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Zgoubi-ing AGS : spin motion with snakes and jump-quads,Gγ = 43.5 through Gγ = 46.5 and beyond

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Collider Accelerator Department

Brookhaven National Laboratory

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C-AD/AP/453

Zgoubi-ing AGS : spin motion with snakes and jump-quads, $G\gamma = 43.5 \longrightarrow G\gamma = 46.5$ and beyond

A work performed at BNL in October and December 2009, in collaboration with
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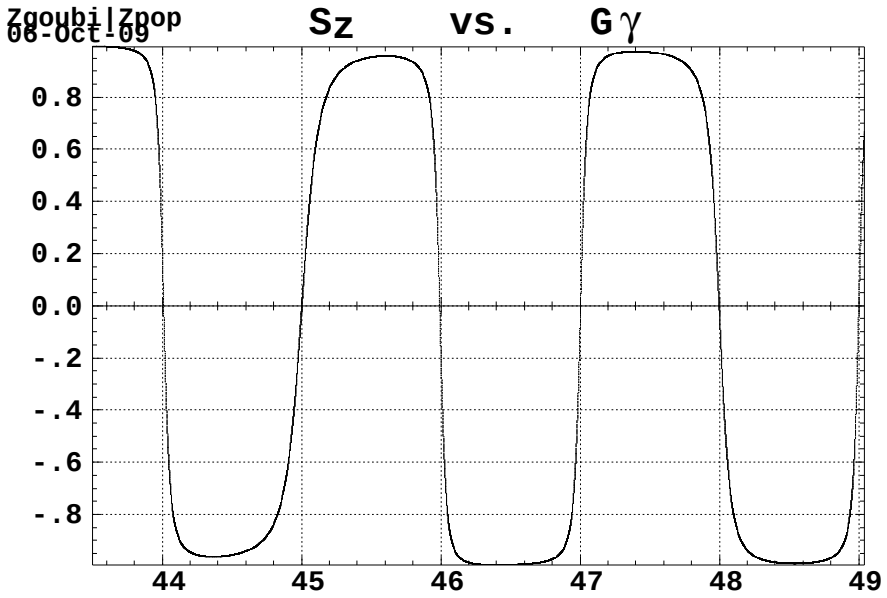


Abstract

This Note reports on the first, and successful, simulations of particle and spin dynamics in the AGS in presence of the two helical snakes and of the tune-jump quadrupoles, using the ray-tracing code Zgoubi.

It includes DA tracking in the absence or in the presence of the two helical snakes, simulation of particle and spin motion in the snakes using their magnetic field maps, spin flipping at integer resonances in the 36+Qy depolarizing resonance region (Figure above), with and without tune-jump quadrupole gymnastics. It also includes details on the setting-up of Zgoubi input data files and on the various numerical methods of concern in and available from Zgoubi.

This work is a follow-on of C-AD/AP/452.

Contents

1 Introduction

AGS with ν_x / $\nu_y = 8.72$ / 8.98 is tracked in presence of the Warm and Cold snakes, with or without tune-jump quadrupoles.

The report describes paraxial and large amplitude properties of the lattice, with snakes as well as without snakes when useful for comparison. A dedicated section addresses the properties of the snakes themselves, as drawn from ray-tracing using their OPERA magnetic field maps. Depolarizing resonance crossing and spin flipping, as well as effects of the tune-jump quadrupoles, are explored by accelerating from $\gamma G = 43.5$ to $\gamma G = 46.5$.

Table 1: AGS parameters from MAD8 (left col.), from Zgoubi "Brute from MAD8" without snakes (middle col.) and with warm and cold snakes (rightmost col.).

		MAD8 no snake	Ray-tracing Brute from MAD8[1] without snake	Ray-tracing Brute from MAD8[1] with w & c snakes
γG		non relevant	non relevant	43.5
Closed orbit length	(m)	807.075652[2]	807.04275[3]	807.04274
Qx, Qy		8.7200, 8.9800	[8].72132, [8].97774	[8].73016, [8].97827[(4,5)]
Q'x, Q'y		-22.4703, 2.6985	-22.5430, 2.6059	-24.844, 2.8446
$\alpha, \sqrt{1/\alpha}$		0.01390, 8.4829	0.0139, 8.470	0.01388, 8.4867
Periodic functions at entrance to "A1BF" :				
$\beta_x,\ \beta_y$	(m)	19.455, 9.682	19.583, 10.241	19.436, 10.036
$\alpha_x,\ \alpha_y$		-1.537, 0.808	-1.550, 0.865	-1.524, 0.843
D_x, D'_x	(m,-)	1.990, 0.120	1.977, 0.123	2.029, 0.126
D_y, D'_y	(m,-)	0, 0	0, 0	0.256, 0.0245
H closed orbit[(2)], x_{co}, x'_{co}	mm, mrad	0, 0	-6.110, -0.413	-5.834, -0.413
V closed orbit[(2)], y_{co}, y'_{co}	mm, mrad	0, 0	0, 0	-1.863, -0.087

(1) All magnets hard-edge, lack of B_s integral in bends is compensated by vertical kick $\delta y' = y * (-\tan(wedge) + FFL/(6.D0 * \rho * \cos(wedge)))$ with FFL=0 here following MAD data - taking $FFL \approx gap$ in Zgoubi changes ν_y by $\approx -10^{-3}$.
Integration step size in Zgoubi : (i) 1 cm in the snakes, (ii) 40 steps in the main dipoles.
(2) MAD uses 'SBEND' for main bends, see App. A.2.
(3) The difference in orbit lengths here arises from the treatment of the closed orbot. The actual theoretical length is 807.09 m, see footnote.
(4) Data obtained from first order mapping.
(5) Data obtained from multiturn and Fourier analysis.

2 Lattice

2.1 Paraxial parameters

The left column in Tab. 1 displays the general optical parameters of AGS bare lattice as obtained from MAD8, without snake. Details concerning respectively MAD input/output data can be found in App. A.1/App. A.3.

Zgoubi input optics file (so-called "zgoubi.dat") is obtained by translation from MAD8 "survey" type of output or MADX "twiss" type of output (an automatic translator is available). Parameter values so obtained with the bare lattice are given in the middle column in Tab. 1 for comparison with MAD ones. Sample zgoubi.dat can be found in Apps. B.1. Note that both Zgoubi and MAD sets of orbit as well as first and second order parameter values have later been brought to very good agreement[1].

[1](i) The ≈ 3.2 cm difference in orbit length arises from the treatment of the reference closed orbit which does not coincide with the

The rightmost column in Tab. 1 gives machine parameters in presence of the two snakes at $\gamma G = 43.5$, snakes' chacteristics are addressed in Sec. 3.

Horizontal and vertical closed orbits in the presence of the snakes are shown in Fig. 1.

Table 2: A list of the depolarizing resonances in the range $43 \leq \gamma G \leq 47$ and beyond. $\nu_x = 8.7302$, $\nu_z = 8.9783$.

Imperfection resonances			
	γG	T	$B\rho$
	43	21.56543	74.99899
	44	22.08877	76.74614
	45	22.61211	78.49324
	46	23.13545	80.24029
	47	23.65879	81.98726
	48	24.18213	83.73419
	49	24.70548	85.48106
	50	25.22882	87.22788
	51	25.75216	88.97466
Intrinsic resonances			
$M \pm \nu_z$	$G\gamma$	T	$B\rho$
52-ν_z	43.02170	21.57678	75.03689
35+ν_z	43.97830	22.07741	76.70824
53-ν_z	44.02170	22.10012	76.78407
36+ν_z	44.97830	22.60075	78.45534
54-ν_z	45.02170	22.62346	78.53116
37+ν_z	45.97830	23.12410	80.20238
55-ν_z	46.02170	23.14680	80.27818
38+ν_z	46.97830	23.64744	81.94936
56-ν_z	47.02170	23.67015	82.02516
Intrinsic resonances, coupled			
$M \pm \nu_x$			
52 $-\nu_x$	43.26980	21.70662	75.47037
35 $+\nu_x$	43.73020	21.94757	76.27477
53 $-\nu_x$	44.26980	22.22996	77.21751
36 $+\nu_x$	44.73020	22.47091	78.02188
54 $-\nu_x$	45.26980	22.75331	78.96460
37 $+\nu_x$	45.73020	22.99425	79.76894
55 $-\nu_x$	46.26980	23.27665	80.71162
38 $+\nu_x$	46.73020	23.51760	81.51594

"Optimum Closed Orbit" (so-called "OCO"), in the present work. The theoretical length of the OCO is 807.09 m, this has been settled in further works, see PAC and IPAC Conference papers, 2010, 2011. (ii) Details on the numerical results and the agreement between MAD and Zgoubi, as long as both codes are given input data that describe the same optics (regardless of the ability of matrix-formalism type of input data to accurately model the real AGS), can be found in IPAC and PAC publications, 2010, 2011

2.2 Spin $\vec{n}$-vector

The spin precession $\vec{n}$-axis is obtained from the ray-tracing by FIT-ting (getting identical) final and initial spin coordinates for the ideal particle (travelling on the on-momentum closed orbit).

The corresponding zgoubi.dat are given in App. B.4.

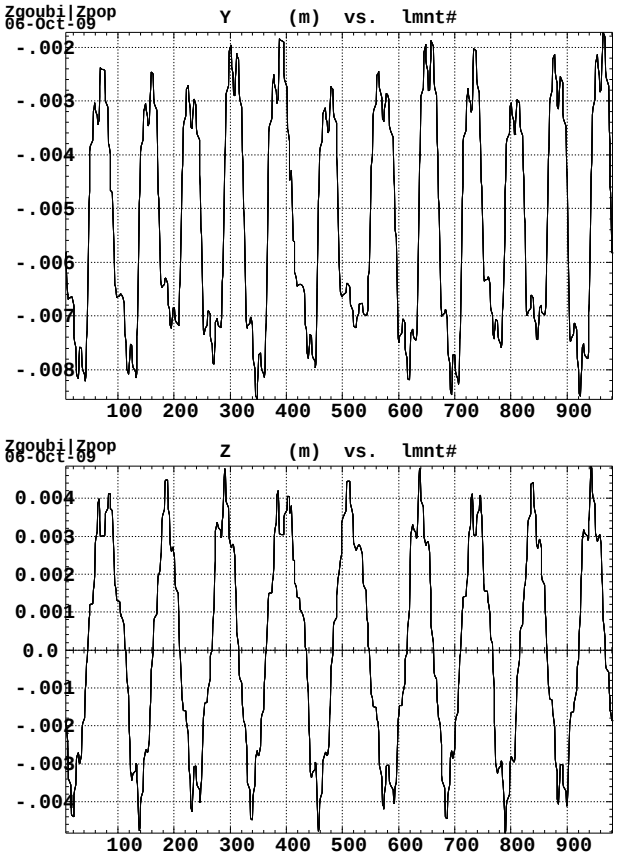


Figure 1: H and V closed orbits in presence of w- and c-snake, recorded at ∼990 different locations along the ring circumference. (closed orbits have later been brought to zero, based on introducing the OCO in Zgoubi data - see footnote page 1.)

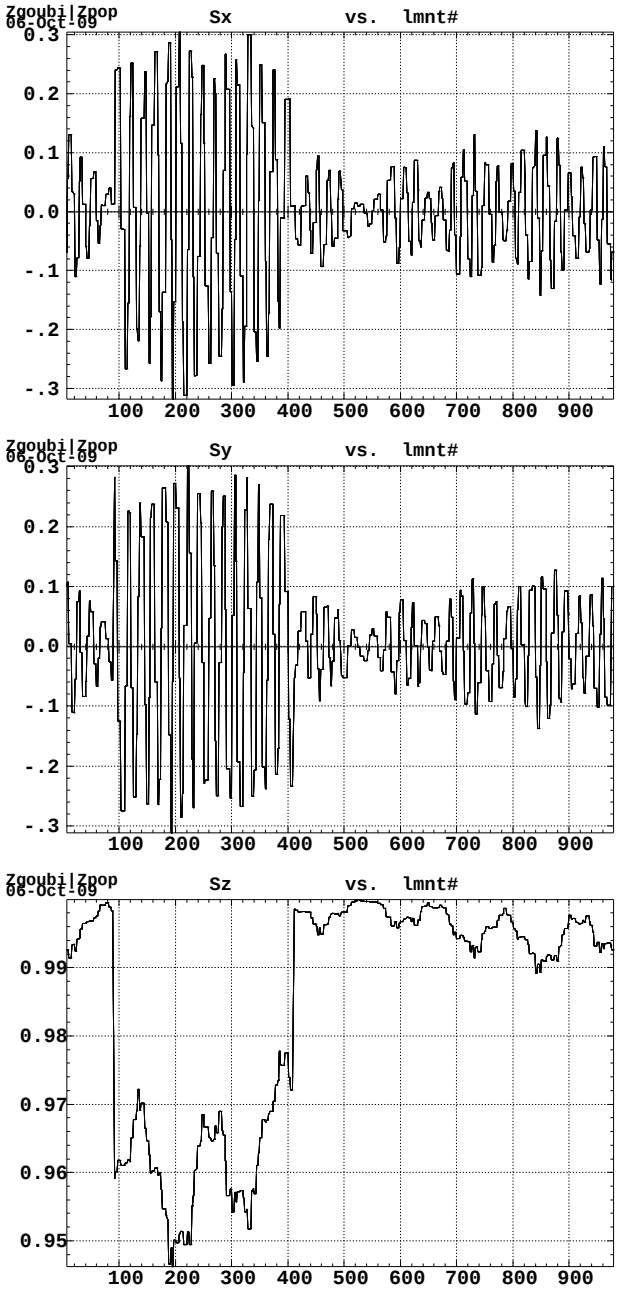


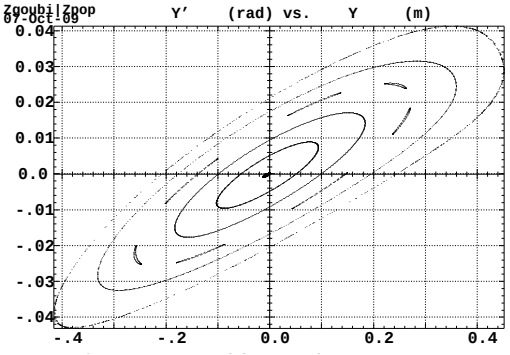
Figure 2: Components of the spin $\vec{n}$-axis in presence of w- and c-snake, as recorded at ∼990 locations along the ring circumference.

