# Field Precision LLC

# GenDist 4.0
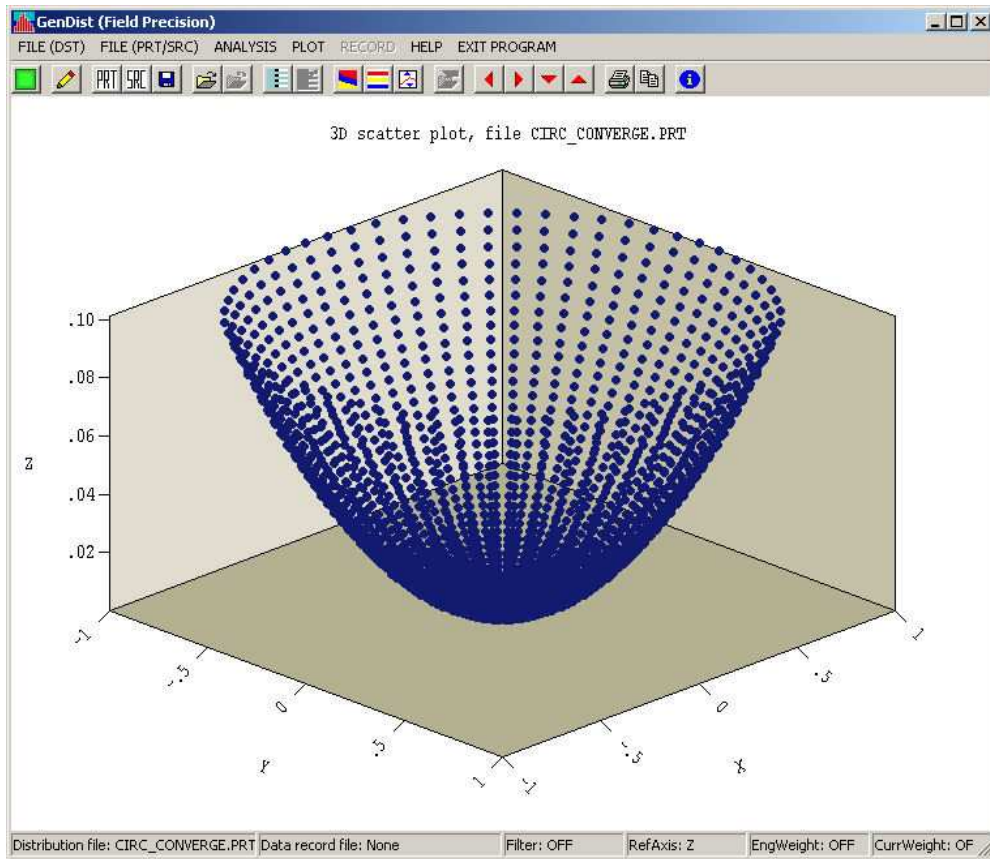## Particle Distribution Utility

# Contents

Figure 1: **GenDist** working environment

# 1 Introduction

## 1.1 Program functions and organization

**GenDist** is a versatile utility to deal with large sets of particles (*distributions*). The program is an essential aid when working with **Trak**, **OmniTrak** and **GamBet**. In this manual we shall refer to the three codes as *particle programs* because their main function is to calculate the effect of electromagnetic fields and materials on particles (electrons, ions, macroparticles, photons, ...).

**GenDist** performs three functions:

1. Creation of input distributions for the particle programs.

2. Plotting and analysis of distributions created by the particle programs.

3. Transformation of distributions before input to a particle program.

Figure 2 shows how **GenDist** interacts with the particle programs. In the *Generation* mode, the program uses an input text file FPrefix.DST to create files FPrefix.PRT or FPrefix.SRC.
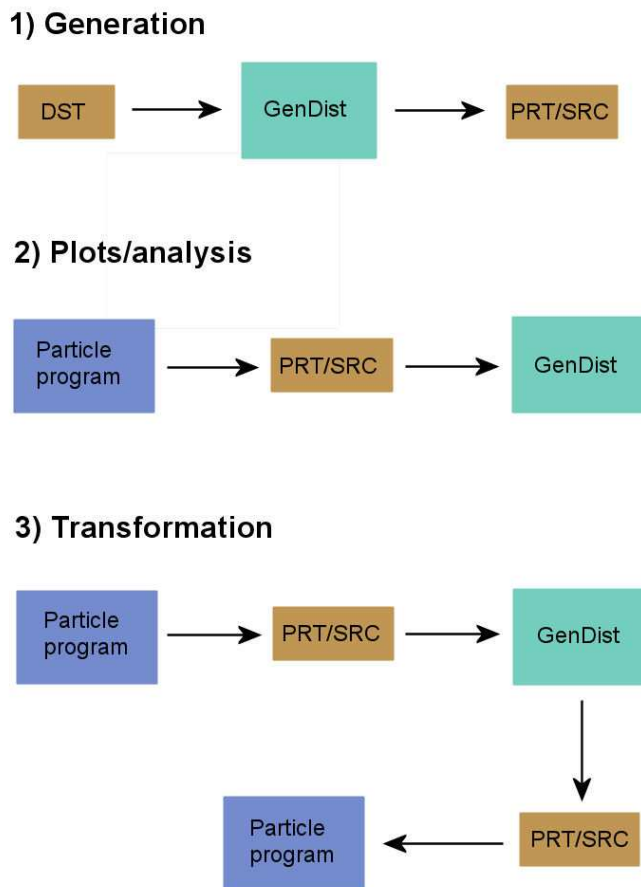
Figure 2: **GenDist** functions

Here, `FPrefix.DST` is a succinct script that describes the distribution. In this application, the use of **GenDist** can save considerable labor. A few data lines can generate initial parameters for thousands of particles. The file `FPrefix.PRT` is a standard input file for **Trak** and **OmniTrak** in calculations of charged-particle orbits in electric and magnetic fields. You can define any type of charged particle by specifying mass, charge, kinetic energy, position and direction. The file `FPrefix.SRC` is standard input for the **GamBet** radiation transport code. Here, particle types are limited to electrons, photons and positrons.

GenDist reads output files from the particle programs for plotting and analysis. **Trak** and **OmniTrak** create `PRT` files that represent particle parameters in one or more diagnostic planes. Similarly, **GamBet** generates an `SRC` file that contains parameters of particles that escape from the solution volume. **GenDist** can create a variety of plots to show properties of distribution. The program also performs statistical analyses to generate quantitative data.

The third program function follows from the fact that output `PRT` files from **Trak** and **OmniTrak** can be used as input for subsequent calculations with **Trak**, **OmniTrak** or **GamBet**. You can use **GenDist** to modify distributions, removing particles by setting filter conditions.

The following section discusses a walkthrough example that illustrates program capabilities and procedures. Chapter 2 describes how to write `DST` files. Chapter 3 covers plot operations, while Chapter 4 summarizes analysis and transformation capabilities.

Table 1: **GenDist** input script `WALKTHROUGH.DST`

```
FILETYPE PRT
RESTMASS 4.0
CHARGE 1.0
ENERGY 150.0E3
DEF CIRC 1.2 100 90
CONVERGE 12.0
ROTATE  0.0 90.0  0.0
SHIFT -2.5 0.0 0.0
DXDIST
  -1.06  1.00
  -0.53  1.00
   0.00  1.00
   0.53  1.00
   1.06  1.00
END
DYDIST
  -1.06  1.00
  -0.53  1.00
   0.00  1.00
   0.53  1.00
   1.06  1.00
END
ENDFILE
```

## 1.2   Application example

The following example illustrates **GenDist** operations. We shall create an input file for a beam transport simulation in **OmniTrak**. A converging beam of He$^+$ ions has kinetic energy $T = 150$ keV and carries 30 mA current. The beam initial radius is 1.2 cm and the particles converge toward a point 12.0 cm downstream. The injection position is (-2.5,0.0,0.0) and the beam moves in the $x$ direction of the simulation space. Finally, the distribution has an angular divergence of about $\pm 1.5°$.

Copy the example file `WALKTHROUGH.DST` to a working directory. Run **GenDist** and pick the command *File (DST)/Process DST*. The program analyzes the input script and generates an output file `WALKTHROUGH.PRT` containing 9000 particle data lines. You can check the contents of the file (shown in Table 1) with the *File (DST)/Edit DST* command.

Choose the command *File (PRT/SCR)/Load PRT* and pick `WALKTHROUGH.PRT` to plot and to analyze the resulting distribution, . The program loads the file and creates the default plot of Fig.3. The plot shows particle positions projected in the $x$-$y$ plane.

We can confirm the validity of the distribution by creating a phase-space plot of position and angle relative to the beam axis. First, we must change the reference axis which is taken along $z$ by default. Click on *Plot/Reference axis* and set the axis to $x$. Then pick *Plot/Plot type* and choose the *Phase-space* type. Finally, click on *Plot/Plot quantity* and choose the type *R-AngR*. The program produces the plot of Fig.4, a typical distribution for a converging beam
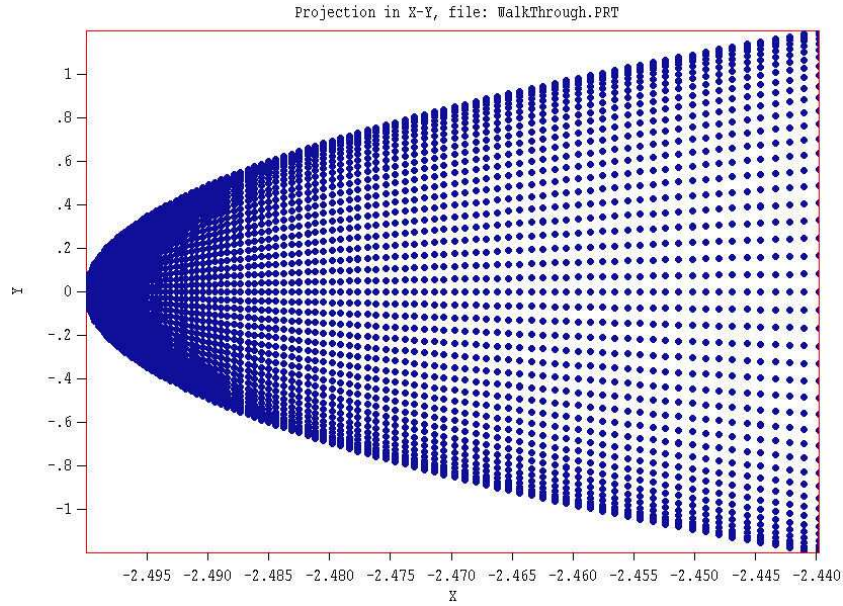
Figure 3: Projection of particles positions to the $x$-$y$ plane, walkthrough example

with angular divergence.

