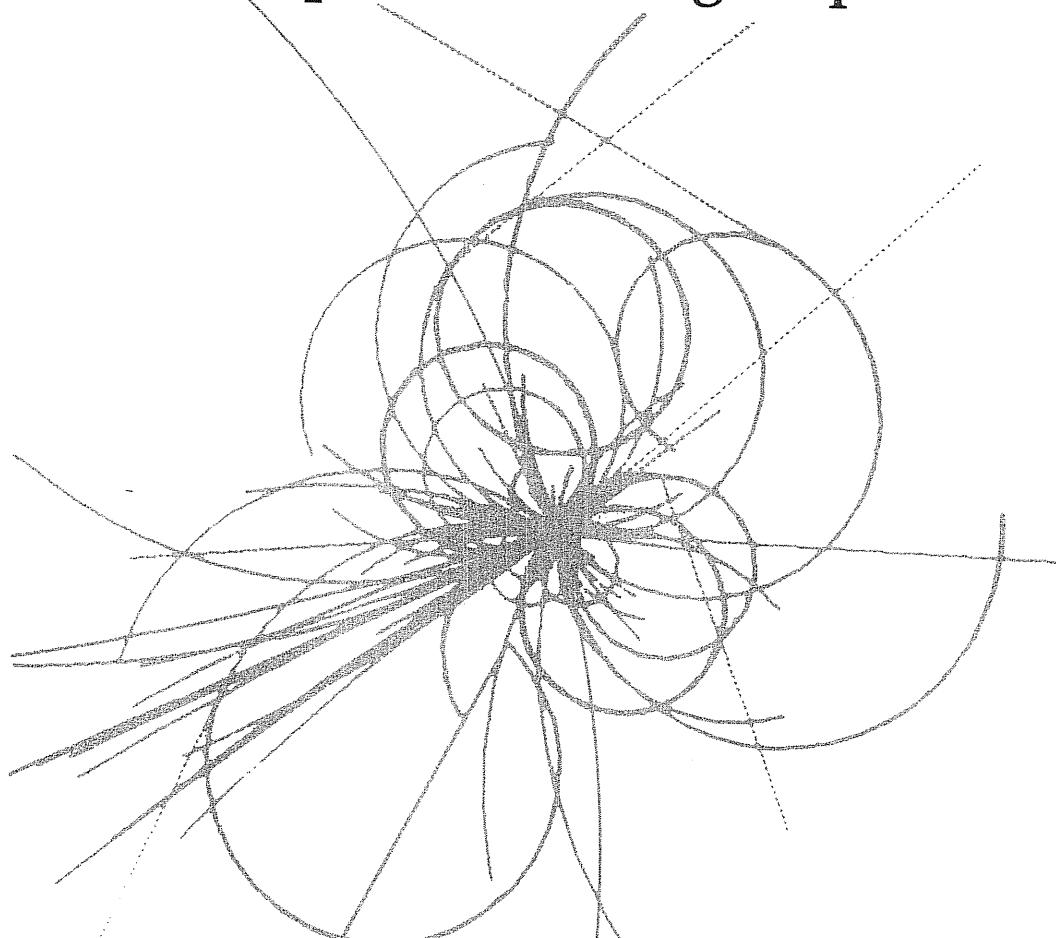


# The Superconducting Super Collider



A Possible New Design  
of the SSC Boosters

L.K. Chen and M.A. Furman

SSC Central Design Group

November 1988



SSC-164

## A POSSIBLE NEW DESIGN OF THE SSC BOOSTERS

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### ABSTRACT

A new design for the lattices of the SSC's three injectors is presented and compared with the CDR. The complex is matched so that the SSC filling factor is 94%, and is designed so that there is no transition crossing at any point. In general, the dispersion function is substantially reduced relative to the CDR design, and it is made to vanish in the straight sections. We also present tracking results which include the effect of the space-charge force, chromatic sextupoles, synchrotron oscillations, and the expected random and systematic dipole magnet errors. We conclude that the CDR magnet design allows adequate dynamic aperture for all three boosters, and that the space-charge force in the LEB has no significant detrimental effect provided the LEB is tuned properly.

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## 1. Introduction

There are three main requirements for the design of the injector system:

1. It is desirable that the dispersion function be small in order to minimize the spread of the closed orbits of particles with different momenta. In particular, it should vanish in the straight sections, where the RF cavities are located, and where injection and extraction are performed.
2. It is desirable that the transition energy not be crossed. There are three reasons for this requirement: to avoid potential degradation of beam quality by emittance dilution; to simplify operation; and to increase the thresholds of single bunch instabilities.
3. Particle tracking including the effects of the space-charge force, sextupole magnets, dipole magnet errors and synchrotron oscillations should be stable out to sufficiently large amplitudes, and the nonlinear effects should have as little as possible effect on emittance dilution. In other words, the dynamic aperture should be sufficiently large and the beam quality should be sufficiently good for the proper operation of the SSC.

We present here new lattice designs for the boosters meeting the above requirements. The primary parameters are listed and compared with the CDR<sup>[1]</sup> in Tables 2.1–3 (a bunch spacing of 4.76 m is assumed for all 3 injectors and the SSC). A description is given in Section 2, which includes values for some beam parameters and single-bunch instability thresholds. Section 3 presents tracking results including the effects of sextupoles, synchrotron oscillations, space-charge force, and magnet errors. Section 4 summarizes our conclusions. The Appendix contains a numerical listing of the lattice functions obtained from SYNCH.<sup>[2]</sup>

## 2. Lattice

### 2.1 OVERVIEW AND BASIC COMPARISON WITH THE CDR

The lattices for all three boosters are based on FODO cells with phase advance close to 90°. The design is such that there is no transition crossing at any point in the chain (as is also the case in the CDR design). The LEB operates below transition, while the MEB, HEB and the SSC operate above transition. The 3 boosters and the SSC are matched so that the harmonic number of each stage is an approximate multiple of the previous one, resulting in an overall filling factor of 94% for the SSC without the need for partial fills or beam chopping. This should be compared with the CDR design, which implies a filling factor of ∼ 85%.<sup>[3]</sup>

**Table 2.1. LEB Parameters**

	<u>CDR</u>	<u>New Lattice</u>
Injection momentum	1.22	1.22 GeV/c
Extraction momentum	8.0	8.45 GeV/c
Circumference	249.6	342.7 m
Harmonic number	52	72
Number of bunches	52	72
Protons per bunch	$1.0 \times 10^{10}$	$1.0 \times 10^{10}$
Circulating current at extraction	99	100 mA
Norm. transv. emittance ( <i>rms</i> )	0.75	0.75 mm-mrad
Longitudinal emittance ( <i>rms</i> )	1.8	1.8 meV-sec
Horizontal tune	4.39	11.84
Vertical tune	4.41	11.78
Transition gamma	10.5	10.3
Natural chromaticities (H , V)	-5.2 , -4.9	-15.3 , -15.6
Lattice type	FODO	FODO
Superperiodicity	5	2
Maximum beta (arcs)	21.5	11.9 m
Maximum dispersion	10.1	0.84 m
Number of dipoles	30	16 / 64
Dipole length	4.5	0.9 / 1.8 m
Dipole field (max)	1.24	1.37 T
Full good field aperture (H)	80	80 mm
Number of quadrupoles	40	94
Quadrupole length	0.3	0.6 m
Max. quadrupole strength ( $B'$ )	18.4	20.6 T/m
Full good field aperture	80	80 mm
Number of sextupoles	10	64
Number of sextupole families	2	2
Max. sextupole strength ( $lB''$ )	5.6	48.5 T/m
RF frequency at injection	49.5	49.9 MHz
RF frequency at extraction	62.0	63.0 MHz
RF voltage at injection	350	350 kV
Synchronous phase angle	30°	30°
Cycle time	0.1	0.1 sec

**Table 2.2 MEB Parameters**

	<u>CDR</u>	<u>New Lattice</u>
Injection momentum	8.0	8.45 GeV/c
Extraction momentum	100	100 GeV/c
Circumference	1900.8	1751.6 m
Harmonic number	396	368
Number of bunches	364	345
Protons per bunch	$1.0 \times 10^{10}$	$1.0 \times 10^{10}$
Circulating current	92	95 mA
Norm. transv. emittance ( <i>rms</i> )	0.83	0.83 mm-mrad
Longitudinal emittance ( <i>rms</i> )	1.8	1.8 meV-sec
Horizontal tune	8.41	9.81
Vertical tune	8.41	9.87
Transition gamma	7.2	8.37
Natural chromaticities (H , V)	-9.4 , -9.3	-12.5 , -12.7
Lattice type	FODO	FODO
Superperiodicity	6	2
Maximum beta (arcs)	67.2	78.1 m
Maximum beta (straights)	67.2	124.0 m
Maximum dispersion	14.2	6.2 m
Number of dipoles	216	128
Dipole length	5.4	9.625 m
Dipole field (max)	1.8	1.7 T
Full good field aperture (H)	80	80 mm
Number of quadrupoles	96	76
Quadrupole length	0.75	1.0 m
Max. quadrupole strength ( $B'$ )	22.8	22.0 T/m
Full good field aperture	80	80 mm
Number of sextupoles	72	56
Number of sextupole families	2	2
Max. sextupole strength ( $lB''$ )	4.4	10.3 T/m
RF frequency	62.5	62.6 MHz
RF voltage	600	600 kV
Synchronous phase angle	30°	30°
Cycle time	4	4 sec

**Table 2.3. HEB Parameters**

	<u>CDR</u>	<u>New Lattice</u>
Injection momentum	100	100 GeV/c
Extraction momentum	1000	1000 GeV/c
Circumference	6000	5335.8 m
Harmonic number	1250	1121
Number of bunches	1092	1035
Protons per bunch	$1.0 \times 10^{10}$	$1.0 \times 10^{10}$
Circulating current	87	95 mA
Norm. tr. emittance ( <i>rms</i> )	0.91	0.91 mm-mrad
Longitudinal emittance ( <i>rms</i> )	35	35 meV-sec
Horizontal tune	25.415	29.23
Vertical tune	21.415	22.29
Transition gamma	18.7	24.2
Natural chromaticities (H , V)	-66.5 , -39.6	-43.0 , -32.3
Lattice type	FODO	FODO
Superperiodicity	6	6
Maximum beta (arcs)	117	76.6 m
Maximum beta (straights)	500	267 m
Maximum dispersion	4.2	4.1 m
Number of dipoles	528	384
Dipole length	7.0	9.65 m
Dipole field (max)	5.66	5.66 T
Full good field aperture (Hor)	26	26 mm
Number of standard quads	150	198
Standard quad length	1.0	1.5 m
Standard quad strength (max)	144.0	133.4 T/m
Full good field aperture	26	26 mm
Number of special quads	36	24
Special quad length	2.0 / 3.0	1.5 / 2.25 m
Special quad strength (max)	144.0	130.1 T/m
Full good field aperture	40	40 mm
Number of sextupoles	138	180
Number of sextupole families	2	2
Sextupole strength (max)	138.0	233.4 T/m
RF frequency	62.5	63.0 MHz
RF voltage	1500	1500 kV
Synchronous phase angle	30°	30°
Cycle time	60	60 sec

The LEB is the injector that has undergone the largest relative change, with an increase in circumference from 250 m to 343 m and a reduction in superperiod from 5 to 2. The total straight section length has remained approximately unchanged ( $5 \times 12$  m in the CDR *vs.*  $2 \times 31$  m now) but of course it is distributed differently. The basic goal in the redesign was to reduce the dispersion in the arcs and to make it as close to zero as possible in the straight sections, while keeping the transition gamma  $\gamma_t$  sufficiently high. In the CDR a high- $\gamma_t$  design was achieved by the device of forcing the dispersion function to be large and positive in some regions and large and negative in others, in such a way that it averages to a small positive value. This has the disadvantage of large closed-orbit spread. In addition, the dispersion in the CDR is quite large in the straight sections. In the solution we present here we achieve small dispersion by having short cells with large phase advance (close to  $90^\circ$ ). In spite of the short cell length, we were forced to a large circumference in order to obtain a sufficiently high  $\gamma_t$ . The reduction of the dispersion in the straight sections was achieved with dispersion suppressors, which were not used in the CDR design. As a result of all this the circumference is larger and the lattice functions are smoother and smaller. In particular, the maximum value of the dispersion in the arcs has been reduced from about 10 m to 0.84 m. Because of the increased circumference, however, the space-charge tune shift at injection energy has changed from  $-0.16$  in the CDR design to  $-0.22$ . This change is potentially detrimental; however, as we discuss in Section 3, the tracking simulations show that this is probably not a serious problem provided the LEB is properly tuned. However, should further studies indicate the desirability of increasing the injection energy in order to ensure a smaller space-charge tune shift, the present lattice could accommodate a larger injection girder. Indeed, a possible upgrade to an 1133 MeV kinetic energy ( $p = 1.847$  GeV/c) linac has been recently discussed.<sup>[13]</sup> This would reduce the space-charge tune shift by approximately a factor of 2. A girder design for the present 600 MeV kinetic energy ( $p = 1.219$  GeV/c) linac<sup>[14]</sup> can be modified so that it would still fit in the longest (6.23 m) drift space in the present LEB lattice design.<sup>[15]</sup>

The MEB posed the greatest challenge for the design because of the desire to accept particles with relatively large momentum offset (say,  $\Delta p \lesssim 3\sigma_p$ ) while maintaining a small spread in their closed orbits. This requires small dispersion, which, in turn, implies a large  $\gamma_t$ . In addition, in order to avoid single-bunch instabilities, it is desirable to have the phase-slip factor not too small, which implies that  $\gamma_t$  cannot be close to  $\gamma$  at injection or extraction. Since  $\gamma_t^2 = R/\bar{\eta}$ , these requirements force the radius  $R$  to be small. The lattice we present is one possible solution with superperiod 2 and a circumference of 1750 m (compared with 6 and 1900 m, respectively, in the CDR). The essential modification was the

addition of dispersion suppressors, which result in a reduction in the maximum dispersion from 14 m to 6 m. The transition gamma is now  $\gamma_t = 8.37$ ; since this is very close to the value of  $\gamma$  at injection, this requires the injection momentum to be increased slightly from the CDR value of 8 GeV/c to 8.45 GeV/c in order to avoid transition crossing and single-bunch instabilities. The total straight section length is now much shorter ( $2 \times 74$  m *vs.*  $6 \times 81$  m in the CDR), although it is still adequate. Since there are now only 2 diametrically opposite straight sections instead of 6 evenly distributed, the position and orientation of the MEB relative to the HEB and the corresponding transfer lines described in the CDR will have to be modified.

The CDR lattice for the HEB is acceptable from the point of view of the dispersion; however, having redesigned the LEB, MEB and SSC,<sup>[5]</sup> the HEB lattice is no longer well matched, so we present a matched solution here. The matching requirements demand a circumference smaller than in the CDR. In order to achieve this while maintaining 6 relatively long straight sections, the dispersion suppressors had to be eliminated. The dispersion remains small in the arcs and zero in the straight sections thanks to an overall fit, but the 90° cell structure causes the  $\eta$  function to have the odd shape seen in Fig. 2.3. The circumference is decreased from 6000 m in the CDR to 5336 m, the superperiod remains 6, and the straight section length is slightly increased from  $6 \times 104$  m to  $6 \times 128$  m.

Figs. 2.1–3 show the lattice functions for half a superperiod obtained with SYNCH;<sup>[2]</sup> these correspond to the numerical listings presented in the Appendix. Figs. 2.4–6 are the layouts for the three boosters.

## 2.2 CIRCUMFERENCE MATCHING

It is desirable to fill each ring with an integral number of cycles from the lower-energy ring that feeds it, since this eliminates the need for a beam chopper and a beam dump in each transfer system. The new circumferences of the three boosters and SSC are approximate multiples of each other, so that this feeding can now be done efficiently. An example of the loading scenario is shown in Fig. 2.7. The kicker and abort gaps are labeled K and A, respectively. We assume a bunch spacing of 4.76 m throughout the system; this is a good candidate for bunch spacing<sup>[4]</sup> for the new 90° lattice design<sup>[5]</sup> of the SSC. It implies a specific choice of RF frequencies and harmonic numbers which are the ones listed in Tables 2.1–3. It takes 5 LEB beam trains to fill the MEB, 3 MEB trains to fill the HEB, and 16 HEB trains to fill the SSC, after allowances for injection, extraction and abort kickers are made. The resulting SSC filling factor is 94%,

which should be compared with the 85% implied by a comparable analysis with the CDR lattices.<sup>[3]</sup>

### 2.3 OTHER PARAMETERS AT INJECTION ENERGY

The maximum tolerable impedances for single-bunch instabilities<sup>[6]</sup> are given in Table 2.4. These thresholds are believed to be easily achievable. Table 2.5 below shows some beam parameters at injection energy for the three boosters assuming the parameters in Tables 2.1–3 as input.<sup>[9]</sup>

The parameters related to the longitudinal phase space have not yet been studied systematically. For example, it has been suggested that the accelerating voltage in the LEB be increased to 500 kV during ramping in order to have a large enough bucket area.<sup>[14]</sup>

Impedance	LEB	MEB	HEB
$Im(Z_{\perp})_{m-c} [\text{M}\Omega/\text{m}]$	11 (e)	6 (i)	123 (i)
long. equivalent $[\Omega]$	158 (e)	17 (i)	35 (i)
$ Z_{\perp} _{\mu\text{wave}} [\text{M}\Omega/\text{m}]$	54 (e)	36 (i)	3179 (i)
long. equivalent $[\Omega]$	786 (e)	105 (i)	906 (i)
$Im(Z_{\parallel}/n)_{m-c} [\Omega]$	196 (e)	78 (e)	233 (e)
$ Z_{\parallel}/n _{\mu\text{wave}} [\Omega]$	35 (e)	14 (e)	41 (e)

**Table 2.4: Instability thresholds** for the transverse and longitudinal mode-coupling ( $m-c$ ) and microwave ( $\mu\text{wave}$ ) instabilities. The “longitudinal equivalent” is obtained from the transverse impedance in the preceding line by the cylindrical-pipe formula  $Z_{\parallel}/n = (\pi b^2/C)Z_{\perp}$ , where  $b$ =pipe radius and  $C$ =ring circumference. The letters (i) and (e) refer to whether this value is at injection or extraction energy (we present the smaller one of the two).

	LEB	MEB	HEB
$\beta$	0.793	0.994	1.0
$\gamma$	1.641	9.064	106.6
$f_0$ [kHz]	693.5	170.1	56.18
$T$ [ $\mu$ sec]	1.44	5.88	17.8
$\sigma_z$ [cm]	47.5	11.2	26.3
$S_B$ [m]	4.76	4.76	4.76
$B_f$	0.25	0.059	0.14
$(\sigma_p/p) \times 10^4$	9.32	5.69	3.98
$\eta_{\text{slip}}$	$3.62 \times 10^{-1}$	$2.10 \times 10^{-3}$	$1.62 \times 10^{-4}$
$\nu_s^{-1}$	25.8	337	480
$\bar{\sigma}_x$ [mm]	2.2	3.2	1.0
$\bar{\sigma}_y$ [mm]	2.1	2.0	0.63
$\Delta\nu_x$	-0.21	-0.053	-0.0005
$\Delta\nu_y$	-0.22	-0.086	-0.0007

**Table 2.5: Other parameters at injection energy.**  $\beta$  is the usual relativistic factor;  $f_0$  and  $T$  are the revolution frequency and revolution period;  $\sigma_z$  is the *rms* bunch length;  $S_B$  is the bunch spacing, which remains constant during acceleration;  $B_f$  is the corresponding bunching factor;  $\sigma_p/p$  is the *rms* fractional momentum spread;  $\eta_{\text{slip}} = |\gamma_t^{-2} - \gamma^{-2}|$  is the “phase-slip factor;”  $\nu_s^{-1}$  is the inverse of the synchrotron tune, which is the number of turns for one synchrotron period; the  $\bar{\sigma}$ ’s are the ring-averaged *rms* transverse beam sizes; and the  $\Delta\nu$ ’s are the space-charge tune shifts calculated in the smooth- $\beta$  approximation for a Gaussian bunch.

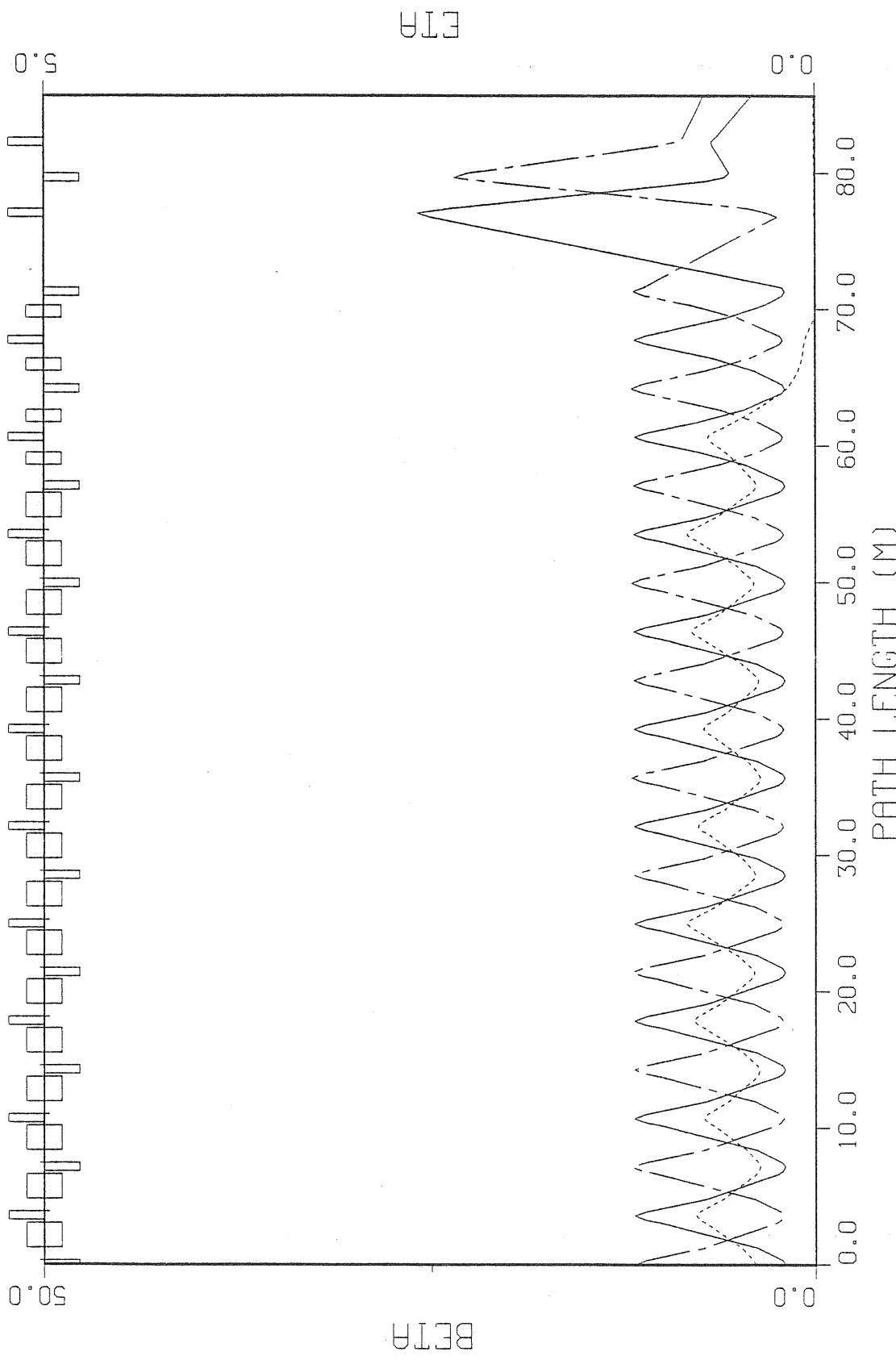


Fig. 2.1 : Lattice functions for one-half of a superperiod for the LEB.

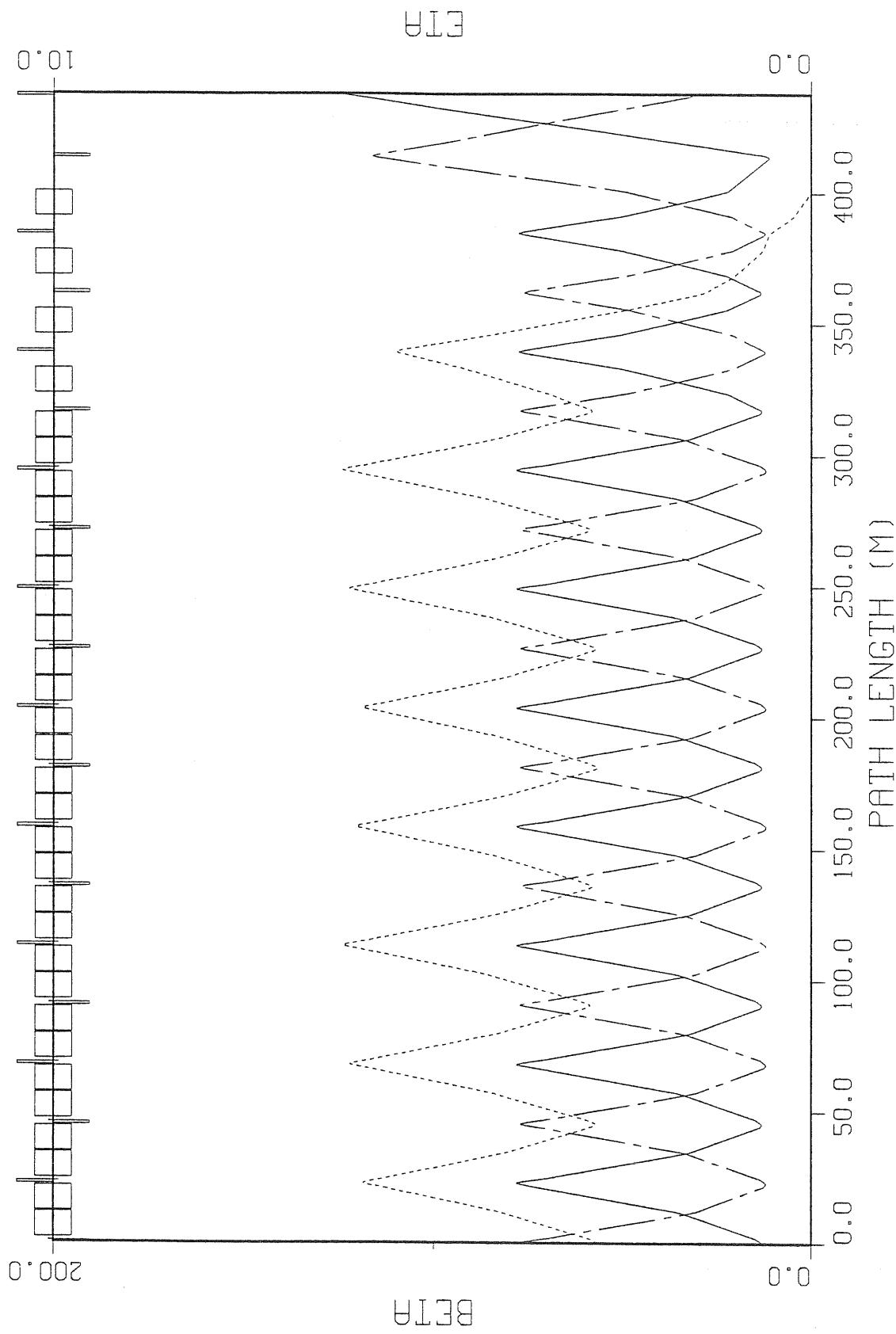


Fig. 2.2 : Lattice functions for one-half of a superperiod for the MEB.

