Beam blowup in KEKB

Two-stream2001 (11th Sep. 2001)

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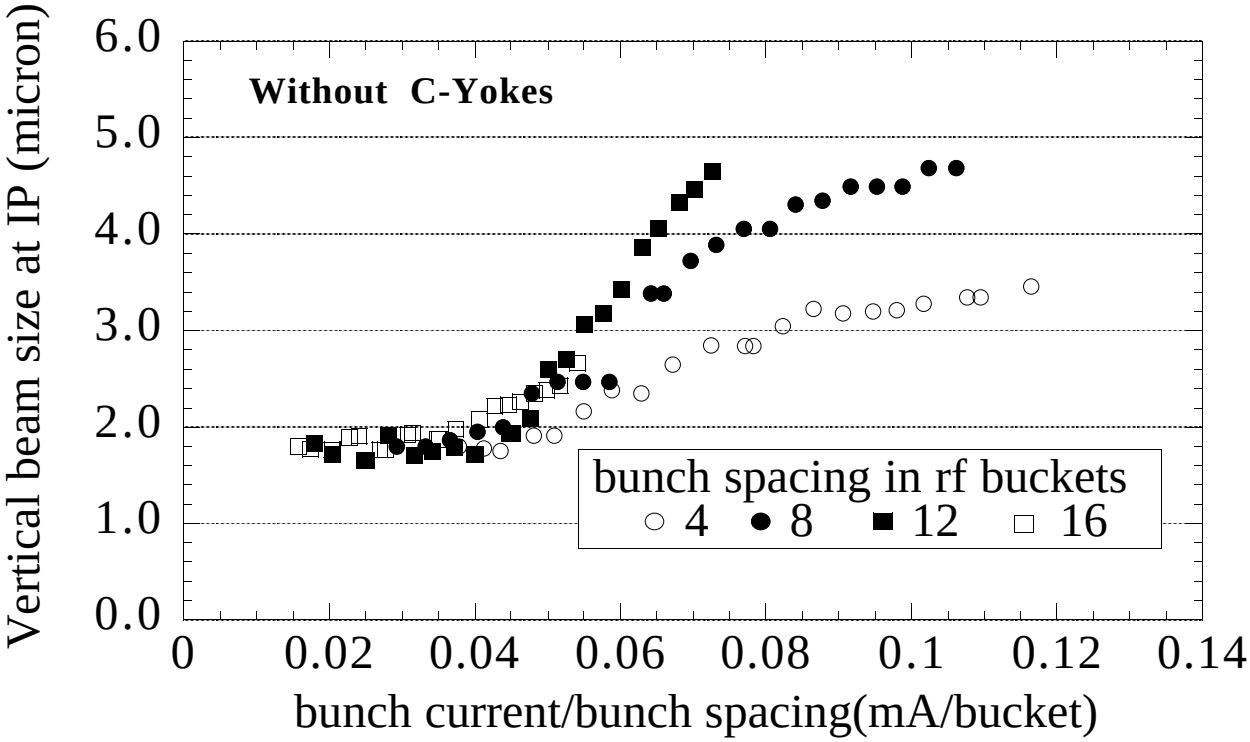
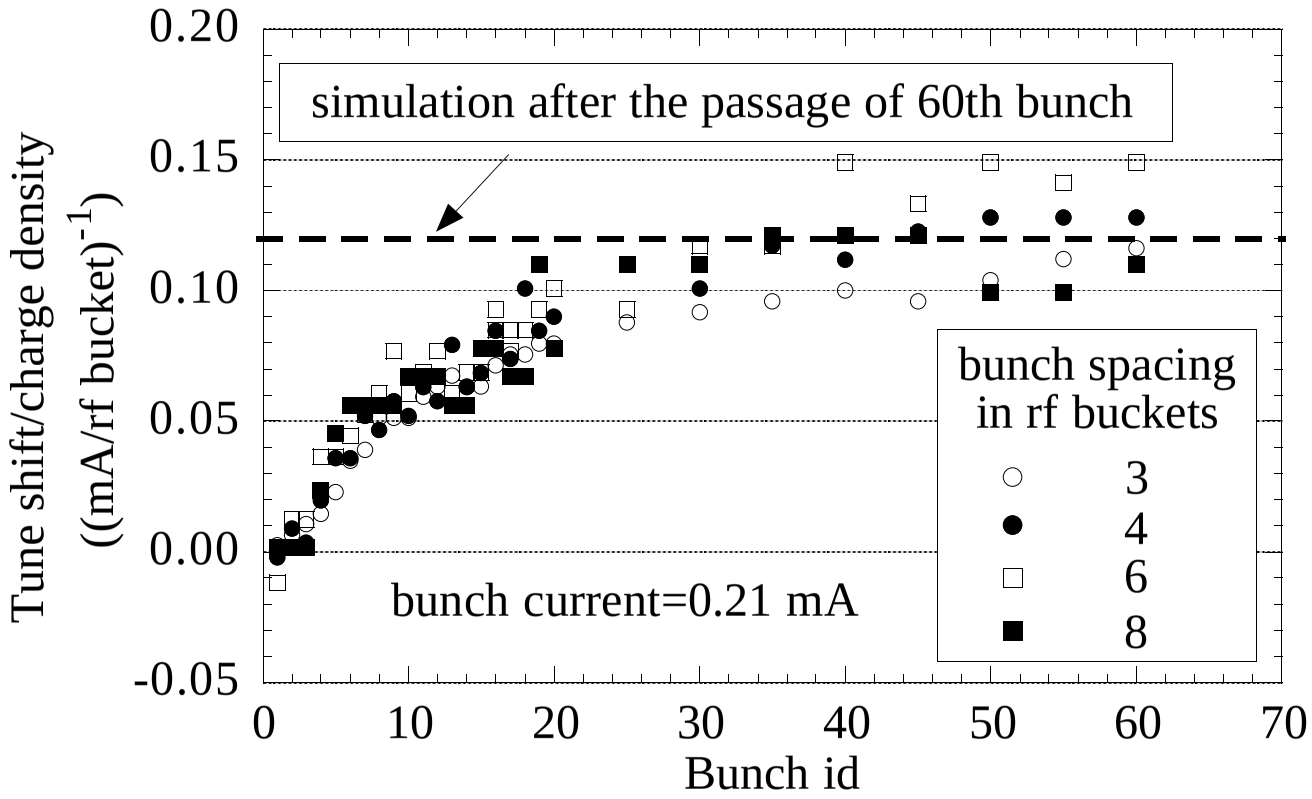
Introduction

- The blowup of the vertical beam size in LER has been observed since early operation period. The beam as a function of beam current started to increase at a threshold beam current and was almost doubled by 300mA under typical operating conditions.

- Characteristics of observed beam blowup were

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.


