lectron cloud instabilit
n low emittance rings

H. Jin (Postech), K. Ohmi (KEK)

ECLOUD'10@Cornell

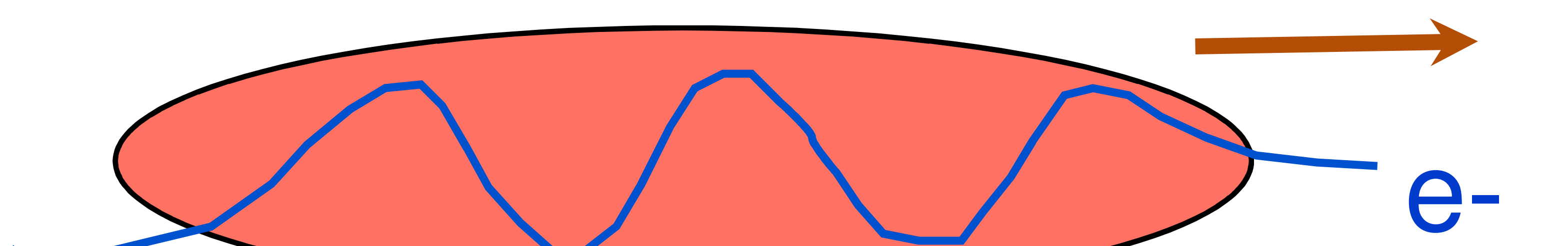
Oct. 8-12, 2010

Introduction

- Fast head-tail instability in CesrTA and SuperKEKB.
- Multibunch instability

Coherent strong head-tail instability

- Coherent motion between inner bunch and electron cloud.
- Electrons oscillate electric force inner bunch along z, $$\omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x + \sigma_y)}}$$
- The instability is characterized by $\omega_e \sigma_z / c$, number of electron oscillation along the bunch.



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

ability condition for $\omega_e \sigma_z/c>1$

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

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

nce $\rho_e=\lambda_e/2\pi\sigma_x\sigma_y$,

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

Origin of Landau damping is momen
compaction

$$\nu_s\sigma_z = \alpha\sigma_\delta L$$

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

Q_{nl}=5-10?, depending on the nonlinear interaction.

haracterizes cloud size effect and pinching.

σ_z/c~12-20 for damping rings.

e use $K=\omega_e \sigma_z/c$ and Q_{nl}=7 for analytical estimation

Parameters

Table 1: Basic parameters of existing positron rings and ILC damping ring

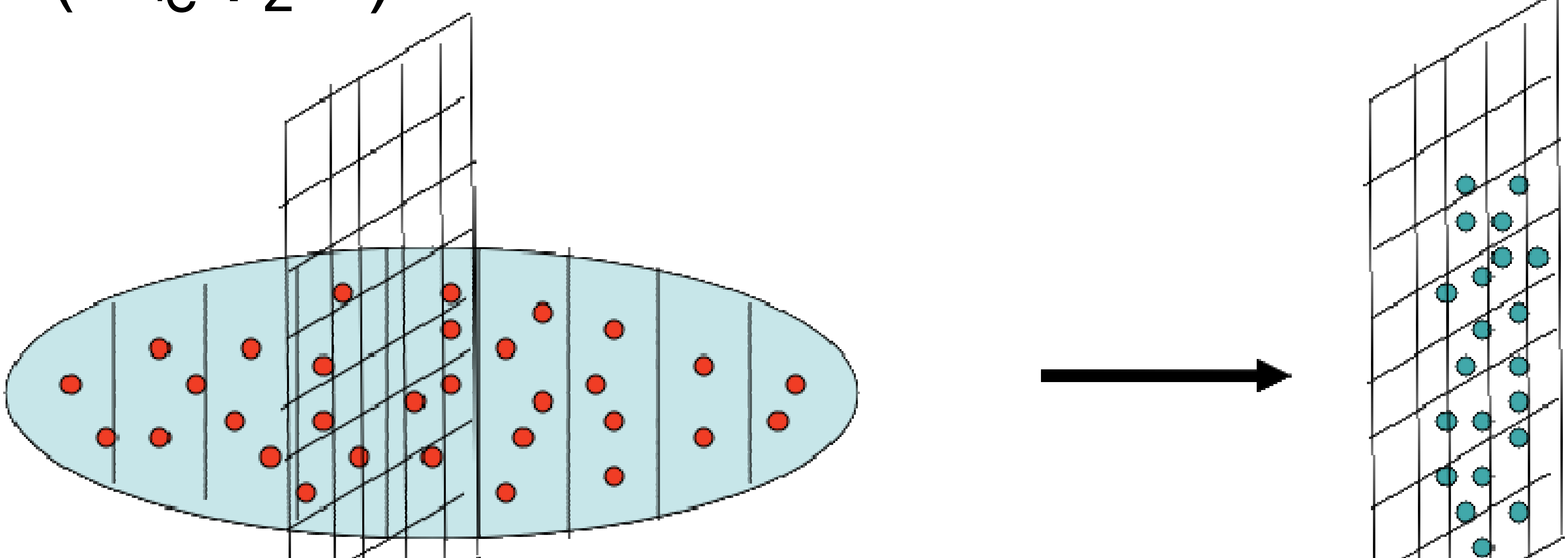
		KEKB	PEP-II	Cesr-TA/5	Cesr-TA/2	ILC-DR	SuperKEKB
Circumference	L(m)	3,016	2,200	768	768	6,414	3016
Energy	E	3.5	3.1	5.0	2.1	5.0	4.0
Bunch population	$N_+(10^{10})$	8	8	2	2	2	9
Beam current	I_+ (A)	1.7	3.0	-	-	0.4	3.6
Emittance	ε_x(nm)	18	48	40	2.6	0.5	2
Momentum compaction	$\alpha(10^{-4})$	3.4		62.0	67.6	4.2	3.5
Bunch length	σ_z(mm)	6	12	15.7	12.2	6	6
RMS energy spread	$\sigma_E/E(10^{-3})$	0.73		0.94	0.80	1.28	0.8
Synchrotron tune	ν_s	0.025	0.025	0.0454	0.055	0.067	0.0256
Damping time	τ_x	40	40		56.4	26	43

Table 2: Threshold of the ILC damping ring and other rings

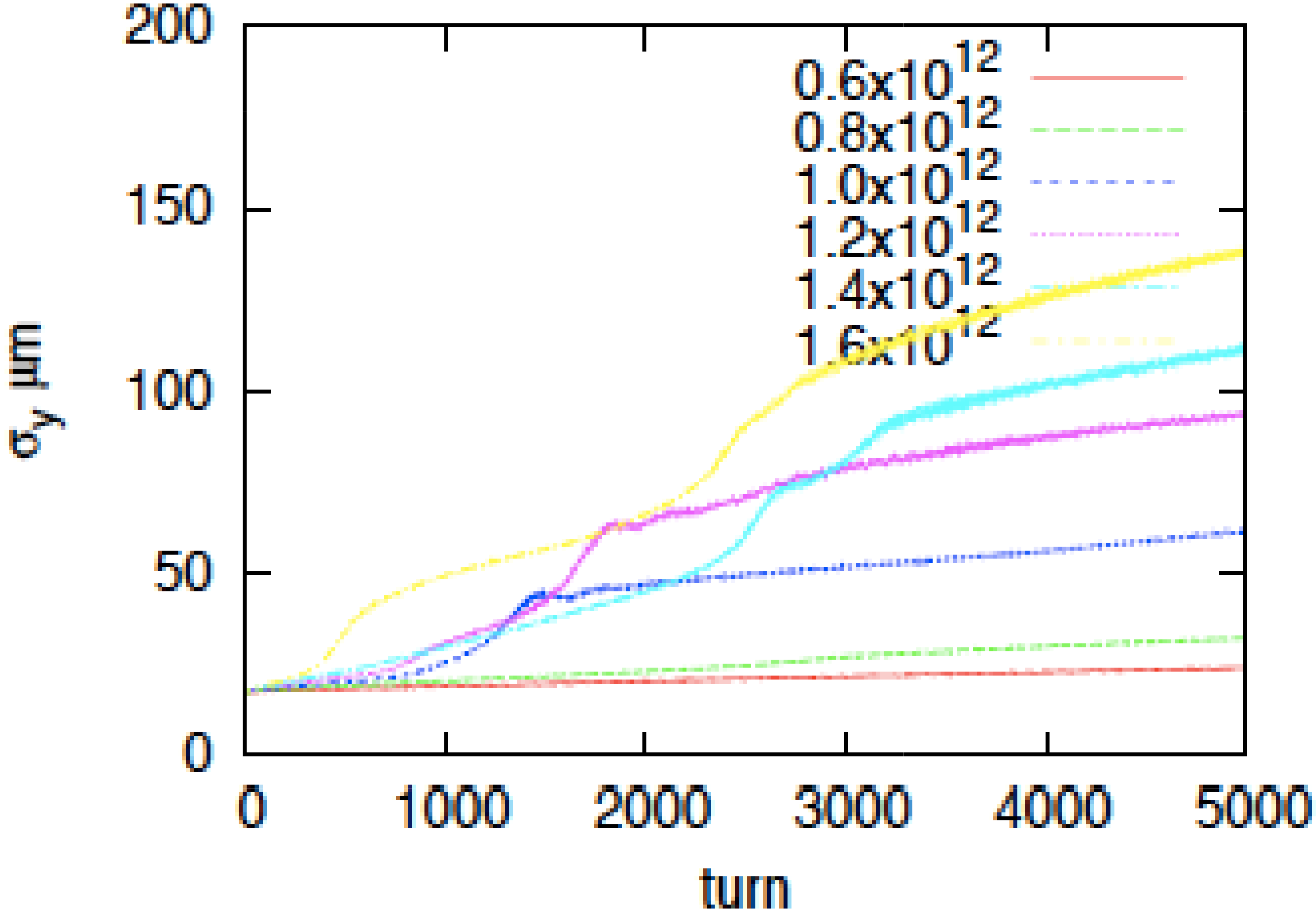
		KEKB[1]	KEKB[2]	PEP-II	CesrTA-5	CesrTA-2	ILC-DR	SuperKEK
pulation	$N_+(10^{10})$	3	8	8	2	2	2	9
ent	I_+ (A)	0.5	1.7	3.0	-	-	0.4	3.6
cing	ℓ_{sp}(ns)	8	7	4	4	4	6	4
requency	$\omega_e/2\pi$(GHz)	28	40	15	9.6	43	100	189
e	$\omega_e\sigma_z/c$	3.6	5.9	3.7	3.2	11.0	12.6	23.8
	ρ_e (10^{12} m^{-3})	0.63	0.38	0.77	7.40	1.70	0.19	0.27
at ρ_e	$\Delta\nu_{x+y}$	0.0078	0.0047	0.0078	0.0164	0.009	0.011	0.003

(PEHTS)

- Electron clouds are located several or many s position in a ring.
- Potential solver based on 2D FFT.
- Beam is sliced into 30-100 pieces (> ⌉$_e$ ⌠$_z$/c).

