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TITLE Improving the Understanding of CERN ISOLDE Optics			

Abstract

For some time, it has been difficult to reconcile ISOLDE operational tunes with `GIOS` calculations. The author visited CERN during October, 2001 to try to discover why and to hopefully resolve the situation. Experiments were performed to characterize the quadrupoles and the initial beam. The main result is that the measured effective length is (27.00 ± 0.15) cm: 10% less than the length used in calculations until now.

1 Differences from ISAC design

As with ISAC, the ISOLDE low energy optics is electrostatic, except for the magnetic dipoles needed for mass separation. There are two separators: GPS = general purpose separator, and HRS = high resolution separator. All quadrupoles are identical and very large compared with ISAC's: electrodes are 30 cm long, aperture diameter = 14 cm (cf. ISAC's 5 cm long by 5 cm dia.). Quad doublets are typically 3 to 5 m apart (cf. 2 m at ISAC). This implies the optics scale is roughly 4 times ISAC's, and beam sizes for a given emittance are roughly 2 times larger. In principle, one length scale works as well as any other, but the complication at ISOLDE is that the electrostatic bender apertures are much smaller than the quadrupoles' (3 cm aperture by 10 cm height; in ISAC, 3.8 cm by 15 cm height). Additionally, ground planes are inserted into the gap at the top and bottom. My guess is that the good field region is only about 3 cm vertically, but this should be verified. This design forces tight foci (H&V) and good beam alignment at each bender. In consequence, though the acceptance is still sufficient, tuning is dominated by the requirement of getting good transmission through the benders.

It is TRIUMF experience that roll angle errors in electrostatic benders are the major source of beam misalignment. (My guess at the reason is that though magnetic dipoles can be accurately aligned for roll by placing an accurate level on the pole, electrostatic dipoles, having curved surfaces, cannot.) In anticipation, non-bend-plane correctors were placed near all ISAC benders. ISOLDE may benefit from more such strategically-placed correctors as well.

2 Measurements

In a first series of measurements, the HRS frontend triplet was used to characterize the beam at the profile grid immediately downstream. 12 x and y profiles were taken for 60 keV beam energy, and 12×2 more for 30 keV. The profiles were used to calculate the 2σ beam sizes, and these were fitted by `TRANSOPTR` to find the source parameters (radius, divergence, waist location) plus the effective length of the quadrupole. Still, a fairly wide range of these 4 parameters gave acceptable fits, so a different series of measurements was undertaken.

In this second series, the first quadrupole of the triplet was used as a steerer while either the second or the third quadrupole was used to focus the beam from the steerer to the profile grid: such condition being detected by the fact that the steerer could no longer move the profile at the grid. The advantage of this technique is that it is only necessary to know the distances between steerer and quad and between quad and grid; the steerer effective length needs not be known, and the source parameters need not be known. The quadrupole voltages were corrected by measuring them directly with a DVM. The corrections were less than 1%. `TRANSOPTR` was used to fit the effective length of the quadrupole. The results are as follows. Using the third quad, we find $L_{\text{eff}} = 27.00 \pm 0.16$ cm, and using Q_2, $L_{\text{eff}} = 27.24 \pm 0.22$ cm. Since fits using series 1 measurements gave $L_{\text{eff}} = 25.5 \pm 2.0$ cm, the 3 results were combined to give the following value, which is used in all subsequent calculations:

$$L_{\text{eff}} = 27.0\,\text{cm}. \tag{1}$$

This is substantially different from the length 30.0 cm which has been used in calculations until now.

Series 1 data were re-analyzed. Best fits give the following parameters.

Large uncertainties in the waist size, and therefore also in emittance, are due to the fact that smallest beam sizes are too small compared with the wire spacing of 2.5 mm. Typical measured beam sizes were 5 mm, so the rms measurement errors indicate good fits. In order to use this technique to measure emittance accurately, it should be repeated with smallest beam sizes measured by sweeping the beam across the wires with the steerer, thus effectively creating a wire scanner with resolution equal to wire thickness instead of spacing.

At the present stage, it is uncertain whether the above results can be used in general, since the

Table 1: *Source parameters fitted from profile measurements. 'Location' is distance of waist from the edge of the first quadrupole. Emittance is product of 'Size' and 'Divergence'. 'RMS error' is rms of difference between measured and calculated profile sizes.*

Energy	Waist Size	Divergence	Location	RMS error	Emittance
60 keV	1 ± 1 mm	4.7 ± 0.2 mrad	47 ± 5 cm	0.6 mm	$5 \pm 4\,\pi\mu$m
30 keV	1.5 ± 0.8 mm	3.8 ± 0.4 mrad	55 ± 9 cm	0.4 mm	$6 \pm 3\,\pi\mu$m

location of the extractor with respect to the ion source is essentially a free parameter. One could think of first adjusting the extractor for maximum yield, then performing a standard experiment such as the above to determine the resulting source parameters, and using these in a transport code to fit optimum values for the quads in the frontend. Such a procedure could even be automated.

3 GPS Tunes

An example of a `GIOS` calculation using an operational tune in the GPS (see table 2 for values) and old effective lengths is shown in the figure 1. This is to be compared with the same calculation using the measured effective length of 27 cm, figure 2. The beam envelopes predicted by the calculation with the new effective length are clearly more realistic.

