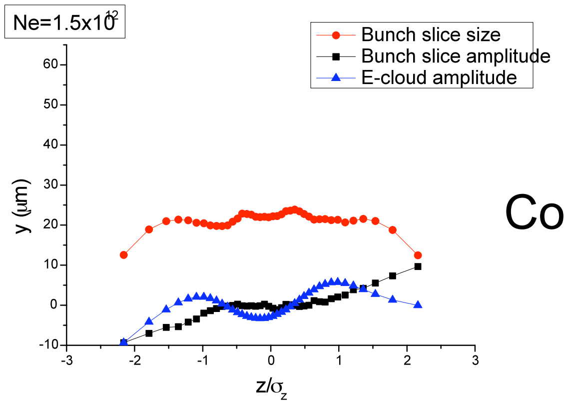
Bunch and e-cloud profiles at 500 turn



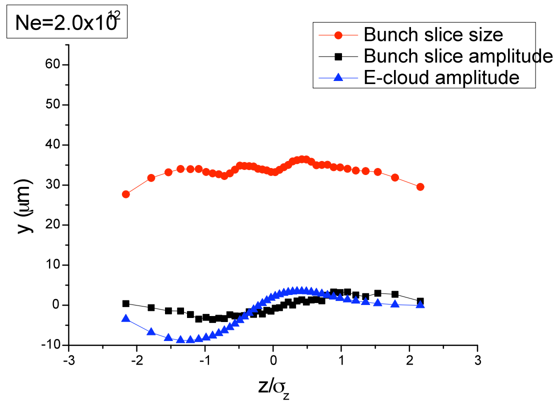
No coherent motion



By H. Jin



Coherent motion



Need to check tune dependence and lattice slice dependence

Summary for CESR and comment on experiments

- The cloud density is ρ_e=1.5-4.5x10^{11} m^{-3} for N=1.2x10^{10}, 14 ns spacing at CESR.
- The density is reasonable for the photo-electron model, and arc section is dominant.
- The coherent instability is observed at 10 times higher cloud density. More bunches with short spacing or lower α may realize the unstable condition.
- The operation with N=2x10^{10}, 6 ns spacing, may achieve the threshold ρ_e~1-2x10^{12} m^{-3}.
- Incoherent emittance growth may be seen in CESR, though may not seen in damping ring nor KEKB lowε.
- The coupled bunch instability should be seen, if bunches are stored uniformly, for example, 4-8 ns spacing, 100 mA depending on chromaticity (head-tail damping).