Observation of Vertical Betatron Sidebands due to Electron Clouds at the KEKB LER

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Observation of Vertical Betatron Sideband due to Electron Clouds in the KEKB Low Energy Ring

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The effects of electron clouds on positively charged beams have been an active area of research in recent years at particle accelerators around the world. Transverse beam-size blowup due to electron clouds has been observed in some machines and is considered to be a major limiting factor in the development of higher-current, higher-luminosity electron-positron colliders. The leading proposed mechanism for beam blowup is the excitation of a fast head-tail instability due to short-range wakes within the electron cloud. We present here observations of betatron oscillation sidebands in bunch-by-bunch spectra that may provide direct evidence of such head-tail motion in a positron beam.

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- Data taken over course of 2003, 2004
  - Some initial observations shown at 2003 MAC
- Paper submitted to PRL July 2004
  - Published 7 Feb., 2005

Introduction

- Vertical beam blow-up has been observed at KEKB LER at bunch currents above a threshold of ~0.35 mA/bunch, at a spacing of 4 rf buckets (~8 ns).
- Bunch-current blowup threshold can be raised by the use of solenoids around the beam pipe.
  - Currently about 95% of drift space in LER is covered.

Blow-up measured by SR interferometer

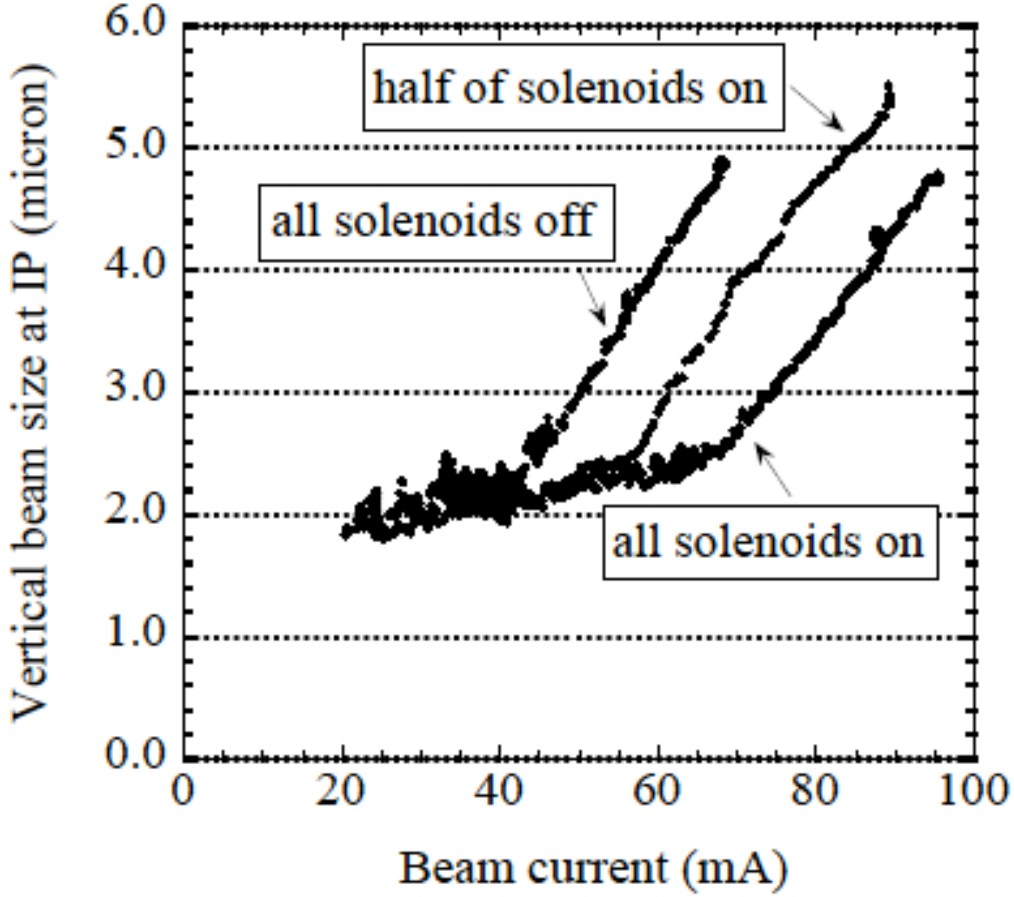


Figure 2: Vertical beam size as a function of the beam current. In the measurement two trains were injected on opposite sides in the ring. Each train contained 60 bunches. Bunch spacing was 4 rf buckets.

Fukuma et al., “Study of Vertical Beam Blow-up in KEKB LER,” HEAC01 proceedings

Bunch-by-bunch beam size along train as measured by gated camera

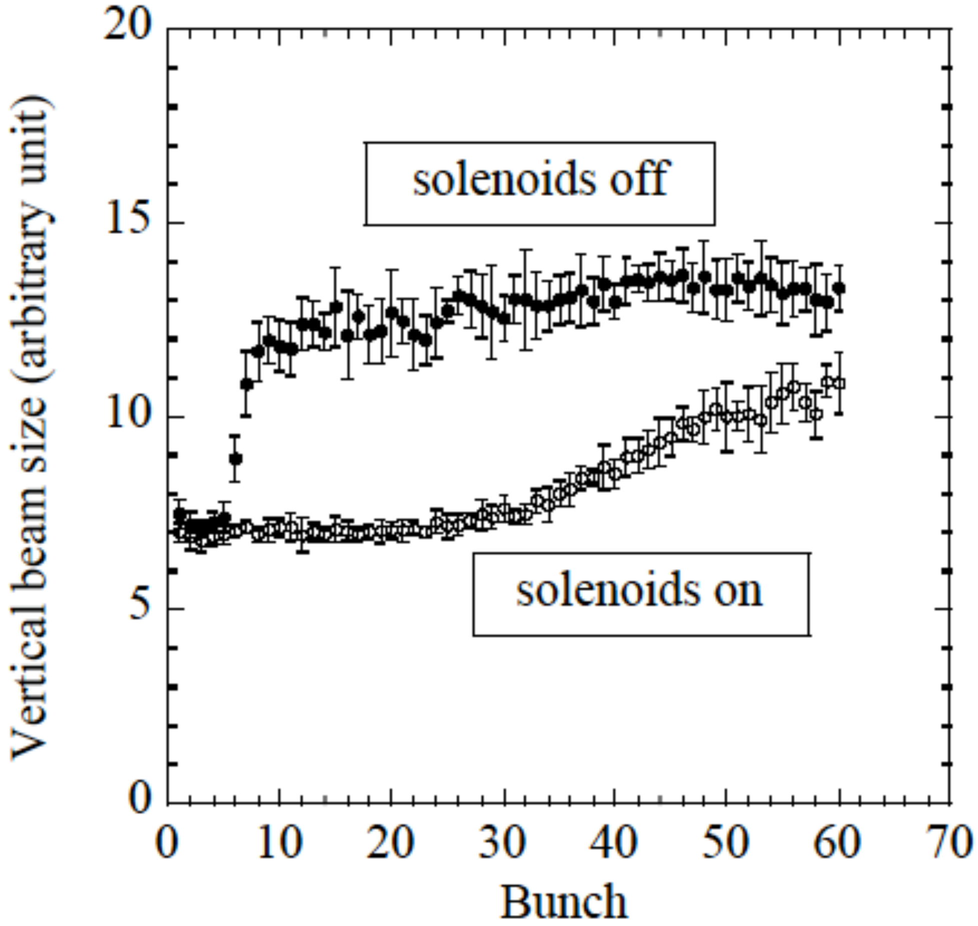


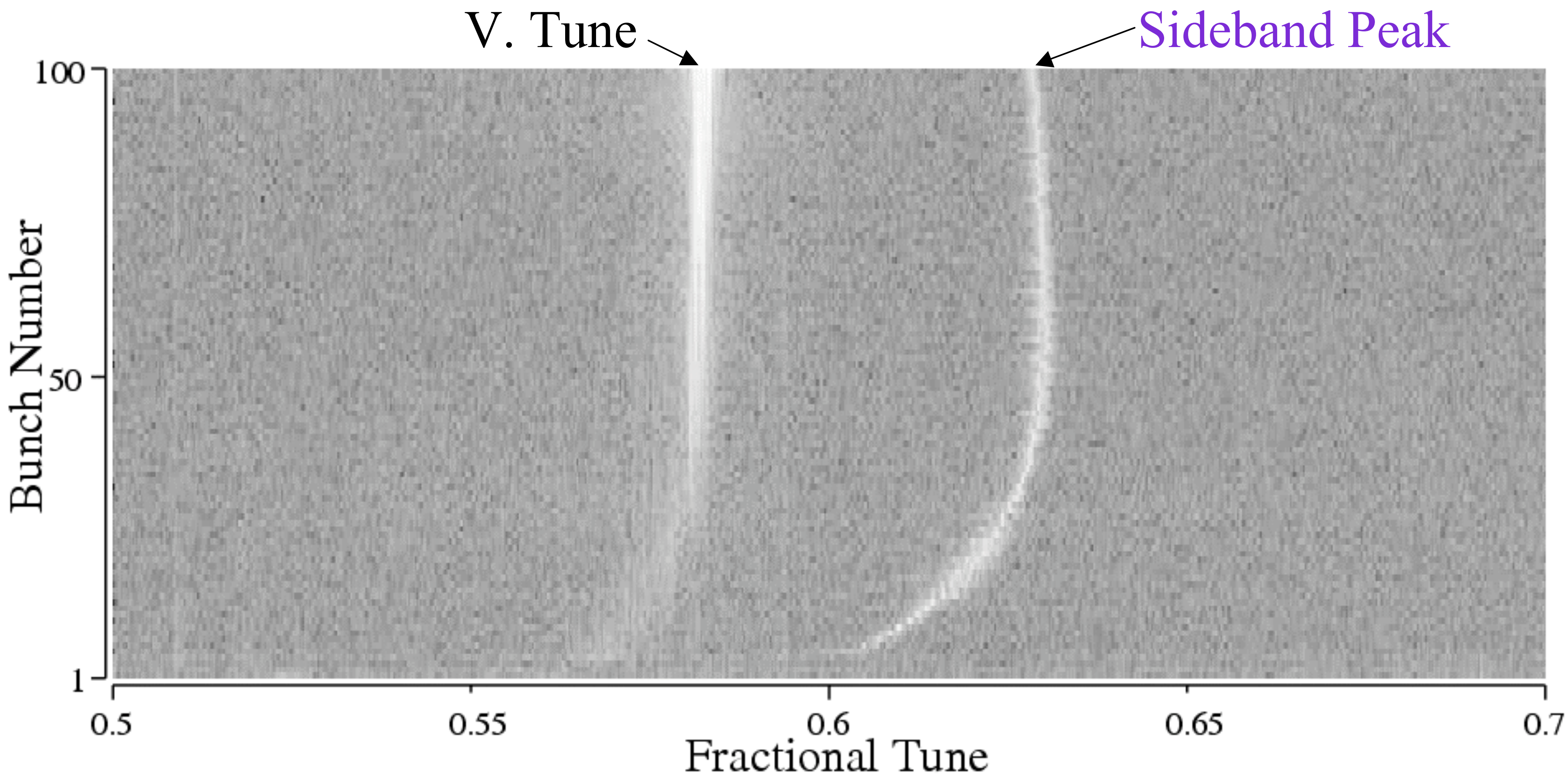
Figure 3: Vertical beam size along a train taken by the gated camera with and without solenoids. The train consisted of 60 bunches. Bunch spacing was 4 rf buckets. Bunch current was 0.67 mA.

