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Spink User's Manual. Version v.2-21-beta

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Abstract

spink is a spin tracking code for polarized spin 1/2 particles. The code tracks both trajectories in 3D and spin. It works using thick element modeling from *MAD* to track trajectories and thin element modeling based on the BMT equation to track spin. The code is written in Fortran77 and typically runs on a Linux platform, either sequentially or MPI-parallel.

[*]Work performed under the auspices of the U.S.Department of Energy.

Acnowledgments

spink has been around for several years. We used and still extensively use it in Brookhaven for polarized proton studies at the AGS and RHIC. The code has been exported and used in other laboratories, notably Jülich in Germany and RIKEN and KEK-JPARC in Japan.

Many peoples have contributed with discussions and actual work on the code, notably Haixin Huang, Nick Tsoupas, Mei Bai, Fanglei Lin at Brookhaven, Andreas Lehrach at Jülich and Meiqin Xiao at RIKEN. Nick D'Imperio (BNL) contributed in a fundamental way to the implementation of the GUI. Constant interest and support by Thomas Roser has been important for the success of the code.

Tracking spin has been always an important tool to understand and to resolve problems of the acceleration of polarized particles. For circular accelerators several code have been written to address full or in part some of the issues, such as *depol* by Ernest Courant (BNL), *snake* by Jean Buon (Saclay), *sprint* by MathiasVogt (DESY). Partly of fully implementation of spin tracking exist in other codes, like *MAD* (CERN) and *COSY-infinity* (Michigan).

spink is just another contribution.

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1 Physical Principles

spink, that may stand for 'Spin Tracking', is a spin tracking code for spin 1/2 polarized particles [1]. The six phase space coordinates for the orbit and three coordinate representing the cartesian components of the unitary spin vector are tracked. Orbit tracking is done by propagating the vector $\vec{r}$ through first and second order maps generated by *MAD* [2]. These maps are for "thick" elements. Spin tracking is done via "thin" elements spin rotation matrices.

The output of *MAD* is transformed by the pre-processor *Mad_read* to an input file (lattice descriptor) suitable for *spink*. Two versions of *MAD* are currently supported by *mad_read*: *mad8c* (CERN) and *BNLMad* (J.Niederer). Work is in progress to accept input from *madX*, which is the only version of *MAD* presently supported by CERN, see 7.1.

spink sequentially tracks several particles, averaging the final results. This task can also be performed "trivially" on a parallel computer since the code has been implemented using the MPI library.

spink uses MKSA units and canonical orbital phase space variables as used by *MAD*, namely

$$\mathbf{r} = \left(x,\, x' = \frac{p_x}{p},\, y,\, y' = \frac{p_y}{p},\, \Delta\phi = -c\Delta t,\, \frac{\Delta E}{pc}\right). \tag{1}$$

The spin is treated as a 3-dimension real vector

$$\mathbf{S} = (S_x,\, S_y,\, S_z)\,. \tag{2}$$

We follow the 'US accelerator' coordinate convention with x radial, y vertical, and z longitudinal, while in the spin literature z is often taken as vertical.

Input and output of phase space are in [mm] and [mrad] for transverse coordinates, (x, x'), radial and (y, y'), vertical. In input units are [rad] for the longitudinal coordinate $\Delta\phi$ and [GeV] for the energy coordinate ΔE. $\Delta\phi$ and ΔE are evaluated with respect to the phase ϕ_s and energy E_s of a reference synchronous particle.

1.1 Orbit and spin tracking

spink uses *MAD* thick elements matrices to track particle orbits to first order. For second order the code uses either second order *MAD* generated maps, or thin element representation of machine elements that would require high order transfer map representation, such as multipoles.

MAD transfer maps are written for coordinate units [m] and [rad] in the transverse phase space, [m] for the phase, since in *MAD* it is $\Delta\phi \to -c\Delta t$, and [0] for the energy coordinate, since in that code it is $\Delta E \to \Delta E/pc$. In *spink* we use *MAD* coordinates.

The propagation of the transverse coordinates of the beam through the lattice is done using the equation

$$r_i^{(\beta)} = \textstyle\sum_j R_{ij} r_j^{(\beta)} + \sum_{jk} T_{ijk} r_j^{(\beta)} r_k^{(\beta)}, \quad i, k = 1, 4 \tag{3}$$

with R_{ij} first order matrices, T_{ijk} second order maps, and $\mathbf{r}^{(\beta)} = \mathbf{r} - \mathbf{r}^{(COD)}$ is the displacement in space and angle of the particle from the closed orbit. The propagation of the longitudinal coordinates is in particular discussed in Sec. 4.13.

The accelerator lattice used by *spink* can be static, *i.e.* read once from *MAD* and never modified, or dynamic. Two ways are implemented in the code to dynamically modify the lattice using tables: (a) reading from a table a list of *MAD* and *mad_read* produced lattice descriptors for different energies, in which case, once a given energy is reached during acceleration, the track initializer routine *TrackInit*, Sec. 4.5, will read the next lattice; (b) reading tables of K1 values of all quadrupoles, etc. and update the transport matrices accordingly, Sec. 4.15.

The propagation of the spin coordinates is done by 3×3 matrices for thin elements. Spin matrices are simply derived from the BMT differential equation for spin motion [3], [4]

$$\frac{d\mathbf{S}}{dt} = \frac{e}{mc}\mathbf{S} \times \left[\frac{1}{\gamma}\left(G\gamma + 1\right)\mathbf{B} - \frac{G\gamma}{\gamma + 1}(\vec{\beta}\cdot\mathbf{B})\vec{\beta} - \left(G + \frac{1}{\gamma + 1}\right)\vec{\beta} \times \mathbf{E}\right] \tag{4}$$

as described in Sec.**??** [5]. $\mathbf{B}$ is the magnetic field, $\mathbf{E}$ is the electric field in the laboratory frame, and $\vec{\beta} = \mathbf{v}/c$ is the relativistic velocity of the particle.

1.2 Siberian Snakes and Spin Rotators

Siberian snakes [6] rotate the spin by a fixed angle. They are essential devices in circular accelerators for polarized beams to break the periodic condition that produces spin resonances and polarization losses.

Spin Rotators are used to orient the spin in a given direction. They are important in polarized beam colliders, to orient the beam polarization longitudinally or transversely at a collision point.

In *spink*, snakes and rotators are modeled in three ways:

- Synthetic
- Table driven
- Analytic

A synthetic snake or rotator is optically a thin element represented in the *MAD* lattice by a unit transfer map. Angle of spin rotation μ and angles of the rotation axis ϕ, longitude, and θ, latitude are given as input, Sec. 7.3.9, and Sec. 7.3.10.

A table driven synthetic snake is a thick element, optically represented by the elements of a 6×6 matrix, tables(11) and (12), and by the three angles, as a function of the relativistic energy γ.

Analytic snakes and rotators are represented by orbit and spin matrices obtained from analytic expressions, Sec. 4.18.

2 Flowchart

The flowchart of *spink* and its pre-processors is shown in Fig.1. To run the code, three actions are needed, in sequence:

1. Run *MAD* to generate the lattice descriptor. Presently it is *mad8c*, as described in Sec. 7.1. *mad8* generates three output files: *runname.twiss, runname.echo, runname.madout.* The first two files are always needed; the third is only needed if there are lattice errors.

2. Whith the names of these files inserted in the input file *mad_read.in*, run *mad_read.* This generates a lattice descriptor that combines the three files in one file *runname.sy*, Sec. 7.2.

3. Using the GUI build the input file *spink.in* to *spink*, and run *spink.* These operations are conveniently done through a Unix script, Sec. 7.3.

The above flowchart only shows the main routines. Individual subprograms will be discussed in the following sections.

3 Include files

Two include files are supplied, *SpinkGlobal* and *SpinkName*

- *SpinkGlobal* contains the definition of data types for all the variables, integer, boolean, real, strings and also all the common blocks used in the program;
- *SpinkName* contains the namelist blocks, with the list of the input variables in the blocks. Input to *spink* is through namelist, contained in the input file *spink.in.*

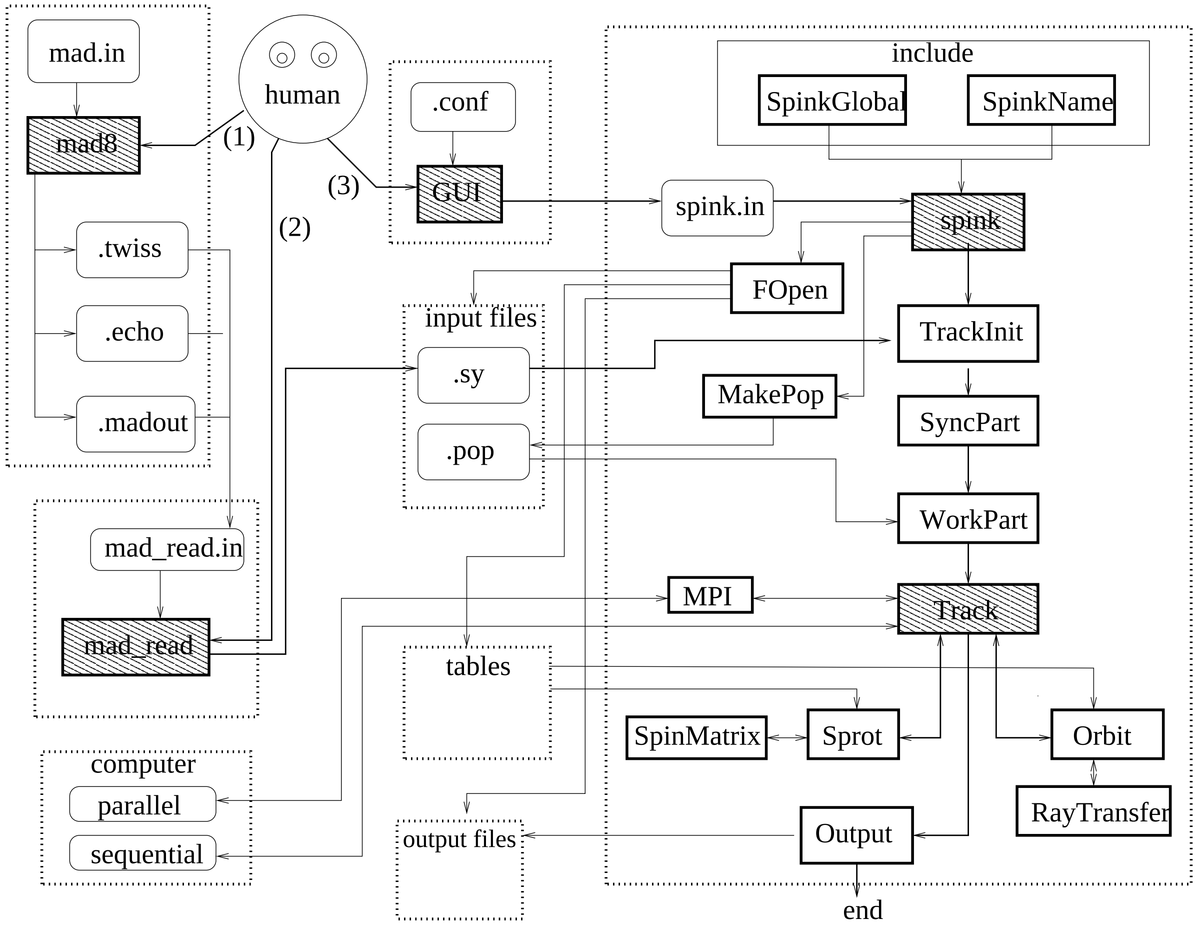

Figure 1: Flowchart of *spink* and its preprocessors

4 *spink* routines

4.1 routine *SpinkData*

In this subroutine variables are initialized.

4.2 routine *FOpen*

Open files and tables.

In this subroutine the following functions are performed

- Namelist blocks are read and parsed through a call to *NmlRead*, Sec. 4.3
- Input and output files are opened. All file names are arbitrary.
- There is a convention here: if a file name has a # (in the GUI), or a blank ′ ′ (in *spink.in*), as a first character, the file is ignored. The opening of a file is equivalent to set a flag, boolean *fstat(n)*=.true. with n the number of the unit associated to the file. Some actions will be performed or not according to a file being open or not, as we will see later. If a file name starts with a ′+′ as a first character, the file is opened with access=append.
- Some actions of the code are driven by a table of values vs. turn number in the tracking or vs. values of the energy, when there is acceleration in the synchrotron, as it will be described later, Sec. 4.4. Tables are initialized (opened) in this routine, with the same conventions used for the files. For tables the status boolean flag is *tstat(n)*, with n the table number.
- Some initialization is performed in *FOpen*, in particular for subsequent averaging: entry *Param*, and entry *pInit*. The program run ends also here: entry *Finis*.

4.3 routine *NmlRead*

Read namelist input.

This routine, called from *FOpen*, serves the dual purpose to accept a namelist driver (input file *spink.in*) created by the GUI or a namelist file directly edited. The point is that in a namelist file created by a GUI some namelist blocks are missing, when the corresponding module is checked off. In this case, Fortran would signal an error in reading and stop execution. A solution to this problem[1] is implemented in the present subroutine.

NmlRead has also a quick diagnostics to signal any error in reding a namelist, a very common source of troubles, if *spink.in* is directly created by editing and not through the GUI.

4.4 routine *Tables*

Tables are being used in *spink* for functions or parameters that vary in the course of a run. Some tables use the number of turns as the independent variable (first column), some use the relativistic energy factor γ.

- The first line of a table contains an integer number: the number of columns after the first, for the rest this line is available for comments or a header.
- A table is read (opened) in the subroutine *FOpen*, Sec. 4.2. For tables we use the same convention as for files, namely if the first character of the table name is a # (GUI) or a blank ′ ′ the table is ignored. Table names included in [ ] brackets (GUI) are intended to be name arrays.
- Tables are read in the entry *Tables:TableRead*, their content is temporarily put in a reserved buffer file, unit(11), and then stored in memory.

[1]thanks to Len Slatest of BNL

- if the first column is turn number, table entries are stored as $nTab(k, j), vTab(k, j, l)$ where k is the table number, j is the row number, l is the column number.
- if the first column in the table is γ, table entries are stored as $gamTab(k, j), vTab(k, j, l)$.
- A specific record in a table can be retrieved calling the entry *Tables:TableReadRecord*
- Interpolation (linear) in the tables is done by calling the entry *Tables:TableInterp*
- A variable value in the last row of the table can be retrieved calling the entry *Tables:TableInterpLast*

The GUI windows for tables is described in Sec. 7.3.4.

