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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 :

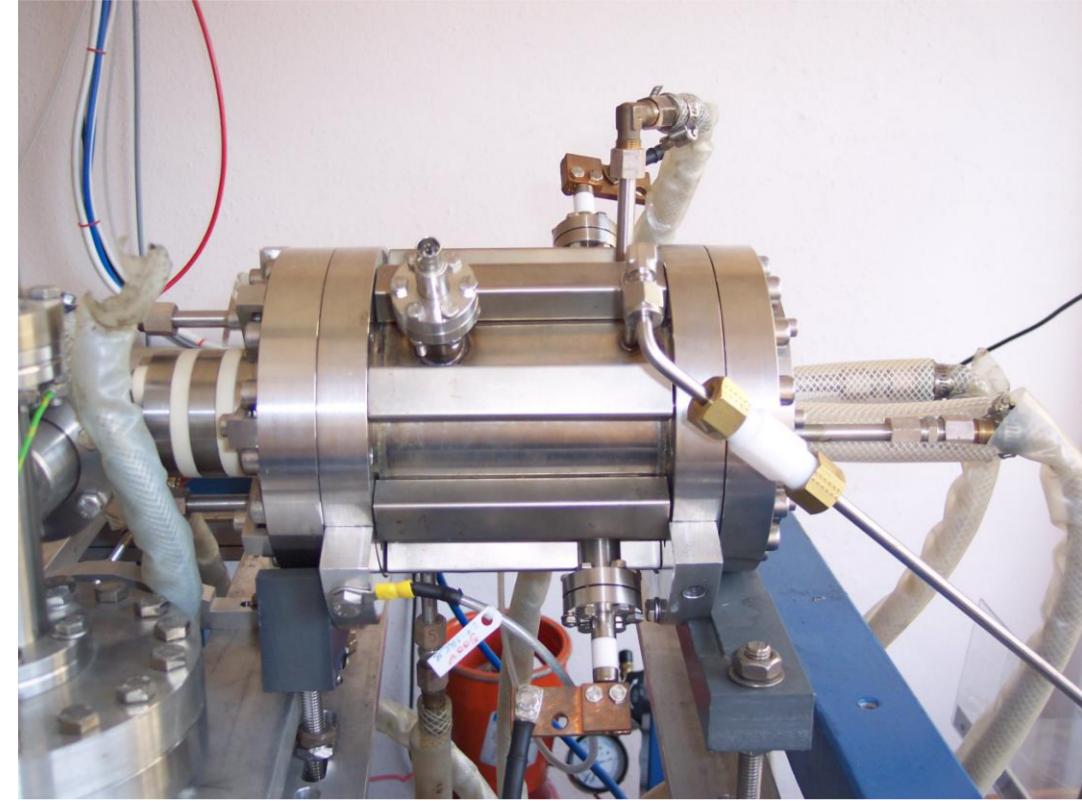


Fig. 1 : Multicusp ion source (L=20cm, R=6cm)

