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# GENESIS 1.3

## User Manual



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# About this Manual

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This manual covers the FEL simulation code GENESIS 1.3. It explains how to set-up an input deck as well as how to extend the capability by using additional input files. The central part of this document is the reference list of all input parameters, which are accepted by GENESIS 1.3. Further information about the code can be found at the website

<http://pbpl.physics.ucla.edu/reiche/>

In particular the novice user of GENESIS 1.3 can find there sample input files, which is a good starting point for setting-up his own input decks. Anyhow a basic understanding of FEL physics is recommended for a successful operation of GENESIS 1.3.

Throughout this document different fonts are used to distinguish text from the plain text of the manual. The italic font and Greek symbols refer to mathematical and physical constants or expression, e.g.

$$E = mc^2$$

Sample input and output files as well as all names referring directly to GENESIS 1.3 are written in typewriter-style such as **GAMMA0** or **XLAMD**.

The manual has a short section on the algorithm of GENESIS 1.3. Its purpose is to let user understand, what is calculated and what are the capabilities and limits of GENESIS 1.3. It is not written to encourage people to modify or extend the code. Anyhow the code is not perfect. If there is a demand to extend the code, please notefy the authors of the code.



# About GENESIS 1.3

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GENESIS 1.3 is a time-dependent three-dimensional FEL code. It is focused to simulate single-pass free-electron lasers, both FEL amplifier and SASE FEL, although the flexible input can be used to easily extend the capacity of GENESIS 1.3 to cover FEL oscillators or multistage set-ups.

GENESIS 1.3 bears its origin in the steady-state 2D code TDA3D, although they have nothing in common except for some naming convention. GENESIS 1.3 has all the features of TDA3D and is intended as a replacement, in particular that there is no more support for TDA3D. For an easier transition GENESIS 1.3 adopted most of the input and output format of TDA3D. TDA3D input file will most likely not work.

The code was written by Sven Reiche as a part of the Ph.D. thesis at DESY, Germany, and then further extended at UCLA and DESY.

## The Particle Equations

Macro particles represent the electron beam in all dimension of the 6D phase space. For convenience the longitudinal position is replaced by the ponderomotive phase of the particle and the transverse momenta are normalized to  $mc$ . The equations of motion are

$$\frac{d\theta}{dz} = k \left( 1 - \frac{1}{\beta_z} \right) + k_u \quad (1)$$

$$\frac{d\gamma}{dz} = -\frac{k f_c a_r a_u}{\beta_z \gamma} \sin(\theta + \Psi) - E_z \quad (2)$$

$$\frac{dx}{dz} = \frac{p_x}{\beta_z \gamma} \quad (3)$$

$$\frac{dp_x}{dz} = -q_x x + b_x + \frac{s}{\gamma} p_y \quad (4)$$

$$\frac{dy}{dz} = \frac{p_y}{\beta_z \gamma} \quad (5)$$

$$\frac{dp_y}{dz} = -q_y y + b_y - \frac{s}{\gamma} p_x \quad (6)$$

where  $\beta_z$  is the electron velocity in  $z$ , normalized to the speed of light,  $k$  is the radiation wave number,  $k_u$  is the undulator wave number,  $f_c$  the coupling factor,  $a_r$  and  $a_u$  are the scalar,

normalized amplitudes of the radiation and undulator field,  $\Psi$  is the phase of the radiation field,  $E_z$  is the electrostatic field,  $b_x$  and  $b_y$  are the normalized dipole strengths in  $x$  and  $y$ ,  $q_x$  and  $q_y$  are the quadrupole field strengths in  $x$  and  $y$  and  $s$  is the solenoid field strength.

The differential equations for energy and phase are solved by a 4th order Runge-Kutta solver, where the field amplitude of the discretized radiation field and electrostatic field is interpolated to the particle position.

Distinct to the main undulator field  $a_u$ , the quadrupole and dipole fields combines many field sources such as the natural focusing of the undulator, strong focusing quadrupoles, undulator field errors and corrector magnets (steering magnets). Per integration step their strength is fixed and the differential equations for the transverse motion is solved analytically. Because these equations depend on the particle energy, a higher precision requires to split the pushing of the transverse variables into two half-steps. While the first step relies on the energy value of the previous iteration, the second uses the updated values of the Runge-Kutta solver for this iteration.

## The Field Equations

Electro-static and electro-magnetic fields are discretized within GENESIS 1.3. The radiation field is described in the paraxial approximation, where the field is separated into a dominant, fast oscillating term and an amplitude, which slowly varies in magnitude and phase. The partial differential equation

$$\left[ \Delta_{\perp} + 2ik \frac{\partial}{\partial z} \right] u = i \frac{e^2 \mu_0}{m} \sum_j \delta(\vec{r} - \vec{r}_j) \frac{f_c a_u}{\gamma_j} e^{-i\theta_j}$$

is of parabolic type where  $u = -ia_r \exp[i\Psi]$  is the complex representation of the radiation field. Note that there is no explicit dependence on  $t$  in the differential equation. Time-dependence effects are discussed below. The transverse profile of the field is discretized on a Cartesian grid with uniform spacing. The Alternating Direction Implicit (ADI) solver guarantees an unconditional stable, fast and memory-efficient method to advance the radiation field one integration step.

Only the longitudinal component of the electro-static field is taken into account within GENESIS 1.3, because it acts as a repulsive force during the formation of the micro bunching. On the scope of a single radiation wavelength the field can be assumed to be periodic in the ponderomotive phase of the electrons. In the Fourier series expansion of the longitudinal field the partial differential equation of the  $l$  coefficient is

$$\left[ \Delta_{\perp} + \frac{l^2 k^2 (1 + a_u^2)}{\gamma_R^2} \right] E_{z,l} = i \frac{ec^2 \mu_0 l k (1 + a_u^2)}{\gamma_R^2} \sum_j \delta(\vec{r} - \vec{r}_j) e^{-il\theta_j}$$



where the resonant energy is defined as  $\gamma_R = \sqrt{k(1 + a_u^2)/2k_u}$ . With a radial grid centered to the electron beam centroid position and the azimuthal decomposition of the Fourier coefficients  $E_{z,l}$  the matrix representation of the partial differential equation is reduced to a tridiagonal matrix, where a fast and memory-efficient solver is applied to. Long-term electro-static fields (e.g. wake fields) must be calculated externally. They can be imported into GENESIS 1.3 and applied to equations of motion for the macro particles.

## Time-Dependent Effects

GENESIS 1.3 supports two modes of calculations: steady-state and time-dependent simulations. Steady-state simulations are based on the assumption of an infinite long electron bunch and radiation field with no longitudinal variation of any parameter. The partial derivative with respect to the time drops out of the field equations resulting in the parabolic equation shown above. The longitudinal description can be reduced to a single wavelength (bucket) with periodic boundary condition in the ponderomotive phase of the macro particles.

Time-dependent simulations would require to keep the entire radiation field and electron bunch at whole in memory, which easily exceeds the capability of today's best single processor machines. For a solution, which is not bounded to memory constraints, GENESIS 1.3 discretizes the radiation field and electron beam in  $t$ , referring to them as slices. Because information on the local electron distribution is carried by the radiation field only in the forward direction (slippage) time-dependent simulations roll over the electron bunch starting from the back. Advancing the radiation field is split into two parts: solving the steady-state field equation and copying the field to the next slice. Using the method only a single slice of an electron beam and the radiation field over the total slippage length, which can be significantly shorter than the bunch length, needs to be kept in memory. Although the spacing of the slices can freely be chosen with GENESIS 1.3, some conditions have to be fulfilled for a valid time-dependent simulation.

The propagation of the radiation field has to be done frequently to avoid collective instabilities of the steady-state field solver per integration step within a single slice. The characteristic parameter of the FEL interaction is

$$\rho = \frac{1}{\gamma} \left[ \left( \frac{a_u f_c}{4k_u \sigma_b} \right)^2 \frac{I_p}{I_A} \right]^{\frac{1}{3}}$$

where  $\sigma_b$  is the electron beam radius,  $I_p$  is the peak current and  $I_A = 17$  kA. The resulting limitation for the integration step size, being much smaller than the gain length, is

$$\Delta z \ll \frac{1}{2k_u \rho}$$

Similar arguments are valid for the separation  $\Delta t$  of the slices, which is related to the integration step size by the inequity  $c\Delta t \geq (k_u/k)\Delta z$ . The constraint for the  $t$ -discretization is therefore

$$\Delta t \ll \frac{1}{2ck\rho}$$

On the other hand each slice has a thickness of one radiation wavelength  $\lambda$ . The time discretization must be  $c\Delta t \geq \lambda$  to avoid overlapping slices. Conflicts might arise if  $\rho$  approaches unity. Anyhow in this case the entire FEL model, on which GENESIS 1.3 is based, is not valid anymore and other simulation tools need to be used to solve this problem.

Very often the time-window  $\Delta T$ , which is spawn by all slices, covers only a subsection of the electron beam. Because GENESIS 1.3 does not know anything about the field, which slips through the back of the time-window, it suppresses the output over the first slippage length. To obtain valid output the time window must be at least as long as the slippage length  $\Delta T_s$ , yielding the constraint

$$\Delta T \geq \Delta T_s = \frac{k_u L_u}{k c}$$

where  $L_u$  is the length of the undulator. In practice the time-window should be significantly larger than the limit given above to allow a frequency analysis of the radiation. The typical width of the FEL spectrum is  $\rho$ . To resolve the spectrum the time-window must fulfill the more stringent constraint

$$\Delta T \gg \frac{\lambda}{c\rho} + \Delta T_s$$

Once GENESIS 1.3 has allocated enough memory to hold the radiation field over one slippage length there is no computational limitation imposed on the maximum size of the time-window.

