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OLIS optics and how to fix

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Abstract: I explore the limits of performance of the current optics in terms of source emittance and the separator resolution. This is in light of recent redesign of the Supernanogan extraction optics. It is suggested that the deficiency of matching to the separator can be resolved by adding one quadrupole.

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1 Introduction

The ISAC low energy section has exclusively electrostatic optics; magnets are used only for separators. It was originally designed for an acceptance of $\sim 50\,\mu$m. The OLIS section was originally designed to match a cusp source to ISAC, with this acceptance and a resolution up to $\sim$ 150[1]. Its acceptance at that resolution is actually only $\sim 30\,\mu$m as we shall see, and that was sufficient for the original requirement, which was to simply provide stable beams to facilitate setting up the transport and accelerators to the experimenters. However, since originally built in 1997, far more demands have been placed on OLIS: 3 sources including an ECR to achieve high charge states, at much higher intensity than originally envisaged.

Originally, the Supernanogan installed had a 2 mm diameter extraction aperture and extracted beams had emittance of $\sim 8\,\mu$m[2][1], but recent new design[3] of the extraction system has a 4 mm dia. aperture and unsurprisingly a 4-times-larger emittance of 33 μm as simulated by `IGUN`.

2 OLIS Optics

2.1 Separator

The pure separator is very simple. a sector-shaped 60° dipole (normal entry and exit) with drifts symmetrically on either side. Focus to focus points (MCOL3A to MCOL3B, see Fig. 1) follow Barber's rule, namely, that these points and the bend centre lie on a straight line. The horizontal transfer matrix is thus a $-I$, and there is no vertical focusing. Matching therefore requires an horizontal waist at entry and exit but a converging beam in the vertical plane, to yield a waist at the bend symmetry point. This is illustrated in the well-matched envelopes case of Fig. 5.

`COSY` runs were made for the separator alone. Here are the three lines of code[2]:

```
dl   0.5196 ;
di 0.3 60. 0.019 0. 0. 0. 0. ;
dl   0.5196 ;
```

These were analyzed using [5]. From Fig. 2 we see that at 8 μm emittance, resolution of 260 is easily obtained. For twice larger beam at same tune (4 times larger emittance, red and orange figures in Fig. 2), resolution is halved. Tuning for tighter focus doubles divergence and this causes sextupole distortion so although the emittance figures are still separate, the horizontal profiles have overlap. A way to summarize

[1] All emittances are 4 times the rms emittance.

[2] Note that I have 19 mm for half gap. In reality it is 25.4 mm. I adjusted it to obtain same focusing as a dipole with $K_1 = 0.317$[4], without fiddling with all six Enge coefficients.

