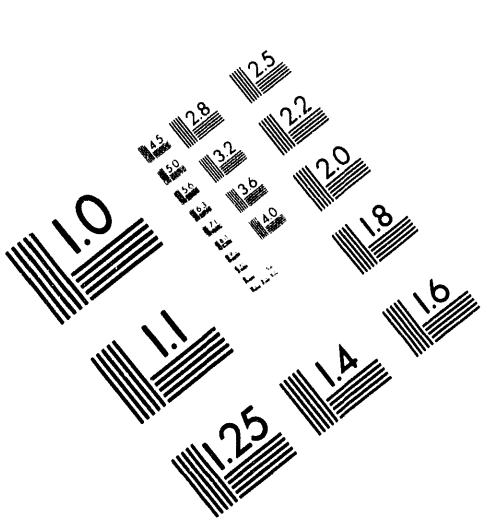

Association for Information and Image Management
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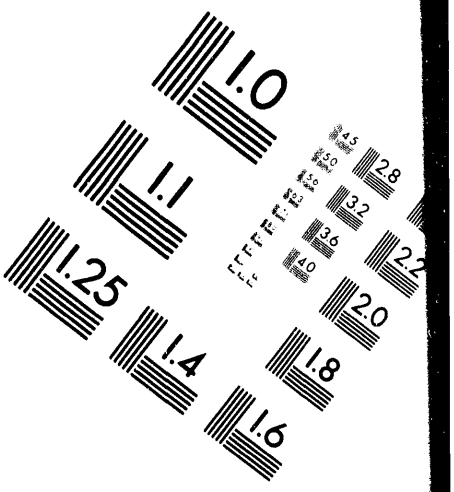
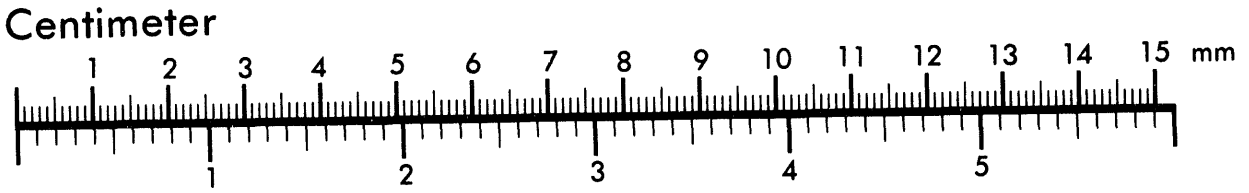
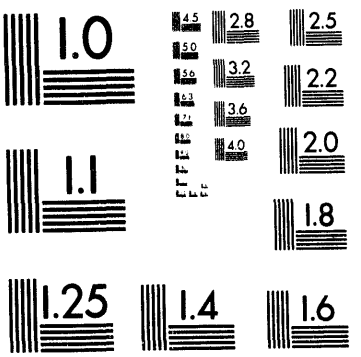
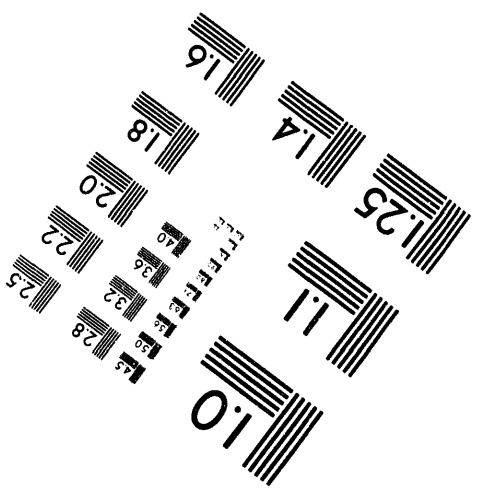
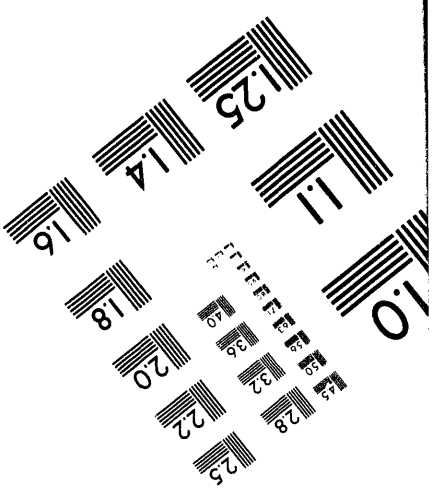
301/587-8202











1 of 1

A BRIEF SUMMARY ON HMS OPTICS AND HALL C BEAMLINE INSTRUMENTATION

C. Yan. Physics Division. CEBAF

July 20, 1993

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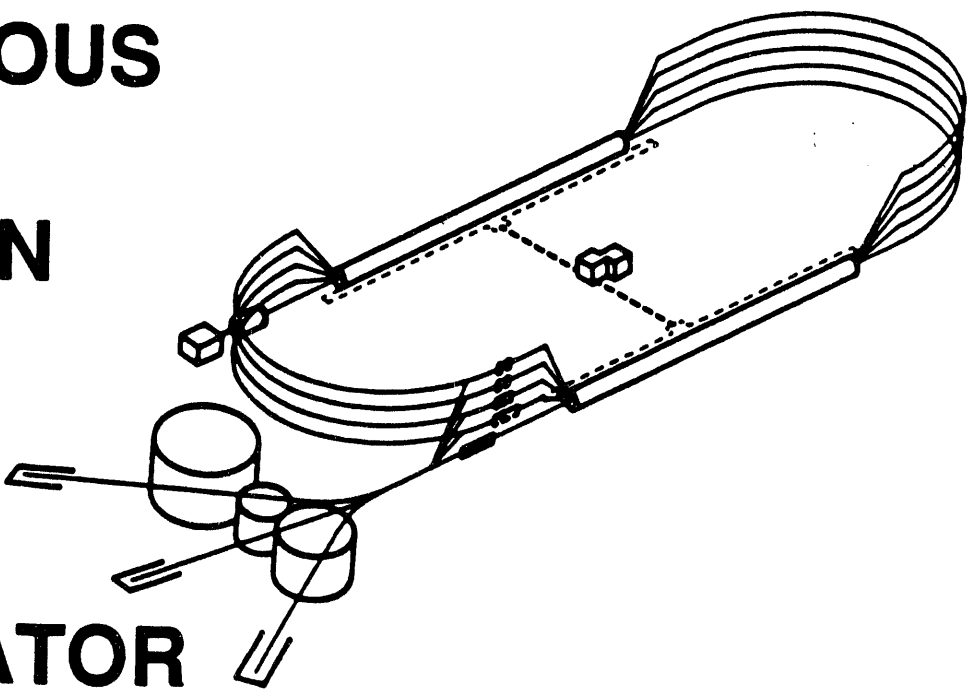

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A BRIEF SUMMARY ON HMS OPTICS AND HALL C BEAMLINE INSTRUMENTATION

C. Yan, Physics Division, CEBAF

1. Modification of HMS Optics

On June 19, 1992 we redefined HMS geometry based on two facts:
1. Having considered that the physical apertures of HMS elements are formed by the warm bore apertures of the cryomodule in the quads and the boundary of the vaccum chamber in the dipole magnet we set up a standard HMS geometry as shown in Figure 1. The effective lengths, physical apertures, and the equivalent lengths of the aperture collimators are listed in the Table 1.

Table 1. Physical apertures of HMS elements

Element	*Effective Length (cm)*	*Physical Aperture*		*Referece Field (Tesla)*
		Diameter (cm)	*Length (cm)*	
Q1	189.0	40.515	237.2	1.508
Q2	215.5	59.68	266.0	1.5293
Q3	218.6	59.68	266.0	0.7721
Dipole	525.59	68.6×40.0	617.92	1.6567

2. The final drift distance from the EFB of the dipole exit to the midpoint of the two wire chambers was reduced from 725 cm to 625 cm duo to the limited space in the shielding house for the 100 cm elongation of detector package (mainly, duo to the elongation of the Cherenkov counter).

The TRANSPORT input data deck of HMS with physical aperture is listed in Table 2.

Table 2. TRANSPORT Input Data Deck for HMS-1

```
'HMS-1 WITH MODIFIED PHYSICAL DIMENSION,
0.                                                    16.      13.      0.0                    '1/R2';
1.  0.01  82.5   5.  22.  0.  5.  6.0  'BEAM';        2.   -6.0                                   'ALPH';
17.                                    '2-ND';        4.     5.26       16.6     0.0           'DIPL';
3.     1.755                           'DRF1';        2.   -6.0                 3               'BETA';
5.01    1.89     15.07763      25.     'Q001';        3.     6.25                                 'DRF5';
3.      1.2275                         'DRF2';        10.    -1.     2.   0.      0.000001      'FIT1';
5.01    2.155      -15.85514     35.    'Q002';        10.    -3.     4.   0.      0.000001      'FIT2';
3.      0.9295                         'DRF3';        10.    -5.     2.   -0.12   0.000001      'FIT3';
5.01    2.186     7.70992       35.    'Q003';        13.   4.;
3.      1.407                         'DRF4';         13.   1.;
16.      5.         21.                 'BGAP';      SENTINEL
16.      12.       0.0                  '1/R1';      SENTINEL
```

Table 3. HMS Field Setting and First-Order Performances in Normal Modes

	HMS-1	HMS-2	HMS-3
$B(Q_1)$ *in kG*	15.04159	14.65548	14.82348
$B(Q_2)$ *in kG*	-15.64286	-14.21163	-14.82344
$B(Q_3)$ *in kG*	7.82593	7.52250	7.65426
B(dipole) in kG	16.6	16.6	16.6
R_{11}	-3.09071	-3.09071	-3.09071
R_{16}	3.70886	3.70886	3.70886
R_{22}	-0.32355	-0.32355	-0.32355
R_{26}	4.12725	4.12725	4.12725
R_{33}	-2.63851	0.0	-1.10726
R_{44}	-0.37900	0.27525	0.0
R_{52}	-0.12	-0.12	-0.12
L in m (for p_o*)*	23.06	23.06	23.06
θ *acceptance in mr*	$\pm$ 82.5	$\pm$ 82.5	$\pm$ 82.5
ϕ *acceptance in mr*	$\pm$ 22.0	$\pm$ 22.0	$\pm$ 22.0
Ω *in msr*	5.70	5.70	5.70
Target length in cm	$\pm$ 5	$\pm$ 5	$\pm$ 5
Momentum range in%	$\pm$ 10	$\pm$ 10	$\pm$ 10
Constraints	$x/\theta = y/\phi = 0$	$x/\theta = y/y = 0$	$x/\theta = \phi/\phi = 0$
Imaging mode	*Pt-Pt*	*Para-Pt*	*Pt-Para*

where the solid angle is estimated by an open ellipsoidal cone with open angles $2\theta_{max}$ and $2\phi_{max}$ from the vertex and then $\Omega = \pi\theta_{max} \times \phi_{max}$.

Enge's fringing field approximation is an intermediate step to transfer field setting from TRANSPORT to RAYTRACE. The input data deck is shown in Table 4.

Table 4. TRANSPORT Input Data Deck with Enge's Fringing Field Approximation

```
'HMS-1 with Enge's FF Approximation, June 24
0.
1.  0.01  82.5   5.  22.  0.  5.  6.   'BEAM';
17.                                     '2-ND';
3.      1.755                           'DRF1';
3.     -0.125;
5.0A      0.25        17.5        50.     'Q001';
5.0A      1.64        17.5        25.     'Q001';
5.0A      0.25        17.5        50.     'Q001';
3.     -0.125;
3.      1.2275                          'DRF2';
3.     -0.175;
5.0B     0.35      -15.85514     70.     'Q002';
5.0B     1.805     -15.85514     35.     'Q002';
5.0B     0.35      -15.85514     70.     'Q002';
3.     -0.175;
3.      0.9295                          'DRF3';
3.     -0.175;
5.0C     0.35       7.70992      70.     'Q003';
5.0C     1.836      7.70992      35.     'Q003';
5.0C     0.35       7.70992      70.     'Q003';
3.     -0.175;
3.      1.407                           'DRF4';
16.       5.         21.                'BGAP';
16.       12.       0.0                 '1/R1';
16.       13.       0.0                 '1/R2';
2.    -6.0                              'ALPH';
4.       5.26       16.6      0.0       'DIPL';
2.    -6.0                              'BETA';
3.       6.25                           'DRF5';
10.     -1.     2.    0.      0.000001  'FIT1';
10.     -3.     4.    0.      0.000001  'FIT2';
10.     -5.     2.   -0.12    0.000001  'FIT3';
13.    4.;
3.     5.  'DRF6';
SENTINEL
SENTINEL
```

Table 5. HMS Field Setting and First-Order Performances in Normal Modes with Enge's FF approximation

	HMS-1	HMS-2	HMS-3
$B(Q_1)$ *in kG*	15.17658	14.78658	14.95492
$B(Q_2)$ *in kG*	-15.82056	-14.38752	-14.99533
$B(Q_3)$ *in kG*	7.90786	7.60102	7.73345
B(dipole) in kG	16.6	16.6	16.6
R_{11}	-3.09071	-3.09071	-3.09071
R_{16}	3.70886	3.70886	3.70886
R_{22}	-0.32355	-0.32355	-0.32355
R_{26}	4.12725	4.12725	4.12725
R_{33}	-2.63766	0.0	-1.10157
R_{44}	-0.37912	0.27307	0.0
R_{52}	-0.12	-0.12	-0.12
L in m	23.06	23.06	23.06
Ω *in msr*	5.70	5.70	5.70
Target length in cm	$\pm$ 5	$\pm$ 5	$\pm$ 5
Momentum range in%	$\pm$ 10	$\pm$ 10	$\pm$ 10
Constraints	$x/\theta = y/\phi = 0$	$x/\theta = y/y = 0$	$x/\theta = \phi/\phi = 0$
Imaging mode	*Pt-Pt*	*Para-Pt*	*Pt-Para*

In order to obtain HMS transmissions, TURTLE code is used to generate a fast histogram display which is based on second-order optics. In TURTLE type code 13.0 causes the program to observe magnet apertures. If 13.0 code is present, the program will terminate all those rays which pass outside the specified apertures of quadrupoles or bending magnets. The quadrupole half aperture is normally taken to be circular and equal to the fourth entry on the type cade card. To meet the physical aperture, both of the field at the pole tip and the radius of quadrupole must be modified as displayed in Table 6.

Table 6. HMS TURTLE Input Data Deck

```
'HMS-1 with physical aperture, February 19, 1993'
100000
1.   0.01   82.5   7.5   22.   0.    10.    6. 'BEAM';
17.    '2-ND';
13.          10.  'APER';
-50.2        6.   -10.    10.       0.25    'P';
-50.2        3.    -5.     5.       0.1     'Y';
-51.2        4.   -22.    22.       2.0     'PH';
-52.2        2.   -82.5   82.5      5.0     'TH';
3.        1.514    'DRF1';
6.        1          20.257      3       20.257 'AP1';
3.        0.241    'DRF2';
5.        1.89        12.18790          20.257    'Q1';
3.        0.241      'DRF2';
6.        1          20.257      3       20.257 'AP1';
3.        0.734      'DRF3';
6.        1          29.84       3         29.84 'AP2';
3.        0.2525       'DRF4';
5.        2.155       -13.33666           29.84   'Q2';
3.        0.2525       'DRF5';
6.        1          29.84         3         29.84  'AP2';
3.        0.44       'DRF6';
6.        1          29.84       3         29.84  'AP3';
3.        0.237      'DRF7';
5.        2.186        6.67216           29.84    'Q3';
3.        0.237      'D08';
6.        1          29.84       3         29.84  'AP3';
3.        0.7104       'D09';
6.        1          34.3          3         20.     'AP4';
3.        0.4596     'D10 ';
16.       5.                20.          'HGAP';
16.       4.                30.          'BWID';
2.       -6.              'ROT1';
4.        5.26        16.6        0      'DIPL';
2.       -6.              'ROT2';
3.        0.4596     'D11 ';
6.        1          34.3          3         20.     'AP4';
3.        5.7904     'D12';
13.       4.;
-53.2;
50.       3.       -40.       40.       2. 'HW1';
50.       1.       -60.       60.       5. 'HW1';
3.        1.;
51.       3.       -50.       50.       2. 'HW2';
52.       1.       -60.       60.       5. 'HW2';
-6.          1     50.25    'SSLX';
-6.          3     25.0     'SSLY';
SENTINEL
SENTINEL
```

In Figure 2 and Figure 3, a series of beam envelopes from TURTLE output is given. In these figures, the features of HMS collective collimator (physical aperture) is clearly displayed. The design of vaccum chamber of dipole magnet as well as the vaccum pipe which connects dipole outlet with the detector section is based on those calculations.

In RAYTRACE code the physical aperture is simulated by placing collimators before, after, and in the middle of element (by using a negative drift distance) as shown in Table 7. Though the simulation of physical aperture by collimators is not as good as what are defined in TURTLE code, most of passing behaviours of a bundle of rays can be described precisely.

Table 7. HMS RAYTRACE Input Data Deck with Physical Apertures

```
HMS-1 (point-to-point) October 28
10.500,0.2
6000.,300.,1.
DRIF
151.4
COLL
1.,0.,0.,20.257,20.257
DRIF
24.1
COLL
1.,0.,0.,20.257,20.257
POLES
8.,8.,8.
0.,0.,189.,25.
1.5269
75.,-60.,-60.,75.
0.0688, 6.2624, -1.0500, 0.788
0.0688, 6.2624, -1.0500, 0.788
1.,1.,1.,1.
COLL
1.,0.,0.,20.257,20.257
DRIF
24.1
COLL
1.,0.,0.,20.257,20.257
DRIF
73.4
COLL
1.,0.,0.,29.84,29.84
DRIF
25.25
COLL
1.,0.,0.,29.84,29.84
POLES
10.,10.,10.
0.,0.,215.5,35.
-1.58757
140.,-85.,-85.,140.
0.1014, 6.0266, -1.2084, -0.0928
0.1014, 6.0266, -1.2084, -0.0928
1.,1.,1.,1.
DRIF
-107.75
COLL
1.,0.,0.,29.84,29.84
DRIF
107.75
COLL
1.,0.,0.,29.84,29.84
DRIF
25.25
COLL
1.,0.,0.,29.84,29.84
DRIF
44.
COLL
1.,0.,0.,29.84,29.84
DRIF
23.7
COLL
1.,0.,0.,29.84,29.84
POLE
10.,10.,10.
0.,0.,218.6,35.0
0.79128
140.,-85.,-85.,140.0
0.1451, 6.3414, -1.9308, 0.2696
0.1451, 6.3414, -1.9308, 0.2696
1., 1.,1., 1.
DRIF
-109.3
COLL
1.,0.,0.,29.84,29.84
DRIF
109.3
COLL
1.,0.,0.,29.84,29.84
DRIF
23.7
COLL
1.,0.,0.,29.84,29.84
DRIF
71.04
COLL
1.,0.,0.,34.3,20.
DRIF
45.96
COLL
1.,0.,0.,34.3,20.
DIPOLE
12.5,12.5,12.5,12.5,1.
0.,0.,42.0, 1205.5, 1.66035
25.,-6.,-6.
0.
120.,-100.,-100.,120.0
0.09030, 3.00572, -0.28534, -0.045, 0.02918
0.09030, 3.00572, -0.28534, -0.045, 0.02918
0.
0.
0.
0.
COLL
1.,0.,0.,34.3,20.
DRIF
45.96
COLL
1.,0.,0.,34.3,20.
DRIF
579.04
SENTINEL
```

2. Special Tuning of HMS

2-1. Limit parameters from TOSCA

A set of limit parameters of HMS quadrupoles from TOSCA calculation is listed in Table 8.

Table 8. Limit parameters from TOSCA design

QUADRUPOLE 1

Maximum cryostable current (Ampere/turn)	1089.6
Effective length at 1089.6 (meter)	1.877 (100% packing factor)
	1.870 (96% packing factor)
Integral quadrupole field (Tesla-m)	3.4232(100% packing factor)
at pole radius	3.4300(96% packing factor)
Central gradient at R=22 cm (Tesla/m)	7.294 (100% packing factor)
	7.3357(96% packing factor)
Maximum field at pole radius (Tesla)	1.8235(100% packing factor)
	1.8339(96% packing factor)

QUADRUPOLE 2,3

Maximum cryostable current (Ampere/turn)	1089.6
Effective length at 1089.6 (meter)	2.102 (100% packing factor)
	2.083 (96% packing factor)
Integral quadrupole field (Tesla-m)	4.5158(100% packing factor)
at pole radius	4.5366(96% packing factor)
Central gradient at R=22 cm (Tesla/m)	6.1448(100% packing factor)
	6.2310(96% packing factor)
Maximum field at pole radius (Tesla)	2.1507(100% packing factor)
	2.1809(96% packing factor)

2-2. 7.5 GeV/c HMS

Second order TRANSPORT: Q_1 is fixed at 1.75 Tesla, adjust Q_2 and Q_3 to satisfy the desired imaging mode.

Table 9. Field setting of 7.5 GeV/c HMS

	HMS-1	HMS-2	HMS-3
$B(Q_1)$ *in kG*	17.5	17.5	17.5
$B(Q_2)$ *in kG*	-19.59979	-17.70097	-18.62028
$B(Q_3)$ *in kG*	10.36460	9.76748	10.06587
B(dipole) in kG	20.75	20.75	20.75
D/M	-1.4919	-1.3699	-1.4286
θ *acceptance in mr*	± 72.5	± 72.5	± 72.5
ϕ *acceptance in mr*	± 25.0	± 25.0	± 25.0
Ω *in msr*	5.69	5.69	5.69
Target length in cm	± 5	± 5	± 5
Momentum range in%	± 5	± 5	± 5

The current 7.5 GeV/c HMS is different to the original 7.4 GeV/c mode reported in HMS manual [1] because no displacement of quadrupoles is required.

2-3. 10 msr HMS

Second order TRANSPORT: Q_1 is fixed at 1.75 Tesla, the quadrupole triplet is moved towards the target for 40 cm, adjust Q_2 and Q_3 to satisfy the desired imaging mode.

Table 10. Tuning parameters of 10 msr HMS

	HMS-1	HMS-2	HMS-3
$B(Q_1)$ *in kG*	17.5	17.5	17.5
$B(Q_2)$ *in kG*	-16.07957	-14.76459	-15.25068
$B(Q_3)$ *in kG*	7.87284	7.39865	7.58060
B(dipole) in kG	16.6	16.6	16.6
D/M	-1.0103	-0.9321	-0.9608
θ *acceptance in mr*	± 95.0	± 99.0	± 99.0
ϕ *acceptance in mr*	± 35.0	± 30.0	± 35.0
Ω *in msr*	10.44	9.33	10.88
Target length in cm	± 1	± 1	± 1
Momentum range in%	± 5	± 5	± 5

There is no interference of fringing field at the target chamber region. The contribution of fringing field of Q_1 on the target position is still zero.

2-4. QQD Variation

A QQD structure of HMS is still working while the first quadrupole is shut down or moved away. There are also three possible tunes in transverse plane: point-to-point, parallel-to-point, and point-to-parallel.

