Calcium production and Hot liner Study with the Phoenix V3 ECR Ion Source

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ECRIS 2018

- Motivation
- Experimental Setup
- Metal vaporization
- ECR Ion Source modelization
- Conclusion

Motivation

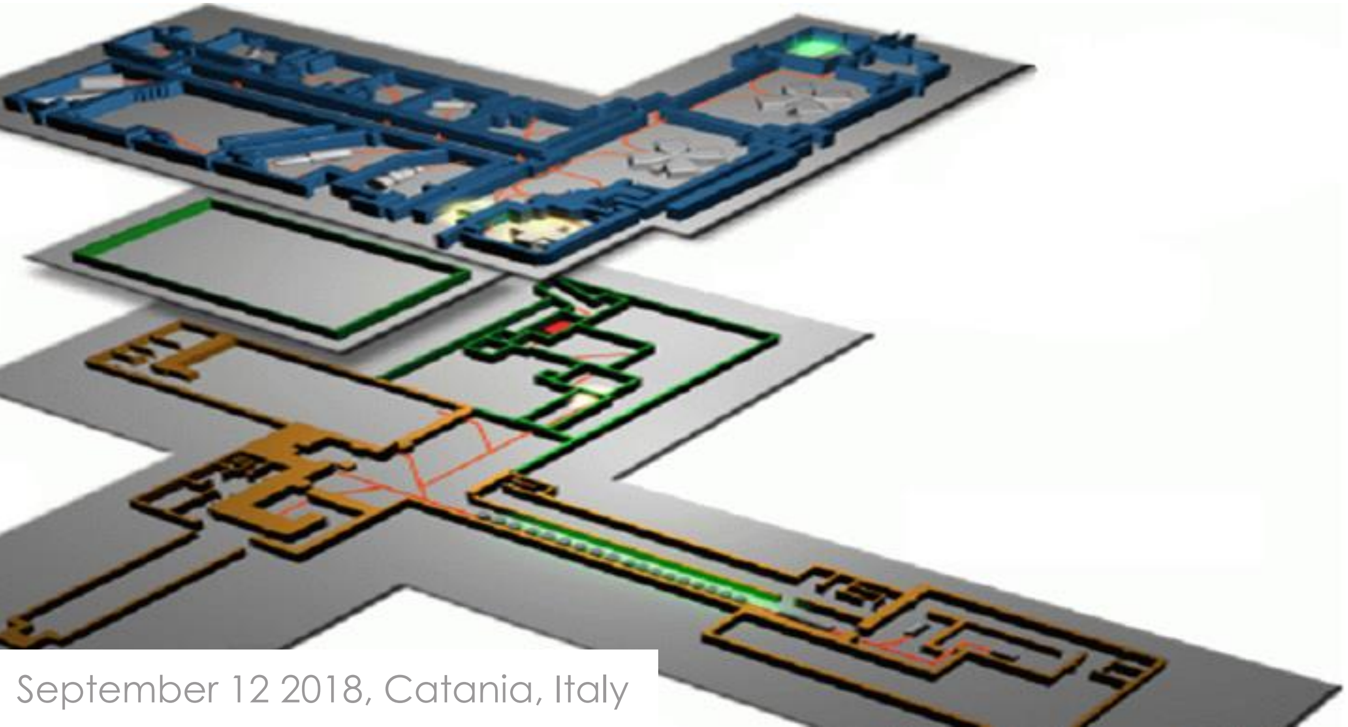
Spiral2 Project at GANIL (Caen, France)

multi-beam driver, light/heavy-ion linac

Metallic ion beam needed for S^3experiments

(e.g. $^{40-48}Ca, ^{48-50}Ti, ^{50}Cr, ^{50}Ni\ \geq 1p\mu A$ for $^{M}/_{Q} = 3$)

Super Separator Spectrometer



Metallic Ion production

global efficiency 10% to 20%

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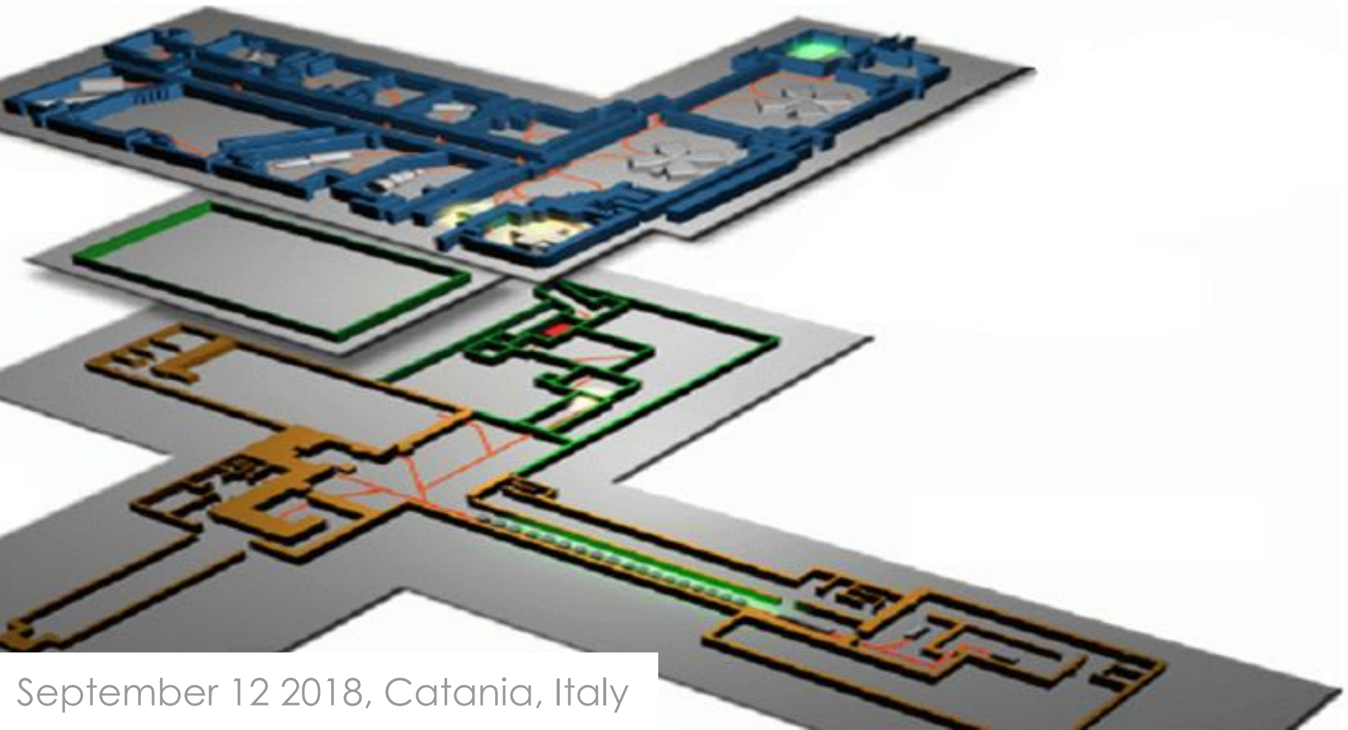

Metallic Ion production

global efficiency 10% to 20%

Motivation

Objective :

double the metallic ion production efficiency

Experimental way :

Increase the ionization efficiency with a thermoregulated heated liner

With simulation :

Study of the dynamic of ion production in an ECR plasma and reproduce experiments

Existing work

Experimental :

Direct ohmic heated Tantalum Liner for Ca^{5+}, Dubna, Russia (70% efficiency)

Tantalum Liner for Ca, Legnaro, Italy

Simulation :

Particle-In-Cell for ECR source plasma , Dubna, Russia
3D simulation of ion dynamics, Dubna, Russia

Project goal

Production Ca^{16+} with liner
Liner simulation in a 3D simulation of ion dynamics

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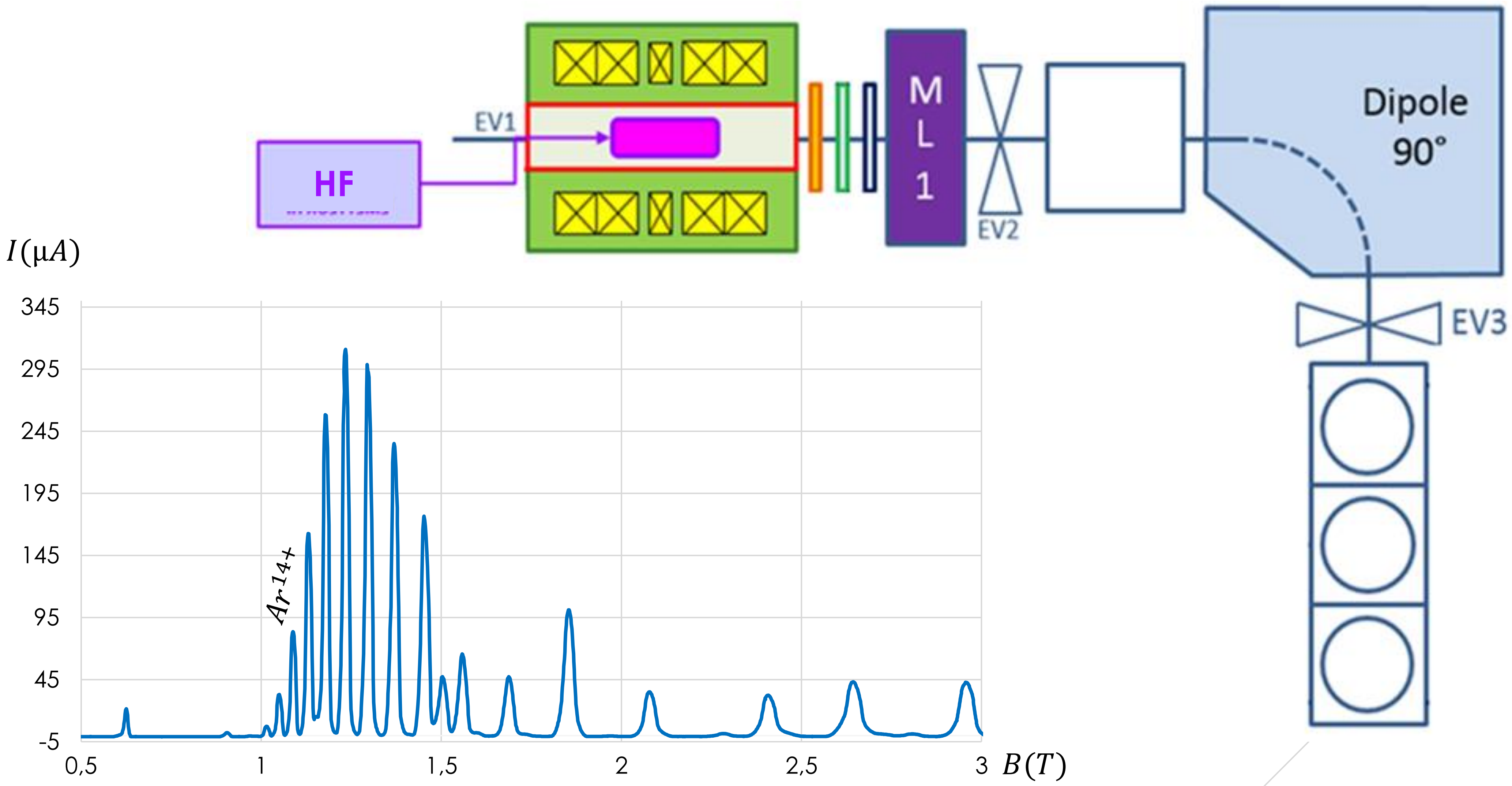
Experimental Setup