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

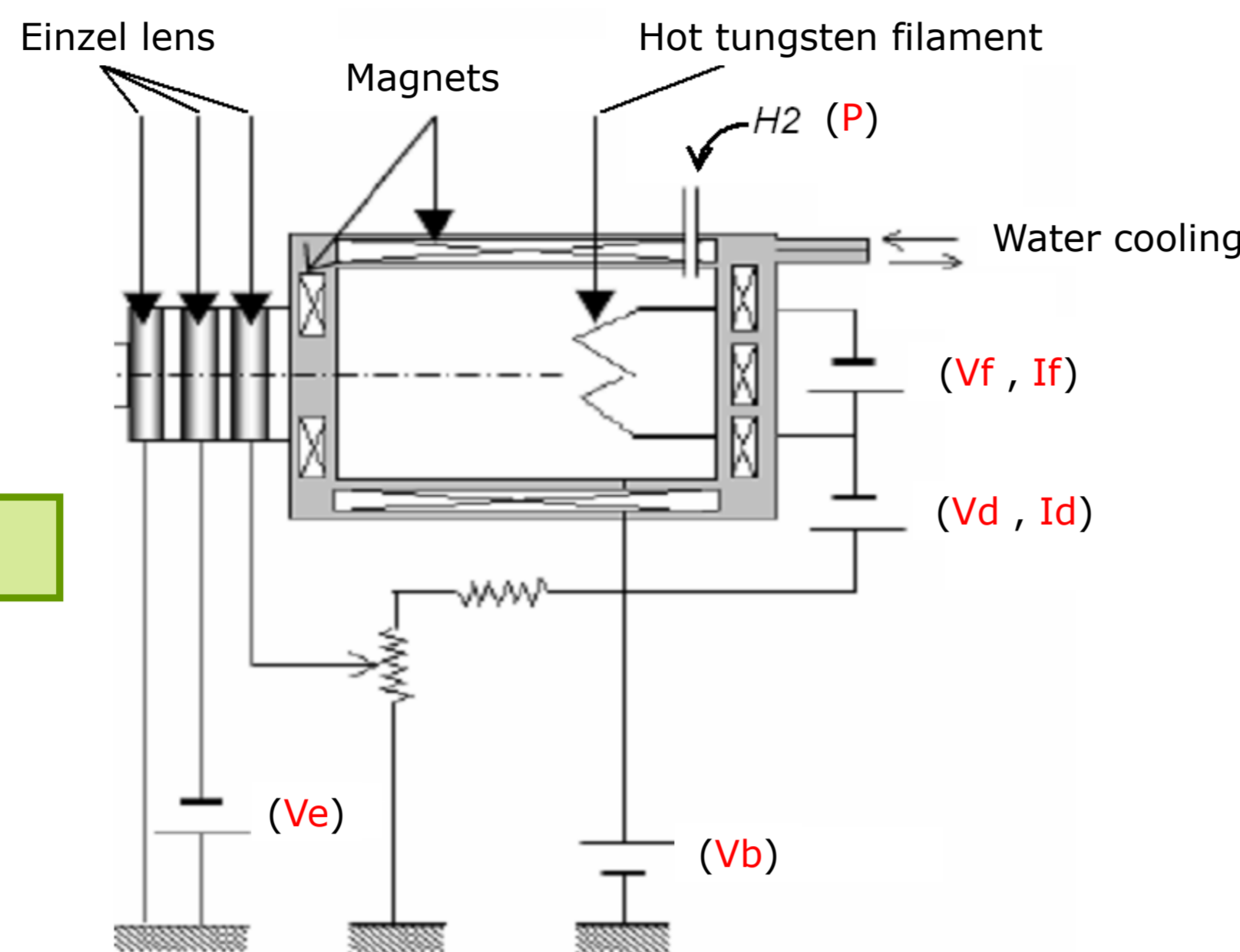


Fig. 2 : Diagram of the ion source

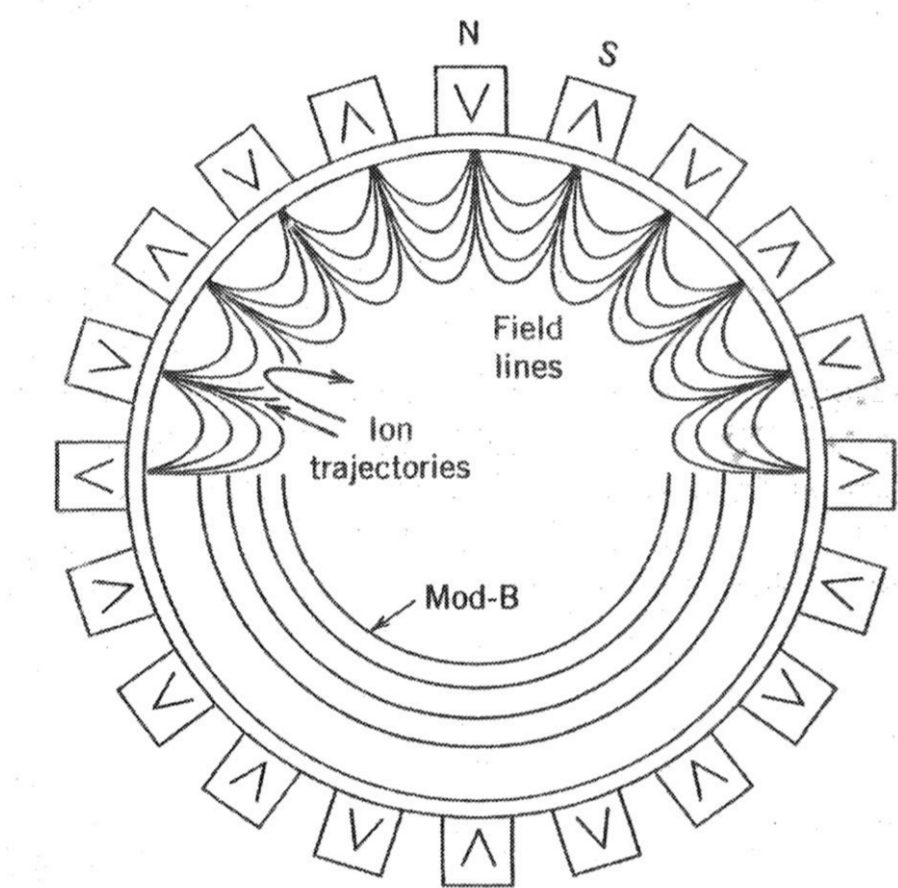


Fig. 3 : Diagram of a magnetic multipole confinement in cylindrical geometry

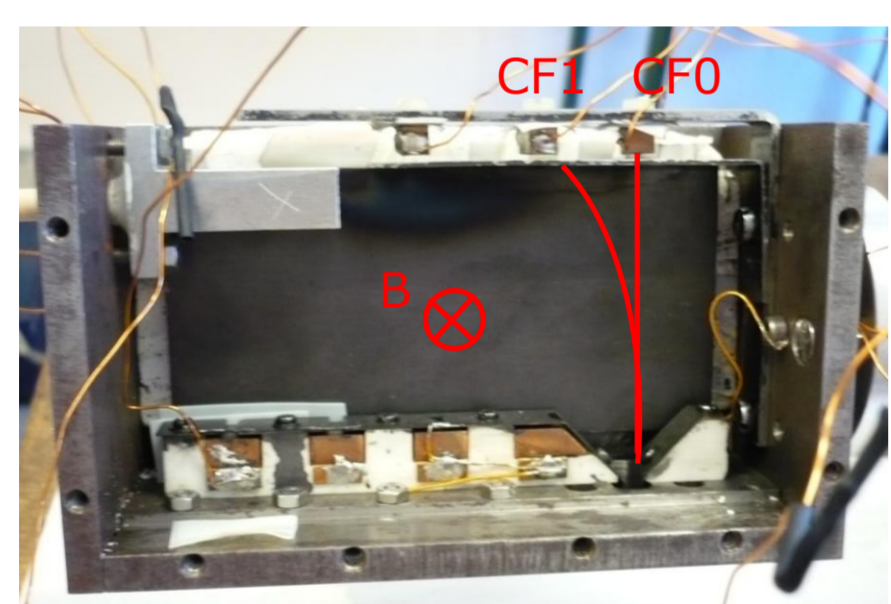
The ion extraction :

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 :

