Static and RF electric field measurement based on Lyman-alpha emission from a hydrogen probe beam

Laurence Chérigier-Kovacic

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1. Introduction

Diagnostic to measure electric field amplitude

Quenching of metastable atoms by an electric field :

Electric Field Induced Lyman-α Emission (EFILE)

Test in vacuum, in a plasma with an externally controlled electric field

outline

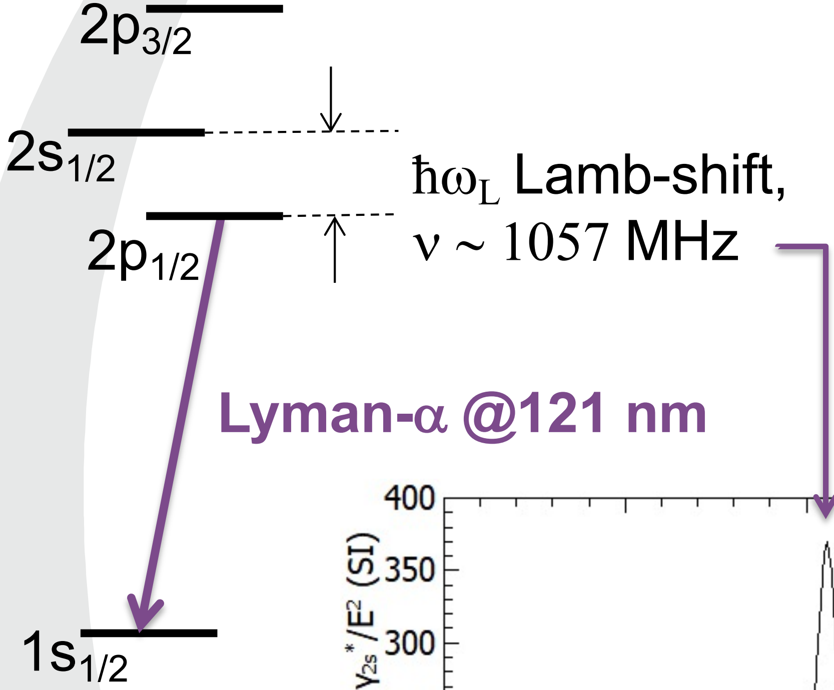
1. Introduction
2. Principle of the experiment
3. Test measurements of a static electric field
   → in vacuum
   → in a plasma : sheath
4. Test measurements of a radiofrequency electric field
   → in vacuum
   → in a plasma
5. Project : Measurement of a radial electric field in a magnetized plasma column
6. Conclusion

2. Principle of the experiment

Quenching of metastable atoms by an electric field

quenching of metastable atoms by the electric field

Lamb & Retherford, PRL **79**,4 (1950)

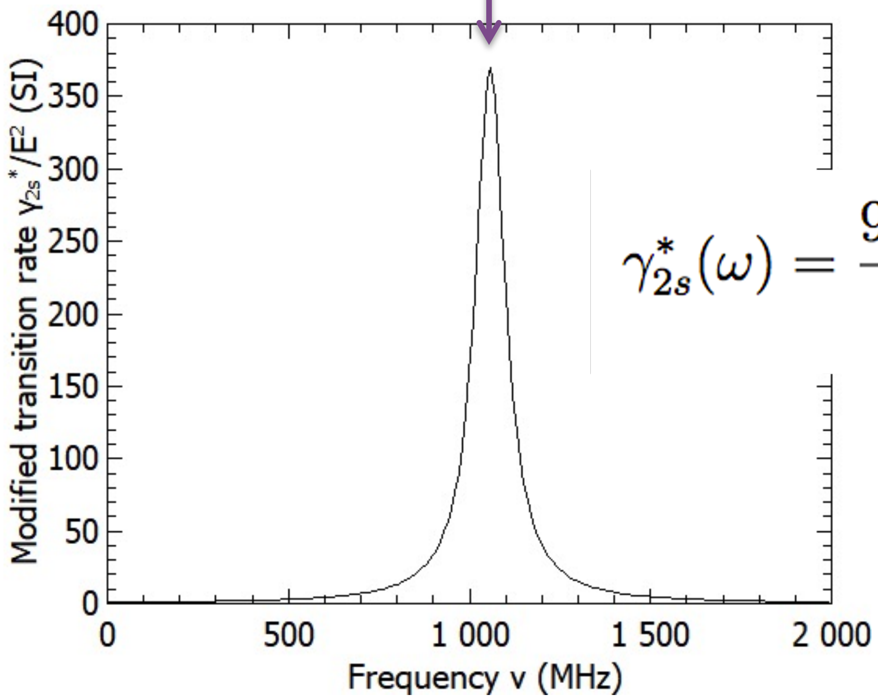


Electric field (E, ω)

→ Stark-mixing $2s_{1/2}$, $2p_{1/2}$

→ $2s_{1/2}$ lifetime reduced

→ emission of **Lyman-α @121 nm**



for E_{stat} < 300 V/cm

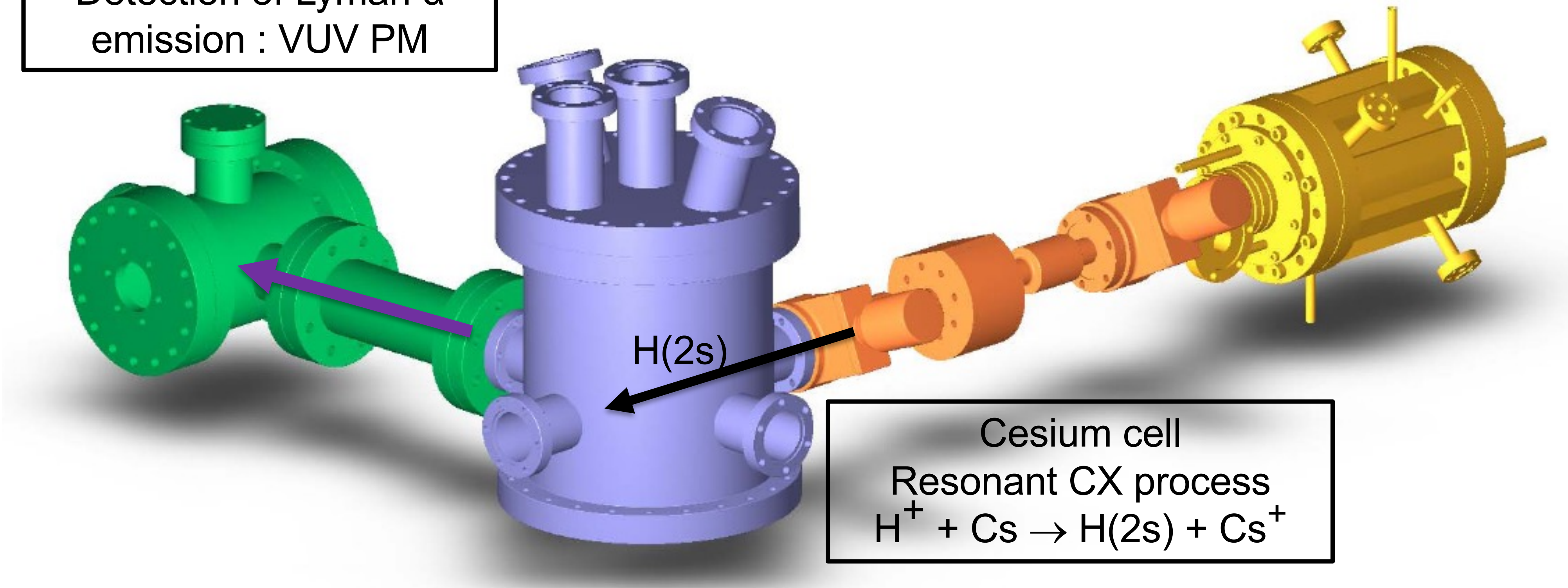
and E_ω < 20 V/cm

$$\gamma_{2s}^{*}(\omega) = \frac{9e^2 a_0^2 E^2}{h^2} \underbrace{\frac{\gamma_{2p}}{(\omega-\omega_L)^2 + \gamma_{2p}^2/4}}_{L(\omega)}$$

experimental device

Plasma source : 500 V polarization
+ Einzel lenses (extraction)

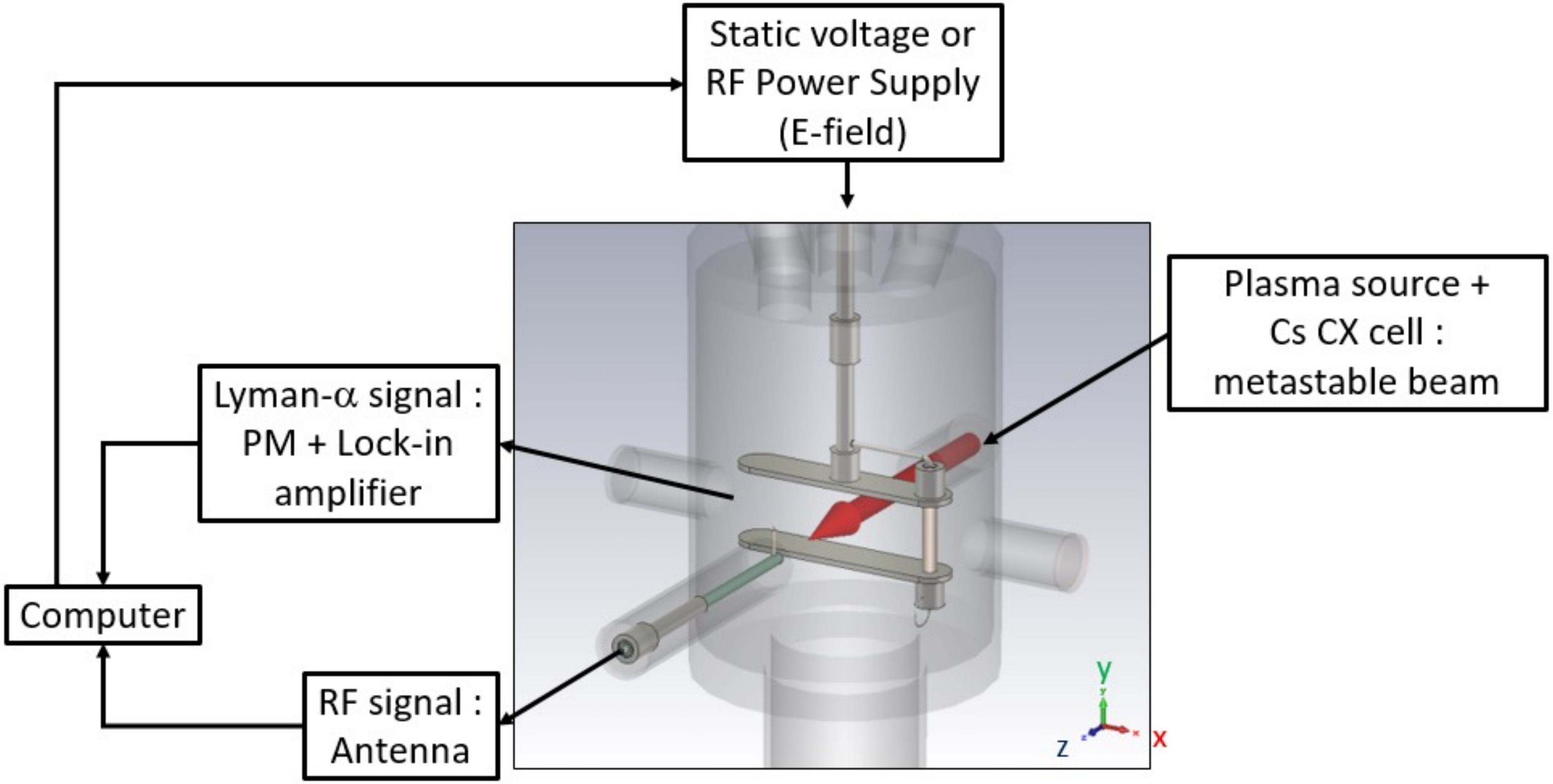
Detection of Lyman α
emission : VUV PM



Cesium cell
Resonant CX process
$H^{+} + Cs \rightarrow H(2s) + Cs^{+}$

Measurement chamber :
interaction between probe beam and electric field
beam / plasma diagnostics

experimental device : external E field generation



limits

- $S \propto E^2$
- Electric field 0.1 V/cm → 500 V/cm
- Time resolution :