Without C-Yokes
Vertical beam size at IP (micron)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
bunch current/bunch spacing(mA/bucket)
bunch spacing in rf buckets
4
8
12
16

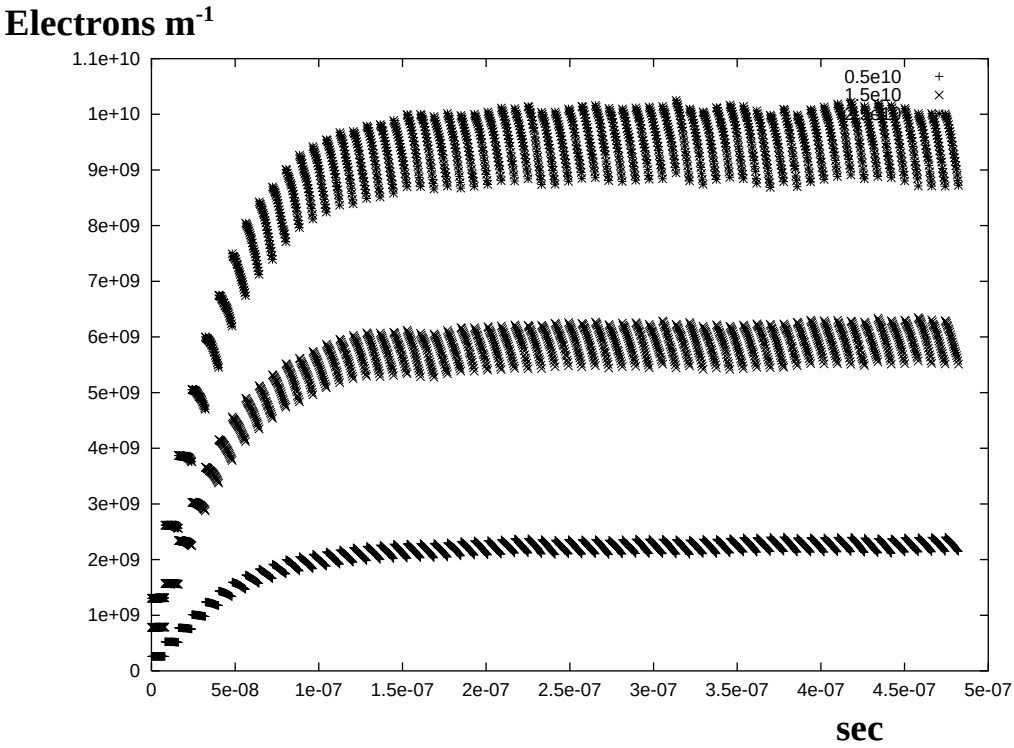

simulation after the passage of 60th bunch
bunch spacing
in rf buckets
3
4
6
8
bunch current=0.21 mA
Tune shift/charge density
((mA/rf bucket)$^{-1}$)
Bunch id
0.20
0.15
0.10
0.05
0.00
-0.05
0
10
20
30
40
50
60
70

- As a model to explain the blowup, the single-bunch head-tail instability caused by the electron cloud was proposed by F. Zimmermann and K. Ohmi.

  Electrons which are generated by the synchrotron radiation form a cloud by the attractive force of multi-bunch positron beam.

  Strong or regular head-tail instability in a bunch occurs by the mediation of the cloud.

  The beam size blowup will be observed as a result of the head-tail oscillation of the instability.



Buildup of electron cloud (Simulation by F. Zimmermann)

Observation after Santa Fe workshop

1. Cloud build up
   - The beam size of two trains with a train-to-train gap was measured to observe the build up or decay of the cloud over two trains. The result showed that

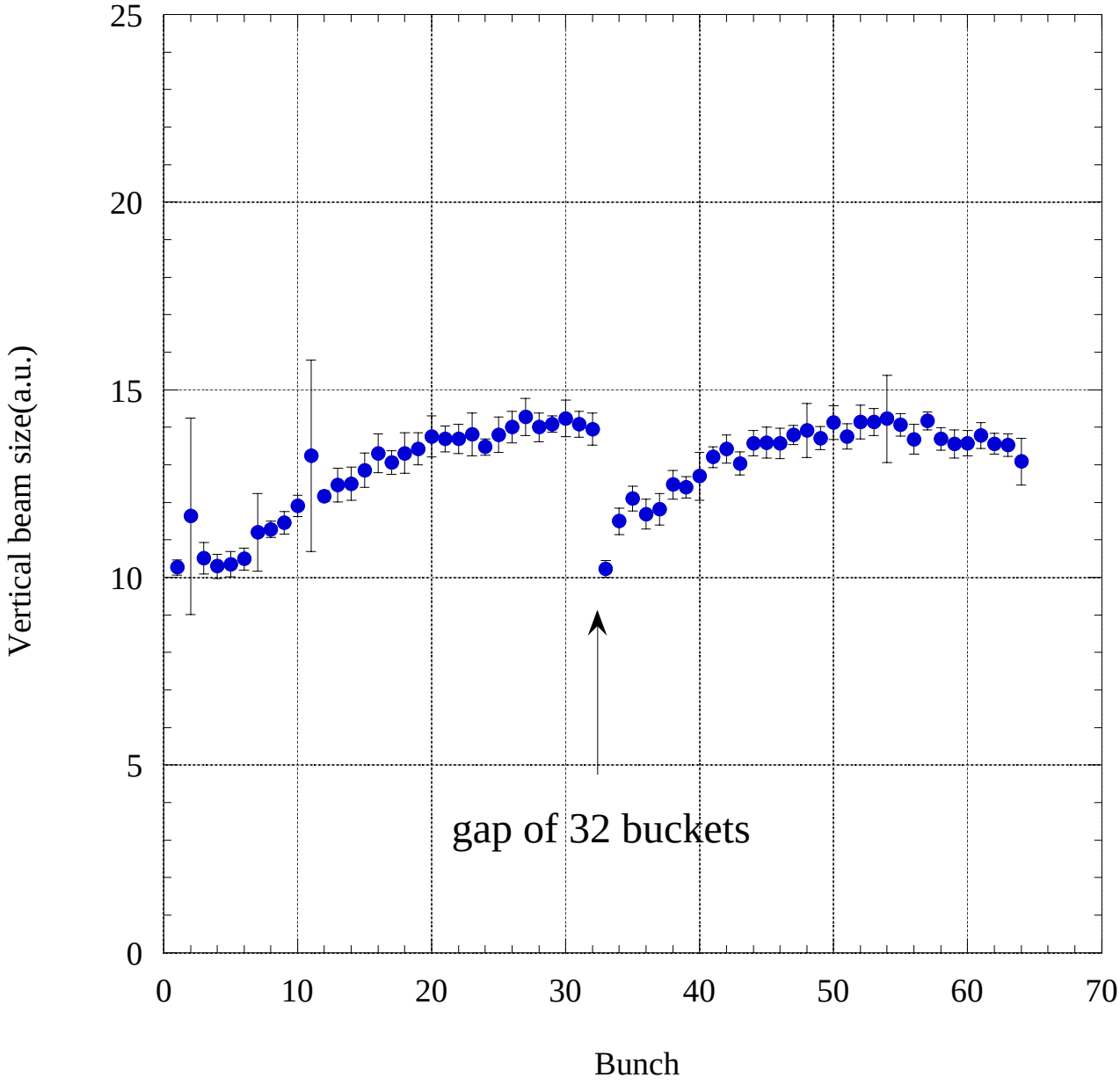
     in the first train, the beam size started to blowup at the 7th bunch,

