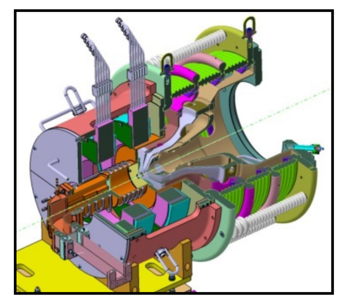
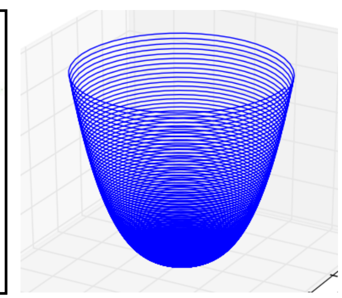
DE LA RECHERCHE À L'INDUSTRIE

# SIMULATIONS OF ECR ION SOURCES





www.cea.fr

BUSAN / 2016-08-30

CEA SACLAY DSM/Irfu/SACM/LEDA
Rémi de Guiran

# OUTLINE

1. General context

2. Numerical method

3. Results

4. Perspectives

# OUTLINE

1. General context
2. 
3. 
4. 

# ECRIS DEVELOPED AT CEA SACLAY

PANTECHNIK

Wide variety of sources developed…

| Project /Source | High Voltage | Extracted intensities | Operation mode | Magnetic Configuration | Talks at ECRIS 2016 (Wednesday) |
|---|---|---|---|---|---|
| **SILHI → IPHI** | 100kV | 100mA $H^+$ | CW / Pulsed | Coils | WEPP01 |
| **SPIRAL2** | 20kV<br>40kV | 5mA $H^+$<br>5mA $D^+$ | CW / Pulsed | Magnets | |
| **SILAP-1** | 40kV | 40mA $H^+$ | Pulsed 50% DC | Magnets | |
| **IFMIF EVEDA** | 100kV | 140mA $D^+$ | CW / Pulsed | Coils | WECO01 |
| **ALISES** | 30kV<br>100kV | 18mA $H^+$<br>Not yet tested | Pulsed 20% DC | Coils | WECO02 |
| **SILHI2** | 50kV | 40mA $H^+$ | CW / Pulsed | Magnets | |
| **FAIR** | 95kV | Not yet tested | Pulsed 4% DC | Coils | WEPP02 |

- Optimization criteria :
  - Power delivered vs Extracted intensities
  - Emittance of the beam
- And cost considerations (size/weight/volume/material quantities)

# R&D ON ECRIS

- Common objective with Pantechnik.

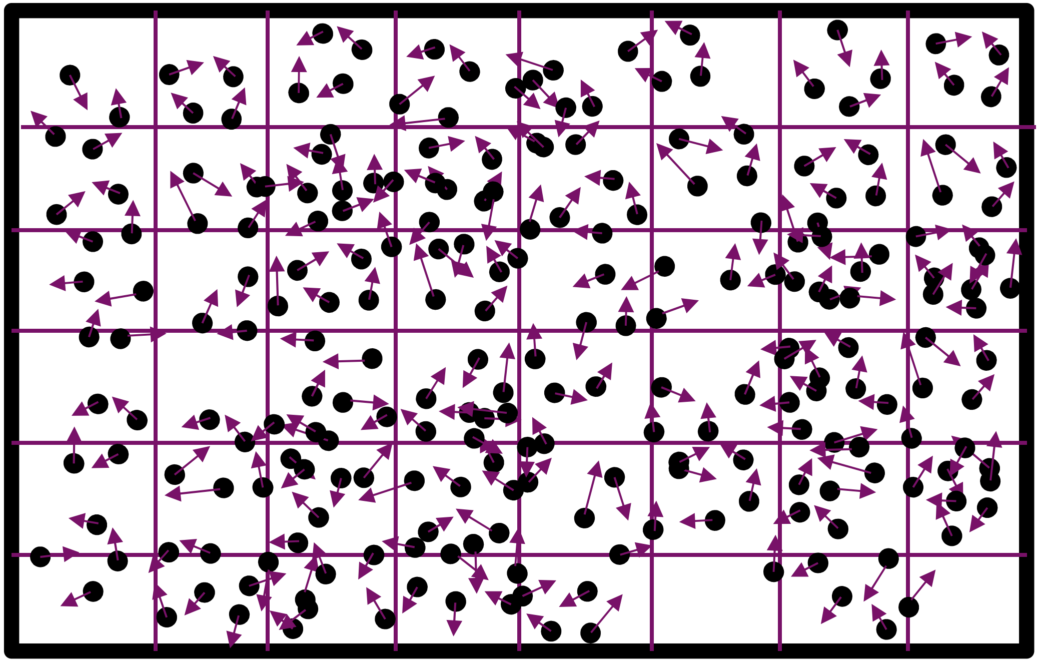
- Get a better understanding of sources :
  - Extracted intensity as a function of what is injected ?
  - The purity of the extracted beam (between 65 an 90 %, why ?)
  - What is affecting the transient regime ?

- How to ? Compare the models/simulations to the measurements performed at CEA (BETSI test bench)

- Objectives:
  - Improving the source performances
  - Reducing building costs
  - Industrialization

# METHOD

- Common method for such plasmas : Particle In Cell



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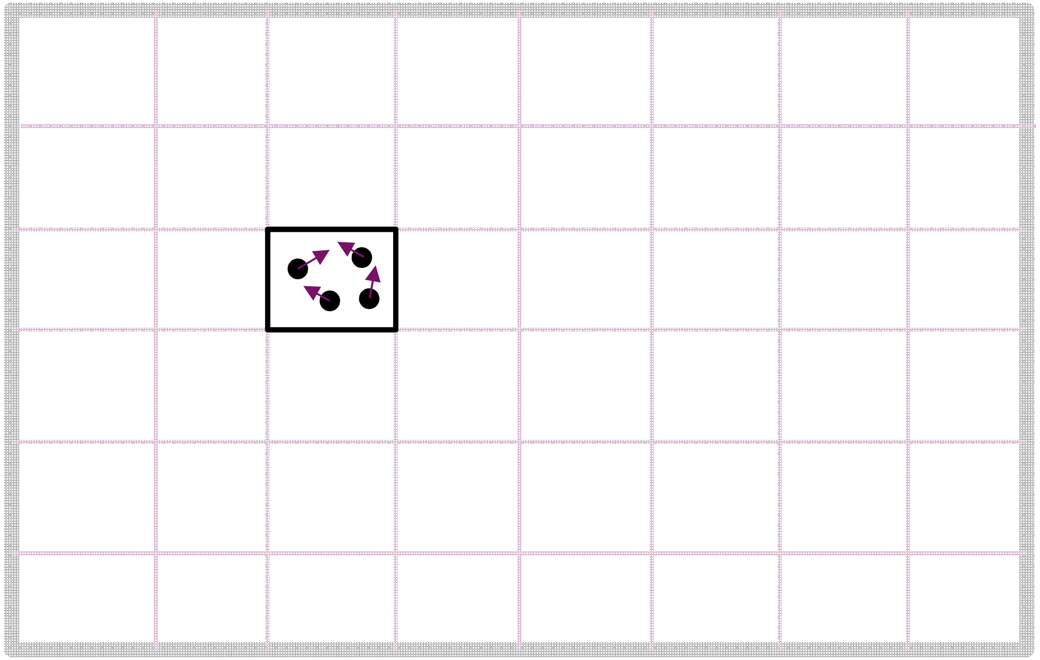

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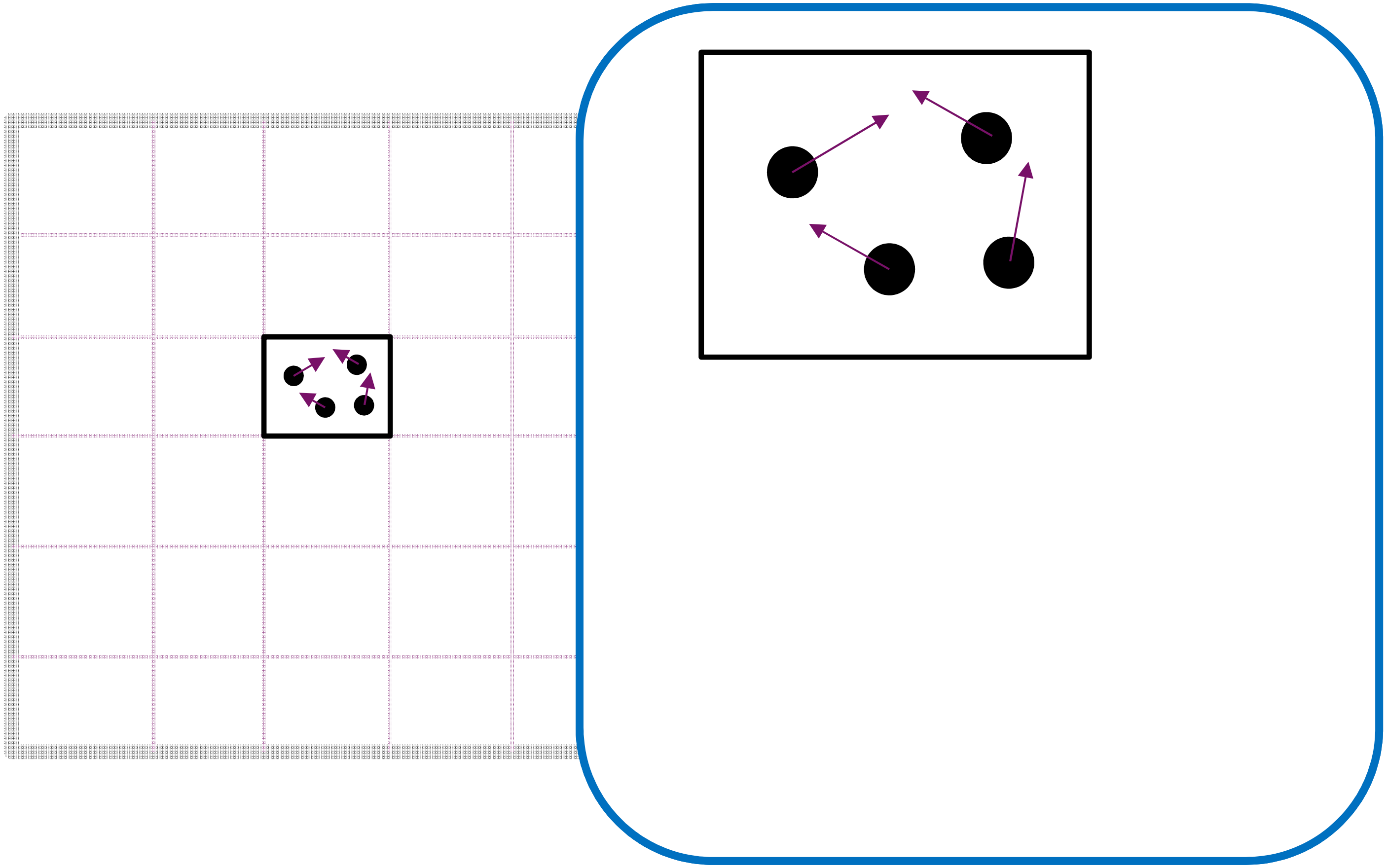

