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ER@CEBAF: Modeling code developments

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Collider Accelerator Department

Brookhaven National Laboratory

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ER@CEBAF : Modeling code developments

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April 13, 2016

Abstract

A proposal for a multiple-pass, high energy, energy-recovery experiment using CEBAF is under preparation in the frame of a JLab-BNL collaboration. In view of beam dynamics investigations regarding this project, in addition to the existing model in use in Elegant a version of CEBAF is developed in the stepwise ray-tracing code Zgoubi,

Beyond the ER experiment, it is also planned to use the latter for the study of polarization transport in the presence of synchrotron radiation, down to Hall D line where a 12 GeV polarized beam can be delivered.

This Note briefly reports on the preliminary steps, and preliminary outcomes, based on an Elegant to Zgoubi translation.

Tech. Note C-A/eRHIC/52 (2016)

Contents

1 Introduction **3**

2 Method **3**

3 Optics **5**

4 “Bunch tracking” outcomes, for illustration **7**

Appendix **9**

A Elegant input data file, 1-pass up, 1-pass down **9**

B Zgoubi sequence out of e2z translator **10**

C Individual element matching **11**

References **12**

1 Introduction

It has recently been decided to present to JLab PAC44 committee, planned for July 2016, a proposal, “ER@CEBAF”, for a multiple-pass, high energy, energy-recovery experiment using CEBAF [1]. This is foreseen as part of the on-going R&D regarding BNL/C-AD linac-ring version of eRHIC EIC, in which an ERL is used to generate and energy-recover a 20 GeV electron beam [2].

This project is subject to a joint JLab-BNL biweekly collaboration meeting and maintains a web site [1] where all relevant details concerning modeling and code developments discussed here, including the optics files used as well as produced, can be found.

In view of this ER@CEBAF project and of related extensive beam dynamics simulations and investigations planned in accompaniment, a version of CEBAF is developed in the stepwise ray-tracing code Zgoubi [3]. This is in addition to the model in use in the computer code Elegant [4] and will allow in particular outcome cross-checks.

These developments in Zgoubi are also part of the efforts towards end-to-end modeling of eRHIC EIC ERL, including possibility of real-life benchmarking at CEBAF.

On the other hand, beyond the ER@CEBAF experiment, it is also planned to profit from the capability of Zgoubi to track spin in the presence of synchrotron radiation (SR) and use it for 9D (6D+spin) electron bunch tracking down to Hall D line.

This Note briefly reports on preliminary steps completed recently, namely, the translation from Elegant to Zgoubi of a 1.4 GeV, 1-pass up, 1-pass down ER configuration. (That configuration is seen as possible initial stage in setting up the 5-pass, 7 GeV ER experiment.) This discussion includes methods for the translation as well as preliminary outcomes. Near-future prospects, towards 5-pass ER, towards 12 GeV polarized bunch tracking, and towards a machine data based model (*à la* AGS [5, 6]), are also briefly addressed.

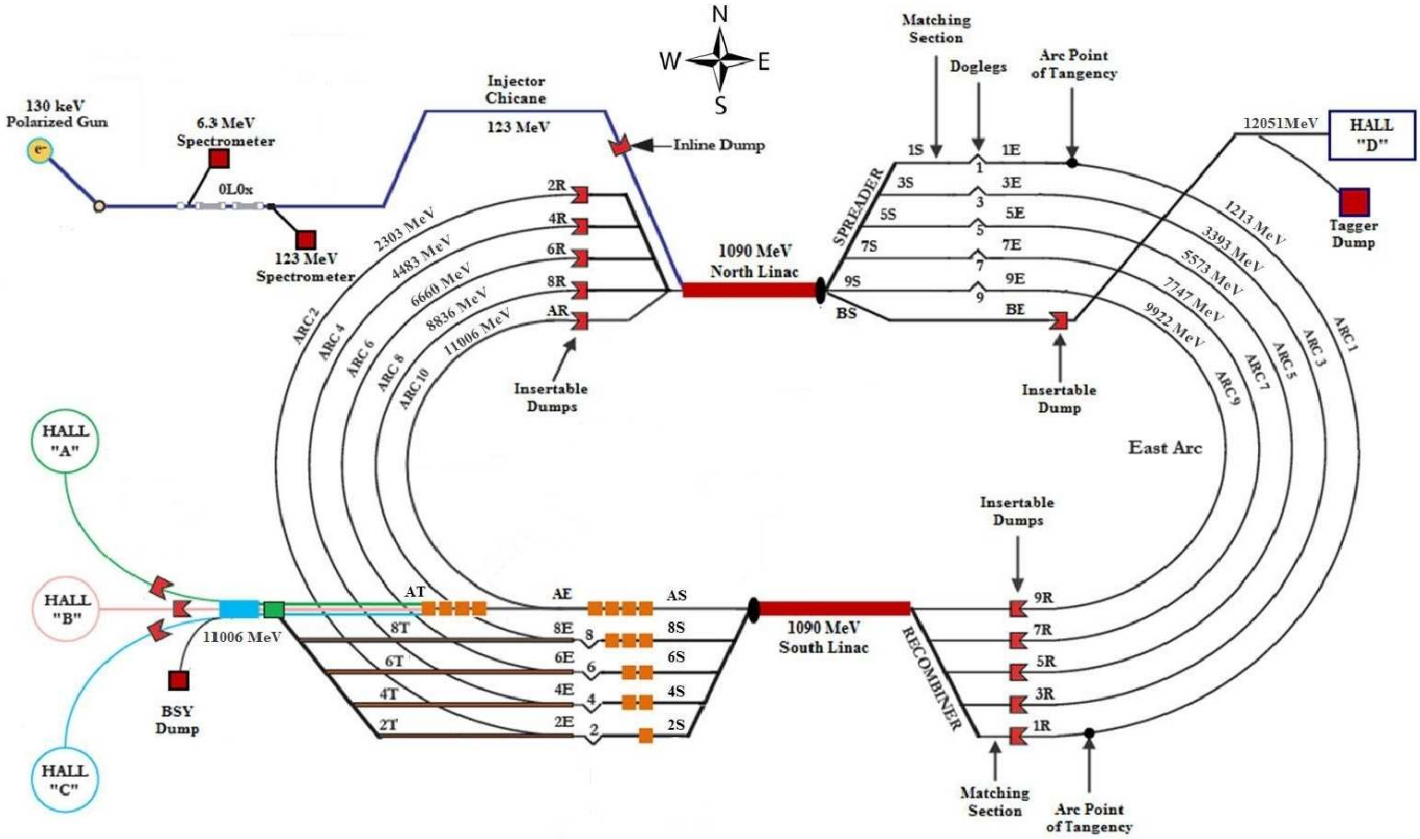


Figure 1: CEBAF recirculator. The ER setup includes a phase chicane in Arc 10 and an extraction and beam dump line at the downstream end of the South linac.

