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Subject A revision of the beam transport to the ISAC-II experimental area		

1. Introduction

Recently, two studies of possible beam-transport configurations to the experimental hall of ISAC-II have been reported[1,2]. In particular, these investigations considered what could be done with magnetic elements that are presently available at TRIUMF.

Of the designs suggested in ref[1] one, figure 8, was selected to serve as a reference design for the configuration of the experimental area[3]. Figure 8 from ref[1] is reproduced here as figure 1.

In this report we present a modification of this layout that is optically superior that of ref[1]. This new configuration was presented at a Science Division meeting by P. Bricault where it was accepted as the new reference design.

2. An overview of the proposed modification

Figure 2 shows the proposed modification of the beam transport to the ISAC-II experimental hall. The differences between the configuration shown in this figure and that shown as figure 1 are as follows. All distances are measured to/from the *effective* edges of the magnetic elements.

1. The distance from the object position to the entrance of the first quadrupole has been increased to 2.20 m from 1.88 m. To maintain symmetry, a similar increase has been made in the distance from the exit of the last quadrupole to the target locations on each of the $+30°+30°$ ($+60°$) and $+30°-30°$ ($0°$) beamlines.

2. The distance between the two doublets that lie between the two dipoles of these beamlines has been decreased from 3.76 m to 1.85 m.

3. One quadrupole has been added in the experimental area between the wall and the first dipole. The distance between the wall and the dipole was not changed. Again to maintain symmetry, one quadrupole has been added in a corresponding location downstream of the second dipole on each of these lines.

4. To provide for future multi-charge beam transport, a straight-through beamline has been designed. Unit sections are required for transport of such beams[4]. The configuration proposed here is a six-quadrupole unit section. Interference between this straight-through beamline and the $-18.5°$ beamline was avoided by increasing the distance from the object position to the entrance of the first quadrupole as indicated above.

As in ref[1] all calculations reported here are for beam emittances of

$$\epsilon_x = \epsilon_y = 2\pi \text{ mm-mrad}$$

and an initial phase space of

$$(x,\, \theta,\, y,\, \phi) = (0.1 \text{ cm},\ 2.0 \text{ mrad}, 0.1 \text{ cm},\ 2.0 \text{ mrad}).$$

Further, all calculations have been made at a proton equivalent momentum of 0.93 GeV/c (a proton equivalent energy of 0.3828 GeV). This corresponds to a beam with a magnetic rigidity of 3.587 T-m. All quadrupoles are of the L2 type because a large number of these are available. In the listings of TRANSPORT input, pole-tip fields of the quadrupoles are given in kG and their half-apertures taken as 100 cm.

Consequently, the gradients of the quadrupoles in T/m are simply found by dividing their pole-tip fields by 10.

For consistency with [1] we continue to use the (non-standard) convention that a positive bend is one to the right when looking in the beam direction.

3. Details of the design

In the following sections we present the design of each line in more detail. A listing of TRANSPORT input for each section is given, as are the beam parameters and elements of the overall transfer matrix. A plot of the half-widths of the beam envelope is also given for each line.

3.1 The +60° beamline

In this section of beamline each dipole bends 30° to the left (looking along the beam direction) for a net deflection of the beam of +60°. As mentioned above, this beamline differs from that shown in figure 8 of ref[1] by the addition of one quadrupole upstream of the first +30° dipole and another symmetrically placed downstream of the second +30° dipole. An input listing for the TRANSPORT program is given in table 1. Beam sizes and elements of the overall transfer matrix are given at the midpoint and target locations in table 5a. Figure 3 is a plot of the calculated half-widths of the beam in the horizontal (x) and vertical (y) planes. Note that the vertical half-width is plotted as a negative quantity.

From table 5a it is seen that at the midpoint of this beamline there is simultaneous point-to-point and waist-to-waist imaging in the horizontal plane. There the dispersion is $-2.3934\,\mathrm{cm}/\%$. In the vertical plane there is simultaneous parallel-to-point and waist-to-waist imaging. At the target location the overall transfer matrix is $+\boldsymbol{I}$ in the horizontal plane and $-\boldsymbol{I}$ in the vertical plane. Thus this beamline could be used for the transport of a multi-charged beam.

3.2 The +0° beamline

In this configuration the first dipole bends +30° to the left and the second bends −30° to the right for a net deflection of the beam of 0°. TRANSPORT input for this case is given in table 2. The calculated beam sizes at the midpoint and target location of this configuration are also given in table 5a. Figure 4 shows the half-widths of the beam profile throughout the beamline.

At the midplane there is a double waist. From table 5a it is seen that there is almost a double focus as well (R_{12} and R_{34} approximately zero). Here the beam is horizontally achromatic in space ($R_{16} = 0$) but dispersed in angle ($R_{26} \neq 0$). At the target location the beam spot is a doubly-achromatic double waist. There also is (almost) a double focus here.

3.3 The straight-through beamline

As its name implies both dipoles are turned off so that the beam passes undeflected through the first dipole. In order for a multi-charged beam to be directed to a target on this line it is necessary that the overall transfer matrix of the beamline be a unit section. We have designed a six-quadrupole unit section for this purpose.

The configuration of this section can be visualized as consisting of a L-Q-$2L$-Q-$2L$-Q-Lsection in which L represents a drift section of length L and Q represents a quadrupole doublet. The quadrupoles of the doublet are powered equally but are of opposite polarity. All doublets are identical. Thus, in principle, only two power supplies—one for the horizontally focusing quadrupoles and one for the vertically focusing quadrupoles—are required to power this section.

