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Assessing Parameters of SPIRAL2/DESIR High Resolution Spectrometer using Zgoubi

Abstract

HRS-DESIR mass spectrometer lattice is reviewed using the stepwise ray-tracing code Zgoubi. Transport coefficients, resolution and other graphs are produced and compared to CENB-G data.

Contents

1 Introduction

Computations with Zgoubi assume $B\rho = 0.40517905522449$ T.m, mass=122957.21 eV, which represents $^{132}Sn^{+}$, 60 keV kinetic energy, $\beta = 0.98790113729\,10^{-3}$.

Fringe fields are modelled using the default Enge coefficients in COSY, for the purpose of further comparison of results so obtained with CENB-G data [1] as derived from COSY simulations, namely,

- in quadrupoles : $C_0 - C_5 =$ 0.296471, 4.533219, -2.270982, 1.068627, -0.036391, 0.022261,

- in dipoles : $C_0 - C_5 =$ .478959 1.911289 -1.185953 1.630554 -1.082657 0.318111.

A note concerning coordinates : Zgoubi coordinates are normally used throughout the text, namely [2], compared to usual standard, $Y \rightarrow x$, $Y'(or\ \theta) \rightarrow x'$, $Z \rightarrow y$, $Z'(or\ \phi) \rightarrow y'$, $X \rightarrow z$.

Fig. 1 shows the shape of the field along MQ1 and MQ2 so obtained. The corresponding Zgoubi data file is given in page 4.

Fig. 2 shows the shape of the field across the bends, at two different elevations in the reference vertical plane. The corresponding BEND data in Zgoubi can be found in page 8.

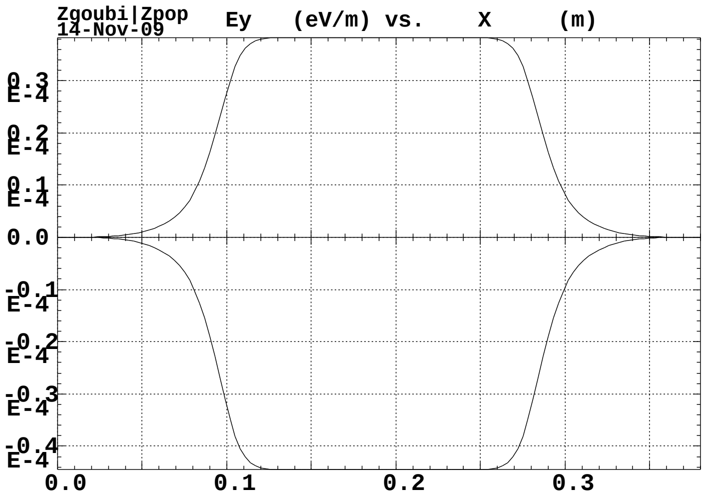

Figure 1: Electric field component E_Y (transverse horizontal) along MQ1, MQ2, as experienced at Y=1 mm (aperture diameter is 4 cm).

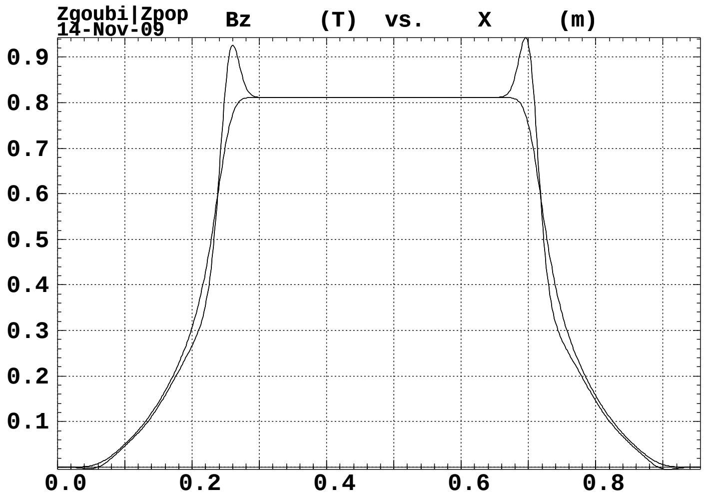

Figure 2: Magnetic field component B_Z (transverse vertical) across BEND, as experienced at constant elevations Z=0 and Z=3 cm. (full gap is 8 cm).

2 HRS-C135 quadrupole doublet

Transport coefficients 1 meter downstream of the object are computed using HRS-Tech. Note potentials in MQ1/-764.4 and MQ2/+889.7, and the fringe field conditions above.

Zgoubi input data file is given in page 4.

What follows clearly shows that the agreement between Zgoubi and HRS-Tech. Note is very good, there is no need for re-tuning, the first order transport matrix is recovered right away with very satisfactory precision.

```
Reference particle (# 1), path length : 100.00000 cm,  relative momentum : 1.

         -0.193427       -3.751609E-05   -1.917396E-13   -1.862570E-18
          -11.3984        -5.17213       -2.158213E-12    1.648494E-16
         -7.251477E-17   -2.893141E-17    -3.42052        1.190471E-04
          6.806318E-17    2.454932E-17    -10.0395       -0.292004

          DetY-1 =       0.0000003115,    DetZ-1 =      -0.0000004299

          R12=0 at  -0.7254E-05 m,        R34=0 at   0.4077E-03 m

      First order symplectic conditions (expected values = 0) :
  3.1149E-07  -4.2985E-07  -3.1950E-17  -1.1945E-18  1.7671E-12  9.9125E-13
```

For comparison, HRS-Tech. Note case, MQ1/-764.4 and MQ2/+889.7, soft-edge quads :

```
            -0.1934    -11.398       0.0000     0.0000
            -0.27E-7    -5.1719      0.0000     0.0000
             0.0000      0.0000     -3.4209   -10.040
             0.0000      0.0000      0.81E-8   -0.2923
             0.0000      0.0000      0.0000     0.0000
```

Hard edge

For reference, the matrix with hard edge field model in MQ1 and MQ2, and same potentials MQ1/-764.4 and MQ2/+889.7, is given below.

```
Reference particle (# 1), path length :   100. cm  relative momentum : 1.00000

          -0.200942      -3.078258E-03    0.0             0.0
         -11.3128        -5.14984         0.0             0.0
           0.0            0.0            -3.40239        -2.347344E-03
           0.0            0.0            -9.94203        -0.300768

          DetY-1 =      -0.0000057847,    DetZ-1 =      -0.0000057854

          R12=0 at  -0.5977E-03 m,        R34=0 at  -0.7804E-02 m

      First order symplectic conditions (expected values = 0) :
 -5.7847E-06   -5.7854E-06  5.1483E-17  9.5701E-18  4.7527E-16  2.0334E-17
```

Quadrupole doublet, soft edge, zgoubi data file

Fig. 3 shows the behavior of four particular rays across the doublet.

Second and higher order transport coefficients are given in page 5.

