BNL-104073-2014-TECH

AGS.SN197;BNL-104073-2014-IR

Measurement of Emittance vs Intensity in the U line

J. F. Ryan

November 1985

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

1/13/86 Number 197

AGS Studies Report

Date:	11/23/85	Time:	01:00-03:15
Experimenters:	J. Ryan and R. Thern		
Reported by:	R. Thern		
Subject:	Measurement of Emittance vs. Intensity in the U Line		

1. Method

The extracted beam size, as a function of intensity, was measured in the U line at the SEM at U56. With the beta functions available from a previous measurement (1), this gives the emittance as a function of intensity. At the same intensities, the internal beam was measured with the IPM at several times (200, 400, 500, and 650 msec. after tØ) during the acceleration cycle.

As the study began, the AGS was operating FEB at an intensity of 15 TP. With the normal settings of UQ1 and UQ2, the spot size at the SEM was wide enough to give good profiles with no channels overflowing their 2047 count limit. Similarly, the IPM gave good profiles with 1 msec integrating time - the shortest available at late times during the AGS cycle - and the residual pressure at E-10 of 4x10-7. No gas was added at the IPM.

The intensity was reduced and a set of measurements taken at approximately 1 TP steps from 15 TP down to 2 TP. The intensity was reduced by using the LOWBM ORTHO file which reduced the linac pulse width (LNPW) and made the appropriate readjustments to injection bump timing (INBSP) and injection peaker fine control (DIFPK). It should be noted that the beam size at reduced intensity may depend on how the intensity was reduced. Thus these measurements may not reflect what the size would be if the intensity were reduced some other way, or, in particular, if the machine were running at reduced intensity due to some problem.

At each intensity, a data file with 10 profiles was taken with the SEM, and also with the IPM at four times during the acceleration. Each profile also has a reading of a current transformer (L20 for the IPM and UX015 for the SEM). These files were then analysed offline to get the beam sizes, shown in Figures 1 and 2 as a function of intensity, for the SEM and one set of IPM data. The horizontal IPM data for 500 and 650 msec is not usable, because two malfunctioning channels in the IPM came on one edge of the profiles and distorted them; at the other times the radius was different and the profile wider so the distortion was not serious. The IPM sizes have been corrected for space charge effects, but that 'correction' is apparently not correct, as will be discussed below.

The tables below show the momenta for the four IPM and one FEB sample times, and the beta and dispersion functions at the two devices. The functions at the SEM were obtained assuming the H13 values from ref. 1.

Beta and dispersion functions (meters)

	ver beta	hor beta	hor xp
IPM	16.5	16.5	1.90
U56 SEM	28.8	15.4	0.56

Time, gauss clock, and momentum

	time	g.c.	momentum	betagamma
IPM	200	7280	3.74	3.98
IPM	400	29005	14.72	15.69
IPM	500	38994	19.77	21.07
IPM	650	52807	26.76	28.52
FEB extraction	694	56398	28.57	30.45

With these values, the vertical emittances can be calculated:

$$\epsilon_y = \sigma_y^2/\beta_y$$

and to compare the values at different momenta, they can be normalized:

$$\epsilon_{y,norm.} = \epsilon_y \cdot \beta\gamma$$

where β and γ are the relativistic parameters ($\beta\gamma$ = p/m). These normalized emittances are shown in Figures 3 and 4 for the data of Figures 1 and 2.

For the horizontal emittance, the beam size should be corrected for the effect of momentum spread and dispersion to get the effect of the betatron oscillations only. Since they are uncorrelated, it is best to subtract them in quadrature:

$$\sigma_{x,betatron}^2 = \sigma_{x,measured}^2 - \left(\frac{dp}{p} \cdot X_p\right)^2$$

There is a problem because the momentum spread was not measured - that requires measuring, on an oscilloscope, the bunch width at each data point, and that was not done. The longitudinal emittance is expected to range from 1 to 4 eV-sec (ref 2), giving an "rms" momentum spread (dp/p) of .044% to .088%. For comparison, Weng (3) uses dp/p = $\pm$.12% for 99% of the beam, which corresponds, assuming a gaussian, to $\pm$.039% rms. Figures 3 and 4 show the normalized horizontal emittance, with corrections for 0, .044%, and .088% momentum spread. The larger momentum spread would be expected after transition at all but the very low intensities. Note that the momentum spread uncertainty is less serious for the SEM than for the IPM because the ratio β/x_p^2 is more favorable by more than a factor of three.

