

Beam Instabilities Diagnostics

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Workshop
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Outline

- I. Introduction
- II. Experimental Background
- III. Examples of Instability Measurements
 - transverse
 - longitudinal
- IV. Potential Technique Development Areas
- V. Summary

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II. Experimental Background

Instabilities that affect beam brightness and lifetime are directly observed in the measurement of fundamental properties.

Transverse

Technique

Beam position (x,y)

rf BPM

Beam profile/emittance (x,y)

x-ray pinhole

camera

Betatron tune (x,y)

rf pickup

Longitudinal

Bunch length

streak camera

Bunch profile

streak camera

Bunch phase

streak, rf probe

Energy

dipole and position reading

Energy spread

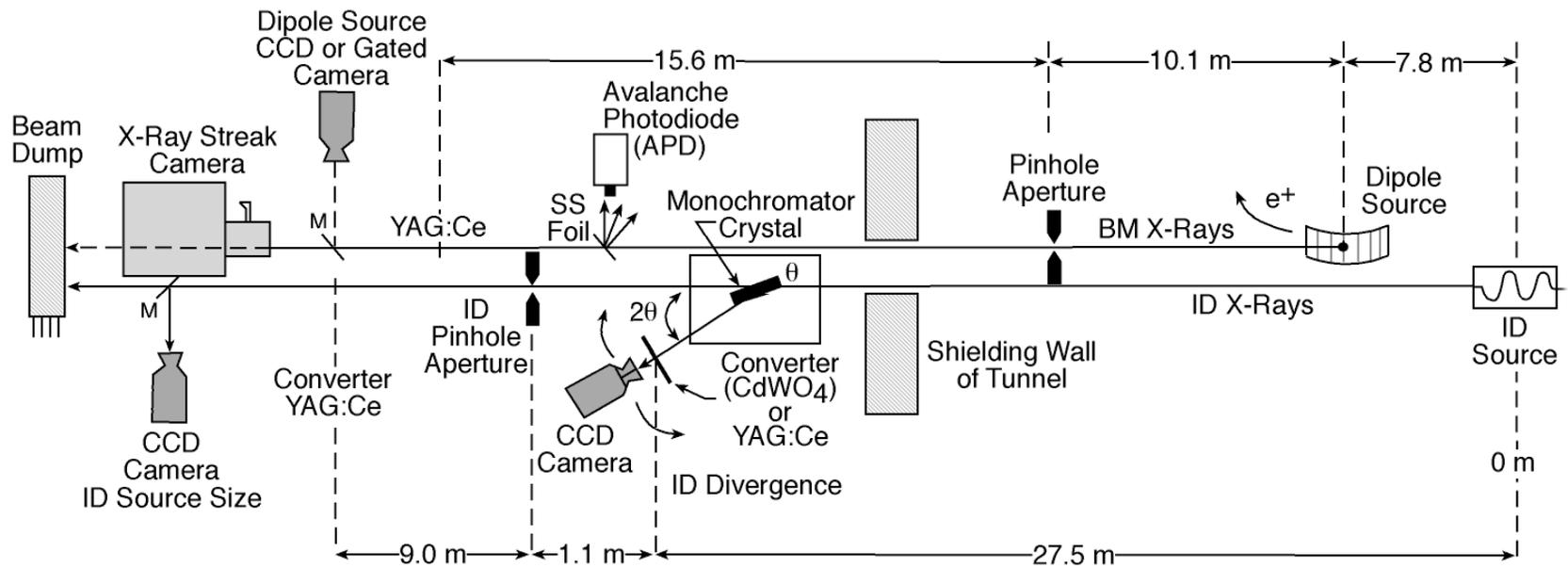
dispersive regime and image

Synchrotron tune

rf pickup

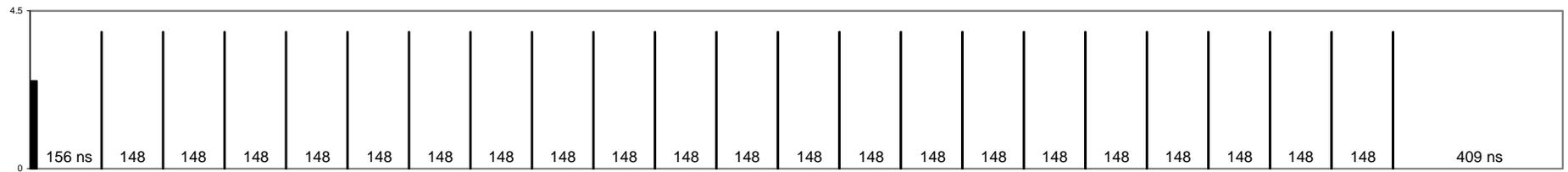
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Schematic of the APS Beam Diagnostics Sector

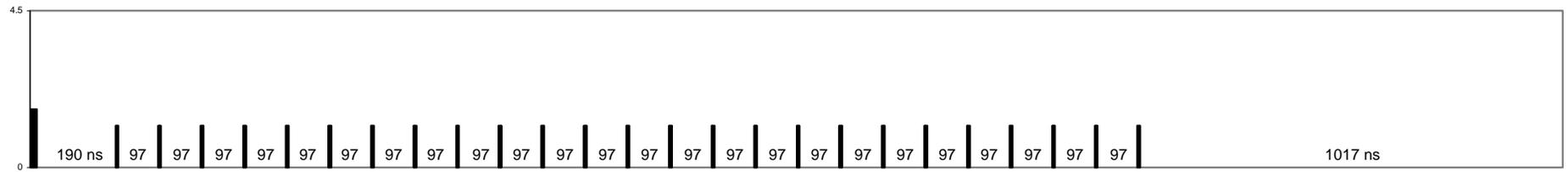


Advanced Photon Source Bunch Patterns

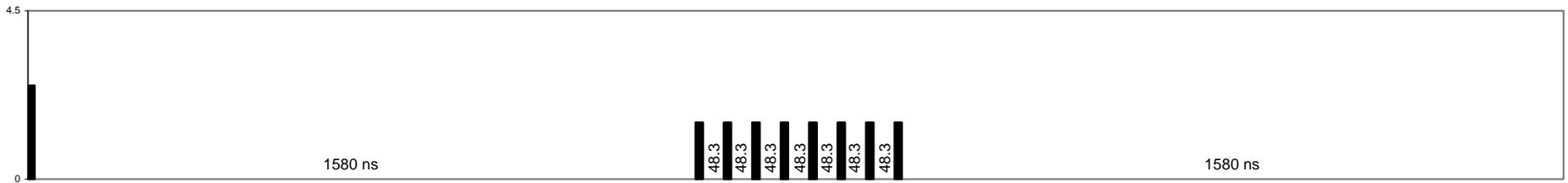
Singlets - 6 + 1*22



Triplets - 6 + 3*25



Hybrid - 6 + 7*8



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III. Examples of Instability Measurements

A. 6 + 22 Singlets Fill (APS User Fill Experiments)

Transverse Instability

Track 35-BM pinhole camera (dispersive point:
use as ref.)

Track bunch length, 35-ID divergence, 35-ID
pinhole images for similar fills

Check lifetime correlation

Check chromaticity effects

Longitudinal Instability

Track 35-BM pinhole image sizes

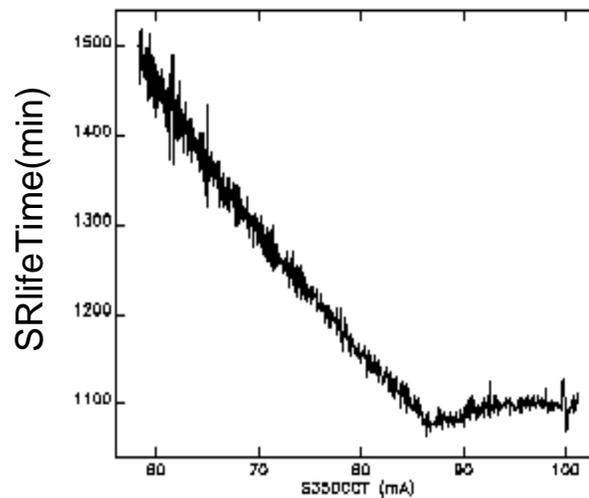
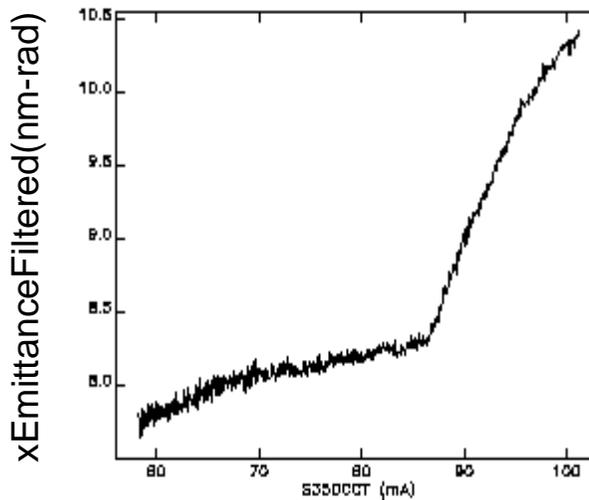
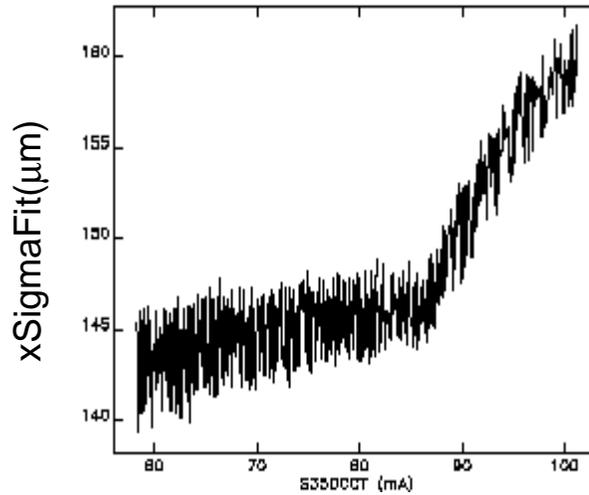
Track 35-BM streak camera data

Display dual-sweep streak images during
instability (10 μ s, 100 μ s, 1 ms)

Vary rf cavity temperature set point

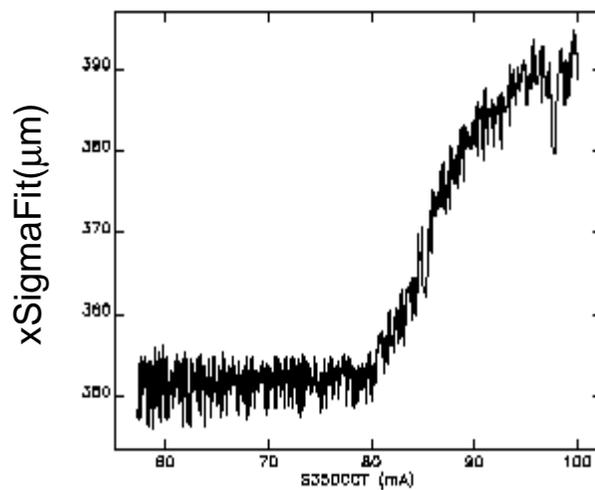
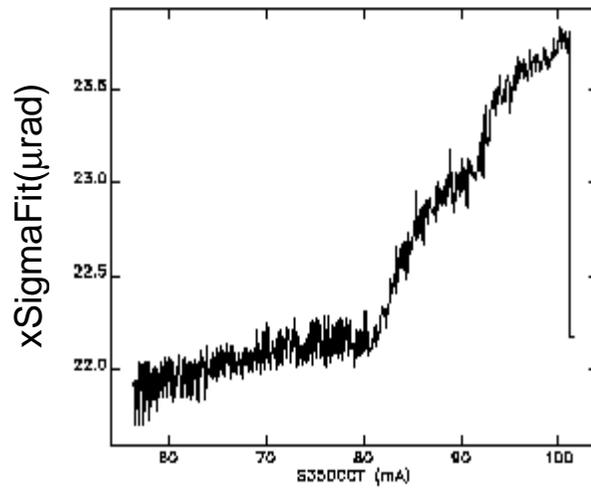
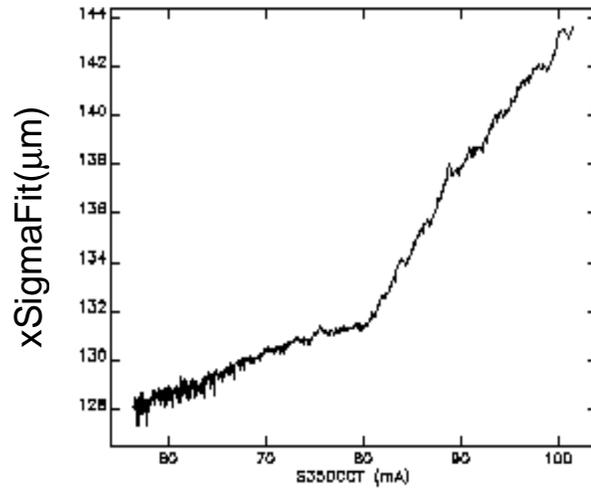
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Horizontal Beam Size and Lifetime
Show Correlated Change at ~ 85 mA (positrons)



