THE NSNS HIGH ENERGY BEAM TRANSPORT LINE

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Abstract

This 116 meter long transport line connects the linac to ring and provides the desired foot-print. This line consists of ten 90° FODO cells, and accommodate a 60° achromat bend, an energy compressor, part of the injection system, and enough diagnostic devices to determine the beam quality before the injection. To reduce the uncontrolled beam losses this line has five beam halo scrapers and very tight tolerances.

1 Introduction

The 1 MW NSNS machine consists of 1 GeV linac, an accumulator ring, and two transfer lines: (a) High Energy Beam Transfer line (HEBT), and (b) Ring to Target Beam Transfer line (RTBT). The main feature of this accelerator is the low uncontrolled beam losses (nA/m) to allow hands on maintenance. To achieve such low beam losses, the beam is prepared very carefully before injecting in to the following accelerator. The HEBT not only prepares the beam for the accumulator but also determines the beam quality before injection. To reduce the probability of uncontrolled beam losses, HEBT is equipped with five sets of beam halo scrapers. The ratio of aperture to rms beam size is kept more than 10. The maximum magnetic field in dipoles and quadrupoles is kept less than 3 kG to keep the stripping losses under control. Another key feature of this line (to reduce the uncontrolled beam loss) is very tight tolerances on elements. The Figure 1 shows the HEBT. Table 1 shows Twiss parameters at entrance and exit of the HEBT. Table 2 shows the component specifications for the HEBT.

2 Functions

The HEBT has following functions: (a) matching from the linac, (b) momentum selection, (c) momentum compaction, (d) preparation for beam injection, (e) diagnostics, and (f) halo cleanup.

Table 1: Twiss Parameters at Entrance and Exit of the HEBT.

At the Entrance

α_x	-3.36	
β_x	16.362	mm/mrad
$\pi\epsilon_x$	0.70	π mm mrad
α_y	4.82	
β_y	16,108	mm/mrad
$\pi\epsilon_y$	0.70	π mm mrad
α_z	-0.021	
β_z	0.005	deg/keV
$\pi\epsilon_z$	2258.0	π keV deg

Exit, (At Stripping Foil)

α_x	2.1	
β_x	22.57	mm/mrad
$\pi\epsilon_x$	0.70	π mm mrad
α_y	-0.57	
β_y	5.29	mm/mrad
$\pi\epsilon_y$	0.70	π mm mrad
α_z	0.14	
β_z	0.05	deg/keV
$\pi\epsilon_z$	2314.	π keV deg

Table 2: Component Specifications for the HEBT.

Type	Quantity	Field	Aperture (dia)	Length
		Dipole		
7.50°	9	0.3 T	8 cm	2.5 m
2.80° (B9)	1	0.3 T	8 cm	1 m
3.00° (BS)	1	0.3 T	8 cm	1.0 m
0.46° (B4)	1	0.1 T	18 cm	0.5 m
Correctors	22	0.03	12 x 12 cm x cm	0.2 m
		Quadrupole		
QF/QD	22	4 T/m	12 cm	0.5 m
		Debuncher		
SCC 16 cell	1	3.4 MV/m		2.6 m

We have tried to decouple these functions in the HEBT. The last two cells of the linac and the first HEBT cell (total six quadrupoles) are used to match beam into the achromat. In addition to the bend to the ring, there is a straight beam line for linac beam characterization (see fig 1). The four cell long achromat provides the momentum selection by cleaning up the beam energy halo at the maximum dispersion point. The energy compressor cavity is located in the cell following the achromat, where the dispersion is zero. The rest of the cells are used for matching beam into the accumulator ring and for three beam halo scrapers. These scrapers are located at maximum, minimum, and zero dispersion points to clean the maximum, minimum energy and transverse halo. These beam energy scrapers are provided to clean up any energy halo which is generated by the compressor cavity. The dispersion value is similar to that in the achromat but the energy spread is an order of magnitude lower.

2.1 Matching From The Linac

The linac has a FDOO lattice with a phase advance of about 50°/cell, and the achromat has a FODO lattice with 90°/cell. To provide a smooth transition, the matching system uses the last two cells (four quadrupoles) of the linac and one cell (two quadrupoles) of the HEBT. Figure 2 shows the TRACE3D output for this matching system. Every quadrupole in the HEBT is followed by a steering magnet to steer the beam in the quadrupole focusing plane. The space between quadrupoles in the first cell of the HEBT is kept for the diagnostics.

2.2 Momentum Selection

A 60° achromat bend starts at the 2nd cell and finishes in four cells with eight 7.5° dipoles. The first four dipoles are shifted upstream and the later 4 dipoles shifted downstream, providing mirror symmetry at the middle of the achromat. The total phase advance in the achromat is 360°. The beam halo scraper is located at the middle cell where the dispersion is maximum (3.5 meter). Figure 3 shows amplitude functions (β_x, β_y) and dispersion function (η_x) along the HEBT.

Table 3: Energy Spread at Foil

E0T (MV/m)	Phase (deg)	Length (m)	ΔE MeV	$\frac{\Delta P}{P}$	Figure No.
3.4	-90	2.6	0.218	$1.50 .10^{-4}$	4a
0.0		2.6	1.715	$1.15 .10^{-3}$	4c
3.4	+90	2.6	3.635	$2.44 .10^{-3}$	4d
5.0	+90	2x2.6	7.588	$5.10 .10^{-3}$	4e

2.3 Momentum Compaction

Momentum compaction is accomplished with a 2.6 meter long 16 cell cavity with 3.4 MV/m field. This cavity is similar to the last cavity of linac. This cavity is located in the 6th cell (65 m from the linac). In this cell the dispersion and its derivative both have zero values. This location of the cavity can provide the desired momentum spread for a 1 MW (28 mA) beam as well as a 2 MW (56 mA) beam (see figure 4 a and b). For beam stability reasons one might like to have about 0.5 % $\frac{\Delta P}{P}$. Table 3 shows the different values of $\frac{\Delta P}{P}$ that can be achieved by changing phase and amplitude of the cavity.

2.4 Preparation of Beam for Injection (Ring Matching Section)

At end of the achromat this line is parallel to the straight section of the ring, but **xx** m away. To inject the beam into the ring this line provides the required " dog leg ". Figure 5 shows the geometrical layout of this section in detail. These bends are necessary to provide dispersion and its derivative to be zero at the foil and enough quadrupoles for matching Twiss parameters in the transverse plane. Figure 6 shows the TRACE3D output for this section. As shown in figure 3 the dispersion has a minimum and maximum of similar amplitude but opposite sign. These are places where beam scrapers are located for energy halo clean up, most probably generated

Table 4: Diagnostic Devices in the HEBT

Device	Number
Beam Loss Monitor	144
Current Toroid	4
Beam Position Monitor	22
Wall Current Monitor	3
Harp	2
Bunch Shape Monitor	2
Time of Flight	2
Wire Scanner	6

by the compressor cavity. A betatron scraper is located where the dispersion is zero. This section has enough 'knobs' (quadrupoles) to match six variables (four amplitude functions and two dispersion functions). There is no vertical bend and no vertical dispersion. Locations of the dipoles are determine by the injection scheme (see design note TN3).

2.5 Diagnostics

In addition to the straight linac diagnostic line, there are enough diagnostic devices to determine beam quality and beam losses. These devices are spread over the entire HEBT and a list of the devices are shown in Table 4

There are 4 beam loss monitors per quadrupole and 4 per dipole and 24 beam loss monitors are left movable for special use. Beam position monitors are located in each quadrupole. The rest of the diagnostics are shown in figure 7. The harp can only be used at low repetition rate, due to thermal constraints.

2.6 Halo and Collimation

There are a total of five collimators in the HEBT. Three are for the momentum collimation and two for the transverse collimation. The momentum collimators are located at maximum and minimum dispersion points. The first is in the middle of the achromat, and the

Table 5: Lattice Functions and Beam Sizes at the Collimator Locations.

	σ (deg)	β_x, β_y m,m	η m	$\frac{\Delta P}{p}$	$\sqrt{\epsilon\beta}$ mm	$\eta\frac{\Delta P}{p}$ mm
			Longitudinal			
p1	0	19.9,4.7	3.5	0.86 10^{-3}	3.71	3.01
p2	360	21.6,2.2	-2.0	0.25 10^{-3}	3.86	0.50
p2	540	22.7,2.2	+2.0	0.16 10^{-3}	3.96	0.32
			Transverse			
b1	0	17.0,13.9	0.0	0.46 10^{-3}	1.23	0.0
b2	540	2.2,20.2	0.0	0.22 10^{-3}	3.41	0.0

second and the third in the ring matching section. The disperson values are similar at these location but the energy spread at the second and the third location are an order of magnitude lower. One beta collimator is located just after the linac and the other one at zero dispersion in the ring matching section. The lattice functions and the beam size at the collimator locations are shown in Table 5.

3 Space Charge and Momentum Spread

The importance of the space charge in the transfer line can be estimated analytically. In the linear approximation, the electric field components that are due to a uniformly charged ellipsoid, are given by

$$E_x = \frac{1}{4\pi\epsilon_0}\frac{3I\lambda}{c\gamma^2}\frac{(1-f)}{r_x(r_x+r_y)r_z}x$$

$$E_y = \frac{1}{4\pi\epsilon_0}\frac{3I\lambda}{c\gamma^2}\frac{(1-f)}{r_y(r_x+r_y)r_z}y$$

Table 6: Tune Depression and Energy Spread

Current (mA)	σ (deg)	σ_0 (deg)	μ	ΔE @ Linac Exit (MeV)	ΔE @ Cavity (MeV)	ΔE @ Foil* (MeV)
0.0	90.0	90.0	1.00	0.854	0.854	0.854
56.0	77.0	90.0	0.86	0.679	1.537	1.722
122.0	67.0	90.0	0.74	0.672	2.070	2.29 9

* Buncher Cavity is off

and

$$E_z = \frac{1}{4\pi\epsilon_0}\frac{3I\lambda}{c}\frac{f}{r_x r_y r_z}z$$

where r_x,r_y and r_z are the semi-axis of the ellipsoid, I is the electrical current averaged over rf prirod, λ is the free-space wavelength of the linac rf frequency, c is the velocity of light, and ϵ_0 is the permittivity of free space. The form factor f is a function of p=$\frac{\gamma r_z}{\sqrt{r_x r_y}}$. The change in the normalized momentum components due to these electric fields during the time interval required for the beam to move a distance Δ s is

$$\Delta(\beta\gamma) = \frac{qE_u \Delta s}{m_0 c^2 \beta},$$

where u represents x, y, or z. This momentum change can be translated to the tune of the line. The tune depression is defined by $\mu = \frac{\sigma}{\sigma_0}$, where σ and σ_0 are the tune with and without the space charge. The Table 6 showed these values for different currents.

To simulate space charge effects we have used TRACE3D and PARMILA programs. The momentum spread at the exit of the linac is 0.680 MeV for 28 mA. There is no longitudinal focusing in the line until momentum compression cavity. The momentum spread at the cavity and at the foil for different currents are also shown.

4 Tolerances

Since this machine should have very low losses, this translates to tight tolerances. The most harmful error to the emittance in the linac and transfer line is quadrupole rotation error. Unfortunately, the linac and transfer line are not built with rotation corrective elements in it. For x, y misalignments the transfer line has corrective steering magnets along the transfer line but, unlike circular machines, there are no skew quadrupoles as corrective elements for the quadrupole rotation error. If the error becomes excessive a proper skew quadrupole arrangements can be added.

The HEBT consists of quadrupoles and dipoles, and a buncher cavity. The emittaance growth due to dipole field and alignments error is given by

$$\epsilon_2 = \epsilon_1 + \frac{\pi}{2}\left[(\Delta y)^2 \frac{(1+\alpha^2)}{\beta} + (\Delta y')^2 \beta\right]$$

where Δy is a magnet alignment error and $\Delta y' = \frac{l\Delta B}{B\rho}$ an angle error from a field error ΔB of lenght l. The gradient errors in the quadrupole give follwing emitance

$$\epsilon_2 = \frac{1}{2}\left(k^2\beta^2 + 2\right)\epsilon_1$$

where $k = \frac{-l\Delta G}{B\rho}$ an amplitute-dependent kick due to a gradient error ΔG of length l.

The quadrupole alignments can be simulated by PARTRACE. Figures 8,9 and 10 show the probability distribution of the beam centroid, radius and emittance respectively for various quadrupole alignment errors.

5 Simulations

We have used following programs to simulate HEBT (a) TRANSPORT, (b) TRACE3D, (c) PARMILA, and (d) PARTRACE.

TRANSPORT code is used to design the line to satisfy certain conditions to be fullfilled by the beam. This code does not include the space charge effects. This simulation strat at beginning of the achromat and finishes at the stripper foil.

TRACE3D is used to optimized the lattice with certain configurations of the RF cavity. It does include the space charge effects in the linear approximation. This simulation starts from 2nd last cavity of the linac and finishes at the foil.

PARMILA is used to simulate the line with full space charge. We have used the transport line option of PARMILA to simulate HEBT. This simulation starts at beginning of the achromat and finishes at the foil. Figure 11 shows the x, $\Delta\phi$, and ΔW profile of the HEBT for the 1 MW case. Figure 12 shows the phase and energy spectrum along with x-y plane and $\Delta\phi - \Delta W$ plane at (a) beginning of the achromat, (b) middle of the achromat, (c) end of the achromat, (d) after the cavity, (e) at the 2nd energy collimator, (f) at the 2nd beta collimator, (g) at the 3rd energy collimator, and (h) at the foil. Figure 13 is similar to figure 12 but with different input distribution (Gaussian instead of waterbag).

PARTRACE is used to estimate the effects of quadrupole alignment errors. The code generate 100 different lines with random errors in the quadrupoles, calculates the beam parameters in the each case, and then arranges each beam parameter in the ascending order.

6 Figures

Figure 01: HEBT layout.

Figure 02: TRACE3D output for matching into achromat.

Figure 03: TRANSPORT output for amplitude functions (β_x, β_y) and dispersion function (η_x) along the HEBT.

Figure 04: TRACE3D output for different phases and amplitudes of cavity. (a) Phase=-90°, E0T=3.4 MV/m, (c) Phase=0.0°, E0T=0.0 MV/m, (d) Phase=+90.0°, E0T=3.4 MV/m, (e) Phase=+90.0°, E0T=5.0 MV/m (double the length), and (b) same as (a) but for 112 mA.

Figure 05: The geometrical layout of the ring matching section in the HEBT.

Figure 06: TRACE3D output for matching into the ring.

Figure 07: The diagnostics distribution in the HEBT.

Figure 08: The probability distribution of maximum beam centroids for various quadrupole alignment errors.

Figure 09: The probability distribution of maximum beam radius for various quadrupole alignment errors.

Figure 10: The probability distribution of transverse emittance for various quadrupole alignment errors.

Figure 11: x, $\Delta\phi$, and ΔW profile of the HEBT.

Figure 12: The phase and energy spectrum along with x-y plane and $\Delta\phi - \Delta W$ plane at (a) beginning of the achromat, (b) middle of the achromat, (c) end of the achromat, (d) after the cavity, (e) at

the 2nd energy collimator, (f) at the 2nd beta collimator, (g) at the 3rd energy collimator, and (h) at the foil for water bag input beam distribution.

Figure 13: The phase and enrgy spectrum along with x-y plane and $\Delta\phi - \Delta W$ plane at (a) beginning of the achromat, (b) middle of the achromat, (c) end of the achromat, (d) after the cavity, (e) at the 2nd energy collimator, (f) at the 2nd beta collimator, (g) at the 3rd energy collimator, and (h) at the foil for Gaussian input beam distribution.

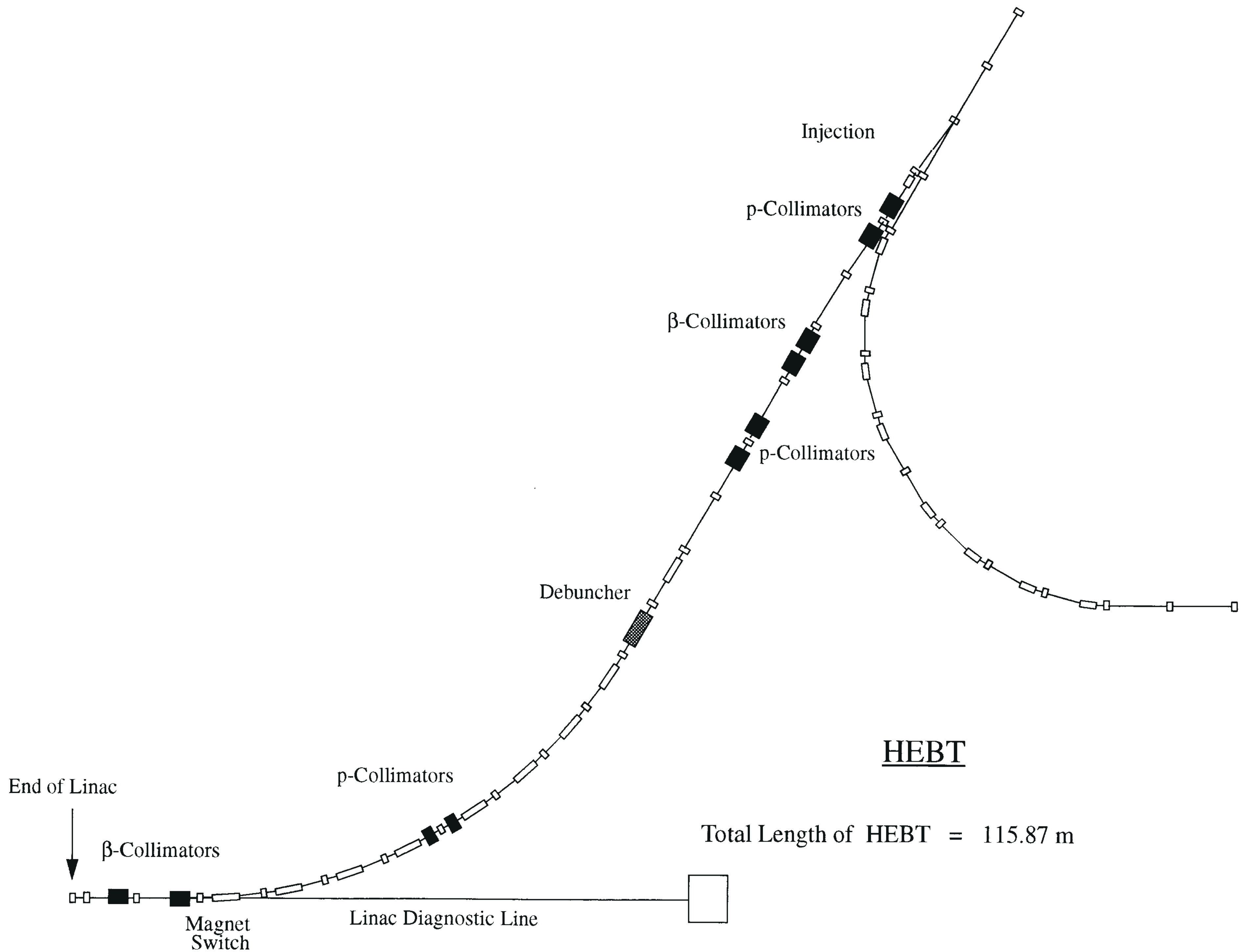
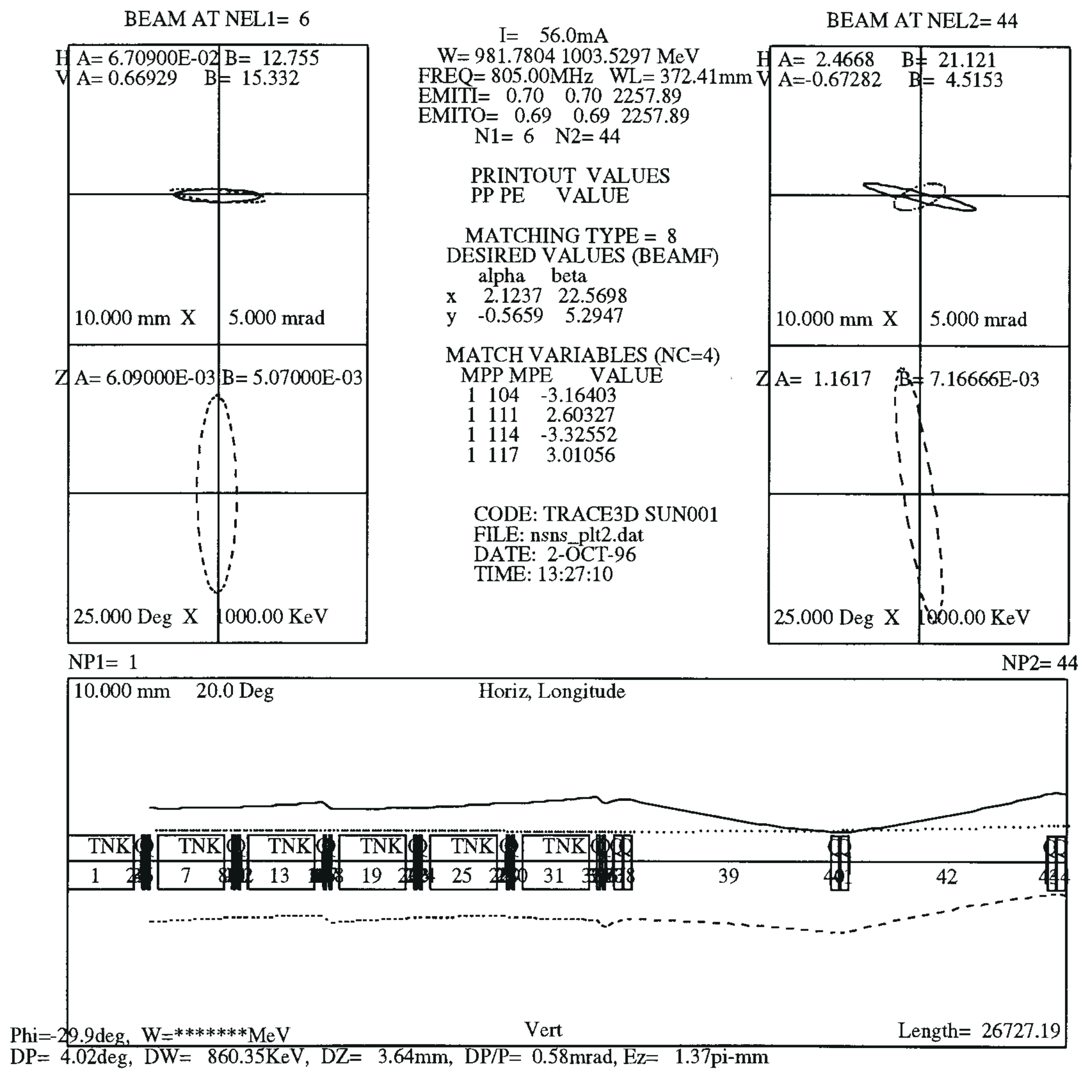

