TRIUMF	UNIVERSITY OF ALBERTA EDMONTON, ALBERTA	
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Author GM Stinson	*Page* 1 *of* 18

Subject An additional beamline in the ISAC-II experimental area

1. Introduction

Recent notes [1,2] have detailed a proposed system for beam transport to the experimental hall of ISAC-II. Since these reports were issued experimenters have requested that an additional beamline be implemented in the area. This report presents a study that addresses that request.

2. Background

The transport system that was proposed initially, figure 2 of ref [1], is reproduced here as figure 1. Experimenters asked if it were possible to add another beamline parallel to, and to the west of, that leading to the location labeled TGT1.

As reported in ref [1], from its object point in the accelerator vault to the target location TGT1 was designed to produce a transfer matrix of $+\boldsymbol{I}$ in the horizontal plane and of $-\boldsymbol{I}$ in the vertical plane. Assuming that these properties were to be maintained, the first thought was to simply add a $+\boldsymbol{I}$ section and take off another beamline from that section. This is illustrated in figure 2 which shows an six-quadrupole $+\boldsymbol{I}$ section added downstream of the point labeled MID in figure 1. This would maintain the operation of the beamlines to targets TGT1 and TGT2 as described in ref [1] and provide a new beamline to a new target that is labeled TGT5 in figure 2. This figure is drawn such that an experimental setup could be moved (on rails, for example) from the target position TGT1 to position TGT5.

There are several drawbacks to such a scheme, one of which is that the overall transfer matrix of the beamline to TGT5 is not a $\pm\boldsymbol{I}$ section. More importantly, however, is that this scheme would use up a lot of valuable space in the experimental area. Further, it would seriously compromise the space available downstream of the target for experimental apparatus. In fact, at least one proposed experiment could not be fitted into the experimental hall!

Consequently, this approach was abandoned and the scheme shown in figure 3 is now proposed. In this figure the outline box is meant to represent the (approximate) locations of the interior walls of the experimental hall. The north wall lies at an x-coordinate of approximately 27 m.

3. The proposed new beamline

3.1 Overview of the new beamline

Figure 3 shows that the configuration of ref [1] is maintained and beam delivery to each of the targets TGT1, TGT2, TGT3, and TGT1 is as described therein. A four-quadrupole unit section has been added downstream of TGT1 to produce a new target location at the point labeled TGT1A to allow experimental apparatus to be moved back and forth between TGT1A and TGT5.

For beam delivery to TGT5 the $\pm 30°$ dipole is turned off and beam exits from its 0° port. At a point downstream of this dipole, indicated in figure 3 by the hash mark between the beamlines to TGT1 and TGT2, the upstream transport system is mirrored to produce the beamline shown that leads to the (new) TGT5. Thus, in effect, this beamline is a slightly altered version of that leading to TGT1.

Because of the symmetry of this new beamline, its overall transfer matrix is $+\boldsymbol{I}$ in each of the horizontal and vertical planes. The beamline is also doubly achromatic ($R_{16} = R_{26} = 0$).

3.2 Detailed optics of the new beamline

Table 1 lists the TRANSPORT input for beam delivery to TGT5. Beam and transfer matrix parameters at the midpoint of the line and at the TGT5 location are given in table 2.

Figure 4 shows the half-widths of the beam envelopes in the horizontal and vertical planes.

4. Production of a 1 mm diameter beam spot

As in ref[1,2], calculations in this report were made for emittances of $\epsilon_x = \epsilon_y = 2\pi$ mm-mr and a nominal beam spot 2 mm in diameter at the TGT1, TGT2, TGT3, and TGT5 locations. Thus all beam profiles in ref[1,2] and this report are for those conditions. Further, it was assumed that all quadrupoles would be of the L2 variety with an effective length of 0.325 m, a full aperture of 52 mm, and a maximum gradient of 28.85 T/m.

Subsequent to the completion of these designs the author was informed that the design of the experimental apparatus was predicated on a beam spot at their target that was 1 mm in diameter[3]. A tune of the four-quadrupole matching section is possible to produce this beam size. In particular, to produce a beam 1 mm in diameter it is necessary to run these quadrupoles at gradients of −28.478 T/m, 19.758 T/m, −19.192 T/m, and 26.577 T/m. For comparison, the corresponding gradients of required to produce a 2 mm diameter spot are −19.021 T/m, 16.528 T/m, −18.479 T/m, and 22.795 T/m.

Thus the production of a beam spot 1 mm in diameter is just within the capabilities of the type L2 quadrupoles. However, for a given emittance, a reduction of the size of the beam size leads to an increase in its divergence and a consequent increase in the beam envelope throughout the transport system.

We consider the effect of this on the beam optics in the section below.

4.1 Effects on beamline optics of producing a 1 mm beam spot

4.1.1 Beam profiles for delivery to the TGT1 location

Because the section of beamline from the WST3 location to the TGT1 location is a unit section, the only retuning that is necessary is to change the matching section from one that produces a 2 mm diameter beam spot to one that produces a 1 mm diameter one. The necessary alterations have been indicated above.

Two TRANSPORT runs were made from the exit of the medium β cavities to the target locations TGT1 and TGT1A indicated in figure 3. For one run the matching section was tuned to produce a beam spot 1 mm in diameter and for the other it was tuned to produce a beam spot 2 mm beam in diameter. The results of these calculations are shown in Figure 5 in which the envelopes for the 1 mm diameter beam spot are plotted as solid lines and those for the 2 mm diameter beam spot are plotted as dotted lines. The effects of the two tunes on the beam envelopes are clear; the beam sizes for 1 mm beam tune at intermediate points in the beamline are roughly twice those for a 2 mm beam tune.

For a 1 mm beam tune, the maximum horizontal and vertical beam sizes between the accelerator exit and the WST3 location, and in the unit section between the TGT1 and TGT1A locations, are approximately ±15 mm. Assuming a clear aperture of ±25 mm, this implies that the beam occupies a maximum of 60% of the beam pipe. We would prefer that this number be 50% or lower (as it is for the 2 mm tune) but 60% is not unreasonable.

However, the horizontal beam size for the 1 mm tune is approximately ±19 mm in the last quadrupole in the accelerator vault and in the second quadrupole upstream of the TGT1 location. This indicates that the beam occupies 76% of the beam tube, a number that we regard as too high. We ran this tune through the computer program REVMOC[4] to see if any beam spill was predicted if the diameter of the beam pipe was 50.8 mm. Assuming no scattering material the beam path, a loss of 1 or 2 particles from an initial beam of 15,000 particles was predicted at the downstream quadrupole. Although this corresponds to a ≈0.01% loss (which is at the limit of the accuracy of the program) this should be taken as an indication that some beam spill might occur at that point.