The first doublet of this section is composed of the two quadrupoles in the accelerator vault. The length L must be chosen to ensure that the second doublet is placed beyond the first dipole in a location that does not interfere with the −18.5° beamline (which requires that the first dipole be reversed in polarity). This is the reason for the choice of the length $L = 2.2\,\mathrm{m}$ because it allows 4.4 m between the effective edges of the first and second dipole.

A TRANSPORT listing for this unit section is given in table 3. Note that in this listing a second shorter unit section is appended to the six-quadrupole one. Table 5b lists the beam parameters at the first and second foci. Figure 5 shows the half-widths of the beam throughout the beamline.

3.4 The −18.5° beamline

This beamline uses the −18.5° port of the first dipole. The design is such that a double focus is produced at location F1 and a circular beam spot nominally 3 mm in diameter is produced at the TGT4 location. There the beam is spatially achromatic ($R_{16} = 0$) but is dispersed in angle.

Table 4 lists the TRANSPORT input for this beamline. Beam parameters and elements of the overall transfer matrix are given in table 5b. Figure 6 shows the half-widths of the beam throughout the beamline.

The beam cannot be made doubly achromatic at the TGT4 location because the initial beam has been assumed achromatic and only one dipole is involved. However, the beam transport could be modified to produce other beam spots at the target location—or at another target location—if required.

4. Discussion

This report has presented an updated design for beam transport to the ISAC-II experimental area. Two of the beamline sections—the +60° line and the straight-through line—are suitable for the transport of a multi-charged beam.

Initial installation of th +60° and +0° beamlines would require only ten power supplies. The three for the last quadrupoles of these lines could be switched from one line to the other.

It should be noted, however, that all ten of the supplies should be either bipolar or equipped with reversing switches.

References

1. G. M. Stinson, *On the use of existing magnets during the initial operation of the* ISAC-II *experimental area*, TRIUMF report TRI-DNA-03-1, March, 2003.
2. Z. H. Peng and R. E. Laxdal, *A Design Layout for ISAC-II Post-SCLinac Beamline (HEBT-II)*, TRIUMF report TRI-DN-01-xx, December, 2003.
3. P. Bricault, *Private communication*, TRIUMF, December, 2003.
4. R. E. Laxdal, *Private communication*, TRIUMF, December, 2003.

