HRS Match/Magnifier Section

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Introduction

The LEBT backbone is a periodic section of doublet cells. The doublet naturally creates waists and the 4-quad matching section to the HRS starts at such a waist in the horizontal plane. A slit (slit "A" for purposes of this note) is placed at this waist. Twiss $\beta_x = 0.147$ m. The 4 quad matching section has tunable magnification in the horizontal plane. The demagnification required to focus an emittance of $3\,\mu$m down from (half)size $\sqrt{\beta_x \epsilon} = 0.664$ mm to the $50\,\mu$m needed to achieve a mass resolution of 24000 is 13.3.

The "pure separator" object slit (slit "B" for the purposes of this note) is placed at the exit of the matching section. Presuming that the x-emittance has already been trimmed to $3\,\mu$m, a clean demagnification of 13 would then allow to use slit A as object and its mirror symmetric partner slit A' at the exit of the 4-quad matching section that matches out of the separator, as the mass selection slit. In this scheme (called "scheme A"), a resolution of 24000 is achieved with slits of full width $2 \times 0.664 = 1.33$ mm.

However, the matching section cannot achieve magnification larger than 10. The limitation is two-fold: a higher magnification requires dangerously high electric fields for our upper limit of 120 keV beam energy, and aberrations at $M >\sim 12$ are comparable to those created by the HRS itself. It is possible that the multipole will be capable of correcting both the HRS aberrations and the matching section aberrations. This remains to be seen and will hopefully be attempted during commissioning.

Nevertheless, ≥ 20000 resolution with $\geq 3\mu$m emittance is achievable by using slit B to select the initial $100\,\mu$m beam width. The disadvantage is that this slit is mechanically more demanding, and can easily be eroded by the bombardment of heavy isotope species. We refer to using slit B as the object and slit B' for mass selection, as “scheme B”.

Match constraints

In the horizontal direction, the HRS has been designed to have a $-I$ transfer matrix, so it is sufficient to tune the entrance matching to be a waist at “B”.

In the vertical direction, there is no necessity to focus at the slits. To ensure that the HRS entrance and exit matching sections have the same tunes (only reversed), it is sufficient to fit vertical phase space to a waist at the exact centre between the two dipoles (call this loacation “C”). Thus there are 3 conditions to fit the 4 quad settings: x-waist at “B” x-size (magnification) at “B”, y-waist at “C”. The remaining degree of freedom is used to minimize the overall third-order aberration arising from the quadrupoles.

Plots

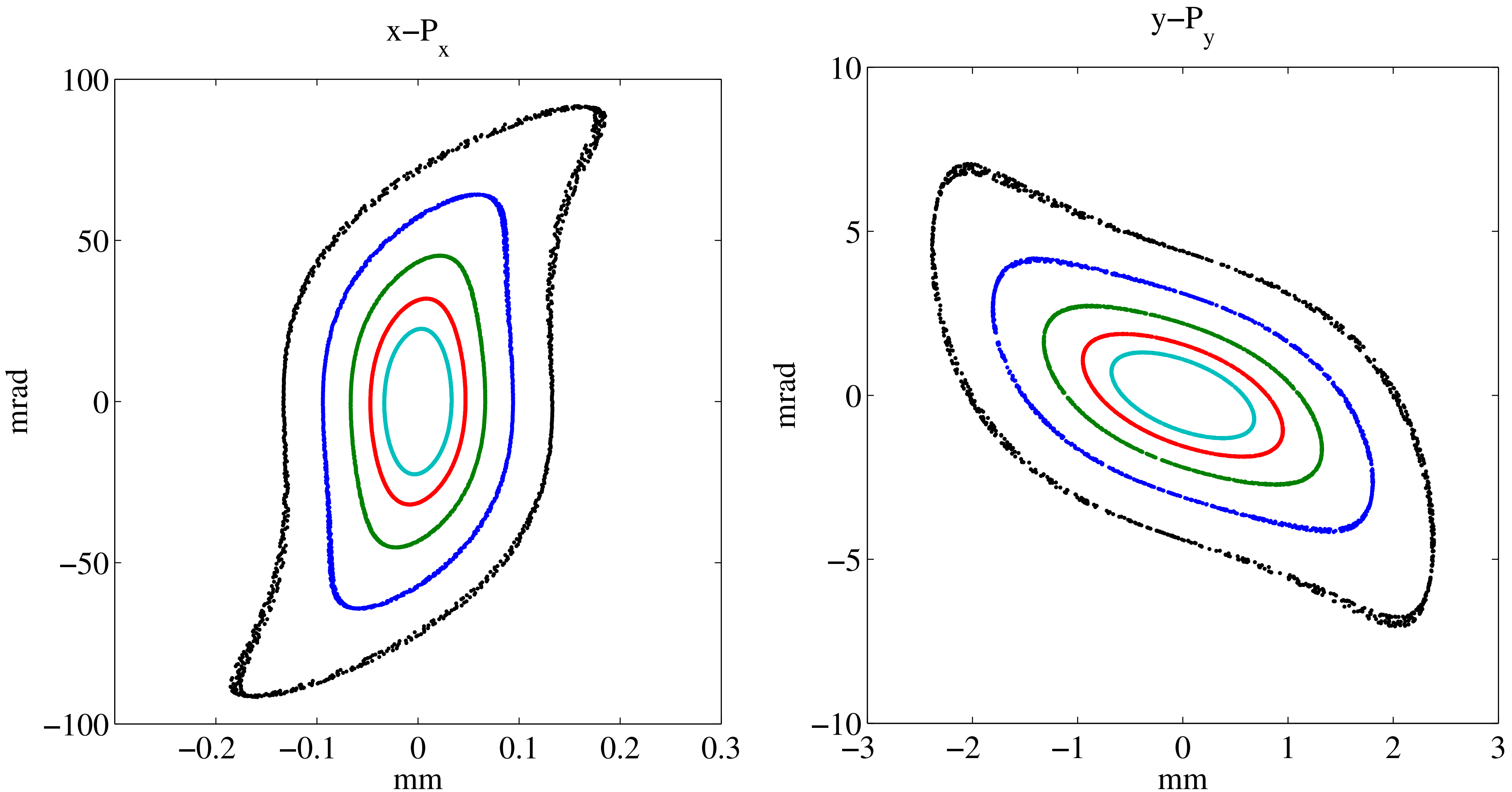
The phase space plots use maps generated by the code COSY-∞. This code can in principle calculate optics to any order, but the plots below are third order. Fifth order was also tried, but the difference is not discernable for the emittances plotted. Plots are generated from the maps using the commercial package Matlab and scripts written by me. These scripts have names like `cosyMC....`

In the following phase space plots, inner to outer is $3\ \mu$m times: $0.25, 0.5, 1.00, 2.00, 4.00$ (cyan, red green blue, black). So nominal is the Green ($3\ \mu$m) in x, and the Blue ($6\ \mu$m) in y.

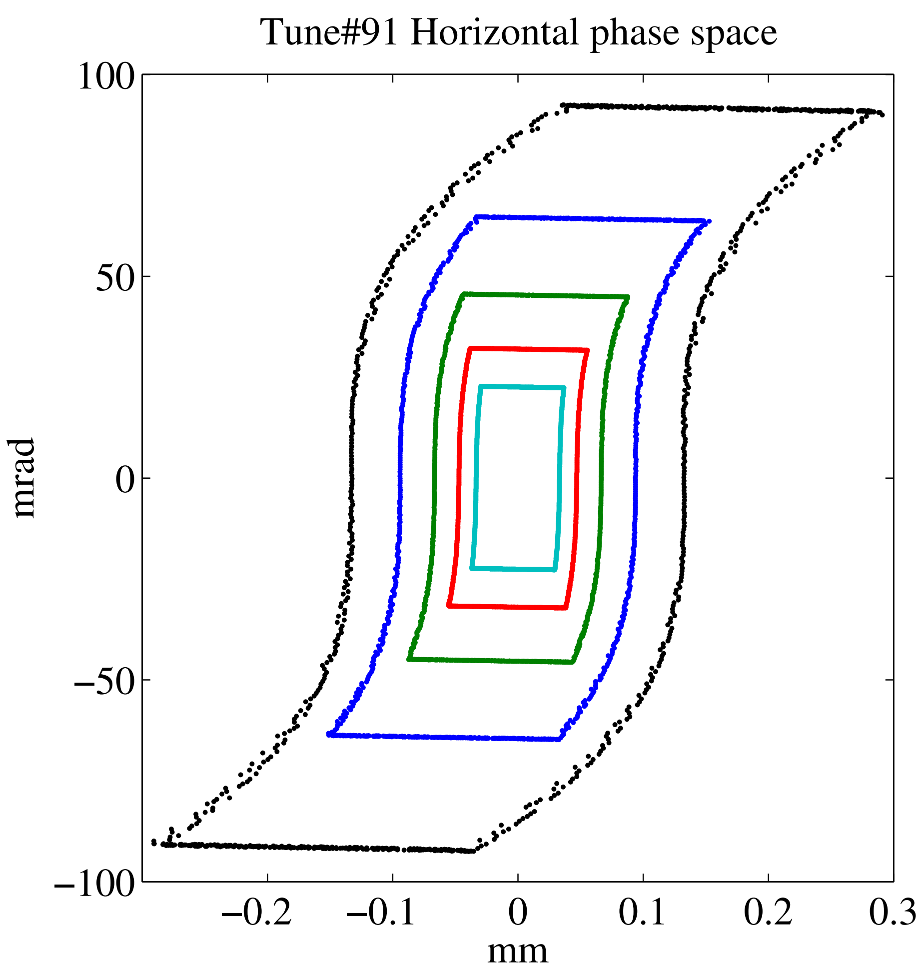
There are two kinds of phase space plots; those with ellipses as starting distributions, and those with rectangles. The phase space areas of the elliptical cases are those given above multiplied by π. For the rectangular case, the multiplier is 4 rather than π. The advantage of the rectangular distributions is that it is more clearly seen how the map is distorted.

