# Preliminary Tests of the Optical Diagnostics for the APS Low-Energy Undulator Test Line Particle Beam*

by

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**Abstract:**

An alternate configuration of the injector linacs (low-energy undulator test line) at the Advanced Photon Source (APS) combined with a thermionic rf gun is projected to provide low, normalized emittance electron beams ($\varepsilon_n \sim 5\pi$ mm mrad). By using the electron linac and the in-line, rephased positron linac, beam energies from 250 to 650 MeV with bunch lengths $\sigma_t \sim 1$ ps are possible. In order to characterize such beams, the present intercepting Chromox screens with limited spatial resolution and temporal response are being complemented by optical transition radiation (OTR) screens at selected positions in the beamline to provide sub-100 μm spatial resolution and sub-ps response times. Initial OTR images have been obtained from a beam at 650 MeV using the conventional thermionic gun to generate a 30-ns-long macropulse. Micropulse bunch lengths as short as 3 to 4 ps ($\sigma$) were also measured using a C5680 streak camera. Additionally, coherent transition radiation (CTR) and diffraction radiation (DR) based techniques will be evaluated. These beam characterizations will support self-amplified spontaneous emission (SASE) scaling experiments.

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## 1. Introduction

An increased interest in diffraction-limited light sources for the next generation sources and the implementation of prototype or scaling experiments has been evident since the Fourth Generation Light Source Workshop held in Grenoble in January 1996 [1]. At the Advanced Photon Source (APS), a research and development effort had been underway for several years [2-4] to use the injector linacs with a low-emittance electron beam source. More specifically, an rf thermionic gun would be used for injection into the 100- to 650-MeV linac subsystem based on the existing 200-MeV electron linac and 450-MeV positron linac. The low, normalized emittance beams ($\varepsilon_n \approx 5\,\pi$ mm mrad) require an upgrade to the existing Chromox viewing screens for characterization of beam transverse size and bunch length. We are in the process of testing optical transition radiation (OTR) screens at selected positions in the beamline to provide sub-100 μm spatial resolution and sub-ps response times [5, 6]. In order to compensate for the reduced brightness of this conversion mechanism, both gated, intensified cameras and streak cameras are also being used to measure the beam properties. Initial tests with beam at 650 MeV (but generated by a conventional thermionic gun) have been done with a charge-injection device (CID) camera, a charge-coupled device (CCD) camera, and a streak camera. Additionally, the feasibility of using coherent transition radiation (CTR) and diffraction radiation (DR) based techniques will be evaluated. The diagnostics will be used to characterize, optimize, and monitor the bright beams needed to support self-amplified spontaneous emission (SASE) scaling experiments at $\lambda \sim 120$ nm and a beam energy of 400 MeV as described separately [7].

## 2. Experimental Background

### 2.1 Linac

The APS facility's injector system uses a 250-MeV S-band electron linac and an in-line S-band 450-MeV positron linac. The electron gun is a conventional thermionic gun in standard operations. For the alternate configuration, an rf thermionic gun, designed to generate low-emittance beams (<5 $\pi$ mm mrad) and configured with an $\alpha$-magnet, injects beam just after the first linac accelerating section [4]. Then both in-line linacs can be phased to produce 100-650 MeV electron beams when the positron converter target is retracted.

The rf-gun's projected, normalized emittance is orders of magnitude lower than that of the conventional gun, and correspondingly much smaller beam spot sizes ($\sigma_{x,y} \approx 100$ $\mu$m) result than from the conventional gun. The standard intercepting screens are based on Chromox of 0.25-mm thickness and with a 300-ms decay time [8]. Previous experiences on the Los Alamos linac-driven free-electron laser (FEL) with a low-emittance photoelectric injector (PEI) support the applicability of optical transition radiation screens in this case [9]. A summary of projected beam properties is given in Table 1. However, initial tests of a Ti foil used as an OTR screen, the transport of the OTR out of the tunnel, and the CCD camera and streak camera setup have been done with a "surrogate" beam from the conventional gun. These were done at a beam energy of 650 MeV, 2-5 nC in the macropulse, and 25-30 pC in each of 80 micropulses.

