Hands-on Notes: Ion Source Beam Simulation

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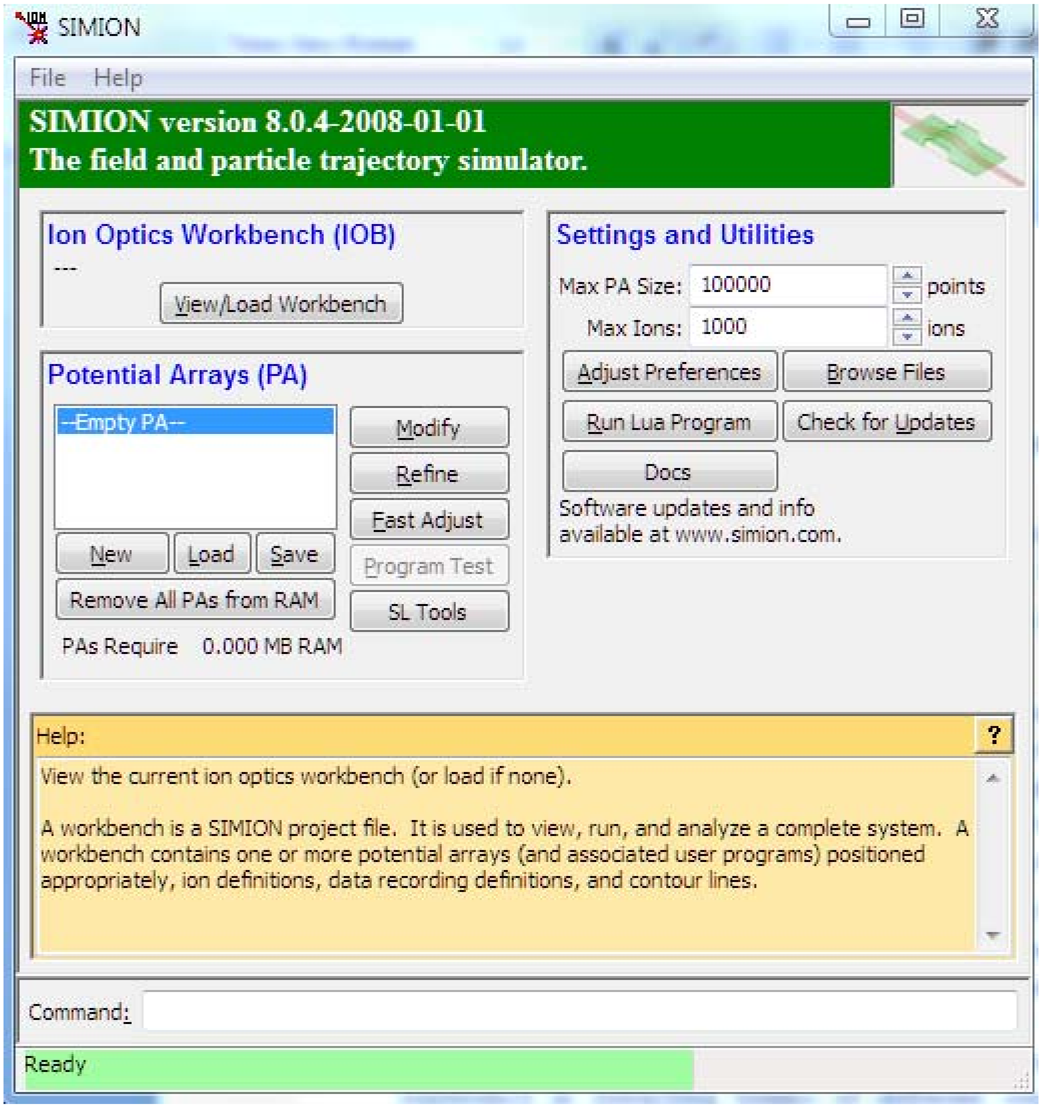
The quality of a particle beam is usually measured in terms of emittance and brightness of the beam. The so-called emittance influences all aspects of accelerator design and operation as well as the mass resolution and suppression of neighboring isotopes at on-line mass separator facilities. Therefore, the knowledge of precise emittance of the ion beams is necessary for the accelerator designers, operators, and experimentalists.

