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► **To cite this version:**

Laurence Chérigier-Kovacic, Aurelien Lejeune, Fabrice Doveil. Study of hydrogen ion species in a multicusp ion source. 35th European Physical Society conference on plasma physics, Jun 2008, Heronissos, Greece. hal-03534323

**HAL Id: hal-03534323**

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Submitted on 19 Jan 2022

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# Study of hydrogen ion species in a multicusp ion source

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Motivation :

How to improve the hydrogen ions yield production in an ion beam from a low pressure plasma ?

Experimental Set-up :

The ion source chamber :

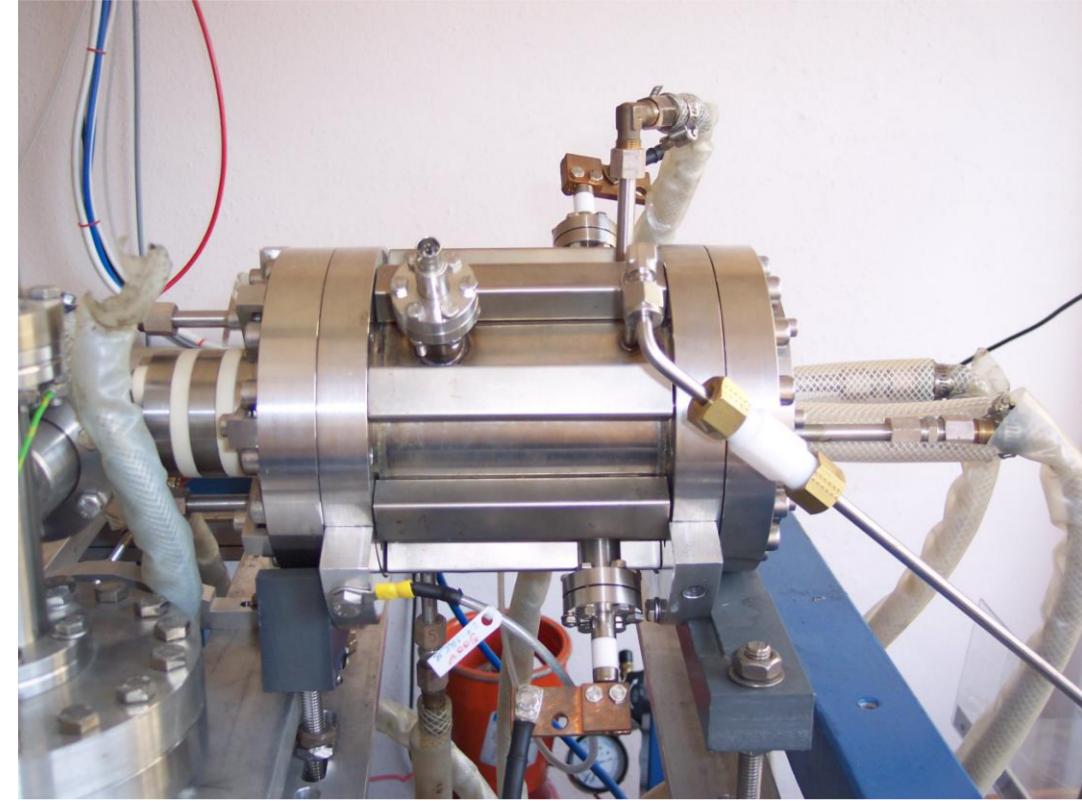


Fig. 1 : Multicusp ion source (L=20cm, R=6cm)

P: Gaz pressure Vf: Filament voltage If: Filament current  
Vd: Discharge voltage Id: Discharge current  
Vb: Wall bias voltage Ve: Lens voltage

