FM, May 2017

On polarization transport in Cornell RCS

Contents

1 Introduction

Table 1 lists the RCS parameters, it is used as the reference for the setup of the polarization transport simulation files in ghe next sections, parameter values effectively used should be close and will be made clear in due place.

Table 1: Parameters of Cornell RCS. Simulations discussed here are based on this list.

$\mathrm{E_{inj}}$	MeV	150	Main field 66 G at 200 MeV
Nominal E	GeV	10	Main field 3.3 kG (can go to 6.6 kG, that corresponds to 20 GeV)
$\mathcal{C}$	m	756	
Bunch			
Nb e per bunch		10^8	
ϵ_x, ϵ_y, norm.	$\pi\mu$m		
Lattice			
Type		FFDD	48 periods
Phase advance/period	^{o}	75.4	
Nb of magnets		192	96 pairs
Field at 10 GeV, 200 MeV	G	3300, 20	
plus 2 pairs of quads, 1 pair at L0 and 1 at L3 long SS			
Max. β_x, β_y	m	$\approx 25 \sim 30$	
Q_x, Q_y		$10.75 \pm \sim 1\%$	
ξ_x, ξ_y		-12	
Longitudinal, RF			
$\mathrm{T_{rev}}$	μs	2.52	
$\mathrm{f_{rev}}$	kHz	396.6	
$\mathrm{f_{rf}}$	MHz	713.94	$\frac{1}{4}$ linac frequency 2855.76 MHz
h		1800	
Nb of accel. stations		4	One station is ok for 5 GeV
rep. rate	Hz	up to 60	Nominal is 60 Hz
voltage/turn	MV		$4.4\sin\omega t + 8.8\sin^8\frac{\omega t}{2}$
Max. voltage at 10 GeV	MV	9.4	(2.5 MV per "synacs" RF station)
ramp duration to 10 GeV	ms	7.5	
SR			
τ_{SR} at 10 GeV, 5 GeV	ms	2.5, 20	$\sim 2.5/E^3$
ϵ_c	keV	22	
RF supply at 10 GeV	MV/turn	10.5	

2 Optics

The RCS files are translated from the regular MADX ones.
◇ Given appropriate radial off-set of the six different families of combined function bends in their zgoubi model, the residual periodic orbit is zero. That offset is required because of the arc of circle trajectory in the straight axis `MULTIPOLE` model used. In addition, it is obtained using a fitting procedure as the trajectory across the combined function bend experiences a non-constant field.

Basic optics outcomes are displayed in the table below and in Figs. 1, 2. They appear to be practically identical to MADX data.

◇ Zgoubi

```
@ LENGTH     %le      755.8699089
@ ALFA       %le     0.9883981798E-02
@ ORBIT5     %le                   -0
@ GAMMATR    %le      10.05851879
@ Q1         %le     0.6192017265        [+ integer]
@ Q2         %le     0.8212950059        [+ integer]
@ DQ1        %le     -12.24979921
@ DQ2        %le     -12.52138684
@ DXMAX      %le      3.18106746E+00    @ DXMIN     %le  1.13381295E-01
@ DYMAX      %le      0.00000000E+00    @ DYMIN     %le  0.00000000E+00
@ XCOMAX     %le      4.70919093E-04    @ XCOMIN    %le -5.24526127E-04
@ YCOMAX     %le      0.00000000E+00    @ YCOMIN    %le  0.00000000E+00
@ BETXMAX    %le      2.89933865E+01    @ BETXMIN   %le  4.94741348E+00
@ BETYMAX    %le      2.58408796E+01    @ BETYMIN   %le  5.41423967E+00
@ DXRMS      %le      6.24872216E-01
@ DYRMS      %le      0.00000000E+00
```

