Injector Simulations with IBSimu

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Simulation of Beam and Plasma Systems

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Outline

- Morning:
  - Overview of ion sources
  - How extraction can be simulated in select cases
  - Sorted from “Easy” to “Hard” (very subjectively)
- Afternoon Lab I:
  - IBSimu crash course
  - Simulations of plasma ion sources using IBSimu
    - “Simple” plasma extraction + Adding B-field + Negative ions
- Afternoon Lab II:
  - Select challenges with low energy beam transport (LEBT)
    - Multiple species + space charge compensation
  - Warp simulations

Codes

- Codes (Raytracing/PIC + Plasma model):
  - IGUN (RZ) http://www.egun-igun.com/
  - IBSimu (RZ, 3D, 2D) http://ibsimu.sourceforge.net/
  - Warp (RZ, 3D, 2D) http://warp.lbl.gov/
  - Kobra-INP (RZ, 3D)
  - ….

Complications:

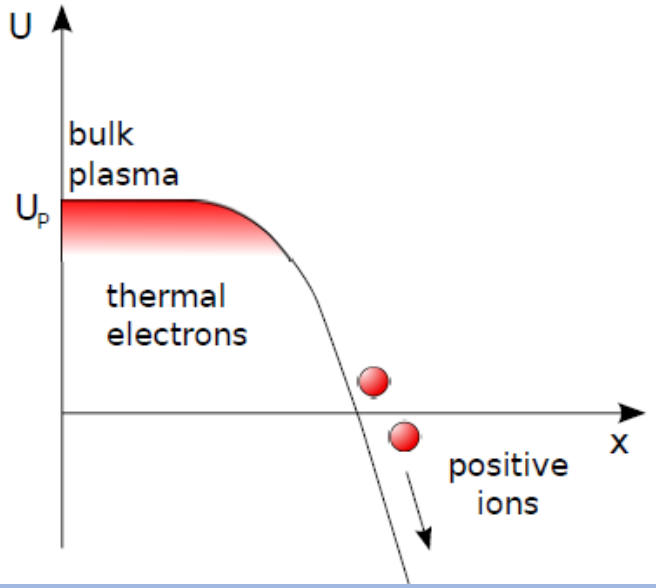
- Multiple ion species
- Added magnetic fields (see next):
  - Solenoid
  - Sextupole
- Negative ions/electrons
- 3D advisable!