The emittances calculated and plotted here are rms values (i.e., one sigma values), and must be multiplied by a factor to compare with some other measures. For example, for 2.5 sigma emittance, multiply by 2.5*2.5 = 6.25, and for 99% emittance (assuming a gaussian distribution), multiply by -2*ln(1-.99) = 9.2.

2. Comparison of IPM and SEM data.

Figure 5 shows all five sets of vertical data on one graph. The normalized emittance from the IPM appears too high at high intensities, since the emittance should not decrease at extraction (losses were low). The IPM sizes have been corrected for space charge effects using parameters determined from a Monte-Carlo simulation of the ion collection in the IPM. Results using these parameters agreed qualitatively but not quantitatively with an experiment changing the IPM high voltage. The results of this study are further evidence that these parameters lead to an undercorrection for the space charge effect, and in fact the data here should allow a better determination of these parameters, by assuming that there is no change in normalized emittance between 650 msec and extraction at 694 msec. The amount of correction made with the present parameters can be seen by comparing Figure 5 with Figure 6, where <u>no</u> space charge correction has been made.

The horizontal IPM data have, in addition to any space charge problems, a strong dependence on the momentum spread, and thus a meaningful determination of the betatron size requires a good measure of the momentum spread.

3. Conclusions.

Figure 7 shows the emittance as a function of intensity, where the intensity has been controlled in a particular way. The smooth curves are drawn to take into account the estimated momentum spread of the beam.

Using the IPM to get an absolute emittance has two problems. First, the space charge distortion of the profiles is large and not yet completely corrected for. Second, in the horizontal plane, the effect of momentum spread on the beam size is large, so better measures of dp/p are needed.

References:

1. AGS Studies Report No. 193.

2. E. Raka, private communication.

3. W-T Weng, The New AGS Fast Extraction System. BNL 51310.

Figure Captions:

1. Measured beam size of the extracted beam vs. beam current, at the U56 SEM in the U line.

2. Measured beam size with the IPM at 400 msec after T0.

3&4. Normalized rms emittance for the data of figures 1 and 2. The horizontal is shown for three values of dp/p.

5. Comparison of vertical emittance from the SEM and IPM data. The IPM is apparently not completely corrected for space charge distortion, as the emittance inside the AGS should not be larger than that outside.

6. Same plot as figure 5, but with no space charge correction applied to the IPM data. Comparing with figure 5 shows the magnitude of the space charge correction as presently done.

7. Normalized rms emittance as measured in the U line. The curves are drawn by hand, and, for the horizontal, take into account the estimated momentum spread of the beam.