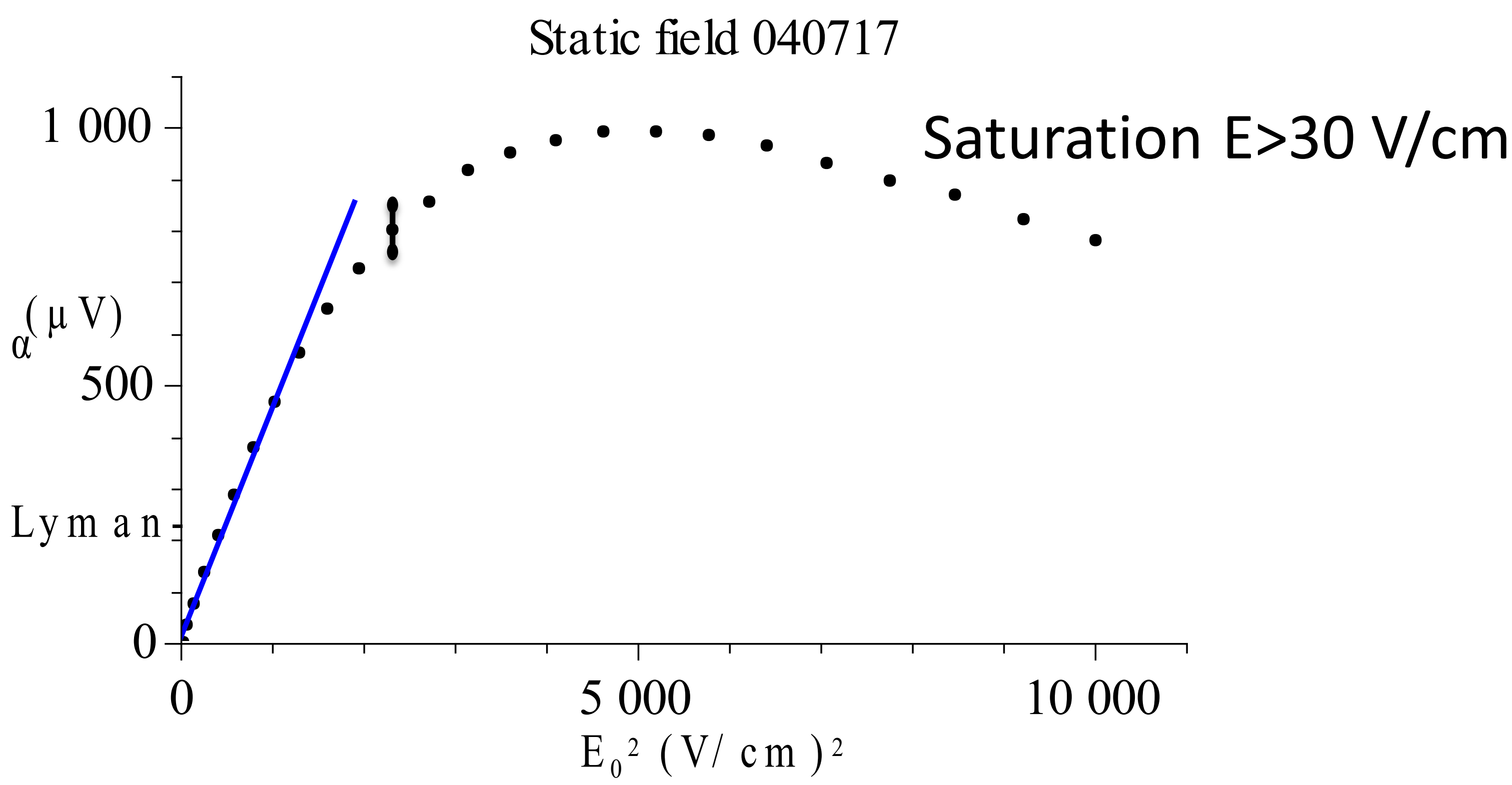
  1 s if pulsed beam,

  period of oscillations of periodic phenomenon
- Spatial resolution : now, 1 cm

3. Measurement of a static electric field

Measurements in vacuum and in a plasma sheath

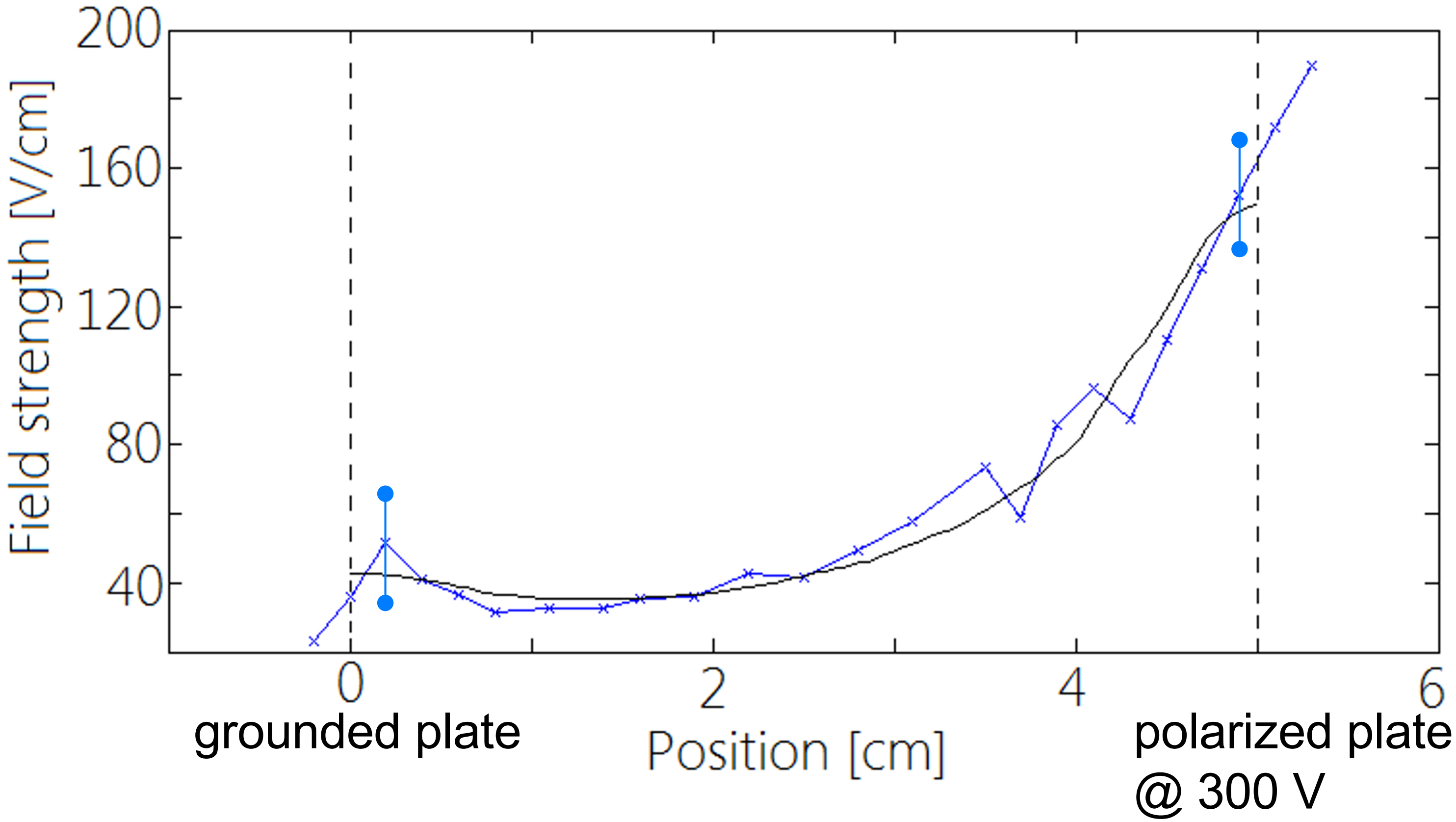
signal in vacuum for a static voltage



Saturation : loss of metastable due to the electric field before the diagnosed volume