4.5 routine *TrackInit*

Track initialization.

The subroutine reads the *runname.sy* file created by the pre-processor *mad_read* from *MAD*, as described in Sec. 7.2, and stores in memory values of the parameters.

- read 1.st record, for the entire lattice:
  1: *version* of *MAD*, *order* of tracking (1.st or 2.nd),
  flag for *errors* in the lattice (0/1), total *number* of machine elements.
- for each machine element, read records 2, 3, 4
  2: *el_name* = element name, *el_keyw* = keyword, or element type, a 4 character string
  el_len = elem. length [m],
  3: *el_ang* = bend angle, *el_k1* = quadrupole gradient = $-(\partial B/\partial r)/B\rho, [m^{-1}]$,
  4: *el_k2* = sextupole gradient =$-(\partial^2 B/\partial r^2)/B\rho, [m^{-2}$, *el_tilt* = tilt angle [rad],
  el_kickh= horizontal kick [rad], *el_kickv*=vertical kick [rad]
- for each element, read records 5, 6 if there are lattice errors:
  5: values of *el_der* = displacement ($\delta x, \delta y, \delta z$ [m]), angle errors ($\delta\phi, \delta\theta, \delta\psi$ [rad]),
  6: values of field errors *el_dk*.see *MAD* manual
- for each element, read record 7, if error, or 5:
  7 [5]: values for the Distorted Closed Orbit, *r_cod* = x,y,z [m], and the longitudinal position of the element end, s_cod [m].
- for each element, read records 8-13, if error, or 6-11:
  6×6 orbit transport matrix *R_mat*:,
- for each element, if track order = 2, and error, read records 9-43, if no error read records 6-41:
  a $6 \times 6 \times 6$ second order transport map *T_mat*.
- finally, for the entire lattice:
  values of *mad_tune* = betatron tunes ν_x, ν_y, *gamtr* = transition gamma = γ_T,
  mad_circ = total lenght of the ring [m], 6×6 one turn matrix *OT_mat*

Some *spink* keywords are not recognized by *MAD*. In this case, *TrackInit* uses their name as keyword. E.g. a (thin) Siberian Snake should be defined as a MARKER in *MAD*, with name SNAK as follows:

SNAK: MARKER

In *spink* both name and keyword will be SNAK.

Keywords used for different machine elements are

Spink			MAD type
keyword	Spink type	Spink translation	
INIT	marker		MARKER
MARK	marker		MARKER
DRIF	drift		DRIFT
SBEN	sector bend		SBEND
QUAD	quadrupole		QUADRUPOLE
SEXT	sextupole		SEXTUPOLE
MULT	multipole		MULTIPOLE
RFCA	RF Cavity		RFCAVITY
SNAK	Snake	el_name → el_keywd	defined as MARKER
SPIN	Spin Rotator	el_name → el_keywd	defined as MARKER
HELI	Helix	el_name → el_keywd	defined as MARKER
KICK	Kicker		KICKER
HKIC	Hor. Kicker		HKICK
VKIC	Vert.Kicker		VKICK
FLIP	Spin Flipper	el_name → el_keywd	defined as MARKER
RFDH	RF Dipole (H)	el_name → el_keywd	defined as MARKER
RFDV	RF Dipole (V)	el_name → el_keywd	defined as MARKER
SOLE	Solenoid		SOLENOID
MATR	Matrix		MATRIX

4.5.1 Betatron tune adjustment

This is a special features of *TrackInit*.

Each quadrupole in the ring is padded by two thin addional quadrupoles, that provide a fine adjustment of the machine tune. This is useful is some run when one may want to scan a small interval of tunes with no need to run *MAD* again for each tune.

The algorithm is contained in the subroutine *Tunes:Detune*.

4.5.2 Discarded elements

Sometimes the lattice contains many machine elements that do not rotate the spin and that we want to discard to expedite *spink* runs. *TrackInit* can find them on a file, unit(14), and just ignores them. This may save substantial run time.

4.6 routine *Track*

This is the most important routine in *SPINK*. *Track* is based on three nested loops

```
call SyncParticle                                                Initialize Synch. particle
{                                                                Loop on particles
            call WorkParticle                                    Read Work Particle
            call npInit                                          Initialize per particle
            {                                                    Loop on turns
                        call ntInit                              Initialize per turn
                        {                                        Loop on components
                                    call Orbit                   Orbit transfer
                                    call Sprot                   Spin rotation
                        }                                        End loop on components
                        call WriteOutput                         Write Output at turn nt_pr
            }                                                    End loop on turns
}                                                                End loop on particles
```

The propagation of the orbit vector **r** is done in *Orbit*, Sec. 4.12, based on *MAD* maps, and the propagation of the spin vector **S** is done in *Sprot*, Sec. **??** with spin matrices based on the BMT equation.

It is important to recall that *spink* deals with low intensity polarized beams, so all particles in the tracking are independent. The only interaction is done when averaging variables over all particles in the beam. *spink* is essentially a sequentially structured code, where each particle is treated separately, hence the outer 'particle' loop.

Since tracking on a large accelerator with many lattice elements may take a considerable time, the use of a multi process parallel platform is essential to determine enseble results. Processors can be run independently, 'one case for each processor'. However, *spink* has also been implemented with the MPI library [7] for parallel computation. For this 'trivial' case MPI features must be enabled at compilation time, Sec. 7.4.

- The first call of *Track* is to *SyncParticle*, subroutine where the parameters of the reference (Synchronous) particle are set.
- The first call inside the particle loop (loop global variable *np*) is to *WorkParticle*, subroutine where the parameters of each individual particle in the simulation are set. This routine reads the coordinates of each Work Particle either defined on the contour of an ellipse of given emittance (see the GUI, variables for the module *Pop* and relative help string) or produced randomly by the subroutine *MakePop*, Sec. 4.8.
- Some variables are initialized per particle in the entry *npInit* in the subroutine *MiscInit*. If active, tables are at this point initialized by a call to the entry *TableInit* of the subroutine *Tables*, Sec. 4.4.
- Then, the loop on turns starts. In this loop the running variable is the *nt* turn number in the synchrotron (a global variable). Another leading variable is $G\gamma$, where G is the gyromagnetic anomaly of the particles (G = 1.7928456 for the proton and =-0.14301 for the deuteron) and γ is the relativistic energy factor, "energy". A run is terminated at the maximum number of turns *n_turn* or, alternatively, by the initial and final value of $G\gamma$, whichever is reached first.
- The first call in the turn loop is to Table(8). This table, if activated, contains a list of names of *MAD*-created input lattice descriptors of the machine and is used to update the lattice at intervals in energy, Sec. 4.4.
- Then, the One Turn Spin matrix is initialized by call to the entry *SpinGoodies:OneTurnSpinMatInit* and quantities per turn are initialized by the entry *MiscInit:ntInit*, in particular the counters for special lattice elements, like snakes, Sec. 4.7.

- Then the loops on lattice elements starts. *Track* explores the lattice and finds all the elements, recognized by their keyword *el_keyw*, Sec. 4.5.
- The phase space vector for the orbit is updated by the subroutine *Orbit*, Sec. 4.12, and the spin is updated by the subroutine *Sprot*, Sec 4.17. Calls to the diagnostic entry *Diagnostics:PrintAtElement* are done if the diagnostics file unit(99) is open.
- The output is written to records when machine elements, spcified in the input, are encountered, by the entry *Output:PrepareOtput*. The record will be written to the specific files (units(51, 52, 53, ...) at turn end in the entry *Output:WriteOutput*.
- Many other operations are performed at the end of each turn, like performing averages or calculate betatron tune and spin tune.
- Similar operations are performed at the end of the other two external loops, turn loop, and particle loop.

4.7 routine *MiscInit*

Some variables must be initialized or re-initialized once per particle, once per turn and once per machine elements in the three nested loops of *Track*. This is done in *MiscInit* that has three entries:

- entry *MiscInit:npInit*. Initialization per particle. RFDipoles (tables(3) and (4)), Sec. 4.23, Froissart-Stora, Sec. 6.1, Spin Flipper, Sec. 4.24, and quantities to be averaged over many particles.
- entry *MiscInit:ntInit*. Initialization per turn of counters for helices, snakes, rotators, bumps, RF cavities, RF dipoles in the lattice.

HLX_k,	counter for helices
SNK_k,	counter for snakes
ROT_k,	counter for spin rotators
BMP_k,	counter for orbit bumps
RF_k,	counter for RadioFrequency cavities
RFDH_k	counter for horizontal RF Dipoles
RFDV_k,	counter for vertical RF Dipoles.

- entry *MiscInit:jelInit*. Initialize and re-initialize quantities per element, such that field components and orbit curvature to zero.

4.8 routine *Makepop*

Generates a random beam with KV, Water Bag, Linear, or Gaussian distribution in 6D, matched in transverse to alfa, beta, emittance (rms) [2].

Makepop writes a particle distribution to unit(13), input file to *spink*. If this unit is read, it overwrites any distribution directly generated according to Sec. 7.3.8. Each record of the file associated to unit(13) contains the phase space and spin coordinates of one particle

$$(\mathbf{r}, \mathbf{S}) \equiv (x, x', y, y', \Delta\phi, \Delta E/pc, S_x, S_y, S_z) \tag{5}$$

4.9 routine *Popul8*

Function *Popul8* = *poprec*, where *poprec* is the string of Eq. (5) containing the phase space and spin coordinate of a particle to be used in *Track:WorkParticle*.

If any of the external population files, unit(13), generated by *Makepop*, Sec. 4.8, or unit(12), manually edited, is enabled, a record of the file is read into *Popul8* = *poprec*.

Otherwise, particle un-normalized transverse coordinates on an ellipse of emittance specified by input parameters, sec. 7.3.8 are created. The distribution is normalized to an invariant emittance in *WorkParticle*, Sec. 4.11.

In this latter case, the algorithm to generate n particles on a phase space ellipse is to put coordinates at equal angles of $2\pi/n$, starting from the prescribed angle.

4.10 routine *SyncParticle*

Defines the synchronous (reference) particle in the beam. *SyncParticle* is the same for all particles, so it it is called before a particle (outermost) loop of *Track* is initiated

Sets initial and final quantities for a track run. Calculates the synchronous phase on the basis of the prescribed energy gain per turn, from input, Sec. 7.3.6, or from acceleration table(1), if enabled, and from the total RF cavities' accelerating voltage

$$\phi_s = \arcsin \frac{E_0 \gamma_s}{eV_{tot}} \tag{6}$$

4.11 routine *WorkParticle*

Reads the initial coordinates of a particle from *Popul8*, Sec. 4.9, and builds work particle parameters. If the flag *coup* is true, coordinates are interpreted in the Edward-Teng couple mode, call *Coup*, Sec. 4.26.

If a non zero closed distorted orbit (COD) is present, transverse coordinates rr, absolute coordinate, and r_β coordinates with rispect to the COD are established

$$rr_i = r_i^{(\beta)} + r_i^{(COD)}, \quad i = 1, 4 \ .$$

Pendulum coordinates for the longitudinal motion are also initialized, Sec. 4.13.

[2] After Giuliano Franchetti

4.12 routine *Orbit*

Orbital phase space propagation. The orbital motion of the particles in *spink* is controlled by subroutine *Orbit* called by *Track* at each element encountered in the lattice.

Algorithms are applied in the following order:

- Define a new phase space variable $\mathbf{r}^{(\beta)} = \mathbf{r} - \mathbf{r}^{(COD)}$, i.e. the particle trajectory with respect to the COD orbit. 5.th and 6.th components of the COD vector are zero.
- Look for the element keyword, Sec. 4.5, and act accordingly. There is an entry for each type of element in the lattice.

keyword	action	subroutine: entry
QUAD	call	*MatrixUpdate: QuadMat*
BEN	call	*MatrixUpdate: DipoleMat*
RFCA	call	*Acceleration*
SNAK	synth=return	Sec 1.2
	table=call	*MatrixUpdate: SnakeMat*
MATR	call	*MatrixUpdate: SnakeMat*, Sec. 1.2
SPIN	return	Sec. 1.2
HELI	return, or call	*Helix: HelixOrbit*. Sec 1.2
RFDH	call	*RFDipole: RFDOrbit*
RFDV	call	*RFDipole: RFDOrbit*
KIC	call	*Bumps: BumpOrbit*
MARK	return	

- Call *RayTransfer* to propagate the phase space vector $\mathbf{r}$ to the next element according to Eq. (3).
- Back transform the phase space vector $\mathbf{r} = \mathbf{r}^{(\beta)} + \mathbf{r}^{(COD)}$

Beam-Beam is recognized by name rather than keyword and is dealt with differently, Sxec. 6.2. So is *SpinFlipper*, Sec. 4.23

4.12.1 Treatment of lattice errors

If the machine lattice has errors, these errors are transmitted to *spink* via the *MAD* output file *runname.madout*, Sec. 7.1, read and processed by *mad_read*. Lattice errors are misalignments in the three directions, x, y, z, and magnet errors, around axes oriented as x, y, z[3]. To deal with misaligment (for spin dynamics vertical errors are especially important) the coordinates of a particle are displaced in *Orbit* with the opposite sign of the misalignment upon entering the element, and restored at the exit.

Similarly, the particle coordinate system should be rotated opposite to the rotation errors [4].

[3]There is an utility, *doom* of *madX* that automatically transfer measured magnet errors from a spreadsheet to *MAD*. This is an additional reason to migrate from *Mad8* to *madX*, Sec. 8

[4]Element rotation is not yet implemented in *spink*

4.13 routine *Acceleration*

Longitudianl orbital phase space

When *Track* find a machine element whose *el_keyw = RFCA*, it increases the momentum of the synchronous particle according to the specified acceleration rate and the momentum of a working particle, proportionally to the applied RF voltage in the cavity. RFCA is an element type known to *MAD*. There can be several RF stations in the lattice, each with its voltage and harmonic number, as specified in the input, Sec. 7.3.6.

Acceleration can be done (1) at a constant rate (linear) by specifying in input the change of γ per turn, or (2) reading a table(1) of γ vs. turn number (if such a table is open, the constant rate is overwritten).

