

EBIS-PIC 2D

2D EBIS Simulation Code

Version 0.1

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by

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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.

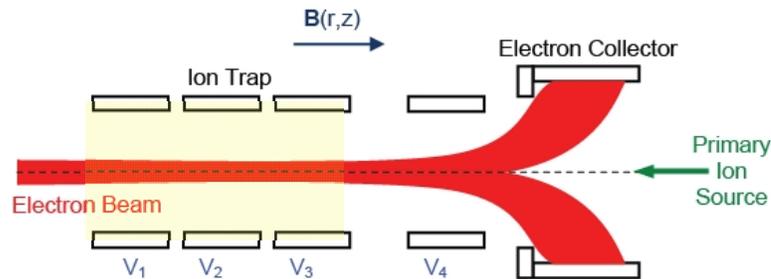


Figure 1: Diagram of EBIS device. The electron beam travels to the right until stopped by the electron collector. The primary ion source is to the right of the collector. The ion trap is indicated by the shaded region.

EBIS-PIC 2D is a 2D, time-dependent, self-consistent, particle-in-cell code to model the dynamics and charge breeding of injected ions in an Electron Beam Ion Source (EBIS). EBIS-PIC 2D calculates the dynamics of the injected primary ions in a background electron beam using Monte Carlo method while the space charge potential is calculated by solving the Poisson equation each time step. Using realistic EBIS operation parameters, EBIS-PIC 2D can calculate trapping efficiency of injected ions, simulate the overlapping of the ion beam with the electron beam and predict the extracted highly charged ion beam. EBIS-PIC 2D provides full phase space information of the ions. From

which we can obtain beam emittance, radial profiles of each ion species, velocity profiles of each ion species, and CSD in a self-consistent space charge potential.

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. L. Zhao and Jin-Soo Kim, "Numerical Simulation of ion charge breeding in electron beam ion source ", Rev. Sci. Instrum. 85, 02B706 (2014).
3. 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

This version of EBIS-PIC 2D code is compiled on CentOS 7.2. To install the program,

Step 1: unzip EBIS-PIC2D_linux.zip and move the files to the directory that you want.

Step 2: Make ebis2d_centos executable by typing:

```
chmod +x ebis2d_centos
```

To run EBIS-PIC 2D in Linux, these packages should be installed on your CentOS:

1. MPICH3.2
2. libusb
3. netcdf

Program Execution from Linux shell

The program can be started from a command line window by executing following command in the directory where the EBIS-PIC 2D is installed:

```
mpiexec -np 4 ebis2d_centos ebis2d.in
```

This is to run the simulation using 4 CPUs and the input file is *ebis2d.in*.

Several MATLAB plotting scripts are included for user to plot EBIS-PIC2D results by following command in MATLAB command window (assume *ebis2d.out* is the output file):

```
PlotEBIS('ebis2d.out').
```

Units Used in EBIS-PIC2D

SI units are used unless specified otherwise:

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

EBIS-PIC2D Input

The input file, with extension *.in, contains the input parameters for EBIS-PIC 2D program. The descriptions of the parameters are built in the example input file, *ebis2d.in*. User can modify this file to make it their own.

Bz.txt is the axial magnetic field.

EBIS-PIC2D Output

The output from EBIS-PIC 2D consists of the profiles of ions, electrons and fields. EBIS-PIC 2D 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-PIC2D run.

****.out***

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

****.dist(0....n)***

These files save the ion positions on CPU rank from 0 to n. Each CPU generates one distribution file.

****.out0***

This file is for saving initial profiles.

****.trj***

This file is used to save the trajectories of ions.

These NETCDF files can be viewed and plotted by most scientific plotting software, such as MATLAB. A MATLAB plotting routine is included to demonstrate how to make plots using EBIS-PIC 2D output.

An Example Run Using EBIS-PIC 2D

An example ion charge breeding is presented here. The Au 1+ ions are injected 0.77 m away from the trap. After $0.2 \mu\text{s}$ injection time, the ion trap is closed by the ramping the bias on the injection drift tube (V3 in Fig.1) from 13kV to 20kV. The ions are then trapped for 0.5 ms. The final profiles of the fields, ion distributions and time evolutions of several quantities are plotted in the following figures.

This test run took only about 20 minutes using 4 CPUs because the number of particles is less than 8k and confinement time is only 0.5 ms. For realistic runs, it would take large amount of computation resources to simulate million particles for tens of ms confinement time. The manual and the example plotting scripts are still in early stage. We will release the comprehensive version in the future.

