SIMULATION TOOLS DEVELOPMENT FOR ECR ION SOURCES AT CEA Saclay

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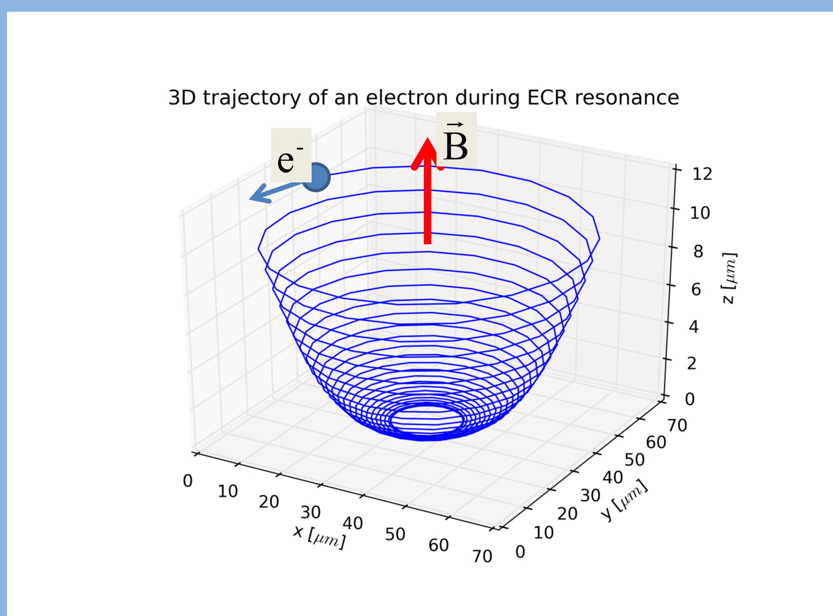
Abstract:
A key point for the size and performance optimization of ECR (electron cyclotron resonance) ion sources is a better understanding of the plasma ionization and heating in the plasma chamber. According to experimental data, the effect of different parameters on the extracted current must be understood. We present here the developments done at CEA Saclay in this purpose.

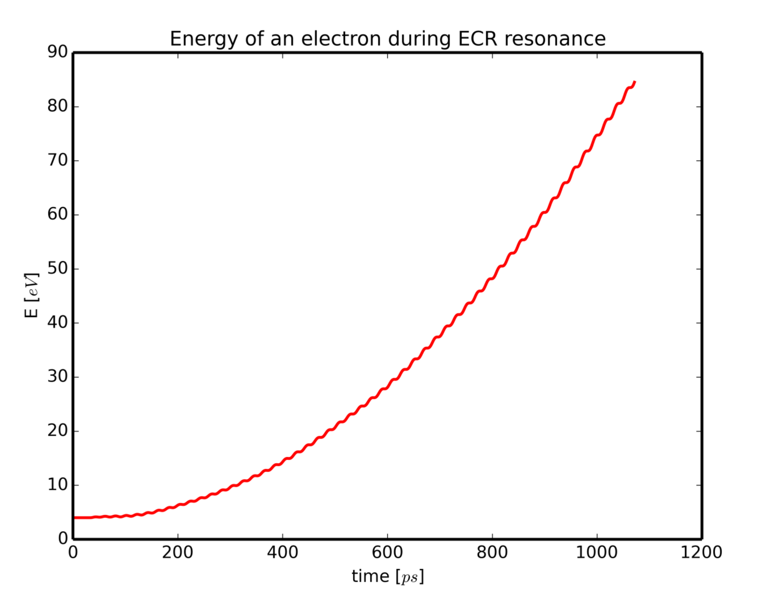
What is ECR heating ?