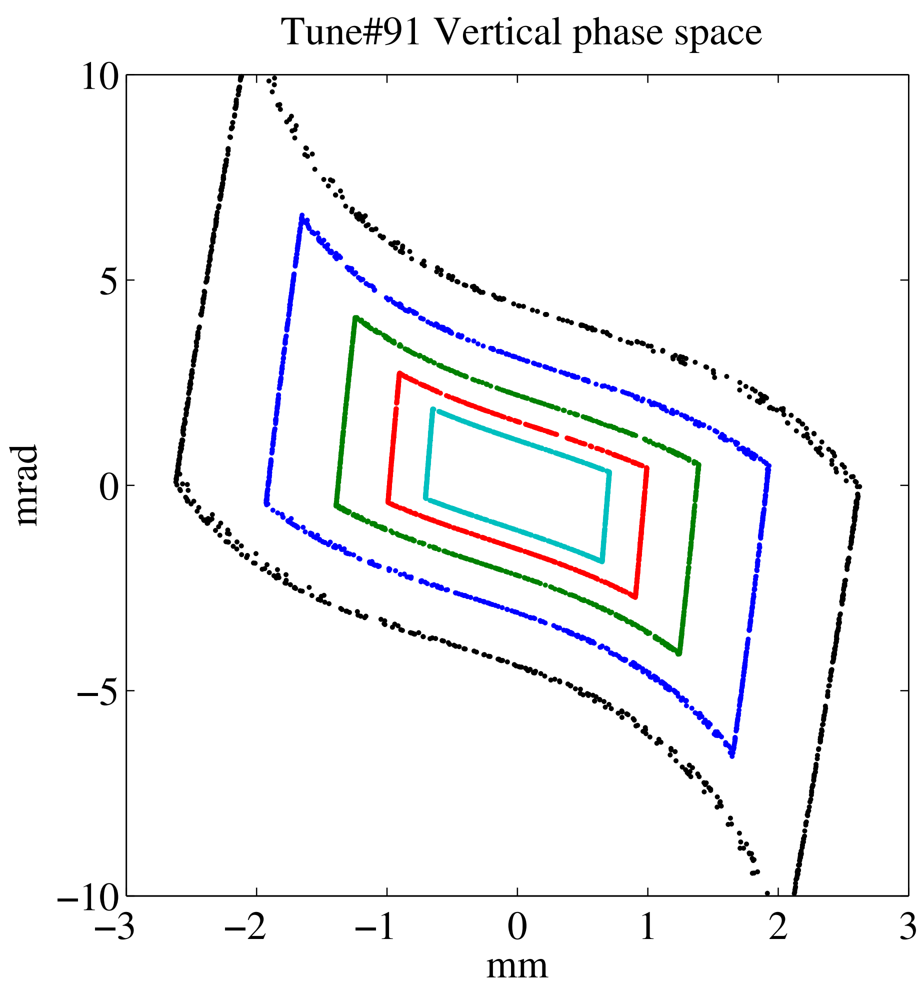
The P_x acceptance of the HRS is ± 60 mrad, and the x acceptance for a resolution of 24000 is $\pm 50\ \mu$m.

Tune 91: Magnification=10., Elliptical Initial Beam



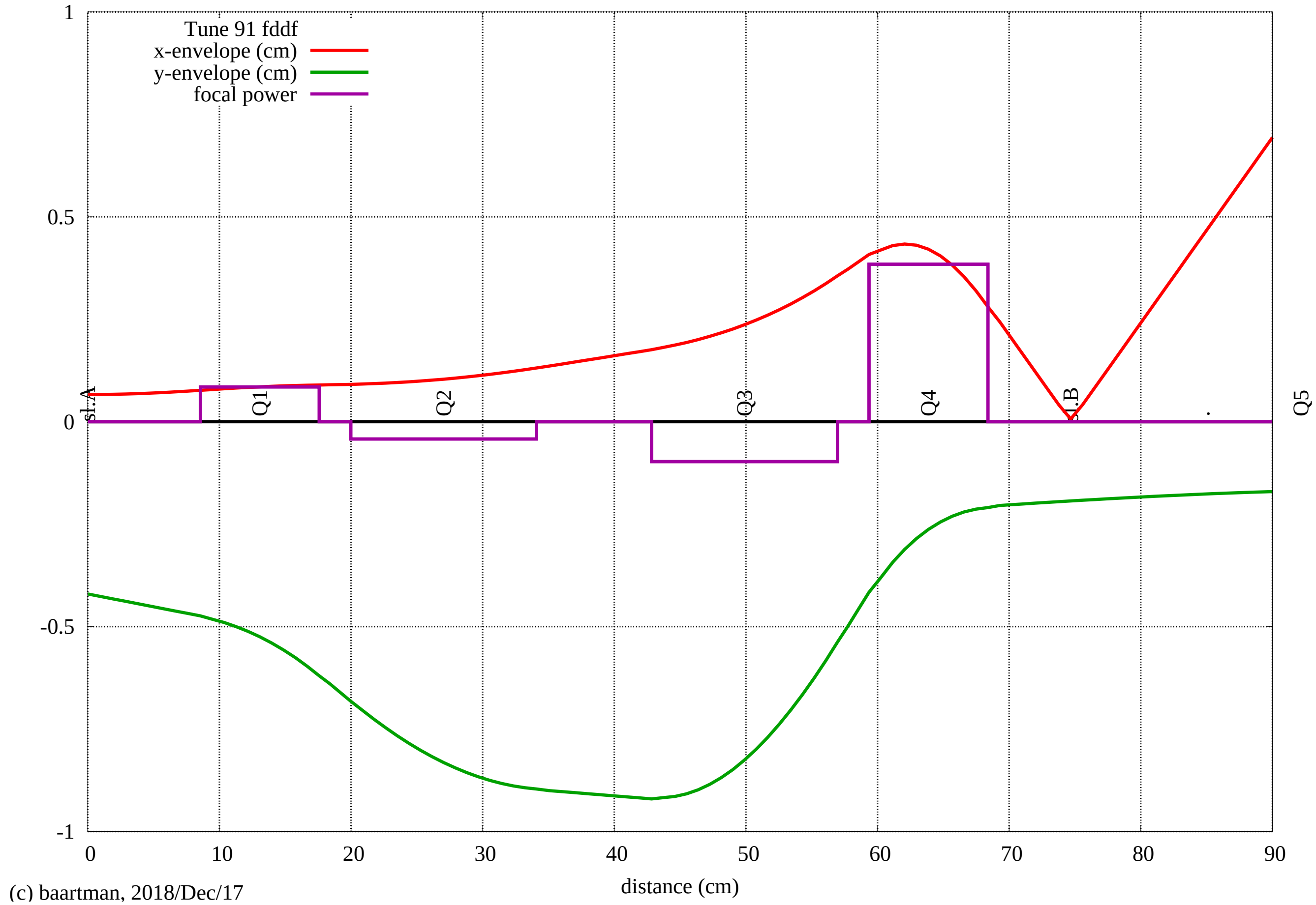
Tune 91: Magnification=10., Rectangular





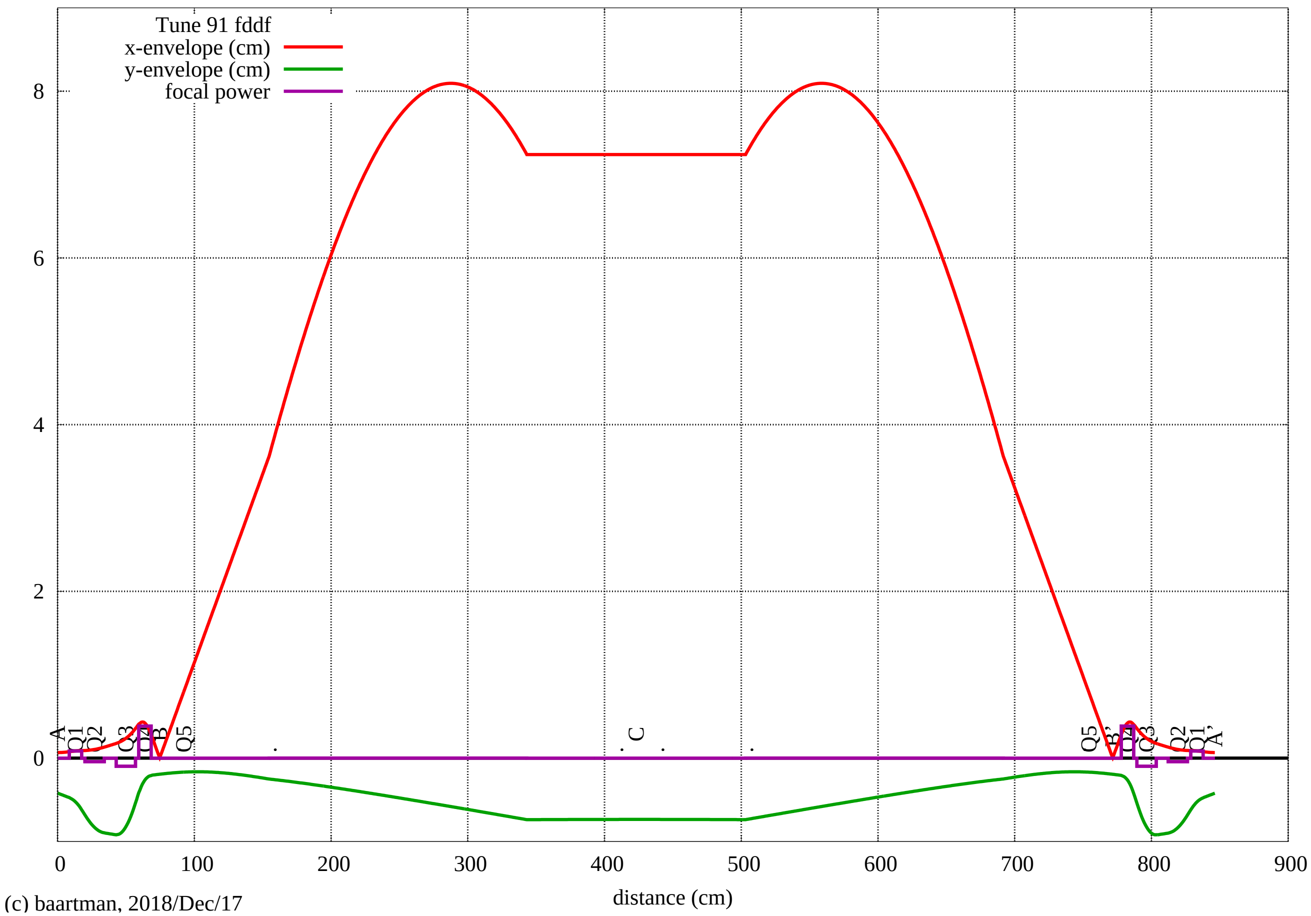
Tune 91: Magnification=10, match section