Fukuma et al., “Study of Vertical Beam Blow-up in KEKB LER,” HEAC01 proceedings

Beam spectrum measurements

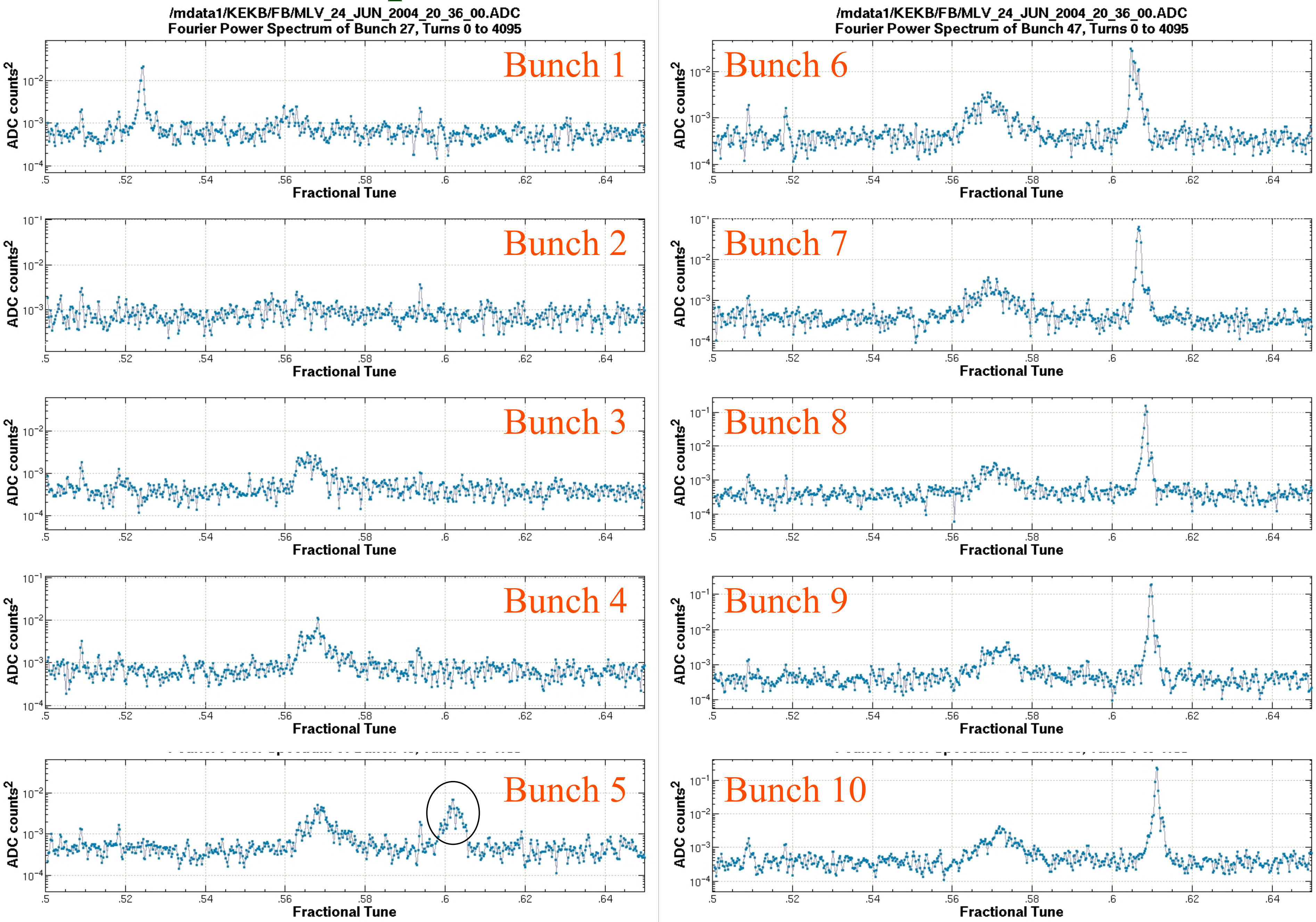
- Bunch Oscillation Recorder
  - Digitizer synched to RF clock, plus 20-MByte memory.
  - Can record 4096 turns x 5120 buckets worth of data.
  - Calculate Fourier power spectrum of each bunch separately.
- Inputs:
  - Feedback BPMs
    - 6 mm diameter button electrodes
    - 2 GHz ($4xf_{rf}$) detection frequency, 750 MHz bandpass
  - Fast PMT

Fourier power spectrum of BPM data

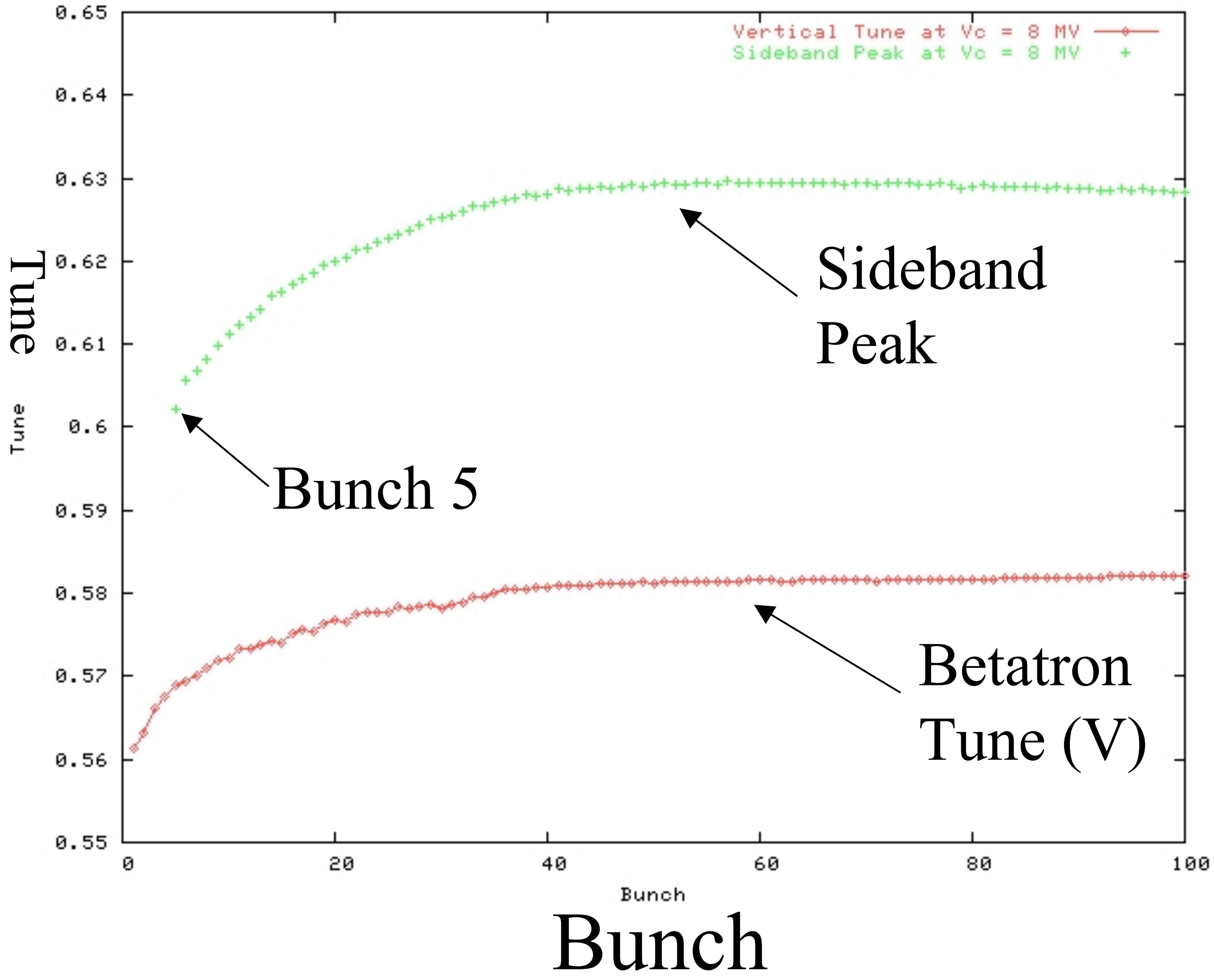


- LER single beam, 4 trains, 100 bunches per train, 4 rf bucket spacing
- Solenoids off: beam size increased from 60 μm ->283 μm at 400 mA
- Vertical feedback gain lowered
  - This brings out the vertical tune without external excitation

Spectra of Bunches 1-10

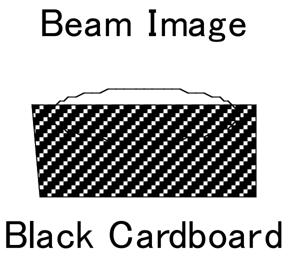


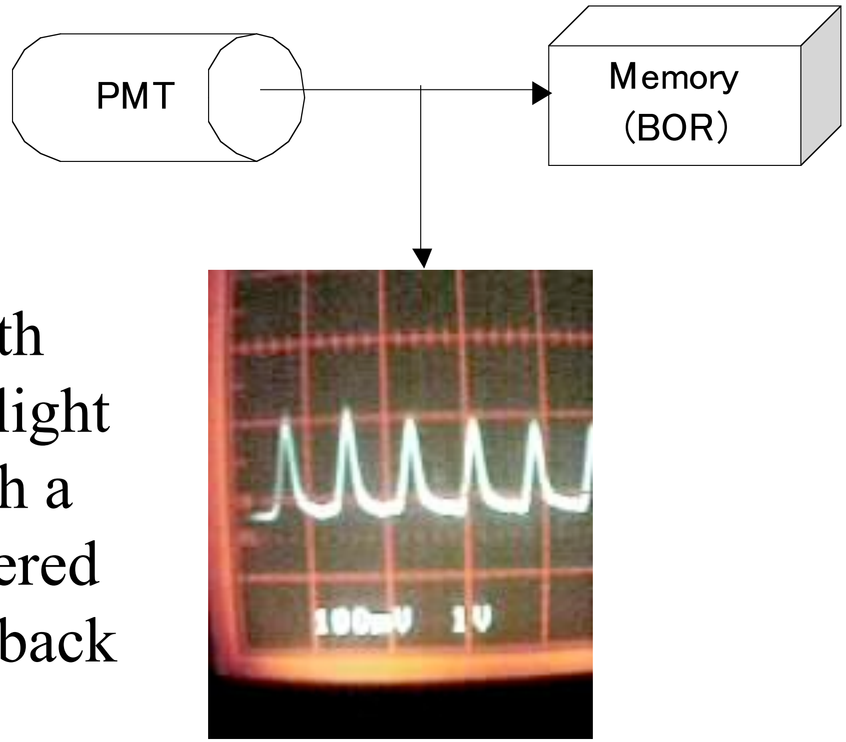
Tune and sideband peaks along train



- Vertical Tune and Sideband Peaks increase in tune along train, saturating near 40th bunch.
- Difference between tune and peak also increases, then saturates near the 40th bunch.
- If vertical tune is changed, sideband peak shifts by equal amount (separation remains constant). Horizontal tune has no effect.

