An Example Removing Bucking Coils from a Super-FOFO Lattice

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1. Introduction

The purpose of bucking coils in Super-FOFO lattices is to force the magnetic field on axis to become small in between the focussing coils. An alternate design of the Super-FOFO lattice is to accomplish the same goal by changing the symmetry of the lattice, so the midpoint between any adjacent coils would always be an **odd** point of symmetry. This new design is here called the RFOFO lattice. Here, an example of a 10 T Super-FOFO generated by Eun-San Kim has been altered to become an RFOFO, for simplicity with the same RF configuration and the same lattice period. The result is a slightly lower rate of cooling due to a larger beta function at the absorber. The lattice period is then increased by about 10%, by stretching the interval where the RF is situated, and the resulting lattice exhibits cooling similar to that of the original Super-FOFO case. The RF was not re-tuned for the new configurations. In all of these cases the initial beam was purely Gaussian; no third order correlations were used. The particle losses were somewhat large, but did not change significantly among the three cases.

2. Comparison of Super-FOFO and RFOFO Geometry

The bucking coils in Super-FOFO reduce the fields in the RF accelerating region caused by the overlap of fringe fields from the focussing coils. By repeating the same pattern of focussing coils from cell to cell, the fringe fields automatically cancel out because adjacent solenoids have opposite orientation. This corresponds to reversing every other pair of solenoids around the low beta point.

In Figure 1, the coil arrangement is shown along with the current density in A/mm^2 for the Super-FOFO and the RFOFO cases with 50.49 cm cell length. Of the two numbers shown for each coil, the first is for RFOFO geometry and the second (in parentheses) is for the original Super-FOFO geometry. For the RFOFO lattice, in addition to removing the bucking coils and changing the orientation of some of the focussing magnets, the current density was reduced by approximately 12% to accept the same momentum particles. In both lattices $B_{\max} \simeq 10$ T and the central momentum is $p_0 \simeq 125$ MeV/c. As a result of removing the bucking coils, there ceases to be a preset limit to the radius of the RF system.

In Figure 2, the coil arrangement is shown along with the current density in A/mm^2 for the RFOFO with 55.49 cm cell length. Again, $B_{\max} \simeq 10$ T and the central momentum is $p_0 \simeq 125$ MeV/c. The RF was kept the same, so there is unused drift space in the this example and the average RF gradient is smaller than in the previous two cases. However, the RF bucket still suffices for the beam emittance considered.

3. Results

For the original Super-FOFO case, the minimum value of the beta function is roughly 4.0 cm. In the RFOFO geometry having the same cell size of 50.49 cm, the minimum beta is roughly 4.5 cm, but the lattice has a larger momentum acceptance. By increasing the cell size 5 cm, the minimum beta and momentum acceptance in the RFOFO geometry closely match the original SFOFO case. Note that the change in geometry requires the beam to travel longer in order to pass through the same amount of absorber.

In Figure 3, the perpendicular emittance of the beam in the three cases are shown as the beam propagates through 40 cells. In Figure 4, the full 6D emittance of the beam in the three cases are shown. Note that the rate of cooling is noticeably slower for the shorter RFOFO lattice, but is comparable for the case of the larger cell size. In Figure 5, the fractional loss of particles is shown for the three cases as a function of distance.

4. Input files

The final pages consist of ICOOL input files for the Super-FOFO example generated by Eun-San Kim, and the RFOFO examples based on this design. Note that the for001.dat input files are roughly the same except for the larger drift region in the longer lattice, and also the parity of the RFOFO is different from that of Super-FOFO, reflected in the SHEET parity flag being set to ".false."

