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FY96 SEB EMITTANCE MEASUREMENTS

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Abstract

Emittance measurements made in the FY96 SEB run are presented along with discussion of the various ways the data was analyzed. Two basic methods of measuring the emittance were studied and both methods are discussed.

1 Introduction: Measuring SEB Emittance

Not since 1981 has a careful emittance measurement been made in the SEB lines.[1,2,3] This year a number of measurements were made using the same device that was used in 1981 and trying another method as well. The SWIC located in front of AD2 in the ring part of the switchyard was used to measure beam widths for different sets of quadrupole strengths in CQ1 and CQ2 (CQ3 and CQ4 off). This is the same SWIC (called CW100) that was used in 1981 measurements. The problems encountered in using this SWIC were the same as were encountered in 1981. Extracting the true beam widths from the measured beam widths is very difficult due to a large Gaussian background on the SWIC. In the 1981 studies this background was not found to be real, since it didn't show up on foil activations. In these studies a good agreement between beam sizes measured on the SWIC and beam sizes predicted by the model could be made for the vertical profiles but not for the horizontal profiles after making a correction for this Gaussian background. In this year's studies we found that comparing the beam widths at full width-half maximum, using three different methods of vertical beam size measurement, gave good agreement between the different measurements. We analyzed the profiles in a number of ways, including the method used in 1981. The results were basically the same, independent of analysis method. We just achieved better (formal) confidence values for some methods as opposed to others (fittings had different chi-squares depending on the analysis method). To be more specific, we found the values for alpha and beta did not change too greatly with analysis method although the scalar emittance did. For the SEB lines it is most important that we get a good optical match to the AGS and so the values of alpha and beta are critical to determining the settings of the first four quadrupoles in the line. The scalar emittance is interesting only in that it should be less than the admittance of the line.

The other method for measuring the beam widths involved using the septum of CP1 (with the power supply off so there was no field on the field side) to scan accross the beam. This method is actually not straight forward because the septum has a fairly long length and the loss monitors had fairly high background rates. In principle, if the septum thickness can be kept constant as it is scanned accross the beam and if the background signals in the loss monitors can be kept low, this measurement can give an absolute measurement of the beam size at the septum. Of course the beam size is assumed not to change too greatly over the length of the septum, which, in principle, it should not. In addition, scans of CP1 and the septum on AD2 were used to try to compare the different methods of measuring the beam size (septum scan, swic, and flag). This is discussed in detail in section 2.1.

Chronologically there were 3 major study periods taken to do emittance measurements. For the first study the CW100 SWIC was not available and so this study used the septum scan. The results from this study were startling enough that it prompted the second study using CW100. The results of the second study basically were in agreement with the septum scan results which prompted the third study. In the third study, emittance scans were done with and without a valve inserted (located 2 feet from the beginning of the Switchyard, in the F13 AGS section). The results of the third study with the valve retracted agreed with the results of the second study.

The most significant result of these studies was the degree to which alpha and beta (at F13) differed from the "canonical" values, measured in 1981. The horizontal alpha and beta now appear to be a factor of about x5 smaller. The vertical alpha and beta are roughly 30 to 50 % larger. The scalar emittance is roughly a factor of x2 to x5 larger in the horizontal and x2 larger in the vertical.

Table 1 summarizes these results along with the results from the 1981 studies. Emittances are expressed as normalized 95 % in units of pi-mm-mrad. Beta's are in meters. Equiv. CW100 is data which was analyzed in the same manner as was outlined by Weisberg[3]. The uncertainties are from the fitting of the the data to the given quadrupole currents and do not include systematics of fitting the actual profiles. Figure 3 demonstrates graphically the difference between the Weisberg measurements and the FWHM at CW100 measurements. The 1σ width is plotted versus the quadrupole strengths for the emittance scan, showing the measured, the fit to the measured, and the predicted values for the horizontal plane.

Table 1: Summary of emittance measurement results
(note: β and α are referred to F13)

	$\epsilon_x^{95\%,N}$	β_x (m)	α_x	$\epsilon_y^{95\%,N}$	β_y (m)	α_y
Weisberg Meas.	31.9	57.61	-6.636	38.8	3.249	0.8708
Equiv. CW100	$160.9\pm$ 16.1	$13.0\pm$ 2.0	$-1.50\pm$ 0.2	$86.90\pm$ 4.3	$4.80\pm$ 0.3	$1.05\pm$ 0.06
FWHM CW100	$64.37\pm$ 9.60	$8.77\pm$ 1.4	$-0.92\pm$ 0.2	$54.71\pm$ 5.0	$4.18\pm$ 0.4	$1.01\pm$ 0.09
CP1 Scan	$5.48\pm$ 4.8	$10.4\pm$ 9.3	$-1.20\pm$ 1.1			

1.1 Scanning Septum Measurement

CP1 is a Lambertson septum magnet with a septum thickness of 0.03 inch at the medium plane. [5] It pitches the A,B, and C beams beam down by about 5.9 mrad. The D line beam normally passes through the field free region. For the study the field was turned off and a single beam was setup (wire septums were retracted out of beam). Using the local loss monitors to collect the data the septum was moved accross the beam in increments greater than 30 mils (typically 50 mil steps). To ensure the septum thickness was kept minimized, the skew was tuned at every few points for minimum loss. The data was collected using GPM, plotting local beam loss versus CP1 position.

A set of scans were also taken using the BB3 wire septum (with high voltage turned off). Not enough of these were taken to allow extracting an emittance measurement.

1.2 The CW100 SWIC Measurement

The CW100 SWIC is an ionization profile monitor with wire spacings of 0.05 inch. It is located in the same box as the CF100 flag and drives up from the bottom of the box. It is the same device used in previous emittance studies.[3] There are 32 wires per plane with 3 nickel wire mesh bias planes. It uses an argon / CO_2 gas mixture. Profiles were captured using a Lecroy digital oscilloscope and saved into disk files on the Sun Workstation using a LabView application. The files were then analyzed using a set of programs written for this purpose.

2 Data Analysis

2.1 Methods of Analysis

The most important step in getting an emittance measurement is to get believable beam widths. If profiles are Gaussian in character then this is trivial; one just fits the data to a Gaussian and extracts the value for sigma. If the profiles are not Gaussian then one can fit to a Gaussian, if it is a good approximation, or one can fit a curve and extract moments to deduce an equivalent sigma. Since we almost always assume an elliptically shaped phase space we almost always fit profiles with Gaussians. Unfortunately the horizontal phase space for the SEB beam is not an ellipse, but is a parallelagram. In principle a profile for a parallelagram phase space should approximate a Gaussian, in most cases, fairly well.[2,3] In practice the error bars on these fits can be fairly large. Our goal is to get measurements of the Twiss parameters that are good enough to get a good agreement between a model and measured beam sizes. Since we are not looking for subtle high order effects, but just want to extract the basic beam parameters, we will restrict our analysis to the Gaussian description.