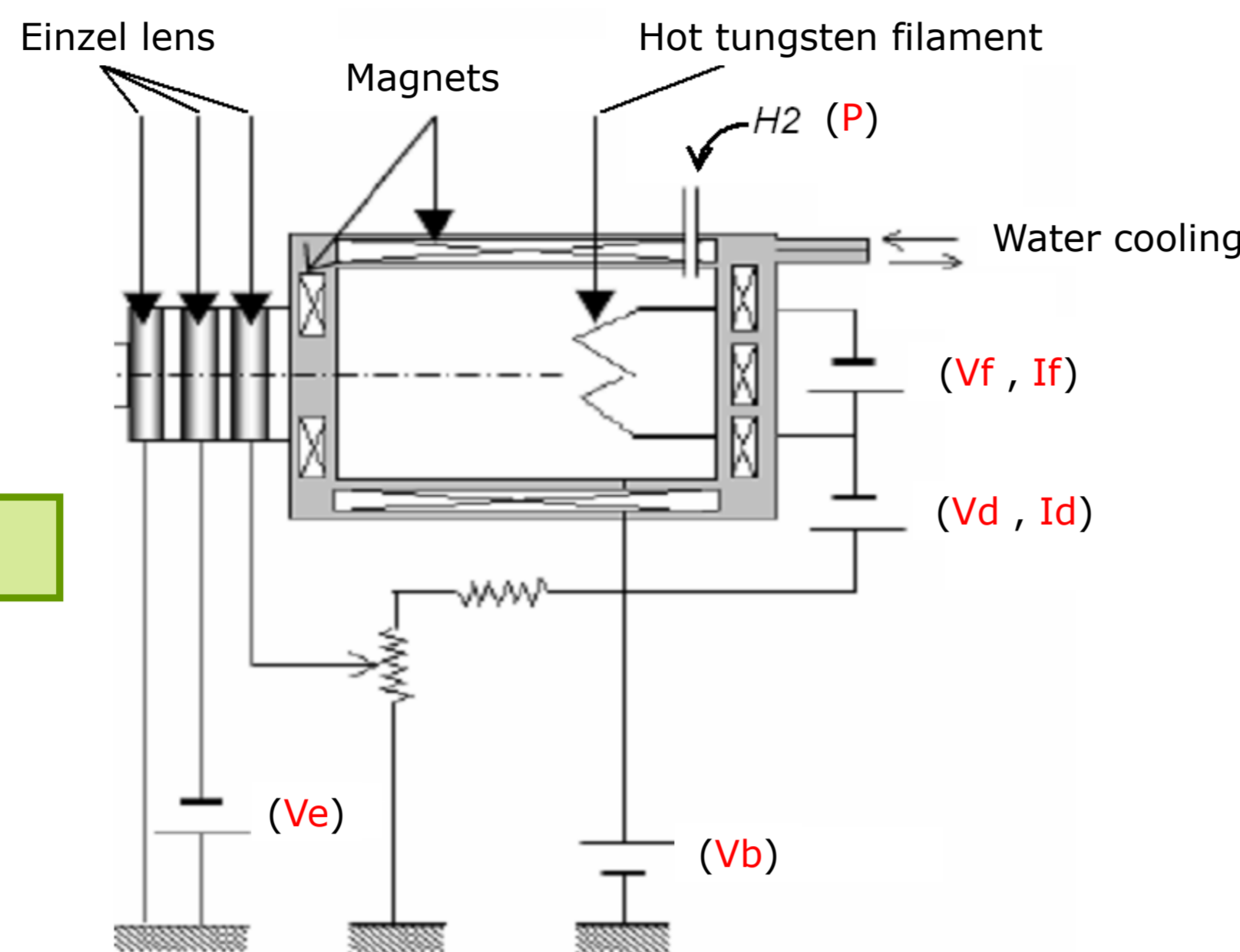


Fig. 2 : Diagram of the ion source

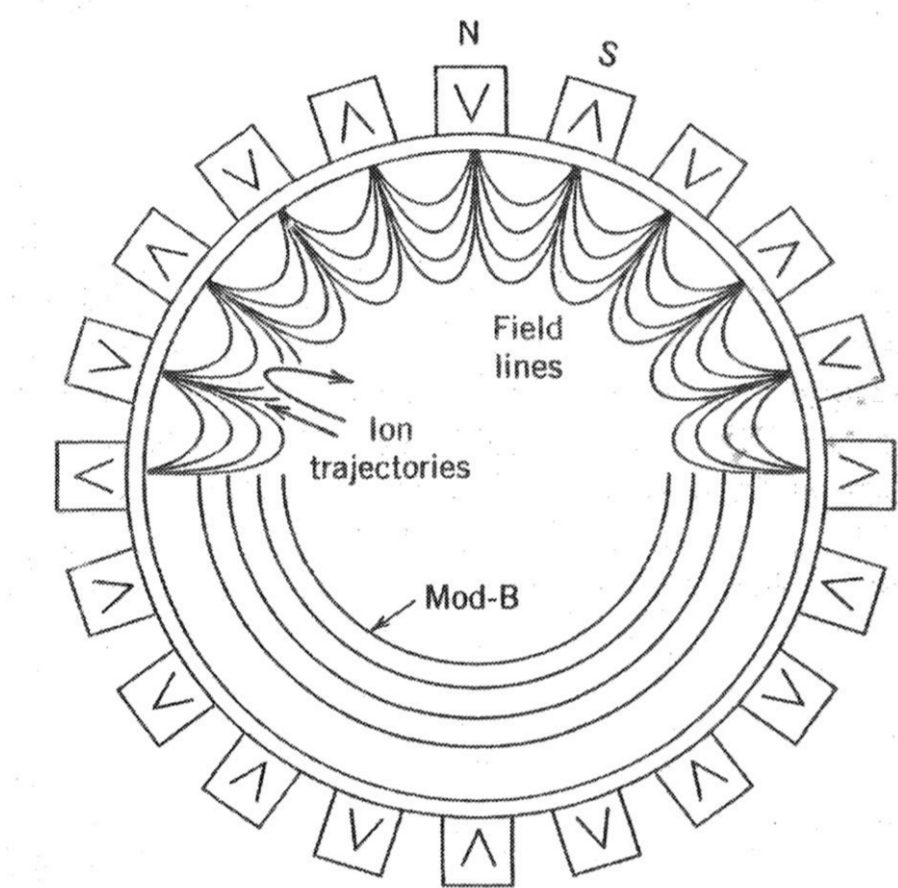


Fig. 3 : Diagram of a magnetic multipole confinement in cylindrical geometry

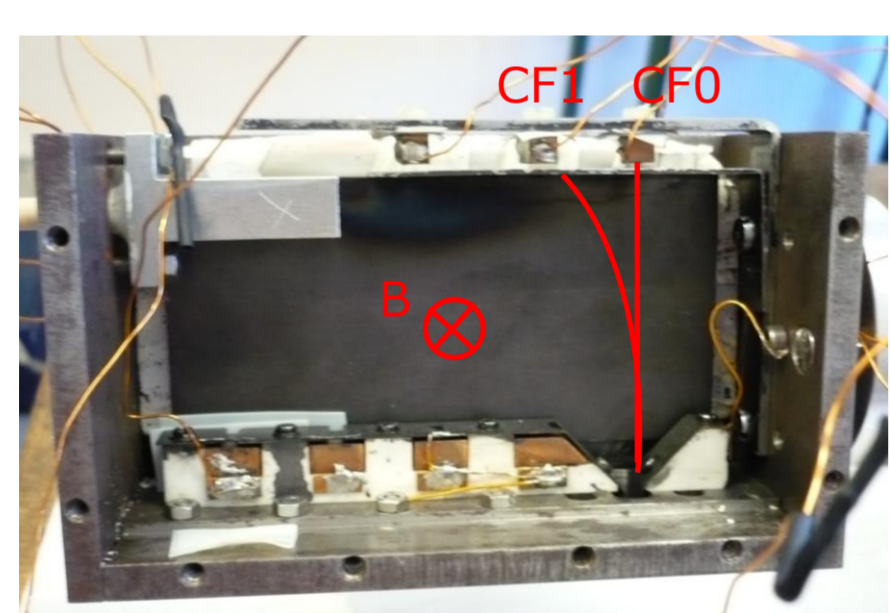
The ion extraction :

Einzel lens = 3 biased electrodes

Vb = +500V (wall chamber)  
V1 = +200V  
V2 = -1800V  
V3 = 0V

Ion beam energy :  
Ec = 500eV

The test chamber with the mass spectrometer :



$F = qv \times B$  Lorentz force → Mass deflection  
 $\omega_c = \frac{qB}{m} = \frac{v}{\rho_L}$  Cyclotronic frequency  
 $E_c = \frac{1}{2}mv^2$  Kinetic incident energy → Mass selection

Fig. 4 : Mass spectrometer with a measurement of the applied magnetic field and the ion current deflected following the selected mass (CF1)

The ion beam is focused inside a vacuum test chamber containing a mass spectrometer

Mass spectra : Fig. 6

Principles of measurement :

Langmuir characteristic :

