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

Laurence Chérigier-Kovacic

XXXIV ICPIG, July 2019, Sapporo, Japan

1. Introduction

Diagnostic to measure electric field amplitude

Quenching of metastable atoms by an electric field :
Electric Field Induced Lyman- α Emission (EFIELD)

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

outline

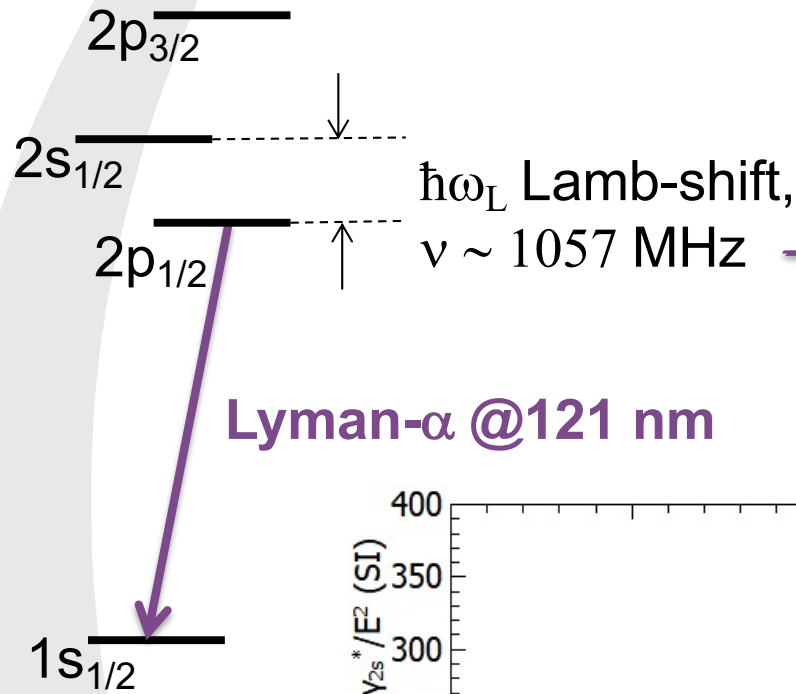
1. Introduction
2. Principle of the experiment
3. Test measurements of a static electric field
 - in vacuum
 - in a plasma : sheath
4. Test measurements of a radiofrequency electric field
 - in vacuum
 - in a plasma
5. Project : Measurement of a radial electric field in a magnetized plasma column
6.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



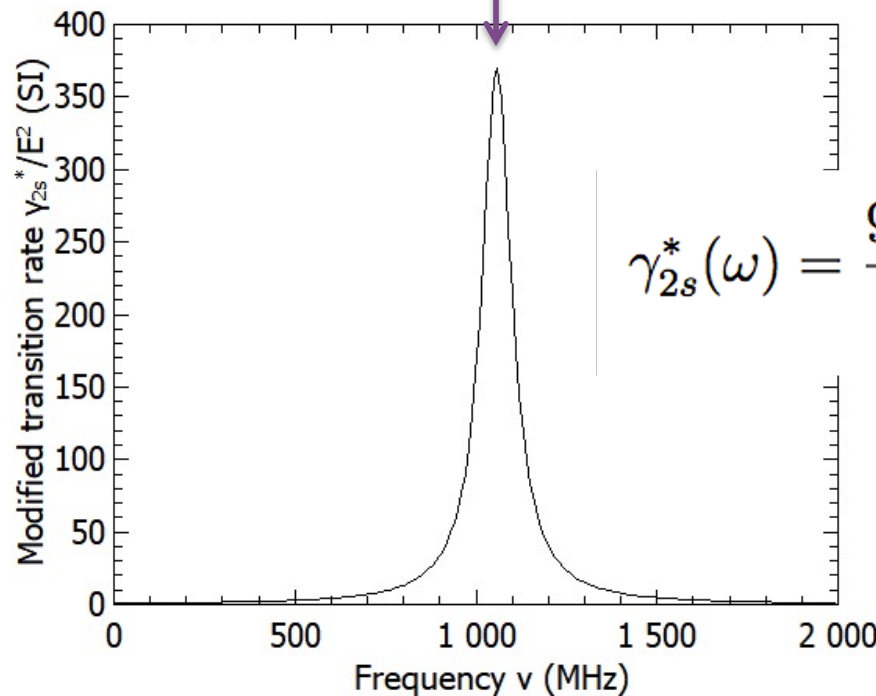
Electric field (E, ω)

→ Stark-mixing $2s_{1/2}, 2p_{1/2}$

→ $2s_{1/2}$ lifetime reduced

→ emission of Lyman- α @121 nm

Lyman- α @121 nm



for $E_{\text{stat}} < 300$ V/cm

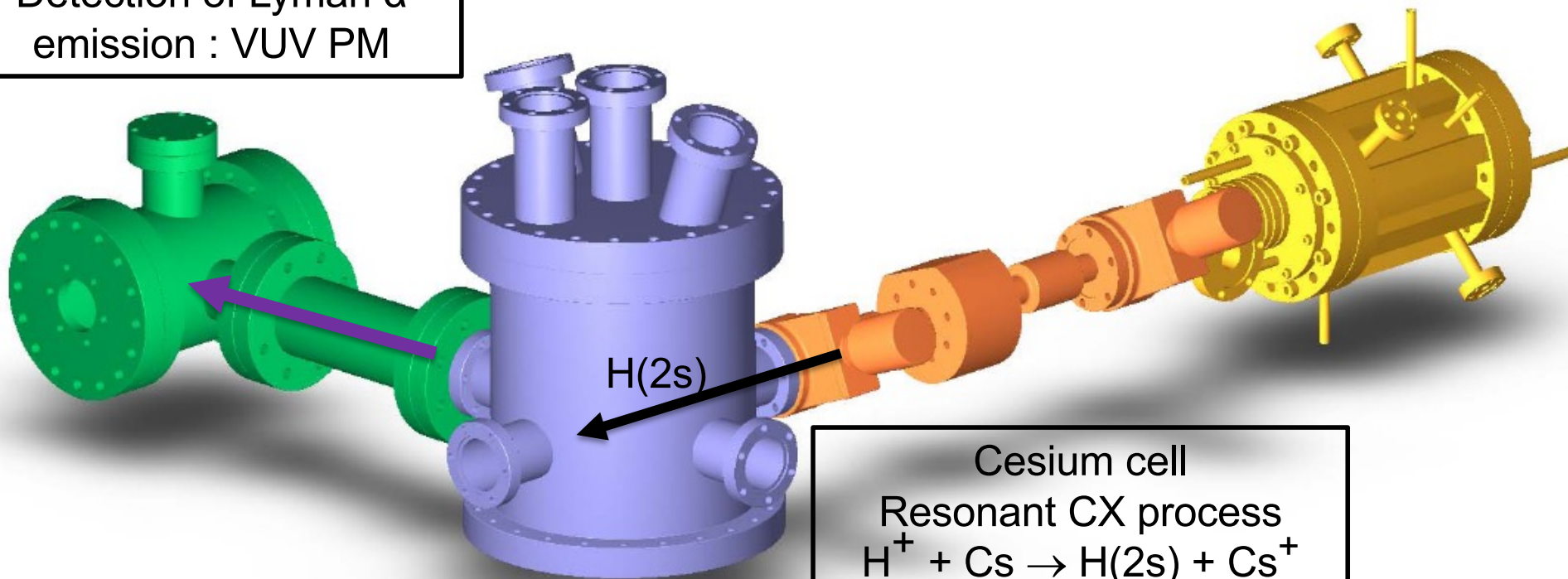
and $E_{\omega} < 20$ V/cm

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

experimental device

Detection of Lyman α
emission : VUV PM

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

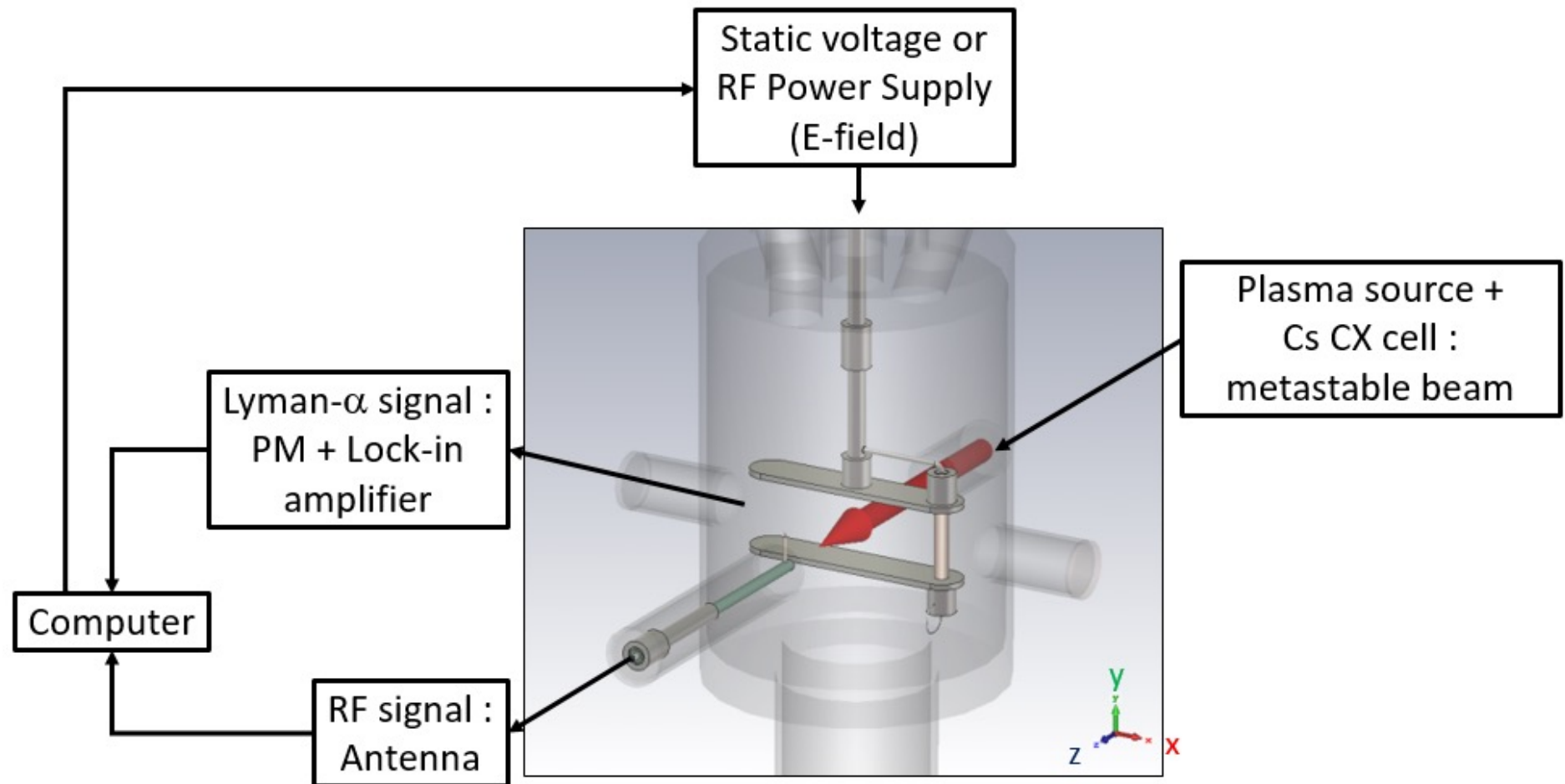


H(2s)