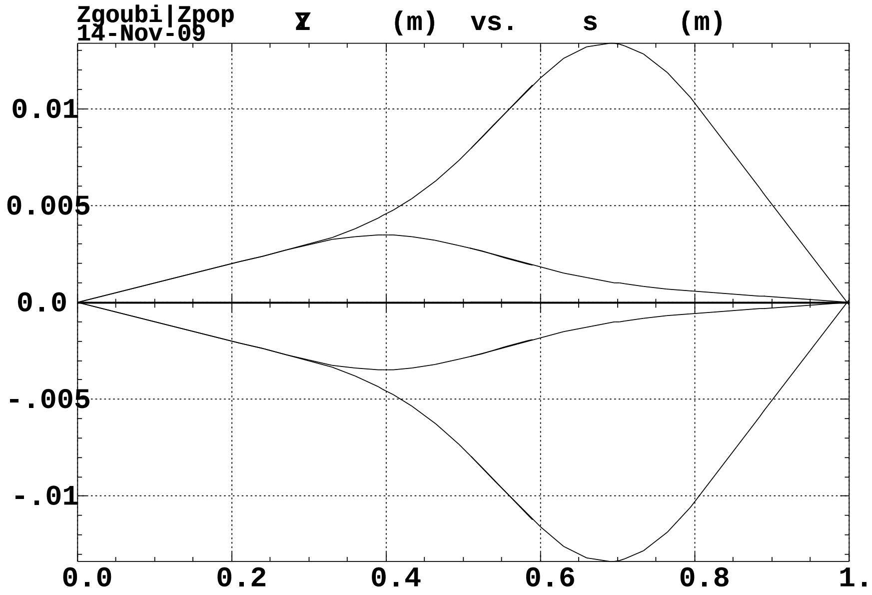

Figure 3: Four trajectories leaving the object with $Y_0' = Z_0' = \pm 10$ mrad.

The data list includes FIT procedure for possibly improving further $R_{12} = R_{34} = 0$ at double focus.

```
%hrsdesir
  'OBJET'                                                                                                                      1
 405.1790552244900274   (Sn132+, 60.58188 KeV)
5
.001 .001 .001 .001 .001 .001
.0 0. 0. 0. 0. 1.
  'PARTICUL'                                                                                                                   2
 122957.208  1.602176487E-19  0.0 0.0 0.0       931.494028*118.710
'FAISCEAU'                                                                                                                     3
  'DRIFT'                                                                                                                      4
 30.00
 'ELMULT'   MQ1                                                                                                                5
  0
  20.  2. 0.  -764.4  0. 0. 0. 0. 0. 0. 0. 0.
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
'FAISCEAU'                                                                                                                     6
  'DRIFT'                                                                                                                      7
 10.00
 'ELMULT'   MQ2                                                                                                                8
  0
  20.  2. 0.  889.7  0. 0. 0. 0. 0. 0. 0. 0.
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
  'DRIFT'                                                                                                                      9
 20.
'FAISCEAU'                                                                                                                    10
'MATRIX'                                                                                                                      11
  1 0
 'FIT'                                                                                                                        12
 2
 5  5  0  .1
 8  5  0  .1
 2
 1  1 2 11 0 1. 0
 1  3 4 11 0 1. 0
'END'                                                                                                                         13
```

Quadrupole doublet, second and higher order coefficients.

.

```
                TRANSFER  MATRIX  ORDRE  2  (MKSA units)

   1 11   0.00       1 21   0.00       1 31   0.00       1 41   0.00       1 51   0.00       1 61   3.90
   1 12   0.00       1 22   0.00       1 32   0.00       1 42   0.00       1 52   0.00       1 62   1.93
   1 13   0.00       1 23   0.00       1 33   0.00       1 43   0.00       1 53   0.00       1 63  1.768E-12
   1 14   0.00       1 24   0.00       1 34   0.00       1 44   0.00       1 54   0.00       1 64 -3.103E-16
   1 15   0.00       1 25   0.00       1 35   0.00       1 45   0.00       1 55   0.00       1 65   0.00
   1 16   3.90       1 26   1.93       1 36  1.768E-12   1 46 -3.103E-16   1 56   0.00       1 66   0.00


   2 11   0.00       2 21   0.00       2 31   0.00       2 41   0.00       2 51   0.00       2 61   21.1
   2 12   0.00       2 22   0.00       2 32   0.00       2 42   0.00       2 52   0.00       2 62   9.41
   2 13   0.00       2 23   0.00       2 33   0.00       2 43   0.00       2 53   0.00       2 63  1.632E-11
   2 14   0.00       2 24   0.00       2 34   0.00       2 44   0.00       2 54   0.00       2 64  7.530E-16
   2 15   0.00       2 25   0.00       2 35   0.00       2 45   0.00       2 55   0.00       2 65   0.00
   2 16   21.1       2 26   9.41       2 36  1.632E-11   2 46  7.530E-16   2 56   0.00       2 66   0.00


   3 11   0.00       3 21   0.00       3 31   0.00       3 41   0.00       3 51   0.00       3 61 -2.910E-14
   3 12   0.00       3 22   0.00       3 32   0.00       3 42   0.00       3 52   0.00       3 62  5.473E-15
   3 13   0.00       3 23   0.00       3 33   0.00       3 43   0.00       3 53   0.00       3 63   7.19
   3 14   0.00       3 24   0.00       3 34   0.00       3 44   0.00       3 54   0.00       3 64   2.03
   3 15   0.00       3 25   0.00       3 35   0.00       3 45   0.00       3 55   0.00       3 65   0.00
   3 16 -2.910E-14   3 26  5.473E-15   3 36   7.19       3 46   2.03       3 56   0.00       3 66   0.00


   4 11   0.00       4 21   0.00       4 31   0.00       4 41   0.00       4 51   0.00       4 61 -9.131E-14
   4 12   0.00       4 22   0.00       4 32   0.00       4 42   0.00       4 52   0.00       4 62  1.432E-14
   4 13   0.00       4 23   0.00       4 33   0.00       4 43   0.00       4 53   0.00       4 63   21.2
   4 14   0.00       4 24   0.00       4 34   0.00       4 44   0.00       4 54   0.00       4 64   5.33
   4 15   0.00       4 25   0.00       4 35   0.00       4 45   0.00       4 55   0.00       4 65   0.00
   4 16 -9.131E-14   4 26  1.432E-14   4 36   21.2       4 46   5.33       4 56   0.00       4 66   0.00


   5 11   21.3       5 21   10.1       5 31   0.00       5 41   0.00       5 51   0.00       5 61   0.00
   5 12   10.1       5 22   4.99       5 32   0.00       5 42   0.00       5 52   0.00       5 62   0.00
   5 13   0.00       5 23   0.00       5 33   17.0       5 43   1.05       5 53   0.00       5 63   0.00
   5 14   0.00       5 24   0.00       5 34   1.05       5 44  0.296       5 54   0.00       5 64   0.00
   5 15   0.00       5 25   0.00       5 35   0.00       5 45   0.00       5 55   0.00       5 65   0.00
   5 16   0.00       5 26   0.00       5 36   0.00       5 46   0.00       5 56   0.00       5 66   0.00


   6 11   0.00       6 21   0.00       6 31   0.00       6 41   0.00       6 51   0.00       6 61   0.00
   6 12   0.00       6 22   0.00       6 32   0.00       6 42   0.00       6 52   0.00       6 62   0.00
   6 13   0.00       6 23   0.00       6 33   0.00       6 43   0.00       6 53   0.00       6 63   0.00
   6 14   0.00       6 24   0.00       6 34   0.00       6 44   0.00       6 54   0.00       6 64   0.00
   6 15   0.00       6 25   0.00       6 35   0.00       6 45   0.00       6 55   0.00       6 65   0.00
   6 16   0.00       6 26   0.00       6 36   0.00       6 46   0.00       6 56   0.00       6 66   0.00
      Second order symplectic conditions (expected values = 0) :

          0.000         0.000       -5.1137E-05     0.000         0.000         0.000         0.000
          0.000         0.000         0.000         0.000         0.000         0.000      -5.4985E-05


             COEFFICIENTS  D'ORDRE  SUPERIEUR  ( MKSA ):

           Y/Y3           -1451.2
           Y/T3           -156.34
           Y/Z3          -1.91654E-03
           Y/P3          -6.33687E-07

           T/Y3           -3992.3
           T/T3           -460.56
           T/Z3          -2.15829E-02
           T/P3           4.41474E-05

           Z/Y3          -1.78771E-08
           Z/T3           1.03192E-05
           Z/Z3           -251.06
           Z/P3           -9.5924

           P/Y3          -1.41965E-07
           P/T3           3.18027E-05
           P/Z3           -357.62
           P/P3           -26.240
  TRAJ 1 IEX,D,Y,T,Z,P,S,time :  1   1.000       0.000       0.000       0.000       0.000          100.00          3.3765
```