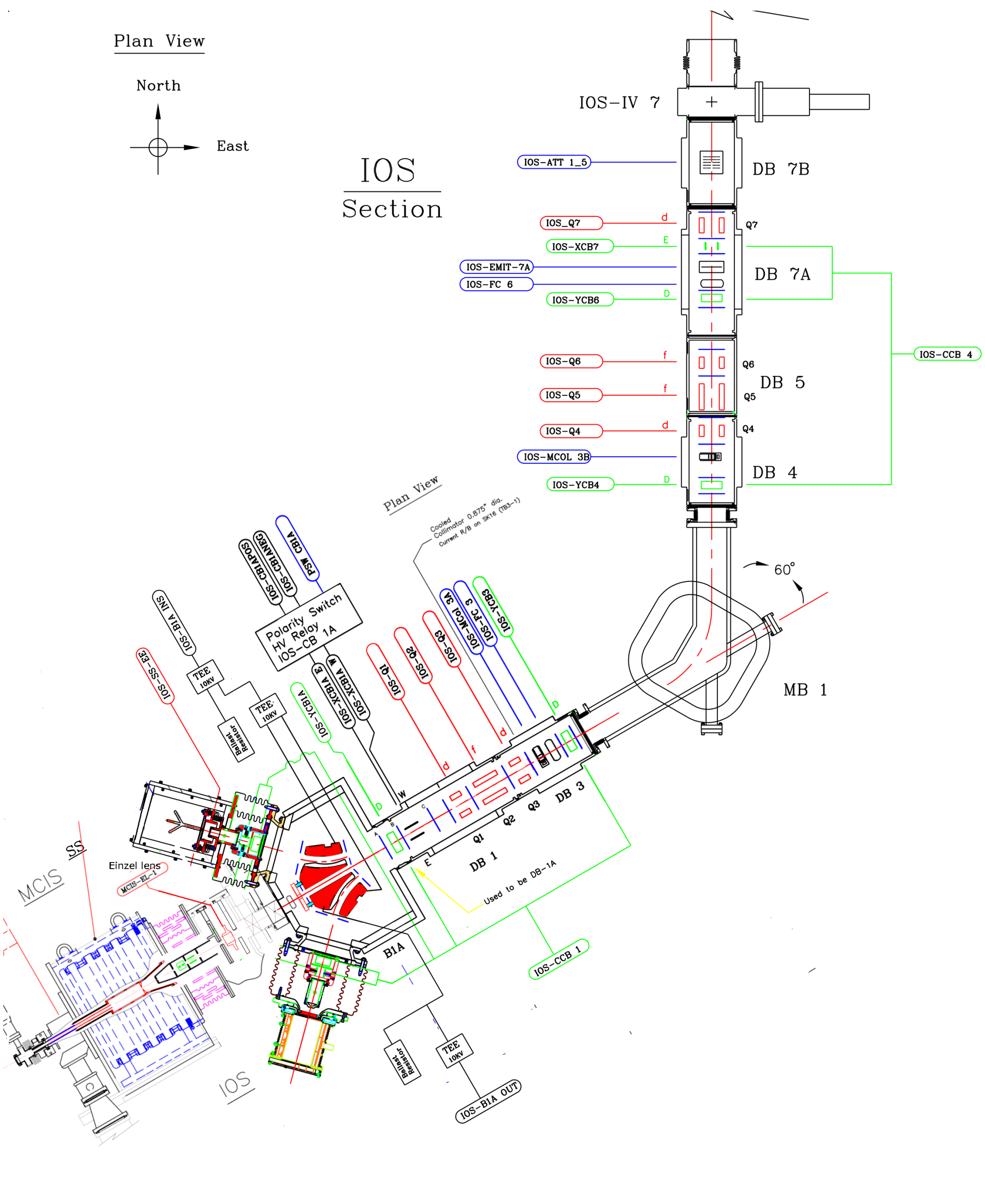

Figure 1: OLIS layout

the limitation is

$$\mathcal{R}^2\epsilon < 0.5\,\text{metre}, \tag{1}$$

where $\mathcal{R}$ is the resolution.

Note as a warning. These results are only for well-centred beam in a well-aligned system, and assumes no magnetic field errors. All tuning data so far suggest that there are significant misalignments.

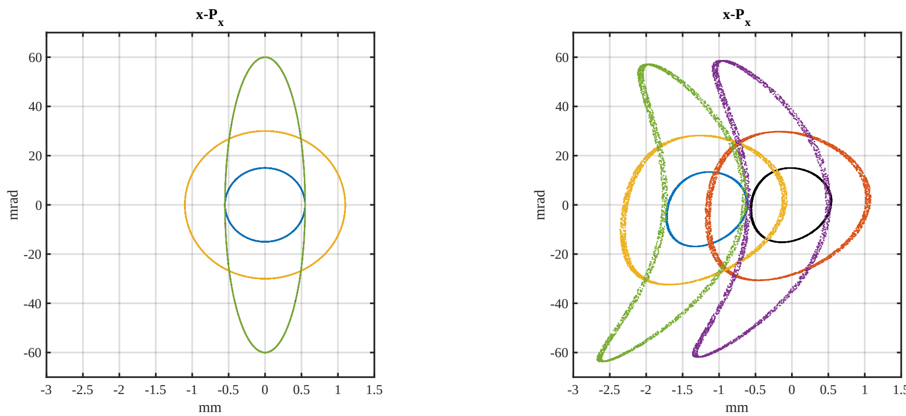

Figure 2: Outer contours of horizontal phase space emittance figures (right) at the mass slit MCOL3B. Black and blue are for $8\,\mu$m, red and orange for $33\,\mu$m, and purple and green are for $33\,\mu$m also, but with a twice tighter focus in x (but unchanged condition in y). Each pair is for masses separated by $\Delta m/m = 1/260$. Input beam MCOL3A is on the left.