It was found empirically that using the full width-half maximum (FWHM) measurement of the profiles gave the most consistant measure of the beam widths between the different methods of measurement. This is a very important observation, since it implies all the methods resolve the core emittance of the beam very realistically. There is also a very simple relationship between the FWHM measurement of profile width and 1 sigma for a Gaussian. This is easily shown:

$$\frac{1}{2} = exp(-\frac{X_{HWHM}^2}{2\sigma^2})$$

In which case:

$$FWHM = 2.35482\sigma$$

Measurements comparing flag profiles to foil activations and vacuum multiwire scans have been made in the past [4], although we haven't been able to dig up a written reference on this. The common perception, and the results reported by [4], is that the visible flag pattern represents > 95 % of the total beam intensity. Of course this resolution can easily be lost if the conditions are other than optimal. In table 2 the flag widths are what is visibly measurable on the flag (full extent) even after some image enhancements (a normalization and a simple equalization).

Figure 1 shows the beam size measurments made while scanning the AD2 septum vertically using CP020. Beam sizes were also measured using the CF100 flag and the CW100 SWIC in the same period (shown in figure 2). Table 2 summarizes the results of this data. Note that the horizontal data does not hold together well, even for a FWHM measurement. This is, as yet, unexplained. Observe, though, that given the ratio of the vertical septum scan to the vertical flag beam size, the expected beam size for the Horizontal in the last row would be about 2.18 cm, or very close to a factor of two smaller than that measured on the SWIC.

Table 2: Comparisons of Beam Widths From Different Instruments

	Flag (cm)	*SWIC (cm)***	*Septum Scan (cm)***
Vert.	full extent = 1.83	FWHM = 0.89 $\sigma = 0.38$ 95% = 2.29	FWHM = 0.97 $\sigma = 0.41$ 95% = 2.44
Horiz.	full extent = 2.39	FWHM = 1.91 $\sigma = 0.81$ 95% = 4.88	no corresponding data
Horiz.*	no corresponding data calc. 2.18	FWHM = 1.78 $\sigma = 0.76$ 95% = 4.56	FWHM = 1.14 $\sigma = 0.49$ 95% = 2.91

* based on data taken for CQ1 and CQ2 at 5.75 kG/inch.

** sigmas are calculated based on the FWHM values.

If the horizontal SWIC profiles are scaled by the ratio of 2.91/4.56 the resulting alpha and beta are unchanged but the scaler emittance is decreased to 26.4 π-mm-mrad (from 64 π-mm-mrad).

For each of the studies the beam intensity was set to around 5 TP. The first two quadrupoles (CQ1 and CQ2) were scanned with equal strengths (in opposite polarity) while the second pair of quadrupoles (CQ3 and CQ4) were turned off. Based on Weisberg results, figure 3 shows the predicted horizontal beam sizes expected at BB3 and CP1 versus the quadrupole strengths used along with the measured results. This shows that the scans sweep through a waist at BB3 and CP1 (and at CW100, which is just after CP1).

2.2 Scanning Septum Data

Figure 4 shows the data taken for the scans of CP1. Figure 5 shows the measured 1 σ widths derived from FWHM beam widths along with the predicted 1 σ beam widths (per Fig. 3) versus the quadrupole strengths in CQ1 and CQ2. The emittance and Twiss parameters shown in table 1 are based on the four outer points of the data. Using the middle point gave an imaginary emittance.

2.3 CW100 Data

Figures 6 and 7 show the data taken using CW100. Basically we used two methods to extract widths from the profiles. The first method we used was to simply fit a Gaussian to the profile (in various ways; i.e., zero baseline, floating baseline, and a fixed width Gaussian baseline - which is the method used by Weisberg). We used a gradient-expansion algorithm to fit a Gaussian to the profile data. This technique provides fast and accurate fits when only one minimum in χ^2 is present, which was the case here. A fair amount of tuning of the fittings was done which resulted in only small variations in the emittance results. The real issue here is trying to find the "true" beam width. Weisberg [3] found that when the background on the vertical profiles was fitted to a Gaussian with a standard deviation of 1.27 cm, he obtained the best agreement in the measured SWIC beam width with measurements made using foil activations. In our own studies we found that fitting the profiles with different baselines didn't change the final results that greatly, although the uncertainties did vary widely. Table 3 shows the results of using the various baselines in the fittings.

Table 3: Emittance measurement results for various baseline fittings (note: β and α are referred to F13)

	$\epsilon_x^{95\%,N}$	β_x (m)	$\alpha_x(m)$
Constant Baseline	156.6± 9.7	8.67 ± 0.62	−0.81± 0.08
Floating Baseline	145.7± 75.7	10.6 ± 5.7	−1.42± 0.78
Constant Gaus. BL	160.9± 16.1	13.0 ± 2.0	−1.50± 0.20

Note: uncertainties from fitting widths to quad settings as in Table 1.

3 Conclusions

Clearly there are many systematic problems with extracting the SEB emittance and Twiss parameters using the existing instrumentation. If we believe the results, though, then they suggest something is significantly changed from the conditions which existed in 1981. In order to understand this requires careful modelling of SEB extraction, which is presently being done. We also need better instrumention in order to get beam profiles which truly represent the beam. New instrumentation is planned to be installed for the next SEB run and we expect to have a system which will allow emittance measurements to be made more easily in the not too distant future.

Certainly one way to gain more confidence in these emittance measurements is to measure beam widths for normal running conditions and compare these to a model using the measured emittance. At the end of the SEB run a new set of optics was employed for CQ1-4 based on this measured emittance for a study. The beam was transported to each of the SEB beam lines individually and beam loss and beam size (on flags) measurements were made. The study was fairly successful in that the losses for the individual beam transports were lower than those of a similar study using the normal optics. Figure 8 shows the beam images seen on the SEB flags for beam transported down A line only (enhanced to show the "full" extent of the beam spots). Figure 9 shows the A line model with the measured beam sizes marked at the flag locations. The agreement is very good, suggesting the emittance measurements are believable.

4 Acknowlegements

J.W. Glenn has been an invaluable resource of information and guidance. L. Ahrens, T. Roser, and P. Pile have each provided valuable technical expertise and a proper amount of skeptisism to keep us on the correct course. I H. Chiang and A. Ravenhall have provided information on the CW100 SWIC.

5 References:

1. Improved Measurements of Slow-Extracted Beam Emittance, H. Weisberg, BNL-26492, 7/79.

2. SEB Emittance Measurements, H. Weisberg, AGS Div. Tech. Note No. 155, 10/79.

3. More SEB Emittance Measurements, H. Weisberg, AGS Div. Tech. Note No. 168, 2/81.

4. J.W.Glenn, Private Communication, 8/96.

5. The AGS Slow External Beam Switchyard, L. Blumberg et al, BNL 24508R, 5/78 (revised 12/79).

6 Figure Captions:

Figure 1: Scan of AD2 Septum with CP020.

Figure 2: CF100 and CW100 images for same conditions.

Figure 3: Variation of Beam Sizes vs Quads Strengths.

Figure 4: CP1 Scans, Normalized Differences.

Figure 5: CP1 Scan Beam Widths.