Injection
p-Collimators
β-Collimators
p-Collimators
Debuncher
HEBT
End of Linac
p-Collimators
β-Collimators
Total Length of HEBT = 115.87 m
Magnet
Switch
Linac Diagnostic Line

Figure 1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25.000 Deg X 1000.00 KeV
I= 56.0mA
W= 981.7804 1003.5297 MeV
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EMITO= 0.69 0.69 2257.89
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MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
alpha beta
x 2.1237 22.5698
y -0.5659 5.2947
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1 111 2.60327
1 114 -3.32552
1 117 3.01056
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Z A= 1.1617 B= 7.16666E-03
25.000 Deg X 1000.00 KeV
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NP2= 44
10.000 mm 20.0 Deg
Horiz, Longitude
TNK
1
7
13
19
25
31
39
42
Vert
Length= 26727.19
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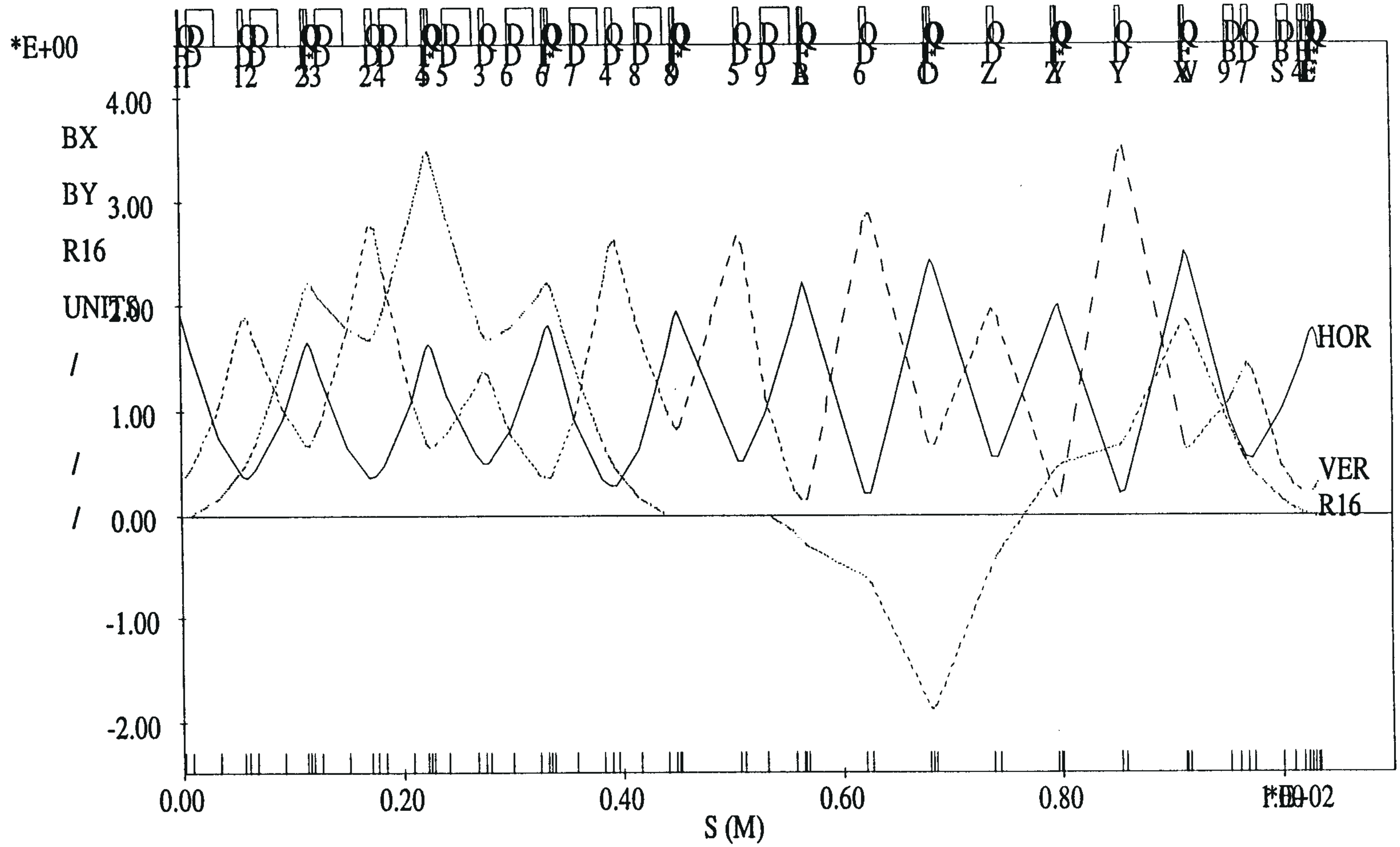
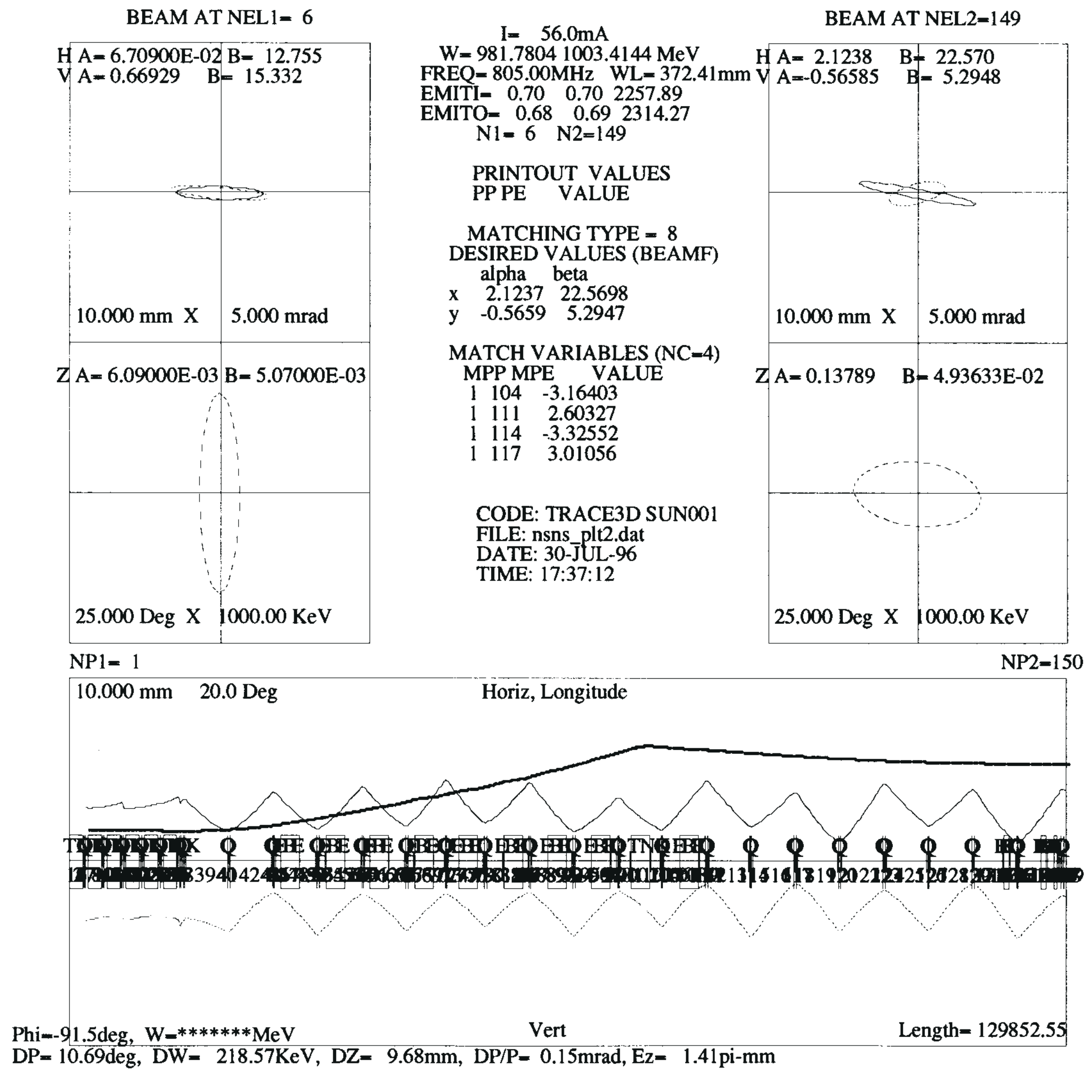
Figure 2



"NSNS LINAC TO BOSTER ARC CELL

Figure 3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25.000 Deg X 1000.00 KeV
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EMITO= 0.68 0.69 2314.27
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MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
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x 2.1237 22.5698
y -0.5659 5.2947
MATCH VARIABLES (NC=4)
MPP MPE VALUE
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1 111 2.60327
1 114 -3.32552
1 117 3.01056
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V A=-0.56585 B= 5.2948
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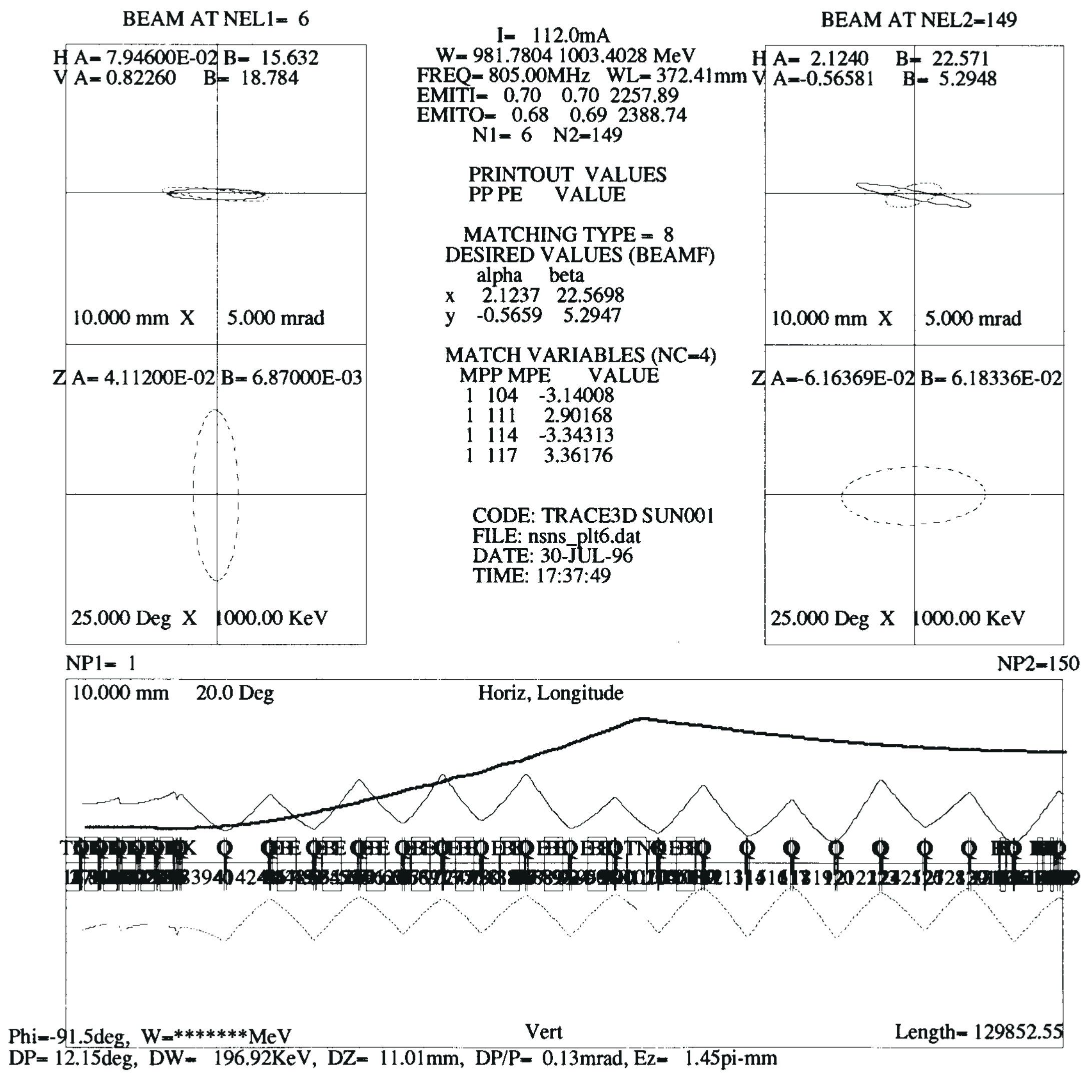
Z A= 0.13789 B= 4.93633E-02
25.000 Deg X 1000.00 KeV
NP1= 1
NP2=150
10.000 mm 20.0 Deg
Horiz, Longitude
Vert
Length= 129852.55
Phi=-91.5deg, W=*******MeV
DP= 10.69deg, DW= 218.57KeV, DZ= 9.68mm, DP/P= 0.15mrad, Ez= 1.41pi-mm

Figure 4a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5.000 mrad
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1000.00 KeV
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PP PE VALUE
MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
alpha beta
x 2.1237 22.5698
y -0.5659 5.2947
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1 111 2.90168
1 114 -3.34313
1 117 3.36176
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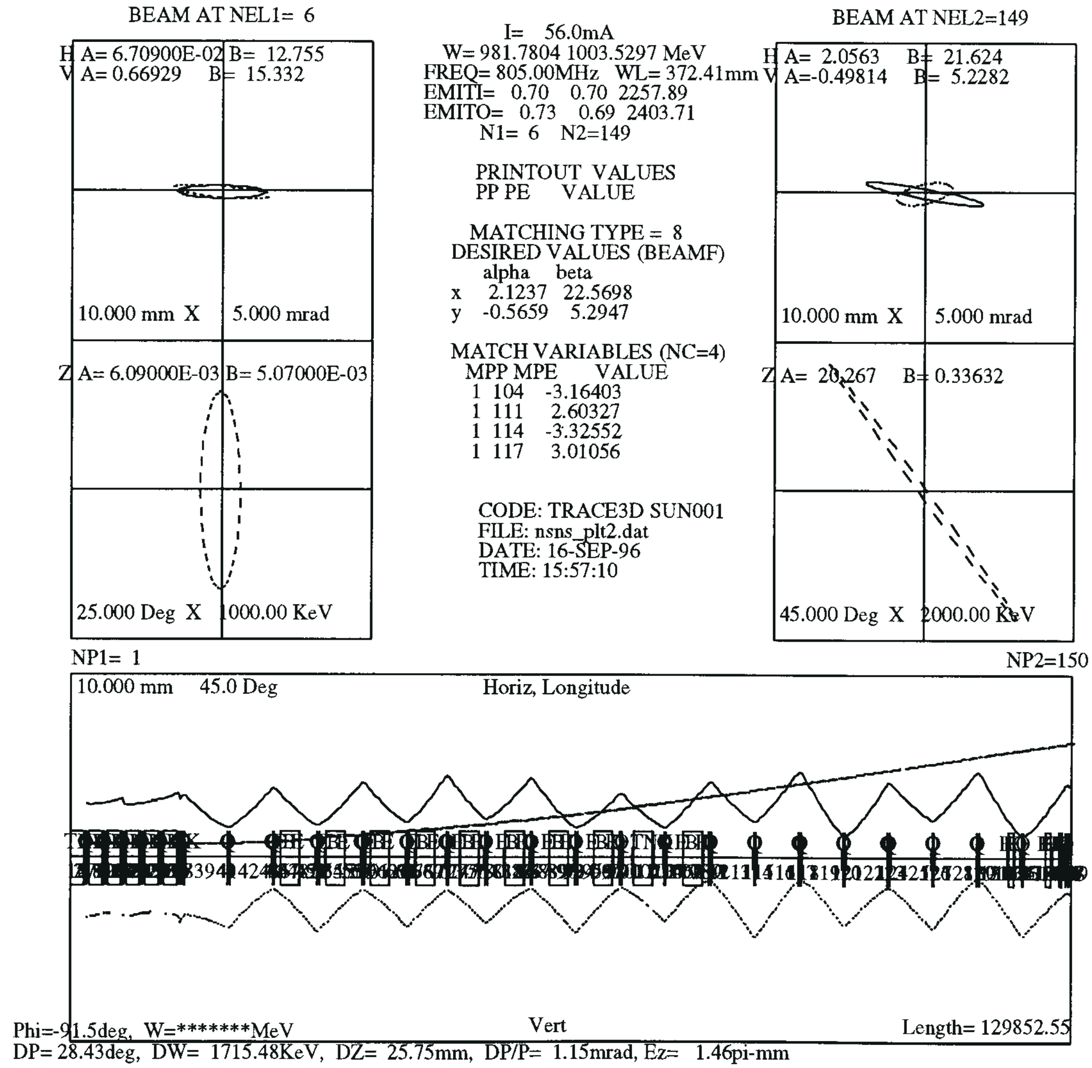
V A=-0.56581 B= 5.2948
10.000 mm X
5.000 mrad
Z A=-6.16369E-02 B= 6.18336E-02
25.000 Deg X
1000.00 KeV
NP1= 1
NP2=150
10.000 mm 20.0 Deg
Horiz, Longitude
Vert
Phi=-91.5deg, W=*******MeV
Length= 129852.55
DP= 12.15deg, DW= 196.92KeV, DZ= 11.01mm, DP/P= 0.13mrad, Ez= 1.45pi-mm

Figure 4b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V A= 0.66929 B= 15.332
10.000 mm X 5.000 mrad
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25.000 Deg X 1000.00 KeV
I= 56.0mA
W= 981.7804 1003.5297 MeV
FREQ= 805.00MHz WL= 372.41mm
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EMITO= 0.73 0.69 2403.71
N1= 6 N2=149
PRINTOUT VALUES
PP PE VALUE
MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
alpha beta
x 2.1237 22.5698
y -0.5659 5.2947
MATCH VARIABLES (NC=4)
MPP MPE VALUE
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1 111 2.60327
1 114 -3.32552
1 117 3.01056
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V A=-0.49814 B= 5.2282
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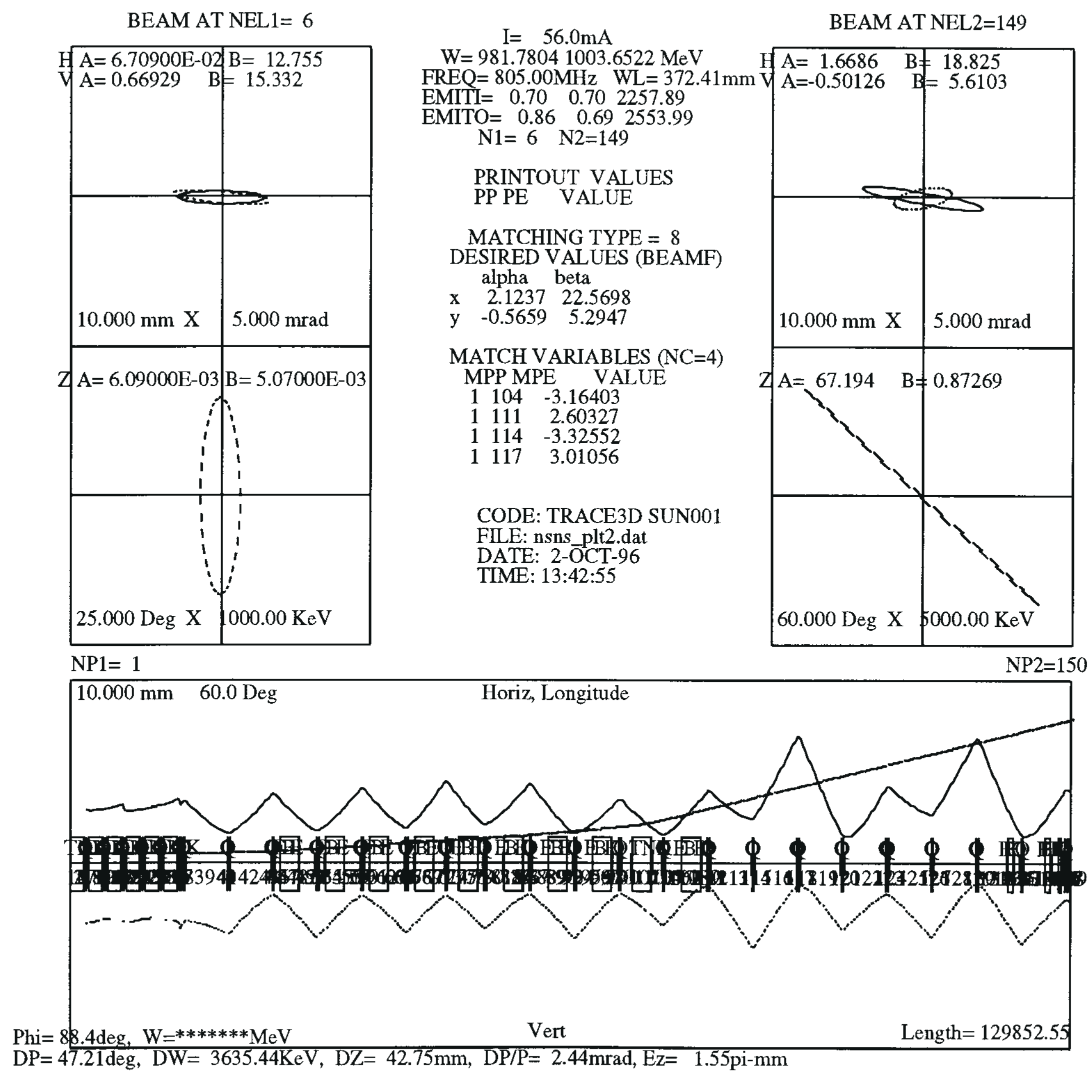
Z A= 20.267 B= 0.33632
45.000 Deg X 2000.00 KeV
NP1= 1
NP2=150
10.000 mm 45.0 Deg
Horiz, Longitude
Vert
Length= 129852.55
Phi=-91.5deg, W=*******MeV
DP= 28.43deg, DW= 1715.48KeV, DZ= 25.75mm, DP/P= 1.15mrad, Ez= 1.46pi-mm