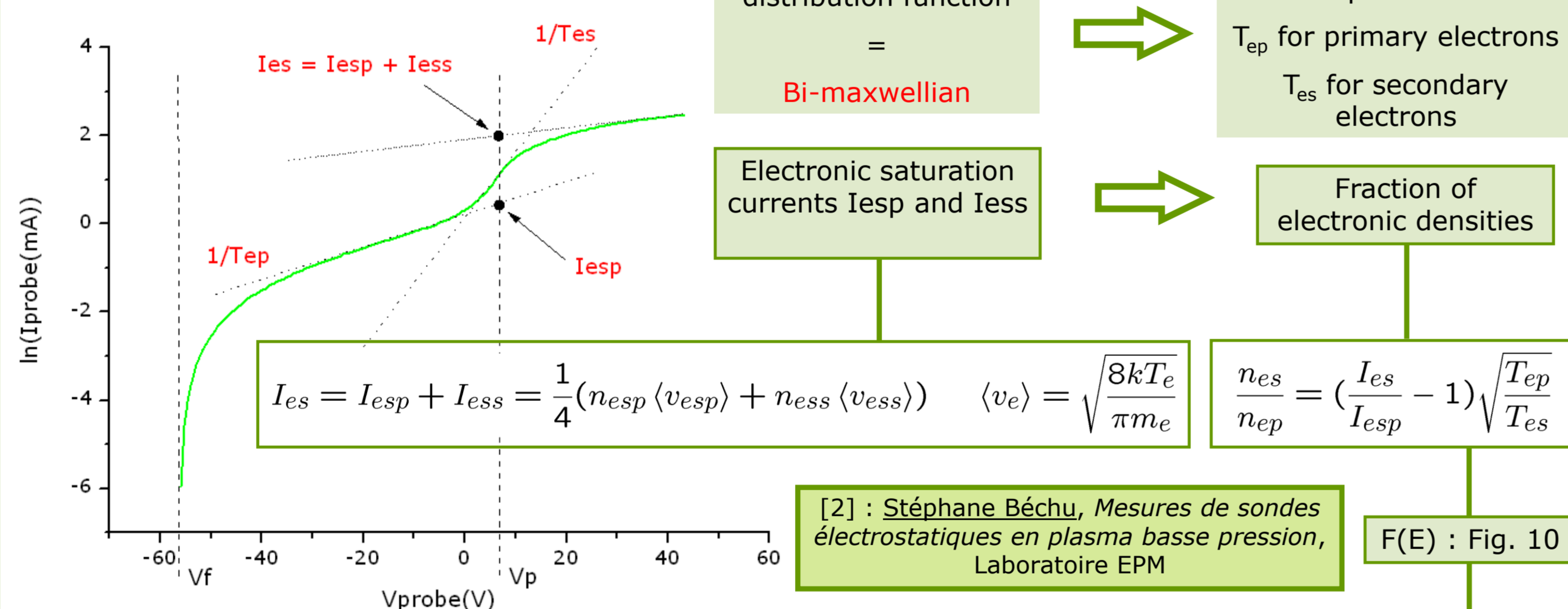


Fig. 5 : Semilogarithmic plot of experimental Langmuir probe characteristic in the center of the ion source along a radius

$$F(E) = F1(E) + F2(E) = \frac{2}{\sqrt{\pi}} \frac{1}{1 + \frac{n_2}{n_1}} \sqrt{E} \frac{1}{(kT_1)^{3/2}} e^{-E/kT_1} + \frac{2}{\sqrt{\pi}} \frac{1}{1 + \frac{n_1}{n_2}} \sqrt{E} \frac{1}{(kT_2)^{3/2}} e^{-E/kT_2}$$

$$k = \langle \sigma v \rangle = \int_0^\infty \sigma(v) v G(v) dv = 10^2 \sqrt{\frac{2e}{m_e}} \int_0^\infty \sigma(\epsilon) \sqrt{\epsilon} F(\epsilon) d\epsilon$$

Ion species spectra :

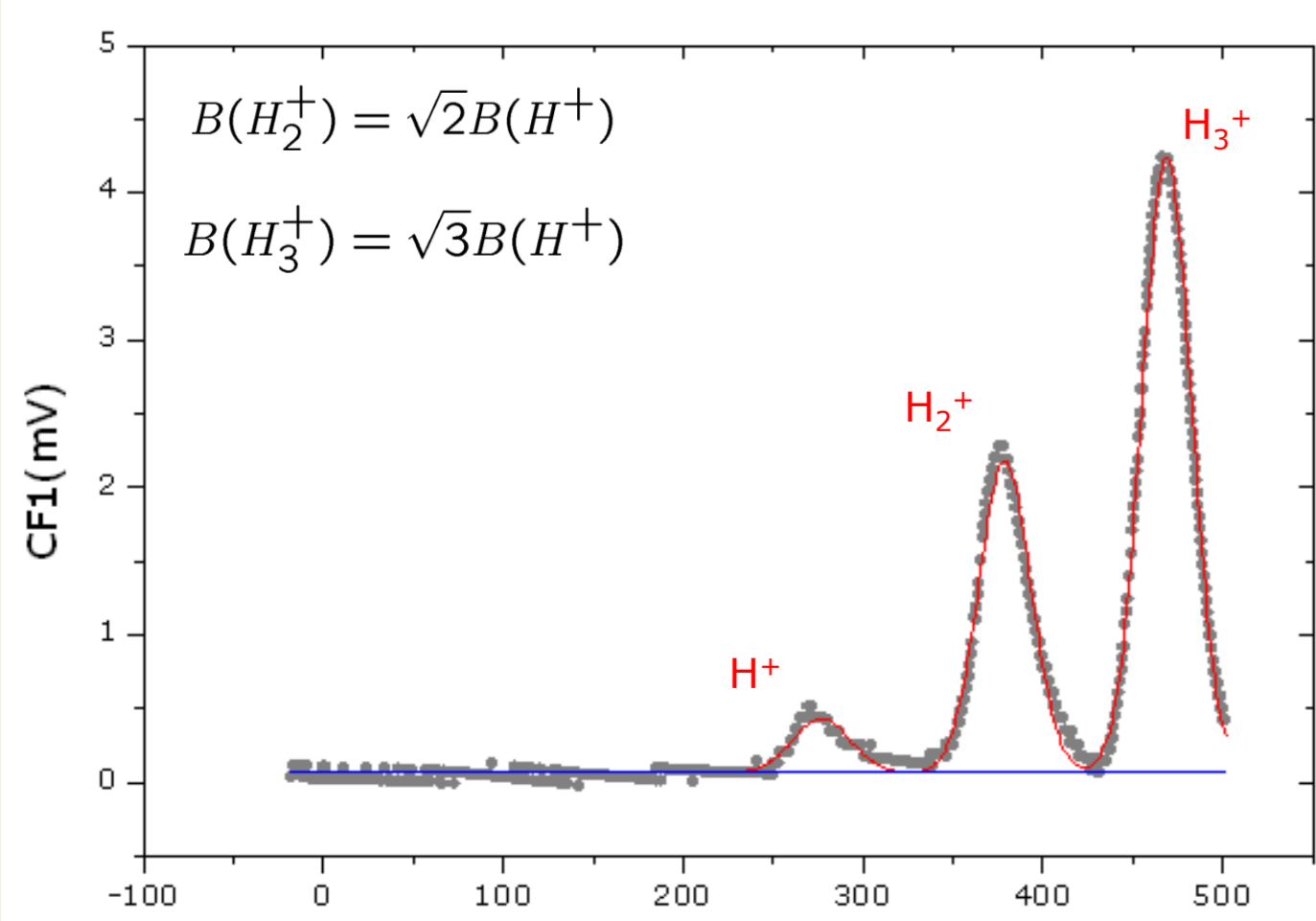


Fig. 6 : Ion currents measured on a Faraday cup through a 1MΩ resistor versus the applied magnetic field in the mass spectrometer

Ion species are selected following their mass according to the applied magnetic field

Sensibility of the mass spectrometer depends on the position of the peak : peak surface areas decrease strongly