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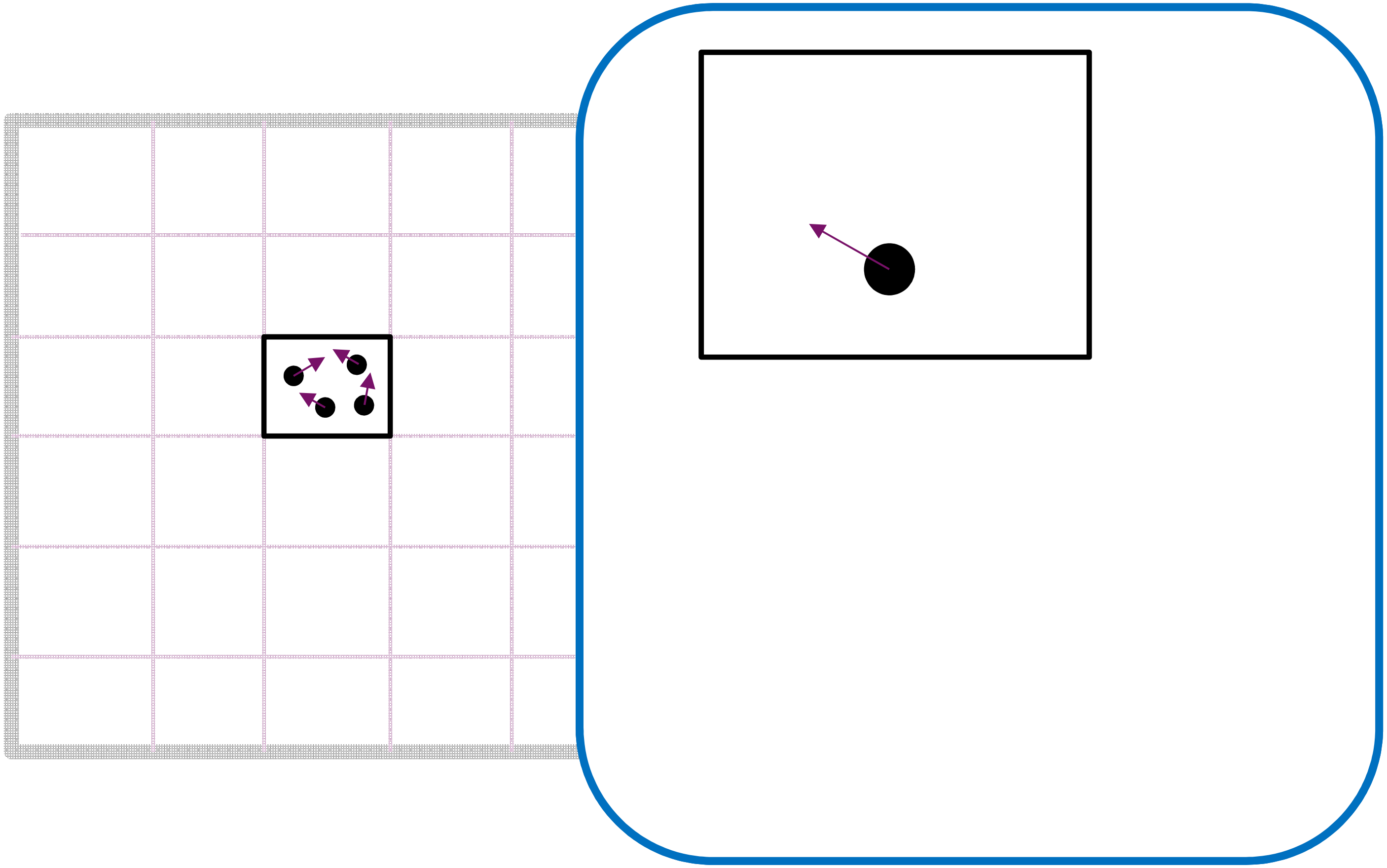

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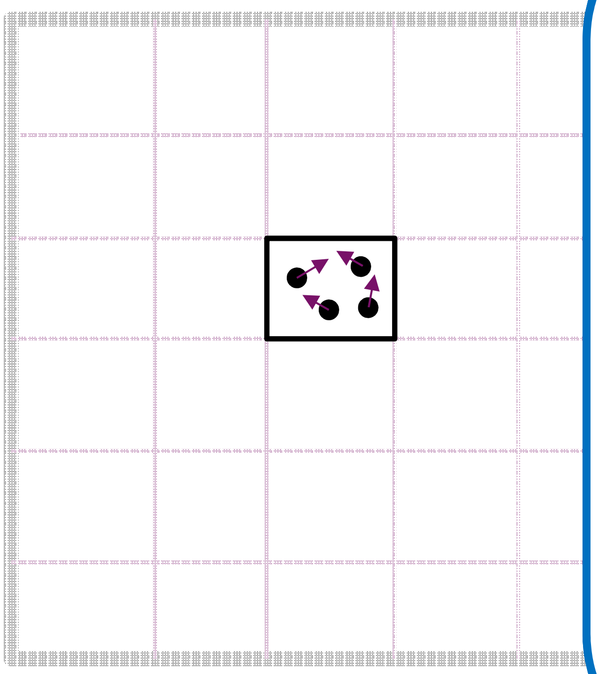

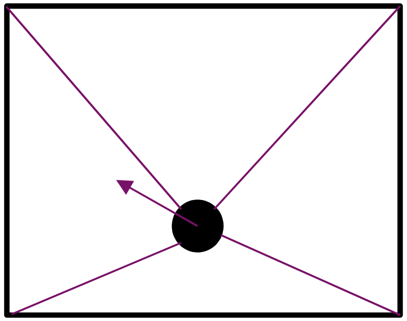

- Charge and speed are deposited on the vertices of the cell so we get $\rho$ and $\vec{J}$
  - ➢ $\vec{E}$ and $\vec{B}$ can be computed using Maxwell equations
  - ➢ Particles are advanced in these fields

# METHOD

- Common method for such plasmas : Particle In Cell

- Standard Particle In Cell codes irrelevant for ECRIS dimensions and timescales
  - Debye length limitation : $\Delta_x < \lambda_d \ll L_{system}$
  - Plasma pulsation : $\Delta_t < 1/\omega_p \ll t_{system}$

| | Plasma | | Source |
|---|---|---|---|
| **Lengths** $(cm)$ | Debye length | $\lambda_d \sim 10^{-3}$ cm | Typical scale $l \sim 10$ cm |
| **Time scales** $(\mu s)$ | Plasma oscillations | $t_{osc} \sim 10^{-5}$ µs | Typical time $t \sim 1$ µs |

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We chose the method developed by M.Lampe
(detailed in ***Lampe98***)
Particle in cell method for quasi-neutral plasmas
Fits well for ECRIS plasmas and ECRIS dimensions

# OUTLINE

1.

2. Numerical method

3.

4.

# METHOD SIGNATURES

Fully explained in ***Lampe 98***
Main signatures recapped below

1. Electrons are assumed to be strongly magnetized. So each electron is frozen on a field line : removes the electron giro-radius and giro-time scale → **Needs a specific grid and specific deposit**

2. Electrons are submitted to an electric field $E_{||}$ parallel to field lines. $E_{||}$ is computed so as to ensure quasi-neutrality. Hypothesis are made to cut off high frequency dynamics.

3. Ions are treated as «jumbo jets », free to move in the chamber under the influence of $\vec{E}$ and $\vec{B}$. A special treatment has to be done in order to compute $E_{\perp}$ transverse to the field lines.

4. Sheath on the edges of the chamber are not resolved → treated as potential barriers for electrons.

5. A presheath is resolved to impose the Bohm criterion for ions.

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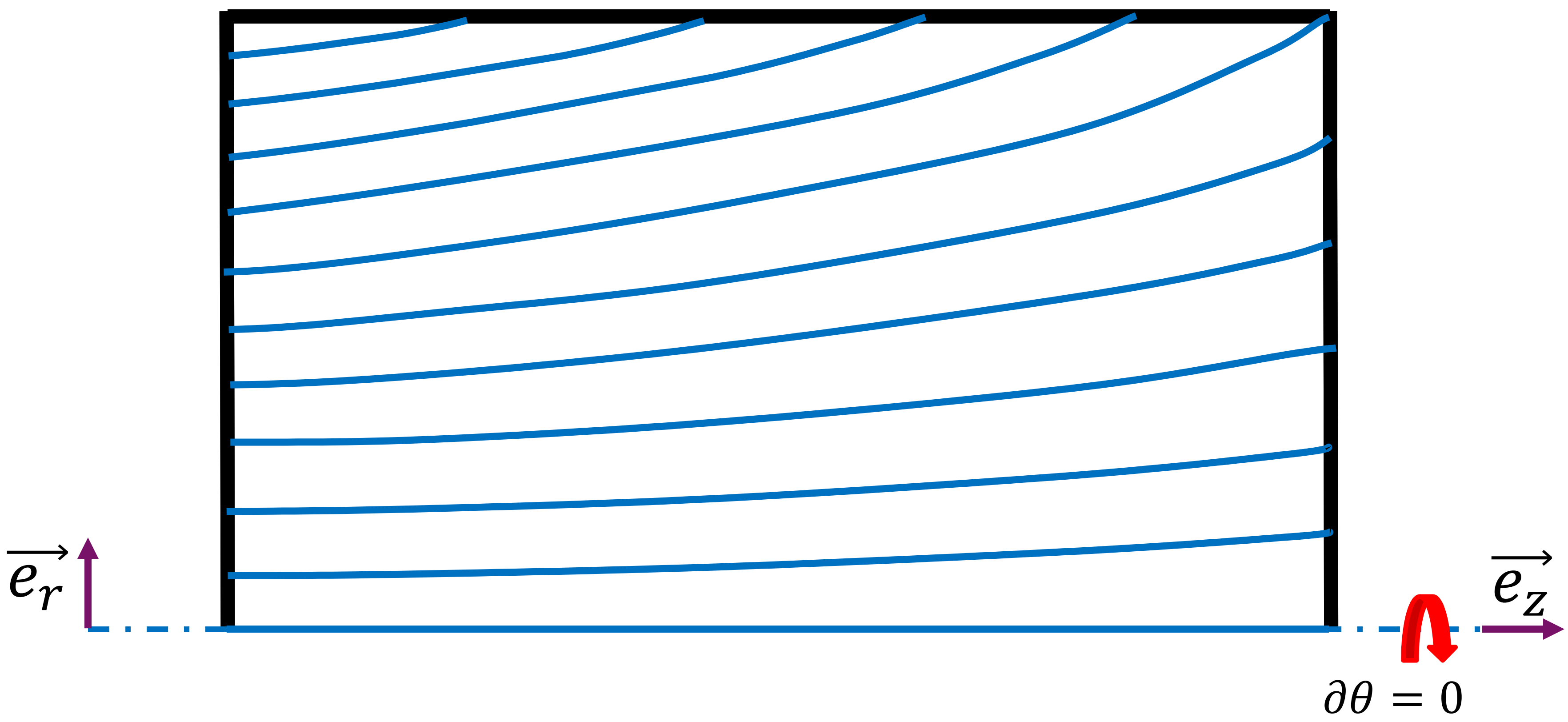
# NON CARTESIAN GRID