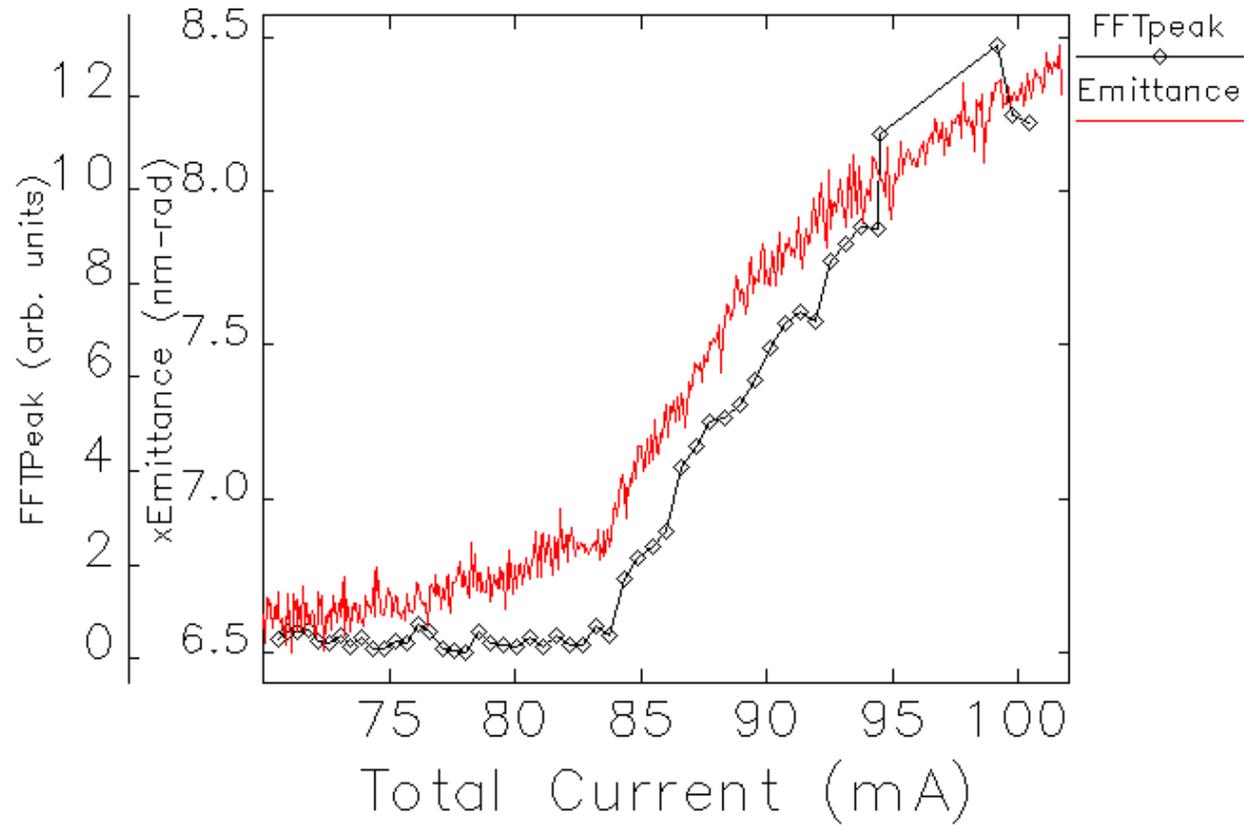
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Correlated Change of Parameter Observed at Bending Magnet and Insertion Device Source Points at 85 mA



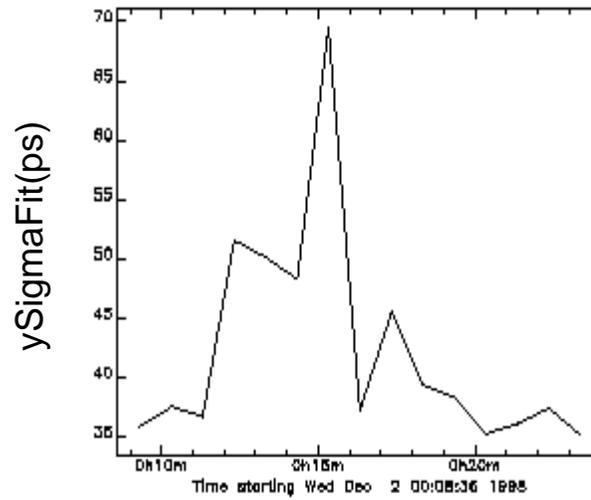
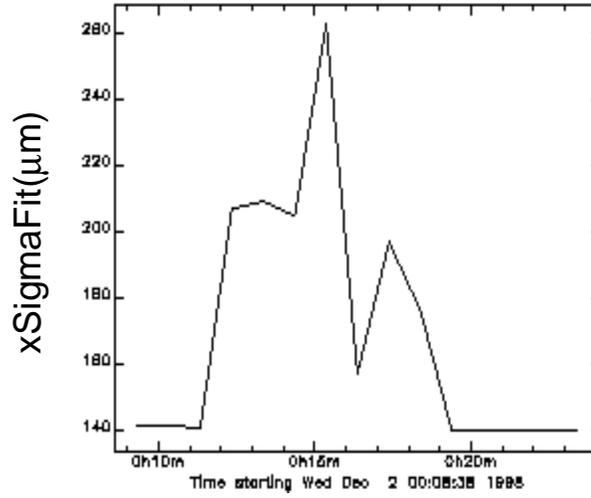
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Correlated Change of Beam Motion and Emittance Observed Near 85 mA



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Correlated Change in Energy Spread and Bunch Length Observed at 101 mA



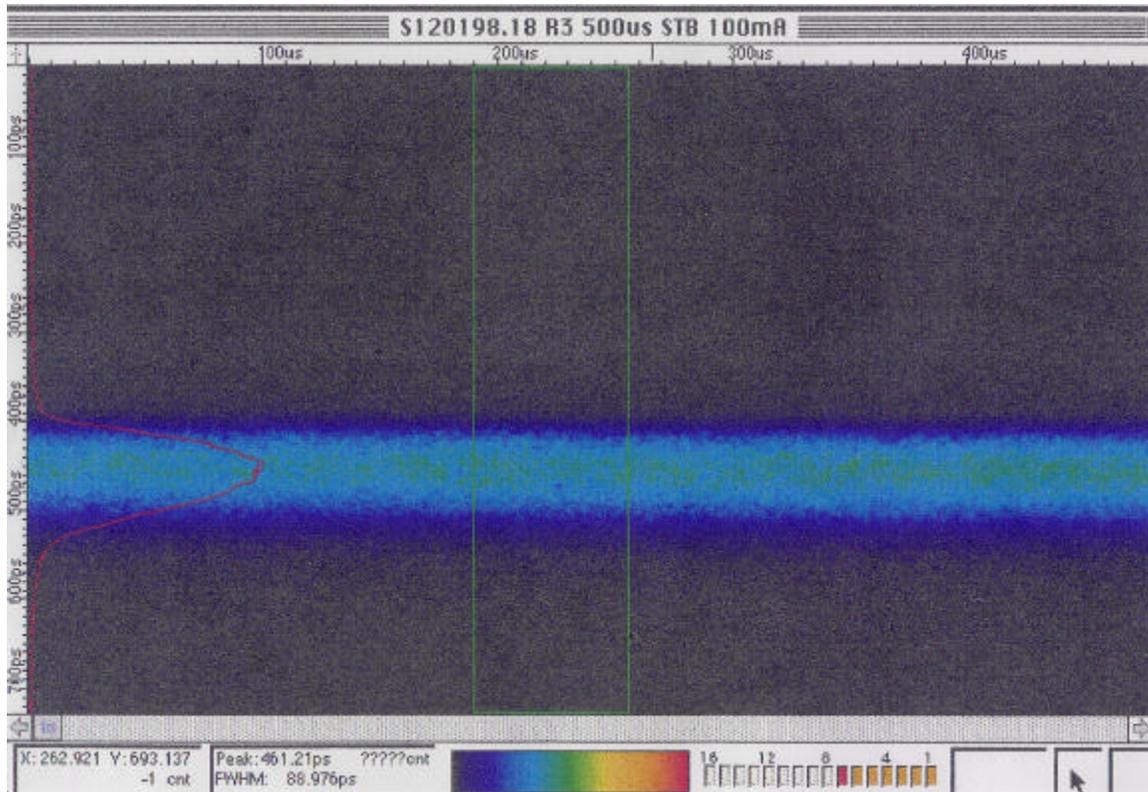
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Streak Camera in Focus Mode



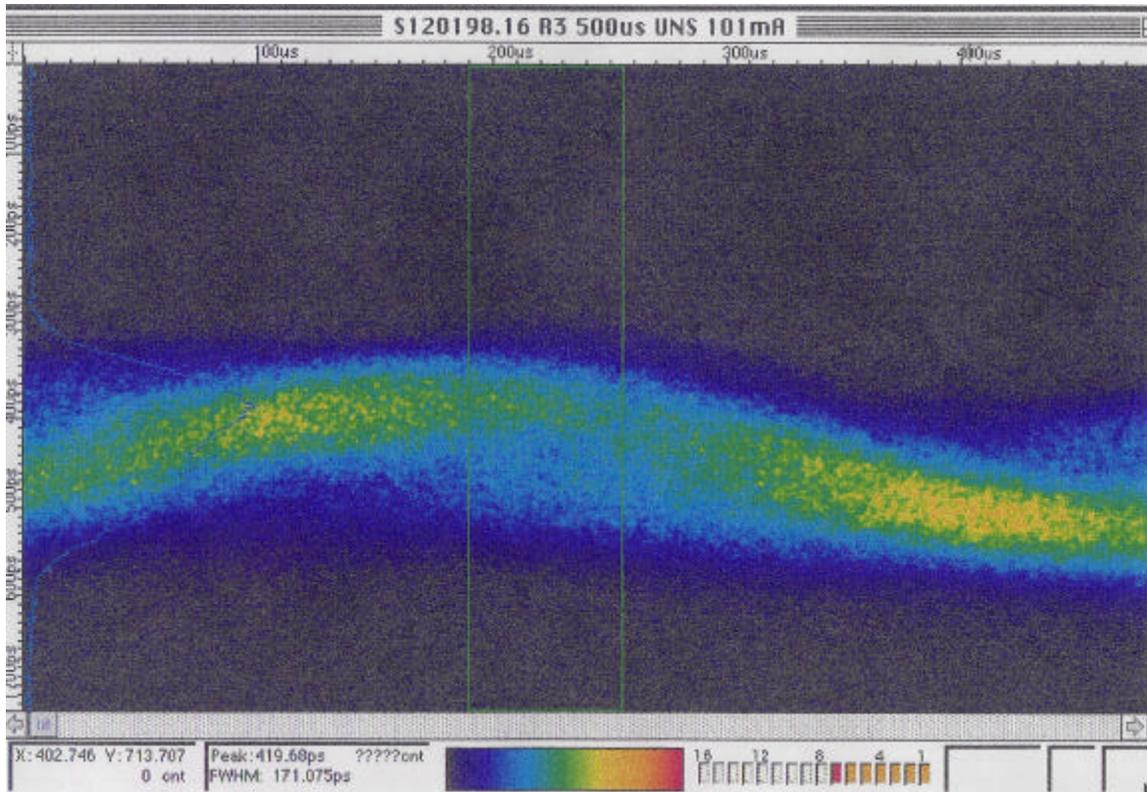
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Dual-Sweep Streak Image: Stable Beam