Table 1

TRANSPORT input for the +60° (+30°+30°) system

```
'ISAC-II AECL +30+30 deg - 10Q Unit to Double Waists - 2.2 m - 2004/01/13 '
 0
13.                     12.00000;
16.00      G/2           5.00000     2.50000;
16.00      K1            7.00000     0.45000;
16.00      K2            8.00000     2.80000;
 1.000000  BEAM          0.10000     2.00000     0.10000     2.00000
                         0.00000     0.10000     0.93000;
 3.0                     2.20000;
 5.00      Q1            0.32500   102.50866   100.00000;
 3.0                     0.30000;
 5.00      Q2            0.32500   114.48215   100.00000;
 3.0                     0.32000;
 3.0       WALL          0.78740;
 3.0                     0.32000;
 5.00      Q3            0.32500   −47.09907   100.00000;
 3.0       B1IN          0.67500;
20.0                   180.00000;
 2.0                     0.00000;
 4.000     B1            1.04720    15.51050     0.00000;
 2.0                     0.00000;
20.0                  −180.00000;
 3.0       B1EX          0.00001;
 3.0                     1.80000;
 5.00      Q4            0.32500   −96.87130   100.00000;
 3.0                     0.30000;
 5.00      Q5            0.32500    76.51190   100.00000;
 3.0       MID           0.92500;
 3.0                     0.92500;
 5.00      Q6            0.32500    76.51190   100.00000;
 3.0                     0.32000;
 5.00      Q7            0.32500   −96.87130   100.00000;
