Particle-in-cell modeling of the inductive discharge inside the drivers of negative ion sources

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Negative ion sources for neutral beam injectors of modern and future tokamak machines, rely on a certain number of cylindrical quartz tubes (drivers) surrounded by an RF coil, in order to create a quasineutral plasma through an inductive discharge. The number of drivers depends on the size of the negative ion source, with SPIDER, the baseline source for the ITER neutral beam injector, featuring a total of 8 drivers, while other smaller experimental machines such as ELISE [1] and BUG [1,2] featuring respectively 4 and 1 drivers. The plasma created inside the drivers then expands into a larger expansion chamber ending with an extraction grid system, which ideally extracts as many negative ions as possible with a spatially uniform profile. Negative ions are mostly created because of neutral atoms interaction with the plasma grid, made of Molibdenum and covered by a layer of cesium to enhance negative ion production. To prevent the system from extracting electrons and losing efficiency, these are filtered by a magnetic field that is orthogonal to the drivers symmetry axis.

The overall simulation of the driver and of the expansion region has been attempted with fluid codes, like in [1,2]. However, these approaches have the limitation of assuming simplified coefficients for both collisional and collisionless electron transport, thus neglecting kinetic effects and instabilities, which might be relevant in the low pressure non-equilibrium plasmas typical of negative ion sources (fractions of a pascal). In this respect, the particle-in-cell (PIC) technique offers the opportunity of assessing such effects self-consistently, at the cost of a higher computational time. However, most PIC attempts to date have considered only electrostatic approaches assuming a non-consistent power deposition map inside the drivers, and have focused mainly on the plasma expansion chamber and on the effects of the magnetic filter ([3,4,5]). This work aims to overcome this inconsistency in the power deposition map, by modeling the driver through a quasi-static particle-in-cell model that accounts for Maxwell's equations for the induced fields. Particle collisions are accounted for by using Monte Carlo and Direct Simulation Monte Carlo methods, including charged particles collisions both against themselves (Coulomb collisions) and against the dominant neutral background.

The chosen code is PICCOLO ([5,6]), a massively parallelized Open MPI code that has been tested over thousands of CPU cores, while the activities have been carried out as part of the Eurofusion HPC project ASTONISH ("Advanced STudy On Negative Ion

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Source Heating"). Preliminary results for the obtained electron density and temperature in the driver of the BUG machine are shown in Fig. 1.

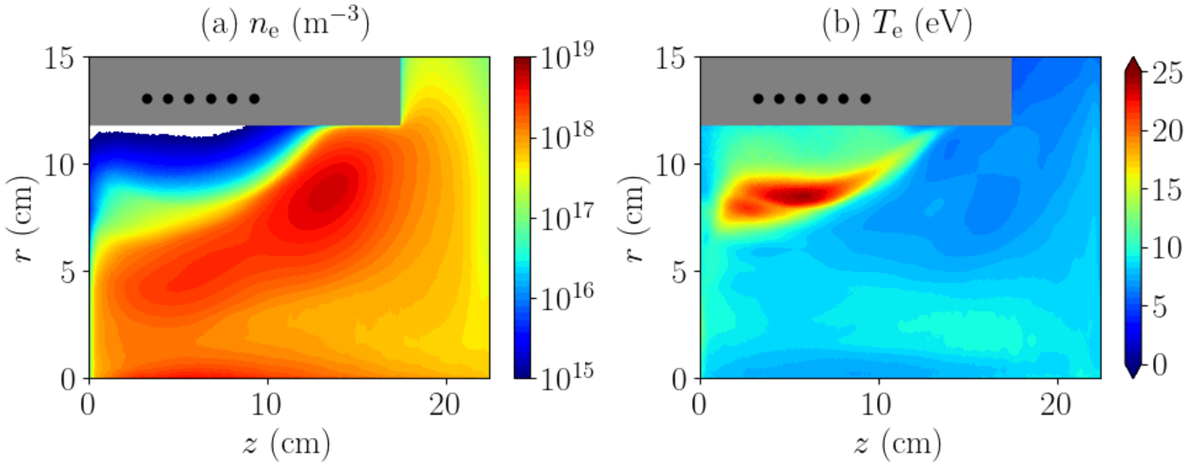

Figure 1: (a) Plasma density and (b) electron temperature after 10 RF cycles in the $r - z$ plane, time averaged over a full RF cycle. The horizontal axis $r = 0$ is the driver symmetry axis, while driver walls are shown in grey and RF coil turns by circle markers.

In this work, we shall present simulation results for different operating conditions of the BUG driver (gas pressure, RF coil current and frequency) thus identifying relevant trends with a direct comparison against any available experimental data, and focusing on the plasma heating physics (consistent plasma heating maps, role of non-equilibrium distribution functions, etc...).

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