4.1.2 Beam profiles for delivery to the TGT3 location

Because this beamline is also a unit section only the four matching quadrupoles need adjustment in order to provide a beam spot 1 mm in diameter at the TGT3 location. Figure 6 shows the beam envelopes along the beamline for each of the 1 mm and 2 mm tunes.

The comments of §4.1.1 regarding beam sizes between the accelerator exit and the WST3 location equally apply to this beamline. There are also two places along the beamline where the horizontal or vertical beam size approaches ± 19 mm. The first is occurs in the last quadrupole in the accelerator vault and the second occurs in the second quadrupole upstream of the TGT3 location. Again, we consider this too high. However, no REVMOC run was made to investigate the possibility of beam spill.

4.1.3 Beam profiles for delivery to the TGT5 location

This too is a unit-section beamline. Consequently, one would expect beam envelopes similar to those of the beamline leading to TGT1. This is indeed borne ought as is shown in figure 7.

Because the beamline section between the accelerator exit is common to all beamlines, comments regarding beam sizes that were made in §4.1.1 remain valid. Similarly, horizontal beam sizes in the last quadrupole in the accelerator vault and the second quadrupole upstream of the TGT5 location are considered too large. In fact, at approximately ± 20 mm, they are predicted to be slightly larger than at equivalent locations in the beamline to TGT1.

4.1.4 Beam profiles for delivery to the TGT2 location

In this case the beamline from the WST3 location to the TGT2 location is *not* a unit section. Consequently, the tune of this section of beamline may depend on the tune of the matching section. We found a slight difference in the settings of the quadrupoles between the WST3 and TGT2 locations depending on whether the matching tune was for a 1 mm or 2 mm beam spot at TGT2. The differences are small—of the order of 1-2%—and could arise simply because of the fitting process. However, we list in table 3 a complete TRANSPORT input from the exit of the medium β cavities to the TGT2 location for a beam spot 1 mm in diameter at TGT2. In table 4 we list for this tune the beam parameters and overall transfer matrix elements at the midpoint of the WST3-to-TGT2 section and at the TGT2 location.

4.2 A solution to the problem

If beam spots of 1 mm diameter are required, there is the possibility of beam spill along the beamline. Further, it this is of concern, then it would appear that the apertures of some quadrupoles must be increased. The question then is "Is that possible?". The simple answer is "Yes.". There are three types of quadrupoles on hand that would suffice; they are as follows.

1. TRIUMF standard 4Q8.5/8.5 quadrupoles have an effective length of 0.266 m, a bore radius of 2 in., and a maximum pole-tip field of 8.5 kG. These are the quadrupoles that have been used on BL1A; there are eight of these quadrupoles available at the present time.

   A TRANSPORT run using this type of quadrupole in two places on the beamline leading to the TGT1 showed that these quadrupoles would be satisfactory. At an equivalent proton momentum of 0.93 GeV/c, a gradient of approximately 14 T/m (or a pole-tip field of 7.11 kG) is required. These quadrupoles, however, begin to show saturation effects at pole-tip fields above 6.5 kG. The effect is not large, but it would be preferable not to use these quadrupoles at high fields.

2. TRIUMF standard 4Q14/8 quadrupoles have an effective length of 0.4090],m, a bore radius of 2 in.,

and a maximum pole-tip field of 8.5 kG. These are the quadrupoles that have been used on the other primary beamlines at TRIUMF. None of these quadrupoles are available at the present time, but some could be scavenged from BL4B.

A TRANSPORT run using this type of quadrupole at an equivalent proton momentum of 0.93 GeV/c showed that a gradient of 9.1 T/m (or a pole-tip field of 4.62 kG) is required. This field is quite low and this type of quadrupole would be a good substitute for the L2 quadrupoles.

3. There are five type L5 quadrupoles that have been obtained from CRNL. These are listed as having an effective length of 0.2 m, a bore radius of 35.5 mm, and a maximum field gradient of 25.35 T/m. None of these quadrupoles are in use at the present time.

   A TRANSPORT run using this type of quadrupole at an equivalent proton momentum of 0.93 GeV/c showed that a gradient of 18.7 T/m is required. This is well within the specifications for this type of quadrupole and, consequently, would be suitable for use. Further, because they were made by the manufacturer that made the L2 quadrupoles, the type L2 and type L5 quadrupoles should have similar characteristics.

Thus there are several choices of types of quadrupoles that could be used to alleviate the possibility of bean spill. It should be remembered, however, that to maintain symmetry a total of five quadrupoles are required: the last quadrupole in the accelerator vault and the second quadrupole upstream of each of the TGT1, TGT2, TGT3, and TGT5 locations.

5. Discussion

This report has presented an updated design for beam transport from the exit of the medium β cavities to the ISAC-II experimental area. Here the proposed beam transport of [1)] has been combined with a simple matching section and two unit sections. It is noted that this front-end section can also be run as a unit section.

References

1. G. M. Stinson, *A revision of the beam transport to the* ISAC-II *experimental area*, TRIUMF report TRI-DNA-04-1, January, 2004.

2. G. M. Stinson, *Beam transport from the medium β exit to beam transport to the* ISAC-II *experimental area*, TRIUMF report TRI-DNA-04-2, February, 2004.

