Electron cloud instability measurement at CesrTA

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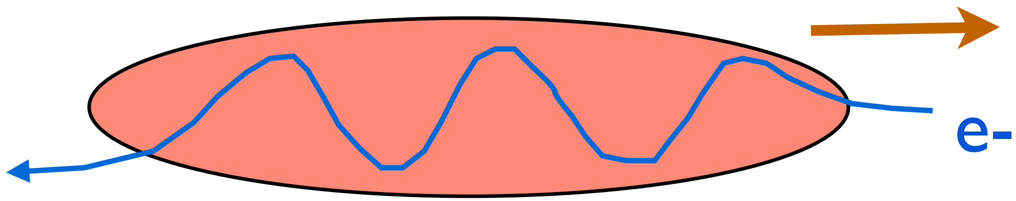
Contents

- Strong head-tail instability
- Incoherent emittance growth
- Coupled bunch 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.



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

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

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

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

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

$$\rho_{e,th} = \frac{2\gamma\nu_s \, \omega_e \sigma_z / c}{\sqrt{3} K Q r_0 \beta L}$$

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.

Parameters for the instability

- Threshold

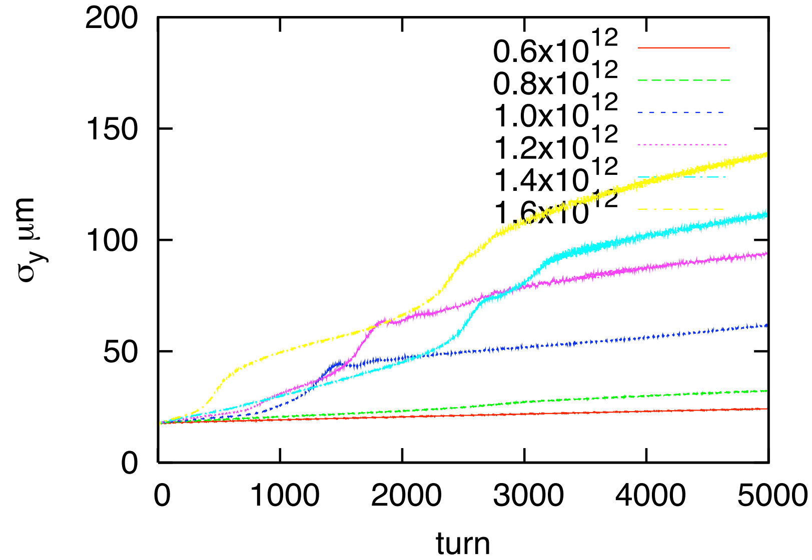
		KEKB	PEP-II	Cesr-TA/5	Cesr-TA/2	ILC-DR
Circumference	L(m)	3,016	2,200	768	768	6,414
Energy	E	3.5	3.1	5.0	2.1	5.0
Bunch population	$N_+(10^{10})$	8	8	2	2	2
Beam current	I_+ (A)	1.7	3.0	-	-	0.4
Emittance	ε_x(nm)	18	48	40	2.6	0.5
Momentum compaction	$\alpha(10^{-4})$	3.4		62.0	67.6	4.2
Bunch length	σ_z(mm)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

		KEKB[1]	KEKB[2]	PEP-II	Cesr-TA/5	Cesr-TA/2	ILC-DR
Bunch population	$N_+(10^{10})$	3	8	8	2	2	2
Beam current	I_+ (A)	0.5	1.7	3.0	-	-	0.4
Bunch spacing	ℓ_{sp}(ns)	8	7	4	4	4	6
Electron frequency	$\omega_e/2\pi$(GHz)	28	40	15	9.6	43	100
Phase angle	$\omega_e\sigma_z/c$	3.6	5.9	3.7	3.2	11.0	12.6
Threshold	ρ_e (10^{12} m^{-3})	0.63	0.38	0.77	7.40	1.70	0.19
Tune shift at ρ_e	$\Delta\nu_{x+y}$	0.0078	0.0047	0.0078	0.016	0.009	0.011

