Observation of Fast Beam-Ion Instability in PLS/KEKB

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PAL

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Introduction I PAL

- ***Fast Beam-Ion Instability(FBII)***

  A recent topic in B-factory (***KEKB, PEP-II***)
  Raubenheimer, Stupakov, Zimmermann

- ***FBII*** is distinguished from ***ion-trapping***

  a) ***Ions trapped in single passage*** of bunch train
  b) ***transient : ions are cleared up*** in the clearing gap
  c) broadband ion spectrum
  d) ***snake- tail oscillation*** $\sim \sigma_y$ or ***bunch size blowup*** at tail of bunch train

$$y(s, z) \approx y_0 \exp[zL(s/c\tau)^{1/2}] \sin(z\omega_i/c - s\omega_\beta/c)$$

$$\omega_i = [4n_b r_p c^2 / 3l\sigma_y(\sigma_x + \sigma_y)A]^{1/2}$$

z : bunch position within a bunch train
l, L : bunch seperation, bunch train length
τ : characteristic growth time of the FBII
n_b: number of electrons in a bunch
A : ion mass

Introduction II

- **Experimental observations**

  a) ***J. Byrd, et al., ALS***
  - first quantitative observation of FBII
  - beam size + oscillation of each ($\mathbf{2 \sim 2.5\sigma_y}$)
  - growth time estimated w/feedback system

  b) ***H. Fukuma, et al., TRISTAN AR***
  - first use of SBPM
    oscillation amplitude ($\sim \mathbf{3\sigma_y}$)

  c) ***M. Kwon, et al., PLS***
  - used SBPM, 1024 turn data
  - demonstration of snake-tail motion
  - oscillation amplitude ($\sim \mathbf{1.5\sigma_y}$)

- Another experiment performed in PLS

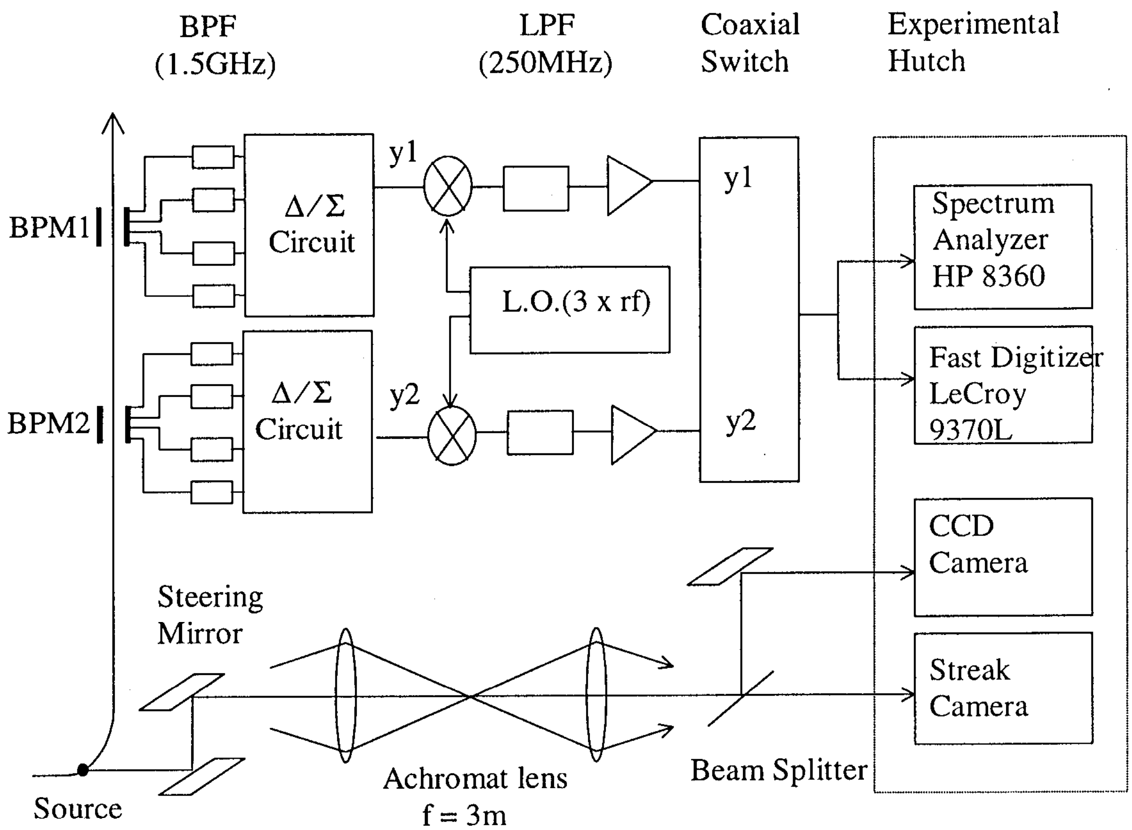
  - ***direct observation of FBII*** from ***spatio-temporal snapshots***
  - ***bunch size*** and ***oscillation amplitude*** measured independently

PLS Parameters **PAL**

• Beam Energy	2	GeV
• Circumference	280	m
• RF Frequency	500	MHz
• Revolution Freq.	1.07	MHz
• Revolution Period	0.93	μsec
• Harmonic Number	468	
• Beam Current		
design	400	mA
operation	200	mA
• Tunes		
ν_x	14.28	
ν_y	8.18	
ν_s	0.011	
• Beam Sizes		
σ_x	185	μm
σ_y	<67	μm
• Damping Times		
τ_{tr}	16.6	msec
τ_s	8.34	msec

