A coupled particle-Poisson-solver code for the extraction of charged particles from a negative ion source

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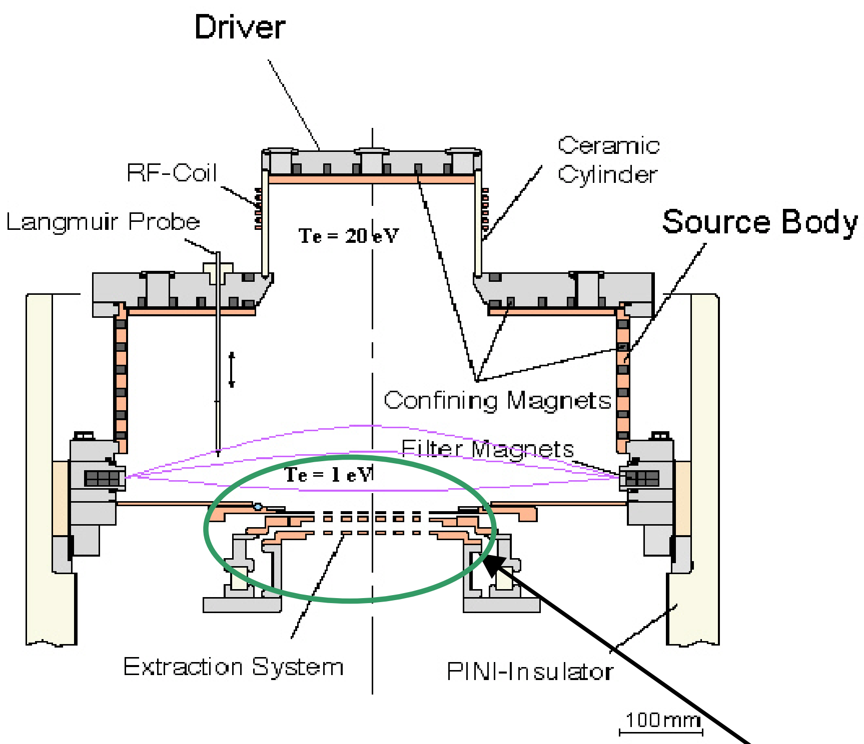
Layout of ITER-relevant ion source



Region of interest for this work

(BATMAN source.

Courtesy: IPP Garching)

Our goal is to provide a description for the extraction of negative ions from the source with strong external electric fields applied.

The ions move affected jointly by the plasma and the external field

However,

The external field affects the plasma, too, while the plasma screens the external field

Hence

self-consistent modelization of the (plasma + external field + negative ions) sought

References:

[1] Whealton J H, Olsen D K, and Raridon R J 1998 *Rev. Sci. Intrum.* **69** 1103

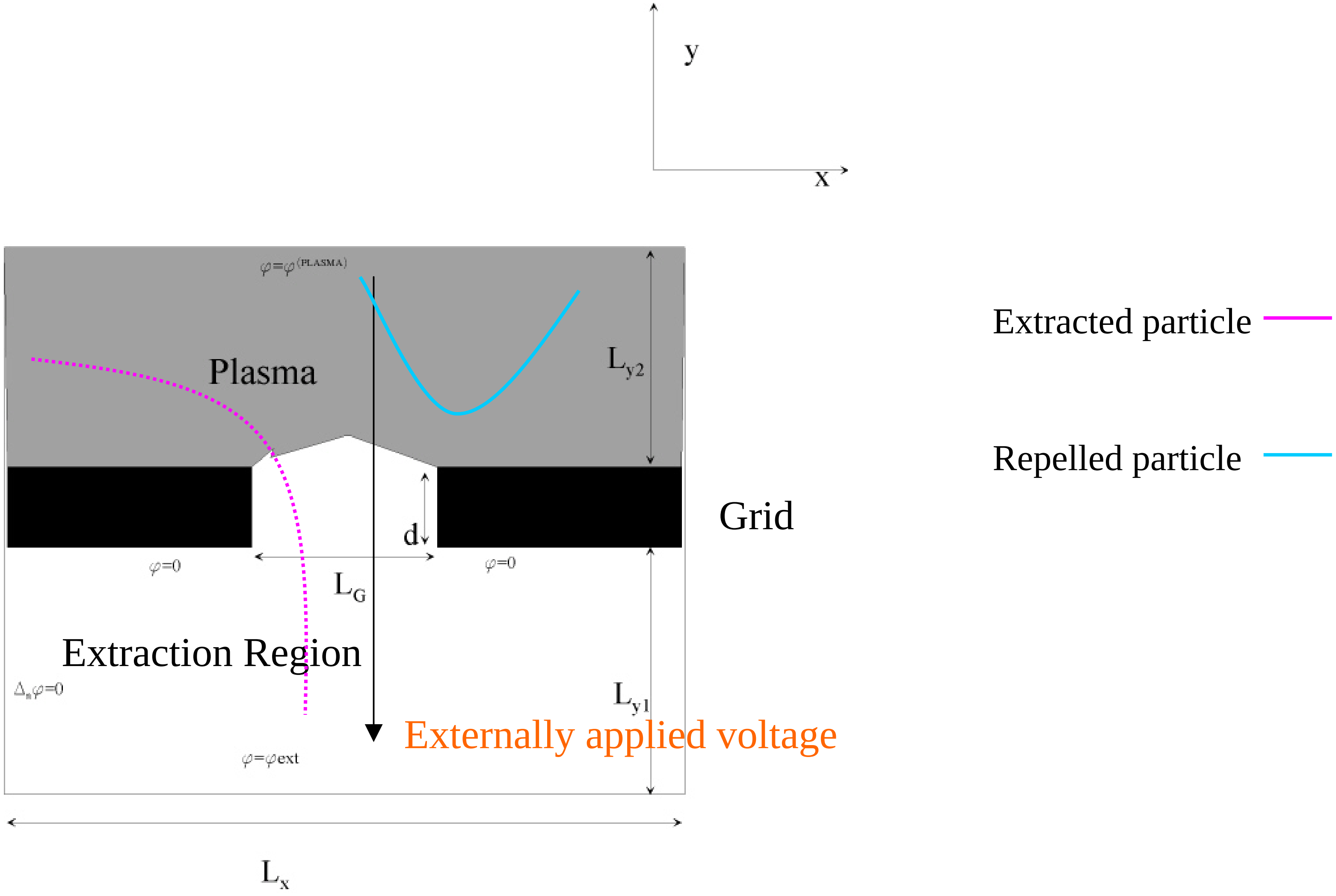
[2] Peters J 2002 *Rev. Sci. Instrum.* **73** 900