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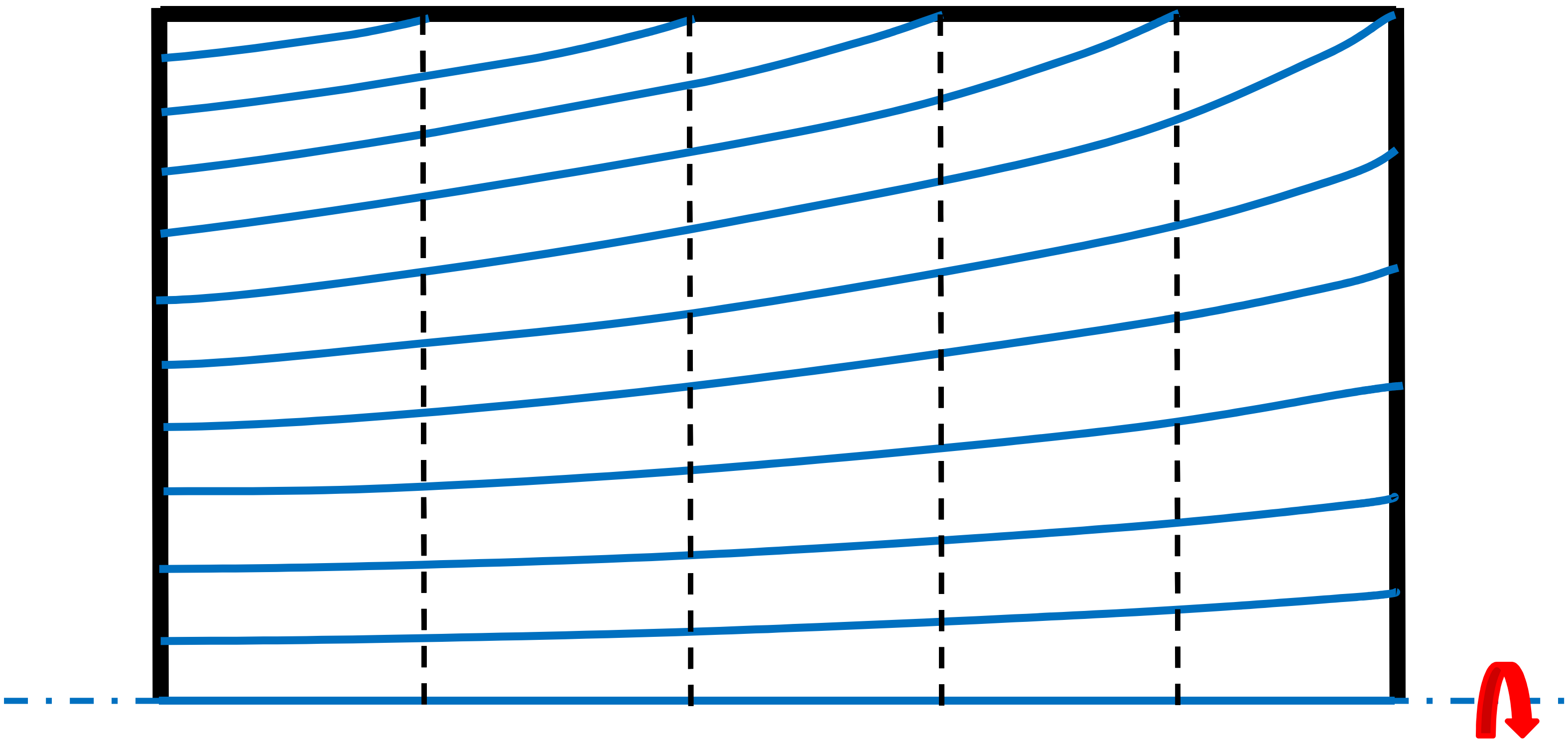

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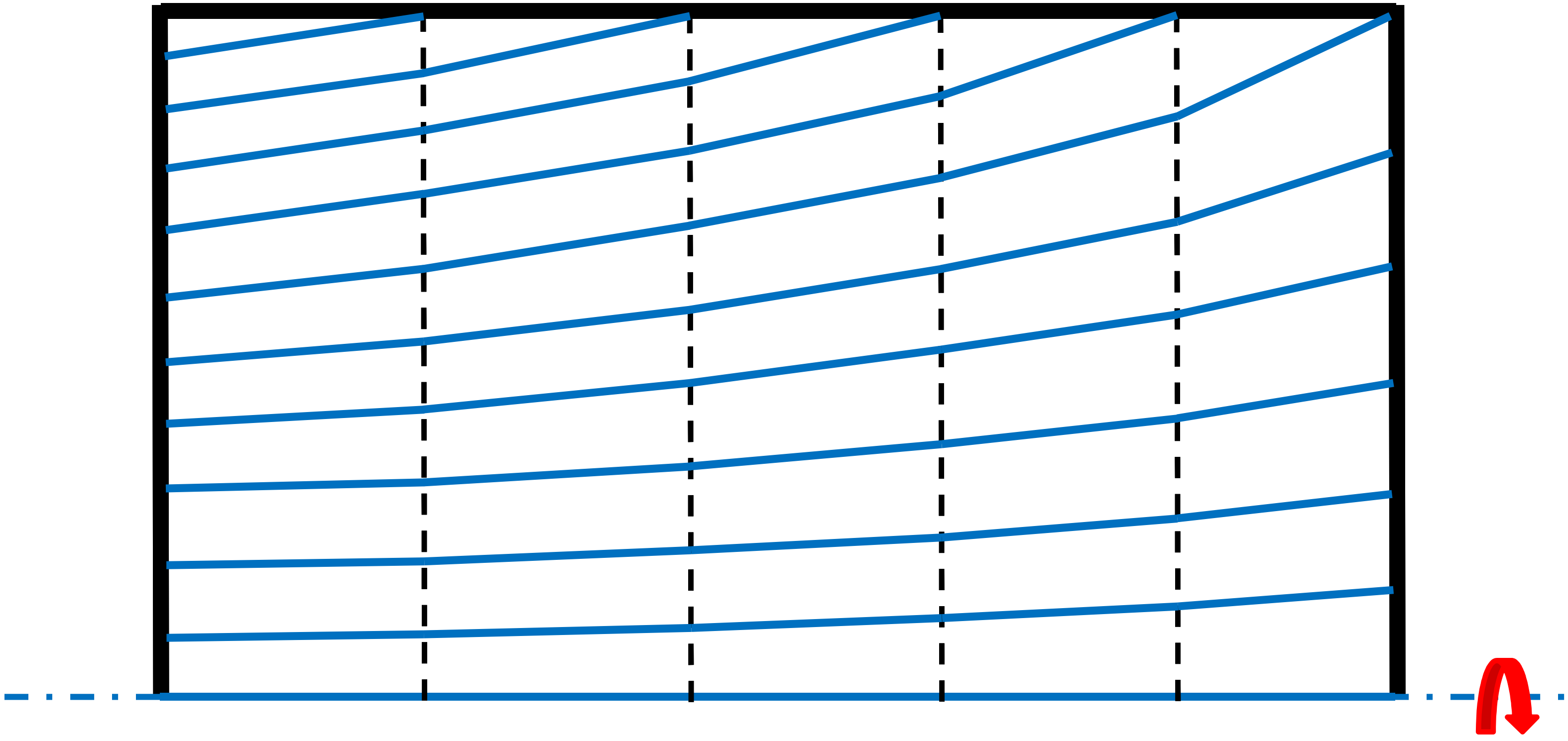
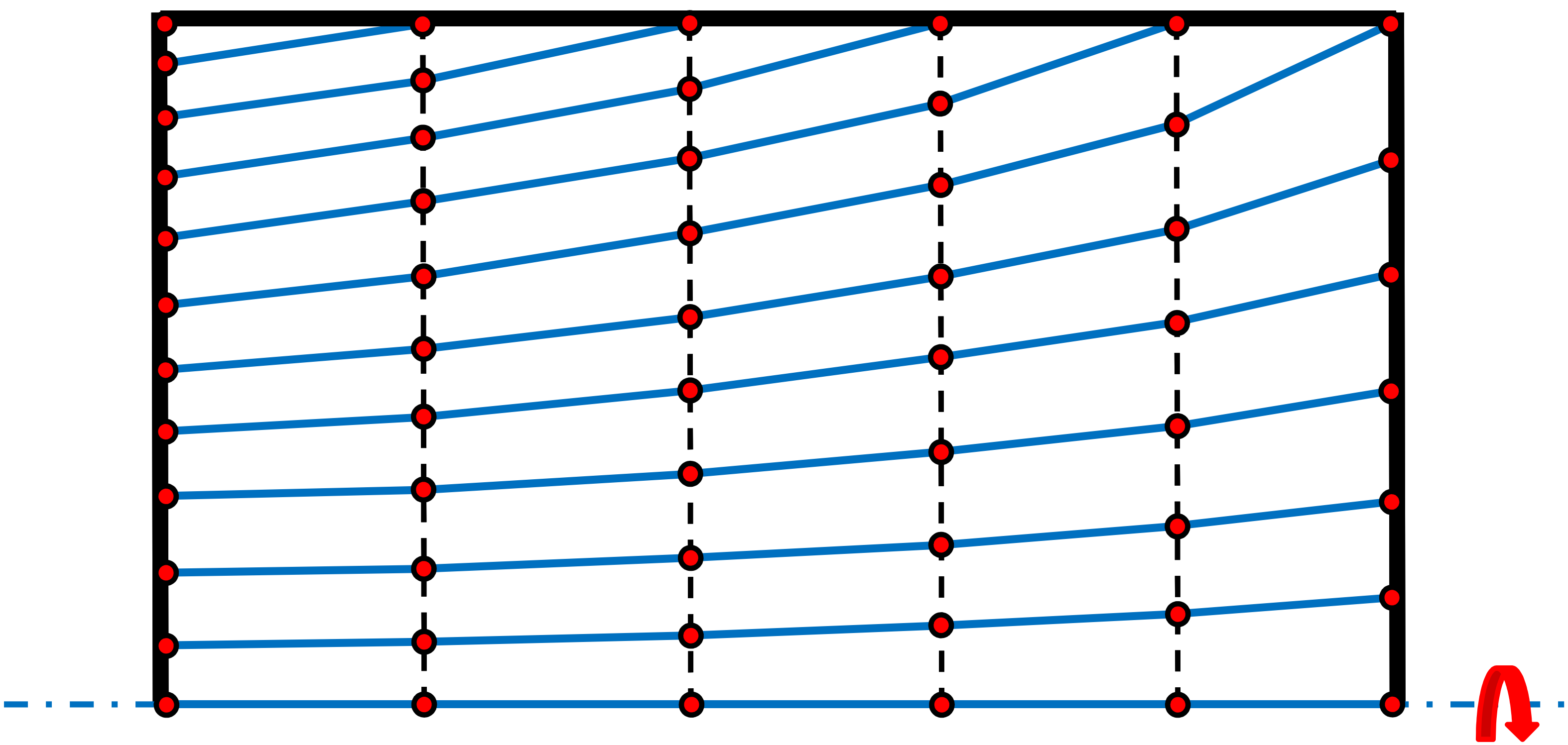


