# A Particle-in-Cell/Monte-Carlo-Collision Code for the Simulation of Stepwise Ionization of Lithium in 2.45 GHz ECR Ion Source

ecris 2018

State Key Laboratory of Nuclear Physics and Technology


J. F. Zhang†, S. X. Peng, W. B. Wu, T. H. Ma, T. Zhang, J. M. Wen, Y. X. Jiang, Y. Xu, A. L. Zhang, J. Sun, H. T. Ren, Z. Y. Guo, J. E. Chen

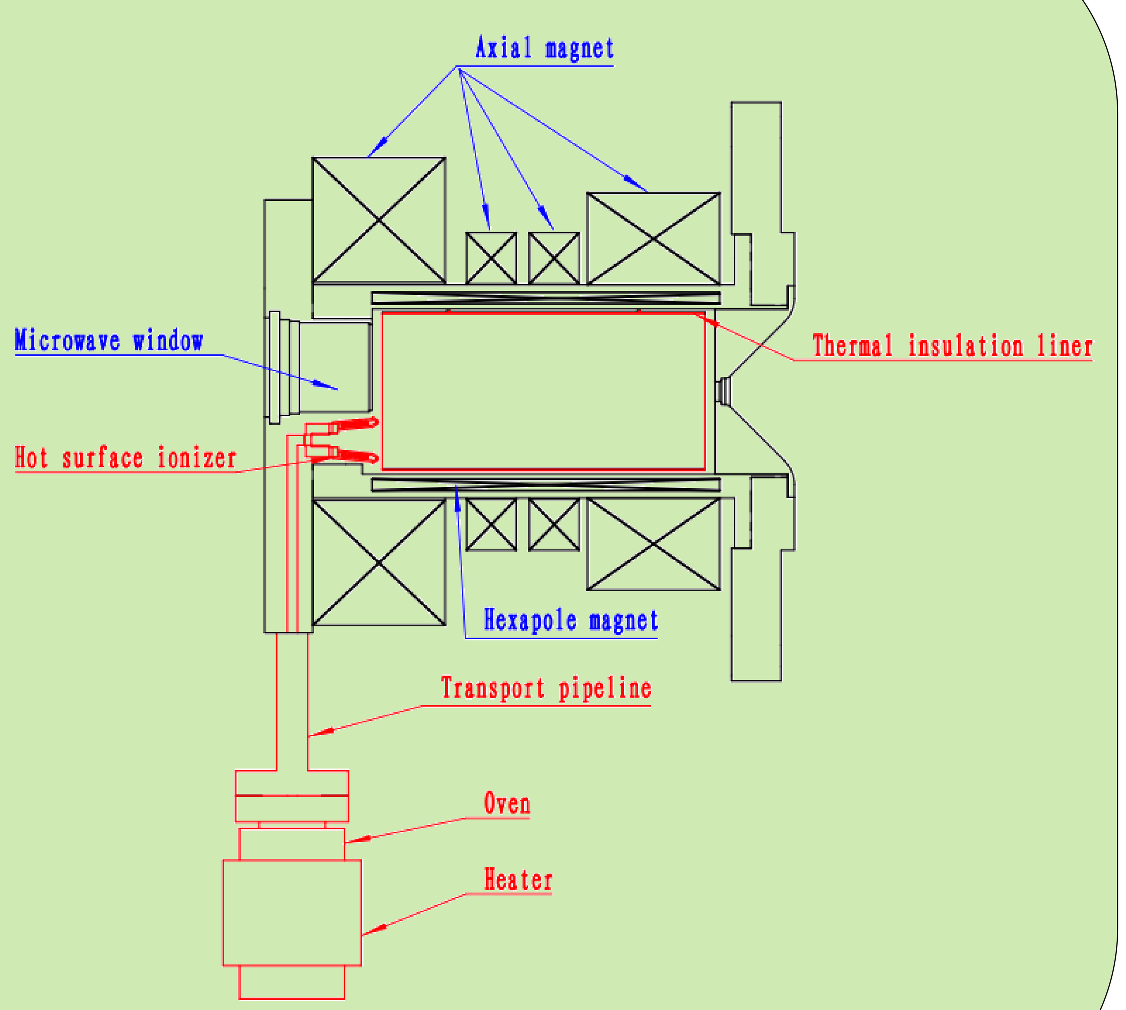
*State Key Laboratory of Nuclear Physics and Technology, Institute of Heavy Ion Physics, Peking University, Beijing 100871, China*

