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MORE SEB EMITTANCE MEASUREMENTS

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AGS DIVISION TECHNICAL NOTE

No.168

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SUMMARY

Beam profiles were measured at three locations in the upstream end of the new Slow Extracted Beam (SEB) switchyard, for various settings of the matching quadrupoles. In addition several profiles were measured by foil activation. Comparison of the foil and SWIC profiles leads to a prescription for correcting the SWIC profiles for the large distortions that are present. When these corrections are made, excellent agreement is obtained with the model of SEB emittance that was used in design of the switchyard, as far as the vertical plane is concerned. In the horizontal plane the observed beam is significantly larger than predicted.

1. INTRODUCTION

Beam profiles were measured[1,2] before constructing the new SEB switchyard[3] to test the validity of the model of SEB emittance that was used in the switchyard design. With the new switchyard now in stable operation, further measurements were made for several reasons:

(1) The switchyard beam loss of approximately six percent is a significant improvement over the performance of the previous system, but it is not equal to the design performance of two percent. Emittance studies are the first step in a systematic program to understand the excess loss.

(2) The improved instrumentation in the new switchyard can provide more accurate measurements.

(3) The measurements are a needed step toward bringing on-line, coupled computer control of the matching and focussing quadrupoles into operation.

(4) Some measurements[4] made in preparation for the D-line construction found beam sizes that are much larger than design values.

2. PROCEDURE

Plunging SWICS (Segmented Wire Ionization Chambers) are provided at C039, C100 and C223 for emittance measurements. The parameters of these SWICS are given in Table I. With normal tuning, C100 is located close to horizontal and vertical waists and C039 and C223 are significantly upstream and downstream of these waists, providing an ideal setup for emittance measurements.

TABLE I

Parameters of the New Plunging SWICS

Vacuum can	Aluminum, 0.020 inch wall thickness
Windows (2)	0.005 inch Nickel
Signal planes (2)	0.002 inch Nickel wires, 0.050 inch spacing
Number of wires per signal plane	32
Bias planes (3)	Nickel wire mesh, 0.002 inch diameter, 100 per inch
Spacing, signal plane to bias plane	0.0625 inch
Gas	90% A, 10% CO_2

Profiles were measured at various settings of the matching quads CQ1-CQ4. These settings were determined by the interactive computer program CQTUNE, to provide a range of specified values of the waist parameters HZ, HX, VZ and VX that characterize the beam in the drift space downstream of CQ4. Here HZ and HX are the longitudinal and transverse waist parameters in the horizontal plane, and VZ and VX are the corresponding waist parameters in the vertical plane. The eleven different quadrupole tunes that were used are given in Table II, and the corresponding predicted envelopes are given in Figures 1 through 3. In Tunes 1-4 VX was varied with the other parameters held fixed (Figure 1); in Tunes 5-8 VZ was varied (Figure 2); and in Tunes 9-11 HX was varied (Figure 3). Tune 2 corresponds to normal AGS running.

TABLE II

Tune Parameters

The quadrupole settings are given in Datacon units. The waist parameters HZ and VZ are in inches from F13, and HX and VX are in mils (3.035 times standard deviation).

TUNE	CQ1	CQ2	CQ3	CQ4	CW5&8	CQ6&7	HZ	HX	VZ	VX
1	-1693	827	-398	862	-1180	900	1171	274	1274	446
2	-1878	1069	-285	521	↓	↓	↓	↓	↓	346
3	-1931	1280	-536	724	↓	↓	↓	↓	↓	246
4	-1842	1278	-830	1179	↓	↓	↓	↓	↓	196
5	-1931	1280	-536	724	↓	↓	↓	↓	1274	246
6	-1792	1143	-727	1117	↓	↓	↓	↓	1474	246
7	-1622	879	-713	1317	↓	↓	↓	↓	1674	246
8	-1380	456	-510	1371	↓	↓	↓	↓	1874	246
9	-1902	1122	-369	580	↓	↓	↓	224	1274	346
10	-1878	1069	-286	522	↓	↓	↓	274	1274	346
11	-1823	1217	-614	784	-1180	900	1171	324	1274	346

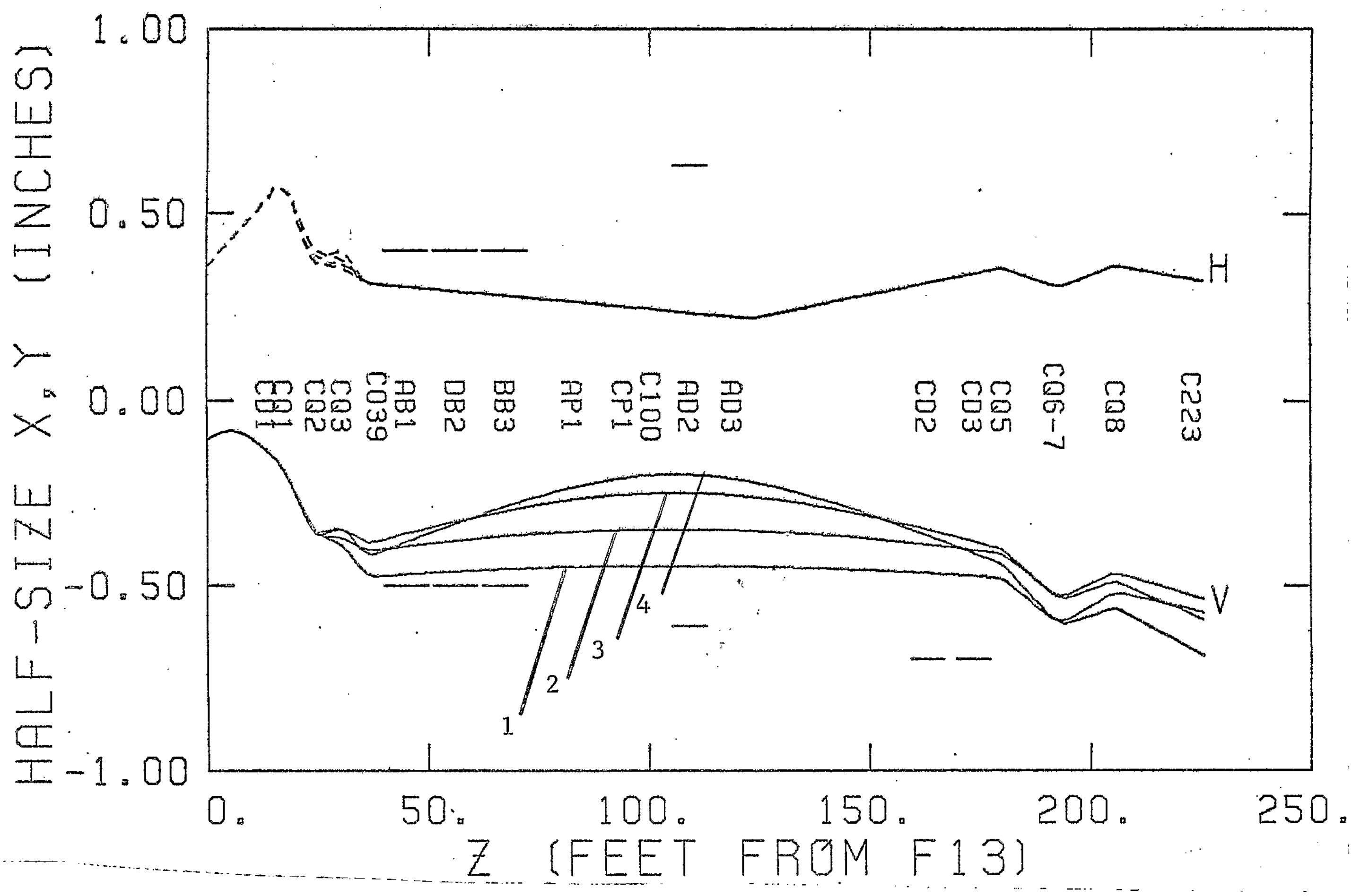

Figure 1. Beam envelopes for Tunes 1-4.