## 2.2 Beam Characterizations

A general description of the proposed techniques for beam characterization is given in Ref. 2. A subset of those based on optical techniques and now in the installation and testing stage are presented here.

*Transverse Characterizations*

The transverse beam sizes and profiles are key to evaluating the beam emittance and its preservation throughout the accelerator and transport lines.

At the 50-MeV station, two additional OTR screens are being installed. Although their axial spacing is less than 1 meter, beam quality will be initially checked at this point using the two-screen beam size measurement technique, as well as the beam size versus quadrupole-field strength scan technique.

Another key station is at the end of the linac in the transport line, nominally the 650-MeV station. At this point an optical transport line has been installed to bring the OTR light to an optical table outside of the linac tunnel. This table will provide an experimental base for measurements with a streak camera and a gated, intensified charge-coupled device (ICCD) camera (Stanford Computer Optics, Quik-05A). With the microchannel plate (MCP)-based shutter, 5-ns-wide samples from the beam macropulse are possible. The gain factor of the MCP also allows for imaging of defocused spots during a quadrupole field scan for an emittance measurement. The tests of these cameras have already been done on the APS positron accumulator ring (PAR) and the booster synchrotron using synchrotron radiation from ~1 nC charge passing through a dipole.

The PAR bypass transport line provides a unique opportunity with its 10-m drift space to perform a three-screen emittance measurement. As described in Ref. 7, the center screen is 4.8 m from the two end ones. Relay optics will bring the images to a lead-shielded ICCD camera. A fourth screen may be used for OTR interferometer experiments in conjunction with the center screen.

*Longitudinal Characterizations*

Because longitudinal beam brightness is related to evaluations of SASE gain, the measurement of bunch duration and profile are also critical in this program.

At the 50-MeV station, one of the OTR screens and one part of the beamline cross will be configured to send the far-infrared (FIR) coherent transition radiation that will be generated by the few-ps or mm-long bunches to a FIR Michelson interferometer. An optical autocorrelation technique will be evaluated as a bunch duration diagnostic [10].

The baseline technique will use a Hamamatsu C5680 dual-sweep streak camera viewing the incoherent OTR signal from the 650-MeV station. The transport of OTR to the optics table outside the tunnel has facilitated these experiments. The most useful vertical sweep plug-in has been a synchroscan unit phase-locked to 119.0 MHz, the 24th subharmonic of the 2856 MHz frequency. Low jitter of the synchronous sum of beam bunches is advantageous in dealing with the very low charge in a single micropulse. Because the S-band micropulse spacing is much smaller than the 119.0-MHz period, the sequence of micropulses will best be displayed using the dual-sweep technique if light levels are sufficient. This particular 119.0-MHz unit has been successfully phase-locked to an rf source at the Duke Storage Ring FEL facility, which is injected by an S-band linac [11]. At the APS, a low-jitter countdown circuit has been built using Motorola ECLIN PS logic to generate the 24th subharmonics. It has been tested with a 0.7 ps (rms) jitter pulse generator, and the total jitter was observed to be 1.1 ps. Bandpass filters on the output result in a clean 119.0-MHz sine wave to be used with the synchroscan unit [12]. The initial results are given in Section 3.

## 3. Results

An initial test of OTR source strength has been done using 1-3 nC of beam in a macropulse from the conventional gun and at energies of 580 and 650 MeV and an in-tunnel camera [13]. Since the Ti foil was placed over only half of the Chromox screen at this station, the e-beam could be steered and focused on the Chromox first and then steered onto the OTR foil. Figure 1 shows a sample beam image using the new optical transport to bring the OTR outside the tunnel to the optics table, and Fig. 2 shows the horizontal and vertical profiles with Gaussian fits. Focused spots (~0.5 mm, FWHM) were readily imaged with the CCD camera with about 3 nC in a macropulse. However, normal transport conditions usually have a larger spot size at this location and are seen much more readily with the Chromox screen. This baseline measurement supports the OTR screen choice because the increased beam image size from the Chromox screen implied it had a 200-μm (σ) resolution limit under these conditions.

