TRIUMF	UNIVERSITY OF ALBERTA EDMONTON, ALBERTA	
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Subject The effect of a window upstream of a target on beam line 2A		

1. Introduction

At the 2A Design Team meeting on Wednesday, September 11, 1966, one of the items that arose was that of the placement of a window at the end of the beam line upstream of the target vessel. Some of us, the author included, had the erroneous impression that beam-line vacuum would be maintained up to the front face of the target vessel. It then became clear that a study of the effect of a window in the line would have both on beam size at the target and additional beam spill.

This note presents a study of such an effect with the use of the program REVMOC.

2. Method of approach

In order to minimize the effect of scattering in a window on the beam size at the target, it is clear that the window should be placed as close to the target as possible. Given that the distance from the entrance of the target vessel to the target proper is of the order of 36 inches and that this region is under relatively poor vacuum, the closest practical point of installation of a window is approximately 1 metre upstream of the target itself.

Consequently, this study was restricted to the placement of a stainless steel window, 0.001 in. thick, at distances of 1 m, 1.5 m and 2 m upstream of the target volume. Because the REVMOC program allows a maximum of three components to be specified for any material placed in the beam path, the stainless steel window was assumed to consist of 75% nickel (Z = 28), 16% chromium (Z = 24) and 9% iron (Z = 26) and to have to have a density of 8.83 gm/cm^3. Further, this study was only conducted at a beam energy of 500 MeV, the assumption being that there would be little change in the results for beam energies between 480 MeV and 500 MeV.

REVMOC runs were made tracing 150,000 particles from the stripper foil to the target with a window installed at each of the three locations noted above. In addition, a run with no window was also made in order to have a reference beam size at the target and a reference beam-spill along the beam line. All runs were made with the same random-number seed.

Note that, as used here, no window means that there is no window in the beam line itself. Any windows external to the beam line proper are *not* included.

3. Results of the study

Results given below are predicated on a 0.00118 in.-thick carbon stripping foil and, as noted above, a 0.001 in.-thick stainless steel window that is located near the end of the beam line. REVMOC predicts that in the stripper foil the 1/e scattering angle is 0.17 mr, the probable energy loss (Landau distribution) is $1.073\times10^{-}2$ MeV and the average energy loss is 1.651×10^{-2} MeV. Similar predictions for the stainless-steel window are 0.69 mr, 2.969×10^{-2} MeV and 4.462×10^{-2} MeV respectively.

The discussion below is broken into two parts. The first sub-section will show the predicted effect of the window on the beam size at the entrance of the target material; the second will present the predicted effect on beam spill in the beam line.

3.1 The effect of the window on beam size at the target

For reference purposes, figure 1 shows the predicted beam spot at the target for a beam energy of 500 MeV. The upper portion of the figure shows what is expected *without* foil scattering. The lower portion shows the predicted beam profile taking foil scattering into account. As pointed out in ref[1], the vertical beam divergence at the scattering foil is quite small. Consequently, foil scattering contributeS significantly to the vertical divergence after stripping and thus also to the vertical size. Conversely, the horizontal divergence is large relative to that contributed by foil scattering and the horizontal beam size is (relatively) unaffected. The overall result is that although the nominal TRANSPORT design is for a beam size 5 mm in diameter at the target, there is a significant increase in the vertical beam size at that point.

(There is provision in TRANSPORT to include effects such as foil scattering and this was in fact done using the scattering predicted by REVMOC. However, in TRANSPORT, such scattering is added in quadrature with the beam divergences whereas in REVMOC such scattering is randomly chosen from the scattering distribution. Thus REVMOC includes some relatively large scattering angles with the result that (relatively) large angle 'tails' can appear in the calculated distributions of the combined divergences. This is clearly shown by comparing figures 2 and 3. The former shows a plot of the horizontal divergence in mr against the horizontal size in cm. The upper portion of figure 2 shows the correlation with *no* scattering; the lower portion shows that with scattering. A tail has developed but most (99.94%) of the beam remains within the ±3.4 mm size that is predicted without scattering. Figure 3 is a similar plot of the vertical divergence against the vertical size. In this case a large tail is developed in the vertical beam size. It is predicted that 1.08% of the scattered beam lies outside of the ±4.5 mm size predicted without scattering.)

Figures 4, 5, 6 and 7 show, on the same scales, the beam-spot predictions at the target for the cases of no window and of a window 1 m, 1.5 m and 2 m upstream of the target respectively. In all cases, foil scattering is included. Note, in particular, that the scales—particularly the horizontal—are larger than those of the previous figures. Therefore these figures cannot be compared directly with the others. They can, however, be compared with each other.

We begin our analysis by *defining* the nominal beam size at the target from the dimensions predicted in figure 4. Thus we define the horizontal beam size at the target to be ±4 mm, a dimension that clearly encompasses greater than 99% of the beam in the horizontal plane. Similarly, we define the vertical beam size at the target to be ±5 mm, again a dimension encompassing approximately 99% of the beam in the vertical dimension.

