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► To cite this version:

Sylvain Iséni, X Damany, G Sretenović, V Kovačević, I Krstić, et al.. Electric field and ionization waves in Pulsed Atmospheric Plasma Streams (PAPS): complementary in situ diagnostics. 6th International Conference on Plasma Medicine (ICPM-6), Sep 2016, Bratislava, Slovakia. , 2016. hal-01670162

HAL Id: hal-01670162

<https://hal.science/hal-01670162>

Submitted on 21 Dec 2017

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Electric field and ionization waves in Pulsed Atmospheric Plasma Streams (PAPS): complementary in situ diagnostics

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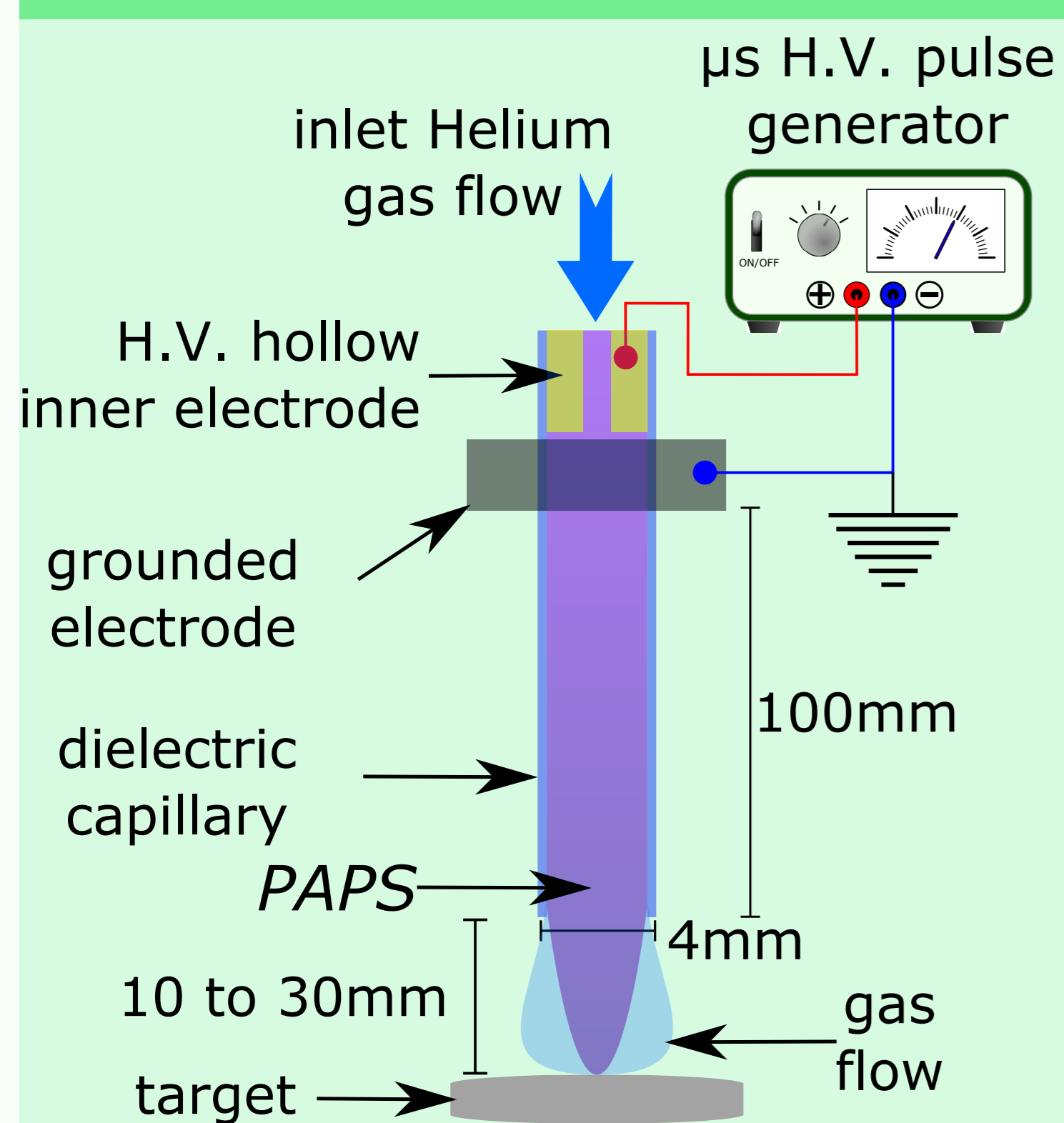