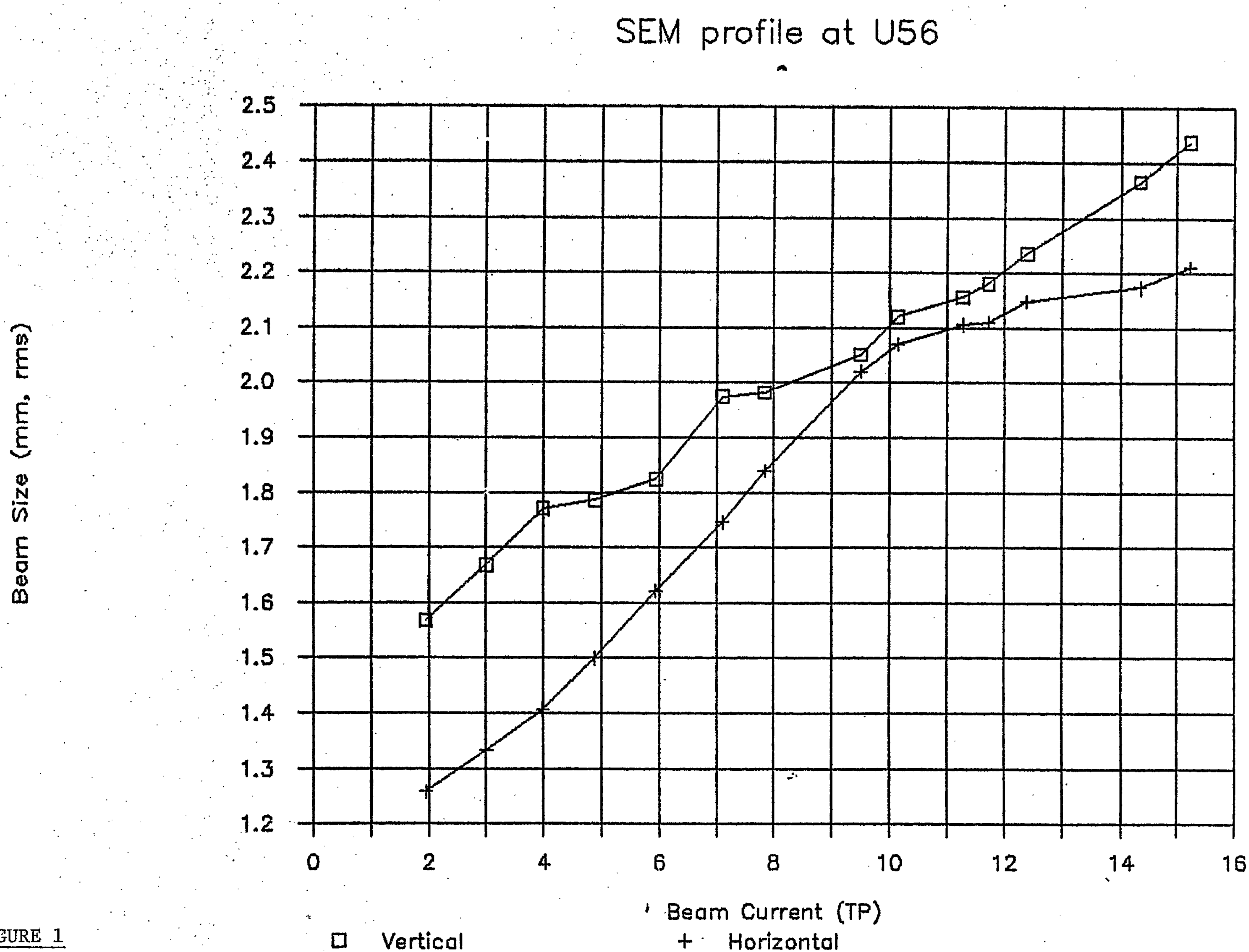
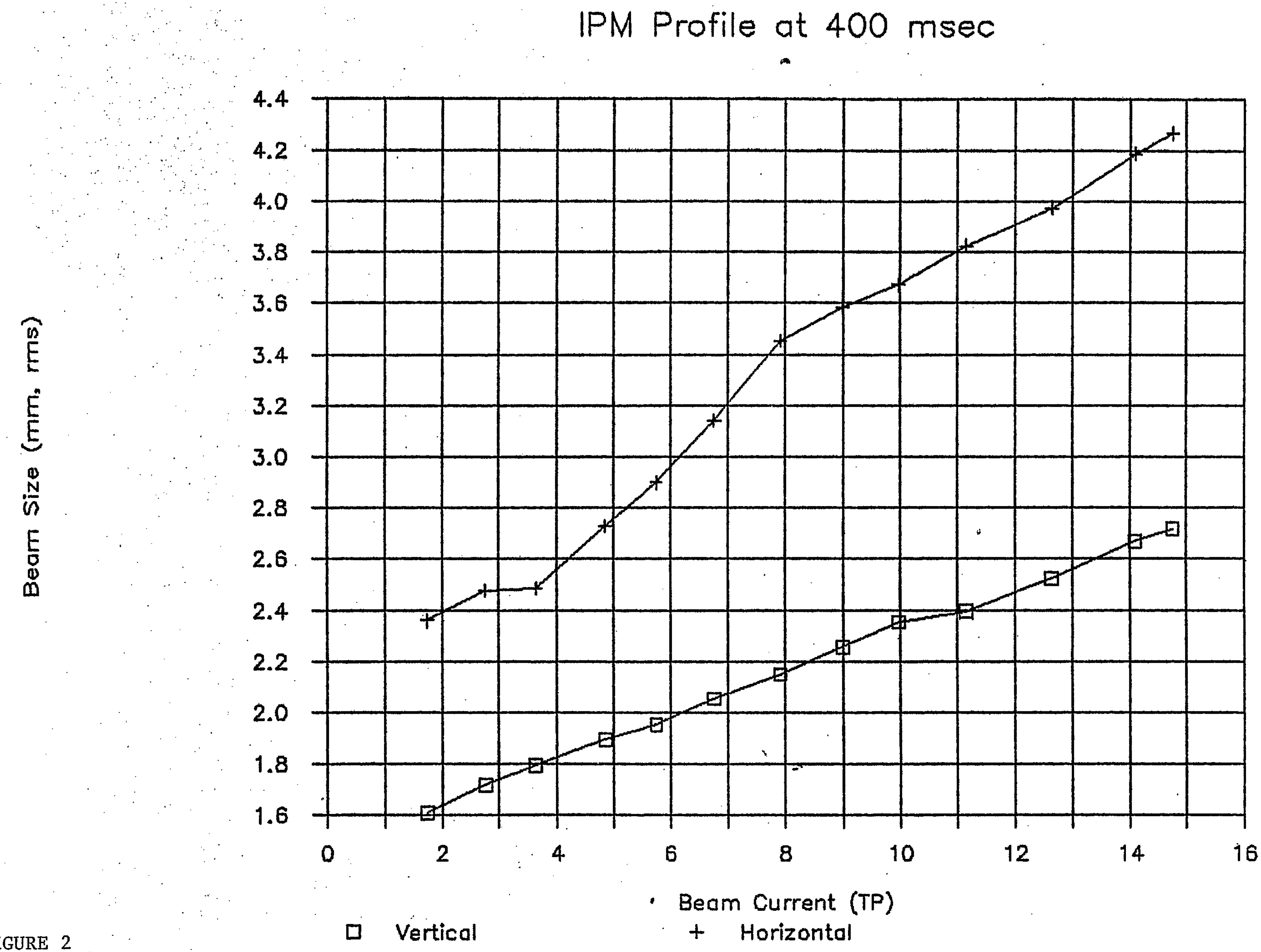
