Electron cloud study for ILC damping ring at KEKB and CESR

K. Ohmi (KEK)

TILC08 at Sendai, JPN

March. 3-6, 2008

Contents

- Electron cloud study for ILC-damping ring at KEKB and CESR.
- Threshold of single bunch instability
- Experiences of KEKB and PEP-II
- Tune shift and cloud density.
- Incoherent emittance growth.

Activities in KEKB for the ILC damping ring study

Table 1. To complete the proposal for feasibility of using KEKB with small emittances for ILC studies, further studies needed:

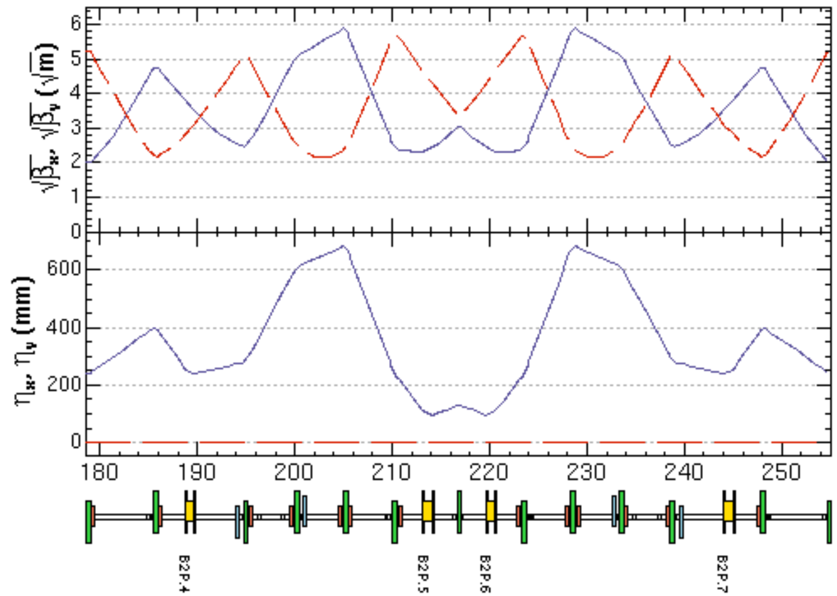
Study:	**By**
Estimate effects at > 0 A: Space-Charge, Tousheck, Intrabeam scattering	Oide
Estimate dynamic aperture	Ohnishi Koiso
Low emittance tuning: further characterization	Koiso Kikuchi Morita
Instrumentation: BPMs, beam size monitors, bunch-by-bunch feed-back system	Fukuma, Flanagan Tobiyama
Characterize electron cloud build-up and instability in LER	Ohmi
Characterize ion instability in HER	Fukuma
Include plans for electron cloud: ILC small aperture chamber	Suetsugu Pivi Kato Kanazawa
Vibration and stabilization	Masuzawa

Optics parameters

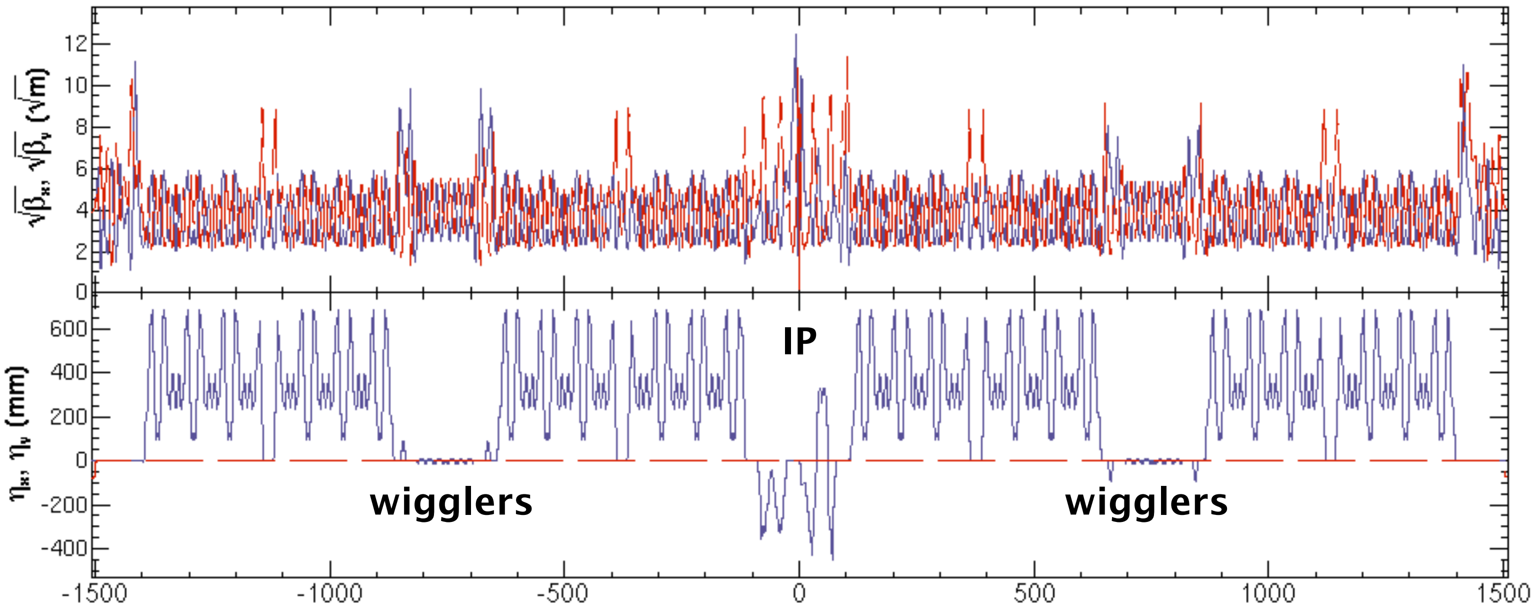
	Physics run	Low emittance	CesrTA	OCS	PEP-II
Circumf. (m)	3016	3016	768	6	2200
E (GeV)	3.5	2.3	2.0	5.0	3.1
ε_x (nm)	18	1.5	2.3	0.5	48
α (10^{-4})	3.4	2.4	64	4.2	13
σ_z (mm)	6	4.2 (6.1)	6.8	6	12
Rf voltage	8.0	2.0 (1.0)	15	24	
σ_δ (%)	0.073	0.048	0.086	0.128	0.081
$\tau_{x,y}$ (ms)	40	150	56.4	26	40
Bucket height		1.86 (1.13)		1.5	