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Figure 6b: CW100 Raw Data, Horizontal Profiles

Figure 7a: CW100 Raw Data, Vertical Profiles

Figure 7b: CW100 Raw Data, Vertical Profiles

Figure 8: Beam Spot Images for A-Only Transport, new optics.

Figure 9: Mad Model of Aline Optics.

Figure 1: Scan of AD2 Septum with CP020

AGS Current = 5 TP, normal extraction

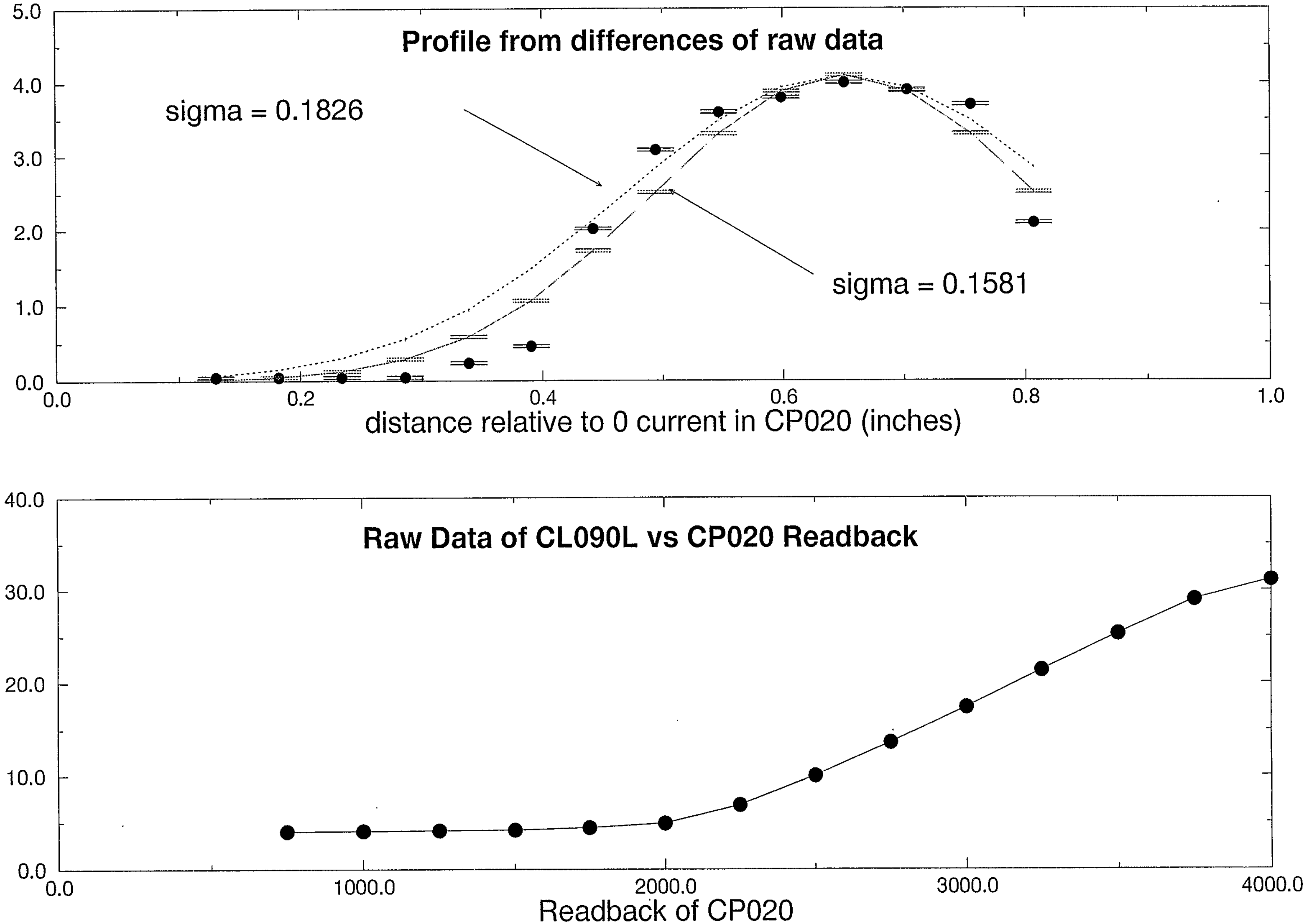
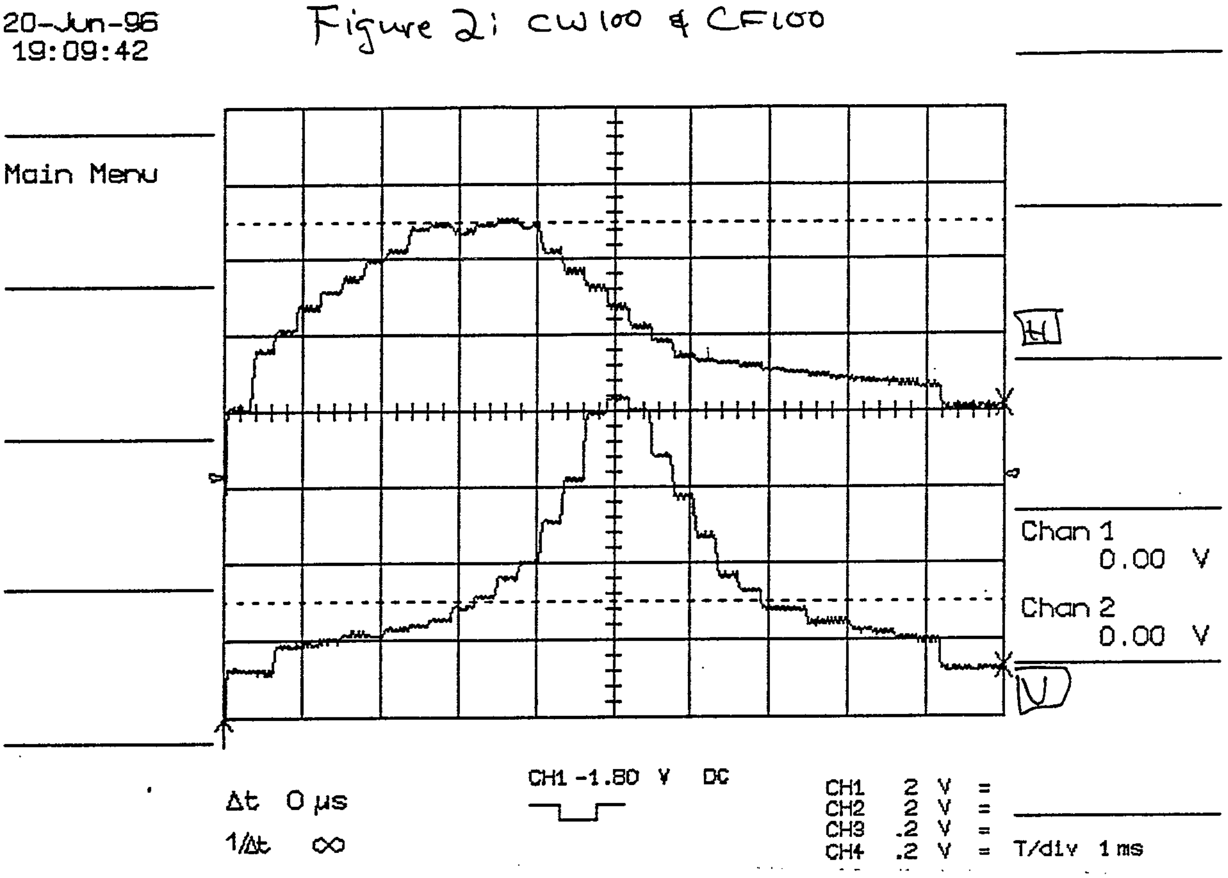


