Beam Instabilities Diagnostics

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Presented at Beam Instabilities
Workshop
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Outline

I. Introduction

II. Experimental Background

III. Examples of Instability Measurements

- transverse
- longitudinal

IV. Potential Technique Development Areas

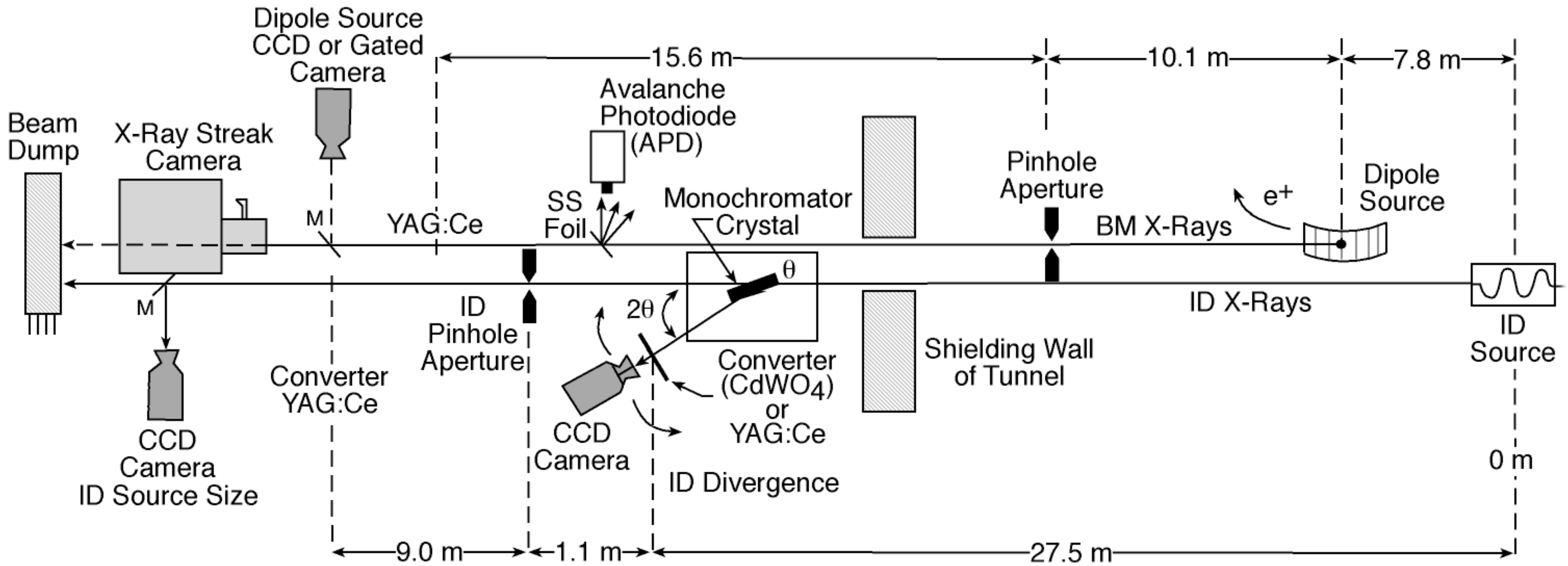
V. Summary

II. Experimental Background

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

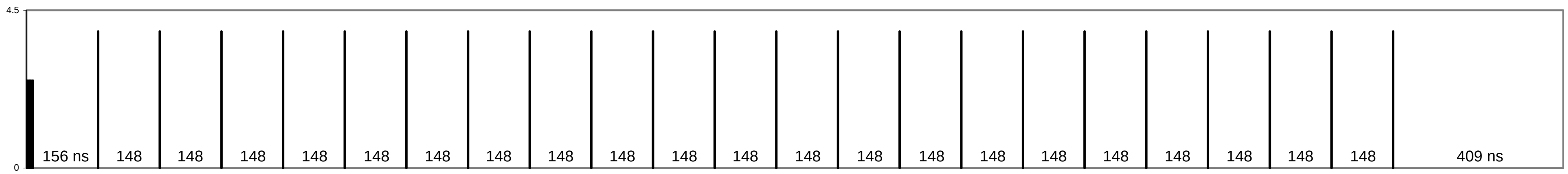
Transverse	Technique
Beam position (x,y)	rf BPM
Beam profile/emittance (x,y)	x-ray pinhole camera
Betatron tune (x,y)	rf pickup
Longitudinal	
Bunch length	streak camera
Bunch profile	streak camera
Bunch phase	streak, rf probe
Energy	dipole and position reading
Energy spread	dispersive regime and image
Synchrotron tune	rf pickup

Schematic of the APS Beam Diagnostics Sector

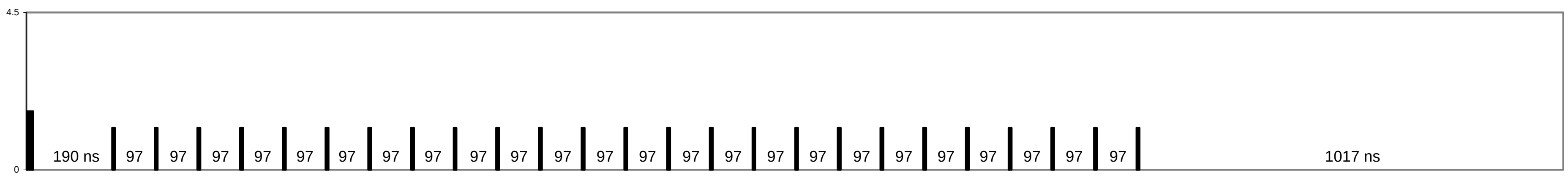


Advanced Photon Source
Bunch Patterns

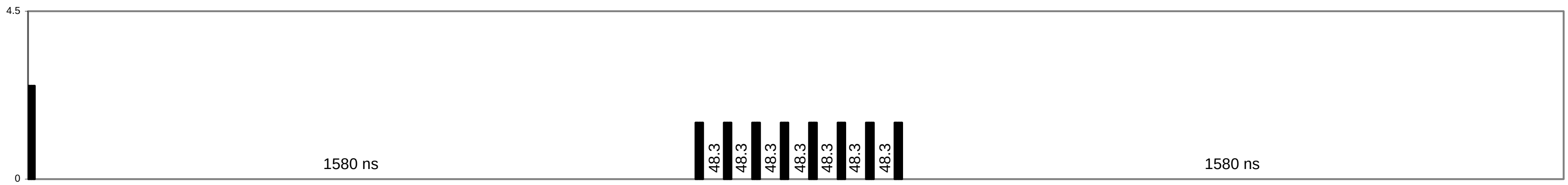
Singlets - 6 + 1*22



Triplets - 6 + 3*25



Hybrid - 6 + 7*8



Courtesy of Y. Chae, APS

III. Examples of Instability Measurements

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

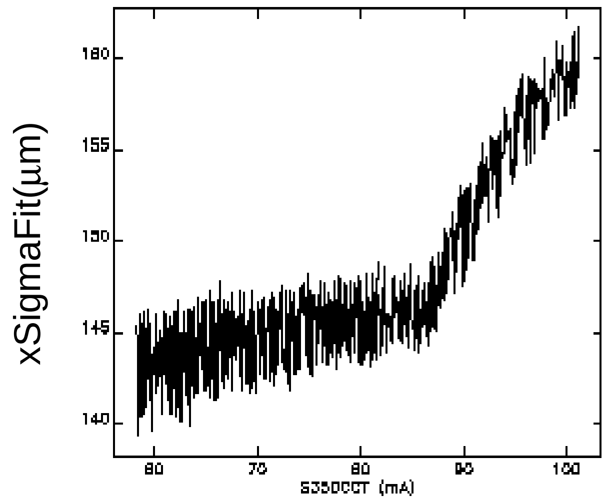
Transverse Instability

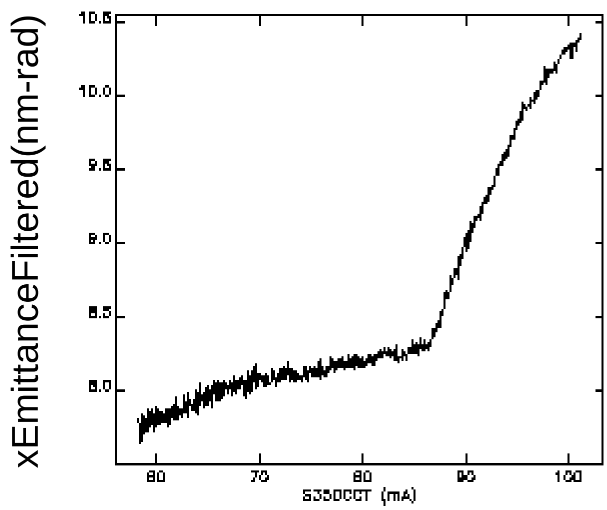
- Track 35-BM pinhole camera (dispersive point: use as ref.)
- Track bunch length, 35-ID divergence, 35-ID pinhole images for similar fills
- Check lifetime correlation
- Check chromaticity effects

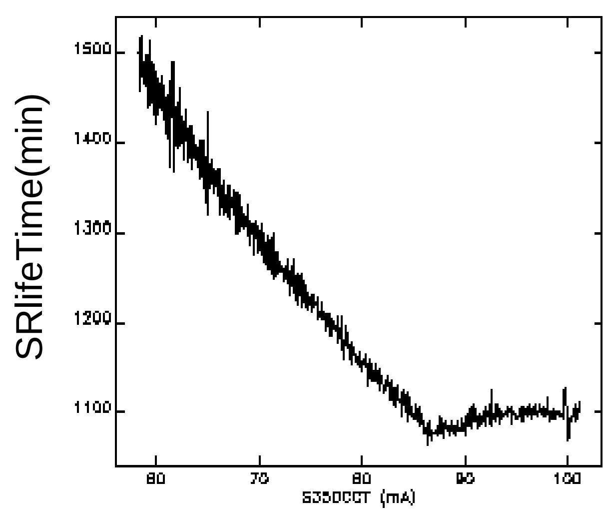
Longitudinal Instability

- Track 35-BM pinhole image sizes
- Track 35-BM streak camera data
- Display dual-sweep streak images during instability (10   s, 100   s, 1 ms)
- Vary rf cavity temperature set point

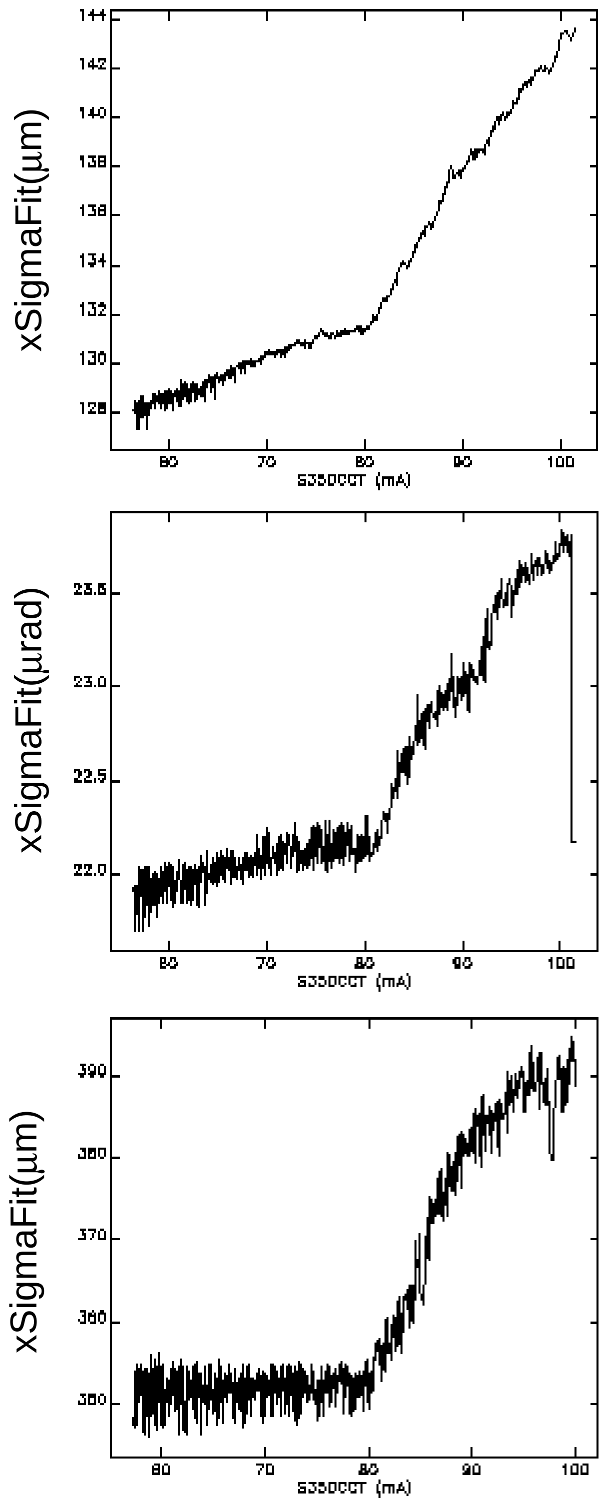
Horizontal Beam Size and Lifetime Show Correlated Change at ~ 85 mA (positrons)



