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	Date 1996-10-07	*File No.* TRI-DNA-96-9
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Subject A revision of the 480 MeV to 500 MeV beam transport system to a ISAC Facility		

1. Introduction

A recent reports[1)] gave a detailed optical design for a beam line for the delivery of beam to an external ISAC. Since that report was issued a revision of the optics of the beam line has been undertaken. The major change is relocation of the the quadrupole that in ref[1)] was between the two 15° dipoles to a location downstream of the last quadrupole of the beam line. At the same time, the ±15° switching magnet was replaced with a 15° rectangular magnet in order that only one design for the 15° magnets was required now. This is because only the west target—denoted TGT2 in this report—will be installed initially. Later, when installation of the east target—designated here as TGT1— is contemplated, it will be necessary to design a ±15° switching magnet of course.

Thus the section of beam line immediately upstream of the target now consists of a quadrupole doublet followed by two 15 ° rectangular dipoles and another quadrupole doublet. *No* other changes to the configuration of the beam line have been made.

This report presents a design for this new configuration.

2. Design Modification

2.1 An overview

Figure 1, taken from ref[1)], shows the beam line configuration that was presented in TRI-DNA-96-5. In that report it was noted that the vertical beam size at the target was affected by foil scattering. In an attempt to reduce the vertical beam size at the target the quadrupole between the two 15° dipoles was relocated downstream of the last quadrupole to form a quadrupole doublet and a double waist was required at the target location. This was relatively easily accomplished in TRANSPORT[2)] but when REVMOC[3)] runs were made it was found that REVMOC predicted that the vertical waist was downstream of the target. Further runs were made with TRANSPORT with a split waist—a horizontal waist at the target and a vertical waist approximately 0.9 m upstream of the target. However, with the use of two rectangular magnets a viable split-waist solution could not be found for *both* targets. Consequently, the split-waist requirement was dropped in lieu of requirements for a vertical waist approximately 0.9 m *upstream* of each target (so as to produce a vertical waist *at* each target), a spatially non-dispersed beam at each target ($R_{16} = 0$ but $R_{26} \neq 0$) and a nominal beam size at each target of $\pm x = \pm y = \pm 2.5$ mm. REVMOC runs then confirmed that there was, indeed, a vertical waist at the each target location.

Figure 2 shows the configuration of the beam line with this modification. An enlarged view of the WST4 to targets section of the beam line is shown in figure 3. As in ref[1)], in each of these figures, and throughout this report, element locations are specified in a Cartesian coordinate system that is located with its origin $(x_0, y_0) = (0,\ 0)$ at the cyclotron center. The positive x-axis is directed east and the positive y-axis is directed north.

For completeness we include the following sub-section taken directly from ref[1)].

2.2 Starting Point of the Beam line

Extraction parameters for beam line 2A were calculated by R. Lee[4)] in October of 1995. Listed in table 1(a) are the relevant data that he has provided for the combination magnet parameters and in table 1(b) for the phase space parameters and the matrix elements for the fringe fields.

Extraction studies track the stripped beam from the stripper foil to a point well beyond the (effective) edge of the combination magnet. Consequently, it is necessary to determine that location in order to specify the location of the components of the beam line.

The upper portion of figure 4 shows the trajectories of the extracted beam as calculated by R Lee. It shows that the crossover point of the combination magnet is located at an (R, θ) coordinate of (412.32 inches, 327.00°) with respect to the centerline of valley 3. Consequently, the radius vector makes an angle of (29° + 327° − 360°) = − 4.0° with respect to the positive x-axis of this report. In this coordinate system then, the crossover point is located at the coordinates

$$\begin{aligned}(x_{co},\ y_{co}) &= (412.32\cos(-4.0^\circ),\ 412.32\sin(-4.0^\circ))\ \text{inches} \\ &= (411.315609,\ -28.761989)\ \text{inches} \\ &= (10.447417,\ -0.730555)\ \text{m}.\end{aligned}$$

Recalling that the effective length of the magnet has been taken as 13.78 inches (0.35 m) and assuming that the crossover point is at the center of the magnet, we then calculate the distance from there to the magnet edge as

$$\begin{aligned}(\delta x,\ \delta y) &= (6.89\cos(35.0^\circ), 6.89\sin(35.0^\circ))\ \text{inches} \\ &= (5.643958,\ 3.951942)\ \text{inches} \\ &= (0.143357,\ 0.100379)\ \text{m}.\end{aligned}$$

Thus the exit edge of the magnet is located at

$$\begin{aligned}x_{magexit} &= x_{co} + \delta x \\ &= 10.447417 + 0.143357\ \text{m} \\ &= 10.590774\ \text{m}\end{aligned}$$

and

$$\begin{aligned}y_{magexit} &= y_{co} + \delta y \\ &= -0.730555 + 0.100379\ \text{m} \\ &= -0.630176\ \text{m}.\end{aligned}$$

From the work of R. Lee we find that at 489.466 MeV the tracing done to generate the fringe-field transfer matrices ends at an $(R_{traj}, \theta_{traj})$ = (436.345 inches, 329.511°). Thus, in the (x, y) system used here, the extracted trajectory makes an angle with respect to the positive x-axis of (29° + 329.511° − 360°) = −1.489° and the end of the fringe-field calculation becomes

$$\begin{aligned}(x_{traj},\ y_{traj}) &= (436.345\cos(-1.489^\circ),\ 436.345\sin(-1.489^\circ))\ \text{inches} \\ &= (436.197660,\ -11.338437)\ \text{inches} \\ &= (11.079421,\ -0.287996)\ \text{m}.\end{aligned}$$

Thus we must back up a distance

$$\begin{aligned}\Delta_{490} &= \sqrt{(x_{traj} - x_{magexit})^2 + (y_{traj} - y_{magexit})^2} \\ &= \sqrt{(11.079421 - 10.590774)^2 + (-0.287996 - (-0.630176))^2} \\ &= \sqrt{0.488647^2 + 0.342180^2} \\ &= 0.596543\ \text{m}\end{aligned}$$

along the exiting trajectory to reach the magnet exit. Similar calculations at an energy of 499.456 MeV [end-point $(R_{traj}, \theta_{traj})$ = (436.169 in., 329.493°)] and 479.477 MeV [end-point $(R_{traj}, \theta_{traj})$ = (436.498 in., 329.526°)] yield values of $\Delta_{500} = 0.590696$ m and $\Delta_{480} = 0.601392$ m respectively. We average these to obtain the average back-up distance

$$\Delta_{av} = 0.596210 \text{ m}.$$

In the TRANSPORT calculations presented here, a back-up distance of 0.59617 m was used (in error). However, the 0.4 mm error introduced will have no effect on the calculations.

3. Beam Line Design

3.1 General Considerations

Because there has been no change in the beam optics upstream of the the WST4 location, the design philosophy followed in ref[1)] was maintained. For completeness, we summarize below the optics of the beam line as given in that reference. Ref[1)] should be consulted for more details of the optical design and for beam profiles in the sections upstream of the WST4 location.

In the cyclotron vault, a quadrupole doublet located downstream of the combination magnet and upstream of the first of two 27.5° dipoles and a second doublet positioned downstream of the second dipole are used to control the vertical beam height in the dipoles and to produce a double waist at the point labelled WST1. In addition, a beam size of $(\pm x, \pm y) = (\pm 1.1, \pm 0.66)$ cm is required at the waist.

The first doublet is composed of two of the standard TRIUMF 4Q14/8 quadrupoles. Those of the second doublet are of a new TRIUMF design[5,6)], modified as suggested by A. Otter[7)], and are akin to the TRIUMF 4Q9/8 quadrupoles that were purchased from Alpha Magnetics some time ago. These new quadrupoles are designated as TRIUMF type 4Q8.5/8.

The section of beam line from the WST1 to the WST3 locations carries the beam through the vault wall and into the 2A tunnel. It consists of the triplet 2AVQ5/6/7 of 4Q8.5/8.5 quadrupoles just inside the north wall of the vault followed by the 2AQ8/9/10 triplet of 4Q14/8 quadrupoles. The first triplet produces a double waist at the position labelled WST2, 8 m from the external wall of the vault. The second triplet produces another waist at the location labelled WST3. These two triplets are tuned to keep the vertical size of the beam small and to produce a vertical beam size of ±0.29 cm at WST3.

The section of beam line between the WST3 and WST4 locations is composed of the quadrupole doublet 2AQ11/12. Quadrupoles of the 4Q6.5/8.5 type are used to produce another double waist at the WST4 location.

3.2 The WST4 to target section

This section of beam line consists of the two quadrupole doublets 2AQ13/14 and 2AQ15/16, and two 15° rectangular dipole magnets 2AB3 and 2AB4. All of the quadrupoles are of the 4Q8.5/8.5 variety. These quadrupoles are used to produce the required beam size at the target location and, at the same time, to produce a vertical waist approximately 1 m upstream of the target and a spatially achromatic beam spot ($R_{16} = 0, R_{26} \neq 0$) at the target.

The difference between this configuration and that of ref[1)] is in the relocation of quadrupole 2AQ15 from between the two 15° dipoles as in ref∗1) to downstream of quadrupole 2AQ16 in this new configuration. Further, in order that only one additional dipole type be designed now, the ±15° switching magnet has been replaced with a rectangular 15° dipole of the same type that lies upstream of the target.

A TRANSPORT listing for delivery of a 500 MeV beam to the west target (TGT2) case is given in table 2. Figure 5 shows the beam envelopes along the beam line for beam delivery to the TGT2 target. Only profiles for 490 and 500 MeV are shown because the 480 MeV envelopes are indistinguishable from those of the 490 MeV tune. (In future plots of beam envelopes, this procedure will be maintained.) The small 'tail' that appears in this plot at the beginning of the beam line results because of the back up to the effective exit of the combination magnet that is required. Figure 6 shows an enlargement of the beam profiles in the WST4 to TGT2 and TGT1 sections of the beam line. We again note that in each of the figures the cyclotron center is taken as $(x, y) = (0{,}0)$.

Beam profiles and an expanded view of this section of beam line are shown figure 7. A nominal beam size at the target of $(\pm x, \pm y) = (\pm 0.25, \pm 0.25)$ cm was the design goal.

4. Settings of the beam-transport elements

Table 3 lists the settings of the various elements of the transport system for the energy range 480, 490 and 500 MeV. In table 4 we list the beam sizes at the various waist locations.

Beam sizes and overall transfer matrices at the TGT2 location are listed in table 5(a); those at the TGT1 location are listed in table 5(b).

5. REVMOC calculations

The program REVMOC[7] was run at all energies to estimate the amount of beam spill to be expected and where such might occur. REVMOC is a Monte Carlo program that traces particles through a beam optics configuration using true second-order optics, although the effects of chromatic aberrations is considered to all orders. The effects of multiple scattering, decay, nuclear scattering and energy loss in scatterers, absorbers, collimators, slits and apertures are included. Geometric effects are considered locally to only second order but higher-order global effects will appear because of the accumulation of the second-order effects. The program does not, however, optimize beam elements and its primary use is to do detailed checks on a beam line that has been designed using the program TRANSPORT[8].

For each energy and each target configuration 150,000 particles (in some cases, 1,500,000 particles) were traced through the beam line. At 500 and 490 MeV a spill of 0.0094% of the beam was predicted to be lost between the stripper foil and the combination magnet exit; at 480 MeV a spill of 0.0093% was predicted in the same region. No beam was predicted to be spilled elsewhere in the beam line. All spill was predicted to occur in the vertical plane.

The reason for spill in the vertical plane only is shown in figure 8, a plot of the vertical divergence (DY) in mr along the vertical axis versus the vertical beam size (Y) in cm along the horizontal axis at the WST1 location. The upper portion of the plot is a prediction of this correlation *without* any foil scattering taken into account; the lower portion is the prediction taking into account the scattering in a carbon stripper foil that is 0.00003 m (0.0012 in.) thick. It is clear that the foil scattering adds significantly to the beam divergence. The reason for this, as discussed in section 3.1, the the extremely low vertical divergence of the beam at the point of stripping.

Figure 9 shows the predicted beam spot at the TGT2 target location for a beam energy of 500 MeV. The spot size shown includes the effect of foil scattering. The units of the vertical and horizontal scales are cm. Figure 10 is a plot of the predicted beam spot at the TGT1 location.

Figures 11 and 12 are similar plots for a beam energy of 490 MeV and figures 13 and 14 those for a beam energy of 480 MeV.

Using the data presented in figure 9, we find that REVMOC predicts that 3.55% (2.60%) of the beam lies *outside* the nominal design spot size of ±0.26 cm in the horizontal (vertical) plane at a beam energy of 500 MeV. From figure 10 we see that 4.07% (2.21%) of the beam lies outside of these nominal dimensions. At 490 MeV we find the corresponding values of percentages of beam outside the nominal design values are3.39% (2.58%) for the horizontal (vertical) plane at TGT2 and 4.07% (2.21%) for the horizontal (vertical) plane at TGT1. At 480 MeV the percentage of beam outside of the nominal design values are 3.38% (2.98 %) for the horizontal (vertical) plane at TGT2 and 4.05% (1.87%) for the horizontal (vertical) plane at TGT1.