Experimental Setup PAL

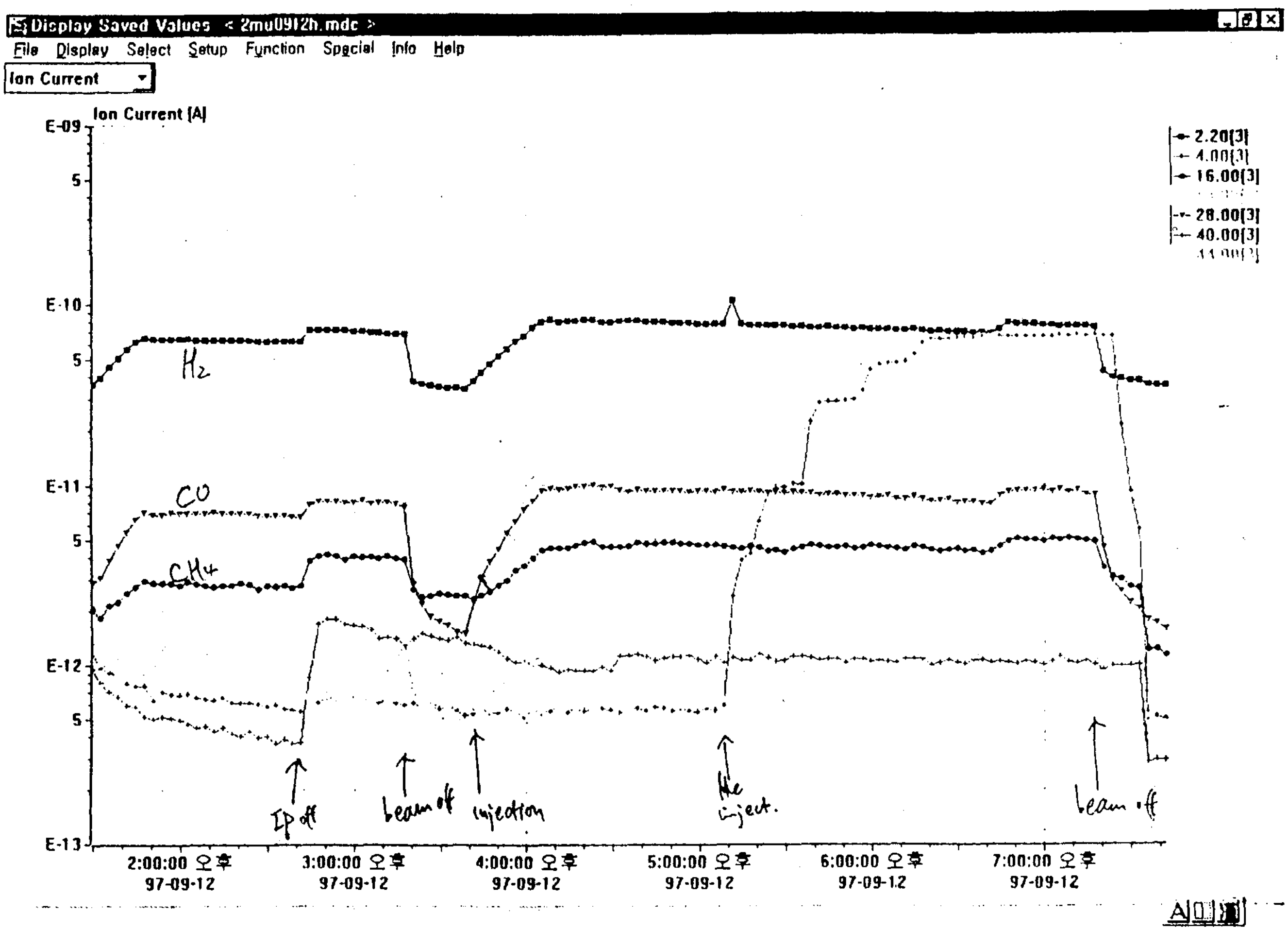
- **Arrangements of detectors**
  for observation of FBII



a) two 250MHz single pass BPMs(***SBPM***)
b) LeCroy 9370L, 500MHz sampling scope
c) HP8360 spectrum analyzer
d) Visible light imaging system
e) CCD camera
f) Hamamatsu C5680 ***streak camera***
   ▸ ***Spatio – temporal snapshots***

Experimental Setup

- **Pressure increase with He injection**

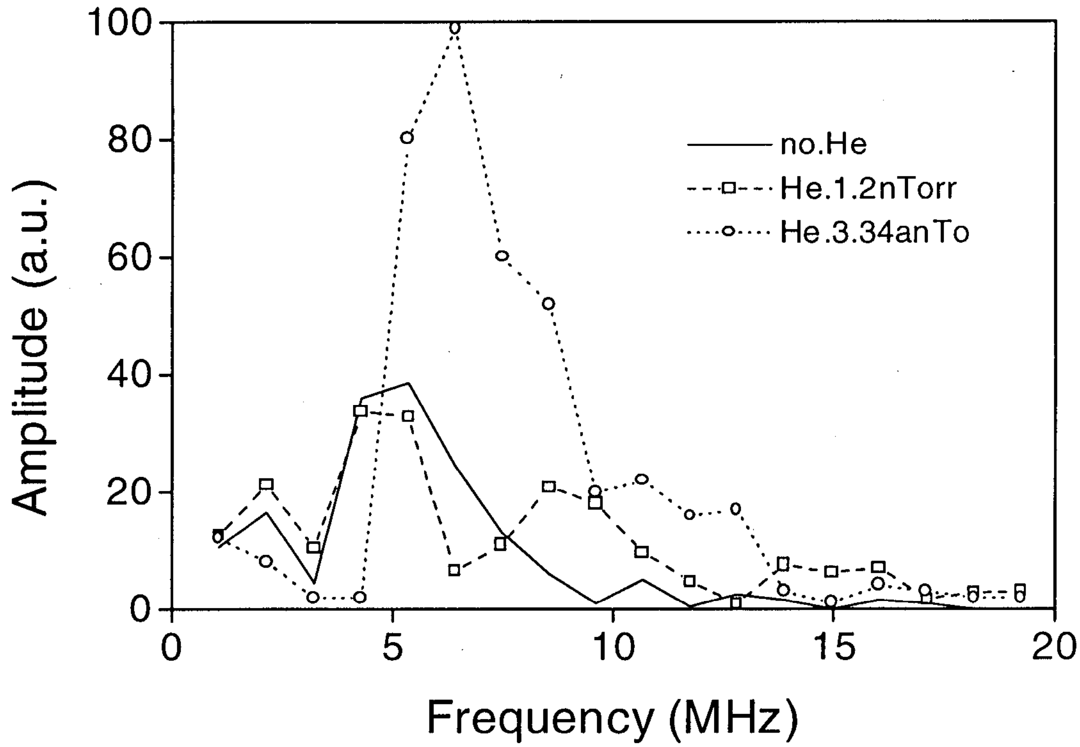


a) normal : 0.4 nTorr
b) ion pump off : 2.2 nTorr
c) 1st injection : 2.4 nTorr
d) 2nd injection : 3.4 nTorr
e) 3rd injection : 5 nTorr
f) 4th injection : 7 nTorr