3. B. Davids, *Private communication*, TRIUMF, March, 2004.

4. C. Kost and P. Reeve, *REVMOC: Monte Carlo Beam Transport Program*, TRIUMF report TRI-DN-82-28, 1982.

Table 1

TRANSPORT input for beam delivery to the TGT5 location in the ISAC-II experimental hall

'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		1.10000;			
3.0		1.10000;			
5.00	Q1	0.32500	−133.63821	100.00000;	
3.0		0.30000;			
5.00	Q2	0.32500	123.88846	100.00000;	
3.0		0.32000;			
3.0	WALL	0.78740;			
3.0		0.32000;			
5.00	Q3	0.32500	−95.46407	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		0.90000;			
3.0		0.90000;			
5.00	Q4	0.32500	24.26269	100.00000;	
3.0		0.30000;			
5.00	Q5	0.32500	−60.65108	100.00000;	
3.0		0.92500;			
3.0		0.92500;			
5.00	Q6	0.32500	75.45052	100.00000;	
3.0		0.30000;			
5.00	Q7	0.32500	−60.66970	100.00000;	
3.0		1.10000;			
3.0		1.10000;			
3.0	MID	1.10000;			
3.0		1.10000;			
3.0		1.10000;			
3.0		1.10000;			
5.00	Q8	0.32500	−60.66970	100.00000;	
3.0		0.30000;			
5.00	Q9	0.32500	75.45052	100.00000;	
3.0		0.92500;			
3.0		0.92500;			
5.00	Q10	0.32500	−60.65108	100.00000;	
3.0		0.32000;			
5.00	Q11	0.32500	24.26269	100.00000;	
3.0		0.90000;			
3.0	B2IN	0.90000;			

Table 1 (Continued)

TRANSPORT input for beam delivery to the TGT5 location in the ISAC-II experimental hall

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	Q12	0.32500	−95.46407	100.00000;
3.0		0.32000;		
3.0		0.78740;		
3.0		0.32000;		
5.00	Q13	0.32500	123.88846	100.00000;
3.0		0.30000;		
5.00	Q14	0.32500	−133.63821	100.00000;
3.0		1.10000;		
3.0	TGT5	1.10000;		
SENTINEL				
SENTINEL				

Table 2

Predicted beam sizes and overall transfer matrices at midpoint and at TGT5

Parameter	MID	TGT5
$\pm x$ (cm)	0.320	0.100
$\pm\theta$ (mr)	1.103	2.000
$\pm y$ (cm)	0.165	0.100
$\pm\phi$ (mr)	1.215	2.000
R_{11} (cm/cm)	−1.8134	1.0000
R_{12} (cm/mr)	0.0000	0.0001
R_{16} (cm/%)	−2.6400	0.0000
R_{21} (mr/cm)	0.0000	0.0001
R_{22} (mr/mr)	−0.5514	1.0000
R_{26} (mr/%)	0.0000	0.0001
R_{33} (cm/cm)	1.6454	1.0000
R_{34} (cm/mr)	0.0000	0.0001
R_{43} (mr/cm)	0.0000	0.0001
R_{44} (mr/mr)	0.6077	1.0000

Table 3

TRANSPORT input for beam delivery to the TGT2 location in the ISAC-II experimental hall – 1 mm spot at TGT2

'2004/03/15 – 2XWR @ TGT2, R16 = R26 = 0, 1 MM WITH L2 QUADRUPOLES'					
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;		
16.00	X0	16.00000	19.00000;		
16.00	Z0	18.00000	26.10100;		
1.000000	BEAM	0.18439	1.09010	0.18439	1.09010
		0.00000	0.10000	0.93000;	
12.000000	CORR	−0.09950	0.00000	0.00000	0.00000
		0.00000	−0.09950	0.00000	0.00000
		0.00000	0.00000	0.00000	0.00000
		0.00000	0.00000	0.00000;	
3.0		0.82500;			
5.00	Q1	0.32500	−284.78098	100.00000;	
3.0		0.20000;			
5.00	Q2	0.32500	197.57786	100.00000;	
3.0		0.82500;			
3.0		0.82500;			
5.00	Q3	0.32500	−191.92321	100.00000;	
3.0		0.20000;			
5.00	Q4	0.32500	265.77325	100.00000;	
3.0	WST1	0.82500;			
3.0		1.67500;			
5.00	Q5	0.32500	99.80433	100.00000;	
3.0		0.30000;			
5.00	Q6	0.32500	−99.80433	100.00000;	
3.0		1.67500;			
3.0		1.67500;			
5.00	Q7	0.32500	99.80433	100.00000;	
3.0		0.30000;			
5.00	Q8	0.32500	−99.80433	100.00000;	
3.0	WST2	1.67500;			
3.0		1.67500;			
5.00	Q9	0.32500	99.80433	100.00000;	
3.0		0.30000;			
5.00	Q10	0.32500	−99.80433	100.00000;	
3.0		1.67500;			
3.0		1.67500;			
5.00	Q11	0.32500	99.80433	100.00000;	
3.0		0.30000;			
5.00	Q12	0.32500	−99.80433	100.00000;	
3.0	WST3	1.67500;			
3.0		2.20000;			
5.00	Q13	0.32500	101.05648	100.00000;	
3.0		0.30000;			
5.00	Q14	0.32500	−121.23874	100.00000;	
3.0		0.32000;			

Table 3 (Continued)

TRANSPORT input for beam delivery to the TGT2 location in the ISAC-II experimental hall – 1 mm spot at TGT2

3.0	WALL	0.78740;		
3.0		0.32000;		
5.00	Q15	0.32500	98.94817	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	Q16	0.32500	130.02346	100.00000;
3.0		0.30000;		
5.00	Q17	0.32500	−87.83354	100.00000;
3.0	MID	0.92500;		
3.0		0.92500;		
5.00	Q18	0.32500	−87.83354	100.00000;
3.0		0.32000;		
5.00	Q19	0.32500	130.02346	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	Q20	0.32500	98.94817	100.00000;
3.0		0.32000;		
3.0		0.78740;		
3.0		0.32000;		
5.00	Q21	0.32500	−121.23874	100.00000;
3.0		0.30000;		
5.00	Q22	0.32500	101.05648	100.00000;
3.0	TGT2	2.20000;		
SENTINEL				
SENTINEL				

Table 4

Predicted beam sizes and overall transfer matrices at midpoint and at TGT2 – 1 mm beam spot

Parameter	MID	TGT2
$\pm x$ (cm)	0.024	0.050
$\pm\theta$ (mr)	8.393	4.000
$\pm y$ (cm)	0.280	0.050
$\pm\phi$ (mr)	0.714	4.000
R_{11} (cm/cm)	−0.0037	−0.0148
R_{12} (cm/mr)	−0.0220	−0.0461
R_{16} (cm/%)	0.0000	0.0000
R_{21} (mr/cm)	45.6376	21.7697
R_{22} (mr/mr)	0.5530	0.1709
R_{26} (mr/%)	5.2883	0.0000
R_{33} (cm/cm)	−0.1941	0.0785
R_{34} (cm/mr)	0.2516	−0.0426
R_{43} (mr/cm)	−3.8600	20.8777
R_{44} (mr/mr)	−0.1486	1.4108