## Pre- and Postprocessors

One of GENESIS 1.3 key feature is the extensive support of additional input files as well the import of modified or process output files of GENESIS 1.3. The generation or processing of these files can be done in the simplest case by hand or by external programs. Although the GENESIS 1.3 website offers several programs for pre- and post-processing they do not officially belong to the GENESIS 1.3 distribution. Experience shows that these programs

are mostly customized and specifically bound to a given project or experiment. With the description of the GENESIS 1.3 input and output files in this manual and the 3rd party programs it should be fairly easy to write programs which fulfill the individual needs of the user.

GENESIS 1.3 does not support the graphical preparation of the output data due to two reasons. First, subroutines and functions would rely on graphic libraries, which makes it more difficult to write a platform independent source code. At least for the FORTRAN version, using the original file format, it is the idea to have a code independent on any library. In addition several graphic packages need to be supported. Otherwise it would force the user to use a graphic package, which does not necessarily agree with his choice.

Second, time-dependent simulations generate typically more data than useful to be plotted. It should be possible for the user to filter out the data, he needs. In addition some data have to be prepared (e.g. Fourier transformation, averaging, binning for histogram plots) for further information on the simulated FEL process. To help the GENESIS 1.3 offers several programs, which can be the base for the user's individual postprocessor.



# Compilation, Installation and Execution

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*The C++ version is currently under development. The manual will be updated, when the source code has been written.*

GENESIS 1.3 is distributed as executables for the Linux and Windows platform, as well as the source code and can be obtained from the official website

GENESIS 1.3 is originally written in FORTRAN but the limit capability of FORTRAN to handle various input and output formats and a restricted string processing, resulted in a C++ version of the code. The simulated physics of both the C++ and FORTRAN version is the same and the only difference is in the extended set of file formats, supported by C++. The support of the Fortran stops with the release of the current version.

The compilation section is only important for those who are building GENESIS 1.3 from the source code. However the distributed executable might depend on addition libraries not included in the distribution. The section on the installation lists all required libraries and environment variables for running GENESIS 1.3

## Compilation of the FORTRAN Source Code

After unpacking the '.tar'-archive the directory `genesis` contains the subdirectory `base` and `extension`. The base directory has all the source code, which is needed to run GENESIS 1.3, supporting only the original fileformat for input and output. Additional source files are located in the extension directory. For FORTRAN only two two extensions are supported: the SDDS file format and the parallelized version, using MPI. By default all extensions are disabled.

The source code has three different types of source files, indicated by their extension. Files with the extension '.f' contain all functions, subroutine and local variables, while variables used in more than one subroutine are grouped into common blocks in the files with the extension '.cmn'. The last type of files is the single file 'genesis.def' which defines constants and function prototypes.

The memory requirement of GENESIS 1.3 can be demanding if time-dependent simulation are performed or external distribution are imported and kept in memory. The file 'timerec.cmn' holds the information of the time records of the slippage field. `NTMAX` is the total record length, if the slippage field is stored in memory. If simulation encounters the case that this size is too small (GENESIS 1.3 will give an error message) `NTMAX` has to be increased.

Another possible way is to export the slippage field to a file. It is done by setting `NOFILE` and `NTMAX` to unity. The file will be deleted at the end of the run. The default setting has a time-record, which demands 160 MByte of free memory - equivalent to 700 records of a grid with 121 times 121 grid points.

The default settings of GENESIS 1.3 is that the external distribution is read from a file for every slice. Due to the processing of the input file it can be time-consuming. To keep the distribution in memory after the first processing two parameters in 'genesis.def' have to be change. `KEEPDIST` has to be set to unity while `NDMAX` defines the maximum number of particles GENESIS 1.3 can hold in memory. Note that 100000 particles correspond to an additional memory demand of 5 MByte.

The FORTRAN follows in general the F77 standard although it is not fully ANSI-F77 compliant. This requires to set specific flags while invoking the compiler. Because compiler option and flags are compiler specific the following list of recommended option just gives a general description. Please refer to the manual of your compiler. The distribution contains a 'Makefile', which works with the Absoft FORTRAN compiler under linux. It might be used as a template for setting up the compiler and linking instruction.

- Optimization should be turned on. In addition if the linker supports a library of optimized mathematical function it should be used
- The compiler should warn or preferable generate an error, if variables are not defined explicitly.
- In general it is a good idea that the compiler issues all warning, but due to the function prototyping in 'genesis.def' the warning of unused variable should be disabled.
- GENESIS 1.3 relies on intrinsic double-precision complex numbers for assignment such as `A=DCMPLX(1.d0,0.d0)`. Most FORTRAN compilers support this by a special `VAX` or `complex` option. As an alternative method the `DCMPLX(..., ...)` statements must be replaced by `CMPLX(..., ... kind=8)` statements by hand.
- It is recommended to generate a symbolic table (debugger option)
- Some compilers do not automatically treat variables in `DATA` blocks as static, but GENESIS relies on it. Either enable this option or, as an alternative, make all local variables static (the size of the executable is increased only by a small amount).
- GENESIS is not written consistently with the same case of all variables through out the source code. A compiler option should fold all variable and function names to lower or upper case letters if the compiler is case-sensitive.

The SDDS extension of GENESIS 1.3 is in the directory `extension/SDDS`. Compilation requires that the SDDS libraries are installed on the computer. In addition the FORTRAN wrapper of SDDS must be linked to the executable to make GENESIS 1.3 work. Unfortunately FORTRAN compilers do not support compiler instructions as C++ compiler do. As a consequence the base source code must be edited to enable calls to the SDDS part of the program. Which files and where to edit are described in the `README.SDDS` file in the root directory of the genesis distribution.

*The MPI version is under development. The manual will be updated, when the source code has been finished.*

## Compilation of the C++ Source Code

*The C++ version is under development. The manual will be updated, when the source code has been finished.*

## Installation

The FORTRAN version of GENESIS is a single executable and can be located anywhere. Under Linux it is preferable in the directory '/usr/local/bin'.

*The C++ version is under development. The manual will be updated, when the source code has been finished.*

Both versions can rely on additional libraries, which have to be installed prior to running GENESIS 1.3. The following lists all possible extensions and links, where further information can be obtained.

## SDDS

The Self-Describing Data Set (SDDS) is a file format, where a header defines the properties of the following data section. The SDDS toolkit allows processing and displaying content of SDDS files. The official link is

<http://www.aps.anl.gov/asd/oag/oagPackages.shtml>

## XML

The eXtensible Markup Language (XML) is a popular file format for platform independent data, mainly in ASCII. XML files can be checked with any XML reader (e.g. Internet Explorer) whether the file does not violates the basic syntax of XML. In addition files can be validated, so that the data has to fulfill user-defined constraints. The standard for XML and its associated formats can be found at

<http://www.w3c.org>

GENESIS 1.3 is build with the Xerces XML libraries of the Apache distribution. The libraries can be downloaded from the Xerces website

<http://xml.apache.org>

## HDF5

The Hirachial Data Format (HDF5) is a standard for platform independent binary data. It is benefical to GENESIS 1.3 because it also allows parallel computation and data compression. The offical website is

<http://hdf.ncsa.uiuc.edu/HDF5/>

## MPI

The Message-Passing Interface is a standard for portable code for parralel computer architecture.

<http://www-unix.mcs.anl.gov/mpi/>

## Running GENESIS 1.3

GENESIS 1.3 requires at least one argument, which is the name of the main input file. In the C++ version it is a command line argument, while the FORTRAN version prompt for the filename. If additional information is needed the program will propt for the missing information. The progress as well as warning and error messages are directed to the standard output channel or redirect to a file if the ILOG parameter is set.

The C++ versions allows addition comand line arguments for more flexibility

*The C++ version is currently under development. The manual will be updated when the source code has been finished.*

On UNIX and LINUX platforms GENESIS 1.3 can be easily executed in the background by redirecting the standard input, output and error to files such as

```
[prompt]$ genesis < GENINPUT > GENOUTPUT 2 >&1 &
```



where GENINPUT contains line by line all file name, which are normally be prompted for by GENESIS. Any output and error message will be written to the file GENOUTPUT. If ILOG is set a log-file is created and GENOUTPUT remains empty.



# Setting-up Simulations

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This section is a guideline for the novice user of GENESIS 1.3 to set up the main input correctly so that reasonable results can be obtained. It does not cover all aspects of GENESIS 1.3. For a more complete reference please check the sections on the input parameters of the main input deck and the usage of additional input and output files. Certain parameters are not mentioned in this section. If they are omitted in the input deck they fall back to their default values. To obtain a valid input deck in the first place start GENESIS 1.3 and type at the prompt the filename of a non-existing file. The template file 'template.in' is generated, which can be edited by any text-editor.

## Step I - The Magnetic Lattice

The coarse layout of the undulator is defined by the undulator period length (XLAMD), the number of periods (NWIG) and number of modules (NSEC). In this coarse lattice the FODO lattice has to fit in a way that a new undulator module starts after the last FODO cell of the section is complete. The length of a FODO cell is determined by  $FL + DL + 2 * DRL$ . Thus the number of FODO cells per undulator section is given by the next higher integer of the ratio between NWIG and the FODO-cell length. As an example with  $NWIG = 100$ ,  $NSEC = 2$ ,  $FL = 4.0$ ,  $DL = 4.0$  and  $DRL = 8.0$  there are 5 FODO cells per section and the two undulator modules are separated by a gap of 20 undulator periods. If F1ST is set to half the value of FL the FODO cell starts in the center of the first quadrupole, which simplifies the matching of the electron beam (ALPHAX, ALPHAY=0).