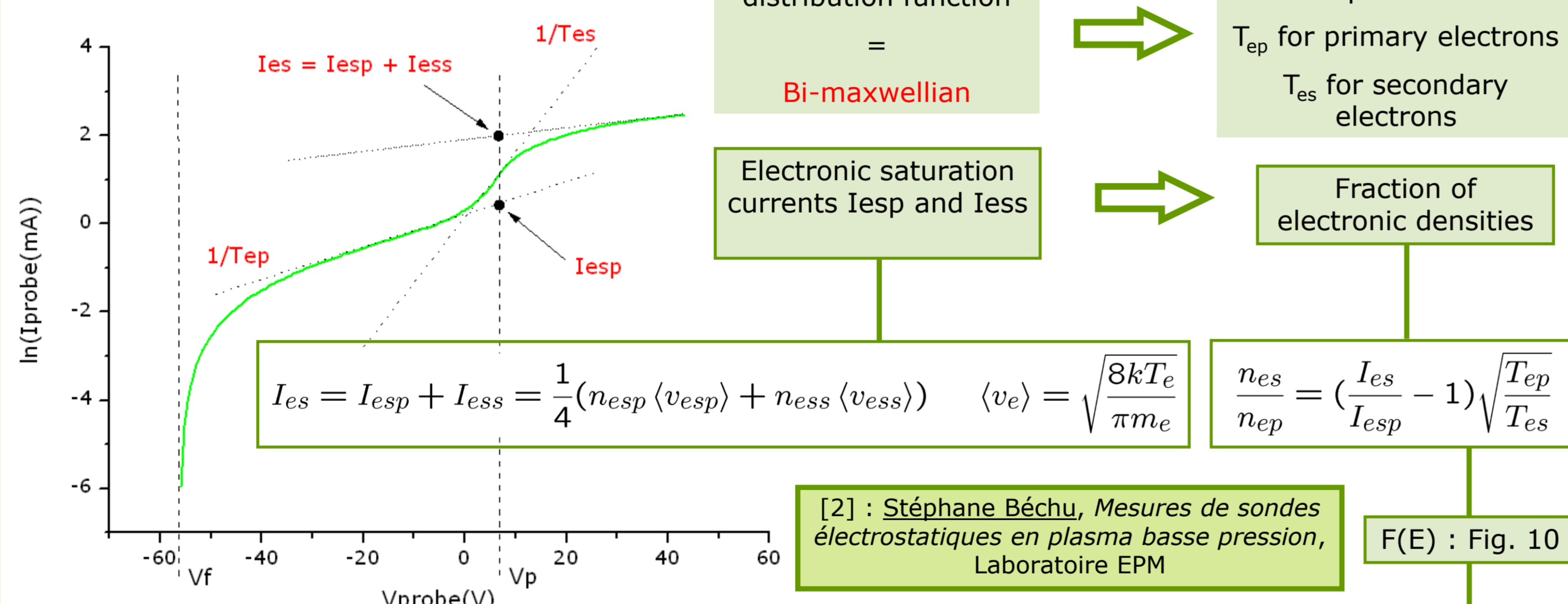


Fig. 5 : Semilogarithmic plot of experimental Langmuir probe characteristic in the center of the ion source along a radius

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

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

Ion species spectra :

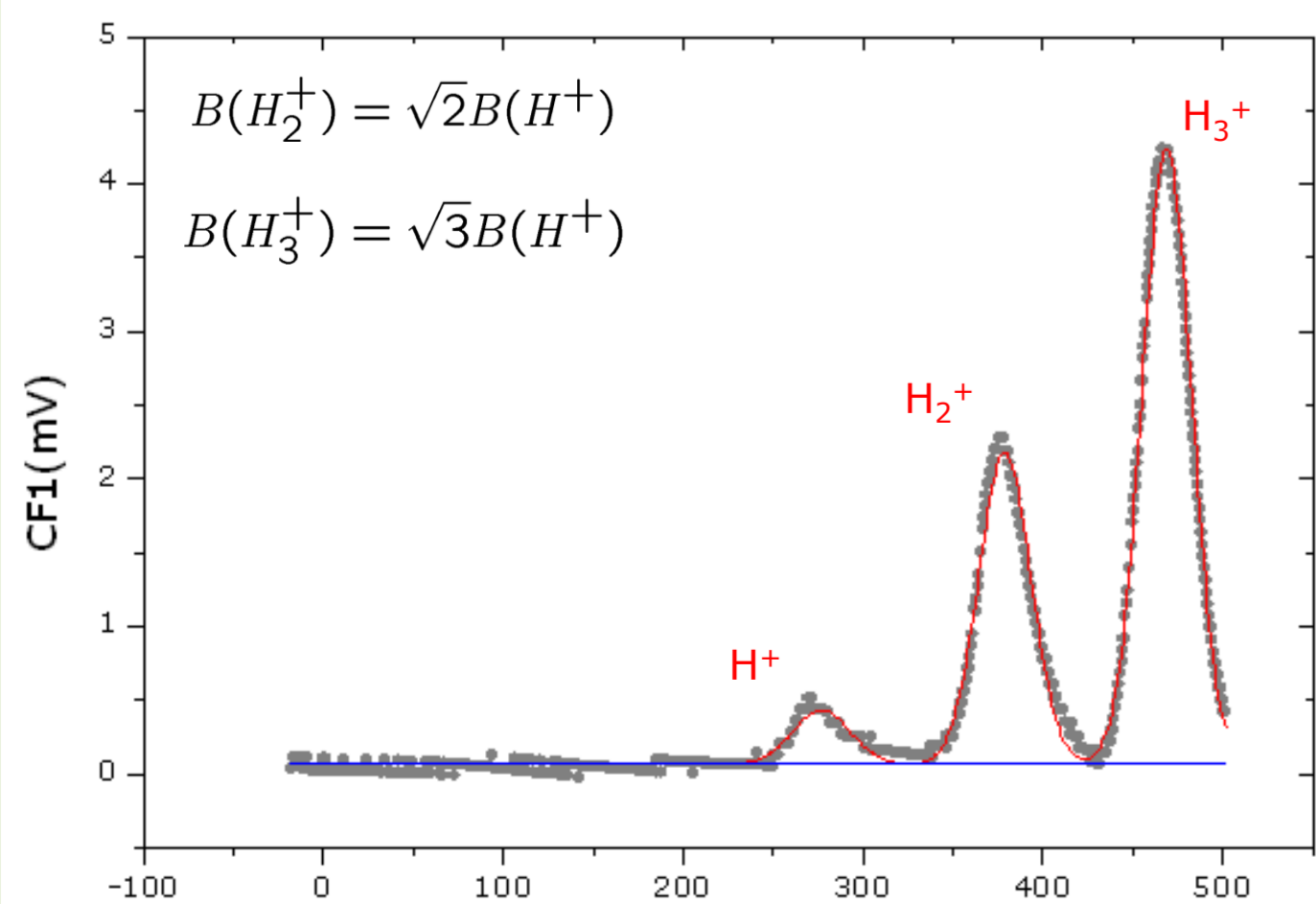


Fig. 6 : Ion currents measured on a Faraday cup through a 1MΩ resistor versus the applied magnetic field in the mass spectrometer