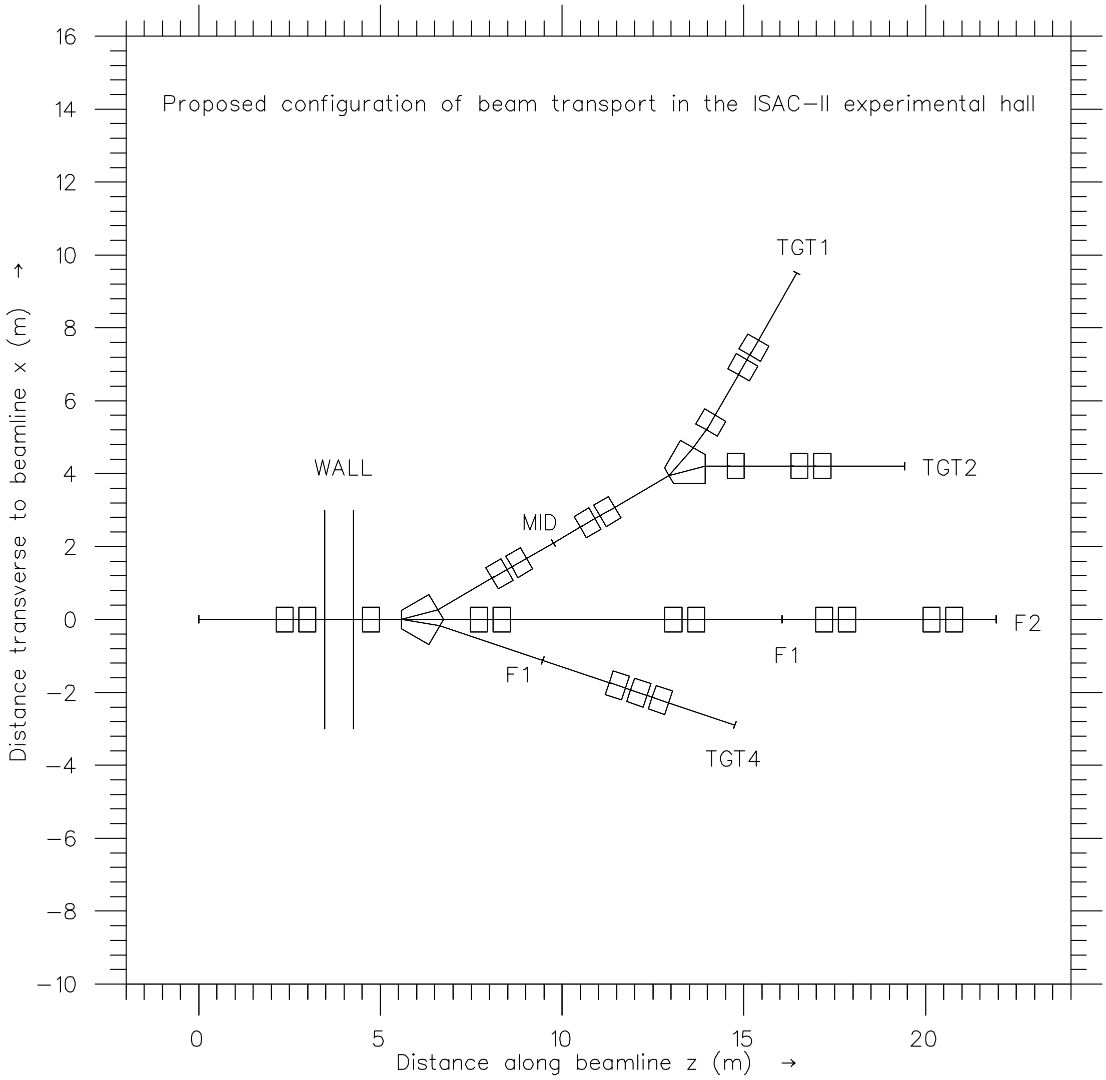

Fig. 1. Beam transport configuration of [1].