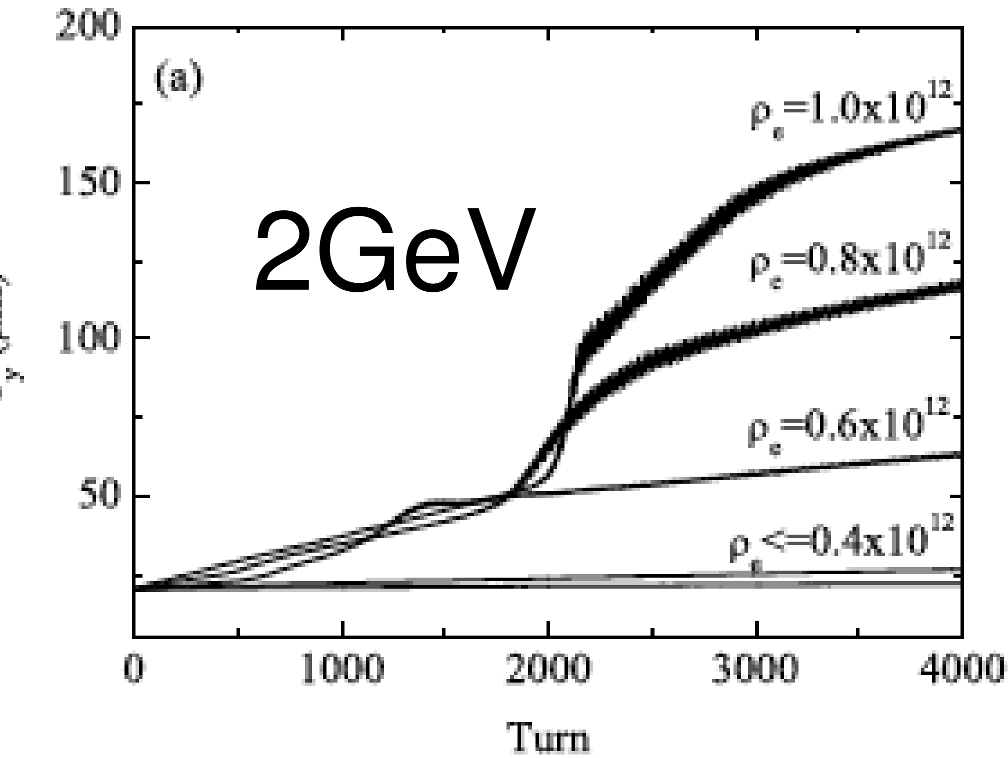


Simulation for CesrTA
I=1.3mA, N=2x10^{10}



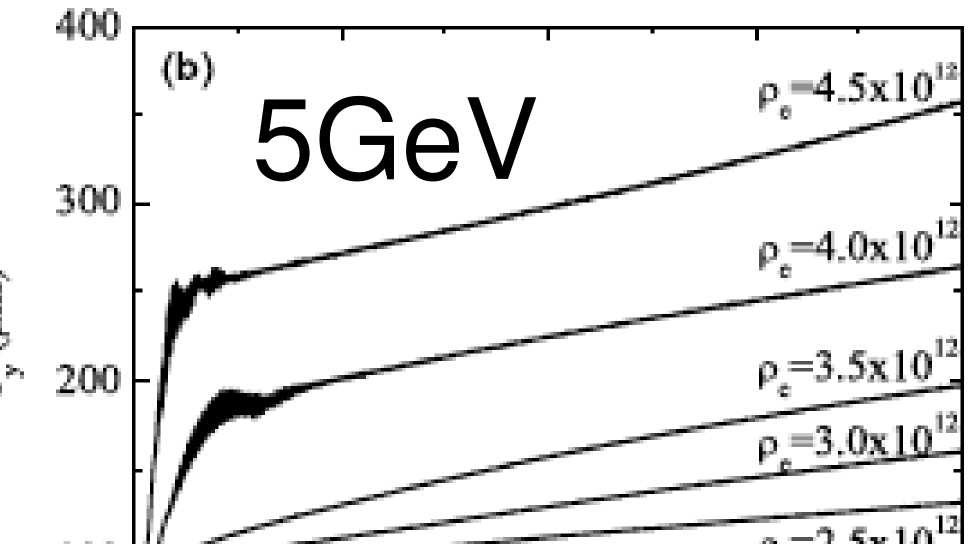
- Simulation ρ_{th}=1x10^{12} m^{-3}.
- Analytic ρ_{th}=1.7x10^{12} m^{-3}.

CesrTA 2 and 5 GeV



ρ_{th}=0.8x10^{12} cm^{-3}

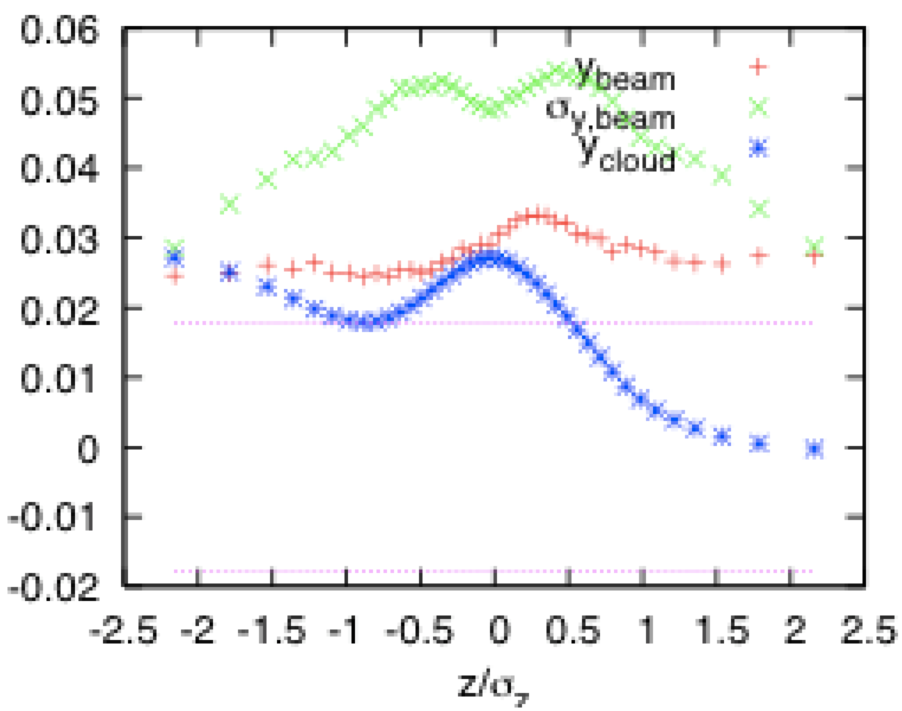
- High(2GeV) and low(5GeV) $\omega_e\sigma_z$

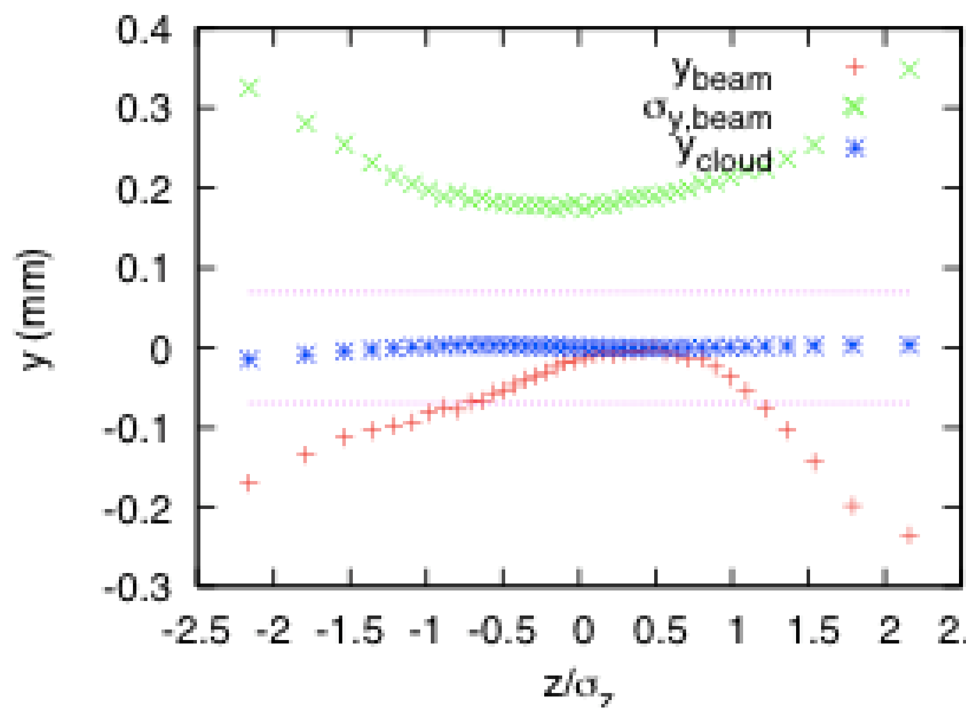


ρ_{th}=4x10^{12} cm^{-3}

Coherent motion in the simulation

- 2 GeV 5 GeV



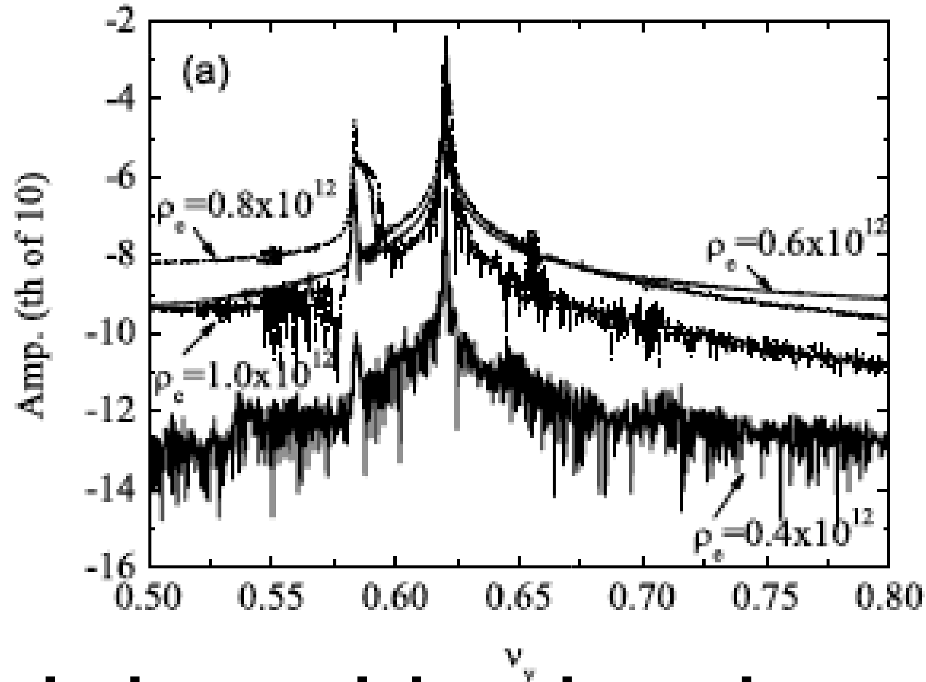


- High(2GeV) and low(5GeV) $\omega_e\sigma_z/c$.