To conclude, we shall move the distribution to a point 12.0 cm downstream (assuming ballistic trajectories) and plot the radial particle distribution to determine the focal spot size. Pick the command *Analysis/Transform distribution* to open a dialog. Type the number 12.0 in the box under *Uniform distance* and click *OK*. Change to the plot type *1D bins* and pick the quantity $f(R)$. Figure 5 shows the resulting plot. To save the modified distribution, pick the command *File (PRT/SRC)/Write PRT/SRC file*. Supply a prefix to create the file FPREFIX.PRT.
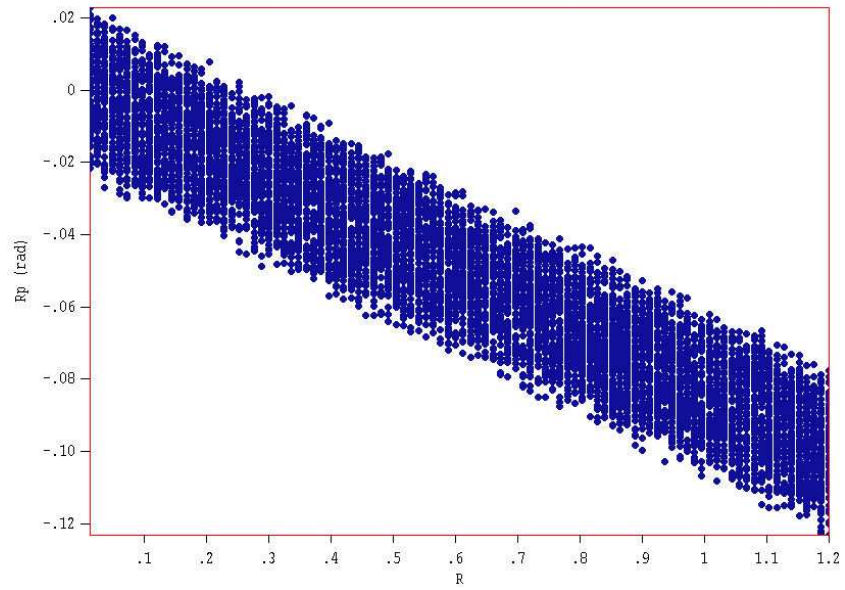
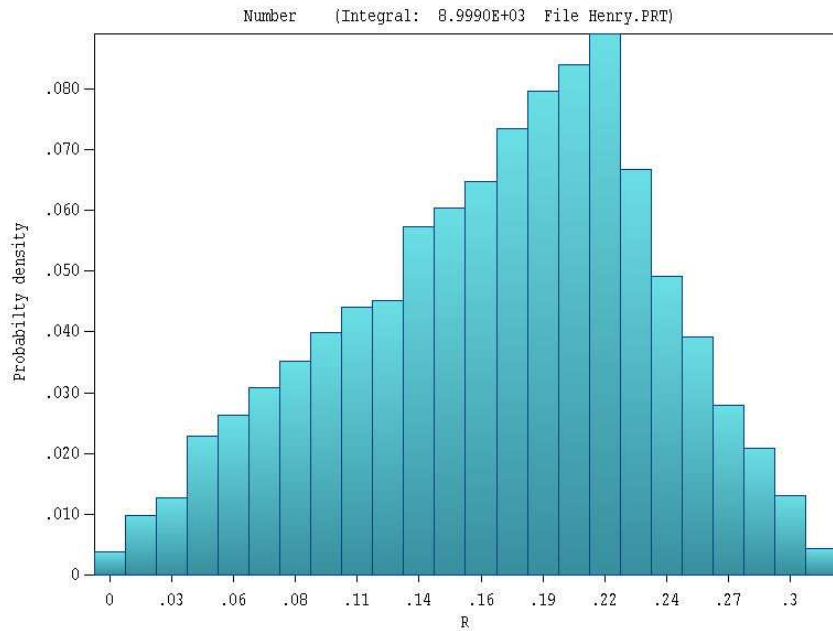Figure 4: Phase-space plot of $r$ versus $r'$, walkthrough example



Figure 5: Histogram of the radial distribution of particles at the ballistic focal point, walkthrough example
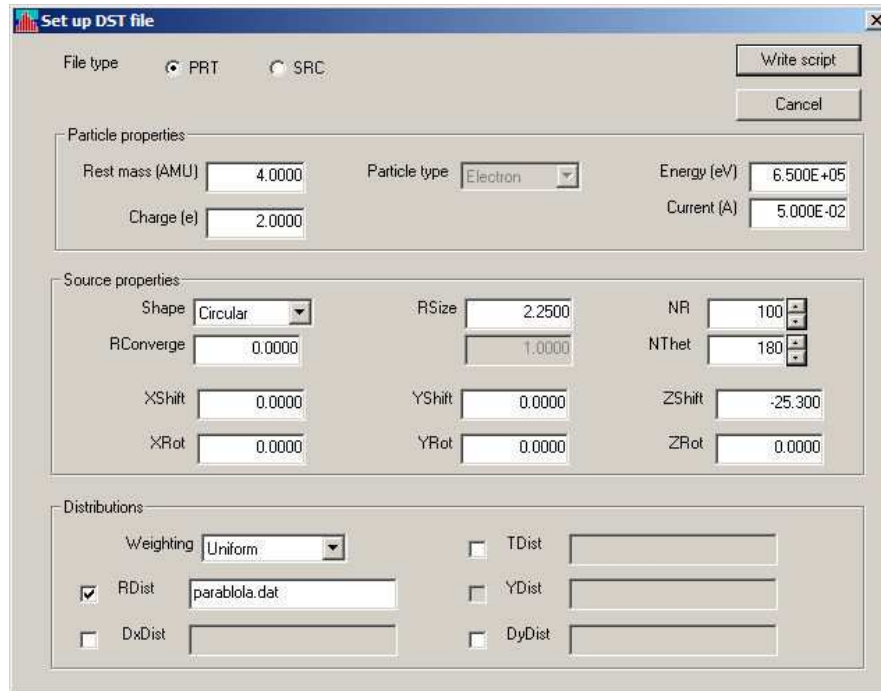
Figure 6: Setup dialog to generate **GenDist** scripts

# 2 Generating distributions

One function of **GenDist** is to interpret scripts to create large input distributions for Field Precision particle tracking programs. The program creates standard particle input files (`PRT`) for **Trak** and **OmniTrak** and source files (`SRC`) for **GamBet**.

The **GenDist** script is a text file that you normally create in an interactive dialog. You can also use a text editor to write the script or to add advanced features. Section 2.1 introduces entries in the dialog, while the remaining sections of this chapter cover the script commands in detail.

## 2.1 Setup dialog

The dialog of Fig. 6 appears if you click on the *File/Setup DST file* menu command or tool. The function is to create a basic **GenDist** script. You can make changes later with a text editor. The setup dialog provides a good reminder of commands and syntax rules. This section reviews the functions of the dialog fields.

**FILE TYPE**

Files of type `PRT` are compatible with **Trak** and **OmniTrak** (electron/ion guns and beam optics), while `SRC` files provide input data to **GamBet** (radiation transport in matter). The main difference is that only electrons, photons and positrons may appear in **GamBet** files, while the orbit codes handle any charged particle types.

Fields in the upper group set the properties the distribution particle.

## RESTMASS
This field is active for PRT files. Enter the particle rest mass in AMU (atomic mass units), where 1.0 AMU = $1.66057 \times 10^{-27}$ kg. A value of 0.0 designates the rest mass of the electron.

## CHARGE
This field is active for PRT files. Enter the particle charge in units of elementary charge ($1.60218 \times 10^{-19}$ coulomb). The proton charge is +1.0 and the electron charge is -1.0.

## PARTICLE TYPE
This field is active for SRC files. Choose the input particle for a **GamBet** simulation.

## ENERGY
Enter the central value of kinetic energy (in eV) that will be assigned to particles at the source. Section 2.5 describes how to introduce an energy spread.

## CURRENT
Set the total current or flux of the particle distribution. Section 2.3 describes the interpretation of the value.

The second group of fields set the properties of the source (how the particles are distributed in space and direction).

## SHAPE
There are three options in the menu: *Rectangular*, *Circular* and *Isotropic*. In the isotropic option (used for internal sources), particles are created uniformly in solid angle over the surface of a sphere. The other two options are used to generate beams. Here, particles are emitted along the $z'$ direction of a reference coordinate frame over a limited region in the $x'$-$y'$ plane. The region may have either a rectangular or circular shape. Section 2.4 gives detailed information on the rules for particle position assignment.

## XSIZE, YSIZE
These fields are active for rectangular sources. The real-number parameters $XSize$ and $YSize$ are the half-widths of the rectangle along the $x'$ and $y'$ directions of the reference frame.

## NX, NY
These fields are active for rectangular sources. The integer entries specify the number of particles to assign in the $x$ and $y$ directions. **GenDist** creates a total number ($N_x \times N_y$) of particles at uniform intervals along $x$ and $y$.

## RIN, ROUT

These fields are active for circular sources. The real-number parameters are the inner and outer radii of an annular beam. Set $R_{in} = 0.0$ for a solid beam.

## RSIZE

This field is active for isotropic sources. The real-number parameter is the source radius.

## NR, NTHET

These fields are active for circular sources. The integer entries specify the number of particles to assign in the $r$ and $\theta$ directions over the area of the source. **GenDist** creates a total number $(N_r \times N_\theta)$ of particles at uniform intervals along $r$ and $\theta$.

## NThet, NPhi

These fields are active for isotropic sources. The integer entries specify the number of particles to assign in the polar $(\theta)$ and azimuthal $(\phi)$ directions over the spherical surface.. **GenDist** creates a total number $(N_\theta \times N_\phi)$ of particles.

## RCONVERGE

Enter a real-number value to assign a radius of curvature to a rectangular or circular source. In this case, a circular source has the shape of a spherical section, while a rectangular source has the shape of a cylindrical section with convergence along $y'$. A positive number gives a convergent beam, while a negative number gives a divergent beam.

The next set of commands is used to orient the reference emission frame relative to the laboratory frame,

## XSHIFT, YSHIFT, ZSHIFT

Initially, the origins of the reference frame and the laboratory frame are coincident. Enter values in these fields to move the source.

## XROT, YROT, ZROT

By default, the axes of the reference and laboratory frame point in the same direction. In this case, the primary emission direction for rectangular and circular sources is along the $z$ axis of the laboratory frame. Enter values in these fields to orient the source. The real number parameters are rotation angles (in degrees) in the $x$, $y$ and $z$ directions. The rotations are performed in the order $XRot$, $YRot$ and $ZRot$. Note that rotations are performed before shifts.

The final group of fields signifies that distributions will be assigned to particles. The following options are available:

- Energy shifts about the central energy.

- Relative probability of emission over the area of the source in the $x'$-$y'$ plane.

- Relative probabilities for emission angle relative to the $z'$ direction.

The action of entries in the fields is to set place holders in the script for distributions. You must prepare and enter distribution information. This data may be prepared with an editor, a spreadsheet, or the *Table generation tool* in the main **GenDist** menu (Sect. 2.9). Sections 2.5, 2.6 and 2.7 describe the syntax for distribution tables.

### WEIGHTING
The choice affects how particles are assigned to the distribution. See Sect. 2.5 for details.

### TDIST
Check the box if you plan to enter energy distribution information of the form $[\Delta T, p(\Delta T)]$. There are two ways to specify the information: 1) as a list of values within the script or 2) as a list of values in an external file. Such a file can be created with the *Table generation tool* (Sect. 2.9). For the second option, include the name of the data file in the string field to the right of the check box. In this case, **GenDist** write a script entry of the form:

```
TDist = gaussian.dat
```

The entry has the following form if the box is checked but no file name appears:

```
TDist
  (Add entries of form T, f(T),
   with T in eV)
End
```

### RDIST
This field is active for circular sources. Check the box if you plan to enter information on the particle density as a function of r. See Sect. 2.6 for a detailed explanation.