[3] Welton R F, *et al* 2002 *Rev. Sci. Instrum.* **73** 1013

[4] Becker R 2004 *Rev. Sci. Instrum.* **75** 1687; *ibid*, 1723.

[5] Sakurabayashi T, Hatayama A, Bacal M 2004 *J. Appl. Phys.* **95** 3937

Zoom of a part of the grid region



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Plasma features:

•Plasma-wall interaction generate the usual ambipolar electric field

Charge density 10^{16-17} m^{-3}

Temperature 1 eV

Debye length 10^{-5} m Electric field $1 / 10^{-5} = 10^{5}$ V/m

On the other hand, externally imposed potentials may reach values of some kV over few mm (Grid-to-grid), hence override plasma-generated-fields.

Experimentally: the plasma makes a double layer of a few cm

[measurements on BATMAN source by A. Tanga *et al*]

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Numerical technique of solution:

Iterative solving of 2D Poisson equation

$$\nabla^2 \varphi^{(k)} = -\frac{e}{\varepsilon_0} \delta n^{(k-1)} \,, \quad k > 0 \qquad (1)$$

Coupled with the solving of dynamical equations of motion for charged particles

$$m_i \frac{d\mathbf{v}_i^{(k+1)}}{dt} = q_i \left(\mathbf{E}^{(k)} + \mathbf{v}_i^{(k+1)} \times \mathbf{B} \right) \quad , \quad i = 1, \ldots, N \qquad (2)$$

Particles trajectories are spread over a numerical grid, approximating local density by the average time spent close to each mesh node.

Plasma features retained (and omitted) in the code

•Plasma is approximated by a finite number of particles (electrons, protons and negative ions).

•Simplified model for plasma dynamics, neglecting particle-particle collisions (including ionization and recombination): just accelerated motion in electromagnetic field.

•Particle-surface collisions lead to absorption of the particle: no reflection is permitted.

•A confining magnetic field (magnetic filter), albeit with a simplified geometry, is explicitly included: part of the simulations will address the issue of the performances of this field over particle confinement. We just limit to a constant magnitude field, directed along *z*-axis (i.e., perpendicular to the plane in figure).

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Plasma features/cont.d

•Three-components-plasmas will be considered: electrons, protons, and negative Hydrogen ions. The presence of doping elements, such as Caesium atoms, is deemed to act as a surface coating, without playing any active role in plasma dynamics: the exact mechanism of generation of H^- ions is not considered.

•2-Dim geometry.

•Only Plasma Grid modelled with some detail. Other grids ignored.

$$\nabla^2 \varphi^{(k)} = -\frac{e}{\varepsilon_0} \delta n^{(k-1)} \; , \quad k > 0$$