Set AWD to the same value as AWO. Similar XKX and XKY should agree with the definition of the undulator (0.0, 1.0 for planar undulator (IWITYP = 0) or 0.5, 0.5 for helical undulator (IWITYP = 1)). It is recommended that the coupling factor is calculated automatically by setting FBESS0 to zero. Disable tapering and undulator field errors.

Finally set the integration step with DELZ so that it can resolve FL, DL, DRL and F1ST. In the example above possible choices are 0.5, 1.0 or 2.0.

## Step II - The Electron Beam

After the energy, energy spread and emittances are defined a good value for the beam size and the twiss parameters ALPHAX, ALPHAY are critical for a good performance. GENESIS 1.3 does not support matching and these values have to be found by external programs. Anyhow

if the FODO lattice start with half a quadrupole or the field strength of all quadrupoles is set to zero than the beam is going through a waist at the undulator entrance for best matching (ALPHAX, ALPHAY=0). In this case initial runs of GENESIS 1.3 allows for an iterative method to find the right values for the beam size while ignoring the radiation results.

It is recommended that the number of macro particles (NPART) is at least 2048 (powers of two numbers allows a better performance). For simulation of wavelengths below 10 nm the number must be even higher to exclude numerical noise.

## Step III - The Radiation Field

In an FEL oscillator the radiation parameter are well defined by the seeding radiation field and the enclosing cavity. Otherwise (FEL amplifier or SASE FEL) they typically need to be optimized. Although SASE simulation significantly reduces the impact of the waist position ZWAIST and the Rayleigh length ZRAYL parameters it is recommended as a pre-optimization step to run steady-state simulation (ITDP = 0). Thus the following is valid for both, FEL amplifier and SASE FEL.

A good estimate of the radiation wavelength is given by the resonant formula

$$\lambda = \frac{\lambda_u}{2\gamma^2} (1 + a_u^2)$$

with  $\lambda$ =XLAMDS,  $\gamma$ =GAMMA0,  $\lambda_u$ =XLAMD and  $a_u$ =AWO. Anyhow diffraction or emittance effects might slightly change the resonant wavelength. The Raylength length should be chosen so that the initial beam size is similar to the beam size of the gain-guided radiation field in the exponential amplification regime. If the radiation waist is at the undulator entrance (ZWAIST=0) the initial beam size is simply given by  $\sqrt{z_r\lambda/\pi}$  with  $z_r$ =ZRAYL.

While the input radiation power is a well-defined input parameter for an FEL amplifier its value has to be estimated for steady-state simulation modelling SASE FELs. With the definition of the FEL parameter

$$\rho = \frac{1}{\gamma} \left[ \left( \frac{a_u f_c \lambda_u}{8\pi\sigma_b} \right)^2 \frac{I_p}{I_A} \right]^{\frac{1}{3}}$$

an approximation of an equivalent input power (shot noise power) of the SASE FEL is

$$P_{in} = 6\sqrt{\pi}\rho^2 \frac{P_b}{N\sqrt{\log(N/\rho)}}$$

with  $f_c = \text{FBESS0}$  or the value GENESIS 1.3 would calculate in the case that FBESS0 is set to zero in the input deck,  $\sigma_b = (\text{RXBEAM} + \text{RYBEAM})/2$ ,  $I_p = \text{CURPEAK}$ ,  $I_A = 17 \text{ kA}$ ,  $P_b = \gamma I_p m c^2 / e$  as the electron beam power and  $N = I_p \lambda / c e$  as the number of electrons per radiation wavelength.

With the parameters for the magnetic field, electron beam and radiation field a run of GENESIS 1.3 should produce some gain. If the results are satisfying the input deck can be used for more advanced simulation (field errors, time-dependent simulation). Otherwise further optimization of the input parameters is needed.

## Step IV - Optimization Using the SCAN-Feature

It can be tedious to find the optimum set of beam energy and radiation wavelength for maximum gain. The scan feature of GENESIS 1.3 helps by performing several runs for different wavelength or energies. To start a scan the scan parameter has to be defined. It is simply done by assigning the name of the parameter to be scanned to SCAN. As an example `SCAN = 'XLAMDS'` scans over the radiation wavelength. Only two other parameters are needed to complete the input for a scan-run. `NSCAN` defines the number of runs of the scan while `SVAR` limits the scan range. As an example `SVAR = 0.1` and `NSCAN = 5` will result in five runs at wavelengths of 90%, 95%, 100%, 105% and 110% of the input wavelength XLAMDS. The scan feature will automatically adjust the input deck internally to start with the same initial conditions at each run.

## Step V - Time-dependent Simulation

To enable time-dependence simply set `ITDP` to one. In addition `IALL` should be zero, `SHOTNOISE` 1.0 and `PRADO` zero for SASE simulations. The start-up regime has typically modes with strong diffraction. Therefore it is recommended to increase the grid size `RMAX0` or `DGRID` by roughly 50-100%. To compensate the coarser grid `NCAR` can be increased as well.

The desired time-window requires some minor calculations. For easier calculation 'time' is scaled by the speed of light ( $s = ct$ ). Assuming a time-window, which starts at the tail  $s_0$  and ends at the head  $s_1$  the required number of slices is  $\text{NSLICE} = (s_1 - s_0) / (\text{ZSEP} * \text{XLAMDS})$ . The first slice has the position  $s_0$ . Therefore `NTAIL` is  $s_0 / (\text{ZSEP} * \text{XLAMDS})$ . Note that in the frame of GENESIS 1.3  $s_0$  has to be smaller than  $s_1$ .

The parameter `IOTAIL` is an indication for GENESIS 1.3 whether radiation is generated outside the time-window but might slip at  $s_0$  into the time-window while the beam propagates through the undulator. This is the case if only a subsection of the electron beam is simulated. Because GENESIS 1.3 can do only a wild guess about the radiation field which slips into the time-window the tail part of the time-window is physically incorrect. To exclude these

slices in the output `IOTAIL` should be set to zero. The number of suppressed slices is simply the number of undulator periods of the entire undulator divided by `ZSEP`.

As an example we assume a Gaussian beam profile with an rms length of 1 mm (`CURLLEN = 1.e-3`) and a radiation wavelength of 5  $\mu\text{m}$  for an undulator with 200 periods. The spacing between the slices is `ZSEP=2.0`. The output should be between -2 mm and 2 mm which cuts out a part of the bunch (`IOTAIL=0`). The total number of slices is 400 slice of output plus 100 suppressed slices (`NSLICES=500`). The first simulated slices is `NTAIL=-300` which is equivalent to  $s_0=-3\text{mm}$ .

In this example the time-window is actually very close to cover the entire beam. With  $s_0=-3$  mm the local beam current is only 1% of the peak current. It is a good assumption that the tail  $s < s_0$  will not significantly amplify any radiation. With only 100 more slices the entire bunch can be simulated. The parameters would be now: `NSLICE=600`, `NTAIL=-300` and `IOTAIL=1`.

## Step VI - External Input for the Magnetic Field

One of the strength of GENESIS 1.3 is the usage of external input files for a more flexible description of the FEL such as a more complicated magnetic lattice. The best way to start using magnetic field input files is to generate one by GENESIS 1.3. This is done by specifying in `MAGOUTFILE` the name of the file to be generated. This file can be edited to set up the undulator. Using the two section undulator from above (`AWD=0.85`, `XLAMD=0.02`) the file contains the lines

```
...
AW 8.5000E-01  2.0000E-02 100
AW 0.0000E-01  2.0000E-02  20
AW 8.5000E-01  2.0000E-02 100
AW 0.0000E-01  2.0000E-02  20
...
```

Example: To remove the gaps and to taper the second module so that the field strength is 5% smaller change the lines to

```
...
AW 8.5000E-01  2.0000E-02 120
AW 8.0750E-01  2.0000E-02 120
...
```

The modified file can then be loaded into GENESIS 1.3 for the next run. The filename of the edited file is assigned to `MAGINFILE`. It is recommended to remove the parameter `MAGOUTFILE` from the input deck or change the assigned filename before running the simulation. Otherwise the file is overwritten again. In this case it does not matter but there are some cases (e.g. field errors) where there are subtle difference in the file used for the input and the overwritten output. For more information refer to the section on input and output files.

## General Tips

At the end of this section some general hints and tips are listed. There are in no particular order or relation to each other.

- Time-dependent simulations are very CPU-expensive. To optimize an input deck, try to do it in steady-state mode (`ITDP=0`).
- The calculation of the diffraction angle of the radiation field as part of the diagnostic is CPU intensive and not needed for the simulation itself. To speed up the execution it is better to save the radiation field at various locations along the undulator. The diffraction angle can then be obtained in a post-processing step.
- The output of the particle and field distributions can generate huge output files. Although GENESIS 1.3 warns about large output files it does not check the available space of the hard disk. Either run GENESIS 1.3, check for warning about large output files and stop the program (if the space is not available) or reduce the size of the output file by increasing the value of `IPRADI`, `ISRADI`, `IPPART` and/or `ISPART`.
- Avoid to use the same parameter several times in the input deck. GENESIS 1.3 will use the last occurrence in the input deck or might even report an error and quit.
- Check whether space charge has a significant impact on the result of the steady-state case. Space charge can be disabled by setting `NSCZ` to zero. If the results are not effected by the space charge routine time-dependent simulations excluding the space charge routine run faster.
- For runs with different field errors change the value of `ISEED` before each run. The same is valid for the phase fluctuation in SASE simulations where `IPSEED` has to be changed.
- Although the loading parameters `ILDPSI`, `ILDGAM`, `ILDX`, `ILDY`, `ILD PX` and `ILD PY` need hardly to be changed at all, do not assign the same number to more than one parameter.
- It is recommended to set the `VERSION` parameter to the latest version number to avoid unexpected behavior (e.g. `IDUMP=1` will not dump the particle distribution if `VERSION` is smaller than 1.0).
- `ZRAYL` and `ZWAIST` are needed to calculate the grid size for the simulation although their primary meanings are obsolete for SASE simulation. If `DGRID` is used and `PRADO` is very small than indeed they have no impact on the simulation. Still `ZRAYL` is required to be larger than 0.