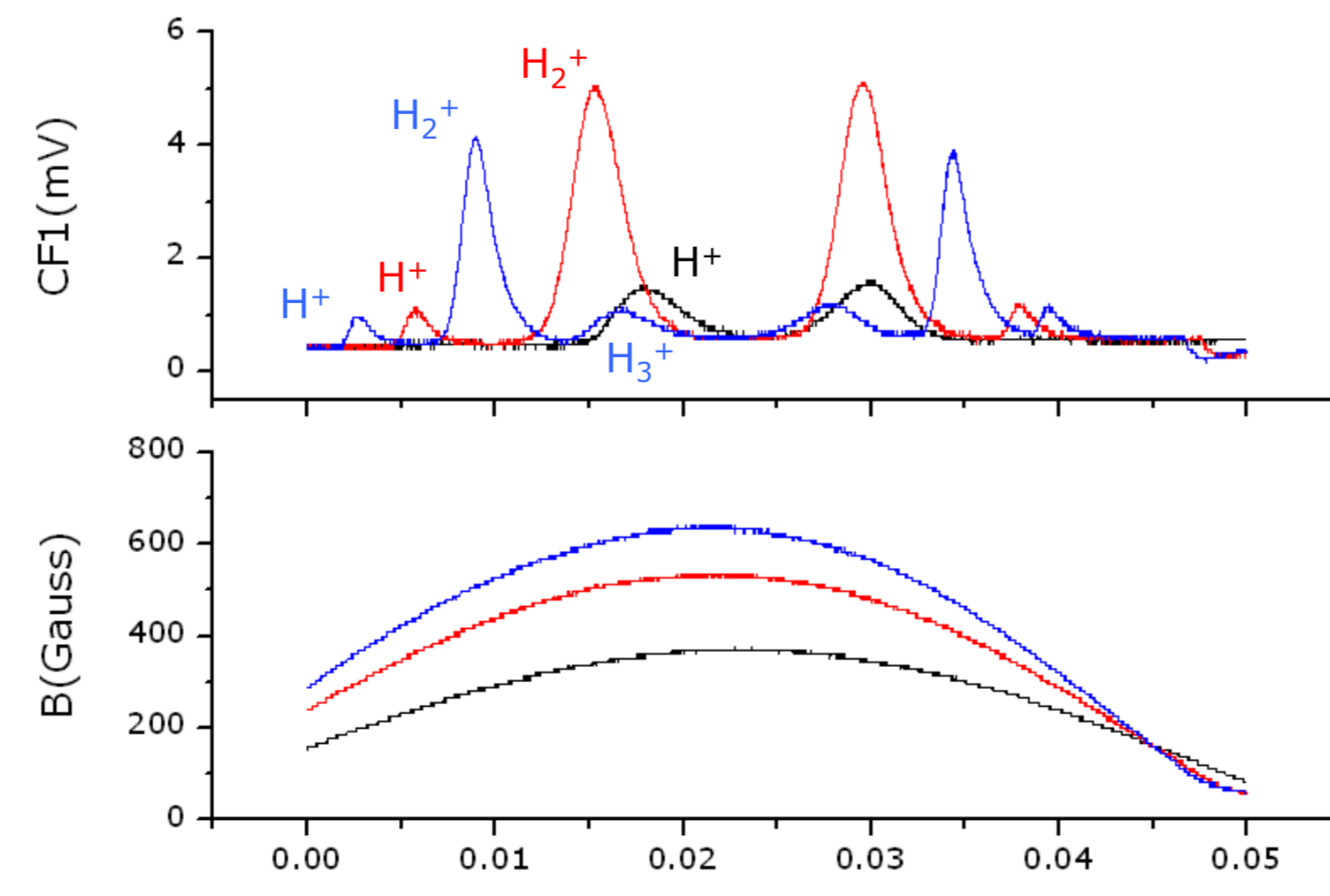


Fig. 7 : Measure of the mass sensibility following the applied magnetic field

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

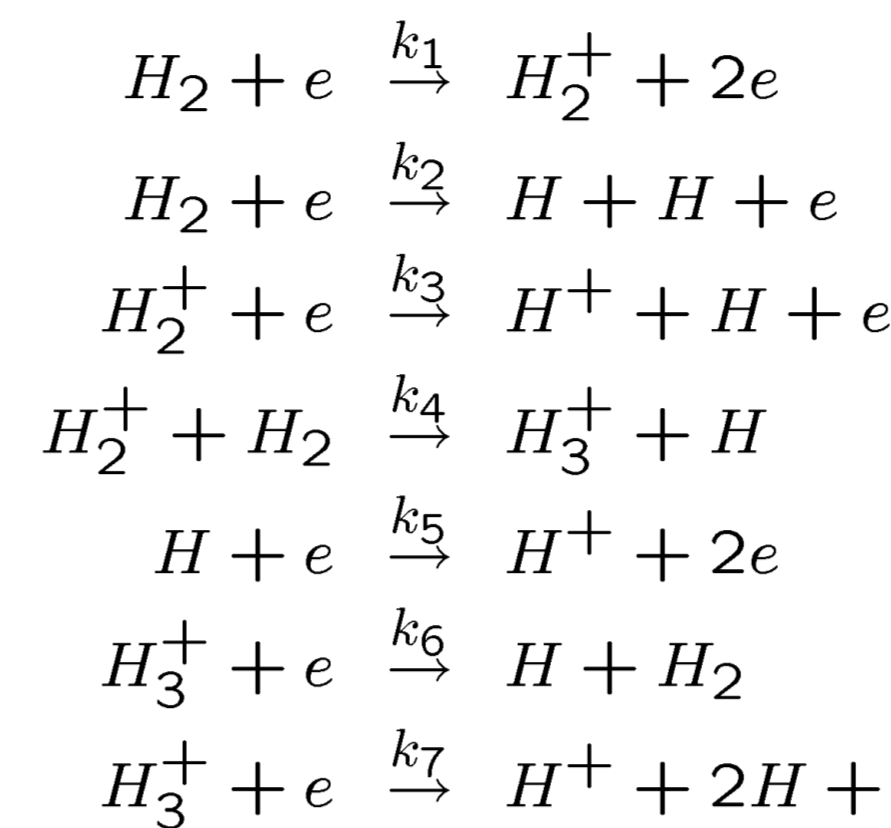
Blue spectra : $H_3^+ = 100\%$ $H_2^+ = 75\%$ $H^+ = 16\%$

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

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 :