### XDIST, YDIST
These fields are active for rectangular sources. Check the box if you plan to enter information on the particle density as function of $x$ and/or $y$.

### DXDIST, DYDIST
Use these fields if you plan to enter information on distributions in angle about $z'$ in the $x'$ and $y'$ directions for rectangular or circular sources.

When all entries are complete, click the *Write script* button and supply a prefix for the DST file. Table 2 shows the script created with the field entries of Fig.6.

Table 2: Script created by the dialog entries of Fig.6

```
* GenDist 3.0 Script (Field Precision)
* File: Demonstration.DST
* Date: 08/26/2006
* Time: 07:23:42

FileType = PRT
RestMass =   4.0000E+00
Charge =   2.0000E+00
Energy =   6.5000E+05
Current =   5.0000E-02
Def(Circ) =   2.2500E+00    100    180
Shift =   0.0000E+00  0.0000E+00 -2.5300E+01
Distribution = Uniform
XDist = parabola.dat


EndFile
```

## 2.2   Script organization

The **GenDist** script has a name of the form `FPREFIX.DST`. The string *FPrefix* is the run name, a descriptive title from 1 to 32 characters in length. The run name is applied to output files. Output files are assigned names of the form `FPREFIX.PRT` or `FPREFIX.SRC`. **GenDist** creates one output distribution per input script. The commands discussed in the Sects.2.3 through 2.7 may appear in any order. The program records parameters from all commands before beginning operation. The script must terminate with the *ENDFILE* command.

GenDist reads the script with a free-form parser. A line consists of a command and one or more parameters separated by any number of delimiter characters. Valid delimiters are space [ ], comma [,], tab, colon [:], left-parenthesis [(], right-parenthesis [)] and equal-sign [=]. You can use any of these characters to give your input files a distinctive style. You can also include indentations for readability. Commands and keywords may be entered in upper or lower case. **GenDist** ignores blank lines and comment lines. A comment line starts with an asterisk [*]. Real number parameters may be entered in any valid format. The following forms are allowed:

```
2.3456
2.63E12
-1.95E+02
5
```

The last number is interpreted as 5.0. You can also include text in any format after the *ENDFILE* command. Table 1 is an example of a typical **GenDist** script.

## 2.3   General distribution properties

**GenDist** creates distributions of particles with the same rest mass, charge, average kinetic energy and (optionally) current or flux. You can make mixed distributions by running multiple

input files and combining the outputs with an editor. The commands described in this section set the basic distribution properties. The allowed commands depend on whether you are creating a `PRT` or `SRC` file.

## FILETYPE [PRT, SRC]
## FILETYPE = SRC

This command determines whether the output file is in the `PRT` format of **Trak** and **OmniTrak** or the `SRC` format of **GamBet**. Default: `PRT`.

The following two commands are recognized only in the `PRT` mode:

## RESTMASS PRestMass
## RESTMASS = 1.0

Enter the particle rest mass in AMU (Atomic Mass Units), where 1.0 AMU = $1.66057 \times 10^{-27}$ kg. A value of 0.0 sets the rest mass of the electron. (Default: electron mass).

## CHARGE PCharge
## CHARGE = 1.0

Enter the particle charge in units of elementary charge ($1.60218 \times 10^{-19}$ coulomb). The proton charge is +1.0 and the electron charge is -1.0. (Default: electron charge).

The following command may appear only under the `SRC` option.

## PARTICLE [1, E, E-, 2, P, 3, E+]
## PARTICLE = E+

Specify the type of particle – **GenDist** automatically sets the mass and charge. The options are electrons ("1", "E" or "E-"), photons ("2" or "P") and positrons ("3" or "E-")

The remaining two commands in this section and all commands in subsequent sections apply in both the `PRT` and `SRC` modes.

## ENERGY KEng
## ENERGY = 200.0E3

Enter the central value of kinetic energy assigned to particles at the source in eV (electron volts). Section 2.5 describes how to introduce an energy spread. (Default: 0.0)

## CURRENT PCurrent
## CURRENT = 12.5

Set the total current or flux of the particle distribution. For charged particles in the `PRT` or `SRC` mode, enter the beam current $I_b$ in amperes (**OmniTrak**, cylindrical solutions in **Trak**, cylindrical or 3D solution in **GamBet**) or amperes/m (planar simulations in **Trak** or **GamBet**). A current $I_b/N_{part}$ is assigned to each particle. For photons in the `SRC` mode, enter the flux in particles/second (**OmniTrak**, cylindrical solutions in **Trak**, cylindrical or 3D solutions in **GamBet**) or particles/second/m (planar simulations in **Trak** or **GamBet**). (Default: No current)
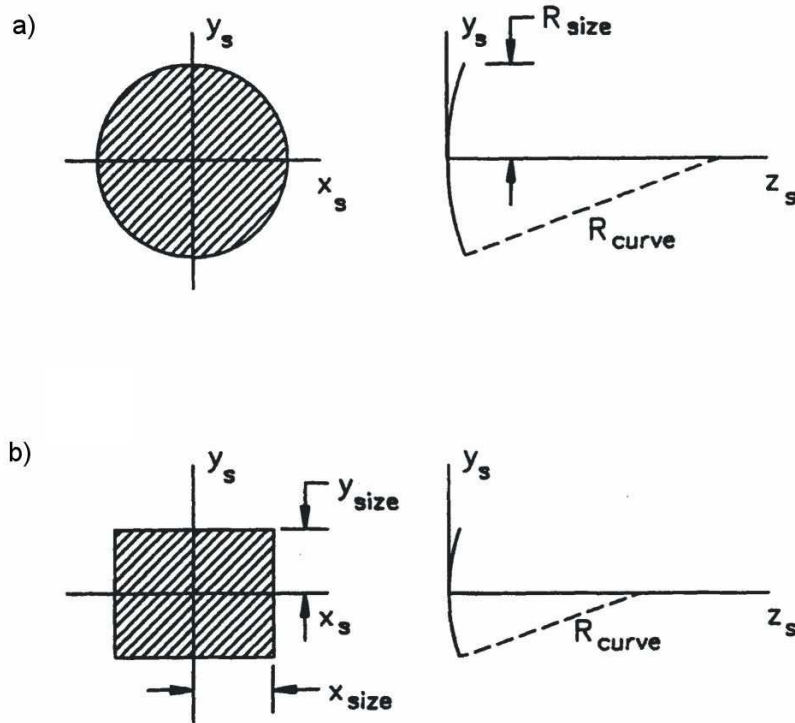
Figure 7: Source coordinate system

## 2.4   Source characteristics

**GenDist** can generate particles over an extended source region. You must define the position, orientation and shape of the source. The program offers a wide latitude to locate the source in three-dimensional space. It is also possible to add spatial weighting of particle emission over the source surface (Sect.2.6).

**GenDist** initiates particles relative to a local coordinate system referenced to the source plane. Figure 7 shows the coordinate systems and geometric parameters. The axes $x_s$ and $y_s$ lie in the source plane. The main emission direction is out of the page along $z_s$. Initially, the origins and axes of the source and field solution space are coincident.

The first step to define a source is to assign the shape and size of the source plane as well as the number of particles in the distribution using the following command:

```
DEF   Iso 0.01 50 50
DEF   Circ  2.5  21   36
DEF   Rect 1.0 4.0 11 11
```

Under the Iso option, GenDist creates an isotropic set of particles moving away from the point $[x_s, y_s, z_s]$ on the surface of a sphere of specified radius. This option is useful for sources internal to an assembly. The other two options are used to create beams of particles. In this case, the shape of the source projected in the $x_s$-$y_s$ plane may be either circular or rectangular. The second form of the command defines a circular source (Fig. 7a). The real-number parameter following the string $CIRC$ is the source radius $R_{size}$ in any units. Coordinates will be converted to meters through the $DUnit$ parameter when the resulting PRT or SRC file is loaded into **Trak**,

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**OmniTrak** or **GamBet**. The two integer parameters are the number of particles to assign along $r$ ($N_r$) and along $\theta$ ($N_\theta$). The total number of particles is $N_{part} = N_r \times N_\theta$.

In the third form of the *DEF* command, the string *RECT* designates a rectangular source (Fig. 7b) in the $x_s$-$y_s$ plane. The real-number parameters are $X_{size}$ and $Y_{size}$. In this case, particles are distributed over the range

$$- X_{size} \le x_s \le +X_{size}, \tag{1}$$
$$-Y_{size} \le y_s \le +Y_{size}. \tag{2}$$

### DEF ISO RSize NThet NPhi
### DEF ISO (0.05, 100, 100)

The string *ISO* implies an isotropic source where particles move away from the point $[x_s, y_s, z_s]$. The real number $R_{size}$ is the radius of a sphere centered on the emission point for the assignment of initial positions. The value $R_{size} = 0.0$ is allowed. The quantity $N_\theta$ is the number of particles in the polar direction ($\theta$) and $N_\phi$ is the number in the azimuthal direction ($\phi$). The total number of particles is $N_\theta \times N_\phi$.

### DEF CIRC RSize NR NThet
### DEF CIRC (2.5, 21, 36)

The string *CIRC* implies a circular source. The real number $R_{size}$ is the radius of the source. The quantity $N_r$ is the number of particles in the $r$ direction and $N_\theta$ is the number in the $\theta$ direction. The total number of particles is $N_r \times N_\theta$.

### DEF CIRC RIn ROut NR NThet
### DEF CIRC (1.2 2.5) 21 36)

Use this form of the command for an annular beam. Here, the real number $R_{in}$ is the inner radius and $R_{out}$ is the outer radius of the source. The quantity $N_r$ is the number of particles in the $r$ direction and $N_\theta$ is the number in the $\theta$ direction. The total number of particles is $N_r \times N_\theta$.

### DEF RECT XSize YSize NX NY
### DEF RECT (1.0, 0.25, 11, 11)

This form of the *DEF* statement has the following parameters: 1) the string *RECT* implies a rectangular source, 2) the real number $X_{size}$ is the half-width of the source along $x$, 3) the real number $Y_{size}$ is the half-width of the source along $y$, 4) the integer $N_x$ is the number of particles along the $x$ direction, and 5) the integer $N_y$ is the number of particles along the $y$ direction. The total number of particles is $N_x \times N_y$.

You can define converging or diverging beams with the command

```
CONVERGE 30.0
```

The command sets a value of the parameter $R_{curve}$. The effect is to modify a circular source to a spherical segment or a rectangular source to a cylindrical section.

## CONVERGE RCurve
## CONVERGE = -80.0

The real-number parameter is $R_{curve}$, the radius of curvature of the source (Fig. 7). A positive number gives a convergent beam, while a negative number gives a divergent beam.

After defining the source shape, the next step is to rotate it so that particles are injected in the desired direction. The source orientation is achieved by first rotating the plane about the $x$ axis of the solution space, then the new $y$ axis, and finally the new $z$ axis. These rotations are controlled by the $ROTATE$ command.

## ROTATE RotX RotY RotZ
## ROTATE = (0.0, 45.0, 30.0)

The real number parameters are rotation angles (in degrees) in the $x$, $y$ and $z$ directions. The rotations to orient the source plane are performed in the order $RotX$, $RotY$ and $RotZ$. Rotations follow the right-hand rule. (If the thumb of your right hand points along the axis in question, the fingers point in the direction of positive angle).