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



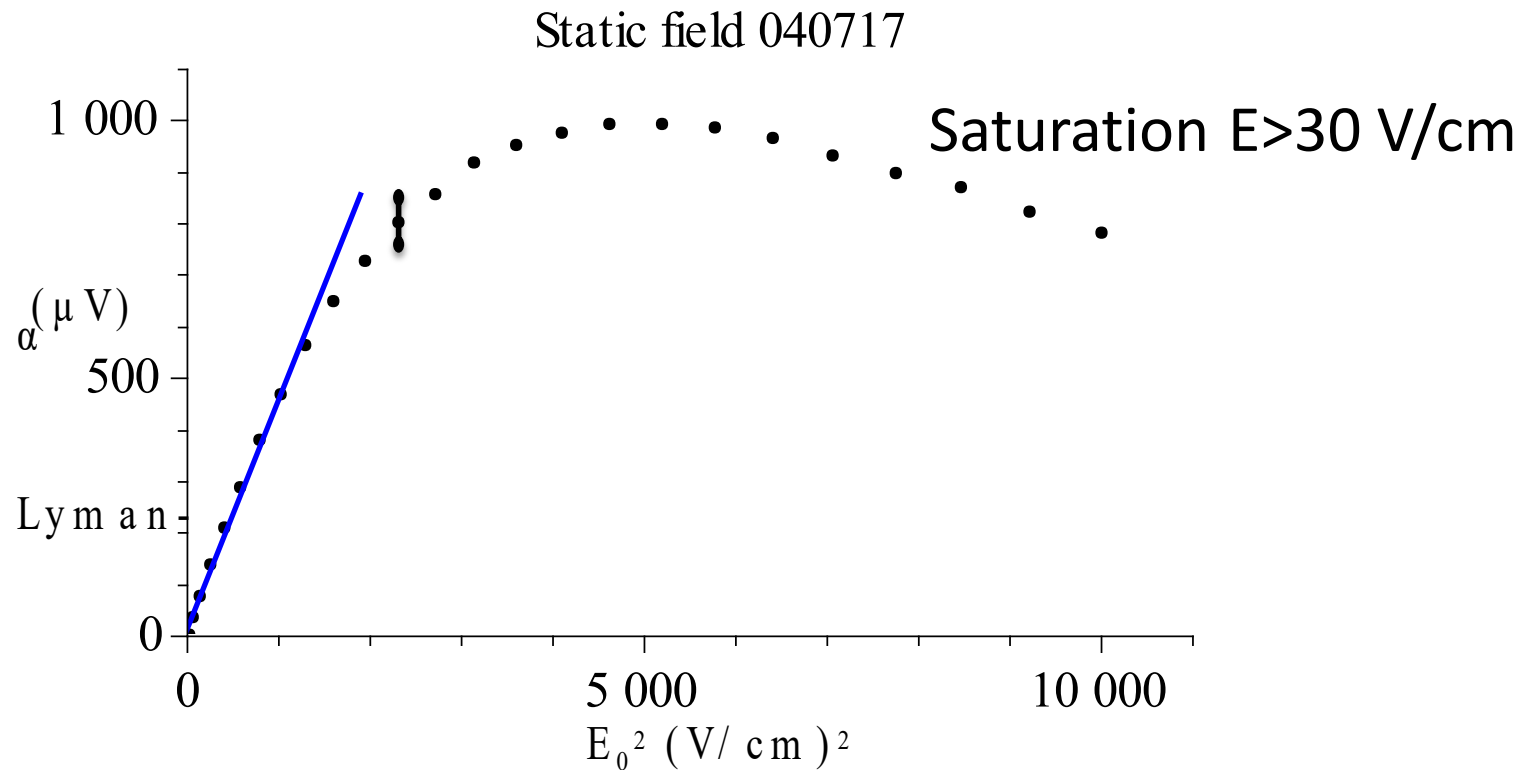
limits

- $S \propto E^2$
- Electric field 0.1 V/cm \rightarrow 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