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

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

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

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

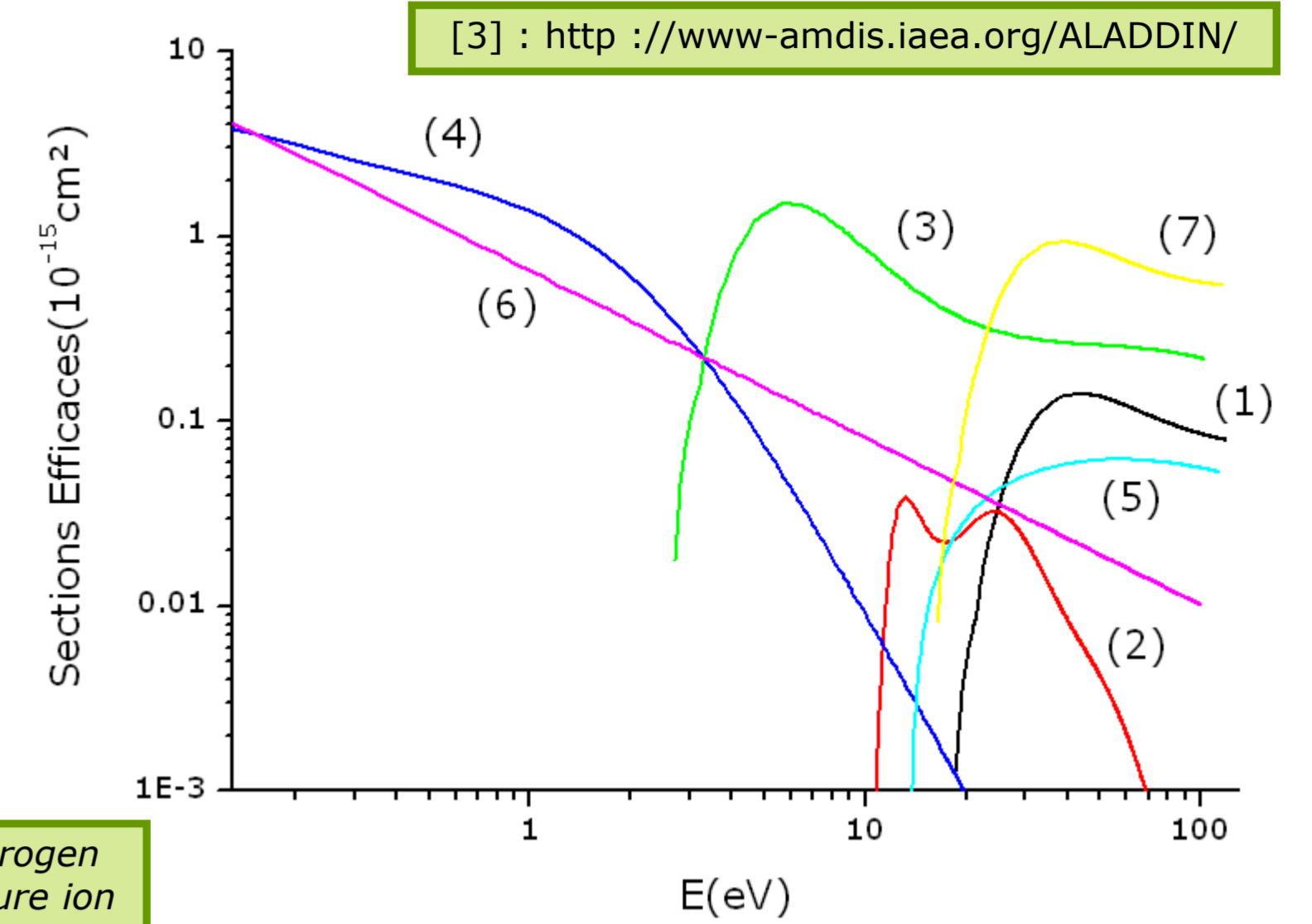


Fig. 8 : Cross sections between 0 and 100eV

