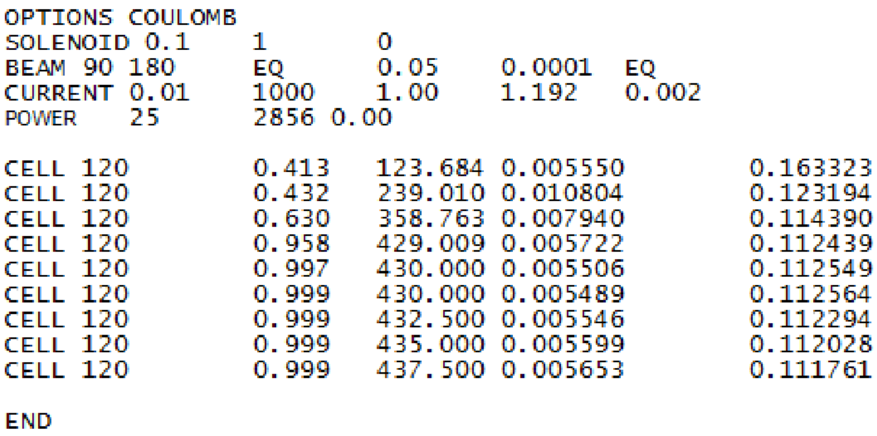
Hellweg2D Interface Guide

To calculate beam dynamics in TW linacs you need to follow some simple steps, describing below.

1. INPUT file.

Program reads the initial data from text file «INPUT.txt» which must be in the same folder as the "Hellweg2D.exe" file. If the data was successfully read, you will see the correct numbers in the main window. If the data is not correct you can look through the «PARSER.txt» file to see what lines were successfully read. The example of an input file is presented in Figure 1.



```
OPTIONS COULOMB
SOLENOID 0.1    1       0
BEAM  90 180    EQ      0.05    0.0001  EQ
CURRENT 0.01    1000    1.00    1.192   0.002
POWER    25     2856 0.00

CELL 120        0.413   123.684 0.005550        0.163323
CELL 120        0.432   239.010 0.010804        0.123194
CELL 120        0.630   358.763 0.007940        0.114390
CELL 120        0.958   429.009 0.005722        0.112439
CELL 120        0.997   430.000 0.005506        0.112549
CELL 120        0.999   430.000 0.005489        0.112564
CELL 120        0.999   432.500 0.005546        0.112294
CELL 120        0.999   435.000 0.005599        0.112028
CELL 120        0.999   437.500 0.005653        0.111761

END
```

Figure 1. INPUT.txt structure

Operators description:

- OPTIONS. This keyword defines extra modes that will be used in calculations.

- *MAGNETIZED*

The code assumes that the beam is born in the magnetic field with Bz(0).

Ex. OPTIONS MAGNETIZED

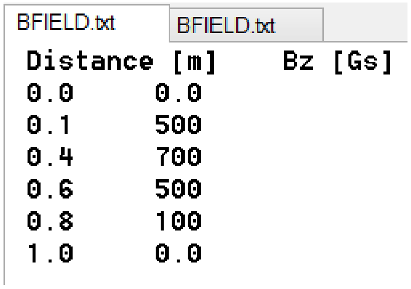
- SOLENOID. This keyword sets the source of external longitudinal magnetic field. There are three parameters to define solenoid specification: magnetic field strength B[T]; solenoid length L[m]; longitudinal coordinate of the start of the solenoid Z_0[m]

Ex. SOLENOID 0.15 0.2 0.1

Custom magnetic field distribution can be imported from file. In this case you add the name of the file with magnetic field data after the keyword SOLENOID.

Ex. SOLENOID BFIELD.txt

The following input file format must be used: first column is z coordinate in [m], second is magnetic field in [Gs]. Z-coordinates can be outside the simulation domain.



```
Distance [m]    Bz [Gs]
0.0       0.0
0.1       500
0.4       700
0.6       500
0.8       100
1.0       0.0
```

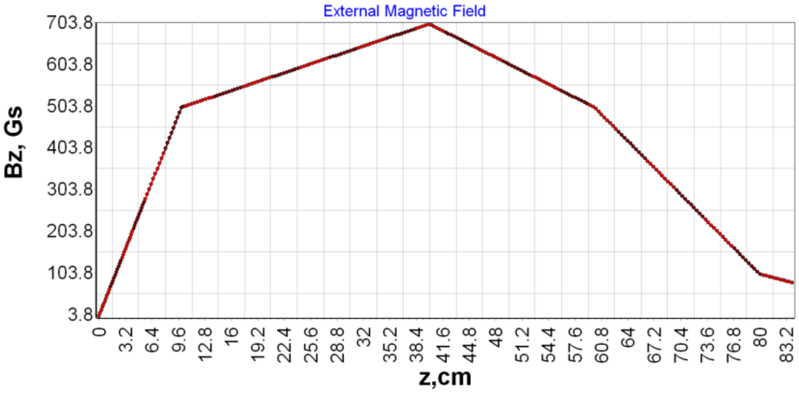


Figure 2. BFIELD.txt file structure and imported field

<u>- BEAM.</u> This line defines the parameters of the initial distribution or import of particles in transversal and longitudinal phase space. Currently, there is a possibility to input the whole particles phase space from one of the standard format files, or define/import the transversal and longitudinal distribution separately. In the latter case the keyword for the longitudinal distribution should immediately follow the transverse distribution definition (see examples section).

