Modelling of plasma tank and related langmuir probe calibration

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THE FRENCH AEROSPACE LAB

return on innovation

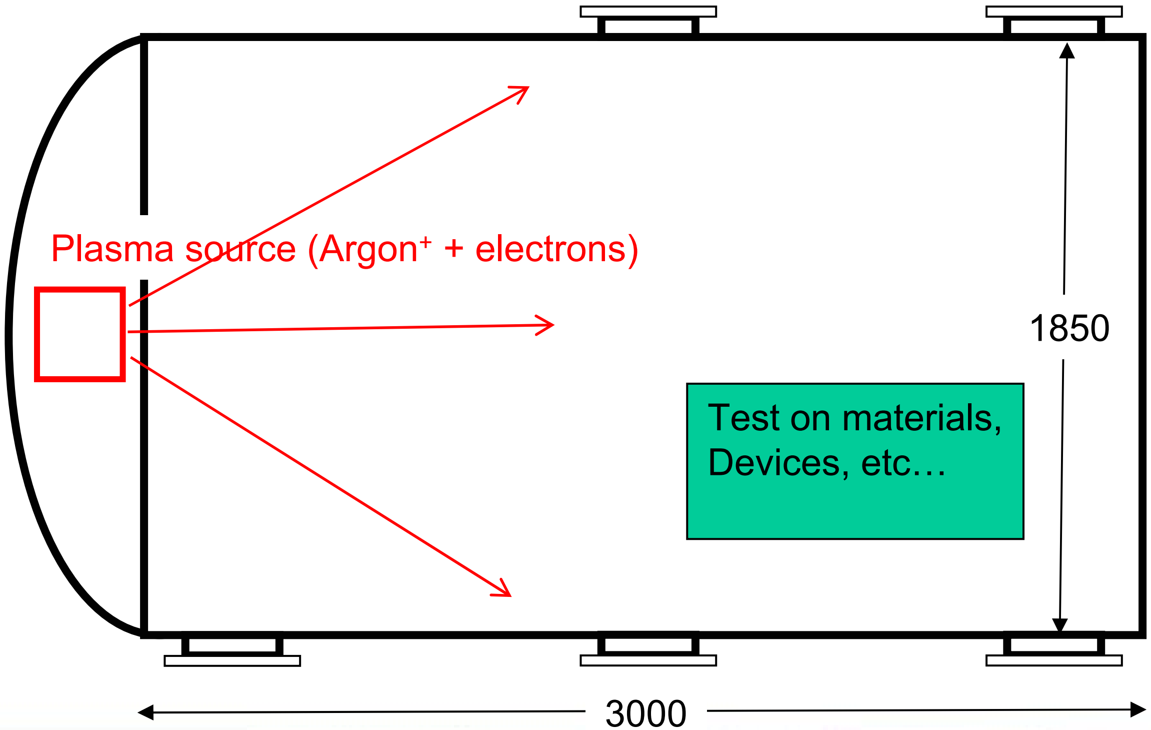
Objectives

- Initial:
  - Validation of SPIS modelling (LEO type conditions)
  - Have a simulation almost ready to simulate our routine experiments (just by changing mock-up, polarisations...)

- Incidental:
  - Improve LP I-V characteristics interpretation method

The Study

- Ionosphere simulation tank JONAS
  - Experiments achieved in 2002
  - SPIS development 2002-2007 → numerical simulations
- CNES R&T funding

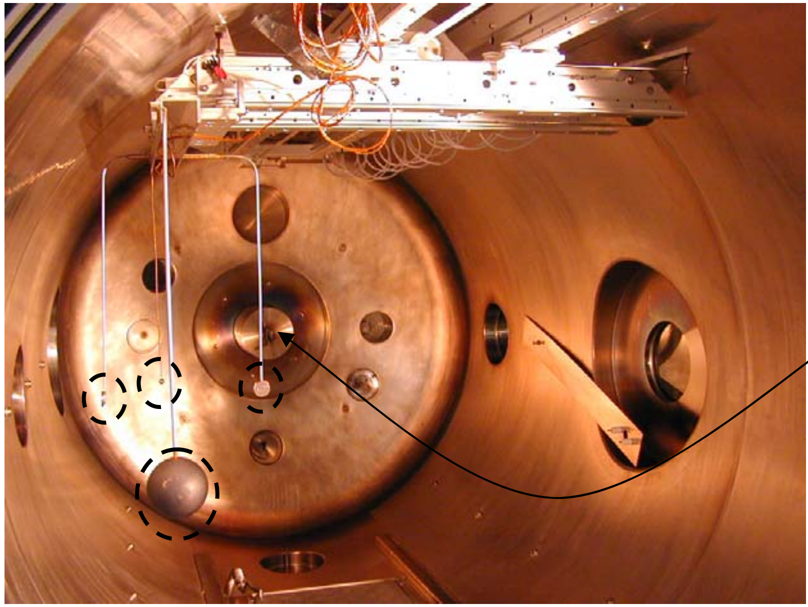


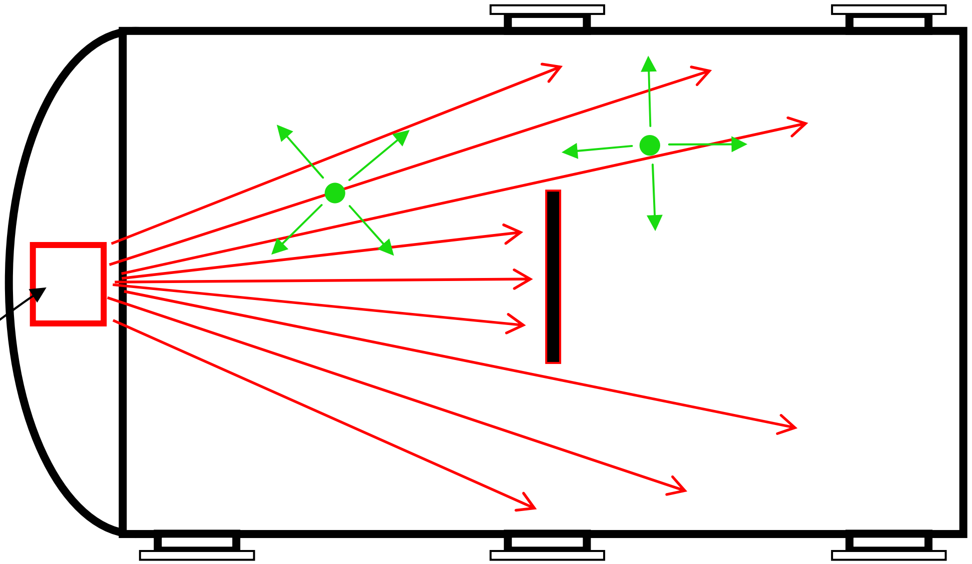
Pressure ~ 5.10^{-6} mbar
Plasma density ~ 10^4 - 10^6 cm^{-3}
Ion energy 10 - 25 eV
Electron temperature ~ 1500°K