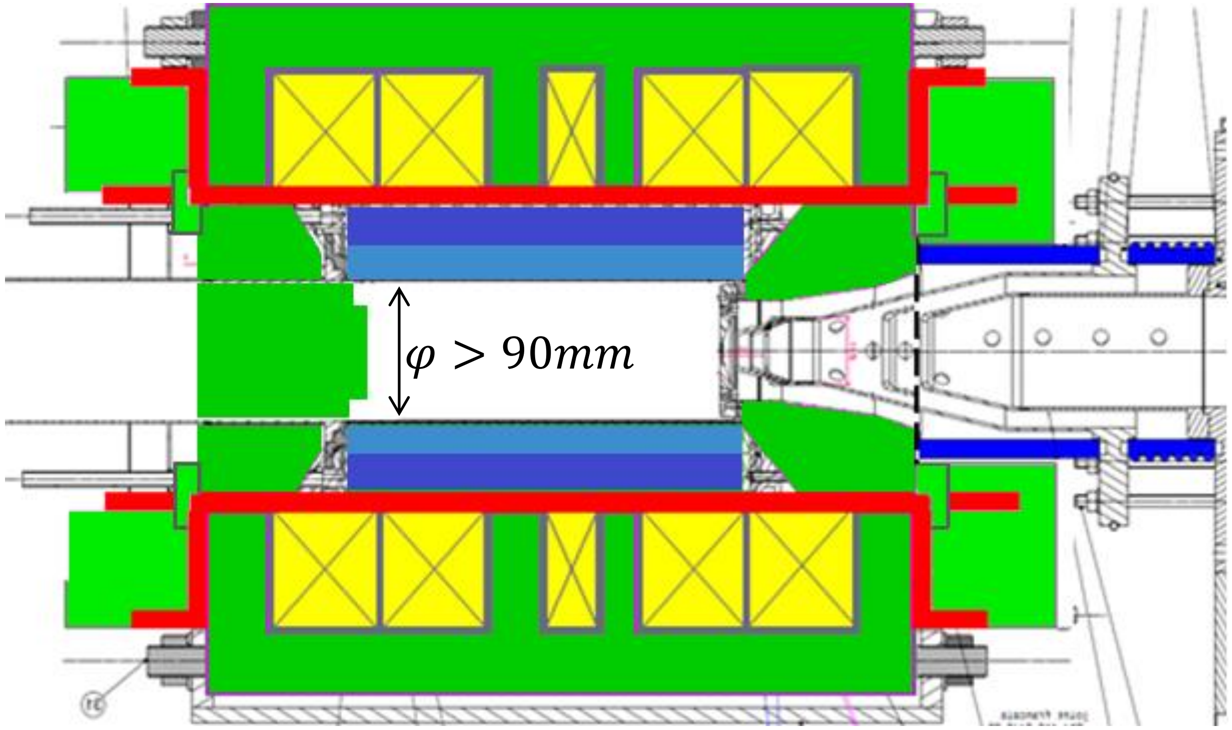
Beam analysis line for Phoenix V3 ECRIS at 18 GHz



Plasma:
Oxygen, Argon

Experimental Setup

PHOENIX V3 ECRIS



Objective : metallic ion production with hot liner

Phoenix V3 for Spiral2

- Length of 220 mm
- Radius of 46 mm
- Volume of 1,45 liter
- ECR Zone of 95 cm^3
- High Frequency 18 GHz

Standard magnetic field
Room temperature

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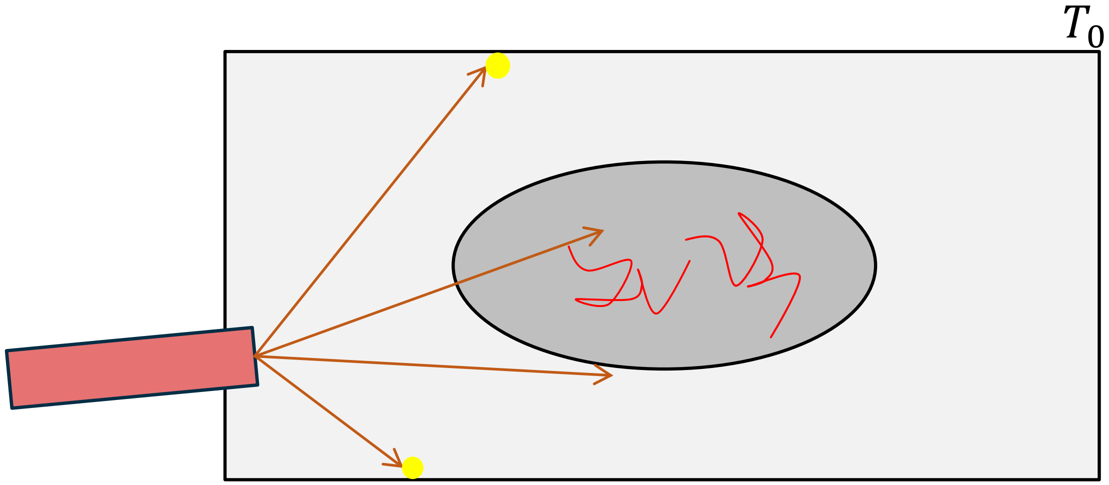
Metal vaporization parameters

Metallic ion Production

Metallic atoms sublimated or evaporated using an oven

Injected in the source toward the plasma

Ionization probability in flight



High bonding probability at the wall

$P_{bonding}$

Low re-emission probability

Metal vaporization parameters

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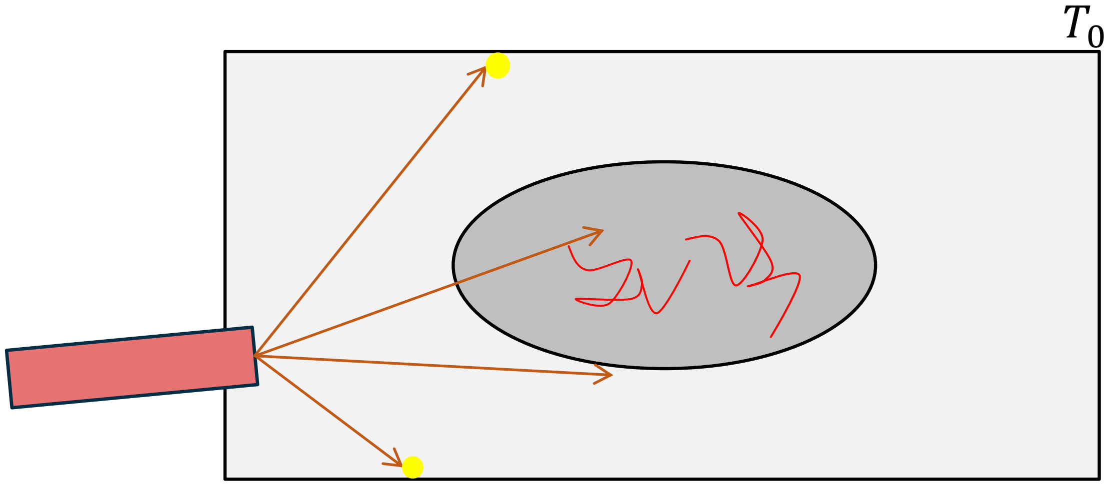
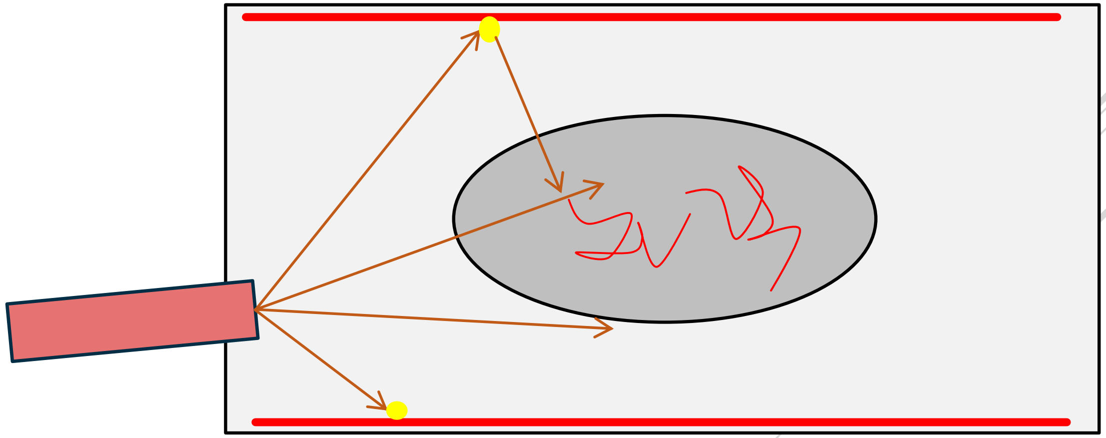


High bonding probability at the wall

$P_{bonding}$

Low re-emission probability

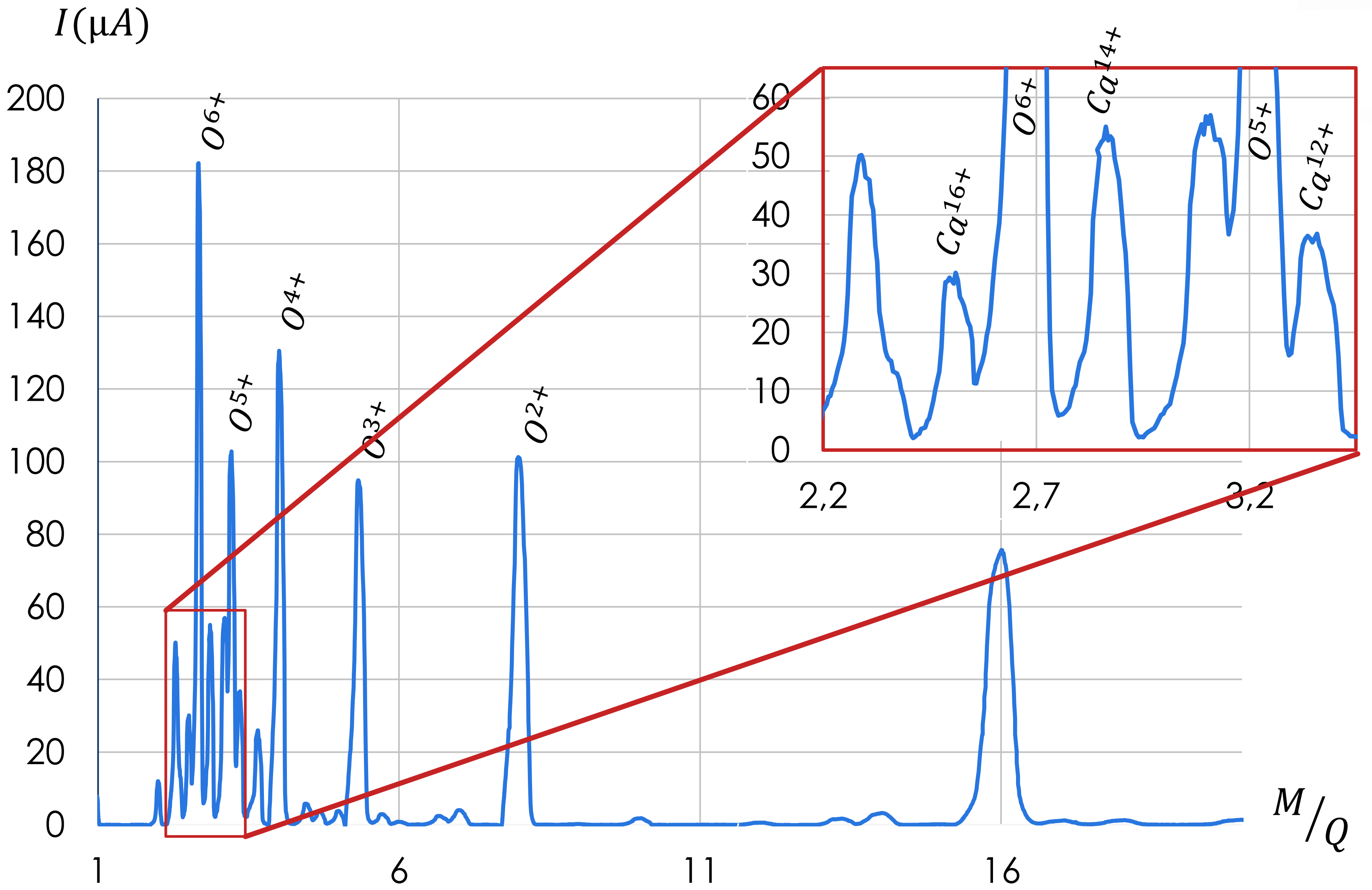
Thermoregulated cylinder (liner $T > T_0$)



Efficiency improvement expected

Metal vaporization

Early test at LPSC with a new oven



low temperature cartridge oven (LBNL, MSU)