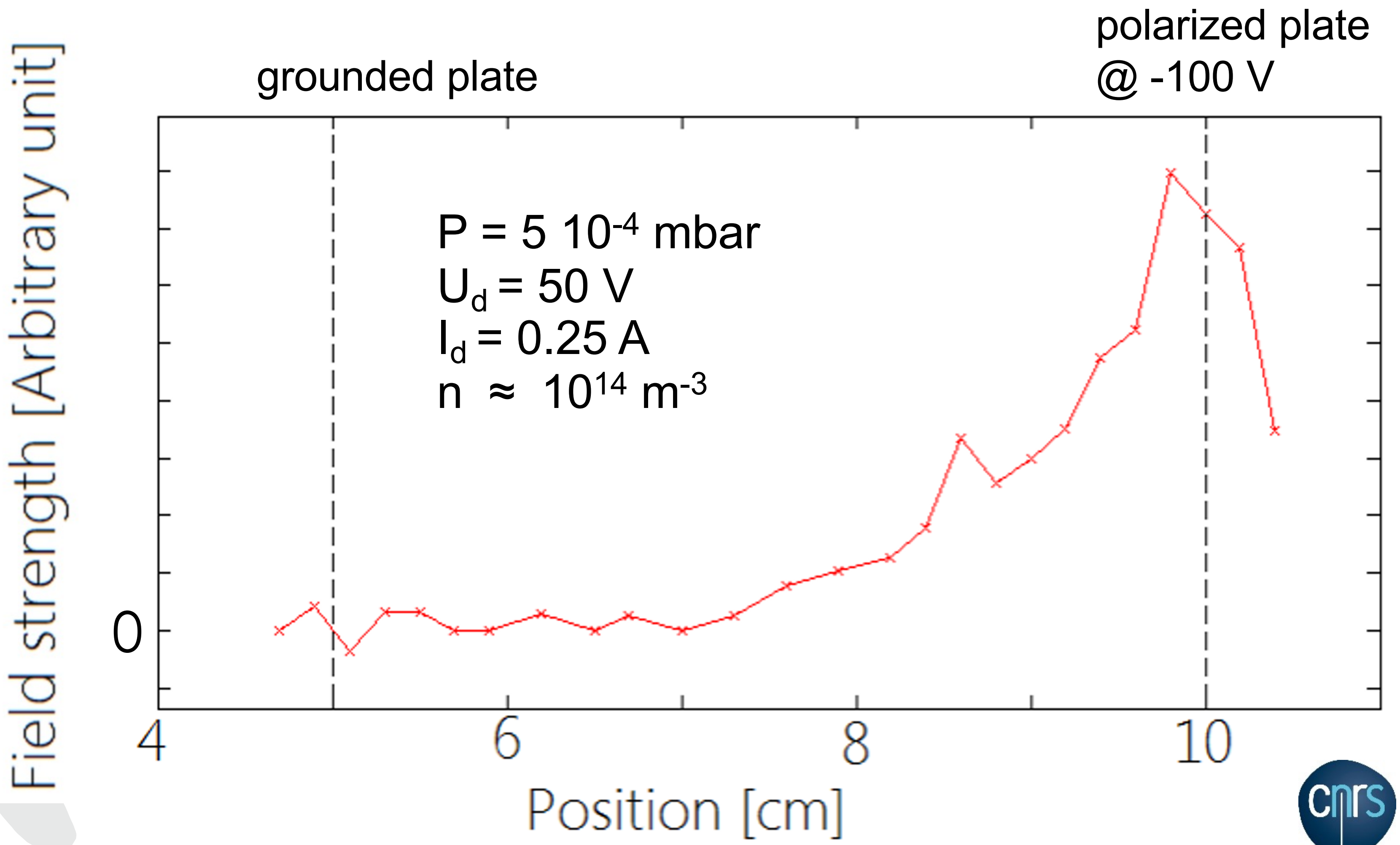
signal in vacuum for a static voltage

Electric field profile between the plates :
Measurements + FEM simulation



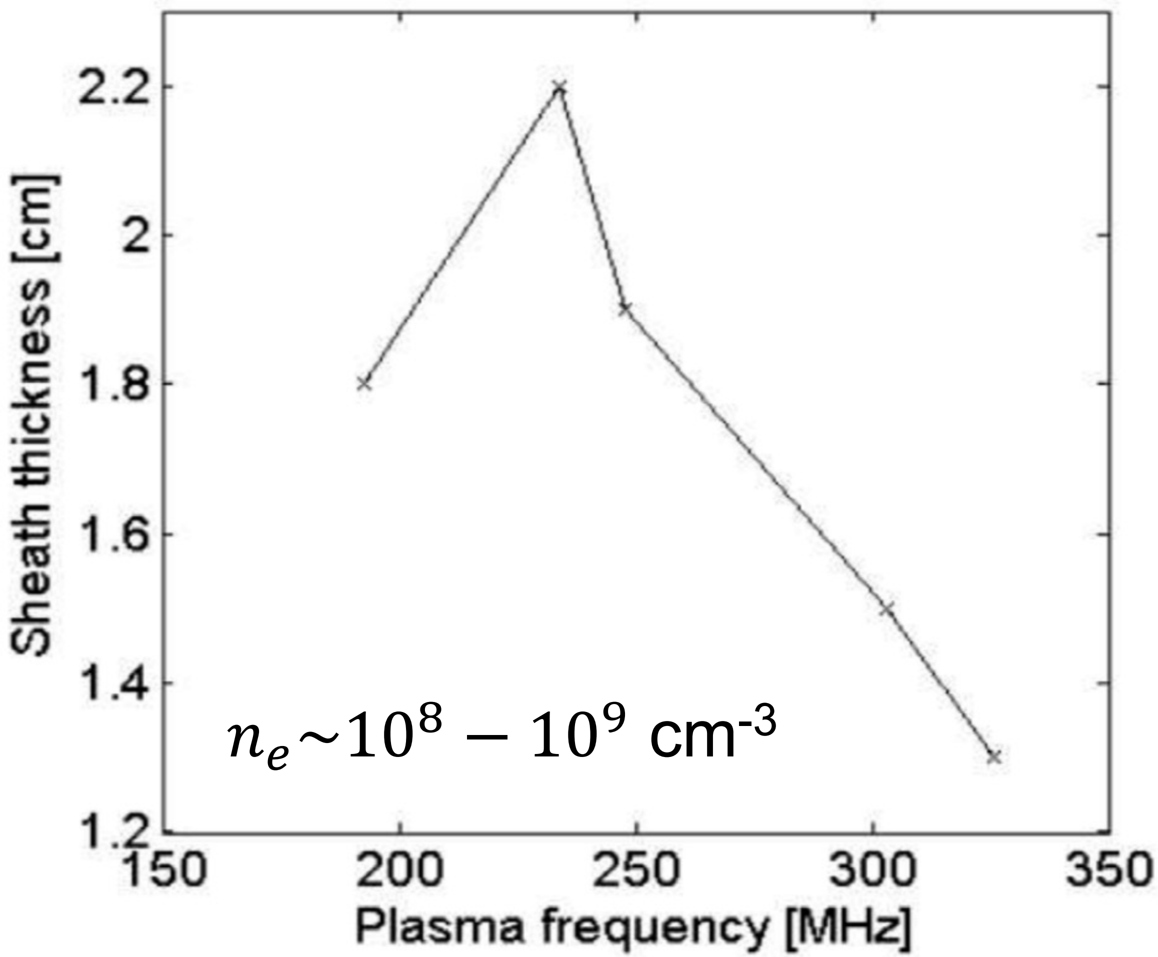
signal in an Ar plasma for a static voltage

Electric field profile between the plates : sheath



signal in an Ar plasma for a static voltage

Electric field profile between the plates : sheath

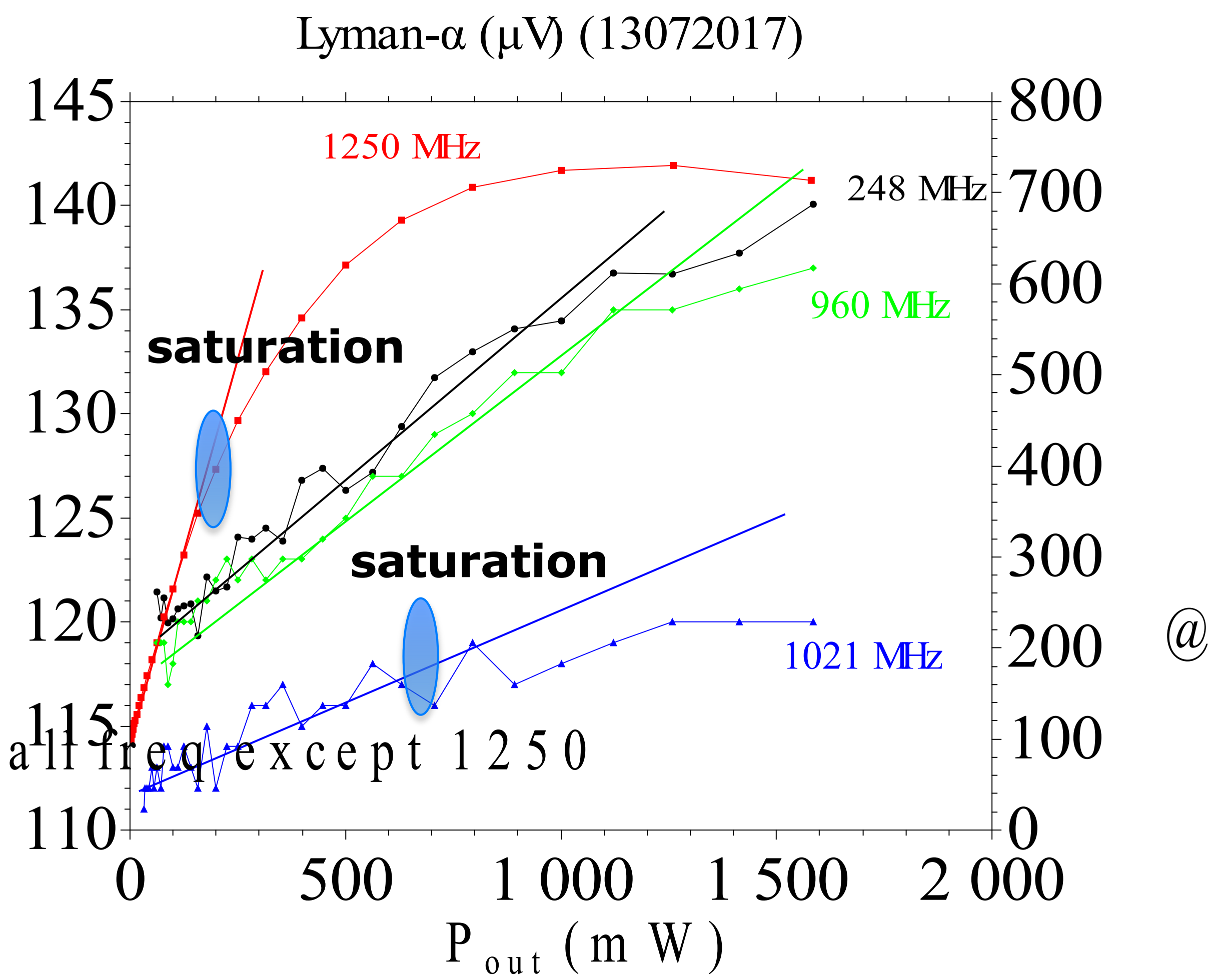


$$\omega_p = \sqrt{\frac{n_e e^2}{m_e \varepsilon_0}} \text{ and } n_e \propto I_d$$