Introduction and motivation

In this study, one focuses on the diagnostic of single pulsed atmospheric plasma streams (PAPS) with the investigation of electric field (E-field) [1]. Experimental E-field characterizations are extremely beneficial for the comprehension of plasma mechanisms and particularly for the validation of numerical simulations. The authors present the results of strength E-field obtained with two different methods:

- ▶ The first technique is a **custom made electro-optic sensor** based on the Pockels effect [2], allowing for recording simultaneously two orthogonal components of the E-field vector, time and spaced resolved [1].
- ▶ The second method uses **Stark polarization dependent** emission spectroscopy of the π -weak- He I line at 492.19 nm [3]. Depending on the experimental conditions, both methods will be either *complementary* or *compared* with each other. The outcomes will bring information about the reliability of each technique and are of high interest for the validation of numerical simulation results.

Plasma source: Plasma Gun (PG)



Operating features:

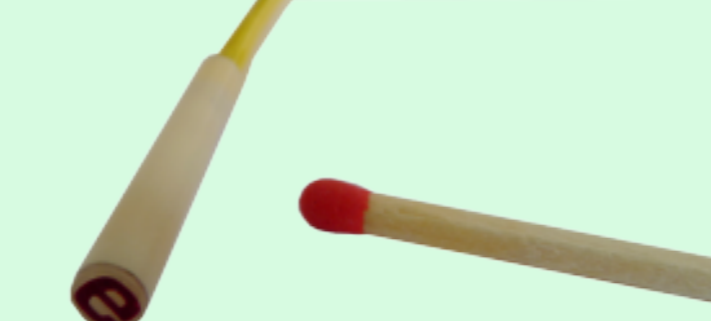
- ▶ kHz pulsed μ s H.V. driver,
 - ▷ 8 kV to 20 kV
 - ▷ 1 kHz to 4 kHz
- ▶ Glass or quartz capillary (100 mm) long,
- ▶ Powered inner hollow electrode,
- ▶ Grounded outer electrode,
- ▶ Polarity: positive or negative,
- ▶ Buffer gas: helium / neon / argon
 - ▷ 50 sccm to 5×10^3 sccm

Electric field diagnostic at GREMI – electro-optic probe

- ▶ Electro-optic sensor
 - ▷ Pockels effect
 - ▷ BSO crystal
 - ▷ \varnothing crystal = 1.8 mm, 1.0 mm long
 - ▷ \varnothing probe = 4.0 mm – alumina
- ▶ Transient E-field
 - ▷ 50 kHz to 1 GHz
 - ▷ $10 \text{ V} \cdot \text{cm}^{-1}$ to $100 \text{ kV} \cdot \text{cm}^{-1}$
- ▶ 2 orthogonal components simultaneously
 - ▷ $\|\vec{E}\| = \sqrt{|\vec{E}_x|^2 + |\vec{E}_r|^2}$
- ▶ Absolute E-field strength