Simulated Unstable spectra

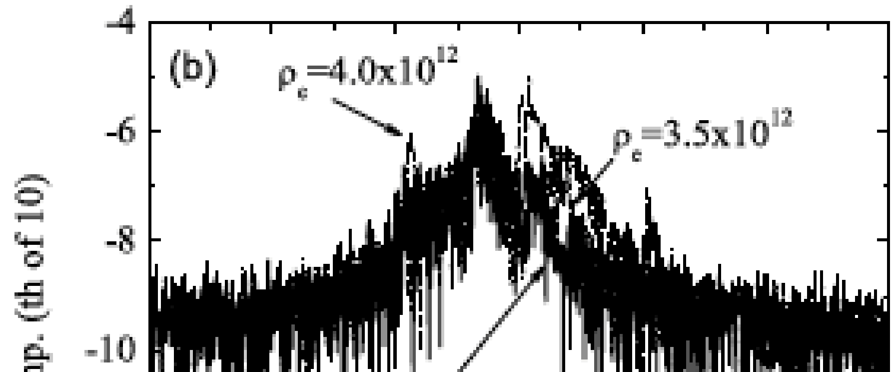
- Lower sideband is dominant for high $\omega_e\sigma_z$ (low emittance).

2 GeV

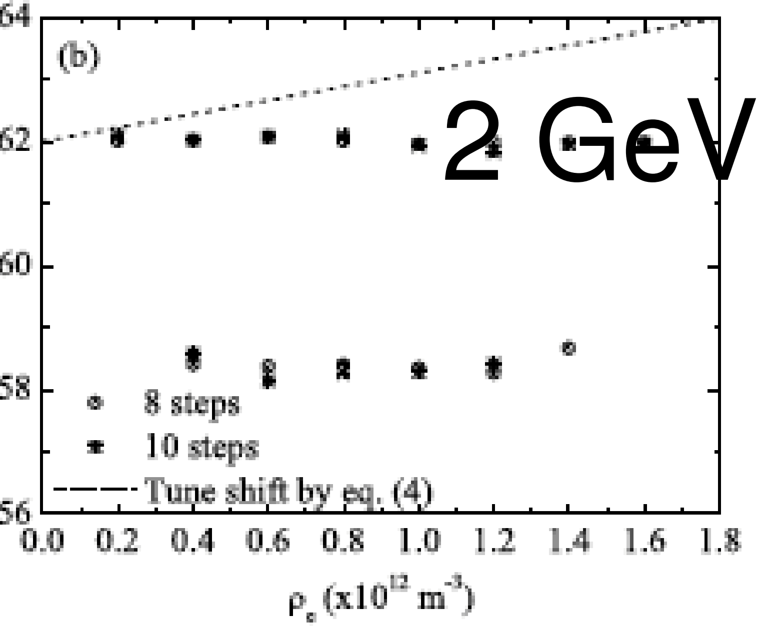


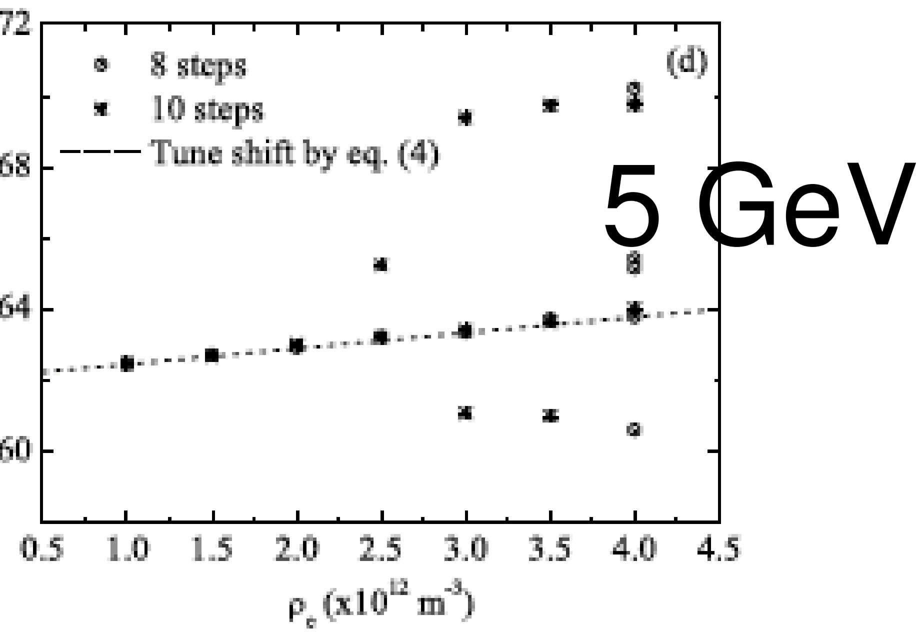
- Upper sideband is dominant for 5GeV

5 GeV



Simulated beam spectra





- Lower sideband is seen for high $\omega_e\sigma_z/c$, 2GeV.
- Upper sideband is seen for low $\omega_e\sigma_z/c$, 5 GeV.

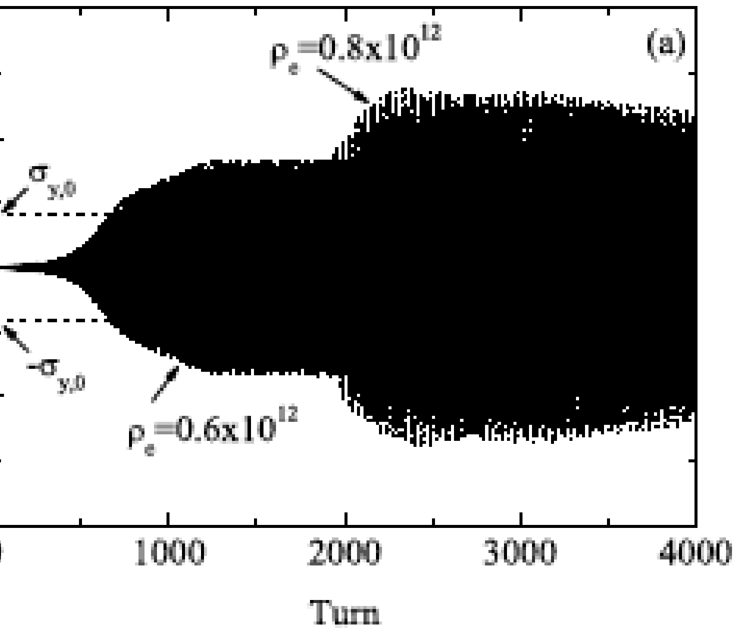
back

- Model, feedback with one turn delay

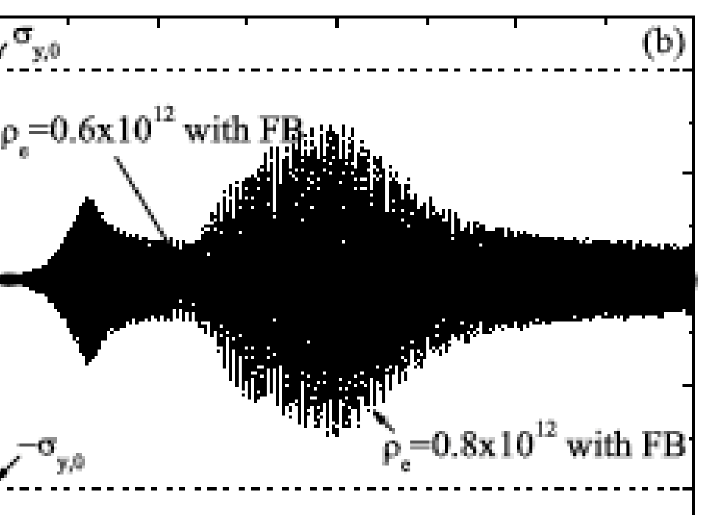
$$\begin{pmatrix} y \\ y' \end{pmatrix}_{n,+} = \begin{pmatrix} y \\ y' \end{pmatrix}_{n,-} - \alpha M \begin{pmatrix} \langle y \rangle \\ \langle y' \rangle \end{pmatrix}_{n-1,+}$$

