1. Introduction

In early February of this year a design review of the ISAC1 to ISAC2 transfer beamline[1)] was held. One comment that arose was that the achromatic sections of the proposed beamline used edge-focusing in the dipoles to obtain adequate vertical beam control and that this should be avoided.

This report presents a possible alternate design that uses rectangular dipoles. To maintain the required vertical focussing, two vertically-focusing quadrupoles have been added between the two dipoles of each of the achromatic sections. With these insertions it becomes necessary to shorten the unit-magnification and matching sections of the transfer beamline.

2. Revision of the existing beamline

Unless otherwise noted, all calculations reported in this section were made for a beam rigidity of $(B\,\rho)_0 =$ 1.05842 T-m and an emittance of 3.6π mm-mr in each of the horizontal and vertical planes. The initial double waist has $\beta_x = 0.2$ and $\beta_y = 0.2$. Consequently, the input beam parameters for TRANSPORT are $(x, \theta, y, \phi) = (\pm 0.085 \text{ cm}, \pm 4.23 \text{ mr}, \pm 0.085 \text{ cm}, \pm 4.23 \text{ mr})$.

2.1 Design parameters

The design parameters for the beamline presented here were as follows.

1. No change was made to the design philosophy of the beamline.
2. The addition of an extra pair of quadrupoles between the dipoles increases the (optical) length of each achromatic section by 0.76 m.
3. To reach the required final image point (see below) it was necessary to *increase* the bend angle of each dipole from 58.259° to 60.792°. All dipoles are rectangular and all are identical.
4. Because of the additional quadrupoles, the overall length of the unit-magnification and matching sections is reduced by approximately 1.2 m from that of the original design. However, their relative lengths have been kept in the same ratio (5.43:3.50) as presented in the original design.
5. Each achromatic section may be described as a QQ-D-QQ-QQ-D-QQ system that is mirror symmetric about its midpoint.

Each of the 60.792° dipoles is designed with a radius of curvature of 1 m. Consequently, its magnetic field in kG is numerically equal to the magnetic rigidity in kG-m of the particle in question and the arc length of the central trajectory ($s = \rho\,\theta = 1.06104$ m) is numerically equal to the bend angle in radians.

2.2 The achromatic sections

As noted above, two vertically-focusing quadrupoles have been added between the two dipoles of each of these sections. The sections were kept symmetrical about their midpoints.

Figure 1 shows the beam envelope for the first achromatic section and table 1 lists the TRANSPORT input for this section. The transfer matrix for this section is given in table 3(a).

In table 1 (and other in this section) the listing of TRANSPORT input shows that the half-apertures of the of the quadrupoles have been taken as 100 cm. Consequently, the quadrupole gradients in T-m are simply the listed fields (given in kG) of the quadrupoles divided by ten.

Table 2 lists the TRANSPORT input for the second achromatic section alone. The transfer matrix for this section is given in table 3(b). Beam profiles throughout this section are shown in figure 2.

The program TRANSPORT allows the floor coordinates of the elements to be calculated. As in ref[1)], we use a Cartesian coordinate system with its origin at the intersection of the north-south RFQ line and the east-west DTL1 line. The positive x-axis is directed east and the positive y-axis is directed north.

In this coordinate system the final focus of the first achromatic section is found to be located at the point$(x, y) = (16.2038\text{ m}, 6.0346\text{ m})$. That point in the calculation of ref[1)] was located at the coordinate $(x, y) = (16.1443\text{ m}, 5.3574\text{ m})$. Thus the final focus of the first achromatic section is shifted slightly east (by approximately 6 cm) and north (by approximately 68 cm).

In anticipation of results given later, we note that when all sections of the beamline are put together the location of its final focus is found to be at the coordinate $(x, y) = (15.6626\text{ m}, 18.9821\text{ m})$. That specified in ref[1)] $(x, y) = (15.6663\text{ m}, 18.9874\text{ m})$. Given that the design goal was for a final y-coordinate of 19.00 m, the discrepancy of a few millimeters between the two calculations is acceptable and easily fixed if necessary. [Recall that the coordinates given above were calculated by TRANSPORT. Ref[1] specifies a final coordinate of $(x, y) = (15.66\text{ m}, 19.00\text{ m})$.]

2.3 The unit-magnification section

Because of the addition of extra quadrupoles in each of the achromatic sections, it was necessary to revise the unit magnification section. The length of this section in the present design is 4.73 m. This is to be compared with a length of 5.43 m in ref[1)]. Optically, this section behaves as a simple lens with magnifications of -1 in each of the horizontal and vertical planes.

Table 4 lists the TRANSPORT input for this revised section by itself as well as its transfer matrix. Figure 3 shows the beam envelope of the section.

2.4 The matching section

This short (3.05 m) section of beamline matches beam from the DTL output of ISAC1 to the input of the medium β section of ISAC2. The length of this section in the original design was 3.50 m.