We have also performed our initial bunch-length measurements using the OTR conversion mechanism and the streak camera operated in synchroscan mode. As noted, the beam was generated by the conventional thermionic gun and our configuration of rf BPM electronics limited us to 100 mA in a macropulse. This corresponded to only about 25-30 pC in each of 80 micropulses that were separated by 350 ps. Although this is an order of magnitude lower charge than projected for rf-gun operations, we were able to obtain streak images by using 8- or 16-event averages in the digitizing system. The synchronous summing of micropulses from the same section in the macropulse was then done. Images on four streak ranges were obtained, and Fig. 3 shows an example from range #2 (R2) that spans ~480 ps. Due to the S-band repetition frequency of the microbunches, more than one micropulse is displayed with the 119 MHz sweep rate. An intriguing feature of the image is the curvature in y-t space displayed. The data are reminiscent of a head-to-tail transverse kick on the submicropulse timescale, perhaps due to transverse beam position offsets while transiting the linac accelerator structures. The displacement of the spatial profile centroid from the early to late part of the micropulse was about 200 μm with the observed bunch length of 10 ps (σ). As the peak current is quite low for this case, further data are needed. A short time later, the e-gun was observed to be arcing, and this resulted in noticeable micropulse arrival time differences. The data were taken without a bandpass filter so some temporal dispersion effects are involved. In Fig. 4 the streak camera focus mode profile (a) is shown to give a limiting resolution of about 2.6 ps, while the micropulses bunch length averaged over 3 micropulses for 4 macropulses is about 3.6 ps in Fig. 4b. The 550 x 40 nm bandpass filter was used to reduce the chromatic dispersion effects. These data involved a streak speed three times slower than the fastest range so 1-ps bunch lengths are addressable.

In the two cases above, an intercepting OTR foil is used. For nonintercepting bunch-length measurements, coherent DR is a possible way to extend the Michelson interferometer technique [14, 15]. In the streak camera case, a bend in the transport line, a special few-period diagnostics wiggler, or the final prototype wiggler for the SASE experiments are potential nonintercepting sources of optical radiation for a bunch-length measurement.

## 4. Summary

In summary, the adjustments of optical diagnostic techniques in preparation for low-emittance beams are well underway in the APS linac. Tests of some techniques (e.g., OTR, gated cameras, and the synchroscan (119.0 MHz) streak camera) have already been done with alternative particle beam sources. Further tests will be done with the conventional injector, and the initial tests with rf-gun injected beam are expected in 1998.

## 5. Acknowledgments

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Figure Captions

Fig. 1. One of the first OTR images of APS linac beam at 650 MeV and ~3 nC in a macropulse from the conventional thermionic gun. A four-frame average was used to improve the statistics.

Fig. 2. The horizontal (a) and vertical (b) spatial profiles for the OTR image in Fig. 1. The observed sizes are smaller than those from the Chromox screen with its 200-μm limiting resolution.

Fig. 3. Synchroscan streak image summing over several micropulses showing a y-t tilt similar to a head-tail Wakefield effect. These data were taken without a bandpass filter so the total bunch length was $\sigma$ = 10 ps or 24 ps (FWHM).

Fig. 4. Streak camera images taken with a 550 x 40 nm bandpass filter for the focus mode (a) and the R2 streak range (b). The total observed bunch length is about 3.6 ps ($\sigma$) from the conventional gun and buncher system.

**Table 1: APS Linac Beam Properties in the Low-emittance Mode (rf Gun)**

| | |
|---|---|
| rf frequency (MHz) | 2856 |
| Beam energy (MeV) | 100-650 |
| Micropulse charge (pc) | 350 |
| Micropulse duration (ps) | 3-5 (FWHM) |
| Macropulse length (ns) | 30 |
| Macropulse repetition rate (Hz) | 1-20 |
| Normalized emittance ($\pi$ mm mrad) | ~5 (1 $\sigma$) |