Here is the list of the possible keywords ("bold" parameters are optional):

- *CST_PID FileName* ***φ0 [deg] Δφ [deg]*** $\boldsymbol{\sigma_\varphi}$ ***[deg]***

The code will import the initial distribution form CST PID file with "FileName" name. The phase normal distribution (see NORM2D) can be optionally defined by two parameters: mean phase (φ0), and phase length (±Δφ). Optionally, the rms deviation (σ_φ) can be defined. If no phase distribution parameters are defined the code will generate the uniform distribution from 0 to 360 deg. If deviation is not defined, the code will assume uniform distribution. The format of "pid" file is the following:

x [m], y [m], z [m], px [], py [], pz [], m0 [kg], q0 [C], I [A]

Ex. BEAM CST_PID cst_example.pid

Ex. BEAM CST_PID cst_example.pid 90 180

Ex. BEAM CST_PID cst_example.pid 90 180 50

- *CST_PID FileName* ***COMPRESS***

The code will import the initial distribution form CST PID file with "FileName" name. If the imported beam consists of multiple bunches, the keyword COMPRESS can be added to compress all particles into one bunch. The particle with time t will have the phase φ=-t*c/λ. The format of this file is the following:

x [m], y [m], z [m], px [], py [], pz [], m0 [kg], q0 [C], Q [C], t [s]

Ex. BEAM CST_PID cst_example.pit

Ex. BEAM CST_PID cst_example.pit COMPRESS

- *FILE2D FileName1* ***FileName2***

The code will import 2D distribution from the file with *FileName1* name. In case of longitudinal distribution, the file should have the following format: *φ [deg], W[MeV]*. In case of transversal distribution, the format must be: *r [cm], r' [rad]*. Optionally, the second file can be defined for transversal distribution only. In this case the code will read *x [cm] x' [rad]* distribution from the first file, and *y[cm] y'[rad]* from the second file, and converts the distribution to cylindrical coordinates r, θ, p_r, and p_θ. The user must ensure that the number of particles from different files match, as well as the order of the particles in the file.

Ex. BEAM FILE2D radius.txt FILE2D energy.txt

Ex. BEAM FILE2D particles_x.txt particles_y.txt FILE2D energy.txt

- *FILE1D FileName φ0 [deg] Δφ [deg]* ***σ_φ [deg]***

The code will import the energy distribution from the file with *FileName* name. The file should have the following column: *W[MeV]*. The phase normal distribution (see NORM2D) should be defined by two parameters: mean phase (φ0), and phase length (±Δφ). Optionally, the rms deviation (σ_φ) can be defined. If deviation is not defined, the code will assume uniform distribution. In case of multiple files are defined, the user must ensure that the number of particles from different files match, as well as the order of the particles in the file. This type of distribution can only be used for longitudinal phase space

Ex. BEAM FILE2D radius.txt FILE1D energy.txt 90 180

Ex. BEAM FILE2D radius.txt FILE1D energy.txt 90 180 20

- *FILE4D FileName*

The code will import the 4D transversal phase space distribution from the file with *FileName* name. The file should have the following format: *x [cm] x' [rad] y[cm] y'[rad]*. In case of multiple files are defined, the user must ensure that the number of particles from different files match, as well as the order of the particles in the file. This type of distribution can only be used for transversal phase space

Ex. BEAM FILE4D phase_space.txt FILE1D energy.txt 90 180

- *TWISS2D α_x, β_x [cm/rad], ε_x [cm*rad]*

The code will generate the x-x' distribution with α_x, β_x [cm/rad], ε_x [cm*rad] Twiss parameters (Figure 3), and y-y' distribution for the same parameters. x-x' and y-y' distributions are independent. Then the code converts the distribution to cylindrical coordinates r, θ, and p_r. p_θ is assumed equal to zero to avoid particle magnetization. This type of distribution can only be used for transversal phase space.

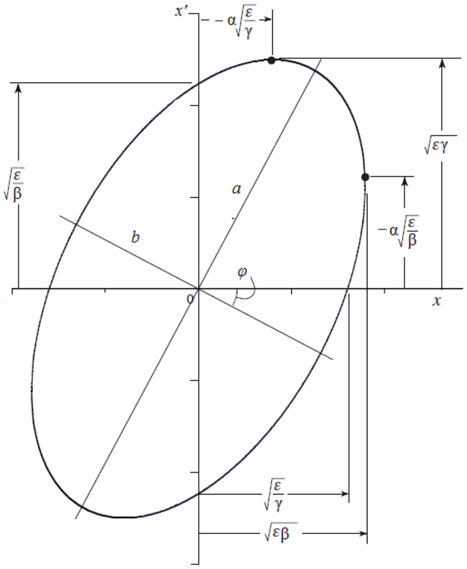

x'
$-\alpha\sqrt{\frac{\varepsilon}{\gamma}}$
$\sqrt{\varepsilon\gamma}$
$\sqrt{\frac{\varepsilon}{\beta}}$
a
b
$-\alpha\sqrt{\frac{\varepsilon}{\beta}}$
φ
0
x
$\sqrt{\frac{\varepsilon}{\gamma}}$
$\sqrt{\varepsilon\beta}$

Figure 3. Phase space defined by Twiss parameters.

Ex. BEAM TWISS2D 0.14 2.0 0.0005 FILE2D energy.txt

- *TWISS4D α_x, β_x [cm/rad], ε_x [cm*rad] α_y, β_y [cm/rad], ε_y [cm*rad]*

The code will generate the x-x' distribution with α_x, β_x [cm/rad], ε_x [cm*rad] Twiss parameters (Figure 3), and y-y' distribution with α_y, β_y [cm/rad], ε_y [cm*rad]. x-x' and y-y' distributions are independent. Then the code converts the distribution to cylindrical coordinates r, θ, and p_r. p_θ is assumed equal to zero to avoid particle magnetization. This type of distribution can only be used for transversal phase space.