We then tabulate for the three locations of the window the percentage of beam lying *outside* of these nominal beam dimensions. In all cases, the window is made of stainless steel that is 0.001 in. thick.

Table 1
The percentage of beam outside of the nominal beam dimension at the target

Window location	Percentage of beam outside	
	$x = \pm 4.0$ mm	$y = \pm 5.0$ mm
No window (Nominal beam size)	0.031	1.097
Window 1.0 m upstream of the target	0.158	1.357
Window 1.5 m upstream of the target	1.260	1.882
Window 2.0 m upstream of the target	2.611	2.554

Table 1 confirms what is to be expected. As the window is moved further upstream from the target, the larger the beam size at the target becomes. The horizontal beam size is affected more than the vertical because the nominal horizontal beam size is smaller than that in the vertical plane and thus is more affected by window scattering. Further, the vertical beam divergence has already been increased significantly by foil scattering so that scattering in the window has relatively little effect on it. However, even with a window located 2 m upstream of the target, approximately 97.5% of the beam is still contained within an area of $(\pm x, \pm y) = (\pm 4$ mm, ± 5 mm$)$.

3.2 The effect of the window on beam spill in the beam line

We tabulate below the beam spill predicted by REVMOC together with the locations at which it is predicted to occur. All percentages are expressed in beam loss from the stripped beam. (The first two lines of the table are included only to check the consistency of the calculations.)

Table 2
The predicted percentages of beam loss for the various window locations

Location	Percentage of initial beam lost along the beam line			
	No Window	Window located upstream of target by 2 m	1.5 m	1 m
Stripper foil	0.0063	0.0057	0.0052	0.0061
Combination magnet exit	0.0033	0.0031	0.0028	0.0033
2.0 m upstream of the target		0.0197		
1.5 m upstream of the target		0.0044	0.0200	
1.0 m upstream of the target		0.0082	0.0047	0.0204
0.5 m upstream of the target		0.0026	0.0076	0.0038
Target		0.0016	0.0026	0.0078

REVMOC predicts that all beam loss in the stripper foil *and* in the windows themselves is by absorption. Consequently, these losses do not contribute to activation of the beam line itself.

It is seen that REVMOC predicts beam spill downstream of any window. For a window located 2 m upstream of the target an additional beam spill of 0.0168% is to be expected downstream of the window. At a beam current of 100 μA this corresponds to a loss of 16.8 nA distributed over a 2 m distance. Similar numbers for a window located 1.5 m and 1 m upstream of the target are, respectively, 0.0149% (14.9 nA) and 0.0116% (11.6 nA).

This makes it clear that if a window is to be installed it should be installed as close to the target as possible.

4. Energy deposition in the window

For completeness, we estimate here the energy loss in a 0.001 in. thick stainless-steel window.

In section 3 it was noted that REVMOC predicts an average energy loss of 4.46×10^{-2} MeV. Consequently, at a beam current of 100 μA a loss of $(4.46\times10^{-2}$ MeV$)\times(100$ μA$) = 4.46$ W is to be expected in the window.

To calculate the power density in the window we assume 5 W is lost. Because the beam is converging toward the target, the beam size on the window will be a function of its distance upstream of the target. These we tabulate on the next page. It is seen that the power density is low.

Table 3
Calculation of the power density in the windows

Parameter	Window located upstream of target by 2 m	1.5 m	1 m
Horizontal size ($\pm x$ mm)	5.25	2.70	1.50
Percent of beam within $\pm x$	98.77	98.80	99.17
Vertical size ($\pm y$ mm)	2.25	4.50	4.50
Percent of beam within $\pm y$	95.71	97.02	99.14
Area ($2x \times 2y$ mm^2)	47.25	48.60	27.00
Power deposited (W)	5.0	5.0	5.0
Power density (W/mm^2)	0.106	0.103	0.185

5. Discussion

This note has presented a study of the optimum location of a window on beam line 2A. As expected, the result is that the window should be located as close to the target as possible.

From the data given in table 1 it may be concluded that, regardless of the window location, there is relatively small increase in the vertical beam size at the target. As the window is moved upstream the increase in the horizontal beam size at the target becomes more pronounced. Indeed, it can be argued that as the window is moved upstream the beam at the target is predicted to become more symmetrical. On the other hand, however, beam spill in the beam line increases.

Thus it appears that the window should be located approximately 1 m upstream of the target. At this location the effect of the window on beam size of the target is minimized. There is virtually no affect to the vertical beam size and a minimal increase in the horizontal beam size. At the same time beam spill is reduced.

The placement of a window approximately 1 m upstream of the target can be accomplished in at least two ways. The simplest may to weld the window to the last 2 m or so of beam tube. An alternate method would be to mount the window on a re-entrant tube that would fit inside of the standard beam tube. In either case, should the window fail it would be necessary to remove the tube to which the window is attached. Presumably the removed tube would be discarded and be replaced with a new section containing a new window.

