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Diagnostics: Synchroscan and Dual-Sweep Streak
Camera Techniques

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THE NEXT GENERATION OF RF-FEL (FREE-ELECTRON LASER) DIAGNOSTICS: SYNCHROSCAN AND DUAL-SWEEP STREAK CAMERA TECHNIQUES*

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ABSTRACT

Time-resolved experiments on rf-linac driven free-electron laser (FEL) experiments have recently been extended to displaying both the submicropulse and submacropulse effects. By using a synchroscan sweep on a streak camera key rf phase effects can be studied, and an additional dual sweep feature can provide this information during the macropulse. Successful measurements to date on the Los Alamos and Boeing FELs include electron-beam micropulse bunching during a macropulse, phase stability effects, micropulse elongation and transit time in a photoinjector, drive-laser phase stability, and FEL output evolution. Several of these measurements are the first of their kind on a FEL system.

I. INTRODUCTION

The importance of time-resolved experiments in rf-linac driven free-electron lasers (FELS) has been well established by "streak" techniques that display either submicropulse or submacropulse effects [1-3]. These techniques generally trade off time resolution, time span, and timing jitter. In the past year we have taken advantage of synchroscan streak cameras that are phase-locked to the reference 108.33 MHz rf

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signal, and thus allow the study of phase and pulse length for single micropulses or a series of them with much less jitter than a single sweep operation.

Additionally, by using a slow ramp deflection on the axis orthogonal to the fast sweep [4], one can obtain submicropulse, submacropulse, and phase information during a single 100-μs long macropulse. Initial results to date from the Los Alamos and Boeing FEL experiments include electron-beam micropulse bunch lengths, cavity length tuning, phase slew/jitter, micropulse length during a macropulse, micropulse elongation and transit time in a photoinjector, drive-laser phase stability, and visible FEL output temporal effects. Several of these demonstrations are the first of their kind on a FEL system (to our knowledge). Selections of some of these results will be given in Section III.

II. EXPERIMENTAL CONSIDERATIONS

Due to space limitations only a summary of these particular experimental techniques will be presented. More detailed descriptions of the Los Alamos HIBAF Facility [5] and Boeing HAP Facility [6] are given elsewhere in these proceedings. Although there are conceptual similarities with other beam line deflectors (rf and dipole type) used by us in the past [1], these particular results used a Hamamatsu C1587 synchroscan streak camera with the appropriate plugins. The dual sweep feature is a hardwired upgrade to the main frame that allowed a selectable slow ramp to be applied to an existing second set of deflection plates in the streak tube. A schematic of this dual sweep effect is illustrated in Fig. 1 where the phase-locked rf sweep at 108.3 MHz on the vertical axis combined with the orthogonal slow sweep provides submicropulse, submacropulse, and phase slew/jitter information in one streak image of a macropulse.

If the horizontal sweep is not employed, the synchroscan sweep axis can be used to monitor phase jitter in a photoinjector drive laser such as at Los Alamos or to monitor the synchronous sum of spontaneous emission micropulses on the Boeing visible FEL experiment. In each case a NARDA or ARRA rf phase shifter was used in the delay line delivering the reference 108.33 MHz to the synchroscan unit. The jitter specification is about 4 ps (FWHM) over seconds at 108 MHz, with <6 ps temporal resolution for a single micropulse event. For example, at Los Alamos the drive-laser beam at 526 nm could be counted down to a single micropulse with electro-optic switching techniques [5]. Phase jitter and/or slew can sometimes be inferred when a series of micropulses synchronously summed has a longer bunch length than a single micropulse. For the temporal behavior of such effects the dual sweep images are needed to avoid ambiguity.

III. RESULTS AND DISCUSSION

Several representative examples of measurements made with these streak camera techniques will be discussed in this section.

A. Synchroscan Results

Figure 2 shows a series of temporal profiles of the synchronous sum of 15-μs (300 micropulses) of drive-laser beam at Los Alamos. Other than the approximate 15-ps bunch length the centroid jitter macropulse to macropulse was a key measurement. These 16 profiles taken at 1 Hz show a noticeable phase jitter. This jitter was dominated by the mode-locked oscillator of the laser, but it resulted in a correlated e-beam energy jitter as shown in Fig. 3. The sensitivity was about 0.1% shift in energy per one picosecond of phase jitter. It also was asymmetric in nature around one set phase point. This physical correlation eliminates the streak camera instrument jitter as the cause of Fig. 2. Additional corroboration of this interpretation is shown in Fig. 4 where a phase stabilizer circuit added to the drive laser's master oscillator reduced the total observed rms jitter from about 11 ps to <2 ps. The synchroscan instrument limit may have been reached on the latter value.

Additionally, Fig. 5 shows that the measured e-beam micropulse length variation with laser phase agreed with the PARMELA transport simulation. Note the 30-80% stretching of the e-beam versus the 11-ps long drive-laser micropulse. This is a measure of space-charge effects. These experiments are addressed in more detail by Lumpkin et al. [7] elsewhere in these proceedings.

As we worked with single e-beam micropulses on the photoelectric injector, we also noticed that one obtained streak images of the field emission electrons emitted at the 1300 MHz rf frequency. The synchroscan system summed the very weak bunches into a detectable image as shown in Fig. 6. These experiments provided the first micropulse temporal structure for field emission electrons on a high quantum efficiency photocathode.

B. Dual Sweep

At the Boeing facility, synchroscan streak images of the spontaneous emission from the 5-m wiggler were used to monitor the e-beam micropulse bunch length as in our earlier simple fast sweep measurements [3]. In Fig. 7 the upper image (28 ps) and lower image (12 ps) show the synchronous sum of ~200 micropulses before and after optimization of the subharmonic bunches (108 and 433 MHz) in the injector. Figure 8 then shows a dual sweep of such a macropulse, phased and dephased. When analyzed, samples during the macropulse apparently are 10-20% narrower than the synchronous sum, a signature of phase jitter/slew (see Table 1). Additionally, in the FEL lasing mode, the dual sweep images in Fig. 9 show the macropulse intensity modulation (Fig. 9a) while also yielding the observed lasing micropulse bunch length of ~8 ps (Fig. 9b). The lasing peaks also were detected at about the same rf phase position as referenced to 108.3 MHz. These data are complemented by a slow streak/spectrometer image in Fig. 10b indicating an apparent wavelength slew over several microseconds. The temporal structures on the macropulse scale are similar, but are not from the same macropulse. This is addressed by Dowell, et al. [6] in their discussion of the recent ring resonator results on a visible FEL.

