Electron cloud effects (ECE) at KEKB

- A review of experimental study -

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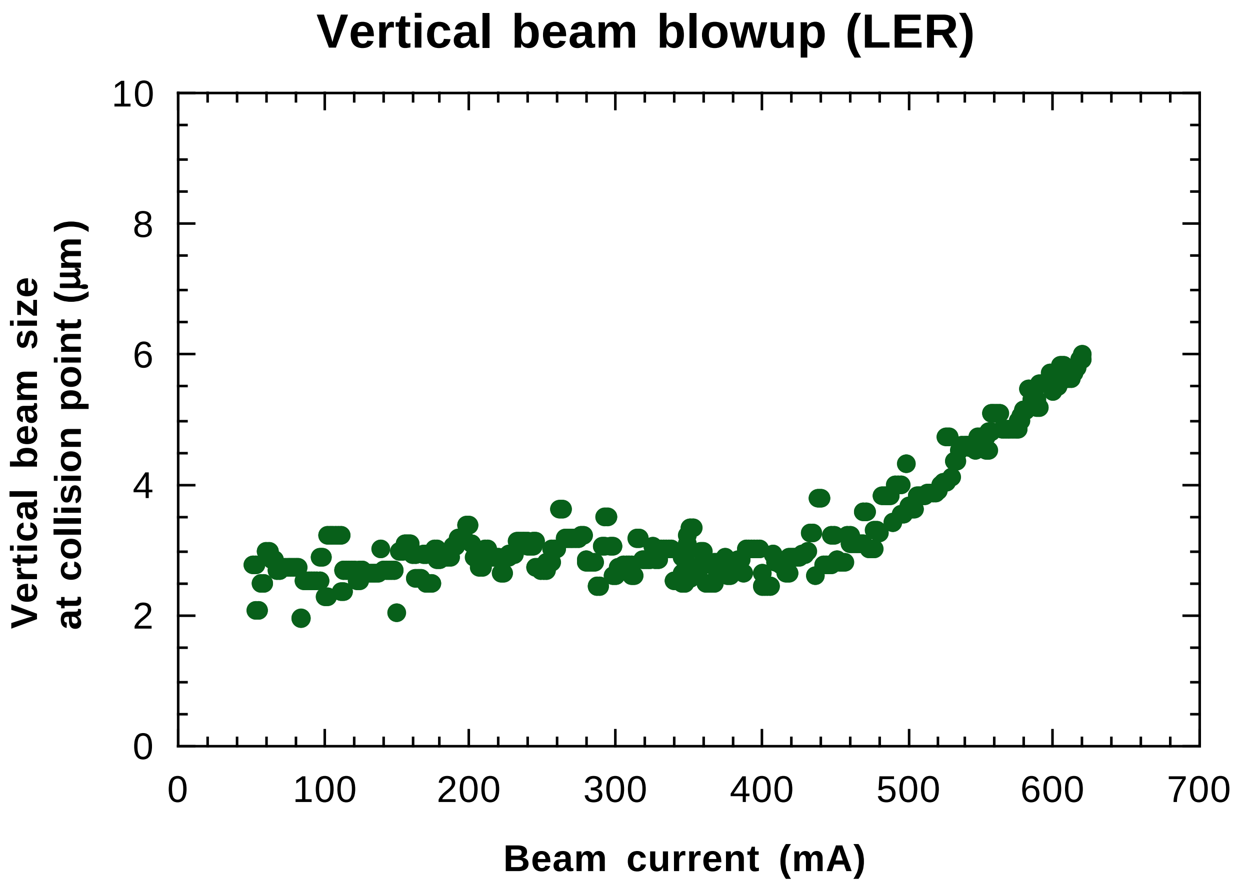
H. Fukuma, KEK, for KEKB group

Outline

1. Introduction
2. Cloud build-up
3. Beam size blowup
4. Coupled bunch instability
5. Effect of solenoid on ECE
6. Open questions
7. Summary

1. Introduction



•Characteristics of blowup observed early operation period

1) Single beam and multibunch effect.

2) Dipole oscillation was not observed when the chromaticity was enough high.

3) The blowup had a threshold which was determined by the charge density (bunch current/bunch spacing).

4) The blowup was almost independent on betatron tunes.

5) Vertical betatron tune increased along the train and almost saturated at about 20th bunch.

6) Not seen in horizontal plane.

Single-bunch head-tail instability caused by the electron cloud by F. Zimmermann and K. Ohmi.

- Short history related to electron cloud (EC) at KEKB LER

1999/ 4 Beam size blowup was observed by interferometer.

10? EC hypothesis by K. Oide.

11 C yoke permanent magnets were installed to see the effect of EC.

12 Single bunch beam break up model by EC was proposed by F. Zimmermann.

2000/ 3 More C yoke magnets were installed.

5 Head-tail instability model by K. Ohmi and F. Zimmermann.

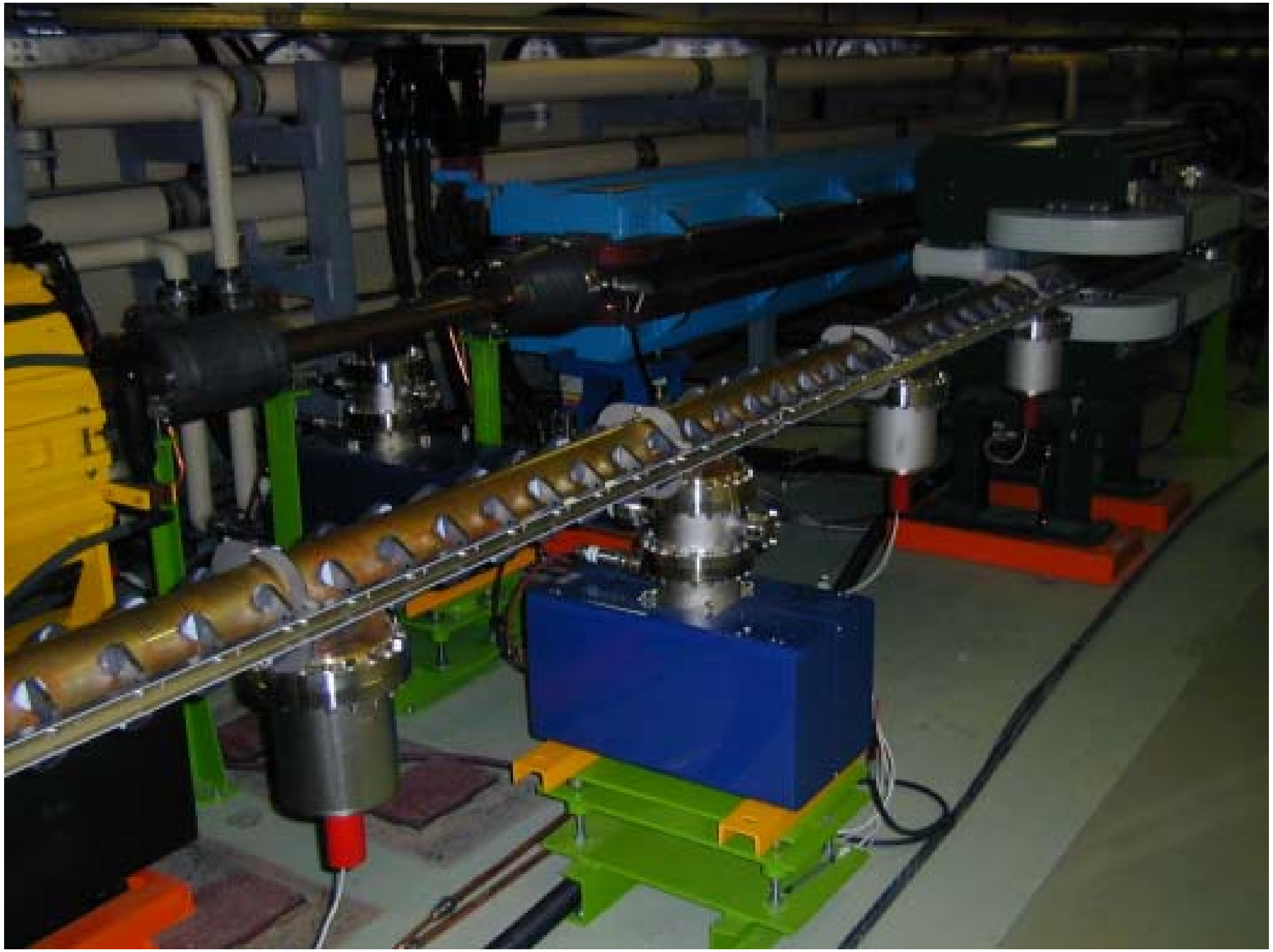
9 C yokes magnets were replaced by solenoids of 2800 pieces.

12 Effect of solenoids on the luminosity was confirmed.

2001/ 1 Solenoids were installed more (1950 pieces).

9 Solenoids were installed more (3450 pieces).

11 Peak luminosity reached to 5.5 nb/s.



C yoke permanent magnets

•Parameters of KEKB LER

Beam energy (GeV)	**3.5**
Circumference (m)	**3016**
Bunch length (mm)	**4**
Bunch spacing (ns)	**8**
Beam current (mA)	**1400**
Particles / bunch (10^{10})	**3 -7**
Emittance ε_x/ ε_y(10^{-8}m)	**1.8 / 0.036**
Average beta function (m)	**15**

Critical energy (keV)	**5.8**
Vacuum chamber	**copper**
Chamber radius [round] (mm)	**47**

•Some numbers related to ECE at KEKB LER

Photons emitted in a bend

$$N_\gamma = \frac{5}{2\sqrt{3}}\alpha\gamma\frac{l}{\rho}$$ **= 4.1 /positron/bend**

Photons emitted in a bend / bunch

$$N_\gamma N_{e^+}$$ **=1.3 x 10^{11}**

Number of photoelectrons / bunch

$$N_\gamma N_{e^+} Y_{pe}$$ **= 1.3 x 10^{10}**

Electric field by the bunch at the wall

$$E = \frac{eN_b}{2\pi\varepsilon_0\sigma_b}\frac{1}{a}$$

Momentum kick at the wall

$$\Delta p / c = eE\frac{\sigma_b}{c}\frac{1}{c} = 2r_e m_e N_b \frac{1}{a}$$ **= 1.8 keV/c**

Velocity change

$$\beta = \frac{p}{E} = \frac{p}{\sqrt{p^2 + {m_e}^2}}$$ **= 0.0037**

Kinetic energy

$$T = E - m_e$$ **= 3.5 eV**

Traversal time of electron

$$\tau = \frac{2a}{\beta c}$$ **= 85 ns**

ρ = 15.9 m, l = 0.89 m,
Energy = 3.5 GeV,
N_{e+} = 3.1 10^{10}, σ_b = 6 mm,
a = 47 mm

- Main source of synchrotron radiation(SR)

Main bend

Total length : 0.9m x 107 = 96m (3.2% of circumference)

Radiation power : 2.1MW at design current of 2.6A

SR emitted by bend starts to hit the vacuum duct at 0.4m apart from the exit of the bend.

Wiggler

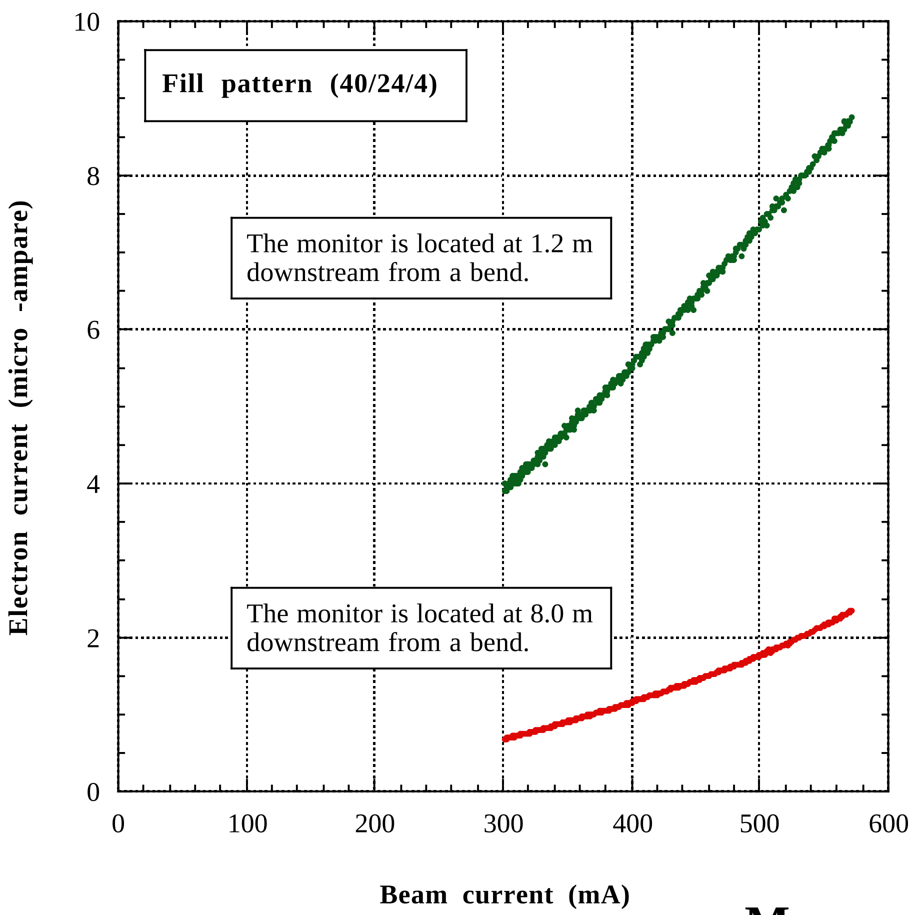
Total length : 105m (3.5% of circumference)