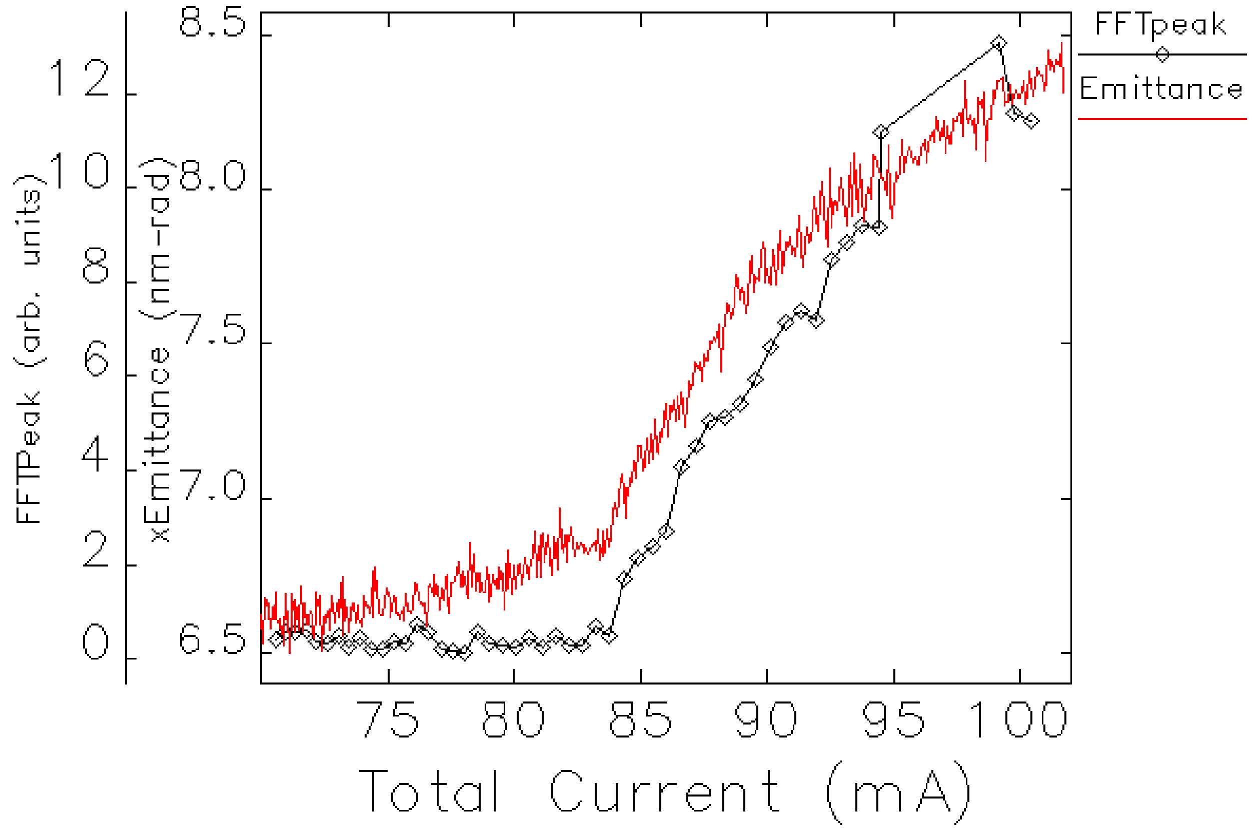




Correlated Change of Parameter Observed at Bending Magnet and Insertion Device Source Points at 85 mA

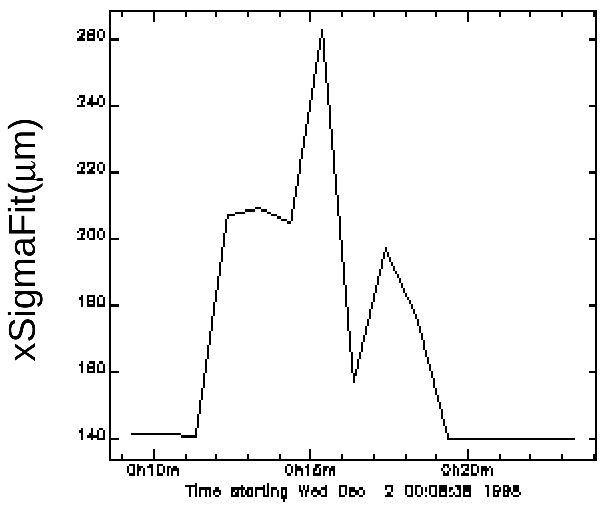


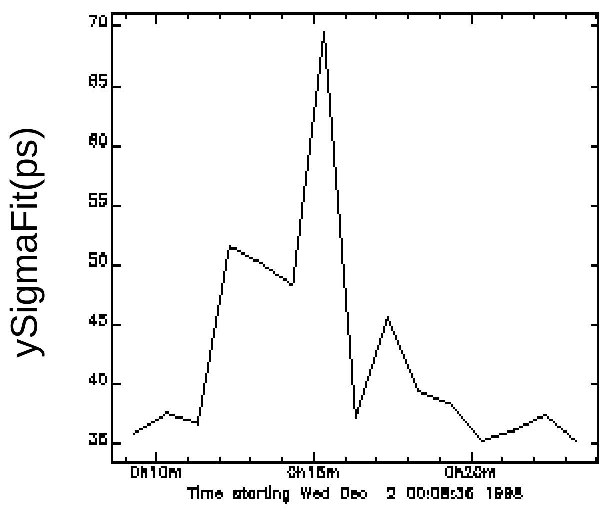
Correlated Change of Beam Motion and Emittance Observed Near 85 mA



