Photo-electron and other instabilities

23th Feb. 2001 KEKB-MAC

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Photo-electron instability

1. Introduction
2. Further observation before installation of solenoids
3. Effect of solenoids
4. Hysteresis of beam size
5. Questions
6. Plans
7. Summary

Coupled bunch instability

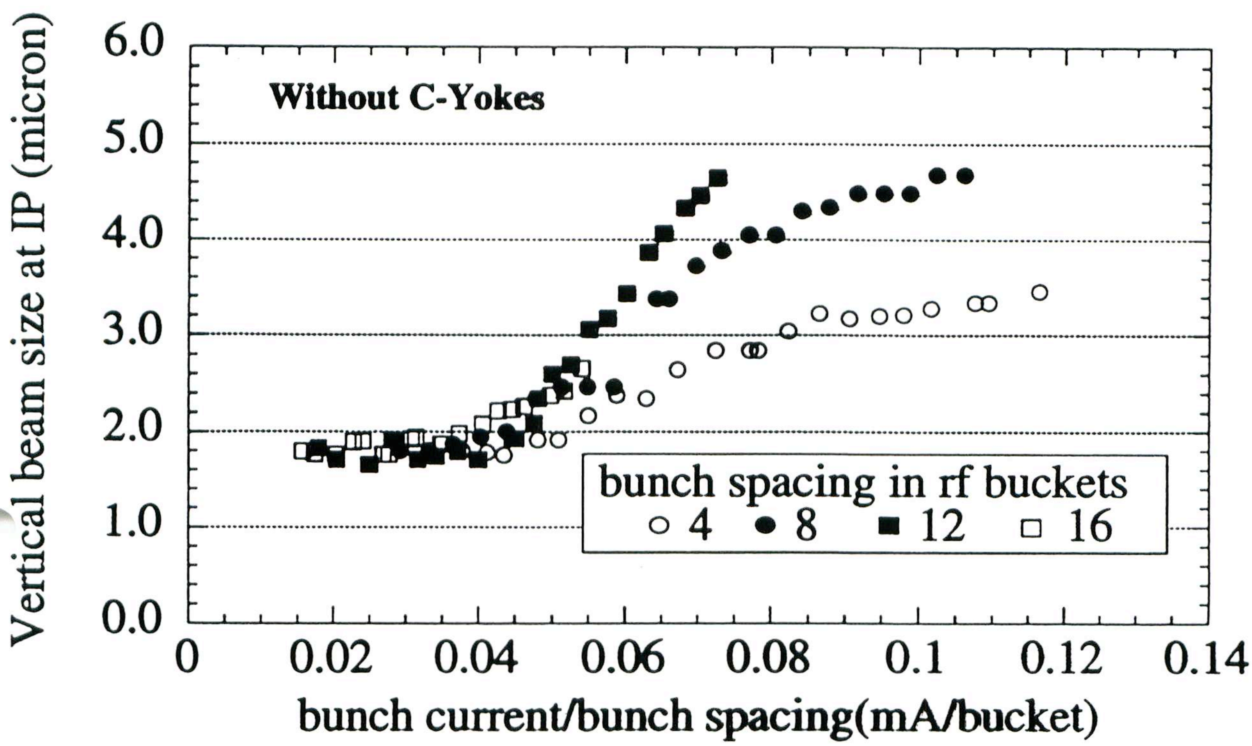
Introduction

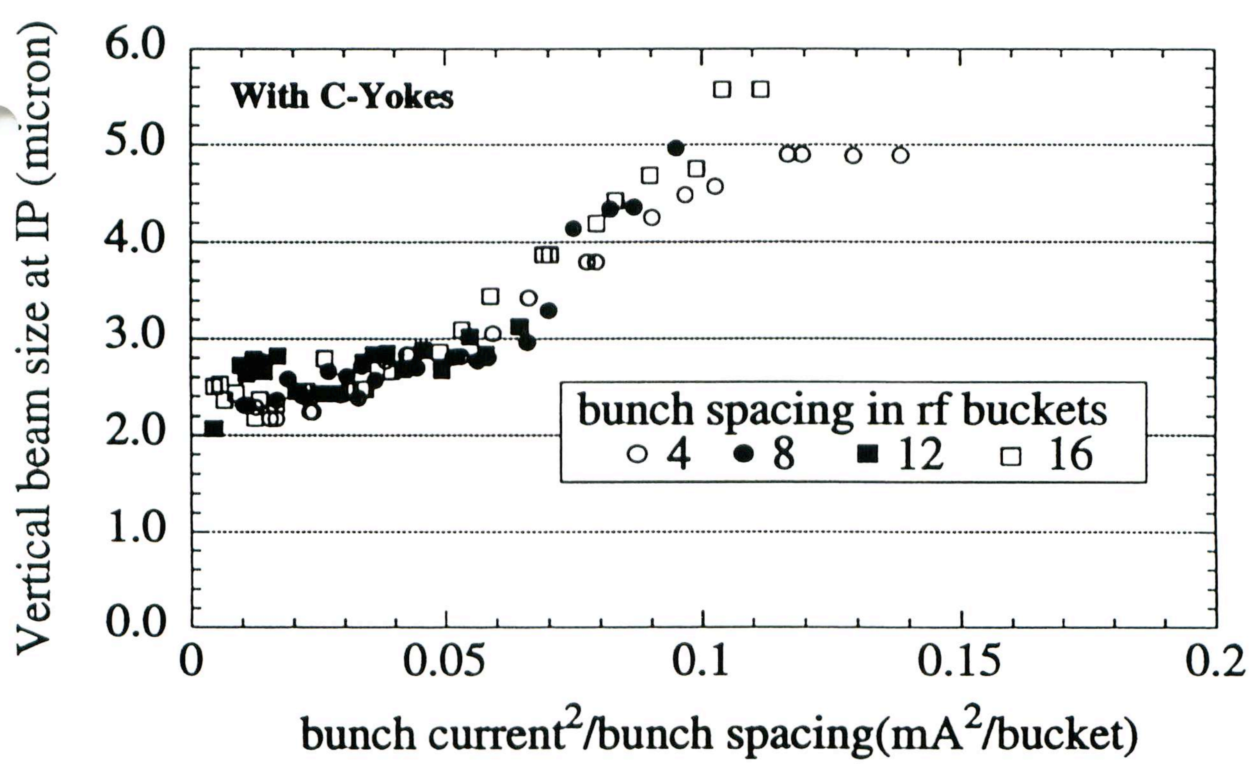
Summary until previous MAC

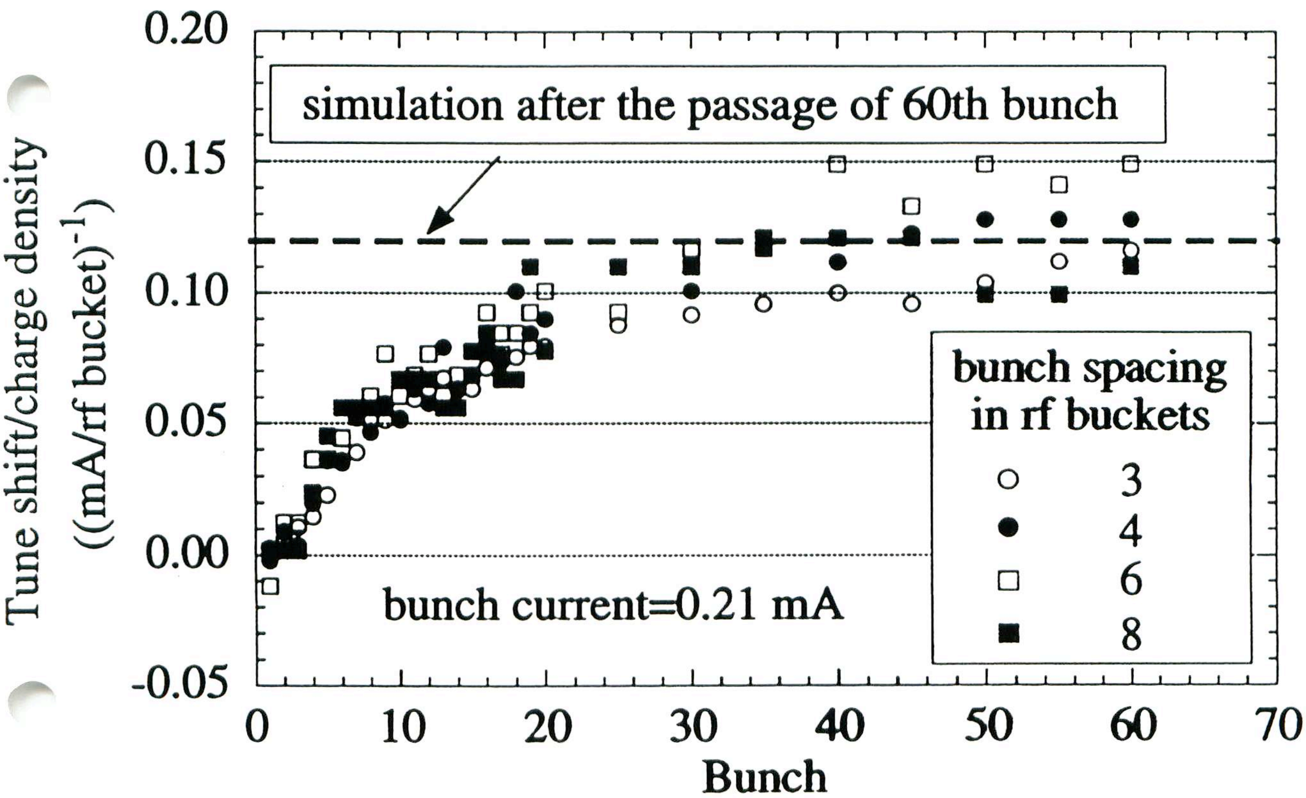
- The beam size of LER as a function of beam current starts to increase at a threshold beam current and is almost doubled by 300 mA under typical operating conditions.

- Characteristics of beam blow-up observed by the interferometer were

1)Single beam and multibunch effect.
2)Dipole oscillation is not observed when the chromaticity is enough high.
3)The blow-up has a threshold which is determined by the charge density (bunch current/bunch spacing).
4)The blow-up is almost independent on betatron tunes.
5)Vertical betatron tune increases along the train and almost saturates at about 20th bunch.
6)No dependence on vacuum pressure was observed (especially on hydrogen) in the arc.
7)No dependence on the excitation of the wigglers.

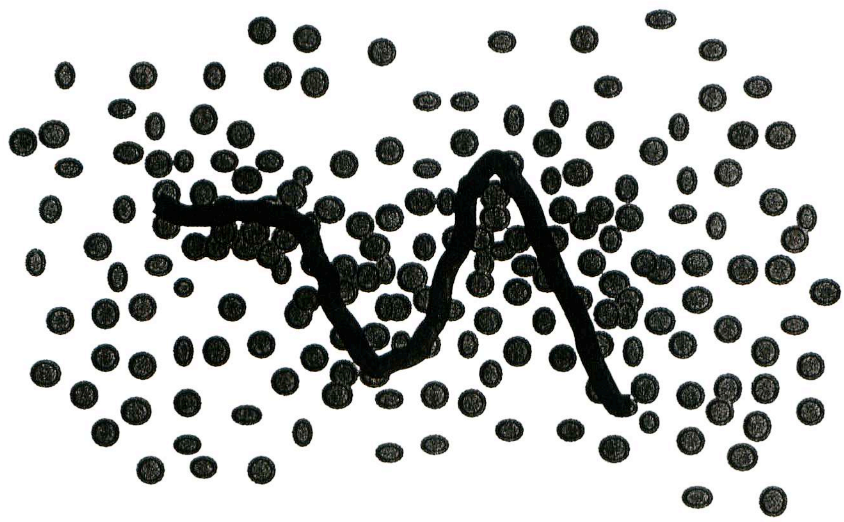

Without C-Yokes
bunch spacing in rf buckets
○ 4 ● 8 ■ 12 □ 16
Vertical beam size at IP (micron)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
bunch current/bunch spacing(mA/bucket)


With C-Yokes
bunch spacing in rf buckets
○ 4 ● 8 ■ 12 □ 16
Vertical beam size at IP (micron)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
0.05
0.1
0.15
0.2
bunch current²/bunch spacing(mA²/bucket)



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

- To explain the blow-up, the single-bunch head-tail instability caused by the electron cloud is proposed by F. Zimmermann and K. Ohmi.



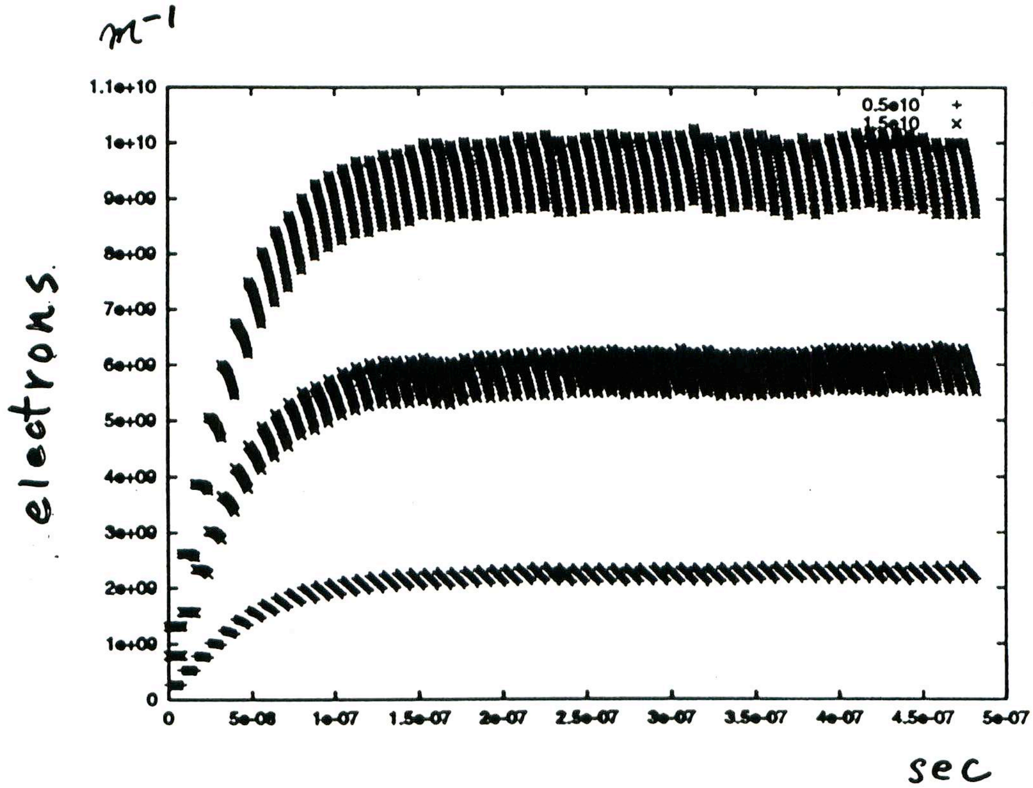
Electrons which are generated by the synchrotron radiation form a cloud by the attractive force of multi-bunch positron beam.

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

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

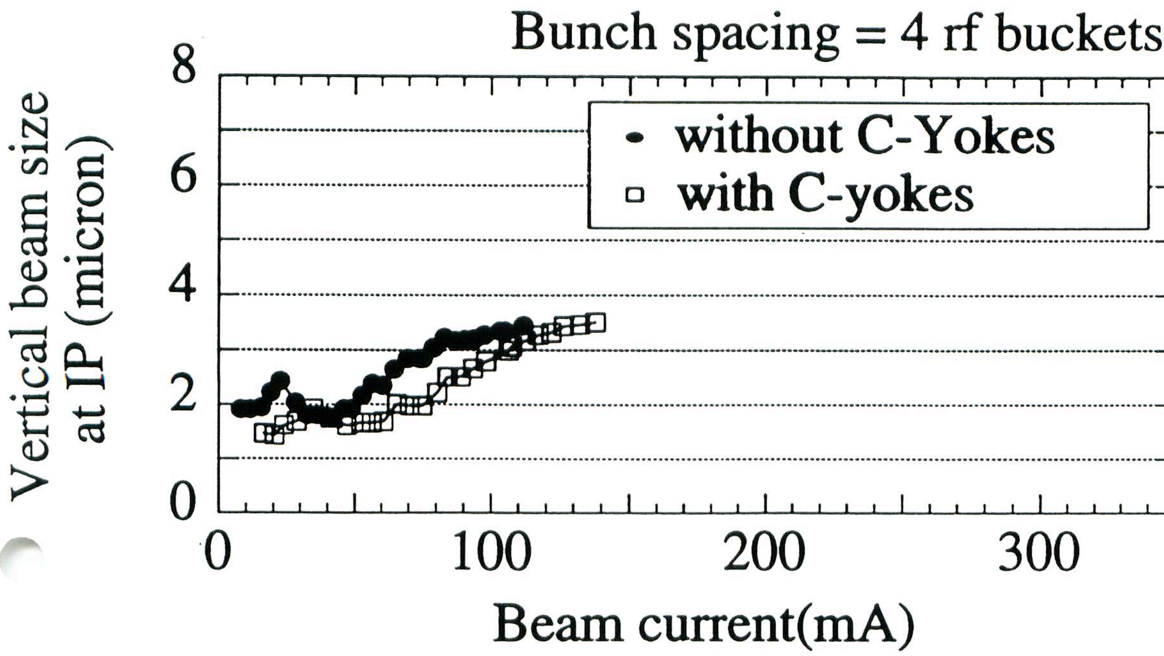
Blow up of electron cloud

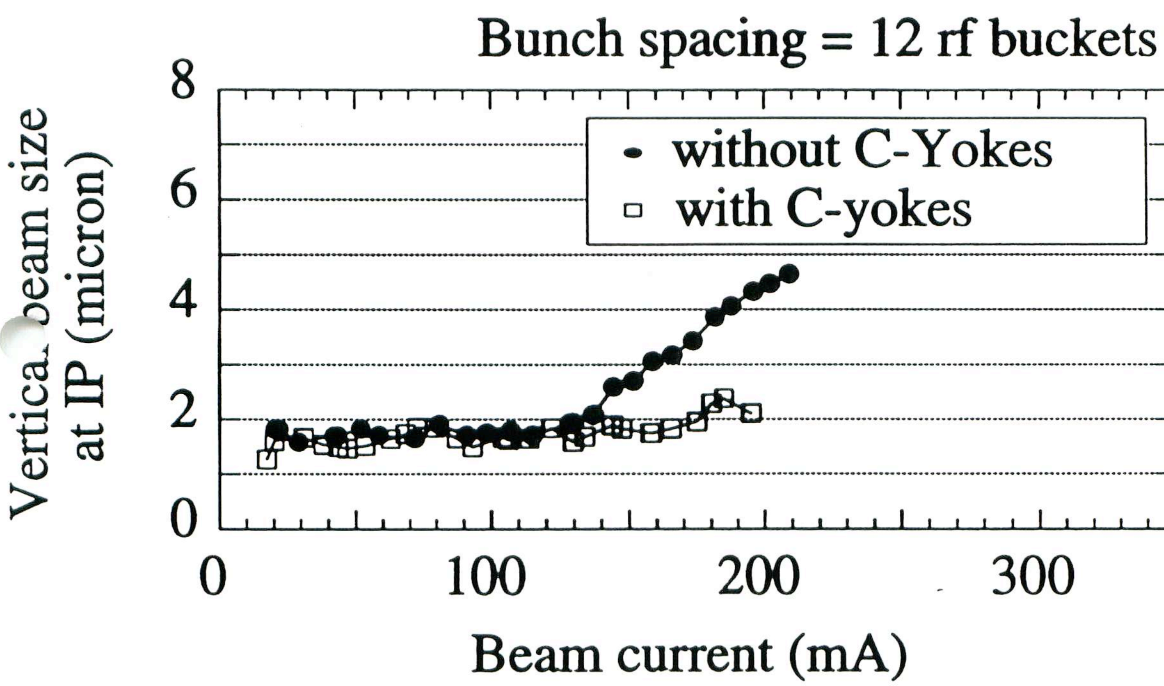
(Simulation by F. Zimmermann



- To remove the electrons, about 5000 permanent magnets were attached on the outer-lateral side of the vacuum chambers where the synchrotron radiation irradiate.