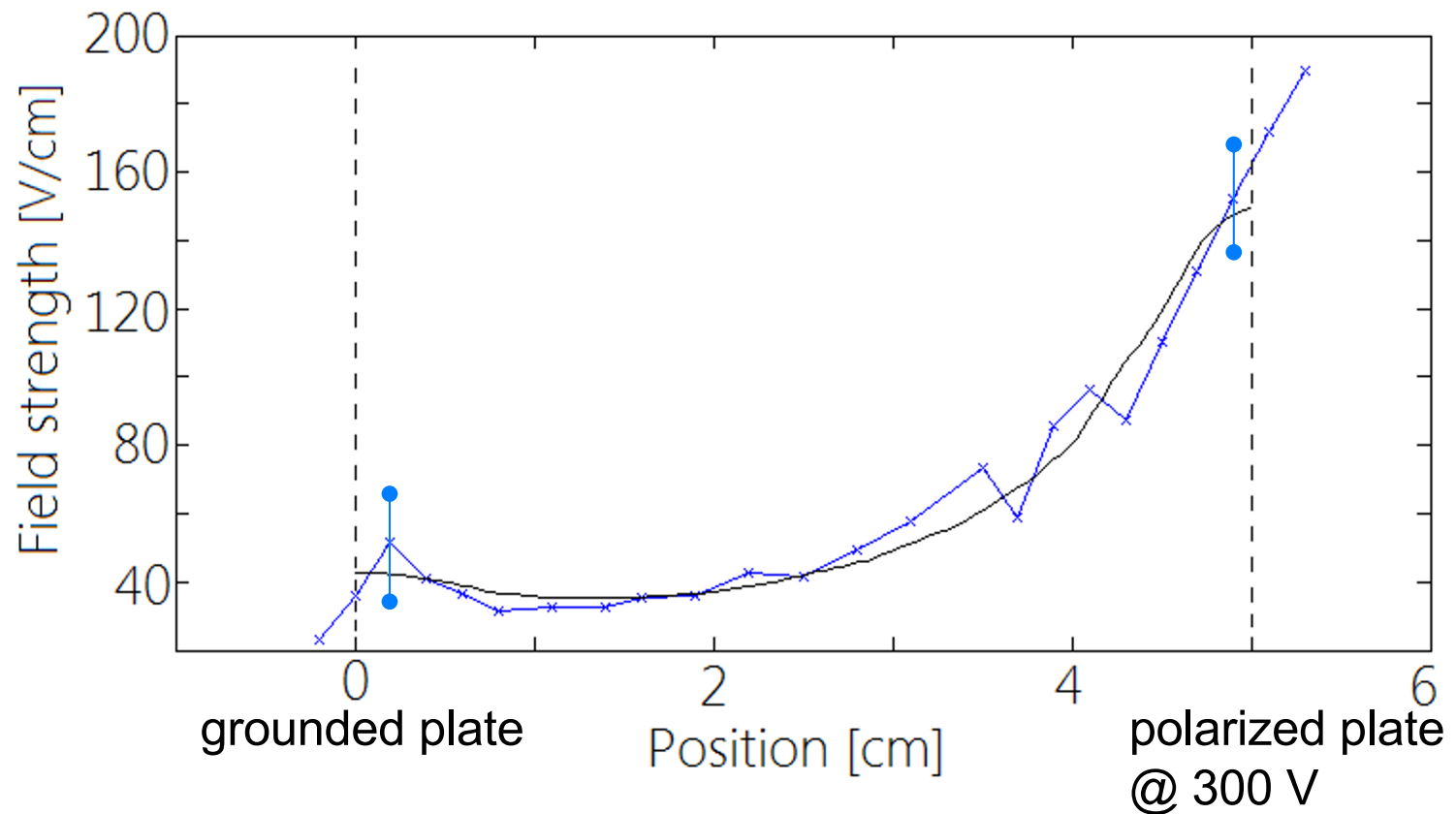
signal in vacuum for a static voltage



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

signal in vacuum for a static voltage

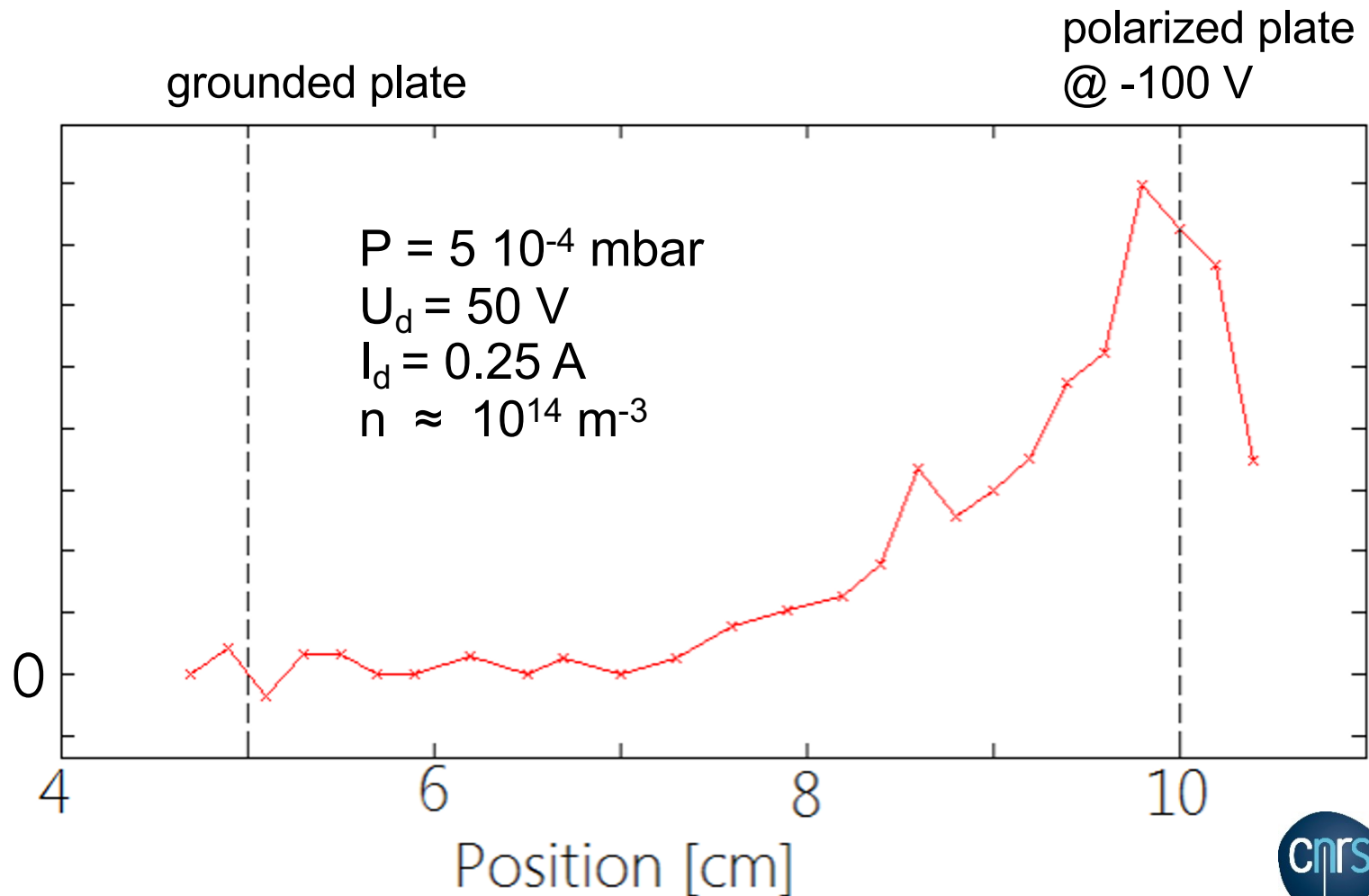
Electric field profile between the plates :
Measurements + FEM simulation



signal in an Ar plasma for a static voltage

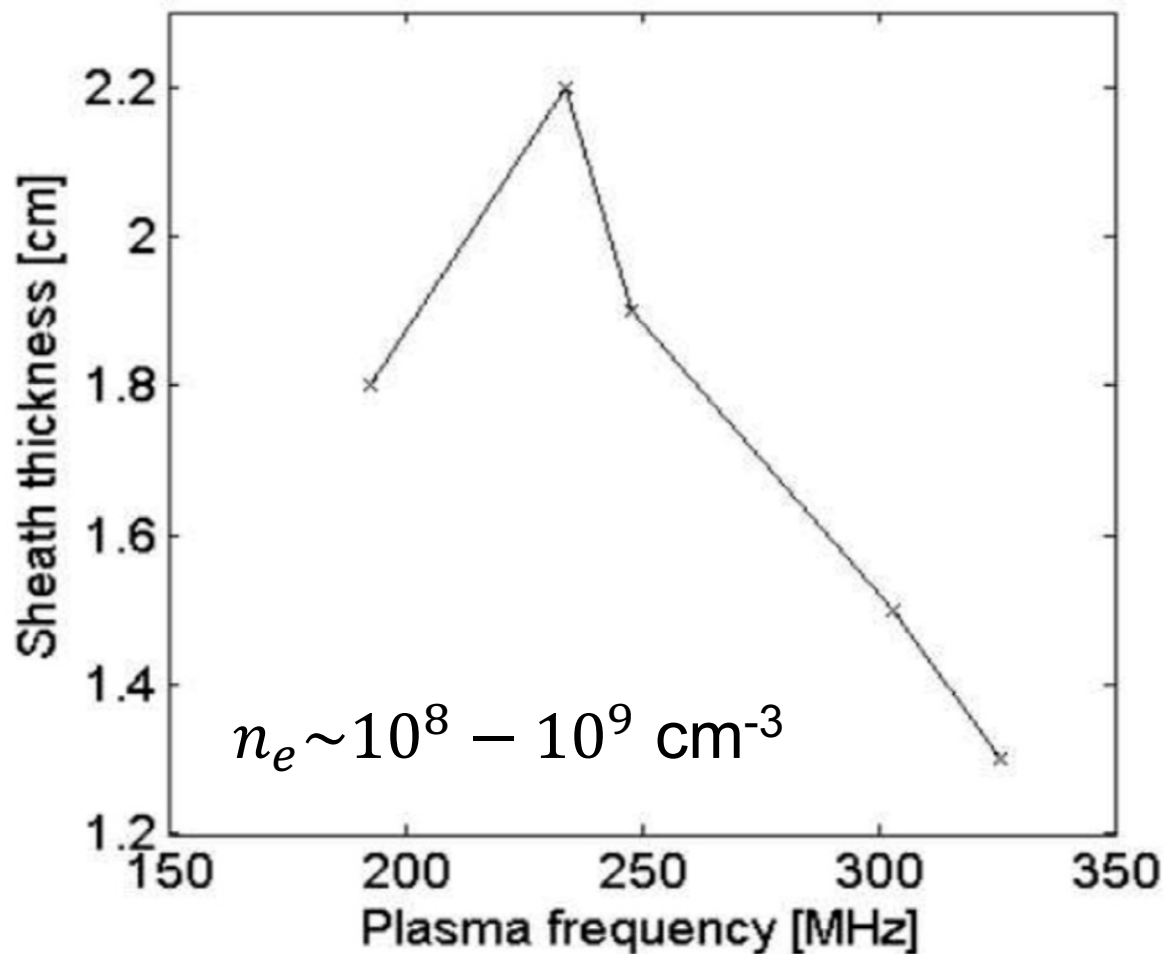
Electric field profile between the plates : sheath

Field strength [Arbitrary unit]



signal in an Ar plasma for a static voltage

Electric field profile between the plates : sheath

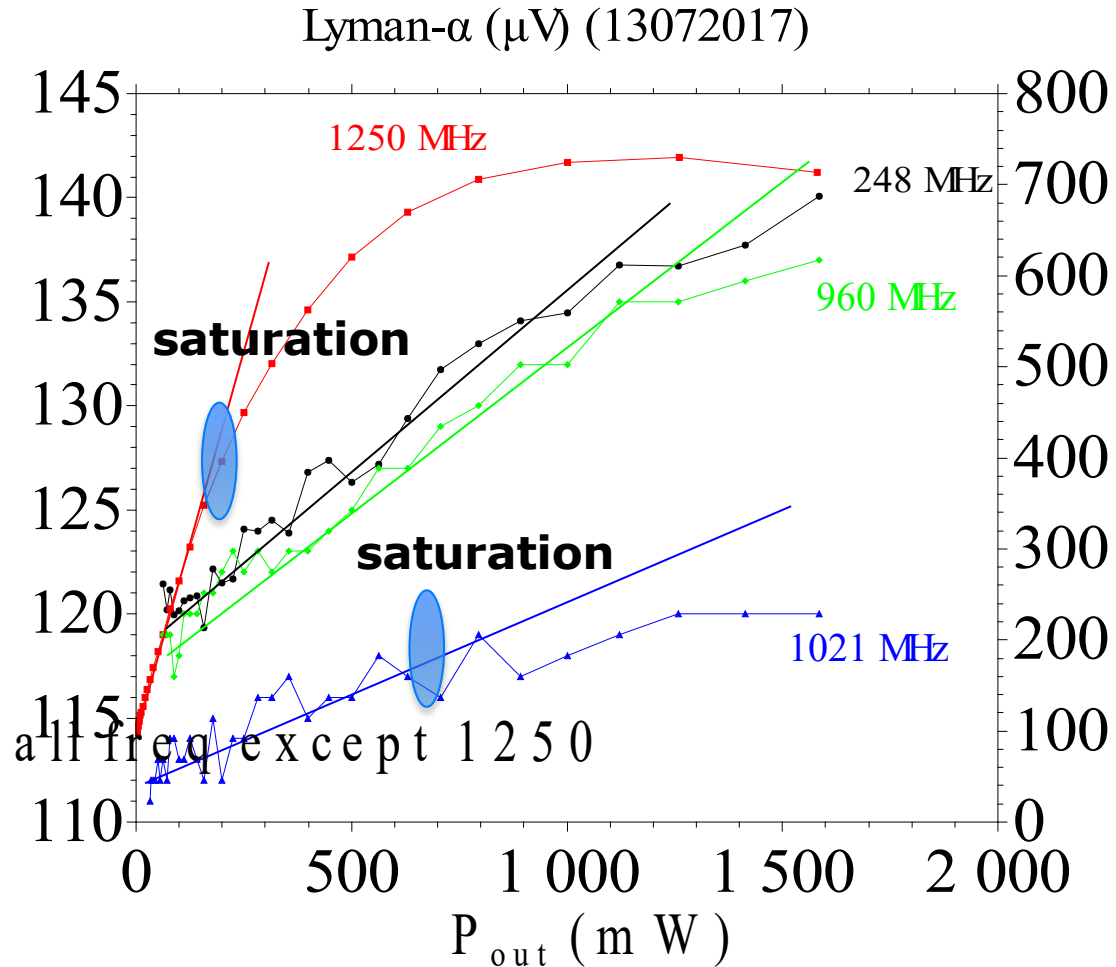


$$\omega_p = \sqrt{\frac{n_e e^2}{m_e \epsilon_0}} \text{ and } n_e \propto I_d$$