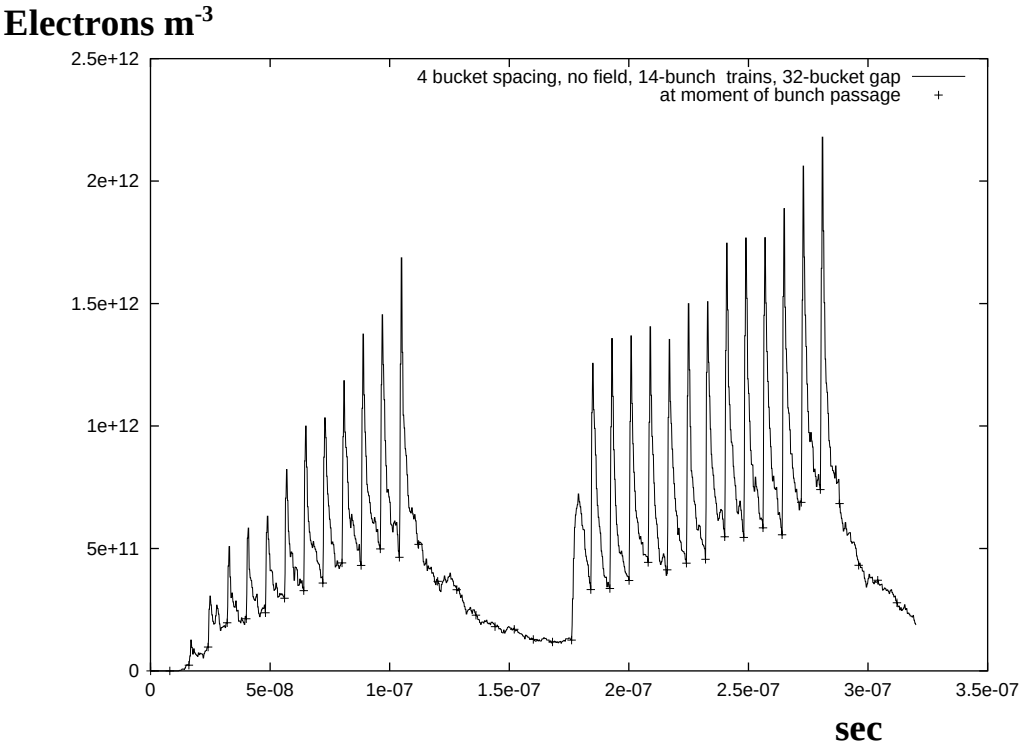
     in the second train, the 2nd bunch already showed a sizable blowup.

2. The higher chromaticity reduced the blowup.

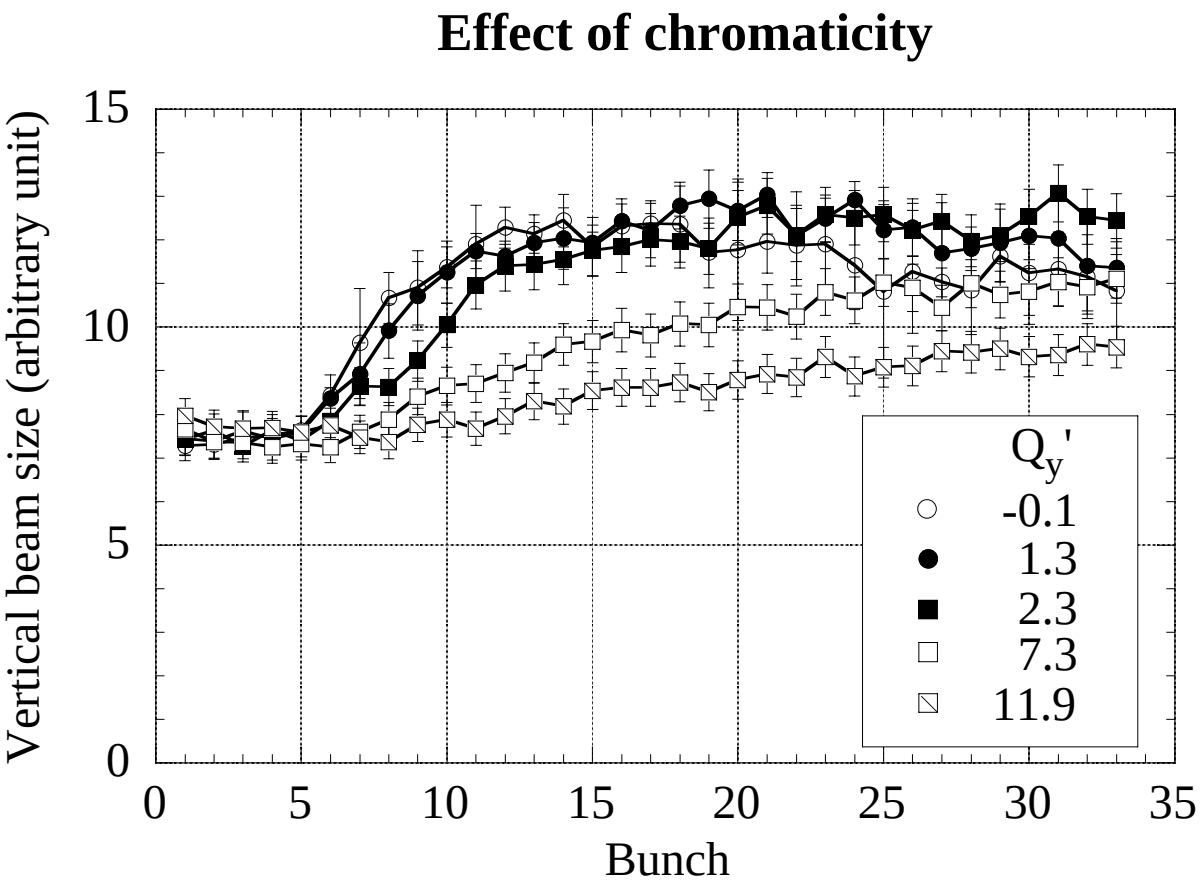
3. Single bunch effect
   - The blowup was enhanced when the charge of the test bunch immediately after the train was increased.