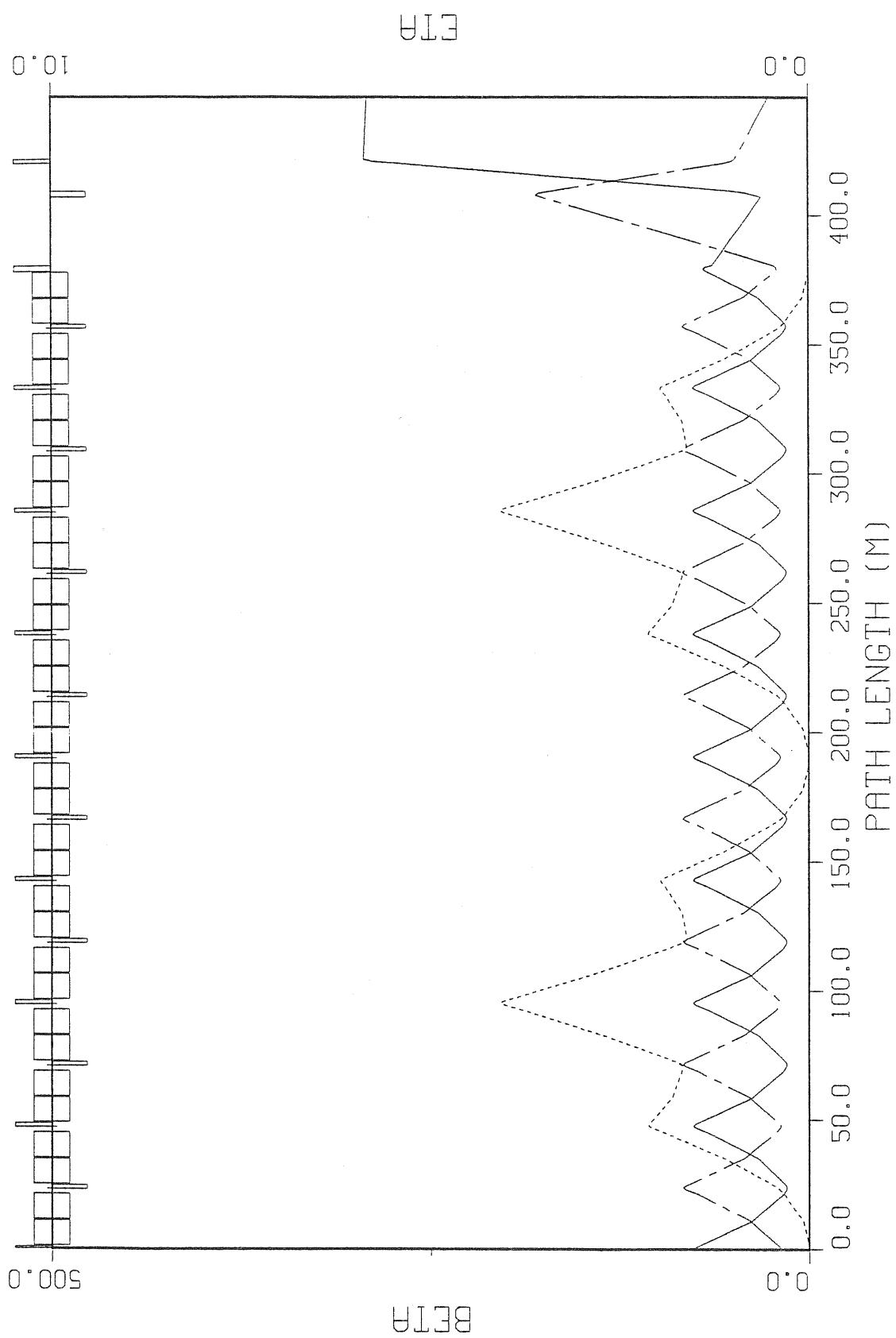


Fig. 2.3 : Lattice functions for one-half of a superperiod for the HEB.

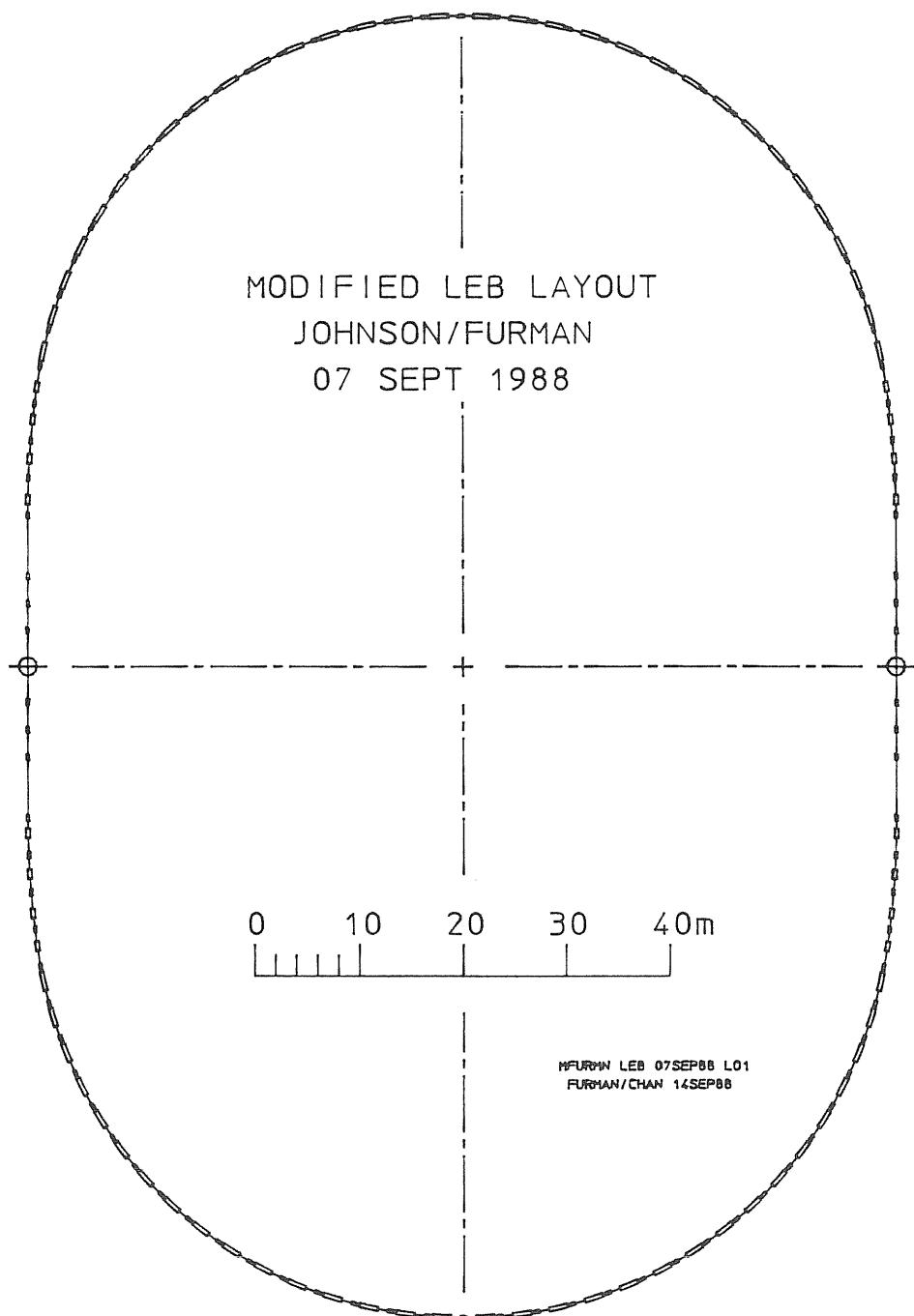


Fig. 2.4: Layout of the LEB.

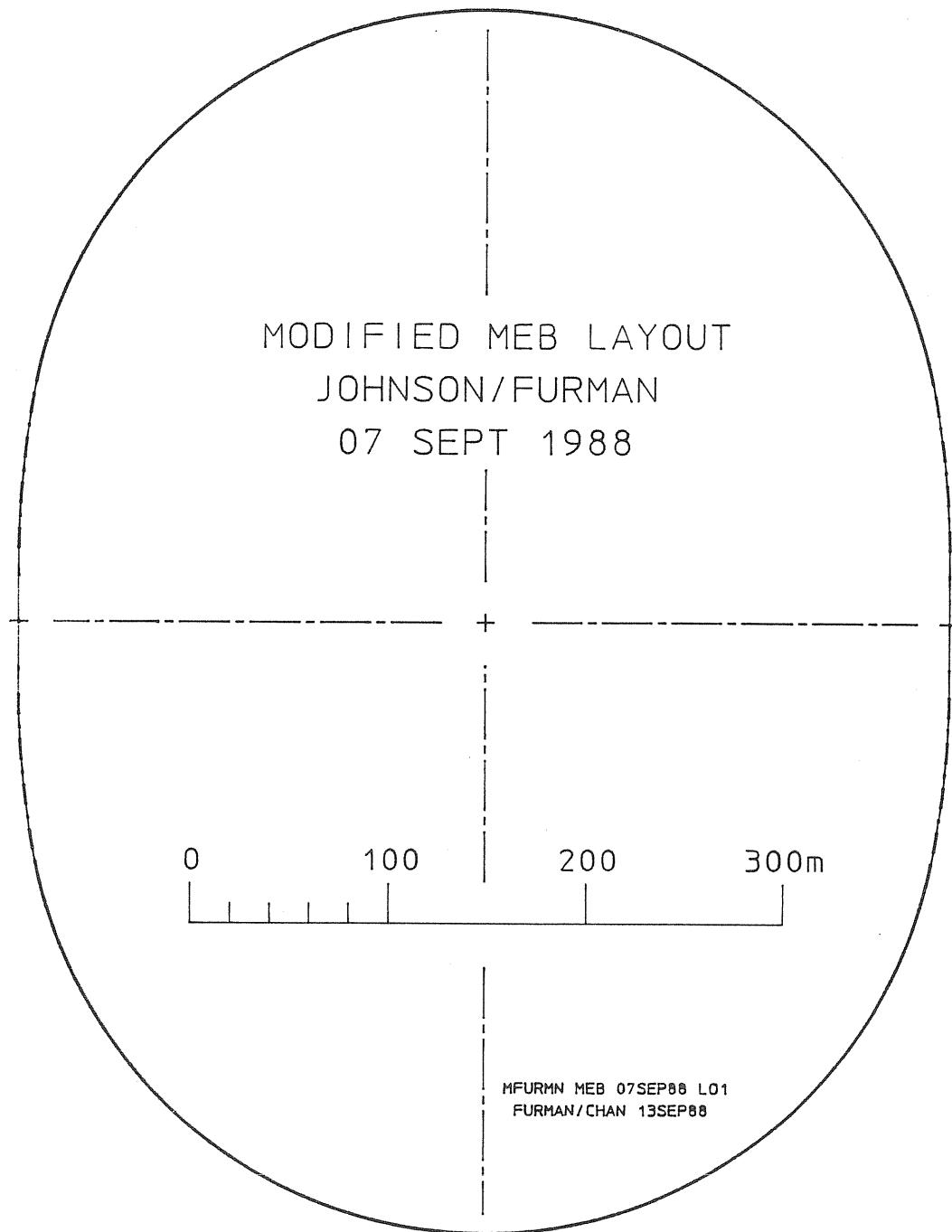


Fig. 2.5: Layout of the MEB.

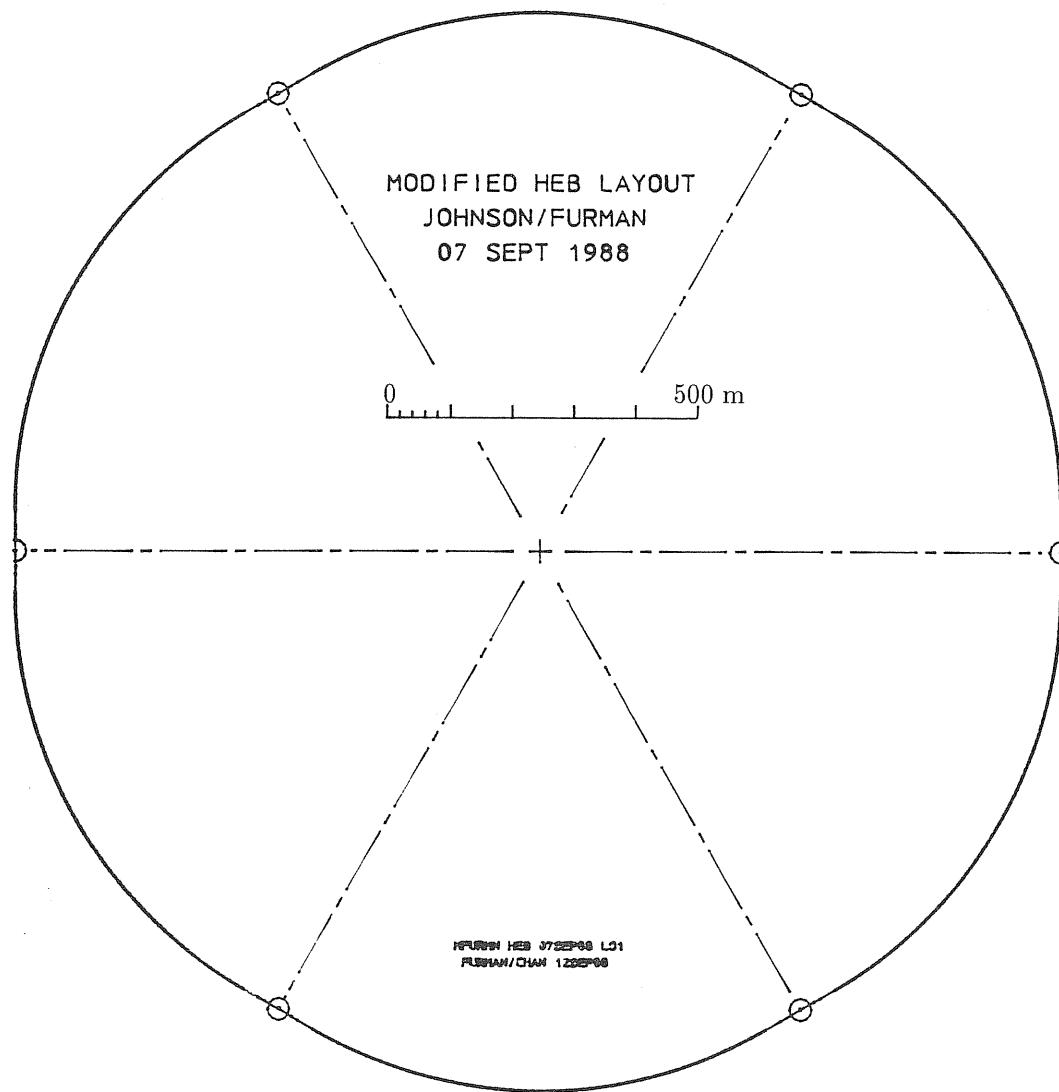


Fig. 2.6 : Layout of the HEB.

### 3. Tracking at Injection Energy

#### 3.1 PROCEDURE

We present tracking results only at injection energy since the space-charge effects are largest at low energy (we neglect the space-charge force altogether for the HEB). These results come from first order, single-particle simulations obtained with the kick code TEAPOT<sup>[10]</sup> suitably augmented to incorporate the space-charge force.<sup>[11]</sup> By “first order” we mean that the effect of the space-charge force is *not* fed back into the bunch shape, which is assumed to remain Gaussian at all times with its three *rms* sizes determined solely by the lattice functions at each point along the lattice. Thus this is not a self-consistent (dynamical) calculation, and its validity is justified only *a posteriori* by the relative smallness of the effect.

The space-charge force is represented in TEAPOT by kicks regularly distributed along the ring. The bunch is assumed to be three-dimensional Gaussian, to travel so that its center moves synchronously along the design trajectory, and to have a length much larger than its width. An ideal simulation would have an infinitely large number of infinitely weak kicks. In practice we adopt the compromise criterion that the space-charge kick should have a typical strength  $\lesssim \frac{1}{20}$  of the typical quadrupole kick. For the specific lattice and beam parameters considered here this implies  $\gtrsim 2$  space-charge kicks per half-cell for the LEB at injection energy (much fewer kicks are required at higher energies, but we maintain 2 kicks per half-cell for the LEB and MEB, which we choose to locate at the center of every quadrupole magnet).

For the purposes of tracking we first adjust the tunes of the lattice to their nominal values (those in Tables 2.1–3) and the chromaticities to zero (if magnet errors are present we adjust the chromaticities to zero after the inclusion of the errors in the data file). The observation point for the tracking simulation is at the very end of the straight sections at the right of the half-superperiods shown in Figs. 2.1–3, where the dispersion is very small and  $\alpha_x = \alpha_y = 0$ . We assume that there are two RF cavities per superperiod, located in the straight sections, so that their total voltage around the ring adds up to the voltage specified in Tables 2.1–3. Table 3.1 below shows the lattice functions and *rms* beam sizes at the tracking point, and the momentum spread. Tables 3.2–3 summarize the assumed random and systematic errors for the dipole magnets. These errors should be considered as reasonable guesses; of course the tracking should be redone when a more complete and reliable list of values becomes available. We do not consider cases in which both random and systematic errors are simultaneously present. Tables 3.4–6 summarize the tracking conditions for all cases.

We measure the particle's six coordinates turn by turn and obtain the Fourier spectra with a version of the program TEVEX.<sup>[12]</sup> The three tunes are obtained by measuring the phase advance and dividing by the number of turns. In order to identify the significant peaks we find the combinations  $m\nu_x + n\nu_y + l\nu_z$  with  $m, n, l = \text{integers}$  such that  $|m| + |n| + |l|$  does not exceed a maximum, and mark with a vertical line those combinations for which the Fourier amplitude has relatively large strength, typically  $\geq 5\%$  of maximum (if the above combination of tunes lies outside the interval  $(0, 1)$ , an appropriate integer is added or subtracted to bring it to this interval; if, then, it exceeds 0.5, it is reflected about 0.5).

	LEB	MEB	HEB
$\beta_x$ [m]	4.13	123	264
$\beta_y$ [m]	7.26	31.4	25.5
$\eta_x$ [mm]	10.6	-2.31	-0.249
$\sigma_x$ [mm]	1.541	3.371	1.503
$\sigma_y$ [mm]	2.045	1.700	0.467
$(\sigma_p/p) \times 10^4$	9.32	5.69	3.98

**Table 3.1: Lattice functions and RMS beam sizes at the tracking point as computed by TEAPOT and used in the tracking simulations (the  $\alpha$ -functions vanish by symmetry). The momentum spread is the same as in Table 2.4.**

Multipoles	LEB & MEB	HEB
$a_2$	0.06	0.41
$b_2$	0.13	1.4
$a_3$	0.026	0.4
$b_3$	0.025	0.2
$a_4$	0.0042	0.07
$b_4$	0.0087	0.29

**Table 3.2:** *RMS values of the random errors* for the dipoles assumed for tracking simulations. The  $a_n$  and  $b_n$  are in units of  $10^{-4}\text{cm}^{-n}$ , and are taken to be 0 for  $n = 1$  and  $n > 4$ . The values for the LEB and MEB, which have conventional magnets, come from Fermilab measurements (D. Johnson note dated 5/23/1988). The values for the HEB, which has superconducting magnets, are quoted from the CDR, p. 252.

Multipoles	LEB	MEB	HEB
$a_2$	0.03	0.018	0.11
$b_2$	0.065	0.039	0.45
$a_3$	0.013	0.0078	-0.07
$b_3$	0.013	0.0075	-0.14
$a_4$	0.0021	0.0013	-0.05
$b_4$	0.0044	0.0026	-0.33

**Table 3.3:** *Systematic errors* for the dipoles assumed for tracking simulations. The  $a_n$  and  $b_n$  are in units of  $10^{-4}\text{cm}^{-n}$ , and are taken to be 0 for  $n = 1$  and  $n > 4$ . The errors for the conventional magnets of the LEB and MEB are assumed to be 0.5 and 0.3, respectively, times the random errors on Table 3.2. The errors for the superconducting magnets of the HEB are based on measured data for the Tevatron appropriately scaled to account for the difference in bore diameter (note from J. Peterson dated 3/20/86, quoting R. Hanft, Snowmass 1984, p. 342).

Fig.	R. Err.	S. Err.	$x_0$	$y_0$	$\Delta p/p$	Turns
2.8	×	×	1.54	2.04	2.79	512
2.9	×	×	15.4	20.4	2.79	512
2.10	✓	×	15.4	20.4	2.79	4096
2.11	×	✓	15.4	20.4	2.79	4096
2.12	×	×	3.85	5.11	0.00	512
2.13	×	×	3.85	5.11	2.79	512

**Table 3.4: Tracking simulation conditions for the LEB.** ✓ means that the effect is included, × means it is not. R. Err. and S. Err. refer to the presence of random or systematic errors in the dipole magnets. The initial tracking point amplitudes  $x_0$  and  $y_0$  are given in mm and the initial momentum offset  $\Delta p/p$  is in units of  $10^{-3}$ .

Fig.	R. Err.	S. Err.	$x_0$	$y_0$	$\Delta p/p$	Turns
2.14	×	×	40.4	20.4	1.71	512
2.15	✓	×	33.7	17.0	1.71	4096
2.16	×	✓	33.7	17.0	1.71	4096

**Table 3.5: Tracking simulation conditions for the MEB.** Same units and definitions as in Table 3.4.

Fig.	R. Err.	S. Err.	$x_0$	$y_0$	$\Delta p/p$	Turns
2.17	×	×	15.0	4.67	1.19	512
2.18	✓	×	15.0	4.67	1.19	4096
2.19	×	✓	15.0	4.67	1.19	4096

**Table 3.5: Tracking simulation conditions for the HEB.** Same units and definitions as in Table 3.4.

Figs. 2.8–2.19 show the results of tracking. The launching amplitudes  $x_0$ ,  $y_0$  shown in each figure are in units of meters, and  $\Delta p/p$  is the relative momentum offset at launching. In all the figures showing the longitudinal phase space the abscissa is  $1000 \times \Delta T/T$  and the ordinate is  $1000 \times (\eta_{\text{slip}}/2\pi\nu_s) \times \Delta p/p$ , where  $T$  is the revolution period of the synchronous particle,  $\Delta T$  is the arrival time of the particle relative to the synchronous particle,  $\eta_{\text{slip}}$  is the frequency slip factor, and  $\nu_s$  is the synchrotron tune. The normalization factor  $\eta_{\text{slip}}/2\pi\nu_s$  is required by the theory in order that the small-amplitude phase space be circular.

In general the phase space is quite linear and there is little smear due to nonlinearities. The phase space plots for the cases with magnet errors correspond approximately to the particle with largest amplitude that survived along the “diagonal,” *i.e.*, with  $x_0/\sigma_x = y_0/\sigma_y$ . For the LEB, where the space-charge-effect is largest, there is a resonance that causes some phase space distortion, as seen in Fig. 2.12. This is discussed in more detail below.