◇ MADX

```
@ LENGTH              %le         755.8698134
@ ALFA                %le      0.009879107538
@ ORBIT5              %le                  -0
@ GAMMATR             %le         10.06099987
@ Q1                  %le         10.61871619
@ Q2                  %le         10.82093461
@ DQ1                 %le        -12.24511849
@ DQ2                 %le        -12.52048053
@ DXMAX               %le         3.180347971
@ DYMAX               %le                   0
@ XCOMAX              %le                   0
@ YCOMAX              %le                   0
@ BETXMAX             %le         29.03562677
@ BETYMAX             %le         25.82891481
@ XCORMS              %le                   0
@ YCORMS              %le                   0
@ DXRMS               %le         1.363039244
@ DYRMS               %le                   0
```

Optical functions

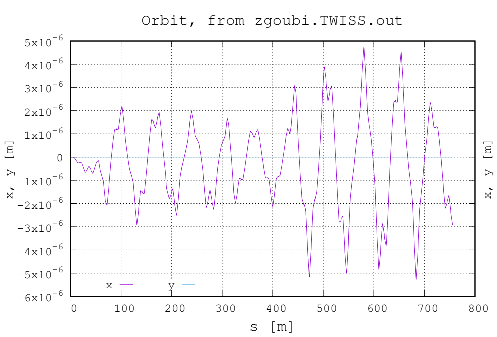

Figure 1: Quasi-zero residual horizontal orbits in zgoubi. The vertical orbit is zero.

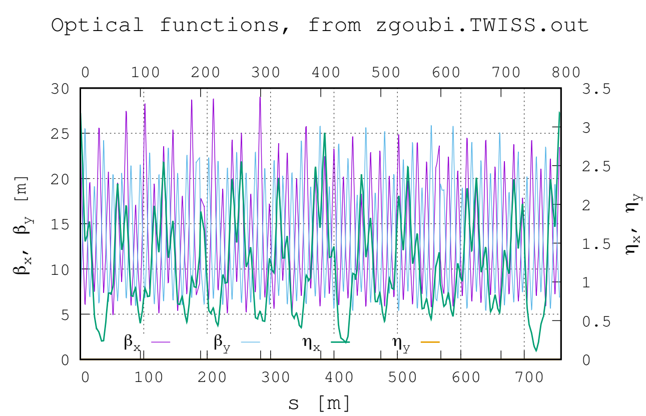

Figure 2: Optical functions.

3 Resonance strengths

Figure 3 shows a $0 < a\gamma < 50$ range ($.2 < E < 22$ GeV), and a zoom on the region of interest to us, $0 < a\gamma < Q_y$ ($.2 < E < 4.8$ GeV)

Using
- $\epsilon_y = 100\pi\ \mu$m invariant value (Fig. 3 is for $10\pi\ \mu$m),
- hence a strength $|\epsilon| \approx 6 \times 10^{-4} \times \sqrt{100/10} = 2 \times 10^{-3}$
- crossing speed $\alpha = \frac{da\gamma}{d\theta} \approx 1.1 \times 10{-}3$ (about 5 ms acceleration ramp to 5 GeV, 3 MV/turn, with $a = 1.15965213627E-03$)

a typical outcome is, at the strongest resonance in the range of interest (at ≈ 4.5 GeV, we do no have to cross it), an encouraging

$$P_f/Pi = 2\exp(-\frac{\pi}{2}\frac{|\epsilon|^2}{\alpha}) - 1 \approx 0.99$$

given that the upstream resonances are at least an order of magnitude weaker.

