laboratoire commun CEA/DRF CNRS/IN2P3

**PhD position in nuclear instrumentation**

# Particle In Cell code applied to the SPIRAL2 injector and extension to the SPIRAL1 charge breeder

## GANIL lab: production and acceleration of stable beam as well as radioactive beam

Stable ion beams as well as radioactive ion beams are the tools of physicists to probe nuclear matter and its organization at the atomic nucleus scale. The understanding of the physical properties of the atomic nuclei makes it possible to give elements of answer to the formation of our universe and the stars composing it. The GANIL laboratory is one of the few laboratories in the world to produce such stable and radioactive ion beams, in particular with the SPIRAL1 installations and the new SPIRAL2 installation. In a context of international competition, the production of increasingly intense and / or exotic beams, elements with specific Z like Calcium, Nickel, Titanium, Chlorine, Iron as well stable as radioactive, is a major interest for a laboratory such the GANIL laboratory, which struggles for excellence in the field of Nuclear Physics research but also in related fields such as Materials Physics with the CIMAP laboratory. GANIL has a long tradition (> 30 years) in the use and development of such objects and more particularly ion sources of the Electron Cyclotron Resonance type providing ions to the GANIL accelerators (cyclotrons as well as linac).

## Ion source using Electron Cyclotron Resonance

Because of their reliability of operation and their performance, the most commonly used ion sources are of the Electron Cyclotron Resonance (ECR) type, ion sources which very quickly replaced those based on heated filaments. The GANIL is one of the machines where the number of these equipments and their variety is the largest because the production of ions must answer to a wide requested range: high intensity (5 mA) of stable singly-charged ions; medium intensity (tens of μA) of stable ions with medium charge state; high intensity (several μAp) of highly charged stable ions (A / Q = 3); high efficiency (maximum as possible) for single-charged and moderately charged radioactive ion production. This broad dynamic explains the numerous source techniques present at GANIL. A large part of the knowledge of this type of ion source (ECR) is based on the experience gained during its operation and many empirical laws are applied as well for the realization - development of new sources as for their operation on accelerators. Even if the routine operation is acquired, there are several areas of obscurities that prevent complete control of this instrument: plasma instabilities limiting microwave power injected; internal electrostatic confinement still poorly understood, playing an important role in the production of highly charged ions; plasma - vacuum interface for creating the extracted ion beam; experimentally measured ionic temperature having great differences with the theory etc... The question to which this thesis work will try to answer is to know if, from a Particle In Cell simulation code, it will be possible to understand the actual limitations of these ion sources and open up new ways to increase ion intensity - high charge states required for GANIL physics experiments.

## Benefit of this thesis:

The aim of this thesis is to understand the dynamics of neutral and charged particles inside the ECR plasma. Indeed, the neutrals, the ions and the electrons of such a plasma have behaviors which are very different but which are also closely related especially for the charged particles. Electrons are magnetized particles that will be the ones transferring their energy from the radiofrequency power to the plasma. The ions will be able to be as well magnetized as

collisional according to their charge and their localization within the plasma. Neutrals are insensitive to electrostatic fields but their directivity (especially for metallic vapors) will play an important role for the final production of intense metal ion beams of very high charge states. In order to answer the question expressed above "will it be possible to understand the current limitations of these ion sources and to open new ways to increase the ion intensity - high charge states", only a simulation taking into account all the species present and their dynamic will be able to respond to it.
A Particle In Cell code has already been the topic of a thesis (Alexandre Leduc) which will be defended in November 2019. This allowed to make a first base for ions and provided some answers on the dynamics of neutrals regarding the overall efficiency of the production of metal ion beams. The LAPLACE laboratory, at the University of Toulouse, is recognized worldwide for its work on plasmas and especially for the development of PIC codes that have demonstrated their ability to model the operation of positive ion sources for propulsion (thrusters) and negative ion sources for the ITER neutral injector. To go towards a complete simulation, it is now necessary to integrate the dynamics of the electrons and solve the Poisson equation to take into account, dynamically, the interactions of the charged particles with the electrostatic fields present in the plasma.

## Work to be done during this thesis:

The work to be done will have two aspects: simulation and experiment. For the simulation part, it will be necessary to modify the existing PIC code by introducing the electrons and solving the Poisson equation. It will also add the stochastic heating of electrons by the microwave wave injected into the ion source. It will thus be necessary to create observables which will be the link between the simulation and the experiments carried out. The experimental part will be carried out near the SPIRAL2 accelerator injector, namely the Phoenix V3 source. Experiments with an Argon plasma alone and mixed with oxygen will validate the simulation code. Then experiments will be carried out with plasmas containing metal ions such as calcium and nickel alone or in the presence of nitrogen. Early steps will be undertaken to apply this code to a charge breeder.

## Expected skills:
Basic of plasma Physics, candidate must be attracted by simulations as well as experimental work, C/C++ - Fortran coding

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