The measurement by the interferometer for a short train (60 bunches/train) showed slight improvement of the blow-up when the bunch spacing is larger than or equal to 8 rf buckets. But the effect was not remarkable.


Bunch spacing = 4 rf buckets
without C-Yokes
with C-yokes
Vertical beam size at IP (micron)
Beam current(mA)
0
2
4
6
8
0
100
200
300


Bunch spacing = 12 rf buckets
without C-Yokes
with C-yokes
at IP (micron)
Beam current (mA)
0
2
4
6
8
0
100
200
300

Works after previous MAC

Date	Event
March/00	More C yokes were installed inner-lateral side of the chambers.
April	Electron monitors were installed.
May	Rearrangement of C yokes (SNNS to SNSN).
July	More C yokes were installed (10%). Rearrangement of C yokes (short to long period).
Sep.	Solenoids were installed.
Jan./01	More solenoids were installed.

And theoretical and simulation works.

Further observation before installation of solenoids

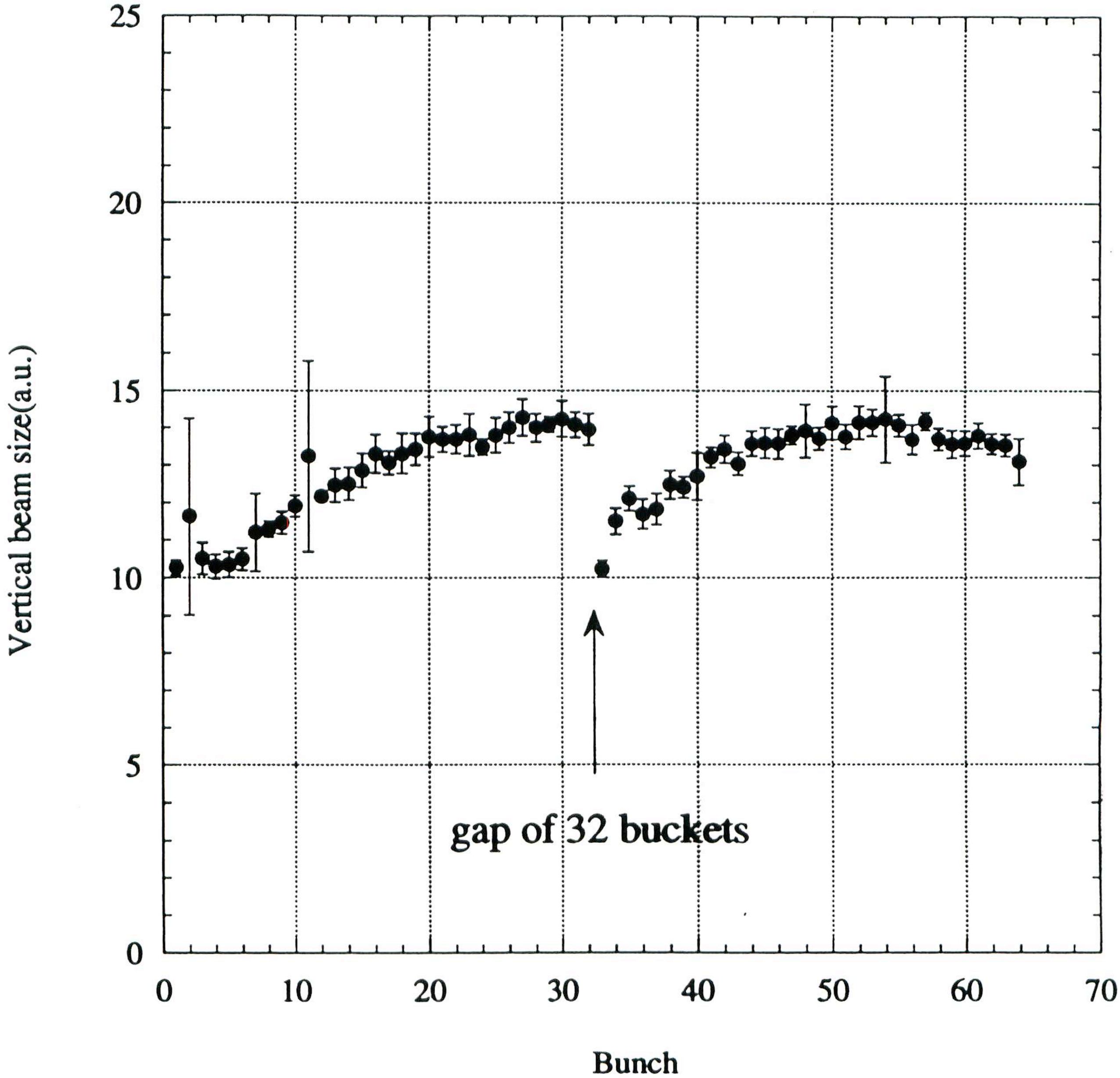
1) Observations which support Zimmermann and Ohmi model

- Observation of the beam size over a first and a second bunch train.
- Effective range of blow-up is about 12 rf buckets.

- The higher chromaticity reduces the blow-up.
- Blow-up is dependent on the charge of a bunch. The blow-up was enhanced when the charge of the test bunch immediately after the train was increased.

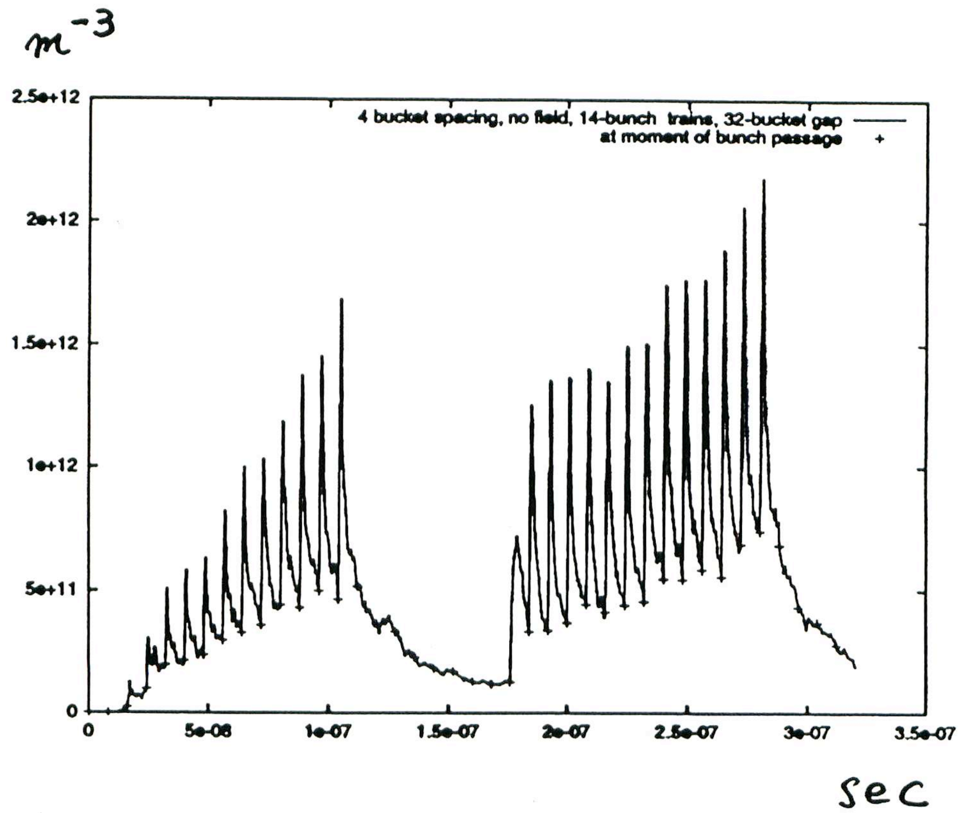
- An amount and energy distribution of electrons in a field free region were measured by electron monitors (energy analyzers). The results were consistent with simulations.

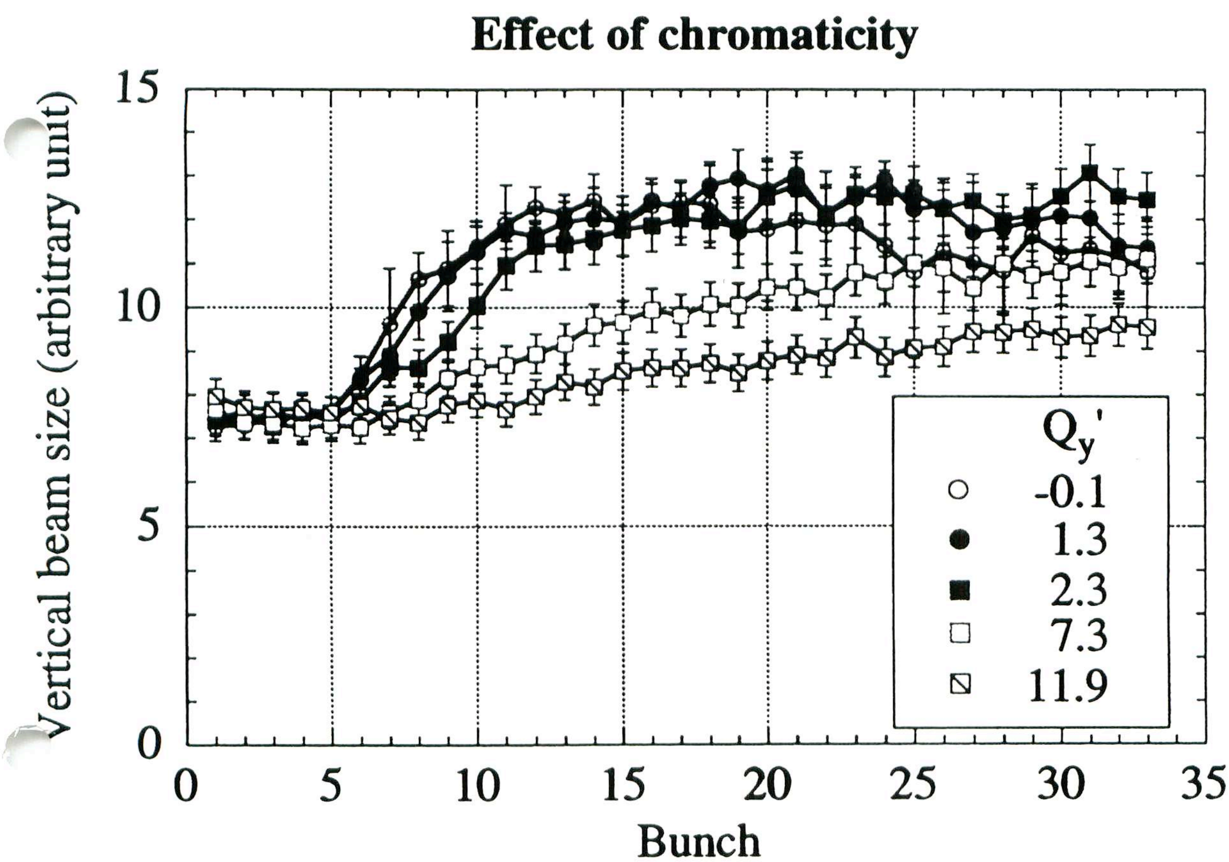
Effect of train gap

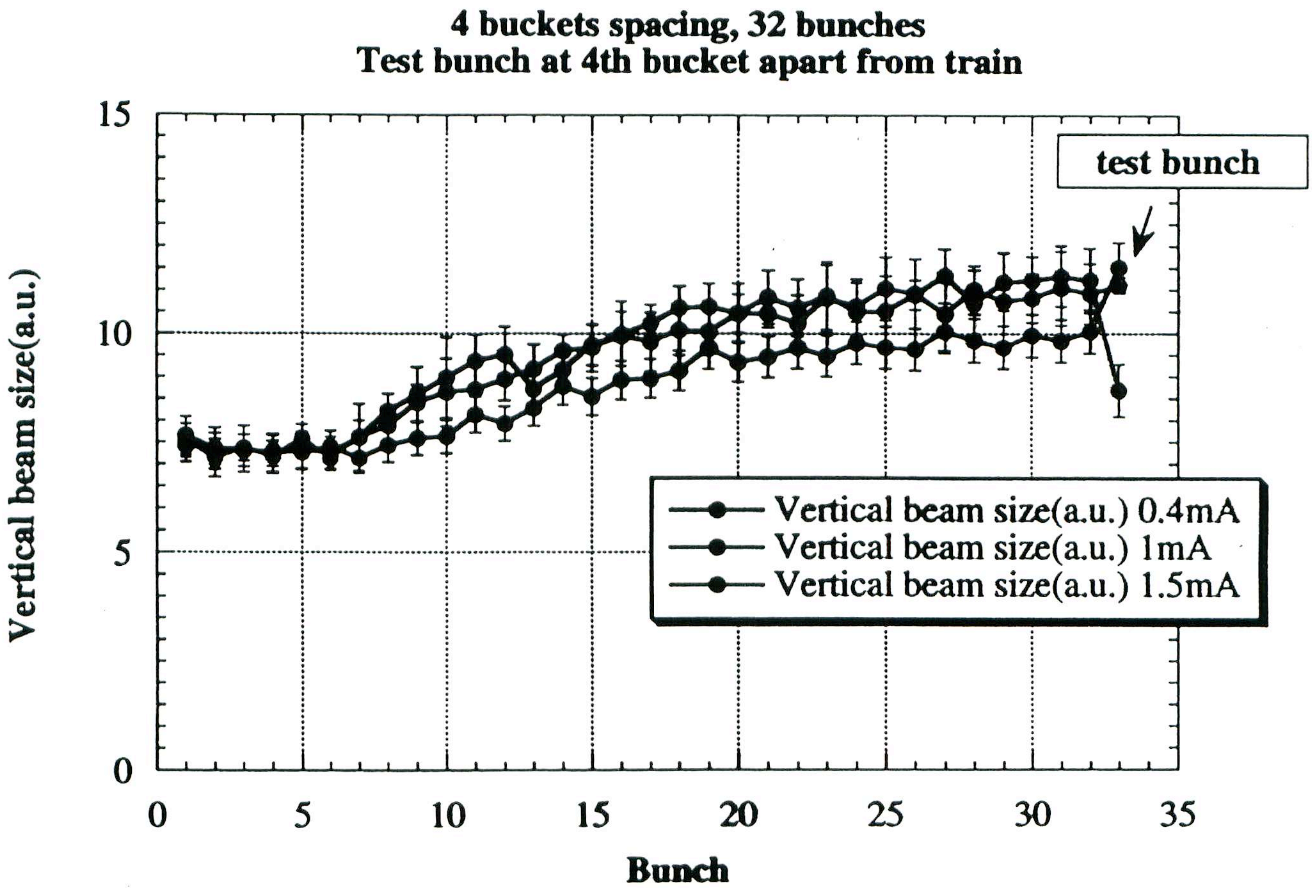


Electron density near the beam

(simulation by F. Zimmermann)




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

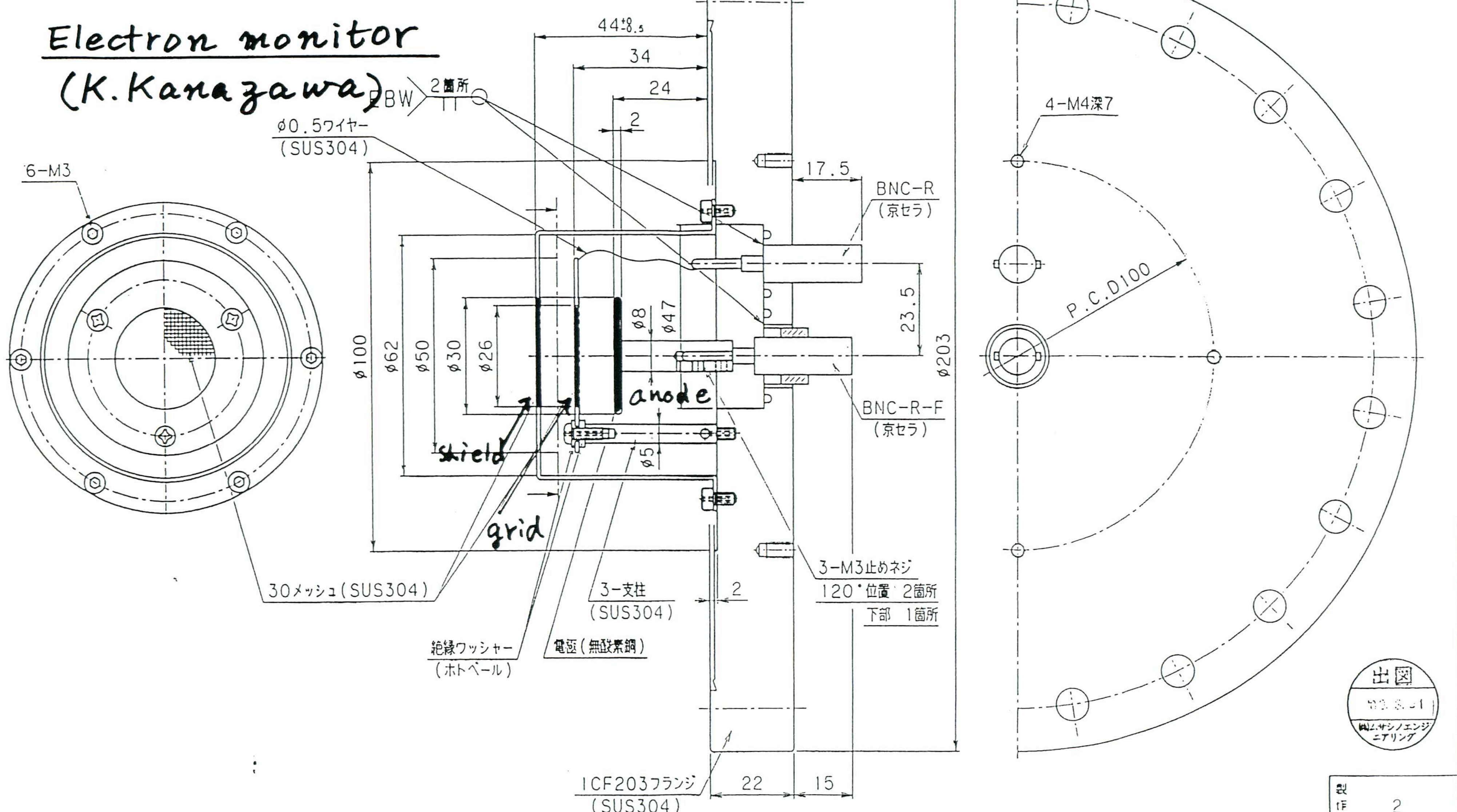

4 buckets spacing, 32 bunches
Test bunch at 4th bucket apart from train
test bunch
Vertical beam size(a.u.)
Bunch
Vertical beam size(a.u.) 0.4mA
Vertical beam size(a.u.) 1mA
Vertical beam size(a.u.) 1.5mA
0
5
10
15
20
25
30
35