Table 11. Tuning parameters of QQD variation

	QQD-1	QQD-2	QQD-3
$B(Q_1)$ *in kG*	0.	0.	0.
$B(Q_2)$ *in kG*	13.63836	13.27144	12.72918
$B(Q_3)$ *in kG*	-10.69976	-9.63605	-8.20826
B(dipole) in kG	16.6	16.6	16.6
D/M	-0.7499	-0.7931	-0.8580
θ *acceptance in mr*	± 67.0	± 67.0	± 67.0
ϕ *acceptance in mr*	± 15.0	± 15.0	± 15.0
Ω *in msr*	3.16	3.16	3.16
Target length in cm	± 1	± 1	± 1
Momentum range in%	± 5	± 5	± 5

For the QQD variation of HMS, the third order correction has to be used to compensate the large chromatic aberration caused by doublet system. The Table 12 shows image distribution along focal plane in RAYTRACE frame and that is also an indication of systimatic momentum resolution (in[illegible]or reconstructed).

Table 12. Image distribution of QQD

$\delta = \Delta p/p$ in %	-5.0	-2.5	0.	2.5	5.0	Ω(msr)	Correction
ΔX_{max} in cm	9.111	10.494	12.412	15.219	19.680	6.4	no
ΔX_{max} in cm	3.689	4.233	4.991	6.103	7.873	2.92	no
ΔX_{max} in cm	1.210	0.947	0.609	0.316	1.034	6.4	yes
ΔX_{max} in cm	0.390	0.283	0.147	0.125	0.446	2.92	yes

The ratio of the octapole component to the quadrupole: 1.01% for Q_2 and 2.05% for Q_3. The beam envelopes of QQD-1, QQD-2, and QQD-3 are displayed in Figure 4, Figure 5, and Figure 6. The image behaviour of QQD is shown in Figure 7.

2-5. Inversed triplet tuning

R. Madey in his G_E^n proposal asks for a large acceptance in the transverse plane and this could be realized by alternately setting the polarities of Q1, Q2, and Q3. The setting parameters in this mode are listed in Table 13. The envelope of HMS with alternate triplet polarities is shown in Figure 8. The momentum acceptance, angular acceptances are shown in Figure 9, 10, 11, respectively.

Table 13. TURTLE parameters of HMS with alternate triplet polarities

```
'Inversed triplet, February 19, 1993'
100000
1.   0.01   22.5   5.0   62.   0.    5.    6. 'BEAM';
17.    '2-ND';
13.          10.   'APER';
-50.2        6.     -5.    5.        0.25    'P';
-50.2        3.     -5.     5.       0.1     'Y';
-51.2        4.    -62.    62.       2.0     'PH';
-52.2        2.    -22.5   22.5      5.0     'TH';
3.         1.514    'DRF1';
6.         1        20.257       3       20.257 'AP1';
3.         0.241    'DRF2';
5.         1.89      -13.77476          20.257  'Q1';
3.         0.241      'DRF2';
6.         1        20.257       3       20.257 'AP1';
3.         0.734     'DRF3';
6.         1        29.84        3        29.84 'AP2';
3.         0.2525       'DRF4';
5.         2.155      12.78857           29.84  'Q2';
3.         0.2525       'DRF5';
6.         1        29.84        3       29.84  'AP2';
3.         0.44      'DRF6';
6.         1        29.84        3       29.84  'AP3';
3.         0.237       'DRF7';
5.         2.186     -8.52571           29.84   'Q3';
3.         0.237     'D08';
6.         1        29.84        3       29.84  'AP3';
3.         0.7104       'D09';
6.         1        34.3          3      20.     'AP4';
3.         0.4596   'D10 ';
16.        5.       20.          'NGAP';
16.        4.       30.          'BWID';
2.        -6.      'ROT1';
4.         5.26     16.6       0     'DIPL';
2.        -6.      'ROT2';
3.         0.4596   'D11 ';
6.         1        34.3         3       20.     'AP4';
3.         5.7904   'D12';
13.        4.;
-53.2;
51.     3.     -40.     40.      2. 'MW1';
52.     1.     -60.     60.      5. 'MW1';
3.      1.;
51.     3.     -50.     50.      2. 'MW2';
52.     1.     -60.     60.      5. 'MW2';
-6.       1    50.25   'SSLX';
-6.       3    25.0    'SSLY';
SENTINEL
SENTINEL
```

3. Hall C beam transport line

The Hall C beam transport lines consists of the separation section, the first match section which match the separator to the arc, the arc section and the second match section matching arc to the target with total length of 146.2 m from the point of tangency to the Hall C target position, including eight 3 meter bending dipole magnets, two 1 meter separation magnets, twenty one 30 cm quadrupole magnets, eight sextupole magnets and several beam correctors distributed along the arc section.

CEBAF beam is transported by waist-to-waist imaging to the point of tangency point, then it is separated by separation section into Hall A, Hall B, and Hall C respectively. Through the first match section the separated Hall C beam enters into the arc section which achromatically bends the beam by 34.3° with a

radius of 40 meters and the second match section sends recombined beam to Hall C target position through a distance of 179.47 feet.

The arc section consists of eight 3 meter length dipole magnets (BA), 11 quadrupoles (QA) with 2.54 cm aperture and 8 sextupoles which provide a complete second order achromatic transport - both of the dispersion and its derivative must be zero. Therefore, the first half of achromat focuses second principal plane of the fourth bending magnet onto the first principal plane of the fifth bending magnet. The effect of the intermediate quadrupole is solely to achieve complete recombination of different momenta.

If the half width of the source is x_0, the the full width of the image is $2x_0.M_x$, two different momenta can be resolved if their spatial separation is at least as great as the width of the image of the source. Therefore, momentum resolution is defined as:

$$R_p = \frac{\Delta P}{P} = \frac{2M_x x_0}{D}$$

M_x - magnification in x-direction, D - dispersion in transverse direction. Different momenta can be separated at the intermediate focal plane of arc achromat that is so-called a beam line spectro meter combination in what is known as the energy-loss mode. At the intermediate focal plane of Hall C arc achromat the dispersion is 2.078 cm/% and magnification is about unit. If a focal plane detector can be placed at the midpoint it will be a high resolution achromatic spectrometer that can be used to analyse a relative beam momentum deviation.

The second match section consists of 5 quadruples $Q_{17}, Q_{18}, Q_{19}, Q_{20}$ and Q_{21}. This 5 quads cluster execute three functions: 1. In normal operation, achromatically focus the beam onto the target with double point-to-point imaging; 2. with seriesly powered $Q_{17} - Q_{18}$ and $Q_{20} - Q_{21}$, the beam can be defocused with an arbitrary beam spot size, for example, 2.5× 2.5 cm² for polarized target, 2.5× 0.01 cm² for high resolution operation of either SOS or HMS, and 0.1× 0.1 cm² for HMS cryogenic target; The results of TURTLE simulations show the two dimentional beam density distribution under the defocusing function. Notice that the variable defocusing properties are approximately achromatic transport in the first order ($\sim$ 1%). This function is used as an emergency protection for Hall C raster system which will be replaced by the defocusing quads cluster as soon as any failure of the raster system occurs; 3. when there is either a dummy target cell or no target in site, the quads cluster sends a defocusing beam to the beam dump through the tunnel with 4× 4 cm² spot size. The beam density distributions on the target under different defocusing operations are obtained from TURTLE runs and are displayed in Figure 13, 14, 15, and 16. The defocusing features of 5 quads cluster are listed in Tabel 14. The second card in a TRANSPORT deck contains an integer which serves as an indicator. When using TURTLE this card constrains an integer indicating how many rays one wishes to run through the system. With a minor modification (2-nd entry card and switch on code 50. cards) the TRANSPORT input deck can be used for TURTLE calculations. The TURTLE input data deck for Hall C beam line is listed in Table 15. A 4.665 m

reduction in the total length has been applied to the original Hall C beam line deck. This difference comes from the offset of the target position to the geometric center of Hall C.

As a part of Hall C safe operations, the defocusing features of the quadrupole cluster can sufficiently protect target materials from overheating effect. There are, of course, several disadvantages such as: non-uniform beam density distribution within the beam spot; degeneration of spectrometer resolution due to the blur of beam image on the target; blow-up of reconstruction accuracy.

In order to simplify operation tunings for the quadrupole cluster a special connection between Q_{18}, Q_{19}, Q_{21}, and Q_{22} are required. The Q_{18}, Q_{19} pair are inversely connected with Q_{21}, Q_{22} pair and therefore, there are only two adjustable parameters in this section as listed in Table 14.

Table 14. Defocusing Features of the Last 5 Quads

Δx_{target} *(cm)*	0.0098	0.1	1.25	1.25
Δy_{target} *(cm)*	0.0361	0.1	1.25	0.1
Δx_{dump} *(cm)*	0.0689	0.4332	4.3825	3.9630
Δy_{dump} *(cm)*	0.1344	0.3298	4.0171	0.4013
$B_{Q_{18,19}}$ *in kG*	-0.74567	-1.19053	-3.58606	-2.76379
$B_{Q_{20}}$ *in kG*	-0.30622	0.19323	-1.25574	1.66338
$B_{Q_{21,22}}$ *in kG*	0.74567	1.19053	3.58606	-2.76379
R_{16}	-0.00011	0.00130	-0.01629	0.01631
R_{26}	0.00019	0.00084	-0.00794	0.00689
Applications	Achromatic	HMS target	UVa target	SOS-HNSS

Table 15. TURTLE input deck of Hall C beam line

```
'Modified Hall C Beam Line,  Chen  June 16, 1993'
0
1    0.010    0.010    0.010    0.010    0.000    0.01    6.000   'BEAM' ;
3     0.4500   'D001' ;
2     0.0000 ;
4     1.0000    -5.5889     0.0000   'B001' ;
2    -1.6000 ;
3    12.0000   'D002' ;
5.     0.3000     1.6356     1.2500   'Q001' ;
3     2.0000   'D003' ;
5     0.3000    -2.5731     1.2500   'Q002' ;
3     2.0000   'D004' ;
5.     0.3000     1.6356     1.2500   'Q003' ;
3    12.0000   'D005' ;
2    -1.6000 ;
4     1.0000    -5.5889     0.0000   'B002' ;
2     0.0000 ;
3     1.0000   'D006' ;
5.     0.3000     2.50850     1.2500   'Q004' ;
3     5.0000   'D007' ;
5.     0.3000    -2.3090    1.2500   'Q005' ;
3     5.0000   'D008' ;
5.     0.3000     2.5518     1.2500   'Q006' ;
3     5.0000   'D009' ;
5.     0.300    -3.2939   1.2500   'Q007' ;
```

```
3     5.0   'D010';
3.    0.4   'D011';
13.   1. ;
13.   4. ;
-10.   -1.    2.    0.    0.00001 'FT01';
-10.   -2.    1.    0.    0.00001 'FT02';
-10.   -3.    4.    0.    0.00001 'FT03';
-10.   -4.    3.    0.    0.00001 'FT04';
3.    0.4     'D012';
5.    0.30     2.31120         1.25    'Q008';
3     0.4000   'D013' ;
18.     0.3000     0.01580     1.2500   'S001' ;
3     0.4000   'D014' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B003' ;
2    -2.1437 ;
3     0.4000   'D015' ;
3     0.4000   'D016' ;
5.     0.3000    -2.2971    1.2500   'Q009' ;
3     0.4000   'D017' ;
18.     0.3000    -0.02760     1.2500   'S002' ;
3     0.4000   'D018' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B004' ;
2    -2.1437 ;
3     0.4000   'D019' ;
3     0.4000   'D020' ;
5.     0.3000     2.31120     1.2500   'Q010' ;
3     0.4000   'D021' ;
18.     0.3000     0.01580     1.2500   'S003' ;
3     0.4000   'D022' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B005' ;
2    -2.1437 ;
3     0.4000   'D023' ;
3     0.4000   'D024' ;
5.     0.3000    -2.2971     1.2500   'Q011' ;
3     0.4000   'D025' ;
18.     0.3000   -0.02760     1.2500   'S004' ;
3     0.4000   'D026' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B006' ;
2    -2.1437 ;
3     0.800    'D027' ;
13.  4.;
13.  1.;
5.     0.1500    2.31120     1.2500   'Q012' ;
13.    4. ;
13.    1. ;
-10.    -2.    6.    0.       0.00001    'FT05';
-10.    -1.    2.    0.       0.00001    'FT06';
-10.    -3.    4.    0.       0.00001    'FT07';
-10.    -5.    2.    0.45     0.00001    'FT08';
5.     0.1500    2.31120     1.2500   'Q012' ;
13.   4.;
13.   1.;
3     0.4      'D029';
18     0.3000     0.01580     1.2500   'S005' ;
3     0.4000   'D031' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B007' ;
2    -2.1437 ;
3     0.4000   'D032' ;
3     0.4000   'D033' ;
5.     0.3000    -2.29710     1.2500   'Q013' ;
3     0.4000   'D034' ;
18     0.3000    -0.02760     1.2500   'S006' ;
3     0.4000   'D035' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B008' ;
2    -2.1437 ;
3     0.4000   'D036' ;
3     0.4000   'D037' ;
5.     0.3000     2.31120     1.2500   'Q014' ;
3     0.4000   'D038' ;
18     0.3000     0.01580     1.2500   'S007' ;
3     0.4000   'D039' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B009' ;
2    -2.1437 ;
3     0.4000   'D040' ;
3     0.4000   'D041' ;
5.     0.3000    -2.29710     1.2500   'Q015' ;
3     0.4000   'D042' ;
18     0.3000    -0.02760     1.2500   'S008' ;
3     0.4000   'D043' ;
2    -2.1437 ;
4     3.0000    -4.9922     0.0000   'B010' ;
2    -2.1437 ;
3     0.4000   'D044' ;
3     0.4000   'D045' ;
5.    0.15     2.31120    1.2500   'Q016' ;
13.     4.;
13.     1.;
-10.     -1.     2.     0.     0.00001    'FT09';
-10.     -3.     4.     0.     0.00001    'FT10';
-10.     -1.     6.     0.     0.00001    'FT11';
-10.     -2.     6.     0.     0.00001    'FT12';
5.    0.15     2.12530    1.2500    'Q016';
3     2.5000   'D046' ;
5.     0.3    -1.17940     1.2500   'Q017';
3     15.1      'D047';
5.0A     0.3       -3.   1.25     'Q018';
3.       0.5     'D049';
5.0A     0.3     -3.   1.25      'Q019';
3        1.5      'D049' ;
5.01          0.3    -0.63691   1.2500   'Q020';
3        1.5      'D050' ;
5.0-A    0.3        3.    1.25      'Q021';
3.     0.5     'D051';
5.0-A       0.3     3.     1.25     'Q022';
3.      22.     'D053';
-10.   -1.    2.   0.     0.00001 'FT20';
-10.   -3.    4.   0.     0.00001 'FT21';
-10.   -1.    6.   0.     0.00001 'FT22';
10.   1.    1.   1.25    0.00001   'FT23';
10.   3.    3.   1.25    0.00001   'FT24';
-52.     3.     -2.5      2.5      0.25   'Y';
-51.     1.     -2.5      2.5      0.25   'X';
13.   1.;
13.   4.;
3.     27.07   'D054';
13.   1.;
13.   4.;
3.     24.33   'DUMP';
13.   1.;
13.   4.;
SENTINEL
SENTINEL
```

4. Beam Energy Measurement by Arc Spectrometer

Beam energy measurement by the arc spectrometer was proposed and de-

veloped in refs. [2], [3], [4], and [5]. Hall C achromatic beam transport line will be used as a spectrometer which has a dispersion of 12 cm/% with all the quadrupoles, sextupoles, and beam correctors switched off. The beam envelope of arc spectrometer is shown in Figure 17. The transverse position and the angle of the beam at the entrance of the arc are precisely measured by a pair of wire scanners spaced by 2.5 m, and the transverse position of the outgoing beam is measured by another pair of wire scanners at the exit of the arc. From these positions and the calibrated bending field in the dipoles, an absolute beam energy is measured. After the absolute beam energy is measured, the arc will be turned into the normal achromatic mode by energizing all the elements. The beam position probe located at the mid-point of the arc will be used to monitor the beam energy in this operational mode. A complete error analysis shows that an absolute beam energy measurement with 10^{-3} accuracy can be achieved. Relative energy measurements at the 10^{-4} level are also obtainable.

The position and the direction of the beam entering the Hall C arc line are determined at the entrance by a pair of high-resolution harps (wire scanners). The position (and direction) of the beam at the exit of the 34.3° bend (41.6 m downstream from the point of tangency) is determined by another pair of calibrated harp(s). For this procedure only the dipoles are energized. During this absolute measurement all other arc magnetic elements such as quads, sextupoles, beam correctors are off. The current in the absolutely calibrated bending magnets is varied to set the position to be along the central ray of the magnets in the arc. With this information, the beam momentum is determined. Thus, this method requires accurate position (and implicitly direction) measurements at the harps and an accurate determination of the magnetic field integral $\int Bdl$ as a function of current I in the arc dipoles.

The quadrupoles and sextupoles are then energized to the values required by the measured energy in the normal achromatic transportation mode. The orbit correctors are activated to center the beam on a beam position measuring device situated at the midpoint of the achromat. Under the assumption that the beam momentum is unchanged during this transition period, we can transfer the absolute momentum calibration to the achromatic mode, which is very sensitive to relative shifts in the beam momentum. Variations in beam energy can then be measured as variations in beam position at the midpoint. This achromatic mode will also be capable of obtaining relative energy measurements with substantially greater accuracy than the absolute mode. Subsequent error analyses obtained from DIMAD and RAYTRACE are shown in the table.

Table 16. Error Sources Analyses

Classified error source	*Figures*	*Contribution*
Harp fiducialization error	50 μm	3.05×10^{-5}
Harp to harp survey error	100 μm	2.29×10^{-5}
Harp pair to harp pair survey error	200 μm	2.25×10^{-5}
Beam steering accuracy at the entrance	100 μm	3.5×10^{-4}
Beam steering accuracy at the exit	100 μm	negligible
$\Delta \int Bdl/\int Bdl$ measurement error	2.5×10^{-4}	2.5×10^{-4}
Magnet positioning accuracy	1 mm	10^{-4}
Magnet orientation accuracy	1 mr	10^{-4}
Magnetic mispowerings (random)	10^{-3}	1.2×10^{-4}
Angle kick in the arc	0.05 mr	1.3×10^{-4}
Intermediate monument location accuracy	20 μrad	1.6×10^{-4}
Sink of support System	2 mm in y	negligible
Thermal expension of support system	2 mm in y	negligible
Beam initial emittance	0.01 cm, 0.01 mr	3.2×10^{-5}
Beam initial energy spread	10^{-4}	10^{-4}

The analyses indicate that an absolute beam energy measurement at the 1.0 to 1.5 $\times 10^{-3}$ level is obtainable with high confidence. The proposed method will also be capable of obtaining relative energy measurements with substantially greater accuracy. In that mode the field normalization error is inapplicable and missteering effects are reduced (by the strong focusing and 180° entrance to arc center phase advance). The dominant error should be harp misalignment and measurement uncertainties. The sum of those errors should be less than $\delta x \sim$ 0.2 mm. The resulting error in $\delta E/E$ (relative) will be on the level of $\delta x/D \sim 10^{-4}$. There is no need to change the hardware or the optical tuning of the achromat in the original beam line design. As the major precision beam position probe, the upgraded CEBAF harp or "Superharp", is developed and tested, a special alignment technique for the superharps must be carefully considered and implemented. At least two of the production arc dipole magnets must be mapped to obtain an absolute field integral measurement with an accuracy of 2.5×10^{-4}.

The proposed method requires a beam position measurement with an accuracy of better than 50 μm. An upgrate CEBAF harp beam profile monitor ("Superharp") [6] is under development. The absolute beam position readout is realized by a multi-turn encoder (COMPUTER CONVERSION CORP. Model no. HTMDS90-64-DB18-1p) which backlashlessly connects the end shaft of stepping motor and provide a parallel binary output with 18 bit resolution. For the beam energy measurement, 6 superharps are required. The basic performance of the "Superharp" is listed below:

Table 17. Specification of Superharp

Material of sensor wire	7 - 10 μ tungsten wire
Minimum step size of translation	0.6 μm (variable)
Accuracy of absolute calibration	better than 10μm
Repeativity of mechanical travel	better than 10μm
Dynamic range of readout	1 - 200 μA
Dynamic range of translation	7.63 cm
Observable vibration magnitude	less than 3μm
Maximum linear velosity	3.81mm/s (variable)
Resolution of the encoder	18 Bit
Total number of units	6
Estimate cost for each	\$8,000

Then the beam position can be expressed as the position of center of mass of beam profile:

$$x_{cm} = \frac{\sum_i n_i x_i}{\sum_i n_i}$$

where x_i and n_i - the position readout and the current readout at i-th step respectively. The accuracy of beam position mainly depends on the precision of translate motion of mechanical driving system.

Now, the first prototype of Superharp is being tested and developed by the collaboration of CEBAF detector group and Hall C group. Instead of directly current readout, Michael Tiefenback used a beam loss monitor (with and without scintillators) to get a secondary emission beam profile which is as good as the current readout. In future, the same technique can be used for beam position measurement at very low current (in the order of few ten nA) by harp (or superharp).

5. Chicane for Polarized Target

The high polarization of the nucleon target is produced when the appropriate target material is irradiated with high frequency microwaves at 1°K in the presence of a strong magnetic field. The UVa polarized target will have a 5 T magnetic field over the active target region with a total Bdl of 2.5 T-m along the axis of the magnet. The bending power of this magnet will require a consideration of the trajectories of the incident beam, the scattered electrons, and any recoil charged particles.

Therefore, a vertical chicane is necessary to transport CEBAF beam to the polarized target as shown in Figure 18. At the entrance of Hall C the incident beam is bended down about 1° by 1m vertical bending magnet BE, and is transported into the second 3 m bending magnet BZ which is placed at 4 m before the target. The beam is vertically deflected by this magnet for about 5° towards the

target. Like a dipole magnet, the 5T magnet (Helmholtz pairs) of polarized target bends the beam in the opposite direction, by about 4° and another 3m bending magnet BZ bends the beam to the beam dump. These bends will have the effect of keeping $\vec{q}$ close enough to horizontal to be acceptable to the HMS and the plane of the neutron detector close enough to horizontal so its placement will not be constrained by the Hall C layout.