Simulation of the strong head-tail instability

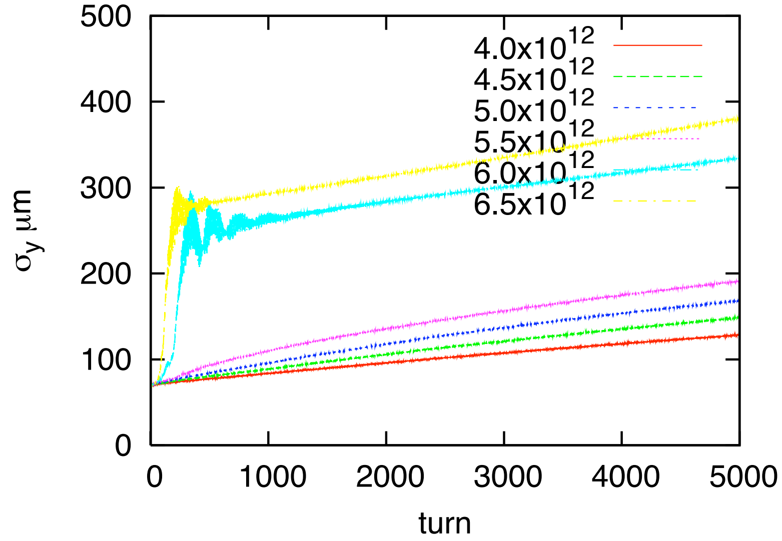
- Uniform beta model, integration step is L/8.