There are two possible operating modes for this section. The first is to do the phase-space matching at the end of the section—that is, at the object point of the second achromatic section. The other is to do the matching at the image point of the second achromatic section thus taking into account any peculiararities of that section. It was found that the latter approach produced a better phase space match.

Again anticipating what follows, we list in table 5 the settings of the matching section for each of these scenarios. Also listed are the beam sizes and the overall transfer matrix elements at the final image point.

2.5 The complete beamline

We now put the first achromatic section, the revised unit-magnification and matching sections, and the second achromatic section together.

Figure 4 shows the resulting beam envelope for the case in which phase-space matching occurs at the exit of the matching section. Similarly, figure 5 shows the beam envelope when phase-space matching is done at the final image point.

3 Discussion

This report presents an alternate approach to the design of the transfer beamline between ISAC1 and ISAC2. The major difference—if, indeed, it be considered such—is the addition of two quadrupoles to each of the achromatic sections of beamline. These were added to compensate for the vertical focusing lost by using wedge angles on each of the dipoles. In the scheme proposed here, all dipoles are rectangular.

Overall, the line presented here and that of ref[1)] are very similar. They both would fit into the tunnel between the two ISAC buildings. This is indicated in the line drawing of figure 6. In this figure, the solid line indicates the beamline of ref[1)]; the dotted line indicates that of the beamline of this report. The tunnel is drawn as it existed in early February. In mid-February the upper-left corner of the tunnel was moved 2.5 feet to the west. This produces t=a tunnel outline as indicated by the dashed line.

References

1. R. E. Laxdal and M. Passini, *ISAC-II Optics Specifications*, TRI-DN-01-xx, TRIUMF, 2002/02/05.

Table 1

TRANSPORT input for the first achromatic section

```
'FIRST ACHROMATIC SECTION -- ISAC1-->ISAC2 -- RECT DIPOLES - 02/02/19
  0
 13.            '    '     12.00000;
 16.00          '    '      5.00000     3.00000;
 16.00          '    '      7.00000     0.45000;
  1.000000      'BEAM'      0.08485     4.24260     0.08485     4.24260
                            0.00000     0.00100     0.31731;
  3.0           'STRT'      0.00001;
  3.0           '    '      0.90000;
  5.00          'QA1 '      0.18000  -109.24630   100.00000;
  3.0           '    '      0.20000;
  5.00          'QA2 '      0.32500    43.26300   100.00000;
  3.0           '    '      0.90000;
 20.0           '    '    180.00000;
  2.0           '    '     30.39550;
  4.000         'BA1 '      1.06104    10.58405     0.00000;
  2.0           '    '     30.39550;
 20.0           '    '   -180.00000;
  3.0           '    '      0.60000;
  5.00          'QA3 '      0.18000   105.81201   100.00000;
  3.0           '    '      0.20000;
  5.00          'QAM '      0.18000   -67.53922   100.00000;
  3.0           '    '      0.20000;
  3.0           'MID1'      0.00001;
  3.0           '    '      0.20000;
  5.00          'QAM '      0.18000   -67.53922   100.00000;
  3.0           '    '      0.20000;
  5.00          'QA4 '      0.18000   105.81201   100.00000;
  3.0           '    '      0.60000;
 20.0           '    '    180.00000;
  2.0           '    '     30.39550;
  4.000         'BA2 '      1.06104    10.58405     0.00000;
  2.0           '    '     30.39550;
 20.0           '    '   -180.00000;
  3.0           '    '      0.90000;
  5.00          'QA5 '      0.32500    43.26300   100.00000;
  3.0           '    '      0.20000;
  5.00          'QA6 '      0.18000  -109.24630   100.00000;
  3.0           'ACR1'      0.90000;
-10.            '    '     -1.00000     2.00000     0.00000     0.00100;
-10.            '    '     -3.00000     4.00000     0.00000     0.00100;
-10.            '    '     -1.00000     6.00000     0.00000     0.00100;
-10.            '    '     -2.00000     6.00000     0.00000     0.00100;
-10.            '    '     -1.00000     1.00000     1.00000     0.00100;
-10.            '    '     -3.00000     3.00000     1.00000     0.00100;
SENTINEL
SENTINEL
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Table 2

TRANSPORT input for the second achromatic section