2 Method

In view of clearly establishing what is done and how it is done, what is contained in the model(s) and what are the further objectives, details regarding the simulation method and materials are given, including various aspects of the codes, the content of the input data files, and other particularities proper to the stepwise ray-tracing method. This is also aimed at providing guidance for further use/developments of these tools.

The translation method benefits from earlier “large scale” similar experience : it is the same as was applied at the AGS in an early stage [5]. It is intended that part of the future work will be to construct a complete Zgoubi model based on magnet power supply data, using a template data file of the accelerator lattice, as was done for the AGS in a later stage [6].

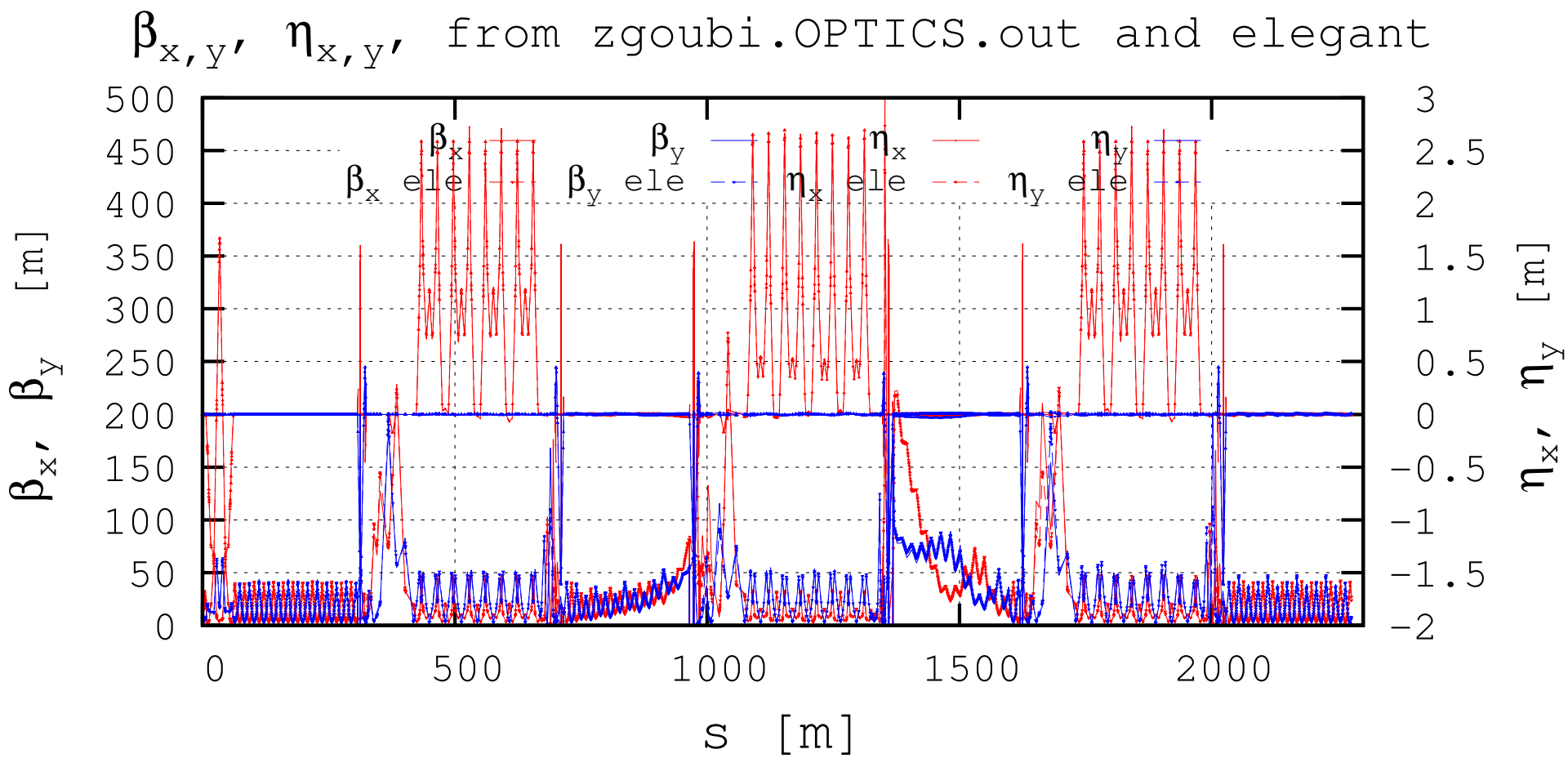


Figure 2: Optical functions in the 1-pass up, 1-pass down ER configuration, from both Elegant and Zgoubi, superimposed.

The 1-pass up, 1-pass down Elegant problem dealt with in this translation, “iERApass.lte”, can be found in App. A [1]. In order to translate from Elegant to Zgoubi, using the translator “e2z” written in that aim, the following Elegant files are created by running “iERApass.lte” (the prefix ’iERApass’ in the following designates the 1-pass up, 1-pass down Elegant files) :

(i) iERApass.parms : CEBAF optical sequence

(ii) iERApass.mat_indiv : individual first order maps of all optical elements

(iii) iERApass.twi : optical functions transported from the start of the sequence, at each optical elements

These files serve the following purposes :

(i) iERApass.parms is read by e2z to create the Zgoubi sequence. The keywords in Zgoubi corresponding to such Elegant ones as ’CSBEND’, ’KQUAD’, etc. can be figured out from App. B

(ii) iERApass.mat_indiv is used to cause, during the translation, identical first order mapping between Elegant individual elements and Zgoubi ones. This is illustrated in App. C

(iii) iERApass.twi provides the optical functions

- on the one hand at the start of each of the main sections in CEBAF lattice, *e.g.*, at start of a linac, of a spreader,
- on the other hand at the end of a section, to further allow its fine tuning after the translation has been completed (for instance, to get perfect cancellation of H and V orbits and dispersion functions).