Ex. BEAM TWISS4D 0.14 2.0 0.0005 0.28 4.0 0.0015 FILE2D energy.txt

- *NORM2D W0 [MeV] ΔW [MeV]* ***σ_W [MeV]*** *φ0 [deg] Δφ [deg]* ***σ_φ [deg]***

The code will independently generate the Gaussian energy and phase distribution with mean energy (W0), energy spread (±ΔW), mean phase (φ0), and phase length (±Δφ). Optionally, the rms deviations (σ_W , σ_φ) can be defined for both energy and phase distribution. It is impossible to define the rms deviation for only one parameter! If deviations are not defined, the code will assume uniform distributions. If ΔW (or Δφ) is zero or negative, the code will generate the Gaussian distribution with no boundaries. If $\Delta W^2 < 12\cdot\sigma_W^2$, the distribution will be uniform! Otherwise, the code generates Truncated Gaussian distribution with the limits W0- ΔW and W0+ΔW. The same for phase distribution. See Figure 4. This type if distribution can only be used for longitudinal phase space

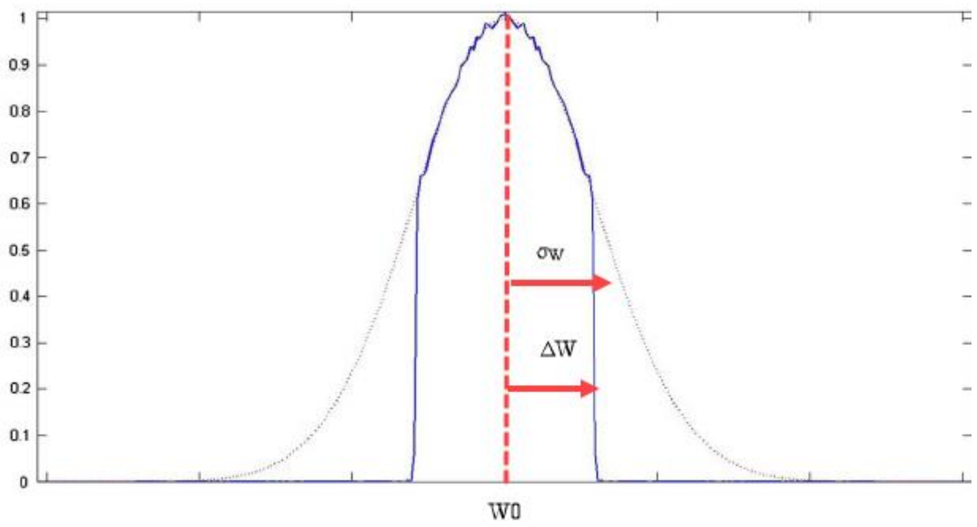


Figure 4. Example of Truncated Gaussian Distribution

Ex. BEAM TWISS2D 0.14 2.0 0.0005 NORM2D 1.0 0.5 0.25 90 180 20

Ex. BEAM FILE2D beam.txt NORM2D 1.0 0.5 90 180

- *SPH2D Rcath [cm],* ***Rsph [cm], kT [eV]***

The code will generate radial distribution from spherical cathode (see Figure 5). *Rcath [cm]* defines the radial limit of the particles. Rayleigh distributions with σ_R= Rcath will be modeled. *Rsph [cm]* is an optional parameter for cathode sphericity. If Rsph=0 or not defined, the cathode will be cylindrical (flat). If Rsph >0, the cathode is concave. If Rsph <0, the cathode is convex. The normal (to the cathode surface) component of r' is defined as r'=-sin(r/Rsph). Optional parameter kT [eV] defines the thermal emittance. This type of distribution can only be used for transversal phase space.

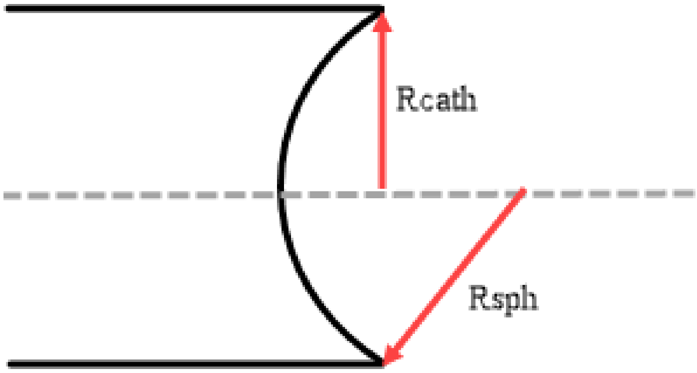


Figure 5. Example of spherical cathode distribution

Ex. BEAM SPH2D 0.564 1.0 10.0 NORM2D 1.0 0.5 90 180

Ex. BEAM SPH2D 0.564 1.0 FILE2D energy.txt

Ex. BEAM SPH2D 0.564 FILE1D energy.txt 90 180

- *ELL2D a_x [cm], b_y [cm],* ***phi [deg], h***

The code will generate radial elliptical distribution with *a_x [cm] and b_y [cm]* half-axes. Optionally, the beam can be rotated in x-y space by angle of phi [deg]. If phi is not defined, it is assumed zero. See Figure 6. Optional parameter h defines the rms deviation of the Gaussian distribution as $\sigma_x = a_x/h$, $\sigma_y = a_y/h$. If not defined, h is assumed equal to 1. No particles will be generated outside of the ellipse. Radial and azimuthal speeds assumed to be zero. This type of distribution can only be used for transversal phase space.