```
'SECOND ACHROMATIC SECTION -- ISAC1-->ISAC2 -- RECT DIPOLES - 02/02/19'
   0
 13.            '    '    12.00000;
 16.00          '    '     5.00000    3.00000;
 16.00          '    '     7.00000    0.45000;
  1.000000      'BEAM'     0.08485    4.24260    0.08485    4.24260
                           0.00000    0.00100    0.31731;
  3.0           '    '     0.90000;
  5.00          'QA21'     0.18000  -95.83297  100.00000;
  3.0           '    '     0.20000;
  5.00          'QA22'     0.18000   99.95628  100.00000;
  3.0           '    '     1.38000;
  2.0           '    '    30.39550;
  4.000         'BA21'     1.06104   10.58405    0.00000;
  2.0           '    '    30.39550;
  3.0           '    '     0.60000;
  5.00          'QA23'     0.18000  -24.99812  100.00000;
  3.0           '    '     0.20000;
  5.00          'QA23'     0.18000   53.05234  100.00000;
  3.0           '    '     0.20000;
  3.0           'MID2'     0.00001;
  3.0           '    '     0.20000;
  5.00          'QA23'     0.18000   53.05234  100.00000;
  3.0           '    '     0.20000;
  5.00          'QA24'     0.18000  -24.99812  100.00000;
  3.0           '    '     0.60000;
  2.0           '    '    30.39550;
  4.000         'BA22'     1.06104   10.58405    0.00000;
  2.0           '    '    30.39550;
  3.0           '    '     1.38000;
  5.00          'QA25'     0.18000   99.95628  100.00000;
  3.0           '    '     0.20000;
  5.00          'QA26'     0.18000  -95.83297  100.00000;
  3.0           'ACR2'     0.90000;
-10.            '    '    -1.00000    2.00000    0.00000    0.00100;
-10.            '    '    -3.00000    4.00000    0.00000    0.00100;
-10.            '    '    -1.00000    6.00000    0.00000    0.00100;
-10.            '    '    -2.00000    6.00000    0.00000    0.00100;
-10.            '    '    -1.00000    1.00000    1.00000    0.00100;
-10.            '    '    -3.00000    3.00000    1.00000    0.00100;
-10.            'ZFIT'     8.00000    3.00000    2.83270    0.00100;
-10.            'XFIT'     8.00000    1.00000   18.98210    0.00100;
SENTINEL
SENTINEL
```

Table 3

Transfer matrices for the two achromatic sections

(a) Transfer matrix for the first achromatic section

1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10.9500	1.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
0.0000	0.0000	−14.4147	1.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	1.0000	−0.3763
0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

(b) Transfer matrix for the second achromatic section

1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
−3.5965	1.0000	0.0000	0.0000	0.0000	−0.0001
0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.5102	1.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	1.0000	−0.3763
0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table 4

TRANSPORT input for the unit-magnification section alone