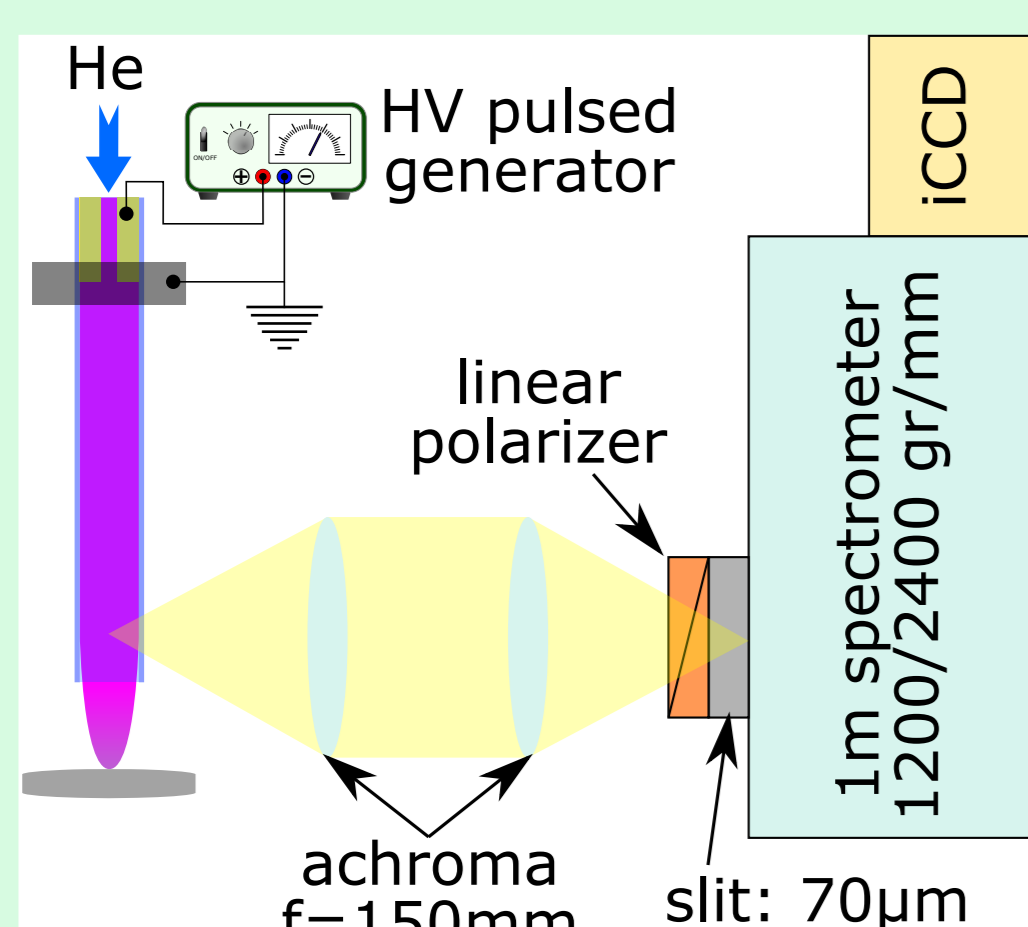
Analyzing unit, eoSense™.