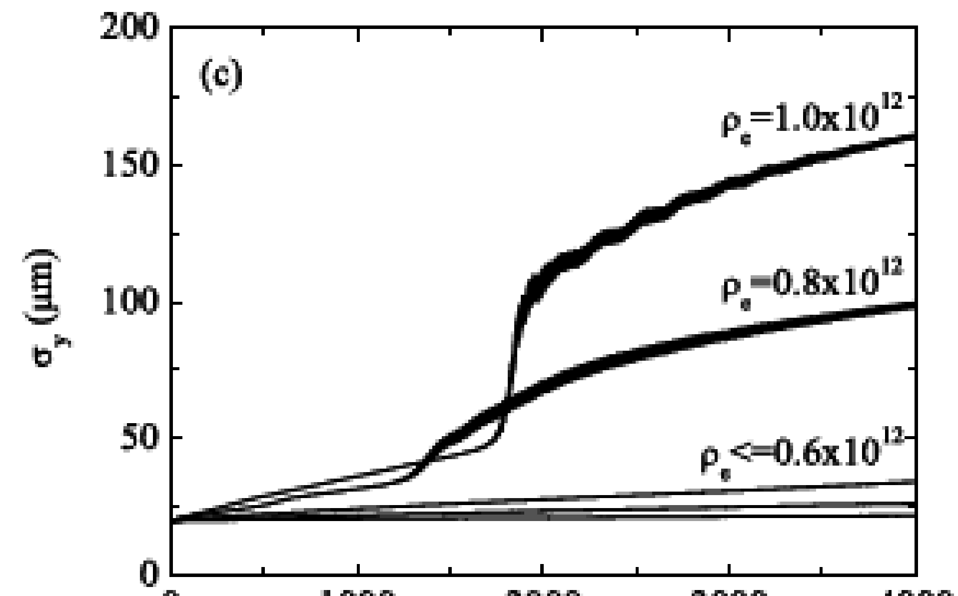
- M: revolution matrix
- α: feedback damping rate
- n: n-th turn
- ±: after or before feedback kick

B suppresses the instability little(2GeV)

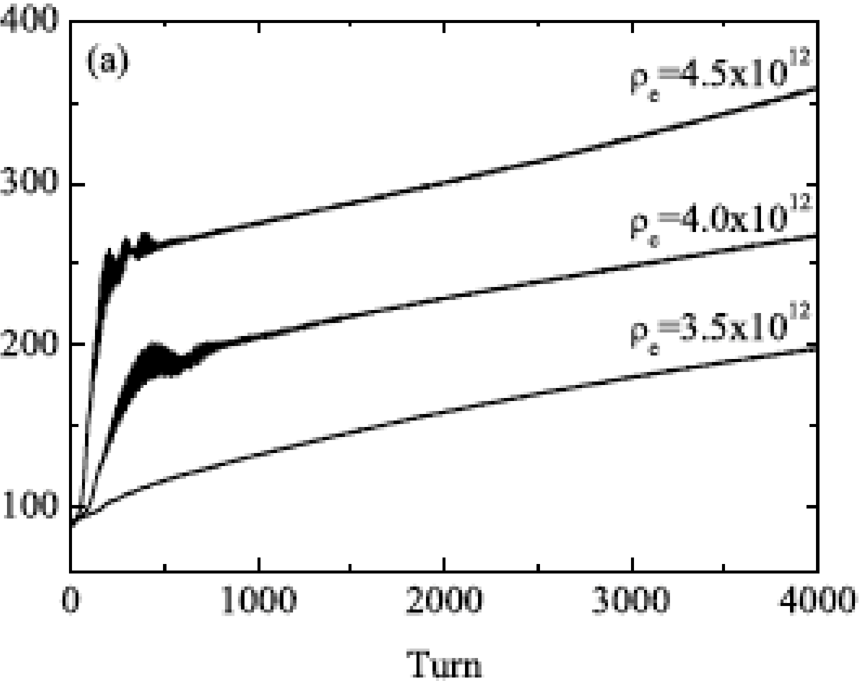


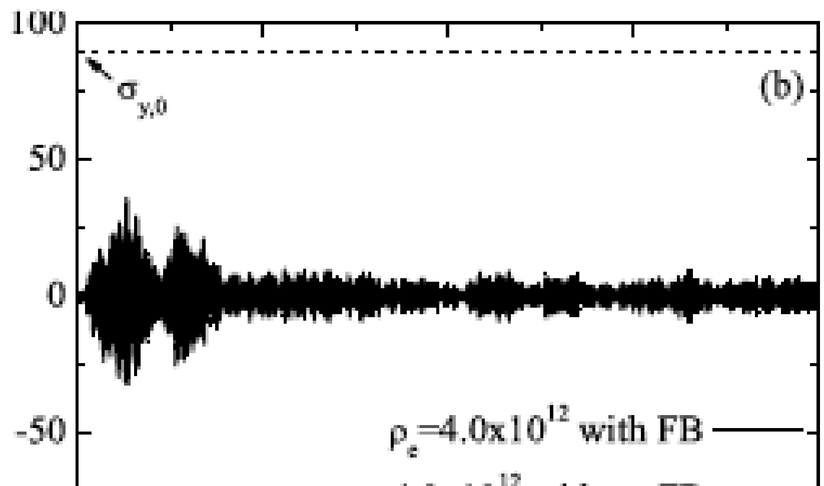
- High $\omega_e \sigma_z/c$, 2GeV.
- Dipole motion is suppressed a little, threshold increase a little.





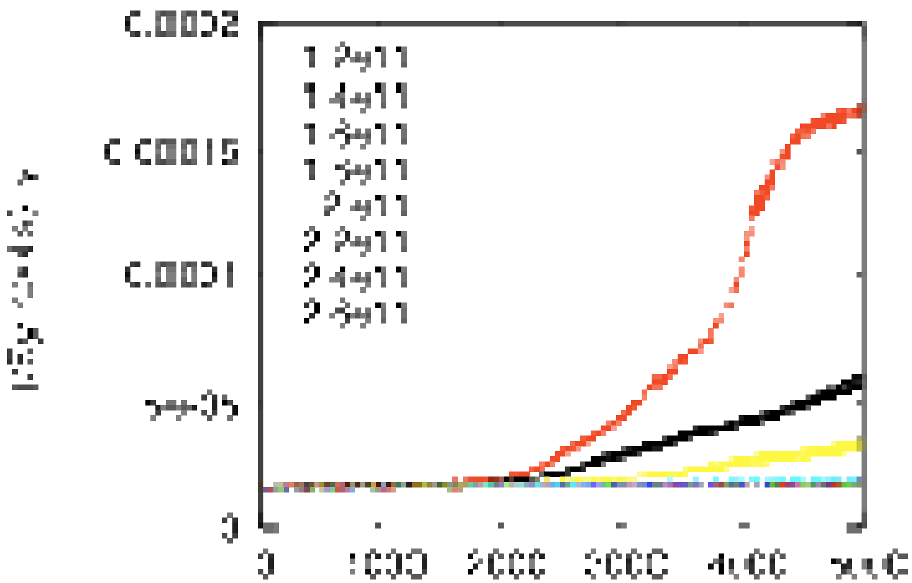
(5GeV)





- Low $\omega_e \sigma_z/c$, 5GeV.
- Dipole motion is suppressed but hea tail motion remains.

SuperKEKB



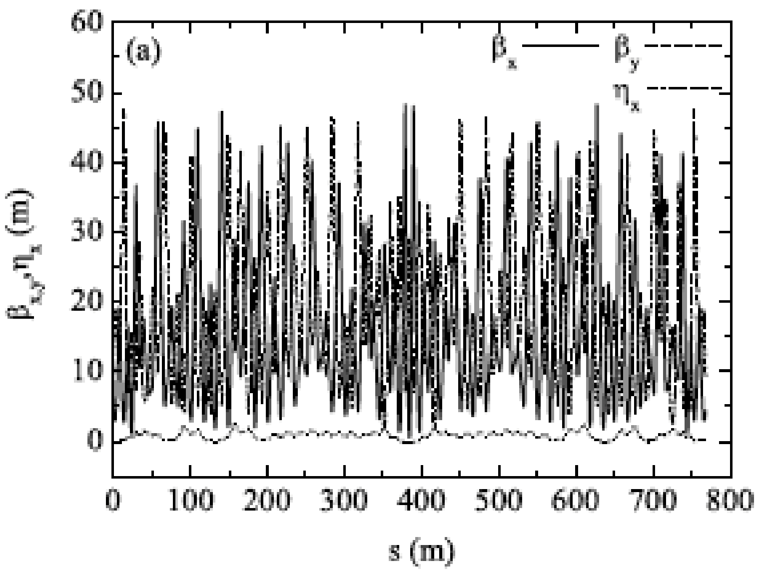
Y. Susaki, K. Ohmi, IPAC1

This simulation is for old parameter νs=0.12. Prese νs=0.26. The threshold sh be twice higher.

- Simulation $\rho_{th}=2.1\times10^{11}$ m^{-3}.
- Analytic $\rho_{th}=1.1\times10^{11}$ m^{-3}.
- **Target $\rho_e<1\times10^{11}$ m^{-3}**
- Update parameters (both for CesrTA and SuperKEKB).
- Take care of high β section. Effects are

Incoherent effect in CesrTA

- Emittance growth due to nonlinear interaction with electron cloud



- Nonlinearity of beam-cloud interaction
- Integrated the nonlinear terms with multip
function and cos (sin) of phase difference

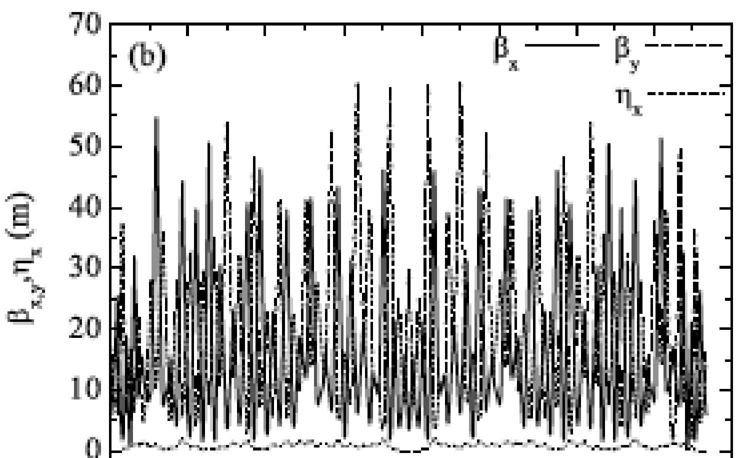
$$M = \mathrm{e}^{-:\phi_1:}\,\mathrm{e}^{-:F_{12}:}\,\mathrm{e}^{-:\phi_2:}\,\mathrm{e}^{-:F_{23}:}\,\mathrm{e}^{-:\phi_3:}\,\mathrm{e}^{-:F_{34}:}\,\mathrm{e}^{-:\phi_4:}\,\mathrm{e}^{-:F_{45}:}\,\mathrm{e}^{-:\phi_5:}\ldots\mathrm{e}^{-:F_{n1}:}$$

$$\approx \mathrm{e}^{-:F_{11}:}\exp\left(-:\sum_{i=1}^{n}\phi_i(e^{-:F_{1i}:}\mathbf{x}):\right)$$