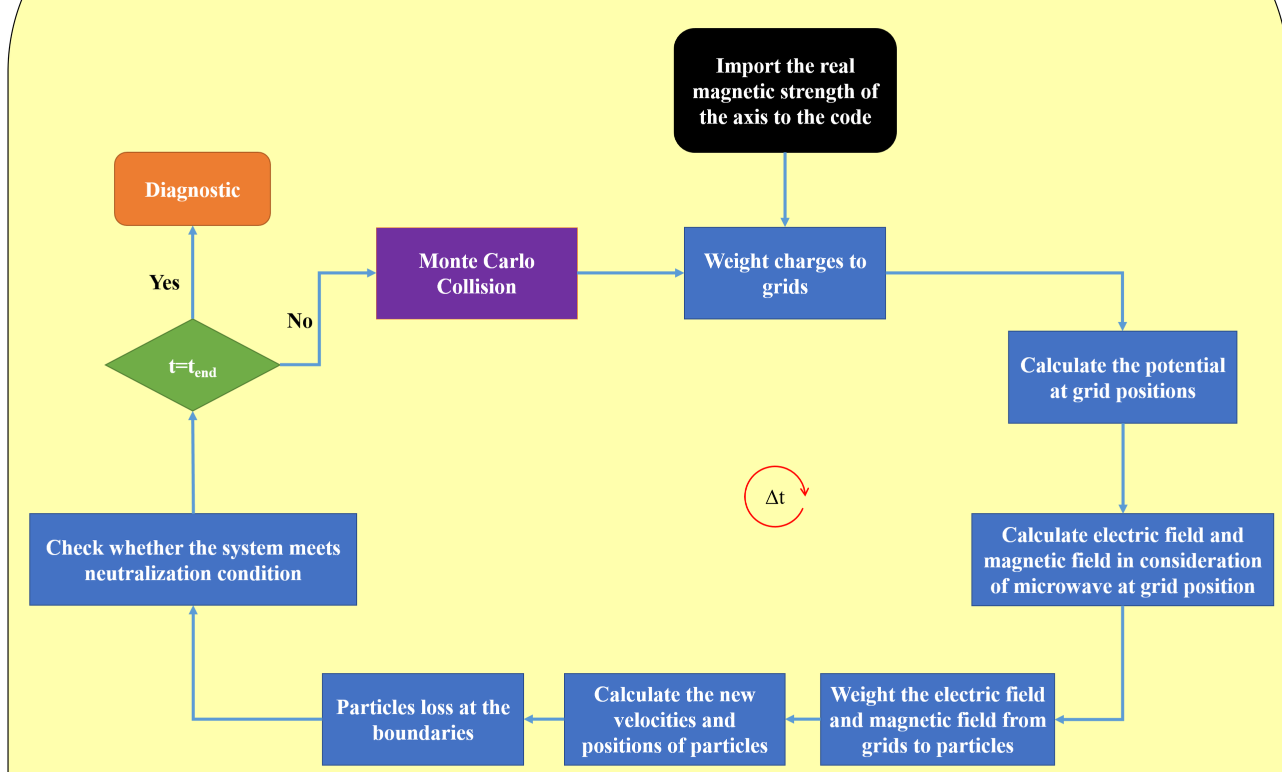
†zhangjingfeng@pku.edu.cn



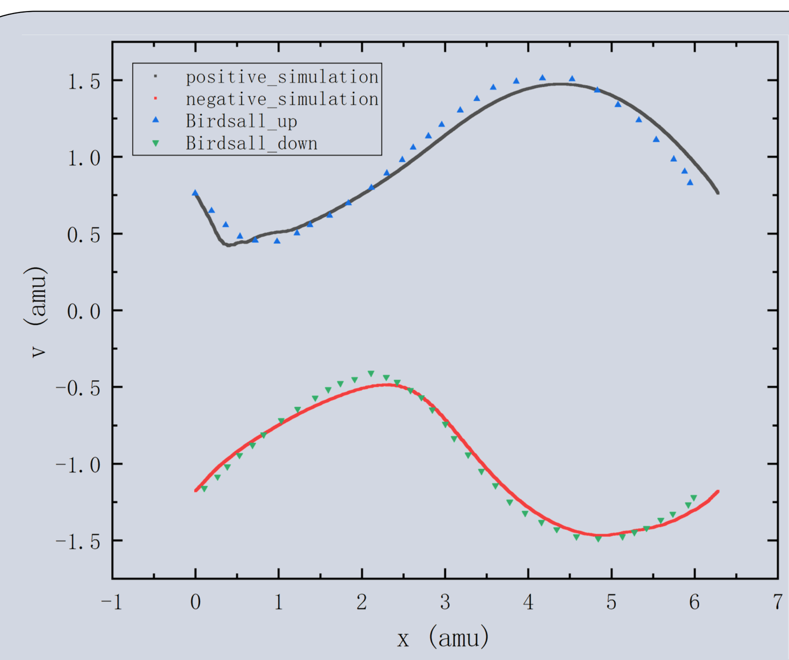
**Abstract:** A 2.45 GHz hybrid $^{7}Li^{3+}$ ion source has been designed at Peking University (PKU). In order to better understand the physical processes inside the hybrid lithium ion source, a Particle-in-Cell/Monte-Carlo-Collision (PIC/MCC) code is developed recently. In this model, the propagation of the 2.45 GHz microwave is processed using Finite-Difference Time-Domain (FDTD) method, and PIC and MCC method are used to handle the interaction of charged particles with electromagnetic field and collision process between particles, respectively. It can be used to simulate the motion of particles in single spatial dimension and three velocity dimensions, abbreviated as 1D3V. The validity of the PIC method has been confirmed by the simulation of two stream instability in this work. The preliminary simulation results show that the 2.45 GHz microwave energy can be absorbed effectively by electrons in the presence of an external magnetic field of 875 G. And the mirror magnetic field can increase the transverse velocities of electrons.