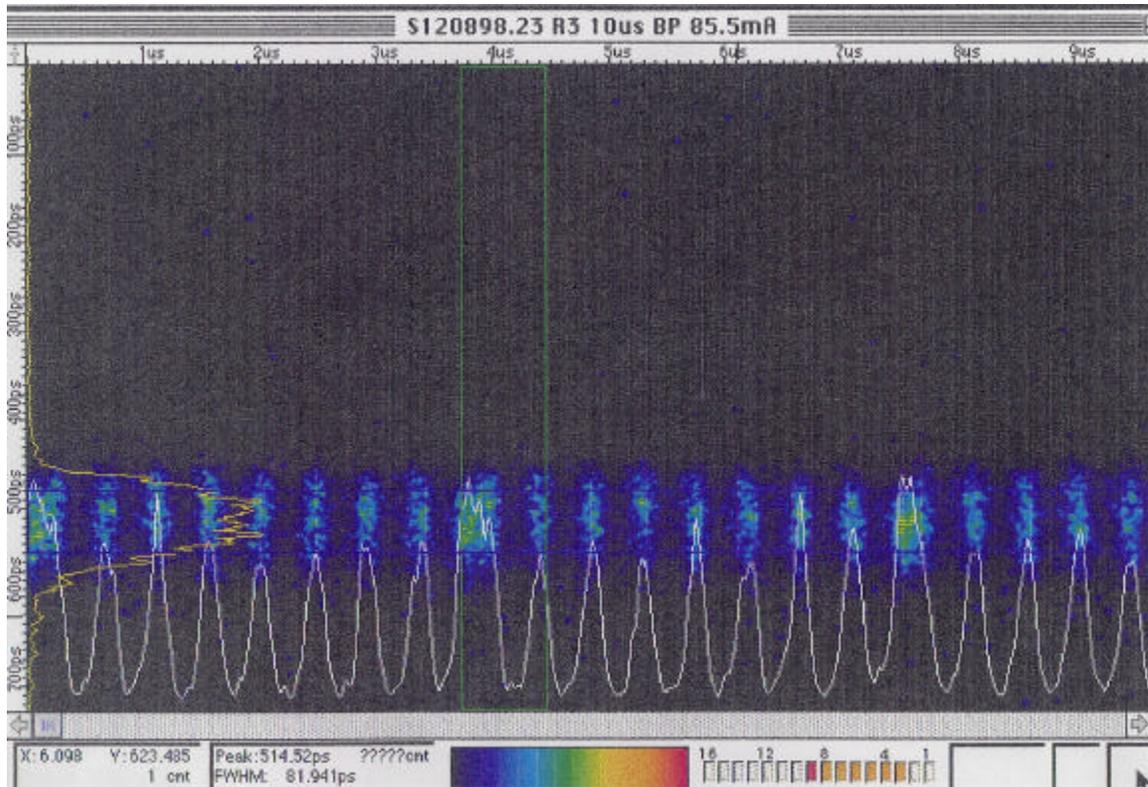
ADVANCED PHOTON SOURCE

Dual-Sweep Streak Image: Unstable Beam



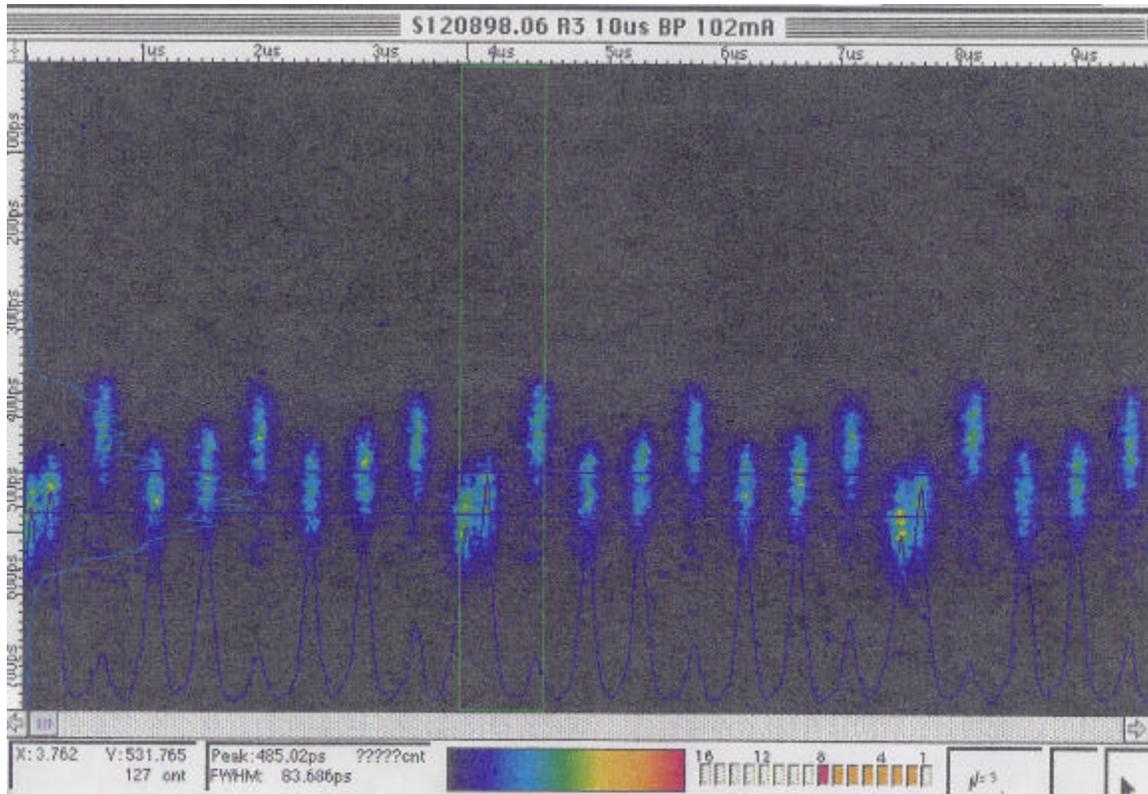
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Dual-Sweep Streak Image: Stable Beam



ADVANCED PHOTON SOURCE

Dual-Sweep Streak Image: Unstable Beam



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III. Examples of Instability Measurements

A. 6 + 22 Singlets Fill (APS Observations)

Transverse Instability

Threshold is 80-85 mA

Horizontal size increase observed (~10%) in averaged files (35-BM pinhole camera)

SR beam lifetime correlated

Emery has previously measured horizontal centroid motion: Chromaticity effect, rf cavity phases (?) observed

Correlation with 35-ID divergence and source size, not bunch length

Longitudinal Instability

Usually seen at 101 mA

Horizontal size increase is significant: $\sigma_x = 135 -$

$> 210 \text{ m}$

Correlated effect with bunch length

Sensitive to rf cavity temperature

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III. Examples of Instability Measurements

B. Further Examples of Instability Measurements (Single Bunch)

Transverse

APS: Head-tail
(A. Lumpkin, B. Yang)

ESRF: Head-tail
(O. Naumann, J. Jacob)

LEP: Head-tail
(E. Rossa)

Longitudinal

SSRL: Long-term wakefield, cavity
(C. Limborg, J. Sebek)

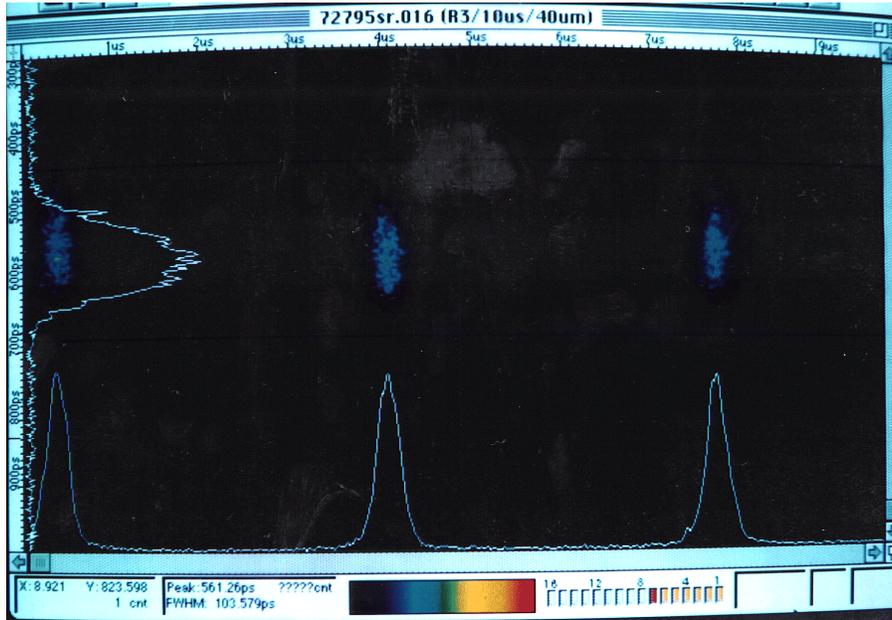
APS: Microwave Instability (?)
(Y. Chae, L. Emery, B. Yang, A. Lumpkin)

ESRF: Energy spread effect
(A. Ropert)

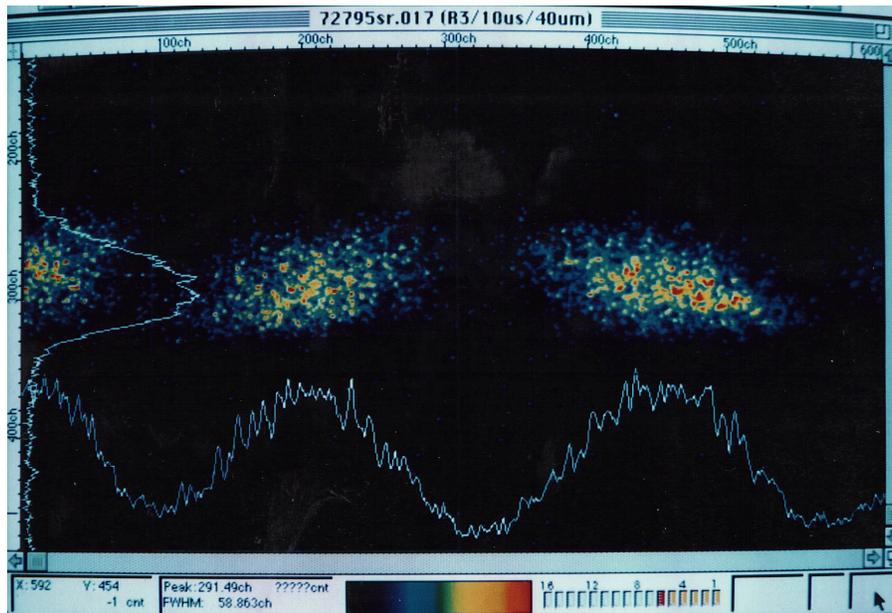
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Dual-Sweep Streak Camera Images Display Head-Tail Beam Instability at APS

