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M15 Tunes

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TRIUMF

Abstract: First order tunes have been derived, using B-I data from Doug Evans' logbooks, but (contrary to all previous work) using soft-edge fields instead of the common hard-edged quad model. The findings are as follows. (1)The hard-edge model gives quad settings incorrect by 10 to 20%. (2)Jaap's `REVMOC` tune contains 3 errors and could not have worked as designed. (3)Operational tunes work well but can be optimized considerably. An optimized tune is given.

Higher order aberrations are also investigated. It is found that the original work based on the second order `REVMOC` calculation overestimates transverse and momentum acceptances by probably a factor of two each.

Lastly, the case of complete failure of the permanent magnet quads QA and QB is investigated and found to reduce muon count by approximately a factor of 5.

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Contents

1 The Quadrupoles

Culled from Doug Evans' logbooks, we have the following parameters for M15 quads:

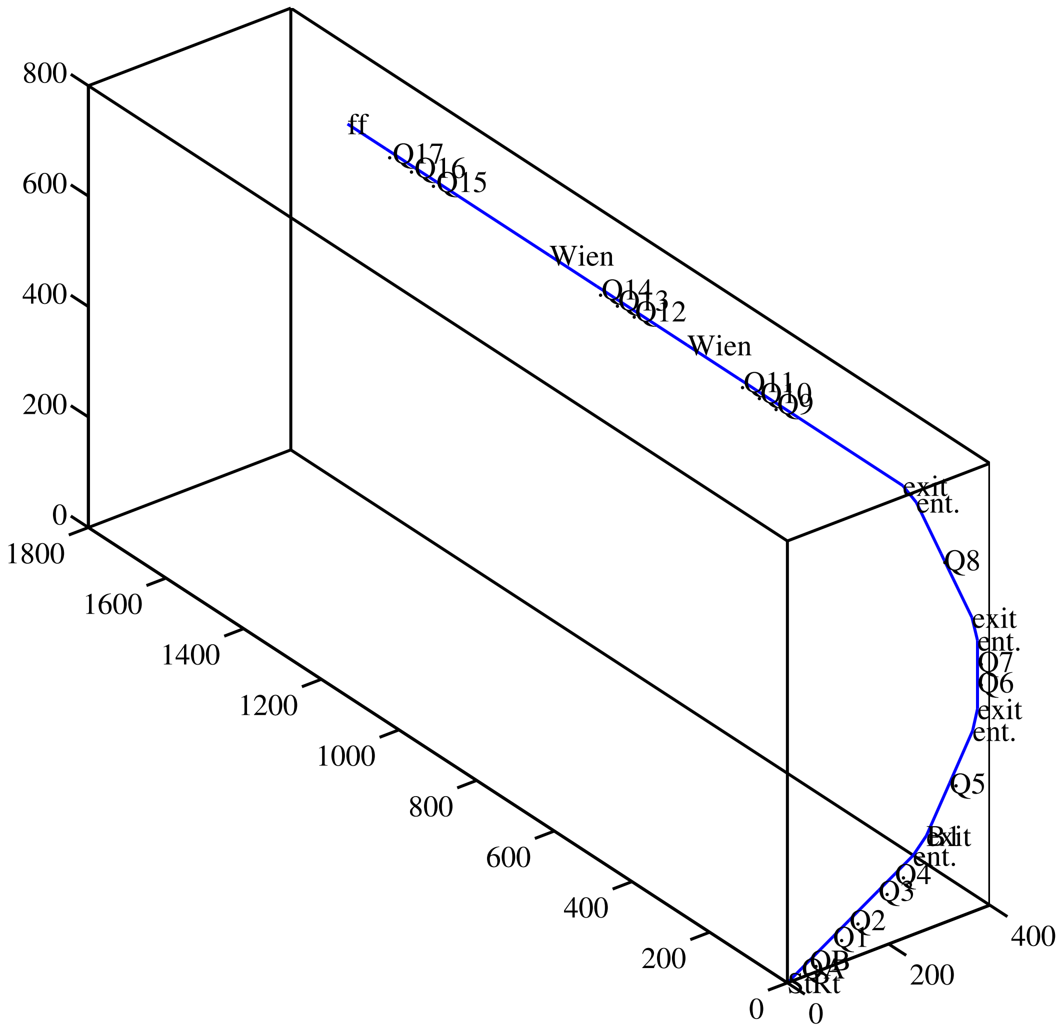
M15 quad	Type	Strength	Ap.Radius
QA	perm.mag.	6260 G	5.24 cm
QB	perm.mag.	3640 G	5.93 cm
Q1,Q2	6Q6 radhard	5.20 G/A	7.94 cm
Q3-Q8	6Q6 normal	47.1 G/A	7.94 cm
Q9-Q11	7Q7 yellow	15.89 G/A	9.84 cm
Q12-Q14	7Q7 blue	15.95 G/A	9.84 cm
Q15-Q17	12Q12	18.15 G/A	15.56 cm

The "Strength" here is not the poletip field (per Amp as the case may be), but the integrated strength $\int B'ds$. This is the right way to parametrize a quadrupole, especially a short one, as then uncertainties in poletip field and effective length have little impact on the focal effect of the quad. In fact, for short quads, there is no unambiguous way to define these parameters, but aperture and integrated strength are, contrariwise, easy to define.[2]

Quads in Jaap's original calculations were modelled as hard-edged. This is not a good approximation when, as is the case here, all the quads are short, length $\approx$ aperture dia. The error incurred in predicting quad strengths will be $\sim 10\%$. This is borne out in the tunes as discussed below.

2 The Beamline Layout

For modelling, the starting point was Jaap's `REVMOC` file `m15rot.rev` (included as an Appendix below), and his beamline design note of 19-9-82[3]. These two are consistent in the placement of the beamline elements. A 3D layout, as output by `TRANSOPTR` is given below. Length units are cm.


800
600
400
200
0
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
ff
Q17
Q16
Q15
Wien
Q14
Q13
Q12
Wien
Q11
Q10
Q9
exit
ent.
Q8
exit
ent.
Q7
Q6
exit
ent.
Q5
exit
ent.
Q4
Q3
Q2
Q1
QB
QA
stRt

quad	tunes (Amps)						
	#1	#2	#3	#4	#5	#6	#7
Q1	12	80	80	80	37	10	77
Q2	0	0	0	0	0	32	27
Q3	28	20	18	18	23	34	25
Q4	29	26	20	20	24	33	28
Q5	38	42	43	43	29	39	41
Q6	17	19	22	22	15	26	27
Q7	17	27	26	26	20	27	35
Q8	34	38	39	39	27	30	38
Q9	72	78	90	86	72	51	50
Q10	122	120	147	143	128	110	94
Q11	72	78	90	86	80	51	50
Q12	53	60	60	60		74	101
Q13	146	135	143	143		139	130
Q14	53	60	60	60		124	101
Q15	64	59	75	74		41	73
Q16	108	104	131	129		122	125
Q17	64	59	75	74		125	73

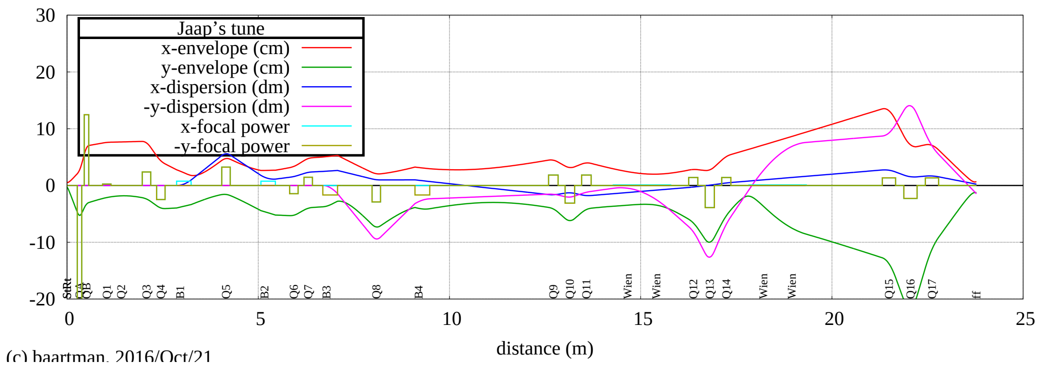
Table 1: M15 tunes: Tune 1 is the original tune derived by Jaap Doornbos. Tunes 2 through 4 are exercises to investigate the effects of short, and therefore soft-edged, quadrupoles. These are for momentum of 30 MeV/c. Tune #5 is from initial commissioning up to just after Q11 (Oct.1984). Tune #6 is an operational tune, and Tune #7 is an optimized version of this tune. #5 to #7 are for 28.86 MeV/c.

3 Jaap's tune

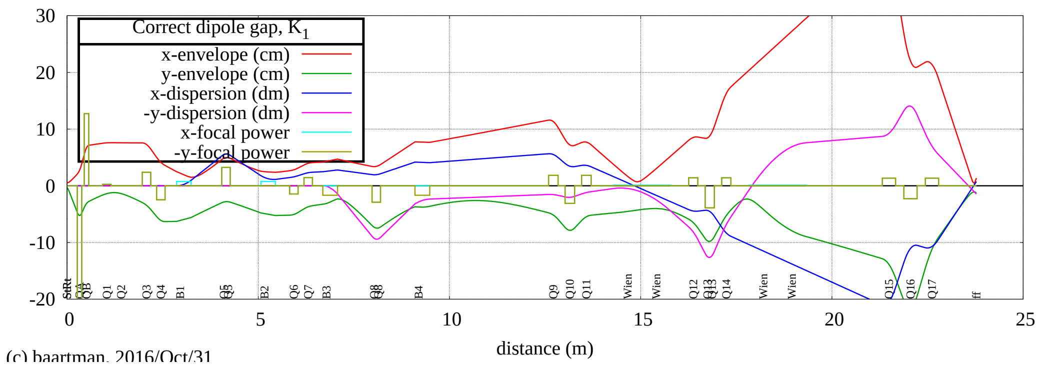
3.1 Tune #1

This is Jaap's original tune as in the `REVMOC` file, converted to currents using the Strengths above. This tune has a serious error: the matrix of the Wien filters has incorrect dispersion elements. (Jaap has acknowledged this error in an email to me.) So it is expected that the Wien-filter-related dispersion is not corrected properly.