References

1. GM Stinson, *A 480 MeV to 500 MeV beam transport system to an ISAC facility*, TRI-DNA-96-5 and TRI-DNA-ISAC-5, July, 1996.

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       DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - NO window up from TGT2 - REF

  Space # 8:  Distribution of particles as a function of  X  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & Y  at TGT2   (Element #150)     (along VERTICAL axis)

   Distribution of particles INITIALLY ACCEPTED
                                                    COUNTS  = 150000.
                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                        1  3  6  9  2  5  6  7  6  5  3  9  6  3  1
                                     2  4  5  3  3  7  0  6  5  6  4  0  8  6  7  4  1
                                     1  0  7  7  9  3  7  9  1  7  4  4  3  7  3  2  9
                0  0  0  0  0  0  3  1  4  9  2  5  1  1  4  2  6  4  3  6  5  8  3  2  1  0  0  0  0  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
Y 0.9900     |                                                                                             |       0 Y
  0.8100     -                                                                                             -       0
  0.6300     |                                                                                             |       0 P
A 0.4500     |                                                                                             |       0 R
T 0.2700     |                                                  1        1        1                        |       3 O
  0.9000E-01 |                      35253659*********************************739267 40  1                  |   29435 J
T -.9000E-01 |                    3139878***************************************866111                     |   91184 E
G -.2700     |                      37273708*********************************781289 41                     |   29375 C
T -.4500     |                                         1  1                    1                           |       3 T
2 -.6300     |                                                                                             |       0 I
  -.8100     |                                                                                             |       0 O
  -.9900     |                                                                                             |       0 N
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  5  5  5  4  4  3  3  3  2  2  1  1  1  0  0  0  0  1  1  1  2  2  3  3  3  4  4  5  5  5
                2  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8
                                                      X  AT TGT2

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

                                                    1  1  1  1  1  1  1
                                        1  3  6  9  2  4  6  7  6  5  3  9  6  3  1
                                     3  5  5  4  5  6  8  4  3  6  2  0  8  5  9  6  3
                            1  1  4  8  4  7  3  1  0  5  9  0  5  0  1  4  3  3  1  4  3  1
                2  2  4  3  2  6  5  5  7  0  3  8  0  8  8  4  1  7  7  0  0  6  2  1  0  2  4  5  2  1  1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   2.610     -                                   1     1  1  1  1                                          -       5
   2.430     |                                      1              1  1     1           1                  |       5
   2.250     |                                   1        1                 1           1                  |       4
   2.070     |                 1                 3  2           1  2                          1            |      10
   1.890     |                                1        2  1     1  1        1  1  1  2                     |      11
   1.710     |                                1           2  1  1  2  1        2  1              1         |      12
   1.530     |                             1        1        1  1  1        2  1           1               |       9
   1.350     |                          1  1  2  1  2              1  2     1     1  1           1         |      14
   1.170     |              1  1  1  2  4  1  2  2  1  4  5  2  1     2  3  2  1  3  1     1               |      40
Y 0.9900     |        1                 1  2  1  9  5  3  4  2  4  4  2  2  1  2  2  4                     |      49 Y
  0.8100     -                 1     3  1  6  2  4  7  7  8  8 10 11  8  5  5  2  1  1                     -      90
  0.6300     |  1           2     3     6  8  9 12  9 27 23 10 25 15 17 13  6  5  2  2  1        2        1|     199 P
A 0.4500     |              1        4 15 17 21 37 57 67 72 81 74 78 58 35 36 24 12  7        1            |     697 R
T 0.2700     |              1  2  4 24 66128244386451581617667630584499375260149 49 21  4  2        2      |    5746 O
  0.9000E-01 |           1  2  1  9 93347819*********************************912402 73  3                  |   35362 J
T -.9000E-01 |              3    12152639***************************************653136 11  2               |   65741 E
G -.2700     |     1           2 10 88377812*********************************925393 61  4  1               |   35098 C
T -.4500     |        2        1  2 13 69147228338507556611695588590481379275148 72 12  1  1               |    5716 T
2 -.6300     |                    2  3  8 12 36 53 61 69 94 74 81 63 62 49 34 19 12  8  1  1  1            |     743 I
  -.8100     |                 1        7  7  5 12 17 14 16 19 18 19 16 11  6  3  3  1  1     1            |     177 O
  -.9900     -     1     1  1  2  1  1  4  2  5  5  2 10 12 13 10  8  8  1  1  4  2  2  1                  -      97 N
  -1.170     |  1              2  1     1  2  3     1  6  8  7  3  4  4  3  3  1     4                     |      54
  -1.350     |              1  1     1     1  3  2  4  1  3  5  1        3  2  1  1  1     3               |      34
  -1.530     |           1           1           1        1  2     1  5  2  2  1                 1         |      18
  -1.710     |                 1              1  1  1  1  1     1  2  1  3                                 |      13
  -1.890     |                                1           2  1        2  1     1  1  1                     |      10
  -2.070     |        1                 1     1  1  1              1        1  1     2  1              1   |      12
  -2.250     |                             1     1                       2           1                     |       5
  -2.430     |                                1  1                 1  1           1                        |       5
  -2.610     |                                1              2                                             |       3
  -2.790     -                                   1           1  2  1     1     1                           -       7
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  5  5  5  4  4  3  3  3  2  2  1  1  1  0  0  0  0  1  1  1  2  2  3  3  3  4  4  5  5  5
                2  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8
                                                      X  AT TGT2
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Figure 1. The predicted beam spot at a target: top, without foil scattering, and bottom, with foil scatterering.