3 Optics

The translation discussed here concerns a very preliminary setup of a 1-pass up, 1-pass down CEBAF lattice [1, “OPTICS” folder], far from any nominal settings (for instance, focussing in the linacs will be substantially different [7], and as a consequence amongst others, the optics in the matching sections to the arcs as well). The present lattice hypotheses can be viewed as a simplified basis for the illustration of some of the aspects of the Elegant→Zgoubi translation and of its outcomes. On the other hand they lay out the path towards a complete translation/simulation of the 5-pass, 7 GeV ER configuration.

Tab. 1 gives basic data relevant to these tracking simulations, regarding this 1-pass up, 1-pass down CEBAF ER lattice configuration.

Table 1: Various parameters in these preliminary investigations regarding the translation from Elegant to Zgoubi, in a 1-pass up, 1-pass down ER configuration (bunch energy is intended total, mass+kinetic).

			Comments
distance, NL in to NL in	m	1312.5	Accelerated pass
distance, from NL in to SL out	m	997.2	Decelerated pass
linac energy	MeV	700	
bunch energy, after 1st pass	MeV	1478.98	Case SR set
ER’ed bunch energy	MeV	78.94	SR loss is ≈ 48 keV/particle
Injected bunch properties (tracking, Sec. 4) :			
injection energy	MeV	78.987	$\approx 0.1127 \times E_{\rm linac}$
energy spread	10^{-4}	± 1	Overall, uniform
bunch length		0	
horizontal/vertical emittances, norm.	$\pi\mu$m	1.55	$10^{-2}\pi\mu$m unnorm. at 79 MeV

First order outcomes

Fig. 2 displays the optical functions over the 2.3 km in the 1-pass up/1-pass down ER configuration, as obtained from both codes, it shows the good agreement between Elegant optics and what the translation to Zgoubi by e2z yields, given the intermediate individual dipole matchings and section matchings which are included in the translation process.

Fig. 3 shows the residual orbits over the 2.3 km 1-pass up, 1-pass down path : the horizontal one reaches 2 mm range in the dispersive regions in the arcs, the vertical one quasi-zero. The horizontal orbit can be set even closer to zero if stronger constraints are applied for the individual matching of the dipoles during the translation process. The spikes are artifacts corresponding to change of reference frame in the optical sequence (gnuplot is used here and does not treat this effect).

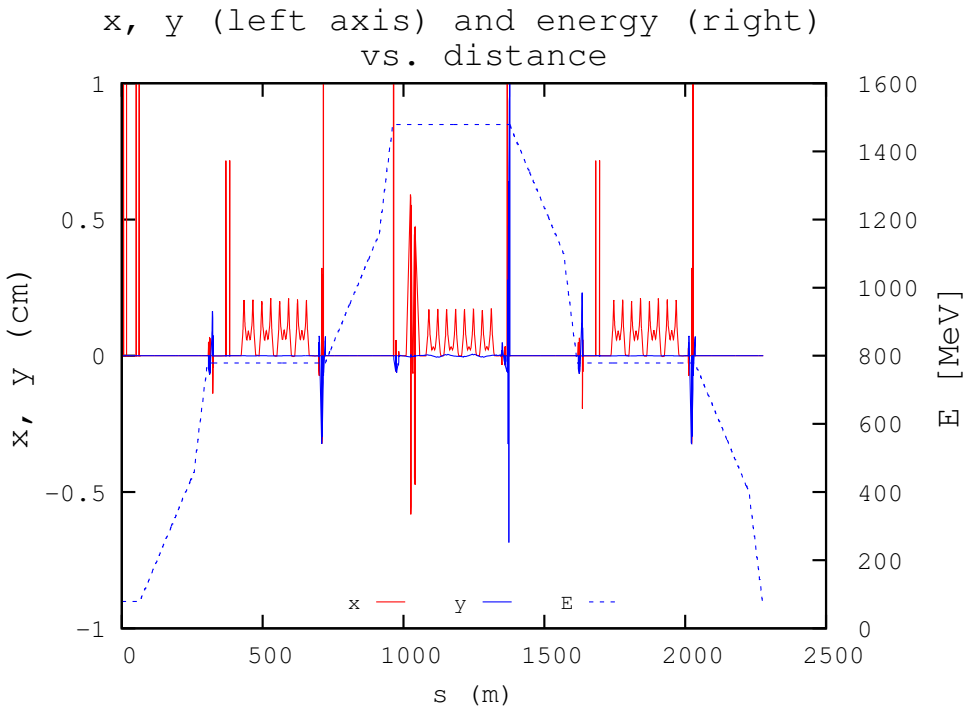


Figure 3: Solid lines, left vertical axis : residual H (red) and V (blue) orbits, out of e2z translator. Dashed line, right vertical axis : particle energy.

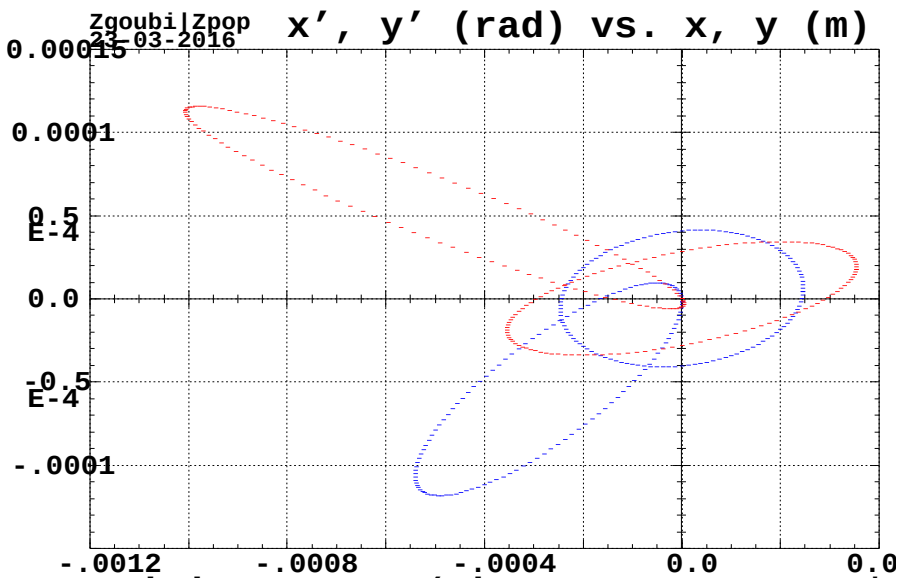


Figure 4: Phase-space portrait of a set of 120 electrons launched at IPM0L06 with identical invariants and evenly spread betatron phase (centered ellipses, red is horizontal, blue is vertical), and the same particle set after ER (uncentered ellipses). SR is off. The off-centering after 2.3 km comes from residual orbit in the optical setting of the translated model.