3 At mid-plane of HRS-C135

Zgoubi input data are given in page 8.

Note : it has been necessary - most naturally - to change BENDs positionning, namely by $\Delta Y = 1.84$ *mm* (the 'CHANGREF' command), and to increase BEND field (radius 50 cm) from $B\rho/\rho = 8.1035811$ to 8.10996287 kG in order to zero the beam orbit downstream of the bend. The corresponding Zgoubi data file is given in page 8.

Given earlier conditions for double focus 1 m downstream of the object, using MQ1/-764.4, MQ2/889.7, and using HRS-Tech. Note value FQ1/1050kV, the following first order matrix at mid-plane is obtained :

```
Reference particle (# 1), path length : 383.59162 cm,  relative momentum : 1.

      -43.5215        -19.2588        -8.881784E-13    0.00000       0.899387
        4.113746E-02   -4.773287E-03   5.788058E-19    0.00000       1.24331
        4.831348E-16    2.346221E-16   5.41127        -1.020119E-02  3.248199E-23
       -8.689044E-16   -3.884897E-16   0.201560        0.184419      2.899134E-22
      -54.1476        -23.9403         9.473903E-12    0.00000       0.135348
        0.00000         0.00000        0.00000         0.00000       1.00000

          DetY-1 =      -0.0000007746,    DetZ-1 =      -0.0000004465

          R12=0 at   -4035.     m,        R34=0 at   0.5532E-01 m

      First order symplectic conditions (expected values = 0) :
 -7.7456E-07 -4.4653E-07  8.0236E-17  3.9306E-17 -4.1311E-14  2.1012E-15
```

For reference, HRS-Tech. Note matrix :

```
 -43.74    0.5186E-1   0.0000       0.0000
 -19.35    0.8250E-4   0.0000       0.0000
 0.0000    0.0000      5.0594       0.1569E-4
 0.0000    0.0000     -0.4550E-4    0.1977
 0.4533    0.6226      0.0000       0.0000
```

Second and higher order coefficients are given on page 7.

From object to mid-plane, second and higher order coefficients.