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       DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - NO window up from TGT2 - REF

  Space # 6:  Distribution of particles as a function of  X  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & DX at TGT2   (Element #150)     (along VERTICAL axis)

   Distribution of particles INITIALLY ACCEPTED
                                                    COUNTS  = 150000.
                                                      X PROJECTION

                                                    1  1  1  1  1  1  1
                                        1  3  6  9  2  5  6  7  6  5  3  9  6  3  1
                                     2  4  5  3  3  7  0  6  5  6  4  0  8  6  7  4  1
                                     1  0  7  7  9  3  7  9  1  7  4  4  3  7  3  2  9
                0  0  0  0  0  0  3  1  4  9  2  5  1  1  4  2  6  4  3  6  5  8  3  2  1  0  0  0  0  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   5.100     -                                                                                             -       0
   4.500     |                                                                   10 39  1                  |      50
   3.900     |                                                              3133469121                     |     726
D  3.300     |                                                          15506***753 32                     |    2696 Y
X  2.700     -                                                       67*********189                        -    5908
   2.100     |                                                   196*********385  2                        |    9369 P
A  1.500     |                                                360*********677  7                           |   13287 R
T 0.9000     |                                            5567*********820 11                              |   16082 O
  0.3000     |                                        10789*********963 15                                 |   18094 J
T -.3000     |                                      5895*********993 15                                    |   18944 E
G -.9000     |                                  11949*********823 17                                       |   17953 C
T -1.500     |                               12856*********620  8                                          |   15973 T
2 -2.100     |                            10663*********380  5                                             |   12851 I
  -2.700     |                          2493*********231                                                   |    9276 O
  -3.300     -                        221********* 96                                                      -    5484 N
  -3.900     |                      55762***469 28                                                         |    2602
  -4.500     |                    3126417123  4                                                            |     673
  -5.100     |                      30  2                                                                  |      32
  -5.700     -                                                                                             -       0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  5  5  5  4  4  3  3  3  2  2  1  1  1  0  0  0  0  1  1  1  2  2  3  3  3  4  4  5  5  5
                2  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8
                                                      X  AT TGT2

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

                                                    1  1  1  1  1  1  1
                                        1  3  6  9  2  4  6  7  6  5  3  9  6  3  1
                                     3  5  5  4  5  6  8  4  3  6  2  0  8  5  9  6  3
                            1  1  4  8  4  7  3  1  0  5  9  0  5  0  1  4  3  3  1  4  3  1
                2  2  4  3  2  6  5  5  7  0  3  8  0  8  8  4  1  7  7  0  0  6  2  1  0  2  4  5  2  1  1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   8.700     -                                                                                            1-       1
   8.100     |                                                                                             |       0
   7.500     |                                                                                         1   |       1
   6.900     |                                                                                   4  2      |       6
   6.300     |                                                                                1  1         |       2
   5.700     |                                                                             5  3            |       8
   5.100     |                                                                       5 14  6               |      25
   4.500     |                                                                 2 32 81 13  1               |     129
   3.900     |                                                              2194565208  3                  |     972
D  3.300     |                                                          27524***833 47                     |    2895 Y
X  2.700     -                                                       95*********182                        -    5949
   2.100     |                                                  2212*********451                           |    9485 P
A  1.500     |                                               1363*********571  4                           |   12953 R
T 0.9000     |                                            4563*********877 17                              |   16057 O
  0.3000     |                                         9764*********967 13                                 |   18008 J
T -.3000     |                                     11840*********918 13                                    |   18552 E
G -.9000     |                                  15983*********827 14                                       |   17812 C
T -1.500     |                                8902*********633 12                                          |   15900 T
2 -2.100     |                             6673*********361  1                                             |   12704 I
  -2.700     |                          5463*********195                                                   |    9217 O
  -3.300     -                        242********* 93                                                      -    5581 N
  -3.900     |                      76833***519 25                                                         |    2719
  -4.500     |                    9233444141  9                                                            |     836
  -5.100     |                 2 25 73 23                                                                  |     123
  -5.700     |              2  7  9  3                                                                     |      21
  -6.300     |              6  4  2                                                                        |      12
  -6.900     |        2  2  2  2                                                                           |       8
  -7.500     |     1  2     2  1                                                                           |       6
  -8.100     |  1  1     1                                                                                 |       3
  -8.700     |  1                                                                                          |       1
  -9.300     -                                                                                             -       0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                6  5  5  5  4  4  3  3  3  2  2  1  1  1  0  0  0  0  1  1  1  2  2  3  3  3  4  4  5  5  5
                2  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8
                                                      X  AT TGT2
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Figure 2. The predicted correlation between horizontal beam divergence and horizontal beam size at a target: top, without foil scattering, and bottom, with foil scattering.