Observation VIII

PAL

- **Ion spectra**



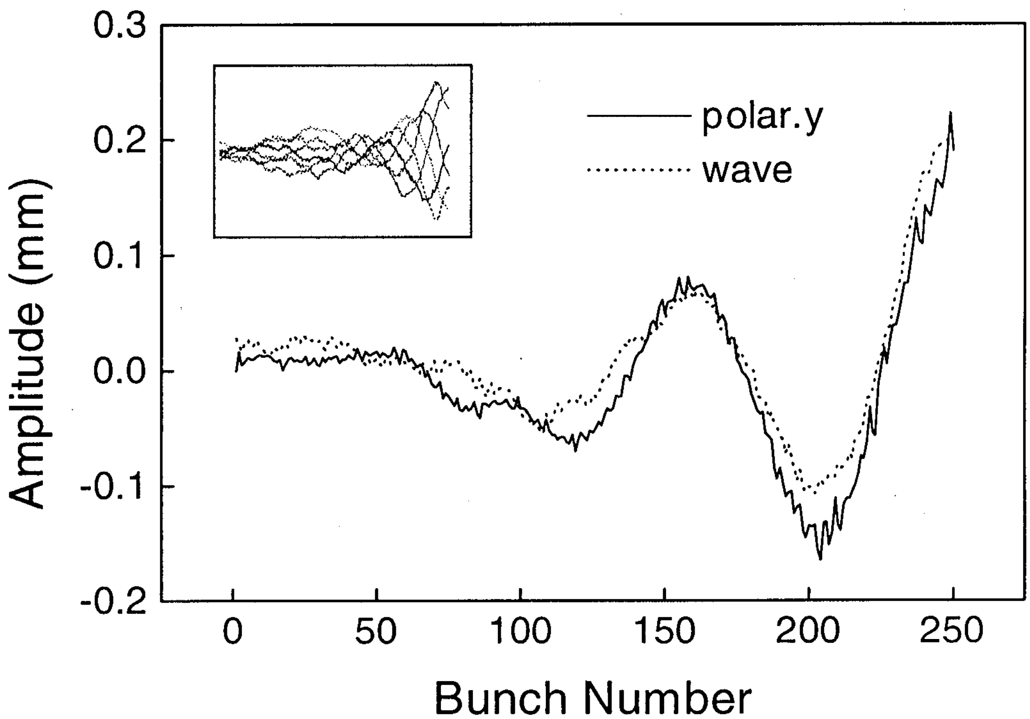
a) ion peaks appear at the frequencies predicted from linear theory

b) 0.2 -1.2 nTorr case shows two distinct peaks corresponding to Co and He

c) at 3.34 nTorr, large peak appear due to large amplitude of oscillation

Observation VII

- **Comparison**
  of single pass wave form
  and reconstructed waves from SBPM data



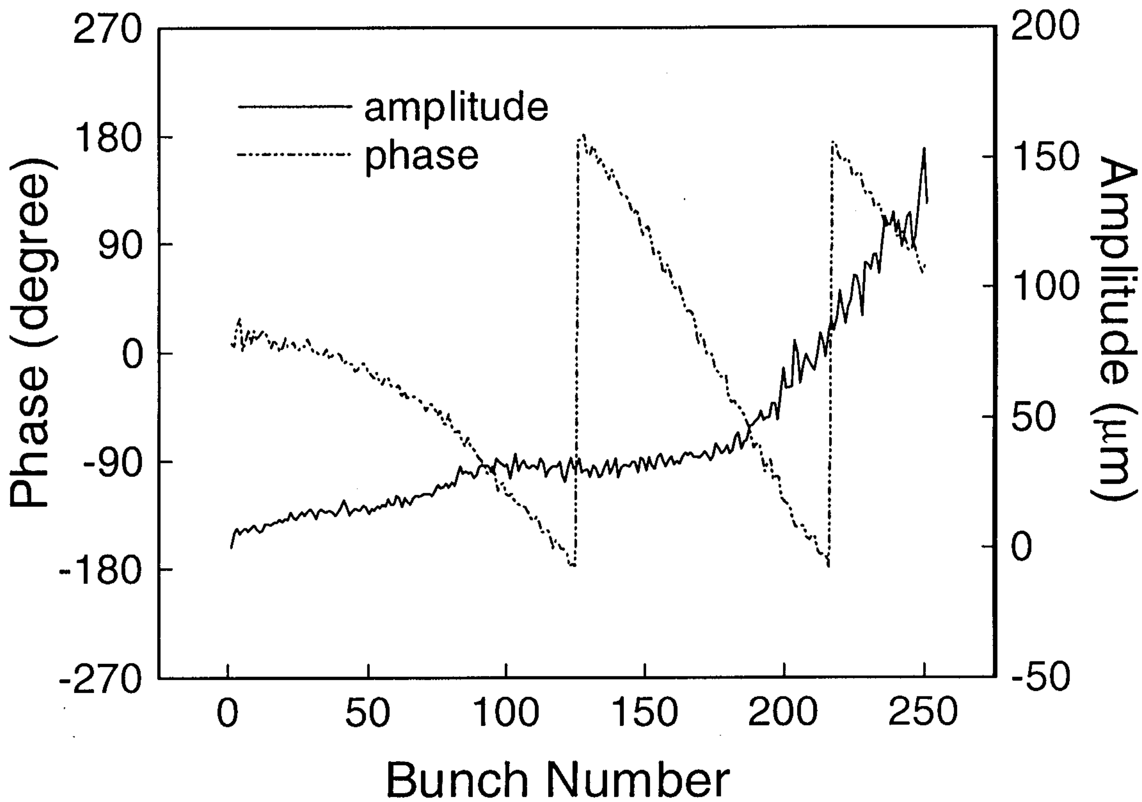
a) dotted line : ***single pass oscillogram***