PMT setup

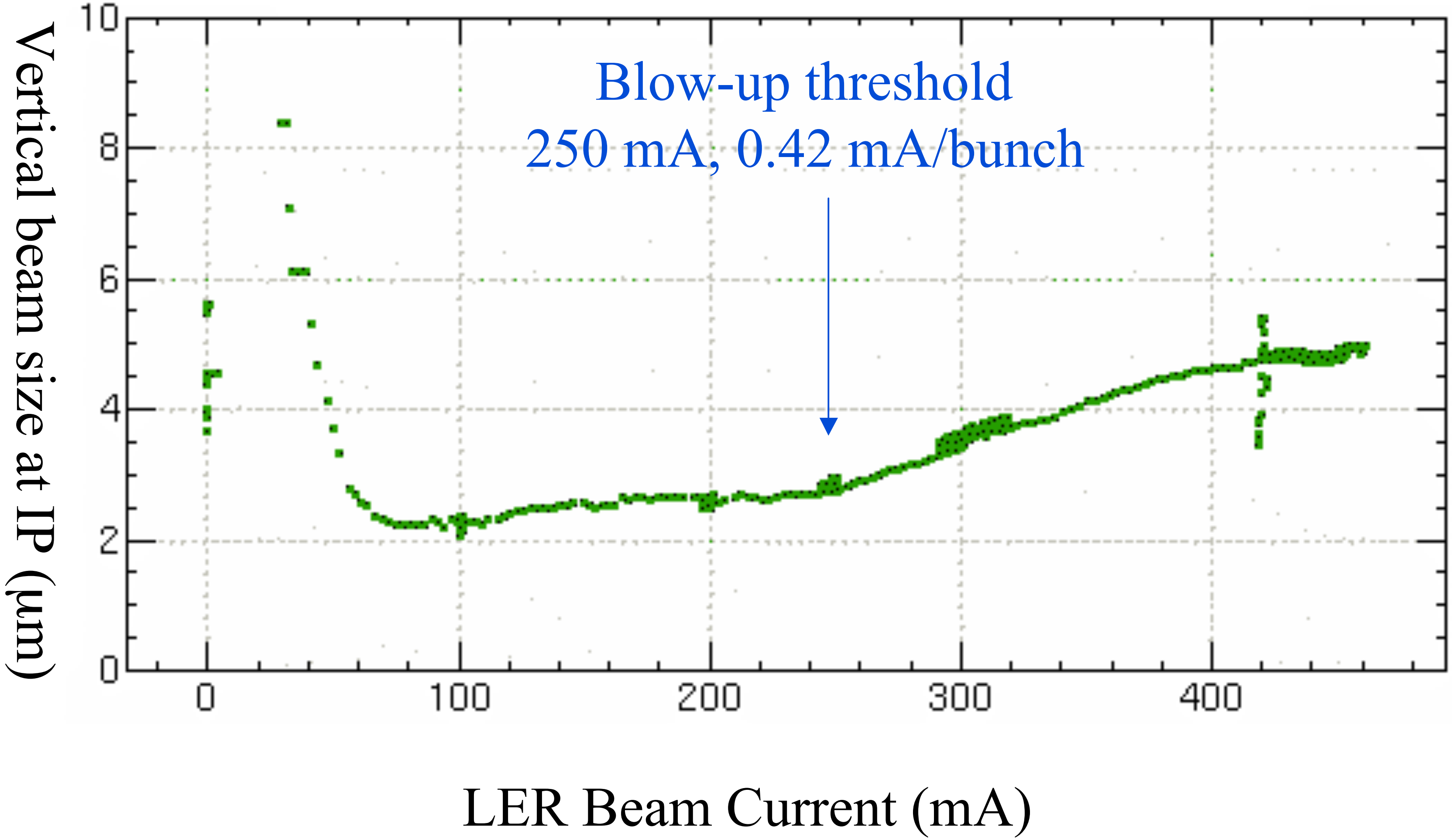




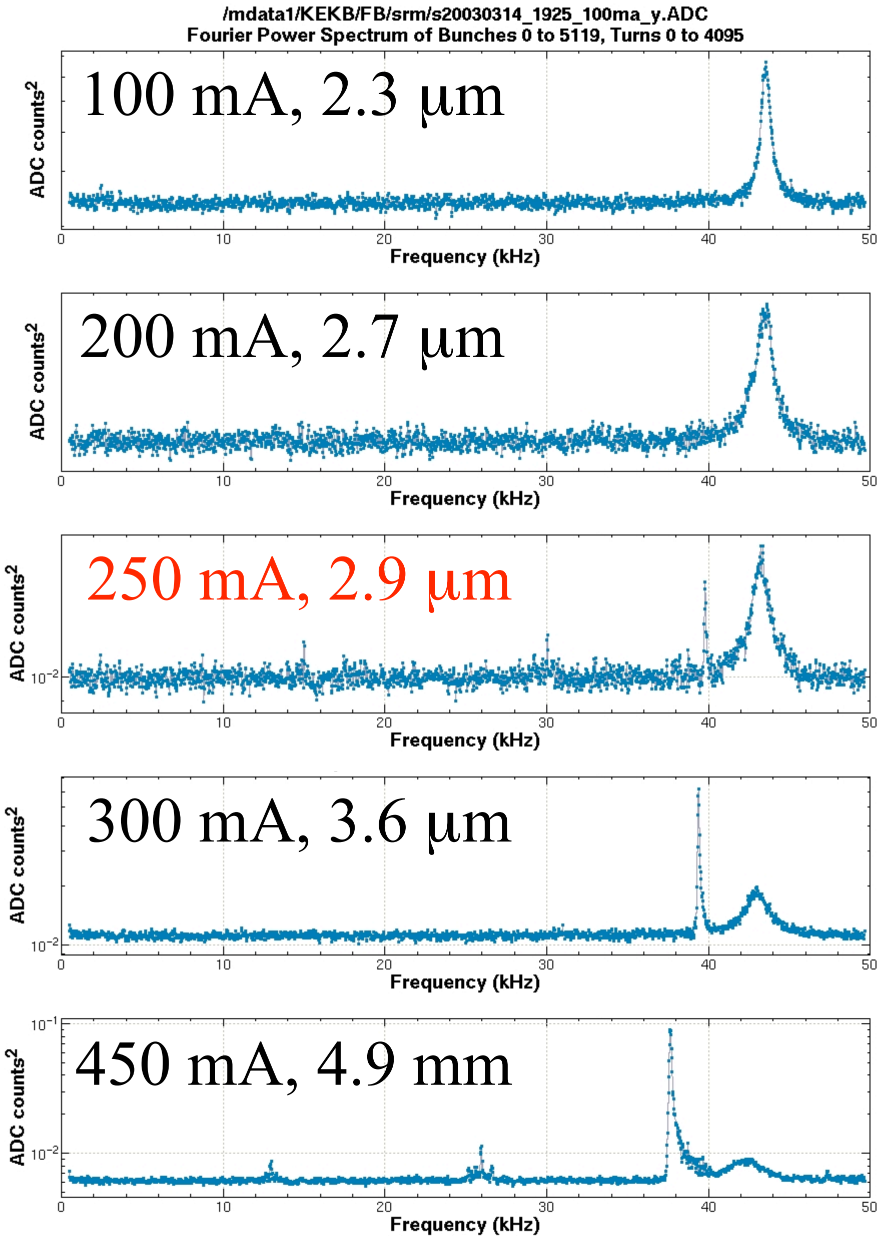
y: 100 mV/division
x: 10 ns/division

Partially block beam image with black cardboard, and measure light intensity of the visible part with a PMT. The PMT signal is buffered and then recorded using a feedback BOR digitizer/memory board.

Beam Blow-up Measurement
4-bucket spacing, 600 bunches
4 trains, 150 bunches/train, 4 rf bucket spacing

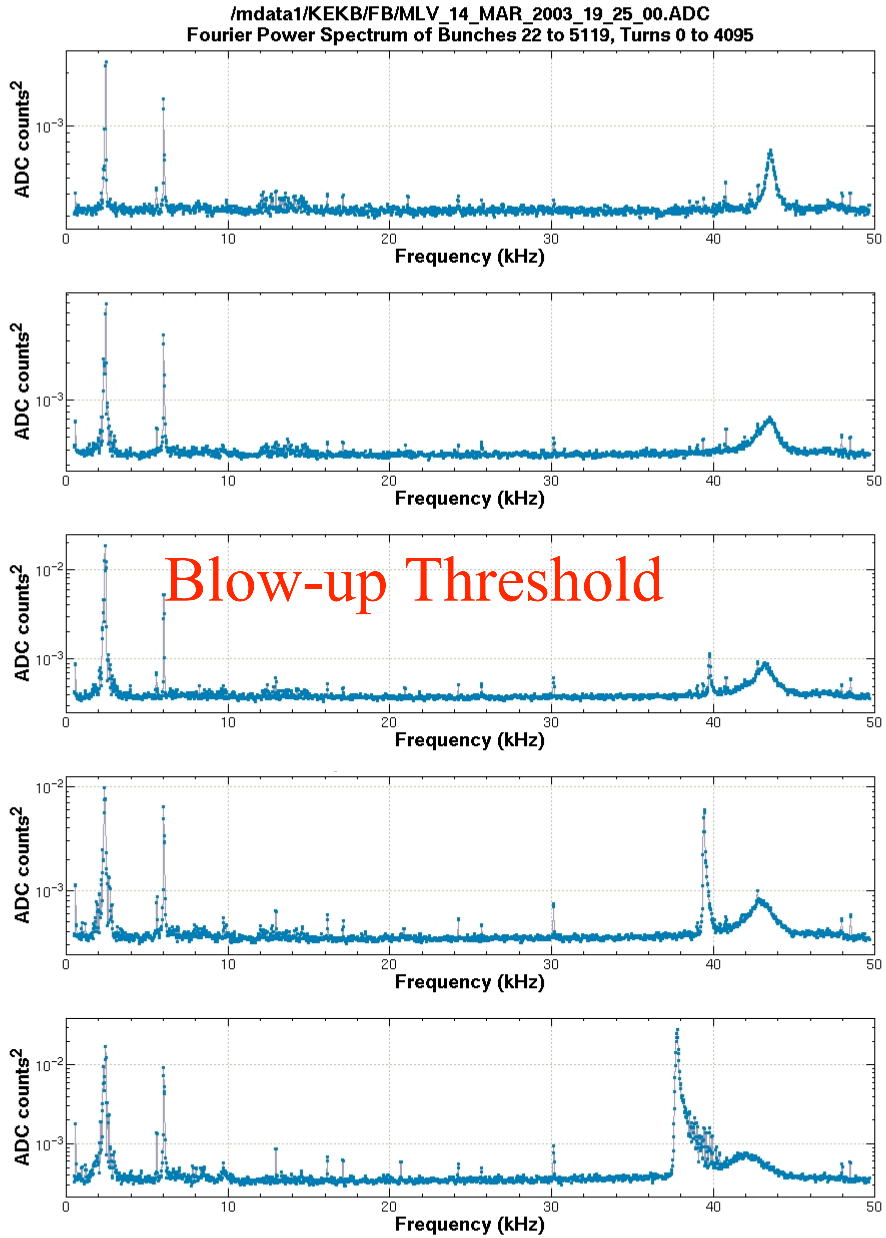


PMT Spectra



1.0 ←Tune 0.5

FB BPM Spectra



1.0 ←Tune 0.5

Summary of BPM + PMT measurements

- Sideband peak appears in both BPM and PMT measurements.
  - Two different types of detector

- Sideband peak appears in both instruments only at and above the beam-size blow-up threshold of beam current
  - Other measurements show that the amplitude of the sideband peak at constant beam current is affected by the strength of the solenoid field. Stronger solenoid field → smaller sideband peak.

Time series data

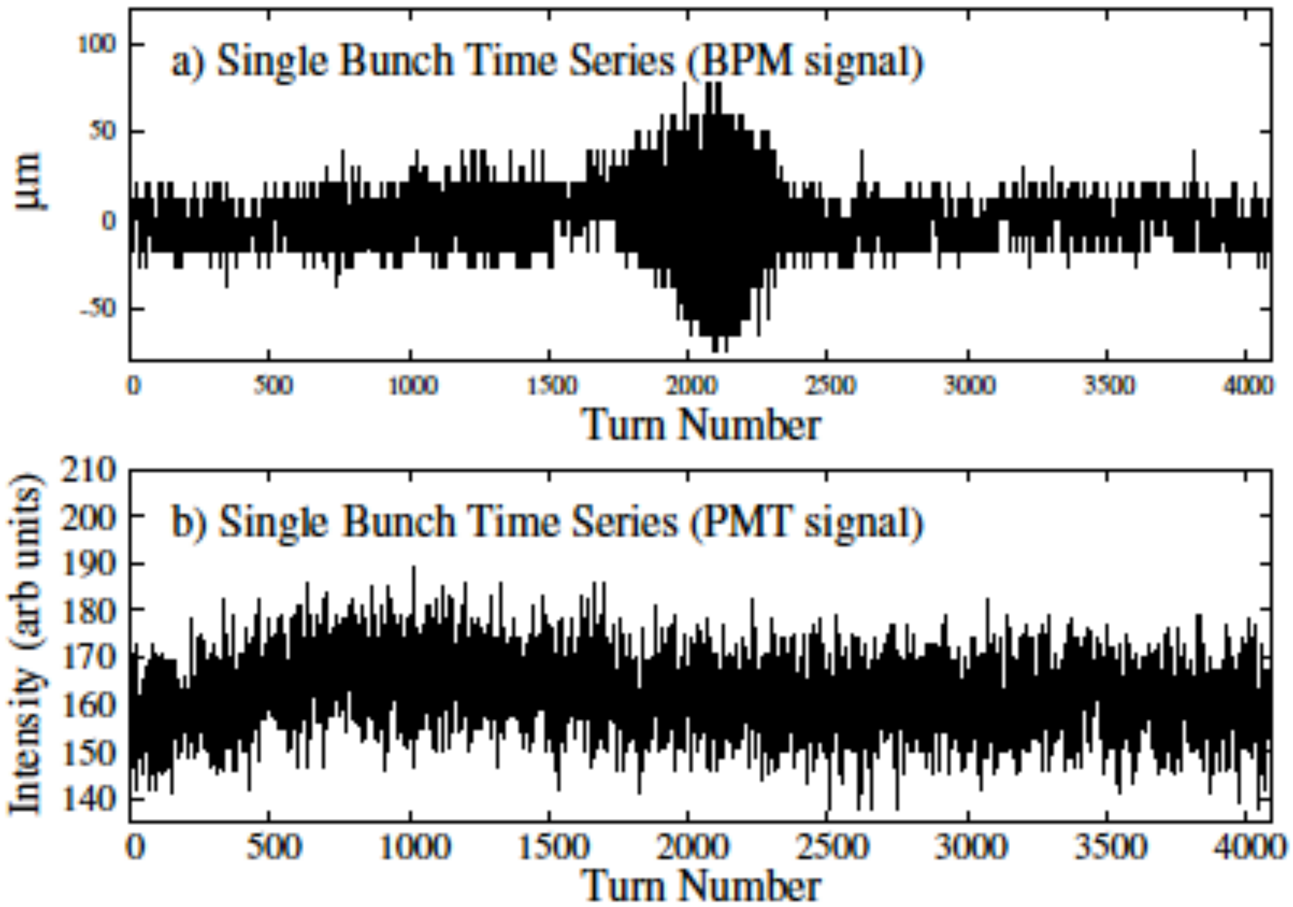


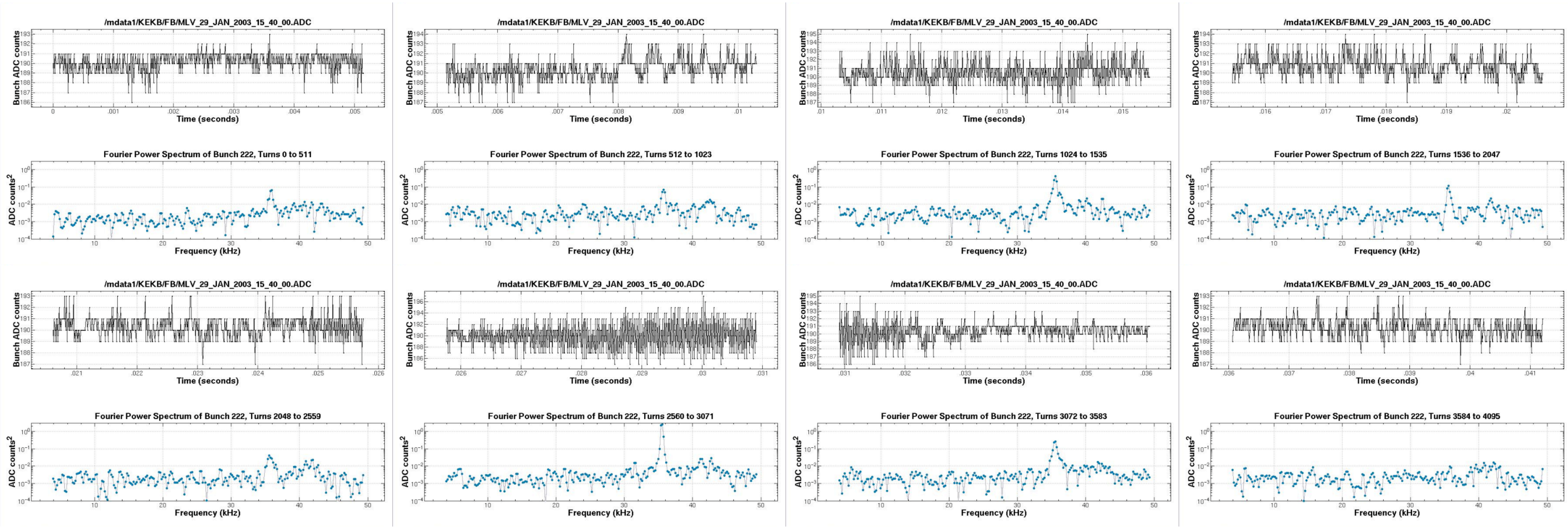
FIG. 4: Example time series of single bunches taken via a) BPM and b) PMT. Different bunches are shown for each detector; the data were taken within one minute of each other. A burst-like behavior is visible in the BPM signal. A fast ramp-up behavior with a similar rise-time as the BPM burst is seen in the PMT signal, followed by a gradual ramp-down.