4. Measurement of a RF electric field

Measurements in vacuum and in a plasma

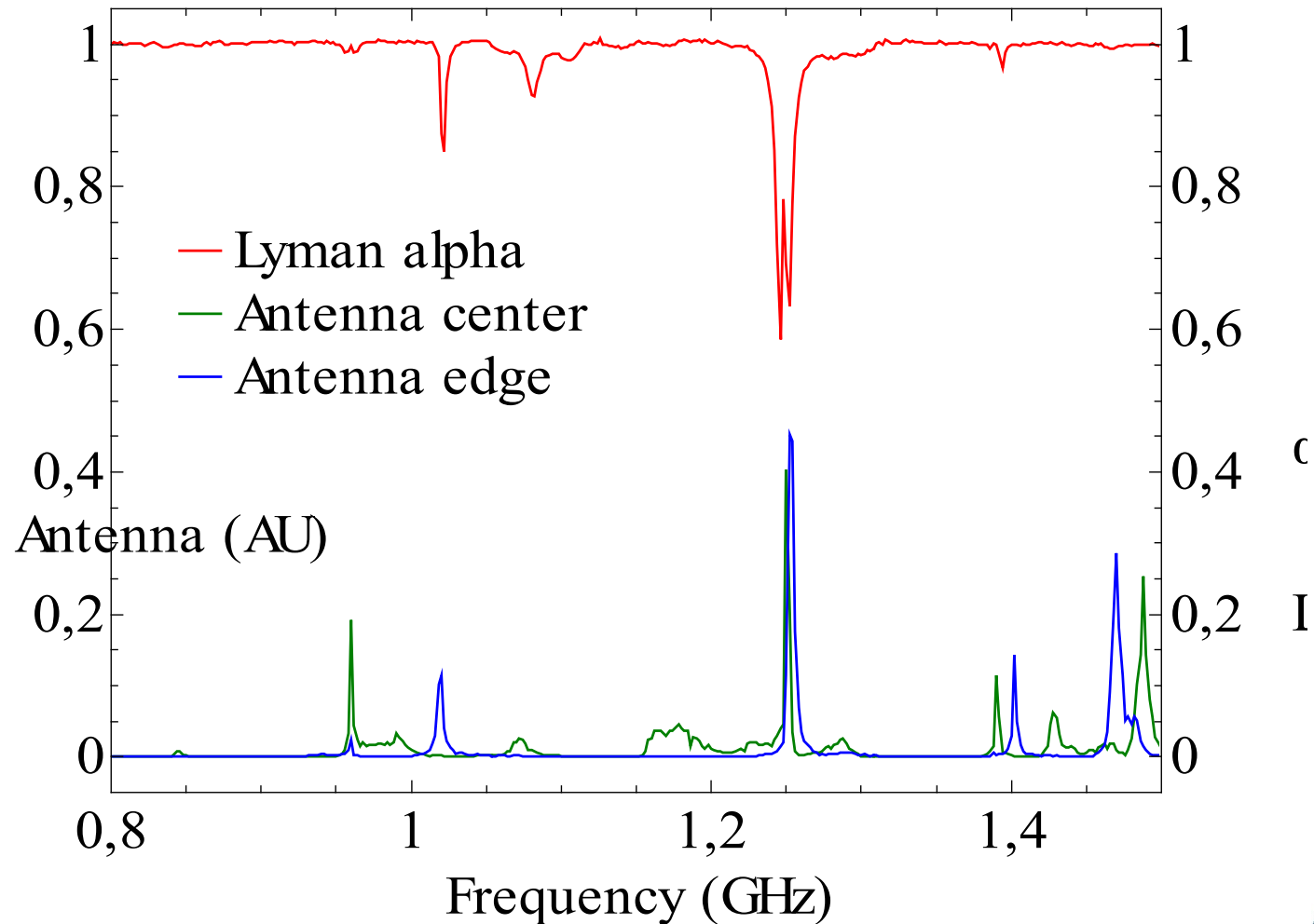
signal in vacuum for a RF voltage



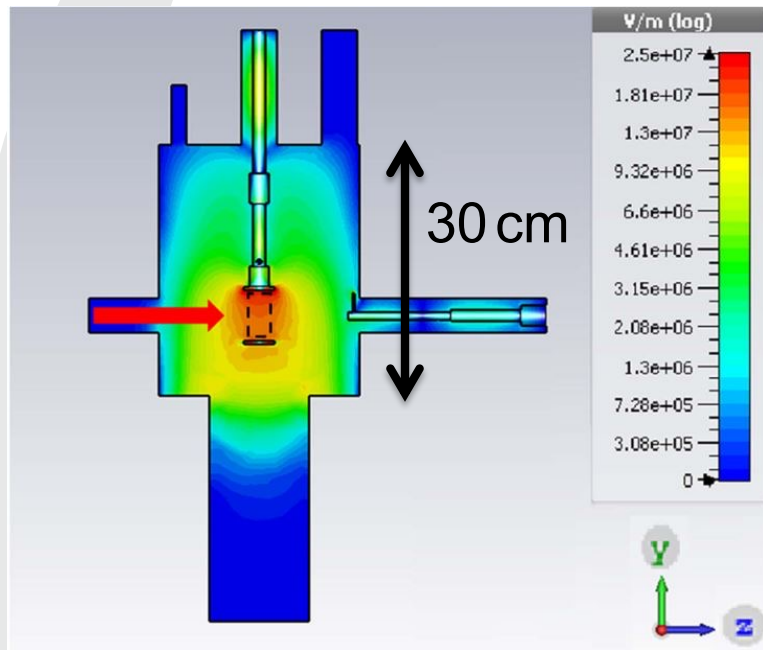
@

geometrical saturation depending on the electric field along the beam path

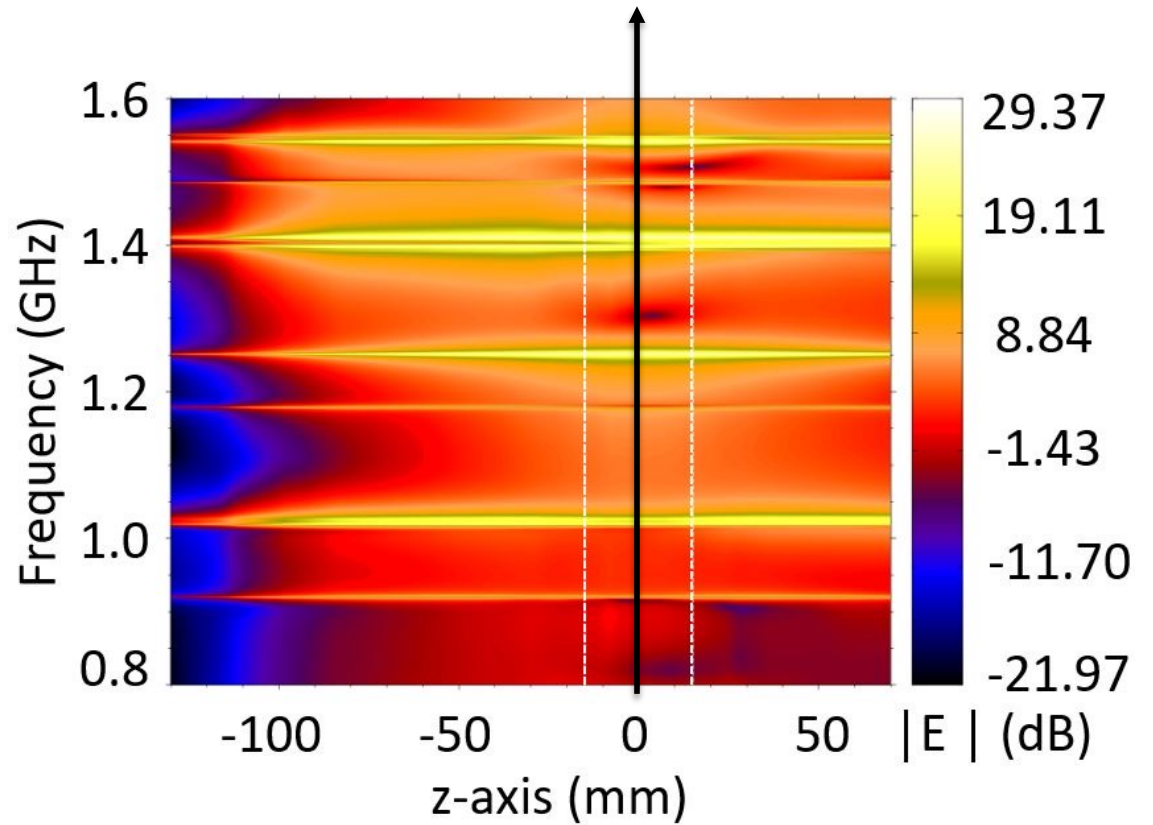
signal in vacuum for a RF voltage @1500 mW



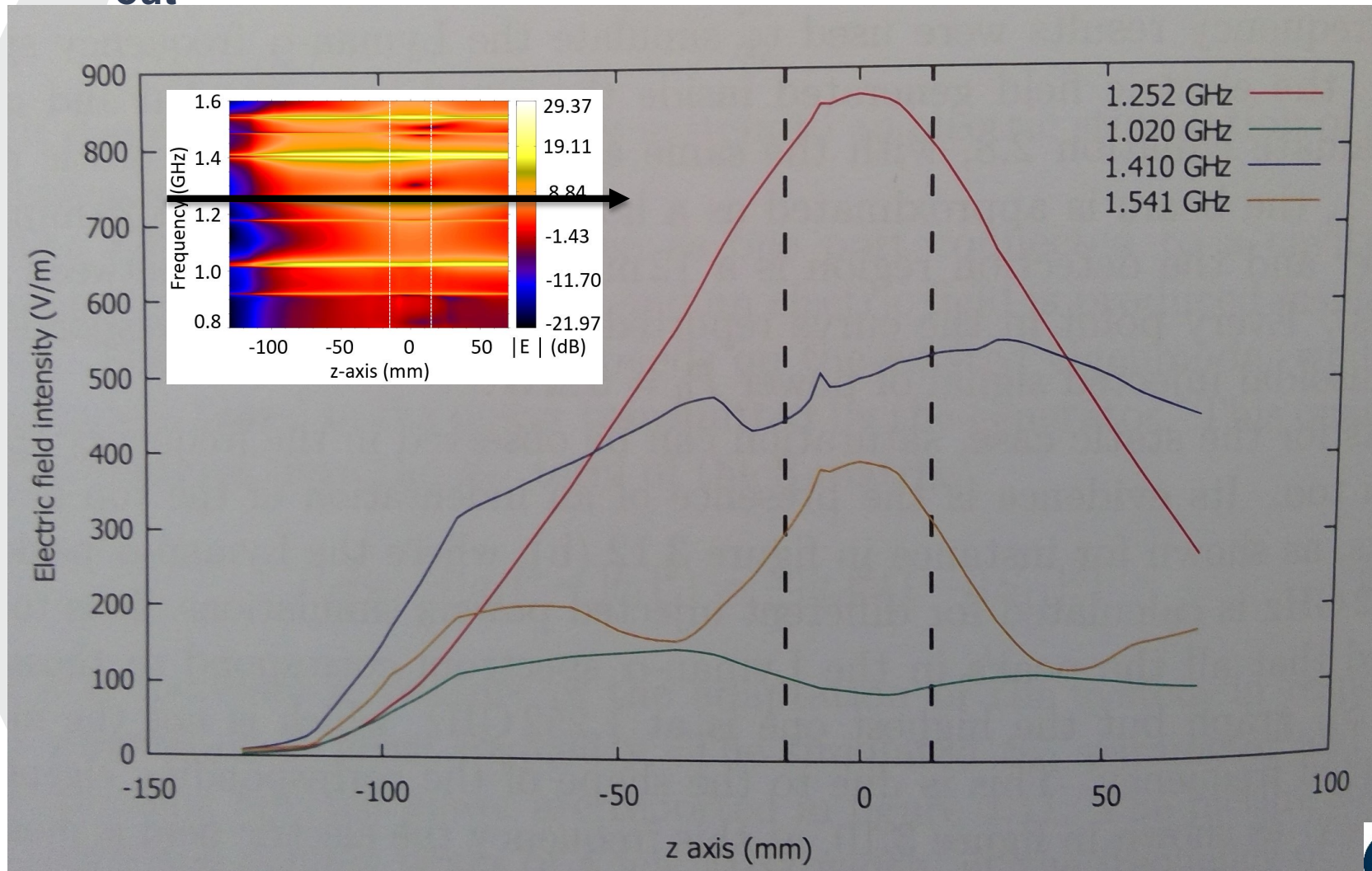
numerical calculation of the electric field in the vessel