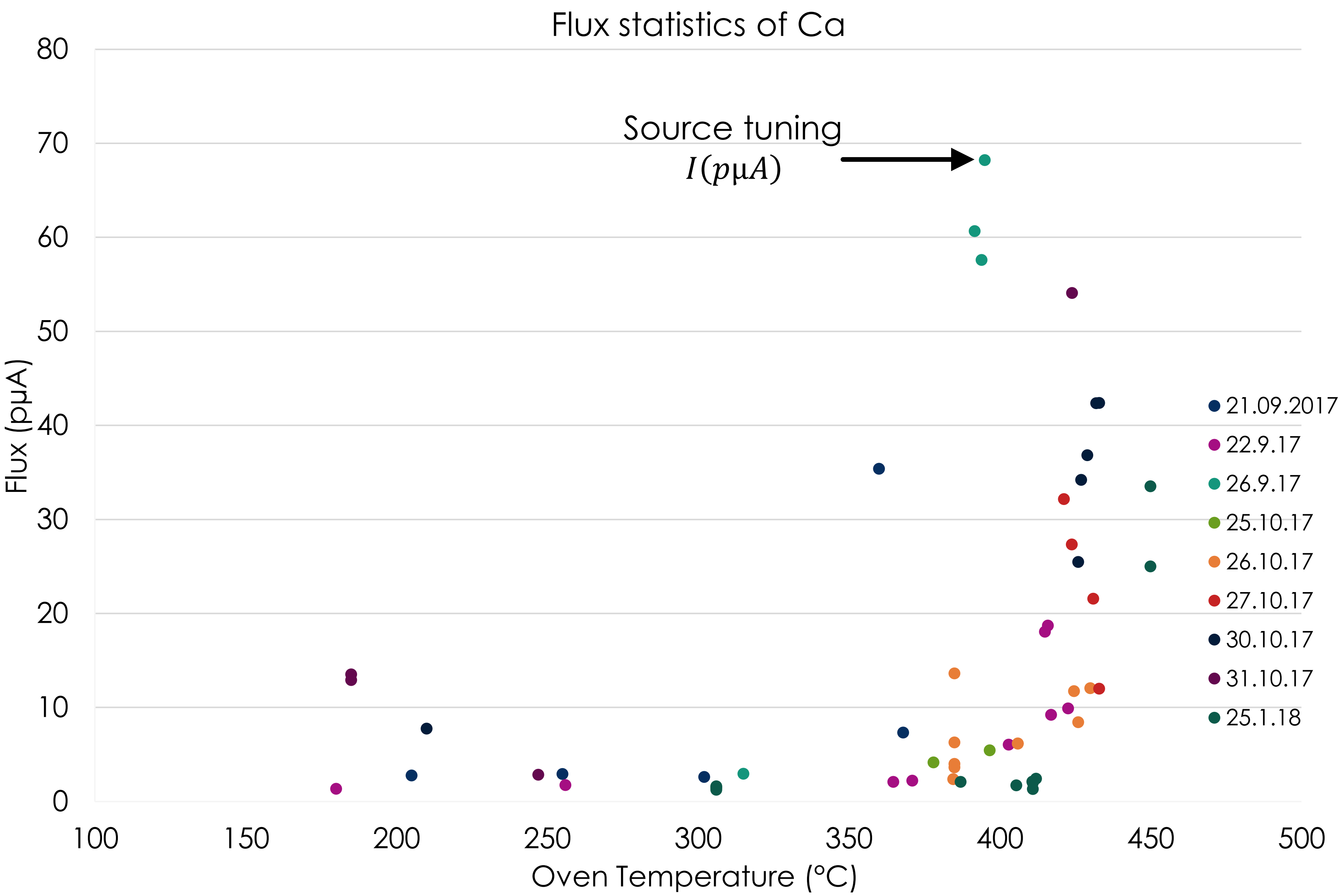
Oven operation
Without liner

Production of ion $^{M}/_{Q} = 3$
$\sim 2\ p\mu A$

Source operation for metallic atoms

Metal vaporization

Calcium Production Test



Efficiency : $\frac{\sum I(p\mu A) * time}{mass_{consumed}}$

around 20% without liner

oxygen buffer gas

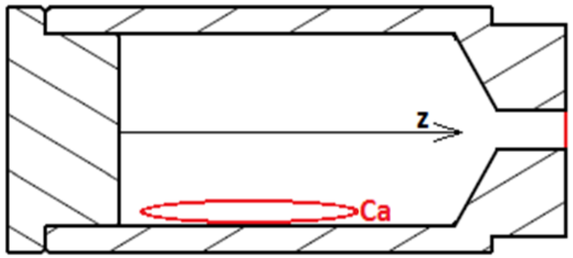
Constraint of the simulation parameters

Metal vaporization

Simulation of Calcium Oven

PIC simulation

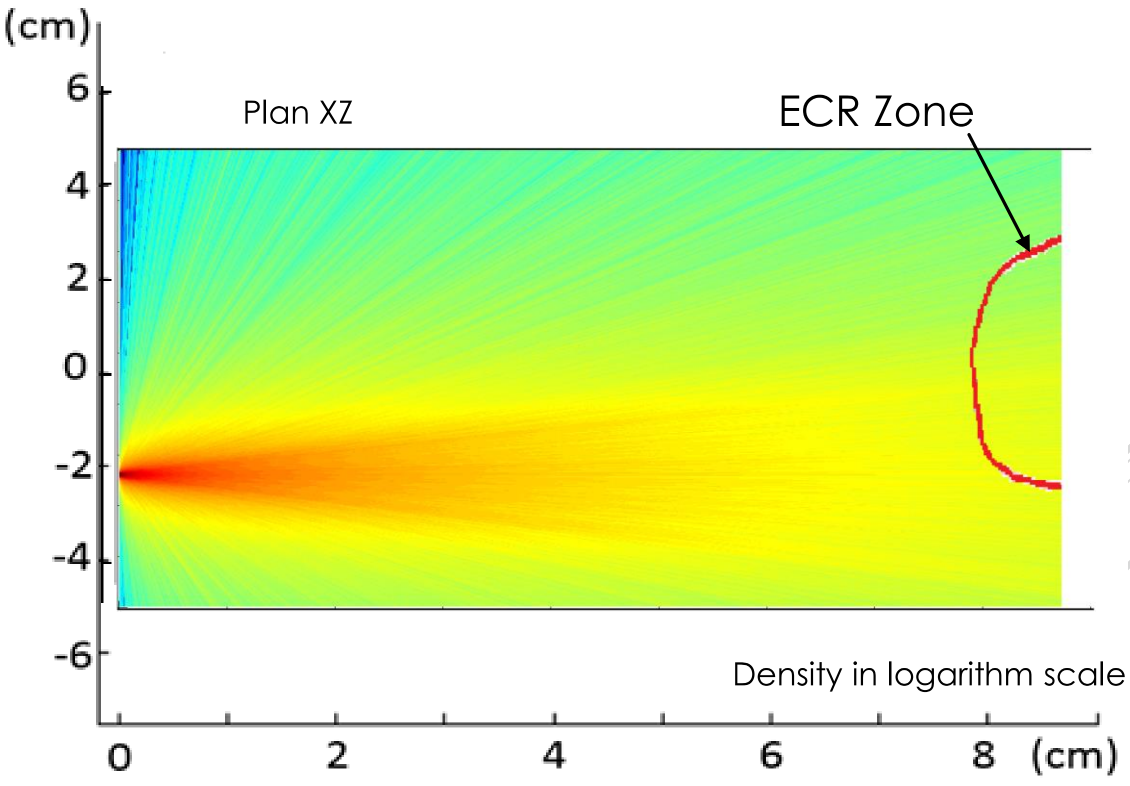
simple dynamic model



Lot of atoms not going to the ECR zone

Liner for the metallic atoms evaporation

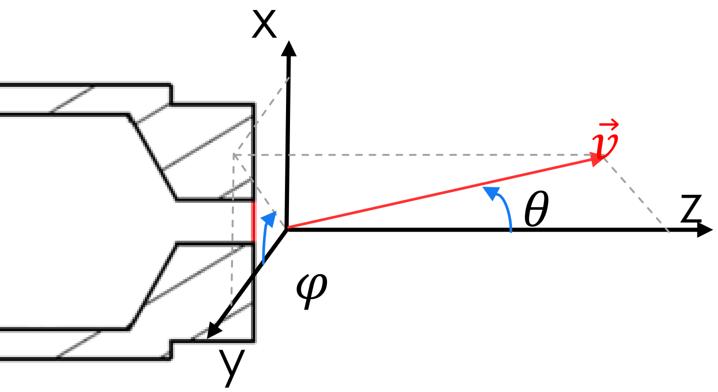
Increase the efficiency

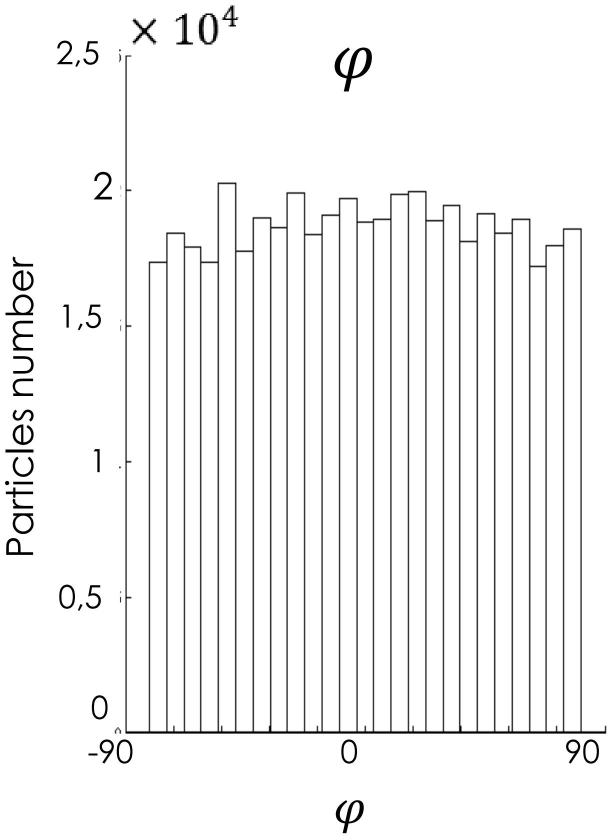


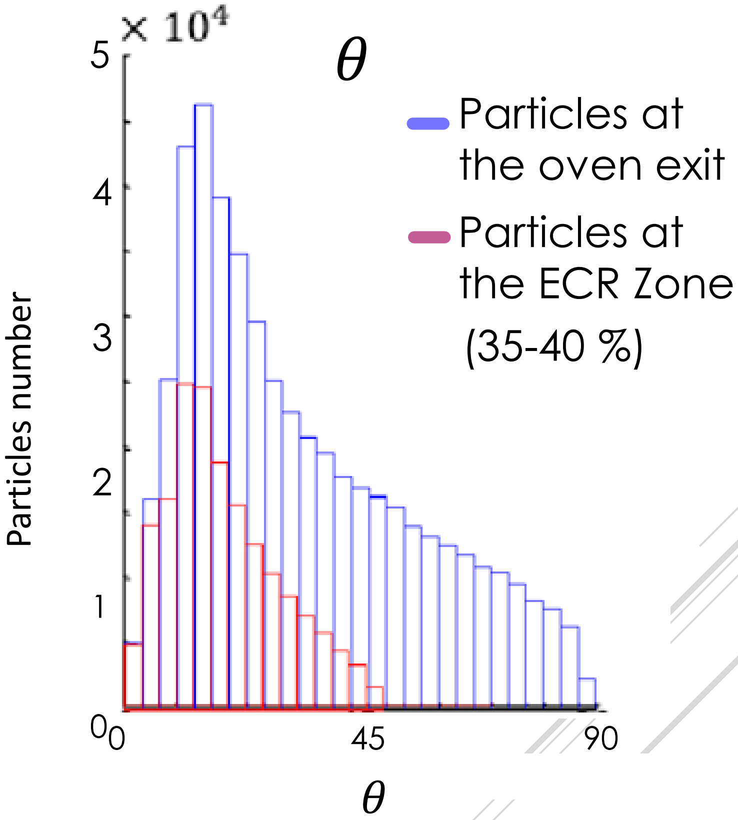
Metal vaporization

Simulation of Calcium Oven

Homogeneous distribution for φ and inhomogeneous for θ







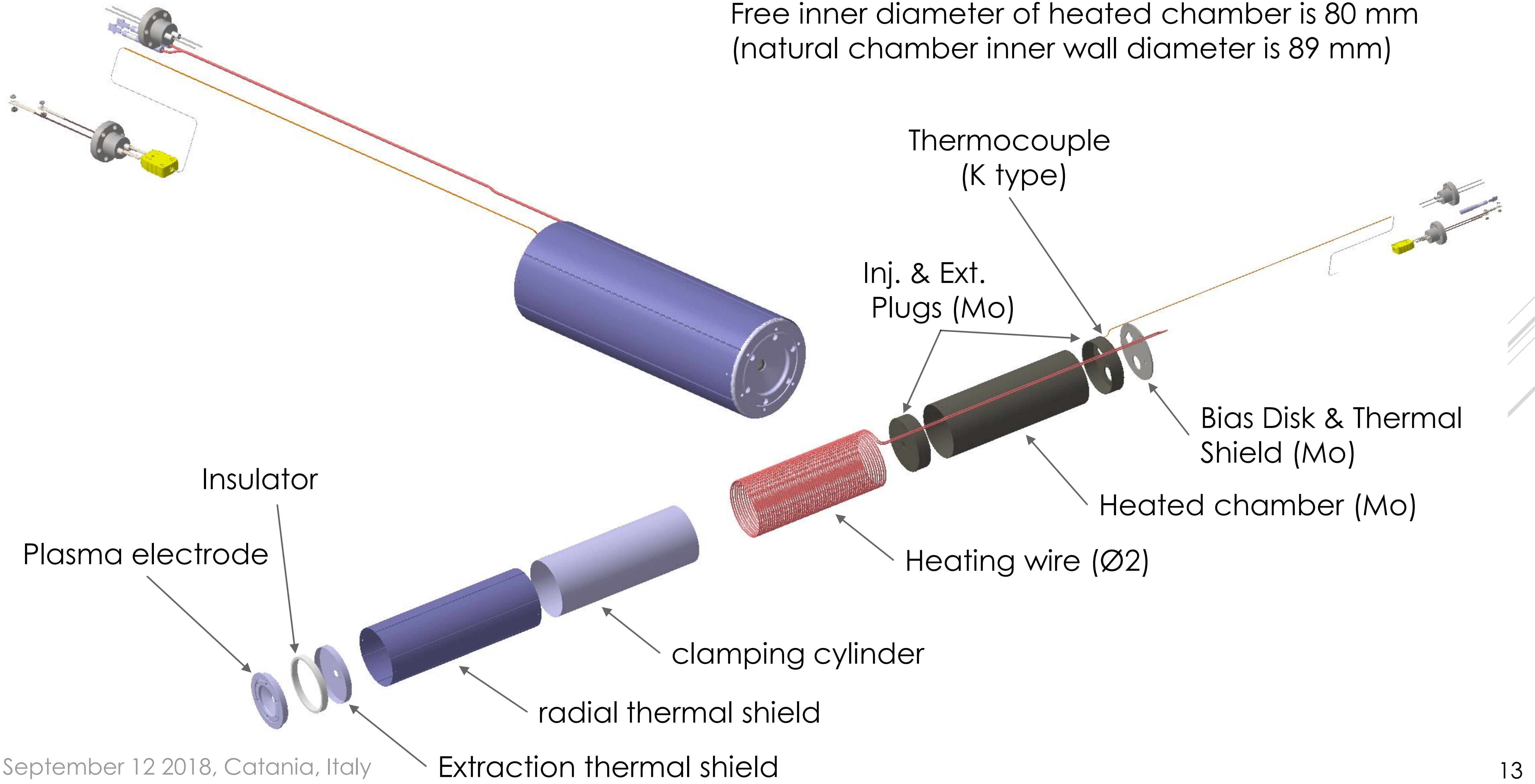
Hollow flux

Liner for the metallic atoms evaporation

Increase the efficiency

Metal vaporization

Free inner diameter of heated chamber is 80 mm
(natural chamber inner wall diameter is 89 mm)



