Emittance growth
Modeling and Experiments

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Coherent instabilities due to electron cloud

Single bunch instability

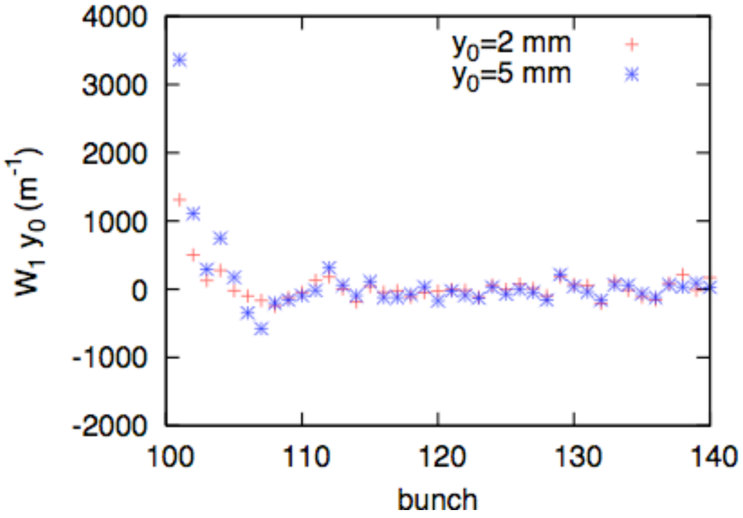
- Threshold is determined by balance with Landau damping due slippage (momentum compaction) factor.
- Dependent on emittance
- Depend only on local electron cloud density

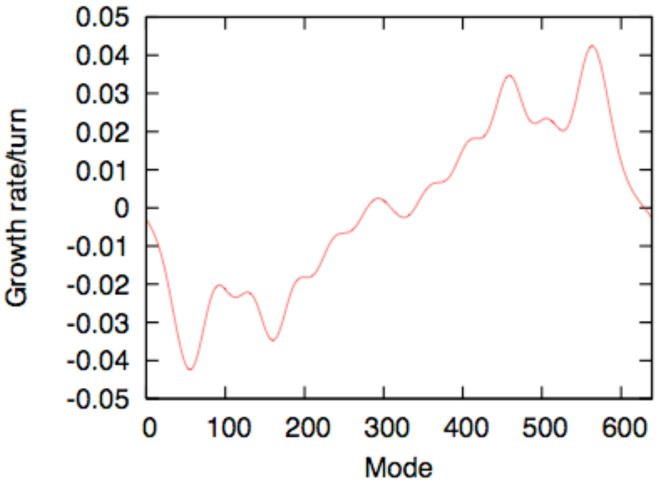
Coupled bunch instability

- Threshold is determined by balance with other damping effects.
- Independent on emittance.
- Independent on momentum compaction.
- Depend on electron cloud density, distribution and motion.

Measurement of electron cloud induced Coupled bunch instability

- Np=1x10^{10}, 4 ns spacing uniformly for example. Number of bunch is 640.
- Cut off the feed back power and measure the positions of all bunches turn by turn.
- Growth time ~25 turn, 64 μsec for this condition.
- Experiments can be done bunch trains with a long length(~100), if the uniform filling is hard.





This spectrum is given for free electron motion. If bending magnet is dominant, different spectrum is obtained.

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

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

- 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.
- $\omega_e\sigma_z/c$~12-20 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	CESR chess	CesrTA	ILC-OCS	PEPII
L	3016	3016	3016	768.44	768.44	6695	2200
gamma	6849	6849	4501	10372	3914	9785	6067
Np	3.30E+10	7.60E+10	2.00E+10	1.12E+11	2.00E+10	2.00E+10	8.00E+10
ex	1.80E-08	1.80E-08	1.50E-09	1.11E-07	2.30E-09	5.60E-10	4.80E-08
bx	10	10	10	10	10	30	10
ey	2.16E-10	2.16E-10	6.00E-12	1.11E-09	1.50E-12	2.00E-12	1.50E-09
by	10	10	10	10	10	30	10
sigx	4.24E-04	4.24E-04	1.22E-04	1.05E-03	1.52E-04	1.30E-04	6.93E-04
sigy	4.65E-05	4.65E-05	7.75E-06	1.05E-04	3.87E-06	7.75E-06	1.22E-04
sigz	0.006	0.007	0.009	0.0173	0.009	0.006	0.012
nus	0.024	0.024	0.011	0.0487	0.098	0.067	0.025
Q	3.6	5.9	7	4.7	7	7	3.7
omegae	1.79E+11	2.51E+11	5.29E+11	8.20E+10	6.84E+11	6.31E+11	9.20E+10
phasee	3.6	5.9	15.9	4.7	20.5	12.6	3.7
K	3.6	5.9	12.5	4.7	20.5	12.6	3.7
rhoeth	6.25E+11	3.81E+11	1.22E+11	5.73E+12	2.92E+12	1.91E+11	7.67E+11