$$\epsilon_x = 3\mu\text{m}, \ \epsilon_y = 6\mu\text{m}$$



Tune 91: Magnification=10., full separator

$$\epsilon_x = 3\mu\text{m},\ \epsilon_y = 6\mu\text{m}$$

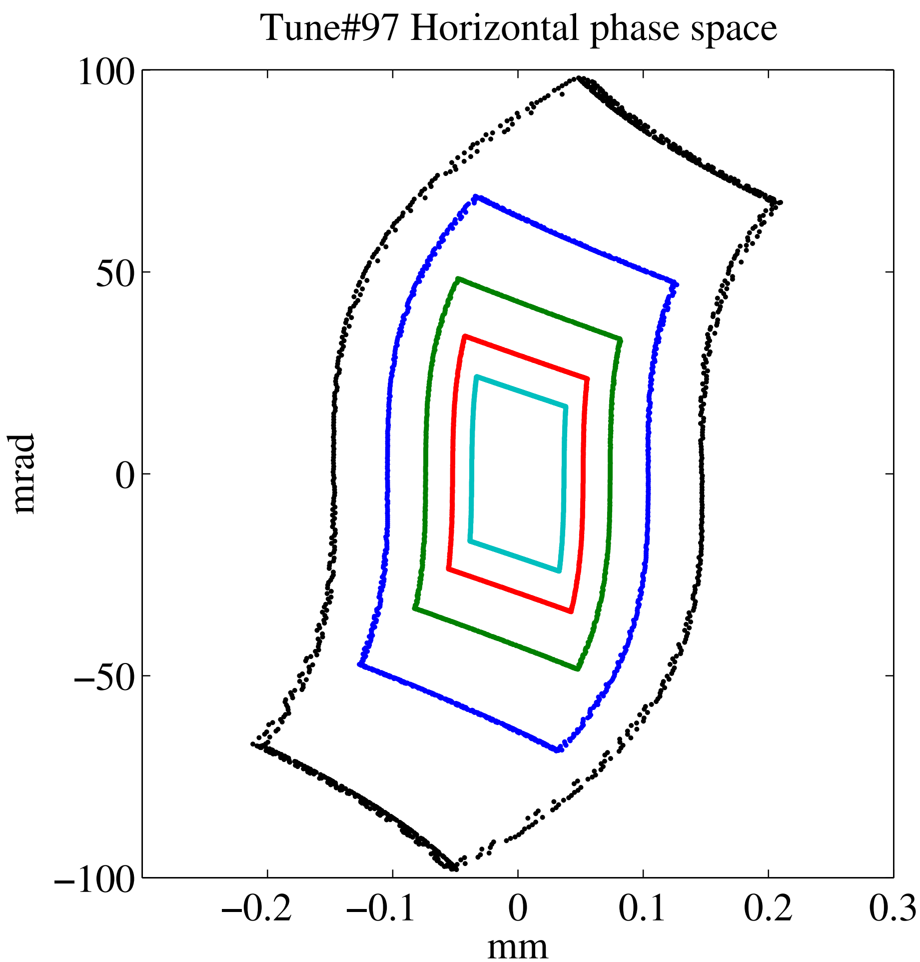


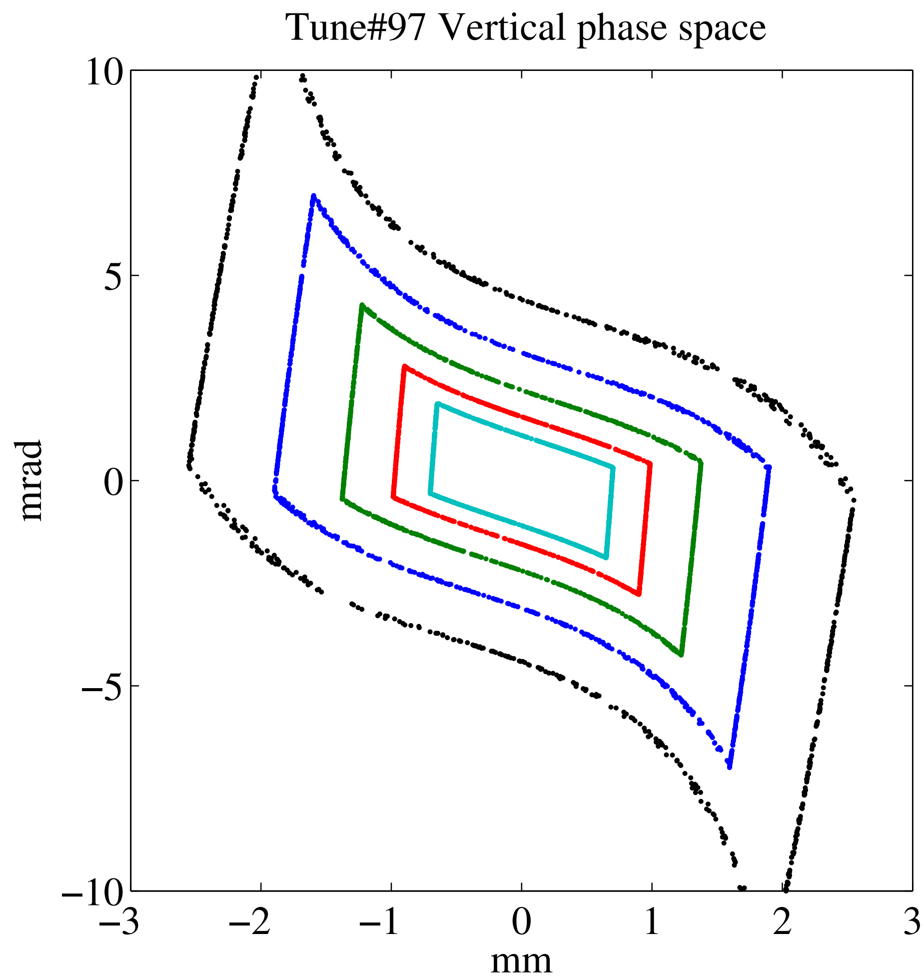
Comments, Tune #91

This tune is appropriate for scheme “A”. It has a near perfect horizontal transfer matrix: $\begin{pmatrix} 1/M & 0 \\ 0 & M \end{pmatrix}$. I.e. angles mapped to angles and positions to positions, so that slit A is imaged onto slit B.

The angular acceptance of the HRS is roughly ± 60 mrad. A pre-selected emittance of $3\,\mu$m (green contour) will have a width of $130\,\mu$m at location of slit B and so will yield a resolution of 18500: > 20000 can be recovered by allowing slightly larger divergence but smaller beam size at slit A.