IV. SUMMARY

In summary, synchroscan and dual sweep streak camera techniques have been successfully used on FELs for measurements including electron-beam micropulse bunching, cavity length tuning, rf phase stability, micropulse length during a macropulse, micropulse elongation in a photoinjector, drive-laser phase stability, and FEL output evolution. These results illustrate the important roles these techniques can play in the characterization and optimization of rf-linac FELs.

V. ACKNOWLEDGMENTS

The author acknowledges the personnel in the operations team at the Los Alamos Facility (D. W. Feldman, R. B. Feldman, and J. E. Early) and the Boeing Facility

(D. H. Dowell, A. R. Lowrey, M. L. Laucks, and P. Johnson), for their providing the beams on which these measurements were made.

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6. D. H. Dowell, et al., "First Operation of a Free-Electron Laser Using a Ring Resonator Optical Cavity," These Proceedings.
7. A. H. Lumpkin, B. E. Carlsten, and R. B. Feldman, "First Measurements of Electron-Beam Transit Times and Micropulse Elongation in a Photoelectric Injector at HIBAF," These Proceedings.

FIGURE CAPTIONS

Fig. 1. Schematic of Dual Sweep Streak technique.

Fig. 2. Synchroscan streak profiles tracking drive laser phase jitter.

Fig. 3. Correlation of phase jitter of Figure 2 to electron beam energy jitter at spectrometer.

Fig. 4. Synchroscan streak analysis of drive laser macropulse jitter with and without phase stabilization.

Fig. 5. Measured e-beam micropulse length variation with laser phase agreed with PARMELA.

Fig. 6. Beamspot and synchroscan streak of field emission electrons.

Fig. 7. Electron beam bunching measurement on visible spontaneous emission radiation from Boeing wiggler.

Fig. 8. First Dual Sweep Streak measurements of e-beam on Boeing Facility.

Fig. 9. Dual sweep streak technique applied to lasing signals from the Boeing/Rocketdyne ring resonator: (a) macropulse temporal structure and (b) micropulse bunch length measurement.

Fig. 10. Streak/spectrometer techniques applied to lasing signals from the Boeing/Rocketdyne ring resonator: a) dual sweep and b) slow sweep on wavelength.

TABLE 1. SUMMARY OF SYNCHROSCAN AND DUAL SWEEP STREAK MEASUREMENTS OF e-BEAM AT BOEING (DATA OF 4-13-90)

MEASUREMENT TECHNIQUE	ACCELERATOR CONDITION	PULSE LENGTH[†] observed (ps)	PULSE LENGTH[†] e-BEAM (FWHM, ps)
Synchroscan	100 μs, as found	28	27
Synchroscan	100 μs, 108 MHz tune	17.5	16
Synchroscan	100 μs, 433 MHz tune	12.3	10
Dual Sweep	Phased, 100-μs span,~10 μs sample	10.6	8
Dual Sweep	Dephased, 108 MHz ~10 μs sample	17.2	16

[†] $\Delta t_{OBS} = \sqrt{(\Delta t_{eB})^2 + (\Delta t_{Res})^2 + (\Delta t_{jitter})^2}$

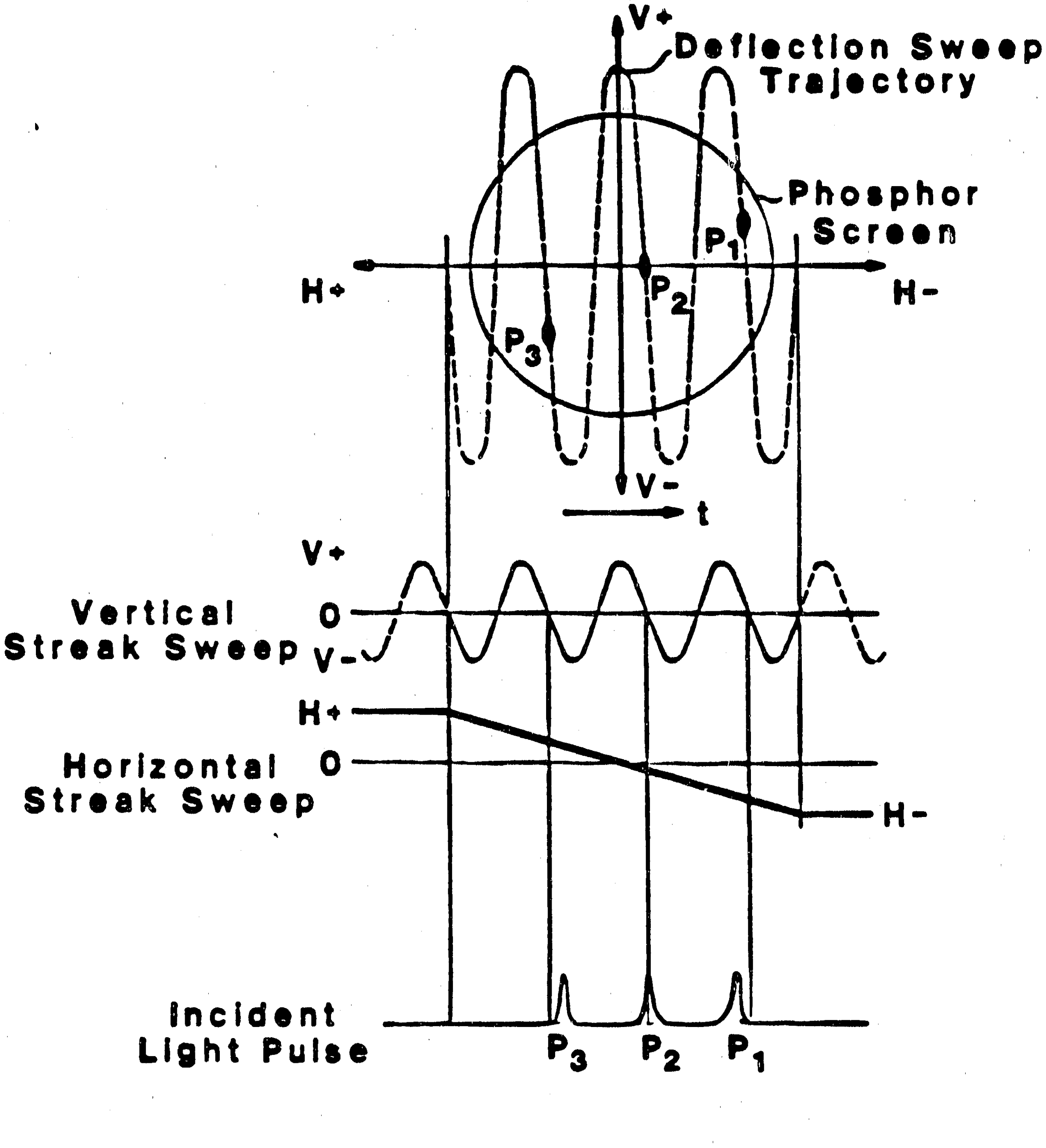
Where:

Δt_{eB} includes intrinsic pulse length for a single micropulse plus jitter and slew for a macropulse

Δt_{Res} = 6 ps of synchroscan sweep

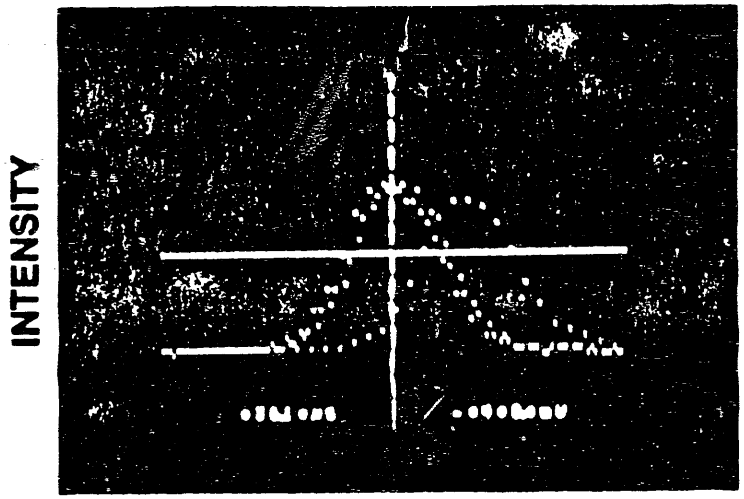
Δt_{jitter} = 4 ps (FWHM) over seconds specification

SCHEMATIC OF DUAL SWEEP STREAK TECHNIQUE

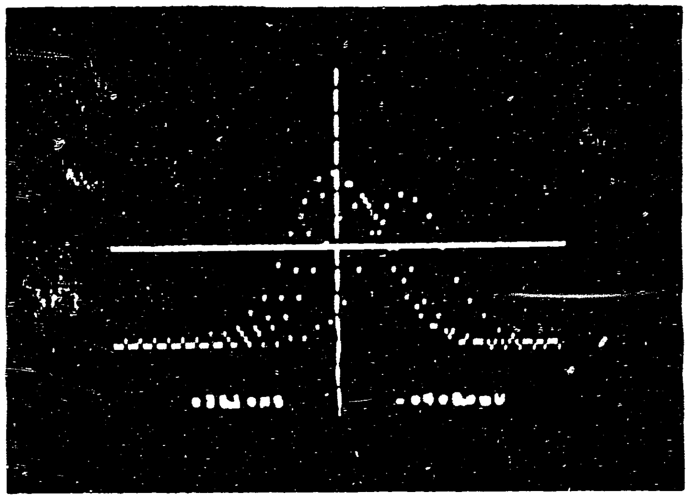


SYNCHROSCAN STREAK PROFILES
TRACK DRIVE - LASER PHASE JITTER (3-13-90)

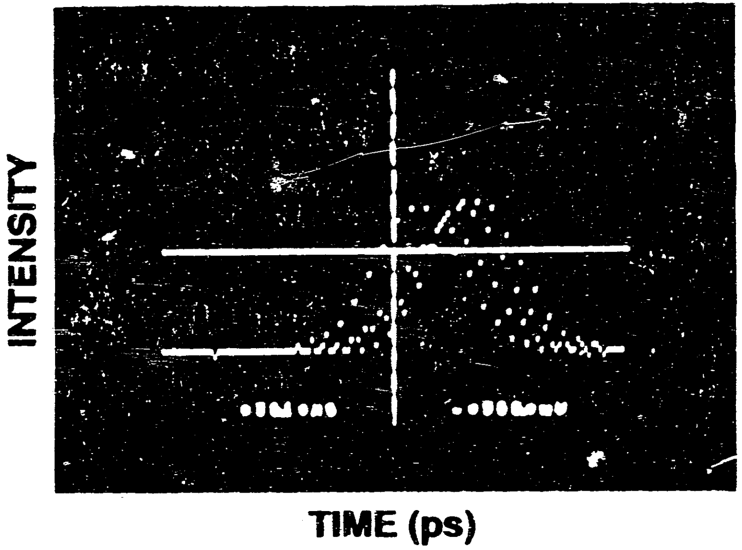
TR 1 (1-4)



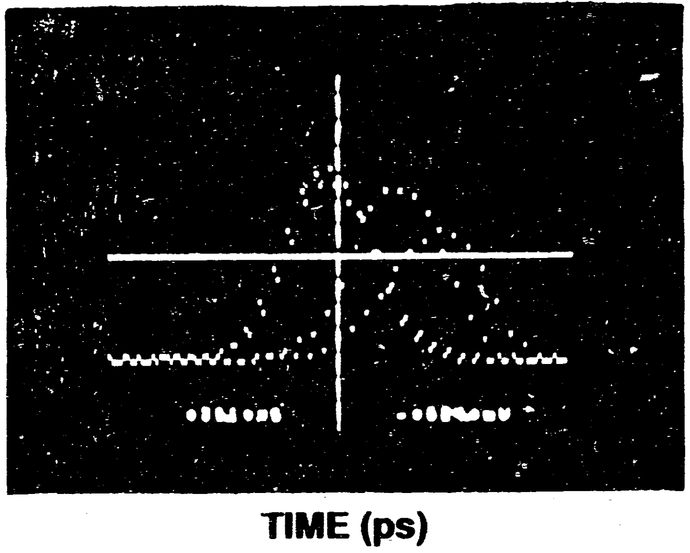
TR 2 (5-8)



