# EBIS-PIC 1D

## 1D EBIS Simulation Code

Version 1.0



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# Introduction

In an EBIS (electron beam ion source), a high current electron beam created by an electron gun is compressed to high density as it enters a strong solenoidal magnetic field (Figure 1). The beam is dumped to an electron collector after passing through a series of drift tubes and exiting the solenoid. The injected primary ions are confined in the radial direction by the potential well created by the space charge of the electrons, and in the axial direction by positive potential barriers on the drift tubes at the two ends of the device. Ions are then ionized to high charge states by electron impact and extracted as the output beam. EBIS devices are one of the best candidates for producing highly charged radioactive ions.

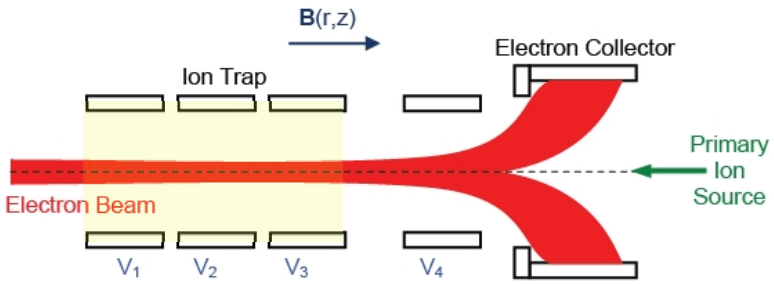



Figure 1: Diagram of EBIS device. The electron beam travels to the right until stopped by the electron collector. The primary ion source is to the right of the collector. The ion trap is indicated by the shaded region.

EBIS-PIC 1D is a code that simulates the ion radial dynamics in the trap region (yellow shaded region in Fig. 1) of EBIS devices. In EBIS-PIC 1D, the profiles of electrons, ions and fields are assumed to vary only in the radial direction when the axial variations are ignored. The electrons' energy and density evolve with the space charge potential while the current and beam radius are kept constant. The injected primary ions are treated as Monte Carlo particles that are moving in the radial direction. The collisions between ions, electrons and ionizations are included in the particle tracking. Full 3D velocities are retained while only the axial velocity is involved in collisions. The neutrals are treated as a fixed background which provides the source of neutral ions. The space charge potential is updated by solving the Poisson equation self-consistently.

The main calculation code is written in FORTRAN and parallelized using MPI. The GUI (graphical user interface) is written in QT. It runs under most windows systems and Linux systems if the code is compiled accordingly. The input parameters of the program are typical operation parameters of EBIS devices, such as electron and ion beam parameters, drift tube geometry and bias voltages. The outputs of the program are the ion spatial distributions and velocity distributions. All these components are integrated into our intuitive, user-friendly GUI. The full problem simulation, from setting up the parameters through viewing output plots can be done through the GUI.

The physical model of EBIS-PIC 1D can be found in the following references, which are listed in chronological order. Over the years, FAR-TECH Inc. has developed EBIS-PIC codes in 0D (named CHASER, which is freely available at http://far-tech.com/chaser.php), 1D and 2D. Also, we have extended PBGUNS functionality to simulate the long, thin electron beam in an EBIS. Reference [1] demonstrates EBIS-PIC2D capabilities for simulating ion injection and extraction; [2] presents EBIS-PIC1D details and results; [3] presents the detailed physical model of EBIS-PIC2D; [4] focuses on electron modeling and ion dynamics.

## References

1. L. Zhao and Jin-Soo Kim, “Simulation of Ion Beam Injection and Extraction in an EBIS ", Rev. Sci. Instrum., 87.2, 02A908 (2016).
2. J. S. Kim, L. Zhao, J. A. Spencer and E. G. Evstatiev " Electron-beam-ion-source (EBIS) modeling progress at FAR-TECH, Inc.", AIP Conf. Proc. 1640, 44 (2015).
3. L. Zhao and Jin-Soo Kim, "'Numerical Simulation of ion charge breeding in electron beam ion source ", Rev. Sci. Instrum. 85, 02B706 (2014).
4. L. Zhao, B. Cluggish, J. S. Kim, and E. G. Evstatiev, "A particle-in-cell Monte Carlo code for electron beam ion source simulation ", Rev. Sci. Instrum. 83, 02A508 (2012).

# Getting Started

### *Installation*

To install EBIS-PIC 1D, simply double-click on “EBIS-PIC1D_Setup.exe” and follow the prompts. Then insert the USB security device. The security device must be plugged in every time you run the simulation. If it is not, you will get the error message “*Please insert the dongle and try again....*” and the simulation will not run.
Microsoft’s MPI and HPC Pack 2008 R2 are required for the program to run. Both packages can be downloaded from the Microsoft website:
https://www.microsoft.com/en-us/download/details.aspx?id=41634
https://www.microsoft.com/en-us/download/details.aspx?id=17017

### *Program Execution from GUI*

To run EBIS-PIC 1D, first open EBIS-PIC1D.exe from a Windows file explorer. A GUI window will pop up (Fig. 2). The default values of input parameters are shown at the start. After modifying the parameters, you should save them into an input data file, *.in, which can be opened by future runs. You can start the simulation by pressing the "run" button,  , as long as the security device is inserted in the computer.