- Motivation
- ECR Ion Source principle
- Metal vaporization
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ECR Ion Source modelization

Hybrid code

PIC & MCC

Simulate about a millisecond

Electron characteristic time	$\sim 10^{-12}s$	(~ 2 years)
Ion characteristic time	$\sim 10^{-8}s$	(~ 2 hours)

Calculation time

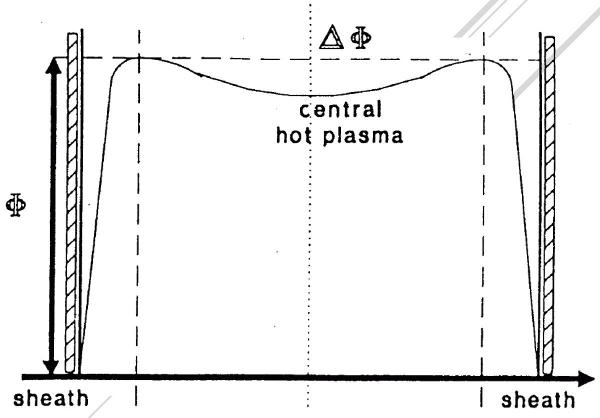
Working hypothesis

No electron propagation

Constant electron energy

No resolution of the Poisson equation (Debye Length $\lambda_D \approx 20 \times 10^{-6} m$)

Electrostatic plasma confinement (potential dip) inside the ECR Zone

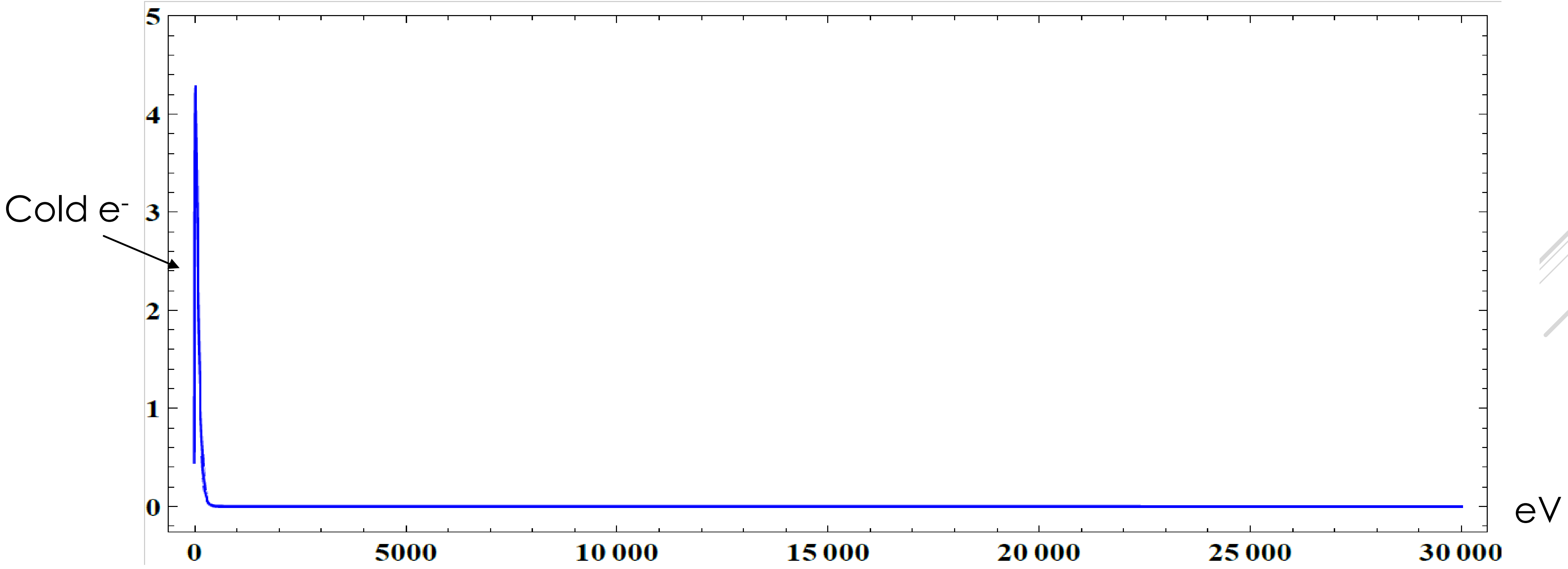


ECR Ion Source modelization

Plasma Characteristic

3 components of the Electron Energy Distribution Function :

Cold electrons 1-50 eV : from ionization or secondary electrons



ECR Ion Source modelization

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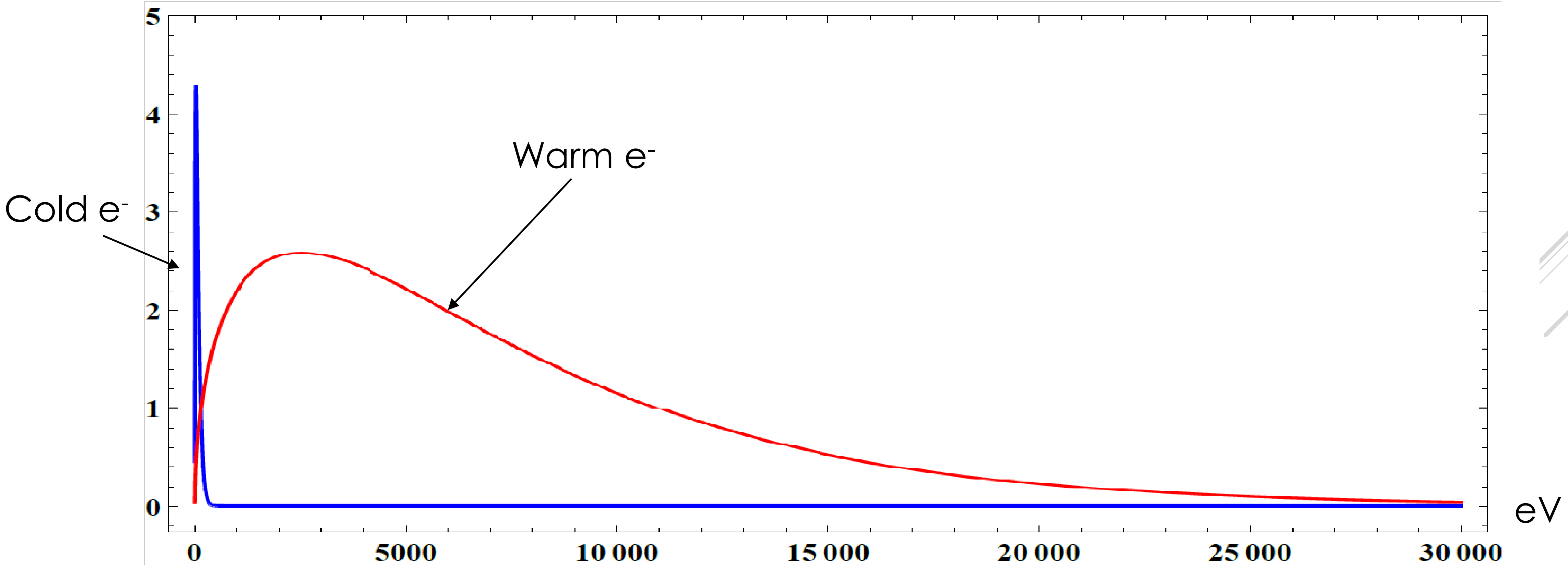
Cold electrons 1-50 eV : from ionization or secondary electrons

Warm electrons 1-5 keV: actively participate in ionization



ECR Ion Source modelization

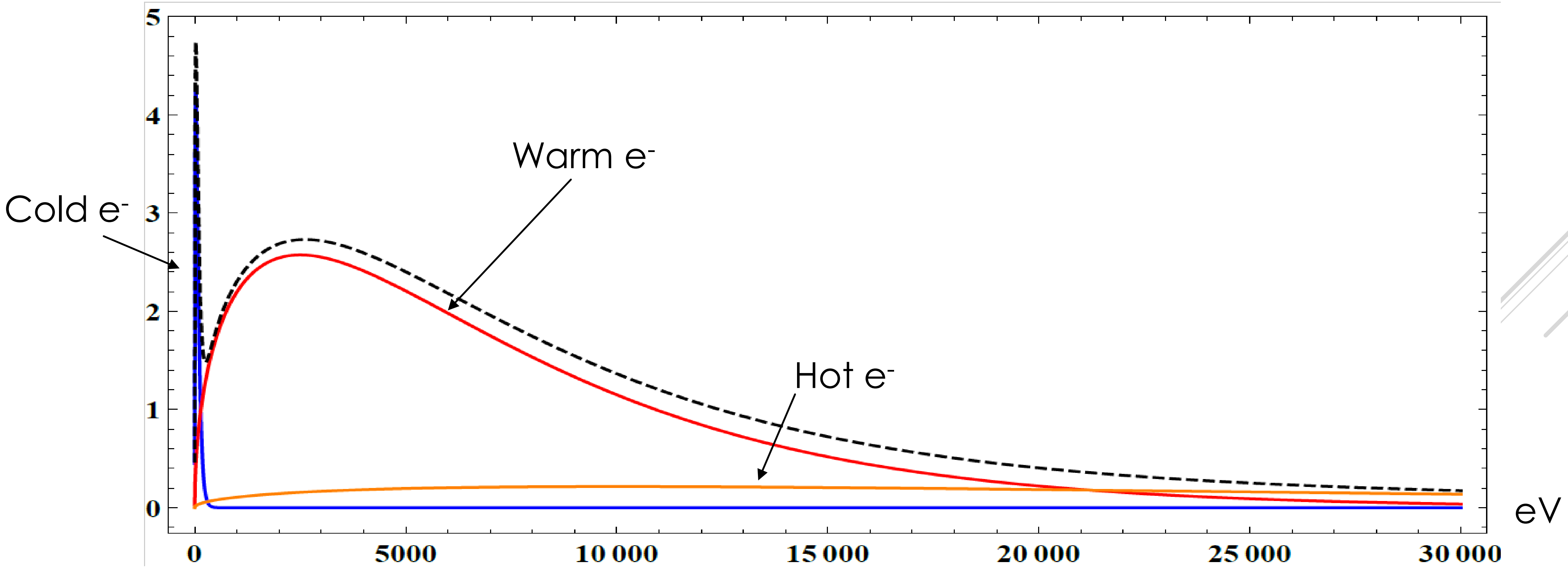
Plasma Characteristic

3 components of the Electron Energy Distribution Function :