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  DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - NO window up from TGT2 - REF

  Space # 7:  Distribution of particles as a function of  Y  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & DY at TGT2   (Element #150)     (along VERTICAL axis)

   Distribution of particles INITIALLY ACCEPTED
                                                    COUNTS  = 150000.
                                                      X PROJECTION

                                                          2  9  2
                                                          9  1  9
                                                          3  1  4
                                                          7  8  3
                0  0  0  0  0  0  0  0  0  0  0  0  0  3  5  4  5  3  0  0  0  0  0  0  0  0  0  0  0  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
D  1.640     -                                                                                             -       0 Y
Y  1.360     -                                                                                             -       0
   1.080     |                                                692  2                                       |     694 P
A 0.8000     |                                             419***  1                                       |    6249 R
T 0.5200     |                                             ******                                          |   15844 O
  0.2400     |                                             ******                                          |   25605 J
T -.4000E-01 |                                          814******                                          |   31150 E
G -.3200     |                                          ******327                                          |   30292 C
T -.6000     |                                          ******                                             |   23081 T
2 -.8800     |                                          ******                                             |   12796 I
  -1.160     |                                         2***108                                             |    4041 O
  -1.440     -                                         1247                                                -     248 N
  -1.720     |                                                                                             |       0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                2  2  2  2  2  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  2  2  2  2
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                7  6  4  2  0  8  7  5  3  1  9  8  6  4  2  0  0  2  4  6  8  9  1  3  5  7  8  0  2  4  6
                9  1  3  5  7  9  1  3  5  7  9  1  3  5  7  9  9  7  5  3  1  9  7  5  3  1  9  7  5  3  1
                                                      Y  AT TGT2

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

                                                          3  6  3
                                                       5  5  5  5  5
                                                 1  7  7  0  7  3  7  6  1
                            1  1  1  1  3  5  9  7  4  1  9  4  6  4  9  9  9  4  4  1     1  1  1
                7  3  5  5  2  0  3  8  4  4  7  7  3  6  8  1  2  6  7  9  0  9  0  4  9  2  1  0  4  5  5
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   4.160     -                                                                                            3-       3
   3.880     |                                                                                         2  1|       3
   3.600     |                                                                                         1  1|       2
   3.320     |                                                                                   2  1      |       3
   3.040     |                                                                             3  6  4  3  2   |      18
   2.760     |                                                                             3  4  2         |       9
   2.480     |                                                                    1  4  3  2  1  1         |      12
   2.200     |                                                                 6  7  1  3  3     1         |      21
   1.920     |                                                              5 10  9  4  1  1               |      30
D  1.640     |                                                        8 18 18 13 15  4  2                  |      78 Y
Y  1.360     -                                                    69 79 49 26  6  8  1                     -     238
   1.080     |                                               1566938193 49 20  8                           |    1775 P
A 0.8000     |                                             577******207 43 18  6                           |    7094 R
T 0.5200     |                                           99*********137 29  2                              |   15851 O
  0.2400     |                                        14*********908 51 11  1                              |   24790 J
T -.4000E-01 |                                      4122*********363 22                                    |   29506 E
G -.3200     |                                   2 32446********* 68                                       |   28675 C
T -.6000     |                                2 15 80*********609  7                                       |   22454 T
2 -.8800     |                               11 32157********* 35                                          |   12986 I
  -1.160     |                          2  5 17 51226******202                                             |    5110 O
  -1.440     -                          1 12 21 38187562201                                                -    1022 N
  -1.720     |                       3  5 15 29 27 56 23                                                   |     158
  -2.000     |                 2  3  2 12 11 14 11  1                                                      |      56
  -2.280     |                 2  5  3  6  8  3  1                                                         |      28
  -2.560     |           1  2  2  2  4  6  3                                                               |      20
  -2.840     |        1  1  4  3  3  5  2                                                                  |      19
  -3.120     |        1  1  1  1     1                                                                     |       5
  -3.400     |              3                                                                              |       3
  -3.680     |     1  1  1  1                                                                              |       4
  -3.960     |  2  2  1  1  1                                                                              |       7
  -4.240     -  5     1                                                                                    -       6
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                2  2  2  2  2  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  2  2  2  2
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                7  6  4  2  0  8  7  5  3  1  9  8  6  4  2  0  0  2  4  6  8  9  1  3  5  7  8  0  2  4  6
                9  1  3  5  7  9  1  3  5  7  9  1  3  5  7  9  9  7  5  3  1  9  7  5  3  1  9  7  5  3  1
                                                      Y  AT TGT2
```

Figure 3. The predicted correlation between vertical beam divergence and vertical beam size at a target: top, without foil scattering, and bottom, with foil scattering.