In this exercise we will discuss the simulation of ion source beam formation, extraction and transport to an emittance measuring device and calculate expected phase space shape & area, i.e. the emittance. The simulation will model the Electron Beam Plasma (EBP) ion source as implemented at the off-line Ion Source Test Facility (ISTF-2). In the companion module, "Beam Emittance Characterization," the students will have hands-on experience in extracting beams of different ions from that ion source, analyzing the beams in mass, measuring beam emittance and analyzing the resulting data. In this module, the students will use SIMION v.8.0 to model those beams, both to visualize the beam and to calculate the emittance and compare it to the real-beam measurement.

We will perform the following tasks:

1. Load the EBP source model, ebp-3cm-gap.iob, into SIMION and view the source geometry and electric fields
2. Generate ensembles of ions at the plasma sheath and fly them thru the fields.
3. Extract ion positions & trajectories at various points along the beamline.
4. Plot the ions on a phase space graph. Calculate the rms emittance, Twiss parameters, and normalized emittance for the simulated beams.
5. Compare the measured emittances of different ion beams with the simulations.



1. Description of SIMION—taken from the simion.com website

SIMION is a software program for doing charged particles optics simulations. Mainly, it calculates 2D/3D electrostatic and certain magnetic fields and calculates the trajectories of charged particles through those fields. Low frequency (quasistatic) fields such as in the oscillating voltages on a quadrupole are supported as well. Ion collision and other special effects can be simulated though the user programming feature. SIMION provides a programming, visualization, and data recording environment for these simulations.