Once the source is oriented, you can adjust its position in the solution space using the $SHIFT$ command. This command specifies the displacement of the source origin along the $x$, $y$ and $z$ axes of the solution space.

## SHIFT XShift YShift ZShift
## SHIFT = (-2.0, 0.0, 10.0)

The real number parameters $X_{shift}$, $Y_{shift}$ and $Z_{shift}$ are the displacements along the $x$, $y$ and $z$ axes.

As an example, consider an electrostatic solution for an einzel lens that extends along the $z$ axis from $z = -20.0$ cm to $z = 20.0$ cm. To inject particles in the $+z$ direction from a source at -18.0 cm, use the command

```
SHIFT 0.0 0.0 -18.0
```

Now suppose we want to incline the source so that particles are injected with a momentum component along $+x$ at an angle of 2.5º with respect to the $z$ axis of the lens. The following two commands orient the source and set it at position $z = -18.0$:

```
ROTATE 0.0 2.5 0.0
SHIFT 0.0 0.0 -18.0
```

In all cases, the rotation operations are performed before translation.

## 2.5   Energy distributions

You may enter a spread about the central value of kinetic energy with the *TDIST* structure. This command line is followed by a set of data lines consisting of two quantities: 1) the energy displacement in eV from the mean value set by the *ENERGY* command, and 2) the relative probability for the energy. The data lines should give a smooth probability function. Any set of relative values is acceptable because **GenDist** will automatically normalize the distribution.

### TDIST

The command is followed by a minimum of 4 and a maximum of 256 data lines. Each data line contains two real numbers:

dT   P(dT)

The quantity $dT$ is the displacement from the central energy in eV, while $P(dT)$ is the relative probability for emission per energy interval. The data list must terminate with an *END* command.

   As an example, the following command lines set a central kinetic energy of 10 keV with a Gaussian energy spread with relative probability,

$$p(\Delta T) = \exp\left[-\left(\frac{\Delta T}{100}\right)^2\right]. \tag{3}$$

```
ENERGY 10.0E3
TDIST
-300.0   0.00012
   ...
    0.0   1.00000
   25.0   0.93941
   50.0   0.77880
   75.0   0.56978
  100.0   0.36788
  125.0   0.20961
  150.0   0.10540
  175.0   0.04677
  200.0   0.01832
  225.0   0.00633
  250.0   0.00193
  275.0   0.00052
  300.0   0.00012
END
```

Figure 8 shows a 21-bin histogram of the resulting energy distribution.

   **GenDist** assigns weighted quantities from a function $P^{-1}(\zeta)$, the normalized inverse of the probability function defined by the data statements. Here, the quantity $\zeta$ is a uniform random variable in the interval $0.0 \leq \zeta \leq 1.0$. There are two options for choosing values of $\zeta$:
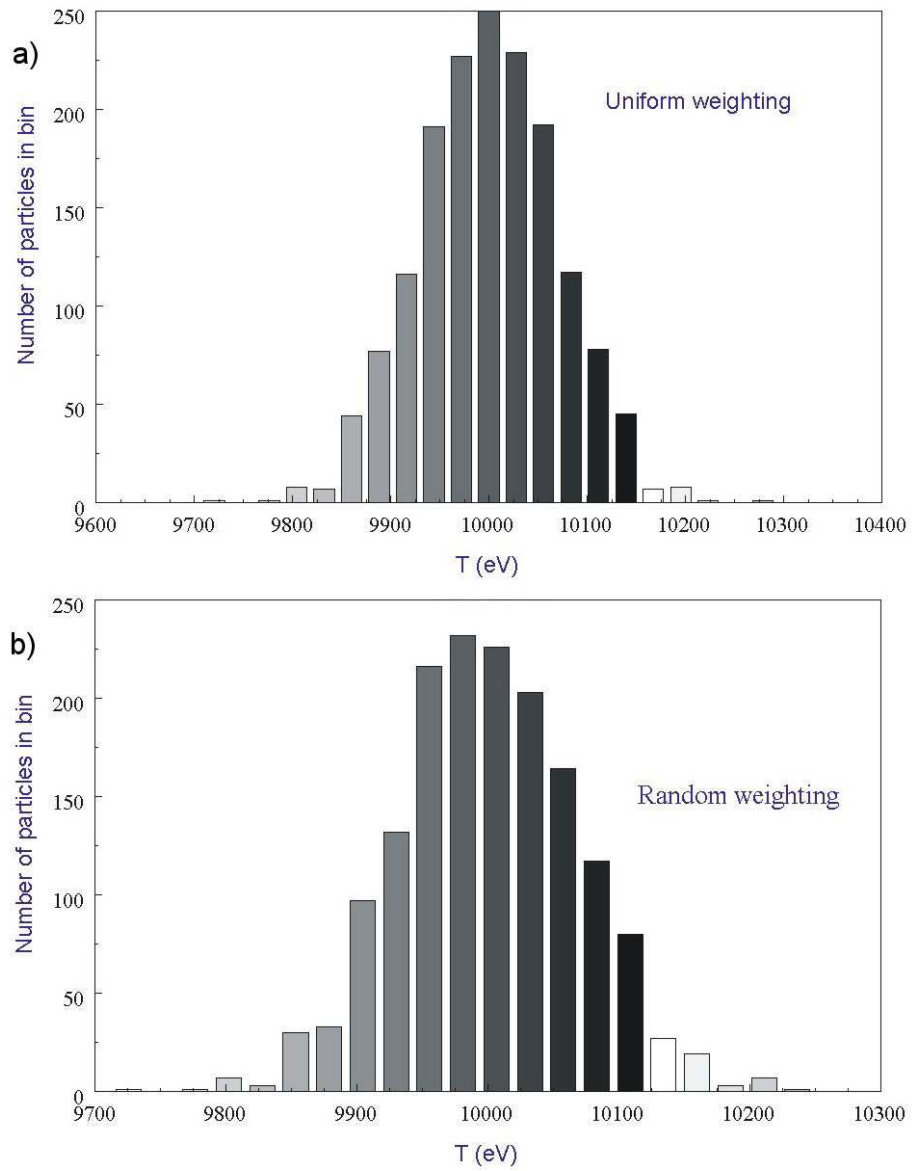
Figure 8: Energy distribution example. *a*) Uniform weighting. *b*) Random weighting.
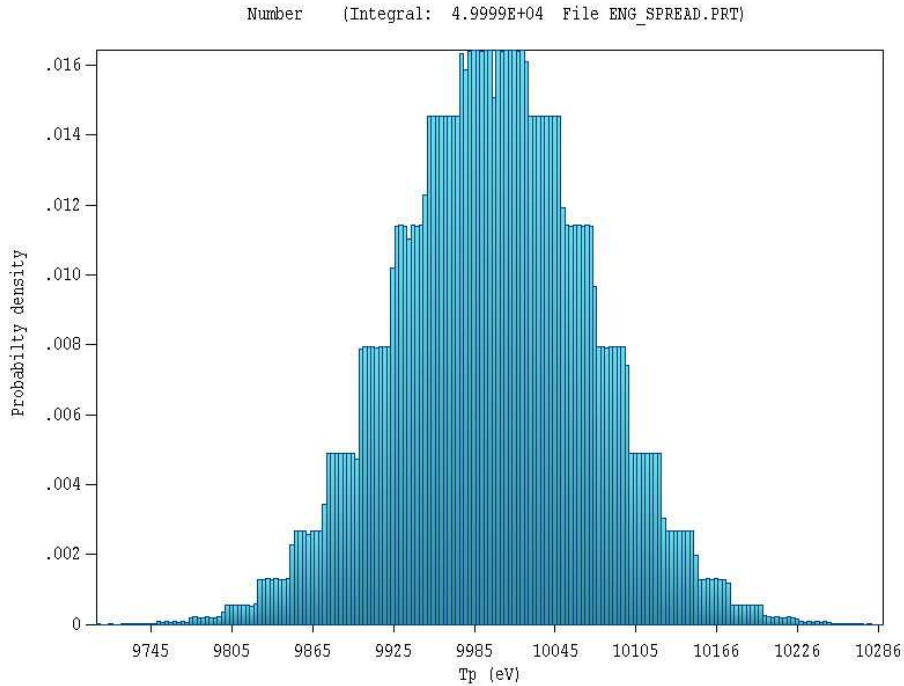
Figure 9: Discontinuities in the probability inversion. Results of Fig. 8 with a large number of particles and bin.

- If the number of particles equals $N$, then we can assign values according to $\zeta = (n - 1)/(N - 1)$ where $1 \leq n \leq N$. We shall call this option *uniform weighting*.

- We can obtain $N$ values from a normalized pseudorandom number function, $\zeta = $ Random(). This option is called *random weighting*.

The *DISTRIBUTION* command controls which method is used. Figure 8 shows distributions created with the two weighting types.

It is important to note that probability density depends on the slope of the inverted distribution. As a result, the distribution has uniform values between points of the data table. To illustrate, Figure 9 shows the energy distribution of Fig. 8 with a large number of particles (50,000) and 195 bins. Use more points if you need a smoother distribution.

**DISTRIBUTION [Uniform, Random]**
**DISTRIBUTION = Uniform**
This command controls the assignment method for all weighted distributions. The options are *Uniform* or *Random*. The default is *Uniform*.

**SEED ISeed**
**SEED = 4536281**
When the *Distribution* type is *Random*, the program sets the random-number seed from the system clock. This means that **GenDist** produces a different set of random values each time a DST file is processed. You can use this command to set the seed explicitly. In this case,

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the program uses the same set of random numbers each time. Enter an integer value (4-byte maximum).

## 2.6   Spatial distributions

You can define spatial distributions over the boundaries of circular or rectangular sources using the *RDIST*, *XDIST* and/or *YDIST* commands. The *RDIST* structure applies to circular and spherical-section sources:

### RDIST

The structure defines a spatial distribution along $r$. The distribution in $\theta$ is always uniform. The *RDIST* structure includes a minimum of 4 and a maximum of 256 data lines. Each data line consists of two real numbers:

```
RNorm   P(RNorm)
```

where $R_{norm}$ is the relative radial position, $R_{norm} = r/R_{size}$ and $P(R_{norm})$ is the relative probability. Therefore, $R_{norm}$ should cover the range 0.0 to 1.0. The structure must terminate with the *END* command.

One common use of the *RDIST* structure is to define a circular beam with uniform current density. Because each model particle carries the same current, the strategy is to set up a distribution where the relative probability of occupying a radial position is proportional to the radius. The input statements to define a 100 A uniform current-density electron beam with $R_{size} = 1.0$ are as follows:

```
DEF Circ 2.5    30  36
RESTMASS 0.0
CHARGE -1.0
CURRENT 100.0
RDIST
  0.0  0.0
  0.2  0.2
  0.4  0.4
  0.6  0.6
  0.8  0.8
  1.0  1.0
END
```

The resulting distribution is plotted in Figure 10.