The Experiment

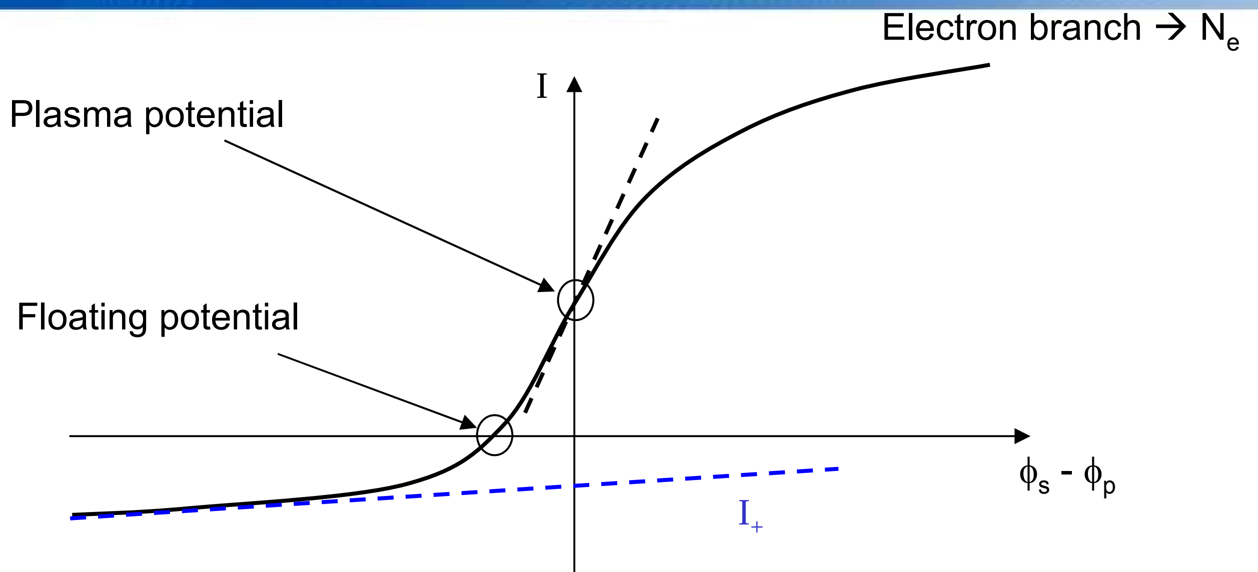
- Plasma I-V characteristics using Langmuir probes (4)
  - plasma density
  - electron temperature
  - plasma potential

- Wake effect using a plate
  - Fast ions (10-25 eV) emitted from the source can not reach the region behind the plate,
  - Slow ions created by charge exchange reactions (CEX) are present in the whole tank ≠ LEO

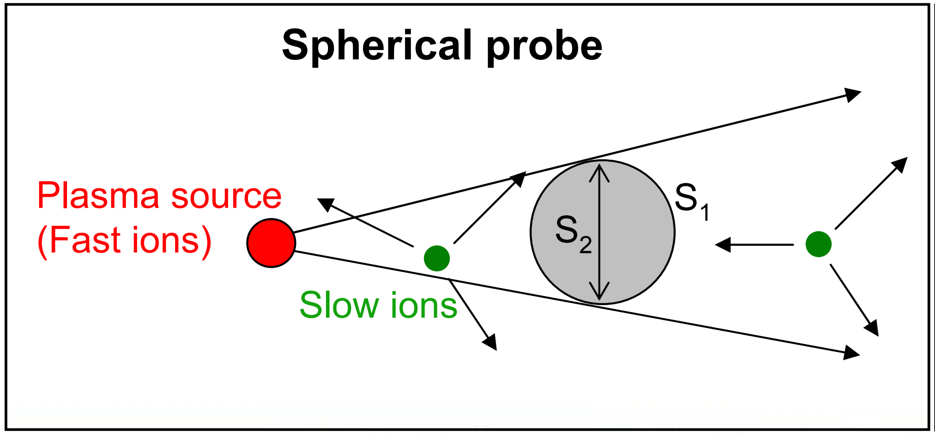


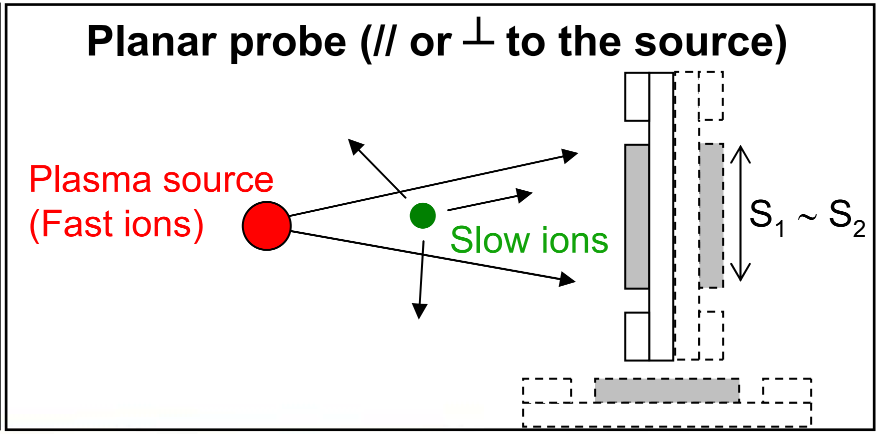


Langmuir probe I-V characteristics interpretation Classical method, method 1 (M1)