2 GeV



$\rho_{th}=1.0\text{x}10^{12}$ cm^{-3}

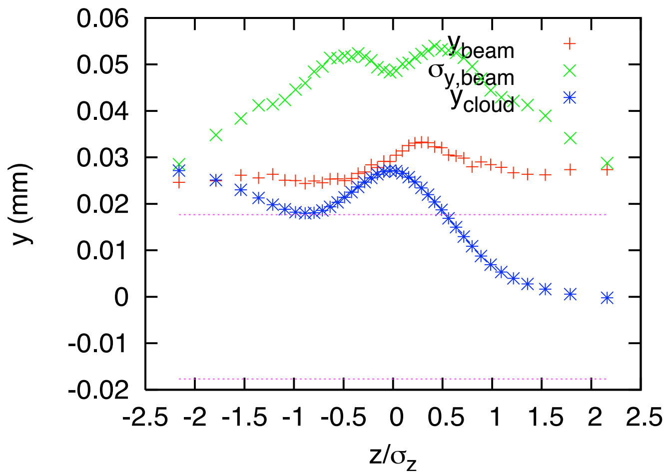
5 GeV



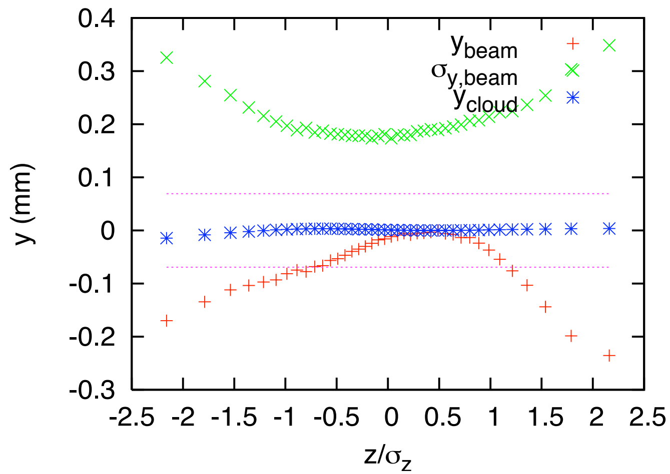
$6\text{x}10^{12}$ cm^{-3}

Coherent motion in the simulation

2 GeV



5 GeV



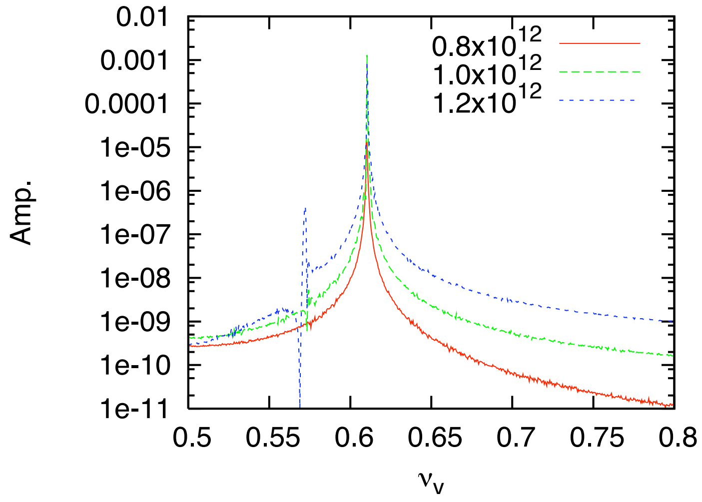
Measurements

- Measure the beam size as a function of the beam current.
- Measure the beam size along the bunch train.
- Fourier spectra of the position monitor and beam size monitor.

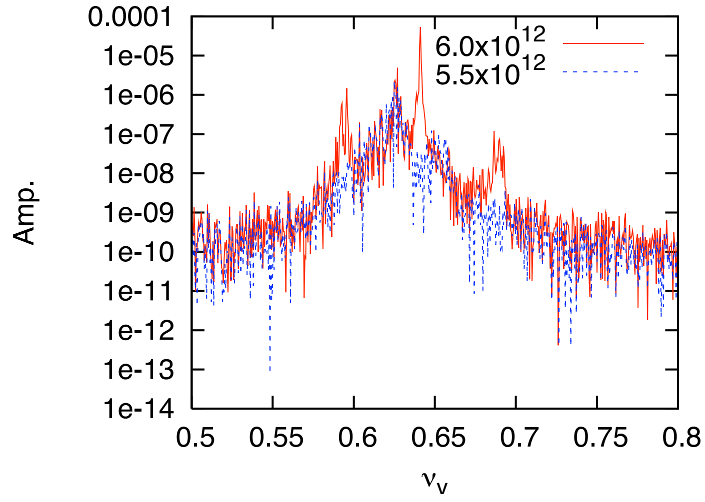
Fourier spectra in the simulation

$\nu_{y0}=0.6$

2GeV — $\nu_s=0.055$



5GeV — 0.0454

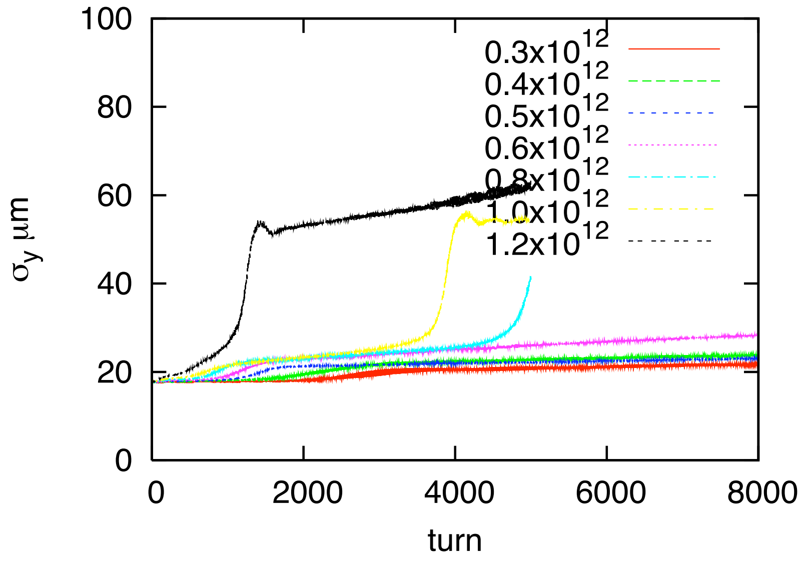


The spectra depend on choice of the cloud size, different between cloud size~σ_y or >>σ_y. Right solution should be given for cloud size>>σ_y.