Figure 2: CW100 & CF100



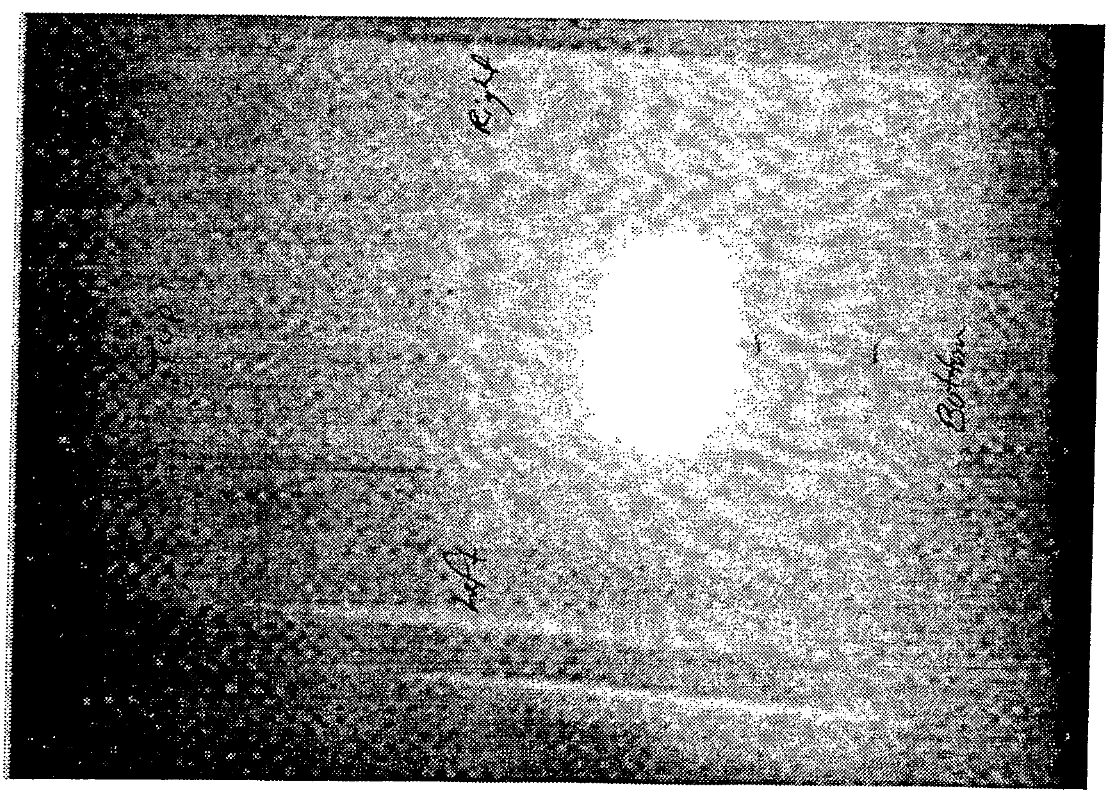


Figure 3: Variation of beam sizes vs Quad Strengths

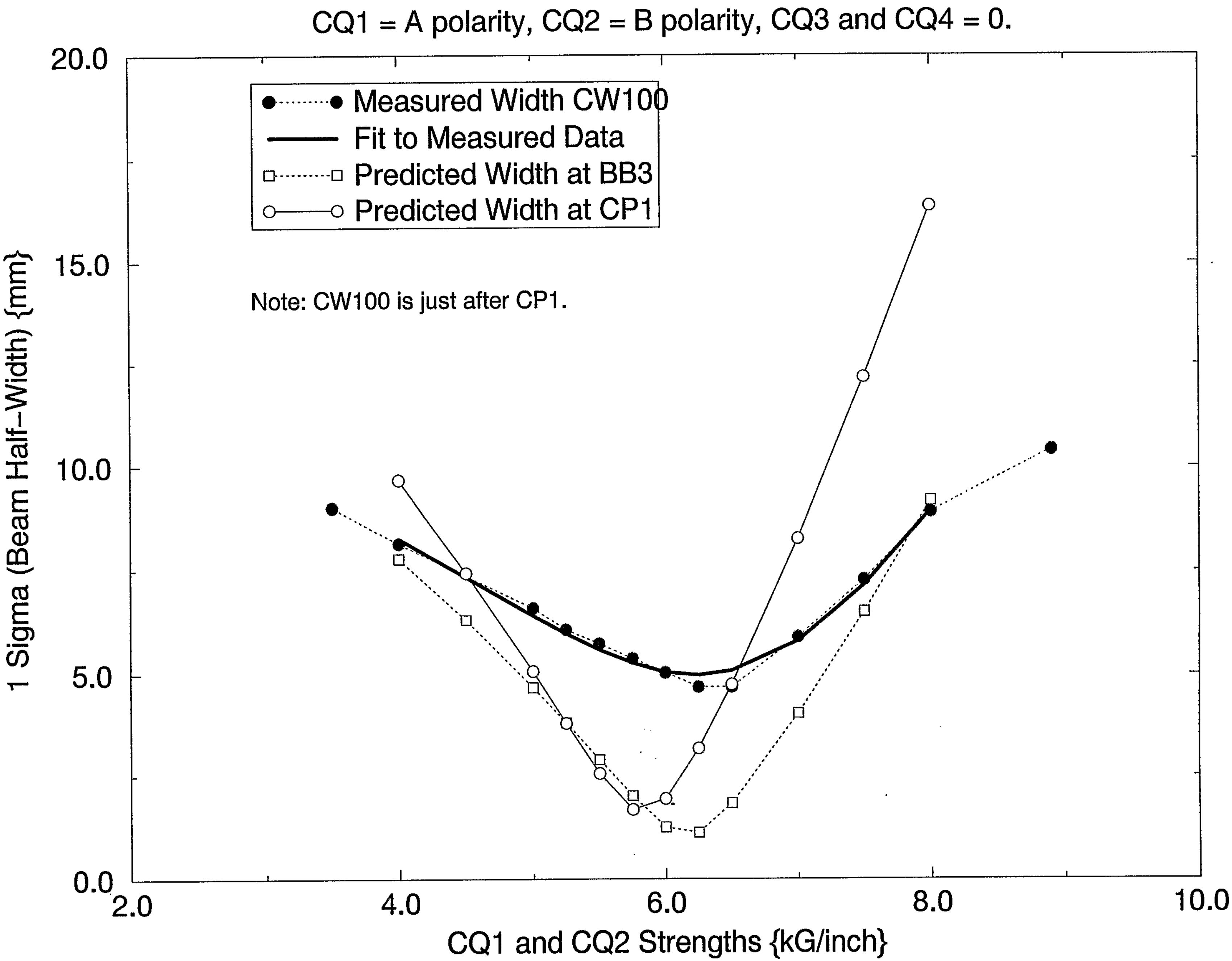