Figure 4c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25.000 Deg X 1000.00 KeV
I= 56.0mA
W= 981.7804 1003.6522 MeV
FREQ= 805.00MHz WL= 372.41mm
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EMITO= 0.86 0.69 2553.99
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PRINTOUT VALUES
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MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
alpha beta
x 2.1237 22.5698
y -0.5659 5.2947
MATCH VARIABLES (NC=4)
MPP MPE VALUE
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1 111 2.60327
1 114 -3.32552
1 117 3.01056
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V A=-0.50126 B= 5.6103
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Z A= 67.194 B= 0.87269
60.000 Deg X 5000.00 KeV
NP1= 1
NP2=150
10.000 mm 60.0 Deg
Horiz, Longitude
Vert
Length= 129852.55
Phi= 88.4deg, W=*******MeV
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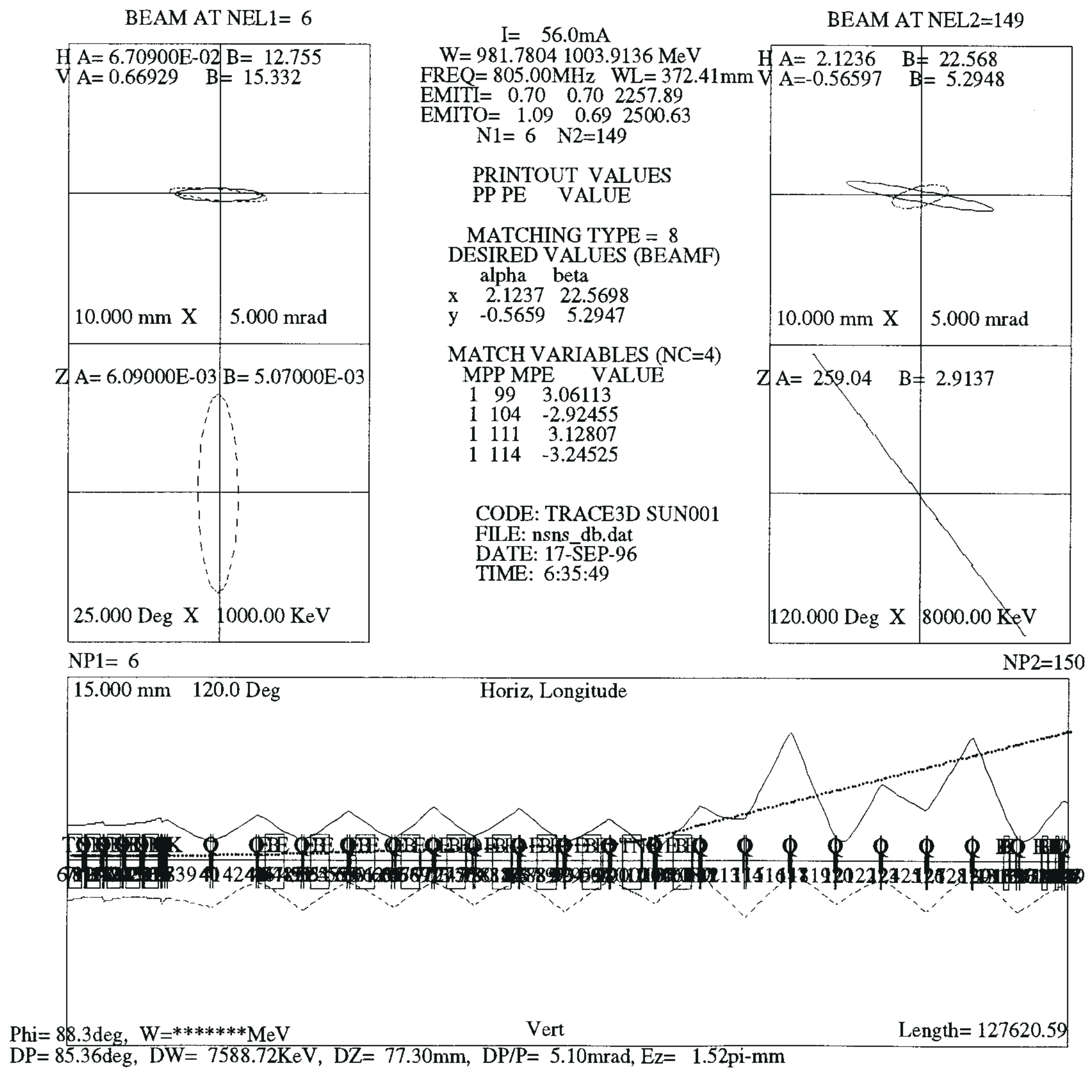
Figure 4d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H A= 6.70900E-02 B= 12.755
V A= 0.66929 B= 15.332
10.000 mm X 5.000 mrad
Z A= 6.09000E-03 B= 5.07000E-03
25.000 Deg X 1000.00 KeV
I= 56.0mA
W= 981.7804 1003.9136 MeV
FREQ= 805.00MHz WL= 372.41mm
EMITI= 0.70 0.70 2257.89
EMITO= 1.09 0.69 2500.63
N1= 6 N2=149
PRINTOUT VALUES
PP PE VALUE
MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
alpha beta
x 2.1237 22.5698
y -0.5659 5.2947
MATCH VARIABLES (NC=4)
MPP MPE VALUE
1 99 3.06113
1 104 -2.92455
1 111 3.12807
1 114 -3.24525
CODE: TRACE3D SUN001
FILE: nsns_db.dat
DATE: 17-SEP-96
TIME: 6:35:49
BEAM AT NEL2=149
H A= 2.1236 B= 22.568
V A=-0.56597 B= 5.2948
10.000 mm X 5.000 mrad
Z A= 259.04 B= 2.9137
120.000 Deg X 8000.00 KeV
NP1= 6
NP2=150
15.000 mm 120.0 Deg
Horiz, Longitude
Vert
Length= 127620.59
Phi= 88.3deg, W=*******MeV
DP= 85.36deg, DW= 7588.72KeV, DZ= 77.30mm, DP/P= 5.10mrad, Ez= 1.52pi-mm

Figure 4e

			Width	Height
BT	2.5 m	3.0 kG	20 cm	8 cm
B9	1.1 m	3.0 kG	20 cm	8 cm
BS	1.0 m	3.0 kG	12 cm	8 cm
B4	0.5 m	1.0 kG	50 cm	19.5 cm
BA	1.5 m	10.0 kG	50 cm	19.5 cm

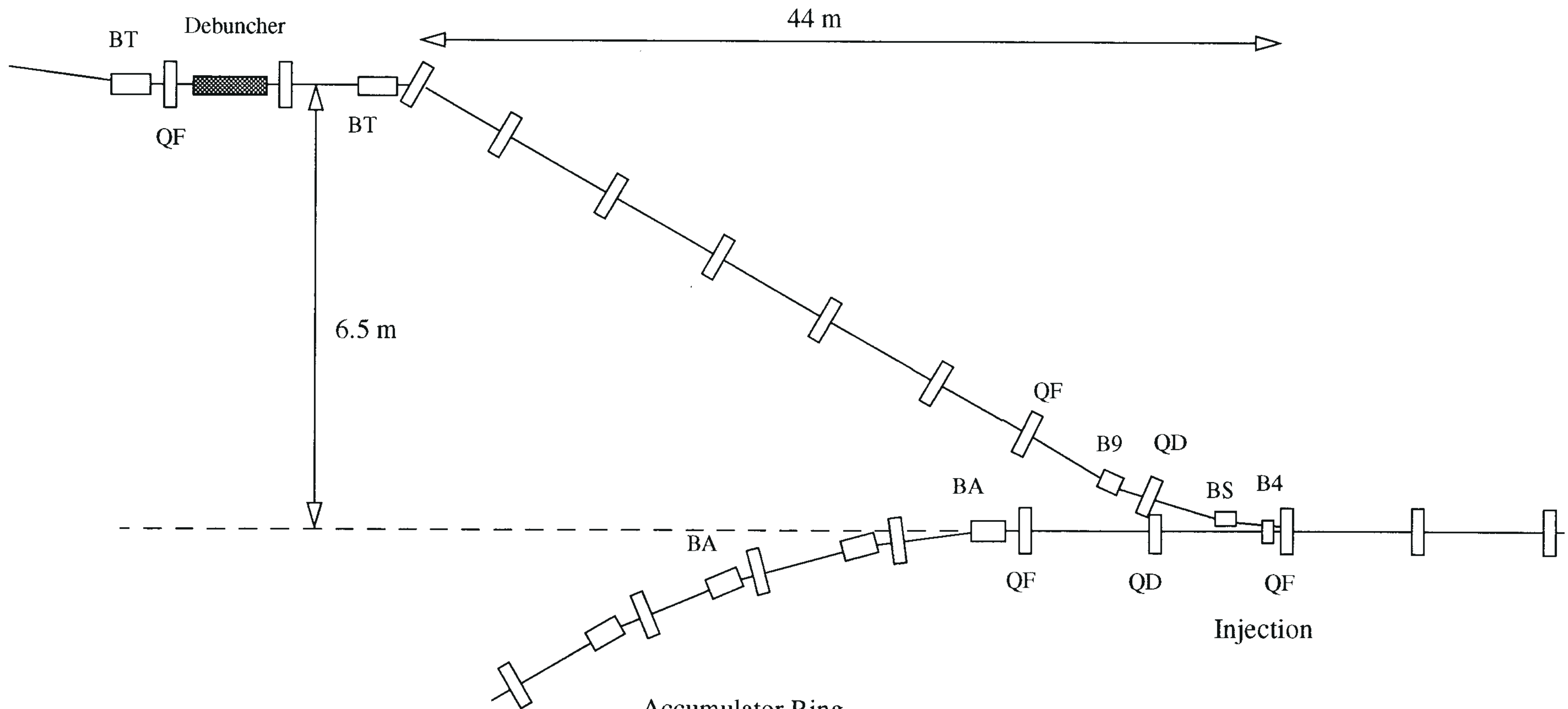


Figure 5

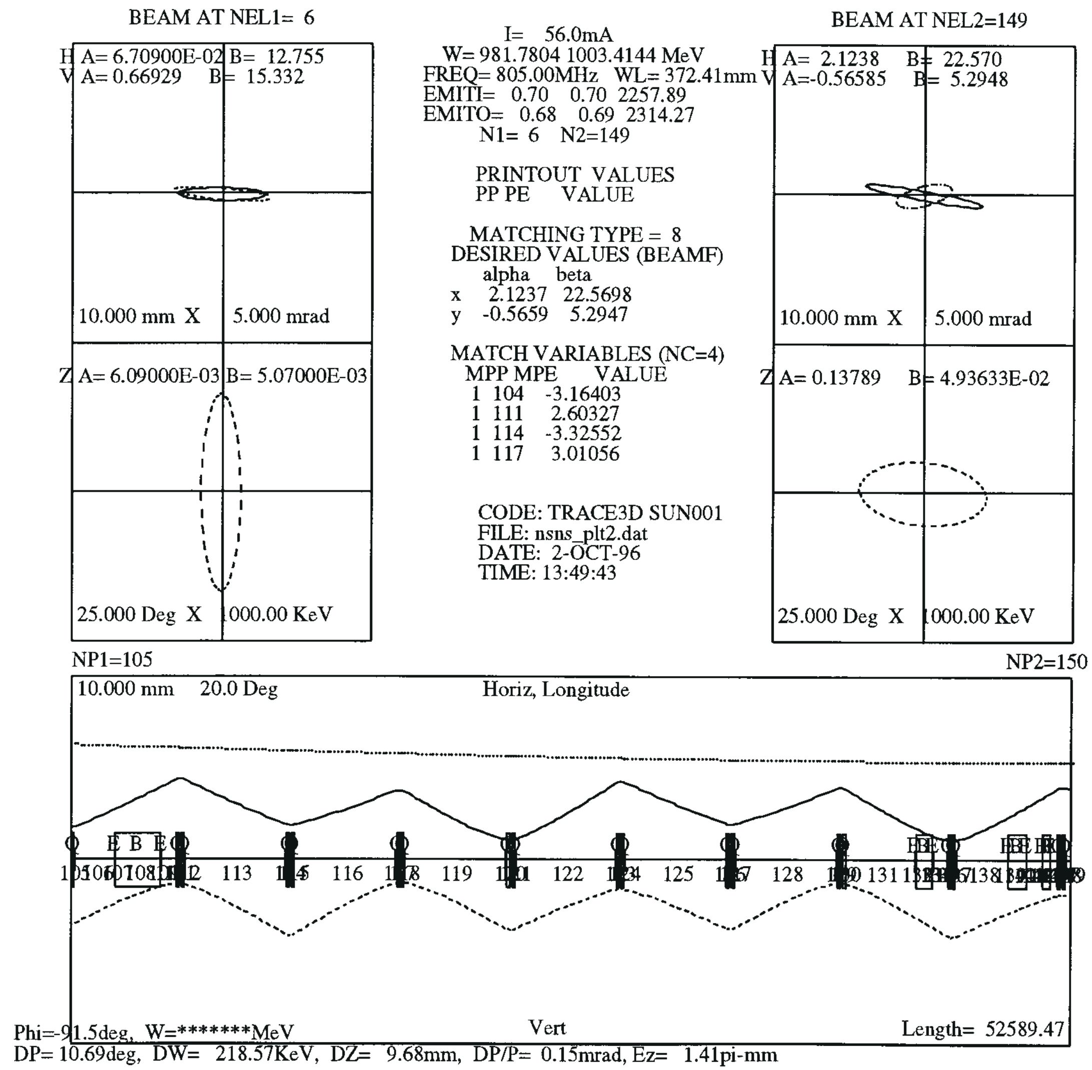

BEAM AT NEL1= 6
H A= 6.70900E-02 B= 12.755
V A= 0.66929 B= 15.332
10.000 mm X 5.000 mrad
Z A= 6.09000E-03 B= 5.07000E-03
25.000 Deg X 1000.00 KeV
I= 56.0mA
W= 981.7804 1003.4144 MeV
FREQ= 805.00MHz WL= 372.41mm
EMITI= 0.70 0.70 2257.89
EMITO= 0.68 0.69 2314.27
N1= 6 N2=149
PRINTOUT VALUES
PP PE VALUE
MATCHING TYPE = 8
DESIRED VALUES (BEAMF)
alpha beta
x 2.1237 22.5698
y -0.5659 5.2947
MATCH VARIABLES (NC=4)
MPP MPE VALUE
1 104 -3.16403
1 111 2.60327
1 114 -3.32552
1 117 3.01056
CODE: TRACE3D SUN001
FILE: nsns_plt2.dat
DATE: 2-OCT-96
TIME: 13:49:43
BEAM AT NEL2=149
H A= 2.1238 B= 22.570
V A=-0.56585 B= 5.2948
10.000 mm X 5.000 mrad
Z A= 0.13789 B= 4.93633E-02
25.000 Deg X 1000.00 KeV
NP1=105
NP2=150
10.000 mm 20.0 Deg
Horiz, Longitude
113 116 119 122 125 128
Vert
Length= 52589.47
Phi=-91.5deg, W=*******MeV
DP= 10.69deg, DW= 218.57KeV, DZ= 9.68mm, DP/P= 0.15mrad, Ez= 1.41pi-mm

Figure 6

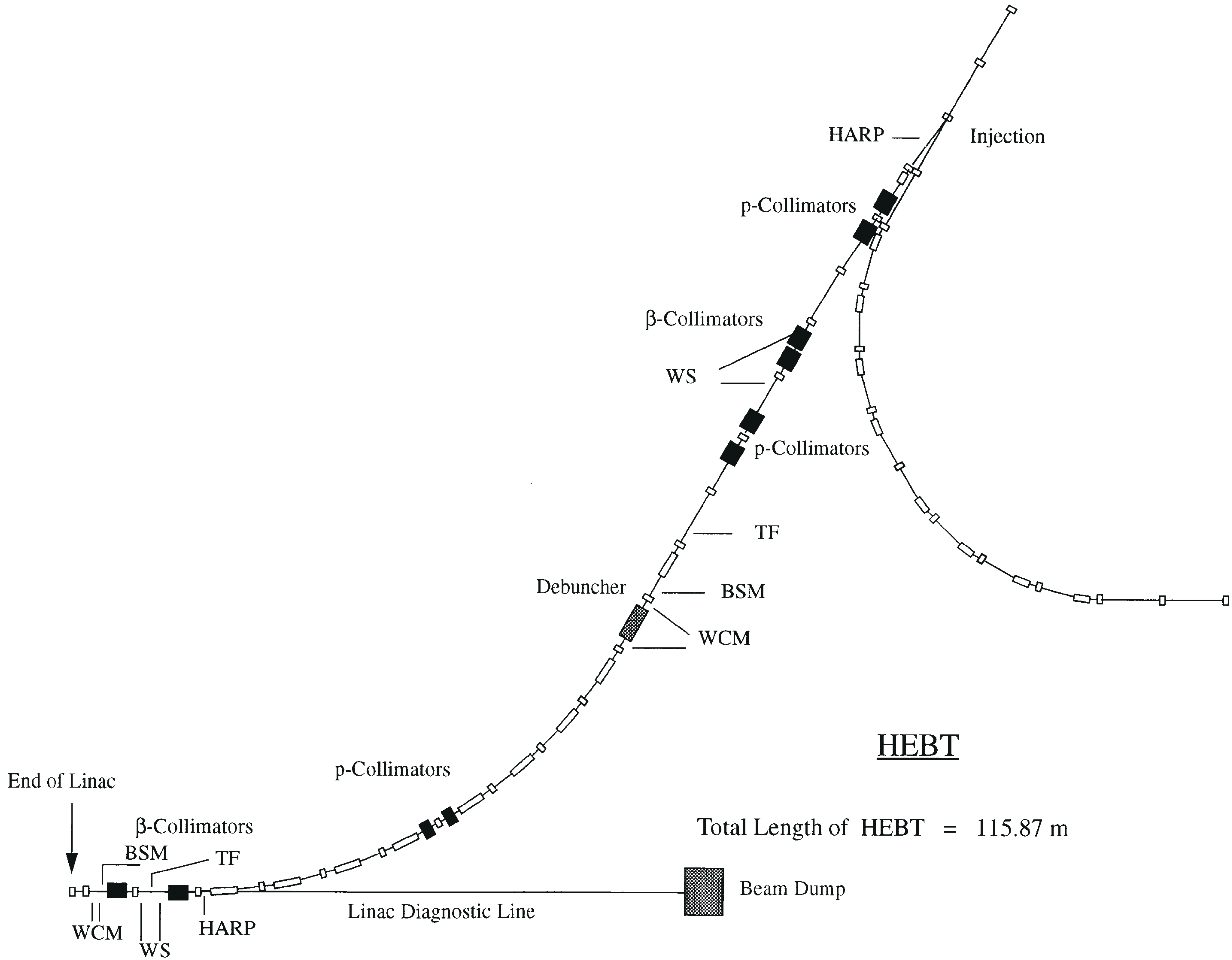

HARP
Injection
p-Collimators
β-Collimators
WS
p-Collimators
TF
Debuncher
BSM
WCM
HEBT
p-Collimators
End of Linac
β-Collimators
BSM
TF
Total Length of HEBT = 115.87 m
Beam Dump
WCM
WS
HARP
Linac Diagnostic Line

Figure 7

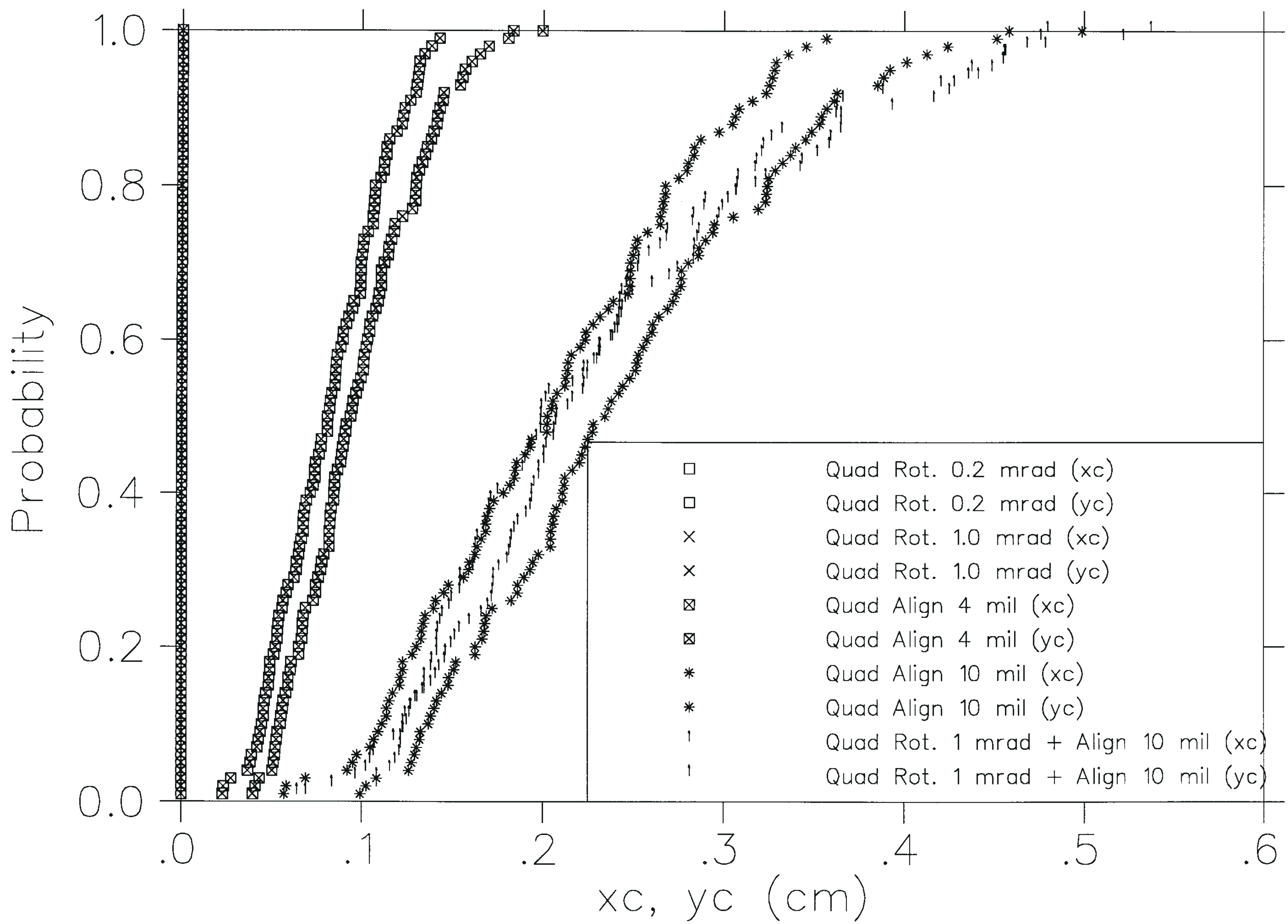

Probability
1.0
0.8
0.6
0.4
0.2
0.0
.0
.1
.2
.3
.4
.5
.6
xc, yc (cm)
Quad Rot. 0.2 mrad (xc)
Quad Rot. 0.2 mrad (yc)
Quad Rot. 1.0 mrad (xc)
Quad Rot. 1.0 mrad (yc)
Quad Align 4 mil (xc)
Quad Align 4 mil (yc)
Quad Align 10 mil (xc)
Quad Align 10 mil (yc)
Quad Rot. 1 mrad + Align 10 mil (xc)
Quad Rot. 1 mrad + Align 10 mil (yc)