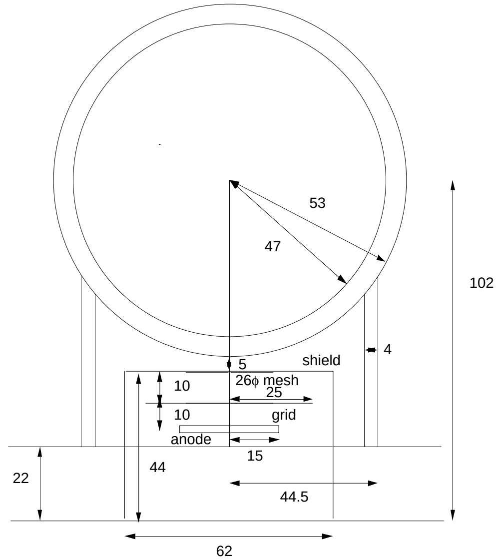
Radiation power : 1.9MW

2. Cloud build-up

- Electron measurement (Electron yield)

Electron current measured by electron monitor





Simulation (K. Ohmi)

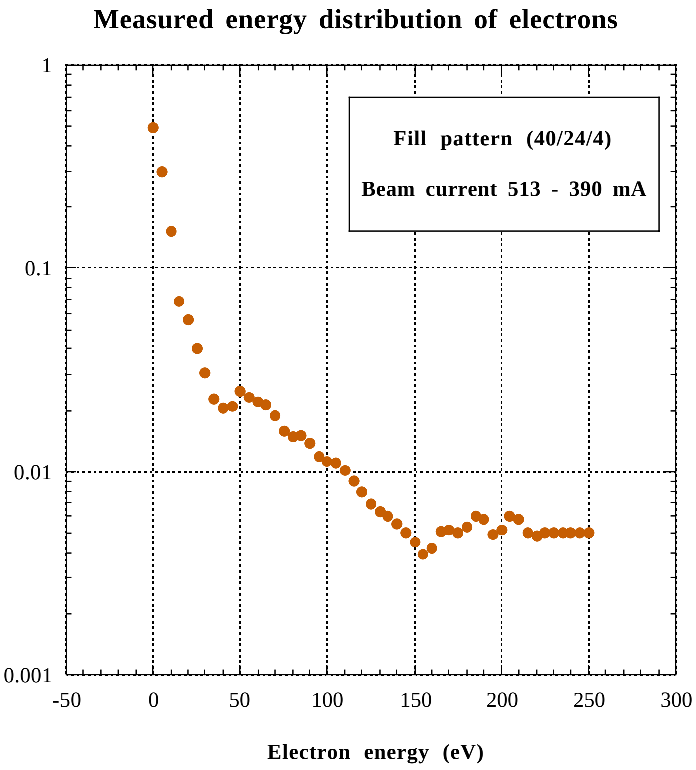
Electron current for 600mA beam

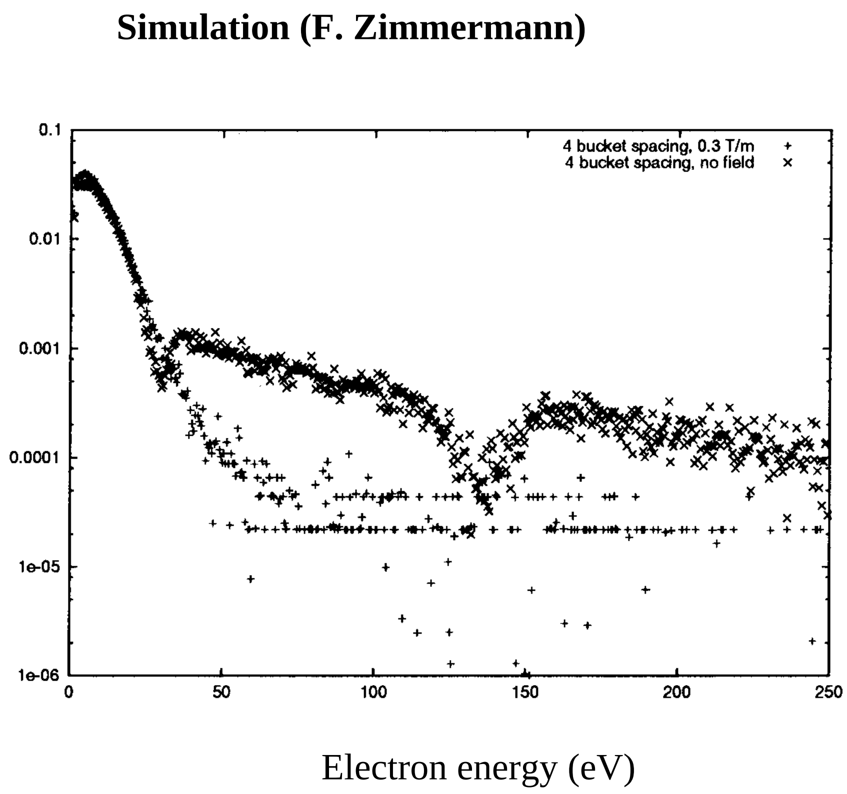
10 micro-amp. at 1.2m down stream

1 micro-amp. at 6.5m down stream

Measurement is roughly consistent with simulation.

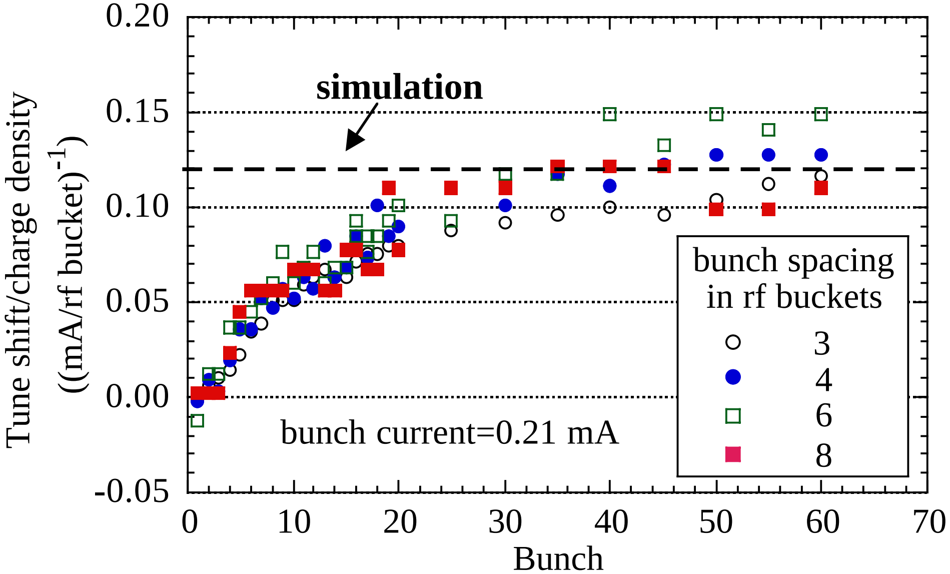
•Electron measurement (Energy distribution)



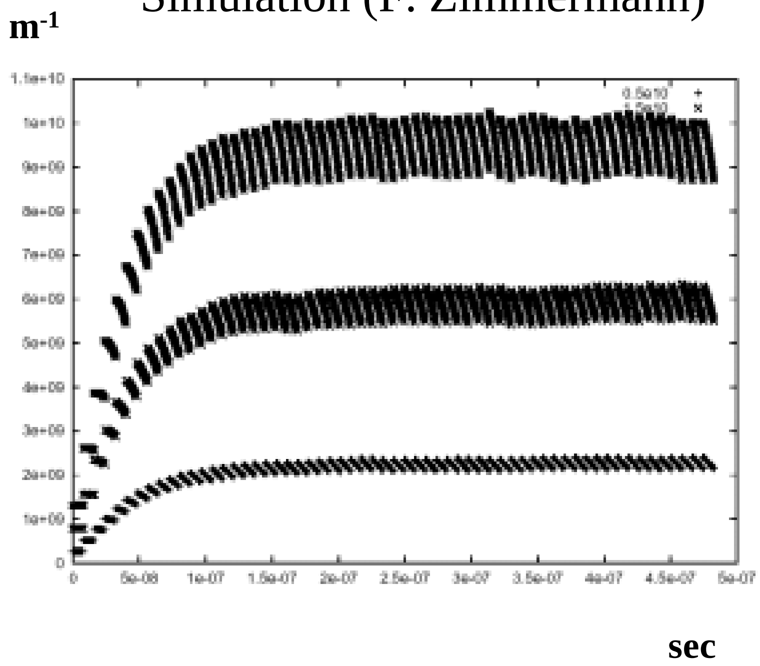


Energy distribution is explained by simulation.

• Tune shift and build-up time



Simulation (F. Zimmermann)



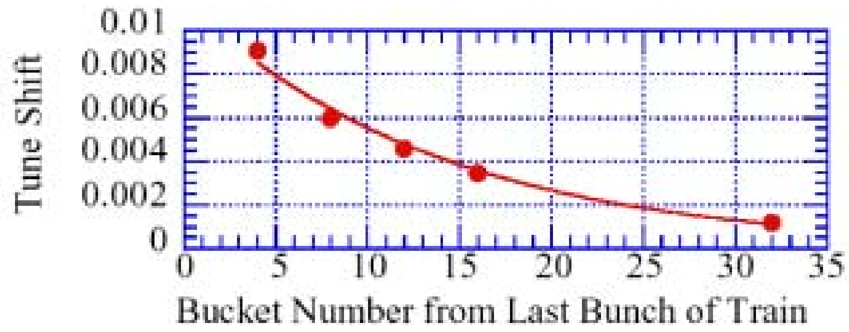
Tune shift and build-up time is consistent with simulation.

•Decay time(1)

Tune shift

2000/7 (with C yokes)

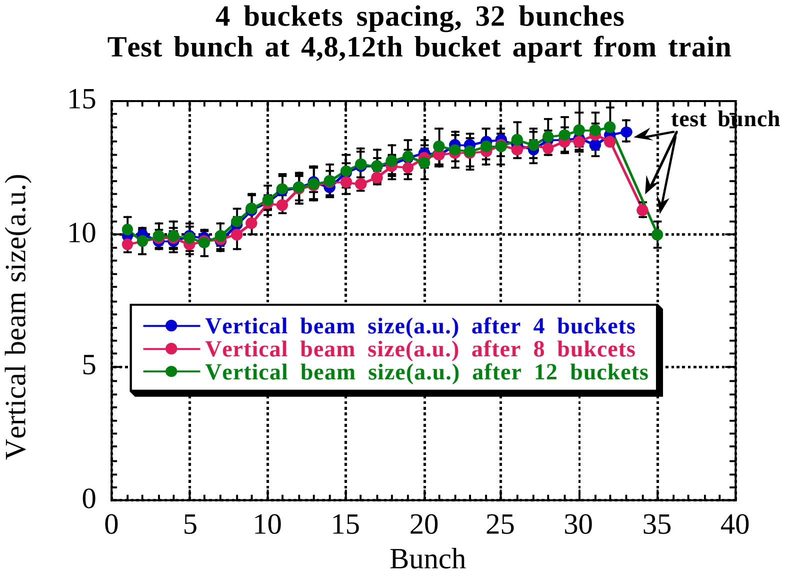
decay time : 30ns



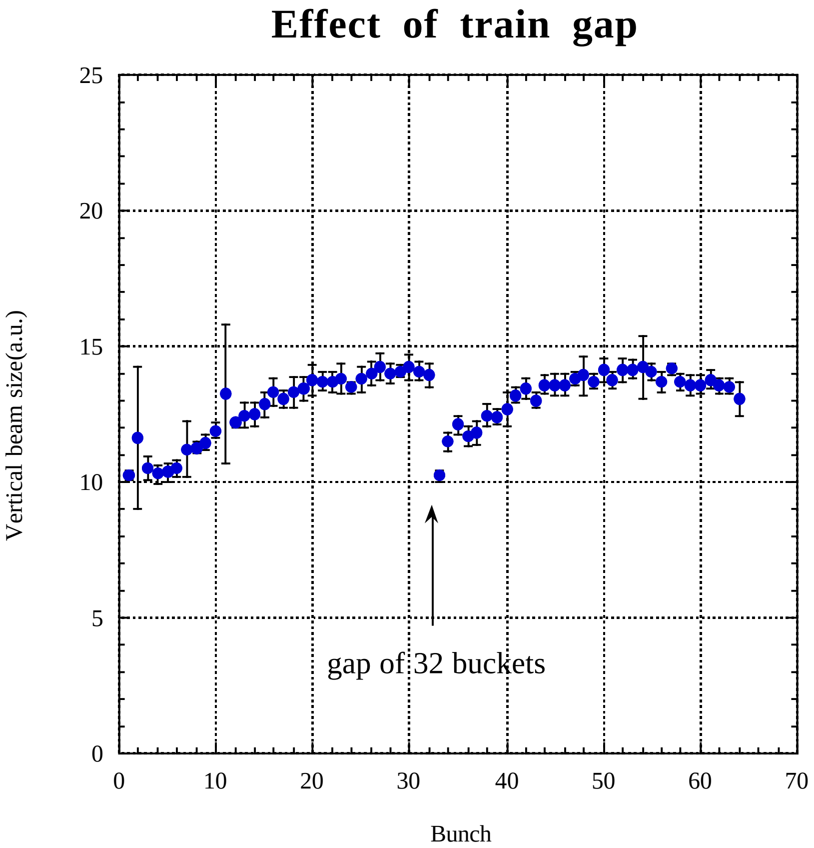
Beam size (gated camera)