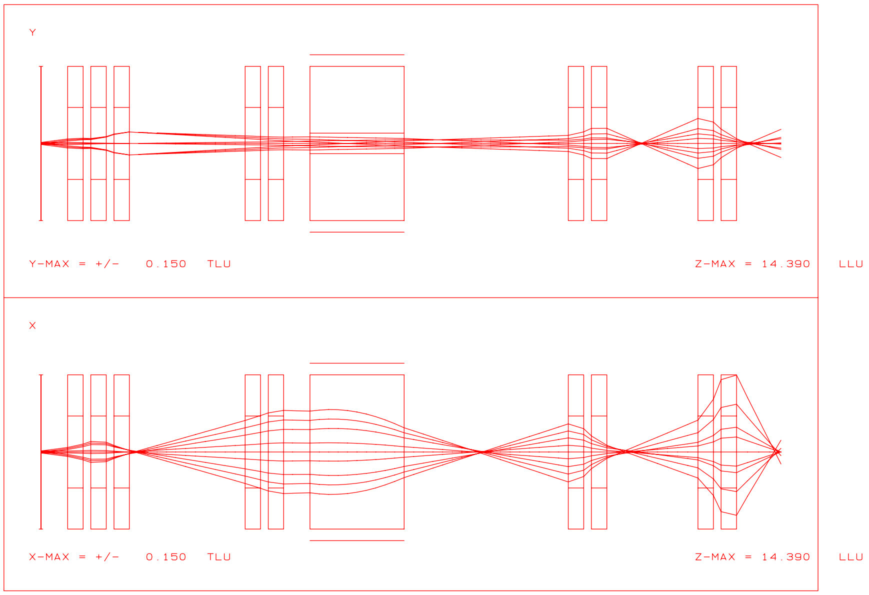

Figure 1: *Typical operational GPS tune, calculated with quadrupole effective length 30.0 cm, emittance = 26 $\pi\mu$m.*

One of the features of this tune is large horizontal beam size in quadrupoles GPS.QP170 and 180. This makes these quads extremely sensitive. A new tune with reduced beam sizes is shown in figure 3. This gives a lower resolution than the operational tune of 200 for an emittance of 20 $\pi\mu$m. If the emittance is closer to that found above, resolution is 400.

The new tune has two other features worthy of note. The operational tune appears to have an

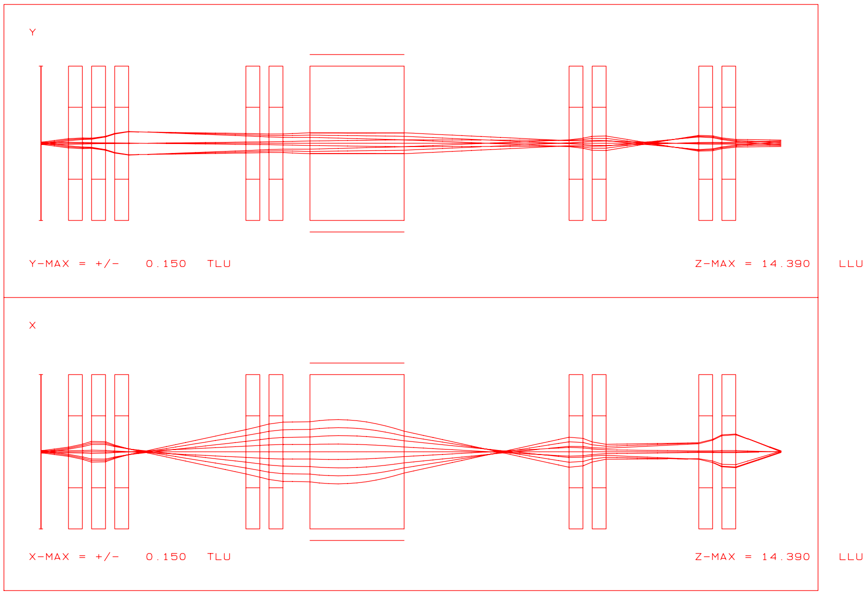

Figure 2: *Typical operational GPS tune, calculated with quadrupole effective length 27.0 cm, emittance = 26 $\pi\mu$m.*

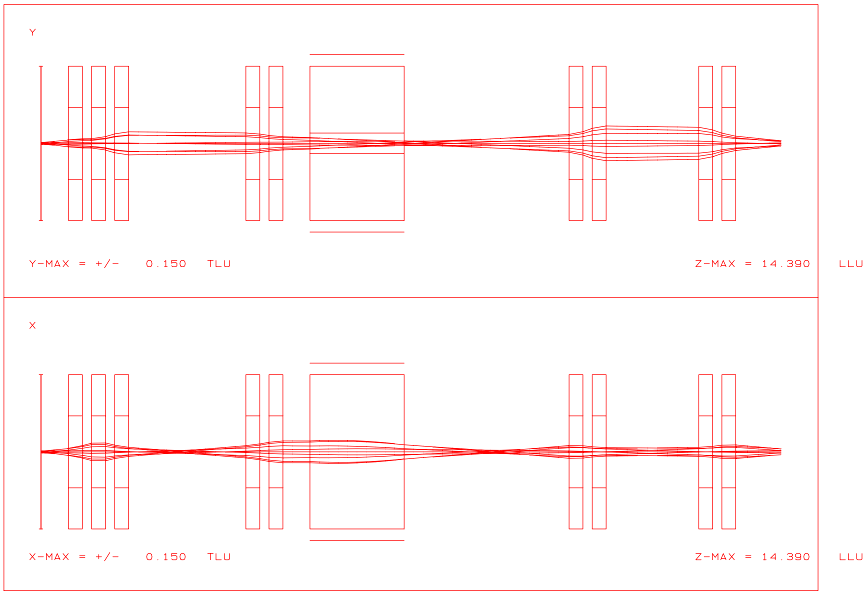

Figure 3: *Suggested GPS tune, with reduced horizontal beam size in doublet before dipole, emittance = 26 $\pi\mu$m. This is for comparison with the previous figures. Real emittances are probably much smaller.*

Table 2: *GPS tunes in volts.*

Quad	Op. tune	New tune
GPS.QS030	-1700	-1576
QP040	3370	2975
QP050	-1740	-1576
QP170	-93	-797
QP180	457	961
QP520	2271	1677
QP530	-2737	-1241
QP540	-2654	-1241
QS550	2660	1677

unnecessary crossover between QP530 and 540. The new tune gets rid of it and is thereby able to use much lower voltages for QP520 through 550.

The new tune sets QS030=QP050, QP520=QP550, QP530=QP540. This should be possible for any desired tune. One should evaluate whether at least 520&550 and 530&540 can simply be jumpered together. (30&50 is a more complicated case, since 30 is steerable, but there may be a way.) This would not only save power supplies, but more importantly would making tuning easier, reducing the number of 'knobs' in this section from 9 to 6.