Cold electrons 1-50 eV : from ionization or secondary electrons

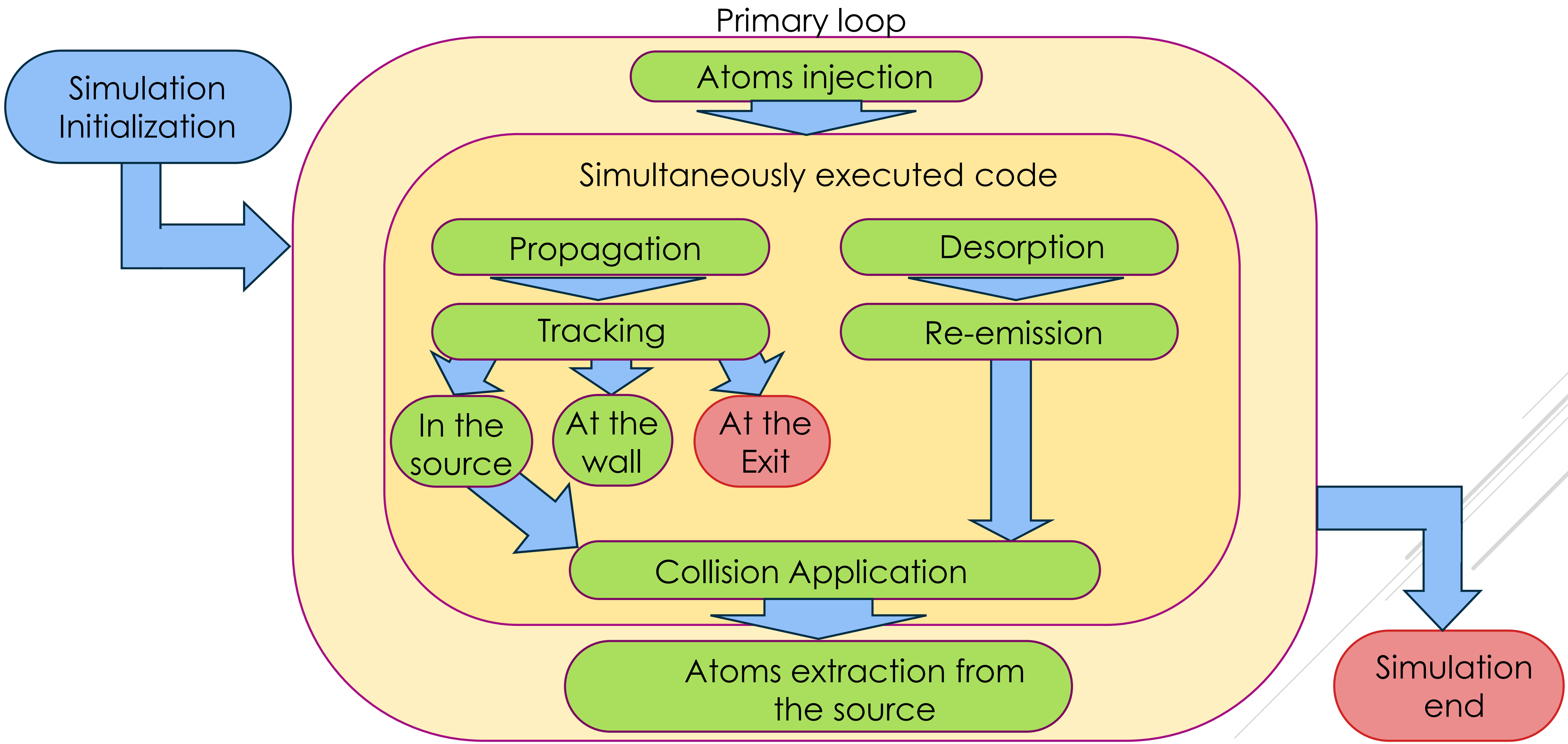
Warm electrons 1-5 keV: actively participate in ionization

Hot electrons > 10 keV : « runaway electrons » observed up to 1 MeV (Bremsstrahlung X-ray emission)



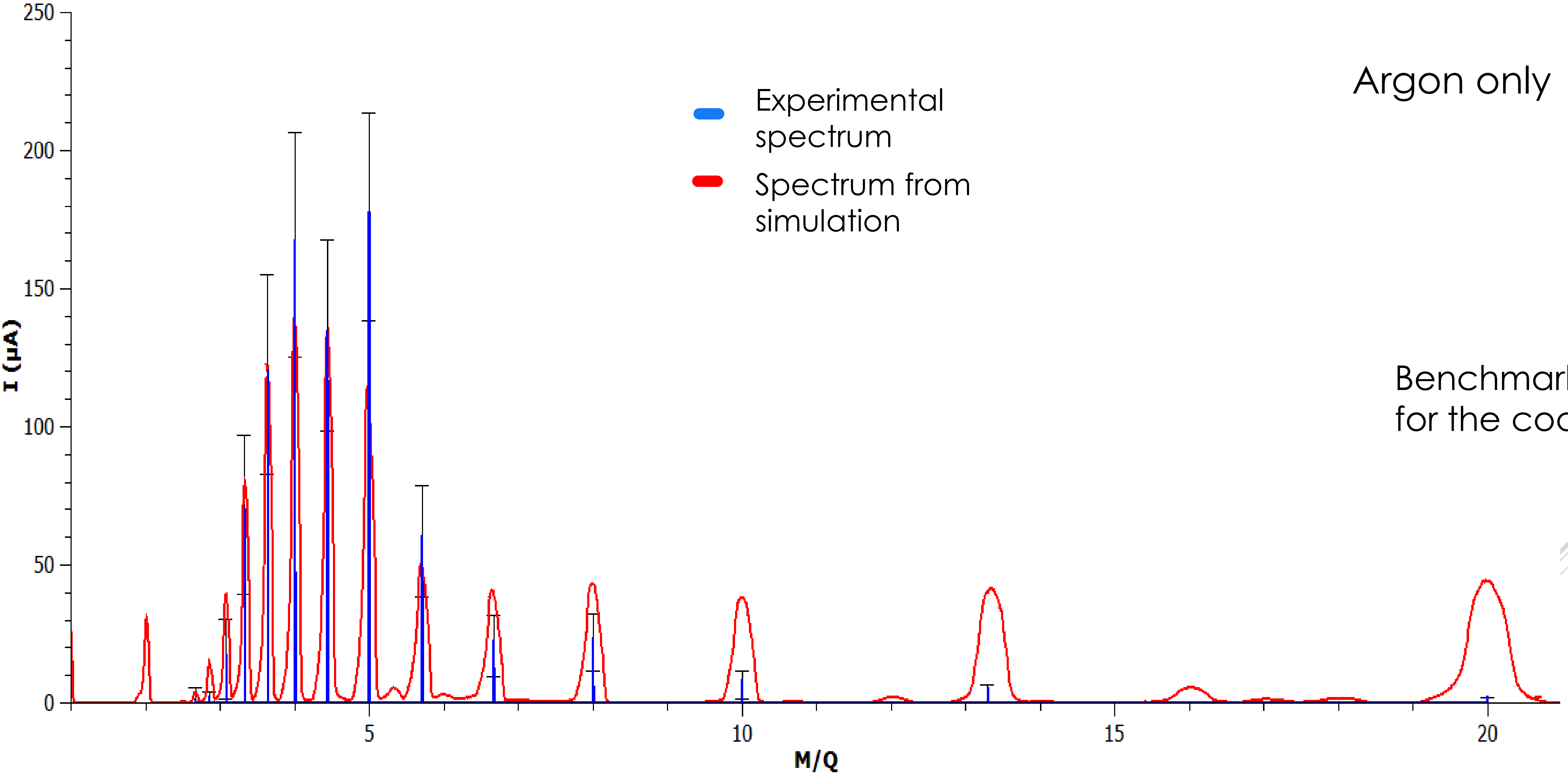
ECR Ion Source modelization

Code organization



ECR Ion Source modelization

Preliminary Simulation Results



Argon only

Benchmark for the code

Conclusion

- Metallic ion Production
- Study of the oven atoms flux
- Preliminary production of ion spectrum with simulation
- Ion source simulation under progress

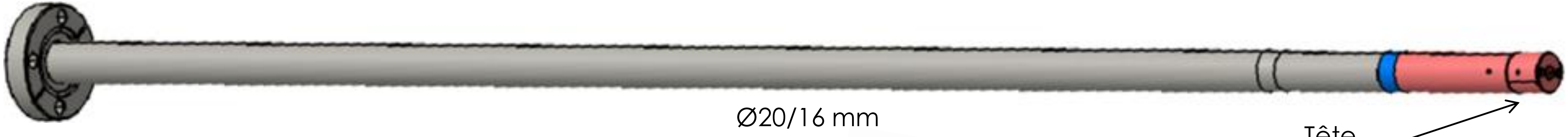
and Prospects

- Experimental study of the metallic atoms re-evaporation with a liner
- Simulation for Ca ion production with and without liner

Thank you for your attention

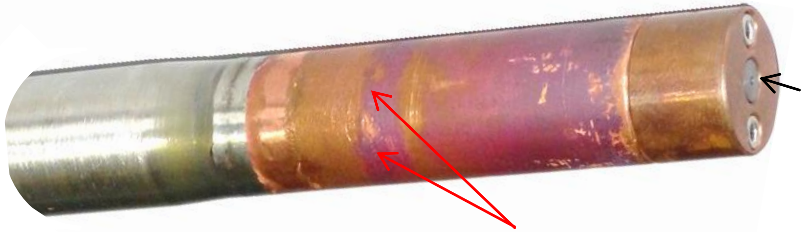
Metal vaporization

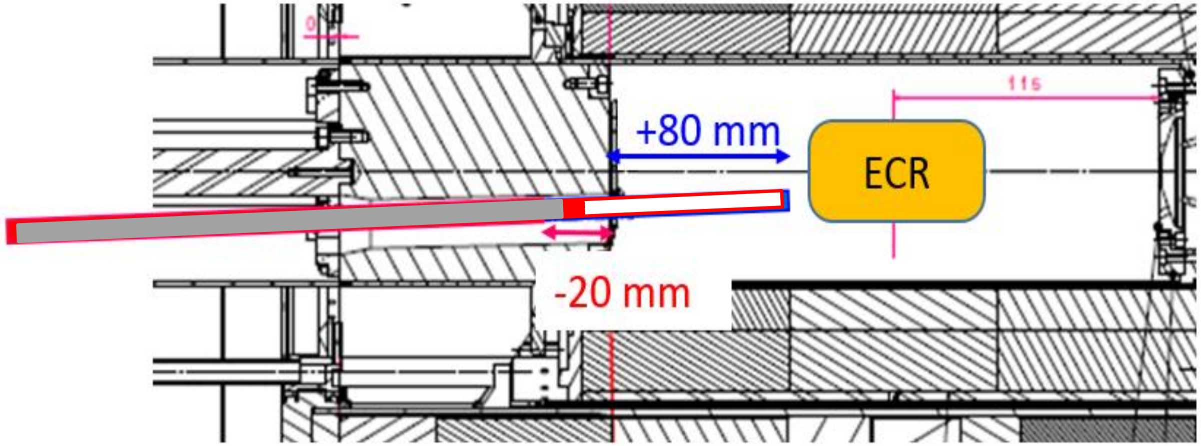
Metal vaporization : PHOENIX V3



Metallic atoms vaporization in crucible

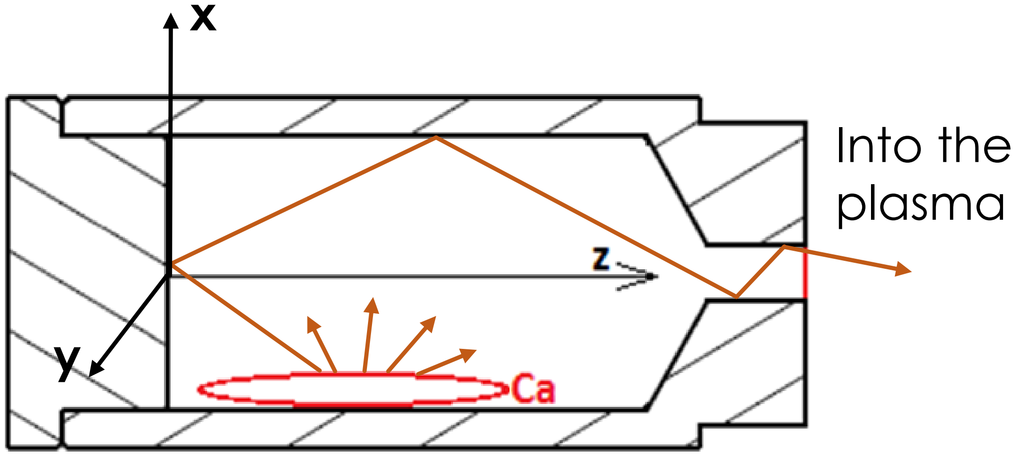
Injection of atoms in the source with a stick





Crucible simulation

Metal vaporization
Calcium Production Simulation



Heated crucible(Ta)