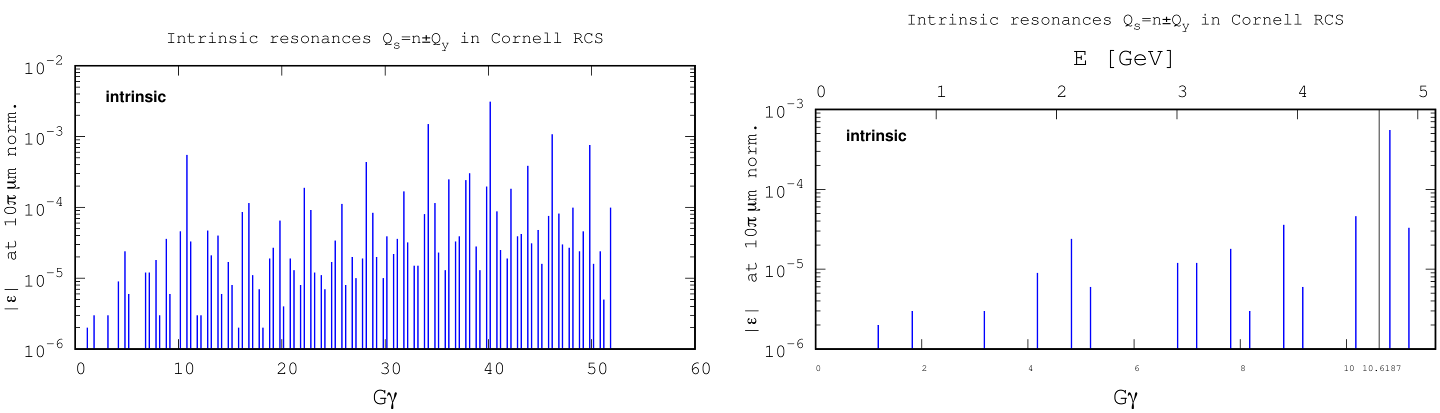

Figure 3: Strength of intrinsic resonances. The vertical bar, right plot, is at $G\gamma = Q_y$.

4 Resonance tracking

Table 2 summarizes the outcomes of tracking simulations, for different error conditions as detailed in the next sections.

The simulation conditions are the following :

- a set of 17 particles is tracked, all launched on the same invariants $\epsilon_x \approx 0$, $\epsilon_y/\pi = 100\,\mu$m normalized ($\epsilon_y/\pi = 250$ nm geom. at injection, 10 nm geom. at 4.5 GeV),
- acceleration is pushed beyond $a\gamma = Q_y$ for the curiosity,
- different types of defects are considered, as indicated in Tab. 2,
- the "final polarization" is that at $a\gamma = 10.2$ (E=4.5 GeV)

Table 2: Average polarization at $a\gamma = 10.2$ (E=4.5 GeV), depending on defect type.

defect type and value	final polarization	comment
Defect free ring		
none		
V kickers, $\delta y_{\rm rms}$		
0.6 mm	0.999	
1.2 mm	0.996	
2.5 mm	0.983	
Bend K1 defect, 1% relative		
	0.9997	
Bend K_0 *roll*		
0.02 deg.	0.995	induced rms V orbit 1.3 mm
0.1 deg.	0.905	induced rms V orbit 10 mm
1 deg.	depolarized	
All of the above : $\delta y_{\rm rms} = 0.6$ *mm,*		
bend K1 defect 1% and K_0 *roll angle* 0.02^o		
all out	0.983	

4.1 No synchrotron motion, first

4.1.1 Starting point

This is the starting orbit and optics conditions for the tracking, prior to injecting errors

The RCS ring lattice is left as found, orbit is zero in both planes (Fig. 1), $10\pi\,\mu$m vertical normalized motion invariant here, optical functions as listed in page 4.1.3.

Fig. 4 shows what comes out in these hypotheses in the matter of polarization transport through the intrinsic resonances (no imperfection, in the absence of noticeable vertical orbit). Fig. 5 shows a typical damped vertical phase space, it will be similar in the simulations including defects, next sections, yet for $100\pi\,\mu$m norm.

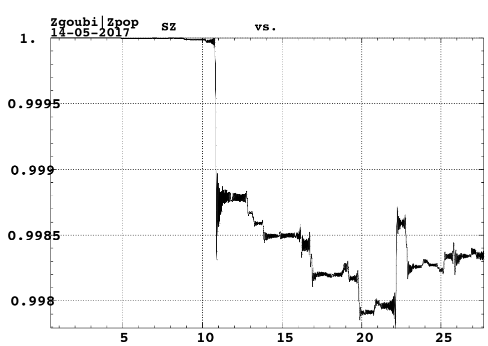

Figure 4: Emittance is $\epsilon_y/\pi = 10\,\mu$m normalized here (100π in the rest of the study). No defect.