Finally, figure 15 shows a plot of momentum p in GeV/c along the vertical axis versus horizontal position x in cm along the horizontal axis at the TGT2 location. That momentum and horizontal position are uncorrelated indicates that the beam is spatially achromatic there. Similar plots for 490 and 480 MeV show the same property.

6. The effect of a window at the end of the beam line

Subsequent to the issue of ref[1)] it was pointed out to the author that a window was required upstream of the target to provide separation of the beam line and cyclotron vacuum systems from the relatively poor and possibly dirty vacuum of the target enclosure. Because of this a study of the effect of such a window on the beam size at the target was undertaken.

The program REVMOC was again used to find the effect of a 0.001 in. thick, stainless steel window at various locations upstream of the targets. In a series of runs, windows were placed 1.0, 1.5 and 2 m upstream of the TGT2 target and their effect on the beam spot at the target examined. These runs were made only at 500 MeV and for the TGT2 location on the assumption that similar effects would be observed at the other energies and at the TGT1 location.

As would be expected, this study showed that the closer to the target the window was, the less the effect on beam size there. The most practical location for a window is approximately 1 m upstream of the target. Figure 16, drawn to the same scales as figure 9, shows the predicted beam size at the TGT2 location with both foil and window scatterings included for such a case. A comparison of the data presented in figures 9 and 16 is useful.

The effect of the window is to increase significantly the percentage of beam outside of the design goal of ± 2.5 mm in each plane. With the window in place, 6.91% of the beam in the horizontal plane and 5.88% in of the beam in the vertical plane lies outside of the nominal dimensions. This is roughly twice the percentages lying outside of the design values that are predicted to occur with no window. On the other hand, only 0.92% of the beam lies beyond values of $x = \pm 3.6$ mm in the horizontal plane and 0.57% of the beam lies beyond values of $y = \pm 3.8$ mm in the vertical plane. Thus, in a sense, the introduction of the window symmetrizes the beam at the expense of an increase of 2 mm in the beam size in each of the horizontal and vertical planes.

7. Discussion

Since a proposal for an ISAC facility was first made, many versions of its beam transport line have been considered. This report presents the results of a revision of the beam line design presented in ref[1)].

Extraction matrices have been produced for energies of 480, 490 and 500 MeV and beam-line optics for these energies have been developed. In addition, beam spill calculations were made. These indicated that beam spill should be contained within the cyclotron vault.

It should be noted, however, that the accuracy to which the program REVMOC was asked to predict beam spill is, at best, at the limit of the program. In normal use, one would expect an accuracy of 0.5% at best. Thus the quoted beam spills should be regarded as indications that spill might occur rather than an absolute value to be quoted.

A study of the effect of a vacuum window at the end of the beam line has been made. The results indicate that the window would increase the beam size by 2 mm in each of the horizontal and vertical planes. It is felt that this increase is reasonable and, in any event, the presence of the window is necessary. It is possible that the optics of the beam line could be modified to produce a smaller beam spot at the targets in the

TRANSPORT design such that in REVMOC simulations the nominal ±2.5 mm goal is reached. This will be attempted at a later date.

References

1. G. M. Stinson, *TRIUMF report* TRI-DNA-96-5, TRIUMF, 1996.
2. K. L. Brown and S. K. Howry, *TRANSPORT/360*, SLAC–91, Stanford Linear Accelerator Laboratory, July, 1970.
3. C. J. Kost and P. A. Reeve, *TRIUMF report* TRI-DN-82-28, TRIUMF, 1982.
4. R. Lee, *Private communication*, October, 1965.
5. G. M. Stinson, *TRIUMF report* TRI-DNA-96-7, TRIUMF, 1996.
6. M. Dehnel, *TRIUMF report* TRI-DN-ISAC-16, TRIUMF, 1996.
7. A. J. Otter, *Private communication*, TRIUMF, June, 1996.

Table 1 (a)
Combination magnet parameters from ref[2)]

Parameter	480 MeV	490 MeV	500 MeV
Entry angle (°)	−0.977	−0.138	0.687
Field (kG)	1.726	0.248	−1.245
Exit angle (°)	0.000	0.000	0.000
Bend angle (°)	−0.977	−0.138	0.687

Table 1 (b)
Fringe field and initial beam parameters from ref[2)]

Parameter	400 MeV	450 MeV	500 MeV
$\pm x$ (cm)	0.127	0.127	0.127
$\pm \theta$ (mr)	1.600	1.600	1.600
$\pm y$ (cm)	0.669	0.669	0.669
$\pm \phi$ (mr)	0.556	0.556	0.556
R_{11} (cm/cm)	−0.03099	−0.01551	−0.06571
R_{12} (cm/mr)	0.32538	0.32610	0.32167
R_{16} (cm/%)	1.36150	1.32879	1.28344
R_{21} (mr/cm)	−3.09350	−3.06770	−3.17670
R_{22} (mr/mr)	0.16141	0.17049	0.16907
R_{26} (mr/%)	2.38040	2.43140	2.45410
R_{33} (cm/cm)	1.12700	1.11600	1.10800
R_{34} (mr/cm)	0.61980	0.61590	0.61200
R_{43} (mr/cm)	0.48200	0.46410	0.44710
R_{44} (cm/cm)	1.15300	1.15300	1.14900

Coordinates of the cross-over point of the combination magnet are:

$R = 412.320$ inches

$\theta = 327.000°$ with respect to the centerline of valley 3

Table 2

TRANSPORT listing for beam delivery of a 500 MeV beam to the west target (TGT2)

'DATA OF 95/10/10 on 96/09/30 – 500 MEV – TGT2 – 2AQ15 MOVED'

0

13.00	' '	12.00000;			
16.00	'1/R1'	12.00000	0.00000;		
16.00	'1/R2'	13.00000	0.00000;		
16.00	'G/2 '	5.00000	5.08000;		
16.00	'X0 '	16.00000	−0.29135;		
16.00	'Z0 '	18.00000	11.07463;		
16.00	'T0 '	19.00000	35.10000;		
1.00	'BEAM'	0.12700	1.60000	0.66900	0.55600
		0.00000	0.10000	1.09007;	
12.00	'12 '	0.00000	0.00000	0.00000	0.00000
		0.00000	−0.96300	0.00000	0.00000
		0.00000	0.00000	0.00000	0.00000
		0.00000	0.00000	0.00000;	
1.00	'FOIL'	0.00000	0.17100	0.00000	0.17100
		0.00000	0.00000	0.00000	0.00000
14.00	'R1 '	−0.06571	0.32167	0.00000	0.00000
		0.00000	1.28344	1.00000;	
14.00	'R2 '	−3.17670	0.16907	0.00000	0.00000
		0.00000	2.45410	2.00000;	
14.00	'R3 '	0.00000	0.00000	1.10800	0.61200
		0.00000	0.00000	3.00000;	
14.00	'R4 '	0.00000	0.00000	0.44710	1.14900
		0.00000	0.00000	4.00000;	
3.00	'CMEX'	−0.59617;			
3.00	' '	0.21004;			
3.00	' '	0.30940;			
5.00	'2VQ1'	0.40900	−3.63609	5.08000;	
3.00	' '	0.25000;			
5.00	'2VQ2'	0.40900	5.21560	5.08000;	
3.00	' '	0.23880;			
3.00	'B1IN'	0.37190;			
20.00	' '	180.00000;			
2.00	' '	13.75000;			
4.00	'BEN1'	1.24595	14.00681	0.00000;	
2.00	' '	13.75000;			
20.00	' '	−180.00000;			
3.00	'B1EX'	0.00001;			
3.00	' '	0.08972;			
3.00	' '	0.27380;			
3.00	' '	0.52450;			
3.00	' '	0.27380;			

Table 2 (continued)

3.00	'B2IN'	0.08972;			
20.00	' '	180.00000;			
2.00	' '	13.75000;			
4.00	'BEN2'	1.24595	14.00681	0.00000;	
2.00	' '	13.75000;			
20.00	' '	−180.00000;			
3.00	'B2EX'	0.00001;			
−10.00	'ZFIT'	8.00000	3.00000	14.07160	0.00100;
3.00	' '	1.00000;			
5.00	'2VQ3'	0.26600	5.61565	5.08000;	
3.00	' '	0.28640;			
5.00	'2VQ4'	0.26600	−4.60155	5.08000;	
3.00	' '	0.40900;			
3.00	' '	0.28640;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	'WST1'	1.78321;			
−10.00	'FXW1'	2.00000	1.00000	0.00000	0.00100;
−10.00	'FYW1'	4.00000	3.00000	0.00000	0.00100;
−10.00	'SXW1'	1.00000	1.00000	1.15000	0.01000;
−10.00	'SYW1'	3.00000	3.00000	0.66000	0.01000;
3.00	' '	1.00000;			
3.00	' '	1.23290;			
5.00	'2VQ5'	0.26600	−1.66483	5.08000;	
3.00	' '	0.28640;			
5.00	'2VQ6'	0.26600	3.12057	5.08000;	
3.00	' '	0.28640;			
5.00	'2VQ7'	0.26600	−1.66483	5.08000;	
3.00	' '	0.95770;			
3.00	'WALL'	1.51760;			
−10.00	'ZFIT'	8.00000	1.00000	15.24000	0.00100;
3.00	'MID2'	0.92100;			
3.00	'WALX'	1.36500;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	'WST2'	1.00000;			
−10.00	'FXW2'	2.00000	1.00000	0.00000	0.00100;
−10.00	'FYW2'	4.00000	3.00000	0.00000	0.00100;
3.00	' '	1.00000;			
3.00	' '	1.00000;			

Table 2 (continued)

3.00	' '	1.00000;			
5.00	'2AQ8'	0.40900	−1.52363	5.08000;	
3.00	' '	0.30480;			
5.00	'2AQ9'	0.40900	2.63611	5.08000;	
3.00	' '	0.30480;			
5.00	'AQ10'	0.40900	−1.52363	5.08000;	
3.00	' '	0.96066;			
3.00	' '	0.96066;			
3.00	' '	1.04211;			
3.00	'WST3'	0.60000;			
−10.00	'FXW3'	2.00000	1.00000	0.00000	0.00100;
−10.00	'FYW3'	4.00000	3.00000	0.00000	0.00100;
−10.00	'SYW3'	3.00000	3.00000	0.29100	0.00500;
3.00	' '	1.00000;			
3.00	' '	1.00000;			
3.00	' '	1.13330;			
5.00	'AQ11'	0.26600	2.32602	5.08000;	
3.00	' '	0.28640;			
5.00	'AQ12'	0.26600	−2.63114	5.08000;	
3.00	' '	1.13330;			
3.00	' '	1.00000;			
3.00	'WST4'	1.00000;			
3.00	' '	1.08328;			
3.00	' '	1.08328;			
3.00	' '	1.08328;			
3.00	' '	1.07408;			
5.00	'AQ13'	0.26600	3.18591	5.08000;	
3.00	' '	0.28640;			
5.00	'AQ14'	0.26060	−3.51541	5.08000;	
3.00	' '	1.07408;			
3.00	' '	1.08328;			
3.00	' '	1.08328;			
3.00	'B3IN'	1.08328;			
16.00	'1/R2'	13.00000	1.73055;		
20.00	' '	180.00000;			
2.00	' '	7.50000;			
4.00	'BEN3'	0.68139	13.97007	0.00000;	
2.00	' '	7.50000;			
20.00	' '	−180.00000;			
3.00	'B3EX'	0.00001;			
3.00	' '	0.75000;			
3.00	' '	0.74200;			
3.00	' '	0.26600;			
3.00	'B4IN'	0.49200;			
16.00	'1/R2'	13.00000	0.00000;		

Table 2 (continued)

20.00	' '	180.00000;			
2.00	' '	7.50000;			
4.00	'BEN4'	0.68139	13.97007	0.00000;	
2.00	' '	7.50000;			
20.00	' '	−180.00000;			
3.00	'B4EX'	0.00001;			
3.00	' '	0.26500;			
3.00	' '	0.26500;			
3.00	' '	0.25580;			
5.00	'AQ15'	0.26600	4.85239	5.08000;	
3.00	' '	0.28640;			
5.00	'AQ16'	0.26600	−5.15018	5.08000;	
3.00	' '	0.32257;			
3.00	' '	0.88377;			
3.00	'YWST'	0.88377;			
−10.00	' '	4.00000	3.00000	0.00000	0.00100;
3.00	'TGT2'	0.88377;			
−10.00	' '	−1.00000	6.00000	0.06000	0.00100;
−10.00	' '	1.00000	1.00000	0.25000	0.01000;
−10.00	' '	3.00000	3.00000	0.25000	0.01000;
−10.00	'ZFIT'	8.00000	1.00000	57.91640	0.00100;
−10.00	'ZFIT'	8.00000	3.00000	10.85215	0.00100;