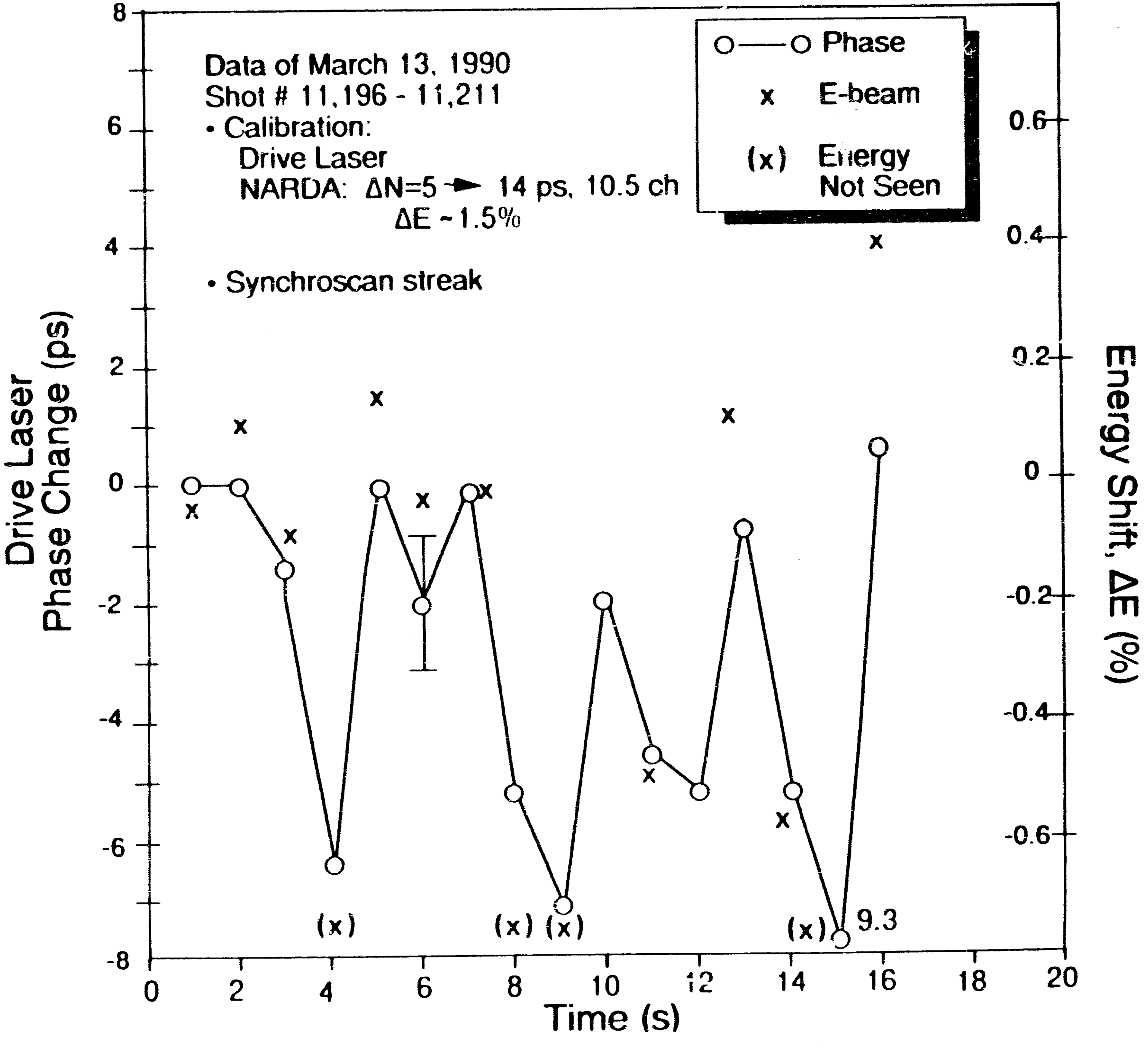
TR 3 (9-12)



TR 4 (13-16)