F: (non)linear lattice tr

ϕ: cloud interaction

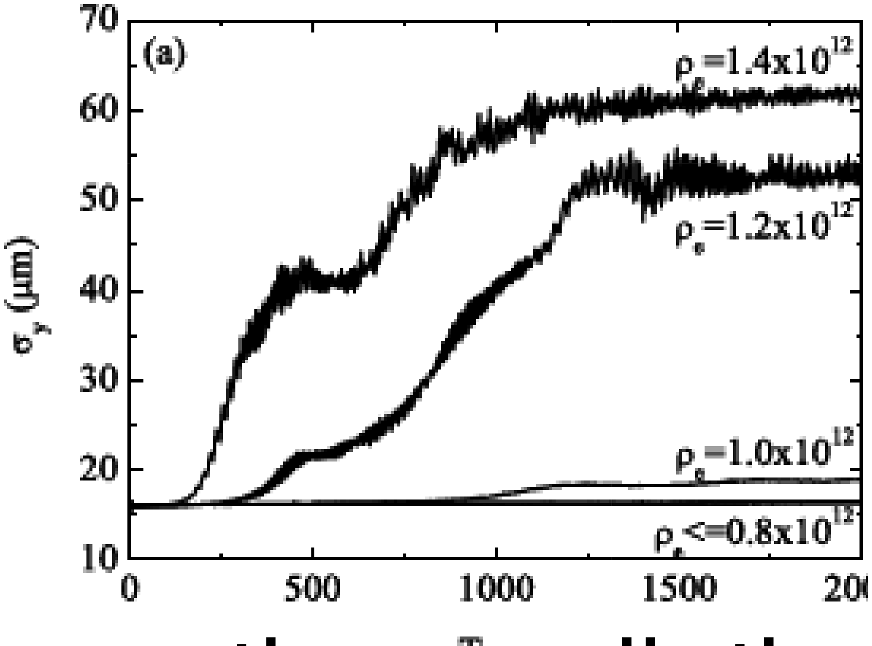
$$kx^m \Rightarrow k\beta_i^{m/2}J^{m/2}\cos(m\Delta\psi_{1i})$$

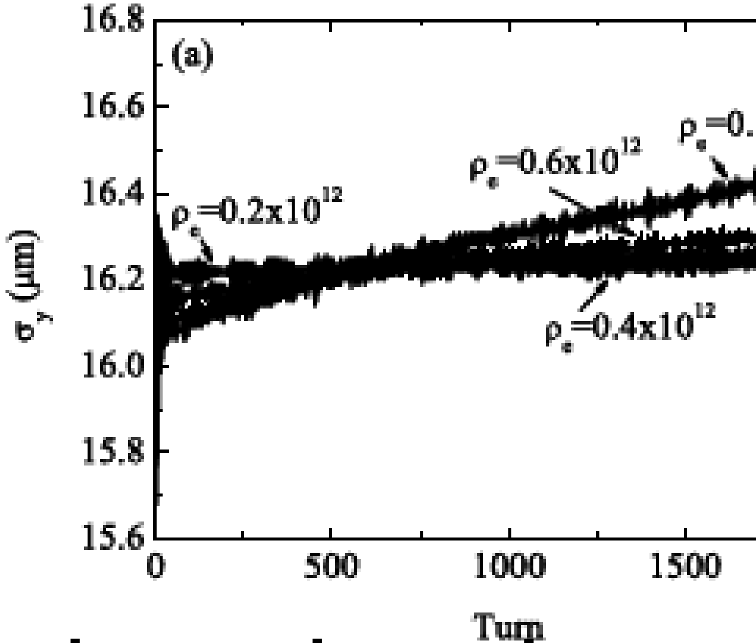


Slow growth lower than the threshold

eV

$=1.2\text{x}10^{12}$

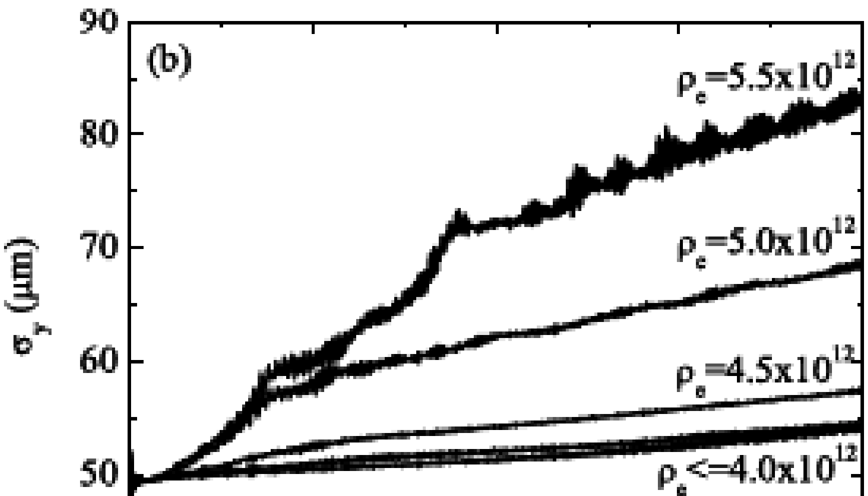


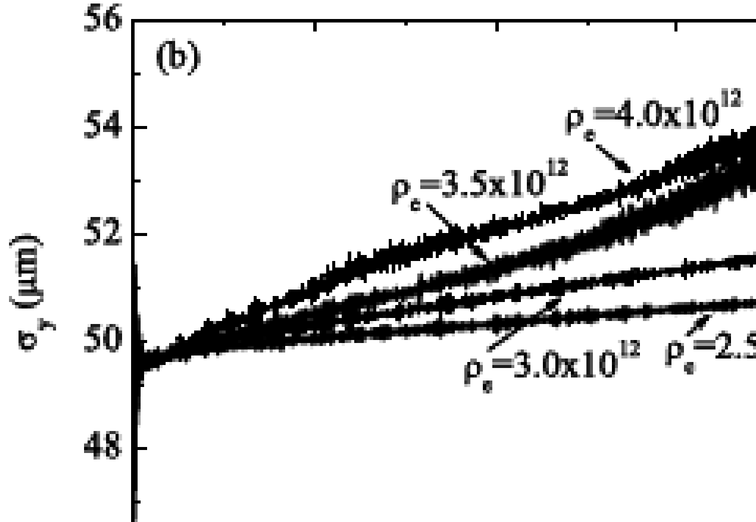


Slower than radiation damping time

eV

$=5\text{x}10^{12}$





Study of multibunch instability

- Self consistent solution of the cloud build up and bunch motion.
- Wake field calculation
- Self consistent simulation
- Multi-bunch instability induces a fast bear loss, though fast head-tail instability does not.

Tracking simulation

K.Ohmi, PRE55,7550 (1997)

K.Ohmi, PAC97, pp16

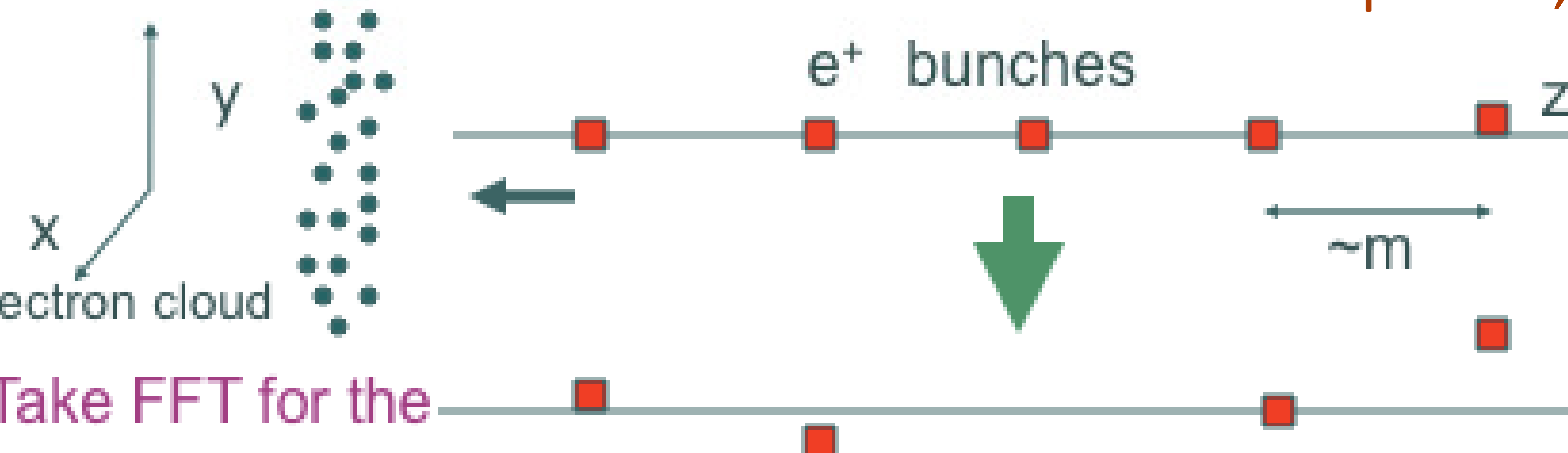
Solve both equations of beam and electrons simultaneously