Tune shift at the threshold

	KEKB	KEKB	KEKB-DRt	Cesr chess	CesrTA	ILC-OCS	PEPII
L	3016	3016	3016	768.44	768.44	6695	2200
gamma	6849	6849	4501	10372	3914	9785	6067
Np	3.30E+10	7.60E+10	2.00E+10	1.12E+11	2.00E+10	2.00E+10	8.00E+10
ρ_{eth}	6.25E+11	3.81E+11	1.22E+11	5.73E+12	2.92E+12	1.91E+11	7.67E+11
$\Delta\nu_{x}+_{y}$@th	0.0078	0.0047	0.0023	0.0120	0.0162	0.0111	0.0078
DampT-xy	40	40	75	22	56.4	26	40
DampR-xy	2.51E-04	2.51E-04	1.34E-04	1.16E-4	4.54E-05	8.58E-04	1.83E-04

- This threshold seems to be very high to detect in Cesr-TA experiments.
- But,…

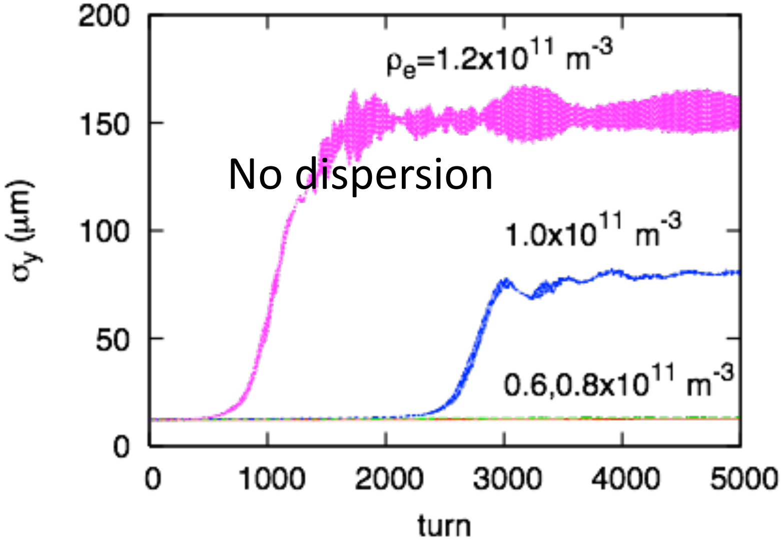
Effect of horizontal dispersion

- Horizontal dispersion degrade the threshold of fast head-tail instability caused by electron cloud (K. Ohmi, proceedings of Snowmass 2005).

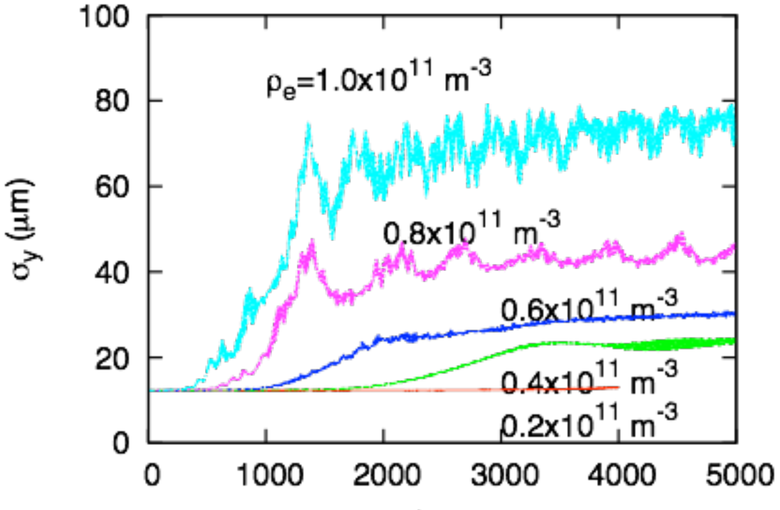
- The oscillation of electron depends on its x coordinate.
- Electrons move in the horizontal plane.
- Thus vertical wake field due to electron cloud is also a function of x.
- Dispersion dominant beam $x=\eta p_z$, where $p_z=\Delta p/p$
- The wake field is actually a function of z and $p_z=\Delta p/p$. The threshold is degraded.