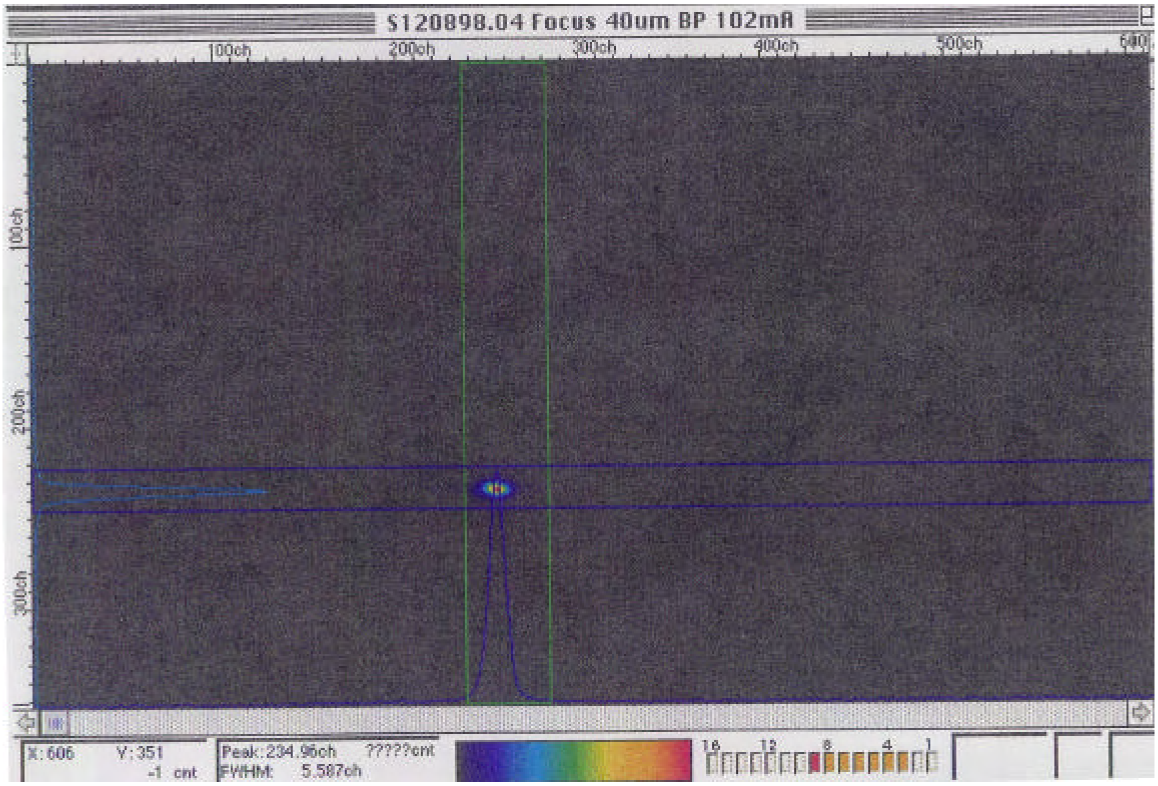
Courtesy of L. Emery, APS

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

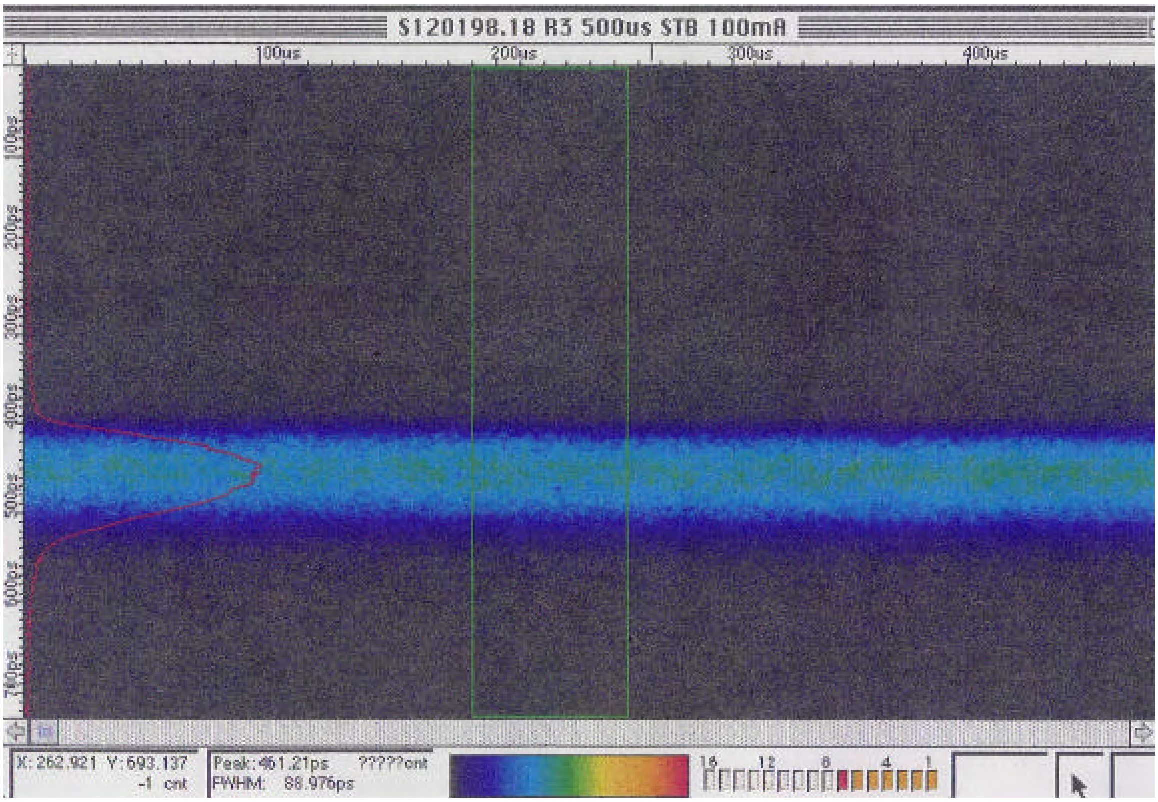




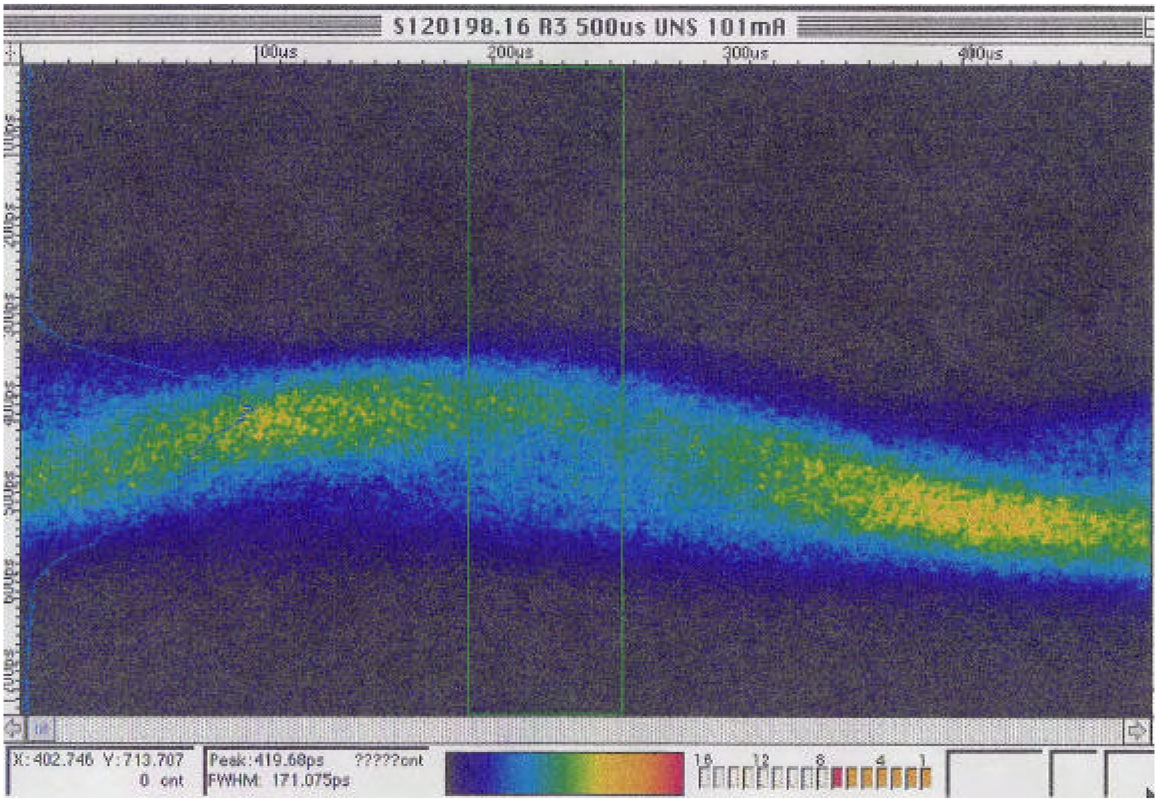
Streak Camera in Focus Mode



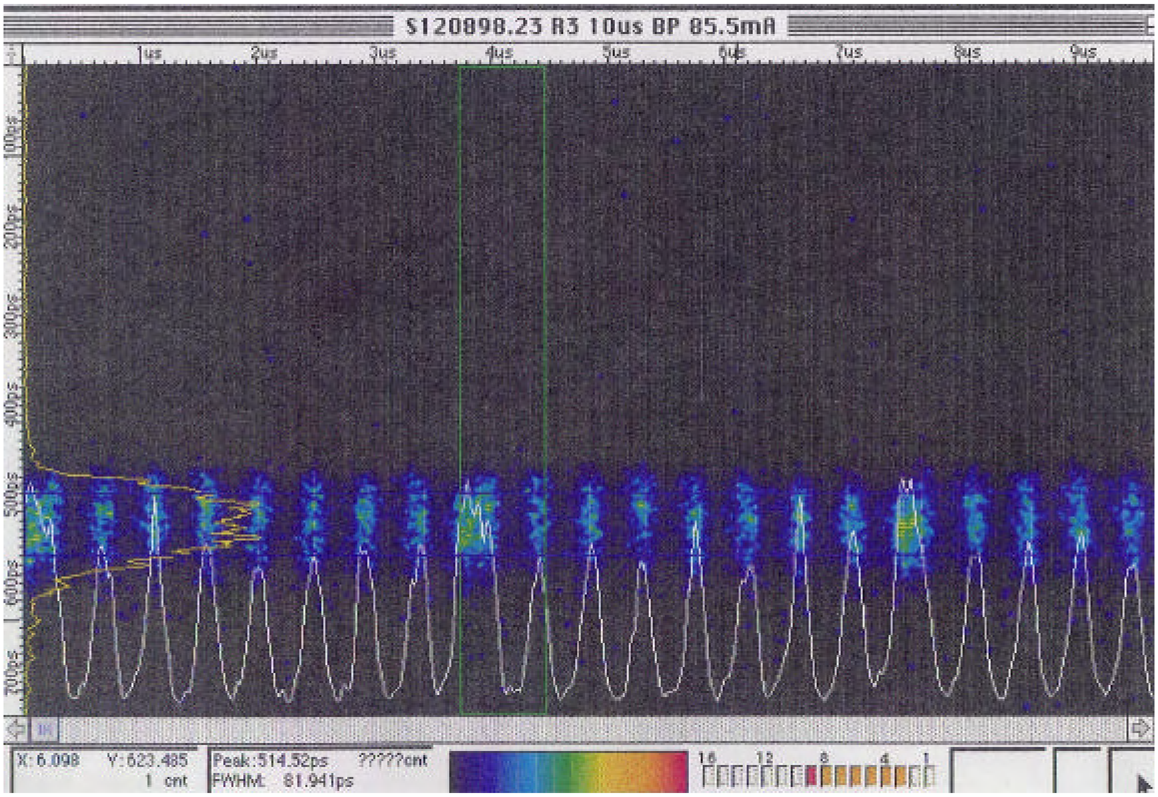
Dual-Sweep Streak Image: Stable Beam



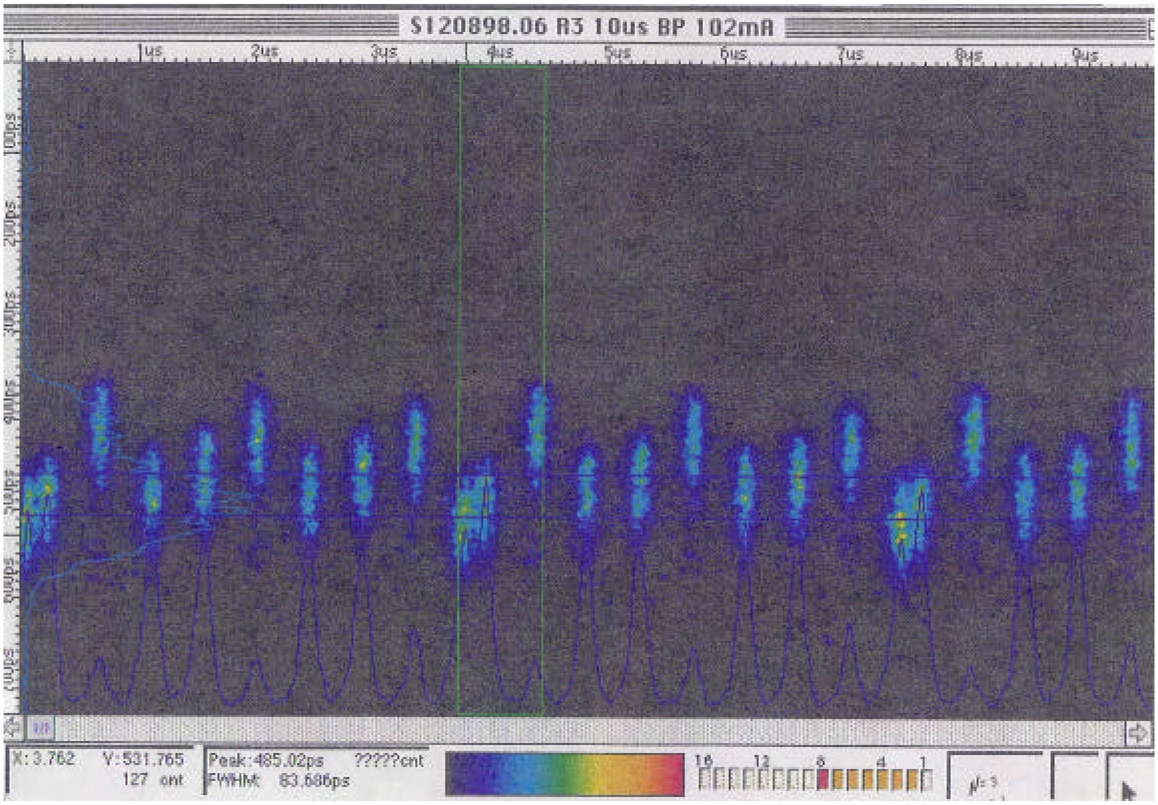
Dual-Sweep Streak Image: Unstable Beam



Dual-Sweep Streak Image: Stable Beam



Dual-Sweep Streak Image: Unstable Beam



III. Examples of Instability Measurements

A. 6 + 22 Singlets Fill (APS Observations)

<u>Transverse Instability</u>

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

<u>Longitudinal Instability</u>

Usually seen at 101 mA
Horizontal size increase is significant: $_{x}$ = 135 -> 210 m
Correlated effect with bunch length
Sensitive to rf cavity temperature

III. Examples of Instability Measurements

B. Further Examples of Instability Measurements (Single Bunch)

<u>Transverse</u>

APS: Head-tail
(A. Lumpkin, B. Yang)
ESRF: Head-tail
(O. Naumann, J. Jacob)
LEP: Head-tail
(E. Rossa)

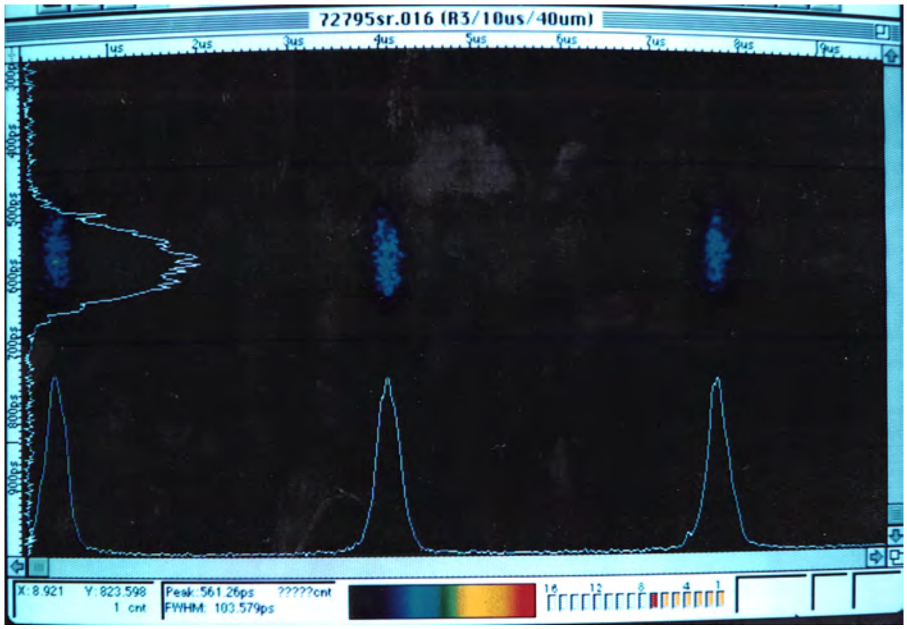
<u>Longitudinal</u>

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)