Figure 8

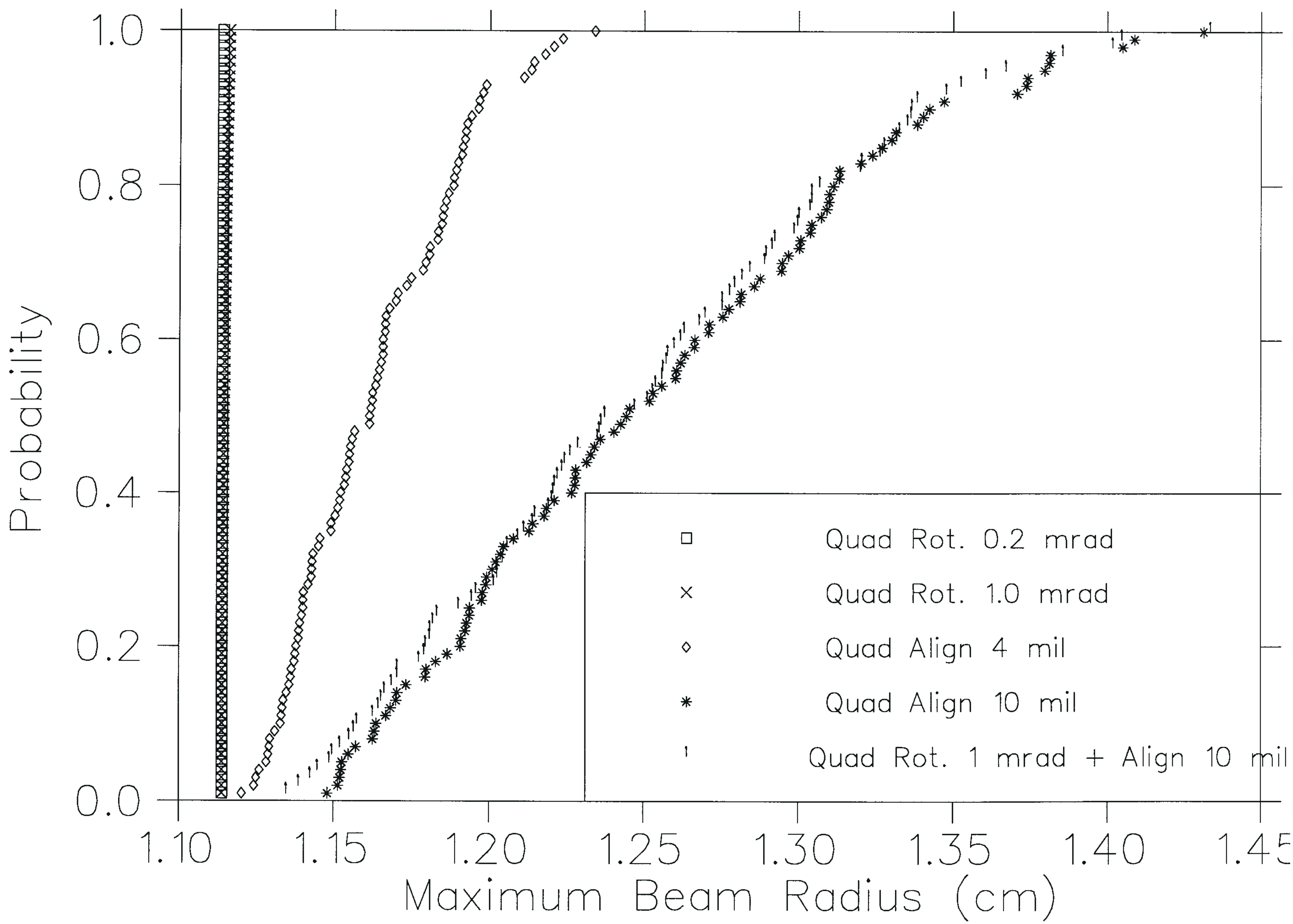

Probability
0.0
0.2
0.4
0.6
0.8
1.0
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
Maximum Beam Radius (cm)
Quad Rot. 0.2 mrad
Quad Rot. 1.0 mrad
Quad Align 4 mil
Quad Align 10 mil
Quad Rot. 1 mrad + Align 10 mil

Figure 9

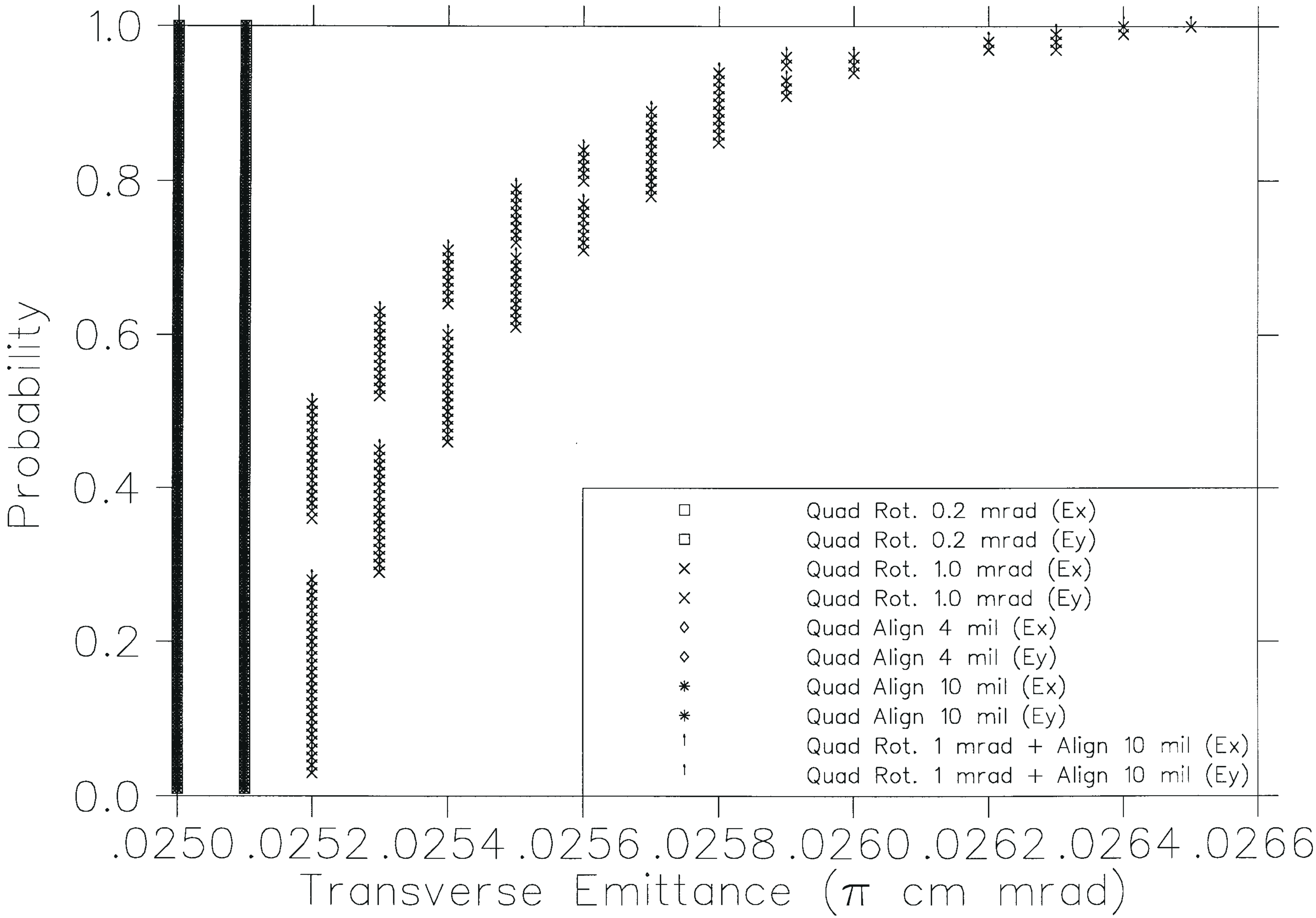

Probability
1.0
0.8
0.6
0.4
0.2
0.0
.0250
.0252
.0254
.0256
.0258
.0260
.0262
.0264
.0266
Transverse Emittance (π cm mrad)
Quad Rot. 0.2 mrad (Ex)
Quad Rot. 0.2 mrad (Ey)
Quad Rot. 1.0 mrad (Ex)
Quad Rot. 1.0 mrad (Ey)
Quad Align 4 mil (Ex)
Quad Align 4 mil (Ey)
Quad Align 10 mil (Ex)
Quad Align 10 mil (Ey)
Quad Rot. 1 mrad + Align 10 mil (Ex)
Quad Rot. 1 mrad + Align 10 mil (Ey)

Figure 10

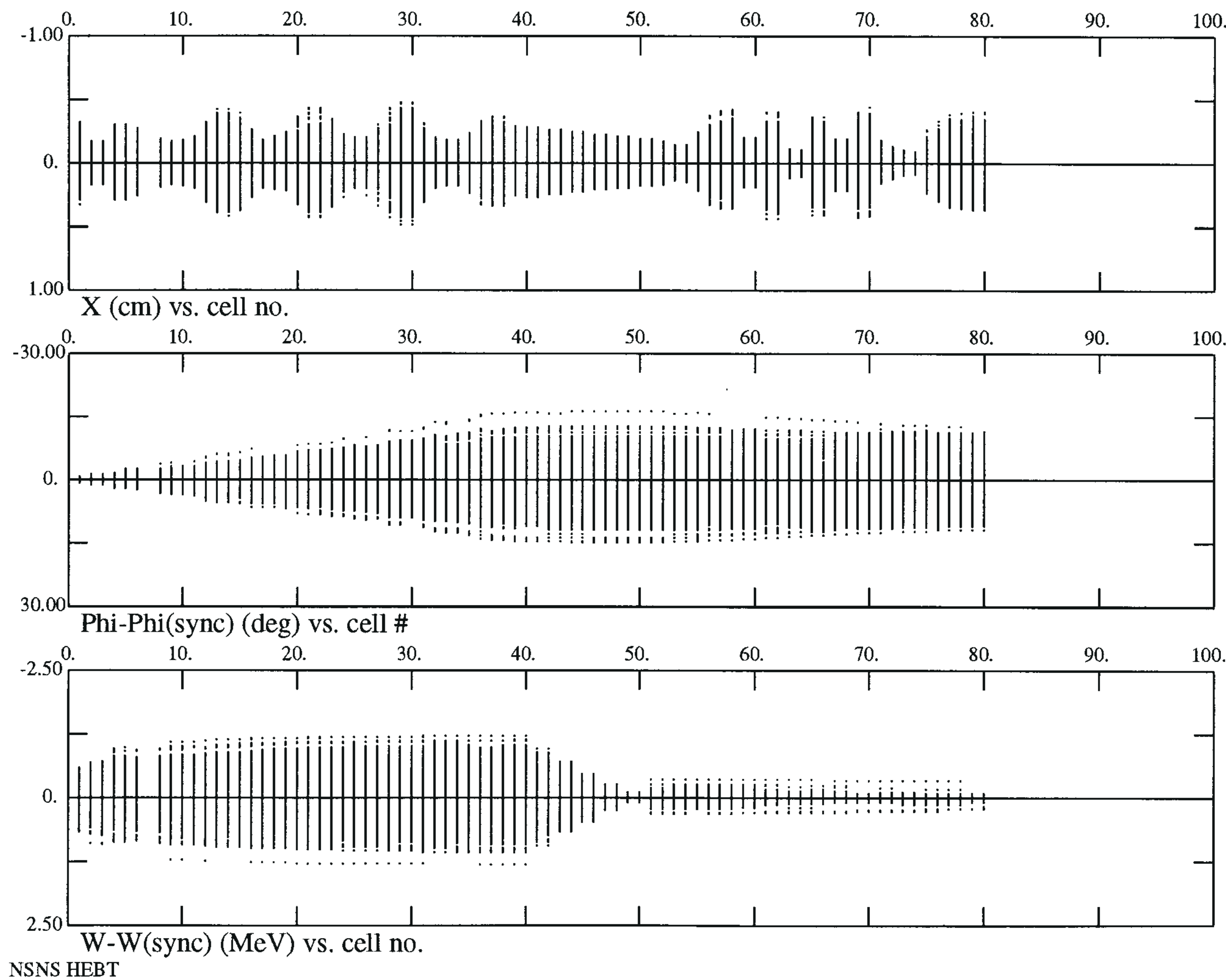
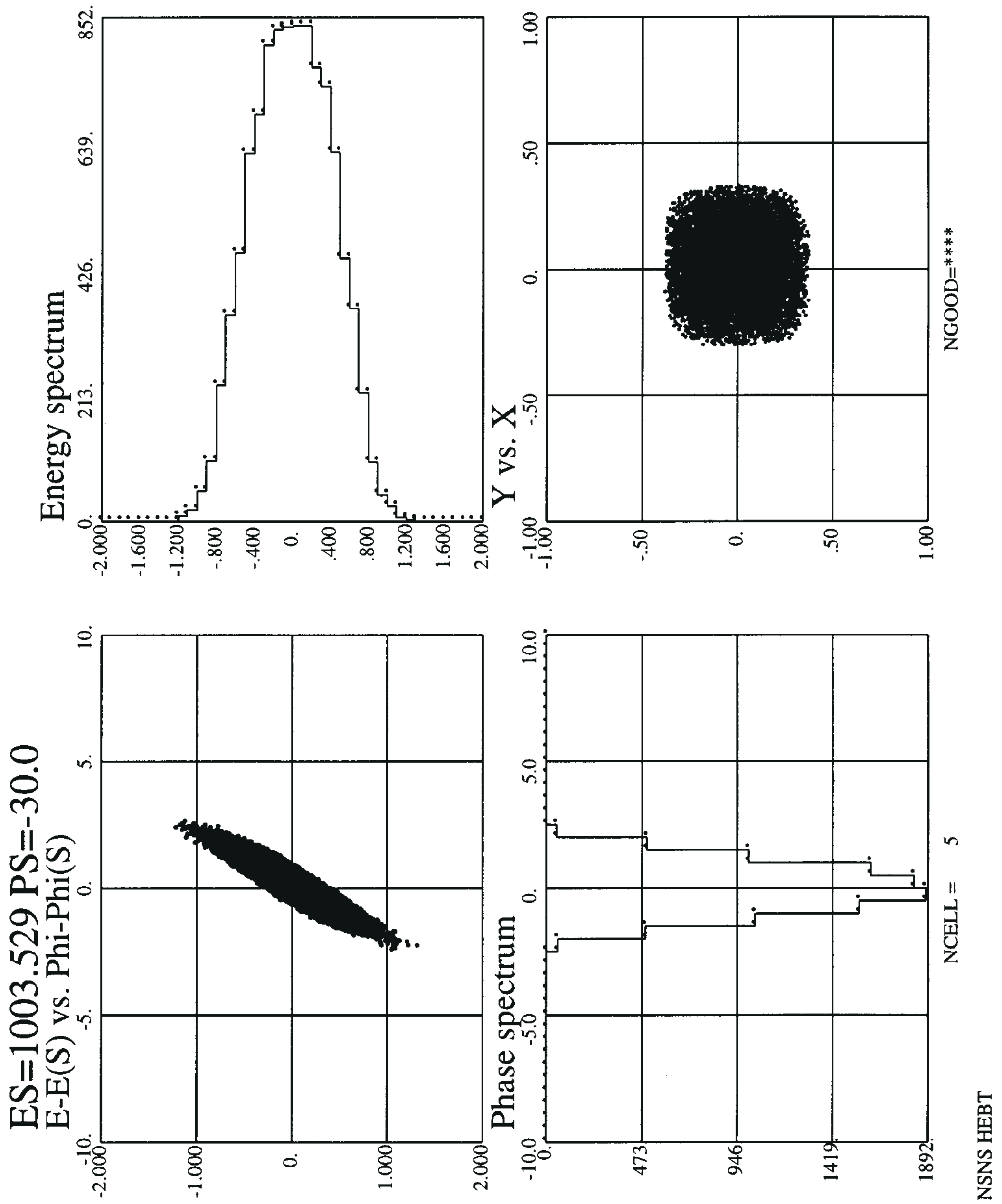

X (cm) vs. cell no.
Phi-Phi(sync) (deg) vs. cell #
W-W(sync) (MeV) vs. cell no.
NSNS HEBT

Figure 11



ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 5
NGOOD=****
NSNS HEBT

Figure 12a

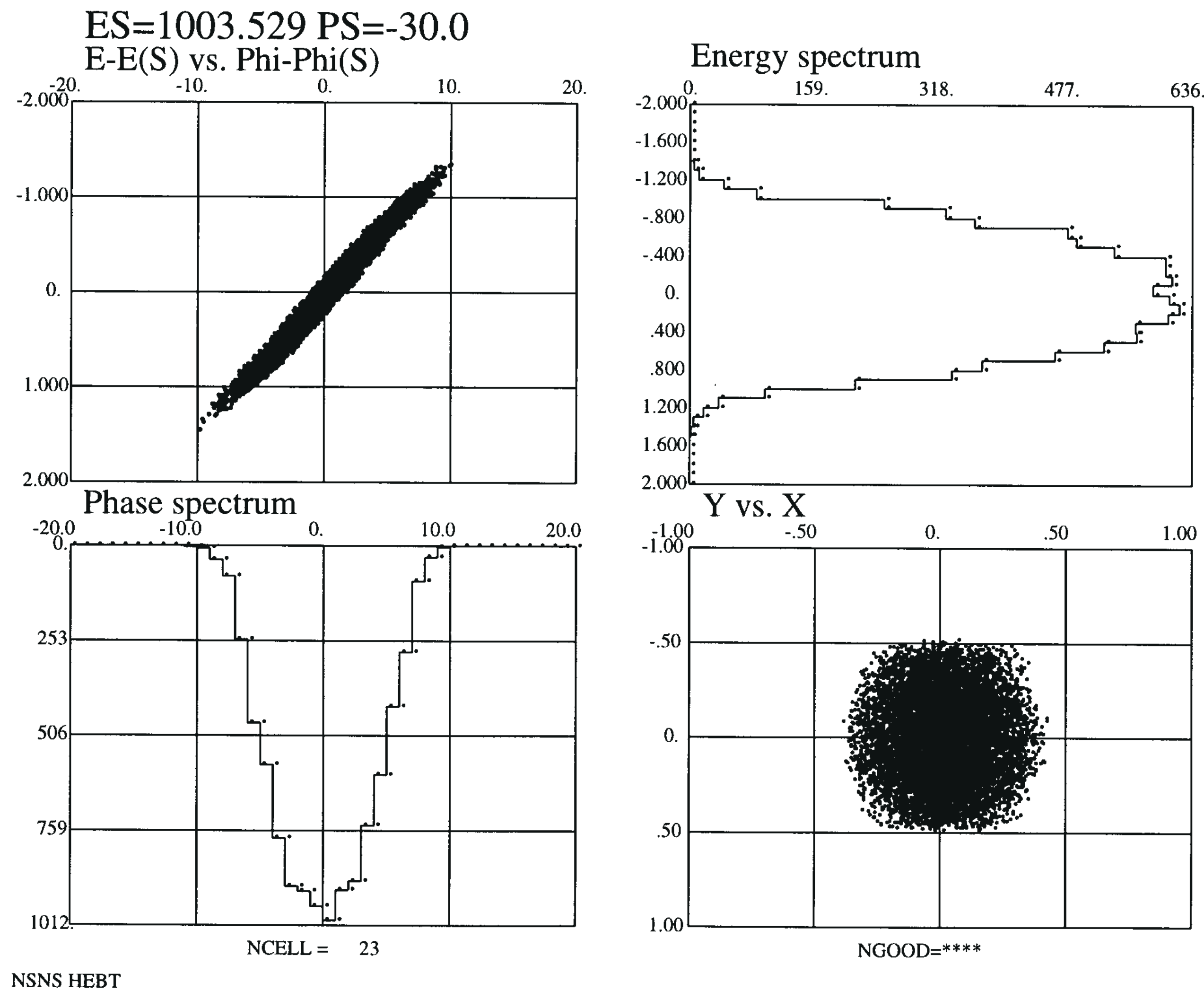

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
-20. -10. 0. 10. 20.
-2.000 -1.000 0. 1.000 2.000
Energy spectrum
0. 159. 318. 477. 636.
-2.000 -1.600 -1.200 -.800 -.400 0. .400 .800 1.200 1.600 2.000
Phase spectrum
-20.0 -10.0 0. 10.0 20.0
0. 253 506 759 1012.
NCELL = 23
Y vs. X
-1.00 -.50 0. .50 1.00
-1.00 -.50 0. .50 1.00
NGOOD=****
NSNS HEBT