# NON CARTESIAN GRID

Typical grid step : few millimeters



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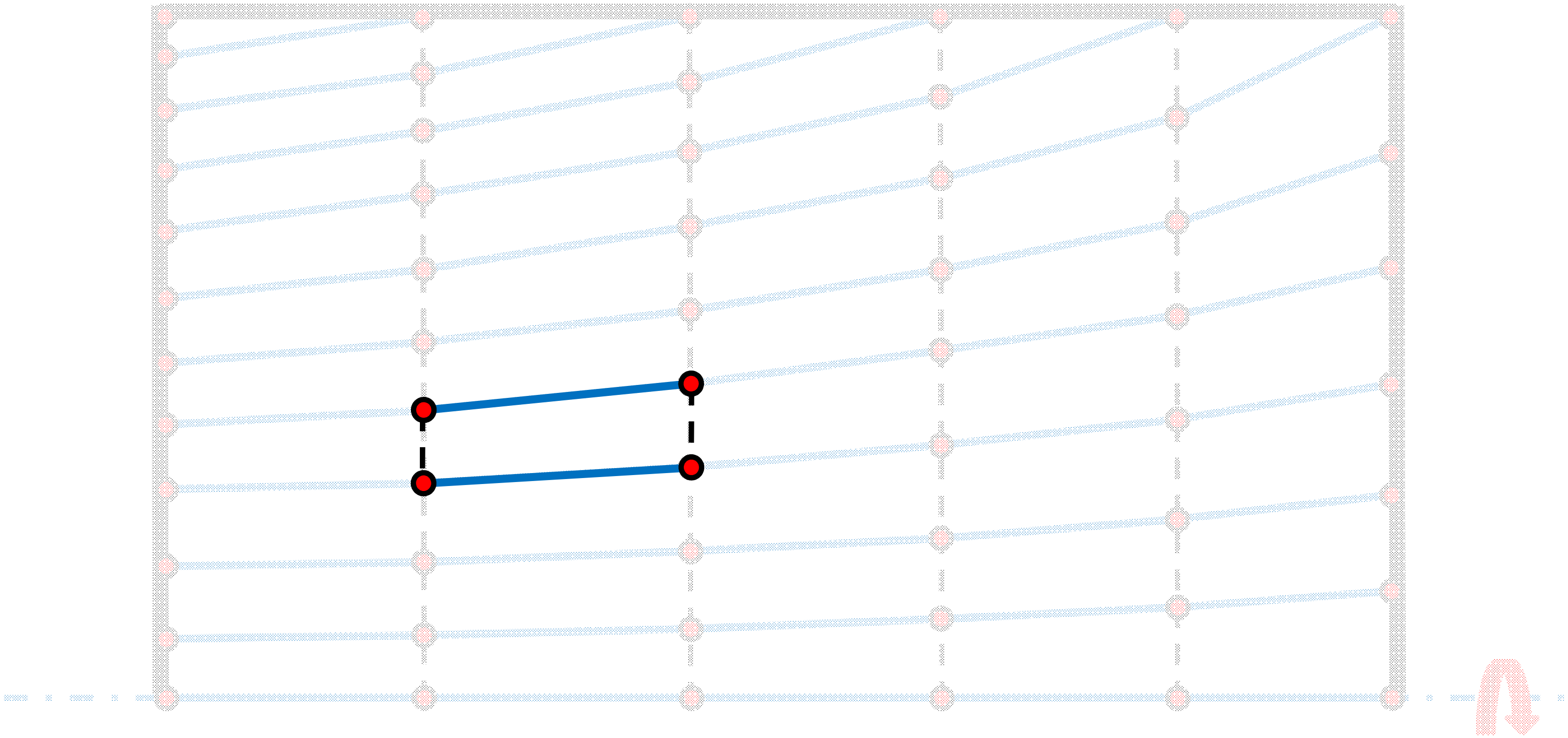
# ION DEPOSITION



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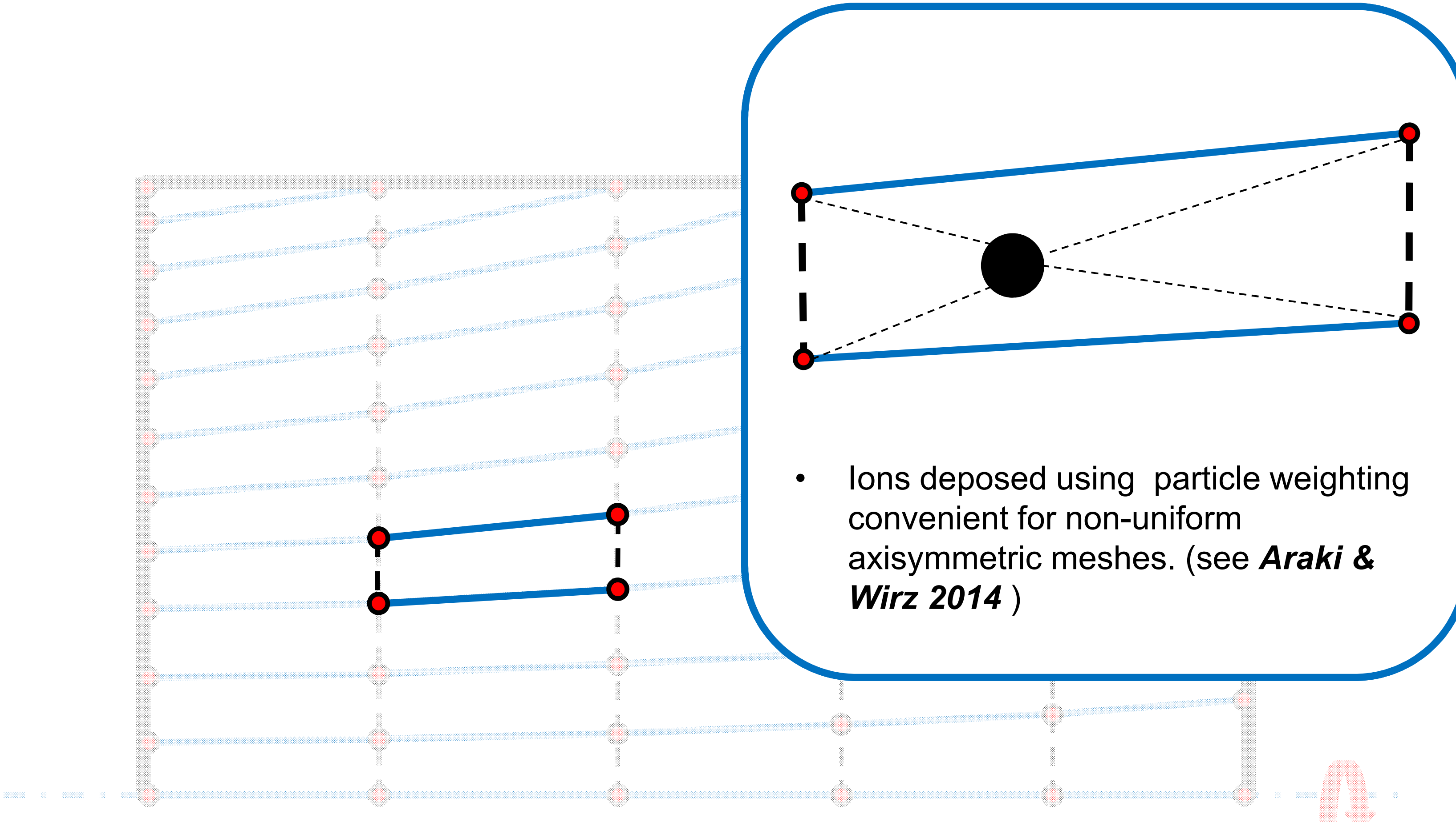
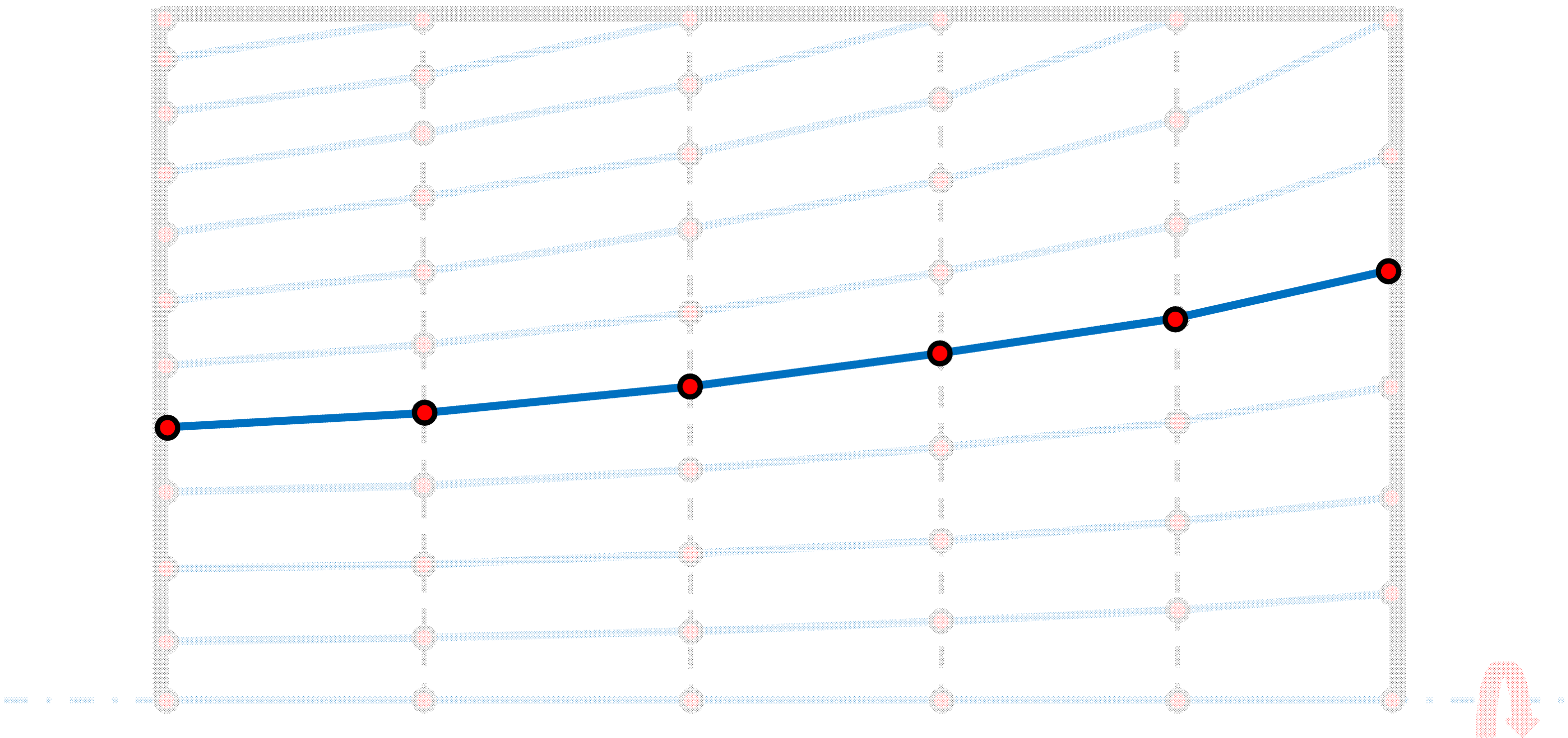