### 3.2 TUNE *vs.* AMPLITUDE: SPACE-CHARGE FORCE

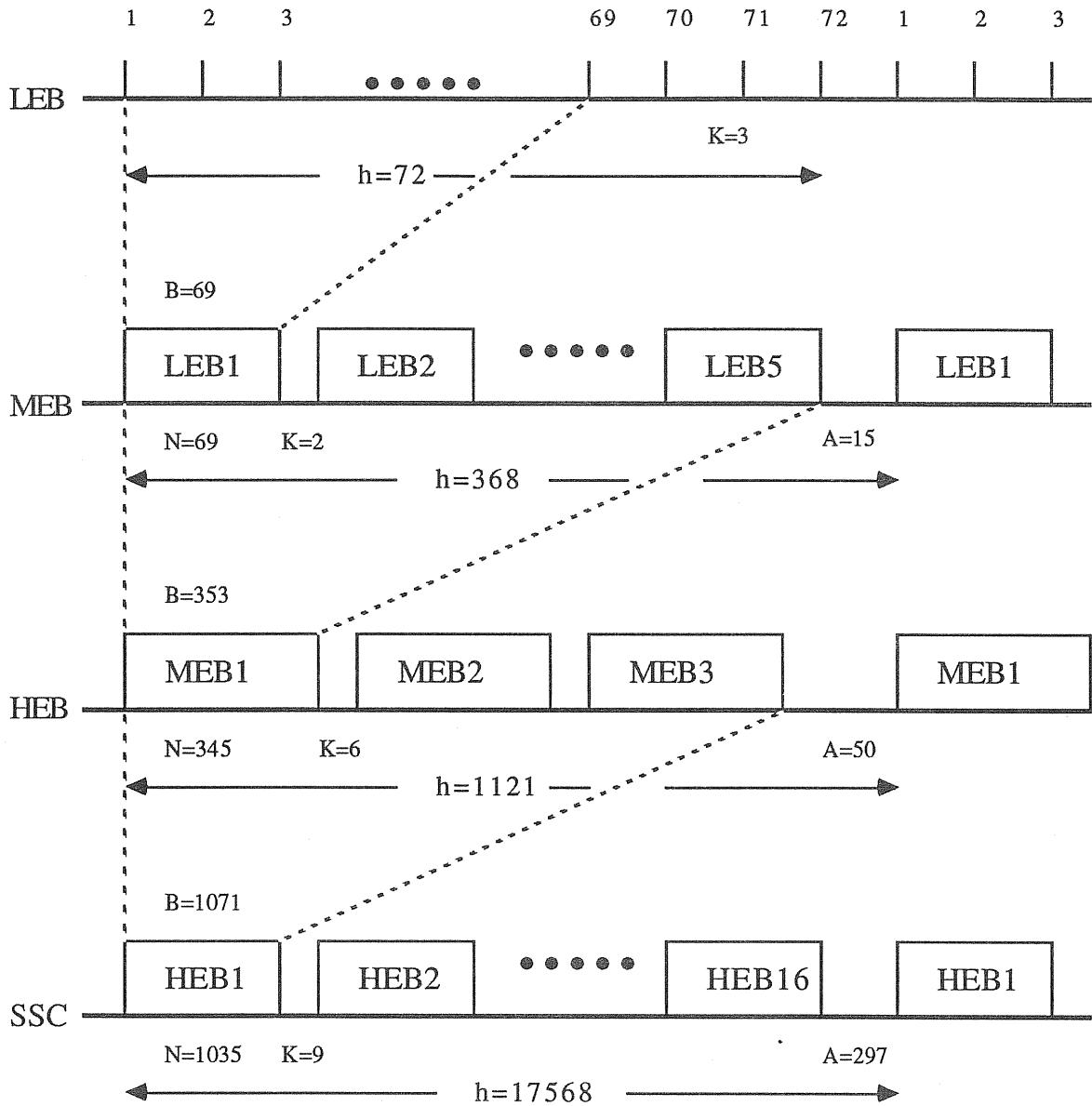
Fig. 2.20 shows the operating point we have chosen for the LEB and the tune distribution of the particles at injection energy. The tune diagram was obtained by tracking 144 on-momentum particles for 256 turns each at various injection amplitudes  $x_0$ ,  $y_0$ . The solid lines have constant  $x_0$  or constant  $y_0$ , and their values are  $x_0 = p\sigma_x$ ,  $y_0 = q\sigma_y$  with  $p, q = 0.1, \dots, 10.0$  (see the figure caption for the exact values). The dashed line along the center of the diagram was obtained from particles on the diagonal. We made the particular choice of tunes so that the resonance  $2\nu_x + 2\nu_y = 3$  is at a fairly large amplitude ( $\sim 2.5\sigma$ ) in order to minimize its effect. This resonance has the potential of diluting the emittance as can be seen in Fig. 2.12, in which the phase-space is clearly distorted. The resonance seems ineffective when synchrotron motion is included, as can be seen in Fig. 2.13, although its effects may reappear in other forms which we have not explored. Incidentally, Fig. 2.13 also exhibits the transverse-longitudinal coupling due to the space-charge force. We believe that this resonance does not degrade the beam quality significantly, although we have not done a quantitative calculation of the emittance dilution, and we have not assessed its effect during acceleration. It is quite possible that there are other good choices for the operating point; we have not carried out a systematic search. It should be kept in mind, however, that the particles tracked are at the center of the bunch in the longitudinal direction, for which the effect of the space-charge force is largest, and so is the tune shift.

Figs. 2.21 and 2.22 show the measured fractional tunes as a function of amplitude for the LEB and MEB, respectively, showing the tune shift due to the space-charge force. In all cases we tracked on-momentum particles with  $x_0/\sigma_x = y_0/\sigma_y$ . The slight dip at  $\sim 2.5\sigma$  for the LEB is caused by the resonance mentioned above. If we neglect the space-charge force, we obtain almost flat tune *vs.* amplitude curves, which are also shown in the figures. In this case, the slight downcurving at large amplitude is due to the effect of the chromatic sextupoles.

For the LEB we read off the space-charge tune shifts  $\Delta\nu_x = -0.21$  and  $\Delta\nu_y = -0.22$ , and for the MEB we obtain  $\Delta\nu_x = -0.060$  and  $\Delta\nu_y = -0.092$ . These values are in good agreement with the “smooth- $\beta$ ” estimates from the linear theory shown in Table 2.5.

### 3.3 DYNAMIC APERTURE

In order to determine the aperture we assume that the vacuum pipe is round and has a radius of 5 cm for the LEB and MEB, and 2 cm for the HEB (the CDR has oval-shape pipes for the LEB, but we assume it round for simplicity in the tracking simulations). By scaling the radius down by the factors  $\sqrt{\beta_{x,y,\text{inj}}/\beta_{\max}}$  we obtain an ellipse which is the “physical aperture.” This ellipse would be the approximate aperture at the tracking point in the absence of all nonlinear effects and  $x - y$  coupling. This is shown in Figs. 2.23–25 along with the  $1-\sigma$  beam profiles. By tracking large amplitude particles for 512 turns (with a spot-check of 4,096 turns) with  $\Delta p/p = 3\sigma_p/p$  and with the errors specified on Tables 3.2–3 we obtain the approximate boundary for stability, *i.e.*, the dynamic aperture. For the cases where random errors gave a different survival aperture than systematic errors, we display the smaller of the two apertures. For the LEB the dynamic aperture is essentially equal to the physical aperture. This implies that the nonlinear effects are not significant, and allows for the possibility of redesigning the magnets with smaller bore. For the MEB and HEB the magnet errors are important, resulting in a dynamic aperture smaller by  $\lesssim 20\%$  than the physical aperture; the corresponding “good-field” regions are approximately equal to (indeed, slightly larger than) those specified in the CDR. Of course the dynamic aperture should be reexamined when a more complete and reliable list of errors becomes available.



**Fig. 2.7: Sample loading scenario.** The first 69 bunches from the LEB are injected into the MEB, leaving behind 3 bunches corresponding to the kicker gap. The MEB is filled with 5 such trains, with kicker gaps 2 bunches long, and an abort gap 15 bunches long, etc. In each train  $B$  is the number of buckets and  $N$  the number of bunches (filled buckets). The harmonic numbers are indicated by  $h$ . The resulting SSC filling factor is thus  $16 \times 3 \times 5 \times 69 / 17568 = 0.94$ .

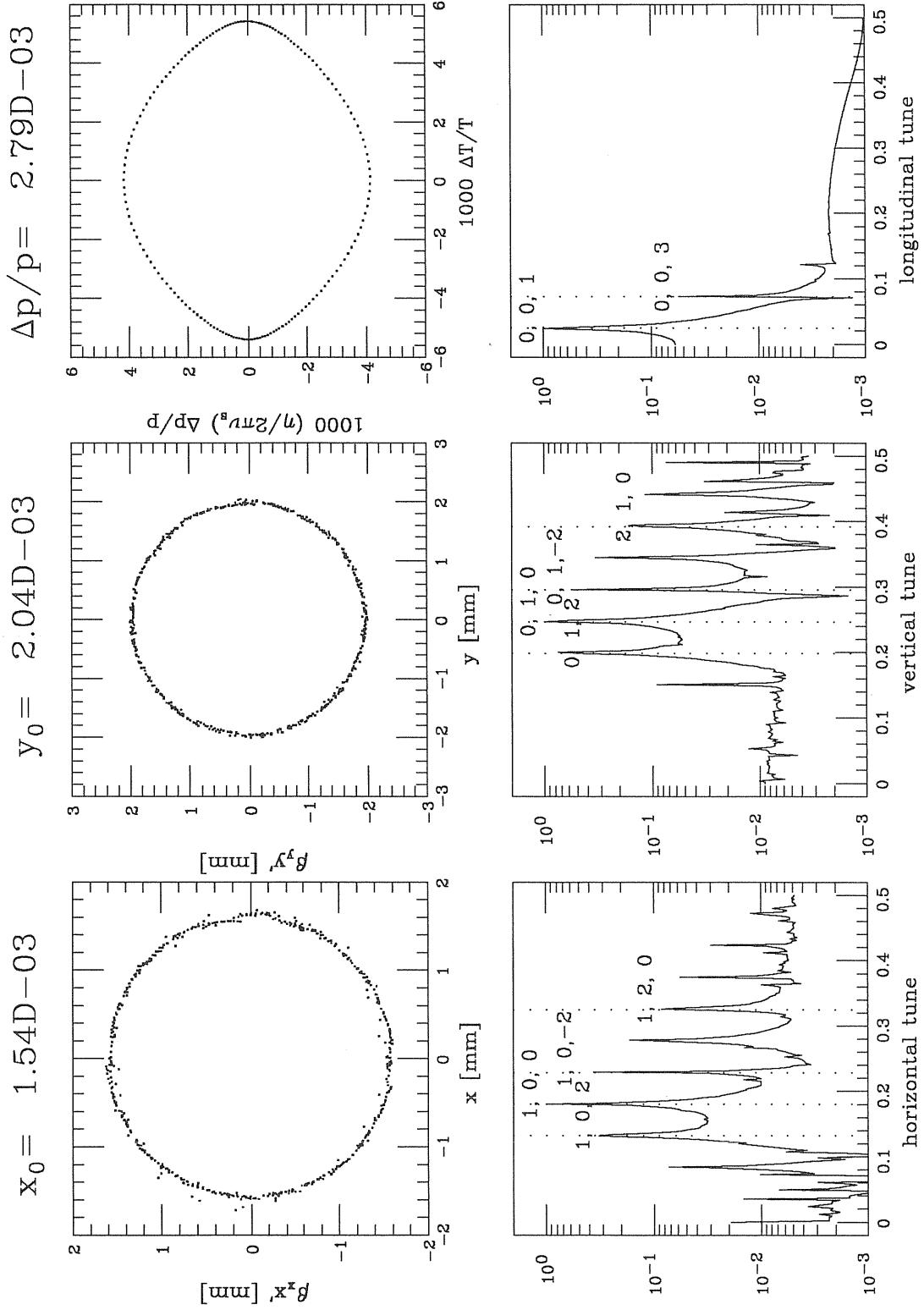


Fig. 2.8 : LEB, no magnet errors,  $1-\sigma$  particle.

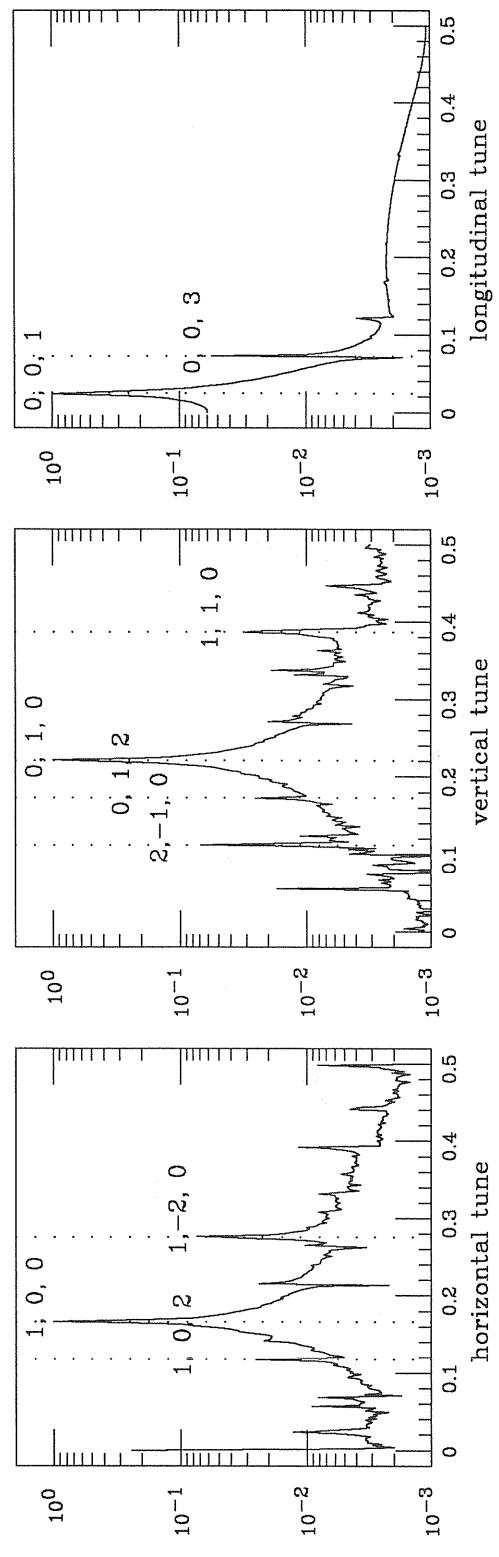
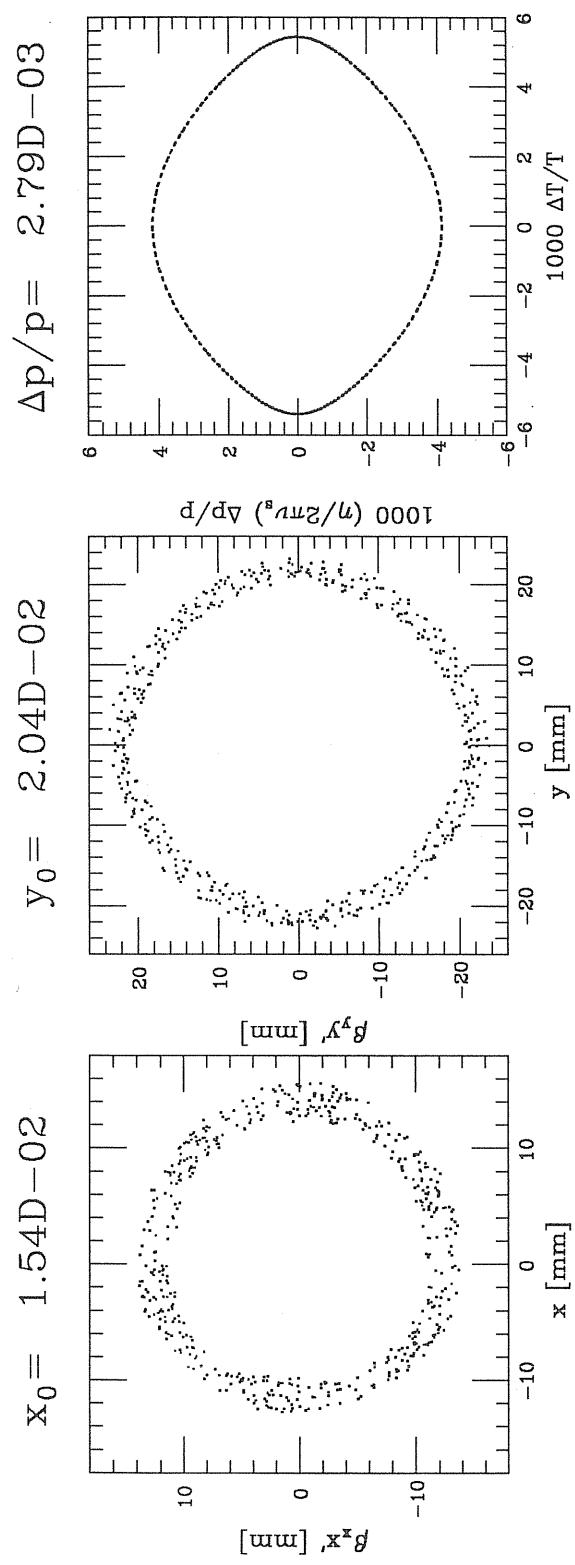


Fig. 2.9 : LEB, no magnet errors,  $10\sigma$  particle.

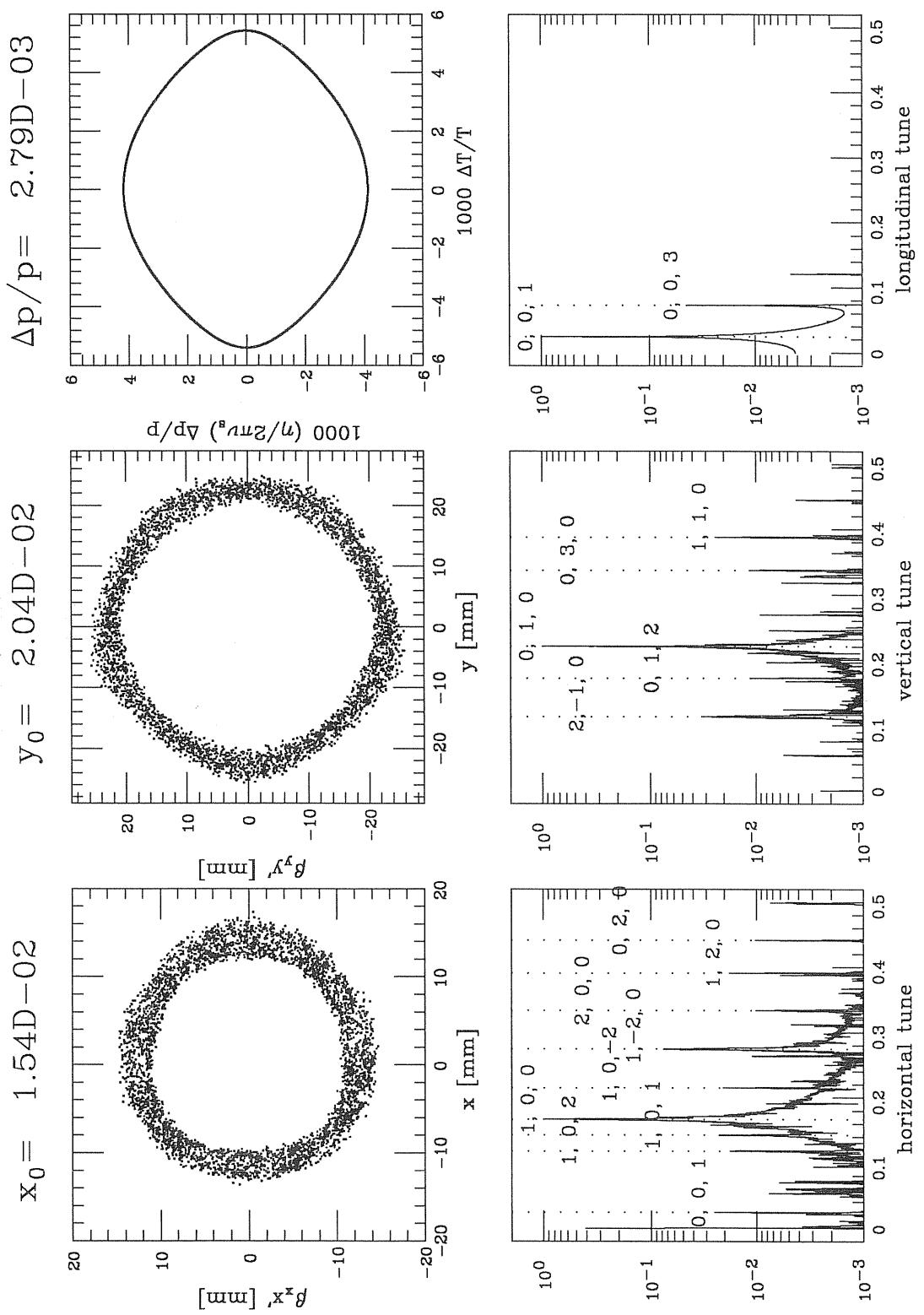


Fig. 2.10 : LEB, random errors, 10- $\sigma$  particle.

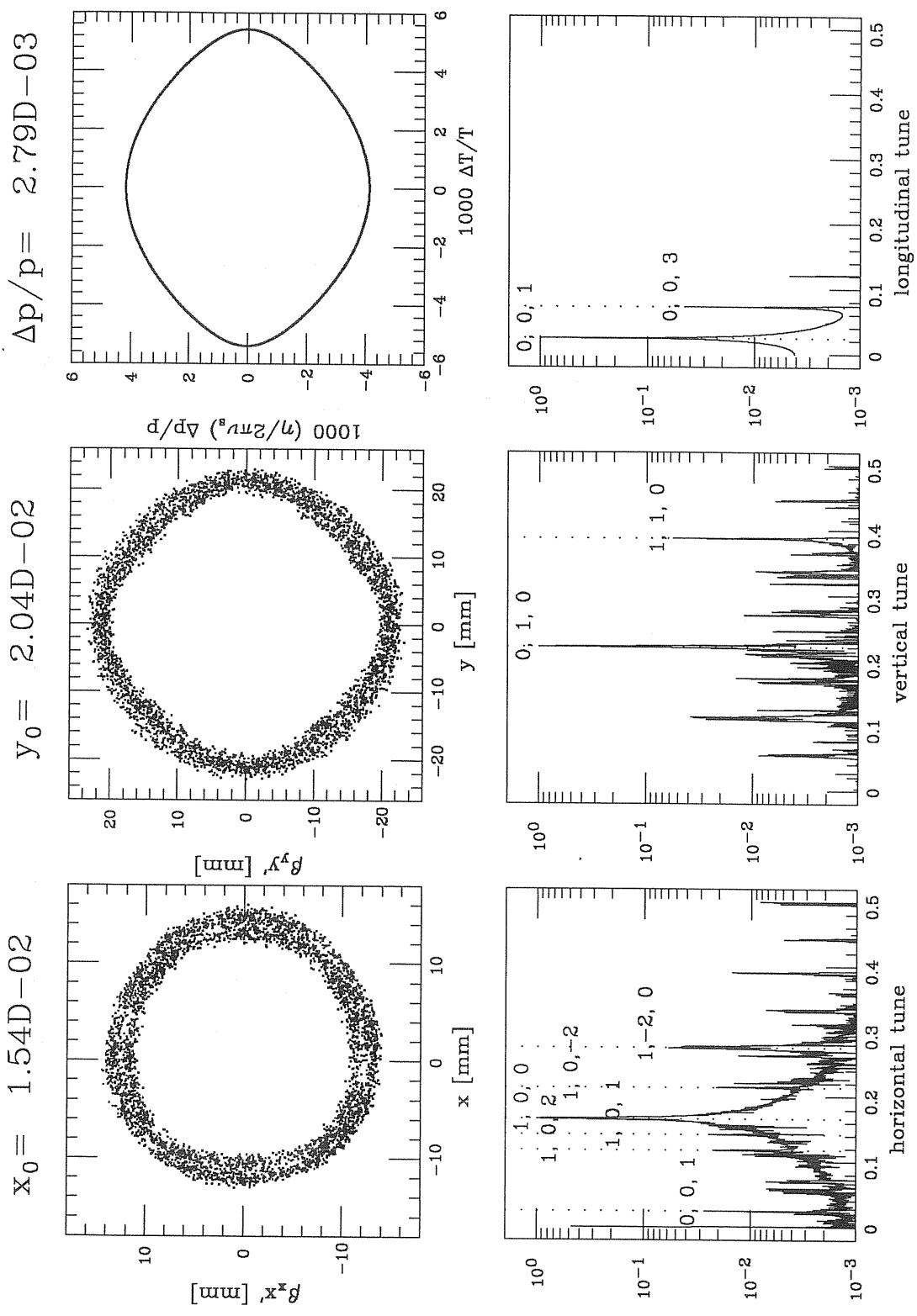


Fig. 2.11 : LEB, systematic errors, 10- $\sigma$  particle.

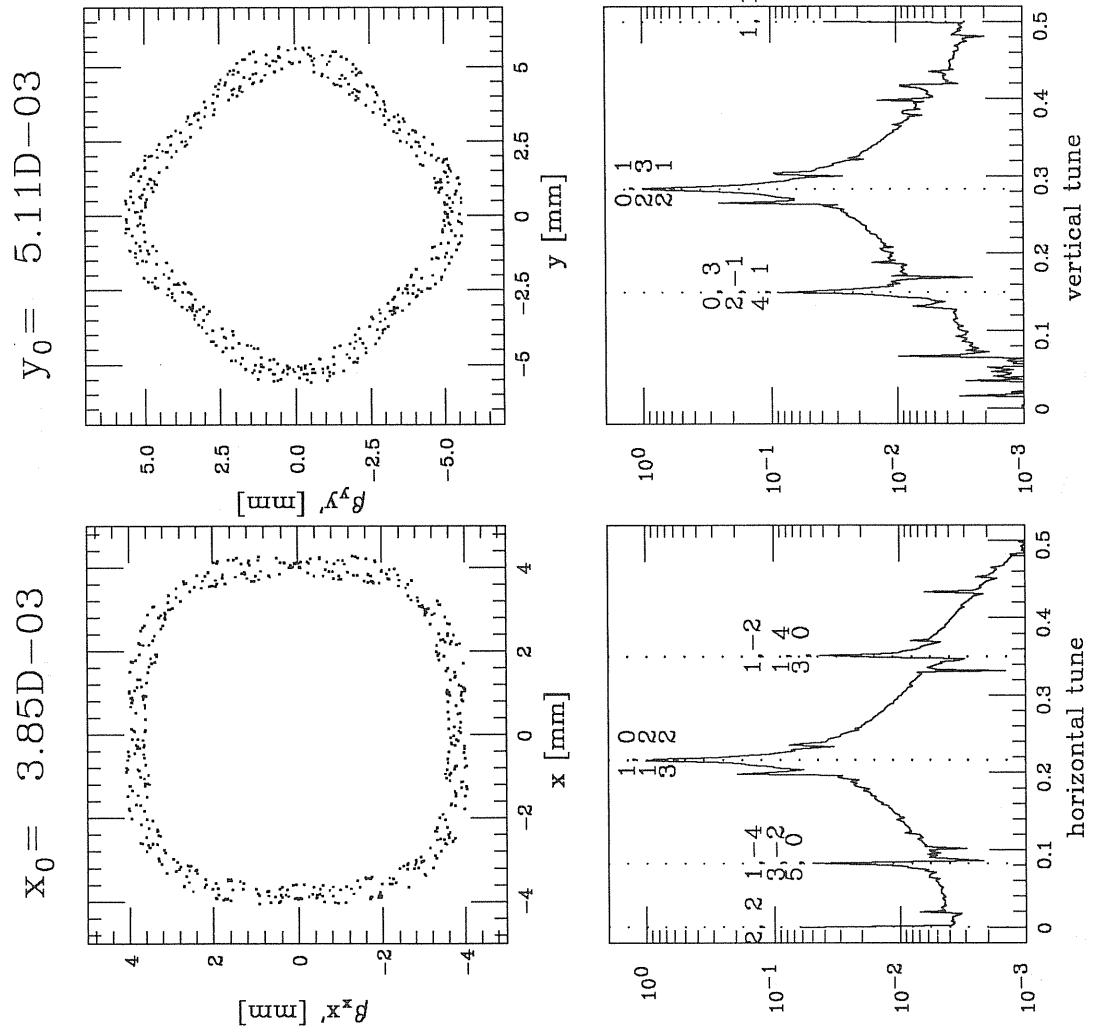


Fig. 2.12 : LEB, no errors, on-momentum 2.5- $\sigma$  particle.