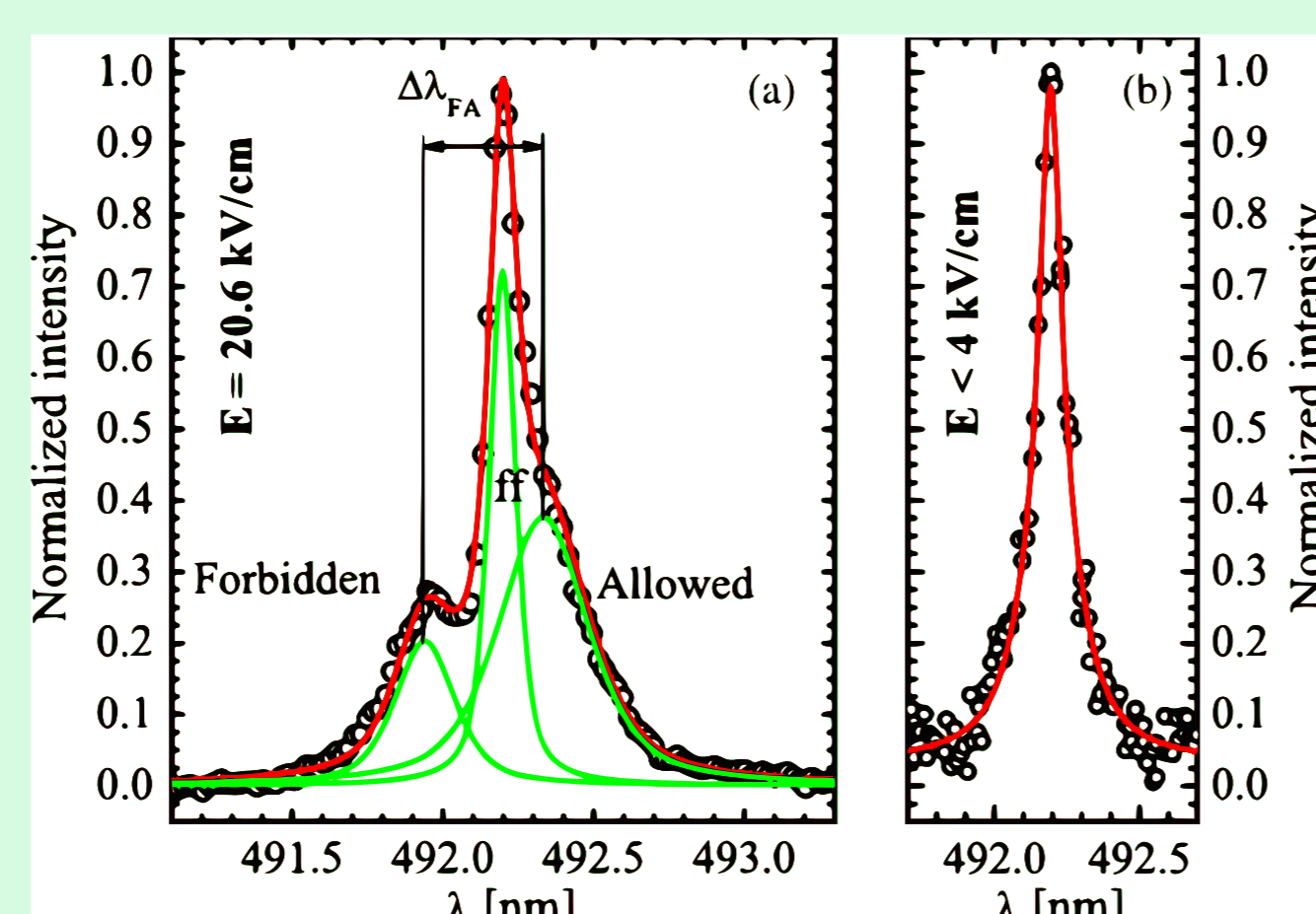
Electro-optic probe.

Electric field diagnostic at LPTP – π -polarization Stark He I

- ▶ Optical emission spectroscopy technique – non-intrusive method,
- ▶ π -polarization Stark \Rightarrow splitting and shifting of the allowed and forbidden counterpart transitions of He I (492.19 nm) depend on the light polarization,
- ▶ Time and space resolved,
- ▶ 1 E-field component,
- ▶ Absolute E-field strength ($\approx 4 \text{ kV} \cdot \text{cm}^{-1}$).