Six beam position monitors will be placed in the exit of BE, the entrance of BZ, the both sides of 5T magnet, and the exit of 2-nd BZ to ensure a reliable beam operation. The polarized target chicane will be also used as beam transport system for HNSS which requires a few cm horizontal offset on the target position. In this case only one BE and one BZ bending magnets are used and the chicane works in the horizontal plane. The final geometry was defined on May 26, 1993. In order to calculate the chicane optics a group of parameters is defined as :

l_1 = 453.06 cm	distance between centers of target and BZ_1
l_2 = 1352.84 cm	distance between centers of BE and BZ_2
l_3 = 1352.84 cm	distance between centers of target and BZ_2
l_4 = 2253.94 cm	distance between center of BZ_2 and 6 m before beam dump
L_{eff} = 54.4 cm	effective length of Oxford magnet
L_1 = 1 m	effective length of BE
L_2 = 2 m	effective length of BZ_1
L_3 = 2 m	effective length of BZ_2
ϕ_0	deflection by Oxford 5 T magnet
ϕ_1	deflection by BE magnet
ϕ_2	deflection by BZ_1 magnet
ϕ_3	deflection by BZ_2 magnet
ϕ_4	the angle from BZ_2 to 6 m in front of dump
h_1	vertical offset of BZ_1
h_2	vertical offset of BZ_2

Table 18. Specifications of Chicane Magnets

Element	*BE*	*1-st BZ*	*2-nd BZ*
Location to target in cm	-1805.9	-453.06	453.06
Effective Length in cm	100.0	200.0	200.0
Gap in cm	2.54	3.81	3.81
Pole Width in cm	11.8	27.9	27.9
Max. $\int$ Bdl in Tm	1.0	2.0	2.0
DC Resistance in Ω	0.055	0.079	0.079
Field Setting in kG	4.48	9.05	8.15
Driving Current in A	228	306	276
Max. Power Dissipation in kW	2.859	7.397	6.017

Table 19. Operational Parameters of Chicane

E_0	$\phi_0(°)$	$h_1(cm)$	$\phi_1(°)$	$\phi_2(°)$	$\phi_3(°)$	$\phi_4(°)$	$B_1(kG)$	$B_2(kG)$	$B_3(kG)$
1.0	23.5257	191.317	8.0493	31.5750	4.8517	28.3774	4.6863	9.1915	8.2607
2.0	11.7007	91.013	3.8488	15.5495	2.3123	14.0130	4.4815	9.0529	8.1584
3.0	7.7929	60.243	2.5455	10.3384	1.5285	9.3214	4.4460	9.0285	8.1404
4.0	5.8427	44.970	1.9039	7.7466	1.1430	6.9857	4.4338	9.0201	8.1341
5.0	4.6735	35.925	1.5211	6.1946	0.9131	5.5866	4.4279	9.0162	8.1313
6.0	3.8942	29.915	1.2668	5.1609	0.7604	4.6546	4.4252	9.0140	8.1297

6. Beam Raster System

6.1 Heating effect in the solid target

Assume that a beam current is 200 μA and the target periphery is kept fixed at the initial target temperature 20 K. The beam spot size is about 0.2 mm diameter. A thin molybdenum target of 2×2 cm^2 is considered. The target thickness is 0.2 mm, which corresponds to about 0.15% radiation length (0.204 g/cm^2) for molybdenum. In this case thermal conduction through the metal target material and the metal frame is considered as the major means of releasing the heat deposited by the beam. With eliminating the blackbody thermal radiation the steady state beam spot temperature reachs 2500 K when the beam spot is fixed at the center of the target. If the beam scans the target with a sinusoidal motion having frequency 100 Hz and amplitude 9.6 mm in one direction, the steady temperature is about 300 K over the target area except the four vertex points of the motion [7]. A further simulation by [8] shows that if a fast two dimensional rastering (f_1 = 2 kHz and f_2 = 0.1176 kHz) is applied to an aluminium target (20 mm × 20 mm), the temperature distribution on the target will be quickly saturated after 1 second exposure to 200 μA electron beam. The temperature rise Δt is below 70 K at an initial temperature 300 K. For the iron target a temperature rise of 500 K occurs due to the worse termal conductivity and the smaller specific heat.

6.2 Heating effect in the cryogenic target

In the case of a 10 cm liquid hydrogen target operating at 20 K the power dissipation due to the energy loss in the target cell by 200 μA beam is about 1 kW. The liquid hydrogen is overheated by the depossited beam energy and bubbles are formed, therefore, a density variation is eventually generated. In order to minimize this bubble formation effect and reduce forced flow velocity to a reasonable level (1 to 10 m/s), the best solution is beam rastering. The global and local beam heating analysis by [9] shows a 18 kHz rastering with 2 mm amplitude is preferable.

6.3 Heating effect in the beam dump

As discussed by [10], for an instantaneous spot size of 100 μm, the critical time constant for drilling a hole into the window is 100 μs. Also, any window material loses its strength after an energy deposition of 10^{18} ergs/gram by the beam. Therefore, the rastering speed and pattern have to be selected carefully to avoid long dwell times. Tentatively, a spot size of 4×4 cm^2 at the dump was adopted. The spot size at the beam dump entrance can be increased nearly arbitrarily by using high speed magnetic rastering.

6.4 Rastering on the polarized target

The polarized target will have a useful width and height of 2.5 cm. To make full use of it, the rastering of the beam on the target should cover at least 2.5× 2.5 cm^2 [11]. An adjustable offset of rastering current is desirable for the beam alignment. In the polarized target experiment the current density is only 100 nA; it is reasonable to require 1 kHz rastering. The Moller polarimeter requires a linear rastering pattern on the iron target with amplitude of 2 mm instead of moving the target [12]. The linear scan of the beam will effectively reduce the temperature rise of the target and keep the polarization at a higher level in the beam current range from 10 to 100 μA.

Table 20. gives rastering parameters required by different target materials.

Table 20. Raster frequency and amplitude, FR: fast raster, SR: slow raster

Parameter	Cryogenic Target	Polarized Targt	Polarimeter Iron Target	Beam Dump Materials
L_{target}(m)	141.6	141.6	101.6	188.6
L_{raster}(m)	121.1	121.1 - 122.2	52.25	139.6
Current(μA)	200	0.1	0.05 - 100	200
Area (cm2)	0.2×0.2	2.5×2.5	linear 0.2	4×4
Frequency(kHz)	10-18	0.1-1	0.1	0.1
Operation	FR	FR+SR	FR	SR

6-5. Raster Magnet Design by TOSCA

Two bedstead air core coils are used as the raster magnets. Based on TOSCA calculation, the specifications of these coils are listed in Table 2.

Table 21. Specification of SR and FR magnets

Design Parameter	SR	FR
Central field (Gauss)	438.8	80.1
Bending angle at 6 GeV	0.84 mr	0.0588
$\int Bdl$ (kG cm)	16.8	1.2
Field uniformity	10^{-2}	10^{-2}
Effective length (cm)	38.34	15
Physical dimension (cm)	48	25
Inner radius (cm)	1.905	1.27
Number of turns	200	20
Ampere-turns (A-T)	4000	240
Current density (A/cm^2)	148	100
Stored energy (Joules)	6.944	0.0167
Inductance (H)	34.7×10^{-3}	84×10^{-6}
DC resistance (Ω)	0.916	3.02×10^{-3}
RMS power (kW)	2.18	0.528
Type of conductors	Awg 8	Litz
Rastering frequency (Hz)	60	10,000

The geometry of the raster magnet is shown in Figure 19. The bedstead shape of the raster coil will generate a larger uniform field region and keep the high order field components, mainly the sextupole component, as small as possible. In order to reach a higher rastering frequency up to 10 kHz, neither iron nor laminate iron material can be used as the raster magnet. A ferrite magnet is also not preferable because its small hysteresis makes it difficult for phase control.

A triangle waveform is selected to drive the raster coil. Based on the Fourier theorem, an arbitary function $F(x)$ can be expressed

$$F(x) = \sum_{n=1}^{\infty}[A_n \sin n\omega_n x + B_n \cos n\omega_n x] \tag{1}$$

where $\omega_n = 2\,\pi f_n$, the amplitude of the n-harmonic is $\sqrt{A_n + B_n}$ and the intensity of the n-harmonic is $A_n^2 + B_n^2$. In the case of an identical triangle waveform

$$y = \begin{cases} -T - x & -T \le x \le -T/2 \\ x & -T/2 \le x \le T/2 \\ T - x & T - x \le x \le T \end{cases} \tag{2}$$

the Fourier expension of the triangle waveform is

$$y = \frac{4T}{\pi^2}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{(2n-1)^2}\sin\frac{(2n-1)\pi x}{T} \tag{3}$$

$$y = \frac{4T}{\pi^2}\left[\sin(\frac{\pi x}{T}) - \frac{1}{9}\sin(\frac{3\pi x}{T}) + \frac{1}{25}\sin(\frac{5\pi x}{T}) - ...\right] \tag{4}$$

therefore, the ratios of the amplitudes and the intensities of the first, the third, and the fifth harmonic compoenets are $1 : \frac{1}{9} : \frac{1}{25}$ and $1 : \frac{1}{81} : \frac{1}{225}$ respectively.

The 20 kHz triangle waveform generated from the Tektronix FG 501A 2 MHz function generator was experimentally analyzed by an HP network analyser. The frequency spectrum is displayed in Figure 20. The ratio of relative amplitudes of the fundamental frequency and the third and the fifth harmonics is as the same as the computation from Fourier analysis mentioned above. The frequency range of a triangle waveform should cover 3-order harmonic.

Losses in a conductor due to the skin effect and proximity effect should be considered. For the FR magneyt, a round Litz cable 660/36 is used for the winding. For the SR magnet, Litz cable is replaced by awg 6 solid cable because the skin depth in copper conductors is 8.5 mm at lower frequency (60 Hz).

6.6 Operational performance

The Hall C raster system is arranged as shown in Figure 21. A fast raster (FR) system is placed at the entrance of Hall C, just in front of the first chicane magnet (BE). With a bending power 0.0588 mr at 6 GeV it is able to provide $2\times$ 2 mm^2 rastering area on the cryogenic target. A combined SR system which is located in front of the FR scans the beam on the polarized target with rastering area $2.5\times$ 2.5 cm^2. The second SR near the target chamber, executes two functions: in the absence of the polarized target it scans the beam to a safety size (4×4 cm^2) on the beam dump, and in the operation of the polarized target, it derasters the beam with opposite phase in order to reduce the large ammount background generated from scattered beam at the beam pipe walls.

Each raster system consists of two pairs of bedstead coils, one for horizontal scan, another for vertical scan. Different rastering patterns have been simulated and compared by two dimensional oscillascopic Lissajous figures. The best ratio (1.721) of the two rastering frequencies was found, which gives the longest trajectory traversal and fast uniform distribution.

The FR magnet is driven by PA03 MOS power amplifier (APEX μTECHNOLOGY CORPORATION), which has excellent features of high supply voltage (150 V), high output current (30 A), and high internal dissipation (500 W). The SR magnet is driven by a resonance circuit, which consists of a π-type LC resonance circuits, impedance match network, and low frequency power amplifier. Both of those drivers are under development.

A ceramic duct should be used as the vaccum pipe of FR magnet. The ceramic vaccum duct avoids the heating-up effect and the field attenuation due to eddy currents induced by alternating magnetic field. A very thin metal coating layer should be applied in the inner wall of the duct conducting the image current produced by the beam.

References

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[11] D. Day and I. Sick, *Memorandum: Considerations Concerning Chicane for* G_{en}, July 23, 1992.

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June 19, 1992

Field dependent variables:

L_1 = 1.889 m at 1.508 Tesla

L_2 = 2.155 m at 1.5293 Tesla

L_3 = 2.186 cm at 0.9321 Tesla

L_4 = 5.2519 m at 1.6563 Tesla

$L_1 - L_4$ effective lengths

HMS magnetic elements arrangement and physical aperture

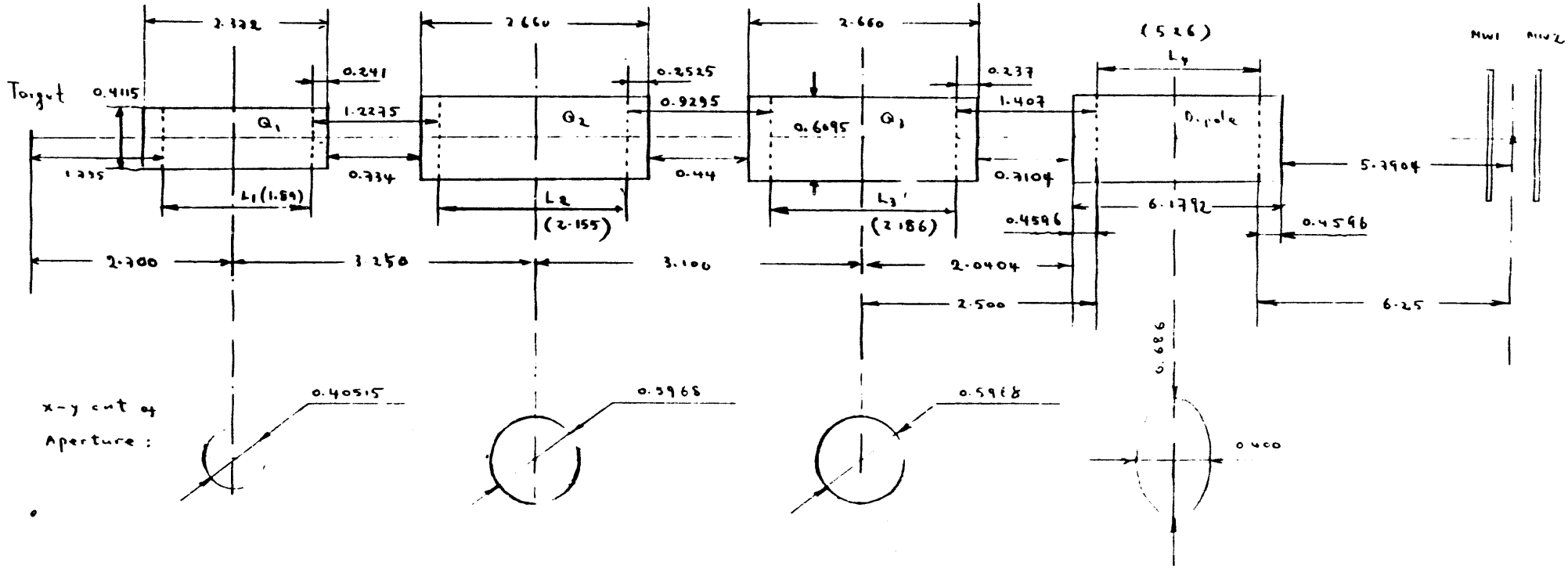

Figure 1. Layout of HMS physical aperture

```
HISTOGRAM NO  4      "Q1  "
HORIZONTAL AXIS      Y IN CM                          3.886 M     FROM THE TARGET
VERTICAL AXIS        X IN CM                          3.886 M     FROM THE TARGET

                    -40.000    -15.000     10.000     35.000    TOTALS
                      I**----**----**----**----**----**----I---------
-60.000 TO -57.500 I                                       I       0
-57.500 TO -55.000 I                                       I       0
-55.000 TO -52.500 I                                       I       0
-52.500 TO -50.000 I                                       I       0
-50.000 TO -47.500 I                                       I       0
-47.500 TO -45.000 I                                       I       0
-45.000 TO -42.500 I                                       I       0
-42.500 TO -40.000 I                                       I       0
-40.000 TO -37.500 I                                       I       0
-37.500 TO -35.000 I                                       I       0
-35.000 TO -32.500 I                                       I       0
-32.500 TO -30.000 I                                       I       0
-30.000 TO -27.500 I                                       I       0
-27.500 TO -25.000 I                                       I       0
-25.000 TO -22.500 I                                       I       0
-22.500 TO -20.000 I                                       I       0
-20.000 TO -17.500 I                 7ITTZVE8              I     171
-17.500 TO -15.000 I               1D$$$$$$$$M2            I     435
-15.000 TO -12.500 I              1DMU$$$$$$$O91           I     552
-12.500 TO -10.000 I             5S$$$$$$$$$$E7            I     664
-10.000 TO  -7.500 I           2BO$$$$$$$$$$UE2            I     759
 -7.500 TO  -5.000 I          6M$$$$$$$$$$$XD6             I     756
 -5.000 TO  -2.500 I         3PV$$$$$$$$$$PM8              I     807
 -2.500 TO   0.000 I        CG$$$$$$$$$$$WN7               I     819
  0.000 TO   2.500 I        DEV$$$$$$$$$$ZBB               I     835
  2.500 TO   5.000 I      19LQ$$$$$$$$$$YI8                I     785
  5.000 TO   7.500 I       2BT$$$$$$$$$$XH2                I     728
  7.500 TO  10.000 I       39O$$$$$$$$$$C2                 I     707
 10.000 TO  12.500 I         4JW$$$$$$$XW67                I     667
 12.500 TO  15.000 I         1AP$$$$$$$MVJ2                I     550
 15.000 TO  17.500 I           CM$$$$$$VF                  I     423
 17.500 TO  20.000 I            7FJ$$VC3                   I     185
 20.000 TO  22.500 I                                       I       0
 22.500 TO  25.000 I                                       I       0
 25.000 TO  27.500 I                                       I       0
 27.500 TO  30.000 I                                       I       0
 30.000 TO  32.500 I                                       I       0
 32.500 TO  35.000 I                                       I       0
 35.000 TO  37.500 I                                       I       0
 37.500 TO  40.000 I                                       I       0
 40.000 TO  42.500 I                                       I       0
 42.500 TO  45.000 I                                       I       0
 45.000 TO  47.500 I                                       I       0
 47.500 TO  50.000 I                                       I       0
 50.000 TO  52.500 I                                       I       0
 52.500 TO  55.000 I                                       I       0
 55.000 TO  57.500 I                                       I       0
 57.500 TO  60.000 I                                       I       0
                      I**----**----**----**----**----**----I---------
                      I                                    I
                      I                1111                I
                      I           13578022087531           I
                      I           5402465247902034         I
                   TOTALS  I 000000010091358519713866000000000 I    9843

TOTAL NUMBER OF ENTRIES =       9843 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 2-1. Histogram display of beam envelope after the first quadrupole from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO  5      "Q2  "
HORIZONTAL AXIS      Y IN CM                          7.280 M     FROM THE TARGET
VERTICAL AXIS        X IN CM                          7.280 M     FROM THE TARGET

                    -40.000    -15.000     10.000     35.000    TOTALS
                      I**----**----**----**----**----**----I---------
-60.000 TO -57.500 I                                       I       0
-57.500 TO -55.000 I                                       I       0
-55.000 TO -52.500 I                                       I       0
-52.500 TO -50.000 I                                       I       0
-50.000 TO -47.500 I                                       I       0
-47.500 TO -45.000 I                                       I       0
-45.000 TO -42.500 I                                       I       0
-42.500 TO -40.000 I                                       I       0
-40.000 TO -37.500 I                                       I       0
-37.500 TO -35.000 I                                       I       0
-35.000 TO -32.500 I                                       I       0
-32.500 TO -30.000 I                                       I       0
-30.000 TO -27.500 I                                       I       0
-27.500 TO -25.000 I                                       I       0
-25.000 TO -22.500 I                1465452 I              I      28
-22.500 TO -20.000 I              126EBHGGGL743            I     134
-20.000 TO -17.500 I            116HFIJPTSIP9GG4           I     247
-17.500 TO -15.000 I           148EDIR$Y$$$ZZPGF91         I     427
-15.000 TO -12.500 I            B9DMX$$X$$$$$ULGC82        I     521
-12.500 TO -10.000 I          22GLPXU$$$$$$$$$ZWL7A3       I     667
-10.000 TO  -7.500 I           DCLR$$$$$$$$$$$MPL44        I     697
 -7.500 TO  -5.000 I         9CLU$Y$$$$$$$$$$$VODA7        I     722
 -5.000 TO  -2.500 I       14JOPS$$$$$$$$$$W$TQEF72        I     737
 -2.500 TO   0.000 I       1ABMV$$$$$$$$$$Z$XQGE9          I     775
  0.000 TO   2.500 I       3ACHO$$$$$$$$$$$$$MM791         I     792
  2.500 TO   5.000 I       26BGOT$$$$$$$$$$ZZTJF8          I     733
  5.000 TO   7.500 I        4D8MP$$$$$$$$$$UXLIF2          I     673
  7.500 TO  10.000 I        27HQN$$$$$$$$Y$$VQLC2          I     677
 10.000 TO  12.500 I        15AKA$$Y$$$$$$YYKMF77          I     589
 12.500 TO  15.000 I         156VKTZ$$$$$$$SMEE53          I     561
 15.000 TO  17.500 I          45BDOV$$$$$$SIME63           I     419
 17.500 TO  20.000 I           34ADFMTV$QOKDM91            I     275
 20.000 TO  22.500 I           16334HPKMC633               I     125
 22.500 TO  25.000 I              21177222                 I      24
 25.000 TO  27.500 I                                       I       0
 27.500 TO  30.000 I                                       I       0
 30.000 TO  32.500 I                                       I       0
 32.500 TO  35.000 I                                       I       0
 35.000 TO  37.500 I                                       I       0
 37.500 TO  40.000 I                                       I       0
 40.000 TO  42.500 I                                       I       0
 42.500 TO  45.000 I                                       I       0
 45.000 TO  47.500 I                                       I       0
 47.500 TO  50.000 I                                       I       0
 50.000 TO  52.500 I                                       I       0
 52.500 TO  55.000 I                                       I       0
 55.000 TO  57.500 I                                       I       0
 57.500 TO  60.000 I                                       I       0
                      I**----**----**----**----**----**----I---------
                      I                                    I
                      I                                    I
                      I       1123456777877654321I         I
                      I      4087794202945422887615        I
                   TOTALS  I 000078786132204211247002841300000 I    9823

TOTAL NUMBER OF ENTRIES =       9823 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 2-2. Histogram display of beam envelope after the second quadrupole from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO  6      "Q3  "
HORIZONTAL AXIS      Y IN CM                    10.380 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                    10.380 M    FROM THE TARGET

                      -40.000    -15.000     10.000     35.000    TOTALS
                         I**----**----**----**----**----**----I--------
-60.000 TO -57.500       I                                     I       0
-57.500 TO -55.000       I                                     I       0
-55.000 TO -52.500       I                                     I       0
-52.500 TO -50.000       I                                     I       0
-50.000 TO -47.500       I                                     I       0
-47.500 TO -45.000       I                                     I       0
-45.000 TO -42.500       I                                     I       0
-42.500 TO -40.000       I                                     I       0
-40.000 TO -37.500       I                                     I       0
-37.500 TO -35.000       I                                     I       0
-35.000 TO -32.500       I                                     I       0
-32.500 TO -30.000       I                                     I       0
-30.000 TO -27.500       I              17AMLC82               I      83
-27.500 TO -25.000       I            11AJI$HOBB1              I     155
-25.000 TO -22.500       I            12CL$$$$QI2              I     243
-22.500 TO -20.000       I            1BDP$$$$WD73             I     326
-20.000 TO -17.500       I            49HY$$$$$QC              I     369
-17.500 TO -15.000       I           15EQ$$$$$$JF5             I     454
-15.000 TO -12.500       I            3BS$$$$$$$L73            I     495
-12.500 TO -10.000       I            8HT$$$$$$SD61            I     512
-10.000 TO  -7.500       I           3AM$$$$$$$M3              I     523
 -7.500 TO  -5.000       I           19E$$$$$$$XP42            I     546
 -5.000 TO  -2.500       I           44T$$$$$$$U7              I     581
 -2.500 TO   0.000       I            8U$$$$$$$G63             I     551
  0.000 TO   2.500       I           26T$$$$$$$Q71             I     590
  2.500 TO   5.000       I            2S$$$$$$WNA1             I     545
  5.000 TO   7.500       I           36K$$$$$$$M9              I     534
  7.500 TO  10.000       I           17LM$$$$$$K72             I     498
 10.000 TO  12.500       I           15LW$$$$$$H51             I     500
 12.500 TO  15.000       I            6GM$$$$$XG5              I     456
 15.000 TO  17.500       I            4BK$$$$$QM94             I     411
 17.500 TO  20.000       I            29LW$$$$L52              I     392
 20.000 TO  22.500       I            16IZ$$$$TFA              I     335
 22.500 TO  25.000       I             7CDXY$ZHE42             I     228
 25.000 TO  27.500       I             1AJQ$ZPIH2              I     191
 27.500 TO  30.000       I               54HQC41               I      75
 30.000 TO  32.500       I                                     I       0
 32.500 TO  35.000       I                                     I       0
 35.000 TO  37.500       I                                     I       0
 37.500 TO  40.000       I                                     I       0
 40.000 TO  42.500       I                                     I       0
 42.500 TO  45.000       I                                     I       0
 45.000 TO  47.500       I                                     I       0
 47.500 TO  50.000       I                                     I       0
 50.000 TO  52.500       I                                     I       0
 52.500 TO  55.000       I                                     I       0
 55.000 TO  57.500       I                                     I       0
 57.500 TO  60.000       I                                     I       0
                         I**----**----**----**----**----**----I--------
                         I                                     I
                         I                111111               I
                         I             3602343063              I
                         I          19324696202191             I
                   TOTALS I 0000000006303413104392400000000000 I    9593

TOTAL NUMBER OF ENTRIES =        9593 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 2-3. Histogram display of beam envelope after the third quadrupole from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO  7      "XF01"
HORIZONTAL AXIS      Y IN CM                    17.310 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                    17.310 M    FROM THE TARGET

                      -40.000    -15.000     10.000     35.000    TOTALS
                         I**----**----**----**----**----**----I--------
-60.000 TO -57.500       I                                     I       0
-57.500 TO -55.000       I                                     I       0
-55.000 TO -52.500       I                                     I       0
-52.500 TO -50.000       I                                     I       0
-50.000 TO -47.500       I                                     I       0
-47.500 TO -45.000       I                                     I       0
-45.000 TO -42.500       I                                     I       0
-42.500 TO -40.000       I                                     I       0
-40.000 TO -37.500       I                                     I       0
-37.500 TO -35.000       I                                     I       0
-35.000 TO -32.500       I                                     I       0
-32.500 TO -30.000       I                                     I       0
-30.000 TO -27.500       I                                     I       0
-27.500 TO -25.000       I                                     I       0
-25.000 TO -22.500       I                                     I       0
-22.500 TO -20.000       I                                     I       0
-20.000 TO -17.500       I            4245989713               I      53
-17.500 TO -15.000       I          141BQS$$$$$QH72            I     433
-15.000 TO -12.500       I           55NXS$$$$$$K711           I     753
-12.500 TO -10.000       I           1AHW$$$$$$O53             I     925
-10.000 TO  -7.500       I            5G$$$$$$Z94              I     957
 -7.500 TO  -5.000       I           15L$$$$$$4                I     908
 -5.000 TO  -2.500       I            5W$$$$$$2                I     835
 -2.500 TO   0.000       I             $$$$$$S7                I     750
  0.000 TO   2.500       I            8$$$$$$TB                I     669
  2.500 TO   5.000       I            8X$$$$$YC                I     599
  5.000 TO   7.500       I           1D$$$$$$KBI               I     537
  7.500 TO  10.000       I           1CR$$$$$Q71               I     451
 10.000 TO  12.500       I            8SX$$$$K91               I     413
 12.500 TO  15.000       I           25P$$$$ZAB3               I     323
 15.000 TO  17.500       I            8KS$$$$XI51              I     286
 17.500 TO  20.000       I            9HRR$S$MD9               I     244
 20.000 TO  22.500       I            7EHMPOLMG5               I     175
 22.500 TO  25.000       I            25MBKJJDF1               I     127
 25.000 TO  27.500       I            29DAIBFB52               I      96
 27.500 TO  30.000       I              3454AA84               I      48
 30.000 TO  32.500       I              2 1 22 1               I       8
 32.500 TO  35.000       I                                     I       0
 35.000 TO  37.500       I                                     I       0
 37.500 TO  40.000       I                                     I       0
 40.000 TO  42.500       I                                     I       0
 42.500 TO  45.000       I                                     I       0
 45.000 TO  47.500       I                                     I       0
 47.500 TO  50.000       I                                     I       0
 50.000 TO  52.500       I                                     I       0
 52.500 TO  55.000       I                                     I       0
 55.000 TO  57.500       I                                     I       0
 57.500 TO  60.000       I                                     I       0
                         I**----**----**----**----**----**----I--------
                         I                                     I
                         I                111111               I
                         I              1404764041             I
                         I           1266011435563             I
                   TOTALS I 0000000010635020990890610000000000 I    9589

TOTAL NUMBER OF ENTRIES =        9589 INCLUDING UNDERFLOW AND OVERFLOW /
```