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

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

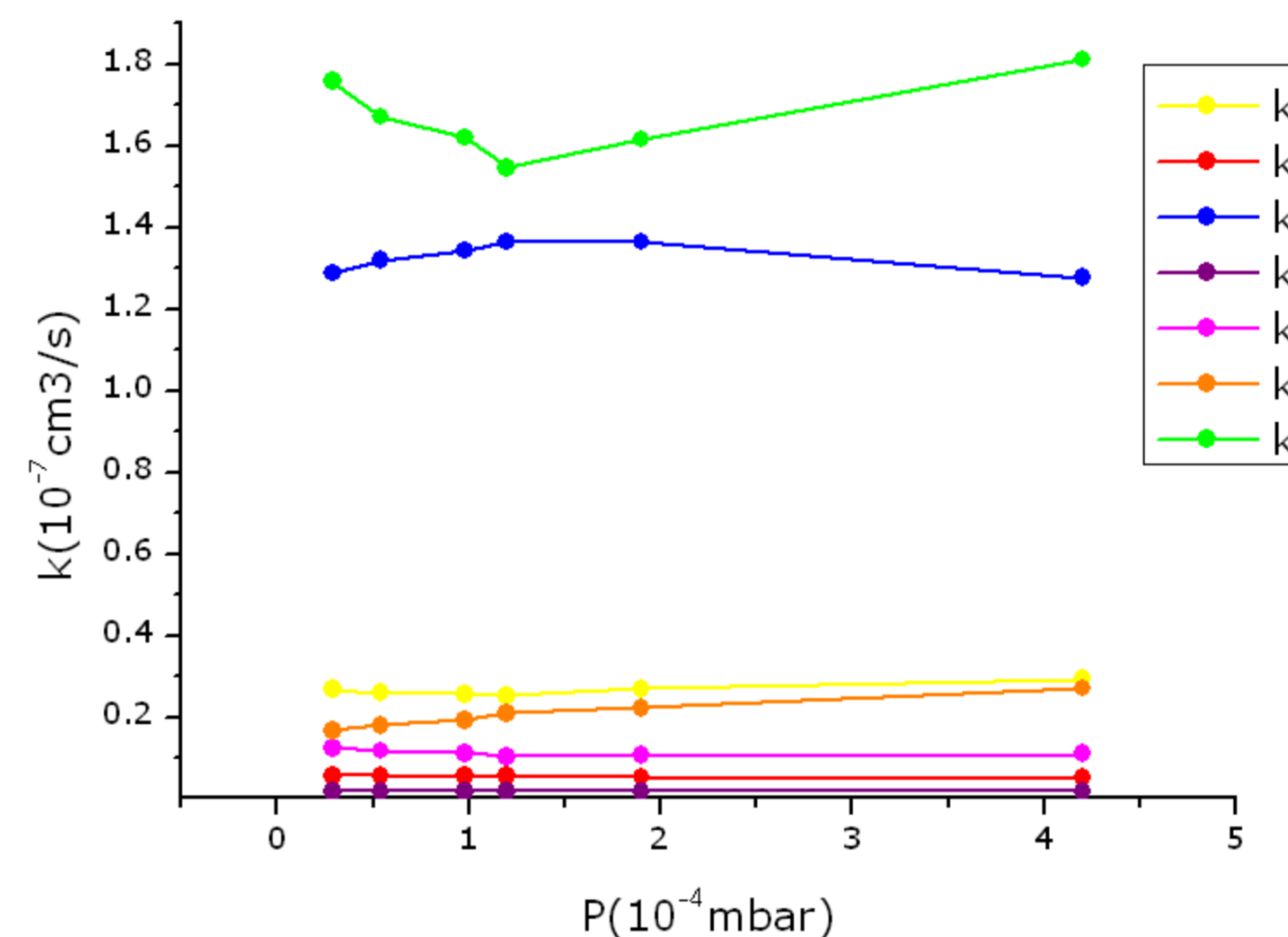


Fig. 9 : Reaction rates

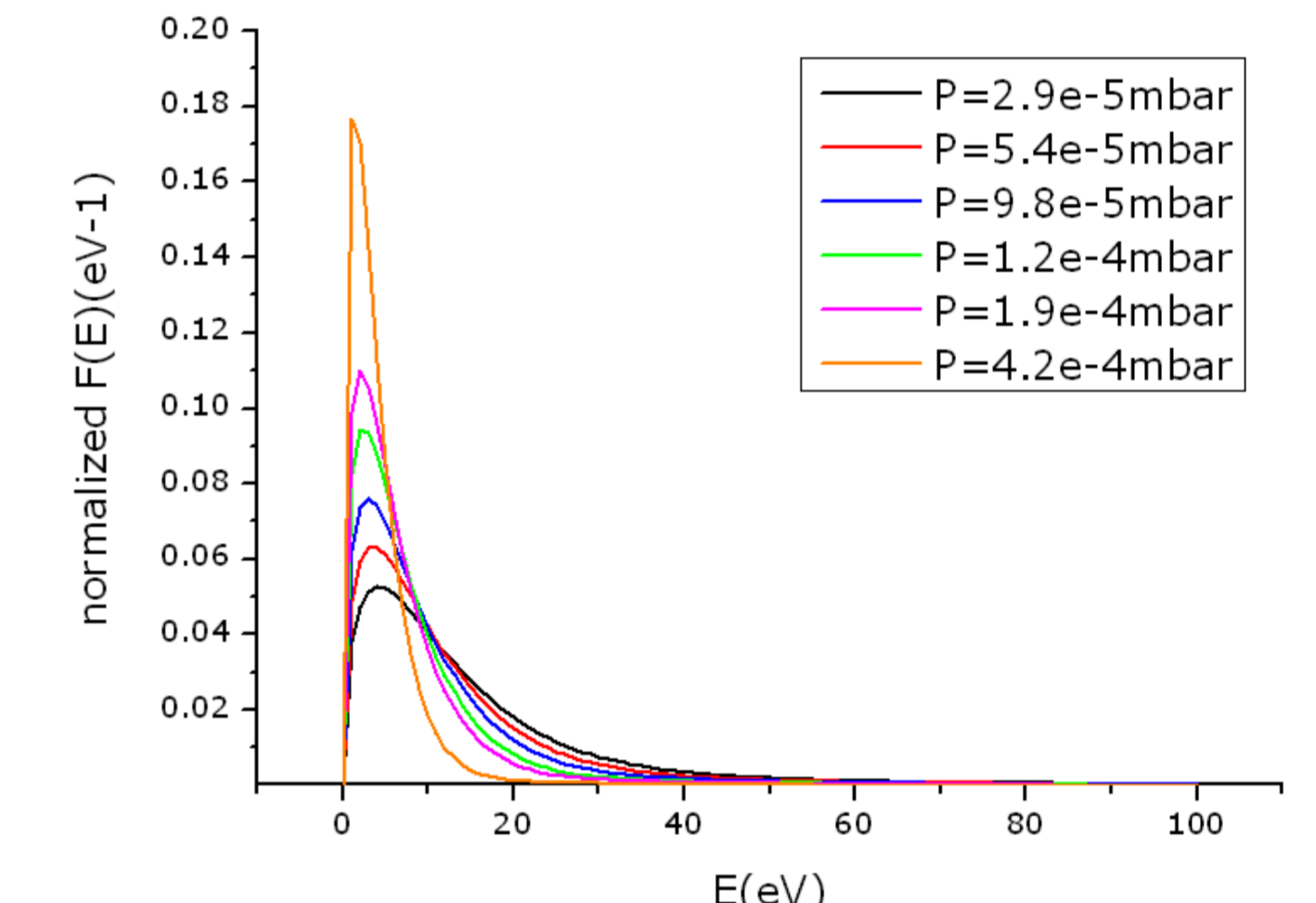


Fig. 10 : Normalized electron energy repartition function

Experimental & Numerical Results :