Emittance increases due to IBS. (ε_x(nm), ε_y(pm))
KEKB-DRT (1.5,1,5)->(5, 5) or (1.5, 6)->(4, 16)
CesrTA (1.8,4.5)->(6,16)

Optics (ring & cell)
(H. Koiso)



- ◆All magnetic fields are scaled from 3.5 to 2.3 GeV.
- ◆Wiggler field: 0.77 → 0.51 T
- ◆Detuned β*x/y: 90/3 cm



Lattice Errors

Multipole components and fringe field have been included in the model lattice.

Following errors are produced with random numbers according to Gaussian.
These numbers are one standard deviation(σ).

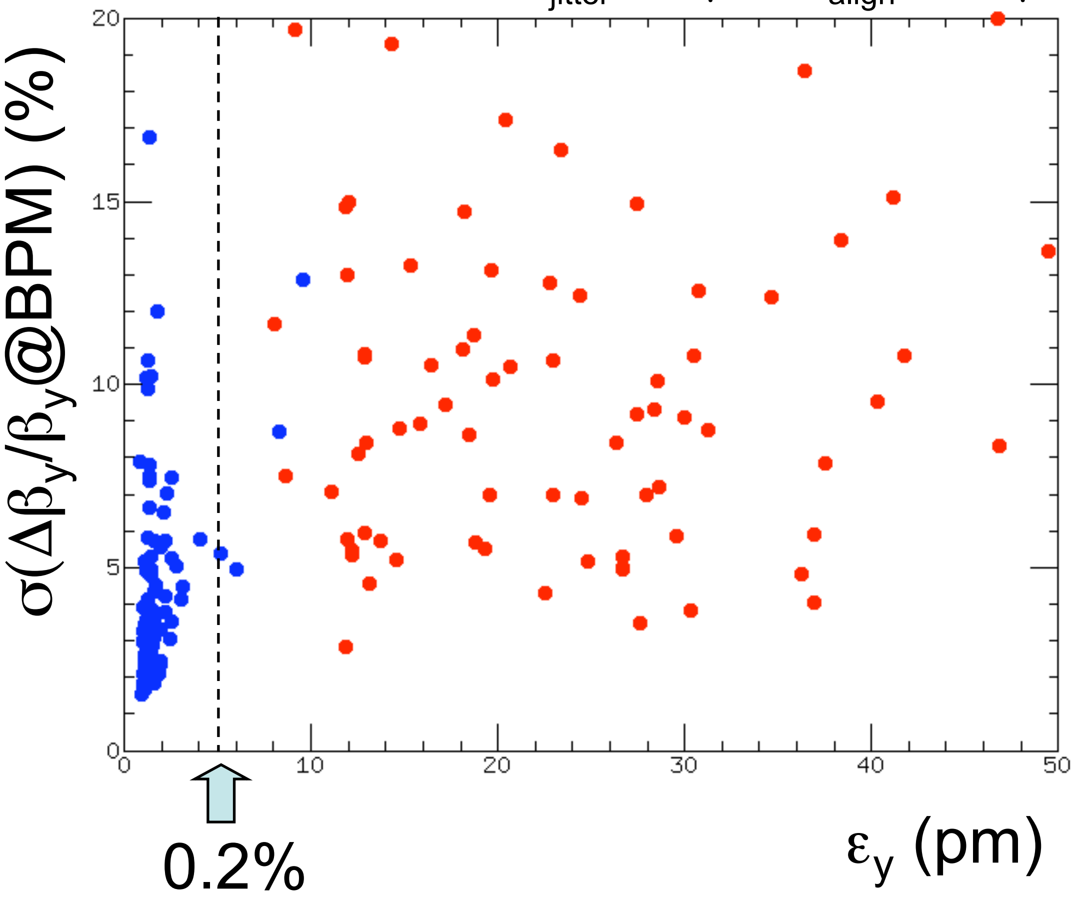
	alignment error Δx (μm)	alignment error Δy (μm)	rotation error $\Delta\theta$ (mrad)	gradient error $\Delta k/k$
Bending magnet	200	200	0.1	5×10^{-4}
Quadrupole magnet	100	100	0.2	1×10^{-3}
Sextupole magnet	200	200	0.2	2×10^{-3}

Optics Correction

- Correction of closed orbit distortion
  - 454 BPMs
  - 166 horizontal and 208 vertical steering magnets
- XY coupling correction
  - measurement:
    - vertical orbit response induced by a horizontal single kick due to a steering magnet.
  - corrector:
    - symmetric vertical local bumps at sextupole pairs(-I' connection)
- Dispersion correction
  - measurement:
    - orbit response changing rf frequency.
  - corrector:
    - asymmetric local bumps at sextupole pairs(-I' connection)
- Beta correction
  - measurement:
    - orbit response induced by a single kick due to a steering magnet.
  - corrector:
    - fudge factors to quadrupole magnet power supplies(families)

One of Results Before Optics Correction and After

Error of BPMs: σ_{jitter} = 3 μm, σ_{align} = 40 μm



#samples : 100

Each point means a different seed number to give machine errors.