```
'UNIT MAGNIFICATION SECTION -- ISAC1-->ISAC2 -- RECT DIPOLES -- 2002/02/14'
   0
 13.            '    '    12.00000;
 16.00          '    '     5.00000     3.00000;
 16.00          '    '     7.00000     0.45000;
 16.00          '    '    18.00000    12.83000;
  1.000         'BEAM'     0.08500     4.24300     0.08500     4.24300
                           0.00000     0.00100     0.31731;
  3.0           'STRT'     0.00001;
  3.0           '    '     0.58000;
  5.00          'QM11'     0.18000  -126.19186   100.00000;
  3.0           '    '     0.30000;
  5.00          'QM12'     0.18000   101.99857   100.00000;
  3.0           '    '     1.12500;
  3.0           'MIDU'     0.00001;
  3.0           '    '     1.12500;
  5.00          'QM1 '     0.18000  -101.99857   100.00000;
  3.0           '    '     0.30000;
  5.00          'QM14'     0.18000   126.19186   100.00000;
  3.0           'FOC'      0.58000;
-10.            '    '    -1.00000     2.00000     0.00000     0.00001;
-10.            '    '    -3.00000     4.00000     0.00000     0.00001;
-10.            '    '    -1.00000     1.00000    -1.00000     0.00001;
-10.            '    '    -3.00000     3.00000    -1.00000     0.00001;
SENTINEL
SENTINEL
```

Transfer matrix for the unit-magnification section