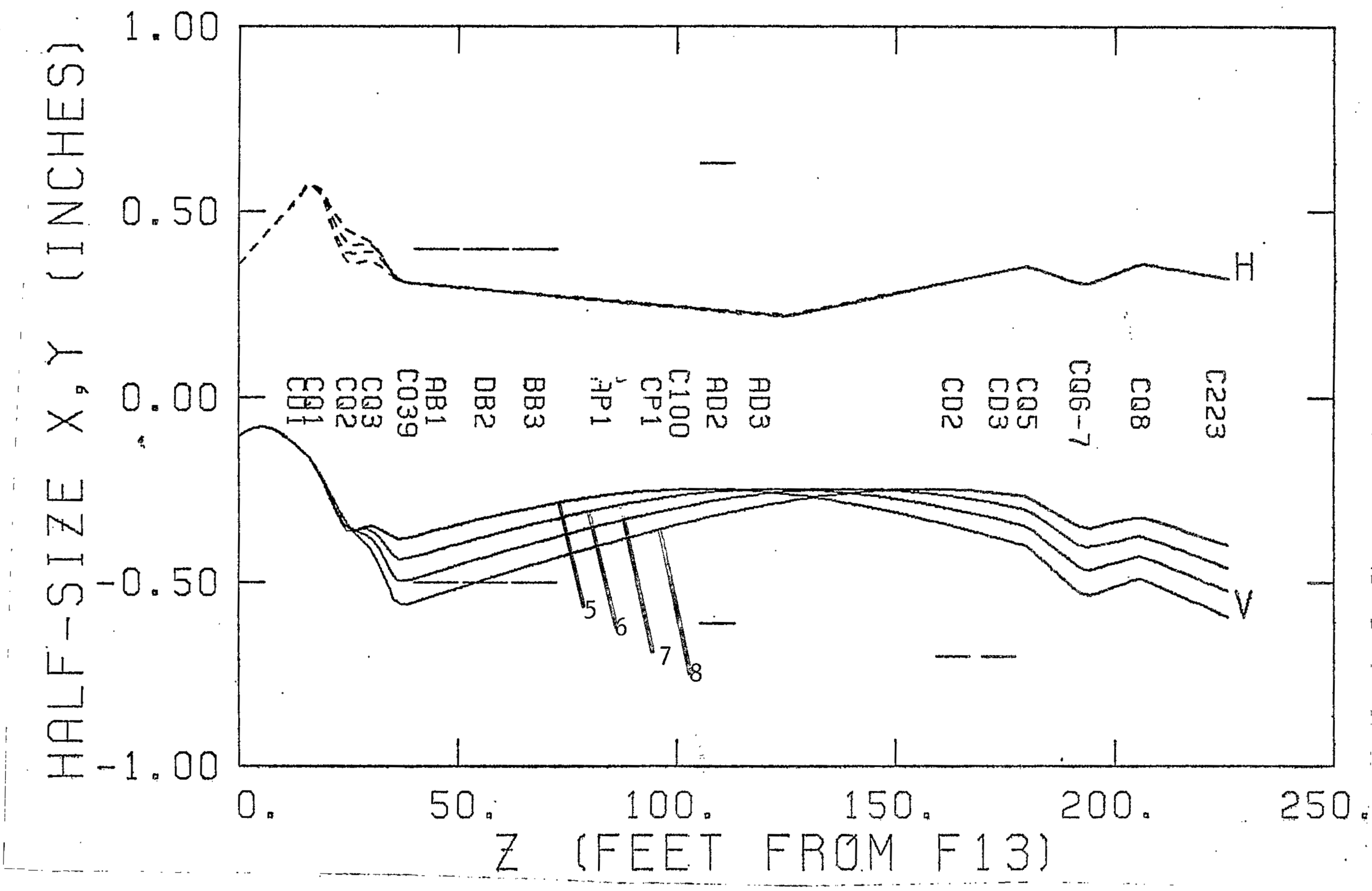

Figure 2. Beam envelopes for Tunes 5-8.

Each SWIC is mounted in an aluminum can that can be inserted into the beamline (Figure 4). Because of scattering, only one unit can be inserted at a time for meaningful results. Therefore separate measurements were made for each of the three SWICS at each of the eleven tunes.

It is important to correct the measured profiles for instrumental effects, since the uncorrected widths are significantly larger than the true beam width[1,5]. Since the SWICS used differ considerably from those in the previous study,[1] a new determination of these systematic effects was made. A comparison profile was obtained at CO39 by exposing aluminum foils to the beam, cutting them in strips, and counting the activity. The design of the instrument box (Figure 4) made it easy to carry out this exposure. A similar instrument box, but without a SWIC, is present at CO10, and a foil profile was also obtained there.

3. MODEL OF BEAM EMITTANCE

The beam distribution in phase space is modeled by parallelograms in the horizontal plane and Gaussian ellipses in the vertical plane, as described in Ref. 1. For interactive tuning in the horizontal plane, the method of r.m.s. emittance is used to obtain waist parameters and to recalculate quadrupole settings. The predicted beam envelope and beam profiles, for comparison with SWIC data, are then obtained by going back to the parallelogram model.

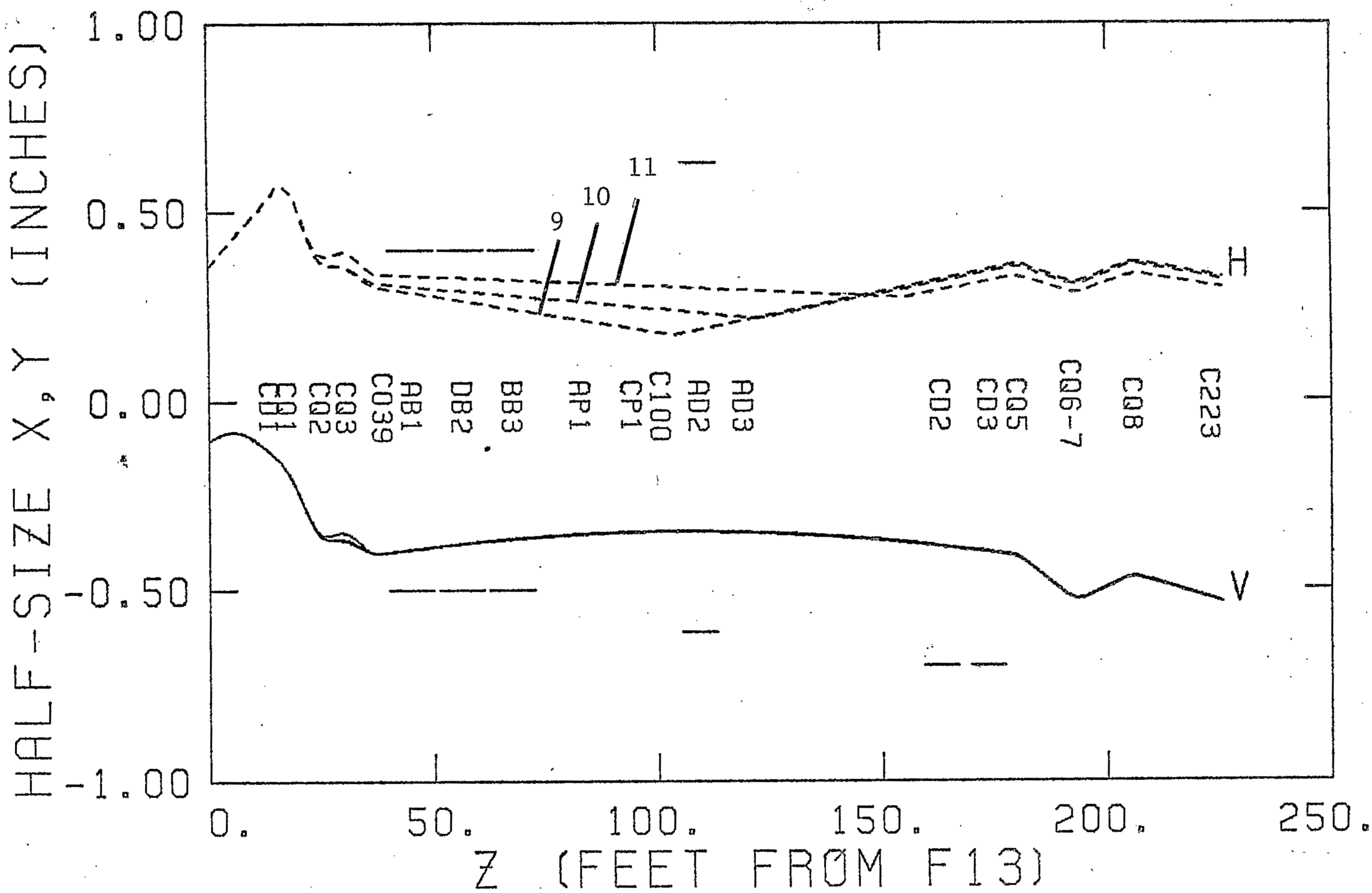

Figure 3. Beam envelopes for Tunes 9-11.