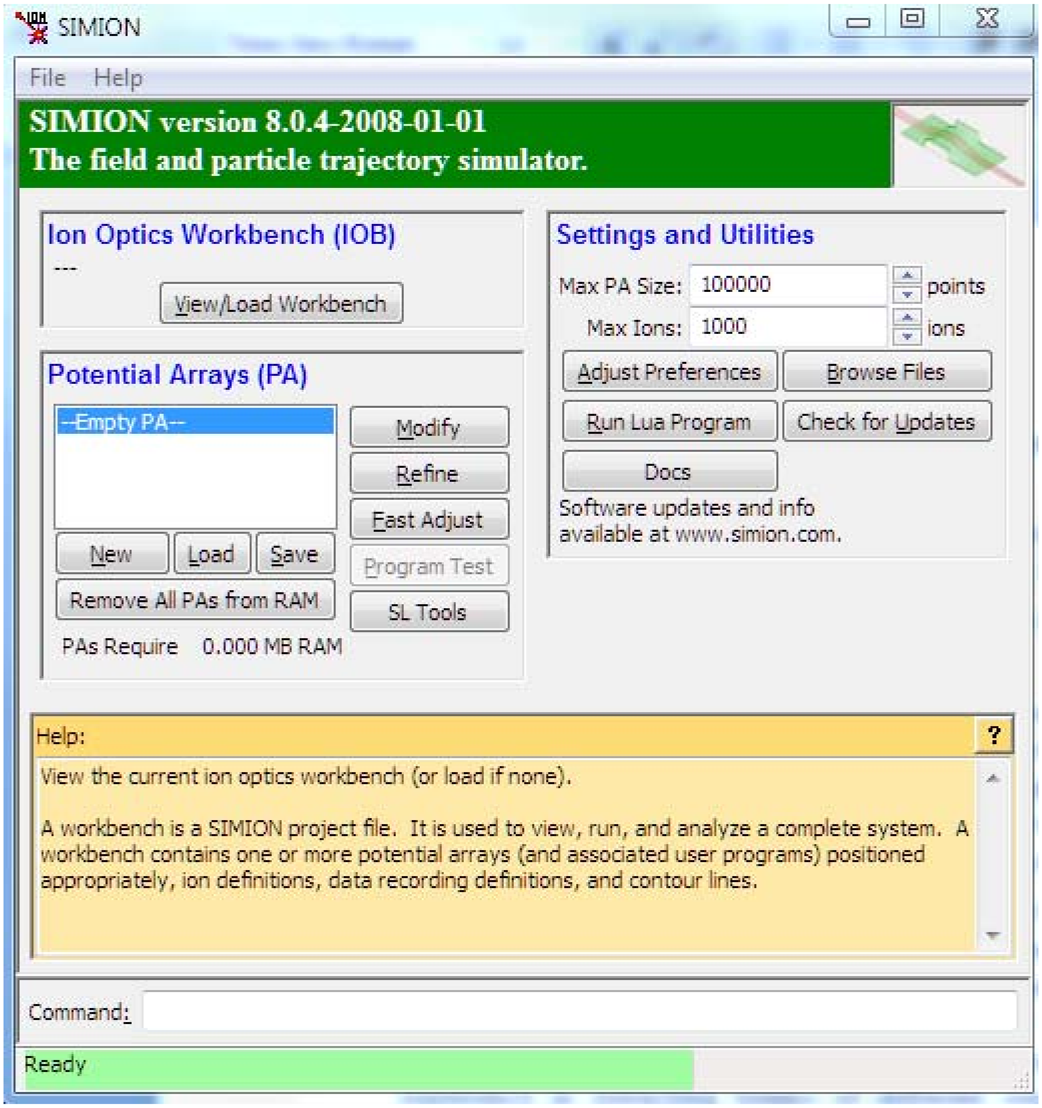
SIMION's methods are fairly direct via finite difference methods (optimized over-relaxation and multimesh methods) and Runge-Kutta for solving the required partial differential equations (PDEs), particularly the Laplace equation, and ordinary differential equations (ODEs) respectively. A workbench strategy allows multiple meshes, or possibly different mesh size and symmetry, to be used in the same simulation. The user programming feature allows these methods to be extended. Geometries can be defined via multiple methods.

SIMION was originally developed by David Dahl at what is now Idaho National Labs. It is now developed by Scientific Instrument Services, Inc. (http://www.sisweb.com/)

