Injector Simulations with warp

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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)
  - ....

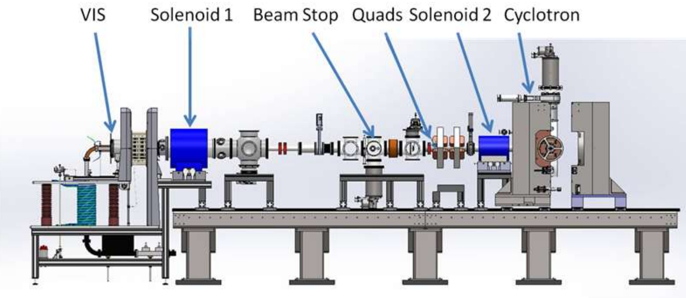
Complications:

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

Task 1

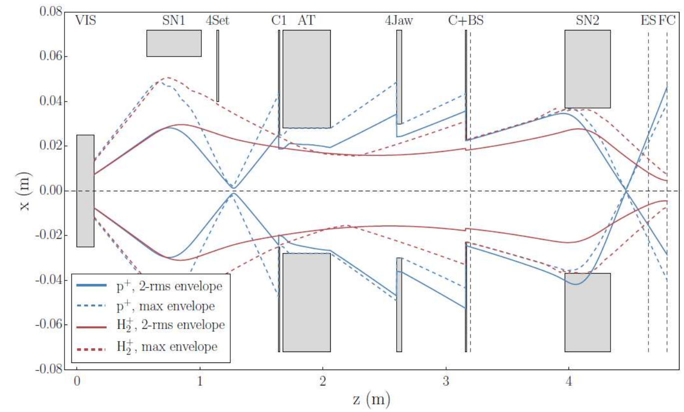
- Download https://people.nscl.msu.edu/~lund/uspas/sbp_2018/lec_inj/03.lebt_examples/solenoid_xy_slice.py
- Run it in warp
- Interpret the plot
- Add the second species (H2+) by looking for "ASSIGNMENT Task 1" in the code and making the requested changes.
- What has changed? Did you change the current to account for two species?
- Now remove the protons and run again. Interpret!

Injection tests at BCS, Inc.

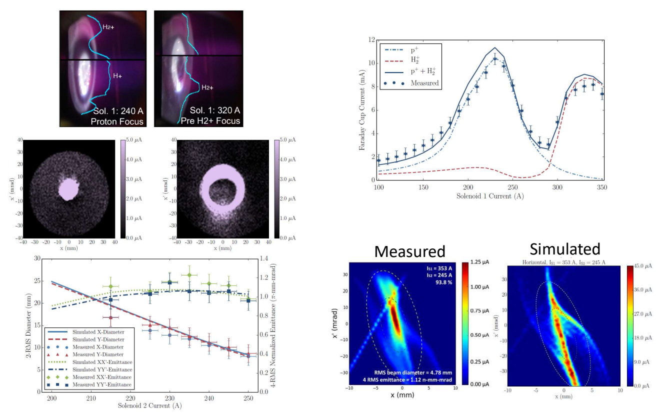


Versatile Ion Source (VIS) loaned from INFN
Cyclotron + Teststand provided by Best Cyclotron Systems, Inc. (BCS)

Simulations and Experiments Agree Well



Simulations and Experiments Agree Well

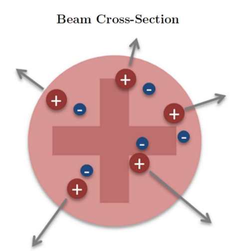


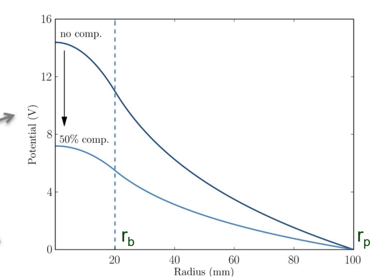
Space Charge Compensation

- Beam interacts with residual gas

$$\sigma_e = \sigma_{ionization}$$
$$\sigma_i = \sigma_{charge-exchange} + \sigma_{ionization}$$

$$\Delta\phi = \frac{I \cdot (1 - f_e)}{4\pi\epsilon_0 v_b}$$





Semi-Analytical Model

- 1975: Gabovich model for f_e, uses:
  - Secondary electron energy balance:

Steady state: energy transferred to electrons through Coulomb collisions = energy necessary to leave beam envelope

$$(\Delta\varphi_{neut})^2 = 3\mathcal{L}\cdot\frac{m_b}{m_e}\cdot\frac{\Phi_i}{U_0}\frac{n_b q e^2}{(4\pi\epsilon_0)^2}\left(\frac{q}{n_0\sigma_e}+\frac{v_b\sigma_i r_b}{2\bar{v}_i\sigma_e}\right)$$

$$f_e = 1-\frac{\Delta\varphi_{neut}}{\Delta\varphi_{full}}$$

$$\Delta\varphi_{full} = \frac{I}{4\pi\epsilon_0 v_b} \qquad \mathcal{L} = 4\pi\ln\left(4\pi\epsilon_0^{3/2}\frac{m_e^{3/2}v_b^3}{qe^3 n_e^{1/2}}\right)$$

M. Gabovich, L. Katsubo, and I. Soloshenko, "*Selfdecompensation of a stable quasineutral ion beam due to coulomb collisions*", **Fiz. Plazmy, vol. 1**, pp. 304-309, 1975.