Two other errors in the original calculation should be mentioned. First, the last bend section, containing Q8, is bracketed by two rotations of 90°. The downstream rotation should be −90° instead. This change has no effect if the section is tuned to be doubly achromatic, but it's not in Jaap's tune, and this makes the dispersion the wrong sign, adding incorrectly to the Wien filter dispersions.



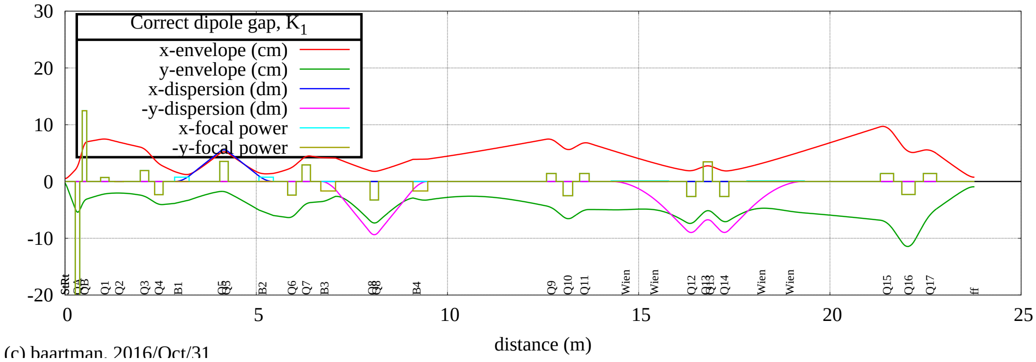
Lastly, and more seriously, Jaap's `REVMOC` file does not contain contain a `FRIN` element establishing the dipole gaps and the fringe field integrals. The off-plane focusing is strongly dependent on the magnet gap since this gap is not small compared with the bend radius. The effect makes far larger errors than the error incurred by using hard-edged quads. See below.



With the correct dipole parameters, most of the muons would be lost between the final Wien filter and the final triplet. This may explain why there was so little success when starting with the theoretical tune.

3.2 Comparison with `REVMOC`

With known calculation issues corrected, it is worthwhile to use `TRANSOPTR` to optimize the hard edge model to compare with `REVMOC`, as the latter has no soft edge quad model. This is shown below.



The REVMOC file was edited to have these strengths and the result is given in Appendix B. The REVMOC-derived total transfer matrix is as follows.

1.50751	0.00138	-0.01308	0.00007	0.00000	0.00000
6.24665	0.66947	2.24800	-0.00238	0.00000	0.00000
-0.00041	0.00001	-3.53076	-0.00198	0.00000	0.00331
-0.01287	-0.00003	-80.79568	-0.32895	0.00000	-0.03184

The REVMOC units are cm, mrad, and % for dp/p. The TRANSOPTR matrix is as follows when converted to these same units:

1.50608	-0.00016	0.00000	0.00000	0.00000	-0.00000
6.47830	0.66328	0.00000	0.00000	0.00000	0.00008
0.00000	0.00000	-3.52987	0.00161	0.00000	0.00023
0.00000	0.00000	-81.7580	-0.24592	0.00000	0.01381

The agreement is on the scale of 1% or so, but the REVMOC matrix is only symplectic to about 1% while the TRANSOPTR matrix is symplectic to a few parts per million. REVMOC has small x-y coupling terms. It's not clear how these arise; there are no elements that couple. I conclude that the TRANSOPTR matrix is the more accurate of the two.

As a test, I re-ran REVMOC with 100 times smaller initial XSIZE,YSIZE. This gives

1.50693	0.00130	0.00000	0.00000	0.00000	0.00000
6.49206	0.66973	-0.00001	0.00000	0.00000	0.00000
0.00000	0.00000	-3.53971	-0.00195	0.00000	0.00331
0.00001	0.00000	-81.49402	-0.32751	0.00000	-0.03184

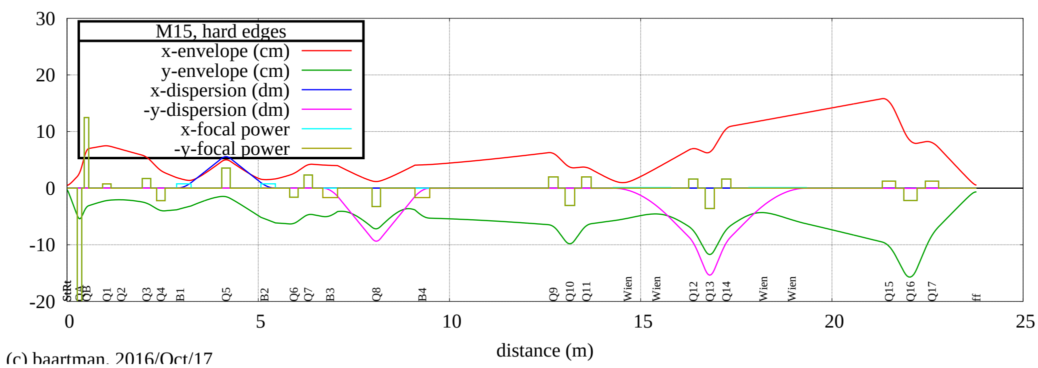
and the coupling disappears, indicating that it's actually some of the higher order effect leaking into first order. It seems that the matrices are find not from the optics, but by fitting the final phase space coordinates to a series expansion of initial coordinates.

4 Effect of soft edges

Tunes #2,3,4 are to investigate the effects of soft versus hard edged quads. These were done with the incorrect dipole parameters. I could have used correct dipole values, but the differences between the hard and soft cases would be very similar.

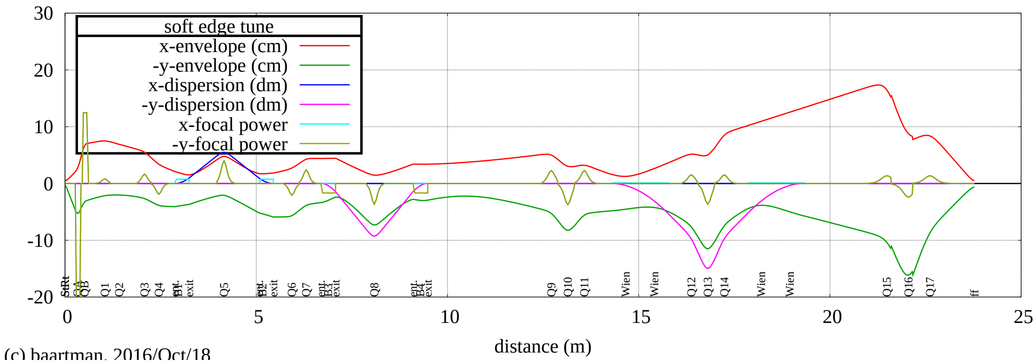
4.1 Tune #2

This is a fitted tune. Fits are to achieve double achromaticity after each dispersive section and that envelopes stay within quad apertures. But it still uses hard-edged quad models.



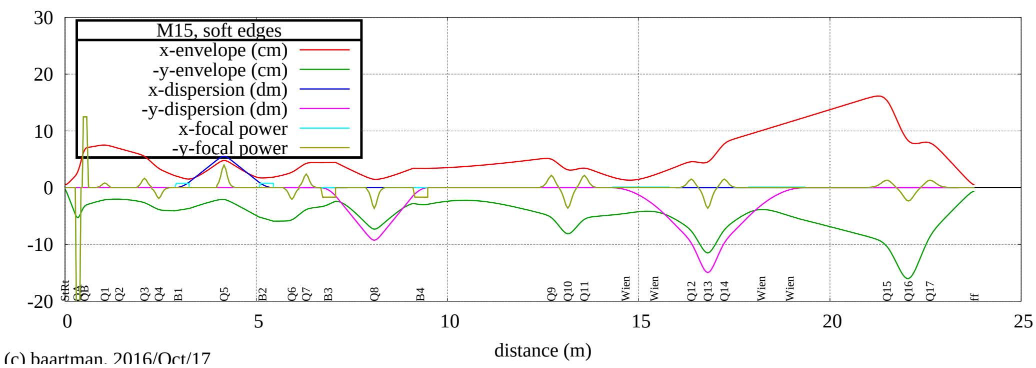
4.2 Tune #3

In this tune all quads have correct (soft) strength functions, but where their fields overlap, backward drifts are used. (This is why the strength functions look strange in fact theproper strengths are overwritten when tracking backward.)



4.3 Tune #4

Here, overlapping quad fields are properly superposed instead of padding the overlaps with backward drifts. The difference from Tune #3 is slight.



4.4 Conclusion

The hard-edge model that was originally used to derive tunes is a poor approximation for the short quads used in M15. Nevertheless, the basic design of the beamline is sound; capable of having large acceptance and double achromaticity.

5 Towards a First Order Model

5.1 Calibrations

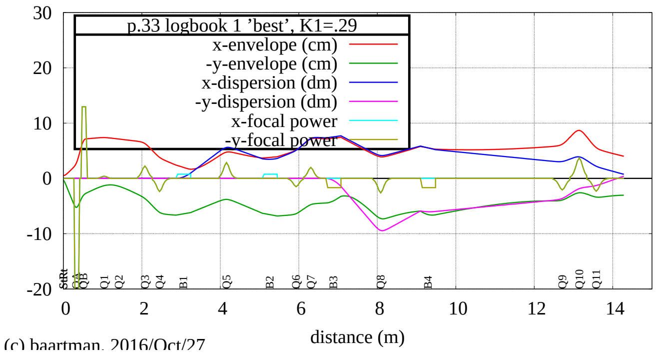
To verify quad calibration, let's take Jaap's Q5 line in `m15rot.rev`:
`QUAD .225  0.793  10.`
This means length=0.225m, poletip=0.793kG, aperture=10cm. This aperture is not meant to be actual; it is only used for scaling to get the gradient 79.3G/cm. Integrated strength is thus 1.784kG. Doug Evans measures effective length 22.1cm, poletip field 16.92G/A, aperture=6.25in/2=7.94cm. So integrated strength is 47.1G/A. We find current 1784G/(47.1G/A)=37.9A. It appears that the muons are 28.86, not 30 MeV/c, so this scales to 36.4A. This is exactly the value Jaap gives in the logbook, so this establishes that the "theoretical" values given by Jaap in logbook 1 are consistent with the `REVMOC` file, and that I am calculating quad currents the same way as Jaap did.