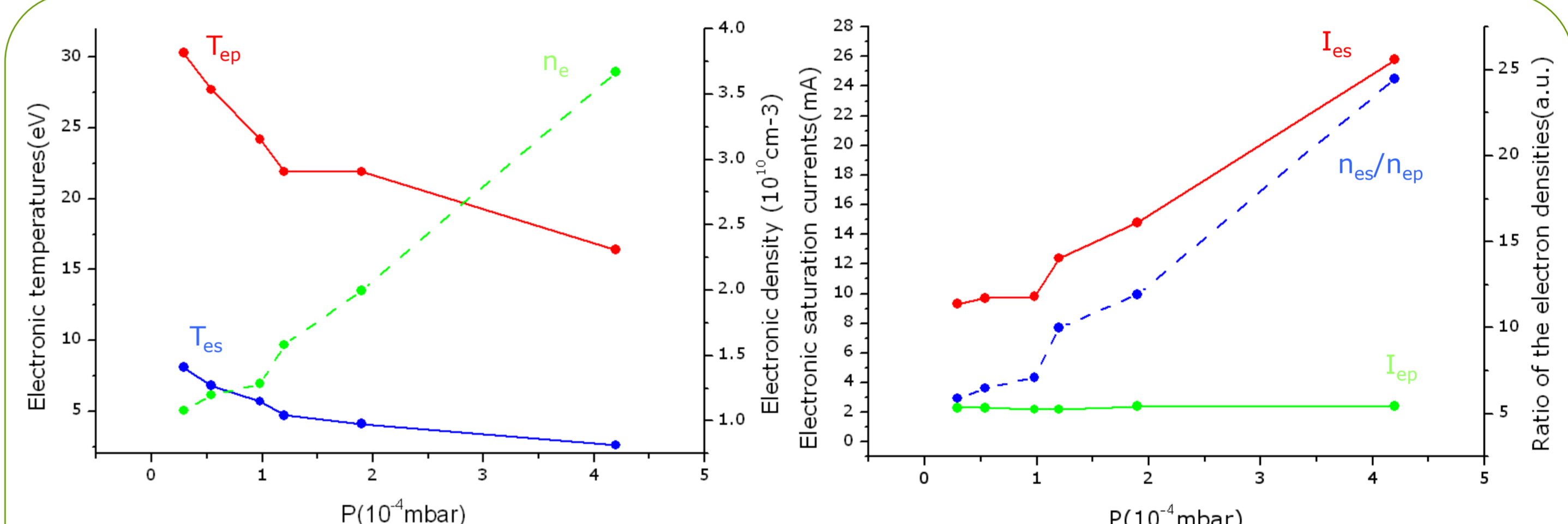


Fig. 11 : Electronic temperatures and density measured with the Langmuir probe

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 γ for the H atoms at the walls (the lower it is, the better it is for the H^+ production yield)

- Without water (Leung [5]) : $H^+ = 5\%$
- With a few % of water : $H^+ = 25\%$

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

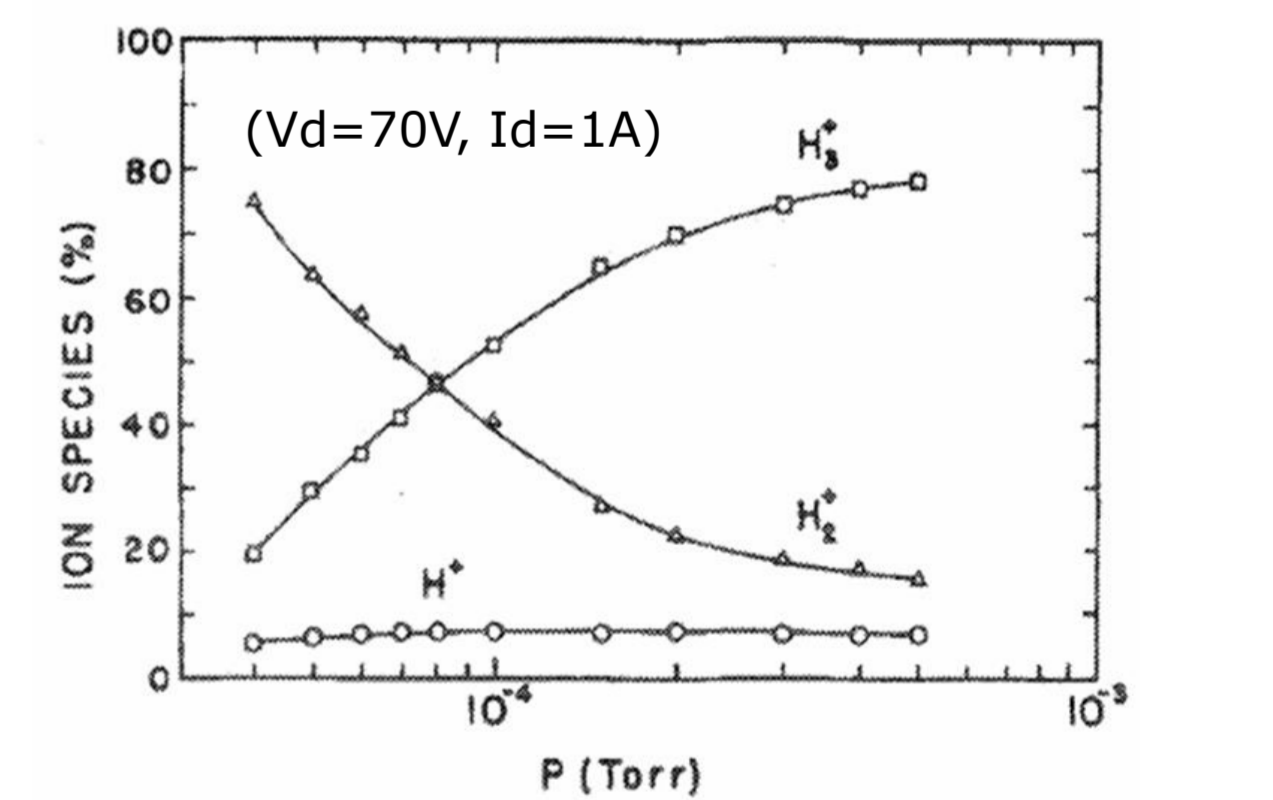


Fig. 13 : Evolution of ion densities measured by Leung with pure H_2 in a similar multicusp ion source