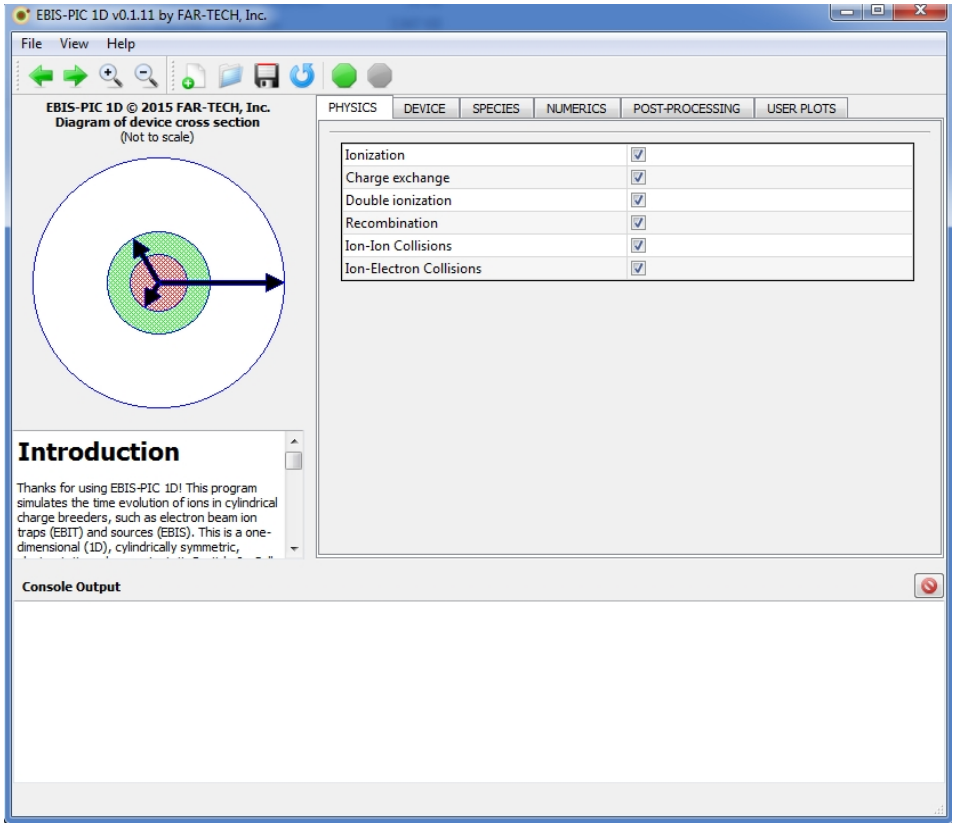



Figure 2: GUI of EBIS-PIC 1D.

During the run, the charge states and run time will be displayed in the console output (Fig. 3). On the first line, the number of time steps out of total expected time steps and current tracking time are displayed. Then the number of total injected ions, trapped ions, trapping efficiency, average charge state and maximum charge state are displayed for both primary ions and neutral gas ions. After that, the speed of the program, total run time that has been passed and left are displayed.

```
------------Time Step =           1 /        48591, T =  0.2058E-08 Seconds --
                    Ninj          Ntrap       Eff         Qavg             Qmax
primary ions     1000000        1000000       1.000       1.000               2
nuetral ions           0              0       0.000       0.000               0
 Speed =   120.0/hr  , TimePassed =     0.0 hr , TimeLeft =   404.8 hr
```

Figure 3: EBIS-PIC1D console display.

While the simulation is running, the plots will be displayed in plotting tabs in real time so that you can monitor the process (Fig. 4). The plots are explained in the information box in the left panel.