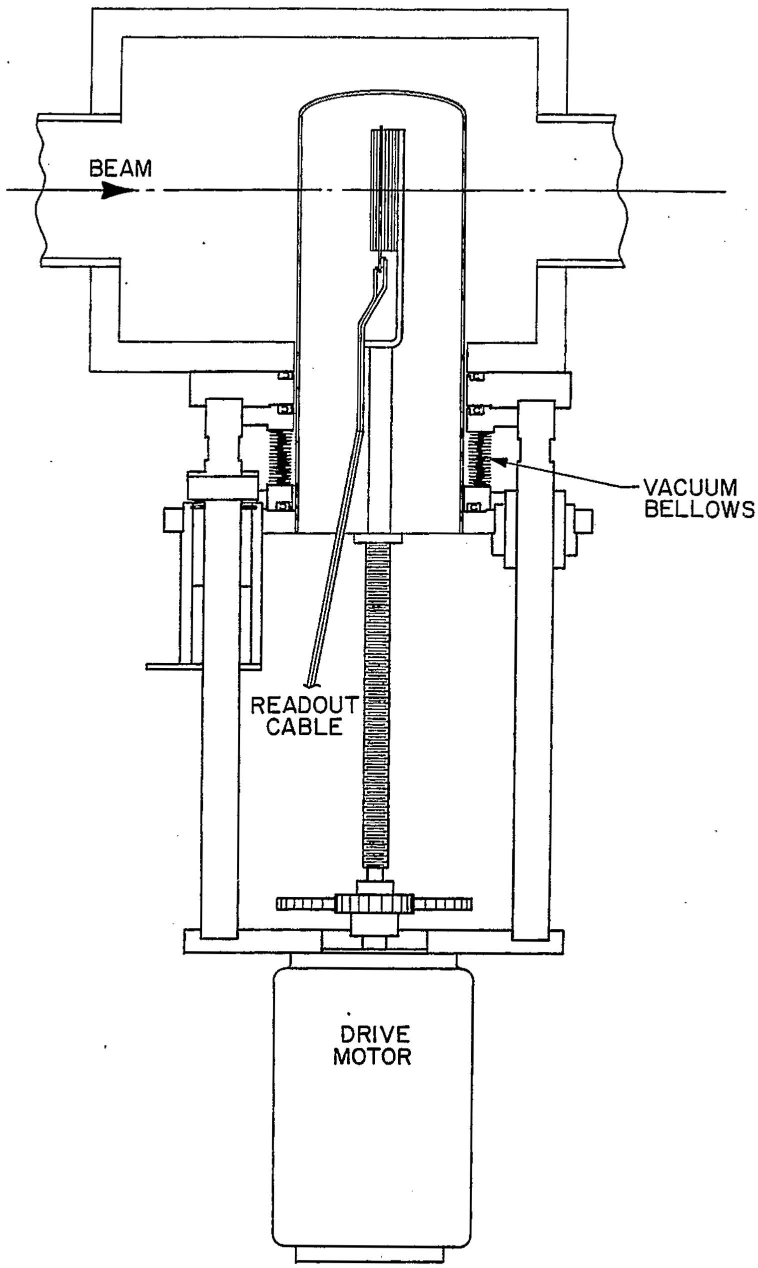

Figure 4. Plunging SWIC, vacuum can, instrument box and insertion mechanism.

In this report the beam widths quoted are 4.50 times the half width at half area. For a beam that is described by Gaussian ellipses, this width corresponds to the projection of the ellipse in phase space that contains 99% of the beam intensity. The same convention is used in Refs. 1-3. For a Guassian profile it corresponds to -2 ln (0.01), or 3.035, times the standard deviation. The half-width at half area is used because it is less likely than other measures, such as standard deviation or half-width at 90% or 99%, to be distorted by systematic errors.

The general conditions under which the measurements were made are given in Table III. Splitter positions were adjusted so that nearly all the beam was transmitted down the C line. The measurements required about 2 hours of AGS Studies time.

TABLE III

Operating Conditions During Measurements

Date and time	19 December 1980, 1200-1400
Momentum	29 GeV/c
Intensity	8×10^{12} protons per pulse
Beam size on F5 flag	0.54 inches

4. FOIL PROFILES AND SWIC SYSTEMATIC ERRORS

Figure 5 shows the beam profiles obtained by foil exposure. The vertical profiles are well described by Gaussians, while the horizontal profiles are asymmetric and not Gaussian. In Figure 6 the same profiles are shown in semi-logarithmic plots against position in units of each profile's own standard deviation, with a perfect Gaussian curve for comparison. Also shown are integral curves of the same profiles. In the vertical plane, the profiles are Gaussian down to the 2.5 or 3 standard deviation level, with a broad "tail" or halo beyond that. The horizontal profiles are non-Gaussian but their integral curves are the same as for a Gaussian out to 2.5 or 3 standard deviations.

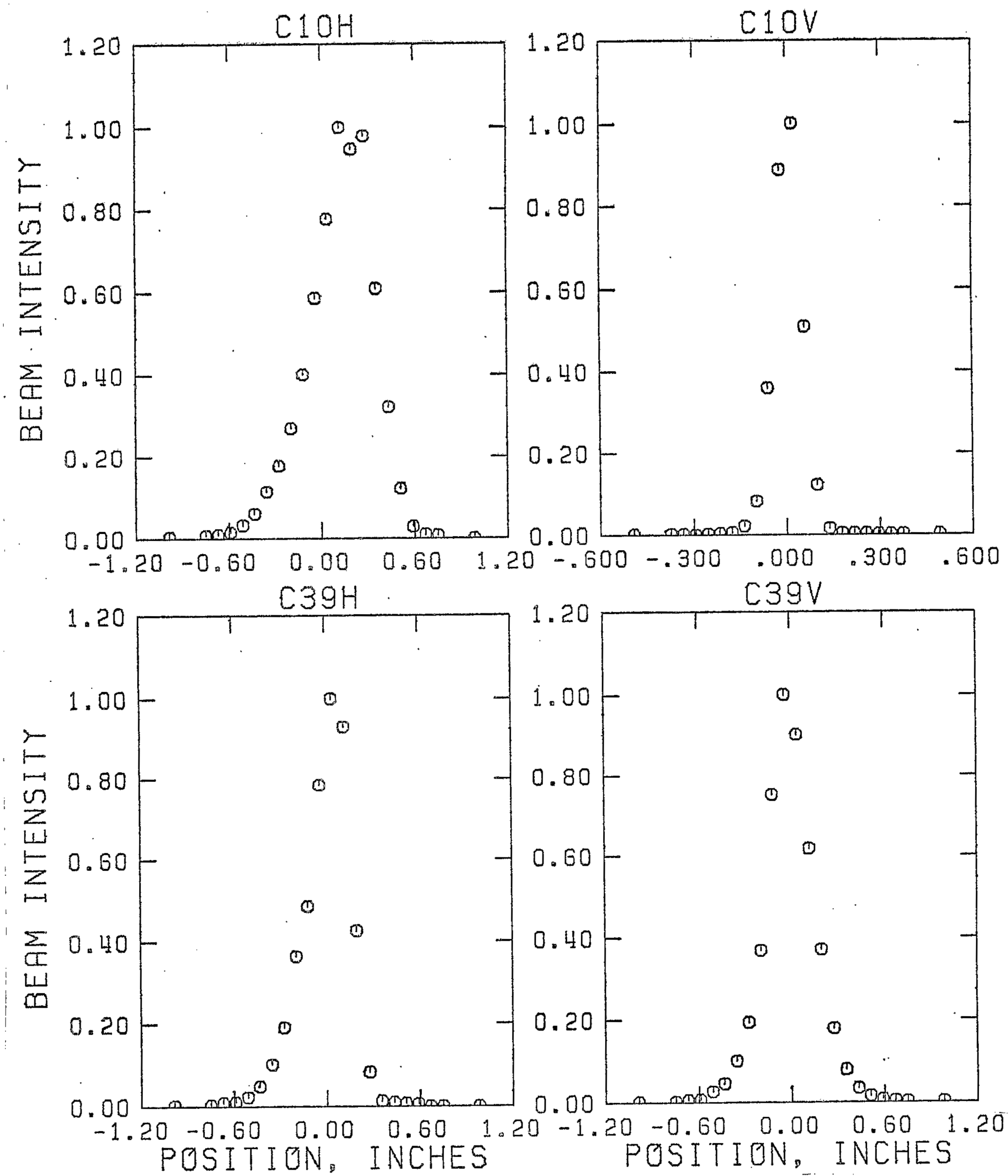

Figure 5. Beam profiles (horizontal and vertical) obtained by foil activation at C010 and C039.