# Input Parameters

---

The main input file of GENESIS 1.3 is controlled by roughly 100 parameters. Some of them become obsolete if additional input files are used. In the case that the main input file cannot be found GENESIS 1.3 creates a template for the main input file and terminates. Parameters, which are not included in the input file, fall back on their default values. All allowed input parameters and their default values, formats and units are listed below.

## Undulator Parameters

**AWO** (0.735 – float – unitless)

The normalized, dimensionless rms undulator parameter, defined by  $AWO = (e/mc)(B_u/k_u)$ , where  $e$  is the electron charge,  $m$  is electron mass,  $c$  is speed of light,  $k_u=2\pi/\lambda_u$  is the undulator wave number,  $\lambda_u$  is the undulator period.  $B_u$  is the rms undulator field with  $B_u = B_p/2$  for a planar undulator and  $B_u = B_p$  for a helical undulator, where  $B_p$  is the on-axis peak field.

**IWITYP** (0 – integer – unitless)

Flag indicating the undulator type. A value of zero indicates a planar undulator, any other value a helical one.

**XKX** (0.0 – float – unitless)

Normalized natural focusing of the undulator in  $x$ . Common values are  $XKX = 0.0$ ,  $XKY = 1.0$  for a planar undulator or  $XKX, XKY = 0.5$  for a helical undulator, but might vary if focusing by curved pole faces is simulated. The values should fulfill the constraint  $XKX + XKY = 1.0$ .

**XKY** (1.0 – float – unitless)

Normalized natural focusing of the undulator in  $x$ . See **XKX** for more information.

**FBESS0** (0.0 – float – unitless)

The coupling factor of the electron beam to the radiation field due to the longitudinal wiggle motion of the electrons. It is 1.0 for a helical undulator and  $J_0(x) - J_1(x)$  for a planar undulator where  $J_0(x)$ ,  $J_1(x)$  are Bessel functions and  $x = AWO^2/2(1+AWO^2)$ . If **FBESS0** is set to 0.0 GENESIS 1.3 calculates the value.

**XLAMD** (2.05e-2 – float – meter)

The undulator period length.

**NWIG** (98 – integer – unitless)

The number of periods within a single undulator module. The product of **NWIG** and **XLAMD** defines the length of the undulator module.

**NSEC** (1 – integer – unitless)

The number of sections of the undulator. Note that a section length is not automatically identical with the undulator module length. GENESIS 1.3 aligns modules to the FODO-lattice. If a module ends within a FODO cell the next module starts with the beginning of the next cell. Sometimes this results in a longitudinal gap between adjacent undulator modules.

**AWD** (0.735 – float – unitless)

A virtual undulator parameter for the gap between undulator modules. The only purpose of this parameter is to delay the longitudinal motion of the electrons in the same manner as **AW0** does within the undulator modules. It is used to keep the electron and radiation phases synchronize up to the point when the interaction at the next undulator module starts again. **AWD** has typically the same value as **AW0**, but might vary for optimum matching between the modules.

**WCOEFZ(1)** (0.0 – float – meter)

Start of undulator tapering. Note that tapering is applied, even the magnetic lattice is defined by an external file.

**WCOEFZ(2)** (0.0 – float – unitless)

The relative change of the undulator field over the entire taper length ( $AW(\text{exit}) = (1 - WCOEFZ(2)) AW(\text{entrance})$ ). In the case of a multi section undulator GENESIS 1.3 tapers the magnetic field over the gaps as well, resulting in a jump of the magnetic field  $AW(z)$  between two modules.

**WCOEFZ(3)** (0.0 – float – unitless)

The taper model:

= 1 for linear taper,

= 2 for quadratic taper,

or no taper otherwise.

**IERTYP** (0 – integer – unitless)

Type of undulator field errors. Either a uniform (+/-1) or Gaussian (+/- 2) distribution can be chosen. If **IERTYP** is negative the errors are correlated to minimize the first and second field integral. **IERTYP** = 0 disables field errors. Field errors requires a integration step size of half an undulator period ( $DELZ = 0.5$ ). Note that field errors are applied even if the magnetic lattice is defined by an external file.

**DELAW** (0.0 – float – unitless)

RMS value of the undulator field error distribution. A value of zero disables field errors.

**ISEED** (-1 – integer – unitless)

The initial seeding of the random number generator for field errors.

## Electron Beam Parameters

**NPART** (8192 – integer – unitless)

The number of macro particles per slice. **NPART** must be a multiple of  $4 \times \text{NBINS}$  and smaller than **NPMAX** defined in the source file 'genesis.def'.

**GAMMA0** (35.2 – float – unitless)

The mean energy of the electron beam in terms of the electron rest mass energy.

**DELGAM** (5.0e-3 – float – unitless)

The RMS value of the energy distribution in terms of electron rest mass energy.

**RXBEAM** (112.1e-6 – float – meter)

The rms value in  $x$  of the transverse, spatial distribution.

**RYBEAM** (112.1e-6 – float – meter)

The rms value in  $y$  of the transverse, spatial distribution.

**EMITX** (2.0e-6 – float – meter)

The normalized rms emittance in  $x$ .

**EMITY** (2.0e-6 – float – meter)

The normalized rms emittance in  $y$ .

**ALPHAX** (0.0 – float – unitless)

Rotation of the transverse phase space distribution in  $x$  according to the standard definition  $\text{ALPHAX} = -\langle xx' \rangle \text{GAMMA0} / \text{EMITX}$ .

**ALPHAY** (0.0 – float – unitless)

Rotation of the transverse phase space distribution in  $y$ . See **ALPHAX** for more information.

**XBEAM** (0.0 – float – meter)

Transverse position in  $x$  of the electron beam at the undulator entrance with respect to the undulator axis.

**YBEAM** (0.0 – float – meter)

Transverse position in  $y$  of the electron beam at the undulator entrance with respect to the undulator axis.

**PXBEAM** (0.0 – float – unitless)

Average normalized transverse momentum  $x$  of the electron beam at the undulator entrance. The momenta are defined as  $\text{PXBEAM} = \beta_x \gamma$  where  $\beta_x = cv_x$  is the average transverse velocity and  $\gamma$  the Lorentz factor of the electron energy.

**PYBEAM** (0.0 – float – unitless)

Average normalized transverse momentum in  $y$  of the electron beam at the undulator entrance. See **PXBEAM** for more information.

**CURPEAK** (250.0 – float – Amperes)

Peak current of the electron beam. Time-independent simulations enforces a constant current.

**CUTTAIL** (-1.0 – float – unitless)

Cut in the transverse phase space in measures of the rms size to collimate transverse beam tails/halos. The cut is applied after the loading and beam current is set accordingly to the reduced number of macro particles. It is disabled if the value is negative or the electron beam is imported from an external file.

**CONDITX** (0.0 – float – m-1)

**CONDITX** is the correlation strength between the amplitude of the electron's betatron oscillation and its energy. If the condition is applied correctly any emittance effects are removed from the FEL amplification and the focal strength can be increased. However it requires a conditioning beamline prior to the FEL to apply the correlation. Refer to the paper of Sessler (A.N. Sessler, *et al.*, Phys. Rev. Lett 68 (1992) 309) for more information.

**CONDITY** (0.0 – float – m-1)

Same as **CONDITX** but for the correlation in the y-plane.

**BUNCH** (0.0 – float – unitless)

Initial value of the bunching factor, when quite loading is used.

**BUNCHPHASE** (0.0 – float – rad)

Phase of initial bunching, when quite loading is used.

**EMOD** (0.0 – float – unitless)

Initial energy modulation, when quite loading is used. The value is the modulation amplitude in terms of gamma.

**EMODPHASE** (0.0 – float – rad)

Phase of initial energy modulation, when quite loading is used.

## Radiation Parameters

**XLAMDS** (12.852e-6 – float – meter)

The resonant radiation wavelength. Due to the bandwidth of time-dependent simulation SASE simulations do not require a very precise value for **XLAMDS**.

**PRADO** (10.0 – float – Watt)

The input power of the radiation field. For SASE simulation **PRADO** should be set to zero value or at least well below the shot noise level.

**ZRAYL** (0.5 – float – meter)

The Rayleigh length of the seeding radiation field. **ZRAYL** is defined as  $\pi w_0^2 / \text{XLAMDS}$  where

$w_0$  is the radius of the optical beam waist. The Rayleigh length is a measure for the diffraction  $w(z)^2 = w_0^2(1 + (z - \text{ZWAIST})^2/\text{ZRAYL}^2)$  and is needed to calculate the size and divergence/convergence of the seeding field at the undulator entrance. Because the field size can determine the grid size it is strongly recommended to supply reasonable numbers for ZRAYL and ZWAIST even for simulation starting from noise.

**ZWAIST** (0.0 – float – meter)

Position of the waist of the seeding radiation field with respect to the undulator entrance. ZWAIST is needed in combination with ZRAYL to calculate the initial radiation field. Note that a waist position within the undulator ( $\text{ZWAIST} > 0$ ) is only used to determine the initial convergence. The FEL interaction might significantly change the beam size and diffraction of the radiation field (gain guiding).