2.3 Large amplitude motion

Integration step size in the following is 1 mm in w- and c-snake 2-D field maps and about 5 cm in main dipoles.

Dynamic aperture in the $\nu_y = 8.98$ bare lattice, no snake

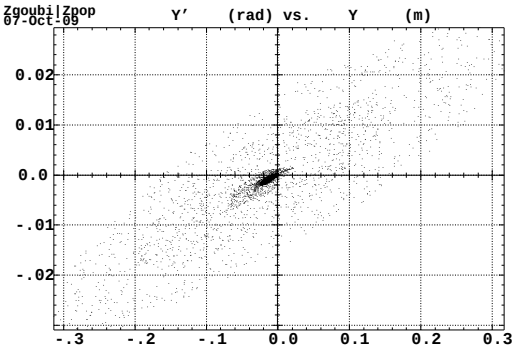
The phase-space portraits in Figs. 3,4 show the maximum stable amplitudes together with intermediate invariants, in the bare lattice without snake (conditions of the middle column in Tab. 1, “ray-tracing, without snake”).
Amplitude detuning is shown next to the plots.
Dynamic aperture is shown in Fig. 5.

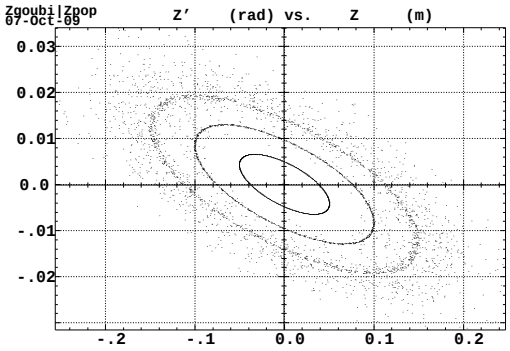


Detuning, from smaller to larger H-amplitude :

Qx	Qy	
7.212472	9.778009	paraxial
7.017703		
6.521219		
5.713944		
5.327142		
7.270152		

Figure 3: 1000-turn maximum stable amplitudes without snake.
Six H invariants ranging from ∼0 to stability limit launched with $\epsilon_y = 0$ (left).
V motion is zero, no $H \rightarrow V$ coupling.





Detuning, from smaller to larger V-amplitude :

Qx	Qy	
0.7254081	0.9770309	paraxial
0.7272465	0.9742884	
0.7322278	0.9671178	
0.7407944	0.9558546	
0.7527732	0.9414990	
0.7513091	0.9361446	

Figure 4: 1000-turn maximum stable amplitudes without snake.
Six V invariants ranging from ∼0 to stability limit launched with $\epsilon_x = 0$ (right) ; induced H motion (left).

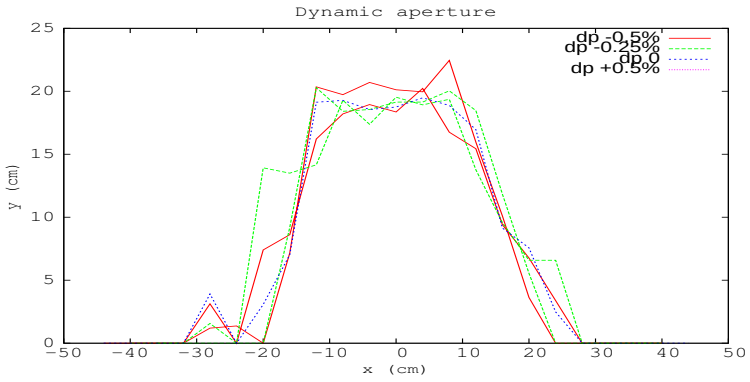
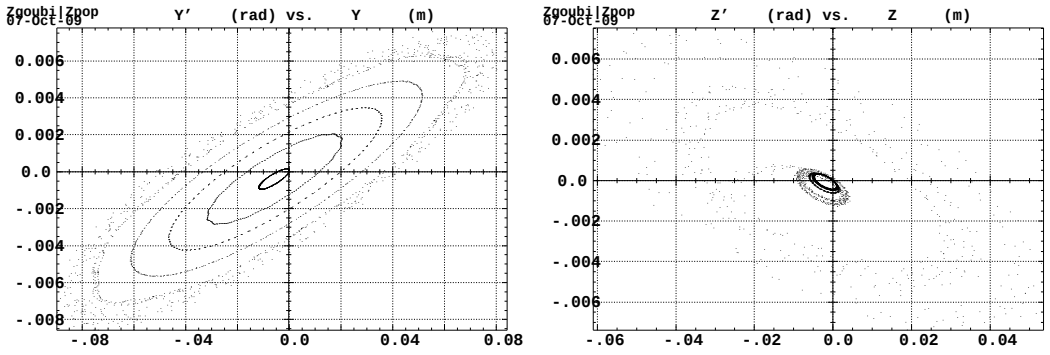


Figure 5: Dynamic apertures without snake.

Dynamic aperture in presence of w- and c-snake, $E = 43.5 M_0/G$

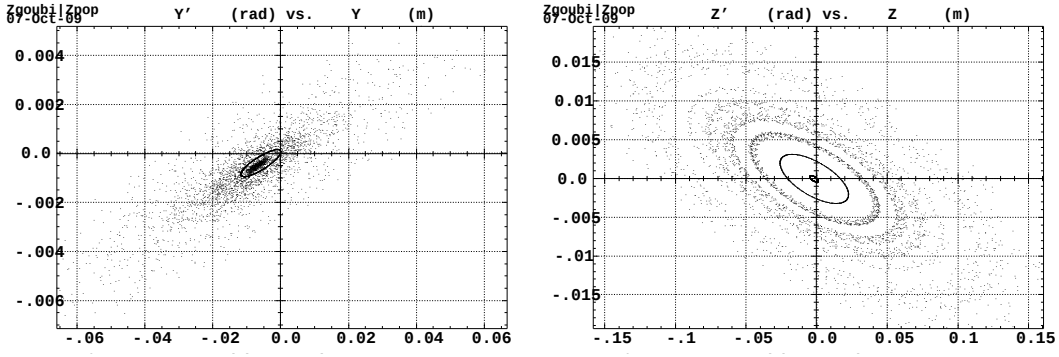
The phase-space portraits in Figs. 6,7 show the maximum stable amplitudes together with intermediate invariants (conditions of the rightmost column in Tab. 1, "ray-tracing, with w & c snakes"). Coupling induces substantial motion from x into y, and reciprocally.
Amplitude detuning is shown next to the plots.



Detuning, from smaller to larger H-amplitude.

Qx	Qy	
7.230739	9.780097	paraxial
7.225548	9.792151	
7.204175	9.811331	
7.173064	9.839407	
7.134487	9.873802	
7.134806	9.863376	

Figure 6: 1000-turn maximum stable amplitudes in presence of w- and c-snake.
Six H invariants ranging from ∼0 to stability limit launched with $\epsilon_y = 0$ (left) ; induced V motion (right).



Detuning, from smaller to larger V-amplitude.

Qx	Qy	
7.230983	9.780104	paraxial
7.261513	9.761524	
7.268293	9.712433	
7.321305	9.656905	
7.391639	9.582119	
7.566290	9.110742	

Figure 7: 1000-turn maximum stable amplitudes in presence of w- and c-snake.
Six V invariants ranging from ∼0 to stability limit launched with $\epsilon_x = 0$ (right) ; induced H motion (left).

Dynamic aperture in presence of the snakes is shown in Fig. 8. Comparison with DA in the bare lattice without snake, Fig. 5, shows that these have a substantial effect.

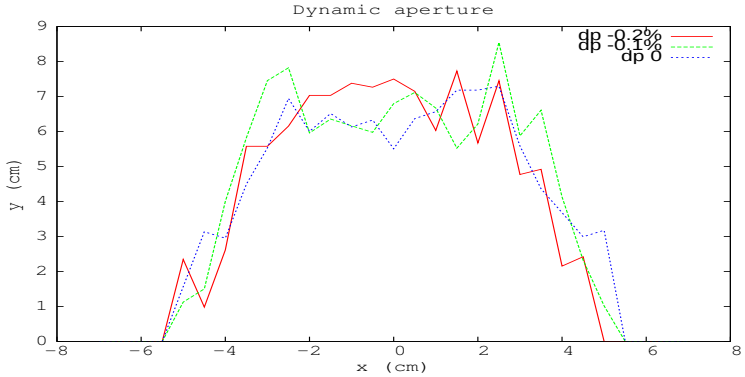


Figure 8: Dynamic apertures in presence of w- and c-snake, for $\delta p/p = 0, \ \pm 0.1\%, \ \pm 0.2\%$, 5 mm step in x, 1 mm precision on vertical boundary.

3 W and C snakes, $E = 43.5 M_0/G$

Basic behavior of magnetic field and of particle and spin motion in w- and c-snake is checked.

W-snake is represented by the 3-D field map "table55.tab". In the AGS lattice file zgoubi.dat, it is encompassed within two negative 0.5 m drifts so to fit into the 3 meters space allotted. C-snake is represented by the 3-D field map "ref+sole.tab". Tracking in Zgoubi is performed using the "TOSCA" procedure ; input data files can be found in App. B.3.

Field components, particle motion and spin motion, along w-snake, are represented in Fig. 9. C-snake ones are represented in Fig. 10.

When used in the ring, W-snake field has the strength shown in Fig. 9, C-snake field has a strength attenuated by 0.7 compared to Fig. 10. Note that for multiturn tracking reported in the other Sections in this paper, midplane 2-D field maps extracted from respectively "table55.tab" "ref+sole.tab" are used rather than the 3-D ones, this yields as good results and has the merit of much smaller data volume, faster reading.

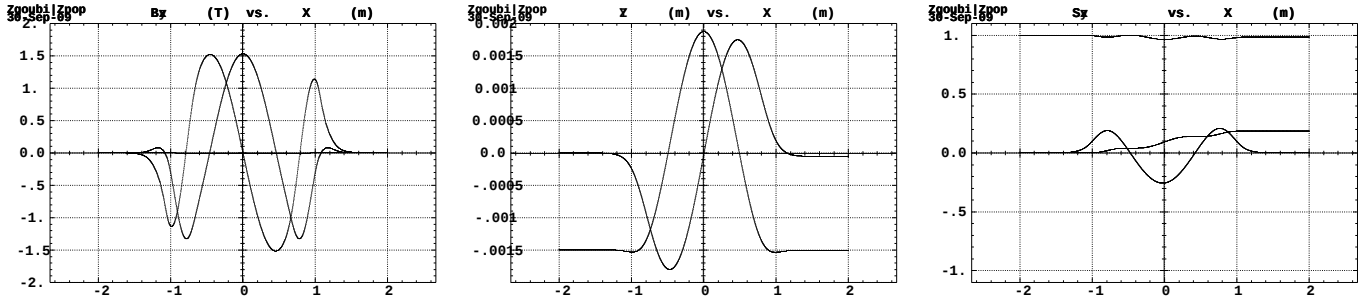


Figure 9: Warm snake, particle with $\gamma G = 43.5$ launched in "table55.tab" with x=-1.5 mm, y=0, x'=y'=0. Bx,By,Bz (left), x,y (middle) and Sx, Sy, Sz (right).

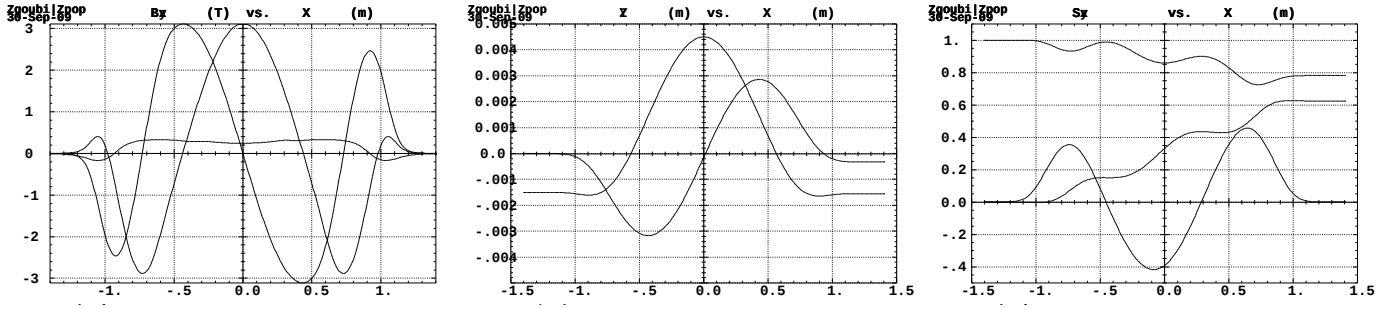


Figure 10: Cold snake with solenoid, particle with $\gamma G = 43.5$ launched in "ref+sole.tab" with x=-1.5 mm, y=0, x'=y'=0. Bx,By,Bz (left), x,y (middle) and Sx, Sy, Sz (right).