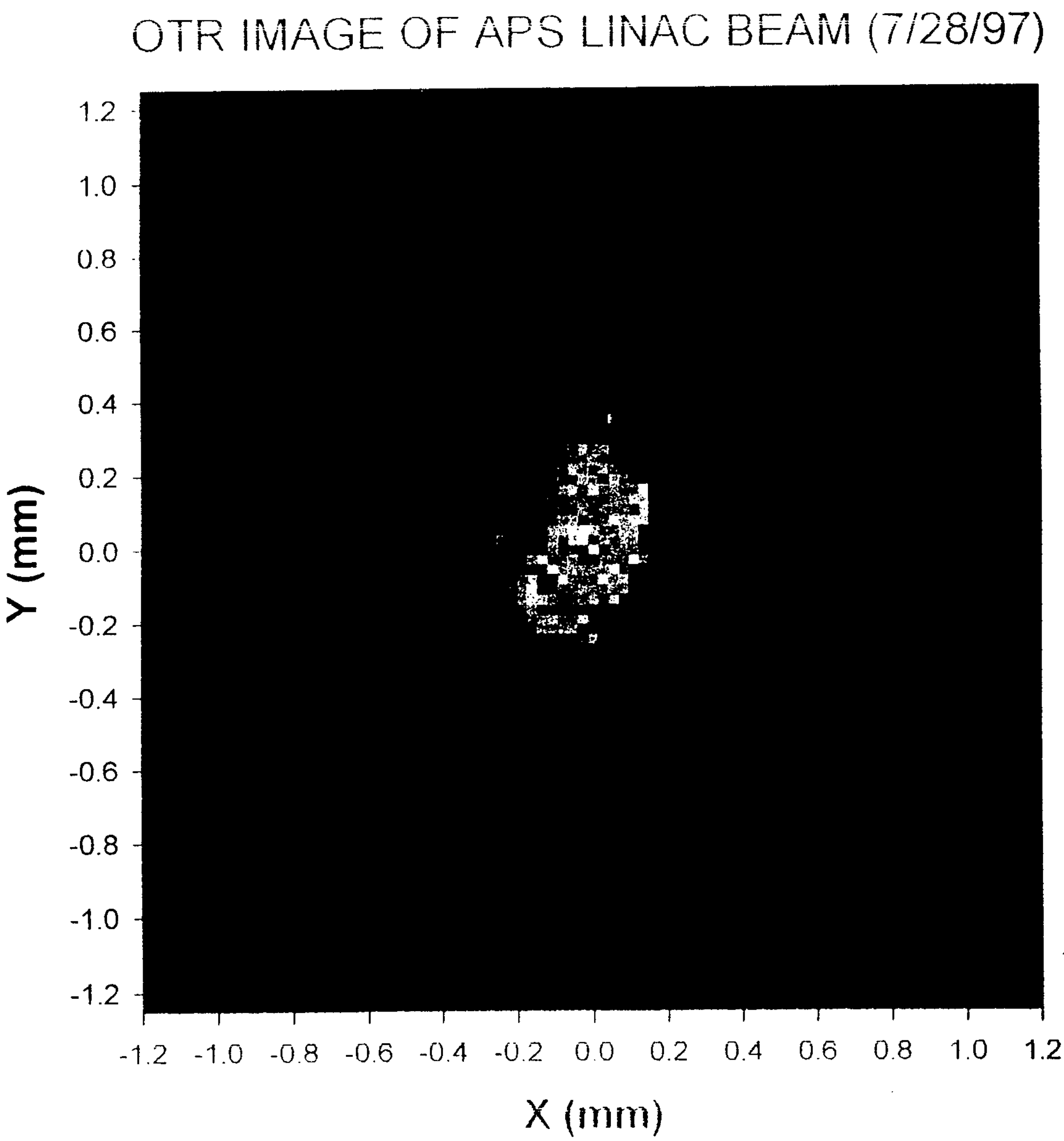