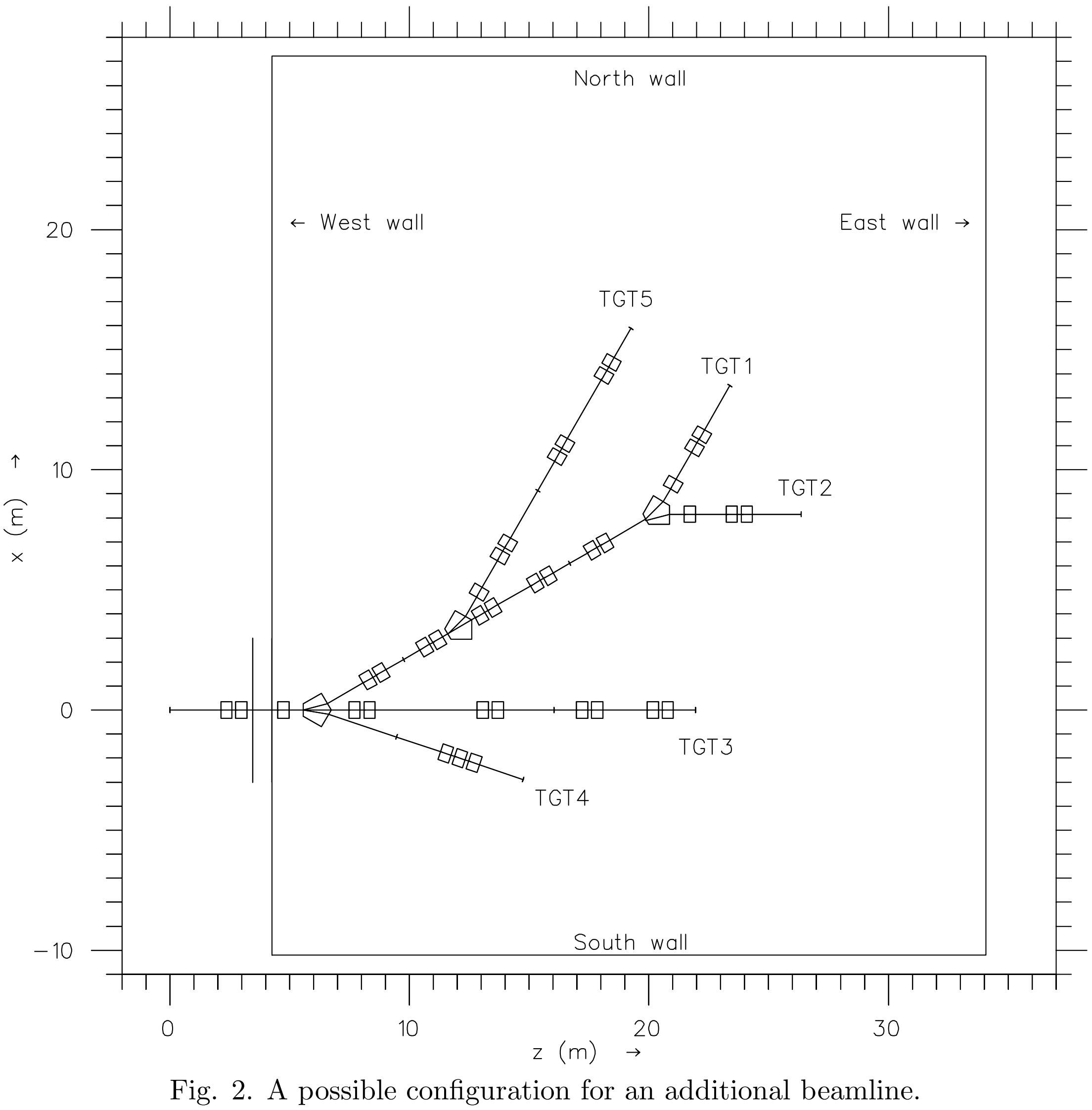

Fig. 2. A possible configuration for an additional beamline.

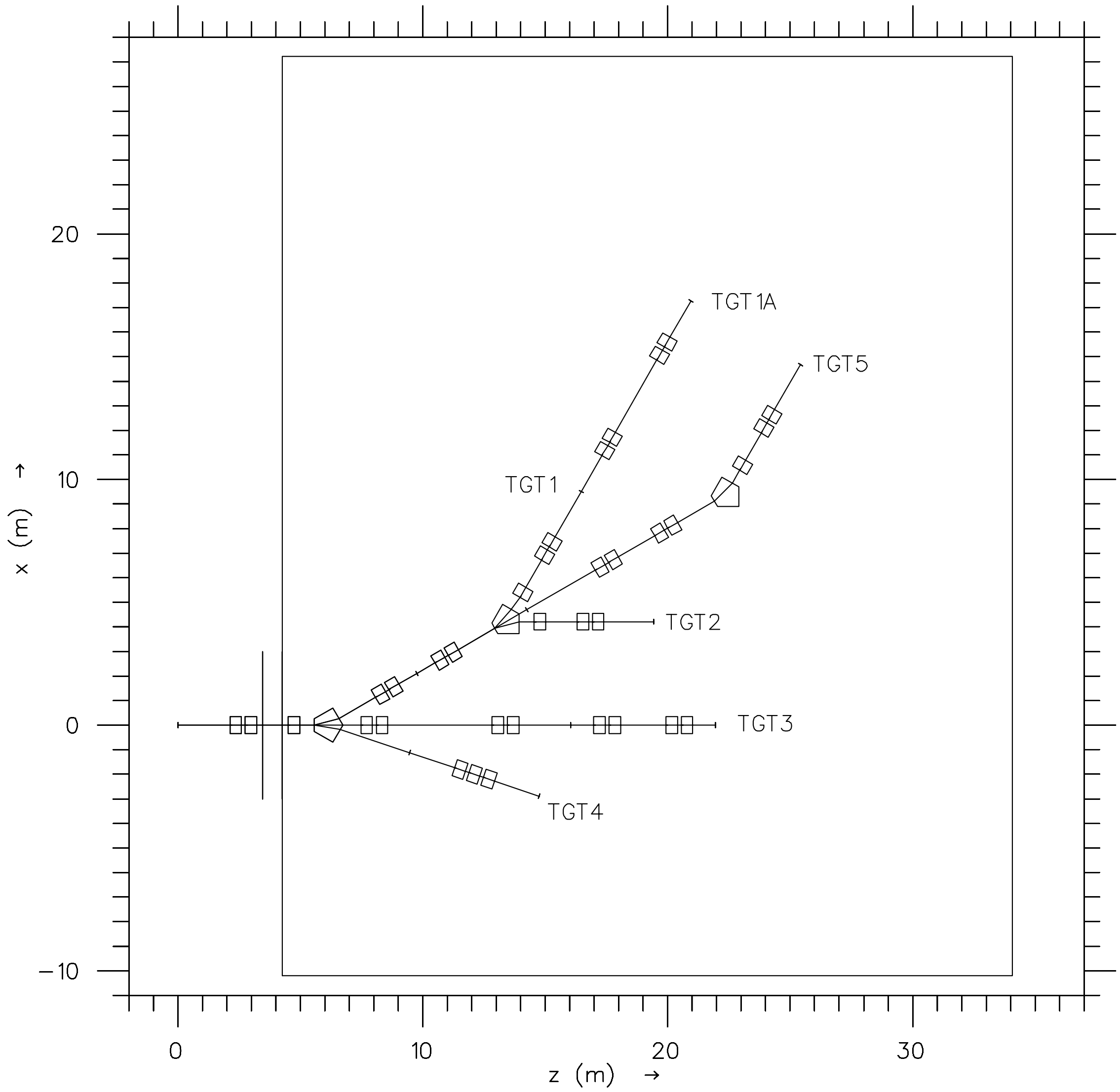

Fig. 3. The proposed beamline configuration for beam delivery an additional target location (TGT5) in the ISAC-II experimental hall.