b) solid line : reconstructed by
fft of ***1024 turn data***

Observation V

PAL

- **Phase and amplitude from snapshots**



a) amplitude increase exponentially at tail

b) phase advance/bunch = 5.4 MHz
equal to the frequency from spectrum

c) phase advance/bunch slows down
at tail due to the *bunch size blow-up*

d) ***amplitude*** at tail ~ ***1.5σ***

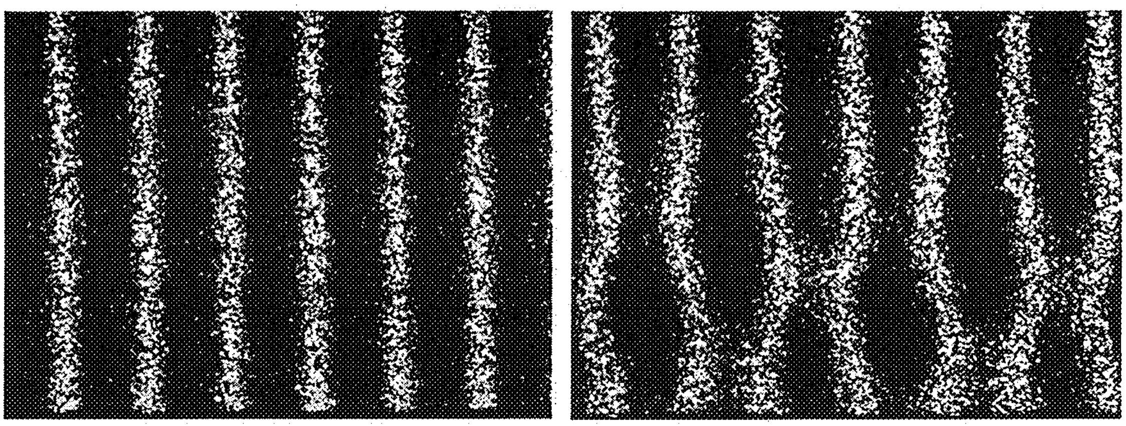
Observation I — *PAL*

- **Snapshots taken every 4μsec.**

  i_b = 0.72 mA/bunch, 250 bunches

  x-span : 25 μsec (6.4 mm)

  y-span : 500 ns



(a) (b)

a) normal case

P_{total} = 0.4 nTorr

P_{CO} = 0.03 nTorr

$\omega_{CO}/2\pi$ = 6.8 MHz

b) ion pumps turned off

P_{total} = 2.2 nTorr

P_{CO} = 0.16 nTorr

$\omega_{CO}/2\pi$ = 5.4 MHz

Observation II

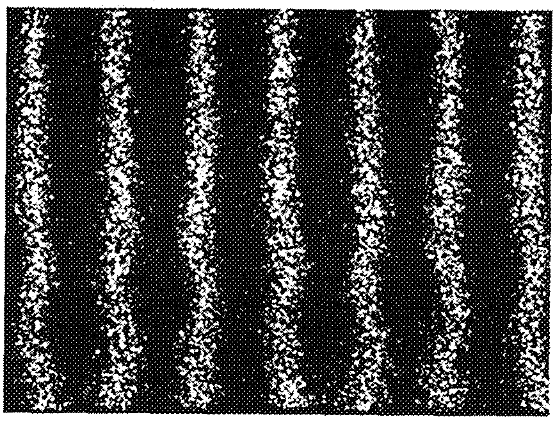
PAL

- **Snapshots II**

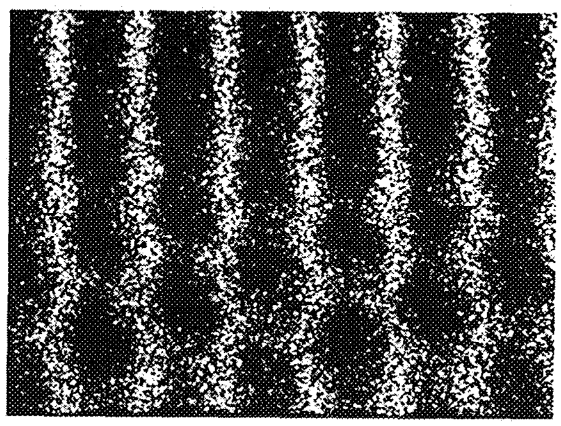
  i_b = 0.72 mA/bunch, 250 bunches

  x-span : 25 μsec (6.4 mm)

  y-span : 500 ns



(a)



(b)

a) 0.2 nTorr He injected

P_{total} = 2.4 nTorr

P_{CO} = 0.19 nTorr

P_{He} = 0.2 nTorr

b) 3.34 nTorr He injected

P_{total} = 7 nTorr

P_{CO} = 0.33 nTorr

$\omega_{He}/2\pi$ = 7 MHz

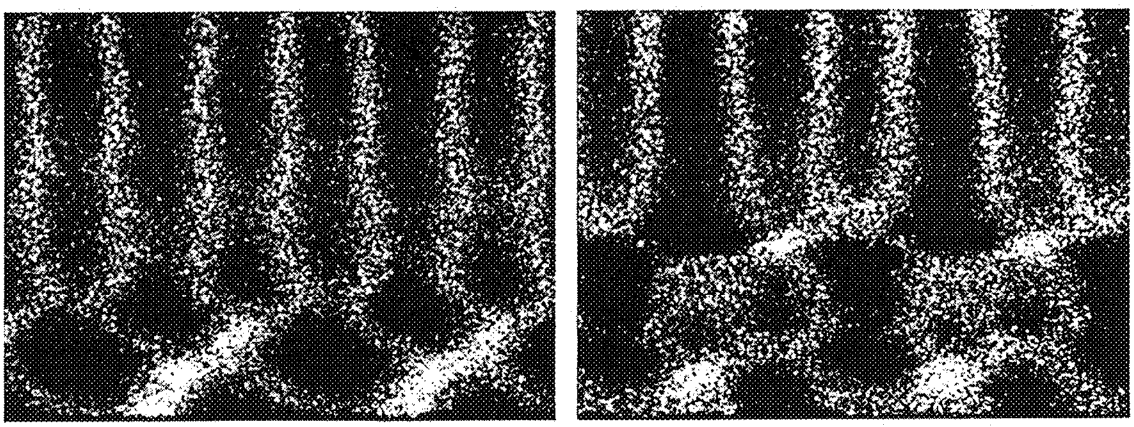
Observation III PAL

- **Snapshots III**

  i_b = 0.72 mA/bunch, 250 bunches

  x-span : 25 μsec (6.4 mm)