BPM Data (Position)

PMT Data (Size)

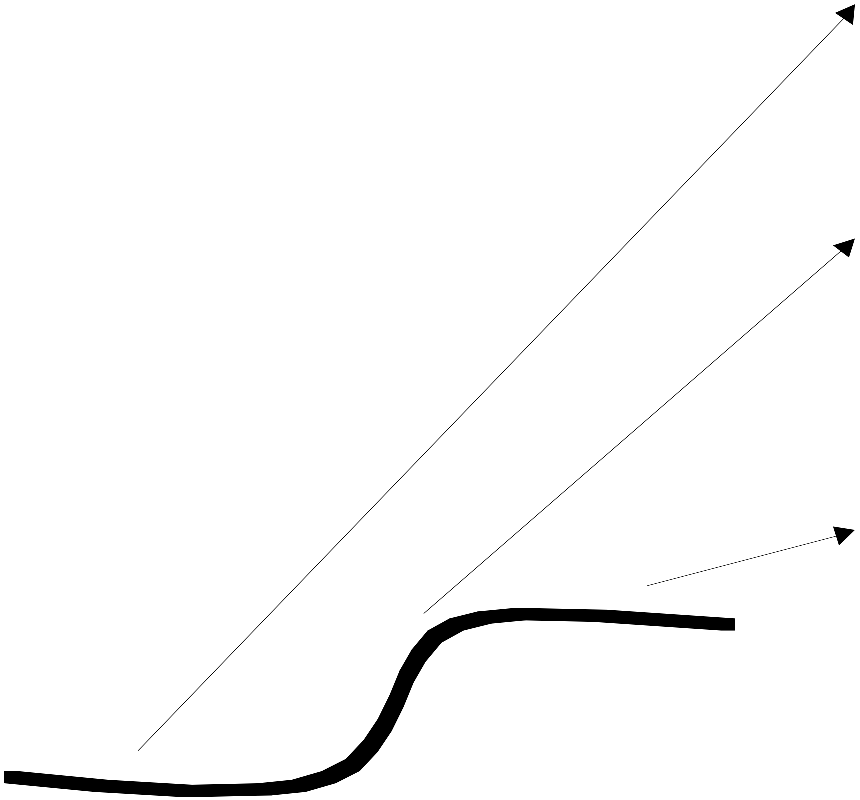
Time Development of Instability: 512-turn slices

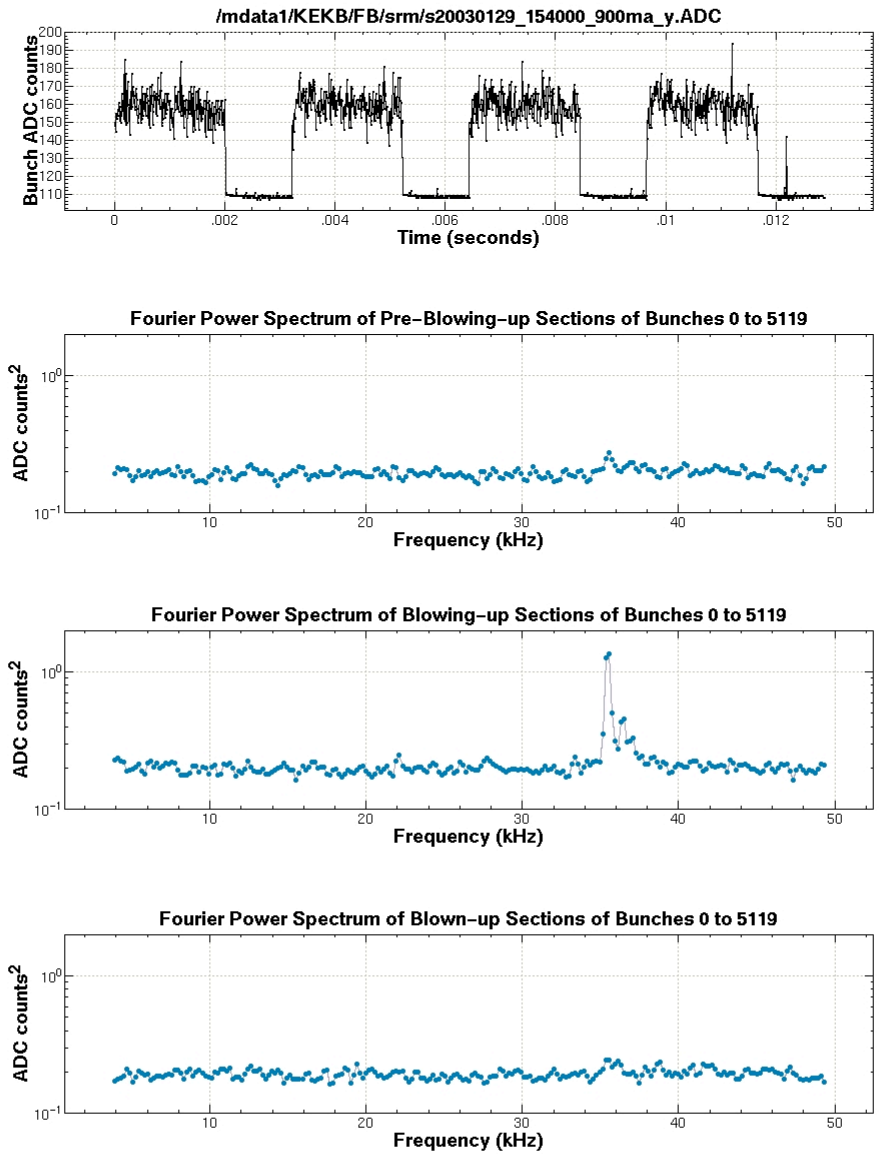
BPM data



Blow-up Pattern Analysis: PMT data

Find a bunch with characteristic blow-up pattern, and take spectra of 3 stages separately. Then average the 3 spectra over all bunches that have this pattern.





Summary of time domain data

- Sideband oscillation has a burst-like structure.
  - Sideband peak is present at a low level, then grows and damps in a burst lasting ~500 turns (5 ms).
  - During this burst, beam size grows ~5% from its already blown-up state
  - Immediately after burst is complete, sideband peak is absent, until beam size damps back down.

Effect of varying vertical feedback gain

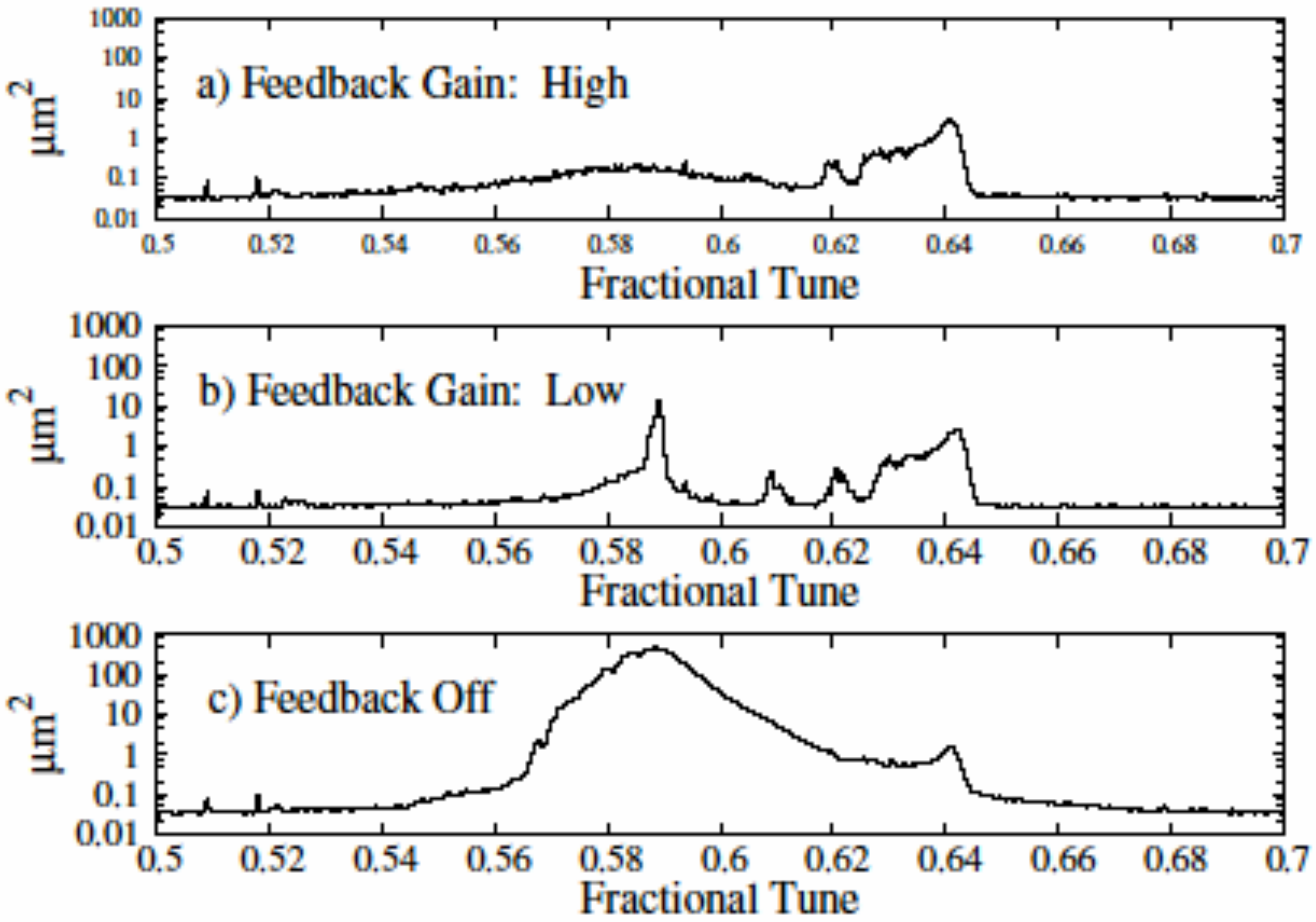


FIG. 2: Averaged spectra of all bunches with the feedback gain a) high, b) low and c) set to zero. The vertical betatron peak is visible at 0.588, and the sideband peak can be seen around 0.64.

→Sideband peak amplitude does not change

Effect of varying synchrotron tune

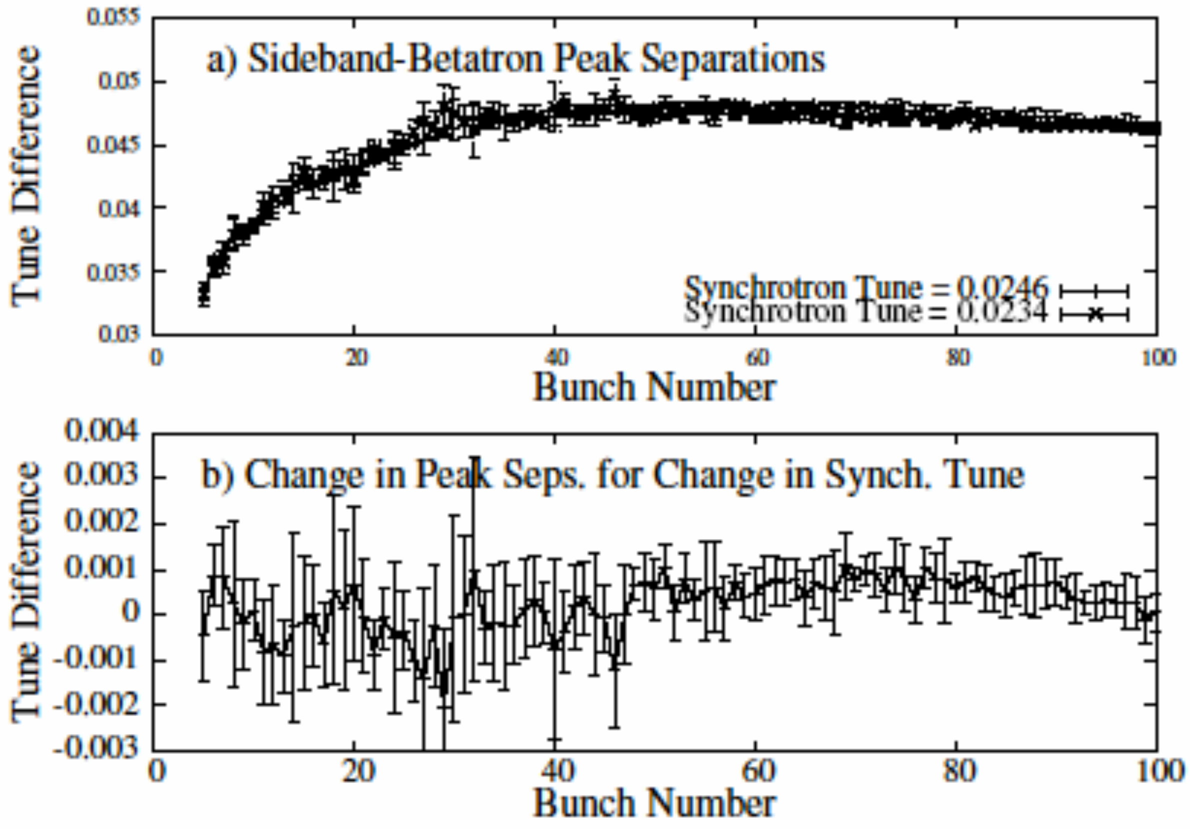


FIG. 3: Effect of changing synchrotron tune on the separation between sideband peak and betatron peak. In a), the sideband-betatron peak separation is plotted along the bunch train for $\nu_s = 0.0246$ (solid lines) and $\nu_s = 0.0234$ (dashed lines). In b), the difference between the two curves is plotted. Statistical 1-sigma error bars are shown.