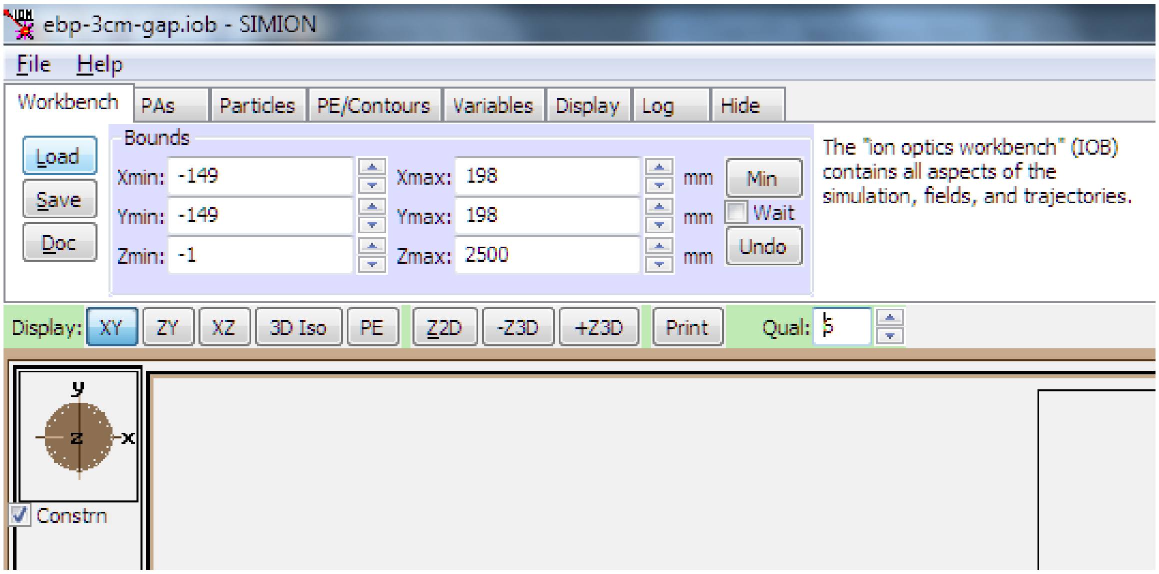
2. Loading the simulation & flying ions

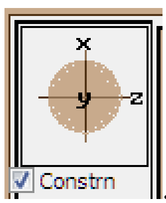
Launch the program by double-clicking its icon on the desktop and then clicking the "OK" button on the startup screen.

Load the ion source simulation, ebp-3cm-gap.iob, by clicking the View/Load Workbench button



Maximize the window, then set the Display: … Qual. = 6. Click the Display buttons (or rotate the world icon) to see different views of the geometry.



Set the view to XZ: 

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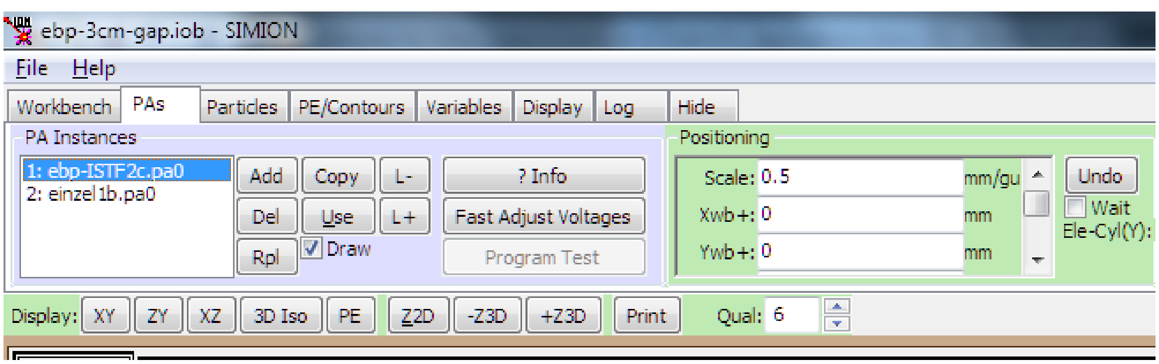
Use the cursor to see the different electric potentials in the model by pointing at different elements. The cursor position and the voltage & voltage gradient at that position are displayed at the bottom of the window.

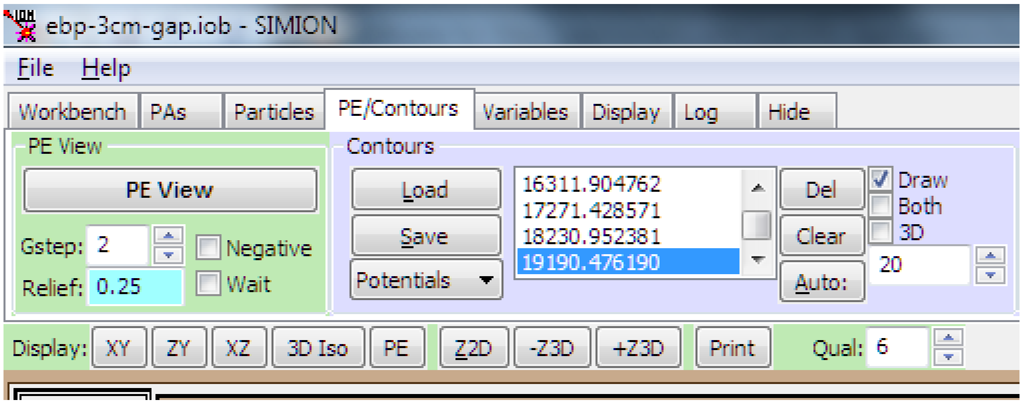
Click the PAs (Potential Arrays) tab. The shows a list of the PAs in this model. In our case there are two: the source PA and the einzel lens PA. Click on the source PA, then check various things like the scale (how many mm's per grid unit) and position in the model, then click Fast Adjust Voltages to see how to set the potentials in the source.