- High frequency wave excitation of strongly magnetized electrons

$$\omega_{cyclo} = \frac{eB}{m} \qquad \omega_{HF} \quad \Bigg\} \quad \omega_{cyclo} = \omega_{HF} \ \text{for } B = 875\,\text{Gauss},\ f_{HF} = 2.45GHz$$

- Excited electrons ionize the gas, creating a plasma





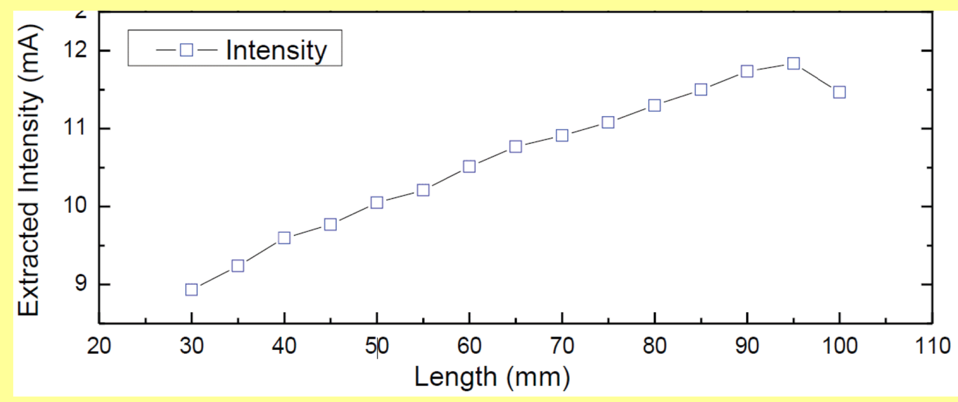
ECR ion source chalenge

- CEA Saclay has developed ECR light ion sources since 90's
- Parameter scan on the extracted beam of ALISES (Tuske et al. 2012)

→ Target : simulate the plasma chamber to understand these effects

Projet /Source	High Voltage	Current	Magnetic Configuration
SILHI ➔ IPHI	100kV	100mA H+	Coils
IFMIF EVEDA	100kV	140mA D+	Coils
SPIRAL2	20kV 40kV	5mA H+ 5mA D+	Permanent Magnets
ALISES	40kV 100kV	15mA Not yet tested	Coils
SILAP-1	40kV	30mA / 60mA	Permanent Magnets
SILHI2	50kV	40mA	Permanent Magnets

Sources developed at CEA Saclay



Extracted Intensity function to the ALISES chamber lenght
Tuske et al 2012

Domains of interest :

Plasma wave interaction :

- Proportion of wave absorbed/reflected ?
- Heating of the electrons ?
- Detuning effects for the wave due to the plasma ?
- Numerical resolution : Electromagnetic with WARP

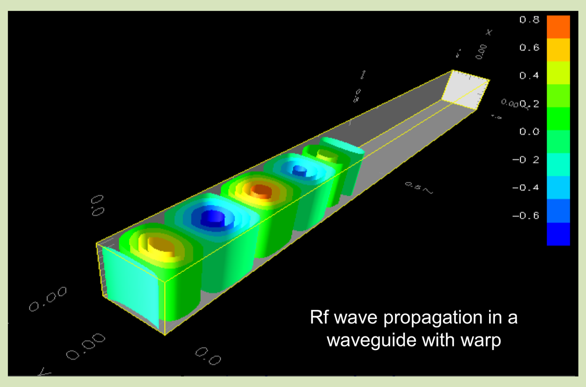
The whole plasma chamber :

- Fully kinetic description necessary : non Maxwellian distribution for particles.
- Processes to consider:
  - Plasma chemistry
  - ECR heating (operator)
  - Edge effects : wall and extraction zone
  - Particle-field interaction

Numerical constraints :

Electromagnetic PIC simulation :

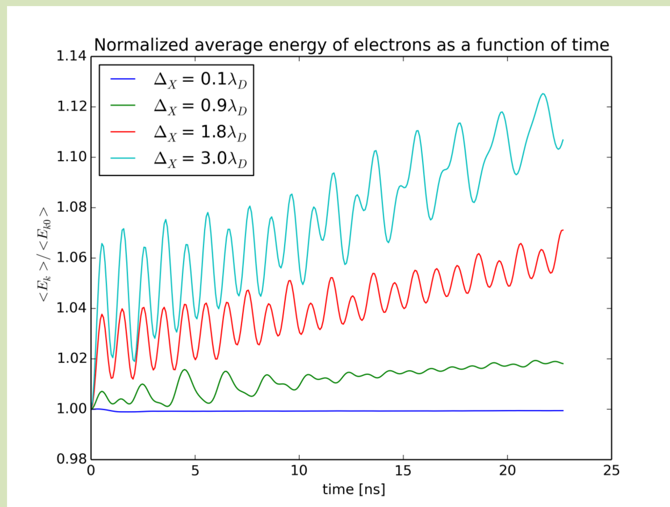
- Drastic stability conditions :
  - Plasma processes : Debye length $\lambda_D \sim 10\ \mu m$
  - Electromagnetic CFL condition $\tau_{el} \sim 1\ ps$
- Allows to simulate on a reduced space (resonance region)