- Ions deposed using particle weighting convenient for non-uniform axisymmetric meshes. (see ***Araki & Wirz 2014*** )

# ELECTRON DEPOSITION



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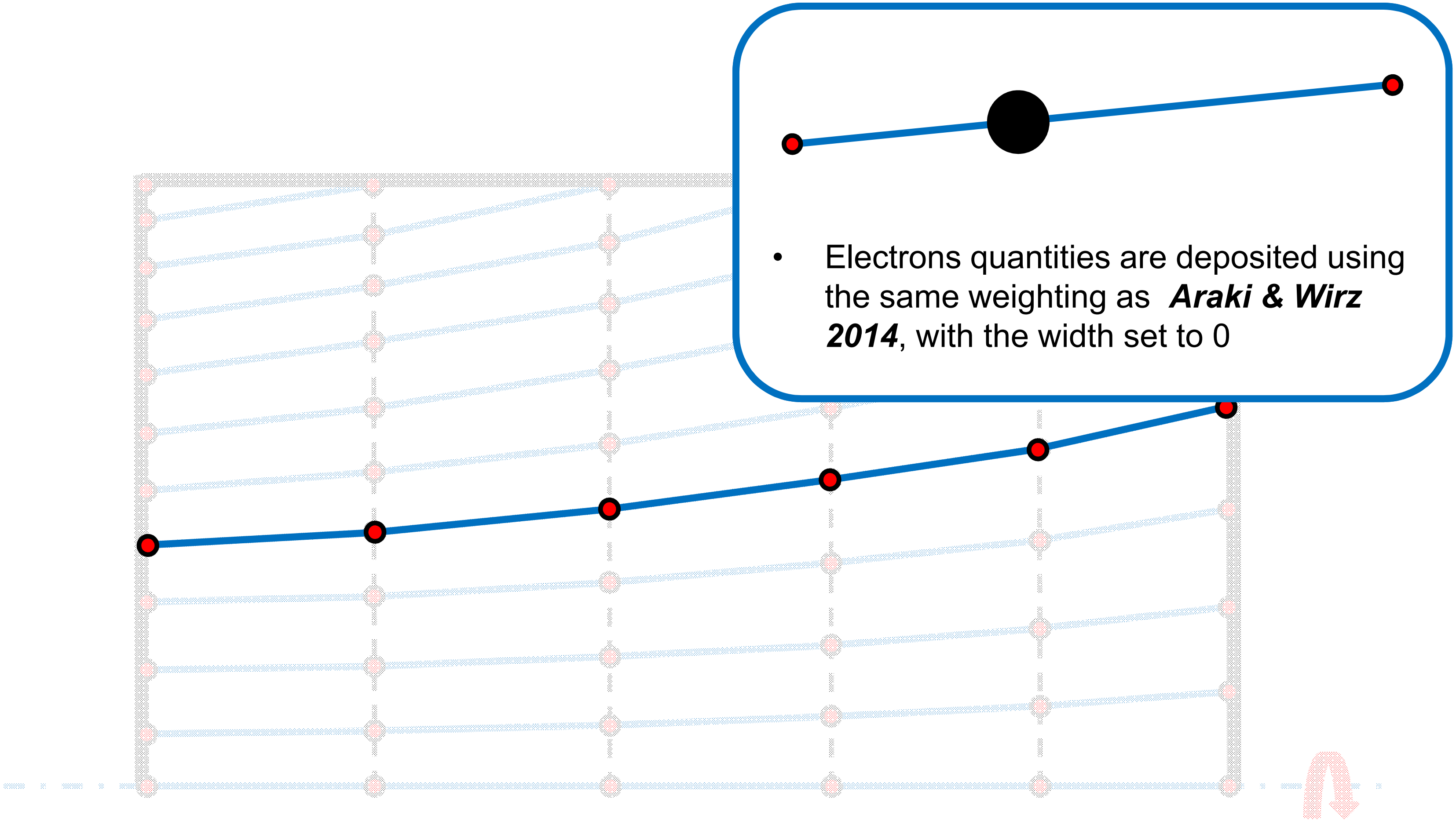

- Electrons quantities are deposited using the same weighting as ***Araki & Wirz 2014***, with the width set to 0

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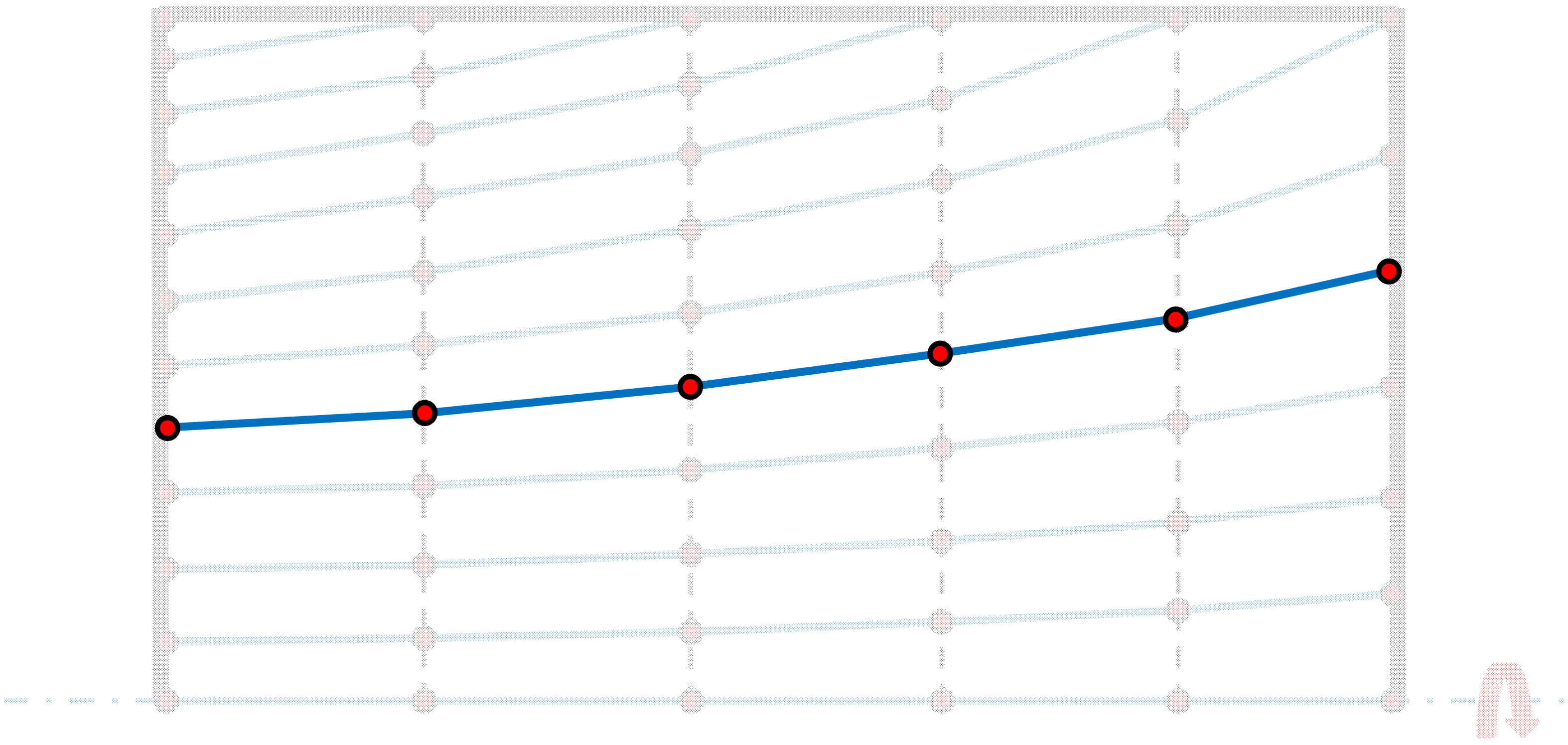
# ELECTRON DYNAMICS



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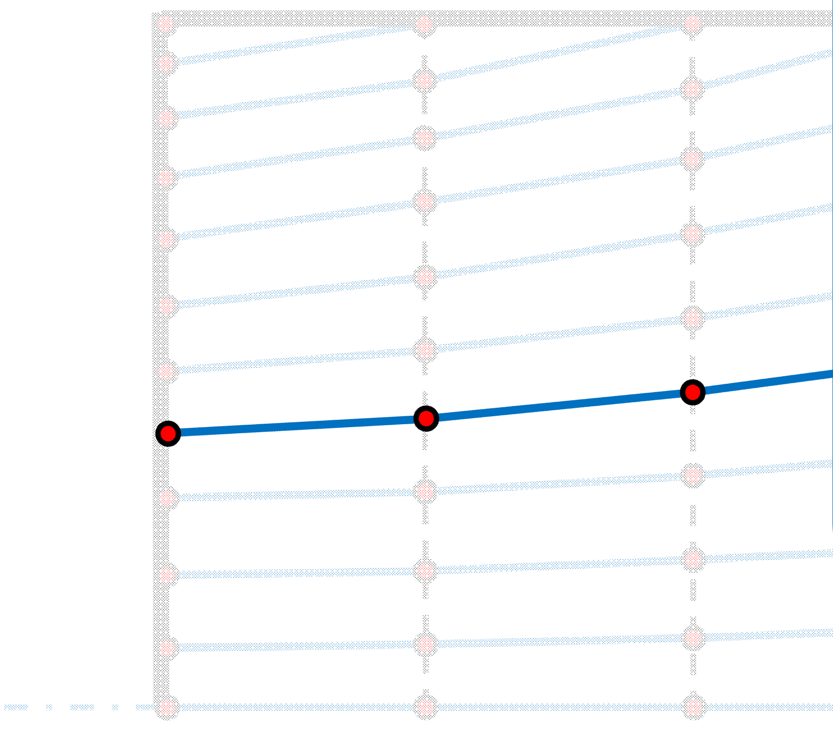