注記

1．指示なきエッヂ部C0.2，コーナー部R0.2とする。

2．リーク量は，1.3×10^{-11} Pa・m³/sec以下とする。

Electron monitor
(K.Kanazawa)



仕上げ記号	
～	特に指定しない
▽	100S
▽▽	25S
▽▽▽	6.3S
▽▽▽▽	0.8S

記号	内容	日付	担当

寸法区分	寸法差
0.5以上 6以下	±0.1
6を超え 30以下	±0.2
30を超え 120以下	±0.3
120を超え 400以下	±0.5
400を超え 1000以下	±0.8
1000を超え 2000以下	±1.2

無記号寸法公差(JIS-0405B-m)　無記号角度公差(JIS-0405B-m)

表面処理

承認	検図	設計	製図
		佐藤	石橋

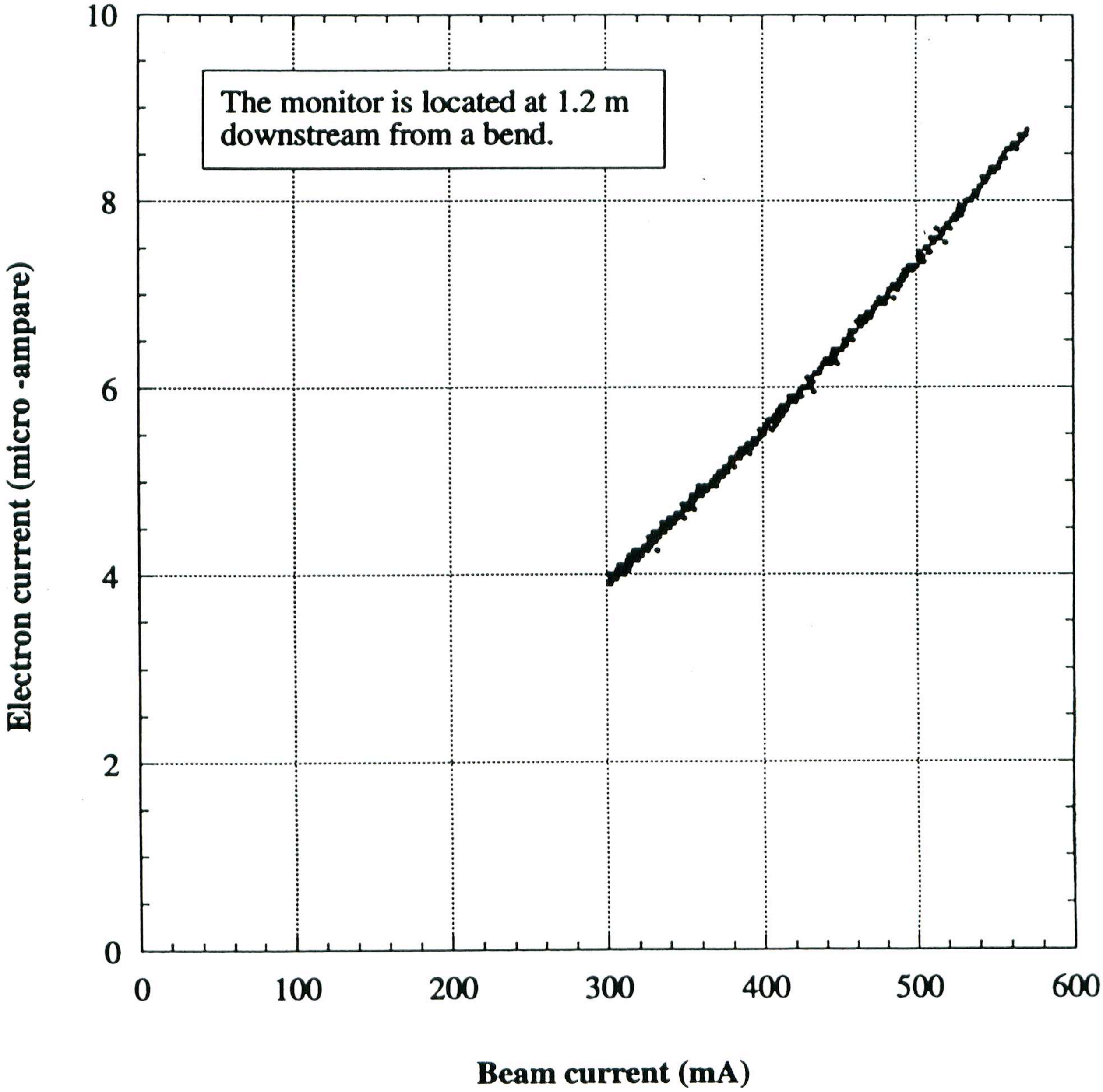
H12年 2月29日

熱処理	HRC
材質	SUS304／他
仕上	1台数
尺度 1/1	シート

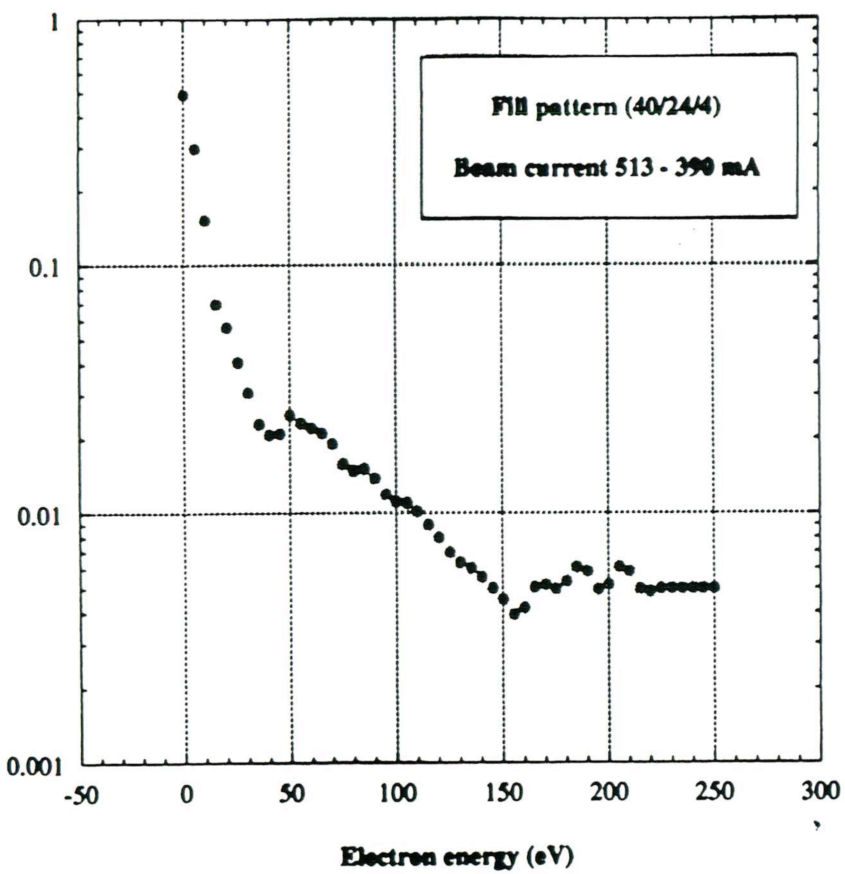
製作数	2
形式	
品名	光電子検出装置
図番	K

(株)ムサシノエンジニアリング　A3

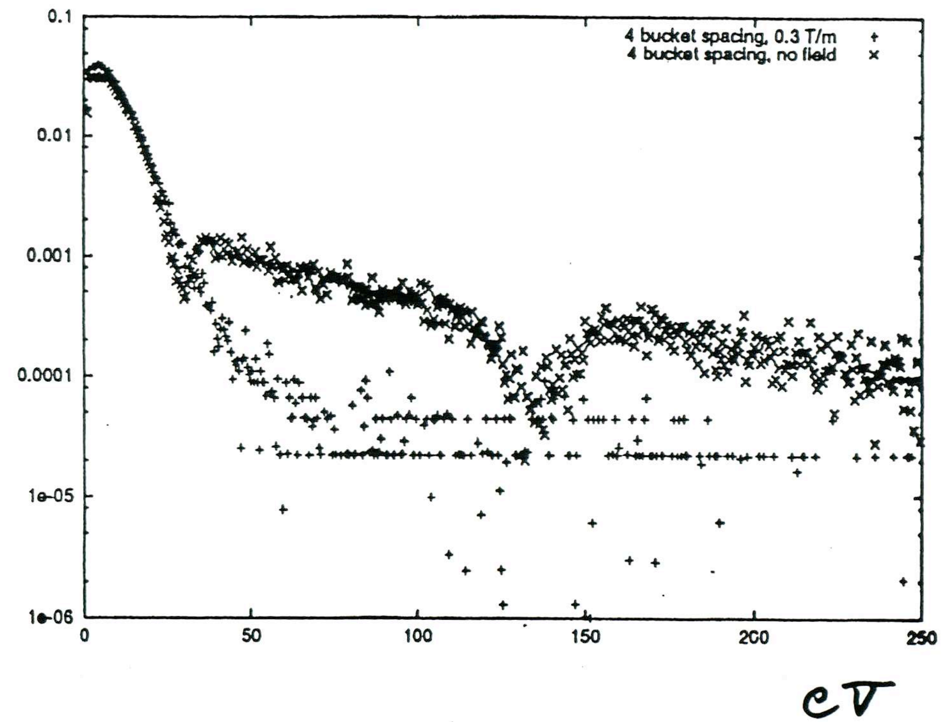
Electron current measured by electron monitor



Measured energy distribution of electrons

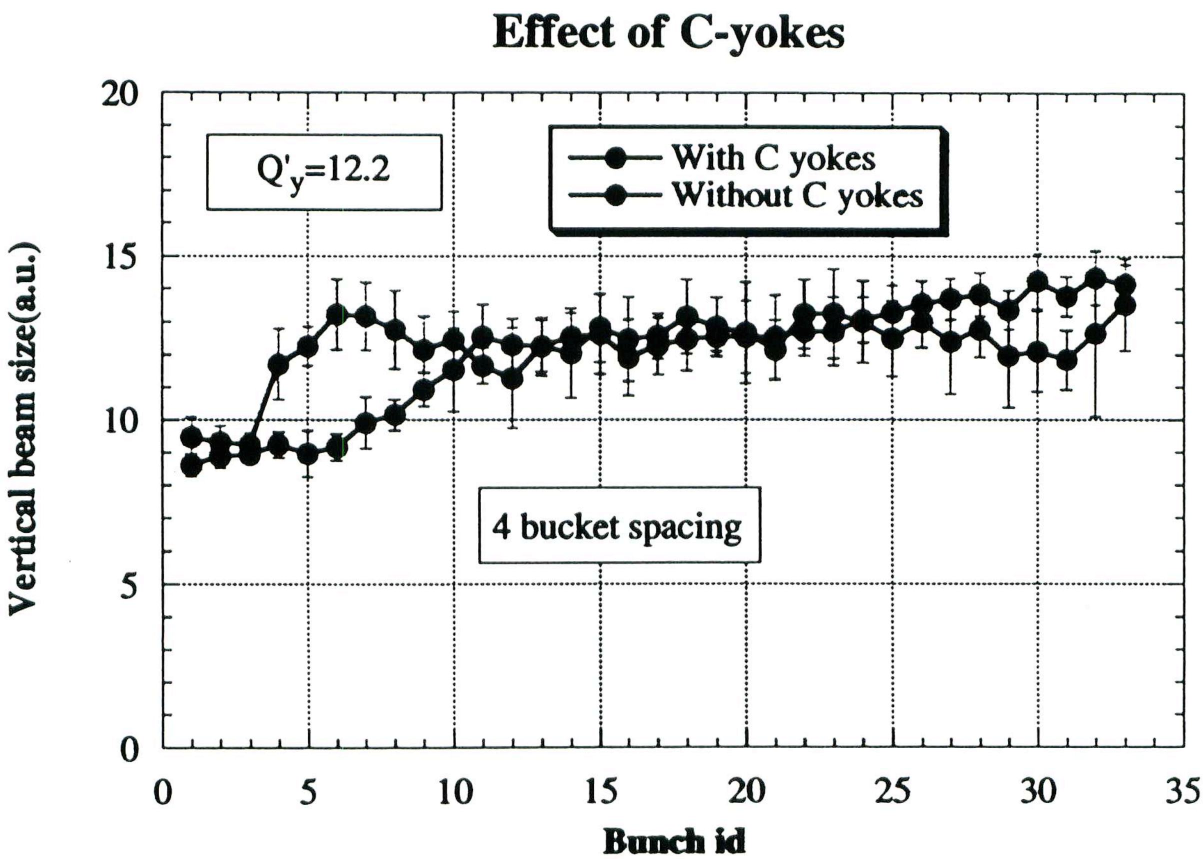


Simulation (F. Zimmermann)



2) Others

- Addition and changes of the configuration of C yokes did not improve the blow-up.
- Solenoid winding around I.P. or Fuji crossing points did not improve the blow-up.
- All C yokes were removed to see the effect of C yokes. The measurement for a short train confirmed previous results.


Effect of C-yokes
Q'y=12.2
With C yokes
Without C yokes
4 bucket spacing
Vertical beam size(a.u.)
Bunch id
0
5
10
15
20
25
30
35

The question why the C yokes were not so effetive to the blow-up was still remained because the simulation by F.Zimmermann showed that the electron density is at least factor ten smaller in a region with C yokes. This led to a suspicion that still large amount of electrons remained in the ring.

The installation of solenoids was decided because

1) the simulation showed they are five to ten times more effeicient than C yokes,
2) An experiment by the vacuum group showed a solenoid was more effective than installed C yokes to remove the electrons.

Effect of solenoids

Solenoids were installed in September 2000 and January 2001.

<u>Solenoid system</u>

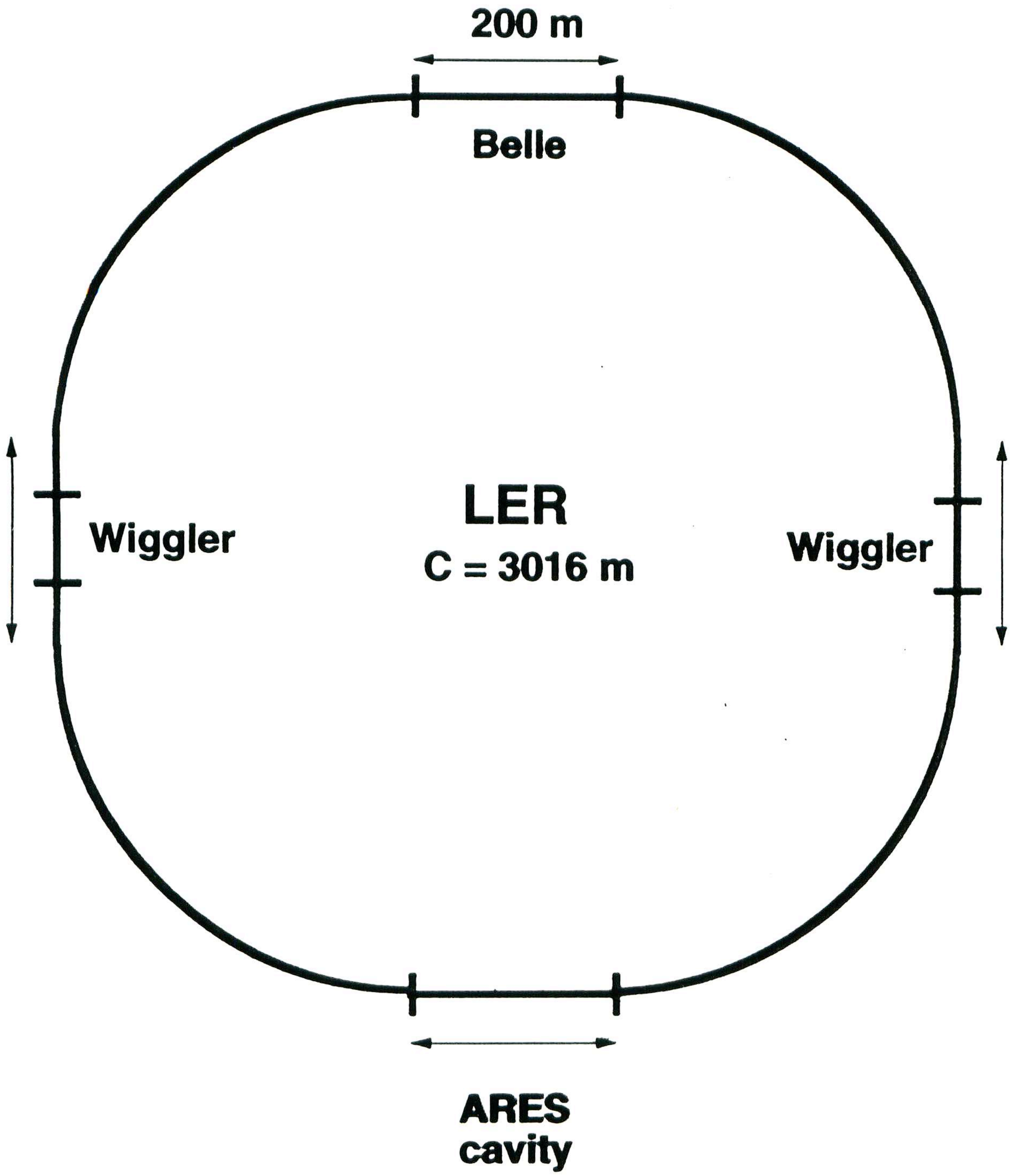
1) First installation (September 2000)

- Solenoids cover straight sections mainly in arcs.
- Total length of solenoids is about 800 m.
- Maximum field strength is 45 Gauss.