4 Spin tracking, $\gamma G = 43.5 \rightarrow 49$

How long that takes : ~ 0.15 second per turn, *real time*, on a DELL Latitude D630 laptop, hence ~ 50 min. for the present 20000-turn run[2].

Working hypothesis in the numerical simulations are the following (see zgoubi.dat in App. B.2).

Total potential $\hat{V} = 290$ kV

Synchronous phase $\phi_s = 150$ degrees

hence energy gain $\Delta E = 145$ keV/turn, then, given $M_0 = 938.27203$ MeV, $G = 1.7928474$

$$\alpha = G\frac{d\gamma}{d\theta} = G\,\frac{1}{2\pi}\frac{\Delta E}{M_0}$$

$\boxed{\alpha = 4.4096356\,10^{-5}}$.

Besides,

$\dot{B} = \Delta E \,/\, (2\pi R\rho) = \Delta E \,/\, (\mathcal{C}\rho)$

Given

$\mathcal{C} = 807.043$ m (Tab. 1)

and $1/\rho = B/B\rho = 0.0117125$, cf. dipole component in 'SBEN' type of magnets, zgoubi.dat file in App. B.1

(Note : $\rho = 85.3785$, packing factor $R/\rho = 9.45254$), then

$\boxed{\dot{B} = 2.104 \text{ T/s}}$

Acceleration from $\gamma G = 43.5$ to $\gamma G = 46$ requires ∼10000 turns, the experiment is pushed to 20000 turns and $\gamma G = 49$. Resonances in that energy region are given in Tab. 2, all imperfection resonances but for $\gamma G = 36 + \nu_z \approx 44.98$.

4.1 Zero emittance

We consider ϵ_x and $\epsilon_y \approx 0$ in this Section.

Spin tracking results are shown in Fig. 11.

Fig. 12 allows monitoring (correctness of) particle dynamics, it can be observed that the particle stays near H and V closed orbits and synchronous phase over the 20000 turns.

[2]For comparison with SPINK : following talks at spin meeting on Oct. 2nd, SPINK takes about 10 hours for $6\,10^5$ turns

S_x, S_y, S_z **versus** $G\gamma$, **for** ϵ_x **and** $\epsilon_y \approx 0$

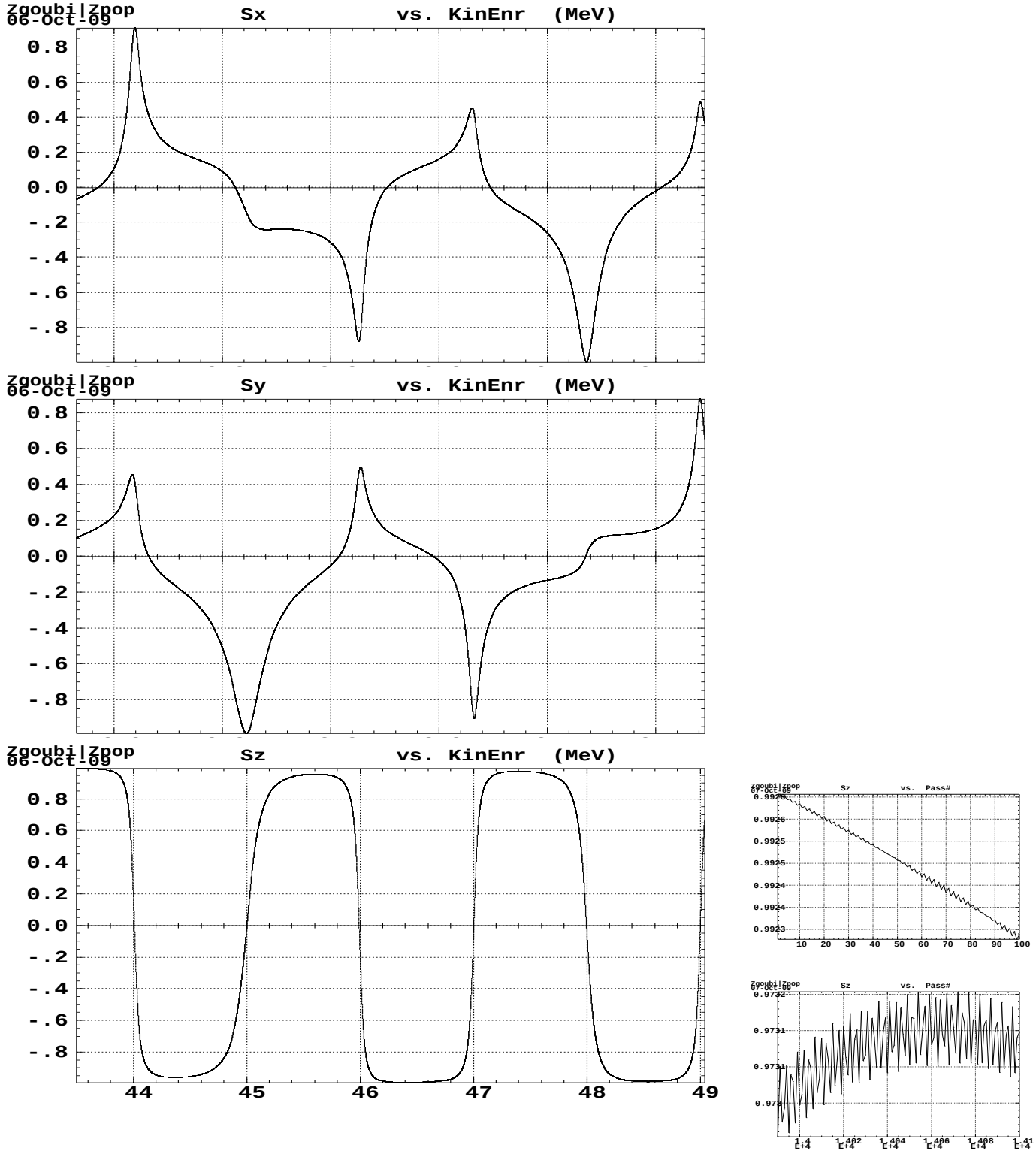


Figure 11: Spin motion experienced by the synchronous particle in presence of w- and c-snake, over $G\gamma \ : \ 43.5 \rightarrow 49$.
The figure shows the spin components S_x (longitudinal), S_y (radial), S_z (vertical) (from top to bottom) observed in an arc over 20000 turns.
The two smaller boxes, lower-right, zoom on the fine structure : initial S_z over the first 200 turns (top box) and S_z over 200 turns in $\gamma G = 47.5$ region (bottom box)

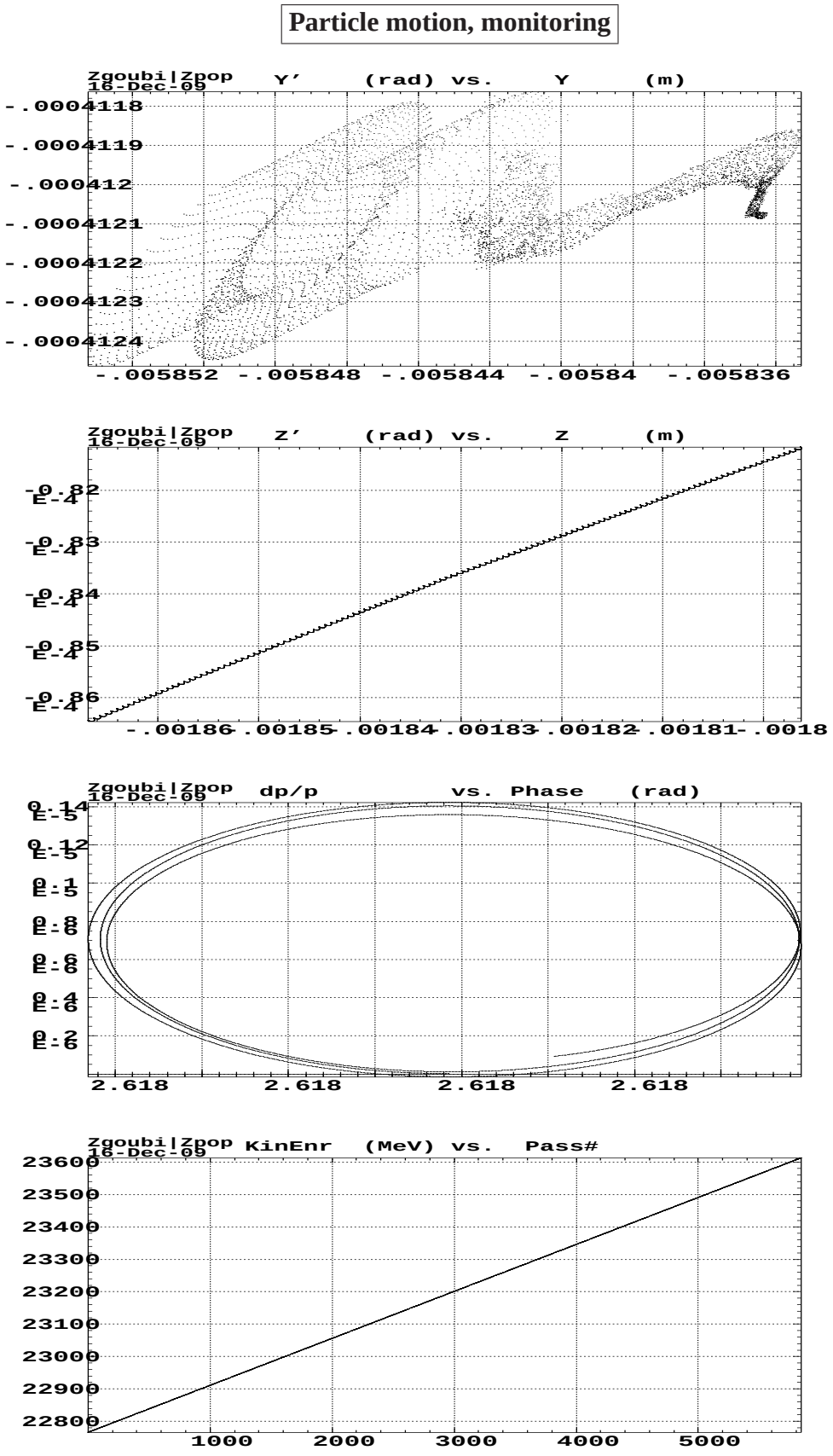


Figure 12: Particle motion. Top : x, x', middle-up : z, z' ; middle-down : phase-dp/p ; these three graphs show good symplectic behavior. Bottom : kinetic energy versus turn number.

4.2 Non-zero horizontal emittance

We consider $\beta\gamma\epsilon_x = 20\pi$ mm.mrad and starting $\epsilon_y = 0$ (not for long : H-V coupling due to the snakes induces V motion) in this Section. Spin tracking results are displayed in Fig. 13. Particle dynamics behavior is monitored in Fig. 12.

S_x, S_y, S_z **versus** $G\gamma$, **for** $\beta\gamma\epsilon_x = 20\pi$ **mm.mrad and** $\epsilon_y \approx 0$