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

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

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

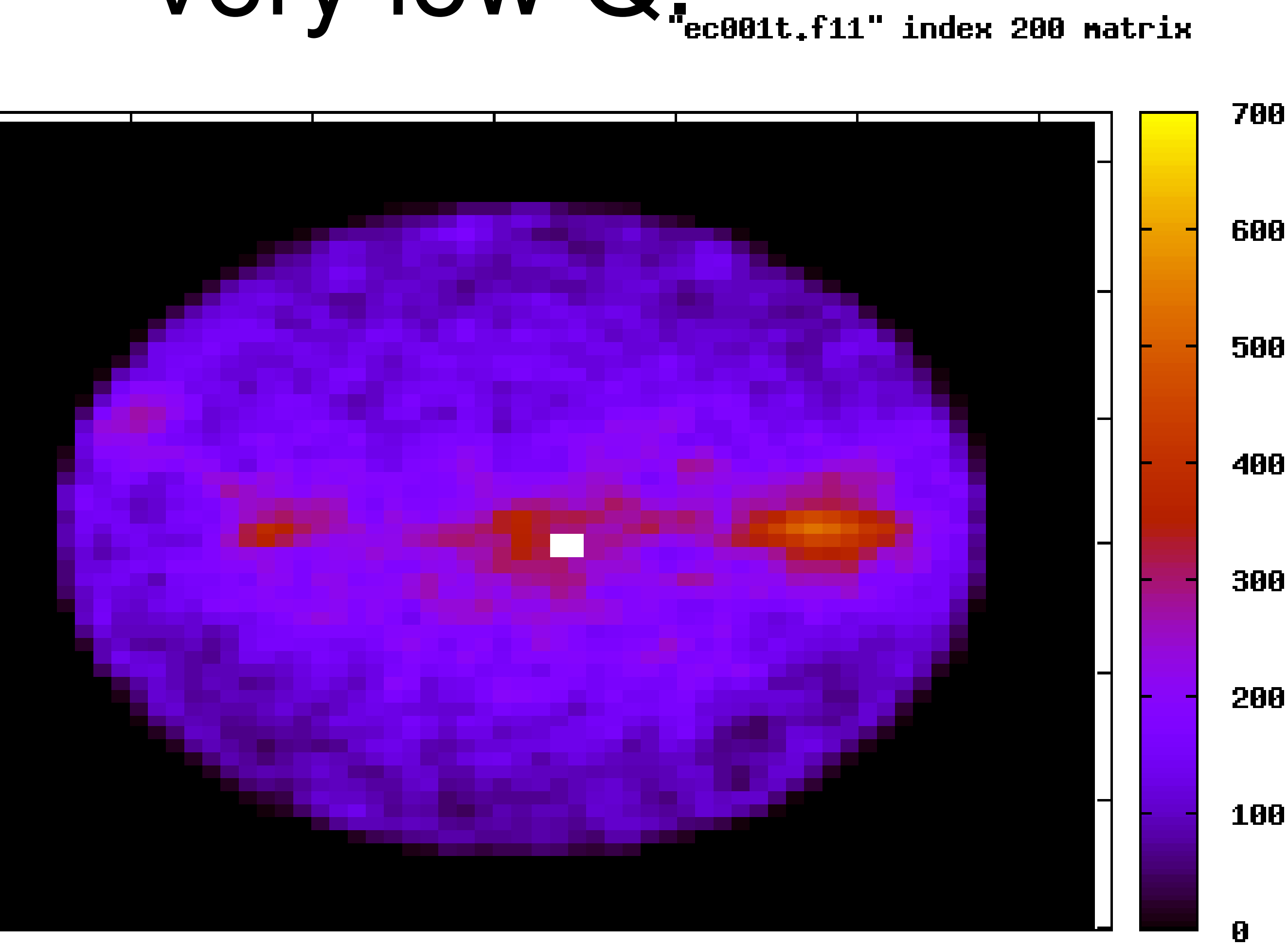
Self consistent build-up code,

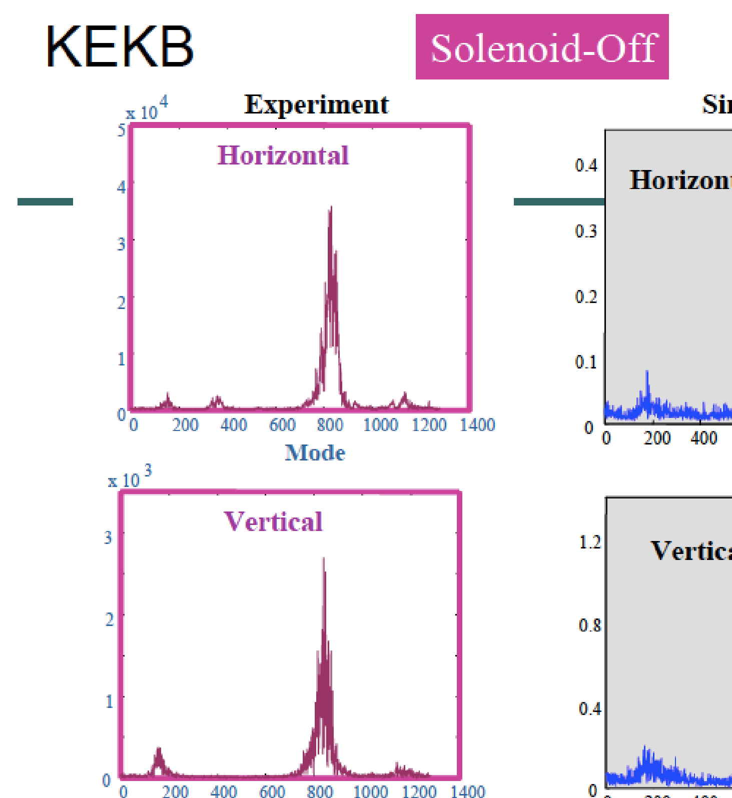


Take FFT for the

Beam dancing with electron cloud

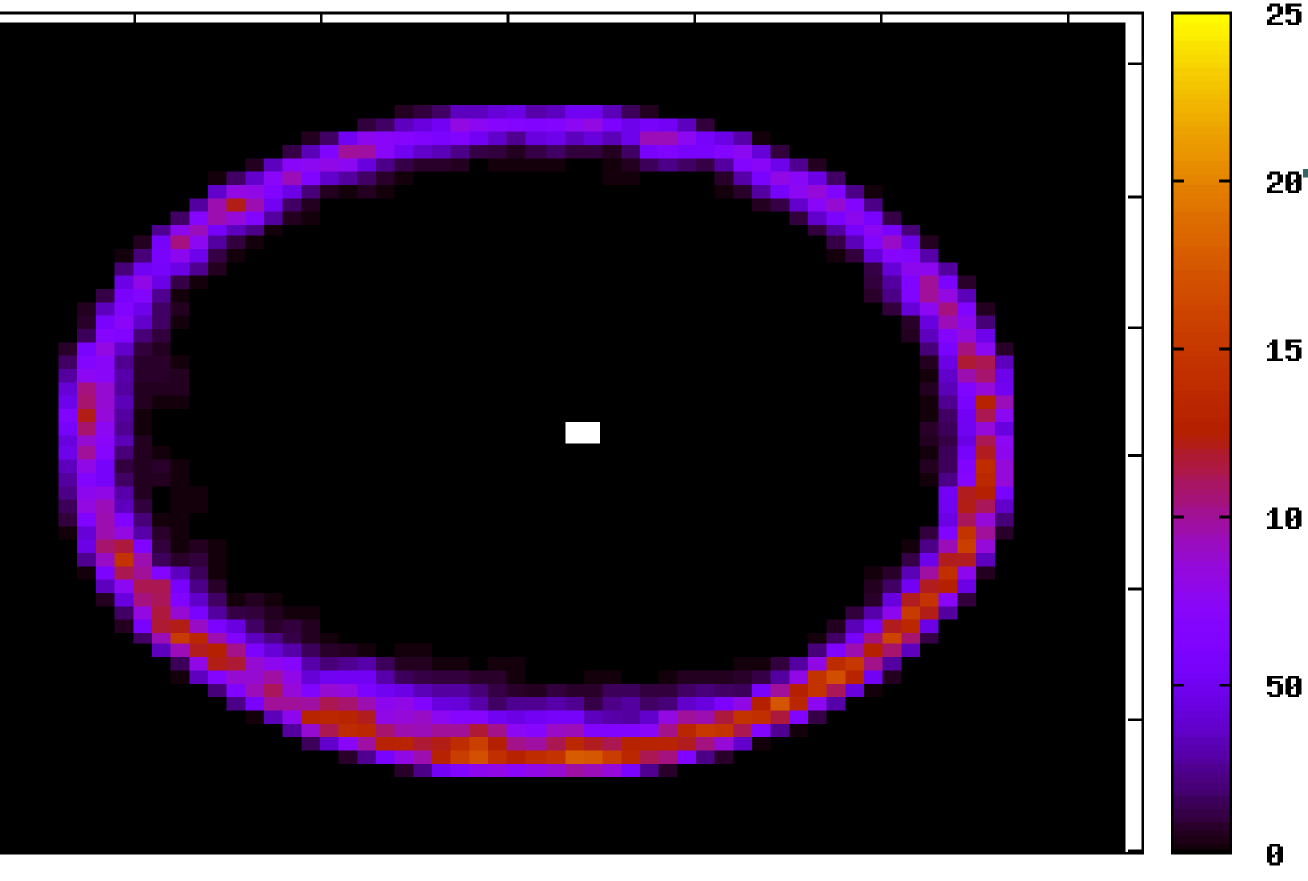
- Drift space
- Electrons move one way
- Bunch by bunch correlation is short, very low Q.

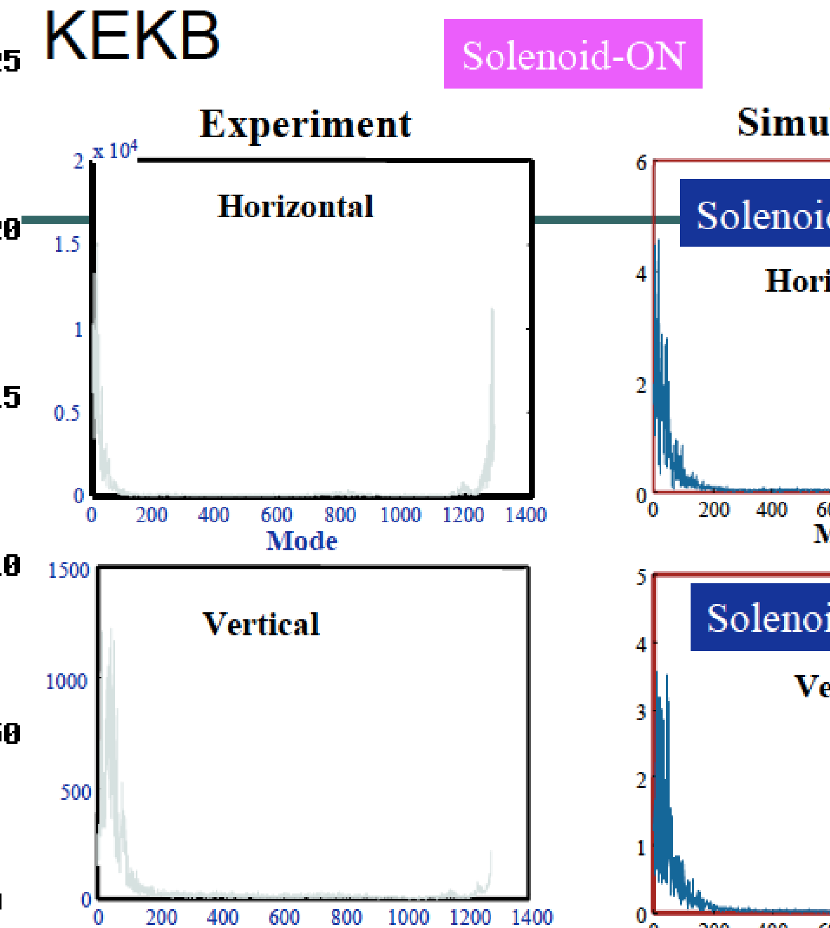




Beam dancing with electron cloud

- In solenoid magnets
- Electrons move along the chamber surface.
- Long life time electron, high Q wake.