4. Measurement of a RF electric field

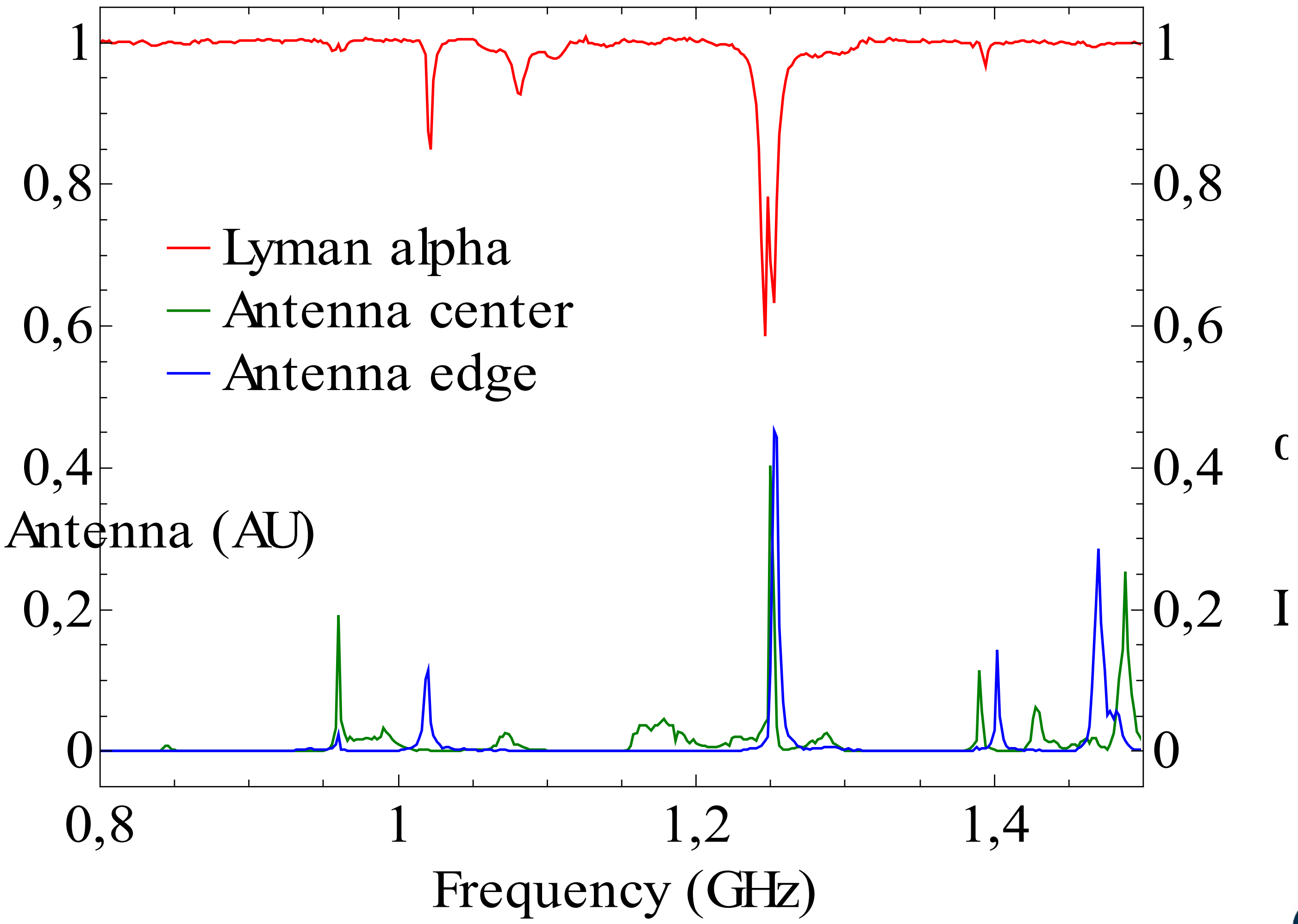
Measurements in vacuum and in a plasma

signal in vacuum for a RF voltage

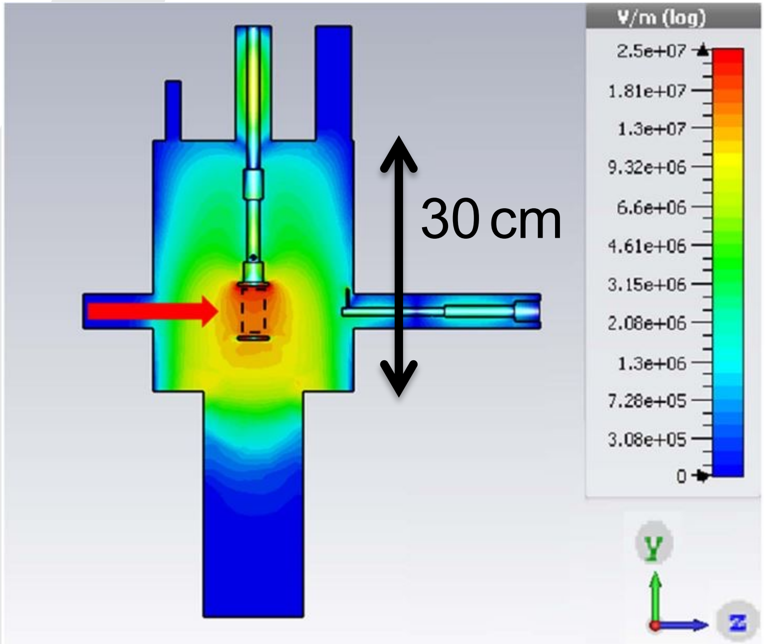


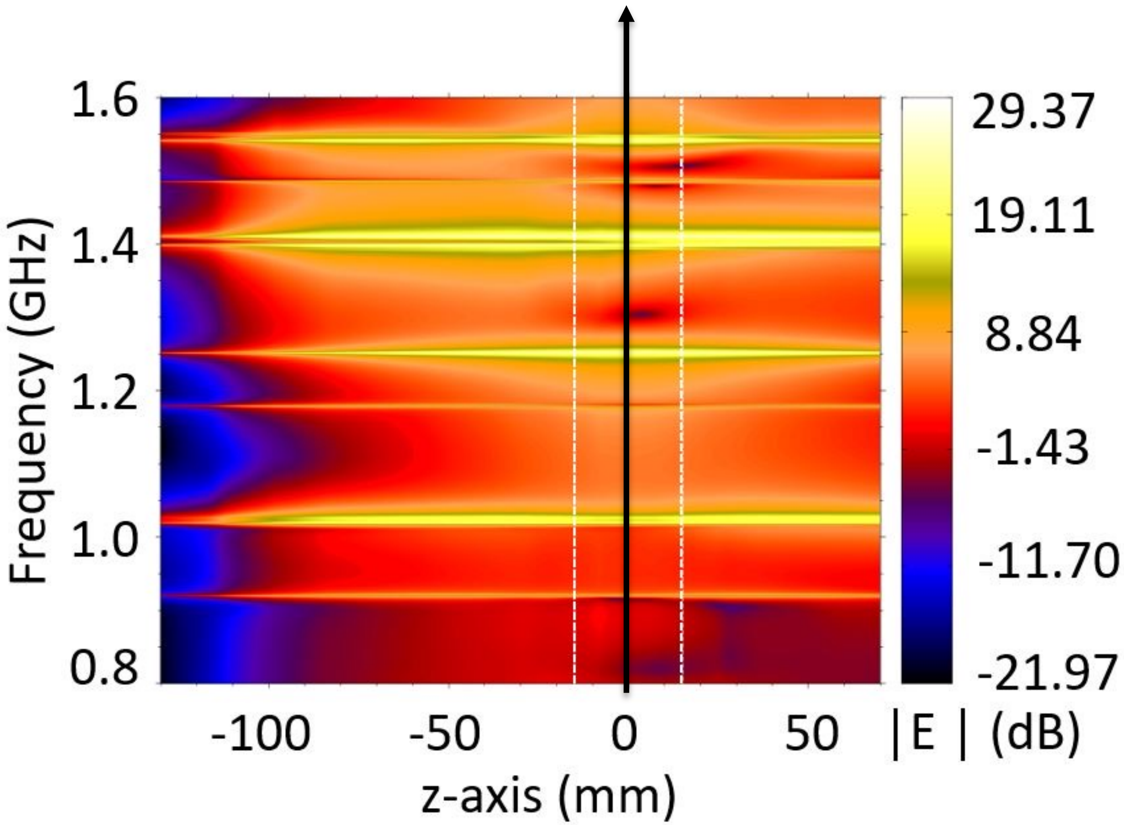
geometrical saturation depending on the electric field along the beam path

signal in vacuum for a RF voltage @1500 mW



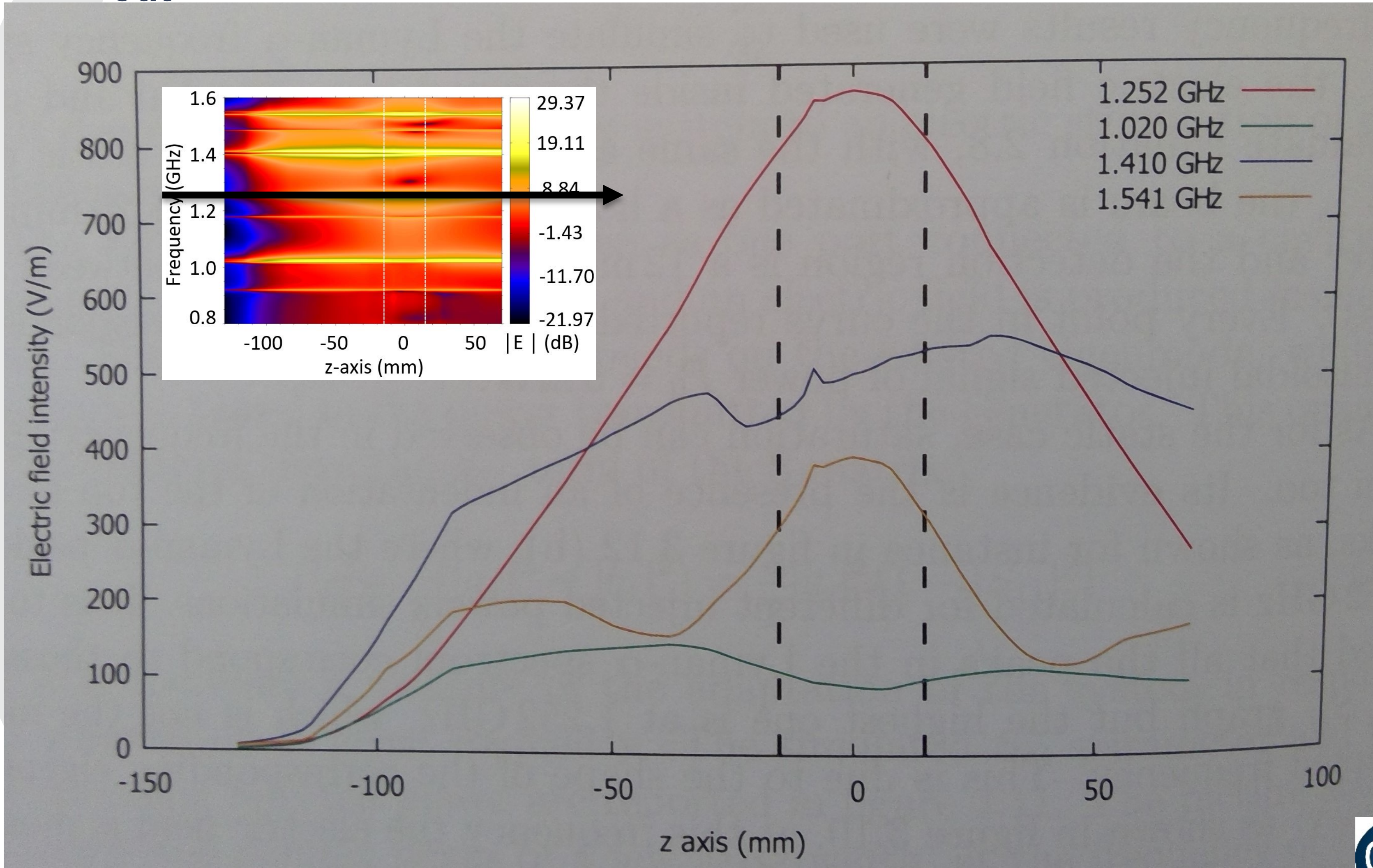
numerical calculation of the electric field in the vessel