Eq. (1) (Poisson Equation) needs boundary conditions

and a starting guess for the density

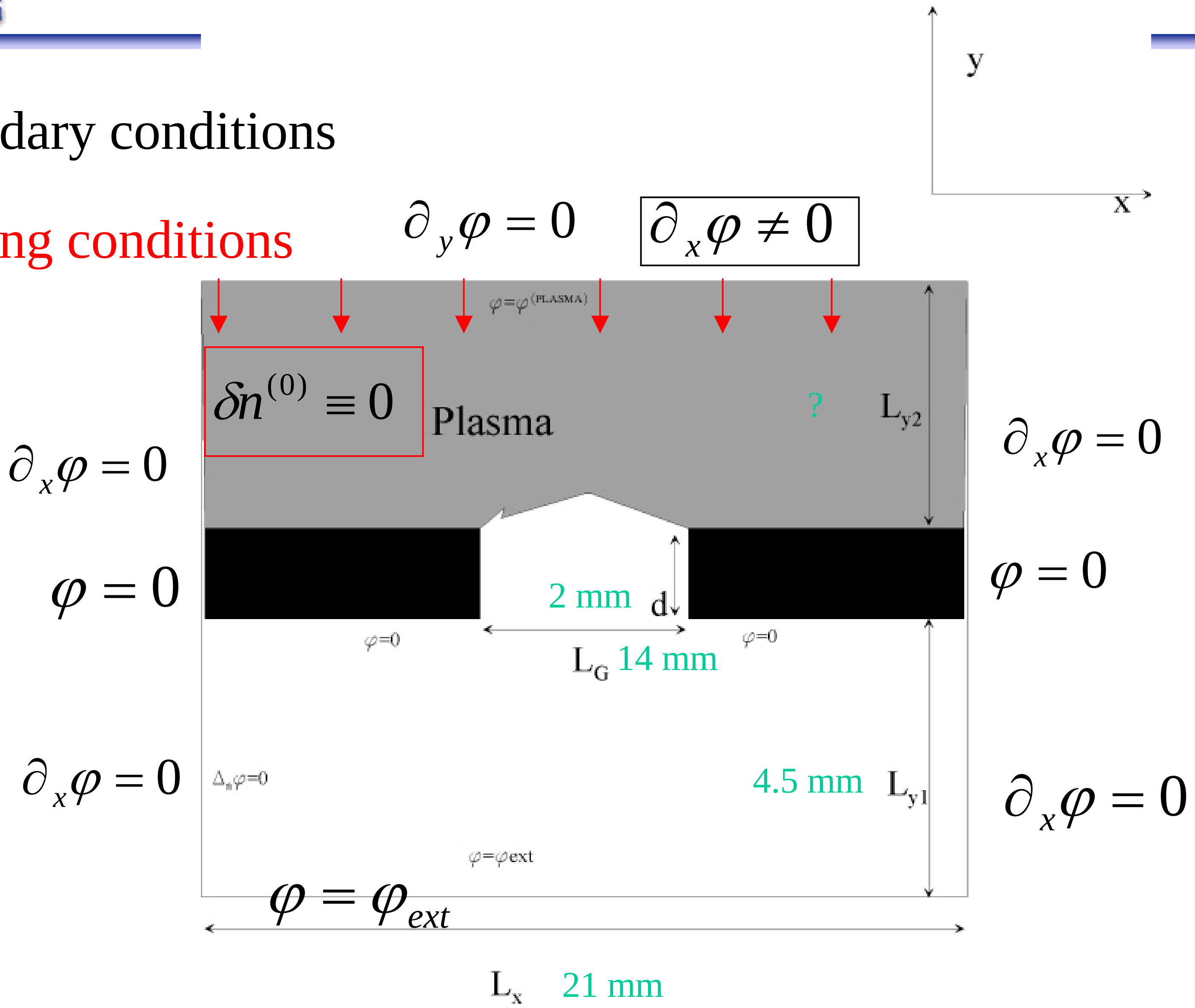
While

$$m_i \frac{d\mathbf{v}_i^{(k+1)}}{dt} = q_i \left(\mathbf{E}^{(k)} + \mathbf{v}_i^{(k+1)} \times \mathbf{B} \right) \quad , \quad i = 1, \ldots, N$$

Eq. (2) (Newton equation) needs starting conditions

Boundary conditions

Starting conditions



First run

Parameters are:

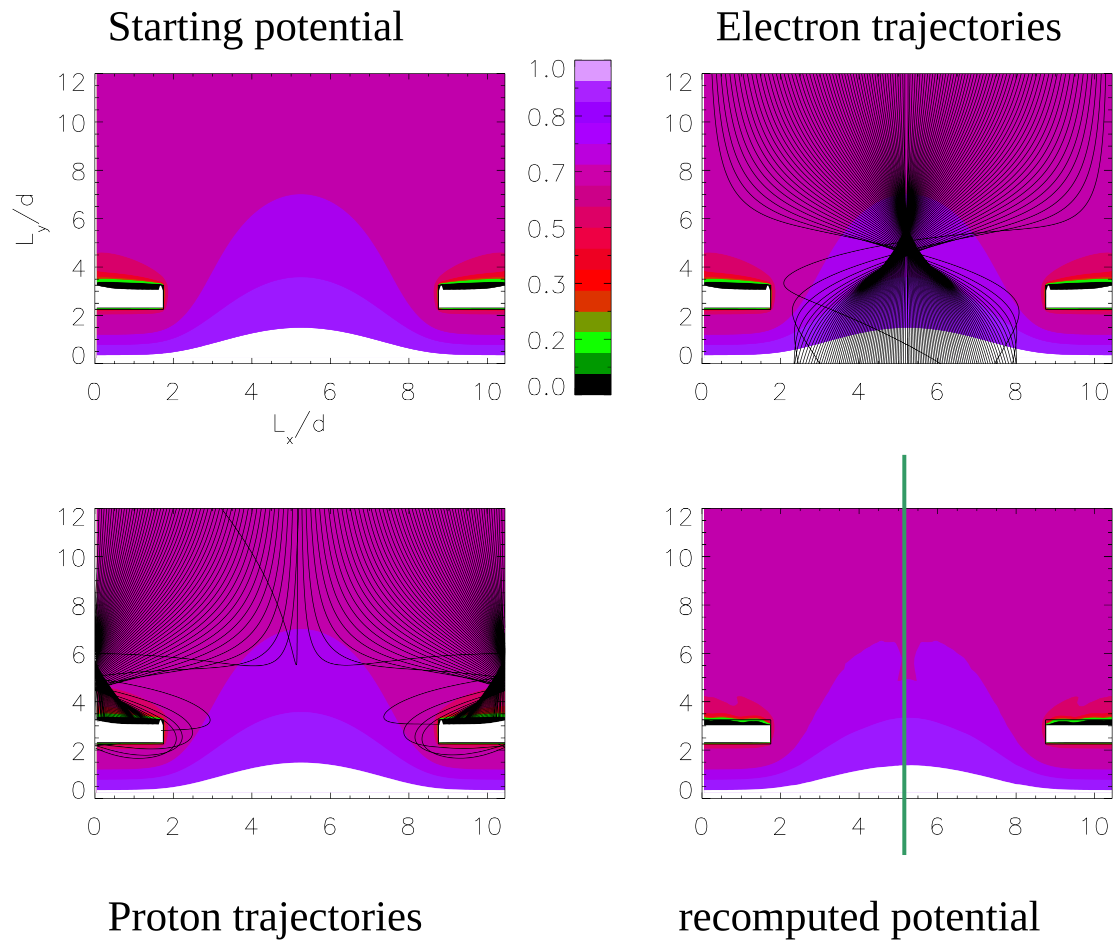
“core” density $n_p = 10^{17}\ m^{-3}$,

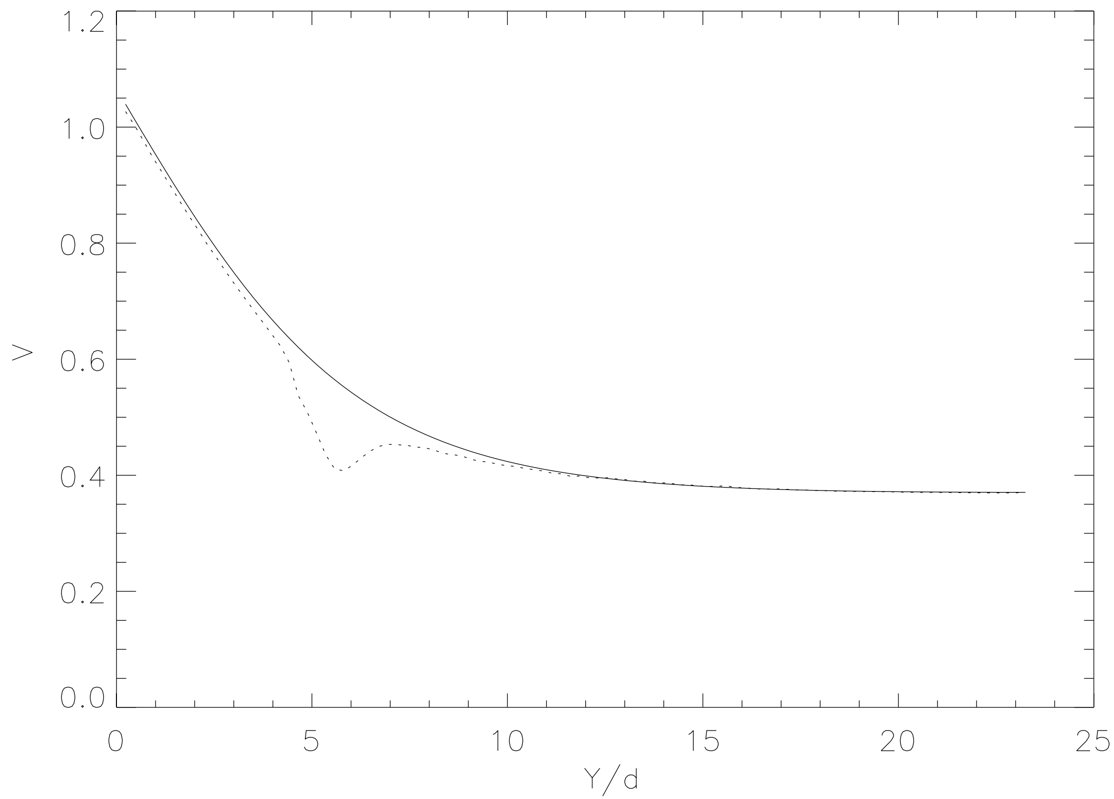
extraction potential $\varphi^{(ext)} = 10$ kV.