Figure 4: CP1 Scans, Normalized Differences

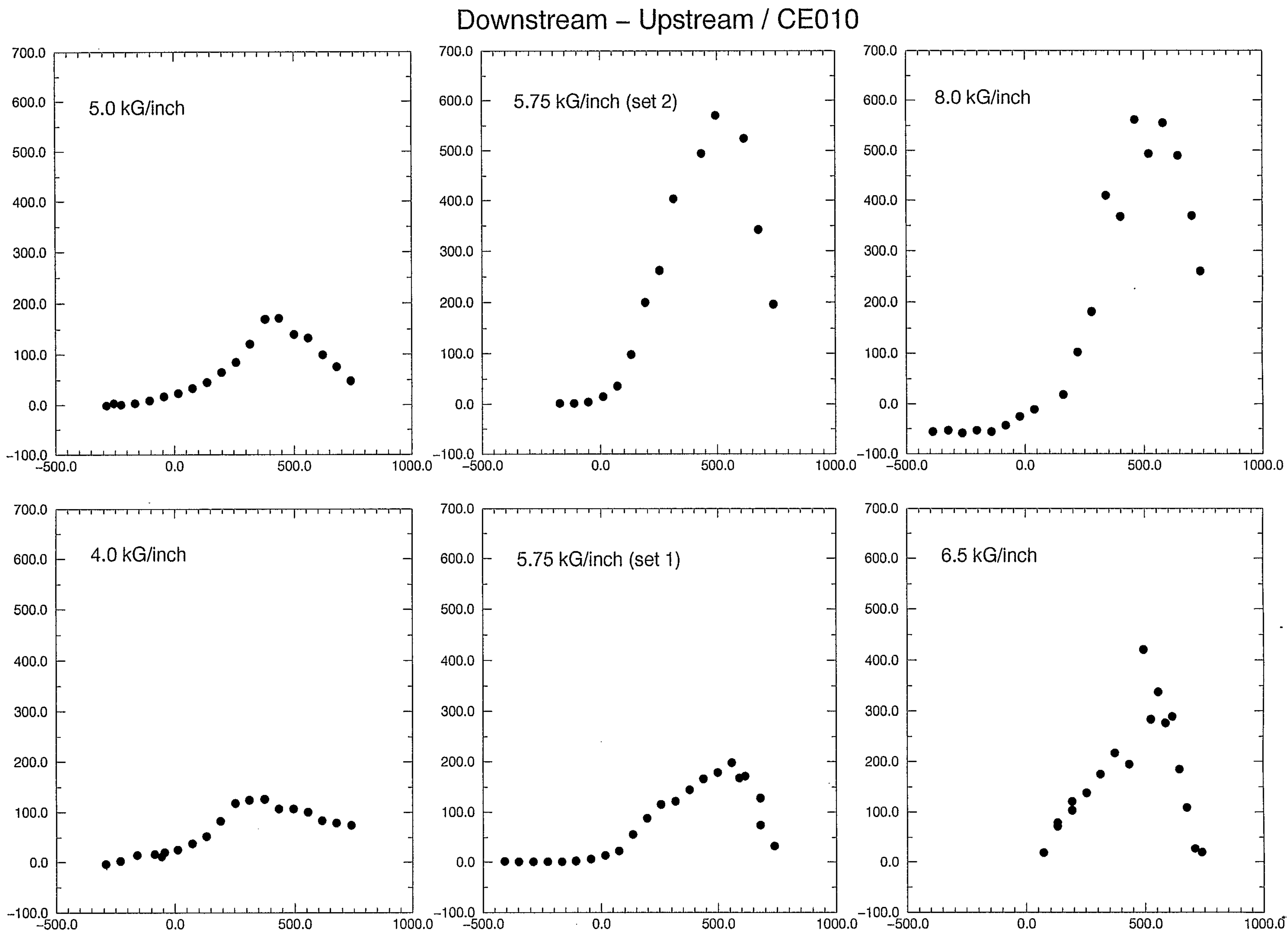


Figure 5: CP1 Scan Beam Widths

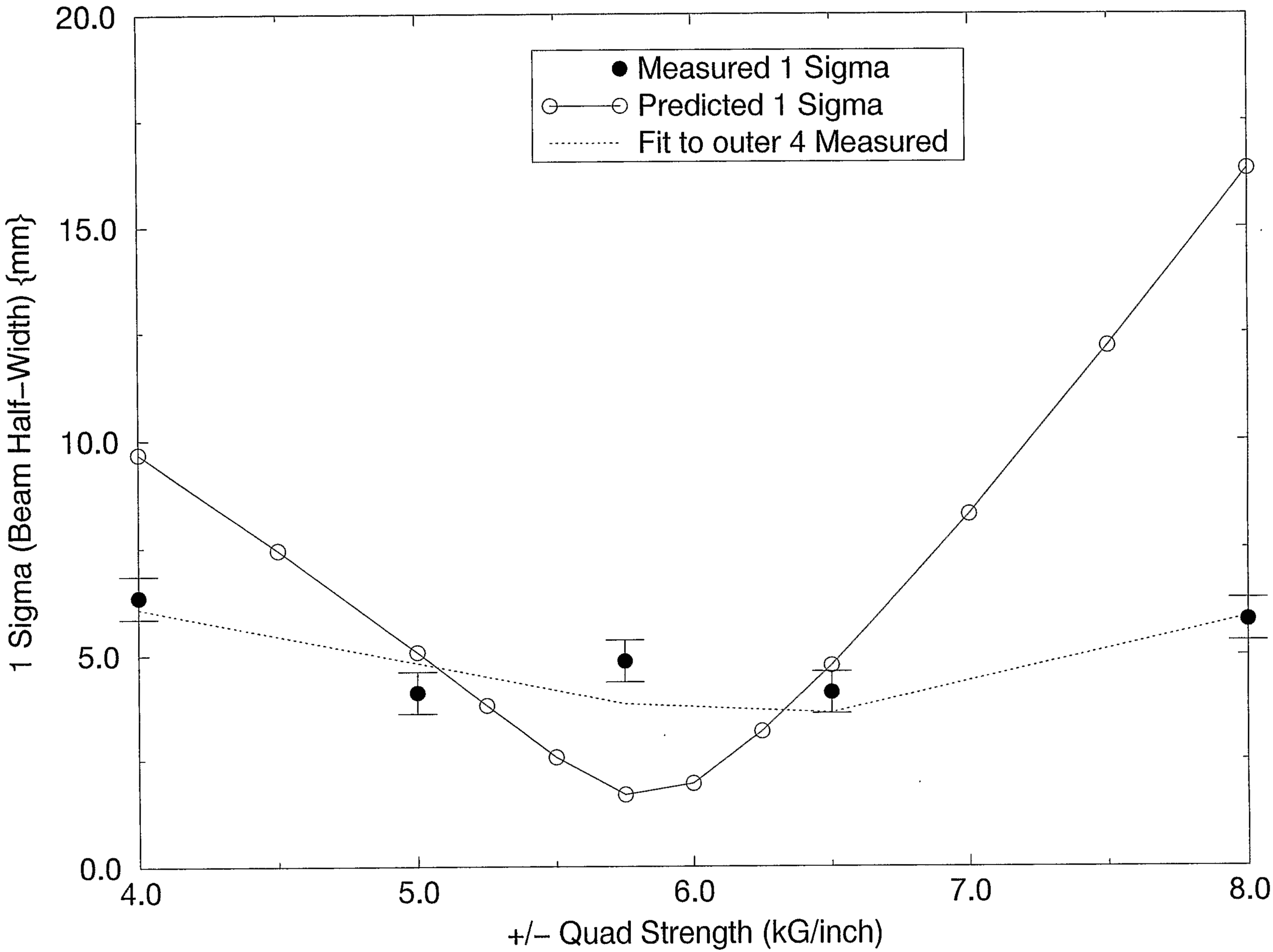