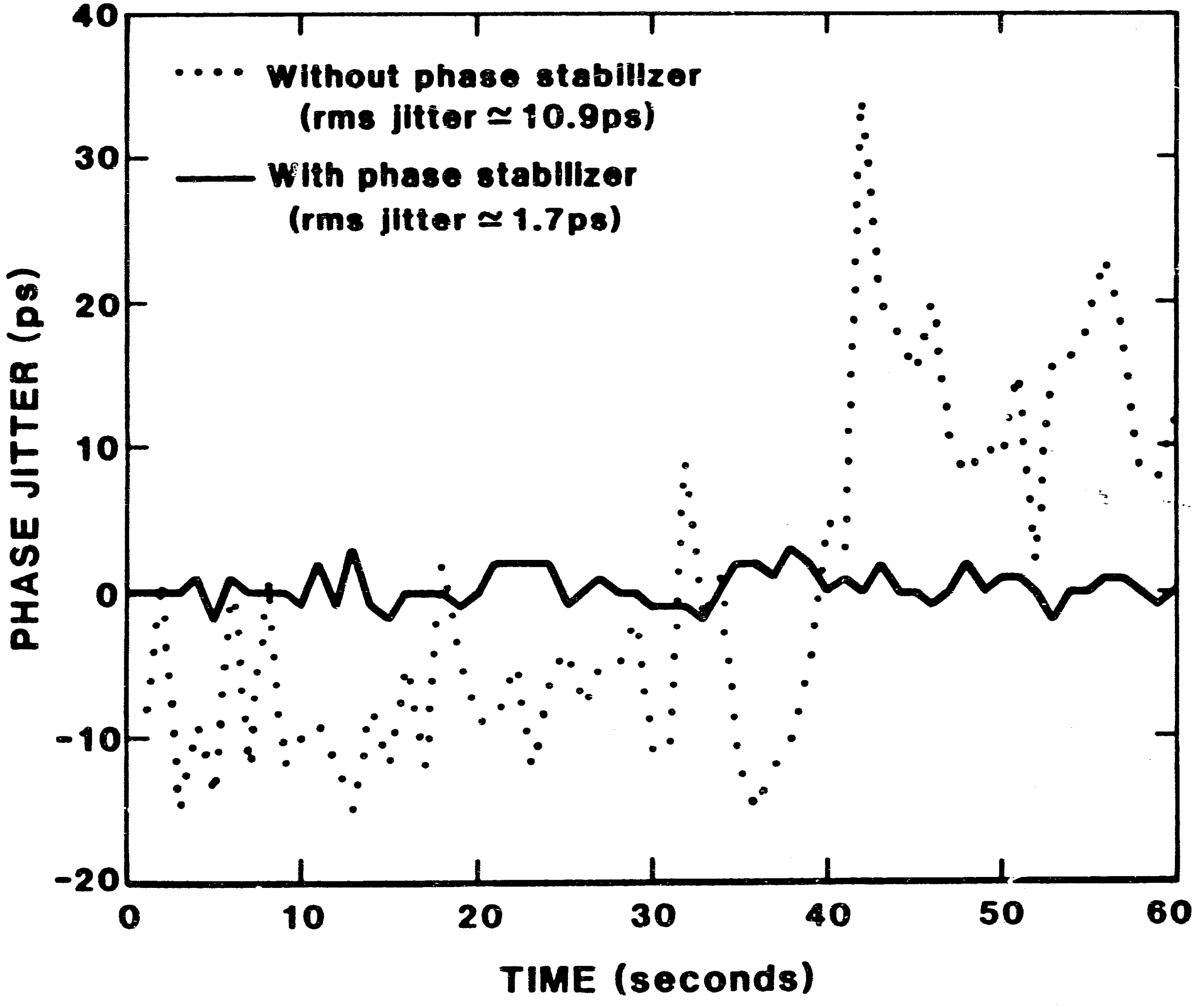


E-BEAM ENERGY JITTER CORRELATED WITH DRIVE LASER PHASE JITTER



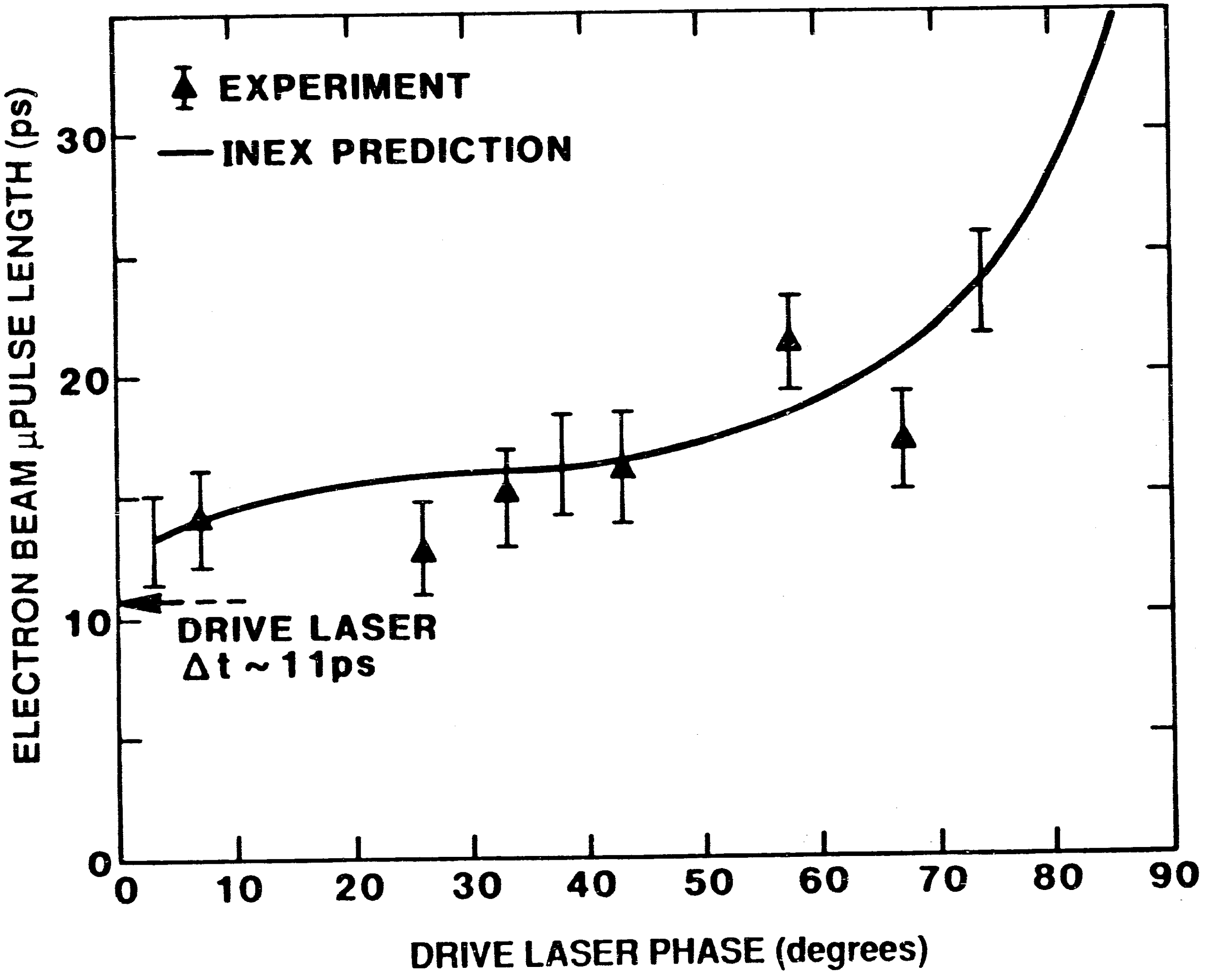
DRAMATIC IMPROVEMENTS IN DRIVE LASER PHASE STABILITY HAVE BEEN DEMONSTRATED

(HIBAF, APRIL 1990)