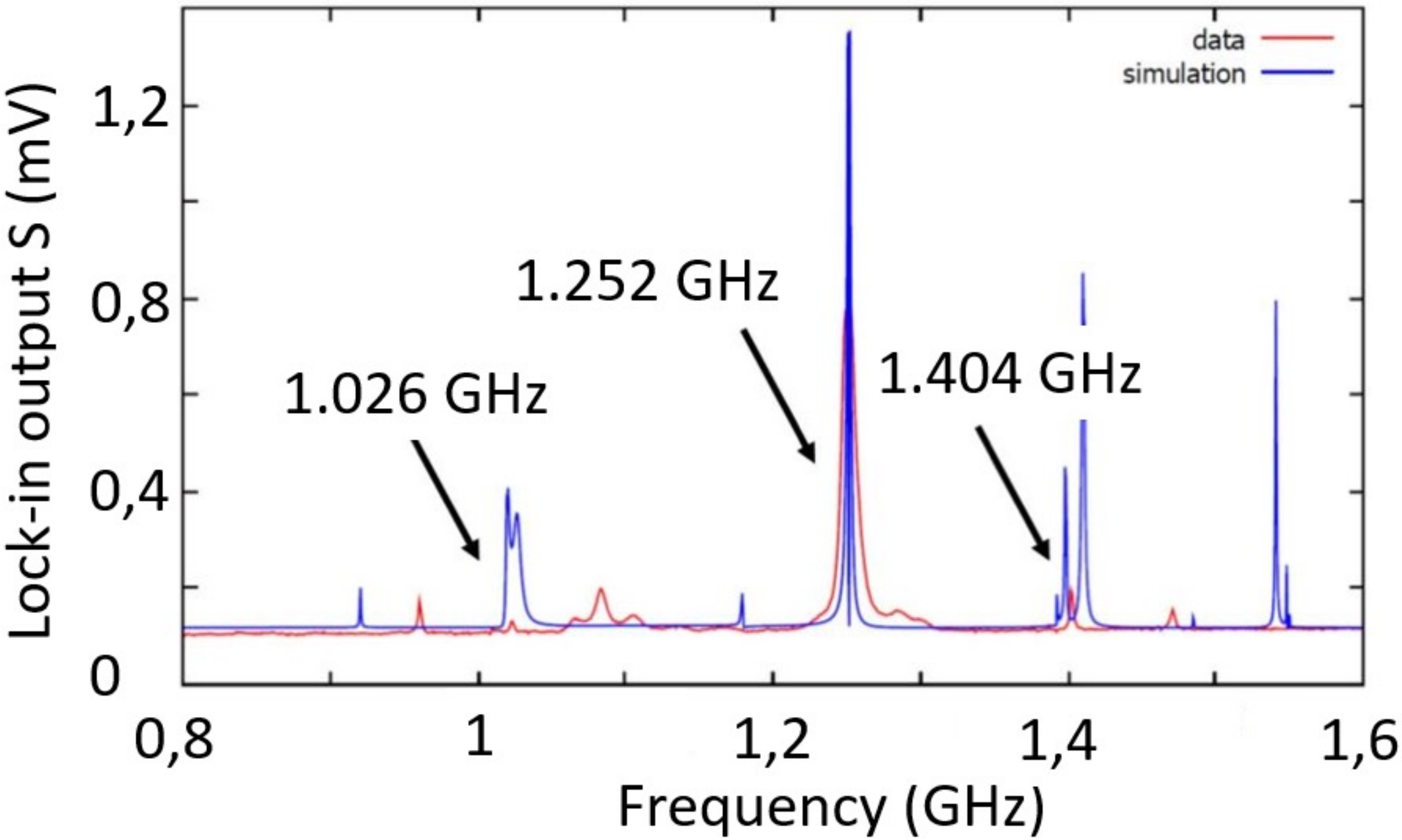


Field map

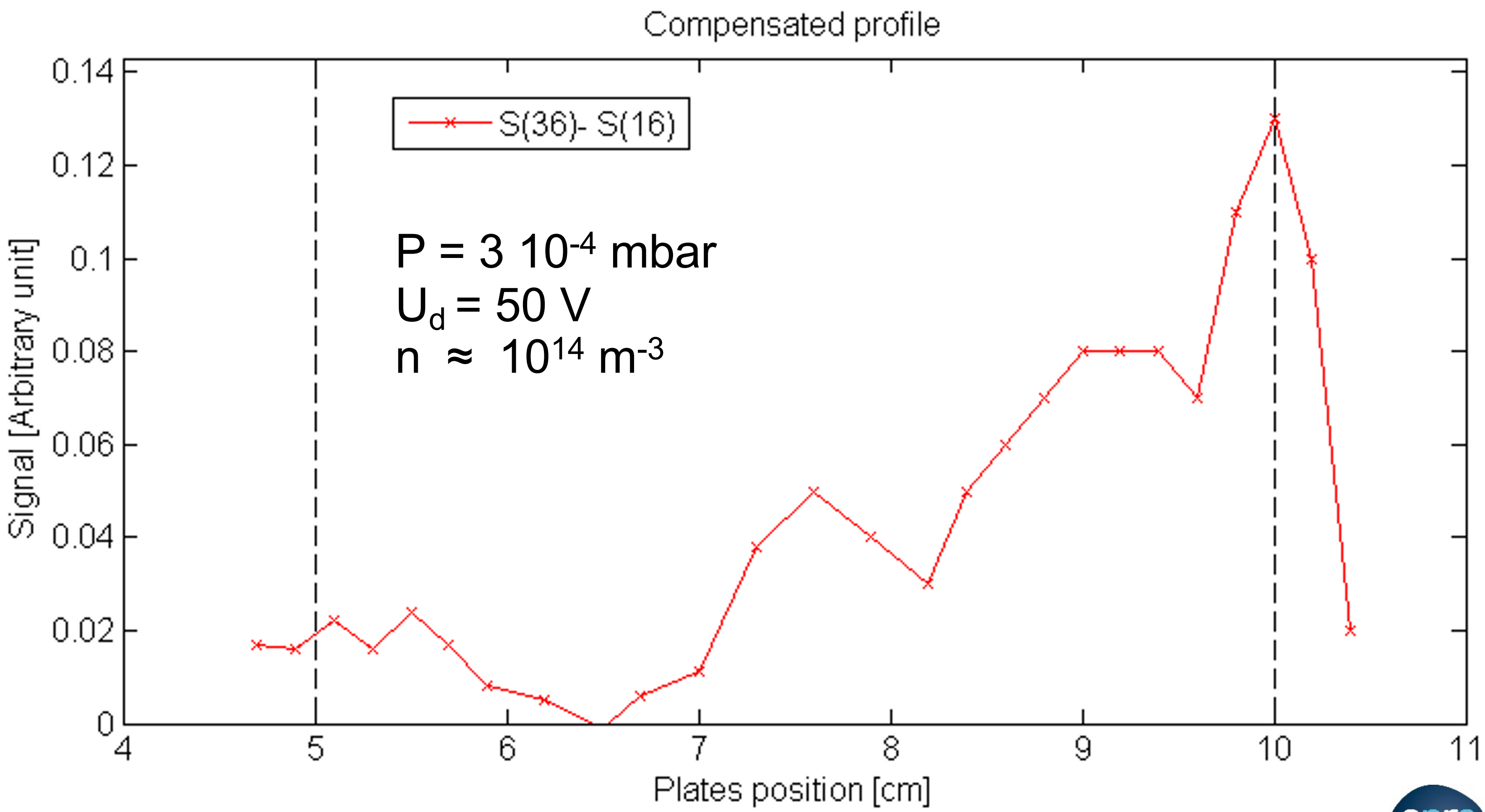
Calculated E field amplitude along the beam path for P_{out}= xx?