Simulation results, By=0

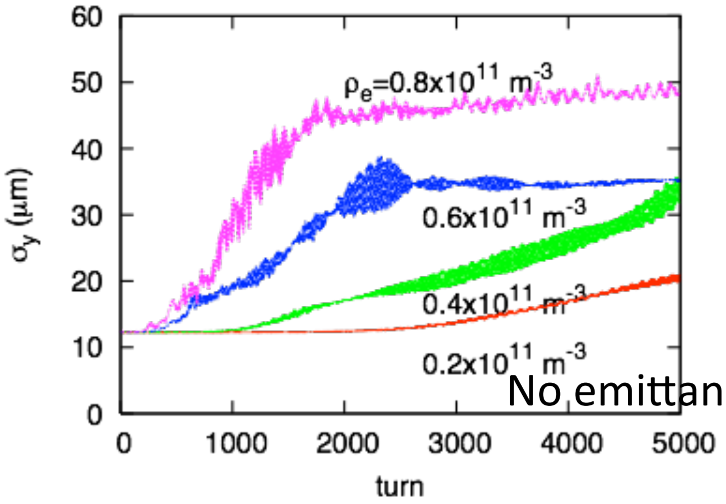
- Dispersion degrades the threshold.



No dispersion



Emittance and Dispersion

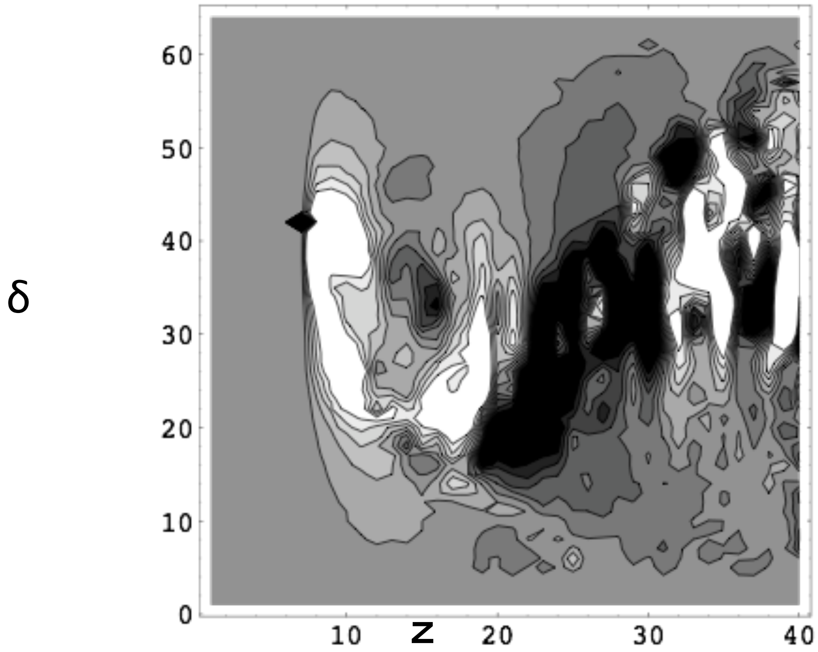


No emittance but dispersion

Vertical wake field in x-z plane

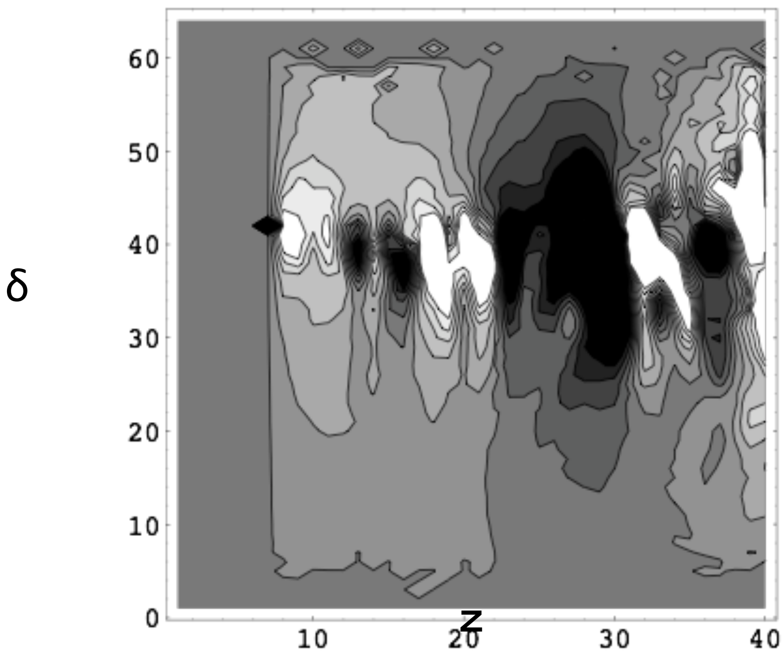
- Wake field is not planar wave along z. W(z,x,z’,x’)
- The wake can be W(z,δ,z’, δ’) due to the dispersion