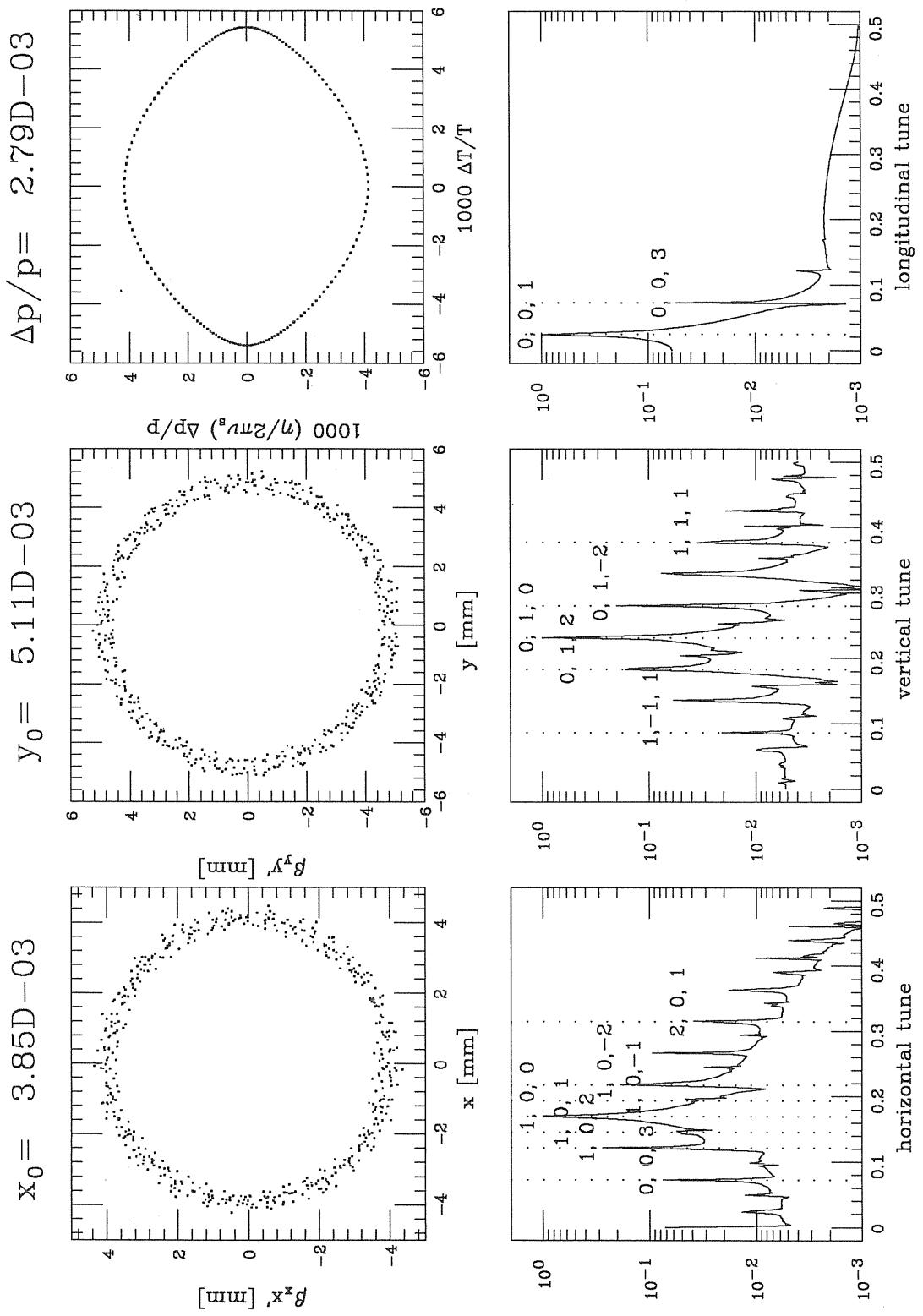


Fig. 2.13 : LEB, no errors, off-momentum 2.5- $\sigma$  particle.

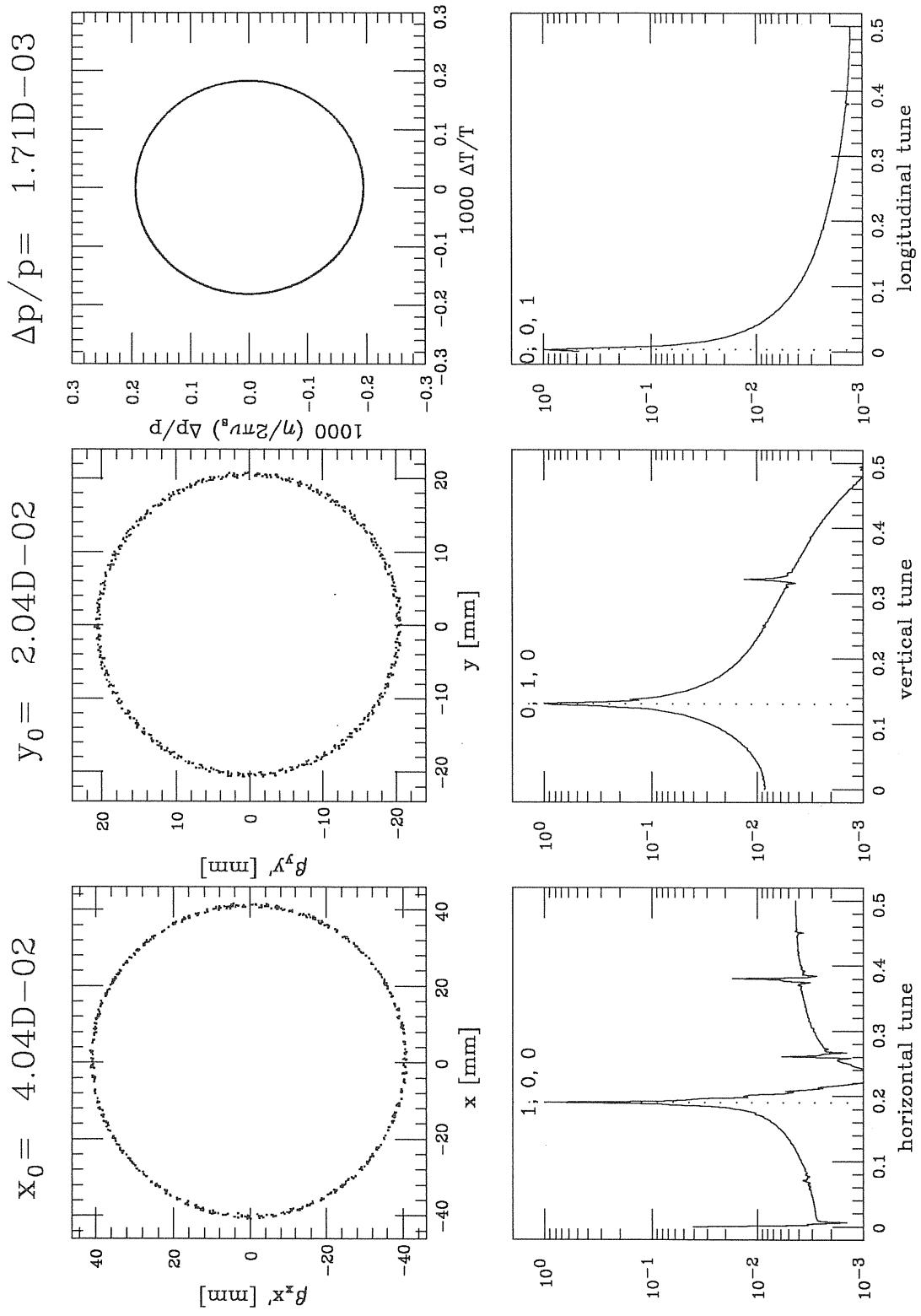


Fig. 2.14 : MEB, no errors, 12- $\sigma$  particle.

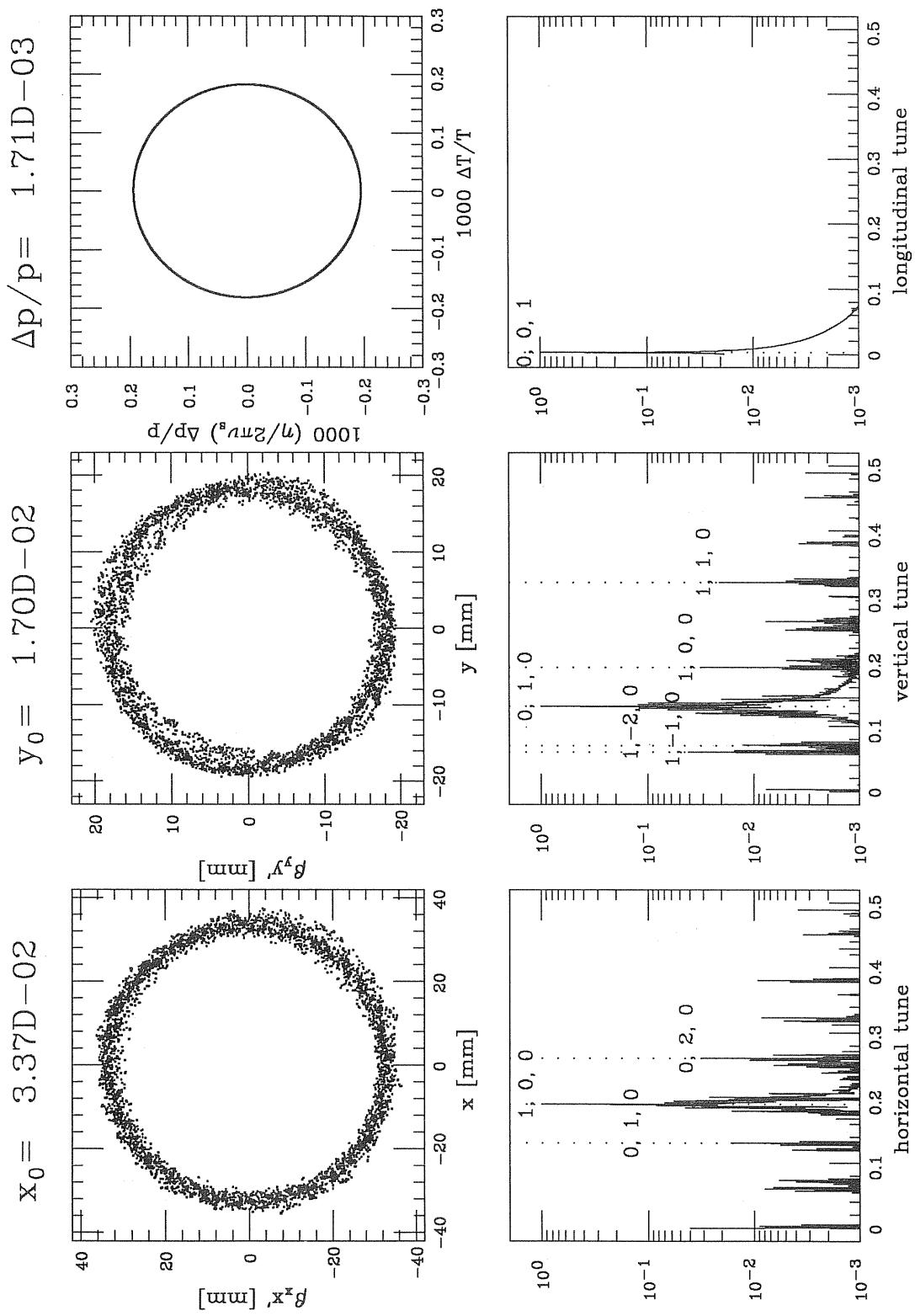


Fig. 2.15 : MEB, random errors,  $10-\sigma$  particle.

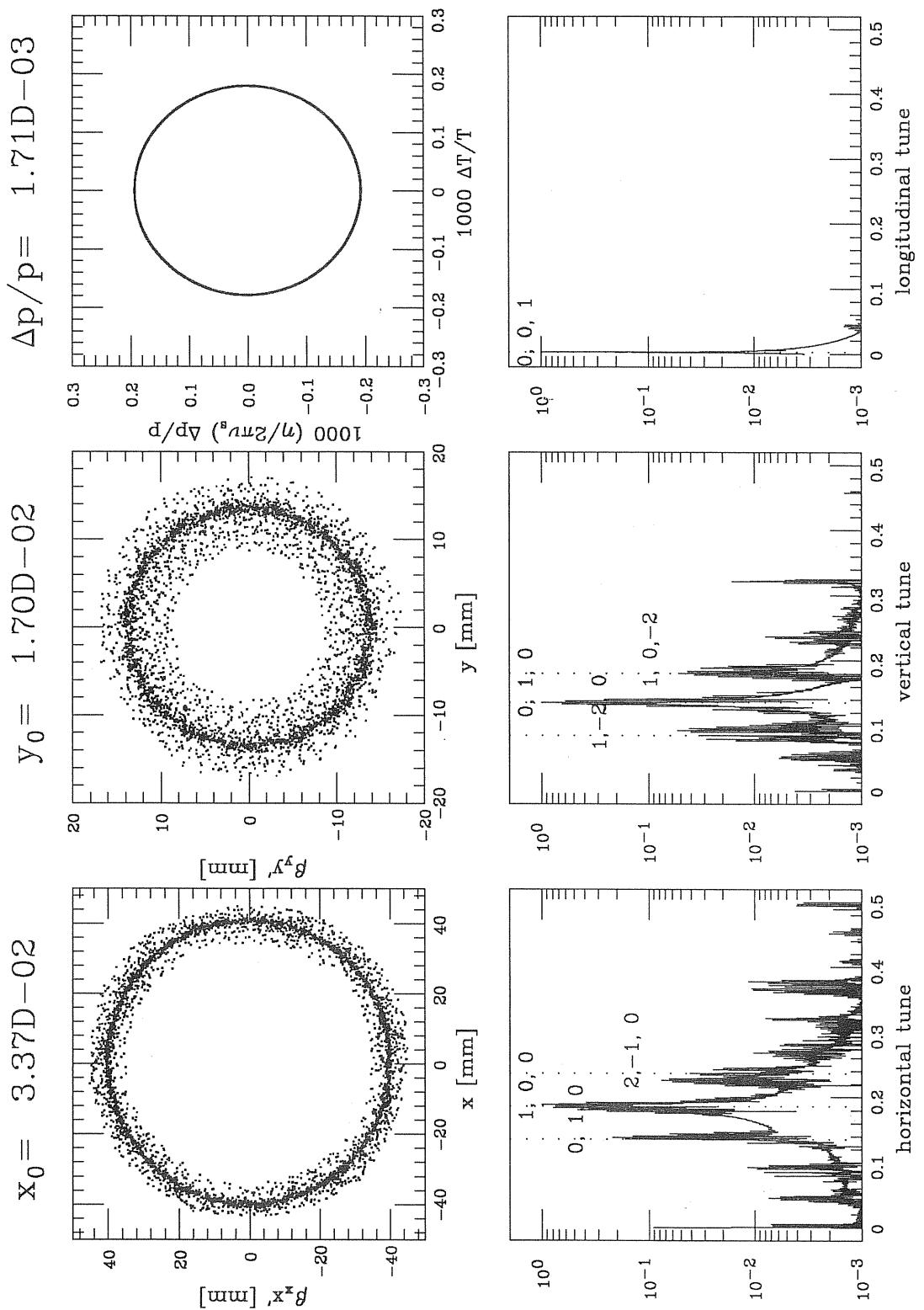


Fig. 2.16 : MEB, systematic errors, 10- $\sigma$  particle.

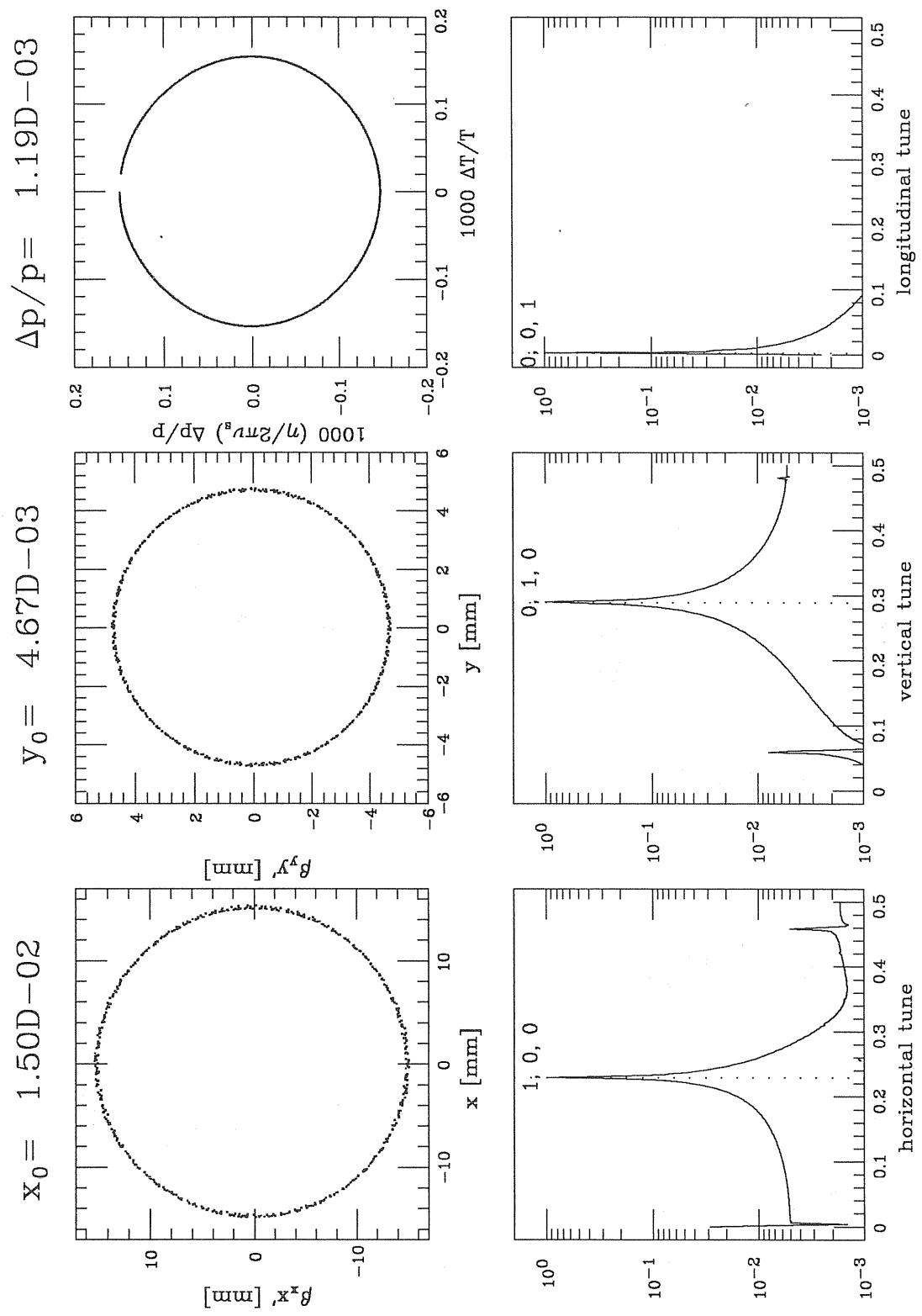


Fig. 2.17 : HEB, no errors, 10- $\sigma$  particle.

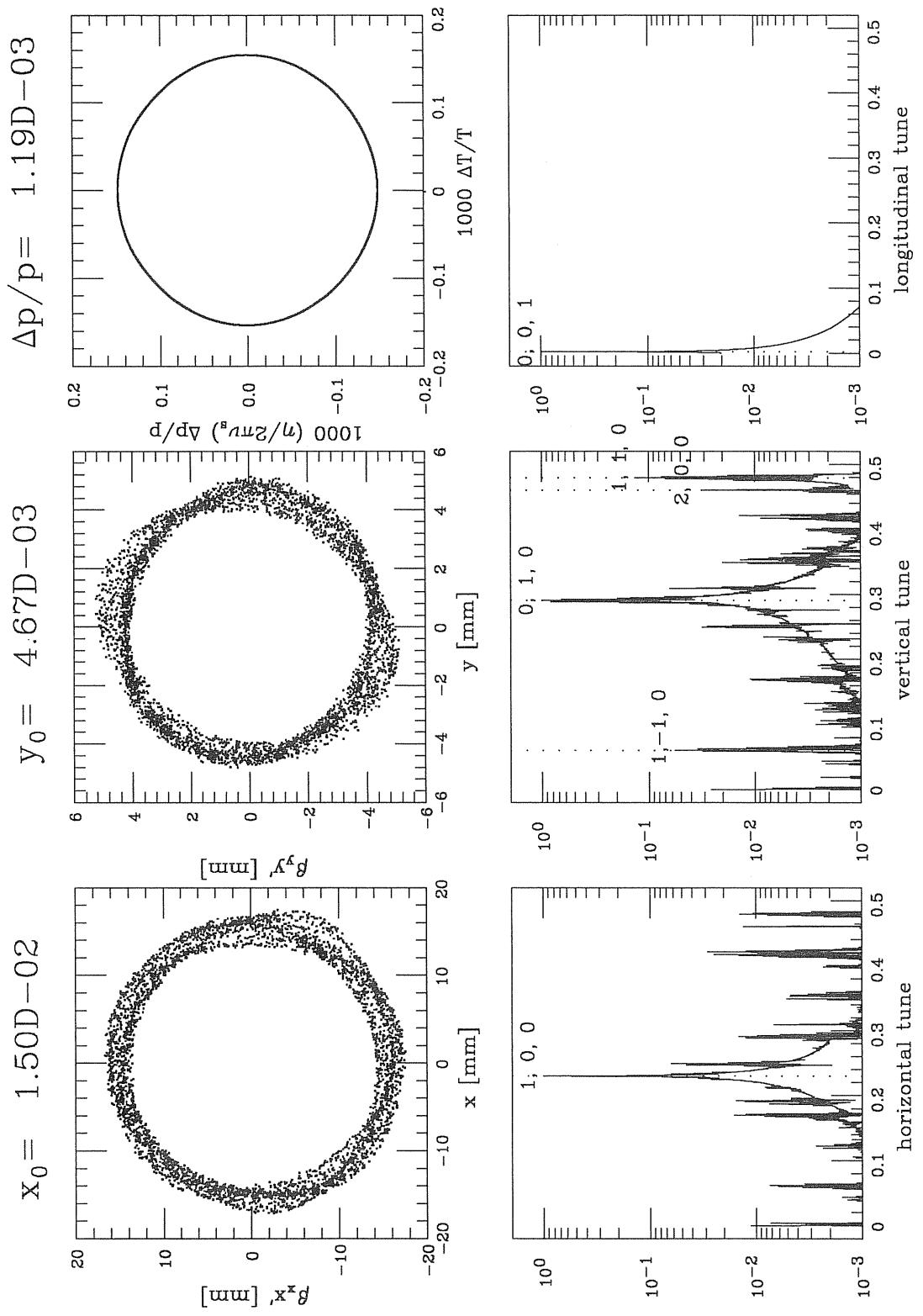


Fig. 2.18 : HEB, random errors, 10- $\sigma$  particle.