4 HRS Tunes

Typical operational tune is shown in figure 4 with old effective length, and in figure 5 with newly measured effective length. Values used are shown in table 2. The calculation with the new effective length looks more realistic than that with the old, though the difference is not as dramatic as it is for the GPS. This can be thought of as due to the fact that the HRS optics is relatively more dependent on the (correctly-described) magnetic dipoles than the quadrupoles.

Table 3: *HRS tunes in volts. A and B are theoretical: for an emittance of 5 $\pi\mu$m, tune A has resolution 2500 and tune B 4500. Higher resolution is of course possible by closing down the object slit.*

Quad	Op.	A	B
HRS.QS030	-1554	-1506	-1393
QP040	2662	2691	2701
QP050	-1590	-1506	-1393
QP170	-1658	-1640	-1732
QP180	2382	2463	2671
QP330	-998	-1165	-1648
QP540	-0	-0	-0
QP550	20	0	0
QP640	-212	-198	-136
QP720	1905	1905	1905
QS730	-1725	-1725	-1725

Theoretical tunes are also shown in table 3. Tune A is simply the operational tune with QP550 set to zero. Tune B is a tune for roughly twice the resolution. Beam envelopes for this tune are shown in figure 6.

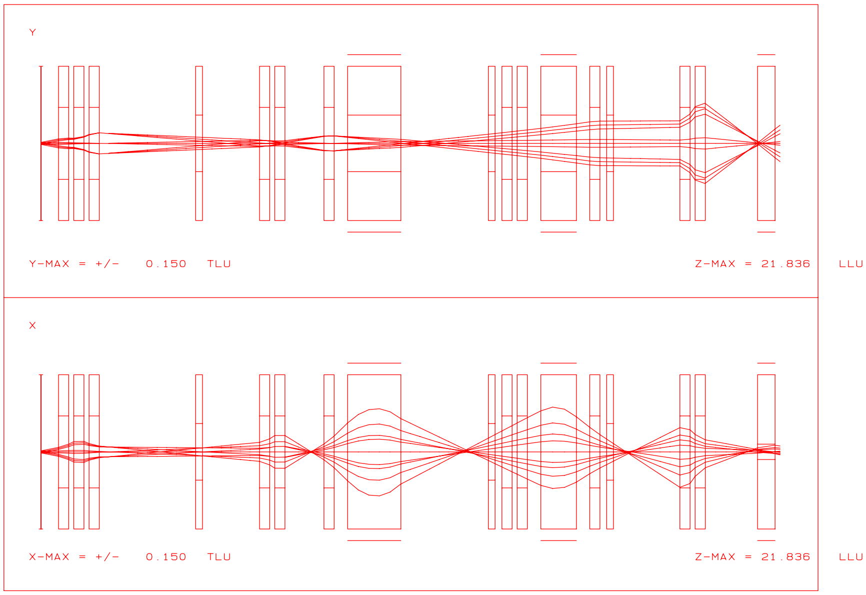

Figure 4: *Typical operational HRS tune, calculated with quadrupole effective length 30.0 cm, emittance = 26 $\pi\mu$m. Multipoles are off.*

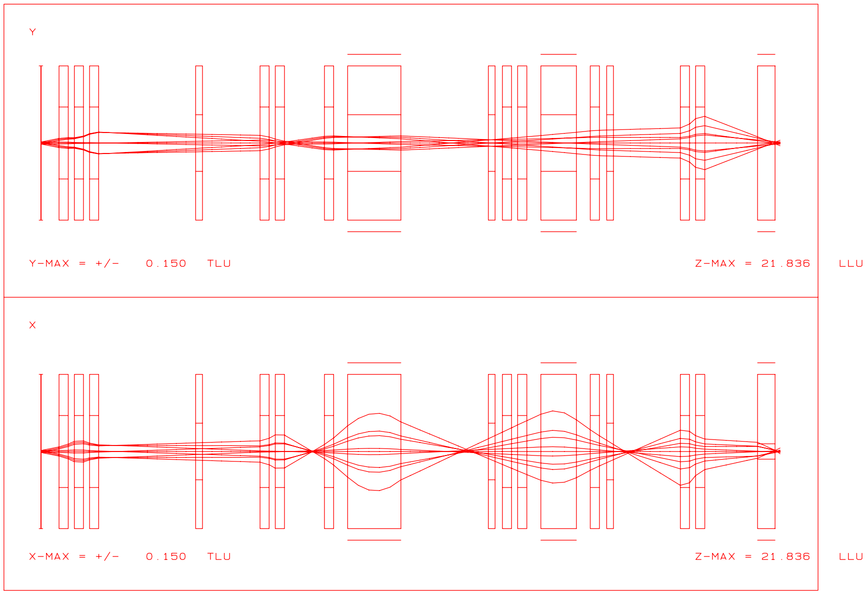

Figure 5: *Typical operational HRS tune, calculated with quadrupole effective length 27.0 cm, emittance = 26 $\pi\mu$m. Multipoles are off.*