.

```
                 TRANSFER  MATRIX  ORDRE  2  (MKSA units)

   1 11   93.0       1 21   47.8       1 31  6.661E-08   1 41   0.00       1 51   0.00       1 61   98.6
   1 12   47.8       1 22   23.8       1 32  2.220E-07   1 42   0.00       1 52   0.00       1 62   44.8
   1 13  6.661E-08   1 23  2.220E-07   1 33  1.233E+03   1 43   10.4       1 53   0.00       1 63 -4.476E-10
   1 14   0.00       1 24   0.00       1 34   10.4       1 44  8.210E-02   1 54   0.00       1 64   0.00
   1 15   0.00       1 25   0.00       1 35   0.00       1 45   0.00       1 55   0.00       1 65   0.00
   1 16   98.6       1 26   44.8       1 36 -4.476E-10   1 46   0.00       1 56   0.00       1 66 -0.944


   2 11  -154.       2 21  -68.1       2 31 -4.527E-11   2 41   0.00       2 51   0.00       2 61  -15.8
   2 12  -68.1       2 22  -30.2       2 32  1.075E-11   2 42   0.00       2 52   0.00       2 62  -7.06
   2 13 -4.527E-11   2 23  1.075E-11   2 33  -6.78       2 43  0.361       2 53   0.00       2 63 -1.110E-11
   2 14   0.00       2 24   0.00       2 34  0.361       2 44 -2.651E-02   2 54   0.00       2 64   0.00
   2 15   0.00       2 25   0.00       2 35   0.00       2 45   0.00       2 55   0.00       2 65   0.00
   2 16  -15.8       2 26  -7.06       2 36 -1.110E-11   2 46   0.00       2 56   0.00       2 66  -1.53


   3 11  3.820E-14   3 21  4.389E-12   3 31   84.7       3 41  -5.60       3 51   0.00       3 61  5.732E-14
   3 12  4.389E-12   3 22 -1.222E-13   3 32   35.9       3 42  -2.49       3 52   0.00       3 62 -9.268E-15
   3 13   84.7       3 23   35.9       3 33 -3.903E-10   3 43 -3.253E-10   3 53   0.00       3 63  -16.6
   3 14  -5.60       3 24  -2.49       3 34 -3.253E-10   3 44  2.471E-12   3 54   0.00       3 64  -3.49
   3 15   0.00       3 25   0.00       3 35   0.00       3 45   0.00       3 55   0.00       3 65   0.00
   3 16  5.732E-14   3 26 -9.268E-15   3 36  -16.6       3 46  -3.49       3 56   0.00       3 66 -1.754E-18


   4 11 -2.240E-13   4 21 -7.136E-12   4 31   48.0       4 41  -3.19       4 51   0.00       4 61 -1.097E-14
   4 12 -7.136E-12   4 22 -4.960E-13   4 32   26.4       4 42  -1.37       4 52   0.00       4 62  4.623E-15
   4 13   48.0       4 23   26.4       4 33  4.821E-10   4 43  7.074E-10   4 53   0.00       4 63   28.0
   4 14  -3.19       4 24  -1.37       4 34  7.074E-10   4 44 -1.807E-11   4 54   0.00       4 64  0.381
   4 15   0.00       4 25   0.00       4 35   0.00       4 45   0.00       4 55   0.00       4 65   0.00
   4 16 -1.097E-14   4 26  4.623E-15   4 36   28.0       4 46  0.381       4 56   0.00       4 66 -3.104E-17


   5 11   950.       5 21   429.       5 31 -7.105E-07   5 41   0.00       5 51   0.00       5 61   149.
   5 12   429.       5 22   194.       5 32  3.469E-09   5 42   0.00       5 52   0.00       5 62   67.6
   5 13 -7.105E-07   5 23  3.469E-09   5 33  1.640E+03   5 43   13.4       5 53   0.00       5 63 -7.102E-09
   5 14   0.00       5 24   0.00       5 34   13.4       5 44  0.456       5 54   0.00       5 64   0.00
   5 15   0.00       5 25   0.00       5 35   0.00       5 45   0.00       5 55   0.00       5 65   0.00
   5 16   149.       5 26   67.6       5 36 -7.102E-09   5 46   0.00       5 56   0.00       5 66  0.352


   6 11   0.00       6 21   0.00       6 31   0.00       6 41   0.00       6 51   0.00       6 61   0.00
   6 12   0.00       6 22   0.00       6 32   0.00       6 42   0.00       6 52   0.00       6 62   0.00
   6 13   0.00       6 23   0.00       6 33   0.00       6 43   0.00       6 53   0.00       6 63   0.00
   6 14   0.00       6 24   0.00       6 34   0.00       6 44   0.00       6 54   0.00       6 64   0.00
   6 15   0.00       6 25   0.00       6 35   0.00       6 45   0.00       6 55   0.00       6 65   0.00
   6 16   0.00       6 26   0.00       6 36   0.00       6 46   0.00       6 56   0.00       6 66   0.00

      Second order symplectic conditions (expected values = 0) :

        -3.3830E-03    0.1443      -5.3116E-04     3.515       -6.5726E-02   -6.6282E-02    0.1700
        -2.9294E-02    7.5182E-02     1.555       -2.9038E-02   -5.5572E-04   -2.5605E-04    2.3969E-03


              COEFFICIENTS  D'ORDRE  SUPERIEUR  ( MKSA ):

          Y/Y3           -11066.
          Y/T3           -1279.4
          Y/Z3          -2.66454E-02
          Y/P3            0.0000

          T/Y3            3658.5
          T/T3            825.90
          T/Z3          -1.00232E-08
          T/P3            0.0000

          Z/Y3           9.38305E-08
          Z/T3          -1.62068E-05
          Z/Z3            384.92
          Z/P3            15.375

          P/Y3          -8.36437E-08
          P/T3          -1.66409E-06
          P/Z3           -22797.
          P/P3          -0.59548
 TRAJ 1 IEX,D,Y,T,Z,P,S,time :  1   1.000       0.000       0.000     -3.7843E-32 -6.4148E-30       383.59           12.952
```

Zgoubi data file, from object to mid-plane

```
HRS DESIR - COSY FF coeffs
  'OBJET'                                                                                    764.4                   1
 405.1790552244900274   (Sn132+, 60.58188 KeV)
6
.001 .001 .001 .001 .001 .001
.0 0. 0. 0. 0. 1.
  'PARTICUL'                                                                                                         2
 122957.208  1.602176487E-19  0.0 0.0 0.0       931.494028*118.710
  'DRIFT'                                                                                                            4
 30.00
 'ELMULT'   MQ1                                                                                                      5
 0
  20.  2. 0.  -764.4  0. 0. 0. 0. 0. 0. 0. 0.
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
  'DRIFT'                                                                                                            7
 10.00
 'ELMULT'   MQ2                                                                                                      8
  0
  20.  2. 0.  889.7  0. 0. 0. 0. 0. 0. 0. 0.
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
   9.  4.  1.  0.  0.  0.  0.  0. 0. 0. 0.
  6  0.296471 4.533219 -2.270982 1.068627 -0.036391 0.022261
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
  'DRIFT'                                                                                                            9
 20.
 'DRIFT'                                                                                                            12
 6.7
'ELMULT'  FS1                                                                                                        13
0 000002  0
  12.  2. 0.  0.  76.89 0. 0. 0. 0. 0. 0. 0.
  0 0 9.  4.  1.    0.  0.  0.  0.  0.  0.  0.  0. 0. 0. 0.
  6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0 0 9.  4.  1.    0.  0.  0.  0.  0.  0.  0.  0. 0. 0. 0.
  6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
  'DRIFT'                                                                                                            14
 6.00
'ELMULT'  FQ1                                                                                                        15
0 000002  0
  24.  4. 0.  -1050. .0  0. 0. 0. 0. 0. 0. 0. 0.
  9.  4.  1.    0.  0.  0.  0.  0.  0.  0.  0. 0. 0. 0.
  6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  9.  4.  1.    0.  0.  0.  0.  0.  0.  0.  0. 0. 0. 0.
  6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
  'DRIFT'                                                                                                            16
 128.2
'CHANGREF'                                                                                                           18
 0.  -0.1843517154  0.
 'BEND'                                                                                                              19
  0
  55.55702330196021776  0.  8.109962870
  20.   8.0      0.4799655442984406337
  6  0.478959 1.911289 -1.185953 1.630554 -1.082657 0.318111
  20.   8.0      0.4799655442984406337
  6  0.478959 1.911289 -1.185953 1.630554 -1.082657 0.318111
  .2
  3     0.      0.    -0.5890486225480862322
'CHANGREF'                                                                                                           20
 0. 0.1843517154  0.
 'FAISCEAU'                                                                                                          21
  'DRIFT'                                                                                                            22
 36.
'ELMULT'  M_half                                                                                                     23
0 000002  0
  12.  20. 0.  0.  -658.2 -16.93 -4.788  -1.08   0. 0. 0. 0.
  0 0 9.  4.  1.    0.  0.  0.  0.  0.  0.  0.  0. 0. 0. 0.
  6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0 0 9.  4.  1.    0.  0.  0.  0.  0.  0.  0.  0. 0. 0. 0.
  6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #60|30|60
  1 0. 0. 0.
'FAISCEAU'                                                                                                           24
'MATRIX'                                                                                                             25
  2 0
'FIT'                                                                                                                26
2
18 2 -20.02  .2    Variable 1 : delta_Y in first CHANGREF, coupled to delta_Y in second CHANGREF
19 12 0 .2         Variable 2 : field in BEND
2
3 1 2 23 0. 1. 0   Constraint 1 : Y(1) after BEND
3 1 3 23 0. 1. 0   Constraint 2 : Y'(1) after BEND
'END'                                                                                                                27
'END'                                                                                                                27
```

Tuning FQ1 to zero (x'/x), (y/y') and (y'/y) at mid-plane

Re-matching FQ1 (using the FIT procedure in Zgoubi), the rest unchanged, allows getting closer to zero (x'/x), (y/y') and (y'/y) at mid-plane.