The source body should be at 20,000V, positive for positive ions. The anode is set 150V higher. The extract electrode is at ground (0V). Click Cancel to exit w/o changing voltages.

Do the same for the einzel PA.

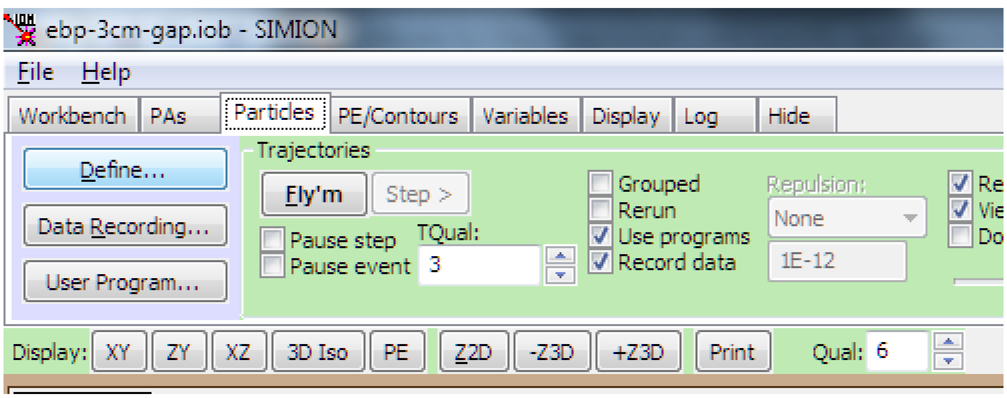
Now click the PE/Contours tab. Set the number of contours to 20 and click the Auto: button to see a display of equipotential lines. Recall, the electric fields are perpendicular to these contour lines.