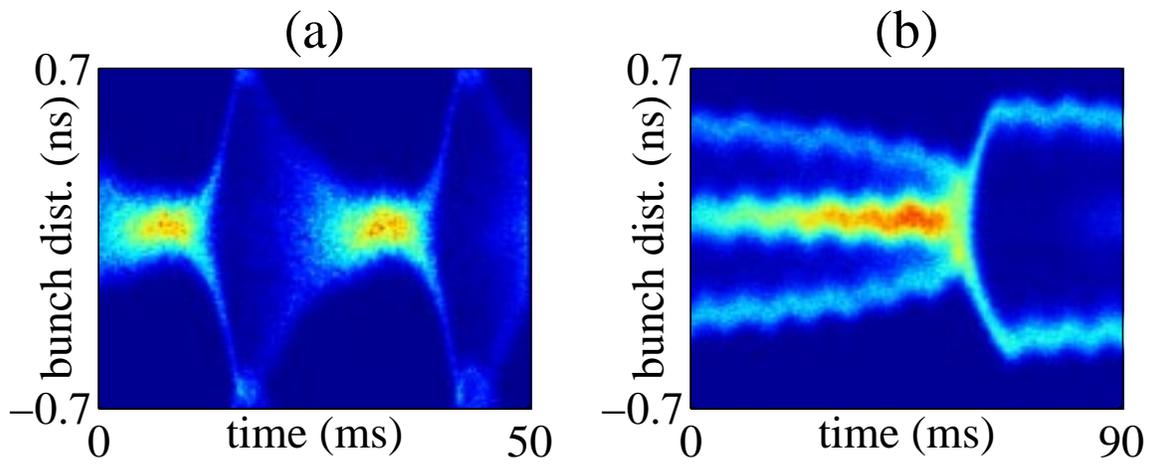
a) Stable



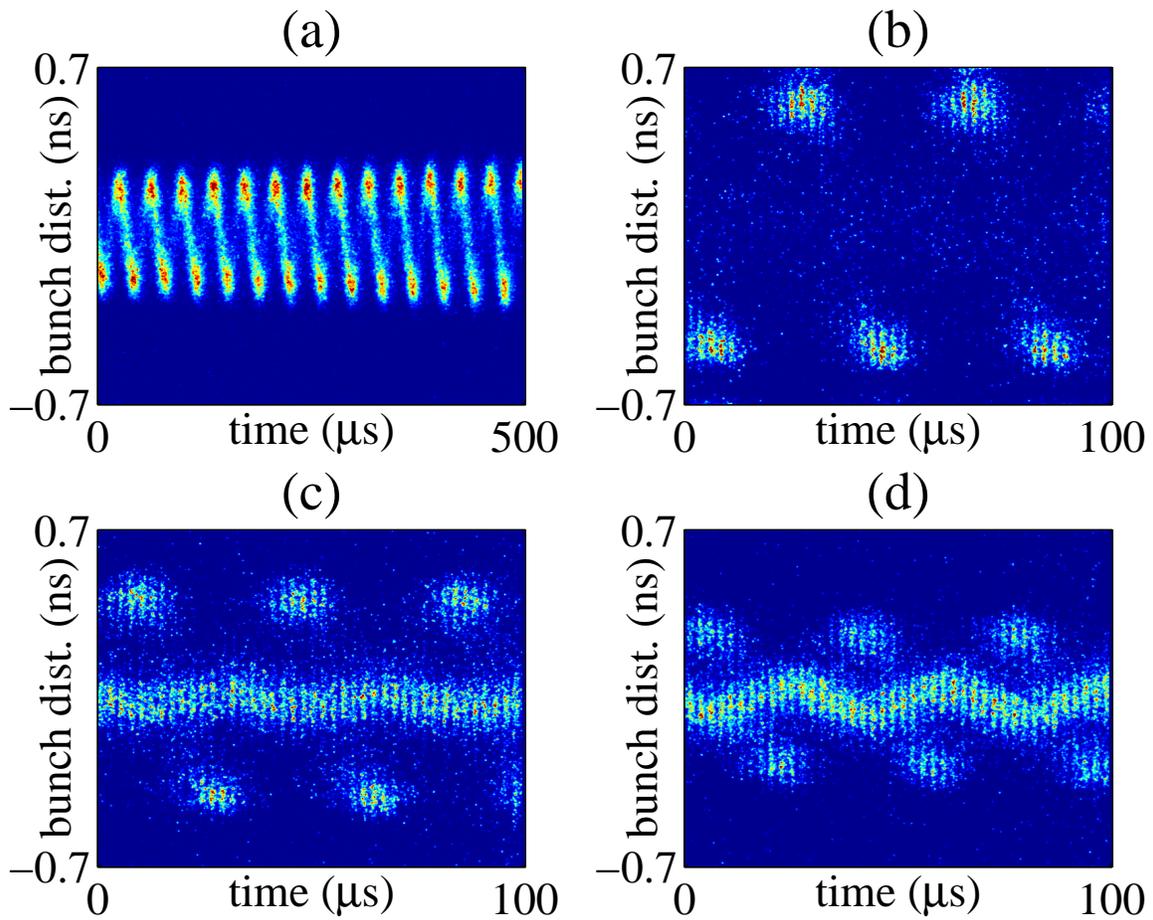
b) Unstable



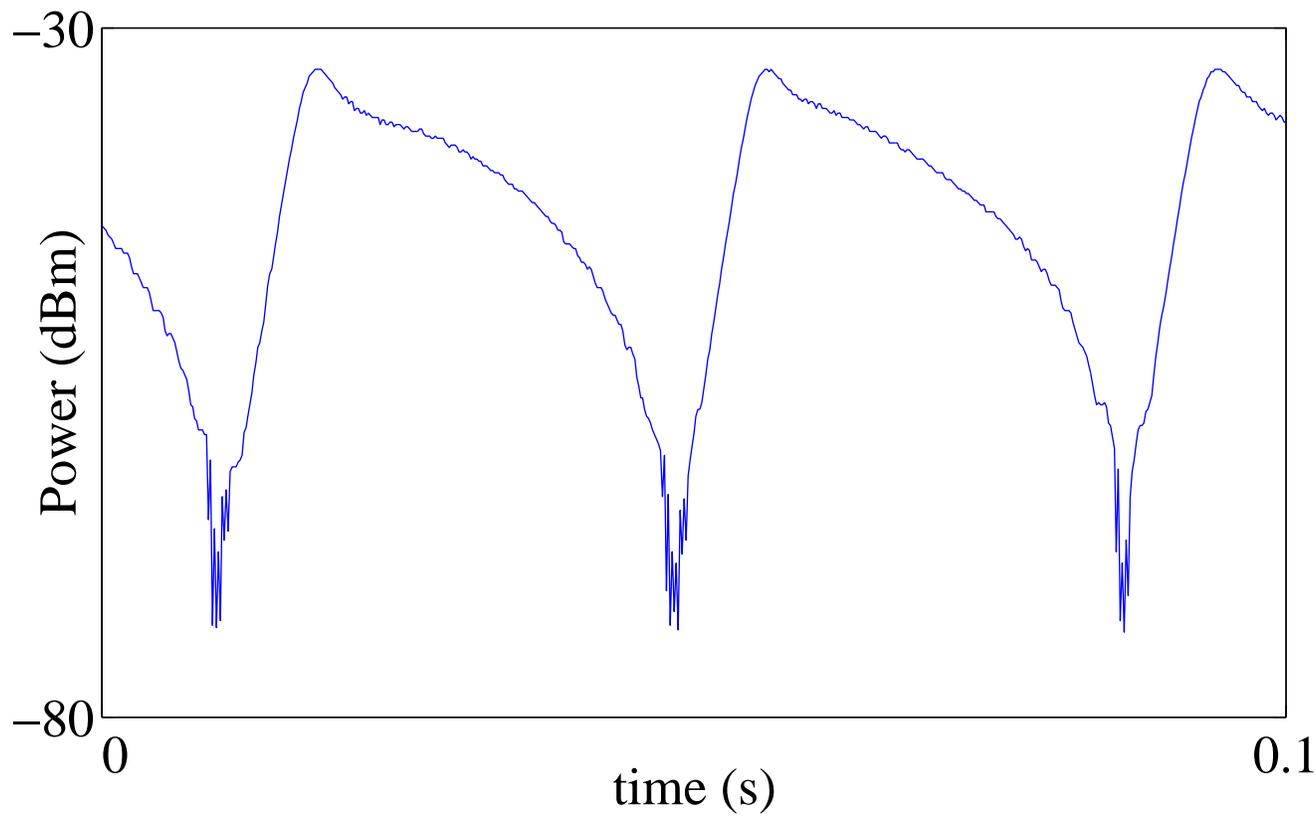
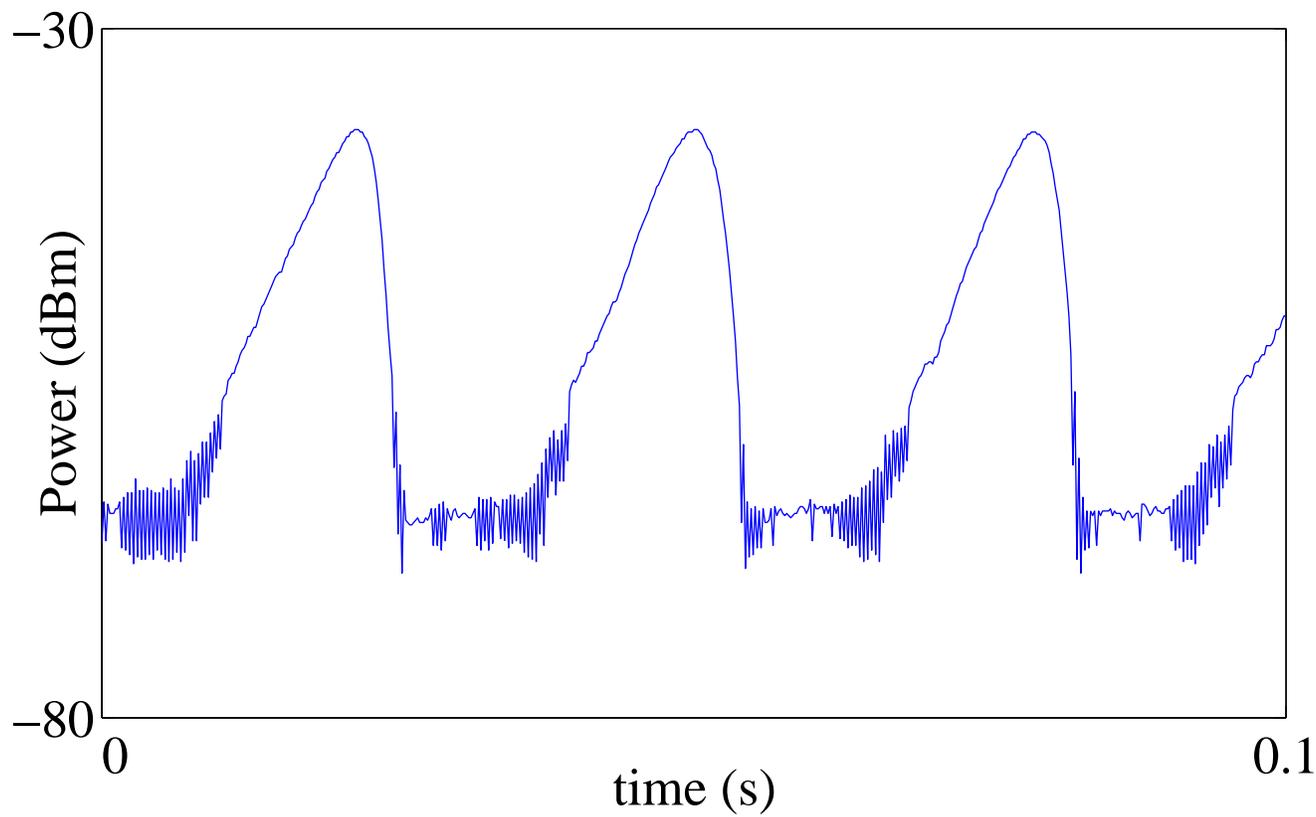
Wakefield Effects on Single Bunch in SPEAR Displayed by Streak Camera

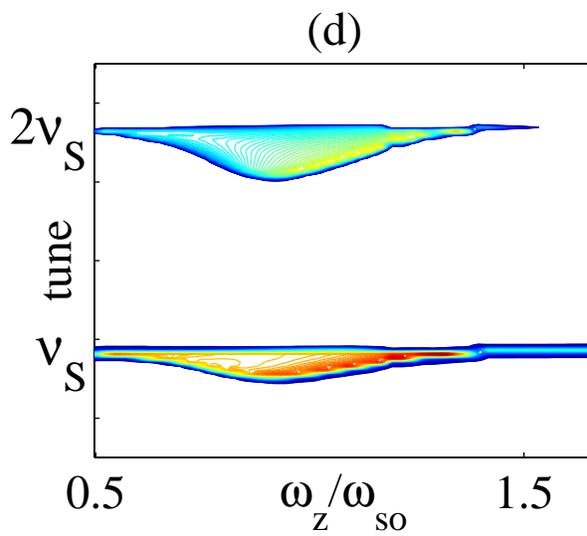
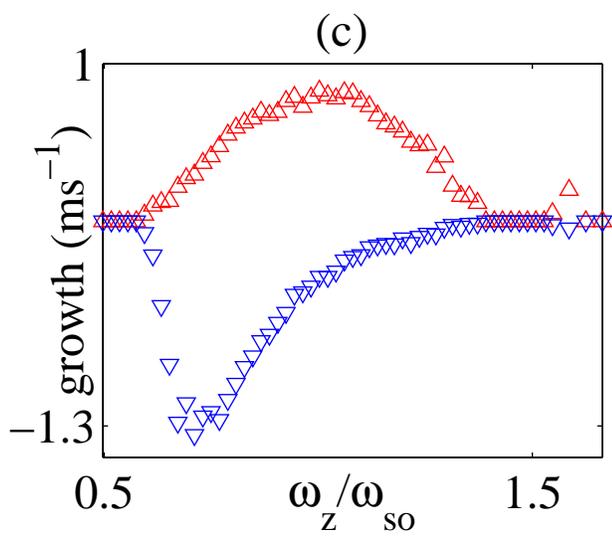
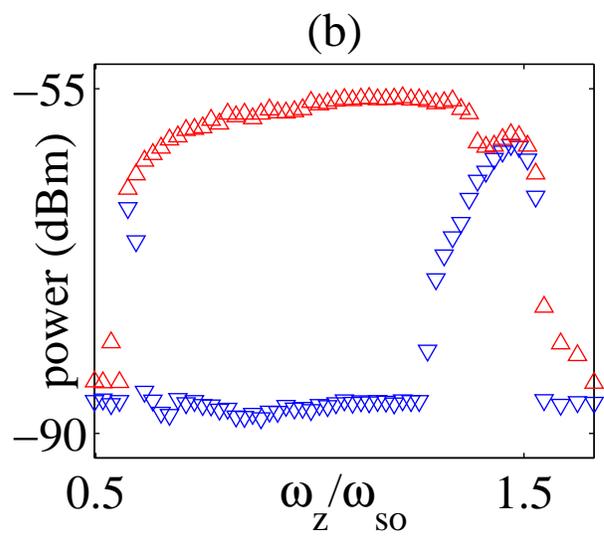
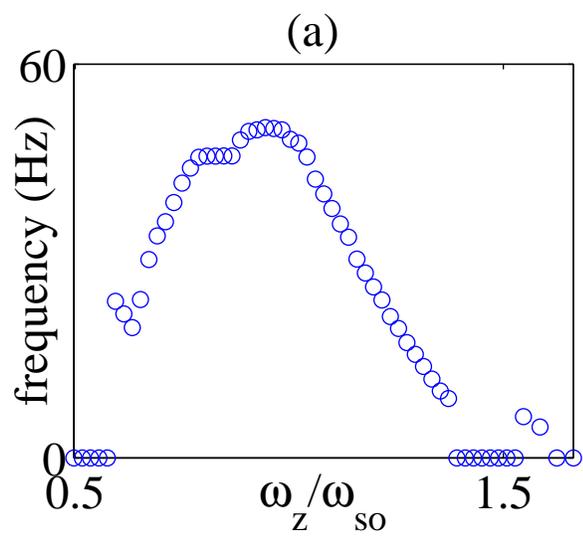