## Particle Loading Parameters

**ILDPSI** (7 – integer – unitless)

Indices of the Hammersley sequence bases for loading the particle phase. GENESIS 1.3 uses the first 26 prime numbers as bases. To avoid correlation between the variables each base should be different.

**ILDGAM** (5 – integer – unitless)

Hammersley base for loading the energy distribution. See ILDPSI for more information. Note that the loading of the energy distribution is Gaussian and uses two bases (ILDGAM and ILDGAM + 1).

**ILDY** (1 – integer – unitless)

Hammersley base for loading the distribution in  $x$ . See ILDPSI for more information.

**ILDY** (2 – integer – unitless)

Hammersley base for loading the distribution in  $y$ . See ILDPSI for more information.

**ILDY** (3 – integer – unitless)

Hammersley base for loading the distribution in  $p_x$ . See ILDPSI for more information.

**ILDY** (4 – integer – unitless)

Hammersley base for loading the distribution in  $p_y$ . See ILDPSI for more information.

**ITGAUS** (1 – integer – unitless)

Defines distribution profile in the transverse variables. The available distributions are:

- Gaussian (ITGAUS=1)
- Uniform (ITGAUS=2)
- Parabolic (otherwise)

**IALL** (0 – integer – unitless)

A non-zero value of IALL enforces that all slices are starting with the same element of the

Hammersley sequences. It is recommend for time-dependent simulation excluding shot noise. `IALL` is set automatically for scans.

**IPSEED** (-1 – integer – unitless)

Initial seed for the random number generator used for particle phase fluctuation (shot noise). GENESIS 1.3 requires a re-initialization of the random number generator to guarantee the same loading whether magnetic field errors are used or not.

**NBINS** (4 – integer – unitless)

Number of bins in the particle phase. The value has to be at least 4 or larger than  $(2+2n)$ , depending on whether the bunching at the  $n$ th harmonics is needed for space charge calculations or output.

## Mesh Parameters

**NCAR** (151 – integer – unitless)

The number of grid points for the radiation field along a single axis. The total number for the mesh is  $NCAR^2$ . `NCAR` must be an odd number to cover the undulator axis with one grid point. Do not exceed `NCMAX` defined in the source file 'genesis.def'.

**LBC** (0 – integer – unitless)

Flag to set the boundary condition for the field solver. The options are Dirichlet boundary condition (`LBC = 0`) and Neumann boundary condition (otherwise). Anyhow the grid should be chosen large enough so that the choice of `LBC` should not change the results.

**RMAX0** (9.0 – float – unitless)

GENESIS 1.3 estimates the size of the grid on which the radiation field is discretized by scaling the averages size of the initial radiation field and beam size with `RMAX0`. The explicit size is `[-DGRID,DGRID]` in both dimensions with  $DGRID = RMAX0(\sigma_{r,beam} + \sigma_{r,field})$ . The electron beam size is the rms sum of `RXBEAM` and `RYBEAM` while the radiation field size is calculated with `ZRAYL` and `ZWAIST`.

**DGRID** (0.0 – float – meter)

Any value larger than zero explicitly sets the grid size, overruling the calculation by the `RMAX0`-parameter.

**NSCZ** (1 – integer – unitless)

Number of longitudinal Fourier components for space charge calculation. `NSCZ` must be greater than 0 to include space charge but less than  $(2NBINS+2)$  for valid results.

**NSCR** (1 – integer – unitless)

Number of azimuthal modes for space charge calculation.

**NPTR** (40 – integer – unitless)

Number of radial grid points, on which the space charge field is evaluated. The radial axis is

automatically chosen by GENESIS 1.3 to be twice as long as the maximum offset of macro particles relative to the center of the electron beam. This excludes effects of the boundary condition even for the case of narrow beams.

## Focusing Parameters

**QUADF** (1.23 – float – Tesla/meter)

The field strength of (F-)quadrupoles, focusing in the  $x$ -plane.

**QUADD** (0.0 – float – Tesla/meter)

The fields strength of (D-)quadrupoles, defocusing in the  $x$ -plane. GENESIS 1.3 automatically applies the correct signs to **QUADF** and **QUADD** indicating the alternating focusing in the FODO-lattice.

**FL** (98.0 – float – unitless)

Length of the F-quadrupoles in measures of the undulator period. The integration step size **DELZ** must resolve the quadrupole length.

**DL** (0.0 – float – unitless)

Length of the D-quadrupoles in measures of the undulator period.

**DRL** (0.0 – float – unitless)

Drift length between F- and D-quadrupoles in measures of undulator period.

**F1ST** (0.0 – float – unitless)

Position within a FODO cell, where GENESIS 1.3 starts the FODO cell lattice. To start with a full F-quadrupole set **F1ST** to zero while a value of **FL/2** begins the cell in the middle of the focusing quadrupole.

**QFDX** (0.0 – float – meter)

Maximum transverse misplacement of the quadrupoles in  $x$ -direction. A random offset between  $[-\text{QDFX}, \text{QDFX}]$  in  $x$  is applied to every quadrupole. Quadrupole position errors are generated even if the magnetic field is defined by an external file.

**QFDY** (0.0 – float – meter)

Maximum transverse misplacement of the quadrupoles in  $y$ -direction, respectively. See **QFDX** for more information.

**SOLEN** (0.0 – float – Tesla)

On-axis field strength of a superimposed solenoid field.

**SL** (0.0 – float – unitless)

Length of solenoid field in measures of undulator period. The solenoid is aligned to the beginning of each undulator section.

## Time-Dependence Parameters

**ITDP** (0 – integer – unitless)

A non-zero value enables time-dependent simulation. Time-dependence is not allowed if the scan-feature is enabled.

**CURLLEN** (1.0e-3 – float – meter)

Bunch length of the current profile. If **CURLLEN** is positive a Gaussian distribution is generated with an rms length given by **CURLLEN**. A negative or zero value yield a constant profile.

**ZSEP** (1.0 – float – unitless)

Separation of beam slices in measures of the radiation wavelength. **ZSEP** must be a multiple of **DELZ**.

**NSLICE** (408 – float – unitless)

Total number of simulated slices. It defines the time window of the simulation with  $NSLICE * ZSEP * XLAMDS/c$ . Note that the output does not start with the first slice unless the parameter **IOTAIL** is set. If **NSLICE** set to zero it automatically adjust **NSLICE** and **NTAIL** to the time-window given by the external input files (**BEAMFILE** or **DISTFILE**). It assumes 6 standard deviation for a Gaussian distribution or the absolute value of **CURLLEN** for a step profile.

**NTAIL** (-253 – integer – unitless)

Position of the first simulated slice in measures of  $ZSEP * XLAMDS$ . GENESIS 1.3 starts with the tail side of the time window, progressing towards the head. Thus a negative or positive value shifts the slices towards the tail or head region of the beam, respectively. For a constant profile ( $CURLLEN < 0$ ) **NTAIL** has no impact.

**SHOTNOISE** (1.0 – float – unitless)

GENESIS 1.3 applies a random offset to each macro particle phase to generate the correct statistic for the bunching factor. Each offset is scaled prior by **SHOTNOISE**, thus **SHOTNOISE** can be set to zero to disable shot noise.

**ISNTYP** (0.0 – integer – unitless)

For **VERSION** below 1.0 only the Pennman algorithm is used for the shot noise, which is only correct for the fundamental wavelength, but for a higher version the default is the Fawley algorithm which applies also the correct shotnoise to all higher harmonics. If the user wants to use the Pennman algorithm at a higher version number (which is not recommended), the value of **ISNTYP** has to be set to a non-zero value.

## Simulation Control Parameters

**DELZ** (1.0 – float – unitless)

Integration step size in measure of the undulator period length.



**ZSTOP** (0.0 – float – meter)

Defines the total integration length. If the undulator length is shorter than ZSTOP or ZSTOP is zero or negative, the parameter is ignored and the integration is performed over the entire undulator.

**IORB** (0 – integer – unitless)

Flag for orbit correction. For any non-zero value the offset due to the wiggle motion is taken into account for the interaction between electron beam and radiation field. The correction is not included in the output values for the beam centroid position.

**ISRAVG** (0 – integer – unitless)

If set to a non-zero value the energy loss due to spontaneous synchrotron radiation is included in the calculation.

**ISRSIG** (0 – integer – unitless)

If set to a non-zero value the increase of the energy spread due to the quantum fluctuation of the spontaneous synchrotron radiation is included in the calculation.

**ELOSS** (0.0 – float – eVolt/meter)

Externally applied energy loss of the electron beam.

**VERSION** (0.1 – float – unitless)

Used for backward compatibility of the input decks. Some parameters might change their behavior for older versions of GENESIS 1.3. The current version is 1.0.

## Scan Parameters

**ISCAN** (0 – integer – unitless)

Selects the parameter for a scan over a certain range of its value:

1. GAMMA0
2. DELGAM
3. CURPEAK
4. XLAMDS
5. AWO
6. ISEED
7. PXBEAM
8. PYBEAM
9. XBEAM
10. YBEAM

11. RXBEAM
12. RYBEAM
13. XLAMD
14. DELAW
15. ALPHAX
16. ALPHAY
17. EMITX
18. EMITY
19. PRADO
20. ZRAYL
21. ZWAIST
22. AWD
23. BEAMFILE
24. BEAMOPT
25. BEAMGAM

The last three enable a user-defined scan, where a steady-state run is performed for each entry of the supplied **BEAMFILE**. **BEAMOPT** differs from **BEAMFILE** that it automatically adjust **XLAMDS** according to the resonance condition and the beam energy, defined in the **BEAMFILE**. The **BEAMGAM** option is similar to **BEAMFILE**, but overwrites the value of energy with **GAMMAO** from the main input file.