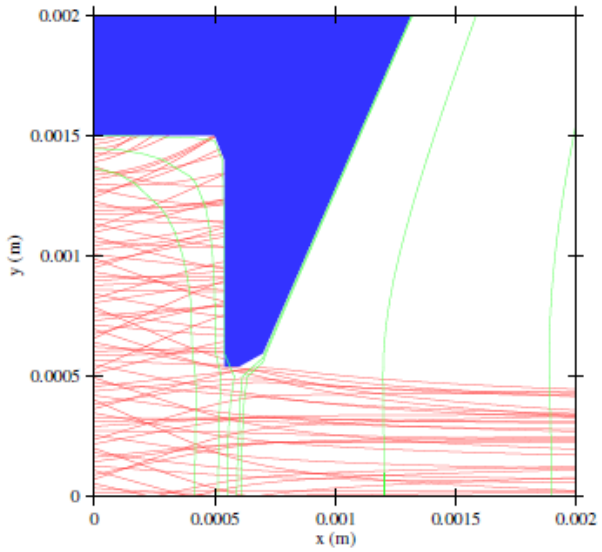
Positive Ion Extraction from Plasma

Modelling of positive ion extraction

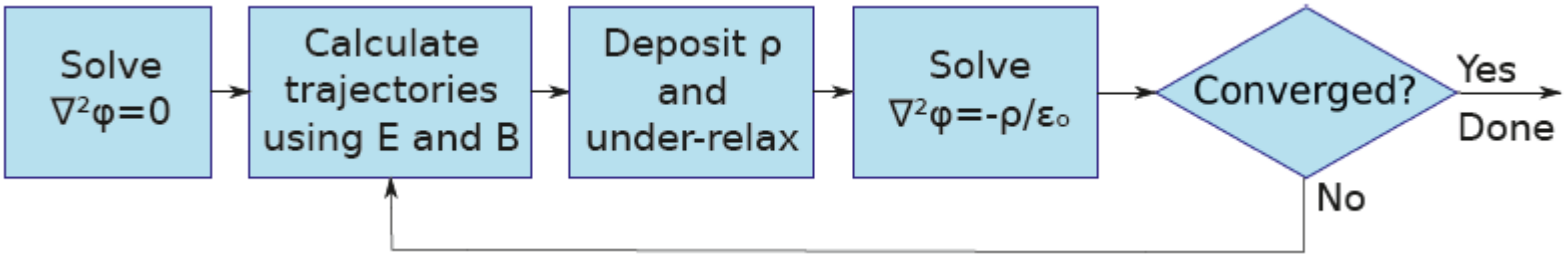
- Ray-traced positive ions entering sheath with initial velocity
- Nonlinear space charge term (analytic in Poisson's equation):

$$\rho_e = \rho_{e0} \exp\left(\frac{U - U_P}{kT_e/e}\right)$$





Algorithm

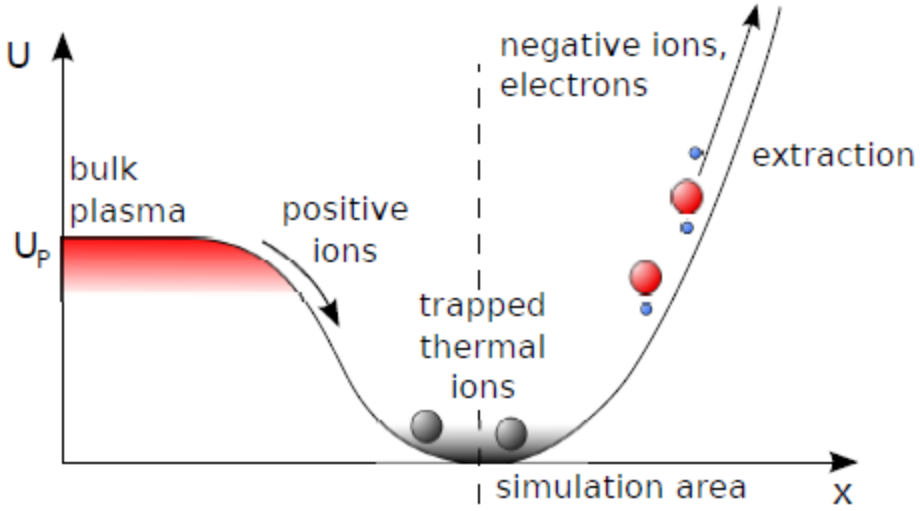


- Relaxation Process
- Maxwellian Electrons included in non-linear Poisson solver.