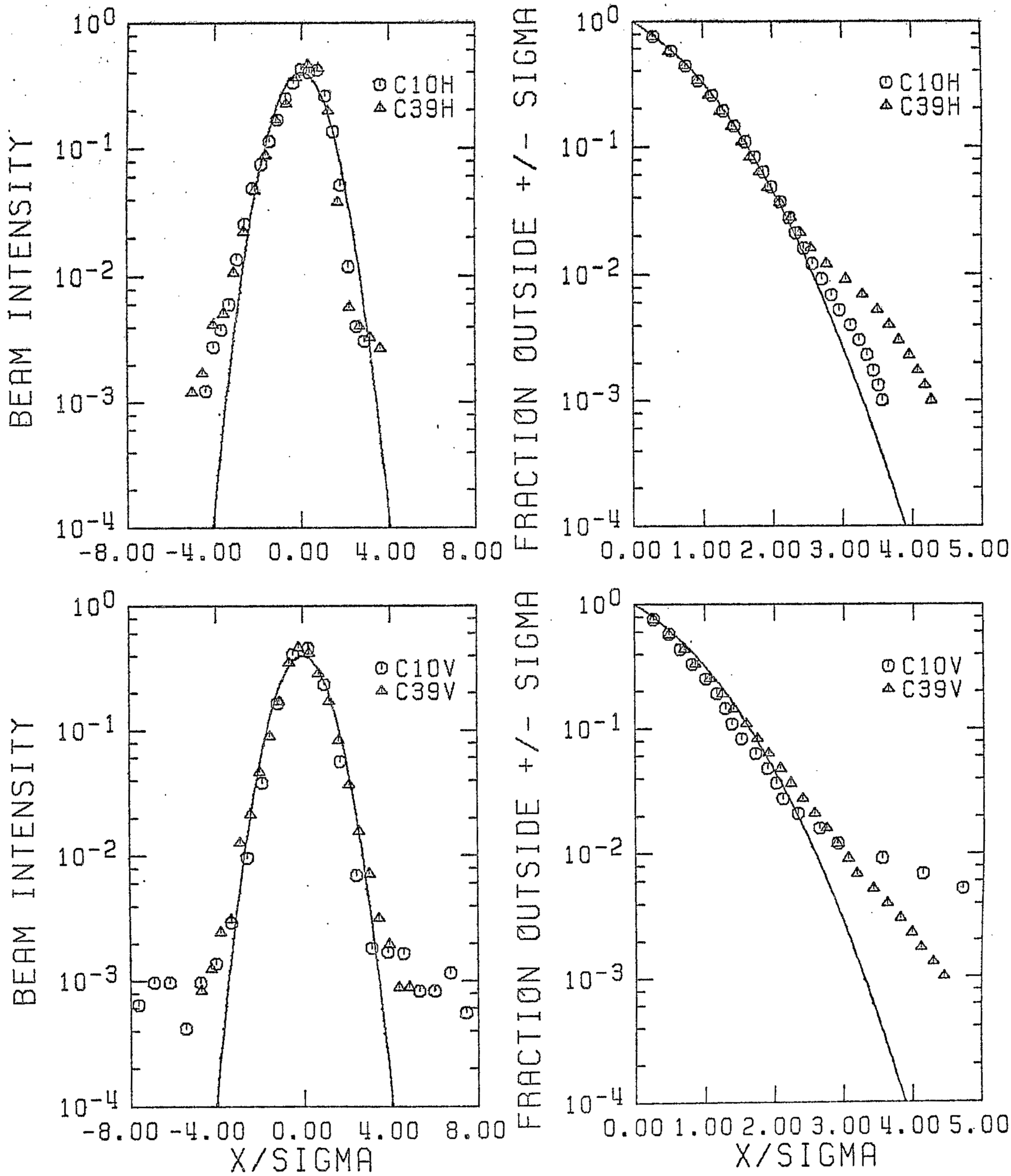

Figure 6. Normalized profiles obtained by foil activation. Data are plotted on a logarithmic scale against beam position in units of each profile's standard deviation. Also shown are integral curves giving the fraction of the total profile area lying outside a given number of standard deviations.

These profiles indicate that a Gaussian ellipse model should work well for describing the beam envelopes (beam width versus distance) for 99% of the beam in each plane. In the horizontal plane a more detailed model will be needed to describe the actual <u>shape</u> of each profile.

Some illustrative SWIC profiles are shown in Figure 7. These profiles ride on a wide background. The smooth curves in Figure 7 are an estimate of this background, obtained by fitting a Gaussian curve to the tails of the profiles. This background Gaussian has a width (standard deviation) of 10 bins or 0.50 inches. A precise determination of this background is not possible because the beam nearly fills the aperture of these small SWICs. For the SWICs used in Reference 1, which had greater wire spacing and greater spacing between planes, the background width was 8 wires or 1.0 inches. It appears that the background width scales with wire spacing or plane spacing.

Figure 8 shows the dependence of signal area, background area, and (background subtracted) signal width on SWIC bias voltage. To minimize the effect of the background, it would be desirable to operate at much higher biases that the 300 volts that was used.

A comparison of SWIC and foil activation beam profiles at C039 is given in Figure 9. The fitted background Gaussian is also shown. If this background is not subtracted, a width will be obtained that is far greater than the true beam width. The discrepancy will be particularly large if measures such as standard deviation or width at 90% or 99% area are used, since these measures are sensitive to the tails of a distribution.

Even when the background is subtracted, however, the width obtained still exceeds the width obtained by foil exposure, as shown in Table IV. It is plausible to attribute this excess to an inherent SWIC resolution. Based on the data in Table IV, a SWIC resolution of 0.09 inches or 1.8 bins (standard deviation) is indicated. This is to be compared with 0.12 inches or 1 bin for the larger SWICs used in Ref. 1.