The *XDIST* and *YDIST* structures apply to rectangular sources. The *XDIST* command is followed by from 4 to 256 data lines. The data lines define a normalized probability table that gives the relative distribution of particles between the limits $-X_{size} \leq x \leq X_{size}$:
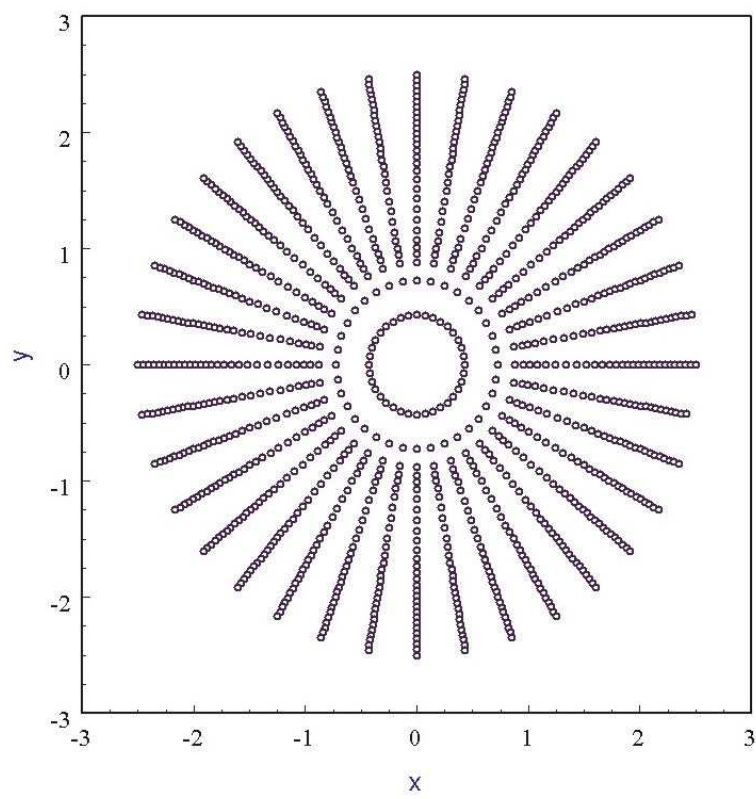
```
XNorm   P(XNorm)
```

Figure 10: Spatial distribution over a circular source for an approximately uniform current density (1080 particles).

The quantity $X_{norm}$ varies from 0.0 to 1.0 and is related to $x$ by

$$X_{norm} = \frac{x + X_{size}}{2X_{size}}.$$ (4)

The following example shows the definition of a rectangular source with truncated Gaussian distributions in the $x$ and $y$ directions. Figure 11 shows the resulting spatial distribution.

```
DEF Rect 2.50 1.00  41   41
XDIST
 0.000 0.36788
 0.050 0.44486
 0.100 0.52729
 0.150 0.61263
 0.200 0.69768
 0.250 0.77880
 0.300 0.85214
 0.350 0.91393
 0.400 0.96079
 0.450 0.99005
  ...
 1.000 0.36788
END
YDIST
 0.000 0.36788
 0.050 0.44486
 0.100 0.52729
 0.150 0.61263
 0.200 0.69768
 0.250 0.77880
 0.300 0.85214
 0.350 0.91393
 0.400 0.96079
 0.450 0.99005
  ...
 1.000 0.36788
END
```
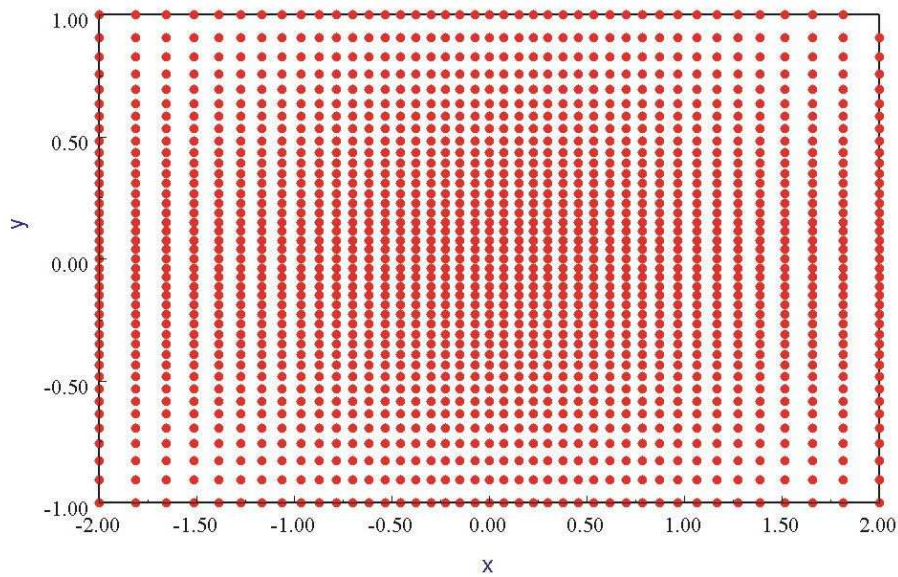
Figure 11: Spatial distribution over a rectangular source with Gaussian position weighting in $x$ and $y$.

## 2.7 Angular distributions

The commands *DXDIST* and *DYDIST* can be used to introduce angular divergence of particle emission about the $z_s$ axis or the emission direction set by the *CONVERGE* command. The *DXDIST* command is followed by from 4 to 256 data lines and the END command. Data lines have the entries:

```
Ang  P(Ang)
```

where *Ang* is the angular displacement in degrees. The angles must be in the range -30º $\leq Ang \leq$ 30º. The *DYDIST* command has a similar syntax. Angular assignment always follows random weighting, independent of the setting of the *DISTRIBUTION* command.

The following example sets up a line distribution of 1000 particles along the x axis uniform distribution in $x'$ over the range $\pm 1.5$ º and y' in the range $\pm 1.8$ º:

```
DEF Rect 1.0 0.0 1000  1
DXDIST
-1.50  1.00
-1.00  1.00
-0.50  1.00
 0.00  1.00
 0.50  1.00
 1.00  1.00
 1.50  1.00
END
DXDIST
-0.80  1.00
-0.40  1.00
-0.00  1.00
 0.40  1.00
 0.80  1.00
END
```

## 2.8   Running GenDist

**GenDist** can process a script (DST) to create a PRT or SRC file either in the interactive or autonomous modes. The program can run non-graphically in the background under batch file control. To start the program in the autonomous mode, enter the following command from the command prompt:

`[ProgPath]\GENDIST [DataPath]\FPrefix`

where the file `FPrefix.DST` is available in the specified directory.

**GenDist** enters the interactive, graphical mode when it is launched without a command line parameter. In this mode, choose the command *FILE (DST)/PROCESS DST* and pick an input script in the dialog. Changing directories in the dialog changes the working directory of the program. **GenDist** displays a text record of operations and reports any errors encountered. Move the mouse cursor into the screen and click any button to continue. Note that processing operations are independent of any current graphics or analysis functions. If you regenerate a currently-loaded PRT or SRC file, you must reload it to update plots.

Distribution processing is controlled by the following commands of the *File (DST)* popup menu.

### PROCESS DST
Pick a DST file and create a PRT or SRC file.

### CREATE DST
Use the internal program editor to write a DST file. Supply a prefix *FPrefix*. **GenDist** creates a template file `FPrefix.DST` and loads it into the editor. As a convenience, allowed commands are listed after the *ENDFILE* command.
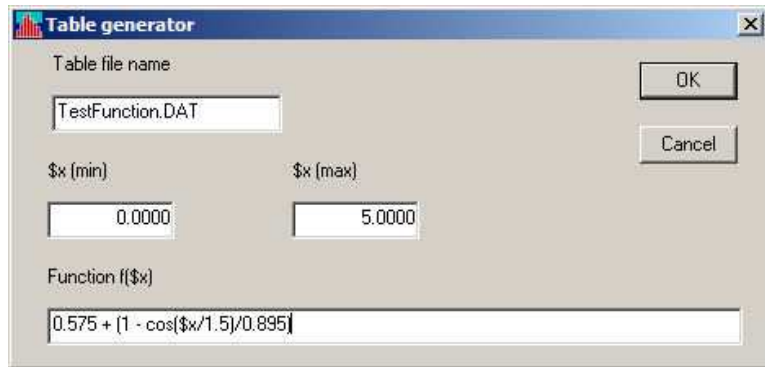
Figure 12: Table generation tool

**EDIT DST**
**EDIT FILE**
Use the internal editor to view or to modify `DST` or general text files.

The following command in the *HELP* popup menu is always available:

**GENDIST MANUAL**
Load this document in your default PDF viewer. The file `gendist.pdf` must be in the same directory as `gendist.exe`.

## 2.9    Table generation tool

This tool provides a quick way to create files of numerical tables for commands like *TDIST* and *RDIST* from mathematical functions. Click on the command *Table generator* in the *Tools* menu to bring up the dialog of Fig. 12. Supply information in the following four fields:

- **Table file name**. Enter a name for the file, such as `TGAUSS067.DAT`. The string may contain up to 36 characters.

- **$x(min) and $x(max)**. The range of the independent variable (real numbers).

- **Function (f($x)**. An algebraic function of the variable `$x` following the rules discussed below. The string may contain up to 255 characters.

When you click OK, the table generator opens a text file, writes a heading and adds 256 data lines, [`$x`, `f($x)`]. The values are evenly spaced along `$x` from `$x(min)` to `$x(max)`. Finally, the table generator appends *ENDFILE*, closes the file and then closes the dialog.

A function is a string (up to 255 characters) that may include the following entities:

- The independent variable `$x`.

- Real and/or integer numbers in any valid format (*e.g.*, `3.1415`, `476`, `1.367E23`, `6.25E-02`, `8.92E+04`,... ). Integers are converted to real numbers for evaluation.

Table 3: Extract from the file `TESTFUNCTION.DAT`

```
* Field Precision Table Generation Tool
*    Number of entries:  256
*    XMin:   0.0000E+00
*    XMax:   5.0000E+00
*    Function: 0.575 + (1 - cos($x/1.5)/0.895)
     0.0000E+00  4.5768E-01
     6.5020E-03  4.5769E-01
     1.3004E-02  4.5772E-01
     1.9506E-02  4.5778E-01
     2.6008E-02  4.5785E-01
     3.2510E-02  4.5794E-01
     ...
     4.9740E+00  2.6754E+00
     4.9805E+00  2.6745E+00
     4.9870E+00  2.6736E+00
     4.9935E+00  2.6728E+00
     5.0000E+00  2.6718E+00
ENDFILE
```

- Binary operations: + (addition), - (subtraction), * (multiplication), / (division) and ∧ (exponentiation).

- Functions: `abs` (absolute value), `sin` (sine), `cos` (cosine), `tan` (tangent), `ln` (normal logarithm), `log` (base 10 logorithm), `exp` (normal exponent) and `sqt` (square root).

- Up to 20 sets of parentheses to any depth.

- Any number of space delimiters.

The parser conforms to the standard algebraic rules and features comprehensive error checking. Errors may include unbalanced parentheses, unrecognized characters and sequential binary operations. To illustrate a valid example, the expression

```
1 - exp(-1.0*(($z^2 + $r^2)/24))
```

corresponds to

$$1 - \exp\left[-\left(\frac{z^2 + r^2}{24}\right)\right]. \tag{5}$$

The entries in the dialog shown in Fig. 12 give the file shown in Table 3.

