Recent electron cloud studies at KEKB

J.W. Flanagan, K. Ohmi, H. Fukuma, S. Hiramatsu, M. Tobiyama, H. Ikeda, T. Ieiri, K. Oide, Y. Funakoshi, E. Perevedentsev, S. Uehara, S. Uno

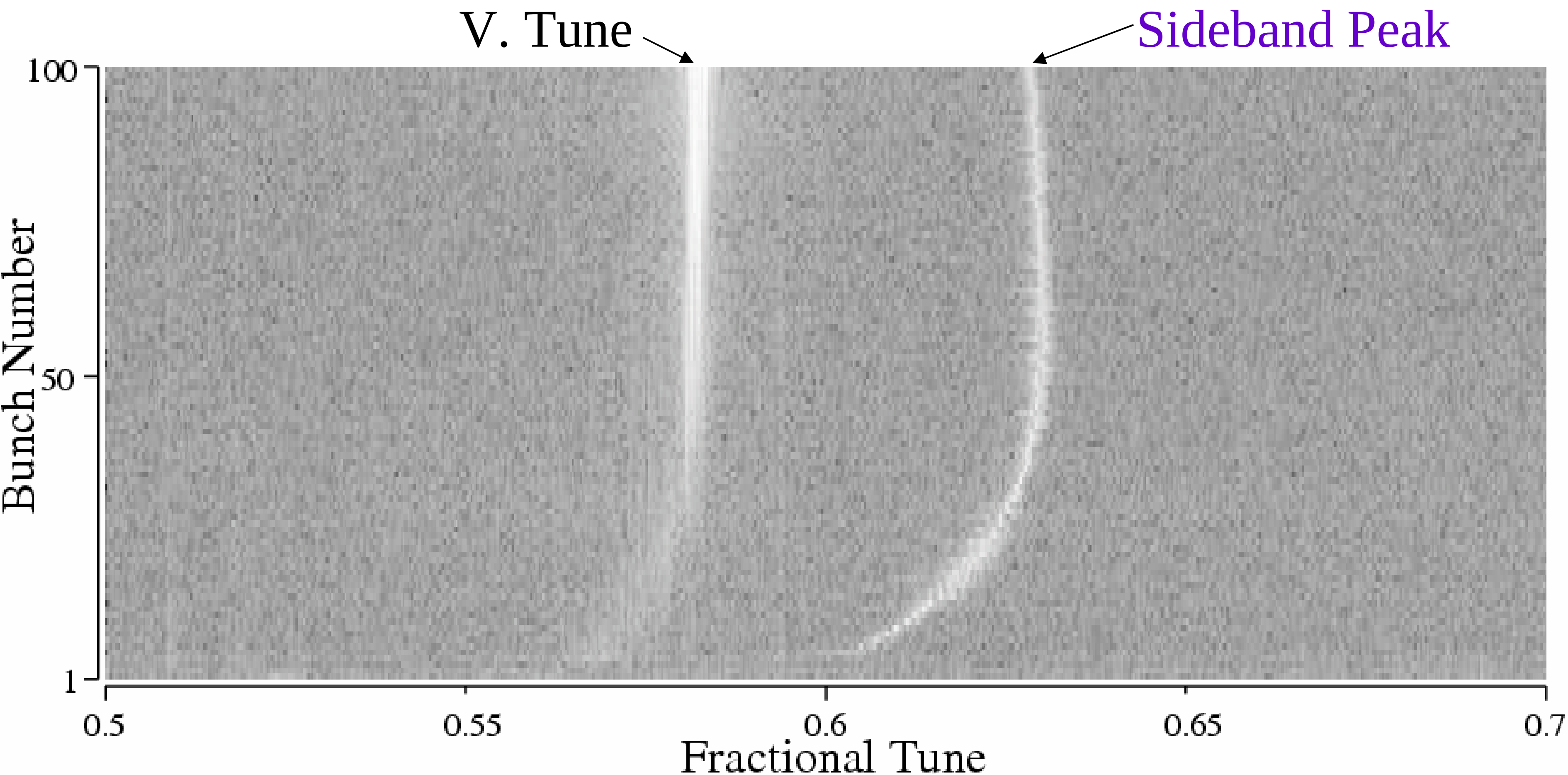
Introduction

- Vertical betatron sidebands found at KEKB which appear to be signatures of fast head-tail instability due to electron clouds.
  - J.W. Flanagan, K. Ohmi, H. Fukuma, S. Hiramatsu, M. Tobiyama and E. Perevedentsev, PRL 94, 054801 (2005)
- Presence of sidebands also associated with loss of luminosity during collision.
  - J.W. Flanagan, K. Ohmi, H. Fukuma, S. Hiramatsu, H. Ikeda, M. Tobiyama, S. Uehara, S. Uno, and E. Perevedentsev, Proc. PAC05, p. 680 (2005)
- Further studies have been performed:
  - Single beam studies:
    - Varying RF voltage
    - Varying chromaticity
    - Varying initial beam size below blow-up threshold (emittance)
  - In-collision studies:
    - Looking at specific luminosity below sideband appearance threshold
    - Looking at specific luminosity closer to head and tail of LER bunch

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 ($4 \times f_{rf}$) detection frequency, 750 MHz bandpass
  - Fast PMT
    - Used in initial studies, agreed with BPM data

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

Effect of varying synchrotron tune (RF voltage)

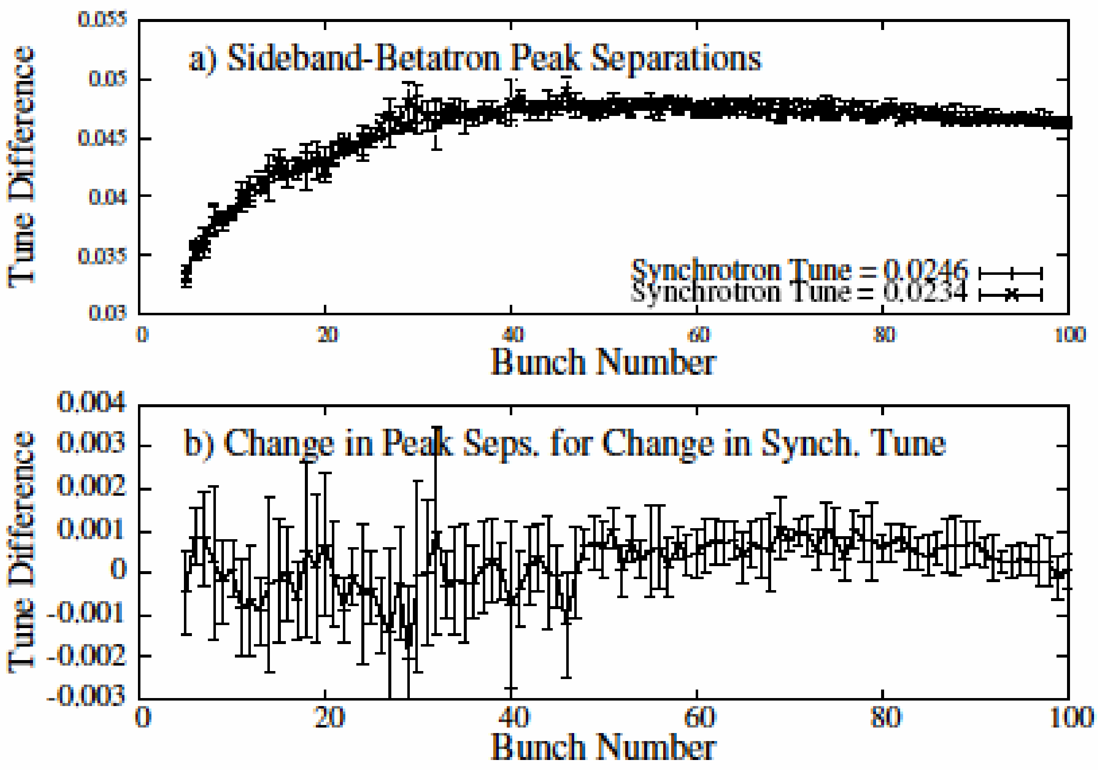


FIG. 3: Effect of changing synchrotron tune on the separation between sideband peak and betatron peak. In a), the sideband-betatron peak separation is plotted along the bunch train for $\nu_s = 0.0246$ (solid lines) and $\nu_s = 0.0234$ (dashed lines). In b), the difference between the two curves is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

→Sideband-tune separation does not change

Or does it? Hard to tell.

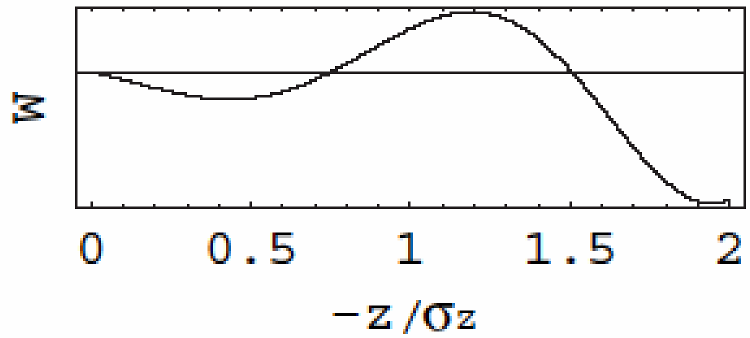


FIG. 5: Model focusing wake. The horizontal axis is longitudinal position normalized to the bunch length.

←Model focusing wake

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:

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

where $\alpha = w_R/2Q$ 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.)

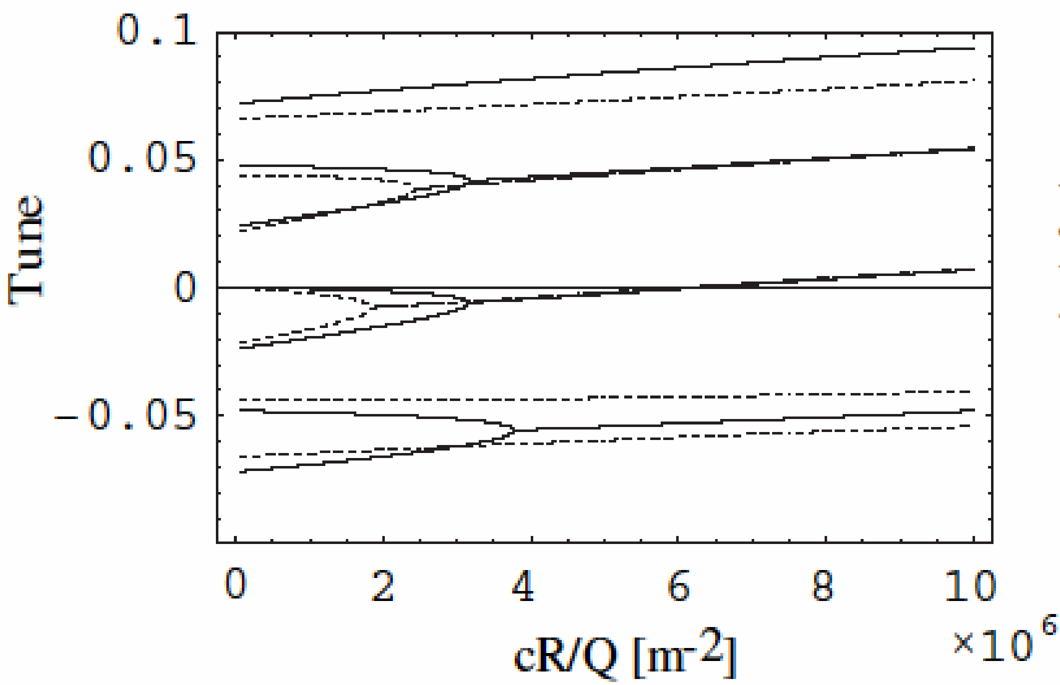


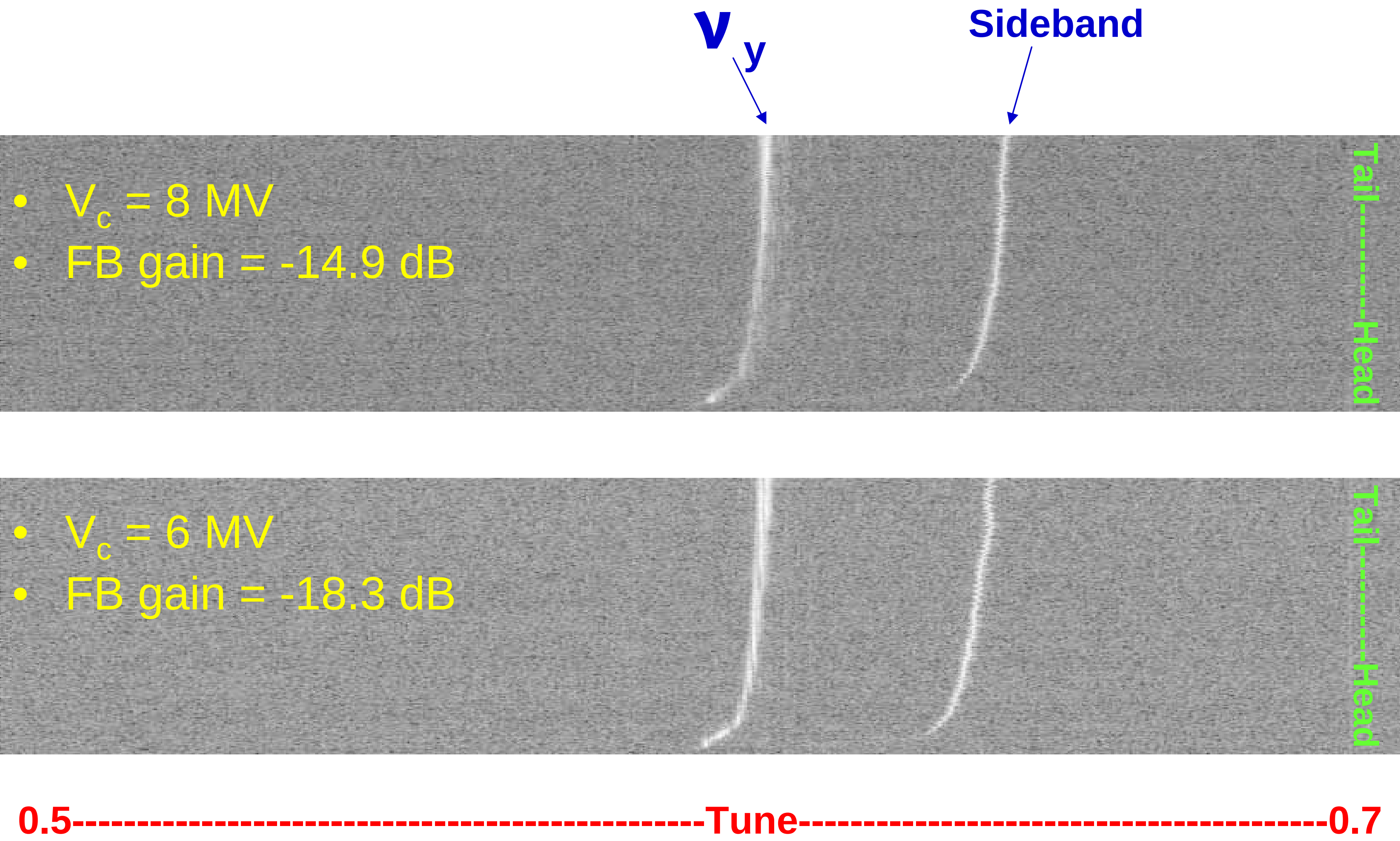
FIG. 6: Example mode spectrum for model focusing wake at $\nu_s = 0.022$ (dashed lines) and $\nu_s = 0.024$ (solid lines).

←Mode spectrum using model wake and airbag charge distribution.

Value of Q chosen to give small ν_s dependence on mode separation, but other solutions possible (in fact more common).

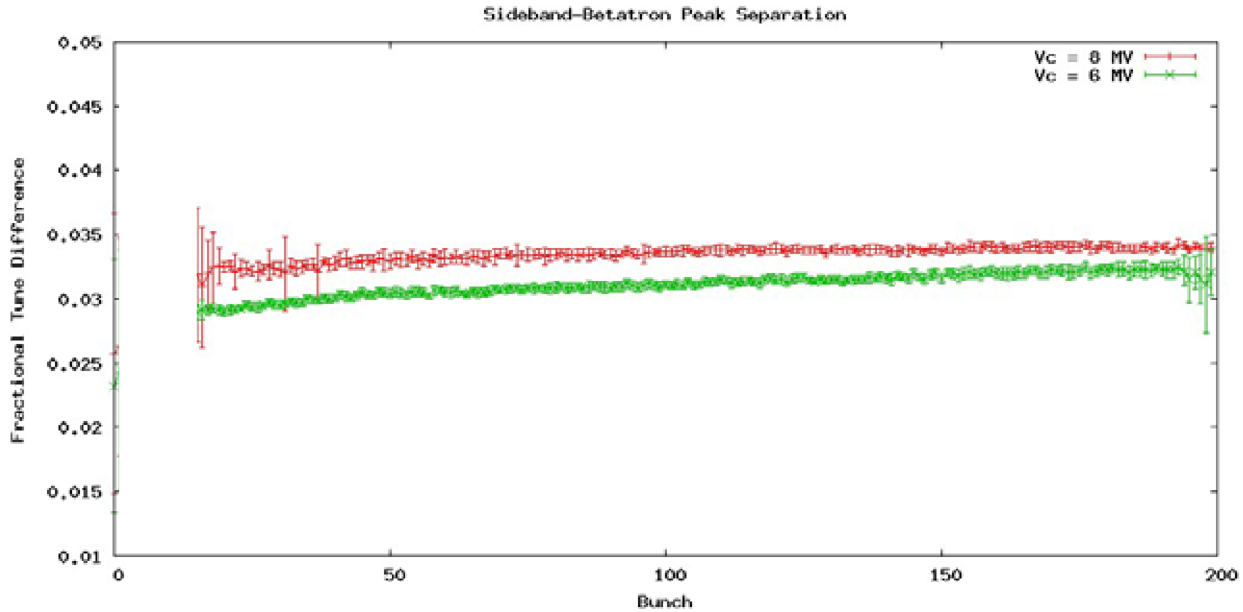
Effect of changing RF voltage

200 bunches/train, 4-bucket spacing, 0.6 mA/bunch, ξy = 4.27

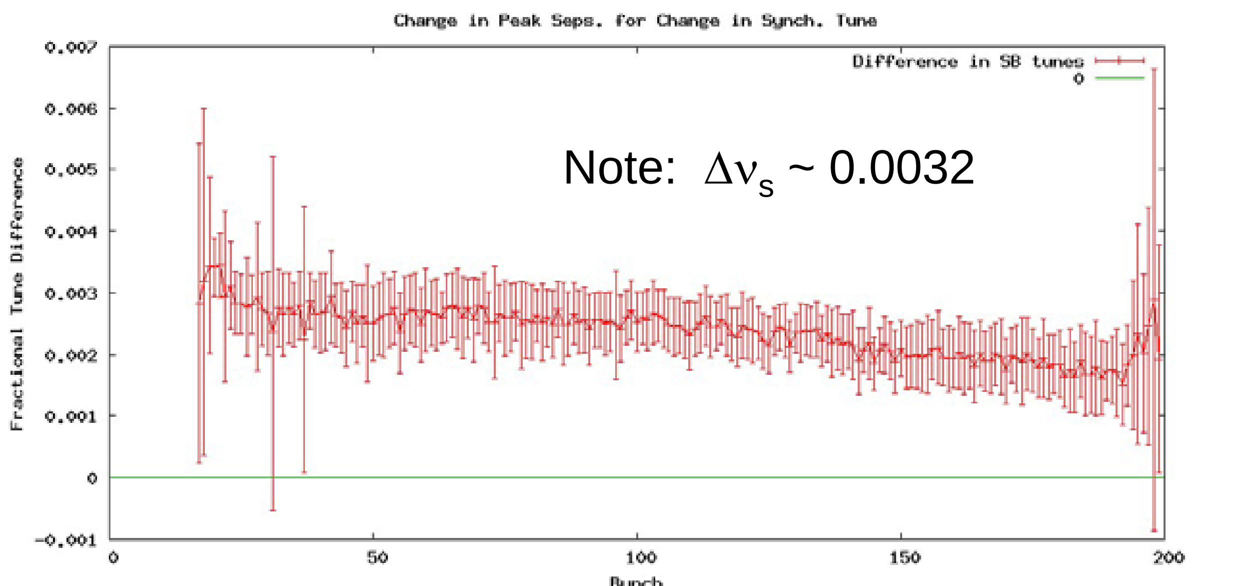


Effect of changing RF voltage

- Distance between sideband peak and betatron peak decreases at lower Vc.