2) Second installation (January 2001)

- Solenoids cover bellows and NEG sections in arcs.
- Total length of solenoids is about 430 m in the region of $B_z > 20G$.
- Field strength at the photon stop in NEG region is about 30 Gauss.

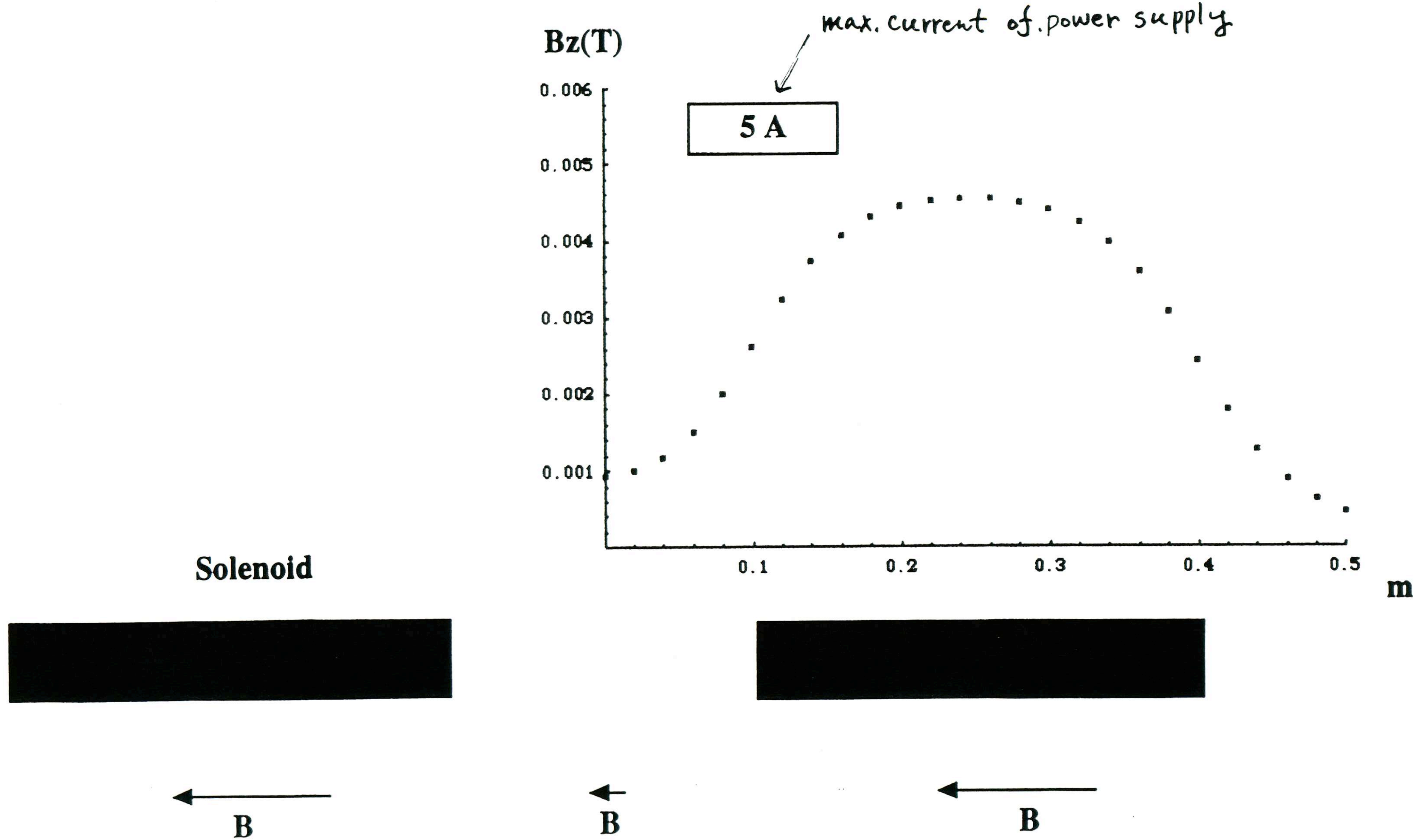
Solenoid coverage

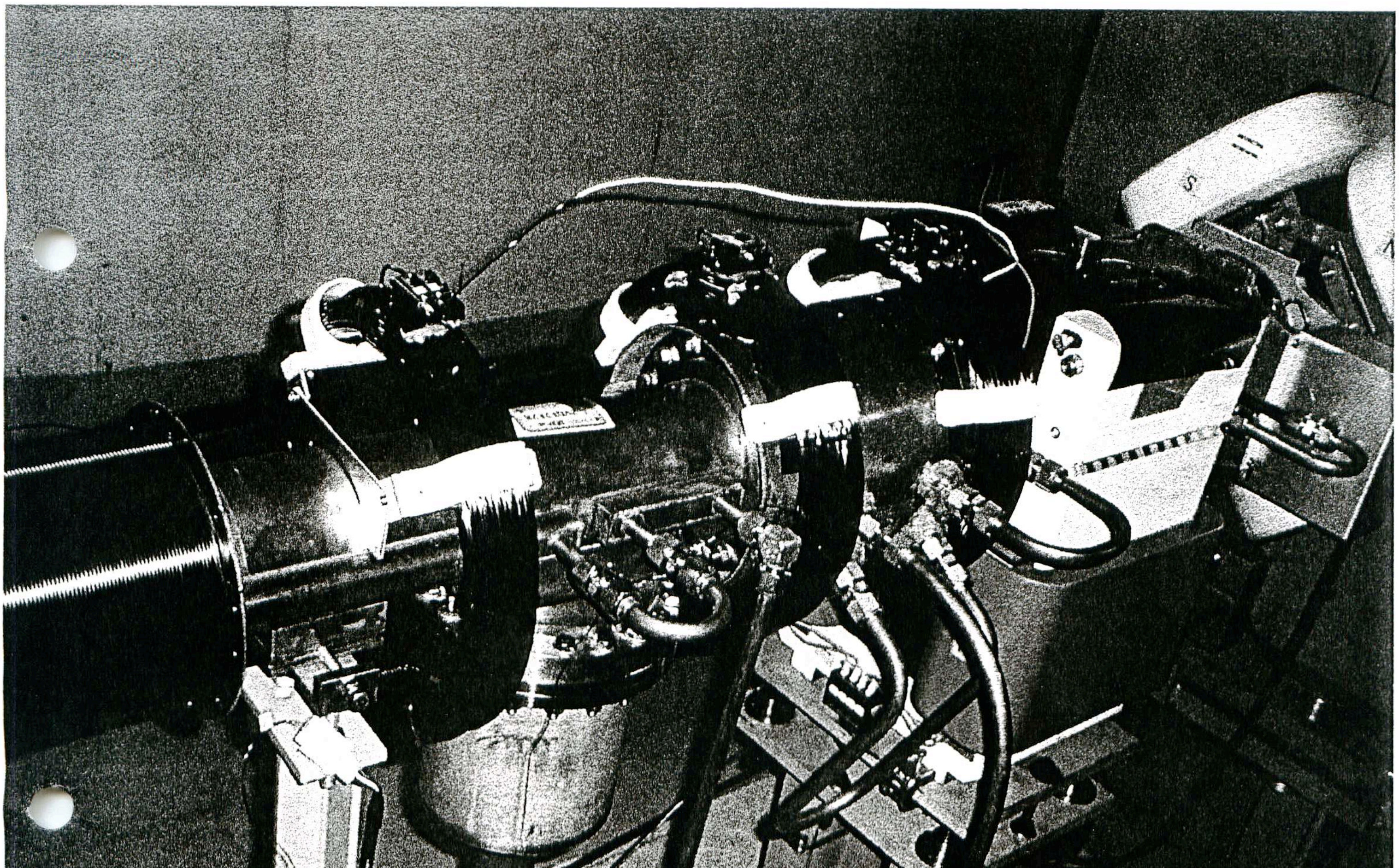


Solenoid (the nunber and length)

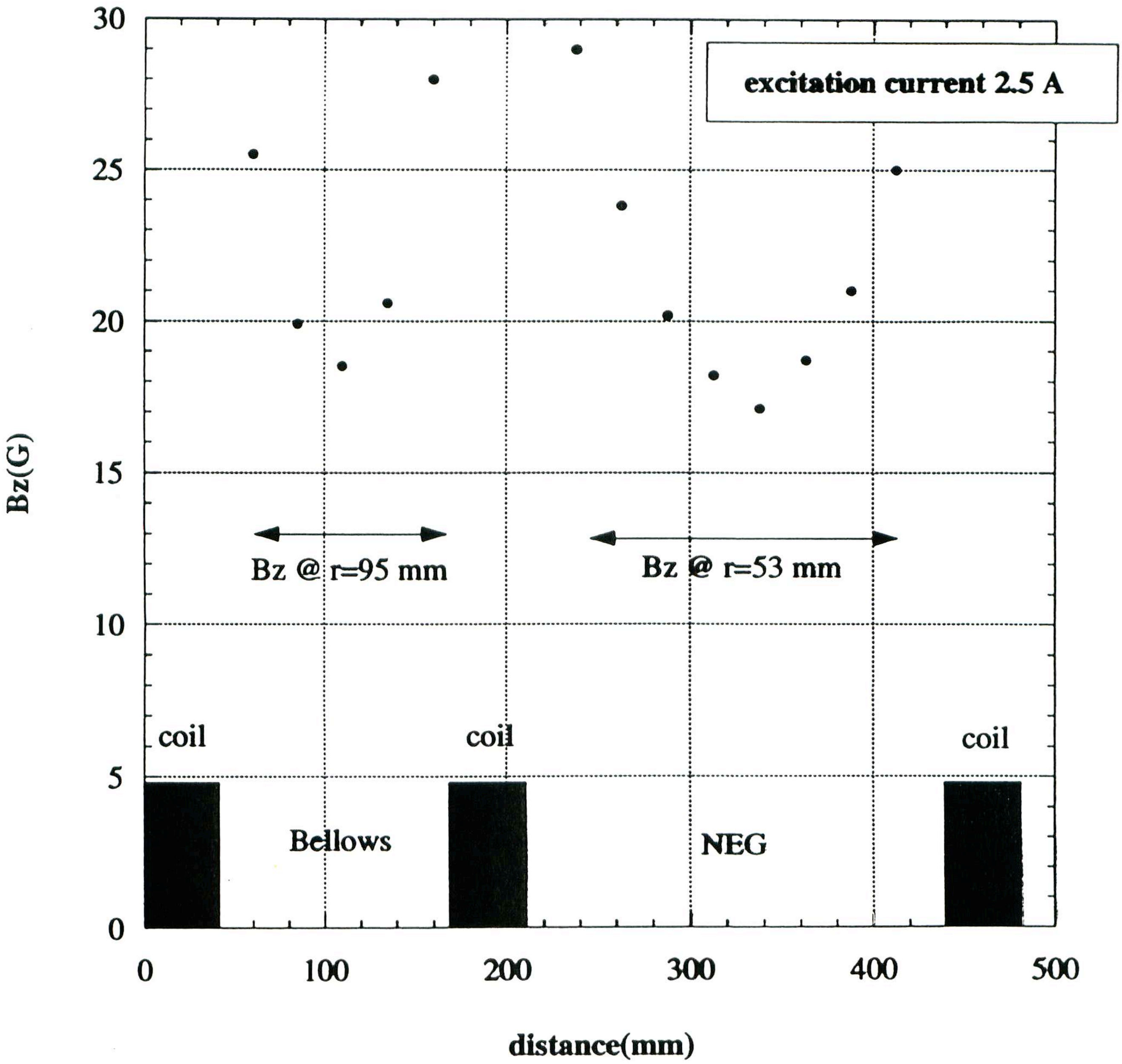
	length(mm)	number	total length(mm)	
	200	546	109200	(in corrector's gap)
	100	185	18500	
	150	231	34650	
	190	135	25650	
	250	308	77000	
	300	662	198600	
	400	352	140800	
	500	273	136500	
	650	91	59150	
total		2783	800050	

Calculated field distribution





Measured field distribution of 3 short solenoids



Field in actual operation is doubled because the excitation current is 5 A.

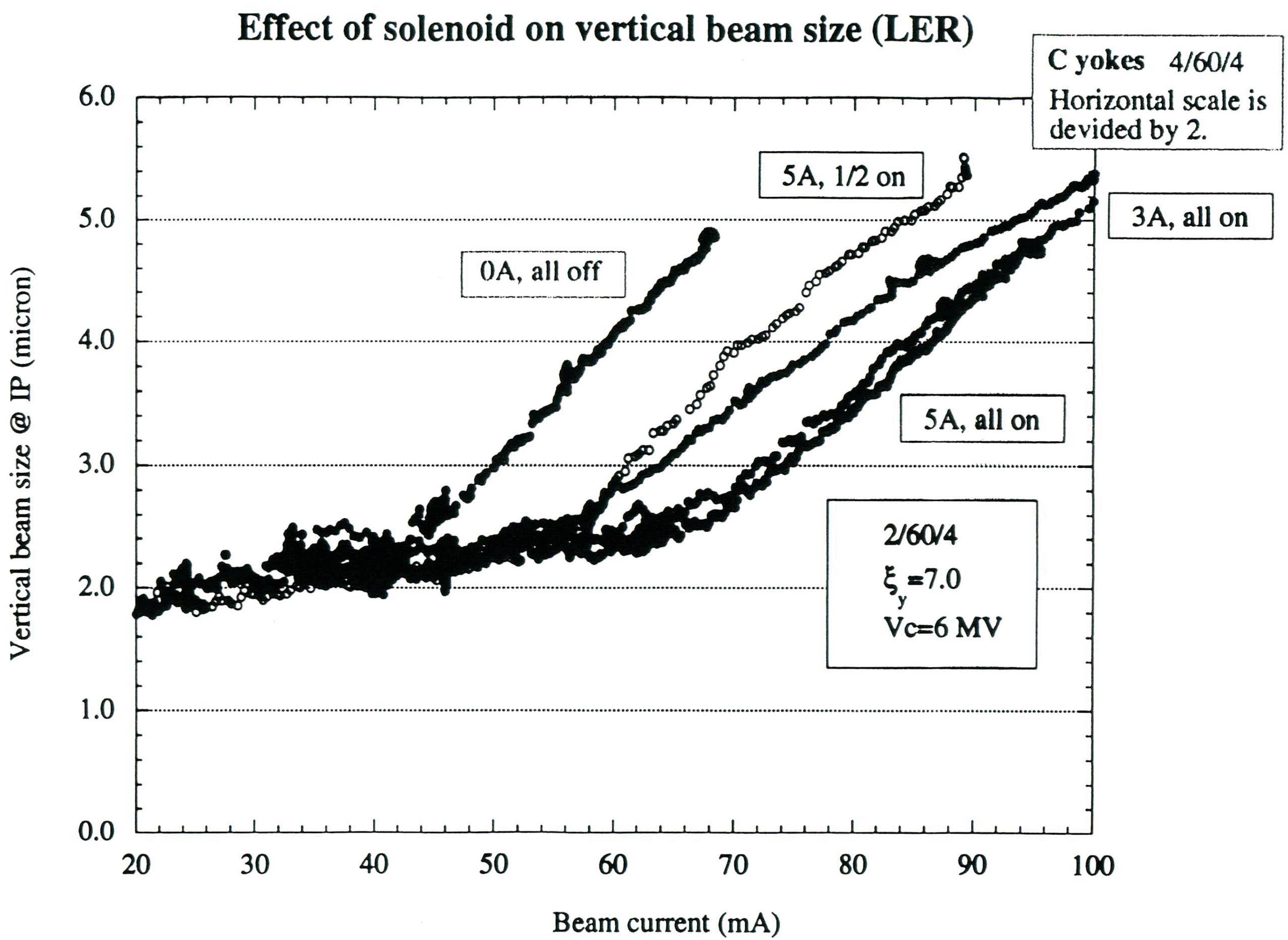
Observations

1) First installation

Single beam

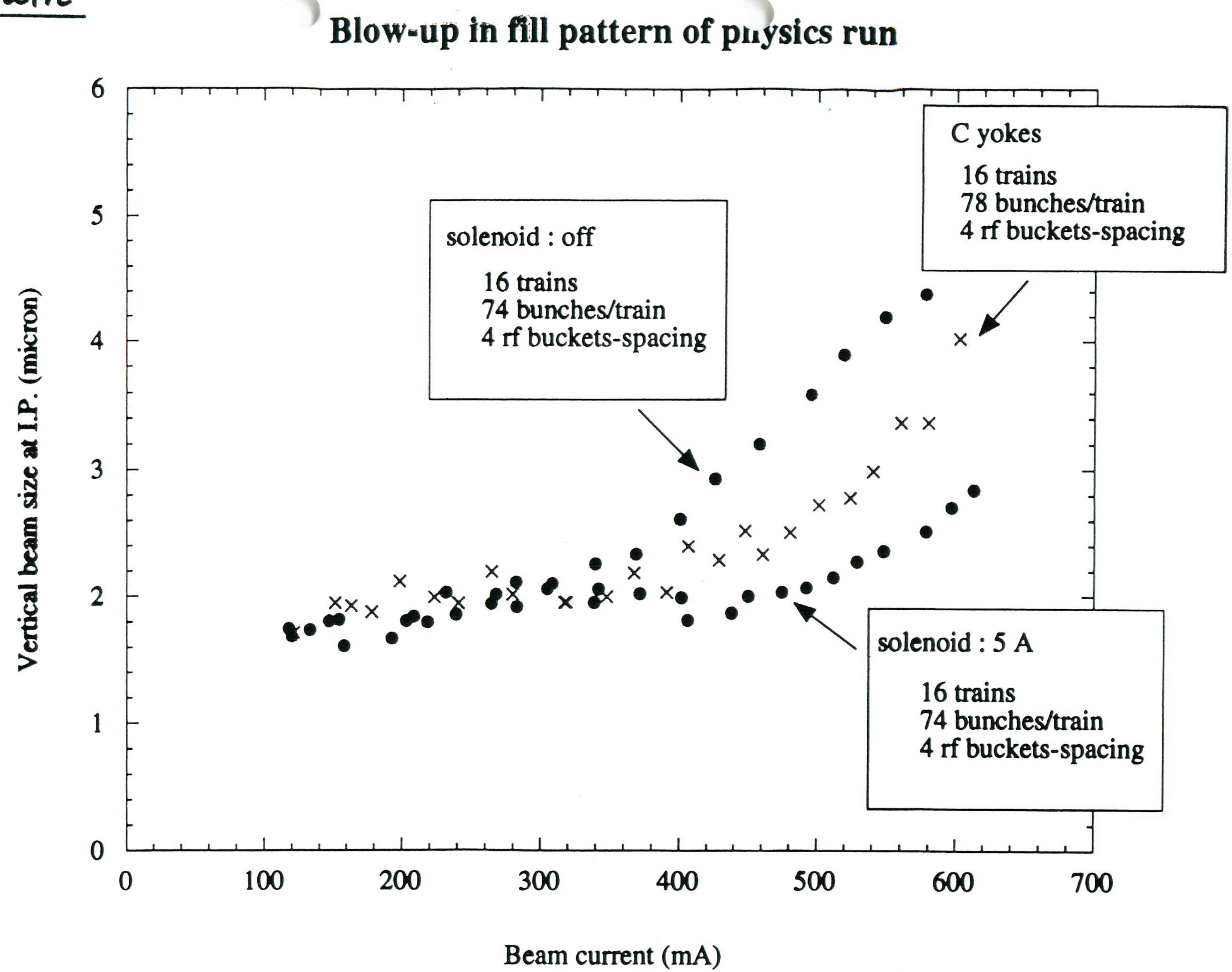
- For a short train solenoids are effective on the blow-up even for 4 rf bucket-spacing where C yokes were not very effective to the blow-up.
- For the fill pattern in physics-run (4 rf bucket-spacing, 1 train, typically 1153 bunches) solenoids are not as effective as expected from the result of short and a few train.