Magnetic field is absent and negative ions were not included.

The Grid-plasma distance L_{y2} is set to $L_{y2} = 40$ mm, insuring a constancy of φ along the upper boundary: $\varphi_{Plasma} = 0.36\times\varphi^{(ext)}$ to within a tolerance of about 1%.

The first iterate of the potential was computed using zero density.





Solid line, starting potential $\varphi^{(1)}$ evaluated in the middle of the cell versus *y* coordinate; dashed line, $\varphi^{(2)}$.

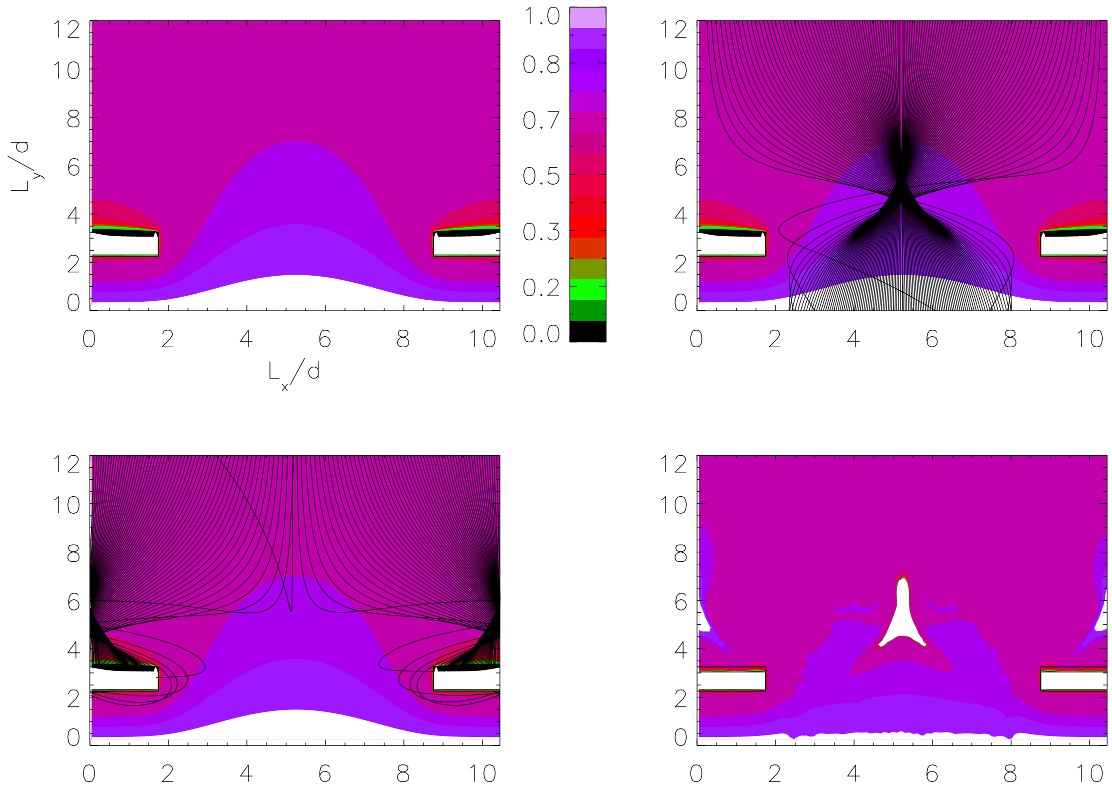
Comparison:

Density increased tenfold

The ratio $r = n_p/\varphi^{(ext)}$ plays the role of small parameter

Starting potential

Electron trajectories



Proton trajectories

recomputed potential

Small parameter in Poisson equation

$$\nabla^2\phi = \frac{q}{\varepsilon_0} n \rightarrow \varepsilon = \frac{q}{\varepsilon_0} L^2 \frac{n_p}{\phi_{ext}}$$

$$L = d \rightarrow \varepsilon \approx \frac{10^{-19}}{10^{-11}} \times 10^{-6} \frac{n_p}{\phi_{ext}}$$

$$n_p = 10^{17}, \quad \phi_{ext} = 10^4 \rightarrow \varepsilon \approx 10^{-1}$$