2000/4 (with C yokes)

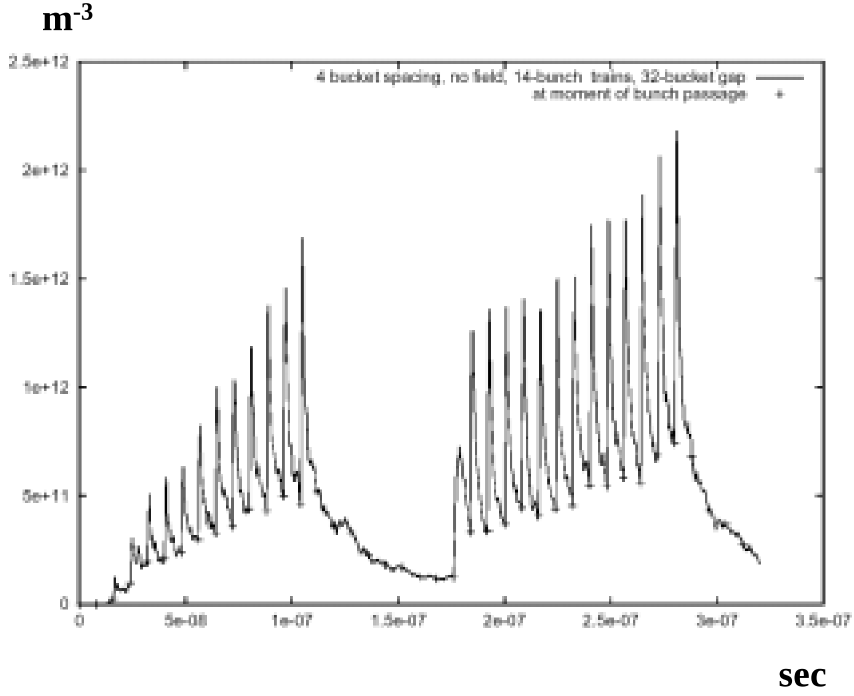
decay time < 24ns



•Decay time(2)



Simulation (F. Zimmermann)

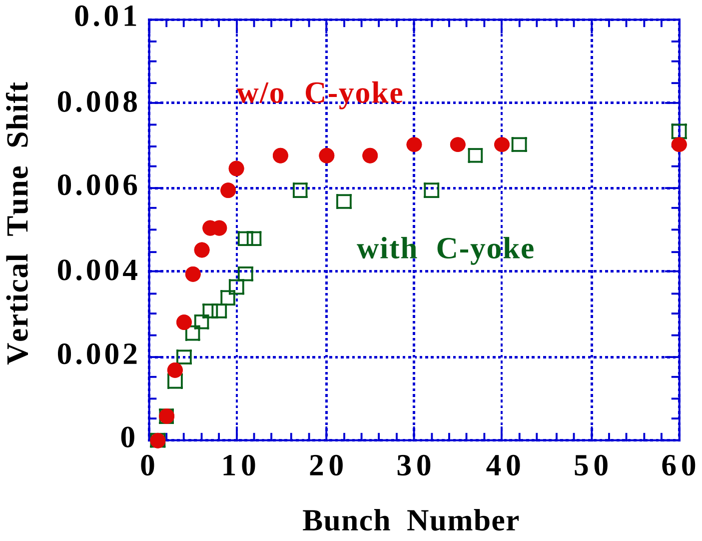


In 2nd train which is 64ns behind 1st train,2nd bunch already blew up.

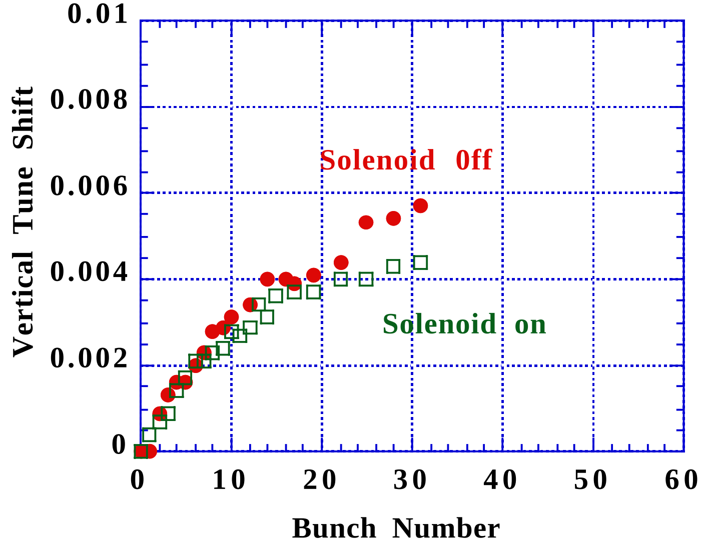
Two components with different decay time (K. Oide) ?

•Change of vertical tune shift

July 2000



April 2001



0.21mA/bunch **0.31mA/bunch**

Comparing the data without C yokes and data of solenoid off,

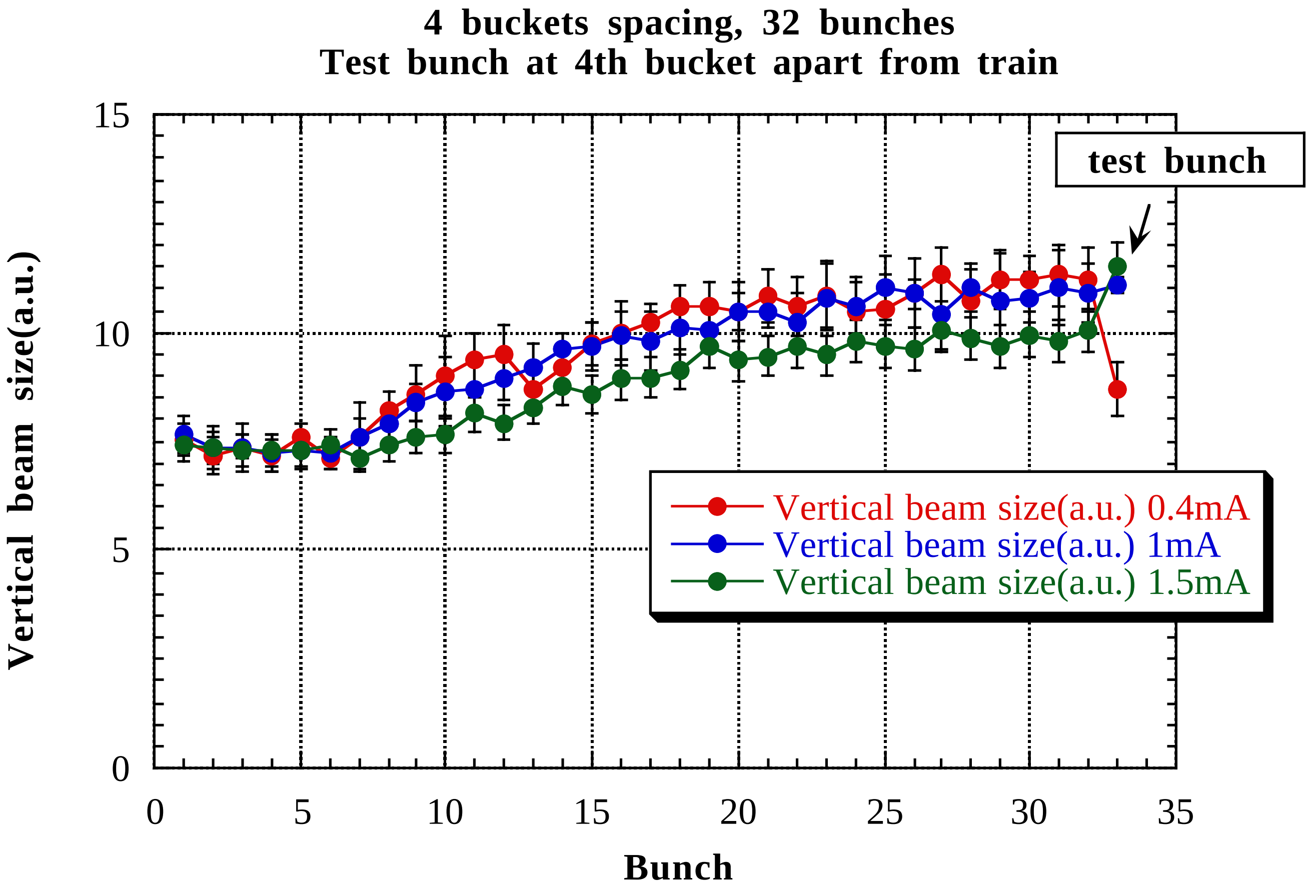
1) Vertical tune shift decreased from 0.007 to 0.005.

2) Rise time of tune shift increased.

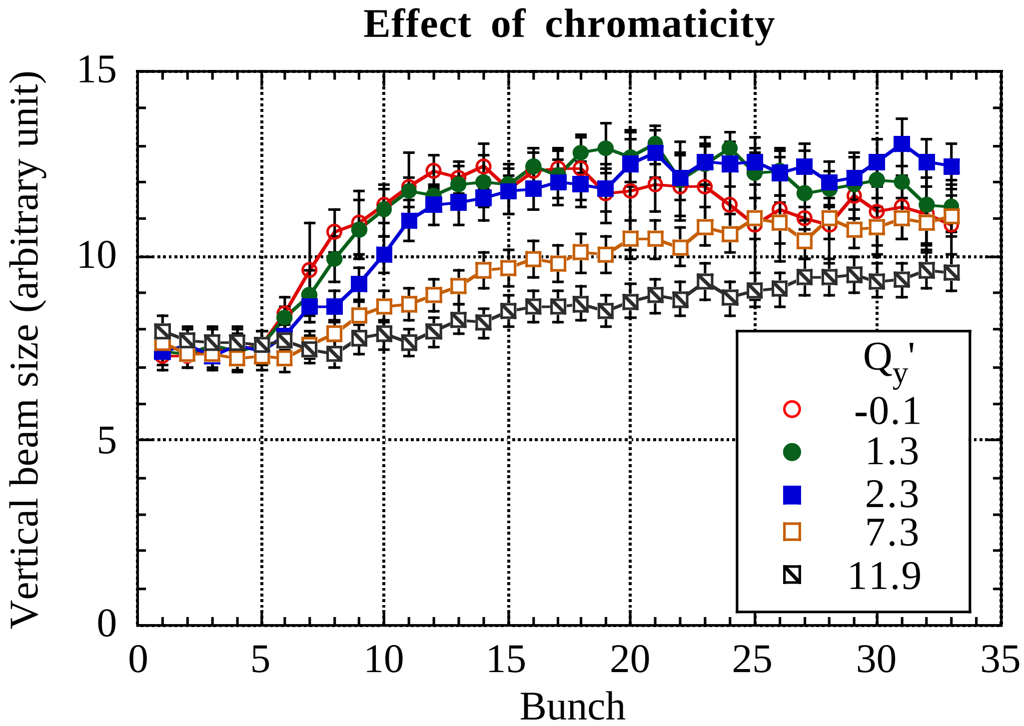
Was cloud density decreased ?