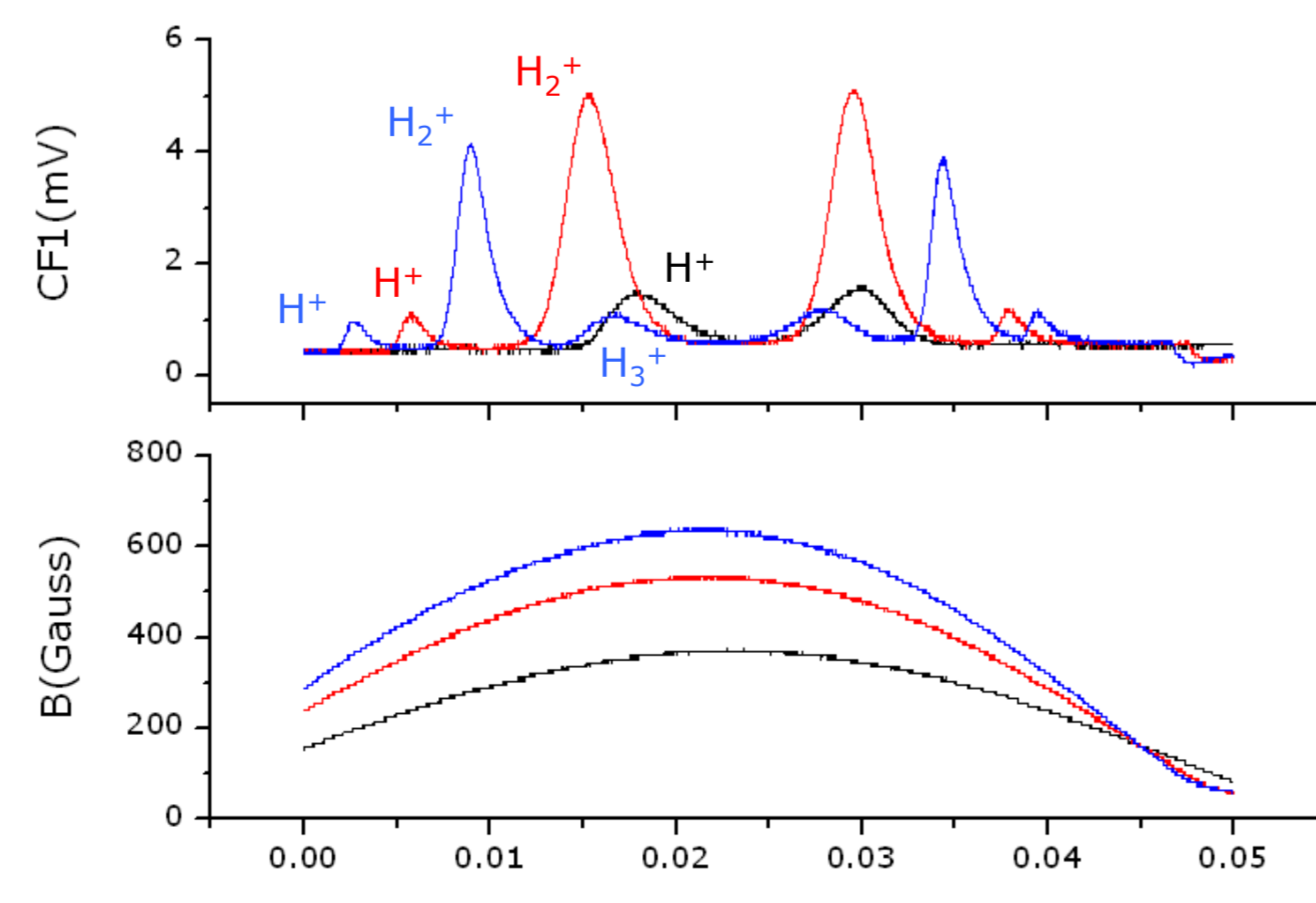


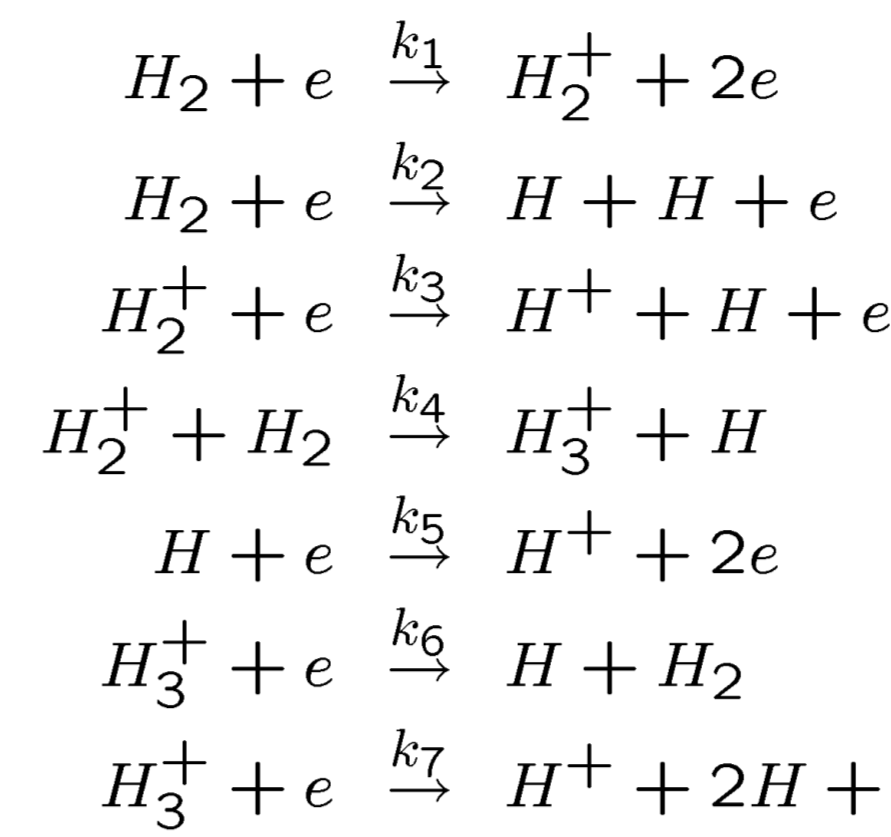
Fig. 7 : Measure of the mass sensibility following the applied magnetic field

Blue spectra : H<sub>3</sub><sup>+</sup> = 100% H<sub>2</sub><sup>+</sup> = 75% H<sup>+</sup> = 16%

Correction for each measured ion current

Numerical approach :

Collisional processes :



[4] : Osamu Fukumasa, Numerical simulation of hydrogen ion species in the steady-state plasma of a low-pressure ion source, J. Phys. D: Appl. Phys. 18 (1985) 2433-2449

Particle balance equations :

$$\frac{\partial n}{\partial t} + \nabla \cdot (nu) = G - L$$

$$\frac{\partial n}{\partial t} = 0 \quad \text{In a steady-state plasma}$$

$$G - L = \pm [A] [B] k_{AB} \quad \text{Gains - Losses}$$

$$\nabla \cdot nu = D \nabla^2 n \approx \frac{D}{\Lambda^2} \frac{n}{\tau} \quad \text{1st Fick law}$$