Figure 2-4. Histogram display of beam envelope after the dipole magnet from TURTLE in HMS-1 focusing mode (point-to-point).

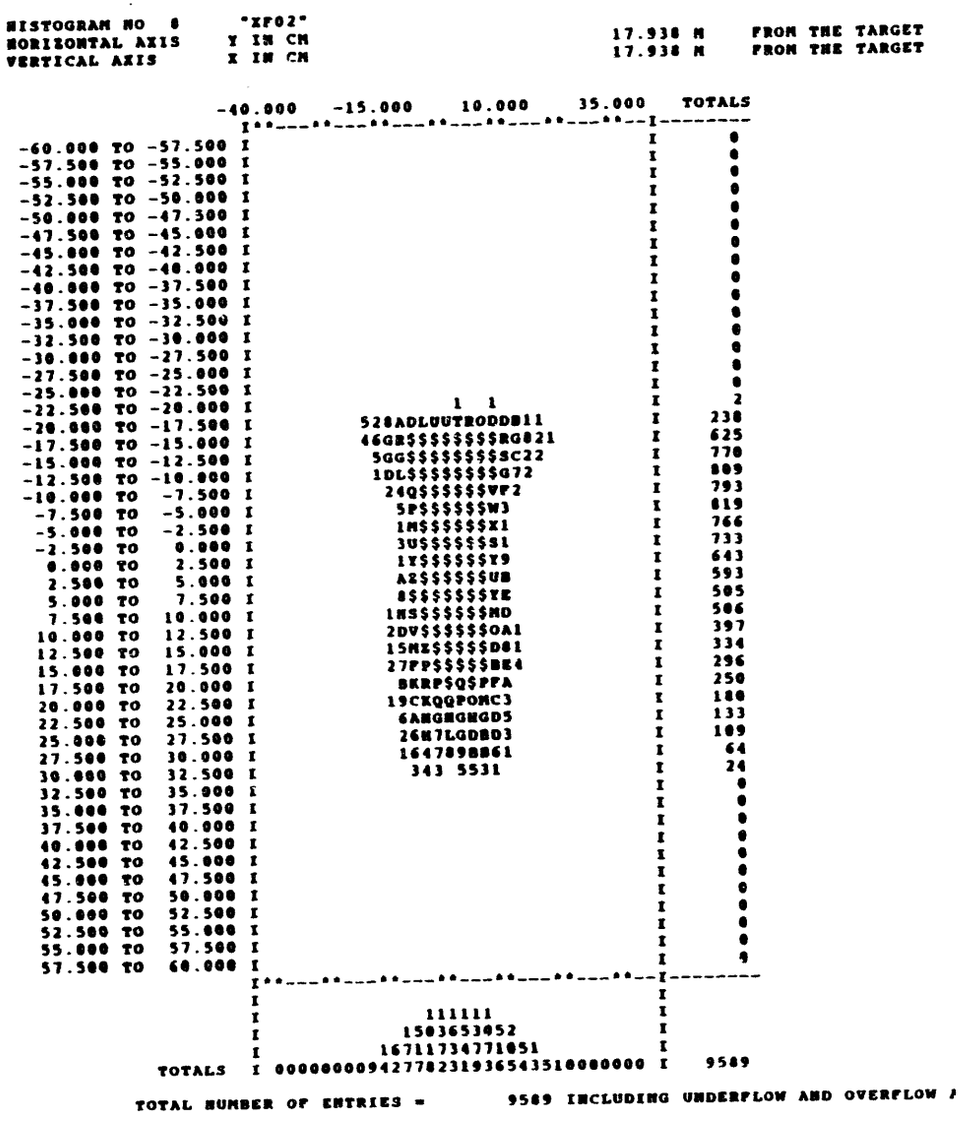

Figure 2-5. Histogram display of beam envelope 0.628 m after the dipole magnet from TURTLE in HMS-1 focusing mode (point-to-point).

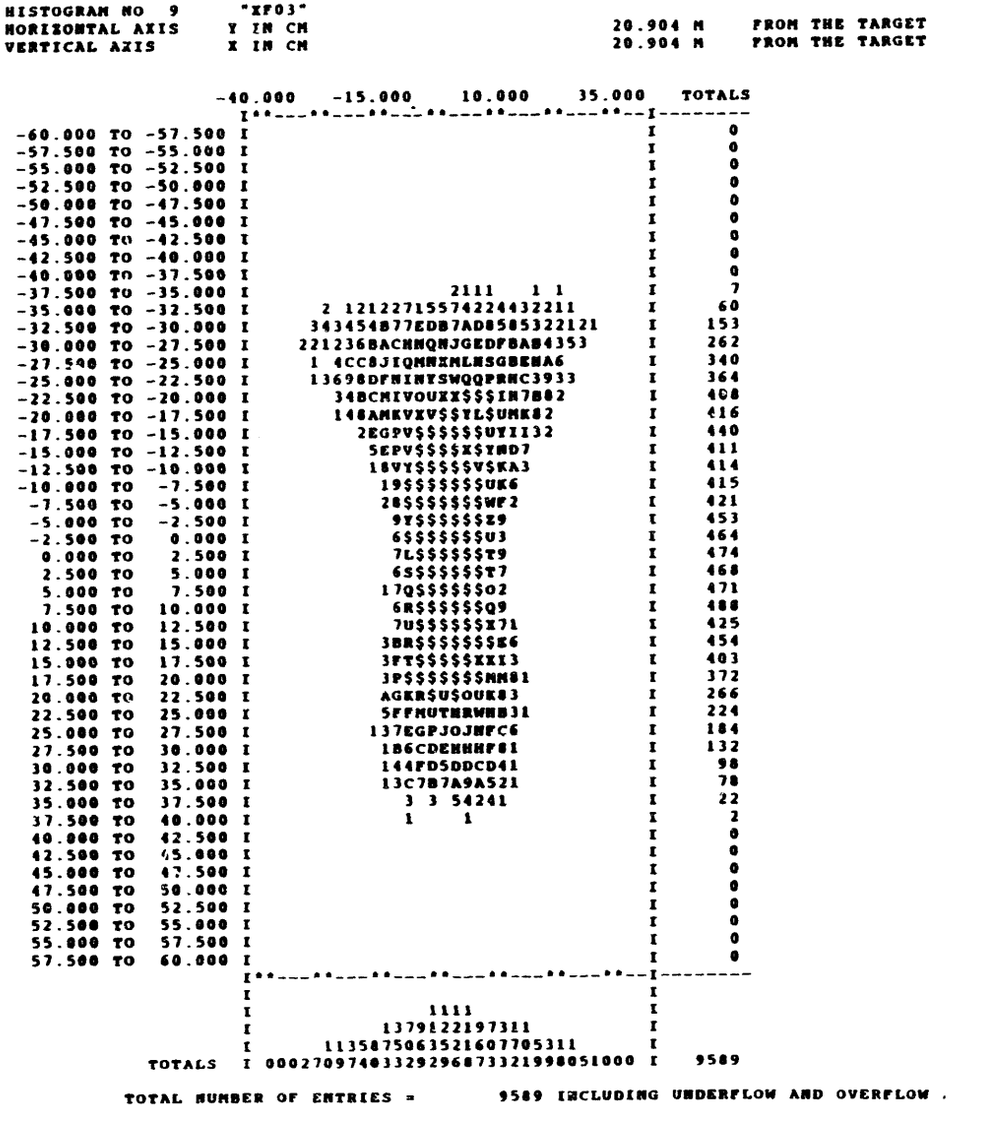

Figure 2-6. Histogram display of beam envelope 3.594 m after the dipole magnet from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO 10      "XF04"
HORIZONTAL AXIS      Y IN CM                          22.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          22.060 M    FROM THE TARGET

                    -40.000   -15.000    10.000    35.000   TOTALS
                    I**---**---**---**---**---**---**--I---------
-60.000 TO -57.500  I                                   I       0
-57.500 TO -55.000  I                                   I       0
-55.000 TO -52.500  I                                   I       0
-52.500 TO -50.000  I                                   I       0
-50.000 TO -47.500  I                                   I       0
-47.500 TO -45.000  I                                   I       0
-45.000 TO -42.500  I                1122 11    1 1     I      10
-42.500 TO -40.000  I          1 3 42224443 113113 1    I      40
-40.000 TO -37.500  I     22 333564A524245434531 1  1   I      82
-37.500 TO -35.000  I   213322252474FC96A95C4473231 11  I     139
-35.000 TO -32.500  I 12111643F88F7LJDDB6A9688631512     I     206
-32.500 TO -30.000  I     24B4659EHHMEN6BHCCA2D85 2      I     245
-30.000 TO -27.500  I    23599AFDEKGITNLVDEJB967521       I     325
-27.500 TO -25.000  I    2 1176CGIFLMOLKLKPIB74921       I     304
-25.000 TO -22.500  I      1355DEGHRFPQSRSTQBD66541       I     357
-22.500 TO -20.000  I      25698GHKYLTQUEGJJIH44          I     334
-20.000 TO -17.500  I        2A9IJOSRYSSSPOOBA34          I     356
-17.500 TO -15.000  I        13EHON$$$ZPSRMHA5 1          I     361
-15.000 TO -12.500  I         25PH$TYI$YPWIK55            I     351
-12.500 TO -10.000  I         14GRTQ$W$$WQKJ51            I     360
-10.000 TO  -7.500  I          17LU$$$VP$UH94             I     352
 -7.500 TO  -5.000  I          15K$W$$$$$XHA1             I     353
 -5.000 TO  -2.500  I           1KT$$$$$$XH1              I     383
 -2.500 TO   0.000  I            EZ$$$$$$HD               I     390
  0.000 TO   2.500  I            8S$$$$$$W9               I     394
  2.500 TO   5.000  I           17$$$$$$$IH1              I     402
  5.000 TO   7.500  I           16S$$$$$ZX8               I     408
  7.500 TO  10.000  I           19O$$$$$P81               I     438
 10.000 TO  12.500  I            8M$$$$$T8                I     388
 12.500 TO  15.000  I           37P$$$$$I72               I     381
 15.000 TO  17.500  I           2GG$$$$$W$F5              I     410
 17.500 TO  20.000  I           4AV$$$$$$F3               I     399
 20.000 TO  22.500  I           4QU$$$$$WRLA              I     369
 22.500 TO  25.000  I          27MTYWVHOZQL61             I     293
 25.000 TO  27.500  I          17GHQJWQPOL86              I     228
 27.500 TO  30.000  I          25BDHJFHKHBE62             I     181
 30.000 TO  32.500  I           476DCGIKHO56              I     148
 32.500 TO  35.000  I           248HA6DFDE71              I     110
 35.000 TO  37.500  I           22A698A89322              I      71
 37.500 TO  40.000  I            12 313334                I      20
 40.000 TO  42.500  I              1                      I       1
 42.500 TO  45.000  I                                     I       0
 45.000 TO  47.500  I                                     I       0
 47.500 TO  50.000  I                                     I       0
 50.000 TO  52.500  I                                     I       0
 52.500 TO  55.000  I                                     I       0
 55.000 TO  57.500  I                                     I       0
 57.500 TO  60.000  I                                     I       0
                    I**---**---**---**---**---**---**--I---------
                    I                                   I
                    I                1111               I
                    I          12469011096421           I
                    I     1144711392540519442844421     I
          TOTALS    I 0148292418077794751880001862144l0 I    9589

TOTAL NUMBER OF ENTRIES =        9589 INCLUDING UNDERFLOW AND OVERFLOW
```

Figure 2-7. Histogram display of beam envelope 4.75 m after the dipole magnet from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO 11      "MW1 "
HORIZONTAL AXIS      Y IN CM                          23.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          23.060 M    FROM THE TARGET

                    -40.000   -15.000    10.000    35.000   TOTALS
                    I**---**---**---**---**---**---**--I---------
-60.000 TO -57.500  I                                   I       0
-57.500 TO -55.000  I                                   I       0
-55.000 TO -52.500  I                                   I       0
-52.500 TO -50.000  I                    11       1     I       3
-50.000 TO -47.500  I              1 123211211 2 121    I      21
-47.500 TO -45.000  I    11 12 3 25251225213 24 1 11    I      47
-45.000 TO -42.500  I     2  333535454142334232351 1  1  I      72
-42.500 TO -40.000  I   2131113633367CA735B394433412 111 I     121
-40.000 TO -37.500  I  212221285488 9DG8CA855556431311   I     163
-37.500 TO -35.000  I 2  157237B486DG7F568E94528331211   I     179
-35.000 TO -32.500  I  11437577A9FEFHGKFGC9FCA6962 1     I     264
-32.500 TO -30.000  I     21766859BFLFQEKIBE8D6737522    I     262
-30.000 TO -27.500  I  11 12578IIGJGJLDIROMIA96471      I     311
-27.500 TO -25.000  I    23437BCCEHFGQHMEENJ6B74322      I     292
-25.000 TO -22.500  I     344789BHGIGQMPHNAF8AA342       I     282
-22.500 TO -20.000  I       4A5FDHMVIHOMFLHMEA532        I     319
-20.000 TO -17.500  I       1 37F8KIPMVSORLHFA9813       I     313
-17.500 TO -15.000  I         19AHTWORZXKHJFFF64         I     334
-15.000 TO -12.500  I         143DLUKSHXSHMKFF51         I     305
-12.500 TO -10.000  I          28IOUP$TPUXDHD32          I     317
-10.000 TO  -7.500  I          15ATIRUZVQR$KE74          I     323
 -7.500 TO  -5.000  I           25KGKXXVWSTFE5           I     283
 -5.000 TO  -2.500  I            AQ$$$$Z$URM6            I     355
 -2.500 TO   0.000  I            5DS$$$Y$YVP3            I     341
  0.000 TO   2.500  I            1MS$$$$$ZSD             I     356
  2.500 TO   5.000  I            1DXZ$X$$$P8             I     340
  5.000 TO   7.500  I           19S$$$$$ZUM4             I     363
  7.500 TO  10.000  I           39X$$$$$$TB1             I     389
 10.000 TO  12.500  I            AB$$$$$WKA1             I     362
 12.500 TO  15.000  I           18GU$$$$$OA1             I     331
 15.000 TO  17.500  I           3DIU$$$$$TC21            I     376
 17.500 TO  20.000  I           3GL$$$$$$UD51            I     370
 20.000 TO  22.500  I           69P$$$$$YKD61            I     350
 22.500 TO  25.000  I          37HV$$$$W$SH61            I     358
 25.000 TO  27.500  I          38HXJ$YTTQWH71            I     303
 27.500 TO  30.000  I          26GHWPVHLTKI9             I     248
 30.000 TO  32.500  I          37CGLLJHOLFE73            I     200
 32.500 TO  35.000  I        1 666DCCGHGR85              I     145
 35.000 TO  37.500  I          25AFC4DHDC42              I     109
 37.500 TO  40.000  I          237777A75633              I      67
 40.000 TO  42.500  I            21212322                I      15
 42.500 TO  45.000  I                                    I       0
 45.000 TO  47.500  I                                    I       0
 47.500 TO  50.000  I                                    I       0
 50.000 TO  52.500  I                                    I       0
 52.500 TO  55.000  I                                    I       0
 55.000 TO  57.500  I                                    I       0
 57.500 TO  60.000  I                                    I       0
                    I**---**---**---**---**---**---**--I---------
                    I                                   I
                    I                11                 I
                    I          1124689009874211         I
                    I    113360439988736609740744Z      I
          TOTALS    I 26759960053853735983533407119742 I    9589

TOTAL NUMBER OF ENTRIES =        9589 INCLUDING UNDERFLOW AND OVERFLOW
```

Figure 2-8. Histogram display of beam envelope at the first wire chamber from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO 12      "MW2 "
HORIZONTAL AXIS      Y IN CM                          24.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          24.060 M    FROM THE TARGET

                  -40.000    -15.000     10.000     35.000    TOTALS
                  I*---**---**---**---**---**---**--I--------
-60.000 TO -57.500 I                                          I       0
-57.500 TO -55.000 I                 12232 2 1 1 1 11         I      17
-55.000 TO -52.500 I       1 12 51131223211 122 11 1          I      34
-52.500 TO -50.000 I 111 311 133122 2111 41233 1 1            I      40
-50.000 TO -47.500 I  1  123432335424237416211332 2           I      73
-47.500 TO -45.000 I 211111236242AAB443853533341311 1         I     106
-45.000 TO -42.500 I 122211242457777AB895653334341111         I     124
-42.500 TO -40.000 I   2172 4664C1A98B656B552423312 42        I     144
-40.000 TO -37.500 I  224646676A86EKAB8676DAA36622             I     201
-37.500 TO -35.000 I 2122425796AC8DAHGEFBAA8494953211          I     244
-35.000 TO -32.500 I  11145417B7CFK8G99GGFC99A43A411           I     241
-32.500 TO -30.000 I 1   3387DEFD9GGHFEHGGDEB35221            I     270
-30.000 TO -27.500 I  114138887BFAFIHHLJCGI77B543211           I     276
-27.500 TO -25.000 I    35357967G9LCGKEFG9A8635252            I     234
-25.000 TO -22.500 I      47587DGGLJMOKCAGHHHA341             I     289
-22.500 TO -20.000 I      135C9HBIHBPRIIJFDB76612             I     278
-20.000 TO -17.500 I     1  3BHEJJHKEQHILFAE575 1             I     292
-17.500 TO -15.000 I       1456ILJPKQQKEOHAHA61              I     290
-15.000 TO -12.500 I        41BDGRJSMJHRGBC9511              I     265
-12.500 TO -10.000 I         6BEJTHRJPHHRHM821               I     296
-10.000 TO  -7.500 I         1299LEKSPWPJSFC954              I     278
 -7.500 TO  -5.000 I           75OSJVTRMLLJ984               I     274
 -5.000 TO  -2.500 I           3ETN$S$HUROKD1                I     314
 -2.500 TO   0.000 I            7GGT$QS$OVJD2                I     287
  0.000 TO   2.500 I            AMSX$R$$$OF4                 I     322
  2.500 TO   5.000 I            6OPT$WS$WQF1                 I     302
  5.000 TO   7.500 I            19UZ$$WY$RK8                 I     319
  7.500 TO  10.000 I            8CR$V$$$$SF4                 I     347
 10.000 TO  12.500 I            2FTY$$$$$NB2                 I     337
 12.500 TO  15.000 I            2BM$U$$$$JG2                 I     313
 15.000 TO  17.500 I            28IT$$$$WWE5                 I     326
 17.500 TO  20.000 I           13ALV$$$Z$OB32                I     331
 20.000 TO  22.500 I            7CF$$$$$VWJ52                I     330
 22.500 TO  25.000 I           37LPX$U$WXI652                I     307
 25.000 TO  27.500 I           28ILTY$$YTULA2                I     327
 27.500 TO  30.000 I           65EOZ$YXLPMG92                I     289
 30.000 TO  32.500 I           36IVVMTQLQSQ9 1               I     277
 32.500 TO  35.000 I           47LCTKQHSQPD65                I     237
 35.000 TO  37.500 I          1294EDGADHJLB621               I     165
 37.500 TO  40.000 I            259G97CJCB53                 I     110
 40.000 TO  42.500 I           1137569A45642                 I      63
 42.500 TO  45.000 I             11121 13 1                  I      11
 45.000 TO  47.500 I                                         I       0
 47.500 TO  50.000 I                                         I       0
 50.000 TO  52.500 I                                         I       0
 52.500 TO  55.000 I                                         I       0
 55.000 TO  57.500 I                                         I       0
 57.500 TO  60.000 I                                         I       0
                  I*---**---**---**---**---**---**--I--------
                  I                                 I
                  I                                 I
                  I          1125689999875311       I
                  I  1113357169257476120018195432   I
            TOTALS I 702873549942142356018259455818B3 I   9580

 TOTAL NUMBER OF ENTRIES =       9589 INCLUDING UNDERFLOW AND OVERFLOW
```

Figure 2-9. Histogram display of beam envelope at the second wire chamber from TURTLE in HMS-1 focusing mode (point-to-point).