# 3 Plotting distributions

## 3.1 PRT/SRC file operations

A `PRT` or `SRC` file must be loaded to use the plotting and analysis functions of **GenDist**. If the file was generated by a particle program, then positions are recorded in units set by the *DUnit* parameter defined within the program (*i.e.*, centimeters, inches, microns, ...). Positions in **GenDist** plots and calculations employ the same units.

The following commands appear in the *File (PRT/SRC)* popup menu:

**LOAD PRT**
Load a file with a name of the form `FPrefix.PRT`. Changing directories in the dialog changes the working directory of the program.

**LOAD SRC**
Load a file with a name of the form `FPrefix.SRC`. Changing directories in the dialog changes the working directory of the program.

**WRITE PRT FILE**
This command and the following one serve two useful functions: 1) record a particle file with an applied filter (*e.g.*, remove all photons) and 2) convert electron/positron distributions between PRT and SRC format. This command records properties of the currently-loaded distribution in a `PRT` file. Only particles that pass the current filter (Sect.4.2) are included. If a file of the type `SRC` has been loaded, only the properties of electrons and positrons are recorded. This command provide a quick method to convert a distribution file format from `SRC` to `PRT`.

**WRITE SRC FILE**
Record properties of the currently-loaded distribution in a file of the type `SRC`. Only particles that pass the current filter (Sect.4.2) are included. If a file PRT file has been loaded, only electrons and positrons are recorded. This command provide a quick method to convert a distribution file format from `PRT` to `SRC`.

**EDIT PRT**
**EDIT SRC**
Use the internal editor to view or to modify `PRT` or `SRC` files.

**OPEN DATA FILE**
**CLOSE DATA FILE**
Information from the *Beam analysis* command and several types of plots can be recorded if a data file is open. Supply a file prefix in the dialog. The file is saved with the name `FPrefix.DAT`. Close the file to start a new one or to use the file in another program.
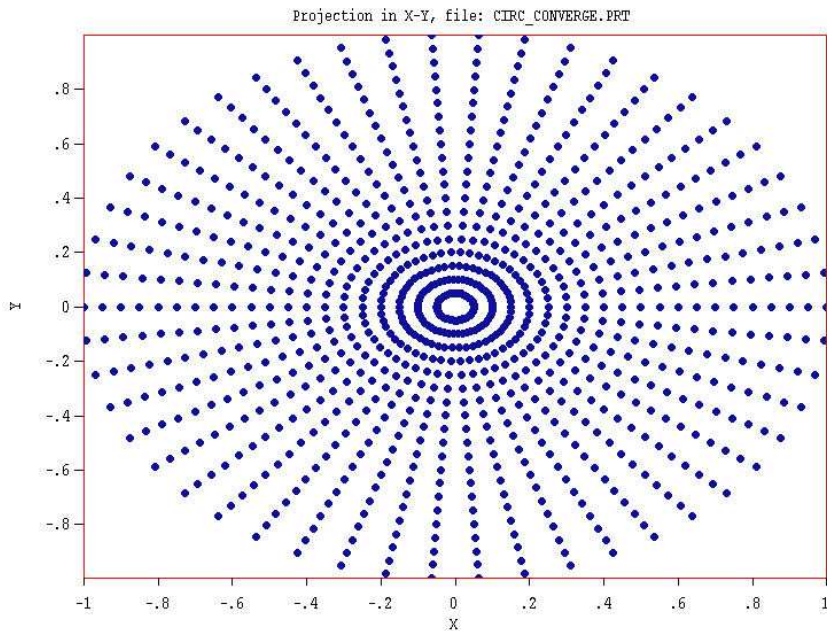
Figure 13: Spatial projection plot type.

## 3.2 Plot types

Distribution plots are useful to analyze outputs from the particle programs and to check the validity of **GenDist** scripts. This section summarizes the available plot styles. Following sections describe how to modify features of the plot. Note that only particles that pass the current filter (Sect. 4.2) are included in the plots.

**Spatial projections**
Particle positions projected to a normal plane (Fig. 13). The options are $x$-$y$, $y$-$z$, $z$-$x$ and $Ref$-$r$. For example, an $x$-$y$ plot shows the position of a particle in the plane normal to $z$, regardless of the particle position in $z$. You could set a filter to restrict plotted orbits to a range in $z$. Quantities in a plot of type $Ref$-$r$ depend on the setting of the reference axis (Sect. 3.3). In analyzing output from a cylindrical simulation in **Trak**, you would normally set the reference axis to $z$. In this case, the radial quantity is

$$r = \sqrt{x^2 + y^2}. \tag{6}$$

**Phase-space plots**
Phase-space distributions relative to the reference axis (Fig. 14). The options are $x$-$x'$, $y$-$y$, $z$-$z$ and $r$-$r'$. To illustrate the meaning of the quantities, suppose the reference axis is $z$ and we choose a plot of $x$-$x'$. The abscissa of the plot is $(x - x_{rig})$ expressed in meters. The ordinate is the quantity

$$x' = \tan^{-1}\left(\frac{p_x}{p_z}\right). \tag{7}$$

expressed in radians. This plot type is useful only if particle orbits are paraxial with respect to the z axis (*i.e.*, the distribution constitutes a beam moving predominantly in $\pm z$). A plot
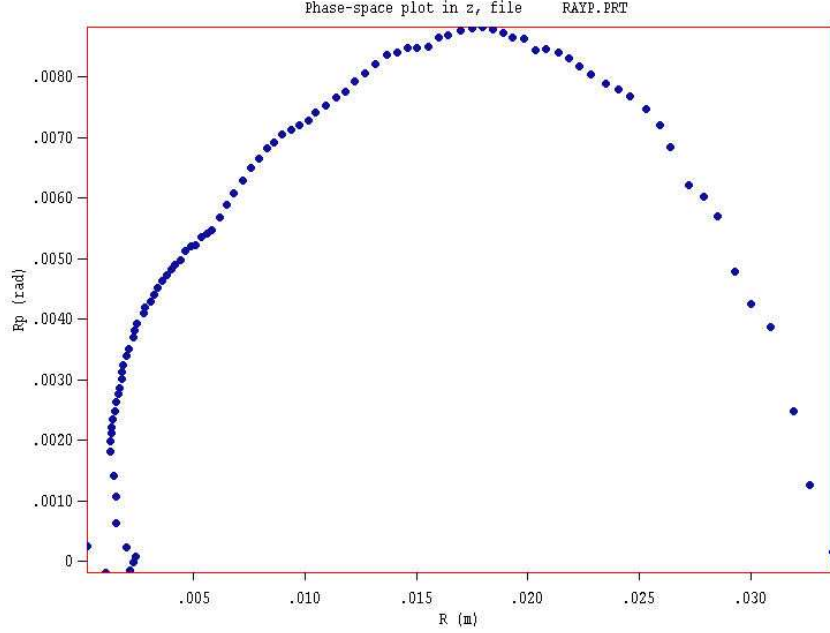
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Figure 14: Phase-space plot type.

is not generated if you pick the option $z$-$z'$ when the reference axis is set to $z$. The quantities in the plot type $r$-$r'$ depend on the setting of the reference axis. For example, if the reference axis is $x$ the plotted quantities are:

$$r = \sqrt{y^2 + z^2}, \quad r' = \tan^{-1}\left(\frac{\sqrt{p_y^2 + p_z^2}}{p_x}\right). \tag{8}$$

You can save values calculated for phase-space plots by clicking on the *Record* command or tool when the plot is active. **GenDist** prompts for a file prefix if a data file is not currently open.

**1D bins**

Histograms of the weighted number of particles organized by a quantity (Fig. 15). Weighting options are discussed in Sect.3.4. The following plot types are supported: $f(x)$, $f(y)$, $f(z)$, $f(r)$, $f(r')$ and $f(T)$. The option $f(x)$ divides particles into bins according to their position in $x$, regardless of their position in $y$ and $z$. The option $f(T)$ plots a distribution in kinetic energy, independent of position or direction. In this case, you can limit the spatial or directional range of particles with a filter. The quantities $r$ and $r'$ depend on the setting of the reference axis. For example, if $y$ is the reference axis particles are assigned to bins according to the values:

$$r = \sqrt{z^2 + x^2}, \quad r' = \tan^{-1}\left(\frac{\sqrt{p_z^2 + p_x^2}}{p_y}\right). \tag{9}$$

The value of a bin quantity is the *probability mass function*, the probability that particles in the distribution that pass the current filter occupy the bin. Therefore, values are in the range 0.0 to 1.0. The integral over the distribution is displayed in the title above the plot. The integral units depend on the weighting type (Sect. 3.4). The options are the total number of particles, total kinetic energy, total current or total power. Note that the quality of a bin plot depends

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on statistical limits set by the number of simulation particles and the number of bins. Click the *Record* command to save the bin calculations in a data file. The data record also shows the cumulative probability distribution.

**2D bins**

Histograms of the number of model particles or the particle current sorted according to position in a normal plane. The following options are available: $f(x,y)$, $f(y,z)$ and $f(z,x)$. For example, in the $f(x,y)$ option particles are assigned to a two-dimensional array of bins according to their positions in $x$ and $y$, regardless of their position in $z$. You can use particle filters to restrict plotted particles to a region of space. The plotted value is the weighted probability that the bin is occupied. The integral over the distribution is displayed in the title above the plot. Because of statistical limitations, this plot type is useful only if the distribution contains a large number of particles.

**3D scatter**

Three-dimensional plot of particle positions, $(x,y,z)$ (Fig. 1). Only particles that pass the present filter are included. When this plot is active, you can shift the viewpoint using the *ROTATION* and *ELEVATION* commands.

## 3.3  Plot controls

**PLOT TYPE**
Pick the plot type from the options described in Sect. 3.2. **GenDist** picks a default plot quantity valid for the current plot type.

**PLOT QUANTITY**
Pick a plotted quantity from one of the options displayed in the dialog. **GenDist** list only options that are valid for the current plot type.

**PLOT LIMITS**
Use the dialog of Fig. 16 to set limits for the plot. Uncheck the *Autoscale* box and enter real number values in the corresponding boxes. The active plot quantities depend on the plot type.

**NUMBER OF BINS** Set the number of bins $N_b$ for 1D and 2D histograms. Statistical variations between bins are determined by the available number of particles, $N_p$. When you load a `PRT` or `SRC` file, **GenDist** sets the default value $N_b = \sqrt{N_p}/4$.