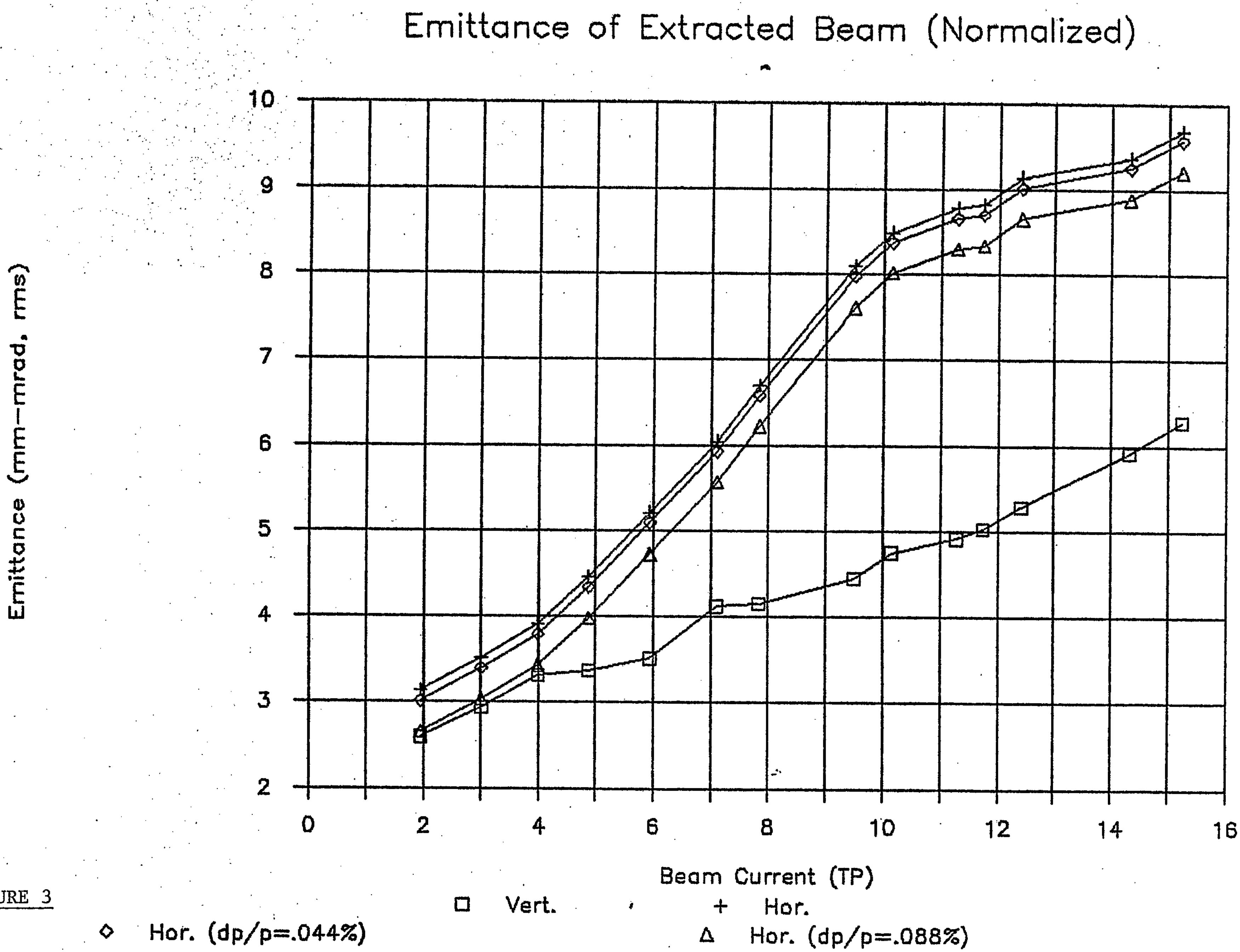