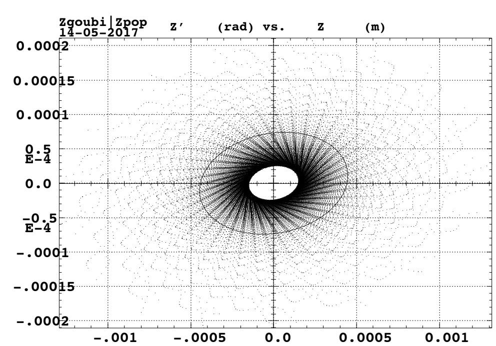

Figure 5: Typical vertical phase space in these polarization tracking simulations.

• The following gives the acceleration conditions in these simulations, same all the way :

```
 'CAVITE'
3                     ! No synchrotron motion. All particles get same kick at each pass.
1 1                   ! T_rev=755.87/c=2.52131092637mu_s -> 10ms/T_rev=3966.19072063 turns
3e6   1.57079632679   ! DE = 12GeV/4000turns=3MV/turn
```

4.1.2 Vertical orbit

• OBJET and ERRORS command data for Fig. 6 (17 particles evenly on 100π invariant, either ± 0.6, ± 1.2 or ± 2.5 mm rms orbit) :

```
 'OBJET'
0.66712601288720230E3    !     33.356409476265092E+03
8
1   17   1
0. 0. 0. 0. 0.  1.
0.089591   23.410413  2.5e-98
-0.145912    6.924692   25.e-8
0.  1.  0.

------
 'ERRORS'
1 1 123466        B_pole  Uniform  dB(kG)
MULTIPOL{KCV}  1  BP A    U 0.d0   100.0  0
                                   200
                                   400
```

"MULTIPOL{KCV}" stands for (the) 46 V-kickers found in the RCS lattice. The orbit is induced by random, uniform dB in these 46 kickers. The orbit has a strong betatron-frequency Fourier component, it can be removed in a refined approach.

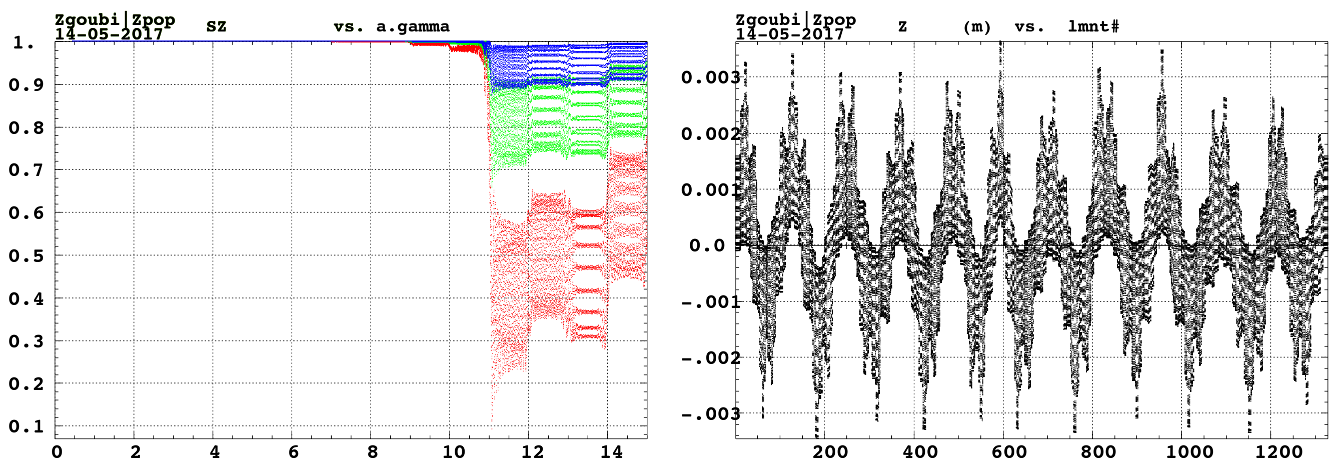

Figure 6: Vertical orbit defect, 17 particles, evenly on invariant $\epsilon_y/\pi = 100\,\mu$m normalized. Three different rms orbit amplitudes considered (orbit source is random uniform kick in 46 vertical kickers) : 0.6, 1.2 and 2.5 mm. The 1.2 mm orbit is illustrated in the right plot.