−1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13.8775	−1.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	−1.0000	0.0000	0.0000	0.0000
0.0000	0.0000	13.8775	−1.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	1.0000	0.000
0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table 5

Parameters of the matching section for differing modes of operation

Element	Length (m)	Aperture (cm)	Field in kG for match at section end	Field in kG for match at final image
Drift	0.5000			
Quadrupole	0.1800	100.0	−126.19186	−145.91833
Drift	0.3000			
Quadrupole	0.1800	100.0	101.99857	149.95639
Drift	0.3650			
Drift	0.3650			
Quadrupole	0.1800	100.0	−101.99857	−139.88550
Drift	0.3000			
Quadrupole	0.1800	100.0	126.19186	207.85578
Drift	0.5000			

Parameter	Match at section end	Match at final image
$\pm x$ (cm)	0.172	0.172
$\pm\theta$ (mr)	2.179	2.090
$\pm x$ (cm)	0.166	0.166
$\pm\phi$ (mr)	2.167	2.171
R_{11} (cm/cm)	0.2690	0.2490
R_{12} (cm/mr)	0.0403	0.0403
R_{16} (cm/%δp/p)	0.0000	0.0000
R_{21} (mr/cm)	−25.3611	−24.4568
R_{22} (mr/mr)	−0.0806	0.0596
R_{26} (mr/%δp/p)	−0.0001	−0.0001
R_{33} (cm/cm)	1.9065	1.9536
R_{34} (cm/mr)	0.5103	0.5115
R_{56} (cm/%δp/p)	−0.7527	−0.7527
β_x (mm/mr)	0.8259	0.8237
α_x	0.2992	0.0022
β_y (mm/mr)	0.7688	0.7635
α_y	−0.0505	−0.0112

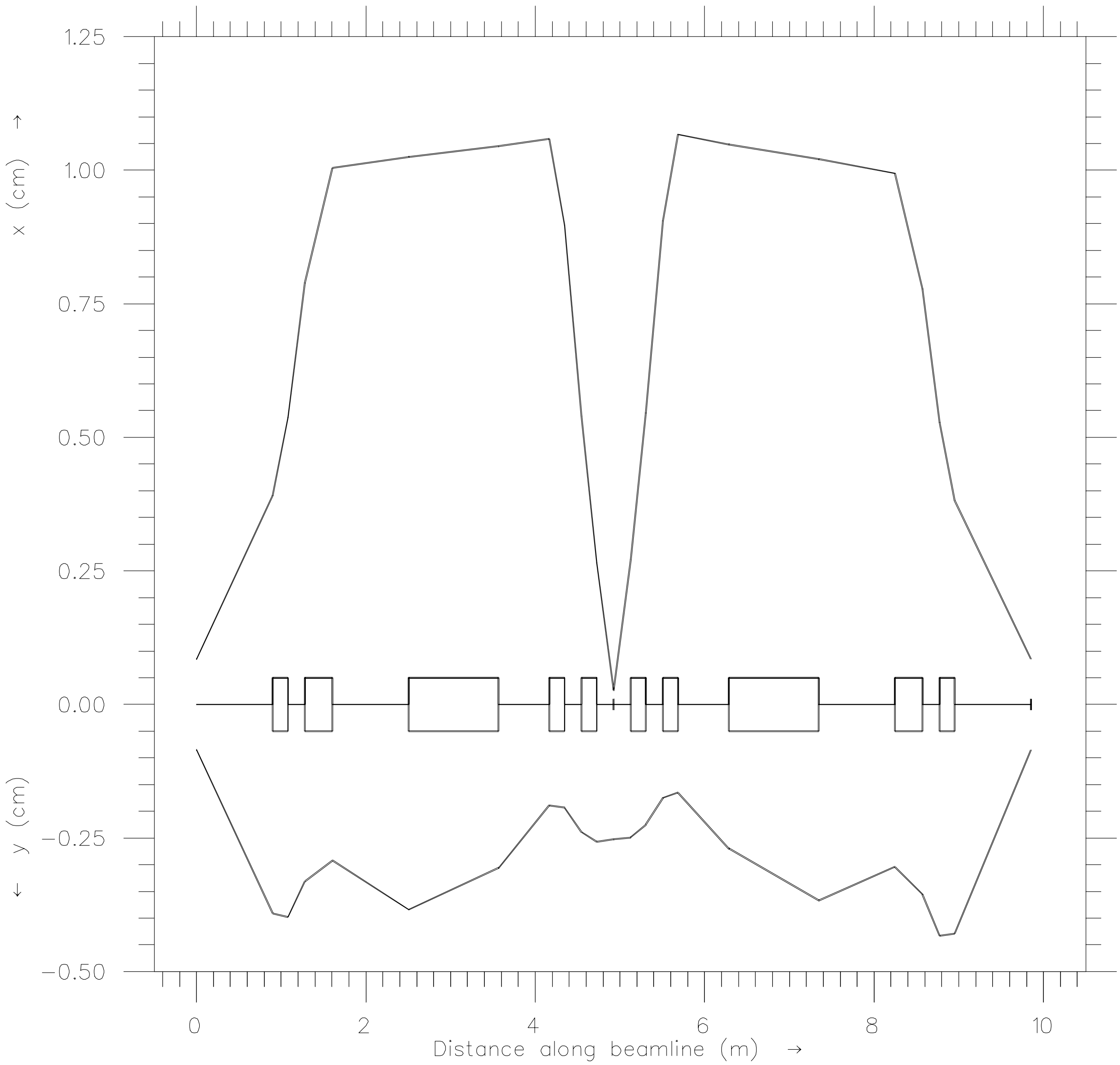

Fig. 1. The beam envelope throughout the first achromatic section of the transfer beamline.