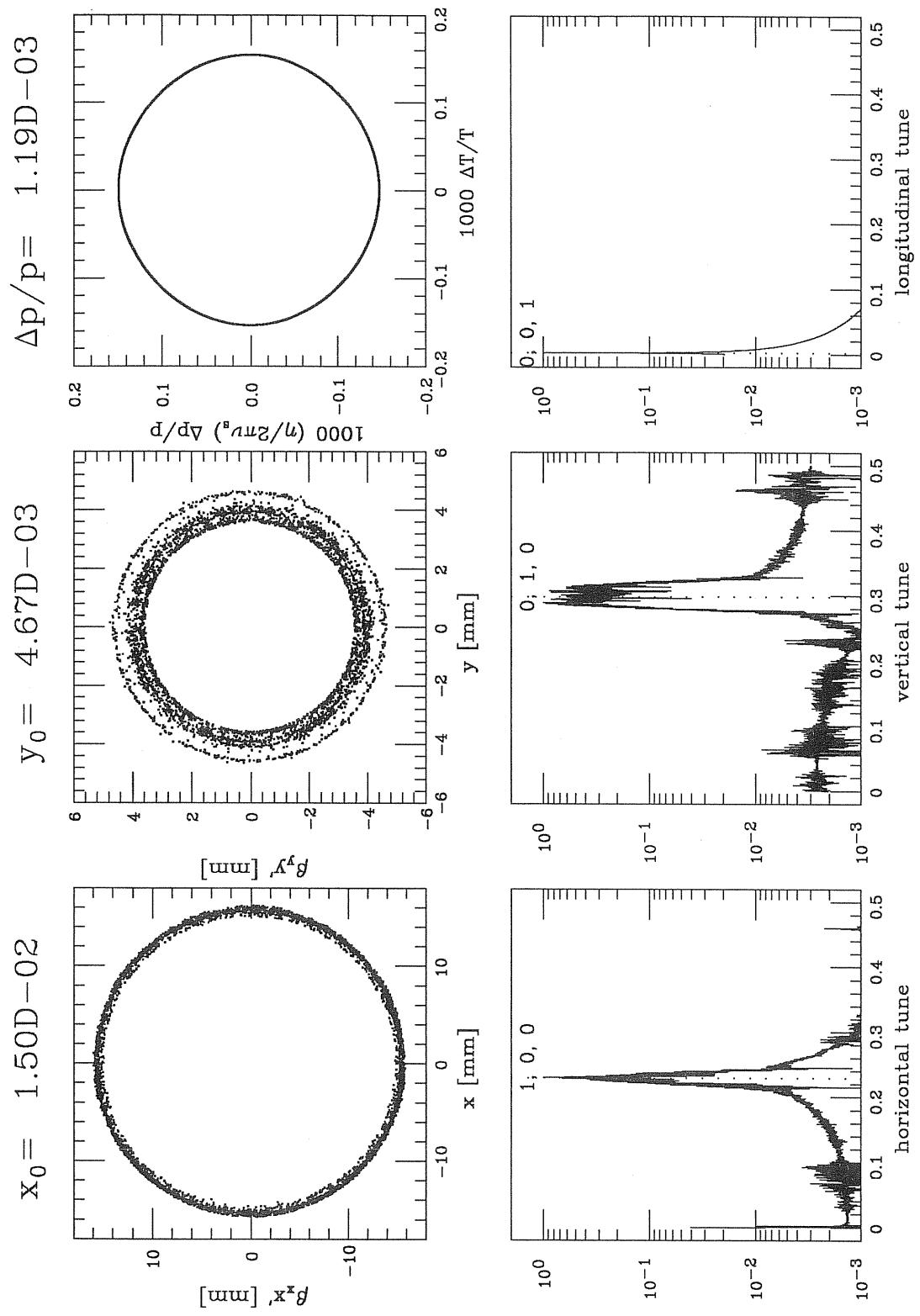
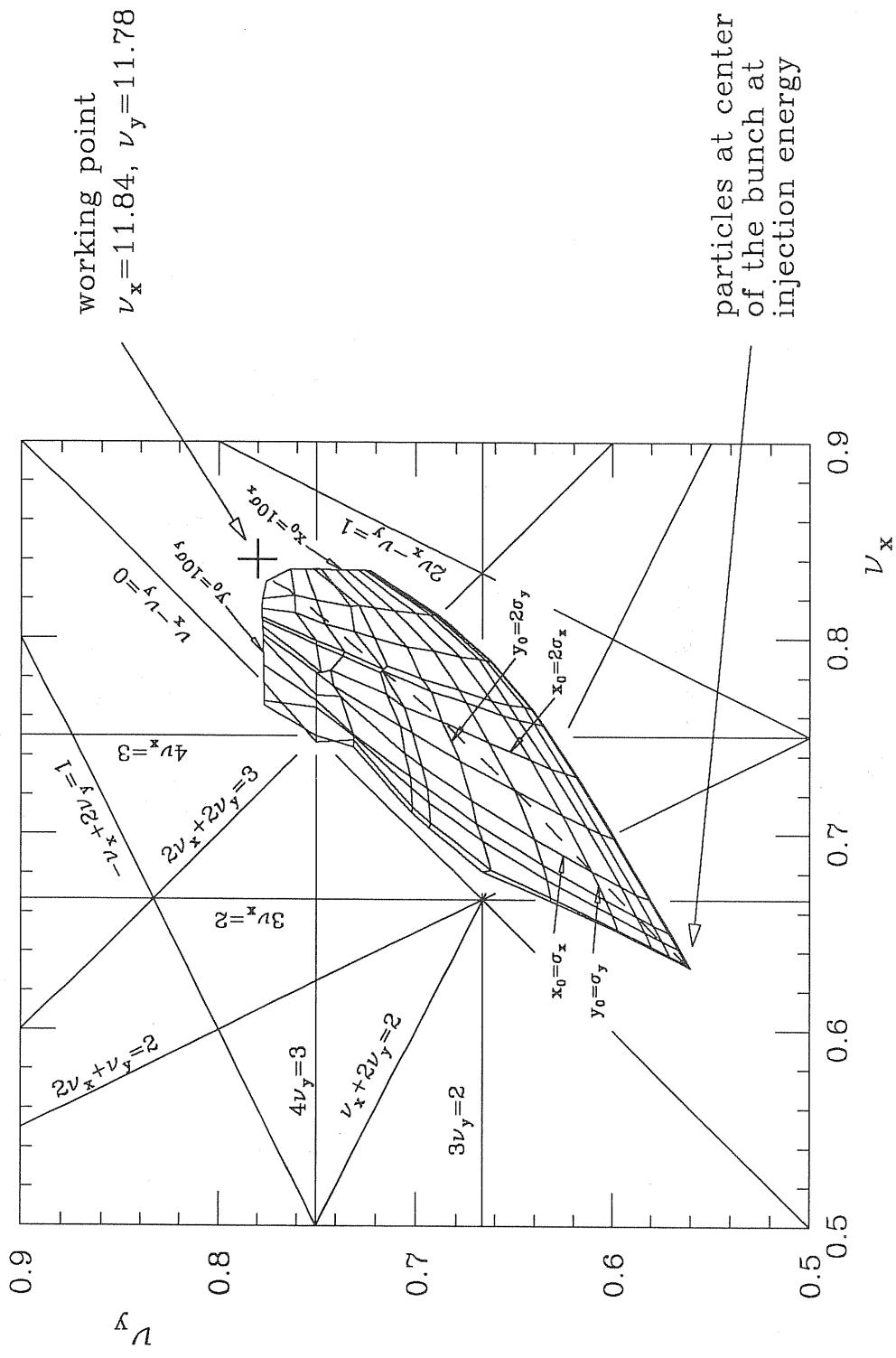
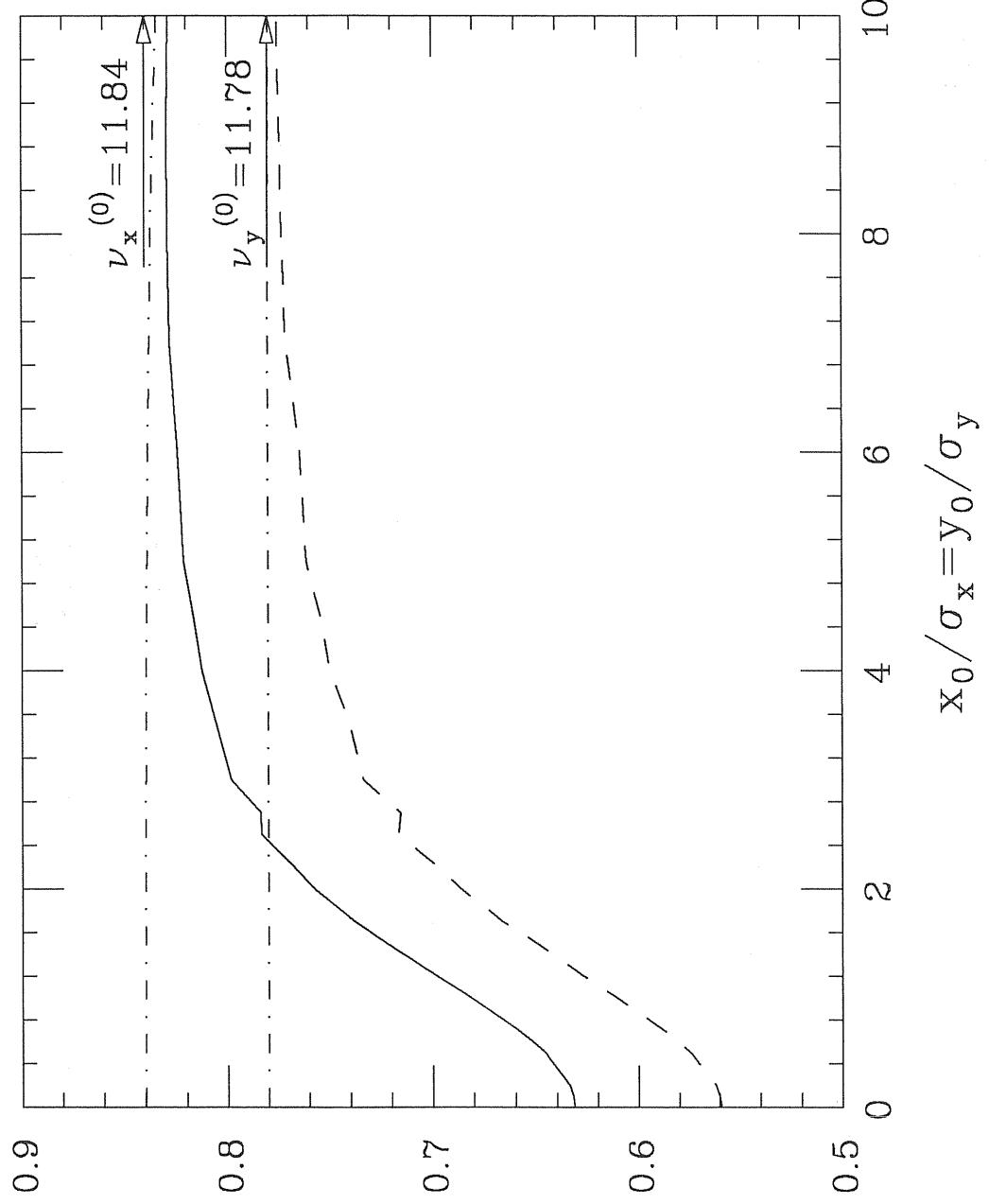


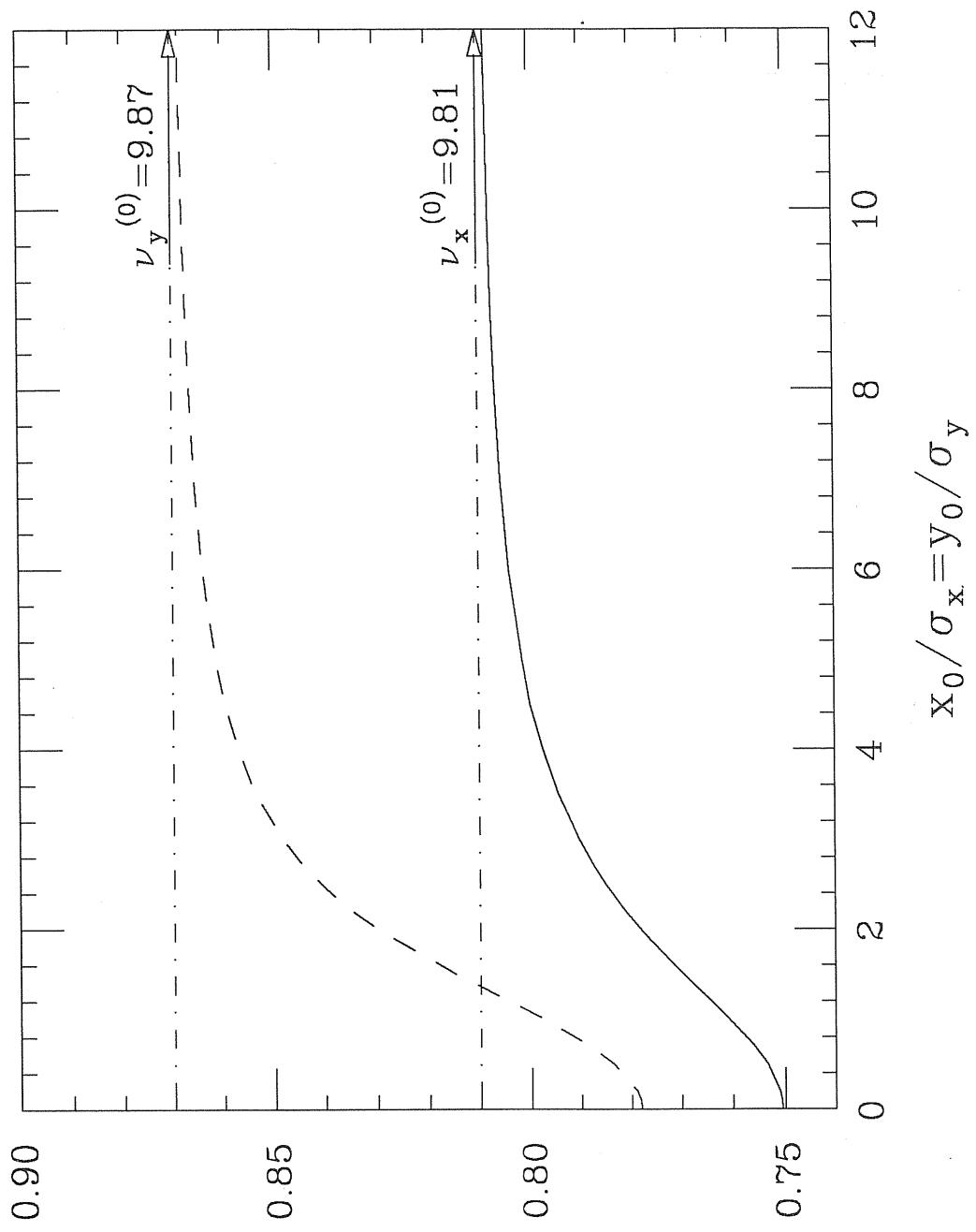
Fig. 2.19 : HEB, systematic errors,  $10-\sigma$  particle.



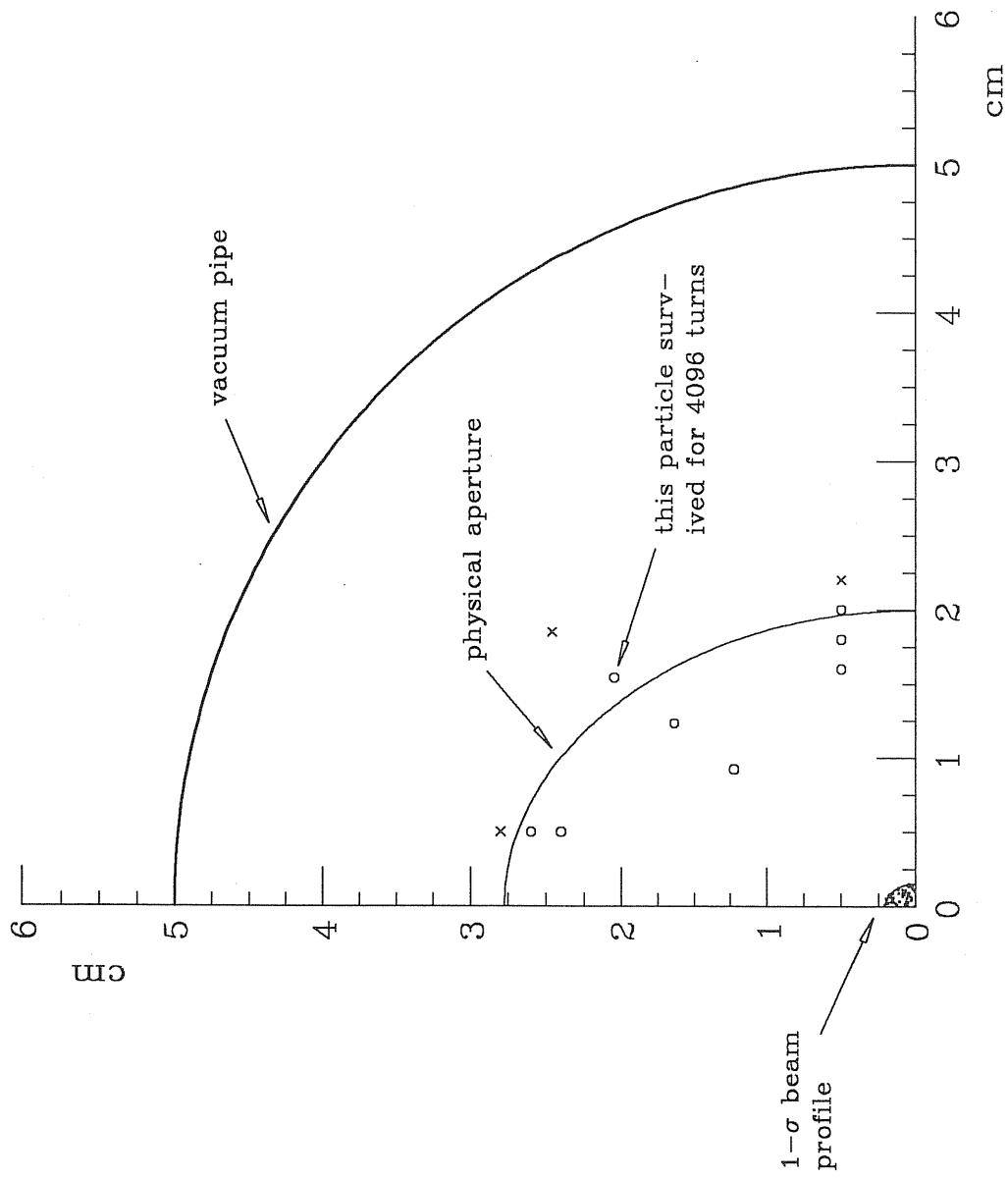
**Fig. 2.20:** Tune distribution of particles in the LEB at injection energy. The solid lines in the "necktie" diagram were obtained by tracking particles with constant  $x_0$  (approximately horizontal lines) or with constant  $y_0$  (approximately vertical lines). The grid is not uniform; the lines are at 0.1, 0.2, 0.5, 0.7, 1.0, 1.5, 2.0, 2.5, 3.5, 5.0 and 10.0  $\sigma$ . The dashed line through the center of the necktie was obtained by tracking with  $x_0/\sigma_x = y_0/\sigma_y$  (this corresponds to Fig. 2.21). The effects of the resonance lines  $\nu_x = 3/4$ ,  $\nu_y = 3/4$  and  $2\nu_x + 2\nu_y = 3$  are apparent in the distortion of the diagram at large amplitudes.



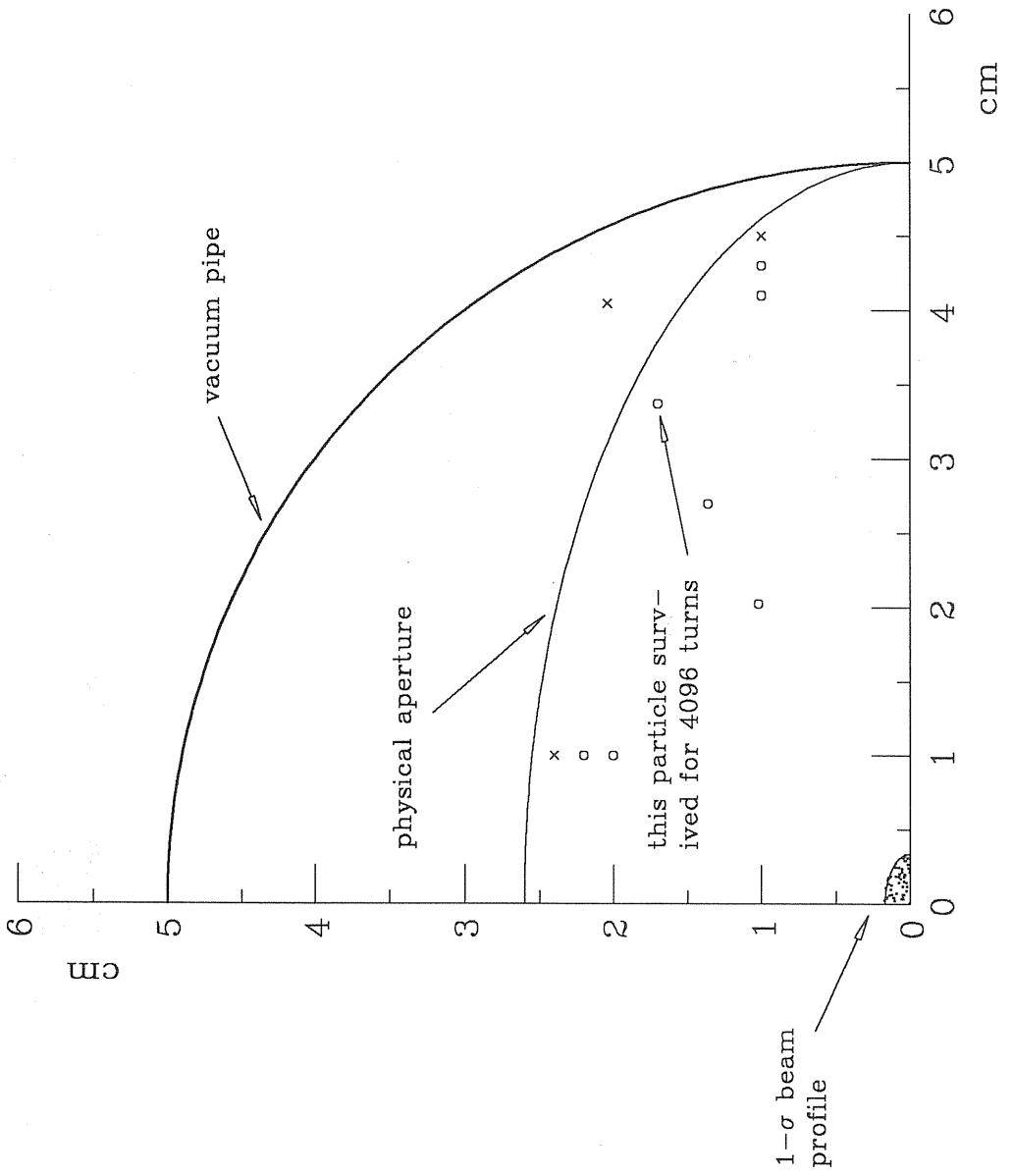
**Fig. 2.21:** Fractional tunes vs. launching amplitude for the LEB at injection energy ( $\nu_x$ =solid,  $\nu_y$ =dash). The effect of the  $2\nu_x+2\nu_y=3$  resonance is seen at  $2.5\sigma$ . The dot-dash lines represent the results in the absence of the space-charge force. The slight downcurving of  $\nu_x$  at large amplitude is due to the effect of the chromatic sextupoles.



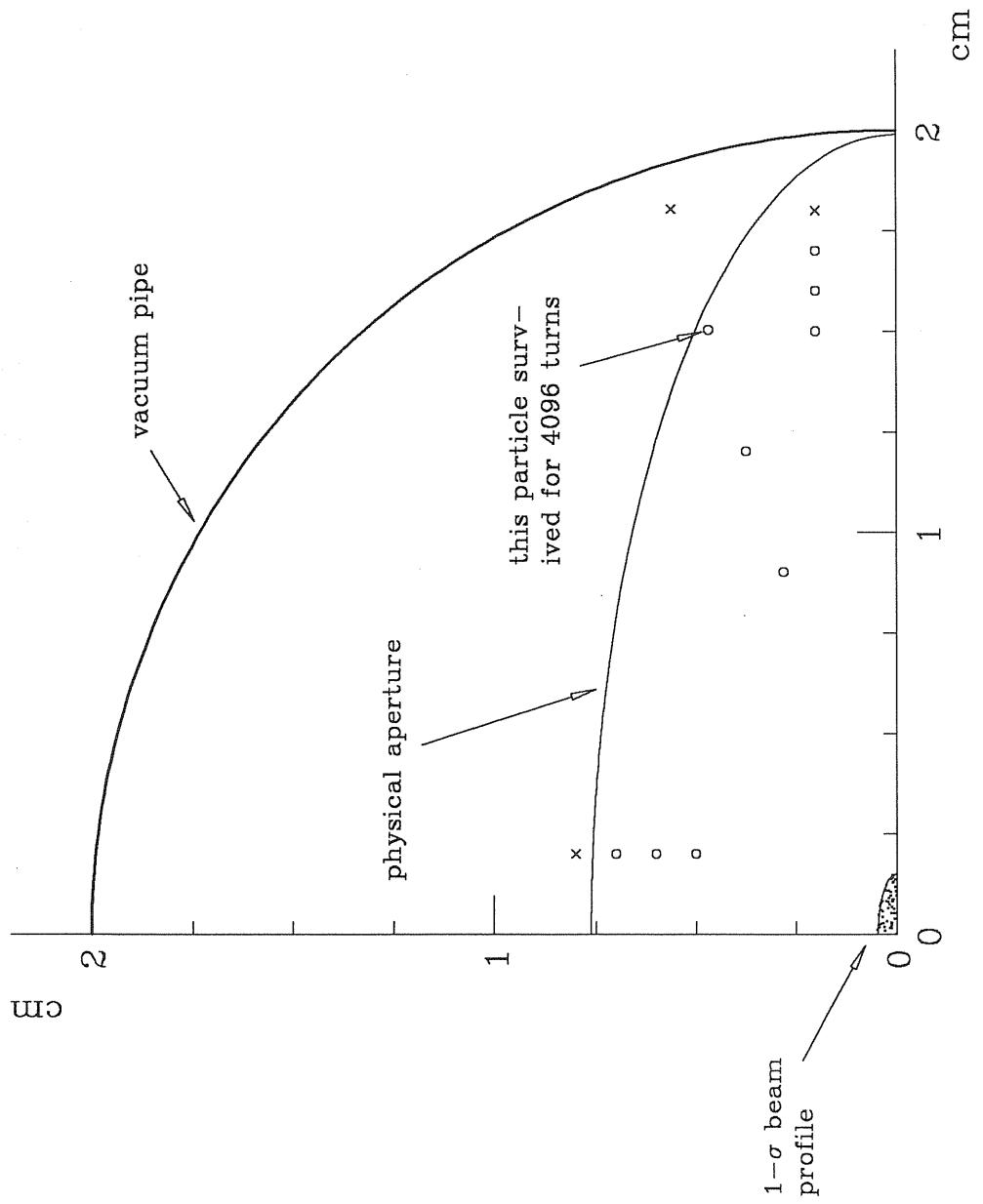
**Fig. 2.22:** Fractional tunes vs. launching amplitude for the MEB at injection energy ( $\nu_x$ =solid,  $\nu_y$ =dash). The dot-dash lines represent the results in the absence of the space-charge force.



**Fig. 2.23: Dynamic aperture of the LEB.** Particles were tracked at different injection amplitudes with  $\Delta p = 3\sigma_p$ , magnet errors included. Circles indicate those which survived 512 turns, crosses those which did not. The "physical aperture" is an analytic estimate of the aperture in the absence of nonlinearities and coupling.



**Fig. 2.24: Dynamic aperture of the MEB.** Particles were tracked at different injection amplitudes with  $\Delta p = 3\sigma_p$ , magnet errors included. Circles indicate those which survived 512 turns, crosses those which did not. The "physical aperture" is an analytic estimate of the aperture in the absence of nonlinearities and coupling.



**Fig. 2.25: Dynamic aperture of the HEB.** Particles were tracked at different injection amplitudes with  $\Delta p = 3\sigma_p$ , magnet errors included. Circles indicate those which survived 512 turns, crosses those which did not. The "physical aperture" is an analytic estimate of the aperture in the absence of nonlinearities and coupling.

## 4. Conclusions

1. We have designed new lattices for the three boosters with linear optics much improved from the CDR design. We have maintained the feature that there is no transition energy crossing at any point in the system. The overall circumference of the 3 boosters is shorter than in the CDR by  $\sim 1$  km. However, because the superperiodicities of the LEB and MEB have been changed relative to the CDR, the layout of the whole complex, including the location and length of the transfer lines, has to be redesigned.
2. The filling factor of 94% is much improved from the CDR, which has a filling factor of 85%.
3. Tracking simulations with space charge, sextupoles, synchrotron oscillations and magnet errors show that the dynamic aperture of the CDR magnet design is adequate. The space-charge force causes a sizable tune shift of  $\sim -0.2$  at injection energy in the LEB, which necessarily implies substantial resonance-crossing. In this note we have chosen a working point so that a certain high-order resonance is at large amplitude in order to minimize the effects of emittance dilution. The corresponding degradation of beam quality is probably not significant, although a quantitative estimate has not been done. The effect of the space-charge on the coupling between transverse and longitudinal motion is apparent, especially for the LEB.
4. It appears that the thresholds of single bunch instabilities are high enough to be of no serious concern.

## ACKNOWLEDGEMENTS

We are particularly indebted to Al Garren and Dave Johnson for their invaluable assistance with lattice design programs, for general advice about lattice design, and for help with the many modifications the designs had to undergo. We are also grateful to Alex Chao, Gene Colton, Steve Peggs, Jack Peterson, Lindsay Schachinger, Dick Talman, Maury Tigner, Arch Thiessen and Tim Toohig for discussions.

## APPENDIX : Lattice Functions from SYNCH<sup>[2]</sup>

The following pages have a description of all 3 lattices and listings of the lattice functions for half of a superperiod. The  $\beta$  functions and dispersion are plotted in Figs. 2.1–3.