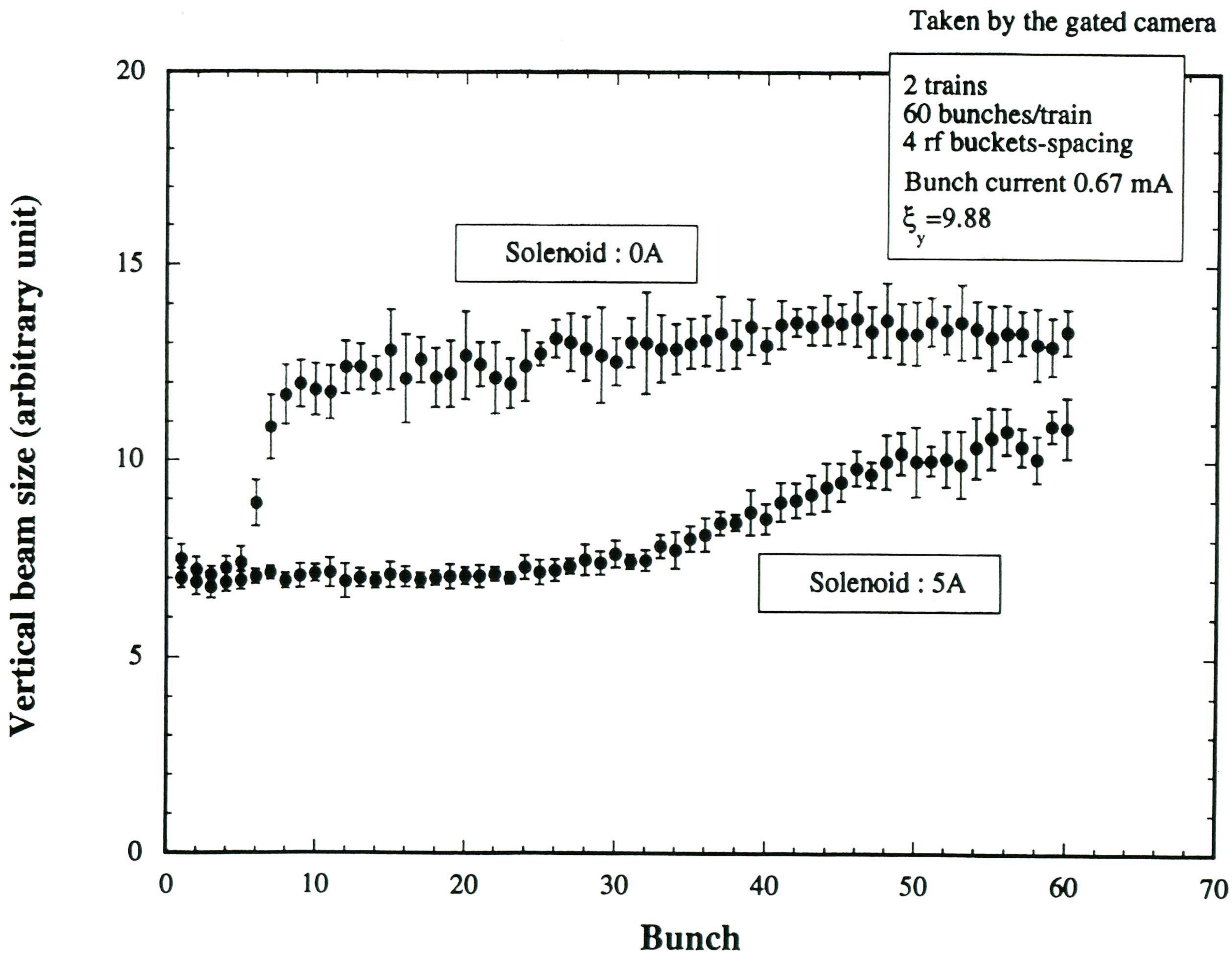
- Even with solenoids the beam size starts to blow-up at 30th bunches and slowly increases.
- Train gap longer than 600 ns is necessary for removing the effect of the forward train.
- Shorter train is better for the blow-up.
- As far as being tried so far, uniform fill without train gaps is best fill pattern against the blow-up when the beam size is compared at same beam current.



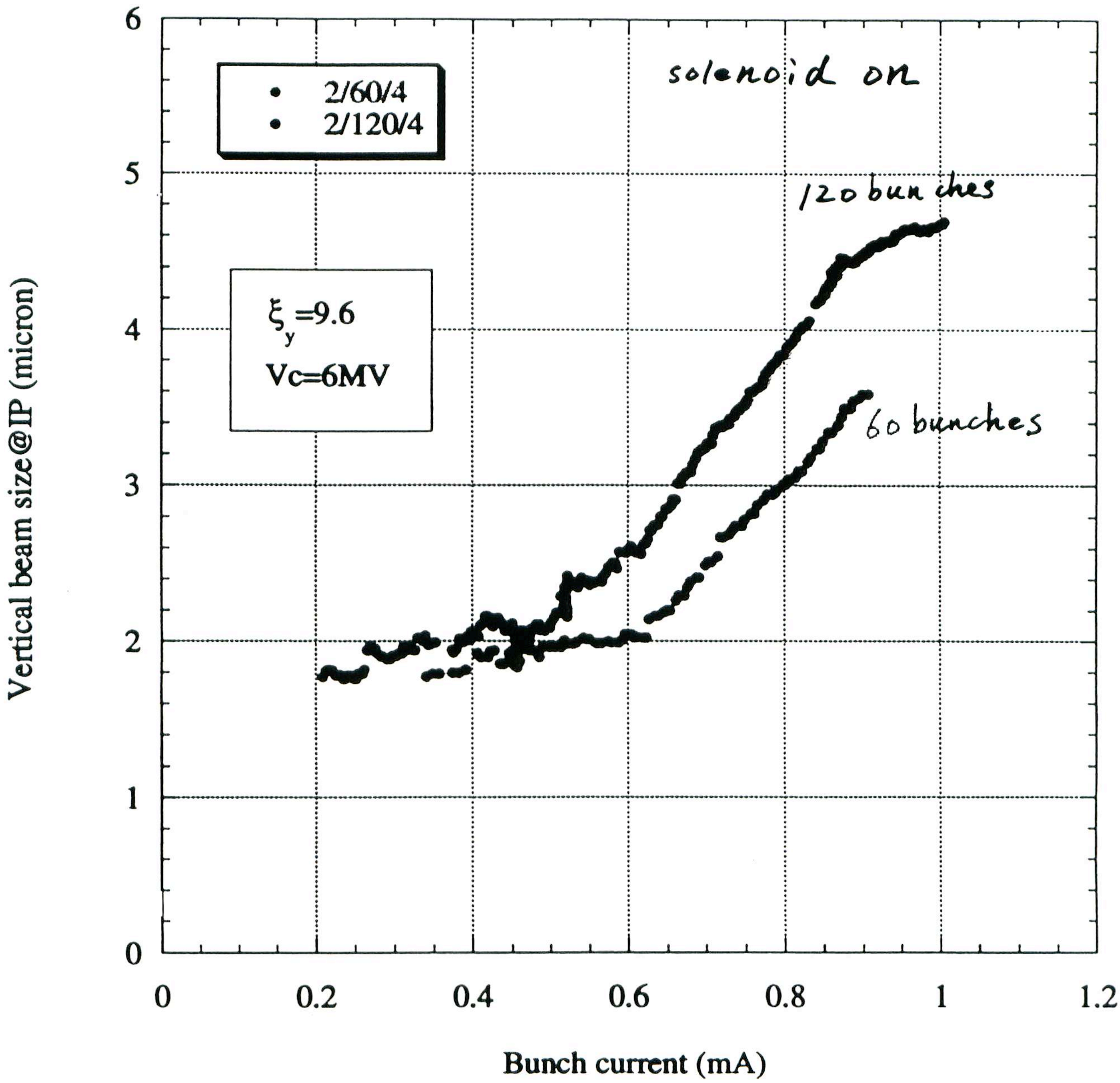
Effect of solenoid on vertical beam size (LER)
C yokes 4/60/4
Horizontal scale is devided by 2.
5A, 1/2 on
3A, all on
0A, all off
5A, all on
2/60/4
ξy =7.0
Vc=6 MV
6.0
5.0
4.0
3.0
2.0
1.0
0.0
20
30
40
50
60
70
80
90
100
Vertical beam size @ IP (micron)
Beam current (mA)

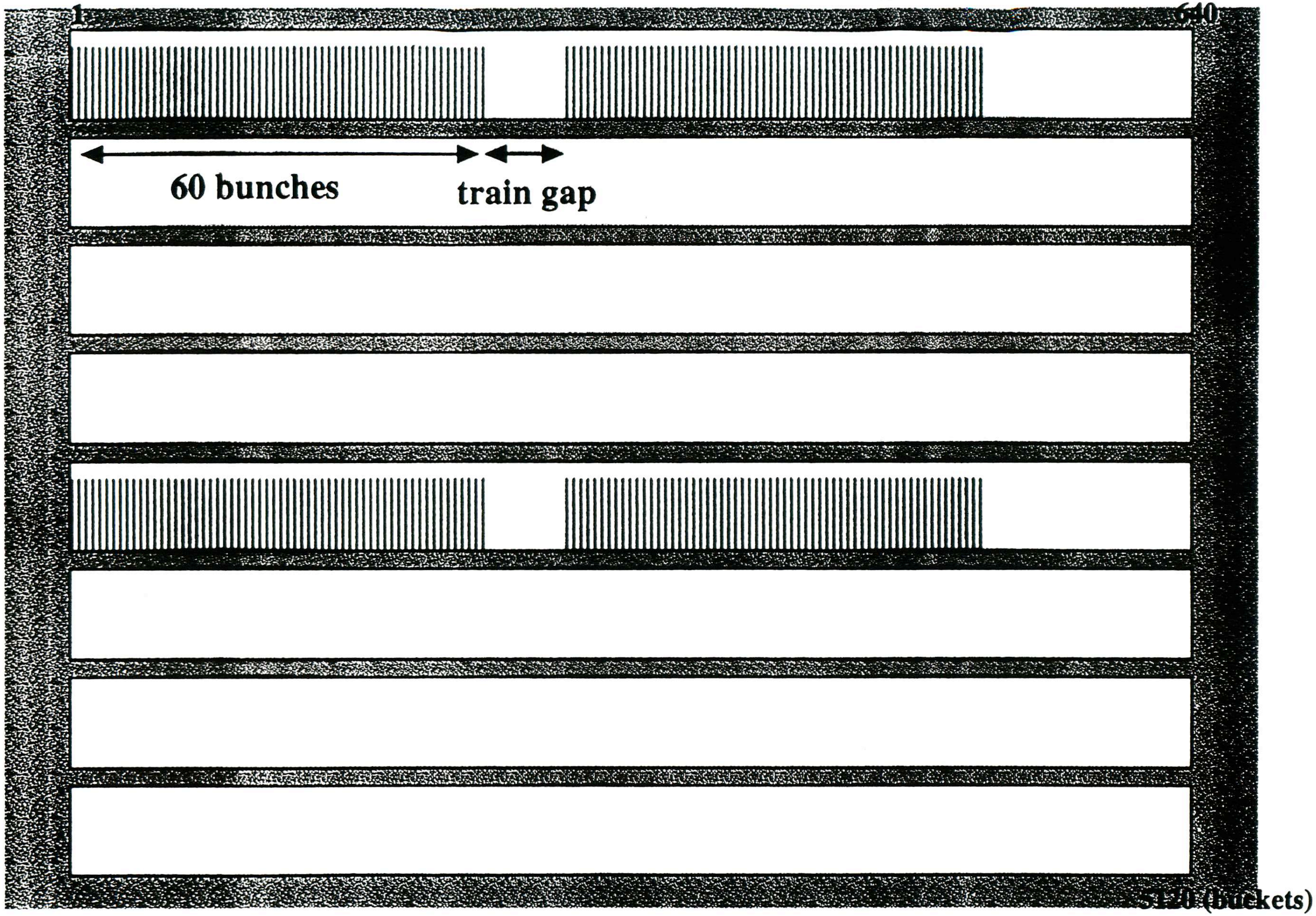
Long train


Blow-up in fill pattern of physics run
Vertical beam size at I.P. (micron)
Beam current (mA)
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700
solenoid : off
16 trains
74 bunches/train
4 rf buckets-spacing
C yokes
16 trains
78 bunches/train
4 rf buckets-spacing
solenoid : 5 A
16 trains
74 bunches/train
4 rf buckets-spacing


Taken by the gated camera
2 trains
60 bunches/train
4 rf buckets-spacing
Bunch current 0.67 mA
ξ_y =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

Effect of train length on the blow-up

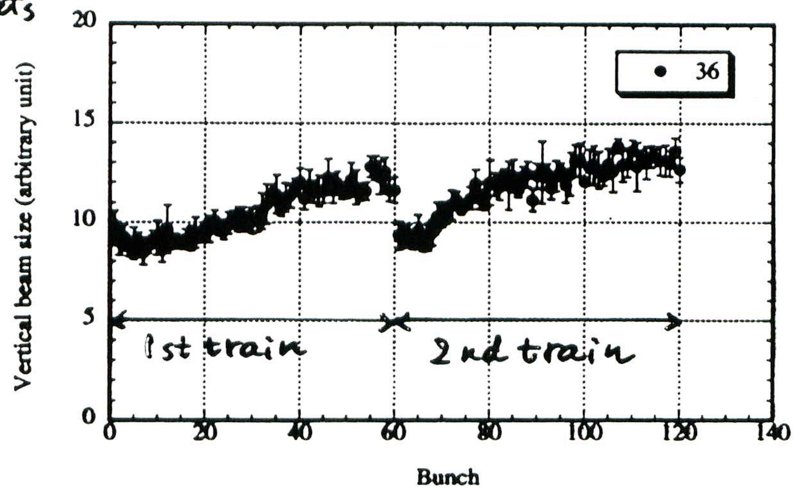



1
640
60 bunches
train gap
5120 (buckets)