3. Beam blowup (single bunch instability)

- Single bunch characteristics



•Effect of chromaticity



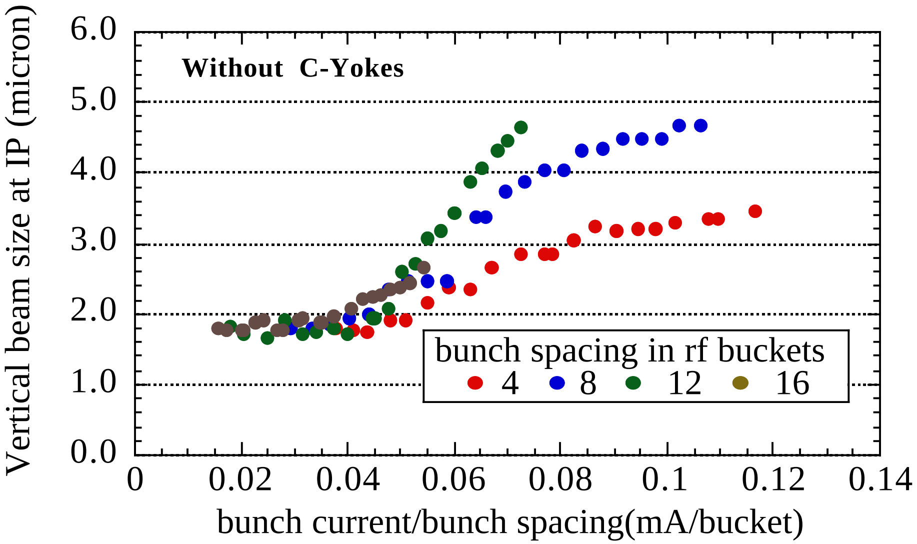
Cloud density at transverse mode coupling instabity (TMCI) threshold ρ_{th}
(K. Ohmi, F. Zimmermann, E. Perevedentsev, HEACC2001)

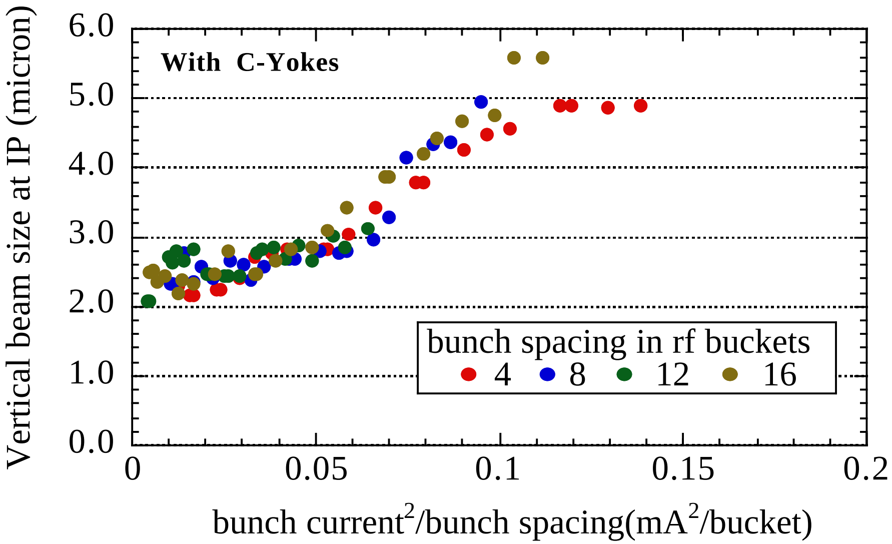
Vertical : [$9.4 \times 10^{11} + 2.4 \times 10^{9}\ Q'_y$] m^{-3}

Contribution of Q'_y to ρ_{th} is only 1% if $Q'_y = 10$.

•Threshold intensity of blowup ($I_{b,th}$)

Scaling





$$I_{b,th} \propto L_{sep.}$$

$$I_{b,th} \propto \sqrt{L_{sep.}}$$

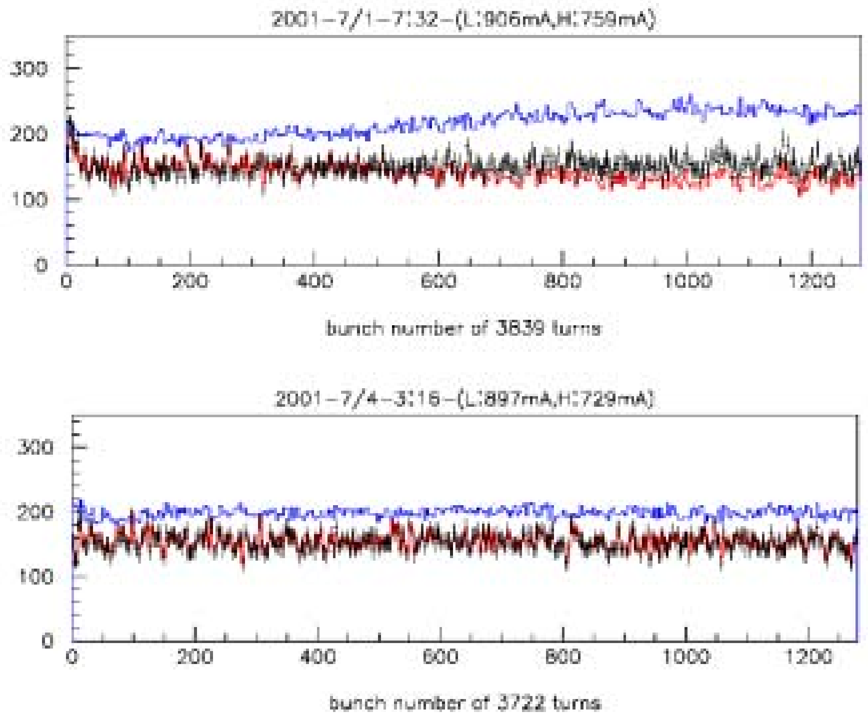
Model (F. Zimmermann)

BBU: $I_{b,th} \propto \sqrt{L_{sep.}}$

Head-tail, TMCI : $I_{b,th} \propto L_{sep.}$

•Bunch by bunch luminosity

above threshold current of single beam blowup



black : event rate

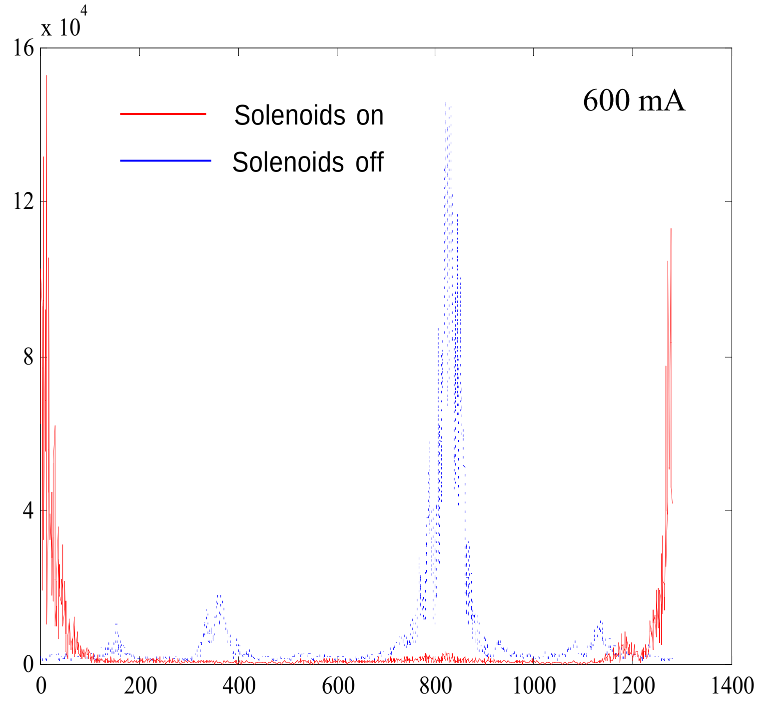
blue : bunch current product

red : specific luminosity (black/blue)

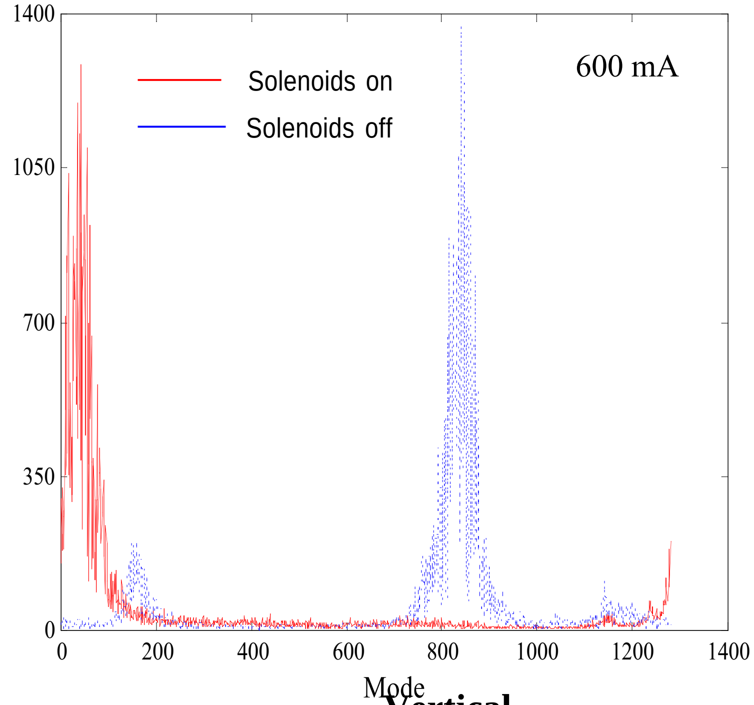
In a beam fill, luminosity at head of train was higher than tail, but in other fill, it was not. It may be difficult to separate single beam blowup and beam-beam blowup.

4. Coupled bunch instability (->S.S.Win's talk)

- Mode spectrum



Horizontal

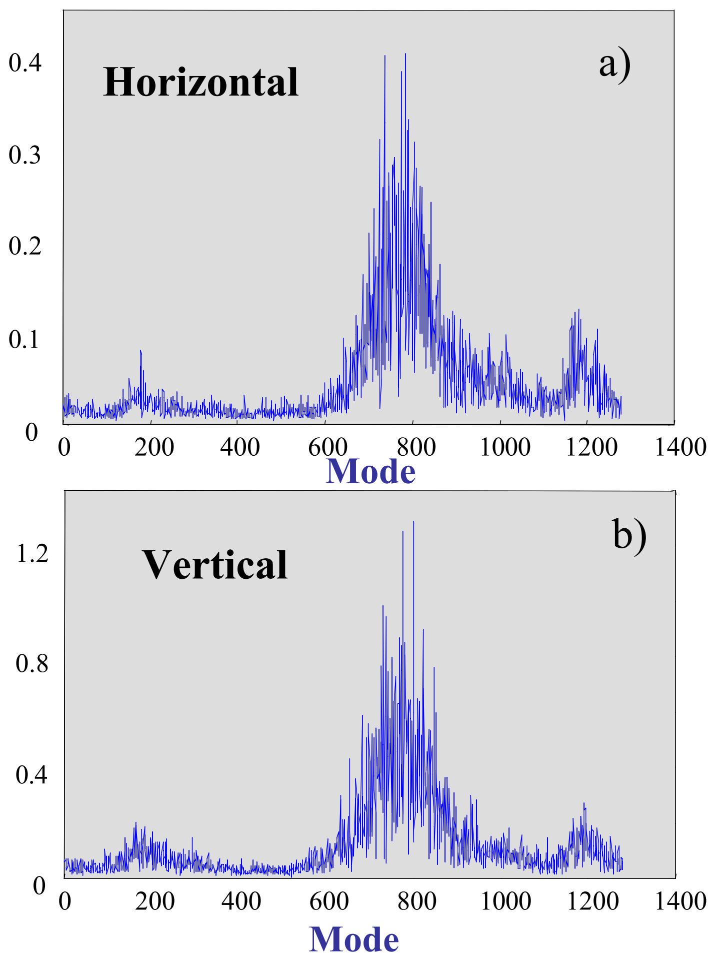


Vertical

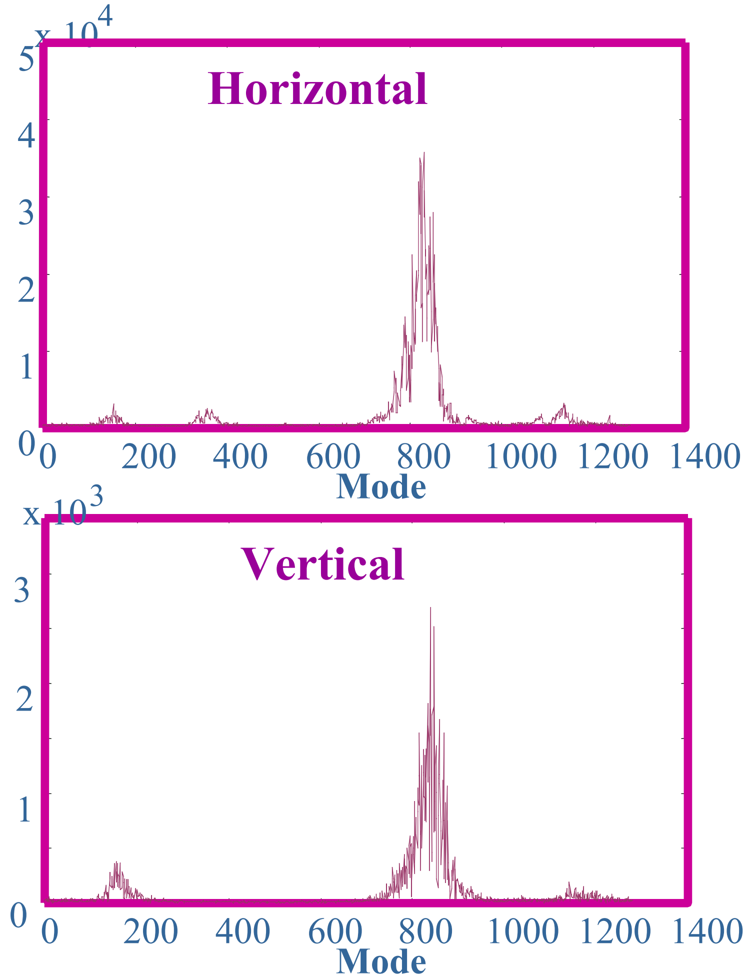
Totally different mode spectrum was observed when solenoid was turned off.