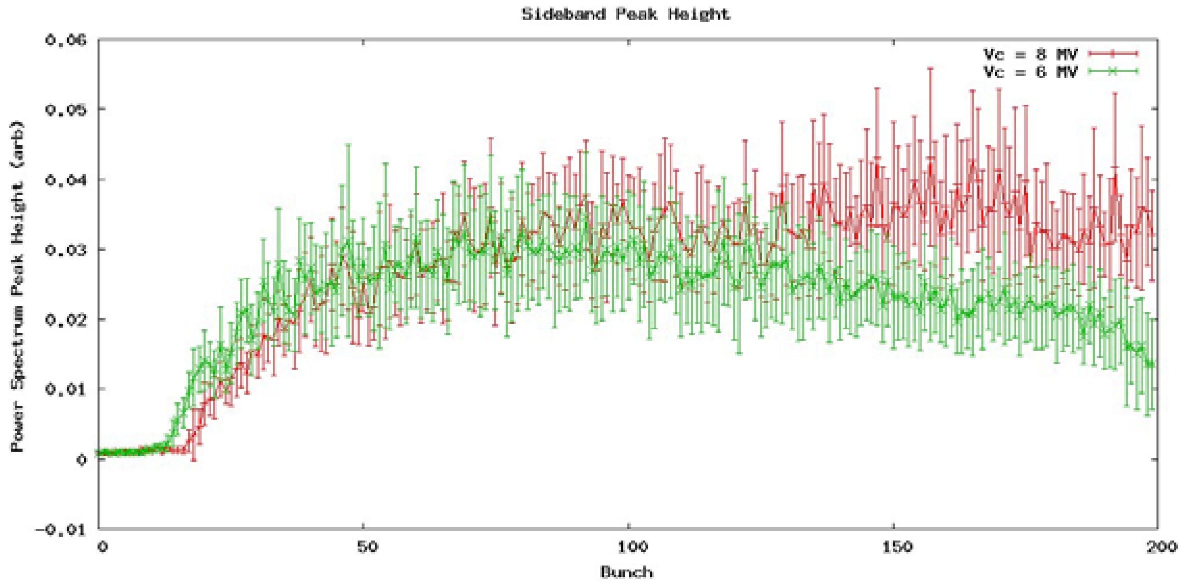


- The difference in peak separations between 8 MV and 6 MV is ~$\Delta\nu_s$ at maximum (towards head of train), decreasing to ~2/3 $\Delta\nu_s$ towards back of train.

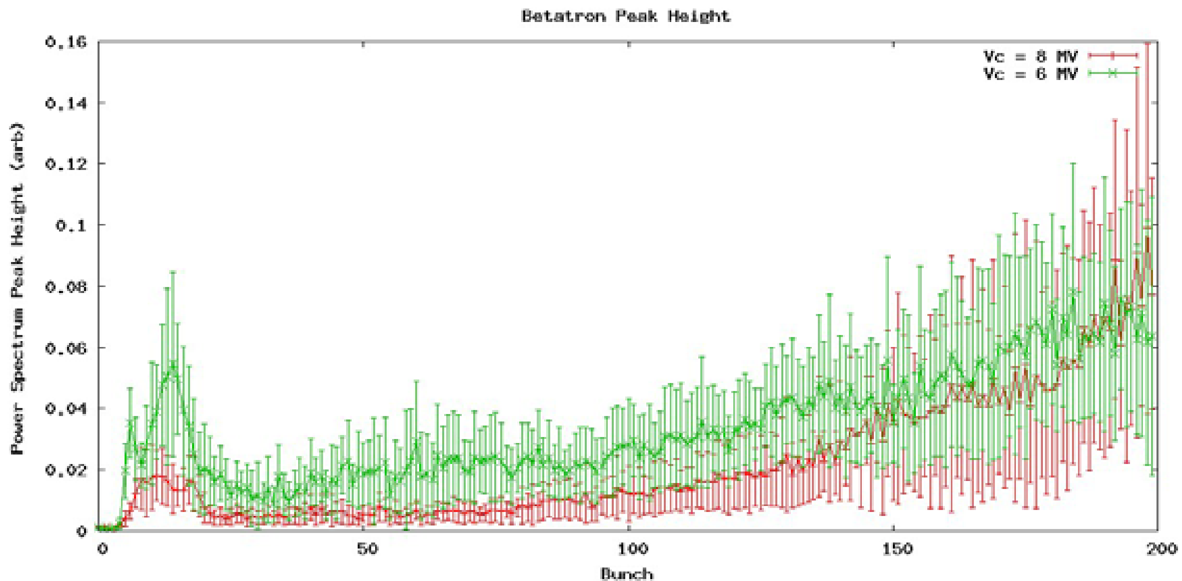


Effect of changing RF voltage

- Sideband onset is delayed along train (~3 bunches).
  - Confirms previous results.



- Betatron peak growth is not delayed.
  - Note that it peaks just before sideband appears



Effect of Changing RF Voltage

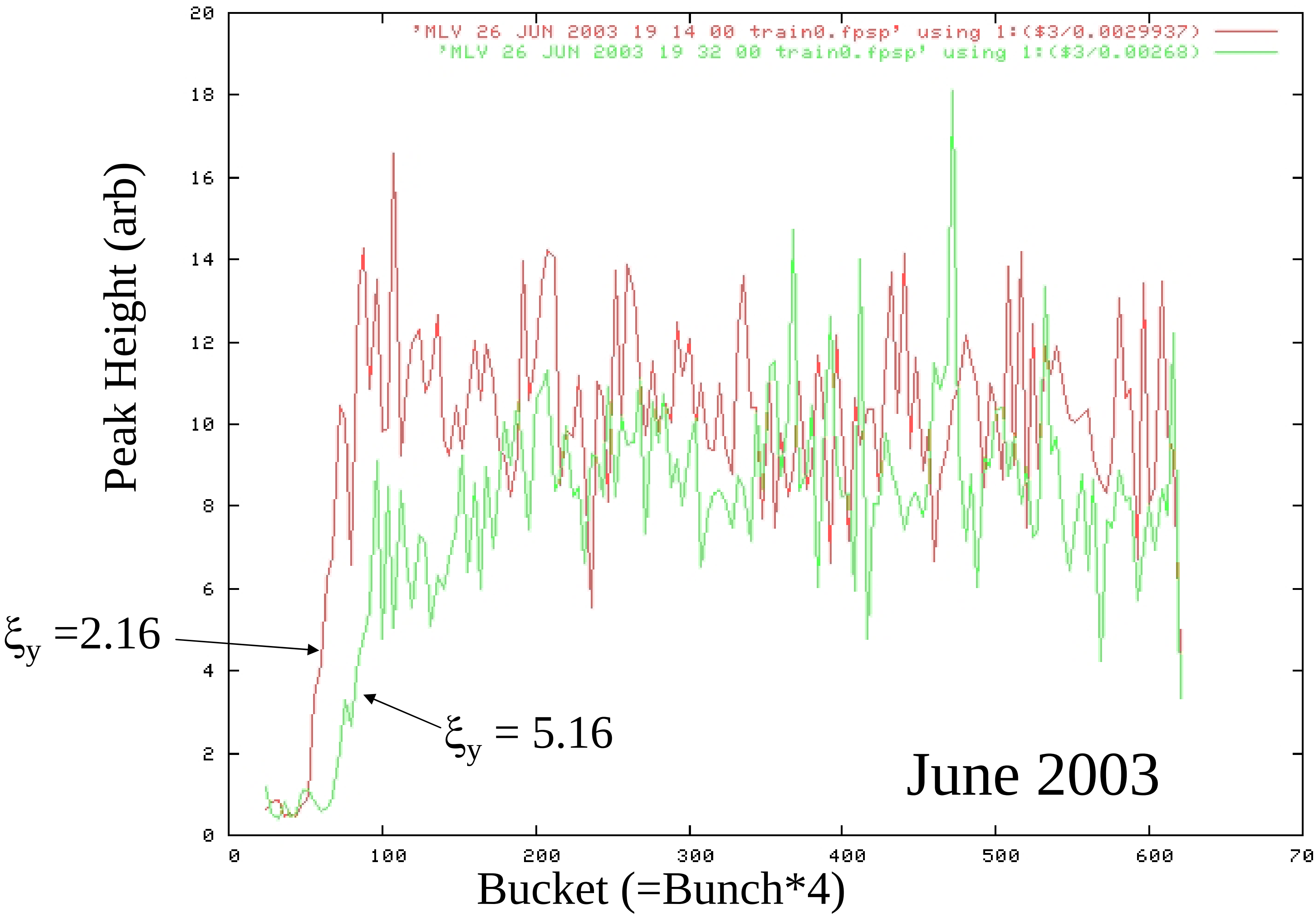
- Conclusion: A new measurement, with better statistics and a larger change in synchrotron tune, finds that the separation between the sideband peak and the betatron peak changes by approximately the same amount as the change in ν_s.
  - Need for parameter tweaking in simple model is relaxed.

Effect of Changing Chromaticity

- An effect predicted by head-tail theory is that the e-cloud density threshold for the onset of the instability should go up if the vertical chromaticity is raised.

- Original data (June 2003) showed such an effect, but differences in beam current at the two different chromaticities rendered interpretation ambiguous.

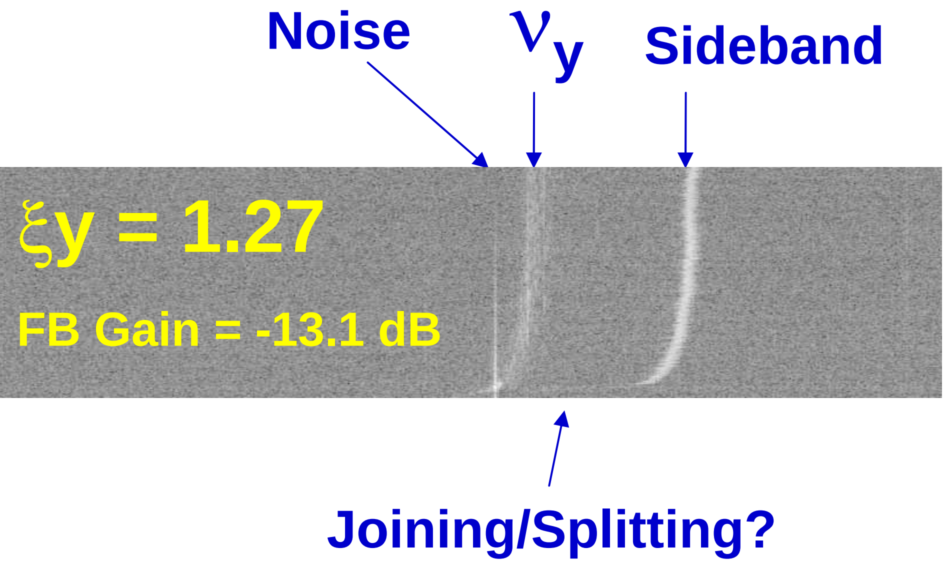
Sideband Peak Height Near Threshold at Different ξ_y

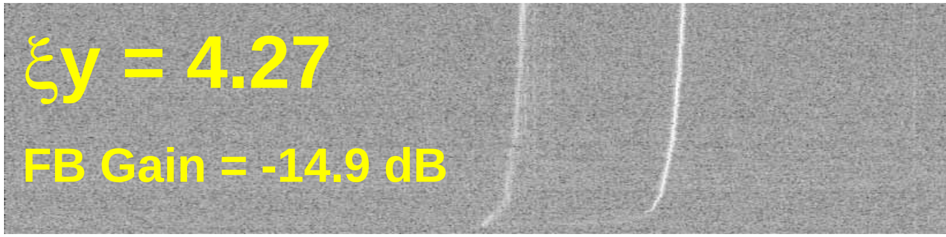


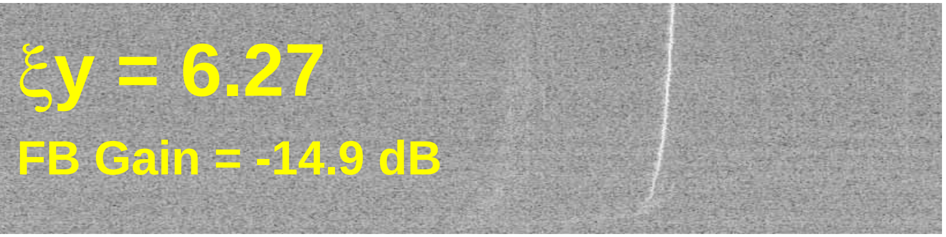
Effect of Changing Chromaticity

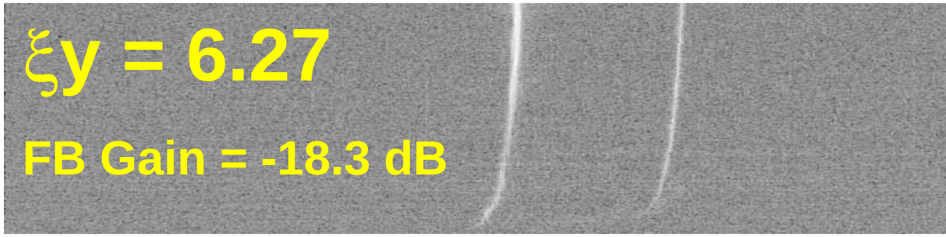
- Data re-taken, at same beam currents (re-injecting between changes in chromaticity).
- Feedback gain was changed at each beam current to make ν_y visible. To make sure this did not affect results, also took data at same chromaticity and two different feedback gains.

Sidebands at Different ξ_y

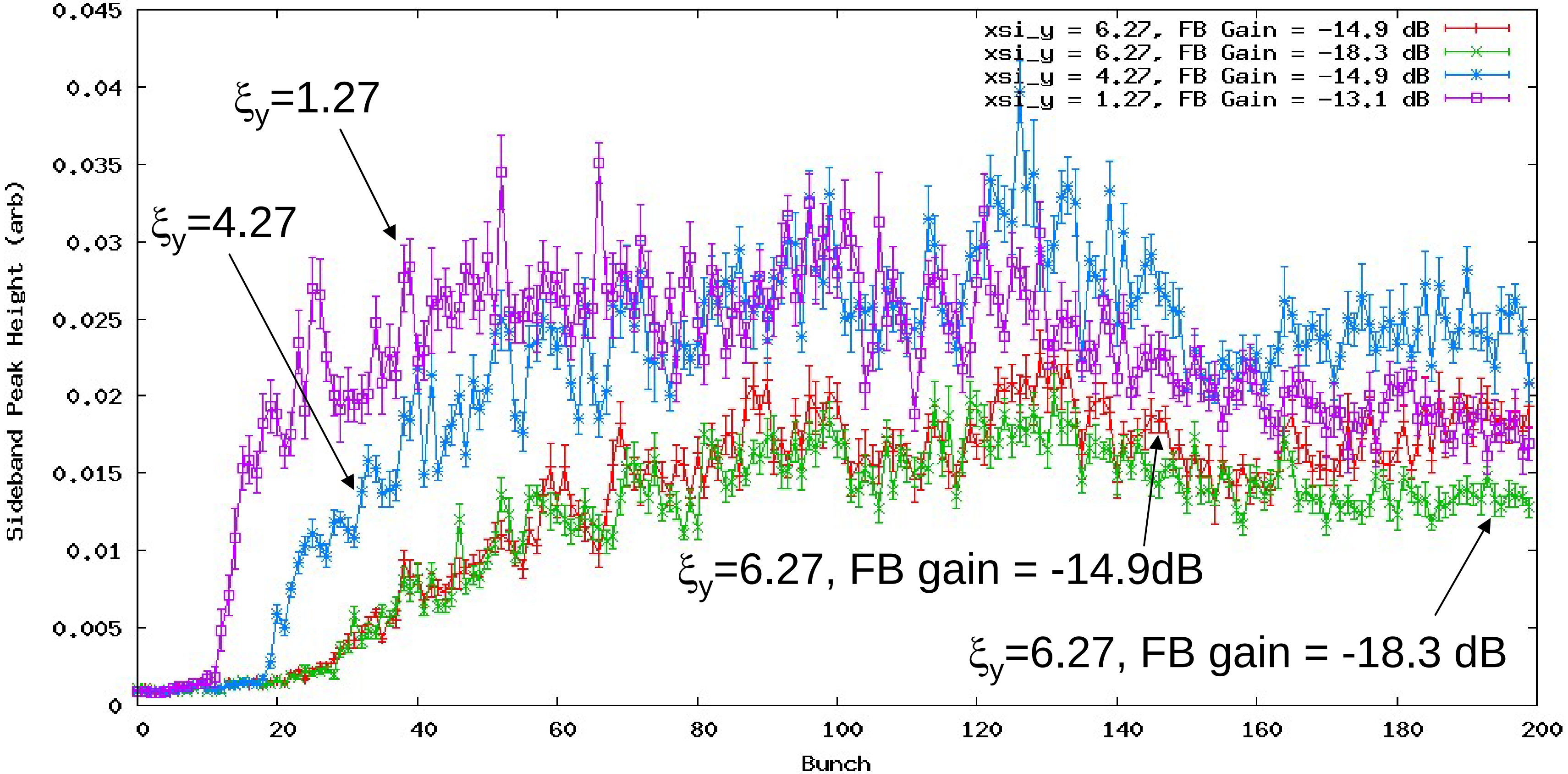








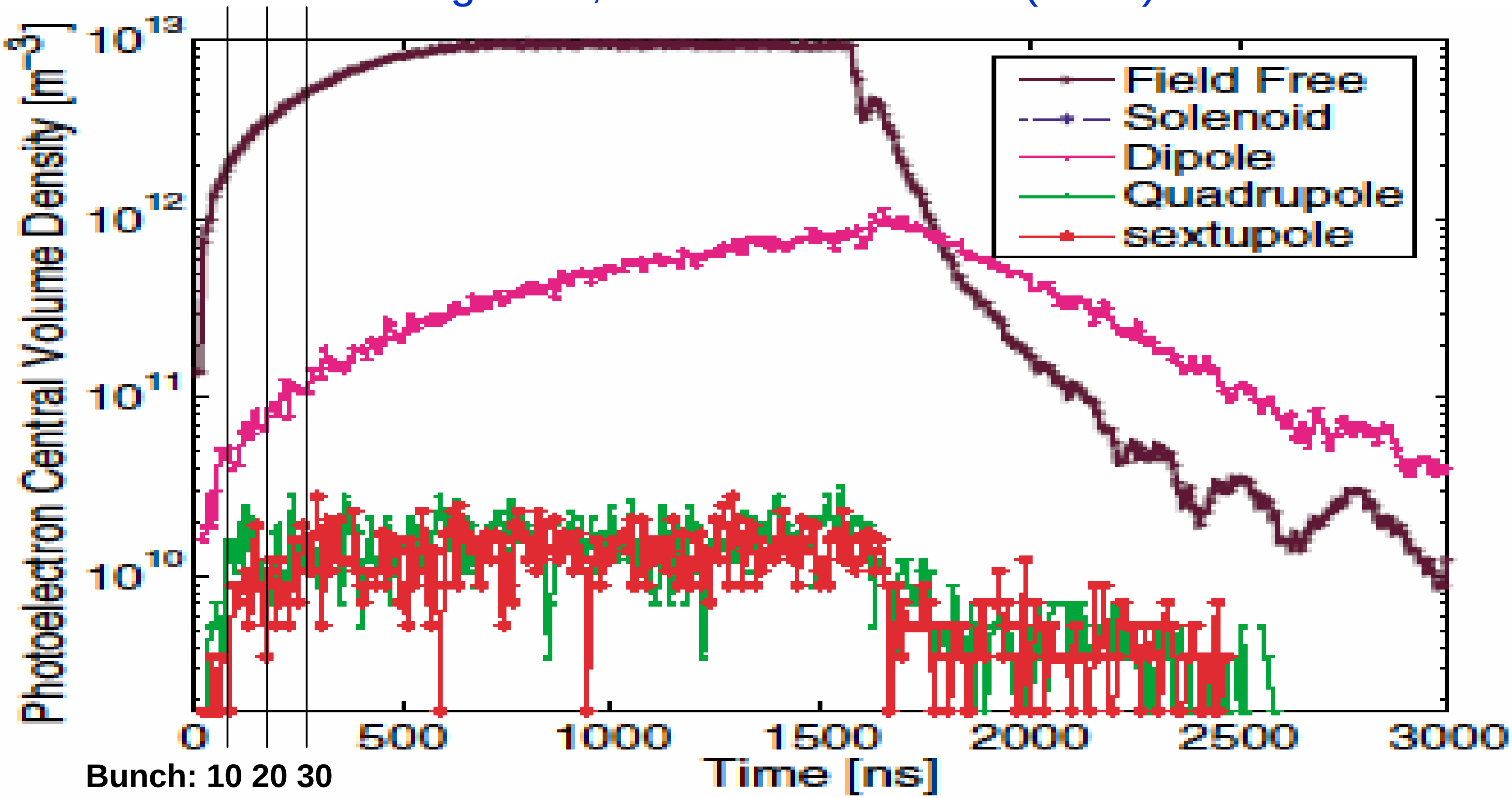
Sideband Peak Heights



Note: For KEKB, $\Delta\xi_y$ ~ 3 should correspond to a change in cloud-density threshold of ~10%

Simulated E-cloud build-up at KEKB

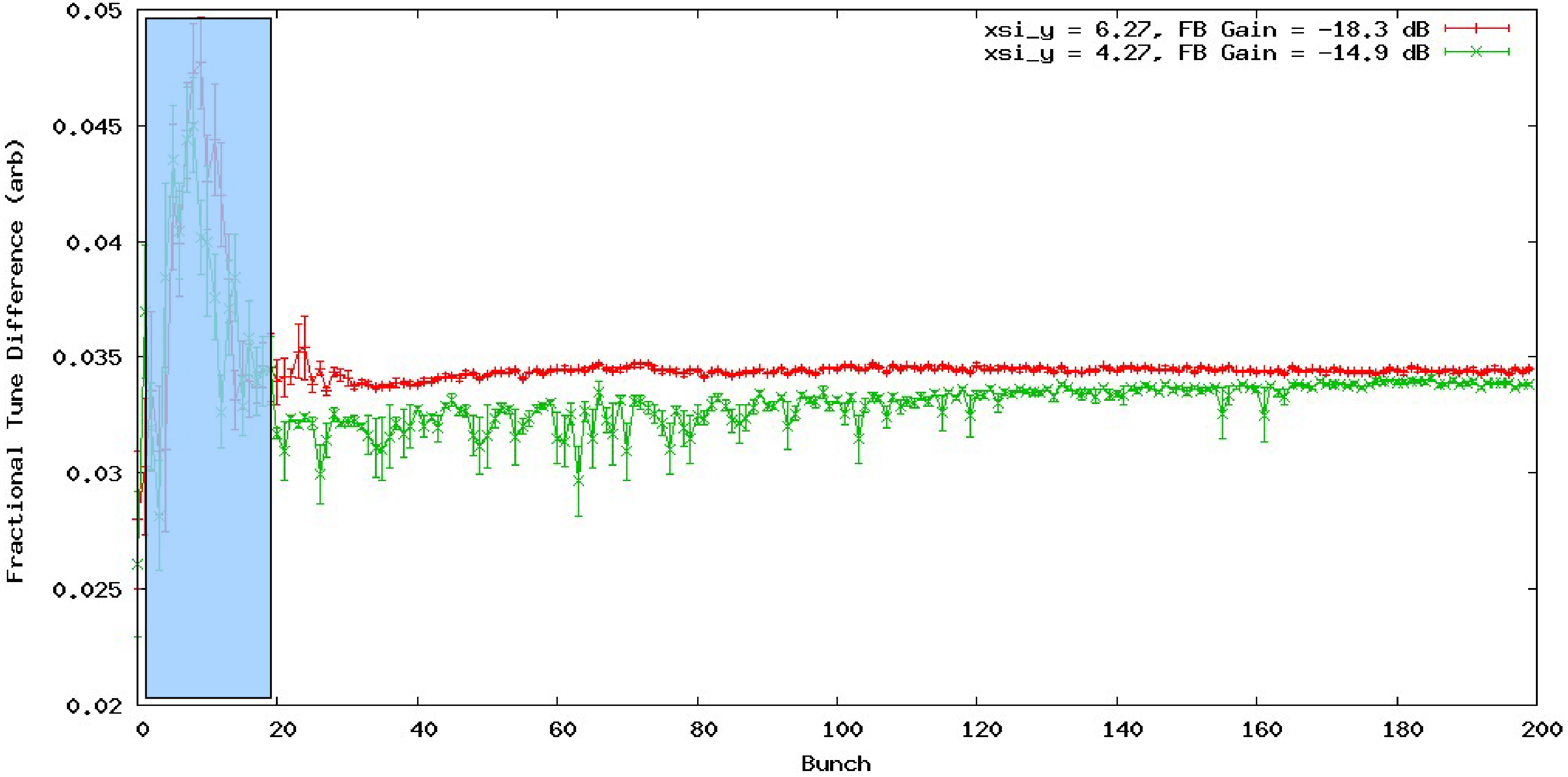
Wang et al., PRSTAB 5 124402 (2002)



(b)

FIG. 18. (Color) Photoelectron average volume densities and volume densities at pipe center in a different magnet field as a function of time for a train with 200 bunches spaced by 7.86 ns and followed by a long bunch train gap. (a) Average volume densities; (b) volume densities at pipe center.