Table 3

Element settings as a function of energy for beam line 2A

Element	Field (kG) at energy					
	480 MeV		490 MeV		500 MeV	
2AVQ1	−3.55885		−3.59340		−3.63609	
2AVQ2	5.03422		5.09663		5.21560	
2AVB1	13.66610		13.83687		14.00681	
2AVB2	13.66610		13.83687		14.00681	
2AVQ3	5.53312		5.59629		5.61565	
2AVQ4	−4.54074		−4.58767		−4.60155	
2AVQ5	−1.59219		−1.61331		−1.66483	
2AVQ6	2.99027		3.03033		3.12057	
2AVQ7	−1.59219		−1.61331		−1.66483	
2AQ8	−1.47043		−1.49054		−1.52363	
2VQ9	2.54777		2.58248		2.63611	
2Q10	−1.47043		−1.49054		−1.52363	
2AQ11	2.25242		2.28376		2.32602	
2AQ12	−2.54611		−2.58129		−2.63114	
2AQ13[a)]	3.13193	4.23486	3.17008	4.29335	3.18591	4.37081
2AQ14[a)]	−3.44725	−4.08818	−3.48921	−4.14287	−3.51541	−4.21070
2AB3	13.63020		13.80052		13.97007	
2AB4	13.63020		13.80052		13.97007	
2AQ15[a)]	4.71716	6.55437	4.77886	6.63379	4.85239	6.70106
2AQ15[a)]	−5.02532	−5.84602	−5.08763	−5.91956	−5.15018	−5.99745

[a)] Two field values are listed for quadrupoles 2AQ13 through 2AQ16. At a given energy, the left value refers to beam delivery to the target labelled TGT2 and the right to beam delivery to that labelled TGT1.

Table 4

Beam sizes at the waist locations

Waist	Parameter	480 MeV	490 MeV	500 MeV
WST1	$\pm x$ (cm)	1.150	1.150	1.182
	$\pm \theta$ (mr)	0.354	0.355	0.364
	$\pm y$ (cm)	0.660	0.660	0.661
	$\pm \phi$ (mr)	0.231	0.231	0.230
WST2	$\pm x$ (cm)	1.050	1.049	1.079
	$\pm \theta$ (mr)	0.387	0.389	0.339
	$\pm y$ (cm)	0.332	0.332	0.329
	$\pm \phi$ (mr)	0.459	0.459	0.461
WST3	$\pm x$ (cm)	1.047	1.046	1.076
	$\pm \theta$ (mr)	0.389	0.390	0.400
	$\pm y$ (cm)	0.294	0.293	0.291
	$\pm \phi$ (mr)	0.518	0.519	0.522
WST4	$\pm x$ (cm)	0.853	0.851	0.875
	$\pm \theta$ (mr)	0.477	0.479	0.492
	$\pm y$ (cm)	0.397	0.397	0.397
	$\pm \phi$ (mr)	0.383	0.383	0.383

Table 5(a)

Beam sizes and overall transfer matrices at the TGT2 location

Parameter	480 MeV	490 MeV	500 MeV
$\pm x$ (cm)	0.250	0.250	0.250
$\pm \theta$ (mr)	0.929	3.931	0.972
$\pm y$ (cm)	0.250	0.250	0.250
$\pm \phi$ (mr)	0.624	0.624	0.623
R_{11} (cm/cm)	-0.7029	-0.6958	-0.6866
R_{12} (cm/mr)	0.1453	0.1454	0.1456
R_{16} (cm/%)	-0.0006	0.0003	0.0001
R_{21} (mr/cm)	-5.2579	-5.2277	-5.1824
R_{22} (mr/mr)	-0.3383	-0.3419	-0.3731
R_{26} (mr/%)	3.4746	3.5108	3.8879
R_{33} (cm/cm)	-0.4510	-0.4475	-0.4530
R_{34} (mr/cm)	-0.0985	-0.0940	-0.1011
R_{43} (mr/cm)	-2.3011	-2.3047	-2.2969
R_{44} (cm/cm)	-2.7214	-2.7204	-2.7190

Table 5(b)

Beam sizes and overall transfer matrices at the TGT1 location

Parameter	480 MeV	490 MeV	500 MeV
$\pm x$ (cm)	0.250	0.250	0.250
$\pm \theta$ (mr)	2.473	2.480	3.547
$\pm y$ (cm)	0.250	0.250	0.250
$\pm \phi$ (mr)	0.624	0.624	0.623
R_{11} (cm/cm)	−0.0054	−0.0028	0.0372
R_{12} (cm/mr)	−0.1554	−0.1554	−0.1553
R_{16} (cm/%)	0.0001	0.0006	−0.0003
R_{21} (mr/cm)	6.4175	6.4057	6.7012
R_{22} (mr/mr)	−0.8228	−0.8237	−0.8138
R_{26} (mr/%)	−19.92276	−19.3231	−20.1184
R_{33} (cm/cm)	−0.3696	−0.3678	−0.3841
R_{34} (mr/cm)	0.0051	0.0074	−0.0131
R_{43} (mr/cm)	−2.3510	−2.3524	−2.3407
R_{44} (cm/cm)	−2.6750	−2.6743	−2.6820

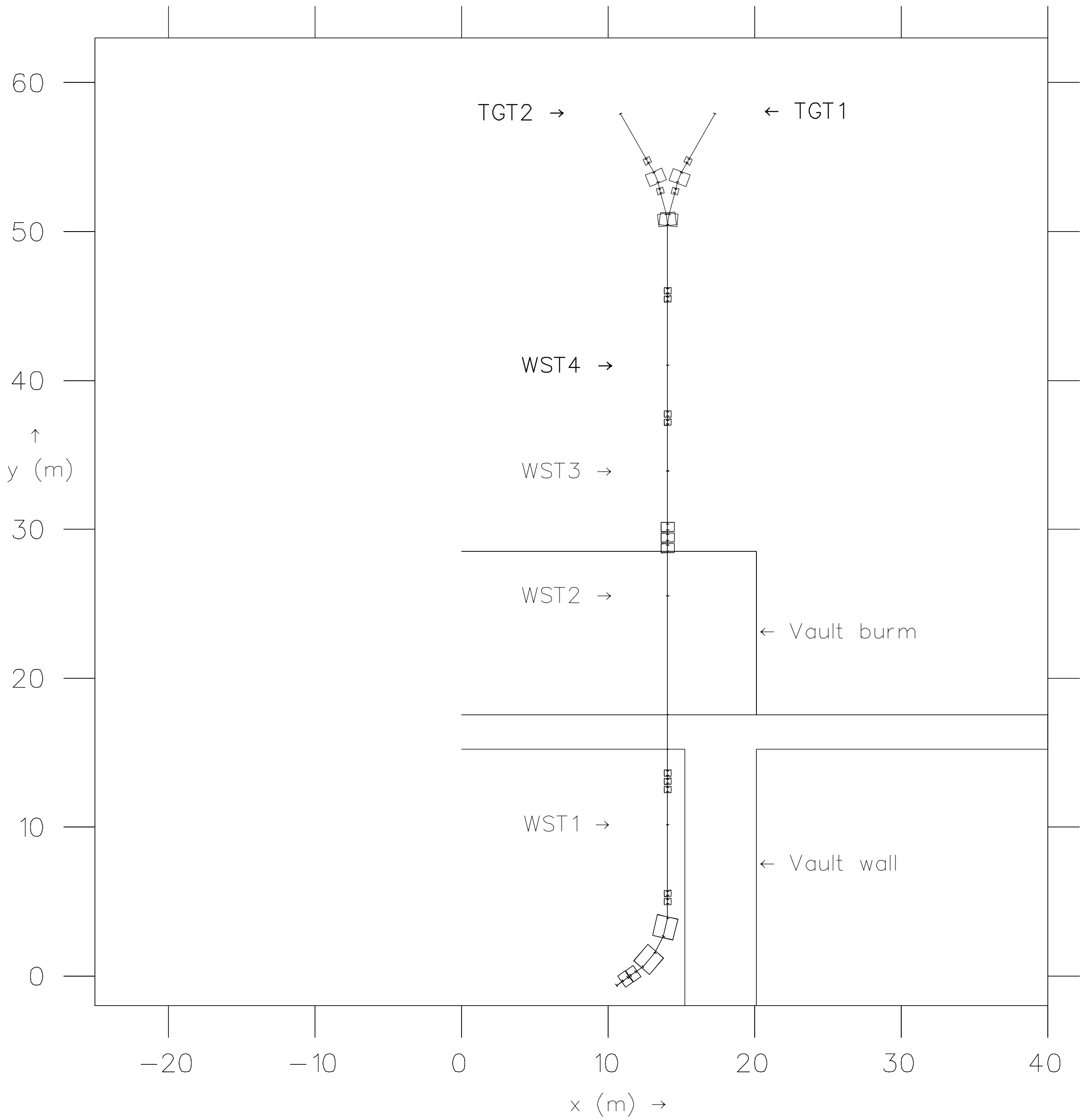

Figure 1. The configuration of beam line 2A given in ref[1].

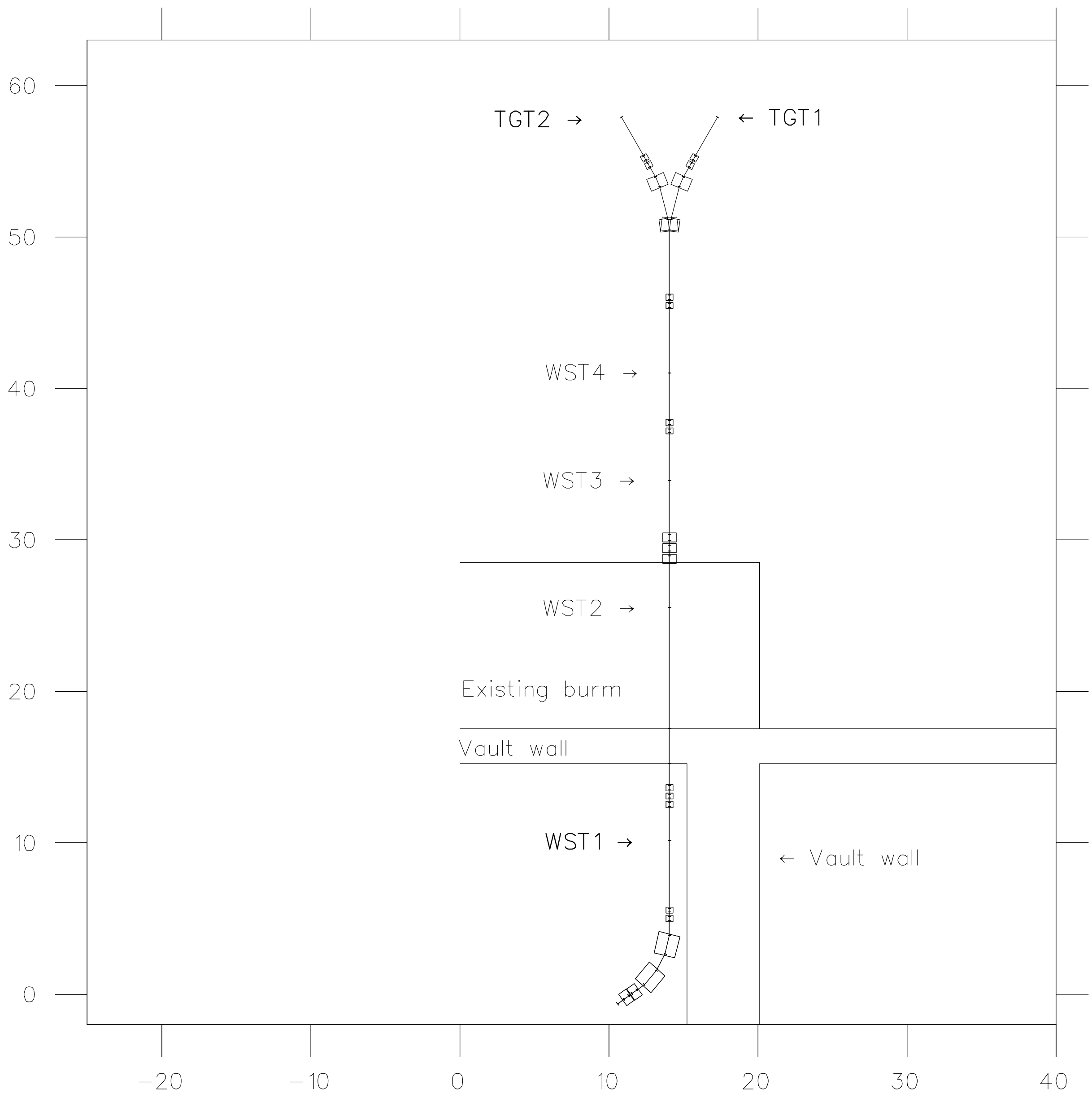

Figure 2. The proposed configuration of beam line 2A.