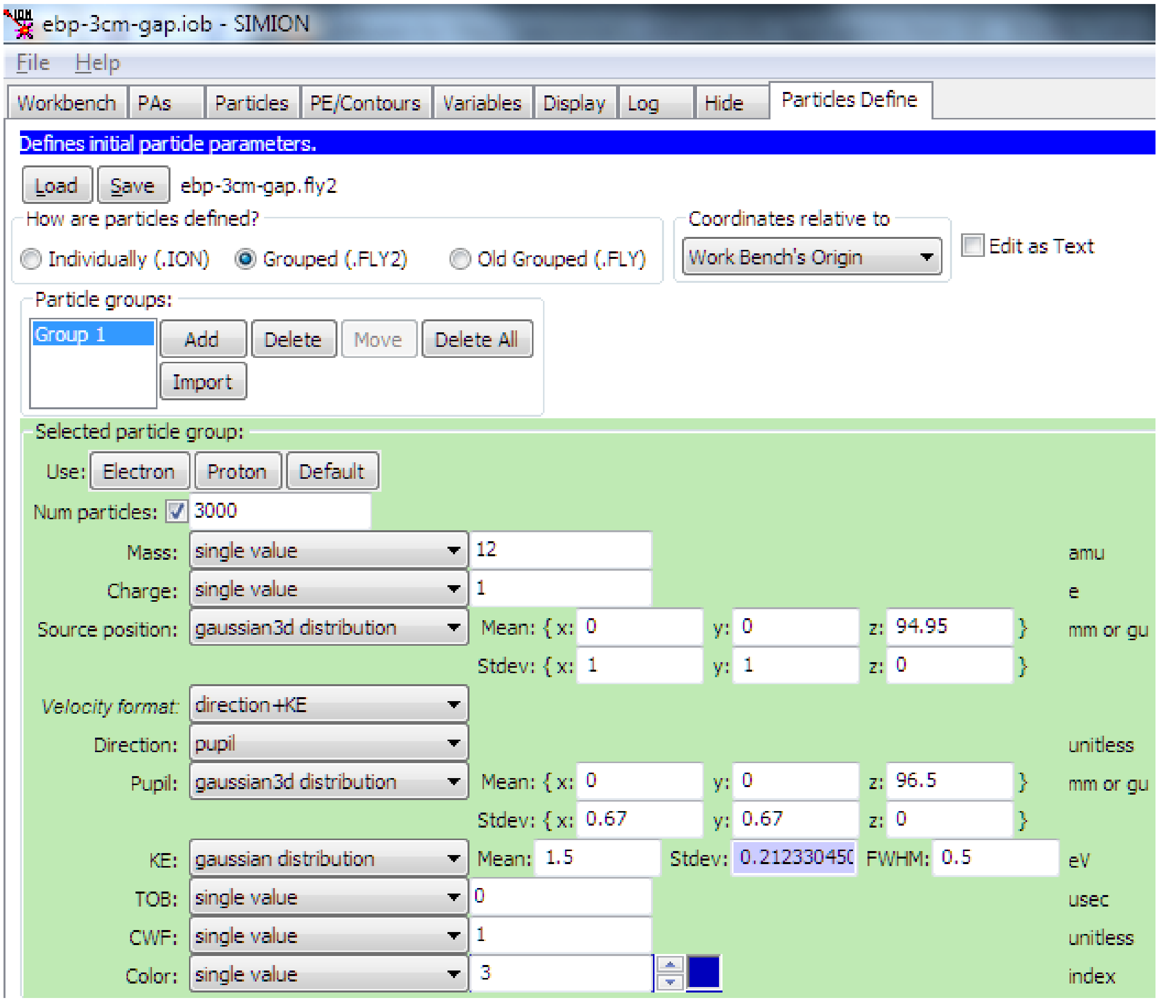
You can zoom in on an area by dragging a box around it and then right clicking. A 2nd right click will return to the previous view.

Clicking the Clear button will remove the contours from the display.

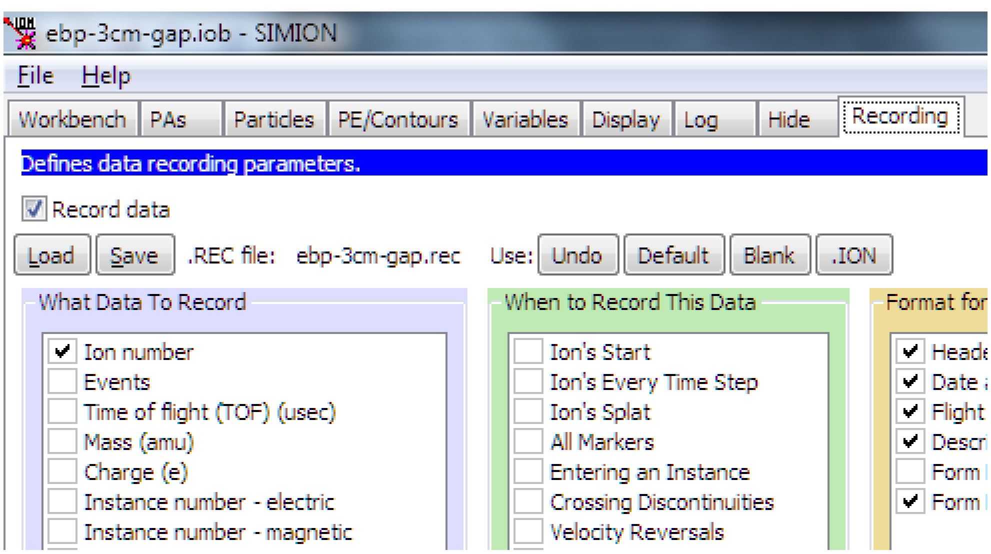
Now click the Particles tab, then click Define.