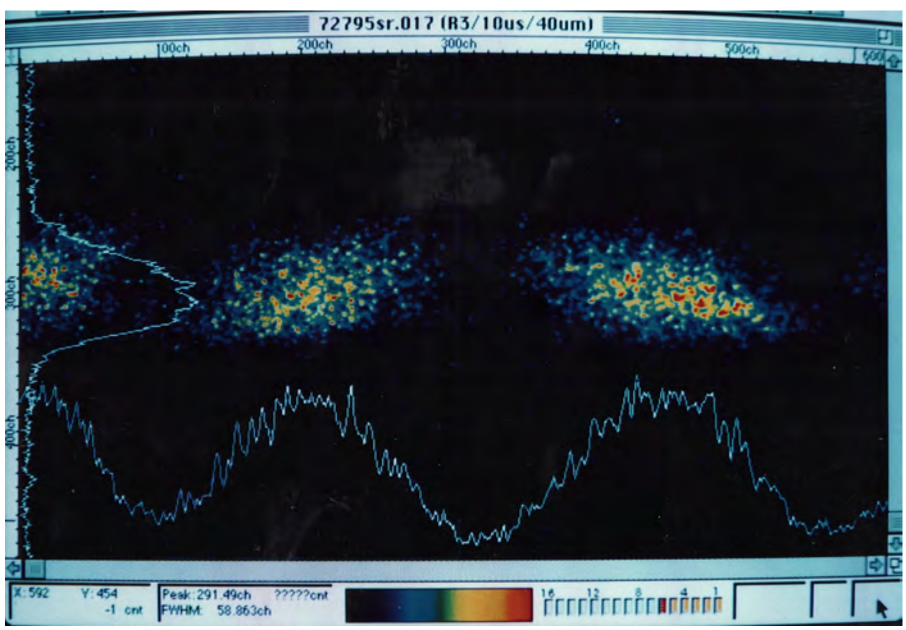
ADVANCED PHOTON SOURCE

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

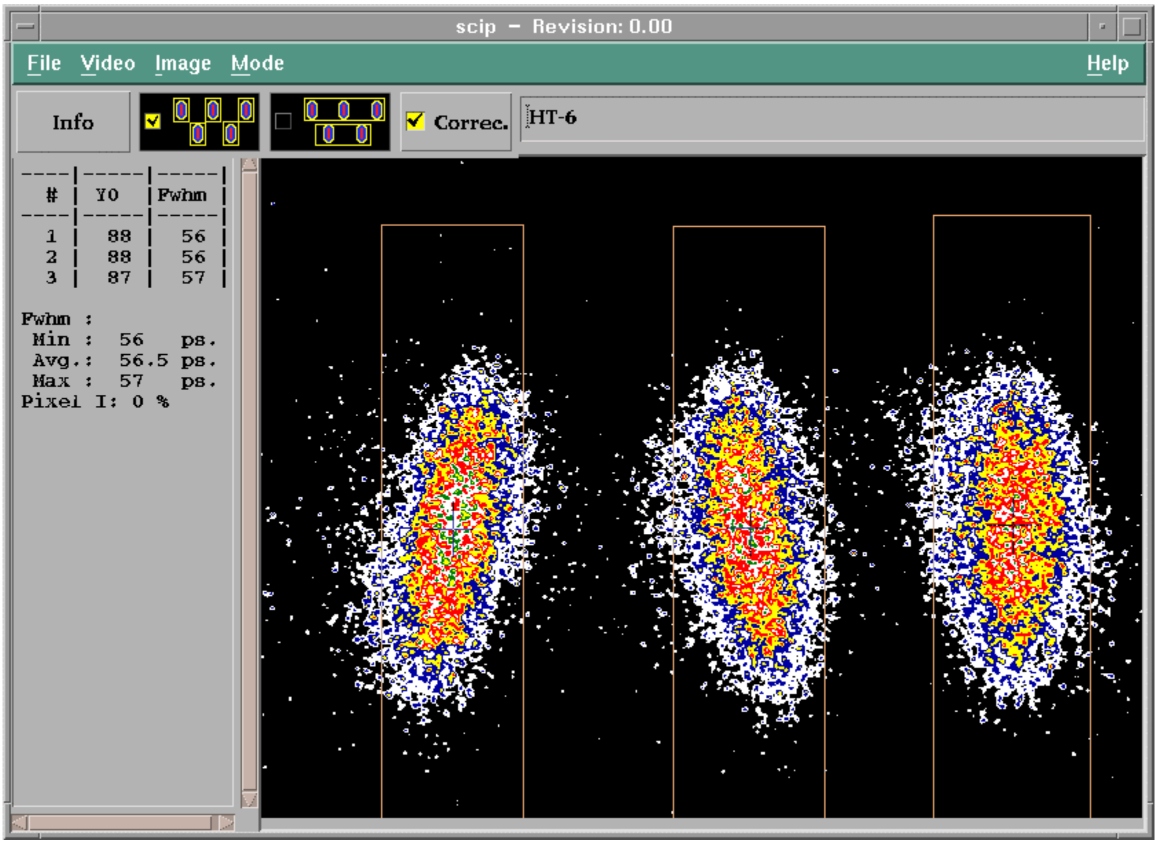
a) Stable



b) Unstable

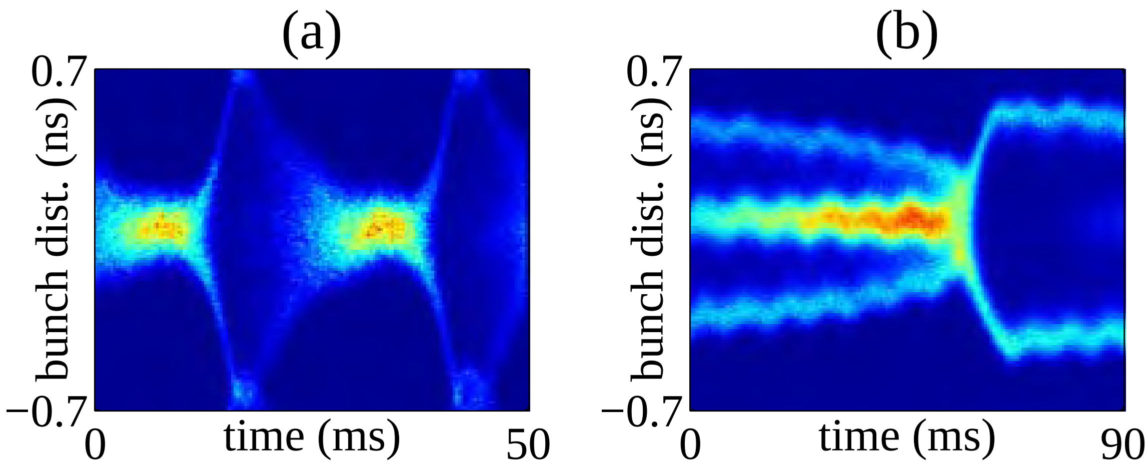


Streak Camera Images of Head-tail Effect in Single Bunch at ESRF



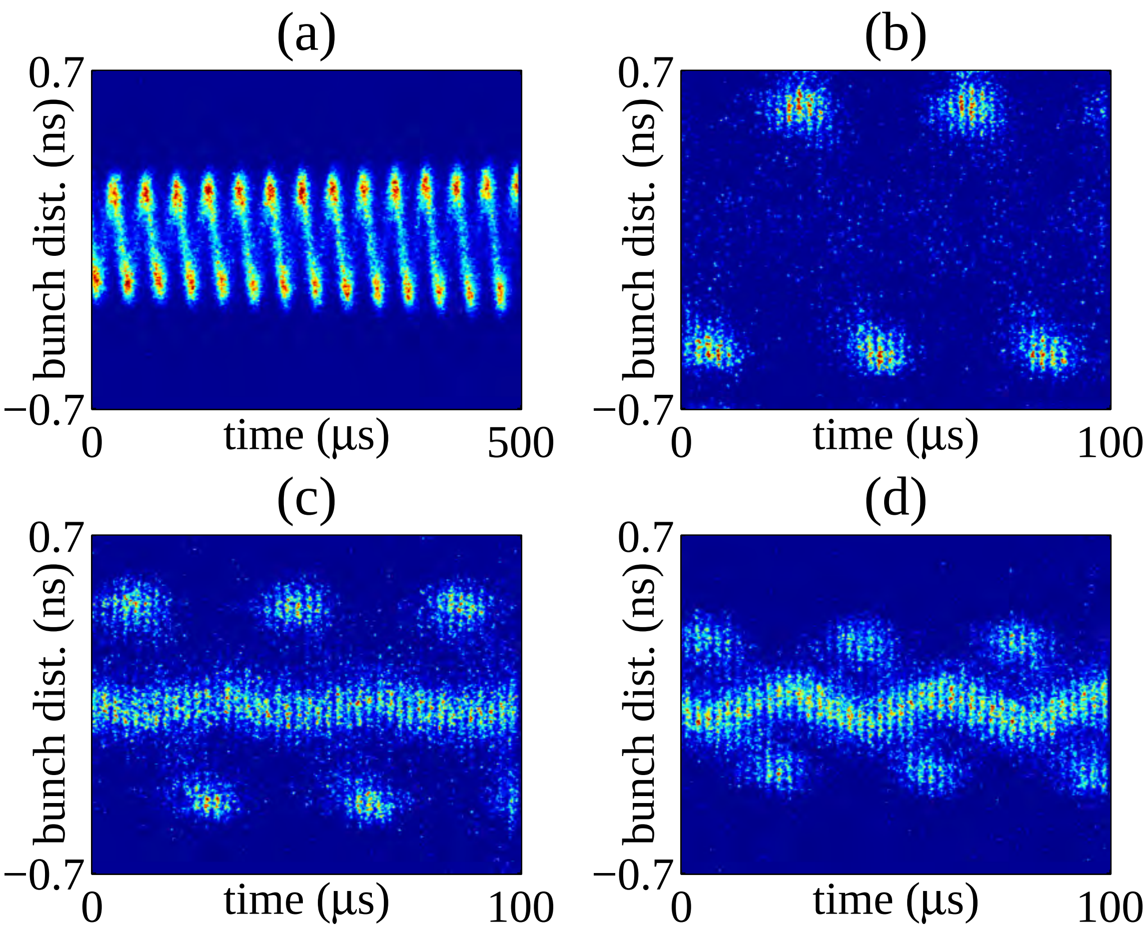
Courtesy of J. Revol, R. Nagaoka, P. Kernel and K. Scheidt, ESRF

Wakefield Effects on Single Bunch in SPEAR Displayed by Streak Camera



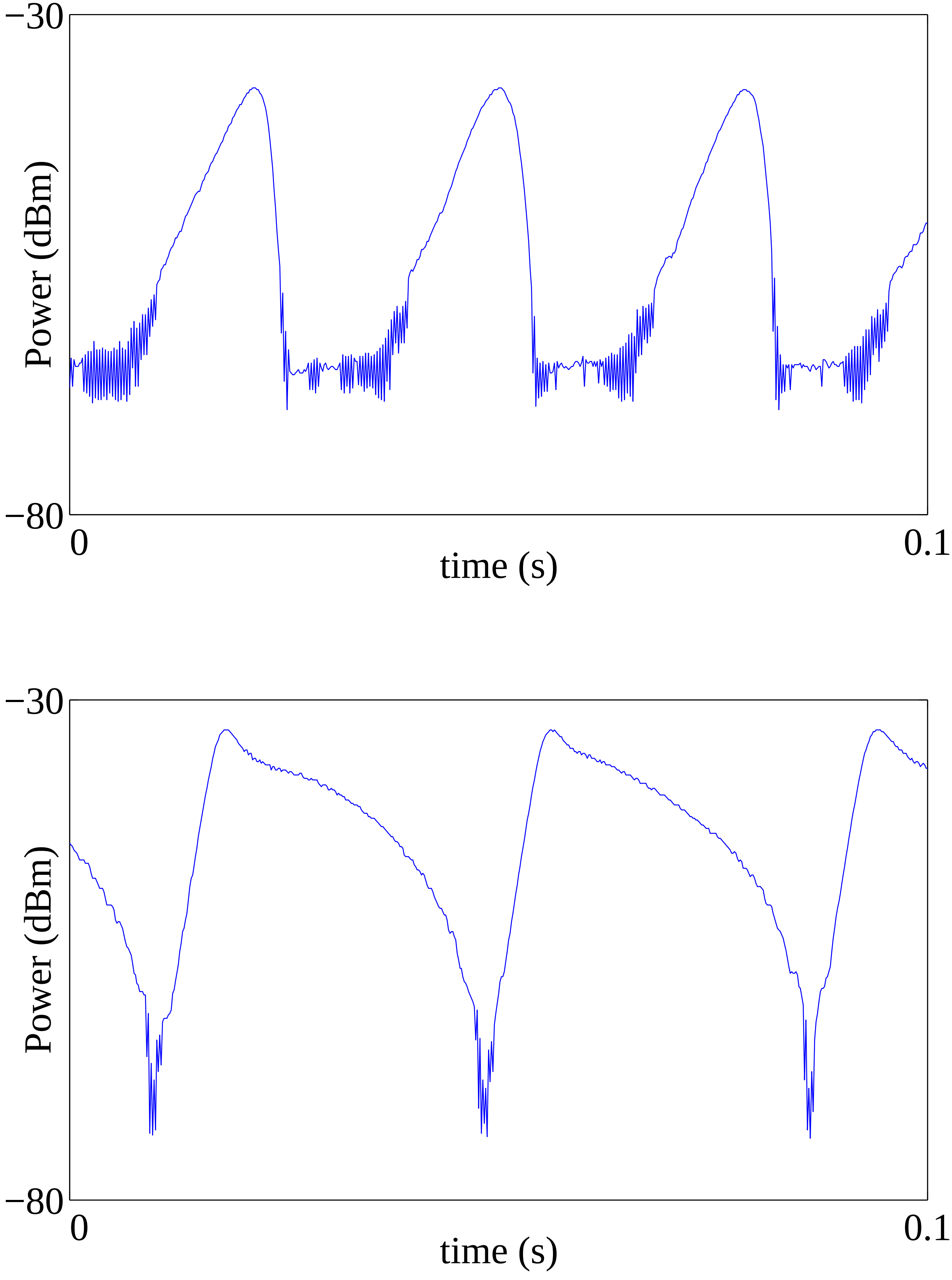
Courtesy of C. Limborg and J. Sebek, SLAC, PAC'99