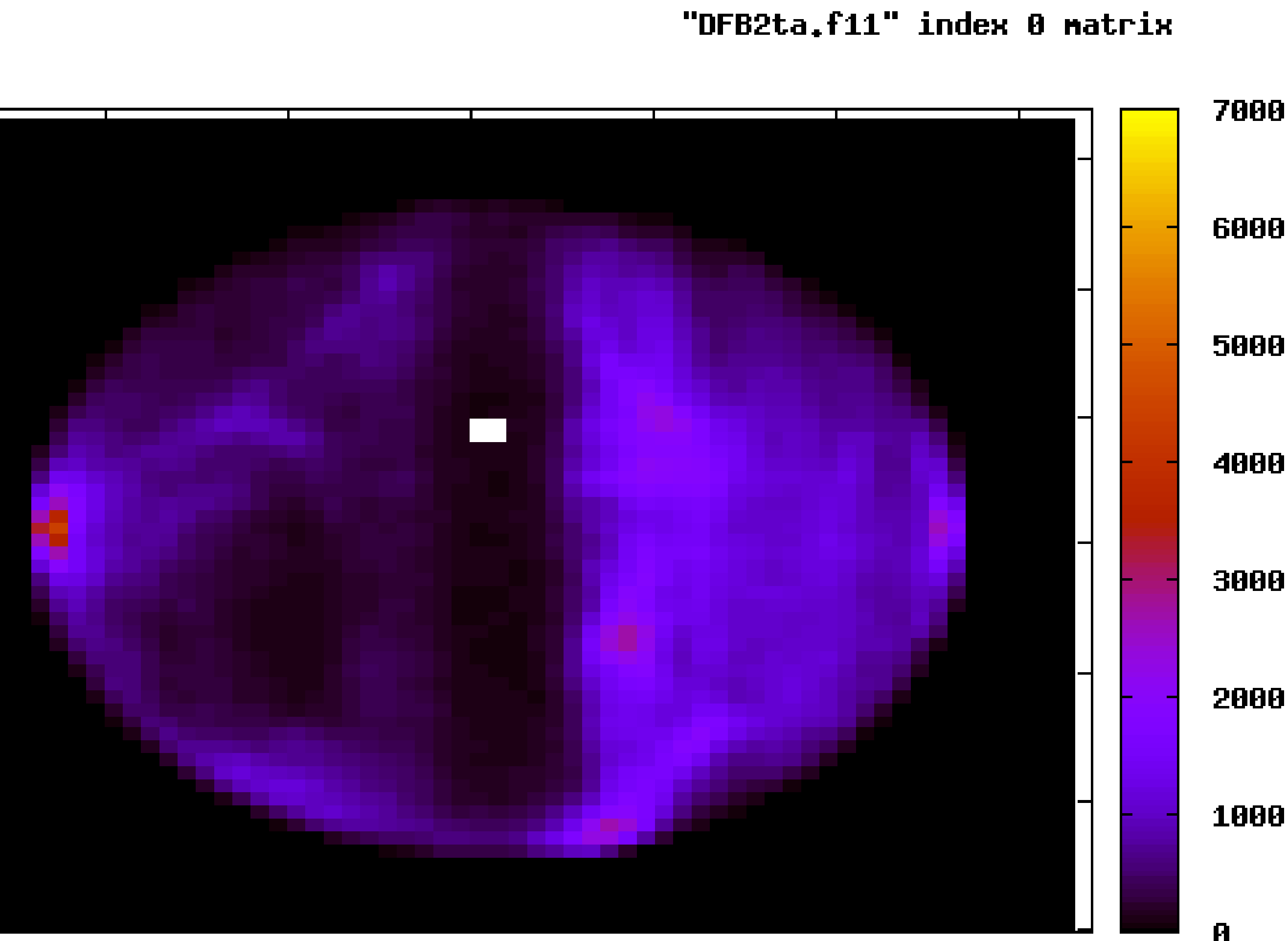


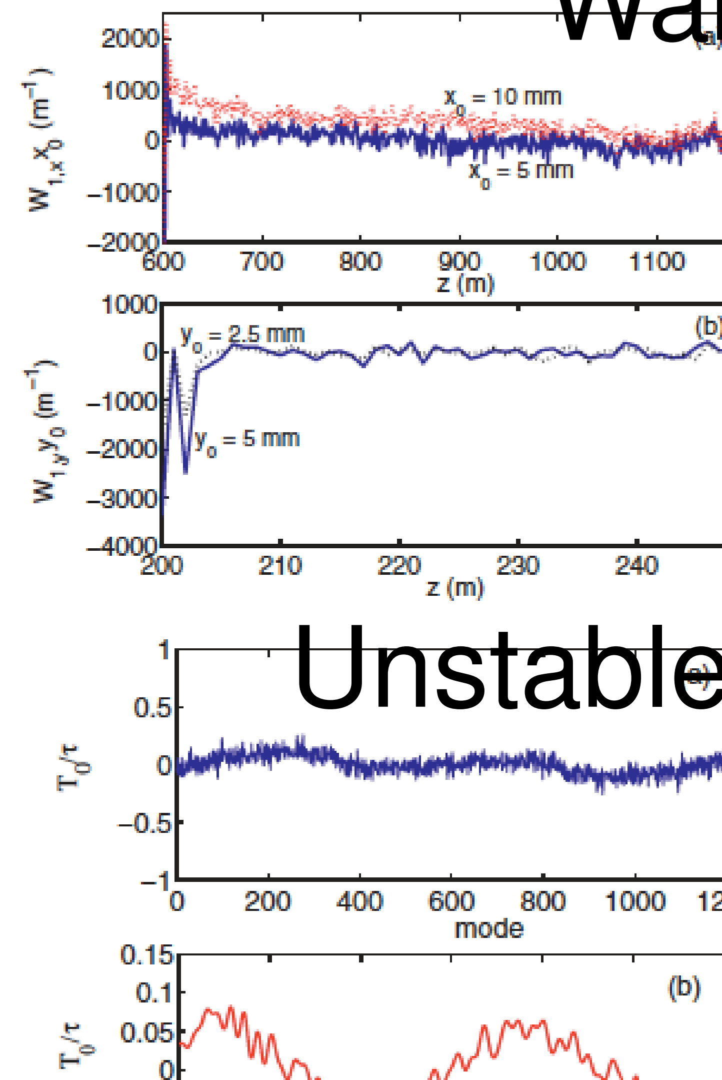
Multi-bunch instability

Beam dancing with electron cloud

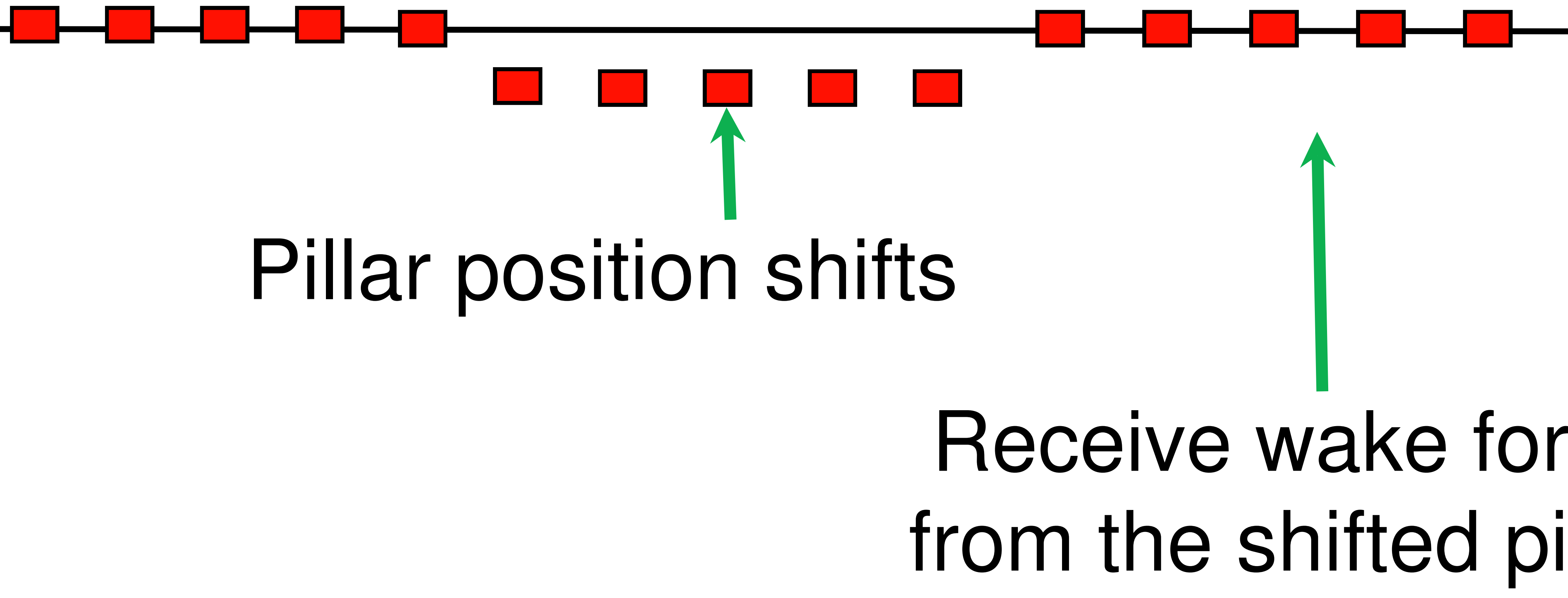
Electron cloud in bending magnet

Does beam dance with electron cloud pillar?