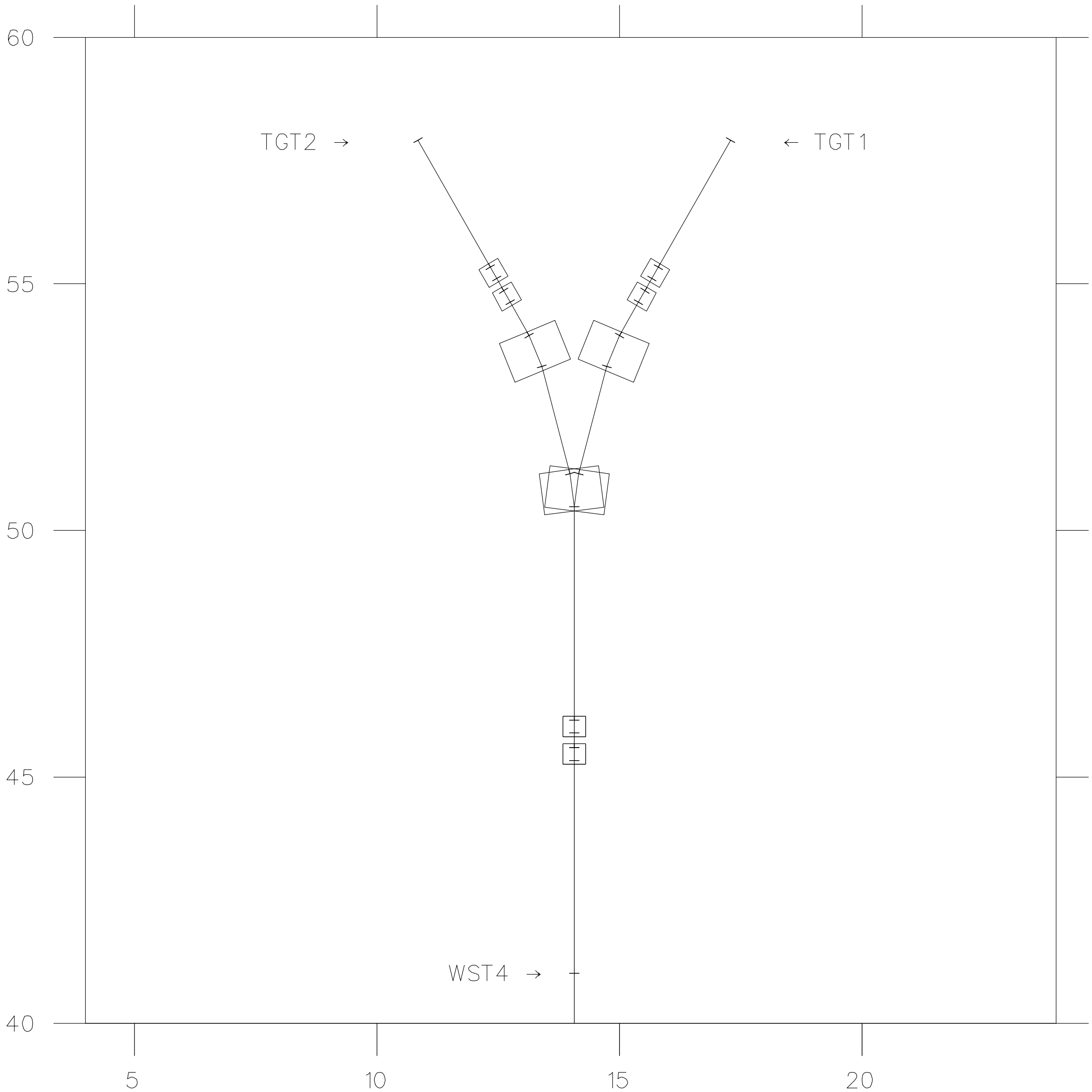

Figure 3. An enlarged view of the WST4 to target region of beam line 2A.

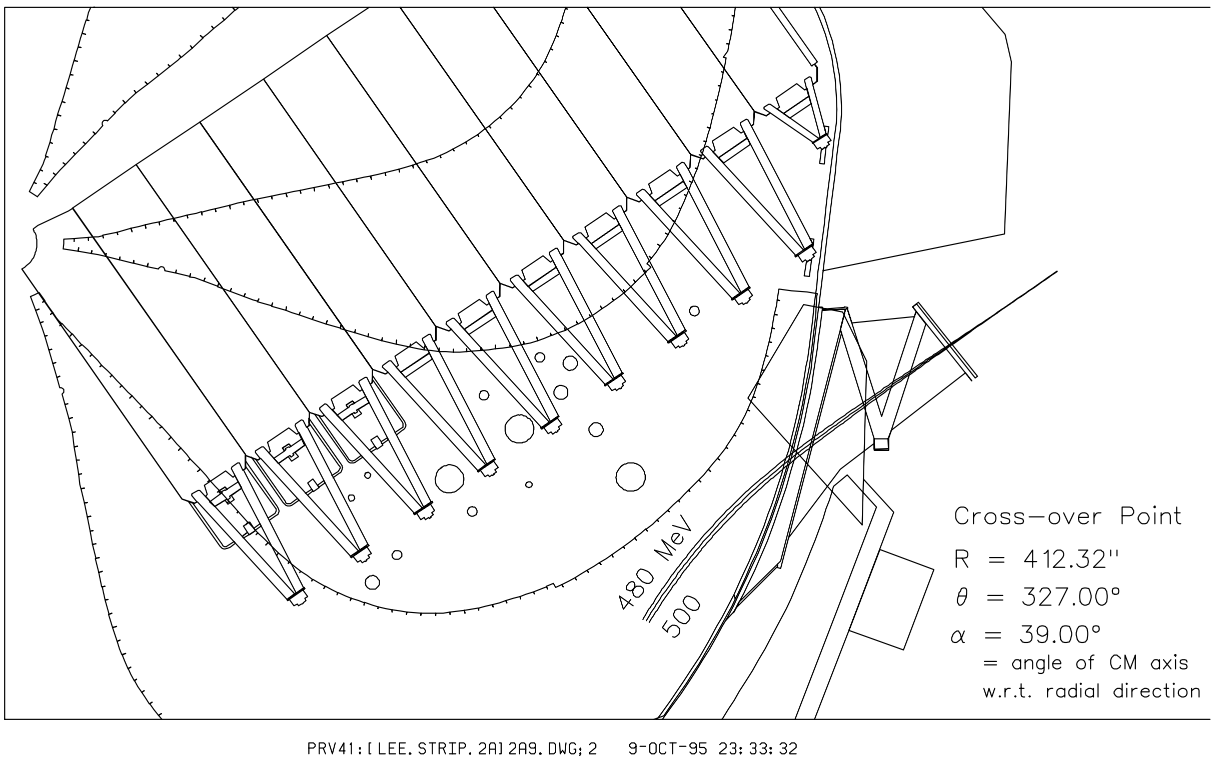

figure 4(a). The extraction trajectories for energies of 480, 490 and 500 MeV.

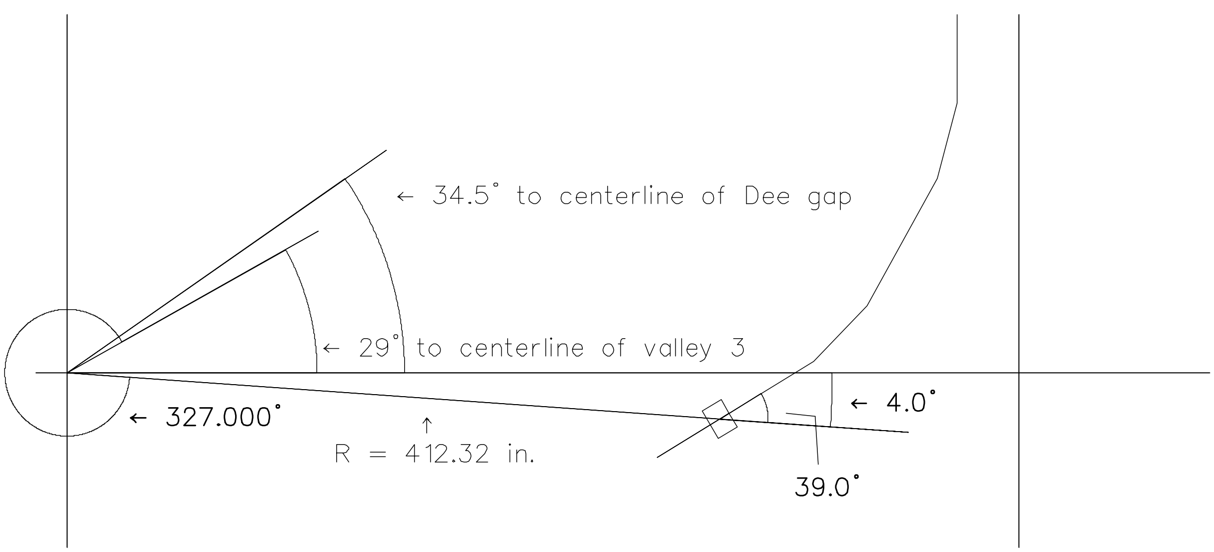

Figure 4(b). The essential geometry of beam line 2A extraction.

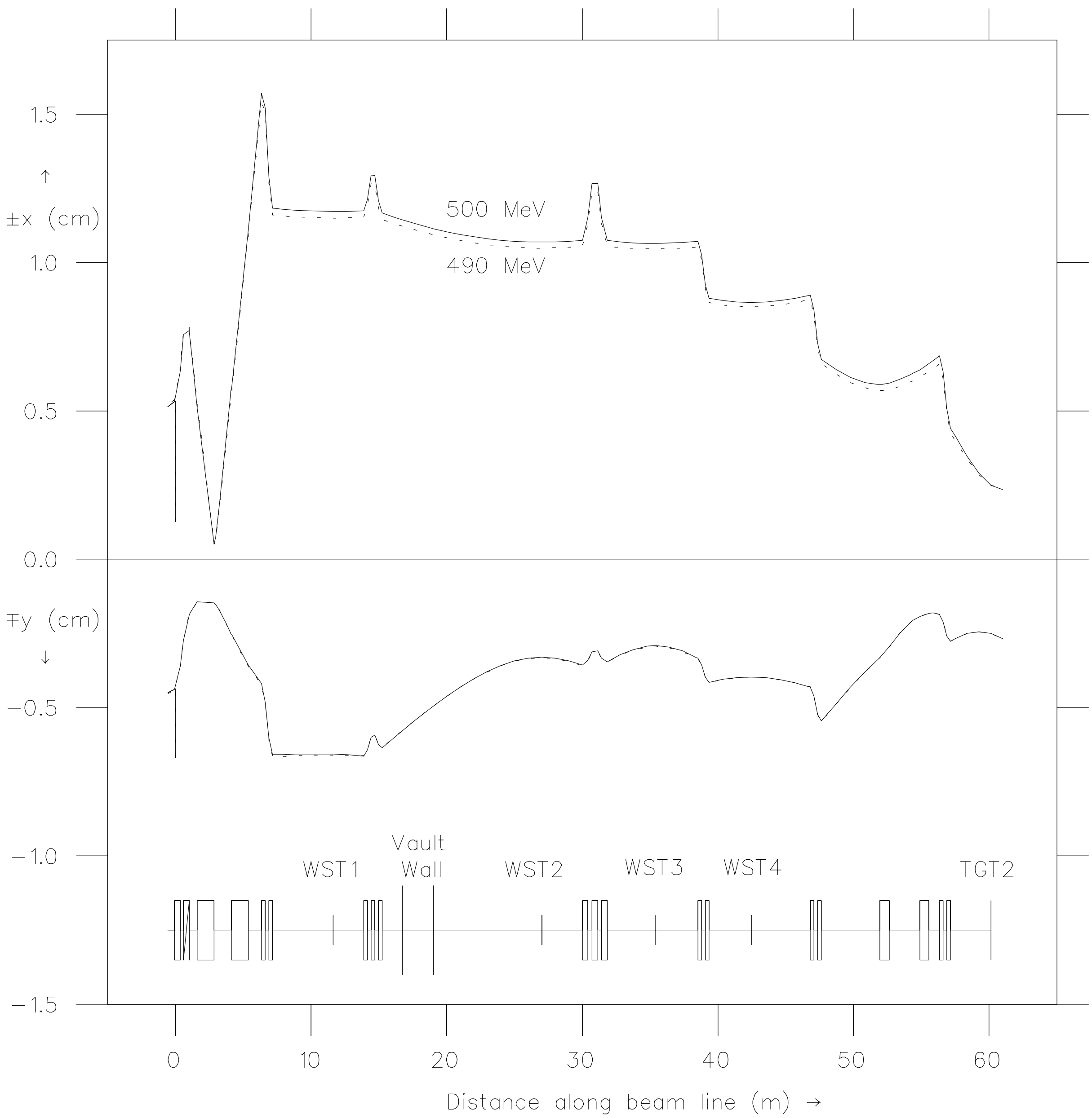

Figure 5. Beam envelopes along beam line 2A—beam delivery to TGT2.