4.1.3 K1 defect in main bends

• `OBJET` and `ERRORS` command data for Fig. 7 (17 particles evenly on 100π invariant, $dK1/K1 \in \pm 1\%$ (random, uniform) in all main bends) :

```
 'OBJET'
0.66712601288720230E3    !     33.356409476265092E+03
8
1   17   1
0. 0. 0. 0. 0.  1.
 0.089591   23.410413  2.5e-98
-0.145912   6.924692   25.e-8
  0.  1.  0.
 'PARTICUL'
5.10998902E-01 1.60217653e-19 1.15965213627E-03 0. 0.
 'SPNTRK'
 3

 'FAISCEAU'
 'FAISTORE'
zgoubi.fai
1

!'SRLOSS'
! 0   srLoss
! MULTIPOL
! 1 123456

 'ERRORS'
1 2 123466                      dVal
MULTIPOL{KCV}  1  BP A U 0.d0    0.0    0
MULTIPOL{B}    2  BP R U 0.d0    1.e-2  0
```

"`MULTIPOL{B}`" stands for the 200 main bends found in the RCS lattice. The optics is perturbed by random, uniform dK1 in these bends.

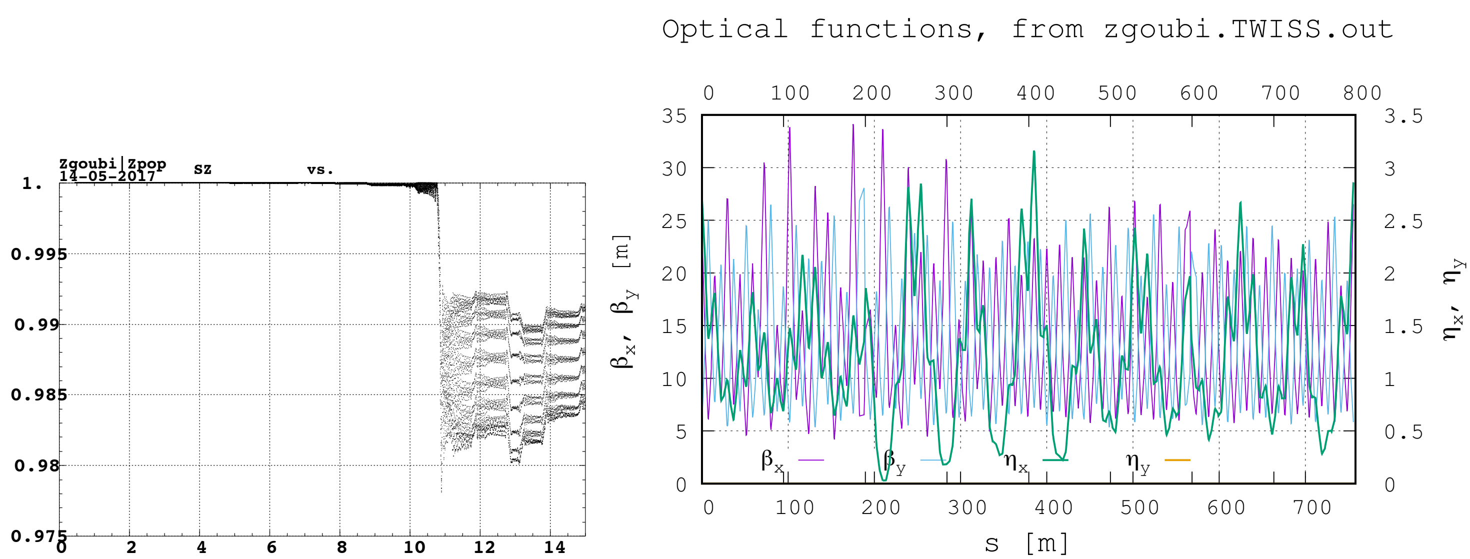

Figure 7: K1 error in bends. 17 particles, evenly on invariant $\epsilon_y/\pi = 100\,\mu$m normalized. K1 error is $\pm1\%$ random uniform in all main bends. The right plot shows the optical functions so obtained, for comparison with Fig. 2.

The table below gives the perturbed optics, for comparison with the unperturbed case page 6.
• Zgoubi

```
@ ALFA              %le    0.9881229300E-02

@ Q1                %le    0.6254805549       [+ integer]
@ Q2                %le    0.8250274850       [+ integer]
@ DQ1               %le    -37.66471269
@ DQ2               %le    -13.99874875