Simulation assuming uniform electron production on the wall produced a mode pattern which is similar to observed one.

Simulation

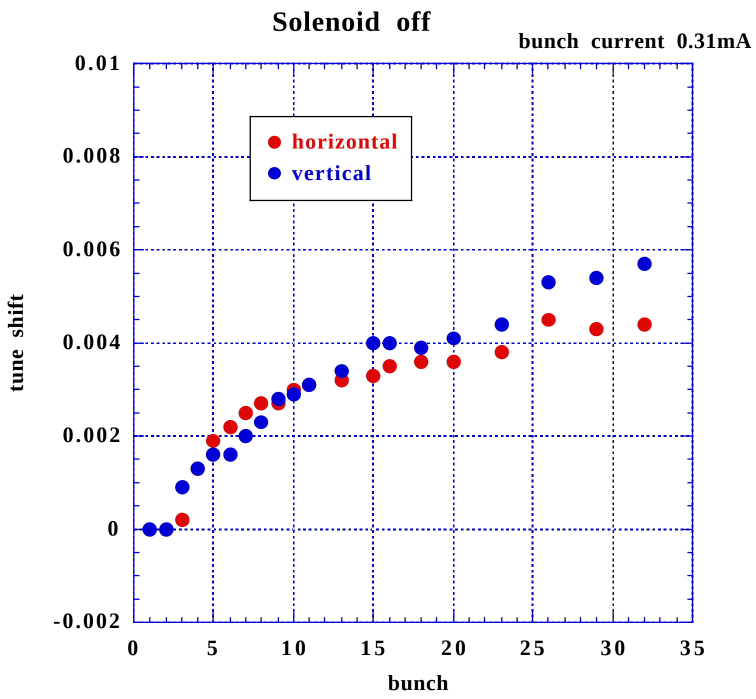


Measurement (solenoid off)



Almost equal horizontal and vertical tune shifts when solenoid was turned off also suggest the cloud distribution is round.

solenoid off



5. Effect of solenoid

- Solenoid system

Solenoid

Type	Length (mm)	Diameter (mm)	Turns	Bz (center) @ 5A (Gauss)
Bobbin	150 - 650	148	250(typ.)	45
Bobbinless	40	220	190, 200	48
Bobbinless	40	250	200	43
Bobbinless	40	300	200	37

Power supply(P.S.)

	KEKB corrector P.S.	TRISTAN corrector P.S.
Current(A)	5	3
Units	616	40

•Installation history

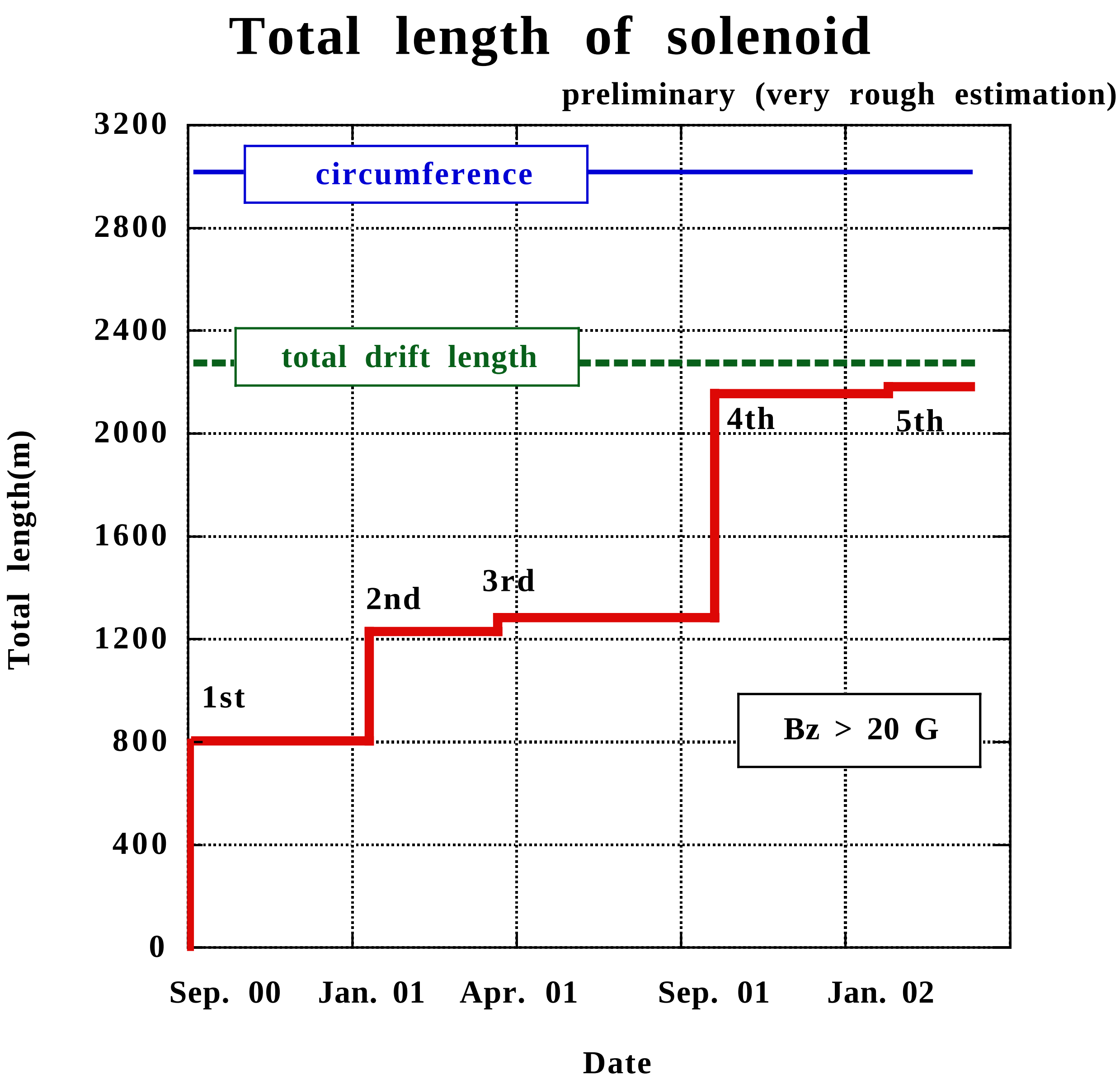
Date	Bobbinless	Bobbin	Location
2000. 9.	0	2783	Arc section straight section (Cu chamber)
2001. 1.	1950	0	Arc section (Bellows+NEG)
2001. 4.	254	10	Straight section of Fuji andTsukuba (Bellows, Cu chamber)
2001. 9.	3411	43	Straight section (Bellows, Cu chamber) Arc section (NEG,IP, Bellows+NEG)
2002. 1.	119	0	Arc section (Between Quad and Sext)
Total	5734	2836	

NEG pump and Bellows

Ion pump

NEG pump

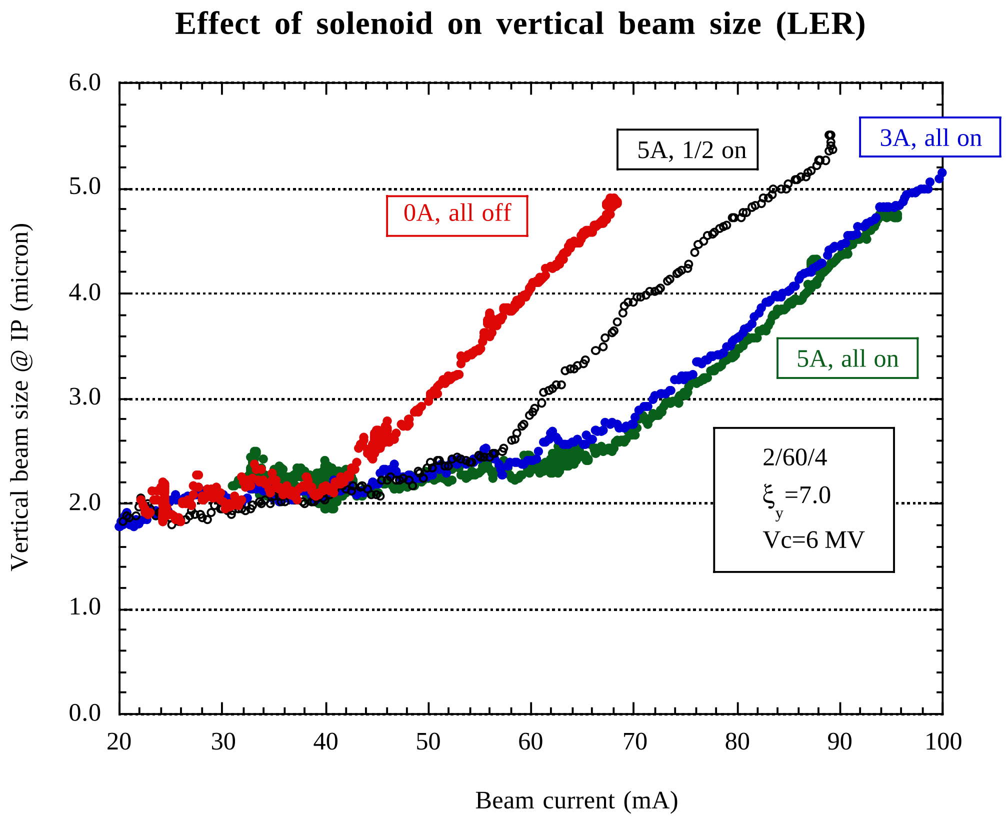
Quad - Sextupole



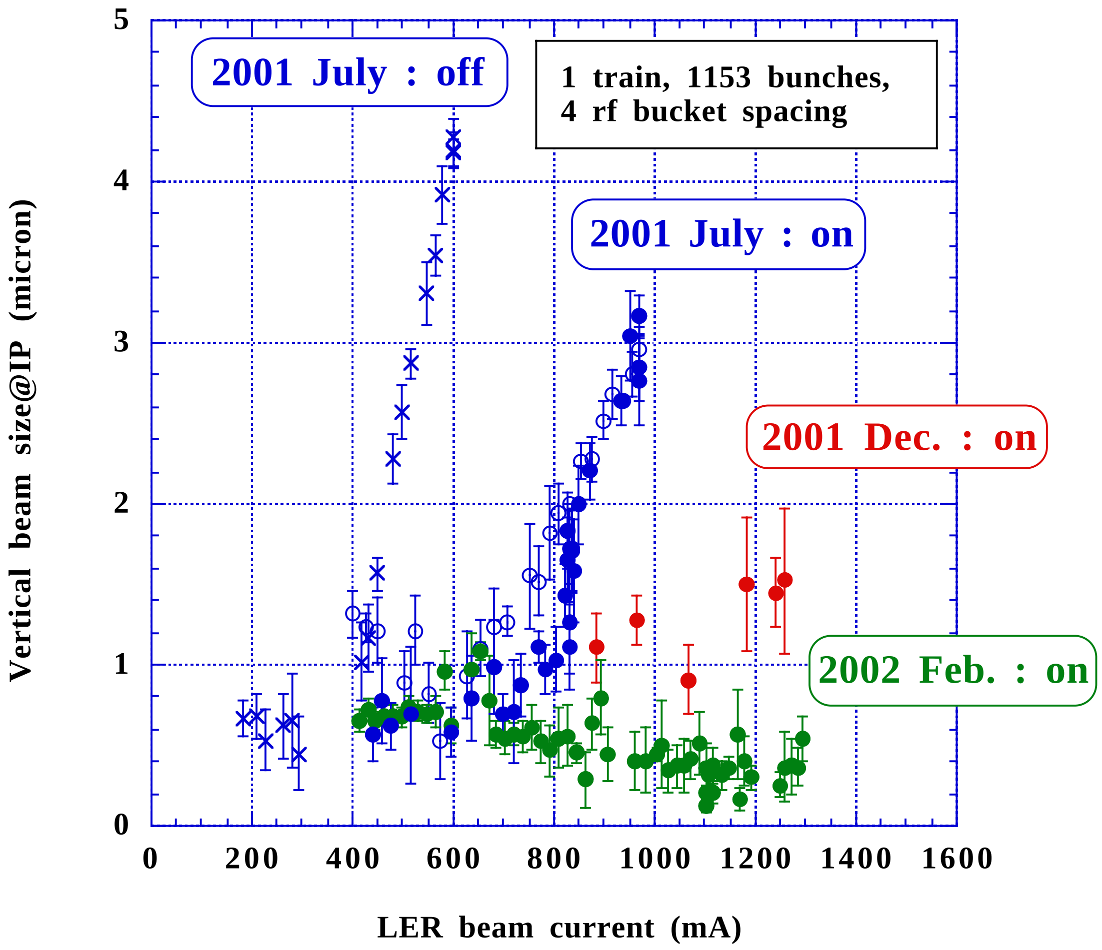
Total length of solenoid
preliminary (very rough estimation)
circumference
total drift length
1st
2nd
3rd
4th
5th
Bz > 20 G
3200
2800
2400
2000
1600
1200
800
400
0
Total length(m)
Sep. 00
Jan. 01
Apr. 01
Sep. 01
Jan. 02
Date