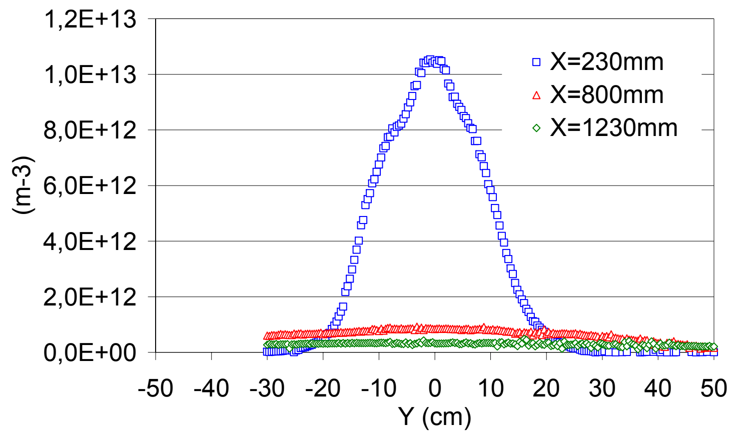
- Classical handling of ion branch: linear interpolation to plasma potential
- Extra difficulty: separate fast and slow ions => need several probes (simultaneous interpretation)

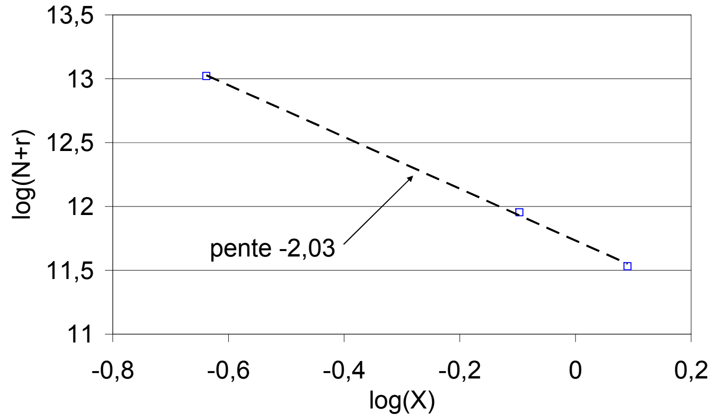




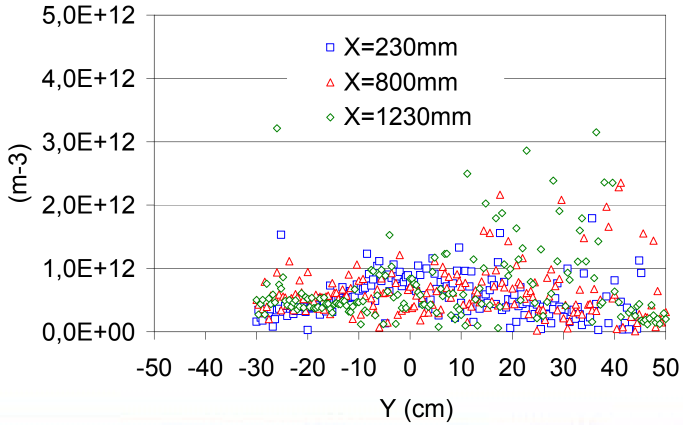
Guarded planar probes results without the plate (method M1)

- Fast ion density profiles at various distances from the source: 1/d² decay



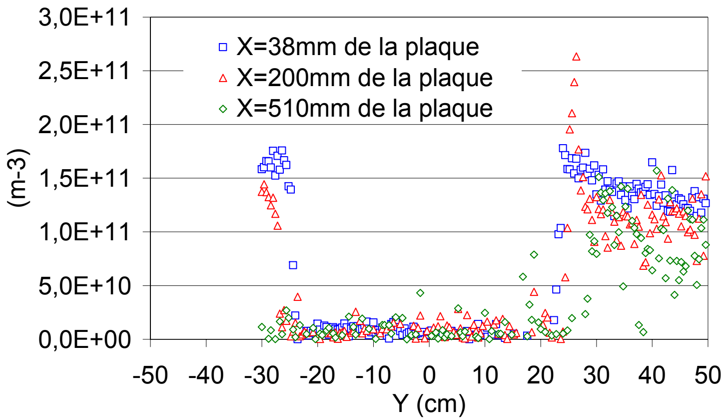


- Slow ion density profiles (noisy)

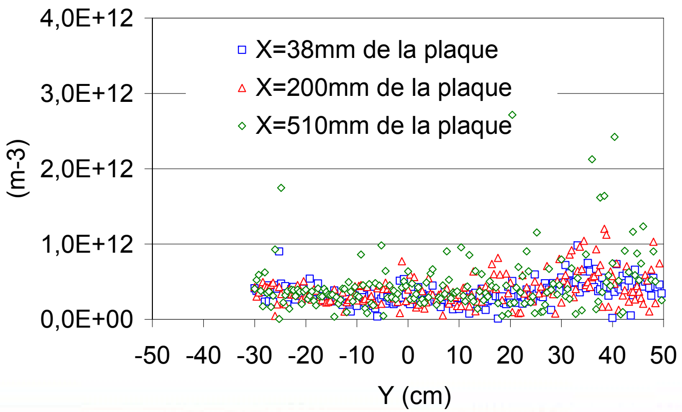


Guarded planar probes results WITH the plate (method M1)