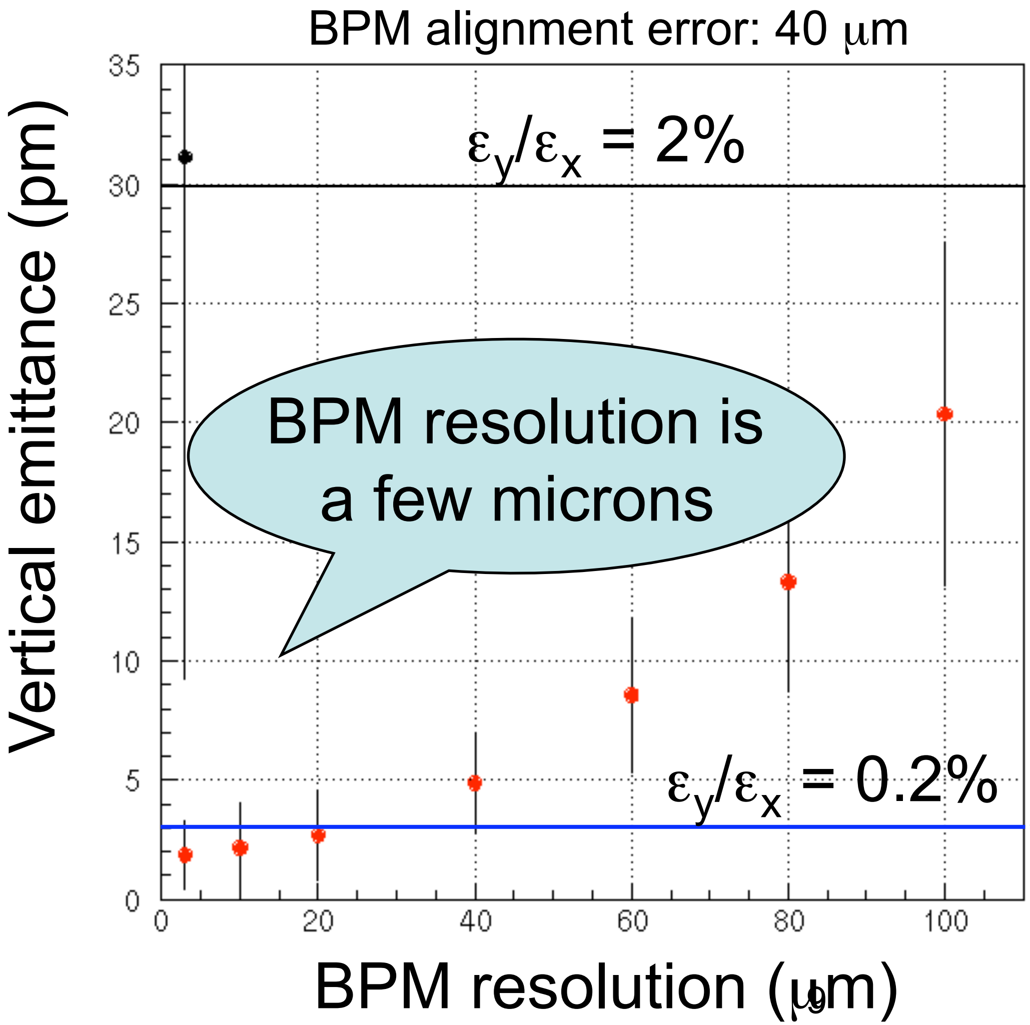
COD correction only

COD+XY+Dispersion +Beta correction

- Optics corrections can achieve $\varepsilon_y/\varepsilon_x$=0.2 %, where ε_x=1.5 nm.
- BPM accuracy of 3 μm resolution(pulse-to-pulse jitter) and 40 μm alignment error is enough to correct the lattice.

BPM Resolution and Optics Correction

Jitter errors of BPM affects corrections of the lattice.



#samples : 100

Black circle:
COD correction only

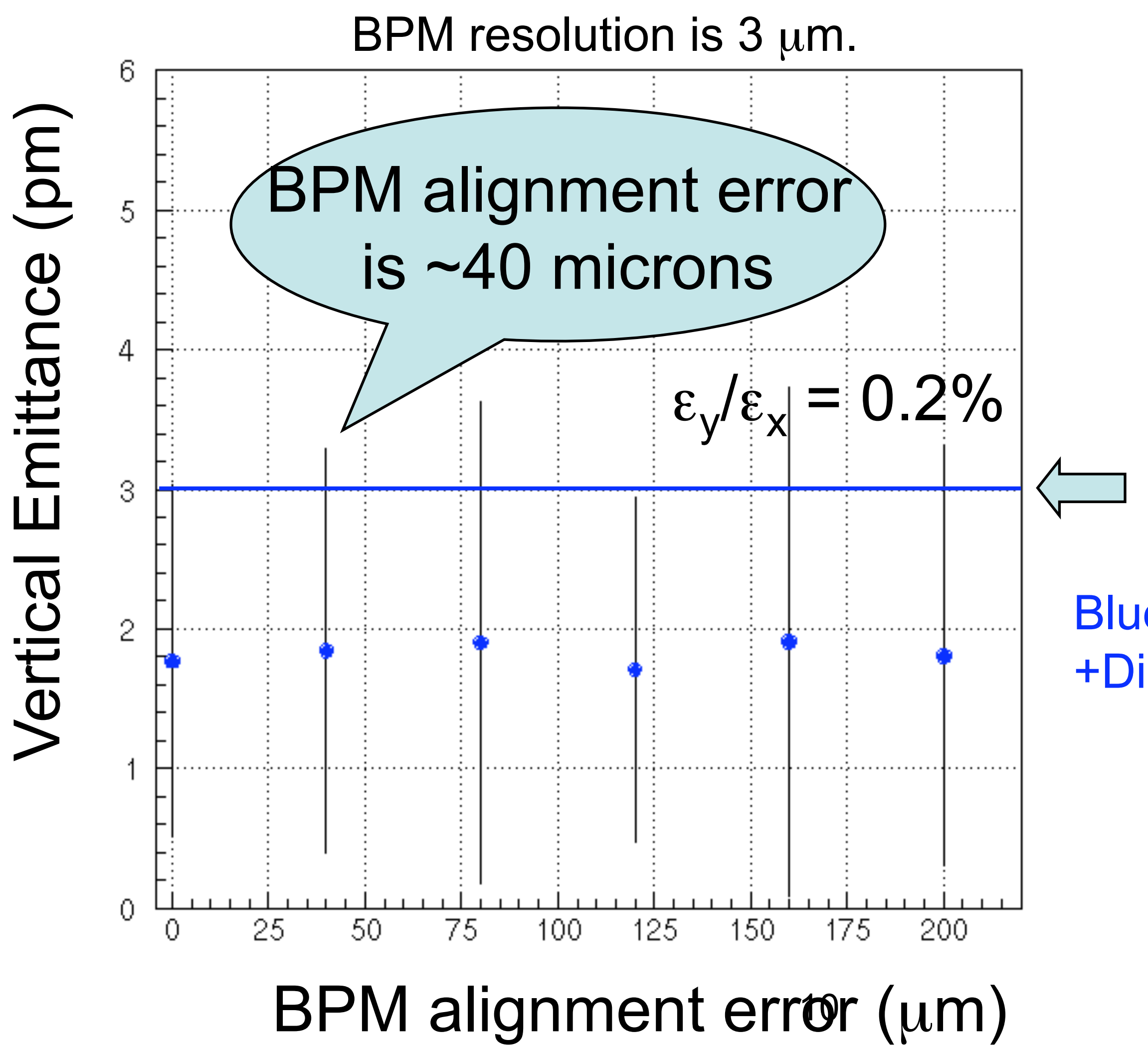
Red circle: COD+XY
+Dispersion+Beta correction