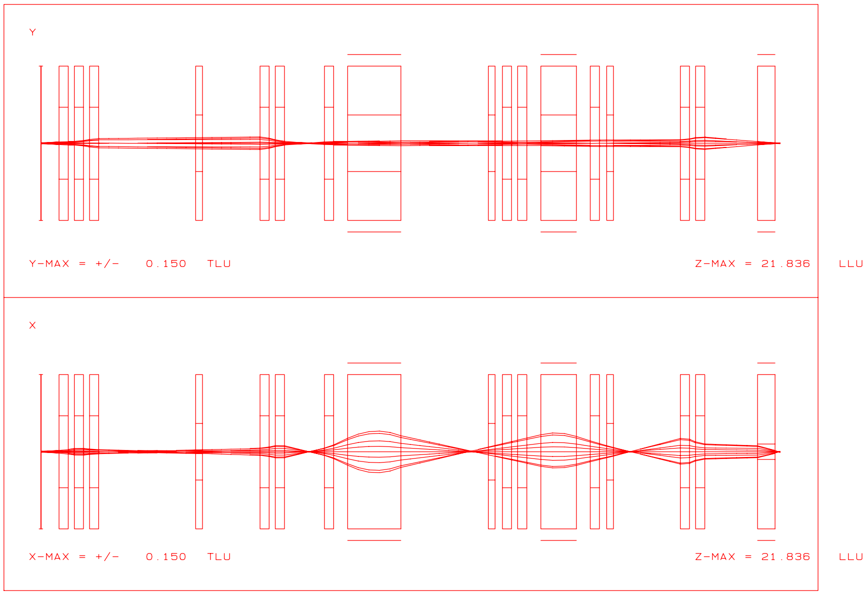

Figure 6: *HRS high resolution tune, emittance = 5 $\pi\mu$m. Multipole MP 650 is set to a sextupole component of -700 volts. Resolution with an emittance of 5 $\pi\mu$m is 4500. Higher resolution is of course possible by closing down the object slit.*

I've set up a `TRANSOPTR` file in such a way that one can specify desired resolution, and the 3 source parameters, and it will calculate quadrupole settings for a tune with the minimal amount of higher order effects. I've calculated tunes for many different conditions, and have not needed QP540 or QP550 for any. These two quads could in principle be shorted to ground. Additionally, QS030 and QP050 can in principal be wired together, as for the GPS.

The character of the beam at the mass slit (small size, large divergence) is ideally suited to the small (10cm by 10cm) emittance scanner we use at TRIUMF. Using such a scanner is by far the easiest way to tune higher order optics.

5 For Further Work

`GIOS` input files which generated the plots shown in this note are given below. One notices from these that quadrupole fringe fields are specified as 'F F 0 0. 0. 0. 0.'. This effectively sets fringe fields to the hard-edge limit, without actually shutting them off. Such an approximation is good enough and avoids worries about whether fringe field integrals have been specified to sufficient accuracy. The same is not true of benders, electrostatic or magnetic, because it would neglect a significant correction to the linear focusing. (See `TRANSPORT` manual under codes 2. and 16.)

All `TRANSOPTR` work was performed in the directory *http://lin12.triumf.ca/ISOLDE/*. This also contains Linux executables both for finding new tunes and for fitting profile data, and the profile datasets. The current report, in both PS and HTML formats is in the *report/* subdirectory.

6 Conclusion

The measured quadrupole effective length of 27.0 cm is 10% less than the length used in calculations until now. This may be the main reason for the difficulty in reconciling theoretical tunes with operational ones.

7 Acknowledgment

The present study was undertaken under the ISAC-ISOLDE agreement. I would like to thank Mats Lindroos and Uwe Georg for facilitating my visit and Uwe also for helping with beam setup and data-taking.