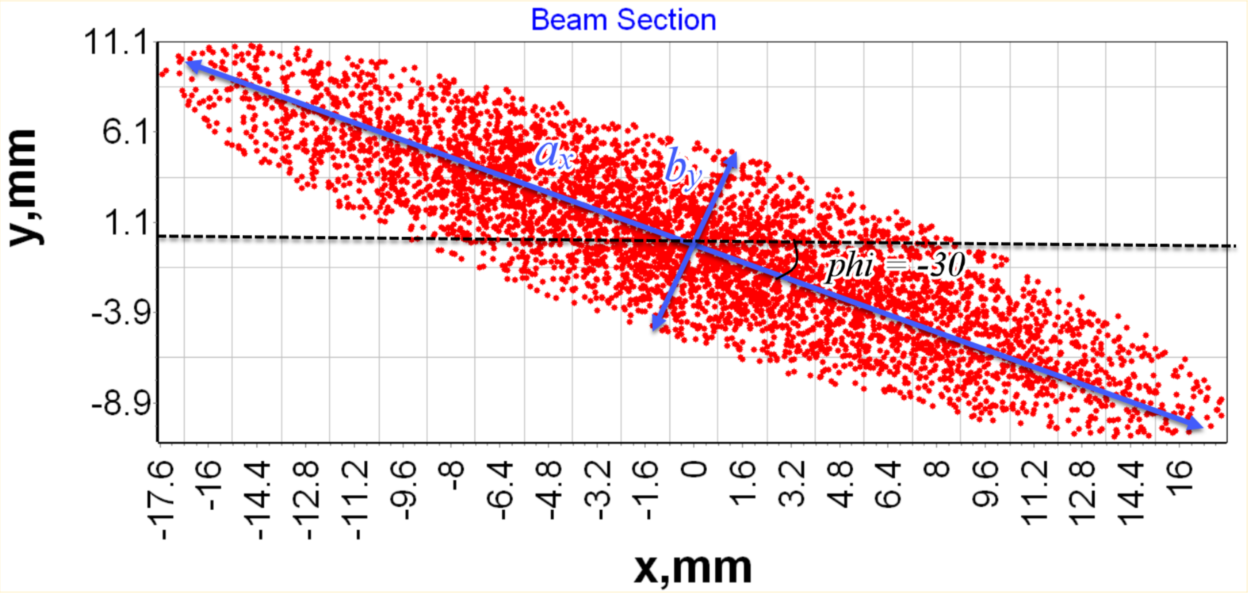


Figure 6. Example of Elliptical distribution

Ex. BEAM ELL2D 2.0 0.5 -30 2 NORM2D 1.0 0.5 90 180

Ex. BEAM ELL2D 2.0 0.5 -30 FILE2D energy.txt

Ex. BEAM ELL2D 2.0 0.5 FILE1D energy.txt 90 180

<u>- CURRENT</u>. This line defines the beam current *I_0[A]* during the RF pulse (*I_0=Q/Tpulse*), and number of particles in beam *Np*. If the beam is generated randomly, the Np parameters must be defined. If the particles distribution is imported from the file, the Np parameter is optional. In this case, if Np is defined and less than number of imported particles, the code will consider only the first Np of the imported particles. If Np is greater than the number of imported particles, it will be ignored.

Ex. CURRENT 0.15 1000

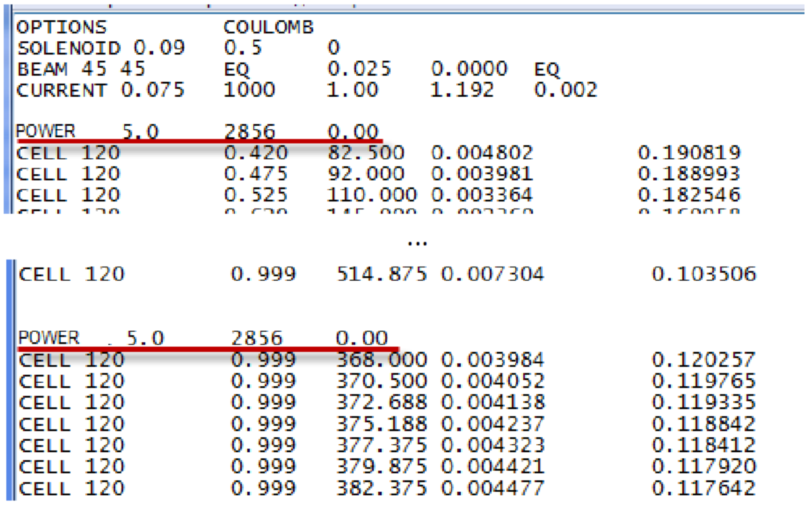
<u>- POWER.</u> Defines RF power input parameters: input pulse power P_0[MW]; operating frequency F_0[MHz]; phase shift from the reference phase Δφ[deg] (this parameter can be undefined – in this case it will be automatically assumed to be zero)

Ex. POWER 2.0 2856

Ex. POWER 4.5 5712 90

It possible to modulate extra RF power inputs by putting operator POWER before coupling CELL line (pic 1.4). This operation equates power counter to value defined in the POWER line (pic.1.5b).

If not power sources are defined, the system wavelength would be assumed to 1 meter!

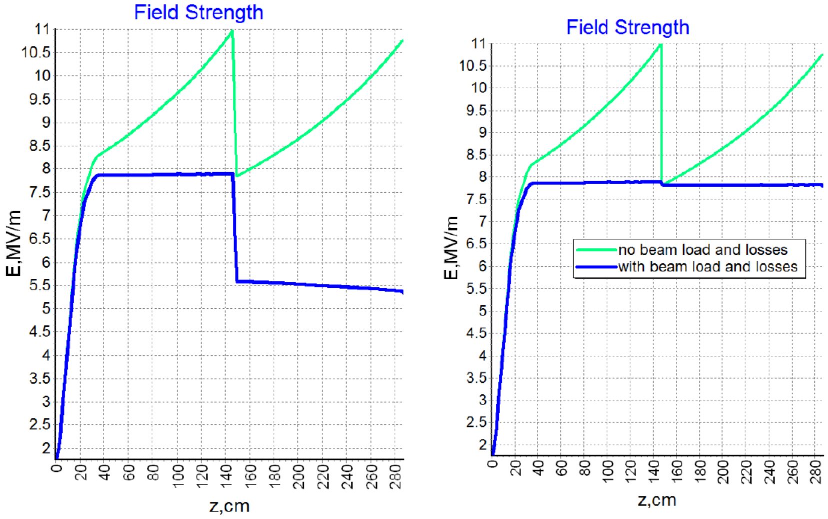


```
OPTIONS             COULOMB
SOLENOID 0.09       0.5       0
BEAM 45 45          EQ        0.025    0.0000   EQ
CURRENT 0.075       1000      1.00     1.192    0.002

POWER     5.0       2856      0.00
CELL 120            0.420     82.500   0.004802           0.190819
CELL 120            0.475     92.000   0.003981           0.188993
CELL 120            0.525     110.000  0.003364           0.182546
```