SYNCH RUN LEB  
2-SEP-88 12:17:27 LOW ENERGY BOOSTER OF SSC INJECTOR COMPLEX

SYNCH VERSION VAX.8704

23 Aug 88 Modified from LKC's data

*** PC =	// 8.45
*** BRHO =	// 28.18861660
*** B0 =	// 1.36650389
*** RHO =	// BRHO /
*** RHOI =	// 1.0 /
*** BRO =	// 1.0 /

-- BEAMLINES

*** .B BML //	O B OO
*** .DBF BML //	QD SD .B QF
*** .FBD BML //	QF SF .B QD
*** .DF1 BML //	.DBF .FBD
*** .DF2 BML //	QD OS1 BB OS2 QF OS3 BB OS4 QD
*** .DF3 BML //	QD OS5 BB OS6 QF OS7 BB OS8 QD
*** .DFO BML //	QD OS1 QF1 OS2 QD1 OS3 QF2 OS4 SYM
*** .SPL BML //	.DF1 .DF1 .DF1 .DF1 .DF1 .DF1 .DF2 .DF3 .DF0

-- ARC CELLS

*** SYM DRF //	0.3
*** LQ = //	1.8
*** LB = //	0.9
*** O DRF //	0.936
*** OO DRF //	0.23
*** OS1 DRF //	1.2243
*** OS2 DRF //	0.8323
*** OS3 DRF //	0.8
*** OS4 DRF //	1.2566
*** OS5 DRF //	1.0
*** OS6 DRF //	1.0566
*** OS7 DRF //	1.3346
*** OS8 DRF //	0.7220
*** B MAG //	LB 0.
*** BB MAG //	LBB 0.
*** SXKF PARA //	0.00000000
*** SXKD PARA //	0.00000000

SF	SXTP	SXTP	SXKF
SD	SXTP	SXKD	BRO
KF	PARA	0.	BRO
KD	PARA	0.719339485506	
QF	MAG	-0.697740242770	
QD	MAG	LQ	KF
KF1	PARA	LQ	KD
KD1	PARA	LQ	
KF2	PARA	0.62540553	
LOO1	PARA	-.72778290	
LOO2	PARA	0.32546759	
LOO3	PARA	5.178476006	
LOO4	PARA	2.	
QD1	MAG	2.	
QF1	MAG	3.116923994	
QF2	MAG	KD1	BRO
OQ1	DRF	LQ	BRO
OQ2	DRF	LQ	BRO
OQ3	DRF	LOO1	
OQ4	DRF	LOO2	
		LOO3	
		LOO4	

```

*** CF1
*** TSPPL
     MMM
     TRKB
     END
     CYC
     // DF1
           // SPL CF1
           // DF1

```

POS	S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DSEQ	DYEQ
0	0.0000	0.00000	0.00000	2.00352	11.97326	0.38093	0.00000	0.00000	0.00534	0.00838	0.00000	0.00000
1 QD	0.3000	0.02318	0.00407	2.17786	11.24127	0.39549	0.00000	0.00000	-0.59324	2.38332	0.08922	0.00000
2 SD	0.3000	0.02318	0.00407	2.17786	11.24127	0.39549	0.00000	0.00000	-0.59324	2.38332	0.08922	0.00000
3 O	1.2360	0.07569	0.02055	3.83226	7.30033	0.47900	0.00000	0.00000	-1.17428	1.82709	0.08922	0.00000
4 B	3.0360	0.12244	0.08809	10.06049	2.61172	0.71789	0.00000	0.0511	-2.29024	0.76444	0.17654	0.00000
5 OO	3.2660	0.12590	0.10304	11.14683	2.29809	0.75849	0.00000	0.0511	-2.43302	0.62524	0.17654	0.00000
6 QF	3.5660	0.13000	0.12500	11.89291	2.11423	0.78646	0.00000	0.0511	0.00000	0.0082	0.00894	0.00000
7 QF	3.8660	0.13410	0.14697	11.14683	2.29706	0.76380	0.00000	0.0511	2.43302	-0.62337	-0.15925	0.00000
8 SF	3.8660	0.13410	0.14697	11.14683	2.29706	0.76380	0.00000	0.0511	2.43302	-0.62337	-0.15925	0.00000
9 O	4.8020	0.15084	0.19697	7.13608	3.99362	0.61474	0.00000	0.0511	1.85198	-1.18919	-0.15925	0.00000
10 B	6.6020	0.22106	0.24251	2.48359	10.18661	0.40695	0.00000	0.0946	0.73602	-2.23825	-0.07192	0.00000
11 OO	6.8320	0.23682	0.24593	2.17786	11.24742	0.39041	0.00000	0.0946	0.59324	-2.37395	-0.07192	0.00000
12 QD	7.1320	0.26000	0.25000	2.00352	11.97326	0.38093	0.00000	0.0946	0.00000	0.00534	0.00838	0.00000

CIRCUMFERENCE =	7.1320 M	THETPX =	0.17453293 RAD	NUX =	0.26000	DNUX/(DP/P) =	-0.32079
RADIUS =	1.1351 M	THEPY =	0.00000000 RAD	NUY =	0.25000	DNUY/(DP/P) =	-0.31447
(DS/S)/(DP/P) =	0.0132612	TGAM=	{ 8.68378, 0.00000}				
MAXIMA	--- BETX( 6 ) =	BETY( 1 ) =	11.89291	XEQ( 6 ) =	0.78646	YEQ( 12 ) =	0.00000
MINIMA	--- BETX( 1 ) =	BETY( 6 ) =	2.00352	XEQ( 1 ) =	0.38093	YEQ( 12 ) =	0.00000
*** LEBS	BEST 1 -2 //	.SPL	SF SD				

## BETATRON FUNCTIONS THRU .SPL

PAGE 1

POS	S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DXEQ	DYEQ
0	0.0000	0.00000	0.00000	2.00352	11.89684	0.39713	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1 QD	0.3000	0.02318	0.00410	2.17786	11.17267	0.40967	0.00000	0.00000	-0.59324	2.36314	0.08400	0.00000
2 SD	0.3000	0.02318	0.00410	2.17786	11.17267	0.40967	0.00000	0.00000	-0.59324	2.36314	0.08400	0.00000
3 O	1.2360	0.07569	0.02066	3.83226	7.26518	0.48829	0.00000	0.00000	-1.17428	1.81153	0.08400	0.00000
4 B	3.0360	0.12244	0.08831	10.06049	2.62272	0.71779	0.00000	0.0515	-2.29024	0.75779	0.17132	0.00000
5 OO	3.2660	0.12590	0.10322	11.14683	2.30589	0.75720	0.00000	0.0515	-2.43302	0.61974	0.17132	0.00000
6 QF	3.5660	0.13000	0.12509	11.89291	2.12552	0.78366	0.00000	0.0515	0.00000	-0.00559	0.00416	0.00000
7 QF	3.8660	0.13410	0.14692	11.14684	2.31289	0.75967	0.00000	0.0515	2.43301	-0.63239	-0.16327	0.00000
8 SF	3.8660	0.13410	0.14692	11.14684	2.31289	0.75967	0.00000	0.0515	2.43301	-0.63239	-0.16327	0.00000
9 O	4.8020	0.15084	0.19653	7.13608	4.02700	0.60684	0.00000	0.0515	1.85198	-1.19892	-0.16327	0.00000
10 B	6.6020	0.22106	0.24171	2.48359	10.25712	0.39182	0.00000	0.0940	0.73602	-2.24907	-0.07595	0.00000
11 OO	6.8320	0.23682	0.24511	2.17786	11.32294	0.37435	0.00000	0.0940	0.59324	-2.38492	-0.07595	0.00000
12 QD	7.1320	0.26000	0.24916	2.00352	12.05050	0.63134	0.00000	0.0940	0.00000	0.01068	0.00084	0.00000
13 QD	7.4320	0.28318	0.25320	2.17786	11.31065	0.37486	0.00000	0.0940	-0.59324	2.40366	0.07768	0.00000
14 SD	7.4320	0.28318	0.25320	2.17786	11.31065	0.37486	0.00000	0.0940	-0.59324	2.40366	0.07768	0.00000
15 O	8.3680	0.33569	0.26959	3.83226	7.33598	0.44556	0.00000	0.0940	-1.17428	1.84279	0.07768	0.00000
16 B	10.1680	0.38244	0.33702	10.06048	2.61290	0.66569	0.00000	0.1414	-2.29024	0.77115	0.16500	0.00000
17 OO	10.3980	0.38590	0.35200	11.14683	2.29046	0.70364	0.00000	0.1414	-2.22760	0.63078	0.16500	0.00000
18 QF	10.6980	0.39000	0.37407	11.89291	2.10308	0.72996	0.00000	0.1414	0.00000	0.00724	0.00947	0.00000
19 QF	10.9980	0.39410	0.39617	11.14683	2.28139	0.70926	0.00000	0.1414	2.43302	-0.61439	-0.14667	0.00000
20 SF	10.9980	0.39410	0.39617	11.14683	2.28139	0.70926	0.00000	0.1414	2.43302	-0.61439	-0.14667	0.00000
21 O	11.9340	0.41084	0.44657	7.13608	3.96051	0.57199	0.00000	0.1414	1.85198	-1.17954	-0.14667	0.00000
22 B	13.7340	0.48106	0.49246	2.48359	10.11680	0.70364	0.00000	0.1822	-2.22760	0.63078	0.16500	0.00000
23 O	13.9640	0.49682	0.49590	2.17786	11.17267	0.73116	0.00000	0.1822	0.59324	-2.36314	0.05934	0.00000
24 QD	14.2640	0.52000	0.50000	2.00352	11.89684	0.36695	0.00000	0.1822	0.00000	0.00000	0.01772	0.00000
25 QD	14.5640	0.54318	0.50410	2.17786	11.17267	0.38390	0.00000	0.1822	-0.59324	2.36314	0.09589	0.00000
26 SD	14.5640	0.54318	0.50410	2.17786	11.17267	0.38390	0.00000	0.1822	-0.59324	2.36314	0.09589	0.00000
27 O	15.5000	0.59569	0.52066	3.83226	7.26518	0.47366	0.00000	0.1822	-1.17428	1.81153	0.09589	0.00000
28 B	17.3000	0.64244	0.58831	10.06049	2.62272	0.72454	0.00000	0.2333	-2.29024	0.75779	0.18321	0.00000
29 OQ	17.5300	0.64590	0.60322	11.14684	2.30589	0.76668	0.00000	0.2333	-2.43302	0.61974	0.18321	0.00000
30 QF	17.8300	0.65000	0.62509	11.89291	2.12552	0.79636	0.00000	0.2333	0.00000	-0.00559	0.01364	0.00000
31 QF	18.1300	0.65410	0.64692	11.14684	2.31289	0.77477	0.00000	0.2333	2.43302	-0.63239	-0.15680	0.00000
32 SF	18.1300	0.65410	0.64692	11.14684	2.31289	0.77477	0.00000	0.2333	2.43302	-0.63239	-0.15680	0.00000
33 O	19.0660	0.67084	0.69653	7.13608	4.02700	0.62801	0.00000	0.2333	1.85198	-1.19892	-0.15680	0.00000
34 B	20.8660	0.74106	0.74171	2.48359	10.25713	0.42461	0.00000	0.2781	0.73602	-2.24907	-0.06948	0.00000
35 OO	21.0960	0.75682	0.74511	2.17786	11.32294	0.40863	0.00000	0.2781	0.59325	-2.38492	-0.06948	0.00000
36 QD	21.3960	0.78000	0.74916	2.00352	12.05050	0.4046	0.00000	0.2781	0.00000	0.01068	0.01476	0.00000
37 QD	21.6960	0.80318	0.75320	2.17786	11.31065	0.41758	0.00000	0.2781	-0.59324	2.40366	0.0993	0.00000
38 SD	21.6960	0.80318	0.75320	2.17786	11.31065	0.41758	0.00000	0.2781	-0.59324	2.40366	0.0993	0.00000
39 O	22.6320	0.85569	0.76959	3.83226	7.33598	0.51111	0.00000	0.2781	-1.17428	1.84279	0.0993	0.00000
40 B	24.4320	0.90244	0.83702	10.06048	2.61290	0.76924	0.00000	0.3329	-2.29024	0.77115	0.18725	0.00000
41 OO	24.6620	0.90590	0.85200	11.14683	2.29046	0.81231	0.00000	0.3329	-2.43301	0.63078	0.18725	0.00000
42 QF	24.9620	0.91000	0.87406	11.89290	2.10308	0.84173	0.00000	0.3329	0.00000	0.00724	0.00781	0.00000
43 QF	25.2620	0.91410	0.89617	11.14683	2.28139	0.81695	0.00000	0.3329	2.43301	-0.61439	-0.17214	0.00000
44 SF	25.2620	0.91410	0.89617	11.14683	2.28139	0.81695	0.00000	0.3329	2.43301	-0.61439	-0.17214	0.00000

## BETATRON FUNCTIONS THRU .SPI

PAGE 2

POS	S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DSEQ	DYEQ
45 O	26.1980	0.93084	0.94657	7.13607	3.96051	0.65583	0.00000	0.3329	1.85198	-1.17954	-0.17214	0.00000
46 B	27.9980	1.00105	0.99246	2.48359	10.11680	0.42487	0.00000	0.3789	0.73602	-2.22760	-0.08481	0.00000
47 OQ	28.2280	1.01682	0.99590	2.17786	11.17267	0.40536	0.00000	0.3789	0.59324	-2.36314	-0.08481	0.00000
48 QD	28.5280	1.04000	1.00000	2.00352	11.89684	0.39245	0.00000	0.3789	0.00000	0.00000	-0.00175	0.00000
49 QD	28.8280	1.06318	1.00410	2.17786	11.17267	0.40430	0.00000	0.3789	-0.59324	2.36314	0.08121	0.00000
50 SD	28.8280	1.06318	1.00410	2.17786	11.17267	0.40430	0.00000	0.3789	-0.59324	2.36314	0.08121	0.00000
51 O	29.7640	1.11569	1.02066	3.83226	7.26518	0.48031	0.00000	0.3789	-1.17428	1.81153	0.08121	0.00000
52 B	31.5640	1.16244	1.08831	10.06049	2.62272	0.70479	0.00000	0.4295	-2.29024	0.75779	0.16853	0.00000
53 OO	31.7940	1.16590	1.10322	11.14684	2.30589	0.74355	0.00000	0.4295	-2.43302	0.61974	0.16853	0.00000
54 QF	32.0940	1.17000	1.12509	11.89292	2.12552	0.76962	0.00000	0.4295	0.00000	-0.00559	0.00437	0.00000
55 QF	32.3940	1.17410	1.14692	11.14684	2.31289	0.74614	0.00000	0.4295	2.43302	-0.63239	-0.16007	0.00000
56 SF	32.3940	1.17410	1.14692	11.14684	2.31289	0.74614	0.00000	0.4295	2.43302	-0.63239	-0.16007	0.00000
57 O	33.3300	1.19084	1.19653	7.13609	4.02700	0.59632	0.00000	0.4295	1.85198	-1.19892	-0.16007	0.00000
58 B	35.1300	1.26105	1.24171	2.48359	10.25713	0.38704	0.00000	0.4713	0.4713	-2.24907	-0.07275	0.00000
59 OO	35.3600	1.27682	1.24511	2.17786	11.32294	0.37031	0.00000	0.4713	0.59325	-2.38492	-0.07275	0.00000
60 QD	35.6600	1.30000	1.24915	2.00352	12.05050	0.35994	0.00000	0.4713	0.00000	0.01068	0.00328	0.00000
61 QD	35.9600	1.32318	1.25320	2.17786	11.31065	0.37230	0.00000	0.4713	-0.59324	2.40366	0.07952	0.00000
62 SD	35.9600	1.32318	1.25320	2.17786	11.31065	0.37230	0.00000	0.4713	-0.59324	2.40366	0.07952	0.00000
63 O	36.8960	1.37569	1.26958	3.83226	7.33226	0.44673	0.00000	0.4713	-1.17428	1.84279	0.07952	0.00000
64 B	38.6960	1.42244	1.33702	10.06048	2.61290	0.66817	0.00000	0.5189	-2.29024	0.77115	0.16684	0.00000
65 OO	38.9260	1.42590	1.35200	11.14683	2.29046	0.70655	0.00000	0.5189	-2.43301	0.63078	0.16684	0.00000
66 QF	39.2260	1.43000	1.37406	11.89290	2.10308	0.73331	0.00000	0.5189	0.00000	0.00724	0.01064	0.00000
67 QF	39.5260	1.43410	1.39617	11.14683	2.28139	0.71286	0.00000	0.5189	2.43301	-0.61439	-0.14625	0.00000
68 SF	39.5260	1.43410	1.39617	11.14683	2.28139	0.71286	0.00000	0.5189	2.43301	-0.61439	-0.14625	0.00000
69 O	40.4620	1.45084	1.44657	7.13607	3.96051	0.57597	0.00000	0.5189	1.85198	-1.17954	-0.14625	0.00000
70 B	42.2620	1.52105	1.49246	2.48359	10.11680	0.39153	0.00000	0.5600	0.73602	-2.22760	-0.05893	0.00000
71 O	42.4920	1.53682	1.49590	2.17786	11.17267	0.37798	0.00000	0.5600	0.59324	-2.36314	-0.05893	0.00000
72 QD	42.7920	1.56000	1.50000	2.00352	11.89684	2.37204	0.00000	0.5600	0.00000	0.00000	0.1916	0.00000
73 QD	43.0920	1.58318	1.50410	2.17786	11.17267	0.38959	0.00000	0.5600	-0.59324	2.36314	0.09845	0.00000
74 SD	43.0920	1.58318	1.50410	2.17786	11.17267	0.38959	0.00000	0.5600	-0.59324	2.36314	0.09845	0.00000
75 O	44.0280	1.63569	1.52066	3.83226	7.26518	0.48174	0.00000	0.5600	-1.17428	1.81153	0.09845	0.00000
76 B	45.8280	1.68244	1.58831	10.06049	2.62272	0.73723	0.00000	0.6120	-2.29024	0.75779	0.18578	0.00000
77 O	46.0580	1.68590	1.60322	11.14684	2.30589	0.77996	0.00000	0.6120	-2.43302	0.61974	0.18578	0.00000
78 QF	46.3580	1.69000	1.62509	11.89292	2.12552	0.80998	0.00000	0.6120	0.00000	-0.00559	0.01329	0.00000
79 QF	46.6580	1.69410	1.64692	11.14684	2.31289	0.78785	0.00000	0.6120	2.43302	-0.63239	-0.16005	0.00000
80 SF	46.6580	1.69410	1.64692	11.14684	2.31289	0.78785	0.00000	0.6120	2.43302	-0.63239	-0.16005	0.00000
81 O	47.5940	1.71084	1.69653	7.13609	4.02700	0.63804	0.00000	0.6120	1.85198	-1.19892	-0.16005	0.00000
82 B	49.3940	1.78105	1.74171	2.48359	10.25713	0.42879	0.00000	0.6575	0.73602	-2.24907	-0.07273	0.00000
83 O	49.6240	1.79682	1.74511	2.17786	11.32294	0.41207	0.00000	0.6575	0.59325	-2.38492	-0.07273	0.00000
84 QD	49.9240	1.82000	1.74915	2.00352	12.05050	0.40302	0.00000	0.6575	0.00000	0.01068	0.01213	0.00000
85 QD	50.2240	1.84318	1.75320	2.17786	11.31065	0.41942	0.00000	0.6575	-0.59324	2.40366	0.09776	0.00000
86 SD	50.2240	1.84318	1.75320	2.17786	11.31065	0.41942	0.00000	0.6575	-0.59324	2.40366	0.09776	0.00000
87 O	51.1600	1.889569	1.76959	3.83226	7.33598	0.51093	0.00000	0.6575	-1.17428	1.84279	0.09776	0.00000
88 B	52.9600	1.94244	1.83702	10.06048	2.61290	0.76517	0.00000	0.7121	-2.29024	0.77115	0.18509	0.00000
89 O	53.1900	1.94590	1.85200	11.14682	2.29046	0.80774	0.00000	0.7121	-2.43301	0.63078	0.18509	0.00000

BETATRON FUNCTIONS THRU .SPL

PAGE 3

POS	S(M)	NUX	NUY	BETTAX(M)	BETTAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DSEQ	DYEQ
90 QF	53.4900	1.95000	1.87406	11.89290	2.10308	0.83666	0.00000	0.7121	0.00000	0.00724	0.00669	0.00000
91 QF	53.7900	1.95410	1.89617	11.14682	2.28139	0.81171	0.00000	0.7121	0.61439	-0.17214	0.00000	0.00000
92 SF	53.7900	1.95410	1.89617	11.14682	2.28139	0.81171	0.00000	0.7121	2.43301	-0.17214	0.00000	0.00000
93 O	54.7260	1.97084	1.94657	7.13607	3.96051	0.65059	0.00000	0.7121	1.85198	-1.17954	-0.17214	0.00000
94 B	56.5260	2.04105	1.99246	2.48359	10.11680	0.41963	0.00000	0.7576	0.73602	-2.22760	-0.08482	0.00000
95 OO	56.7560	2.05682	1.99590	2.17786	11.17267	0.40012	0.00000	0.7576	0.59324	-2.36314	-0.08482	0.00000
96 QD	57.0560	2.08000	2.00000	2.00352	11.89684	0.38704	0.00000	0.7576	0.00000	0.00000	-0.0286	0.00000
97 QD	57.3560	2.10318	2.00410	2.17786	11.17267	0.39838	0.00000	0.7576	-0.59325	2.36314	0.07892	0.00000
98 OS1	58.5803	2.16668	2.02746	4.56095	6.26964	0.49500	0.00000	0.7576	-1.35325	1.64162	0.07892	0.00000
99 BB	59.4803	2.19126	2.05705	7.49853	3.78296	0.58563	0.00000	0.7811	-1.91176	1.18772	0.12256	0.00000
100 OS2	60.3126	2.20579	2.10224	11.11086	2.33303	0.68764	0.00000	0.7811	-2.42842	0.62335	0.12256	0.00000
101 QF	60.6126	2.20991	2.12385	11.85658	2.15173	0.70187	0.00000	0.7811	-0.00342	-0.00602	-0.02819	0.00000
102 QF	60.9126	2.21402	2.14542	11.11479	2.34058	0.67091	0.00000	0.7811	2.42245	-0.63699	-0.17712	0.00000
103 OS3	61.7126	2.22786	2.18897	7.63436	3.74415	0.52921	0.00000	0.7811	1.92810	-1.11748	-0.17712	0.00000
104 BB	62.6126	2.25195	2.21879	4.66510	6.23306	0.38949	0.00000	0.8010	1.37213	-1.64534	-0.13348	0.00000
105 OS4	63.8692	2.31621	2.24271	2.19241	11.30727	0.22177	0.00000	0.8010	0.59563	-2.39271	-0.13348	0.00000
106 QD	64.1692	2.33924	2.24676	2.01726	12.04065	0.18830	0.00000	0.8010	0.00040	-0.0048	-0.09078	0.00000
107 QD	64.4692	2.36226	2.25081	2.19191	11.30782	0.16673	0.00000	0.8010	-0.59473	2.39187	-0.05382	0.00000
108 OS5	65.4692	2.41710	2.26858	3.99896	7.11846	0.11291	0.00000	0.8010	-1.21232	1.79757	-0.05382	0.00000
109 BB	66.3692	2.44494	2.29443	6.68037	4.35393	0.08413	0.00000	0.8051	-1.76797	1.27118	-0.01018	0.00000
110 OS6	67.4258	2.46452	2.34814	11.10592	2.33829	0.07337	0.00000	0.8051	-2.42051	0.63640	-0.10118	0.00000
111 QF	67.7258	2.46863	2.36974	11.84713	2.14969	0.67799	0.00000	0.8051	0.00338	0.00578	-0.02551	0.00000
112 QF	68.0258	2.47275	2.39136	11.10204	2.33105	0.05823	0.00000	0.8051	2.42641	-0.62331	-0.03921	0.00000
113 OS7	69.3604	2.49951	2.45491	5.73046	5.05575	0.00591	0.00000	0.8051	1.59845	-1.48187	-0.03921	0.00000
114 BB	70.2604	2.53239	2.47740	3.35634	8.07907	-0.00973	0.00000	0.8049	1.04029	-1.93778	0.00443	0.00000
115 OS8	70.9824	2.57542	2.48950	2.17756	11.18403	-0.00653	0.00000	0.8049	0.59238	-2.36272	0.00443	0.00000
116 QD	71.2824	2.59860	2.49359	2.00371	11.90718	-0.00539	0.00000	0.8049	-0.00079	0.00288	0.00319	0.00000
117 QD	71.5824	2.62178	2.49769	2.17855	11.18072	-0.00460	0.00000	0.8049	-0.59416	2.36777	0.00215	0.00000
118 OO1	76.7609	2.74560	2.78043	24.98728	2.50293	0.00656	0.00000	0.8049	-3.81036	-0.69202	0.00215	0.00000
119 QF1	77.0609	2.74746	2.79768	25.86327	3.13163	0.00701	0.00000	0.8049	-0.94539	-1.44281	0.00087	0.00000
120 QF1	77.3609	2.74937	2.81083	23.89490	4.30001	0.00708	0.00000	0.8049	5.49226	-2.52458	-0.00045	0.00000
121 OO2	79.3609	2.77383	2.84437	7.14287	21.25741	0.00617	0.00000	0.8049	2.88376	-5.94112	-0.00045	0.00000
122 QD1	79.6609	2.78124	2.84649	5.93419	23.46467	0.00624	0.00000	0.8049	1.23274	-1.24206	0.00089	0.00000
123 QD1	79.9609	2.78962	2.84853	5.59814	22.68365	0.00671	0.00000	0.8049	-0.08820	3.78837	0.00230	0.00000
124 OO3	81.9609	2.84269	2.86948	6.67101	10.23726	0.01131	0.00000	0.8049	-0.44824	2.43482	0.00230	0.00000
125 QF2	82.2609	2.84977	2.87445	6.75726	9.11199	0.01183	0.00000	0.8049	0.16352	1.35263	0.00117	0.00000
126 QF2	82.5609	2.85695	2.87988	6.47859	8.58221	0.01201	0.00000	0.8049	0.75631	0.43049	0.00000	0.00000
127 OO4	85.6778	2.96001	2.94458	4.12123	7.24041	0.01201	0.00000	0.8049	0.00000	0.00000	0.00000	0.00000
128 SYM	85.6778	2.96001	2.94458	4.12123	7.24041	0.01201	0.00000	0.8049	0.00000	0.00000	0.00000	0.00000
129 REFL	171.3556	5.92001	5.88915	2.00352	11.89684	0.39713	0.00000	1.6098	0.00000	0.00000	0.00000	0.00000