- No fast ions in the plate wake



- Slow ions in the plate wake



Discussion of LP data interpretation

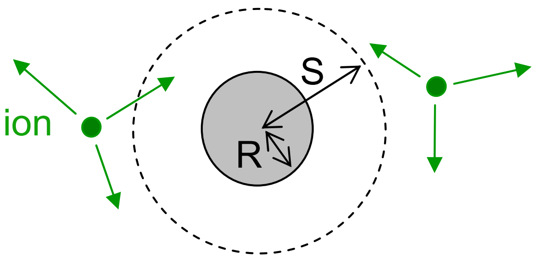
- Ion branch linear interpolation to plasma potential:
  - Only an approximation
  - Quite valid :
    - fast ions: small influence of potential, and not far from linear
    - in OML conditions: theory => linear for a sphere
  - But not really:
    - in non-OML conditions (larger r / λ_d ratio)
    - fast + slow ions: more complicated

- Improvements:
  - General idea: use a realistic ion branch model(ling)
  - Other ~ analytical theory when available: Langmuir-Blodgett instead of Langmuir-Mott-Smith (OML): cf. below, in the wake
  - Numerical method, interesting in more complicated situations (SPIS), as e.g. fast + slow ions

Spherical probe in a non-drifting plasma (method M2)

- Application = wake:

  slow ions only, far from linear



- In a Maxwellian non-drifting plasma, sheath size *S* (Langmuir et Blodgett 1924 + Parker 1980) :

$$\frac{S}{R}=\frac{1}{2}+\left(\frac{1}{4}+\frac{D}{R}\right)^{1/2}+0.052\frac{D}{R}H(\frac{D}{R}-0,2) \quad \text{for } \frac{D}{R_3}\leq 19$$

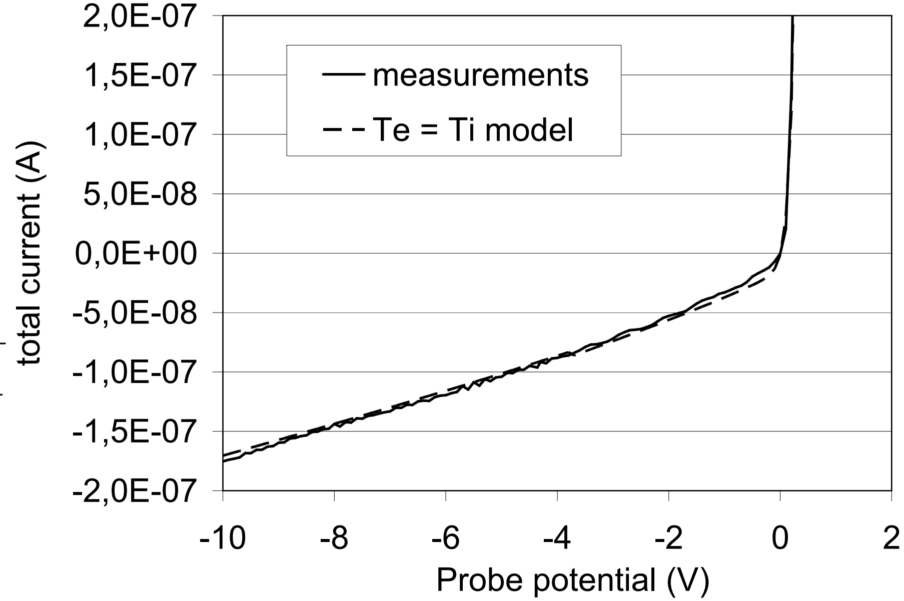
$$\frac{S}{R}=\left(1+\left(\frac{D}{R}\right)^{.753}\right)^{.752} \quad \text{for } \frac{D}{R_3}>19$$

- where D is 1D Child-Langmuir sheath size

$$D=1.26\lambda_D\left(\frac{eV}{kT}\right)^{3/4} \qquad \lambda_D=\sqrt{\frac{\varepsilon_0 k_B T}{Ne^2}}$$