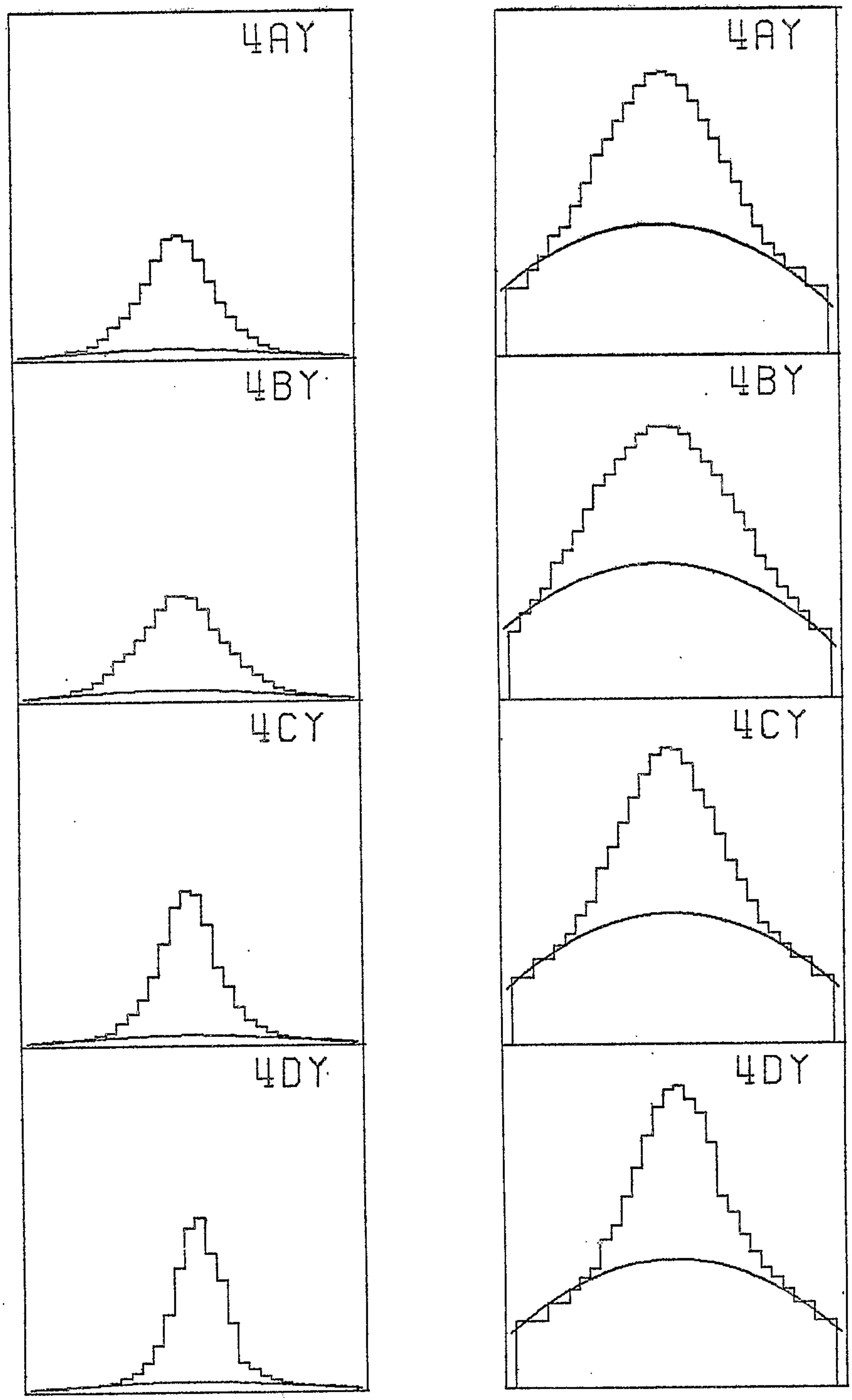

Figure 7. SWIC profiles for the vertical plane of C100 for Tunes 1-4. The profiles are plotted on linear (left) and logarithmic (right) scales. The raw data (with constant baseline subtracted) are shown, along with the fitted Gaussian background.

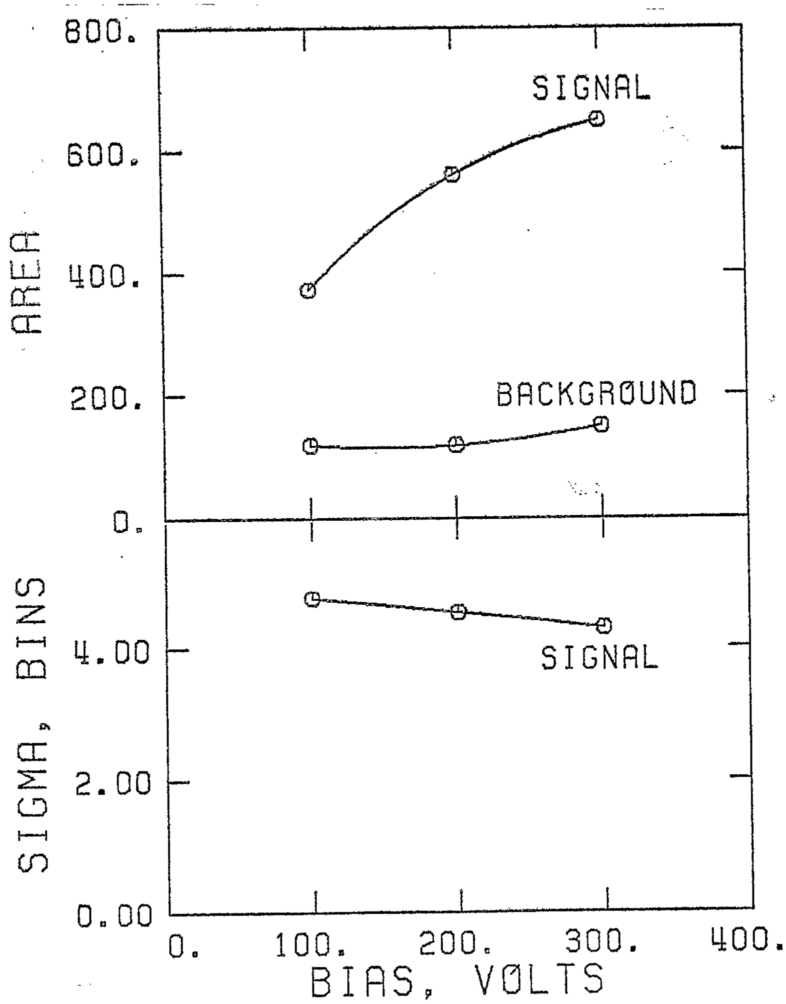

Figure 8. Dependence of signal area, background area, and (background subtracted) signal width on bias voltage, for the vertical plane of C039 in Tune 2.

TABLE IV

RMS widths (inches) of profiles at C039 by foil and SWIC

	Horizontal	Vertical
(1) Foil	0.164	0.173
(2) SWIC (no background subtraction)	0.247	0.236
(3) SWIC (background subtracted)	0.178	0.198
(4) SWIC resolution, $[(3)^2-(1)^2]^{1/2}$	0.069	0.096

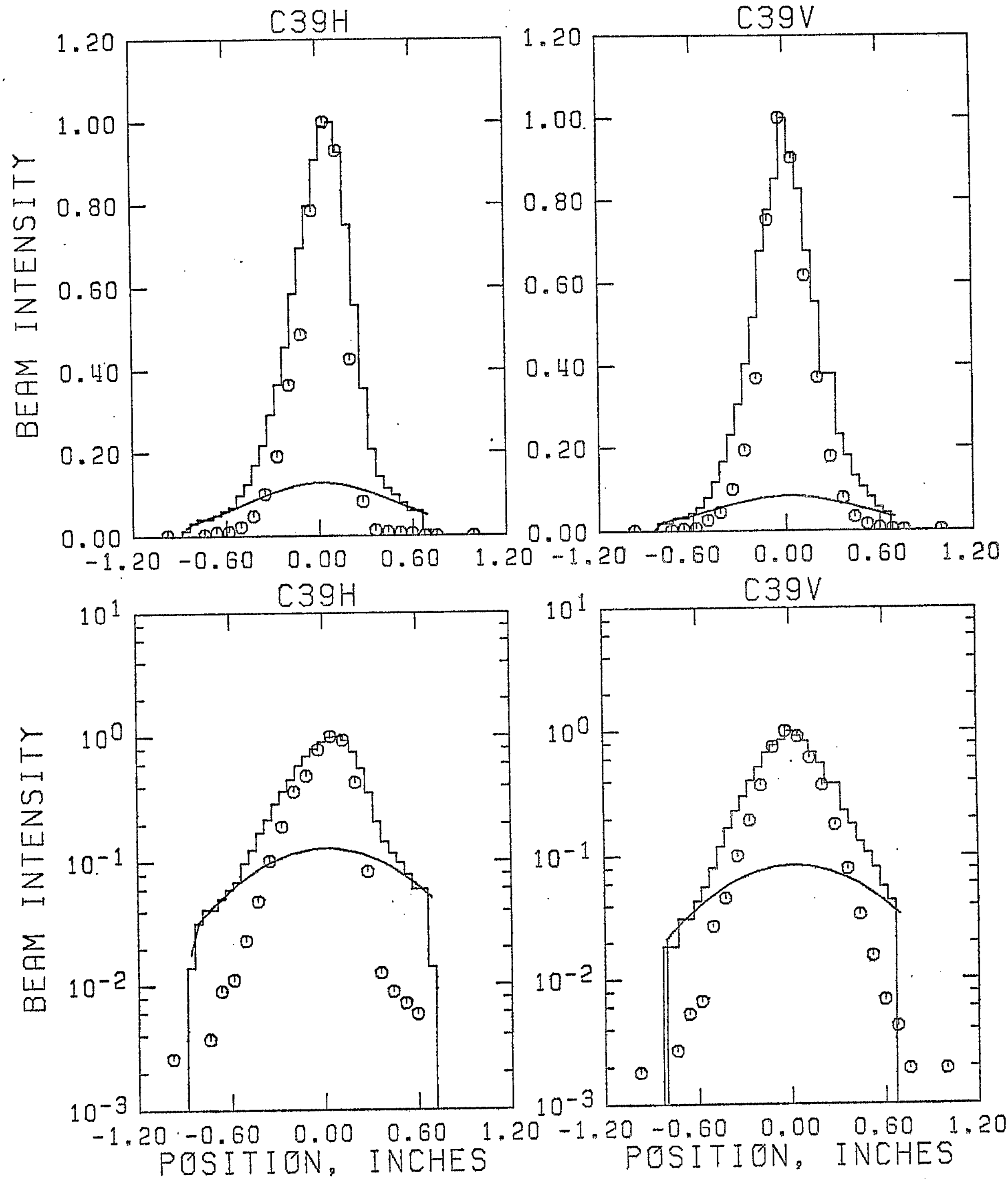

Figure 9. Comparison of foil and SWIC profiles at C039. The raw SWIC data (with constant baseline subtracted) are shown, along with the fitted Gaussian background. Plots are shown for both horizontal and vertical planes, and with both linear and logarithmic scales.