5.2 Polarities

As designed, Q1-Q7 should alternate in polarity, yet clearly Q1 had wrong polarity and every time tuning knobbing was done, it was found to prefer zero strength, reversed, and then run up. Finally polarity was established at p.33 of logbook (Oct.1984). From there, polarities seem to be correct up to Q8. Q9-Q11 have VHV polarity page 13 logbook 1, but then page 45 logbook 2, were changed to HVH. At that time (April 1985), Q9-Q17 were set to HVH VHV HVH, i.e., middle triplet was opposite to the others. This disagrees with Jaap's `REVMOC` which has all triplets same polarity. I assume HVH VHV HVH is the present state of polarity.

5.3 Benders, Tune #5

Using these polarities and the calibrations, we can now check the first "good" tune recorded page 33 logbook 1. But a difficulty is that we do not know the fringe field integrals K_1, K_2 that are used in `TRANSPORT/TRANSOPTR` and `REVMOC`. The beam tune is exquisitely sensitive to K_1 because the magnet gaps, 15 cm, are not small compared with the bends 3&4 radii 49 cm. So I fit it and find $K_1 = 0.29 \pm 0.05$, and this is well within the range of the typical. K_2 is not very sensitive, so leave it at a typical value of 3.0. The resulting envelopes are shown below. Notice the envelopes are quite well contained inside the 6-inch beampipe but that the dispersions (blue and magenta) are not well corrected.



5.4 Modelling

Page 39, logbook 1, headed "Note. Theory" appears to be the last time it was attempted to reconcile "knobbed tunes" with theory. Further, it is not possible to make such analysis after the fact because from page 48 on, only MUX and DAC values are recorded and conversions to actual current are not given.

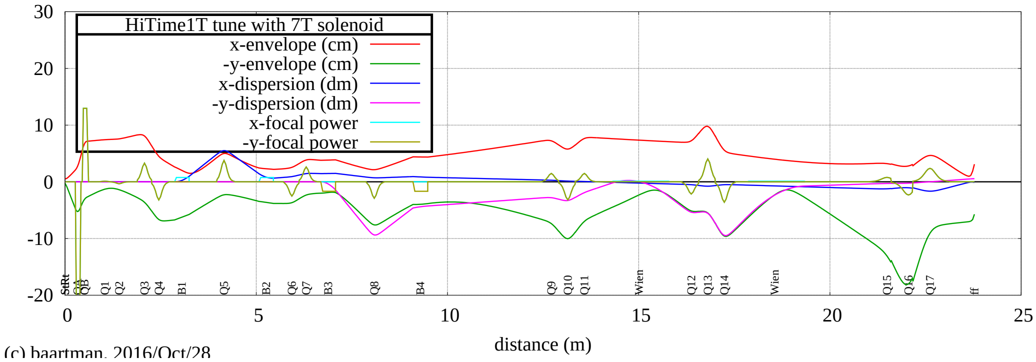
Lack of effort at reconciliation is extremely regrettable. Doug Evans had measured the quadrupoles and all data was in hand to exactly characterize the quadrupoles: it was never used. Why not? I am quite sure that the carefully-designed-in double achromaticity of the beamline has to the present time (30 years later) never been used.

The only "commissioning" that took place was to measure, again and again, muon rates as function of each and every magnet element; quads and dipoles; sometimes inserting various sized collimators or slits.

The unfortunate legacy of never achieving agreement between theoretical tune and knobbed tunes is that experimenters operate with a prejudice that such a thing is not possible or not worth the effort.

Let's try a recent optimized tune. This is named `HiTime1T` in the EPICS-restorable tune directory, and I use directly the field of the HiTime solenoid from Doug Evans' measurement #20021101

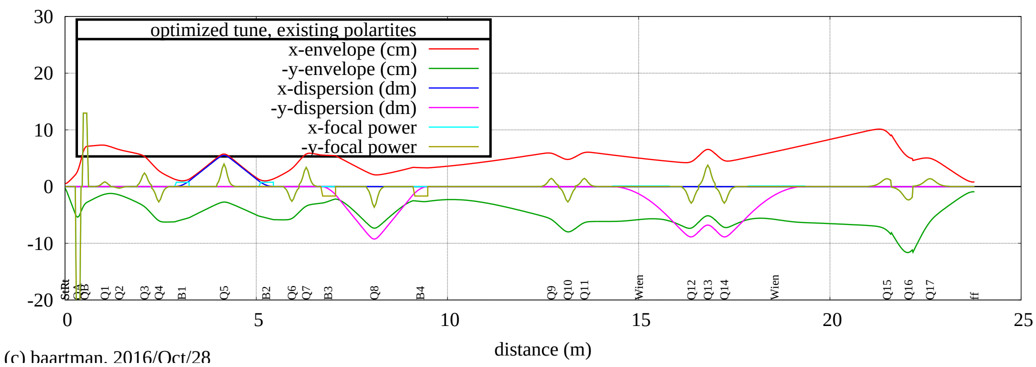
5.4.1 Tune #6



This seems to work though it gives a beam at final focus that is much taller than wide, at least it fits through all the quadrupoles. Importantly, it is close to being doubly achromatic.

5.4.2 Tune #7

Since model is working after a fashion, let us find an optimum tune using the existing polarities. This is shown below. Notice it is doubly achromatic everywhere possible and easily fits into the beam pipe everywhere.



5.5 Conclusions

The model is consistent with operating tunes and can be used to find new tunes. It is not a surprise that the operational tunes are far from optimum. It is not possible to optimize rate in a 17-dimensional space. `TRANSOPTR` needs typically a thousand runs through the beamline and this is aided by having about 39 constraints: Minimize beam sizes in all quads (34), double achromaticity (3) and the final focus (2).

As an exercise, and in order to establish `REVMOC` run that as far as I know has errors corrected (except of course for the error of using hard-edge quads), I again ran `TRANSOPTR` to find settings for hard-edge quads, with a tune close to tune #7. This, and output, are included in appendix B.

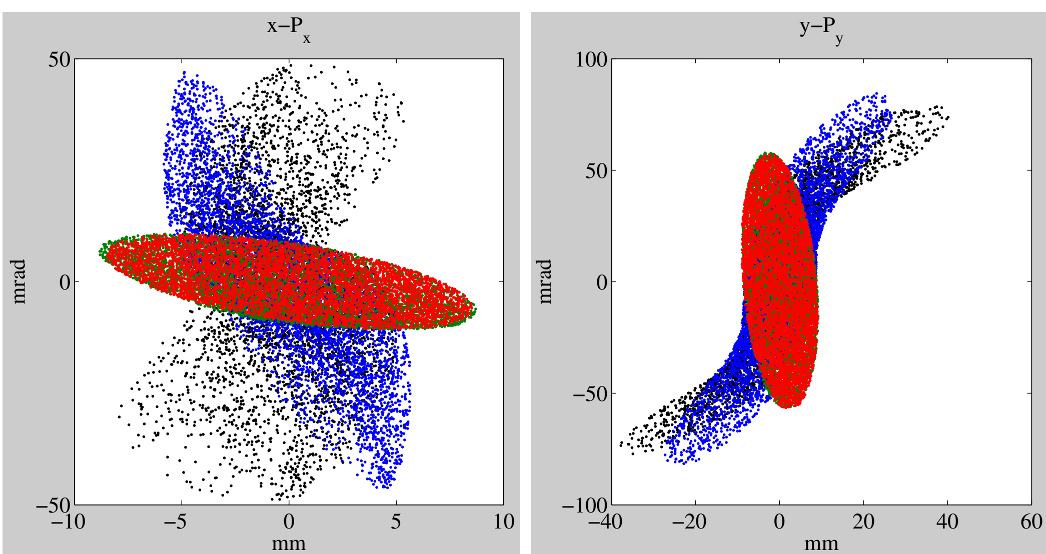
6 Higher Order

Is the `REVMOC` model sufficient to understand the beamline? In a word, **NO**. `REVMOC` is supposed to be correct to second order, and this can be checked against a proven higher order code such as `COSY-`∞. A soft-edge quadrupole model was constructed for `COSY-`∞ (see Appendix C), and the resulting maps up to fifth order were used to test the acceptance.

The `REVMOC` input file in the Appendix A contains starting phase space 0.2cm by 150mrad in X, 0.5cm by 400mrad in Y, and 15% (= 0.0045/0.030) momentum bite. For these very large starting spreads, `REVMOC` finds about half the initial particles make it to the target.

6.1 Transverse

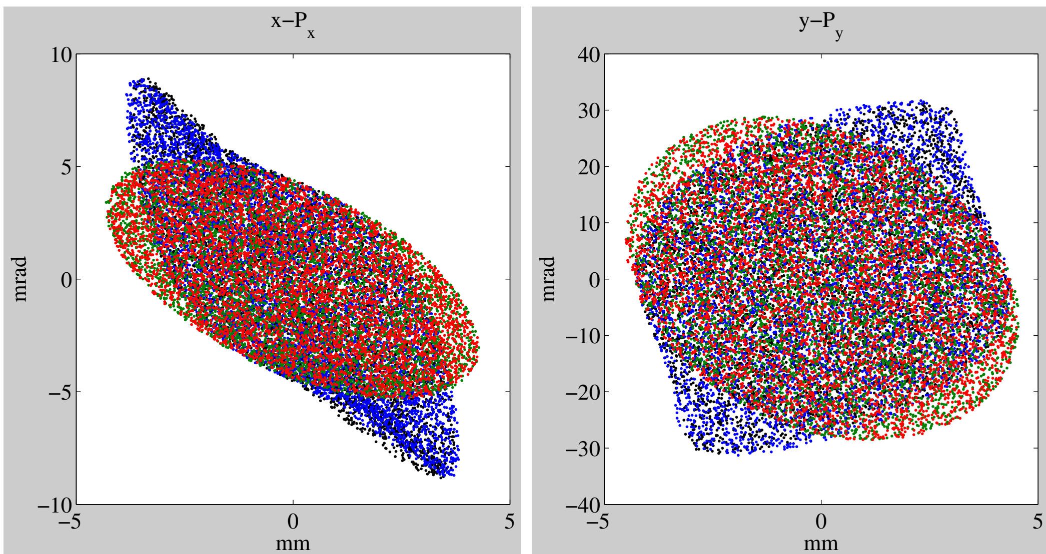
Setting $\Delta p/p = 0$, we run with 0.2cm by 150mrad in X, 0.5cm by 400mrad in Y. The resulting phase spaces are shown below. X phase space on left and Y on right.