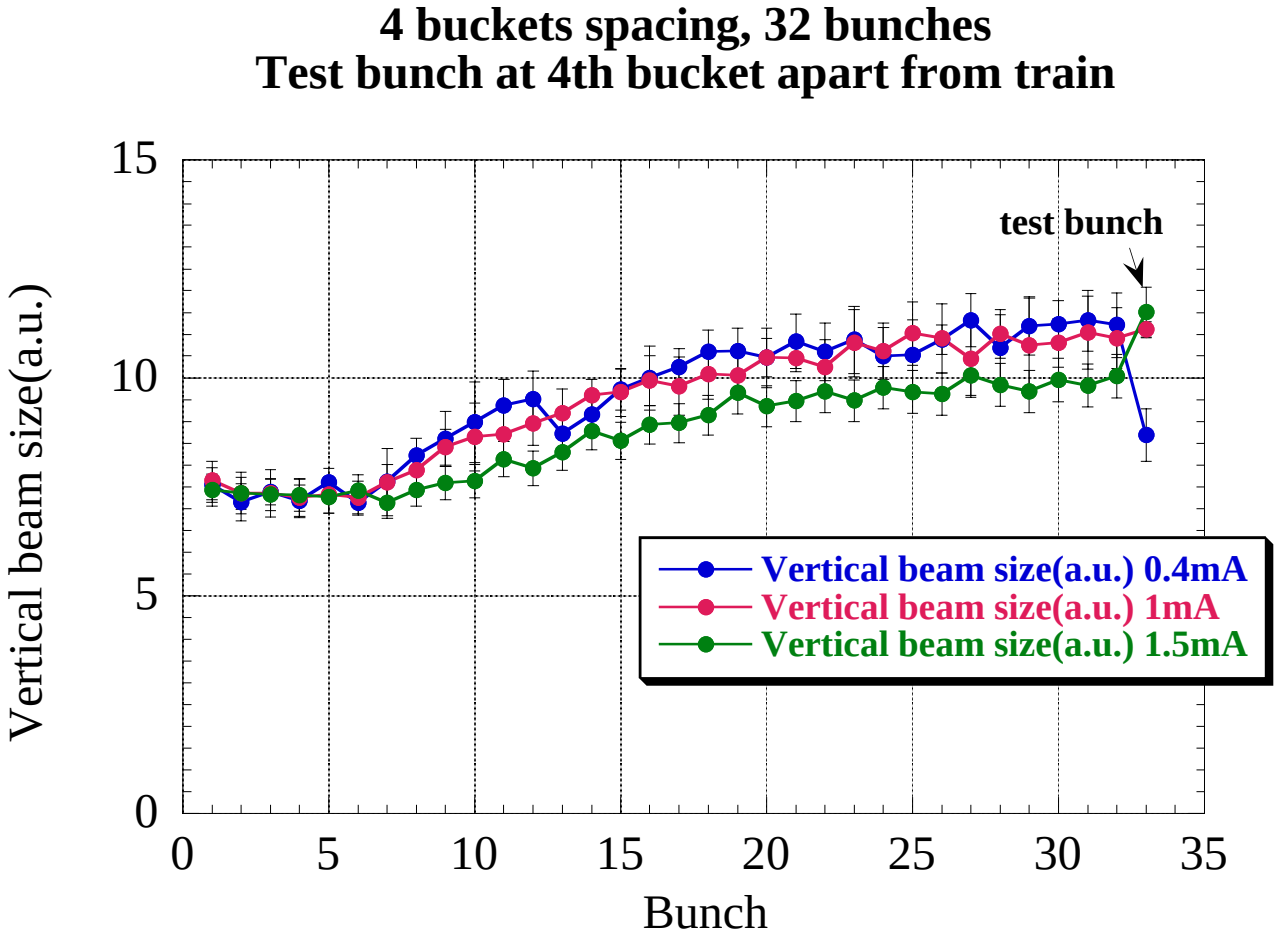
Effect of train gap





Electron density near the beam (Simulation by F. Zimmermann)


Effect of chromaticity
Vertical beam size (arbitrary unit)
Bunch
0
5
10
15
0
5
10
15
20
25
30
35
Qy'
-0.1
1.3
2.3
7.3
11.9


4 buckets spacing, 32 bunches
Test bunch at 4th bucket apart from train
test bunch
Vertical beam size(a.u.) 0.4mA
Vertical beam size(a.u.) 1mA
Vertical beam size(a.u.) 1.5mA
Vertical beam size(a.u.)
Bunch
0
5
10
15
0
5
10
15
20
25
30
35

Solenoid system

To remove the electrons, many permanent magnets called C-yokes were installed in the ring.

Then C-yokes were replaced with solenoids because

1) the simulation showed they are five to ten times more efficient than C yokes to reduce the density of the cloud,

2) an experiment by the vacuum group showed solenoids were more effective than installed C yokes to remove the electrons.

Solenoids were installed in three stages.

1) First installation (September 2000)
   - Solenoids covered straight sections mainly in arcs.
   - Total length of solenoids was about 800 m.
   - Maximum field strength was 45 Gauss.

2) Second installation (January 2001)
   - Solenoids covered bellows and NEG sections in arcs.
   - Total length of solenoids was about 430 m in the region of Bz > 20G.
   - Field strength at the photon stop in NEG region was about 30 Gauss.

3) Third installation (April 2001)
   - Solenoids covered the straight section near IR and around Fuji crossing point where the beam pipe is made of aluminum.
   - Total length of solenoids was about 40 m.

QCF 6-TL

Effect of solenoids

1)Single beam measurement

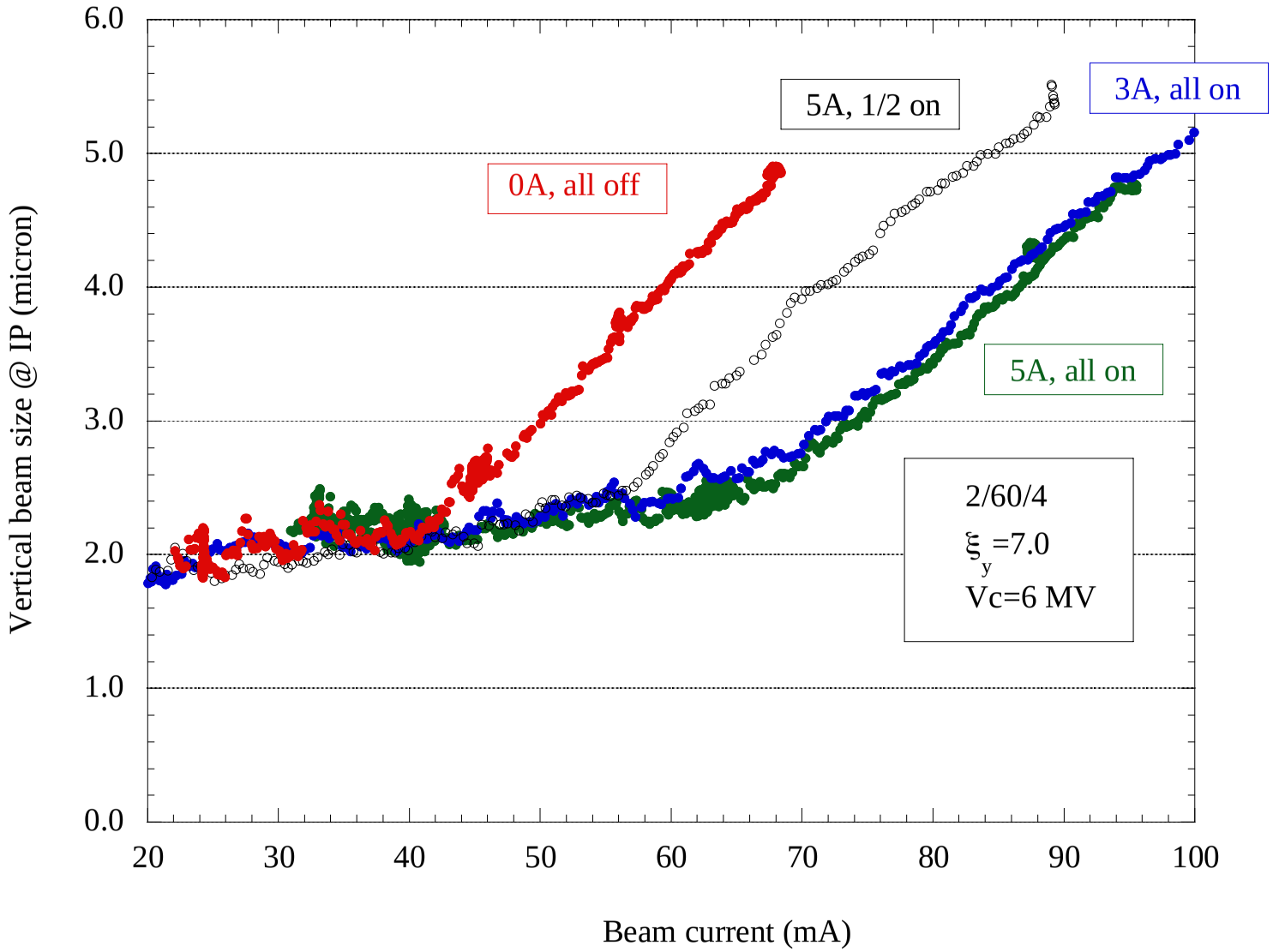
- The threshold current of the blowup measured by the interferometer was increased when the solenoids were excited.