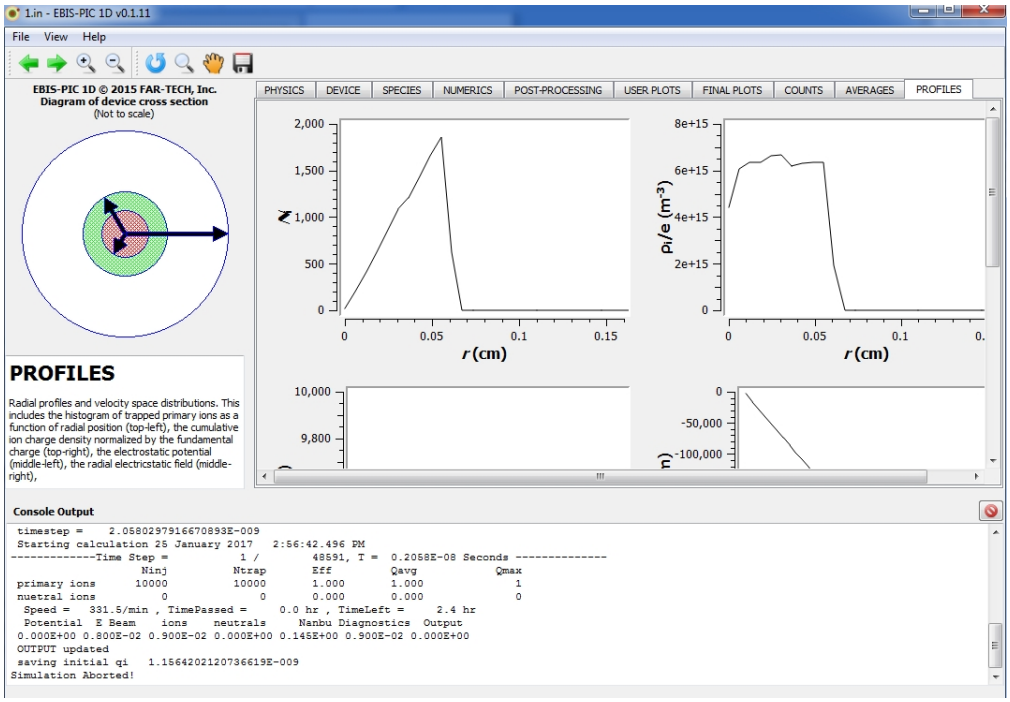



Figure 4: The figure window during an EBIS-PIC1D run.

### *Data Plotting with GUI*

The data can be plotted without running the program as long as the *.in file and data files are in the same directory. The plots will be generated automatically in the GUI when the *.in file has been loaded through ***file--->open***. In this mode, the security device is not needed but the input file (*.in) and output files (*.out and *.dist) must be provided.

### *Program Execution from Command Line*

The program can be started from a command line window by executing following command in the directory where the EBIS-PIC 1D is installed:

*mpiexec -n 4 ebis1d.exe test.in*

This is to run the simulation using 4 CPUs and the input file is test.in. We recommend this method for bigger job runs because this way will reduce the risk of GUI crashing. You can still check the process of the run using GUI by loading the input file but the figure update is not in real time.

# Units Used in EBIS-PIC1D

SI units are used unless specified otherwise:

time……second
length……...meter
current…….Ampere
energy……..eV
potential……...Volts
magnetic field……..Tesla
charge……..Coulomb

# EBIS-PIC1D Input

The input parameters for EBIS-PIC1D are specified in the GUI. The description of an input parameter is displayed when you click on it. The input parameters are located in the input tabs, as shown in Figures 5-9.

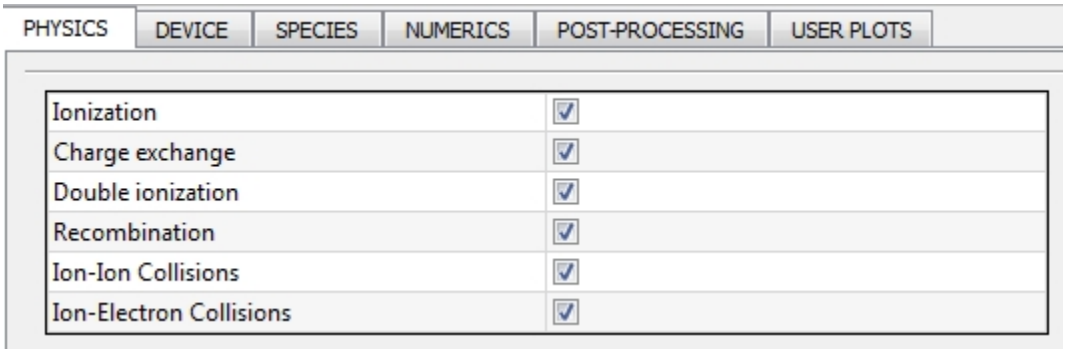



Figure 5: PHYSICS tab: parameters that control the physical models.

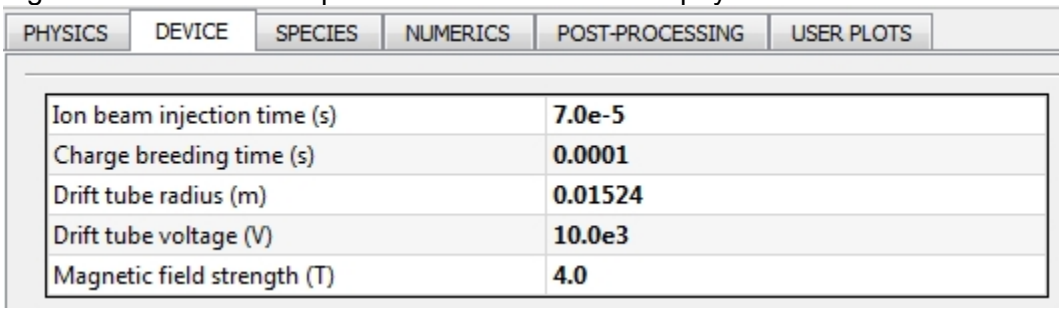



Figure 6: DEVICE tab: the parameters that are related to the EBIS device and operation.