Red is first order, Green is second order, Blue is third order, Black is fifth order. 5000 particles uniformly distributed in phase space.

Note that first and second order are identical; this is because second order effects only show up for momentum offset. But third order is very different from second order. Thus, for such large phase space, a second order calculation is insufficient.

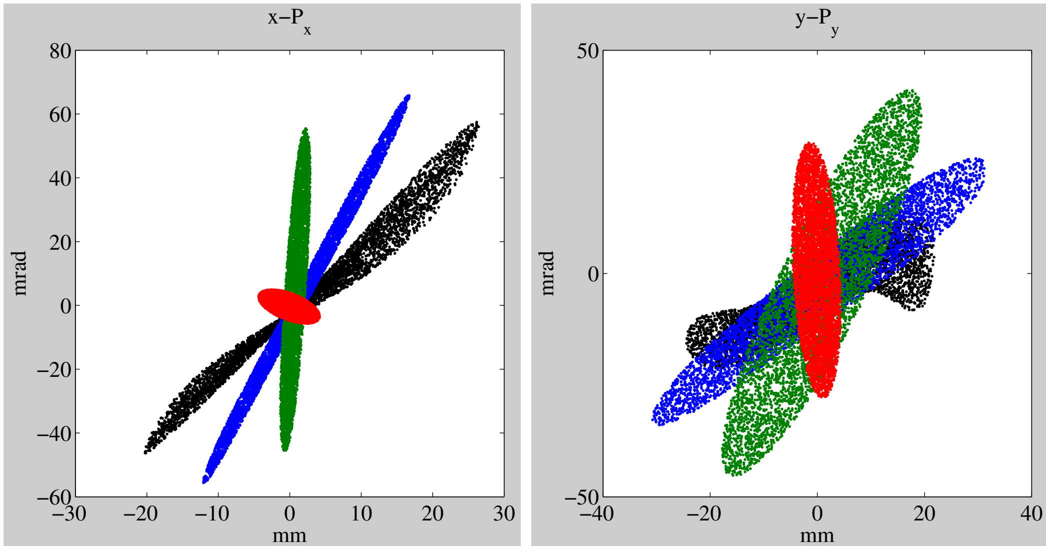
Worse, fifth order diverges strongly from third order: the calculation has not converged. To investigate further, the calculation was run with all phase space dimensions reduced by a factor of 2, i.e. emittances are 1/4 of Jaap's. This is below with the same colour scheme.



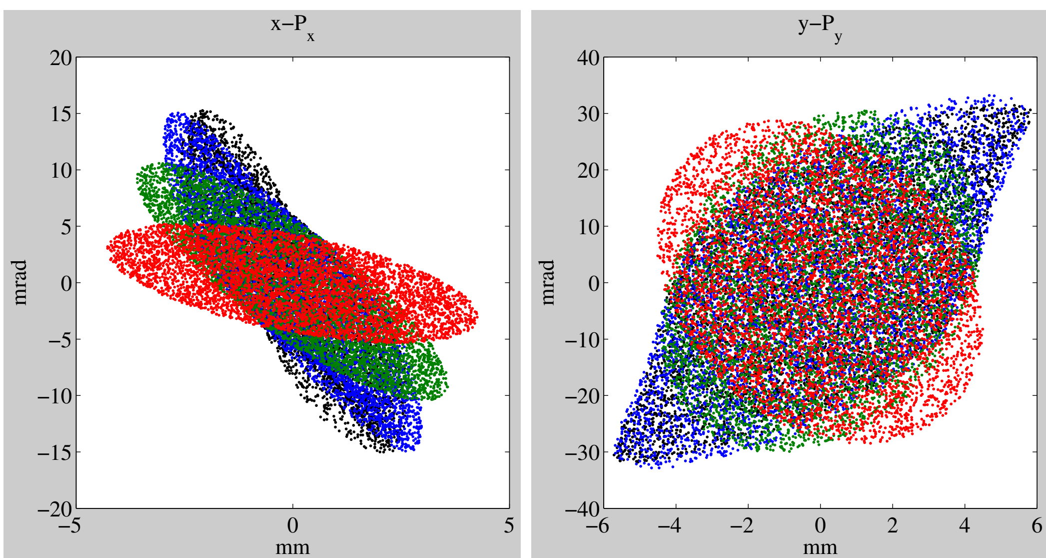
Here we see that fifth and third order agree, meaning that the calculation has converged. The third order effect has a simple explanation. The effect in any quadrupole as an aberrant angular kick $\Delta x' \sim x^3/(f^2L)$[1] where f is the focal length and L the effective length. Hence, the cubic-polynomial-like distortion we can see here. The intended kick is x/f, so errors in focusing are $\sim x^2/(fL)$. When this quantity is not small compared to 1, third order errors are important; in many cases more important than second order. In M15, maximum x is close to aperture radius and the quads are short and strong so both f and L are as small as an aperture diameter. So these errors can be very large.

6.2 Momentum offset

With this smaller phase space, can we still achieve a 15% momentum bite? No. See below. Colour scheme is same as before, but $\Delta p/p = -7.5\%$

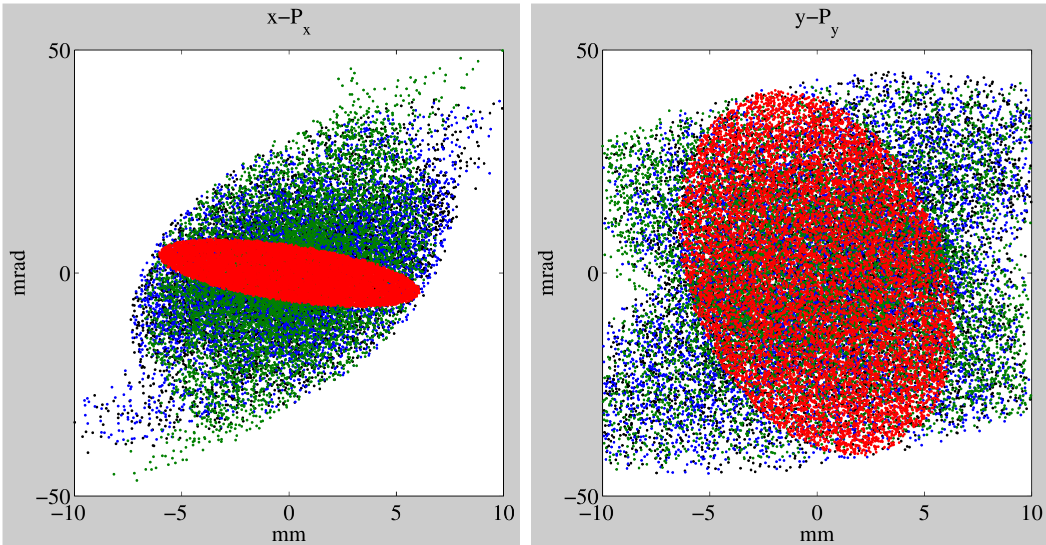


Notice that all are centred on the origin, meaning that they are first order doubly achromatic. But there is an extremely large chromatic effect and it's not converging. Even at $\Delta p/p = -1.0\%$ convergence is marginal. See below.



6.3 Conclusion

Using the phase space reduced by a factor $\sqrt{2}$ (one half the emittance in each transverse plane, one half the solid angle acceptance of Doornbos) and using a full width momentum spread of 6%, splitting the `COSY` calculation at each quadrupole to test for particles that have reached the aperture limit (this is therefore like a higher order "REVMOC-like" calculation), we find $> 90\%$ of particles make it to target, generously assumed to be 20 mm diameter. (I am neglecting decay.) The phase spaces are below, with same colour scheme as before.

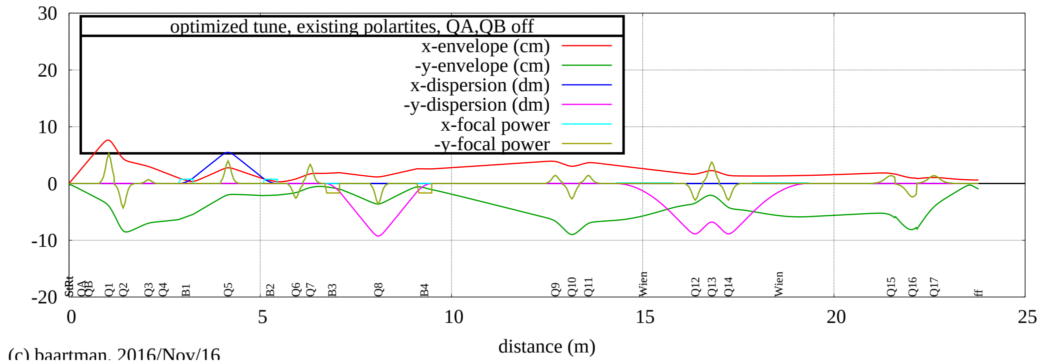


Using the full values of Doornbos, only about 30% survive, but as stated above, the calculation has no validity because the calculation at fifth order has not converged.

Thus we can say that a solid angle of 25 millisteradians and momentum of 6% has good transmission through M15. Outside of these values, there is little gain.

7 QA, QB off

As response to accumulated dose, the permanent magnet quadrupoles QA and QB are expected to degrade over time. A calculation was made for the case of these strengths at zero. The result is that the front end then becomes the acceptance bottleneck. Acceptance solid angle drops by a large factor. The quads Q1-Q4 were re-optimized using `TRANSOPTR`, with the initial beam reduced to the acceptance. The envelopes are shown here.



The strengths for Q1-Q4 for this case are 491A, 403A, 7A, 0A; Q3 and Q4 can just as well also be off. In effect, Q1 and Q2 take over the role of QA and QB. Note that downstream of these quads, the beam envelope is very small.

This is confirmed by `COSY`. From surface muon production target to exit of Q2, using the same $>90\%$ beam as used for QA and QB on, only 20% is accepted, and almost nothing additional is lost all the way to the final focus.

References

[1] R. Baartman. Intrinsic Third Order Aberrations in Electrostatic and Magnetic Quadrupoles. In *Proc. Particle Accelerator Conference, 12-16 May 1997, Vancouver, British Columbia, Canada*, pages 1415–1417. IEEE, 1997.