8 Appendix 1: `TRANSOPTR` files

8.1 GPS

8.1.1 System subroutine

```
      subroutine tsystem
      common /BLOC1/q1,q2,q3,q4,q5,q6,q7,q8,q9,q10,q11,
     $     dx,dl2,ak1m,ak1e,wq
      d2x=dx/2.
      if(q3.eq.0.)then
         q3s=q1
         else
            q3s=q3
            endif
c GPS front end to LA1 U.G. Feb. 2001
! GPS.QP030 / Q1
      call dr( 52.-d2x+dl2, 0,0)
      call eq( q1     , 7., 30.+dx, wq,0,0)
! GPS.QP040 / Q2
      call dr( 15.-dx, 0,0)
      call eq( q2     , 7., 30.+dx, wq,0,0)
! GPS.QP050 / Q3
      call dr( 15.-dx, 0,0)
      call eq( q3s     , 7., 30.+dx, wq,0,0)
      call dr( 90.-d2x, 0,0)
c$$$      call fit(1,1,1,0.,10.,1)
c$$$      call fit(1,1,2,0.,10.,1)
c$$$      call fit(1,3,3,0.,1.,1)
! GPS.QP170 / Q4
      call dr( 135.-d2x, 0,0)
      call eq( q4     , 7., 30.+dx, wq,0,0)
!
! GPS.QP180 / Q5
      call dr( 15.-dx, 0,0)
      call eq( q5     , 7., 30.+dx, wq,0,0)
!
      call dr( 50.-d2x, 0,0)
! ** Separator Magnet GPS.MAG70 **
      call ea(18.61,150. ,70.,0.0,ak1m,0.0,4.,0.0,wq,0,0)
      call be( 150., 70., 0.0, 0,0)
      call ea(19.88,150. ,70.,0.0,ak1m,0.0,4.,0.0,wq,0,0)
      call dr( 168.4, 1,1)
c$$$      call fit(1,1,1,0.,10.,1)
c$$$      call fit(1,1,2,0.,10.,1)
c$$$      call fit(1,3,3,0.,1.,1)
!
! FIT (X,A) 0 99999                          ! Point-to-point focusing!
! FIT (Y,B) 0                           ! Point-to-point focusing!
!
!
!****************************Central Mass Beamline***************************************
!
! GPS.QP520 / Q6
      call dr( 150.8-d2x, 0,0)
```

```
      call eq(  q6    , 7., 30.+dx, wq,0,0)
!
!
! GPS.QP530 / Q7
      call dr( 15.-dx, 0,0)
      call eq(  q7    , 7., 30.+dx, wq,0,0)
!
      call dr(90.-dx,0,0)
!
! GPS.QP540 / Q8
      call dr( 87.14-dx, 0,0)
      call eq(  q7    , 7., 30.+dx, wq,0,0)
!
!
! GPS.QP550 / Q9
      call dr( 15.-dx, 0,0)
      call eq(  q6    , 7., 30.+dx, wq,0,0)
!
!
      call dr( 123.548-d2x, 0,0)
!
!
!****************************Merging Switchyard***************************************
!
! GPS.BE560
      call rt(180. ,0,0)
      call EE( 60.,12.582, 0.0,ak1e,3.,wq,0,0)
      call ebe( 60., 6.291, 0.0, 0,0)
      call ebe( 60., 6.291, 0.0, 0,0)
      call EE( 60.,12.582, 0.0,ak1e,3.,wq,0,0)
!
      call dr( 16., 0,0)
c      call fit(1,1,1,0.,1.,1)
      call fit(2,1,2,0.,1.,1)
c      call fit(1,3,3,0.,1.,1)
      call fit(2,3,4,0.,1.,1)
      call dr( 16.759, 0,0)
!
! CA0.KI10
      call EE( 84.2743, 7.5,0.0,ak1e,4.,wq,0,0)
      call ebe( 84.2743, 7.5, 0.0, 0,0)
      call EE( 84.2743, 7.5,0.0,ak1e,4.,wq,0,0)
!
!****************************CA0 Section***************************************
!
!
      call dr( 8.79, 0,0)
!
!
      call dr( 40.0257-d2x, 0,0)
!
! ** Doublet **
! CA0.QS40
      call eq(  q11   , 7., 30.+dx, wq,0,0)
!
! CA0.QP50
      call dr( 15.-dx, 0,0)
      call eq(  q10   , 7., 30.+dx, wq,0,0)
!
      call dr( 91.2-d2x, 0,0)
!  DRIFT LENGTH 0.912 commented out? That’s an error.
!
! CA0.KI70
!  DRIFT LENGTH 0.188   ! If kicker is OFF commented out???
      call EE( 84.2743, 7.5,0.0,ak1e,4.,wq,0,0)
      call ebe( 84.2743, 7.5, 0.0, 0,0)
      call EE( 84.2743, 7.5,0.0,ak1e,4.,wq,0,0)
!
      call dr( 29.3575, 0,0)
!
c      call fit(1,1,1,0.,1.,1)
c      call fit(2,1,2,0.,1.,1)
c      call fit(1,3,3,0.,1.,1)
c      call fit(2,3,4,0.,1.,1)
!
!*********************** LA0 Section ****************************************
```

```
!
! LA0.BE10
      call EE( 60., 27.5,0.0,ak1e,4.,wq,0,0)
      call ebe( 60., 27.5, 0.0, 0,0)
      call EE( 60., 27.5,0.0,ak1e,4.,wq,0,0)
!
      call dr( 70.-d2x, 0,0)
!
! LA0.QP20 / Q7
      call eq( -2.000 , 7., 30.+dx, wq,0,0)
!
!
! LA0.QP30 / Q8
      call dr( 15.-dx, 0,0)
      call eq(  1.600 , 7., 30.+dx, wq,0,0)
!
!
! LA0.QS40 / Q9
      call dr( 15.-dx, 0,0)
      call eq(  0.600 , 7., 30.+dx, wq,0,0)
!
!
      call dr( 70.-d2x, 0,0)
!
! LA0.KI70
!  DRIFT LENGTH 0.188   ! If kicker is OFF
      call EE(  63.2057, 10.,0.0,ak1e,4.,wq,0,0)
      call ebe( 63.2057, 10., 0.0, 0,0)
      call EE(  63.2057, 10.,0.0,ak1e,4.,wq,0,0)
!
      call dr( 38.875, 0,0)
!
!  FIT (X,A) 0 999                          ! Point-to-point focusing!
!  FIT (Y,B) 0                           ! Point-to-point focusing!
!
!*********************** LA1 Section ****************************************
!
! LA1.BE10
      call EE( 60., 50.,0.0,ak1e,4.,wq,0,0)
      call ebe( 60., 50., 0.0, 0,0)
      call EE( 60., 50.,0.0,ak1e,4.,wq,0,0)
!
      call dr( 106.5-d2x, 0,0)
!
! LA1.QP20 / Q7
      call eq( -0.9605, 7., 30.+dx, wq,0,0)
!
!
! LA1.QP30 / Q8
      call dr( 15.-dx, 0,0)
      call eq(  1.140 , 7., 30.+dx, wq,0,0)
!
!
      call dr( 201.-dx, 0,0)
!
! LA1.QP40 / Q9
      call eq( -1.000 , 7., 30.+dx, wq,0,0)
!
! LA1.QP50 / Q7
      call dr( 15.-dx, 0,0)
      call eq( -0.430 , 7., 30.+dx, wq,0,0)
!
!
! LA1.QS60 / Q8
      call dr( 15.-dx, 0,0)
      call eq(  1.700 , 7., 30.+dx, wq,0,0)
!
!
      call dr( 90.-d2x, 0,0)
!
c FIT:   FIT (X,A) 0 999                          ! Point-to-point focusing!
c FIT:   FIT (Y,B) 0 999                          ! Point-to-point focusing!
!
!
!**************************************************************************************
!                                END OF BEAM
```

```
!**************************************************************************************
      RETURN
      END
```

8.1.2 Data file

```
 0.06 0 0 93100. 1 3.e-09
 1 3 1. 0.5e-5
 0 -0.
  .2 .013 .2 .013 0. 0.
 1. 1. 1. 1. 1. 1. 0. 1.
 0
 16
 -1.576  -5. 0. 0
  2.975   0. 5. 0
 -0.000  -5. 0. 0
 -0.797  -5. 0. 0
  0.961   0. 5. 0
  2.2405  0. 5. 1
 -2.     -2. 0. 1
 -0.000  -5. 0. 0
  0.000   0. 5. 0
 -2.450  -5. 0. 0
  3.300   0. 5. 0
 -3. -10. 10. 0
   0. -20. 20. 0
 0.26 0.0 0.5 0
 0.26 0.0 0.5 0
 0.001 .0 10. 0
 1.e-8 200
 01 .0 0.95 20
```