Sideband-Betatron Peak Separations



Effect of Changing Chromaticity

- Conclusion: Threshold is found to depend on ξ_y, as expected under head-tail theory. Size of threshold shift is crudely consistent with expectation.

Effect of Changing Emittance

- Experiment was done to see if the beam blow-up and sideband-appearance thresholds change when the initial vertical beam size is changed.
- Vertical beam size at low current was changed by using a dispersion bump (iSize) to change the emittance, then beam current ramped up.
  - Beam size data taken continuously, beam spectrum data taken at 50 mA steps.

Blowup Threshold dependence on ε_y (iSize Bump)

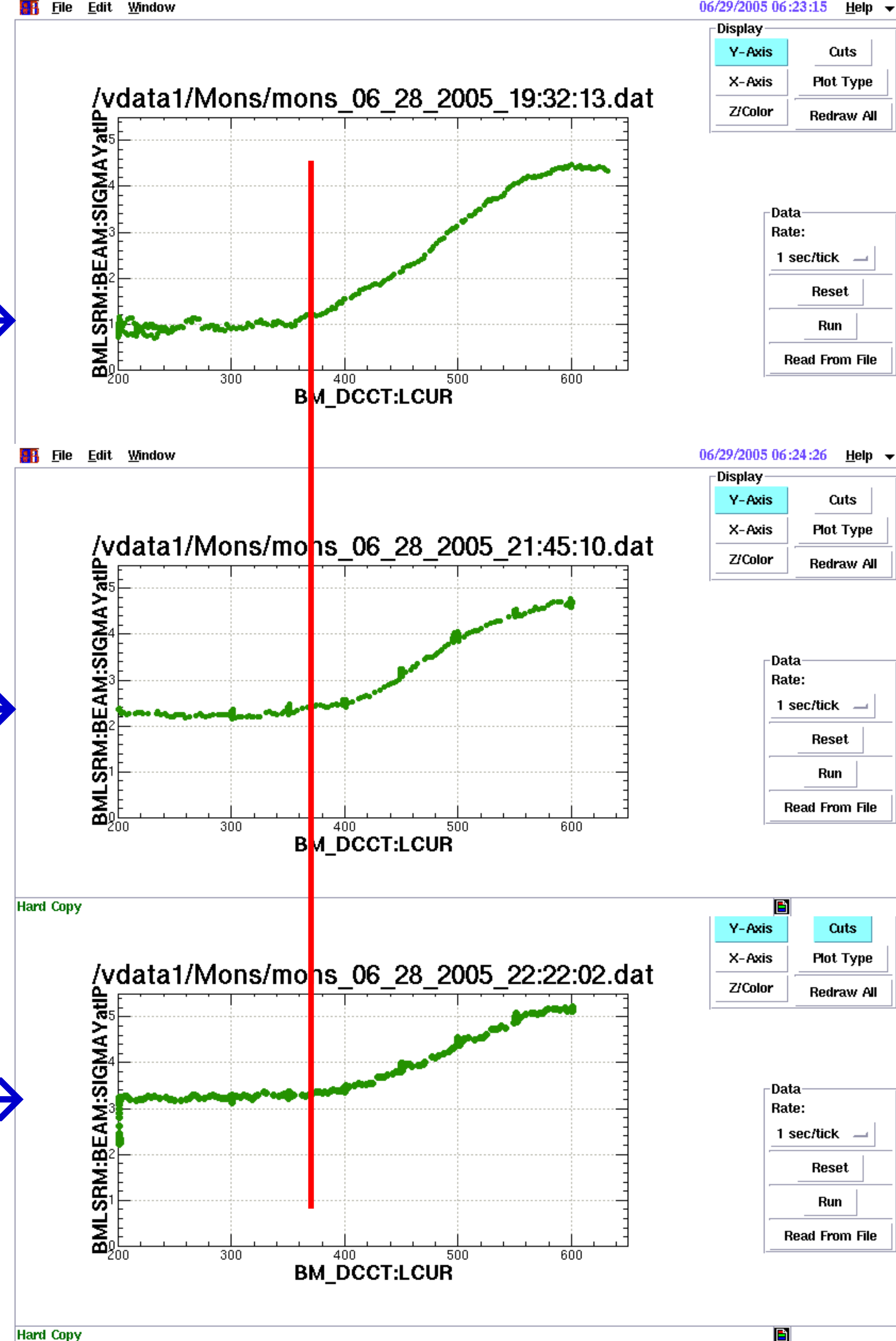
σ_{y0}= 1 μm→

Pattern: 4/200/4

σ_{y0}= 2.2 μm→

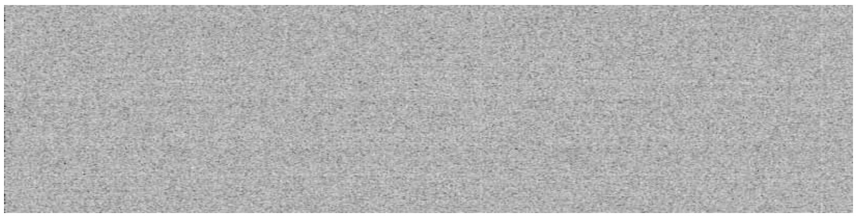
Beam-size blowup threshold does not change much, if at all.

σ_{y0}= 3.2 μm→

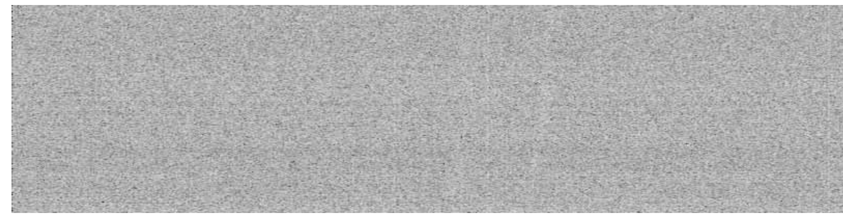


$\sigma^{*}_{y0} = 1\ \mu m$

300 mA

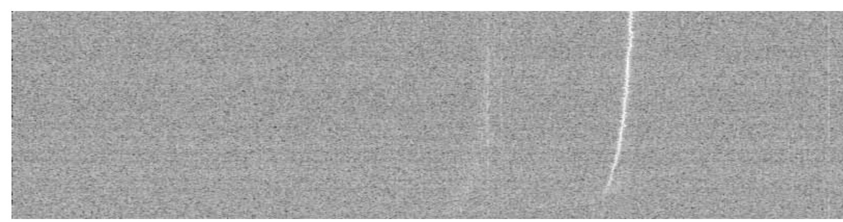


350 mA



400 mA

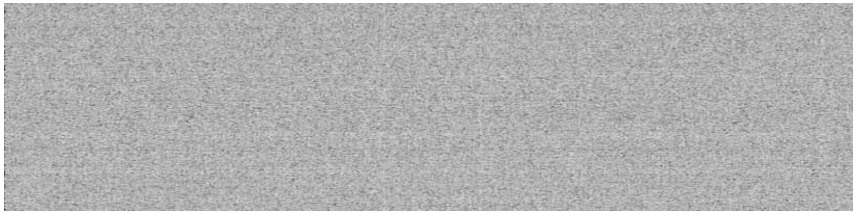
450 mA



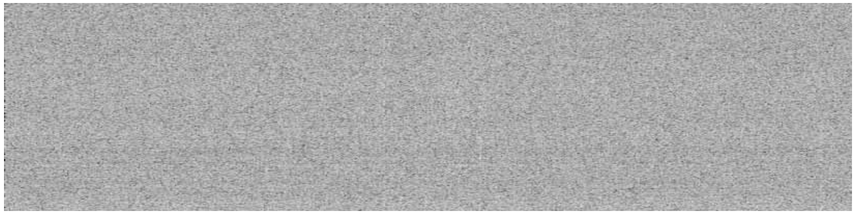
0.5--------------Tune----------------0.7 **0.5--------------Tune----------------0.7**

$\sigma^*_{y0} = 2.2\ \mu m$

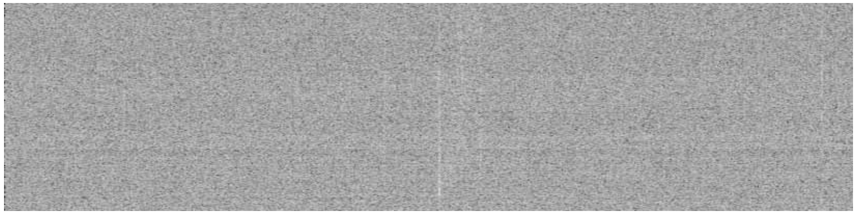
300 mA



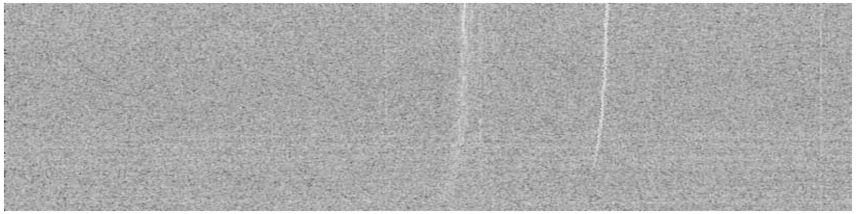
350 mA



400 mA



450 mA

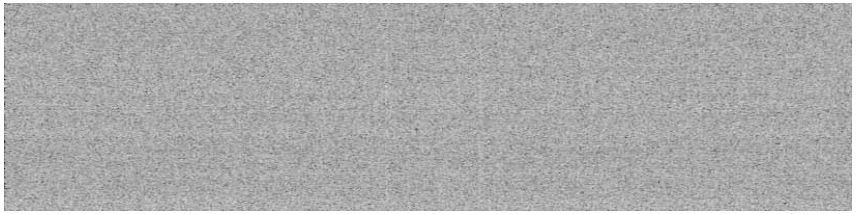


0.5---------------Tune-----------------0.7 **0.5---------------Tune-----------------0.7**