**SCAN** ( ' ' – string)

By supplying the parameter name to scan over it overrules the setting of **ISCAN**.

**NSCAN** (3 – integer – unitless)

Number of steps per scan.

**SVAR** (0.01 – float – unitless)

Defines the scan range of the selected scan parameter. The parameter is varied between  $(1-SVAR)$  and  $(1+SVAR)$  of its initial value. One exception is the scan over **ISEED** where the random number generator is not reinitialized.

## Input and Output Control Parameters

**IPHSTY** (1 – integer – unitless)

Generate output in the main output file at each **IPHSTY**th integration step. To disable output set **IPHSTY** to zero.

**ISHSTY** (1 – integer – unitless)

Generate output in the main output file for each ISHSTYth slice.

**IPPART** (0 – integer – unitless)

Write the particle distribution to file at each IPPARTth integration step. To disable output set IPPART to zero. The filename is the same of the main outputfile + the extension '.par'.

**ISPART** (0 – integer – unitless)

Write the particle distribution to file for every ISPART slice.

**IPRADI** (0 – integer – unitless)

Write the field distribution to file at each IPRADIth integration step. To disable output set IPRADI to zero. The filename is the same of the main outputfile + the extension '.fld'.

**ISRADI** (0 – integer – unitless)

Write the field distribution to file for every ISRADI slice.

**IOTAIL** (0 – integer – unitless)

If set to a non-zero value the output time window is the same as the simulated time window. Otherwise the output for the first slices covered by the slippage length is suppressed. Needed for bunches which are completely covered by the time-window.

**OUTPUTFILE** (' ' – string)

The name of the main output file. The prompt for the output filename at the beginning of a GENESIS 1.3 run will be suppressed.

**MAGIN** (0 – integer – unitless)

If set to a non-zero value the user is prompted to type in the file name containing a explicit description of the magnetic field.

**MAGOUT** (0 – integer – unitless)

Similar to MAGIN to write out the magnetic field lattice used for the simulation.

**MAGINFILE** (' ' – string)

Defines a file, which contains the magnetic field description, bypassing the interactive request of MAGIN.

**MAGOUTFILE** (' ' – string)

Defines the file to which the magnetic field lattice is written to, bypassing the interactive request of MAGOUT.

**IDUMP** (0 – integer – unitless)

If set to a non-zero value the complete particle and field distribution is dumped at the undulator exit into two outputfiles. The filenames are the filename of the main output file plus the extension '.dpa' and '.dff', respectively.

**IDMPFLD** (0 – integer – unitless)

Similar to IDUMP but only for the field distribution.

**IDMPPAR** (0 – integer – unitless)

Similar to **IDUMP** but only for the particle distribution.

**BEAMFILE** ( ' ' – string)

Specifying a file containing a lookup table for the electron beam parameters at different position along the bunch.

**RADFILE** ( ' ' – string)

Specifying a file containing a lookup table for the seeding radiation pulse at different position along the bunch.

**DISTFILE** ( ' ' – string)

If **DISTFILE** is defined, the 6d distribution is imported into GENESIS 1.3 and used to load the phase space. The quiet start algorithm is bypassed.

**NDCUT** (0 – integer – unitless)

When loading a slice, only particles of the external distribution are used, which falls within a small time-window centered around the current position of the slice. If **NDCUT** has a value larger than zero the width is calculated by  $(t_{max}-t_{min})/NDCUT$ , where  $t_{max}$  and  $t_{min}$  are determined, while scanning through the particle distribution. If **NDCUT** is zero, the time-window is adjusted, so that in average  $NPART/NBINS$  particles fall in each slice.

**FIELDFILE** ( ' ' – string)

Defines the file containing the field distribution. The distribution is directly imported into the arrays, holding the field and the time-records.

**ALIGNRADF** (0 – integer – unitless)

When the **FIELDFILE** feature is used than Genesis 1.3 aligns the radiation field to the electron beam so that the radiation field is one full slippage behind the electron beam. In this case there is no unphysical calculation because the field which slips through the back into the first electron slice is fully defined. However this alignment depends on the undulator length. To disable the automatic alignment **ALIGNRADF** has to be set to a non-zero value. If this is the case the last slice of the radiation field is aligned with the last electron slice. Field slices, which slips into the first electron slice and which is not defined by the **FIELDFILE** is generated by the internal method of using the fundamental Gauss-Hermite mode

**OFFSETRADF** (0 – integer – unitless)

If the automatic alignment of the radiation field is disabled by setting **ALIGNRADF** to a non-zero value, the default alignment is that the first slice of the radiation field overlaps with the first slice of the electron beam. However the relative position can be controlled by **OFFSETRADF**. The value of **OFFSETRADF** defines the number of slice to skip before filling it for the first electron slice. E.g. a value of 4 will use the 5th slice for the simulation of the first slice. slices one to 4 will be used to fill up the slippage field. If Genesis 1.3. require to fill a slice which is not defined by the **FIELDFILE** then it uses the internal method of a fundamental Gauss-Hermite mode.

**PARTFILE** ('' – string)

Defines the file containing the particle distribution. The distribution is directly imported into the arrays holding the particle variables.

**CONVHARM** (1 – integer – unitless)

When the particle distribution is imported from a **PARTFILE** Genesis 1.3 allows the up-conversion to a higher harmonics. The harmonic number is specified with **CONVHARM** and has a default value of 1, corresponding to no up-conversion. The user has to make sure that in the input deck **XLAMDS** is adjusted, according to the new wavelength.

**MULTCONV** (0 – integer – unitless)

If an imported particle distribution from a **PARTFILE** is up-converted to a higher harmonics the default behavior is that the number of slices is preserved. This requires that **ZSEP** is adjusted together with **XLAMDS**. However if frequency resolution is a problem then a particle distribution can be converted and used multiple times to keep **ZSEP** constant. The disadvantage is that the CPU execution time is increased as well.

**IBFIELD** (0.0 – float – Tesla)

When the **PARTFILE** feature is used the imported particle distribution can be tracked through a generic 4 magnet chicane before running the Genesis simulation. The chicane consists out of 4 bending magnets of the field strength **IBFIELD** and length **IMAGL** separated by 5 drifts of length **IDRIL**. If the field strength of the magnet is set to zero the feature of a chicane is disabled (default behavior)

**IMAGL** (0.0 – float – meter)

The length of each bending magnet of the chicane. If the magnet length is set to zero but **IDRIL** is not the resulting beam line correspond to a simple drift of the length 5 times **IDRIL**.

**IDRIL** (0.0 – float – meter)

The length of the 5 drift lengths of the magnetic chicane (three between the magnets and one before and after the magnets).

**ILOG** (0 – integer – unitless)

If set to a non-zero value all further run-information and error messages are redirect to a log file. The name is the main output file name plus the extension '.log'.

**FILETYPE** ('ORIGINAL' – string)

Indication of the file type of all output files.

**NHARM** (1 – integer – unitless)

Defines the number of harmonics in the bunching factor to be calculated for output purposes.

**LOUT** (1 1 1 1 1 0 1 1 1 1 0 0 0 0 0 0 0 0 – array of integers – unitless)

Defines, which parameter is included in the main output file:

1. radiation power

2. logarithmic derivative of the power growth
3. power density at the undulator axis
4. radiation phase at the undulator axis
5. transverse radiation size
6. rms diffraction angle of the radiation
7. beam energy
8. bunching factor
9. beam size in x
10. beam size in y
11. error in energy conservation
12. beam position in x
13. beam position in y
14. energy spread
15. on-axis field intensity in the far field zone
16. bunching at the 2nd harmonic
17. bunching at the 3rd harmonic
18. bunching at the 4th harmonic
19. bunching at the 5th harmonic
20. bunching phase of the 1st harmonic
21. bunching phase of the 2nd harmonic
22. bunching phase of the 3rd harmonic
23. bunching phase of the 4th harmonic
24. bunching phase of the 5th harmonic

Note that the calculation of the diffraction angle is very CPU intensive. It is recommended to save some radiation profile distributions and apply the Fourier transformation in the post-processing part.

### FFSPEC (0 – integer – unitless)

To calculate a spectrum a post-processing step requires amplitude and phase, which are written to the output file, defined by LOUT of column 3 and 4. The values depend on the choice of FFSPEC. If the value is equal the near field on-axis intensity and phase is written, while for a negative value it is the same but in the far field zone. For a positive value the near field intensity is replaced by the total radiation power, assuming transverse coherence.

# Input and Output Files

---

The capability of GENESIS 1.3 can widely be extended by additional input and output files. In total GENESIS 1.3 depends on up to 14 files including such files containing the magnetic field or a sample phase space distribution of the electron beam.

For all runs the main input file is mandatory. It contains the vast majority of the information needed to run the simulation. Besides the main output file, which is always created, the main input file defines, whether additional input and output files are read or written. All output files except for the magnetic output file, uses the filename of the main output file as the root for their filenames and appends a three letter filename extension. Input files can have independent filenames, which are defined in the main input. The main output file and the magnetic input and output files are not needed to be specified in the input file. GENESIS prompts for the name if necessary.

Genesis 1.3 has support for different file formats, depending on the programming language and built of the executable. The original file format is always supported. Input files are automatically checked for file formats, which are supported by the executable. If GENESIS 1.3 cannot identify any special format, it assumes the original file format and starts processing the file. The file format of output files are set by the input parameter `FILETYPE`. Request for unsupported file formats will cause an error message and the termination of GENESIS 1.3

Besides the principle support of a specific file format, certain input and output files are not suitable for all file formats. The following table lists all files and the implicit support for them. The last column is the default filetype of output files for the C++ version of Genesis if the filetype is not explicitly defined. If that file format is not supported GENESIS 1.3 falls back to the original file format as default. The FORTRAN default is the original format for all output files.