**ENERGY WEIGHTING** Activate or deactivate energy weighting in plots (see Sect. 3.4).

**CURRENT WEIGHTING** Activate or deactivate energy weighting in plots (see Sect. 3.4). This command is active only if the `PRT` or `SRC` file contains current or flux information.
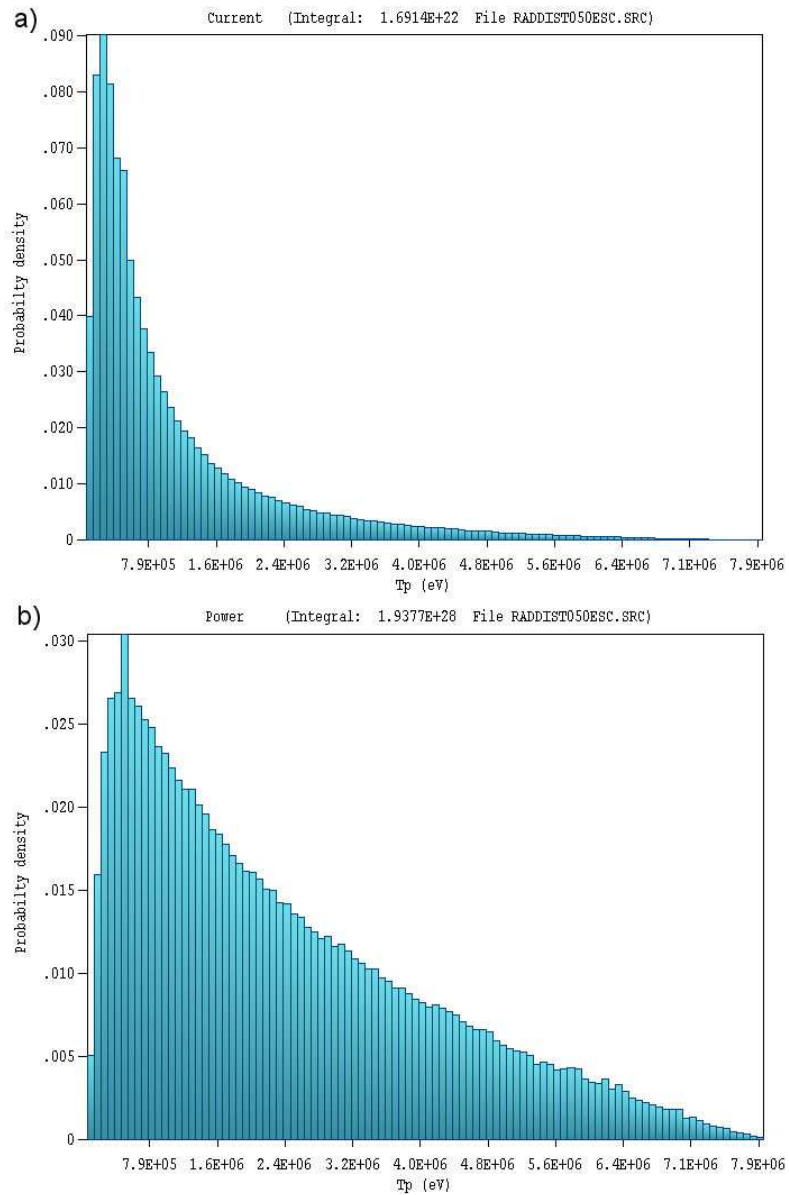
Figure 15: 1D bin plot type bremsstrahlung radiation spectrum *a*) Number of particles. *b*) Number of particles weighted by energy.
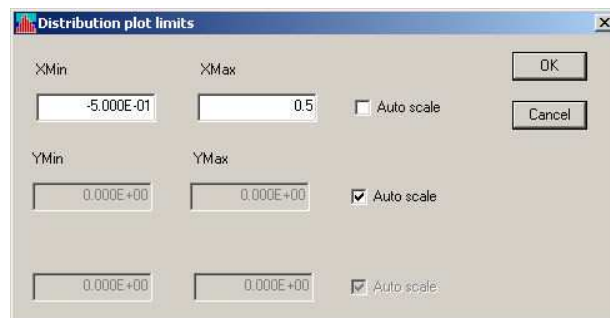


Figure 16: Plot limit dialog.

**REFERENCE AXIS**

All available quantities in phase-space plots and the quantity $Ref$-$r$ in a projection plot are calculated with respect to a reference axis. Use this command to set the axis to $x$, $y$ or $z$. You can also set an origin for the axis in the normal plane. For example, if the reference axis is $z$ and $x_{orig} = 1.0$ and $y_{orig} = 1.5$, then positions $(x - 1.0)$ and $(y = 1.5)$ will be used to construct plots. Enter $x_{orig}$ and $y_{orig}$ in the units used in the current PRT or SRC file.

The following commands are active for plot types *2D bins* or *3D scatter*:

**ROTATION (UP)**
**ROTATION (DOWN)**
Rotate the plot in azimuth.

**ELEVATION (UP)**
**ELEVATION (DOWN)**
Shift the view (polar angle)

## 3.4 Energy and current weighting

There are several options for calculating the relative probability in 1D and 2D bin plots. The basic plot consists of a sum of particles that fall into each bin divided by the total number of particles. For example, the plot of Fig. 15a shows the number of photons from a bremsstrahlung target as a function of kinetic energy. Another option to fill bins is the sum:

$$\frac{\sum_{bin} T_i}{\sum_{all} T_i}.$$  (10)

where $T_i$ is the kinetic energy of particle $i$. In this case, the numerator is the sum of the kinetic energies of particles that occupy the bin divided by the sum over the full distribution. Figure 15*b* shows the resulting plot. This distribution represents the relative photon energy flux from a bremsstrahlung target. Click the *Energy weighting* command to activate this feature.

You can apply current weighting to distributions that contain current or flux information. In this case, the plot displays the quantity:

$$\frac{\sum_{bin} I_i}{\sum_{all} I_i}.$$  (11)

where $I_i$ is the current or linear current density of particle $i$. The plotted quantity is the relative current as a function of an independent variable such as position. Click the command *Current weighting* to activate the feature.

When both current and energy weighting are active, the plotted quantity is

$$\frac{\sum_{bin} I_i T_i}{\sum_{all} I_i T_i}.$$  (12)

In this case, the plot shows the relative beam power. The status bar shows whether energy and/or current weighting is active.

## 3.5   Exporting plots

All screen displays created by **GenDist** may be exported to hardcopy devices and plot files using the following commands:

### DEFAULT PRINTER

This command sends a copy of the current plot to the default Windows printer. If you have several printers, use the *Settings/Printers* option on the Windows Start Menu to make changes in the default before running **GenDist**.

### SAVE PLOT FILE

Use this command to create a graphics file of the current plot in either Windows Bitmap (BMP) or Portable Network Graphics (PNG) formats. In the dialog, specify the format, the size in pixels and the file prefix. The graphics file is created in the current directory.

### COPY TO CLIPBOARD

Copy the current plot to the Windows clipboard (in Windows Metafile format) where you can paste it into other applications.

# 4 Analyzing and modifying distributions

Analysis commands control calculation of numerical data from values in `PRT` and `SRC` files. The following commands are included in the *Analysis* popup menu:

**BEAM ANALYSIS** Calculate and record average properties of particles with respect to the current reference axis (see Sect. 4.1. The results are most useful if the particle constitute a beam moving predominantly along the reference axis. **GenDist** prompts for a file prefix and opens a data record if a file is not currently open.

**REFERENCE AXIS** Set the current reference axis to $x$, $y$ or $z$. The choice effects the *Beam analysis* calculation and subsequent plots.

**APPLY FILTER** Set the current filter to determine which classes of particles are included in the *Beam analysis* calculation (Sect. 4.2). The choice also affects subsequent plots.

**REMOVE FILTER** Deactivate particle filtering.

**TRANSFORM DISTRIBUTION** Modify positions and/or directions of particles in the currently loaded distribution (Sect. 4.3).

## 4.1 Beam analysis

In response to the *Beam analysis* command, **GenDist** performs a statistical analysis of particles that pass the current filter. Quantities are calculated in absolute space and relative to the reference axis. Results are recorded in a data file – the program prompts for a prefix if a file is not open. The results are most useful when the particles constitute a beam (*i.e.*, the particles are localized in space and travel predominantly in one direction). Table 4 shows an example.

The following quantities are included in the report:

- The present reference axis and filter criteria if a filter is applied.

- The average beam position, direction and kinetic energy in absolute Cartesian space.

- The displacement of the beam from the origin of the current reference axis.

- The average direction relative to the reference axis.

- The angular spread of orbits about the reference axis (root-mean-squared average).

- The RMS emittance relative to the reference axis (PRT files only).

- The root-mean-squared spread of kinetic energy about the mean.

When analyzing an `SRC` file, **GenDist** calculates separate statistics for electrons, photons and positrons.

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Table 4: Beam analysis listing

```
Beam distribution analysis for file EmitCalcOut.PRT
     Reference axis: Z
         X(origin):  0.0000E+00
         Y(origin):  0.0000E+00
     (Distributions are weighted by current/flux)


Current magnitude:  4.5118E-07 (A)
Averaged quantities in absolute space
  Total number of entries in file:      100
  Average current per particle:  4.5118E-09 (A)
  Average position
     X:  1.8025E-08
     Y:  5.5120E-08
     Z:  9.9999E+01
  Average direction vector
     Ux:  0.0000000
     Uy:  0.0000000
     Uz:  0.9982296
  Average energy:  2.5000E+05 (eV)
Averaged quantities relative to the reference axis
  Average displacement
     X-XRef:  1.8025E-08
     Y-YRef:  5.5120E-08
  Average angle (degrees)
     ThetaX:     0.000
     ThetaY:     0.000
  RMS angular spread (degrees)
     dThetaX:     0.074
     dThetaY:     3.410
  RMS position spread relative to reference axis
     dX:  2.6026E-02
     dY:  1.3656E+00
     dR:  1.3659E+00
  RMS position spread relative to average position
     dX:  2.6026E-02
     dY:  1.3656E+00
     dR:  1.3659E+00
  RMS emittance
     EpsiX:  1.0238E-04
     EpsiY:  2.5012E-01
  RMS energy spread:  2.8010E-01 (eV)
```
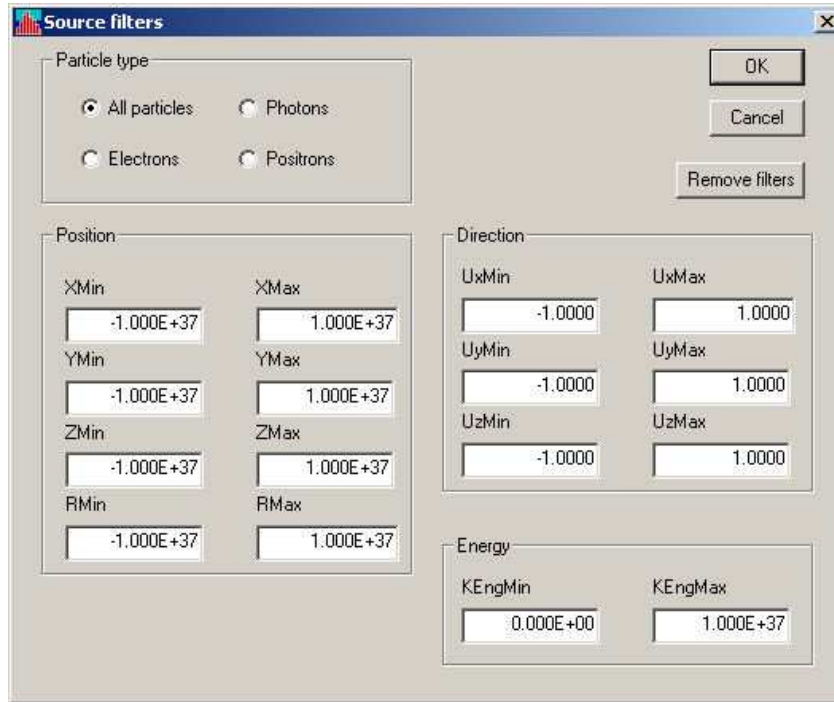
Figure 17: Filter dialog for SRC analysis.