```
HISTOGRAM NO  4      "Q1  "
HORIZONTAL AXIS      Y IN CM                          3.886 M     FROM THE TARGET
VERTICAL AXIS        X IN CM                          3.886 M     FROM THE TARGET

                  -40.000    -15.000     10.000     35.000    TOTALS
                  I*---**---**---**---**---**---**--I--------
-60.000 TO -57.500 I                                          I       0
-57.500 TO -55.000 I                                          I       0
-55.000 TO -52.500 I                                          I       0
-52.500 TO -50.000 I                                          I       0
-50.000 TO -47.500 I                                          I       0
-47.500 TO -45.000 I                                          I       0
-45.000 TO -42.500 I                                          I       0
-42.500 TO -40.000 I                                          I       0
-40.000 TO -37.500 I                                          I       0
-37.500 TO -35.000 I                                          I       0
-35.000 TO -32.500 I                                          I       0
-32.500 TO -30.000 I                                          I       0
-30.000 TO -27.500 I                                          I       0
-27.500 TO -25.000 I                                          I       0
-25.000 TO -22.500 I                                          I       0
-22.500 TO -20.000 I                                          I       0
-20.000 TO -17.500 I                4HWU$YF7                  I     182
-17.500 TO -15.000 I              1EX$$$$$$$H                 I     445
-15.000 TO -12.500 I            1EIZ$$$$$$$O91                I     545
-12.500 TO -10.000 I            3U$$$$$$$$$$G5                I     660
-10.000 TO  -7.500 I          2AM$$$$$$$$$WC1                 I     759
 -7.500 TO  -5.000 I          5K$$$$$$$$$$UE4                 I     738
 -5.000 TO  -2.500 I          3OU$$$$$$$$$MI7                 I     803
 -2.500 TO   0.000 I          8JZ$$$$$$$$$SI6                 I     810
  0.000 TO   2.500 I          CFU$$$$$$$$$9A1                 I     827
  2.500 TO   5.000 I          9KM$$$$$$$$YG8                  I     774
  5.000 TO   7.500 I          2BU$$$$$$$$WH2                  I     719
  7.500 TO  10.000 I          28P$$$$$$$$XE1                  I     695
 10.000 TO  12.500 I           3KT$$$$$$$V86                  I     655
 12.500 TO  15.000 I           1BP$$$$$$WRI3                  I     553
 15.000 TO  17.500 I             CSX$$$$$TH                   I     432
 17.500 TO  20.000 I              6KM$$UD4                    I     212
 20.000 TO  22.500 I                                          I       9
 22.500 TO  25.000 I                                          I       0
 25.000 TO  27.500 I                                          I       0
 27.500 TO  30.000 I                                          I       0
 30.000 TO  32.500 I                                          I       0
 32.500 TO  35.000 I                                          I       0
 35.000 TO  37.500 I                                          I       0
 37.500 TO  40.000 I                                          I       0
 40.000 TO  42.500 I                                          I       0
 42.500 TO  45.000 I                                          I       0
 45.000 TO  47.500 I                                          I       0
 47.500 TO  50.000 I                                          I       0
 50.000 TO  52.500 I                                          I       0
 52.500 TO  55.000 I                                          I       0
 55.000 TO  57.500 I                                          I       0
 57.500 TO  60.000 I                                          I       0
                  I*---**---**---**---**---**---**--I--------
                  I                                 I
                  I                1111             I
                  I          135780220B7531         I
                  I          43003662488910033      I
            TOTALS I 0000000035986589719060391000000000 I   9809

 TOTAL NUMBER OF ENTRIES =       9809 INCLUDING UNDERFLOW AND OVERFLOW AS
```

Figure 3-1. Histogram display of beam envelope after the first quadrupole from TURTLE in HMS-2 focusing mode (parallel-to-point).

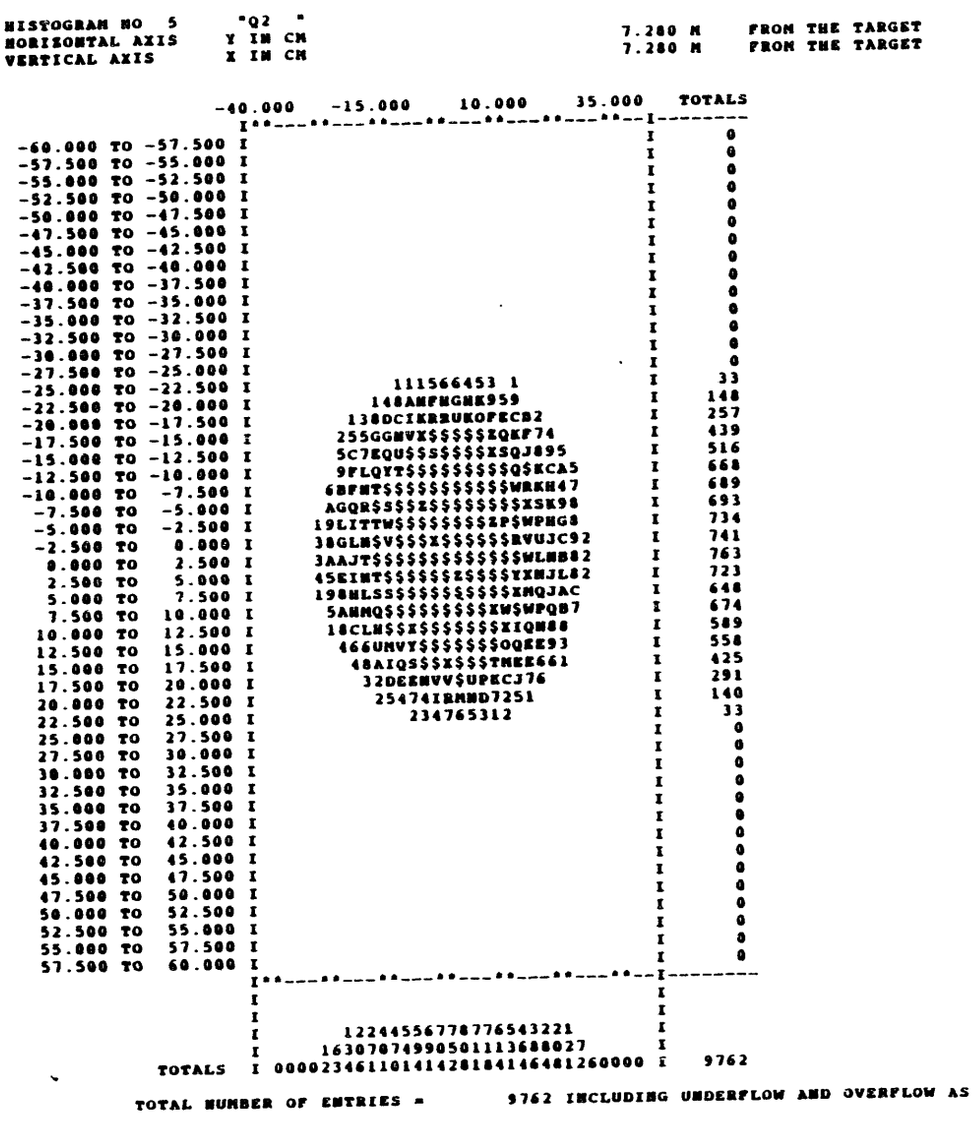

Figure 3-2. Histogram display of beam envelope after the second quadrupole from TURTLE in HMS-2 focusing mode (parallel-to-point).

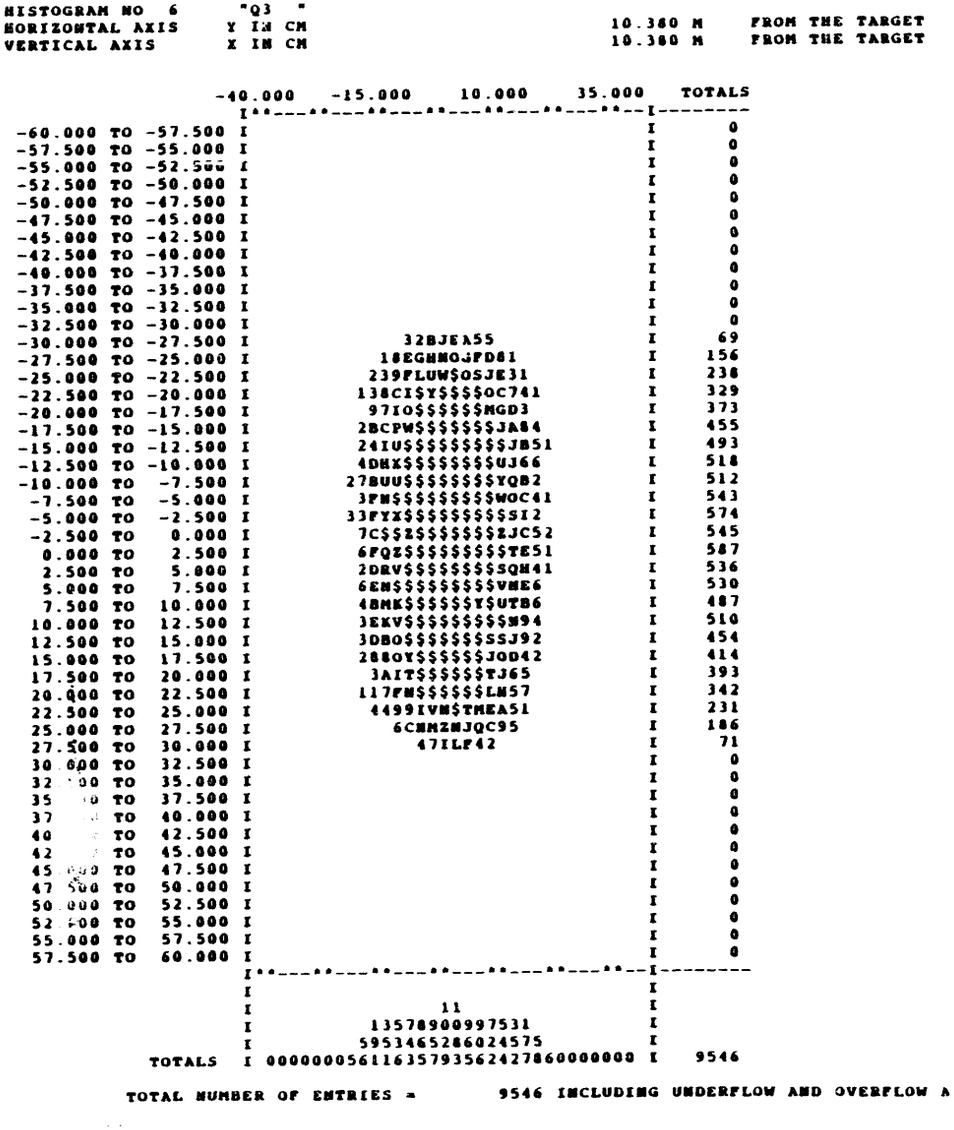

Figure 3-3. Histogram display of beam envelope after the third quadrupole from TURTLE in HMS-2 focusing mode (parallel-to-point).

```
HISTOGRAM NO  7     "XF01"
HORIZONTAL AXIS     Y IN CM                          17.310 M    FROM THE TARGET
VERTICAL AXIS       X IN CM                          17.310 M    FROM THE TARGET

                          -40.000   -15.000    10.000    35.000   TOTALS
                          I**----**----**----**----**----**----I--------
-60.000 TO -57.500        I                                     I       0
-57.500 TO -55.000        I                                     I       0
-55.000 TO -52.500        I                                     I       0
-52.500 TO -50.000        I                                     I       0
-50.000 TO -47.500        I                                     I       0
-47.500 TO -45.000        I                                     I       0
-45.000 TO -42.500        I                                     I       0
-42.500 TO -40.000        I                                     I       0
-40.000 TO -37.500        I                                     I       0
-37.500 TO -35.000        I                                     I       0
-35.000 TO -32.500        I                                     I       0
-32.500 TO -30.000        I                                     I       0
-30.000 TO -27.500        I                                     I       0
-27.500 TO -25.000        I                                     I       0
-25.000 TO -22.500        I                                     I       0
-22.500 TO -20.000        I                                     I       0
-20.000 TO -17.500        I              13DLHB3                I      69
-17.500 TO -15.000        I               B$$$$$$7              I     428
-15.000 TO -12.500        I             2$$$$$$$$5              I     736
-12.500 TO -10.000        I           5$$$$$$$$$$2              I     883
-10.000 TO  -7.500        I         5K$$$$$$$$$$T2              I     949
 -7.500 TO  -5.000        I        1J$$$$$$$$$$$$S4             I     908
 -5.000 TO  -2.500        I        DQ$$$$$$$$$$$$OF             I     819
 -2.500 TO   0.000        I        BTW$$$$$$$$$$WNK             I     733
  0.000 TO   2.500        I        FQ$$$$$$$$$$Y$VA             I     659
  2.500 TO   5.000        I        GPXZQ$$$$$$Z$Y$K             I     576
  5.000 TO   7.500        I        FUZ$RY$$$$S$$UQOD            I     516
  7.500 TO  10.000        I        FULQ$W$QU$U$HQIA             I     427
 10.000 TO  12.500        I        8FLTIERSU$$RNJJ9             I     371
 12.500 TO  15.000        I        4IDFMNVZQXLGBDB1             I     293
 15.000 TO  17.500        I        2FFIMKLPKIOLIDF1             I     263
 17.500 TO  20.000        I         9FGBINMCHINJ98              I     214
 20.000 TO  22.500        I         19CABC8A9KCA7               I     131
 22.500 TO  25.000        I          498EA9A5E489               I     104
 25.000 TO  27.500        I          15465AAG745                I      73
 27.500 TO  30.000        I            116332441                I      25
 30.000 TO  32.500        I            1  121 1                 I       6
 32.500 TO  35.000        I                                     I       0
 35.000 TO  37.500        I                                     I       0
 37.500 TO  40.000        I                                     I       0
 40.000 TO  42.500        I                                     I       0
 42.500 TO  45.000        I                                     I       0
 45.000 TO  47.500        I                                     I       0
 47.500 TO  50.000        I                                     I       0
 50.000 TO  52.500        I                                     I       0
 52.500 TO  55.000        I                                     I       0
 55.000 TO  57.500        I                                     I       0
 57.500 TO  60.000        I                                     I       0
                          I**----**----**----**----**----**----I--------
                          I                                     I
                          I                                     I
                          I          1234689999864321           I
                          I          0458512595569340           I
                    TOTALS I 000000000666384707678203000000000 I    9183

TOTAL NUMBER OF ENTRIES =        9183 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 3-4. Histogram display of beam envelope after the dipole magnet from TURTLE in HMS-2 focusing mode (parallel-to-point).

```
HISTOGRAM NO  8     "XF02"
HORIZONTAL AXIS     Y IN CM                          17.938 M    FROM THE TARGET
VERTICAL AXIS       X IN CM                          17.938 M    FROM THE TARGET

                          -40.000   -15.000    10.000    35.000   TOTALS
                          I**----**----**----**----**----**----I--------
-60.000 TO -57.500        I                                     I       0
-57.500 TO -55.000        I                                     I       0
-55.000 TO -52.500        I                                     I       0
-52.500 TO -50.000        I                                     I       0
-50.000 TO -47.500        I                                     I       0
-47.500 TO -45.000        I                                     I       0
-45.000 TO -42.500        I                                     I       0
-42.500 TO -40.000        I                                     I       0
-40.000 TO -37.500        I                                     I       0
-37.500 TO -35.000        I                                     I       0
-35.000 TO -32.500        I                                     I       0
-32.500 TO -30.000        I                                     I       0
-30.000 TO -27.500        I                                     I       0
-27.500 TO -25.000        I                                     I       0
-25.000 TO -22.500        I                                     I       0
-22.500 TO -20.000        I                3211                 I       7
-20.000 TO -17.500        I              AL$$$$U3               I     262
-17.500 TO -15.000        I             2R$$$$$$R               I     600
-15.000 TO -12.500        I             7$$$$$$$$B              I     764
-12.500 TO -10.000        I           1$$$$$$$$$$1              I     781
-10.000 TO  -7.500        I         2M$$$$$$$$$$J               I     785
 -7.500 TO  -5.000        I        1C$$$$$$$$$$$$I2             I     810
 -5.000 TO  -2.500        I        7M$$$$$$$$$$$$M9             I     752
 -2.500 TO   0.000        I        1CY$$$$$$$$$$$$MO1           I     727
  0.000 TO   2.500        I        2GY$$$$$$$$$$$$YVC6          I     631
  2.500 TO   5.000        I        2MRPTX$$$$$$$$$VG2           I     563
  5.000 TO   7.500        I        1DZWVSZ$$$XO$TPGUM5          I     484
  7.500 TO  10.000        I        3RHNZOXSYS$$$YTHM1           I     482
 10.000 TO  12.500        I         DIQMIJVUP$TOKKIA            I     361
 12.500 TO  15.000        I         9LJHOJPPTSOFHJF5            I     311
 15.000 TO  17.500        I         5GGFHHJTOJJPGCD2            I     264
 17.500 TO  20.000        I          GECEKLGAJIEMCB2            I     221
 20.000 TO  22.500        I          2DE8BCBB7IAA85             I     140
 22.500 TO  25.000        I           77AA6984F5872             I      98
 25.000 TO  27.500        I           345CC9AC8692              I      92
 27.500 TO  30.000        I           12133467333               I      36
 30.000 TO  32.500        I            11 222112                I      12
 32.500 TO  35.000        I                                     I       0
 35.000 TO  37.500        I                                     I       0
 37.500 TO  40.000        I                                     I       0
 40.000 TO  42.500        I                                     I       0
 42.500 TO  45.000        I                                     I       0
 45.000 TO  47.500        I                                     I       0
 47.500 TO  50.000        I                                     I       0
 50.000 TO  52.500        I                                     I       0
 52.500 TO  55.000        I                                     I       0
 55.000 TO  57.500        I                                     I       0
 57.500 TO  60.000        I                                     I       0
                          I**----**----**----**----**----**----I--------
                          I                                     I
                          I                                     I
                          I          1234689999865321           I
                          I          2667310474531 4421         I
                    TOTALS I 000000095256328932445722500000000 I    9183

TOTAL NUMBER OF ENTRIES =        9183 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 3-5. Histogram display of beam envelope 0.628 m after the dipole magnet from TURTLE in HMS-2 focusing mode (parallel-to-point).

```
HISTOGRAM NO  9      "XF03"
HORIZONTAL AXIS      Y IN CM                          20.904 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          20.904 M    FROM THE TARGET

                    -40.000    -15.000     10.000     35.000    TOTALS
                    I**----**----**----**----**----**----I---------
-60.000 TO -57.500  I                                    I       0
-57.500 TO -55.000  I                                    I       0
-55.000 TO -52.500  I                                    I       0
-52.500 TO -50.000  I                                    I       0
-50.000 TO -47.500  I                                    I       0
-47.500 TO -45.000  I                                    I       0
-45.000 TO -42.500  I                                    I       0
-42.500 TO -40.000  I                                    I       0
-40.000 TO -37.500  I                                    I       0
-37.500 TO -35.000  I                 1 1 1              I       3
-35.000 TO -32.500  I                1 49DFA8            I      60
-32.500 TO -30.000  I                34GOOYHBB3          I     153
-30.000 TO -27.500  I                4KB$$$$TC2          I     268
-27.500 TO -25.000  I               1BHX$$$$$ZH5         I     338
-25.000 TO -22.500  I               1BF$$$$$$O7          I     357
-22.500 TO -20.000  I               1CP$$$$$$LD3         I     408
-20.000 TO -17.500  I               2AH$$$$$$UH1         I     415
-17.500 TO -15.000  I               4N$$$$$$$$J6         I     438
-15.000 TO -12.500  I              15HY$$$$$$$UB         I     407
-12.500 TO -10.000  I              3IOQ$$$$$W$QM2        I     409
-10.000 TO  -7.500  I              ELOYYY$$$ZZTP5        I     413
 -7.500 TO  -5.000  I              AKQ$$$$H$WT$OM        I     413
 -5.000 TO  -2.500  I              OUV$$$$$YXSRLI3       I     453
 -2.500 TO   0.000  I             CHPYYYY$$$YSQ$H6       I     461
  0.000 TO   2.500  I            3BSOZS$$$X$TYSWRME4     I     470
  2.500 TO   5.000  I            5GRSSVHZ$UYXHRVPG6      I     455
  5.000 TO   7.500  I            7TLIX$TSXVZ$VSQHL4      I     471
  7.500 TO  10.000  I            GIILOXHTSX$ZYKWJQE      I     463
 10.000 TO  12.500  I           1IKOFJIMMPMUQJRUGOE2     I     394
 12.500 TO  15.000  I           4IPPHYHHHWPHRHSUKOJ5     I     445
 15.000 TO  17.500  I           2BJMQDKPMIFOQJHHHOB5     I     359
 17.500 TO  20.000  I           5AKQOPIHEGLEHIDKHHD3     I     334
 20.000 TO  22.500  I           17DIGGDKC8DEGJHC8751     I     230
 22.500 TO  25.000  I            3BEBG6GADBAHCBDA73      I     194
 25.000 TO  27.500  I            1466A8CB7B7C8A93711     I     134
 27.500 TO  30.000  I              6265C998978A2751      I     106
 30.000 TO  32.500  I             1333645576894 53       I      72
 32.500 TO  35.000  I              142358357522 2        I      49
 35.000 TO  37.500  I                 1 1 3 3 21         I      11
 37.500 TO  40.000  I                                    I       0
 40.000 TO  42.500  I                                    I       0
 42.500 TO  45.000  I                                    I       0
 45.000 TO  47.500  I                                    I       0
 47.500 TO  50.000  I                                    I       0
 50.000 TO  52.500  I                                    I       0
 52.500 TO  55.000  I                                    I       0
 55.000 TO  57.500  I                                    I       0
 57.500 TO  60.000  I                                    I       0
                    I**----**----**----**----**----**----I---------
                    I                                    I
                    I                                    I
                    I          1334678899764322          I
                    I        19904904281170996091        I
                TOTALS  I 0000003998356542611576015700000 0 I   9183

TOTAL NUMBER OF ENTRIES =       9183 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 3-6. Histogram display of beam envelope 3.594 m after the dipole magnet from TURTLE in HMS-2 focusing mode (parallel-to-point).

```
HISTOGRAM NO 10      "XF04"
HORIZONTAL AXIS      Y IN CM                          22.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          22.060 M    FROM THE TARGET

                    -40.000    -15.000     10.000     35.000    TOTALS
                    I**----**----**----**----**----**----I---------
-60.000 TO -57.500  I                                    I       0
-57.500 TO -55.000  I                                    I       0
-55.000 TO -52.500  I                                    I       0
-52.500 TO -50.000  I                                    I       0
-50.000 TO -47.500  I                                    I       0
-47.500 TO -45.000  I                                    I       0
-45.000 TO -42.500  I                   11221            I       7
-42.500 TO -40.000  I                 145A957            I      41
-40.000 TO -37.500  I               1219GCDB762          I      80
-37.500 TO -35.000  I                39PGLPR895          I     138
-35.000 TO -32.500  I                99MXW$RO94          I     205
-32.500 TO -30.000  I               199QT$$V$D7          I     252
-30.000 TO -27.500  I               2BGR$$$$XQA          I     321
-27.500 TO -25.000  I               47KS$$$$YB84         I     304
-25.000 TO -22.500  I               1BT$$$$$QRC2         I     353
-22.500 TO -20.000  I               48LZ$$$$$OI2         I     335
-20.000 TO -17.500  I               5GQ$Y$$$$UI9         I     354
-17.500 TO -15.000  I              37HZ$$$$$ZTG9         I     359
-15.000 TO -12.500  I              3EMMXQ$$SZYWM3        I     348
-12.500 TO -10.000  I              ABMMV$$$$MYKD3        I     355
-10.000 TO  -7.500  I             1DGLUSUYTUVOQMF1       I     351
 -7.500 TO  -5.000  I              FJK$SMMUZQSZJC3       I     352
 -5.000 TO  -2.500  I             2KLQS$$$$KYSHJMH7      I     373
 -2.500 TO   0.000  I            1BGTTT$Q$UQVFOLG7       I     389
  0.000 TO   2.500  I            4DGIOMXTVTVPYLTHC2      I     390
  2.500 TO   5.000  I            8EPLUMPSYKRRKPOSF7      I     401
  5.000 TO   7.500  I            DKFMPVQMWOVZPJJIDB1     I     403
  7.500 TO  10.000  I           3CJNHMPISVPYTYLUMMB      I     426
 10.000 TO  12.500  I           1DMDILOKPKVSMMMIKKF2     I     373
 12.500 TO  15.000  I           4CMKJMIFGQJOPMMJJMF5     I     364
 15.000 TO  17.500  I           7MMKMKMFHMOPREMZDK98     I     377
 17.500 TO  20.000  I           8CLMMILQOIEMMMJGJIIB     I     370
 20.000 TO  22.500  I          7EOMGLIMEIICJJEIJKF51     I     337
 22.500 TO  25.000  I          8B9IKFCE989DBMGE8DB53     I     249
 25.000 TO  27.500  I         1239FC7ECDCC89FE8C563      I     192
 27.500 TO  30.000  I         2486A65CC699A4B68A21       I     141
 30.000 TO  32.500  I          124538999A7AA96771        I     117
 32.500 TO  35.000  I          1256615758657531          I      73
 35.000 TO  37.500  I            33 2562645133           I      43
 37.500 TO  40.000  I               1  1 3 3  2          I      10
 40.000 TO  42.500  I                                    I       0
 42.500 TO  45.000  I                                    I       0
 45.000 TO  47.500  I                                    I       0
 47.500 TO  50.000  I                                    I       0
 50.000 TO  52.500  I                                    I       0
 52.500 TO  55.000  I                                    I       0
 55.000 TO  57.500  I                                    I       0
 57.500 TO  60.000  I                                    I       0
                    I**----**----**----**----**----**----I---------
                    I                                    I
                    I                                    I
                    I        1233457788876532 21        I
                    I        4310679298684009 7124      I
                TOTALS  I 0000012065841965305022973140000 0 I   9183

TOTAL NUMBER OF ENTRIES =       9183 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 3-7. Histogram display of beam envelope 4.75 m after the dipole magnet from TURTLE in HMS-2 focusing mode (parallel-to-point).