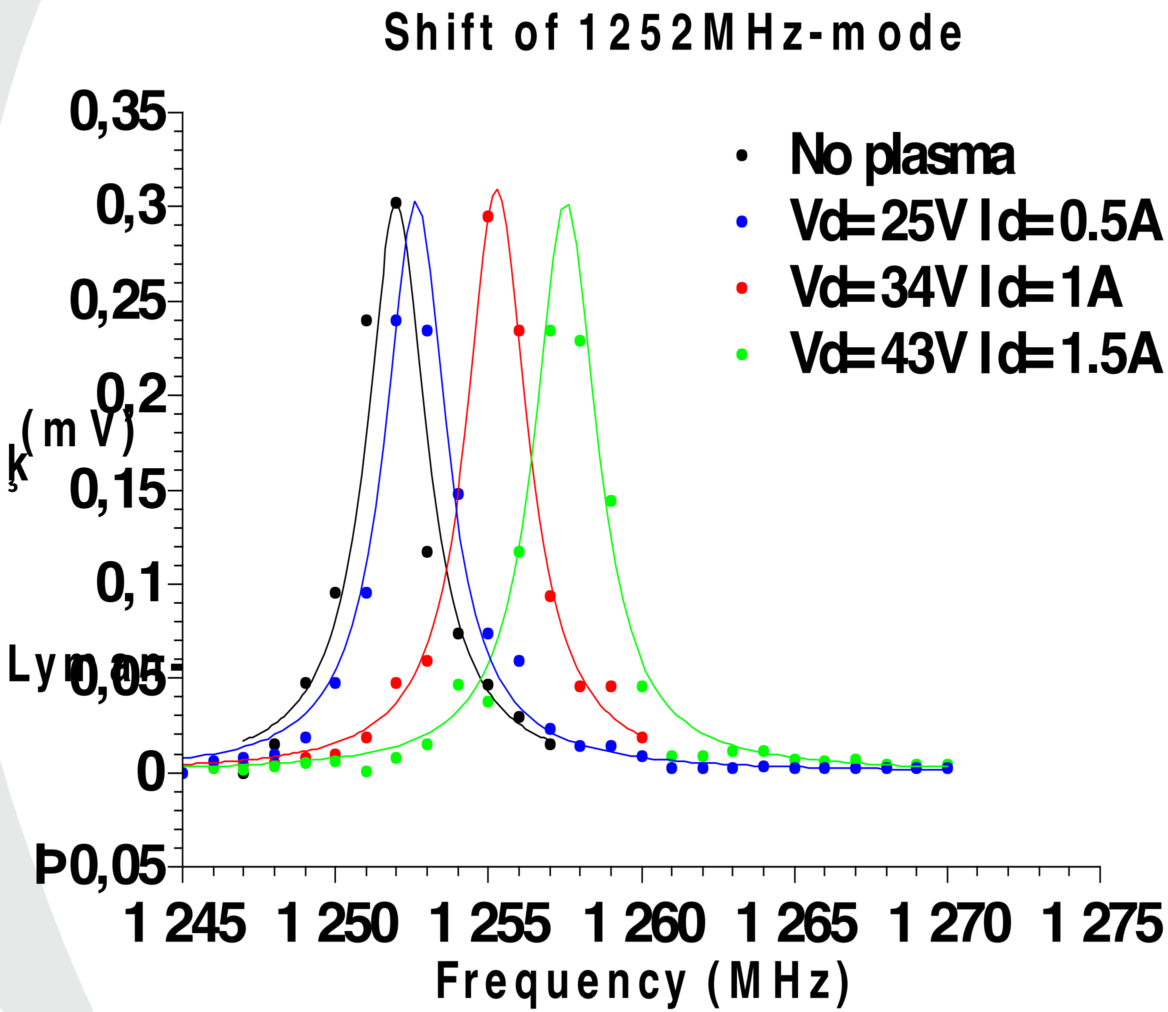
simulation / experiment comparison



Lyman-α signal in presence of 1 GHz voltage between the plates



observation of resonance mode shift

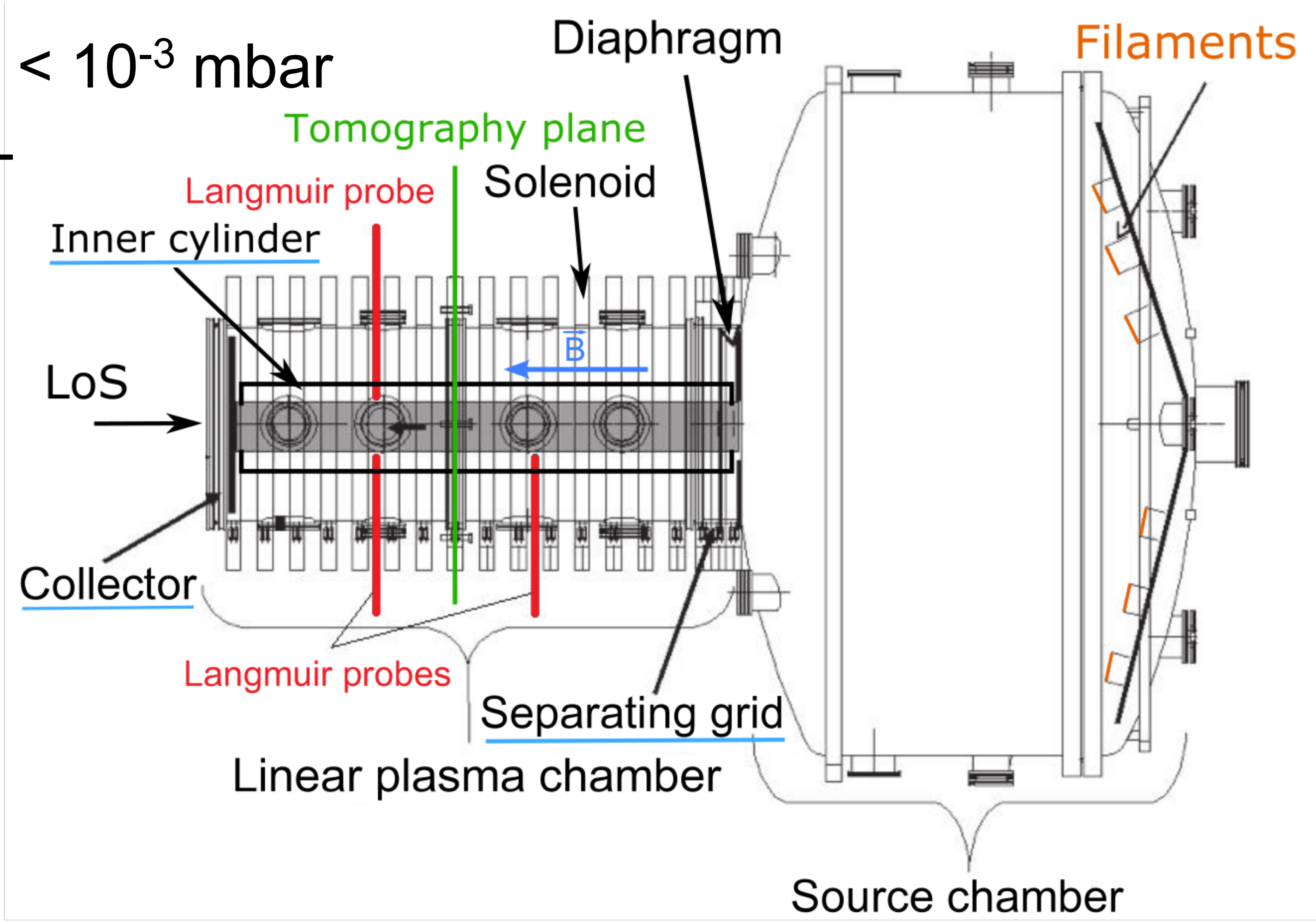


F (MHz)	n_e (cm^{-3})
1252	0
1252,6	$1{,}8\ 10^7$
1255,3	$1{,}0\ 10^8$
1257,5	$1{,}7\ 10^8$

$$n_e = \frac{2 m_e \varepsilon_0 \omega^2}{e^2} \frac{\Delta\omega}{\omega_0}$$

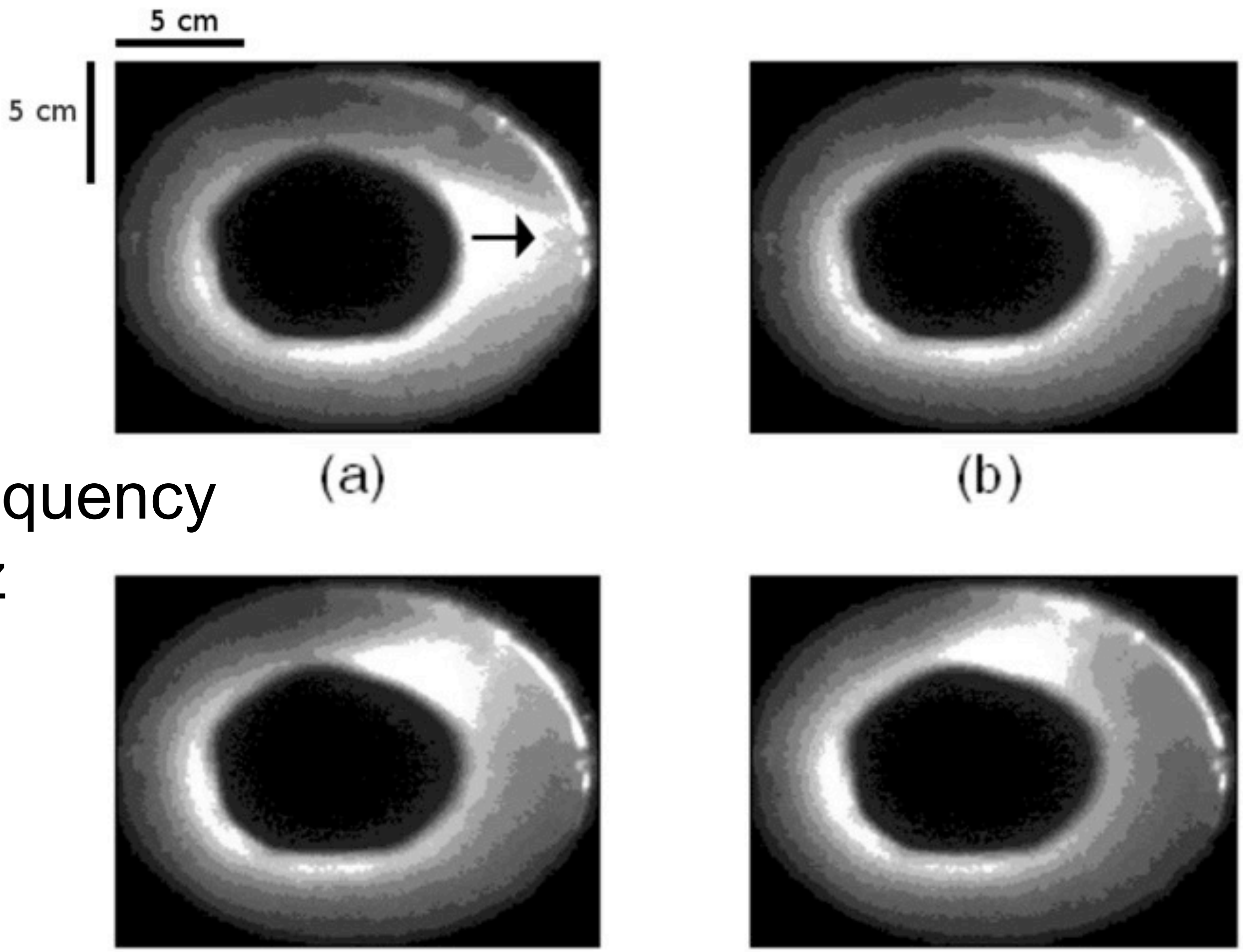
5. Project : measurement of the radial electric field in a magnetized plasma column (MISTRAL)

- $L = 1.2$ m, $r_{inner\ cylinder} = r_{plasma} = 36$ mm
- 5.10^{-5} mbar < P < 10^{-3} mbar
- $B_{solenoid} < 25$ mT



fast camera results (end view of the plasma) : rotating arm of plasma ejected from core