Wakefield Effects on Single Bunch in SPEAR Displayed by Streak Camera



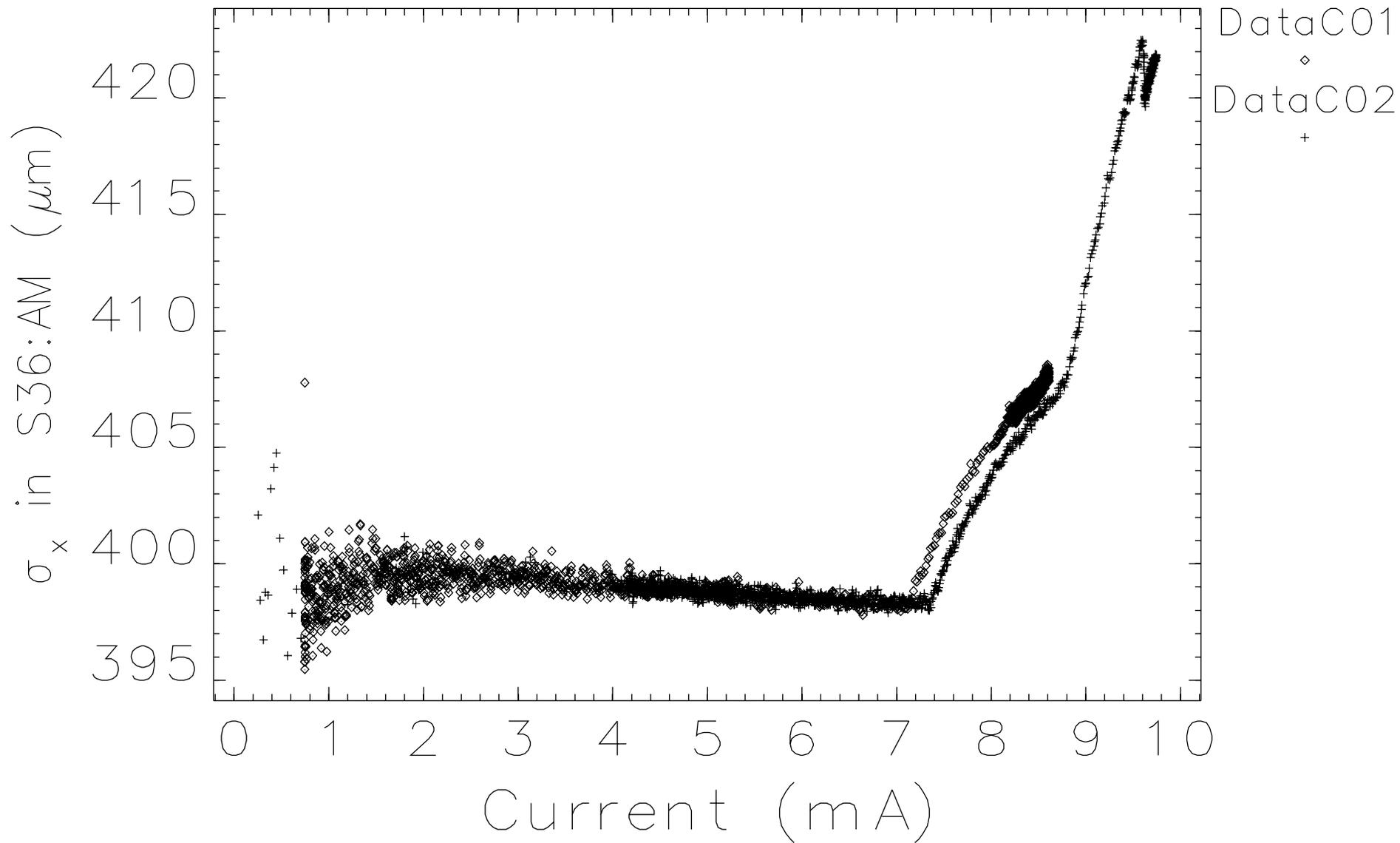
power of upper v_s sideband vs time





Horizontal Beam Size at S36:AM with High Dispersion

10:47
13 Mar 00

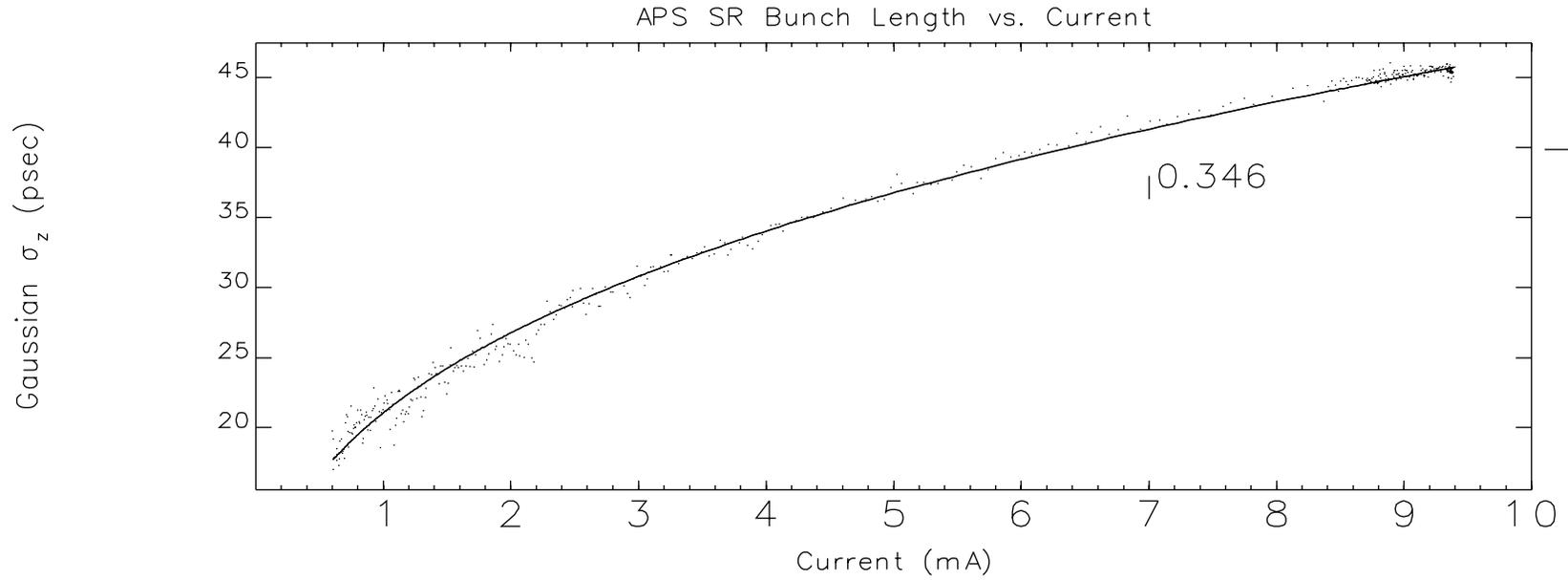


Lattice Parameter: $\eta_x=0.34$ m, $\beta_x=8.1$ m, $\varepsilon_x=8$ nm

10:48
13 Mar 00

Measured

Fitted

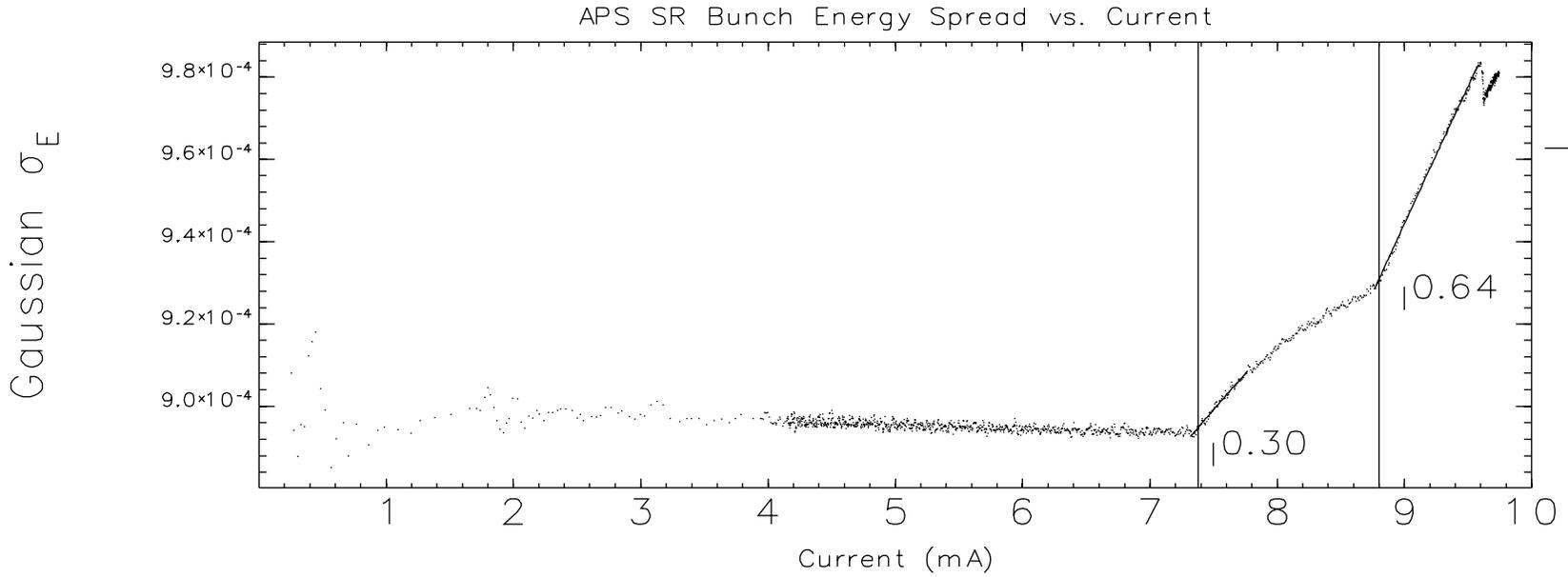


S35BM Streak Camera Used, $V_{rf}=9.48$ MV, Date=Mar0100

10:48
13 Mar 00

Measured

Fitted



S36AM $\eta_x=0.34$ m, $\beta_x=8.1$ m, $\epsilon_x=8$ nm

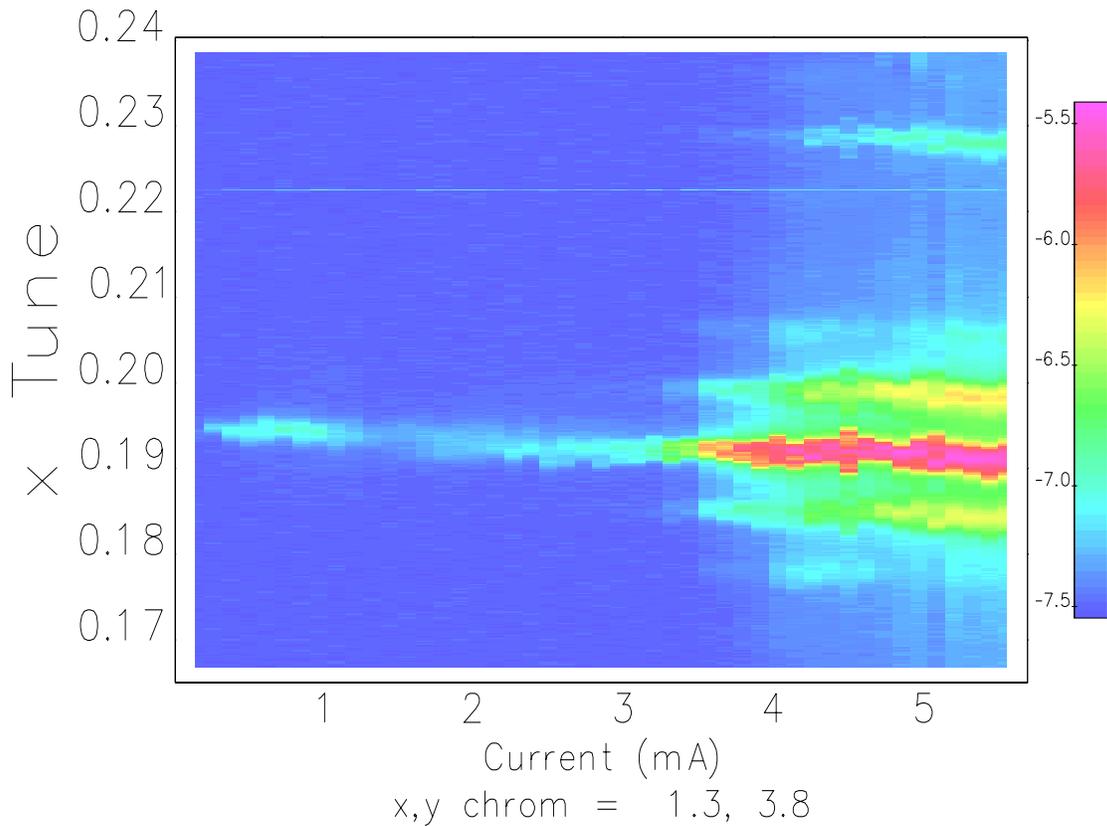
APS STORAGE RING SINGLE-BUNCH INSTABILITY DATA

1. SELF-EXCITATION OF X-TUNE ABOVE THRESHOLD
(HP Vector Signal Analyzer spectrum)
 - inject beam in small increments and measure x,y tunes using drive and pickup striplines and an HP VSA
 - display waveform vs. freq (tune) and current in contour plot
 - x tune amplitude blows up at current threshold; tune is also observed undriven