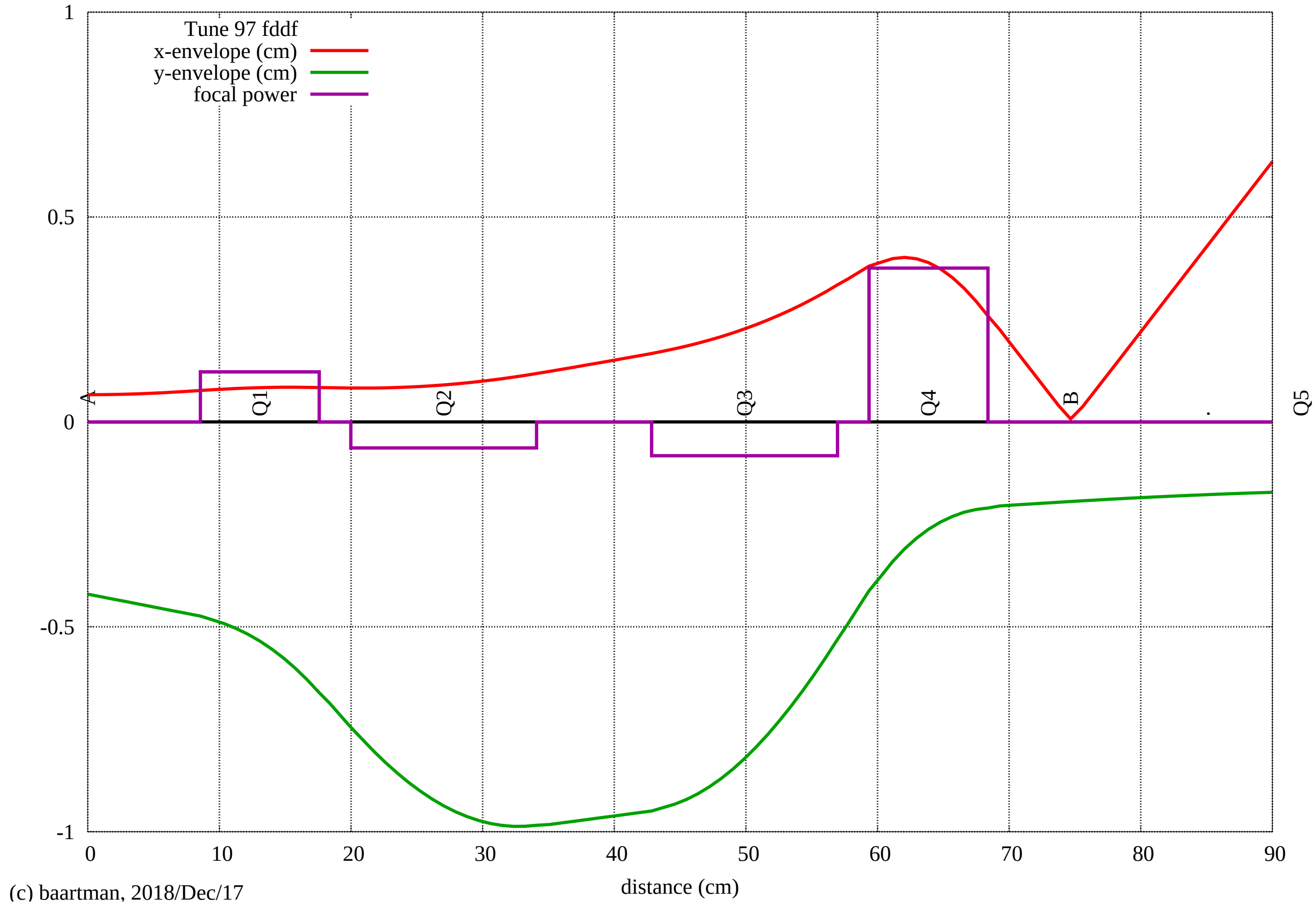
Tune 97: Magnification=9.0, Rectangular





Tune 97: Magnification=9.0, match section

$$\epsilon_x = 3\mu\text{m},\ \epsilon_y = 6\mu\text{m}$$

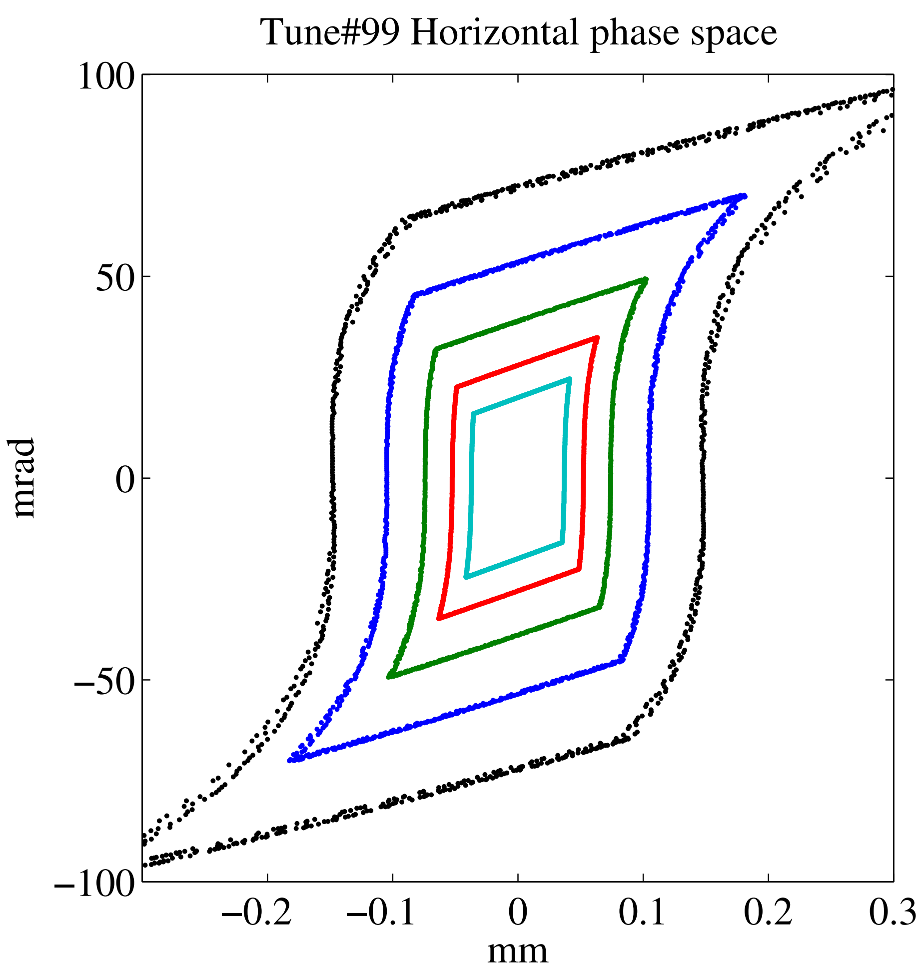


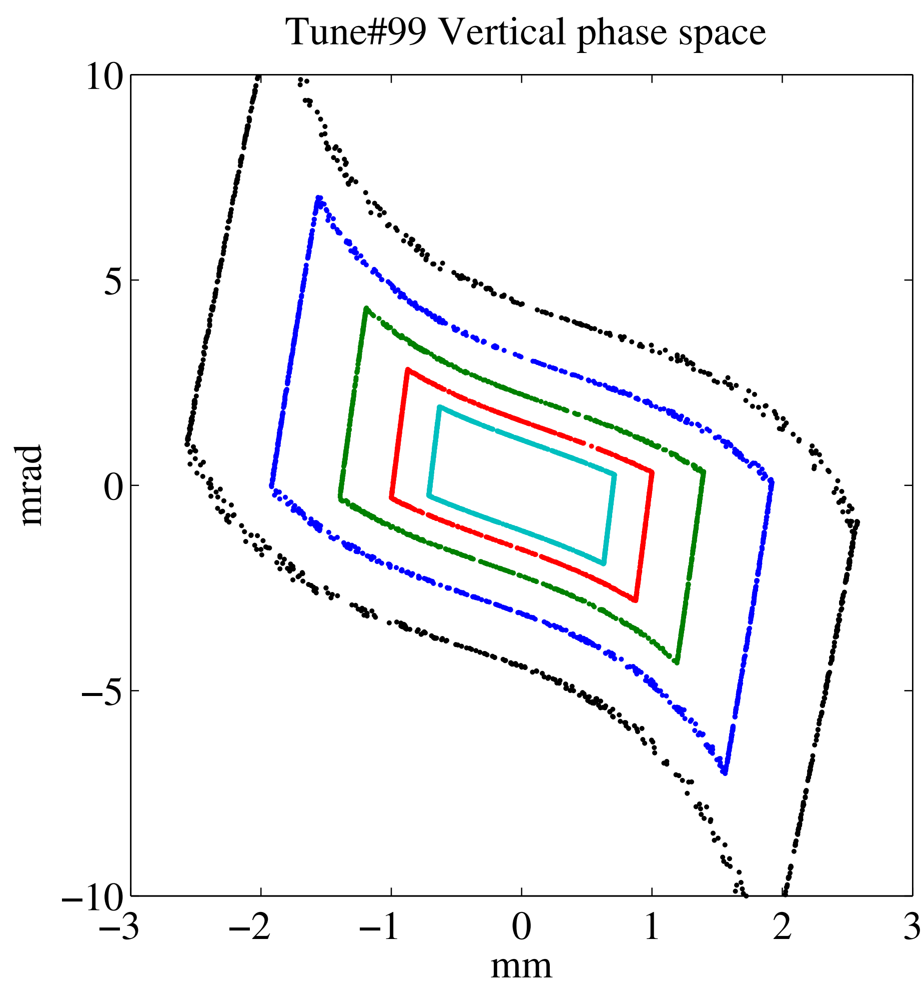
Comments, Tune #97

At this magnification the horizontal transfer matrix is not as ideal in the sense that the 21 transfer matrix element is not zero. This is why the rectangles are skewed into parallelograms. $M(2,1)=0$ is not essential for imaging slit A to slit B, but it can cause longer angular tails because although initial angles have no effect on positions, initial positions do affect final angles.

This is the smallest magnification tune possible with polarity dffd.