Correlation time of the pillar (stripe)



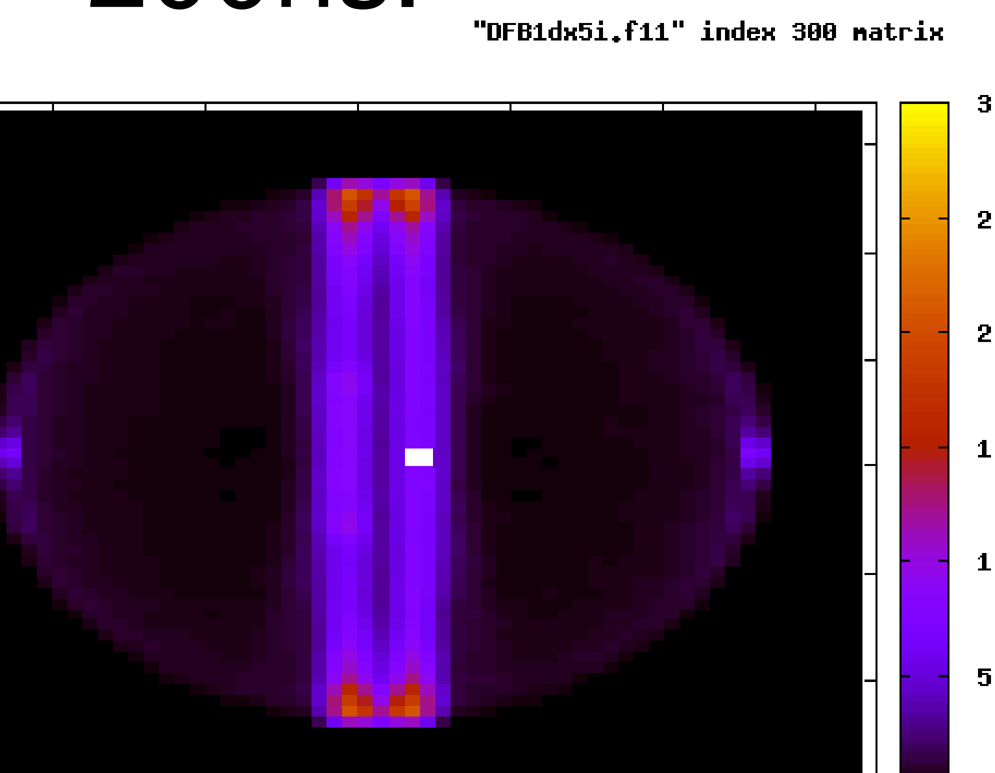
- Bunch length ~1cm, bunch spacing ~1m

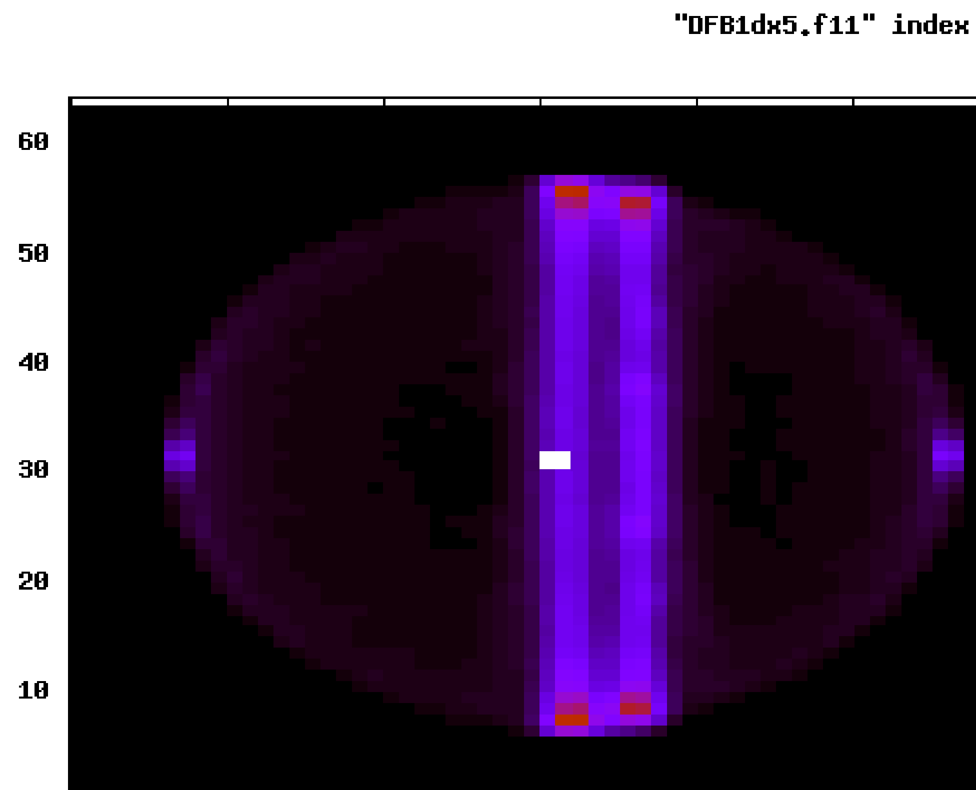
Characteristic time of pillar formation

DAFNE parameter, ~200ns

Formed pillar and then shift beam position

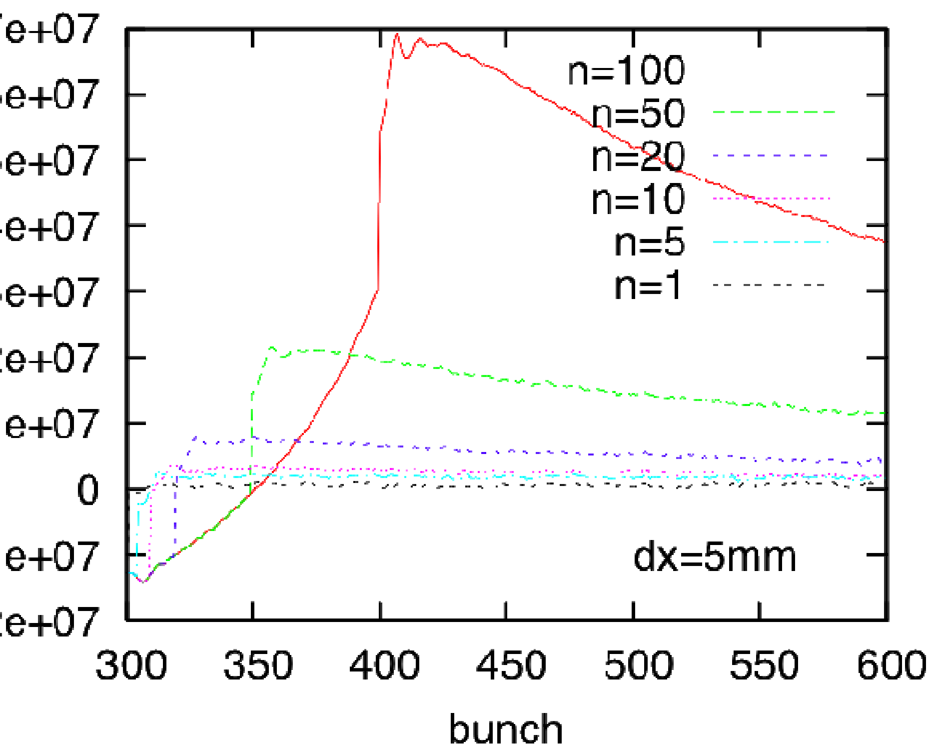
Pillar position shifts to beam position in ~200ns.

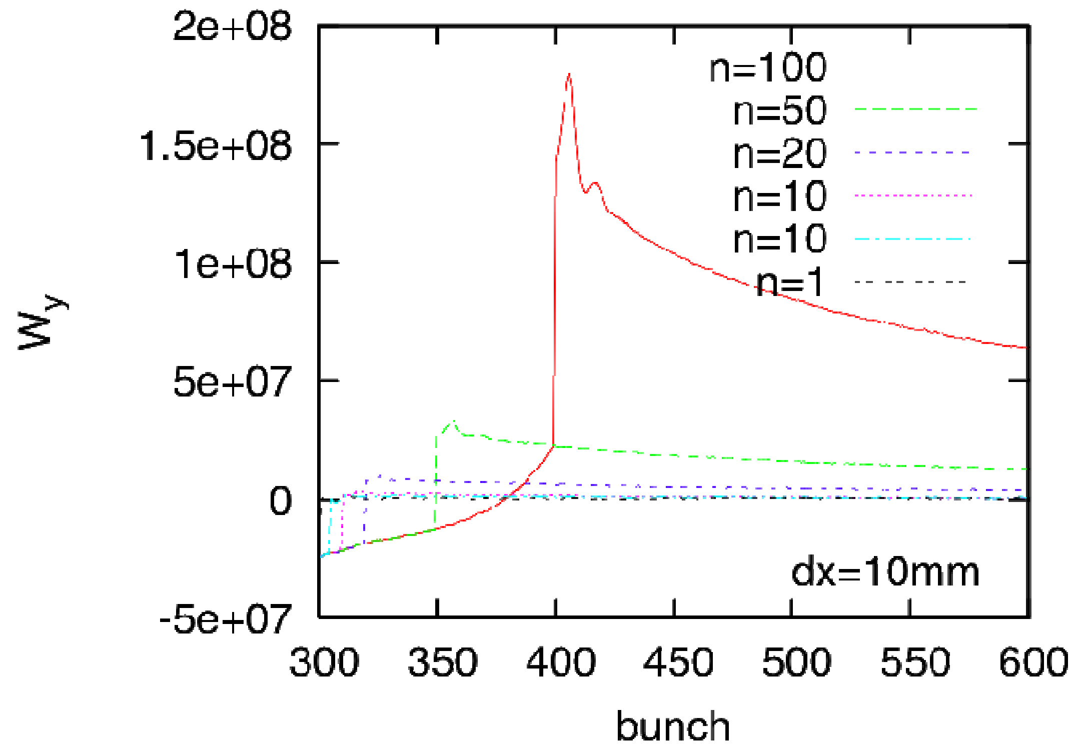




Wake force for the pillar formation

- Bunch by bunch correlation of slowest mode, m=-1, will be induced.





- Characteristics of the fast head tail instability is determined by $\omega_e \sigma_z / c$.
- Appearance of upper or lower sideband, and feedback response depend on $\omega_e \sigma_z / c$.
- The threshold (2GeV) is $\rho_{th}=1\text{x}10^{12}$ cm^{-3} for simulation and $1.7\text{x}10^{12}$ cm^{-3} for analytic.
- The threshold (5GeV) is $\rho_{th}=5\text{x}10^{12}$ cm^{-3} for simulation and $7\text{x}10^{12}$ cm^{-3} for analytic.
- Incoherent emittance growth is week in positron machines.
- Movies for coupled bunch instability. Slowest mode is induced by electrons in bending