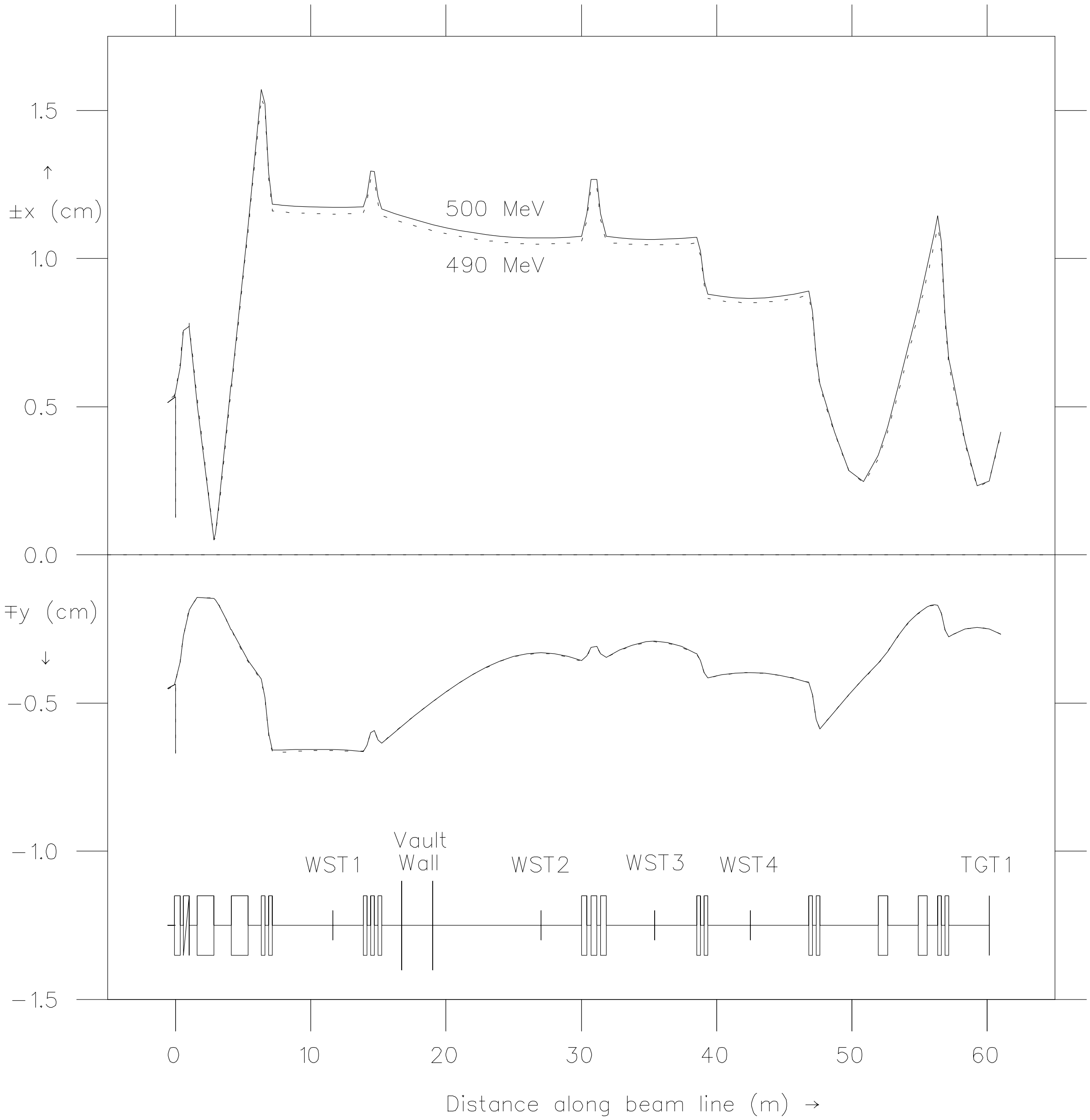

Figure 6. Beam envelopes along beam line 2A—beam delivery to TGT1.

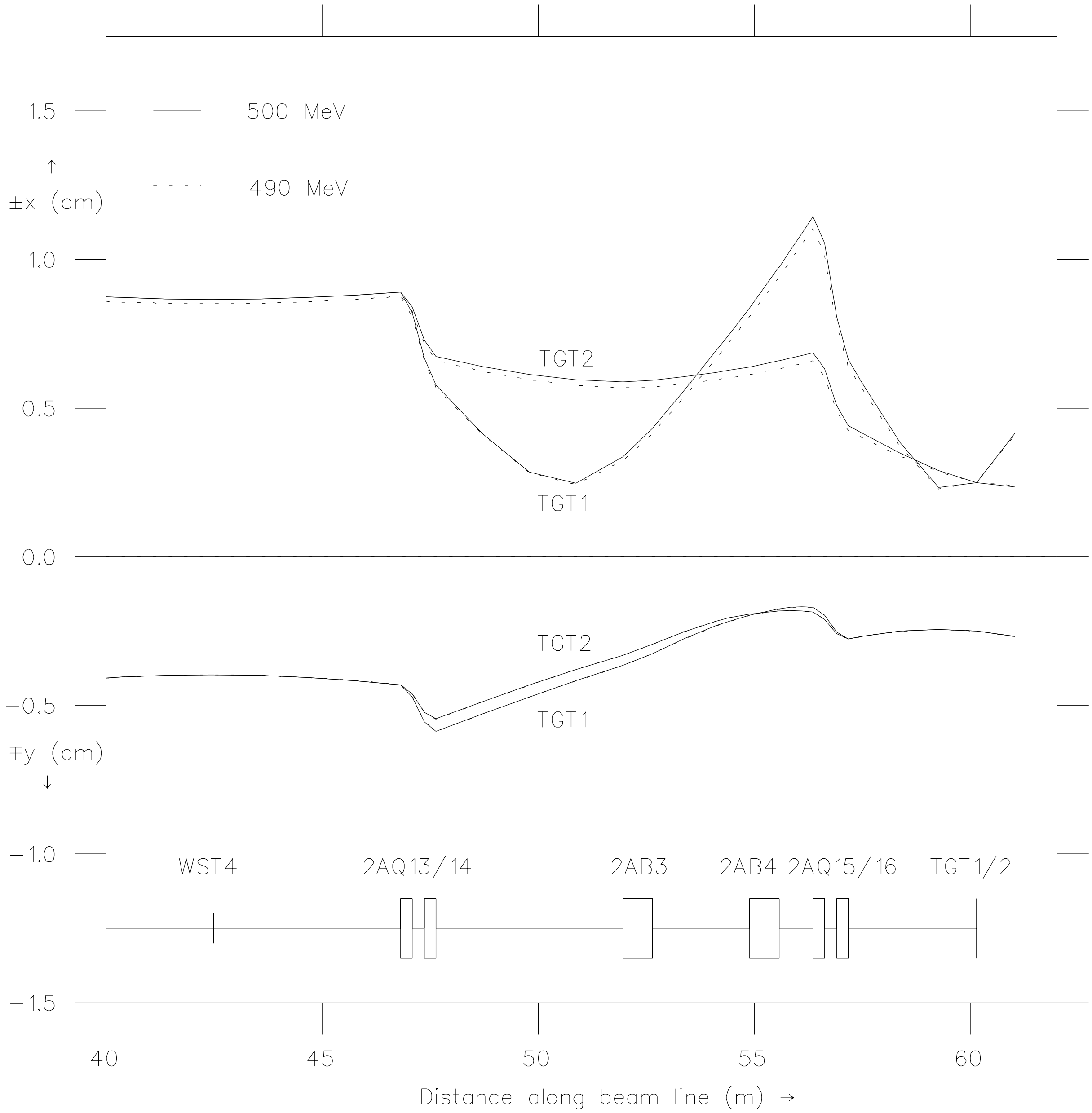

Figure 7. Enlarged beam profiles between WST4 and TGT1/2 locations on beam line 2A.

```
        DATA OF 95/10/10 ON 96/06/25 - 500 MEV ON 2-A - NEW TRIPLETS - 2xWst AT WST1 - TGT2

   Space # 1:  Distribution of particles as a function of  Y  AT WST1   (Element # 45)     (along HORIZONTAL axis)
                                                         & DY at WST1   (Element # 45)     (along VERTICAL axis)

    Distribution of particles INITIALLY ACCEPTED
                                                    COUNTS  = 150000.
                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                        2  4  7  9  2  4  5  6  5  4  2  9  7  4  2
                                     6  1  3  0  7  4  4  7  2  9  4  5  9  0  3  0  6
                                  4  8  7  1  8  7  3  5  0  9  4  3  8  6  8  0  5  2  3
                0  0  0  0  0  0  9  3  3  5  1  0  8  0  5  9  4  3  7  0  9  5  6  5  8  0  0  0  0  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   1.430     |                                                                                             |      0
D  1.210     |                                                                                             |      0 Y
Y 0.9900     -                                                                                             -      0
  0.7700     |                                                                                             |      0 P
A 0.5500     |                                                                                             |      0 R
T 0.3300     |                                                                                             |      0 O
  0.1100     |                         15 96281569909******************874519228 49  5                     |  11971 J
W -.1100     |                   49678*********************************************620 38                  | 125954 E
S -.3300     |                       5 68253482857******************913613292 81 13                        |  12075 C
T -.5500     |                                                                                             |      0 T
1 -.7700     |                                                                                             |      0 I
  -.9900     |                                                                                             |      0 O
  -1.210     -                                                                                             -      0 N
  -1.430     |                                                                                             |      0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  3  2  1  0  9  8  7  6  5  4  3  2  1  0  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4
                5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
                                                      Y  AT WST1

    REAL! Distribution of FINAL RUN FOUND HERE
                                                    COUNTS  = 149981.
                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                        2  4  7  9  2  4  5  6  5  4  2  9  7  4  2
                                  1  7  2  3  0  7  4  4  5  3  8  4  4  8  1  3  0  7
                                  0  2  1  5  1  7  5  2  6  1  6  0  8  9  4  5  6  1  6
                1  0  0  0  3  8  6  5  6  7  7  4  4  2  6  9  5  9  1  7  8  9  4  0  9  6  4  1  0  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   3.190     -                                                                                             -      0
   2.970     |                 1        1                                                                  |      2
   2.750     |                       1     1     1                                                         |      3
   2.530     |  1           2  1     1  1        1                                                         |      7
   2.310     |                                1  2  2  2        1                                          |      8
   2.090     |                 1           1  1  1     1  2                                                |      7
   1.870     |                    1  1        1     4  2     1     1                                       |     11
   1.650     |                    1  1  1  2     1  2  1  2  3                                             |     14
   1.430     |              1  1  2     2  1     2  4  3  1  3        1  1                                 |     22
D  1.210     |                    2  1  1  2  4  3  7  1  4  3  4  1  2     1                              |     36 Y
Y 0.9900     -                    2  1  3  4  4  3  9  7  7  3  7  8  4  2                                 -     64
  0.7700     |                 1  4  4  4 12 10 10 16 21 18 14 10 10  6  4  4                              |    148 P
A 0.5500     |                    3  7 16 22 30 42 35 43 48 32 42 31 20 14 11  3                           |    399 R
T 0.3300     |                 3  7 22 66107146185255290328314277248206142111 56 12                        |   2775 O
  0.1100     |                   41194514978*********************************773306 82                     |  31145 J
W -.1100     |                   42408*********************************************401 27                  |  80632 E
S -.3300     |                    1 81350750*********************************929493175 27  1               |  31097 C
T -.5500     |                       3 12 38 95162200247296317340267269236157109 49 24  6                  |   2827 T
1 -.7700     |                          1  7  9 22 31 29 38 44 43 48 48 29 35 29 13  9  3  2               |    440 I
  -.9900     |                             1  2  5  4 13 16 18 19 18 20  9  6  7  8  2  1  1               |    150 O
  -1.210     -                                1  2  3  7  3  9  6  8  7  5  8  5  4  4  2                  -     74 N
  -1.430     |                                      3  3  3  1  4  4  3  2  2  7  4  4                     |     40
  -1.650     |                                      3  1     4        4  4     2     2                     |     20
  -1.870     |                                               2  1  4  1        1  3  4  2     1            |     19
  -2.090     |                                            2        2  2     1  2     3     1  1  1         |     15
  -2.310     |                                               1  1        1  2  1                           |      6
  -2.530     |                                               1     2     2     1  1        1  1            |      9
  -2.750     |                                               1           1  1                 1            |      4
  -2.970     |                                                              1  2  2     1                  |      6
  -3.190     |                                                              1                              |      1
  -3.410     -                                                                                             -      0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  3  2  1  0  9  8  7  6  5  4  3  2  1  0  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4
                5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
                                                      Y  AT WST1
```