BPM resolution is
a few microns

Target emittance ratio

BPM Alignment and Optics Correction

Alignment errors of BPM does not affect corrections of the lattice.



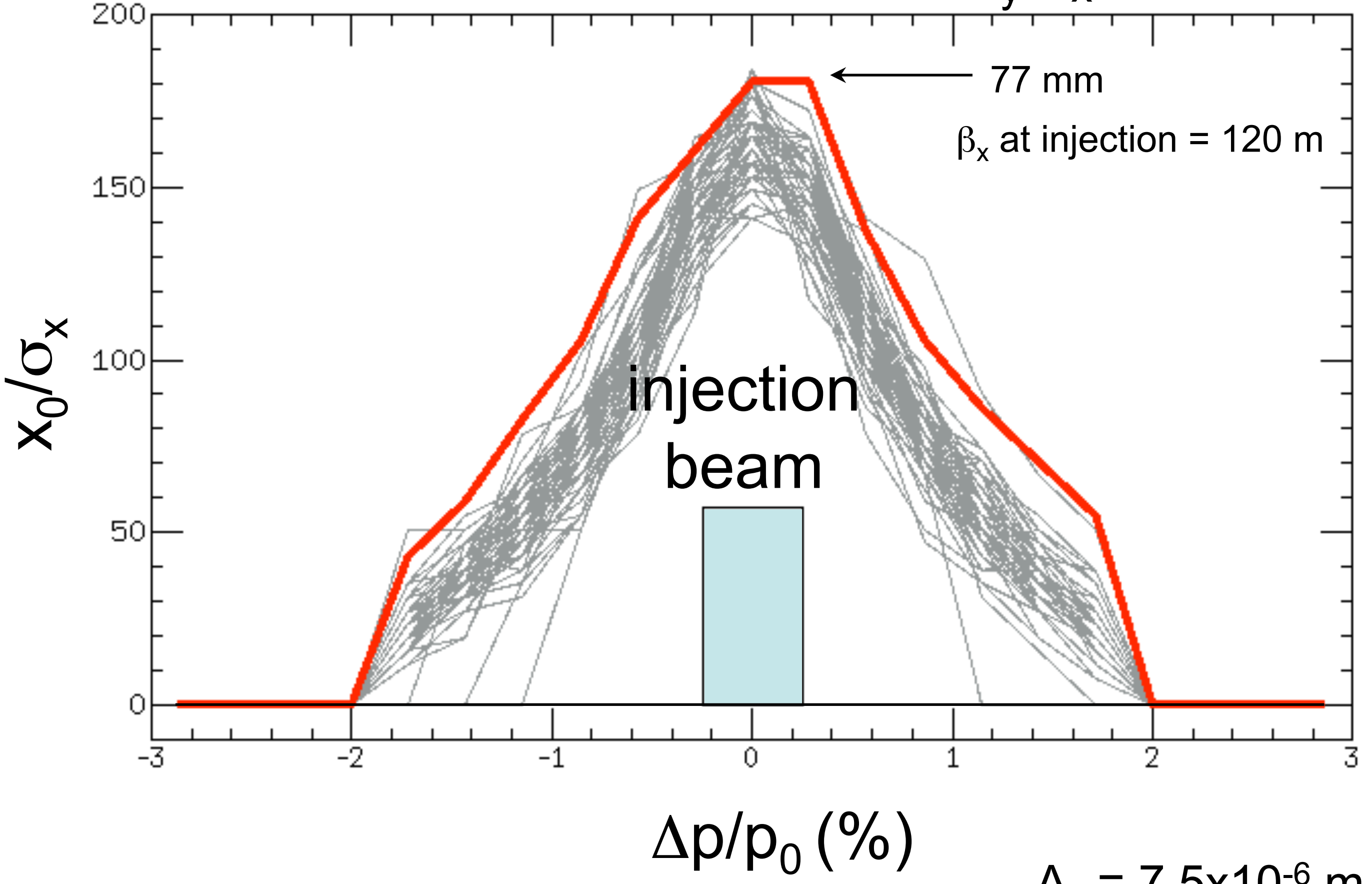
#samples : 100

Target emittance ratio

Blue circle: COD+XY +Dispersion+Beta correction

Dynamic Aperture for Injection Beam

Horizontal aperture with $J_y/J_x = 0.16$

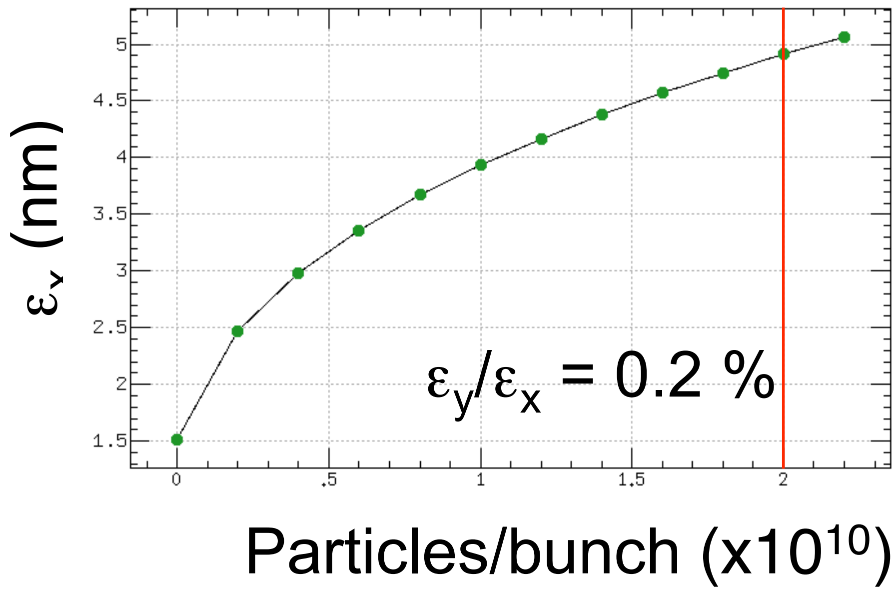


$A_x = 7.5\times10^{-6}$ m
$A_y = 1.2\times10^{-6}$ m

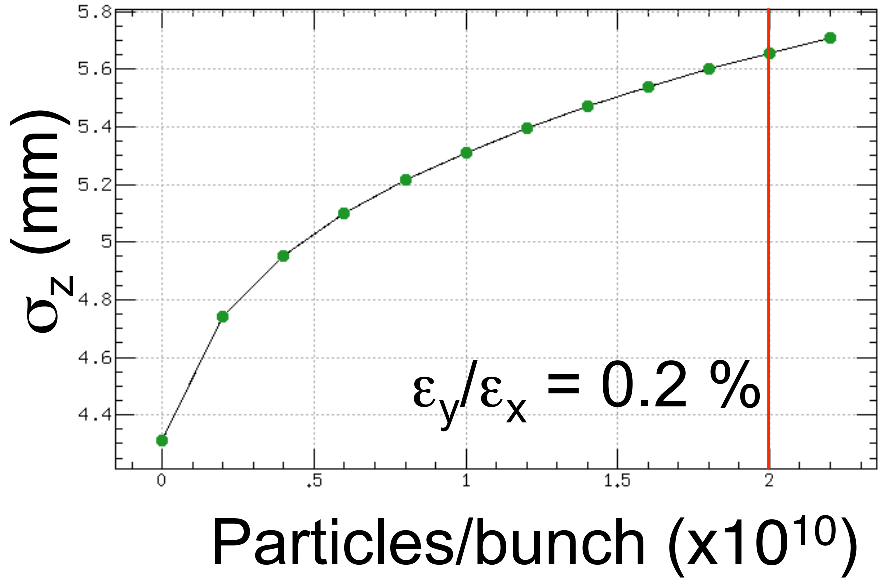
Intra-beam Scattering

E = 2.3 GeV

Emittance



Bunch Length



Touschek lifetime ~ 130 min($\varepsilon_y/\varepsilon_x$=0.2%, N=$2\times10^{10}$)

Electron cloud effect in CesrTA and KEKB-lowε

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

These do not depend on emittance.

- Single bunch instability
- Incoherent emittance growth

These depends on emittance.