Now load the ion definition file “ebp-3cm-gap.fly2.” Change the number of particles to 20 to make it easy & fast to view multiply flight passes. When we are ready to record data for the emittance calculation, we will increase the number to get better statistics. Take note of the source position and velocity distribution, and then click OK at the bottom of the screen.



Now click the Data Recording… button and deselect the Record data checkbox. Click OK at the bottom of the screen.

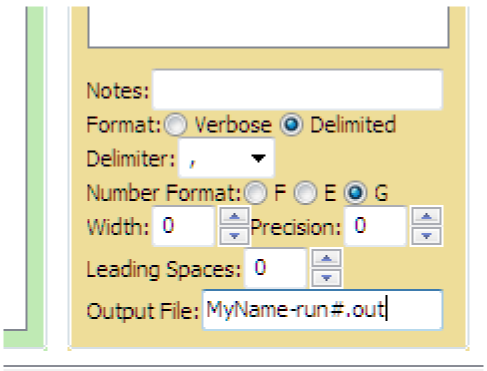


Now zoom in on the extraction region and press Fly'm to see what happens. Do this a number of times to see different randomly generated ions fly. Zoom out and inspect the trajectories an number of places, in particular, see how the einzel lens affects the beam. Those interested may want to Fast Adjust the einzel to see how varying the voltage changes the focusing.

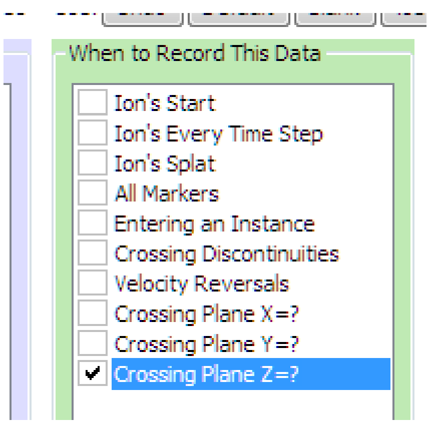
Now we're ready to record some data. Return to the particle definition page (click Define on the Particles tab), and change the number of particles to 1000. Now go to the Data Recording screen, check the Record data option and choose which parameters you want to record. An Excel spreadsheet will be set up to expect the following columns of data:

Ion N	X	Y	Z	Vt	Vx	Vy	Vz	KE	KE Error

Type the file name in the appropriate field for the destination where the output data will be written:



Click on Crossing Plane Z=?, and set the value along the z-axis where you want to record data. The field for that value is at the bottom of the "When to Record This Data" column.



Particular z-values of interest are:

Z=97, entrance to extraction gap; Z=330, source exit aperture; Z=1962, einzel focus for a 20.15keV beam with 12.263kV on the lens; Z=2542, the simulated position of the emittance measuring apparatus.

3. Analyzing the SIMION output

Open the Excel spreadsheet, “emittance-ISTF2-sim. Note that two sheets have been set up to receive data: z=358mm and z=1962mm. These sheets can be copied to make places for data from other positions. There are a number of formulas set up in these sheets, most notable are those to calculate the beam moments and Twiss parameters. Note that these formulas may need to be adjusted if the number of particles is changed.

Open your output data file using Notepad. You will find a comma-delimited set of data. Select & copy just the numbers. Paste them into the spreadsheet at the appropriate cell. You may have to convert from text to columns at this point. Plot the data on a phase space graph. Next calculate and plot the rms-emittance ellipse for the data.

If you are comparing emittances of beams of different energies, you’ll want to normal the emittance by multiplying the rms emittance by the relativistic factors $\beta\gamma$.

As time permits, you should investigate how varying different parameters affects the shape of the emittance ellipse. Some things to consider: ion initial position, beam size in the einzel lens, beam divergence/convergence/waist at the z_out point and anything else that strikes your interest.