  y-span : 500 ns



(a) (b)

a) 3.34 nTorr He, i = 130mA

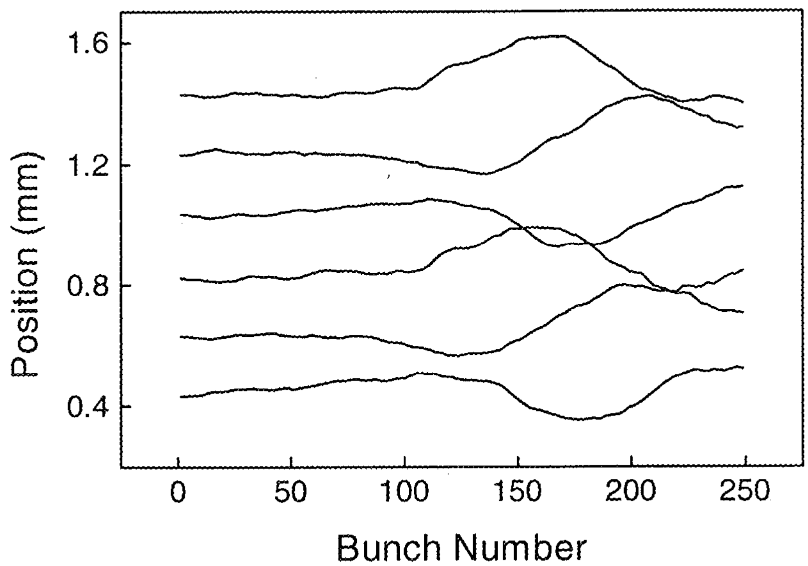
Large triangular wave form excites intermittently