[2] R. Baartman and D. Kaltchev. Short quadrupole parametrization. In *Particle Accelerator Conference, 2007. PAC. IEEE*, pages 3229–3231. IEEE, 2007.

[3] J. Doornbos. M15. Technical Report TRI-BN-82-05, TRIUMF, 1982.

A Jaap's original REVMOC file

```
1 M15ROT.REV
T  .010  .5  0.  0.  0.  150.0
D  BEG  .26787  5.239
QUAD .05854 -5.514  10.
D  .00001  5.239
QUAD  .05854 -5.514  10.
D  .00001  5.239
D  .0656  5.931
QUAD  .05838  3.184  10.
D  .00001  5.931
QUAD  .05838  3.184  10.
D  .00001  5.931
D  SL1  .25962  7.50
D  .10  7.50
QUAD  .225  0.06238 10.
D  .15  7.50
QUAD  .225 -.00001  10.
D  SL2  0.357  7.50
D  .081  7.50
QUAD .225  0.5868  10.
D  .15000  7.50
QUAD .225 -.61174  10.
D  .00001  7.50
D  .30  7.5  -7.5  7.50 -7.50
ENTR  15.
BEND .37932  1.38132  0.  0.  .030
EXIT  15.
D  .00001  7.5  -7.5 7.50 -7.50
D  .80  7.50
QUAD .225  0.793  10.
D  .80  7.5  -7.5  7.50  -7.50
ENTR  15.
BEND  .37932  1.38132  0.  0.  .030
EXIT  15.
D  .00001  7.5  -7.5  7.50  -7.50
D MM  .37  7.50
QUAD .225  -.3518 10.
D  .15  7.50
QUAD .225  0.3640  10.
D  .00001  7.50
ROTATE  90.
D  .27  7.5  -7.5  7.50  -7.50
ENTR  0.000
BEND  .38481  2.04237  0.  0.  .030
EXIT  22.50
D  .00001  7.5  -7.5  7.50  -7.50
D .375  7.50
SEXT  .225  -0.000  10.0
D  SL34  .15  10.0  -10.0   10.0  -10.0
D  .15  7.50
QUAD .225  0.721  10.
D  .00001  7.50
D  0.30  7.50
SEXT  .225  +.0001  10.
D .375  7.5  -7.5  7.50  -7.50
ENTR  22.50
BEND  .38481  2.04237  0.  0.  .030
EXIT  0.000
D  .00001  7.5  -7.5  7.50  -7.50
D  0.42  8.90
ROTATE  90.
D  SL56 1.1256 8.90
D 1.5449  8.9
QUAD  .282  0.405  10.
D  0.15  8.9
QUAD  .282 -0.686  10.
D  .15  8.90
QUAD  .282  +0.405  10.
D  .28000  20.
D  *  .00000017  15.
1  1.110
0.796  6.  0.028  1.  0.176  8.
D  SEPI .2832 10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.  -0.13980
0.  0.  -2.0038  0.9239  0.  -3.7778
D  SEPM  .00001  10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.  -0.13980
0.  0.  -2.0038  0.9239  0.  -3.7778
D  SEPF  .00001  10.0  -10.0  6.0  -6.0
D  .45  8.90
QUAD  .282  0.302  10.
D  .15000  8.90
QUAD  .282  -0.824  10.
```

```
D  .15  8.90
QUAD  .282  0.302  10.
D  TEPI  .45  10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.  -0.13980
0.  0.  -2.0038  0.9239  0.  -3.7778
D  TEPM  .00001  10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.  -0.13980
0.  0.  -2.0038  0.9239  0.  -3.7778
D  TEPF  .00001  10.0  -10.0  6.0  -6.0
D  0.25  15.
D  *  .00000001  15.
1.  1.110
0.796  6.  0.028  1.  0.176  8.
D  0.25 15.0
D  1.50  15.
QUAD .323  0.3580  10.
D  .00001  15.
D  .24  15.
QUAD .323 -0.609  10.
D  .00001  15.
D  .24  15.
QUAD .323  0.3580  10.
D  F   1.00  15.
XSIZE  .2  150.
YSIZE  .5  400.
P  .030  .0045 .030  .000001
MASS  *  .105659  0.  0.  100000000.
1.  .000050  0.
GROUP  1. 20.0  0.  0.  0.  1.
NSPAC 1.0 -1.
2.
X  F  20.  5.
Y  F  20.  5.
END
FINIS
```

B New REVMOC file and its output

This is a file based upon optimized tune #7, but still with hard-edged quads. It has the 3 errors of the original file corrected. Quad settings were calculated with TRANSOPTR. The plots show good yield and corrected achromaticity.

```
1             ####################################################################################################
              #                                                                                                  #
              #            1 M15ROT.REV                                                                          #
              #                                                                                                  #
              ####################################################################################################

                                                                                 REVMOC, TRIUMF-LPC VERSION,  JULY 25, 2000


 DATA READ FROM UNIT 5 ARE LISTED BELOW:


 1 M15ROT.REV
 T  .010  .5  0.  0.  0.  150.0
 FRIN 7.94 .2875 3.
 D  BEG  .26787  5.239
 QUAD QA1 .05854 -.534351
 D  .00001  5.239
 QUAD QA2  .05854 -.534351
 D  .00001  5.239
 D  .0656  5.931
 QUAD QB1  .05838  .31197
 D  .00001  5.931
 QUAD QB2  .05838  .31197
 D  .00001  5.931
 D  SL1  .25962  7.50
 D  .102  7.50
 QUAD Q1  .221  0.0177757
 D  .154  7.50
 QUAD Q2  .221 -.00085
 D  SL2  0.359  7.50
 D  .083  7.50
 QUAD Q3 .221  0.04812
 D  .15400  7.50
 QUAD Q4 .221 -.05820
 D  .00001  7.50
 D  .302  7.5  -7.5  7.50 -7.50
 ENTR  15.
 BEND .37932  1.38132  0.  0.  .030
 EXIT  15.
 D  .00001  7.5  -7.5 7.50 -7.50
 D  .802  7.50
 QUAD Q5 .221  0.0887665
 D  .802  7.5  -7.5  7.50  -7.50
 ENTR  15.
 BEND  .37932  1.38132  0.  0.  .030
 EXIT  15.
 D  .00001  7.5  -7.5  7.50  -7.50
 D MM  .372  7.50
 QUAD Q6 .221  -.0601866
 D  .154  7.50
 QUAD Q7 .221  0.0732595
 D  .00001  7.50
 ROTATE  90.
 D  .272  7.5  -7.5  7.50  -7.50
 ENTR  0.000
 BEND  .38481  2.04237  0.  0.  .030
 EXIT  22.50
 D  .00001  7.5  -7.5  7.50  -7.50
 D .375  7.50
 SEXT  .225  -0.000  10.0
 D  SL34  .15  10.0  -10.0   10.0  -10.0
 D  .152  7.50
 QUAD Q8 .221  0.0814159
 D  .00001  7.50
 D  0.302  7.50
 SEXT  .225  +.0001  10.
 D .375  7.5  -7.5  7.50  -7.50
 ENTR  22.50
 BEND  .38481  2.04237  0.  0.  .030
 EXIT  0.000
 D  .00001  7.5  -7.5  7.50  -7.50
 D  0.42  8.90
 ROTATE  -90.
 D  SL56 1.1256 8.90
 D 1.56144  8.9
 QUAD Q9  .24892  0.0352559
```

```
D  0.18308  8.9
QUAD Q10 .24892 -00.0627439
D  .18308  8.90
QUAD Q11 .24892  0.0352559
D  .29654  20.
D  *  .00000017  15.
1  1.110
0.796  6.  0.028  1.  0.176  8.
D  SEPI .2832 10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.13980
0.  0.  -2.0038  0.9239  3.7778
D  SEPM  .00001  10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.13980
0.  0.  -2.0038  0.9239  3.7778
D  SEPF  .00001  10.0  -10.0  6.0  -6.0
D  .471366  8.90
QUAD Q12 .239268  -.0660000
D  .192732  8.90
QUAD Q13 .239268  0.0868919
D  .192732  8.90
QUAD Q14 .239268  -.0660000
D  TEPI  .471366  10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.13980
0.  0.  -2.0038  0.9239  3.7778
D  TEPM  .00001  10.0  -10.0  6.0  -6.0
MAT  .75  1  3  4
1.0  0.075  0.  0.  0.  0.
0.  0.  0.9239  0.07310  0.13980
0.  0.  -2.0038  0.9239  3.7778
D  TEPF  .00001  10.0  -10.0  6.0  -6.0
D  0.25  15.
D  *  .00000001  15.
1.  1.110
0.796  6.  0.028  1.  0.176  8.
D  0.25 15.0
D  1.4889  15.
QUAD Q15 .3452  0.0351974
D  .00001  15.
D  .2178  15.
QUAD Q16 .3452 -0.0571025
D  .00001  15.
D  .2178  15.
QUAD Q17 .3452  0.0351974
D  F  0.9889  15.
XSIZE  .2  150.
YSIZE  .5  400.
P  .030  .0045 .030  .000001
MASS   .105659  0.  0.
GROUP  1. 20.0  0.  0.  0.  3.
NSPAC 5.0 -1.
2. 2. 2. 2. 2.
X  F  20.  5.
Y  F  20.  5.
X  F  20.  5.
DX  F  20.  200.
Y  F  20.  5.
DY  F  20.  200.
X F 20. 5.
P F 20. .005 .03
Y F 20. 5.
P F 20. .005 .03
END

====================================================================
SETUP COMPLETED
1

     M15ROT.REV


     IN THE FOLLOWING TABULATION OF RESULTS
     INITIAL OR INITIALLY MEANS PARTICLES WERE TRACED THROUGH SYSTEM WITH NO DECAY,SCATTERING,ABSORPTION OR ENERGY LOSS
       FINAL OR FINALLY   MEANS PARTICLES WERE TRACED THROUGH SYSTEM WITH    DECAY,SCATTERING,ABSORPTION AND ENERGY LOSS
         NUMBER OF TRIAL PARTICLES TRACED THROUGH SYSTEM =        20000.00
                 NUMBER OF PARTICLES ACCEPTED  INITIALLY =         9540.00
                   NUMBER OF PARTICLES ACCEPTED  FINALLY =         9540.00
1

     M15ROT.REV


                        PARTICLES INITIALLY REJECTED FROM TOTAL TRIALS          PARTICLES FINALLY REJECTED FROM TOTAL TRIALS
-----------------------------------------------------------------------------------------------------------------------------------
     Z(M) LABEL   TYPE   >HOR. LIM.    %    >VER. LIM.   %                   > HOR. LIM.     %     >VER. LIM.       %        SUM%
9    0.000        TARG
9    0.000        FRING
```