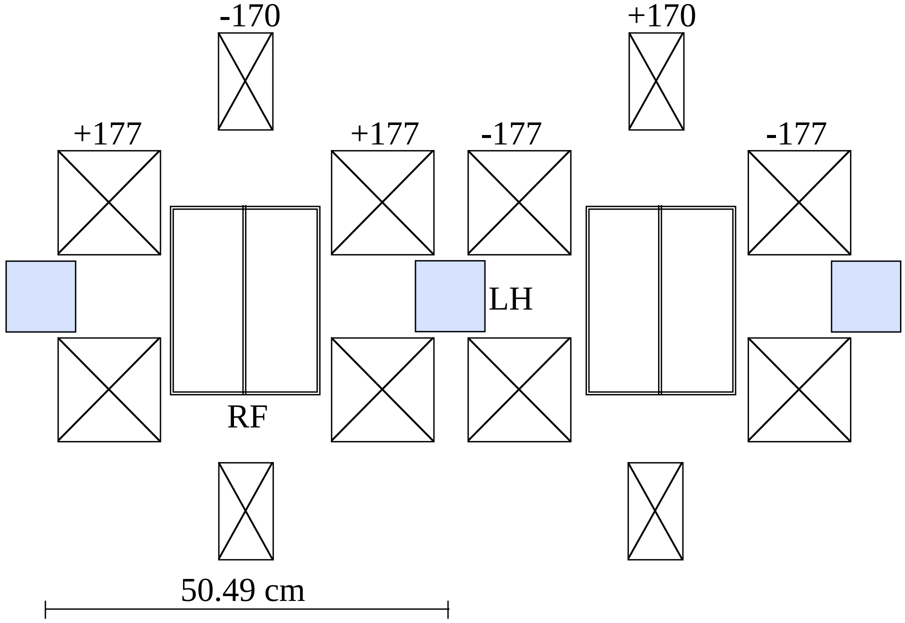

Figure 1: Coil configuration corresponding to the two lattices. Numbers correspond to current density, the first number for RFOFO and the second for Super-FOFO. The large solenoids are 12.6 cm long and 12.6 cm thick, with a bore diameter of 10.1 cm. The bucking coils (small solenoids) are 7.1 cm long and 12.6 cm thick, with a bore diameter of 40.4 cm. Horizontal and vertical axes are to scale.

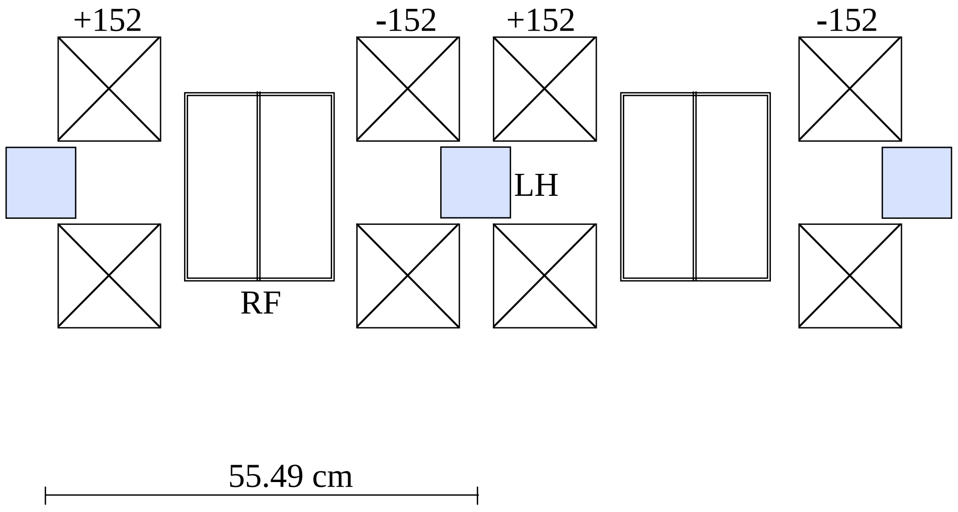

Figure 2: Coil configuration corresponding to RFOFO with 55.49 cm cell length. Numbers correspond to current density in A/mm^2. The solenoids are 12.6 cm long and 12.6 cm thick, with a bore diameter of 10.1 cm. Horizontal and vertical axes are to scale.

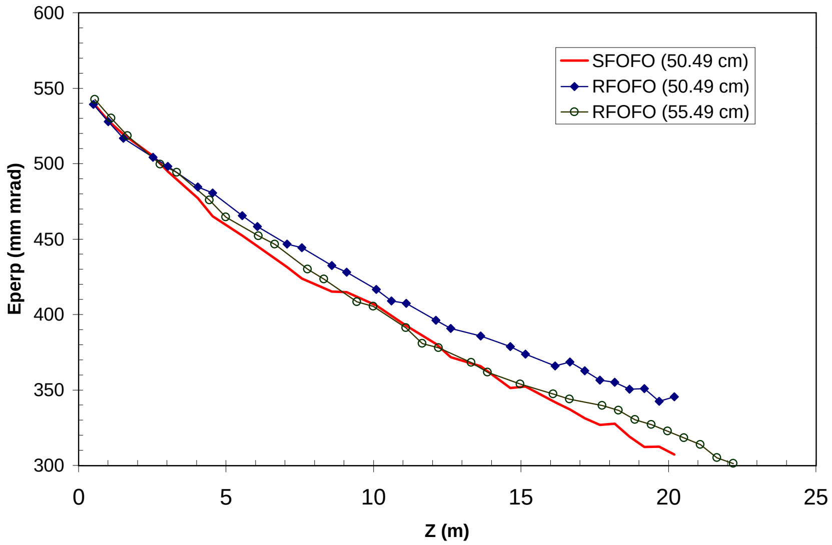

Figure 3: Transverse emittance as a function of distance for the SFOFO, RFOFO, and stretched RFOFO lattices.