Electrostatic PIC simulation :

- Mesh size smaller than Debye length ($T_e \sim\sim$eV) $\lambda_D \sim 10\ \mu m$

→ Too CPU-consuming to simulate directly with standard PIC simulations



Developments :

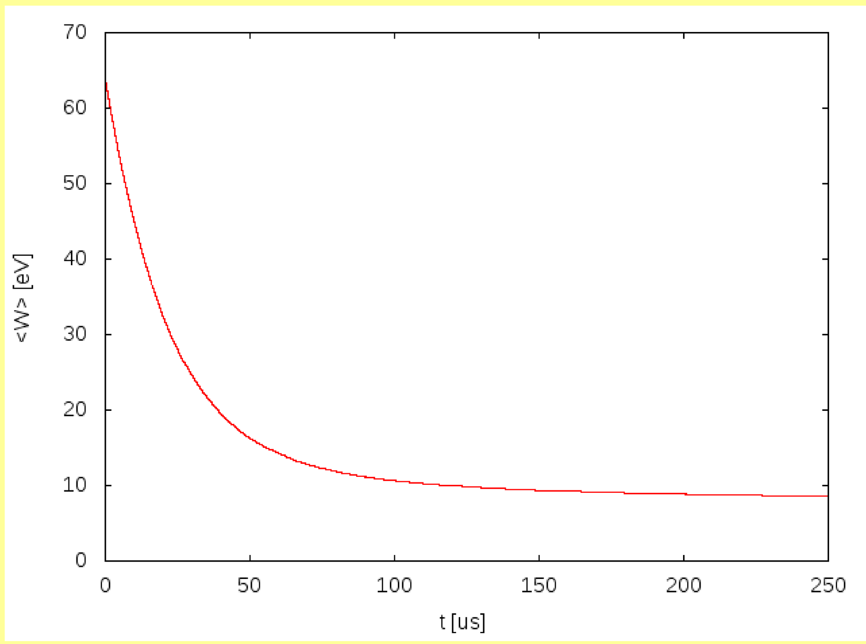
Plasma chemistry :

- Extension of WARP module to conserve energy

→ Dynamical model conserving energy and momentum :

$$T_{e0} - B = T_{e1} + T_{e2}$$
$$\overrightarrow{p_{e0}} = \overrightarrow{p_{e1}} + \overrightarrow{p_{e2}}$$

Use of cross section database



Statistical evolution of the energy of an electron initially at 60 eV

WARP extension : QUASI NEUTRAL PIC *(LAMPE 98)*

- Consider a strongly magnetized Plasma
- Assume permanent quasi-neutrality
  - The electron dynamic is directly constrained
  - Not necessary to resolve Debye length and electron plasma oscillation
  - Plasma/wall interaction can be computed

→ The whole plasma chamber can be simulated

- Use of full EM PIC simulation to quantify the heating
- Discussions with LPGP for the development

Conclusions & perspectives :

- Quasi neutral PIC extension of WARP is an important part of the project, and is in development.
- The transition zone between the plasma chamber and the beam is a crucial point. We still have no clear idea on how it influences the plasma chamber. This must be treated as a boundary condition for the simulation, and requires an important development.
- An experiment to measure the electron temperature in the plasma chamber is being developed at CEA Saclay. This project which involves CEA, LPGP and GSI, is based on the measurement of the incoherent Compton scattering of a laser by the plasma electrons. The comparison between the simulations and measurements will be an important point to validate the code.

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