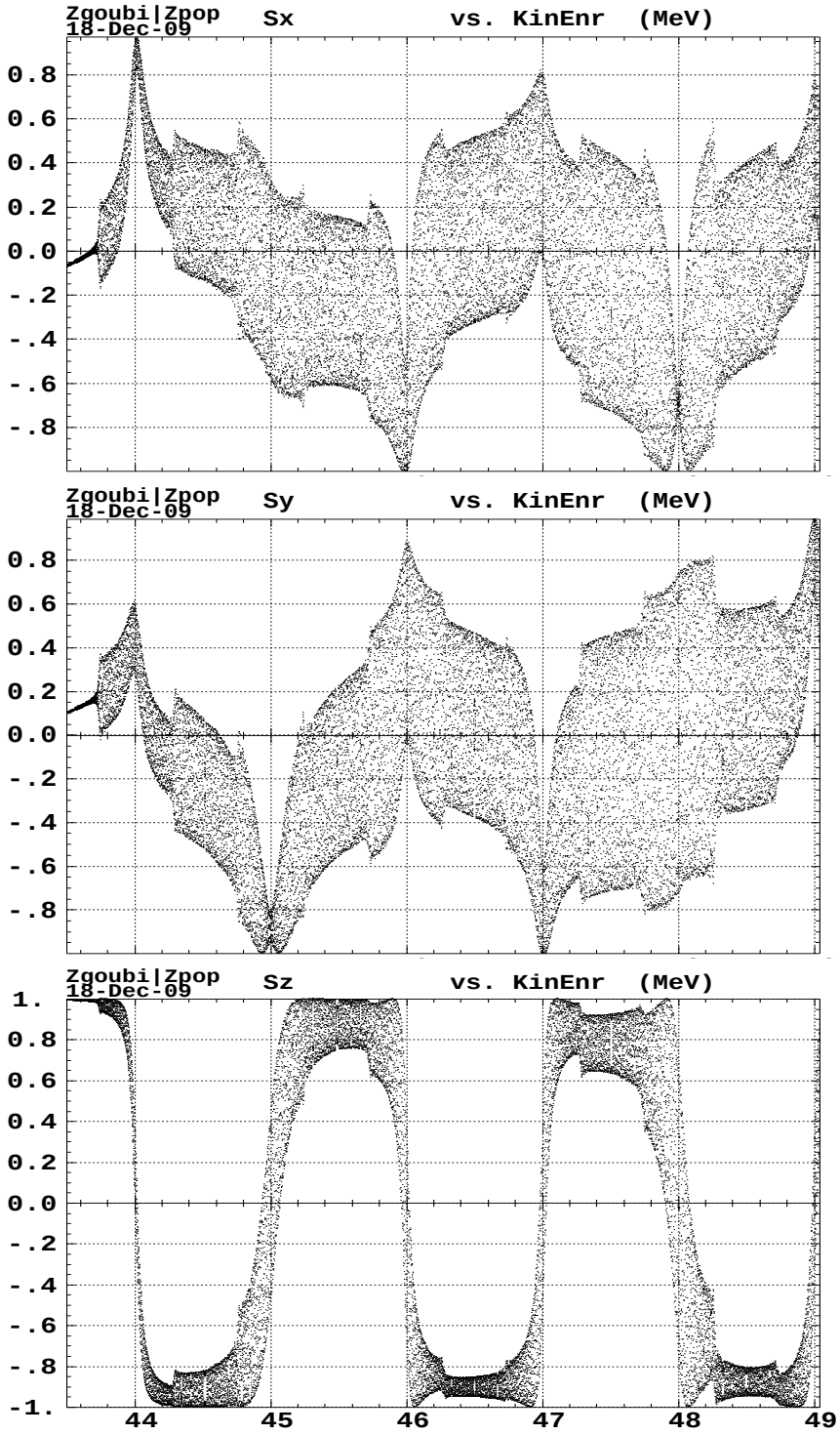


Figure 13: Spin motion experienced by the synchronous particle in presence of w- and c-snake, over $G\gamma : 43.5 \rightarrow 49$.
The figure shows the spin components S_x (longitudinal), S_y (radial), S_z (vertical) (from top to bottom) as recorded in an arc.
The bottom graph clearly shows the effect of spin coupling resonances at $G\gamma \pm Q_x =$integer.

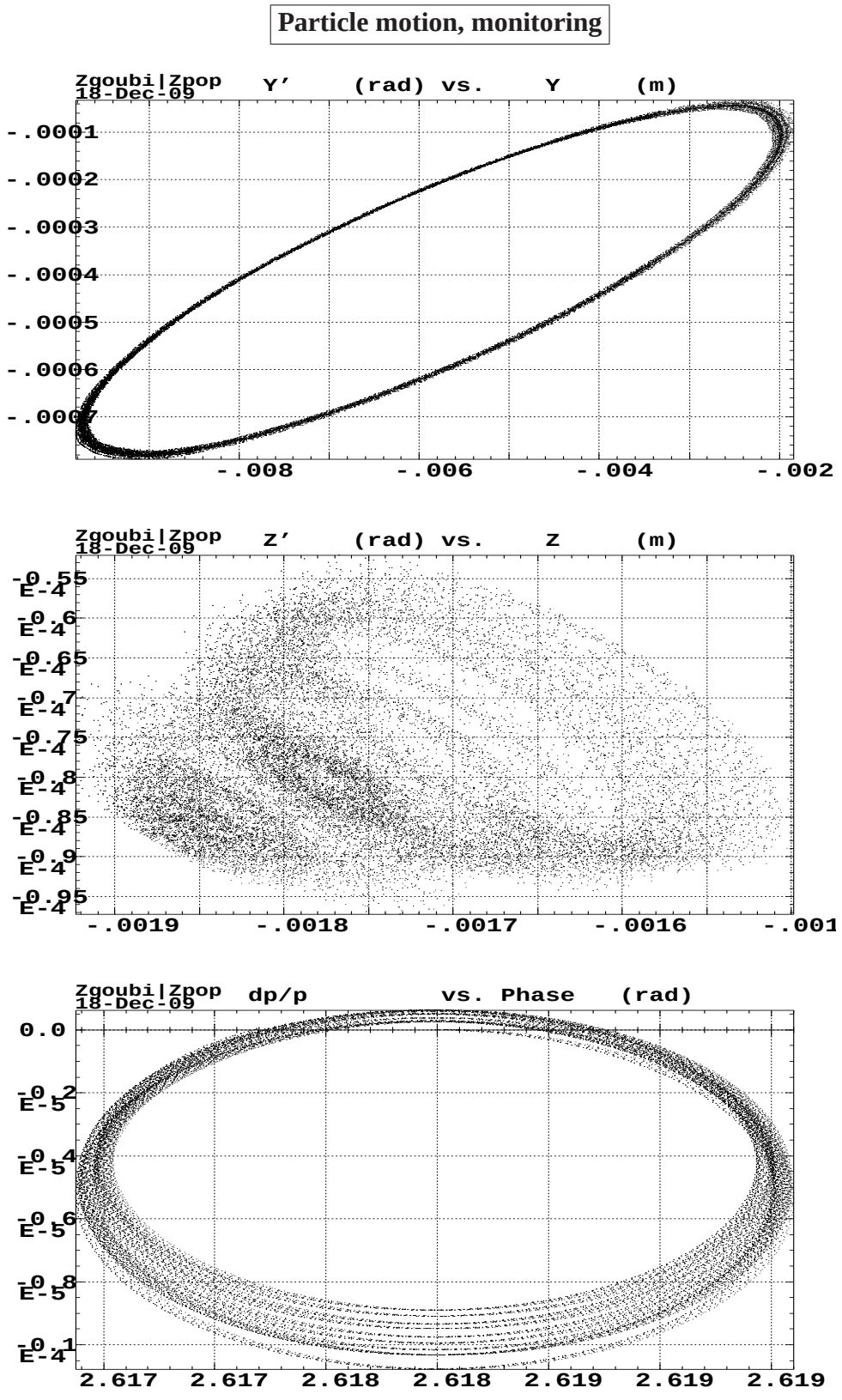


Figure 14: Particle motion, symplecticity. Top : x, x', middle : z, z' ; bottom : phase-dp/p. H-V coupling (the snakes are the cause) induces V motion.

5 Spin tracking, $\gamma G = 43.5 \rightarrow 49$, including Q-jump

Conditions are the same as in Section 4.2, in particular $\beta\gamma\epsilon_x = 20\pi$ mm.mrad and starting $\epsilon_y = 0$.

A Q-jump scheme is added, causing $\Delta\nu_x = 0.04$, namely $\nu_x : 8.73 \rightarrow 8.77$ (and also, since H and V controls are not fully separated, $\nu_y : 8.9783 \rightarrow 0.9636$).

It uses two quads, `QJUMI` at I5A and `QJUMJ` at J5A. Their strengths satisfy K[`QJUMJ`] = K[`QJUMI`], and approximately K[`QJUMI`] + K[`QJUMJ`] $\approx \Delta\nu_x/\beta_x$, with $\beta_x \approx 25.65$ m at both quads.

Typical cycling of the two quads is shown in Fig. 15. Zgoubi allows free access to the starting point of the cycle ($G\gamma = 43$ here), to the center point of the ramp in a period of the cycle (0.25 from the integer here), and to the length of the ramp (± 20 turns around center point, here). The cycle is obtained using the '`SCALING`' procedure, a new 'function generator' option, '-87', has been introduced for that - details concerning the input data (the content of zgoubi.dat) can be found on the next page and in App. B.5.

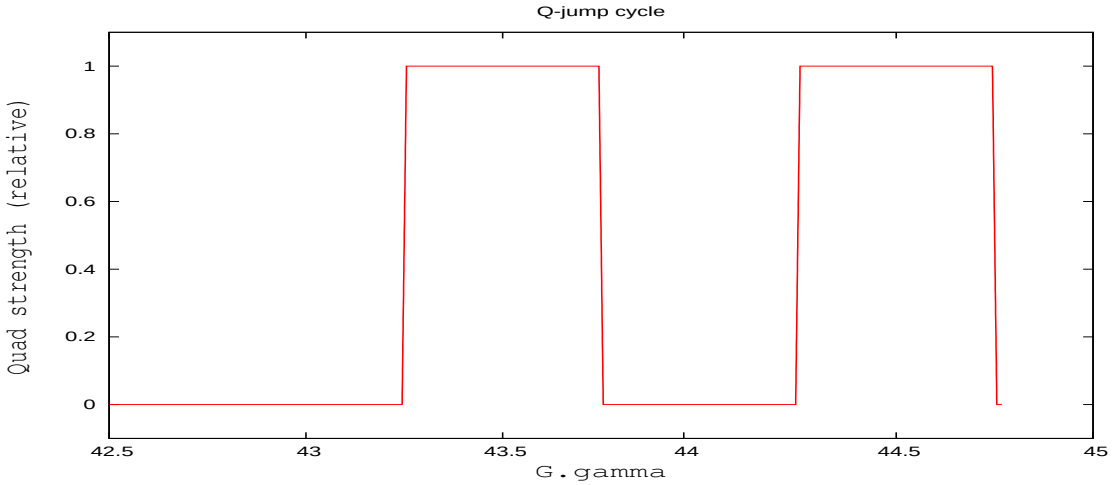


Figure 15: Q-jump cycle, causing $\nu_x : 8.73 \rightarrow 8.77$. The ramp up is centered at $N + 0.25$, the ramp down at $N + 0.75$, ramping in 40 turns.

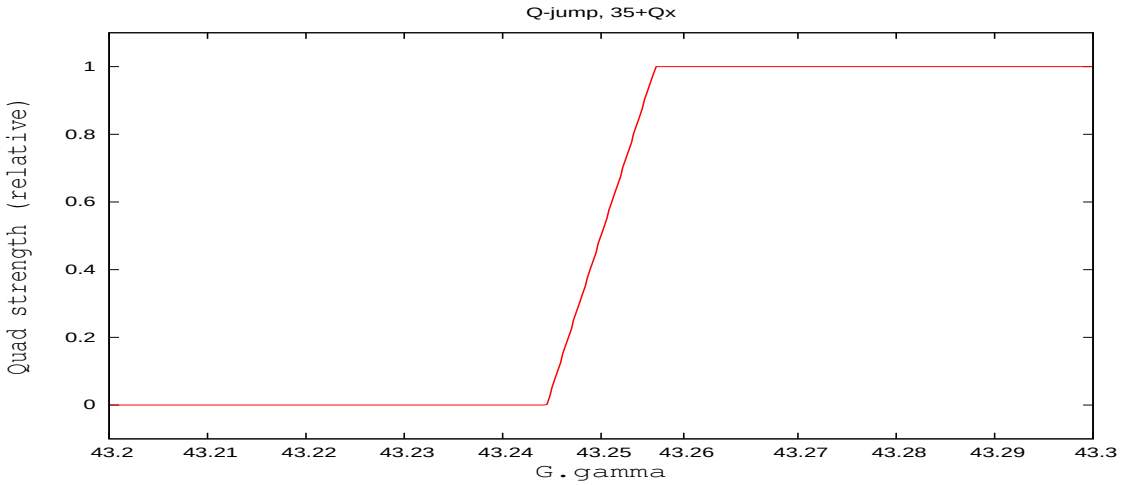


Figure 16: A zoom on the $35 + \nu_x$ region. The ramp up here is centered at +0.25 from the integer.

Input data to Zgoubi, allowing a ramp in two jump quadrupoles QJUMI, QJUMJ.

This 'function generator' is based on the existing '`SCALING`' keyword. An option ('-87') and three knobs (see below) have been added to allow control of the jump.

In the example below, Qjump cycling starts when $G\gamma = 43$, the ramps are centered at +0.25 (ramp up) and -0.75 (ramp down) from all subsequent integer $G\gamma$. The ramp length is 40 turns.

```
Data generated by searchCO
'OBJET'                                                                                                  1
75.8725752916200e3
2
1  1                    CLOSED ORBIT COORDINATES :
 -5.834246E-01 -4.120793E-01  -0.18669206     -8.64476501E-02  0.0E+00  1.00000000E+00   'o'
1
 'FAISCEAU'                                                                                              2
  'SCALING'             FUNCTION GENERATORS
  1  3
   MULTIPOL SBEN               MAIN BENDS
   -1
   75.8725752916200            field factor
   1
   MULTIPOL QUAD               QUADRUPOLES  (UNUSED)
   -1
   75.8725752916200            field factor
   1
   MULTIPOL QJUMI QJUMJ        JUMP QUADS
   -87
  75.8725752916200             field factor
   43 0.25 40                  43=starting G.gamma, N+/-0.25=center of ramp, 40 turns=length of ramp
 'PARTICUL'                                                                                              4
 938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
'MARKER'   #Start                                                                                        5
'MULTIPOL' SBEN      A1BF                                                                                6
0  .Dip
 200.6554  10.00   0.11712499   0.04844450  -0.00053604 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 #20|200|20    Dip A1BF
           3   0.    0. -1.175115045000000E-002
.............
'MULTIPOL'   QJUMI       Betax, Alphax :  2.5743E+01 -1.9636E-01,   Betax, Alphax : 8.9566                691
0  .Quad                 xco = -0.84698959, yco=-0.26546500
  76.1927 10.00    0.0  0.01514 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 #30|76|30    Quad  QJUMI
2 0.  -0.8443957063  0.
.............
'MULTIPOL'   QJUMJ    2.37xQJUMI   Betax, Alphax:  2.5599E+01 -1.0912E-01,  Betay, Alphay:             768
0  .Quad     xco=-0.74307103, yco=-0.10033425      3.37*kl=4pi*dQ/betx=4pi*0.04/25.6=0.01963    b1(T)=Brho*(k
  76.1927 10.00    0.0  0.01514  0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 #30|76|30    Quad  QJUMJ
2 0.  -0.7406596043
.............
  'CAVITE'                                                                                               985
  2   .1                          .1 is to fill zgoubi.CAVITE.Out for plot using zpop/7/20
  807.042748   12.
  290.d3  2.617993877991494365       9cavitiesx32kV, phi_s=150deg
 'MARKER'  #End                                                                                         986
'SPNPRT'                                                                                                 987
'FAISCEAU'                                                                                               988
'REBELOTE'                                                                                               989
 19999 0.2 99
'END'                                                                                                    990
```