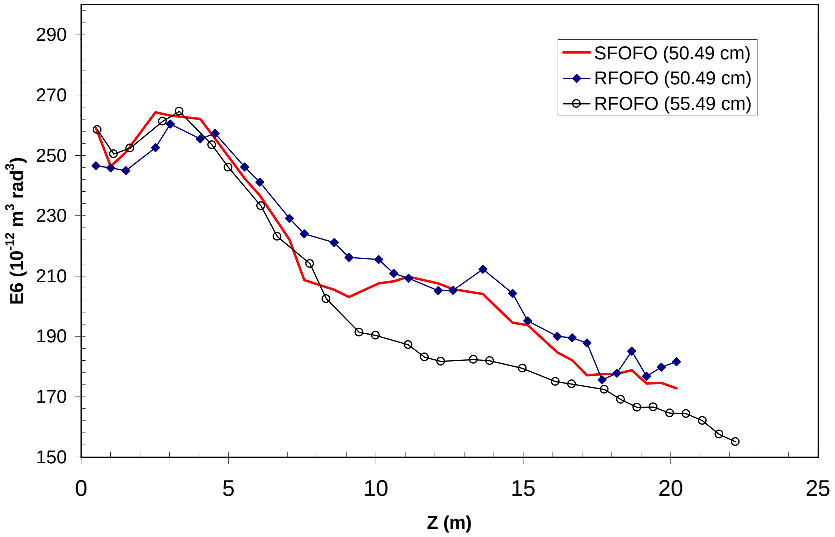

Figure 4: Full 6D emittance as a function of distance for the SFOFO, RFOFO, and stretched RFOFO lattices.

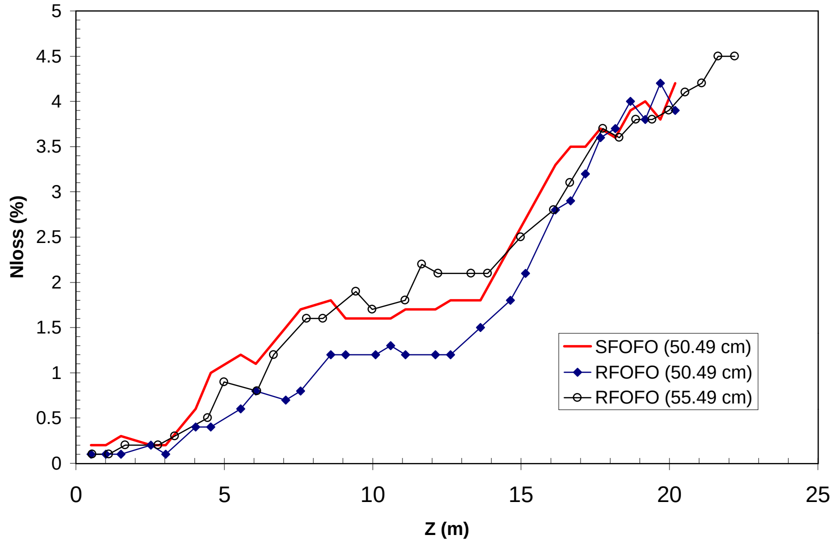

Figure 5: Fractional loss of particles as a function of distance for the SFOFO, RFOFO, and stretched RFOFO lattices. A cutoff in distance from the bunch center is incorporated.