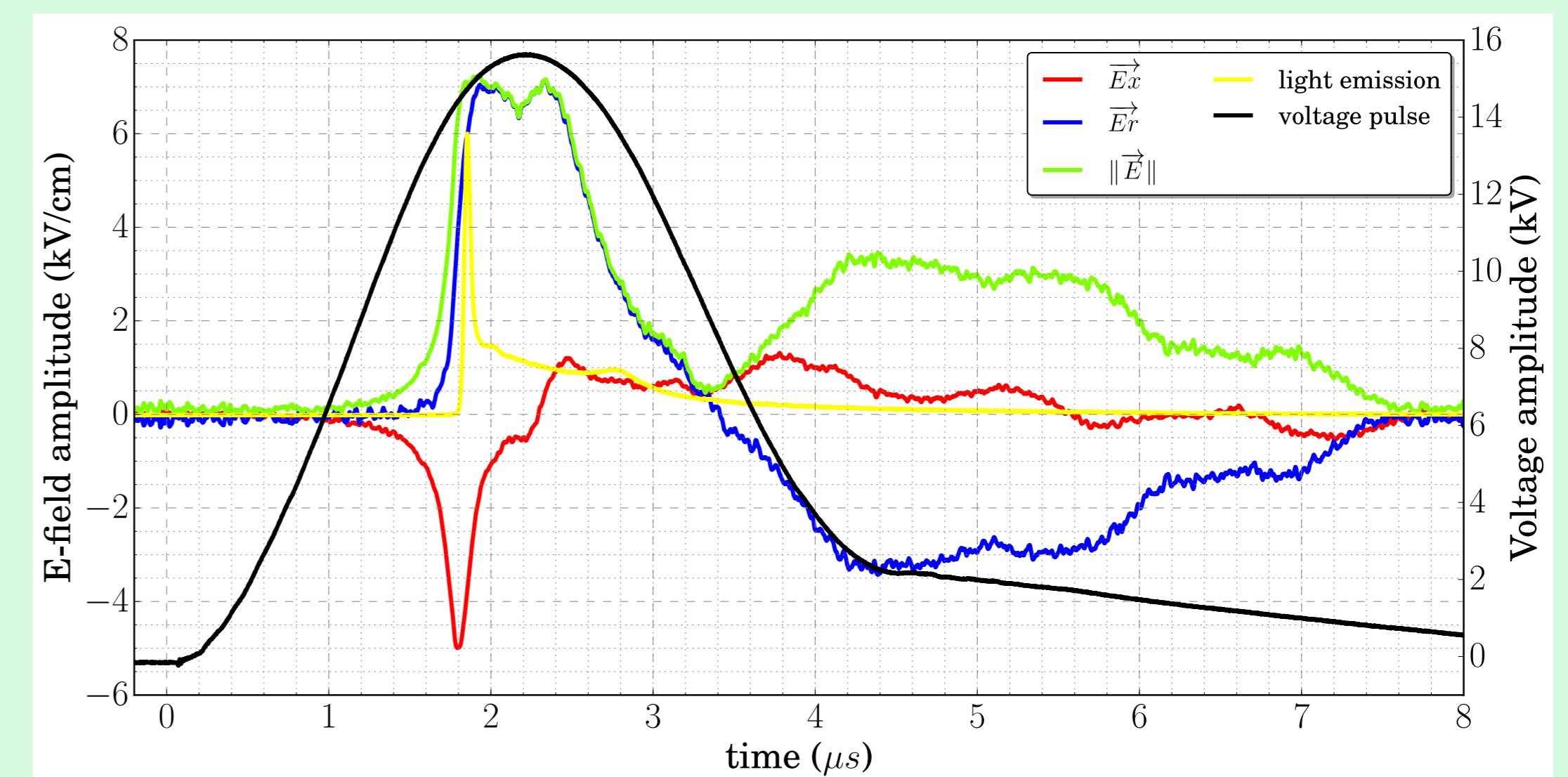
Experimental setup.



Typical π -polarized spectra of the He I in a plasma jet [4].

Evidence of the ionization front

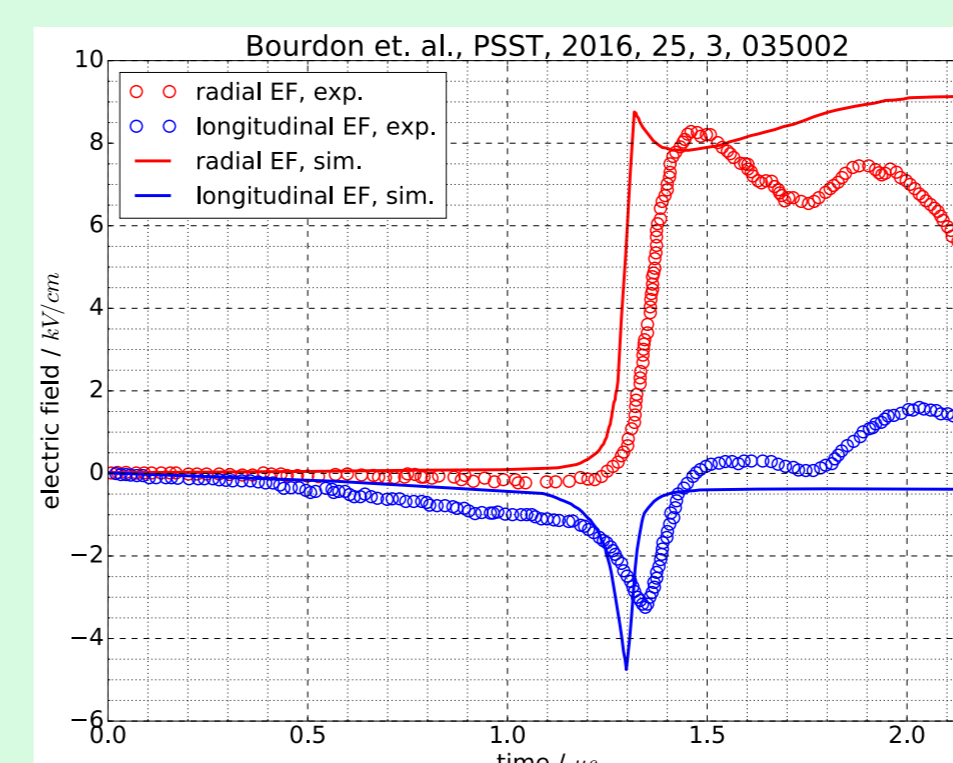
The ionization wave allowing for the ignition of atmospheric pressure plasma jets operating in the kHz regime are often reported as *plasma bullet*. This phenomenological description accounts only for the light emission of the ionization front. The graph below presents the inception of the discharge and evidences the fast rise of \vec{E}_x then followed by \vec{E}_r [1].