 3.0       B2IN          1.80000;
20.0                   180.00000;
 2.0                     0.00000;
 4.000     B2            1.04720    15.51050     0.00000;
 2.0                     0.00000;
20.0                  −180.00000;
 3.0       B2EX          0.00001;
 3.0                     0.67500;
 5.00      Q8            0.32500   −47.09907   100.00000;
 3.0                     0.32000;
 3.0                     0.78740;
 3.0                     0.32000;
 5.00      Q9            0.32500   114.48215   100.00000;
 3.0                     0.30000;
 5.00      Q10           0.32500   102.50866   100.00000;
 3.0       F2            2.20000;
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Table 2

TRANSPORT input for the +0° (+30°−30°) system

'ISAC-II AECL +30-30 deg - 10Q to Double Achromatic Waists - 2.2 m - 2004/01/13 '					
0					
13.		12.00000;			
16.00	G/2	5.00000	2.50000;		
16.00	K1	7.00000	0.45000;		
16.00	K2	8.00000	2.80000;		
1.000000	BEAM	0.10000	2.00000	0.10000	2.00000
		0.00000	0.10000	0.93000;	
3.0		2.20000;			
5.00	Q1	0.32500	102.50866	100.00000;	
3.0		0.30000;			
5.00	Q2	0.32500	−125.64016	100.00000;	
3.0		0.32000;			
3.0	WALL	0.78740;			
3.0		0.32000;			
5.00	Q3	0.32500	98.92205	100.00000;	
3.0	B1IN	0.67500;			
20.0		180.00000;			
2.0		0.00000;			
4.000	B1	1.04720	15.51050	0.00000;	
2.0		0.00000;			
20.0		−180.00000;			
3.0	B1EX	0.00001;			
3.0		1.80000;			
5.00	Q4	0.32500	129.25079	100.00000;	
3.0		0.30000;			