The algorithms that are applied, are, in this order:

- Increase the energy of the syncronous particle

$$E_s := E_s + \delta\gamma_{s,i} E_0,$$

where $\delta\gamma_{s,i}$ is the increase of γ_s per turn in the $i-$th cavity;

- Calculate the synchronous phase

$$\phi_s = \arcsin \frac{E_0 \delta\gamma_s}{eV},$$

where $\delta\gamma_s = \sum \delta\gamma_{s,i}$ total variation of γ_s per turn, and $eV = \sum eV_i$ total voltage in the cavities (vector sum);

- Transform the phase of the working particle being considered from the unit of $r(5) = -c\Delta t$, meters, to a unit of angle, radians

$$\Delta\phi = -2\pi \frac{h_i \beta_s}{L} r(5), \tag{7}$$

where h_i is the harmonic number of the $i-$th cavity, β_s is the relativistic velocity of the synch. particle, L is the entire length of the accelerator;

- Check if the energy is above transition. In this case, apply a phase jump

$$\phi_s := \pi - \phi_s, \text{ and} \phi := \pi - \phi$$

.

- Apply a step increase to the energy of the working particle, calculated as

$$r(6) := r(6) + \frac{eV_i}{pc_s} \left(\sin\phi - \sin\phi_s \right), \tag{8}$$

where the sixth phase space coordinate is $r(6) = \Delta E/pc$.

- Apply a kick to the transverse momenta of the particle[5]

$$p_x := \frac{p_x}{1 + \delta p/p}, \text{ and } p_y := \frac{p_y}{1 + \delta p/p}, \tag{9}$$

where $\delta p/p = \delta\gamma_s / (\gamma_s \beta_s^2)$

The increment of energy per turn is subdivided in parts proportional to the voltage in each cavity

$$\delta\gamma_i = \delta\gamma_s \frac{eV_i}{\sum eV_i}$$

[5]This kick produces a change in the amplitude of the transverse oscillation of the beam, so that the Courant-Snyder emittance of the beam changes by a factor $1/\sqrt{\beta\gamma}$ and the normalized emittance stays constant

4.14 routine ***RayTransfer***

This routine actually propagate the 6D phase space vector $\mathbf{r}^{(\beta)}$ across a machine element. The equation implemented here is Eq. (3), to first and second order tracking.

Since second order tracking may be rather lengthy for large lattices, we may want to execute it only for certain machine elements, *e.g.* sextupoles. An input string corresponding to a class of elements, Sec. 7.3.17, switches on this action for that class. The string could be: NONE (no element tracked to second order), ALL (all elements to second), SEXT (only sextupoles to second), etc.

4.15 routine ***MatrixUpdate***

Update matrices for a dynamical representation of the lattice using tables.

The general form of a first order transfer matrix with no coupling[6] is

$$\mathbf{R} = \begin{pmatrix} c_x & s_x & 0 & 0 & 0 & D \\ c'_x & s'_x & 0 & 0 & 0 & D' \\ 0 & 0 & c_y & s_y & 0 & 0 \\ 0 & 0 & c'_y & s'_y & 0 & 0 \\ E & E' & 0 & 0 & 1 & G \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}, \tag{10}$$

with c, c', s, s' matrix elements for the transverse motion, D, D' dispersion terms, E, E' synchro-betatron terms, and G the transition term, that can be defined through the momentum compaction. For a symplectic matrix it is $E' = -D, E = -D'$.

Entries of *MatrixUpdate* for different type of matrices are

- Entry *MatrixUpdate:QuadMat.* For a quadrupole whose name is found in table(9), the K1 strength vs. γ is interpolated in the table and the 4×4 matrix transverse elements are updated. Note that to first order a quadrupole matrix has no dispersion terms, then no coupling between phase space variables ϕ and $\Delta E/pc$.

- Entry *MatrixUpdate:DipoleMat.* For a dipole with combined functions whose name is found in table(10), the K1 strength vs. γ is interpolated in the table. The 4×4 matrix transverse elements are updated. this way. A dipole matrix has dispersion terms that are a function of energy, and also the transition element is a function of energy, namely

  $$D = A/\gamma^2, \quad D' = B/\gamma^2, \quad G = C - H/\gamma^2.$$

  with A, B, C, H quantities defined in *MAD* [8].

- Entry *MatrixUpdate:SnakeMat.* For Siberian Snakes whose name is found in tables(11) and (12), two for the moment, the optics is changing with energy, so all the matrix elements should be updated according with the tables.

[6] and for the most common case of a synchrotron entirely laying on a horizontal plane

4.16 routine *OneTurnOrbitMatrix*

Update the OneTurnOrbitMatrix to calculate betatron tunes turn by turn.

Betatron tunes are calculate in *spink* with three methods, two of them based on counting orbit betatron oscillation, Sec. 4.25 or by an FFTof the orbit, Sec. 6.3. In the present routine betatron tunes (the fractional part of) are calculated from the eigenvalues of the one turn orbit matrix, so they are available turn-by-turn.

The routine has three entries:

- entry *OneTurnOrbitMatrix:OTMatrixInit*. Here, the one turn matrix is initialized at the beginning of a turn.
- entry *OneTurnOrbitMatrix:OTMatrixUpdate*. Here, the one turn matrix is calculated at each machine element by progressive multiplication of the element orbit matrices.
- entry *OneTurnOrbitMatrix:FracTuneFromOTMat*. Here, the fractional part of the betatron tunes is calculated from the trace of the one turn matrix.

4.17 routine *Sprot*

Spin rotation,

At variance with orbital phase space propagation, spin rotation 3×3 matrices are built on the fly, because spin rotation is a function of the magnetic field found at the instantaneous position of the particle. Spin matrices are constructed starting from the BMT Eq. (4), for thin elements [9]

$$\frac{d\mathbf{S}}{dt} = \vec{\omega} \times \mathbf{S}$$

where $\vec{\omega}$ is a function of the magnetic field calculated at the instantaneous position of the particle.

$$S_n = \sin\mu, \; C_s = 1 - \cos\mu$$

The Spin rotation matrix *S_mat* is

$$\mathbf{M}^{(S)} = \begin{pmatrix} 1-\left(a_2^2+a_3^2\right)C_s & a_1a_2C_s + a_3S_n & a_1a_3C_s - a_2S_n \\ a_2a_1C_s - a_3S_n & 1-\left(a_1^2+a_3^2\right)C_s & a_2a_3C_s + a_1S_n \\ a_3a_1C_s + a_2S_n & a_3a_2C_s - a_1S_n & 1-\left(a_1^2+a_2^2\right)C_s \end{pmatrix}, \tag{11}$$

with

$$\begin{cases} a_1 = C\left[(1+G\gamma)B_x - G(\gamma-1)(\mathbf{r}'\cdot\mathbf{B})x'\right] \\ a_2 = C\left[(1+G\gamma)B_y - G(\gamma-1)(\mathbf{r}'\cdot\mathbf{B})y'\right] \\ a_3 = C\left[(1+G\gamma)B_z - G(\gamma-1)(\mathbf{r}'\cdot\mathbf{B})\right] \end{cases},$$

$$\omega^2 = a_1^2 + (a_2 - 1/\rho)^2 + a_3^2, \quad \mu = \omega L \; .$$

$C = \frac{1}{B\rho}(1 + x/\rho)$, L is the length of a machine element, and the field components are calculated midway through the element.

Sprot is called by *Track* after *Orbit* and calls in turn *SpinMat* that produces matrices for different type of machine elements, Sec. 4.18. In the case of elements that do not rotate spin, like DRIFT or MARKER *Sprot* returns immediately to *Track*.

4.18 routine *SpinMat*

Spin Matrices.

The routine has many entries, for different types of machine elements. In this routine the magnetic field at the particle transverse position and in the middle of the machine element, $\mathbf{r}_W$ is calculated and returned to *Sprot*.

- entry *SpinMat:UnitSprot*. Initialize a spin matrix as unitary.
- entry *SpinMat:BendSprot*. Spin rotation in a bend. If a bend is pure, *i.e.* has no gradient nor sextupole, its magnetic field is simply vertical and the entry returns with that component of the field. If the bend has multipoles, it returns to *Sprot* but subsequently multipole spin rotation is called.
- entry *SpinMat:MultipoleSprot*. Magnetic field at the particle', for quadrupoles, tilt quadrupoles and sextupoles.
- entry *SpinMat: SolenoidSprot*. In good approximation the magnetic field of a solenoid is purely longitudinal.
- entry *SpinMat:SnakeSynthSprot*. For each Synthetic Siberian Snake in the lattice, in sequence (Snake counter *SNK_k*, with rotation angles given as input, Sec. 7.3.9, all coefficients for the spin matrix of *Sprot* are calculated and returned.
- entry *SpinMat:SnakeTabSprot*. For a snake represented by a table, coefficients for spin matrix are calculated from angles in the table and returned to *Sprot*
- entry *SpinMat:SpinrSynthSprot*. Spin rotators, treated as for synthetic snakes, with rotation angles given as input, Sec. 7.3.10
- entry *SpinMat:SprotInKicker*. Calculate and return spin matrix elements in kickers, horizontal and vertical kicks.

For each element the global variable spin rotation angle $\mu \equiv mu$ is calculated.

4.19 routine *Helix*

Orbit and spin matrix for a helix based on some analytical description.

Some Siberaian snakes and spin rotators are made with a sequence of helical dipoles [10]. Input parameters for a helix are the helix field, the helix pitch, the helicity sign (right- or left-handed), and the orientation of the field.with the vertical. Parameters are entered through the GUI, Sec. 7.3.11, for their description. A counter *HLX_k* numbers helices accordindg to their occurrence while visiting the accelerator.

Helix has two entries:

- entry *Helix:HelixOrbit*. E.Courant model [11]. Here the beam transfer matrix elements are calculated, then the routine returns to *Orbit*.
- entry *Helix:HelixSprotAnalyt*. M.Syphers model [12]. Here the spin matrix alements are calculated, the the routine returns to *Sprot*.

4.20 routine *SpinGoodies*

Some spin related quantities.

Entries are:

- entry *SpinGoodies:SpinInit.* Called from *WorkParticle* Initializes spin components, after two of them (out of three) have been read from input, Sec. 7.3.8, or from unit(12) or (13) associated with the population file.. Initializes One Turn Spin Matrix quantities for spin tune calculation.
- entry *SpinGoodies:SpinAngles.* Called from *Track.* Calculates and print on unit(33) (diagnostics file) the spin components and the anles of longitude and latitude of the spin vector along the orbit.
- entry *SpinGoodies:SpinSum.* Called from *Track.* For spin average over many particles, builds

  $$\sum_{np} S(i), \quad and \quad \sum_{np} S(i)^2, \quad i = 1,3$$

  .
- entry *SpinGoodies:SpinTuneDo*, called from *Track.* Writes on unit(34) (diagnostics file) spin and spin cone data at the beginning of a turn and then collects and writes to (34) spin tune calculated from spin precession. Deprecated
- entry *SpinGoodies:SpinAverage*, called from *Track.* Calculates spin averaged by stroboscopic mean and variance over all particles at the end of each turn. Calculates and prints at the end of the run the angles of spin cone. If we want to center the input spin cone on the stable axis, we use

  the input spin cone of beam on stable axis, the stroboscopic averaged spin components are written on the input population file, unit(13), next to the phase space coordinates[7].

  In this entry also the average spin tune from the eigenvalues of the One Turn Spin matrix are calculated and printed to stdout at the end of the run.
- entry *SpinGoodies:SpinFileWrite.* Deprecated
- entry *SpinGoodies: OneTurnSpinMatInit*, called from *Track.* Initialize one turn spin matrix at the beginning of each turn. If unit(44) (diagnostics) is alive the stable axis is also initialized.
- entry *SpinGoodies:OneTurnSpinMatAtTurnEnd*, called from *Track.* If unit(30) (diagnostics), is alive, Calculate Spin One Turn matrix trace and stable axis components at turn end
- entry *SpinGoodies:SpinTune3.* Called at turn end. Calculate spin One-Turn variables betweenn points of same phase space by averaging spin tune over turns (stroboscopic average). There is an approximation to calculate spin tune in one spin one-turn and re-normalize the One Turn Spin Matrix [8].
- entry *SpinGoodies:StoreSpinSum.* Store spin and tune sums at marker #1 for sequential average over particles. Write and read spin to unit(24), use unit(91) (disposable) as buffer. Write and read spin tune to unit(25), use unit(92) (disposable) as buffer.
- entry *SpinGoodies:MultiPartAverage.* Averages spin and tune values at marker #1 over all npart particles at run end. Writes results for spin average to unit(24) and spin tune average to unit(25).

[7]this file will be used in a next run

[8]An exact one-turn for spin is when the particle is back in phase space where it started. It may take many accelerator turns because of betatron motion

4.21 routine *Bumps*

Orbit Bumps

Orbit bumps are sometimes used on circular machines for special purposes. An example are the horizontal orbit bumps to offset the orbit in an helical Siberian Snake[13]. Orbit bumps must be represented by *RayTransfer matrices* for the orbital motion as well as by Spin matrices, because they generate a spin rotation. Bumps are called in sequence, with counter *BMP_k*

Bumps has two entries

- entry *Bumps:BumpOrbit*. Bumps effect on orbit. Called from *Orbit* for the orbital motion. Uses bump table(7). Bumps may be horizontal and vertical. Angle kicks on p_x or p_y, respectively.
- entry *Bumps:BumpSprot*. Bump effect on spin. Called from *Sprot* for the spin motion. Bumps may be horizontal and vertical. Spin matrix elements are calculated and returned.

4.22 routine *Output*

Prepares and prints out tracking output files.

spink can generate several output files, for orbit and spin coordinates at given location around the ring. Each location (here a MARKER) is tagged by the *el_name* of an element in the lattice. The list of print location is an input to the code.

- The entry *Output:PrepareOutput* is called at each one of the markers as they are found in the lattice during the element loop in *Track* and a record containing the variables at the marker is written for each marker (up to 9). In this entry, also the transverse Courant-Snyder invariants for the beam are calculated and recorded[9]

$$\epsilon_n = \frac{\gamma_T u^2 + 2\alpha_T uv + \beta_T v^2}{\sqrt{\beta\gamma}}, \quad with \quad u, v = x, x', \quad or \quad y, y',$$

  with $\alpha_T, \beta_T, \gamma_T$ Twiss parameters, and β, γ relativistic factors
- In the entry *Output:WriteAtMarkers* spin information can be written to a special file, unit(29).
- The entry *Output:WriteOutput* is called at give print intervals, Sec. 7.3.6, where output files, units(51),..(59) are written, one for each marker.
- Other files are written by the latter entry:
  unit(40), spin rotation in the snakes,
  unit(20), containing betatron tune and spin tune,
  unit(30), containing stable spin axis components, calculated from the One Turn Spin Matrix, and the projection of the spin vector on that axis.