8.2 HRS

8.2.1 System subroutine

```
      subroutine tsystem
      COMMON/PRINT/IPRINT
      common /BLOC1/wq,dx,dl,ak1m,ak1e,res,
     $     q1,q2,q3,q4,q5,q6,q7,q8,q9,q10,q11,q12,q13
      tdx=2.*dx
      wb=wq/10.
      wmp=(res/30000.)**2
c bend aberrations don't matter as much since will be controlled by multipoles
comment:  HRS high res optics Feb 2001    !
comment:                                  ! Pre MAG90 focus
comment:                                  !
      call dr(62.+dl-dx,0,0)
      call eq( q1    , 7.0,30.+tdx,wq,0,0)
      call dr( 15.-tdx, 0,0)
      call eq( q2    , 7.0,30.+tdx,wq,0,0)
      call dr( 15.-tdx, 0,0)
      call eq( q1    , 7.0,30.+tdx,wq,0,0)
      call fit(1,3,3,0.,.05,2) !seems like design small y here
      call dr( 284.6-dx, 0,0)
      call fit(1,1,1,0.,wmp,1) !multipole is for y
      call dr(20.,0,0)          ! ] MP 140
      call dr( 88.4-dx, 0,0)
      call dr( 80., 0,0)
      call fit(1,3,3,0.,.05,2) !seems like design small y here
      call eq( q4    , 7.0,30.+tdx,wq,0,0)
      call dr( 15.-tdx, 0,0)
      call eq( q5    , 7.0,30.+tdx,wq,0,0)
c      call fit(1,3,3,0.,.03,1) !seems like design small y here
      call dr(40.-dx, 0,0)
      call dr(40., 0,1)
      call fit(1,1,2,0.,.1,1)
      call fit(1,1,1,0.,.3,1)  ! #######-------Focus #1
      call rt(180. ,0,0)
      call dr(35.-dx, 0,0)
      call eq( q6    , 7.0,30.+tdx,wq,0,0)
      call dr(40.-dx, 0,0)
      call ea( 0.,100. ,90.,0.0,ak1m,0.0,11.,0.0,wb,0,0)
```

```
      call be( 100., 30., 0.0, 0,0)
      call be( 100., 30., 0.0, 0,0)
      call be( 100., 30., 0.0, 0,0)
      call ea(20.,100. ,90.,0.0,ak1m,0.0,11.,0.0,wb,0,0)
      call dr( 150.00, 0,0)
      call dr(  40.00, 0,0)
      call dr(   8.63, 0,1)
      call fit(1,1,2,0.,.1,1)
      call fit(1,1,1,0.,.3,1)  ! #######-------Focus #2
      call rt(180. ,0,0)
      call dr(30., 0,0)
      call dr(30., 0,0)
      call fit(1,3,3,0.,wmp,1) !multipole is for x
      call dr(20.,0,0)                   ! ] MP 510
      call dr(20.-dx, 0,0)
      call eq( q7    , 7.0,30.+tdx,wq,0,0) ! ] QP 540
      call dr( 15.-tdx, 0,0)
      call eq( q8    , 7.0,30.+tdx,wq,0,0) ! ] QP 550
      call dr(40.-dx, 0,0)
      call ea( 0.,100. ,60.,0.0,ak1m,0.0,11.,0.0,wb,0,0)
      call be( 100., 20., 0.0, 0,0)
      call be( 100., 20., 0.0, 0,0)
      call be( 100., 20., 0.0, 0,0)
      call ea( 0.,100. ,60.,0.0,ak1m,0.0,11.,0.0,wb,0,0)
      call dr(40.-dx, 0,0)
      call eq( q9    , 7.0,30.+tdx,wq,0,0)
      call dr(20.-dx, 0,0)
      call fit(1,3,3,0.,wmp,1) !multipole is for x
      call dr(20.,0,0)                   ! ] MP 650
      call dr(25., 0,0)
      call dr(25., 1,1)
comment:                                  !
      call fit(1,1,1,0.,.3,1)
      call fit(1,3,3,0.6,.1,0)
      call fit(1,1,2,0.,.1,1)
      call fit(1,3,4,0.,.1,1)
      call resolution(1,res,10.,-1)
      call find(2,1,6,disp)
      call find(1,1,1,siz)
      call find(1,3,3,sizy)
      if(iprint.eq.1)then
         rewind 7
         write(7,30)dl
         write(7,20)disp/siz/4. !mass dispersion
         write(7,10)q1,q2,q3,q4,q5,q6,q7,q8,q9
         write(7,40)10.*siz,10.*sizy
         endif
comment:                                  ! #######-------Focus #3
comment:                                  ! #######-------Merging Switchyard
comment:                                  !
      call dr( 145.88-dx, 0,0)
      call eq( q10   , 7.0,30.+tdx,wq,0,0) !] QP 720
      call dr( 15.-tdx, 0,0)
      call eq( q11   , 7.0,30.+tdx,wq,0,0) !] QS 730
      call dr( 154.11-dx, 0,0)
      call EE( 60.,49.5, 0.0,ak1e,3.,wq,0,0)
      call ebe( 60., 49.5, 0.0, 0,0)
      call EE( 60.,49.5, 0.0,ak1e,3.,wq,0,0)
      call dr(16.38, 0,0)
c$$$      call dr(16.38, 0,0)
c$$$      call EE( 84.3,7.5, 0.0,ak1e,4.,wq,0,0)
c$$$      call ebe(84.3, 7.5, 0.0, 0,0)
c$$$      call EE( 84.3,7.5, 0.0,ak1e,4.,wq,0,0)
c$$$      call dr(48.82-dx, 0,0)
c$$$      call eq( q12   , 7.0,30.+tdx,wq,0,0) !] QS 40
c$$$      call dr( 15.-tdx, 0,0)
c$$$      call eq( q13   , 7.0,30.+tdx,wq,0,0) !] QP 50
c$$$      call dr(40.00-dx, 0,0)
 10   format(9(f9.3,’ &’,/))
 20   format(f9.0,’ &’)
 30   format(f9.2,’ &’)
 40   format(f4.2,’,’,f4.2,’ &’)
      RETURN
      END
```