5.00	Q5	0.32500	−85.01575	100.00000;	
3.0	MID	0.92500;			
3.0		0.92500;			
5.00	Q6	0.32500	−85.01575	100.00000;	
3.0		0.32000;			
5.00	Q7	0.32500	129.25079	100.00000;	
3.0	B2IN	1.80000;			
−20.0		180.00000;			
2.0		0.00000;			
4.000	B2	1.04720	15.51050	0.00000;	
2.0		0.00000;			
−20.0		−180.00000;			
3.0	B2EX	0.00001;			
3.0		0.67500;			
5.00	Q8	0.32500	98.92205	100.00000;	
3.0		0.32000;			
3.0		0.78740;			
3.0		0.32000;			
5.00	Q9	0.32500	−125.64016	100.00000;	
3.0		0.30000;			
5.00	Q10	0.32500	102.50866	100.00000;	
3.0	F2	2.20000;			
SENTINEL					
SENTINEL					

Table 3

TRANSPORT input for the straight-through (+0°+0°) system

'ISAC-II AECL +30-30 deg - 10Q to Double Achromatic Waists - 2.2 m - 2004/01/13 '

0					
13.		12.00000;			
16.00	G/2	5.00000	2.50000;		
16.00	K1	7.00000	0.45000;		
16.00	K2	8.00000	2.80000;		
1.000000	BEAM	0.10000	2.00000	0.10000	2.00000
		0.00000	0.10000	0.93000;	
3.0		2.20000;			
5.00	Q1	0.32500	107.36949	100.00000;	
3.0		0.30000;			
5.00	Q2	0.32500	−107.36949	100.00000;	
3.0	MID1	2.20000;			
3.0		2.20000;			
5.00	Q3	0.32500	107.36949	100.00000;	
3.0		0.30000;			
5.00	Q4	0.32500	−107.36949	100.00000;	
3.0	MID2	2.20000;			
3.0		2.20000;			
5.00	Q5	0.32500	107.36949	100.00000;	
3.0		0.30000;			
5.00	Q6	0.32500	−107.36949	100.00000;	
3.0	F1	2.20000;			
−10.0		−1.00000	1.00000	1.00000	0.00100;
−10.0		−1.00000	2.00000	0.00000	0.00100;
−10.0		−2.00000	1.00000	0.00000	0.00100;
−10.0		−2.00000	2.00000	1.00000	0.00100;