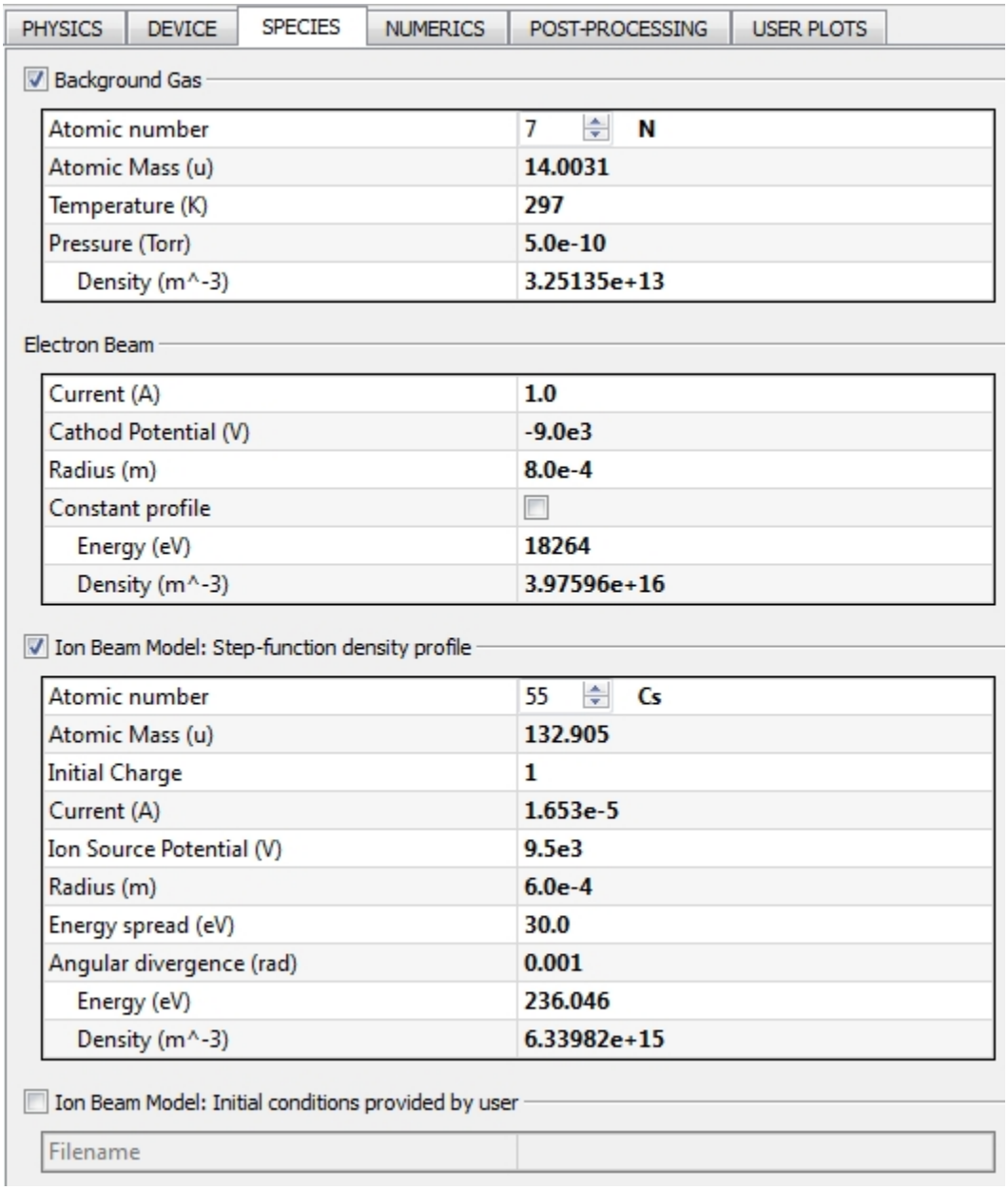



Figure 7: SPECIES tab: parameters of electron, ion and neutral species.