PIC Modelling

Maxwell velocity distribution

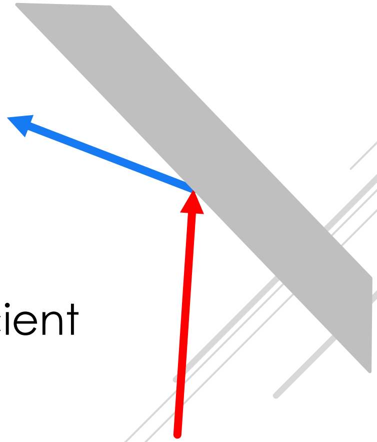
Particle bonding

$$P_{bonding} = C_{bonding}$$

and Desorption

Sticking time

$$\tau = \tau_0 e^{\left(\frac{E_d}{kT}\right)}$$



Particle thermalization

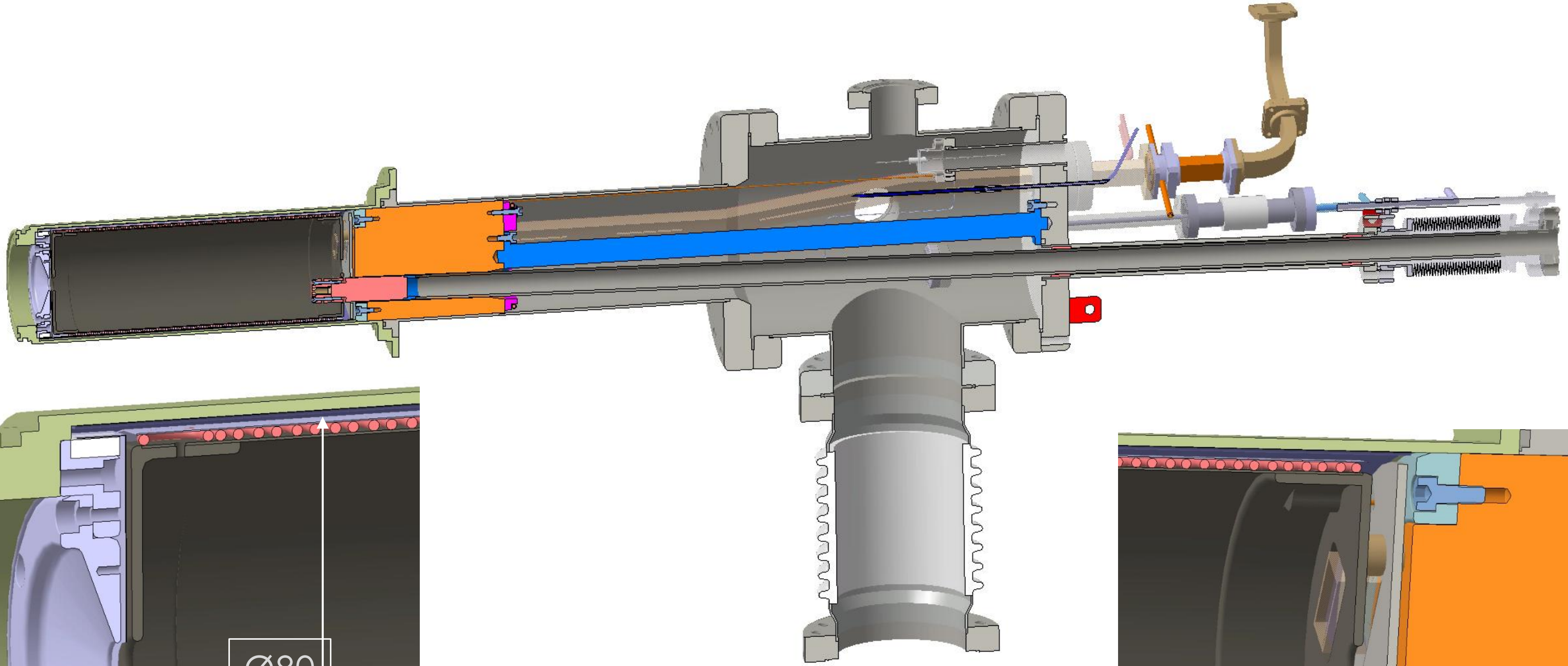
$$E_r = E_i + \alpha(E_w - E_i)$$

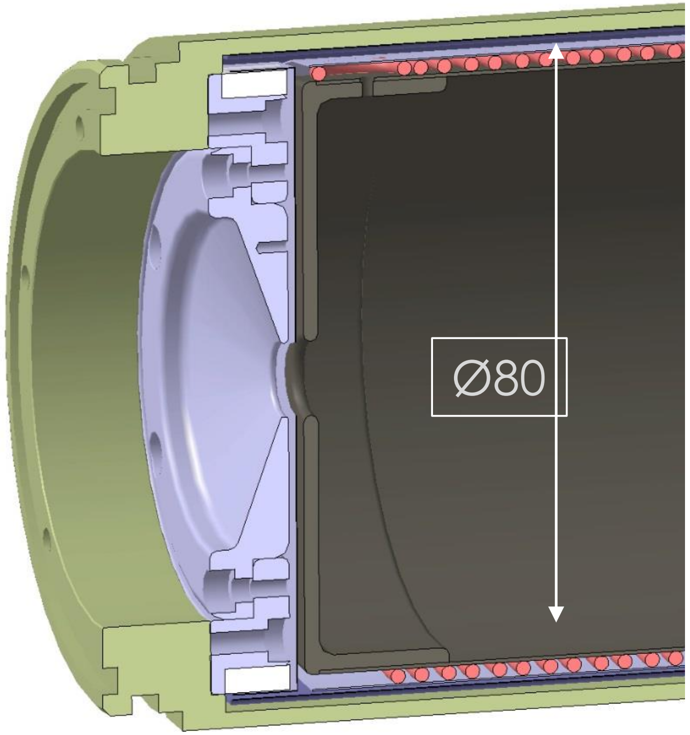
α thermal accommodation coefficient

Working hypothesis
- No particle interaction
- Linear temperature profile between the bottom and the outlet of the crucible

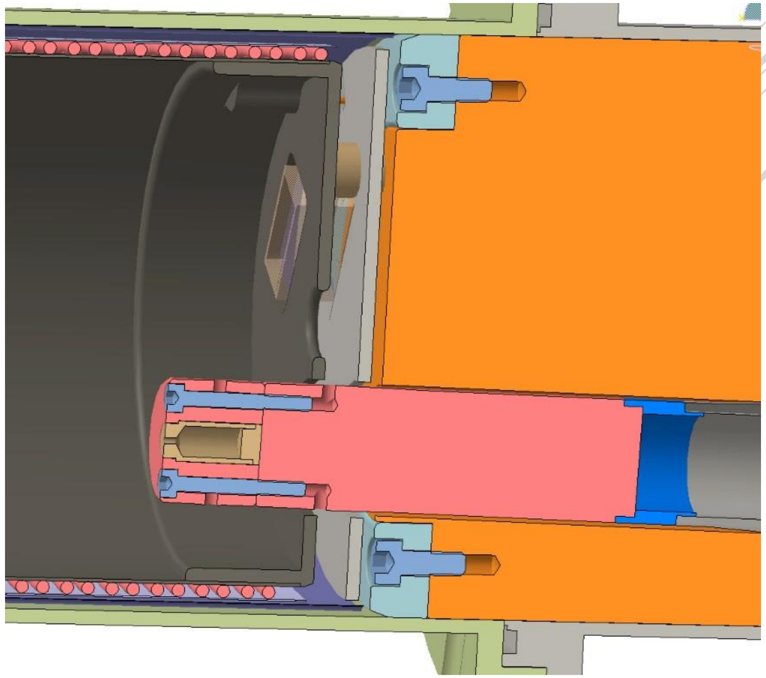
$C_{bonding}$et $E_{desorption}$ unknown for the couple Ca-Ta