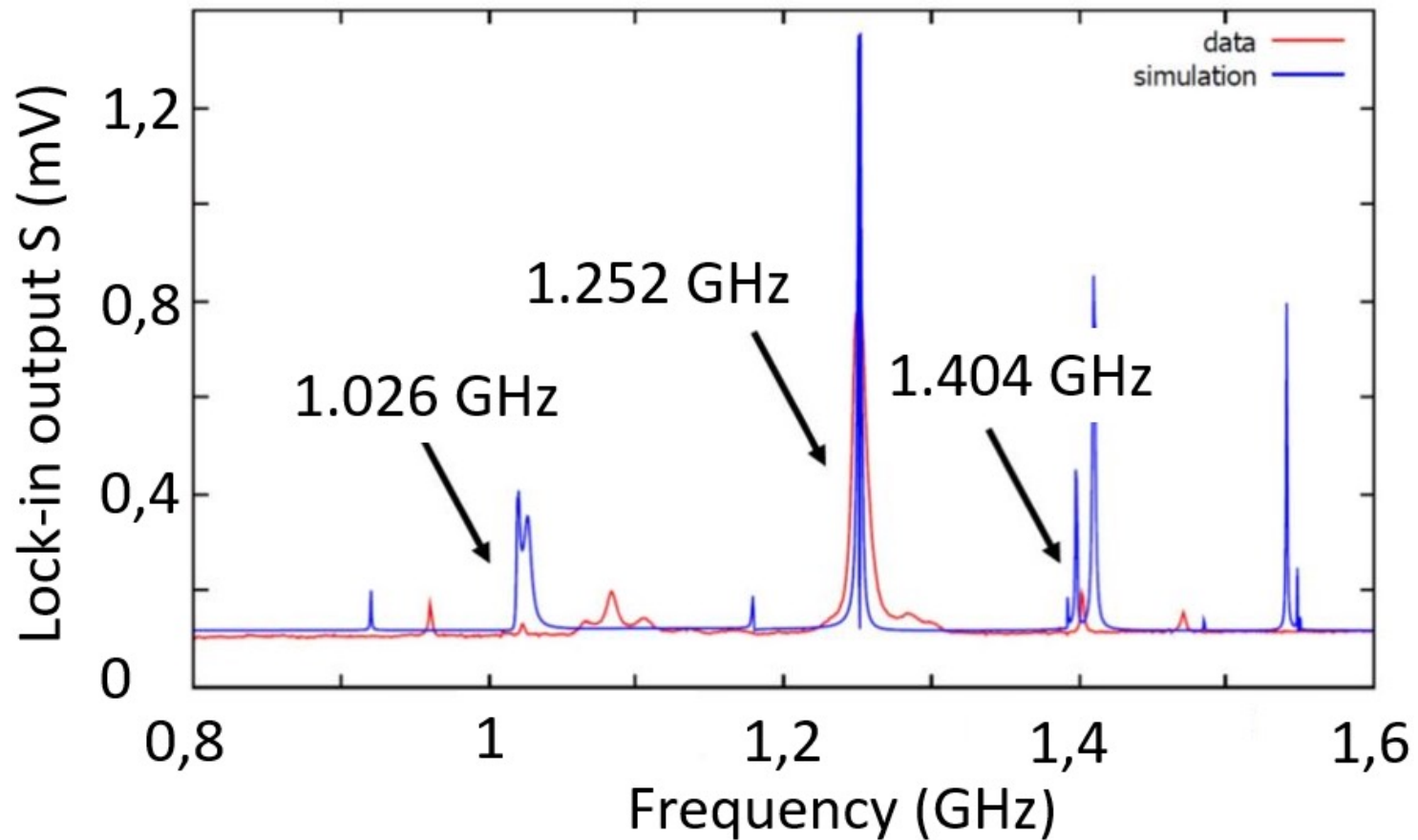
Field map



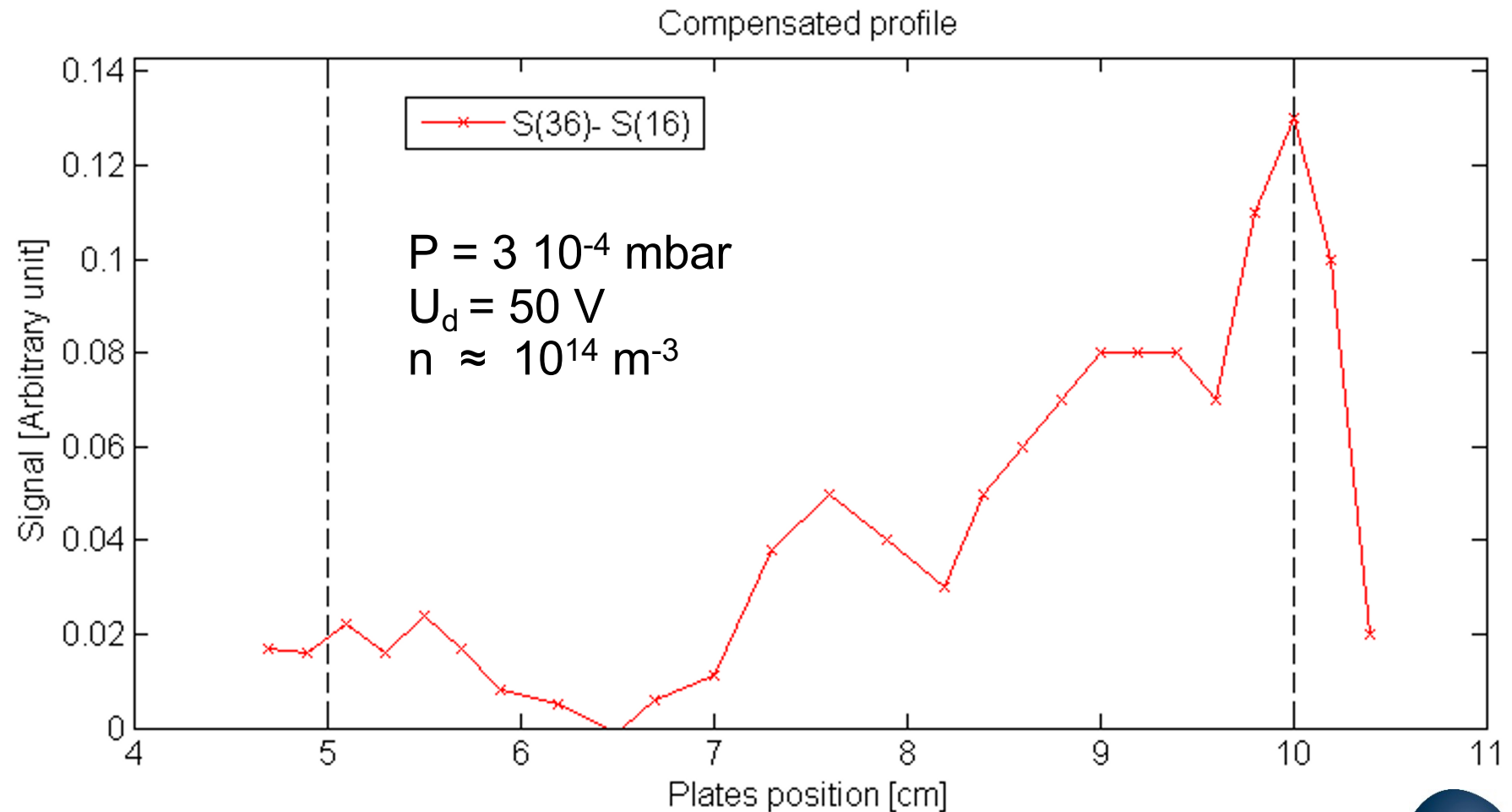
Calculated E field amplitude along the beam path for $P_{out} = xx$?