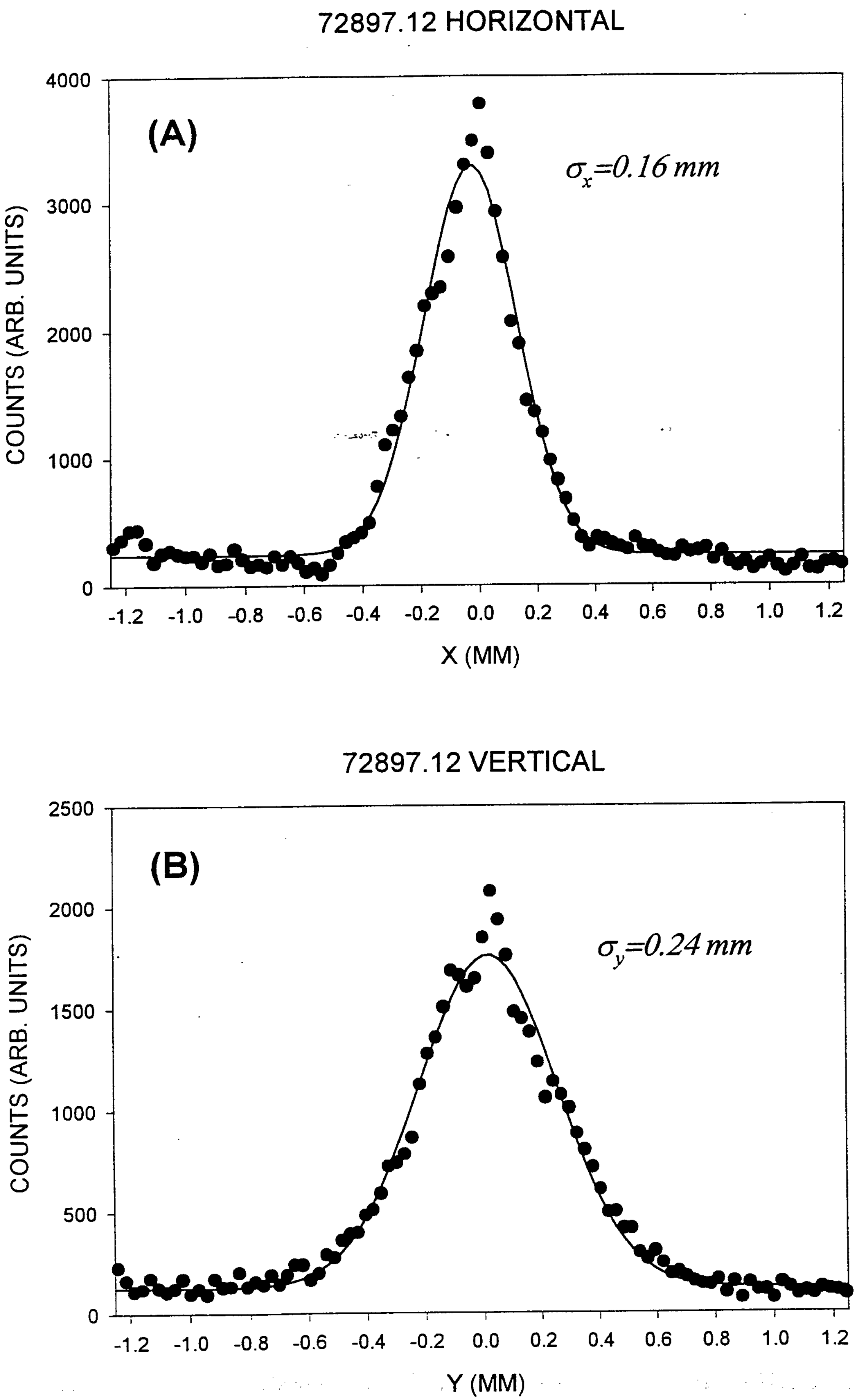