−10.0		−3.00000	3.00000	1.00000	0.00100;
−10.0		−3.00000	4.00000	0.00000	0.00100;
−10.0		−4.00000	3.00000	0.00000	0.00100;
3.0		1.00000;			
5.00	Q3	0.32500	126.88231	100.00000;	
3.0		0.30000;			
5.00	Q4	0.32500	−126.88231	100.00000;	
3.0	MID3	1.00000;			
3.0		1.00000;			
5.00	Q5	0.32500	126.88231	100.00000;	
3.0		0.30000;			
5.00	Q6	0.32500	−126.88231	100.00000;	
3.0	F2	1.00000;			
−10.0		−1.00000	1.00000	1.00000	0.00100;
−10.0		−1.00000	2.00000	0.00000	0.00100;
−10.0		−2.00000	1.00000	0.00000	0.00100;
−10.0		−2.00000	2.00000	1.00000	0.00100;
−10.0		−3.00000	3.00000	1.00000	0.00100;
−10.0		−3.00000	4.00000	0.00000	0.00100;
−10.0		−4.00000	3.00000	0.00000	0.00100;
SENTINEL					
SENTINEL					

Table 4

TRANSPORT input for the $-18.5°$ system

'ISAC-II AECL – -18.5 deg – 3 mm diameter and $R_{16} = 0 at F2 - 04/01/14$'					
0					
13.		12.00000;			
16.00	G/2	5.00000	2.50000;		
16.00	K1	7.00000	0.45000;		
16.00	K2	8.00000	2.80000;		
1.000000	BEAM	0.10000	2.00000	0.10000	2.00000
		0.00000	0.10000	0.93000;	
3.0		2.2000;			
5.00	Q1	0.32500	159.94370	100.00000;	
3.0		0.30000;			
5.00	Q2	0.32500	−137.21811	100.00000;	
3.0		0.32000;			
3.0	WALL	0.78740;			
3.0		0.32000;			
5.00	Q3	0.32500	94.73307	100.00000;	
3.0		0.30000;			
3.0	B1IN	0.37500;			
−20.0		180.00000;			
2.0		0.00000;			
4.000	B1	1.06262	9.42604	0.00000;	
2.0		0.00000;			
−20.0		−180.00000;			
3.0	B1EX	0.00001;			
3.0		1.00000;			
3.0		1.80000;			
3.0	F1	1.80000;			