→Sideband-tune separation does not change

←Model focusing wake

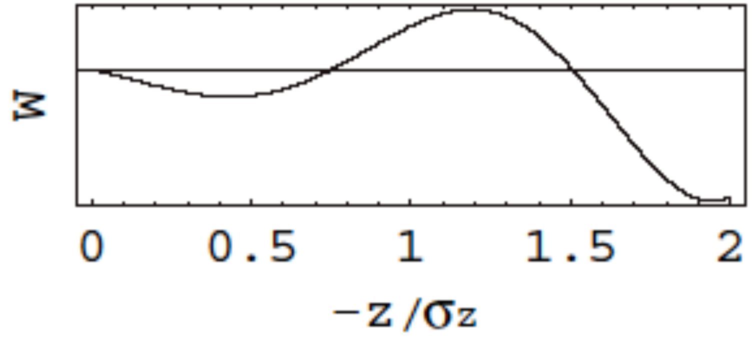


FIG. 5: Model focusing wake. The horizontal axis is longitudinal position normalized to the bunch length.

When the synchrotron tune is changed, the average separation between the sideband peak and the betatron peak does not change significantly. In the case of strong head-tail instability, the coupled mode frequency does not necessarily depend strongly on ν_s. As an illustration, mode spectra were generated using a toy model with an airbag charge distribution and a simple effective wake, shown in Fig. 5, which uses a resonator-like wake W, increasing along $(-z)$ to represent the enhancement of the wake near the tail of the bunch due to pinching of the electron cloud:

$$W(z) = c\frac{R}{Q}e^{-\alpha z/c}\sin\omega_R\frac{z}{c}, \quad (1)$$

where $\alpha = \omega_R/4$, and $\omega_R = 2\pi \times 40$ GHz. (Note: the oscillation frequency of cloud electrons as calculated from the LER beam size and positron charge density is $\sim 2\pi \times 43$ GHz.)

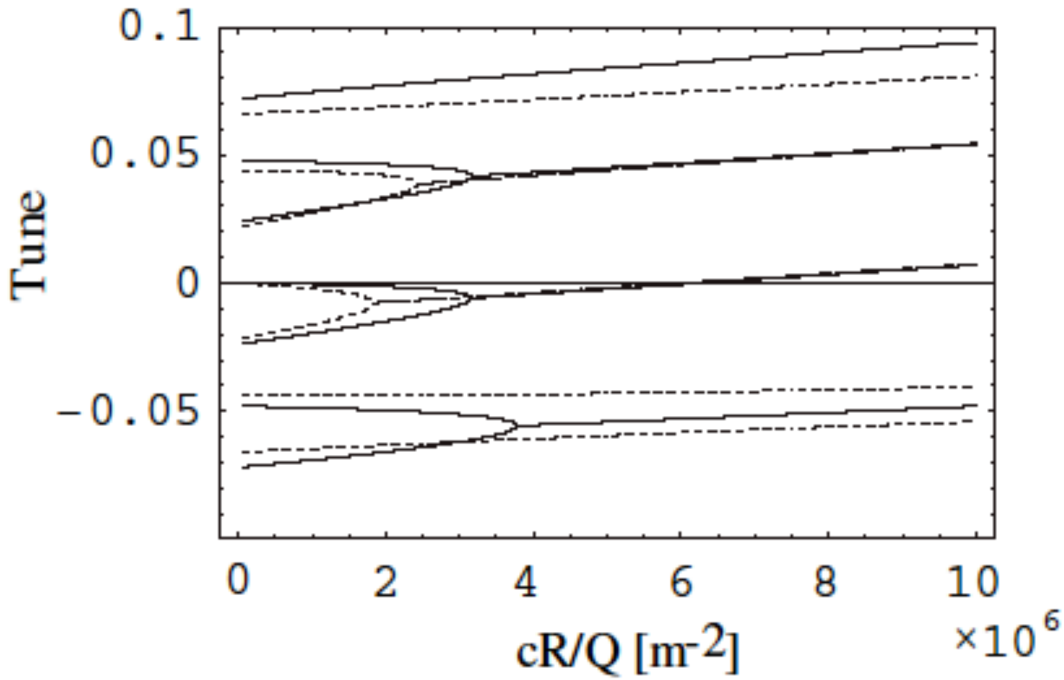
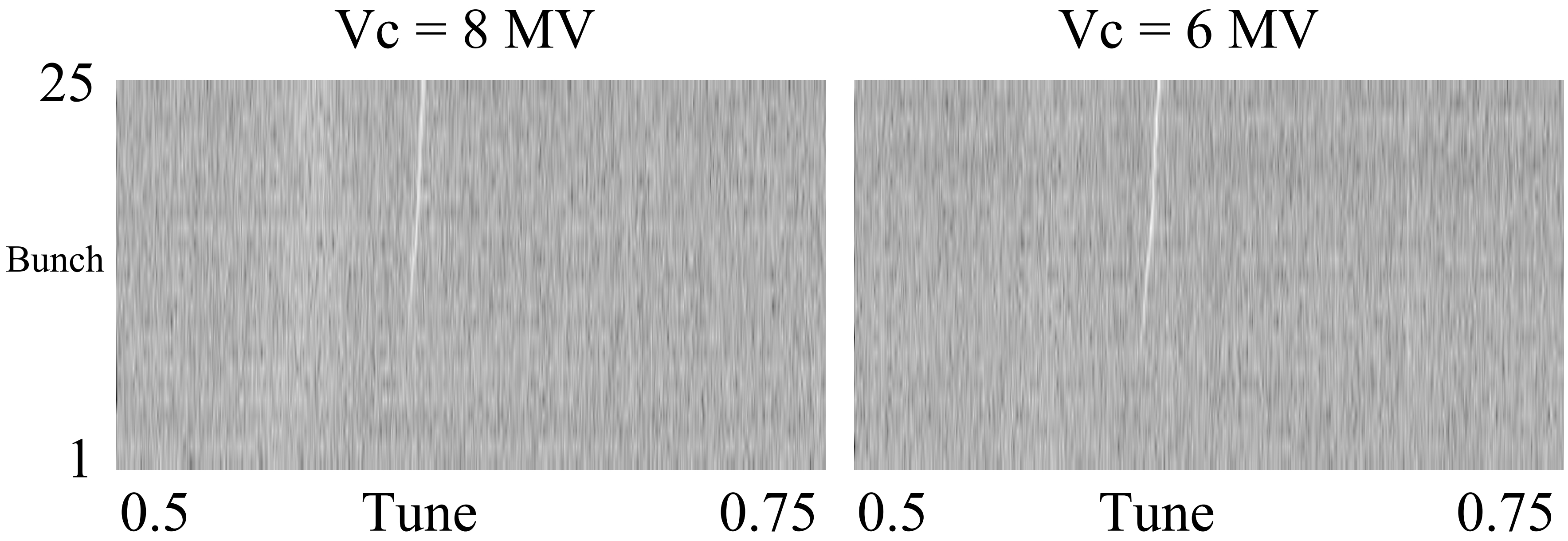


FIG. 6: Example mode spectrum for model focusing wake at $\nu_s = 0.022$ (dashed lines) and $\nu_s = 0.024$ (solid lines).

←Mode spectrum using model wake and airbag charge distribution

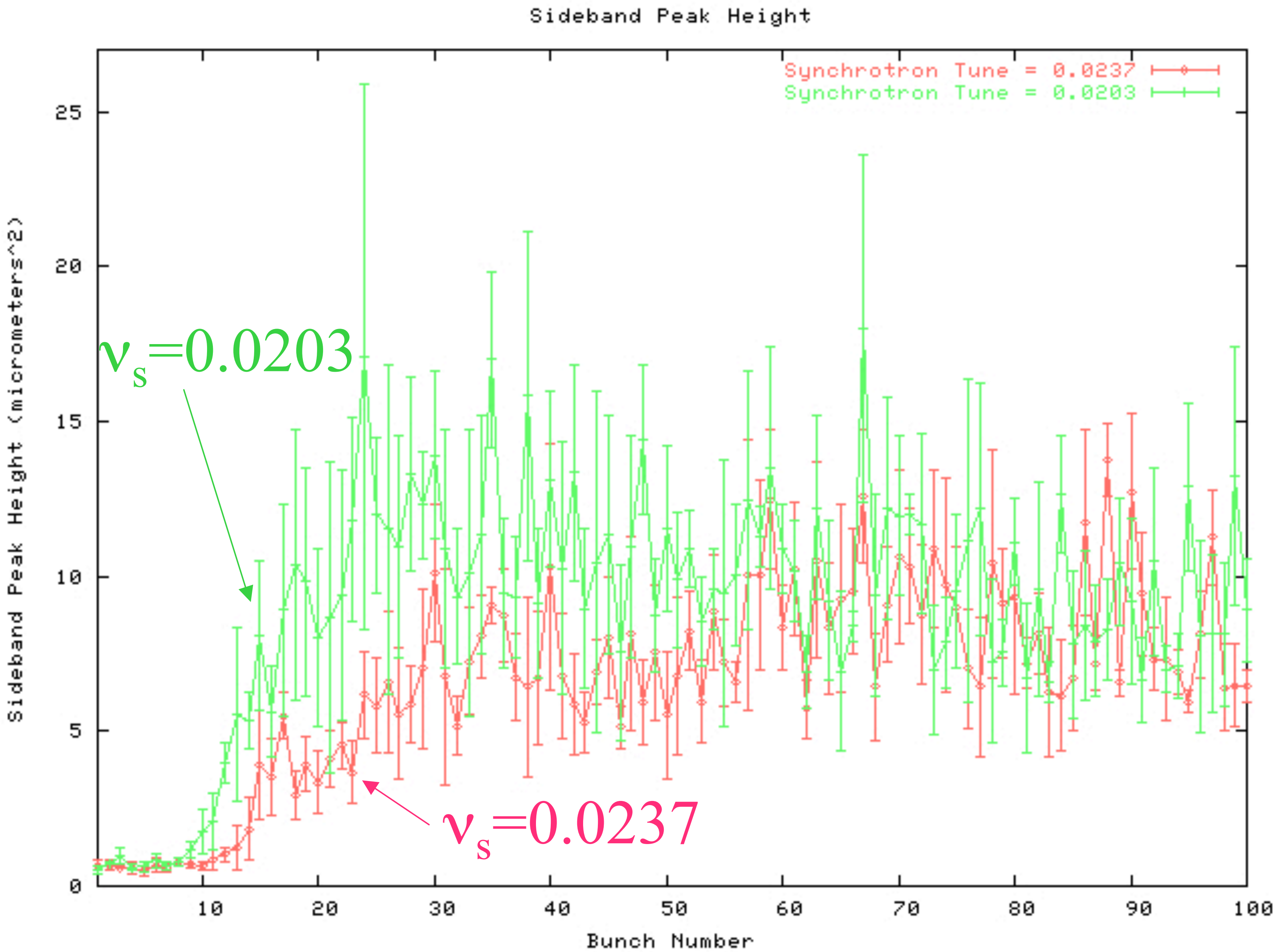
Threshold dependence on synchrotron tune