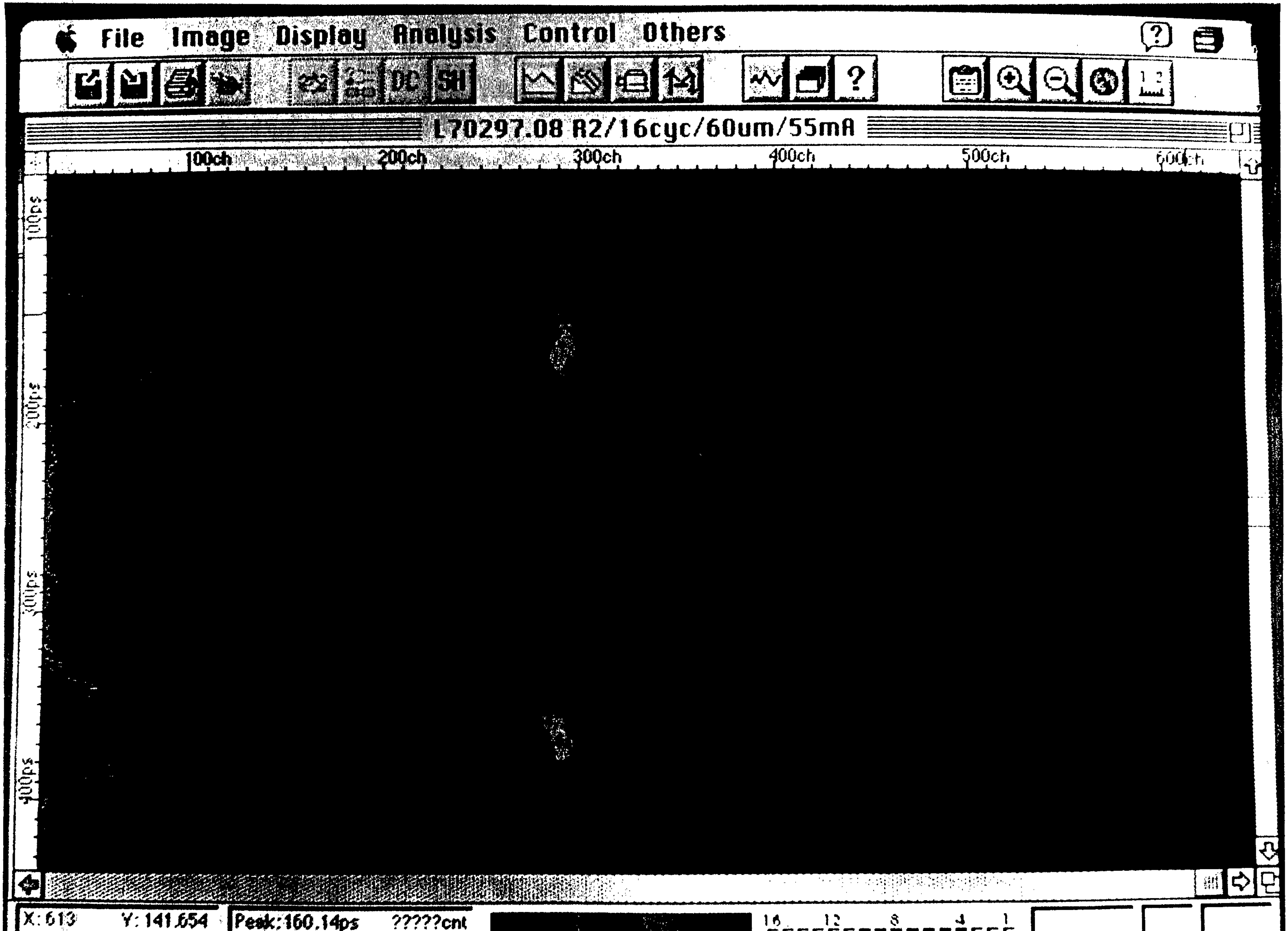