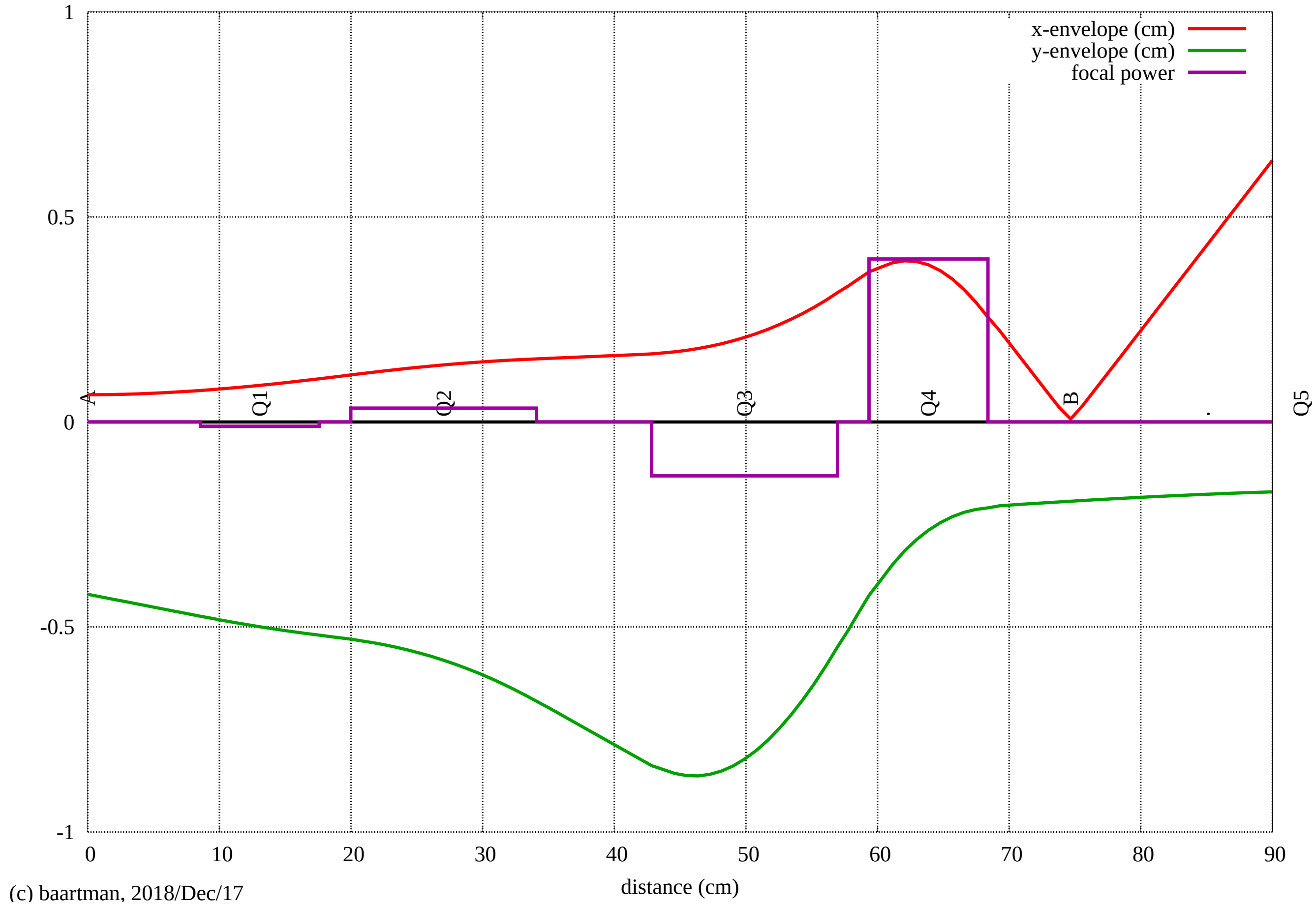
Tune 99: Magnification=9.0, Rectangular





Tune 99: Magnification=9.0, match section

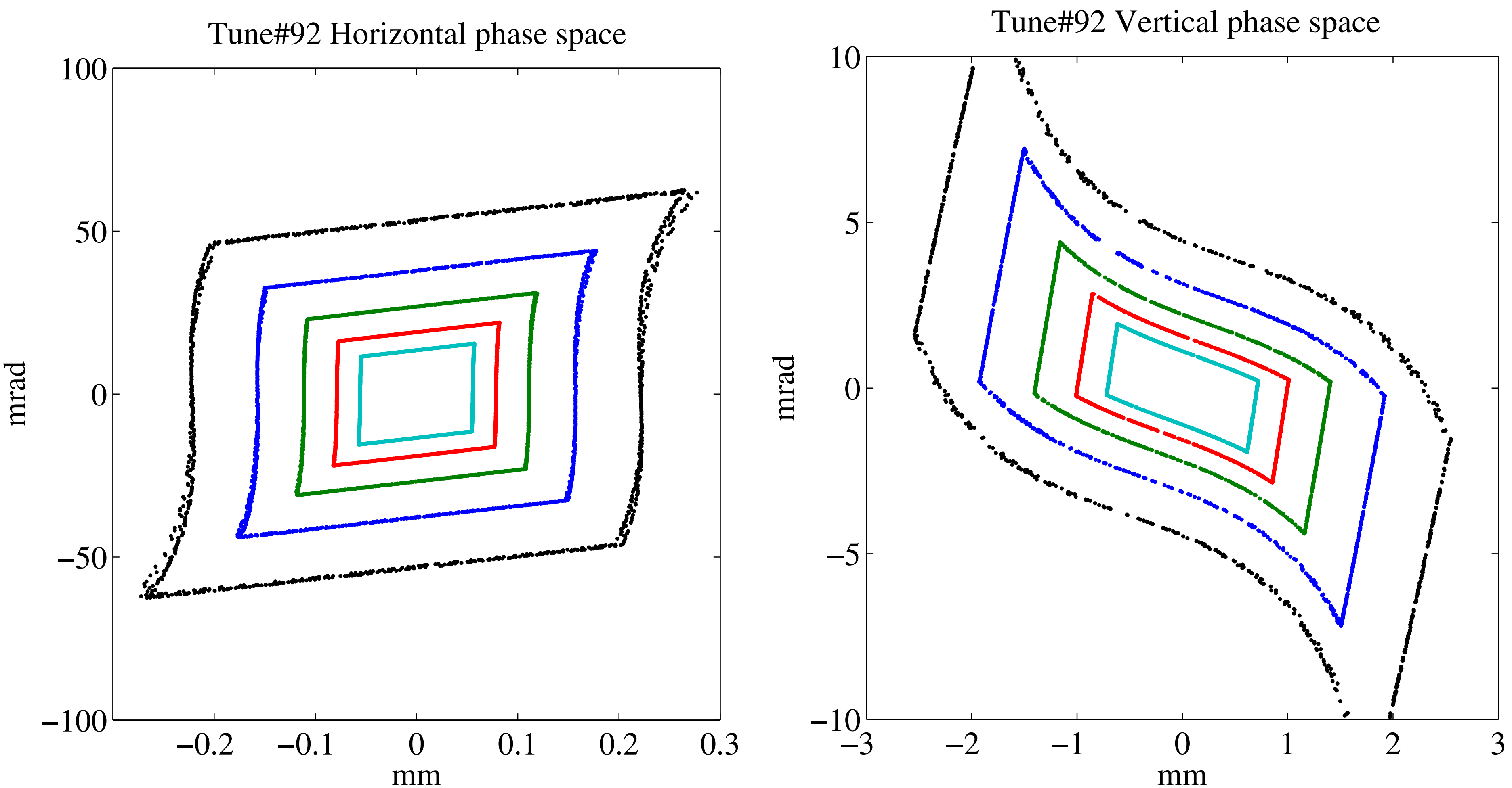
$\epsilon_x = 3\mu\text{m}$, $\epsilon_y = 6\mu\text{m}$



Comments, Tune #99

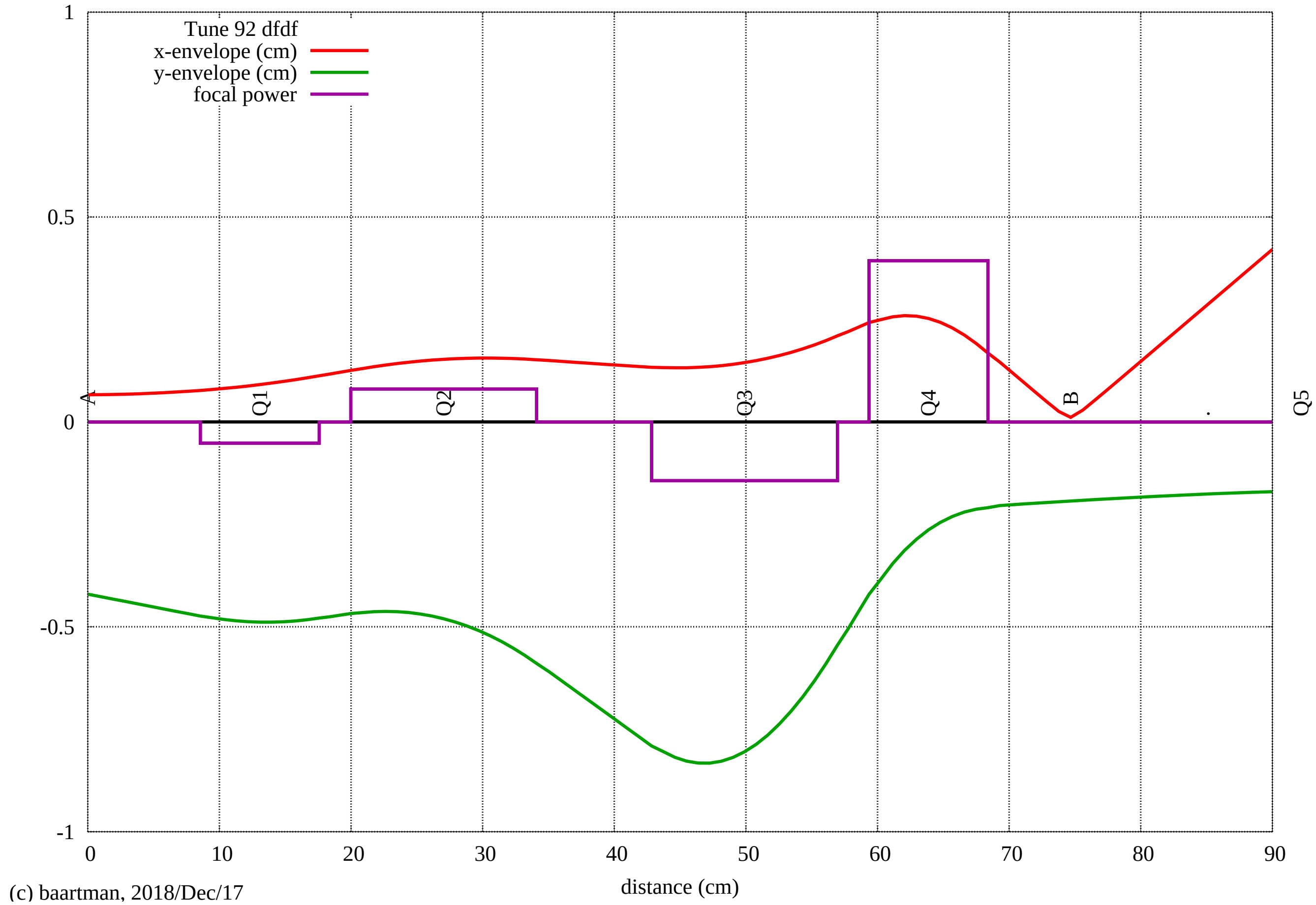
This tune has opposite polarity for quads 1 and 2; it is the largest magnification tune possible for this polarity (dfdf). As with #97, the horizontal transfer matrix does not satisfy $M(2,1) = 0$.