$\delta\nu_s$ Data: 23 Dec 2003

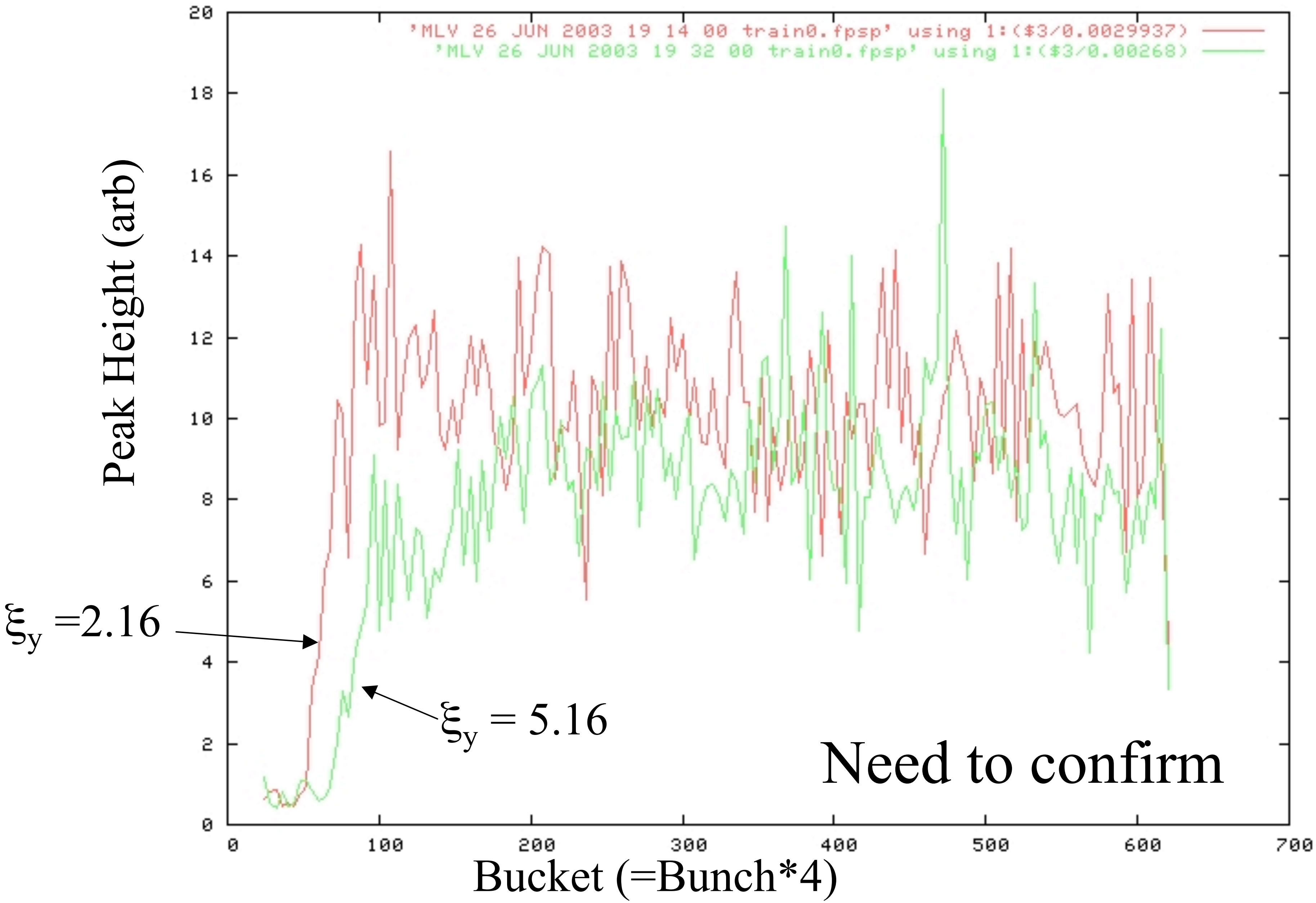


- Data taken at 8 MV and 6 MV.
  - Sequence: 8 MV×2, 6 MV×2, 8 MV×2, 6 MV×1
  - Synch. Tune = 0.0237 @ 8 MeV, 0.0203 @ 6 MeV (measured from spectral peak).
  - Peak frequency bin in sideband region found, peak height averaged for 8 MV and 6 MV subsets separately.

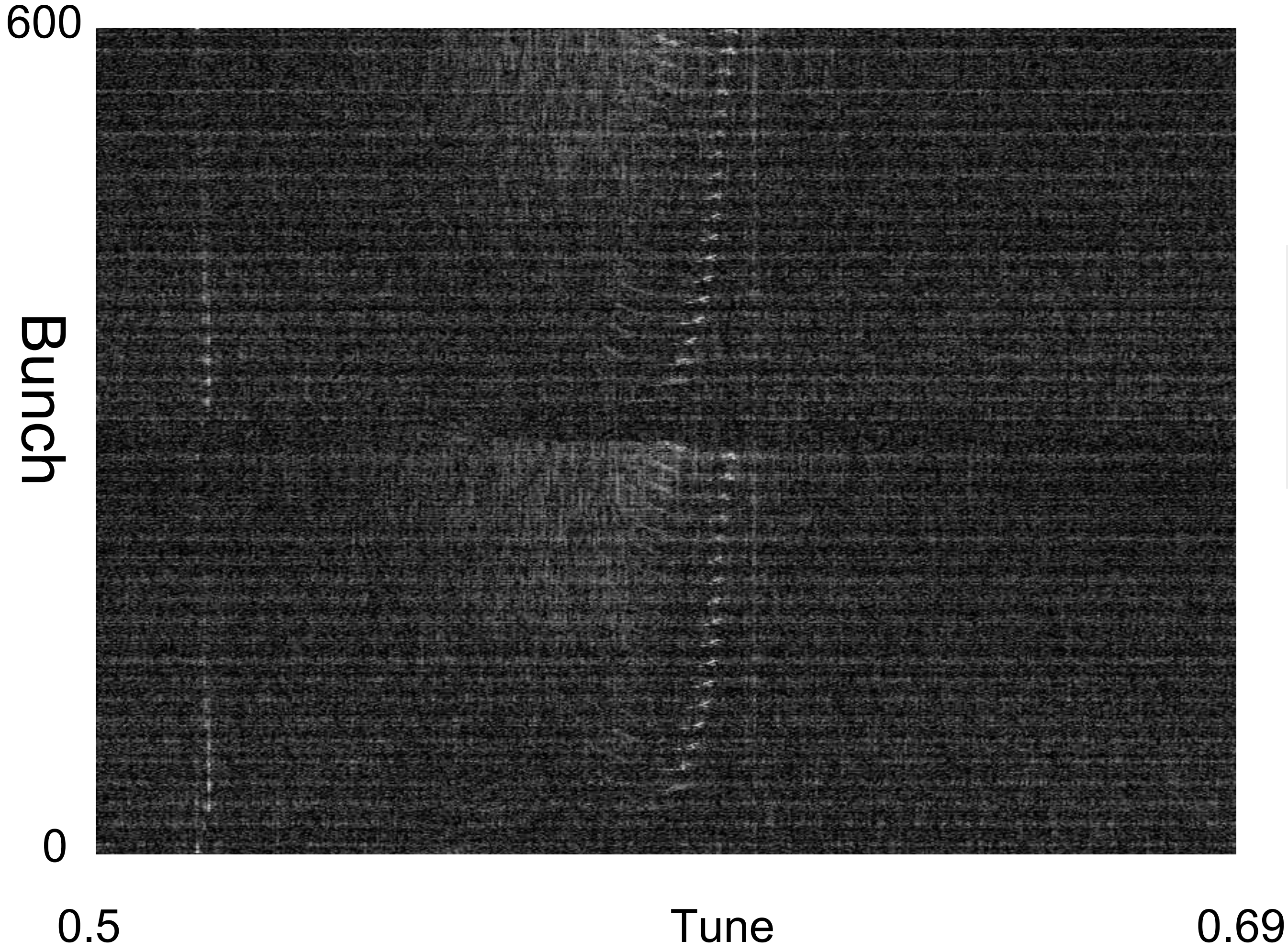
Sideband Peak Height Near Threshold at Different ν_s



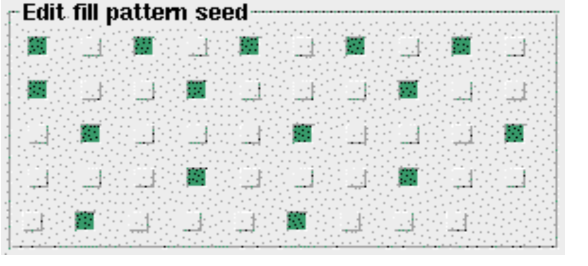
Sideband Peak Height Near Threshold at Different ξ_y



LER Single beam, 650 mA
2004.12.17 Study



Fill Pattern



Summary

- A betatron sideband peak has been found in the vertical tune spectrum of positron bunches in the presence of beam-size blow-up due to electron clouds. The sideband peak is on the upper side of the betatron peak in terms of fractional tune, first appears early in the bunch train, and the separation between this peak and the betatron tune peak increases going along the train, until it saturates at a certain point.
- The best explanation for it is that it is a signature of the head-tail instability hypothesized to explain transverse beam blow-up due to electron clouds.
- The presence of this sideband peak also provides a sensitive diagnostic for the presence of electron clouds.

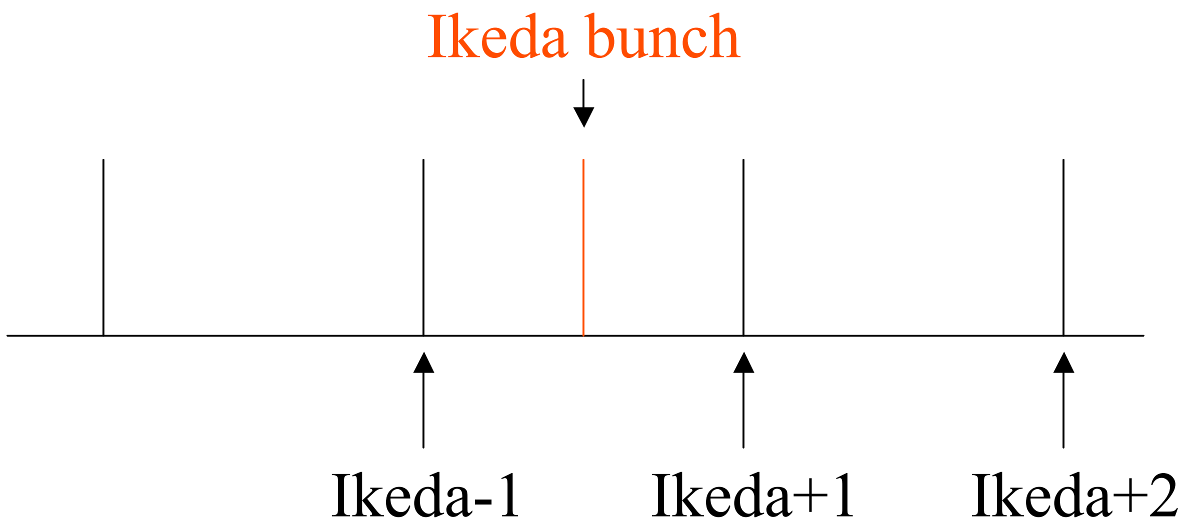
Topics for Further Study

- Better simulation model
- (Re-)Measure change in threshold as function of chromaticity
- More sensitive measurement near the threshold conditions
- Measure at other machines
  - PEP-II
  - DAΦNE?
  - …?

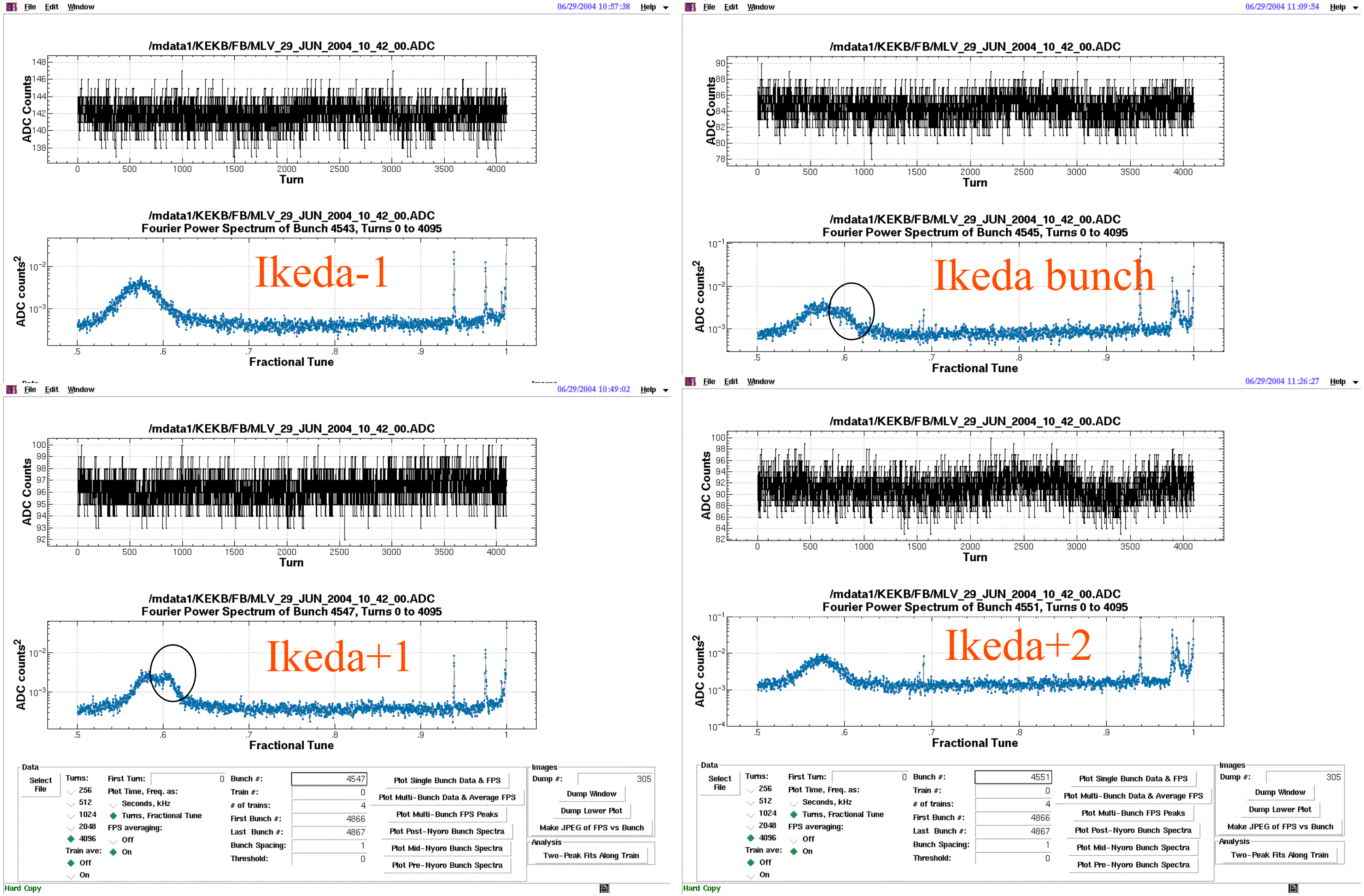
SPARES

Extra: Sidebands in collision

Fill Pattern:

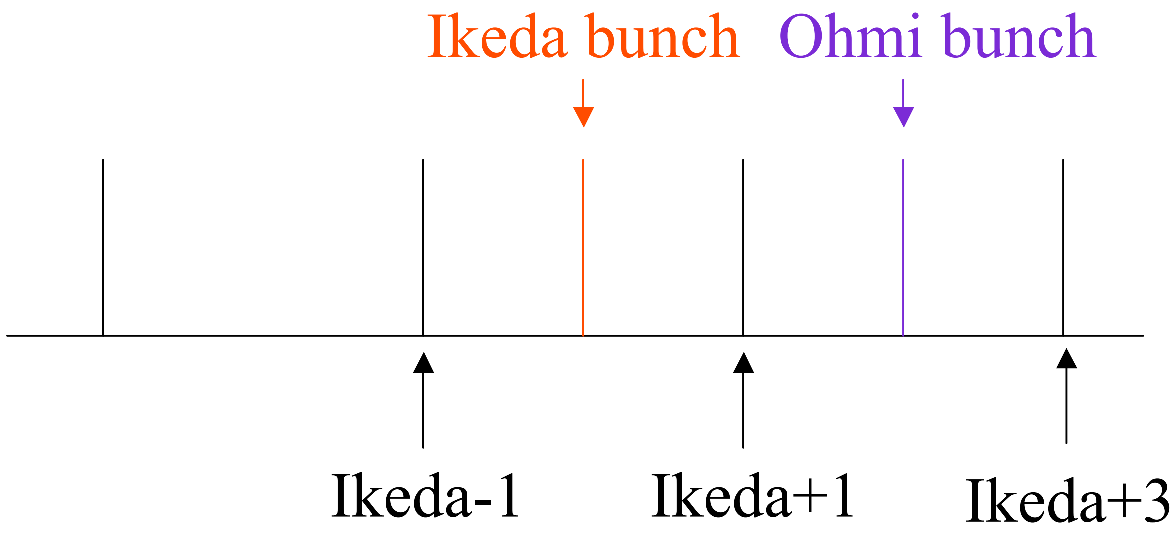


Sidebands in collision (6.29)



Sidebands in collision

Fill Pattern:

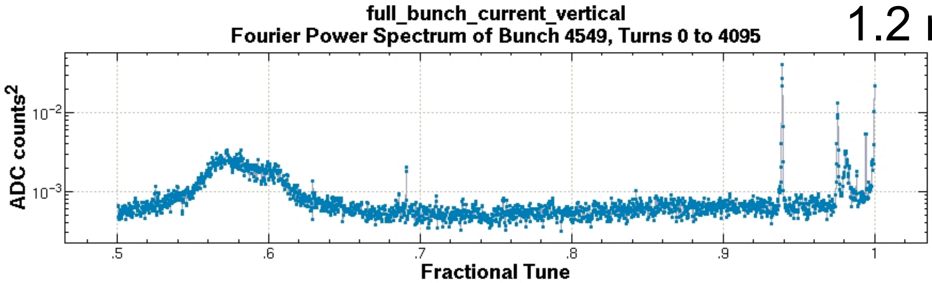


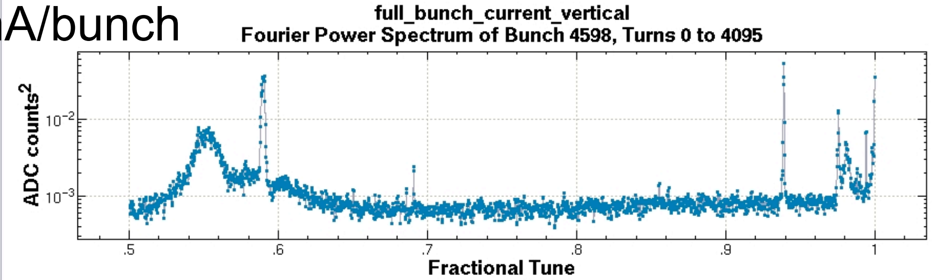
Observation during physics run (6.30)

Ohmi bunch (colliding bunch)