b) i = 150 mA

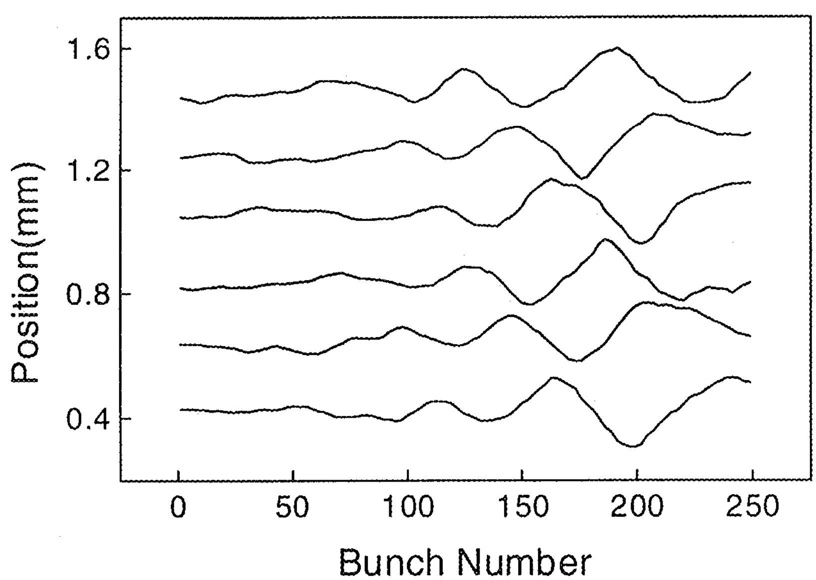
Irregular (chaotic) oscillation of tail

Observation IV

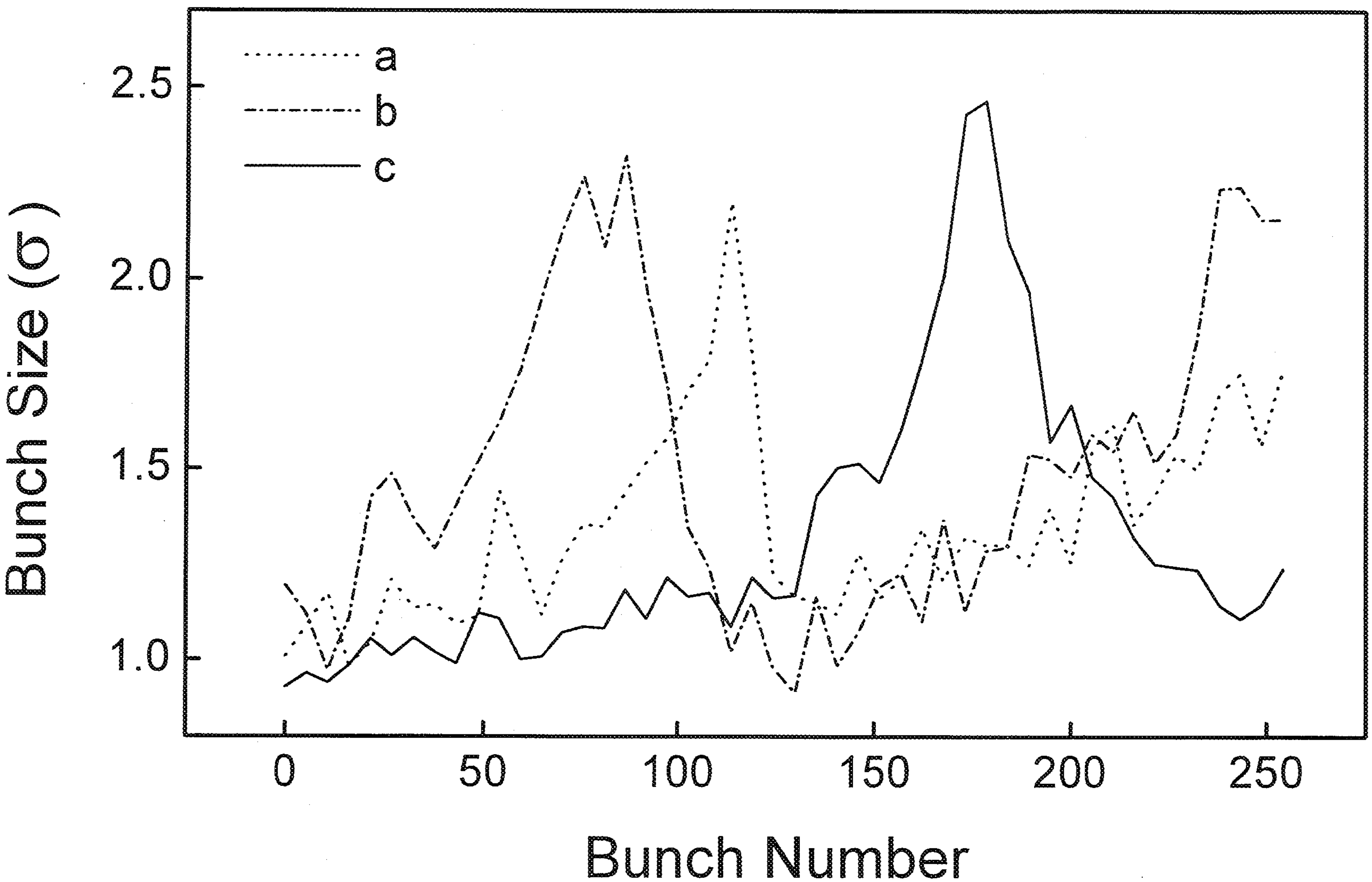
- **Mountain views from snapshots**



a) before He injection



b) 3.34 nTorr He injection

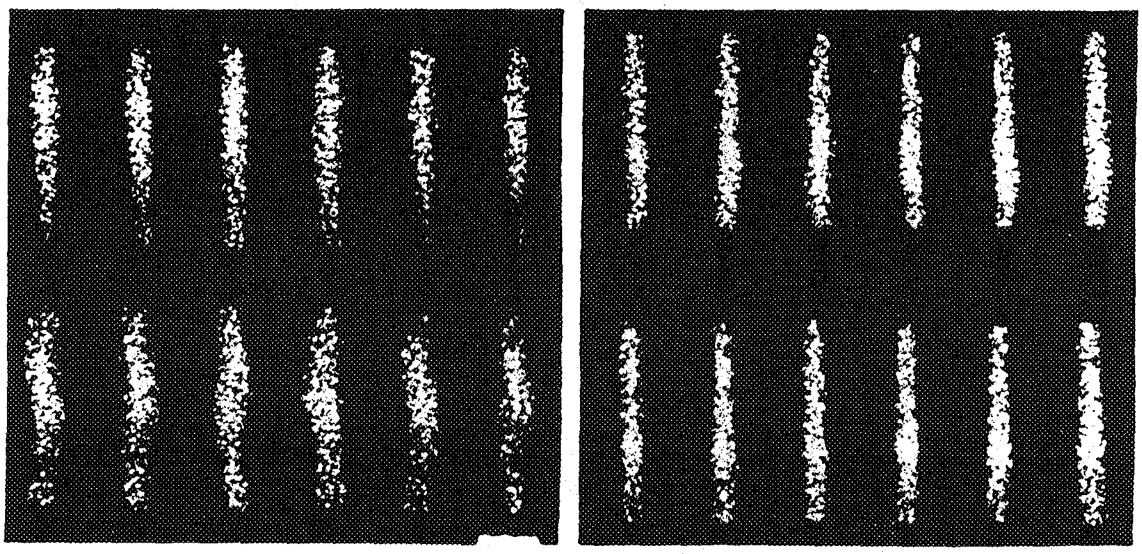


a
b
c
2.5
2.0
1.5
1.0
Bunch Size (σ)
0
50
100
150
200
250
Bunch Number

Observation III

PAL

Possible Cure for FBII



(a) (b)

Two snapshots taken for two different clearing gap lengths: (a) ~~10~~ 25 L_sep and (b) 50 L_sep showing suppression of the tail oscillation at longer gap length

Summary PAL

- **Experimental Results**
  - ***Direct observations*** of FBII
    - Transient data recording (SBPM)
    - Snapshots of FBII (streak camera)
  - ***Quantitative measurement*** of FBII
    - oscillation amplitude (~ $\mathbf{1.5}\sigma_y$)
    - bunch size blowup (~ $\mathbf{2}\sigma_y$)
  - ***Cure*** of FBII ?
    - control of clearing gap showed "cure" effect