Tune 92: Magnification=6.0, Rectangular



Tune 92: Magnification=6.0, match section

$\epsilon_x = 3\mu\text{m}, \, \epsilon_y = 6\mu\text{m}$

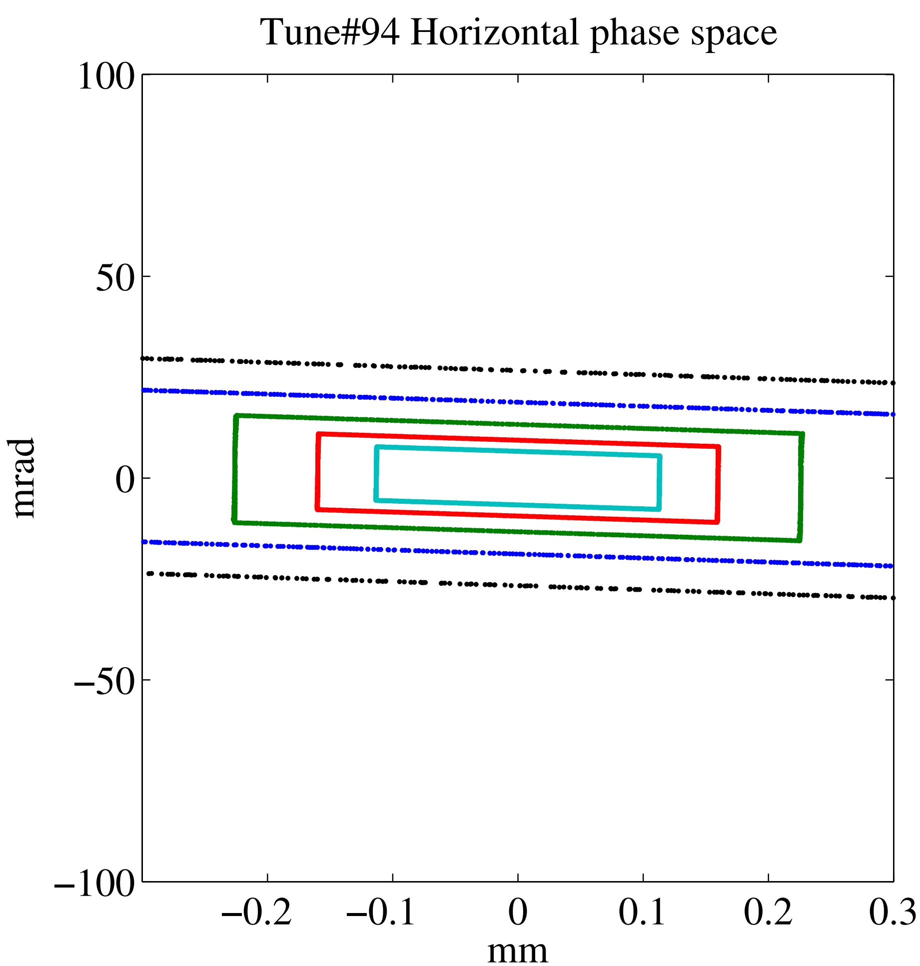


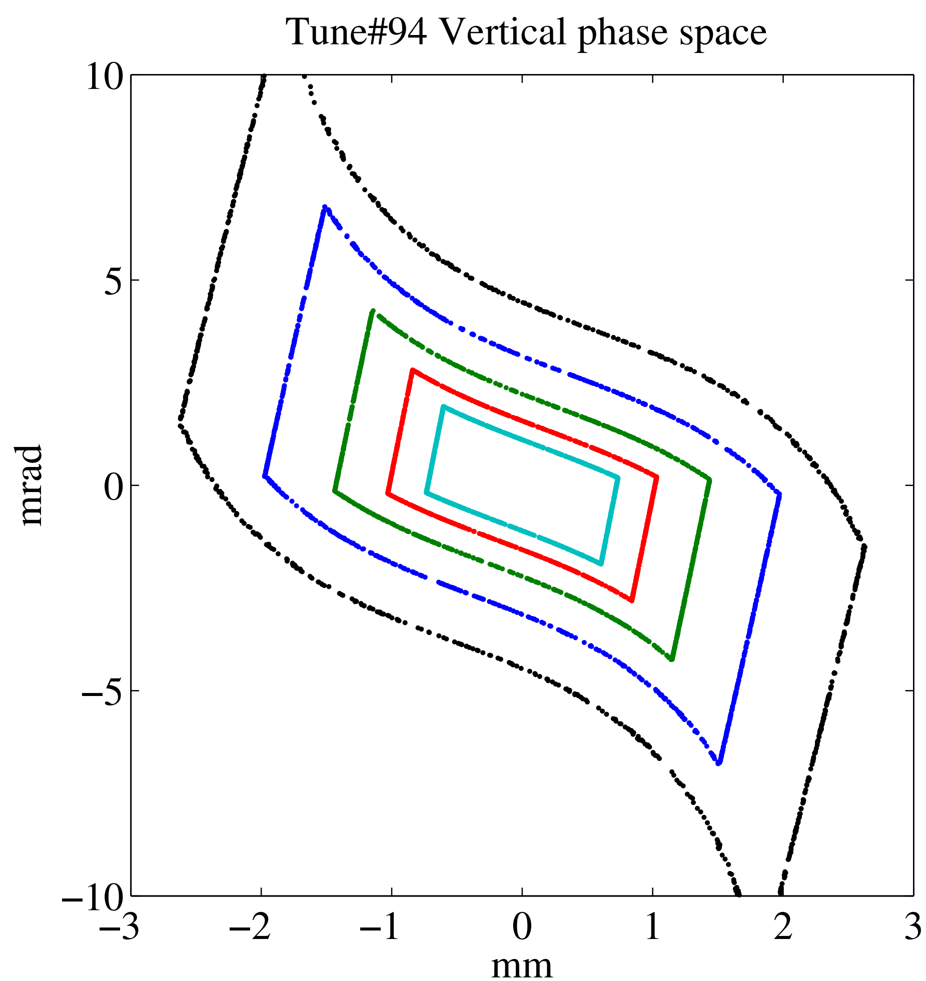
Comments, Tune #92

Suitable for scheme “B”, we would set slit “B” to $100\,\mu$m full width. Then an initial $12\,\mu$m emittance would fill the angular acceptance of the HRS, and resolution of 24000 achieved with a transmission of 25%.

Notice that the polarity is dfdf.