[9]These quantities must remain constant if the tracking is corret, or equivalently the emittances must decrease as $(\beta\gamma)^{-1/2}$

4.23 routine *RFDipole*

Radio frequency dipoles

The formalism is due to Mei Bai [14]. An RF Dipole gives a RF kick to the beam and produces both an orbit bump and a spin rotation. Input parameters are the integrated magnetic field strength *Bdl*, in [Tesla.meter] and the RFD tune ν_m. The orbit kick and phase are given by

$$K = \frac{B\,dl}{B\rho} \cos\phi + phase, \quad \phi = 2\pi \int \nu_m.$$

The kick is applied to the beam, either in the horizontal or vertical direction, as

$$p_x := p_x - K, \quad \text{or} \quad p_y := p_y - K.$$

The spin rotation angle is

$$\mu = (1 + G\gamma)\, K$$

and the spin rotation matrices are

$$\sigma_H = \begin{pmatrix} \cos\mu & 0 & \sin\mu \\ 0 & 1 & 0 \\ -\sin\mu & 0 & \cos\mu \end{pmatrix}, \quad \sigma_V = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{pmatrix},$$

for the horizontal and vertical plane, respectively.

Each RF Dipole must appear in the *MAD* description as elements with name RFDH or RFDV and type MARKER. Since *MAD* doesn't have those element types, the routine *TrackInit* recognizes the name (el_name) and convert it into a keyword (el_keyw) RFDH or RFDV, Sec. 4.5 .

When *Track* find in the lattice a machine element with *el_keyw* = RFD, the RFD action is modeled in two routine entries: *RFDipole:RFDOrbit*, that calculates and applies a kick to the orbit, and *RFDipoleRFDSprot*, that calculates and applies a kick to the spin.

Reference value for $B\,dl$ and ν_m and *phase* are given as input, Sec. 7.3.16. The arrays of value refer to the first, second, ... RFD found in the lattice. In the example, only the second RFD found is active.

RF Dipoles are activated by enabling table(3) and (4). for an horizontal field RFD, and for a vertical field RFD, respectively After a first row containing the number of columns-1 to be read by *TableRead*, an RFD table contains, for each dipole

turn number, a multiplier for RFD_BdlMax, a multiplier for RFD_tune_m0

....

An example of table for two RFDV's (RFDV.tab, for the example above) is the following

		1.st dipole			2.nd dipole		
6	turn	Bdl	tune	phase	Bdl	tune	phase
	0	0.000000	1.000000	90.	...		
	300	0.000000	1.000000	90.	...		
	3300	1.000000	1.000000	90.	...		
	9300	1.000000	1.000000	90.	...		
	12300	0.000000	1.	90.	...		
	13300	0.000000	1.	90.	...		
	20000	0.000000	1.	90.	...		

In the example, the kick is linearly built between turns 300 and 3300, stays constant between 3300 and 9300, and linearly decays to zero between 9300 and 12300. Any shape is possible, since *TableInterp* interpolates between values in the table.

If activated, two files are written, for RFDH, unit(35), and for RFDV, unit(36), containing columns of

$$nt \quad Bdl \quad \nu_m \quad \phi \quad \text{Kick}$$

4.24 routine ***SpinFlipper***

This is for a Radio Frequency spin flipper. A Rf field is applied to the beam and generates a rotation of spin around an axis in the horizontal x-z plane, or the axis of a RF solenoid. The frequency may sweep through the resonant condition or, in the case of the solenoid may remain constant. The temporal shape of the applied field can be prescribed my means of table(13).

SpinFlipper has one entry

- *SpinFlipper:SFSprot*, called from *Sprot*. Specify as input, Sec. 7.3.14, at what turn to start action, the value of the integrated field *Bdl*, the spin flipper frequency, the frequency variation per turn, and how the field is applied, whether rotating or transverse, in x or y. or oscillating longitudinally (solenoid).

SpinFlipper calculates and returns to *Sprot* the spin matrix elements.

4.25 routine ***Tunes***

Calculate tune and detune from betatron oscillations zero counts.

It is one of the methods to calculate betatron tunes. A better one, turn-by-turn, is to calculate betatron tunes (fractional part of) from the eigenvalue of the orbital one turn metrix.

Tunes has 5 entries:

- entry *Tunes:TuneInit*. Initialize tune average over particles.
- entry *Tunes:CountBetaZero*. Count orbit zero crossings for tune evaluation, or comparing a tune oscillation wavelengt with the circumferende of the ring.
- entry *Tunes:BetaTuneDo*. Calculate betatron tune for each particle at end of run.
- entry *Tunes:TuneAverage*. Average tune for many particles
- entry *Tunes:Detune*, called by *TrackInit*, Sec. 4.5. Padding quadrupoles with two thin quads to obtain detuning. Every quadrupole transport matrix is transformed as follows

$$\mathbf{R}_x = \begin{pmatrix} R_{1,1} - \frac{1}{4}R_{1,2}\delta q & R_{1,2} \\ R_{2,1} - R_{1,1}\delta q + \frac{1}{4}R_{1,2}\delta q^2 & R_{2,2} - \frac{1}{2}R_{1,2}\delta q \end{pmatrix}$$

$$\mathbf{R}_y = \begin{pmatrix} R_{3,3} + \frac{1}{2}R_{3,4}\delta q & R_{3,4} \\ R_{4,3} + R_{3,3}\delta q + \frac{1}{4}R_{3,4}\delta q^2 & R_{4,4} + \frac{1}{2}R_{3,4}\delta q \end{pmatrix}.$$

with δq a (small) detuning parameter given in input, Sec. 7.3.6.

4.26 routine ***Coup***

After the formalism of Edwards and Teng [15] [16]

If the boolean flag *couple* = .true. after the introduction of a few matrices based on the One Turn Matrix (OTM), we end up building a 4×4 matrix **EDR** that is being used in *WorkParticle* to transform the coupled input phase space coordinates **u** to **r**

$$\mathbf{r} = \mathbf{EDR} \cdot \mathbf{u}.$$

The latter equation is in *WorkParticle*

5 Diagnostics routines

5.1 routine *Diagnostics*

Various debugging diagnostics.

Diagnostics has three entries:

- entry *Diagnostics:PrintAtElement*. Print at element for turns between *nt_pr_0* and *nt_pr_1*, given as input, Sec. 7.3.6. If unit(99) is open many relevant dynamic quantities, including phase space particle position $\vec{r}$ and spin $\vec{S}$, are printed element by element for a limited number of turns (1) before *Orbit*, (2) before *Sprot*, (3) after *Sprot*.
- entry *Diagnostics:PrintAllMatrices*. Print all orbit matrices at a certain energy on unit(42). Deprecated.
- entry *Diagnostics:PrintStatusAtTrackEnd*. Write phase space and spin at end of track on unit(43).

5.2 routine *Sequence*

Track and profile call sequence and spink flow.

Activate at compilation time with the directive *SEQ*=true.

6 Additional routines

6.1 routine *FroissartStora*

Polarization loss crossing an isolated spin resonance is well modeled by the Froissart-Stora formula [17]

$$P_2 = P_1 \left[\exp - \frac{\pi \epsilon_k^2}{2\alpha} - 1 \right] , \tag{12}$$

where P_2 is the polarization after the resonance and P_1 is the pol. before the resonance, ϵ is the resonance strenght and α the speed of resonance crossing.. Conversely, the formula can be used to calculate the resonance strenght by knowing P_2/P_1.

This is what is done in this routine. We specify in input, Sec. 7.3.13, at what energy *FroSto_Ggam* we want to do this, and after how many turn we want to look at P_2 and the routine calculates the resonance ϵ_k and writes it to stdout.

6.2 routine *BeamBeam*

In a collision between two beams of polarized hadrons, the particles in both beams suffer a deflection and also the polarization may change due to the motion of a polarized particle in the field of the other beam. In *BeamBeam* these effects are simulated by studying the kicks on orbit and spin of a particle in the field generated by a distribution, assumed Gaussian, of the other counterstreaming beam [18]. It is the so-called 'weak-strong beam-beam scenario'. Collision happen at a location specified in input, Sec. 7.3.15, coincident with one of the lattice elements, *e.g.* a marker. We specify also at what energy we want BeamBeam to occur and the number of particles in the beam.

BeamBeam contains three entries:

- entry *BeamBeam:BBCoast*. Slow down acceleration. Gradually turn on beam-beam. We want to see the effect on a coasting beam.
- entry *BeamBeam:BBOrbit*. Calculate Beam-beam orbit matrix -angle kick.
- entry *BeamBeam:BBSprot*. Beam-beam spin matrix. Calculate Beam-beam spin matrix.

6.3 routine *OrbitFFT*

Betatron tune an orbit harmonics content is calculated by FFT. First, sample orbit at equal intervals, then calculates tune using routines *four1.fft* and *twofft.f* from 'Numerical Recipes in Fortran' [19] that are included..

6.4 routine *MPIOutput*

Output for parallel computing with the MPI (Message Passing Interface) library.

To use MPI the boolean at compilation time is USEMPI = true. Each particle in the simulation is assigned a rank number *my_rank*, is individually tracked, and the results are averaged on the fly, at variance with sequential averaging were the averages are completed at run end. It is a trivial parallelization[10]. If there is only one particle and one process, as for sequential average, the rank of the particle is *my_rank*=0.

After a first block where spin averages are done, the routine presents two entries

- entry *MPIOutput:MPILogRec.* Write to Internal records initial and final parameters for each macro.
- entry *MPIOutput:MPILogOut.* Retrieve and write to log file 7 initial and final parameters for each macro

6.5 routine *Clock*

Set clock to measure run time for the first particle in a run. Enable in input, with *cclock*=.true. Sec. 7.3.5.

7 Pre Processors

7.1 *mad8*

At present use *mad8*. Work is in progress to accept input from *madX*.

Run with the command
=> *mad8c runname.mad*

The driver file *runname.mad* will produce the following

- A *runname.twiss* file containing the Twiss functions calculated at the physical end of each machine component and the distorted closed orbit COD, generated by the *mad8* command
  TWISS, tape='runname.twiss'
- A *runname.echo* file[11], that contains the first and second order orbit transfer maps, generated by the command
  SELECT, FLAG=first [second], RANGE=#*S*/#*E*
- A *runname.madout* file, containing tables of misalignment and field errors in the machine elements (if any), generated with the commands
  PRINT, RANGE=#*S*/#*E*
  SELECT, ERROR ; EPRINT, RANGE=#*S*#*E*

runname.twiss, *runname.echo* *runname.madout* constitute the input to *mad_read*.

[10]A better use of a parallel computer is in the parallelization of some algorithm or, in particular in the case of high intensity beams, in the study of space charge effects on beam dynamics and polarization

[11]The echo file was originally meant for diagnostics. Luckily it can contain the transport maps

7.2 *mad_read*

mad_read reads and combines the three *MAD* output files to create a single file *runname.sy* that contains Twiss functions, transfer maps, COD and information about machine component misalignment or field errors. If there are no errors, only the first two files are needed. All namefiles must be included in the driver file for *mad_read.in*.

The program is run with
=> mad_read < mad_read.in

The symplecticity of the matrices translated from *MAD* to *runname.sy* is improved with the use of an iterative algorithm and routine due to F.Neri.

The arrangement of *runname.sy* is as follows:

First record contains:

1	Mad vers.,	track order [=1 or 2]	errors [= 0 or 1]	n# of elementss [= jel]

If track order = 1, and no errors, for each machine element a block of 12 lines follows:

2	el. #	name	keyword	length		
3	angle	K1	K2	tilt	Hkick	Vkick
4	orbit - 4 values (deprecated)					
5	α_x	β_x	mu_x	D_x	D'_x	
6	α_y	β_y	mu_y	D_y	D'_y	
7	COD - 4 values				s coord.	
8-13	6×6 transfer matrix *R_mat*					

If track order = 2, and no errors, 36 lines follow for each block, containing the elements of *T_mat*:

14-50	$6 \times 6 \times 6$ second order transfer map elements

If there are errors, after line 3 there are two lines containing position and angle errors, and field errors (see *MAD* for the description)

3a	δx	δy	δz	$\delta\phi$ [pitch]	$\delta\theta$ [yawl]	$\delta\psi$ [roll]
3b	δB	$\delta K1$	$\delta K2$	$\delta K3$		

7.3 *GUI*

SPINK is launched through a motif-window based GUI. The GUI is a convenient interface to set values for the variables in the program, and to minimize errors of transcription

At the prompt, the GUI is started with the command

=> *uspink [runname]*

where *uspink* is a C-shell Unix script and *runname* is an arbitrary name for the run. If a configuration file *runname.conf* exists because it has been previously created, a menu window with 3 buttons shows up, as in Fig. 2. If the conf file does not exist you will be warned.

To edit the configuration file, click on $\boxed{\text{Setup}}$: a windows containing a list of the modules of *SPINK* will appear, Figs. 3, for 18 modules.

On this, and on each of the other module editing windows there is a help button $\boxed{?}$ that commentss the meaning of each variable, string or Boolean parameter. The variable names are the same used in the actual code. When finished with editing, go back to the start GUI window of Fig. 2 (still open on the screen) and select $\boxed{\text{Store}}$.

There is also another button, $\boxed{\text{Load}}$, that allows the user to load into the GUI the values of another configuration file previously created .

When finished with the GUI, close the window with the upper right cross $\boxed{\text{X}}$. The script will convert the conf file to a namelist input *runname_spink.in*and run *SPINK*.

One can also run directly *SPINK*, if you have already the *spink.in* file as follows

=> *spink* < *spink.in*

We will now visit all modules (GUI windows) that will be opened by clicking on $\boxed{\text{edit}}$, with detailed explanation of the meaning of all variables

7.3.1 GUI: input files

The GUI windows for input files is shown in Fig. 4, left. Some filenames in the example have a # as a first character. These files will not be opened. An array of values is indicated by a [...]