FQ1 potential value of -1060.718743 comes out of that matching (1% from the HRS Note -1050 value), and yields the following transport coefficients,

```
Reference particle (# 1), path length : 383.59162 cm,  relative momentum : 1.

 -43.7583         -19.3614         -2.664535E-12    0.00000        0.899389
   2.644502E-02    -1.115203E-02  -1.852885E-19    0.00000        1.24331
   4.965226E-16     2.124660E-16   5.51406         -8.619779E-03  2.702200E-23
  -8.876981E-16    -3.782987E-16   2.876244E-04    0.181354      -1.384385E-22
 -54.4289         -24.0621         0.00000          0.00000        0.135347

          DetY-1 =       0.0000061632,    DetZ-1 =      -0.0000004726

          R12=0 at   -1736.     m,        R34=0 at   0.4753E-01 m

      First order symplectic conditions (expected values = 0) :
  6.1632E-06 -4.7262E-07  8.2395E-17  3.5271E-17 -7.5367E-14  2.7625E-14
```

For comparison, HRS-Tech. Note case :

-43.74	0.5186E-1	0.0000	0.0000
-19.35	0.8250E-4	0.0000	0.0000
0.0000	0.0000	5.0594	0.1569E-4
0.0000	0.0000	-0.4550E-4	0.1977
0.4533	0.6226	0.0000	0.0000

A good agreement is observed as to horizontal plane coefficients (including R_{16} and R_{26}, the factor of 2 difference is a matter of convention in transport coefficient notation). The agreement is not as good as to the position of the vertical focus, the reason may be in fringe field extent in FQ1 (4 cm aperture here, 8 cm in Ref. [1]) or in a different behavior of BEND.

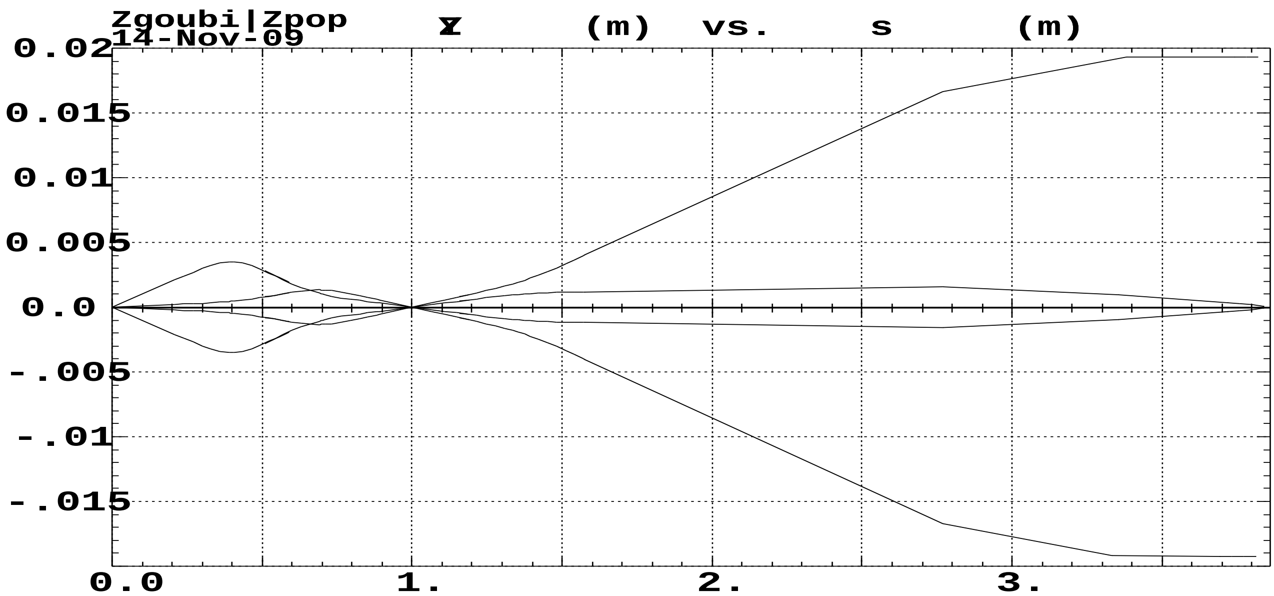

Figure 4: Particle tracks from object to mid-plane, $Y_0' = Z_0' = \pm 1$ mrad (z is $\times$ by 10).

4 Final focus of HRS-C135

Compared to earlier Section 3 that accounts for data given in page 8, we re-tune MQ1 and MQ2 at both ends, as well as FQ1s (by means of the FIT procedure), leaving the rest unchanged, this is the only way to obtained exact constraints $R22 = R34 = R43 = 0$ at mid-plane, so yielding expected transport coefficient values at final-focus.

The following quadrupole potentials come out, however not more than about 1% away from the HRS-Tech. Note values (764.4, 889.7 and 1050 Volts for respectively MQ1, MQ2, FQ1)

```
STATUS OF VARIABLES  (Iteration #   142)
LMNT  VAR  PARAM  MINIMUM     INITIAL         FINAL          MAXIMUM      STEP
 MQ1    1      5   -917.       -768.       -768.2787104      -612.      4.38E-09
 MQ1    1      5   -768.       -768.       -768.2787104      -612.      4.38E-09
 MQ2    2      5    712.        908.        908.3420294      1.068E+03  5.10E-09
 MQ2    2      5    908.        908.        908.3420294      1.068E+03  5.10E-09
 FQ1    3      5  -1.273E+03  -1.061E+03   -1061.441496      -849.      6.08E-09
 FQ1    3      5  -1.061E+03  -1.061E+03   -1061.441496      -849.      6.08E-09
 STATUS OF CONSTRAINTS
 TYPE   IJ   LMNT#       DESIRED           WEIGHT          REACHED          KI2
  1   R22    25      0.0000000E+00     1.0000E+00   -9.1975256E-08   9.802E-01
  1   R34    25      0.0000000E+00     1.0000E+00   -1.2925242E-08   1.935E-02
  1   R43    25      0.0000000E+00     1.0000E+00    1.7702539E-09   3.631E-04
```

• The matrix so obtained at mid-plane is the following, not so different from the Section 3 one (page 6) :

```
Reference particle (# 1), path length : 383.59162 cm,  relative momentum : 1.

 -45.5706        -20.2189        -4.440892E-12   0.00000       0.899389
   4.945875E-02   -9.197526E-08  -1.852885E-19   0.00000       1.24331
   5.319653E-16    1.707222E-16   5.61788       -1.292524E-08  2.702200E-23
  -9.526677E-16   -4.403285E-16   1.770254E-09   0.178003     -1.384385E-22
 -56.7028        -25.1384         0.00000        0.00000       0.135347
```

• The matrix so obtained at final-focus is the following, in excellent agreement with HRS-Tech. Note one :

```
Reference particle (# 1), path length : 767.18324 cm,  relative momentum : 1.

  -0.999771       1.100992E-04    4.310789E-11    6.776264E-17   -51.0101
  -4.50720       -0.999751        9.723464E-11    1.852885E-16  -114.371
   3.400504E-17   3.629090E-18    0.999999        5.408260E-08     0.0
  -1.086809E-14  -4.892574E-15    1.116133E-04    1.00000          0.0
-113.317        -50.2767          0.00000         0.00000          2.35362

          DetY-1 =       0.0000190469,    DetZ-1 =      -0.0000009590

          R12=0 at   0.1101E-03 m,        R34=0 at  -0.5408E-07 m

      First order symplectic conditions (expected values = 0) :
  1.9047E-05 -9.5900E-07  1.5418E-16  7.1396E-17 -9.7094E-11 -4.3113E-11
```

Second and higher order coefficients are given on page 11.