Figure 8. Predicted $\phi - y$ correlation at the WST1 location on beam line 2A.

```
 DATA OF 95/10/10 ON 96/06/25 - 500 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT2 - Y WAIST 0.9 M UPSTREAM OF TGT

Space # 3:  Distribution of particles as a function of  X  AT TGT2   (Element #149)     (along HORIZONTAL axis)
                                                   & Y  at TGT2   (Element #149)     (along VERTICAL axis)

 REAL! Distribution of FINAL RUN FOUND HERE
                                                COUNTS  = 149986.

                                                   X PROJECTION

                                                    1  1  1  1  1  1  1
                                     1  3  5  7  9  1  3  4  4  4  3  1  9  7  5  3  1
                               1  7  9  4  4  6  6  5  0  2  3  1  1  7  9  5  2  3  6  6  1
                            5  7  5  0  5  9  5  7  5  8  0  5  9  6  5  4  7  2  0  2  1  3  2  1
                5  6  6  8  0  5  5  1  1  8  2  2  7  6  7  3  9  9  5  9  3  9  8  4  8  2  3  0  5  1  9
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.5400     -                                                                                             -      0
  0.5000     |                                                  1                                          |      1
  0.4600     |                       1                                                                     |      1
  0.4200     |                                                        1     1                              |      2
  0.3800     |                       2                          2              1                           |      5
  0.3400     |                       1  1     3  1  2  3     2  5  1  5  3  1     1     1  1               |     31
  0.3000     |     1           2  1 10 12  9 10 29 29 27 20 44 40 25 30 19 20 15  6  6  1  1  1            |    358
  0.2600     |              2     4 10 39 51 81101106122142151159146124124 77 67 47 12  8  1  1            |   1575
Y 0.2200     |  1           1  4 16 50 96154198245281323326327357324314257164125 86 42 14  3  2  1         |   3711 Y
  0.1800     -        1  1  4  4 34 88131238327421496576665618589612485407332240132 59 25  5        1      -   6491
  0.1400     |  1           3  9 44141223350503659726879943883886839713628471337209 87 52  9  1            |   9596 P
A 0.1000     |        1  1  3 12 66162300461612839986***************991846657435267147 58 14  2  1        1|  12687 R
T 0.6000E-01 |     1     1  3 20 77208350521749974************************748583344161 49 12  2  2        2|  15202 O
  0.2000E-01 |  1     1  3  6 25 91227377619867***************************839560403168 70 15  4     1     2|  16760 J
T -.2000E-01 |  1        1  3 22 88195400619892***************************880595380188 76 13  2  1  2      |  17186 E
G -.6000E-01 |     1        9 23 92223408580909***************************853570346175 64 10  3  1         |  16717 C
T -.1000     |              4 19 77167357602782983************************780525333181 66 12  1            |  15334 T
2 -.1400     |           1  2 12 63151271441636782960***************897849638415273148 58 12     2        1|  12460 I
  -.1800     |     1  1     4  9 56119225357467619711827874904920795738666506358206102 33 10  1  1     1  1|   9512 O
  -.2200     -  1  2        2  4 25 80138255344411516576639662613584477451317201157 81 16  9  2            -   6563 N
  -.2600     |              2  5 16 45 83143170242294326376379407345285277199126 72 46 18  4     1  1      |   3862
  -.3000     |              1  4  5 17 29 80 82 93115127188129151118138 79 65 60 38 14  9  1               |   1543
  -.3400     |              1  1     4 10 17 19 17 21 26 35 37 30 30 21 24 23 15  7  5        1            |    344
  -.3800     |                                1  1  2  1  5  2  4  1  2  3  2  1  1  1                    2|     29
  -.4200     |        1                 1        2     2        2     1                                    |      9
  -.4600     |                             1        1     1  1                       1                     |      5
  -.5000     |                                                                                             |      0
  -.5400     |        1                                                                                    |      1
  -.5800     -                                               1                                             -      1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  4  4  3  3  3  2  2  2  1  1  1  0  0  0  0  0  0  1  1  1  2  2  2  3  3  3  4  4  4
                2  9  5  2  9  5  2  8  5  2  8  5  1  8  5  1  1  5  8  1  5  8  2  5  8  2  5  9  2  5  9
                7  3  9  5  1  7  3  9  5  1  7  3  9  5  1  7  7  1  5  9  3  7  1  5  9  3  7  1  5  9  3
                                                      X  AT TGT2
```

Figure 9. Predicted beam spot at the TGT2 location at 500 MeV.

```
 DATA OF 95/10/10 ON 96/09/30 - 500 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT1 - Y WAIST 0.9M UPSTREAM OF TGT

Space # 3:  Distribution of particles as a function of  X  AT TGT1   (Element #145)     (along HORIZONTAL axis)
                                                    & Y  at TGT1   (Element #145)     (along VERTICAL axis)

 REAL! Distribution of FINAL RUN FOUND HERE
                                               COUNTS  = 149981.

                                                 X PROJECTION

                                                    1  1  1  1  1  1  1
                                           2  5  9  2  6  8  9  8  6  3  9  5  2
                                        5  2  1  1  9  1  4  3  5  3  0  1  4  4  6
                                  1  5  9  0  4  6  8  8  1  8  6  4  6  6  6  7  5  4  1
                す  1  2  1  4  3  6  6  2  5  1  8  6  5  0  1  3  7  1  6  9  3  9  8  7  6  6  6  3  3  1  2
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.3625     -                                                                                             -        0
  0.3375     |                                                 1  1                                        |        2
  0.3125     |                             2     6  9  6 11 13 13 11 11  9  1  2                           |       94
  0.2875     |                      1  2 11 18 32 40 52 40 62 42 52 42 27 15  7  1                         |      444
  0.2625     |                         2 20 37 59 88109129141118110103 51 29 23  6                         |     1025
  0.2375     |                   1  1  5 19 48107167220261218247188174138 76 30  5                         |     1905
  0.2125     |          1           2 14 40106186263293363343384324236168102 39 11  1                      |     2876
  0.1875     |                   1  1 23 68134252375471504543499463350240181 74 17  1                      |     4197
  0.1625     |                      3 14 75186337425598658707670578446345201109 22  3     1                |     5378
Y 0.1375     |             1     2  1 29114224406575735793862800745539393257 91 29  2  1  1     1  1  1    |     6603 Y
  0.1125     -                1  1  2 22117276443726840931***950851717492297139 34  3              1       -     7864
  0.8750E-01 |          1  1     1  3 30136327518744931*********916749546345125 38  1  1                   |     8747 P
A 0.6250E-01 |                1  1  2 40131333598793991************850602384159 47  2  1  1              1|     9593 R
T 0.3750E-01 |                   1  5 47138357647839***************884643387177 51  3  1                   |    10324 O
  0.1250E-01 |  1        1           2 37146334628911***************952662380182 48  3  5                   |    10690 J
T -.1250E-01 |                      5 54156380669918***************909626375167 47  6        3             |    10823 E
G -.3750E-01 |                      3 41139392596913***************898650360178 46  2  1                   |    10590 C
T -.6250E-01 |     2        1  1  3  1 43131364630947***************922620349167 44  5  1                   |    10139 T
1 -.8750E-01 |                   1  7 35140329568860***************838589336163 40  6  1  2                |     9610 I
  -.1125     |                1     4 39122275502763961*********963781551319132 47     2        1          |     8752 O
  -.1375     -       1           1  2 34123248501704788913947967876677475254127 31  1  2     1             -     7673 N
  -.1625     |                      5 28118233442566673793847801684590397239106 32  3           1          |     6558
  -.1875     |                1  2  1 17 90180352457621687710646564470324206112 22  3                      |     5465
  -.2125     |                        12 66147283331444497520493450348223145 65 14  1        1           1|     4041
  -.2375     |          1        1  1 11 50 91178237337370391371302261172106 49 12           1     1       |     2943
  -.2625     |                1        8 26 74115178223203233216217186120 62 25 12        1                |     1900
  -.2875     |                         3 18 34 74 94112144141136151 85 73 34 21  2                         |     1122
  -.3125     |                         4  5 18 27 44 54 53 84 55 58 42 30 20  9     1                      |      504
  -.3375     |                               3  9 16 10 14 17 15 16  6  3  3  1                            |      113
  -.3625     |                         1        1  2        1     1                                       |        6
  -.3875     -                                                                                             -        0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  6  6  5  5  4  4  3  3  2  2  2  1  1  0  0  0  0  1  1  2  2  2  3  3  4  4  5  5  6  6
                9  5  0  6  1  7  2  8  3  9  4  0  5  1  6  2  2  6  1  5  0  4  9  3  8  2  7  1  6  0  5
                7  2  8  3  7  2  8  2  8  3  8  3  8  3  7  3  2  7  2  7  2  7  2  7  2  8  2  7  3  7  2
                                                 X  AT TGT1
```

Figure 10. Predicted beam spot at the TGT1 location at 500 MeV.

```
   DATA OF 95/10/10 ON 96/09/30 - 490 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT2 - Y WAIST 0.9M UPSTREAM OF TGT

  Space # 3:  Distribution of particles as a function of  X  AT TGT2   (Element #149)     (along HORIZONTAL axis)
                                                        & Y  at TGT2   (Element #149)     (along VERTICAL axis)

   REAL! Distribution of FINAL RUN FOUND HERE
                                                   COUNTS  = 149986.

                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                     1  3  5  7  9  1  3  4  4  4  3  1  9  7  5  3  1
                               1  6  8  3  4  6  6  5  1  2  5  2  2  8  9  5  1  2  6  5  1
                            4  6  9  3  7  6  0  9  6  4  8  5  3  6  2  3  5  8  1  0  6  2  2
                5  6  6  7  1  1  5  0  1  5  5  7  9  5  2  3  9  9  2  7  0  7  3  0  1  5  1  9  5  1  9
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.5800     -                                                                                             -        0
  0.5400     |                                                                                             |        0
  0.5000     |                                                                                             |        0
  0.4600     |                                                  1                                          |        1
  0.4200     |                                 1                                      1                    |        2
  0.3800     |                                 2                    1        1                             |        4
  0.3400     |                                 1  1     3     1        3  3  1  3  3  1  2                 |       22
  0.3000     |                 2     8 12  6 12 29 30 29 18 41 43 24 30 18 20 15  2  6  2  1  1            |      349
  0.2600     |     1        1     5 11 37 49 81 98104125143148166147132114 82 68 49 12  8  2  1            |     1584
Y 0.2200     |  1           2  2 15 49 82157198250284332327320374327309257166118 80 42 17  1  1  1         |     3712 Y
  0.1800     -        1  1  3  2 35 90140233320431502561652649580618480407336246131 55 20  5  1     1      -     6500
  0.1400     |  1           4  8 41135208347501661728883967893912842742620472322196 96 44  7  1            |     9631 P
A 0.1000     |        1  1  3 10 59145309462612833985******************837663433272130 57 12  2  1        1|    12639 R
T 0.6000E-01 |     1     1  2 18 68202328526742987************************753565325176 40 12  1  2        3|    15235 O
  0.2000E-01 |  1     1  3  3 21 95214370621838***************************826577377158 69 17  3     1     1|    16717 J
T -.2000E-01 |  1           3 22 78204379629891***************************873573390180 66 13  2  1  1      |    17204 E
G -.6000E-01 |              8 23 82205399588884***************************858575325179 56 11  3  1  1      |    16731 C
T -.1000     |     1        3 18 68162359583782986************************772528330180 51 13               |    15324 T
2 -.1400     |        1  1  2 11 60144269432642785959***************882845620412271143 58 11     3        1|    12458 I
  -.1800     |     2        2 12 47111223343480598722829888921919805755667506345202 97 33  9  1        1  1|     9519 O
  -.2200     -  1  1        1  6 23 81137253337416520555649673619575474453316207151 78 13  7  2     1      -     6549 N
  -.2600     |              2  3 14 44 77144181238307334385386400353286279195125 71 49 19  3  1            |     3896
  -.3000     |              1  2  5 19 30 75 83 86115119179138149125141 83 68 58 34 13  7  1               |     1531
  -.3400     |              1  1     2 10 16 18 20 21 27 35 36 32 29 25 21 19 18  6  4  1     1            |      343
  -.3800     |        1              1        3  2  2  3  1  1     3  2  3     1  1                    2|       26
  -.4200     |                          1        1     1  1  2                    1                        |        7
  -.4600     |                                                                                             |        0
  -.5000     |        1                                                                                    |        1
  -.5400     |                                           1                                                 |        1
  -.5800     |                                                                                             |        0
  -.6200     -                                                                                             -        0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  4  4  3  3  3  2  2  2  1  1  1  0  0  0  0  0  0  1  1  1  2  2  2  3  3  3  4  4  4
                2  9  5  2  9  5  2  8  5  2  8  5  1  8  5  1  1  5  8  1  5  8  2  5  8  2  5  9  2  5  9
                7  3  9  5  1  7  3  9  5  1  7  3  9  5  1  7  7  1  5  9  3  7  1  5  9  3  7  1  5  9  3
                                                      X  AT TGT2
```