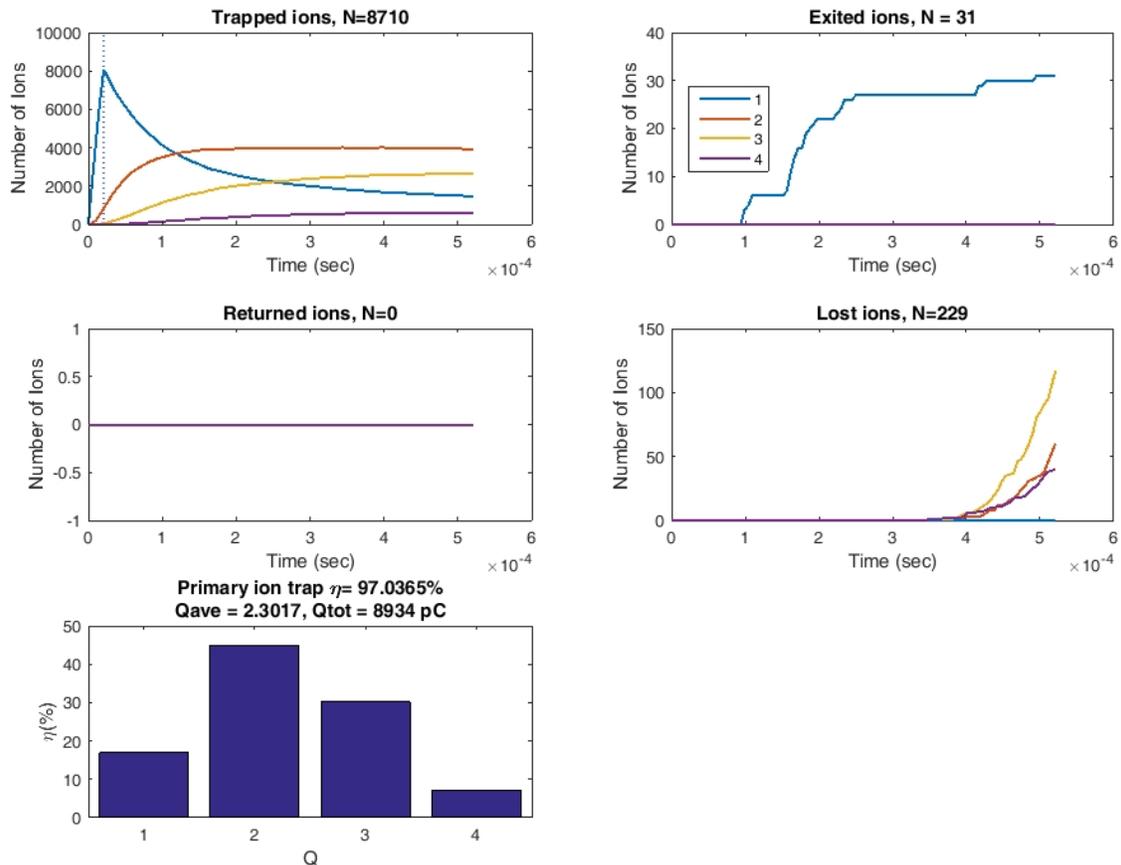


Figure 2: Time evolution of the number of 1) trapped ions; 2) ions that travel through the trap; 3) ions are reflected back; 4) ions lost to the wall. 5) Ion charge state distribution.