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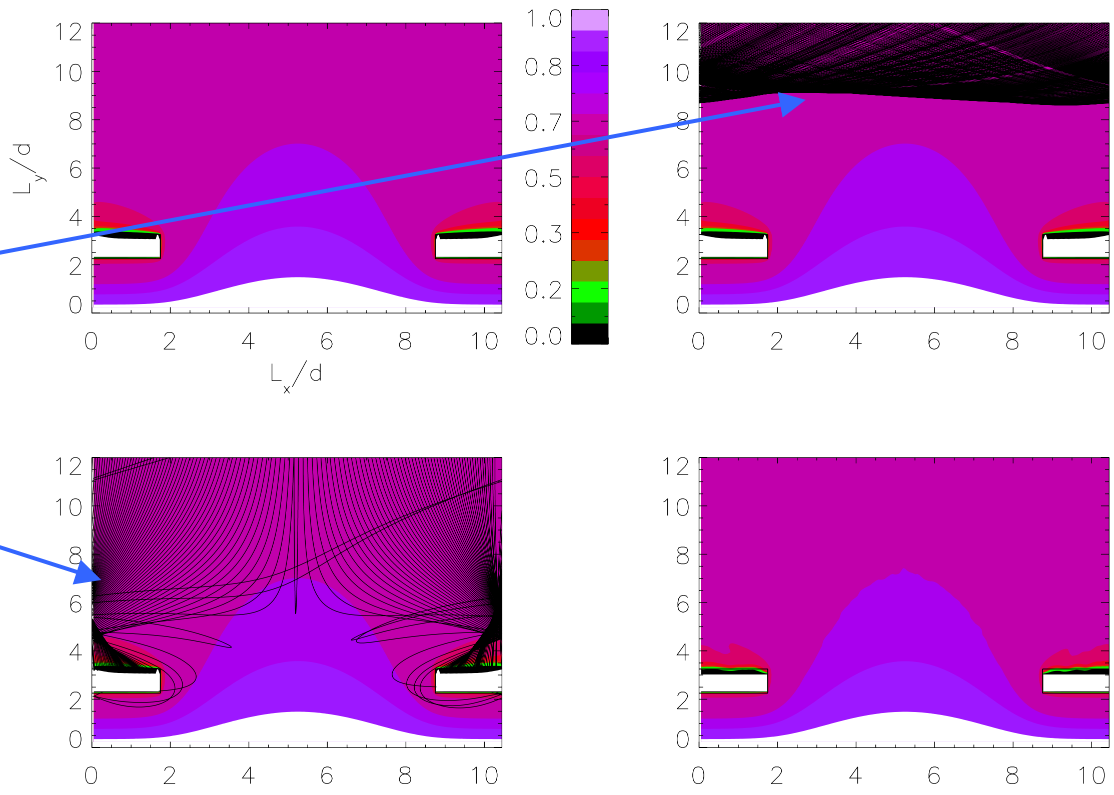
Let us add the Magnetic field

B = 50 Gauss along z-axis

Electrons are completely shielded

Protons are practically unaffected



Starting potential

Electron trajectories

Proton trajectories

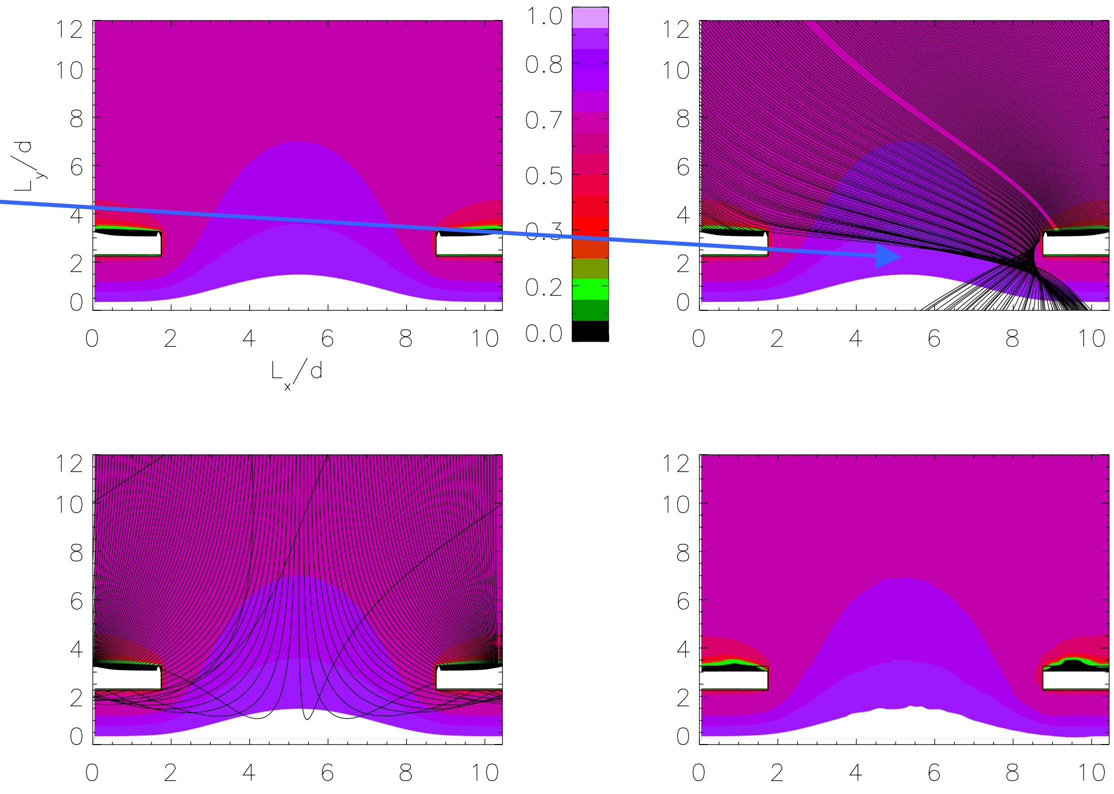
recomputed potential

What if ...