Figure 6a: CW100 Raw Data, Horizontal Profiles

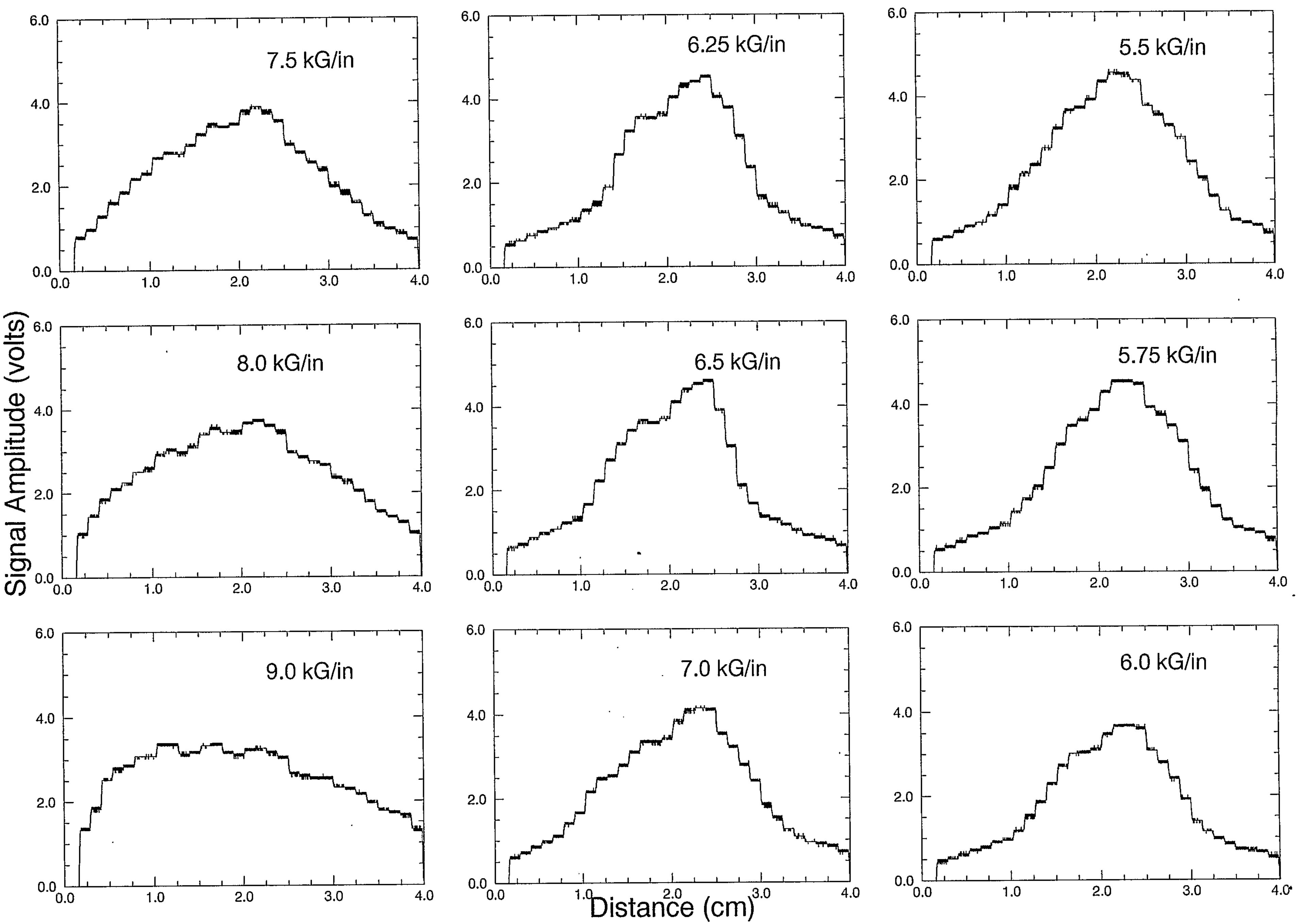


Figure 6b: CW100 Raw Data, Horizontal Profiles

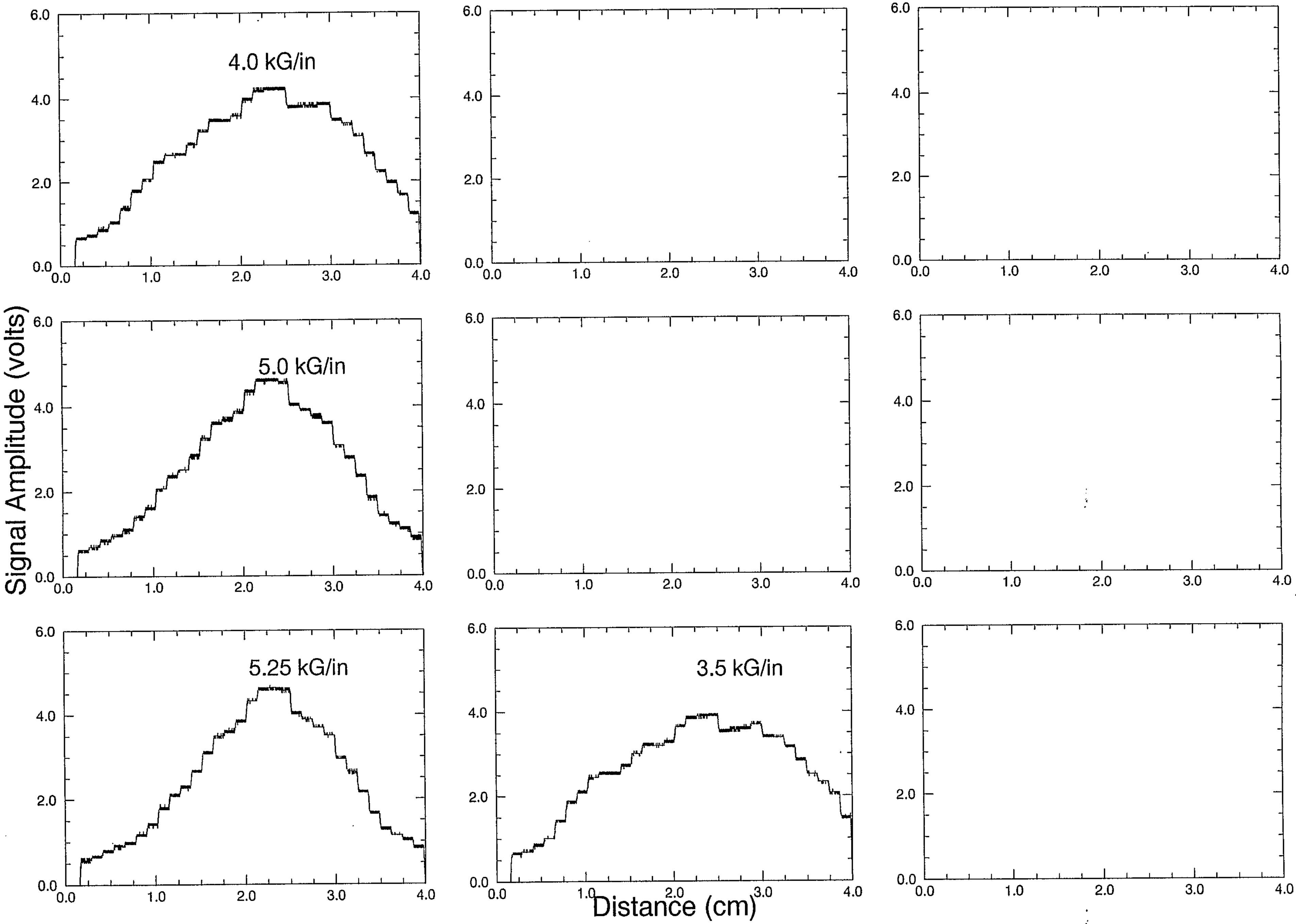