File names are arbitrary. Files whose first character is # are ignored.

file	example	description $\boxed{?}$
ffile(6)	terminal	This "file" is the stdout (the screen)
ffile(12)	pop_manual.dat	To manually input population data
		The file contains a series of strings Popul8
		each containing the 6+3 coordinates of a particle
		x ,px ,y ,py ,cDt ,$\Delta E/pc$,spino
ffile(13)	pop_auto.dat	Contains generated population
		This file is automatically built and used if it is enabled
		In this case, it contains a population of npart particles
		randomly generated with the parameters prescribed in Pop
		each record contains
		x ,px ,y ,py ,cDt ,$\Delta E/pc$,spino
ffile(14)	blue.sy	Input lattice descriptor
		This file is created first by *MAD* and then by
		the pre-processor *mad_read*
ffile(17)	DiscardedElements.dat	Contains machine elements not to be used
		in order to decrease the size of the lattice file
		If enabled, the file is read by TrackInit
		each record contains the name of a discarded element

7.3.2 GUI: output files

The GUI windows for output files is shown in Fig. 4, right. Some filenames in the example have a # as a first character. These files will not be opened. An array of values is indicated by a [...]

file	example	description $\boxed{?}$
ffile(7)	spink.log	Log file.
		It is a copy of the screen plus some more info on the run
		For many particles run, it contains only the 1.st particle
ffile(8)	orbit.dat	Detailed orbit of the first particle in the simulation
ffile(15)	#COD_short.dat	Closed Distorted Orbit.
		Contains:elem_no, s, x_COD, y_COD
ffile(20)	#tunes.dat	File contains
		$G\gamma$, γ, beta-tune(fraction), spin-tune
ffile(21)	#fine_orbit.dat	Orbit at each location in the machine.
		Contains s(extended), x, y
ffile(23)	#COD.dat	closed distorted orbit from machine descriptor
		el#, s, x_COD, px_COD, y_COD, py_COD
ffile(24)	#spin_ave.dat	spin average over many particles
		nt, $G\gamma$, $< Sx >$, $< Sy >$, $< Sz >$, $< Sx > -\sigma$. ... $< Sx > +\sigma$, ...
ffile(25)	#tune_ave.dat	tunes average over many particles
		nt, $G\gamma$, $< Qx >$, $< Qy >$, $< Qz >$, $< Qx > -\sigma$, ... $< Qx > +\sigma$, ...
ffile(28)	#phs.dat	phase space output
[ffile(31)]	RFD_spin1.dat	array of strings
	RFD_spin2.dat	outputs for radio frequency dipole.
	...	presently up to 2 files
		units 31 and 32 for 1.st and 2.nd RFD, respectively.
		Contains nt ,Bdl, tune, phase, kick
[ffile(35)]	#RFD_orb1.dat	array of strings
	RFD_orb2.dat	orbit outputs for radio frequency dipole
	....	presently up to 2 files: units 35 and 36
		for 1.st and 2.nd RFD, respectively. Contains:
		nt, Bdl, tune, phase, kick
		keep units 37 and 38 for extension
[ffile(51)]	NE260_INIT.dat ...	array of strings
		output at markers one
		presently for up to six markers
		units 51, 52, 53, 54, 56, 57, respectively
		nt, $G\gamma$, Sx, Sy, Sz, x, px, y, py, frac(Q), S-tune
[ffile(71)]	#process_1.dat ...	array of strings
		units 71 and up taken for MPI work
[ffile(81)]	#process_1.dat ...	array of strings
		units 81 and up taken for MPI work

7.3.3 GUI: diagnostics files

The GUI windows for diagnostics files is shown in Fig. 5, left. Some filenames in the example have a # as a first character. These files will not be opened. An array of values is indicated by a [...]

file	example	description $\boxed{?}$
ffile(9)	#sequence.dat	sequence of subroutines visited
		For diagnostics
ffile(29)	#spin_at_markers.dat	spin and spin_norm at markers
ffile(30)	#spin_axis.dat	evolution of spin axis and projection
		of spin on SA
		$G\gamma$, Spin_axis, spin·spin_axis
ffile(33)	#kick.dat	details of kicks. For each kick:
		KickH: elkick,mu=',kickh,mu
		KickV: elkick,mu=',kickv,mu
ffile(34)	#fine_spin.dat	details of: spino, theta_cone, phi_cone
ffile(40)	#mu_snk_out.dat	details of: SP_Ggam,SP_gam,mu_snk_out
ffile(41)	#OTMat.dat	One Turn Matrix
ffile(42)	#Matrices.dat	all orbit matrices
		el#, Rmat
ffile(43)	#StatAtTrackEnd.dat	Print Status At Track End
ffile(44)	#SpinMatrix.dat	Spin Matrix and One Turn Spin matrix
ffile(91)	#spin_ave_sum.dat	auxiliary for spin average over particles
		it accumulates spin sum and spin^2 sum
		for all turns
ffile(92)	#tune_ave_aux.dat	auxiliary for tune average
ffile(94)	#r_mat.dat	print all orbit matrices
ffile(98)	#FFT_aux.dat	writes:
		s(continuous), x, y, field, element_name
ffile(99)	diagnostics.dat	writes:
		s(continuous), x, y, field, element_name

7.3.4 GUI: tables

The GUI windows for tables is shown in Fig. 6, left. Some table names in the example have a # as a first character. These tables will not be used. An array of values is indicated by a [...]

file	example	description $\boxed{?}$
table(1)	#gamma.tab	Table of γ vs. turn no. Acceleration ramp
table(2)	#detune.tab	Table of detune parameter vs. turn no.
table(3)	RFDH.tab	Horizontal kick RF dipole table. Up to 6 RFDH table contains nturn, for first RFD:v1 v2, for second RFD:v1,v2,...
table(4)	#RFDV.tab	Vertical kick RF dipole table. Up to 6 RFDV nturn, for first RFD:v1 v2, for second RFD:v1,v2,...
table(5)	#SF.tab	Spin Flipper table vs. turn no.
table(6)	#Snake.tab	Snake table snake μ, ϕ(axis), θ(axis) vs. turn no.
table(7)	#Movable_Snake_Bump.tab	Snakes' bump table vs. turn no.
table(8)	#gamma_step_lattice.tab	To update the machine descriptor during acceleration contains the name of lattice files vs. γ
table(9)	#quadK1.tab	Table of quad K1 values vs. γ
table(10)	#snake_1.tab	Table of dipole K1 values vs. γ
table(11)	#snake_1.tab	Table of snake_1 matrix elements and mu vs. γ
table(12)	#snake_2.tab	Table of snake_2 matrix elements and mu vs. γ
table(13)	#SolSpinFlipper.tab	Table of solenoidal Spin Flipper Bdl vs. turn no.

7.3.5 GUI: flags

The GUI windows for logical flags is shown in Fig. 6, right. Some table names in the example have a # as a first character. These tables will not be used. An array of values is indicated by a [...]

variables	example	description $\boxed{?}$
Flags	on	Activate flags
no_spin	off	No spin track, only orbit
show_markers	off	Results at given markers in the lattice
cclock	on	Show clock run time
Ereno	off	Force renormalization of the Courant-Snyder invariant to control emittance in acceleration
couple	off	Edwards-Teng coupled injection
stable_spin	off	Automated calculation of stable spin direction to inject spin on the stable axis via stroboscopic average
Sprot_dmp	off	Diagnostics dump at *Sprot* use with small number of turns: it dumps at all machine elements
field_correction	off	Field correction in dipoles

7.3.6 GUI: dynamics

The GUI windows for dynamic variable setting for tracking is shown in Fig. 7, left. Some table names in the example have a # as a first character. These tables will not be used. An array of values is indicated by a [...]

variable	type	example	description $\boxed{?}$
Dyna	boolean	on	This module must be on
nturn	integer	100,000	Total number of turns (1)
dnt_pr	integer	117	Turn print step
nt_pr_0	integer	1	Turn where print starts
nt_pr_1	integer	1,000,000	Turn where prin stops
SP_Ggam0	double	250.	Sync Particle start $G\gamma$
SP_Ggamf	double	270.	Sync Particle end $G\gamma$ (1)
SP_dgam0	double	3.2E-005	Rate of increase of γ per turn if acceleration table is not used (2)
dq	double	0.	Quadrupole detuning factor(3)
err_corr	double	1.	Correction factor for lattice errors = 0. means: cancel all magnet errors
kick_corr	double	1.	Corr. factor for kicks = 0. means: cancel all kicks
cod_corr	double	1.	Corr. factor for Closed Distorted Orbit = 0. means: cancel distortions of orbit
particle	sring	p	At present only protons (p) and deuterons (d)
[harm(1)]	double array	280 9 ..	Harmonic in each RF cavity
[volt(1)]	double array	0.005 0.001	Voltage in each RF cavity $[GV]$

Notes: (1) track stop when nturn or SP_Ggamf is reached
(2) Table(2), Sec. 4.4
(3) Sec. 4.5

7.3.7 GUI: Orbit FFT

GUI window in Fig.7, right.

variable	type	example	description $\boxed{?}$
OrbFFT	boolean	off	FFT of the orbit
FFT_ntOrb1	integer	200	Turn at which start FFT
FFT_ntOrb2	integer	225	Turn at which end FFT
FFT_nOrb	integer	8192	Turns for FFT
FFT_OrbDz	double	1.	Longitudinal step for orbit FFT
FFT_Orbq1	double	2.7	Start frequency range
FFT_Orbq2	double	3.2	End frequency range

7.3.8 GUI: Population

GUI window in Fig.8, left.

variable	type	example	description $\boxed{?}$
Pop	boolean	on	Initial distribution of particles
npart	integer	1	No. of particles in the simulation
popseed	integer	1936	Seed for random extraction of population
deltaph	double	0.	$\Delta\phi$ longit. coordinate
deltap	double	0.	$\Delta E/pc$ longit. coordinate
[emit(1)]	double array	6.0E-006 6.0E-006	Emittance (H and V) [m-rad]
[angle(1)]	double array	0. 0.	Angles, if particles are generated on an ellipse(1)
[spino(1)]	double array	0. 1. 0.	Initial spin coordinates for one particle. If a pop file is used, each particle may have an individual set of spin coordinates It is enough to give two coords., *spink* calculates the 3.rd

Notes: (1) Sec. 4.9

7.3.9 GUI: Synthetic Snakes

GUI window in Fig.8, right.

variable	type	example	description $\boxed{?}$
Synth_Snakes	boolean	on	Setting of synthetic snakes a synth snake is a thin snake. it is represented by a marker called SNAKE in the MAD lattice descriptor. up to 6 snakes
[snake_mu(1)]	double array	180. 180.	Spin rotation angle in each snake [deg]
[snake_ax_phi(1)]	double array	135. 45.	Snake axis angle in the horizontal plane [deg]
[snake_ax_theta(1)]	double array	0. 0.	Snake axis angle of elevation [deg]

7.3.10 GUI: Synthetic Spin Rotators

GUI window in Fig.9, left.

variable	type	example	description
Synth_SpinRot	boolean	off	Setting of synthetic spin rotator. a synth snake is a thin snake. it is represented by a marker called SPINR in the MAD lattice descriptor. normally, spin rotators go in pairs up to 2 spin rotator pairs.
[spinr_mu(1)]	double array	90. -90. 90. -90.	Spin rotation angle in each rotator [deg]
[spinr_ax_phi(1)]	double array	4*90.	Spin rotator axis angle in the horizontal plane [deg]
[spinr_ax_theta(1)]	double array	4*0.	Spin rotator angle of elevation [deg]
[spinr_bend(1)]	double array	0.21 2*-0.21 0.21	Arc bend between rotators and the encompassed center point spin rotation is around an axis of angle given by $\phi + bend \cdot G\gamma$

7.3.11 GUI: Helix

GUI window in Fig.9, right.

variable	type	example/description $\boxed{?}$
Helix	boolean	off
		/Parameters of snakes and spin rotators helices
snake_tab	boolean	off
		/Use snake table
helix_analyt	boolean	off
		Analytical field of helices
		(Luccio, Courant, Syphers)
[helix_hand(1)]	double array	-1 1 -1 1 1 -1 1 -1 -1 1 -1 1
[helix_hand(13)]	double array	1 -1 1 -1 -1 1 -1 1 1-1 1 -1
		/Chirality of helix windings
[helix_alfa(1)]	double array	16*90. 0. 180. 0. 180. 180. 0. 180. 0.
		/Angle of field at helix entrance. with the vertical
[helix_B(1)]	double array	2.047 2*2.654 2.047 2.047 2*2.654 2.047
[helix_B(9)]	double array	2.047 2*2.654 2.047 2.047 2*2.654 2.047
[helix_B(17)]	double array	1.25513 2*4.03239 1.25513 1.25513 2*4.03239 1.25513
		/Field in the helices, snakes and rotators [T]

7.3.12 GUI: Stable Axis

GUI window in Fig.10, left.

variable	type	example	description $\boxed{?}$
Stable_axis	boolean	on	Spin stable axis search by stroboscopic average
spin_eps	double	2E-004	Accuracy of spin
ps_ang.eps	double	1E-002	Accuracy for location of phase space
OTSMtuneEps	double	1E-006	Accuracy of tune from one turn spin matrix

7.3.13 GUI: Froissart-Stora

GUI window in Fig.10, right.

variable	type	example	description $\boxed{?}$
Froissart-Stora	boolean	off	Froissart-Stora calculation of an isolated
			Spin resonance strength from spin tracking
FroSto_Ggam	double	3.82E002	$G\gamma$ value where to calculate Froissart-Stora

7.3.14 GUI: Spin Flipper

GUI window in Fig.11, left.

variable	type	example	description $\boxed{?}$
SFlipper	boolean	off	Activate Spin Flipper
SF_nt	integer	5000	How many turns SF is active
SF_Bdl	double	2.5E-002	Integrated field in Spin Flipper
SF_freq0	double	3.8E004	Start frequency
SF_dfreq	double	1E-001	Frequency variation per turn
SF_rot	string	x	Direction of field, “x”, “y”, “r”, “s”
			transverse, rotating, solenoidal

7.3.15 GUI: BeamBeam

GUI window in Fig.11.

variable	type	example	description ?
BBeam	boolean	off	Activate beam-beam
BB_Npp0	double	2E011	No. of particles in beam
BB_Ggam0	double	4.7E002	Start energy
BB_Ggam	double	4.8E002	Stop energy
BB_loc	string	CLOCK8	Collision location name in the lattice

7.3.16 GUI: RF Dipole

GUI window in Fig.12, left.

variable	type	example	description ?
RFD	boolean	off	Activate radio frequency dipole one needs tables. up to six
[RFDH_BdlMax(1)]	double array	0.02 0.02	Max Bdl in each horizontal RFD The 2.nd, 4th.. column in Table(3) will be multiplied by these values
[RFDH_Tune0(1)]	double array	0.49 0.49	Tune in each horizontal RFD the 3.nd, 5th.. column in Table(3) will be multiplied by these values
[RFDH_Dphase(1)]	double array	0. -90.	Phase shift in each horizontal RFD [deg]
[RFDV_BdlMax(1)]	double array	0. 0. 0. 0.	Max Bdl in each vertical RFD
[RFDV_Tune0(1)]	double array	0. 0. 0. 0.	Tune in each vertical RFD
[RFDV_Dphase(1)]	double array	0. 0. 0. 0.	Phase shift in each vertical RFD [deg]

7.3.17 GUI: Cycle

GUI window in Fig.12, right.

variable	type	example	description ?
Cycle	boolean	on	Activate cycle and diagnostics
gam_diag	double	1E002	Value of gamma for diagnostics
[marker(1)]	string array	INITIAL CLOCK6	List of lattice locations where to record data
[second(1)]	string array	SEXT SNAKE	Machine elements to be tracked to second order options: el_names, NONE, ALL

7.4 Compilation and Run

For portability, *SPINK* has been written in Fortran77. The code makes use of include files that contain Global and Local variables, Common and Namelist definitions, so it is very easy to add and subtract variables.