A. Escarguel, ExB workshop, Princeton Plasma Physic Lab, nov 2018.

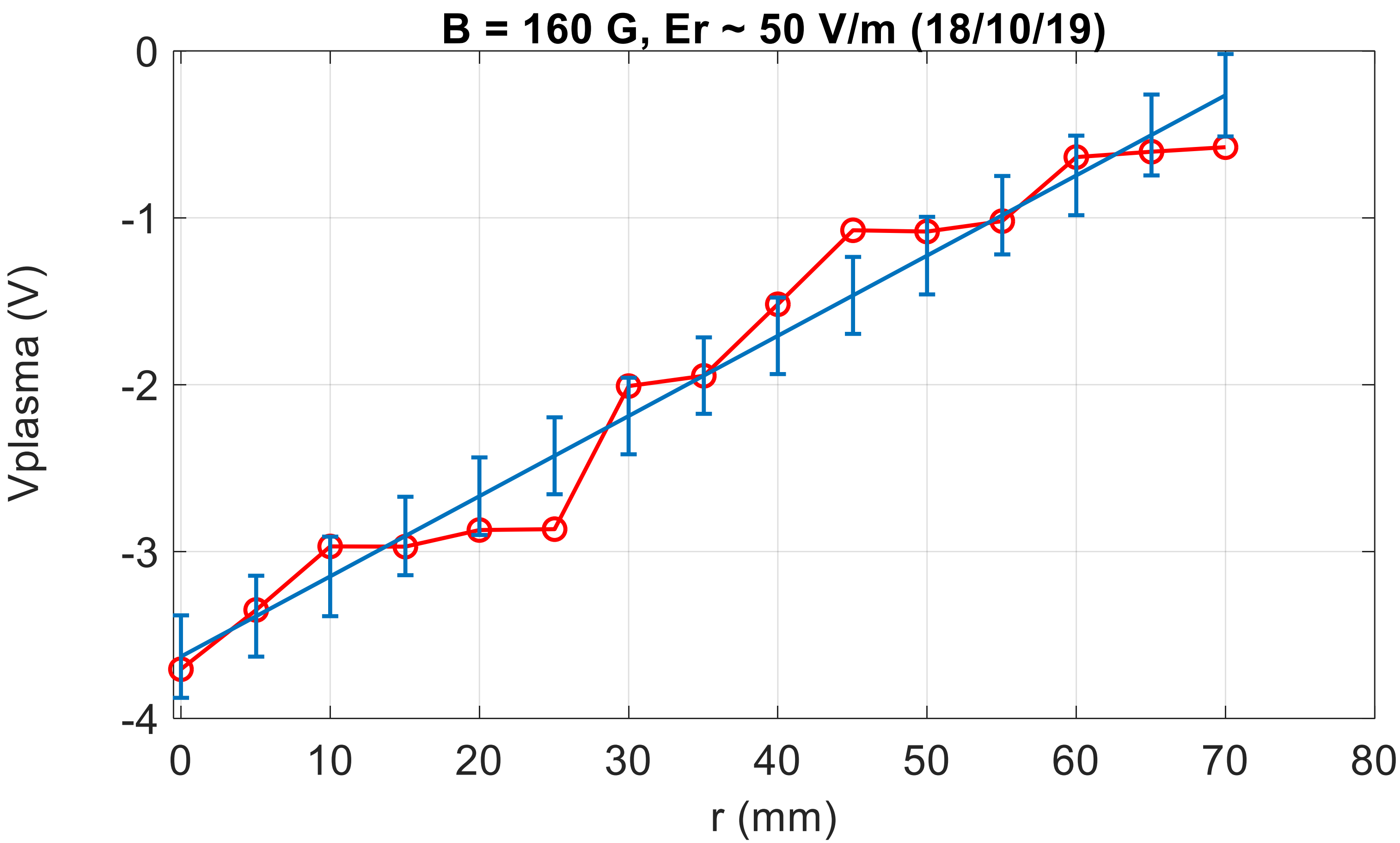


(a) (b)

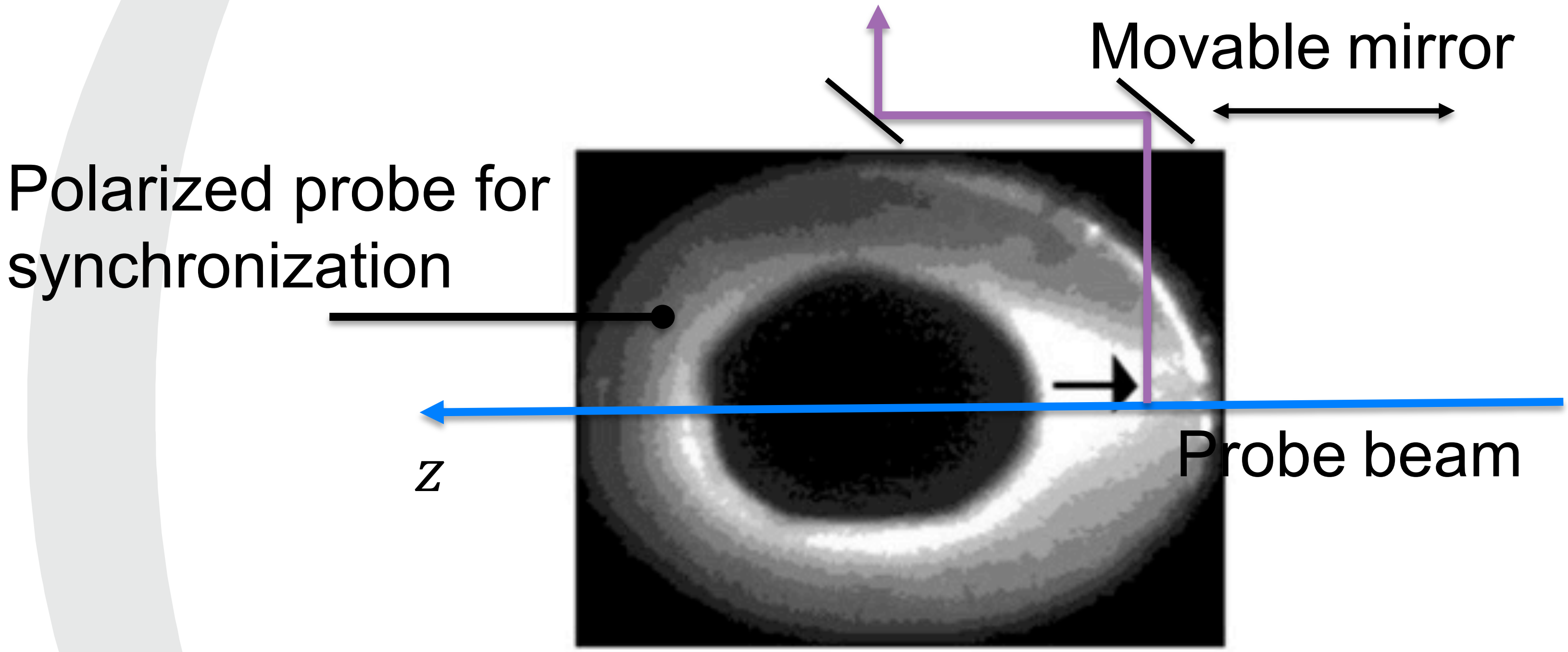
(c) (d)

→ Rotation frequency = a few kHz

measurement of the radial electric field in MISTRAL : Langmuir probe, synchronized with the rotating arm



principle of the experiment



$$\frac{dN}{dz} = \frac{N(z)}{\tau_{2s}^{*}(E)v}$$

$$N(z) = \beta \int_{z}^{\infty} I(z')dz'$$

Like in Pradel *&al.* PRA, **10**(3) 1974

conclusion :

- Measurement of the electric field in vacuum and in a plasma 10^8 cm^{-3} by EFILE

- Static or radiofrequency, up to 1.4 GHz

- Signal at resonant frequencies of our vessel
  - good correlation with simulations in vacuum
  - RF signal in a plasma OK

- Next issue : calibration, superposition of static and RF voltages

- 2019 ongoing work – installation on a magnetized plasma column (MISTRAL) : test of EFILE against other method

collaborators :

- Fabrice Doveil (PIIM, CNRS)

- Carlo Poggi (M2 – Erasmus Université de Padoue/AMU)
- Théo Guillaume (M2 – AMU)

- Veronica Gonzalez (post-doc, PIIM, Eurofusion)
- Alexandre Escarguel (PIIM, AMU)

- Institut Fresnel, AMU : G. Demesy, P. Sabouroux, M. Dubois

thank you for your attention

aknowledgements :

cnrs

FR FCM

RÉGION SUD
PROVENCE
ALPES
CÔTE D'AZUR

[Hoh; Simon Phys. Fluids 1963 ; Jaeger PhD 2009]

Simon-Hoh instability CSHI (Phys. Fluids 1963)

ExB drift:

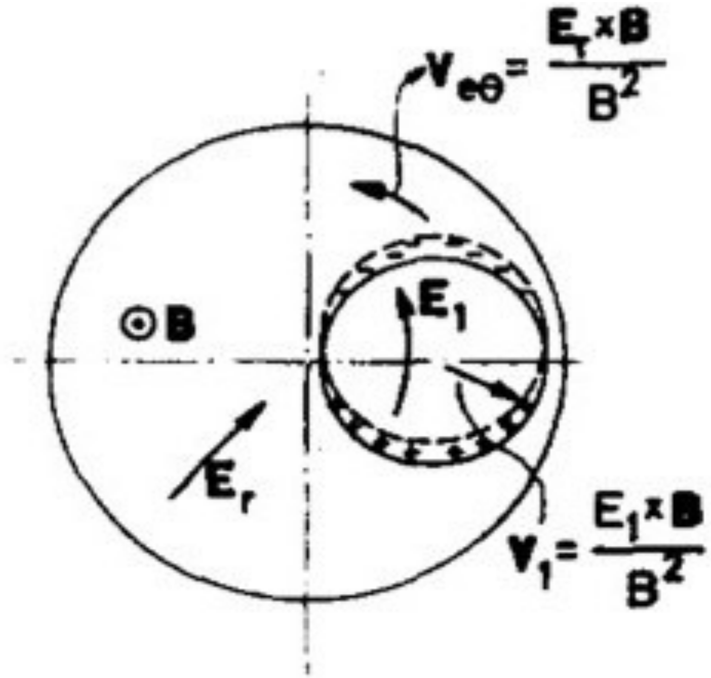
- Electrons : $v_{e\theta}$
- Friction forces (e-neutrals)

→ Ions slowed down:

$$v_{i\theta} < v_{e\theta}$$

→ Charge separation: E_1

→ Rotation frequency instability:

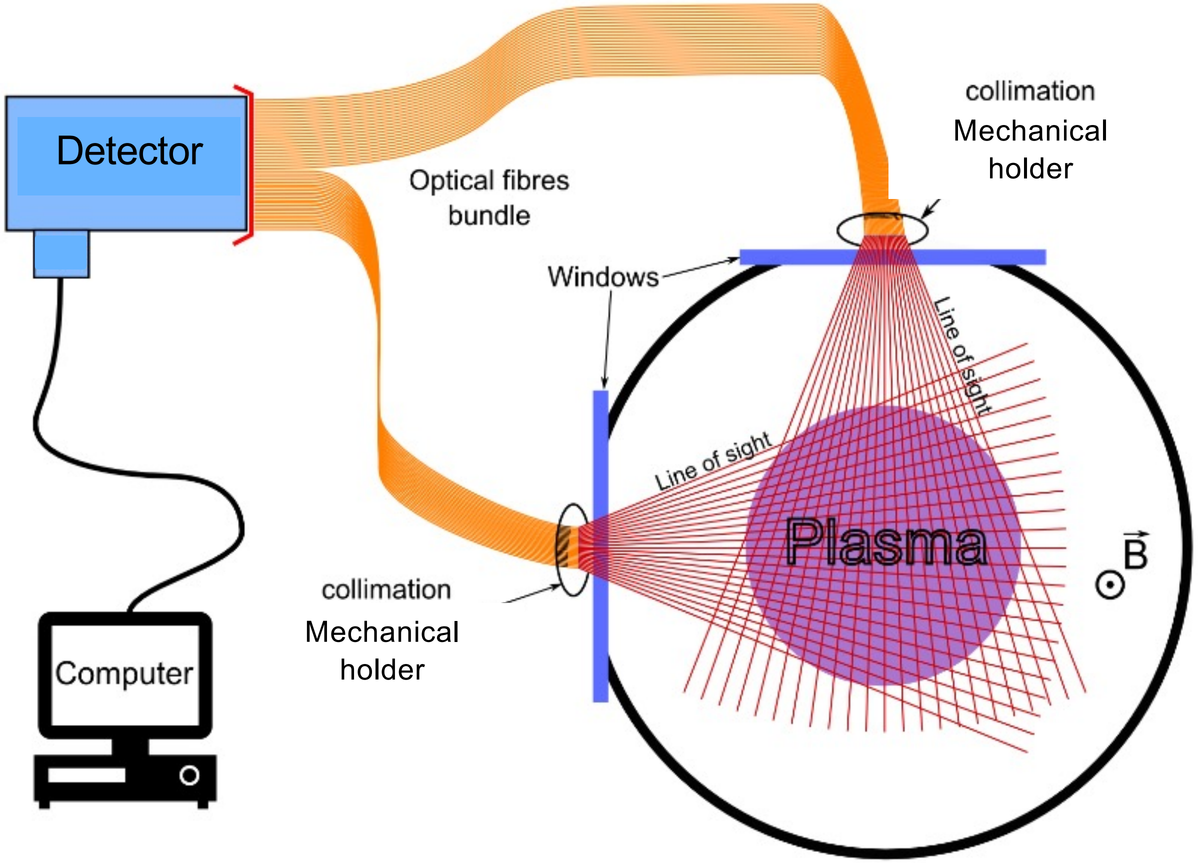


$$\upsilon_{spoke} = \frac{1}{\pi R_0}\sqrt{\frac{eE_r L_n}{m_i}} \qquad L_n = \frac{n_e}{\frac{\partial n_e}{\partial r}} \qquad \upsilon_{spoke} \propto \sqrt{B} \qquad E_r \propto B$$

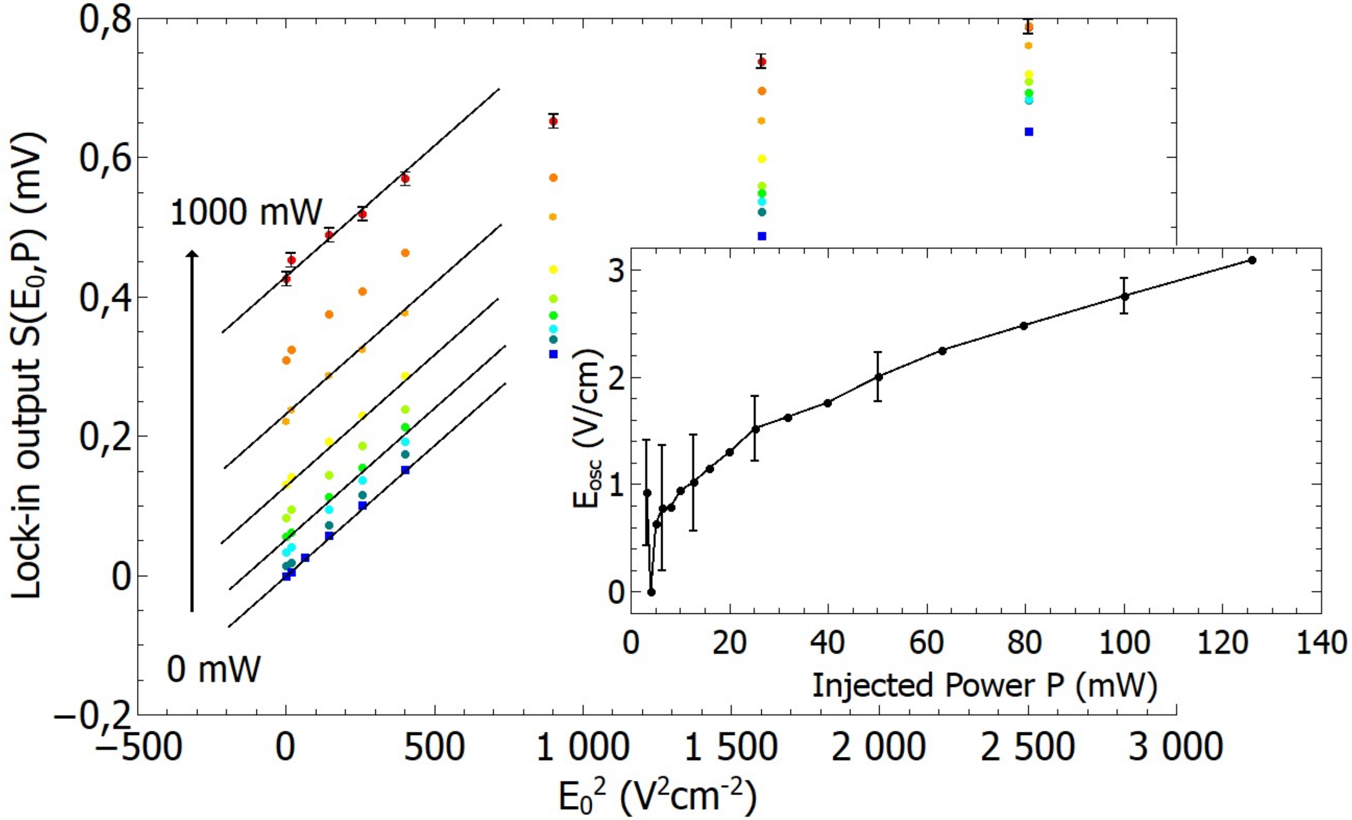
Smolyakov PPCF (2017) ; POWIS POP (2018)

Tomography : experimental set-up

→ Instantaneous measurements, or on reproducible phenomenons : spatial structure study of regular modes.



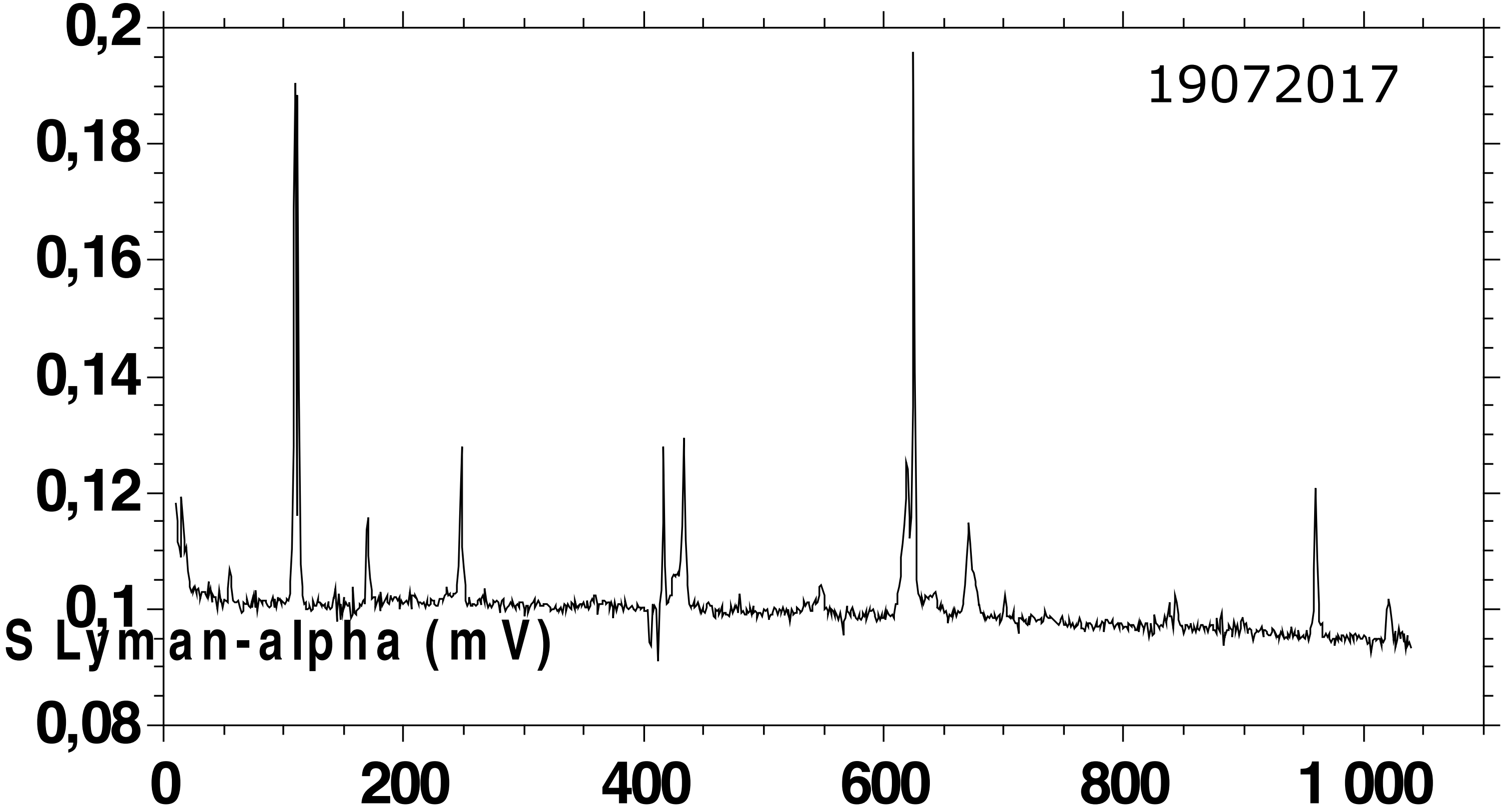
Calibration : superposition champs RF @1.25 GHz et statique



Signal non saturé :

$$S(E_0, P) \propto \gamma^*_{2s} = \beta L(0) E_0^2 + \beta L(\omega) E^2_{\mathrm{rf}}(P)$$

Spectre Lyman alpha 10-1000MHz



Network analyzer