@ DXMAX             %le     3.16135583E+00    @ DXMIN             %le     2.82633051E-02
@ DYMAX             %le     0.00000000E+00    @ DYMIN             %le     0.00000000E+00
@ XCOMAX            %le     2.43336261E-03    @ XCOMIN            %le    -1.98725097E-03
@ YCOMAX            %le     0.00000000E+00    @ YCOMIN            %le     0.00000000E+00
@ BETXMAX           %le     3.41298678E+01    @ BETXMIN           %le     4.19935803E+00
@ BETYMAX           %le     2.80638369E+01    @ BETYMIN           %le     5.38178320E+00
@ DXRMS             %le     6.38282104E-01
```

4.1.4 Main bend roll

• The ERRORS command data for Fig. 8, K_0 roll $\in \pm 1^o$ (random, uniform) at all main bends :

```
 'ERRORS'
1 3 123466                      dVal
MULTIPOL{KCV}  1  BP A U 0.d0    0.0        0
MULTIPOL{B}    2  BP R U 0.d0    0.0        0
MULTIPOL{B}    1  ZR R U 0.d0    17.45e-3   0
```

"MULTIPOL{B}" stands for the 200 main bends found in the RCS lattice.

Figure 8 shows resonance crossing at all $a\gamma$=integer. This is due to the K_0 roll induced vertical orbit, *e.g.*, 9.9 mm rms for a 0.1 deg K_0 roll, Fig. 9.

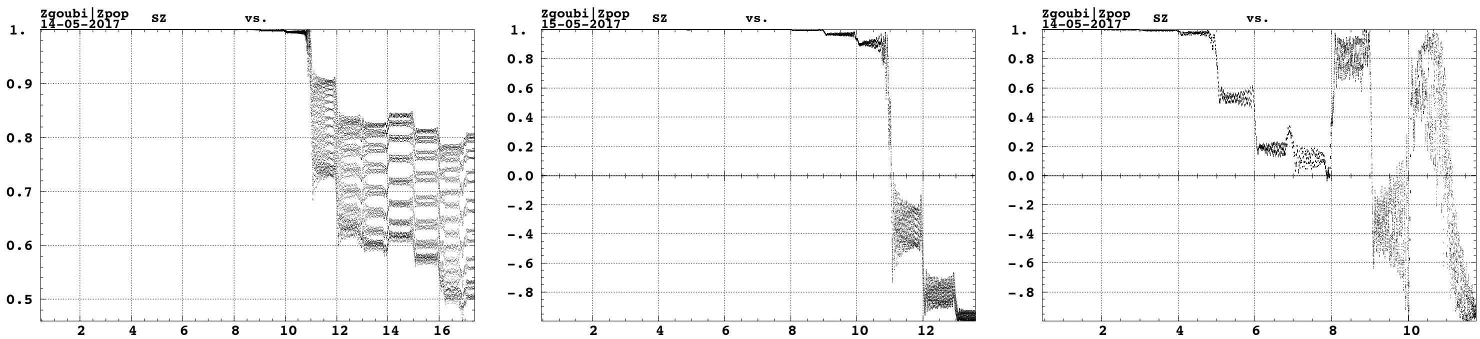

Figure 8: K_0 roll at all main bends. 17 particles, evenly on invariant $\epsilon_y/\pi = 100\,\mu$m normalized. K_0 roll angle $\in \pm 0.02^o$ (left), $\in \pm 0.1^o$ (middle), $\in \pm 1^o$ (right), random uniform.