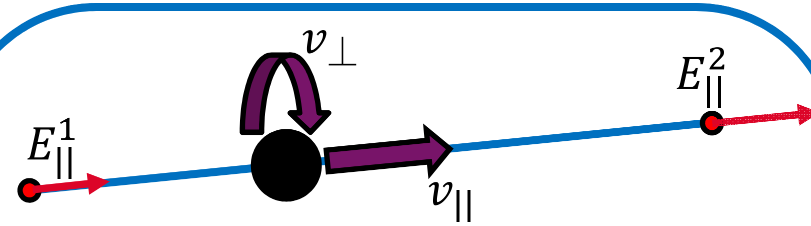


- As each electron is linked to a field line, phase space can be reduced to $(i_l, z, v_{||}, v_\perp)$, which is equivalent to $(i_l, z, v_{||}, \mu_m)$ with $\mu_m = m_e v_{e\perp}^2 / 2|B|$
- $E_{||}$ is computed given deposited quantities from ions and electrons
- Then electrons can be pushed to the next time step

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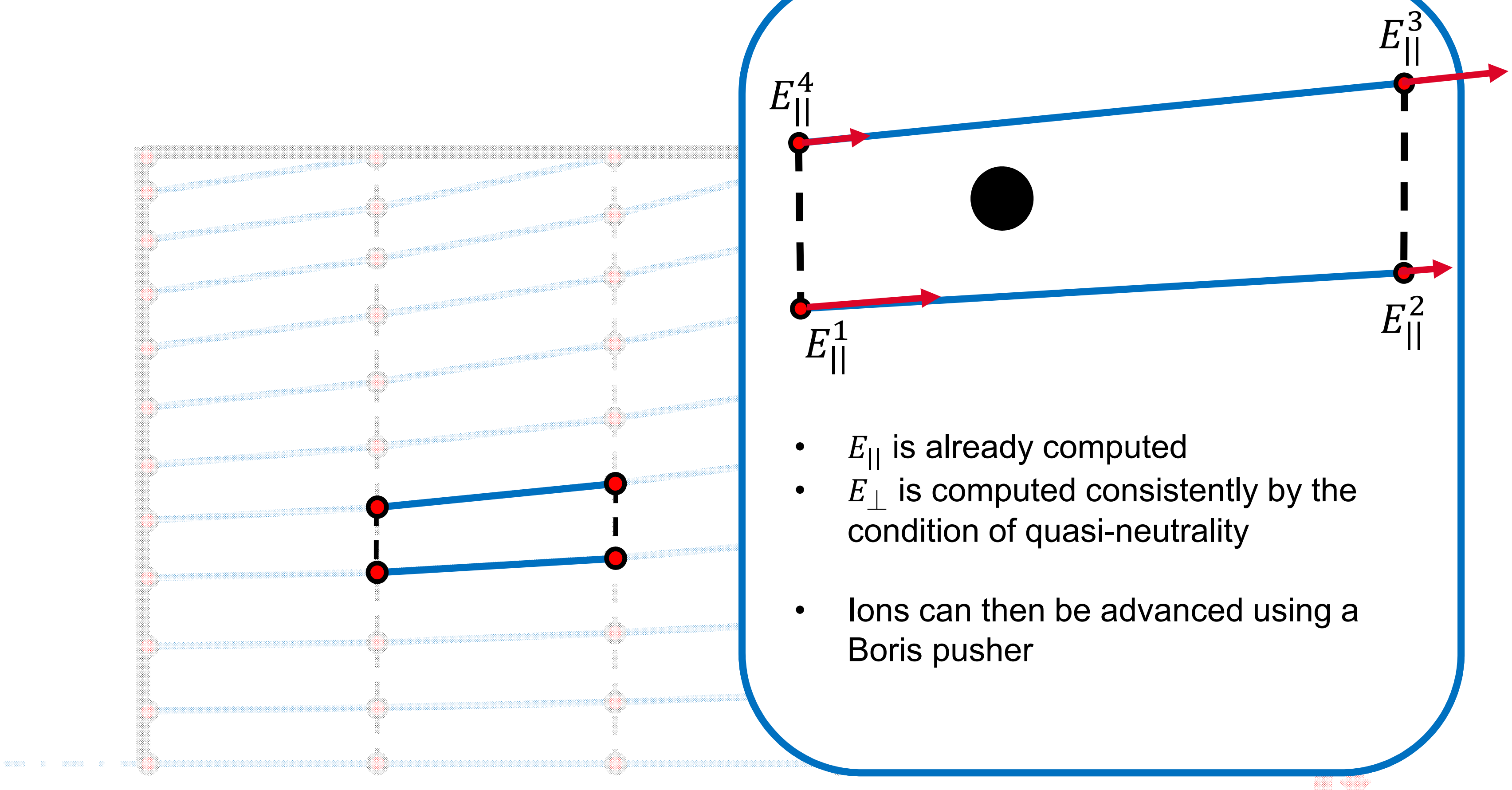


- $E_{||}$ is already computed
- $E_{\perp}$ is computed consistently by the condition of quasi-neutrality
- Ions can then be advanced using a Boris pusher

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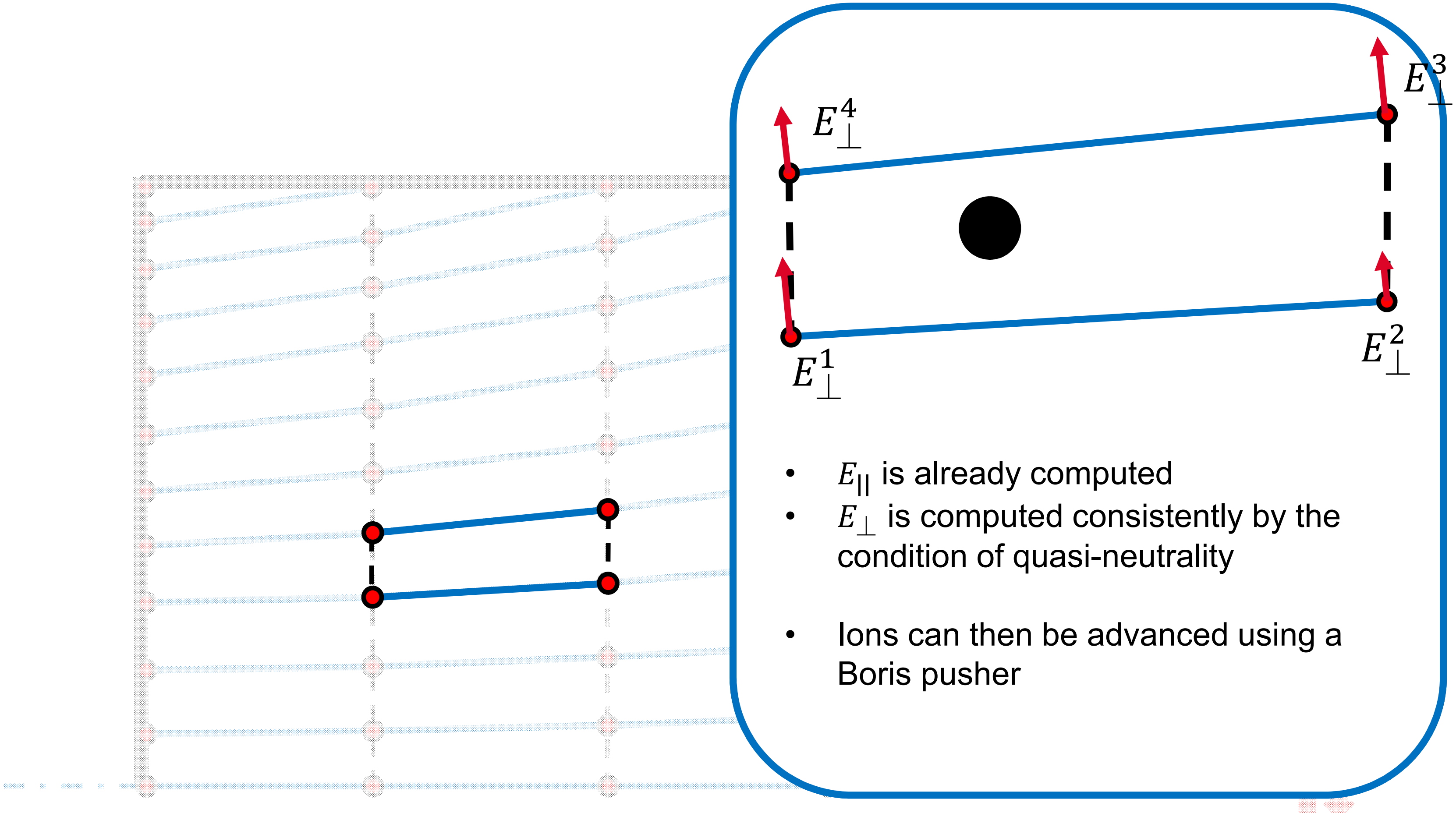