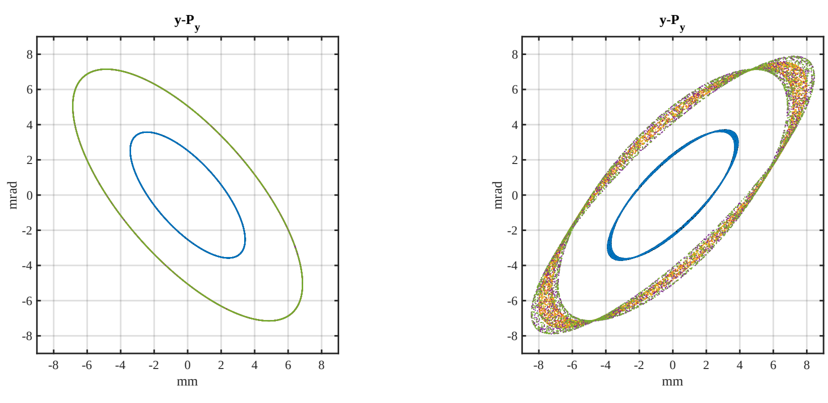

Figure 3: Same as Fig. 2, but for vertical plane. Smearing happens at large x divergence due to nonlinear coupling.

2.2 Matching

Quadrupole triplets match into and out of the separator. Originally only a single source was installed, and it was mounted at the current location of the 3-way bend. The bend itself is spherical and so is doubly focusing, but the Supernanogan MCIS source is on the straight path and so has no focusing element for a stretch of about 75 cm. Thus beam arrives at the triplet as largish, diverging and axially symmetric. The triplet cannot match this to the separator, where as stated above, a small horizontal focus and a vertically converging beam are needed. The optimum, which is shown in Fig. 4, has a vertically converging beam but it is too large. The slit MCOL3A has been sized in the `TRANSOPTR` model to force size to be less than 2cm tall.

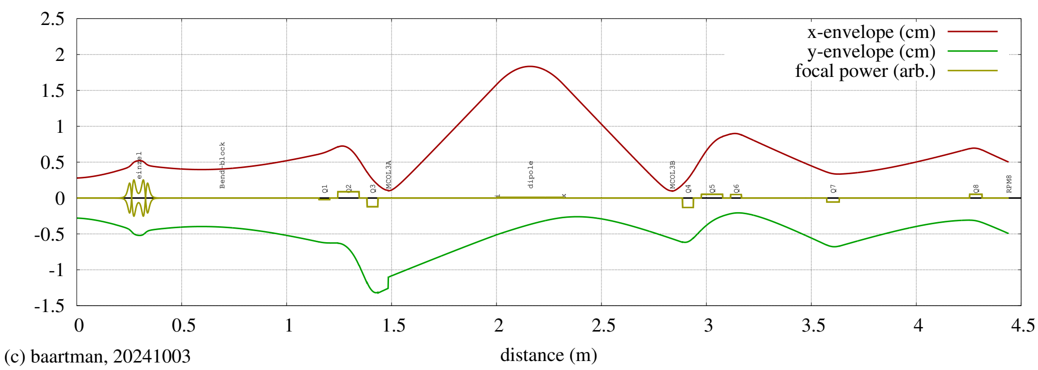

Figure 4: Envelopes for the optimized case for large (33 μm) emittance with existing optics.

Matching all 4 characteristics (Twiss α, β in both planes) requires 4 quadrupoles. There is little space, but a short one could be placed ahead of Q1. The result is shown in Fig. 5. Slits MCOL3A,3B can be sized at 2.2 mm by 14 mm tall for the 33 μm beam and half those sizes for the more typical 8 μm case.