Effect of dispersion

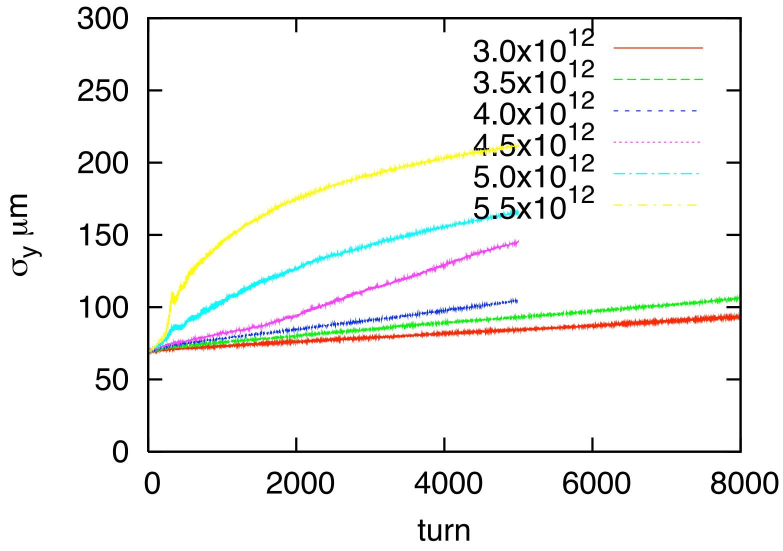
- η_x=1.5 m

2 GeV



ρ_{th}=0.8x10^{12} cm^{-3}

5 GeV

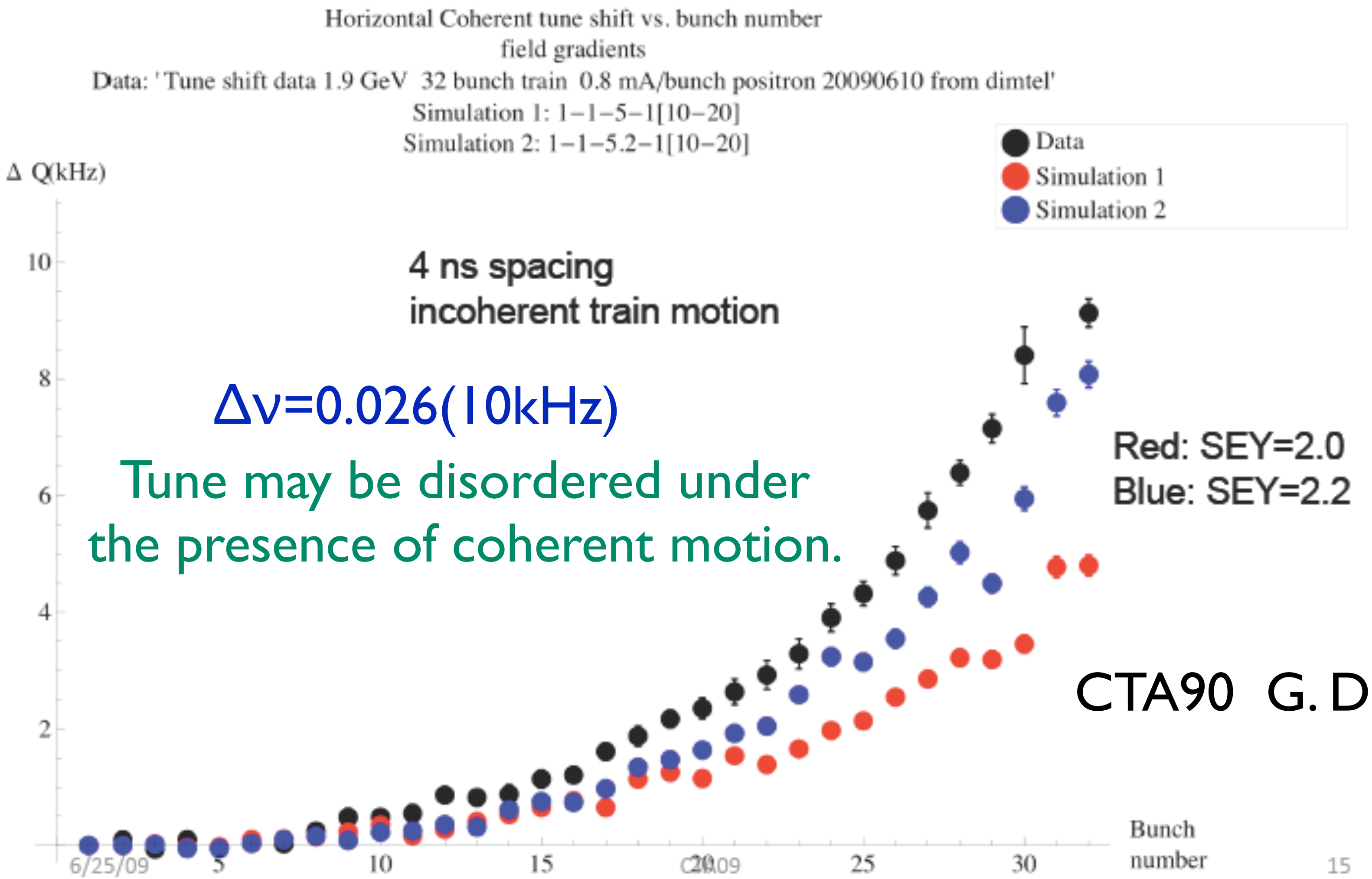


4.5x10^{12} cm^{-3}

- Not big effect

Cornell University
Laboratory for Elementary-Particle Physics

2.1 GeV positrons 32 bunch train



4 ns spacing
incoherent train motion