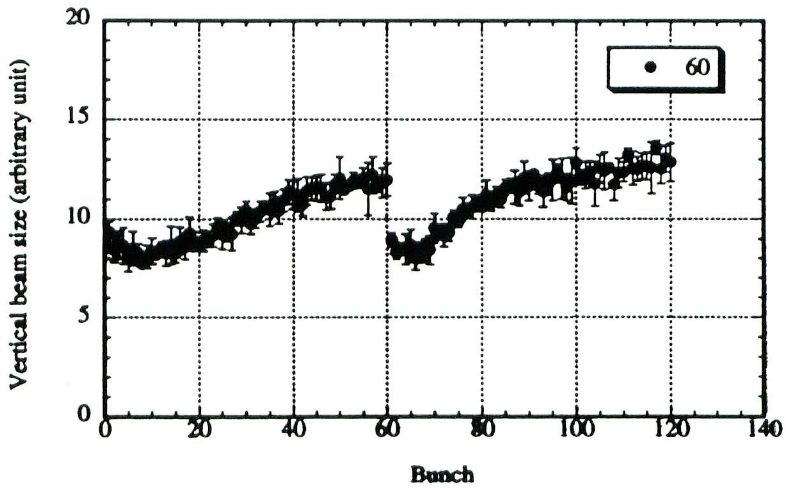
Train gap - solenoid on

train spacing

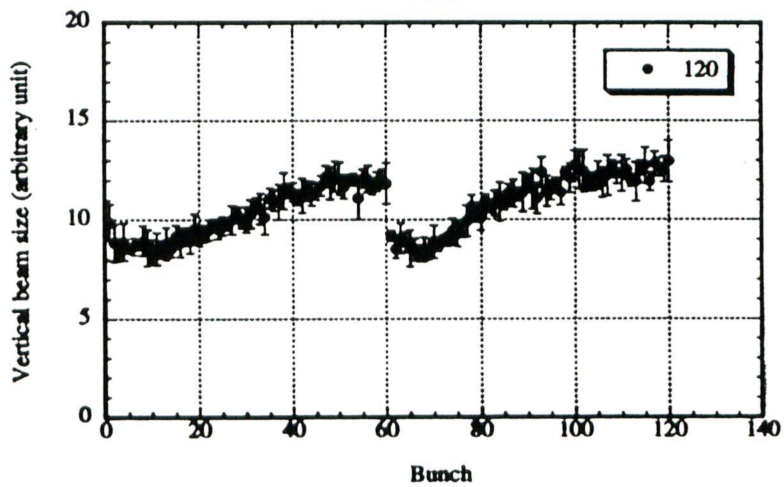
36 rf buckets



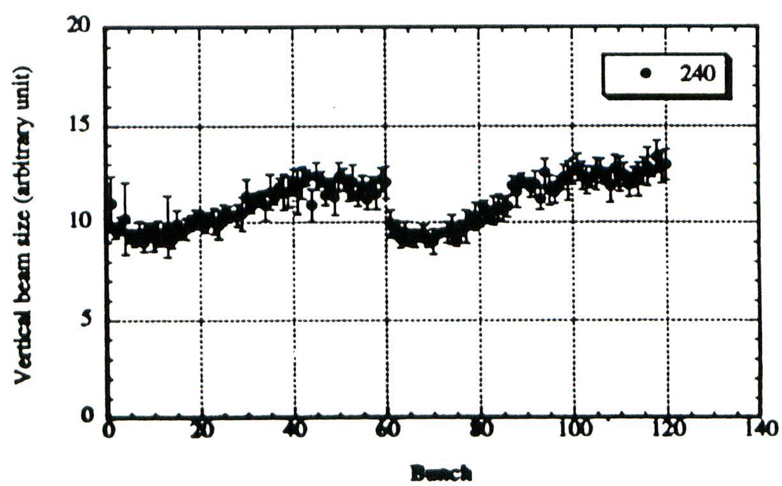
60



120

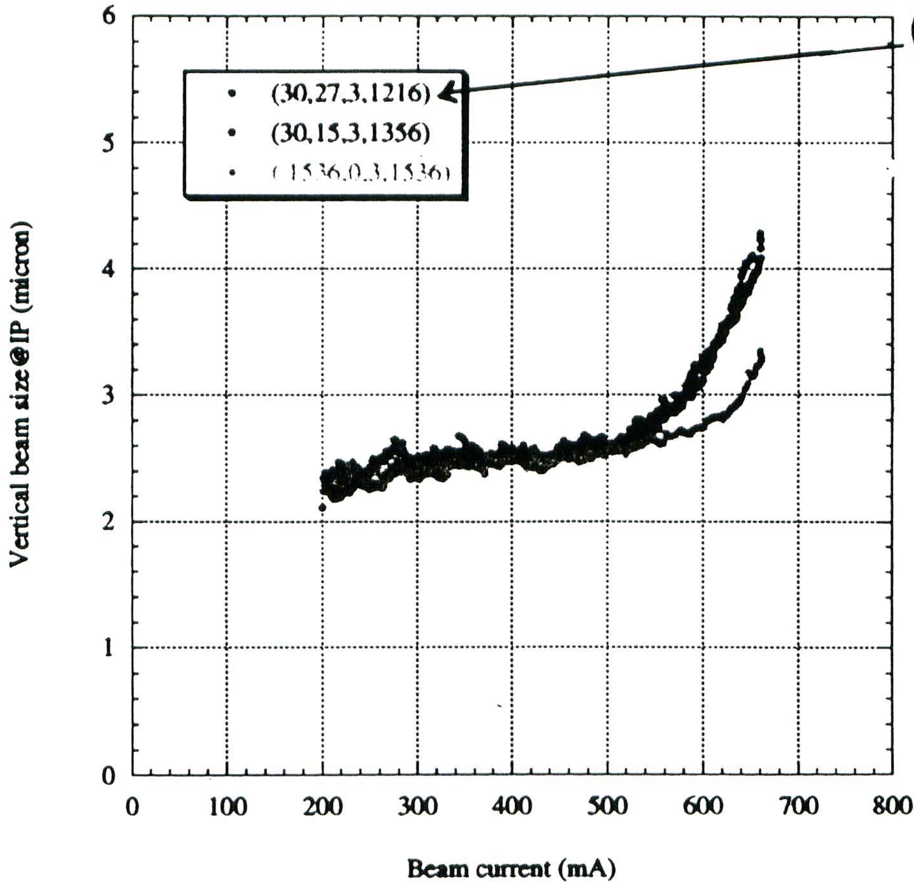


240



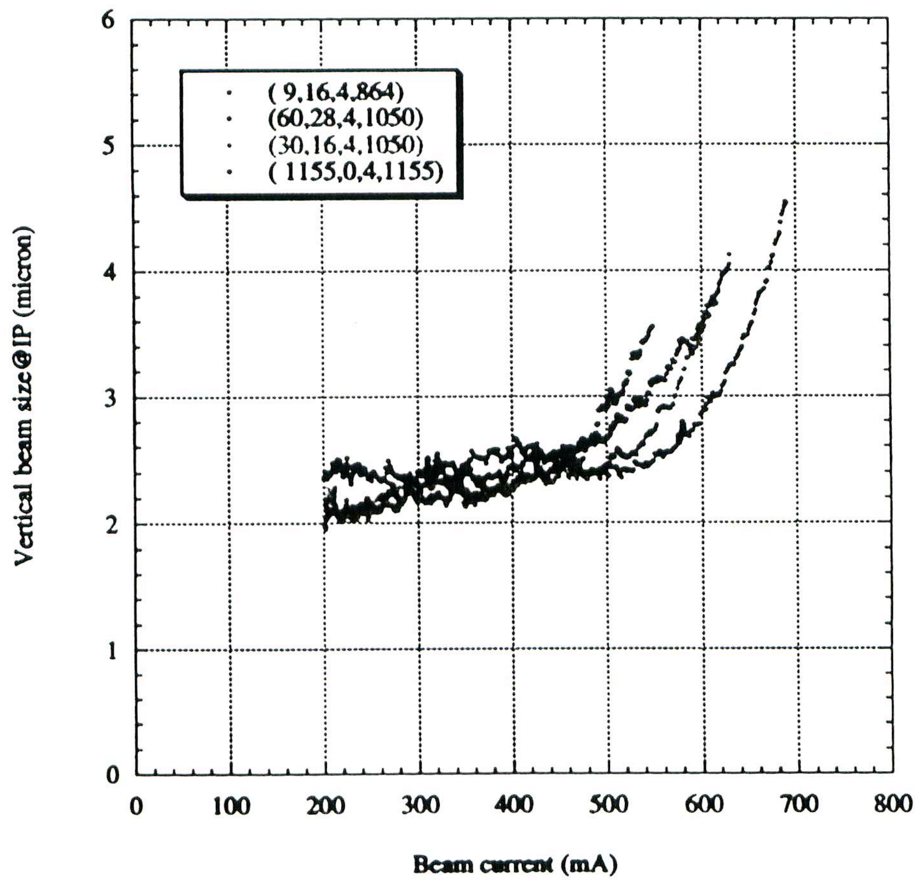
Fill pattern

3 rf bucket spacing

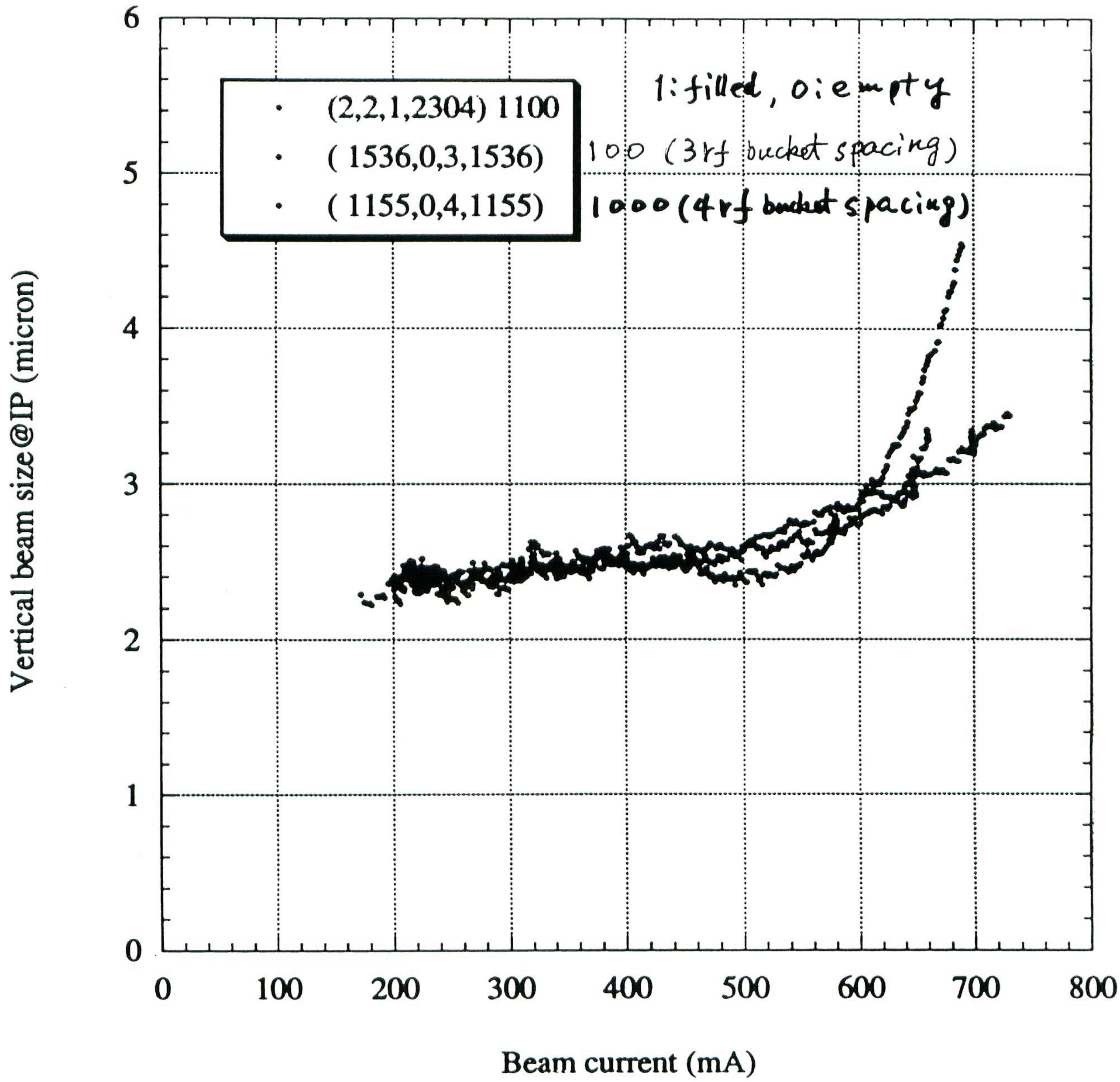


(bunches/train,
train gap,
bunch spacing,
total number of bunches)

4 rf bucket spacing

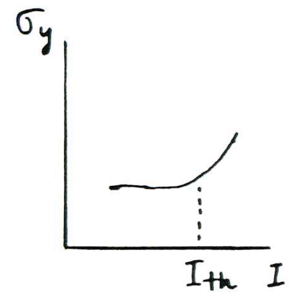


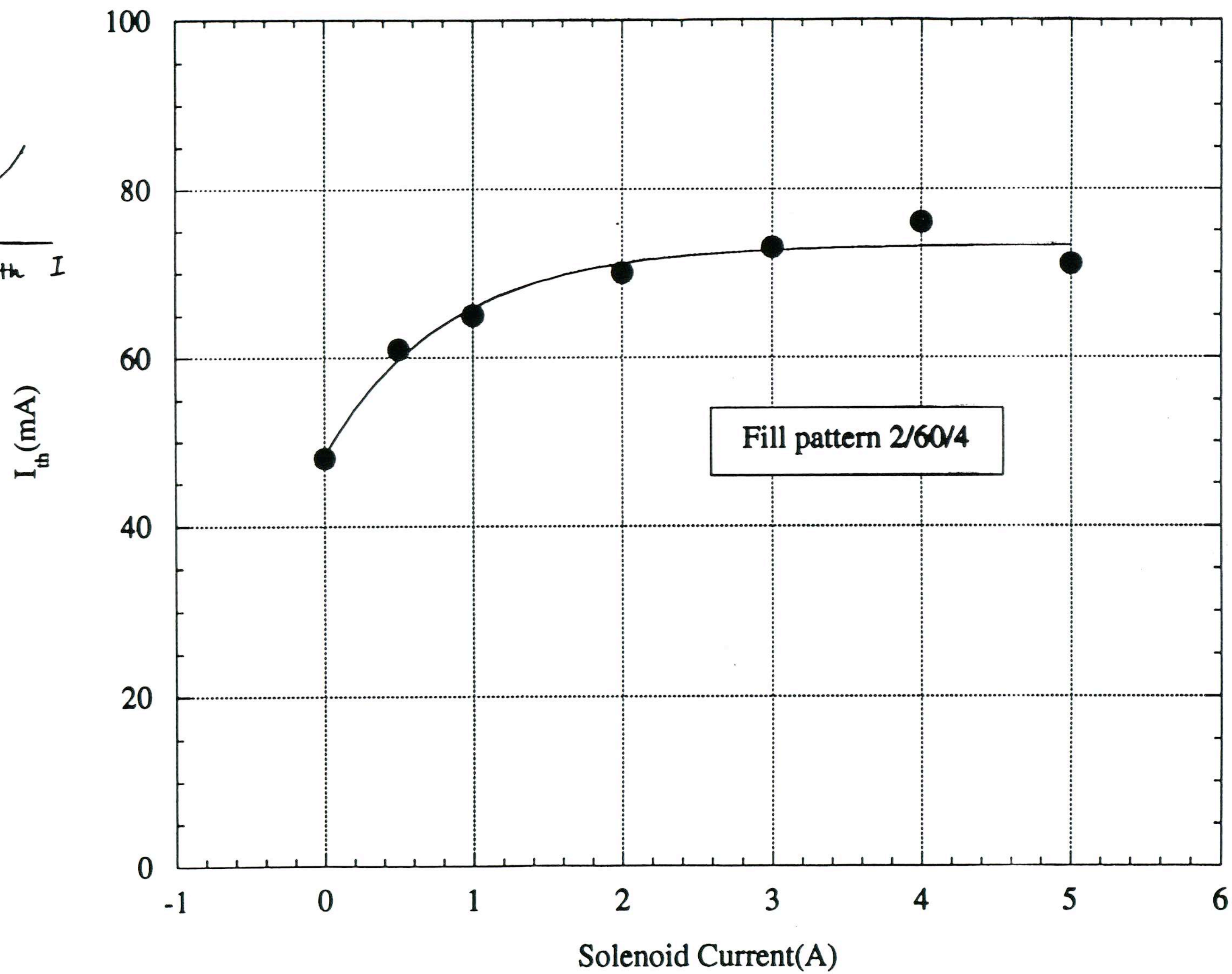
Fill pattern



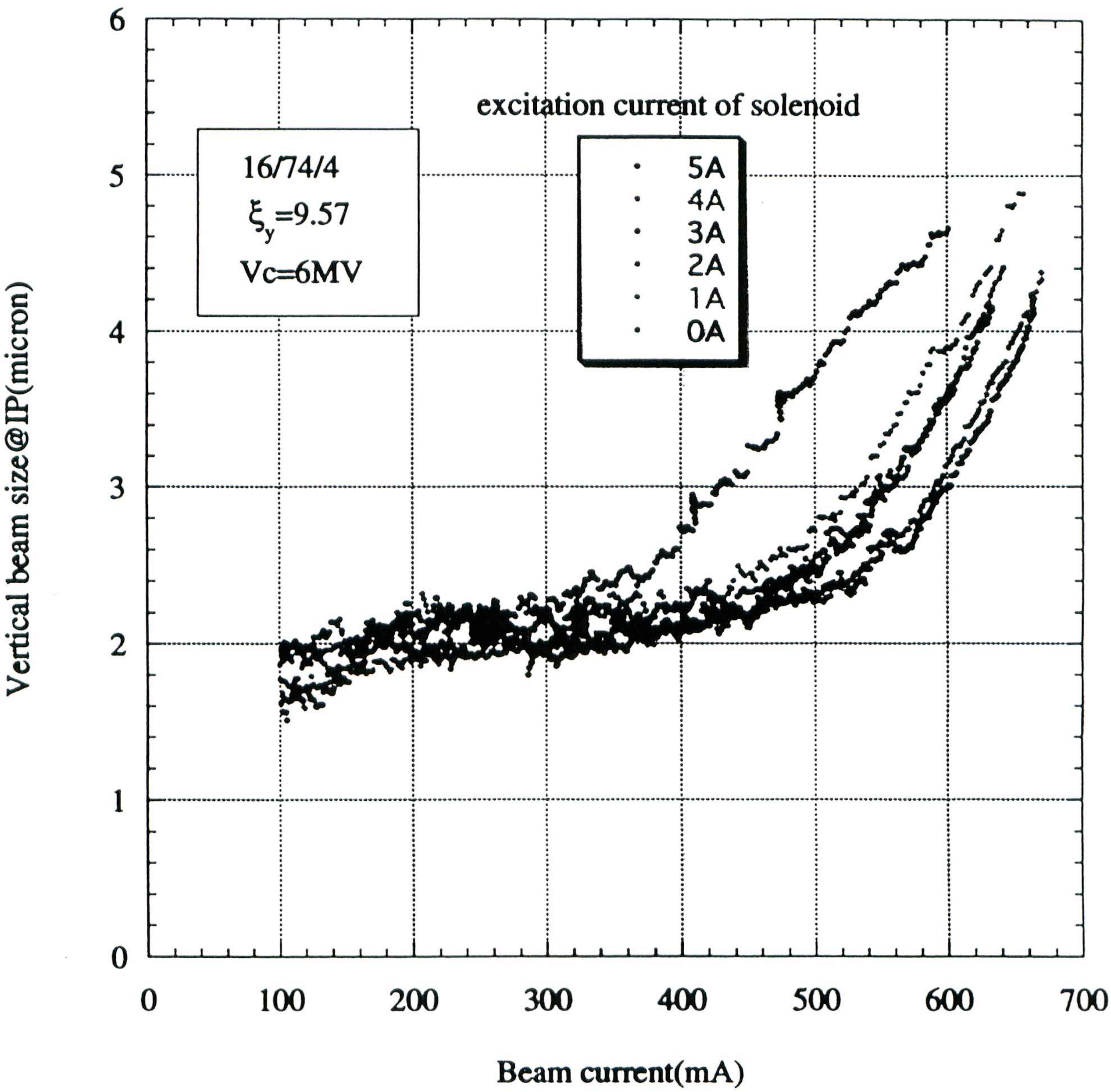
- Solenoid field of 40 Gauss seems to be enough to suppress the blow-up.
- The solenoids away from the bends give a substantial effect to the blow-up.