The complete procedure for reducing a measured SWIC profile to a corrected beam width is then as follows:

1. Subtract a constant baseline (determined by the ADC offset).
2. Fit and subtract a background Gaussian with a standard deviation of 10 bins.
3. Determine the half-width at half area.
4. Divide by 0.675 to convert to a measure of standard deviation.
5. Subtract, in quadrature, the resolution of 0.09 inches.
6. Multiply by 3.035.

With this procedure the SWIC data may be used for semi-quantitative work. The uncorrected profiles are qualitative at best.

5. MEASURED PROFILES COMPARED WITH MODEL PREDICTIONS

Predicted and observed profiles for the vertical plane are shown in Figure 10. In these curves the SWIC backgrounds have been subtracted, and SWIC resolution has been allowed for by broadening the predicted curves correspondingly. The dependence of predicted and measured widths on quadrupole tunes is summarized in Figure 11. The agreement is as nearly perfect as could be expected, especially considering the fact that <u>no adjustment of parameters has been carried out</u>.

Figures 12 and 13 give the corresponding results for the horizontal plane. Here there is a large discrepancy, too much to be explained by larger than expected internal AGS emittance. These results indicate that there was malfunctioning equipment at the time these measurements were made, magnet ripple being a prime suspect.

Whatever the source of the problem, its effect is equivalent to an effective doubling of the beam emittance. Curing the problem should reduce beam divergence, and hence beam loss, on the wire septa, and it should reduce beam size, and hence beam loss, at various apertures. Further work will be done on tracking down the source of the problem during the next SEB run.

6. CONCLUSION

The plunging SWICs, although not perfect, provide information that is sensitive to beam emittance. This information may prove useful in reducing beam loss. In the vertical plane, the ability to model the beam envelopes and control them interactively has been proven. In the horizontal plane more work is needed.

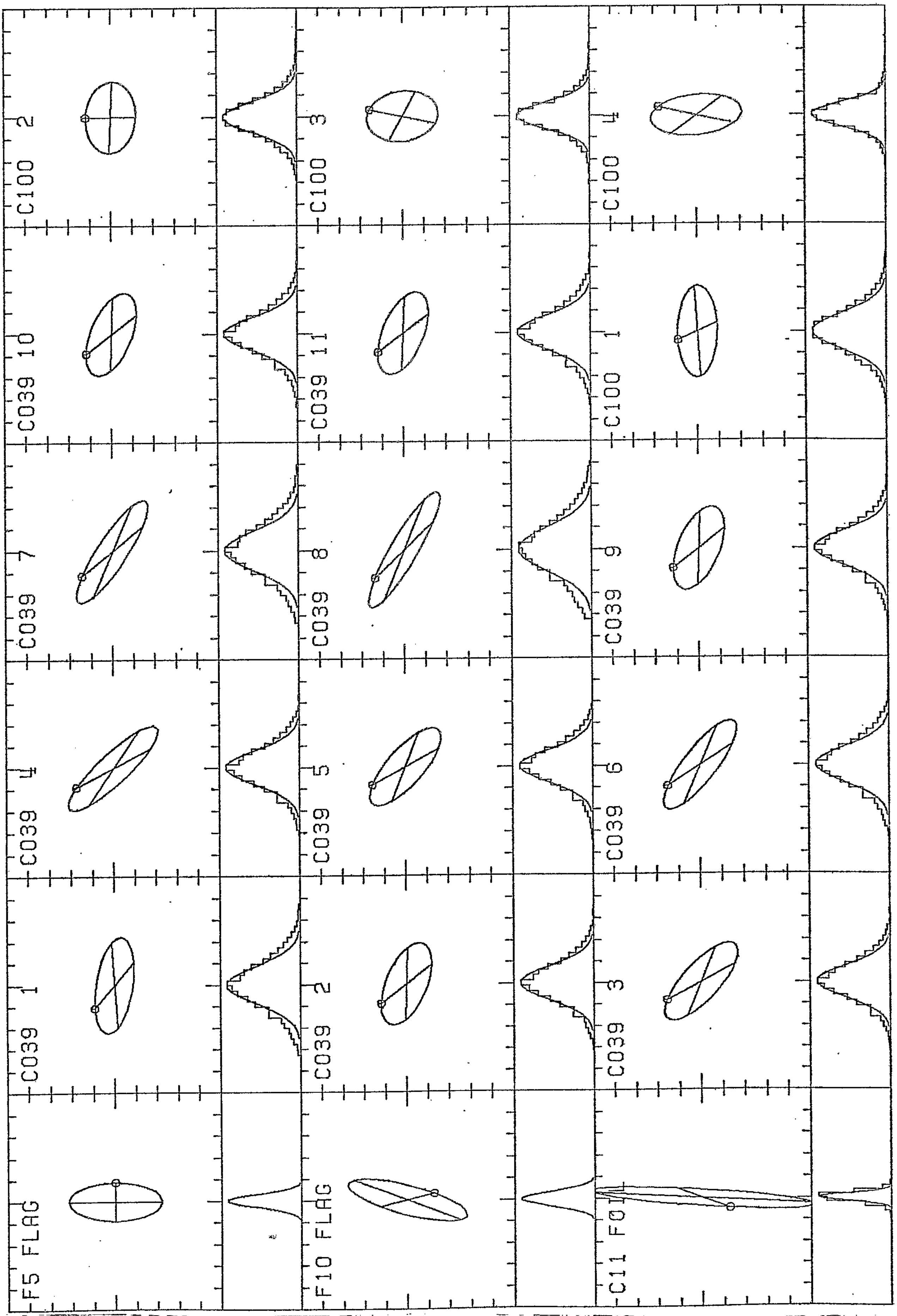

Figure 10. Measured profiles (histograms) and predicted profiles (smooth curves) in the vertical plane at each tune. Also shown are predicted beam outlines in phase space. Horizontal scale: ± 1 inch; vertical scale: ± 1 mrad. (Sheet 1 of 2).