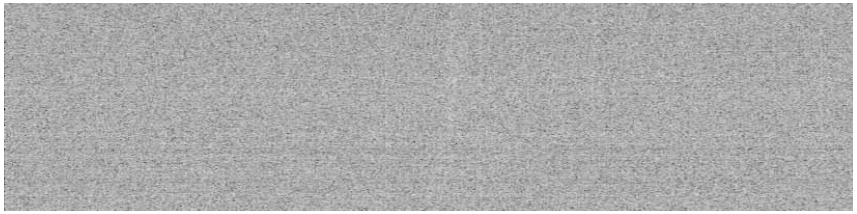
$\sigma^*_{y0} = 3.2\ \mu m$

300 mA

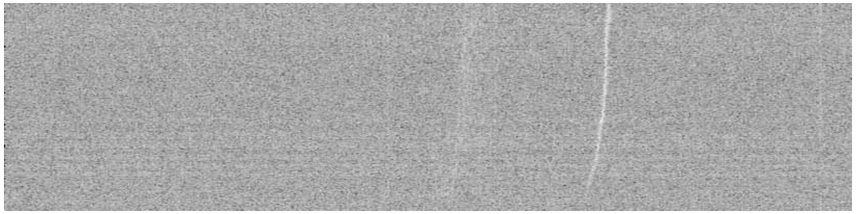
350 mA



400 mA



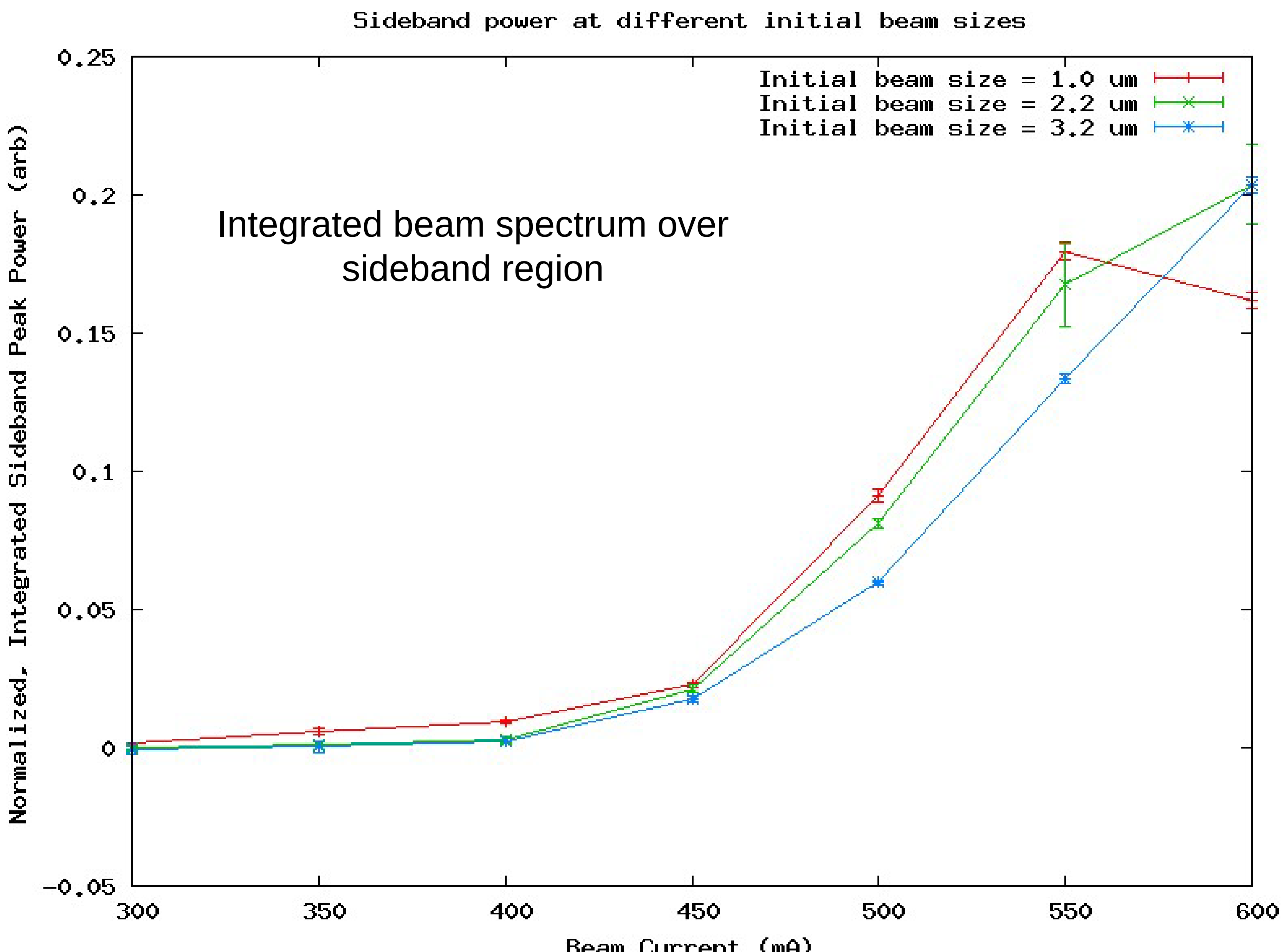
450 mA



0.5---------------Tune-----------------0.7

0.5---------------Tune-----------------0.7

Sideband growth at different σ^*_{y0}

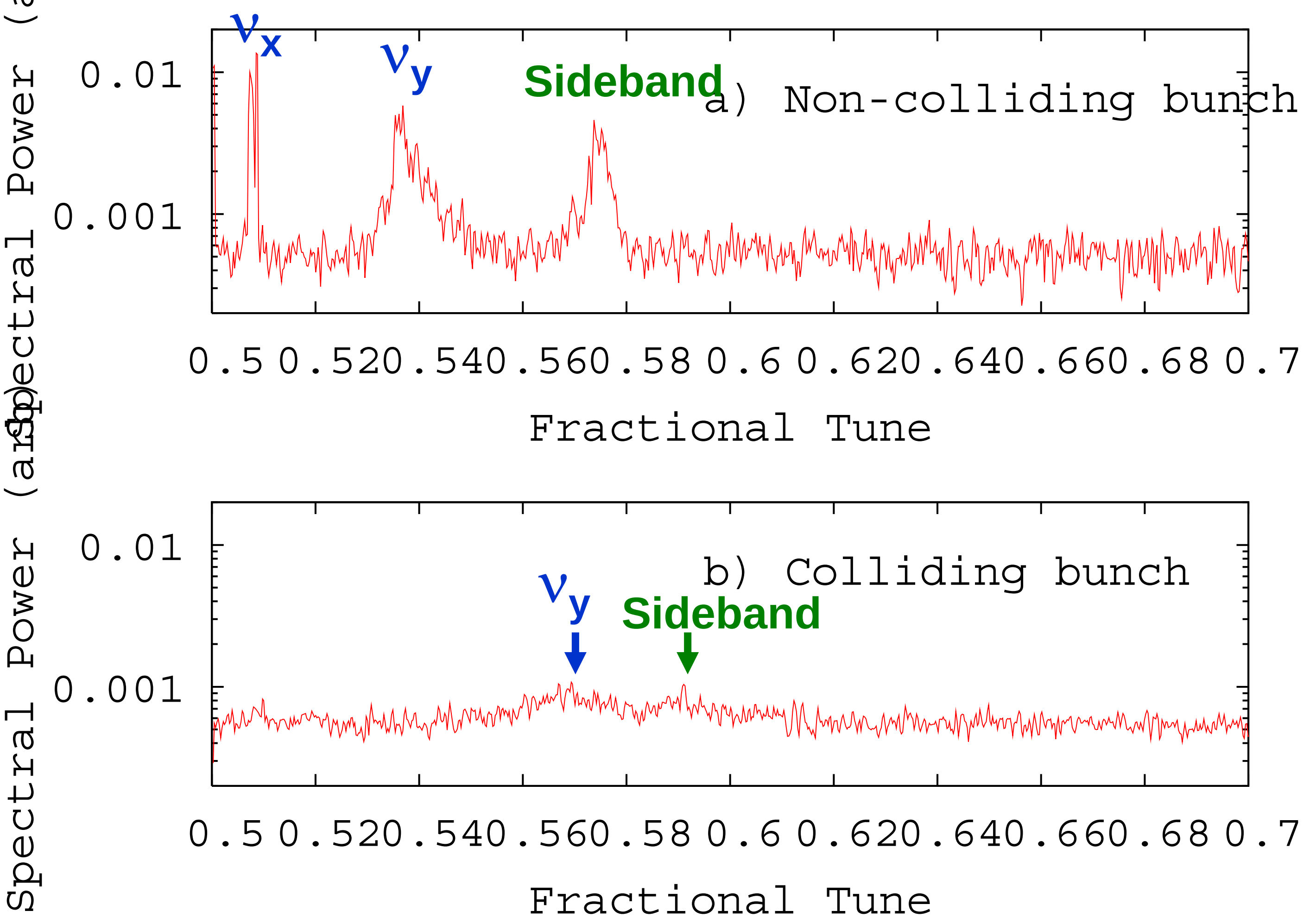


Effect of Changing Emittance

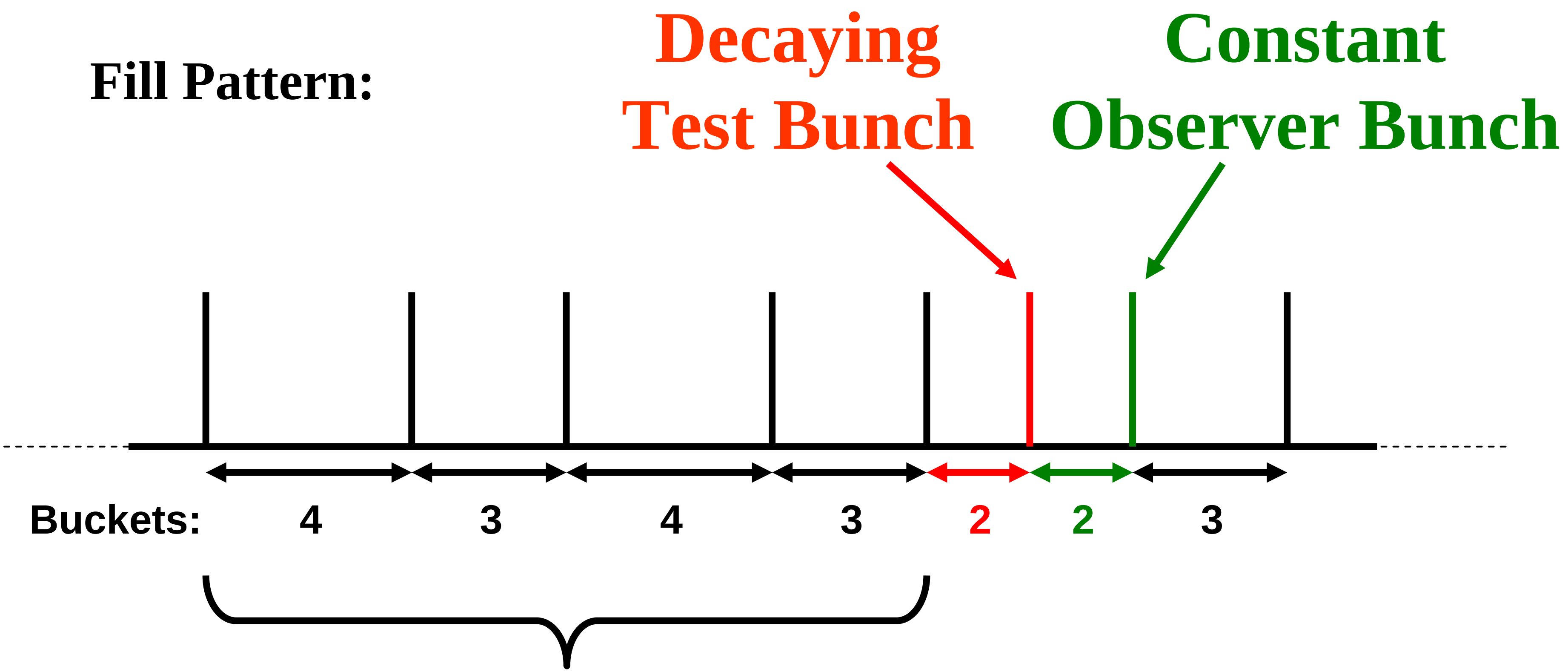
- Conclusion: Threshold is found not to depend on initial vertical beam size.

Sidebands in Collision

- Sidebands present in collision, but smeared out compared to their appearance in non-colliding bunches.
- =>Strategy: Measure spectrum of non-colliding bunch, and specific luminosity of colliding bunch under same conditions.

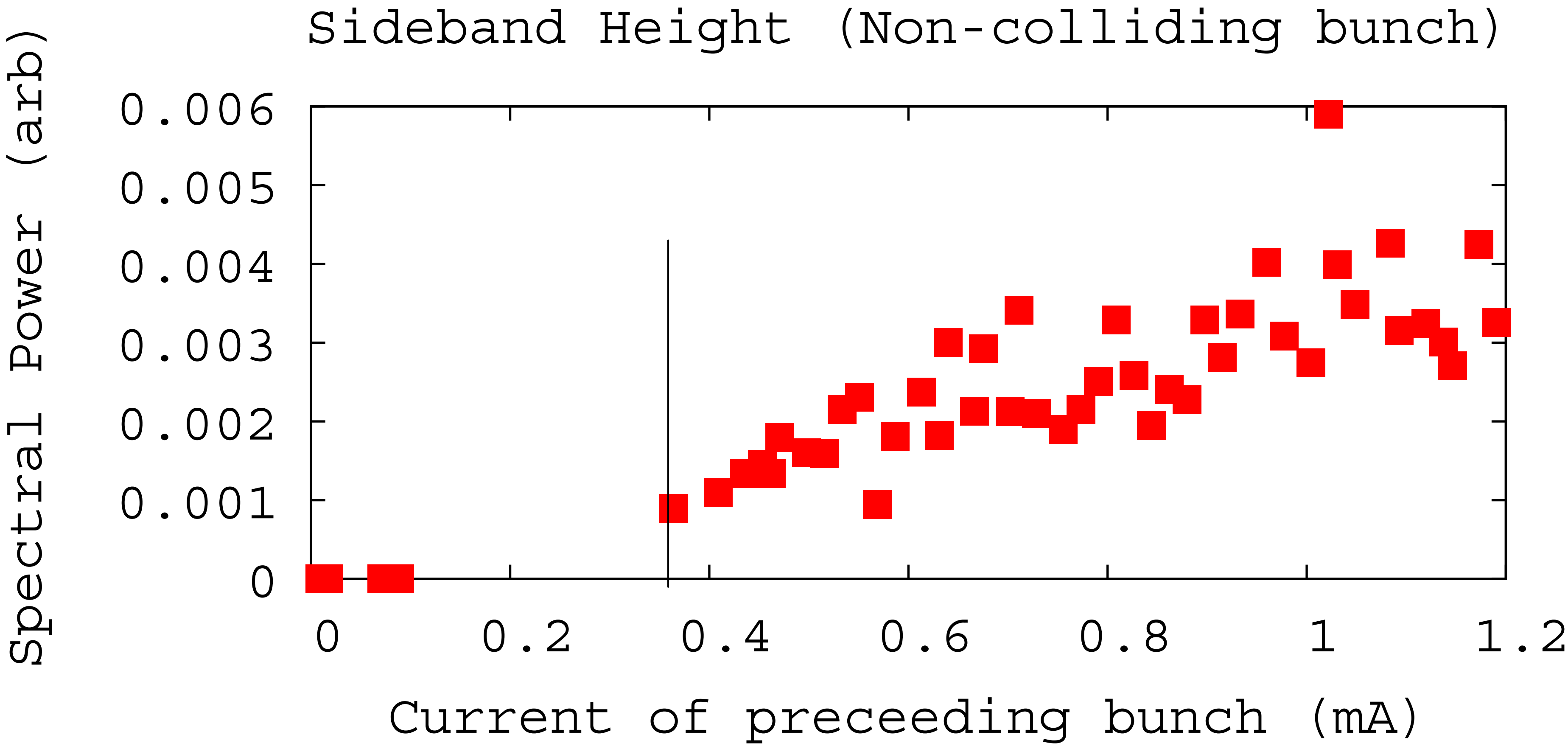


Decaying Cloud, Constant Bunch Current Study



Regular physics pattern bunches
Average spacing: 3.5 buckets
Bunch current: Constant 1.2 mA
(using continuous injection)

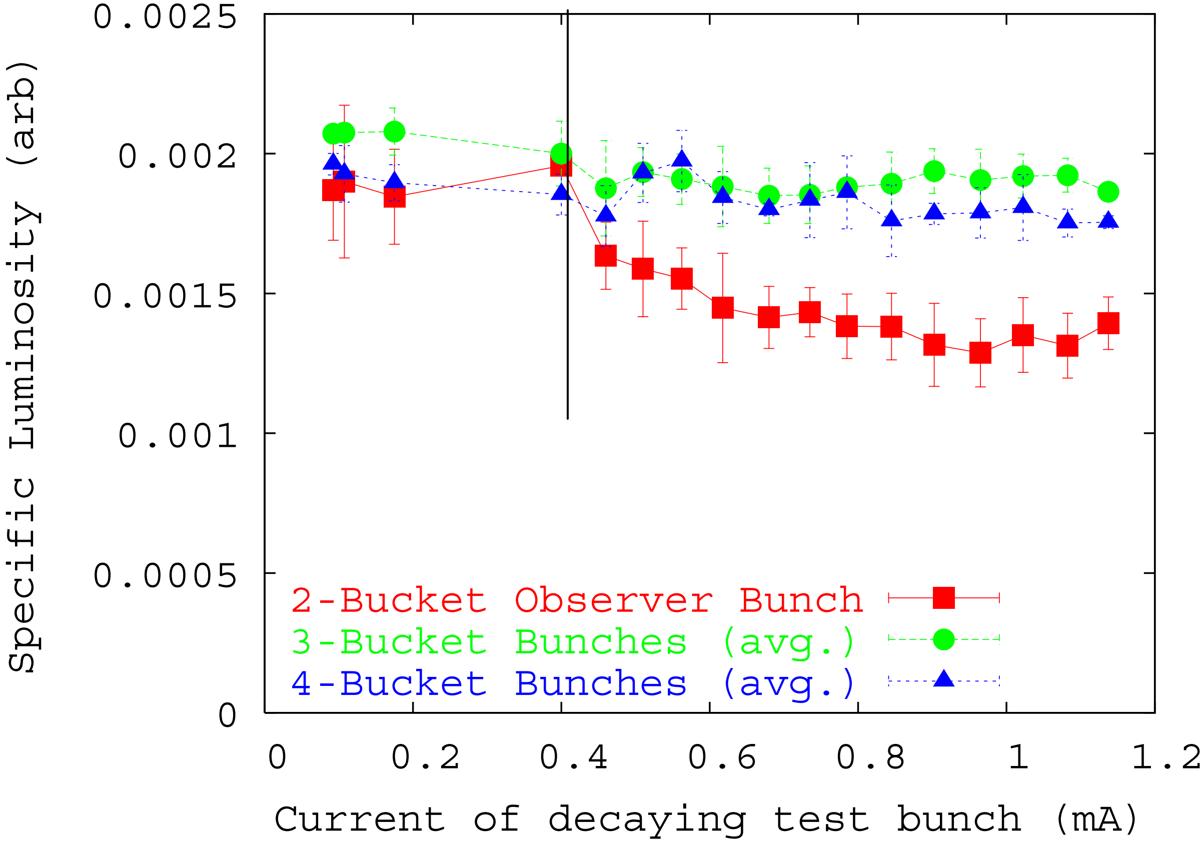
Decaying Cloud, Constant Bunch Current
Sideband Peak Heights



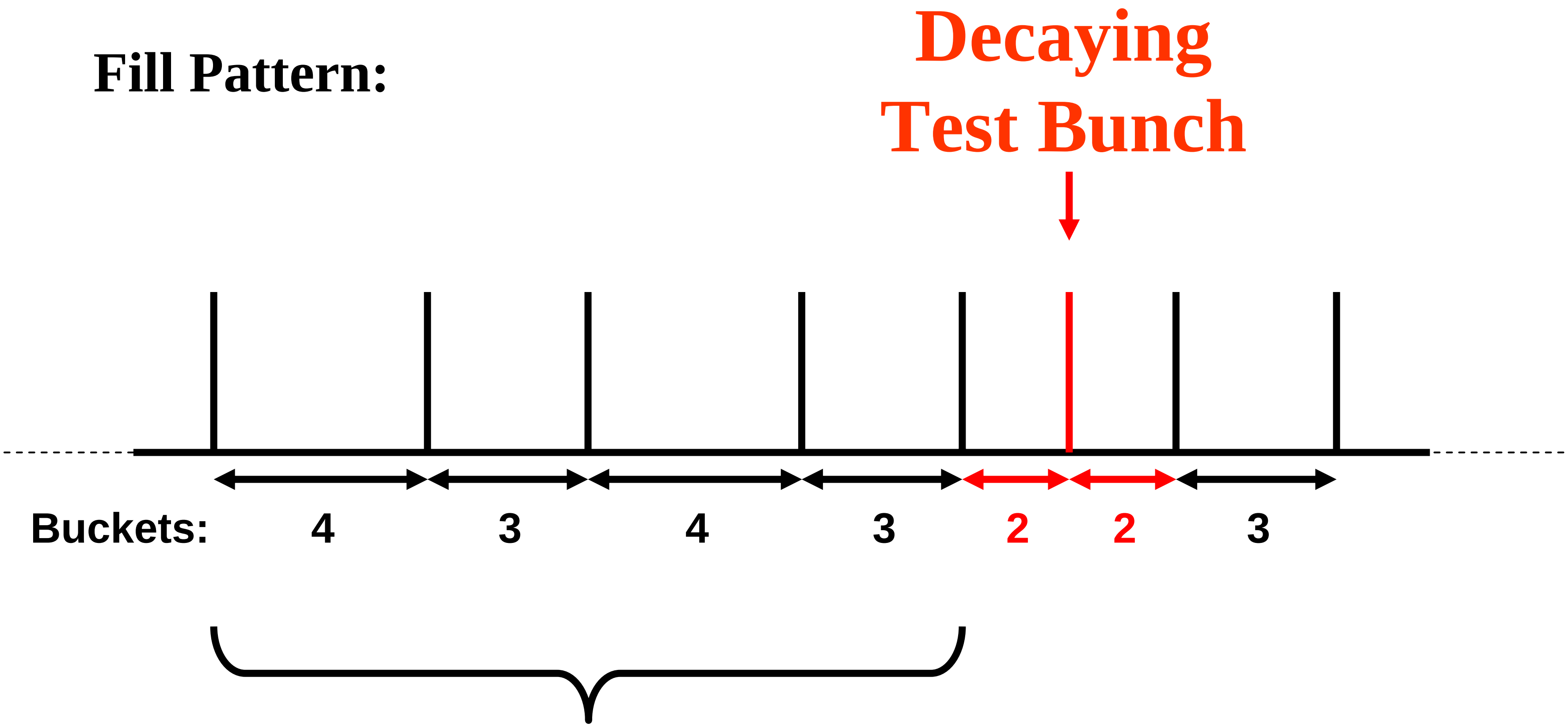
Sidebands disappear below test bunch current of ~0.4 mA

Decaying Cloud, Constant Bunch Current Specific Luminosity

- Specific luminosity of observer bunch is lower than that of regular bunches above 0.4 mA, but is nearly the same below 0.4 mA.
  - Consistent with sideband behavior, and explanation that loss of specific luminosity is due to electron cloud instability.

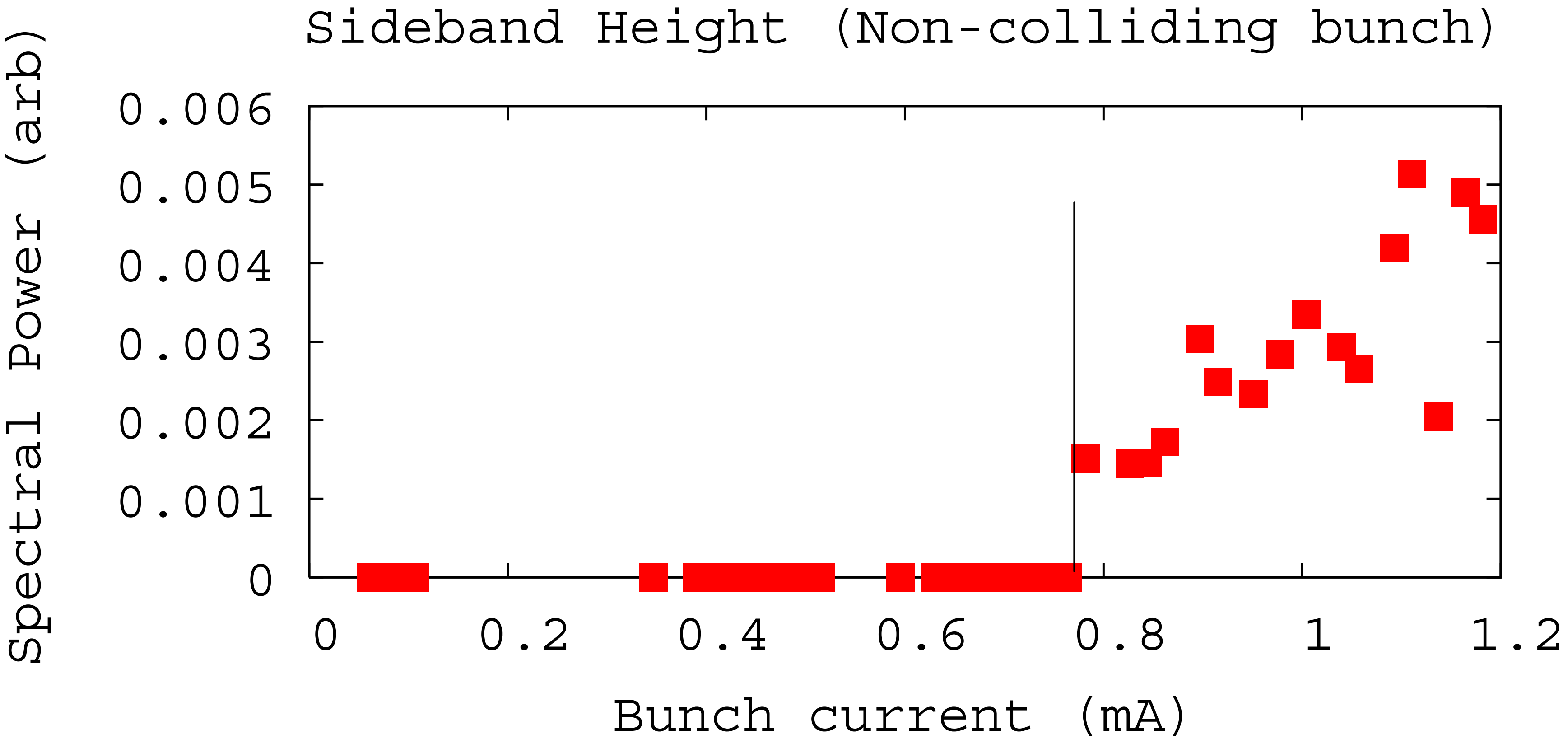


Constant Cloud, Decaying Bunch Current Study



Regular physics pattern bunches
Average spacing: 3.5 buckets
Bunch current: 1.2 mA constant
(using continuous injection)

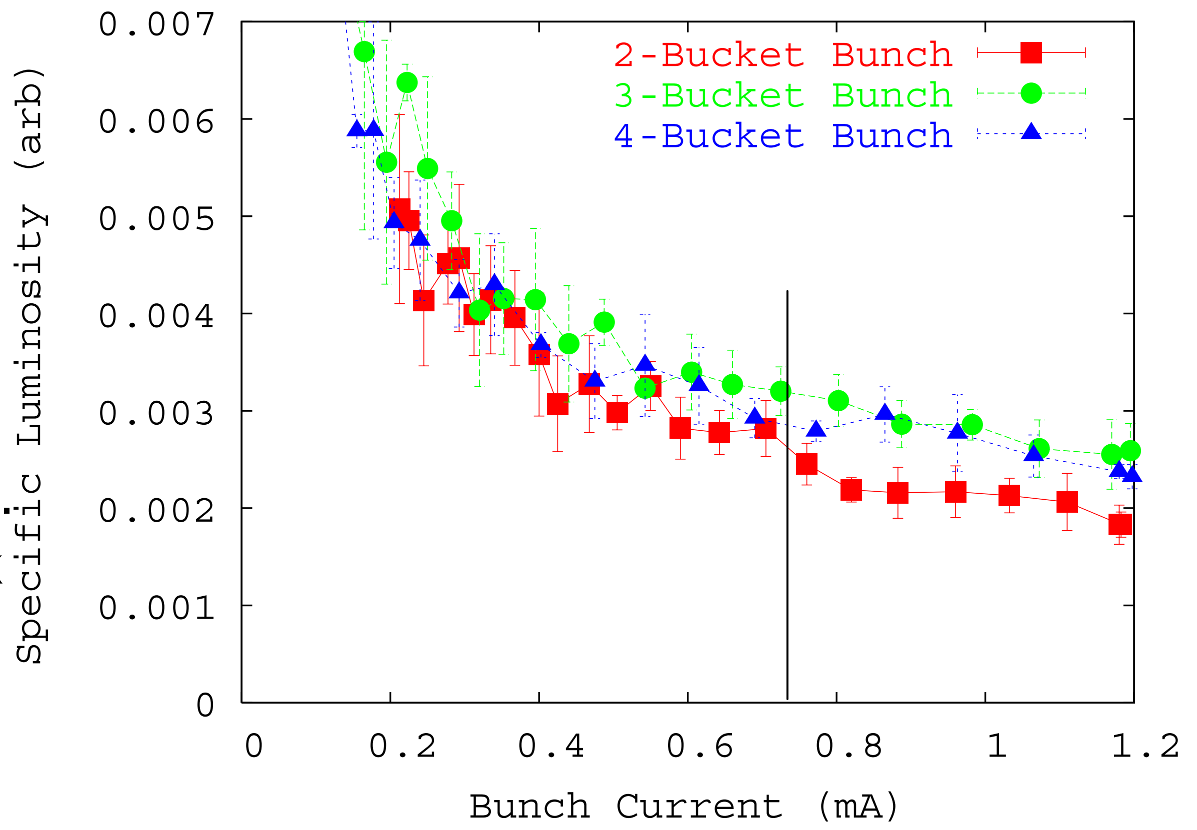
Constant Cloud, Decaying Bunch Current
Sideband Peak Heights