Fig. 3 also shows the acceleration-deceleration cycle, from 78.987 MeV (total) up to 1.479 GeV at the first pass, down to 78.94 MeV at the second pass, with the difference with injection energy resulting from SR.

Fig. 4 displays a set of 120 electrons launched at IPM0L06 with identical invariants and evenly spread betatron phase, at start (the two centered ellipses, respectively horizontal (red) and vertical (blue) particle positions in phase space), and after ER (uncentered particle position ellipses) via 1.479 GeV top energy (not shown). It can be observed that the ellipse support is well preserved, the ellipse surface as well (negligible change).

4 “Bunch tracking” outcomes, for illustration

A 1-pass up, 1-pass down tracking simulation is performed, to evaluate the consistency of what precedes, namely, a 10^4-particle bunch is launched at IPM0L06 in the injector line, with (Tab. 1) initial length zero, momentum spread dp/p of particles taken random uniform in $[-10^{-4}, +10^{-4}]$, transverse emittances Gaussian with *rms* value $\epsilon_x = \epsilon_y = 1.55\pi\mu$m, normalized ($10^{-2}\pi\mu$m unnorm. at injection).

Simplifying hypotheses have been included in the simulation, as follows :

- the bunch centroid is artificially aligned (zero excursion, zero angle) on the optical axis at entrance into the linacs at all 4 linac passes,
- at each cavity, all particles in the bunch are assumed to be on-crest,
- SR is either on or off (!), as indicated.

The tracking takes 170 seconds CPU on a single CPU, including SR and spin.

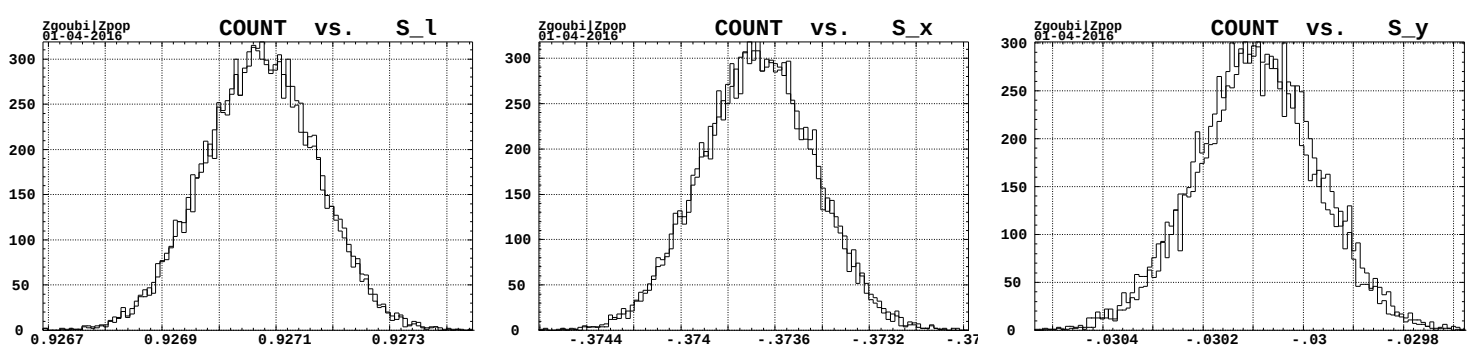
Results are given under the form of a series of figures, as follows :

- Fig. 5 shows the transverse phase spaces at the three steps in energy (injection, 1.4 GeV and back to 79 MeV). Computation of the *rms* ellipse shows that the normalized transverse emittances are well preserved by Zgoubi numerical integrator (a Taylor series method [3]), similar result for the momentum spread, preserved as well by the tracking.
- Fig. 6 shows the energy histograms at injection, 1.4 GeV and back to injection energy, in the cases with and without SR.
- Fig. 7 shows the effects of synchrotron radiation, expected to induce $\frac{\sigma_E}{E}$, $\Delta\epsilon_x$ and $\Delta\epsilon_y \propto \gamma^5/\rho^2$, however very weak effects at that energy.

Spin

The figures below show the distribution of the spins of the above 10^4 particles, at 1.4 GeV. All spins are launched vertical at IPM0L06, polarization ends up quasi-longitudinal at SL exit as expected (’MQL2L27’-down).

The spin dispersion stems from momentum dispersion in the bunch, SR induced diffusion is negligible as is SR induced dp/p (Fig. 6).



Polarization at 1.4 GeV, exit of SL, cases with or without SR superimposed.
10^4 *electrons tracked (Figs. 5-7), all launched from injection line with spin vertical.*