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

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

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

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

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

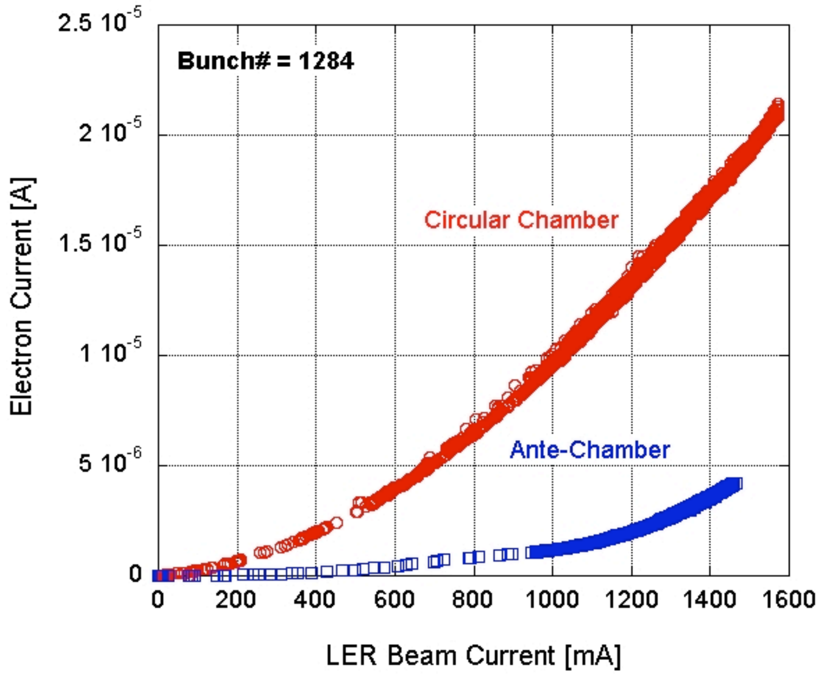
Threshold for various rings

	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

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

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

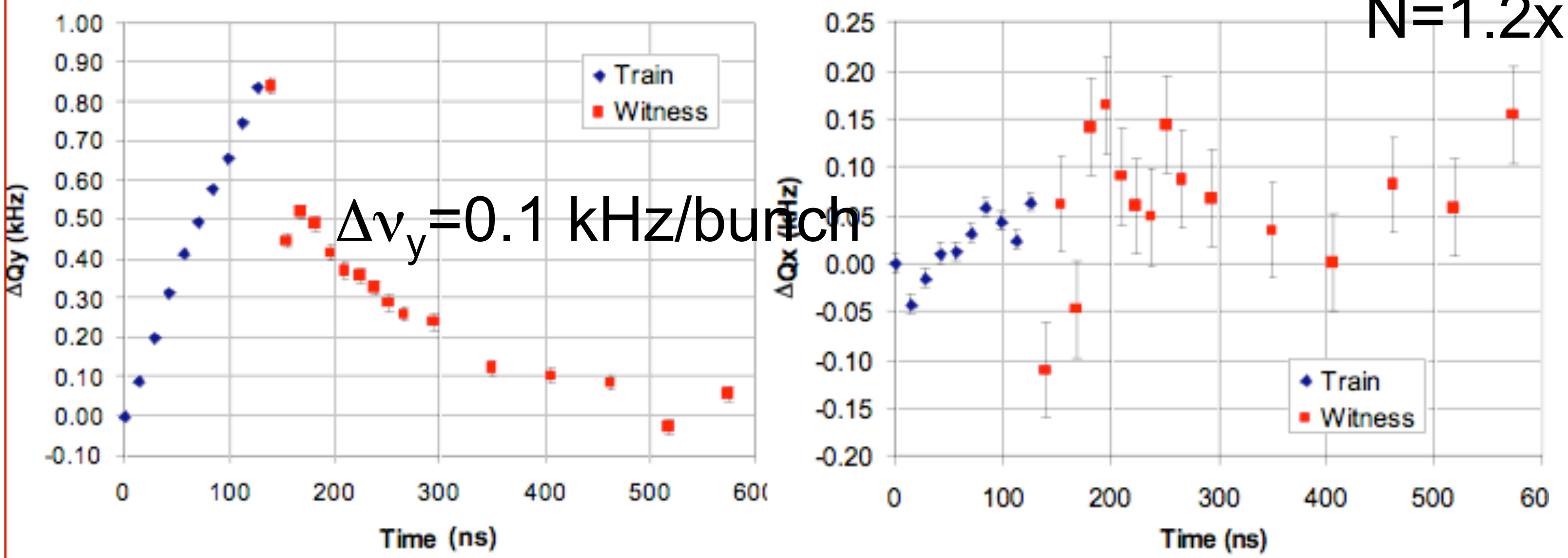
Witness Bunch Studies – e^+ Vertical Tune Shift

- 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

$N=1.2\times10^{10}$