Wakefield Effects on Single Bunch in SPEAR Displayed by Streak Camera



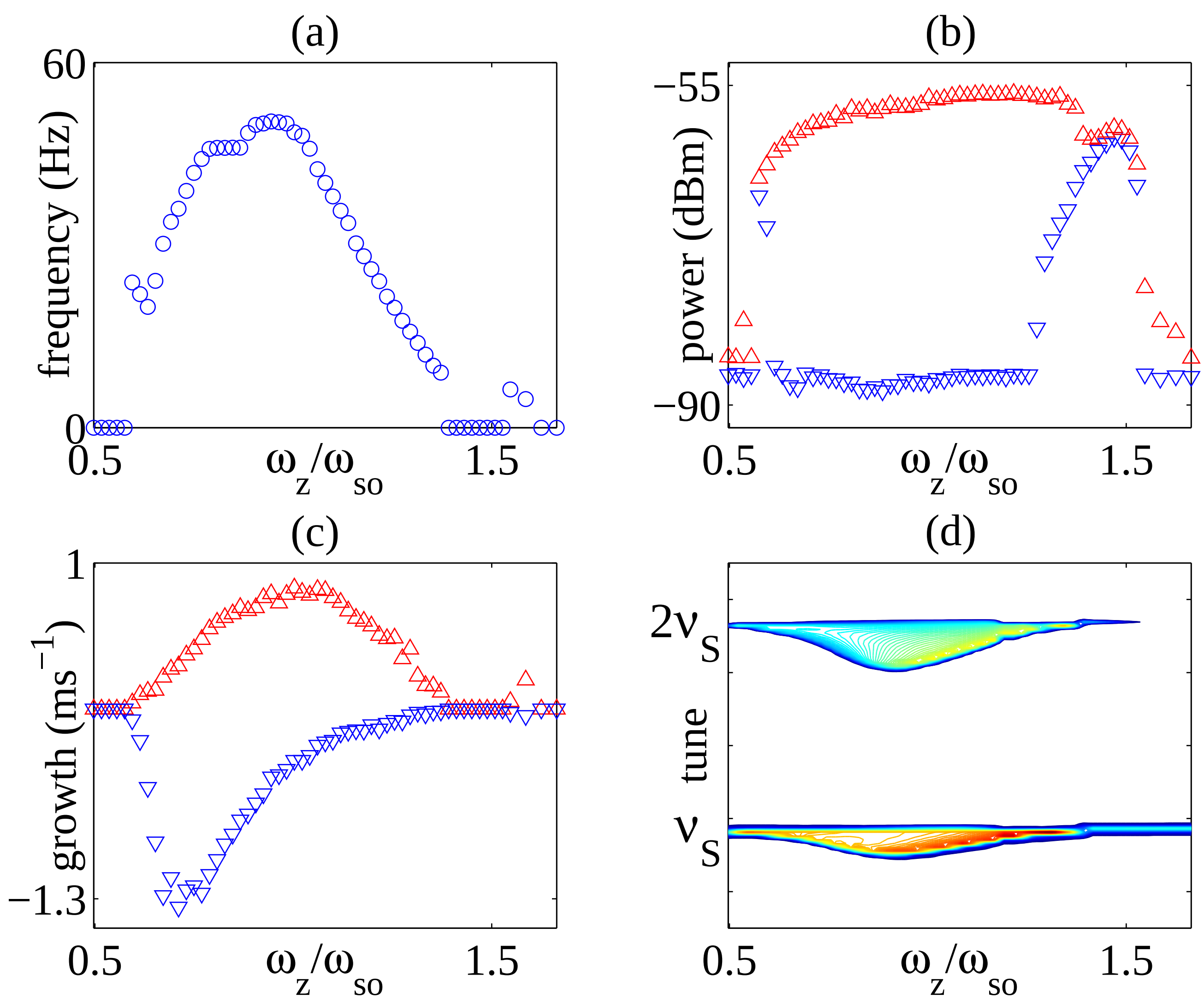
Courtesy of C. Limborg and J. Sebek, SLAC, PAC'99

power of upper ν_s sideband vs time

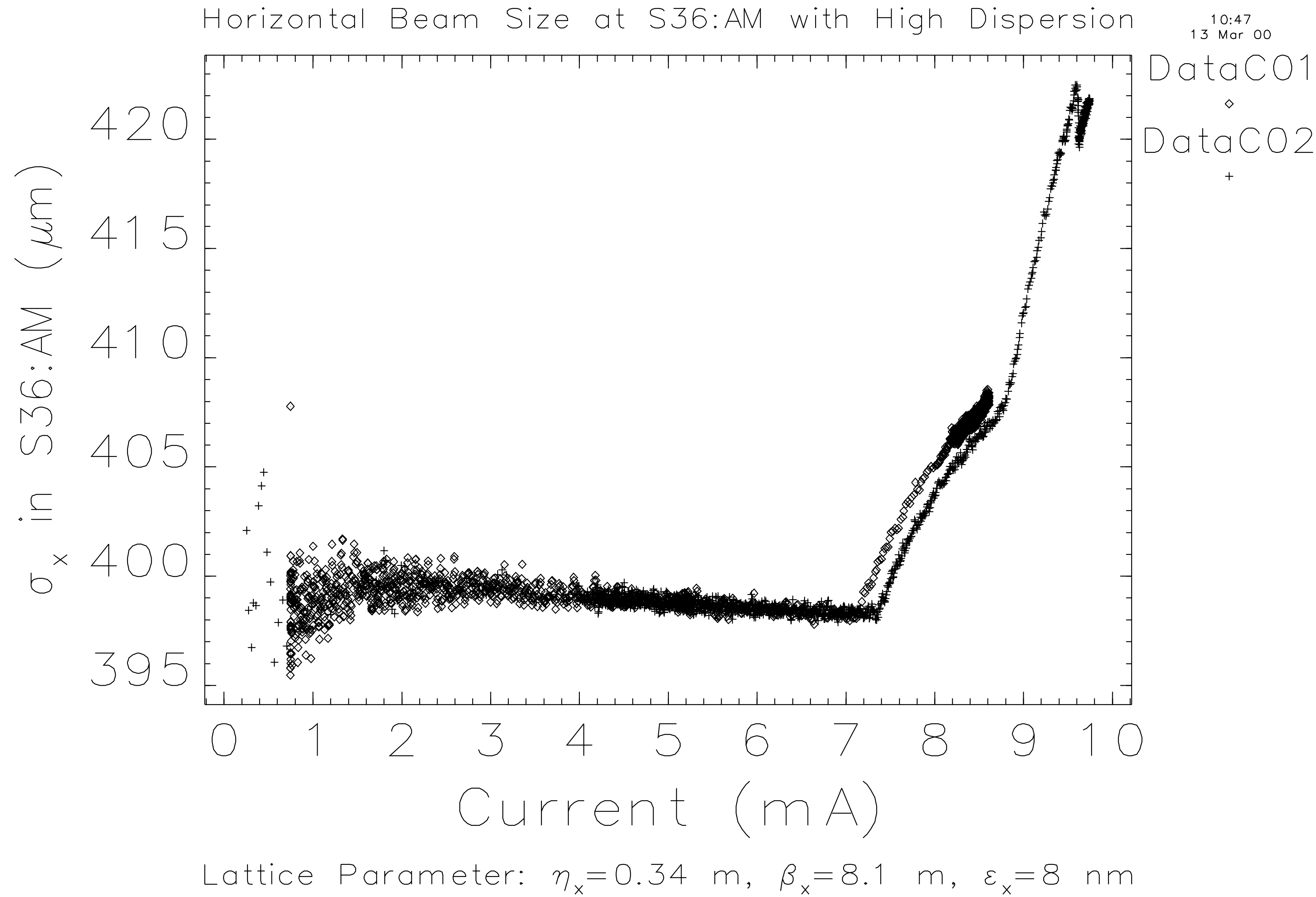


Courtesy of C. Limborg and J. Sebek, SLAC, PAC'99

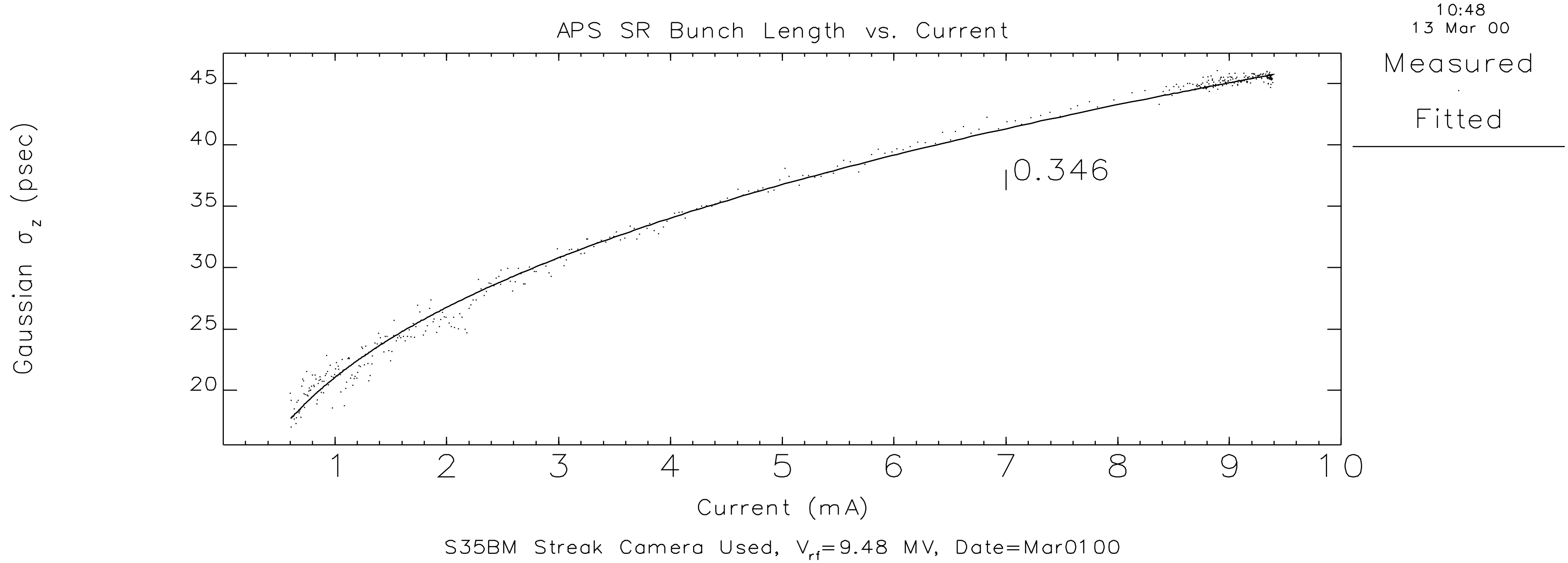
Summary of Spectrum Analyzer Data as Resonator Frequency is Increased

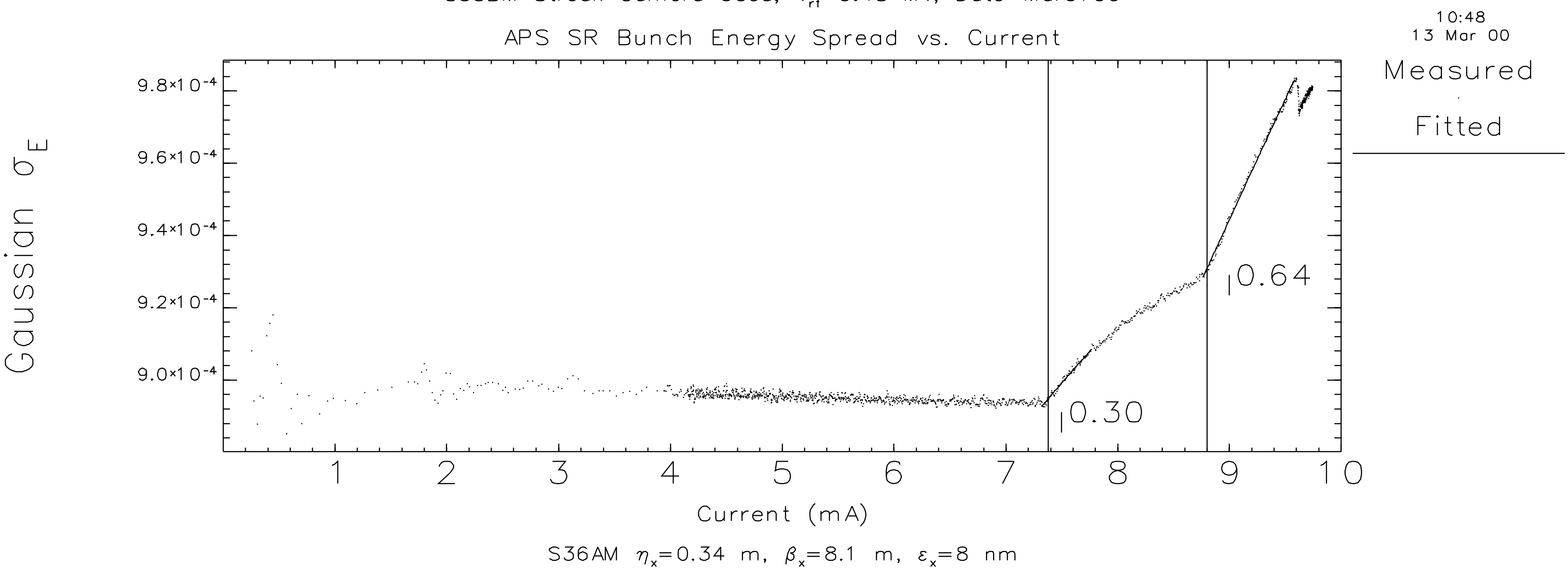


Courtesy of C. Limborg and J. Sebek, SLAC, PAC'99



Courtesy of Y. Chae, APS





Courtesy of Y. Chae, APS

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)