…the electrons are given enough velocity to overcome magnetic filter ?

Starting potential

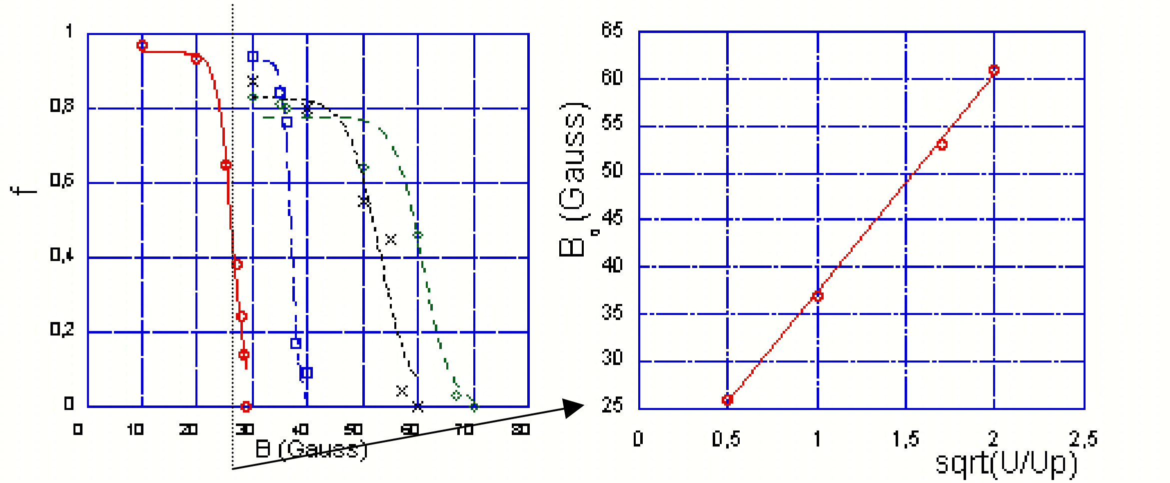
Electron trajectories



Proton trajectories

recomputed potential

Particles are bound inside the source depending upon their Larmor radius: $\rho < L_{y2}$



Fraction f of electrons escaping from the source *versus* applied magnetic field.