Figure 7a: CW100 Raw Data, Vertical Profiles

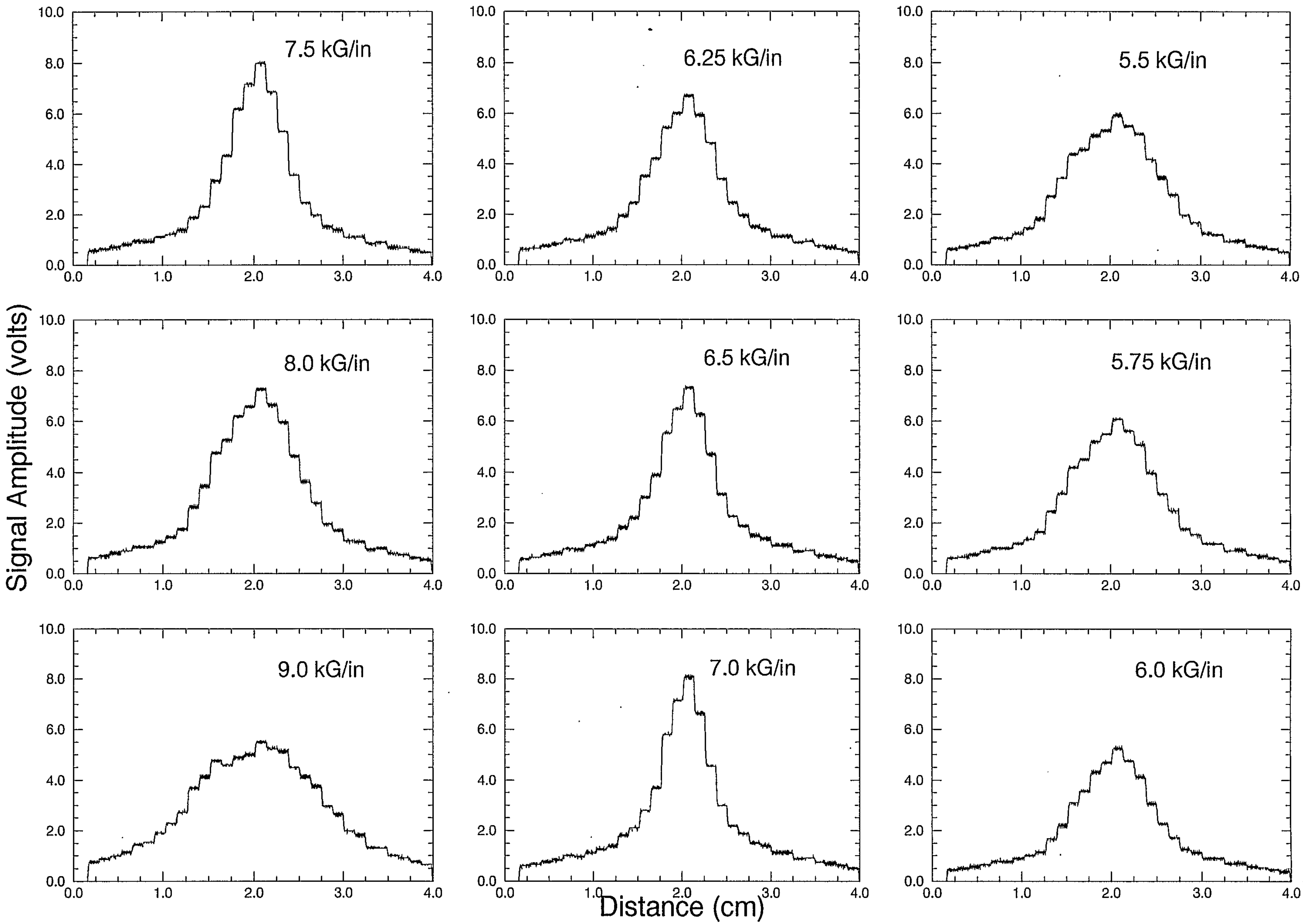


Figure 7b: CW10 Raw Data, Vertical Profiles

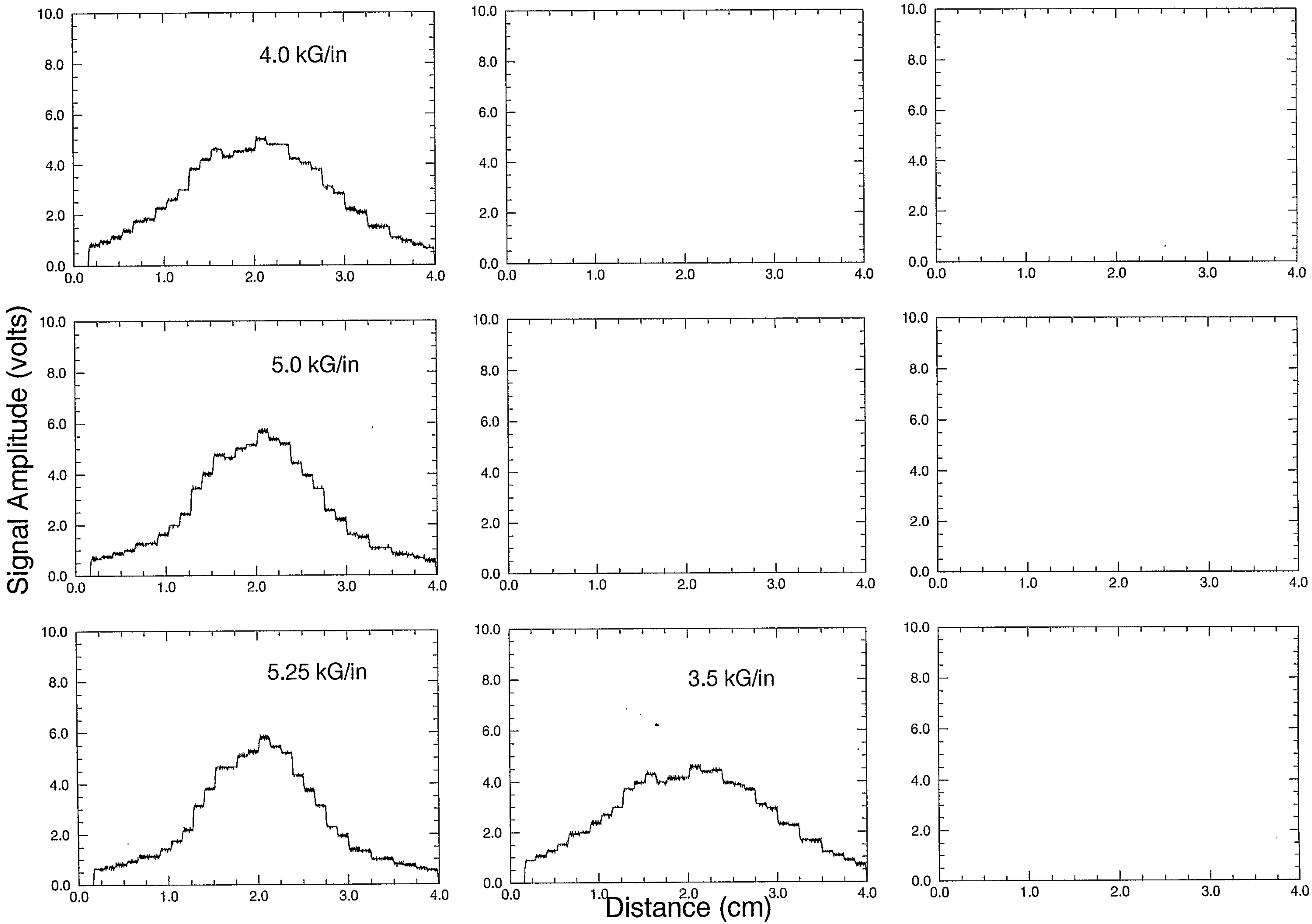