$\Delta\nu=0.026(10\text{kHz})$

Tune may be disordered under the presence of coherent motion.

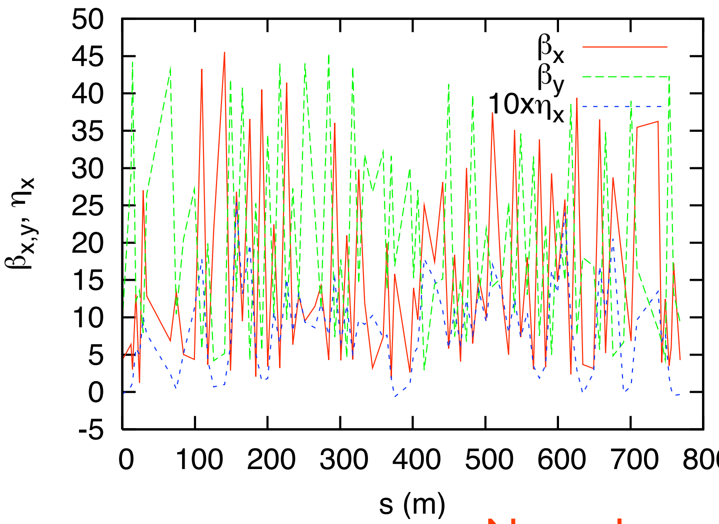
Red: SEY=2.0
Blue: SEY=2.2

CTA90 G. Dugan

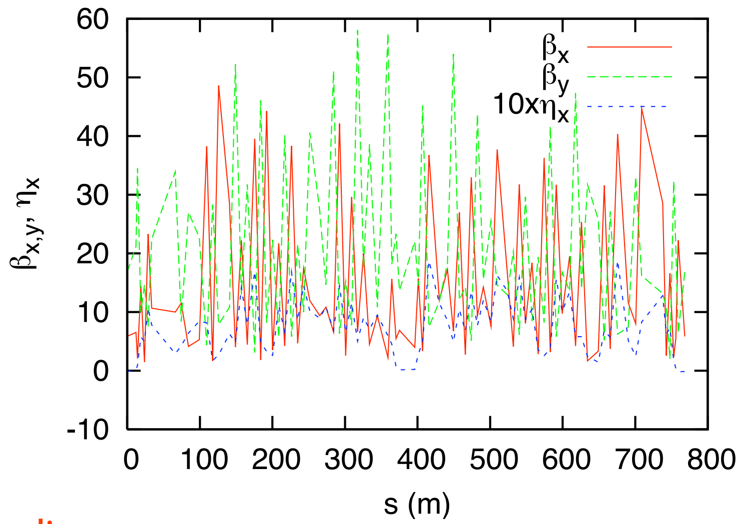
Incoherent emittance growth

- Electron cloud is located in bending magnets.
- β, phase and η are taken into account.