$B(f = 0.5)$ *versus* velocity

$U/U_p = 1/4$. $U/U_p = 1$

$U/U_p = 3$ $U/U_p = 4$

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Negative ions

Four different starting conditions

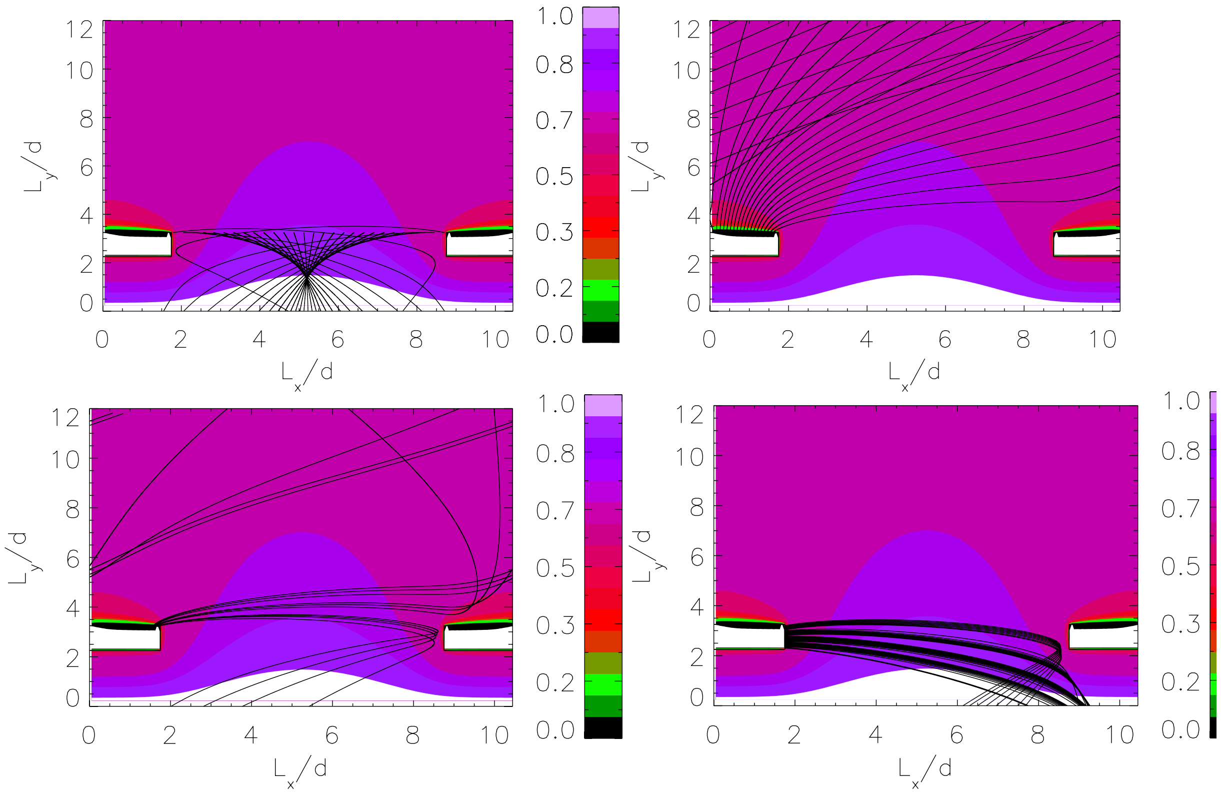
Extraction efficiency

strongly dependent upon

edge details (for surface production)

...uniformly from the plasma...

...from the grid, upper face



...from the very edge...

...and still from the grid,

now vertical face

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Future Developments

•Investigating the effects of realistic magnetic filters

•3-D geometry

Work in progress:

•Going beyond the collisionless approximation for the particles

This issue is currently being developed in parallel to the present code: a charged fluid model both collisional and magnetized (at present only 1-D geometry), by M. Cavenago. First calculations presented elsewhere [M. Cavenago, V. Antoni, F. Sattin, A. Tanga, *to be presented at* 2005 Particle Accelerator Conference, 16-20 May, Knoxville, Texas]

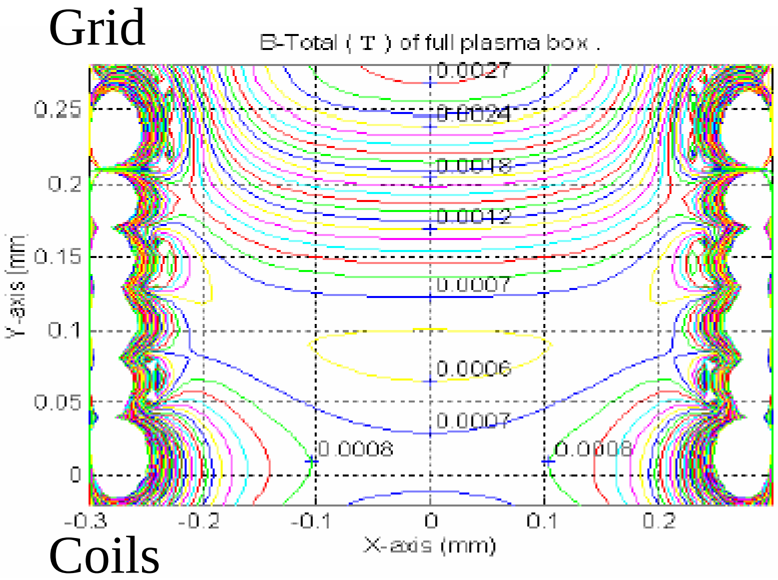

Fig.1 . Total magnetic field contour inside the plasma box.

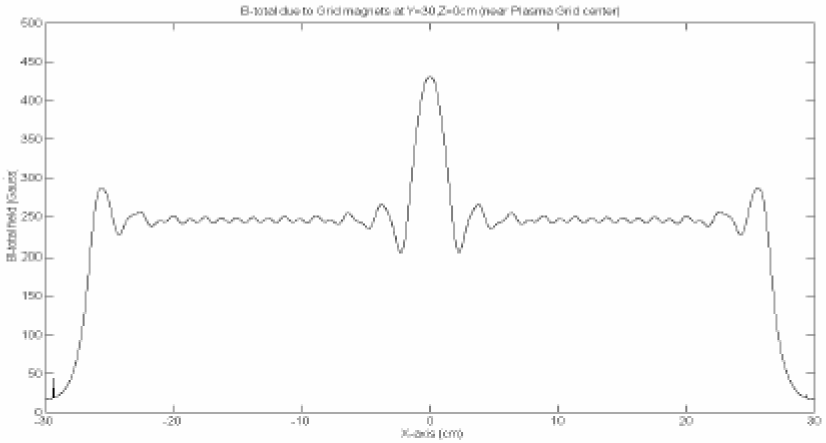

Fig.2 Total magnetic field along X-axis at Y=30cm Z=0. This field pattern is mainly generated by all the Grid magnets. The longer side of all the grid magnets are sitting perpendicular to the plane of the paper (x-axis).

Courtesy:

Mainak Bandyopadhyay