The *Spink* source is being distributed through a directory that contains also a makefile for compilation. The code has been run on different Unix platforms, but it is advisable to recompile it when it is imported to a new computer.

The code is write protected through RCS, so a user who would like to modify or add to it should first check out a routine with the command

=>*co -l routinename.F*

and after the file has been modified, check it in again with

=>*ci -u routinename.F*

For sequential run of the code, the compilation is done (in Linux) with the gnu compiler

g77

and for parallel code with the compiler and directive

mpif77 -DUSEMPI

Of course one can use other compilers in different machines.

To compile, do

=>[*make cleanall*] , for the first time, then =>*make*

To run the code through the GUI (recommended), invoke

=> *uspink runname*

To run the code directly

=>*spink* < *spink.in*

where *spink.in* is the driver file containing namelist blocks.

8 Suggested improvements

spink is still under development and probably will always stay in this state. Immediate and not-so immediate improvements are

1. Since *madX* is currently supporetd at CERN, while *mad8* is not any more, modifying *mad_read* to work with the former lattice generator seems a clear choice.

2. The present code works with thin spin rotation elements. This approximation seems well adequate to deal with large storage rings, like RHIC. For smaller machines thick spin elements are preferable. Already for tracking in the AGS we found that subdividing the bends in a few parts give results more in accord with experimental data.

3. Dynamic representation of the lattice. This is already implemented in the code in two different ways as explained in this manual. However, a real smooth implementation using tables is not yet working as we would like.

4. More work is needed for a complete characterization of the spin stable axis, stroboscopic averaging, and other spin goodies.

5. Tracking other particles and other spin states. Tracking vector and tensor polarization will require dealing with spin matrices with more dimensions.

6. Spin motion in the self field of intense beams may become an important issue for high luminosities colliders. This problem is addressed in *spink* in the *BeamBeam* routine, but a real study will require a large effort. For multi particle intense beam dynamics simulation an effective non-trivial parallelization is a must.

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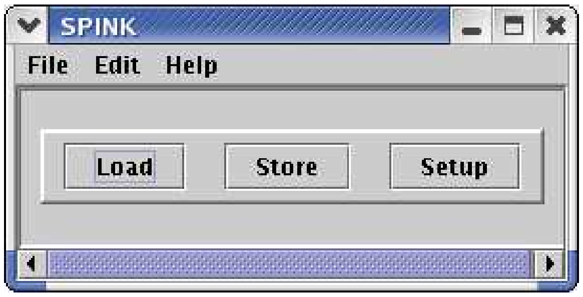
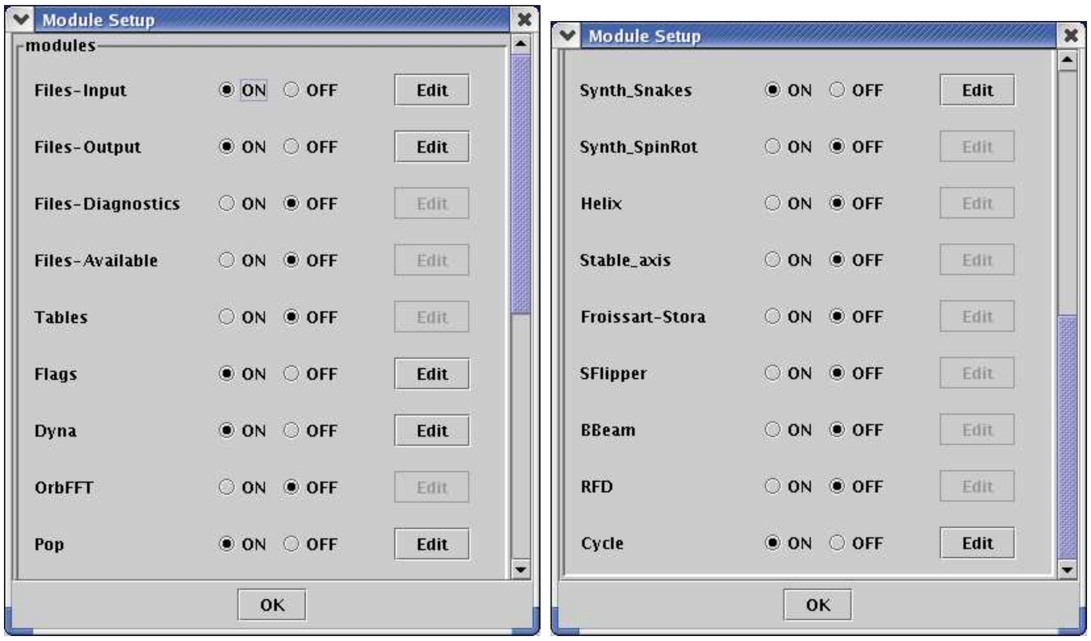


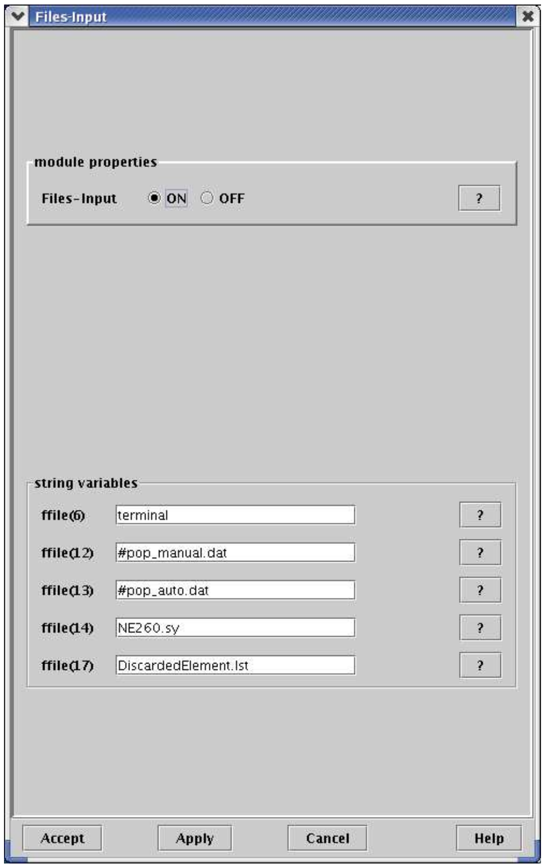
Figure 2: *SPINK* driving menu



Files-Input	[✓ ON]	OFF	Edit
Files-Output	[✓ ON]	OFF	Edit
Files-Diagnostics	ON	[✓ OFF]	Edit
Files-Available	ON	[✓ OFF]	Edit
Tables	ON	[✓ OFF]	Edit
Flags	[✓ ON]	OFF	Edit
Dyna	[✓ ON]	OFF	Edit
OrbFFT	ON	[✓ OFF]	Edit
Pop	[✓ ON]	OFF	Edit

Synth_Snakes	[✓ ON]	OFF	Edit
Synth_SpinRot	ON	[✓ OFF]	Edit
Helix	ON	[✓ OFF]	Edit
Stable_axis	ON	[✓ OFF]	Edit
Froissart-Stora	ON	[✓ OFF]	Edit
SFlipper	ON	[✓ OFF]	Edit
BBeam	ON	[✓ OFF]	Edit
RFD	ON	[✓ OFF]	Edit
Cycle	[✓ ON]	OFF	Edit

Figure 3: *SPINK* modules

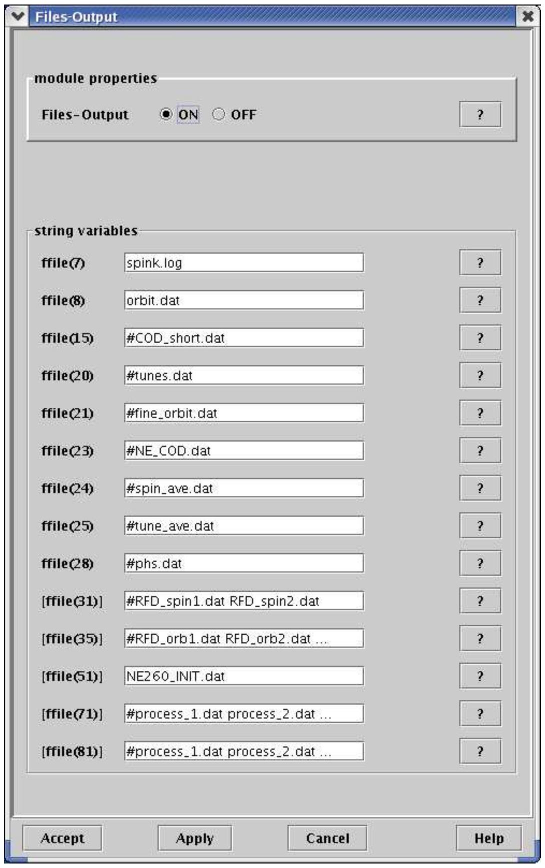


module properties

Files-Input [✓ ON] OFF

string variables

ffile(6)	terminal
ffile(12)	#pop_manual.dat
ffile(13)	#pop_auto.dat
ffile(14)	NE260.sy
ffile(17)	DiscardedElement.lst



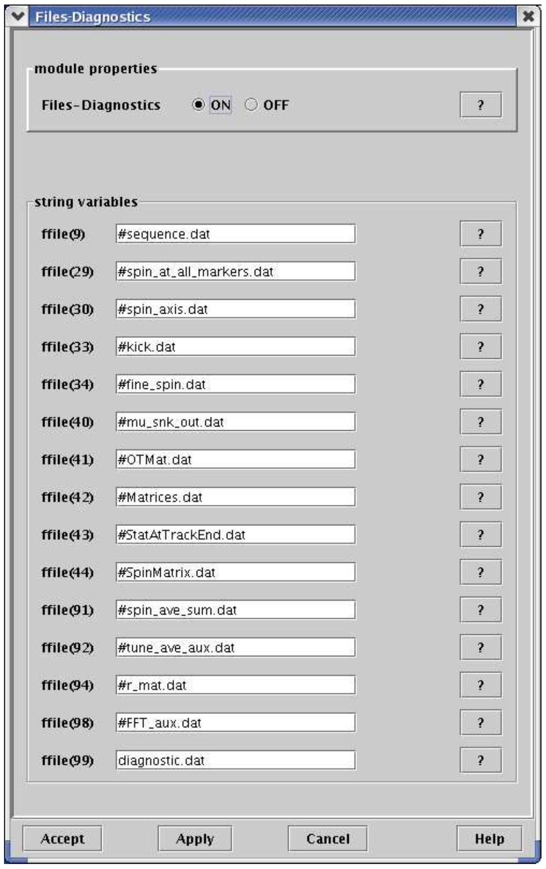
module properties

Files-Output [✓ ON] OFF

string variables

ffile(7)	spink.log
ffile(8)	orbit.dat
ffile(15)	#COD_short.dat
ffile(20)	#tunes.dat
ffile(21)	#fine_orbit.dat
ffile(23)	#NE_COD.dat
ffile(24)	#spin_ave.dat
ffile(25)	#tune_ave.dat
ffile(28)	#phs.dat
[ffile(31)]	#RFD_spin1.dat RFD_spin2.dat
[ffile(35)]	#RFD_orb1.dat RFD_orb2.dat ...
[ffile(51)]	NE260_INIT.dat
[ffile(71)]	#process_1.dat process_2.dat ...
[ffile(81)]	#process_1.dat process_2.dat ...