Case 1: Super-FOFO lattice, 50.49 cm cell

```
-----------------------
Case 1, for001.dat:
-----------------------

SUPER-FOFO, 50.49 cm cell length
$cont npart=1000 nsections=1 timelim=500.  bgen=.true.
varstep=.true.  nprnt=0 epsstep=1e-4 prlevel=1 ntuple=.false.
phasemodel=4 bunchcut=550e-12 $
$bmt nbeamtyp=1 $
1 2 1.  1
0.  0.0 0.  0.  0.  0.125
0.0044 0.0044 0.0165 0.0129 0.0129 0.0038
0
2 0 0 0 0.1
$ints ldedx=.true.  lscatter=.true.  delev=2 scatlev=4$
$nhs nhist=1 $
0.030 0.002 50 10 1
&nsc nscat=1$
-0.6e-9 3e-11 40 7 1 -0.050 5e-3 20 6 1
$nzh nzhist=2 $
4 0.  0.05 70 0.  0.01 14
1 0.  0.02571 70 0.  0.01 33
$nrh $
$nem nemit=30 pxycorr=.true.  pzcorr=.true $
10 18 26 42 50 66 74 90 98 114 122 138 146 162 170
178 194 202 218 234 242 258 266 274 282 290 298 306
314 322
$ncv ncovar=30 $
10 18 26 42 50 66 74 90 98 114 122 138 146 162 170
178 194 202 218 234 242 258 266 274 282 290 298 306
314 322
SECTION
REFP
2 0.1225 -1.4e-10 12.6
CELL
40
SHEET
.true.
3 14 0.005 0.005 0.5049 0.11 1 2 30 0 0 0 0 0 0
SREGION ! 1st absorber half
0.0285 1 0.003
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
LH
CBLOCK
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! window
50e-6 1 10e-6
1 0 0.05
NONE
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
AL
CBLOCK
0 0 0 0 0 0 0 0 0 0
SREGION ! 1st drift space
```

```
0.13373 1 1e-2
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! RF 1
0.09 1 0.01942
1 0.  0.109
ACCEL
2.  605.  26 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! RF 2
0.09 1 0.01942
1 0.  0.109
ACCEL
2.  605.  26 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! 2nd drift space
0.13373 1 1e-2
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! window
50e-6 1 10e-6
1 0 0.05
NONE
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
AL
CBLOCK
0 0 0 0 0 0 0 0 0 0
SREGION ! 2nd absorber half
0.0285 1 5e-3
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
LH
CBLOCK
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
ENDCELL
ENDSECTION
```

```
-----------------------
Case 1, for014.dat:
-----------------------

39
1 -.4848738 .126275 6.629437E-02 5540000
2 -.4848738 .126275 9.786312E-02 5540000
3 -.4848738 .126275 .1294319 5540000
4 -.4848738 .126275 .1610006 5540000
5 -.2879600 .07102 .2178244 -5300000
6 -.2879600 .07102 .2493931 -5300000
7 -.2879600 .07102 .2809619 -5300000
8 -.2879600 .07102 .3125306 -5300000
9 -.1463012 .126275 6.629437E-02 5540000
10 -.1463012 .126275 9.786312E-02 5540000
11 -.1463012 .126275 .1294319 5540000
12 -.1463012 .126275 .1610006 5540000
13 1.043081E-07 5.051E-07 .075765 0
14 2.00262E-02 .126275 6.629437E-02 -5540000
15 2.00262E-02 .126275 9.786312E-02 -5540000
16 2.00262E-02 .126275 .1294319 -5540000
17 2.00262E-02 .126275 .1610006 -5540000
18 .2169400 .07102 .2178244 5300000
19 .2169400 .07102 .2493931 5300000
20 .2169400 .07102 .2809619 5300000
21 .2169400 .07102 .3125306 5300000
22 .3585988 .126275 6.629437E-02 -5540000
23 .3585988 .126275 9.786312E-02 -5540000
24 .3585988 .126275 .1294319 -5540000
25 .3585988 .126275 .1610006 -5540000
26 .5051008 5.051E-07 .075765 0
27 .5249262 .126275 6.629437E-02 5540000
28 .5249262 .126275 9.786312E-02 5540000
29 .5249262 .126275 .1294319 5540000
30 .5249262 .126275 .1610006 5540000
31 .7218400 .07102 .2178244 -5300000
32 .7218400 .07102 .2493931 -5300000
33 .7218400 .07102 .2809619 -5300000
34 .7218400 .07102 .3125306 -5300000
35 .8634988 .126275 6.629437E-02 5540000
36 .8634988 .126275 9.786312E-02 5540000
37 .8634988 .126275 .1294319 5540000
38 .8634988 .126275 .1610006 5540000
39 1.010201 5.051E-07 .075765 0
```