$\Delta\nu_y=0.1$ kHz/bunch



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

$\beta=30$m

Preliminary

Tune shift at KEKB

(T. Ieiri, Proceedings of Ecloud07)

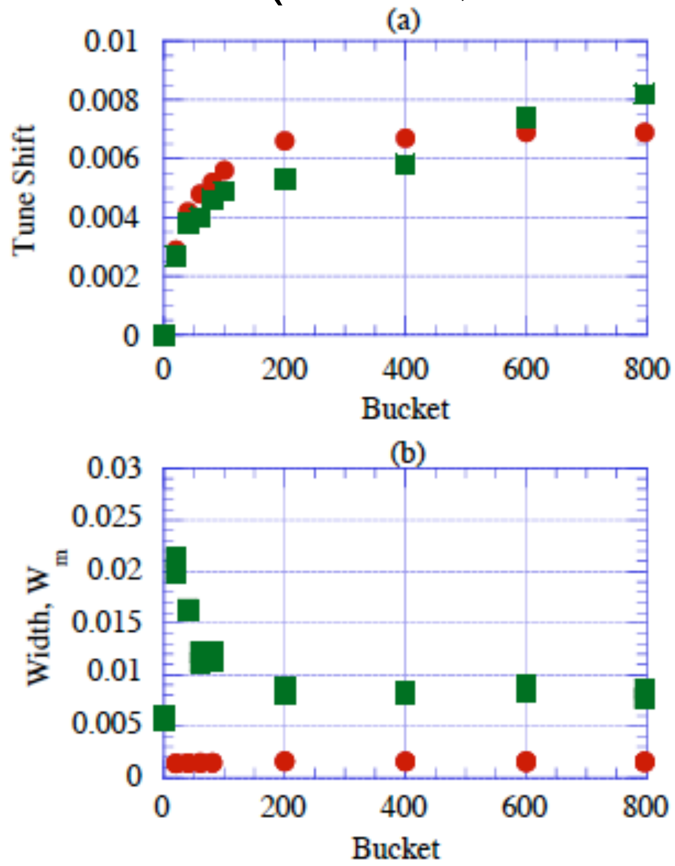


Figure 4: Tune shift (a) and spectrum width (b) along a train. The red dots (horizontal) and green squares (vertical) are measured at a bunch current of 0.5 mA. The tune of the head bunch of the train is used as the reference.

Without solenoid

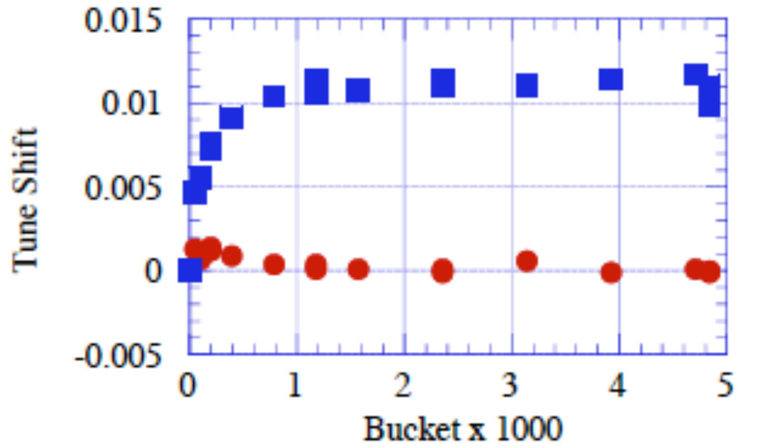


Figure 11: Horizontal (red dots) and vertical (blue squares) tune-shifts along the bunch-train. The bunch current is 1.0 mA with an average spacing of 7 ns.