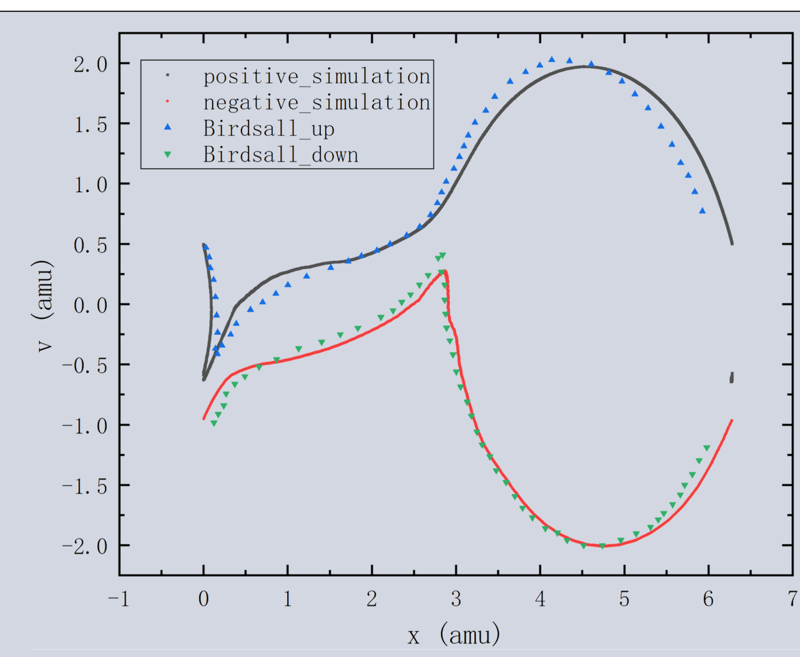

To fulfil the requirement of the Compact Intense Fast NEutron Facility (CIFNEF) which is proposed by Peking University (PKU) and China Institute of Atomic Energy (CIAE), a 2.45 GHz hybrid ion source for the production of $^{7}Li^{3+}$ is designed. This hybrid $^{7}Li^{3+}$ ion source is composed of a hot surface ionizer and a 2.45 GHz microwave ion source. To get lithium vapour, an oven and a heater are used. In order to avoid the condensation of the lithium vapour, the transport pipeline and the liner are all adiabatic. The red boundary will be hot surface. Like other ECR ion source developed at PKU, a three-layer $Al_2O_3$ plus a BN disc will be used to introduce the 2.45 GHz microwave into the plasma chamber. A minimum-B magnetic configuration generated by permanent magnets will be used to confine the plasma.