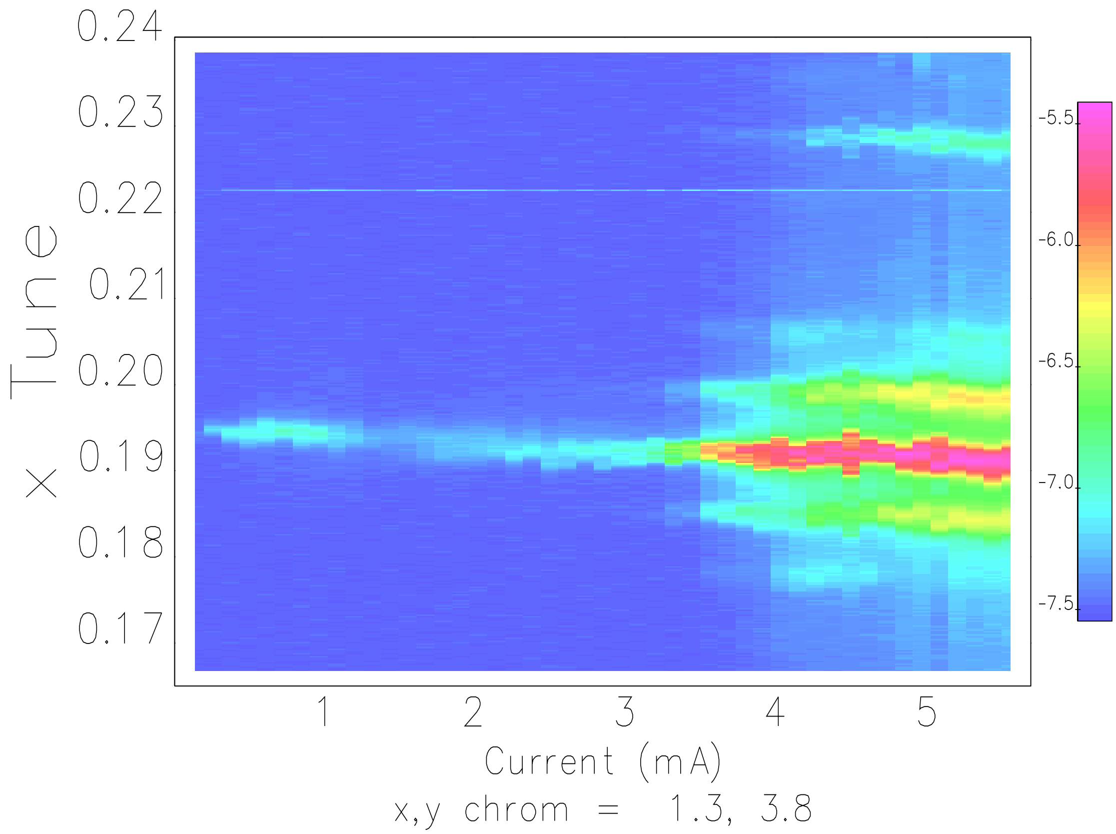
- x-diff signal acquired every other turn, total 8192 points
- "bursting mode" behavior seen above instability threshold
- BPM at dispersion; observe both x- and fs-tunes

3. DUAL-SWEEP STREAK CAMERA IMAGING: x vs. t

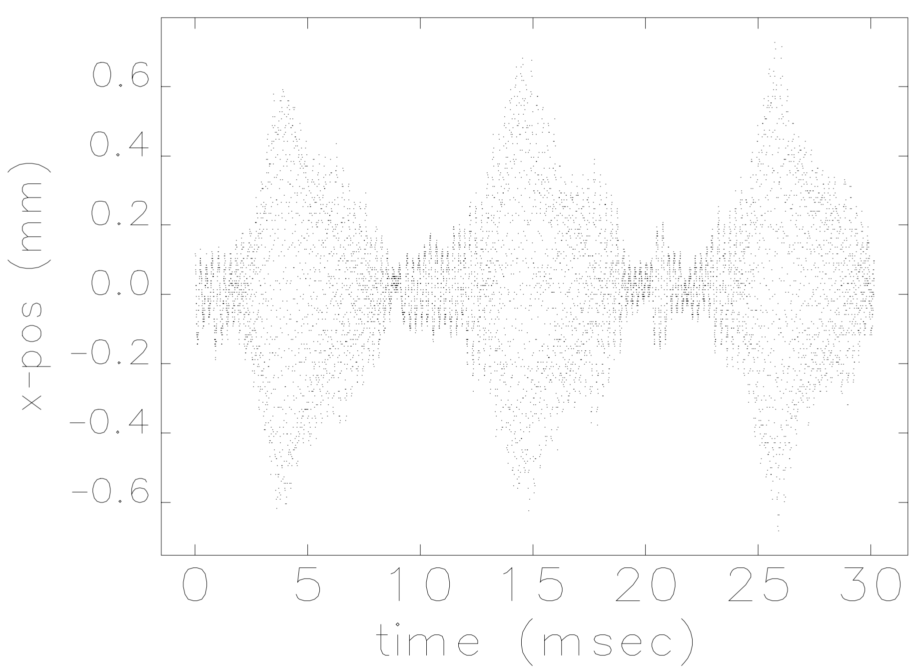
- distinctly shows that the bunch size does not decohere on the falling side of the bursts, which is the usual observation in saw-tooth-like instabilities

Courtesy of K. Harkay, APS

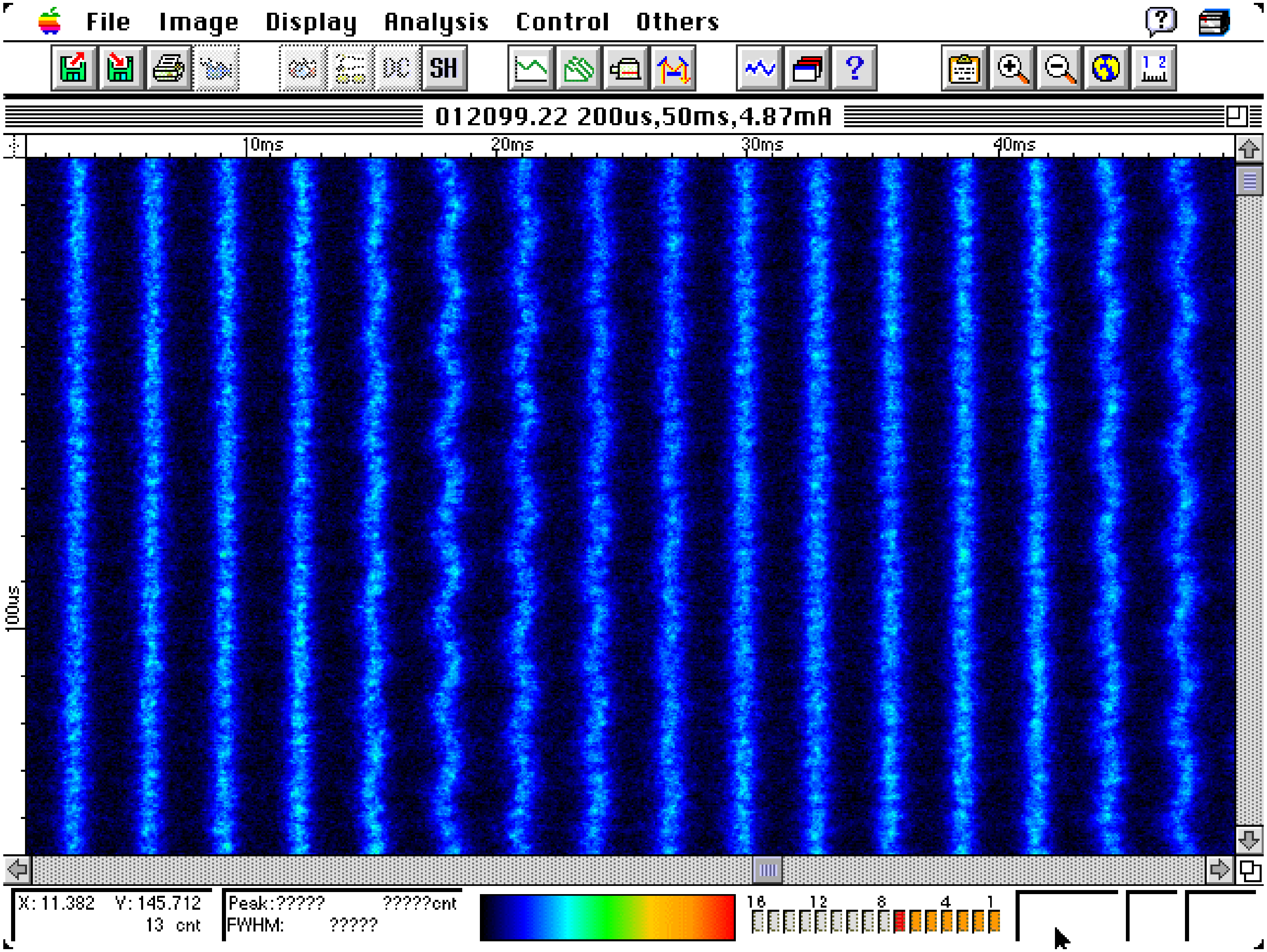
SELF-EXCITATION OF X-TUNE ABOVE THRESHOLD
(HP Vector Signal Analyzer spectrum)



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



Courtesy of K. Harkay, APS



Courtesy of B. Yang and K. Harkay, APS

III. Examples of Instability Measurements

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

<u>Transverse</u>

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

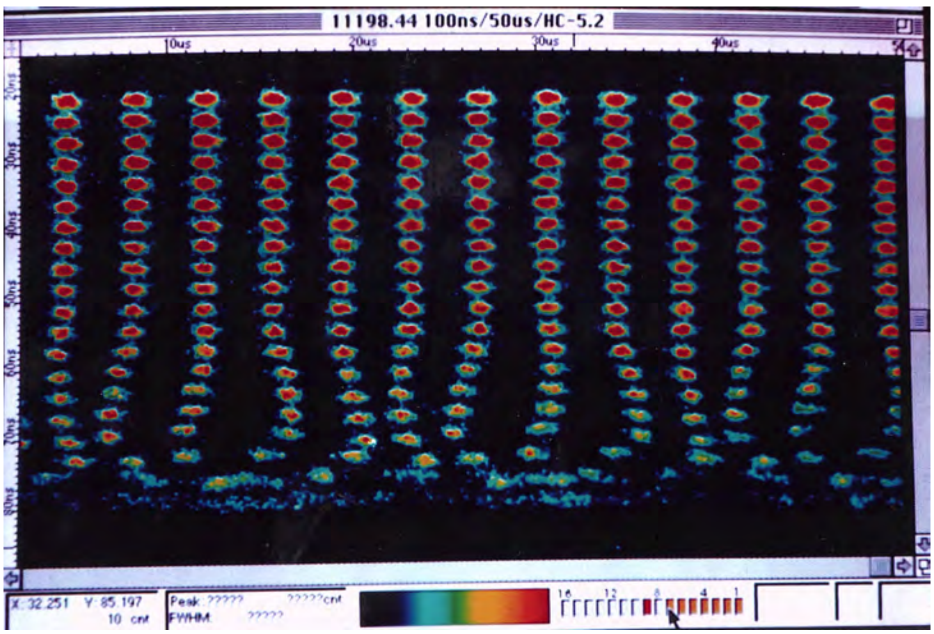
<u>Longitudinal</u>

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

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

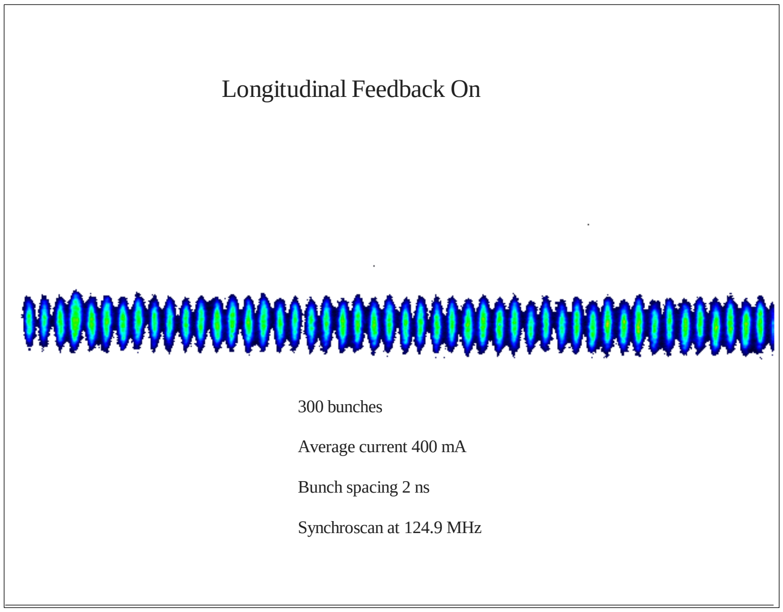
PEPII: Hundreds of bunches in HER, 0.75-A target
(A. Fisher, A. Lumpkin, U. Wienands)