## 4.2 Filters

You can apply a filter to limit particles included in plots, beam analyses and files created by the *WRITE PRT/SRC FILE* command (Sect. 3.1). In response to the *Apply filter* command or tool, **GenDist** displays the dialog shown in Fig 17 if an SRC file has been loaded. Filtering options include particle type, position, direction and/or kinetic energy. In the position group, the quantity $r$ is the distance from the current reference axis. The default limits for position quantities are $\pm 1.0 \times 10^{37}$ (numerical infinity). The direction quantities refer to the sine of the direction vector relative to the Cartesian axes of absolute space. The filter dialog for PRT file analysis includes options for filtering by particle mass and charge.

## 4.3 Distribution transformations

Use the command *Transform distribution* to modify the position and direction vectors of particles in the currently-loaded distribution. You can then save the transformed distribution using the *Write SRC file* and *Write PRT file* commands. Choose the *Analysis/Transform distribution* command to display the dialog of Fig.18. There are four options for transformations:

- **General**. Apply position shifts along and rotations about the Cartesian axes. Enter the angles in degrees. Rotations are performed in the order $\theta_x$, $\theta_y$ and $\theta_z$. Translations are applied after rotations. This option is useful for transferring PRT files between **Trak**, **OmniTrak** and **GamBet** calculations that use different coordinate systems.

- **Minimum distance to a line**. Particles are projected back along their direction vectors until they intersect a given line parallel to the $x$, $y$ or $z$ directions. The real number fields
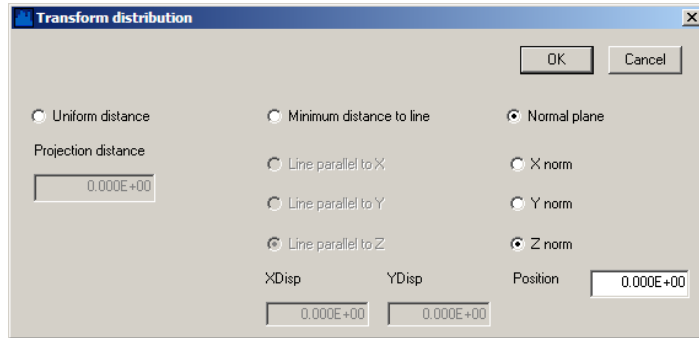
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Figure 18: Distribution transformation dialog.

specify the position of the line in the normal plane ($y$-$z$ for the $x$ axis, $z$-$x$ for the $y$ axis and $x$-$y$ for the $x$ axis). This transformation may be useful to find the effective size of a line source of bremsstrahlung radiation.

- **Uniform distance** Particles are projected a fixed distance forward or backward along their direction vectors. The real-number field is the distance. This option may be useful to find the effective size of a line source of bremsstrahlung radiation.

- **Projection to a normal plane** Particles are projected forward or backward along their direction vectors until they intersect a given plane normal to the Cartesian axis ($x$, $y$ or $z$). The real-number field is the position of the plane along the axis.

The parameter fields in a group become active when the option is chosen. Note that the transformation is applied only to particles with the current filter. The filter is based on the *initial* position and direction of the particle.

## 4.4   Beam section and unit conversion tools

The beam section tool has two applications:

- Conversion of a two-dimensional distribution to a three-dimensional distribution. Suppose, for example, that you design a high-current electron gun with **Trak** and you want to use **OmniTrak** to investigate the effect of a bending magnet on the output beam. The **Trak** PRT file contains a radial line of particles that would not be suitable for a space-charge calculation in **OmniTrak**. The beam section tool can create a PRT file where the original particles are replicated at multiple azimuthal positions to represent a full circular beam.

- Expansion of a three-dimensional solution in one quadrant to selected quadrants. To illustrate, consider an **OmniTrak** solution for a planar beam gun. To save time, the solution is performed in a single quadrant with symmetry about $x = 0.0$ and $y = 0.0$. For a transport calculation in a solenoid-type field, we may need the full beam distribution over the $x$-$y$ plane. The beam section tool may be used to create a PRT file with additional particles mirrored about reflection planes.
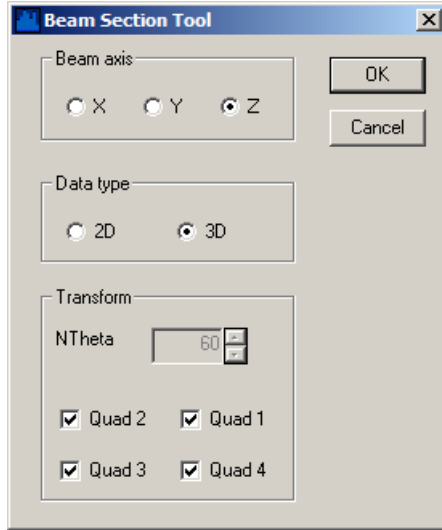
Figure 19: Beam section tool dialog.

Click on the command *Analysis/Beam section tool* to bring up the dialog of Fig. 19. The geometric operations are performed about a reference axis, usually $z$. The option *2D* in the *Data type* group expands a two-dimensional distribution to three dimensions by rotation about the reference axis. The quantity $N_\theta$ is the number of azimuthal intervals (default, $N_\theta = 60$). The rotations are applied relative to the initial particle azimuth. In a **Trak** simulation with only electric fields, particles in the initial PRT file are usually located on or near the $x$ axis. When there is an applied solenoid field, the rotated particles may have different azimuthal positions.

Figure 20 shows the quadrants for three-dimensional distributions relative to the reference axis. In a right-handed coordinate system, the horizontal and vertical coordinates in the graph are $y$-$z$ for reference axis $x$, $z$-$x$ for $y$ and $x$-$y$ for $z$. Use the check boxes in the dialog to show which quadrants should be included in the output PRT file. The default is to include all quadrants. The type of transformation depends on the choice of quadrants:

- If all quadrants are checked, the a particle in any quadrant is replicated in the other three quadrants. The most common application is to transform a distribution in Quadrant 1 so that it fills all four quadrants symmetrically (Fig. 20).

- If one quadrant is checked, then all initial particles are replicated only in that quadrant. This feature is useful for transferring particles from one quadrant to another or consolidating all orbits in one quadrant.

- The status of quadrants may used to mirror a beam distribution.

If $h$ and $v$ represent the horizontal and vertical coordinates relative to the reference axis with direction vector $u_h$ and $u_v$, then particles are generated with the following properties:

- Initial quadrant (if active):
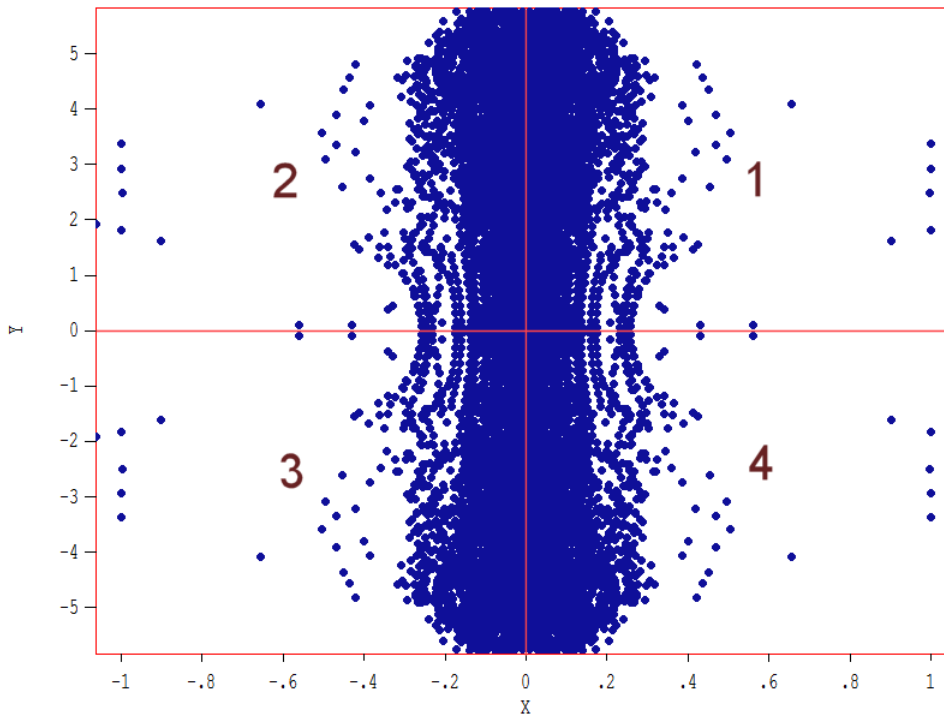$h' = h, v' = v, u'_h = u_h$ and $u'_v = u_v$.

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Figure 20: Mirroring a three-dimensional beam, definition of quadrants. The view is taken from the positive direction of the reference axis.

- Adjacent quadrant in the horizontal direction (if active):
  $h' = -h, v' = v, u'_h = -u_h$ and $u'_v = u_v$.

- Adjacent quadrant in the vertical direction (if active):
  $h' = h, v' = -v, u'_h = u_h$ and $u'_v = -u_v$.

- Opposite quadrant (if active):
  $h' = -h, v' = -v, u'_h = -u_h$ and $u'_v = -u_v$.

The new particles have the same type, mass, charge, and kinetic energy. For a three-dimensional transformation, the new particles have the same current. In this case, replication in all four quadrants increases the net beam current by a factor of 4.0. In the two-dimensional transformation, particle currents are divided by $N_\theta$ to maintain the same total beam current. In both the 2D and 3D cases, **GenDist** prompts for a prefix for the transformed PRT file. You can load the new PRT file into the program and use the plot capabilities to confirm the operation.

The unit conversion tool changes the units of the spatial coordinates of distributions. The tool could be applied, for example, to transfer the output of an electron gun simulation performed with dimensions in inches to a transport calculation where the field solution files have units of millimeters. Clicking on the tool brings up the dialog of Fig. 21. Pick the original units from the menu on the left and the final units from the menu on the right and then click *OK*. **GenDist** calculates the multiplication factor $m_u$ and then converts the positions of particles in memory according to $x' = m_u x, y' = m_u y$ and $z' = m_u z$. Use the *Write PRT file* or *Write SRC file* commands to save the result. If the desired original and final units are not available in the lists, you can set a value of $m_u$ manually. Activate the *Multiplication factor* checkbox, supply
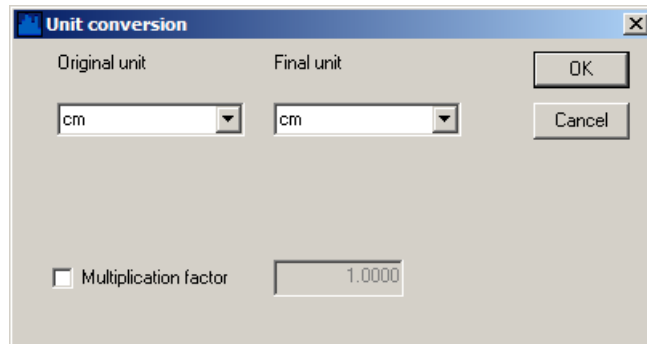
Figure 21: Unit conversion dialog

a real-number value and click *OK*. This option may also be useful for scaling or mirroring a distribution.

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