Figure 12b

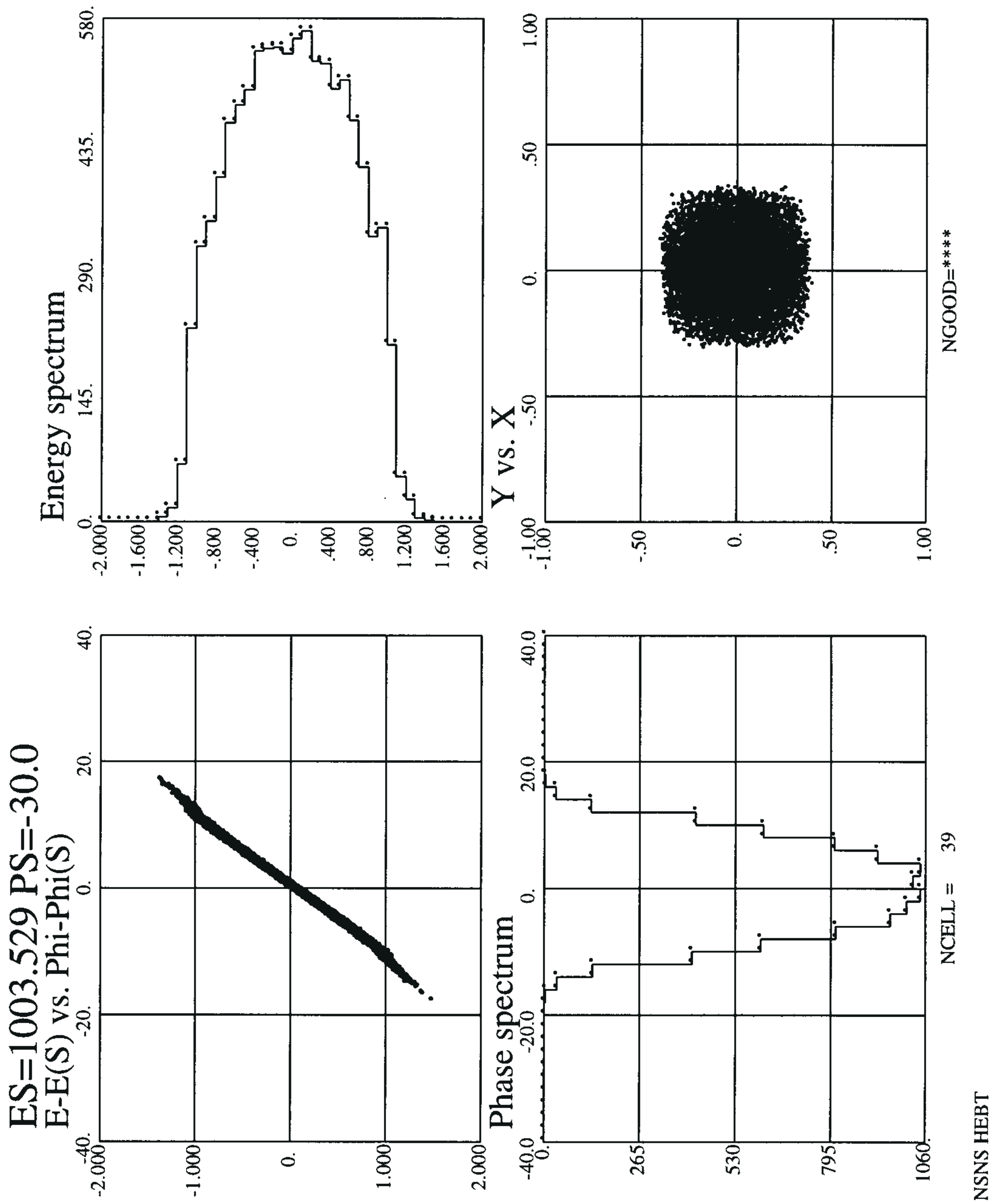
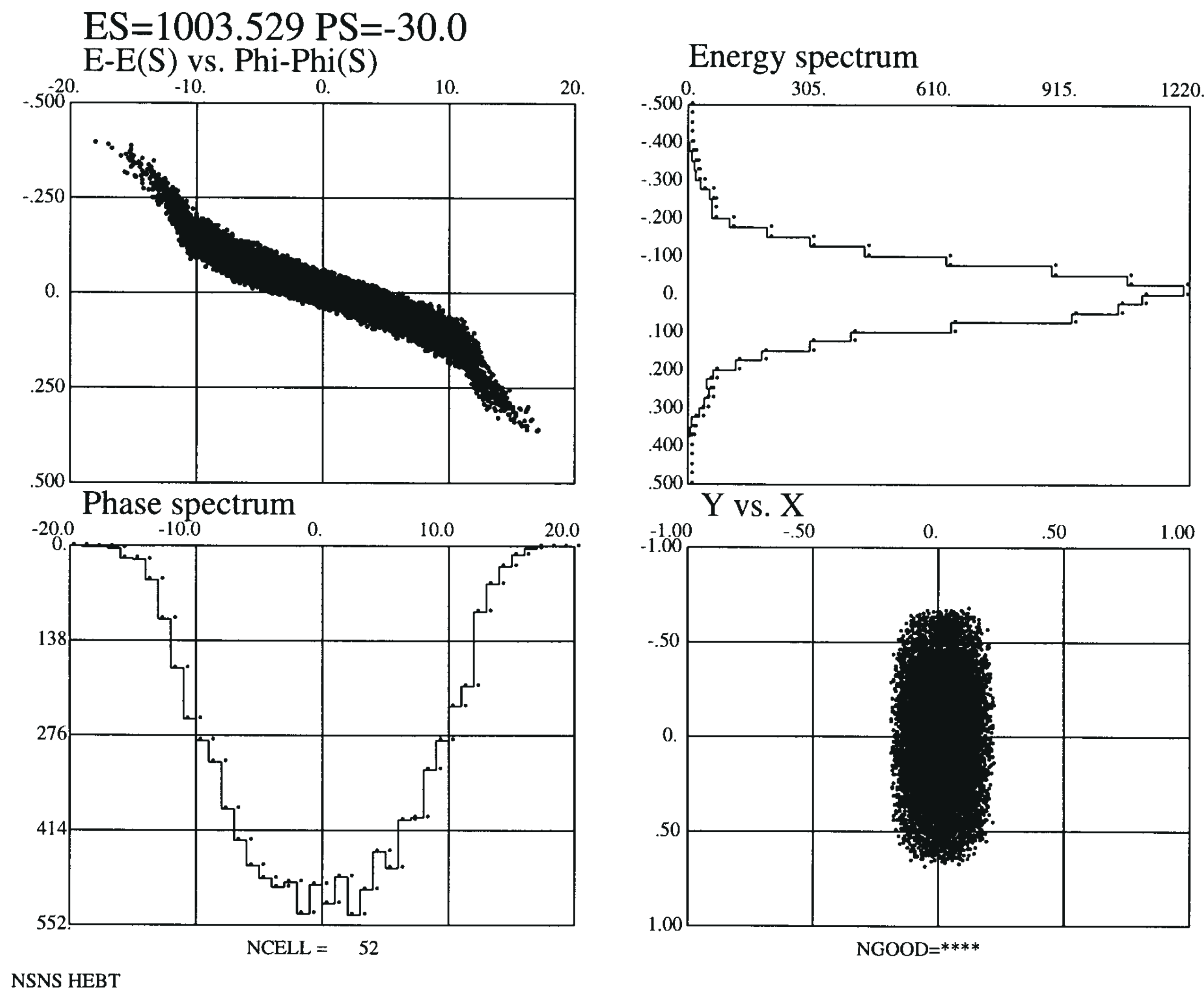
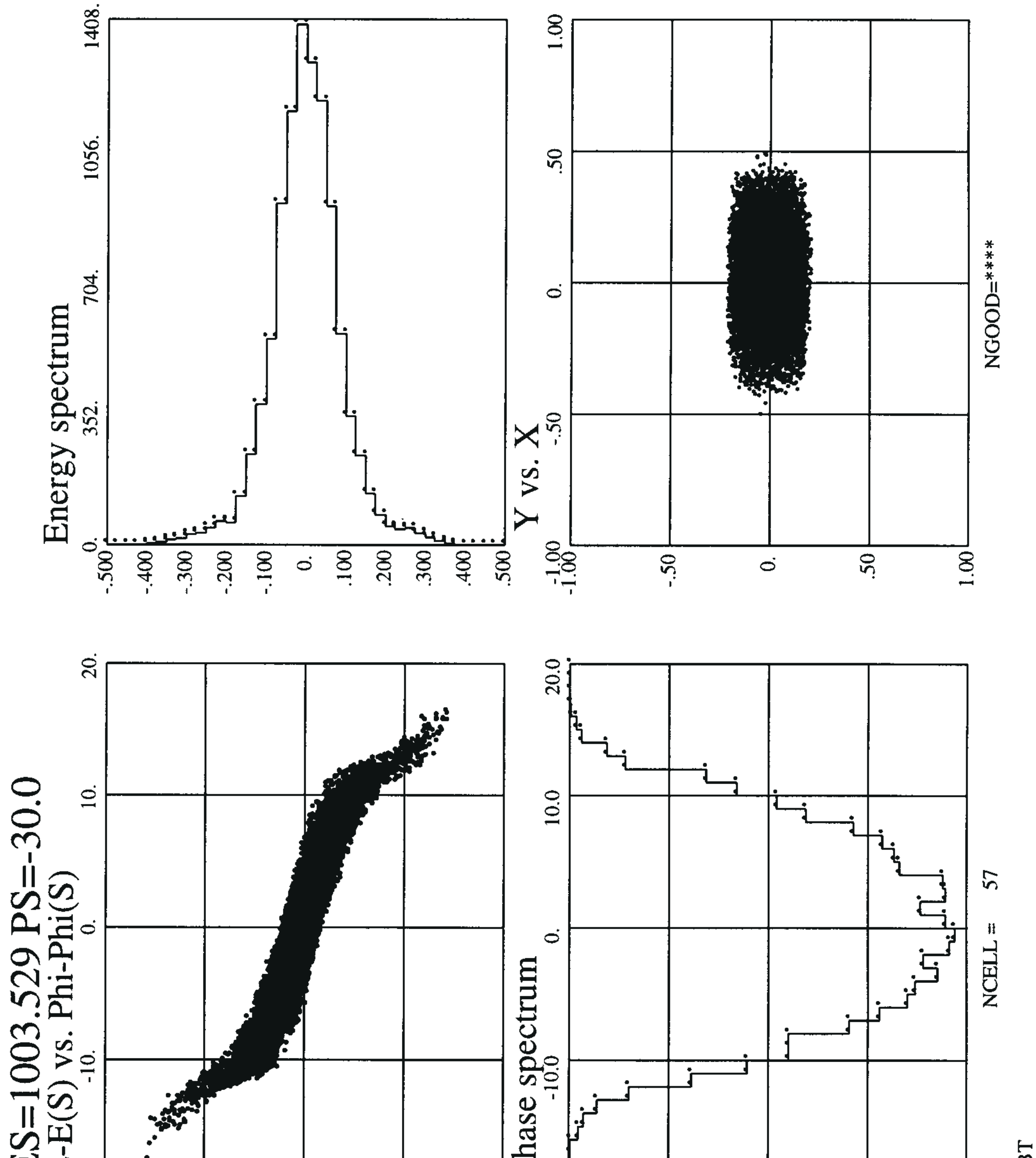

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 39
NGOOD=****
NSNS HEBT

Figure 12c



ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 52
NGOOD=****
NSNS HEBT

Figure 12d



ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Y vs. X
Phase spectrum
NCELL = 57
NGOOD=****
NSNS HEBT

Figure 12e

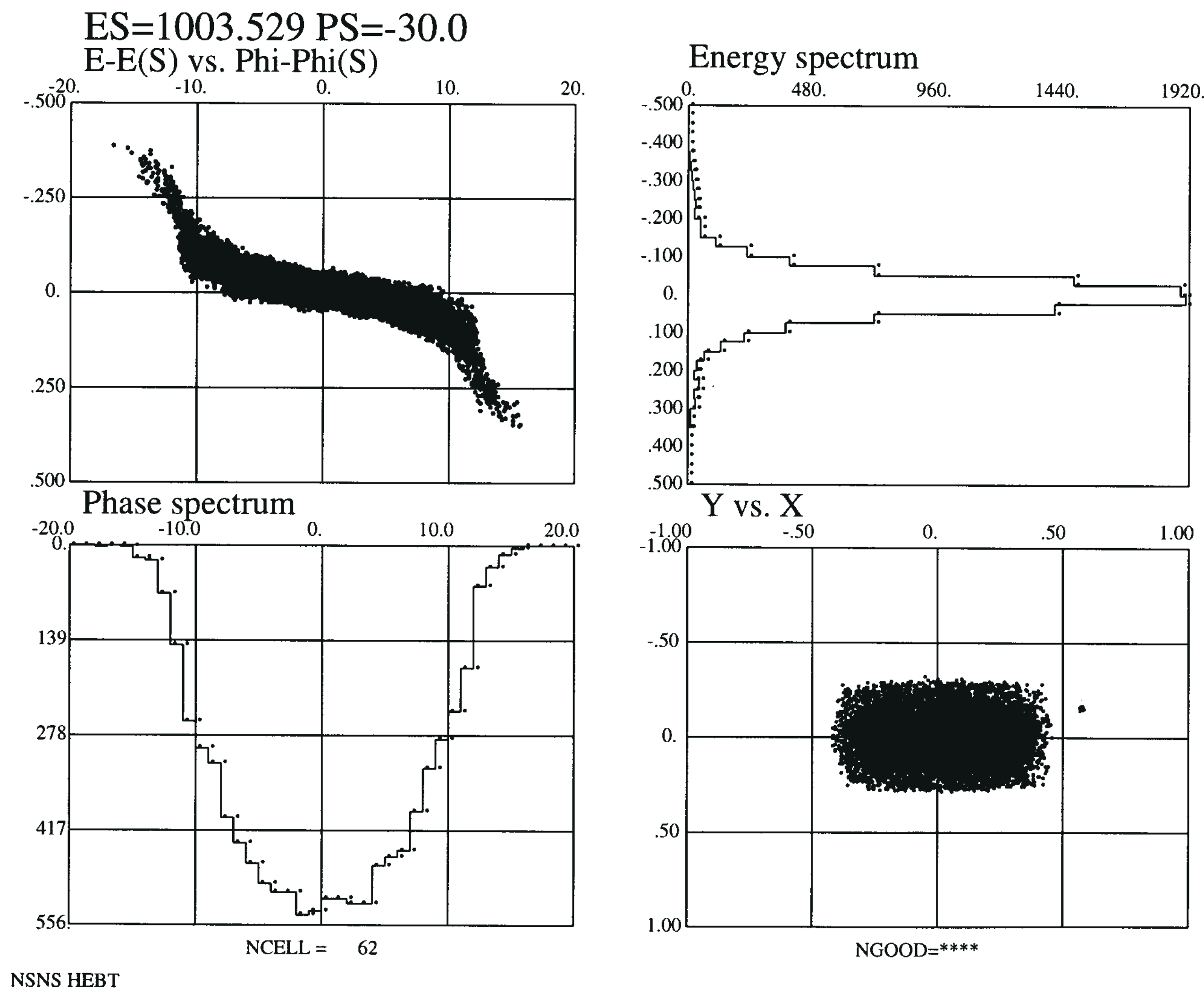

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
-20.
-10.
0.
10.
20.
-.500
-.250
0.
.250
.500
Energy spectrum
0.
480.
960.
1440.
1920.
-.500
-.400
-.300
-.200
-.100
0.
.100
.200
.300
.400
.500
Phase spectrum
-20.0
-10.0
0.
10.0
20.0
0.
139
278
417
556
NCELL = 62
Y vs. X
-1.00
-.50
0.
.50
1.00
NGOOD=****
NSNS HEBT