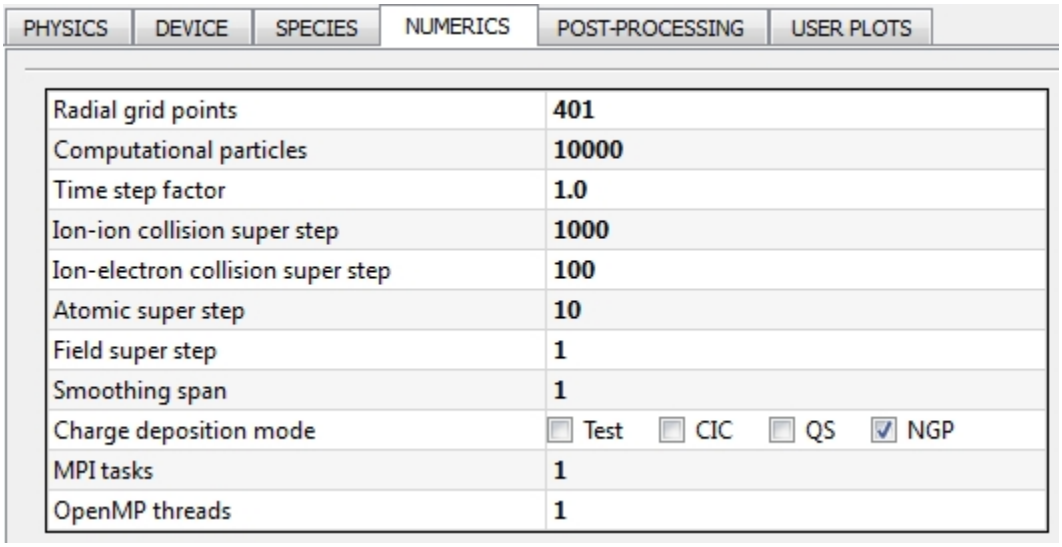



Figure 8: NUMERICS tab: control parameters for numerical calculations.

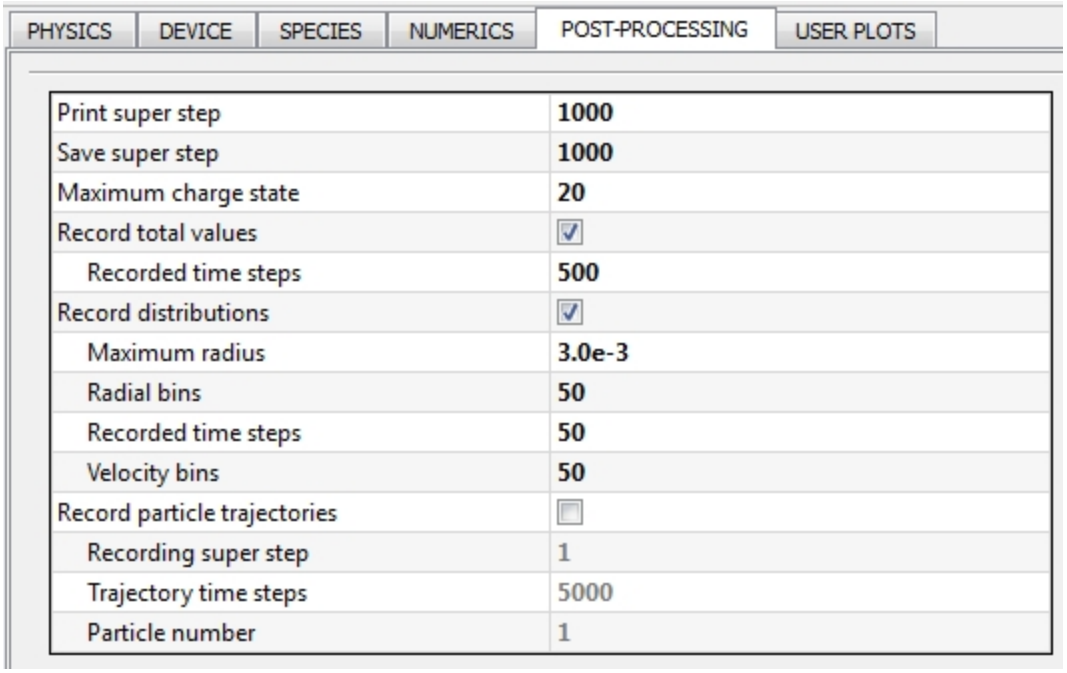



Figure 9: POST-PROCESSING tab: parameters that control the diagnostics.

## EBIS-PIC1D Output

The output from EBIS-PIC 1D consists of the profiles of ions, electrons and fields. EBIS-PIC 1D generates the following output files, which are in *NETCDF* format except the log file.

***.log***

This text file provides a simple summary of the EBIS-PIC1D run.

***.out***

This file is used to save profiles of beams and fields and diagnostic data for plotting.

***.dist***

This file saves the ion positions.

***.out0*** and ***.dist0***

These two files are for saving initial profiles and ion positions.