Second and higher order transport coefficients

- Second order matrix obtained at final-focus accounting for data given in page 10 :

```
                TRANSFER  MATRIX  ORDRE  2  (MKSA units)

   1 11  6.830E+03   1 21  3.030E+03   1 31 -2.529E-07   1 41 -5.909E-09   1 51   0.00       1 61   867.
   1 12  3.030E+03   1 22  1.352E+03   1 32 -4.944E-06   1 42 -9.339E-10   1 52   0.00       1 62   376.
   1 13 -2.529E-07   1 23 -4.944E-06   1 33   326.       1 43  4.423E-03   1 53   0.00       1 63  3.132E-04
   1 14 -5.909E-09   1 24 -9.339E-10   1 34  4.423E-03   1 44   8.71       1 54   0.00       1 64 -5.261E-06
   1 15   0.00       1 25   0.00       1 35   0.00       1 45   0.00       1 55   0.00       1 65   0.00
   1 16   867.       1 26   376.       1 36  3.132E-04   1 46 -5.261E-06   1 56   0.00       1 66  1.081E+03


   2 11  1.539E+04   2 21  6.828E+03   2 31 -5.065E-07   2 41 -1.310E-08   2 51   0.00       2 61  1.888E+03
   2 12  6.828E+03   2 22  3.046E+03   2 32 -1.113E-05   2 42 -2.033E-09   2 52   0.00       2 62   819.
   2 13 -5.065E-07   2 23 -1.113E-05   2 33   734.       2 43   1.23       2 53   0.00       2 63  3.797E-04
   2 14 -1.310E-08   2 24 -2.033E-09   2 34   1.23       2 44   18.0       2 54   0.00       2 64 -7.507E-06
   2 15   0.00       2 25   0.00       2 35   0.00       2 45   0.00       2 55   0.00       2 65   0.00
   2 16  1.888E+03   2 26   819.       2 36  3.797E-04   2 46 -7.507E-06   2 56   0.00       2 66  2.605E+03


   3 11  1.735E-12   3 21  8.532E-12   3 31   1.22       3 41  -1.96       3 51   0.00       3 61 -6.405E-13
   3 12  8.532E-12   3 22  1.409E-11   3 32  1.238E-05   3 42 -0.872       3 52   0.00       3 62  1.020E-11
   3 13   1.22       3 23  1.238E-05   3 33 -5.873E-10   3 43 -6.505E-10   3 53   0.00       3 63   44.5
   3 14  -1.96       3 24 -0.872       3 34 -6.505E-10   3 44 -7.906E-11   3 54   0.00       3 64  -1.77
   3 15   0.00       3 25   0.00       3 35   0.00       3 45   0.00       3 55   0.00       3 65   0.00
   3 16 -6.405E-13   3 26  1.020E-11   3 36   44.5       3 46  -1.77       3 56   0.00       3 66 -8.321E-14


   4 11 -6.573E-11   4 21 -4.561E-11   4 31   728.       4 41  -1.22       4 51   0.00       4 61  3.010E-12
   4 12 -4.561E-11   4 22  4.440E-10   4 32   323.       4 42 -7.449E-05   4 52   0.00       4 62 -1.530E-10
   4 13   728.       4 23   323.       4 33 -4.574E-08   4 43 -1.850E-08   4 53   0.00       4 63  3.551E+03
   4 14  -1.22       4 24 -7.449E-05   4 34 -1.850E-08   4 44 -1.084E-10   4 54   0.00       4 64  -31.0
   4 15   0.00       4 25   0.00       4 35   0.00       4 45   0.00       4 55   0.00       4 65   0.00
   4 16  3.010E-12   4 26 -1.530E-10   4 36  3.551E+03   4 46  -31.0       4 56   0.00       4 66 -2.313E-13


   5 11  1.756E+03   5 21   795.       5 31   0.00       5 41   0.00       5 51   0.00       5 61   529.
   5 12   795.       5 22   360.       5 32   0.00       5 42   0.00       5 52   0.00       5 62   209.
   5 13   0.00       5 23   0.00       5 33  3.405E+03   5 43   30.6       5 53   0.00       5 63  1.927E-05
   5 14   0.00       5 24   0.00       5 34   30.6       5 44  0.939       5 54   0.00       5 64 -4.832E-06
   5 15   0.00       5 25   0.00       5 35   0.00       5 45   0.00       5 55   0.00       5 65   0.00
   5 16   529.       5 26   209.       5 36  1.927E-05   5 46 -4.832E-06   5 56   0.00       5 66  2.982E+03


   6 11   0.00       6 21   0.00       6 31   0.00       6 41   0.00       6 51   0.00       6 61   0.00
   6 12   0.00       6 22   0.00       6 32   0.00       6 42   0.00       6 52   0.00       6 62   0.00
   6 13   0.00       6 23   0.00       6 33   0.00       6 43   0.00       6 53   0.00       6 63   0.00
   6 14   0.00       6 24   0.00       6 34   0.00       6 44   0.00       6 54   0.00       6 64   0.00
   6 15   0.00       6 25   0.00       6 35   0.00       6 45   0.00       6 55   0.00       6 65   0.00
   6 16   0.00       6 26   0.00       6 36   0.00       6 46   0.00       6 56   0.00       6 66   0.00
      Second order symplectic conditions (expected values = 0) :

        -0.1389        38.86         22.67         11.02        1.9980E-02    2.0478E-02     38.64
         9.1065E-03     15.68         4.876        9.0680E-03    4.9829E-04    3.8493E-05     26.87


              COEFFICIENTS  D'ORDRE  SUPERIEUR  ( MKSA ):

           Y/Y3          -2.10023E+05
           Y/T3            5164.3
           Y/Z3           -3.4695
           Y/P3            0.0000

           T/Y3          -4.63770E+05
           T/T3            12458.
           T/Z3           -7.8178
           T/P3            0.0000

           Z/Y3          -1.84640E-07
           Z/T3          -3.32802E-06
           Z/Z3           -397.97
           Z/P3            5.6978

           P/Y3          -7.17481E-07
           P/T3           3.26001E-05
           P/Z3          -3.23992E+05
           P/P3            1.0914
 TRAJ 1 IEX,D,Y,T,Z,P,S,time :  1   1.000       0.000       0.000      3.9101E-22  8.3465E-21       767.18           25.904
```

5 Full structure, some tracking

5.1 Three momenta, observed at mid-plane and final-focus

The object used is 1π mm.mrad in both planes (the initial YY' and ZZ' distributions are plotted in Fig. 5), with three momenta at $\Delta p/p = 0, \pm 0.0005$, all three with zero momentum dispersion. The images at mid-plane and at final-focus are shown in respectively Figs. 6, 7.