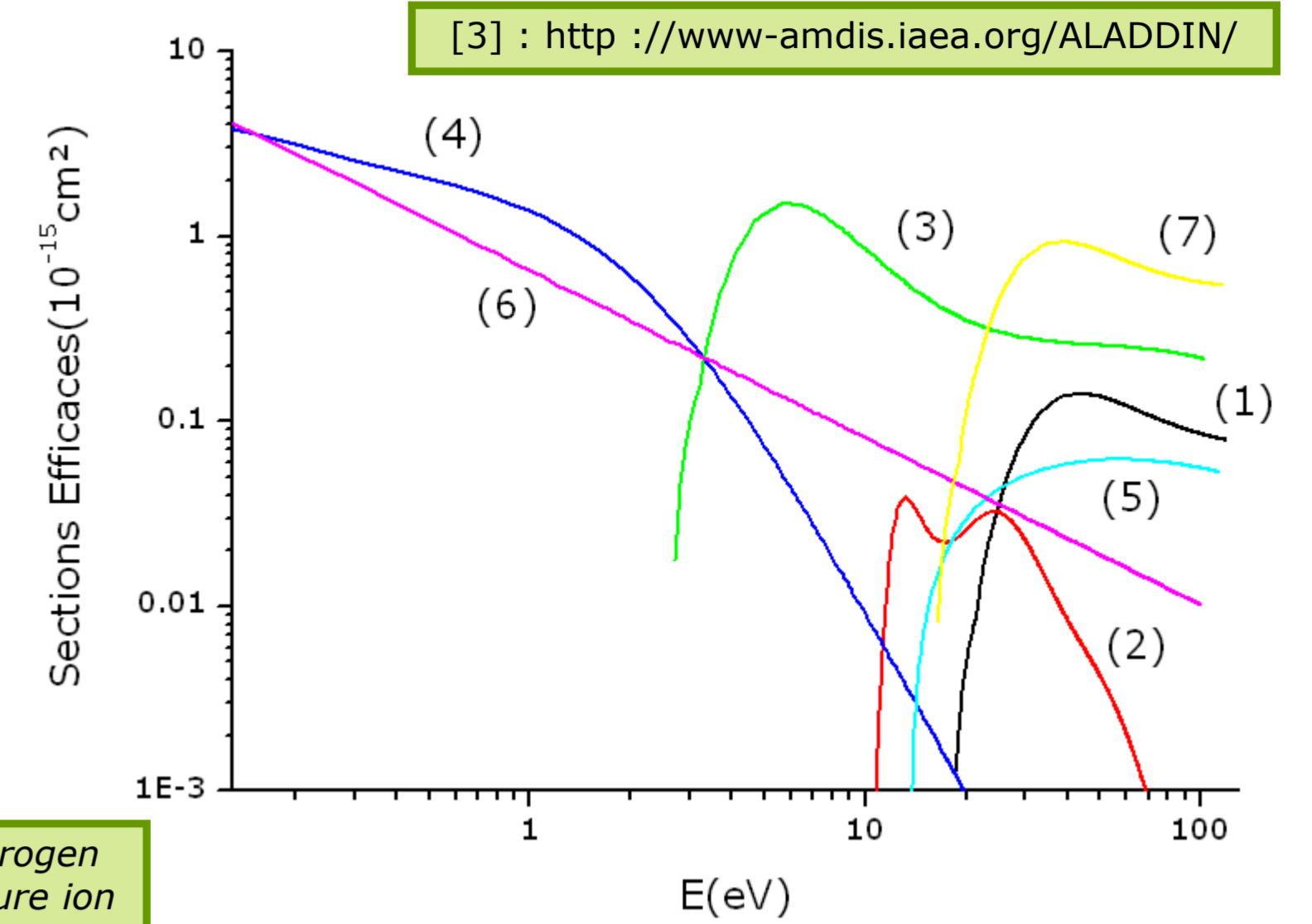


Fig. 8 : Cross sections between 0 and 100eV

$$\begin{aligned} N_2 &\approx N_0 - \frac{N_1}{2} (*) \quad n_2 N_2 \approx n_2 N_0 (**) \\ N_1 &= \frac{2n_e N_0 k_2 + n_2 (n_e k_3 + N_0 k_4) + n_3 n_e (k_6 + 2k_7)}{n_e k_5 + (\gamma/T_1)} \\ n_2 &= \frac{n_e k_1 N_0}{(1/\tau_1) + N_0 k_4 + n_e k_3} \\ n_3 &= \frac{N_0 k_4 n_2}{(1/\tau_3) + n_e (k_6 + k_7)} \\ n_1 &= \tau_1 n_e (N_1 k_5 + n_2 k_3 + n_3 k_7) \end{aligned}$$