```
HISTOGRAM NO 11      "MW1 "
HORIZONTAL AXIS      Y IN CM                    23.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                    23.060 M    FROM THE TARGET

                    -40.000   -15.000    10.000    35.000   TOTALS
                    I**---**---**---**---**---**---**--I--------
-60.000 TO -57.500  I                                   I        0
-57.500 TO -55.000  I                                   I        0
-55.000 TO -52.500  I                                   I        0
-52.500 TO -50.000  I                 2                 I        2
-50.000 TO -47.500  I               425731              I       22
-47.500 TO -45.000  I           1 171C86611             I       44
-45.000 TO -42.500  I           1137G99A882             I       74
-42.500 TO -40.000  I            671EDEM7A21            I      120
-40.000 TO -37.500  I           17CFOPSDMA42            I      164
-37.500 TO -35.000  I           256PSPUSEB41            I      179
-35.000 TO -32.500  I           3BAMP$$$ZM7             I      260
-32.500 TO -30.000  I           5AEM$$$UVPE             I      262
-30.000 TO -27.500  I           3AM$$$$$ZE86            I      315
-27.500 TO -25.000  I           38QP$$$$UMA31           I      286
-25.000 TO -22.500  I           49AV$$U$$GG4            I      280
-22.500 TO -20.000  I          15EJ$T$$$ZMK72           I      321
-20.000 TO -17.500  I          44CZZT$$XRPF52           I      308
-17.500 TO -15.000  I         17CMKWSE$$UTOG5           I      333
-15.000 TO -12.500  I         24APSK$$NZKPM92           I      299
-12.500 TO -10.000  I         37FIJOM$W$MUJGE1          I      318
-10.000 TO  -7.500  I         5BFERQRUQTVMMGA5          I      318
 -7.500 TO  -5.000  I         3CGFTMJIMPLJQJ56          I      277
 -5.000 TO  -2.500  I         7KDTL$V$GQQMMMFB          I      353
 -2.500 TO   0.000  I        3BKMLMTUSYQOJMGC91         I      344
  0.000 TO   2.500  I        3AIMMSMFSRMPTMSMA3         I      348
  2.500 TO   5.000  I        8LBMJKMSVOMMLFIID7         I      338
  5.000 TO   7.500  I       1CBGMPVMMKLMSRIFLEA         I      360
  7.500 TO  10.000  I       3FLIIMKPOMITOPJVMKK2        I      387
 10.000 TO  12.500  I       57CIMJMMRMPQJOMFMMA         I      342
 12.500 TO  15.000  I       4MJADLJ8KKKOKOIM9IK2        I      329
 15.000 TO  17.500  I      1BDMGGMIKPOPIRJOPQFF81       I      355
 17.500 TO  20.000  I      26KJMUDGKCGGMKPKLDM8B2       I      337
 20.000 TO  22.500  I      39EQPJIDJM9PMMDIDKMG92       I      318
 22.500 TO  25.000  I       7KMLJKJLMPMPBMPMBKM92       I      319
 25.000 TO  27.500  I      26K9KJ8GB9GBDCIGDMKAA3       I      272
 27.500 TO  30.000  I      254AKAAIPK88A9ACC97A62       I      205
 30.000 TO  32.500  I      147A4D27ABBDBB79A76622       I      164
 32.500 TO  35.000  I       123542A677759985A431        I      108
 35.000 TO  37.500  I         1 5356 8367849431         I       73
 37.500 TO  40.000  I           4112452544 351          I       41
 40.000 TO  42.500  I             1  1 2 2             I        6
 42.500 TO  45.000  I                                   I        0
 45.000 TO  47.500  I                                   I        0
 47.500 TO  50.000  I                                   I        0
 50.000 TO  52.500  I                                   I        0
 52.500 TO  55.000  I                                   I        0
 55.000 TO  57.500  I                                   I        0
 57.500 TO  60.000  I                                   I        0
                    I**---**---**---**---**---**---**--I--------
                    I                                   I
                    I                                   I
                    I        12234577888765322I         I
                    I      1644985918344300991561       I
              TOTALS I 0000012828472554574423330040000O I    9183

 TOTAL NUMBER OF ENTRIES =        9183 INCLUDING UNDERFLOW AND OVERFLOW A
```

Figure 3-8. Histogram display of beam envelope at the first wire chamber from TURTLE in HMS-2 focusing mode (parallel-to-point).

```
HISTOGRAM NO 12      "MW2 "
HORIZONTAL AXIS      Y IN CM                    24.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                    24.060 M    FROM THE TARGET

                    -40.000   -15.000    10.000    35.000   TOTALS
                    I**---**---**---**---**---**---**--I--------
-60.000 TO -57.500  I                                   I        0
-57.500 TO -55.000  I                 215531            I       17
-55.000 TO -52.500  I               32584632            I       33
-52.500 TO -50.000  I            11255482631            I       38
-50.000 TO -47.500  I            1338A99B9831           I       75
-47.500 TO -45.000  I             4BBCEFGA831           I      105
-45.000 TO -42.500  I             27CEIKMBEA42          I      131
-42.500 TO -40.000  I           1365MJGRJD671           I      145
-40.000 TO -37.500  I             68DYUVXPG5            I      201
-37.500 TO -35.000  I            7CEMPZYMTPD2           I      241
-35.000 TO -32.500  I            73EL$W$YMA941          I      245
-32.500 TO -30.000  I            2CMRXL$Y$FB3           I      268
-30.000 TO -27.500  I            78PTU$$XPEB51          I      273
-27.500 TO -25.000  I            297TQWS$TFD33          I      232
-25.000 TO -22.500  I           23DQT$$$Z$GH5           I      290
-22.500 TO -20.000  I           35EQTLX$WMMMA2          I      274
-20.000 TO -17.500  I         169MMWQRYTSLMD42          I      293
-17.500 TO -15.000  I          34DMJIWRQ$MKQ82          I      282
-15.000 TO -12.500  I          195IPJMTUUKKFAB3         I      267
-12.500 TO -10.000  I          37J8TMPYPKQRPA77         I      294
-10.000 TO  -7.500  I           6AMCIOQPGSOMMGA6        I      278
 -7.500 TO  -5.000  I           3EDJBOCTMMLEKI94        I      271
 -5.000 TO  -2.500  I         1DFEMFWULGMQFKMCB1        I      309
 -2.500 TO   0.000  I          77AKGIQOMUIFMGIBA2       I      287
  0.000 TO   2.500  I          36KIMJJGOOMPPGMK84       I      316
  2.500 TO   5.000  I          BFDBJQQDSTFLM9AMB61      I      303
  5.000 TO   7.500  I        2DFBMMIEPICLMIOIFDC2       I      318
  7.500 TO  10.000  I        5FC9MGPJRJOQJKJMIG85       I      342
 10.000 TO  12.500  I        4BDMELIMJMKDOGIMMBC2       I      322
 12.500 TO  15.000  I        6CBJIEMGGIEQMKJEFMD5       I      307
 15.000 TO  17.500  I        6JB0JCK7IKLMKPJFCMD6       I      311
 17.500 TO  20.000  I       1CGHEEMCDEIKGGDGEKFFD3      I      314
 20.000 TO  22.500  I       399FMLADMIEEMGIIDIAD64      I      304
 22.500 TO  25.000  I       5DOLMDLBEF9F8E8EEB9GA2      I      284
 25.000 TO  27.500  I        25DGFKE8GAJEJDEDEI9M88     I      285
 27.500 TO  30.000  I        48ACMF8MDEBACAFDGE8BB2     I      262
 30.000 TO  32.500  I       4776EA9MFCB5CAAIAMB9941     I      228
 32.500 TO  35.000  I      1419D796BC76CE8DACB5C541      I      193
 35.000 TO  37.500  I       2245536C6A896B77784431      I      130
 37.500 TO  40.000  I         213436273747778513        I       73
 40.000 TO  42.500  I           4121241545 3321         I       38
 42.500 TO  45.000  I             1  1 1 1             I        4
 45.000 TO  47.500  I                                   I        0
 47.500 TO  50.000  I                                   I        0
 50.000 TO  52.500  I                                   I        0
 52.500 TO  55.000  I                                   I        0
 55.000 TO  57.500  I                                   I        0
 57.500 TO  60.000  I                                   I        0
                    I**---**---**---**---**---**---**--I--------
                    I                                   I
                    I                                   I
                    I        12334567888753321          I
                    I      2882076996040281811682       I
              TOTALS I 0000150661939625049090318682000O I    9183

 TOTAL NUMBER OF ENTRIES =        9183 INCLUDING UNDERFLOW AND OVERFLOW
```

Figure 3-9. Histogram display of beam envelope at the second wire chamber from TURTLE in HMS-2 focusing mode (parallel-to-point).

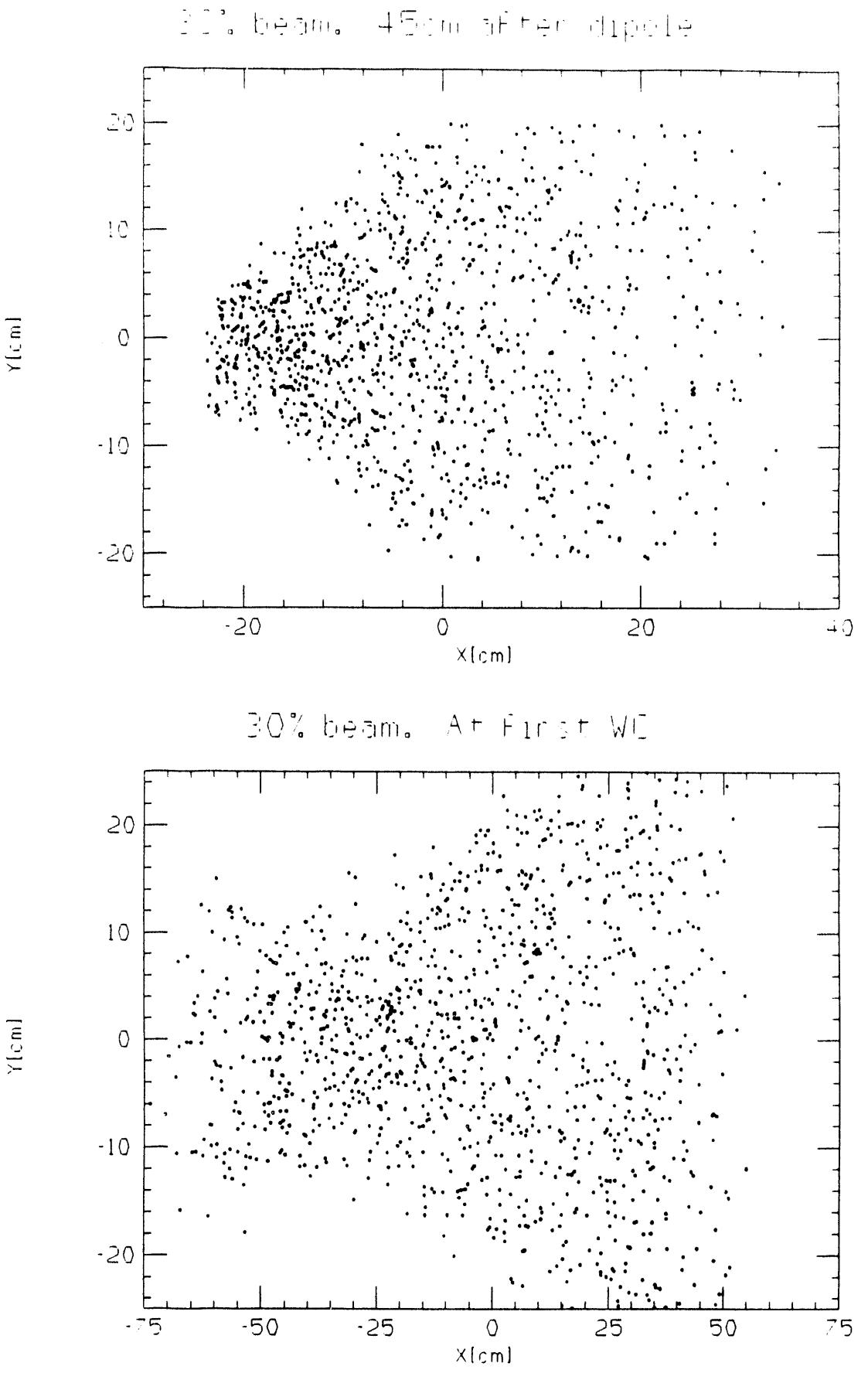

Figure 3-10. Beam envelope displayed by MOTER for HMS-2 at the first and second wire chambers.

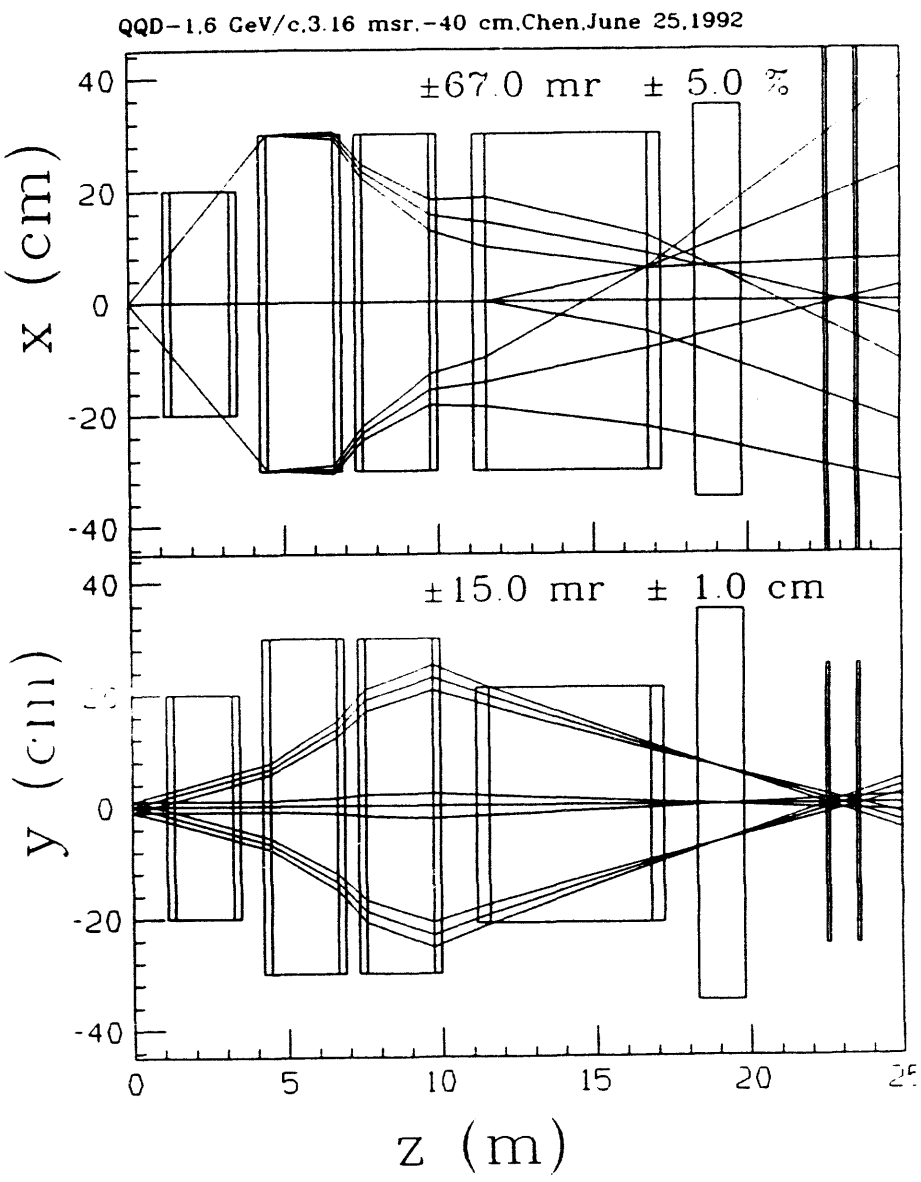

Figure 4. The beam envelope through HMS in QQD-1 (shut down Q1, point-to-point mode)

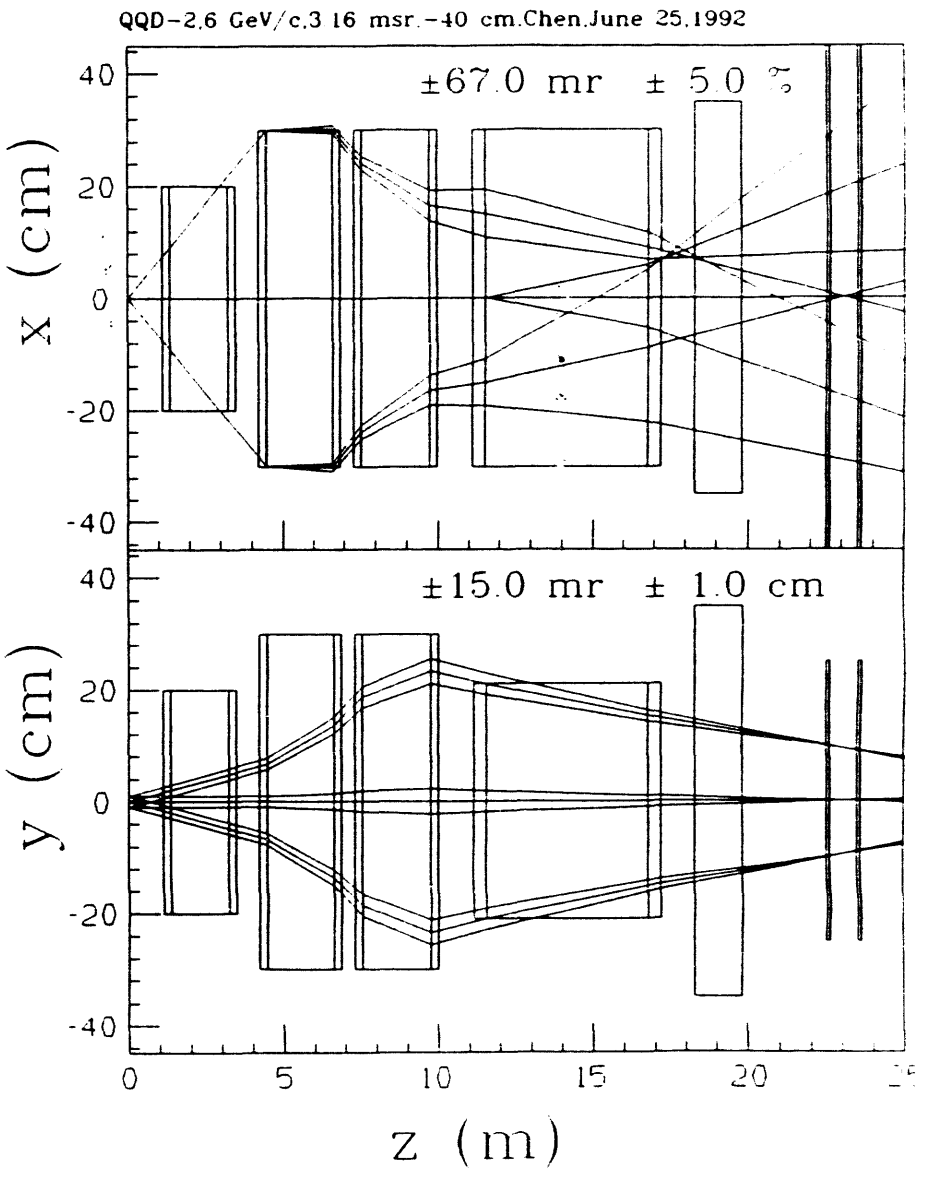

Figure 5. The beam envelope through HMS in QQD-2 (shut down Q1, parallel -to-point mode)

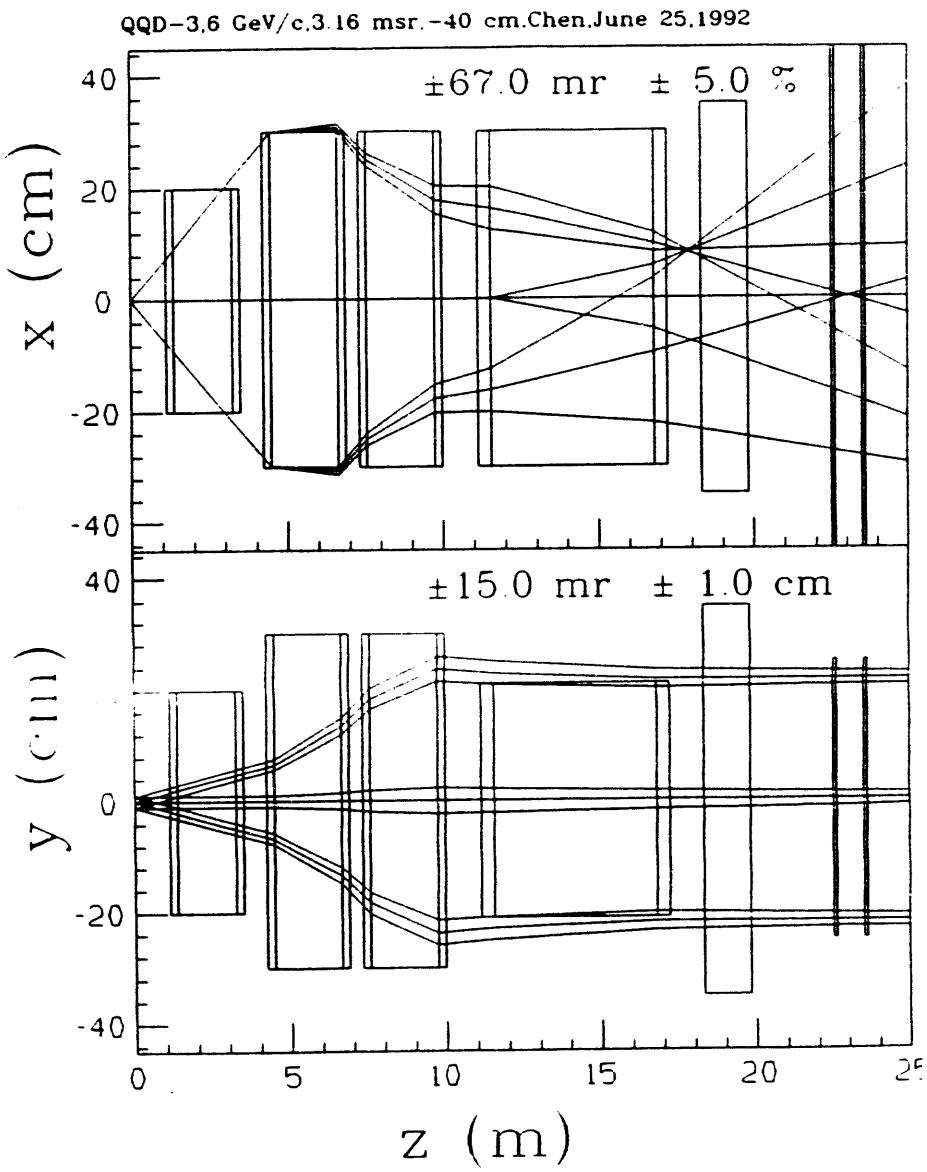

Figure 6. The beam envelope through HMS in QQD-3 (shut down Q1, point-to-parallel mode)

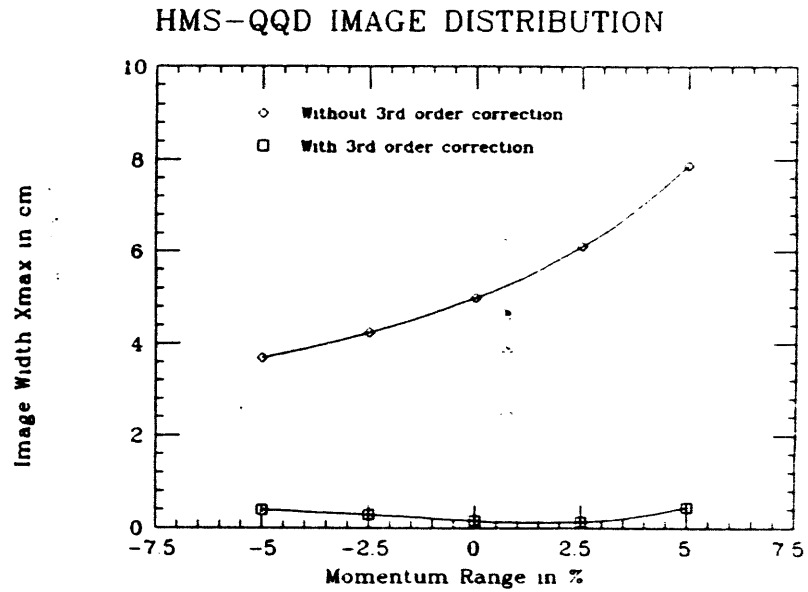

Figure 7. Image behaviour along the focal plane in QQD mode. The main contribution to image widths comes from the 3-rd order aberrations. With a proper 3-rd correction QQD can also keep a resolution better than 10E-3 over 10% momentum range.