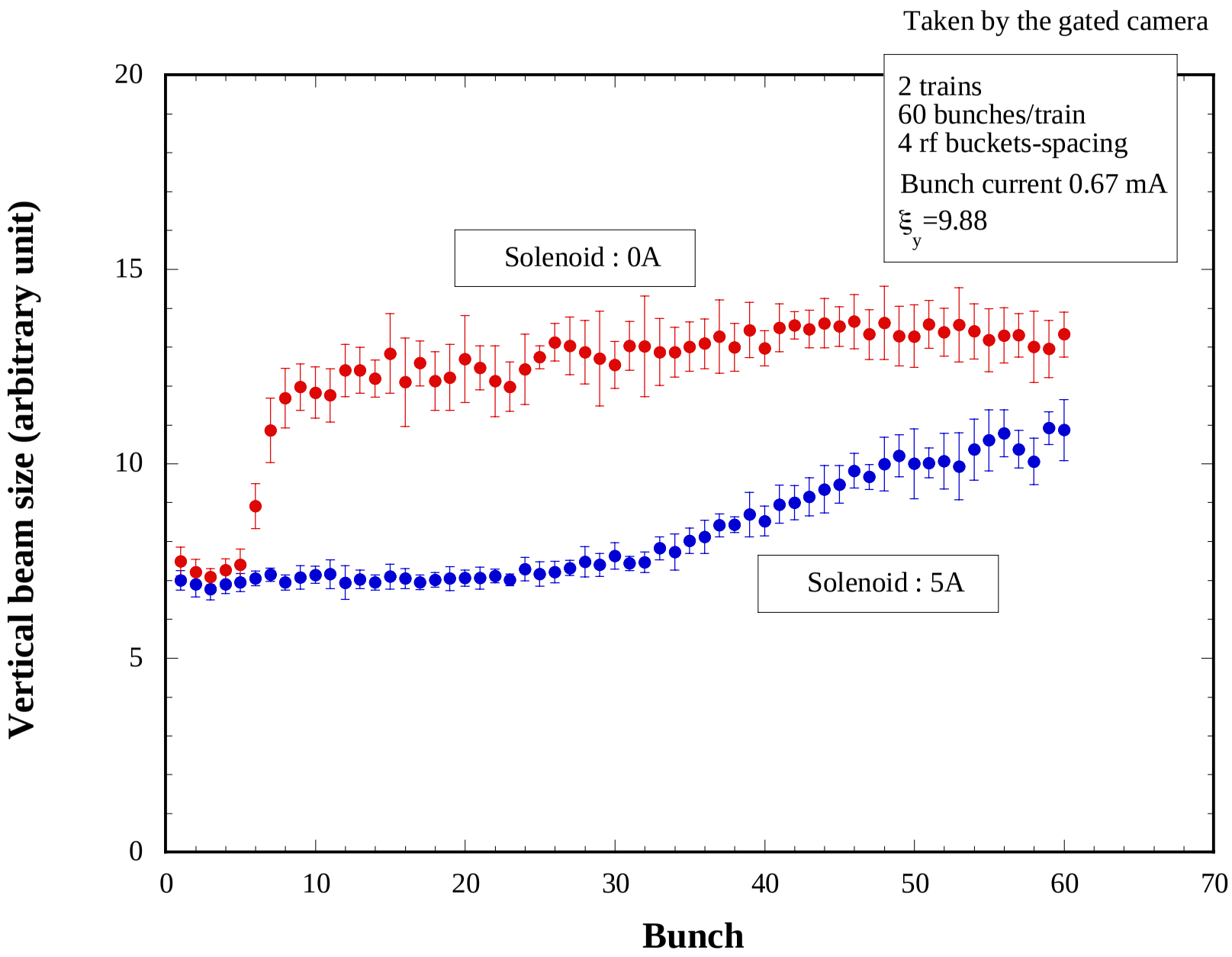
- The vertical beam size along a train was measured by a gated camera. The data clearly showed that the solenoids were effective to suppress the blowup especially in the forward part of the train.

- The vertical tune of each bunch in a train was measured by a gated tune meter. The tune increased along the train then saturated. The tune shift at saturation was enhanced about 30% when the solenoids were turned off.

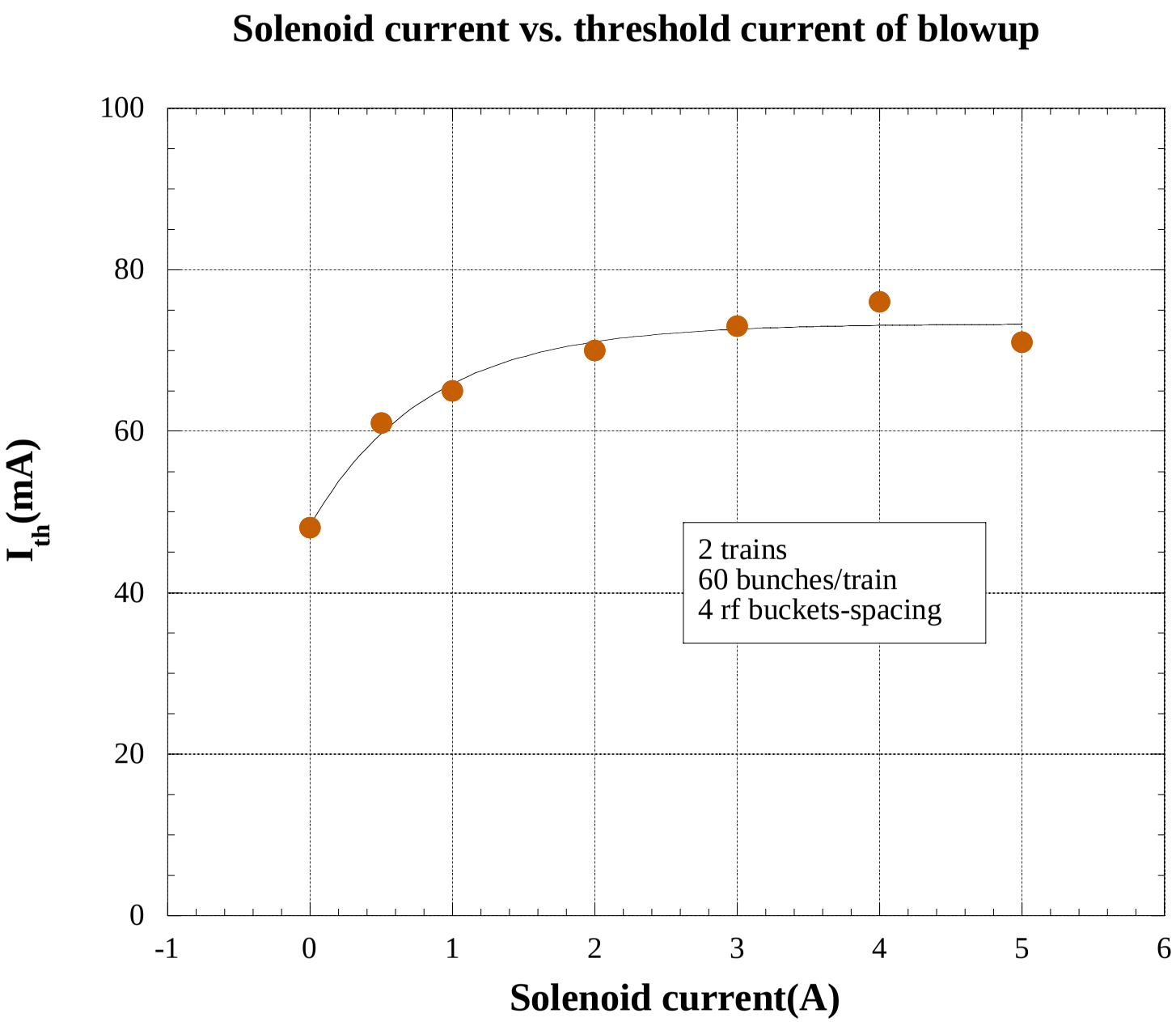
  → T. Ieiri's talk

Effect of solenoid on vertical beam size (LER)




Taken by the gated camera
2 trains
60 bunches/train
4 rf buckets-spacing
Bunch current 0.67 mA
ξy =9.88
Solenoid : 0A
Solenoid : 5A
Vertical beam size (arbitrary unit)
Bunch
0
5
10
15
20
0
10
20
30
40
50
60
70