•Beam size

Effect on solenoid in a short train

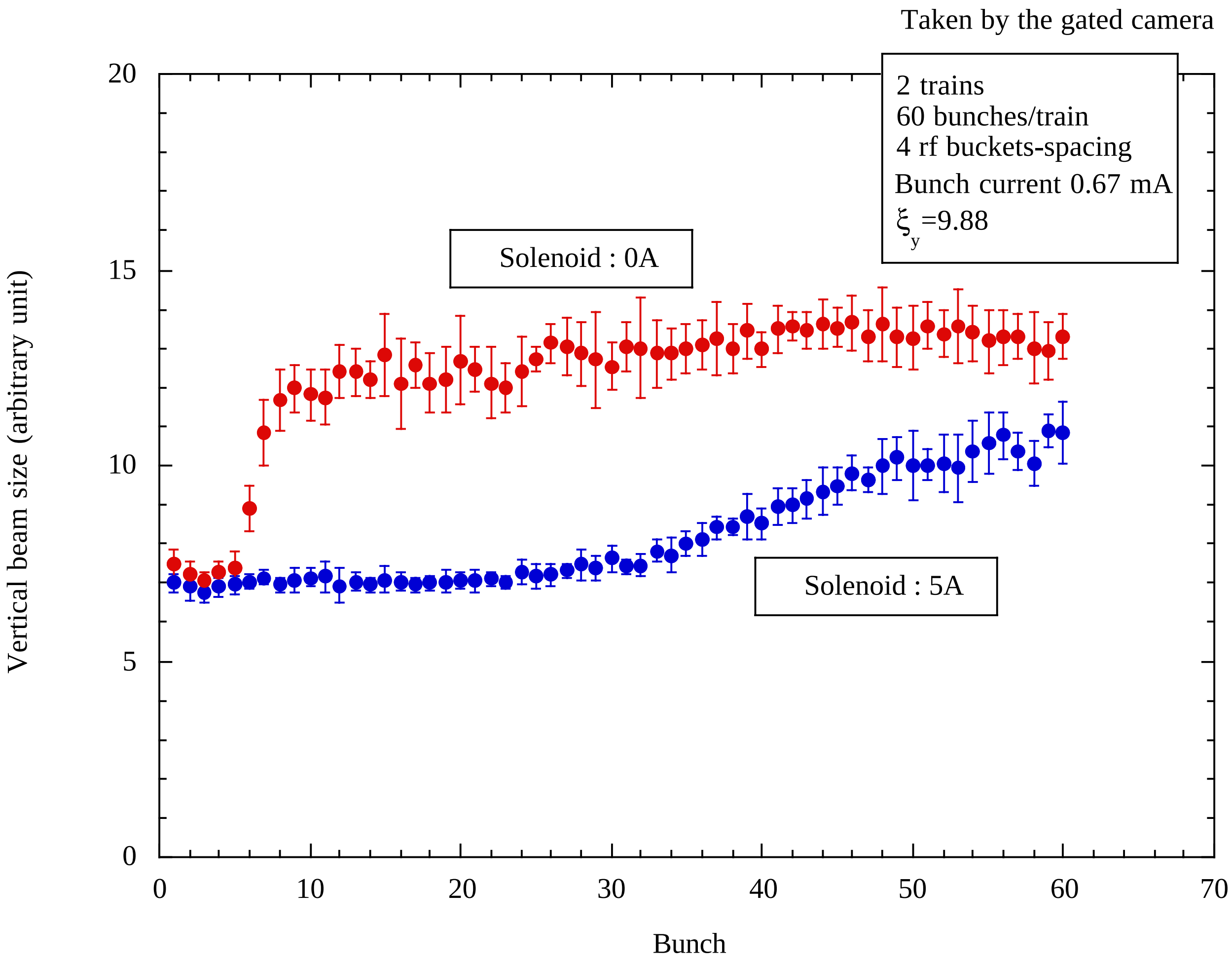


Effect of solenoid in a physics fill pattern (4 rf buckets spacing)



After last installation of solenoid, blowup was disappeared up to 1300mA.

Vertical beam size along train

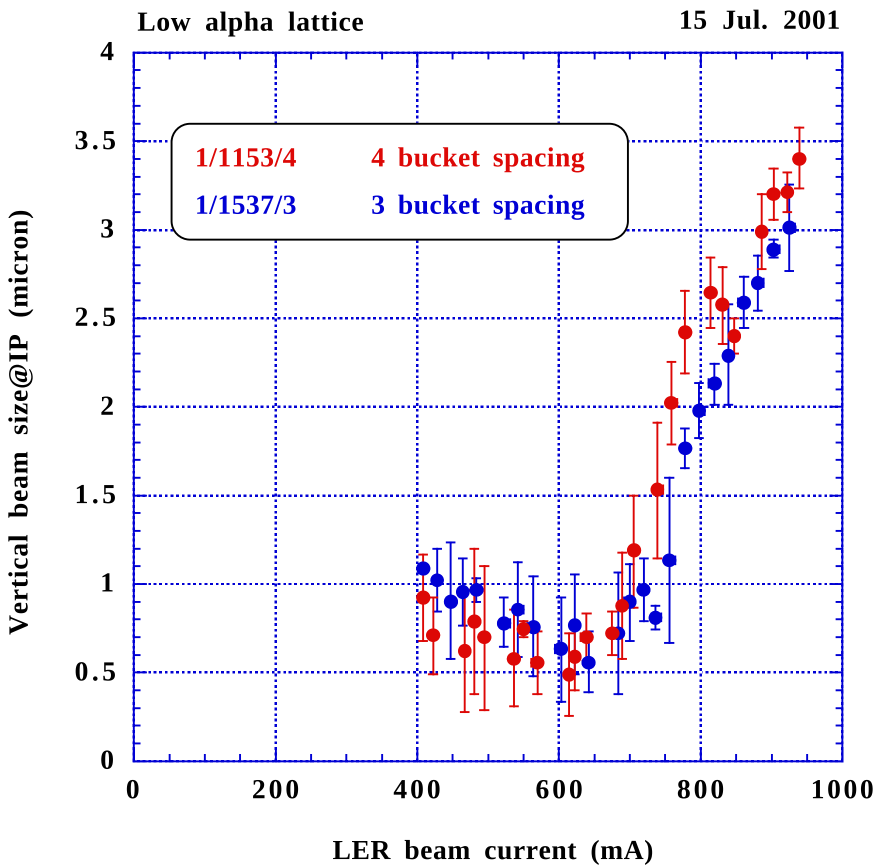


•Scaling of threshold current of beam blowup

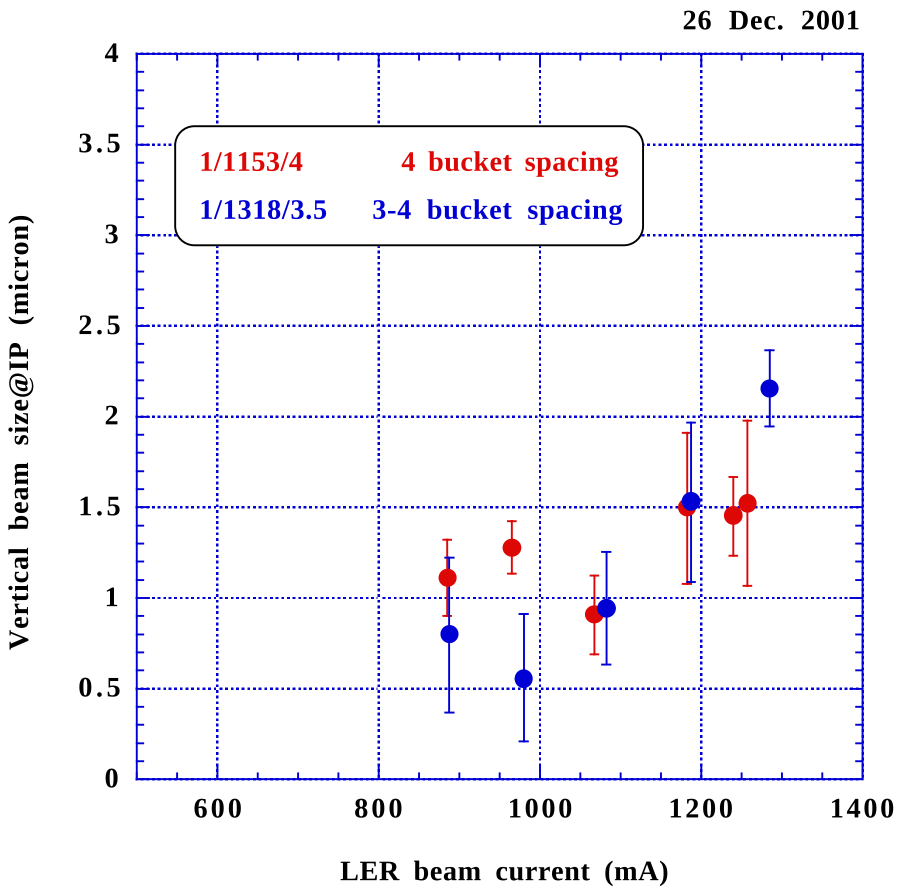
Same average beam density I_b / $L_{sep.}$ was set in two measurements.

Scaling of $I_{b,th} \propto L_{sep.}$ is still seen.

2001 July



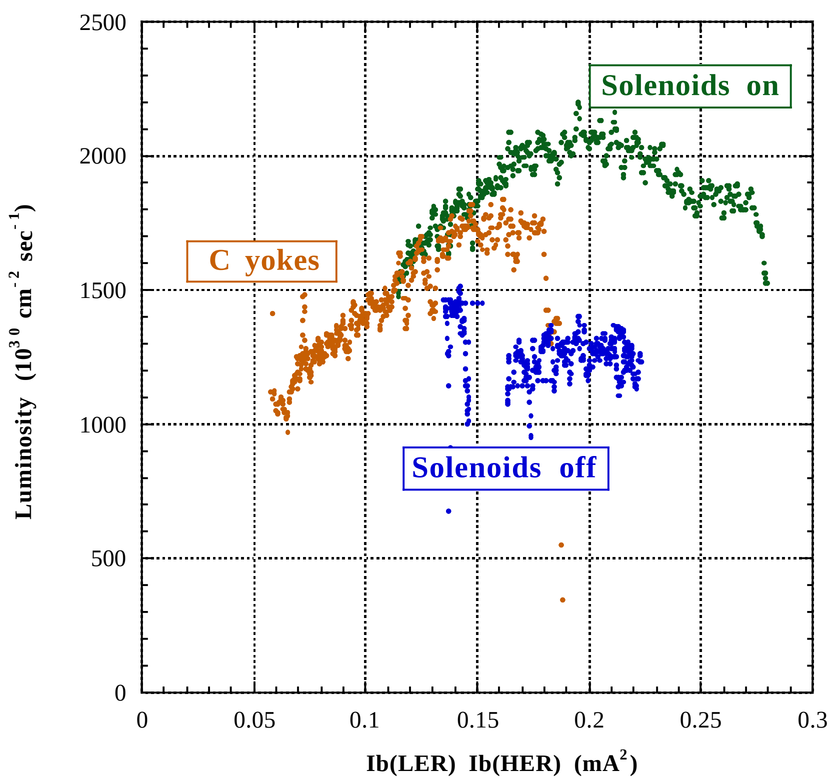
2001 Dec.

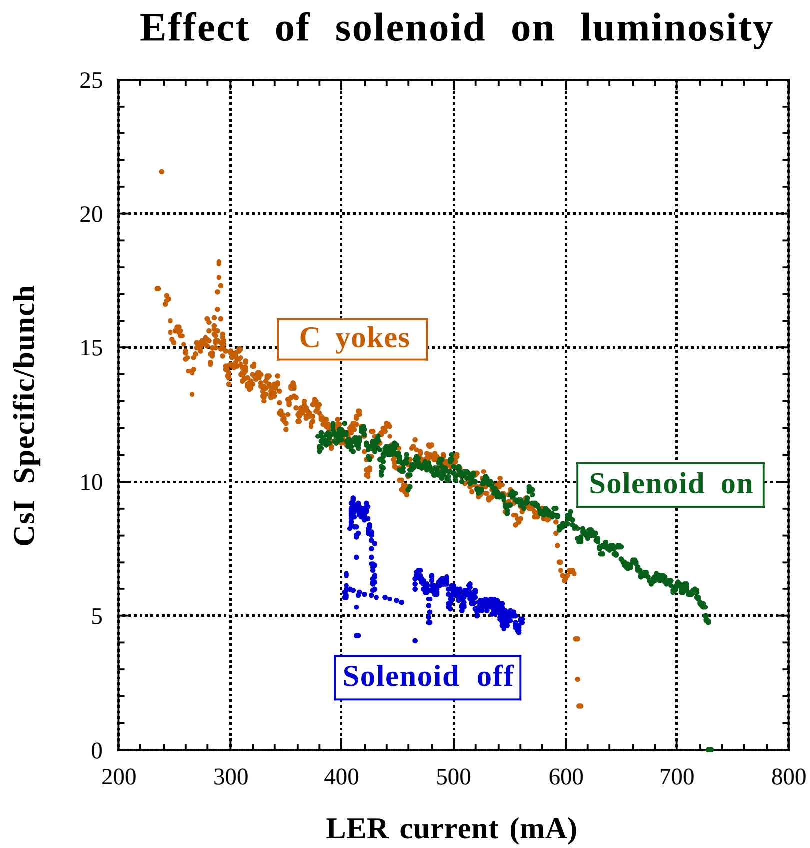


•Luminosity

Effect of solenoid was confirmed at each installation stage of solenoid.