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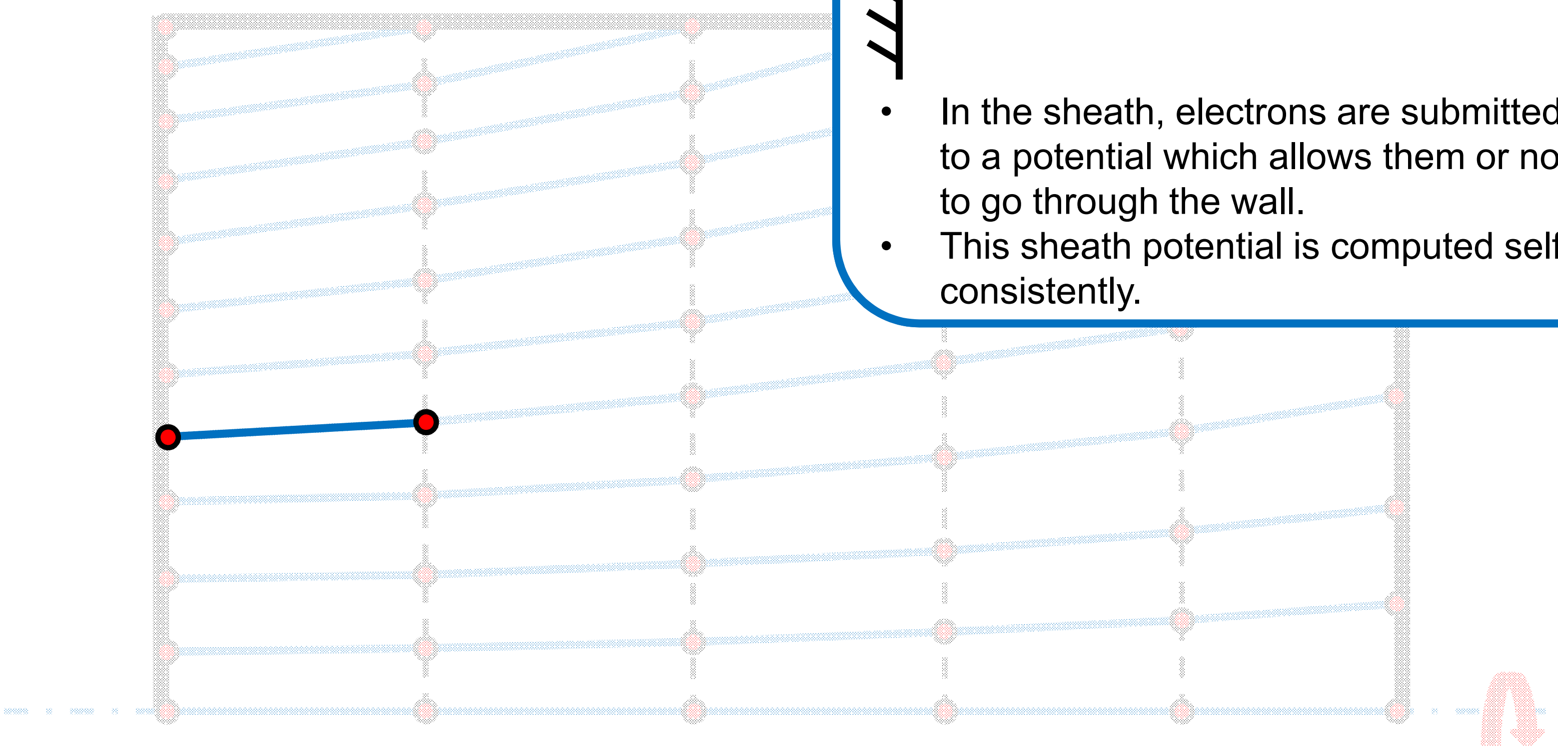
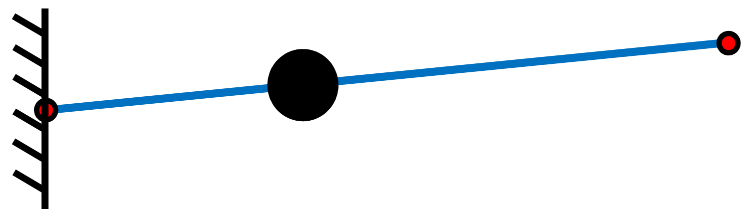
# SHEATH (ELECTRON BOUNDARIES)





- In the sheath, electrons are submitted to a potential which allows them or not to go through the wall.
- This sheath potential is computed self-consistently.

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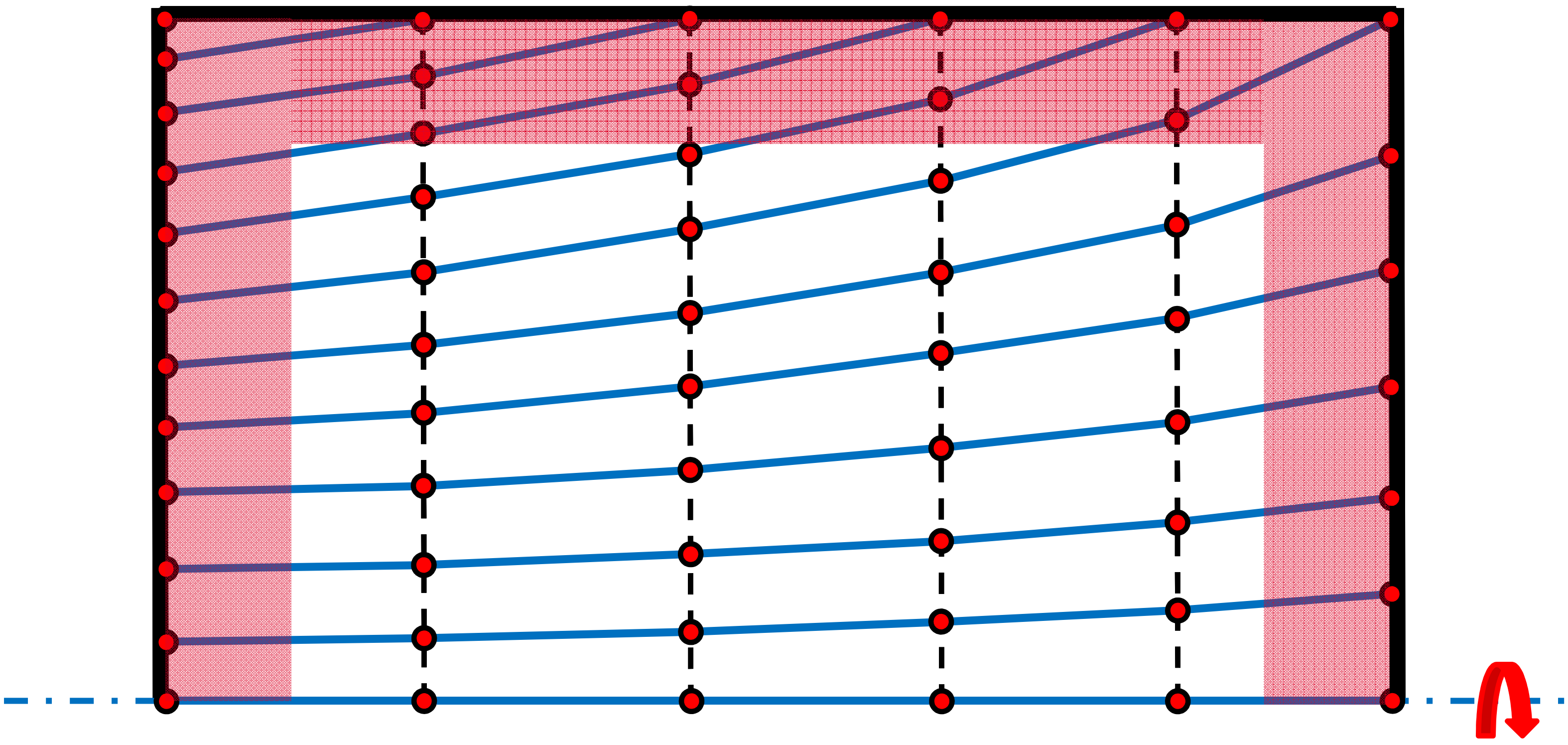
# PRESHEATH (ION BOUNDARIES)



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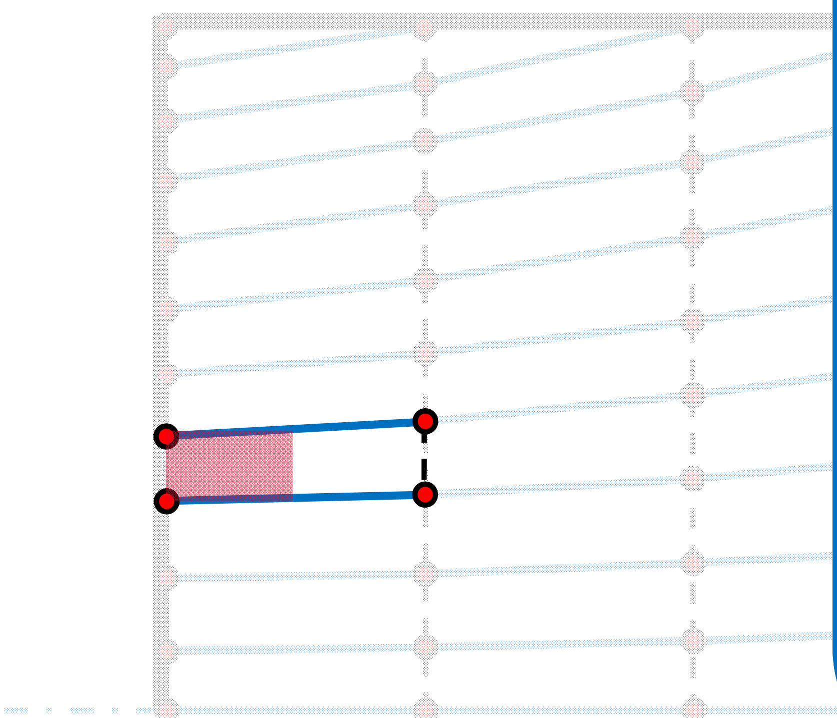
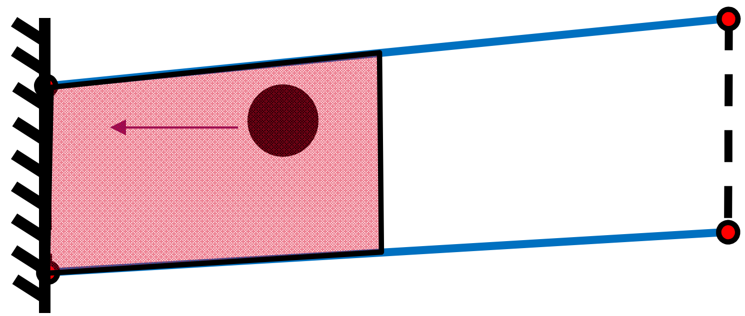




- We impose a certain width for a presheath in which we impose the Bohm criterion.

→ If an ion in this sheath is going to the wall, it is accelerated by an incremental speed, so that the Bohm criterion is satisfied.

# OUTLINE

1.

2.

3. Results

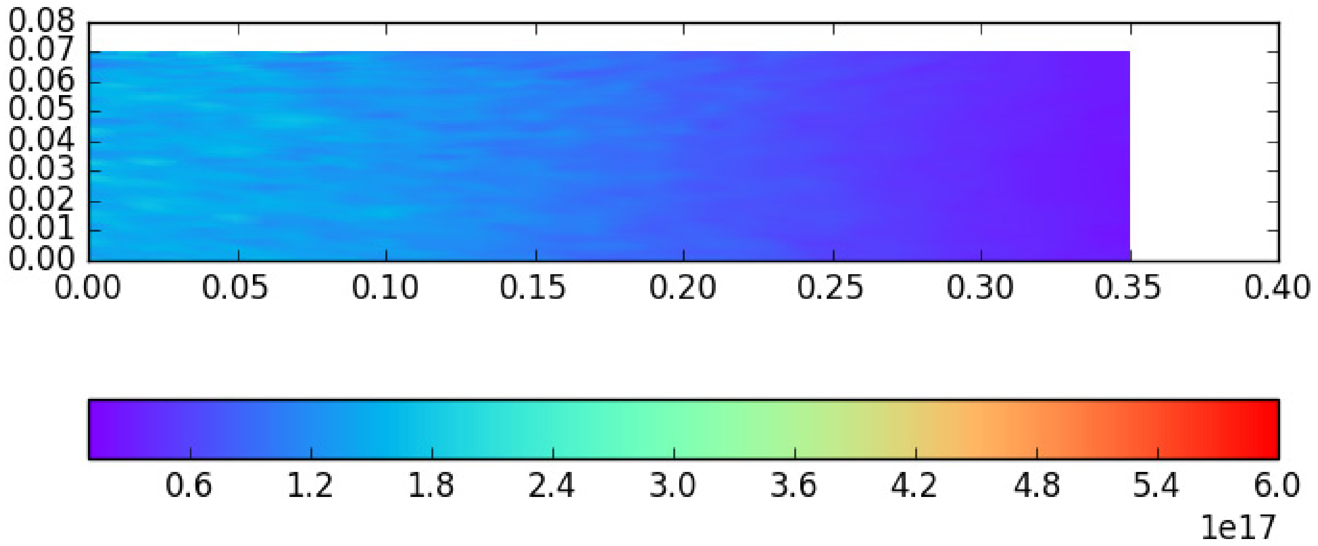
4.