OTR IMAGE OF APS LINAC BEAM (7/28/97)
Y (mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2
X (mm)

Fig. 1



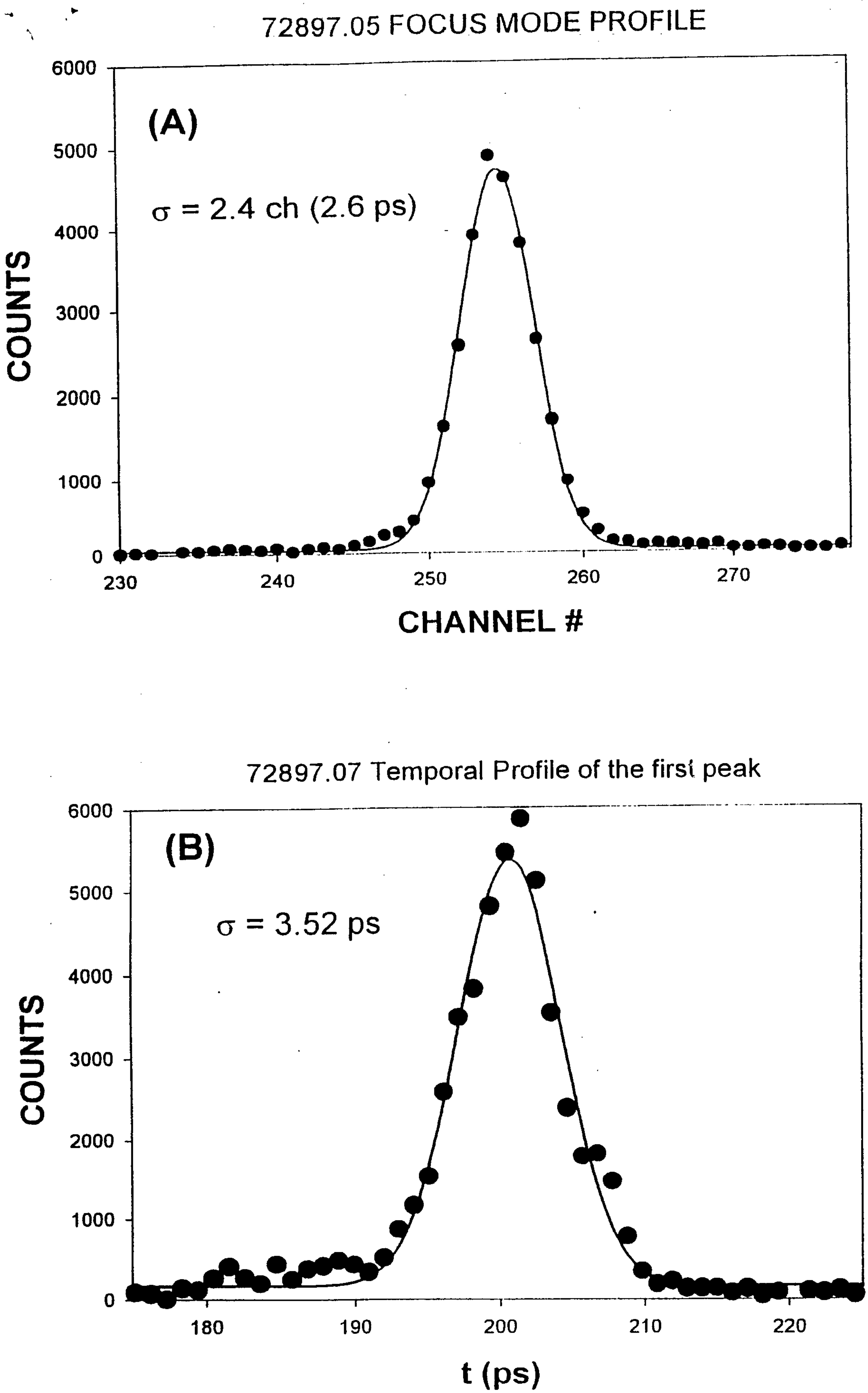
72897.12 HORIZONTAL
(A)
$\sigma_x$=0.16 mm
COUNTS (ARB. UNITS)
X (MM)
72897.12 VERTICAL
(B)
$\sigma_y$=0.24 mm
COUNTS (ARB. UNITS)
Y (MM)


**Fig. 2**



File Image Display Analysis Control Others
L70297.08 A2/16cyc/60um/55mA
100ch
200ch
300ch
400ch
500ch
600ch
100ps
200ps
300ps
400ps
X: 613 Y: 141.654
0 cnt
Peak: 160.14ps ?????cnt
FWHM: 24.687ps
16 12 8 4 1


Fig. 3



72897.05 FOCUS MODE PROFILE
(A)
σ = 2.4 ch (2.6 ps)
COUNTS
6000
5000
4000
3000
2000
1000
0
230
240
250
260
270
CHANNEL #
72897.07 Temporal Profile of the first peak
(B)
σ = 3.52 ps
COUNTS
6000
5000
4000
3000
2000
1000
0
180
190
200
210
220
t (ps)


**Fig. 4**

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