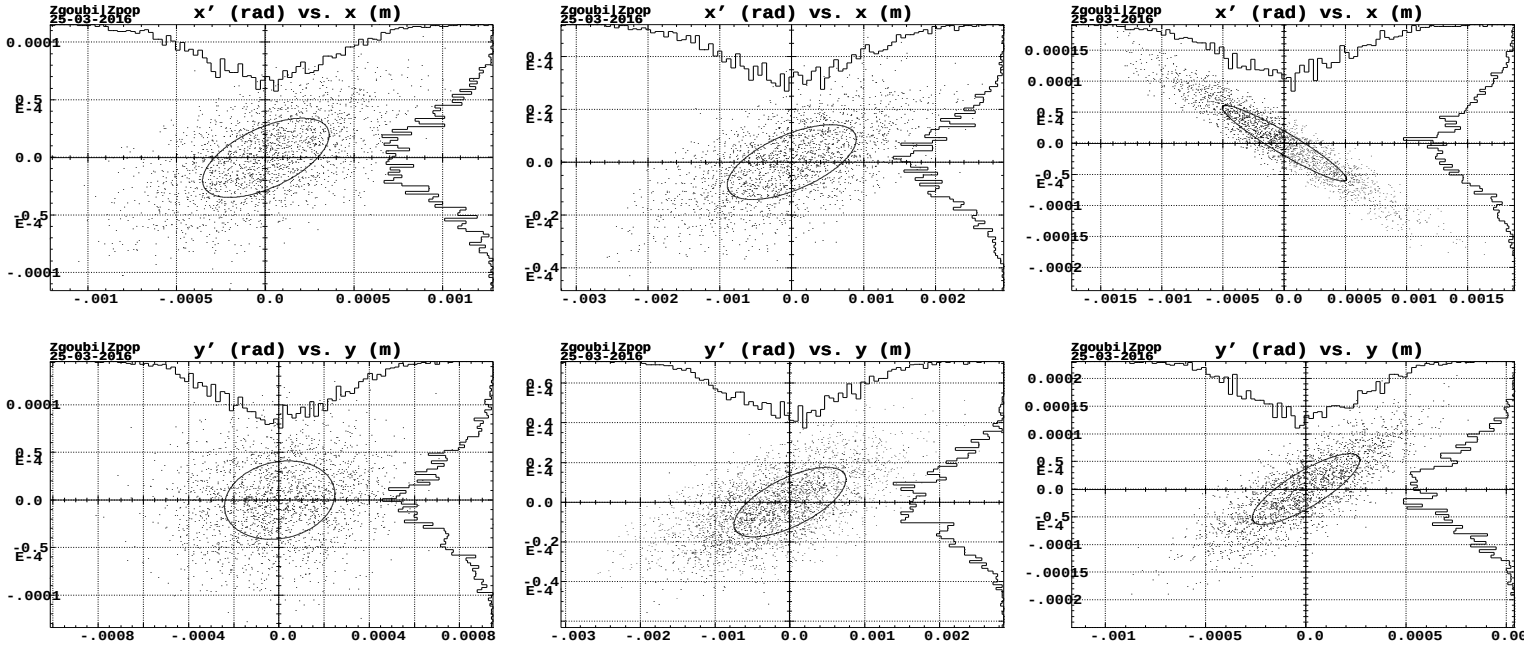


Figure 5: Horizontal (top row) and vertical (bottom) phase space at start (left graph), 1.479 GeV (exit of South linac, middle), and energy-recovered (exit of South linac, right graph). SR is off.

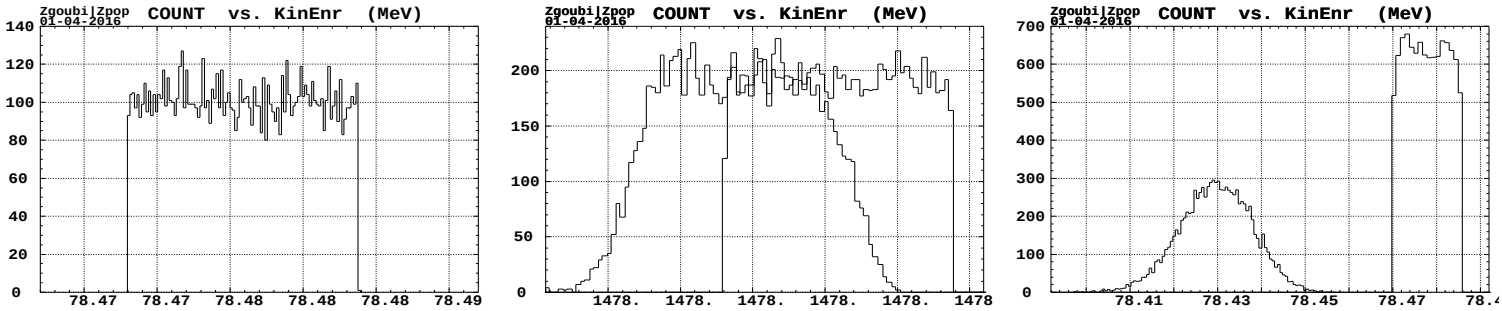


Figure 6: Energy histograms (10^4 electrons) at injection, 1.4 GeV and after ER, in the cases with and without SR.

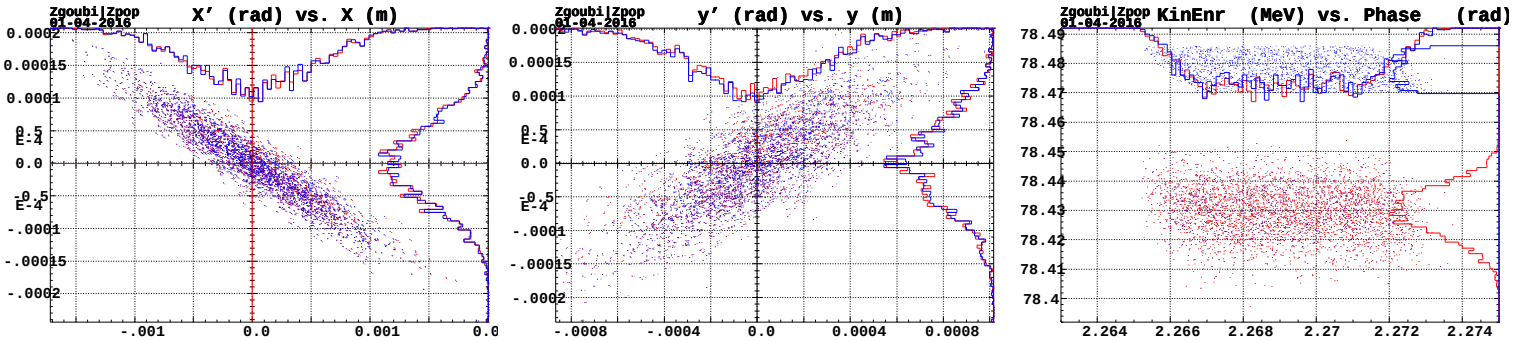


Figure 7: Phase-space portraits of the ER’ed bunch, observed at exit of South linac. Red is in the presence of SR, blue is without SR. Horizontal (left), vertical (middle) and longitudinal (right).