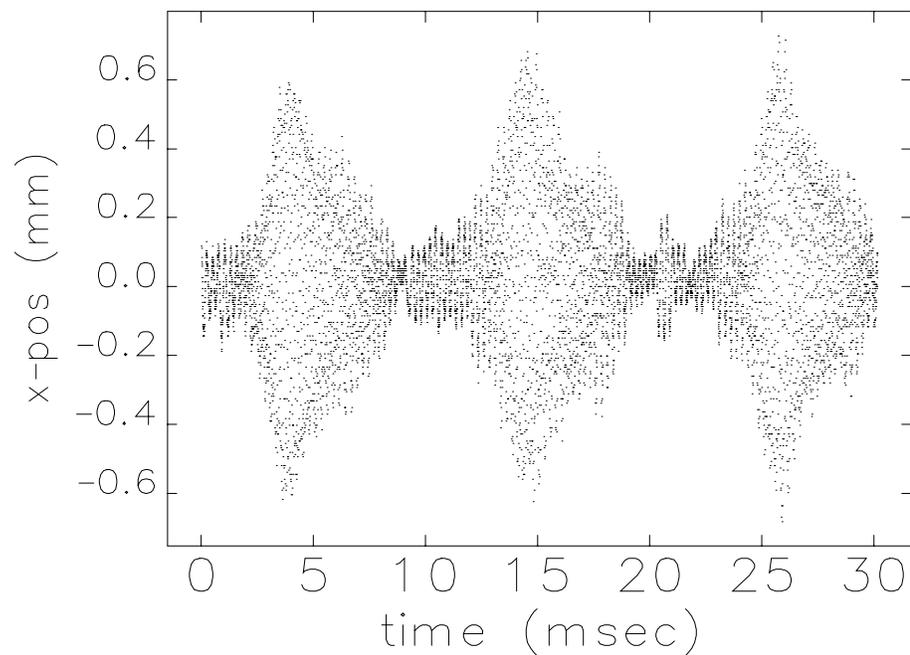
2. BPM BEAM HISTORY at HIGH DISPERSION; 5.2 mA,
NOM CHROM (chrom values on plot 1 above)
 - x-diff signal acquired every other turn, total 8192 points
 - "bursting mode" behavior seen above instability threshold
 - BPM at dispersion; observe both x- and fs-tunes

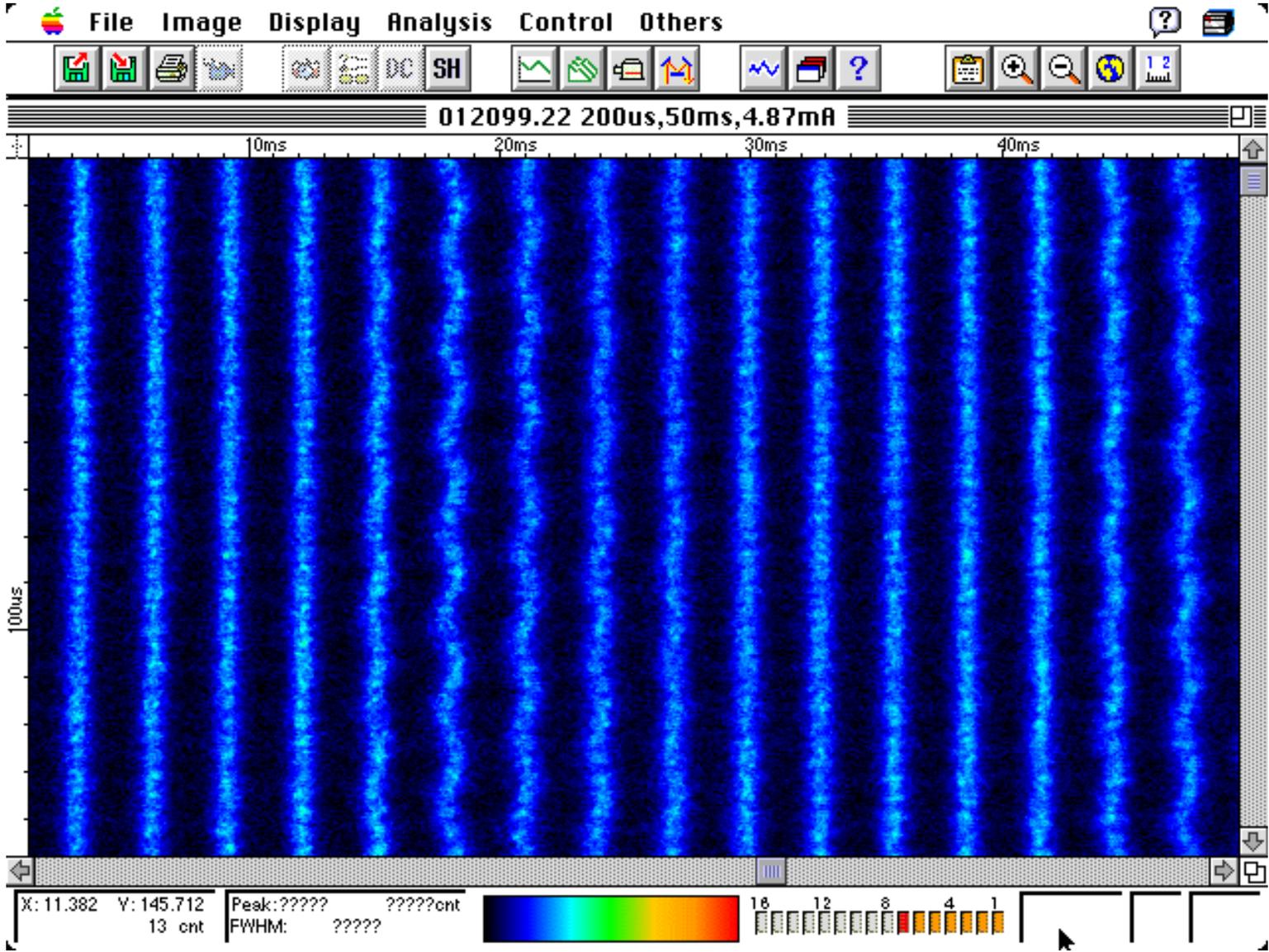
3. DUAL-SWEEP STREAK CAMERA IMAGING: x vs. t
 - distinctly shows that the bunch size does not decohere on the falling side of the bursts, which is the usual observation in saw-tooth-like instabilities

SELF-EXCITATION OF X-TUNE ABOVE THRESHOLD (HP Vector Signal Analyzer spectrum)



BPM BEAM HISTORY at HIGH DISPERSION; 5.2 mA, NOM CHROM





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III. Examples of Instability Measurements

C. Further Examples of Instability Measurements (Multi-Bunch)

Transverse

APS: 20-bunch train, chromaticity effects
(K. Harkay, B. Yang)

Longitudinal

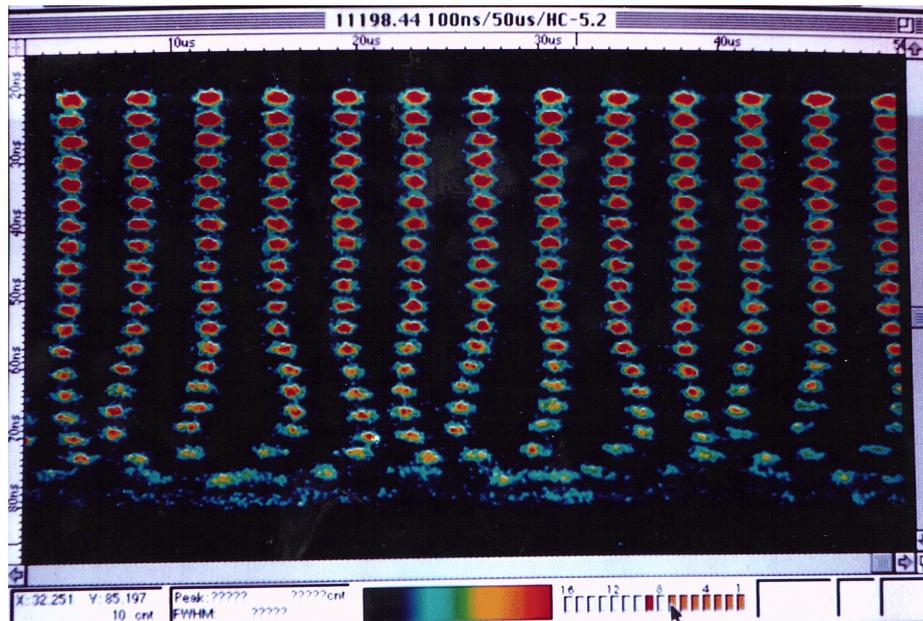
ALS: 300 bunches, longitudinal feedback effect
(J. Hinkson)

CESR: 9 x 2 or 4 bunches (dipolar), quadrupolar
(M. Billings, R. Holtzapple)

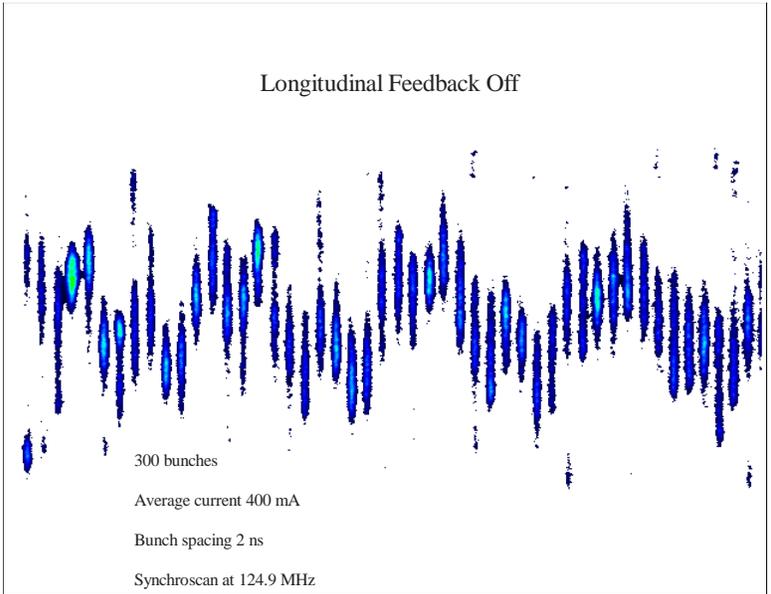
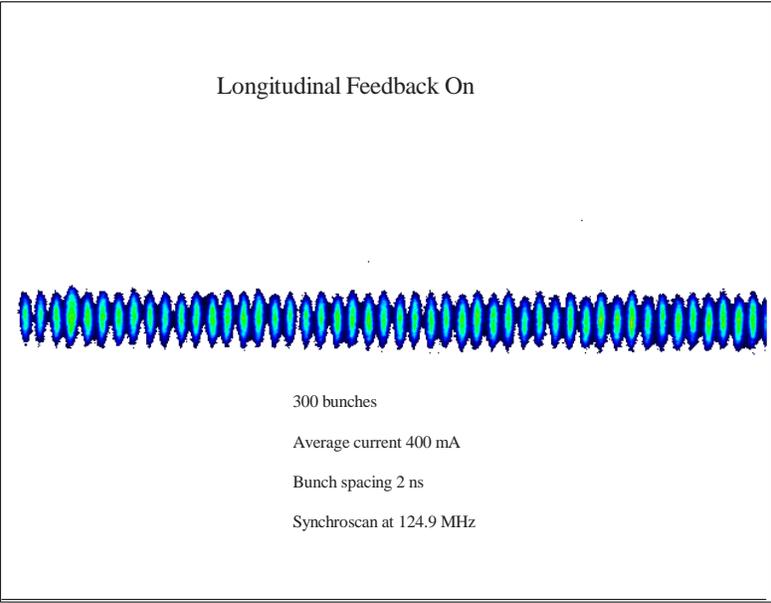
PEP-II: Hundreds of bunches in HER, 0.75-A
target
(A. Fisher, A. Lumpkin, U. Wienands)

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Dual-Sweep Streak Camera Image Shows
Multi-Bunch, Transverse Instability at APS
(20-Bunch Train)



Effects of Longitudinal Feedback Clearly Displayed with Streak Camera at ALS Storage Ring