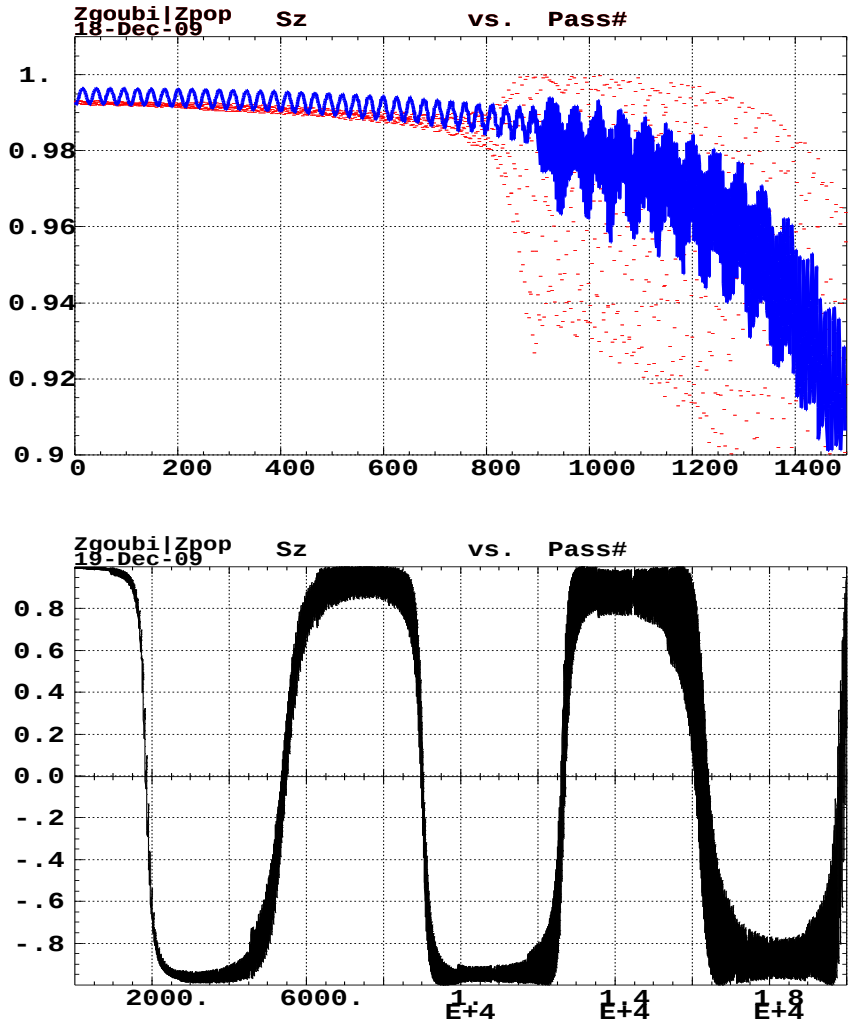


Figure 17: Vertical projection of $\vec{S}$.
Top : single particle, a zoom on the $\nu_s = 35 + \nu_x$ region, with (blue dots) and without (red dots) Q-jump.
Bottom : single particle, acceleration from $G\gamma = 43.5$ to $G\gamma = 49$ in presence of Q-jump at all $G\gamma \pm \nu_x$.

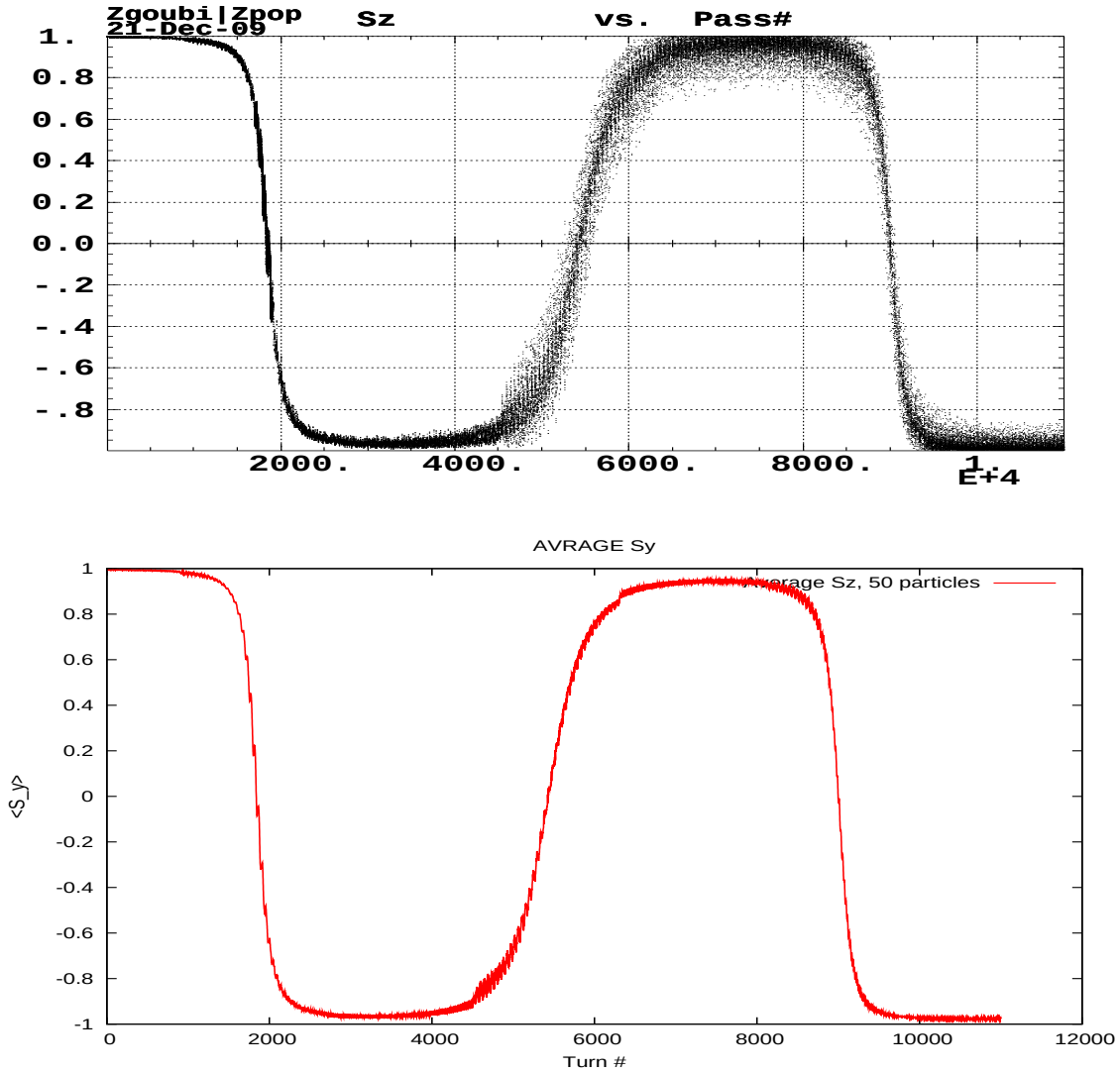


Figure 18: Vertical projection of $\vec{S}$, 50 particles taken at random in horizontal Gaussian distribution with $\beta\gamma\epsilon = 2.5\pi$ mm.mrad.
Top : all 50 cases $S_z(turn\#)$ are superimposed,
Bottom : average over the 50 particles, turn by turn.

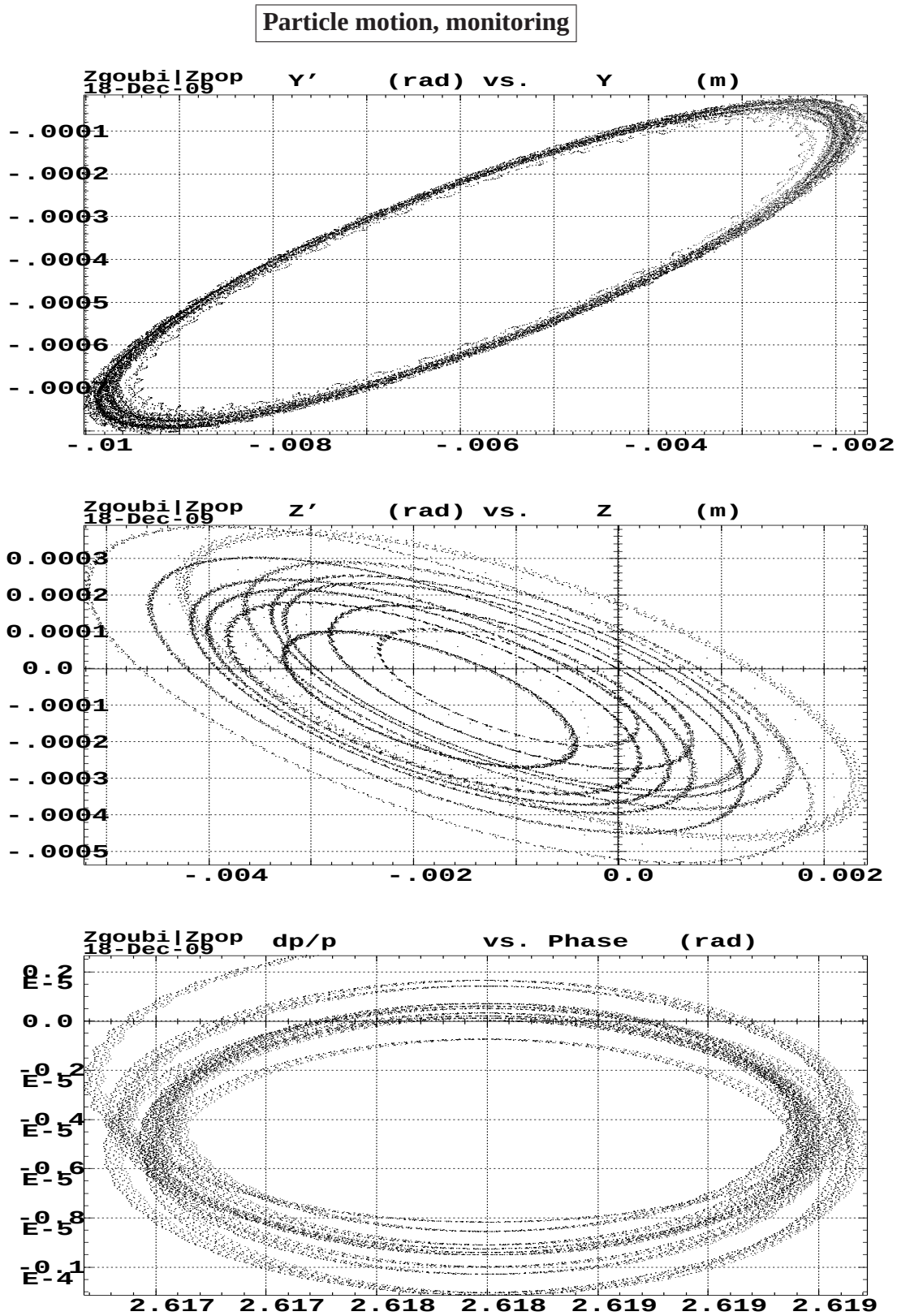


Figure 19: Particle motion, 20000 turns. Top : x, x', middle : z, z' ; bottom : phase-dp/p.
Note that, (i) the vertical emittance is not zero, this is due to coupling with (x,x') induced by the snakes ; (ii) the jump quadrupoles have not been vertically aligned, so that the jump causes a shift of the vertical ellipse in the (z,z') phase space.

Improving beam dynamics

Non-zero horizontal closed orbit causes the quasi-zero vertical phase space portrait of Fig. 14 as obtained with jump quads off, to transform when jump quads are on into the vertical phase space portrait of Fig. 19 which shows both closed orbit effects (in particular the vertical closed orbit jumps during the on/off cycling of the quads) and induced vertical emittance. This behavior is due to H/V coupling induced by the snakes, correlated with so induced vertical closed orbit in the jump quads,

In the case of Fig. 19 the jump quadrupoles `'QJUMI'` and `'QJUMJ'` are centered onto their local horizontal closed orbit (by respective $\Delta x = -0.8443$ cm and $\Delta x = -0.7406$ cm, see data on page 16). Introducing further vertical centering of `'QJUMI'` and `'QJUMJ'` (respectively $\Delta y = -0.8443$ cm and $\Delta y = -0.7406$ cm, see page 22) does improve the vertical phase space portrait, see Fig. 21, namely, yielding quasi-zero phase portrait, closer to the jump quad free case shown in Fig. 14.

Matching H and V closed orbits to zero is performed using the '`FIT`' procedure, see next page.

A new type of argument to the `'CHANGREF'` procedure in Zgoubi (up to recently limited to X-, Y-shift and Z-rotation) has been developed for that purpose. It allows arbitrary sequence of up to 9 transforms, X-, Y-, Y-shift and X-, Y-, Z-rotation. Details on page 16.