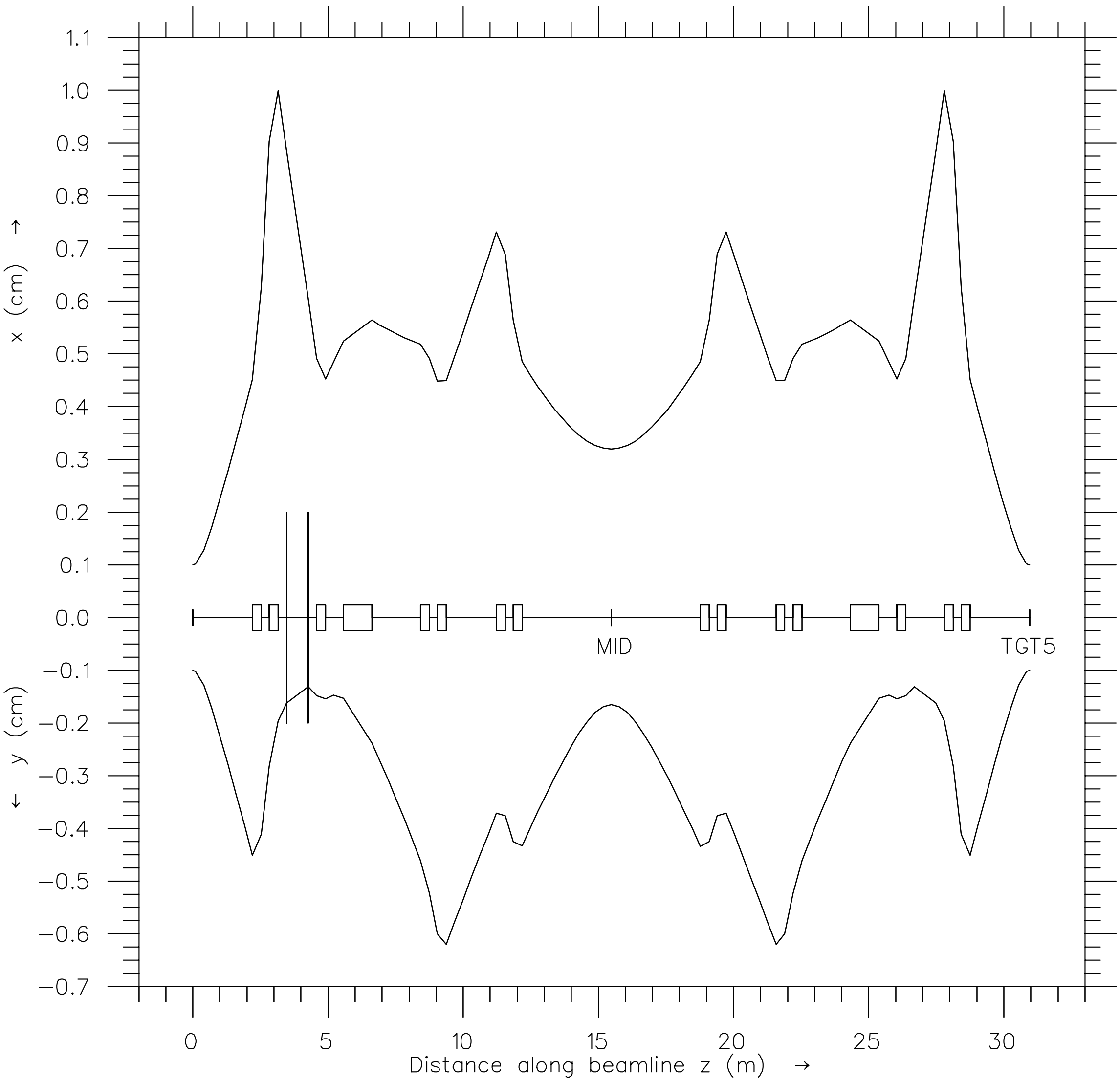

Fig. 4. Beam envelopes along the beamline to the additional target TGT5.

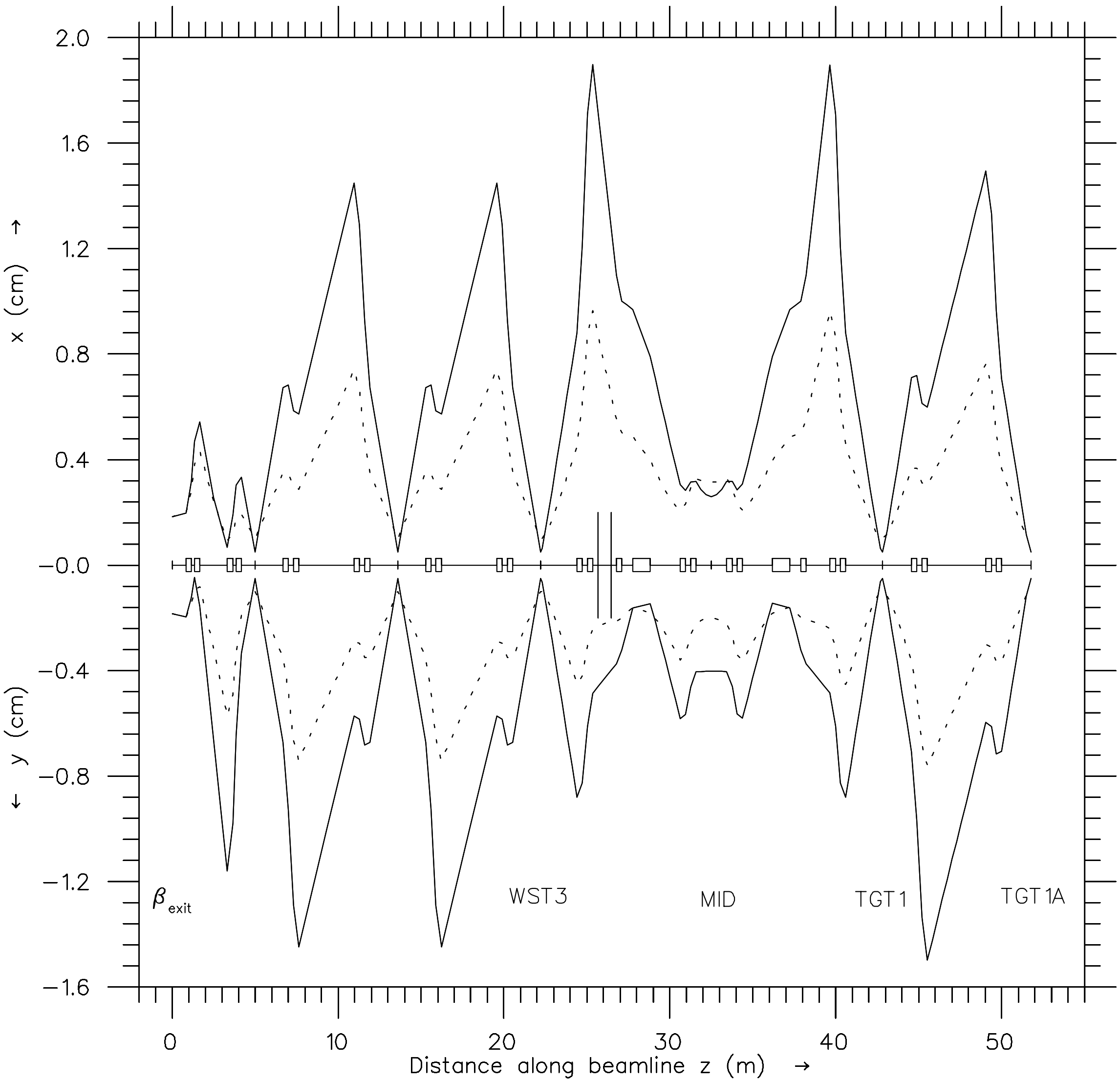

Fig. 5. Beam envelopes along the beamline to TGT1 for 1 mm and 2 mm diameter beam spots. mode.