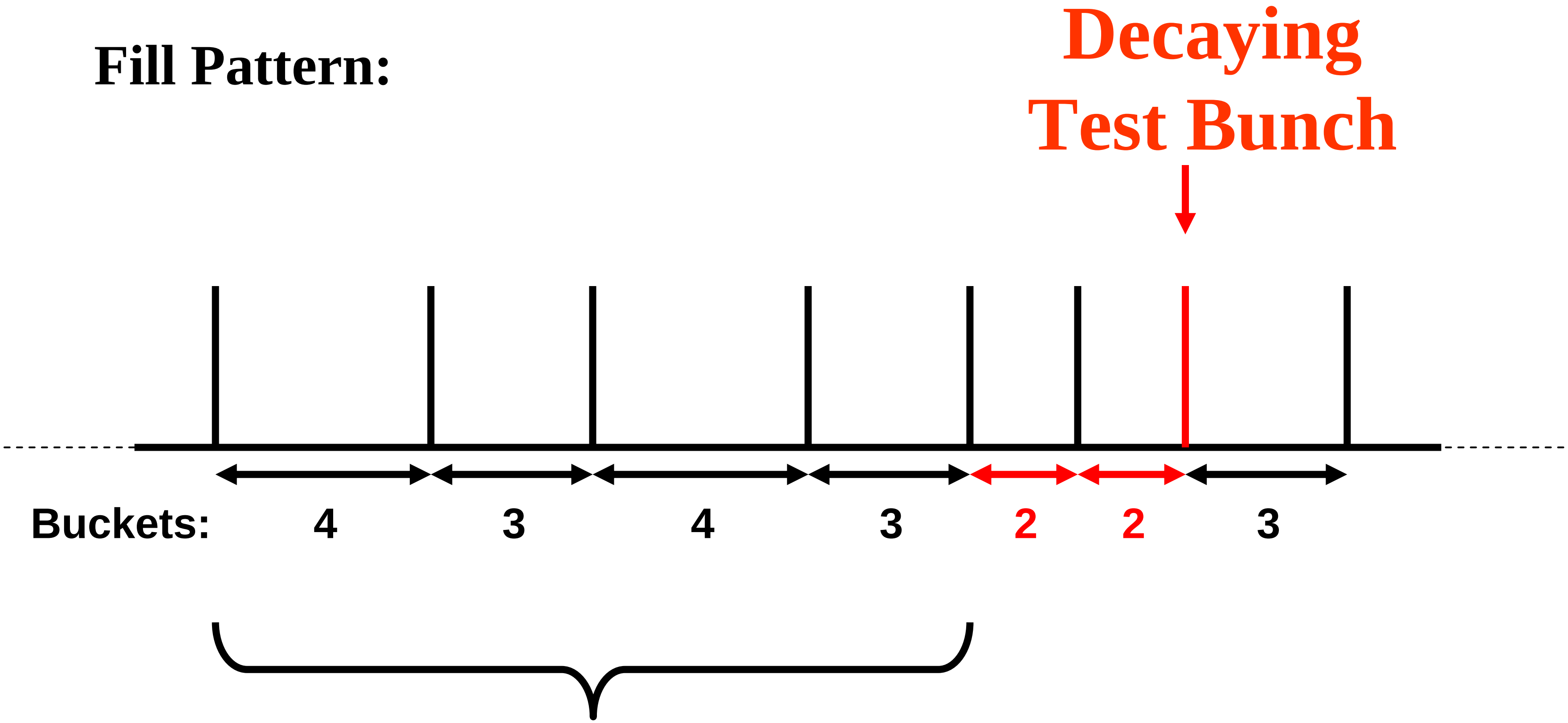
Sidebands disappear below test bunch current of ~0.75 mA

Constant Cloud, Decaying Bunch Current
Specific Luminosity

- Specific luminosity of observer bunch is lower than that of regular bunches above 0.75 mA, but is nearly the same below 0.75 mA.
- Again, consistent with sideband behavior, and explanation that loss of specific luminosity is due to electron cloud instability.
- Also consistent with streak camera observations of vertical bunch size: bunch larger above ~0.8 mA.
  - H. Ikeda et al., PAC05 poster RPAT052.



Constant Cloud, Decaying Bunch Current
Study II



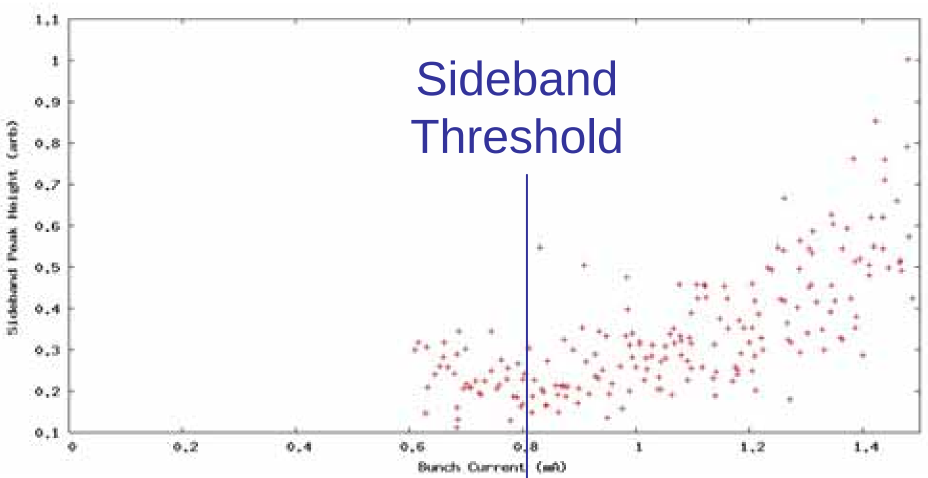
Regular physics pattern bunches
Average spacing: 3.5 buckets
Bunch current: 1.2 mA constant
(using continuous injection)

Sidebands and Spec. Lum.

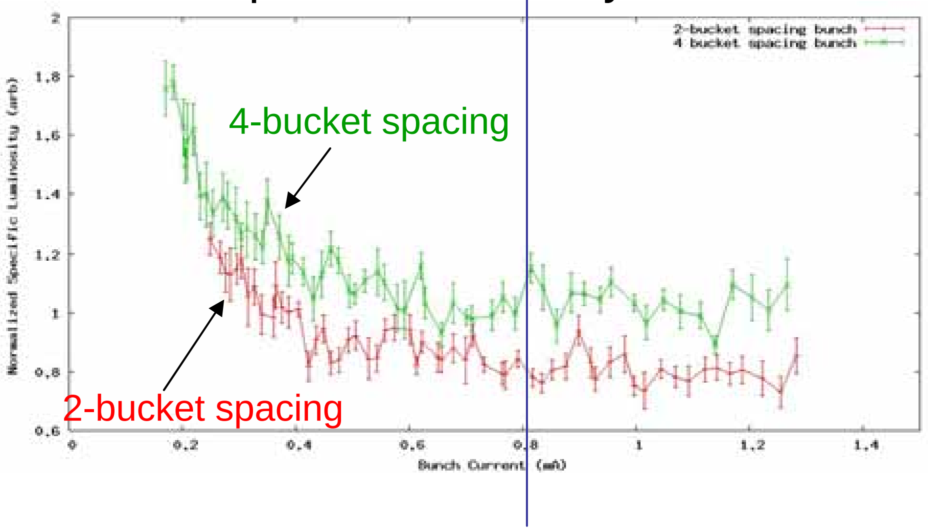
- Sidebands disappear at around a bunch current of 0.8 mA.

- Specific luminosity of 2-bucket and 4-bucket spacing bunches do not merge at that point, however.
  - Possible that sidebands continue, but below noise level.
  - OR, possible indication of the presence of an incoherent component below the sideband threshold (non-linear focusing by cloud leading to non-Gaussian beam tails, e.g.)

Sideband Peak Height



Specific Luminosity

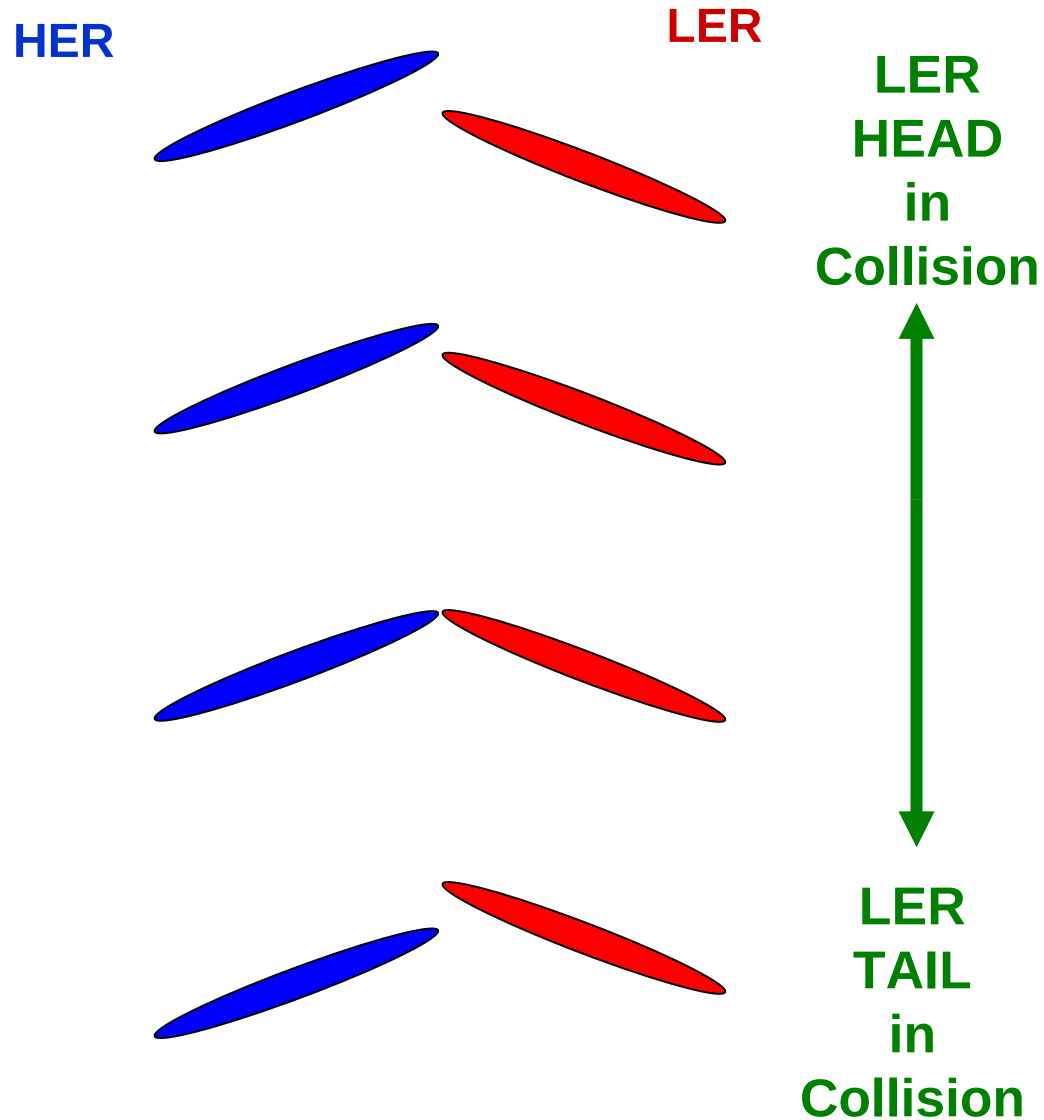


Collision Offset Study

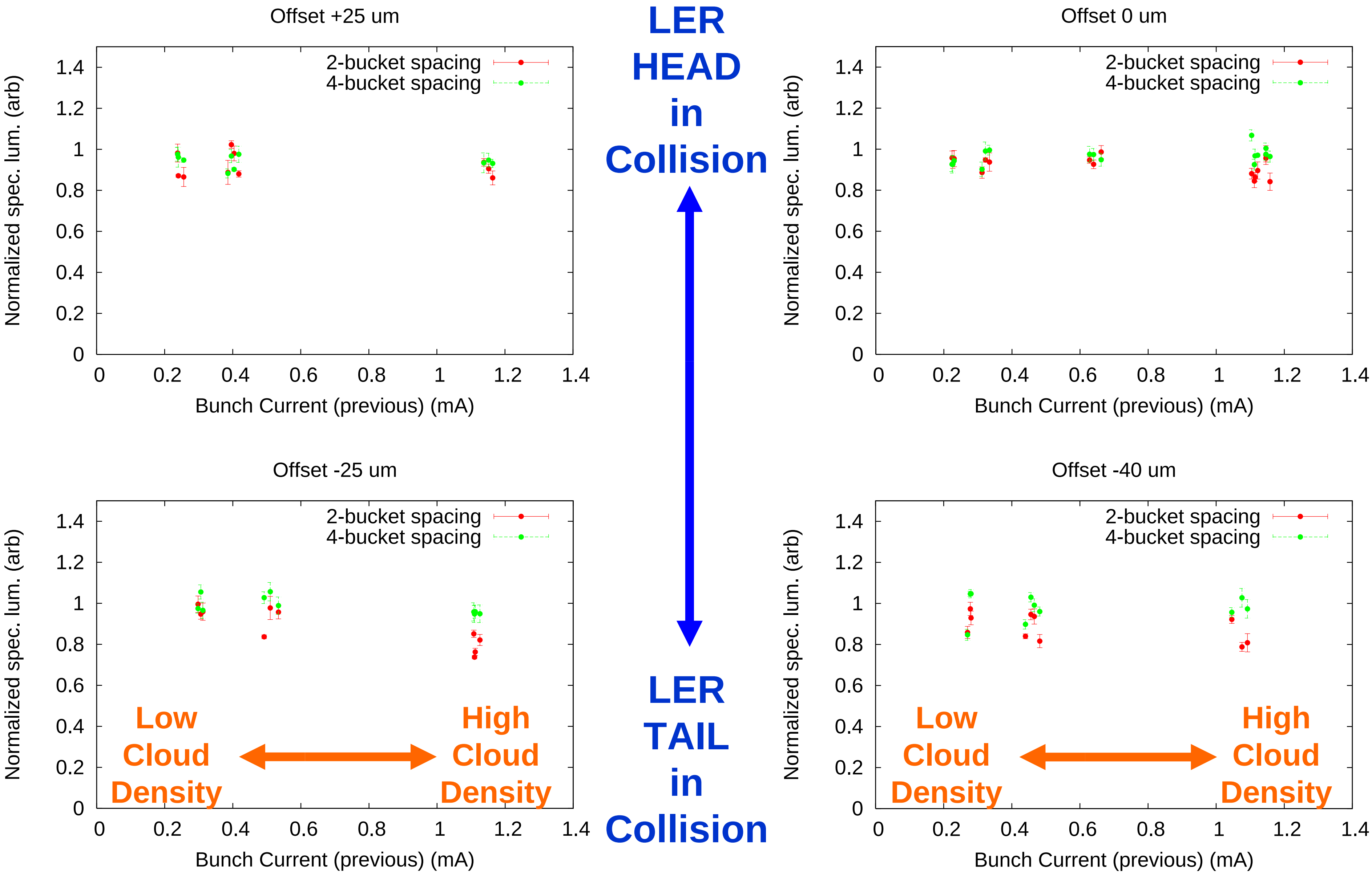
- Background: We get the best luminosity with a non-zero horizontal offset at the interaction point.
- Question: Could this be due to electron cloud blow-up in the tail of the LER bunch?
- Measured: Specific luminosity of high-cloud (2-bucket spacing) and low-cloud (4-bucket spacing) bunches at several collision offsets.