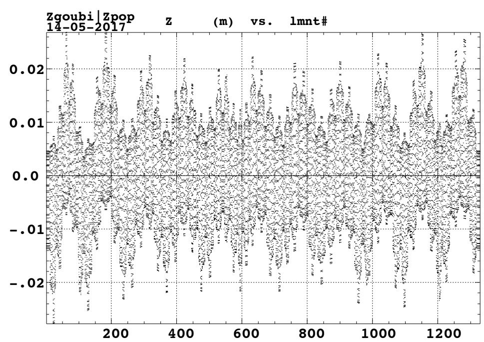

Figure 9: 10 mm rms vertical orbit induced by a 0.1 deg random K_0 roll error in the main bends.

4.1.5 All errors out

• The OBJET and ERRORS command data for Fig. 10 :

```
 'OBJET'                                                                                       1
0.66712601288720230E3    !     33.356409476265092E+03
8
1   17   1
0. 0. 0. 0. 0.  1.
0.089591   23.410413  2.5e-98
-0.145912    6.924692   25.e-8   ! *********
0.  1.  0.
 'PARTICUL'                                                                                    2
5.10998902E-01 1.60217653e-19 1.15965213627E-03 0. 0.
 'SPNTRK'                                                                                      3
3

 'FAISCEAU'                                                                                    4
 'FAISTORE'                                                                                    5
zgoubi.fai      ! ************
1

!'SRLOSS'                                                                                           6
! 0   srLoss
! MULTIPOL
! 1 123456

 'ERRORS'                                                                                      6
1 3 123466                        dVal
MULTIPOL{KCV}  1  BP A U 0.d0    200.       0   ! ************
MULTIPOL{B}    2  BP R U 0.d0    1e-2       0   ! ************
MULTIPOL{B}    1  ZR R U 0.d0    0.349e-3  0   ! ************
```

"MULTIPOL{B}" stands for the 200 main bends found in the RCS lattice.

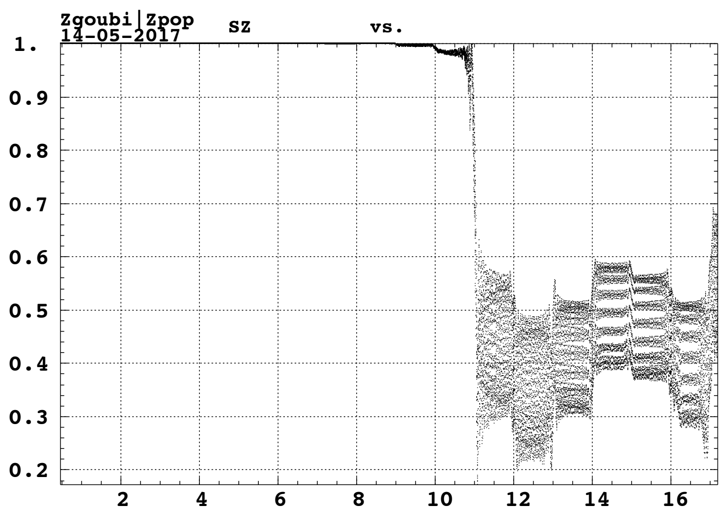

Figure 10: Errors include 1.2 mm rms orbit contribution from the 46 vertical kickers, dK1/K1 $\in \pm 1\%$ in all main bends, K_0 roll $\in \pm 0.02^o$ in all main bends, all random uniform. 17 particles, evenly on invariant $\epsilon_y/\pi = 100\,\mu$m normalized.