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CIRCUMFERENCE = 342.7112 M          THETX = 6.28318531 RAD      NUX = 11.8403
RAD = 54.5442 M          THETY = 0.00000000 RAD      NUY = 11.77830
(DS/S)/(DP/P) = 0.0093946          TGAM=( 1.0.31719, 0.00000)
                                         0.00000)

MAXIMA --- BETX( 119) = 25.86327   BETY( 122) = 23.46467   XEQ( 42) =
MINIMA --- BETX( 129) = 2.00352    BETY( 18) = 2.10308   XEQ( 114) =
                                         0.00000

SEXTOPOLE STRENGTHS ----- KSF = 0.88125034E+00   KSD = -0.17223209E+01
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SYNCH RUN MEB 12:03:37 MEDIUM ENERGY BOOSTER OF SSC INJECTOR COMPLEX  
8-AUG-88 9.81, 9.87

SYNCH VERSION VAX 8704

8 Aug 88 Modified from LKC's data

New tunes 9.81, 9.87

***	PC	=	// 100.0
***	BRHO	=	// 333.564095
***	B0	=	// 1.70117291
***	RHO	=	// BRHO /
***	RHOI	=	// 1.
***	BRO	=	// 1.0

-- BEAMLINES

***	.B	BML	// OO	B	O	B	O
***	.BB	BML	// OS	B	OS		
***	.DBF	BML	// QD	SD	.B	QF	
***	.FBD	BML	// QF	SF	.B	QD	
***	.DF1	BML	// DBF	.FBD			
***	.DF1	BML	// QD	.BB	QF		
***	.DHF	BML	// QF	.BB	QD		
***	.FHD	BML	// .DHF	.FHD			
***	.DF2	BML	// .DHF	QF	OS		
***	.DF3	BML	// OO1	QD1	B		
***	.DFO	BML	// .DF1	.DF1	QF1	SYM	
***	.SPL	BML	// .DF1	.DF1	QF1		
***					DF1	DF2	DF3
***					DFO		

-- ARC CELLS

***	SYM	DRF	///	0.5			
***	LQ	=	///	9.625			
***	LB	=	///	0.5			
***	O	DRF	///	1.4			
***	OO	DRF	///	5.95121			
***	OS	DRF	///	12.8			
***	OO1	DRF	///	22.35			
***	OO2	DRF	///	10.			
***	OO3	DRF	///	LB	0.	BRO	RHOI
***	B	MAG	///	0.00000000			\$
***	SXKF	PARA	///	0.00000000			
***	SXKD	PARA	///	0.00000000			
***	SF	SXTD	///	0.	SXKF	BRO	
***	SD	SXTD	///	0.	SXKD	BRO	
***	QF	MAG	///	LQ	KF	BRO	
***	OD	MAG	///	LQ	KD	BRO	
***	QD1	MAG	///	LQ	KD1	BRO	
***	QF1	MAG	///	LQ	KF1	BRO	
***	KF	PARA	///	0.06383886344			
***	KD	PARA	///	-0.065656002323			
***	KD1	PARA	///	-0.049929646			
***	KF1	PARA	///	0.032909545			
***	LOO1	PARA	///	12.8			
***	LOO2	PARA	///	22.35			
***	CF1	MM	///	.DF1			
***	MEBS	BEST	1	-2 //	.SPL	SF	SD

## BETAPTRON FUNCTIONS THRU .SPL

PAGE 1

POS	S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHYA	DSEQ	DYEQ
0	0.0000	0.00000	0.00000	13.12015	77.07276	2.82450	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1 QD	0.5000	0.00603	0.00104	13.35585	75.81182	2.84771	0.00000	-0.47396	2.49613	0.09298	0.00000	0.00000
2 SD	0.5000	0.00603	0.00104	13.35585	75.81182	2.84771	0.00000	-0.47396	2.49613	0.09298	0.00000	0.00000
3 OO	1.9000	0.02187	0.00412	14.86267	69.01558	2.97787	0.00000	-0.60234	2.36262	0.09298	0.00000	0.00000
4 B	11.5250	0.09124	0.03681	34.94068	32.25585	4.10860	0.00000	0.1720	-1.48453	1.45166	0.14207	0.00000
5 O	12.0250	0.09347	0.03934	36.44813	30.83127	4.17964	0.00000	0.1720	-1.53038	1.40350	0.14207	0.00000
6 B	21.6500	0.12305	0.12020	74.38375	12.69576	5.78273	0.00000	0.4147	-2.41257	0.47844	0.19117	0.00000
7 O	22.1500	0.12410	0.12658	76.81925	12.24152	5.87832	0.00000	0.4147	-2.45842	0.43004	0.19117	0.00000
8 OF	22.6500	0.12513	0.13316	78.05489	12.0264	5.92680	0.00000	0.4147	0.000030	0.00001	0.00251	0.00000
9 QF	23.1500	0.12615	0.13974	76.81866	12.24150	5.88082	0.00000	0.4147	2.45899	-0.43002	-0.18618	0.00000
10 SF	23.1500	0.12615	0.13974	76.81866	12.24150	5.88082	0.00000	0.4147	2.45899	-0.43002	-0.18618	0.00000
11 OO	24.5500	0.12919	0.15702	70.11327	13.6327	5.62057	0.00000	0.4147	2.33057	-0.56553	-0.18618	0.00000
12 B	34.1750	0.16087	0.23144	33.75899	33.44287	4.06505	0.00000	0.6505	1.44801	-1.48992	-0.13709	0.00000
13 O	34.6750	0.16328	0.23377	32.33391	34.95887	3.99651	0.00000	0.6505	1.40215	-1.53806	-0.13709	0.00000
14 B	44.3000	0.23841	0.26420	13.84458	73.36416	2.91377	0.00000	0.8182	0.51959	-2.44749	-0.08799	0.00000
15 O	44.8000	0.24427	0.26527	13.34792	75.63547	2.86977	0.00000	0.8182	0.47373	-2.49514	-0.08799	0.00000
16 QD	45.3000	0.25030	0.26630	13.11234	77.08912	2.84924	0.00000	0.8182	0.00000	0.00158	0.00575	0.00000
17 QD	45.8000	0.25633	0.26734	13.34792	75.63234	2.87554	0.00000	0.8182	-0.47373	2.49819	0.09959	0.00000
18 SD	45.8000	0.25633	0.26734	13.34792	75.83234	2.87554	0.00000	0.8182	-0.47373	2.49819	0.09959	0.00000
19 OQ	47.2000	0.27218	0.27042	14.85415	69.02456	3.01497	0.00000	0.8182	-0.60215	2.36451	0.09959	0.00000
20 B	56.8250	0.34158	0.30312	34.93215	32.24222	4.20935	0.00000	0.9936	-1.48471	1.45242	0.14869	0.00000
21 O	57.3250	0.34381	0.30565	36.43980	30.81391	4.28370	0.00000	0.9936	-1.53038	1.40420	0.14869	0.00000
22 B	66.9500	0.37340	0.38660	74.38277	12.67591	5.95045	0.00000	1.2429	-2.41213	1.47799	0.19779	0.00000
23 O	67.4500	0.37445	0.39300	76.81883	12.22214	6.04934	0.00000	1.2429	-2.45900	0.42954	0.19779	0.00000
24 QF	67.9500	0.37547	0.39959	78.05506	12.00848	6.09976	0.00000	1.2429	-0.00030	0.00006	0.00363	0.00000
25 QF	68.4500	0.37650	0.40618	76.81942	12.22202	6.05296	0.00000	1.2429	2.45842	-0.42942	-0.19058	0.00000
26 SF	68.4500	0.37650	0.40618	76.81942	12.22202	6.05296	0.00000	1.2429	2.45842	-0.42942	-0.19058	0.00000
27 OQ	69.8500	0.37953	0.42348	70.11556	13.61432	5.78615	0.00000	1.2429	2.33005	-0.56509	-0.19058	0.00000
28 B	79.4750	0.41121	0.49799	33.76779	33.42383	4.18874	0.00000	1.4858	1.44786	-1.49057	-0.14148	0.00000
29 O	79.9750	0.41362	0.50031	32.34286	34.93850	4.111800	0.00000	1.4858	1.40201	-1.53876	-0.14148	0.00000
30 B	89.6000	0.48872	0.53076	13.855274	73.36961	2.99296	0.00000	1.6585	0.51981	-2.44927	-0.09239	0.00000
31 O	90.1000	0.49457	0.53182	13.35585	75.84273	2.94677	0.00000	1.6585	0.47397	-2.49697	-0.09239	0.00000
32 QD	90.6000	0.50060	0.53286	13.12015	77.02809	2.92467	0.00000	1.6585	0.00001	0.00386	0.00000	0.00000
33 QD	91.1000	0.50663	0.53390	13.35584	75.84275	2.95064	0.00000	1.6585	-0.47396	2.49695	0.10016	0.00000
34 SD	91.1000	0.50663	0.53390	13.35584	75.84275	2.95064	0.00000	1.6585	-0.47396	2.49695	0.10016	0.00000
35 OO	92.5000	0.52247	0.53698	14.86266	69.03826	3.09087	0.00000	1.6585	0.00000	2.36340	0.10016	0.00000
36 B	102.1250	0.59184	0.56966	34.94060	32.26848	4.29073	0.00000	1.8377	-1.48453	1.45223	0.14926	0.00000
37 O	102.6250	0.59407	0.57219	36.44805	30.84033	4.36536	0.00000	1.8377	-1.5037	1.40406	0.14926	0.00000
38 B	112.2500	0.62365	0.65303	74.38359	12.69614	6.03759	0.00000	2.0912	-2.41257	0.47878	0.19836	0.00000
39 O	112.7500	0.62470	0.65942	76.81908	12.24156	6.13677	0.00000	2.0912	-2.45841	0.43037	0.19836	0.00000
40 QF	113.2500	0.62573	0.66600	78.05471	12.02735	6.18678	0.00000	2.0912	0.000030	0.000334	0.00141	0.00000
41 QF	113.7500	0.62675	0.67257	76.81849	12.24088	6.13818	0.00000	2.0912	2.45899	-0.42967	-0.19555	0.00000
42 SF	113.7500	0.62675	0.67257	76.81849	12.24088	6.13818	0.00000	2.0912	2.45899	-0.42967	-0.19555	0.00000
43 OO	115.1500	0.62979	0.68985	70.11311	13.63363	5.86441	0.00000	2.0912	2.33057	-0.56516	-0.19555	0.00000
44 B	124.7750	0.66147	0.76429	33.75892	33.43226	4.21918	0.00000	2.33368	1.44801	-1.48937	-0.14645	0.00000

## BETATRON FUNCTIONS THRU .SPL

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POS	S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DXEQ	DYEQ
45 O	125.2750	0.66388	0.766662	32.33385	34.94569	4.14596	0.00000	2.3368	1.40215	-1.53750	-0.14645	0.00000
46 B	134.9000	0.73901	0.79706	13.84457	73.34031	2.97310	0.00000	5.01956	-2.44675	-0.09736	0.00000	0.00000
47 O	135.4000	0.74487	0.79813	13.34791	75.81088	2.92442	0.00000	2.5096	0.47372	-2.49438	-0.09736	0.00000
48 OD	135.9000	0.75090	0.79917	13.11234	77.06417	2.89964	0.00000	2.5096	0.00000	0.00152	-0.00189	0.00000
49 QD	136.4000	0.75693	0.80021	13.34792	75.80786	2.92252	0.00000	2.5096	-0.47373	2.49733	0.09354	0.00000
50 SD	136.4000	0.75693	0.80021	13.34792	75.80786	2.92252	0.00000	2.5096	-0.47373	2.49733	0.09354	0.00000
51 OO	137.8000	0.77278	0.80329	14.85416	69.00245	3.05348	0.00000	2.5096	-0.60216	2.36368	0.09354	0.00000
52 B	147.4250	0.84218	0.83600	34.93222	32.23371	4.18967	0.00000	2.6855	-1.48471	1.45184	0.14264	0.00000
53 O	147.9250	0.84441	0.83852	36.43987	30.80597	4.26099	0.00000	2.6855	-1.53058	1.40364	0.14264	0.00000
54 B	157.5500	0.87400	0.91949	74.38293	12.67639	5.86955	0.00000	2.9323	-2.41314	0.47769	0.19174	0.00000
55 O	158.0500	0.87505	0.92588	76.81900	12.22293	5.96542	0.00000	2.9323	-2.45901	0.42924	0.19174	0.00000
56 QF	158.5500	0.87607	0.93247	78.00957	12.00524	6.01349	0.00000	2.9323	-0.00030	-0.00026	0.00030	0.00000
57 QF	159.0500	0.87710	0.93906	76.81959	12.23445	5.96572	0.00000	2.9323	2.45843	-0.42977	-0.19114	0.00000
58 SF	159.5000	0.87710	0.93906	76.81959	12.23445	5.96572	0.00000	2.9323	2.45843	-0.42977	-0.19114	0.00000
59 OO	160.4500	0.88013	0.95636	70.11571	13.61677	5.69813	0.00000	2.9323	2.33006	-0.56546	-0.19114	0.00000
60 B	170.0750	0.91181	1.03085	33.76786	33.43481	4.09538	0.00000	3.1707	1.44786	-1.49107	-0.14204	0.00000
61 O	170.5750	0.91422	1.03318	32.34292	34.94998	4.02436	0.00000	3.1707	1.40201	-1.53928	-0.14204	0.00000
62 B	180.2000	0.98932	1.06361	13.85274	73.39221	2.89397	0.00000	3.3386	0.51982	-2.44991	-0.09294	0.00000
63 O	180.7000	0.99517	1.06467	13.35585	75.86597	2.84750	0.00000	3.3386	0.7397	-2.49761	-0.09294	0.00000
64 QD	181.2000	1.00120	1.06571	13.12015	77.12160	2.82431	0.00000	3.3386	0.00000	0.00011	0.00003	0.00000
65 QD	181.7000	1.00723	1.06675	13.35584	75.86575	2.84753	0.00000	3.3386	-0.47396	2.49783	0.09300	0.00000
66 SD	181.7000	1.00723	1.06675	13.35584	75.86575	2.84753	0.00000	3.3386	-0.47396	2.49783	0.09300	0.00000
67 OO	183.1000	1.02307	1.06983	14.86265	69.00507	2.97773	0.00000	3.3386	-0.60233	2.36424	0.09300	0.00000
68 B	192.7250	1.09244	1.10250	34.94053	32.27551	4.10867	0.00000	3.5107	-1.48152	1.45280	0.14210	0.00000
69 O	193.2250	1.09467	1.10502	36.44798	30.84681	4.17972	0.00000	3.5107	-1.53037	1.40461	0.14210	0.00000
70 B	202.8500	1.12425	1.18587	74.38342	12.69481	5.78304	0.00000	3.7533	-2.41256	0.47904	0.19119	0.00000
71 O	203.3500	1.12530	1.19225	76.81890	12.23999	5.87863	0.00000	3.7533	-2.45811	0.43062	0.19119	0.00000
72 QF	203.8500	1.12633	1.19883	78.05454	12.02550	5.92713	0.00000	3.7533	0.00030	0.00063	0.00253	0.00000
73 QF	204.3500	1.12735	1.20541	76.81831	12.23871	5.88115	0.00000	3.7533	2.45898	-0.4832	-0.18618	0.00000
74 SF	204.3500	1.12735	1.20541	76.81831	12.23871	5.88115	0.00000	3.7533	2.45898	-0.42932	-0.18618	0.00000
75 OO	205.7500	1.13039	1.22270	70.11295	13.63046	5.62050	0.00000	3.7533	2.33056	-0.56479	-0.18618	0.00000
76 B	215.3750	1.16207	1.29715	33.75886	33.42140	4.06540	0.00000	4.1569	3.75892	-1.48893	-0.13708	0.00000
77 O	215.8750	1.16448	1.29948	32.33378	34.93439	3.99686	0.00000	3.9892	1.40214	-1.53706	-0.13708	0.00000
78 B	225.5000	1.23961	1.32994	13.84457	73.31992	2.91414	0.00000	4.1569	0.51959	-2.44624	-0.08799	0.00000
79 O	226.0000	1.24547	1.33100	13.34791	75.78997	2.87015	0.00000	4.1569	0.47372	-2.49387	-0.08799	0.00000
80 OD	226.5000	1.25150	1.33204	13.11234	77.04310	2.84962	0.00000	4.1569	-0.00001	0.00134	0.00577	0.00000
81 QD	227.0000	1.25753	1.33308	13.34792	75.78732	2.87593	0.00000	4.1569	-0.47373	2.49646	0.09962	0.00000
82 SD	227.0000	1.25753	1.33308	13.34792	75.78732	2.87593	0.00000	4.1569	-0.47373	2.49646	0.09962	0.00000
83 OO	228.4000	1.27338	1.33616	14.85417	68.98427	3.01540	0.00000	4.1569	-0.60216	2.36286	0.09962	0.00000
84 B	238.0250	1.34278	1.36888	34.93230	32.2845	4.21004	0.00000	4.3323	-1.48472	1.45132	0.14872	0.00000
85 O	238.5250	1.34501	1.37141	36.43995	30.80123	4.28440	0.00000	4.3323	-1.53058	1.40313	0.14872	0.00000
86 B	248.1500	1.37460	1.45237	74.38310	12.67850	5.95141	0.00000	4.5817	-2.41314	0.47748	0.19781	0.00000
87 O	248.6500	1.37565	1.45877	76.81918	12.2523	6.0531	0.00000	4.5817	-2.45505	0.42905	0.19781	0.00000
88 QF	249.1500	1.37667	1.46535	78.05541	12.01209	6.10074	0.00000	4.5817	-0.00050	-0.00053	0.00363	0.00000
89 QF	249.6500	1.37770	1.47194	76.81977	12.2626	6.05393	0.00000	4.5817	2.45843	-0.43011	-0.19062	0.00000

## BETATRON FUNCTIONS THRU .SPL

PAGE 3

POS	S(M)	MUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHY	DXFQ	DYFQ
90 SF	249.6500	1.37770	1.47194	76.81977	12.22626	6.05393	0.00000	4.5817	2.45843	-0.43011	-0.19062	0.00000
91 OS	251.0500	1.38073	1.48924	70.11587	13.62053	5.78707	0.00000	4.5817	2.33006	-0.56580	-0.19062	0.00000
92 B	260.6750	1.41241	1.56370	33.76793	33.44510	4.18932	0.00000	4.8246	1.44786	-1.49142	-0.14152	0.00000
93 O	261.1750	1.41482	1.56603	32.34299	34.96062	4.11856	0.00000	4.8246	1.40202	-1.53962	-0.14152	0.00000
94 B	270.8000	1.48992	1.59645	13.85275	73.40953	2.99319	0.00000	4.9973	0.51982	-2.45026	-0.09242	0.00000
95 O	271.3000	1.49577	1.59751	13.35584	75.88364	2.94698	0.00000	4.9973	0.47397	-2.49796	-0.09242	0.00000
96 QD	271.8000	1.50180	1.59855	13.12015	77.13933	2.92486	0.00000	4.9973	0.00001	0.00035	0.00000	0.00000
97 QD	272.3000	1.50783	1.59959	13.35584	75.88296	2.95081	0.00000	4.9973	0.47396	2.49864	0.10014	0.00000
98 SD	272.3000	1.50783	1.59959	13.35584	75.88296	2.95081	0.00000	4.9973	0.47396	2.49864	0.10014	0.00000
99 OS	273.7000	1.52367	1.60267	14.86264	69.07386	3.09101	0.00000	4.9973	0.60233	2.36500	0.10014	0.00000
100 B	283.3250	1.59304	1.63534	34.94046	32.27877	4.29065	0.00000	5.1766	-1.48452	1.45326	0.14924	0.00000
101 O	283.8250	1.59527	1.63786	36.44790	30.84962	4.36527	0.00000	5.1766	-1.53036	1.40505	0.14924	0.00000
102 B	293.4500	1.62485	1.71871	74.38325	12.69201	6.03728	0.00000	5.4300	-2.41255	0.47918	0.19833	0.00000
103 O	293.9500	1.62590	1.72510	76.81873	12.23706	6.13645	0.00000	5.4300	-2.45840	0.43074	0.19833	0.00000
104 QF	294.4500	1.66293	1.73168	78.05436	12.02241	6.18645	0.00000	5.4300	0.00030	0.00083	0.00140	0.00000
105 QF	294.9500	1.62795	1.73826	76.81814	12.23537	6.13785	0.00000	5.4300	2.45898	-0.42902	-0.19555	0.00000
106 SF	294.9500	1.62795	1.73826	76.81814	12.23537	6.13785	0.00000	5.4300	2.45898	-0.42902	-0.19555	0.00000
107 OS	296.3500	1.63099	1.75555	70.11280	13.62629	5.86408	0.00000	5.4300	2.33055	-0.56450	-0.19555	0.00000
108 B	305.9750	1.66267	1.83003	33.75879	33.41211	4.21883	0.00000	5.6756	1.44800	-1.48869	-0.14646	0.00000
109 O	306.4750	1.66508	1.83236	32.33372	34.92487	4.14560	0.00000	5.6756	1.40214	-1.53682	-0.14646	0.00000
110 B	316.1000	1.74021	1.86282	13.84456	73.30640	2.97272	0.00000	5.8484	0.51959	-2.44606	-0.09736	0.00000
111 O	316.6000	1.74607	1.86389	13.34791	75.77628	2.92404	0.00000	5.8484	0.47372	-2.49369	-0.09736	0.00000
112 QD	317.1000	1.75210	1.86492	13.11234	77.02946	2.89926	0.00000	5.8484	-0.00001	0.00106	-0.00190	0.00000
113 QD	317.6000	1.75813	1.86596	13.34793	75.77118	2.92213	0.00000	5.8484	-0.47374	2.49575	0.09352	0.00000
114 OS	323.5512	1.81427	1.88146	22.23539	49.44743	3.47867	0.00000	5.8484	-1.01965	1.92801	0.09352	0.00000
115 B	333.1762	1.86069	1.92962	21.09664	4.61460	0.00000	6.0451	-1.90221	1.01398	0.14261	0.00000	
116 OS	339.1274	1.87600	1.98951	12.3271	5.46333	0.00000	6.0451	-2.44813	0.44185	0.14261	0.00000	
117 QF	339.6274	1.87703	1.99591	77.47151	12.20979	5.49091	0.00000	6.0451	-0.00815	0.06363	-0.03244	0.00000
118 QF	340.1274	1.87807	2.00247	76.25293	12.1985	5.43097	0.00000	6.0451	2.43234	-0.42871	-0.20699	0.00000
119 OS	346.0786	1.89335	2.06269	50.51455	20.89825	4.19915	0.00000	6.0451	1.89256	-0.99594	-0.20699	0.00000
120 B	355.7036	1.93942	2.11140	22.49342	48.82673	2.44388	0.00000	6.2063	1.01990	-1.90222	-0.15789	0.00000
121 OS	361.6548	1.99475	2.12709	13.56652	74.81776	1.50424	0.00000	6.2063	0.48011	-2.46513	-0.15789	0.00000
122 QD	362.1548	2.00068	2.12815	13.32784	76.05817	1.43744	0.00000	6.2063	-0.00014	-0.00210	-0.10967	0.00000
123 QD	362.6548	2.00662	2.12920	13.56680	74.82191	1.39427	0.00000	6.2063	-0.48040	2.46107	-0.06325	0.00000
124 OS	368.6061	2.06194	2.14489	22.49776	48.86957	1.01783	0.00000	6.2063	-1.02030	1.89978	-0.06325	0.00000
125 B	378.2311	2.10800	2.19350	50.52820	20.96262	0.64543	0.00000	6.2452	-1.89313	0.99615	-0.01416	0.00000
126 OS	384.1823	2.12328	2.25349	76.27403	12.47211	0.56118	0.00000	6.2452	-2.43302	0.43054	-0.01416	0.00000
127 QF	384.6823	2.12431	2.25994	77.49296	12.26097	0.54965	0.00000	6.2452	-0.00815	-0.00602	-0.03191	0.00000
128 QF	385.1823	2.12534	2.26639	76.25791	12.48428	0.52935	0.00000	6.2452	2.44880	-0.44298	-0.04915	0.00000
129 OS	391.1335	2.14065	2.32607	50.36071	21.15036	0.23683	0.00000	6.2452	1.90278	-1.0321	-0.04915	0.00000
130 B	400.7585	2.18706	2.37416	22.23980	49.45695	0.00011	0.00000	6.2491	1.02005	-1.92419	-0.00006	0.00000
131 OQ1	413.5585	2.33801	2.40139	11.15889	114.29452	-0.00060	0.00000	6.2491	-0.15435	-3.14125	-0.00006	0.00000
132 OQ1	414.0585	2.34506	2.40208	11.47743	116.01261	-0.00063	0.00000	6.2491	-0.48538	-0.28064	-0.00007	0.00000
133 OQ1	414.5585	2.35182	2.40277	12.13775	114.85114	-0.00067	0.00000	6.2491	-0.84075	2.59392	-0.00009	0.00000
134 OQ2	436.9085	2.45141	2.46236	119.96382	32.51620	-0.00263	0.00000	6.2491	-3.98369	1.08997	-0.00009	0.00000

## BETATRON FUNCTIONS THRU .SPL,

PAGE 4

POS	S (M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEO(M)	ALPHA/X	ALPHA/Y	DSEQ	DYEQ
135 QF1	437.4085	2.45206	2.46484	122.97647	31.70537	-0.00266	0.00000	6.2491	-2.02507	0.53614	-0.00004	0.00000
136 QF1	437.9085	2.45271	2.46737	123.99179	31.43803	-0.00268	0.00000	6.2491	0.00000	0.00000	0.00000	0.00000
137 SYM	437.9085	2.45271	2.46737	123.99179	31.43803	-0.00268	0.00000	6.2491	0.00000	0.00000	0.00000	0.00000
138 REFL	875.8169	4.90542	4.93473	13.12015	77.07276	2.82450	0.00000	12.4981	0.00000	0.00000	0.00000	0.00000
CIRCUMFERENCE	1751.6339 M	THETAX =	6.28318532 RAD	NUX =	9.81083	DNUX/(DP/P) =	-12.53215					
RADIUS	278.7812 M	THETY =	0.00000000 RAD	NUY =	9.86946	DNUY/(DP/P) =	-12.69107					
(DS/S)/(DP/P) =	0.0142703	TGAM= (	8.37113, 0.00000)									
MAXIMA	--- BETX( 137) =	BETY( 132) =	116.01261	XEQ( 40) =	6.18678	YEQ( 138) =	0.00000					
MINIMA	--- BETX( 131) =	BETY( 24) =	12.00848	XEQ( 137) =	-0.00268	YEQ( 138) =	0.00000					
SEXTUPOLE STRENGTHS	---	KSF = 0.14754516E-01	KSD = -0.30881045E-01									
*** PLT BEP 2 1 // MEBS		0 136	200.	0.	10.							