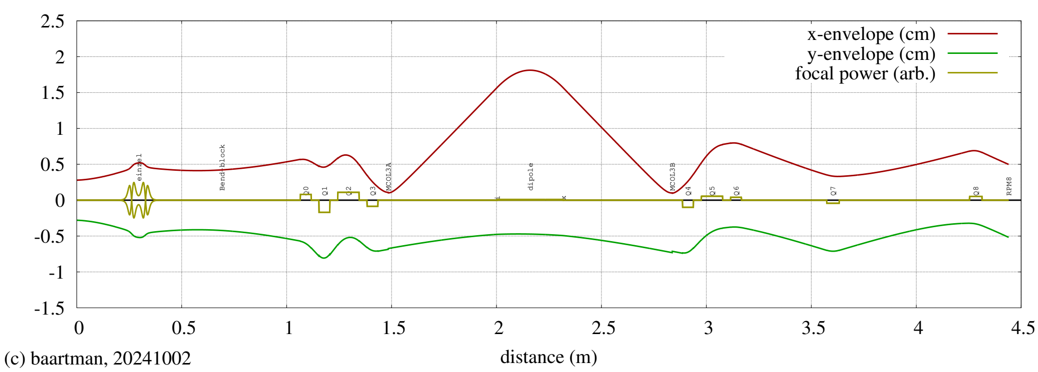

Figure 5: Envelopes for the optimized case for large (33 μm) emittance with the added quadrupole Q0.

Codes:

A TRANSOPTR

A.1 sy.f

```
      SUBROUTINE tSYSTEM
      dimension ecrmat(6,6)
      COMMON/MOM/P,BRHO,PMASS,ENERGK,GSQ,ENERGKI,CHARGE,CURRENT,ENERGKS
      COMMON /PRINT/IPRINT,iq(8)
      common /disptype/massdisp
      logical massdisp
      COMMON /BLOC1/Becr,
     $     evolt,q0,q1,q2,q3,q4,q5,q6,q7,q8,slitx,slity,wt
      data rho/30./,ak1/0.317/,ecrmat/36*0./
      COMMON/SCPARM/QSC,ISC,cmps
      cmps=0.1 ! this fineness needed for the Einzel
      iq(1)=4
      massdisp=.true.
      dsep=rho*sqrt(3.)
      fdr=29.464
      bdr=39.624
      do i=1,6
         ecrmat(i,i)=1.
      enddo
      ecrmat(2,3)=Becr/200./Brho
      ecrmat(4,1)=-ecrmat(2,3)
      call vective(10)
      call tmat(ecrmat,0,0)
      call vective(1)
c      write(6,*)ecrmat
c      return
      call DRIFT(                     -86.4997,".")
      call vective(10)
      egap=1.524
      eap=1.8 !cm seems small because of small entrance aperture
      elen=5.08+2.*egap+8.*eap  !inch
c If not in space charge mode, use a thin lens and einzel voltage
c     becomes focal length
      IF(ISC.NE.0)then
      call DR(fdr-elen/2.    ,0,0)
      call EINZELLENS(evolt,eap,elen,egap,-1,1.,'    einzel')
      call DRift(bdr-elen/2.    ,'  Bend-block')
      else
         call DR(fdr    ,0,0)
         call thineilens3(evolt*2.54,-eap,wt,0,0) !(flu,apu,wt,IVECT,IMAT)
      call DRift(bdr,'  Bend-block')
      endif
      call vective(1)
      call fringeQ(   0.1080,   0.0040,   0.0420,  -0.2340)
      call DRIFT(                      37.3812,".")
      call EQUAD(   Q0,   2.5400,   5.1816,wt,"     Q1 ")
      call DRIFT(                       3.7084,".")
      call EQUAD(  -Q1,   2.5400,   5.1816,wt,"     Q1 ")
      call DRIFT(                       3.7846,".")
```

```
      call EQUAD(   Q2,   2.5400,  10.1600,wt,"     Q2 ")
      call DRIFT(                        3.7846,".")
      call EQUAD(  -Q3,   2.5400,   5.1816,wt,"     Q3 ")
      call DRIFT(                        4.9022,".")
      call twissmatch( 1,   0.0000,   3.5000,   1.0000, 1)
      call SLIT(slitx,slity,1.,'  MCOL3A')
      call DRIFT(                       51.9614,".")
c The value for K1 is from Bob's note Oct. 10, 1996
c TRI-BN-96-03
      call edge(0.,30.,60.,0.,0.3170,2.,5.0800,0.,wt)
      call BEND(30.00,     60.00,      0.00,"          dipole")
      call edge(0.,30.,60.,0.,0.3170,2.,5.0800,0.,wt)
      call DRIFT(                       51.9614,".")
      call print_transfer_matrix
      call slit(slitx,slity,1.,'  MCOL3B')
c      call fit(1,1,1,0.,1.,1)
c      call resolution(1,200.,1.e-3,-1) !resolution does not work with slits in
      call DRIFT(                        4.9022,".")
      call EQUAD(  -Q4,   2.5400,   5.1816,wt,"     Q4 ")
      call DRIFT(                        3.7846,".")
      call EQUAD(   Q5,   2.5400,  10.1600,wt,"     Q5 ")
      call DRIFT(                        3.7846,".")
      call EQUAD(   Q6,   2.5400,   5.1816,wt,"     Q6 ")
      call DRIFT(                       27.9146,".")
      call fringeQ(   0.0870,   0.0050,   0.0330,  -0.2340)
      call DRIFT(                       12.7292,".")
      call EQUAD(  -Q7,   2.5400,   5.9385,wt,"     Q7 ")
      call DRIFT(                       62.1234,".")
      call EQUAD(   Q8,   2.5400,   5.9385,wt,"     Q8 ")
      call DRIFT(                       12.7292,"            RPM8")
      call twissmatch( 1,   2.2040,  84.8000,   1.0000, 1)
      call twissmatch( 3,  -2.2040,  84.8000,   1.0000, 1)
      call vective(10)
      call print_transfer_matrix
      RETURN
      END
```