*The flow chart of the PIC/MCC code*

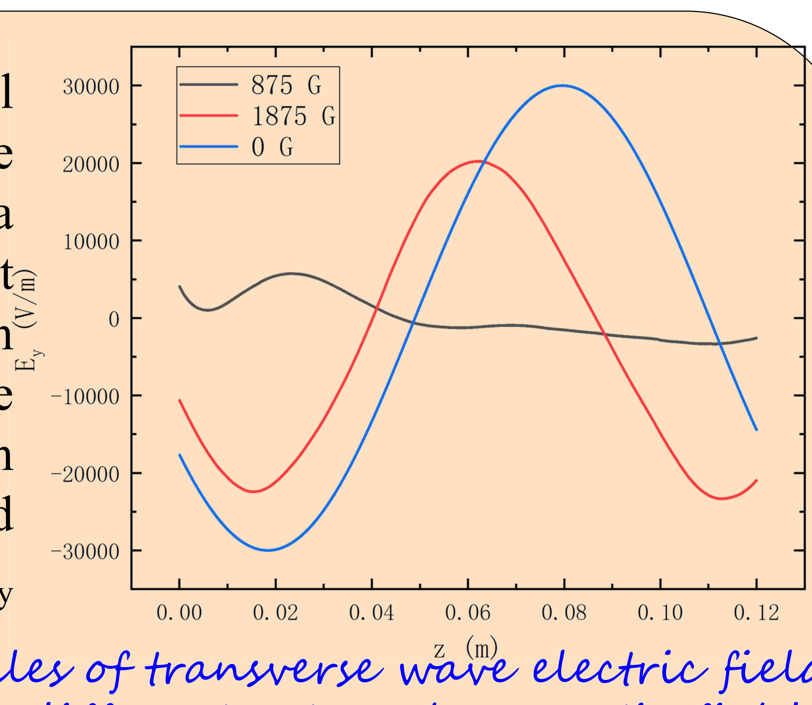



*The phase space plots of two stream instability (left: t = 16, right: t = 18).*

In order to validate the PIC code, the two stream instability process is performed and compared with the results got by Birdsall. Two opposing streams of charged particles with a perturbation in their density are unstable. Two streams of particles with the same mass charge ratio are loaded in the system, and the velocities of the two streams are set as $v_x$=1 and $v_x$ = -1 which are non-dimensional. The perturbation is carried out by adding a small sinusoidal perturbation in the density of the particles of each species. The boundary of the system is periodic. Left figures show the comparison of our simulation results with Birdsall's. It can be seen that the results show good agreement with those from Birdsall, which validates the PIC part of our code.

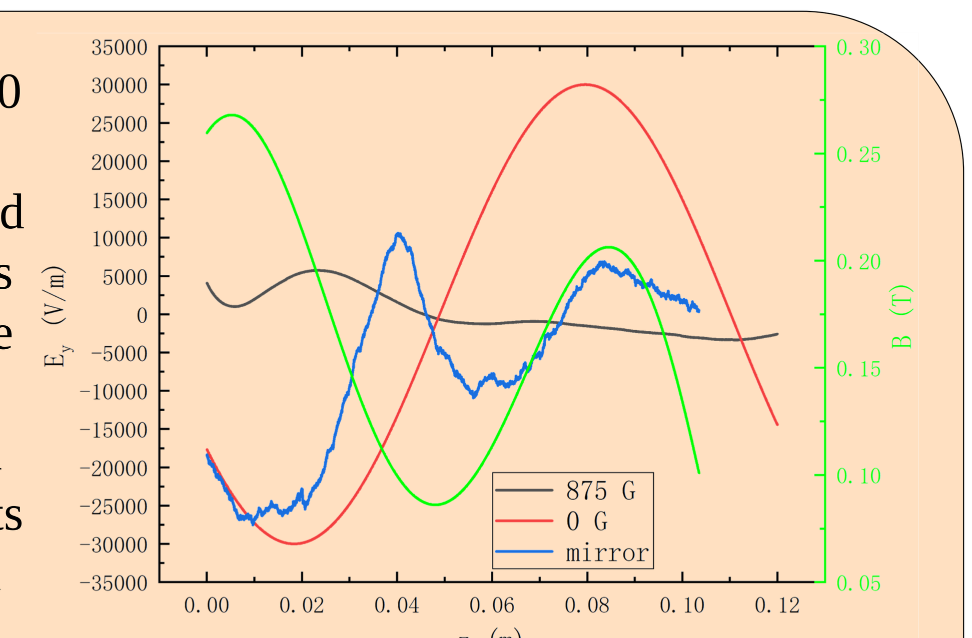
When there are no particles and external magnetic field in the system, the microwave propagates along the axis in a shape of perfect sinusoidal wave. It confirms the validation of the propagation of microwave of the code. When the external magnetic field is 875 G which corresponds to the resonant magnetic field of 2.45 GHz microwave, the profile of $E_y$ shrinks nearly around the zero line.