Zgoubi data :

```
 'MCOBJET'
 409.3505601114    (Sn132+, 60 KeV)
2
2000
2      2      2      2      1      1
0.     0.     0.     0.     0.     1.
1      1      1      1      1      3
0.     0.     0.     0.     0.     0.0005
.5e-3 2.e-3 .5e-3  2.e-3   0.    .0
4      4      4      4      1      1
1 0. 0. 0. 0.
 123456 234567 345678
```

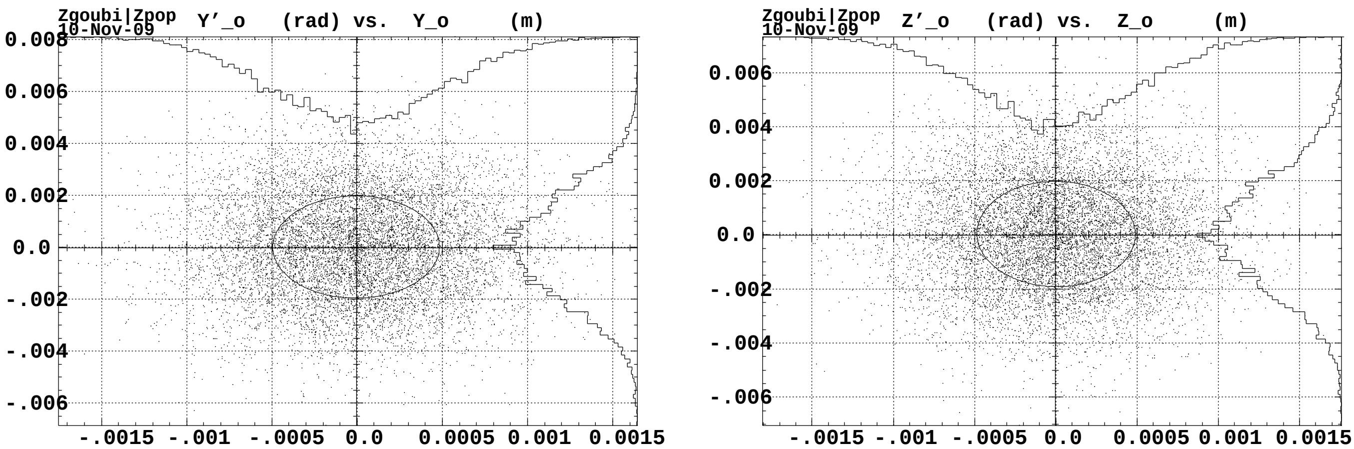

Figure 5: YY' and ZZ' distributions at beginning of HRS-C135.

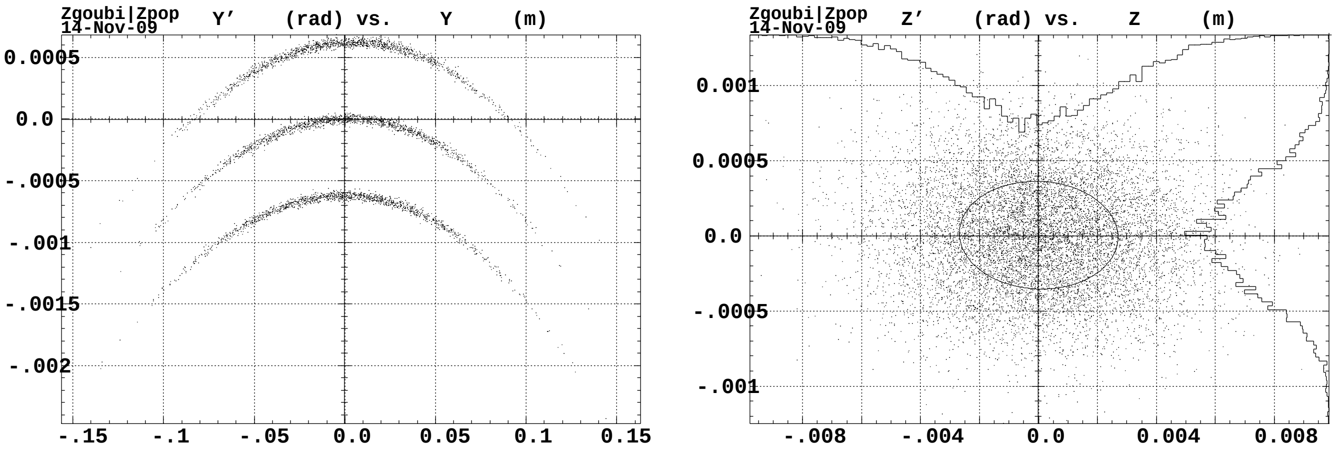

Figure 6: Observation of three momenta at $\Delta p/p = 0, \ \pm 0.0005$, at mid-plane of HRS-C135, H (left) and V (right) phase-spaces, 10000 particles.