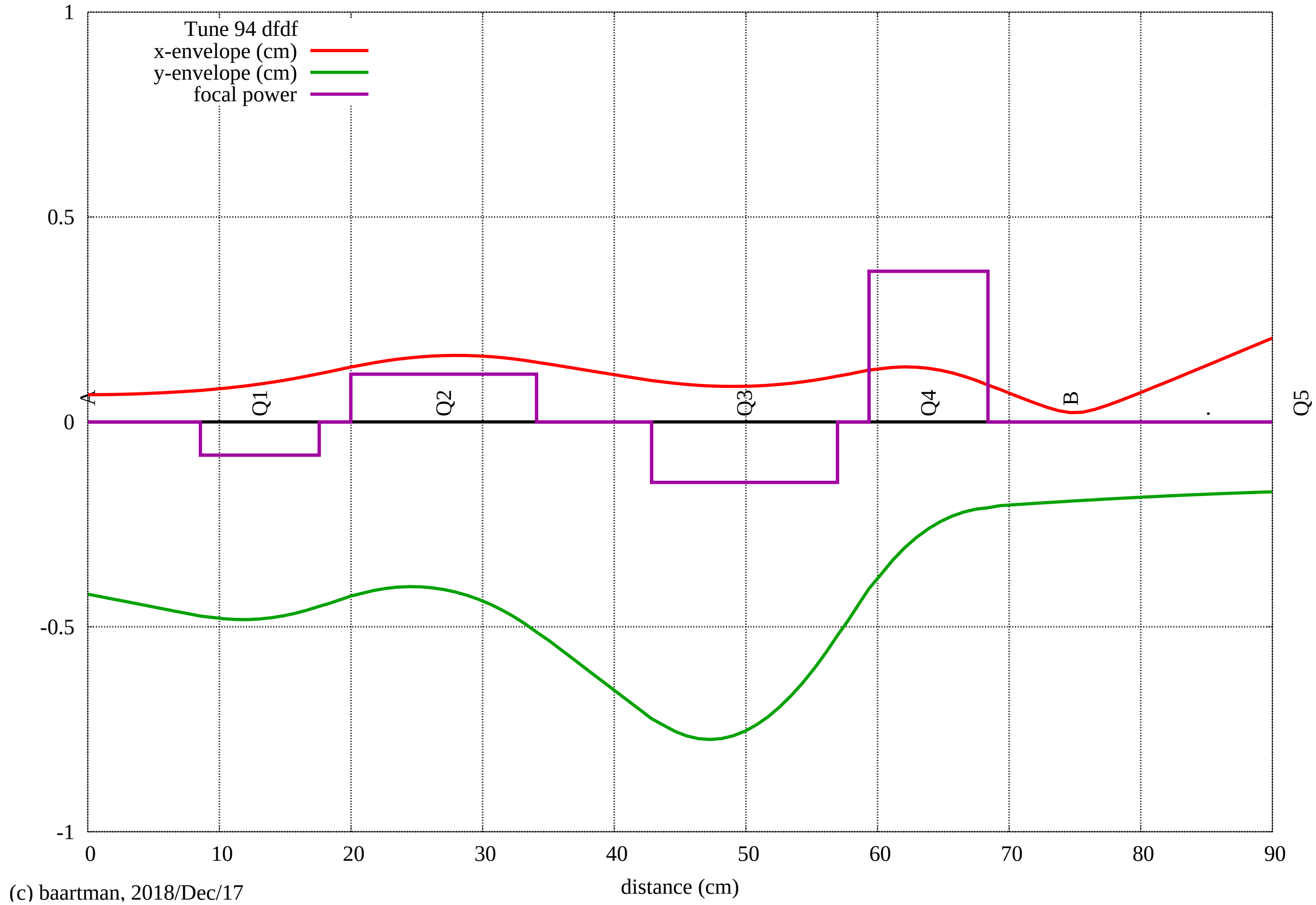
Tune 94: Magnification=3.0, Rectangular





Tune 94: Magnification=3.0, match section

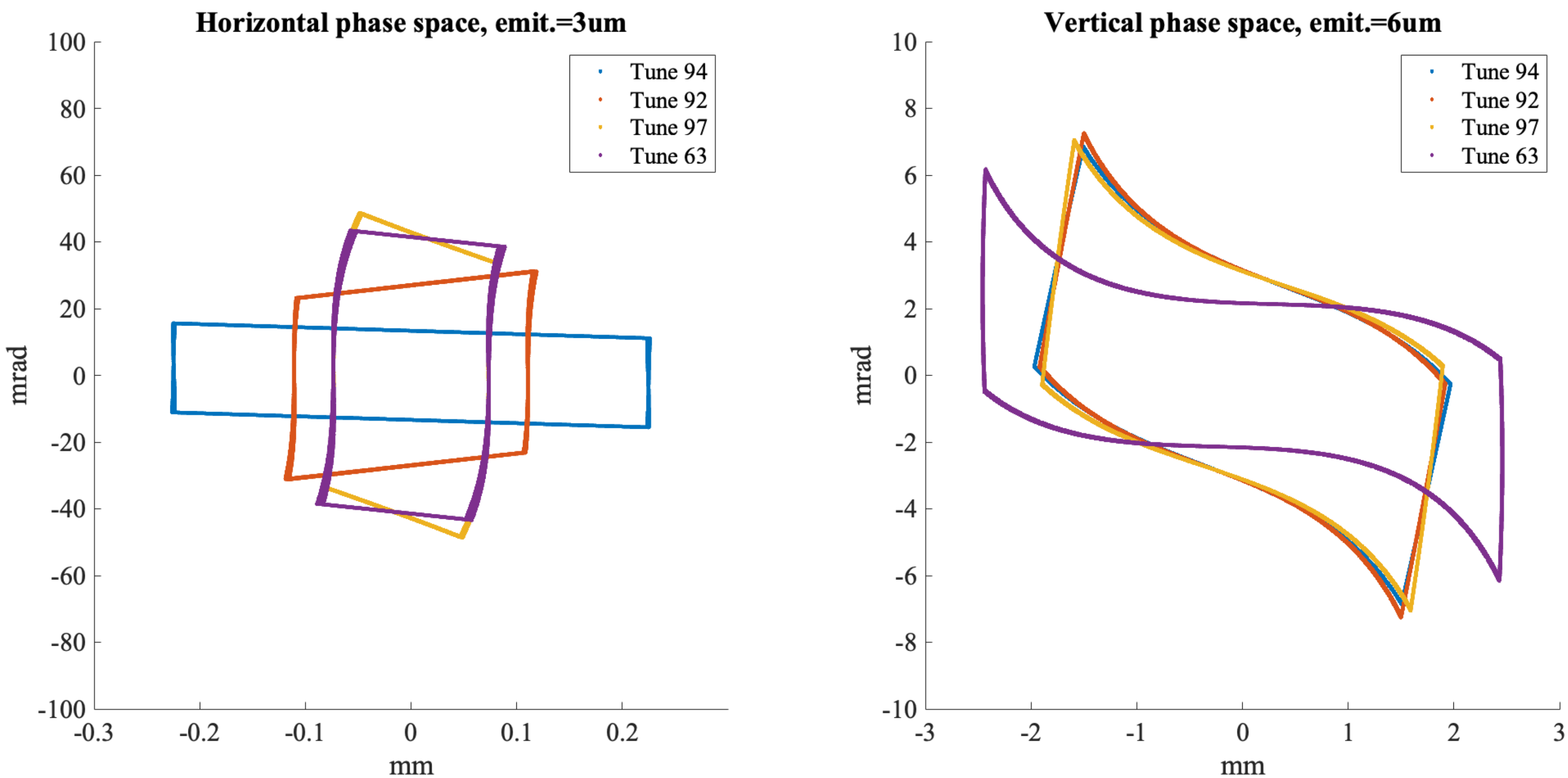
$\epsilon_x = 3\mu\text{m}, \epsilon_y = 6\mu\text{m}$



Comments, Tune #94

This is an undemanding tune, useful for threading through the separator, without the need for multipole correction.

Tunes compared on same plot



Quadrupole Parameters

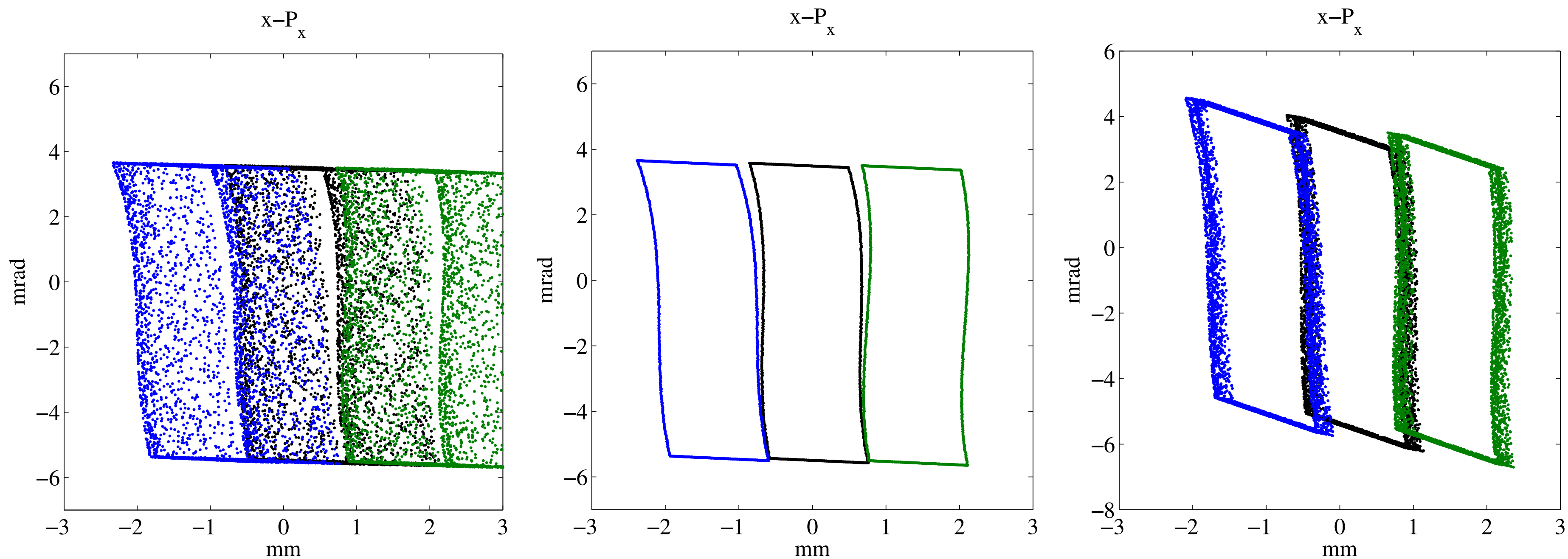
The given voltages are for 60 keV energy. For 120 keV, double them. Tune number is an arbitrary label. The quantity M is the demagnification factor in the horizontal (x) plane.

The location is with respect to the upstream slit (slit "A") at $s = 0.0$ mm. The "pure separator" slit "B" is at $s = 746.7$ mm.

	Tune#	M	Q1	Q2	Q3	Q4
Voltage/kV	91	$10.$	$+1.644$	-0.812	-1.885	$+7.438$
	97	9.0	$+2.362$	-1.229	-1.597	$+7.267$
	99	9.0	-0.201	$+0.654$	-2.542	$+7.693$
	92	6.0	-1.002	$+1.553$	-2.776	$+7.617$
	94	3.0	-1.571	$+2.255$	-2.853	$+7.114$
	63	9.0	$+1.471$	-0.258	-2.310	$+7.645$
Electrode length/mm			76.2	127.0	127.0	76.2
Effective length/mm			90.4	141.2	141.2	90.4
Aperture dia./mm			50.8	50.8	50.8	50.8
Skimmer dia./mm			50.8	50.8	50.8	50.8
Location s/mm			130.7	270.4	499.0	638.7

COSY HRS end-to-end

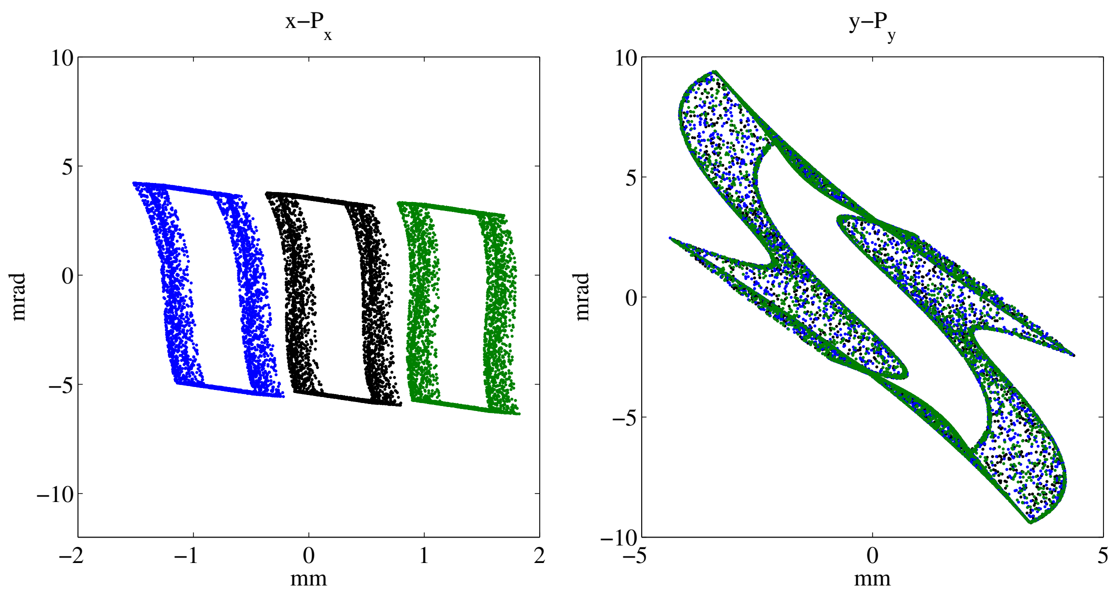
Taking tune #91 through the separator from magnified slit A to magnified slit B with $\epsilon = 3\ \mu$m emittance, calculated for masses differing by ± 1 part in 16667, results in following horizontal plot on the left:



but with the vertical emittance reduced to near zero, we get the plot at centre.