Solenoid current vs. threshold current of blow-up (short train)



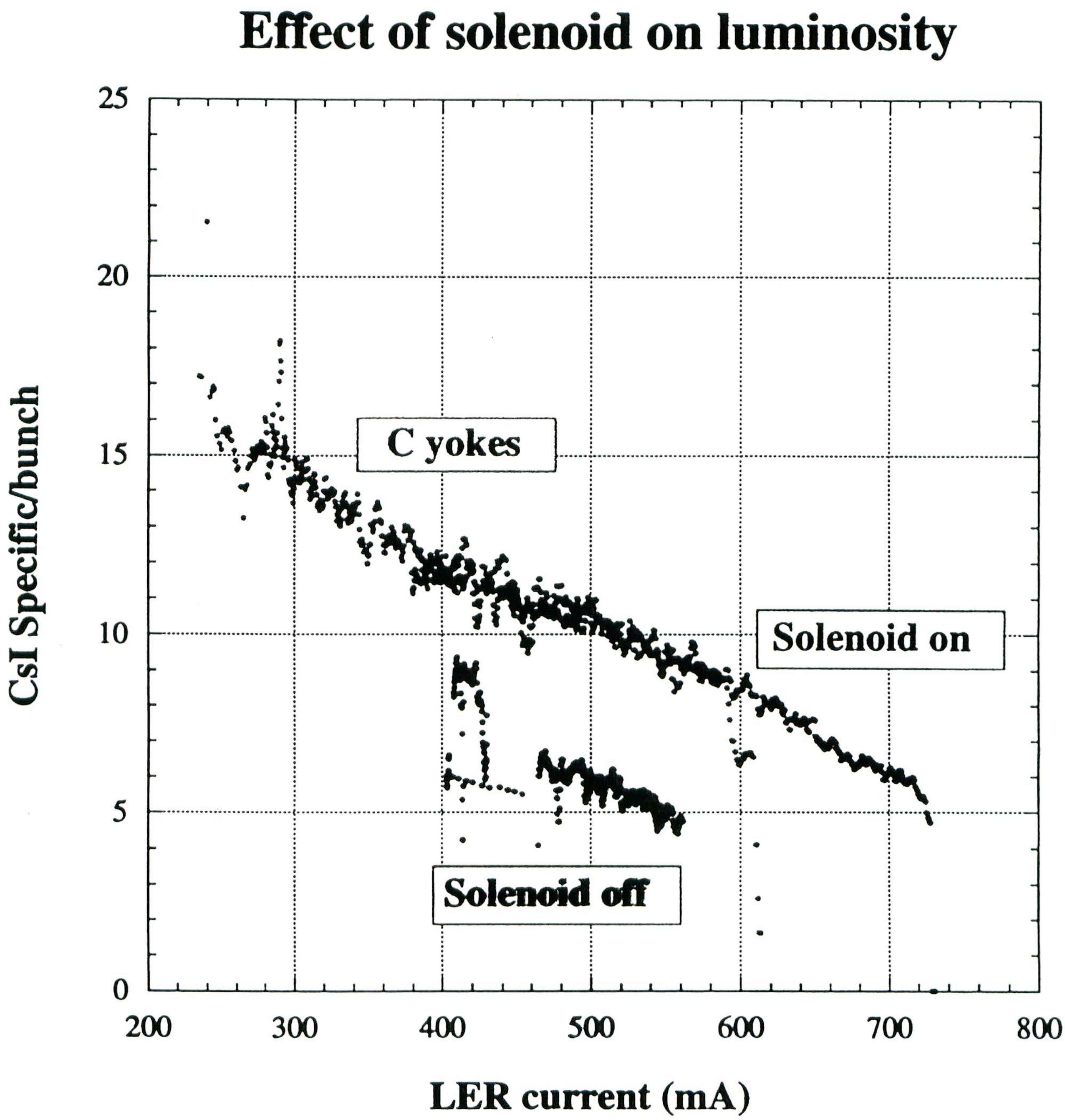


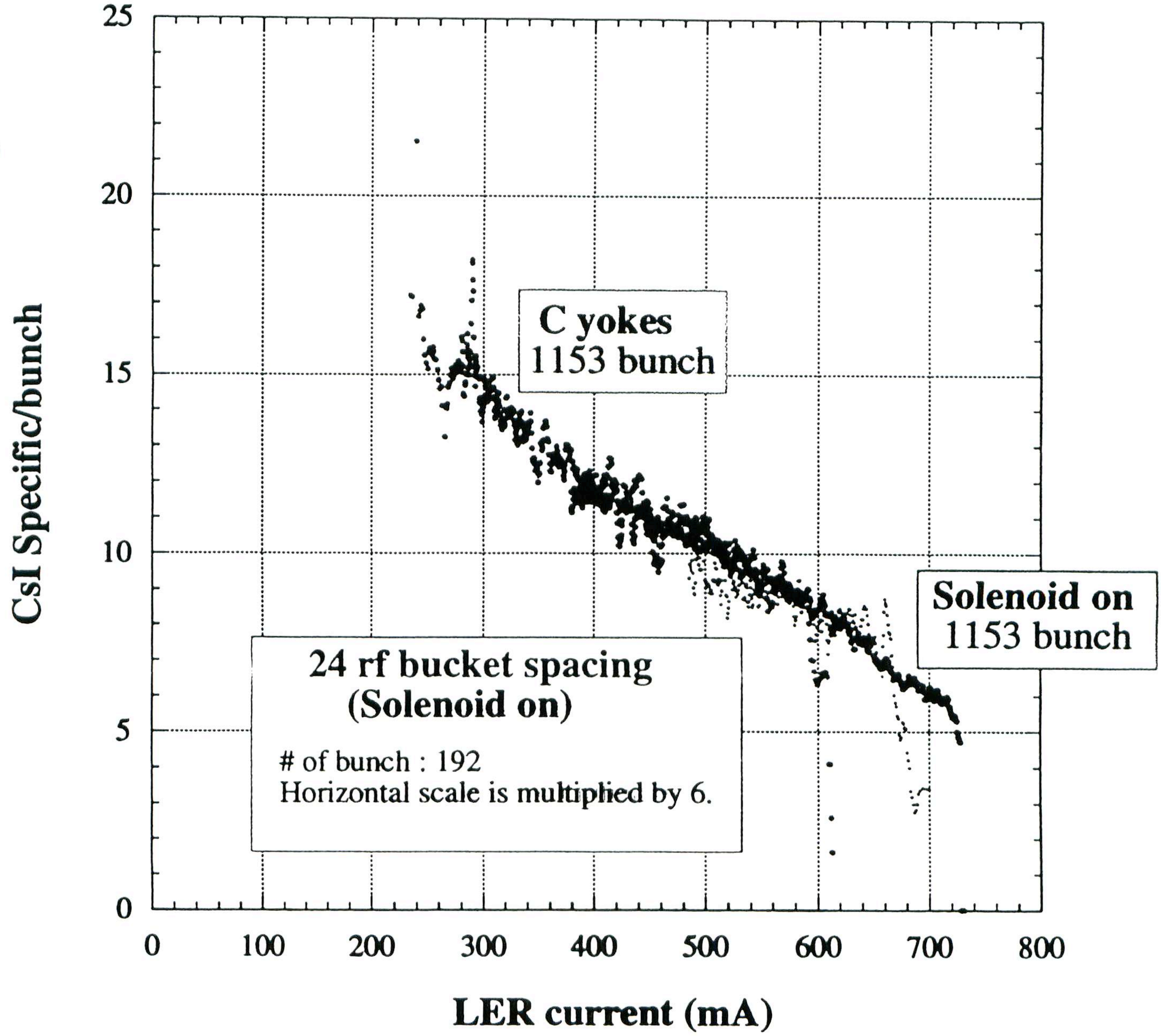
Effect of field strength on beam size (LER)
(Physics-fill pattern)



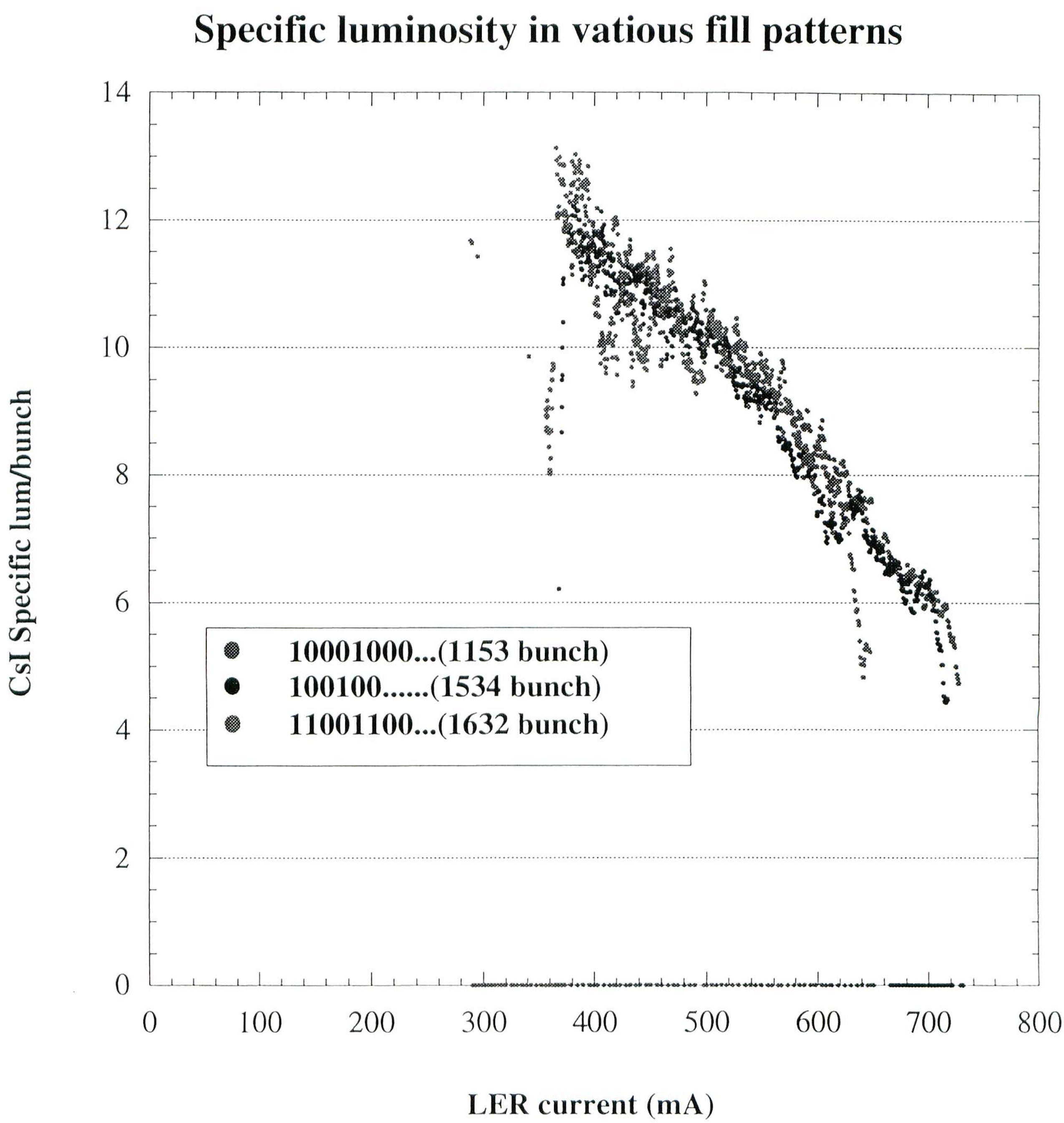
Luminosity

- Solenoids are effective to improve the specific luminosity in the physics fill pattern.
- When the bunch spacing was large enough (24 rf buckets) the specific luminosity was almost same with and without solenoids.
- The effect of C yokes and solenoids on the specific luminosity are almost same. Thus the luminosity was not increased after installation of solenoids.
- Specific luminosity seems lay on a universal line which is determined only by the beam current of LER even if bunch spacing or bunch current is different.
- Fill patterns of short and many trains did not improve the luminosity.


Effect of solenoid on luminosity
CsI Specific/bunch
LER current (mA)
C yokes
Solenoid on
Solenoid off
0
5
10
15
20
25
200
300
400
500
600
700
800



C yokes
1153 bunch
Solenoid on
1153 bunch
24 rf bucket spacing
(Solenoid on)
# of bunch : 192
Horizontal scale is multiplied by 6.
CsI Specific/bunch
LER current (mA)
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800


Specific luminosity in vatious fill patterns
CsI Specific lum/bunch
LER current (mA)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
10001000...(1153 bunch)
100100......(1534 bunch)
11001100...(1632 bunch)

2) Second installation

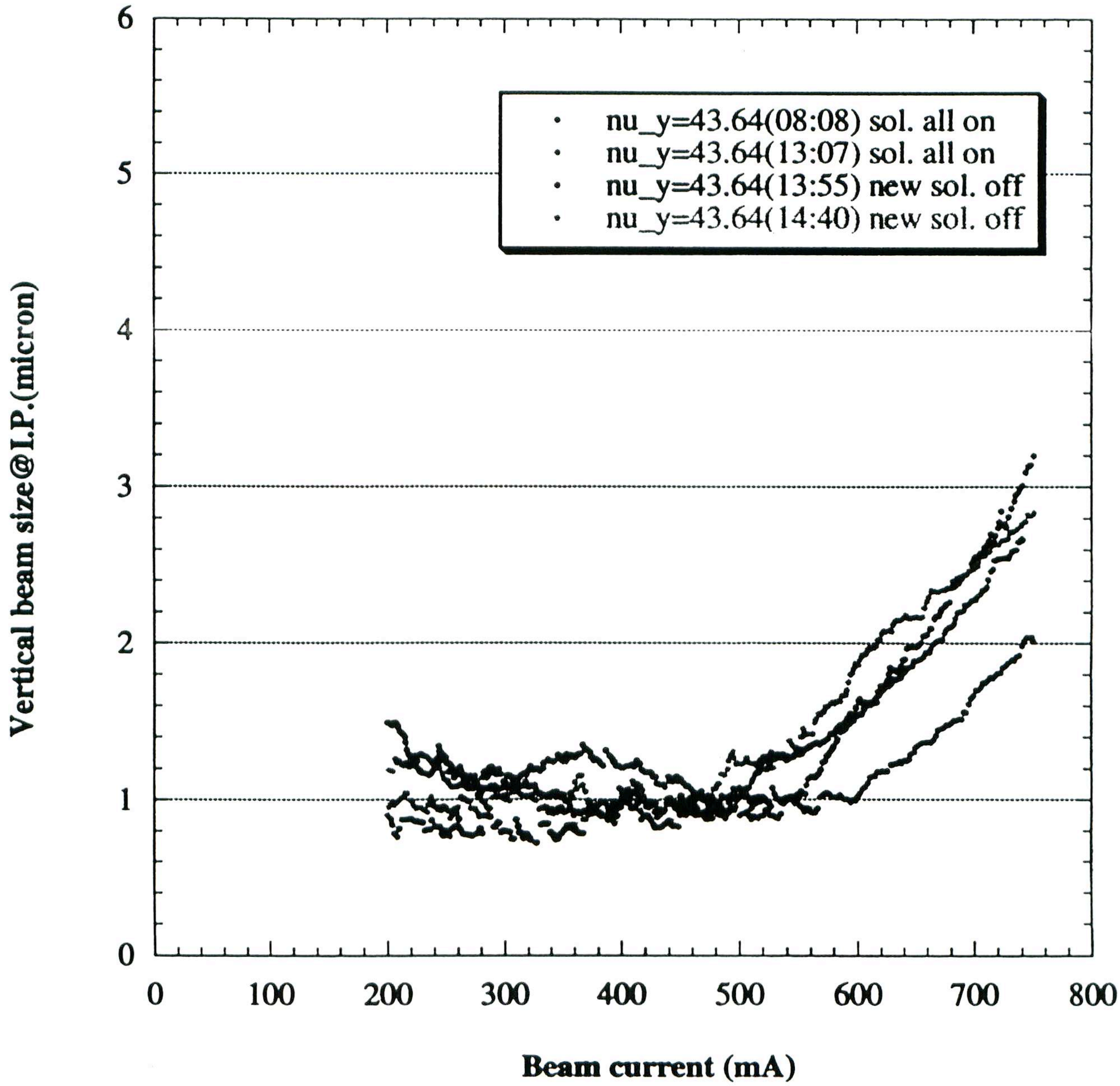
Single beam

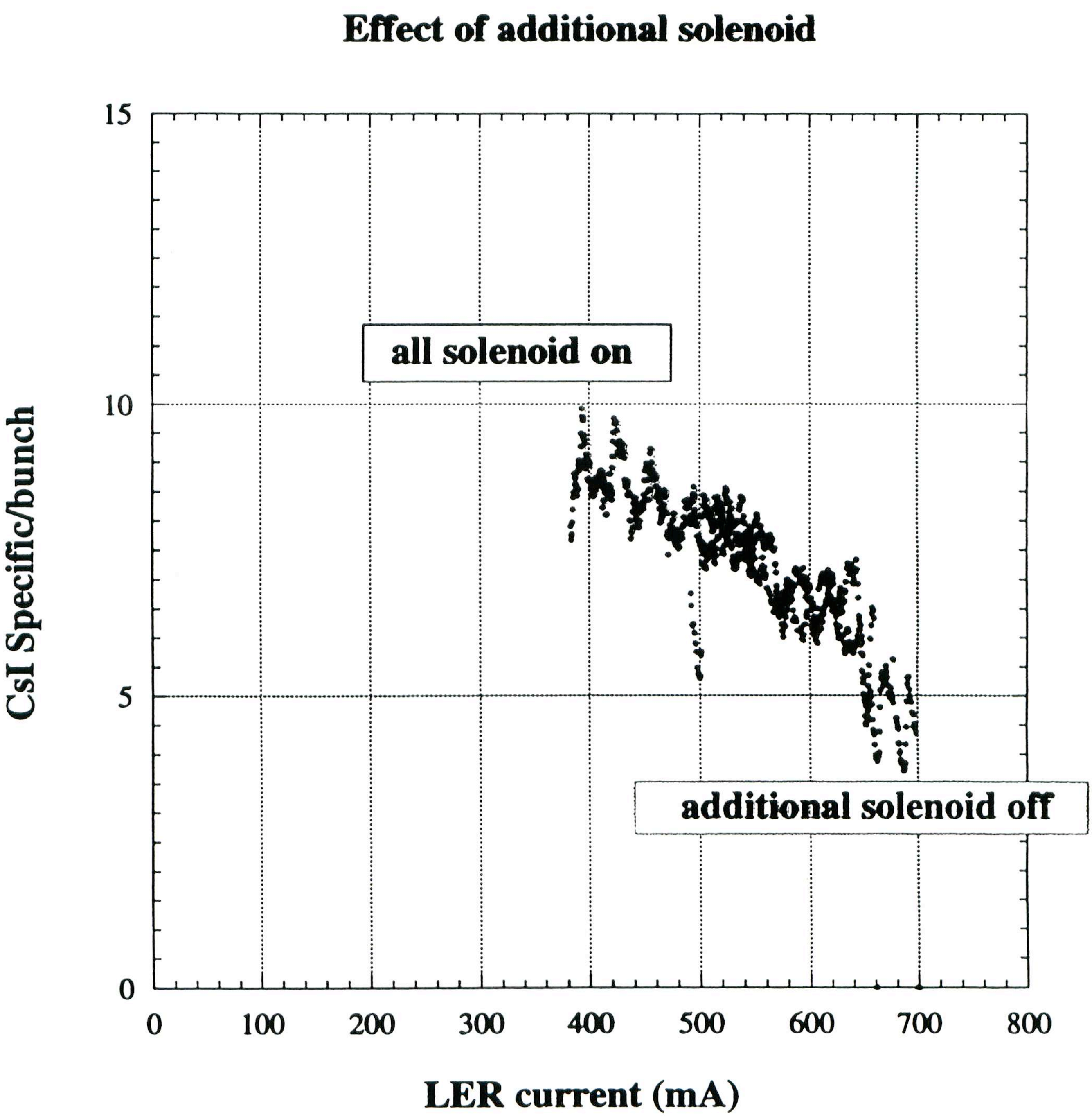
- No improvement on the blow-up was observed in physics fill pattern within the reproducibility of the data. (During the measurement the reproducibility of the data taken by the interferometer was not good.)

Luminosity

- Specific luminosity as a function of LER current was not improved by the additional solenoids in bellows and NEG sections.