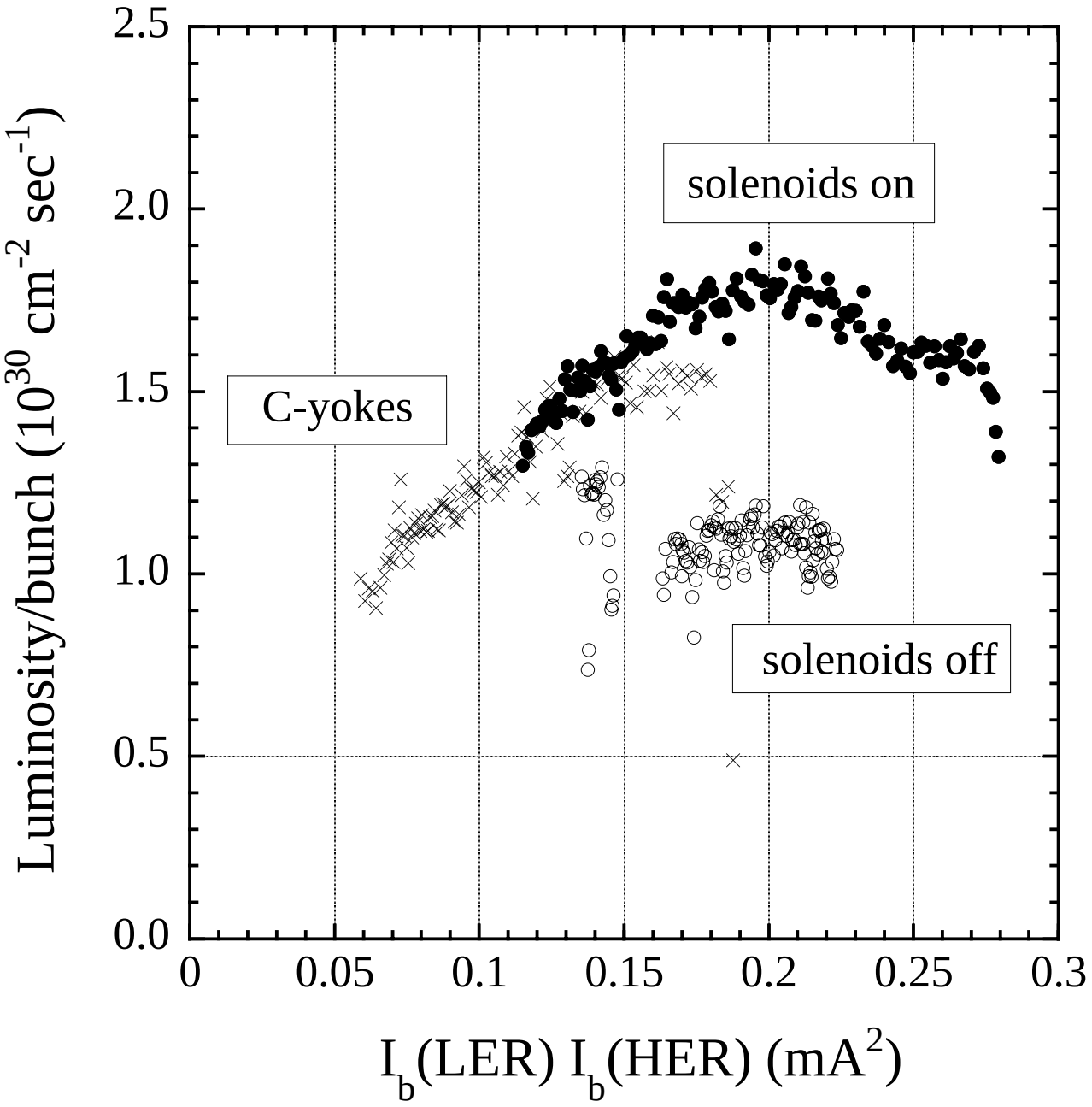
- The threshold beam current at which the blowup started was measured by the interferometer as a function of the solenoid It shows that the threshold beam current is nearly saturated at 3 A, i.e. at about a 30 Gauss solenoid field.


Solenoid current vs. threshold current of blowup
100
80
60
40
20
0
-1
0
1
2
3
4
5
6
I_{th}(mA)
Solenoid current(A)
2 trains
60 bunches/train
4 rf buckets-spacing

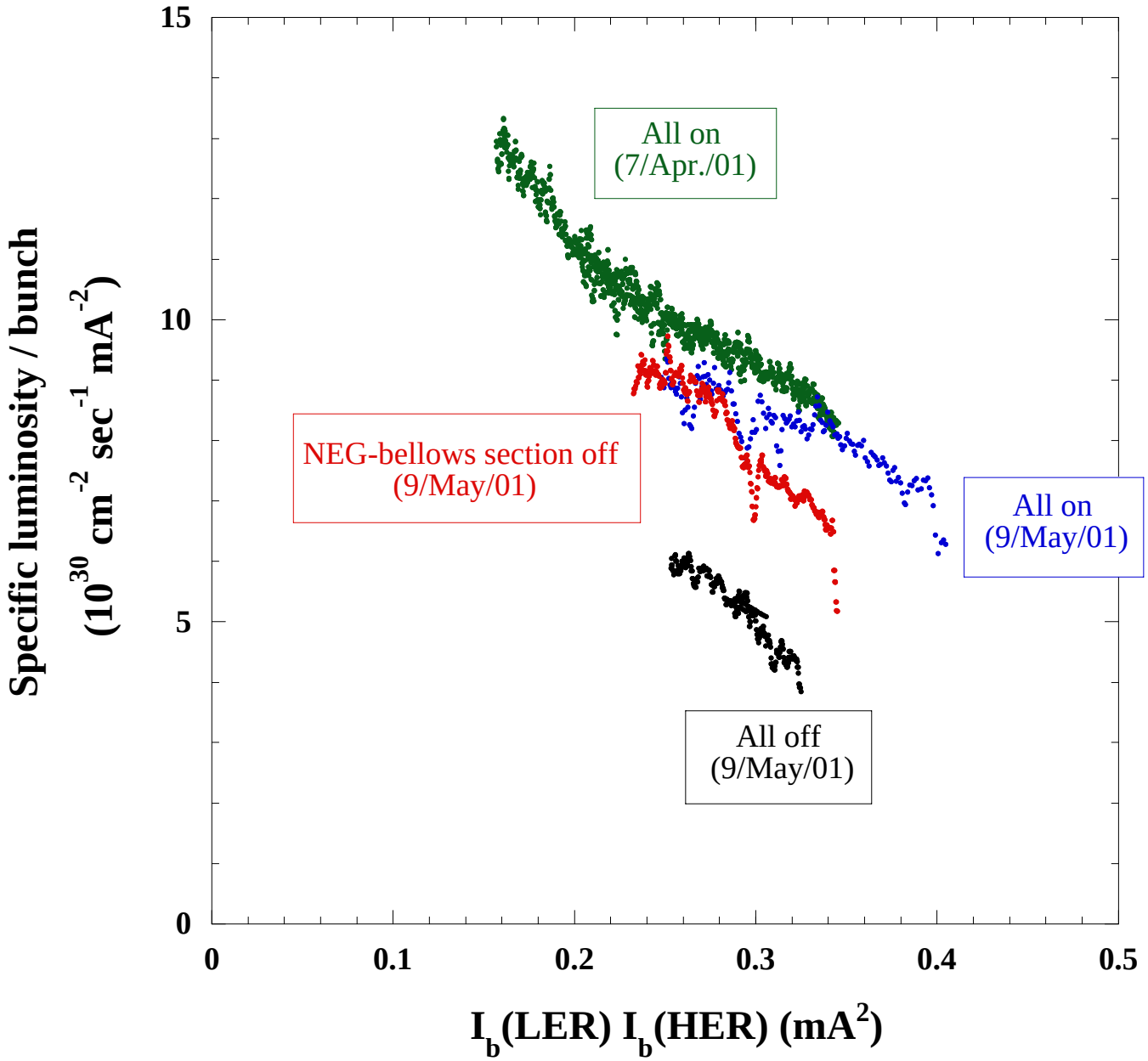
2)Luminosity

- Solenoids were effective to improve the luminosity in the physics fill pattern.