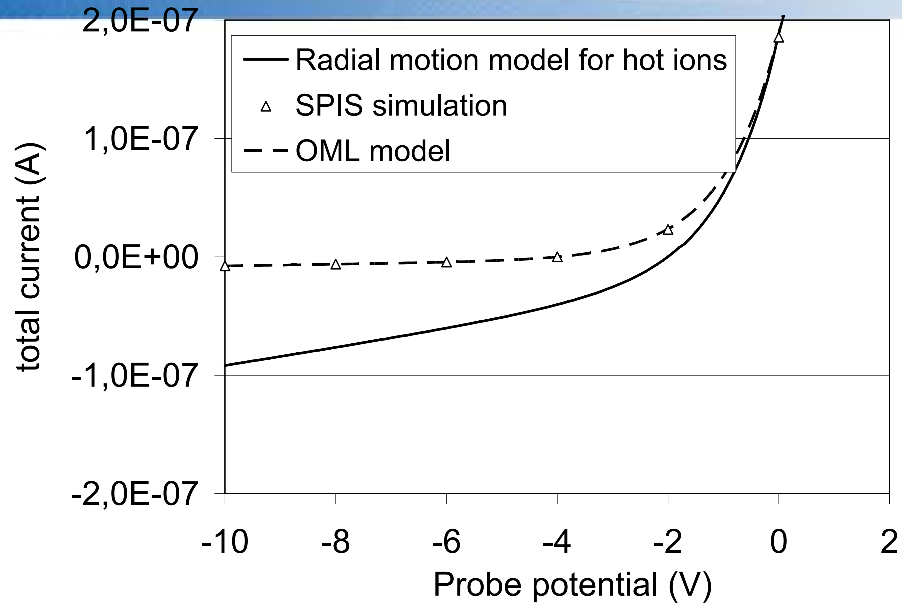
- Then current =

$$I=eN4\pi S^2\sqrt{\frac{k_B T}{2\pi m_+}}$$

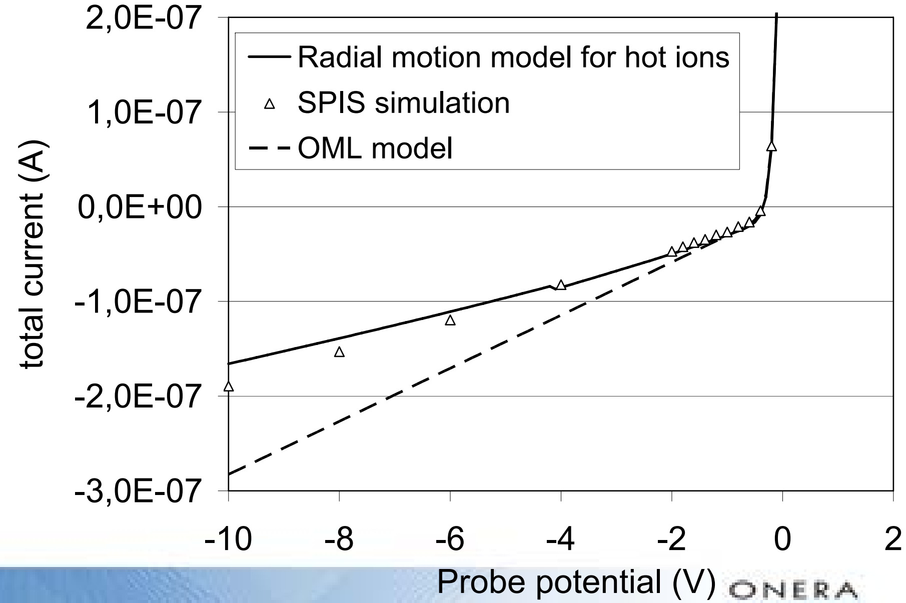


Other approach: probe modelling with SPIS (not used here)

- spherical probe 15 mm in diameter
- Maxwellian plasma at rest.
- $N = 1.0 \times 10^{10} m^{-3}$, $Te = Ti = 1$ eV
- OML theory valid

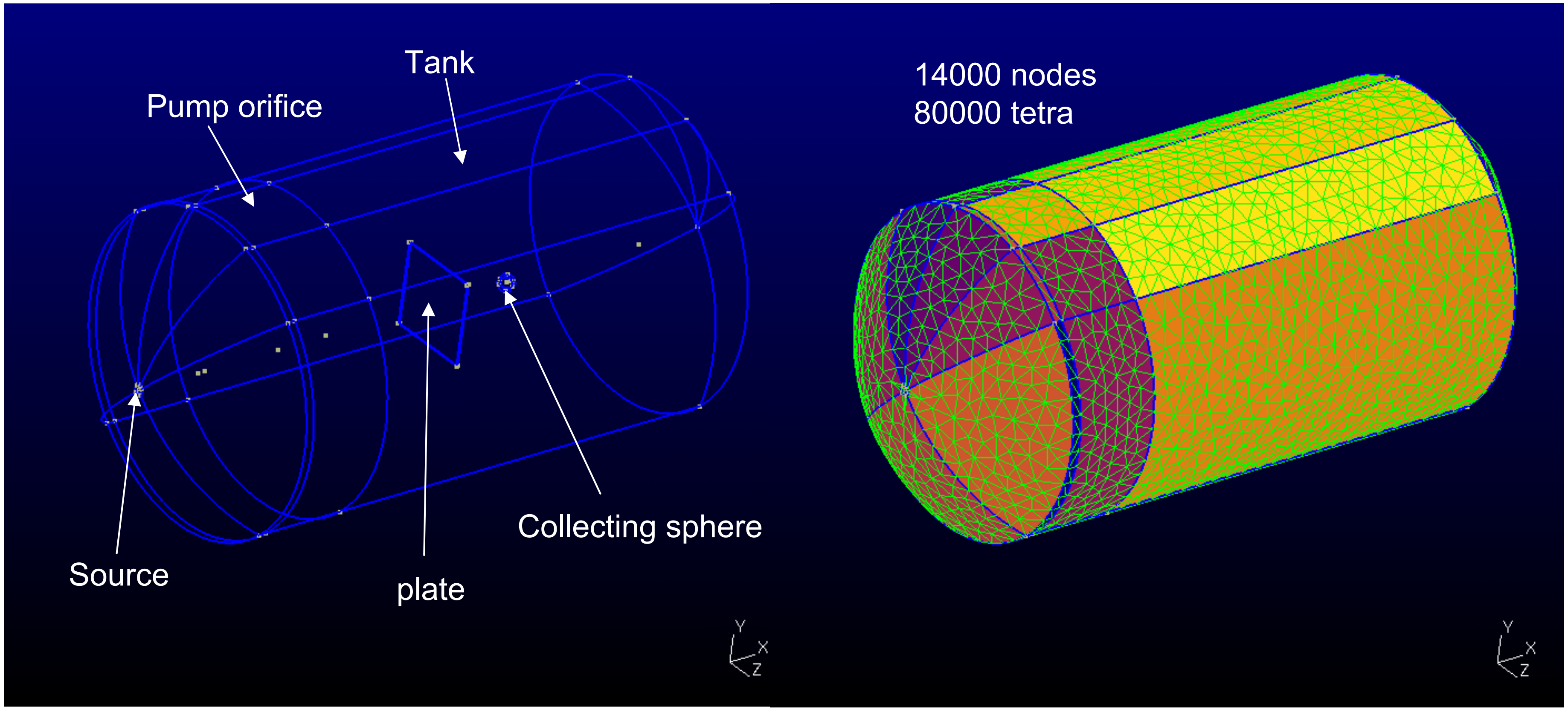


- spherical probe 15 mm in diameter
- Maxwellian plasma at rest
- $N = 1.2 \times 10^{11} m^{-3}$, $Te = Ti = 0.09$ eV
- Langmuir-Blodget theory valid