- **More to do**
  -
  - Measurement of ***growth time*** in controlled way

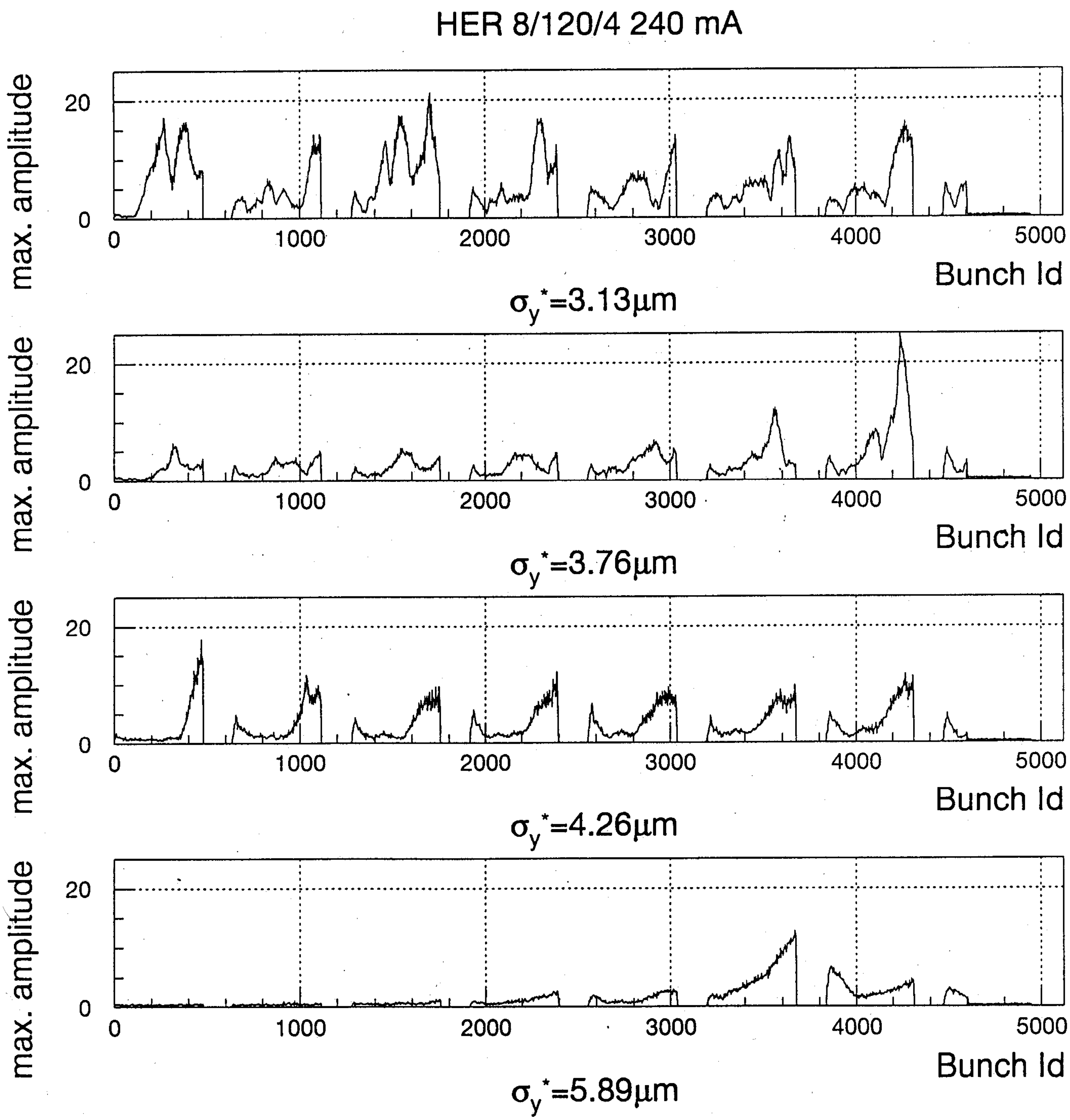
Observation of fast beam-ion instability in KEKB HER

- Vertical bunch oscillation was measured as a function of vertical beam size by the Bunch Oscillation Recorder after turn-off the bunch feedback system.

- Fill pattern was 8 trains/120 bunches in a train/bunch spacing of 4 rf buckets.

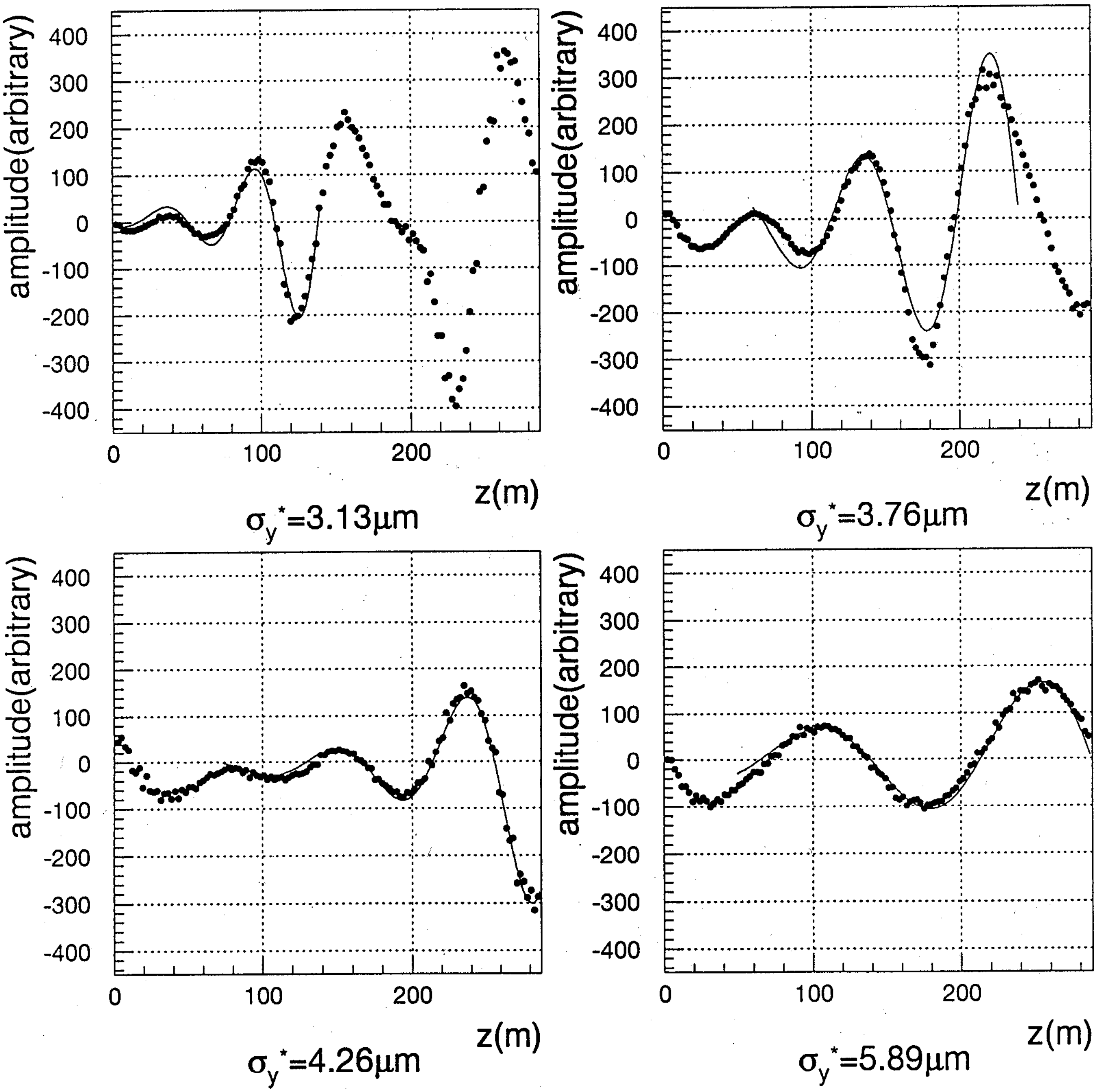
- Beam size was controlled by vertical dispersion which was produced by orbit bump at sextupoles and measured by the interferometer.