SEM profile at U56
Beam Size (mm, rms)
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0
2
4
6
8
10
12
14
16
Beam Current (TP)
Vertical
Horizontal

FIGURE 1



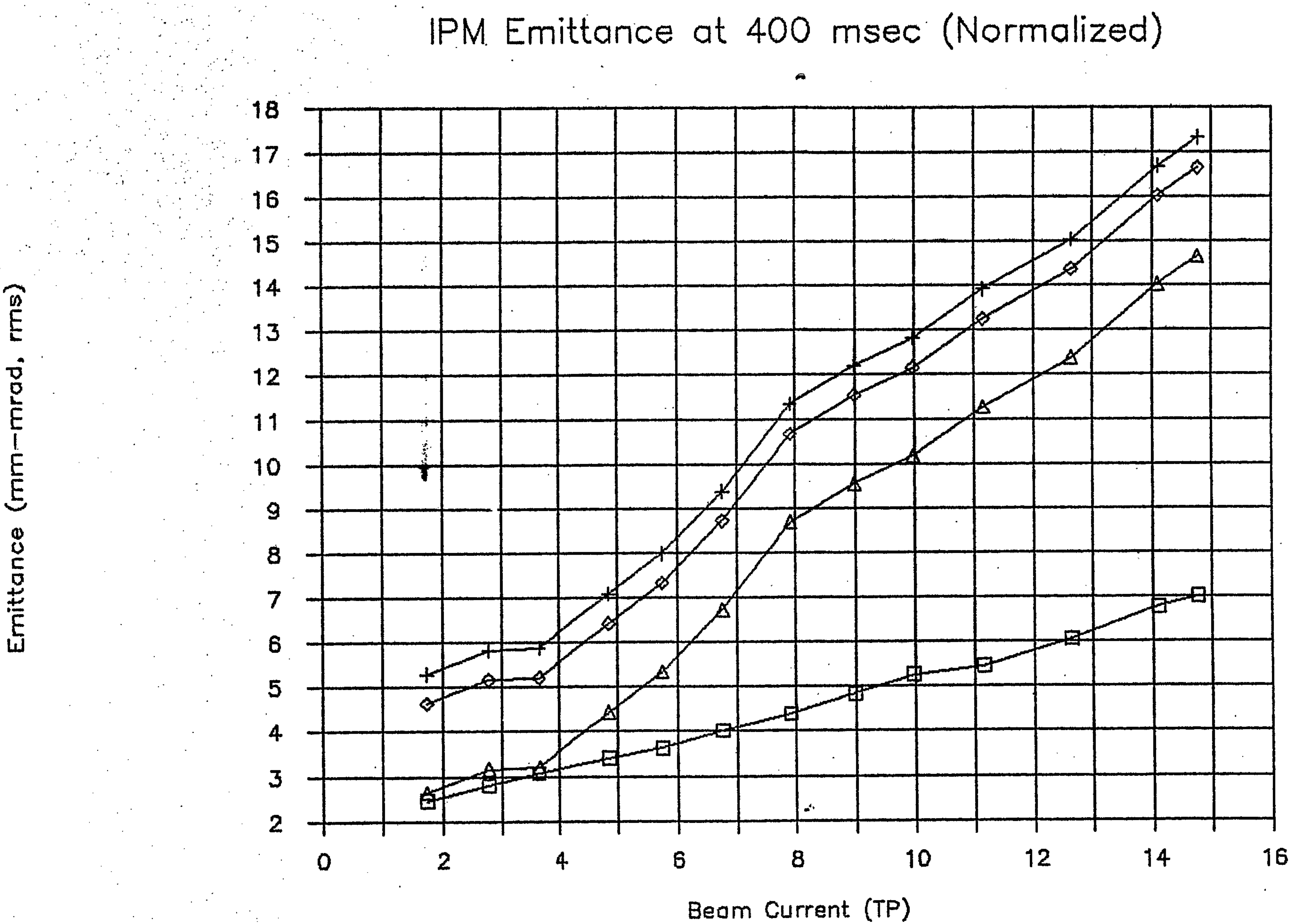
IPM Profile at 400 msec
Beam Size (mm, rms)
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
0
2
4
6
8
10
12
14
16
Beam Current (TP)
□ Vertical
+ Horizontal