***.trj***

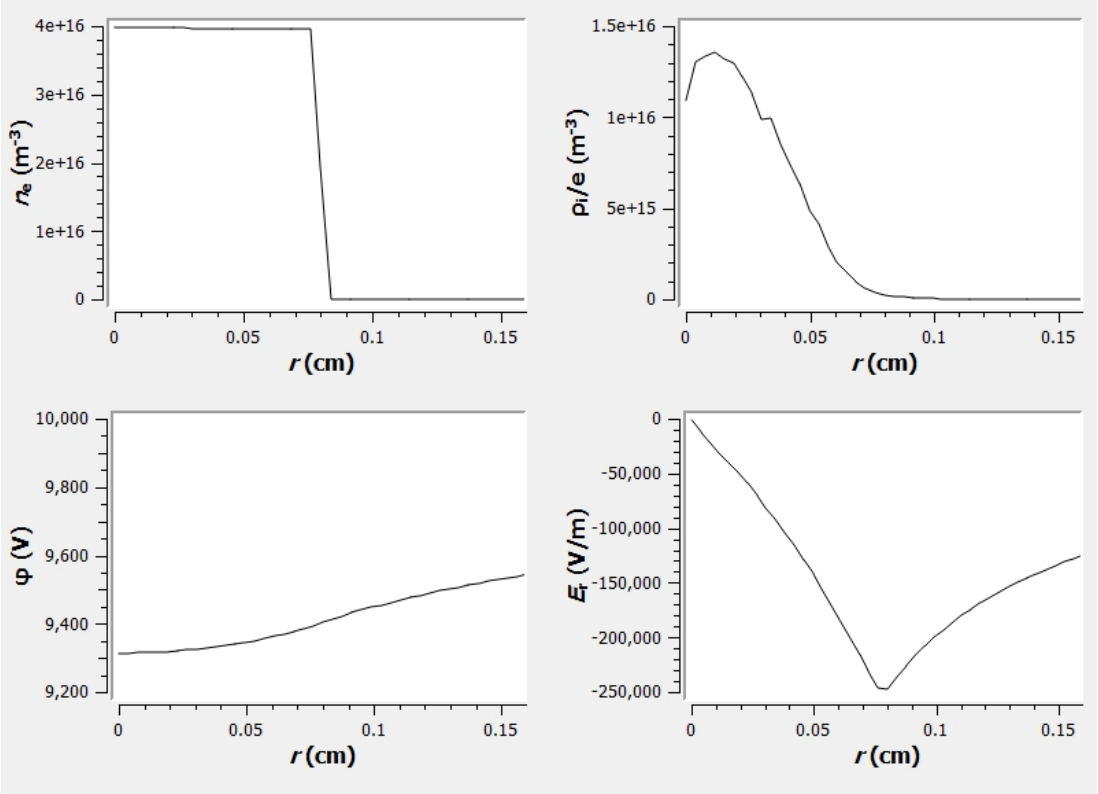
This file is used to save the trajectories of ions.

These output files are used to plot the figures shown in the GUI window, which can be saved in *.pdf format. Also, these NETCDF files can be viewed and plotted by most scientific plotting software.