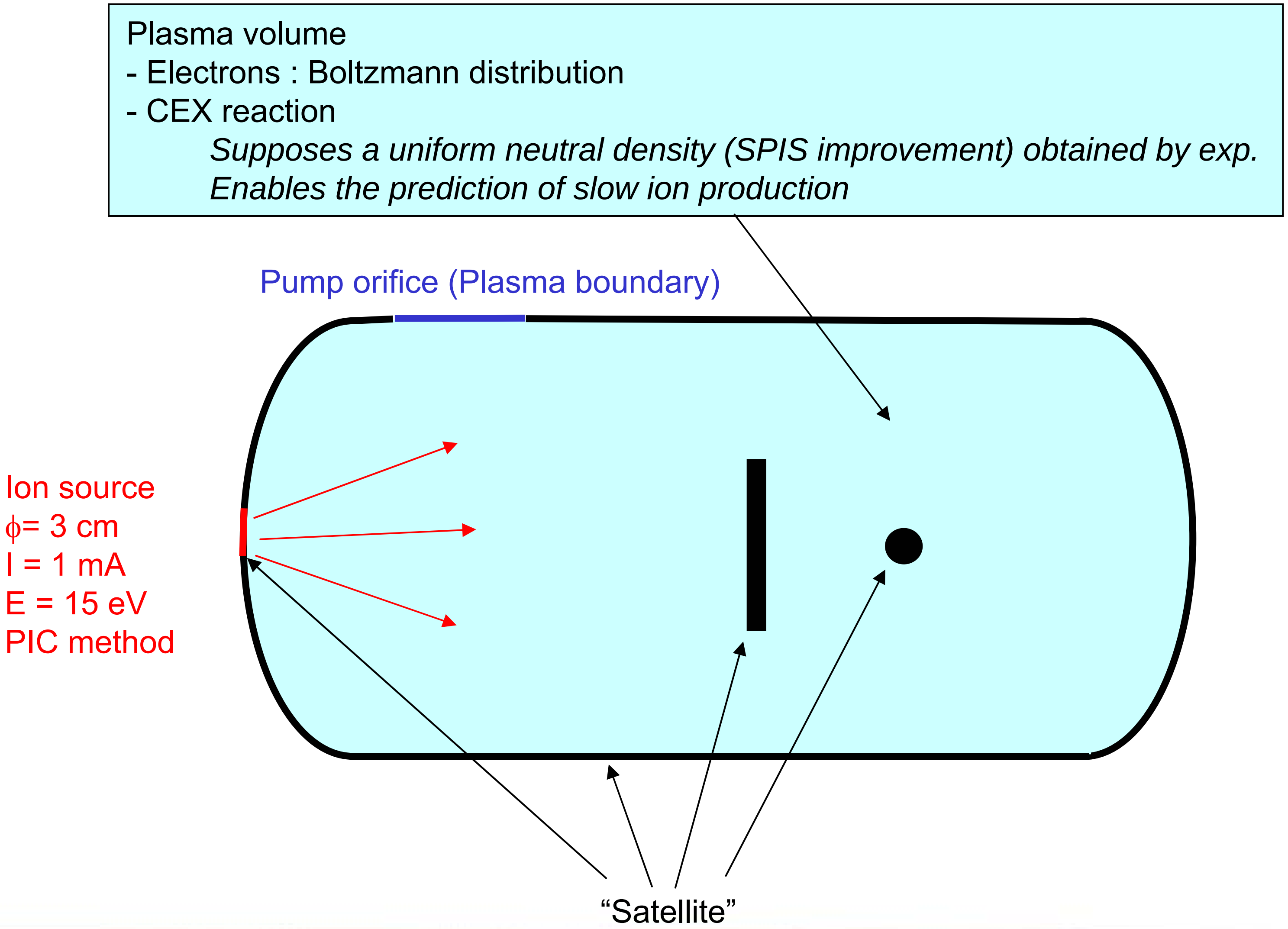


JONAS tank numerical modelling (SPIS)

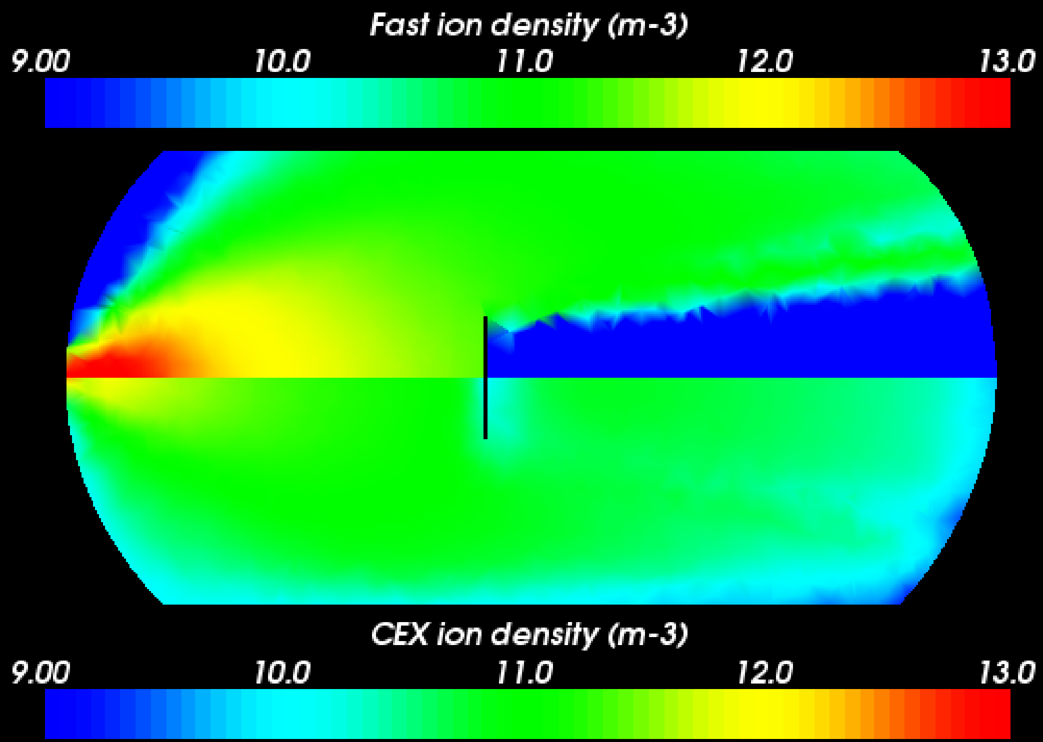
- CAD model and mesh using Gmsh



Numerical simulations (SPIS Model)