Figure 4: Left: input files, Right: output files. If a file name has a # as a first character, the file will be ignored. The opening of some file is equivalent to a flag to do something

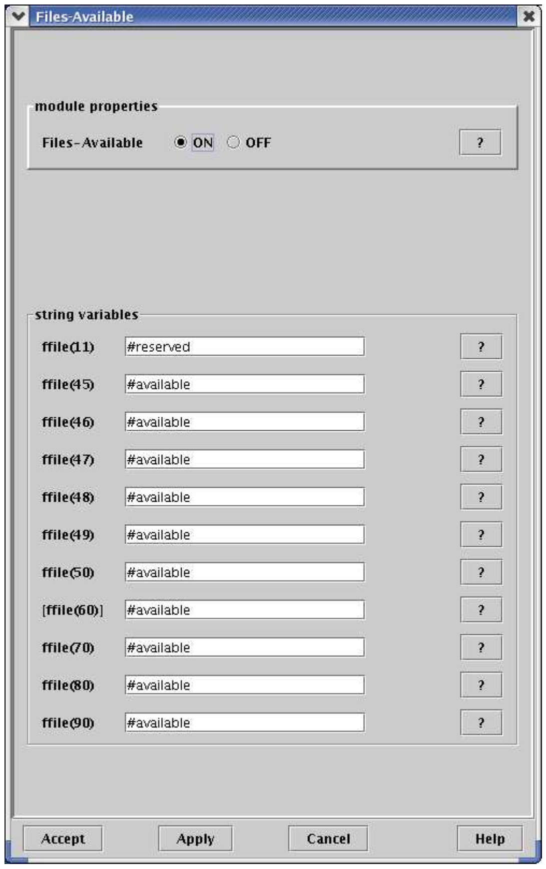


module properties

Files-Diagnostics [✓ ON] OFF

string variables

ffile(9)	#sequence.dat
ffile(29)	#spin_at_all_markers.dat
ffile(30)	#spin_axis.dat
ffile(33)	#kick.dat
ffile(34)	#fine_spin.dat
ffile(40)	#mu_snk_out.dat
ffile(41)	#OTMat.dat
ffile(42)	#Matrices.dat
ffile(43)	#StatAtTrackEnd.dat
ffile(44)	#SpinMatrix.dat
ffile(91)	#spin_ave_sum.dat
ffile(92)	#tune_ave_aux.dat
ffile(94)	#r_mat.dat
ffile(98)	#FFT_aux.dat
ffile(99)	diagnostic.dat



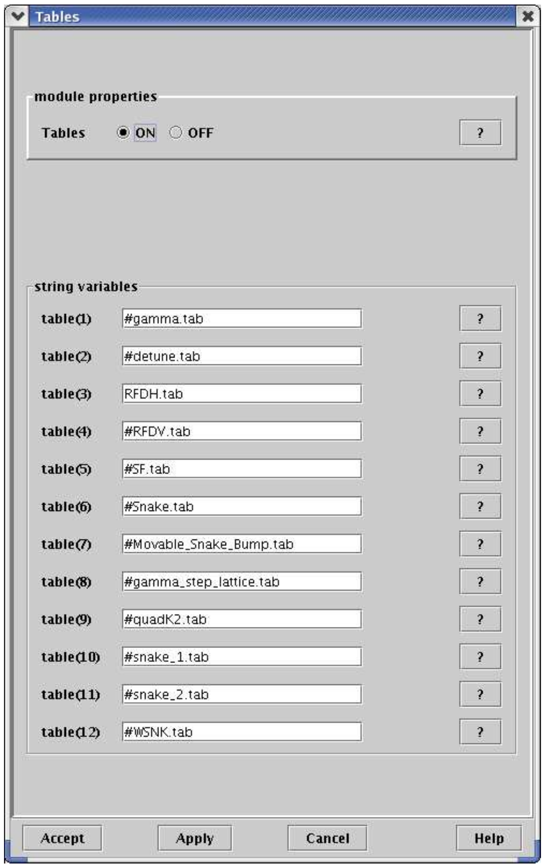
module properties

Files-Available [✓ ON] OFF

string variables

ffile(11)	#reserved
ffile(45)	#available
ffile(46)	#available
ffile(47)	#available
ffile(48)	#available
ffile(49)	#available
ffile(50)	#available
[ffile(60)]	#available
ffile(70)	#available
ffile(80)	#available
ffile(90)	#available

Figure 5: Left: diagnostics files. Right: available files. If a file name has a # as a first character, the file will be ignored. The opening of some file is equivalent to a flag to do something

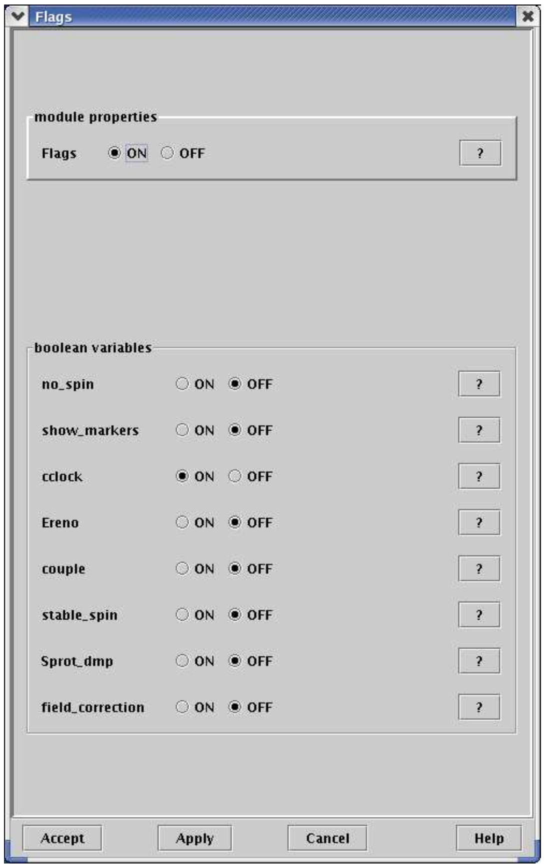


module properties

Tables [✓ ON] OFF

string variables

table(1)	#gamma.tab
table(2)	#detune.tab
table(3)	RFDH.tab
table(4)	#RFDV.tab
table(5)	#SF.tab
table(6)	#Snake.tab
table(7)	#Movable_Snake_Bump.tab
table(8)	#gamma_step_lattice.tab
table(9)	#quadK2.tab
table(10)	#snake_1.tab
table(11)	#snake_2.tab
table(12)	#WSNK.tab



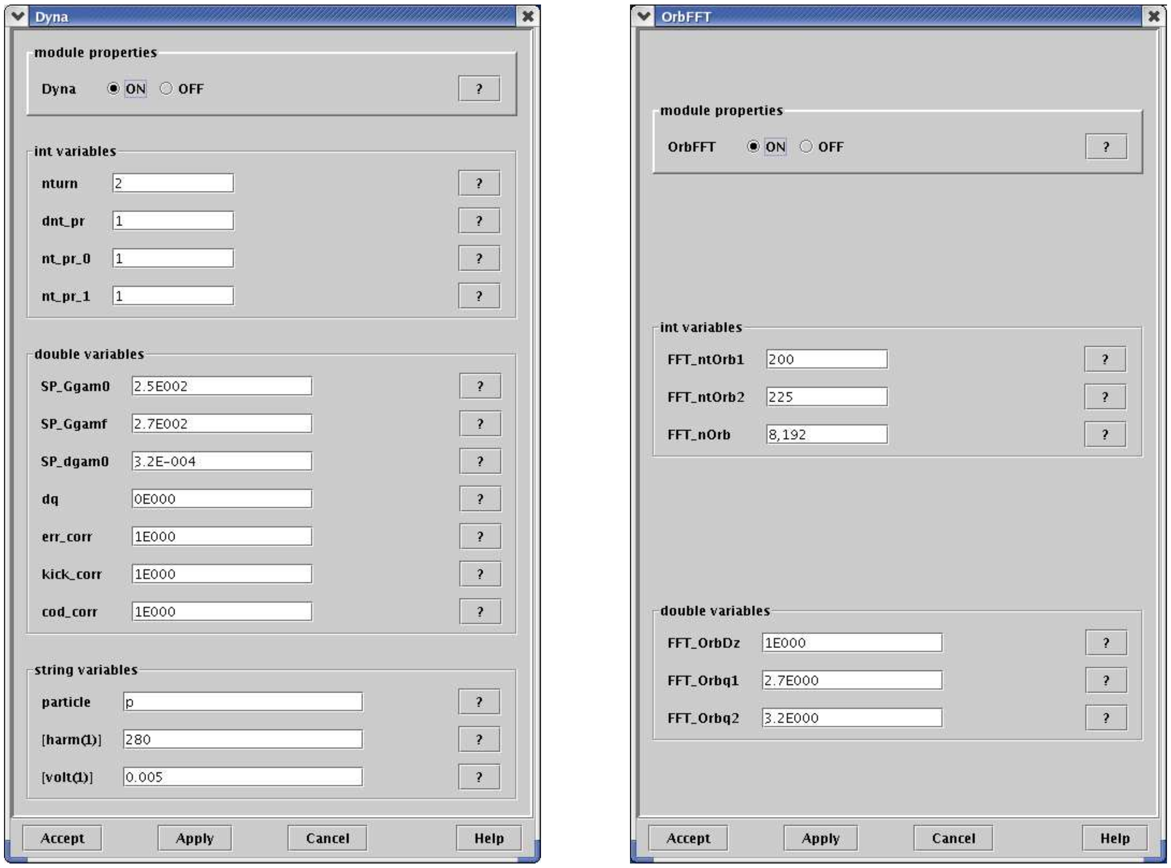
module properties

Flags [✓ ON] OFF

boolean variables

no_spin	ON [✓ OFF]
show_markers	ON [✓ OFF]
cclock	[✓ ON] OFF
Ereno	ON [✓ OFF]
couple	ON [✓ OFF]
stable_spin	ON [✓ OFF]
Sprot_dmp	ON [✓ OFF]
field_correction	ON [✓ OFF]

Figure 6: Left: Tables. If a table name starts with #, the table will be ignored. The opening of some table is equivalent to a flag to do something.
Right: Logical flags


Dyna

module properties

Dyna [✓ ON] OFF ?

int variables

nturn	2	?
dnt_pr	1	?
nt_pr_0	1	?
nt_pr_1	1	?

double variables

SP_Ggam0	2.5E002	?
SP_Ggamf	2.7E002	?
SP_dgam0	3.2E-004	?
dq	0E000	?
err_corr	1E000	?
kick_corr	1E000	?
cod_corr	1E000	?

string variables

particle	p	?
[harm(1)]	280	?
[volt(1)]	0.005	?

Accept Apply Cancel Help

OrbFFT

module properties

OrbFFT [✓ ON] OFF ?

int variables

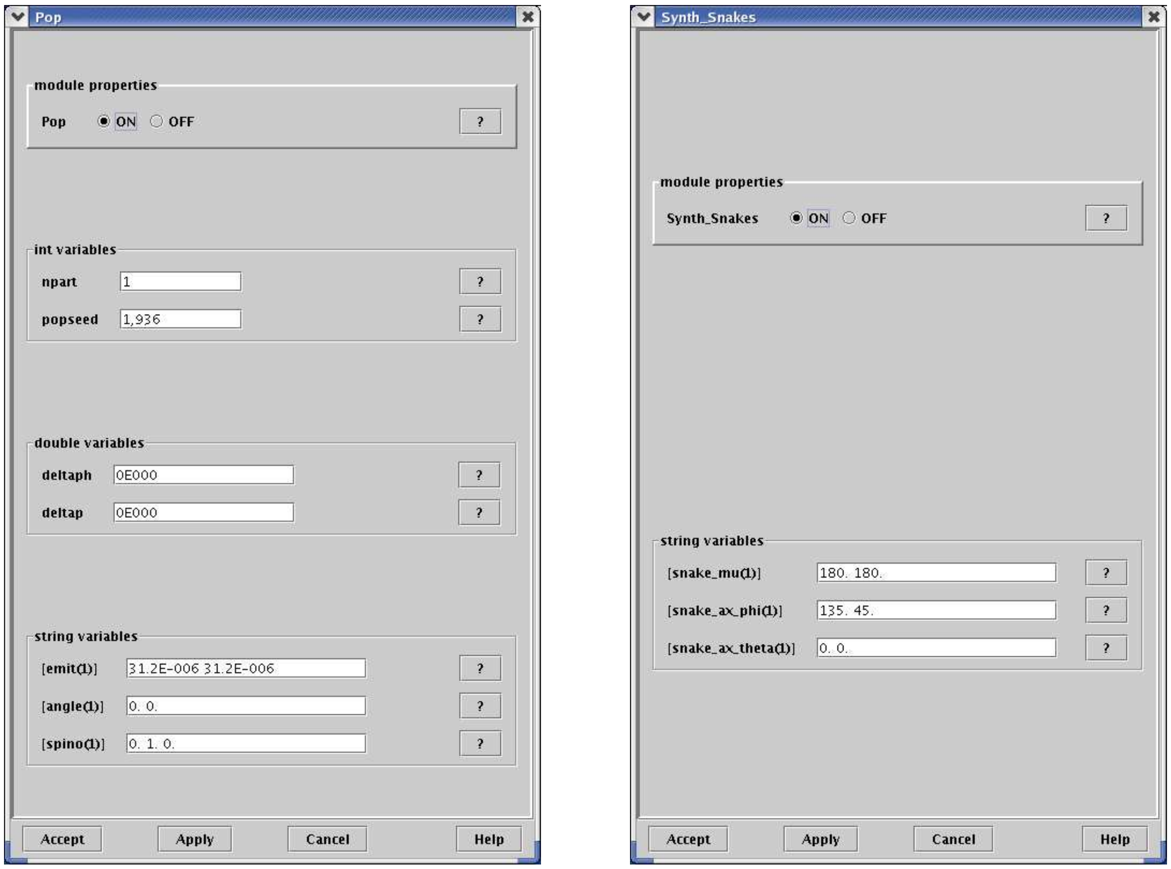
FFT_ntOrb1	200	?
FFT_ntOrb2	225	?
FFT_nOrb	8,192	?

double variables

FFT_OrbDz	1E000	?
FFT_Orbq1	2.7E000	?
FFT_Orbq2	3.2E000	?

Accept Apply Cancel Help

Figure 7: Left: Dynamic variables for tracking. Right: OrbitFFT variables



Pop

module properties

Pop [✓ ON] OFF

int variables

npart 1

popseed 1,936

double variables

deltaph 0E000

deltap 0E000

string variables

[emit(1)] 31.2E-006 31.2E-006

[angle(1)] 0. 0.

[spino(1)] 0. 1. 0.

Synth_Snakes

module properties

Synth_Snakes [✓ ON] OFF

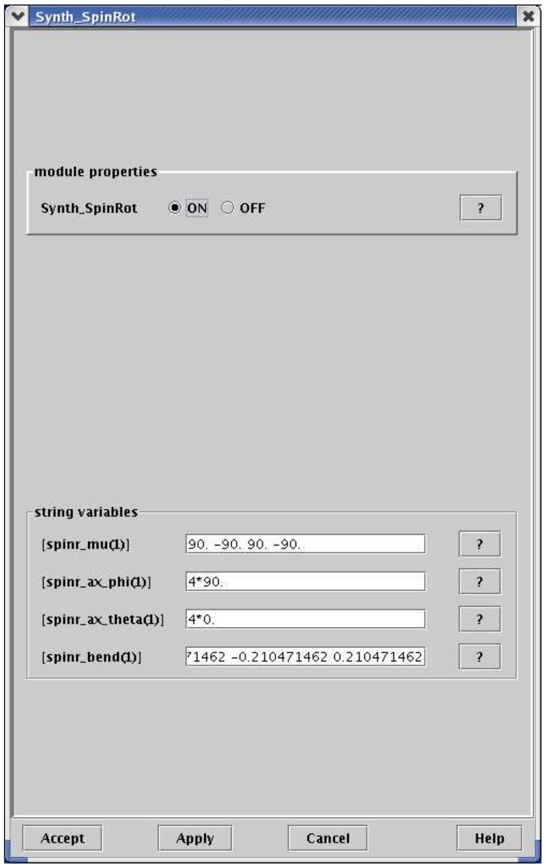
string variables

[snake_mu(1)] 180. 180.