2 GeV



5GeV



Note: plot only at bending magnets

Emittance growth due to nonlinear diffusion

- Nonlinearity in one turn map

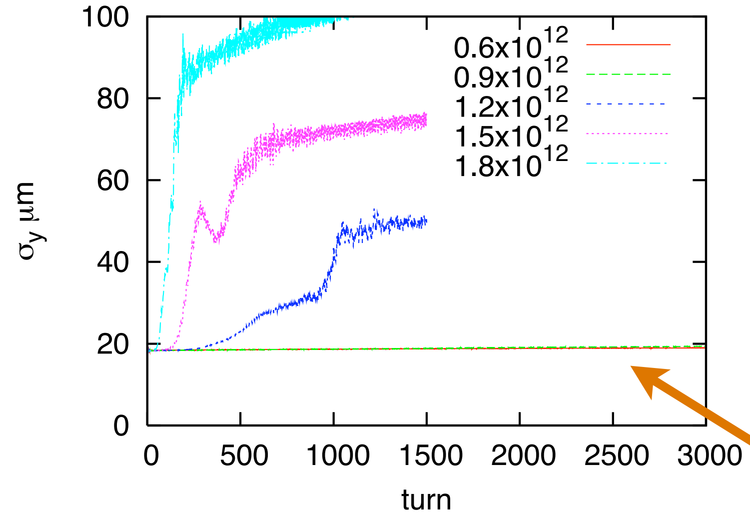
$$H_n \sim \oint a_n(s) x(s)^n |_{x(s)=\sqrt{\beta/\beta_0}\cos\varphi(s)x_0+\ldots} ds = \oint a_n(s) \frac{\beta(s)^{n/2}}{\beta_0^{n/2}} \cos n\varphi(s) ds \times x_0^n + \ldots$$

- Electron cloud density ~a(s) β, phase are integrated.
- Uniform β model cancels phase dependence, therefore no emittance growth, H(J).
- β and phase variations are essential for the emittance growth.

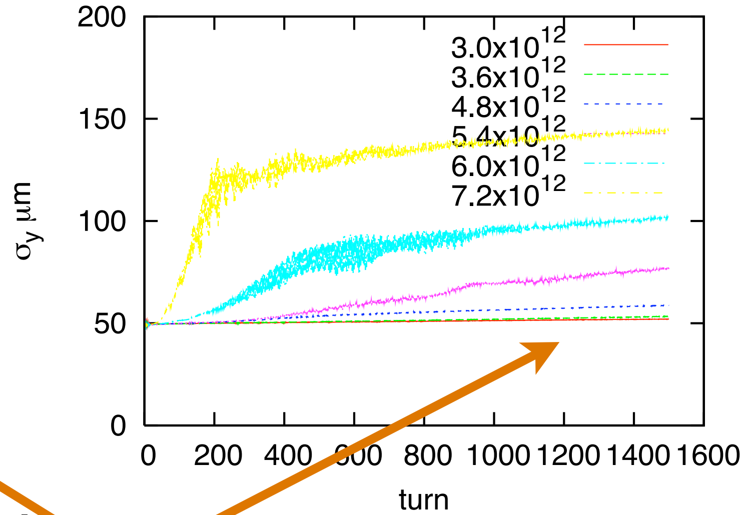
Simulation of the Incoherent emittance growth

- Bending magnet section 475/768 m
- The electron density ρ is the averaged one, ρ_{bend}x475/768

2 GeV



5 GeV



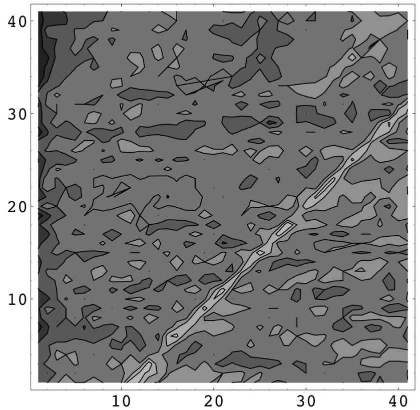
- Incoherent growth is very slow.