9	0.268	BEG	DRIFT	0.000	0.00	1211.000	6.05	0.000	0.0000	0.000	0.0000	0.000
9	0.326	QA1	QUAD									
9	0.326		DRIFT	0.000	0.00	2319.000	11.60	0.000	0.0000	0.000	0.0000	0.000
9	0.385	QA2	QUAD									
9	0.385		DRIFT	52.000	0.26	225.000	1.12	0.000	0.0000	0.000	0.0000	0.000
9	0.451		DRIFT	154.000	0.77	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	0.509	QB1	QUAD									
9	0.509		DRIFT	1663.000	8.31	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	0.567	QB2	QUAD									
9	0.567		DRIFT	779.000	3.89	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	0.827	SL1	DRIFT									
9	0.929		DRIFT									
9	1.150	Q1	QUAD									
9	1.304		DRIFT									
9	1.525	Q2	QUAD									
9	1.884	SL2	DRIFT	1.000	0.00	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	1.967		DRIFT									
9	2.188	Q3	QUAD									
9	2.342		DRIFT	0.000	0.00	396.000	1.98	0.000	0.0000	0.000	0.0000	0.000
9	2.563	Q4	QUAD									
9	2.563		DRIFT	0.000	0.00	245.000	1.23	0.000	0.0000	0.000	0.0000	0.000
9	2.865		DRIFT									
9	2.865		ENTR									
9	3.244		BEND									
9	3.244		EXIT									
9	3.244		DRIFT									
9	4.046		DRIFT	216.000	1.08	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	4.267	Q5	QUAD									
9	5.069		DRIFT									
9	5.069		ENTR									
9	5.449		BEND									
9	5.449		EXIT									
9	5.449		DRIFT									
9	5.821	MM	DRIFT	1.000	0.00	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	6.042	Q6	QUAD									
9	6.196		DRIFT	465.000	2.33	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	6.417	Q7	QUAD									
9	6.417		DRIFT	315.000	1.58	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	6.417		ROTAT									
9	6.689		DRIFT									
9	6.689		ENTR									
9	7.073		BEND									
9	7.073		EXIT									
9	7.073		DRIFT									
9	7.448		DRIFT									
9	7.673		SEXT									
9	7.823	SL34	DRIFT									
9	7.975		DRIFT	308.000	1.54	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	8.196	Q8	QUAD									
9	8.196		DRIFT	9.000	0.05	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	8.498		DRIFT									
9	8.723		SEXT									
9	9.098		DRIFT	0.000	0.00	8.000	0.04	0.000	0.0000	0.000	0.0000	0.000
9	9.098		ENTR									
9	9.483		BEND									
9	9.483		EXIT									
9	9.483		DRIFT	0.000	0.00	3.000	0.01	0.000	0.0000	0.000	0.0000	0.000
9	9.903		DRIFT									
9	9.903		ROTAT									
9	11.029	SL56	DRIFT	81.000	0.41	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	12.590		DRIFT	473.000	2.37	85.000	0.43	0.000	0.0000	0.000	0.0000	0.000
9	12.839	Q9	QUAD									
9	13.022		DRIFT	0.000	0.00	703.000	3.52	0.000	0.0000	0.000	0.0000	0.000
9	13.271	Q10	QUAD									
9	13.454		DRIFT	1.000	0.00	0.000	0.00	0.000	0.0000	0.000	0.0000	0.000
9	13.703	Q11	QUAD									
9	14.000		DRIFT									
9	14.000		DRIFT									
9	14.283	SEPI	DRIFT	0.000	0.00	188.000	0.94	0.000	0.0000	0.000	0.0000	0.000
9	15.033		MATRX									
9	15.033	SEPM	DRIFT	0.000	0.00	2.000	0.01	0.000	0.0000	0.000	0.0000	0.000
9	15.783		MATRX									
9	15.783	SEPF	DRIFT	0.000	0.00	171.000	0.86	0.000	0.0000	0.000	0.0000	0.000
9	16.254		DRIFT									
9	16.494	Q12	QUAD									
9	16.686		DRIFT									
9	16.926	Q13	QUAD									
9	17.118		DRIFT	0.000	0.00	5.000	0.03	0.000	0.0000	0.000	0.0000	0.000
9	17.358	Q14	QUAD									
9	17.829	TEPI	DRIFT	0.000	0.00	328.000	1.64	0.000	0.0000	0.000	0.0000	0.000
9	18.579		MATRX									
9	18.579	TEPM	DRIFT									
9	19.329		MATRX									
9	19.329	TEPF	DRIFT	0.000	0.00	53.000	0.26	0.000	0.0000	0.000	0.0000	0.000
9	19.579		DRIFT									
9	19.579		DRIFT									
9	19.829		DRIFT									
9	21.318		DRIFT									
9	21.663	Q15	QUAD									
9	21.663		DRIFT									
9	21.881		DRIFT									
9	22.226	Q16	QUAD									

```
9    22.226        DRIFT
9    22.444        DRIFT
9    22.789 Q17    QUAD
9    23.778 F      DRIFT


     TOTAL LOSSES----->   4518.000  22.59   5942.000  29.71                 0.000        0.0000    0.000        0.0000     0.000
1

    M15ROT.REV
```

DISTRIBUTIONS OF ACCEPTED PARTICLES AS A FUNCTION OF STARTING CONDITIONS OF PARTICLE AT TARGET

MOMENTUM(GEV/C)				POSITION ALONG TARGET(CM)			
GEV/C	INITIAL BEAM	FINAL BEAM	FINAL.NOT(INITIAL)	CM	INITIAL BEAM	FINAL BEAM	FINAL.NOT(INITIAL)
0.278625E-01	85.0000	85.0000	0.00000	-0.475000	501.000	501.000	0.00000
0.280875E-01	165.000	165.000	0.00000	-0.425000	455.000	455.000	0.00000
0.283125E-01	248.000	248.000	0.00000	-0.375000	448.000	448.000	0.00000
0.285375E-01	280.000	280.000	0.00000	-0.325000	506.000	506.000	0.00000
0.287625E-01	362.000	362.000	0.00000	-0.275000	451.000	451.000	0.00000
0.289875E-01	487.000	487.000	0.00000	-0.225000	490.000	490.000	0.00000
0.292125E-01	539.000	539.000	0.00000	-0.175000	439.000	439.000	0.00000
0.294375E-01	575.000	575.000	0.00000	-0.125000	527.000	527.000	0.00000
0.296625E-01	572.000	572.000	0.00000	-0.750000E-01	505.000	505.000	0.00000
0.298875E-01	634.000	634.000	0.00000	-0.250000E-01	465.000	465.000	0.00000
0.301125E-01	649.000	649.000	0.00000	0.250000E-01	490.000	490.000	0.00000
0.303375E-01	678.000	678.000	0.00000	0.750000E-01	506.000	506.000	0.00000
0.305625E-01	655.000	655.000	0.00000	0.125000	458.000	458.000	0.00000
0.307875E-01	689.000	689.000	0.00000	0.175000	490.000	490.000	0.00000
0.310125E-01	676.000	676.000	0.00000	0.225000	474.000	474.000	0.00000
0.312375E-01	607.000	607.000	0.00000	0.275000	429.000	429.000	0.00000
0.314625E-01	577.000	577.000	0.00000	0.325000	485.000	485.000	0.00000
0.316875E-01	464.000	464.000	0.00000	0.375000	469.000	469.000	0.00000
0.319125E-01	342.000	342.000	0.00000	0.425000	470.000	470.000	0.00000
0.321375E-01	256.000	256.000	0.00000	0.475000	482.000	482.000	0.00000

POSITION IN HORIZONTAL PLANE(CM)				ANGLE IN HORIZONTAL PLANE(MR)			
CM	INITIAL BEAM	FINAL BEAM	FINAL.NOT(INITIAL)	MR	INITIAL BEAM	FINAL BEAM	FINAL.NOT(INITIAL)
-0.950000E-01	446.000	446.000	0.00000	2546.74	2.00000	2.00000	0.00000
-0.850000E-01	484.000	484.000	0.00000	2554.24	118.000	118.000	0.00000
-0.750000E-01	430.000	430.000	0.00000	2561.74	410.000	410.000	0.00000
-0.650000E-01	513.000	513.000	0.00000	2569.24	488.000	488.000	0.00000
-0.550000E-01	478.000	478.000	0.00000	2576.74	566.000	566.000	0.00000
-0.450000E-01	481.000	481.000	0.00000	2584.24	650.000	650.000	0.00000
-0.350000E-01	478.000	478.000	0.00000	2591.74	630.000	630.000	0.00000
-0.250000E-01	491.000	491.000	0.00000	2599.24	644.000	644.000	0.00000
-0.150000E-01	479.000	479.000	0.00000	2606.74	693.000	693.000	0.00000
-0.499999E-02	511.000	511.000	0.00000	2614.24	700.000	700.000	0.00000
0.500001E-02	467.000	467.000	0.00000	2621.74	662.000	662.000	0.00000
0.150000E-01	470.000	470.000	0.00000	2629.24	650.000	650.000	0.00000
0.250000E-01	463.000	463.000	0.00000	2636.74	596.000	596.000	0.00000
0.350000E-01	474.000	474.000	0.00000	2644.24	598.000	598.000	0.00000
0.450000E-01	447.000	447.000	0.00000	2651.74	520.000	520.000	0.00000
0.550000E-01	484.000	484.000	0.00000	2659.24	559.000	559.000	0.00000
0.650000E-01	470.000	470.000	0.00000	2666.74	537.000	537.000	0.00000
0.750000E-01	478.000	478.000	0.00000	2674.24	377.000	377.000	0.00000
0.850000E-01	486.000	486.000	0.00000	2681.74	135.000	135.000	0.00000
0.950000E-01	510.000	510.000	0.00000	2689.24	5.00000	5.00000	0.00000