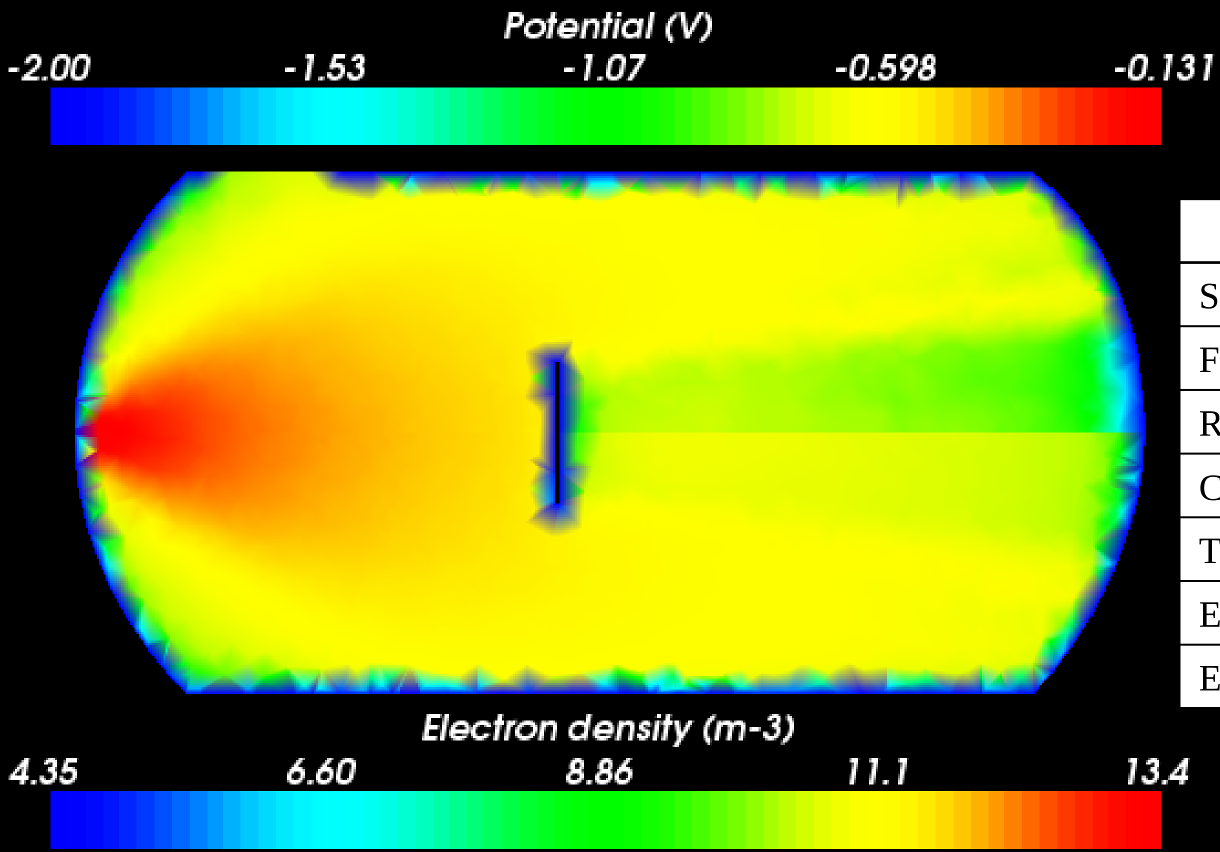
Numerical simulations (SPIS)



Parameter	Value
Simulation time	2.0×10^{-2} s
Fast ion current	1,1 mA
Residual gas pressure	4.3×10^{-4} Pa
CEX cross section σ	0.4×10^{-18} m^2
Tank voltage	-2 V
Electron temperature	0,09 eV
Electron density N_0	10^{14} m^{-3}

- Numerical results
  - Fast ion density : 10^{11}-10^{14} m^{-3}
  - Realistic decrease of ion density (~ $1/r^2$ for fast ions)
  - Wake effect clearly demonstrated for fast ions
  - Important amount of slow ions > 10^{11} m^{-3}, which is in agreement with measurements

Numerical simulations (SPIS)



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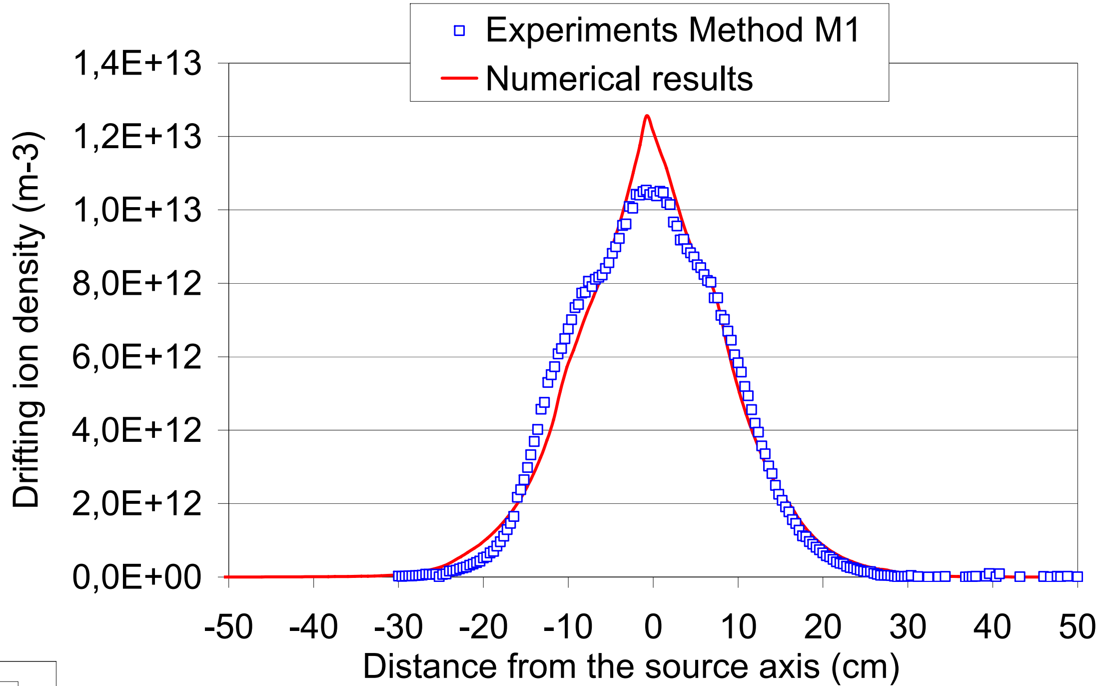
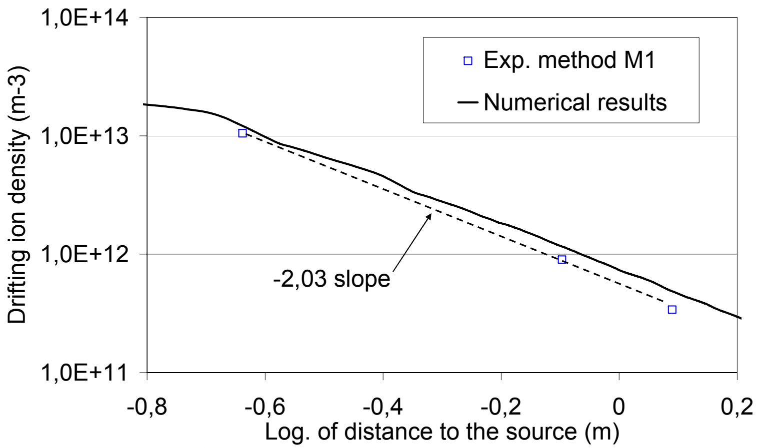
- Numerical results
  - Electron density and potential : Boltzmann distribution $N_e \propto N_0 \exp((V-V_0)/k_B T)$
  - Quasi neutral plasma