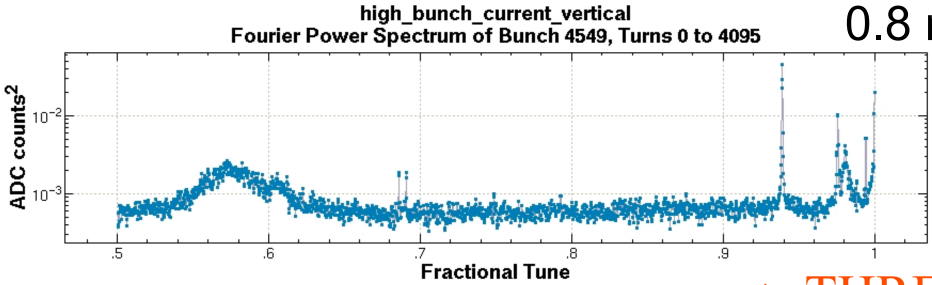
Ohmi+49 bunch（non-colliding）

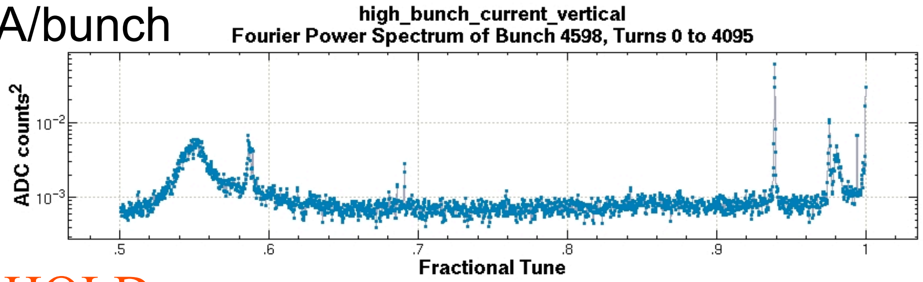
1.2 mA/bunch





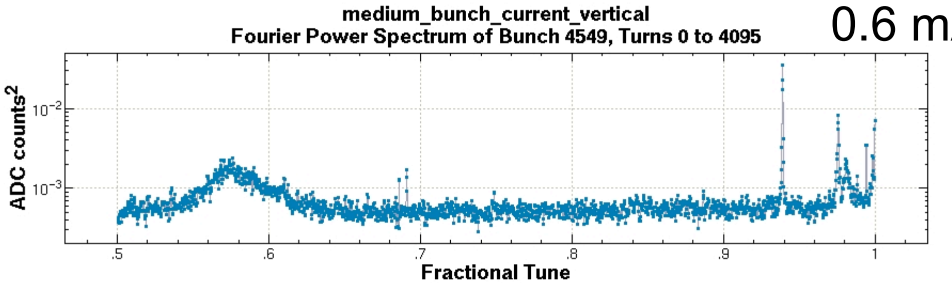
0.8 mA/bunch

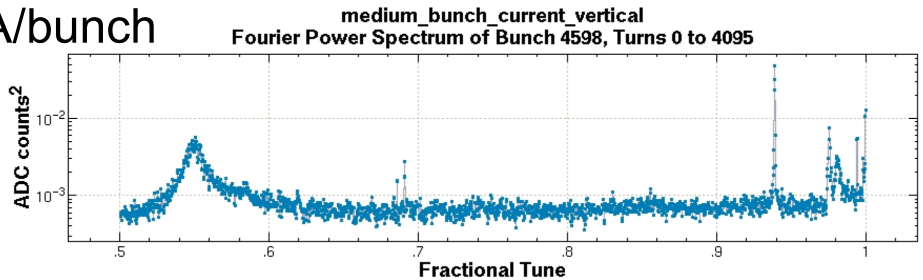




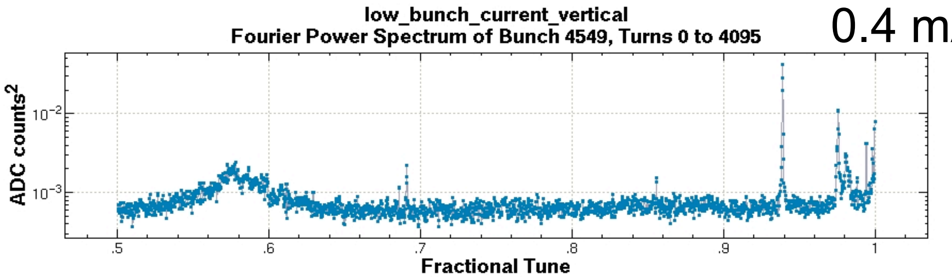
←THRESHOLD→

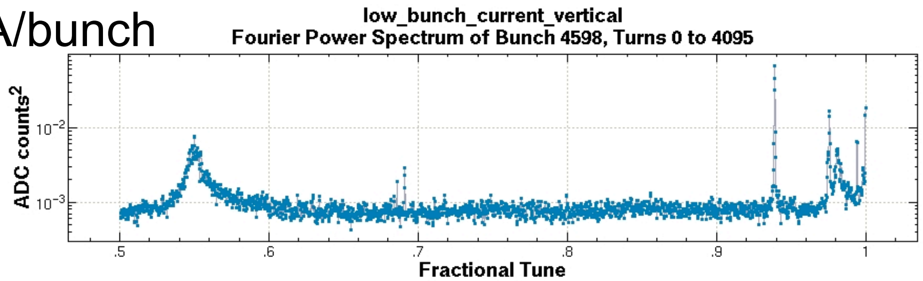
0.6 mA/bunch



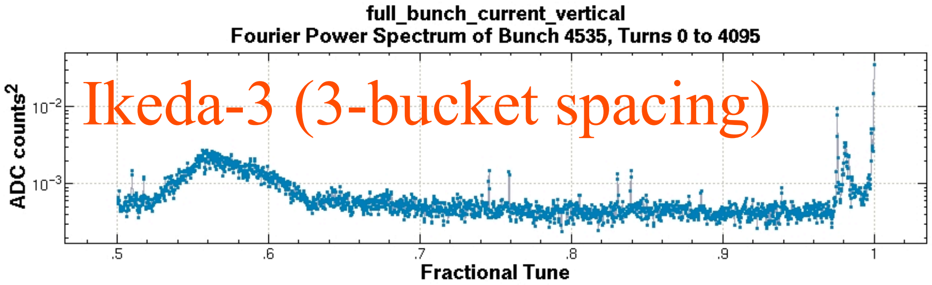


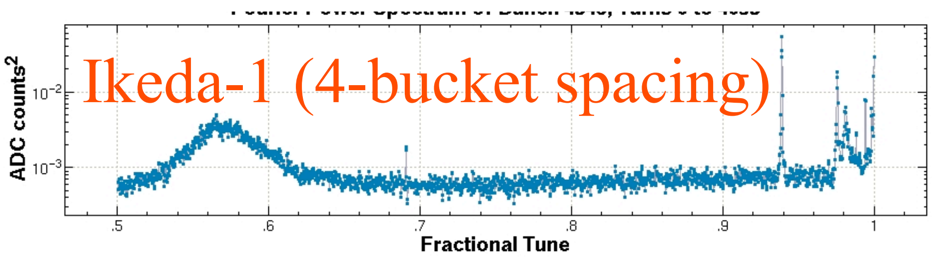
0.4 mA/bunch

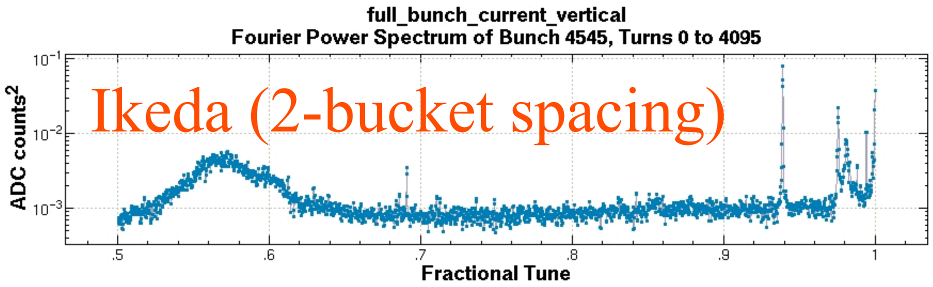


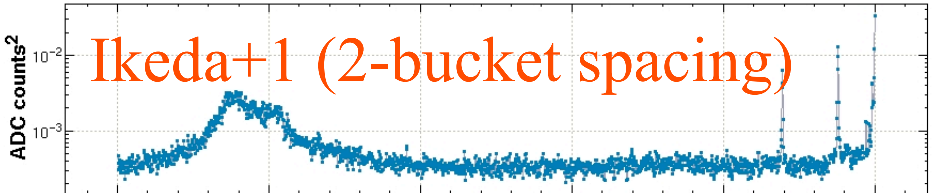


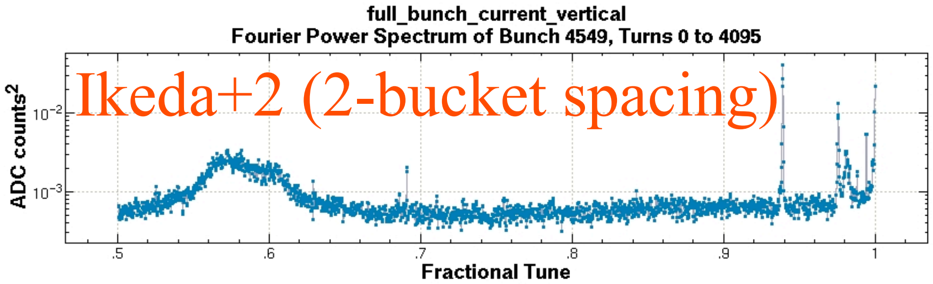
Colliding Bunch Spectra

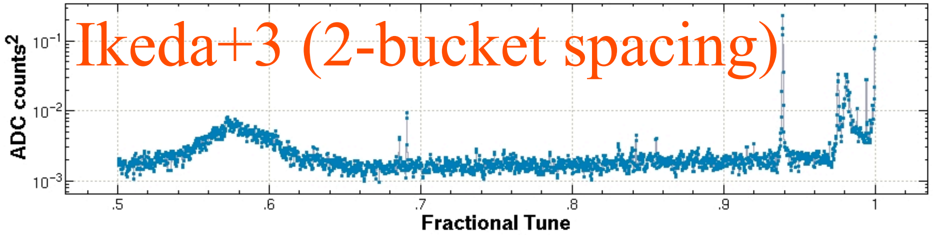


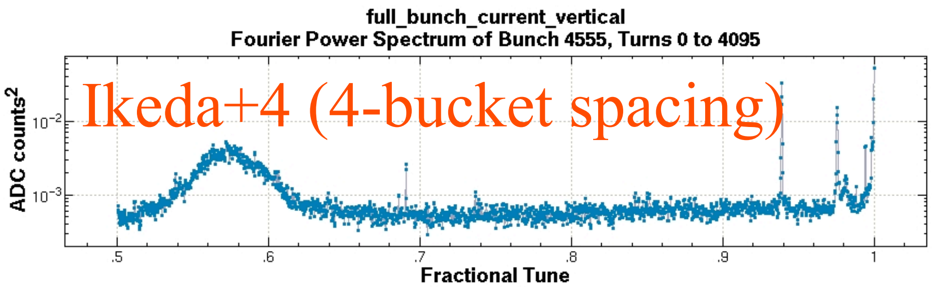




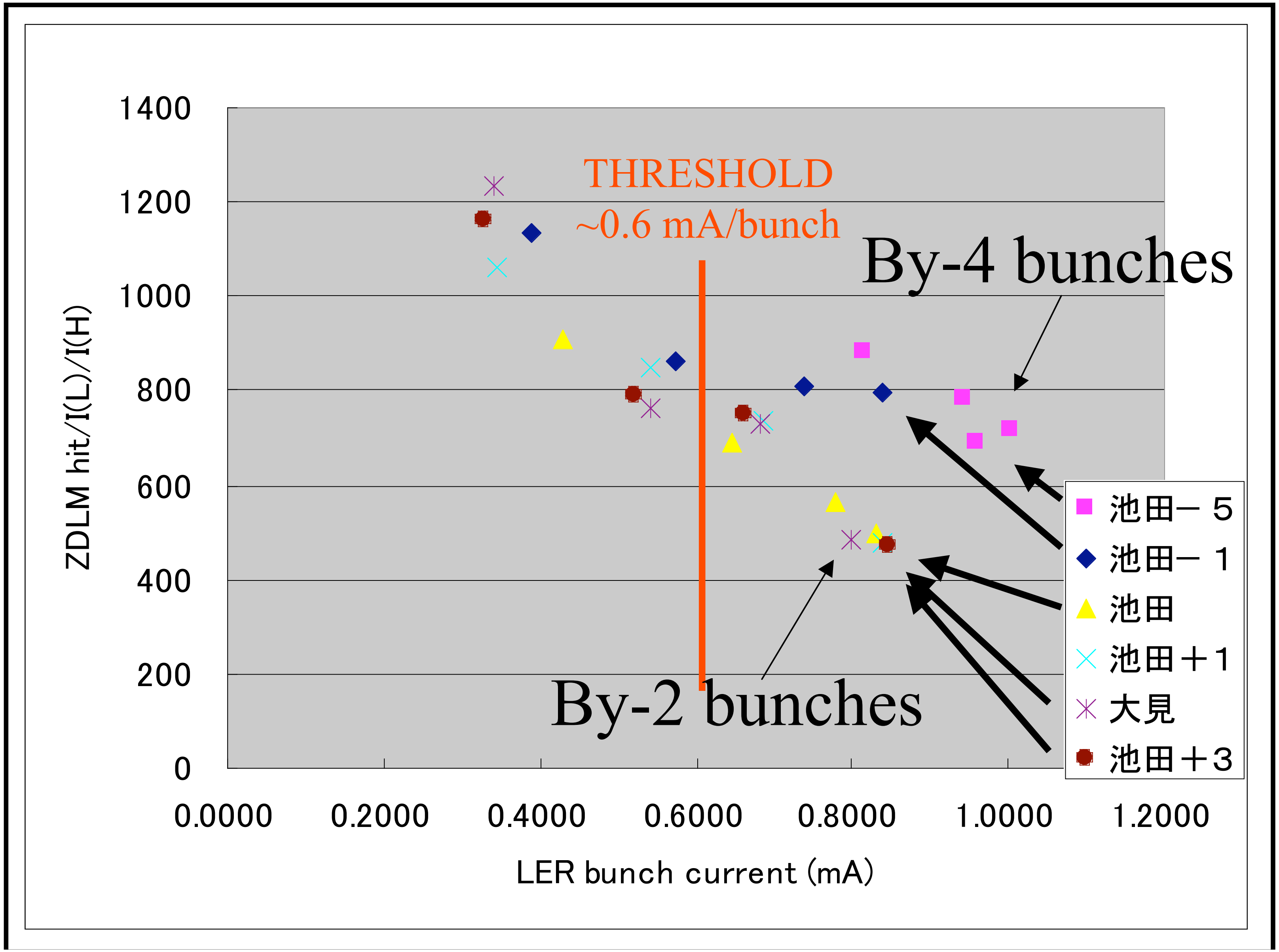








Specific Luminosity by Bunch



Summary 2

- In collision, peak shows up at bunch-spacing of 2 buckets, over a threshold of ~0.6 mA/bunch.
  - This is accompanied by lower specific luminosity.
  - 3-bucket spacing shows a small peak, too.
- This peak is smeared out during collision.
- Could this be limiting our luminosity after all?

PMT

- フィルパッタン： 4/150/4（計600ﾊﾞﾝﾁ）
- ソレノイド完全にOff
- νy=0.569, νx=0.5178, νs=0.0249 (2.47 kHz)
- ξy=0.7, ξx=1.1
- BOR データ:
  - PMT - V
  - FB BPM - V
  - FB BPM - H
- Blowup Threshold: 250 mA (0.42 mA/bunch)

LER Electron-cloud suppression solenoids

Figure 1: Solenoids in the LER tunnel. The three solenoids on the right side are those installed in bellows-NEG pump sections. The long solenoid on the left side was installed in the first installation.

Fukuma et al., "Study of Vertical Beam Blow-up in KEKB LER," HEAC01 proceedings

Detection of photoelectrons at wall

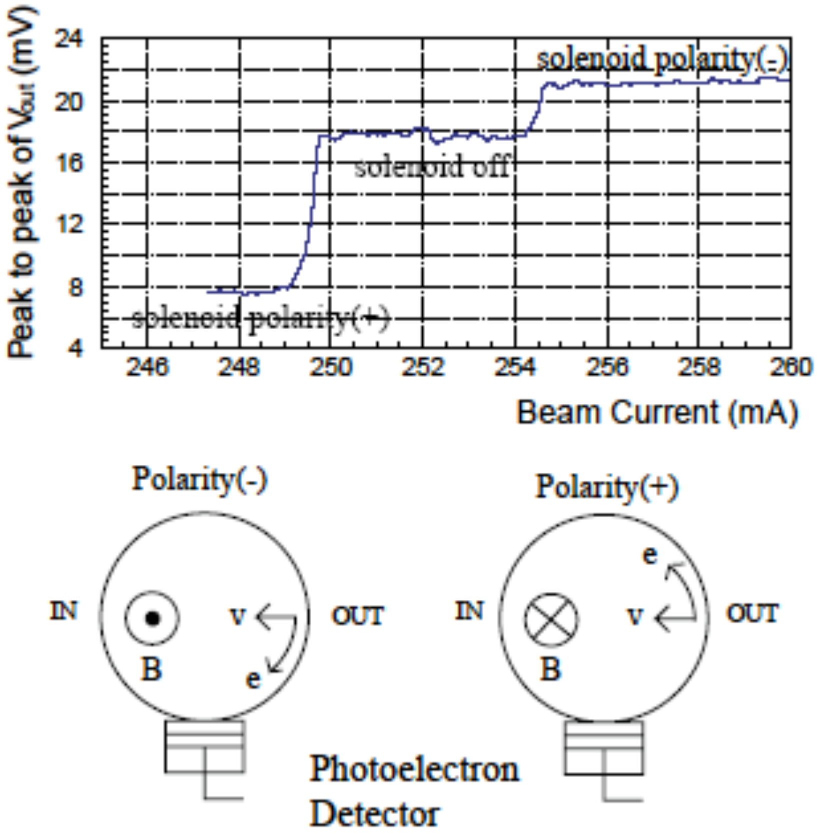
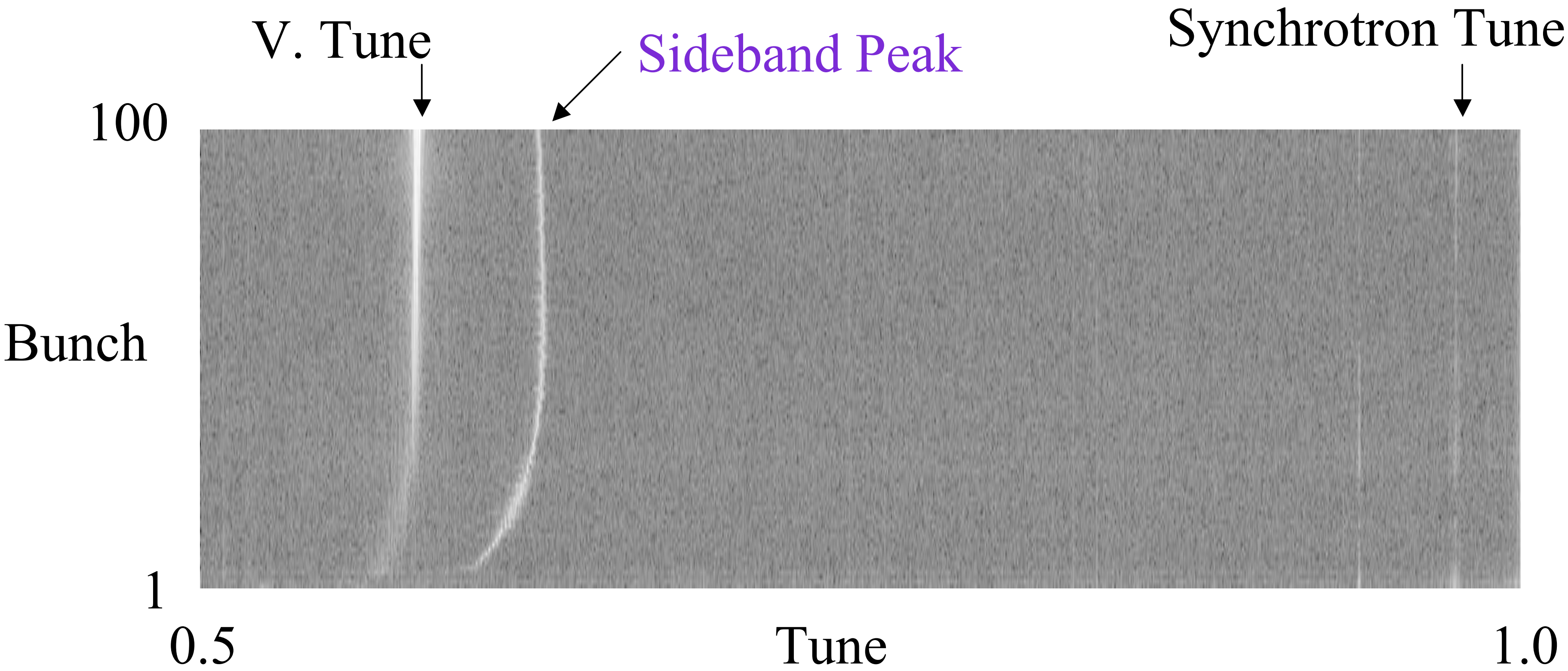


Figure 5: Effects of solenoid field in the vacuum chamber. Synchrotron light emitted from beam through the bending magnet hits the outer wall of vacuum chamber. Peak-to-peak output voltages of negative and positive polarities of solenoid filed, and no solenoid filed are shown.

Ohnishi et al., "DETECTION OF PHOTOELECTRON CLOUD IN POSITRON RING AT KEKB," HEAC01

Fourier power spectrum of BPM data



- LER single beam, 4 trains, 100 bunches per train, 4 rf bucket spacing
- Solenoids off: beam size increased from 60 μm ->283 μm at 400 mA
- Vertical feedback gain lowered
  – This brings out the vertical tune without external excitation