Figure 12f

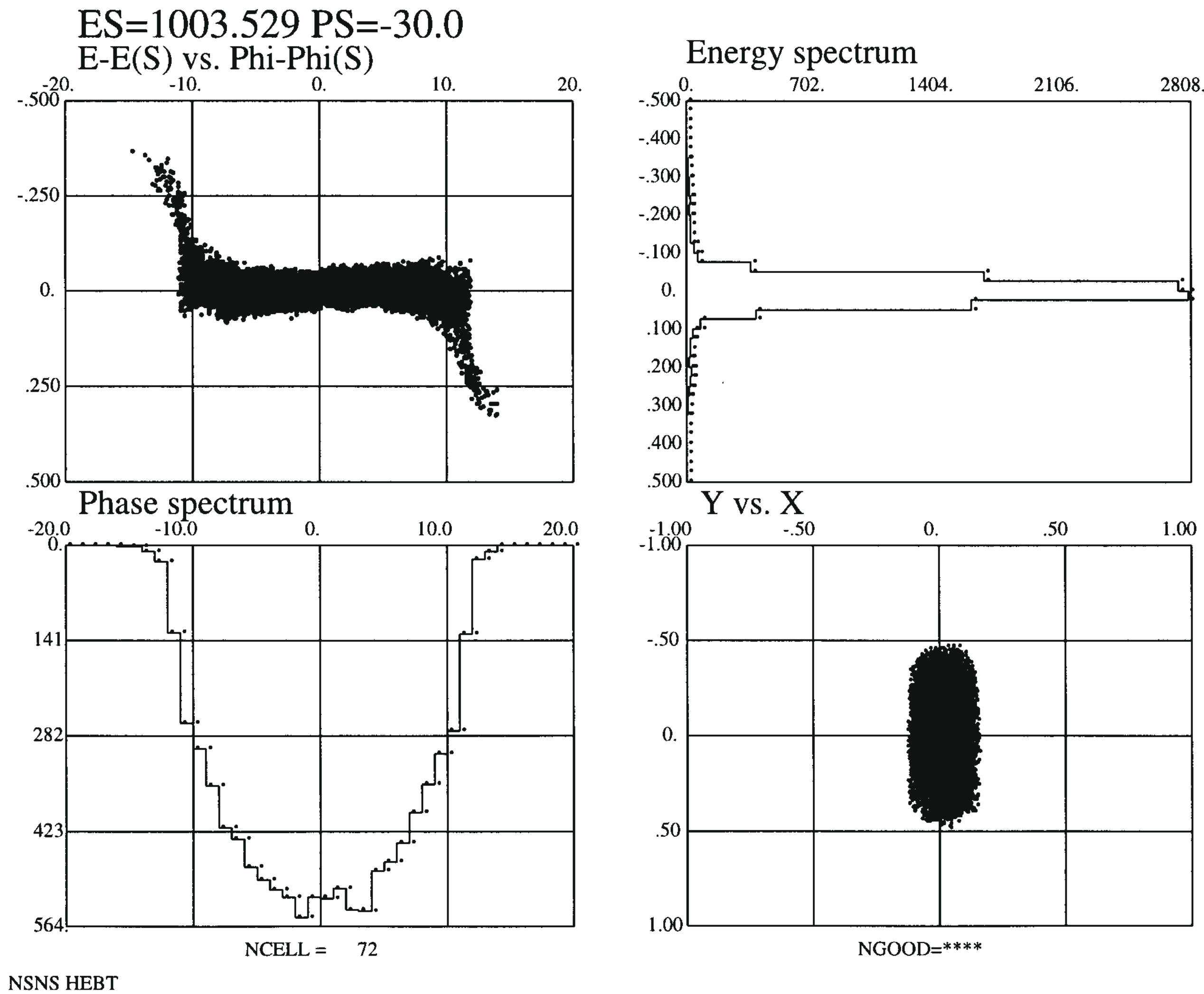

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 72
NGOOD=****
NSNS HEBT

Figure 12g

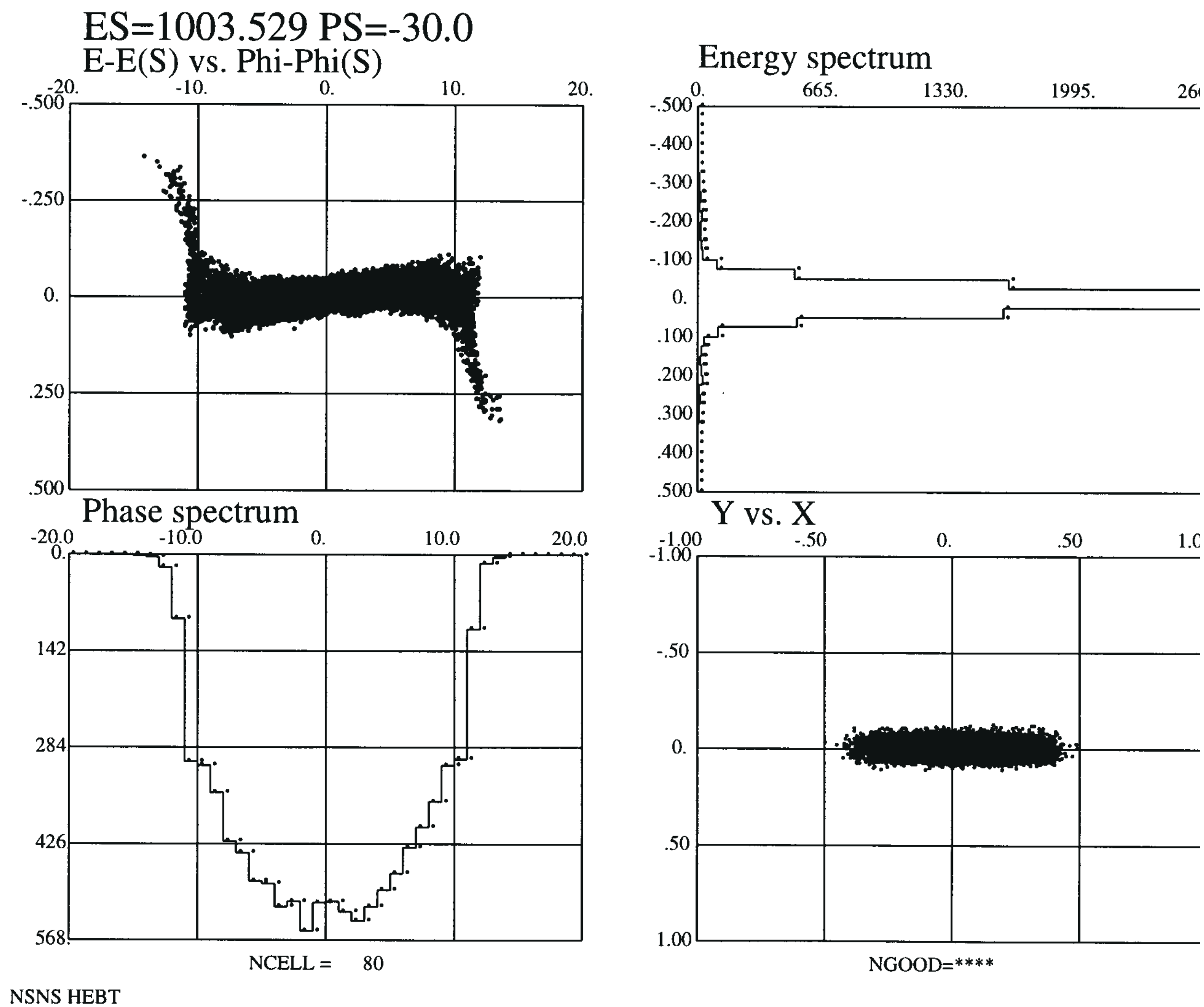
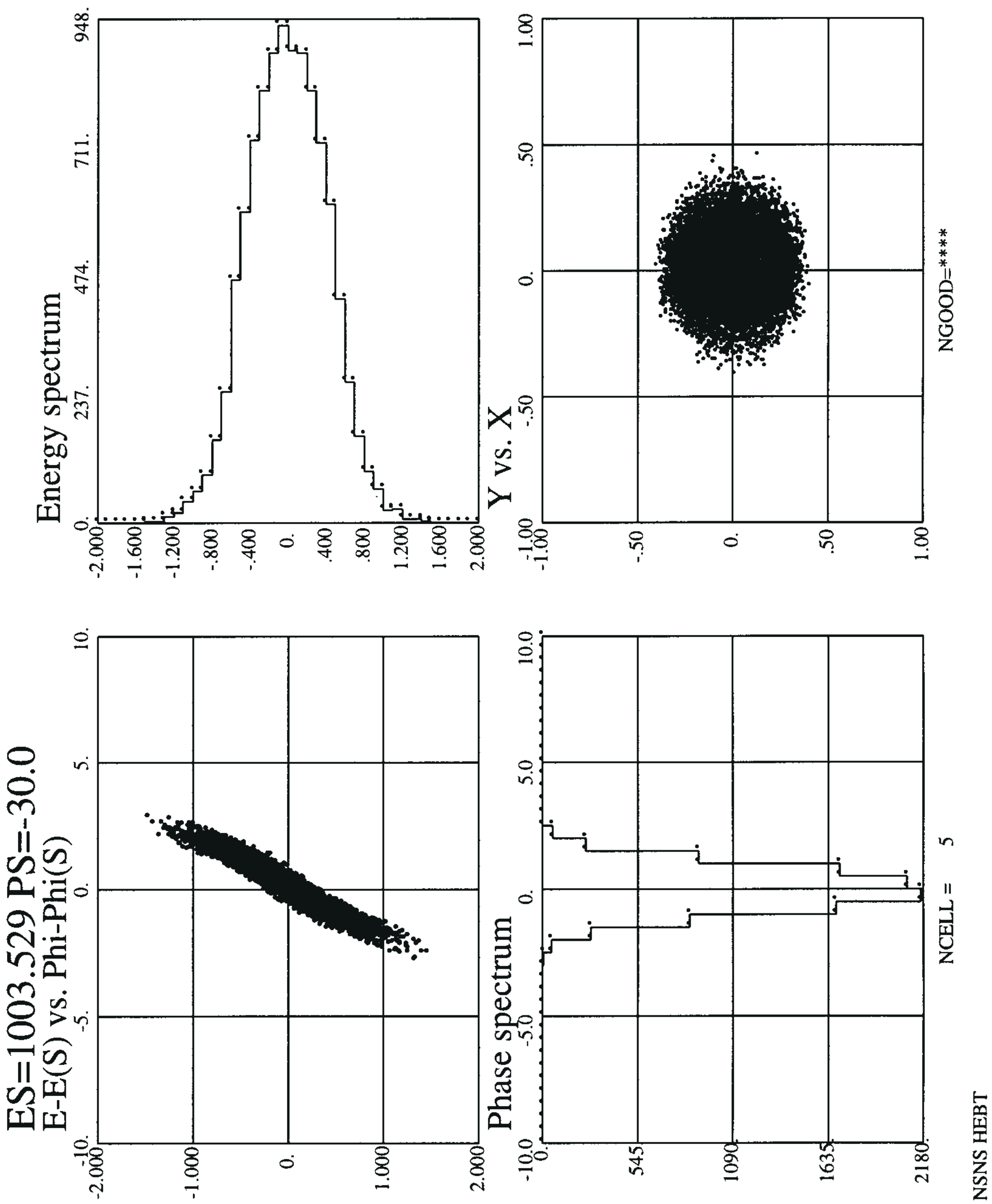
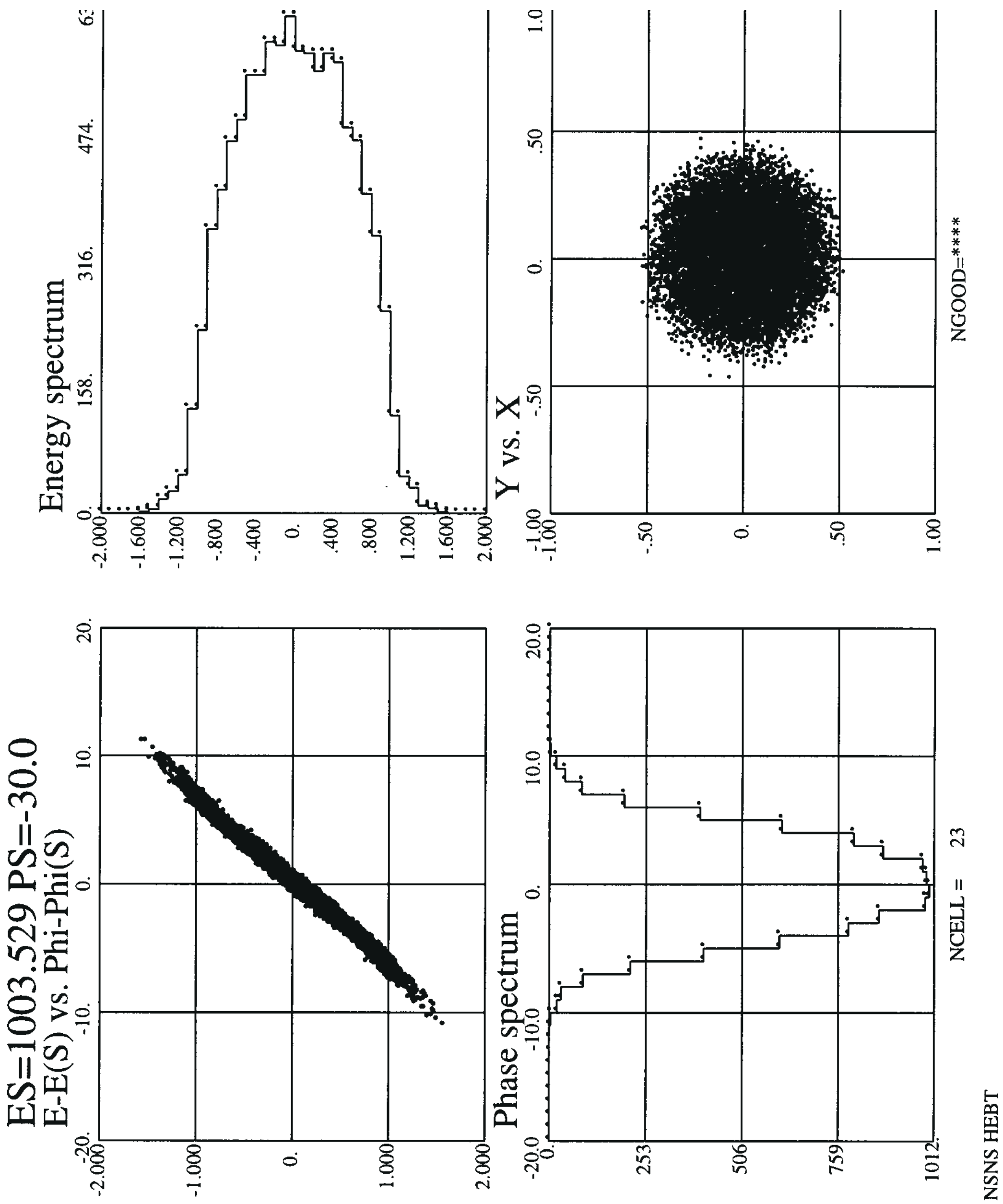

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 80
NGOOD=****
NSNS HEBT

Figure 12h



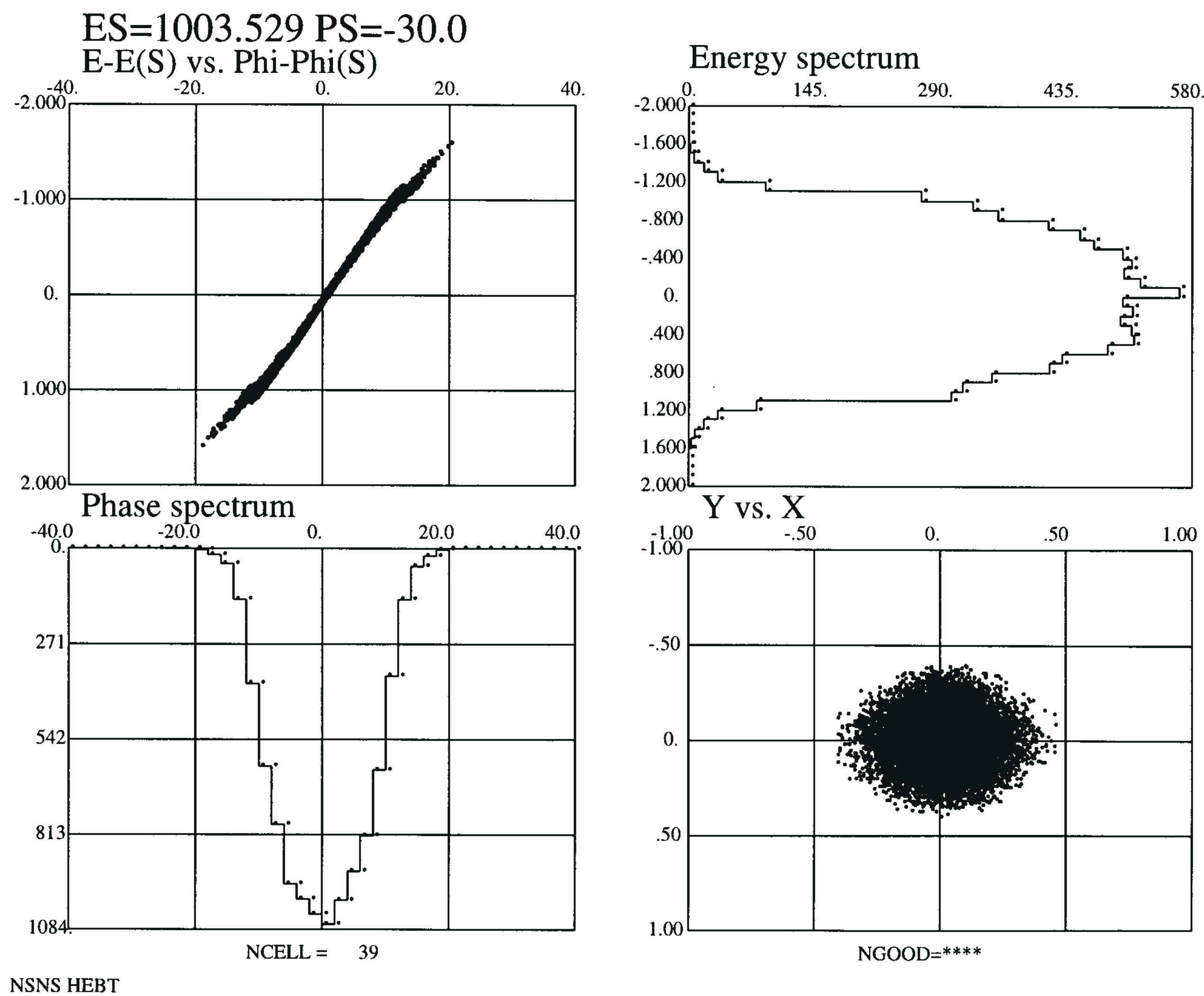
ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Y vs. X
Phase spectrum
NGOOD=****
NCELL = 5
NSNS HEBT

Figure 13a



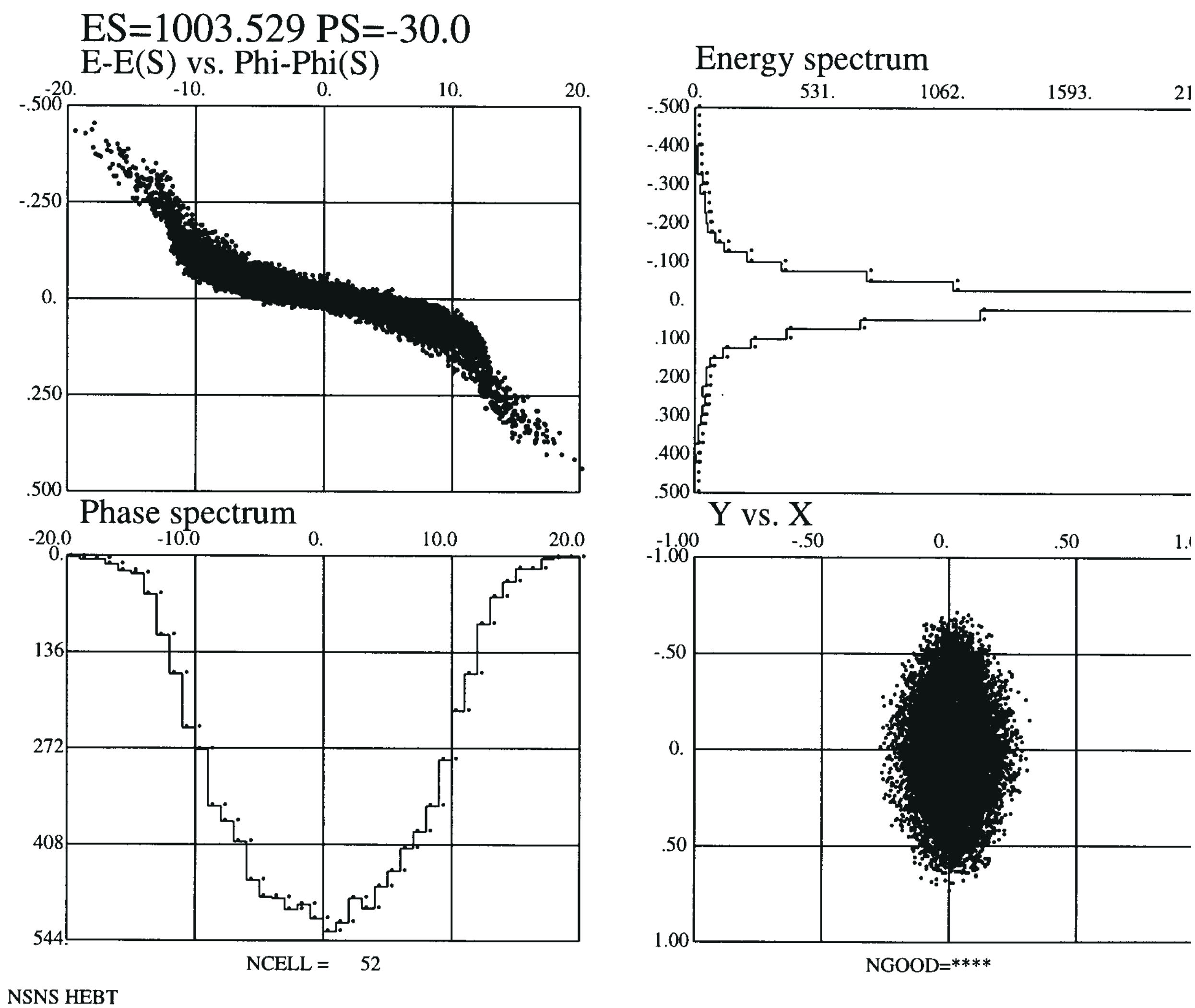
ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 23
NGOOD=****
NSNS HEBT

Figure 13b



ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 39
NGOOD=****
NSNS HEBT

Figure 13c



ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 52
NGOOD=****
NSNS HEBT

Figure 13d

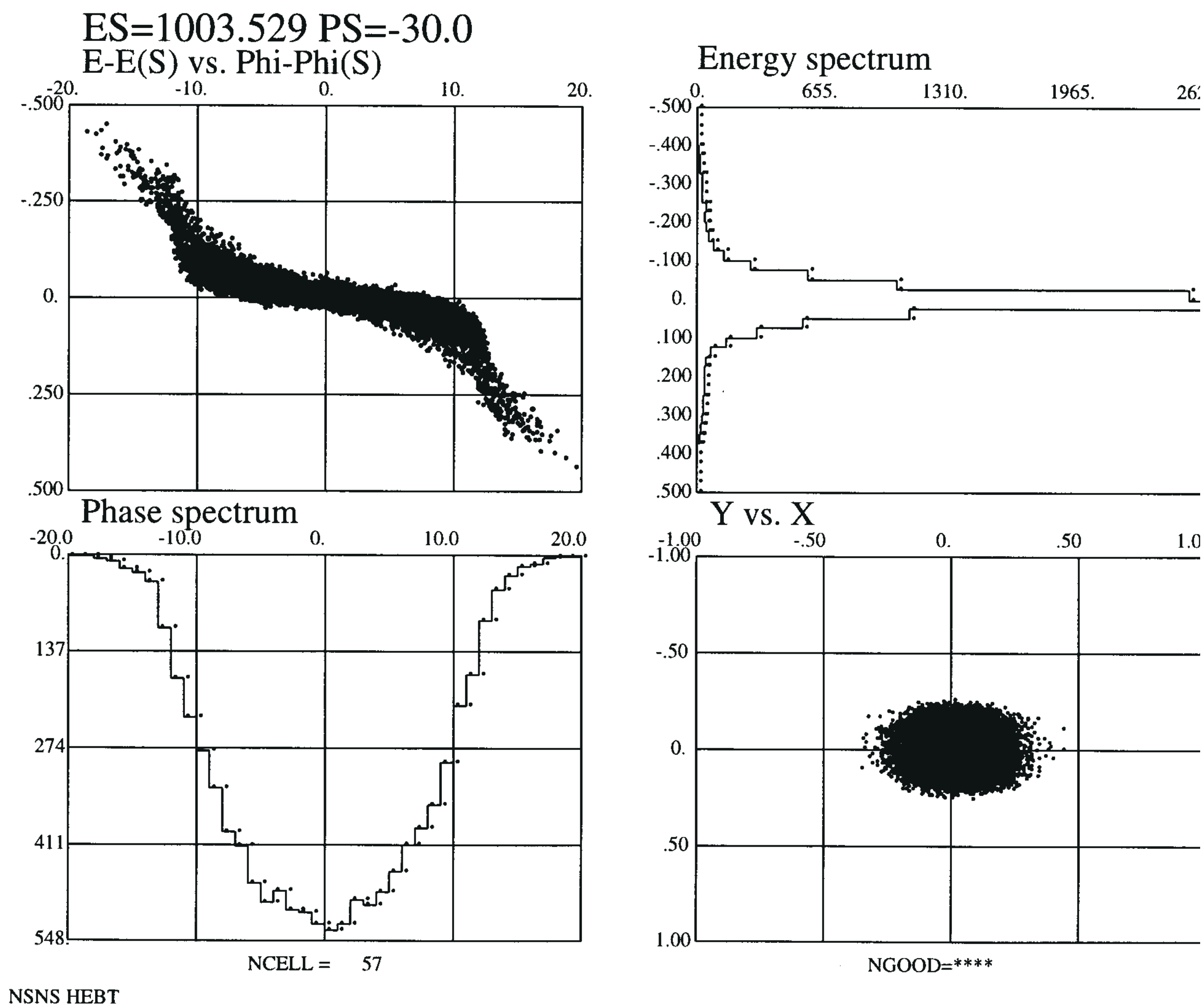

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
-20.
-10.
0.
10.
20.
-.500
-.250
0.
.250
.500
Energy spectrum
0.
655.
1310.
1965.
-.400
-.300
-.200
-.100
.100
.200
.300
.400
Phase spectrum
-20.0
-10.0
10.0
20.0
137
274
411
548
Y vs. X
-1.00
-.50
.50
1.00
1.0
NCELL = 57
NGOOD=****
NSNS HEBT