Case 2: RFOFO lattice, 50.49 cm cell

```
----------------------
Case 2, for001.dat:
----------------------

RFOFO adapted from Super-FOFO case, 50.49 cm cell length
$cont npart=1000 nsections=1 timelim=500.  bgen=.true.
varstep=.true.  nprnt=0 epsstep=1e-4 prlevel=1 ntuple=.false.
phasemodel=4 bunchcut=550e-12 lgraph=1 $
$bmt nbeamtyp=1 $
1 2 1.  1
0.  0.0 0.  0.  0.  0.125
0.0044 0.0044 0.0165 0.0129 0.0129 0.0038
0
2 0 0 0 0.1
$ints ldedx=.true.  lscatter=.true.  delev=2 scatlev=4$
$nhs nhist=1 $
0.030 0.002 50 10 1
&nsc nscat=1$
-0.6e-9 3e-11 40 7 1 -0.050 5e-3 20 6 1
$nzh nzhist=2 $
4 0.  0.05 70 0.  0.01 14
1 0.  0.02571 70 0.  0.01 33
$nrh $
$nem nemit=30 pxycorr=.true.  pzcorr=.true $
10 18 26 42 50 66 74 90 98 114 122 138 146 162 170
178 194 202 218 234 242 258 266 274 282 290 298 306
314 322
$ncv ncovar=30 $
10 18 26 42 50 66 74 90 98 114 122 138 146 162 170
178 194 202 218 234 242 258 266 274 282 290 298 306
314 322
SECTION
REFP
2 0.1225 -1.4e-10 12.6
CELL
40
SHEET
.false.
3 14 0.005 0.005 0.5049 0.11 1 2 30 0 0 0 0 0 0
SREGION ! 1st absorber half
0.0285 1 0.003
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
LH
CBLOCK
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! window
50e-6 1 10e-6
1 0 0.05
NONE
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
AL
CBLOCK
0 0 0 0 0 0 0 0 0 0
SREGION ! 1st drift space
```

```
0.13373 1 1e-2
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! RF 1
0.09 1 0.01942
1 0.  0.109
ACCEL
2.  605.  26 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! RF 2
0.09 1 0.01942
1 0.  0.109
ACCEL
2.  605.  26 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! 2nd drift space
0.13373 1 1e-2
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! window
50e-6 1 10e-6
1 0 0.05
NONE
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
AL
CBLOCK
0 0 0 0 0 0 0 0 0 0
SREGION ! 2nd absorber half
0.0285 1 5e-3
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
LH
CBLOCK
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
ENDCELL
ENDSECTION
```

```
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Case 2, for014.dat:
-----------------------

39
1 -.4848738 .126275 6.629437E-02 -4850000
2 -.4848738 .126275 9.786312E-02 -4850000
3 -.4848738 .126275 .1294319 -4850000
4 -.4848738 .126275 .1610006 -4850000
5 -.2879600 .07102 .2178244 0
6 -.2879600 .07102 .2493931 0
7 -.2879600 .07102 .2809619 0
8 -.2879600 .07102 .3125306 0
9 -.1463012 .126275 6.629437E-02 4850000
10 -.1463012 .126275 9.786312E-02 4850000
11 -.1463012 .126275 .1294319 4850000
12 -.1463012 .126275 .1610006 4850000
13 1.043081E-07 5.051E-07 .075765 0
14 2.00262E-02 .126275 6.629437E-02 -4850000
15 2.00262E-02 .126275 9.786312E-02 -4850000
16 2.00262E-02 .126275 .1294319 -4850000
17 2.00262E-02 .126275 .1610006 -4850000
18 .2169400 .07102 .2178244 0
19 .2169400 .07102 .2493931 0
20 .2169400 .07102 .2809619 0
21 .2169400 .07102 .3125306 0
22 .3585988 .126275 6.629437E-02 4850000
23 .3585988 .126275 9.786312E-02 4850000
24 .3585988 .126275 .1294319 4850000
25 .3585988 .126275 .1610006 4850000
26 .5051008 5.051E-07 .075765 0
27 .5249262 .126275 6.629437E-02 -4850000
28 .5249262 .126275 9.786312E-02 -4850000
29 .5249262 .126275 .1294319 -4850000
30 .5249262 .126275 .1610006 -4850000
31 .7218400 .07102 .2178244 0
32 .7218400 .07102 .2493931 0
33 .7218400 .07102 .2809619 0
34 .7218400 .07102 .3125306 0
35 .8634988 .126275 6.629437E-02 4850000
36 .8634988 .126275 9.786312E-02 4850000
37 .8634988 .126275 .1294319 4850000
38 .8634988 .126275 .1610006 4850000
39 1.010201 5.051E-07 .075765 0
```