−10.0		−1.00000	2.00000	0.00000	0.00100;
−10.0		−3.00000	4.00000	0.00000	0.00100;
3.0		1.00000;			
3.0		1.00000;			
3.0		1.00000;			
5.00	Q4	0.32500	80.34370	100.00000;	
3.0		0.30000;			
5.00	Q5	0.32500	−141.36654	100.00000;	
3.0		0.30000;			
5.00	Q6	0.32500	88.60354	100.00000;	
3.0		1.00000;			
3.0		1.00000;			
3.0	F2	1.00000;			
−10.0		−1.00000	6.00000	0.00000	0.00100;
−10.0		1.00000	1.00000	0.10000	0.00100;
−10.0		3.00000	3.00000	0.10000	0.00100;
SENTINEL					
SENTINEL					

Table 5a

Predicted beam sizes and overall transfer matrices at the experimental locations on the +60° and 0° beamlines — Doublet in vault, one quadrupole added

Parameter	+60° leg		0° leg	
	at MID	at TGT1	at MID	at TGT2
$\pm x$ (cm)	0.314	0.100	0.048	0.100
$\pm\theta$ (mr)	0.984	2.000	4.230	2.000
$\pm y$ (cm)	0.201	0.100	1.147	0.101
$\pm\phi$ (mr)	0.994	2.000	0.174	1.986
R_{11} (cm/cm)	−2.0326	1.0000	0.4743	0.9810
R_{12} (cm/mr)	−0.0004	0.0004	−0.0023	−0.0097
R_{16} (cm/%)	−2.3934	0.0000	0.0000	0.0000
R_{21} (mr/cm)	−0.0001	0.0003	4.0936	3.8834
R_{22} (mr/mr)	−0.4920	1.0000	2.0882	0.9810
R_{26} (mr/%)	0.0001	−0.0003	5.3372	0.0000
R_{33} (cm/cm)	0.0000	−1.0000	−7.2269	−0.1985
R_{34} (cm/mr)	−0.1006	−0.0001	−0.4452	0.0494
R_{43} (mr/cm)	9.9413	0.0000	1.3461	−19.4567
R_{44} (mr/mr)	0.0006	−1.0000	−0.0555	−0.1985

Table 5b

Predicted beam sizes and overall transfer matrices at the experimental locations on straight-through and −18.5° beamline — Doublet in vault, one quadrupole added