Comparison of simulations to experimental data

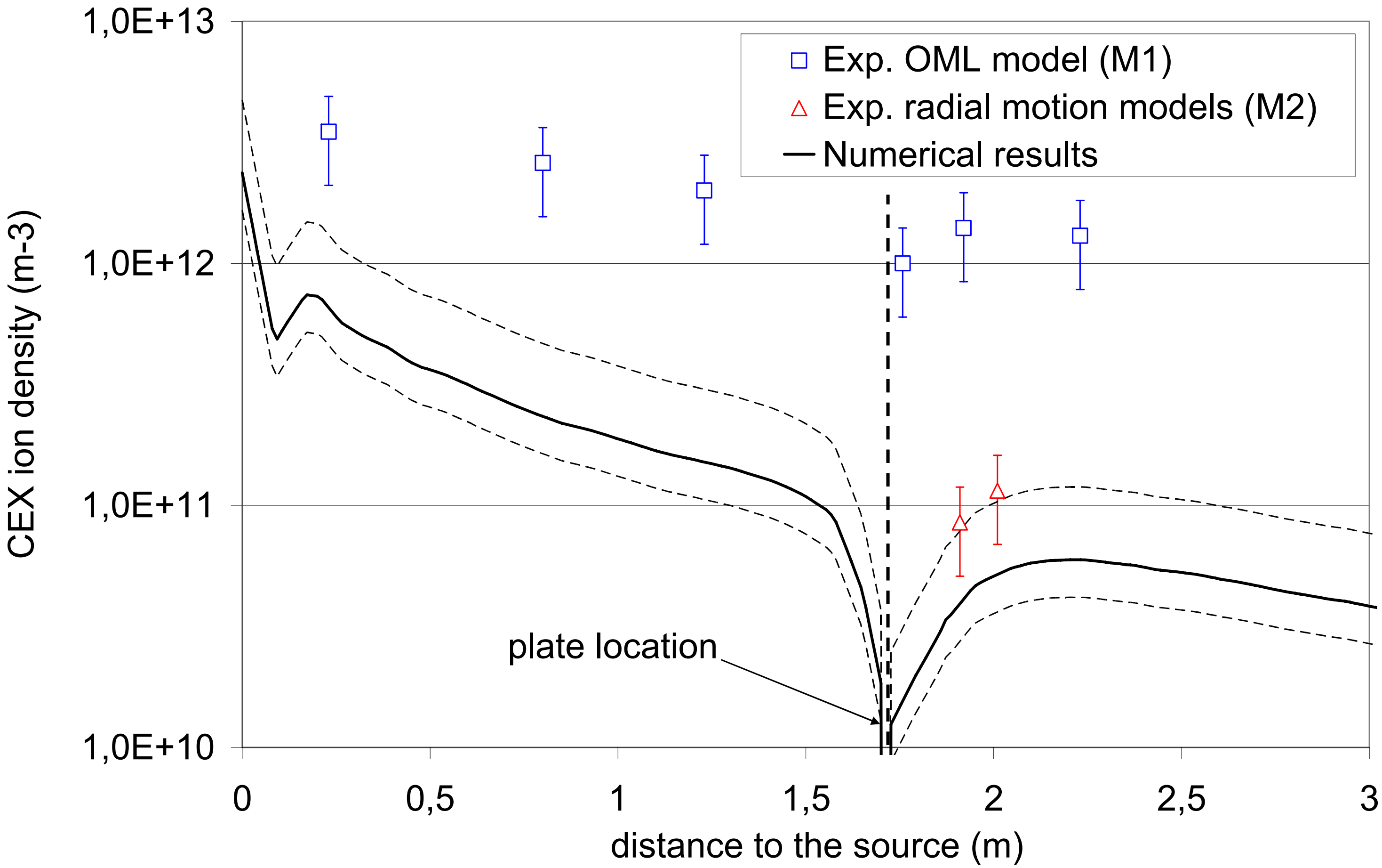
- Fast ion density





Comparison of simulations to experimental data

- Slow ion density



- Much better agreement with M2 method

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Conclusions and perspectives

- Validation of the numerical approach for plasma tank modelling

- The final model will help to simulate the experiments to be conducted in the ONERA tank

- Future possible improvements of the approach
  - Using SPIS for generic LP I-V characteristics interpretation
  - Improved tank model: a DSMC for CEX would allow predicting the neutral pressure, and possible inhomogeneities (here taken from measurements)