Negative Ions

Modelling of negative ion extraction

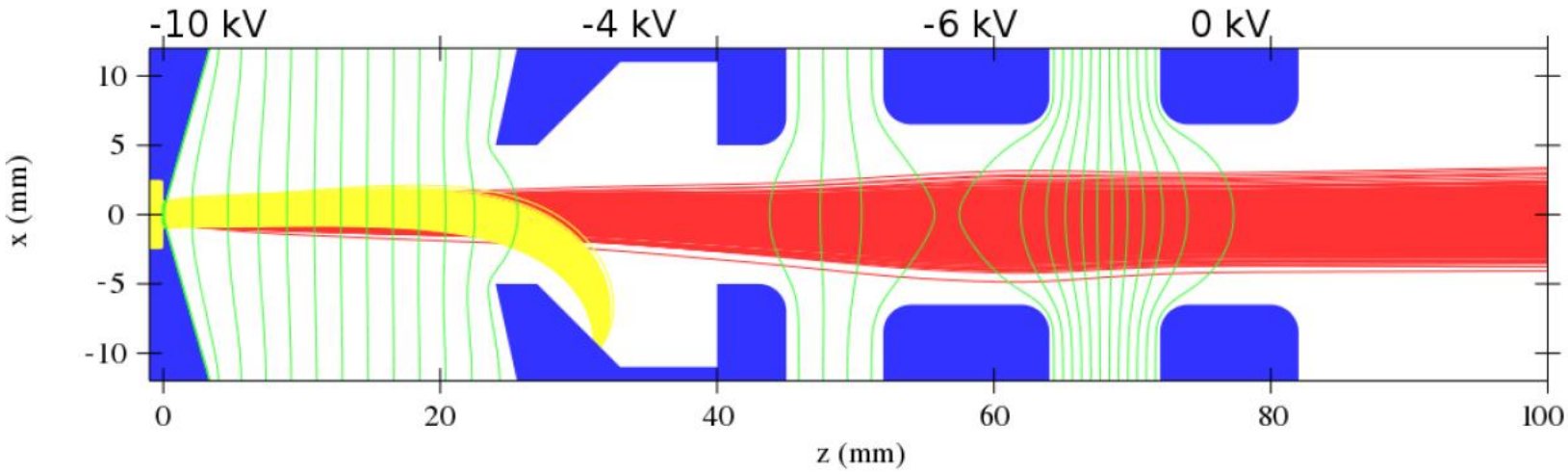
- Ray-traced negative ions and electrons
- Analytic thermal and fast positive charges
- Magnetic field suppression for electrons inside plasma



$$\rho_{\mathrm{th}} = \rho_{\mathrm{th0}} \exp\left(\frac{-eU}{kT_i}\right)$$

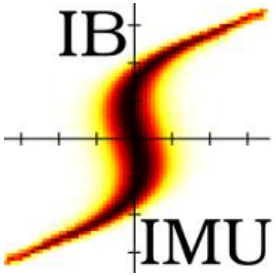
$$\rho_{\mathrm{f}} = \rho_{\mathrm{f0}} \left(1 + \mathrm{erf}\left(\frac{eU}{E_i}\right)\right)$$

Challenge: Negative Ions



About the code

- On lab computers: IBSimu 1.0.6dev (installation covered later)
- Source: http://ibsimu.sourceforge.net
- If you want to use it at home you'll need:
  - Linux (duh!)
  - GSL (Gnu Scientific Library)
  - autotools, git, zlib
  - libgtk-3-dev (optional, for postprocessing GUI)
  - something to edit DXF-files with (AutoCAD, LibreCAD)
  - something to plot with (maybe not gnuplot)
  - optional: GtkGLExt, UMFPACK, CSG



Getting Started

- IBSimu is a C++ library
- So we must write and compile our simulations in C++!
- Luckily, all examples are provided with a Makefile that contains the necessary information…
- Download the files from https://people.nscl.msu.edu/~lund/uspas/sbp_2018/lec_inj/
- Keep the folder structure, otherwise you won't know which files belong together ;o)

RZ vs 3D

- Download the files from the two folders `einzelRZ/` and `einzel3D/`
- Modify the two files so that you have the same geometry, voltages and beam species
- Make sure you have the same initial beam conditions
- Run both and compare the emittances.

Simple Example: Plasma Extraction in RZ

- Go to folder plasmacyl/
- make and run, can you see the “plasma meniscus”?
- Modify the current density J to extract the beam converging, then clearly diverging.
- Play with the GTK viewer, create a slice and plot the phase space. What is the emittance
- Compare this emittance to the formula shown in class this morning. How does it compare? Why?

$$\epsilon_{\mathrm{rms,n}} = \frac{1}{2}\sqrt{\frac{kT}{3m}}\frac{w}{c}$$

ECRIS Simulation

- Go into the folder `ECRIS/`
- Make and run, this takes a minute or two…
- How many ion species are in the simulation and which mass to charge ratios do they have?
- What is the total extracted current?
- How does the emittance compare to the two simple formulas from class?
- Turn off the magnetic field, how does the simulation change?
- How does the emittance change?

Negative Ion Source Example

- Go into folder `LIISA_neg_source/`
- Nope :(takes too long…
- But you can leave it on over night, if you don't need the lab computer :)