Parameter	Straight-through leg		−18.5° leg	
	at F1	at F2	at F1	at TGT4
$\pm x$ (cm)	0.100	0.100	0.261	0.150
$\pm\theta$ (mr)	2.000	2.000	1.369	1.875
$\pm y$ (cm)	0.100	0.100	0.277	0.150
$\pm\phi$ (mr)	2.000	2.000	0.965	1.476
R_{11} (cm/cm)	1.0000	−1.0000	2.3586	0.5853
R_{12} (cm/mr)	0.0000	0.0000	0.0000	0.0690
R_{16} (cm/%)	0.0000	0.0000	1.1220	−0.0001
R_{21} (mr/cm)	0.0000	0.0000	10.2648	−16.6656
R_{22} (mr/mr)	1.0000	−1.0000	0.4240	−0.2576
R_{26} (mr/%)	0.0000	0.0000	3.1730	−6.8890
R_{33} (cm/cm)	1.0000	−1.0000	−2.7702	−0.5072
R_{34} (cm/mr)	0.0000	0.0000	0.0000	−0.0706
R_{43} (mr/cm)	0.0000	0.0000	−6.4032	14.6866
R_{44} (mr/mr)	1.0000	−1.0000	−0.3610	0.0727

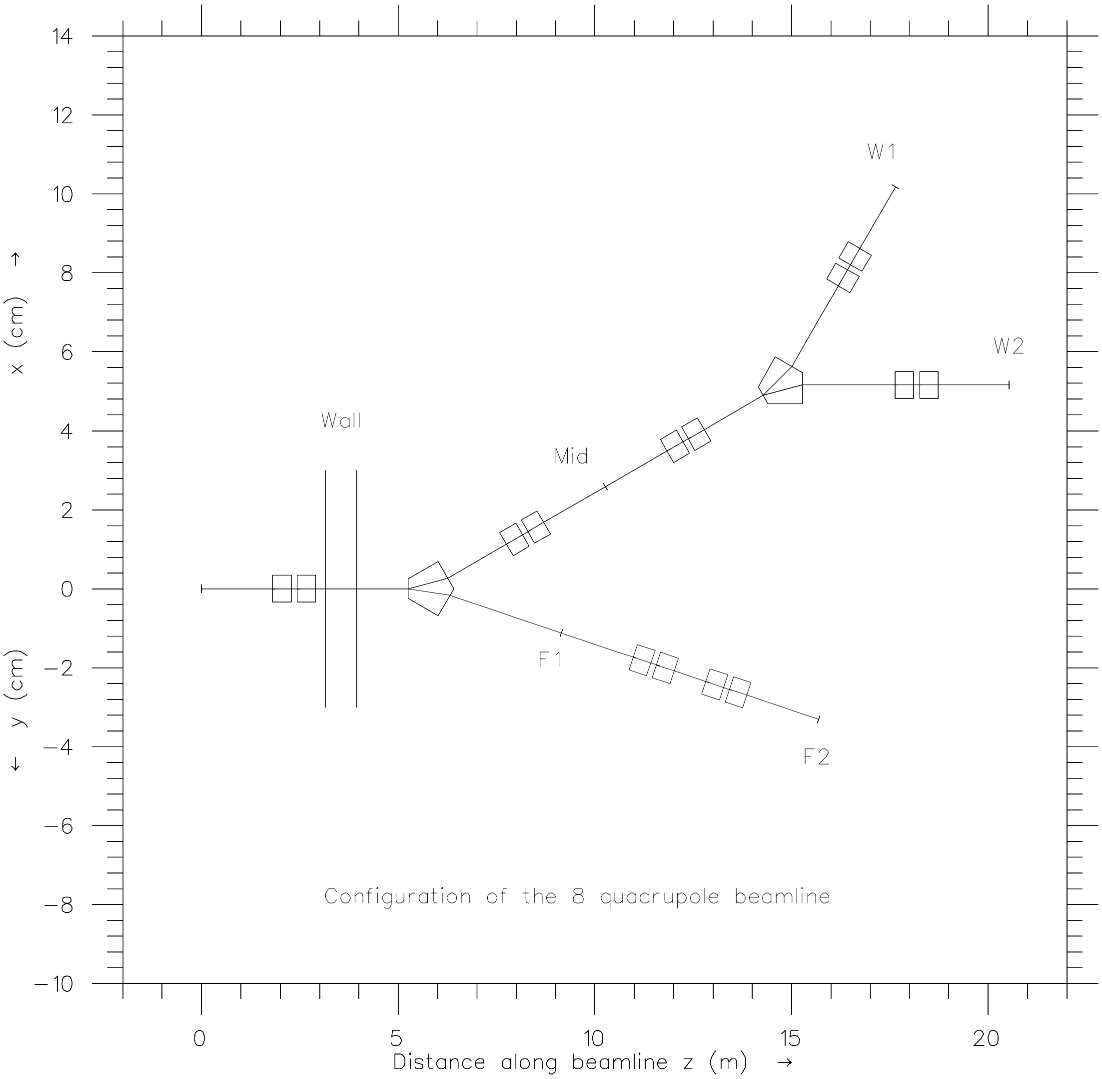

Fig. 1. The beamline configuration selected from reference 1.

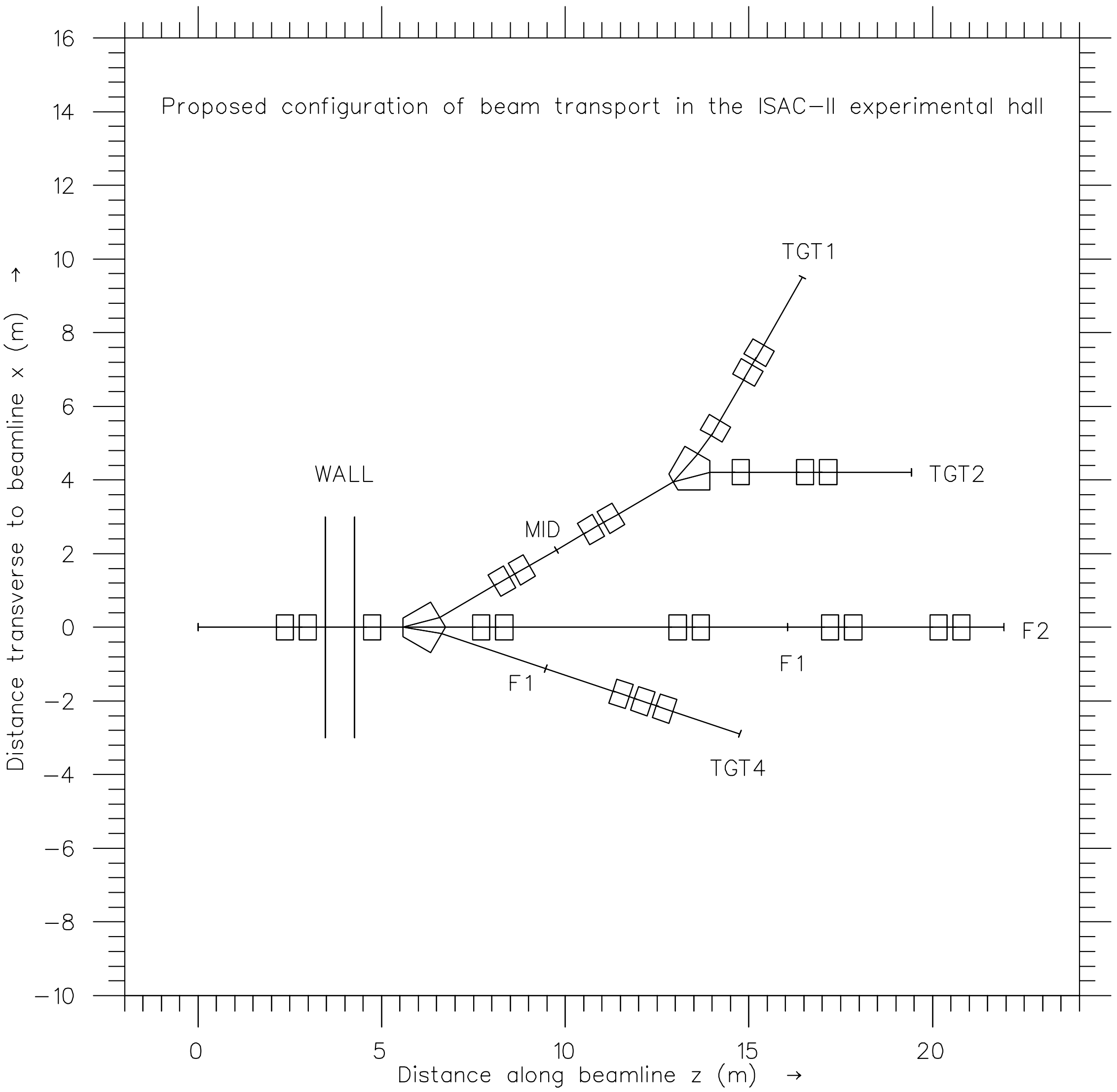

Fig. 2. The modification of the beam-transport configuration proposed in this report.

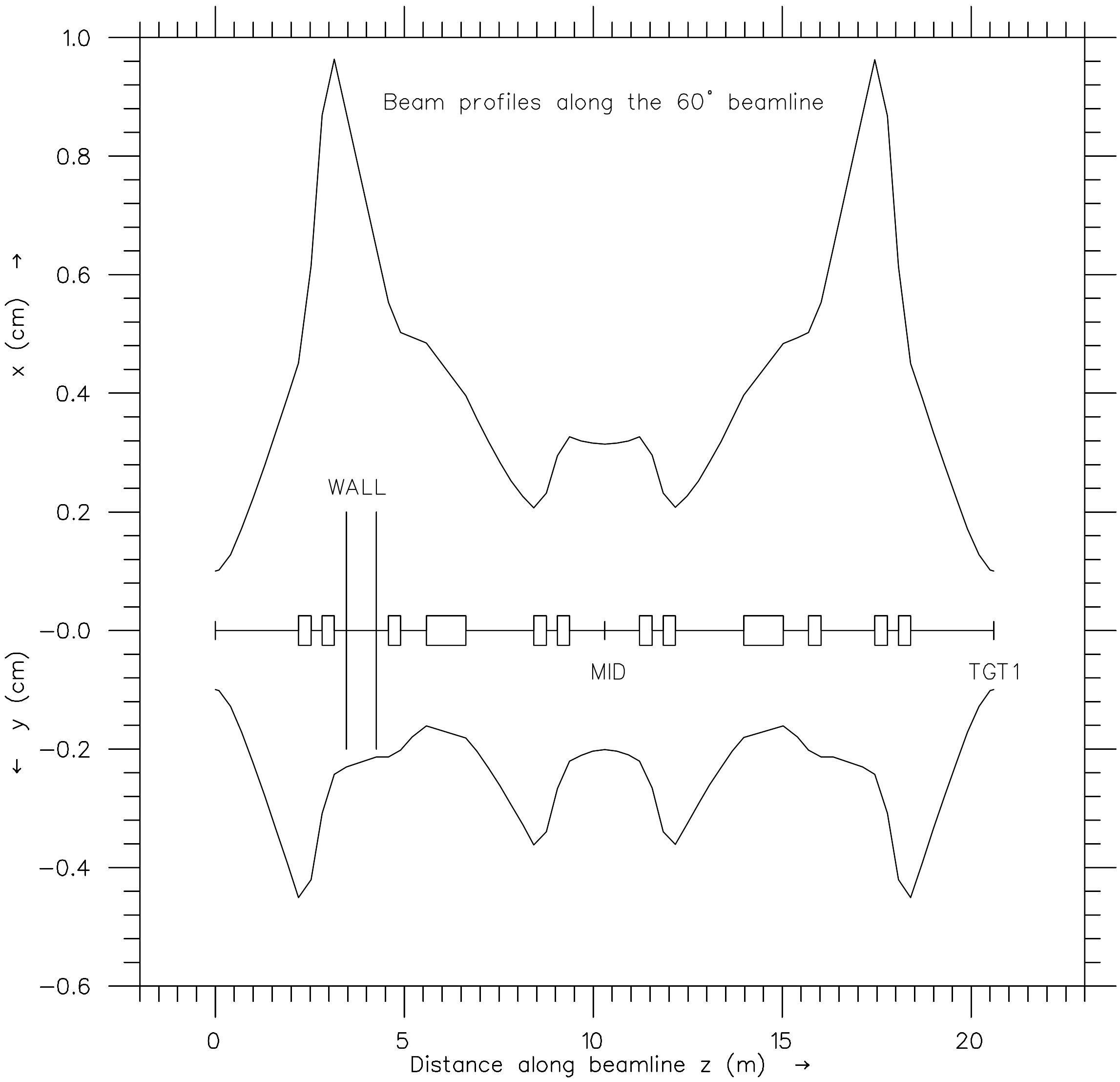

Fig. 3. Beam envelopes on the +60° beamline — Doublet in vault and added quadrupoles.

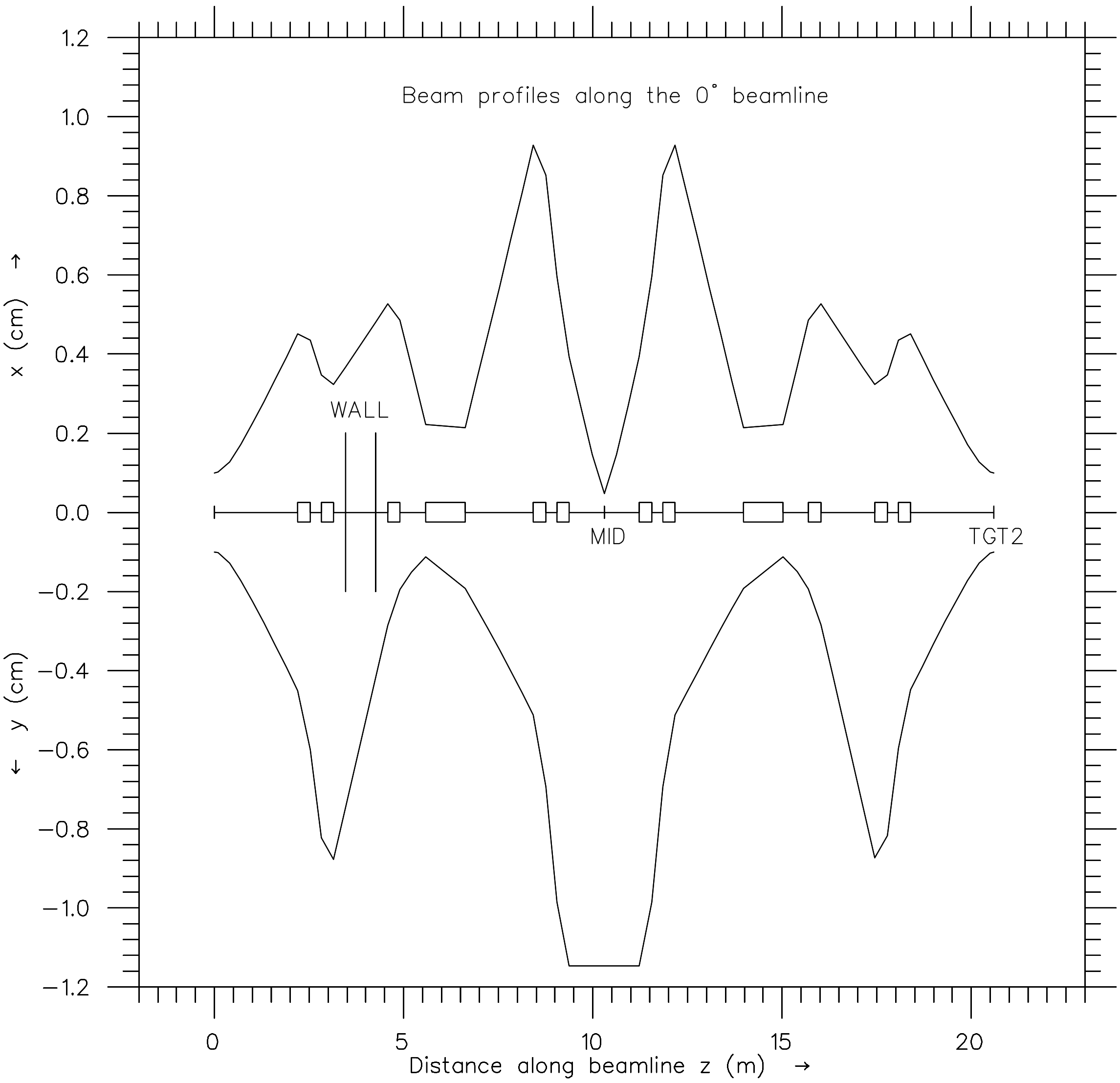

Fig. 4. Beam envelopes on the +0° beamline — Doublet in vault and added quadrupoles.

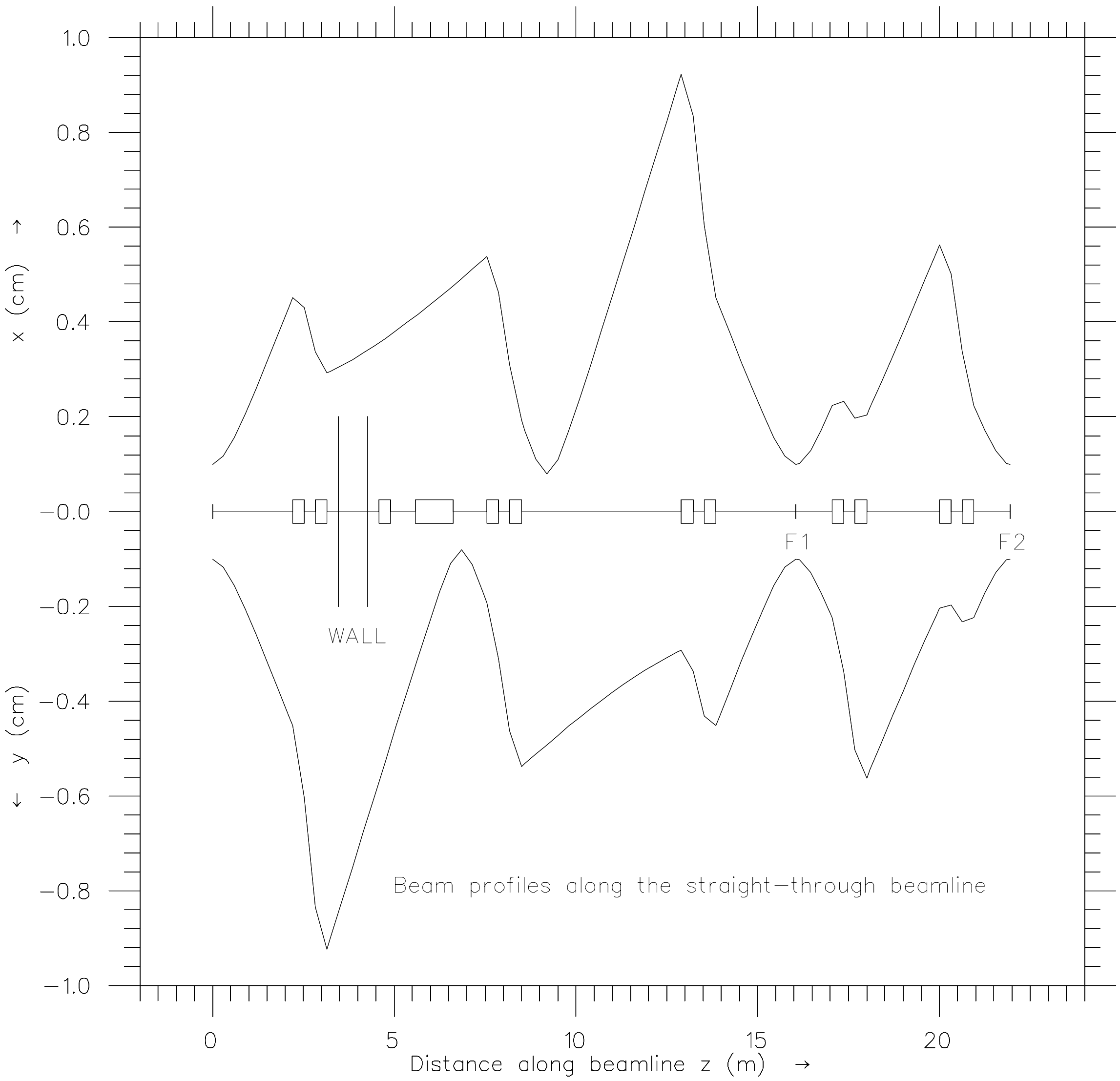

Fig. 5. Beam envelopes on the straight-through beamline — Doublet in vault and added quadrupoles.

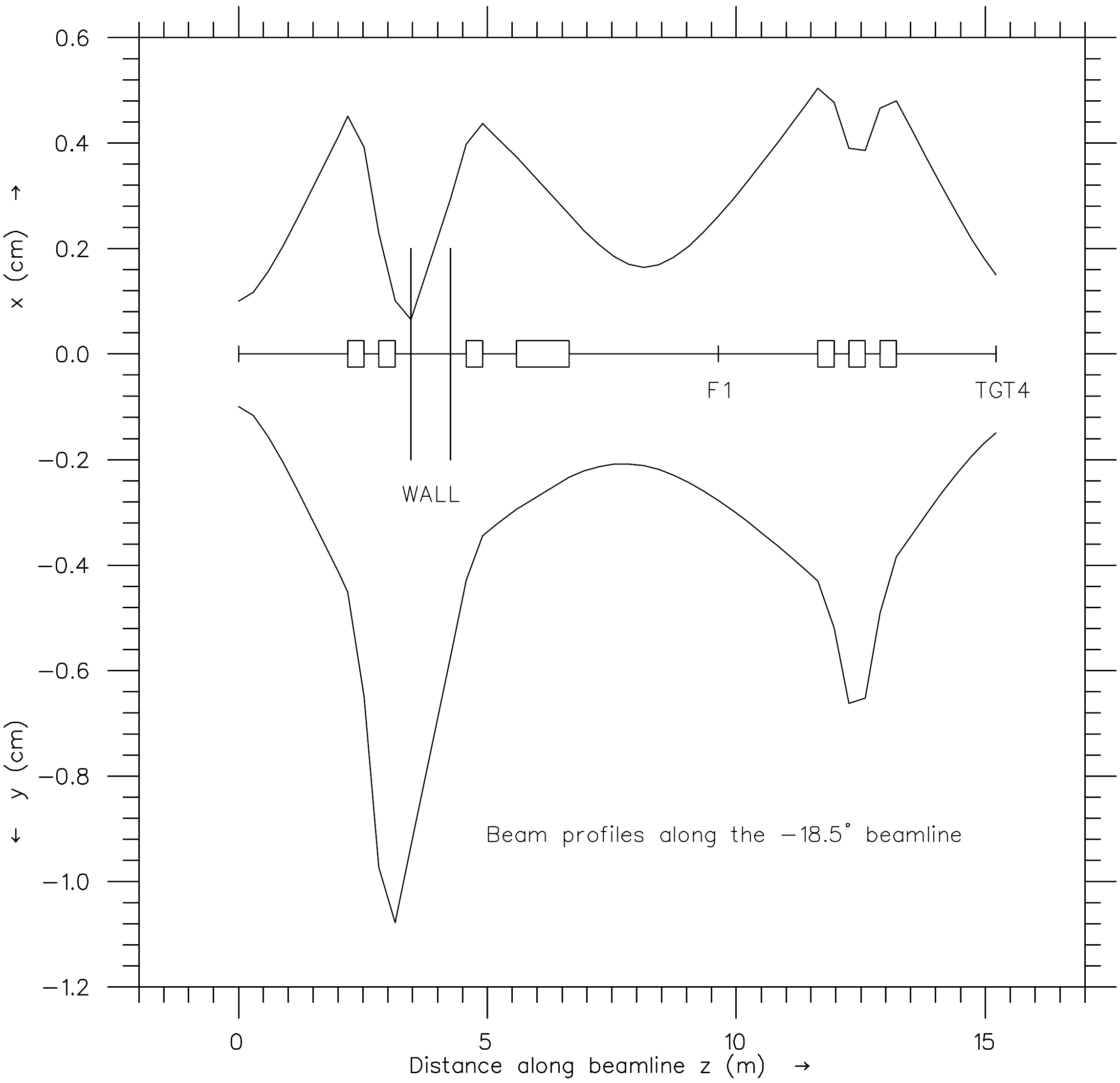

Fig. 6. Beam envelopes on the $-18.5°$ beamline — Doublet in vault and added quadrupoles.