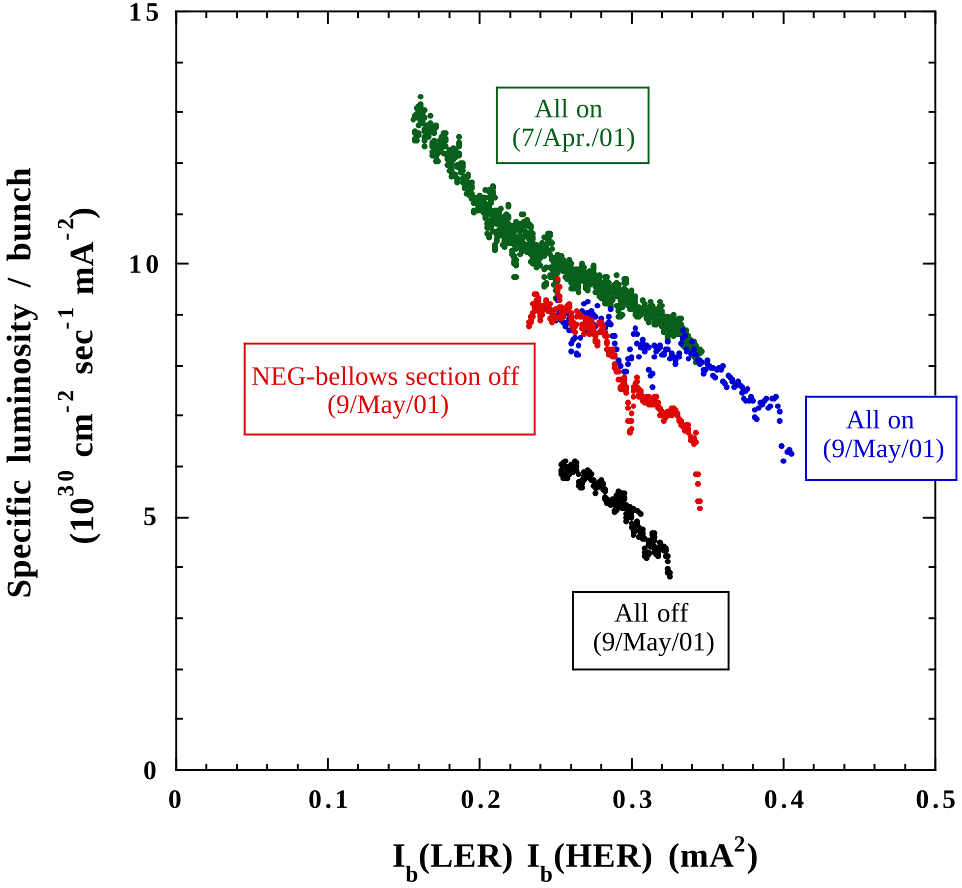
After 1st installation (2000.12)



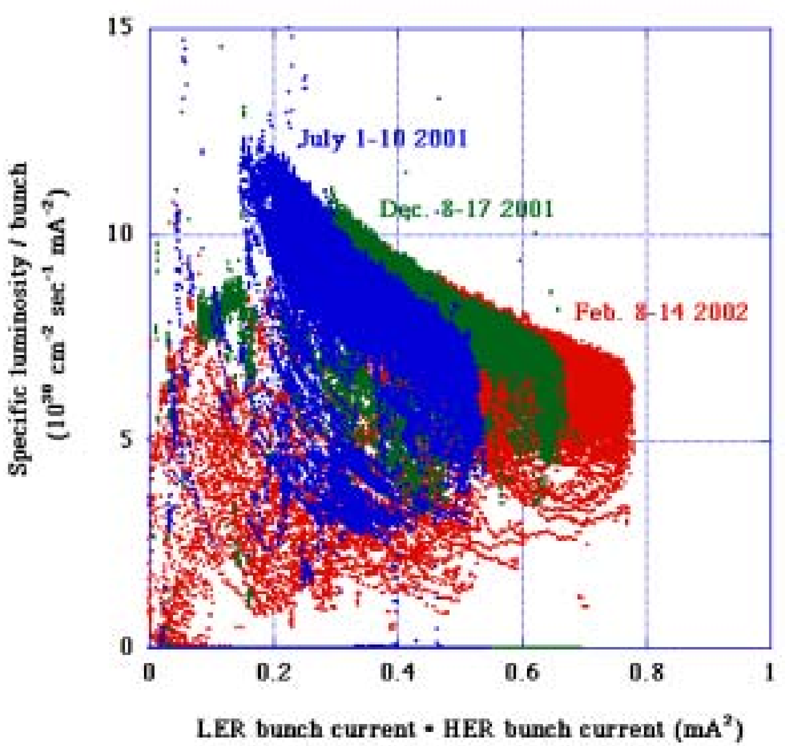


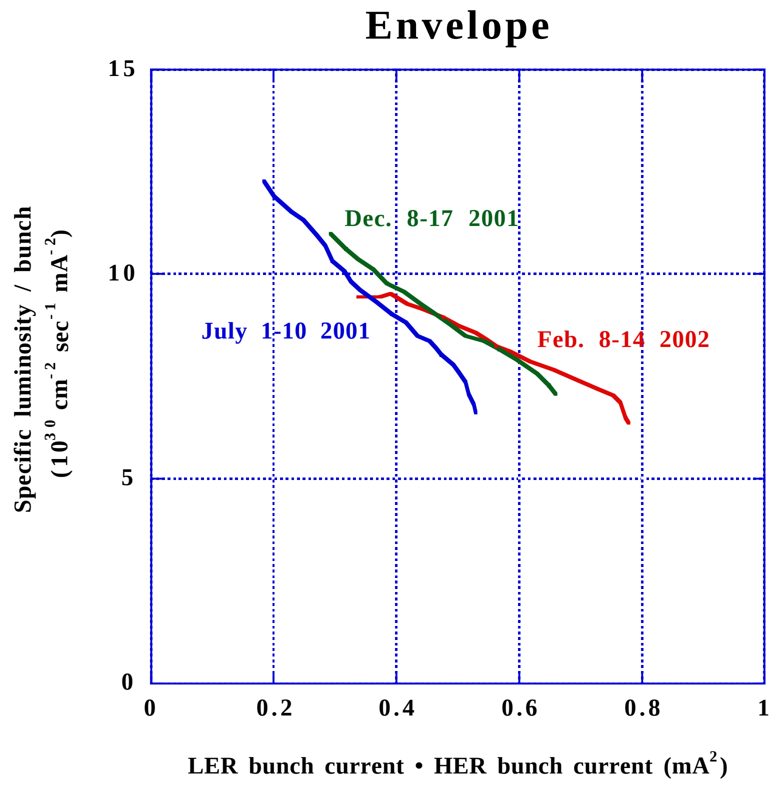
Effect of solenoid (after second installation)

2001.4



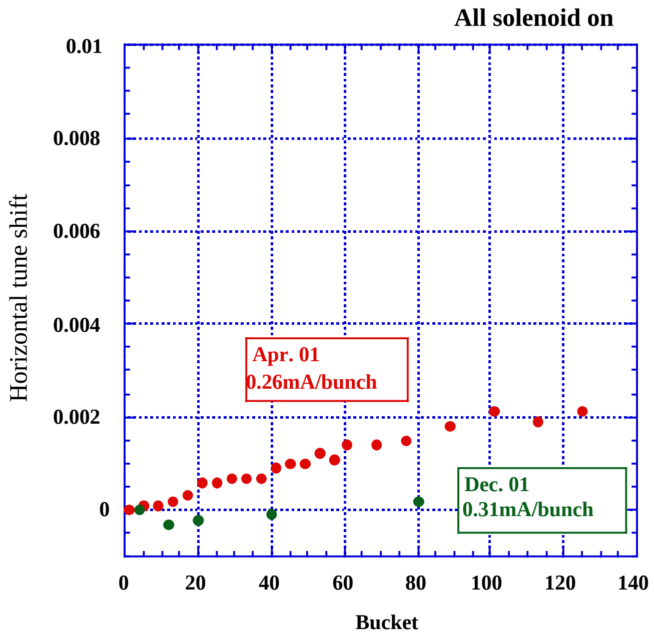
After 4th and 5th installation (2001.12 & 2002.2)

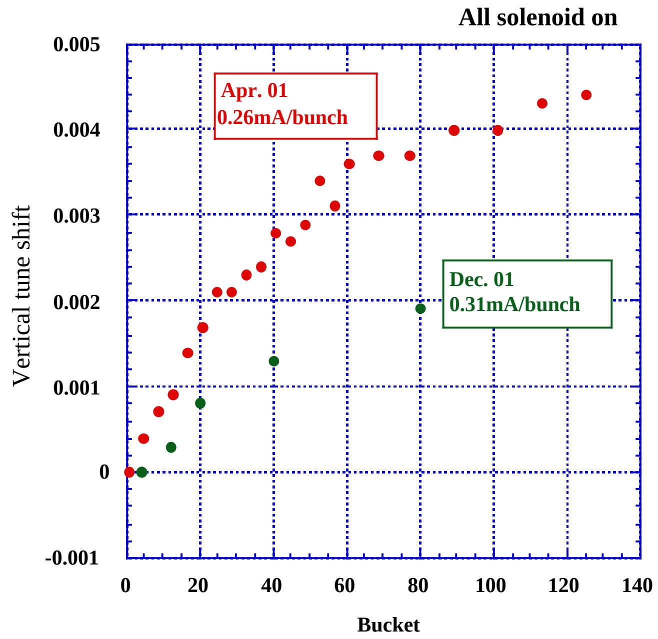




•Tune shift

Tune shift measured by gated tune meter (T. Ieiri)