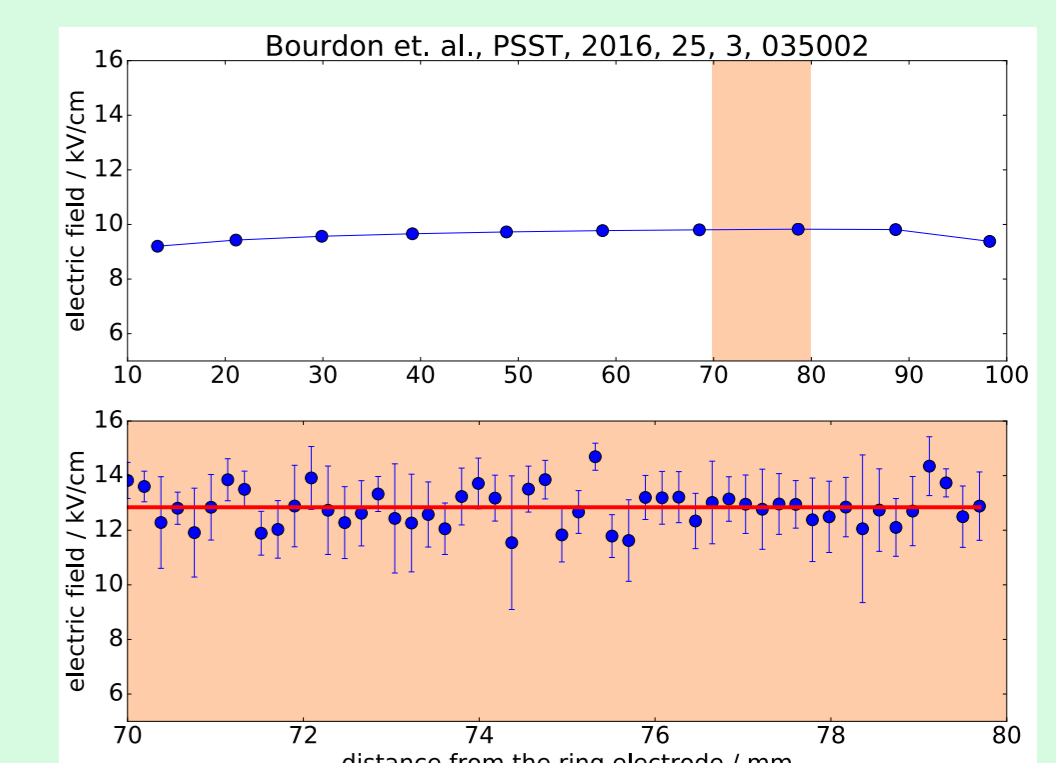
Time evolution of the ionization front.

- ▶ Establishment of \vec{E}_x about 500 ns before the emission of the light,
- ▶ $\|\vec{E}\|$ is in the order of $10 \text{ kV} \cdot \text{cm}^{-1}$ to $20 \text{ kV} \cdot \text{cm}^{-1}$ [4].