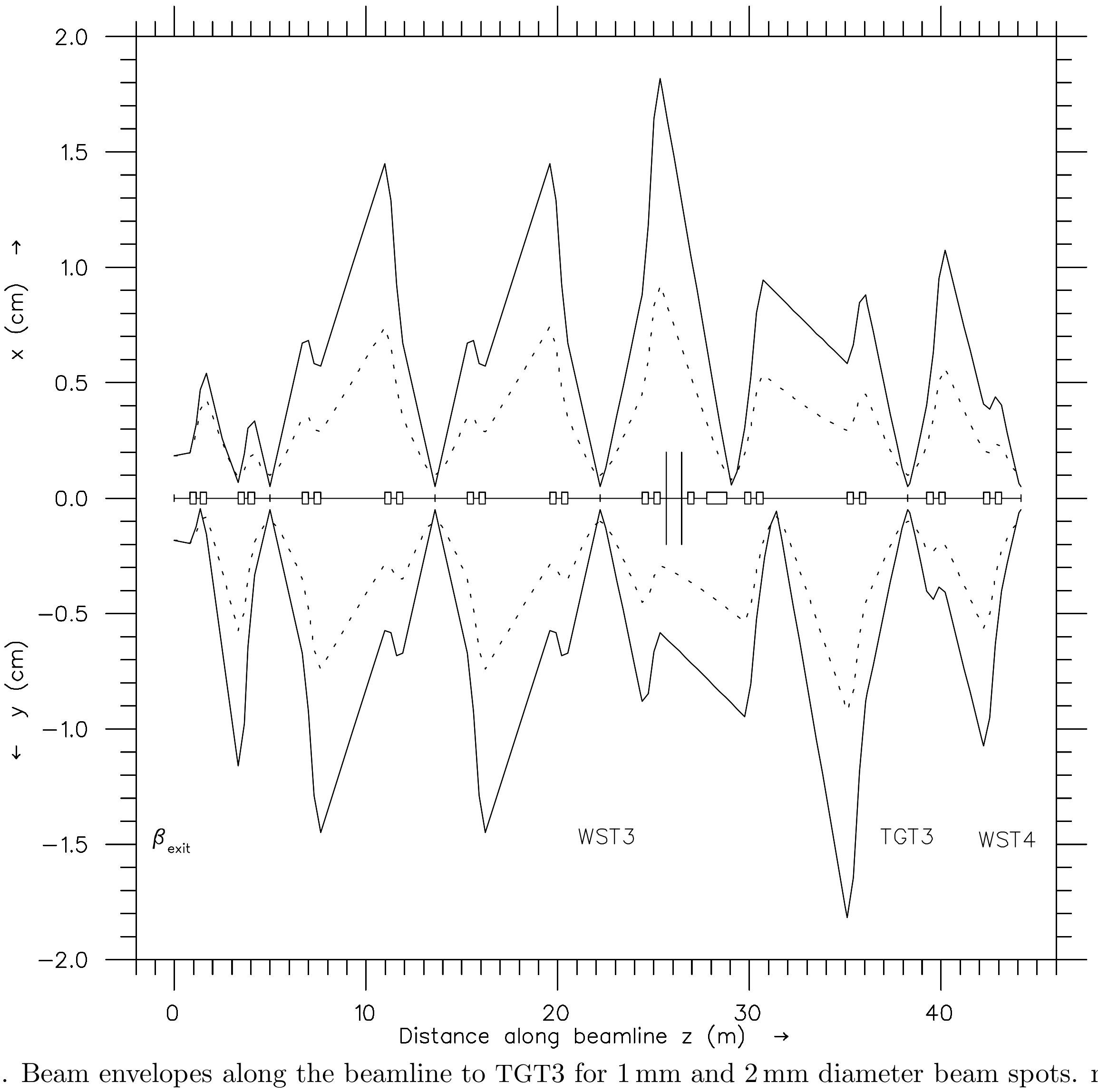

Fig. 6. Beam envelopes along the beamline to TGT3 for 1 mm and 2 mm diameter beam spots. mode.