It is strongly recommended that the original file format is not used, because it is of all formats the least platform-independent format. Also if more than one record of the electron or field distribution is written, the SDDS and HDF5 file formats yield much smaller file sizes. The XML output is always ASCII and the base64 encoding is not supported.

In the following all individual file are described for the original file format. All other file formats share the same content of information as the original but might have also additional information for more self-consistent sets of data files. The difference and addition for the other file formats are explained in the last sections of this chapter.

File	Original	SDDS	XML	HDF5	Default
Main Input	yes	no	yes	no	-
Main Output	yes	yes	yes	yes	XML
Particle Output	yes	yes	yes	yes	HDF5
Field Output	yes	yes	yes	yes	HDF5
Particle Dump	yes	yes	yes	yes	HDF5
Field Dump	yes	yes	yes	yes	HDF5
Particle Input	yes	yes	yes	yes	-
Field Input	yes	yes	yes	yes	-
Beam Description	yes	yes	yes	yes	-
Field Description	yes	yes	yes	yes	-
Beam Distribution	yes	yes	yes	yes	-
Magnet Input	yes	no	yes	no	-
Magnet Output	yes	no	yes	no	XML
Log File	yes	no	yes	no	XML
Time Record	yes	no	no	no	-

## The Main Input File

All input parameters are contained by a FORTRAN namelist. The namelist has to fulfill a specific syntax, otherwise GENESIS 1.3 reports an error message and quits. The error support for namelist is minimal and does not help to identify the problem.

- The first character of every line must be blank.
- The namelist starts with `$newrun` and ends with `$end`. Any text outside the namelist is ignored.
- The format of an entry in a namelist is: parameter name, equal sign, value (e.g. `NPART = 2048`).
- Parameter names and name list names are case insensitive
- Arrays element are either defined by the index (`LOUT(4) = 1`) or by a list of several elements separated by spaces (`LOUT =1 1 0 0`), starting with the first element in the array.
- Strings are assigned by using single, double or no quotation marks at all (e.g. `BEAMFILE = 'beam.dat'`, `MAGINFILE = undulator.lattice`).
- Multiple entries per line have to be separated by commas.

## The Main Output File

The main output file is in ASCII format and is split into three parts: the header, the global parameters and the parameters for each slice. After some information about version,



platform and name of the input file, a namelist repeats all input parameters. It is possible to rerun GENESIS 1.3 with the output file because the header fulfills the requirement of a valid input file. Still header part several auxiliary parameters are listed which describes the following data set as well as some information about additional output for the radiation field and particle distribution (see below). These information can be used by any postprocessor to correctly read the output files.

The global parameters are mainly the position along the undulator for each output and the corresponding undulator and quadrupole field at that position.

For each slice an entire table is written containing a header and the main body. The header lists the slice number, the local current and the column names. In scan mode the current is replaced by the value of the scan parameter. The data follows directly the header. The rows correspond to the  $z$ -positions given in the block of the global parameters. The size of the table is controlled by the LOUT parameter.

## The Radiation and Particle Output File

As an addition to the main output file the distribution of the radiation field or the electron beam can be written to binary files. The file names are derived from the file name of the main output file by adding the extension '.fld' and '.par', respectively. In most cases these files are large even in their binary format (ASCII output would increase the file size by roughly a factor of 3). The output order is similar to the output of the main output file with a consecutive output along the undulator. The output for a single slice at a certain position within the undulator is referred to as a record in  $z$ . All  $z$  records of a single slices form a record in  $t$ . The total number of  $z$ - and  $t$ -records are given in the header of the main output file.

Each particle record in  $z$  starts with the energy of all particles followed by the output of the particle phases, positions in  $x$  and  $y$  and the momenta in  $x$  and  $y$ . The momenta are normalized to  $mc$ .

The radiation field record contains the real part of the discretized field and then the imaginary part. The field is normalized so that the square sum of the real and imaginary part yields the field intensity with respect to a unit area. To obtain the real intensity each value has to be divided by the area each grid point covers. The order of the grid points starts with the lower left corner ( $x, y < 0$ ) along the  $x$ -axis. At the end of each row in  $x$  it jumps back in  $x$  and advance  $y$  by one step.

## The Log File

If the log feature is enabled any output of genesis to the screen is redirected into a log-file. The purpose of the log-file is to support background calculation of GENESIS 1.3. Thus the execution will be terminated if GENESIS 1.3 needs further information (e.g. file names for additional input files). The log feature is more reasonable for the C++-version of GENESIS 1.3 because the input file name can be supplied as a command line argument while starting GENESIS 1.3. The FORTRAN version still needs to request the input file name thus defying the purpose of a background job. Anyhow to start it as a background job type the command: `'genesis < geninput > genoutput 2>&1 &'`

where `geninput` is a simple ASCII file containing the file name of the input file. The file `genoutput` will catch any output, which cannot be handled by the log file (e.g. error messages). In the ideal case `genoutput` contains only the initial text lines for requesting the input file name.

## Reading-in and Dumping the Particle and Radiation Distribution

With the parameters `IDMPFLD` and `IDMPPAR` set to a non-zero value the field and particle distribution is written to binary files for each slice at the end of the undulator. The file format is similar to that of the particle and field output file (see above) with a few differences. The particle phase is absolute and not relative to the radiation phase. The radiation field has the same format as in the radiation output files (see above), representing the intensity if real and imaginary parts are summed in square, but instead listing real and imaginary part separately, the field dump has the complex value listed instead (pairs of real and imaginary part). The radiation field escaping the last slice is added to the output so that the radiation field, escaping first, is the last record in  $t$ . Note that there is only one record in  $z$  for both files.

These files can be used to simulate the effect of a bunch compressor or a monochromator and then reused as an input for a consecutive run of GENESIS 1.3. To indicate GENESIS 1.3 to skip the internal generation of the radiation field or particle distribution the file names of these files are given as the input values for `FIELDFILE` and `PARTFILE`.

There are some restrictions of using these files.

- The number of slices must be equal or smaller than the number of  $t$ -records in the particle file
- The grid spacing and the radiation wavelength must be the same to guarantee energy conservation of the radiation field.
- The number of slices plus the length of the slippage field record must be smaller than the number of  $t$ -records in the field file.

While the first point is obvious the second needs some explanation. Because the radiation slips through several electron slices the time-window of the radiation field must be larger than the time-window of the simulated electron beam. It is extended by the slippage length `NSLP`, which is the number of radiation slices which slips through a single electron beam slice over the entire undulator length. The length is the undulator length divided by `XLAMD` and `ZSEP` and rounded to the lower integer. The radiation initially seen by the first beam slice is the `NSLP+1` record of the radiation input file. The records between the first and `NSLP`th slice are copied in the time-record. During the integration these slices are pushed into the location of the simulated electron slice. Generally speaking the time window of the radiation field is shifted forwards with respect to the time window of the electron beam during the integration. In the case that the second GENESIS 1.3 run uses a longer undulator than the first run, which dumped the radiation field and beam distribution, the number of beam slices has to be reduced to match the file length of the input radiation field.

Note that Genesis does not check for consistency. The field dump is associated to a certain grid size and radiation wavelength. If a field is imported for a simulation, where these values differ, the energy of the field is not conserved.

## The Magnet Description Input and Output File

The magnet description file is in ASCII format and contains the explicit profile of all magnetic components or a subset of it. After processing the file GENESIS 1.3 recalculates the undulator length and adjusts the number of integration steps. Field errors and tapering is always enforced, when the corresponding parameters in the main input file are set. This allows that different sets of field errors or taper gradients can be simulated while using only a single input file. The output of the magnetic lattice, if requested, includes the field lattice, seen by particle of the simulation. Even if field error and taper is disabled the output file might differ from the input file in the format, but not in the content.

If any line of the input file starts with a space the content of the entire line is treated as a comment. Also any character beyond the 30th position is ignored. These two restrictions do not apply for the C++ version. In general the processing of the file is case insensitive.

Each line is categorized either as

- content line,
- comment line,
- command line,
- information line.

The content line actually holds information about the magnetic structure. The format of each line depends on the version of the input file. There is a difference between the current

version 1.0 and earlier versions ( $<1.0$ ). The version number is defined by an information line in the header of the file. If omitted GENESIS 1.3 assumes a version prior to 1.0.

Each line has four elements, where the first two are version independent. The first element is a two-character string, indicating the type of structure. Following types are supported

- AW - Main magnetic field
- AD - Drift section
- QF - Quadrupole strength
- QX - Quadrupole offset in  $x$
- QY - Quadrupole offset in  $y$
- SL - Solenoid strength
- CX - Corrector strength in  $x$
- CY - Corrector strength in  $y$

Next the strength/offset value of that structure is specified.

For earlier version the next two numbers define the length of the structure. The first of those is a unit length, common for all structure. Typically it is the undulator period length. The second number is the length of the structure in measure of the unit length. As an example the following lines describe a 1 m long undulator with an rms strength of 1.30:

```
AW 1.3 2.e-2 50
```

Note that for a file version  $< 1.0$  the absence of any structure must be included in the input file as well. The strength/offset value is zero. Thus a two cell FODO lattice with a 4 cm quadrupole length and a drift length of 8 cm is defined by

```
QF 2.5e+1 2.e-2 2
QF 0.0e+0 2.e-2 4
QF -2.5e+1 2.e-2 2
QF 0.0e+0 2.e-2 4
QF 2.5e+1 2.e-2 2
QF 0.0e+0 2.e-2 4
QF -2.5e+1 2.e-2 2
QF 0.0e+0 2.e-2 4
```

For the latest version the unit length is declared once in the header of the file and is mandatory. The third number is the length of the structure in measure of the unit length, while the last number is the distance to the previous element of the same kind, again in measure of the unit length. The definition of the FODO cell becomes now

```
? VERSION=1.0
? UNITLENGTH=2.e-2
QF 2.5e+1 2 0
QF -2.5e+1 2 4
QF 2.5e+1 2 4
QF -2.5e+1 2 4
```

The usage of the lines, starting with the question marks, are explained below. A comment line is indicated by a -sign as its first character. The remaining content of the line is ignored. Similar lines, which do not contain any printable characters (spaces excluded) are treated as comment lines.