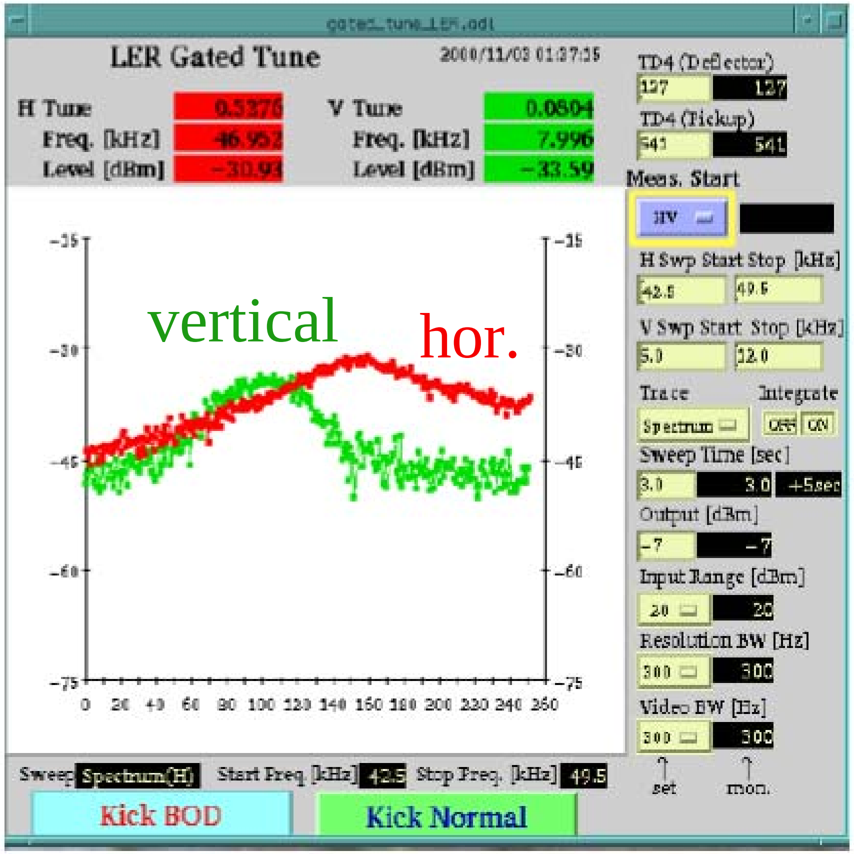




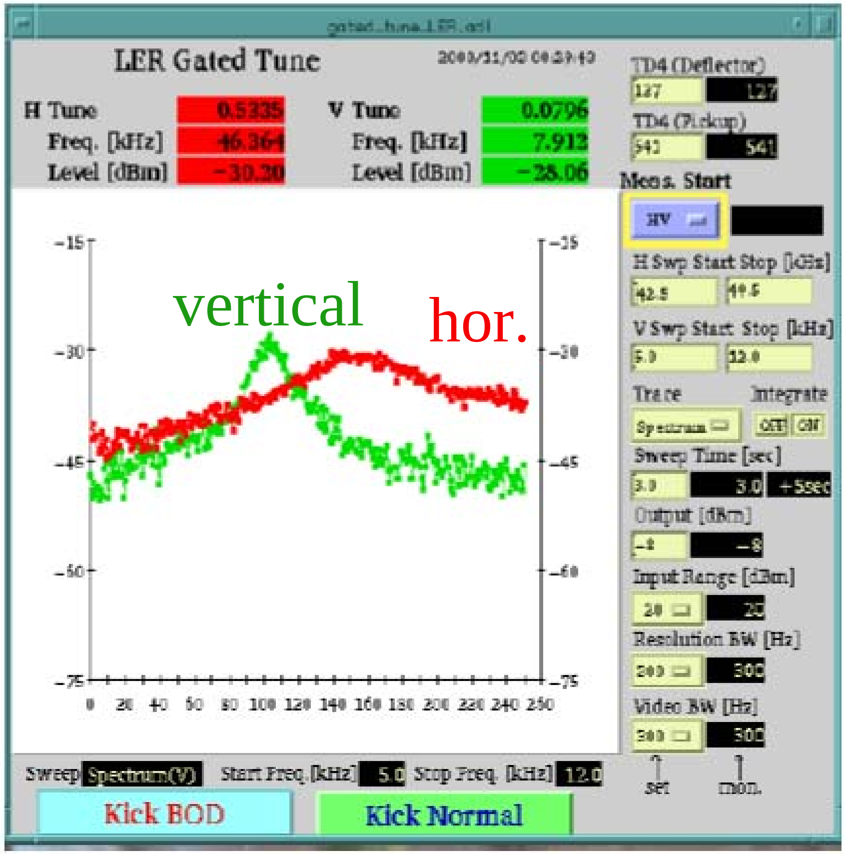
Tune shift decreased after 4th installation of solenoid at 2001 summer.

Tune sprectra of 10th bunch (Nov. 2000)

solenoid off



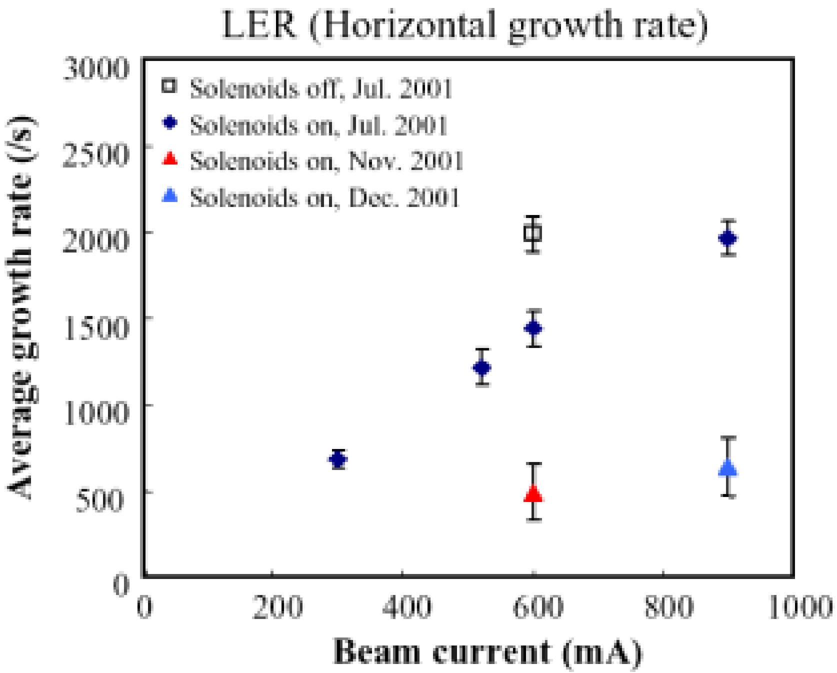
solenoid on

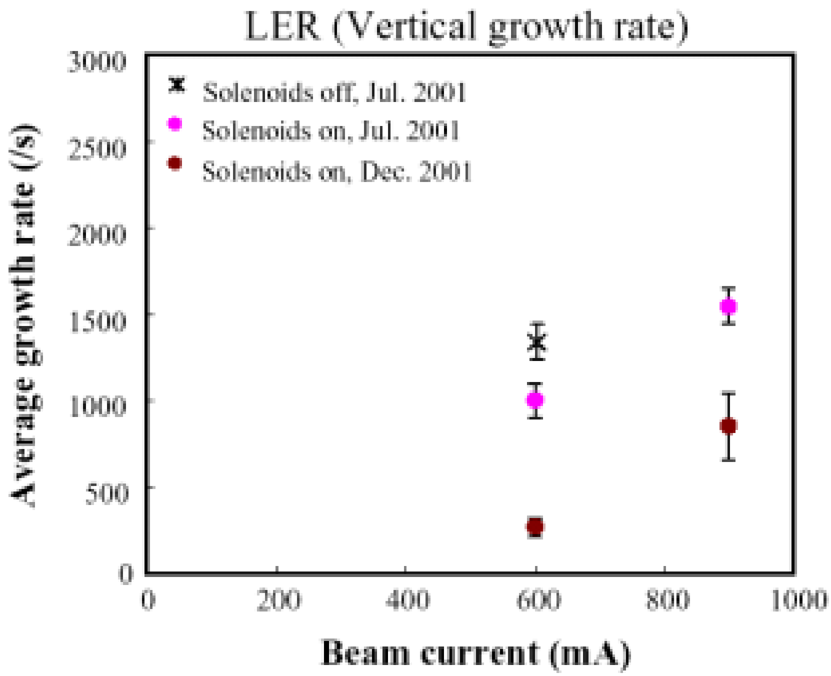


Width of vertical tune spectrum was decreased when solenoid was turned on.

•Coupled bunch instability

Growth rate





Growth rate was decreased when solenoid was turned off.

After installation of solenoid at 2001 summer, growth rate decreased further.

Observed growth rate without solenoid is roughly consistent with simulation.

Observed : 2000 s^{-1}(H) , 1330 s^{-1}(V), Simulation : 1790 s^{-1}(H) , 2080 s^{-1}(V)

6. Open questions

1) Why horizontal blowup is not observed ?

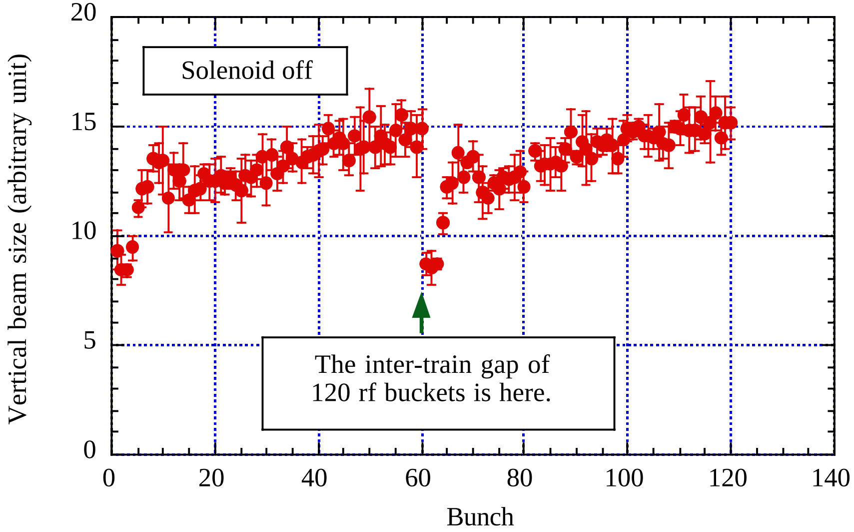
Cloud density at TMCI threshold
(K. Ohmi, F. Zimmermann, E. Perevedentsev et al., HEACC2001)

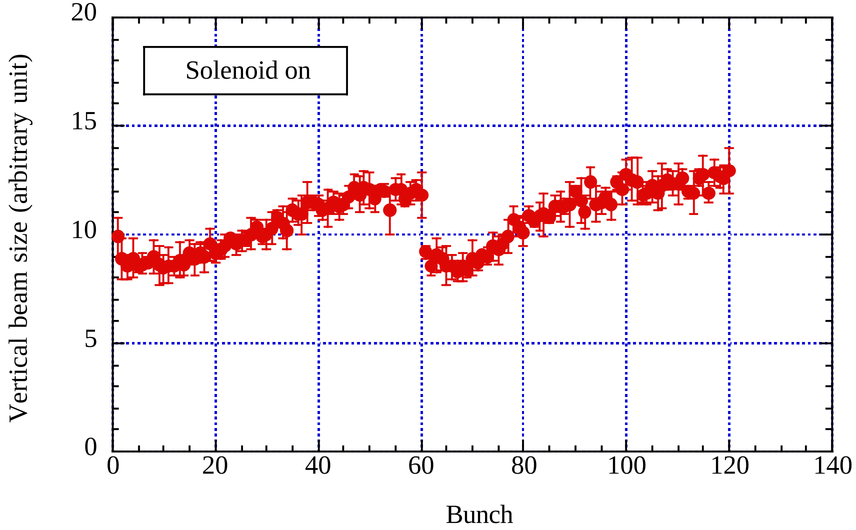
Horizontal : 2×10^{12} m^{-3}

Vertical : 3×10^{12} m^{-3}

2) Decay time of cloud

- **Very long ?**

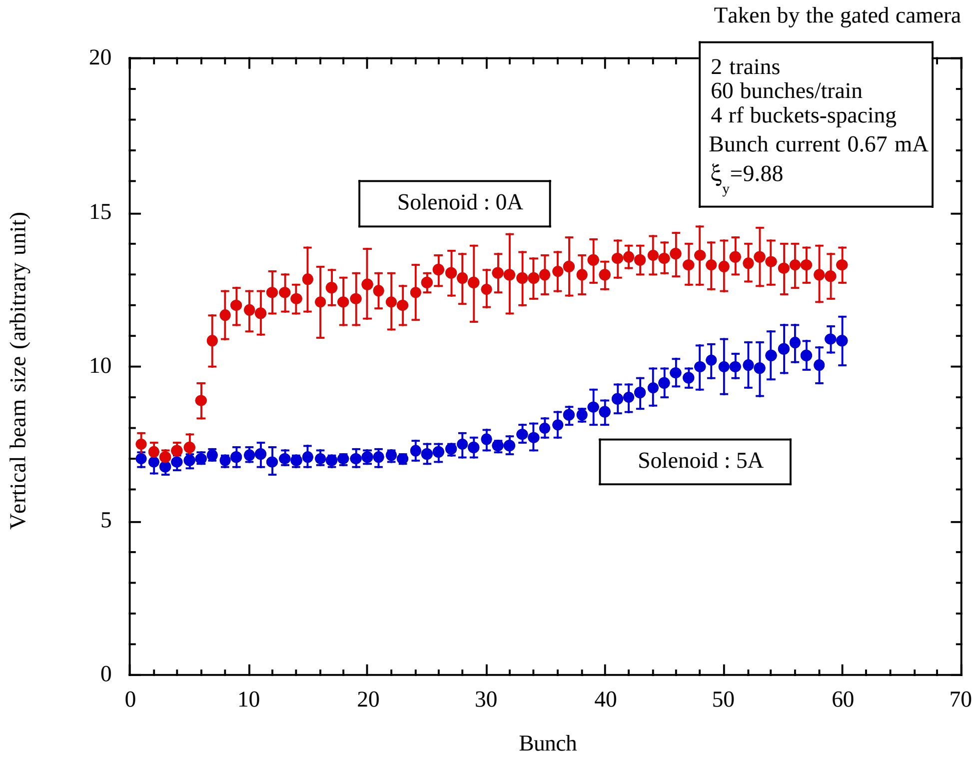




Trapping in quad and sextupole ? (->L. Wang's talk)

- **Two components ?**

3) Slow blowup after installation of solenoid



4) Scrubbing effect ?

Change of tune shift

Luminosity was not improved immediately after the installation of solenoid.

5) Space distribution of cloud , round or flat ?

Mode spectrum of coupled bunch instability

Almost equal horizontal and vertical tune shift

7. Summary

1) Cloud buildup is well explained by simulation.

Electron yield, energy distribution, tune shift,
buildup time of tune shift and beam size blowup along train.

2) As for beam blowup,

most observations are consistent with
single bunch head-tail instability model.

Single bunch characteristics, threshold current
Chromaticity dependence ?

Direct observation of head-tail oscillation may be necessary to confirm the model.

3) As for CBI,

observed mode spectrum is explained by simulation assuming uniform production of electron on the wall and,

observed growth rate is roughly consistent with simulation.

4) Effect of weak solenoid field on ECE was confirmed by measurements of beam size, luminosity, tune shift and CBI.

5) Several questions are remained.

No horizontal blowup,
decay time of cloud,
very slow blowup after installation of solenoid,
scrubbing effect,
space distribution of cloud etc.