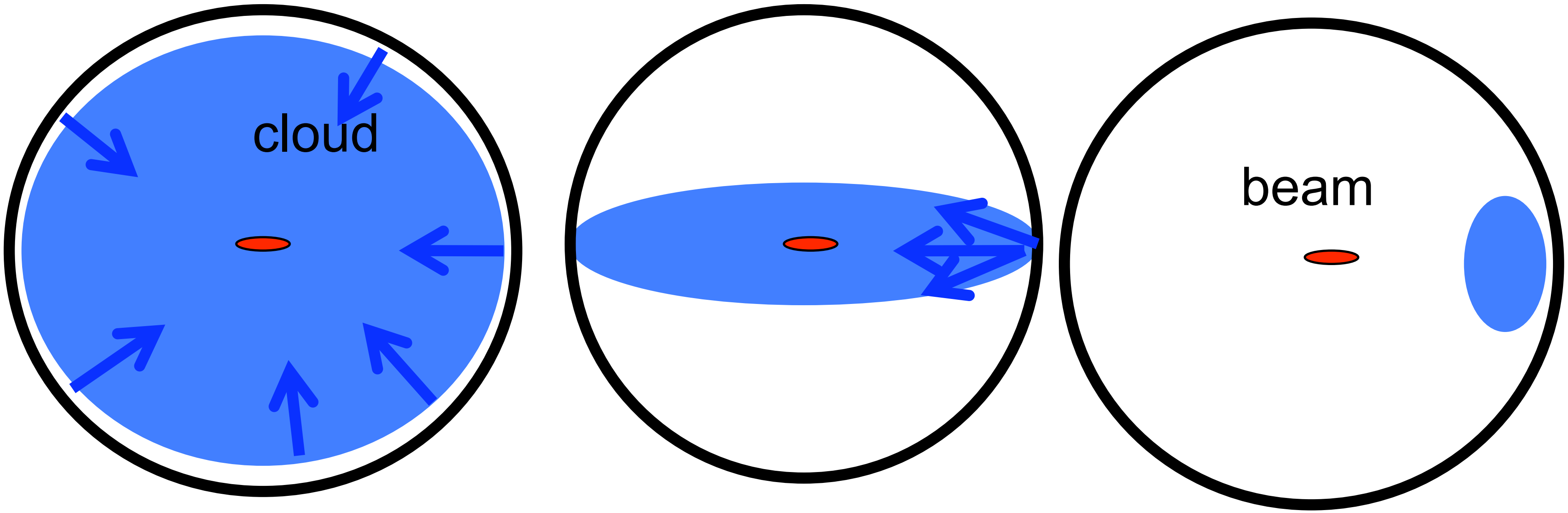
With solenoid

- Both showed similar density because of $\nu_x+\nu_y$=0.015 and 0.012.
- Round cloud for no solenoid and flat cloud for solenoid. How do we think?

Typical cloud distribution and tune shift

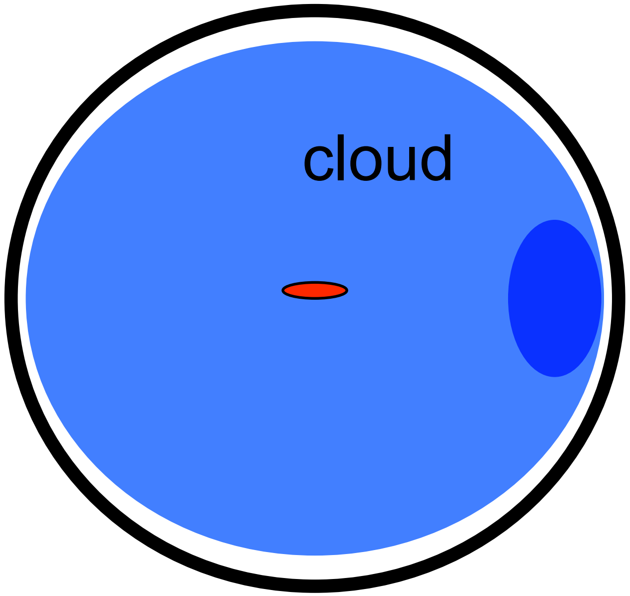
- Tune shift is determined by the electron distribution.
- Electron distribution depends on the initial condition and magnetic filed

Straight section — Magnetic field section



$\Delta\nu_y \sim \Delta\nu_x$ — $\Delta\nu_y > 0 \; \Delta\nu_x = 0$ — $\Delta\nu_y \sim -\Delta\nu_x > 0$

Combination



- $\Delta\nu_y$ >0 $\Delta\nu_x$~0 can be realized, if $\Delta\nu_x$ is cancelled in two distributions.

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-TA 2GeV (arc) =4000 → Y_{pe}=0.034/m, Ec=100 eV
- KEKB 3.5 GeV =7000 → Y_{pe}=0.015/m,

- Bunch population
  $N_p=1.2\times10^{10}$ (0.75mA) 3.3×10^{10} (KEKB)
- electrons created by a bunch passage in a meter
  $N_p \times Y_{pe}=1.0\times10^{9}$ (5GeV) 4.0×10^{8} (2GeV) 4.9×10^{8} (KEKB)
- Increase of volume density per bunch ($\Delta\rho$[$m^{-3}bunch^{-1}$])
  2.0×10^{11} (5GeV) 8.1×10^{10}(2GeV) 6.2×10^{10} (KEKB)
- Tune shift per bunch
  0.00045 (5GeV) 0.00045 (2GeV) 0.00077 (KEKB)
- Beam line density $N_p/4.2=2.9\times10^{9}$ (Cesr) 1.4×10^{10} (KEKB)

Tune shift at the space charge limit

		Cesr 14 ns	Cesr 14 ns	KEKB 8ns
Bunch popu.	Np	1.2e10	2.0e10	3.3e10
Spacing	Lsp (m)	4.2	4.2	2.4
Line density	$\lambda p\ (m^{-1})$	2.9e9	4.8e9	1.4e10
Neutralized density	$\rho_e (m^{-3})$	5.7e11	9.5e11	1.7e12
Tune shift	$\Delta\nu$	0.0032	0.0053	0.021

- Threshold density can be achievable for 6 ns spacing in Cesr.
- Electron cloud neutralized in the whole ring is necessary to cause instability.
- The tune shift at the instability threshold is somewhat ambiguous, see later.