- The effect of C yokes and firstly installed solenoids on the specific luminosity were almost same. Thus the luminosity was not increased after the first installation of solenoids.


2.5
2.0
1.5
1.0
0.5
0.0
0
0.05
0.1
0.15
0.2
0.25
0.3
Luminosity/bunch (10^{30} cm^{-2} sec^{-1})
I_b(LER) I_b(HER) (mA^2)
solenoids on
C-yokes
solenoids off

Effect of solenoid



Questions

1.Persistent blowup

- Even after installation of solenoids the beam size still starts to blowup at 30th bunches and slowly increases.
- Train gap longer than 600ns is necessary for removing the effect of the forward train.

2.Hysteresis

- The beam size continues to blowup even after the injection stops. The time when beam size reaches to a maximum value is delayed typically 100 sec after the injection stops (K. Oide).

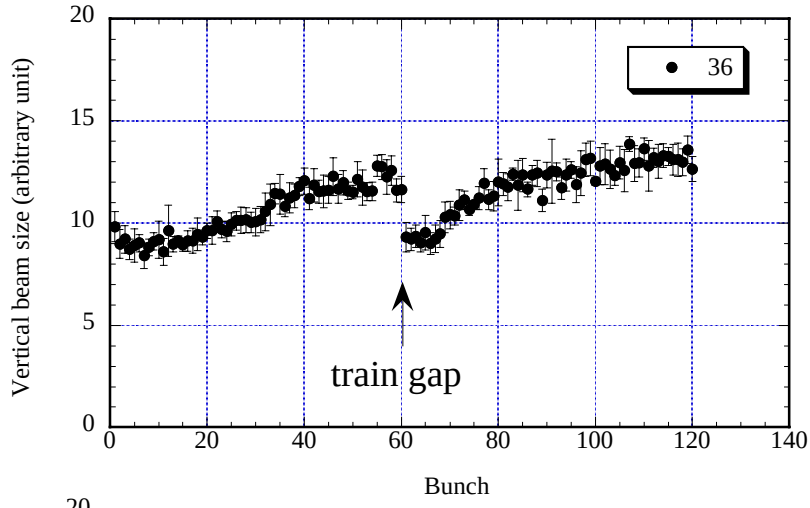
3.Luminosity in shorter bunch spacing

- The specific luminosity in 3 rf buckets spacing was only 65% of that in 4 rf buckets spacing even when the average charge density of the beam was same in both fill patterns.

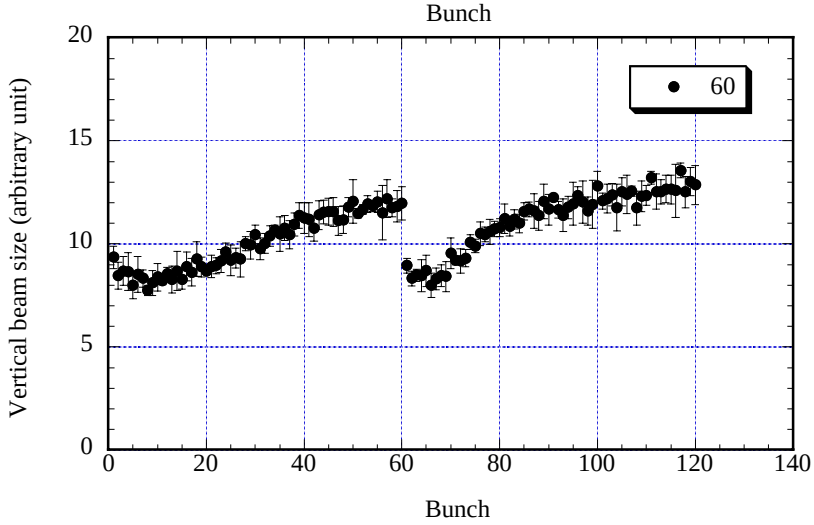
Effect of train gap (solenoid on)