Semi-Analytical Model

- Major contributions to cross sections:

$$\sigma_e = \sigma_{ionization}$$
$$\sigma_i = \sigma_{charge-exchange} + \sigma_{ionization}$$

- Large uncertainties in available cross-section data!
- Other simplifications:
  - Round, uniform beam
  - Secondary ions: simple balance of produced ions = leaving ions
  - Quasineutrality of the beam plasma $n_e = q\cdot n_b + n_i$

$$(\Delta\varphi_{neut})^2 = 3\mathcal{L}\cdot\frac{m_b}{m_e}\cdot\frac{\Phi_i}{U_0}\frac{n_b q e^2}{(4\pi\epsilon_0)^2}\left(\frac{q}{n_0\sigma_e}+\frac{v_b\sigma_i r_b}{2\bar{v}_i\sigma_e}\right)$$

$$f_e = 1-\frac{\Delta\varphi_{neut}}{\Delta\varphi_{full}}$$

Semi-Analytical Model

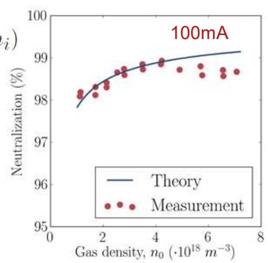
- Pressure in ECR transport line are as low as possible to reduce charge exchange (therefore low production of electrons)
- ECR beams are probably far from neutralized

$$n_e = q\cdot n_b + n_i \longrightarrow n_e = fe\cdot(q\cdot n_b + n_i)$$

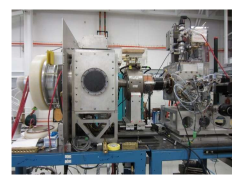
$$f_e = 1-\sqrt{f_e}\cdot\frac{\Delta\varphi_{neut,Gabovich}}{\Delta\varphi_{full}}$$

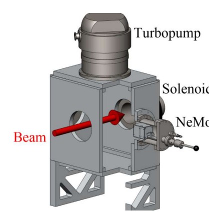
$$\chi = \frac{\Delta\varphi_{neut,Gabovich}}{\Delta\varphi_{full}}$$

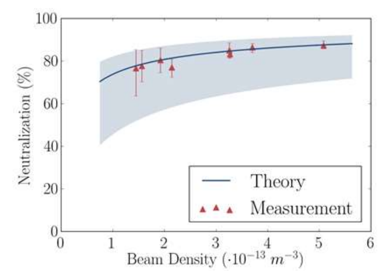
$$f_e = 1+\frac{\chi^2}{2}-\frac{\chi}{2}\sqrt{\chi^2+4}$$



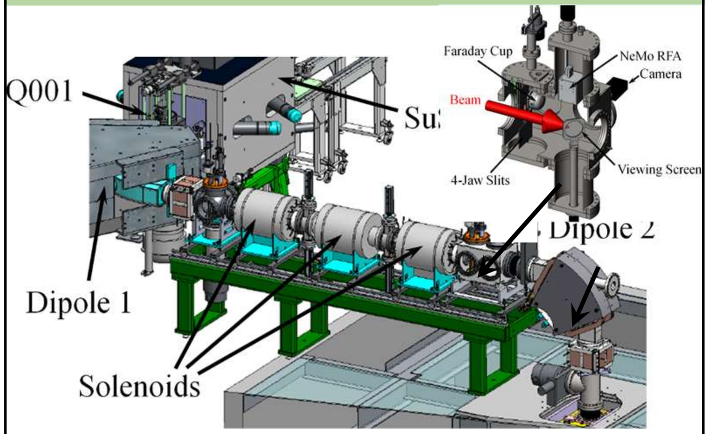
LEDA Injector Source



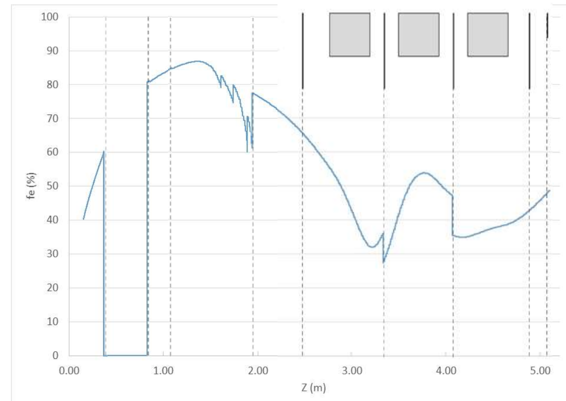




SuSI Beamline



f_e in SuSI beamline



Task 2

- Go back to using only protons in the python script. Now activate space charge compensation by looking for the line with “ASSIGNMENT Task 2” and uncommenting the installbeforestep() function.
- Run and interpret what you see. Save the figure
- After the run, calculate the mean fe and use it instead of the function by commenting installbeforestep again and reducing the current appropriately.
- Run again and compare with the saved plot.