Resulting spin behavior is displayed in Fig. 22. Clearly improvement is observed by comparison with Fig. 17, as to preservation of the polarization over $G\gamma \ : \ 43.5 \to 49$. Note that the spin vector is better matched at start as a consequence of zero-er closed orbit (initial particle as well as spin coordinates unchanged, same as in the case of Fig. 17).

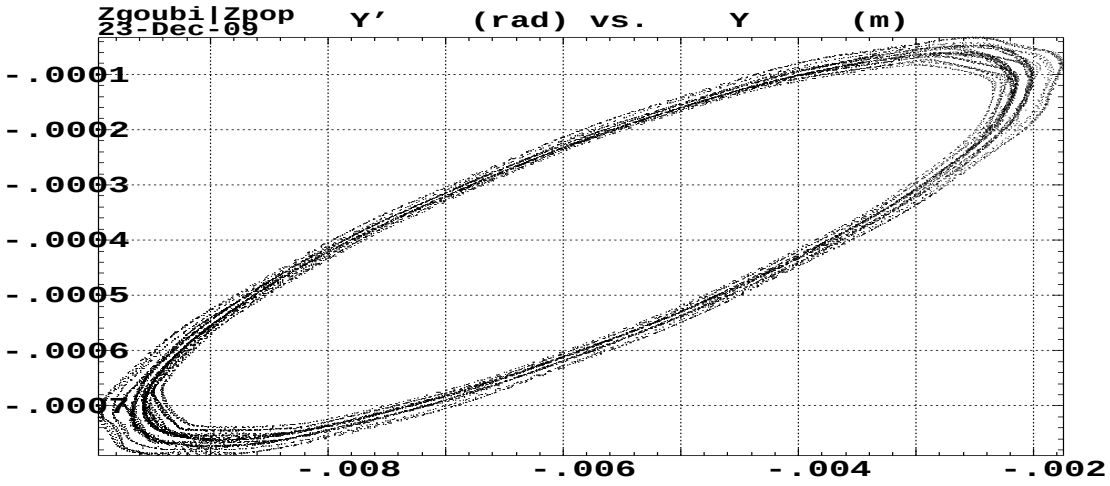


Figure 20: Particle motion, 16000 turns, improved H motion in presence of zero H and V closed orbits in jump quadrupoles. To be compared to Fig. 19-top with jump quads on and sole H centering, it can in particular be observed that the orbit jump upon jump quad on/off switching is better resolved.

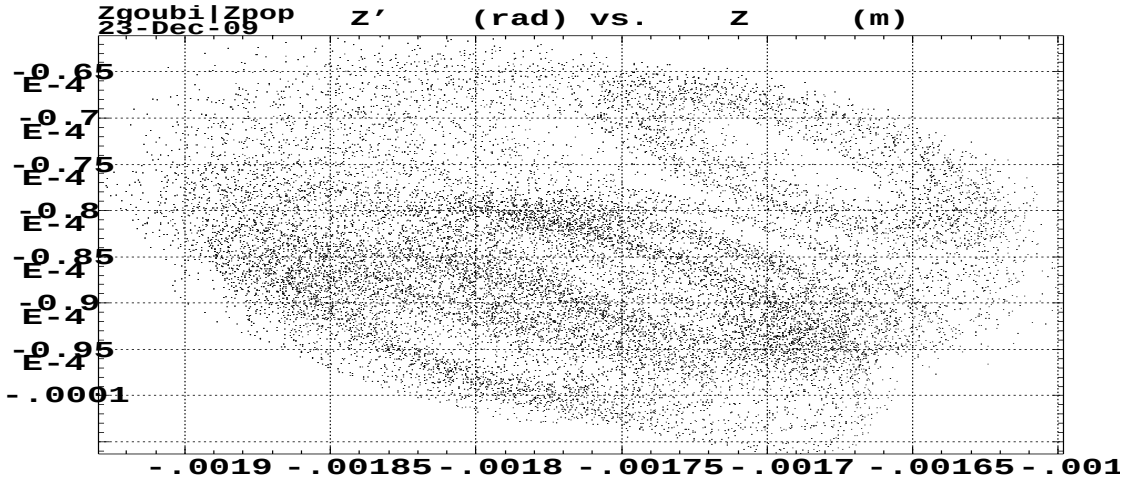


Figure 21: Particle motion, 16000 turns, quasi-zero vertical phase space portrait in presence of H&V centering of the jump quadrupoles on their local H and V closed orbits, to be compared to Fig. 19-middle with jump quads on and sole H centering, and to Fig. 14-middle with jump quads off.

```
Data generated by searchCO
'OBJET'
75.8725752916200e3
8
1  1  1
 -5.834246E-03 -4.120793E-04  -0.18669206e-2     -8.64476501E-05  0.0E+00  1.00000000E+00
-1.475186  19.261771   .825e-6
0.830823 9.919738  0
0 1 0
 'FAISCEAU'                                                                                                    2
  'SCALING'                                                                                                    3
  1  3
   MULTIPOL SBEN
   -1
   75.8725752916200
   1
   MULTIPOL QUAD
   -1
   75.8725752916200
   1
   MULTIPOL QJUMI QJUMJ
   -87
   75.8725752916200
   43 .235 40                starting Gg value,  dN,   #Turns/ramp
  'PARTICUL'                                                                                                   4
  938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
 'SPNTRK'                                                                                                      5
  4.1
-6.8707152746E-02 0.1015767981 0.9924522556
 'FAISTORE'
 b_zgoubi.fai  #End
 1
 'SPNSTORE'
 b_zgoubi.spn    #Start
 1
 'MARKER'   #Start
 'MULTIPOL' SBEN      A1BF                                                                                     8
 0  .Dip
  200.6554  10.00   0.11712499   0.04844450  -0.00053604 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #20|200|20    Dip A1BF
            3   0.    0. -1.175115045000000E-002
.............
'CHANGREF'                                                                                                   690
 YS -0.8422696264  ZS -0.2749666097
 'MULTIPOL'   QJUMI       Betax, Alphax :  2.5743E+01 -1.9636E-01,   Betax, Alphax : 8.9566E+00 -8.9363E-03
 0  .Quad                 xco = -0.84698959, yco=-0.26546500
   76.1927 10.00    0.0  0.01514 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #30|76|30    Quad  QJUMI
 1 0. 0. 0.
'CHANGREF'                                                                                                   692
YS  0.8422696264  ZS 0.2749666097
.................
'CHANGREF'                                                                                                   767
 YS -0.7387819677 ZS -7.6666666667E-02
 'MULTIPOL'       QJUMJ   =QJUMI   Betax, Alphax:  2.5599E+01 -1.0912E-01,  Betay, Alphay: 8.1776E+00  3.2910E-02
 0  .Quad         xco=-0.74307103, yco=-0.10033425      3.7*kl=4pi*dQ/betx=4pi*0.04/25.6=0.01963    b1(T)=Brho*(kl/l*2.37/3.37)*a
   76.1927 10.00    0.0  0.01514 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  #30|76|30    Quad  QJUMJ
 1 0. 0. 0.
'CHANGREF'                                                                                                   769
 YS  0.7387819677 ZS 7.6666666667E-02
.......................
.......................
.......................


Constraining zero H and V closed orbits in jump quads :

'FIT'                                                                                                        980
4    !!!fit qjump position to center on closed orbit (i.e., so to get xco,zco=0 in qjumps)
 690 1  -692.001 20.
 690 2  -692.002 6.
 767 1  -769.001 6.
 767 2  -769.002 6.
4
 3 1 2 690 0. 1. 0
 3 1 4 690 0. 1. 0
 3 1 2 767 0. 1. 0
 3 1 4 767 0. 1. 0
'END'                                                                                                        981
```

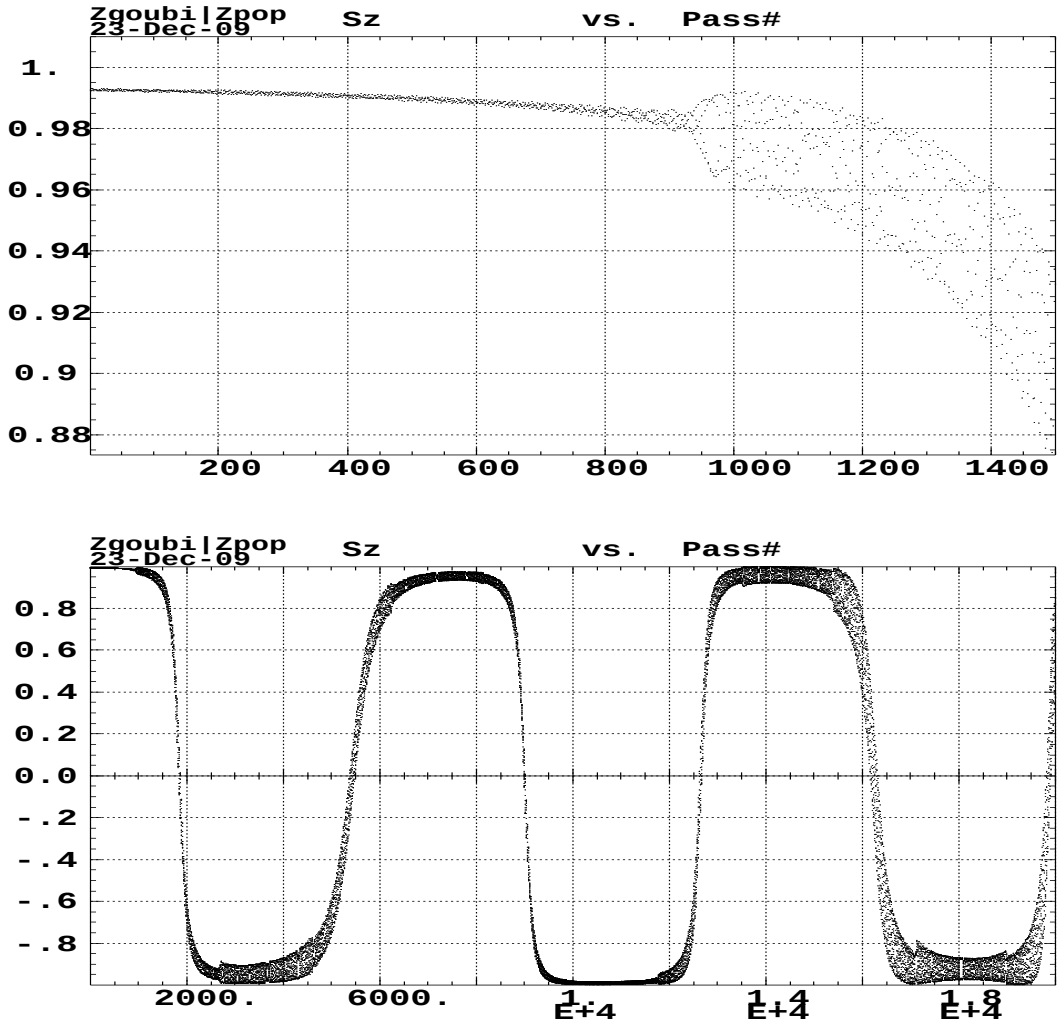


Figure 22: Vertical projection of $\vec{S}$, single particle, in presence of H & V closed orbit in jump quads. To be compared to Fig. 17.
Top : a zoom on the $\nu_s = 35 + \nu_x$ region.
Bottom : acceleration, from $G\gamma = 43.5$ to $G\gamma = 49$.

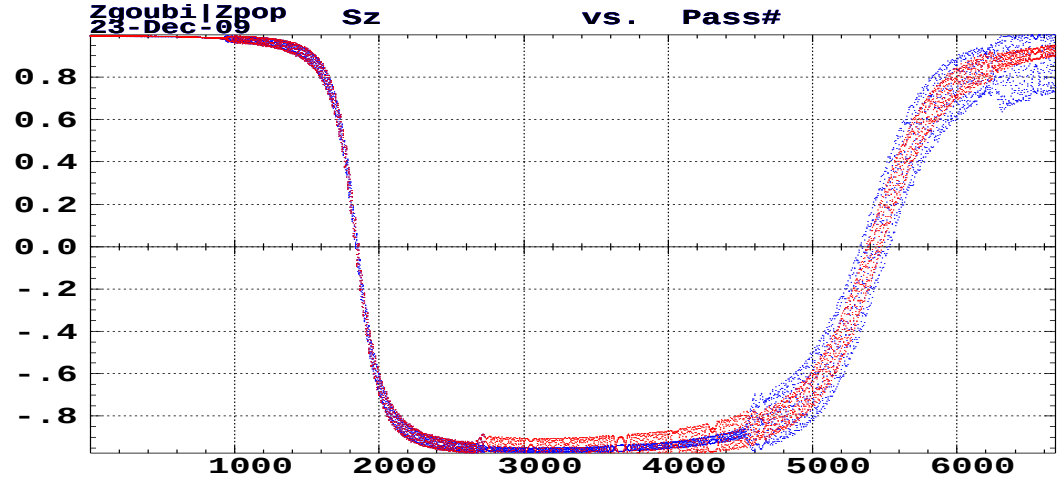


Figure 23: Vertical projection of $\vec{S}$, two particles. Conditions differ by the value of 'dN' in the argument of 'SCALING', namely, dN=0.237 (red) and dN=0.244 (blue).

APPENDIX

A MAD files

Excerpts of MAD files are reproduced, for reference.