A command line starts with an exclamation mark. For the magnetic field only two commands are recognized. The first command `!LOOP = x` marks the beginning of a loop where `x` is the number of loops to be performed. Note that there can be an arbitrary number of spaces on both sides of the equal sign as long as the entire line is no longer than 30 characters. The end of the loop is indicated by `!ENDLOOP`. Loops cannot be nested and starting a new loop before the current loop is not closed will cause an error and the termination of GENESIS 1.3. The following lines define the same FODO lattice as above but this time with 10 cells

```
? VERSION=1.0
? UNITLENGTH=2.e-2
QF 2.5e+1 2 0
! LOOP=9
QF -2.5e+1 2 4
QF 2.5e+1 2 4
! ENDLOOP
QF -2.5e+1 2 4
```

The last class of input lines is information lines, which helps GENESIS 1.3 to process the file correctly. These lines have to start with a question mark. One example is to set the version number with `?VERSION = n.m` for compatibility reason, where `m.n` is the version number. Currently only versions below 1.0 and below are supported. The remaining other option is

setting the unitlength with ? UNITLENGTH = x, where x is the numeric value of the length in meter. As for the command line spaces can separate keyword, equal sign and value.

Note that GENESIS 1.3 stops processing a line, once it obtained all needed information. This allows, also not recommended, to add comments at the end of each line.

## The Beam Description File

The beam description file contains a table of beam parameters such as emittance and energy at certain positions along the bunch. The positions listed in the file must be ordered starting with the tail. In GENESIS 1.3 smaller number refers to a position towards the tail of the bunch. Note that you have to adjust the simulation time-window in GENESIS 1.3 (ZSEP, NSLICE and NTAIL) to the range, defined in the beam description file. Genesis 1.3 uses relative positions within the time-window, starting at zero for the first entry in the beam description file. This corresponds to NTAIL = 0.

Each line can contain up to 15 parameters: corresponding to the input parameters of the main input deck:

- ZPOS or TPOS
- GAMMA0
- DELGAM
- EMITX
- EMITY
- RXBEAM or BETAX
- RYBEAM or BETAY
- XBEAM
- YBEAM
- PXBEAM
- PYBEAM
- ALPHAX
- ALPHAY
- CURPEAK
- ELOSS

Besides ZPOS and TPOS, which refers to the position within the bunch, most of the remaining parameters correspond to the input parameter of the main input file. If BETAX is defined instead of RXBEAM the beam size is calculated, using the specified beam energy and emittance. The same is valid for BETAY.

If a time coordinate specifies the position (TPOS) instead of a space coordinate (ZPOS), Genesis 1.3 enforces the convention that time and space coordinate differ with a relative sign. For the right order in the beam description file the ZPOS values should increment, while the TPOS should decrement.

The format of the beam description file is similar to the magnetic field input file. All numbers are given in ASCII format. The input file can contain content lines, comment lines and information lines. Commands lines are not needed and thus not supported.

Empty lines and lines starting with a #-sign are treated as comment lines. They are ignored while processing the beam description file.

A question mark indicates an information line. The VERSION-keyword is the same as in the magnetic field input file, defining the version of the input file. Note that there is a difference between earlier versions (<1.0) and the current version 1.0 (see below). The SIZE parameter is optional. It should contain the number of information lines in the input file. At the end of processing the file GENESIS 1.3 compares the number of valid lines with the number defined by SIZE and prints out a warning message if the two numbers differs. If no SIZE statement is included the check is omitted.

The last information keyword is COLUMNS. It controls the number and order of columns in the beam description file by simply adding the parameter names after the COLUMNS keyword. Parameters, which are excluded in the beam description file, fall back to their default value, defined in the main input deck. Omitting the current results in a step profile. The column ZPOS is mandatory and GENESIS 1.3 with given an error message when it is not specified in the COLUMN information line. If no COLUMNS-statement is given all input parameter are required in the order as they appear in the list above.

As an example the following line describes a 100  $\mu\text{m}$  long, uniform beam with an energy chirp of 1% along the beam.

```
? VERSION=1.0
? SIZE=2
? COLUMNS ZPOS GAMMAO
-50.0e-6 99.5
 50.0e-6 100.5
```

Any version before 1.0 required that the number of input lines, containing the beam parameters, must be listed in the beginning of the file as the first information line before the actual

data lines started. To guarantee backwards compatibility this is still valid if the version is no defined to be 1.0 and the **SIZE**-statement is omitted. The example above would be then

```
? COLUMNS ZPOS GAMMAO
2
-50.0e-6  99.5
 50.0e-6 100.5
```

Again the specified value (here 2) is only used to check with the number of data lines, which is processed by GENESIS 1.3 without any error.

The beam description file can also be used for a scan ( $\text{NSCAN} = 23,24$ ). Each line correspond to a run of the scan. The meaning of the **ZPOS** column becomes obsolete. However it is still required for a correct parsing of the file.

## The Radiation Description File

Similar to the external beam description file, a file can be used to defined the seeding radiation field in form of a look-up table. The filename is specified by the **RADFILE** parameter. The keywords **VERSION**, **REVERSE**, and **SIZE** are identical to the one in the beam description file.

When the version is set to 1.0 or higher, Genesis 1.3 allows for a more flexible input and the definition of the input set, using the **COLUMNS** keyword. The number of allowed columns is less than for the beam description file. Parameters, which are not defined in **RADFILE** are filled with their value in the main input file. The list of allowed input parameters are:

- ZPOS or TPOS
- PRADO
- ZRAYL
- ZWAIST
- PHASE

The input parameter **PHASE** is the radiation phase at that position and has no equivalent in the main input deck. The default value is 0. Because Genesis 1.3 samples the radiation field with a reference wavelength **XLAMDS** a linear change in **PHASE** correspond to a shift in the input frequency, while a quadratic dependence describes a linear chirp. Still Genesis fills the



slices with a fundamental Gaussian mode. If higher modes are desired the user has to create his own distribution on a grid and import them with the `FIELDFILE` option.

A new keyword is `OFFSET` allows to shift the radiation field with respect to the electron beam. The value is the offset in meters. Note that for version 1.0 and higher, Genesis 1.3 aligns first the defined input range so that the first line in the look-up table is at zero of the internal, co-moving coordinate system.

## The External Distribution File

GENESIS 1.3 support external phase space distribution, generate by other simulation codes (e.g. ELEGANT). To enable the feature the input parameter `DISTFILE` points to a file, which contains the particle distribution of the entire bunch.

The format is ASCII and for each particle all 6 coordinates must be supplied per line. Additional information can be added per particle (such as particle ID), which is ignored by GENESIS 1.3 in the current version.

Similar to the beam description file and the magnetic field input file the functionality is extended by additional file information or comments.

Lines starting with the `#`-sign and empty lines are ignored. The question mark indicates information lines. The `VERSION` and the `SIZE` keywords are the same as in the beam description file. Again if the version is smaller than 1.0 and the `SIZE` keyword is omitted the first line, containing data, must be the size of the following data set. This value is used to check for consistency and completeness of the distribution file. A required information the charge in Coulombs, defined by the `CHARGE` keyword

The order of the 6 coordinates and additional values is set by the `COLUMNS` keyword followed by the names of each column in the data set. In the current version the total number of columns is limited to ten, but only those columns are used where the column name matches one of the following recognized keywords:

- `X` - position in  $x$  in meters
- `PX` or `XPRIME` - momentum in  $x$  normalized to  $mc$  or divergence in  $x$ , respectively
- `Y` - position in  $y$  in meters
- `PY` or `YPRIME` - momentum in  $y$  normalized to  $mc$  or divergence in  $y$ , respectively
- `T` or `Z` - longitudinal position in seconds or meters, respectively
- `P` or `GAMMA` - total momentum or energy, normalized to  $mc$  or  $mc^2$ , respectively.

The longitudinal position has to be defined exclusive either to be T or Z. The same is valid for the other pairs listed above. If not all 6 dimensions are given GENESIS 1.3 will terminate and report an error message. Note that GENESIS follows the rule that the longitudinal position is reversed if a time is specified by the T column. In this case smaller numbers correspond to particle in the tail of the distribution.

The default behavior of GENESIS 1.3 corresponds to the lines:

```
? VERSION = 0.1
? COLUMNS X PX Y PY T P
```

Note that with this default behaviour the first data line must be the number of particles (= information lines) in the distribution file.

## The Time-Record File

This is an file, which is created by GENESIS if the NOFILE parameter is set to a non-zero value in the file 'timerec.cmn'. It is only for internal use and will be deleted, when GENESIS 1.3 terminates.

## The SDDS File Format

*Currently not implemented. The manual will be updated, when the source code, supporting new file formats, has been written*

## The XML File Format

*Currently not implemented. The manual will be updated, when the source code, supporting new file formats, has been written*

## The HDF5 File Format

*Currently not implemented. The manual will be updated, when the source code, supporting new file formats, has been written*

# The GENESIS 1.3 Algorithm

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*Has to be written*



# Where to Find Further Information

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