Figure 11. Predicted beam spot at the TGT2 location at 490 MeV.

```
    DATA OF 95/10/10 ON 96/09/30 - 490 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT1 - Y WAIST 0.9M UPSTREAM OF TGT

  Space # 3:  Distribution of particles as a function of  X  AT TGT1   (Element #145)     (along HORIZONTAL axis)
                                                        & Y  at TGT1   (Element #145)     (along VERTICAL axis)

   REAL! Distribution of FINAL RUN FOUND HERE
                                                    COUNTS  = 149981.

                                                      X PROJECTION

                                                  1  1  1  1  1  1  1
                                         2  5  9  2  6  8  9  8  6  3  9  5  2
                                      5  2  1  1  9  1  4  3  5  3  0  1  4  4  6
                                1  5  9  0  4  6  8  8  1  8  6  4  6  6  6  7  5  4  1
                1  2  1  4  3  6  6  2  5  1  8  6  5  0  1  3  7  1  6  9  3  9  8  7  6  6  6  3  3  1  2
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.3625     -                                                                                             -       0
  0.3375     |                                               1  1                                          |       2
  0.3125     |                              2     6  9  6 11 13 13 11 11  9  1  2                          |      94
  0.2875     |                        1  2 11 18 32 40 52 40 62 42 52 42 27 15  7  1                       |     444
  0.2625     |                           2 20 37 59 88109129141118110103 51 29 23  6                       |    1025
  0.2375     |                     1  1  5 19 48107167220261218247188174138 76 30  5                       |    1905
  0.2125     |           1           2 14 40106186263293363343384324236168102 39 11  1                    |    2876
  0.1875     |                     1  1 23 68134252375471504543499463350240181 74 17  1                    |    4197
  0.1625     |                        3 14 75186337425598658707670578446345201109 22  3     1              |    5378
Y 0.1375     |              1     2  1 29114224406575735793862800745539393257 91 29  2  1  1     1  1  1   |    6603 Y
  0.1125     -                  1  1  2 22117276443726840931***950851717492297139 34  3              1      -    7864
  0.8750E-01 |           1  1     1  3 30136327518744931*********916749546345125 38  1  1                  |    8747 P
A 0.6250E-01 |                  1  1  2 40131333598793991************850602384159 47  2  1  1              1|    9593 R
T 0.3750E-01 |                     1  5 47138357647839***************884643387177 51  3  1                  |   10324 O
  0.1250E-01 |  1        1           2 37146334628911***************952662380182 48  3  5                  |   10690 J
T -.1250E-01 |                        5 54156380669918***************909626375167 47  6        3            |   10823 E
G -.3750E-01 |                        3 41139392596913***************898650360178 46  2  1                  |   10590 C
T -.6250E-01 |     2        1  1  3  1 43131364630947***************922620349167 44  5  1                  |   10139 T
1 -.8750E-01 |                     1  7 35140329568860***************838589336163 40  6  1  2               |    9610 I
  -.1125     |                  1     4 39122275502763961*********963781551319132 47     2        1         |    8752 O
  -.1375     -        1           1  2 34123248501704788913947967876677475254127 31  1  2     1            -    7673 N
  -.1625     |                        5 28118233442566673793847801684590397239106 32  3           1         |    6558
  -.1875     |                  1  2  1 17 90180352457621687710646564470324206112 22  3                     |    5465
  -.2125     |                           12 66147283331444497520493450348223145 65 14  1        1           1|    4041
  -.2375     |           1        1  1 11 50 91178237337370391371302261172106 49 12           1     1      |    2943
  -.2625     |                  1        8 26 74115178223203233216217186120 62 25 12        1               |    1900
  -.2875     |                           3 18 34 74 94112144141136151 85 73 34 21  2                        |    1122
  -.3125     |                           4  5 18 27 44 54 53 84 55 58 42 30 20  9     1                     |     504
  -.3375     |                                 3  9 16 10 14 17 15 16  6  3  3  1                           |     113
  -.3625     |                           1        1  2        1     1                                       |       6
  -.3875     -                                                                                             -       0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  6  6  5  5  4  4  3  3  2  2  2  1  1  0  0  0  0  1  1  2  2  2  3  3  4  4  5  5  6  6
                9  5  0  6  1  7  2  8  3  9  4  0  5  1  6  2  2  6  1  5  0  4  9  3  8  2  7  1  6  0  5
                7  2  8  3  7  2  8  2  8  3  8  3  8  3  7  3  2  7  2  7  2  7  2  7  2  8  2  7  3  7  2
                                                      X  AT TGT1
```

Figure 12. Predicted beam spot at the TGT1 location at 490 MeV.

```
  DATA OF 95/10/10 ON 96/09/30 - 480 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT2 - Y WAIST 0.9M UPSTREAM OF TGT

Space # 3:  Distribution of particles as a function of  X  AT TGT2   (Element #148)     (along HORIZONTAL axis)
                                                    & Y  at TGT2   (Element #148)     (along VERTICAL axis)

 REAL! Distribution of FINAL RUN FOUND HERE
                                                COUNTS  = 149984.

                                                  X PROJECTION

                                                    1  1  1  1  1  1  1
                                     1  3  5  7  9  1  3  4  4  4  3  1  9  7  5  3  1
                               1  6  8  4  2  7  8  7  2  1  4  1  1  5  8  5  3  3  6  5  1
                            2  5  6  4  0  8  5  2  3  2  9  7  3  6  8  0  9  8  0  6  8  1  2
                8  0  9  9  4  8  1  2  4  0  5  7  3  3  3  0  9  3  7  1  7  9  8  4  1  9  2  5  5  4  4
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.4350     -                                                  1                                          -       1
  0.4050     |                                                                                             |       0
  0.3750     |                              1  3                     2  1                              |       7
  0.3450     |                 3     1        3     3  1  1  3  3  1     1  3  1                           |      24
  0.3150     |        1        1  1  3     9  4  4 10 18 12  6  5 13 19 11  9  5  3  4  1                  |     139
  0.2850     |              1     3 10 10 24 36 32 35 59 55 55 52 61 46 35 40 20 13  4  1                  |     592
  0.2550     |        1        1  9 21 37 42 76111121137146122134126136 89 72 58 26 11 11           1      |    1488
  0.2250     |  2        1     7 13 38 61100143192207248254261262251216167123111 77 27 11  1               |    2773
  0.1950     |              3  3 17 65 89165220284328355417423427379346305225157107 40 21  4        1      |    4381
Y 0.1650     |           1     6 24 84136195300396454573625544572553462428326212128 82 21  7        1      |    6130 Y
  0.1350     -           2  2 12 35107186283412528617696695756741698591519409273172 77 22  5               -    7838
  0.1050     |  1     1  2    13 42119225316487598764884893876913849767598524313201111 46 10  1  1     1   |    9556 P
A 0.7500E-01 |                 6 41118241396556710852964*********965781670561364240110 39  9  1  1         |   10789 R
T 0.4500E-01 |  1     1     3  8 46130266421648778972***************900798618433255117 50  9  2     1      |   11974 O
  0.1500E-01 |           1  3  8 45150272443724863924***************978892629483279147 38  9  3  1        1|   12699 J
T -.1500E-01 |        1     2 11 60156296476658821******************973775620470277157 57  8  4     1      |   12850 E
G -.4500E-01 |        2     1 15 63154268463664792******************982864627451278144 43 10  2            |   12662 C
T -.7500E-01 |  1     1  1  1 13 55154279411595784946***************972765615444267127 53  9  2  1         |   12087 T
2 -.1050     |              2 16 45148263385552740805************943801743542413244126 41  6  3           1|   11006 I
  -.1350     |              1 12 48115234315491670748813927974848808737631493335218 98 34  7  1        1  1|    9560 O
  -.1650     -              2 10 38 98159283397497654689705792724712611506380315179 89 35 10  1            -    7886 N
  -.1950     |  1           2  2 23 64150217322391488529605553570539514404301200144 79 26  6  1           1|    6132
  -.2250     |  1     1        5 22 49117159222286323359411407433406362280210159 95 57 17  6           1   |    4388
  -.2550     |  1        1  1  4 16 27 68 93137191199225245304243235212168139 97 60 25  7  2               |    2700
  -.2850     |                 2  9 23 28 56 71 96106136146162153142113 96 79 48 31 21  3  1  1            |    1523
  -.3150     |                    4  7 13 25 32 47 41 47 55 60 59 59 57 44 38 21 14  8  4                  |     635
  -.3450     |                    2  1  4  2  4 12  7 18 12 15 17  6 11 10 11  5     3           1         |     141
  -.3750     |                                   1  2  3  1     3              1                           |      11
  -.4050     |                          1           2     1  1              1                              |       6
  -.4350     |                          1           1           1           1                              |       4
  -.4650     -                             1                                                         1     -       2
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  4  4  3  3  3  2  2  2  1  1  1  0  0  0  0  0  0  1  1  1  2  2  2  3  3  3  4  4  4
                2  9  5  2  9  5  2  8  5  2  8  5  1  8  5  1  1  5  8  1  5  8  2  5  8  2  5  9  2  5  9
                7  3  9  5  1  7  3  9  5  1  7  3  9  5  1  7  7  1  5  9  3  7  1  5  9  3  7  1  5  9  3
                                                  X  AT TGT2
```

Figure 13. Predicted beam spot at the TGT2 location at 480 MeV.

```
 DATA OF 95/10/10 ON 96/09/30 - 480 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT1 - Y WAIST 0.9M UPSTREAM OF TGT

Space # 3:  Distribution of particles as a function of  X  AT TGT1   (Element #144)     (along HORIZONTAL axis)
                                                      & Y  at TGT1   (Element #144)     (along VERTICAL axis)

 REAL! Distribution of FINAL RUN FOUND HERE
                                                   COUNTS  = 149986.

                                                     X PROJECTION

                                                    1  1  1  1  1  1  1
                                           2  5  9  3  6  8  9  8  6  3  9  5  2
                                        5  2  1  0  0  0  3  0  4  6  1  3  5  3  6
                                  1  8  4  9  4  6  4  8  1  5  8  7  2  2  9  7  2  8  2
                0  2  0  2  3  3  7  1  8  2  7  7  7  6  0  8  5  4  4  2  4  6  5  6  1  6  6  3  1  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.3625     -                                                                                             -       0
  0.3375     |                                1                       1                                    |       2
  0.3125     |                             4  4  5  4  6  9 19 14 19 13  6  3  3  1                        |     110
  0.2875     |                      1  1  2  8 14 21 34 53 51 42 60 39 40 31 11  8  2                        |     418
  0.2625     |                            6 12 37 60 87133132134121100 99 58 46 21  3  2              1      |    1052
  0.2375     |                      1  1 14 29 66106148215232229248207150140 61 34  6  1     1               |    1889
  0.2125     |                      1  1  5 55108172271349322378378330276179116 37 11  5     2               |    2996
  0.1875     |                         3 18 52116270364431547488499415345242134 78 18  1        1            |    4022
  0.1625     |                         3 23 82188312453552671662658623464333193 91 22     2     1            |    5333
Y 0.1375     |                         5 25104252395621693801862816730594368249100 26  4                     |    6645 Y
  0.1125     -                   1  1  4 25106270482696861938995911859679493268115 33  5  1                  -    7743
  0.8750E-01 |     1                1  3 27137315506784931*********971749563344132 23  4  2     1  1         |    8748 P
A 0.6250E-01 |           1     1     5 34147371544877997************822609392160 39  4                     |    9561 R
T 0.3750E-01 |                         5 42151326623886***************890629401140 50  3  3  2     1         |   10244 O
  0.1250E-01 |                      3  4 35149365654909***************929674369154 33  7  1                  |   10582 J
T -.1250E-01 |                      1  5 37181365646907***************954666405187 47 11  1  1     1         |   10846 E
G -.3750E-01 |              1     2  3 37163390666925***************906653362154 43  7                     |   10543 C
T -.6250E-01 |                      1  4 45180357623859***************913688393175 48  5  1     1            |   10461 T
1 -.8750E-01 |              1        5 41144306596810***************881602378163 39  9  1                  |    9751 I
  -.1125     |           1        1  8 28132282549767945************740521329139 44  3  1     2            |    8882 O
  -.1375     -                   1  1  7 21127247476643835939957976825658472286128 36  5  2                  -    7642 N
  -.1625     |              1     1  4 19 93211395579700779798837714604369239105 25  3  1                  |    6477
  -.1875     |                         4 23 80174320425574663741630609520365211 64 29  1  2                  |    5435
  -.2125     |     1                1  4 17 59148249377448487487484464352225184 78 19  3                     |    4087
  -.2375     |                      1  2 13 40109167283293366425346312227193112 53 15  3  1                  |    2961
  -.2625     |                            2 34 73113170171231248238208176131 65 27  4     2                  |    1893
  -.2875     |                            6 14 36 76 97 91121143134122 91 80 29 17  3                        |    1060
  -.3125     |                            3  8 10 38 56 70 58 54 52 43 43 24 11 10  4                        |     484
  -.3375     |                               1  6  3 14 14 16 17  8 12  7  8  3  3  2                        |     114
  -.3625     |                                           1  1     1     1  1                                    |       5
  -.3875     -                                                                                             -       0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  6  6  5  5  4  4  3  3  2  2  2  1  1  0  0  0  0  1  1  2  2  2  3  3  4  4  5  5  6  6
                9  5  0  6  1  7  2  8  3  9  4  0  5  1  6  2  2  6  1  5  0  4  9  3  8  2  7  1  6  0  5
                7  2  8  3  7  2  8  2  8  3  8  3  8  3  7  3  2  7  2  7  2  7  2  7  2  8  2  7  3  7  2
                                                     X  AT TGT1
```