(\*) : weakly ionised plasma (\*\*): weakly dissociated plasma

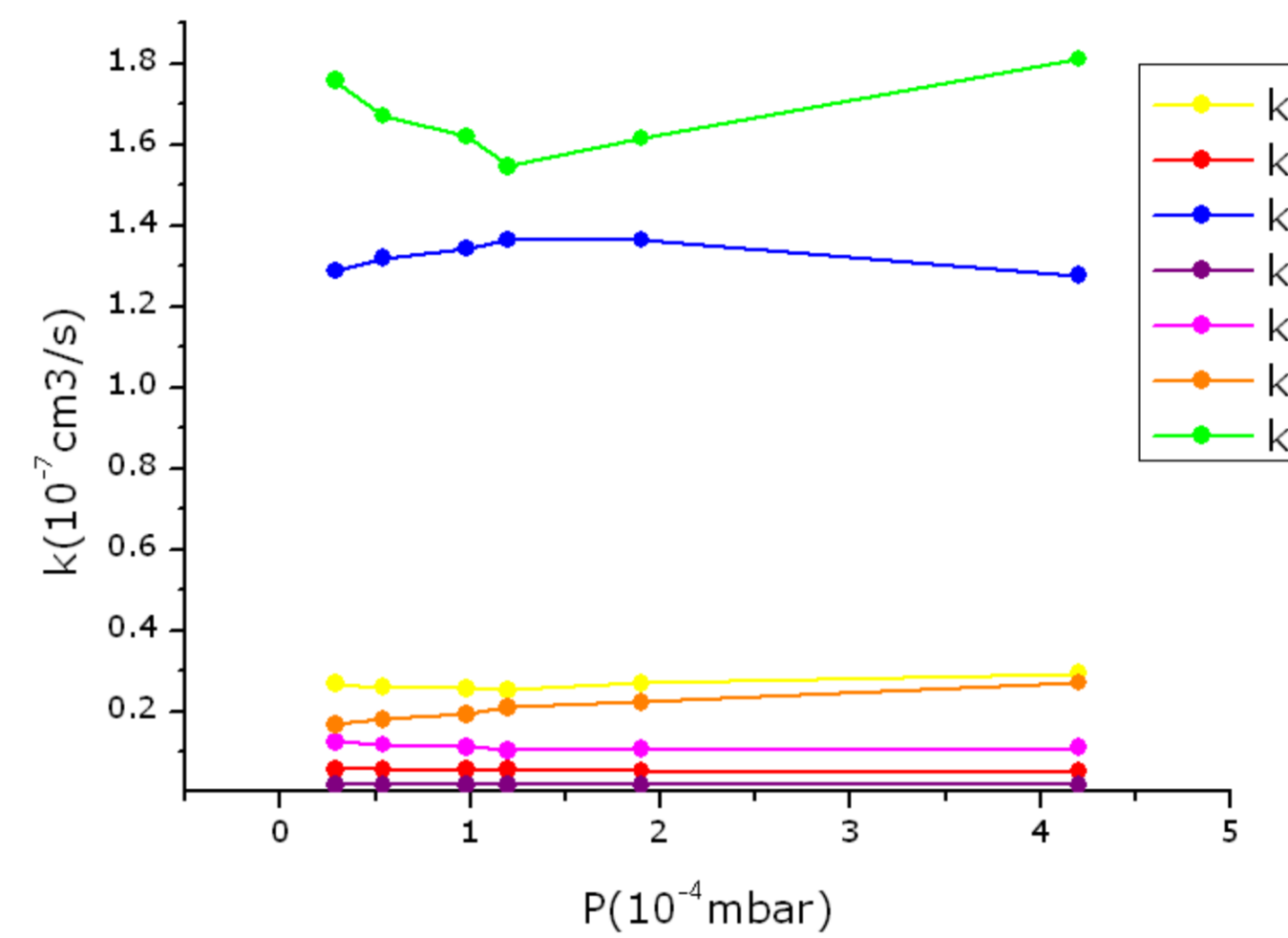


Fig. 9 : Reaction rates

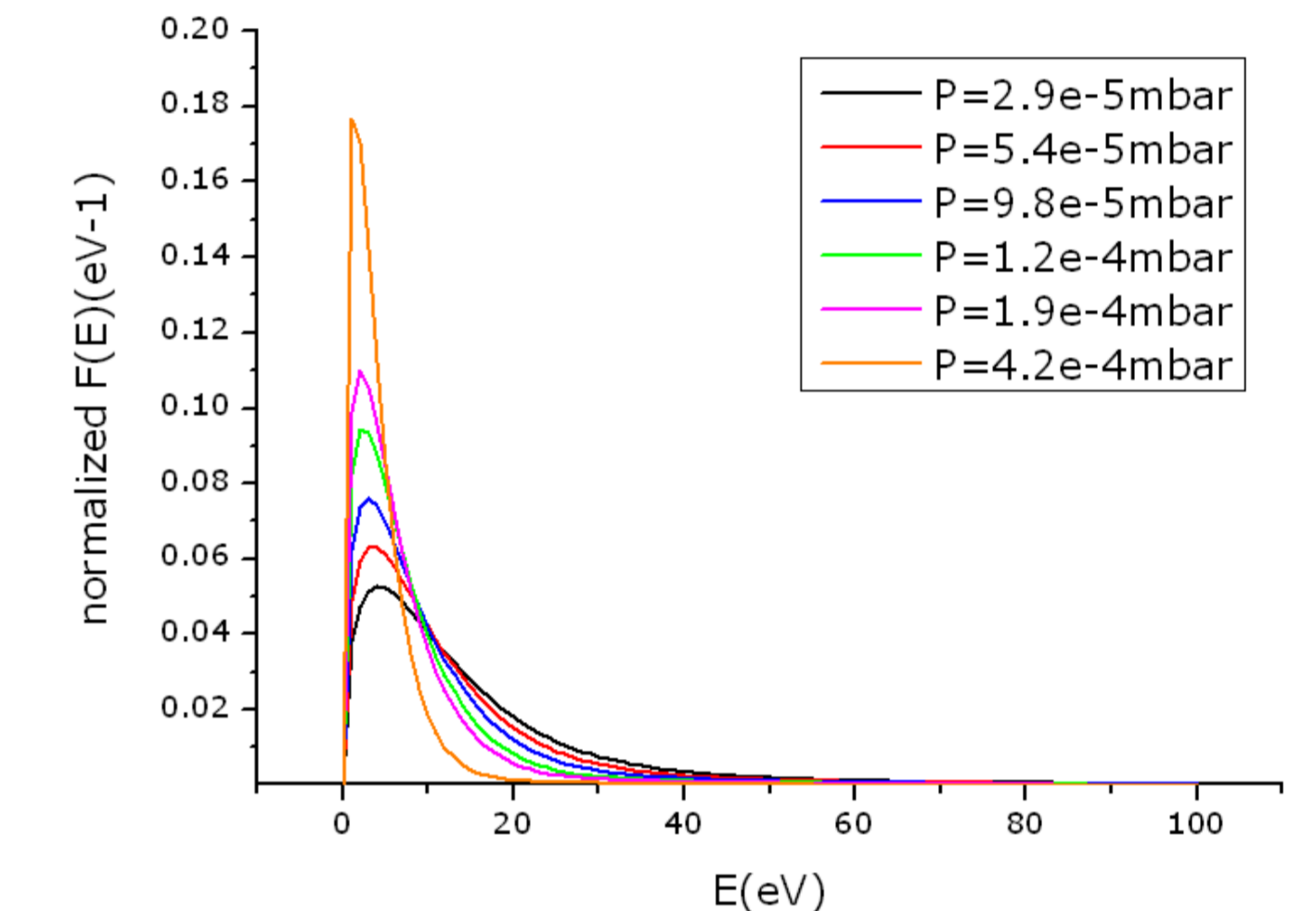


Fig. 10 : Normalized electron energy repartition function

Experimental & Numerical Results :