Collision Offset Study

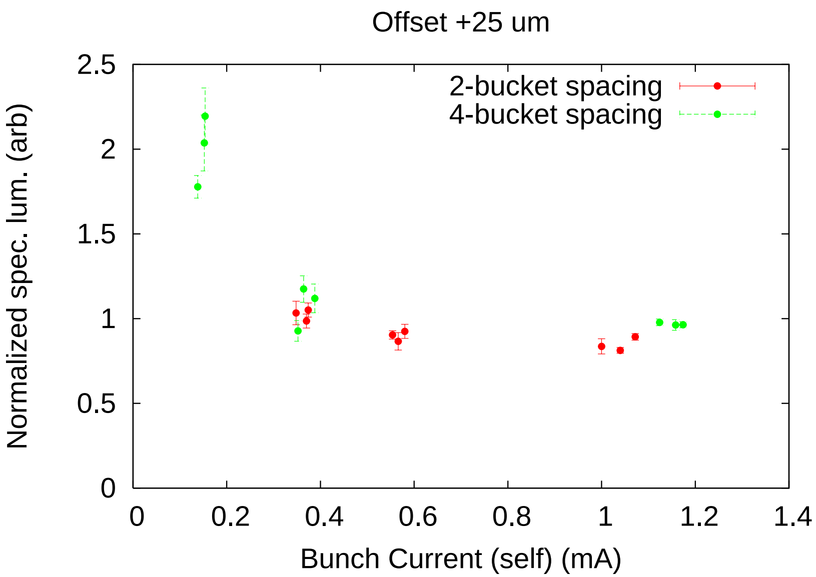
- +25 μm
- 0 μm
- -25 μm
- -40 μm

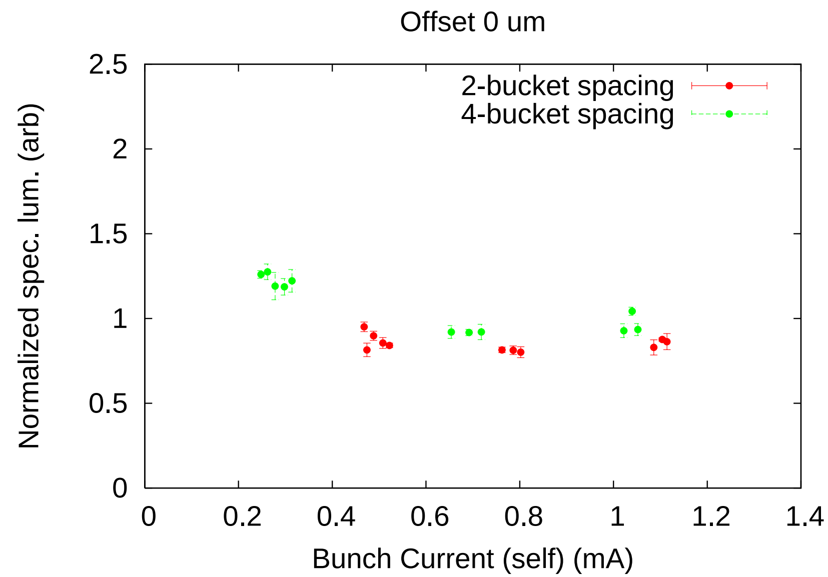


Decaying Cloud, Constant Current



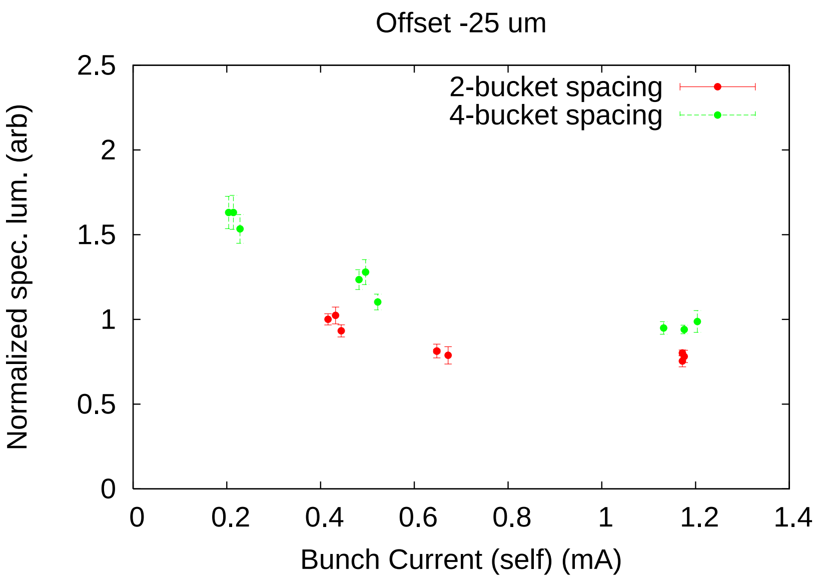
Constant Cloud, Decaying Current

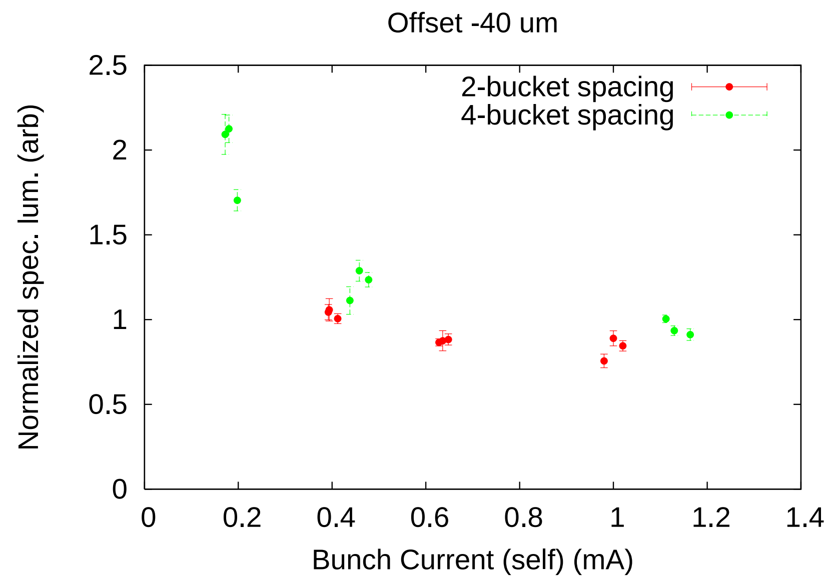




LER HEAD in Collision

LER TAIL in Collision



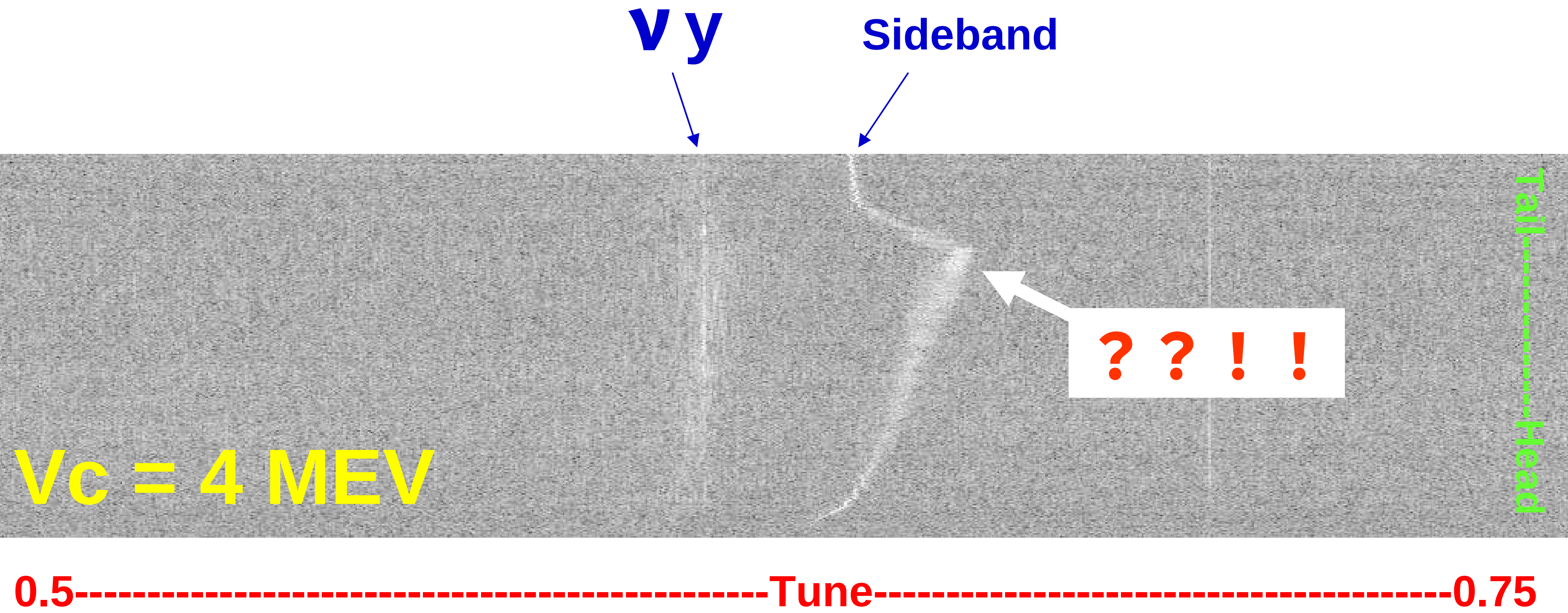


Collision Offset Study

- **Conclusion:**
  - Under high-cloud conditions, specific luminosity appears to be lower towards the tail of the LER bunch than towards the head.
  - Under low-cloud conditions, there is no specific luminosity difference between the head and tail of the LER bunch.

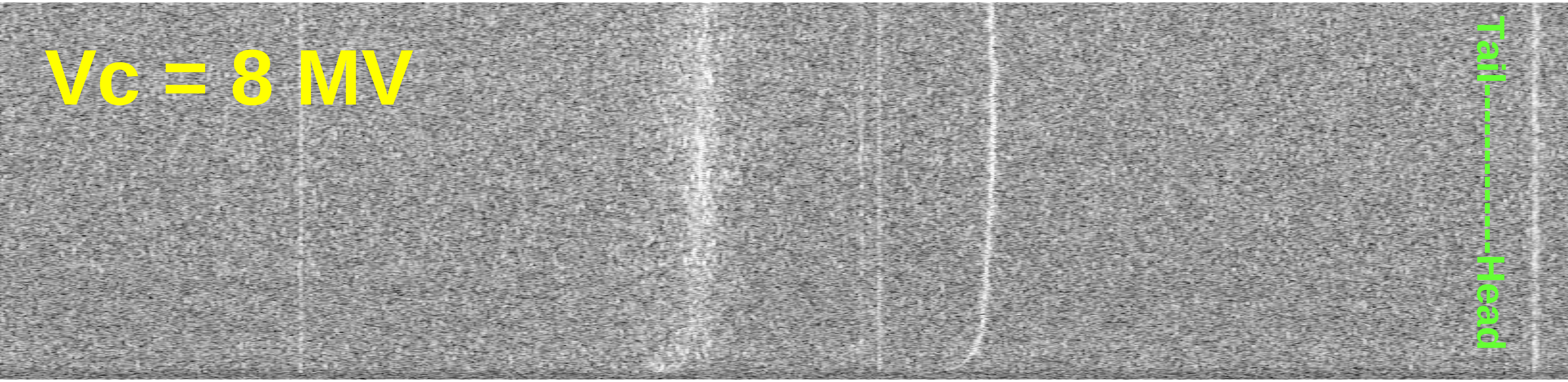
Miscellaneous Topics

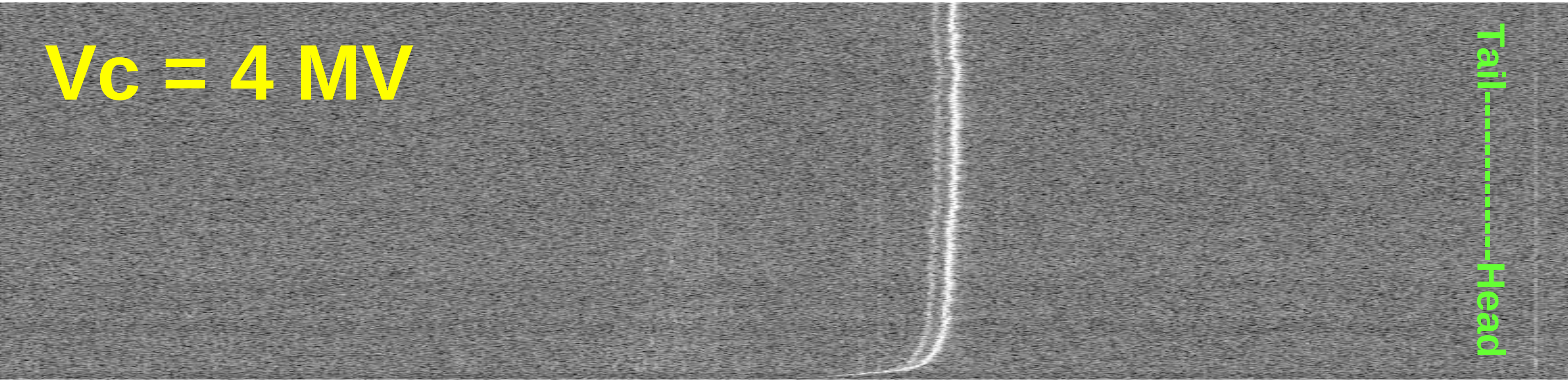
Sideband Dependence on ν_s (Vc)



→Dec. 2005 Study: Try to reproduce spectrum from June 2005, and take data with streak camera and longitudinal BOR in addition.

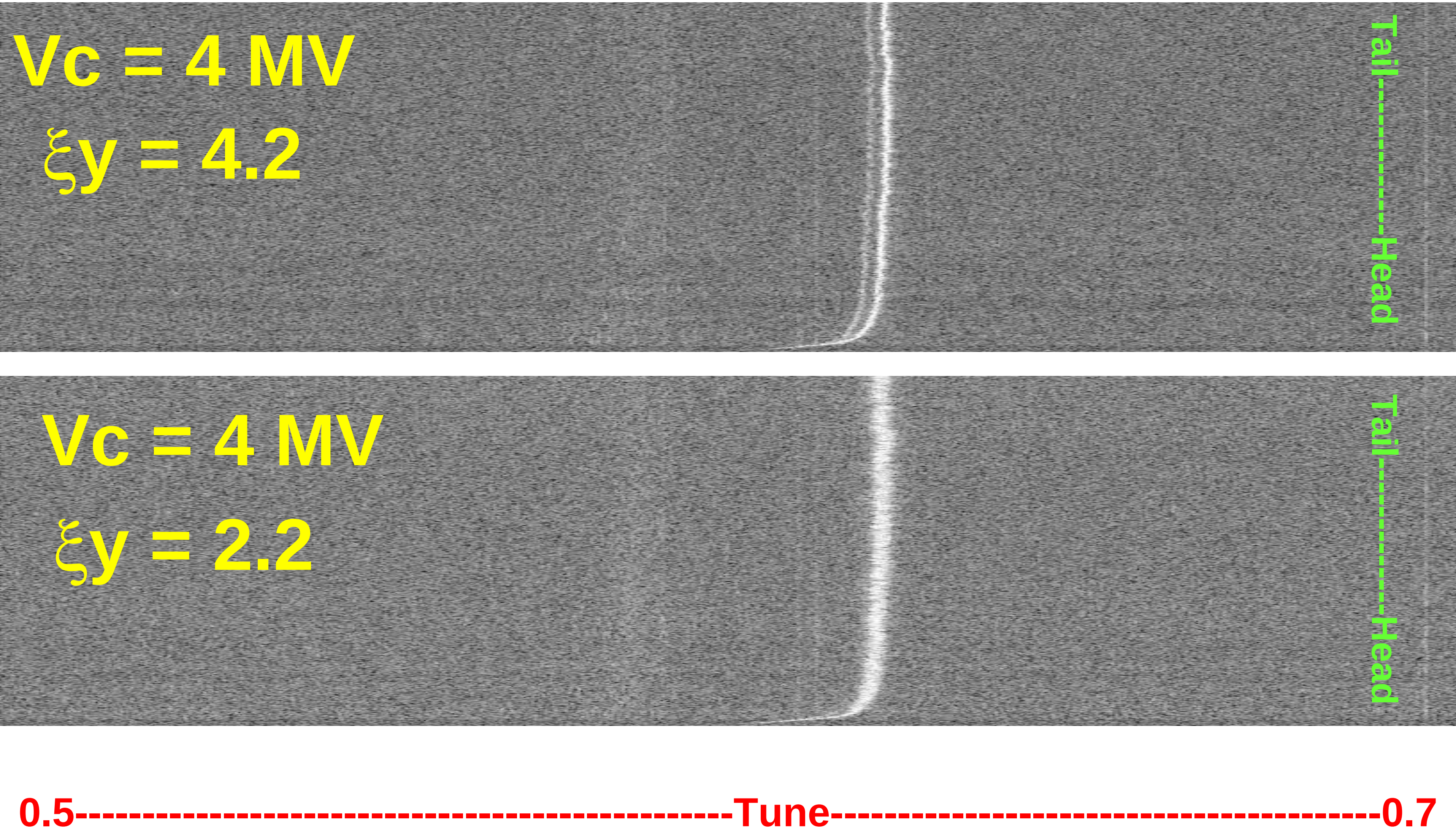
Results: Cannot reproduce!
But sideband splits…



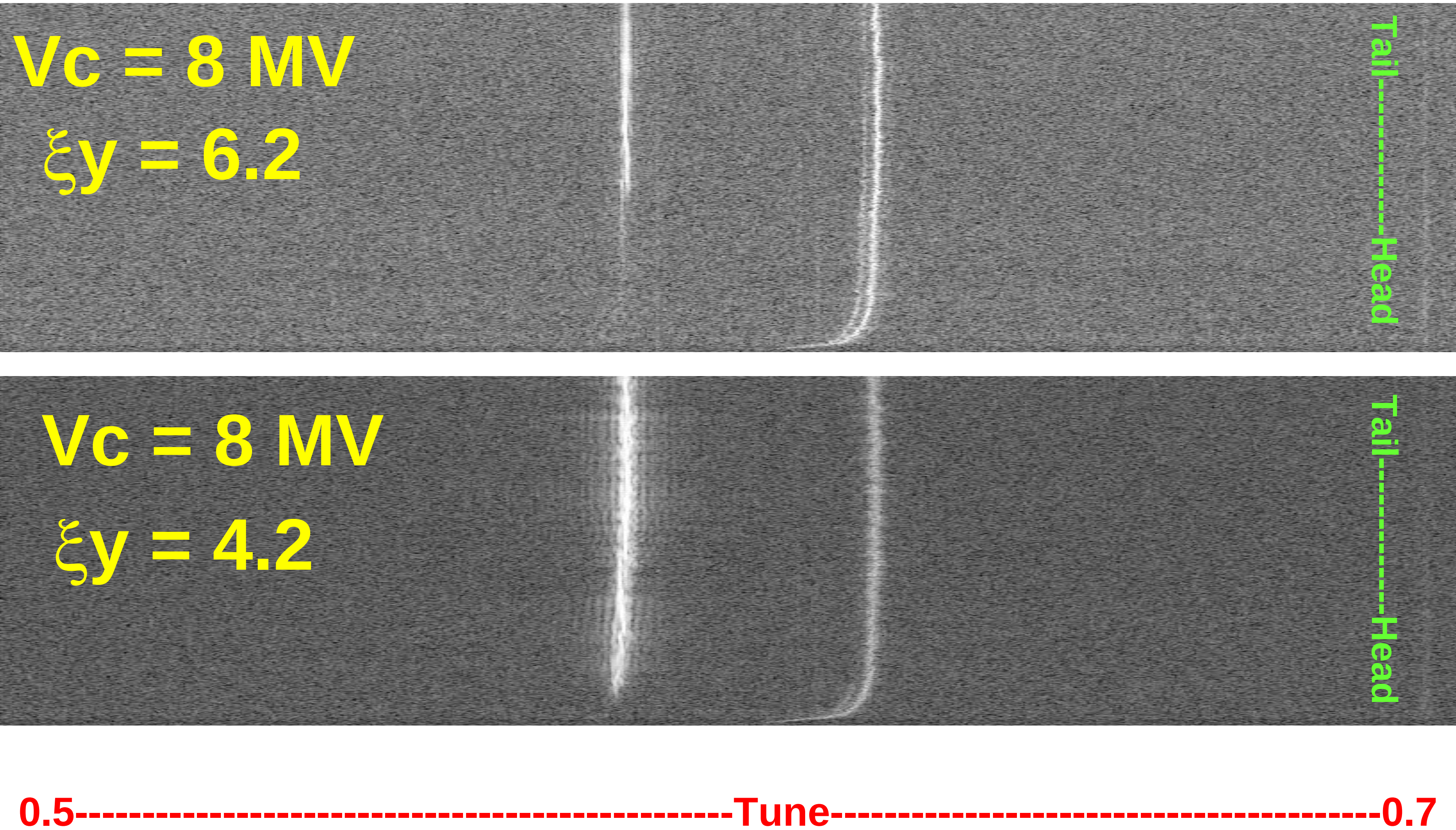


0.5--Tune--0.7

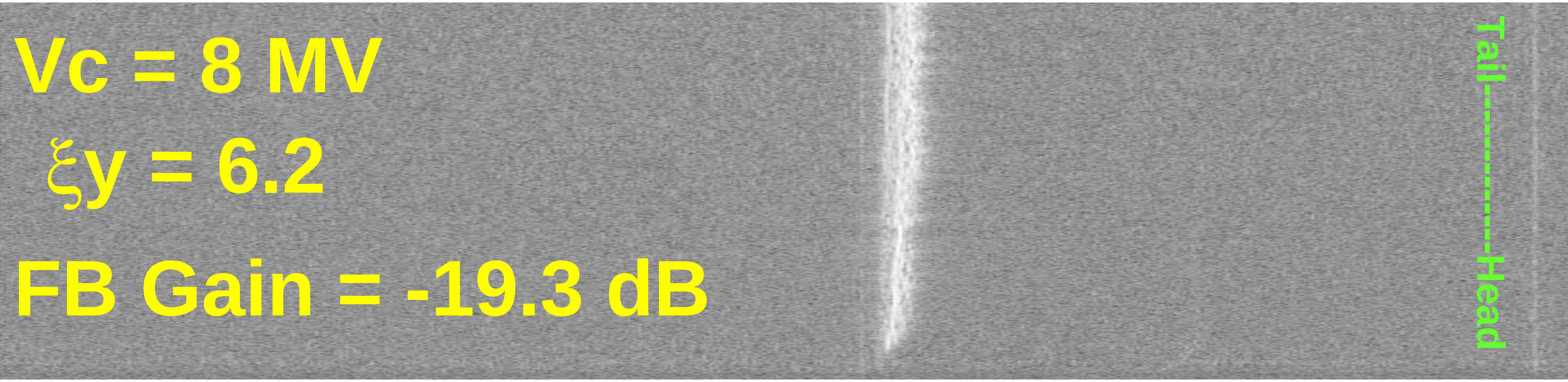
…And reunifies (blurs) if vertical chromaticity lowered

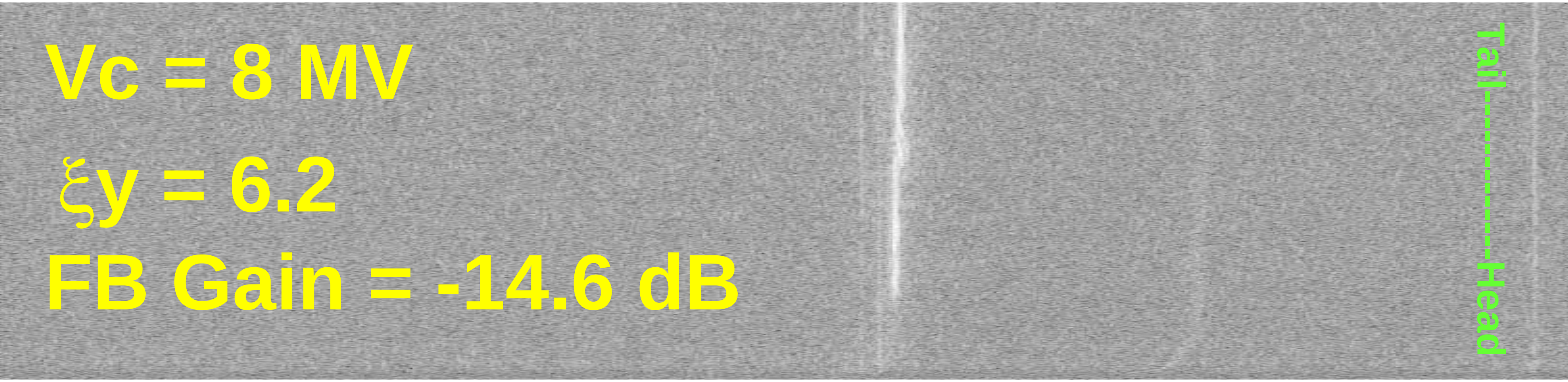


This also happens back at 8MV, though chromaticity threshold for splitting is higher