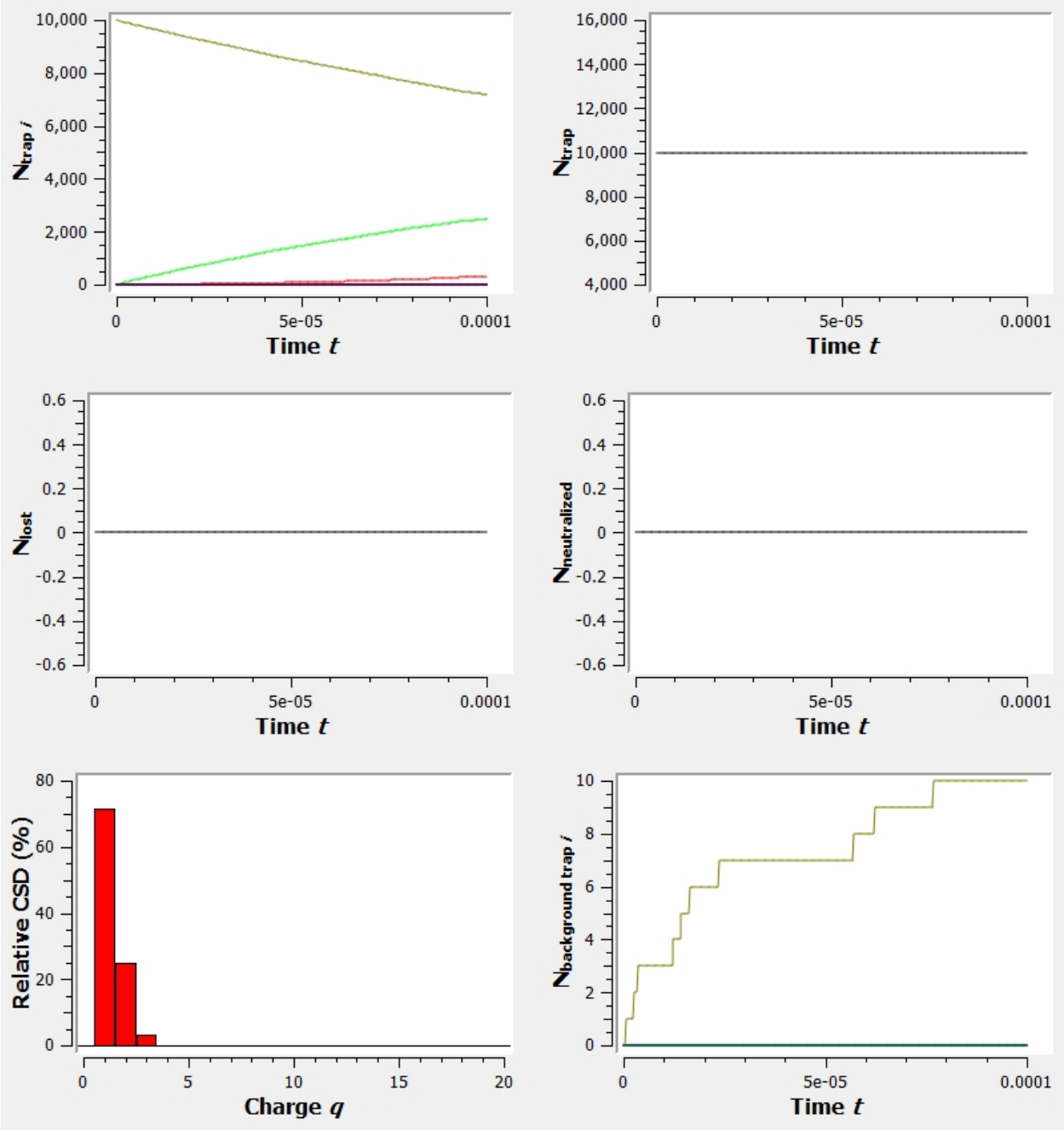
## An Example Run Using EBIS-PIC 1D

An example run is presented here to help the user get accustomed to the program. The input for this example is obtained by loading the default input parameters (by clicking the restore button,  ).

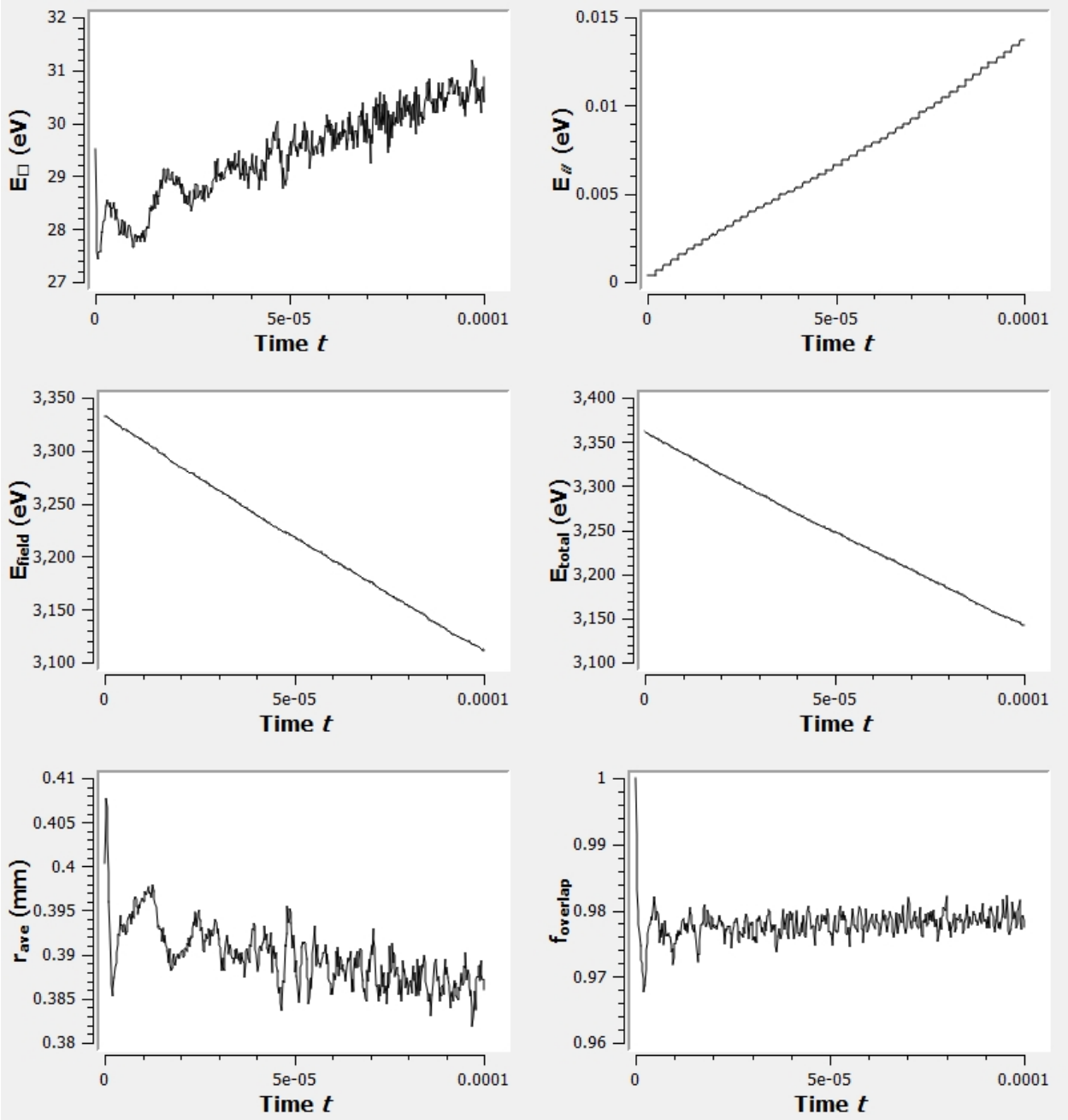
This example simulates the charge breeding of Cs ions in a 1A electron beam with all atomic and Coulomb collisions turned on. The charge breeding time is 0.1 ms. It will take about 3 to 5 minutes to run using a single CPU on a PC with Corei7 CPU. After it is done, the plotting tabs will pop up. The plotting tabs displaying the results of this simulation are shown in the following figures.