Figure 13e

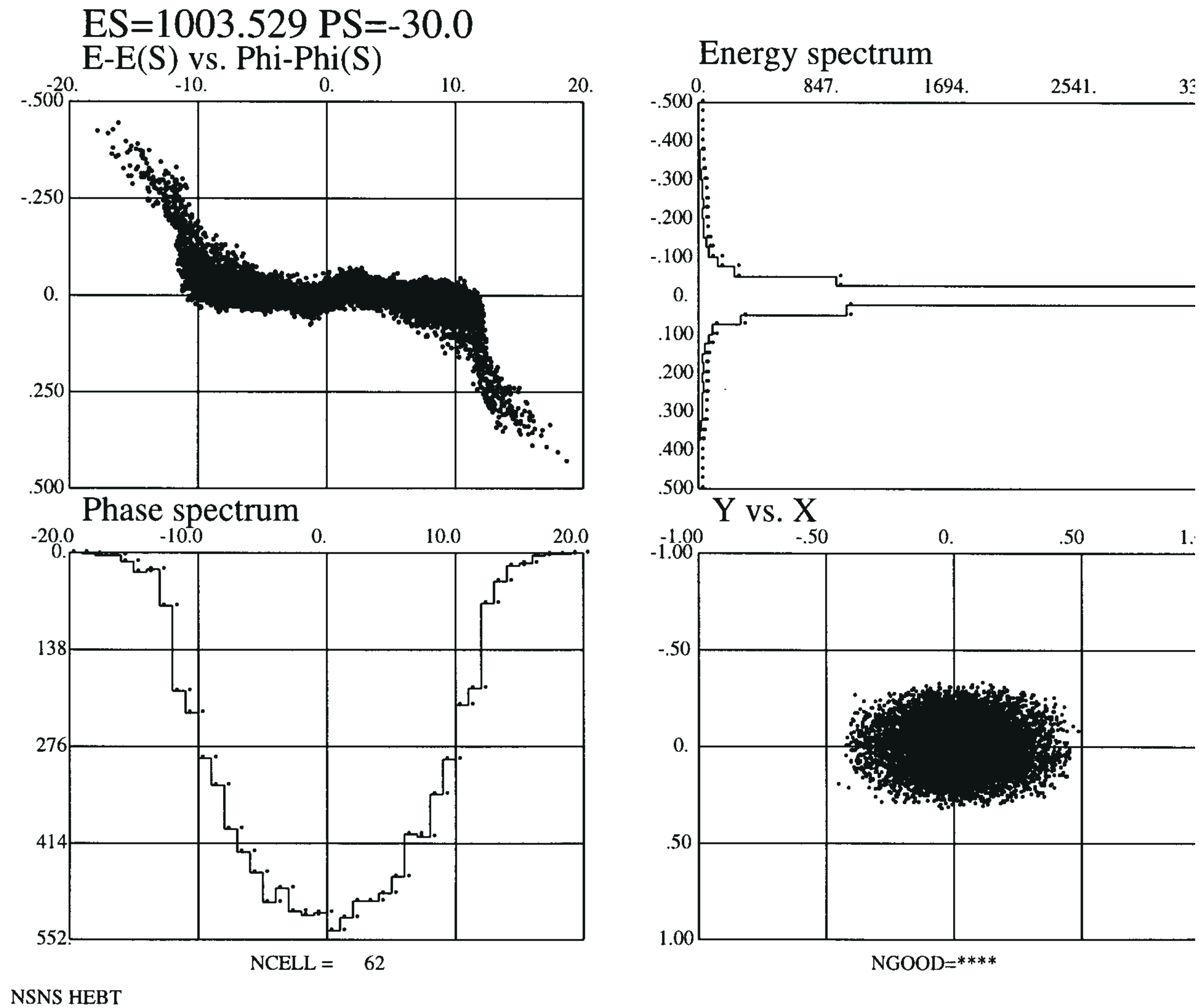

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 62
NGOOD=****
NSNS HEBT

Figure 13f

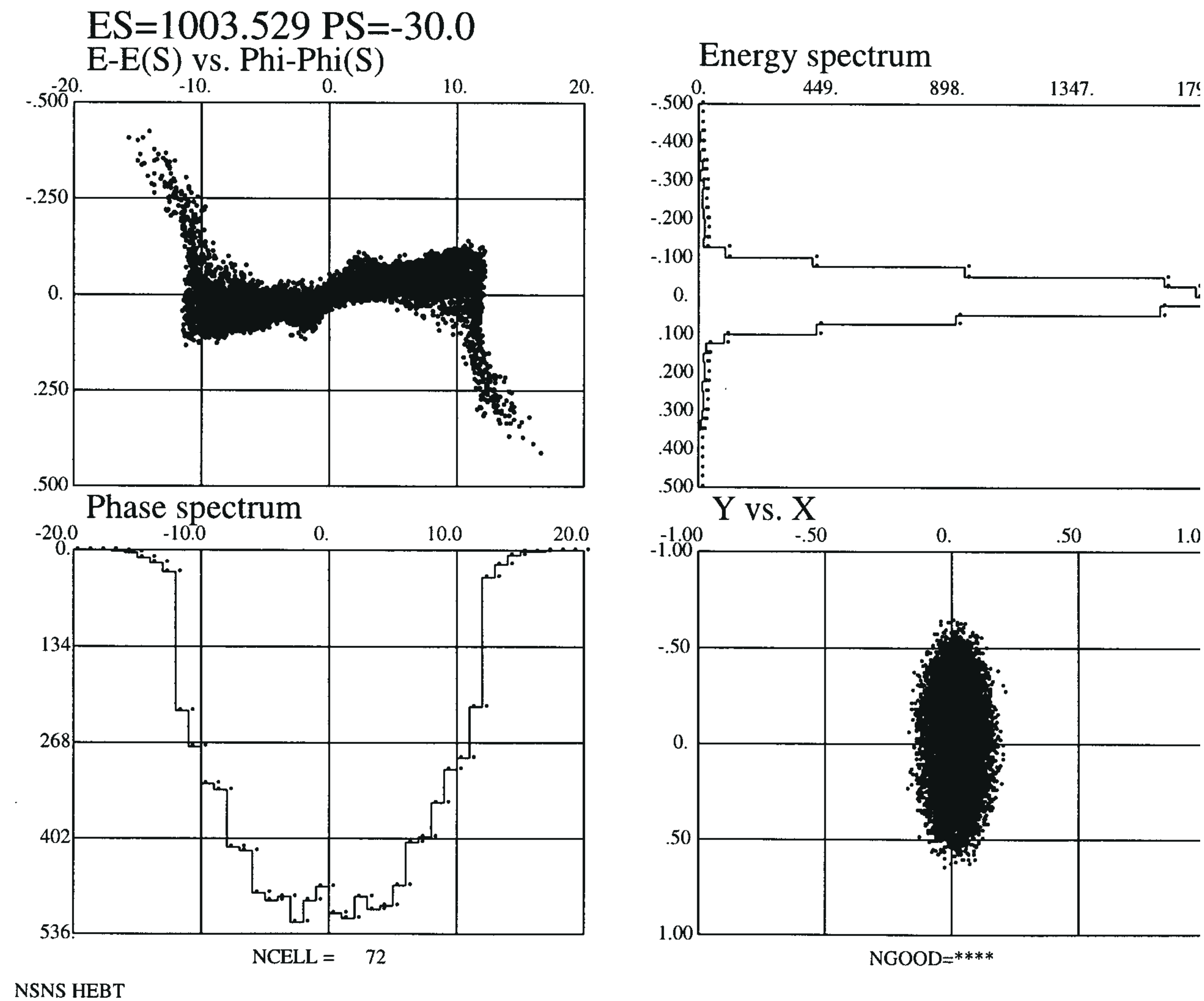

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 72
NGOOD=****
NSNS HEBT

Figure 13g

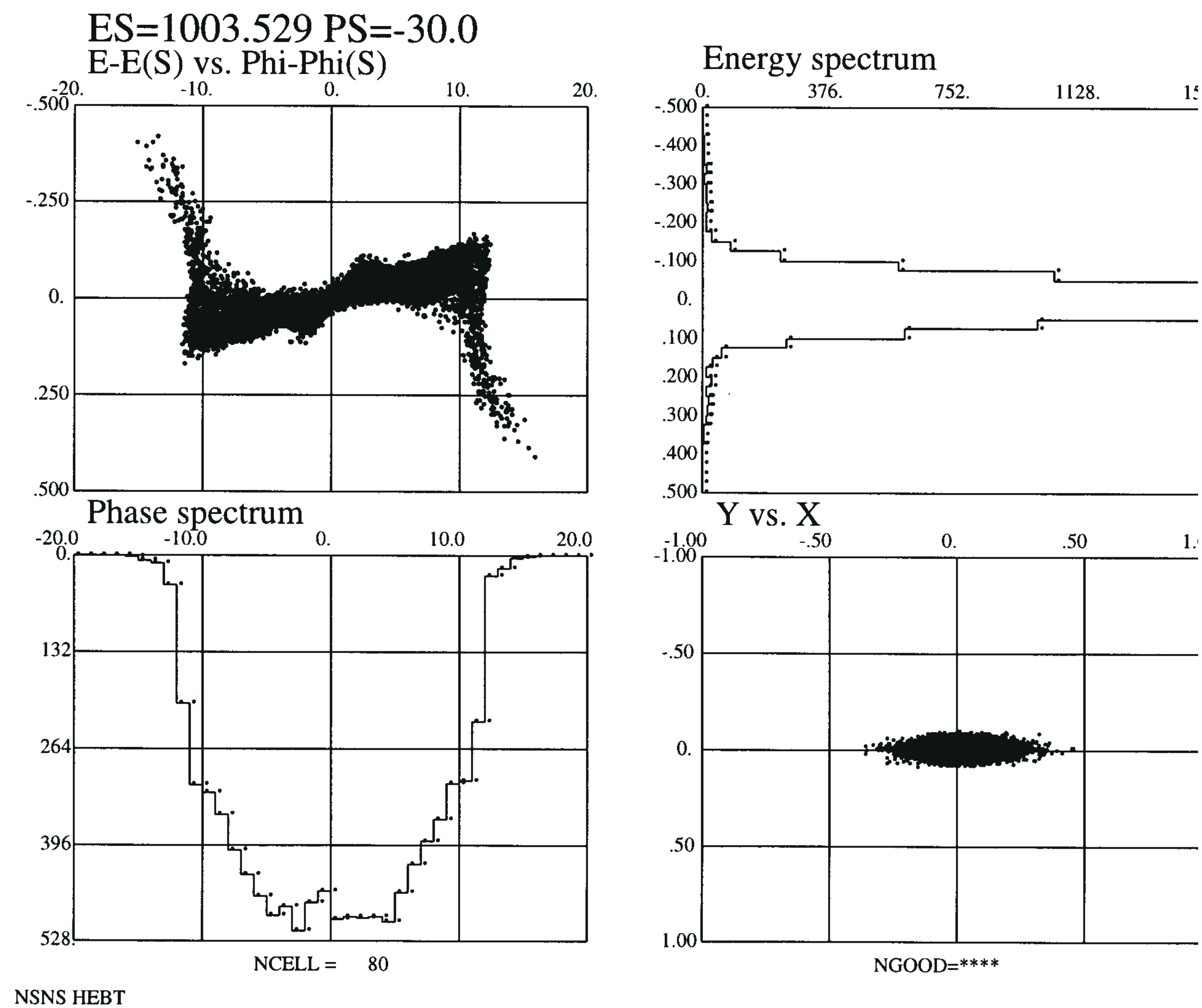

ES=1003.529 PS=-30.0
E-E(S) vs. Phi-Phi(S)
Energy spectrum
Phase spectrum
Y vs. X
NCELL = 80
NGOOD=****
NSNS HEBT

Figure 13h

Appendices

A Input file for TRANSPORT

```
" NSNS LINAC TO BOSTER ARC CELL"
    0 ;
    PRINT, REFER ;
    PRINT, BEAM, ON ;
    PRINT, TRANS, ON ;
    PRINT, ACCEL, ON ;
    PRINT, ONELINE ;
    BM: BEAM.0000,BETAX=1.93523,ALPHAX=-0.021,BETAY=.35017,ALPHAY=0.0002,P0=1.6960 ;
    QF:=2.79383 ;
    QD:=-2.85883 ;
    QL1:=0.2500 ;
    QL2:=0.5000 ;
    QAR:=10.00 ;
    QF1: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    LL1: DRIFT, L=0.720 ;
    DR1: ROTAT, ANGLE=0.0 ;
    DD1: BEND, L=2.500, ANGLE= 7.5 ;
    DR2: ROTAT, ANGLE=0.0 ;
    LL2: DRIFT, L=2.073,
    QD1: QUAD.00, L=QL2, B=-2.41536, APER=QAR ;
    LL3: DRIFT, L=0.720,
    DR3: ROTAT, ANGLE=0.0 ;
    DD2: BEND, L=2.500, ANGLE=7.5 ;
    DR4: ROTAT, ANGLE=0.0 ;
    LL4: DRIFT, L=2.073,
    QF2: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    QF3: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    LL5: DRIFT, L=0.720 ;
    DR5: ROTAT, ANGLE=0.0 ;
    DD3: BEND, L=2.500, ANGLE= 7.5 ;
    DR6: ROTAT, ANGLE=0.0 ;
    LL6: DRIFT, L=2.073,
    QD2: QUAD.00, L=QL2, B=-2.41536, APER=QAR ;
    LL7: DRIFT, L=0.720,
    DR7: ROTAT, ANGLE=0.0 ;
    DD4: BEND, L=2.500, ANGLE=7.5 ;
    DR8: ROTAT, ANGLE=0.0 ;
    LL8: DRIFT, L=1.3966367,
    QF4: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    QF5: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    LL9: DRIFT, L=1.3966367 ;
    DR9: ROTAT, ANGLE=0.0 ;
    DD5: BEND, L=2.500, ANGLE= 7.5 ;
    DRA: ROTAT, ANGLE=0.0 ;
    LLA: DRIFT, L=0.720,
    QD3: QUAD.00, L=QL2, B=-2.41536, APER=QAR ;
    LLB: DRIFT, L=2.073,
    DRB: ROTAT, ANGLE=0.0 ;
    DD6: BEND, L=2.500, ANGLE=7.5 ;
    DRC: ROTAT, ANGLE=0.0 ;
    LLC: DRIFT, L=0.720,
    QF6: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    QF7: QUAD.00, L=QL1, B=2.72141, APER=QAR ;
    LLD: DRIFT, L=2.073 ;
    DRD: ROTAT, ANGLE=0.0 ;
    DD7: BEND, L=2.500, ANGLE= 7.5 ;
    DRE: ROTAT, ANGLE=0.0 ;
    LLE: DRIFT, L=0.720 ;
    QD4: QUAD.00, L=QL2, B=-2.41536, APER=QAR ;
    LLF: DRIFT, L=2.073,
    DRF: ROTAT, ANGLE=0.0 ;
    DD8: BEND, L=2.500, ANGLE=7.5 ;
    DRG: ROTAT, ANGLE=0.0 ;
    LLG: DRIFT, L=0.720,
    QF8: QUAD.0A, L=QL1, B=2.72141, APER=QAR ;
    FPX1: -FIT -11 2. 0.999999 0.00001 ;
    FPY1: -FIT -13 4. 0.999999 0.00001 ;
    QF9: QUAD.0A L=QL1, B=2.72141, APER=QAR ;
    LLH: DRIFT, L=5.2932734 ;
    QD5: QUAD.01 L=QL2, B=-2.85883, APER=QAR ;
    LLK: DRIFT, L=2.0732734 ;
    DRH: ROTAT, ANGLE=0.0 ;
    DD9: BEND, L=2.500, ANGLE=-7.5 ;
    DRI: ROTAT, ANGLE=0.0 ;
    LLL: DRIFT, L=0.720 ;
```

```
QFA: QUAD.0B, L=QL1, B=2.92383, APER=QAR ;
QFB: QUAD.0B, L=QL1, B=2.92383, APER=QAR ;
LLI: DRIFT, L=5.2932734 ;
QD6: QUAD.01 L=QL2,B=-2.97883, APER=QAR ;
LLJ: DRIFT, L=5.2932734 ;
QFC: QUAD.0C, L=QL1, B=2.92383, APER=QAR ;
QFD: QUAD.0C, L=QL1, B=2.92383, APER=QAR ;
LLZ: DRIFT, L=5.2932734 ;
QDZ: QUAD.01 L=QL2,B=-2.97883, APER=QAR ;
LLY: DRIFT, L=5.2932734 ;
QFZ: QUAD.0D, L=QL1, B=2.89383, APER=QAR ;
QFY: QUAD.0D, L=QL1, B=2.89383, APER=QAR ;
LLX: DRIFT, L=5.2932734 ;
QDY: QUAD.01 L=QL2,B=-2.95883, APER=QAR ;
LLW: DRIFT, L=5.2932734 ;
QFX: QUAD.0G, L=QL1, B=2.89383, APER=QAR ;
QFW: QUAD.0G, L=QL1, B=2.89383, APER=QAR ;
LLM: DRIFT, L=3.6398737 ;
DRJ: ROTAT, ANGLE=0.0 ;
DB9: BEND, L=0.9333996668, ANGLE=2.8001990 ;
DRK: ROTAT, ANGLE=0.0 ;
LLN: DRIFT, L=0.720 ;
QD7: QUAD.01, L=QL2, B=-2.85883, APER=QAR;
LLO: DRIFT, L=2.7163793 ;
DRL: ROTAT, ANGLE=0.0 ;
DBS: BEND, L=1.012225, ANGLE=3.036676 ;
DRM: ROTAT, ANGLE=0.0 ;
LLP: DRIFT, L=0.800 ;
DRN: ROTAT, ANGLE=0.0 ;
DB4: BEND, L=0.464668998, ANGLE=0.464669 ;
DRO: ROTAT, ANGLE=0.0 ;
LLQ: DRIFT, L=0.300;
QFE: QUAD.0H, L=QL1, B=2.89383, APER=QAR ;
QFF: QUAD.0H, L=QL1, B=2.89383, APER=QAR ;
LLR: DRIFT, L=0.2000 ;
FPBT: FIT, BETAX=2.256983,TOLER=0.001 ;
FPB1: FIT, ALPHAX=2.12371, TOLER=0.001 ;
FPB2: FIT, BETAY=.529471,TOLER=0.001 ;
FPB3: FIT, ALPHAY=-0.56593,TOLER=0.001 ;
10 -1 6 0.0000 0.01;
10 -2 6 0.0000 0.01 ;
SENTINEL
SENTINEL
```

B Input file for TRACE

```
$DATA
     ER= 939.29000, Q= 1., W= 981.78039, XI= 56.000,
     EMITI(1)= 0.698032, 0.698049, 2257.887085,
     BEAMI(1)= 0.06709, 12.75481, 0.66929, 15.33173, 0.00609, 0.00507,
     FREQ= 805.000, PQEXT= 2.50, ICHROM= 0,
     XM= 10.0000, XPM= 5.0000, YM= 10.00, DPM= 125.00, DWM= 800.00, DPP= 20.00,
     XMI= 10.0000, XPMI= 5.0000, XMF= 10.0000, XPMF= 5.0000,
     DPMI= 25.0000, DPMF= 25.0000, DWMI=1000.0000, DWMF=1000.0000,
     N1= 6, N2= 149, SMAX= 200.0, PQSMAX= 2.5, NEL1= 6, NEL2= 149, NP1= 1, NP2= 150,
     BEAMF(1)= 2.12371, 22.56983, -0.56593, 5.29471, 0.00609, 0.00502,
     MT= 8,NC= 4,MP=1, 104 , 1, 111 , 1, 114 , 1, 117 , 0, 0 , 0, 0 ,
     MVC=0, 0, 0 , 0, 0, 0 , 0, 0, 0 , 0, 0, 0 , 0, 0, 0 , 0, 0, 0 ,
     IJM=2,6, 1,6, 0,0, 0,0, 0,0, 0,0,
     VAL= 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000,
     ISECURE=0, CMT( 1)=' ' NT( 1)= 13, A(1, 1)= 2.8000000 , 1786.1000 ,-29.885000 , 11.000000 ,
     CMT( 2)=' ' NT( 2)= 1, A(1, 2)= 203.86000 ,
     CMT( 3)=' ' NT( 3)= 3, A(1, 3)= 42.000000 , 96.000000 ,
     CMT( 4)=' ' NT( 4)= 1, A(1, 4)= 50.000000 ,
     CMT( 5)=' ' NT( 5)= 3, A(1, 5)=-42.000000 , 96.000000 ,
     CMT( 6)=' ' NT( 6)= 1, A(1, 6)= 203.86000 ,
     CMT( 7)=' ' NT( 7)= 13, A(1, 7)= 2.8000000 , 1787.3700 ,-29.894000 , 11.000000 ,
     CMT( 8)=' ' NT( 8)= 1, A(1, 8)= 204.08000 ,
     CMT( 9)=' ' NT( 9)= 3, A(1, 9)=0.00000000E+00, 96.000000 ,
     CMT( 10)=' ' NT( 10)= 1, A(1, 10)= 50.000000 ,
     CMT( 11)=' ' NT( 11)= 3, A(1, 11)=0.00000000E+00, 96.000000 ,
     CMT( 12)=' ' NT( 12)= 1, A(1, 12)= 204.08000 ,
     CMT( 13)=' ' NT( 13)= 13, A(1, 13)= 2.8000000 , 1788.6300 ,-29.916000 , 11.000000 ,
     CMT( 14)=' ' NT( 14)= 1, A(1, 14)= 204.34000 ,
     CMT( 15)=' ' NT( 15)= 3, A(1, 15)= 42.000000 , 96.000000 ,
     CMT( 16)=' ' NT( 16)= 1, A(1, 16)= 50.000000 ,
     CMT( 17)=' ' NT( 17)= 3, A(1, 17)=-42.000000 , 96.000000 ,
     CMT( 18)=' ' NT( 18)= 1, A(1, 18)= 204.34000 ,
     CMT( 19)=' ' NT( 19)= 13, A(1, 19)= 2.8000000 , 1789.8800 ,-29.878000 , 11.000000 ,
     CMT( 20)=' ' NT( 20)= 1, A(1, 20)= 204.54000 ,
     CMT( 21)=' ' NT( 21)= 3, A(1, 21)=0.00000000E+00, 96.000000 ,
     CMT( 22)=' ' NT( 22)= 1, A(1, 22)= 50.000000 ,
     CMT( 23)=' ' NT( 23)= 3, A(1, 23)=0.00000000E+00, 96.000000 ,
     CMT( 24)=' ' NT( 24)= 1, A(1, 24)= 204.54000 ,
     CMT( 25)=' ' NT( 25)= 13, A(1, 25)= 2.8000000 , 1791.1200 ,-29.901000 , 11.000000 ,
     CMT( 26)=' ' NT( 26)= 1, A(1, 26)= 204.77000 ,
     CMT( 27)=' ' NT( 27)= 3, A(1, 27)= 9.4965500 , 96.000000 ,
     CMT( 28)=' ' NT( 28)= 1, A(1, 28)= 50.000000 ,
     CMT( 29)=' ' NT( 29)= 3, A(1, 29)=-9.4965500 , 96.000000 ,
     CMT( 30)=' ' NT( 30)= 1, A(1, 30)= 204.77000 ,
     CMT( 31)=' ' NT( 31)= 13, A(1, 31)= 2.8000000 , 1792.3600 ,-29.899000 , 11.000000 ,
     CMT( 32)=' ' NT( 32)= 1, A(1, 32)= 205.00000 ,
     CMT( 33)=' ' NT( 33)= 3, A(1, 33)= 52.095449 , 96.000000 ,
     CMT( 34)=' ' NT( 34)= 1, A(1, 34)= 50.000000 ,
     CMT( 35)=' ' NT( 35)= 3, A(1, 35)=-65.796814 , 96.000000 ,
     CMT( 36)=' ' NT( 36)= 1, A(1, 36)= 205.00000 ,
     CMT( 37)=' QF1 ' NT( 37)= 3, A(1, 37)= 3.7319065 , 250.00000 ,
     CMT( 38)=' QF1 ' NT( 38)= 3, A(1, 38)= 3.7319065 , 250.00000 ,
     CMT( 39)=' L ' NT( 39)= 1, A(1, 39)= 5293.2734 ,
     CMT( 40)=' QD1 ' NT( 40)= 3, A(1, 40)=-2.0500000 , 250.00000 ,
     CMT( 41)=' QD1 ' NT( 41)= 3, A(1, 41)=-2.0500000 , 250.00000 ,
     CMT( 42)=' L ' NT( 42)= 1, A(1, 42)= 5293.2734 ,
     CMT( 43)=' QF2 ' NT( 43)= 3, A(1, 43)= 2.7706699 , 250.00000 ,
     CMT( 44)=' QF2 ' NT( 44)= 16, A(1, 44)= 43.000000 ,
     CMT( 45)=' D ' NT( 45)= 1, A(1, 45)= 720.00000 ,
     CMT( 46)=' E ' NT( 46)= 9, A(1, 46)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 47)=' B ' NT( 47)= 8, A(1, 47)=-7.5000000 ,-19098.573 ,0.00000000E+00,
     CMT( 48)=' E ' NT( 48)= 9, A(1, 48)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 49)=' O ' NT( 49)= 1, A(1, 49)= 2073.2734 ,
     CMT( 50)=' QD2 ' NT( 50)= 3, A(1, 50)=-2.8069856 , 250.00000 ,
     CMT( 51)=' QD2 ' NT( 51)= 16, A(1, 51)= 50.000000 ,
     CMT( 52)=' D ' NT( 52)= 1, A(1, 52)= 720.00000 ,
     CMT( 53)=' E ' NT( 53)= 9, A(1, 53)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 54)=' B ' NT( 54)= 8, A(1, 54)=-7.5000000 ,-19098.573 ,0.00000000E+00,
     CMT( 55)=' E ' NT( 55)= 9, A(1, 55)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 56)=' O ' NT( 56)= 1, A(1, 56)= 2073.2734 ,
     CMT( 57)=' QF3 ' NT( 57)= 16, A(1, 57)= 43.000000 ,
     CMT( 58)=' QF3 ' NT( 58)= 16, A(1, 58)= 43.000000 ,
     CMT( 59)=' D ' NT( 59)= 1, A(1, 59)= 720.00000 ,
     CMT( 60)=' E ' NT( 60)= 9, A(1, 60)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 61)=' B ' NT( 61)= 8, A(1, 61)=-7.5000000 ,-19098.573 ,0.00000000E+00,
     CMT( 62)=' E ' NT( 62)= 9, A(1, 62)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 63)=' O ' NT( 63)= 1, A(1, 63)= 2073.2734 ,
     CMT( 64)=' QD3 ' NT( 64)= 16, A(1, 64)= 50.000000 ,
     CMT( 65)=' QD3 ' NT( 65)= 16, A(1, 65)= 50.000000 ,
     CMT( 66)=' D ' NT( 66)= 1, A(1, 66)= 720.00000 ,
     CMT( 67)=' E ' NT( 67)= 9, A(1, 67)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
     CMT( 68)=' B ' NT( 68)= 8, A(1, 68)=-7.5000000 ,-19098.573 ,0.00000000E+00,
     CMT( 69)=' E ' NT( 69)= 9, A(1, 69)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
```