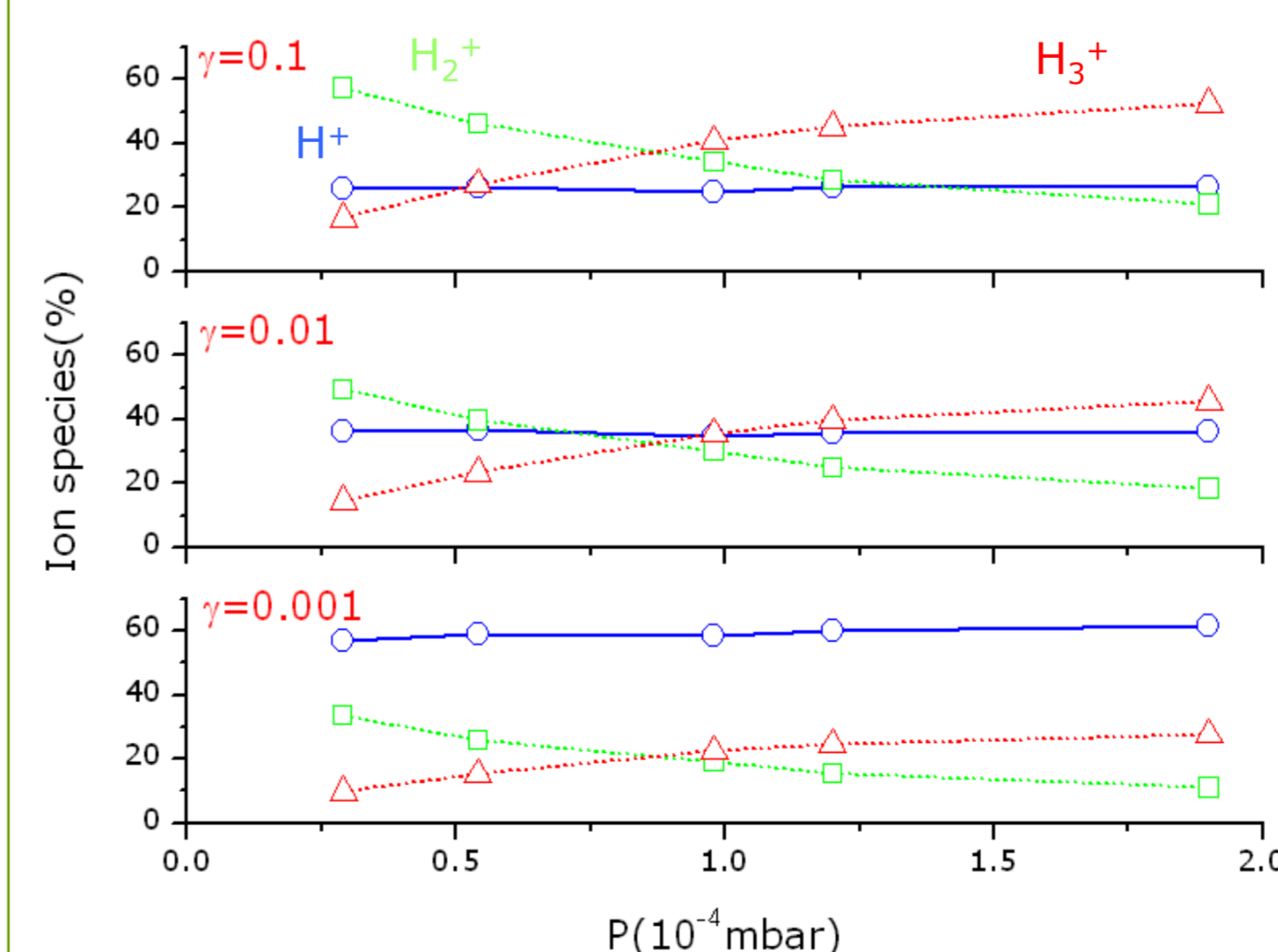


Fig. 14 : Numerical results, evolution of ion densities with the gas pressure and the sticking parameter γ

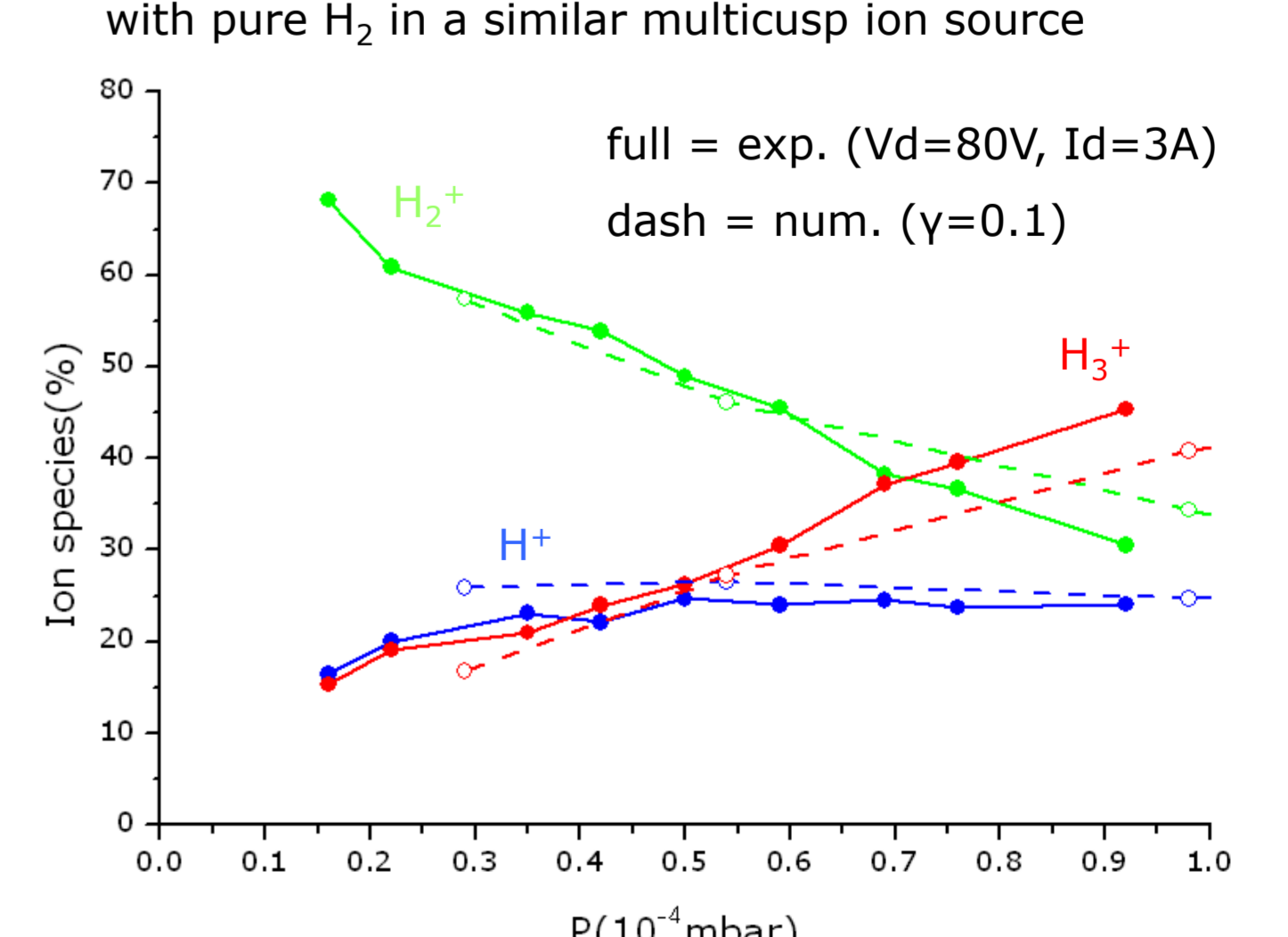


Fig. 15 : Numerical and experimental results, evolution of ion densities with the pressure

Conclusion :

- The multidipole device is able to produce an ion beam of 500eV from a low pressure plasma with 25% of H^+
- The γ 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 T_{ep} is high enough