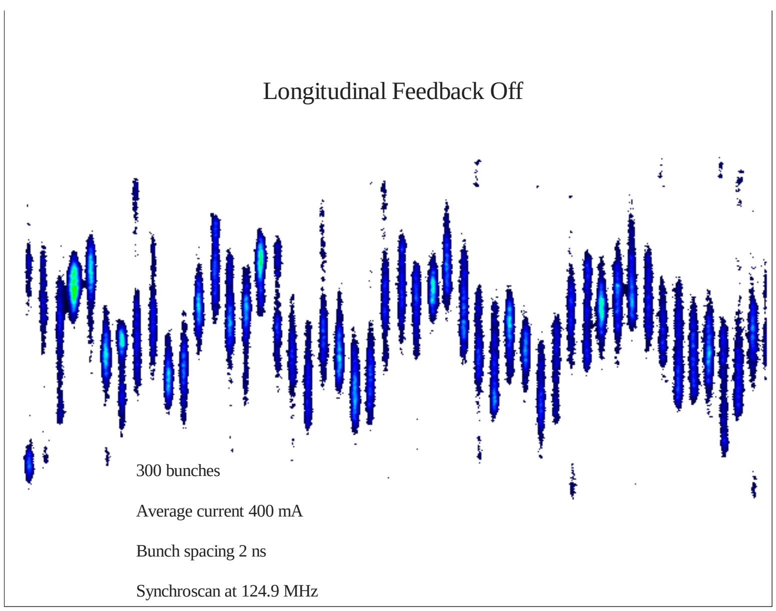
Dual-Sweep Streak Camera Image Shows
Multi-Bunch, Transverse Instability at APS
(20-Bunch Train)



Courtesy of B. Yang, APS

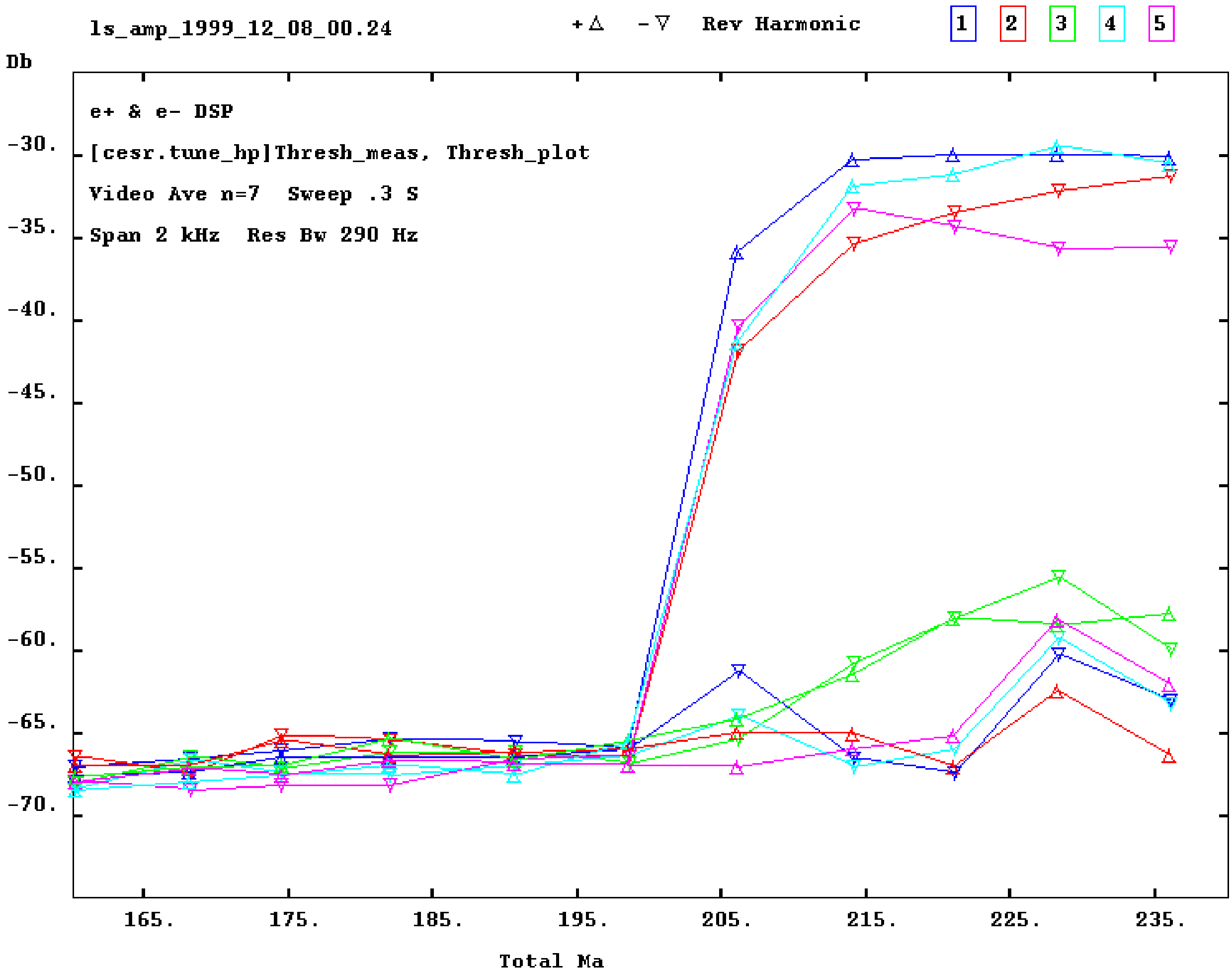
Effects of Longitudinal Feedback Clearly Displayed with Streak Camera at ALS Storage Ring