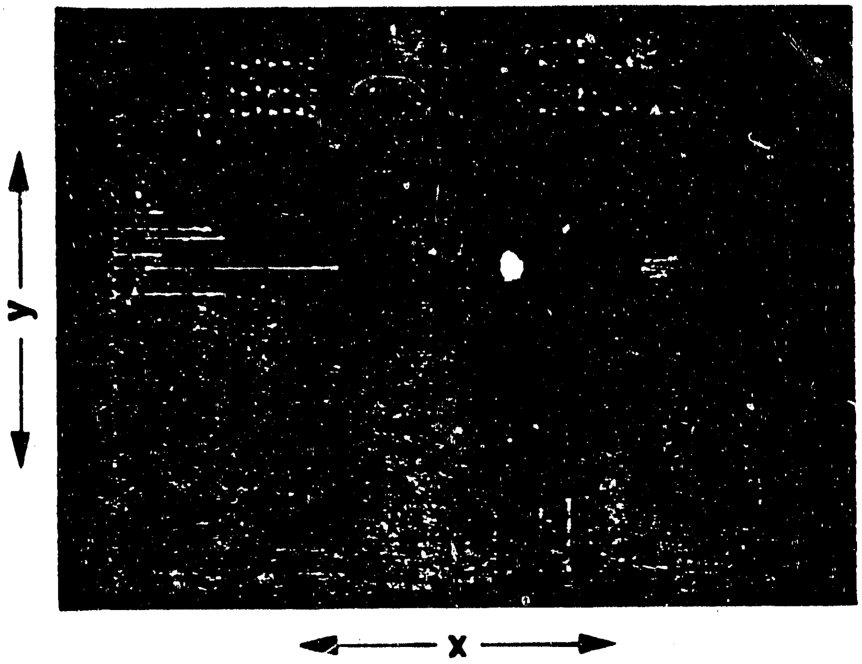
F-4

MEASURED μPULSE LENGTH VARIATION WITH LASER PHASE IN INJECTOR AGREES WITH INEX PREDICTION



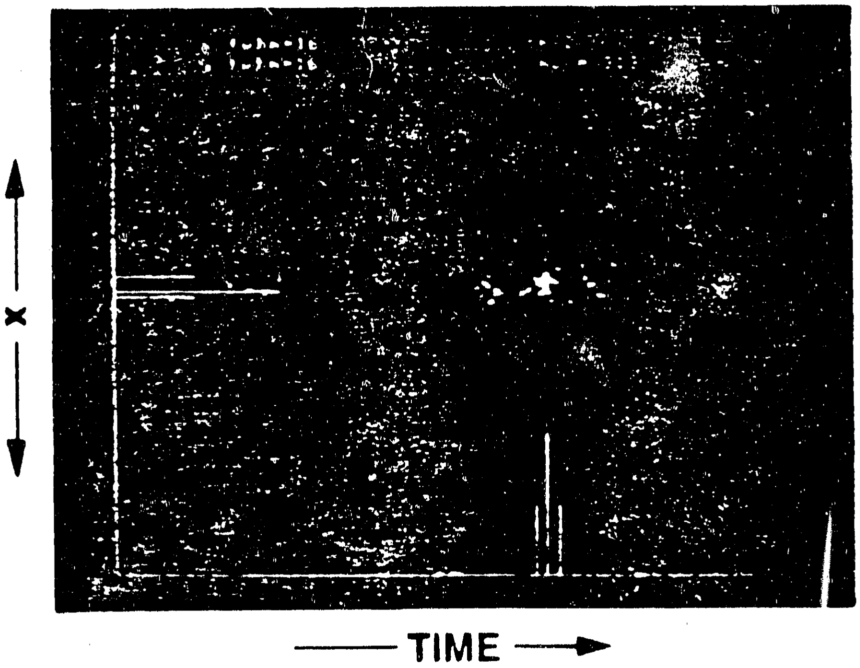
FIELD EMISSION ELECTRONS COMPARABLE TO SINGLE MICROPULSE

(3-15-90)



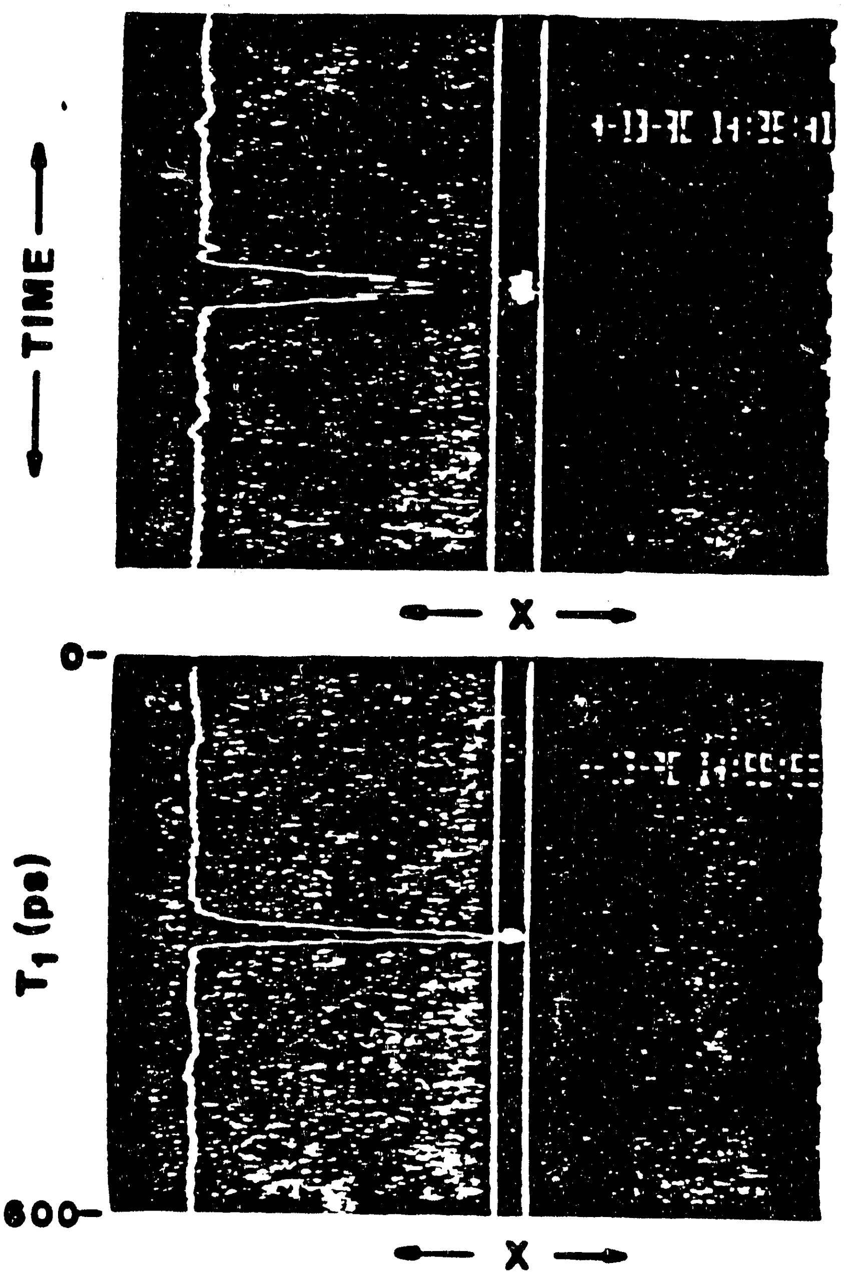
BEAMSPOTS

- Field Emission
- Single μ Pulse



Synchroscan
Streak of
Field Emission
Electrons Only
Δt ~ 20 ps

SYNCHROSCAN STREAK PROVIDES BUNCHING DIAGNOSTIC FROM OUTCOUPLED SPONTANEOUS RADIATION (MACROPULSE)