Effect of additional solenoids in bellows section on blow-up



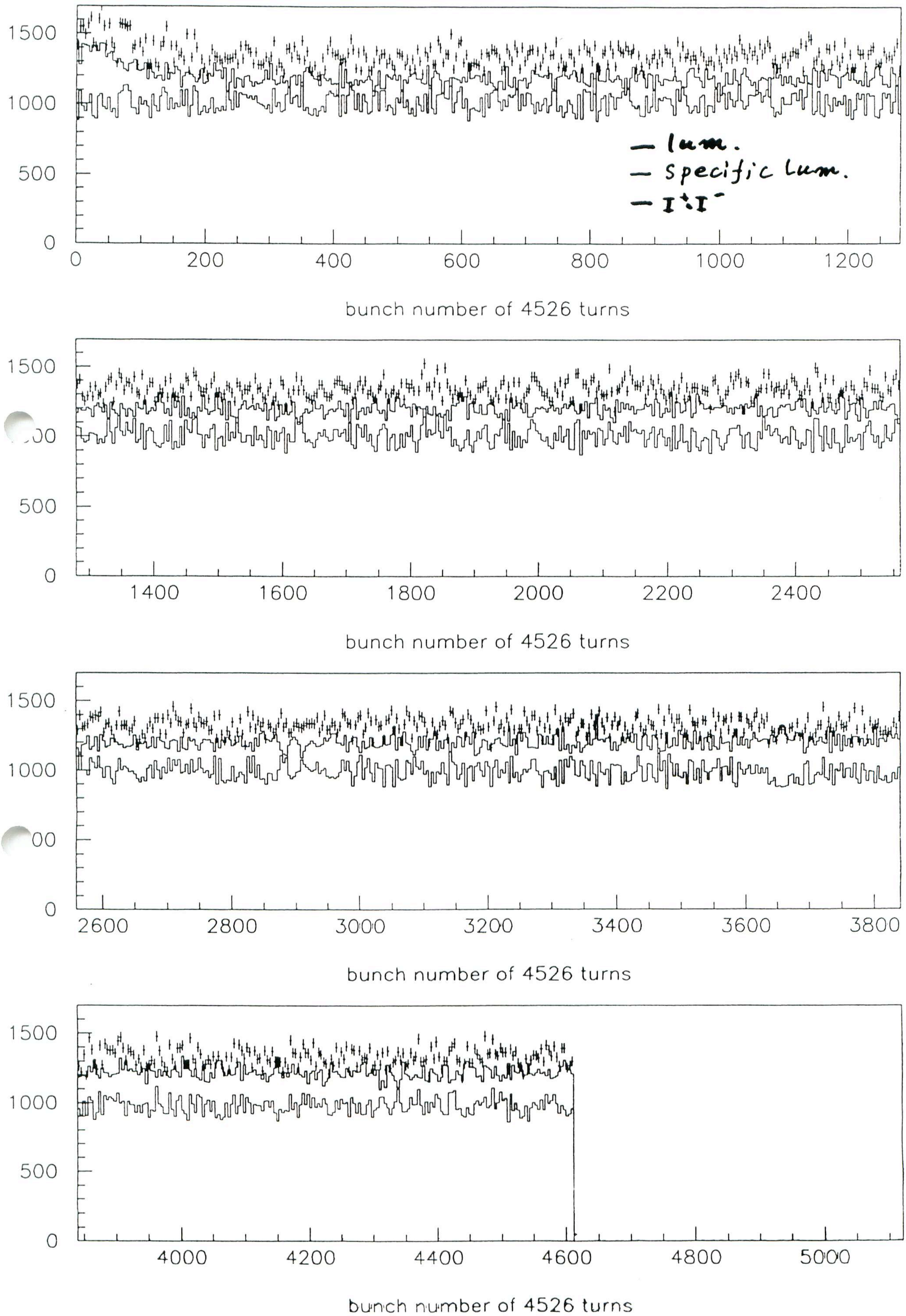

Effect of additional solenoid
all solenoid on
additional solenoid off
CsI Specific/bunch
LER current (mA)
0
5
10
15
0
100
200
300
400
500
600
700
800

- Bunch-by-bunch luminosity started the operation. It showed that the specific luminosity of forward 20 bunches was higher than that of remaining bunches when the beam current is above 600 mA.

<u>Vertical tune above half integer</u>

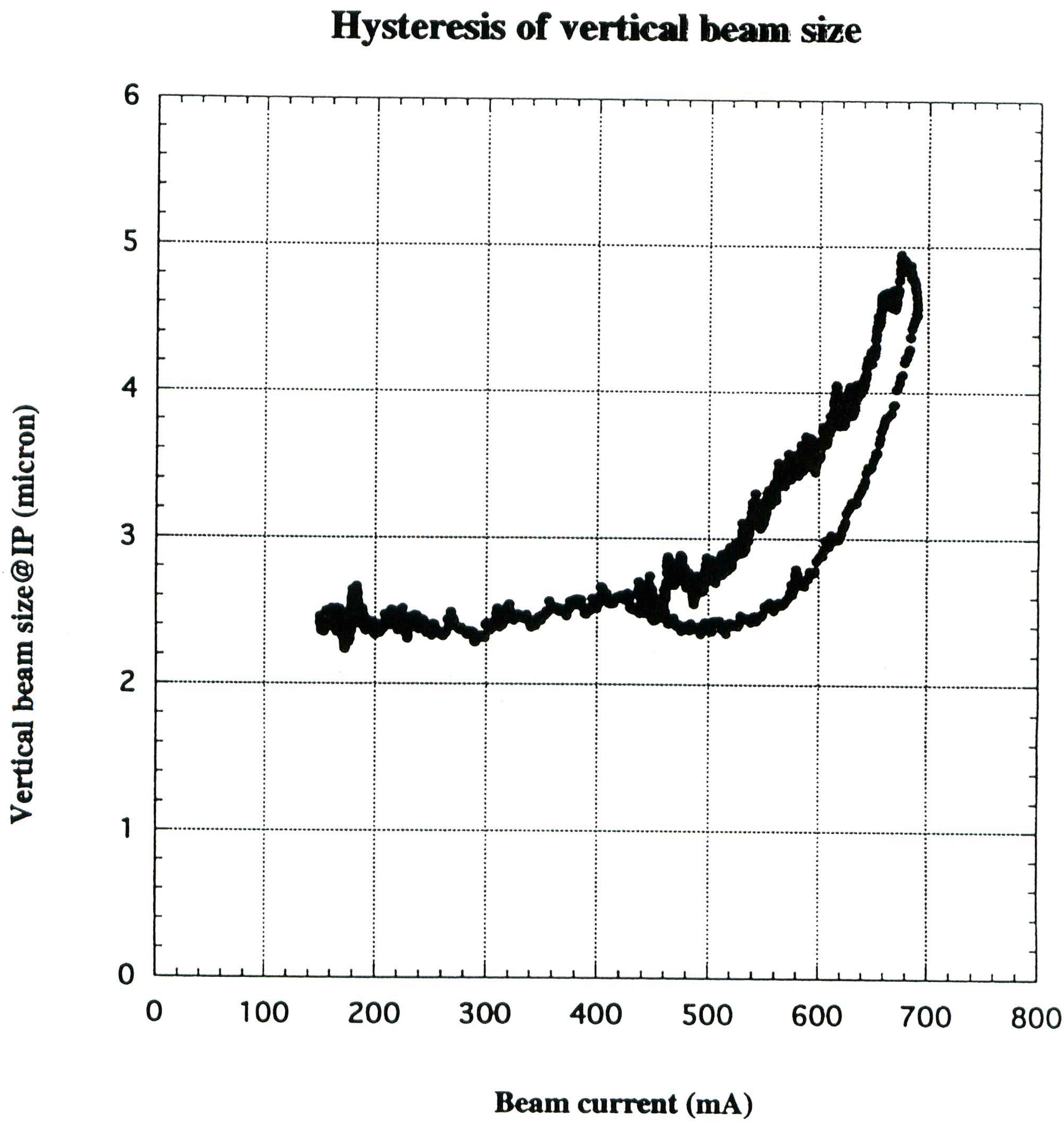
- No improvement on the blow-up was observed at the tune above half integer.

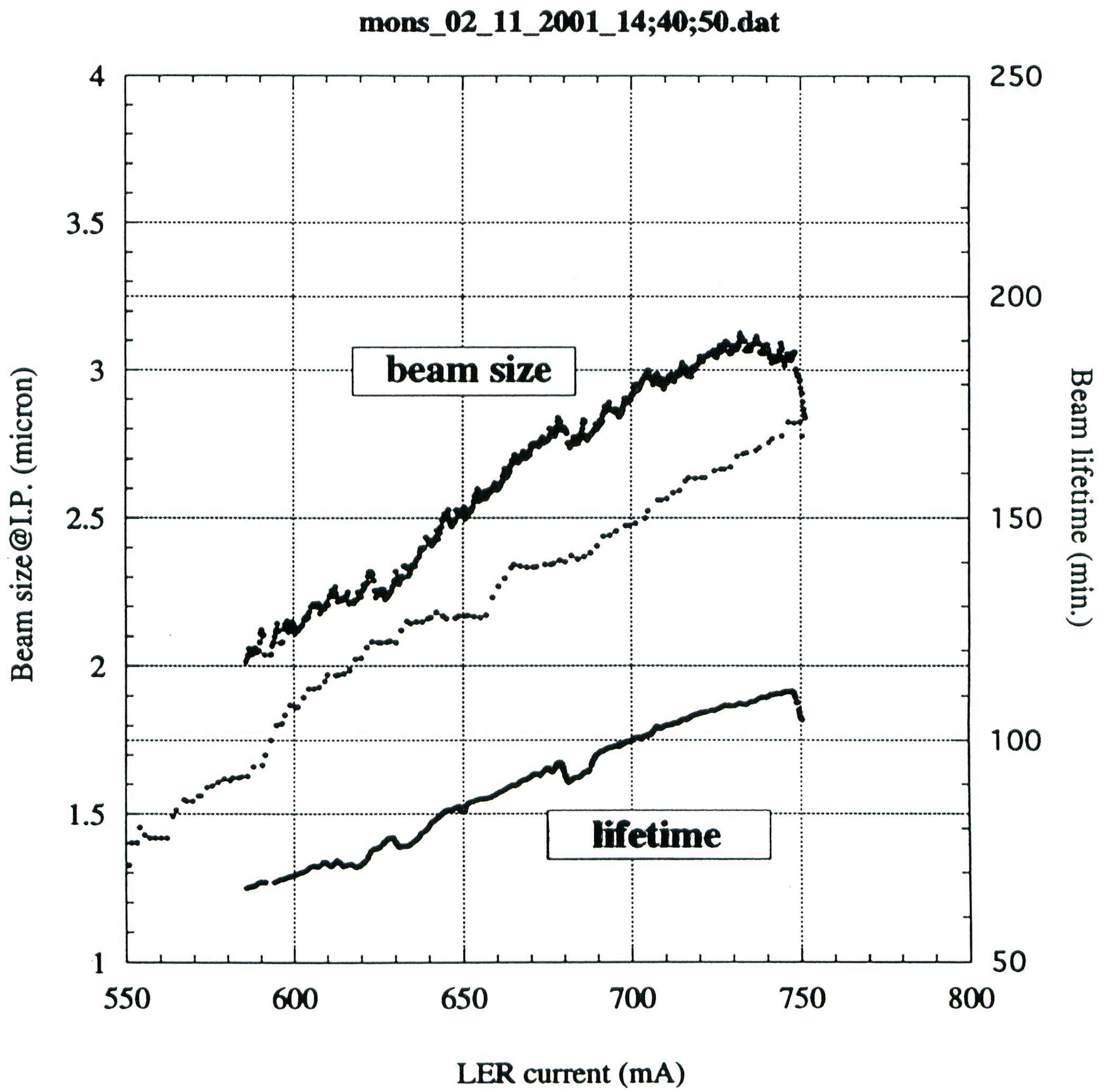
Bunch by bunch luminosity (S. Uehara)

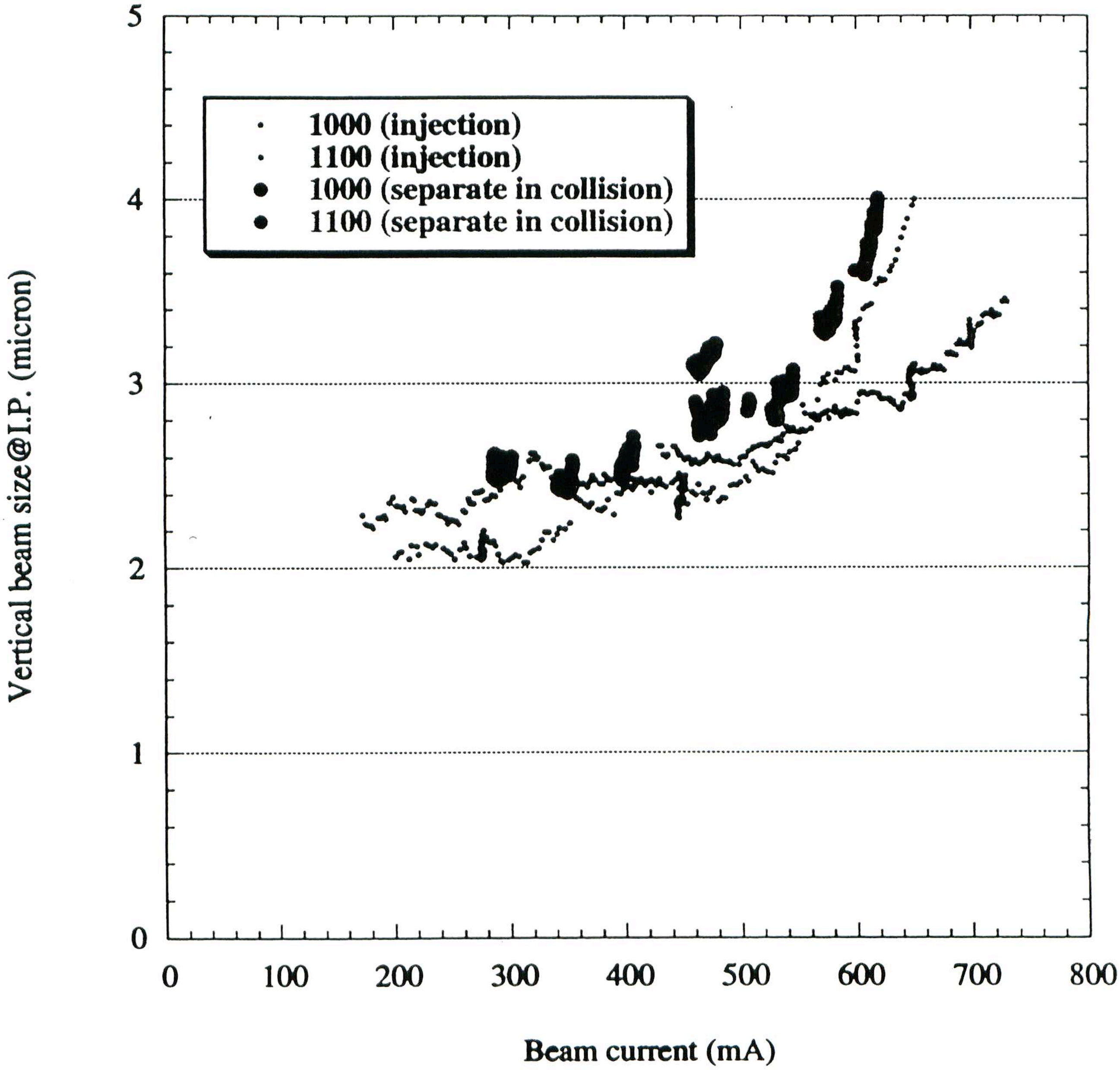


Hysteresis

- The beam size continues to blow-up even after the injection stops. The time when beam size reaches to a maximum value is delayed typically 100 sec after the injection stops.
- The hysteresis seems "real".
- The beam size may be different at the injection and at the collision due to hysteresis. There is a data which shows the beam size at the collision is almost same in the fill pattern "1000" and "1100" while the beam sizes are different at the injection.
- The vacuum pressure also shows hysteresis but the time constant of the pressure-increase after stopping the injection is smaller than that of the beam size.
- The electron yield measured by the electron monitor does not show the hysteresis.
- The hysteresis is not explained by the Zimmermann and Ohmi model.


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


mons_02_11_2001_14;40;50.dat
beam size
lifetime
Beam size@I.P. (micron)
Beam lifetime (min.)
LER current (mA)
4
3.5
3
2.5
2
1.5
1
250
200
150
100
50
550
600
650
700
750
800



1000 (injection)
1100 (injection)
1000 (separate in collision)
1100 (separate in collision)
Vertical beam size@I.P. (micron)
0
1
2
3
4
5
0
100
200
300
400
500
600
700
800
Beam current (mA)

Questions

A) Why solenoids and C yokes are not so effective when a bunch train is long ?

Hyposesis (K. Oide)

- There exsist at least two types of the blow-up.
  1) A blow-up explaned by the Zimmermann and Ohmi model
  2) Another blow-up by “long-sustained source(s)” which affect to the blow-up for a long train.
     i)Universal curve of specific luminosity which is determined only by LER current.
     ii)The beam size slowly increases along the train with solenoids.
     iii)Large train gap necessary for removing the effect of the forward train.
     iv)Shorter train is better for the blow-up.
     v)Fill patterns of short and many trains did not improve the luminosity.

- Blow-up 1) caused by the electron cloud in field free sections of arc is alredy suppressed by the solenoids.

  But blow-up 2) is still remained.

At present, we are not sure whether the source of 2) is electron cloud or not ?

B) Hysteresis

There are no models to explaine the hysteresis of the beam size.

Plans

- Search electron sources (Bend, wiggeler, Fuji crossing point, IR etc.)
- Study of hysteresis effect on the blow-up
- New model and/or simulation
- Detection of bunch oscillation
- Shorter bunch length
- More solenoid in straight sections ?
- Vacuum chamber (ante-chamber) ?

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.

  Hysteresis

  Slow build-up of the beam size along the train
- Most important problem is why solenoids and C yokes are not so effective when a bunch train is long ?
- There may be another source of the blow-up for a long train.

Coupled bunch instability

<u>LER</u>

- Fill pattern (1920 bunches)
  Bunch spacing : 4rf buckets, 32 trains,
  60 bunches/train, train gap : 24 rf buckets
- Beam current 640 mA
- Growth time
  Horizontal : <1 ms, Vertical : about 2 ms
- Mode
  Broad both in horizontal and vertical

<u>HER</u>

- Fill pattern (1152 bunches)
  Bunch spacing : 4rf buckets, 1 train
- Beam current 400 mA
- Growth time
  Horizontal : 4 ms, Vertical : 10 ms
- Mode
  Horizontal : sharp mod at low frequency
  Vertical : broad