```
        DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - NO window up from TGT2

  Space # 8:  Distribution of particles as a function of  X  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & Y  at TGT2   (Element #150)     (along VERTICAL axis)

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

                                                          3  6  3
                                                       3  7  5  9  3
                                                       4  8  9  0  5
                                                    2  7  3  5  9  8  1
                0  0  0  0  0  0  0  0  0  0  0  2  7  2  0  2  7  9  6  1  0  0  0  0  0  0  0  0  0  0  0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   2.900     -                                               1                                             -       1
   2.700     |                                               2                                             |       2
   2.500     |                                            1  2  2                                          |       5
   2.300     |                                            2  1  1  1                                       |       5
   2.100     |                                            4  3     1  1                                    |       9
   1.900     |                                         1  3  3  2  2                                       |      11
   1.700     |                                            1  7  3  2  1                                    |      14
   1.500     |                                         1  2  3  2  2  1                                    |      11
   1.300     |                                         2  5  4  7  1  1                                    |      20
Y  1.100     |                                      1  8 10 12  8 10                                       |      49 Y
  0.9000     -                                      1  7 24 20 10  5                                       -      67
  0.7000     |                                   1  2  9 29 69 42  5  1  1                                 |     159 P
A 0.5000     |                                      1 21106190122 21  2                                    |     463 R
T 0.3000     |                                      1102*********113  2                                    |    4127 O
  0.1000     |                                      5772*********809                                       |   34047 J
T -.1000     |                                      4***************  2                                    |   72153 E
G -.3000     |                                      1788*********804  1                                    |   33924 C
T -.5000     |                                      2116*********112  1                                    |    4090 T
2 -.7000     |                                        19115208121 20  1                                    |     484 I
  -.9000     |                                      2  8 36 62 27 10                                       |     145 O
  -1.100     -                                      3  6 14 35 17  5                                       -      80 N
  -1.300     |                                   1  1  3  9 11  6  9                                       |      40
  -1.500     |                                      2  1  3  5 11     1                                    |      23
  -1.700     |                                         1  3  5  6                                          |      15
  -1.900     |                                            1  3  4  2                                       |      10
  -2.100     |                                      1  1  3     3  4  1                                    |      13
  -2.300     |                                         1  1     1  1                                       |       4
  -2.500     |                                            2  2  1  1                                       |       6
  -2.700     |                                            1  3                                             |       4
  -2.900     |                                            1  1  3                                          |       5
  -3.100     -                                                                                             -       0
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                2  2  2  2  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  2  2  2
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                4  3  1  0  8  6  5  3  2  0  8  7  5  4  2  0  0  2  4  5  7  8  0  2  3  5  6  8  0  1  3
                8  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2
                                                      X  AT TGT2
```

Figure 4. The predicted beam spot at a target with no window and foil scattering included.

```
       DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - 0.001" SS WINDOW 1 m up from TGT2

  Space # 8:  Distribution of particles as a function of  X  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & Y  at TGT2   (Element #150)     (along VERTICAL axis)

   REAL! Distribution of FINAL RUN FOUND HERE
                                                            COUNTS  = 149938.
                                                      X PROJECTION