1

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POSITION IN VERTICAL PLANE(CM)				ANGLE IN VERTICAL PLANE(MR)			
CM	INITIAL BEAM	FINAL BEAM	FINAL.NOT(INITIAL)	MR	INITIAL BEAM	FINAL BEAM	FINAL.NOT(INITIAL)
-0.237500	415.000	415.000	0.00000	-190.000	0.00000	0.00000	0.00000
-0.212500	449.000	449.000	0.00000	-170.000	139.000	139.000	0.00000
-0.187500	445.000	445.000	0.00000	-150.000	320.000	320.000	0.00000
-0.162500	455.000	455.000	0.00000	-130.000	390.000	390.000	0.00000
-0.137500	494.000	494.000	0.00000	-110.000	489.000	489.000	0.00000
-0.112500	505.000	505.000	0.00000	-90.0000	559.000	559.000	0.00000
-0.875000E-01	501.000	501.000	0.00000	-70.0000	631.000	631.000	0.00000
-0.625000E-01	514.000	514.000	0.00000	-50.0000	626.000	626.000	0.00000
-0.375000E-01	524.000	524.000	0.00000	-30.0000	714.000	714.000	0.00000
-0.125000E-01	507.000	507.000	0.00000	-9.99999	699.000	699.000	0.00000
0.125000E-01	517.000	517.000	0.00000	10.0000	696.000	696.000	0.00000
0.375000E-01	476.000	476.000	0.00000	30.0000	673.000	673.000	0.00000
0.625000E-01	483.000	483.000	0.00000	50.0000	660.000	660.000	0.00000
0.875000E-01	490.000	490.000	0.00000	70.0000	719.000	719.000	0.00000
0.112500	516.000	516.000	0.00000	90.0000	608.000	608.000	0.00000
0.137500	512.000	512.000	0.00000	110.000	584.000	584.000	0.00000
0.162500	457.000	457.000	0.00000	130.000	501.000	501.000	0.00000
0.187500	477.000	477.000	0.00000	150.000	388.000	388.000	0.00000
0.212500	422.000	422.000	0.00000	170.000	144.000	144.000	0.00000
0.237500	381.000	381.000	0.00000	190.000	0.00000	0.00000	0.00000

CENTRAL VALUES AND WIDTHS OF DISTRIBUTIONS IN STARTING MOMENTA AND ANGLES

```
(THESE RESULTS  ARE ROUGH ESTIMATES ONLY-FOR ACCURATE VALUES THE DISTRIBUTIONS SHOULD BE PLOTTED)
                                  INITIAL BEAM              FINAL BEAM
                           CENTRE        WIDTH       CENTRE        WIDTH
          MOMENTUM(GEV/C)    0.302E-01    0.322E-02    0.302E-01    0.322E-02
     HORIZONTAL ANGLE(MR)    0.262E+04     109.        0.262E+04     109.
       VERTICAL ANGLE(MR)     4.92         281.         4.92         281.
1

      M15ROT.REV

  DISTRIBUTION OF PARTICLES FINALLY ACCEPTED
 SPACE # 1:  DISTRIBUTION OF PARTICLES AS A FUNCTION OF  X  AT F      (ELEMENT # 98)     (ALONG HORIZONTAL AXIS)
                                                       & Y  AT F      (ELEMENT # 98)     (ALONG VERTICAL AXIS)
                                              COUNTS =  9540.00
                                                 X PROJECTION


                                                  1   1   1   1
                                      1   4   8   4   8   7   2   8   3   2   1
                              1   8   9   5   6   5   4   6   6   0   8   4   1   3
                  0   2   4   3   9   7   7   8   0   8   8   6   0   2   3   3   6   4   0   0
              +---|-------------------|-------------------|-------------------|----------------+
    2.250     |                                                                                |        0
    2.000     |                                                                                |        0
    1.750     |                                       6   3   2   2                            |       13
    1.500     |                       1   1  24  34  45  38  26  17   4                        |      190
Y   1.250     |                       1  12  42  69  76  81  70  46  17   3                    |      417 Y
    1.000     |                       2  23  61 103 126 114 104  68  21   8                    |      630
   0.7500     |                       2  36  68 107 150 154 100  66  42  19   3                |      747 P
A 0.5000      |                      16  37  75 145 201 188 126  83  38  20   4                |      933 R
T 0.2500      |                   4  18  44  97 167 201 204 142  79  43  28  13   1            |     1041 O
    0.000     -                      26  55  93 146 181 192 147  83  30  24  20   7            -     1004 J
F -.2500      |                  10  29  57  79 162 203 192 143  83  42  35  13   7   1        |     1056 E
  -.5000      |               1  10  25  54  94 146 196 202 122  76  38  33  22   7   2        |     1028 C
  -.7500      |           2   3  22  23  56  71 118 160 155 107  64  38  34  16  10   1        |      880 T
   -1.000     |               2  21  26  36  58 101 119 118  77  55  26  18  10   2            |      669 I
   -1.250     |               2  14  13  26  49  53  69  56  51  42  21  12   6   2            |      416 O
   -1.500     |               1   3   9  12  29  41  45  38  33  19  18   7   6                |      261 N
   -1.750     |       2   1   2   3   1   3  21  28  38  17  13  11   3   1                    |      144
   -2.000     |           1   2   2   2   4   5  24  26  12   2   4   1                        |       85
   -2.250     |                       3   1   2   4   6   4       2       1                    |       23
   -2.500     -                                   2           1                                -        3
              +---|-------------------|-------------------|-------------------|----------------+
                  -   -   -   -   -   -   -   -   -   -
                  2   2   2   1   1   1   1   0   0   0   0   0   0   0   1   1   1   1   2   2
                  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .
                  5   2   0   7   5   2   0   7   5   2   0   2   5   7   0   2   5   7   0   2
                  0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5
                                                 X  AT F
1

      M15ROT.REV

  DISTRIBUTION OF PARTICLES FINALLY ACCEPTED
 SPACE # 2:  DISTRIBUTION OF PARTICLES AS A FUNCTION OF  X  AT F      (ELEMENT # 98)     (ALONG HORIZONTAL AXIS)
                                                       & DX AT F      (ELEMENT # 98)     (ALONG VERTICAL AXIS)
                                              COUNTS =  9540.00
                                                 X PROJECTION


                                                  1   1   1   1
                                      1   4   8   4   8   7   2   8   3   2   1
                              1   8   9   5   6   5   4   6   6   0   8   4   1   3
                  0   2   4   3   9   7   7   8   0   8   8   6   0   2   3   3   6   4   0   0
              +---|-------------------|-------------------|-------------------|----------------+
    90.00     |                                                                                |        0
    80.00     |                                                                                |        0
    70.00     |                                                                                |        0
    60.00     |                                                           2   3       1        |        6
D   50.00     |                                               2   5   6   6   4                |       23 Y
X   40.00     |                               5   3  10  11  17   8   5   4                    |       63
    30.00     |                       4  31  40  75  82  74  62  30   4                        |      402 P
A   20.00     |                  11  33  77  90 119 144 125  98  53  16   1                    |      767 R
T   10.00     |               1  22  48  85 157 202 254 242 148  85  44  22   3                |     1313 O
    0.000     -               2  18  39  86 169 345 424 394 246 163  60  39  23   6            -     2014 J
F  -10.00     |                  12  26  79 141 276 399 416 301 186  94  61  32  18   2        |     2043 E
   -20.00     |                   1  15  41 111 231 274 269 196 133  72  65  33  10   1        |     1452 C
   -30.00     |                          19  91 120 163 153 115  82  51  30  15   2            |      841 T
   -40.00     |                   1  11  20  37  61  81  76  76  50  30  13                    |      456 I
   -50.00     |               1   7   6  11  17  16  17   8   5   5                            |       93 O
   -60.00     |               3  12   9   8  10   2                                            |       44 N
   -70.00     |       1   4   6   5   6                                                        |       22
   -80.00     |       1                                                                        |        1
   -90.00     |                                                                                |        0
   -100.0     -                                                                                -        0
              +---|-------------------|-------------------|-------------------|----------------+
                  -   -   -   -   -   -   -   -   -   -
                  2   2   2   1   1   1   1   0   0   0   0   0   0   0   1   1   1   1   2   2
                  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .
                  5   2   0   7   5   2   0   7   5   2   0   2   5   7   0   2   5   7   0   2
```

```
                0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5
                                                 X  AT F
1

      M15ROT.REV

  DISTRIBUTION OF PARTICLES FINALLY ACCEPTED
 SPACE # 3:  DISTRIBUTION OF PARTICLES AS A FUNCTION OF  Y  AT F      (ELEMENT # 98)     (ALONG HORIZONTAL AXIS)
                                                      & DY AT F      (ELEMENT # 98)     (ALONG VERTICAL AXIS)
                                             COUNTS =  9540.00
                                                X PROJECTION


                                                  1   1   1   1
                          1   2   4   6   8   0   0   0   0   9   7   6   4   1
                  2   8   4   6   1   6   8   2   5   0   4   3   4   3   1   9   1
              3   3   5   4   1   6   9   0   8   6   4   1   3   7   0   7   0   3   0   0
             +---|-------------------|-------------------|-------------------|----------------+
   90.00     |                                                                                |       0
   80.00     |                                                                                |       0
   70.00     |                                                                                |       0
   60.00     |                                                                                |       0
D  50.00     |                                   2       2   2   4   3   1   2                |      16 Y
Y  40.00     |                           2   8  18  22  32  30  30  28  25  26   6            |     227
   30.00     |                       5  15  41  59  60  59  55  49  26  30  33  29   1        |     462 P
A  20.00     |                   5  34  54  68  88  97  92  84  91  79  56  42  12   4        |     806 R
T  10.00     |                  15  49  70  95 131 147 138 150 139 131  98  53  29            |    1245 O
   0.000     -               1  23  49  85  96 167 190 181 178 186 154 124  73  40   2        -    1549 J
F -10.00     |               3  32  50 119 192 187 178 161 181 158 120 104  84  42   4        |    1615 E
  -20.00     |          11  10  41  57 117 136 153 144 142 166 131 103 106  68  23   1        |    1409 C
  -30.00     |       9  22  42  54  66  98 132 133 134 117 118  88  79  73  35   8   1        |    1209 T
  -40.00     |   3  13  30  54  58  73  69  67  52  55  54  57  49  19  10   1   1            |     665 I
  -50.00     |       1  20  32  28  27  39  42  37  26  26  20   8   5   3                    |     314 O
  -60.00     |           2   2   5   6   1   3   1   3                                        |      23 N
  -70.00     |                                                                                |       0
  -80.00     |                                                                                |       0
  -90.00     |                                                                                |       0
  -100.0     -                                                                                -       0
             +---|-------------------|-------------------|-------------------|----------------+
                 -   -   -   -   -   -   -   -   -   -
                 2   2   2   1   1   1   1   0   0   0   0   0   0   0   1   1   1   1   2   2
                 .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .
                 5   2   0   7   5   2   0   7   5   2   0   2   5   7   0   2   5   7   0   2
                 0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5
                                                 Y  AT F
1

      M15ROT.REV

  DISTRIBUTION OF PARTICLES FINALLY ACCEPTED
 SPACE # 4:  DISTRIBUTION OF PARTICLES AS A FUNCTION OF  X  AT F      (ELEMENT # 98)     (ALONG HORIZONTAL AXIS)
                                                      & P  AT F      (ELEMENT # 98)     (ALONG VERTICAL AXIS)
                                             COUNTS =  9540.00
                                                X PROJECTION


                                                  1   1   1   1
                                      1   4   8   4   8   7   2   8   3   2   1
                              1   8   9   5   6   5   4   6   6   0   8   4   1   3
              0   2   4   3   9   7   7   8   0   8   8   6   0   2   3   3   6   4   0   0
             +---|-------------------|-------------------|-------------------|----------------+
  0.3225E-01 |                                                                                |       0
  0.3200E-01 |                           5  10  32  60  73  60  33  12   6   3                |     294
  0.3175E-01 |                   3   5  18  27  60  78  60  56  43  33  17   6   3            |     409
  0.3150E-01 |               1  11  31  40  52  75  52  61  62  46  34  48  21   9   1        |     544
P 0.3125E-01 |               1  20  39  62  65  62  53  76  63  62  55  45  41  16   1        |     661 Y
  0.3100E-01 |               1  21  28  71  68  66  81  76  85  82  52  54  19   8   1        |     713
  0.3075E-01 |                   9  34  63  84  86  96  92  86  86  47  40  15                |     738 P
A 0.3050E-01 |                      18  55  91 116 121 123  97  82  48  14   1                |     766 R
T 0.3025E-01 |                       2  18  52 127 164 185 113  67  19                        |     747 O
  0.3000E-01 -                              20 102 219 244 118  13   2                        -     718 J
F 0.2975E-01 |                           1  25 108 204 214 120  21                            |     693 E
  0.2950E-01 |                       1  14  67 106 119 139 109  69  17   1                    |     642 C
  0.2925E-01 |                       5  34  79  96 114  87 100  83  33   4                    |     635 T
  0.2900E-01 |                       3  25  98  96 113  82  75  68  15   2                    |     577 I
  0.2875E-01 |                           4  45 131 138  98  50  12                            |     478 O
  0.2850E-01 |                              21 100 145  62   6                                |     334 N
  0.2825E-01 |                       7  17  38  64  48  65  42   8   2                        |     291
  0.2800E-01 |           2   6  15  16  20  18  17  32  25  18  18   9   7                    |     203
  0.2775E-01 |       2   2   4  10   8  10   8   6  11   6   6   7   4   5   7       1        |      97
  0.2750E-01 -                                                                                -       0
             +---|-------------------|-------------------|-------------------|----------------+
                 -   -   -   -   -   -   -   -   -   -
                 2   2   2   1   1   1   1   0   0   0   0   0   0   0   1   1   1   1   2   2
                 .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .
                 5   2   0   7   5   2   0   7   5   2   0   2   5   7   0   2   5   7   0   2
                 0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5
                                                 X  AT F
1
```

```
    M15ROT.REV

 DISTRIBUTION OF PARTICLES FINALLY ACCEPTED
SPACE # 5:  DISTRIBUTION OF PARTICLES AS A FUNCTION OF  Y  AT F      (ELEMENT # 98)     (ALONG HORIZONTAL AXIS)
                                                         & P  AT F      (ELEMENT # 98)     (ALONG VERTICAL AXIS)
                                              COUNTS =  9540.00
                                                 X PROJECTION


                                                 1   1   1   1
                          1   2   4   6   8   0   0   0   0   9   7   6   4   1
                  2   8   4   6   1   6   8   2   5   0   4   3   4   3   1   9   1
              3   3   5   4   1   6   9   0   8   6   4   1   3   7   0   7   0   3   0   0
             +---|-------------------|-------------------|-------------------|----------------+
  0.3225E-01 |                                                                                |       0
  0.3200E-01 |                           3   9  23  28  37  34  33  41  56  22   8            |     294
  0.3175E-01 |                       5  18  33  32  44  38  52  51  43  48  33  11   1        |     409
  0.3150E-01 |                   2  15  26  38  47  57  58  72  70  55  54  33  15   2        |     544
P 0.3125E-01 |                   7  44  58  63  57  61  67  72  67  54  50  37  22   2        |     661 Y
  0.3100E-01 |                  22  35  60  65  65  58  47  70  72  58  68  58  35            |     713
  0.3075E-01 |               1  25  45  52  56  74  80  76  70  66  59  72  39  21   2        |     738 P
A 0.3050E-01 |               3  19  38  49  71  91  84  84  88  82  68  44  36   8   1        |     766 R
T 0.3025E-01 |                   8  17  49  75 109 120 108  89  62  60  33  16   1            |     747 O
  0.3000E-01 -                       2  45  92 112 102  98 114  92  42  17   2                -     718 J
F 0.2975E-01 |                       7  49 102 119  99  94 111  75  31   6                    |     693 E
  0.2950E-01 |                   6  26  48  71  74  96  98  75  60  52  29   7                |     642 C
  0.2925E-01 |               7  29  41  54  52  70  68  71  53  52  51  37  39  11            |     635 T
  0.2900E-01 |           5  27  26  42  52  43  43  42  40  46  61  44  43  39  22   2        |     577 I
  0.2875E-01 |       1  25  35  34  32  37  24  27  41  27  33  37  39  33  26  24   3        |     478 O
  0.2850E-01 |       3  16  23  24  18  26  21  36  29  18  21  23  20  22  22  12            |     334 N
  0.2825E-01 |   2   7  16  18  24  22  16  19  19  24  26  24  24  25  17   8                |     291
  0.2800E-01 |   1  10  11  15  16  17  21  30  18  19  16  17   6   5   1                    |     203
  0.2775E-01 |       2  12  15  19  10   6  16  12   4   1                                    |      97
  0.2750E-01 -                                                                                -       0
             +---|-------------------|-------------------|-------------------|----------------+
                 -   -   -   -   -   -   -   -   -   -
                 2   2   2   1   1   1   1   0   0   0   0   0   0   0   1   1   1   1   2   2
                 .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .
                 5   2   0   7   5   2   0   7   5   2   0   2   5   7   0   2   5   7   0   2
                 0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5   0   5
                                                Y  AT F


REPLACEMENT DATA FOR NEXT RUN IS LISTED BELOW
============================================================
FINIS


FINI CODE ENCOUNTERED FOLLOWING CALCULATION #  1; NORMAL TERMINATION OF PROGRAM.
```