Appendix

A Elegant input data file, 1-pass up, 1-pass down

Below is the file as found in the ER@CEBAF meeting dropbox [1, “Optics/lattices/elegant” folder].

```
&run_setup
        lattice="iERApass.lte",
        use_beamline="IERA1",
        p_central_mev=6.27924163615229,
        final="%s.fin"
        parameters="%s.parms"
        centroid=%s.cen
        always_change_p0=0
        sigma=%s.sig
&end

&matrix_output
!  individual_matrices = 1
!  SDDS_output=%s.mat_indiv
!  individual_matrices = 0
  SDDS_output=%s.mat_cumul
!  start_from=MBL0R04
  start_from=IPM0L06
&end


&alter_elements
 name=*
 type=CSBEND
 item=N_KICKS
 value=30
&end
&alter_elements
 name=*
 type=KQUAD
 item=N_KICKS
 value=30
&end

&alter_elements name=R04[12345678]* item=VOLT
multiplicative=1 value=0.524721  verbose=0 &end

&alter_elements name=R1[23456789ABCDEFGHIJKLMNOPQ]* item=VOLT multiplicative=1
value=0.642201834862385 verbose=0 &end
&alter_elements name=R2[23456789ABCDEFGHIJKLMNOPQ]* item=VOLT multiplicative=1
value=0.642201834862385 verbose=0 &end

&alter_elements name=* type=CSBEND item=SYNCH_RAD value=1 verbose=0 &end
&alter_elements name=* type=CSBEND item=ISR value=1 verbose=0 &end
&alter_elements name=* type=KQUAD item=SYNCH_RAD value=1 &end
&alter_elements name=* type=KQUAD item=ISR value=1 &end
&alter_elements name=R04[12345678]* item=PHASE  value=-10.4 differential=1 verbose=0 &end
&alter_elements name=R04[12345678]* item=VOLT multiplicative=1 value=1.0325  verbose=0 &end
&alter_elements name=R1[23456789ABCDEFGHIJKLMNOPQ]* item=PHASE
value=270 s_start=998 s_end=20000 verbose=0 &end
&alter_elements name=R2[23456789ABCDEFGHIJKLMNOPQ]* item=PHASE
value=90 s_start=0 s_end=998 verbose=0 &end

!=====================================================
! scale the quads in the linac to the proper gradient.
! scalelinacs script will produce these sdds files to load.
!
&load_parameters
 allow_missing_elements=1
 change_defined_values=1
 filename="NLq.sdds"
 include_item_pattern=B
 include_name_pattern="MQ*"
 verbose=0
&end
&load_parameters
 allow_missing_elements=1
 change_defined_values=1
 filename="SLq.sdds"
 include_item_pattern=B
 include_name_pattern="MQ*"
&end
&load_parameters
 allow_missing_elements=1
 change_defined_values=1
 filename="REINJq.sdds"
 include_item_pattern=B
 include_name_pattern="MQ*"
 verbose=0
&end
! we load the result of the matches
!
&load_parameters
 filename=rematch.parms
 include_item_pattern=K1
 change_defined_values=1
 allow_missing_elements=1
 verbose=0
&end
&load_parameters
 filename=ARC2SMATCH.sdds
 change_defined_values=1
 allow_missing_elements=1
 verbose=1
&end
&load_parameters
 filename=ARC2RMATCH.sdds
change_defined_values=1
allow_missing_elements=1
verbose=1
&end
!
! load the dogleg adjustments
!
&load_parameters
 filename=DOG2E.sdds
 change_defined_values=1
 allow_missing_elements=1
 verbose=0
&end
!
! sextupole corrections to make ARC1 2nd order achromat
!
!
&load_parameters
 filename=ARC1SEXT.sdds
 change_defined_values=1
 allow_missing_elements=1
 verbose=1
&end

&twiss_output
filename="%s.twi",
matched=0,radiation_integrals=1,
beta_x=2.997926428896469, alpha_x=-0.5359458777507575,
beta_y=2.744088102614352, alpha_y=-0.36807740722565
&end
&run_control n_steps=1
&end
&floor_coordinates
filename="%s.flr",
 X0=80.6,Y0=100,Z0=-249.21407,
 theta0=0,phi0=0
&end
&bunched_beam
n_particles_per_bunch=1024,
        momentum_chirp=0,
emit_nx=7.5e-7, emit_ny=7.5e-7,
beta_x=2.997926428896469, alpha_x=-0.5359458777507575,
beta_y=2.744088102614352, alpha_y=-0.36807740722565
sigma_dp=2e-4,sigma_s=300e-6,
distribution_type[0] = 3*"gaussian",
distribution_cutoff[0] = 3*3,
enforce_rms_values[0]=1,1,1
&end
&track &end
```

B Zgoubi sequence out of e2z translator

• ’Parent’ zgoubi data file (the file that is run by zgoubi executable) :

```
 Generated using elegant -> Zgoubi translator
’OBJET’
26.34662897E+01     reference momentum (MeV/c) = 78.98520660
5.01
.001 .001 .001 .001 0. .0001
0. 0. 0. 0. 0. 1.
-6.8047E-01  1.2548E+01 -1.5568E-01  6.0697 0. 1.  0.  0.  0.  0.
’SCALING’
1  4
DIPOLE
-1
  26.3466290E-02
1
MULTIPOL
-1
  26.3466290E-02
1
MULTIPOL  MQS1L*  MQD1L*  MQB1L* MQN1L*
2
1.    1.
1     9999
MULTIPOL  MQS2L*  MQB2L*  MQL2L*
2
1.    1.
1     9999

’INCLUDE’
1
inj.inc[inj_#S:inj_#E]
’INCLUDE’
1
linN.inc[linN_#S:linN_#E]
’INCLUDE’
1
spr_E1.inc[spr_E1_#S:spr_E1_#E]
’INCLUDE’
1
fod_A1.inc[fod_A1_#S:fod_A1_#E]
’INCLUDE’
1
rec_E1.inc[rec_E1_#S:rec_E1_#E]
’INCLUDE’
1
linS.inc[linS_#S:linS_#E]
’INCLUDE’
1
spr_W2.inc[spr_W2_#S:spr_W2_#E]
’INCLUDE’
1
fod_A2.inc[fod_A2_#S:fod_A2_#E]
’INCLUDE’
1
rec_W2.inc[rec_W2_#S:rec_W2_#E]
’INCLUDE’
1
dwSeg.inc[dwSeg_#S:dwSeg_#E]
’MATRIX’
1  0
’END’
```