Figure 8: Beam Spots for A-only transport

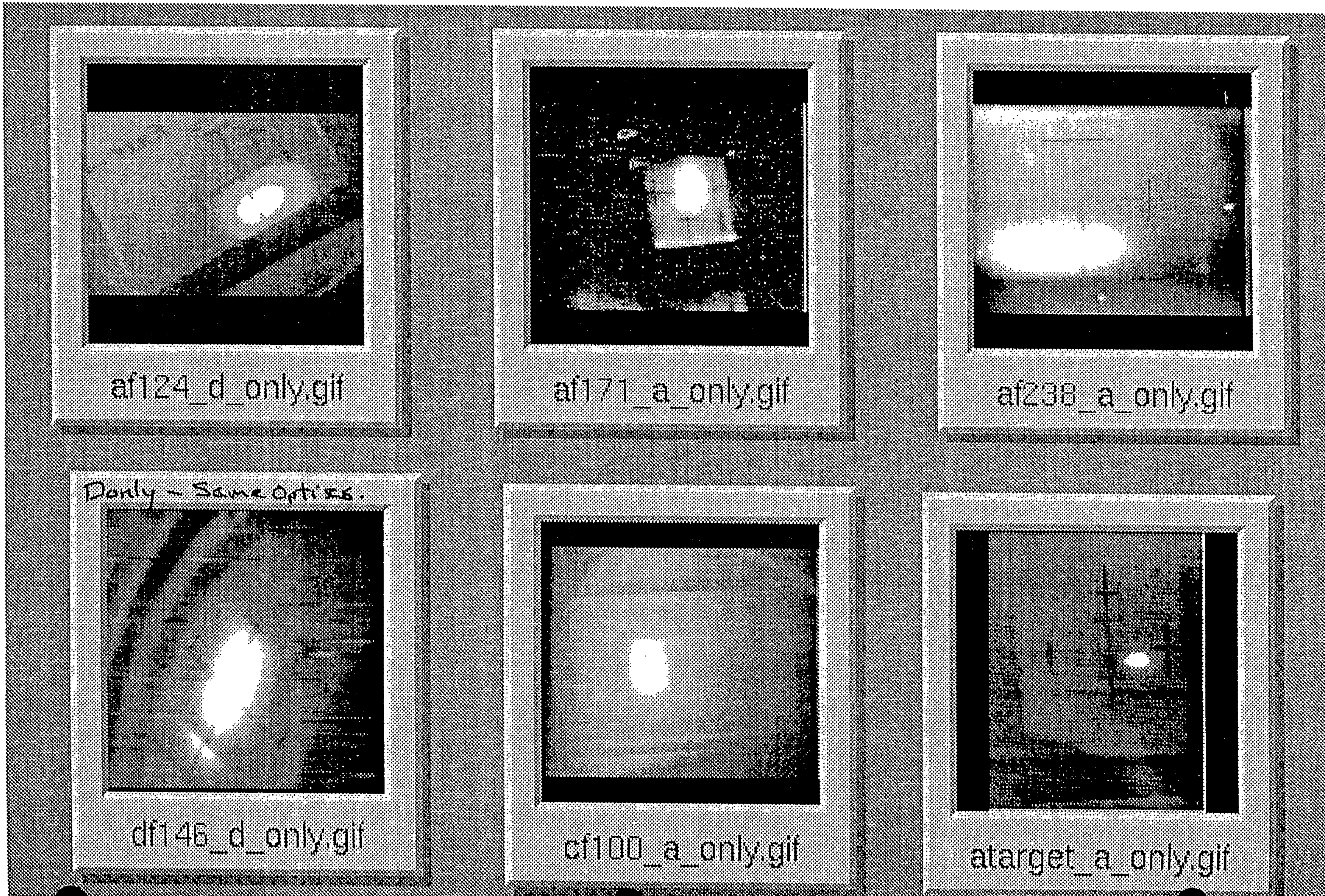


Figure 9: Mad Model of A Line

For 25.2 GeV/c protons 5/96 Measured Emitt.