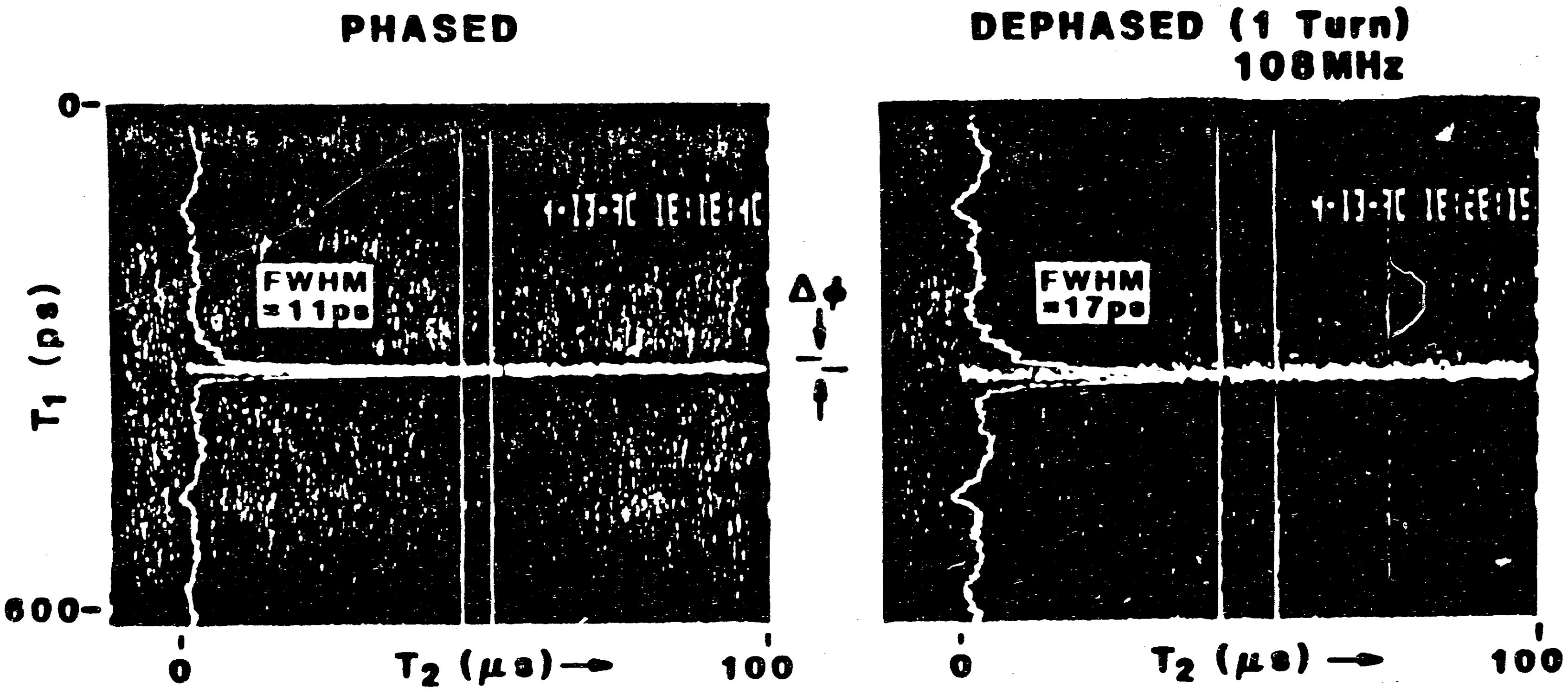


FWHM
=27.8ps

FWHM
=12ps

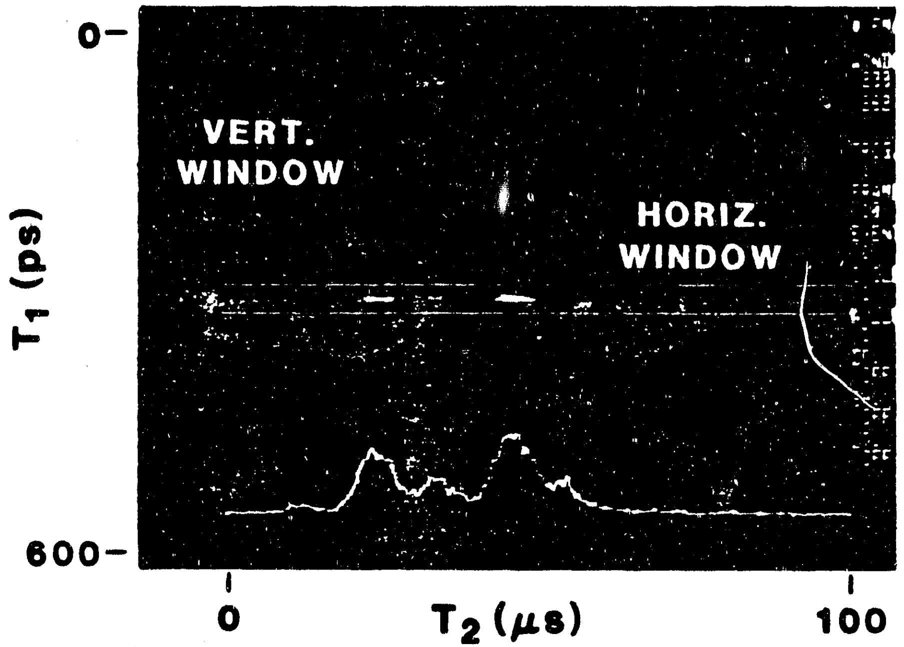
108MHz SHB(1)
433MHz SHB($^1/_3$)