• Example of the first spreader section, ’spr_E1.inc’ in the ’Parent’ file above (just head and tail of the file).

```
 Generated using elegant -> Zgoubi translator
’OBJET’
26.34662897E+01   reference momentum (MeV/c) = 78.98520660
5.01
.001 .001 .001 .001 0. .0001
0. 0. 0. 0. 0. 1.
-7.3780E-02  6.3225E+00 -1.8465E+00  2.6757E+01 0. 1.  0. 0. 0. 0.
’SCALING’
1  4
DIPOLE
-1
  26.3466290E-02
1
MULTIPOL
-1
  26.3466290E-02
1
MULTIPOL  MQS1L*  MQD1L*  MQB1L* MQN1L*
2
1.    1.
1     9999
MULTIPOL  MQS2L*  MQB2L*  MQL2L*
2
1.    1.
1     9999
’MARKER’   spr_E1_#S

’TRAROT’   MXQ1S01               SBEN
0. 0. 0.  -1.570796E+00 0. 0.
’CHANGREF’ MXQ1S01
 XS    -22.0023076
’DIPOLE’   MXQ1S01                SBEN
0  .Dipole
    26.6341335     314.64765811
     4.0000000       3.17815809     0.00000000 0. 0.
 8. -1.         face 1
 4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
     0.0000000       0.0000000   1.E6 -1.E6 1.E6 1.E6
 8. -1.         face 2
 4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
   -18.6341335     -18.6341372   1.E6 -1.E6 1.E6 1.E6
 0.  0.         face 3
 4 .1455 2.2670 -.6395 1.1558 0. 0. 0.
 0. 0.   1.E6 -1.E6 1.E6 1.E6  0.
 2   64
 .2
 2    314.6476581    -0.0698132   314.6476581     0.0698132            ! 63-67
’CHANGREF’ MXQ1S01
 XS    -22.0023076                                                    ! RM*tan(ACN-omga+ ==ACN)
’YMY’      YMY_OUT
’TRAROT’   MXQ1S01               SBEN
0. 0. 0.   1.570796E+00 0. 0.

’DRIFT’    D200                   DRIF
    336.202330
’DRIFT’    IPM1S00                MONI
      0.0000
’DRIFT’    D201                   DRIF
     46.092037
-----------------------------------------
-----------------------------------------
’DRIFT’    D217                   DRIF
     19.609000
’MULTIPOL’ MBT1E03V               VKIC
0  .kicker
    0.000100   10.00    -0.000000000     0.000000000 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0
.0 .0  1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
.0 .0  1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 1.570796327 0. 0. 0. 0. 0. 0. 0. 0. 0.
#20|4|20  Kick
1 0. 0. 0.
’DRIFT’    D235                   DRIF
     70.155000
’DRIFT’    IHA1E03                MONI
      0.0000
’DRIFT’    D236                   DRIF
   1493.396000
’DRIFT’    IPM1A01                MONI
      0.0000
’DRIFT’    D215                   DRIF
     29.965000
’MARKER’   ARC1MS                 DRIF

’MARKER’   spr_E1_#E

’FIT2’
 9   save
 28  5 0 [-1.5,1.5]      ! MQB1S01 - zro Dy
 46  5 0 [-1.999,1.999]  ! MQN1S03
 58  5 0 [-1.5,1.5]      ! MQN1S04 alf, bet
 64  5 0 [-2.99,2.99]    ! MQL1S05
 70  5 0 [-1.99,1.99]    ! MQB1S06
 74  5 0 [-1.88,1.88]    ! MQL1S07
 82  5 0 [-1.88,1.88]    ! MQL1S08
 92  5 0 [-1.88,1.88]    ! MQL1S09
 98  5 0 [-1.99,1.99]    ! MQB1S10
 12        1.0E-10
 0 1 1    60    1.818984E+01      1. 0   ! sprE1 at ITV1S04
 0 1 2    60   -5.156477E+00      .2 0   ! sprE1 at ITV1S04
 0 1 6    60    0.000000E+00      1. 0   ! sprE1 at ITV1S04
 0 2 6    60    0.000000E+00      .2 0   ! sprE1 at ITV1S04
 0 3 3    60    7.511530E+00      1. 0   ! sprE1 at ITV1S04
 0 3 4    60   -5.781945E-01      .2 0   ! sprE1 at ITV1S04
 0 3 6    60    0.000000E+00      .5 0   ! sprE1 at ITV1S04
 0 4 6    60    0.000000E+00      .1 0   ! sprE1 at ITV1S04
 3 1 2    60 0. 1. 0
 3 1 3    60 0. 1. 0
 3 1 4    60 0. .2 0
 3 1 5    60 0. .1 0
’END’
```

• All the ’INCLUDE’ files in the ’Parent’ file (’inj.inc’, ’linN.inc’, etc.) have that very form : starting with an object definition (’OBJET’ keyword) that generates an 11-particle sample proper to transport matrix computation from the ray-tracing, followed by the sequence proper, and ending with a fitting procedure (’FIT’) which will allow (i) canceling the orbit in zgoubi and (ii) tuning the sequence to the optical functions (betatron and dispersion function values) as read from Elegant file iERApass.twi.

Note that, while these ’INCLUDE’ files are structured to be run independently for matching purposes, only that part of the file which is comprised between the two markers as specified in the ’Parent’ file (’spr_E1_#S’ and ’spr_E1_#E’ in the above example of the East spreader) is effectively included in the CEBAF sequence. When launching zgoubi execution, that developed sequence is printed out in ’zgoubi.dat’, and it can be found as well as the header part in the execution listing ’zgoubi.res’.

C Individual element matching

Example of the West spreader first dipole : the data below show

- left column : that element in iERApass.parms, and its first order transport coefficients as read from iERApass.mat_indiv (bottom of the column)

- right column : its description in zgoubi and the first order transport coefficients so obtained. The difference observed with Elegant ones is not tolerable, it leads within a short distance to prohibitive discrepancies in the transported betatron and dispersion functions. In addition to that, the vertical orbit in zgoubi is not strictly zero, this is not tolerable either and requires dedicated treatment.

As a consequence, a re-match of zgoubi data is necessary, in order to get, (i) zero orbit in zgoubi, and (ii) transport coefficients identical to Elegant ones.