8.2.2 Data file

```
 0.060 0 0 93100. 1 3.e-09
 1 3 1. 0.5e-5
 0 -0.
  .1 .005 .1 .005 0. 0.00
 1. 1. 1. 1. 1. 1. 0. 1.
 0
  19
 1.1 0. 10. 0 !aberration weight
 -1.5 -5. 5. 0   !1/2 eff. length addition
  -10. -50. 50. 0   ! length
 0.26 0. 1. 0 !K1 magnetic
 0.26 0. 1. 0 !K1 electric
 10000. 100. 100000. 0 !resolution
    -1.849 -3. 0. 1
     2.819  0. 3. 1
    -0.000 -3. 0. 0
    -1.198 -3. 0. 1
     2.464  0. 3. 1
    -1.648 -3. 0. 0
     0.000 -3. 0. 0
     0.000  0. 3. 0
    -0.136 -3. 0. 0
 +1.905  0. 5. 0
 -1.725 -5. 0. 0
 +2.890  0. 5. 0
 -2.734 -5. 0. 0
 1.e-6 400
 01  1. 0.95 200
```

9 Appendix 2: `GIOS` input files

The following are the theoretical tune for the GPS and the resolution 2500 tune for the HRS. The typical tunes are identical, but with quadrupole values as appropriate from the tables 2 and 3.

9.1 GPS

```
A theoretical low res. tune for GPS
;
;*** particle and beam definitions ***
;
  REFERENCE PARTICLE 0.06 100 1         ; K =60keV, M =100 daltons, Q =1
  REFERENCE LENGTH 1.0 1.0              ; LLU=1.0 meter, TLU=1.0 meter
;
  PHASE_SPACE X_DIRECTION .002 .013     ; X =2mm,   A =13mrad -> 104mm mrad
  PHASE_SPACE Y_DIRECTION .002 .013     ; Y =2mm,   B =13mrad
;
  D P 0.005 0.0 ;
;
  C O 3 3                               ; Calculation Order 3 in x 3 in y
;
; *** GPS Section ***
;
; ** TRIPLET **
; GPS.QP030 / Q1
  DRIFT LENGTH .52                      ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                     ;
  ELECTRO QUADR .27 -1.576 0.07          ; 30cm long, apert. radius 7cm
  F F 0 .0 .0 .0 .0                     ;
  DRIFT LENGTH .015 ;
;
; GPS.QP040 / Q2
  DRIFT LENGTH .15                      ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                     ;
  ELECTRO QUADR .27 2.975 .07            ;
  F F 0 .0 .0 .0 .0                     ;
  DRIFT LENGTH .015 ;
;
```

```
; GPS.QP050 / Q3
  DRIFT LENGTH .15                      ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                     ;
  ELECTRO QUADR .27 -1.576 .07           ;
  F F 0 .0 .0 .0 .0                     ;
  DRIFT LENGTH .015 ;
;
  DRIFT LENGTH .9                       ;
;
; Fitting for SLIT position at Wire-grid
; FIT (X,A) .02 99                         ; Point-to-point focusing;
; FIT ENVELOPE Y .02                    ;
; FIT (X,X) -1 9999                     ; Magnification of -1 in x
;
 PLOT QUALITY .1 .3 .5 .7 .9            ;
 PLOT PHASE_S (X,Y) 1000 .04 .04 1      ;
;
;   C R .03 100 1                         ; Change Refpart
;
; PLOT M                                ; Plot Matrix
  PLOT ENVELOPE                         ; Plot Envelope
;
; ** Doublet **
; GPS.QP170 / Q4
  DRIFT LENGTH 1.35                      ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                      ;
  ELECTRO QUADR .27 -.797 .07            ;
  F F 0 .0 .0 .0 .0                      ;
  DRIFT LENGTH .015 ;
;
; GPS.QP180 / Q5
  DRIFT LENGTH .15                       ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                      ;
  ELECTRO QUADR .27 .961 .07              ;
  F F 0 .0 .0 .0 .0                      ;
  DRIFT LENGTH .015 ;
;
  DRIFT LENGTH .17                        ;
;
 PLOT QUALITY .1 .3 .5 .7 .9            ;
 PLOT PHASE_S (X,Y) 1000 .04 .04 1      ;
;
  DRIFT LENGTH .34                        ;
;
;
; Fitting for a parallel beam in X AND Y with defined envelopes
; H = ABS((Y,Y)*Y)+ABS((Y,B)*B)         ; Envelope Y
; FIT (A,A) 0 999                       ; Point-to-parallel focusing in x
; FIT ALGEBRAIC H .02                   ; Make y-Envelope attain value .02
; FIT ENVELOPE X .4                     ; Make x-Envelope attain value .02
; FIT (B,B) 0 999                       ; Point-to-parallel focusing in y
;
;
 PLOT ENVELOPE                          ; Plot Envelope
;
; ** Separator Magnet GPS.MAG70 **
  FRINGING FIELD 1 18.61     ; FF,table 1, entrance angle 18.61deg
  MAGNETIC SECTOR 1.5 70 .02            ; 1.5m radius, angle 70deg, 2cm HALF-air gap
  FRINGING FIELD 1 19.88     ; FF,table 1, entrance angle 19.88deg
  DRIFT LENGTH 1.684                    ;
;
; FIT (X,A) 0                           ; Point-to-point focusing;
; FIT (Y,B) 0                           ; Point-to-point focusing;
;
;
 PLOT BEAM P 40 .15 .15 2.5 2 .5 3 3 1 1 3 3  ; show beam envelopes
;
;
; PLOT QUALITY .1 .3 .5 .7 .9            ;
; PLOT PHASE_S (X,A) 1000 .02 .05 1      ;
;
; PLOT QUALITY .1 .3 .5 .7 .9            ;
; PLOT PHASE_S (Y,B) 1000 .02 .05 1      ;
```

```
;
 PLOT QUALITY .1 .3 .5 .7 .9             ;
 PLOT PHASE_S (X,A) E 10000 .01 .02 3    ;
;
;
;  C R .03 100 1                         ; Change Refpart
;
; GPS.QP520 / Q6
  DRIFT LENGTH 1.508                     ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                      ;
  ELECTRO QUADR .27 1.6775 .07              ;
  F F 0 .0 .0 .0 .0                      ;
  DRIFT LENGTH .015 ;
;
;
; GPS.QP530 / Q7
  DRIFT LENGTH .15                       ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                      ;
  ELECTRO QUADR .27 -1.2405 .07              ;
  F F 0 .0 .0 .0 .0                      ;
  DRIFT LENGTH .015 ;
;
;
; GPS.QP540 / Q8
  DRIFT LENGTH 1.7714                      ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                      ;
  ELECTRO QUADR .27 -1.2405 .07              ;
  F F 0 .0 .0 .0 .0                      ;
  DRIFT LENGTH .015 ;
;
;
; GPS.QP550 / Q9
  DRIFT LENGTH .15                       ;
  DRIFT LENGTH .015 ;
  F F 0 .0 .0 .0 .0                      ;
  ELECTRO QUADR .27 1.6775 .07              ;
  F F 0 .0 .0 .0 .0                      ;
  DRIFT LENGTH .015 ;
;
;
  DRIFT LENGTH .864                       ;
;
;
; FIT (X,A) 0                          ; Point-to-point focusing;
; FIT (Y,B) 0                           ; Point-to-point focusing;
;
;
 PLOT BEAM E 40 .15 .15 2.5 2 .5 3 3 1 1 3 3  ; show beam envelopes
;
;
; PLOT QUALITY .1 .3 .5 .7 .9            ;
; PLOT PHASE_S (X,A) 1000 .02 .05 1      ;
;
; PLOT QUALITY .1 .3 .5 .7 .9            ;
; PLOT PHASE_S (Y,B) 1000 .02 .05 1      ;
;
 PLOT QUALITY .1 .3 .5 .7 .9             ;
 PLOT PHASE_S (X,Y) 1000 .02 .02 1       ;
;
  END ;
```