B=0T



strong correlation for δ

B=1T



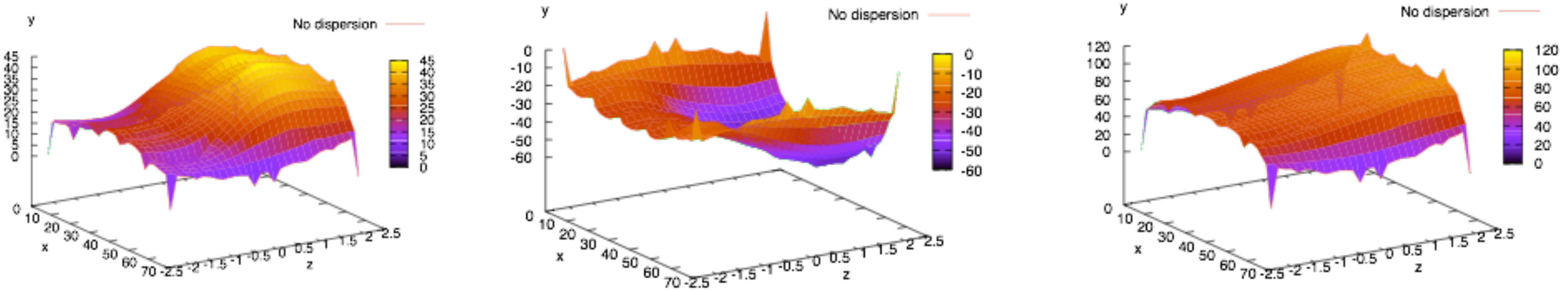
No corelation

z z

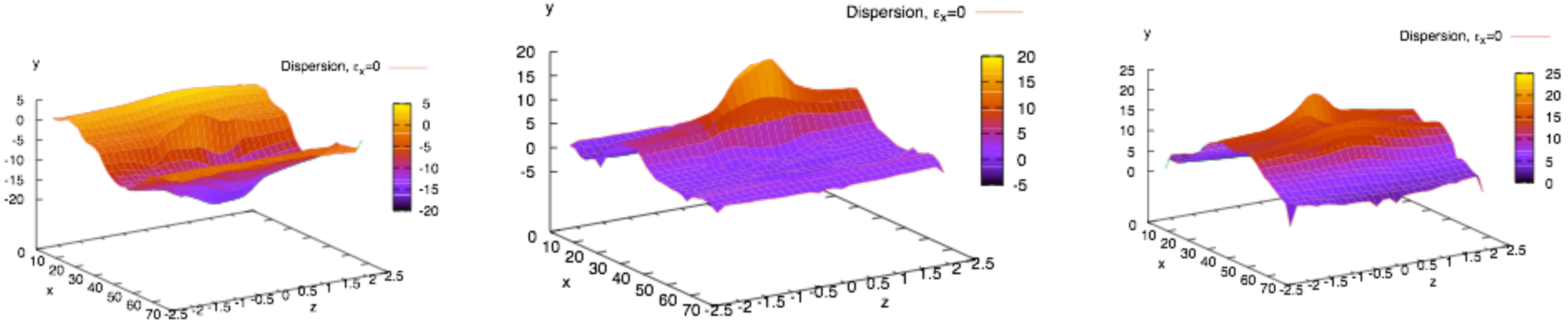
Unstable oscillation

- Vertical dipole amplitude in x-z space

No dispersion

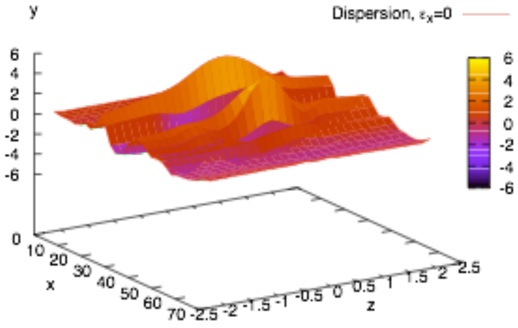


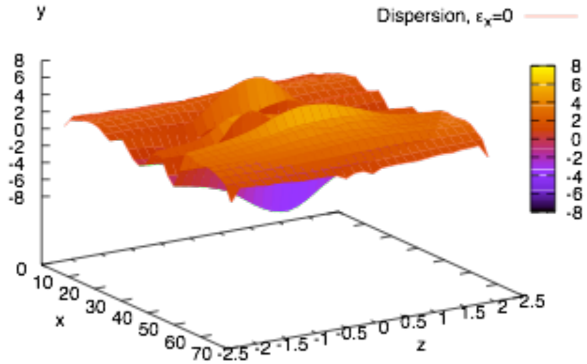