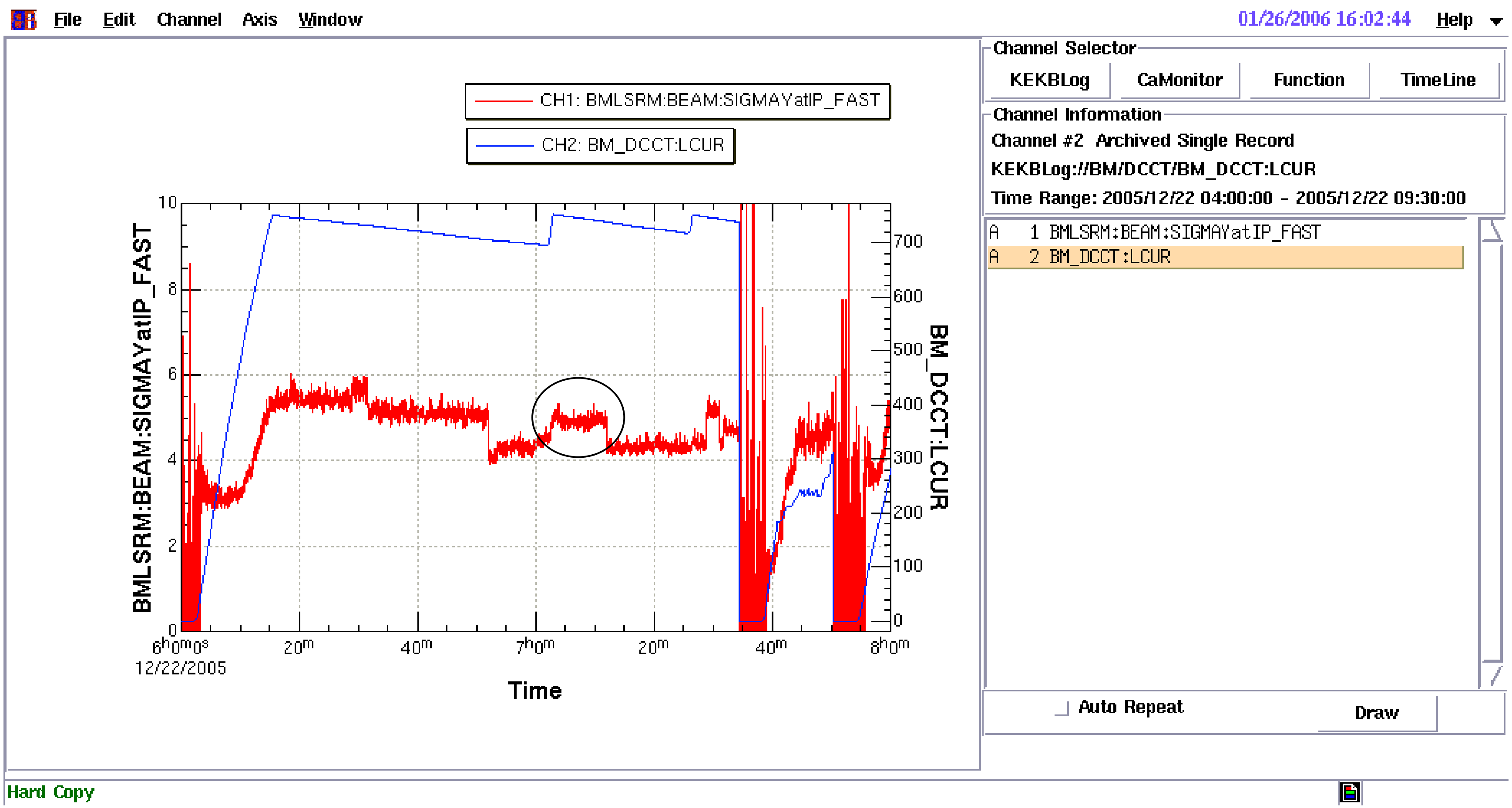
And sometimes (almost) disappears



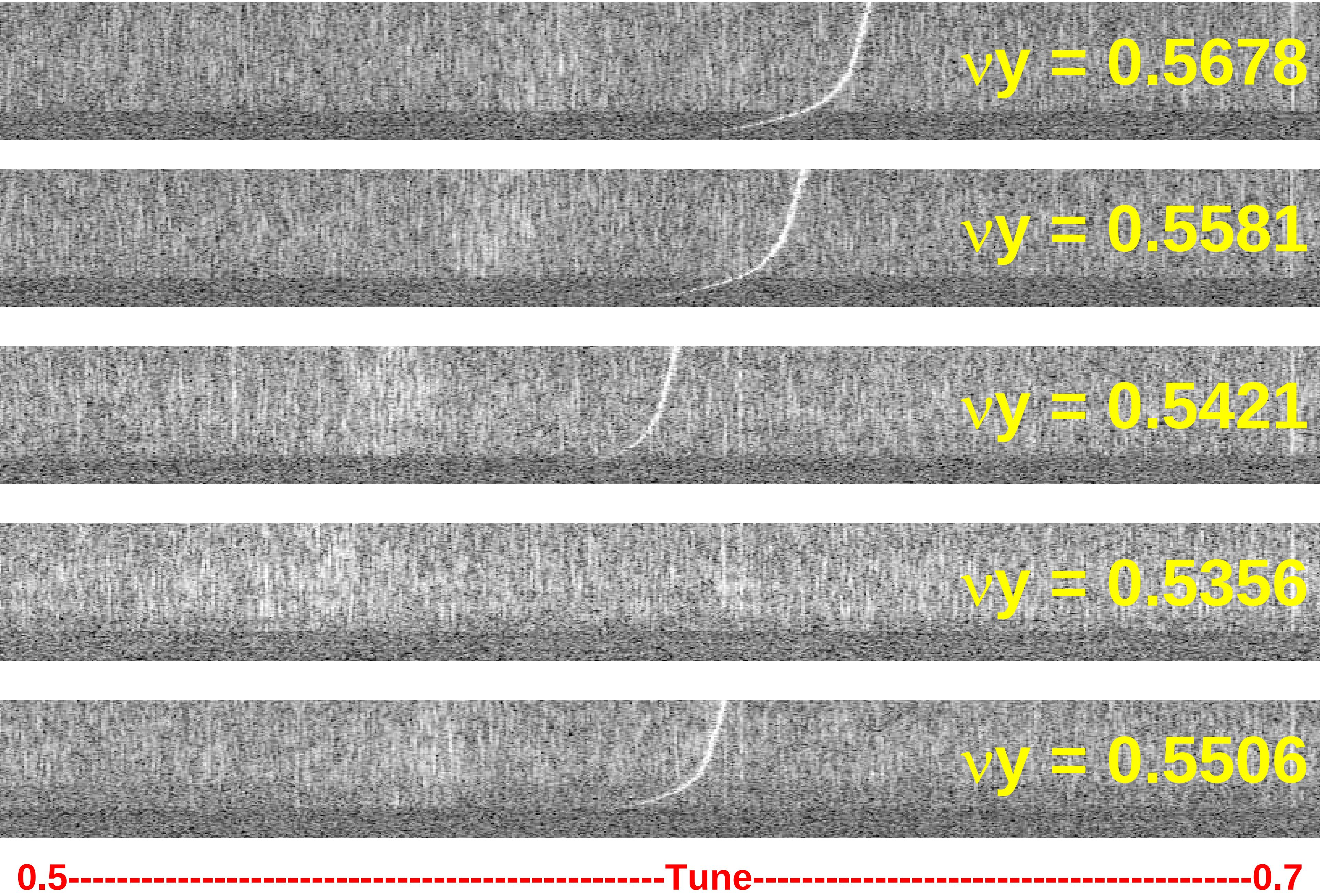


0.5--Tune--0.7

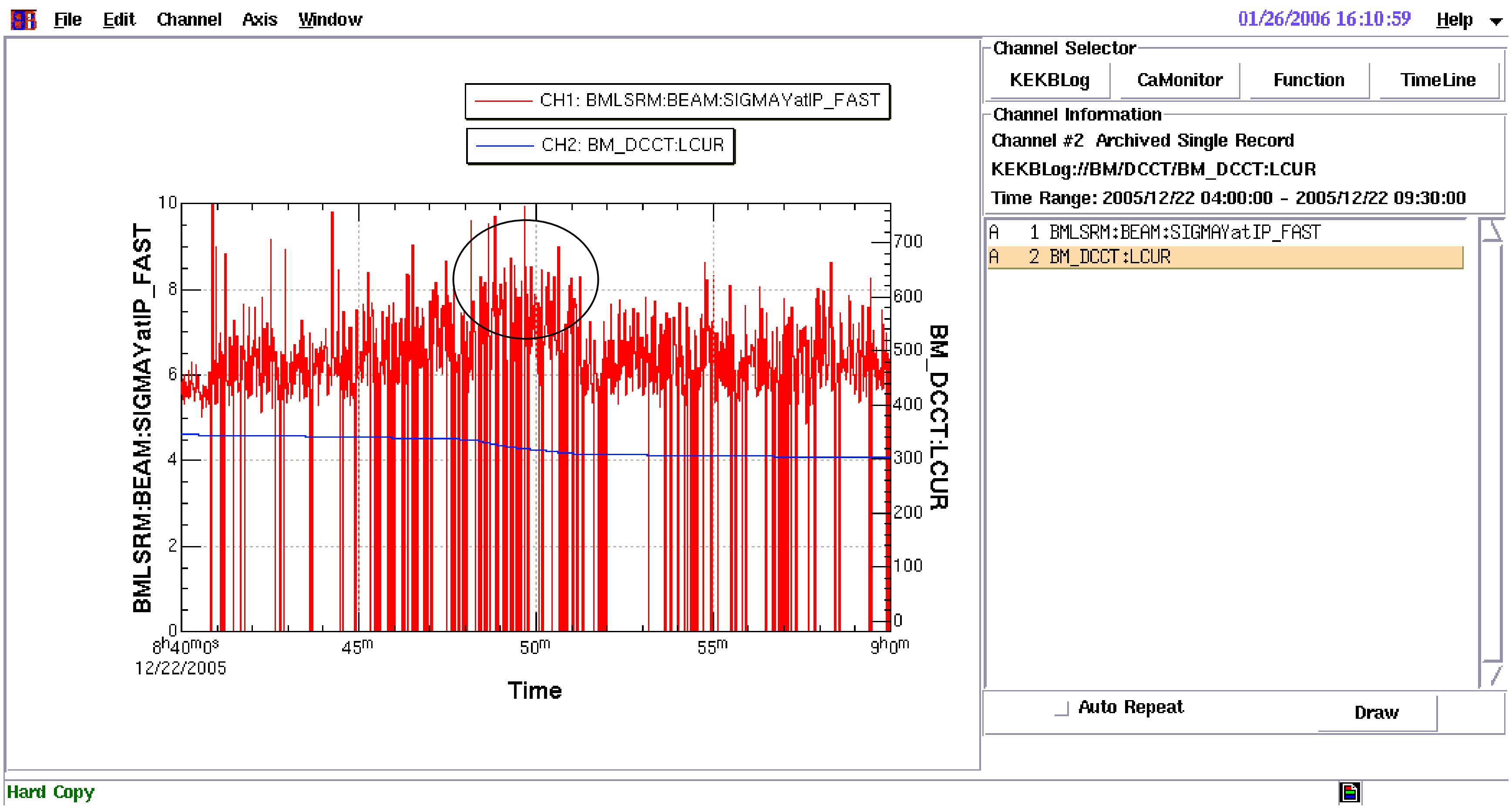
When sidebands disappear (in circle)



Goal 2: Hunt for left sideband via v. tune



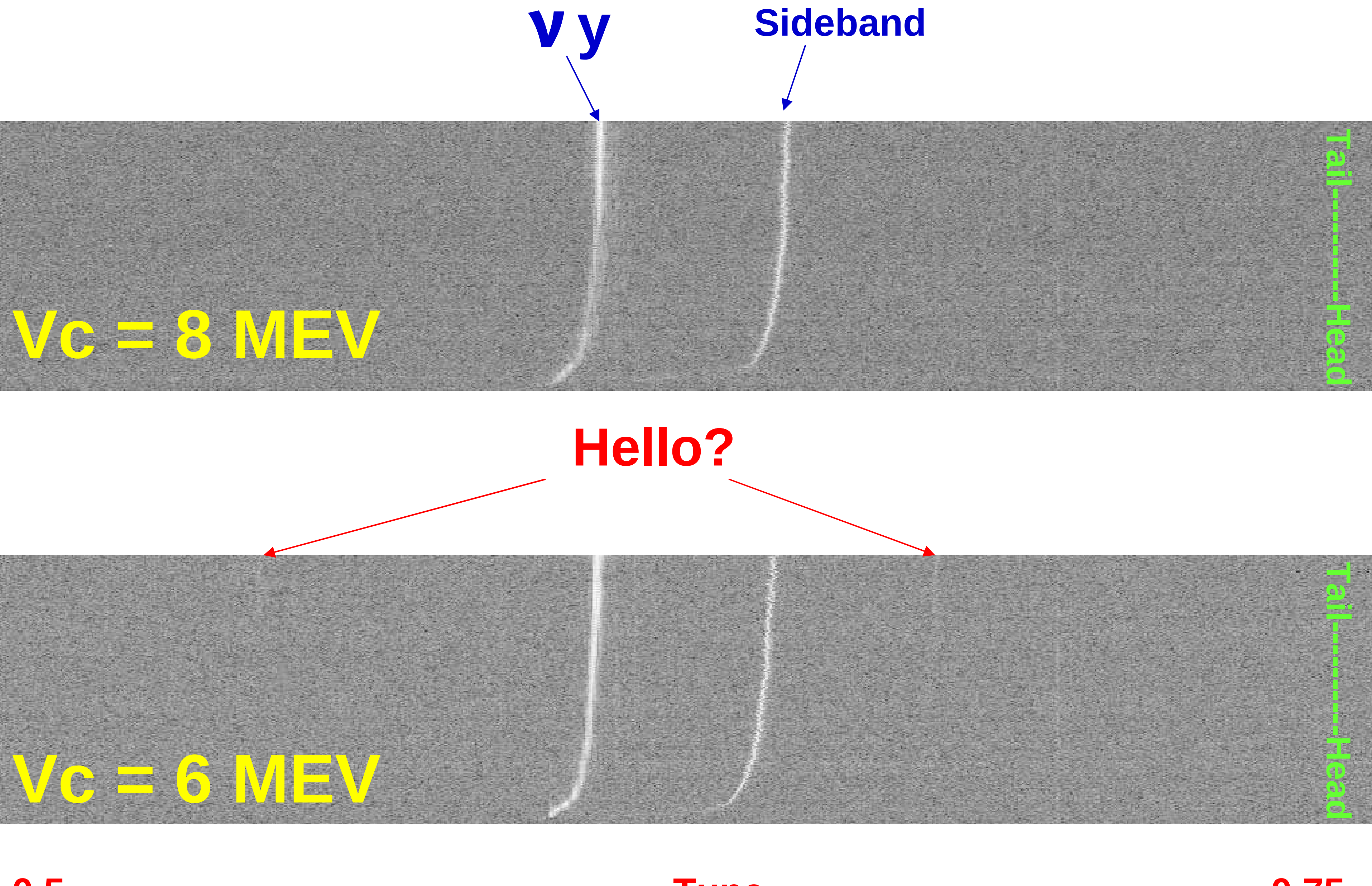
When sidebands disappear (in circle)



Miscellaneous Results

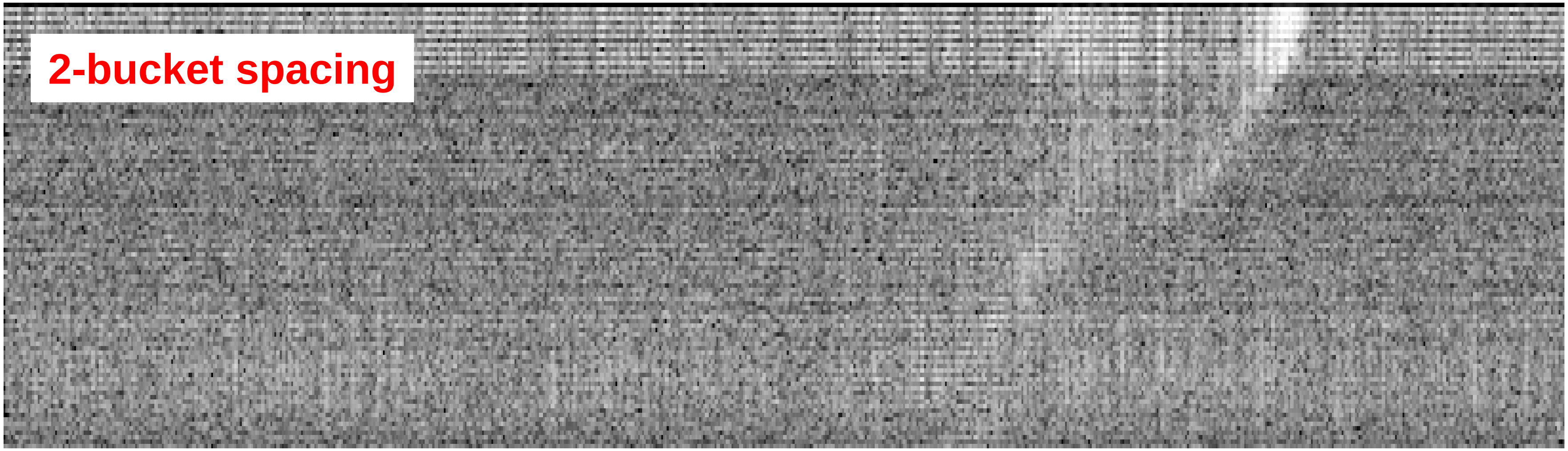
- Failed to reproduce strange behavior at Vc=4MV
  - But found sideband splitting at higher chromaticity
  - Also found sidebands disappear when betatron amplitude large (FB gain low)
    - Not clearly seen before
    - Betatron oscillations interfere with cloud pinching?
    - Something else going on?
- Failed to find left sideband
  - But sideband disappeared at very low νy, and reappeared when νy was raised again.
  - Looking at beam size, beam size was a bit larger when sideband had disappeared. (So no help for luminosity…?)

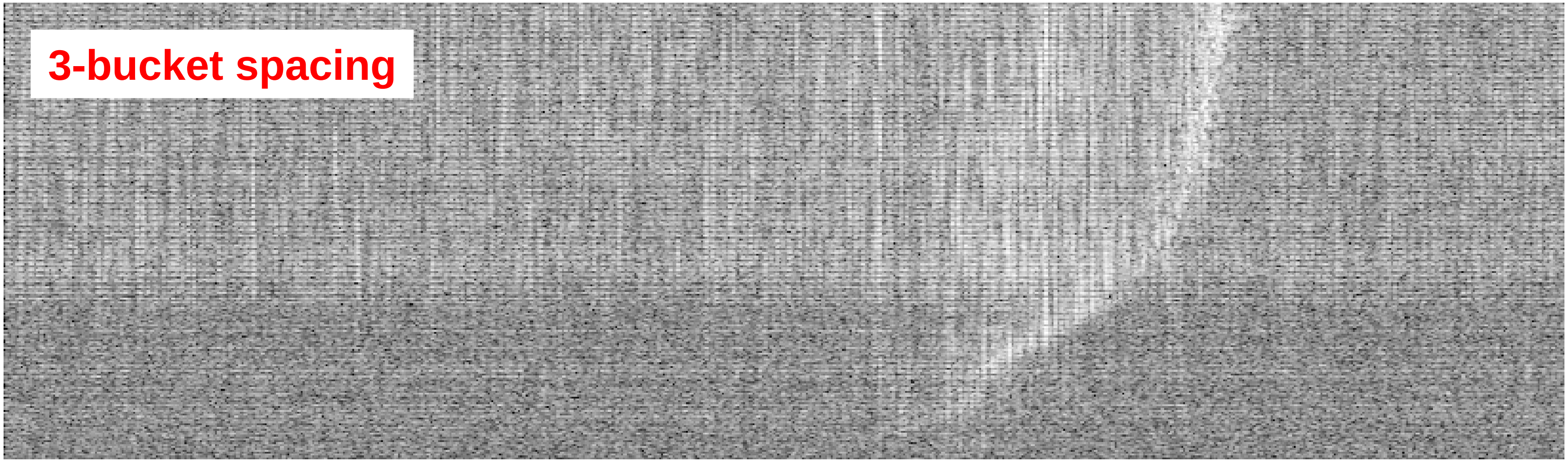
Extra: extra sidebands?



Sideband Splits off from Betatron Line?

From Quadropole Solenoid study (to be reported on in detail by H. Fukuma)





Final Summary

- Found sideband-betatron separation dependence on ν_s.
- Found sideband appearance threshold dependence on ξ_y.
  - Sizes of above 2 effects seem consistent with head-tail theory.
- Found no apparent threshold dependence on σ_{y0}.
  - Under study
- Found cases where specific luminosity remains suppressed even below sideband threshold
  - Possible indication of incoherent effects
- Found specific luminosity is lower at tail of LER bunch than at head, when electron cloud density is high.
  - Possible indication of blow-up towards tail of bunch
- Found cases where sidebands disappear or almost disappear
  - Conditions similar to those where luminosity is highest (low ν_y, V. FB gain).
- Found examples where sideband line seems to have split off from the betatron line near the head of the train.
  - Never clearly observed before

Spares

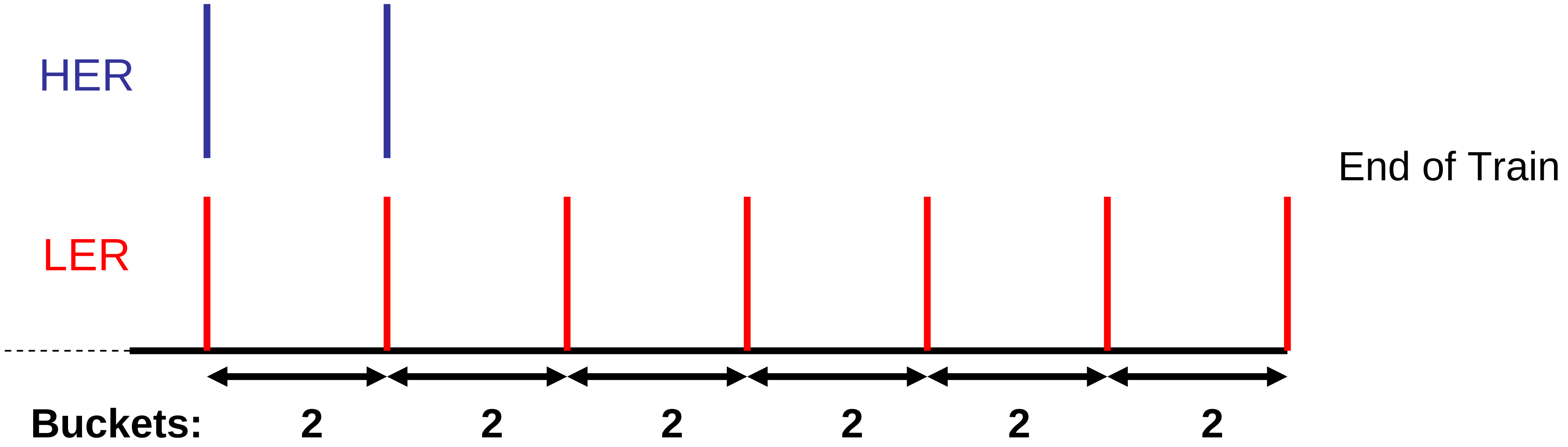
Measurements at PEP-II

With U. Wienands, D. Teytelman

- What would be nice to do at PEP-II:
  - Ideally, turn off solenoids
    - create e-clouds, and look at beam spectra.
    - Don't necessarily need to turn off all solenoids. Perhaps a limited region, to minimize impact on orbit, would be sufficient.
  - Alternatively, create localized e-cloud regions along the train.
    - Increase bunch currents of a set of bunches at end of train.
    - Pack a few extra bunches into train, at by-1 spacing.
    - Can be done more-or-less parasitically
  - Note: may even already have clouds
    - May be worth creating and looking at some pilot bunches in the LER with the current fill pattern.