Train spacing in RF buckets

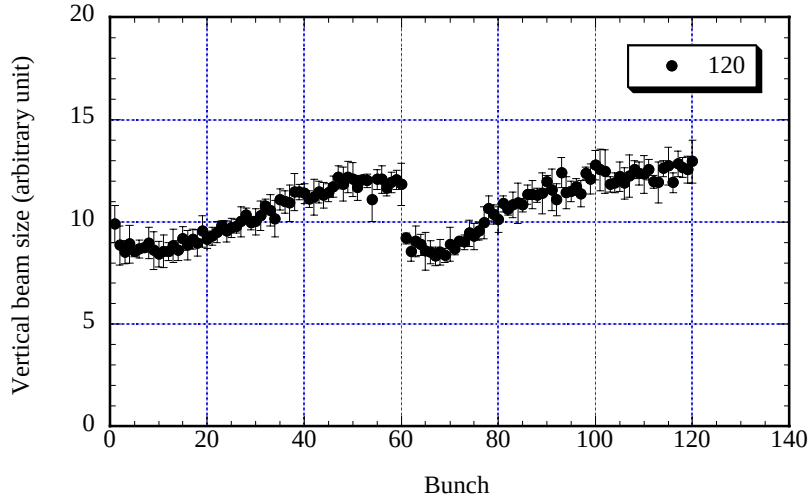
36



60



120



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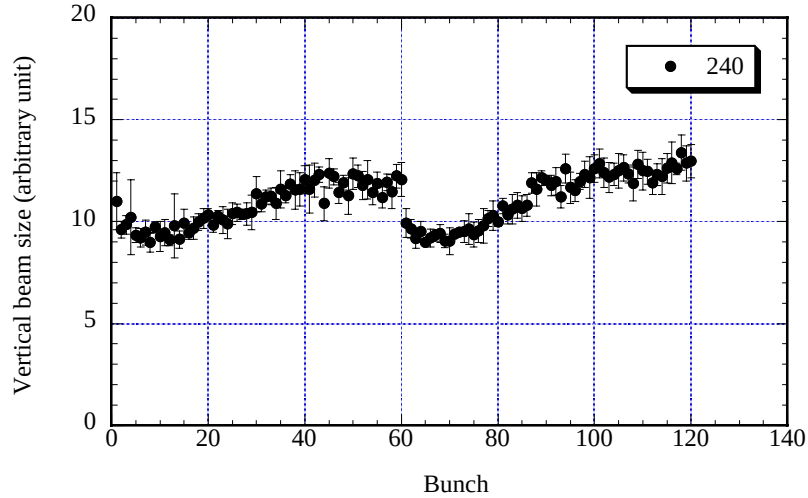
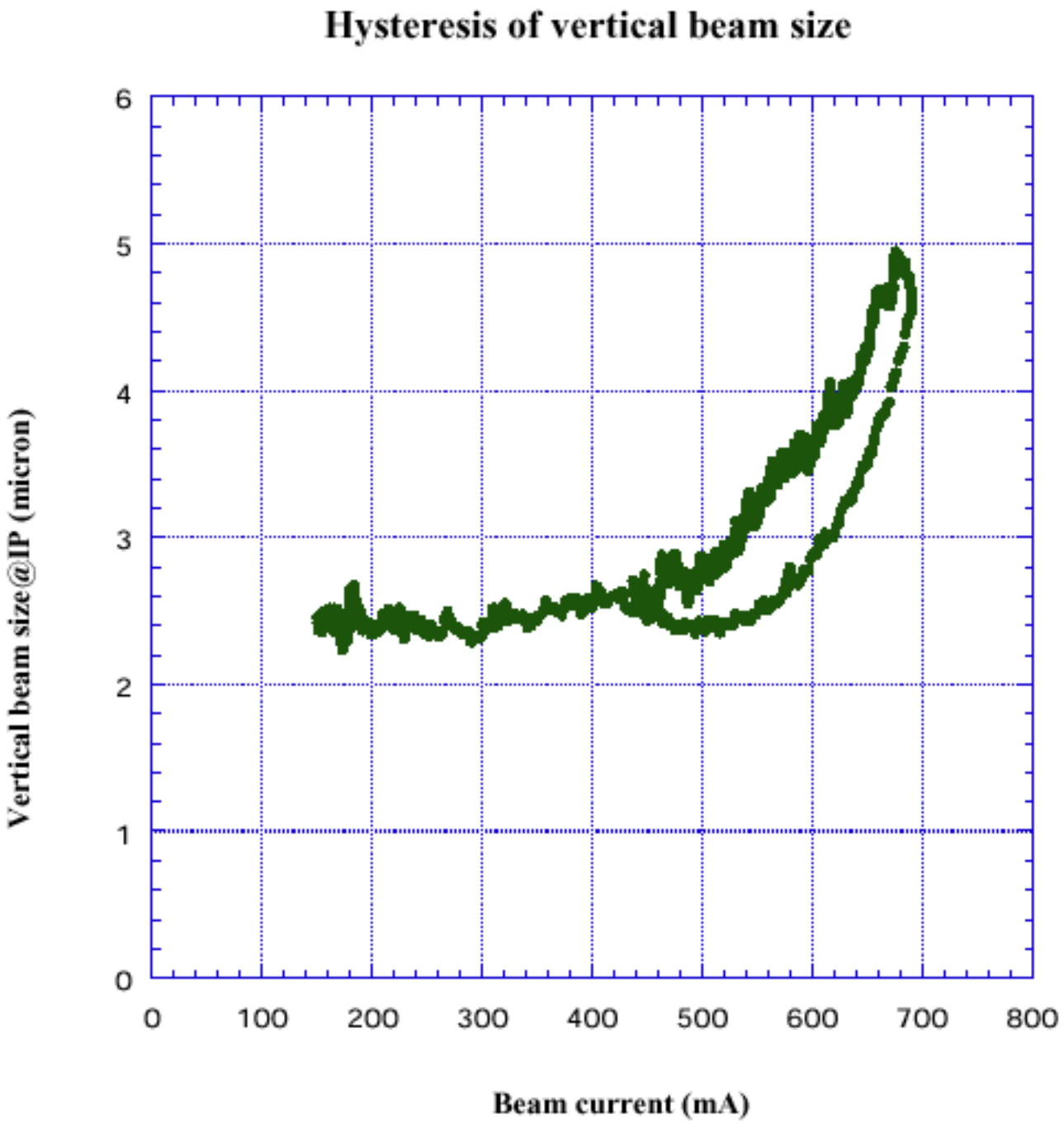
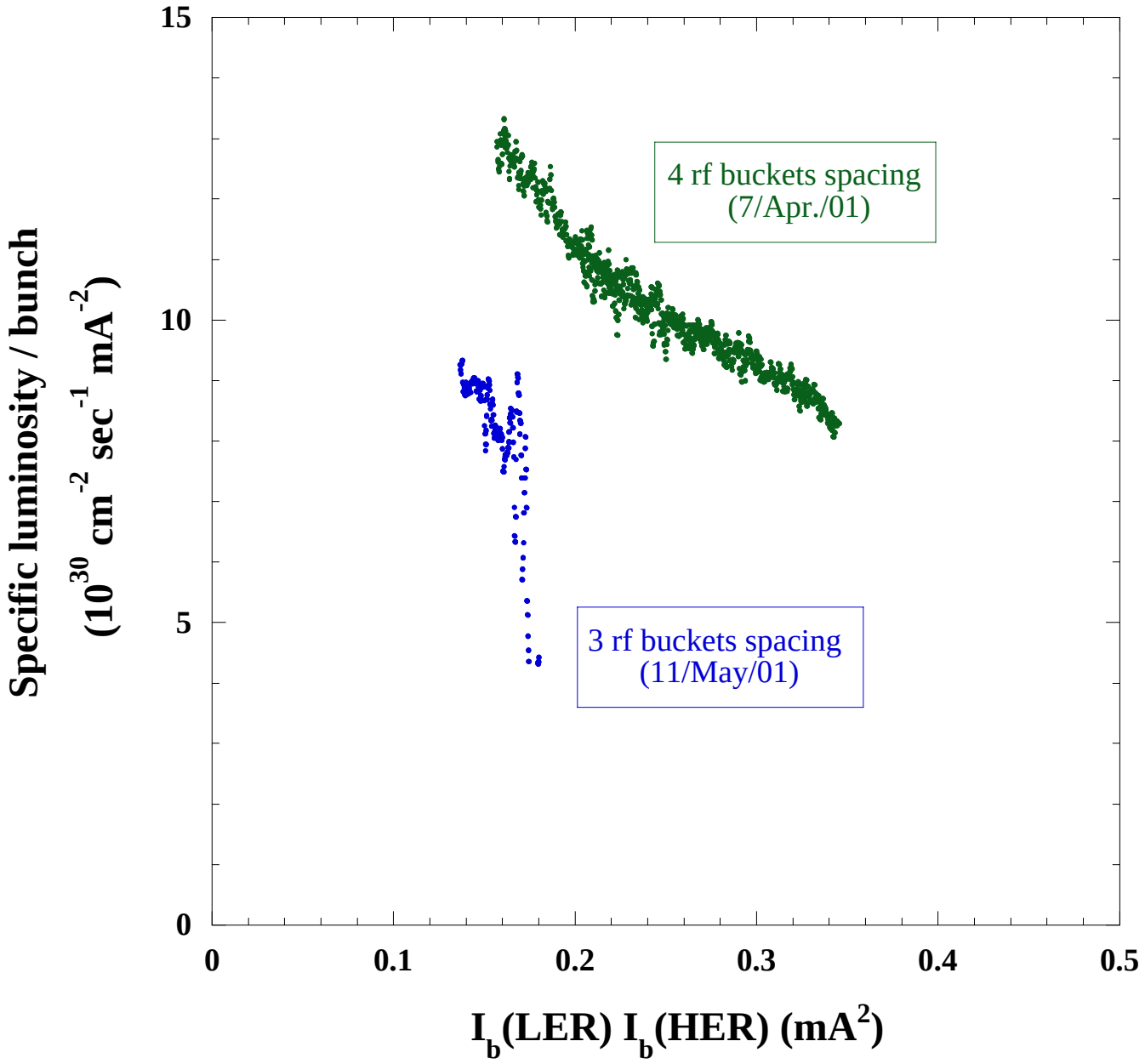



Hysteresis of vertical beam size
Vertical beam size@IP (micron)
Beam current (mA)
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700
800

3 & 4 rf buckets spacing



Plans

1. More solenoids
   About 3350 solenoids were installed in this summer shutdown.

2. A prototype of ante-chamber will be installed in this summer shutdown.

3. Operation in shorter bunch length

Summary

- Many observations are explained by the single-bunch head-tail model caused by the electron cloud.

- There are also some observations which can not be explained by the model.

  Persistent blowup
  Hysteresis

- The most important question is why the luminosity in 3 buckets spacing is low.

- It is very interesting that how much the luminosity will increase after further installation of solenoids.