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CMT( 70)=' O ' NT( 70)= 1, A(1, 70)= 1396.6367 ,
CMT( 71)=' QF4 ' NT( 71)= 3, A(1, 71)= 3.0000000 , 250.00000 ,
CMT( 72)=' QF4 ' NT( 72)= 16, A(1, 72)= 71.000000 ,
CMT( 73)=' D ' NT( 73)= 1, A(1, 73)= 1396.6367 ,
CMT( 74)=' E ' NT( 74)= 9, A(1, 74)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 75)=' B ' NT( 75)= 8, A(1, 75)=-7.5000000 ,-19098.573 ,0.00000000E+00,
CMT( 76)=' E ' NT( 76)= 9, A(1, 76)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 77)=' O ' NT( 77)= 1, A(1, 77)= 720.00000 ,
CMT( 78)=' QD4 ' NT( 78)= 16, A(1, 78)= 50.000000 ,
CMT( 79)=' QD4 ' NT( 79)= 16, A(1, 79)= 50.000000 ,
CMT( 80)=' D ' NT( 80)= 1, A(1, 80)= 2073.2734 ,
CMT( 81)=' E ' NT( 81)= 9, A(1, 81)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 82)=' B ' NT( 82)= 8, A(1, 82)=-7.5000000 ,-19098.573 ,0.00000000E+00,
CMT( 83)=' E ' NT( 83)= 9, A(1, 83)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 84)=' O ' NT( 84)= 1, A(1, 84)= 720.00000 ,
CMT( 85)=' QF5 ' NT( 85)= 16, A(1, 85)= 43.000000 ,
CMT( 86)=' QF5 ' NT( 86)= 16, A(1, 86)= 43.000000 ,
CMT( 87)=' D ' NT( 87)= 1, A(1, 87)= 2073.2734 ,
CMT( 88)=' E ' NT( 88)= 9, A(1, 88)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 89)=' B ' NT( 89)= 8, A(1, 89)=-7.5000000 ,-19098.573 ,0.00000000E+00,
CMT( 90)=' E ' NT( 90)= 9, A(1, 90)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 91)=' O ' NT( 91)= 1, A(1, 91)= 720.00000 ,
CMT( 92)=' QD5 ' NT( 92)= 16, A(1, 92)= 50.000000 ,
CMT( 93)=' QD5 ' NT( 93)= 16, A(1, 93)= 50.000000 ,
CMT( 94)=' D ' NT( 94)= 1, A(1, 94)= 2073.2734 ,
CMT( 95)=' E ' NT( 95)= 9, A(1, 95)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 96)=' B ' NT( 96)= 8, A(1, 96)=-7.5000000 ,-19098.573 ,0.00000000E+00,
CMT( 97)=' E ' NT( 97)= 9, A(1, 97)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 98)=' O ' NT( 98)= 1, A(1, 98)= 720.00000 ,
CMT( 99)=' QF6 ' NT( 99)= 3, A(1, 99)= 2.7214100 , 250.00000 ,
CMT( 100)=' QF6 ' NT( 100)= 16, A(1, 100)= 99.000000 ,
CMT( 101)=' L ' NT( 101)= 1, A(1, 101)= 1343.2110 ,
CMT( 102)='Debunch ' NT( 102)= 13, A(1, 102)= 3.4000000 , 2606.5780 ,-90.000000 , 16.000000 ,
CMT( 103)=' ' NT( 103)= 1, A(1, 103)= 1343.2110 ,
CMT( 104)=' QD6 ' NT( 104)= 3, A(1, 104)=-3.1640254 , 250.00000 ,
CMT( 105)=' QD6 ' NT( 105)= 16, A(1, 105)= 104.00000 ,
CMT( 106)=' D ' NT( 106)= 1, A(1, 106)= 2073.2734 ,
CMT( 107)=' E ' NT( 107)= 9, A(1, 107)=0.00000000E+00, 19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 108)=' BT ' NT( 108)= 8, A(1, 108)= 7.5000000 , 19098.573 ,0.00000000E+00,
CMT( 109)=' E ' NT( 109)= 9, A(1, 109)=0.00000000E+00, 19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 110)=' O ' NT( 110)= 1, A(1, 110)= 720.00000 ,
CMT( 111)=' QF7 ' NT( 111)= 3, A(1, 111)= 2.6032678 , 250.00000 ,
CMT( 112)=' QF7 ' NT( 112)= 16, A(1, 112)= 111.00000 ,
CMT( 113)=' L ' NT( 113)= 1, A(1, 113)= 5293.2734 ,
CMT( 114)=' QD7 ' NT( 114)= 3, A(1, 114)=-3.3255216 , 250.00000 ,
CMT( 115)=' QD7 ' NT( 115)= 16, A(1, 115)= 114.00000 ,
CMT( 116)=' L ' NT( 116)= 1, A(1, 116)= 5293.2734 ,
CMT( 117)=' QD7 ' NT( 117)= 3, A(1, 117)= 3.0105572 , 250.00000 ,
CMT( 118)=' QD7 ' NT( 118)= 16, A(1, 118)= 117.00000 ,
CMT( 119)=' L ' NT( 119)= 1, A(1, 119)= 5293.2734 ,
CMT( 120)=' QD7 ' NT( 120)= 3, A(1, 120)=-3.1859592 , 250.00000 ,
CMT( 121)=' QD7 ' NT( 121)= 16, A(1, 121)= 120.00000 ,
CMT( 122)=' L ' NT( 122)= 1, A(1, 122)= 5293.2734 ,
CMT( 123)=' QF8 ' NT( 123)= 3, A(1, 123)= 2.9619400 , 250.00000 ,
CMT( 124)=' QF8 ' NT( 124)= 16, A(1, 124)= 123.00000 ,
CMT( 125)=' L ' NT( 125)= 1, A(1, 125)= 5293.2734 ,
CMT( 126)=' QD7 ' NT( 126)= 3, A(1, 126)=-3.1859600 , 250.00000 ,
CMT( 127)=' QD7 ' NT( 127)= 16, A(1, 127)= 126.00000 ,
CMT( 128)=' L ' NT( 128)= 1, A(1, 128)= 5293.2734 ,
CMT( 129)=' QF8 ' NT( 129)= 3, A(1, 129)= 2.9619400 , 250.00000 ,
CMT( 130)=' QF8 ' NT( 130)= 16, A(1, 130)= 129.00000 ,
CMT( 131)=' D ' NT( 131)= 1, A(1, 131)= 3639.8737 ,
CMT( 132)=' E ' NT( 132)= 9, A(1, 132)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 133)=' B9 ' NT( 133)= 8, A(1, 133)=-2.8001990 ,-19098.573 ,0.00000000E+00,
CMT( 134)=' E ' NT( 134)= 9, A(1, 134)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 135)=' O ' NT( 135)= 1, A(1, 135)= 720.00000 ,
CMT( 136)=' QD8 ' NT( 136)= 3, A(1, 136)=-3.0088800 , 250.00000 ,
CMT( 137)=' QD8 ' NT( 137)= 16, A(1, 137)= 136.00000 ,
CMT( 138)=' D ' NT( 138)= 1, A(1, 138)= 2716.3793 ,
CMT( 139)=' E ' NT( 139)= 9, A(1, 139)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 140)=' BS ' NT( 140)= 8, A(1, 140)=-3.0366760 ,-19098.573 ,0.00000000E+00,
CMT( 141)=' E ' NT( 141)= 9, A(1, 141)=0.00000000E+00,-19098.573 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 142)=' O ' NT( 142)= 1, A(1, 142)= 800.00000 ,
CMT( 143)=' E ' NT( 143)= 9, A(1, 143)=0.00000000E+00,-57295.719 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 144)=' B4 ' NT( 144)= 8, A(1, 144)=-.46466900 ,-57295.719 ,0.00000000E+00,
CMT( 145)=' E ' NT( 145)= 9, A(1, 145)=0.00000000E+00,-57295.719 , 195.20000 ,0.44999999 , 2.8000000 ,
CMT( 146)=' O ' NT( 146)= 1, A(1, 146)= 300.00000 ,
CMT( 147)=' QF9 ' NT( 147)= 3, A(1, 147)= 2.7938300 , 250.00000 ,
CMT( 148)=' QF9 ' NT( 148)= 16, A(1, 148)= 147.00000 ,
CMT( 149)=' O ' NT( 149)= 1, A(1, 149)= 200.00000 ,

$END
```

C Input file for PARMILA

```
RUN 1 1
    TITLE
    NSNS HEBT CHARGE 1
    LINAC 1 1003.529 805.000 1.001089
    TANK 1 1005.0 -30.0 0.046 0.00 0.046 0.0 0.0 3.0 -3.0
    3.8 1 2 11 0 0.5 0.0 0.0 0.0 1.0 0 0 0 0 0 1.0
    INPUT -38 -10000 -3.3613 1636.2 0.000069 4.8238 1610.8 0.0000690
    0.02097 282.9216080 0.000032103
    OUTPUT 3 1 0 0 0 0 1
    OUTPUT 2 1 0 0 0 0 1 300 1
    OUTPUT 1 1 1 0 0 0 1 200
    ELIMIT 5
    SCHEFF 56 0.5 0.5 20 40 0 0 3 1 3
    TRANS1 1 3 373.19065 50.0 06 0. 1 1 7 1
    TRANS1 2 1 529.32734 50.0 06 0. 1 1 7 1
    TRANS1 3 3 -204.76695 25.0 06 0. 1 1 7 1
    TRANS1 4 1 529.32734 50.0 06 0. 1 1 7 1
    TRANS1 5 3 277.06699 50.0 06 0. 1 1 7 1
    TRANS1 6 1 72.00000 7.0 06 0. 1 1 7 1
    TRANS1 7 13 4.00000 0.0 0 1003 0
    TRANS1 8 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 9 1 207.32734 20.0 06 0. 1 1 7 1
    TRANS1 10 3 -280.69856 50.0 6. 0. 1 1 7 1
    TRANS1 11 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 12 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 13 1 207.32734 20.0 6. 0. 1 1 7 1
    TRANS1 14 3 277.06699 50.0 0. 1 1 7 1
    TRANS1 15 1 72.00000 7.0 06 0. 1 1 7 1
    TRANS1 16 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 17 1 207.32734 20.0 6. 0. 1 1 7 1
    TRANS1 18 3 -280.69856 50.0 6. 0. 1 1 7 1
    TRANS1 19 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 20 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 21 1 139.66367 20.0 6. 0. 1 1 7 1
    TRANS1 22 3 300.00000 50.0 6 0. 1 1 7 1
    TRANS1 23 1 139.66367 20.0 6. 0. 1 1 7 1
    TRANS1 24 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 25 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 26 3 -280.69856 50.0 6. 0. 1 1 7 1
    TRANS1 27 1 207.32734 20.0 6. 0. 1 1 7 1
    TRANS1 28 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 29 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 30 3 277.06699 50.0 6 0. 1 1 7 1
    TRANS1 31 1 207.32734 20.0 6. 0. 1 1 7 1
    TRANS1 32 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 33 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 34 3 -280.69856 50.0 6. 0. 1 1 7 1
    TRANS1 35 1 207.32734 20.0 6. 0. 1 1 7 1
    TRANS1 36 4 -7.5000 -1909.8573 0 0. 0 1 7 1
    TRANS1 37 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 38 3 272.14100 50.0 6 0. 1 1 7 1
    TRANS1 39 1 134.32110 7.0 6 0. 1 1 7 1
    TRANS1 40 1 21.721483 2.0 6 0. 1 1 7 1
    TRANS1 41 2 1.000000 -90.0 1 6 1 1 7 1
    TRANS1 42 1 43.442967 4.0 6 0. 1 1 7 1
    TRANS1 43 2 1.000000 -90.0 1 6 1 1 7 1
    TRANS1 44 1 43.442967 4.0 6 0. 1 1 7 1
    TRANS1 45 2 1.000000 -90.0 1 6 1 1 7 1
    TRANS1 46 1 43.442967 4.0 6 0. 1 1 7 1
    TRANS1 47 2 1.000000 -90.0 1 6 1 1 7 1
    TRANS1 48 1 43.442967 4.0 6 0. 1 1 7 1
    TRANS1 49 2 1.000000 -90.0 1 6 1 1 7 1
    TRANS1 50 1 43.442967 4.0 6 0. 1 1 7 1
    TRANS1 51 2 1.000000 -90.0 1 6 1 1 7 1
    TRANS1 52 1 21.721483 2.0 6 0. 1 1 7 1
    TRANS1 53 1 134.32110 7.0 6 0. 1 1 7 1
    TRANS1 54 3 -316.40254 50.0 6. 0. 1 1 7 1
    TRANS1 55 1 207.32734 20.0 6. 0. 1 1 7 1
    TRANS1 56 4 7.5000 1909.8573 0 0. 0 1 7 1
    TRANS1 57 1 72.00000 7.0 6 0. 1 1 7 1
    TRANS1 58 3 260.32678 50.0 6 0. 1 1 7 1
    TRANS1 59 1 529.32734 50.0 6 0. 1 1 7 1
    TRANS1 60 3 -332.55216 50.0 6. 0. 1 1 7 1
    TRANS1 61 1 529.32734 50.0 6 0. 1 1 7 1
    TRANS1 62 3 301.05572 50.0 6 0. 1 1 7 1
    TRANS1 63 1 529.32734 50.0 6 0. 1 1 7 1
    TRANS1 64 3 -318.59592 50.0 6. 0. 1 1 7 1
    TRANS1 65 1 529.32734 50.0 6 0. 1 1 7 1
    TRANS1 66 3 296.19400 50.0 6 0. 1 1 7 1
    TRANS1 67 1 529.32734 50.0 6 0. 1 1 7 1
    TRANS1 68 3 -318.59592 50.0 6. 0. 1 1 7 1
    TRANS1 69 1 529.32734 50.0 6 0. 1 1 7 1
    TRANS1 70 3 296.19400 50.0 6 0. 1 1 7 1
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TRANS1 71 1 393.98737 50.0 6 0. 1 1 7 1
TRANS1 72 4 -2.80020 -1909.8573 0 0. 0 1 7 1
TRANS1 73 1 72.00000 7.0 6 0. 1 1 7 1
TRANS1 74 3 -300.88000 50.0 6. 0. 1 1 7 1
TRANS1 75 1 271.63793 27.0 6 0. 1 1 7 1
TRANS1 76 4 -3.03668 -1909.8573 0 0. 0 1 7 1
TRANS1 77 1 80.00000 7.0 6 0. 1 1 7 1
TRANS1 78 4 -0.46467 -1909.8573 0 0. 0 1 7 1
TRANS1 79 3 279.38300 50.0 6 0. 1 1 7 1
TRANS1 80 1 20.00000 7.0 6 0. 1 1 7 1
START 0
STOP 0
BEGIN
END 1 0
```

D Input file for PARTRACE

```
run 1 1
     title
     NSNS HEBT
     charge 1
     linac 1 1003.529 805.000 1.001089
     tank 1 1005.0 -30.0 0.046 0.00 0.046 0.0 0.0 3.0 -3.0
     3.8 1 2 11 0 6.0 0.0 0.0 0.0 1.0 0 0 0 0 0 1.0
     input 3 -3.3613 1636.2 0.000069 4.8238 1610.8 0.0000690 3.3 .6 0.
     error 10. 0. 10. 0. 0. 0. 0. 0.001 0.05
     output 3 1 0 0 0 0 1
     output 2 1 0 0 0 0 1 300 1
     output 1 1 1 0 0 0 1 200
     optcon 3 3
     elimit 5
     scheff 56 0.5 0.5 20 40 0 0 3 1 3
     transl 1 3 373.19065 50.0 06 1. 1 1 7 1
     transl 2 1 529.32734 50.0 06 0. 1 1 7 1
     transl 3 3 -204.76695 25.0 06 1. 1 1 7 1
     transl 4 1 529.32734 50.0 06 0. 1 1 7 1
     transl 5 3 277.06699 50.0 06 1. 1 1 7 1
     transl 6 1 72.00000 7.0 06 0. 1 1 7 1
     transl 7 13 4.00000 0.0 0 1003 0
     transl 8 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 9 1 207.32734 20.0 06 0. 1 1 7 1
     transl 10 3 -280.69856 50.0 6. 1. 1 1 7 1
     transl 11 1 72.00000 7.0 6 0. 1 1 7 1
     transl 12 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 13 1 207.32734 20.0 6. 0. 1 1 7 1
     transl 14 3 277.06699 50.0 1. 1 1 7 1
     transl 15 1 72.00000 7.0 06 0. 1 1 7 1
     transl 16 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 17 1 207.32734 20.0 6. 0. 1 1 7 1
     transl 18 3 -280.69856 50.0 6. 1. 1 1 7 1
     transl 19 1 72.00000 7.0 6 0. 1 1 7 1
     transl 20 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 21 1 139.66367 20.0 6. 0. 1 1 7 1
     transl 22 3 300.00000 50.0 6 1. 1 1 7 1
     transl 23 1 139.66367 20.0 6. 0. 1 1 7 1
     transl 24 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 25 1 72.00000 7.0 6 0. 1 1 7 1
     transl 26 3 -280.69856 50.0 6. 1. 1 1 7 1
     transl 27 1 207.32734 20.0 6. 0. 1 1 7 1
     transl 28 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 29 1 72.00000 7.0 6 0. 1 1 7 1
     transl 30 3 277.06699 50.0 6 1. 1 1 7 1
     transl 31 1 207.32734 20.0 6. 0. 1 1 7 1
     transl 32 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 33 1 72.00000 7.0 6 0. 1 1 7 1
     transl 34 3 -280.69856 50.0 6. 1. 1 1 7 1
     transl 35 1 207.32734 20.0 6. 0. 1 1 7 1
     transl 36 4 -7.5000 -1909.8573 0 0. 0 1 7 1
     transl 37 1 72.00000 7.0 6 0. 1 1 7 1
     transl 38 3 272.14100 50.0 6 1. 1 1 7 1
     transl 39 1 134.32110 7.0 6 0. 1 1 7 1
     transl 40 1 21.721483 2.0 6 0. 1 1 7 1
     transl 41 2 1.000000 -90.0 1 6 1 1 7 1
     transl 42 1 43.442967 4.0 6 0. 1 1 7 1
     transl 43 2 1.000000 -90.0 1 6 1 1 7 1
     transl 44 1 43.442967 4.0 6 0. 1 1 7 1
     transl 45 2 1.000000 -90.0 1 6 1 1 7 1
     transl 46 1 43.442967 4.0 6 0. 1 1 7 1
     transl 47 2 1.000000 -90.0 1 6 1 1 7 1
     transl 48 1 43.442967 4.0 6 0. 1 1 7 1
     transl 49 2 1.000000 -90.0 1 6 1 1 7 1
     transl 50 1 43.442967 4.0 6 0. 1 1 7 1
     transl 51 2 1.000000 -90.0 1 6 1 1 7 1
     transl 52 1 21.721483 2.0 6 0. 1 1 7 1
     transl 53 1 134.32110 7.0 6 0. 1 1 7 1
     transl 54 3 -316.40254 50.0 6. 1. 1 1 7 1
     transl 55 1 207.32734 20.0 6. 0. 1 1 7 1
     transl 56 4 7.5000 1909.8573 0 0. 0 1 7 1
     transl 57 1 72.00000 7.0 6 0. 1 1 7 1
     transl 58 3 260.32678 50.0 6 1. 1 1 7 1
     transl 59 1 529.32734 50.0 6 0. 1 1 7 1
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     transl 61 1 529.32734 50.0 6 0. 1 1 7 1
     transl 62 3 301.05572 50.0 6 1. 1 1 7 1
     transl 63 1 529.32734 50.0 6 0. 1 1 7 1
     transl 64 3 -318.59592 50.0 6. 1. 1 1 7 1
     transl 65 1 529.32734 50.0 6 0. 1 1 7 1
     transl 66 3 296.19400 50.0 6 1. 1 1 7 1
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     transl 68 3 -318.59592 50.0 6. 1. 1 1 7 1
```

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transl 69 1 529.32734 50.0 6 0. 1 1 7 1
transl 70 3 296.19400 50.0 6 1. 1 1 7 1
transl 71 1 393.98737 50.0 6 0. 1 1 7 1
transl 72 4 -2.80020 -1909.8573 0 0. 0 1 7 1
transl 73 1 72.00000 7.0 6 0. 1 1 7 1
transl 74 3 -300.88000 50.0 6. 1. 1 1 7 1
transl 75 1 271.63793 27.0 6 0. 1 1 7 1
transl 76 4 -3.03668 -1909.8573 0 0. 0 1 7 1
transl 77 1 80.00000 7.0 6 0. 1 1 7 1
transl 78 4 -0.46467 -1909.8573 0 0. 0 1 7 1
transl 79 3 279.38300 50.0 6 1. 1 1 7 1
transl 80 1 20.00000 7.0 6 0. 1 1 7 1
start 0
stop 0
begin 100
end 1 0
```