ρ_{th}=1.2x10^{12} cm^{-3} 5.4x10^{12} cm^{-3}

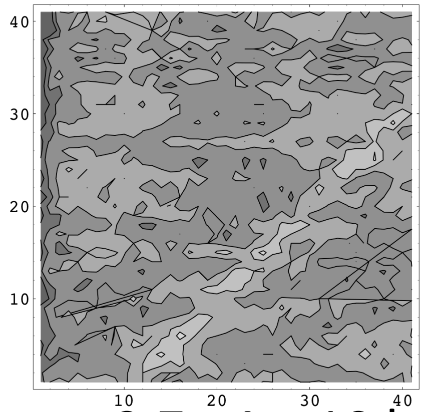
When electrons distribute also in drift space, the incoherent growth may be slower.

Measurement of the incoherent emittance growth

- The same beam size measurement as is done for coherent strong head-tail.
  - ★ Beam size measurement as a function of the beam current.
  - ★ Measure the beam size along the bunch train.
  - ★ Fourier spectra (check no coherent signal).
- Beam size measurement in tune space, ν_x-ν_y.



single bunch

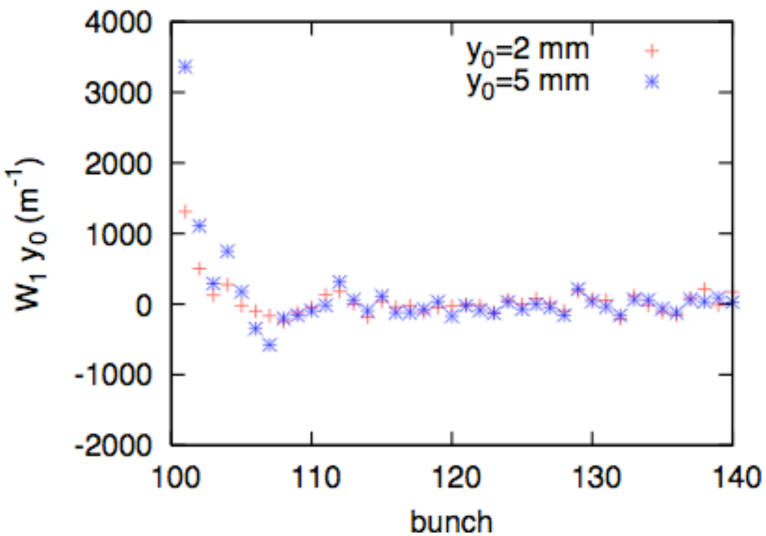


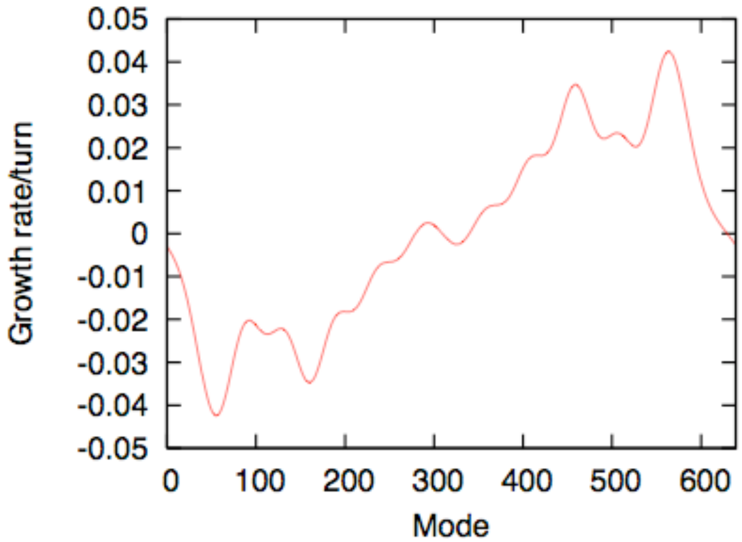
2.7mA x 10 bunches, 14ns

No signal in the measurement on June 27-29, 2008.
5.3 GeV chess mode

Measurement of electron cloud induced Coupled bunch instability

- Np=1x10^{10}, 4 ns spacing uniformly for example. Number of bunch is 640. It is possible to do 14 ns, 90 bunches.
- The analysis is easy for uniform filling, but is possible for partial filling.
- 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.





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