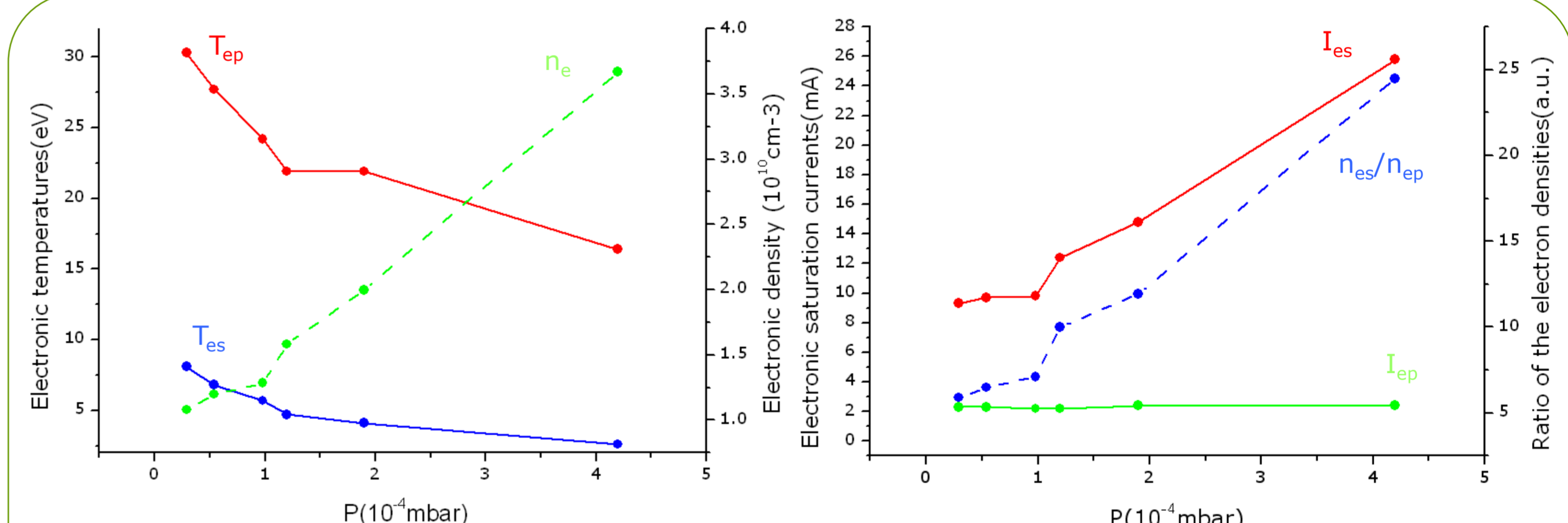


Fig. 11 : Electronic temperatures and density measured with the Langmuir probe

Fig. 12 : Electronic saturation currents measured with the Langmuir probe ; ratio of electronic densities

- The 2 electronic temperatures decrease with the pressure
- The primary electron density is a constant (depends on the filament current If)
- The secondary electron density increases with the pressure

- Numerical results show the effect of the adsorption probability  $\gamma$  for the H atoms at the walls (the lower it is, the better it is for the H<sup>+</sup> production yield)

- Without water (Leung [5]) : H<sup>+</sup> = 5%
- With a few % of water : H<sup>+</sup> = 25%

[5] : K. N. Leung, Characteristics of a multidipole device, Rev. Sci. Instrum., Vol. 49, No. 3, March 1978

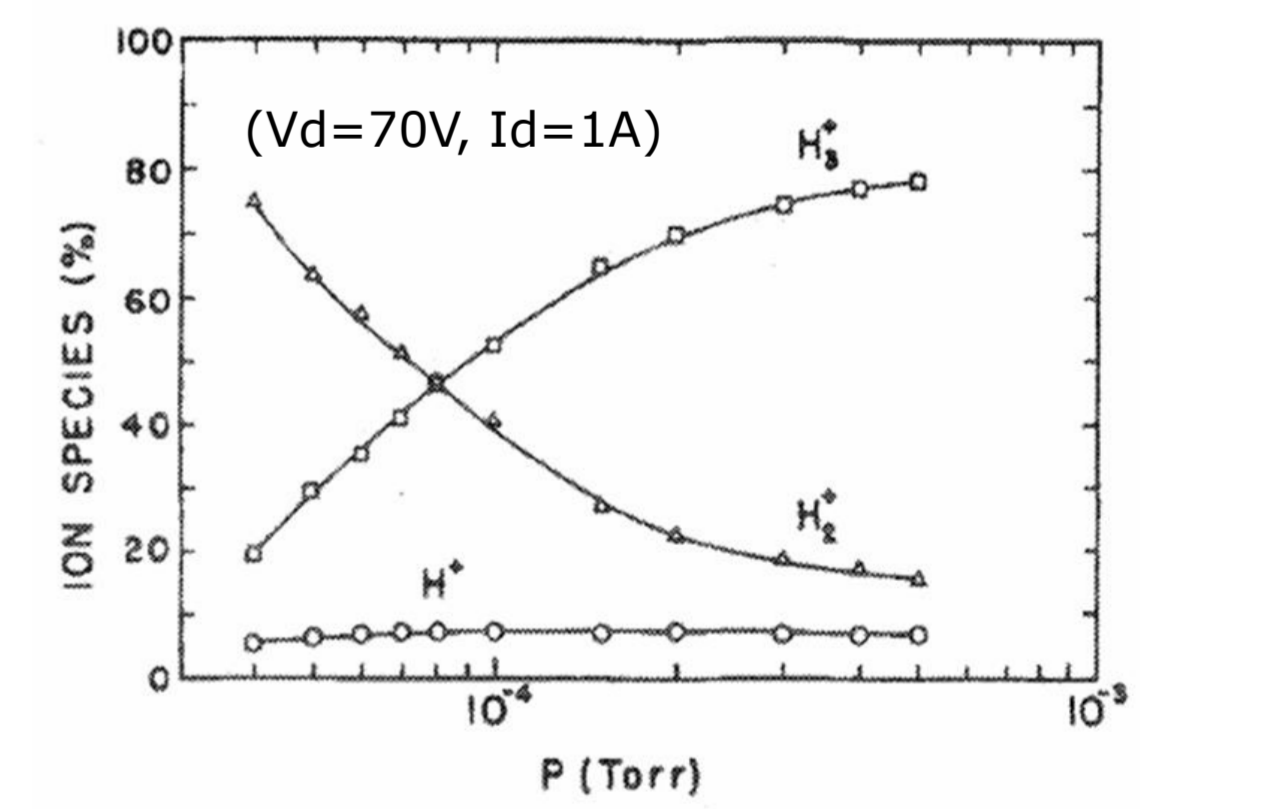


Fig. 13 : Evolution of ion densities measured by Leung with pure H<sub>2</sub> in a similar multicusp ion source