...

```
CELL 120            0.999    514.875 0.007304           0.103506


POWER   . 5.0       2856     0.00
CELL 120            0.999    368.000 0.003984           0.120257
CELL 120            0.999    370.500 0.004052           0.119765
CELL 120            0.999    372.688 0.004138           0.119335
CELL 120            0.999    375.188 0.004237           0.118842
CELL 120            0.999    377.375 0.004323           0.118412
CELL 120            0.999    379.875 0.004421           0.117920
CELL 120            0.999    382.375 0.004477           0.117642
```

Fig. 1.4 Example of extra RF power input



a b

Fig.1.5 Longitudinal electrical field in linac (a – without extra POWER line; b- with extra POWER line)

- CELL. In this line 5 cells parameters are defined: phase shift per cell θ*grad+; relative phase speed β_{phase}; normalized value of electrical accelerating field intensity ; normalized attenuation factor $\alpha\lambda_{3/2}$[m$_{1/2}$]; normalized aperture radius a/λ (If last 2 parameters are not defined, program automatically recalculates it for DLS structure using tables. But in this case only modes π/2 and 2π/3 can be calculated)

Ex. CELL 120 0.999 380.0 0.01 0.12

Ex. CELL 90 0.8 200.0

-CELLS. Almost the same function as CELL, but this line defines N number of cells with equal parameters

Ex. CELLS 6 120 0.999 380.0 0.01 0.12

-DRIFT. You can define a drift tube using 2 parameters: length L[cm]; radius a[cm]. Optionally, it is possible to add the number of mesh points for drift element after the radius that will override the global mesh settings.

Ex. DRIFT 10.0 2.0

Ex. DRIFT 10.0 2.0 100

Please, note that the DRIFT element will terminate any power used before.

-SAVE. If this line is present, the code will export the live particle parameters (phase, energy, radius, azimuth and radial velocity) at position define in the INPUT to the defined file

Ex. CELLS 3 120 0.999 380.0

SAVE beam.log

DRIFT 10.0 2.0

In this example the particle parameters will be exported at the position between 3 cells and a drift. Multiple export commands are possible, but two SAVE lines at the same position will be overwritten.

It is possible to define the number of particles to be exported or the region of particles numbers after the name of file

Ex. SAVE beam.log 500

Ex. SAVE beam.log 1000 2000

In the first example, the first 500 particles will be exported. In the second one, only the particles with numbers from 1000 to 2000 will be exported. Lost particles are not exported.

Several flags are allowed to define the particular parameters to be exported. If no flags are defined, all parameters (except live status) will be exported. If at least one flag is set, only flagged parameters wil be exported.

LOST – export the lost or live status of the particle

PHASE – export the phase of the particle

ENERGY – export the energy of the particle

RADIUS – export the radius of the particle

AZIMUTH – export the azimuth of the particle

VX – export the radial velocity of the particle

The flags must be defined in any combination after the number of elements region or after the file name if the region is not defined.

Ex. SAVE beam.log LOST ENERGY

Ex. SAVE beam.log 500 ENERGY PHASE RADIUS

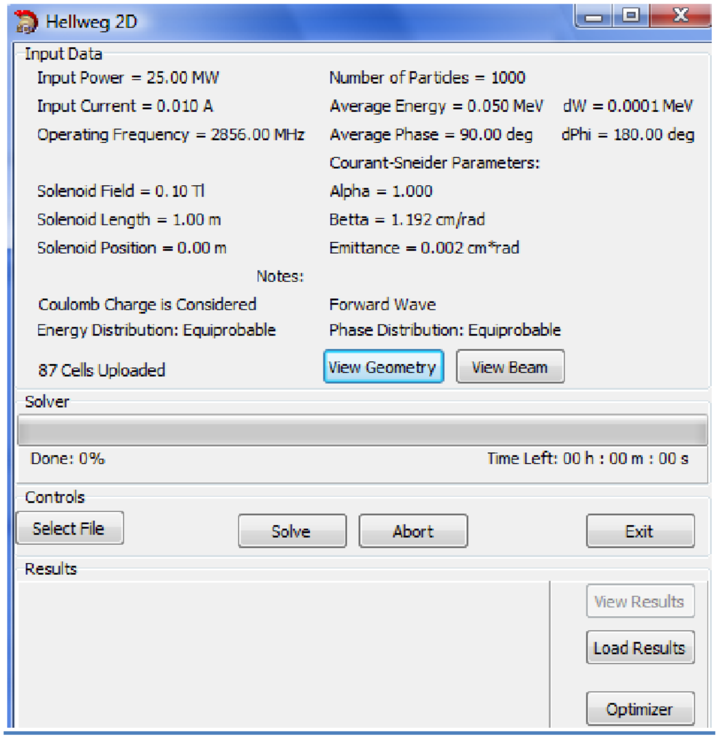
Ex. SAVE beam.log 500 2000 LOST RADIUS VX