Figure 14. Predicted beam spot at the TGT1 location at 480 MeV.

```
   DATA OF 95/10/10 ON 96/06/25 - 500 MEV ON 2-A - MOVE Q15 - 2xWst @ WST1 - TGT2 - Y WAIST 0.9 M UPSTREAM OF TGT

  Space # 5:  Distribution of particles as a function of  X  AT TGT2   (Element #149)     (along HORIZONTAL axis)
                                                        & P  at TGT2   (Element #149)     (along VERTICAL axis)

   REAL! Distribution of FINAL RUN FOUND HERE
                                                    COUNTS  = 149986.

                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                     1  3  5  7  9  1  3  4  4  4  3  1  9  7  5  3  1
                               1  7  9  4  4  6  6  5  0  2  3  1  1  7  9  5  2  3  6  6  1
                            5  7  5  0  5  9  5  7  5  8  0  5  9  6  5  4  7  2  0  2  1  3  2  1
                5  6  6  8  0  5  5  1  1  8  2  2  7  6  7  3  9  9  5  9  3  9  8  4  8  2  3  0  5  1  9
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   1.091     -                                                                                             -      0
   1.091     |  1     1     2  7 26 86112180272342371431502490440449405312281178111 57 36  7  1           1|   5101
   1.091     |              2 12 28 59134198291362398455465509528488412362271202115 66 34  6     1         |   5398
   1.091     |  1        1  1  8 26 79121214280363387460487496516467444415283178119 59 28  5              1|   5439
   1.091     |           1  1  5 28 75119194280346438487472506509494435359321188129 58 23  7     2     1   |   5478
   1.091     |     2        5  7 23 62117188259344384479517478547477439365271210131 62 22  7        1      |   5397
   1.091     |           1     4 19 78105189269331441460546552510510415399271198127 55 24  7  1     1      |   5513
   1.091     |     1     1  1  6 30 83139185278348432494519519489494414372240208133 60 21  7               |   5474
   1.091     |              1  6 30 61123205299377440462525525518476439341274200105 59 13  1               |   5480
P  1.090     |        1     1  5 27 70132224271365401476521516537478410367286195128 54 21  7              1|   5494 Y
   1.090     -  1              4 28 76128195273346431484516486537466437336287198107 54 26  3               -   5419
   1.090     |     1        3  8 29 90121196279356402451525550532475427392291191107 62 26  4  2  1         |   5521 P
A  1.090     |           1  2  7 29 62118203291353428482548492537475451322305201126 71 21  6  1           1|   5533 R
T  1.090     |           1  2  4 34 62111202259347420455495491498451436364245180143 58 28  4  2  1         |   5293 O
   1.090     |           1  1  7 26 51138224263356374503515506499478399378271186125 67 21  5  2  1         |   5397 J
T  1.090     |        2     4  3 29 73130200279388441453502562511452398338299186118 64 19  7               |   5458 E
G  1.090     |              4 13 26 72118186291345420462528547507492421349286195119 77 19  8  3  1         |   5489 C
T  1.090     |              1  5 30 66105215281348441456540551530460417374290183117 70 24  3     1         |   5508 T
2  1.090     |  1     1     1 10 31 55106198306332441460520520523475394371250183139 55 20  5        1     1|   5399 I
   1.090     |              3  5 32 69152208300325394522511535514453423354240198123 60 25  5  1           1|   5453 O
   1.090     -              3  4 25 75131178272336448494521527511444431356271179108 57 18  4  1  1         -   5395 N
   1.089     |  1        1  2  3 26 66115208268347437526524531507553436352277199120 48 17  5  3     1      |   5573
   1.089     |              1  6 29 56126187275349439478518529528452414370246194115 53 27  2               |   5394
   1.089     |              2 10 28 75156196282344429469535542518470444358263158131 55 17     1            |   5483
   1.089     |        1     4  7 24 60129216301351393496517506533507459364268185109 48 19  3        1     1|   5502
   1.089     |              1  3 24 72128193235343452501498532522482462377286179118 50 25  6  1  1        1|   5492
   1.089     |     1           6 24 65127205257401435492544541531459459356294203102 56 19  3  1            |   5581
   1.089     |              1  8 27 62130200285345406462497542488520399354247168110 56 15  2  3            |   5327
   1.089     |     1        1  2 17 41 80111154179234235298271279272235192159105 73 33 10  3              1|   2986
   1.089     |                             2  3     1  1  1                 1                              |      9
   1.089     -                                                                                             -      0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  4  4  3  3  3  2  2  2  1  1  1  0  0  0  0  0  0  1  1  1  2  2  2  3  3  3  4  4  4
                2  9  5  2  9  5  2  8  5  2  8  5  1  8  5  1  1  5  8  1  5  8  2  5  8  2  5  9  2  5  9
                7  3  9  5  1  7  3  9  5  1  7  3  9  5  1  7  7  1  5  9  3  7  1  5  9  3  7  1  5  9  3
                                                      X  AT TGT2
```

Figure 15. Predicted correlation of momentum and horizontal position at the TGT2 location at 500 MeV.

```
      DATA OF 95/10/10 ON 96/09/26 - 500 MEV - MOVE 2AQ15 - 0.001" SS 1.0 M UPSTREAM

 Space #3:  Distribution of particles as a function of  X  AT TGT2   (Element #152)     (along HORIZONTAL axis)
                                                      & Y  at TGT2   (Element #152)     (along VERTICAL axis)

  REAL! Distribution of FINAL RUN FOUND HERE
                                                    COUNTS  = 149944.

                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                    1  2  3  5  7  9  1  2  3  3  3  2  1  9  7  5  3  2  1
                1        1  3  7  4  5  8  6  6  3  1  1  1  4  1  3  1  4  7  5  7  3  3  6  2  1        1
                5  4  6  4  0  2  0  5  7  5  4  9  8  8  1  5  3  2  6  0  1  2  9  9  0  0  8  3  6  4  3
                5  7  3  9  5  1  9  6  5  9  1  5  7  9  5  3  4  5  6  0  5  8  6  9  3  0  7  0  2  0  9
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
  0.5800     - 18  3  1  3  1     2  2  1  2  3  3  2  3  1  1  2  2  5  6  1  2  3  1  3  2  2     1  1 18-       95
  0.5400     |  1                 2     1     1  2     1  1  1  2        2  1                          1   |       16
  0.5000     |  1        1  1     1        1  1        1     2  3  2     1  2  1     2  1        1         |       22
  0.4600     |  3     1     3  3  3  1  2  3        1  1  2  2  2  1  1  1  1  1           2  1            |       35
  0.4200     |  1     1     1  1  2  3  3  3  3  2  2  5  5  6  3  5  7  4  4  1  7  2  1  3     2        2|       79
  0.3800     |  2     1     5  2  2  3  6  6  7  7 10 10 15 13 13 13 17  8  7  4  3  5  3  2  1  1  1     5|      172
  0.3400     |  5  1  2  2  4  5  4 10  8 17 18 20 38 42 47 45 38 28 19 35 26 11 13  9  9  3  4     1  2  2|      468
  0.3000     |  7     1  1  1  6 17 18 35 36 49 60 70 90103101 94104 84 65 51 44 27 27 12  6  6  2  2     2|     1121
  0.2600     |  1     1  1  3 12 34 40 60 95145144191201205228203172169150115100 73 43 24  7  2  3  3  3  5|     2433
Y 0.2200     |  5  1  1  4 11 28 39 78 87157227284379352362387405351326293218150103 79 42 20  9  6  3     7|     4414 Y
  0.1800     -  3     1  7 11 36 81121192232356428496552550588598575501422347261187115 47 23  8  8     1  3-     6750
  0.1400     |  7     4  7 20 45 83173243382501608693775864827845809689588517361213132 78 37 16 11  3  3  3|     9537 P
A 0.1000     |  4  3  4  7 28 53 98203292458601774947983************952794604427306210108 50 29 11  3  5  6|    12195 R
T 0.6000E-01 |  6  7  2 13 26 74124229366533724921*********************926759522355224114 44 20 10  7  3  7|    14204 O
  0.2000E-01 |  3     3 15 34 60138260416601817958*********************938795576365223151 50 27 13 10  6  9|    15448 J
T -.2000E-01 |  8  4  8 18 22 70174295405625856************************994825613415251129 67 25 14  2  1  7|    16234 E
G -.6000E-01 |  7  5  7 18 33 68132237423614772************************941845586389236144 71 38  4  3     9|    15579 C
T -.1000     | 10  7  9  9 43 65125224375505676874*********************900716500339215111 69 29 11  5     9|    14089 T
2 -.1400     |  9  1  5 12  8 66103202297436607763912989*********920940750630442326187 84 44 15  8  7  4  4|    11923 I
  -.1800     |  8  1    11 14 39 98167247364461578691771855899831741674653446345237156 90 38 15  6  2  3  8|     9449 O
  -.2200     -  4  7  2  2 11 37 62128169265357419487529629633585556519436350245168109 58 26  8  2  2  1  3-     6809 N
  -.2600     |  8  3  2  5  9 21 36 87118173247266335386378389410307338257244164135 90 44 20 14  5  1     2|     4494
  -.3000     |  4     1  4  6  8 23 38 76 83102139190203194225200202185142130 98 69 41 20  9  7  3  2  1  1|     2406
  -.3400     |  3  1  1  3  2 12 10 18 28 36 62 76 81 85 91 98 83 83 67 55 39 46 34 22 12  3  5  3     1  3|     1063
  -.3800     |  4  1  1  1  4  3  6 11 10 18 23 32 33 36 36 34 39 31 32 23 25 17 17 10 11     2  3     1  2|      466
  -.4200     |  1        1     1  4  6  7  7  8  9  7 13 16 21 13  9 17 11  9  4  5  1  3     1           2|      176
  -.4600     |  1  1                 1  4  2  8  5  5  8  4  6  6  6  6  1  3  4  2  1     2  1     1     1|       79
  -.5000     |  2     1     1  1  3              4  3  1  2  1  3     4  3  1  2  1  1        1     1     2|       38
  -.5400     |        1  1  1  1        2  1  4  1  1  3  1  4  2  1        2     2  3  1           1     3|       36
  -.5800     |  2     1     1              1  1     2  2  1        1  2              1                    2|       17
  -.6200     - 17  1  1  3  1  4  3  1  2  3  4  2  2  4  4  2  3  3  2  1  2  1  2  3  3  2  1  3  1  3 11-       95
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                5  4  4  4  3  3  3  2  2  2  1  1  1  0  0  0  0  0  0  1  1  1  2  2  2  3  3  3  4  4  4
                2  9  5  2  9  5  2  8  5  2  8  5  1  8  5  1  1  5  8  1  5  8  2  5  8  2  5  9  2  5  9
                7  3  9  5  1  7  3  9  5  1  7  3  9  5  1  7  7  1  5  9  3  7  1  5  9  3  7  1  5  9  3
                                                      X  AT TGT2
```

Figure 16. Predicted beam spot at the TGT2 location at 500 MeV including foil and window scattering.