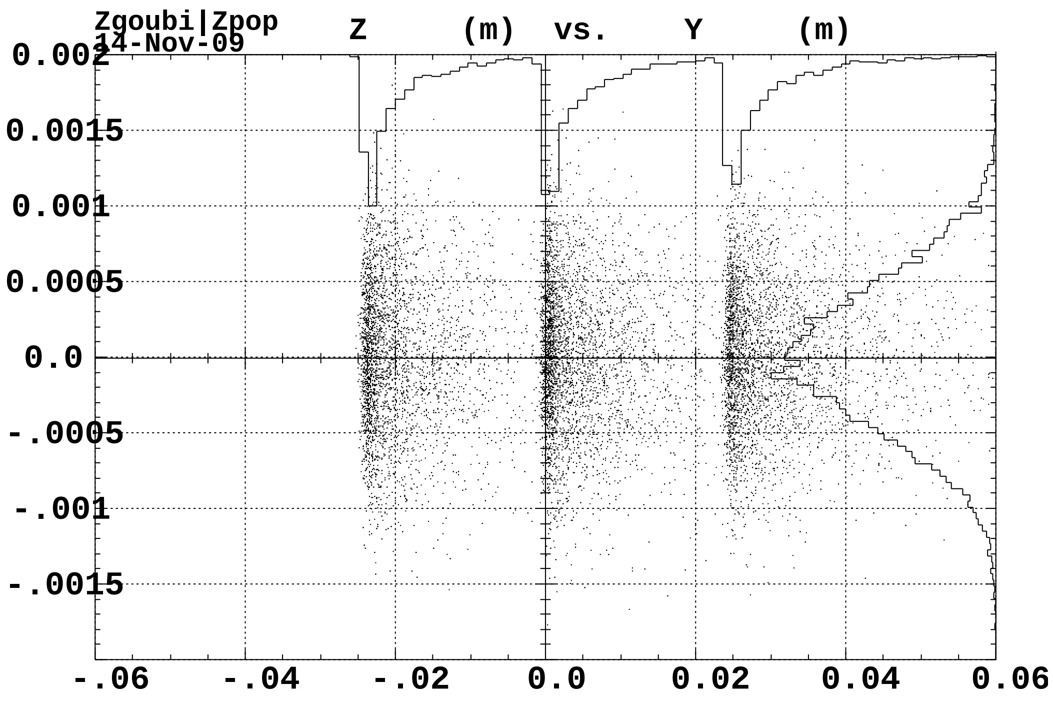

Figure 7: Separation of three momenta $\Delta p/p = 0, \ \pm 0.0005$, at final-focus of HRS-C135, beam cross section, 10000 particles. Effect of strong second order aberration (Y/θ^2) is visible.

5.2 Two different masses, observed at mid-plane and final-focus

The object now comprises two masses, differring by $\Delta m/m = 0.0005$, both having same energy, 60 keV. The image at final-focus is shown in Fig. 8.

First mass :

```
 'MCOBJET'
 405.1790552244900274   (Sn132+, 60. KeV)
2
5000
2       2       2       2       1     1
0.      0.      0.      0.      0.    1.
1       1       1       1       1     1
0.      0.      0.      0.      0.    0.
.5e-3  2.e-3    .5e-3    2.e-3    0.   .0
4       4       4       4       1     1
1 0. 0. 0. 0.
 123456 234567 345678
  'PARTICUL'
 122957.208 1.602176487E-19  0.0 0.0 0.0
```

Second mass :

```
 'MCOBJET'
 405.2803499882961495   (Sn132+ + delta_m, 60. KeV)
2
5000
2       2       2       2       1     1
0.      0.      0.      0.      0.    1.
1       1       1       1       1     1
0.      0.      0.      0.      0.    0.
.5e-3  2.e-3    .5e-3    2.e-3    0.   .0
4       4       4       4       1     1
1 0. 0. 0. 0.
 123456 234567 345678
  'PARTICUL'
 123018.686604 1.602176487E-19  0.0 0.0 0.0
```

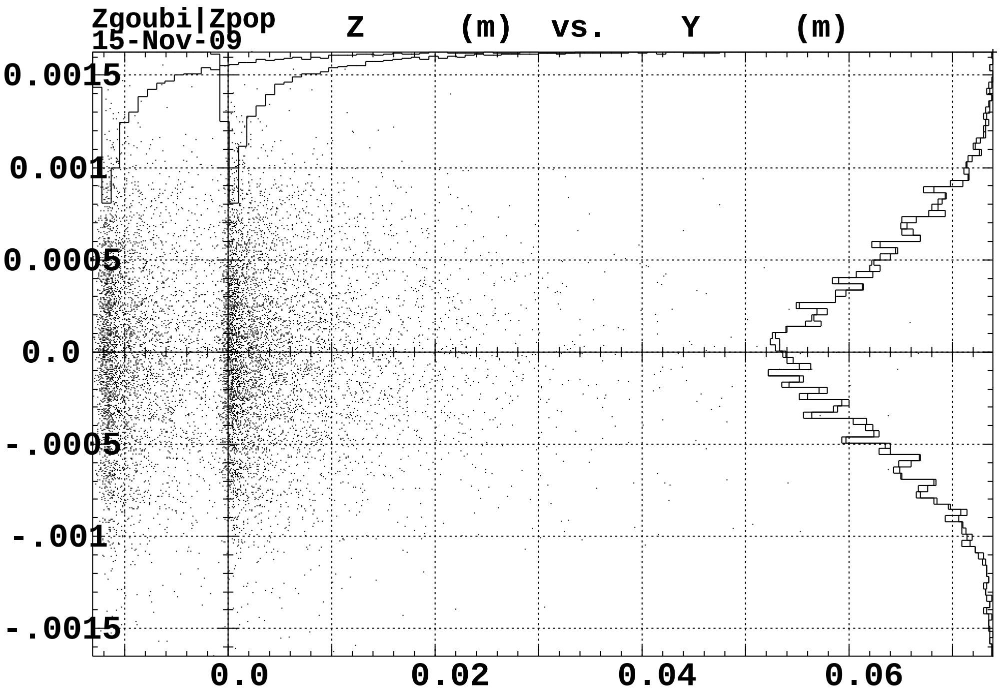

Figure 8: Separation of two masses $\Delta m/m = 0, +0.0005$, 60 keV, at final-focus of HRS-C135, beam cross section, 10000 particles.

6 Comments

The goal of these exercises was two-fold, as follows.

- Cross-checking based on these simulations essentially confirms the data exposed in Ref. [1], in particular the agreement with the COSY method is good,
  - practically identical results are obtained as far as electrostatic quadrupoles are concerned
  - very good agreement on global focusing at mid-plane and at final-focus is obtained after re-tuning the quadrupoles by less than about 1% (an effect attributed to magnetic bend simulation specificities, to be clarified)
  - momentum and mass separation at final-focus come out as expected.

- As to using further the ray-tracing code Zgoubi [2] in the design of the HRS DESIR mass spectrometer for SPIRAL2, the exercises performed so far show that
  - all features necessary for designing such type of beam line are provided in Zgoubi, as
    - electrostatic and magnetic elements,
    - even further if needed, magneto-electrostatic elements [3],
    - various access-free parameters as mass, momentum, kinetic energy, random distributions,
    - a powerful fitting procedure with many available constraints, as particles coordinates, beam functions, phase advances, transmission rates, etc.
  - the code provides many additional convenient features as
    - Monte Carlo objects with arbitrary number of particles,
    - data analysis and plotting, in particular using zpop,
    - open source, downloadable on sourceForge [2],

    liable to satisfy regular design requirements.

References

[1] Technical status report of the HRS for SPIRAL2/DESIR, B. Blank et al., Tech. Rep. IWS HRS, IN2P3/CENB-G, 06 Nov. 2009.

[2] (a) Zgoubi users' guide, F. Méot and S. Valero, report CEA DAPNIA SEA-97-13 and FERMILAB-TM-2010 (1997),
(b) On the net : 'sourceForge Zgoubi' will lead to downloadable, maintained versions of Zgoubi and Zpop softwares, users' guide, and examples.

[3] Generalization of the Zgoubi method for ray-tracing to include electric fields, F. Méot, NIM A 340 (1994) 594-604.