```
HISTOGRAM NO  1      'MW1 '
HORIZONTAL AXIS      Y IN CM                          23.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          23.060 M    FROM THE TARGET

                    -40.000   -20.000     0.000     20.000    40.000 TOTALS
                    I**---**---**---**---**---**---**---**I---------
 -60.000 TO -55.000 I                                      I       0
 -55.000 TO -50.000 I                                      I       0
 -50.000 TO -45.000 I                                      I       0
 -45.000 TO -40.000 I                                      I       0
 -40.000 TO -35.000 I                                      I       0
 -35.000 TO -30.000 I           53FHU$Z$$$$$$$XPTVA63      I     568
 -30.000 TO -25.000 I       3BR$$$$$$$$$$$$$$$$$$$$$Y72    I    3058
 -25.000 TO -20.000 I     17O$$$$$$$$$$$$$$$$$$$$$$$$$K7   I    6022
 -20.000 TO -15.000 I     4J$$$$$$$$$$$$$$$$$$$$$$$$$$S6   I    8613
 -15.000 TO -10.000 I     9R$$$$$$$$$$$$$$$$$$$$$$$$$$$TA  I    9999
 -10.000 TO  -5.000 I    17Y$$$$$$$$$$$$$$$$$$$$$$$$$$$VE  I    9999
  -5.000 TO   0.000 I    1BQ$$$$$$$$$$$$$$$$$$$$$$$$$$M5  I    9999
   0.000 TO   5.000 I     7K$$$$$$$$$$$$$$$$$$$$$$$$$$Q7  I    9999
   5.000 TO  10.000 I     4K$$$$$$$$$$$$$$$$$$$$$$$$$N1   I    8848
  10.000 TO  15.000 I     29X$$$$$$$$$$$$$$$$$$$$$$$$TE   I    7408
  15.000 TO  20.000 I      8K$$$$$$$$$$$$$$$$$$$$$$$Q6    I    6057
  20.000 TO  25.000 I      4DW$$$$$$$$$$$$$$$$$$$$$VE41   I    4611
  25.000 TO  30.000 I      479Q$$$$$$$$$$$$$$$$$$$$PD42   I    3203
  30.000 TO  35.000 I       18J$$$$$$$$$$$$$$$$$$IJ61     I    2049
  35.000 TO  40.000 I          3JU$$$$$$$$$$$$$RD62       I    1044
  40.000 TO  45.000 I            1156FNNQVLJQLOA63        I     255
  45.000 TO  50.000 I                                     I       0
  50.000 TO  55.000 I                                     I       0
  55.000 TO  60.000 I                                     I       0
                    I**---**---**---**---**---**---**---**I---------
                    I                                     I
                    I          1123345566666655433211     I
                    I       14839528516044541505815844841 I
                    I     486547601302058357764590947994  I
              TOTALS I 0000251209909695100803090860061414400000 I  97482
```

```
HISTOGRAM NO  2      'MW2 '
HORIZONTAL AXIS      Y IN CM                          24.060 M    FROM THE TARGET
VERTICAL AXIS        X IN CM                          24.060 M    FROM THE TARGET