Temperature controlled liner in PHOENIX V3 ion source



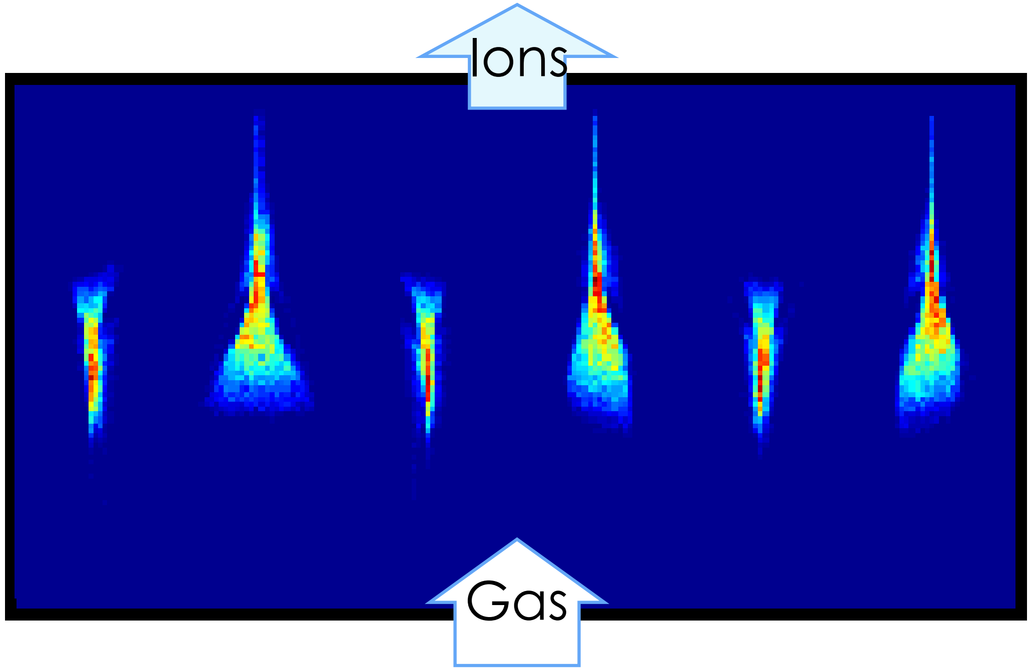


Max Temperature ~600°C
Max heating power ~1 kW



Metal vaporization
Heating Wall

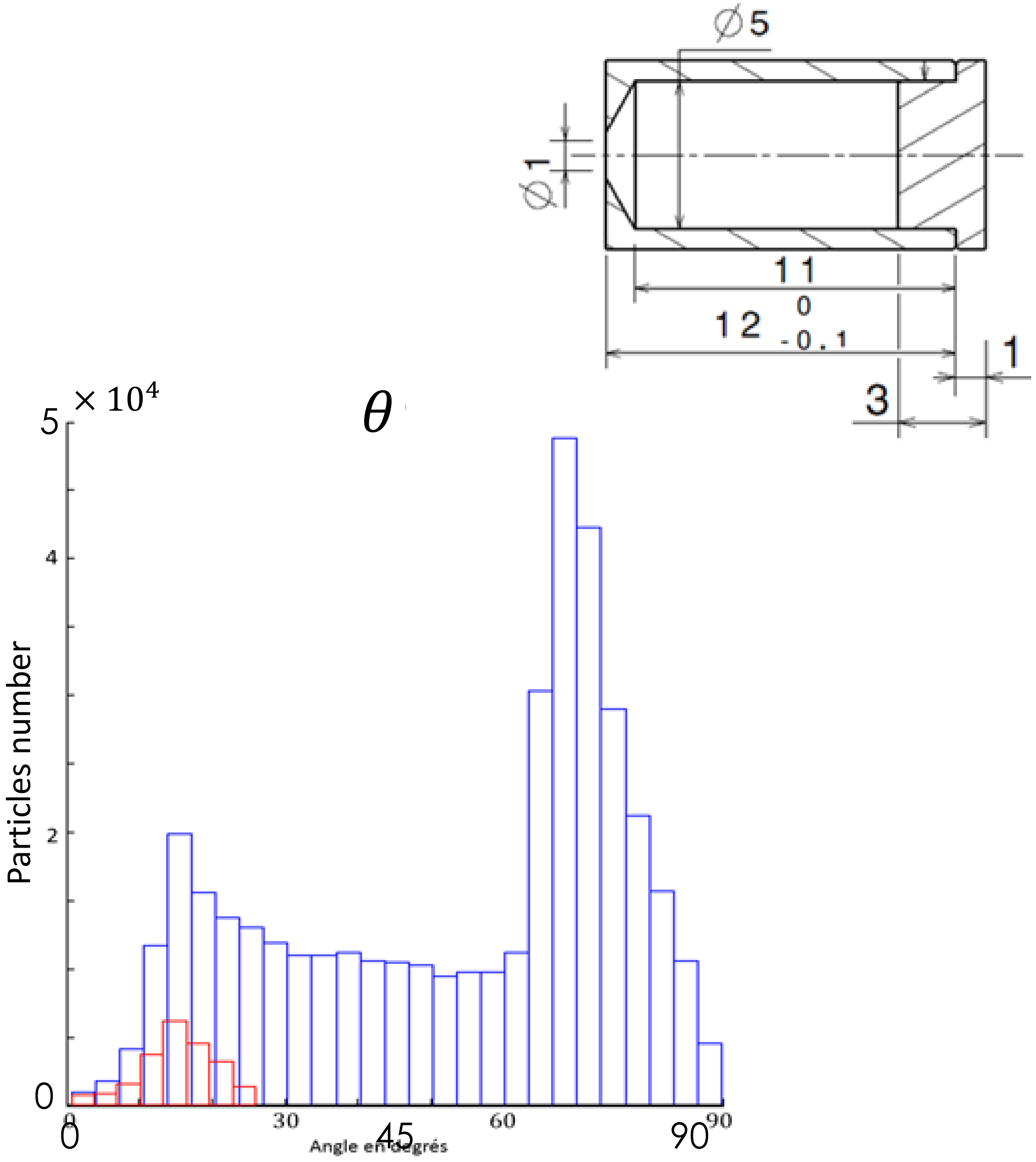
Electron heating

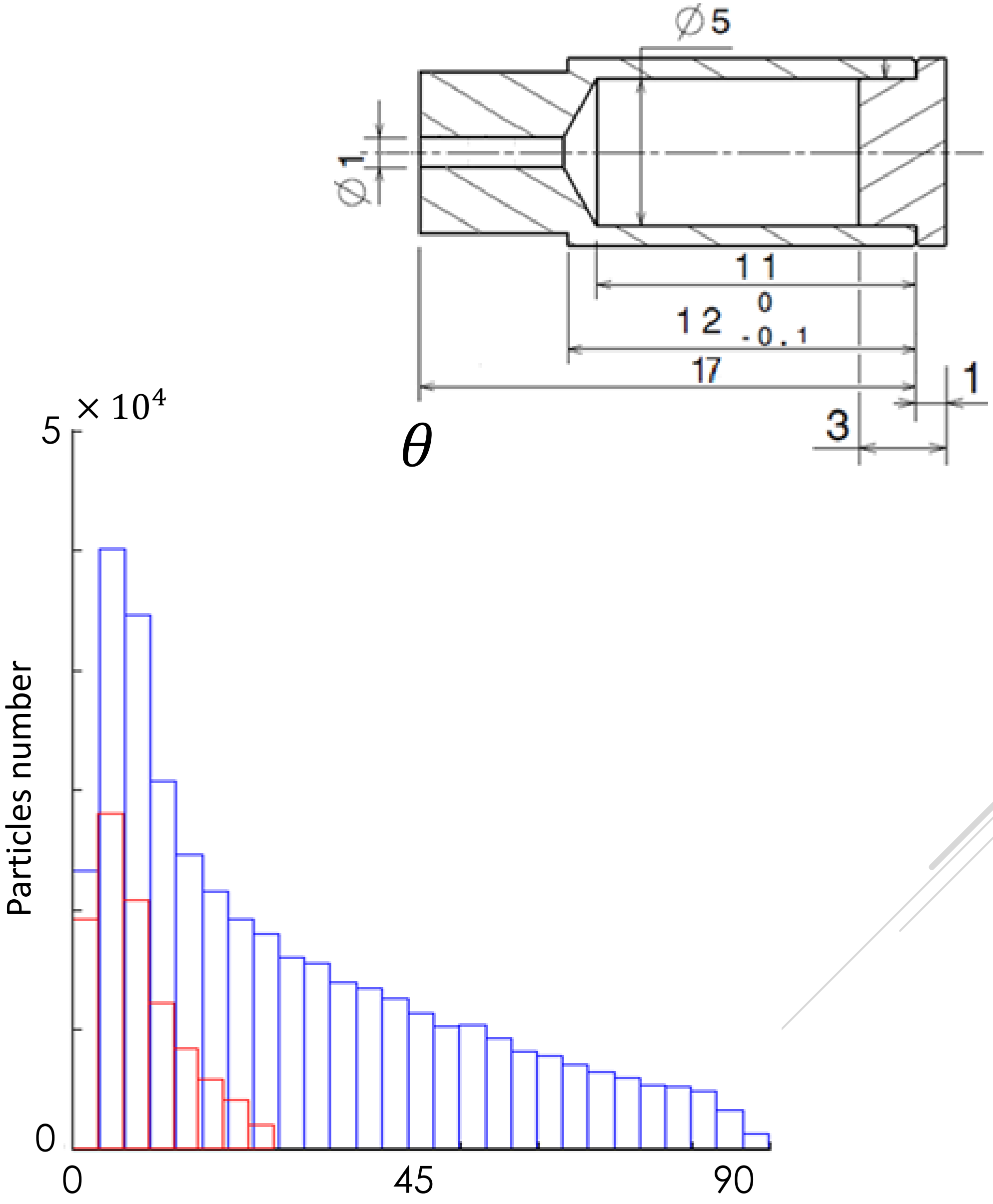


inhomogeneous

Metal vaporization

Calcium Production Simulation

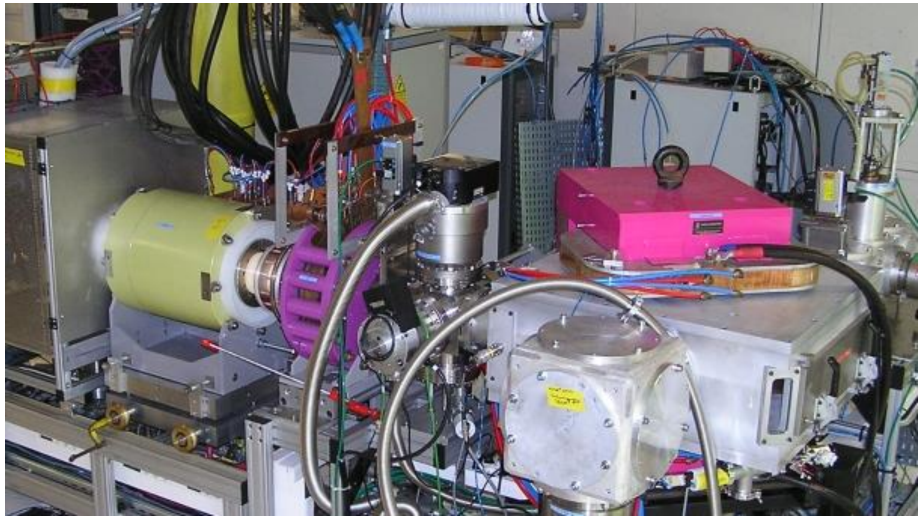




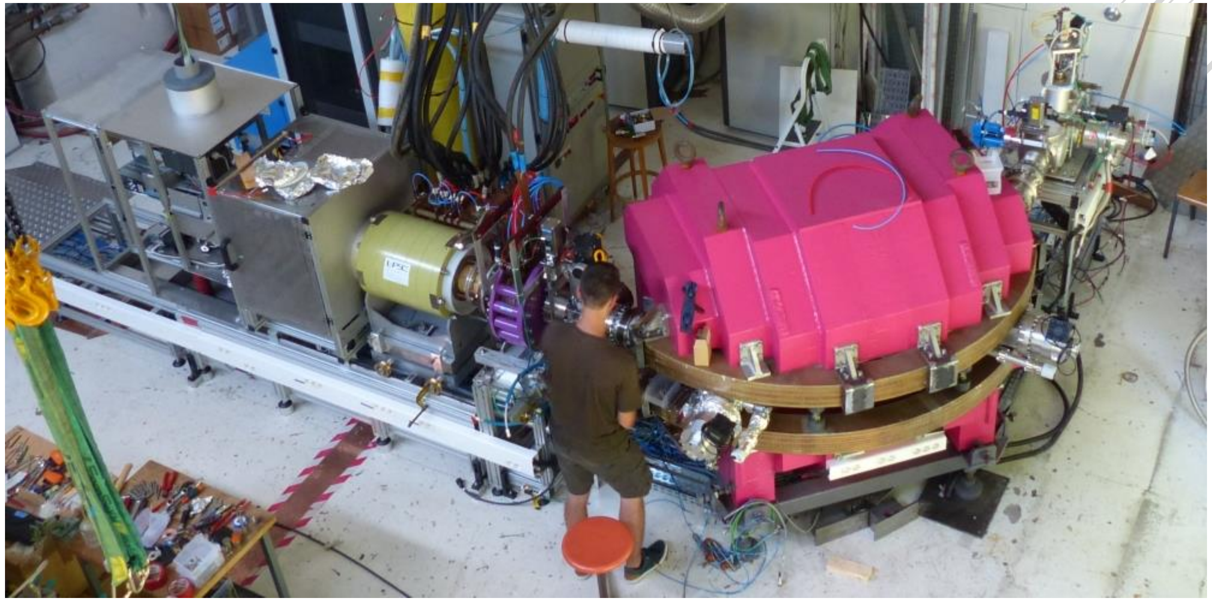
LPSC Test bench upgrade for calcium experiments

- Install a refurbished and upgraded large aperture bending magnet from the former SARA cyclotron cave(LPSC)
  - Gap: 80 to 150 mm
  - Focusing edges
- To improve the beam transmission (70%→90%)
- To improve the beam separation ($\frac{M}{\Delta M}$ doubled)
- Today: early commissioning

2017: dipole in the cyclotron cave



04/2018



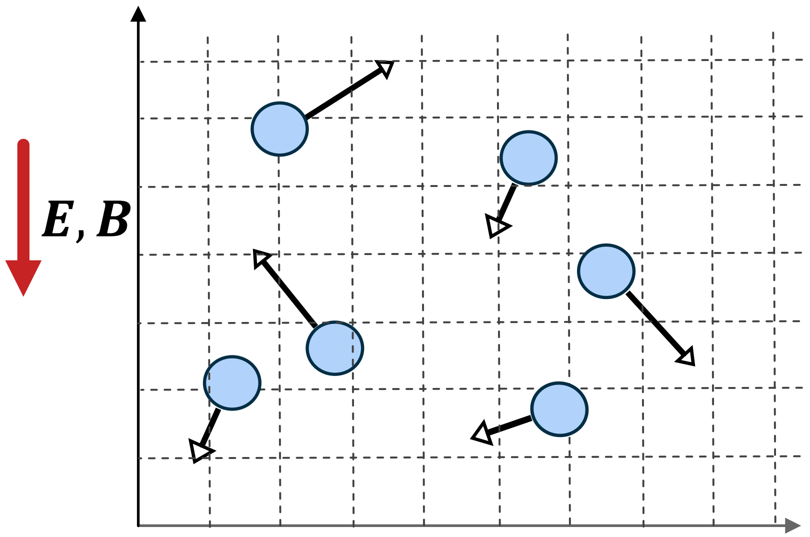
06/2018

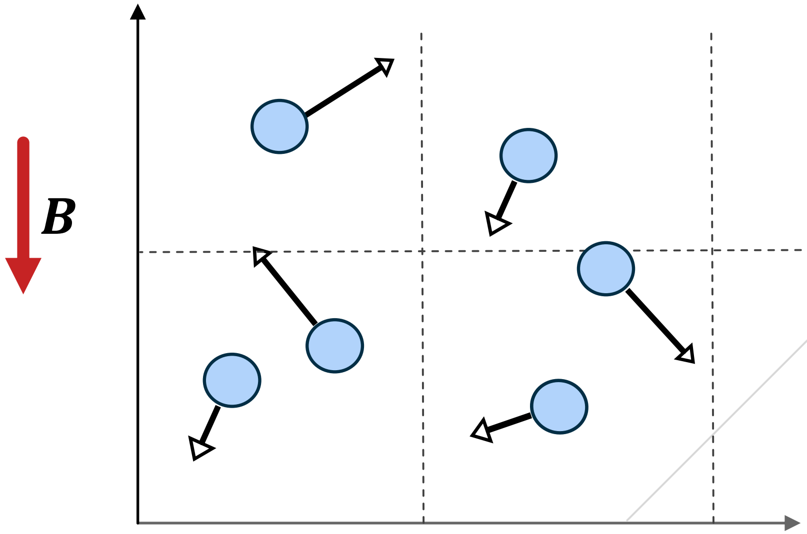
ECR Ion Source medialization

Particle In Cell Simulation

- Space thin meshing
- Charged and neutral particles propagation
- Resolution of the Poisson equation
- Random draw of the collision