COMMENTS. Any line with improper format will be ignored and not copied into the output file. To make a comment use '!' symbol in the beginning of the line

Ex. !This line is a comment

2. Simulation and post-processing results.

Program interface is presented in Figure 2.1



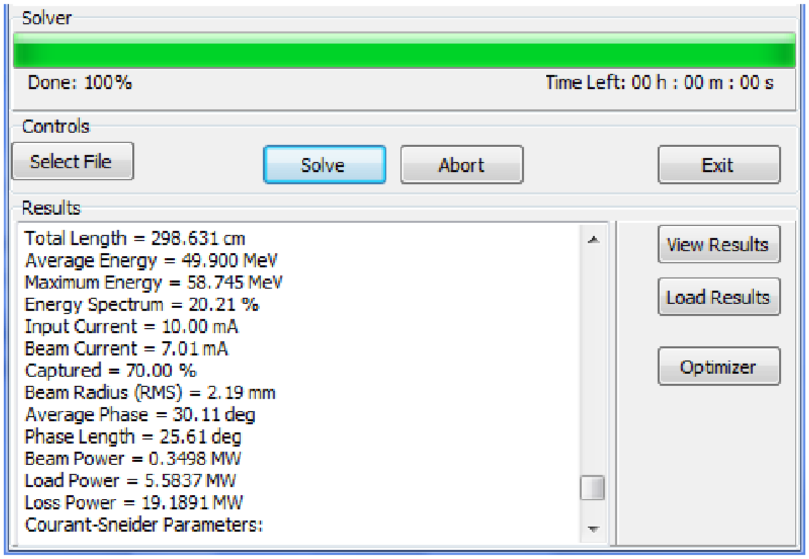
```
Input Power = 25.00 MW                  Number of Particles = 1000
Input Current = 0.010 A                 Average Energy = 0.050 MeV   dW = 0.0001 MeV
Operating Frequency = 2856.00 MHz       Average Phase = 90.00 deg    dPhi = 180.00 deg
                                        Courant-Sneider Parameters:
Solenoid Field = 0.10 Tl                Alpha = 1.000
Solenoid Length = 1.00 m                Betta = 1.192 cm/rad
Solenoid Position = 0.00 m              Emittance = 0.002 cm*rad
                                 Notes:
Coulomb Charge is Considered            Forward Wave
Energy Distribution: Equiprobable       Phase Distribution: Equiprobable

87 Cells Uploaded

Done: 0%                                          Time Left: 00 h : 00 m : 00 s
```

Fig. 2.1 Hellweg2D Interface

Hellweg2D automatically reads an input file and displays user defined parameters.

You can watch defined cells parameters on the graphs by pushing “View Geometry” and defined beam parameters on the graph by pushing ”View Beam”

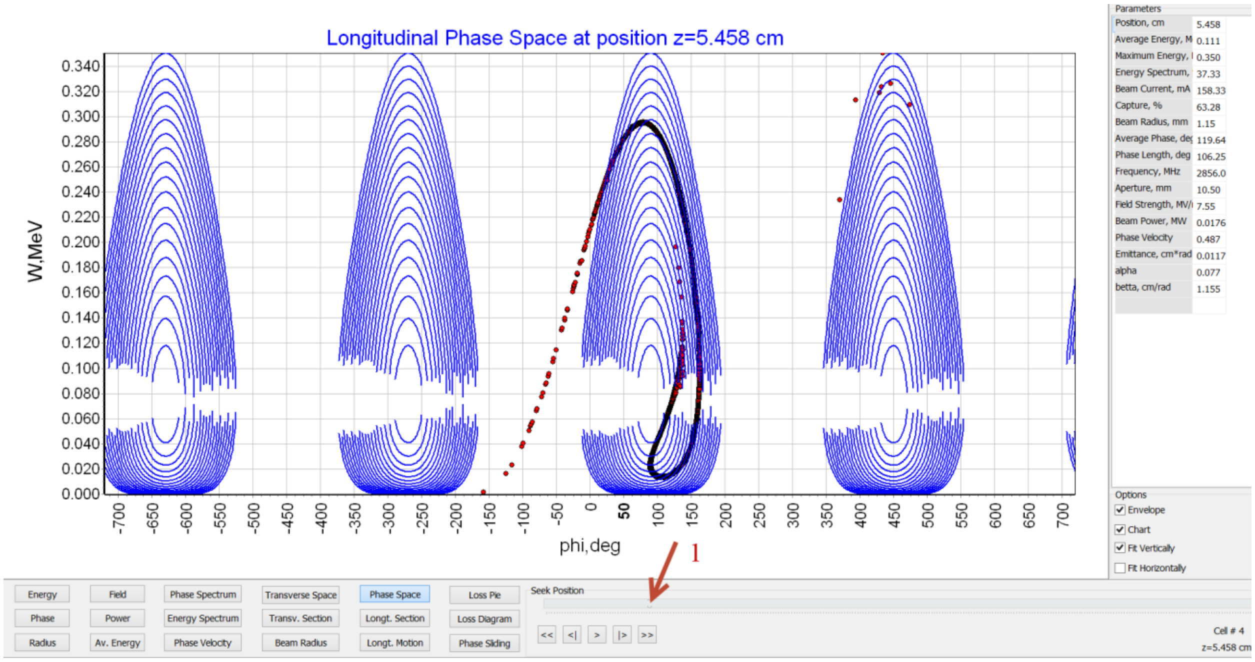
After solving the problem (button “Solve”) «OUTPUT.txt» file is automatically generated. You can watch results of calculations in the Hellweg2D window (Fig.2.2) or you can find OUTPUT.TXT in program folder.



```
Done: 100%                                        Time Left: 00 h : 00 m : 00 s

Total Length = 298.631 cm
Average Energy = 49.900 MeV
Maximum Energy = 58.745 MeV
Energy Spectrum = 20.21 %
Input Current = 10.00 mA
Beam Current = 7.01 mA
Captured = 70.00 %
Beam Radius (RMS) = 2.19 mm
Average Phase = 30.11 deg
Phase Length = 25.61 deg
Beam Power = 0.3498 MW
Load Power = 5.5837 MW
Loss Power = 19.1891 MW
Courant-Sneider Parameters:
```

Fig. 2.2 Results of calculation

Button “View Result” lets user to watch graphical results such as Field vs. coordinate; phase space; energy spectrum, etc (Fig.2.3).