9.2 HRS

```
HRS res 2500 optics ;
                                ; Pre MAG90 focus
                                ; ===============
                                ;
                                ; #######-------Particle definitions
                                ;
R P .06 200 1                   ; Particle energy[MeV], mass, charge
P X 0.001 0.005                 ; Ion source half-width, angle spread
```

```
P Y 0.001 0.005                 ; Ion source half-height, angle spread
D P 0.0005 0                    ;
                                ;
                                ; #######-------Fit settings
                                ;
C O 3 3                         ; Calculation order X,Y
F S                             ; Fit Simplex
 ;F G                             ; Fit Gradient
                                ;
                                ; #######-------Frontend
                                ;
D L 0.52                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -1.506 0.070         ; ] QS 30 : length, voltage, radius (coupled to QP50)
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.15                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   2.691 0.070          ; ] QP 40 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.15                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -1.506 0.070         ; ] QP 50 : length, voltage, radius (coupled to QS30)
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 2.846                       ; Drift length
                                ;
                                ; #######-------First dipole
                                ;
F F 0 0 0 0 0                   ; \
E M 0.20 0 0 0 0.055            ; ] MP 140 : length, V-quad, V-hex, V-oct, radius
F F 0 0 0 0 0                   ; /
D L 1.684                       ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -1.640 0.070         ; ] QP 170 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.15                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   2.463 0.070          ; ] QP 180 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.80                        ; Drift length
                                ; #######-------Focus #1
                                ;
P Q 0.1 0.3 0.5 0.7 0.9         ;
P P (X,A) E 10000 0.005 0.05 1  ;
                                ;
                                ; #######-------Fit #1
                                ;
                                ; #######-------Magnet 90
                                ;
C B                             ;
D L 0.35                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -1.165 0.070         ; ] QP 330 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.40                        ; Drift length
F F 1 0 0                       ; \
M S 1 90 0.055 0 0 0            ; ] MAG 90 : radius, angle, half-gap, quad, hex, oct
F F 1 20 0                      ; /
D L 1.9863                      ; Drift length
                                ;
                                ; #######-------Focus #2
                                ;
P Q 0.1 0.3 0.5 0.7 0.9         ;
P P (X,A) E 10000 0.005 0.05 3  ;
                                ;
```

```
                                ; #######-------Fit #2
                                ;
                                ; #######-------Magnet 60
                                ;
C B                             ;
D L 0.60                        ; Drift length
F F 0 0 0 0 0                   ; \
E M 0.20 0 0 0 0.055            ; ] MP 510 : length, V-quad, V-hex, V-oct, radius
F F 0 0 0 0 0                   ; /
D L 0.20                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -0.000 0.070         ; ] QP 540 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.15                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   +0.000 0.070         ; ] QP 550 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.40                        ; Drift length
F F 1 0 0.2438                  ; \
M S 1 60 0.055 0 0 0            ; ] MAG 60 : radius, angle, half-gap, quad, hex, oct
F F 1 0 0.2438                  ; \
D L 0.40                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -0.198 0.070         ; ] QP 640 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.20                        ; Drift length
F F 0 0 0 0 0                   ; \
E M 0.20 0 0 0 0.055            ; ] MP 650 : length, V-quad, V-hex, V-oct, radius
F F 0 0 0 0 0                   ; /
D L 0.50                        ; Drift length
                                ;
                                ; #######-------Focus #3
                                ;
P Q 0.1 0.3 0.5 0.7 0.9         ;
P P (X,A) E 10000 0.005 0.05 3  ;
                                ;
                                ; #######-------Fit #3
                                ;
                                ; #######-------Merging Switchyard
                                ;
D L 1.4588                      ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   +1.905 0.070         ; ] QP 720 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 0.15                        ; Drift length
D L 0.015                       ; \
F F 0 0 0 0 0                   ; \
E Q 0.27   -1.725 0.070         ; ] QS 730 : length, voltage, radius
F F 0 0 0 0 0                   ; /
D L 0.015                       ; /
D L 1.5411                      ; Drift length
F F 1 0                         ; \
E S 0.6 49.5 0.015              ; ] BE 750 : radius, angle, half-gap
F F 1 0                         ; /
D L 0.1638                      ; Drift length
                                ;
                                ; #######-------Output
                                ;
P B E 40 0.15 0.15 2.5 2 0.5 3 3 1 1 3 3 ;
END ;
END ;
```