- Large meshing
- Ions and atoms propagation
- Random draw of the collision





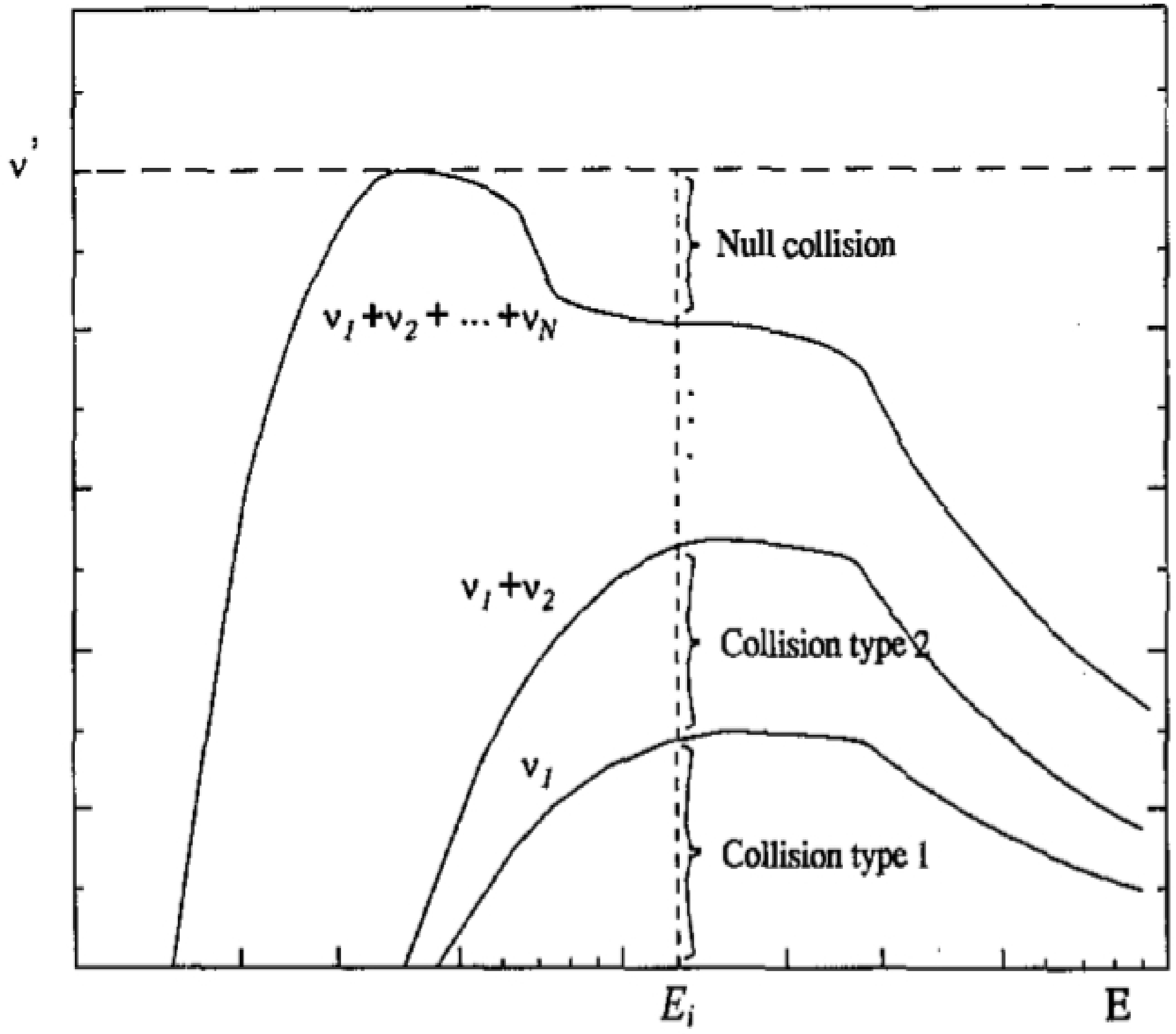
ECR Ion Source medialization

Collisions

Null Collision

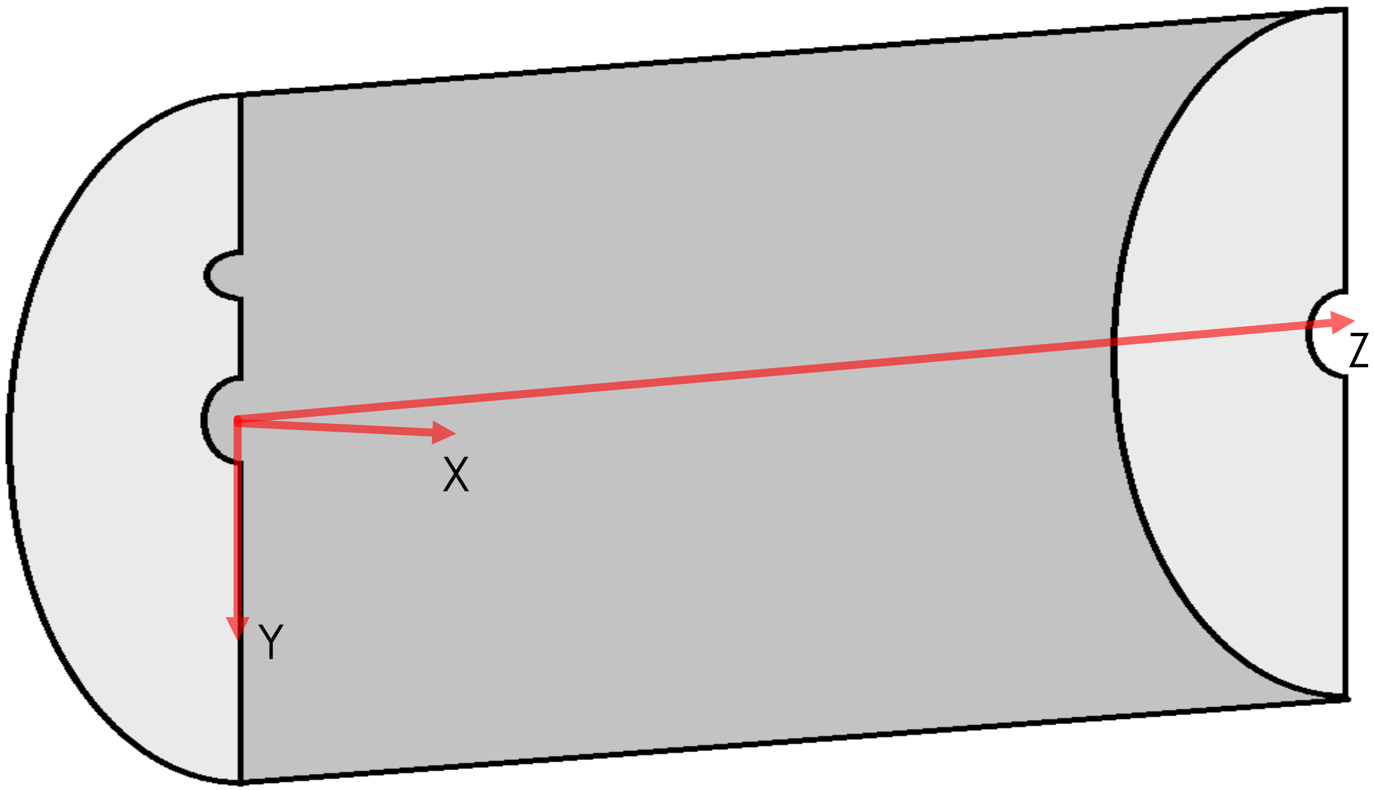
- Ionizations (simple and double) (Lotz)
- Charge Exchange (Müller)
- Recombination (Hahn)

Coulomb collisions
(**"Theory of cumulative small-angle collisions in plasmas"** of K. Nanbu)

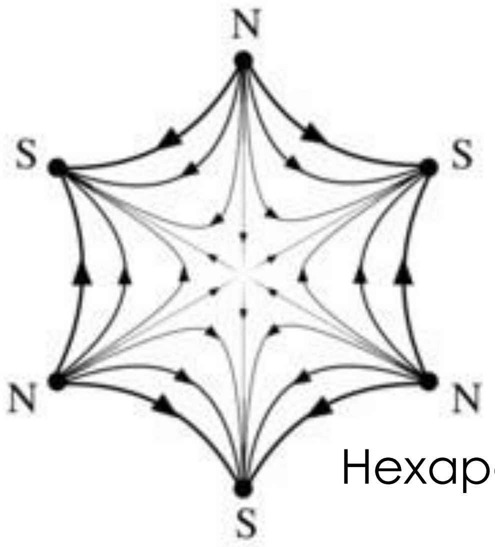


ECR Ion Source medialization

PHOENIX V3



Simulation of an ion source half

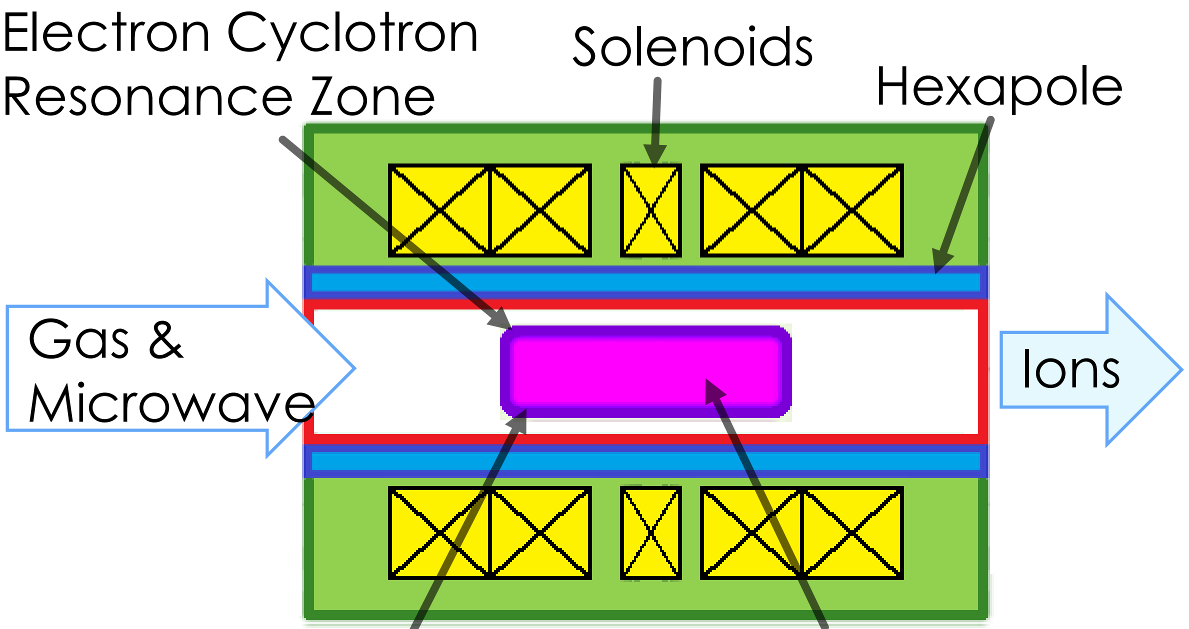


Hexapole

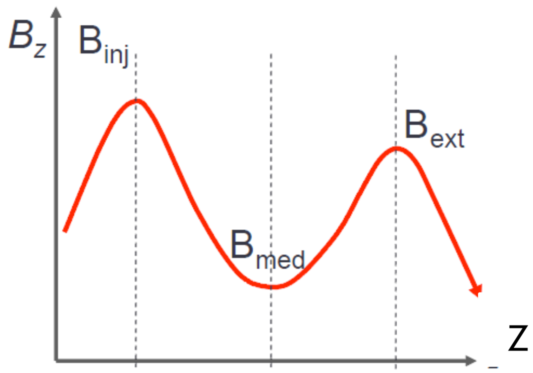
Coil
    Cylindrical symmetry
Hexapole
    3 planes of symmetry
Gas Injection, Gas Extraction
    1 plane of symmetry

ECR Ion Source principle

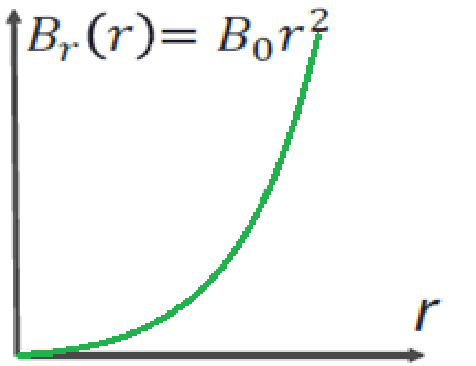
Plasma Characteristic



$$f_{waves} = f_{ec} = \frac{q\,B}{2\pi\,m}$$

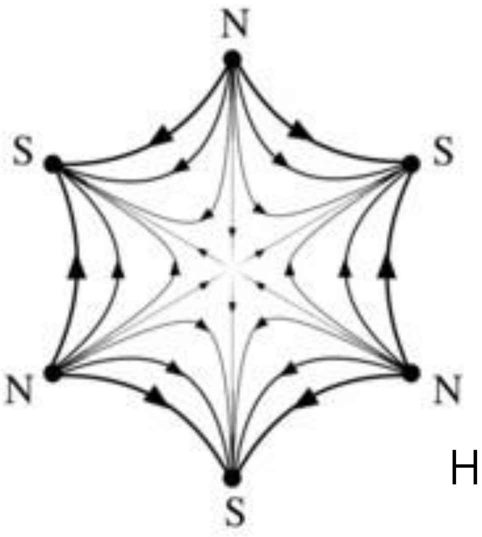


Axial Magnetic Field



Radial Magnetic Field

Support gas use
Magnetic confinement



Hexapole

[] Efremov, A., et al. "Ohmic heated sheet for the Ca ion beam production." *Review of Scientific Instruments* 79.2 (2008), Dubna, Russia
[] Galatà, A., et al. "Application of the Ta liner technique to produce Ca beams at INFN-Legnaro National Laboratories (INFN-LNL)." *Review of Scientific Instruments* 85.2 (2014), Legnaro, Italy

[] Mironov, V., and J. P. M. Beijers. "Three-dimensional simulations of ion dynamics in the plasma of an electron cyclotron resonance ion source." *Physical Review Special Topics-Accelerators and Beams*. Dubna, Russia
[] Shirkov, G., et al. "Particle-in-cell code library for numerical simulation of the ECR source plasma." *Review of scientific instruments*. Dubna, Russia