Parameters

Position, cm	5.458
Average Energy, M	0.111
Maximum Energy, I	0.350
Energy Spectrum,	37.33
Beam Current, mA	158.33
Capture, %	63.28
Beam Radius, mm	1.15
Average Phase, deg	119.64
Phase Length, deg	106.25
Frequency, MHz	2856.0
Aperture, mm	10.50
Field Strength, MV/	7.55
Beam Power, MW	0.0176
Phase Velocity	0.487
Emittance, cm*rad	0.0117
alpha	0.077
betta, cm/rad	1.155

Options

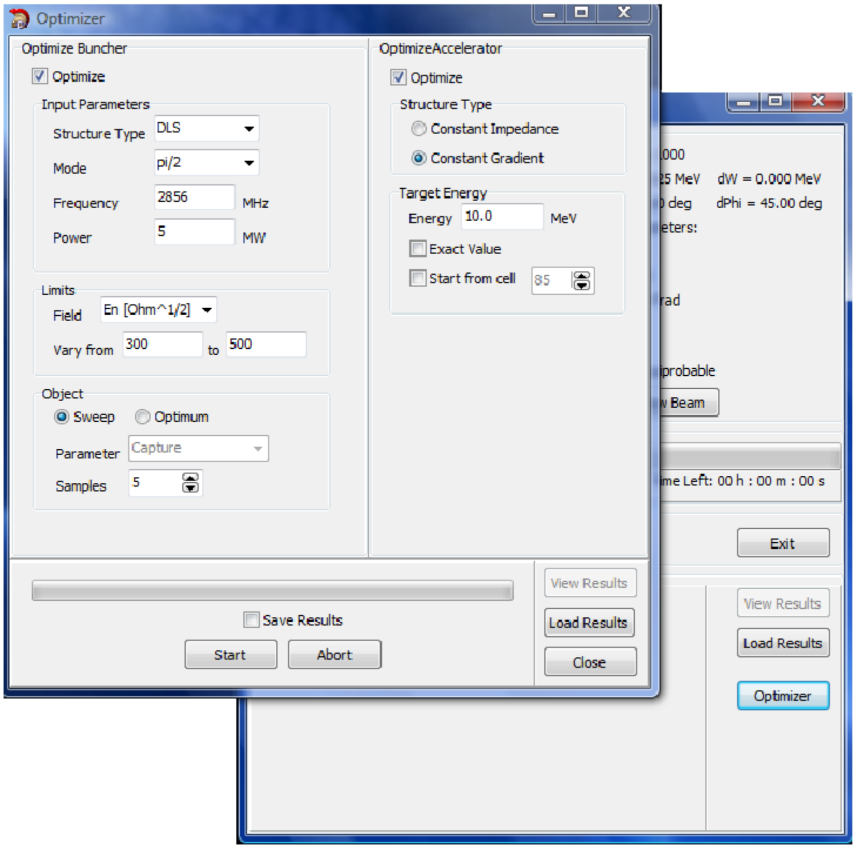
☑ Envelope
☑ Chart
☑ Fit Vertically
□ Fit Horizontally

Fig 2.3 Graphical results

Using marker 1 (Fig. 2.3) user can watch beam parameters in any longitudinal coordinate

<u>3. Optimizer.</u>

Hellweg2D has a very convenient feature – Optimizer (Fig. 3.1)



Optimizer

Optimize Buncher

☑ Optimize

Input Parameters

Structure Type DLS

Mode pi/2

Frequency 2856 MHz

Power 5 MW

Limits

Field En [Ohm^1/2]

Vary from 300 to 500

Object

● Sweep ○ Optimum

Parameter Capture

Samples 5

OptimizeAccelerator

☑ Optimize

Structure Type

○ Constant Impedance

● Constant Gradient

Target Energy

Energy 10.0 MeV

□ Exact Value

□ Start from cell 85

□ Save Results

000

5 MeV dW = 0.000 MeV

0 deg dPhi = 45.00 deg

eters:

rad

probable

me Left: 00 h : 00 m : 00 s

Fig. 3.1 Optimizer interface

This function can calculate DLS cells parameters (relative phase speed β_{phase}; normalized value of electrical accelerating field intensity ; normalized attenuation factor $\alpha\lambda_{3/2}[m_{1/2}]$; normalized aperture radius a/λ) using included tables to obtain the desired energy on the end of the accelerator without access to the INPUT file.

<u>- Optimize Buncher.</u> In this window user defines coupler parameters and desired buncher field parameters.

·*Input parameters:* Choice between π/2 and 2π/3 modes; operating frequency; input pulse power.

·*Limits:* It necessary to define allowable variations of the values of the accelerating electrical field on the end of the buncher. User can choose between 3 field dimensions: dimensionless field A; normalized electrical field ; absolute value of electrical field E [MV/m].

·*Object:* There are 2 algorithms to calculate buncher cells parameters: *Sweep* divides an interval defined in Limits for equal parts (Samples) and calculates field in them using table’s data; *Optimum* chooses the best field value to obtain the best capture coefficient/energy spectrum/phase spectrum (Parameter).