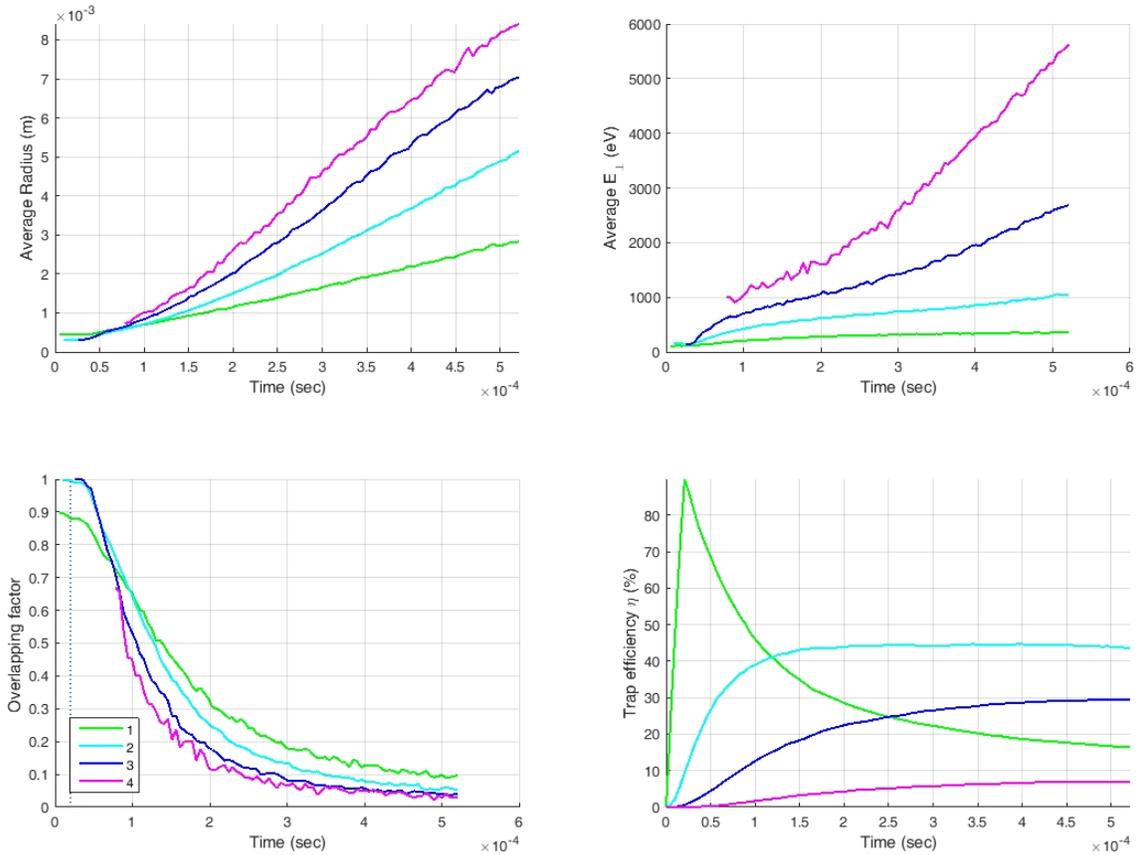


Figure 3: Averaged quantities vs. time and charge state. 1) ion radial positions 2) perpendicular energy; 3) overlapping factor; 4) trapping efficiency.

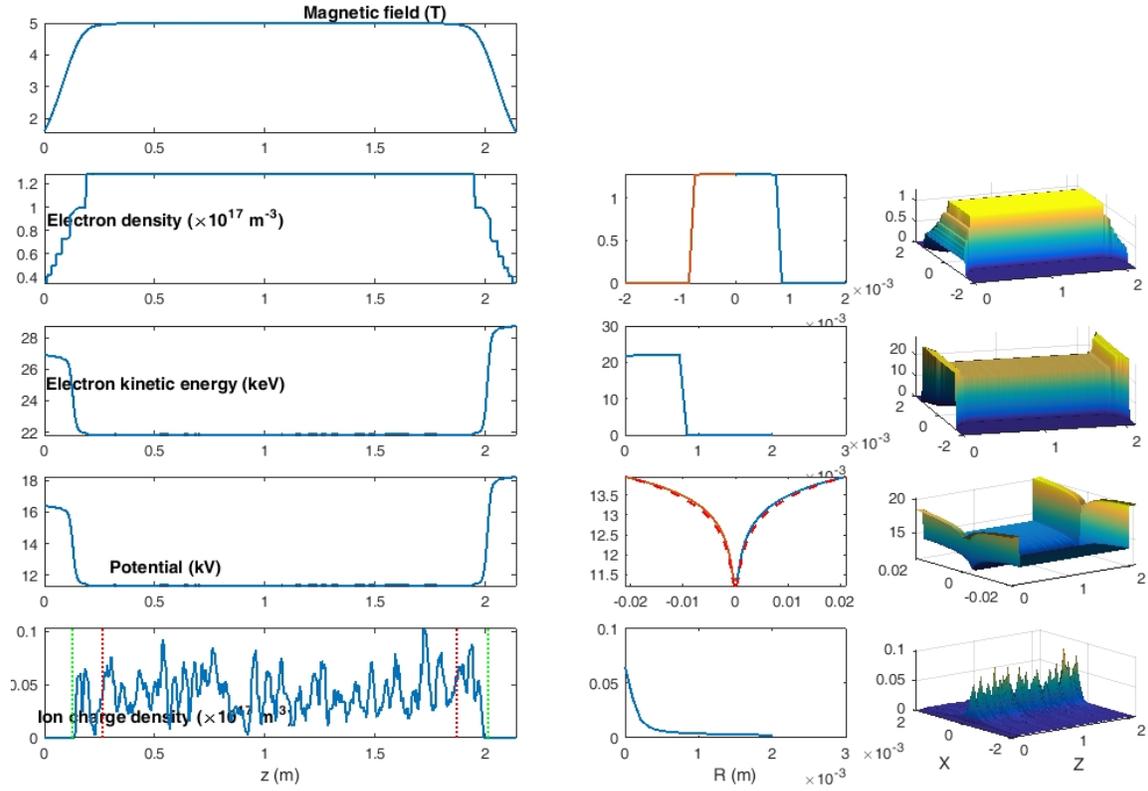


Figure 4: 1) Axial profile of magnetic field; Axial, radial and 2D profiles of 2) electron density; 3) electron kinetic energy; 4) potential; and 5) ion charge density