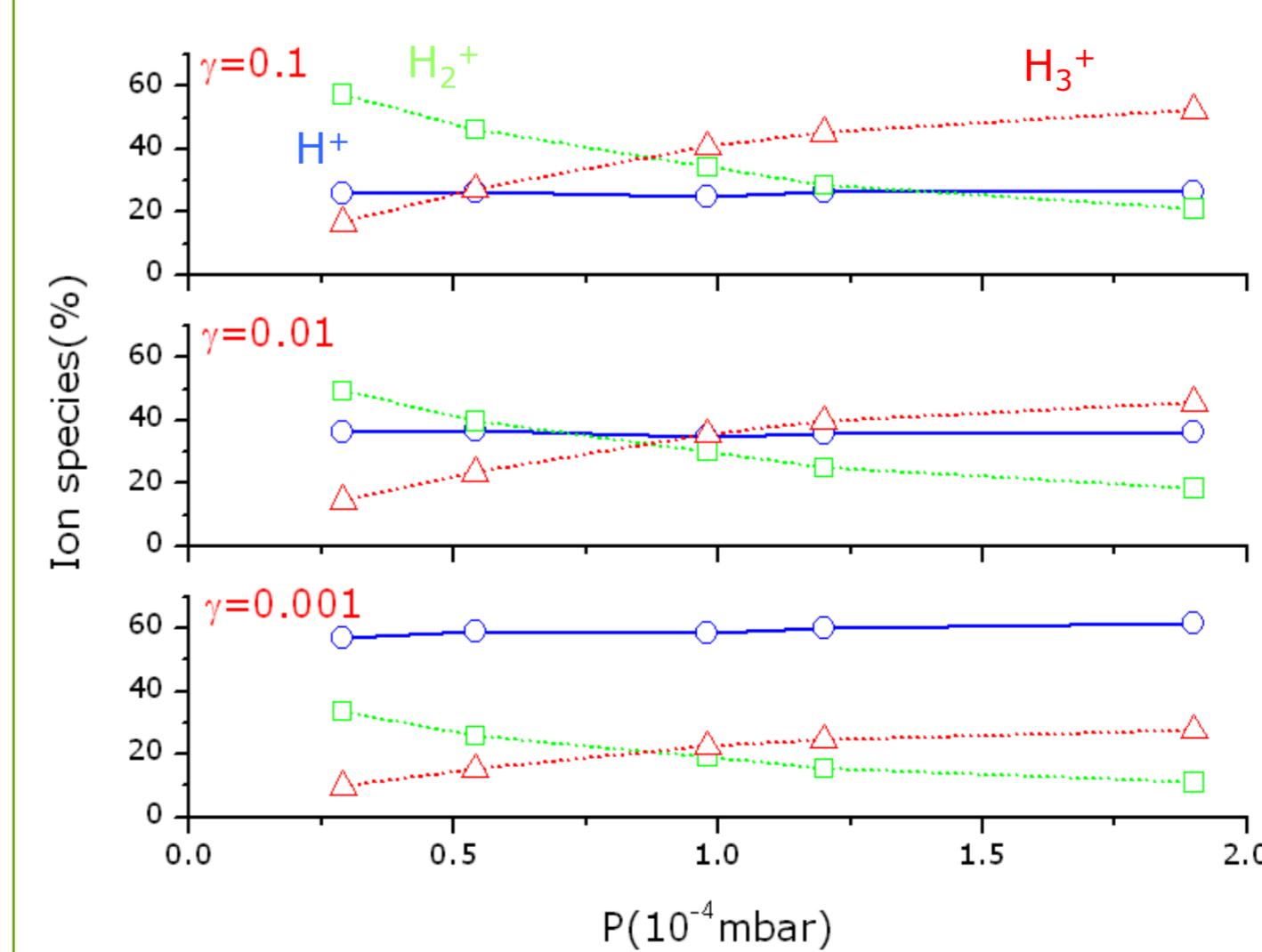


Fig. 14 : Numerical results, evolution of ion densities with the gas pressure and the sticking parameter  $\gamma$

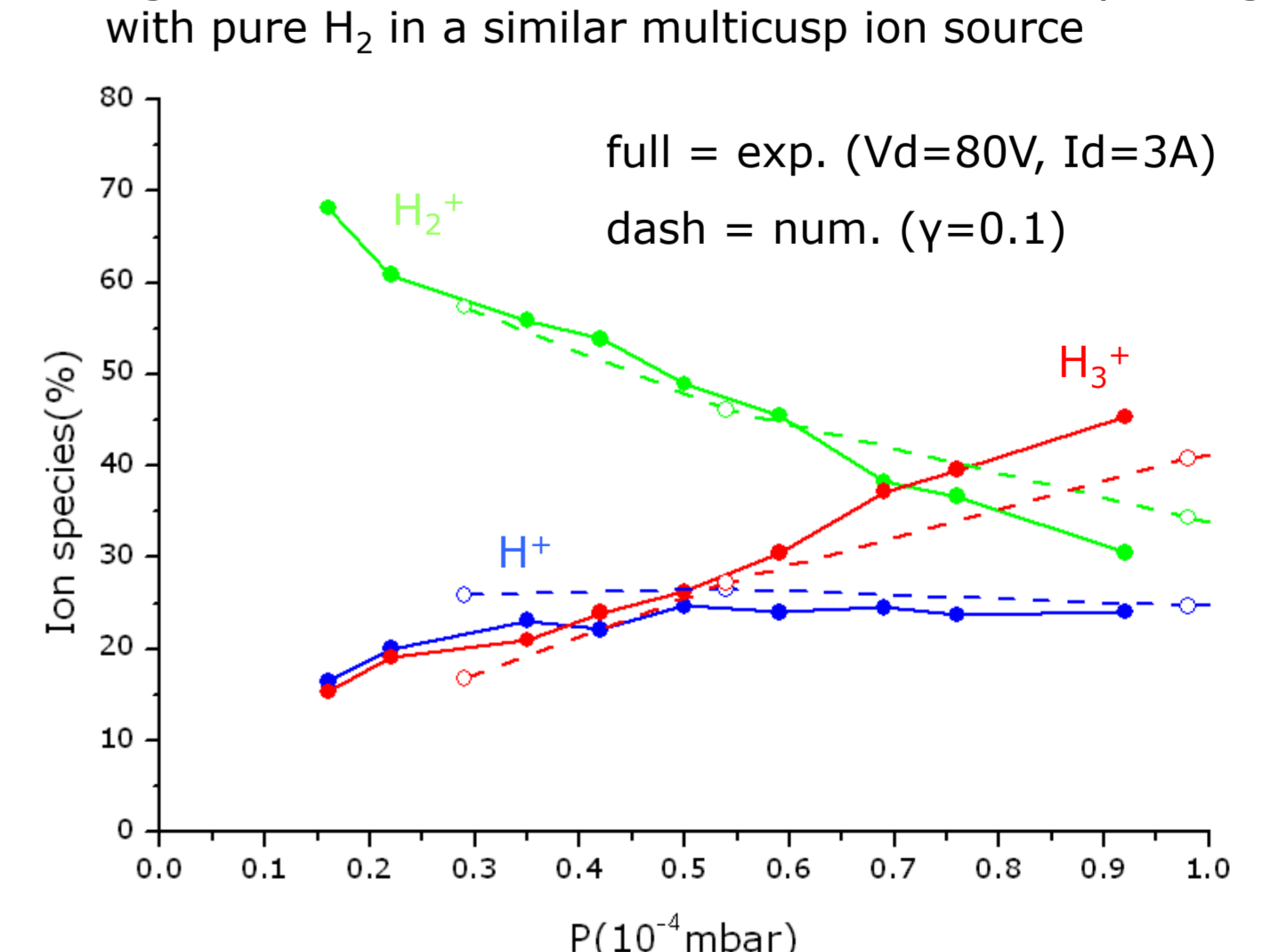


Fig. 15 : Numerical and experimental results, evolution of ion densities with the pressure

Conclusion :

- The multidipole device is able to produce an ion beam of 500eV from a low pressure plasma with 25% of H<sup>+</sup>
- The  $\gamma$  parameter is linked to the surface state of the wall i.e. to the quantity of water introduced
- There is no significant result with Helium gas mixing to increase the electronic temperature because Tep is high enough