*Profiles of transverse wave electric field $E_y$ in different external magnetic fields.*

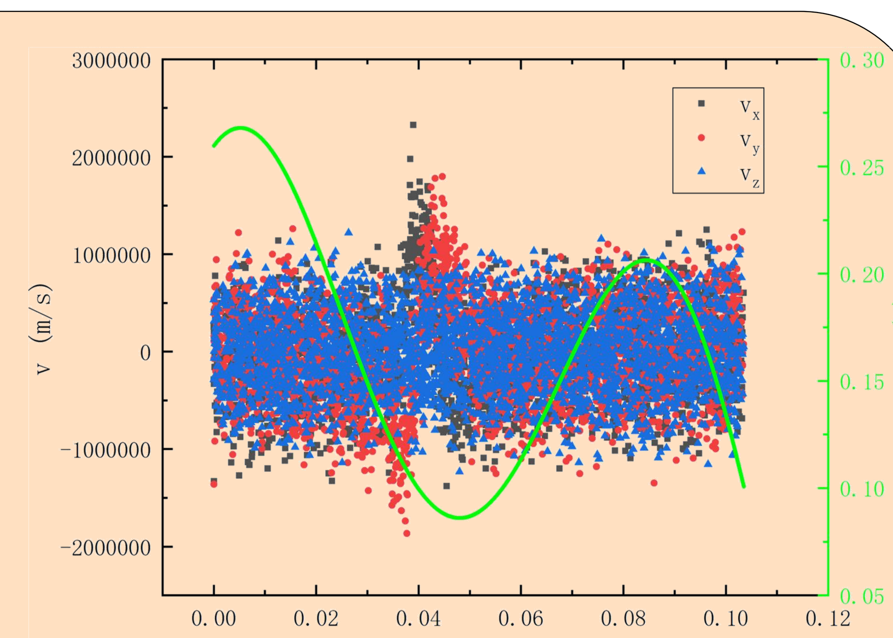
It means that the energy of microwave is strongly absorbed by particles mainly electrons in cyclotron resonance conditions. When the magnetic field is changed to 1875 G, the resonant magnetic field of 5.25 GHz microwave which is much larger than the frequency of the incoming microwave, the profile of $E_y$ damps slightly, which indicates that the microwave can propagate the plasma fluently.

It is apparent that within the first 40 mm in the axial direction, the strength of mirror field declines and the profile of $E_y$ in mirror field gets close to the zero line faster than the profile of $E_y$ without plasma. After 40 mm, the strength of mirror field arrives at the lowest point and starts to get through the second peak and the profile of $E_y$ in mirror field oscillates around the zero line with smaller amplitude compared with the profile of $E_y$ without plasma. The results show that the energy of microwave is absorbed dramatically at the valley of the mirror field.




*Profiles of transverse wave electric field $E_y$ in constant external magnetic field and mirror field.*

There is a significant increase of the transverse velocities of electrons at the valley of the mirror field. This phenomenon corresponds to the results of the propagation of microwave that the electrons are confined at the valley of the mirror field and absorb the energy of microwave propagating at this area. The axial velocities of electrons do not show any particular change.




*v-z phase space distribution of electrons within the mirror field.*

A 1D3V PIC/MCC code is developed to simulate the propagation of 2.45 GHz microwave in lithium plasma with constant magnetic field and mirror field and the v-z phase space distribution of electrons within the mirror field is also studied. The simulation results show that the energy of microwave is absorbed significantly when the external magnetic field is 875 G. Electrons trapped in the mirror field can dramatically absorb the energy of microwave, leading to the increase of the transverse velocities. The motion of electrons in mirror field is meaningful for us to understand the physics of the lithium ion source.

In the future, the behaviour of lithium ions will be considered, including the charge state distribution, the ionization rate, the influence of the density of lithium vapour and so on. All these researches are in progress, and will be reported later.