A.1 Command file

```
Title, "AGS+cv43+755 snakes. 2quad sol. AUL matrices"
!______Physical costants_____________________________
CONV:    constant=0.0254          !meter per inch
E0:      constant= 0.938272310   !proton mass [GeV]
C:       constant= 2.99792458e8  !speed of light [m/sec]
!______Machine parameters____________________________
RHO:     constant=85.378          !AGS curv. radius [m]
DIPL:    constant=999             !AGS dipole calibration [T/A]
!_____________________________________________________
!                        |
      gamma:=24.264      !!!24.385706
!      call 'gamma.ins'
!_____________________ |
setopts, -echo
EE := E0*GAMMA ; Ek := EE - E0 ; PC := sqrt(EE*EE - E0*E0)
BRHO := 1.e9*PC/C ; BETA := sqrt(1-1/((1+Ek/E0)*(1+Ek/E0))) ;
B := BRHO/RHO
value GAMMA ; value PC ; value EE ; value Ek ; value BETA ; value BRHO ;
value B

beam, particle=proton, pc=PC
!PCINJ:=1.143 !this is the equivalent with gold beam, if betagamma=0.48
PCINJ:=2.303 !this is injection momentum
BDOT  := 0. ; DK2   := 0.04244*BDOT*PCINJ/PC     !where is this from?
call 'lattice/ags4.lat'  !lattice file
!call 'kickstrength.ins' !kickers strength
!!_____________________________________________________________________
!!     Snakes represented by a matrix. 3 m long. AUL July 03            |
  SNAKE: marker ; DSNK:  drift, l=0.023839                             !

  call 'CSNK_B2.0_NoSol.Tmat/SY_CSNK_B2.0_243.mat'      !!!!!243 means 23.4=gamma
!  call 'CSNK_B2.5+0.75sol.Tmat/CSNK_B2.5+0.75sol_49.mat'
  CSNKL: line=(DSNK,CSNK,SNAKE,DSNK) !cv43 cold snake line           !
!  CSNKL: line=(DSNK,DRFMAT,SNAKE,DSNK) !cv43 cold snake line           !

  call 'WSNK_B1.53.Tmat/WSNK_B1.53_243.mat'
  WSNKL: line=(DSNK,WSNK,SNAKE,DSNK) !t55 warm snake line             !
!  WSNKL: line=(DSNK,DRFMAT,SNAKE,DSNK) !t55 warm snake line             !

setopts, echo
!!_____________________________________________________________________|
!!    Quad scales
BRHOO := 7.17113418 ! at gamma=2.5
BRHOscale:= (BRHOO/BRHO)*(BRHOO/BRHO)
!
!call 'Csnake_field.ins'
!BCSNAKE := 2.5
!Cscale:= (BCSNAKE/3.123)*(BCSNAKE/3.123)
!
!call 'Wsnake_field.ins'
!BWSNAKE := 1.53
!Wscale:= (BWSNAKE/3.123)*(BWSNAKE/3.123)

!Bscale := (1.53/2.5)*(1.53/2.5)
Bscale := (1.53/2.0)*(1.53/2.0)
!!_____________________________________________________________________|
!!    Courant quadrupoles
!COLD SNAKE, WARM SNAKE
!KCA17:=-0.1012; KCA19:=-0.21513; KCB1:=-0.26535; KCB3:=-0.15387
!KCE17:=-0.17495;KCE19:=0.21857;KCF1:=-0.21857;KCF3:=0.

!!!!!comment-----------for 15% Cold snake -------------------------------
!KCA17C:=-0.232498891301*BRHOscale !-0.096498967516
!KCA19:=-0.116067942892*BRHOscale !-0.21           !-0.21192166075
!KCB1 :=-0.256023389862*BRHOscale !-0.21  !KCA19           !-0.288662622487
!KCB3 :=-0.111548158531*BRHOscale !-0.152715283932
!
!KCE17C:=-0.105710632359*BRHOscale !-0.147949275317
!KCE19:= 0.23558686779491*BRHOscale  !0.072       ! 0.0747633511
!KCF1 :=-0.23552239053742*BRHOscale !-KCE19       !-0.069533016847
!KCF3 := 0.098109749898*BRHOscale  !-0.084075610041
!!!!!endcomment----------for 15% Cold snake -------------------------------

!!!!!comment-----------for 10% Cold snake -------------------------------
KCA17C:=-0.232498891301*0.8*BRHOscale !-0.096498967516
KCA19:=-0.116067942892*0.8*BRHOscale !-0.21           !-0.21192166075
KCB1 :=-0.256023389862*0.8*BRHOscale !-0.21  !KCA19           !-0.288662622487
KCB3 :=-0.111548158531*0.8*BRHOscale !-0.152715283932
!
KCE17C:=-0.105710632359*0.8*BRHOscale !-0.147949275317
KCE19:= 0.23558686779491*0.8*BRHOscale  !0.072       ! 0.0747633511
KCF1 :=-0.23552239053742*0.8*BRHOscale !-KCE19       !-0.069533016847
KCF3 := 0.098109749898*0.8*BRHOscale  !-0.084075610041
!!!!!endcomment----------for 10% Cold snake -------------------------------

!!_____________________________________________________________________
```

```
!!    Tune Quad currents [A]
!XQH := 13.08 ; XQV := -23.408
!KQH := 0.0 ; KQV := 0.0
!KQJM := 0.01
!KQH := 0.179079846975E-01;  KQV := -0.249486131375E-02     ! Gg  4.5
!KQJM := 0.0129331838272
!KQJM := 0.012701886853
KQH := 0.166268687200E-01;  KQV :=  -0.380045229870E-01     ! Gg 43.5
KQJM :=  0.0142600853986
LENQC := 0.35 ; LDSQC = (LDSQ - LENQC)/2.
D2SC:  drift, l=(LD2S - LENQC)/2. ; DSQC: drift, l=LDSQC
KCA17:= KCA17C + KQH
QCA17: quad, l=LENQ,  k1=KCA17
QCA19: quad, l=LENQC, k1=KCA19
QCB1 : quad, l=LENQC, k1=KCB1
QCB3 : quad, l=LENQ,  k1=KCB3
DSQH:  drift, l=LDSQ+LENQ
DSQV:  drift, l=LD5L/2-LENQC
KCE17:= KCE17C + KQH
QCE17: quad, l=LENQ,  k1=KCE17
QCE19: quad, l=LENQC, k1=KCE19
QCF1 : quad, l=LENQC, k1=KCF1
QCF3 : quad, l=LENQ,  k1=KCF3

D2SX: drift, L=(23.99664*CONV - LQB1)/2 !=0.154757
!_____________________________________________________________________

use, AGS_CW
!_____________________________________________________________________
!------Match----------------------------------------
  cell
!   vary, XQH, step=0.1, lower=-2000., upper=2000.
!   vary, XQV, step=0.1, lower=-2000., upper=2000.
   vary, KQH, lower=-0.05, upper=0.04, step=0.00001
   vary, KQV, lower=-0.04, upper=0.01, step=0.00001
   constraint, range=#E, MUX=8.72, MUY=8.98
   lmdif, calls=2000, tolerance=1.0e-9
  endmatch

!  call file='ags.tune'
!-------------------------------------------------
!MATCH
!comment
!cell
!vary, XQH, lower=-700, upper=700, step=0.001
!vary, XQV, lower=-700, upper=700, step=0.001
!vary, KQH, lower=-0.05, upper=0.04, step=0.00001
!vary, KQV, lower=-0.05, upper=0.04, step=0.00001
!vary, KQJM, lower=-0.1, upper=0.1, step=0.00001

!call "match.ins"
! constraint, #e, mux=  8.719
! constraint, #e, mux=  8.619
! constraint, #e, muy=  8.969

!simplex, calls=60000, tolerance=1e-9
!endmatch
!endcomment
!_____________________________________________________________________

print, #E

select, flag=FIRST, range=#S/#E
    survey, tape='ags.survey'
twiss, tunes='Q.psh', tape='ags.twiss', deltap=0.
archive, table='Q.psh'

push, KQH, KQV, KQJM, Qx, Qy
endpush, save='quad.psh'

push,   gamma,KCA17,KCA19,KCB1,KCB3,KCE17,KCE19,KCF1,KCF3,KQH,KQV
endpush, save='quadK1.psh'
push,   gamma,K1AD,K1AF,K1BD,K1BF,K1CD,K1CF
endpush, save='dipK1.psh'

stop
```

A.2 "dipole1" file

Description of the superperiods in MAD8 using 'SBEND'

```
LENA: = 2.3876 !94*CONV !length in meters
LENB: = 2.0066 !79*CONV
LENC: = 2.3876 !94*CONV

ANGA: = 0.0279650307   !angle in radians
ANGB: = 0.0235023009
ANGC: = 0.0279650307

!Dipole Names
AD: sbend, l=LENA, angle=ANGA, k1=K1AD, k2=K2AD, e1=ANGA/2., e2=ANGA/2.
AF: sbend, l=LENA, angle=ANGA, k1=K1AF, k2=K2AF, e1=ANGA/2., e2=ANGA/2.
BD: sbend, l=LENB, angle=ANGB, k1=K1BD, k2=K2BD, e1=ANGB/2., e2=ANGB/2.
BF: sbend, l=LENB, angle=ANGB, k1=K1BF, k2=K2BF, e1=ANGB/2., e2=ANGB/2.
CD: sbend, l=LENC, angle=ANGC, k1=K1CD, k2=K2CD, e1=ANGC/2., e2=ANGC/2.
CF: sbend, l=LENC, angle=ANGC, k1=K1CF, k2=K2CF, e1=ANGC/2., e2=ANGC/2.
```

```
A1BF:  BF ; A2BF:  BF ; A3CD:  CD ; A4CD:  CD ; A5AF:  AF
A6AF:  AF ; A7CD:  CD ; A8CD:  CD ; A9BF:  BF ; A10BF: BF
A11BD: BD ; A12BD: BD ; A13CF: CF ; A14CF: CF ; A15AD: AD
A16AD: AD ; A17CF: CF ; A18CF: CF ; A19BD: BD ; A20BD: BD

B1BF:  BF ; B2BF:  BF ; B3CD:  CD ; B4CD:  CD ; B5AF:  AF
B6AF:  AF ; B7CD:  CD ; B8CD:  CD ; B9BF:  BF ; B10BF: BF
B11BD: BD ; B12BD: BD ; B13CF: CF ; B14CF: CF ; B15AD: AD
B16AD: AD ; B17CF: CF ; B18CF: CF ; B19BD: BD ; B20BD: BD

C1BF:  BF ; C2BF:  BF ; C3CD:  CD ; C4CD:  CD ; C5AF:  AF
C6AF:  AF ; C7CD:  CD ; C8CD:  CD ; C9BF:  BF ; C10BF: BF
C11BD: BD ; C12BD: BD ; C13CF: CF ; C14CF: CF ; C15AD: AD
C16AD: AD ; C17CF: CF ; C18CF: CF ; C19BD: BD ; C20BD: BD

D1BF:  BF ; D2BF:  BF ; D3CD:  CD ; D4CD:  CD ; D5AF:  AF
D6AF:  AF ; D7CD:  CD ; D8CD:  CD ; D9BF:  BF ; D10BF: BF
D11BD: BD ; D12BD: BD ; D13CF: CF ; D14CF: CF ; D15AD: AD
D16AD: AD ; D17CF: CF ; D18CF: CF ; D19BD: BD ; D20BD: BD

E1BF:  BF ; E2BF:  BF ; E3CD:  CD ; E4CD:  CD ; E5AF:  AF
E6AF:  AF ; E7CD:  CD ; E8CD:  CD ; E9BF:  BF ; E10BF: BF
E11BD: BD ; E12BD: BD ; E13CF: CF ; E14CF: CF ; E15AD: AD
E16AD: AD ; E17CF: CF ; E18CF: CF ; E19BD: BD ; E20BD: BD

F1BF:  BF ; F2BF:  BF ; F3CD:  CD ; F4CD:  CD ; F5AF:  AF
F6AF:  AF ; F7CD:  CD ; F8CD:  CD ; F9BF:  BF ; F10BF: BF
F11BD: BD ; F12BD: BD ; F13CF: CF ; F14CF: CF ; F15AD: AD
F16AD: AD ; F17CF: CF ; F18CF: CF ; F19BD: BD ; F20BD: BD

G1BF:  BF ; G2BF:  BF ; G3CD:  CD ; G4CD:  CD ; G5AF:  AF
G6AF:  AF ; G7CD:  CD ; G8CD:  CD ; G9BF:  BF ; G10BF: BF
G11BD: BD ; G12BD: BD ; G13CF: CF ; G14CF: CF ; G15AD: AD
G16AD: AD ; G17CF: CF ; G18CF: CF ; G19BD: BD ; G20BD: BD

H1BF:  BF ; H2BF:  BF ; H3CD:  CD ; H4CD:  CD ; H5AF:  AF
H6AF:  AF ; H7CD:  CD ; H8CD:  CD ; H9BF:  BF ; H10BF: BF
H11BD: BD ; H12BD: BD ; H13CF: CF ; H14CF: CF ; H15AD: AD
H16AD: AD ; H17CF: CF ; H18CF: CF ; H19BD: BD ; H20BD: BD

I1BF:  BF ; I2BF:  BF ; I3CD:  CD ; I4CD:  CD ; I5AF:  AF
I6AF:  AF ; I7CD:  CD ; I8CD:  CD ; I9BF:  BF ; I10BF: BF
I11BD: BD ; I12BD: BD ; I13CF: CF ; I14CF: CF ; I15AD: AD
I16AD: AD ; I17CF: CF ; I18CF: CF ; I19BD: BD ; I20BD: BD

J1BF:  BF ; J2BF:  BF ; J3CD:  CD ; J4CD:  CD ; J5AF:  AF
J6AF:  AF ; J7CD:  CD ; J8CD:  CD ; J9BF:  BF ; J10BF: BF
J11BD: BD ; J12BD: BD ; J13CF: CF ; J14CF: CF ; J15AD: AD
J16AD: AD ; J17CF: CF ; J18CF: CF ; J19BD: BD ; J20BD: BD

!!special nomenclature required here due to overlaps
!!also appears in definiton of K superperiod

K1PBF: BF ; K2PBF: BF ; K3CD:  CD ; K4CD:  CD ; K5AF:  AF
K6AF:  AF ; K7CD:  CD ; K8CD:  CD ; K9BF:  BF ; K10BF: BF
K11BD: BD ; K12BD: BD ; K13CF: CF ; K14CF: CF ; K15AD: AD
K16AD: AD ; K17CF: CF ; K18CF: CF ; K19BD: BD ; K20BD: BD

L1BF:  BF ; L2BF:  BF ; L3CD:  CD ; L4CD:  CD ; L5AF:  AF
L6AF:  AF ; L7CD:  CD ; L8CD:  CD ; L9BF:  BF ; L10BF: BF
L11BD: BD ; L12BD: BD ; L13CF: CF ; L14CF: CF ; L15AD: AD
L16AD: AD ; L17CF: CF ; L18CF: CF ; L19BD: BD ; L20BD: BD

return
```