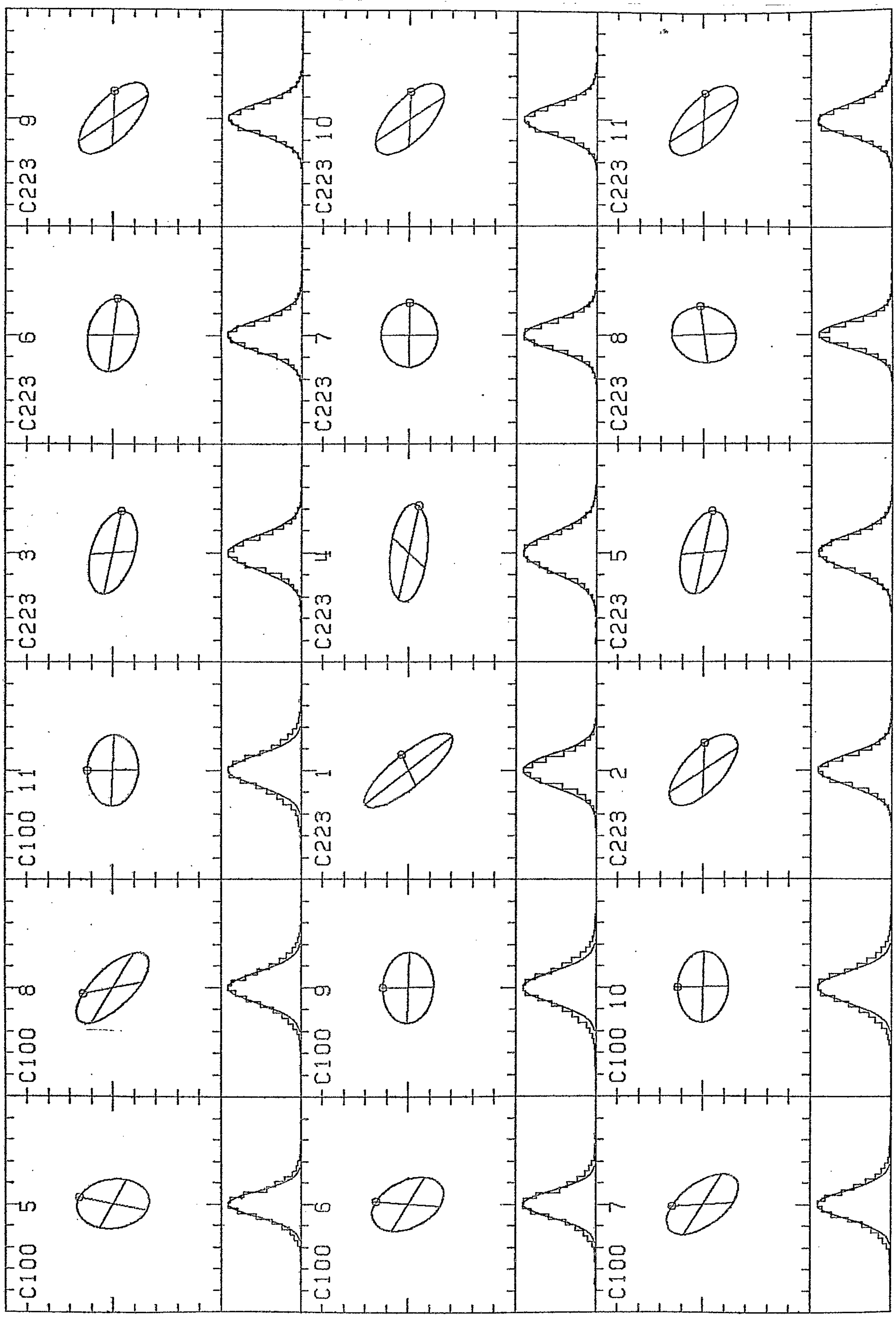

Figure 10. Measured profiles (histograms) and predicted profiles (smooth curves) in the vertical plane at each tune. Also shown are predicted beam outlines in phase space. Horizontal scale: ±1 inch; vertical scale: ±1 mrad. (Sheet 2 of 2).

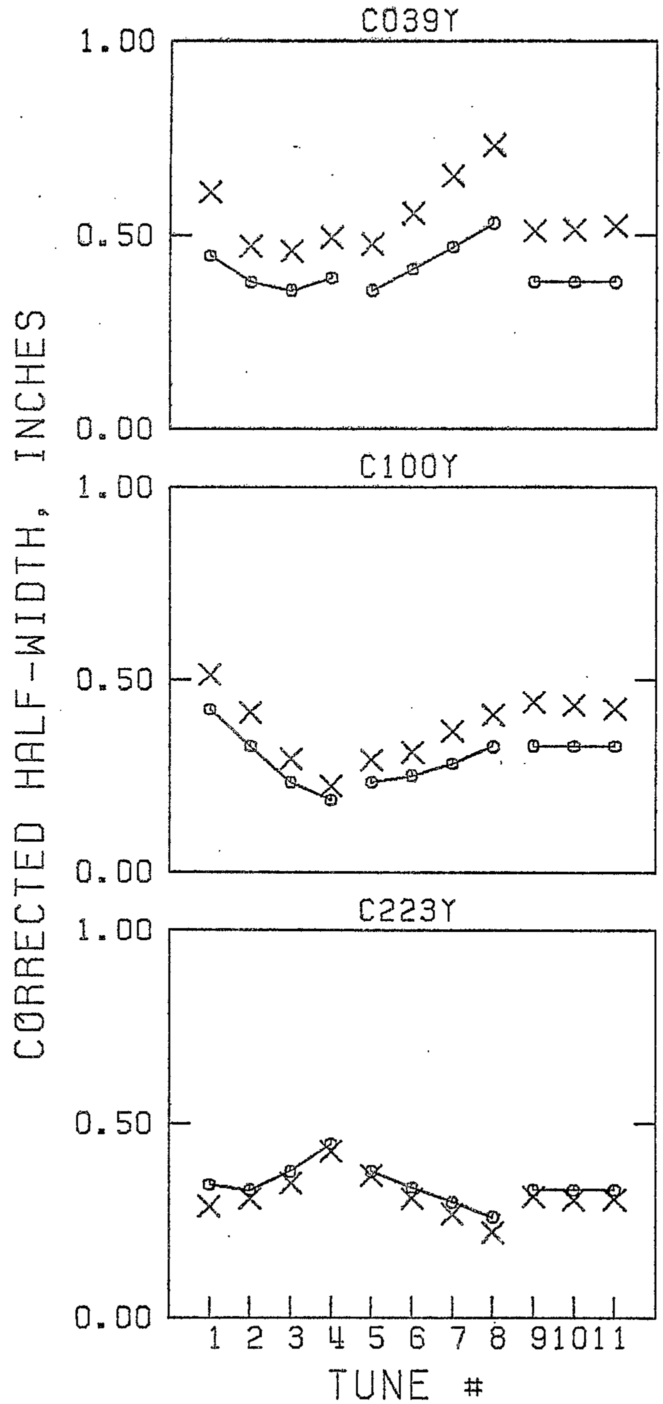

Figure 11. Corrected vertical beam widths versus tune number at each of the three SWICs. Points: predicted widths; crosses: measured widths.

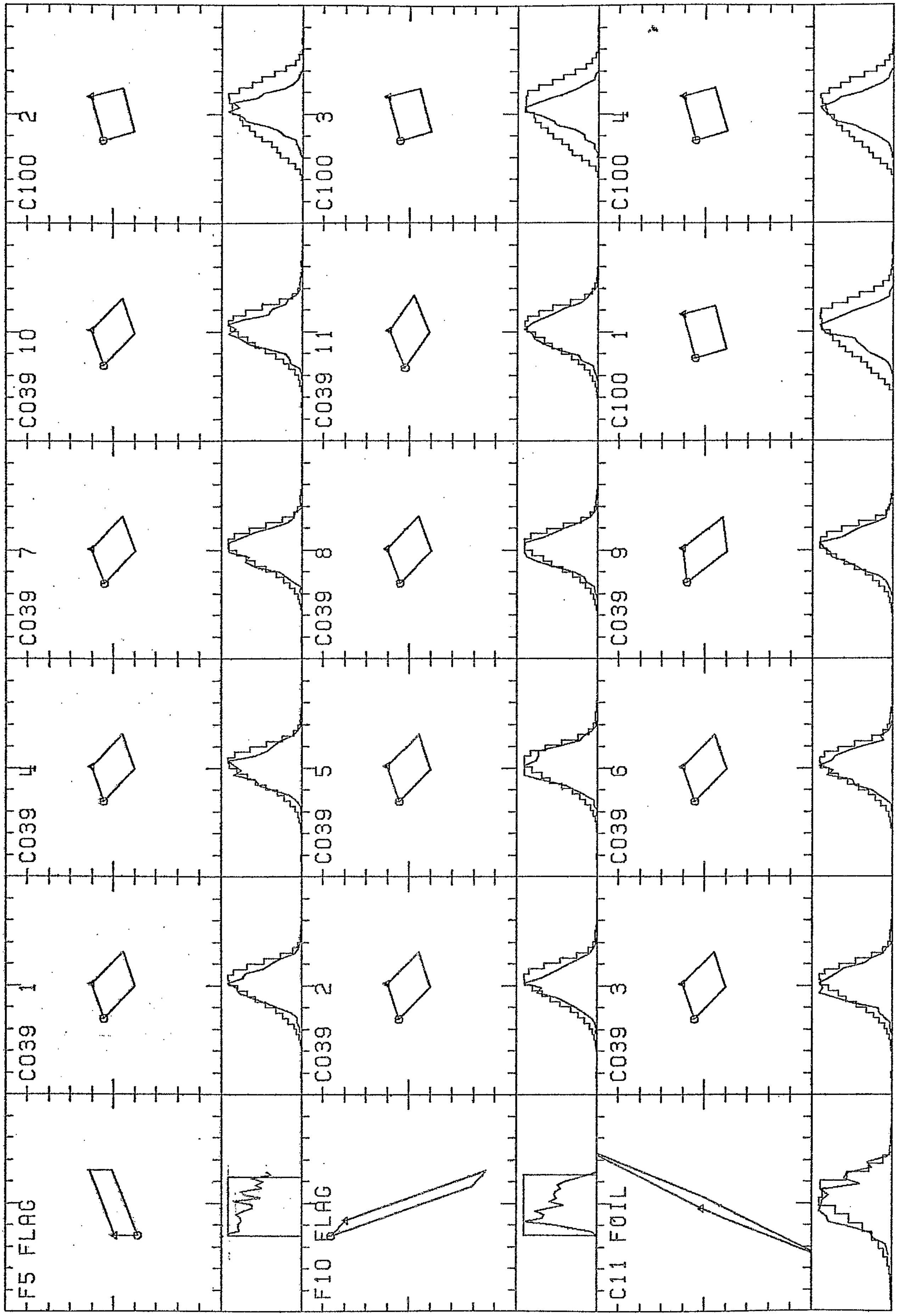

Figure 12. Measured profiles (histograms) and predicted profiles (smooth curves) in the horizontal plane at each tune. Also shown are predicted beam outlines in phase space. Horizontal scale: ± 1 inch; vertical scale: ± 1 mrad. (Sheet 1 of 2).