So clearly there is nonlinear coupling between the planes. This can be minimized by changing the tune to reduce the vertical beam size through the HRS. Tune 63 reduces this size from 7.4 mm to 4.3mm, as seen in the figure on the right.

The coupling is strongly reduced, but magnification is down to 9. Because of the reduced magnification of this tune, and some remaining nonlinear coupling, resolution is barely 15000, but can be increased to 20000 again by reducing slit A size from 1.33 mm to 0.66 mm, bringing the horizontal acceptance down to $1.5\ \mu$m. This is shown in figures below, which are for masses differing by ± 1 part in 20000.



Remember: by using slit B (scheme B) and the vertical slit at HRS symmetry point, to limit beam size, resolution of 20000 can still be achieved for the nominal $3\ \mu$m by $6\ \mu$m emittance.

TRANSOPTR data file

```
 0.060 0. 0. 27930.0 1. 0. ! mass not relevant
 1 3 5. 0.5E-5
 0 -0.
 0.1 4.2 0.3 8.3 1. 0.0000083 !transverse values not used because CIC cal
 1.  1.  1.  1.  1.  1. 0. 1. ! 1eV => dp/p=0.0000083
 0
 5
-0. -5.0        5.0            1
 0. -5.0        5.0            1
-2. -5.0        0.0            1
 7.  0.0        9.0            1
11. 0. 100. 0
 1.E-4  900
 1 1.   0.98  50
```

TRANSOPTR routine

```
      SUBROUTINE tSYSTEM
      COMMON/BLOC1/q1,q2,q3,q4,xmagn
      COMMON/PRINT/IPRINT,IQ(8)
      COMMON/SCPARM/QSC,ISC,cmps
      cmps=1.
      IQ(1)=5
      wab=1.
      betxstart=14.6873 ! cm
      betxend=betxstart/xmagn**2
      emitx=0.0003 ! units ar cm-rad.
      emity=0.0006
      xsz=sqrt(betxend*emitx)
      dx=0.279*2.54 !extra length at each end of quad is 0.279 inch
      tdx=2.*dx
         call fringeQ(0.123,-0.005,0.044,-0.276)
      call cic(0.,betxstart,emitx,-4.36478,115.945*2.54,emity)
c
```

```
      call DRIFT(-dx+9.2595,"    .")
      call EQUAD(   q1,2.5400,7.62+tdx,   wab," Q1 ")
      call DRIFT(-tdx+3.8100,"    .")
      call EQUAD(   q2,2.5400,12.70+tdx,   wab," Q2 ")
      call DRIFT(-tdx+10.1600,"    .")
      call EQUAD(   q3,2.5400,12.70+tdx,   wab," Q3 ")
      call DRIFT(-tdx+3.8100,"    .")
      call EQUAD(   q4,2.5400,7.62+tdx,   wab," Q4 ")
      call DRIFT(-dx+6.9941,"sl.B")
c
      call FIT( 2, 1, 2,  -0.0,  1.0, 1)
      call FIT(1,1,1,xsz,0.,1)
      call print_transfer_matrix
      call vective(1)
c
      call DRIFT(                      10.0," .  ")
      call EQUAD(  -0.0,   2.5,  15.0,   0.0100," Q5 ")
      call DRIFT(                      55.0," .  ")
      call Ea(26.5651,120.,90.,0.,0.2442,4.,7.,0.,1.e-9,0,0)
      call BEND(120.,90.,0.,"dip1")!wt=1.e-9 so aberrations listed but no
```

```
      call Ea(26.5651,120.,90.,0.,0.2442,4.,7.,0.,1.e-9,0,0)
      call DRIFT(                               65.0," .  ")
      call DRIFT(                               15.0,"   C")
      call FIT( 1, 3, 4,  -0.0,  4.0, 1)
c
      if(iprint.eq.0)return
      call DRIFT(                               15.0," .  ")
      call DRIFT(                               65.0," .  ")
      call Ea(26.5651,120.,90.,0.,0.2442,4.,7.,0.,1.e-9,0,0)
      call BEND(120.,90.,0.,"dip2")
      call Ea(26.5651,120.,90.,0.,0.2442,4.,7.,0.,1.e-9,0,0)
      call DRIFT(                               55.0," .  ")
      call EQUAD(  -0.0,   2.5,  15.0,   0.0100," Q5 ")
      call DRIFT(                               10.0,"slB'")
c
      call DRIFT(-dx+6.9941,"   .")
      call EQUAD(   q4,2.5400,7.62+tdx,   wab," Q4 ")
      call DRIFT(-tdx+3.8100,"   .")
      call EQUAD(   q3,2.5400,12.70+tdx,   wab," Q3 ")
      call DRIFT(-tdx+10.1600,"   .")
```

```
      call EQUAD(   q2,2.5400,12.70+tdx,    wab," Q2 ")
      call DRIFT(-tdx+3.8100,"    .")
      call EQUAD(   q1,2.5400,7.62+tdx,    wab," Q1 ")
      call DRIFT(-dx+9.2595,"slA'")
      write(6,10)q1,q2,q3,q4 ! for COSY
10    format('QA:=',f9.5,';QB:=',f9.5,';QC:=',f9.5,';QD:=',f9.5,';')
      RETURN
      END
```

COSY file

```
INCLUDE '/home/baartman/bin/COSY' ;
{This is now a case with quads having the extra
 length due to eff.len.-phys.len.}
procedure run ;
VARIABLE QA 1 ; VARIABLE QB 1; VARIABLE QC 1 ; VARIABLE QD 1;
VARIABLE EDGE 1;
procedure zoom a b c d e;
    dl    0.08551 ;
    eq    0.09037 A  0.02540 ;
    dl    0.02393 ;
    eq    0.14117 B  0.02540 ;
    dl    0.08743 ;
    eq    0.14117 C  0.02540 ;
    dl    0.02393 ;
    eq    0.09037 D  0.02540 ;
    dl    0.06285 ;
    dl    0.8 ;
```

```
 di     1.2000  90.    0.0350  E    0.4468  E    0.4468 ;
    dl     0.8 ;
    dl     0.8 ;
 di     1.2000  90.    0.0350  E    0.4468  E    0.4468 ;
    dl     0.8 ;
    dl     0.06285 ;
    eq     0.09037 D  0.02540 ;
    dl     0.02393 ;
    eq     0.14117 C  0.02540 ;
    dl     0.08743 ;
    eq     0.14117 B  0.02540 ;
    dl     0.02393 ;
    eq     0.09037 A  0.02540 ;
    dl     0.08551 ;
endprocedure;
ov 3 3 1 ;
RP     0.06  30*PARA(1)   1.0000;
sb  .000663792 .00451949 0 .00420357 .00639152 .974745 0 0 0 0 0 ;
   fc 2 1 2  0.0320    6.8911   -0.5288    2.6070       0         0 ;
   fc 2 2 2  0.0320    6.8911   -0.5288    2.6070       0         0 ;
```

```
   fr  3;
um;
{QA:= -1.54698;QB:=  2.25630;QC:= -2.87647;QD:=  7.27243;}
{QA:= -1.05251;QB:=  1.60970;QC:= -2.78248;QD:=  7.56505;}
{QA:=  1.17321;QB:= -0.50440;QC:= -2.06072;QD:=  7.52078;}
{QA:=  2.93126;QB:= -1.42482;QC:= -1.48704;QD:=  7.24042;}
{QA:= -0.00045;QB:=  0.45084;QC:= -2.47166;QD:=  7.66102;}
{QA:=  2.48310;QB:= -1.28794;QC:= -1.55428;QD:=  7.26526;}
{QA:= -0.57536;QB:=  1.04355;QC:= -2.65238;QD:=  7.66020;}
{QA:=  1.64421;QB:= -0.81226;QC:= -1.88516;QD:=  7.43818;}
{QA:=  2.36218;QB:= -1.22866;QC:= -1.59668;QD:=  7.26988;}
{QA:= -0.20091;QB:=  0.65361;QC:= -2.54244;QD:=  7.69261;}
{QA:= -1.00199;QB:=  1.55262;QC:= -2.77612;QD:=  7.61734;}
{QA:= -1.57135;QB:=  2.25483;QC:= -2.85299;QD:=  7.11370;}
QA:=  2.28308;QB:= -0.82367;QC:= -2.01323;QD:=  7.50580;
EDGE:=26.533;
zoom qa qb qc qd edge;
pm 61;
endprocedure ;
run ; end ;
```