• 'MXR2S01', first dipole of the West spreader, as found in iERApass.parms sequence, and its first order mapping :

```
MXR2S01   CSBEND   L   1.020612064100000e+00   1   ""
MXR2S01   CSBEND   ANGLE   1.885282999360320e-01   1   ""
MXR2S01   CSBEND   K1   4.438959208821460e-03   1   ""
MXR2S01   CSBEND   K2   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   K3   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   K4   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   K5   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   K6   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   K7   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   K8   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   E1   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   E2   1.885283539520330e-01   1   ""
MXR2S01   CSBEND   TILT  -1.5707963267949e+00   1   ""
MXR2S01   CSBEND   H1   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   H2   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   HGAP   1.9050000000000e-02   1   ""
MXR2S01   CSBEND   FINT   5.0000000000000e-01   1   ""
MXR2S01   CSBEND   DX   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   DY   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   DZ   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   FSE   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   ETILT   0.0000000000000e+00   1   ""
MXR2S01   CSBEND   N_KICKS   3.00000000000e+01   1   ""
MXR2S01   CSBEND   NONLINEAR   1.000000000e+00   1   ""
MXR2S01   CSBEND   SYNCH_RAD   1.000000000e+00   1   ""
MXR2S01   CSBEND   EDGE1_EFFECTS   1.00000e+00   1   ""
MXR2S01   CSBEND   EDGE2_EFFECTS   1.00000e+00   1   ""
MXR2S01   CSBEND   EDGE_ORDER   1.00000000e+00   1   ""
MXR2S01   CSBEND   FRINGE   0.000000000000e+00   1   ""
MXR2S01   CSBEND   INTEGRATION_ORDER   4.00e+00   1   ""
MXR2S01   CSBEND   EDGE1_KICK_LIMIT   -1.00e+00   1   ""
MXR2S01   CSBEND   EDGE2_KICK_LIMIT   -1.00e+00   1   ""
MXR2S01   CSBEND   KICK_LIMIT_SCALING   0.0e+00   1   ""
MXR2S01   CSBEND   USE_BN   0.00000000000e+00   1   ""
MXR2S01   CSBEND   EXPANSION_ORDER   0.00e+00   1   ""
MXR2S01   CSBEND   B1   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B2   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B3   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B4   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B5   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B6   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B7   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   B8   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   XREFERENCE   0.0000000e+00   1   ""
MXR2S01   CSBEND   F1   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F2   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F3   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F4   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F5   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F6   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F7   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   F8   0.000000000000000e+00   1   ""
MXR2S01   CSBEND   ISR   1.00000000000000e+00   1   ""
MXR2S01   CSBEND   ISR1PART   1.000000000e+00   1   ""
MXR2S01   CSBEND   SQRT_ORDER   0.0000000e+00   1   ""
MXR2S01   CSBEND   USE_RAD_DIST   1.00000e+00   1   ""
MXR2S01   CSBEND   ADD_OPENING_ANGLE  1.e+00   1   ""
MXR2S01   CSBEND   REFERENCE_CORRECTION   0.e+00  1   ""
```

```
R     1          2           3           4          5      6
1   1.00297e+0 1.02139e+0  0.          0.          0.   0.
2  -2.94515e-2 9.67039e-1  0.          0.          0.   0.
3   0.         0.          9.79983e-1  1.01379e+0  0.  -9.58855e-2
4   0.         0.         -4.55440e-3  1.01571e+0  0.  -1.90648e-1
5   0.         0.         -1.87268e-1 -9.58855e-2  1.   6.03379e-3
```

• 'MXR2S01' in spr_W2.inc zgoubi sequence, as provided by the translation, *prior to its matching to Elegant first order mapping* :

```
'TRAROT'   MXR2S01               SBEN
0. 0. 0.  -1.570796E+00 0. 0.
'CHANGREF'
 YS   3.222601E+00 ZR   0.000000E+00
'MULTIPOL' MXR2S01               SBEN
0  .Dip
 101.457688  10. -0.00784220 8.06507337 0. 0. 0. 0. 0. 0. 0. 0.
20.00  -2.69 1. 0. 0. 0. 0. 0. 0. 0. 0. MXR2S01      FFin
4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
20.00  -2.69 1. 0. 0. 0. 0. 0. 0. 0. 0. MXR2S01      FFout
4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 #30|101|30    Dip MXR2S01
  1 0. 0. 0.
'CHANGREF'
 YS   0.000000E+00 ZR  -1.080188E+01
'TRAROT'   MXR2S01               SBEN
0. 0. 0.   1.570796E+00 0. 0.
```

• Orbit and first order mapping out of Zgoubi, before re-matching :

```
      x (cm)          x' (mrad)          y (cm)          y' (mrad)
  5.57970490E-09  -6.49690055E-09  -1.70740270E-02   1.98806671E-02
```

```
R      1          2          3          4        5       6
1   0.9979     1.025      4.52E-09   5.45E-09    0.   3.12E-08
2  -2.09E-02   0.9805    -2.45E-09  -7.13E-09    0.   6.20E-08
3   4.52E-09   5.45E-09   0.9841     1.009       0.  -9.5702E-02
4  -2.45E-09  -7.15E-09  -1.3393E-02 1.002       0.  -0.1898
5   6.14E-08   3.12E-08  -0.1880    -9.5629E-02  1.   6.066E-03
```

• The matching variables used in Zgoubi's 'MXR2S01' above in order to better cancel the residual (vertical) orbit an to target Elegant's first order mapping are : dipole field, field index, fringe field extent, and magnet radial positioning ('YS' data in 'CHANGREF' above). Obviously, these variable will undergo very small change, given the proximity of the two sets of first order coefficients.

References

[1] Documentation on the project can be found in the collaboration “dropbox”, https://dl.dropboxusercontent.com/u/78214125/index.html

[2] “eRHIC Design Study, Electron-Ion Collider at BNL”, E.C. Aschenauer et al., arXiv:1409.1633, Sept. 2014.

[3] The ray-tracing code Zgoubi - Status, F. Méot, NIM A 767 (2014) 112125.
Zgoubi users’ guide, F. Méot, http://www.osti.gov/scitech/biblio/1062013

[4] http://www.aps.anl.gov/Accelerator_Systems_Division/Accelerator_Operations_Physics/oagPackages.shtml

[5] Development of a stepwise ray-tracing based on-line model at AGS, L. Ahrens et al., Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA.

[6] Modelling of the AGS using Zgoubi - status, F. Méot et al., Proceedings of IPAC2011, San Sebastin, Spain.

[7] ER@CEBAF Linac Optics Exploratory Study, A. Bogacz, in [1].