Study Fill Patterns at PEP-II

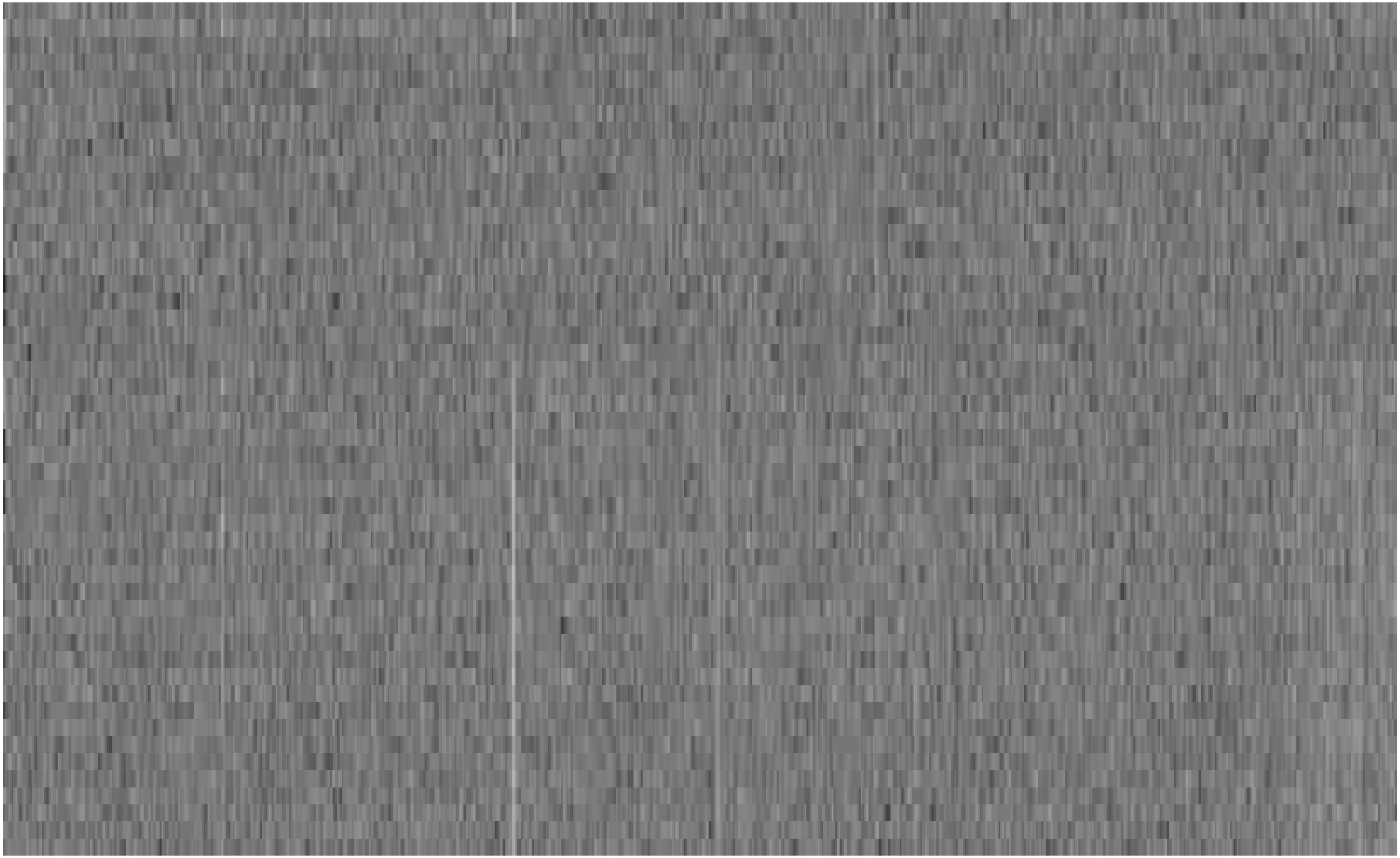
Fill Pattern 1 (least disruptive):



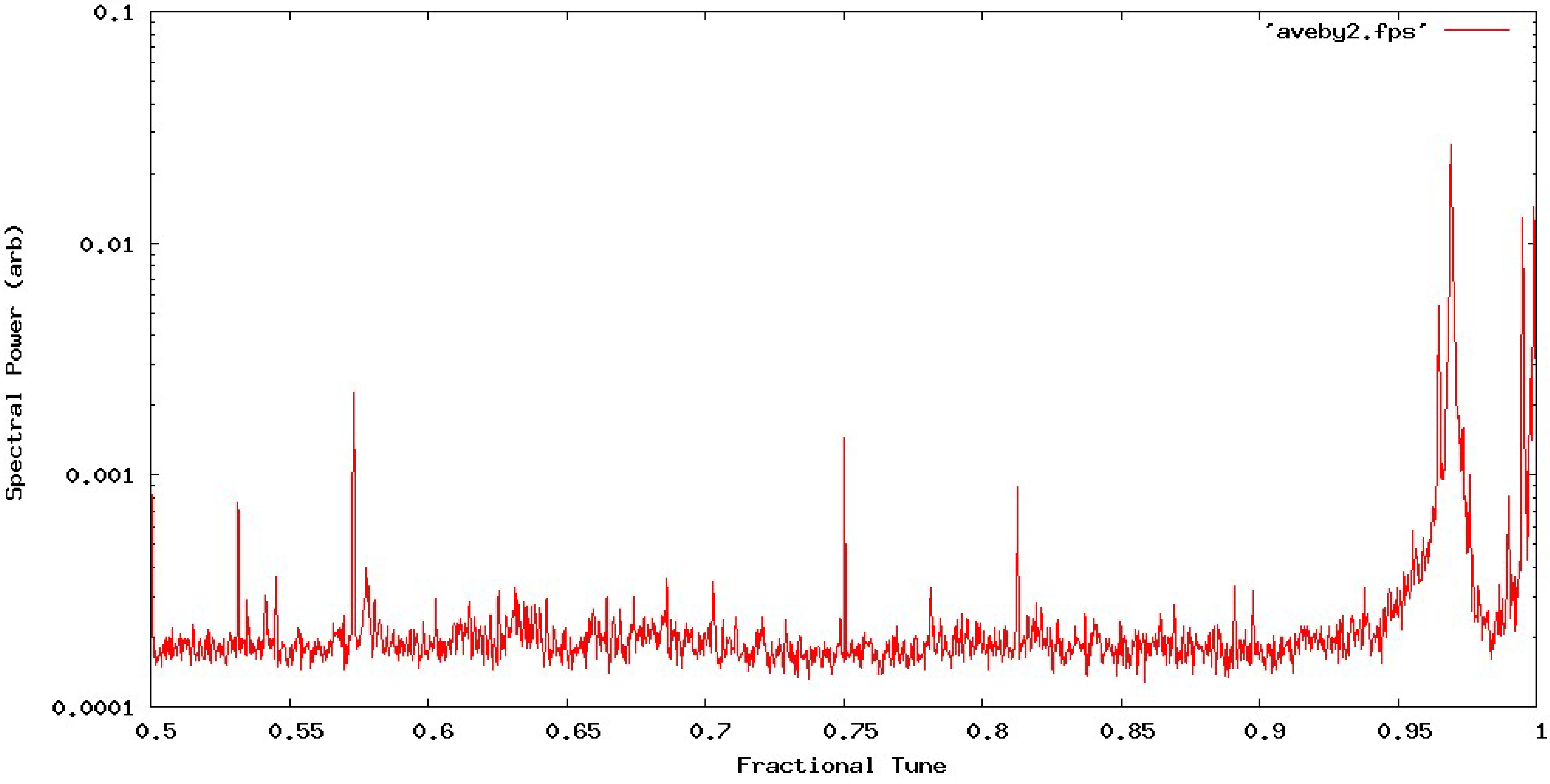
Create a few non-colliding bunches at the end of the train, examine transverse beam spectrum. If instability signal appears, try letting non-colliding LER bunches decay.

TRIED: No signal found at 1 mA/bunch. May retry with higher pilot bunch currents, and longer pilot bunch train.

Study Pattern 1: By-2 Pilot Bunches



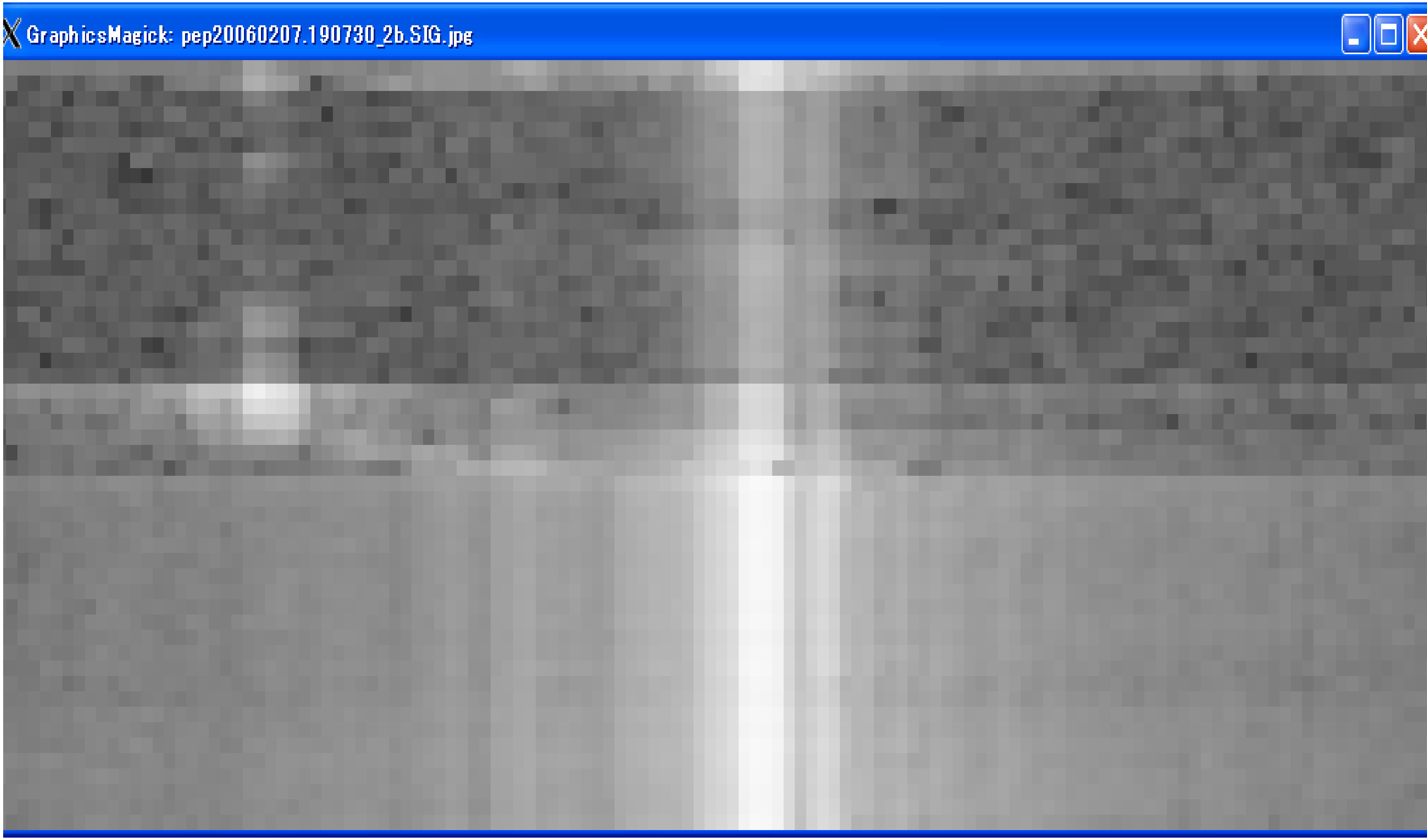
Study Pattern 1: By-2 Pilot Bunches



Sample spectrum at PEPII

(GAGE abort log)

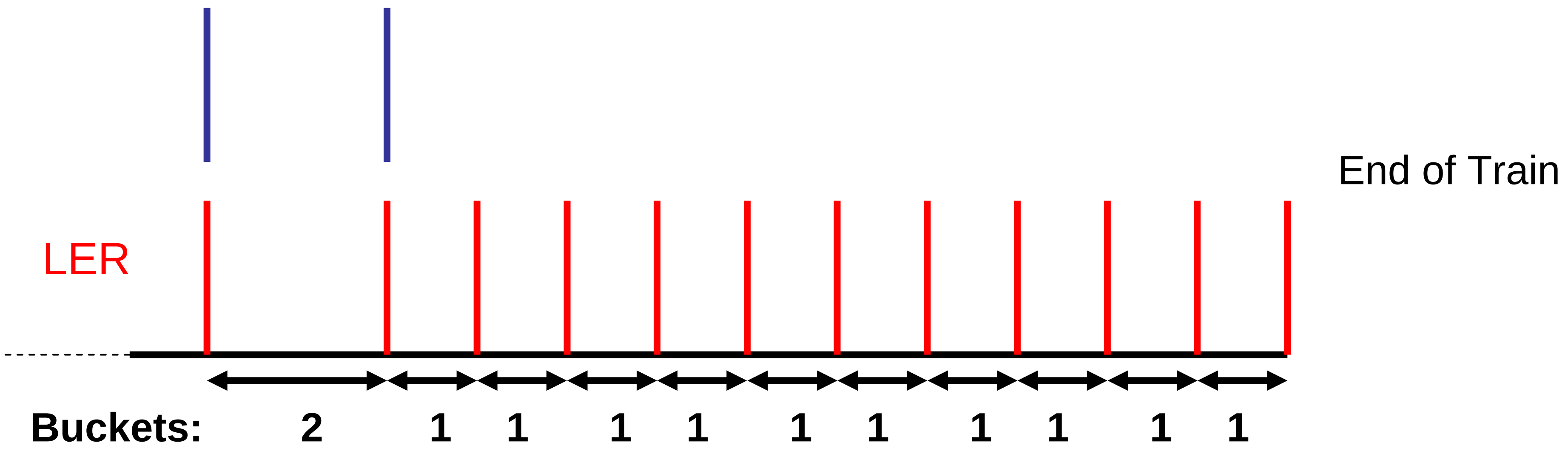
Bunch



0.58 Fractional Tune 0.59

Study Fill Patterns at PEP-II

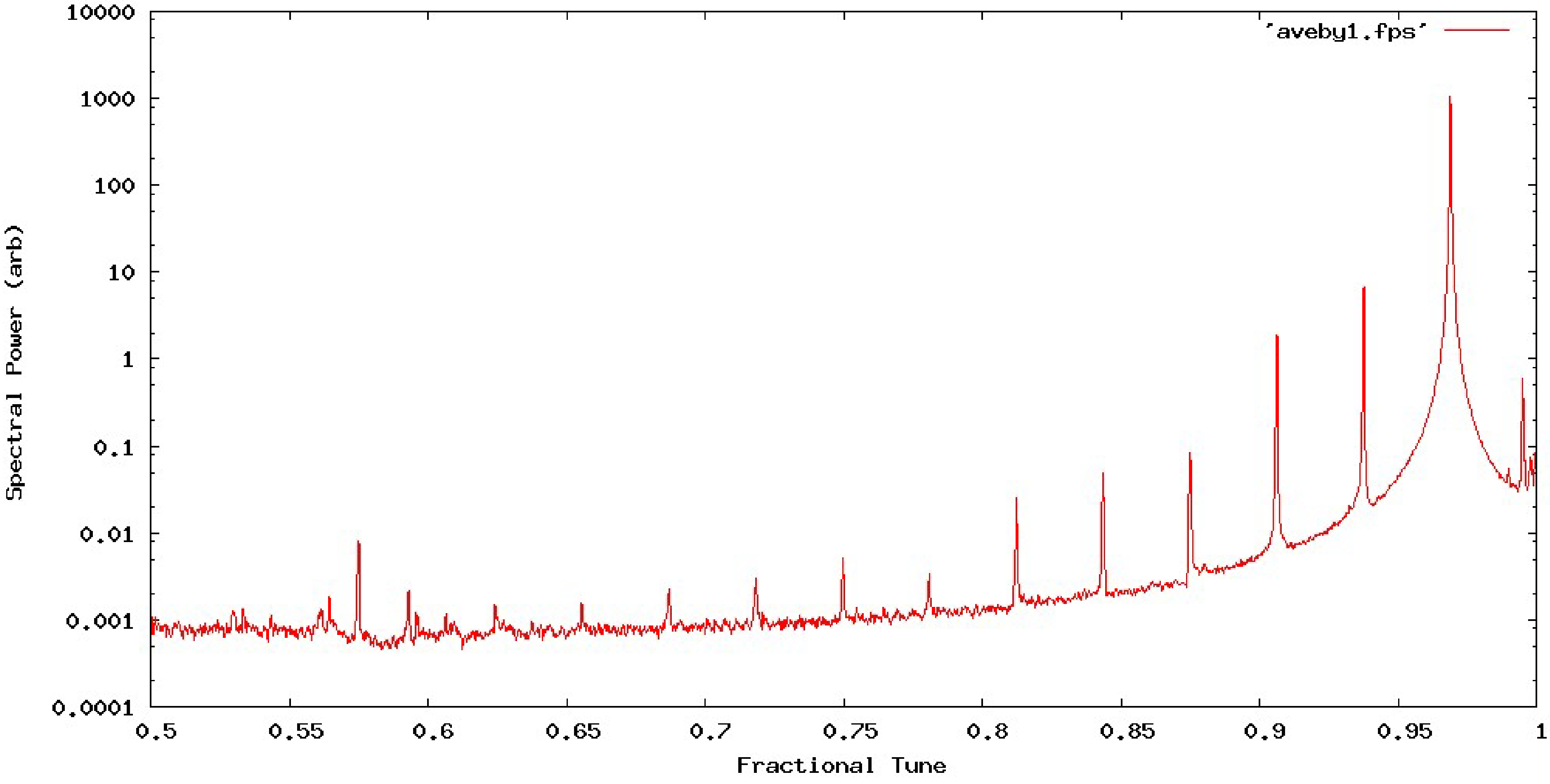
Fill Pattern 2 (tricky, but still parasitic with physics running):



Same as Pattern 1, but add some extra bunches between existing bunches to increase electron cloud density.

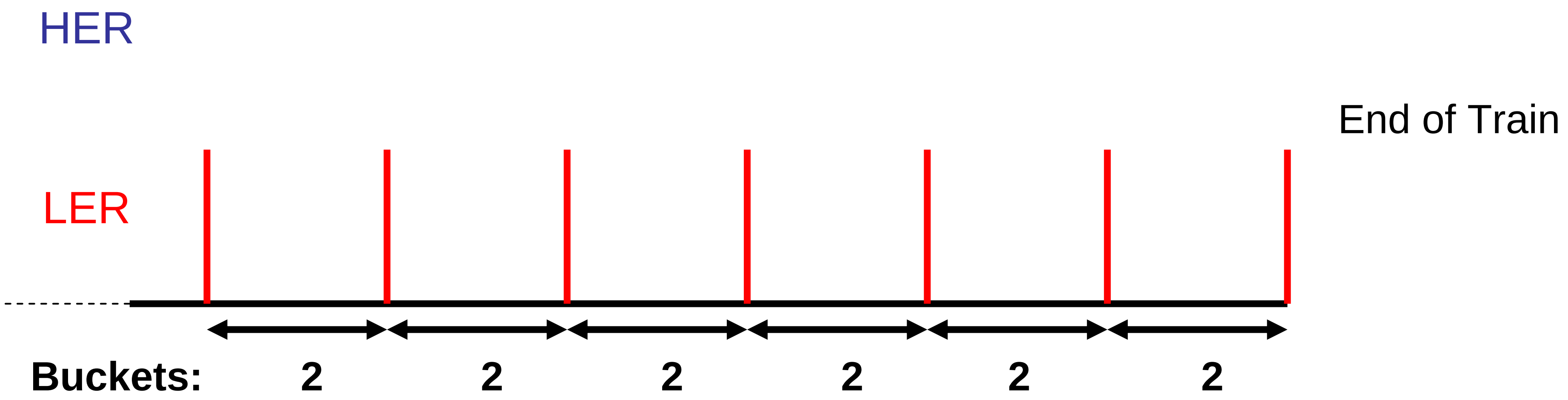
TRIED: Strong synchrotron harmonics appear all over the spectrum. May retry with longitudinal feedback turned off in pilot section of fill.

Study Pattern 2: By-1 Pilot Bunches



Study Fill Patterns at PEP-II

Fill Pattern 3 (dedicated machine time needed):



LER single-beam, or at least not in collision.
Turn solenoids off, correct steering, fill to enough current to create clouds, take beam position spectra while injecting. Monitor beam size in parallel.
Could be done in parallel with other activities in the HER.

Not yet tried.

Can we understood this behavior?

- Threshold

$$\rho_{e,th} = \frac{2\gamma\nu_s\,\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L}$$

$Q=\min(Q_{nl}, \omega_e\sigma_z/c)$

$$\omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}$$

- ω_e of numerator is cancelled by ω_e in Q so perfectly?

  Future problem 3

- Maybe true, since $\omega_e\sigma_z/c=2.5$ for KEKB.

K. Ohmi, Snowmass 2005

Threshold and Chromaticity

Note: For KEKB, $\Delta\xi_y$ ~ 3 should give a change in cloud-density threshold of ~10%, if $\rho_{thresh}\ \alpha\ (\omega_e - \xi\omega_0/\alpha)/\omega_e$