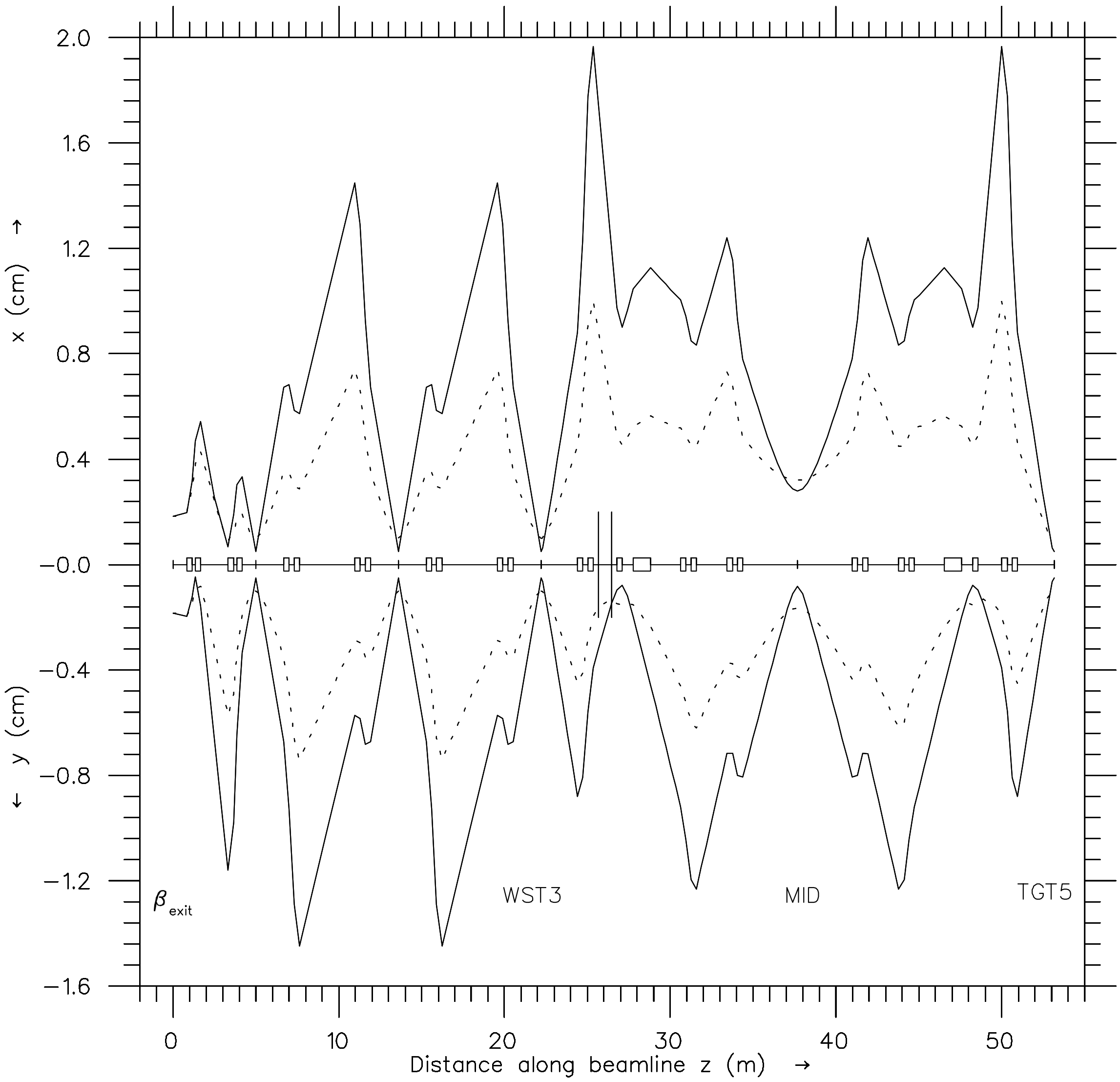

Fig. 7. Beam envelopes along the beamline to TGT5 for 1 mm and 2 mm diameter beam spots. mode.

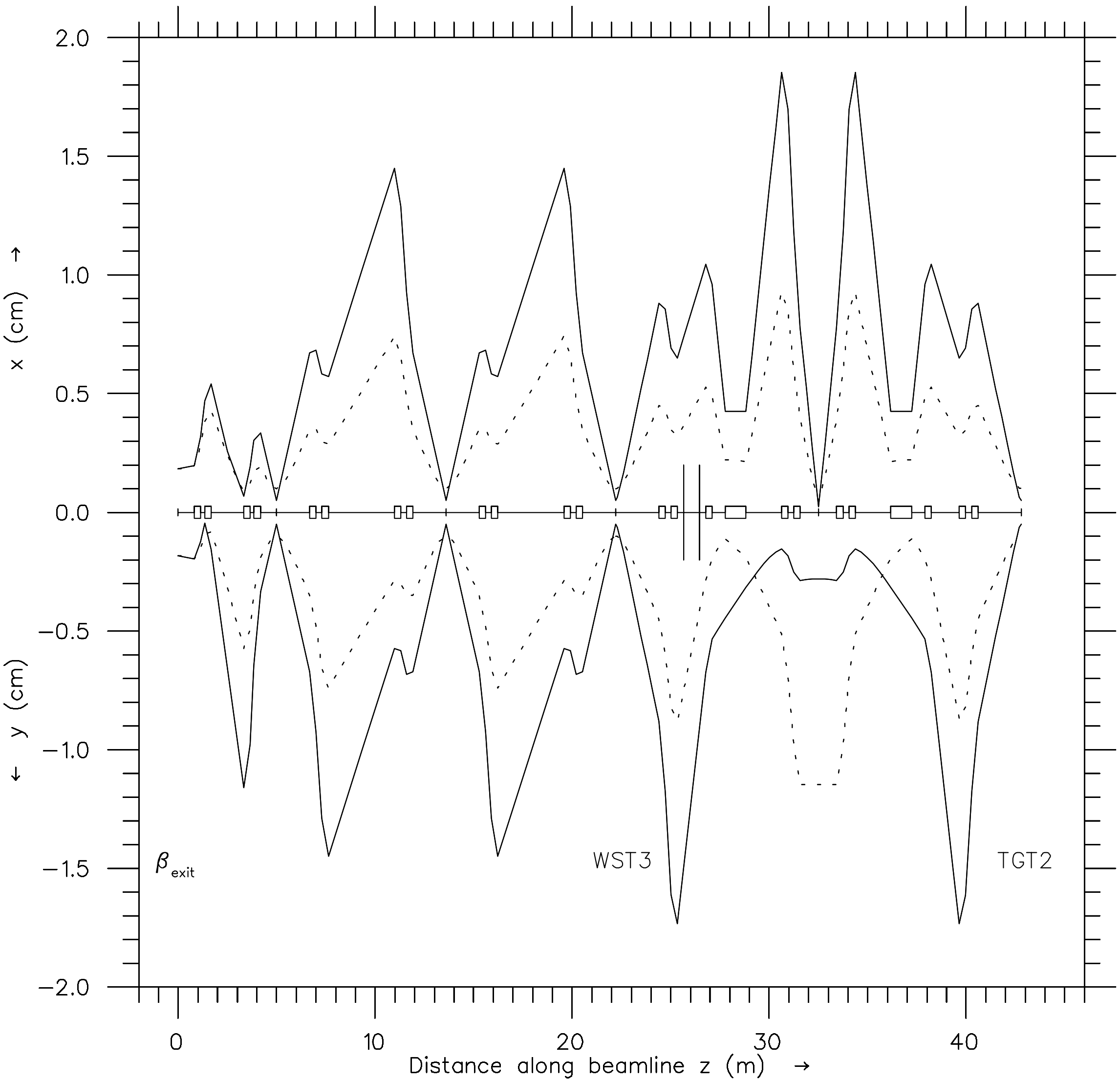

Fig. 8. Beam envelopes along the beamline to TGT2 for 1 mm and 2 mm diameter beam spots. mode.