FIGURE 2



Emittance of Extracted Beam (Normalized)
Emittance (mm-mrad, rms)
10
9
8
7
6
5
4
3
2
0
2
4
6
8
10
12
14
16
Beam Current (TP)
□ Vert.
+ Hor.
◇ Hor. (dp/p=.044%)
Δ Hor. (dp/p=.088%)

FIGURE 3



IPM Emittance at 400 msec (Normalized)
Emittance (mm-mrad, rms)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
0
2
4
6
8
10
12
14
16
Beam Current (TP)
□ Vert.
+ Hor.
◇ Hor. (dp/p=.044%)
Δ Hor. (dp/p=.088%)

FIGURE 4

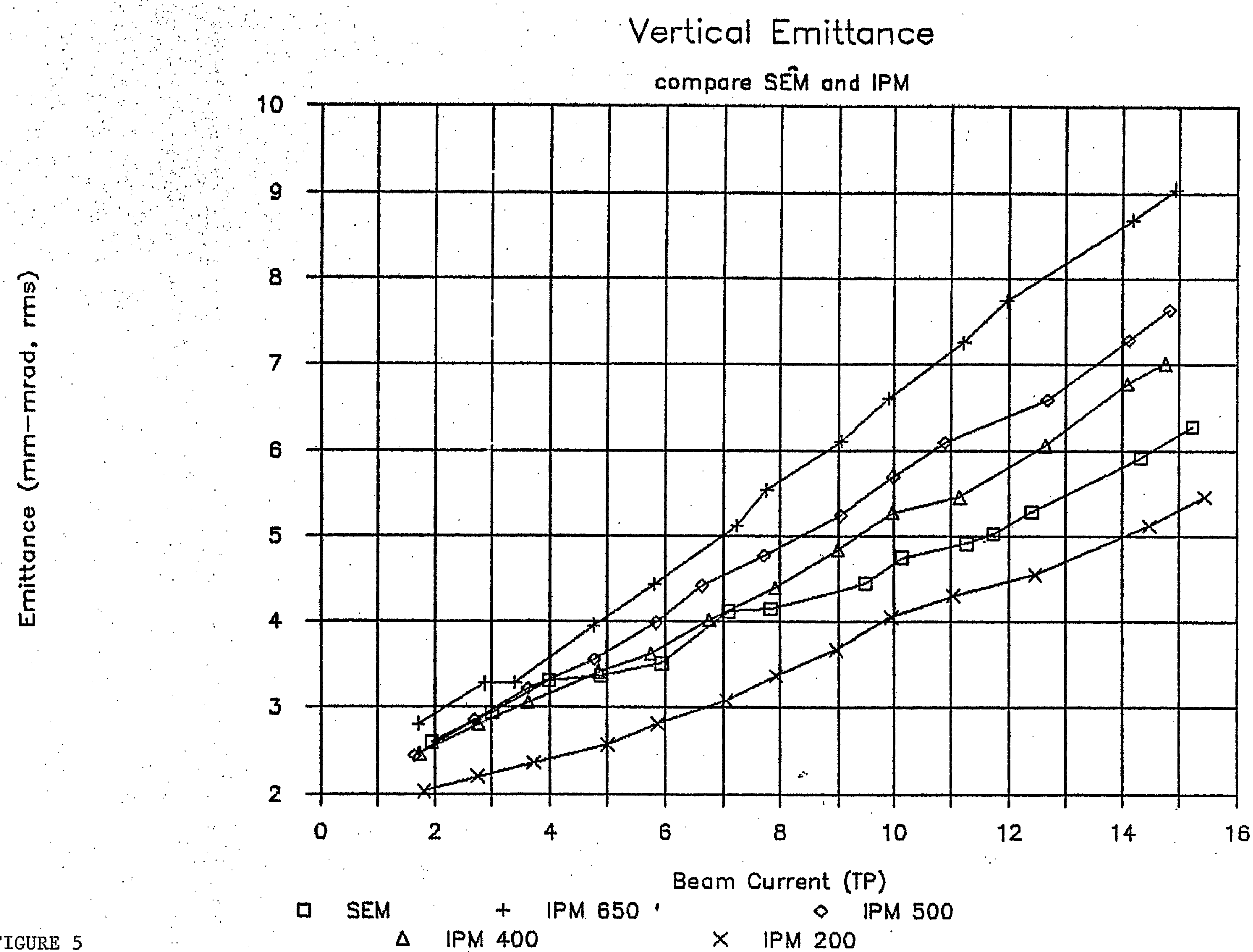
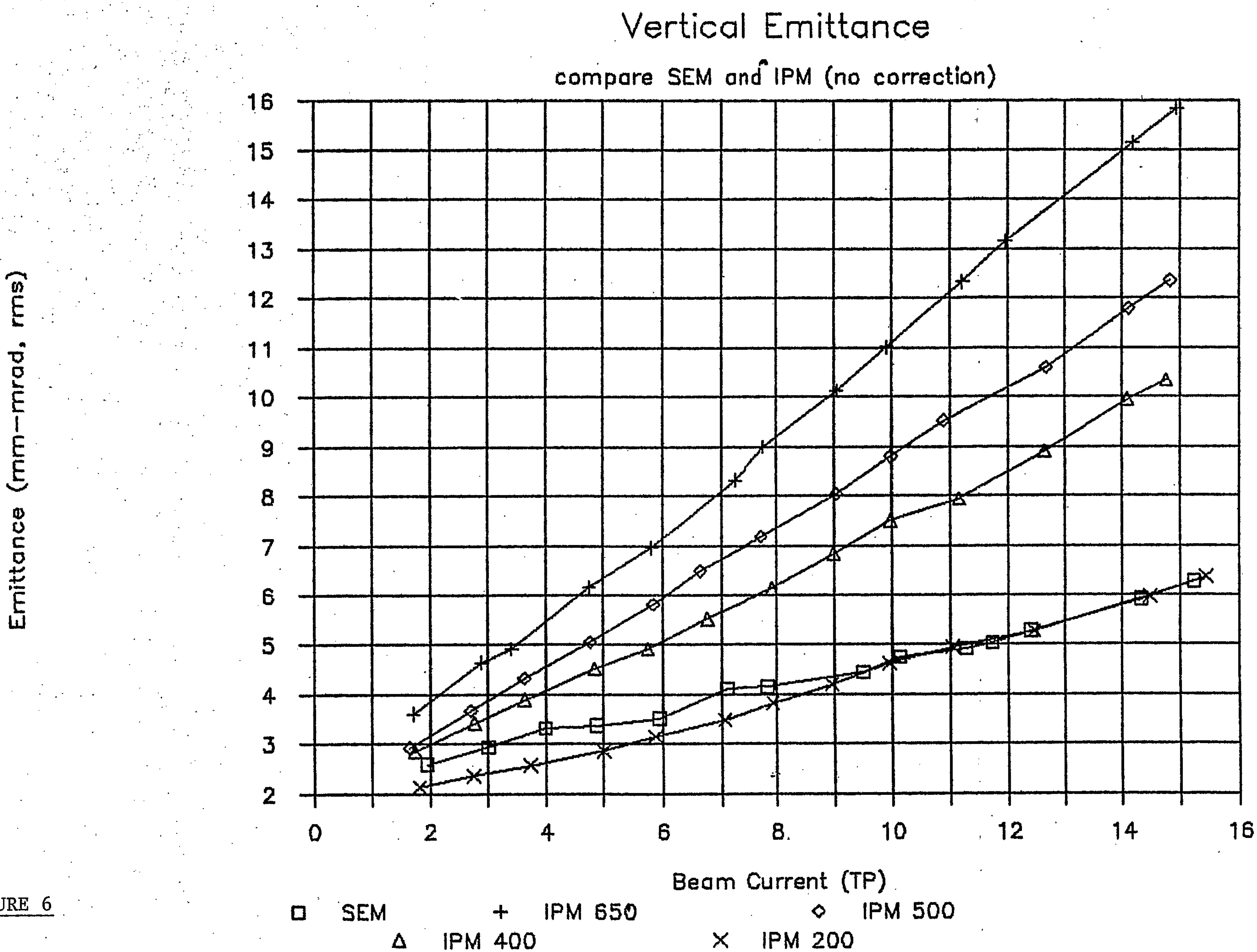
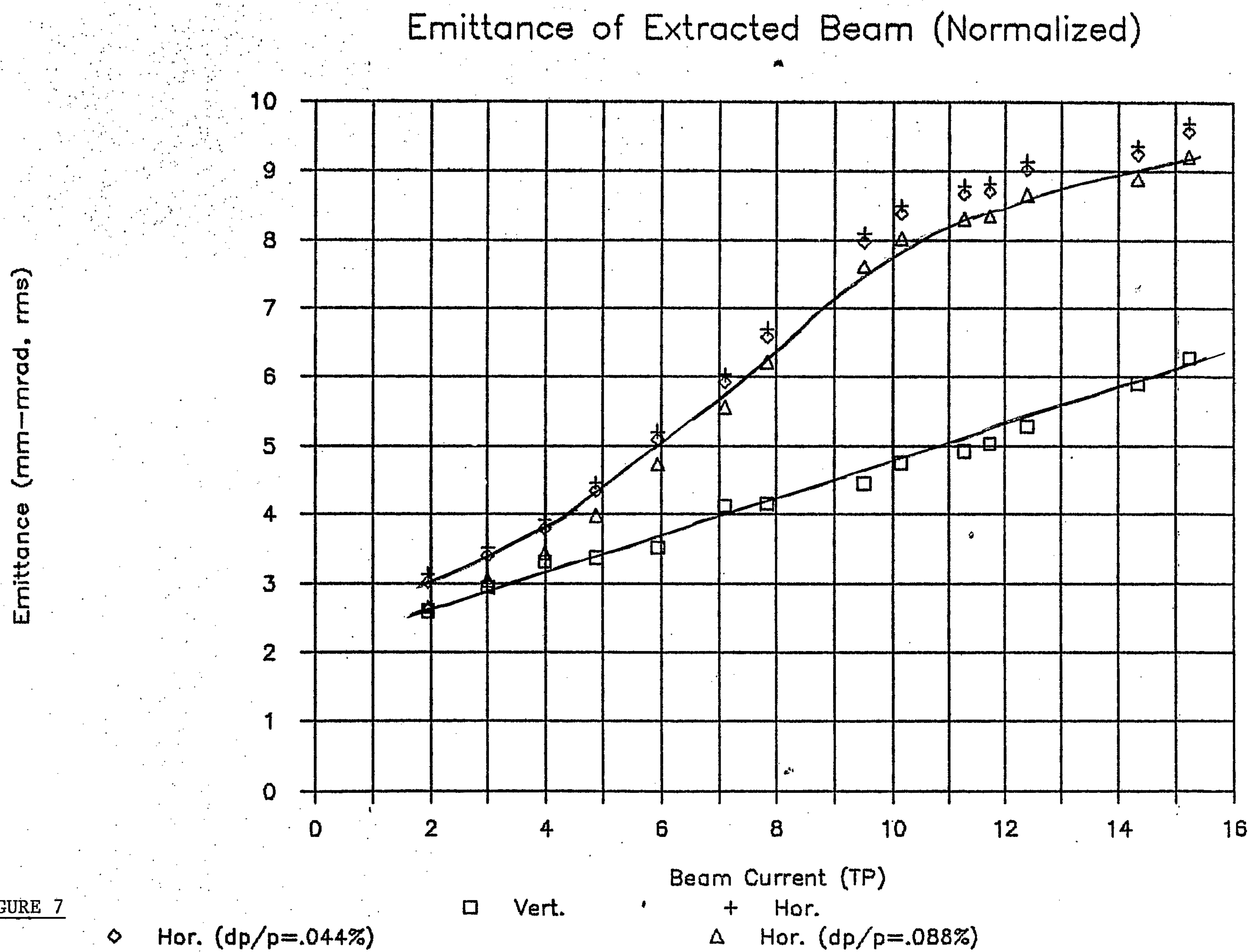

Vertical Emittance
compare SEM and IPM
Emittance (mm-mrad, rms)
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14
16
Beam Current (TP)
SEM
IPM 650
IPM 500
IPM 400
IPM 200

FIGURE 5



Vertical Emittance
compare SEM and IPM (no correction)
Emittance (mm-mrad, rms)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
0
2
4
6
8.
10
12
14
16
Beam Current (TP)
SEM
IPM 650
IPM 500
IPM 400
IPM 200

FIGURE 6



Emittance of Extracted Beam (Normalized)
Emittance (mm-mrad, rms)
10
9
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
12
14
16
Beam Current (TP)
Vert.
Hor.
Hor. (dp/p=.044%)
Hor. (dp/p=.088%)

FIGURE 7