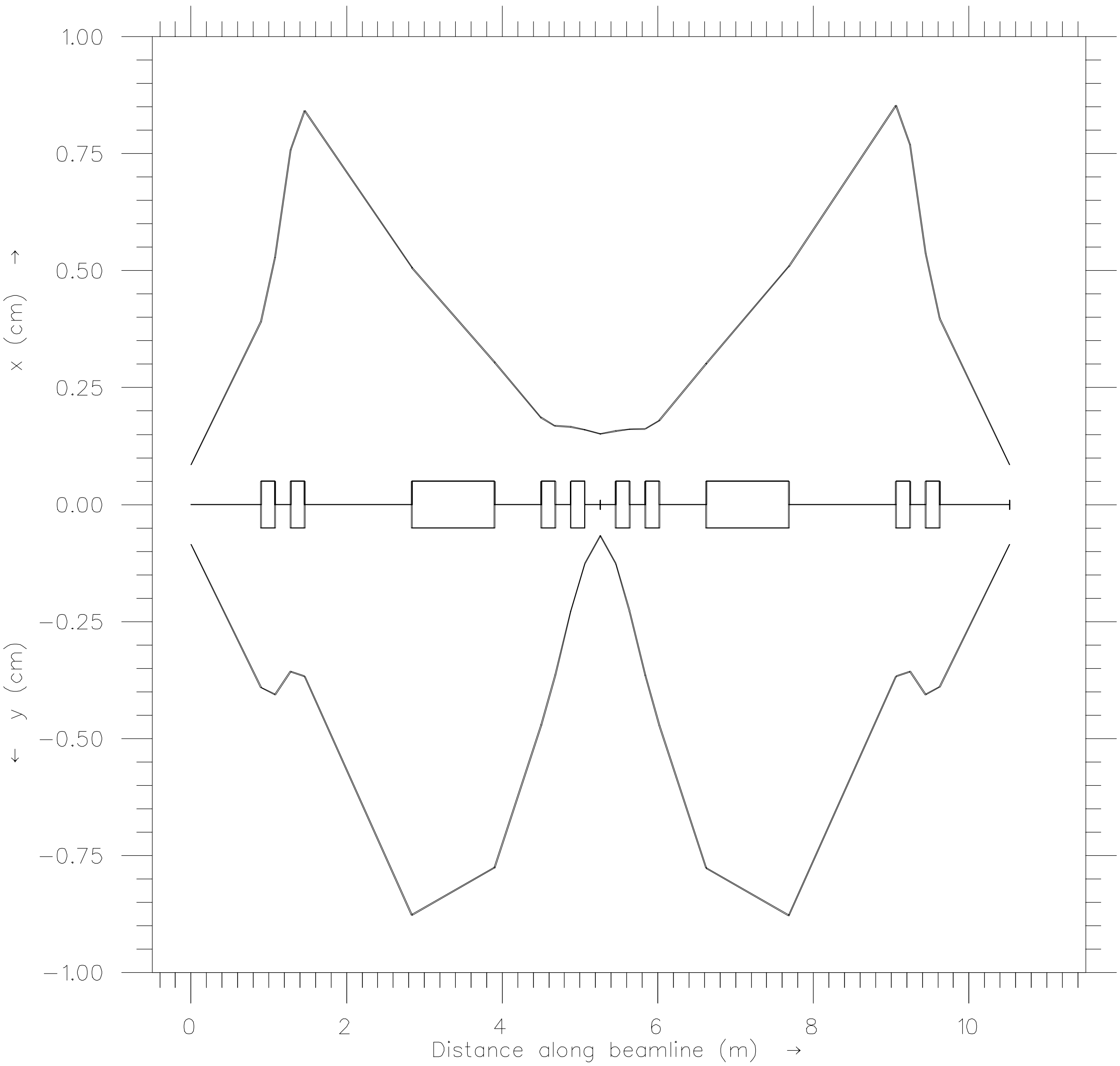

Fig. 2. The beam envelope throughout the second achromatic section of the transfer beamline.

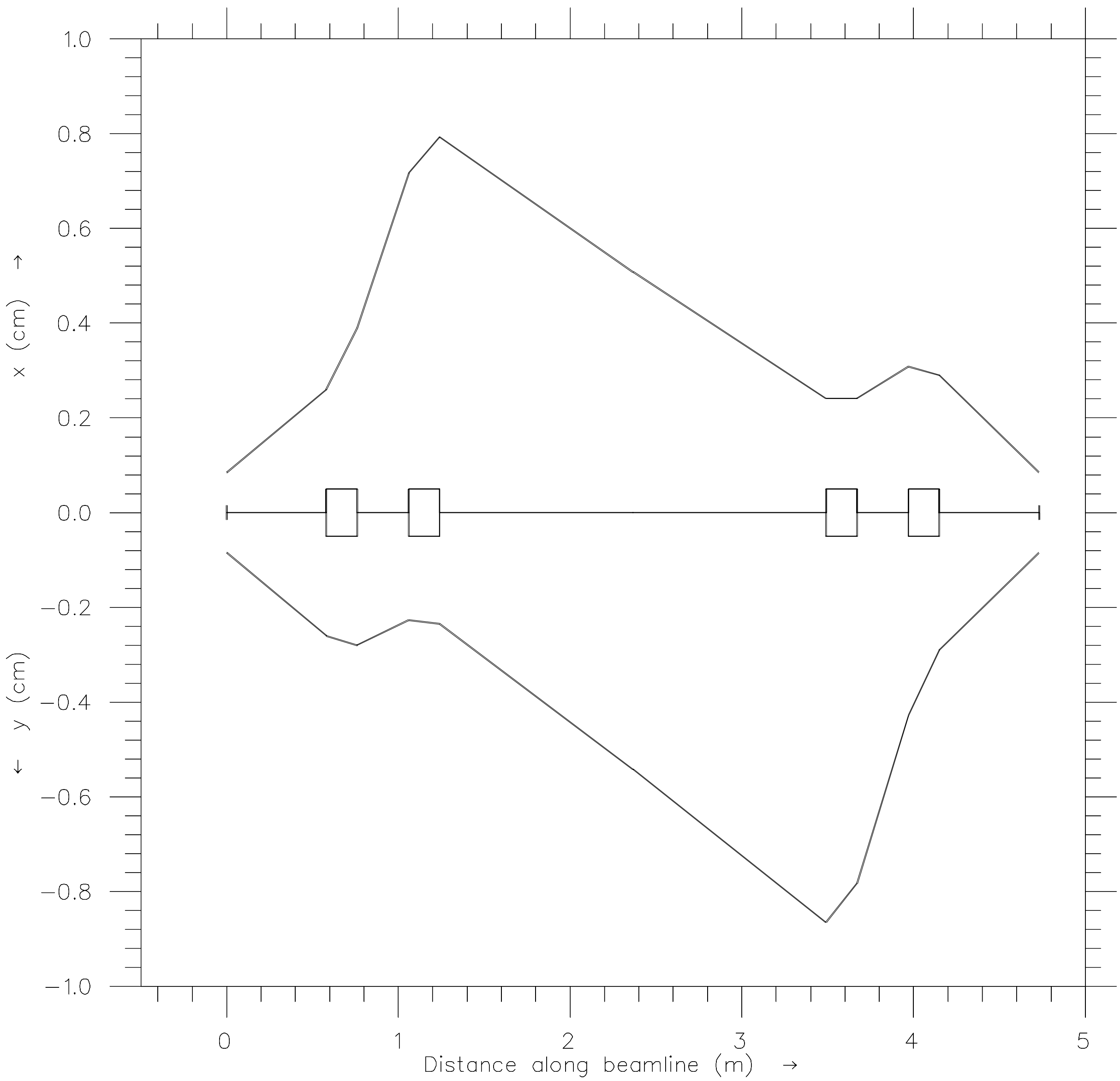

Fig. 3. The beam envelope throughout the unit-magnification second section of the transfer beamline.

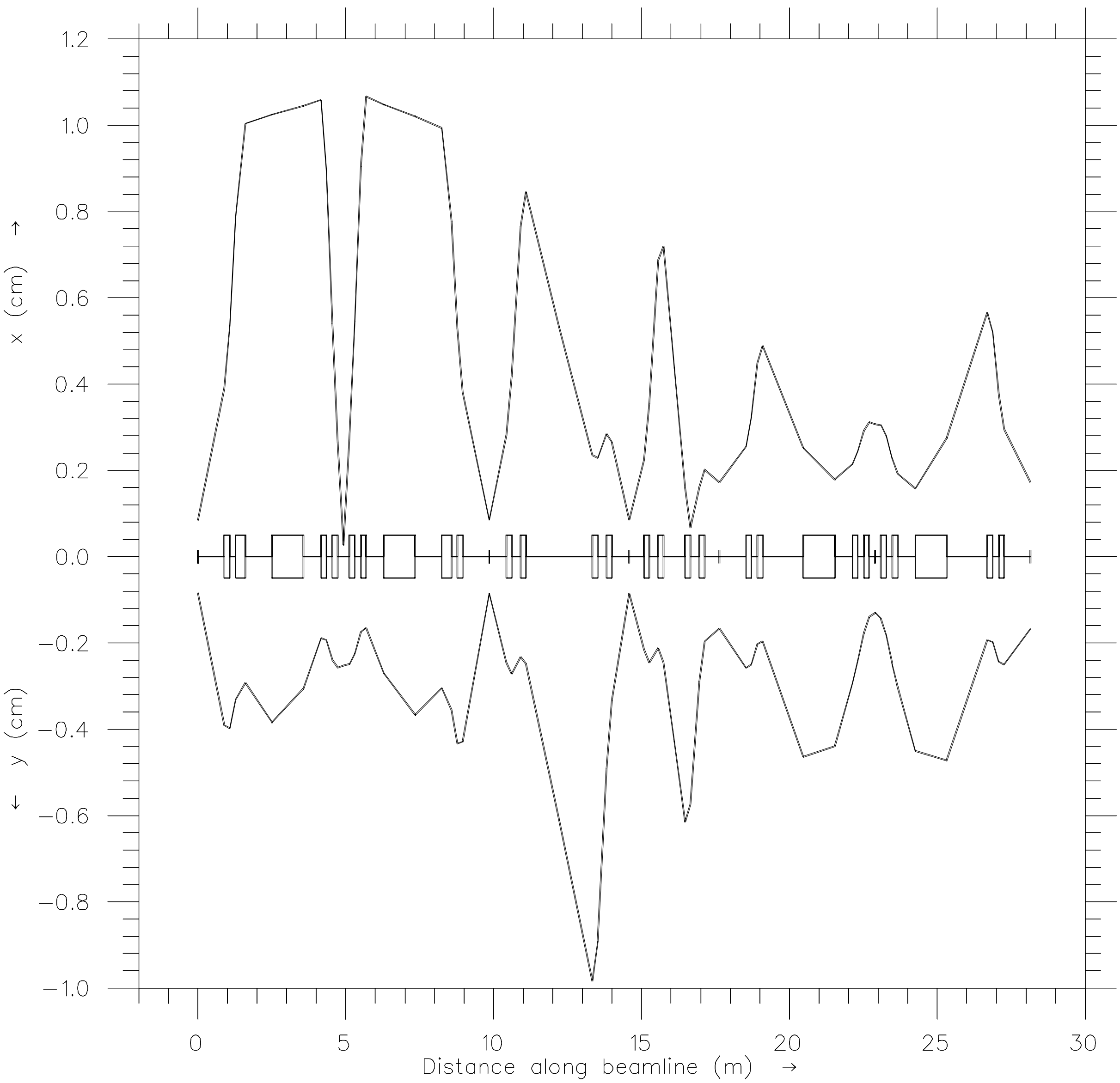

Fig. 4. The beam envelope of the complete beamline with matching at the end of the matching section.

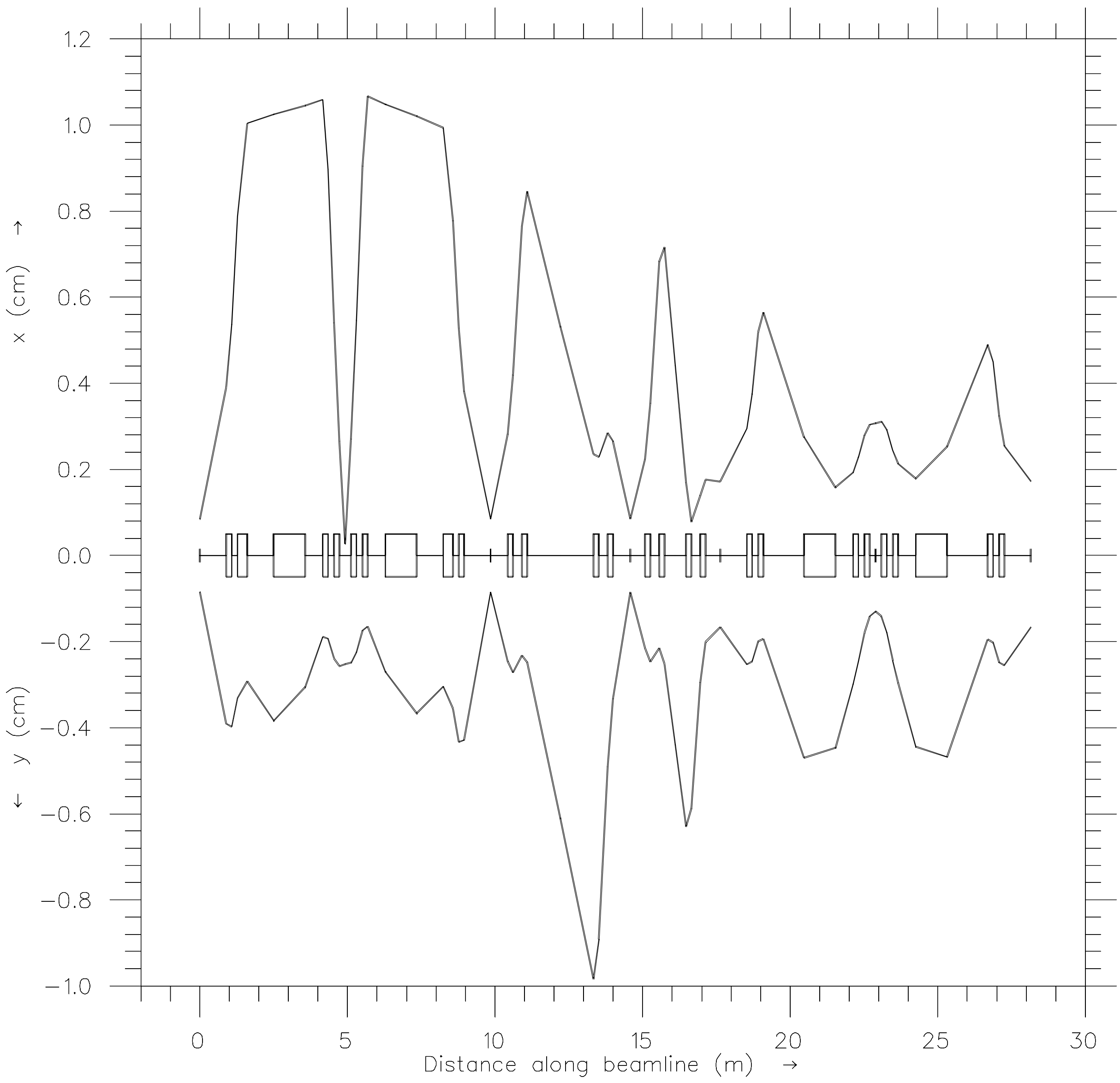

Fig. 5. The beam envelope of the complete beamline with matching at the final image point.

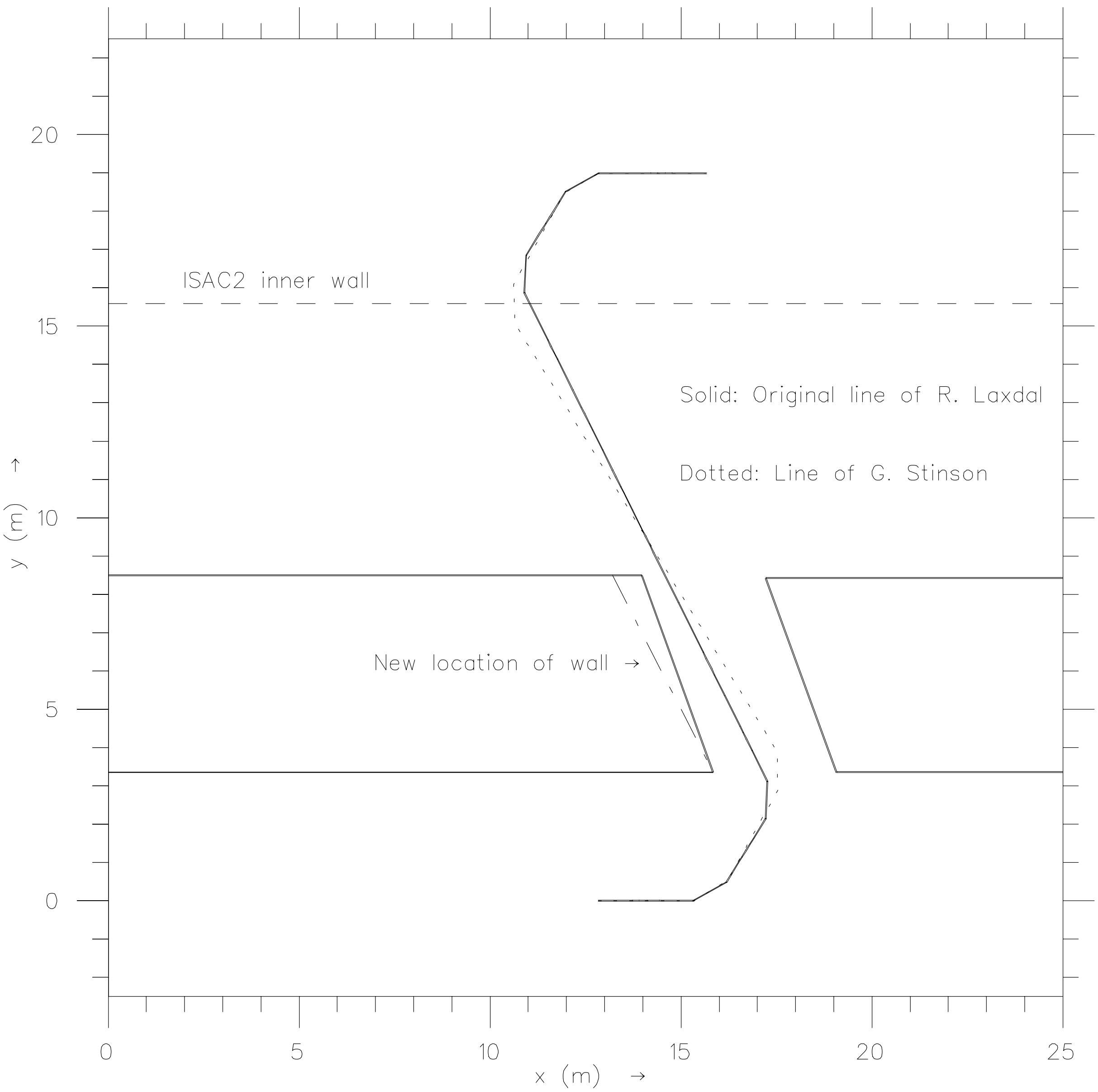

Fig. 6. A line drawing of the beamline of ref[1] and of this report.