Dispersion, No emittance

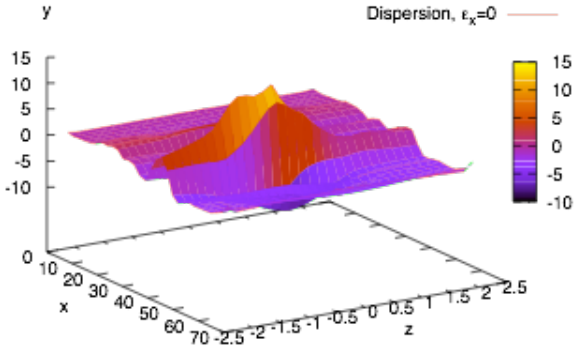


Unstable oscillation B=1T

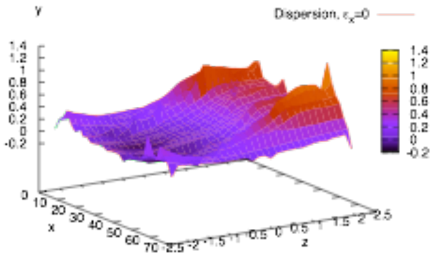
- Dispersion, No emittance, Weak correlation for x (δ)

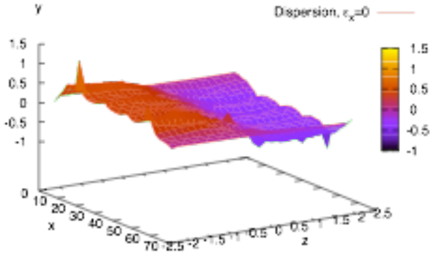


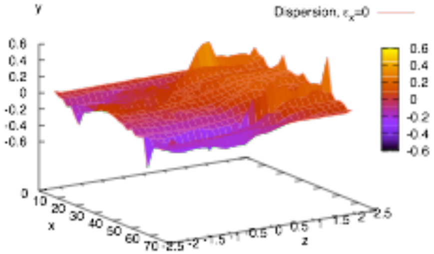




No dispersion, equal betatron phase for x(δ)