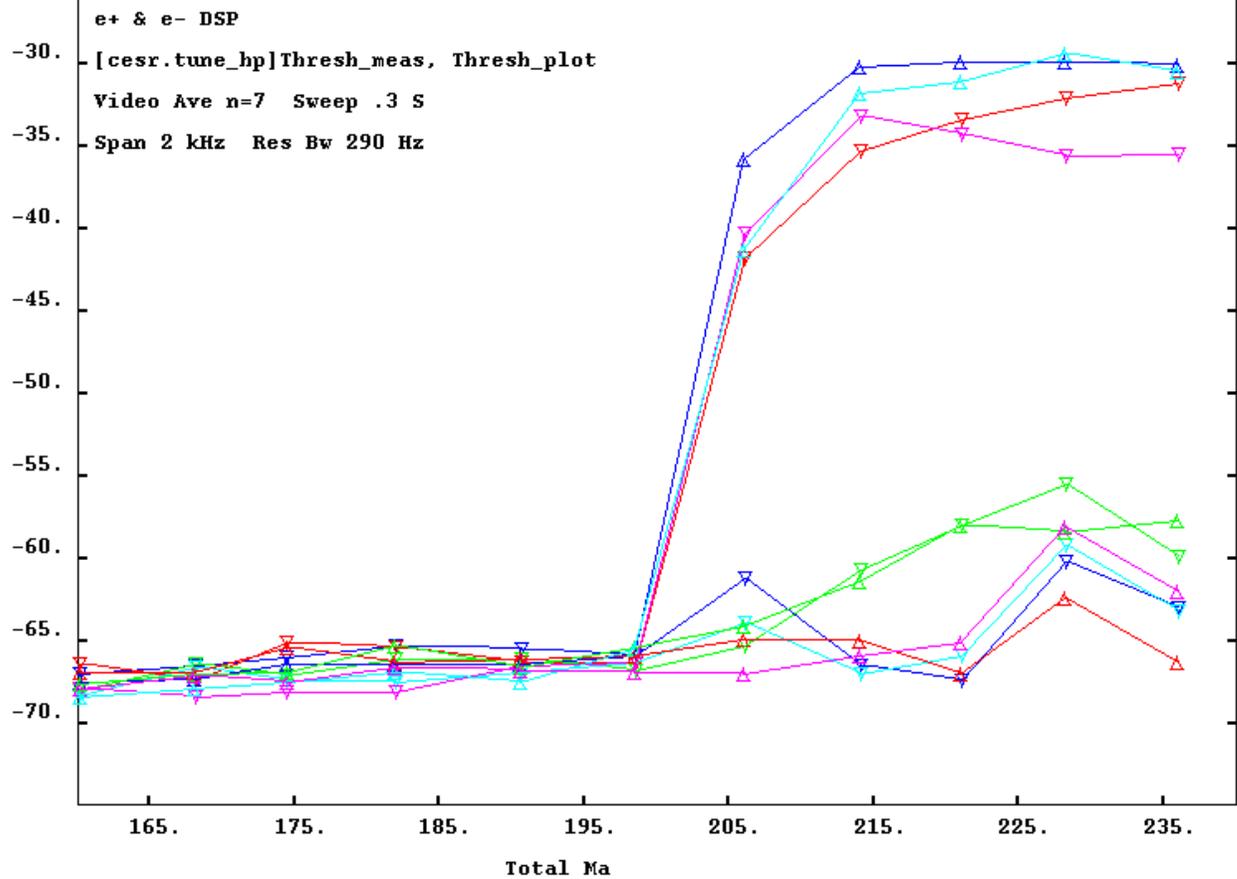


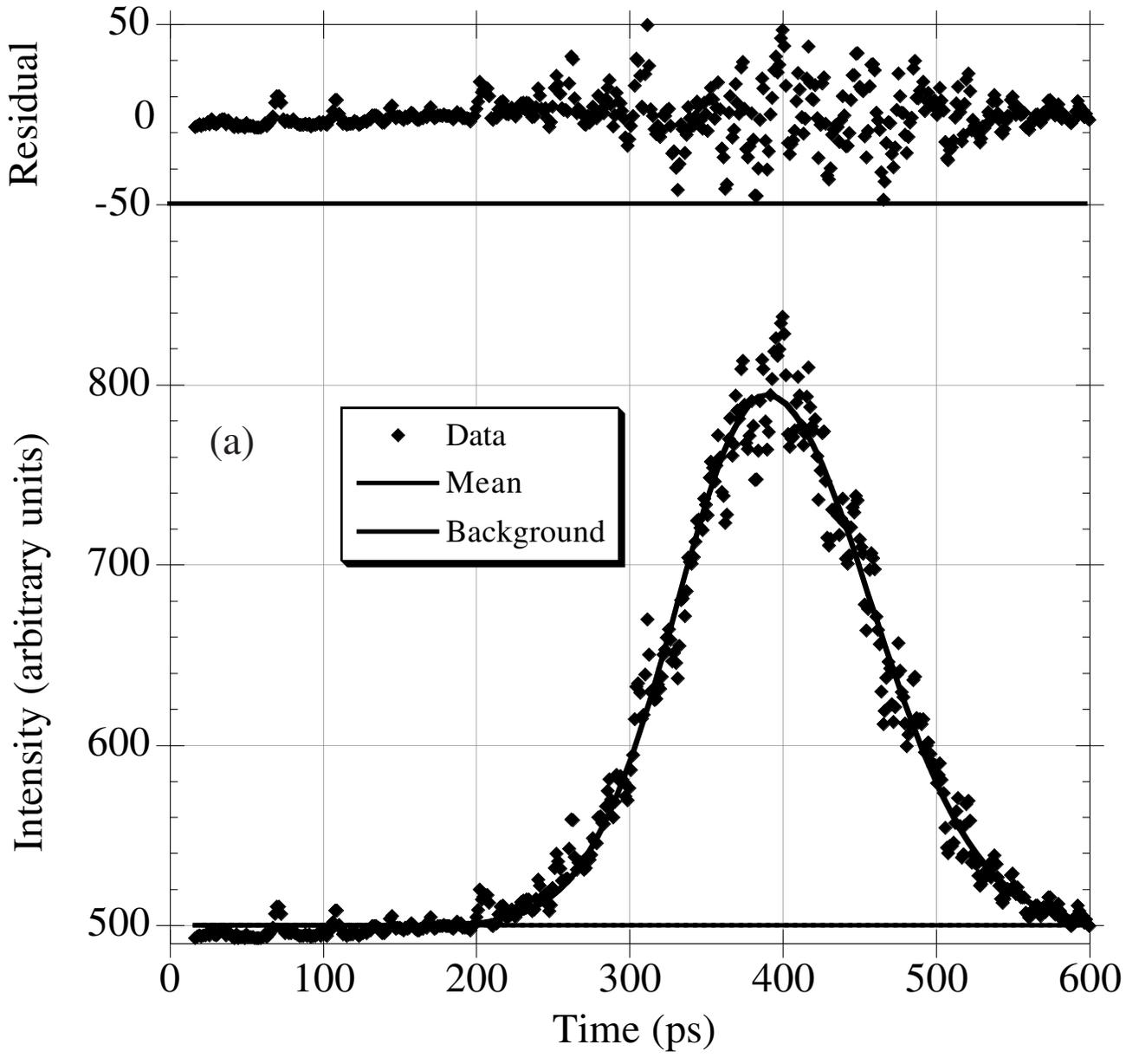
ls_amp_1999_12_08_00.24

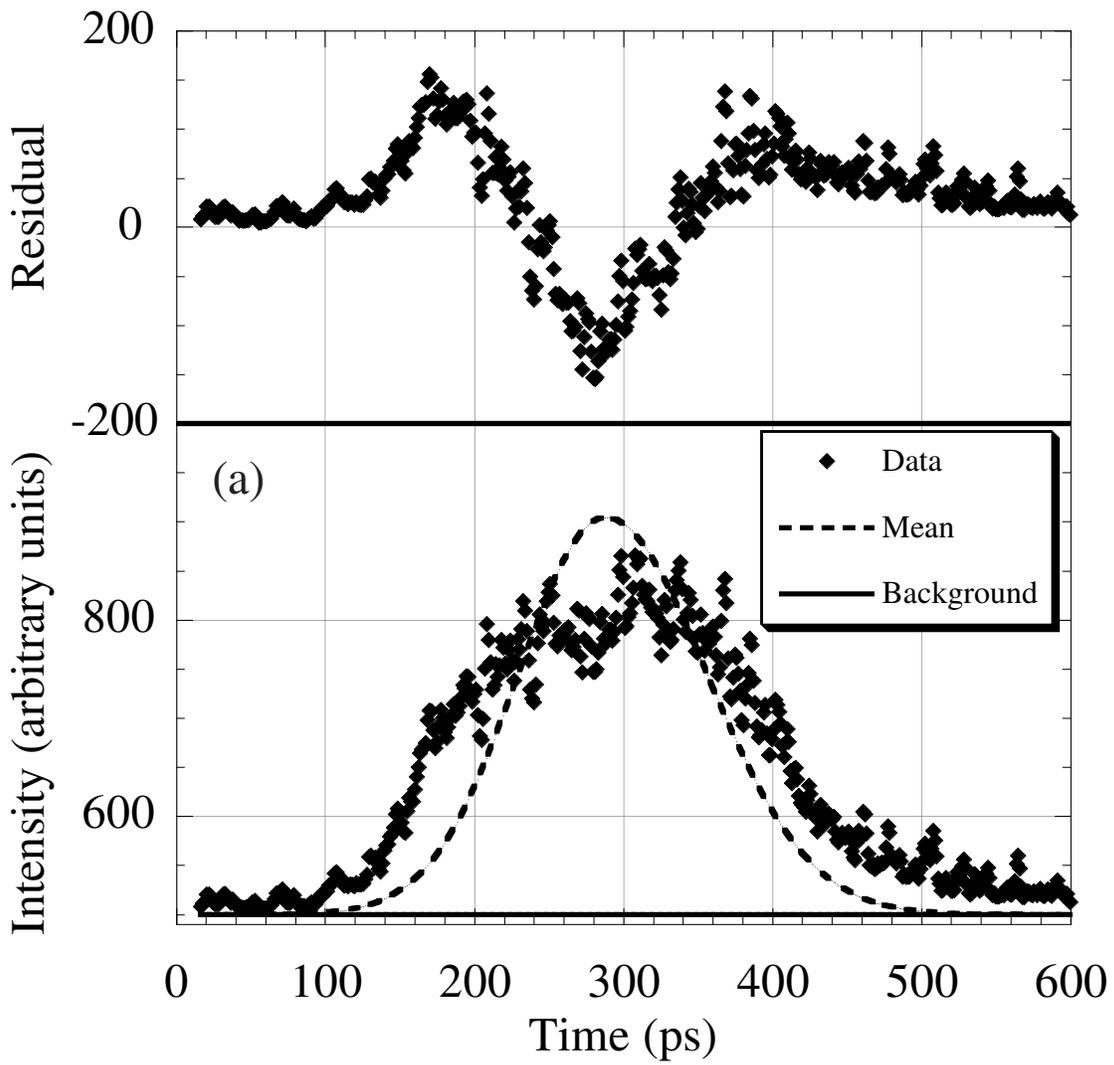
+ Δ - ∇ Rev Harmonic

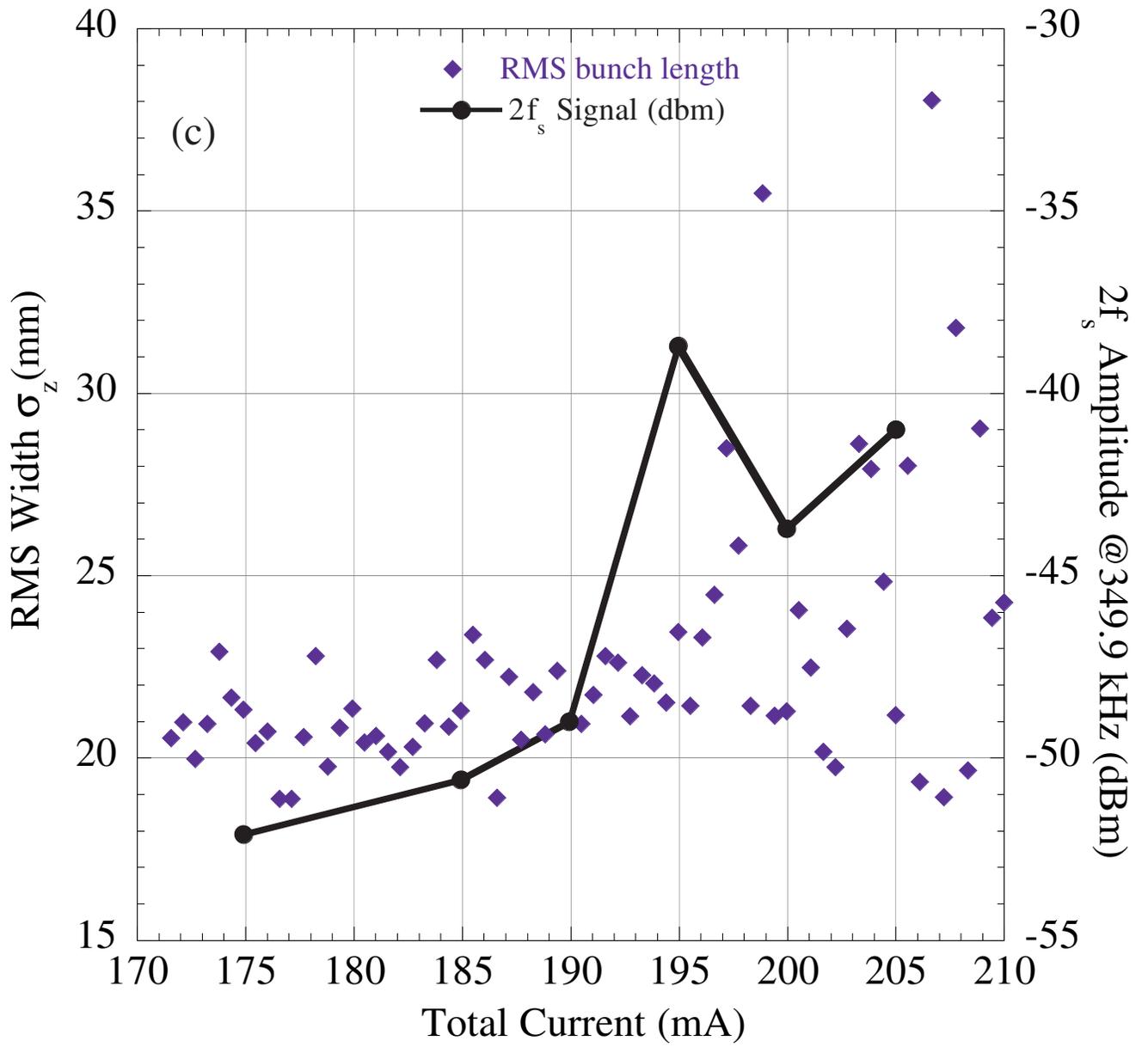
1 2 3 4 5

Db







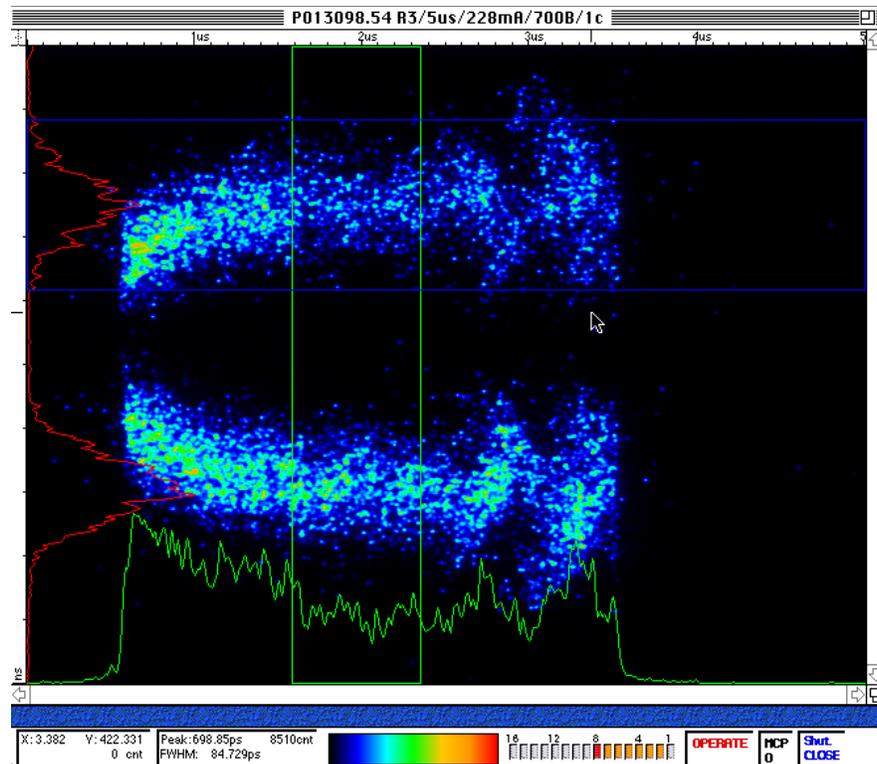


Dual-Axis Synchroscan Streak-Camera Image

700-Bunch Sequential Fill, Every 4.2 ns ("Richter-Dorfan" fill), 228 mA

Alex Lumpkin and Alan Fisher
30 January 1998

1 ns Full Vertical Scale



5 μ s Full Horizontal Scale

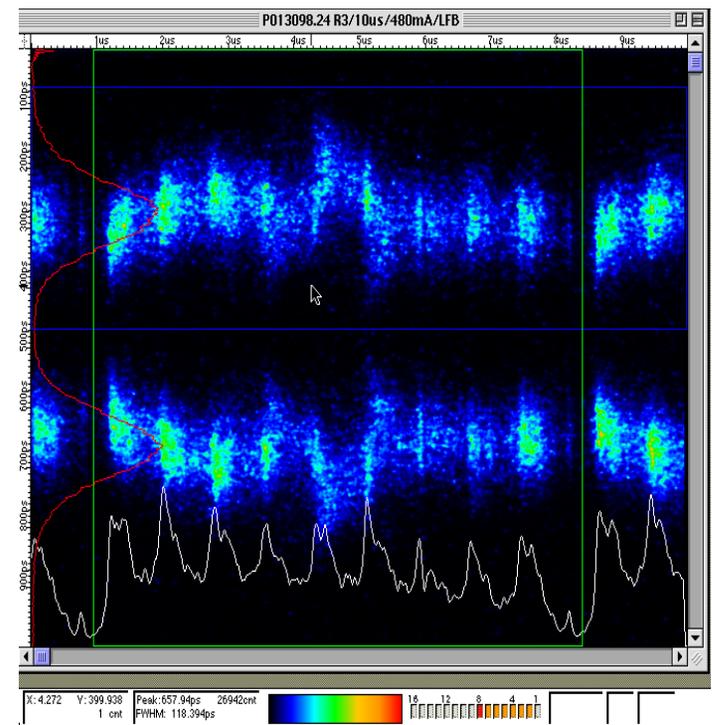
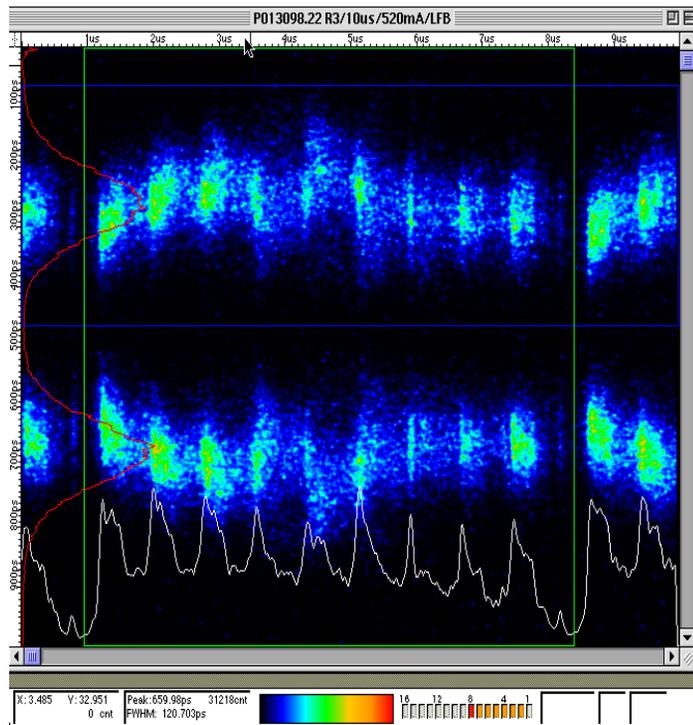
- Time within a bunch is dispersed vertically, while the bunches in the train are displayed horizontally.
- Because the camera is swept vertically at 119 MHz, half of the bunch-train frequency, even and odd numbered bunches are 180° apart and are swept in opposite directions. They are separated for clarity by a small delay from the precise zero crossing.
- For this charge per bunch, the train displays these longitudinal instabilities when the length reaches about 500 bunches, but stabilizes again after about 1200 bunches.
- However, with a 500-mA 1658-bunch fill, the middle of the train was unstable.

Longitudinal Instability at 500 mA

30 January 1998

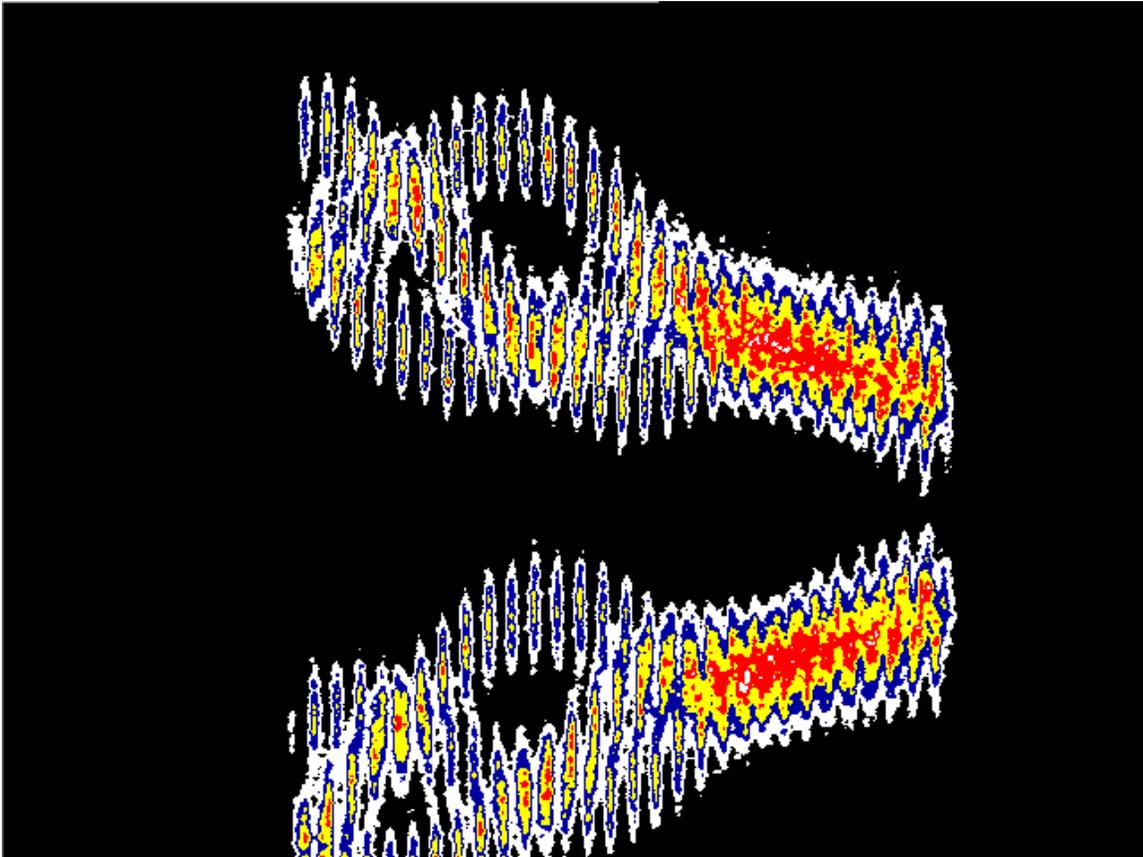
1658-bunch train (every 4.2 ns, plus one gap), filled in 9 zones to ≈ 500 mA.
Only the middle of the train became unstable.

1 ns full vertical scale, 10 μ s full horizontal scale (just over 1 turn)



Courtesy of A. Fisher, SLAC

Streak Camera Image of Longitudinal Coupled-Bunch Oscillations (with Landau Damping) at ESRF



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IV. Potential Technique Development Areas

How does one better display the signature of a given instability? (time resolution, bandwidth, sensitivity).

- a. Lattice manipulations may increase sensitivity or allow control.
- b. Use of dual-sweep streak camera for longitudinal dynamics is well established, but the use of time-dependent transverse measurements has also been demonstrated at APS.
- c. X-ray streak camera provides improved spatial resolution with time resolution.
- d. Gated, intensified cameras can be used for single bunch, single-turn measurements.
- e. Bunch-by-bunch rf BPMs with digital beam histories are being demonstrated.
- f. Digital data from the feedback system can be utilized to track transients.
- g. High-resolution energy spread measurement with an x-ray monochromator has been demonstrated.
- h. Others to be identified in this Workshop.

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V. Summary

The operating storage rings from the second and third generations provide numerous examples of instability observation and control. Time-resolved imaging techniques continue to develop for both longitudinal and transverse effects.

Time-dependent capabilities in instrumentation for rf pickup devices are very powerful (position, tunes, beam spectra, etc.)

The complementary use of several diagnostics is particularly encouraged.

Further exchange of ideas at this Workshop may lead to better diagnostics at each of our facilities.