Wiggler section in Cesr

- 1.3m (1m effective)x12, 2.1T, θ_{tot}=3.78 rad.
- $N_{pe,tot}=15.9\times2\times10^{10}=3.2\times10^{11}$ (5.2×10^{11} in arc).
- If the electrons localized in 20 m (for example), electrons are accumulated by $N_{pe}=2.6\times10^{10}$ $m^{-1}bunch^{-1}$.
- Beam line density $N_p/4.2=4.8\times10^{9}$ 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.

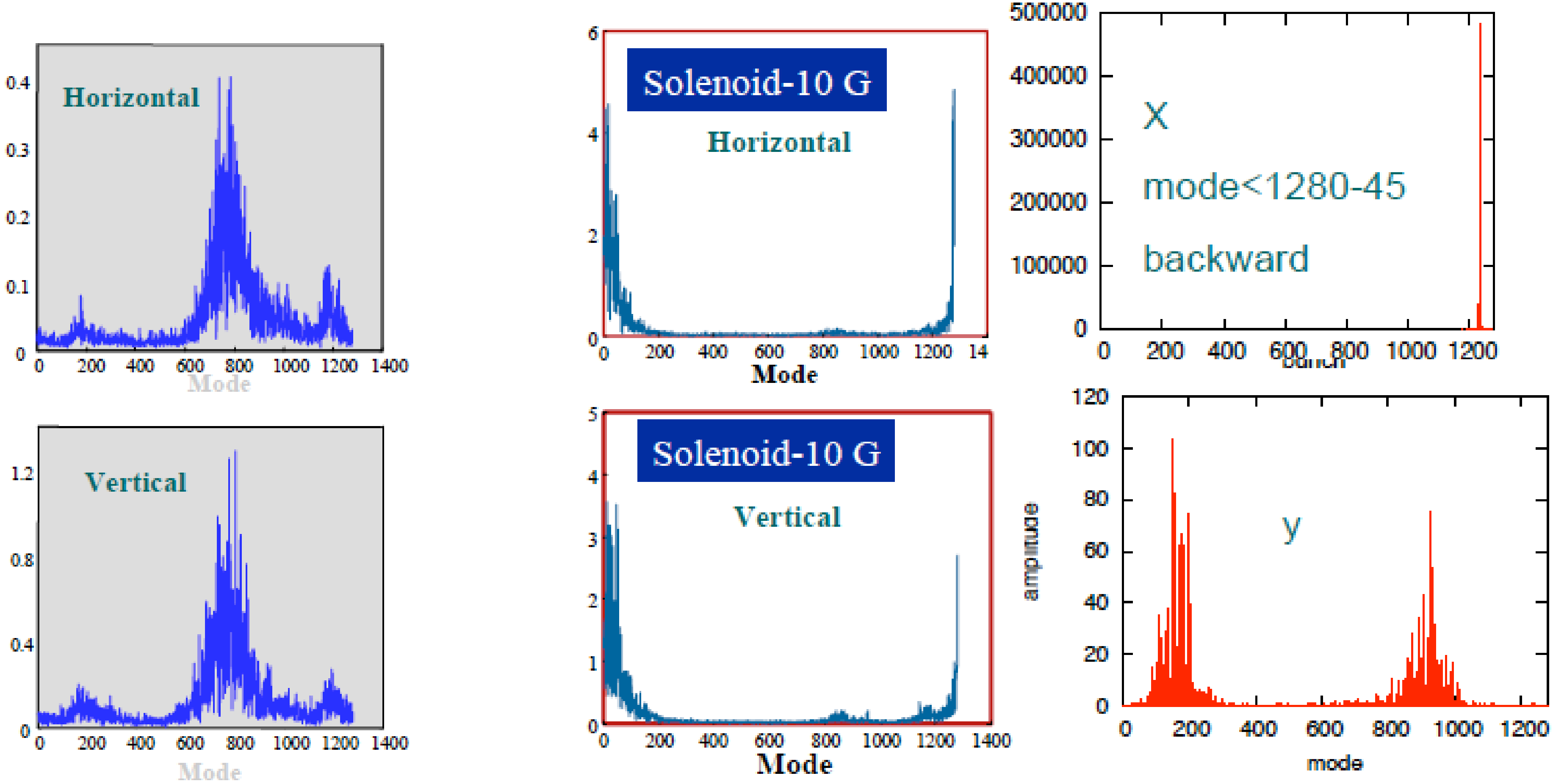
Tune shift at the threshold

	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	2.92E+12	1.91E+11	7.67E+11
dnx+y@th	0.0078	0.0047	0.0023	0.0162	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

- The tune shift $\Delta\nu_x+\Delta\nu_y$ near the threshold at KEKB is ~0.015.The threshold tune shift is smaller than the measurement.
- Tune is complex quantity. We are not sure whether the simple formula is applicable for considering coherent tune shift.

Motion of electrons reflects unstable mode of the coupled bunch instability

drift | solenoid | bend



Comment on Cesr 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}, 4-6 ns spacing, may achieve the threshold ρ_e~2.9x10^{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. The spectrum gives information where electrons exist.

CesrTA and KEKB lowe

- Momentum compaction

  Cesr: high KEKB:low

- Cloud density by photoemission

  Cesr:high KEKB: low(solenoid)