SYNCH RUN HEB HIGH ENERGY BOOSTER OF SSC INJECTOR COMPLEX  
8-AUG-88 16:15:33

SYNCH VERSION VAX.8704

8 Aug 88 Modification of LKC's data  
New tunes 29.23, 22.29

***	PC	=	// 1000.0
***	BRHO	=	// 3335.64095
***	B0	=	// 5.65588575
***	RHO	=	BRHO /
***	RHOI	=	// 1.
***	BR0	=	// 1.0

-- BEAMLINES

***	.B	BML	// O	B	O	B	OO
***	.DBF	BML	// QD	.B	SF	QF	
***	.FBD	BML	// QF	.B	SD	QD	
***	.DF1	BML	// .FBD	.DBF			
***	.DF3	BML	// .FBD	QD	O	B	
***	.DF4	BML	// OO1	QF1	QF1	OO2	QD1
***	.DF5	BML	// OO3	QF2	QF2	SYM	
***	.SPL	BML	// .DF1	.DF1	.DF1	DF3	DF4 .DF5

-- ARC CELLS

```

***      SYM      DRF      0.75      //|      0.75
***      LQ       =        //|      9.65      //|      9.65
***      LB       =        //|      .5       //|      .5
***      O        DRF      //|      2.0       //|      2.0
***      CO       DRF      //|      3.       //|      3.
***      OO1      DRF      //|      LB      0.00000000      LB      0.
***      B        MAG      PARA     0.00000000      BRO      RHO]
***      SXKF     PARA    //|      0.00000000      BRO      BRO
***      SXKD     PARA    //|      0.00000000      BRO      BRO
***      SF       SXTP    //|      0.00000000      BRO      BRO
***      SD       SXTP    //|      0.00000000      BRO      BRO
***      QF       MAG      MAG      //|      0.00000000      BRO      BRO
***      QD       MAG      MAG      //|      0.00000000      BRO      BRO
***      QD1      MAG      MAG      //|      0.00000000      BRO      BRO
***      QF1      MAG      MAG      //|      0.00000000      BRO      BRO
***      QF2      MAG      MAG      //|      0.00000000      BRO      BRO
***      OO1      DRF      DRF      //|      0.00000000      BRO      BRO
***      OO2      DRF      DRF      //|      0.00000000      BRO      BRO
***      OO3      DRF      DRF      //|      0.00000000      BRO      BRO
***      OO4      DRF      DRF      //|      0.00000000      BRO      BRO
***      KF       PARA    PARA     0.039587037779      BRO      BRO
***      KD       PARA    PARA     -0.035694537291      BRO      BRO
***      KD1      PARA    PARA     -0.029505283      BRO      BRO
***      KF1      PARA    PARA     0.039246981      BRO      BRO
***      KF2      PARA    PARA     0.036085791      BRO      BRO
***      LOO1     PARA    PARA     3.       //|      3.
***      LOO2     PARA    PARA     26.108101571      BRO      BRO
***      LOO3     PARA    PARA     10.278989480      BRO      BRO
***      LOO4     PARA    PARA     23.914508949      BRO      BRO
***      TSPL     TRKB   //|      .SPL CF1      BRO      BRO
***      END      0       0       //|      0.00000000      BRO      BRO
***      HEBS     BEST    1       -6 //|      SPL      SF      SD

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## BETATRON FUNCTIONS THRU .SPL

PAGE 1

POS	S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DXEQ	DYEQ
0	0.0000	0.00000	0.00000	76.61054	18.75563	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1 QF	0.7500	0.00157	0.00631	74.92452	19.20660	0.00000	0.00000	0.223133	-0.60575	0.00000	0.00000	0.00000
2 O	1.2500	0.00265	0.01039	72.71314	19.83014	0.00000	0.00000	2.19143	-0.64133	0.00000	0.00000	0.00000
3 B	10.9000	0.03209	0.06692	37.85079	40.17459	0.07895	0.00000	1.42141	-1.32714	0.01636	0.00000	0.00000
4 O	11.4000	0.03423	0.06894	36.44932	40.17332	0.08713	0.00000	1.38151	-1.36269	0.01636	0.00000	0.00000
5 B	21.0500	0.09716	0.09743	17.21762	73.08145	0.32397	0.00000	0.61150	-2.04702	0.03273	0.00000	0.00000
6 O	23.0500	0.11696	0.10156	15.09082	81.55362	0.38942	0.00000	0.45190	-2.18906	0.03273	0.00000	0.00000
7 SD	23.0500	0.11696	0.10156	15.09082	81.55362	0.38942	0.00000	0.45190	-2.18906	0.03273	0.00000	0.00000
8 QD	23.8000	0.12499	0.10300	14.75407	83.20659	0.41796	0.00000	0.00009	-0.00014	0.04351	0.00000	0.00000
9 QD	24.5500	0.13302	0.10445	15.09053	81.55403	0.45491	0.00000	0.0036	-0.45171	2.18879	0.05518	0.00000
10 O	25.0500	0.13822	0.10544	15.56219	79.38299	0.48250	0.00000	0.0036	-0.49160	2.15329	0.05518	0.00000
11 B	34.7000	0.20882	0.13141	32.47903	44.42109	1.09390	0.00000	0.0163	-1.26152	1.46922	0.07154	0.00000
12 O	35.2000	0.21122	0.13324	33.76050	42.96965	1.12967	0.00000	0.0163	-1.30141	1.43367	0.07154	0.00000
13 B	44.8500	0.24391	0.18415	66.30600	21.91361	1.89897	0.00000	0.0408	-2.07133	0.74801	0.08790	0.00000
14 O	46.8500	0.24843	0.19969	74.91046	19.20623	2.07478	0.00000	0.0408	-2.23090	0.60568	0.08790	0.00000
15 SF	46.8500	0.24843	0.19969	74.91046	19.20623	2.07478	0.00000	0.0408	-2.23090	0.60568	0.08790	0.00000
16 QF	47.6000	0.25000	0.20600	76.59617	18.75536	2.11741	0.00000	0.0408	-2.23090	0.60568	0.08790	0.00000
17 QF	48.3500	0.25157	0.21232	74.91046	19.20642	2.11297	0.00000	0.0408	-2.23090	0.60580	0.08790	0.00000
18 O	48.8500	0.25265	0.21640	72.69951	19.83001	2.09429	0.00000	0.0408	-2.19101	0.64139	0.08790	0.00000
19 B	58.5000	0.28210	0.27293	37.84426	38.82977	1.81271	0.00000	0.0726	1.42109	-1.32723	-0.02100	0.00000
20 O	59.0000	0.28424	0.27494	36.44311	40.17479	1.80221	0.00000	0.0726	1.38120	-1.36279	-0.02100	0.00000
21 B	68.6500	0.34718	0.30344	17.21651	73.08523	1.67853	0.00000	0.1008	0.61128	-2.04716	-0.00464	0.00000
22 O	70.6500	0.36698	0.30756	15.09053	81.55797	1.66925	0.00000	0.1008	0.45171	-2.18921	-0.00464	0.00000
23 SD	70.6500	0.36698	0.30756	15.09053	81.55797	1.66925	0.00000	0.1008	0.45171	-2.18921	-0.00464	0.00000
24 QD	71.4000	0.37501	0.30900	14.75407	83.21108	1.68255	0.00000	0.1008	-0.00009	-0.00017	0.04015	0.00000
25 QD	72.1500	0.38304	0.31045	15.09082	81.55847	1.72969	0.00000	0.1008	-0.45190	2.18888	0.08575	0.00000
26 O	72.6500	0.38823	0.31144	15.56267	79.38873	1.72556	0.00000	0.1008	0.49180	1.51538	0.08575	0.00000
27 B	82.3000	0.45883	0.33741	32.48433	44.42380	2.67898	0.00000	0.1370	-1.26182	1.46922	0.10212	0.00000
28 O	82.8000	0.46123	0.33924	33.76609	42.97228	2.73004	0.00000	0.1370	-1.30172	1.43375	0.10212	0.00000
29 B	92.4500	0.49391	0.39015	66.31840	21.91479	3.79436	0.00000	0.1902	-2.07173	0.74808	0.11848	0.00000
30 O	94.4500	0.49843	0.40569	74.92452	19.20714	4.03131	0.00000	0.1902	-2.23133	0.60575	0.11848	0.00000
31 SF	94.4500	0.49843	0.40569	74.92452	19.20714	4.03131	0.00000	0.1902	-2.23133	0.60575	0.11848	0.00000
32 QF	95.2000	0.50000	0.41200	76.61054	18.75618	4.07504	0.00000	0.1902	0.00000	-0.00002	-0.00209	0.00000
33 QF	95.9500	0.50157	0.41832	74.92452	19.20719	4.02819	0.00000	0.1902	2.23133	-0.60578	-0.12260	0.00000
34 O	96.4500	0.50265	0.442239	72.71134	19.83076	3.96689	0.00000	0.1902	2.19143	-0.64137	-0.12260	0.00000
35 B	106.1000	0.53209	0.47892	37.85079	38.82964	2.86277	0.00000	0.2459	1.42141	-1.32717	-0.10624	0.00000
36 O	106.6000	0.53423	0.48094	36.44932	40.17459	2.80965	0.00000	0.2459	1.38151	-1.36272	-0.10624	0.00000
37 B	116.2500	0.59716	0.50943	17.21762	73.08331	1.86343	0.00000	0.2839	0.61150	-2.04705	-0.08988	0.00000
38 O	118.2500	0.61696	0.51356	15.09082	81.55559	1.68367	0.00000	0.2839	0.45190	-2.18909	-0.08988	0.00000
39 SD	118.2500	0.61696	0.51356	15.09082	81.55559	1.68367	0.00000	0.2839	0.45190	-2.18909	-0.08988	0.00000
40 QD	119.0000	0.62499	0.51500	14.75407	83.20858	1.63297	0.00000	0.2839	0.00009	-0.00012	-0.04556	0.00000
41 QD	119.7500	0.63302	0.51644	15.09053	81.55594	1.61511	0.00000	0.2839	-0.45171	2.18887	-0.00215	0.00000
42 O	120.2500	0.63822	0.51743	15.56219	79.38483	1.61403	0.00000	0.2839	-0.49160	2.15336	-0.00215	0.00000
43 B	129.9000	0.70882	0.54341	32.47903	44.42172	1.67221	0.00000	0.3106	-1.26152	1.46927	0.01421	0.00000
44 O	130.4000	0.71122	0.54523	33.76605	42.97022	1.67931	0.00000	0.3106	-1.30141	1.43372	0.01421	0.00000

## BETATRON FUNCTIONS THRU .SPL

PAGE 2

POS	S(M)	NUX	NUY	BFTAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DXEQ	DYEQ
45 B	140.0500	0.74391	0.59615	66.30600	21.91344	1.89538	0.00000	0.3396	-2.07133	0.74804	0.03057	0.00000
46 00	142.0500	0.74843	0.61169	74.91046	19.20596	1.95653	0.00000	0.3396	-2.23090	0.60570	0.03057	0.00000
47 SF	142.0500	0.74843	0.61169	74.91046	19.20596	1.95653	0.00000	0.3396	-2.23090	0.60570	0.03057	0.00000
48 QF	142.8000	0.75000	0.61800	76.59617	18.75505	1.95763	0.00000	0.3396	-2.23090	0.60576	0.02764	0.00000
49 QF	143.5500	0.75157	0.62432	74.91046	19.20606	1.91522	0.00000	0.3396	-2.23090	0.60576	0.08524	0.00000
50 0	144.0500	0.75265	0.62839	72.69951	19.82961	1.87260	0.00000	0.3396	2.19101	-0.64135	-0.08524	0.00000
51 B	153.7000	0.78210	0.68493	37.84426	38.82850	1.12901	0.00000	0.3639	1.42109	-1.32718	-0.06888	0.00000
52 0	154.2000	0.78424	0.68694	36.44311	40.17346	1.09457	0.00000	0.3639	1.38120	-1.36274	-0.06888	0.00000
53 B	163.8500	0.84718	0.71544	17.21651	73.08280	0.50887	0.00000	0.3768	0.61128	-2.04710	-0.05252	0.00000
54 00	165.8500	0.86698	0.71956	15.09053	81.55528	0.40384	0.00000	0.3768	0.45171	-2.18914	-0.05252	0.00000
55 SD	165.8500	0.86698	0.71956	15.09053	81.55528	0.40384	0.00000	0.3768	0.45171	-2.18914	-0.05252	0.00000
56 QD	166.6000	0.87501	0.72101	14.75407	83.20835	0.36838	0.00000	0.3768	0.45190	-0.00018	0.04220	0.00000
57 QD	167.3500	0.88304	0.72245	15.09082	81.55581	0.34033	0.00000	0.3768	0.45190	2.18880	-0.03273	0.00000
58 0	167.8500	0.88823	0.72344	15.56267	79.38476	0.32397	0.00000	0.3768	0.49180	2.15330	-0.03273	0.00000
59 B	177.5000	0.95883	0.74942	32.48433	44.42256	0.08713	0.00000	0.3768	0.45171	-2.18914	-0.05252	0.00000
60 0	178.0000	0.96123	0.75124	33.76669	42.97109	0.07895	0.00000	0.3800	-1.30172	1.43369	-0.01636	0.00000
61 B	187.6500	0.99391	0.80215	66.31840	21.91456	0.00000	0.00000	0.3804	-2.07173	0.74804	0.00000	0.00000
62 00	189.6500	0.99843	0.81769	74.92452	19.20706	0.00000	0.00000	0.3804	-2.23133	0.60571	0.00000	0.00000
63 SF	189.6500	0.99843	0.81769	74.92452	19.20706	0.00000	0.00000	0.3804	-2.23133	0.60571	0.00000	0.00000
64 QF	190.4000	1.00000	0.82400	76.61054	18.75615	0.00000	0.00000	0.3804	-1.26182	1.46924	-0.01636	0.00000
65 QF	191.1500	1.00157	0.83032	74.92452	19.20721	0.00000	0.00000	0.3804	2.23133	-0.60581	0.00000	0.00000
66 0	191.6500	1.00265	0.83440	72.71314	19.83082	0.00000	0.00000	0.3804	2.19143	-0.64140	0.00000	0.00000
67 B	201.3000	1.03209	0.89092	37.85079	38.83058	0.07895	0.00000	0.3808	1.42141	-1.32722	0.01636	0.00000
68 0	201.8000	1.03429	0.89294	36.44932	40.17558	0.08713	0.00000	0.3808	1.38151	-1.36278	0.01636	0.00000
69 B	211.4500	1.09716	0.92113	17.21762	73.08559	0.32397	0.00000	0.3840	0.61150	-2.04713	0.03273	0.00000
70 00	213.4500	1.11169	0.92556	15.09082	81.55819	0.38942	0.00000	0.3840	0.45190	-2.18917	0.03273	0.00000
71 SD	213.4500	1.11169	0.92556	15.09082	81.55819	0.38942	0.00000	0.3840	0.45190	-2.18917	0.03273	0.00000
72 QD	214.2000	1.12499	0.92700	14.75407	83.21124	0.41796	0.00000	0.3840	0.00009	-0.00013	0.04351	0.00000
73 QD	214.9500	1.13302	0.92845	15.09053	81.55856	0.45491	0.00000	0.3840	-0.45171	2.18893	0.05518	0.00000
74 0	215.4500	1.13822	0.92943	15.56219	79.38739	0.48250	0.00000	0.3840	-0.49160	2.15342	0.05518	0.00000
75 B	225.1000	1.20882	0.95541	32.47903	44.42321	1.09390	0.00000	0.3967	-1.26152	1.46932	0.07154	0.00000
76 0	225.6000	1.21122	0.95723	33.76050	42.97166	1.12967	0.00000	0.3967	-1.30141	1.43377	0.07154	0.00000
77 B	235.2500	1.25157	1.00815	66.30600	21.91400	1.89897	0.00000	0.4212	-0.07133	0.74808	0.08790	0.00000
78 00	237.2500	1.24843	1.02369	74.91046	19.20637	2.07478	0.00000	0.4212	-2.23090	0.60574	0.08790	0.00000
79 SF	237.2500	1.24843	1.02369	74.91046	19.20637	2.07478	0.00000	0.4212	-2.23090	0.60574	0.08790	0.00000
80 QF	238.0000	1.25000	1.03000	76.59617	18.75541	2.11741	0.00000	0.4212	0.00000	0.4212	0.02556	0.00000
81 QF	238.7500	1.25157	1.03631	74.91046	19.20638	2.11297	0.00000	0.4212	2.23090	-0.60574	-0.03736	0.00000
82 0	239.2500	1.25265	1.04339	72.69951	19.82991	2.09429	0.00000	0.4212	2.19101	-0.64133	-0.03736	0.00000
83 B	248.9000	1.28210	1.09692	37.84426	38.82818	1.81271	0.00000	0.4530	1.42109	-1.32714	-0.02100	0.00000
84 0	249.4000	1.28424	1.09894	36.44311	40.17310	1.80221	0.00000	0.4530	1.38120	-1.36270	-0.02100	0.00000
85 B	259.0500	1.34718	1.12744	17.21651	73.08136	1.67853	0.00000	0.4812	0.61128	-2.04703	-0.00464	0.00000
86 00	261.0500	1.36698	1.13156	15.09053	81.55355	1.66925	0.00000	0.4812	0.45171	-2.18907	-0.00464	0.00000
87 SD	261.0500	1.36698	1.13156	15.09053	81.55355	1.66925	0.00000	0.4812	0.45171	-2.18907	-0.00464	0.00000
88 QD	261.8000	1.37501	1.13300	14.75407	83.20655	1.68255	0.00000	0.4812	-0.00015	0.04015	0.00000	0.00000
89 QD	262.5500	1.38304	1.13445	15.09082	81.55401	1.72969	0.00000	0.4812	-0.45190	2.18878	0.08575	0.00000

## BETATRON FUNCTIONS THRU SPL

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POS	S (M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	DXEQ	DYEQ
90 O	263.0500	1.38823	1.13544	15.56267	79.38298	1.77256	0.00000	0.4812	-0.49180	2.15327	0.08575
91 B	272.7000	1.45883	1.16142	32.48433	44.42126	2.67898	0.00000	0.5174	-1.26182	1.46922	0.10212
92 O	273.2000	1.46123	1.16324	33.76609	42.96982	2.73004	0.00000	0.5174	-1.30172	1.43366	0.10212
93 B	282.8500	1.49391	1.21415	66.31840	21.91383	3.79436	0.00000	0.5706	-2.07173	0.74801	0.11848
94 O0	284.8500	1.49843	1.22969	74.92452	19.20645	4.03131	0.00000	0.5706	-2.23133	0.60568	0.11848
95 SF	284.8500	1.49843	1.22969	74.92452	19.20645	4.03131	0.00000	0.5706	-2.23133	0.60568	0.11848
96 QF	285.6000	1.50000	1.23601	76.61054	18.75558	4.07504	0.00000	0.5706	0.00000	-0.00006	-0.00209
97 QF	286.3500	1.50007	1.24232	74.92452	19.20664	4.02819	0.00000	0.5706	2.23133	-0.60581	-0.12260
98 O	286.8500	1.50265	1.24640	72.71314	19.83025	3.96689	0.00000	0.5706	2.19143	-0.64140	-0.12260
99 B	296.5000	1.53209	1.30293	37.85079	38.83018	2.86277	0.00000	0.6263	1.42141	-1.32724	-0.10624
100 O	297.0000	1.53423	1.3094	36.44932	40.17520	2.80965	0.00000	0.6263	1.38151	-1.36280	-0.10624
101 B	306.6500	1.59716	1.3334	17.21762	73.08578	1.86343	0.00000	0.6643	0.61150	-2.07176	-0.08983
102 O0	308.6500	1.61696	1.33556	15.09082	81.55853	1.68367	0.00000	0.6643	0.45190	-2.18921	-0.08983
103 SD	308.6500	1.61696	1.33756	15.09082	81.55853	1.68367	0.00000	0.6643	0.45190	-2.18921	-0.08983
104 QD	309.4000	1.62499	1.33900	14.75407	83.21164	1.63297	0.00000	0.6643	0.00009	-0.00016	-0.04556
105 QD	310.1500	1.63302	1.34045	15.09053	81.55901	1.61511	0.00000	0.6643	-0.45171	2.18890	-0.00215
106 O	310.6500	1.63822	1.34144	15.56219	79.38786	1.61403	0.00000	0.6643	-0.49160	2.15340	-0.00215
107 B	320.3000	1.70882	1.3674	32.47903	44.42393	1.67221	0.00000	0.6910	-1.26152	1.46932	0.01421
108 O	320.8000	1.71122	1.36924	33.76050	42.97239	1.67931	0.00000	0.6910	-1.30141	1.43377	0.01421
109 B	330.4500	1.74391	1.42015	66.30600	21.91468	1.89538	0.00000	0.7200	-2.07133	0.74809	0.03057
110 OO	332.4500	1.74843	1.43569	74.91046	19.20700	1.95653	0.00000	0.7200	-2.23090	0.60575	0.03057
111 SF	332.4500	1.74843	1.43569	74.91046	19.20700	1.95653	0.00000	0.7200	-2.23090	0.60575	0.03057
112 QF	333.2000	1.75000	1.44200	76.59617	18.75604	1.95763	0.00000	0.7200	0.00000	-0.00001	-0.02764
113 QF	333.9500	1.75157	1.44831	74.91046	19.20702	1.91522	0.00000	0.7200	2.23090	-0.60577	-0.08524
114 O	334.4500	1.75265	1.45239	72.69951	19.83058	1.87260	0.00000	0.7200	2.19101	-0.64135	-0.08524
115 B	344.1000	1.78210	1.50892	37.84426	38.82917	1.12901	0.00000	0.7443	1.42109	-1.32715	-0.06888
116 O	344.6000	1.78424	1.51094	36.44311	40.17410	1.09457	0.00000	0.7443	1.38120	-1.36271	-0.06888
117 B	354.2500	1.84718	1.53943	17.21651	73.08249	0.50887	0.00000	0.7572	0.61128	-2.04703	-0.05252
118 OO	356.2500	1.86698	1.54356	15.09053	81.55469	0.40384	0.00000	0.7572	0.45171	-2.18907	-0.05252
119 SD	356.2500	1.86698	1.54356	15.09053	81.55469	0.40384	0.00000	0.7572	0.45171	-2.18907	-0.05252
120 QD	357.0000	1.87501	1.54500	14.75407	83.20766	0.36838	0.00000	0.7572	-0.00009	-0.00012	-0.04220
121 QD	357.7500	1.88304	1.54644	15.09082	81.55505	0.34033	0.00000	0.7572	-0.45190	-2.18884	-0.03273
122 O	358.2500	1.88823	1.54743	15.56267	79.38397	0.32397	0.00000	0.7572	-0.49180	2.15333	0.03273
123 B	367.9000	1.95883	1.57341	32.48433	44.42133	0.08713	0.00000	0.7604	-1.26182	1.46925	0.01636
124 O	368.4000	1.96123	1.57523	33.76609	42.96986	0.07895	0.00000	0.7604	-1.30172	1.433370	-0.01636
125 B	378.0500	1.99391	1.62615	66.31840	21.91340	0.00000	0.00000	0.7608	-2.07173	0.74802	0.00000
126 OO1	378.3500	1.99463	1.62835	67.56662	21.47099	0.00000	0.00000	0.7608	-2.09567	0.72667	0.00000
127 QF1	379.1000	1.99637	1.63401	69.22989	20.88270	0.00000	0.00000	0.7608	-0.10304	0.06348	0.00000
128 QF1	379.8500	1.99810	1.63969	67.87320	21.27773	0.00000	0.00000	0.7608	1.89863	-0.59406	0.00000
129 QF1	380.6000	1.99991	1.64515	63.61746	22.69122	0.00000	0.00000	0.7608	3.73387	-1.30445	0.00000
130 OO2	406.7081	2.39539	1.71377	28.74352	171.95879	0.00000	0.00000	0.7608	-2.39812	-4.41284	0.00000
131 QD1	407.4581	2.39927	1.71446	32.99317	175.73345	0.00000	0.00000	0.7608	-2.29339	-0.59218	0.00000
132 QD1	408.2081	2.40262	1.71514	38.75158	173.71572	0.00000	0.00000	0.7608	-4.42092	3.26759	0.00000
133 QD1	408.9581	2.40544	1.71584	46.40315	166.03880	0.00000	0.00000	0.7608	-5.83756	6.91162	0.00000
134 OO3	419.2371	2.42077	1.73300	24.6.28054	54.98464	0.00000	0.00000	0.7608	-13.60767	3.89238	0.00000

BETATRON FUNCTIONS THRU .SPL

POS	S (M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	YEQ(M)	ZEQ(M)	ALPHAX	ALPHAY	DXEQ	DYEQ
135 QF2	419.9871	2.42124	1.73527	261.87396	50.35675	0.00000	0.7608	-7.04269	2.31983	0.00000	0.00000	
136 QF2	420.7371	2.42169	1.73771	267.12386	47.93057	0.00000	0.7608	0.09026	0.33692	0.00000	0.00000	
137 OO4	444.6516	2.43602	1.85753	264.96545	25.52454	0.00000	0.00000	0.7608	0.00000	0.00000	0.00000	
138 SYM	444.6516	2.43602	1.85753	264.96545	25.52454	0.00000	0.00000	0.7608	0.00000	0.00000	0.00000	
139 REFL	889.3032	4.87203	3.71506	76.61054	18.75563	0.00000	0.00000	1.5216	0.00000	0.00000	0.00000	

CIRCUMFERENCE = 5335.8192 M  
 RADIUS = 849.2220 M  
 $(DS/S)/(DP/P) = 0.0017110$   
 THETX =  $6.28318532 \text{ RAD}$   
 THETY =  $0.00000000 \text{ RAD}$   
 TGAM=( 24.17523, 0.00000)  
 MAXIMA ---- BETX( 136) = 267.12386 BETY( 131) = 175.73345 XEQ( 96) = 4.07504  
 MINIMA ---- BETX( 120) = 14.75407 BETY( 48) = 18.75505 XEQ( 138) = 0.00000  
 SEXTUPOLE STRENGTHS ----- KSF = 0.44568121E-01 KSD = -0.70424964E-01

\*\*\* PLT BEP 2 1 // HEBS 0 138 500. 0. 10.  
 \*\*\* PLT BEP 2 1 // HEBS 0 138 500. 0. 10.

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