<u>- Optimize Accelerator.</u> In this window user defines desired output parameters.

·*Structure type:* The choice between Constant Gradient or Constant Impedance structures. In the first case the optimizer will add the cells identical to the last one. In second case, it will adjust the aperture radius in order to maintain the same electrical field gradient.

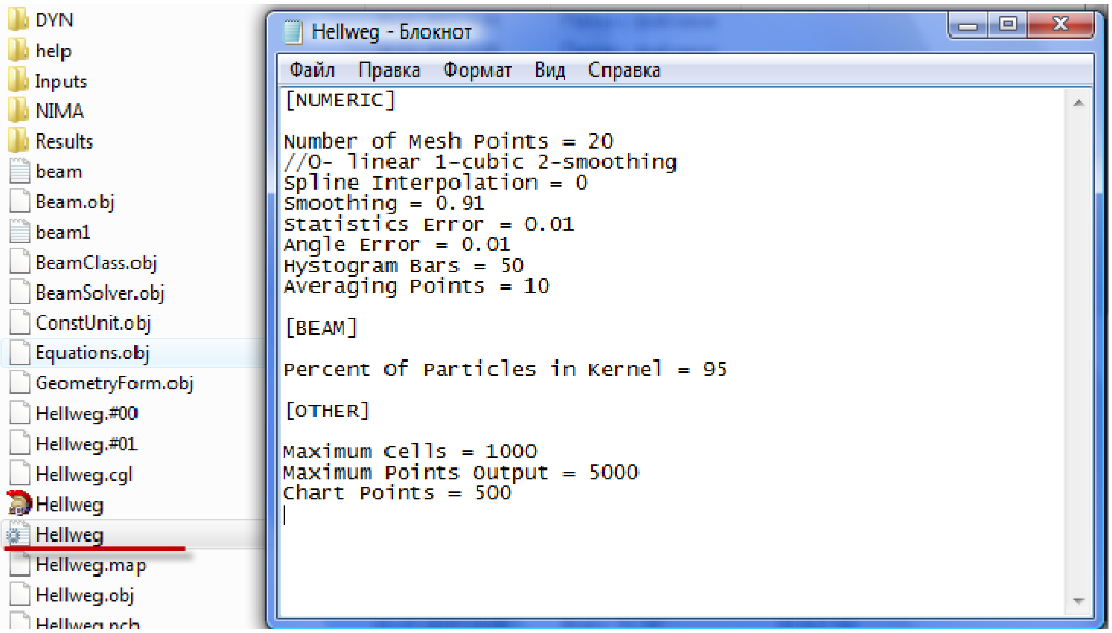
·*Target Energy:* It is necessary to define desired output energy. Marker "Exact Value" varies beam current to obtain exact value of average beam energy.

Marker "Start from cell" is used when it is necessary to modulate accelerating structure after the already defined cells parameters in INPUT file (Optimize Buncher marker is switched off)

<u>- Get Results</u>. You can find results in the OUTPUT file in the Results folder

<u>4. Configuration file.</u>

Mesh parameters and interpolation parameters are defined in file Hellweg.ini which placed in program folder (Fig. 4.1)

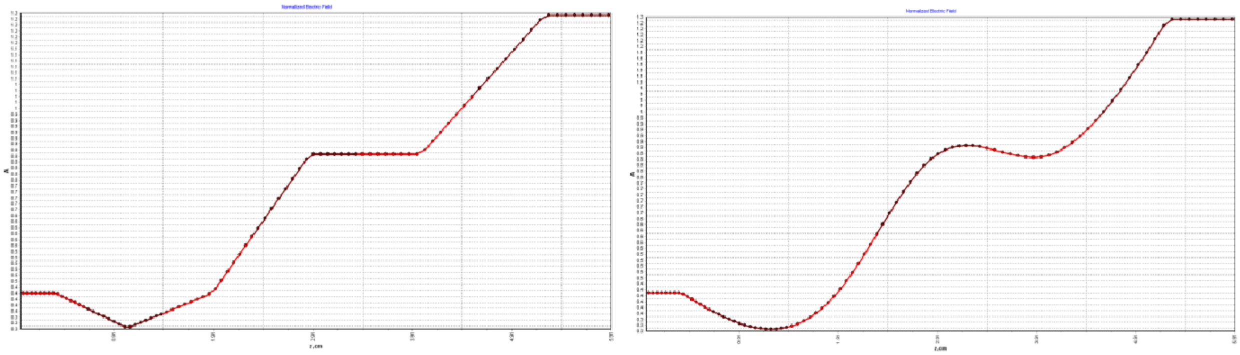


```
[NUMERIC]

Number of Mesh Points = 20
//0- linear 1-cubic 2-smoothing
Spline Interpolation = 0
Smoothing = 0.91
Statistics Error = 0.01
Angle Error = 0.01
Hystogram Bars = 50
Averaging Points = 10

[BEAM]

Percent of Particles in Kernel = 95

[OTHER]

Maximum Cells = 1000
Maximum Points Output = 5000
Chart Points = 500
```

Fig. 4.1 Hellweg2D configuration file

- Number of mesh points. This value of mesh points will be used for accelerating field interpolation in cell. Please, note that the same number of points will be used for a single DRIFT element.

- Interpolation. Relative phase speed and value of accelerating electrical field are defined in the centers of cells. Then these values are interpolated for other mesh cells (Number of mesh points). In Figure 4.2 are presented 2 kinds of interpolations (linear and cubic). It is recommended to use linear interpolation to avoid nonphysical field oscillations. Smoothing spline can be used for example to obtain spectrum envelope.



a b

Fig. 4.2 Interpolation types (a-linear; b-cubic)

Thank you for using our program!

Have a good simulation time with Hellweg2D!