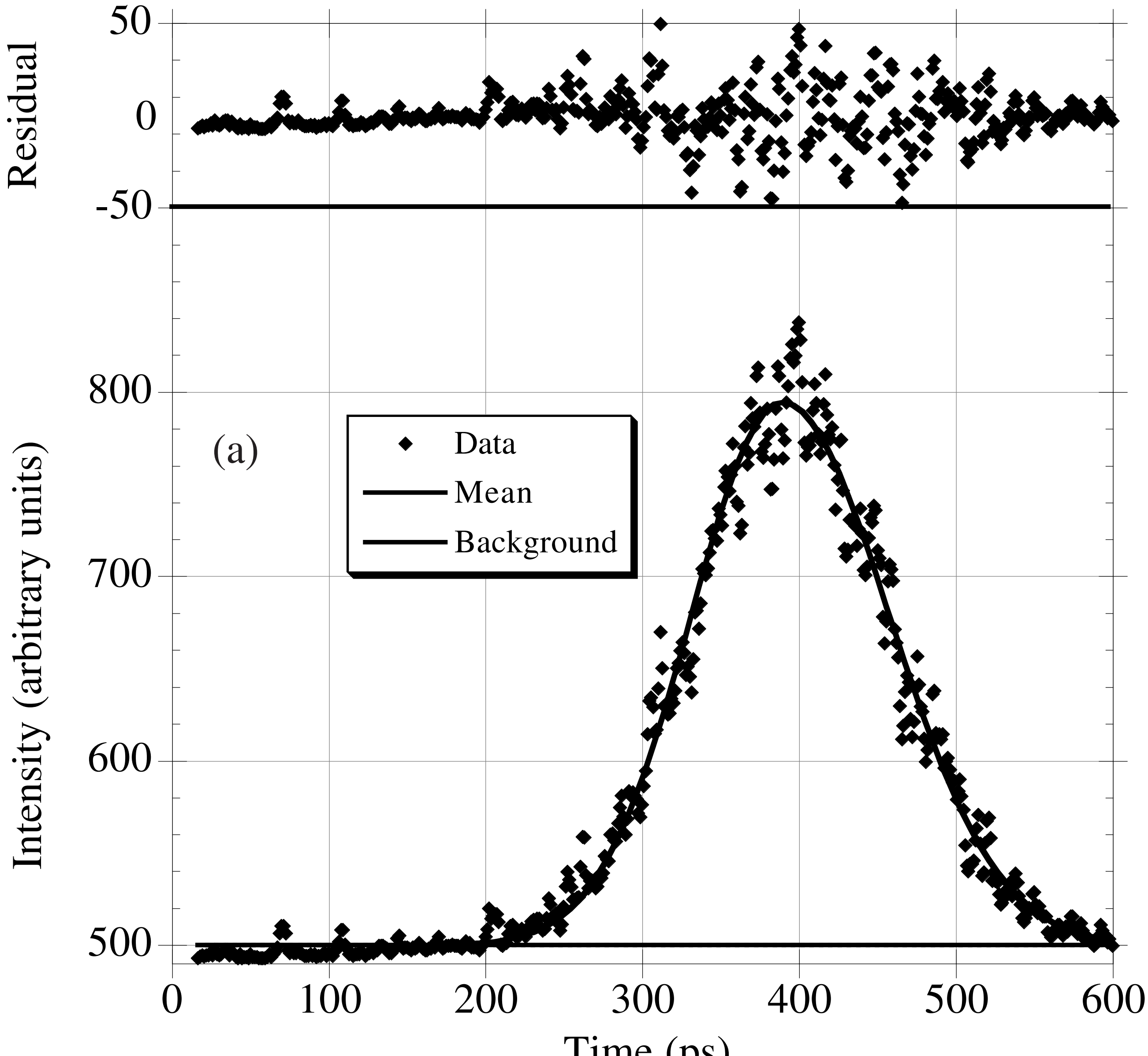
Courtesy of J. Hinkson, ALS, PAC'97

Coupled Bunch Longitudinal Dipole Instability at CESR



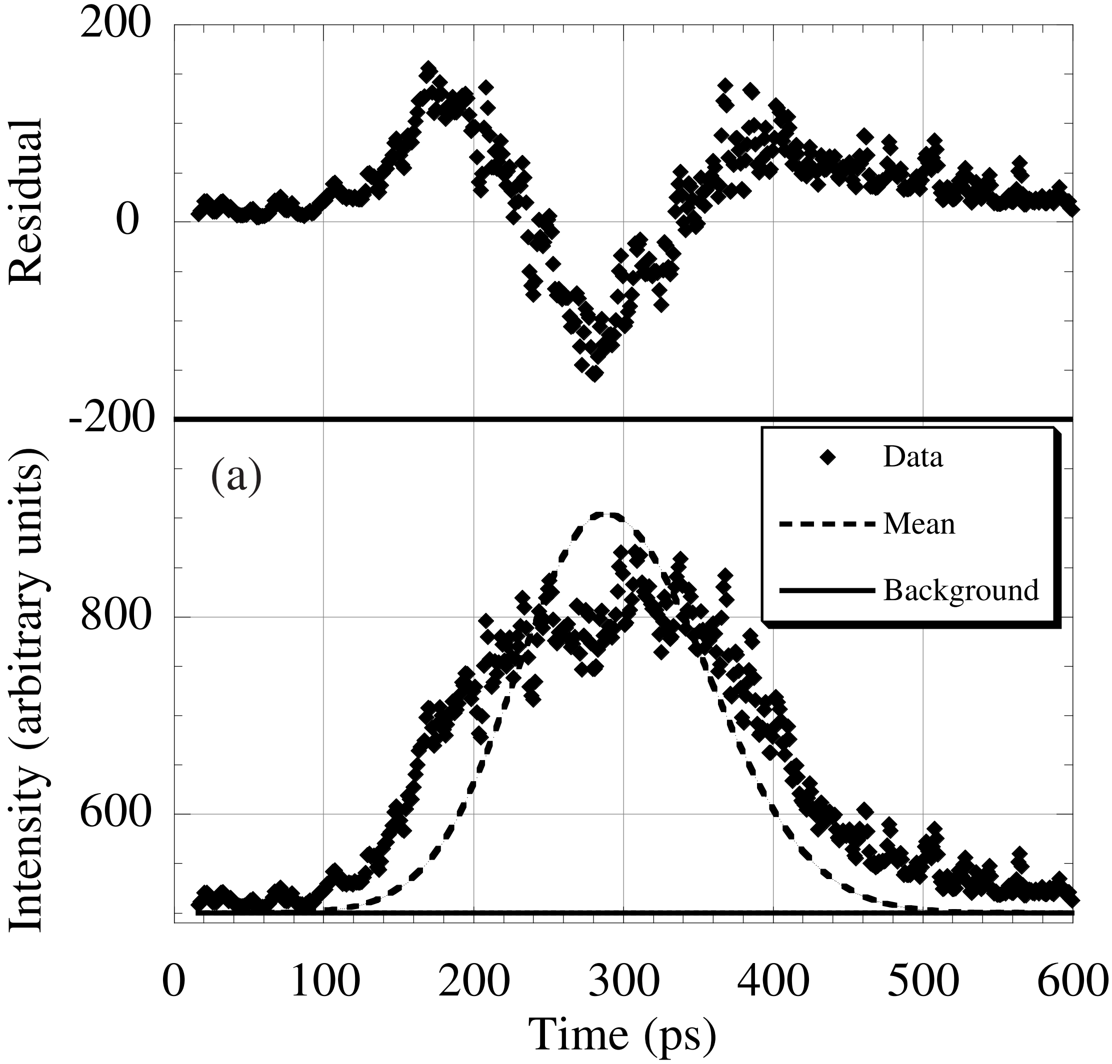
Courtesy of M. Billing, Cornell

Coupled Bunch Longitudinal Dipole Instability at CESR



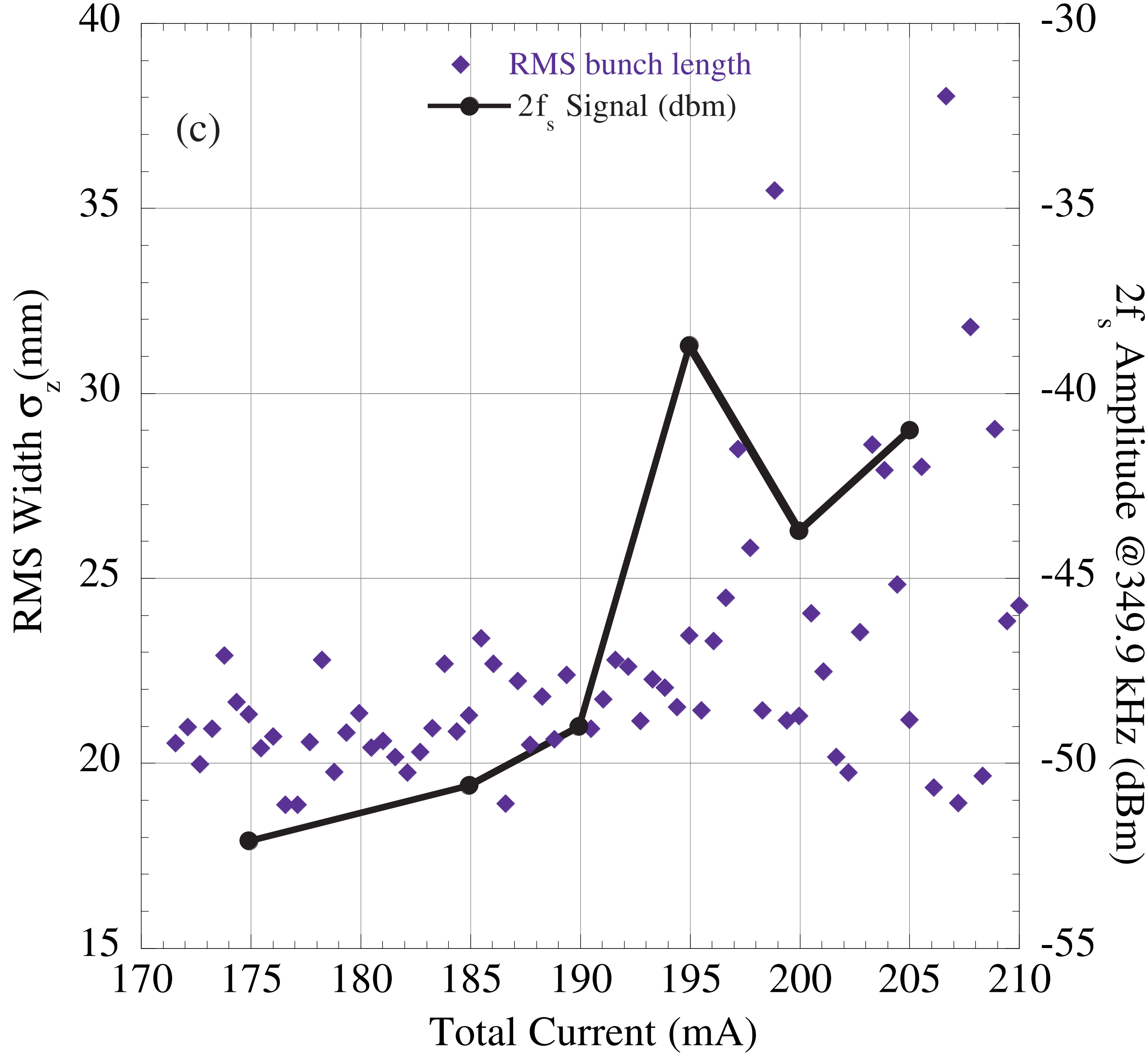
Courtesy of R. Holtzapple and M. Billing, Cornell, PAC'99

Coupled Bunch Longitudinal
Dipole/Quadrupole Instability at CESR



Courtesy of R. Holtzapple and M. Billing, Cornell, PAC'99

Coupled Bunch Longitudinal Dipole/Quadrupole Instability at CESR

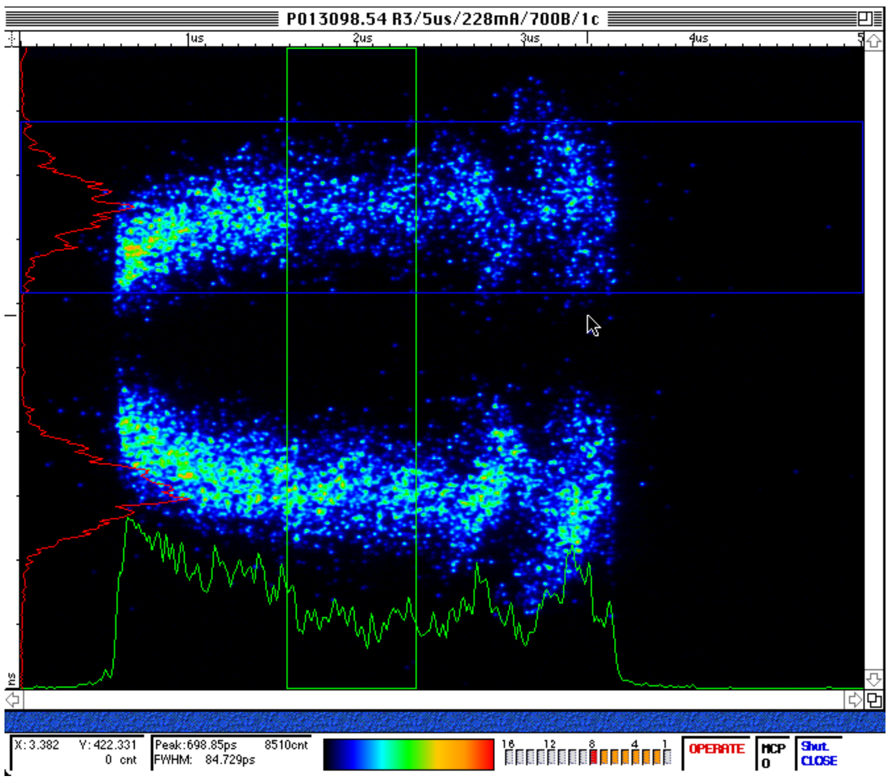


Courtesy of R. Holtzapple and M. Billing, Cornell, PAC'99

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 µs 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.

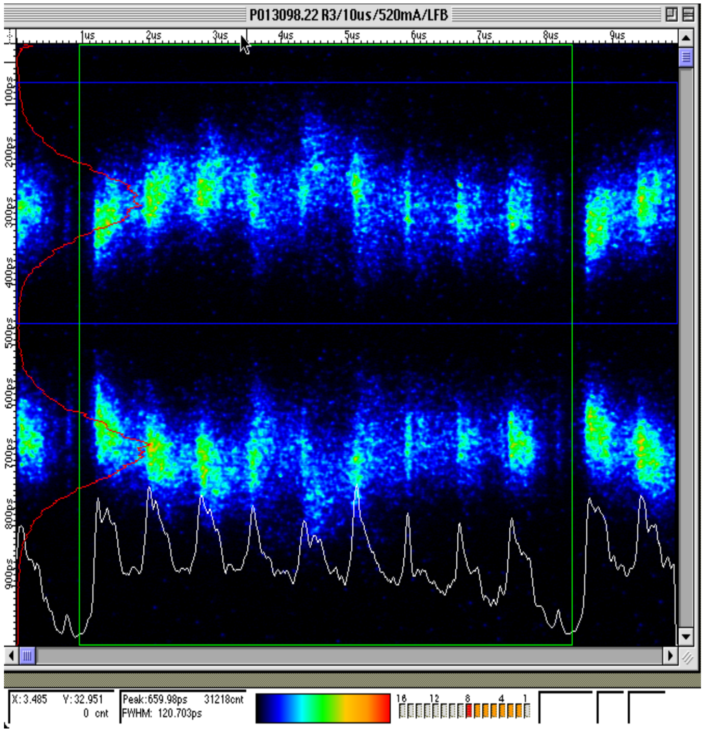
Courtesy of A. Fisher, SLAC

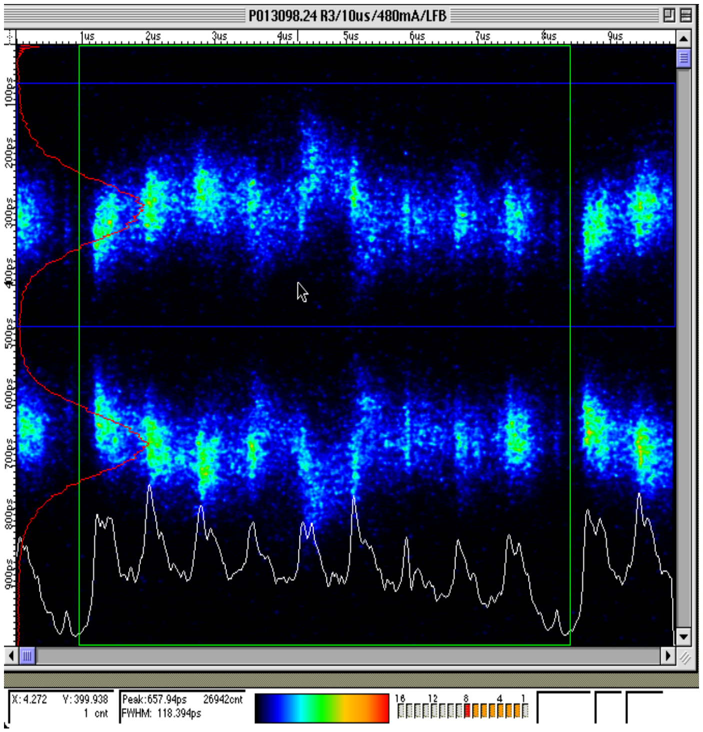
Longitudinal Instability at 500 mA

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.

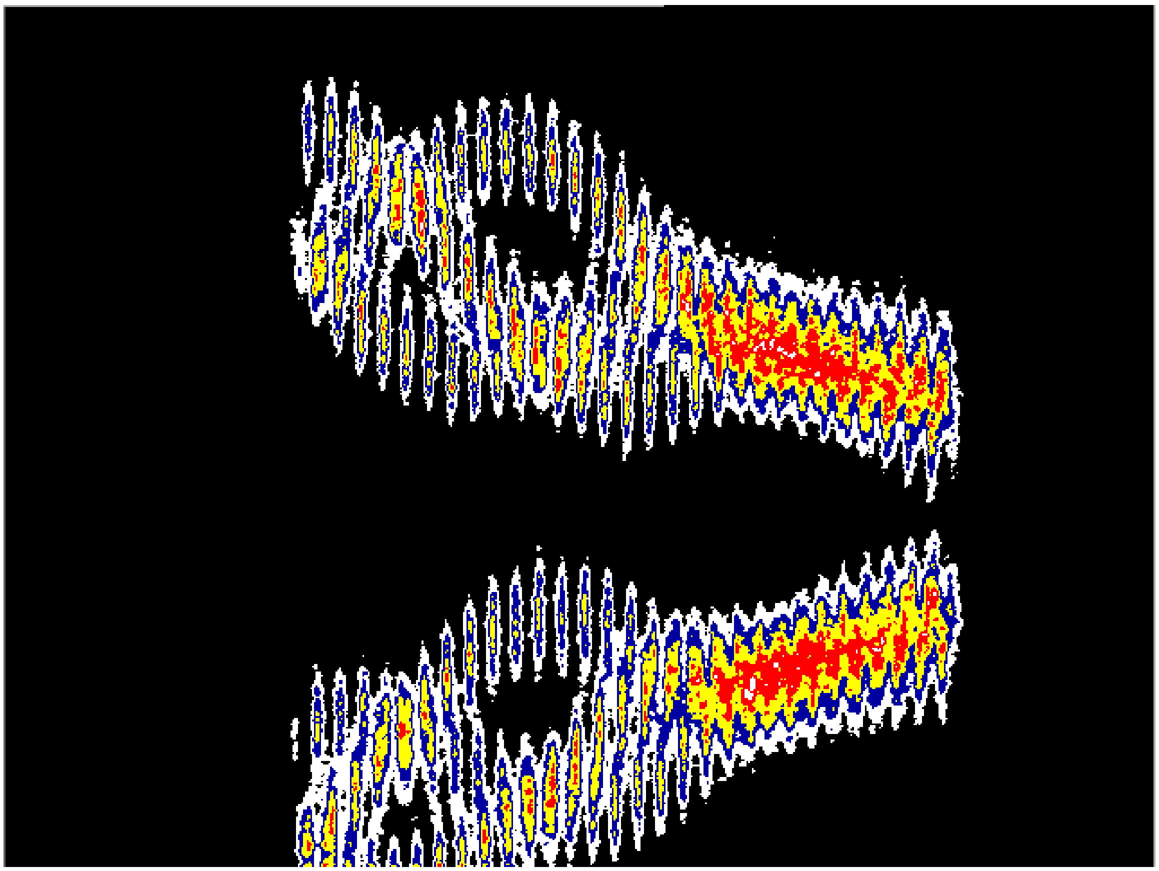
1 ns full vertical scale, 10 µs full horizontal scale (just over 1 turn)





Courtesy of A. Fisher, SLAC

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



Courtesy of O. Naumann and J. Jacob, ESRF

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.

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.