                                                          3  6  3
                                                       5  7  1  7  6
                                                    2  9  2  9  9  0  2
                                     1     1  2  4  5  7  2  5  8  8  3  5  2
                3  0  1  0  0  0  0  1  8  5  2  7  5  5  4  9  5  7  3  5  8  9  7  8  0  0  0  0  0  0  1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   2.900     -                          0                                                                  -       0
   2.700     |      0                                   1                                                  |       1
   2.500     |                                             2  2                                            |       4
   2.300     |                                    1  2  1  2  3                                            |       9
   2.100     |  0                                    1     4  2  2  1                                      |      10
   1.900     |                                       1  1     1  1                                         |       4
   1.700     |                                          1  1  3  1                                         |       6
   1.500     |      0           0              1     1  3  3  4                                            |      13
   1.300     |                                    2     6  4  5  1                                         |      18
Y  1.100     |                                    1  1  6 15 12  4                                         |      39 Y
  0.9000     -                           1  1  1  3 10 15 19 16  7  4  4  1  2  1                          -      85
  0.7000     |                     1        1  1  1 10 24 69 45 12  6  1  2                                |     173 P
A 0.5000     |  0                           2  4 11 40153204161 24  5  1  3  1  3                          |     612 R
T 0.3000     |  0                     1  1  1  3 19251*********258 19 10  4  2  1  2                      0|    5339 O
  0.1000     |                     3  1  1  4  4 60*************** 45  9  5     1                          |   34787 J
T -.1000     |  0                     1  1  4 10 73*************** 62  8  2     1  3                       |   67753 E
G -.3000     |                     1     4  6 11 47*************** 57 14  3        1                      0|   34656 C
T -.5000     |                     3  2  4  1  6 24239*********229 18  3  3  2     1                       |    5365 T
2 -.7000     |                     1  3  1     2  6 52130244165 47  7  4  5  1                             |     668 I
  -.9000     |                     2     2  2  2  3 15 27 69 42 17  2  1     1     1                       |     186 O
  -1.100     -                                 2  2  5 24 21 25  8  5                                      -      92 N
  -1.300     |                                       4  8 18  7  5  2                                      |      44
  -1.500     |                                       2  3  6  5  4                                         |      20
  -1.700     |                                    2  1  4  6  3                                            |      16
  -1.900     |                                       1  2  4  1  3                                         |      11
  -2.100     |  0                                          1  2  3                                         |       7
  -2.300     |                                       1     1                                               |       2
  -2.500     |                                       1     1     2                                         |       4
  -2.700     |                                       2  1     1  1                                         |       5
  -2.900     |                                             1  1                                            |       2
  -3.100     -  1              0              0     0     0  0                                             -       3
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                2  2  2  2  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  2  2  2
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                4  3  1  0  8  6  5  3  2  0  8  7  5  4  2  0  0  2  4  5  7  8  0  2  3  5  6  8  0  1  3
                8  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2
                                                      X  AT TGT2
```

Figure 5. The predicted beam spot at a target with window 1 m upstream of the target with foil and window scattering included.

```
       DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - 0.001" SS WINDOW 1.5 m up from TGT2

  Space # 8:  Distribution of particles as a function of  X  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & Y  at TGT2   (Element #150)     (along VERTICAL axis)

   REAL! Distribution of FINAL RUN FOUND HERE
                                                            COUNTS  = 149937.
                                                      X PROJECTION

                                                          3  5  3
                                                       8  6  7  7  8
                                                 1  6  2  7  6  1  2  7  1
                                     2  1  2  5  2  7  6  3  6  5  1  1  0  5  2  1  1
                0  0  2  2  3  8  5  1  6  9  4  6  1  6  8  7  4  9  8  5  5  8  6  0  7  6  4  0  2  0  1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   2.900     -                                                                                             -       0
   2.700     |                                               1                                             |       1
   2.500     |                                               1                                             |       1
   2.300     |                                               1  4  1                                       |       6
   2.100     |                                         2  2  1     3                                       |       8
   1.900     |                                         1  1  1  1                             0            |       4
   1.700     |                                1        5  3  3  1  4        1                              |      18
   1.500     |                             1     2     2  4  3  3  2  1        1     1                     |      20
   1.300     |              1                 1           4  9  7  3  2  1  1        2                     |      31
Y  1.100     |                       1              2  9 14  7 11  5  2        1        1                  |      53 Y
  0.9000     -                    1  3     1  2  3  3 15 24 27 24  9  1  6     1     1                     -     121
  0.7000     |                 1  1  2  2  1     3  9 22 40 64 54 22  5  3  3     2           1            |     235 P
A 0.5000     |                 1  1  3  2  4  6  7 14 67217302198 72 19  4  2  4  2                     0|     925 R
T 0.3000     |        1  1     1     1  1  3  1 13 40379*********400 62  7  5  2     1  1              0   |    6622 O
  0.1000     |        1     1  2           5 16 24158***************160 16  8  3  2  1  2                  |   35329 J
T -.1000     |                       2  1  2  7 24211***************238 22 12  1  4  1     1  1            |   63444 E
G -.3000     |                       4  2  4  4 20144***************139 23  6  5  1  1     2               |   35034 C
T -.5000     |                 1        1  2  6 16 51427*********400 61  7  9  7  3     2           2     0|    6683 T
2 -.7000     |  0           1     1  1  3  2  5  8 17 63210272216 62 16  8  2  2  1        1               |     891 I
  -.9000     |                    1  1  3  2  1  1 11 24 43 79 55 19  6  5  2  1        1                  |     255 O
  -1.100     -           1     1        1  1  2  1  4  6 16 38 18  8     2  1                 1            -     101 N
  -1.300     |                       1           3  1  4 14 19  7  6  1              1     2               |      59
  -1.500     |                 1     2              3  1  5  7  6  1  2              1        1            |      30
  -1.700     |                                2     1  3  1  3  6  5  3     2     1                        |      27
  -1.900     |                             1     1  2  1     2  3  1     1  1                              |      13
  -2.100     |                       0                 1  2  4  1                                          |       8
  -2.300     |                                               1  1                                          |       2
  -2.500     |                                         2  3  1  2                                          |       8
  -2.700     |                          0                    2                                             |       2
  -2.900     |                                            1  1                                          0|       2
  -3.100     -                             0                             0                                 -       1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                2  2  2  2  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  2  2  2
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                4  3  1  0  8  6  5  3  2  0  8  7  5  4  2  0  0  2  4  5  7  8  0  2  3  5  6  8  0  1  3
                8  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2
                                                      X  AT TGT2
```

Figure 6. The predicted beam spot at a target with window 1.5 m upstream of the target with foil and window scattering included.