# SET UP

1. Chamber Size : z = 35 cm, r = 7 cm
2. Argon inside the chamber n(z=0) =1.5*10^11 cm^-3
3. $n \; \alpha \; B_z \; \alpha \; z^2$
4. Heating using a very simple operator
5. Ionization using Ar cross section

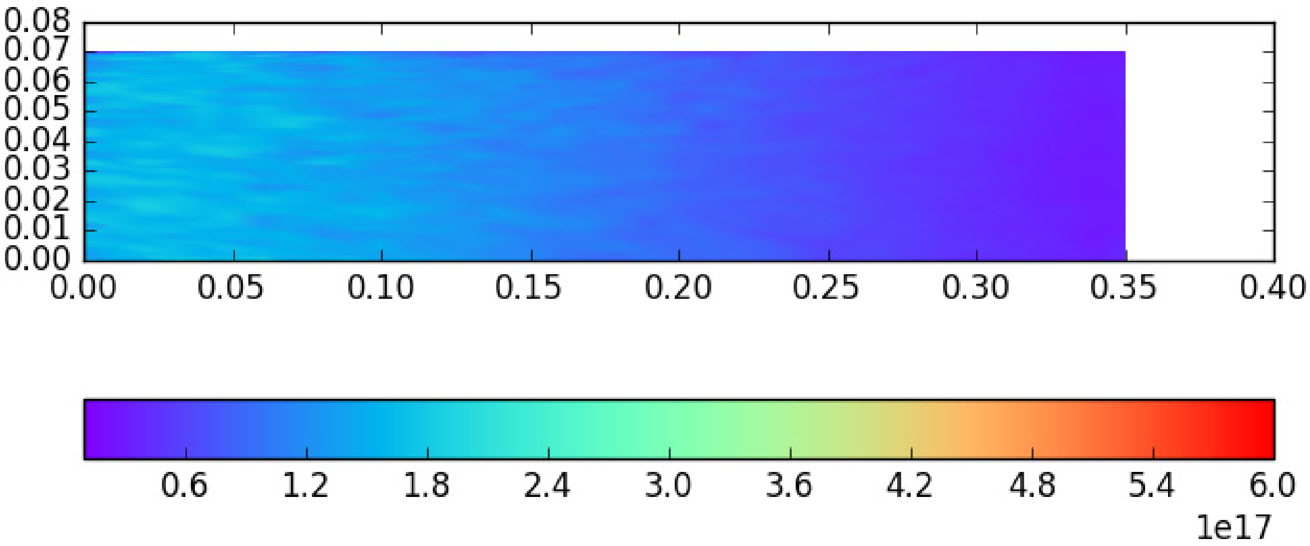
# RESULTS

t = 0 *µs




n (m^-3)

t = 1 *μs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0.6
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1.8
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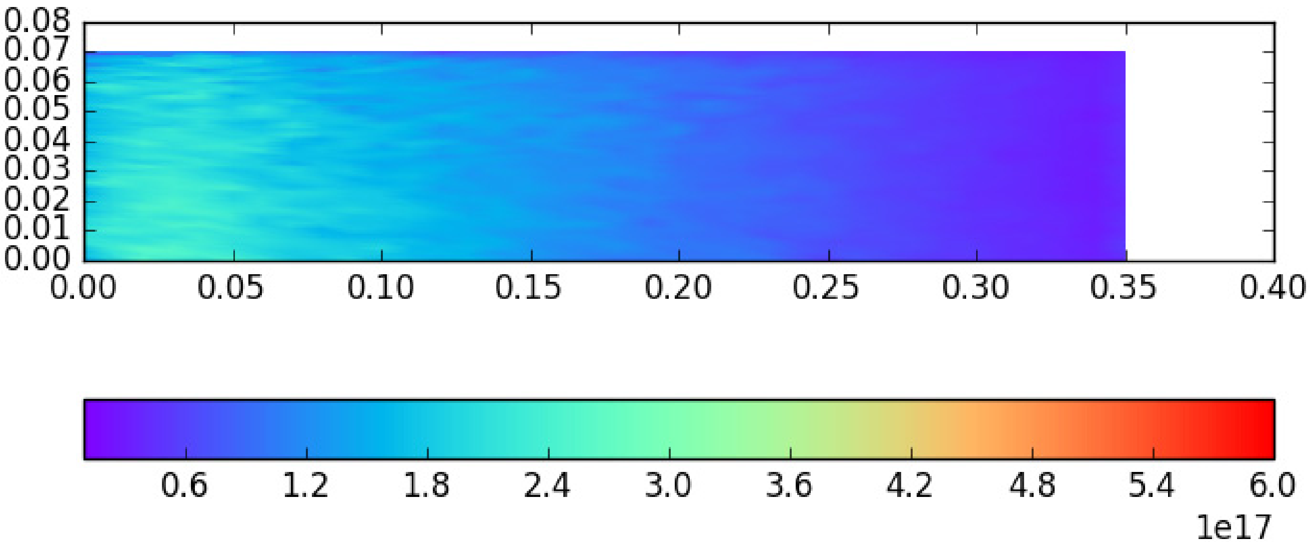
3.0
3.6
4.2
4.8
5.4
6.0
1e17

n (m^-3)

t = 3 *µs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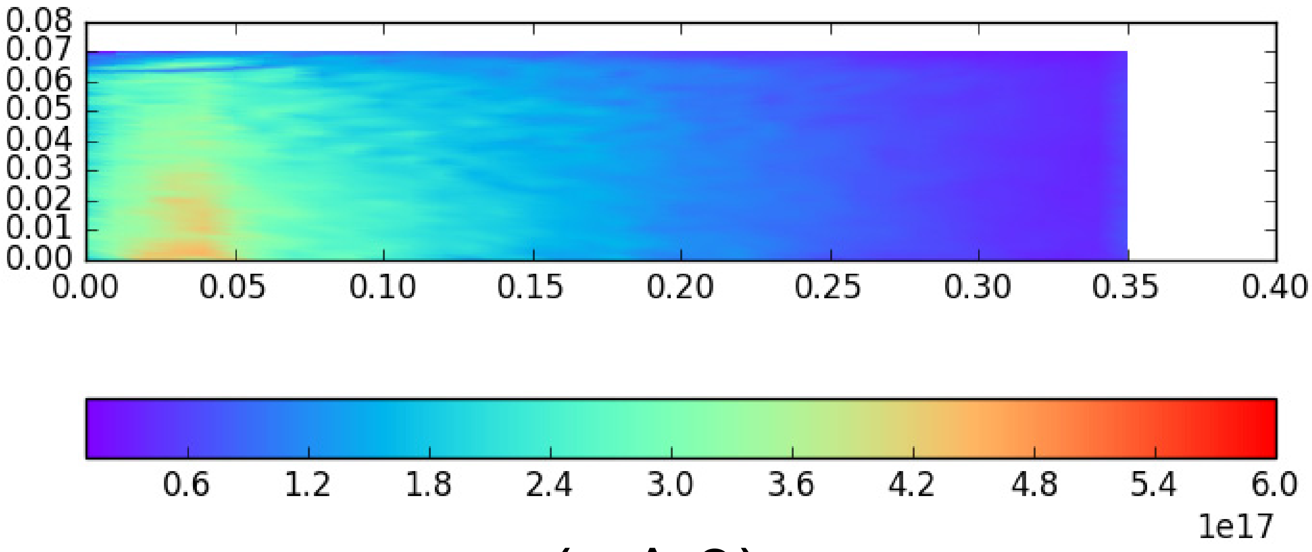
4.8
5.4
6.0
1e17

n (m^-3)

t = 7 *µs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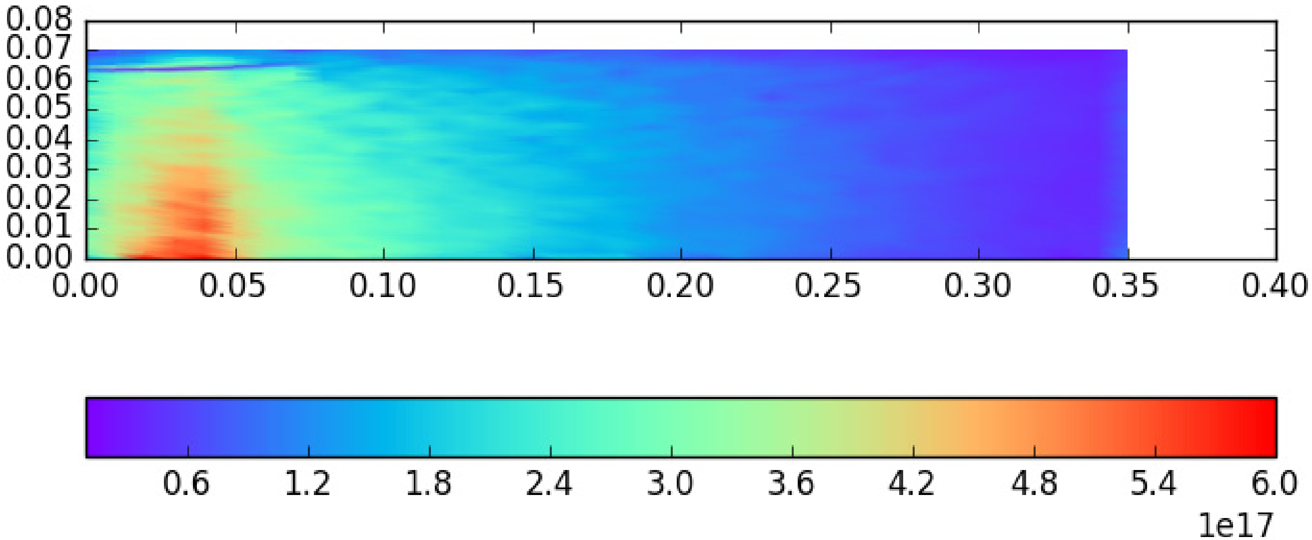
1.2
1.8
2.4
3.0
3.6
4.2
4.8
5.4
6.0
1e17

n (m^-3)

# RESULTS

t = 9 *µs Boundary conditions problem !




n (m^-3)

# OUTLINE

1.

2.

3.

4. Perspectives

# PERSPECTIVES

1. First fix the numerical problem

1. Implementation of the coulombian collisions.

2. Better heating operator.

3. Including the extraction

# THANK YOU