INITIAL DUAL SWEEP STREAK IMAGES PROVIDE SIMULTANEOUS MICROPULSE AND MACROPULSE INFORMATION

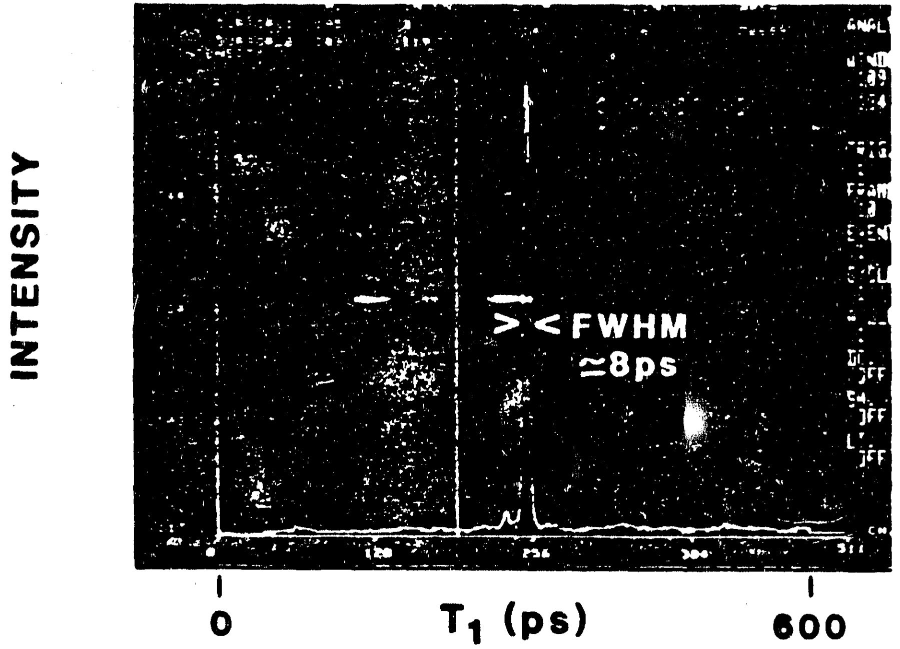


DUAL SWEEP STREAK IMAGE DISPLAYS BOTH MACRO AND MICROPULSE LASING EFFECTS

(MAY, 1990)



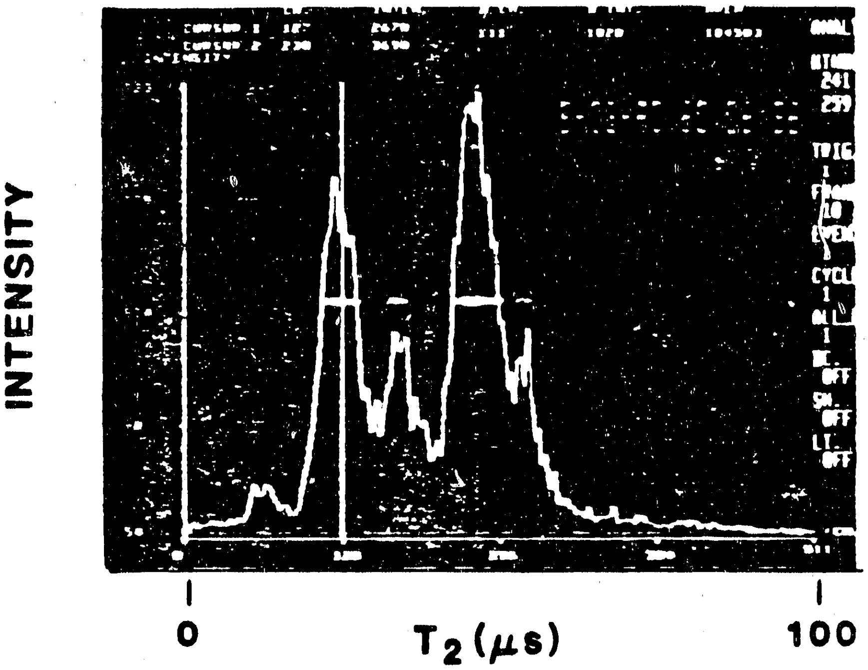
a)
MACROPULSE WINDOW (HORIZONTAL)



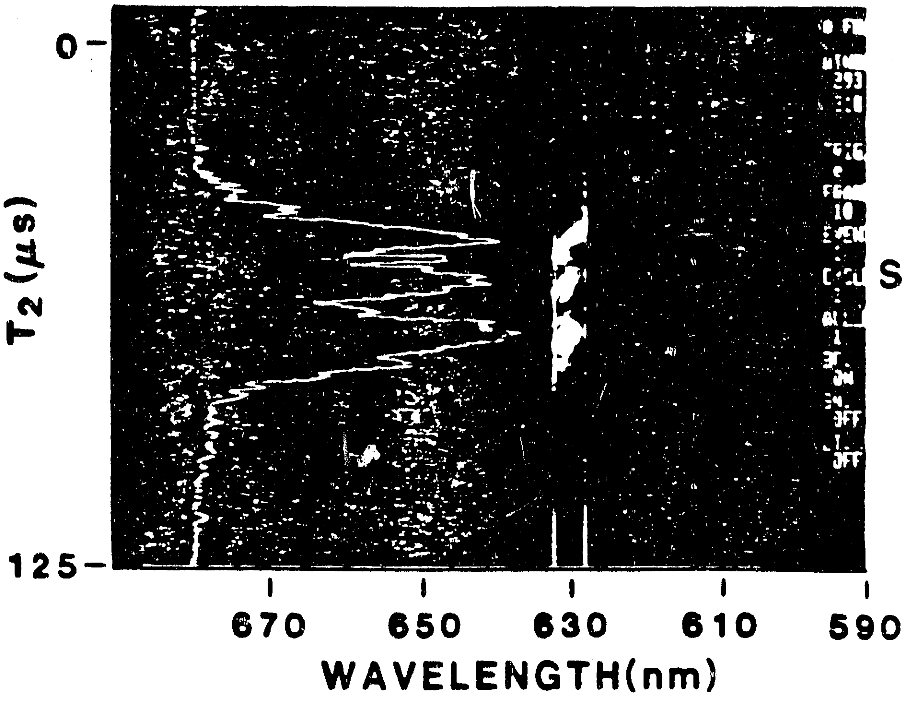
b)
MICROPULSE WINDOW (VERTICAL)

(ANALYSIS MODE)

ADVANCED STREAK TECHNIQUES DISPLAY RING RESONATOR LASING PERFORMANCE (MAY, 1990)



a)
DUAL SWEEP:
$X(T_1, T_2)$



b)
SLOW SWEEP:
$(\lambda(T_2))$

END

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