simulation / experiment comparison

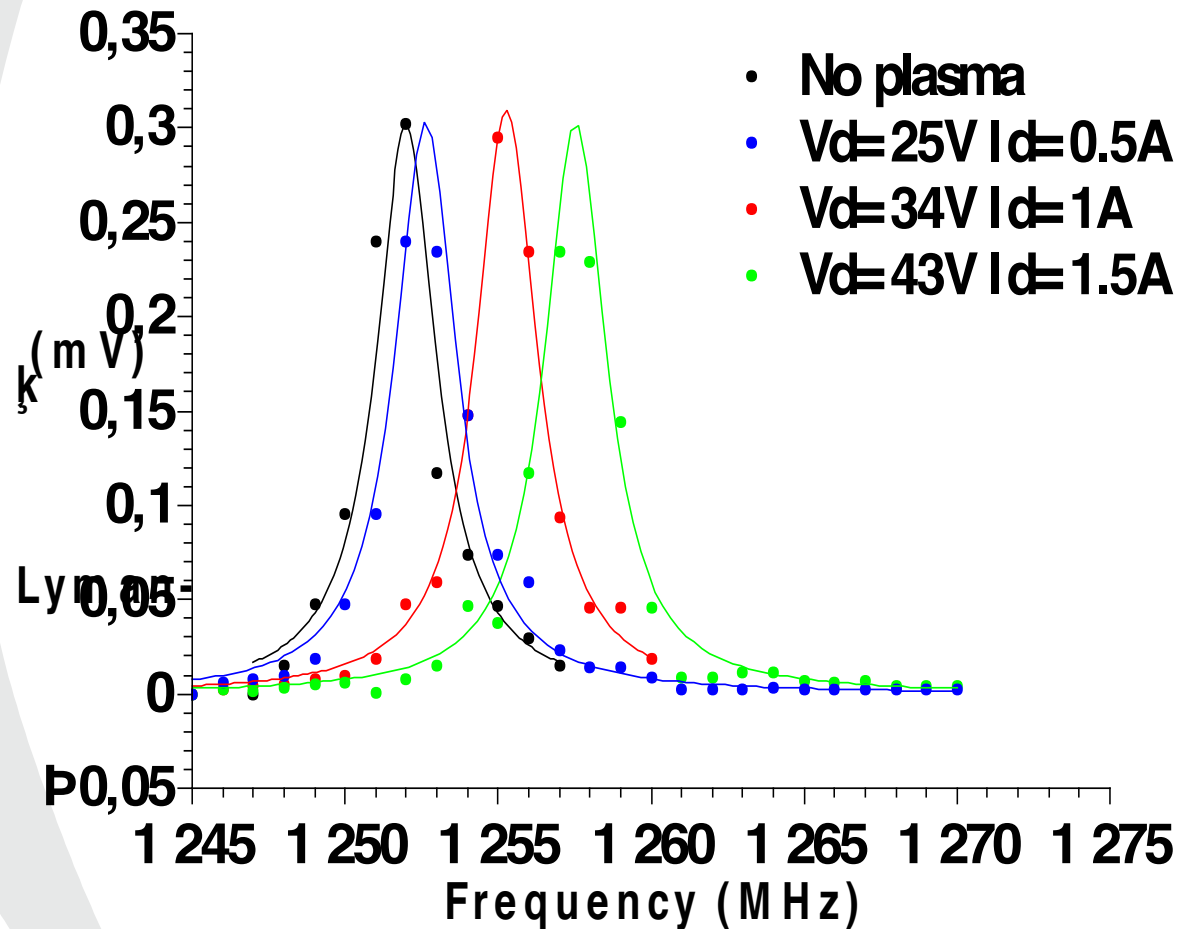


Lyman- α signal in presence of 1 GHz voltageage between the plates



observation of resonance mode shift

Shift of 1252 MHz-mode

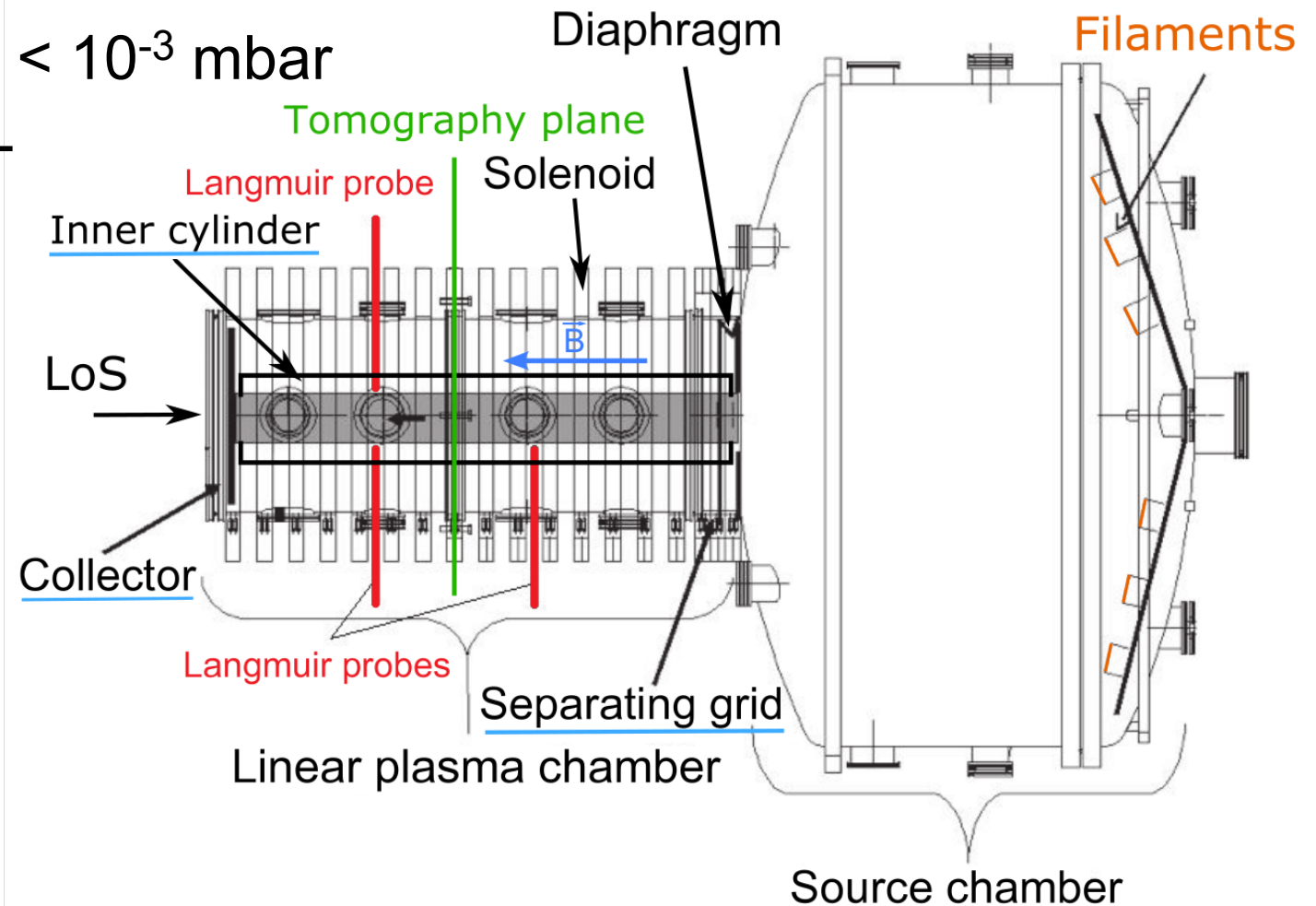


F (MHz)	n_e (cm ⁻³)
1252	0
1252,6	$1,8 \cdot 10^7$
1255,3	$1,0 \cdot 10^8$
1257,5	$1,7 \cdot 10^8$

$$n_e = \frac{2m_e \epsilon_0 \omega^2 \Delta\omega}{e^2 \omega_0}$$

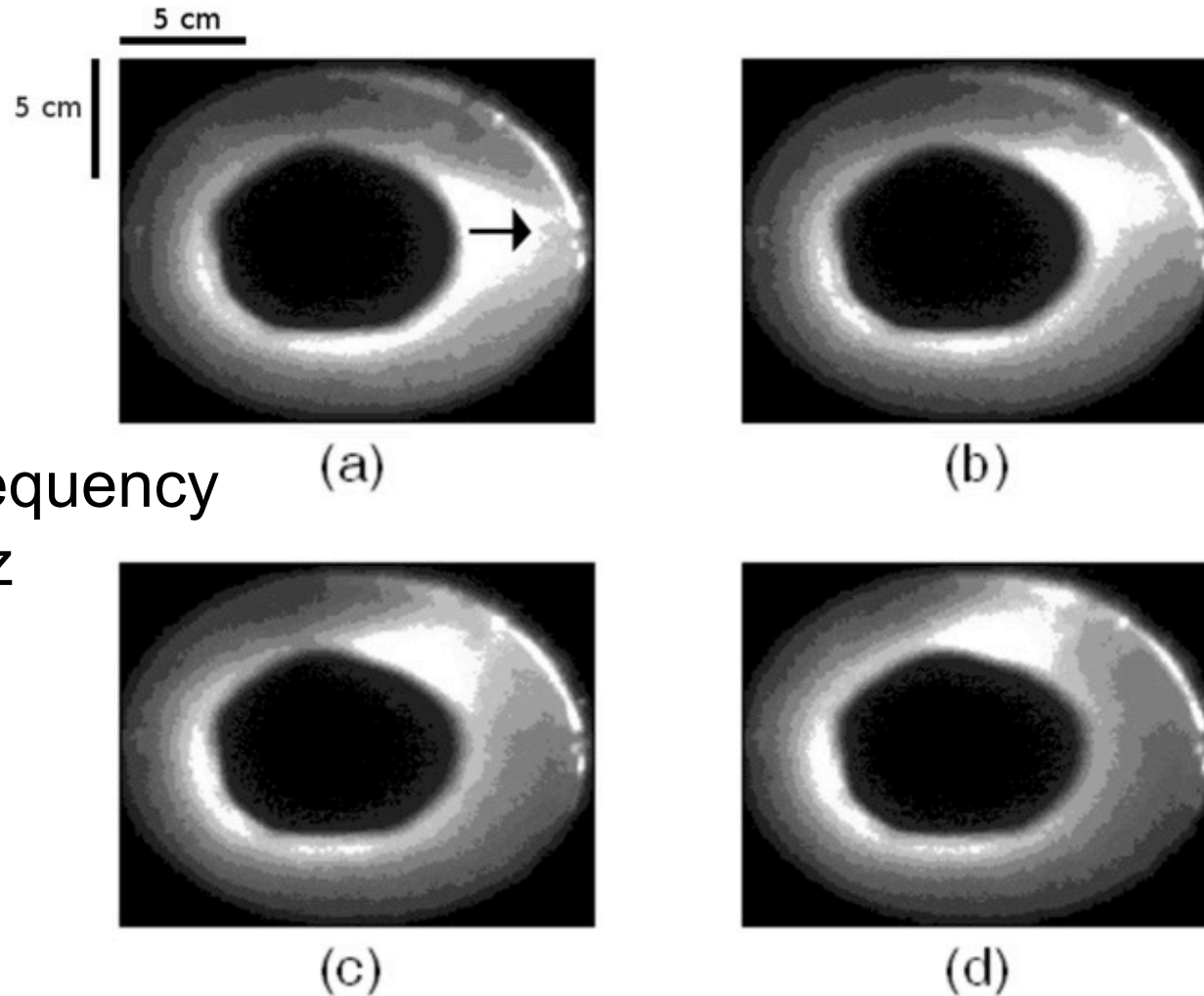
5. Project : measurement of the radial electric field in a magnetized plasma column (MISTRAL)