                    -50.000   -30.000   -10.000    10.000    30.000    50.000 TOTALS
                    I**---**---**---**---**---**---**---**---**I---------
 -60.000 TO -55.000 I                                                I       0
 -55.000 TO -50.000 I                                                I       0
 -50.000 TO -45.000 I                                                I       0
 -45.000 TO -40.000 I                                                I       0
 -40.000 TO -35.000 I                  1112 42335111221              I      30
 -35.000 TO -30.000 I             12BEQ$$$$$$$$$$$$$$$THE53          I    1212
 -30.000 TO -25.000 I          25FP$$$$$$$$$$$$$$$$$$$$$WC12         I    3694
 -25.000 TO -20.000 I          AQ$$$$$$$$$$$$$$$$$$$$$$$$$M42        I    6423
 -20.000 TO -15.000 I         1F$$$$$$$$$$$$$$$$$$$$$$$$$$L5        I    8647
 -15.000 TO -10.000 I         7L$$$$$$$$$$$$$$$$$$$$$$$$$$$M4       I    9999
 -10.000 TO  -5.000 I        15P$$$$$$$$$$$$$$$$$$$$$$$$$$$$9       I    9999
  -5.000 TO   0.000 I         8M$$$$$$$$$$$$$$$$$$$$$$$$$$K5        I    9999
   0.000 TO   5.000 I         6I$$$$$$$$$$$$$$$$$$$$$$$$$$K2        I    9999
   5.000 TO  10.000 I         3C$$$$$$$$$$$$$$$$$$$$$$$$$$M4        I    8557
  10.000 TO  15.000 I         2CO$$$$$$$$$$$$$$$$$$$$$$$$$E         I    7171
  15.000 TO  20.000 I          5K$$$$$$$$$$$$$$$$$$$$$$$$I9         I    5997
  20.000 TO  25.000 I          7ES$$$$$$$$$$$$$$$$$$$$$$U92         I    4726
  25.000 TO  30.000 I          368P$$$$$$$$$$$$$$$$$$$$$QC44        I    3501
  30.000 TO  35.000 I          238DT$$$$$$$$$$$$$$$$$$UND53         I    2241
  35.000 TO  40.000 I            119TRY$$$$$$$$$$$$$$LG652          I    1359
  40.000 TO  45.000 I               13BJK$R$$$$$$$$HBB711           I     491
  45.000 TO  50.000 I                   12171476347413              I      51
  50.000 TO  55.000 I                                               I       0
  55.000 TO  60.000 I                                               I       0
                    I**---**---**---**---**---**---**---**---**I---------
                    I                                               I
                    I              11223344556666655444332211       I
                    I          13706263849470000848402615273I       I
                    I       3580922443736013552362194570I663        I
              TOTALS I 0000000012430054569435670440300080372693I000000000 I  97482
```

Figure 8-1. Beam envelope at the first and second wire chambers for HMS with alternate quadrupole polarities from TURTLE.

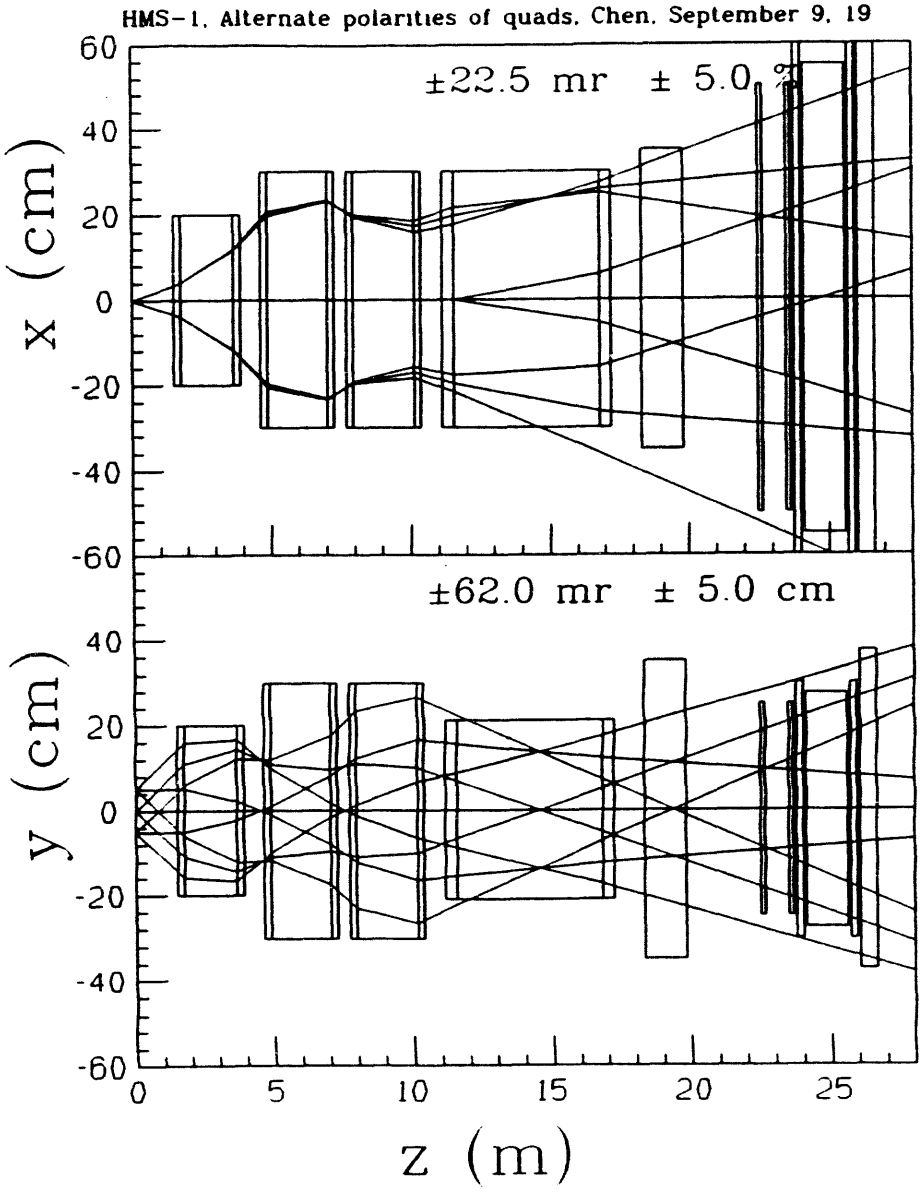

Figure 8-2. Beam envelope along the central axies for HMS with alternate quadrupole polarities from TRANSPORT.

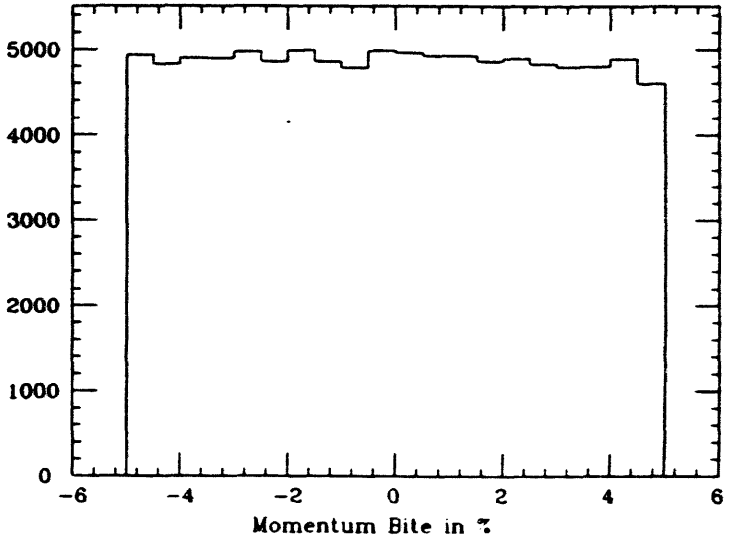

Figure 9. Momentum acceptance for HMS with alternate quadrupole polarities from TURTLE.

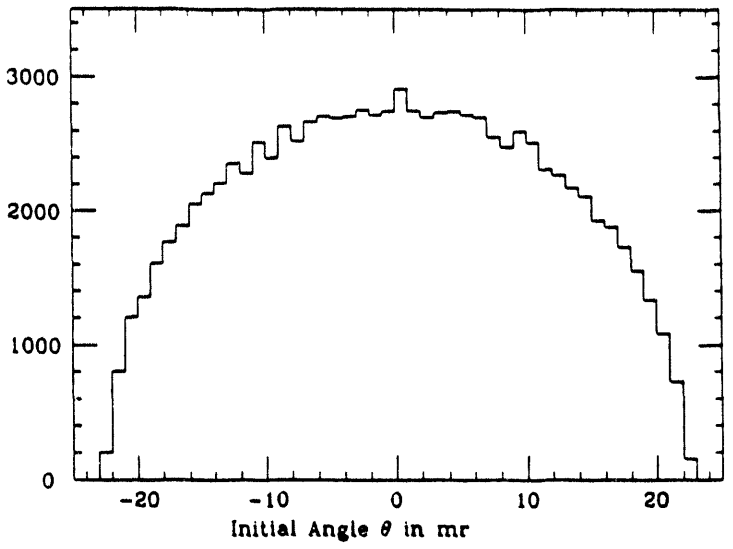

Figure 10. Geometric acceptance (incident angle) for HMS with alternate quadrupole polarities from TURTLE.

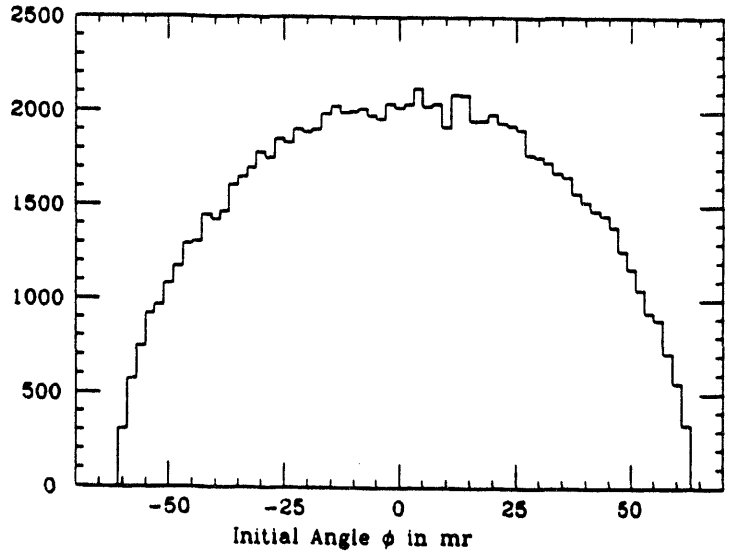

Figure 11. Geometric acceptance (scattering angle) for HMS with alternate quadrupole polarities from TURTLE.

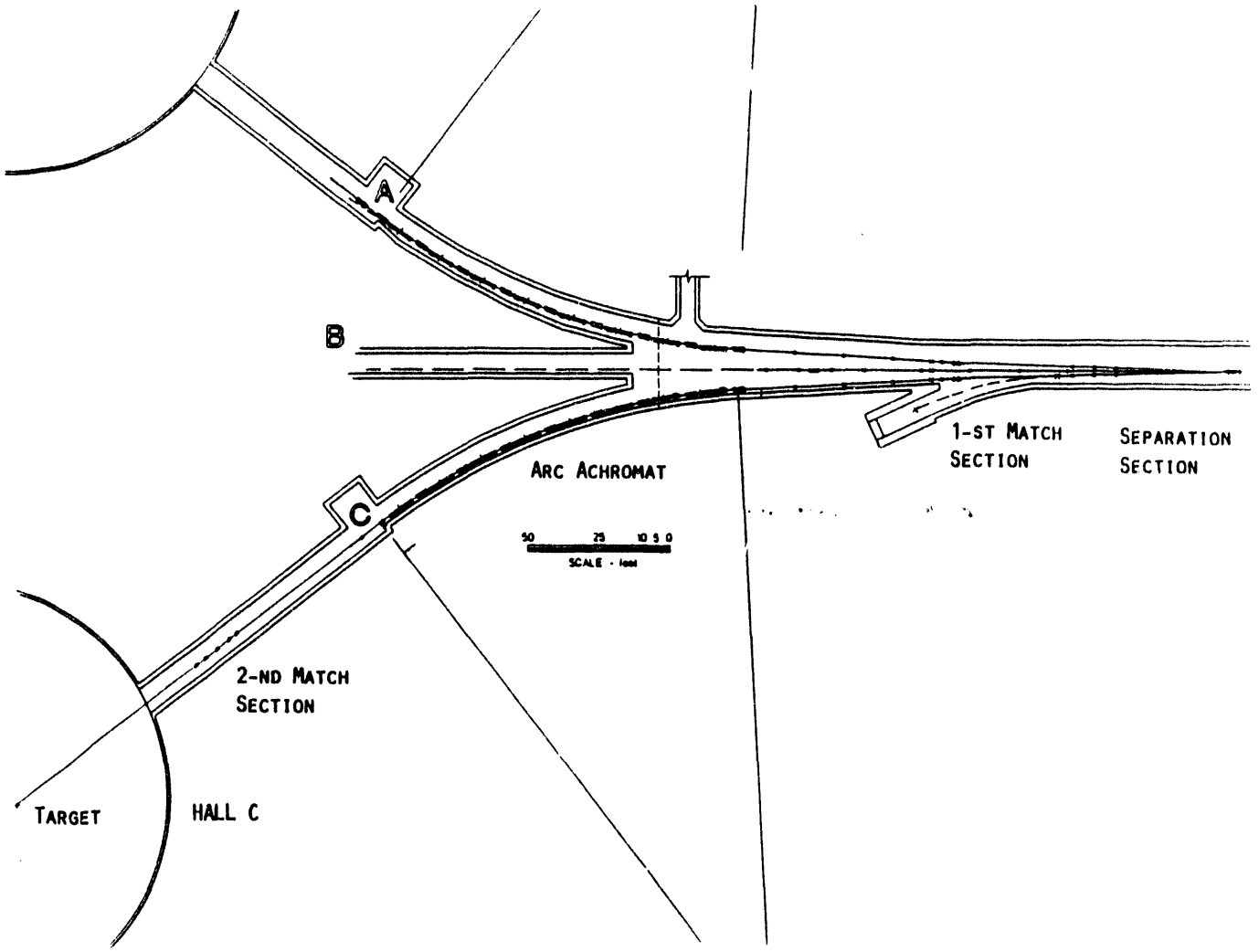

Figure 12. Layout of Hall C beam line

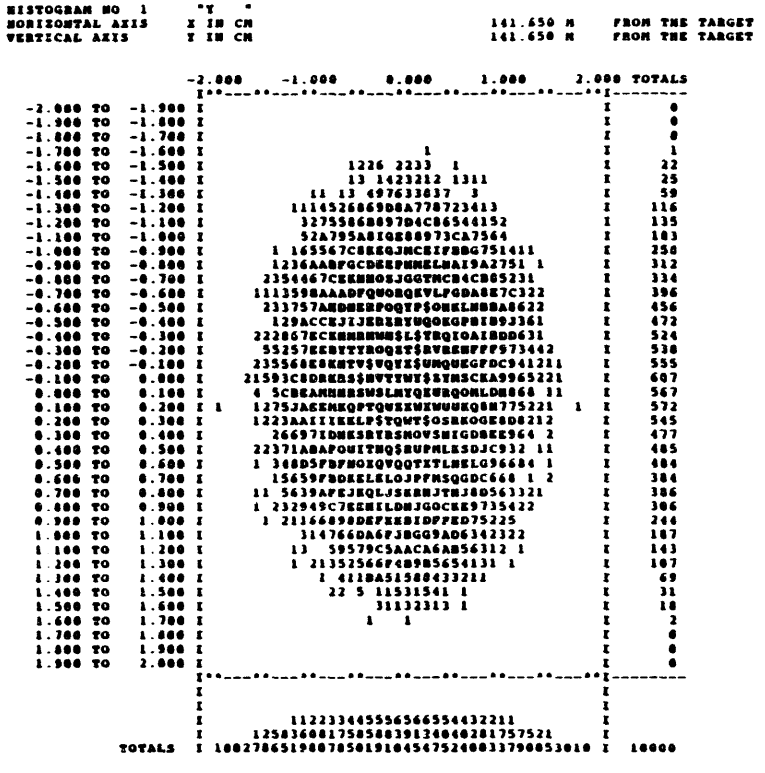

Figure 13. The histogram of beam spot on the polarized target. The beam is defocused to 2.5x2.5 cm2 by the quadrupole cluster in the second match section.

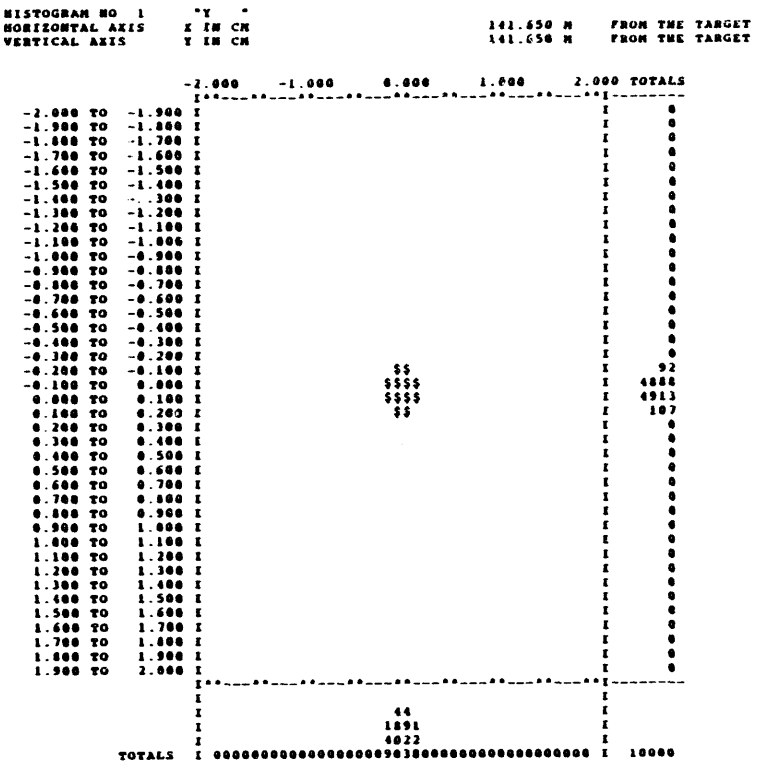

Figure 14. The histogram of beam spot on the cryogenic target. The beam is defocused to 0.1x0.1 cm2 by the quadrupole cluster in the second match section.

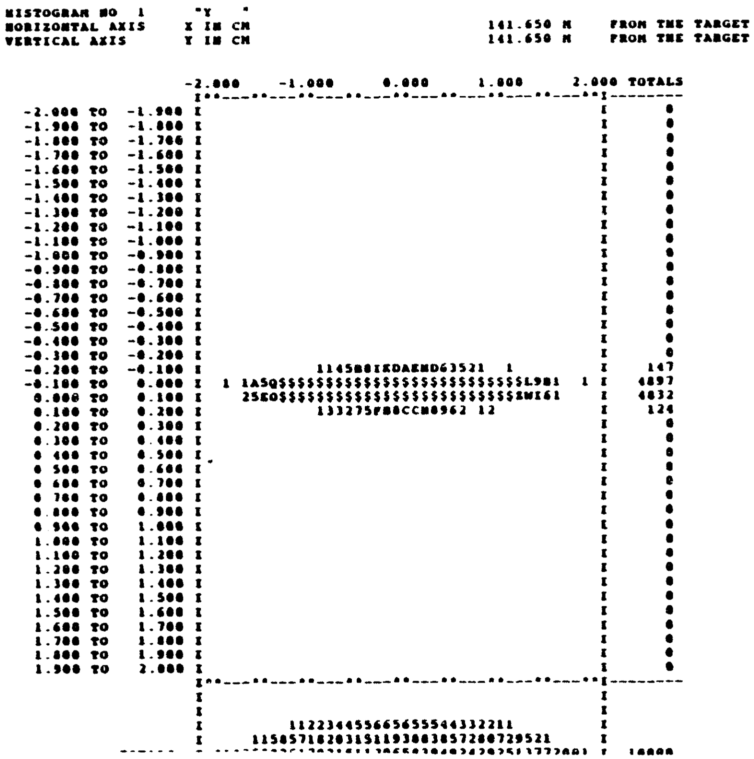

Figure 15. The histogram of beam spot on the SOS-HNSS target. The beam is defocused to 2.5x0.1 cm2 by the quadrupole cluster in the second match section.

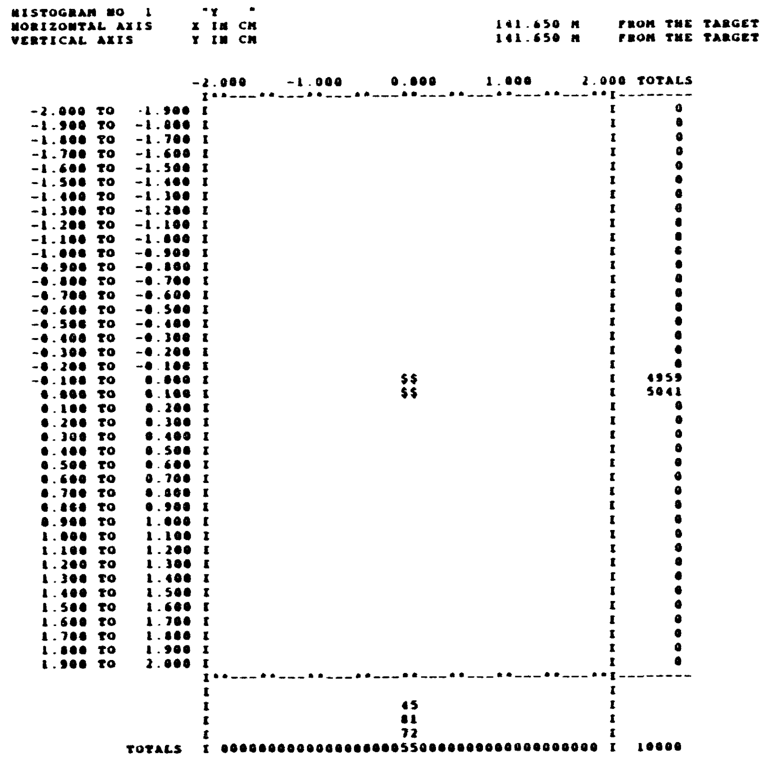

Figure 16. The histogram of beam spot on the HMS target. The beam is achromatically transported by the quadrupole cluster in the second match section.

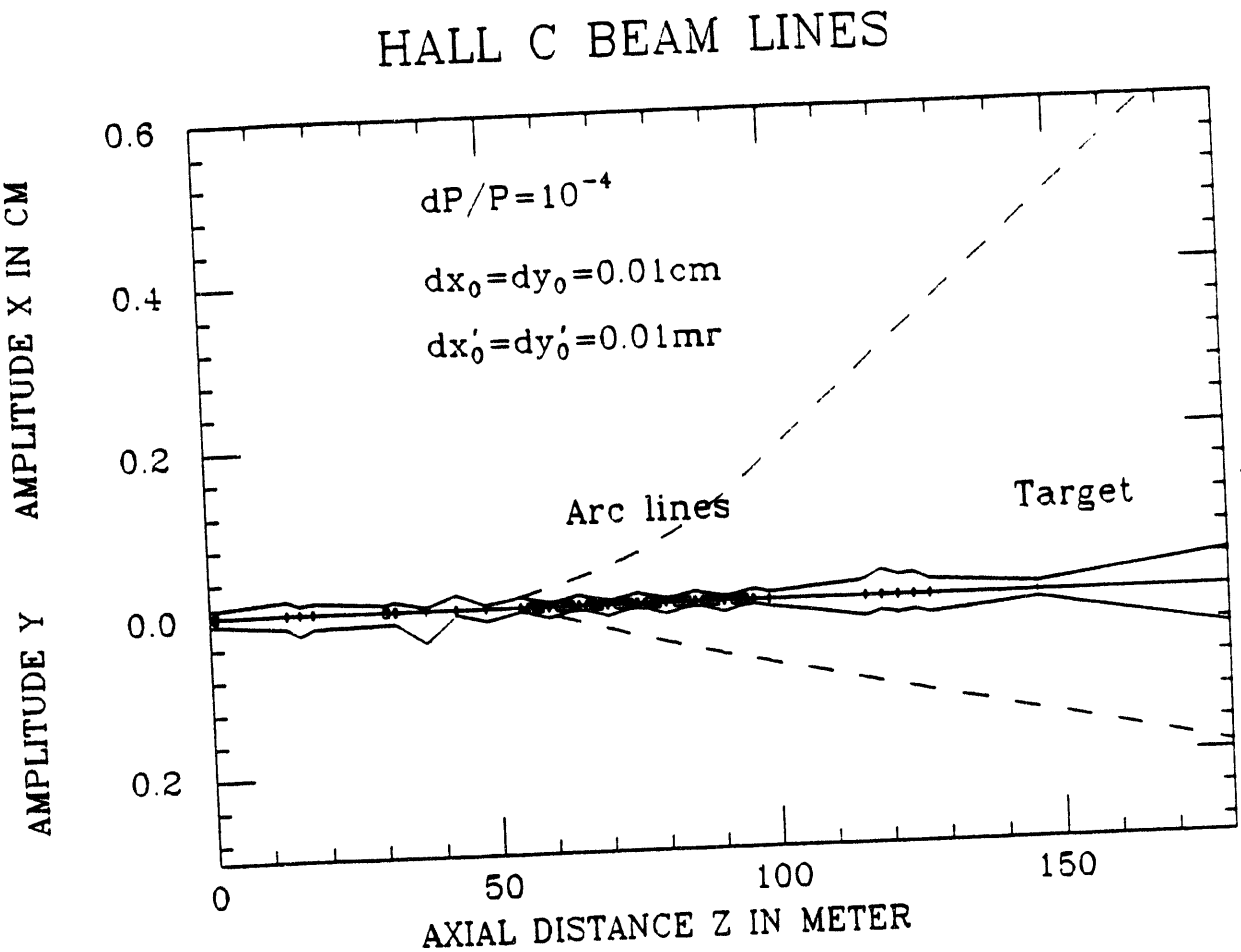

Figure 17. The beam envelope along Hall C beam line for beam energy measurement. The all sextupoles and beam correctors are switched off, therefore, the arc works as "spectrometer" mode.

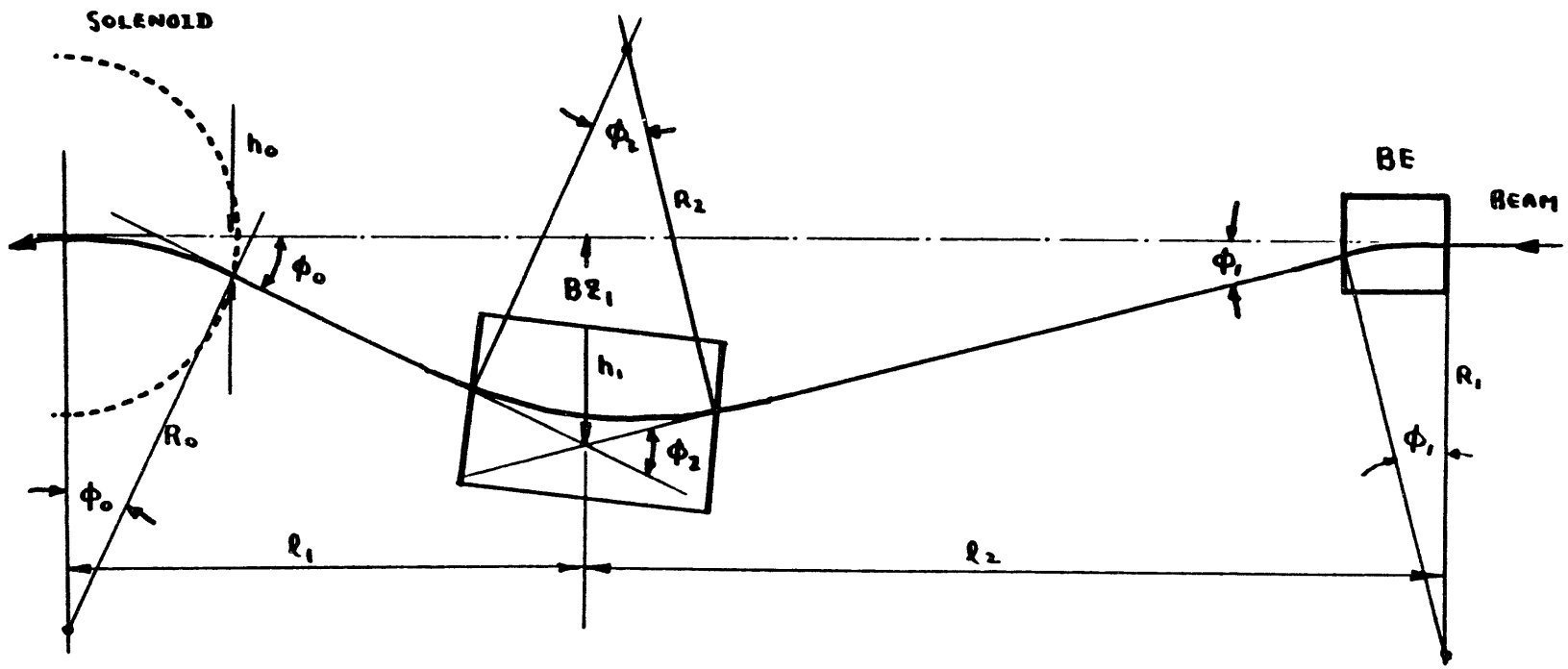

Figure 18. Layout of Hall C chicane system for UVa polaried target. The system is also used for compensation of Hall sink. After rotating 90 degree chicane will be used to transfer the beam to HNSS target which has 6 cm offset to the HMS target position.

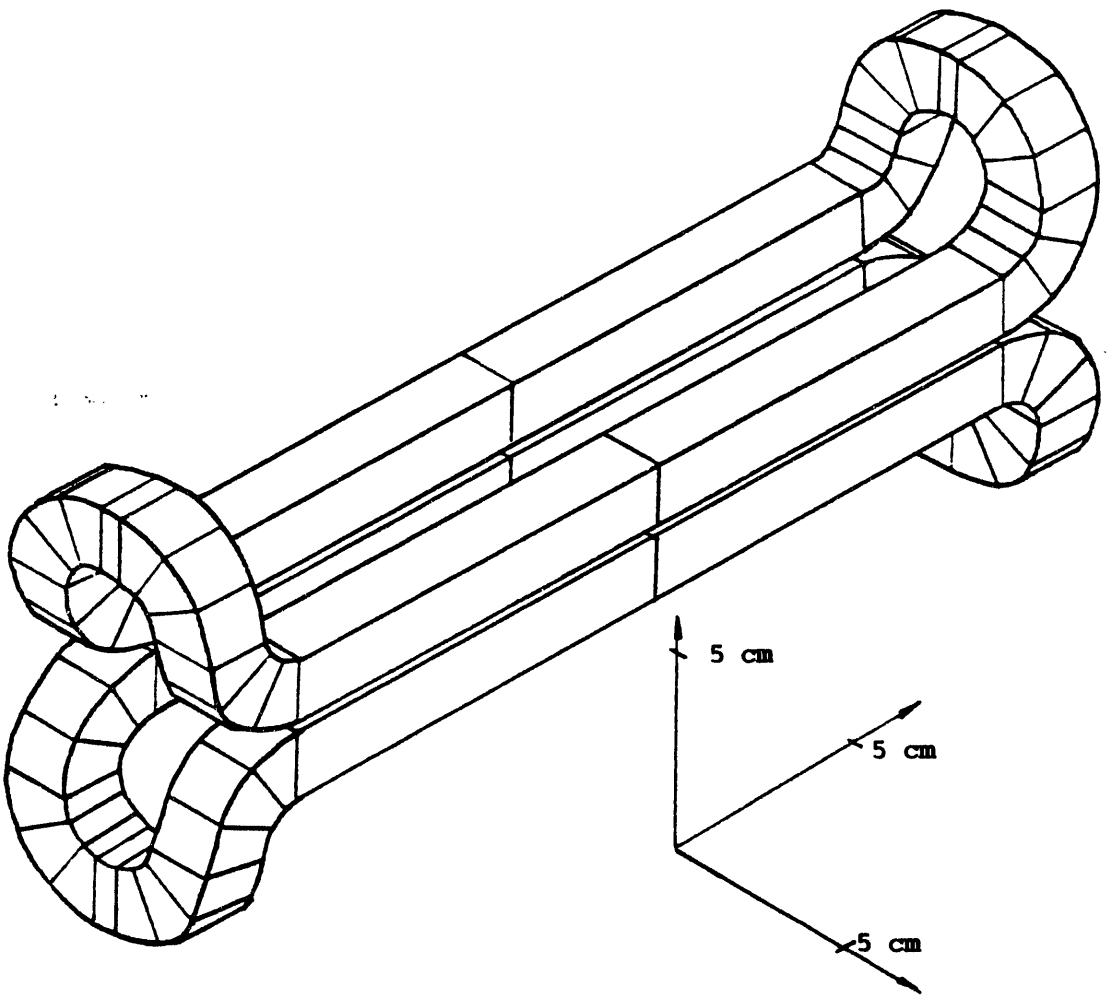

Figure 19. Fast raster geometry used in TOSCA calculations.

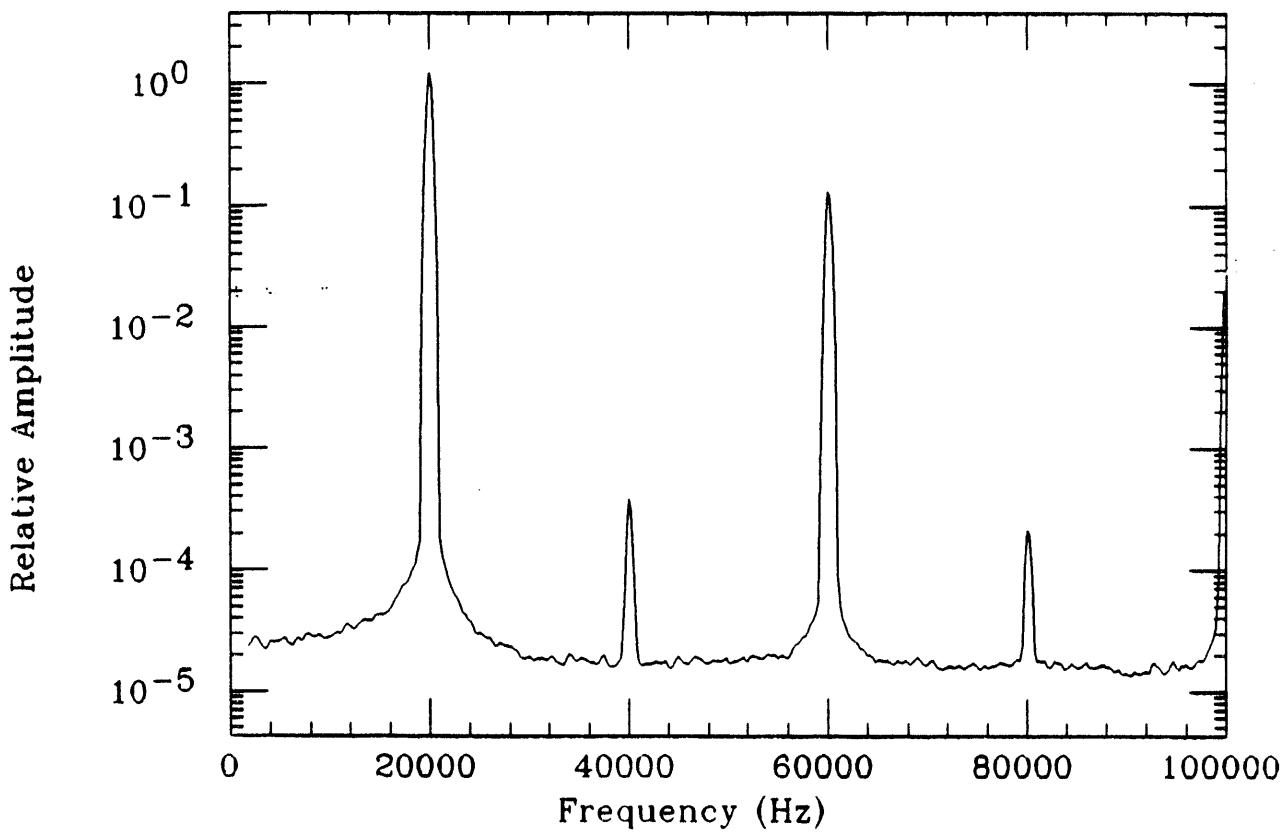

Figure 20. Frequency spectrum of triangle driving waveform for fast raster magnet. The fundamental frequency is 20 kHz and the main harmonic components are 3-rd (60 kHz) and 5-th (100 kHz).

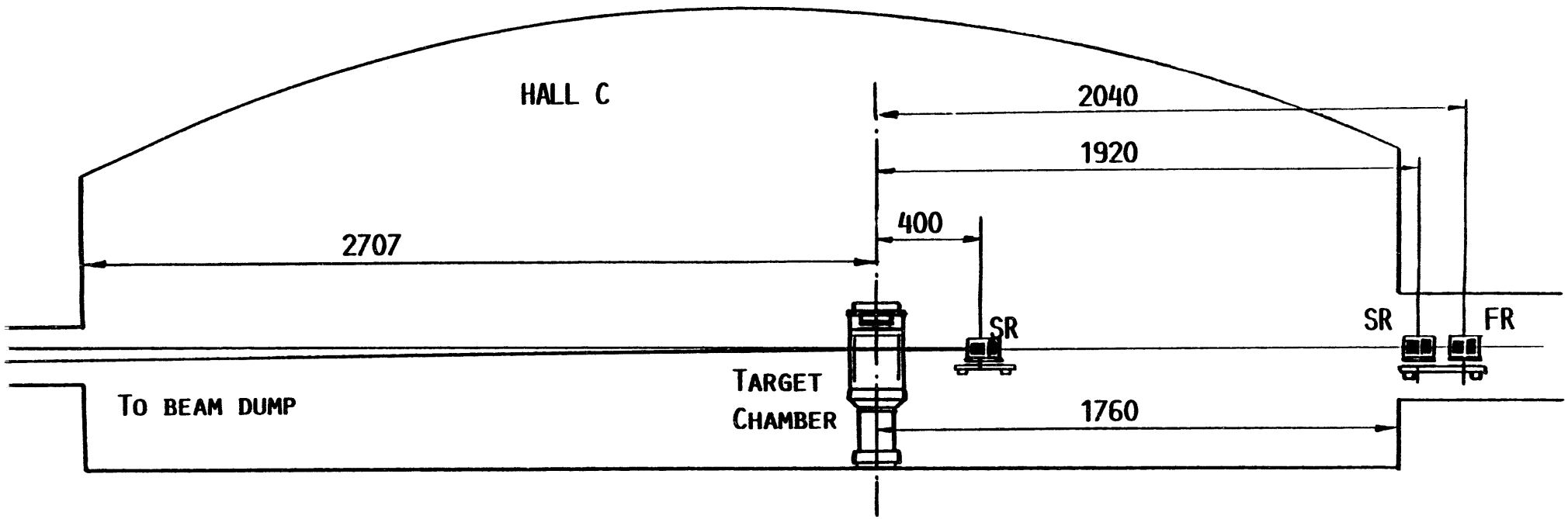

Figure 21. The raster system in Hall C.
(FR = fast raster, SR = slow raster) The fast raster, located at the entrance of Hall C, provides 10 - 15 kHz rastering on HMS cryogenic target. Together with the first slow raster, this FR generates a composite rastering pattern on UVa polarized target. The second slow raster placed 4 m in front of the target provides 4x4 cm2 pattern on the beam dump.

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