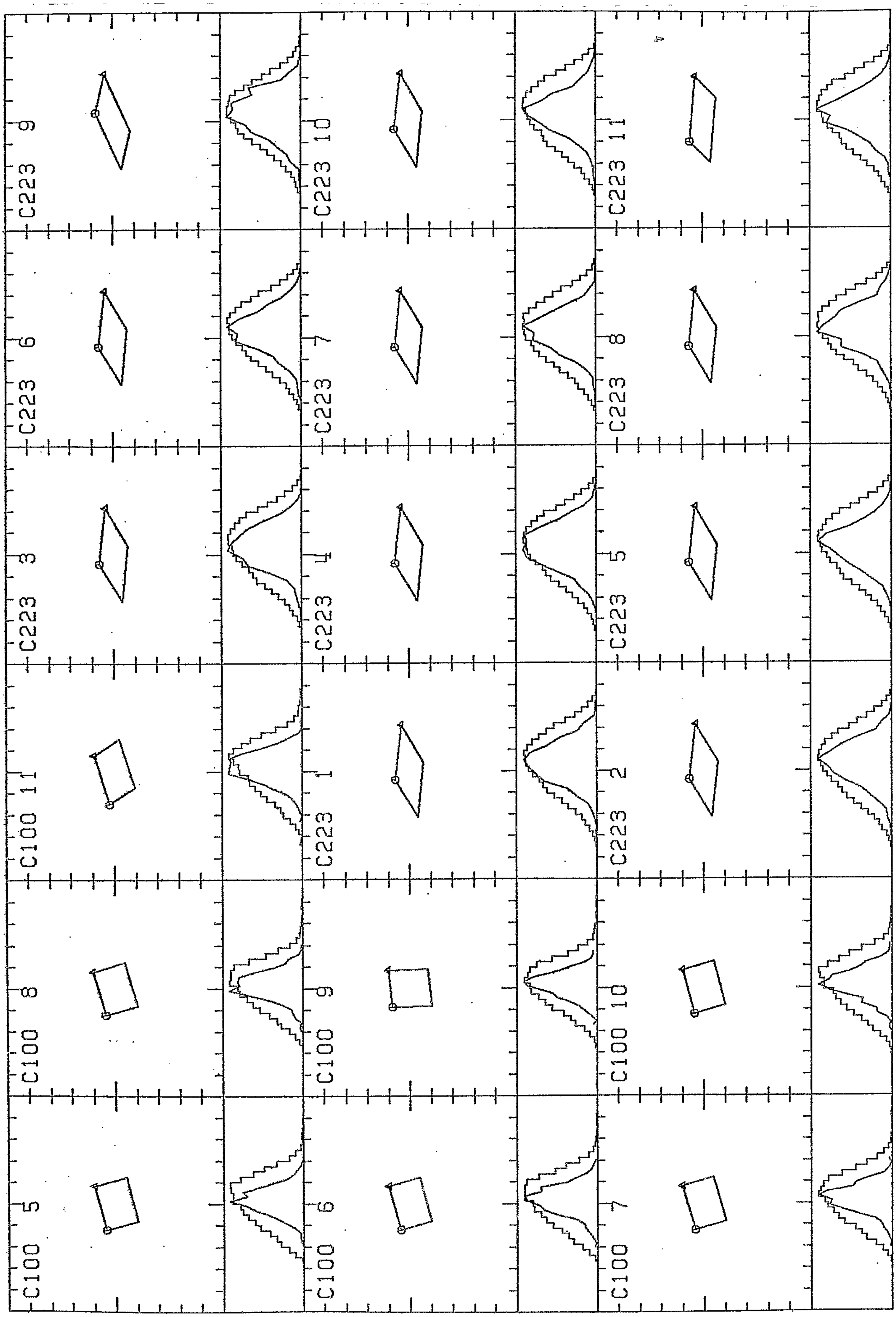

Figure 12. Measured profiles (histograms) and predicted profiles (smooth curves) in the horizontal plane at each tune. Also shown are predicted beam outlines in phase space. Horizontal scale: ± 1 inch; vertical scale: ± 1 mrad. (Sheet 2 of 2).

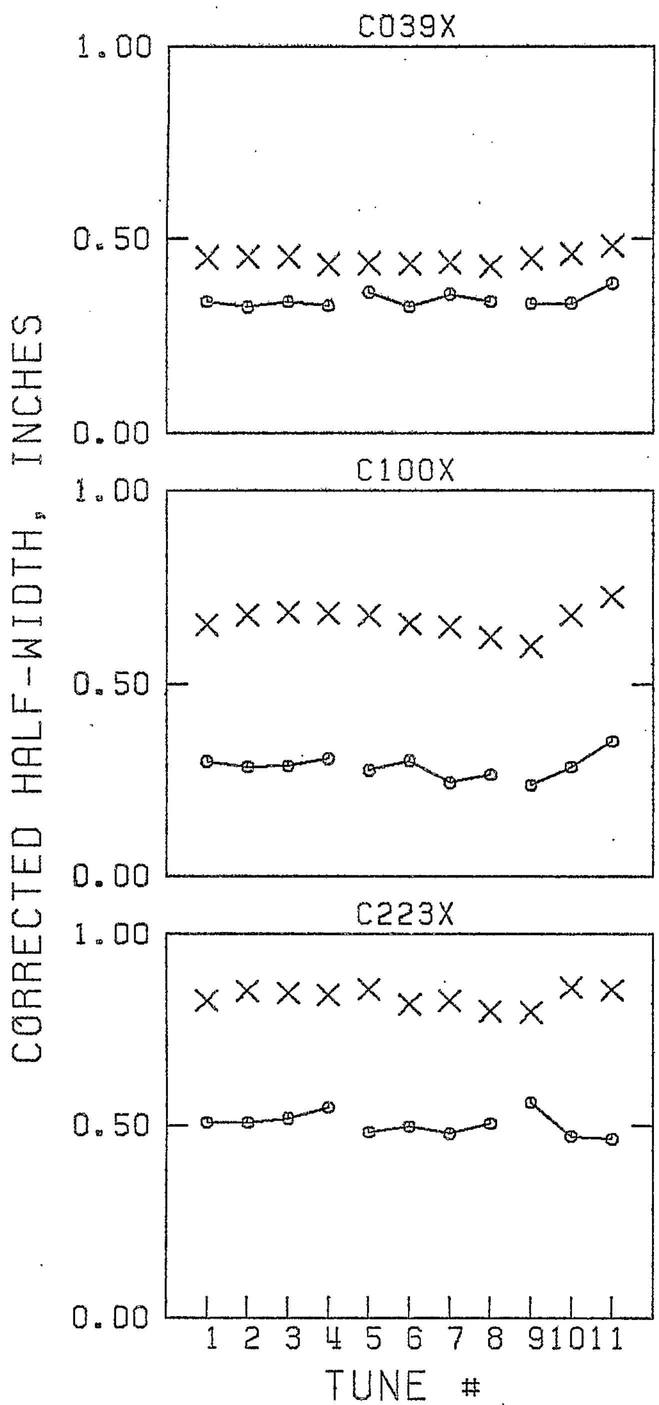

Figure 13. Corrected horiontal beam widths versus tune number at each of the three SWICs. Points: predicted widths; crosses: measured widths.

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