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



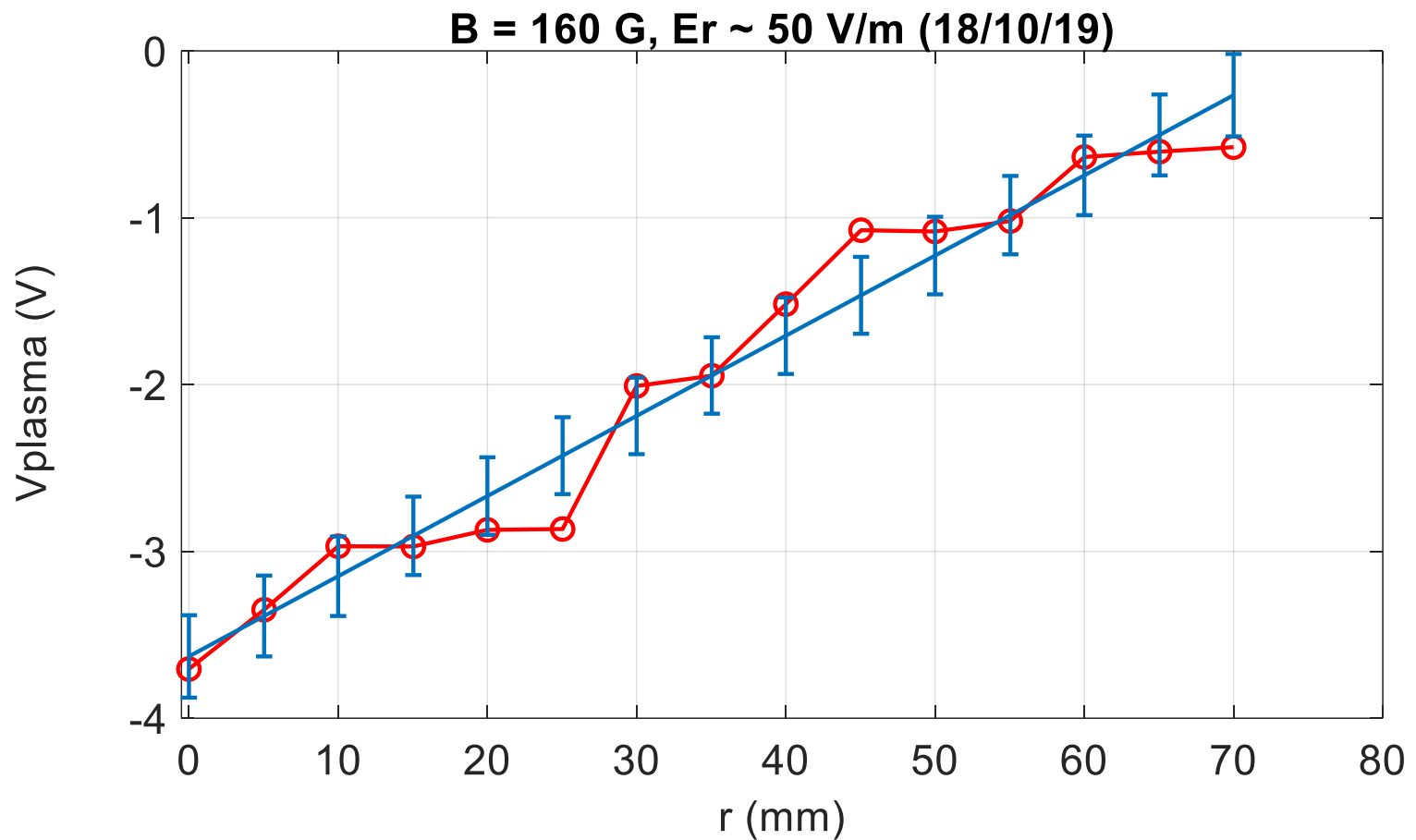
fast camera results (end view of the plasma) : rotating arm of plasma ejected from core

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



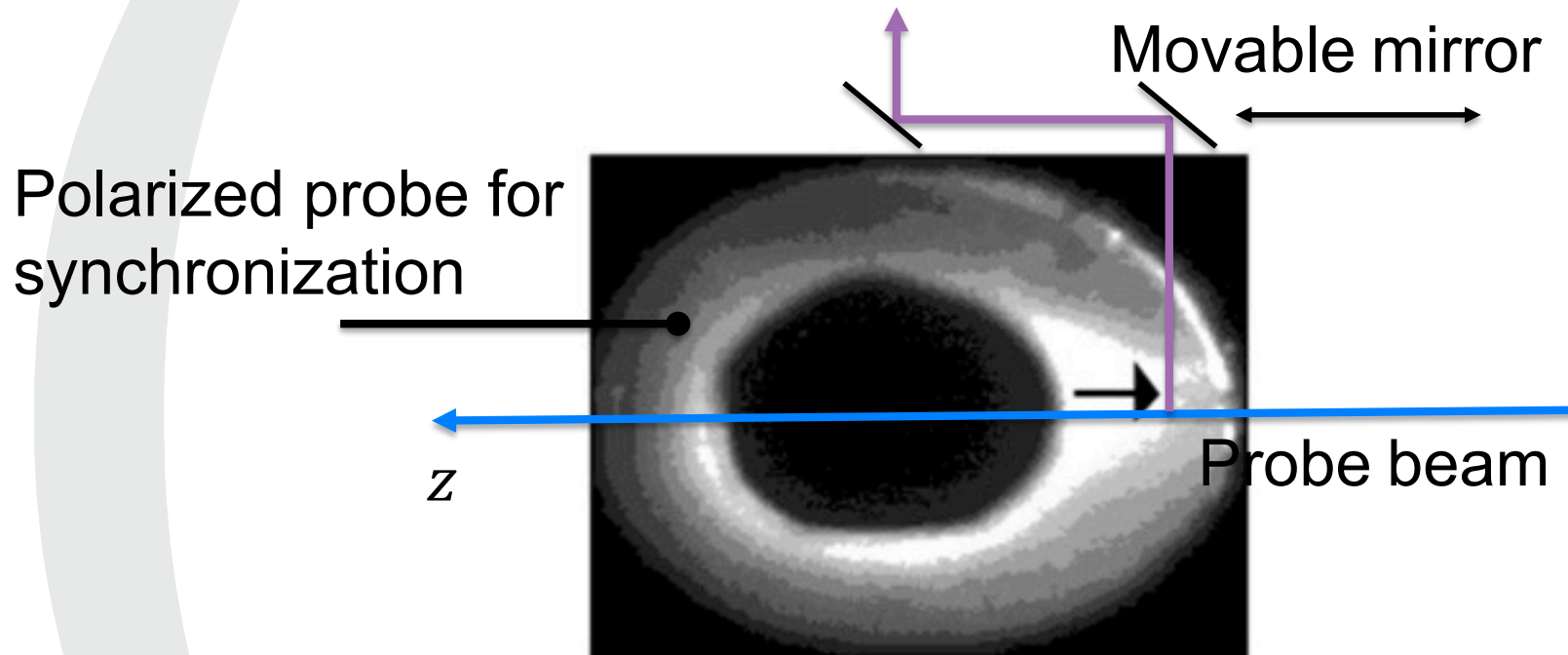
→ Rotation frequency
= a few kHz

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



principle of the experiment

VUV detection $\rightarrow I(z)$



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

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

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

acknowledgements :



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

Simon-Hoh instability **CSHI** (Phys. Fluids 1963)

ExB drift:

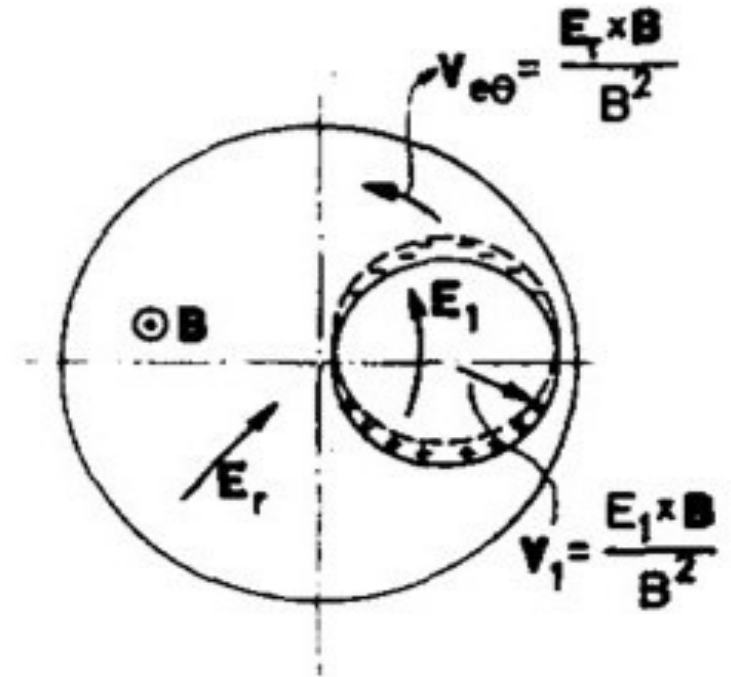
- Electrons : $v_{e\theta}$
- Friction forces (e-neutrals)

→ Ions slowed down:

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

→ Charge separation: E_1

→ Rotation frequency instability:

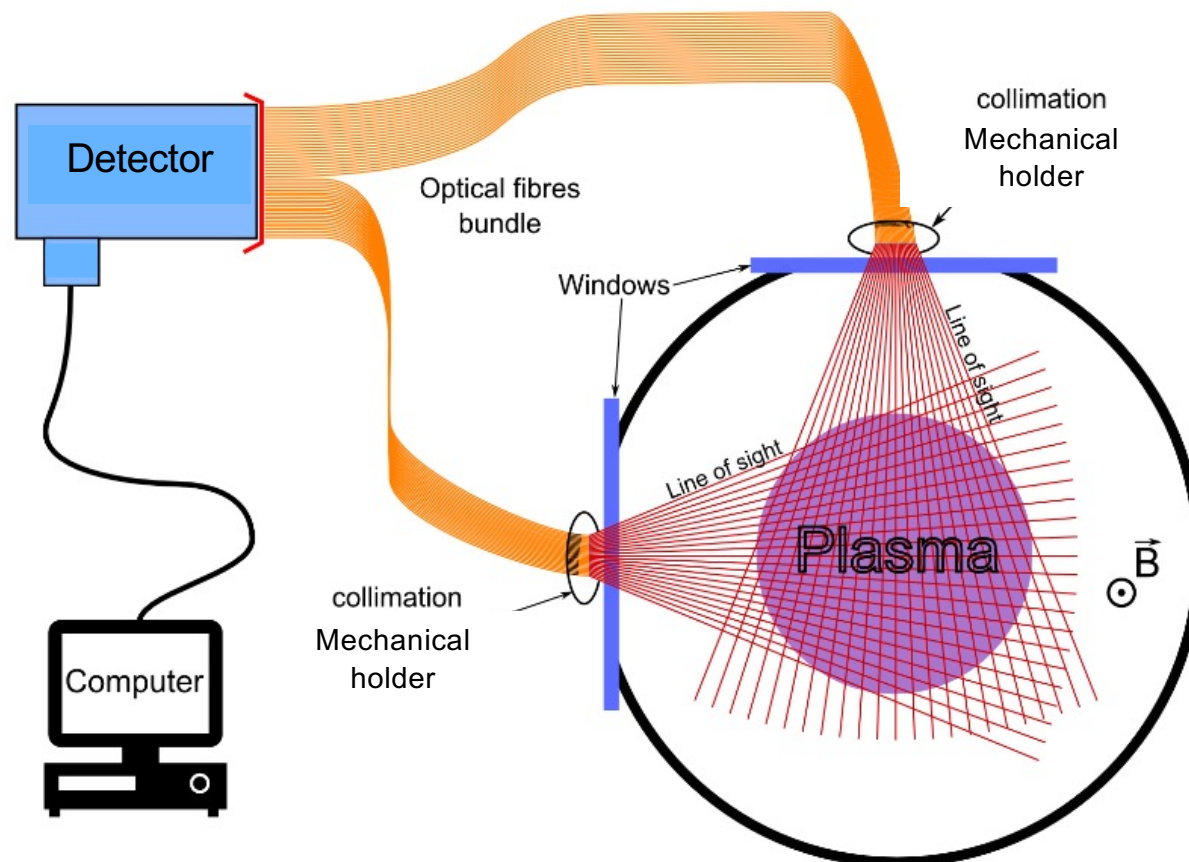


$$v_{spoke} = \frac{1}{\pi R_0} \sqrt{\frac{e E_r L_n}{m_i}} \quad L_n = \frac{n_e}{\frac{\partial n_e}{\partial r}} \quad v_{spoke} \propto \sqrt{B} \quad E_r \propto B$$

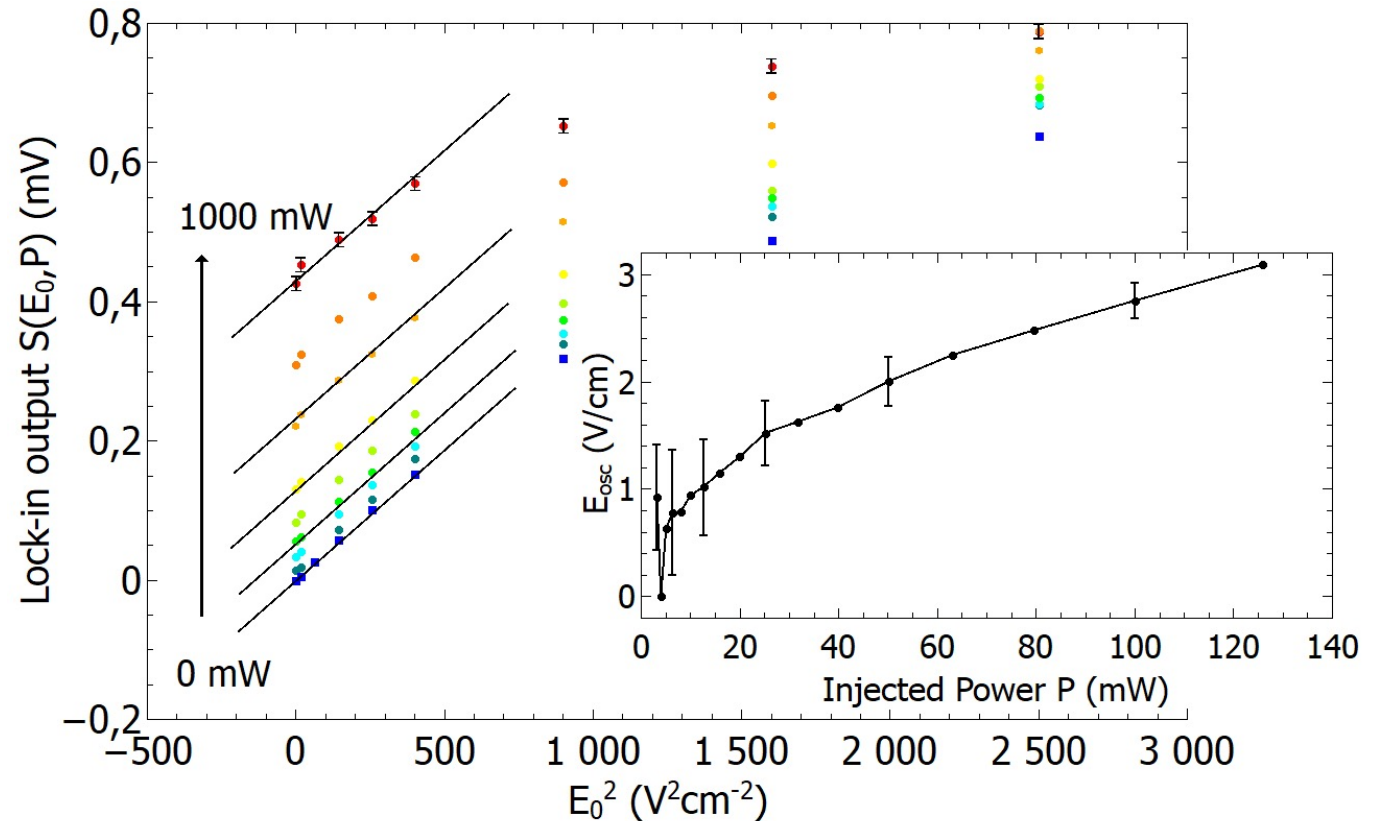


Tomography : experimental set-up

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



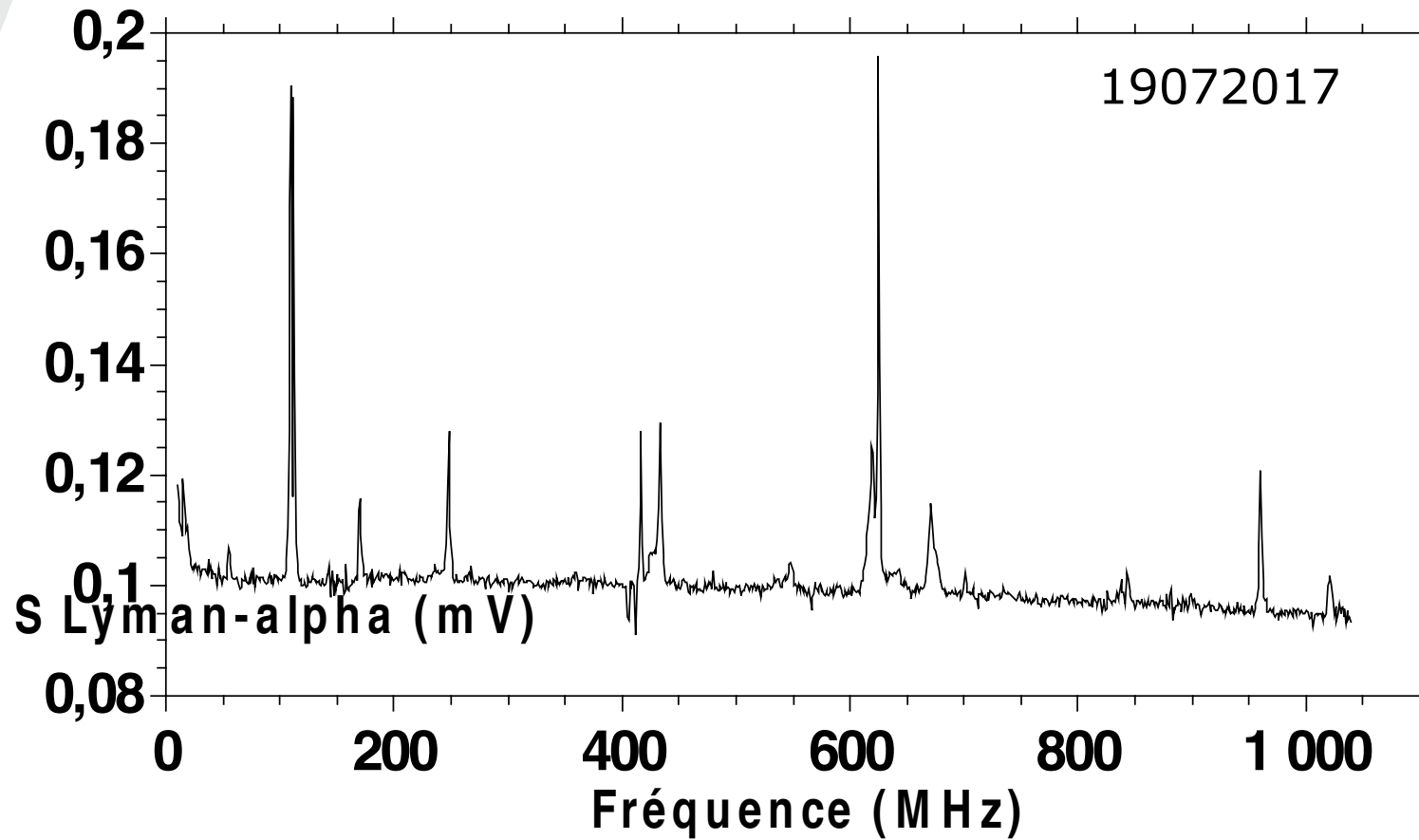
Calibration : superposition champs RF @1.25 GHz et statique



Signal non saturé :

$$S(E_0, P) \propto \gamma_{2s}^* = \beta L(0) E_0^2 + \beta L(\omega) E_{rf}^2(P)$$

Spectre Lyman alpha 10-1000 MHz



960 1020 1254 1400 MHz