Case 3: RFOFO lattice, 55.49 cm cell

```
-----------------------
Case 3, for001.dat:
-----------------------

RFOFO adapted from Super-FOFO case, 55.49 cm cell length
$cont npart=1000 nsections=1 timelim=500.  bgen=.true.
varstep=.true.  nprnt=0 epsstep=1e-4 prlevel=1 ntuple=.false.
phasemodel=4 bunchcut=550e-12 lgraph=1 $
$bmt nbeamtyp=1 $
1 2 1.  1
0.  0.0 0.  0.  0.  0.125
0.0044 0.0044 0.0165 0.0129 0.0129 0.0038
0
2 0 0 0 0.1
$ints ldedx=.true.  lscatter=.true.  delev=2 scatlev=4$
$nhs nhist=1 $
0.030 0.002 50 10 1
&nsc nscat=1$
-0.6e-9 3e-11 40 7 1 -0.050 5e-3 20 6 1
$nzh nzhist=2 $
4 0.  0.05 70 0.  0.01 14
1 0.  0.02571 70 0.  0.01 33
$nrh $
$nem nemit=30 pxycorr=.true.  pzcorr=.true $
10 18 26 42 50 66 74 90 98 114 122 138 146 162 170
178 194 202 218 234 242 258 266 274 282 290 298 306
314 322
$ncv ncovar=30 $
10 18 26 42 50 66 74 90 98 114 122 138 146 162 170
178 194 202 218 234 242 258 266 274 282 290 298 306
314 322
SECTION
REFP
2 0.1225 -1.4e-10 12.6
CELL
40
SHEET
.false.
3 14 0.005 0.005 0.5549 0.11 1 2 30 0 0 0 0 0 0
SREGION ! 1st absorber half
0.0285 1 0.003
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
LH
CBLOCK
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! window
50e-6 1 10e-6
1 0 0.05
NONE
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
AL
CBLOCK
0 0 0 0 0 0 0 0 0 0
SREGION ! 1st drift space
```

```
0.15873 1 1e-2
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! RF 1
0.09 1 0.01942
1 0.  0.109
ACCEL
2.  605.  26 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! RF 2
0.09 1 0.01942
1 0.  0.109
ACCEL
2.  605.  26 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! 2nd drift space
0.15873 1 1e-2
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
VAC
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
SREGION ! window
50e-6 1 10e-6
1 0 0.05
NONE
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
AL
CBLOCK
0 0 0 0 0 0 0 0 0 0
SREGION ! 2nd absorber half
0.0285 1 5e-3
1 0.  0.05
NONE
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
LH
CBLOCK
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
ENDCELL
ENDSECTION
```

```
-----------------------
Case 3, for014.dat:
-----------------------

27
1 -.5348738 .126275 6.629437E-02 -4800000
2 -.5348738 .126275 9.786312E-02 -4800000
3 -.5348738 .126275 .1294319 -4800000
4 -.5348738 .126275 .1610006 -4800000
5 -.1463012 .126275 6.629437E-02 4800000
6 -.1463012 .126275 9.786312E-02 4800000
7 -.1463012 .126275 .1294319 4800000
8 -.1463012 .126275 .1610006 4800000
9 1.043081E-07 5.051E-07 .075765 0
10 2.00262E-02 .126275 6.629437E-02 -4800000
11 2.00262E-02 .126275 9.786312E-02 -4800000
12 2.00262E-02 .126275 .1294319 -4800000
13 2.00262E-02 .126275 .1610006 -4800000
14 .4085988 .126275 6.629437E-02 4800000
15 .4085988 .126275 9.786312E-02 4800000
16 .4085988 .126275 .1294319 4800000
17 .4085988 .126275 .1610006 4800000
18 .5551008 5.051E-07 .075765 0
19 .5749262 .126275 6.629437E-02 -4800000
20 .5749262 .126275 9.786312E-02 -4800000
21 .5749262 .126275 .1294319 -4800000
22 .5749262 .126275 .1610006 -4800000
23 .9634988 .126275 6.629437E-02 4800000
24 .9634988 .126275 9.786312E-02 4800000
25 .9634988 .126275 .1294319 4800000
26 .9634988 .126275 .1610006 4800000
27 1.110201 5.051E-07 .075765 0
```