C COSY-∞ file

```
include 'COSY' ;
   PROCEDURE RUN ;
   OV 5 3 0 ; RPR    0.0963   0.1134   1.0000;
   um ;
   fc 1 1 1 0. 3.5 0 0 0 0 ;
   fc 1 2 1 0. 3.5 0 0 0 0 ;
   fr  0;

    dl    0.26787 ;
    mq    0.11708 -0.28000  0.05240 ;
    dl    0.06560 ;
    mq    0.11676  0.18500  0.05930 ;
    dl    0.47212 ;
   fr 3;
    msq    0.04029  0.10110 ;
    dl    0.37500 ;
    msq   -0.01385  0.10110 ;
    dl    0.66300 ;
    msq    0.11632  0.10110 ;
    dl    0.37500 ;
    msq   -0.13139  0.10110 ;
    dl    0.41250 ;
 di    0.7244  30.0000   0.0794  15.0000   0.0000  15.0000   0.0000 ;
    dl    0.91250 ;
    msq    0.19356  0.10110 ;
    dl    0.91250 ;
 di    0.7244  30.0000   0.0794  15.0000   0.0000  15.0000   0.0000 ;
    dl    0.30000 ;
    dl    0.18250 ;
    msq   -0.12668  0.10110 ;
    dl    0.37500 ;
    msq    0.16436  0.10110 ;
    dl    0.38250 ;
ra  90.;
 di    0.4900  45.0000   0.0794   0.0000   0.0000  22.5000   0.0000 ;
ra  -90.;
    dl    0.37500 ;
    dl    0.22500 ;
    dl    0.15000 ;
    dl    0.26250 ;
    msq   -0.17708  0.10110 ;
    dl    0.41250 ;
    dl    0.22500 ;
    dl    0.37500 ;
ra  90.;
 di    0.4900  45.0000   0.0794  22.5000   0.0000   0.0000   0.0000 ;
ra  -90.;
    dl    0.42000 ;
    dl    1.12560 ;
    dl    1.68590 ;
    msq    0.07911  0.11401 ;
    dl    0.43200 ;
    msq   -0.14901  0.11401 ;
    dl    0.43200 ;
    msq    0.07911  0.11401 ;
    dl    0.42100 ;
    dl    0.28320 ;
   fr 1;
   ra -90.;
   wf    1.8380   1.8380   1.5000 .06;
ra   90.;
    dl    0.59100 ;
    msq   -0.16079  0.11401 ;
    dl    0.43200 ;
    msq    0.20737  0.11401 ;
    dl    0.43200 ;
    msq   -0.16079  0.11401 ;
    dl    0.59100 ;
ra -90.;
   wf    1.8380   1.8380   1.5000 .06;
ra   90.;
    dl    0.25000 ;
    dl    0.25000 ;
    dl    1.66150 ;
    msq    0.13284  0.19812 ;
    dl    0.56300 ;
    msq   -0.22612  0.19812 ;
    dl    0.56300 ;
    msq    0.13284  0.19812 ;
    dl    1.16150 ;
   pm 65;     ENDPROCEDURE ; RUN ; END ;
```