A.3 “print” file

```
 ------------------------------------------------------------------------------------------------------------------------------
1AGS+cv43+755 snakes. 2quad sol. AUL matrices                                "MAD" Version: 8.23/08   Run: 01/10/09  12.36.37
 Linear lattice functions.    TWISS              line: AGS_CW               range: #S/#E
 Delta(p)/p:     0.000000     symm: F            super:   1                                                      page     1
 ------------------------------------------------------------------------------------------------------------------------------
      ELEMENT SEQUENCE       I              H O R I Z O N T A L             I              V E R T I C A L
 pos.  element occ.     dist I   betax  alfax   mux    x(co)  px(co) Dx    Dpx  I   betay  alfay   muy    y(co)  py(co) Dy    Dpy
 no.   name    no.      [m]  I   [m]    [1]     [2pi]  [mm]   [.001] [m]   [1]  I   [m]    [1]     [2pi]  [mm]   [.001] [m]   [1]
 ------------------------------------------------------------------------------------------------------------------------------
 begin AGS_CW     1     0.000   19.455 -1.537   0.000  0.0000  0.000  1.990 0.120    9.682  0.808   0.000  0.0000  0.000 -0.011 0.000
 end   AGS_CW     1   807.076   19.455 -1.537   8.720  0.0000  0.000  1.990 0.120    9.682  0.808   8.980  0.0000  0.000 -0.011 0.000
 ------------------------------------------------------------------------------------------------------------------------------
 total length =        807.075652          Qx           =          8.720000          Qy           =          8.980000
 delta(s)     =          0.000000 mm       Qx'          =        -22.470306          Qy'          =          2.698546
 alfa         =          0.138967E-01      betax(max)   =         25.738300          betay(max)   =         27.478694
 gamma(tr)    =          8.482905          Dx(max)      =          2.423274          Dy(max)      =          0.024185
                                           Dx(r.m.s.)   =          1.811437          Dy(r.m.s.)   =          0.013532
                                           xco(max)     =          0.000000          yco(max)     =          0.000000
                                           xco(r.m.s.)  =          0.000000          yco(r.m.s.)  =          0.000000
 ------------------------------------------------------------------------------------------------------------------------------
```

B Zgoubi data file specimen

B.1 1-turn first order mapping, input file

Typical zgoubi.dat file including snakes and appropriate commands for MATRIX calculation including chromaticities, etc.

```
Data generated by searchCO
'OBJET'
75.8725752916200e3
5.03
 .1 .001 .001 .001 0. .001
 -7.847E-01 -5.374E-01 -1.638E-01 -6.812E-02  0E+00  9.990E-01 'o'
 -5.834E-01 -4.120E-01 -1.862E-01 -8.664E-02  0E+00  1.000E+00 'o'
 -3.809E-01 -2.865E-01 -2.184E-01 -1.160E-01  0E+00  1.001E+00 'o'
 'FAISCEAU'
  'SCALING'
  1  2
   MULTIPOL SBEN
   -1
   75.8725752916200
   1
   MULTIPOL QUAD
   -1
   75.8725752916200
   1
  'PARTICUL'
  938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
  'PICKUPS'
  1
  #End
 'FAISTORE'
 b_zgoubi.fai
  1
 'MARKER'  #Start
 'MARKER'  Begin
 'MULTIPOL' SBEN      A1BF
 0  .Dip
200.6554 10. 0.11712499 0.0484445 -0.00053604 0 0 0 0 0 0 0
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
  0 0 0 0 0 0 0 0. 0. 0.
  #20|200|20    Dip A1BF
 3   0.00       0.000      -1.175115045000000E-002
 'DRIFT'    DRIF      D2S
      60.9515
.....................
.....................
 'DRIFT'    DRIF      DSNK
       2.3839
 'MARKER'   MATR      CSNK
 'DRIFT'    DRIF      MATR CSNK
     10.0000
 'MAP2D'
  0  0
      .7e-3   100. 100. 100.
   HEADER_4 csnake
   281 29
   ref+sole.map2d
       0 0 0 0
       2
      .1
    2  0.  .15  0.  0.
 'DRIFT'
     10.0000
.....................
.....................
'DRIFT'    DRIF      DSNK
       2.3839
 'MARKER'   MATR      WSNK
 'DRIFT'    DRIF      MATR WSNK
   -50.
 'MARKER'   MATR      WSNK
 'MAP2D'
  0  0
    1.e1   100. 100. 100.
   HEADER_4 wsnake
   801 29
  table55.map2d
       0 0 0 0
       2
      .1
    2  0.  .15  0.  0.
 'DRIFT'    DRIF      MATR WSNK
   -50.
 'MARKER'   MARK      SNAKE
 'DRIFT'    DRIF      DSNK
       2.3839
.....................
.....................
 'MULTIPOL' HKIC      SML20
 0  .kicker
 0.2413E+03 10.00 0.0 0. 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.
  0.000000000 0 0 0 0 0 0 0 0. 0.
 #20|20|20  Kick
 1 0. 0. 0.
 'DRIFT'    DRIF      DSG10
      31.7339
 'MARKER'  #End
 'FAISCEAU'
 'MATRIX'
  1  11
 'FAISCEAU'
 'END'
```

B.2 Acceleration, using "CAVITE"

```
  'CAVITE'
  2.1  .1 is to fill zgoubi.CAVITE.Out for plot using zpop/7/20
  807.042748   12.     0435
  290.d3  2.617993877991494365       9cavitiesx32kV, phi_s=30deg
   'MARKER'  #End
```

B.3 zgoubi.dat for w- and c-snake

Snake files, 3 meter extent, using 3D field maps.

Warm snake :

```
WSNK
'OBJET'
77.64321e3
2
1 1
.0  0. . 0. 0. 1. 'o'
1
 'PARTICUL'
 938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
 'SPNTRK'
  3
   'TOSCA'
     0  1
     1.e1   100. 100. 100.
  HEADER_4 csnake
  801 29 29  12.1
 table55.tab
      0 0 0 0
      2
      .1
   2  -0.15  0.  0.  0.
   'FAISCEAU'
    'END'
```

Cold snake :

```
CSNK
'OBJET'
77.64321e3
2
1 1
-.15 0. 0. 0. 0. 1. 'o'
1
 'PARTICUL'
 938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
 'SPNTRK'
  3
   'TOSCA'
     0  1
     1.e-3   100. 100. 100.
  HEADER_4 csnake
  281 29 29  12.1
 ref+sole.tab
      0 0 0 0
      2
      1
   2  0.  0.  0.  0.
   'FAISCEAU'
    'END'
```

Snake data, 3 meter extent, using mid-plane 2D field maps.

See App. B.1.

B.4 Spin $\vec{n}$-vector

Typical zgoubi.dat data for spin-$\vec{n}$ vector finding using the 'FIT' procedure.

```
Data generated by searchCO
'OBJET'
75.8725752916200e3
2
  1  1
-5.834E-01 -4.120E-01  -0.1866 -8.644E-02  0.0E+00  1.E+00 'o'
 1 1 1 1 1
 'FAISCEAU'
  'SCALING'
  1  2
   MULTIPOL SBEN
   -1
   75.8725752916200
   1
   MULTIPOL QUAD
   -1
   75.8725752916200
   1
  'PARTICUL'
  938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
 'SPNTRK'
  4.1
-6.8608394896E-02  0.1001299394  0.9926061069
 'MARKER'  Begin
 'MULTIPOL' SBEN      A1BF
 0  .Dip
200.6554 10.00 0.1171 0.0484  -0.00053604 0 0 0 0 0 0 0
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
..............
..............
 'FIT'   3
 5 10  0   2   Sx_0 variable
 5 11  0   2   Sy_0
 5 12  0   1   Sz_0
  4
 10.1 1 1  980  0. .3 0   Sx_final = Sx_0  constraint
 10.1 1 2  980  0. .3 0   Sy_final = Sy_0
 10.1 1 3  980  0. 1. 0   Sz_final = Sz_0
 10   1 4  980  1. 2. 0   |S|=1
 'END'
```

B.5 Q-jump

Typical zgoubi.dat data for Q-jump simulation.

```
Data generated by searchCO
'OBJET'
75.8725752916200e3
2
  1  1
-5.834E-01 -4.120E-01 -0.18669 -8.6447E-02 0.  1.00E+00 'o'
 1 1 1 1 1
 'FAISCEAU'
  'SCALING'
  1  3
   MULTIPOL SBEN
   -1
   75.8725752916200
   1
   MULTIPOL QUAD
   -1
   75.8725752916200
   1
   MULTIPOL QJUMI QJUMJ
   -87
   75.8725752916200
   44 .25 40         start-Turn#  dN   #Turns/ramp  dWs/turn (MeV)
  'PARTICUL'
  938.27203d0  1.602176487d-19  1.7928474d0 0. 0.
 'SPNTRK'
  4.1
-6.8608394896E-02  0.1001299394  0.9926061069
 'FAISTORE'
 b_zgoubi.fai  #Start
 1
 'SPNSTORE'
 b_zgoubi.spn    #Start
 1
 'MARKER'   #Start
 'MULTIPOL' SBEN      A1BF
 0  .Dip
  200.6554  10.00 0.1171  0.0484  -0.00053604 0 0 0 0 0 0 0
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
  0 0 0 0 0 0 0 0. 0. 0.
  #20|200|20    Dip A1BF
            3   0.0 0.0  -1.175115045E-002
.................
 'MULTIPOL' SBEN      I5AF
 0  .Dip
  238.7522  10.00   0.11712611   0.04865458  -0.00045118 0 0 0 0 0 0 0
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
  0 0 0 0 0 0 0 0. 0. 0.
  #20|200|20    Dip I5AF
            3   0.    0. -1.398251535000000E-002
 'DRIFT'    DRIF      D2H
      76.1927
 'MULTIPOL'   QJUMI
! Betax, Alphax : 2.57E+01 -1.96E-01, Betax, Alphax : 8.95E+00 -8.93E-03
 0  .Quad
   76.1927 10.00    0.0  0.00818 0.0 0 0 0 0 0 0 0
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0 0 0 0 0 0 0 0. 0. 0.
  #30|76|30    Quad  QJUMI
 1 0. 0. 0.
..................
 'MULTIPOL' SBEN      J5AF
 0  .Dip
  238.7522  10.00   0.11712611   0.04865458  -0.00045118 0 0 0 0 0 0 0
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
 0. 0. 10.00  4.0  0.800 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 4  .1455   2.2670  -.6395  1.1558  0. 0.  0.
  0 0 0 0 0 0 0 0. 0. 0.
  #20|200|20    Dip J5AF
            3   0.    0. -1.398251535000000E-002
 'DRIFT'    DRIF      D2H
      76.1927
 'MULTIPOL'   QJUMJ
! 2.7xQJUMI Betax,Alphax:  2.55E+01 -1.09E-01; Betay,Alphay: 8.17E+00 3.29E-02
 0  .Quad
! 3.7*kl=4pi*dQ/betx=4pi*0.04/25.6=0.01963
! b1(T)=Brho*(kl/l*2.7/3.7)*a=1*0.01963/3.7*0.1=0.001433
   76.1927 10.00    0.0  0.0221 0.0 0 0 0 0 0 0 0
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
 0. 0. 6.00  3.00 1.00 0.00 0.00 0.00 0.00 0. 0. 0. 0.
 6  .1122 6.2671 -1.4982 3.5882 -2.1209 1.723
  0 0 0 0 0 0 0 0. 0. 0.
  #30|76|30    Quad  QJUMJ
 1 0. 0. 0.
..............
 'DRIFT'    DRIF      DSG10
      31.7339
  'CAVITE'
  2 .1          .1 is to fill zgoubi.CAVITE.Out for plot using zpop/7/20
  807.042748   12.     0435
  290.d3  2.617993877991494365       9cavitiesx32kV, phi_s=150deg
   'MARKER'  #End
'SPNPRT'
'FAISCEAU'
'REBELOTE'
 19999 0.2 99
'END'
```