[snake_ax_phi(1)] 135. 45.

[snake_ax_theta(1)] 0. 0.

Figure 8: Left: Particle distribution variables. Right: Synthetic snakes parameters



module properties

Synth_SpinRot [✓ ON] OFF

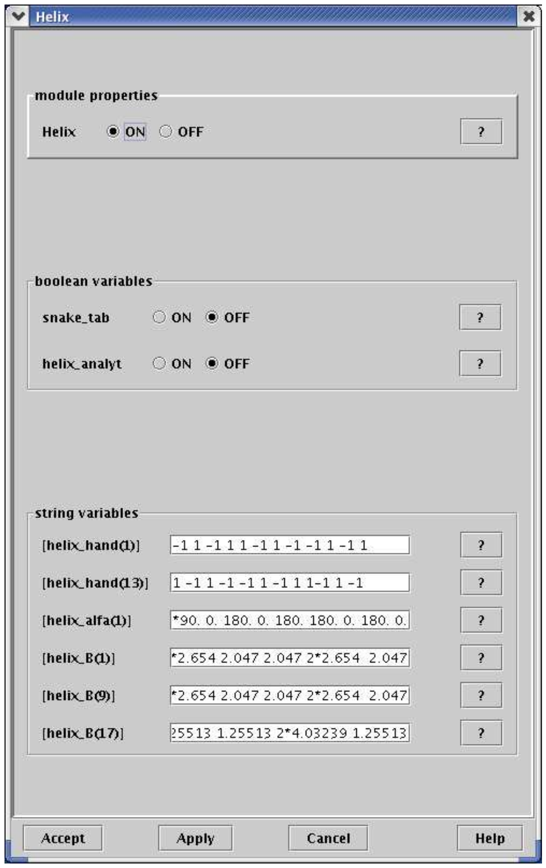
string variables

[spinr_mu(1)] 90. -90. 90. -90.

[spinr_ax_phi(1)] 4*90.

[spinr_ax_theta(1)] 4*0.

[spinr_bend(1)] '1462 -0.210471462 0.210471462



module properties

Helix [✓ ON] OFF

boolean variables

snake_tab ON [✓ OFF]

helix_analyt ON [✓ OFF]

string variables

[helix_hand(1)] -1 1 -1 1 1 -1 1 -1 -1 1 -1 1

[helix_hand(13)] 1 -1 1 -1 -1 1 -1 1 1-1 1 -1

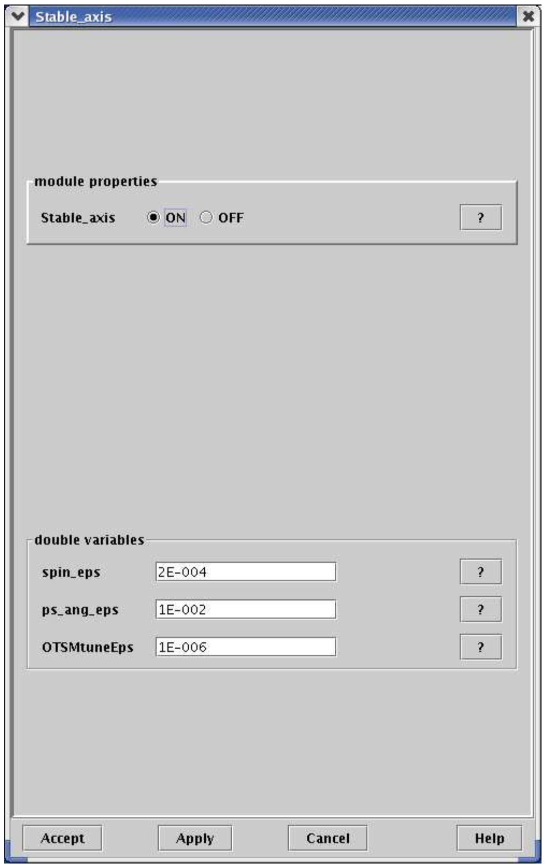
[helix_alfa(1)] *90. 0. 180. 0. 180. 180. 0. 180. 0.

[helix_B(1)] *2.654 2.047 2.047 2*2.654 2.047

[helix_B(9)] *2.654 2.047 2.047 2*2.654 2.047

[helix_B(17)] 25513 1.25513 2*4.03239 1.25513

Figure 9: Left: Synthetic snakes parameters. Right: Helix parameters



Stable_axis

module properties

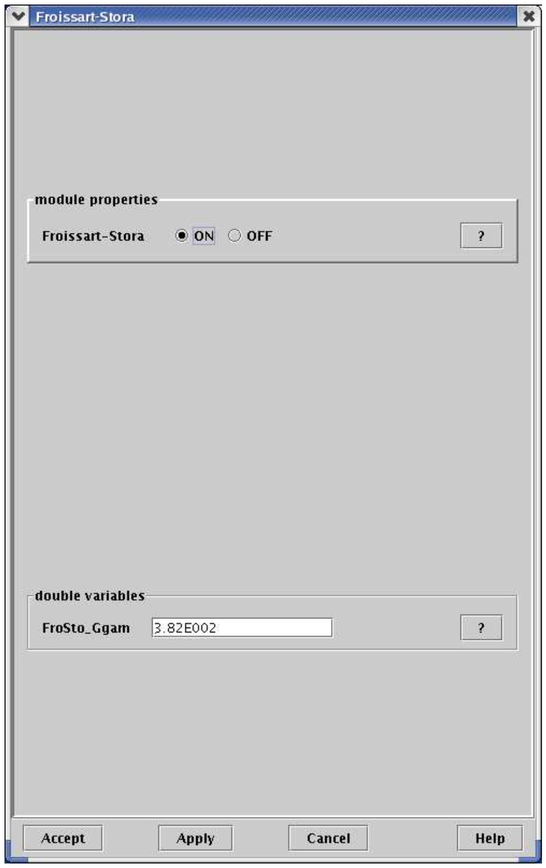
Stable_axis [✓ ON] OFF

double variables

spin_eps 2E-004

ps_ang_eps 1E-002

OTSMtuneEps 1E-006



Froissart-Stora

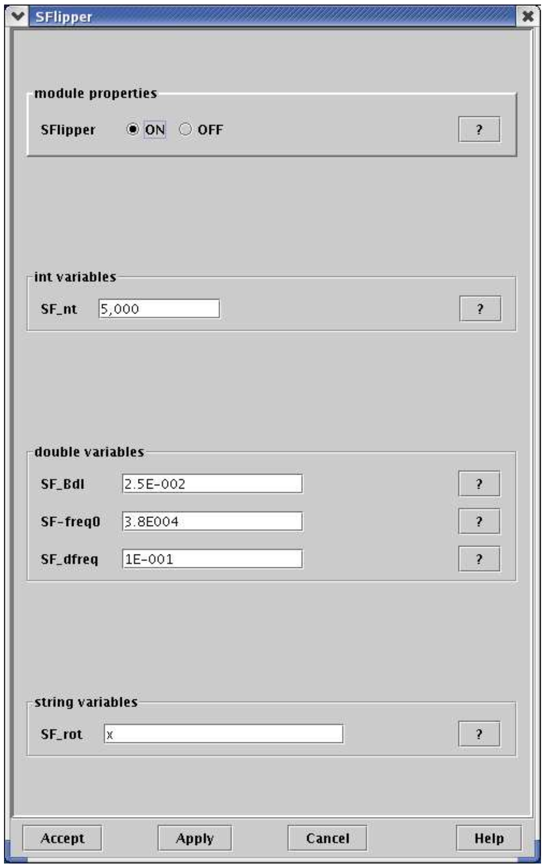
module properties

Froissart-Stora [✓ ON] OFF

double variables

FroSto_Ggam 3.82E002

Figure 10: Left: Parameters for stable axis calculation. Right: Parameters for Froissart-Stora calculation



SFlipper

module properties

SFlipper (● ON ○ OFF)

int variables

SF_nt 5,000

double variables

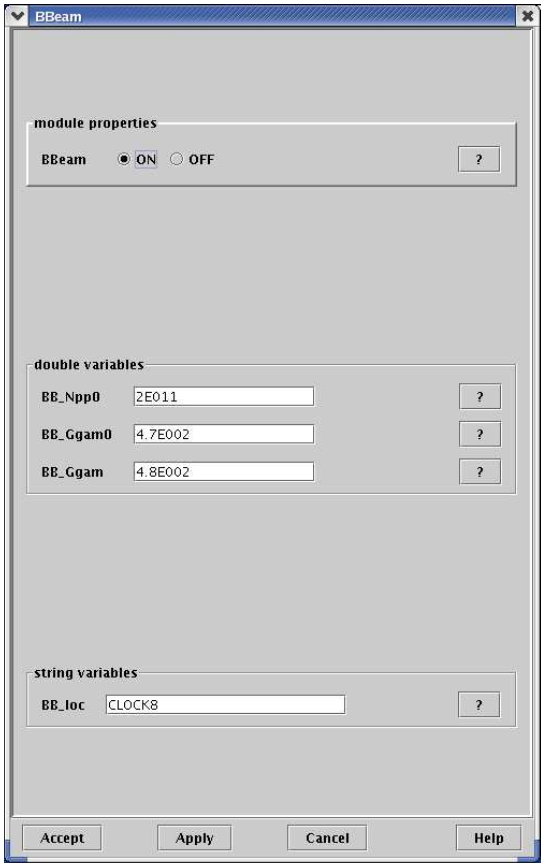
SF_Bdl 2.5E-002

SF-freq0 3.8E004

SF_dfreq 1E-001

string variables

SF_rot x



BBeam

module properties

BBeam (● ON ○ OFF)

double variables

BB_Npp0 2E011

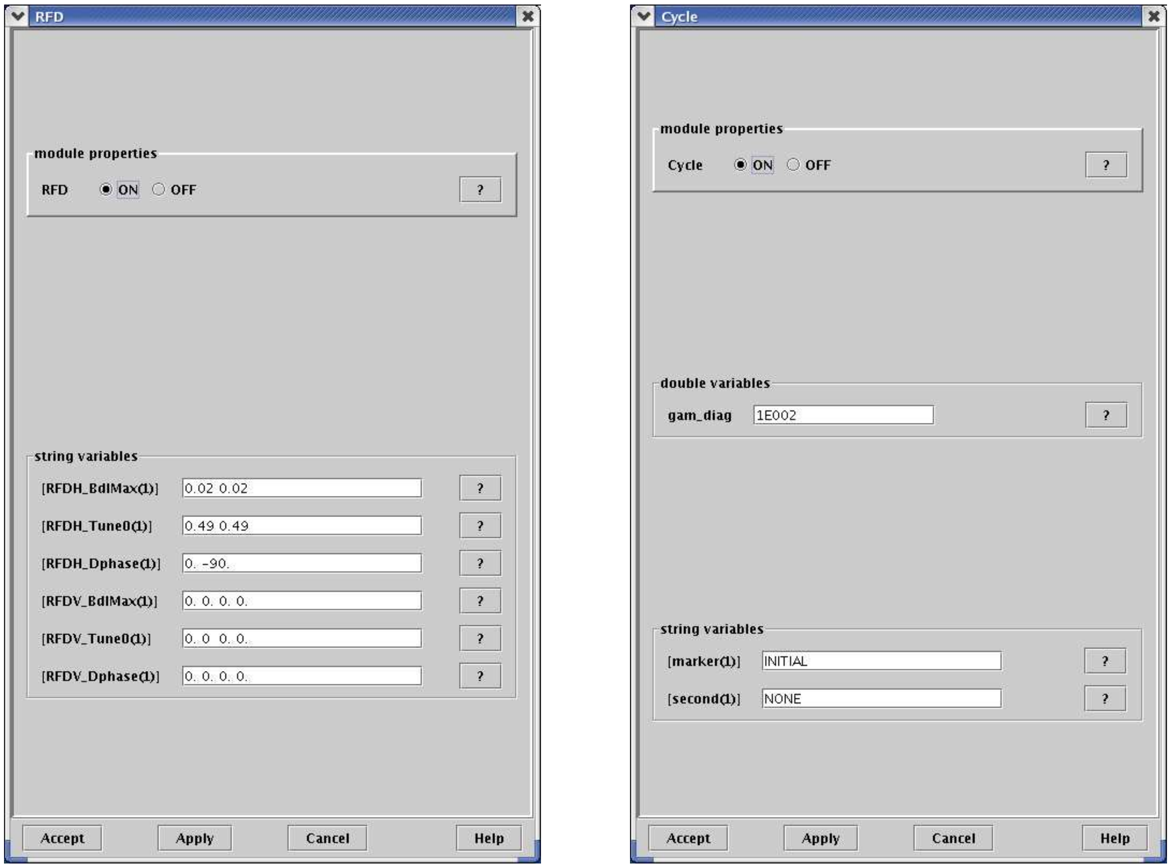
BB_Ggam0 4.7E002

BB_Ggam 4.8E002

string variables

BB_loc CLOCK8

Figure 11: Left: Spin flippers parameters. Right: BeamBeam parameters



RFD [✓ ON] OFF

[RFDH_BdlMax(1)]	0.02 0.02
[RFDH_Tune0(1)]	0.49 0.49
[RFDH_Dphase(1)]	0. -90.
[RFDV_BdlMax(1)]	0. 0. 0. 0.
[RFDV_Tune0(1)]	0. 0 0. 0.
[RFDV_Dphase(1)]	0. 0. 0. 0.

Cycle [✓ ON] OFF

gam_diag	1E002
[marker(1)]	INITIAL
[second(1)]	NONE

Figure 12: Left: Radio frequency dipole parameters. Right: Cycle parameters