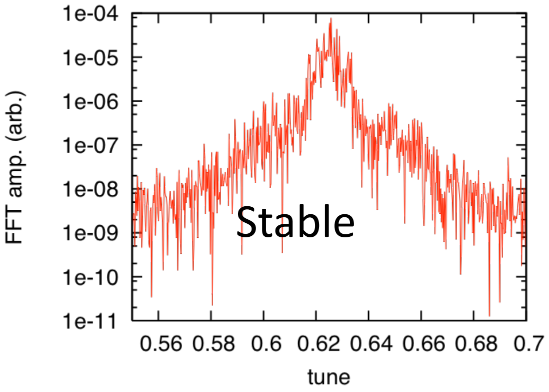


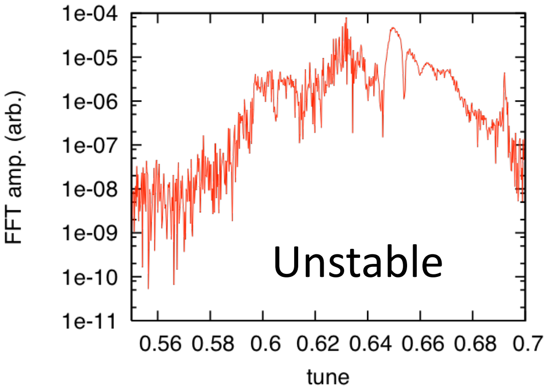


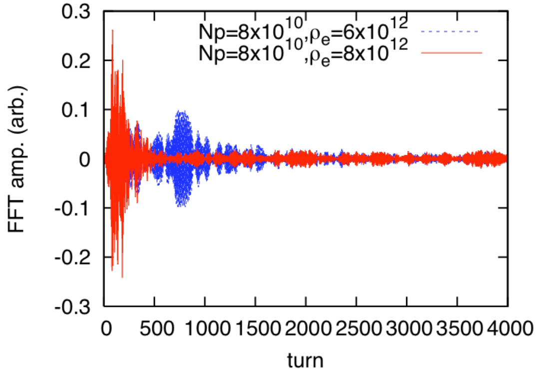


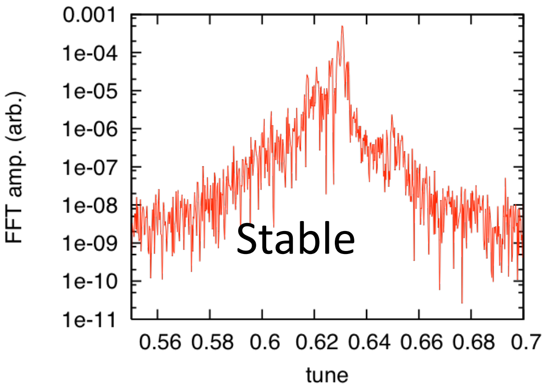
Typical unstable mode of the instability

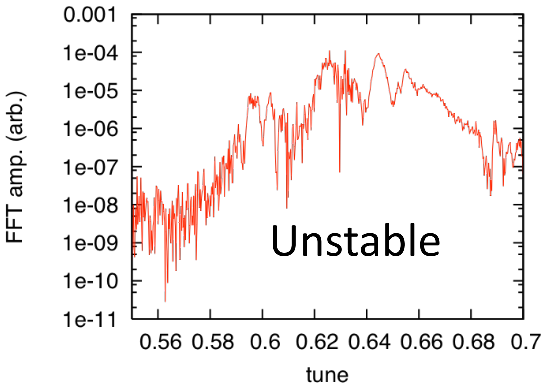
- FFT spectra under and over the threshold in the simulations
- ν_{y0}=0.6, ν_s=0.0486











Maybe signal near ν_β+ν_s is observed.

Experiment for the coherent signal in this summer

- Coherent single bunch instability may be observed in Cesr-TA due to the threshold degradation.
- Detailed threshold density will be evaluated before experiments.
- Beam size and synchro-beta sideband should be measured. It is better to measure bunch by bunch.

Incoherent emittance growth

- Studied and observed in beam-beam and space charge effects.
- Related to resonance and chaotic behaviors of beam particle motion.
- Beam-beam is localized interaction. All resonance harmonics exist.
- Electron cloud and space charge is not localized. Lattice structure, super period, cloud density distribution along s determines resonance harmonics. For the same tune shift as beam-beam, the incoherent effect due to electron cloud may be weaker than that due to beam-beam.

Results of the experiment in 2008

- This type of emittance growth should depend on tune.
- Beam size measurement in tune space is
- No clear emittance growth relate to resonances were not seen, even very high current 7mA/bunchx10bunch, 14ns. While beam-beam interaction induced many resonances.
- The resonance line ν_x-ν_y-2ν_s=n is weakened as similar as KEKB.

Experiment for the incoherent signal in this summer

- Measure the beam size bunch by bunch.
- Check no coherent signal.
- Measure the beam size in tune space. It is better to measure bunch by bunch, because tune shift depends on bunch position in the train.
- Simulations will be done to compare the measurements.