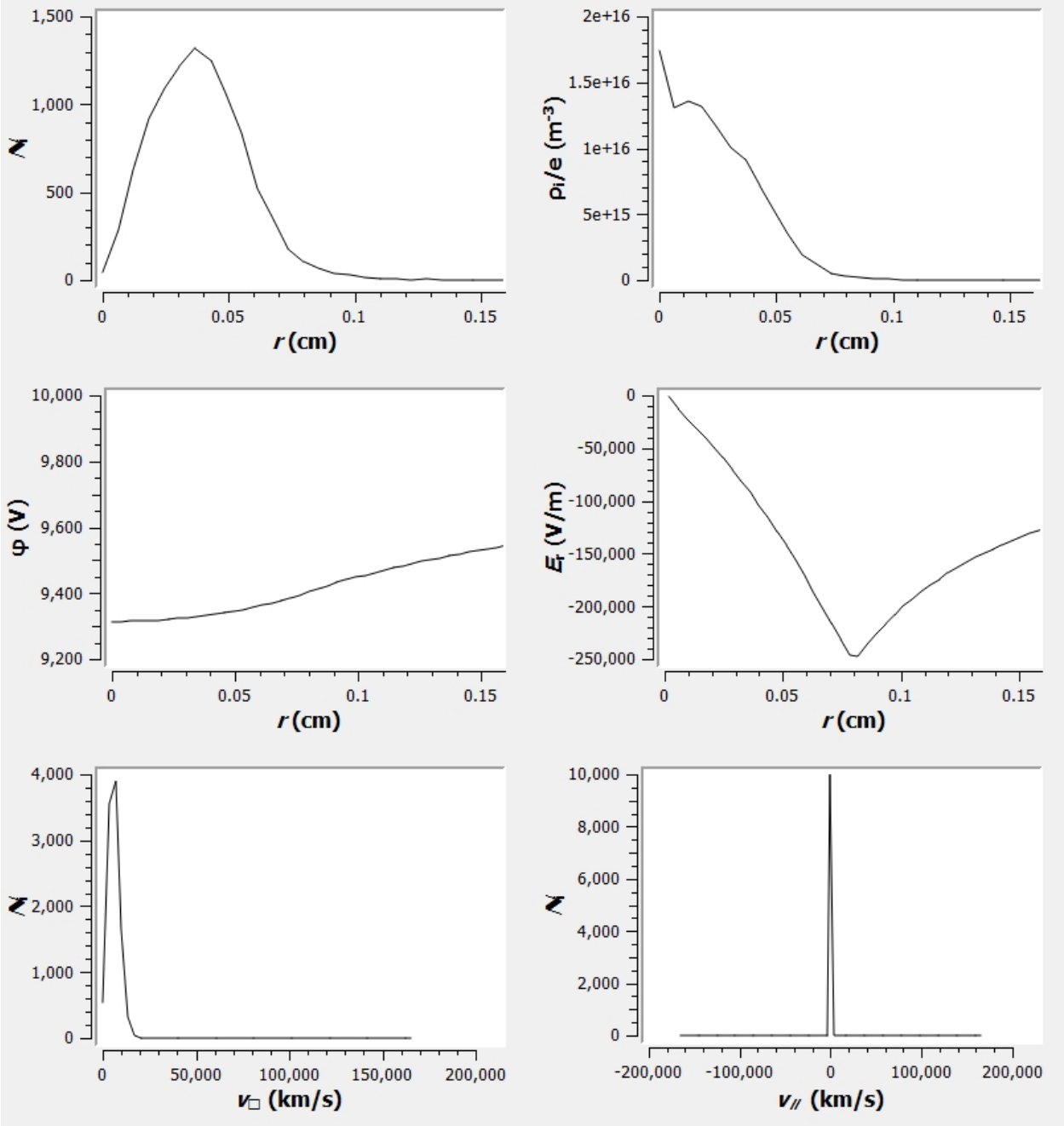

**Final Plots tab**: Radial profiles of 1) electron density; 2) ion charge density; 3) potential; 4) electrical field.




**Counts tab**: time evolution of 1) ion charge states; 2) number of trapped particles; 3) number of ions that are lost to the wall; 4) number of neutralized ions; 5) relative charge state distribution; 6) number of the neutral gas ions.




**Averages**: Time evolution of averaged 1) perpendicular energy; 2) parallel (axial) energy; 3) field energy; 4) total energy; 5) average ion radial position; 6) ion overlapping percentage with electron beam.




**Profiles tab**: Radial distributions of 1) ion number; 2) ion charge density; 3) potential; 4) electrical field; 5) perpendicular velocity distribution; 6) axial velocity distribution.

## Known Bugs

1. If the secure dongle is not inserted, the program will crash instead of displaying a warning window.
2. Simulation with large amount particles (>=1 million) might not run in GUI mode.

3. The GUI window may crash occasionally.