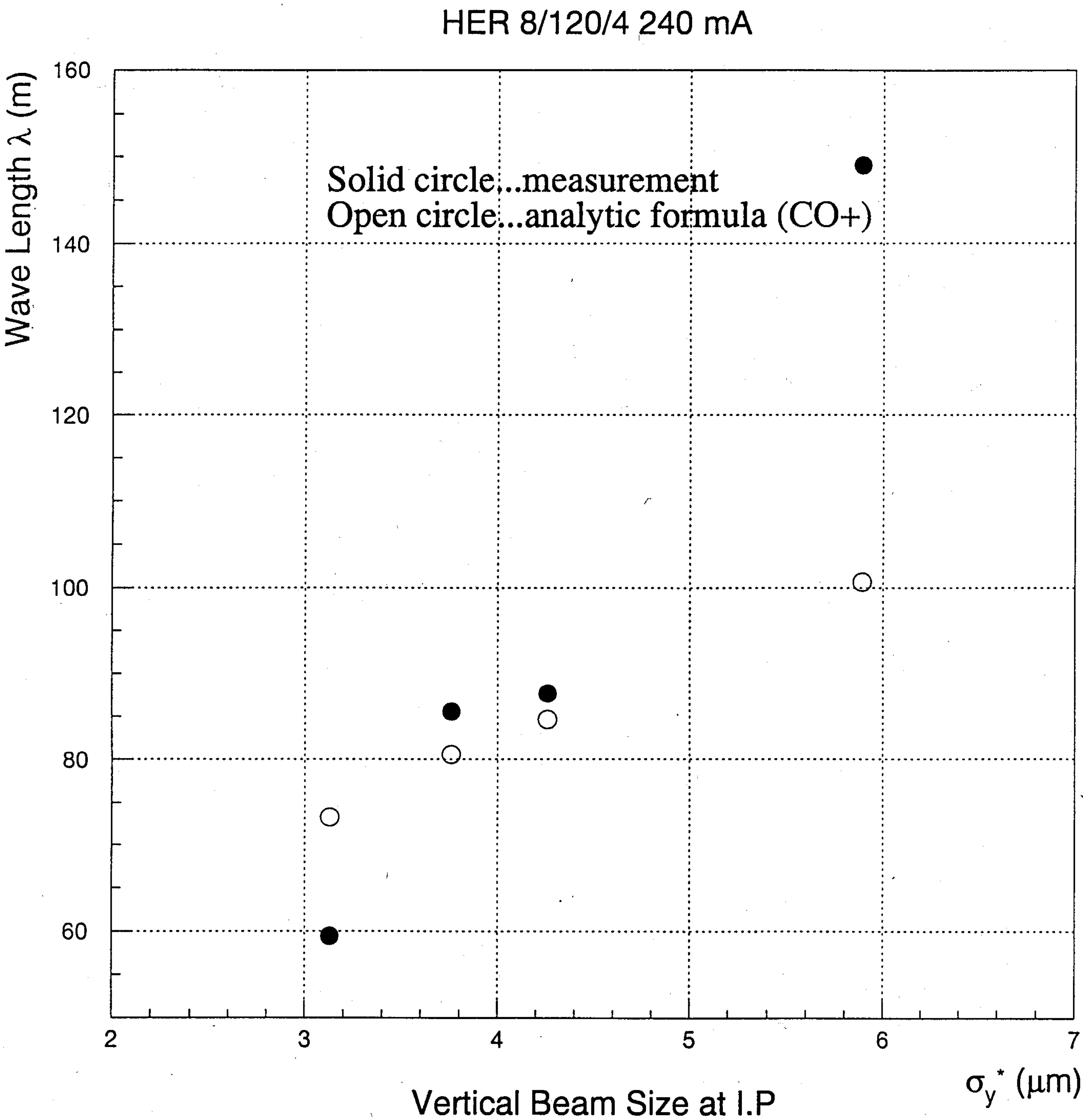
- Result
  1) Oscillation amplitude grows along the train.
  2) Oscillation amplitude decrease as the beam size increases.
  3) As the beam size increases, wave length of the oscillation along the train increases as predicted by the theory of FBII.



HER 8/120/4 240 mA
max. amplitude
20
0
0
1000
2000
3000
4000
5000
Bunch Id
σ_y^*=3.13μm
max. amplitude
20
0
0
1000
2000
3000
4000
5000
Bunch Id
σ_y^*=3.76μm
max. amplitude
20
0
0
1000
2000
3000
4000
5000
Bunch Id
σ_y^*=4.26μm
max. amplitude
20
0
0
1000
2000
3000
4000
5000
Bunch Id
σ_y^*=5.89μm

HER 8/120/4 240 mA




HER 8/120/4 240 mA
Solid circle...measurement
Open circle...analytic formula (CO+)
Wave Length λ (m)
160
140
120
100
80
60
2
3
4
5
6
7
Vertical Beam Size at I.P
σy* (μm)