A.2 data.dat

```
  0. 0.0 0.03512 78163. 17.0 0.0e-9
 3 4 1. 1.0E-3
 0 86.5
 1.09157 11.8976 1.09157 11.8976 10. 1.e-6
 1.  1000.  1.  1000.  1.  100. 1. 1
 4
 1 2  0.9671
 3 4  0.9671
 1 4  0.2489
 2 3 -0.2489
 14
 0.0 -10. 10. 0 !Becr (Tesla) 0.019054
5.714   -15.   15. 0 ! MCIS:EL1 DATA V
0.6286  -2. 2. 0 ! test extra quad
1.314 -2. 2. 0 ! IOS:Q1 DATA V
0.852 -2. 2. 0 ! IOS:Q2 DATA V
0.6633  -2. 2. 0 ! IOS:Q3 DATA V
0.7687  -2. 2. 0 ! IOS:Q4 DATA V
```

```
0.4317 -2. 2. 0 ! IOS:Q5 DATA V
0.3130 -2. 2. 0 ! IOS:Q6 DATA V
0.3320  0. 2. 0 ! IOS:Q7 DATA V
0.411  0. 2. 0 ! IOS:Q8 DATA V
.125 .001 1 0 !slitx
1.25 .001 10 0 !slity
.25 0. 10. 0 ! aberration weight
 1.E-3 2000
 1 1. 0.9 10

extra Quad
5.713   -15.   15. 0 ! MCIS:EL1 DATA V
0.6278  -2. 2. 0 ! test extra quad
1.314 -2. 2. 0 ! IOS:Q1 DATA V
0.852 -2. 2. 0 ! IOS:Q2 DATA V
0.6633  -2. 2. 0 ! IOS:Q3 DATA V
0.7687  -2. 2. 0 ! IOS:Q4 DATA V
0.4317 -2. 2. 0 ! IOS:Q5 DATA V
0.3130 -2. 2. 0 ! IOS:Q6 DATA V
0.3320  0. 2. 0 ! IOS:Q7 DATA V
0.411  0. 2. 0 ! IOS:Q8 DATA V

no extra Quad
5.713   -15.   15. 0 ! MCIS:EL1 DATA V
0. -2. 2. 0 ! IOS:Q0 DATA V
0.1672 -2. 2. 0 ! IOS:Q1 DATA V
0.6858 -2. 2. 0 ! IOS:Q2 DATA V
0.9373  -2. 2. 0 ! IOS:Q3 DATA V
1.022  -2. 2. 0 ! IOS:Q4 DATA V
0.4096 -2. 2. 0 ! IOS:Q5 DATA V
0.3795 -2. 2. 0 ! IOS:Q6 DATA V
0.4321   0. 2. 0 ! IOS:Q7 DATA V
0.411   0. 2. 0 ! IOS:Q8 DATA V
```