```
       DATA OF 95/10/10 ON 96/06/25 - FINAL 500 MEV ON 2-A - 0.001" SS WINDOW 2 m up from TGT2

  Space # 8:  Distribution of particles as a function of  X  AT TGT2   (Element #150)     (along HORIZONTAL axis)
                                                        & Y  at TGT2   (Element #150)     (along VERTICAL axis)

   REAL! Distribution of FINAL RUN FOUND HERE
                                                            COUNTS  = 149932.
                                                      X PROJECTION

                                                       1  3  5  3  1
                                                    1  0  5  3  6  0  1
                                                 2  4  2  5  4  4  3  4  2
                               1  1  2  2  4  9  5  8  0  3  7  7  6  0  3  9  5  2  1  1     1
                6  3  6  9  6  1  8  2  9  5  5  0  6  4  8  1  5  4  8  7  3  3  7  7  2  9  0  5  8  8  6
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
   2.900     -                                                     1  0              0                     -       2
   2.700     |                                            1  1  1     1                                    |       4
   2.500     |                                1     1  1     2  2     1                                    |       8
   2.300     |                       1              1  2  3  1     3                                       |      11
   2.100     |                          1              1  2  2                                             |       6
   1.900     |                 2        1        1  2  1  1  2  1  2           1                    1      |      15
   1.700     |              1                 1           4  3  4  3  2           1                        |      19
   1.500     |              1           1     2  1     3  7  5  5  2  1              1        1            |      30
   1.300     |        1  1           1  1  1     2     5  2  7  5  4  5  4     1           1        1  2   |      44
Y  1.100     |           1           1  1     3  1  2  5  9 13 17  5  1  6  2     1     1     1     1      |      71 Y
  0.9000     -        1  1     2        2  2  1  2  8 12 24 25 24 14  3  2  2     1  3     1     1         -     131
  0.7000     |                    2     1  1  5  8 13 33 62 94 64 36 10  3  4  3     1                 1  2|     343 P
A 0.5000     |     1     2  1  1  1  1  1  2  4  8 33108287364279107 26 15 10  2  1  3  2  2  1  1  1      |    1264 R
T 0.3000     |        1        1  2  3  2  4 10 24104617*********564 82 29 10  4  1  2  3                  |    8064 O
  0.1000     |                    2  2  4  4 10 46312***************338 45  7  7  5           1     1     1|   35337 J
T -.1000     |  3     1           2  2  5  5 12 59511***************464 42 18  9  4  3  1  1  1  2         |   59257 E
G -.3000     |              1        1  1  8 18 45326***************291 42 15 12  3     1     2            |   35140 C
T -.5000     |  1  1     2     2  3  4     7 10 31117579*********619116 28  8  3  3     1  1  1     1  2   |    8223 T
2 -.7000     |        1              1     2  8 12 28106249451265108 39 12  6  7  2  1  1              1   |    1300 I
  -.9000     |  1                    2  1  3  6  3 14 18 74 77 65 27 18  2  6  1     1     1     1  1     1|     323 O
  -1.100     -     1  1        1  1  1  4  3     2  4 11 26 29 18 13  3  1  2  1                          2-     124 N
  -1.300     |  1        2     2                 3  5  2 13 10 10  9  2  5  2  1  3     1           1  1   |      73
  -1.500     |              1     1  1  1     1  1     2  6 12 12  6  2                    2               |      48
  -1.700     |              1                 1     2  3  5  3  4  2        1           1                  |      23
  -1.900     |                    2     2  2     1  1  3  3  4  1     2                       1            |      22
  -2.100     |                                1     1  2  2  3  2  3           1  1  1        1        1   |      19
  -2.300     |                    1        1  1     1  1  2        1  1  1        1  1                     |      12
  -2.500     |                    1  1                 1  1  3  1                                          |       8
  -2.700     |                                            3  2  1  1                                       |       7
  -2.900     |                                            1  2                                             |       3
  -3.100     -                                                     1                                       -       1
             +--|--------------|--------------|--------------|--------------|--------------|--------------|+
                -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
                2  2  2  2  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  2  2  2
                .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .
                4  3  1  0  8  6  5  3  2  0  8  7  5  4  2  0  0  2  4  5  7  8  0  2  3  5  6  8  0  1  3
                8  2  6  0  4  8  2  6  0  4  8  2  6  0  4  8  8  4  0  6  2  8  4  0  6  2  8  4  0  6  2
                                                      X  AT TGT2
```

Figure 7. The predicted beam spot at a target with window 2 m upstream of the target with foil and window scattering included.