B COSY-∞ for extra quad case

B.1 fox file:

```
INCLUDE 'COSY' ;
{yes, works with version 10}
   PROCEDURE RUN ;
      OV 3 3 1 ;
   RPR    0.0351  83.9114*para(1)  17.0000;UM;
  fc 2 1 2   0.0269    6.9097   -0.4747    2.6449       0         0 ;{2"dia skimmer}
  fc 2 2 2   0.0269    6.9097   -0.4747    2.6449       0         0 ;
    dl   -0.86500 ;{back to source exit}
    dl    0.26924 ;
   dl     0.02540 ;
   cea    5.73050  0.01800  0.05080  0.01524 ;{einzel}
   dl     0.02540 ;
    dl    0.37084 ;
    dl    0.37381 ;
    eq    0.05182  0.62780  0.02540 ;{Q0}
    dl    0.03708 ;
    eq    0.05182 -1.31400  0.02540 ;{Q1}
```

```
    dl    0.03785 ;
    eq    0.10160  0.85200  0.02540 ;{Q2}
    dl    0.03785 ;
    eq    0.05182 -0.66330  0.02540 ;{Q3}
    dl    0.04902-0.008 ;{oddly, had to shift separator by 8mm}
  pm 160;
    dl    0.51961 ;
 di    0.3000  60.0000   0.019   0.0000   0.0000   0.0000   0.0000 ;
    dl    0.51961 ;
  pm 161;
    dl    0.04902+0.008 ;{8mm shift}
    eq    0.05182 -0.76870  0.02540 ;{Q4}
    dl    0.03785 ;
    eq    0.10160  0.43170  0.02540 ;{Q5}
    dl    0.03785 ;
    eq    0.05182  0.31300  0.02540 ;{Q6}
    dl    0.27915 ;
   fc 2 1 2 -0.1322    7.5951    3.6330   10.6639       0         0 ;{1" dia skimmer}
   fc 2 2 2 -0.1322    7.5951    3.6330   10.6639       0         0 ;
    dl    0.12729 ;
    eq    0.05939 -0.33200  0.02540 ;{Q7}
    dl    0.15316 ;
    dl    0.15745 ;
    dl    0.15745 ;
    dl    0.15316 ;
    eq    0.05939  0.41100  0.02540 ;{Q8}
    dl    0.12729 ;
  pm 166;
      ENDPROCEDURE ; RUN ; END ;
```

B.2 COSY-Matlab-tools script

This is at the mass slit MCOL3B, where `pm 161;` above printed output into fort.161. It outlines the two emittance figures separated in mass by 1 part in 140.

```
ellipses=[ 10.9157 11.8976 10.9157 11.8976 10. 1.e-8]/1000;
correlations=[0.9671 0.9671 0];distf=-1;
cosyMC(161,10000,distf,-1,ellipses,correlations,[0 0 0 0 0 0 0]);
cosyMC(161,10000,distf,1,ellipses,correlations,[0 0 0 0 0 0 1/140]);
```

References

[1] R. Laxdal, Beam Optics Design for the ISAC Off-Line Source (figures missing), Tech. Rep. TRI-BN-96-02, TRIUMF, http://lin12.triumf.ca/text/ISAC/ISAC-pre2004/laxdal/optics.pdf (1996).

[2] K. Jayamanna, G. Wight, D. Gallop, R. Dube, V. Jovicic, C. Laforge, M. Marchetto, M. Leross, D. Louie, R. Laplante, R. Laxdal, M. McDonald, G. J. Wiebe, V. Wang, F. Yan, A multicharge ion source (Supernanogan) for the OLIS facility at ISAC/TRIUMF, Review of Scientific Instruments 81 (2) (2010) 02A331. arXiv:https://pubs.aip.org/aip/rsi/article-pdf/doi/10.1063/1.3303819/13930496/02a331_1_online.pdf, doi:10.1063/1.

3303819.
URL https://doi.org/10.1063/1.3303819

[3] J. Adegun, O. Shelbaya, C. Charles, F. Ames, K. Jayamanna, O. Kester, R. Baartman, Design and Optimization of a New Extraction System for TRIUMF's Offline Supernanogan ECR Ion Source, submitted to Nuclear Physics B.

[4] R. Laxdal, Corrections and Additions to Optics Design for the ISAC Off-line Source (figures missing), Tech. Rep. TRI-BN-96-03, TRIUMF, http://lin12.triumf.ca/text/ISAC/ISAC-pre2004/laxdal/optic_corr.pdf (1996).

[5] R. Baartman, Matlab tools for COSY maps, Tech. Rep. TRI-BN-24-10, TRIUMF (2024).