Comparison with numerical simulation results

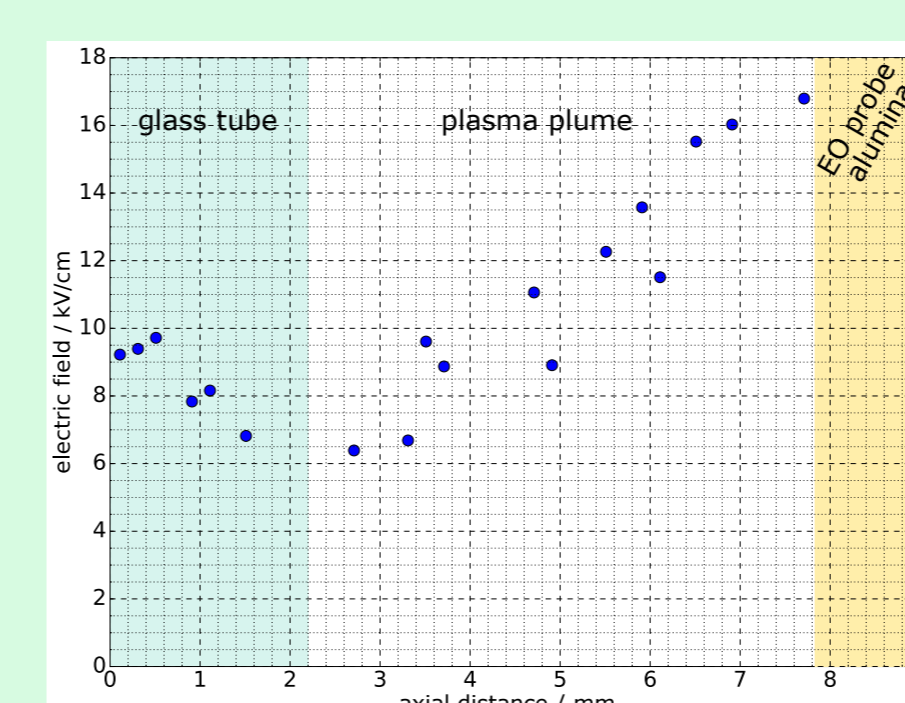


Time evolutions of the \vec{E}_x and \vec{E}_r of the E-field, fig. 16 [5].

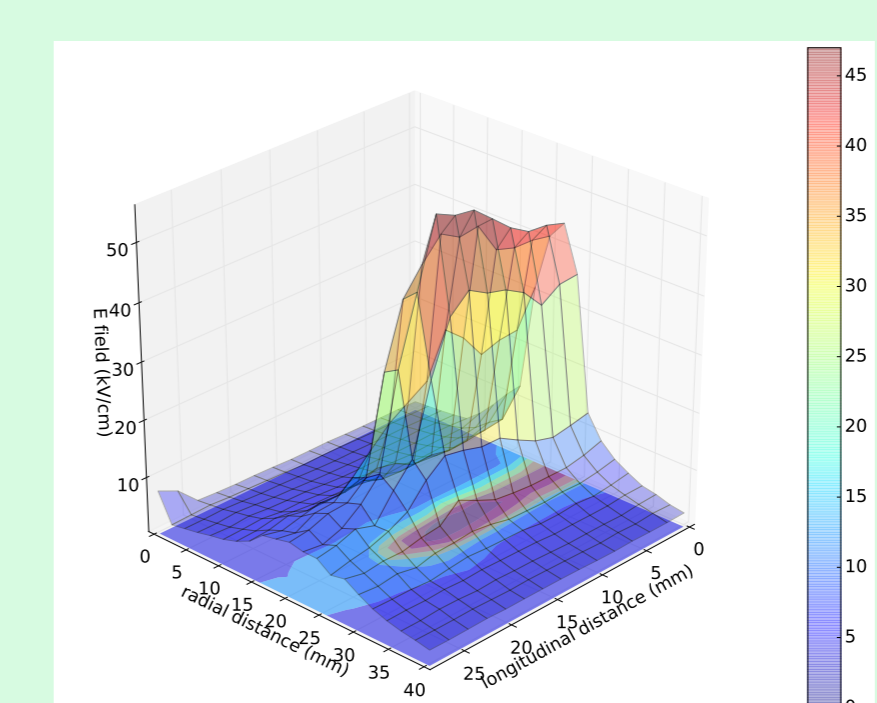


\vec{E}_x of the E-field computed and measured by π -polarization Stark He I.

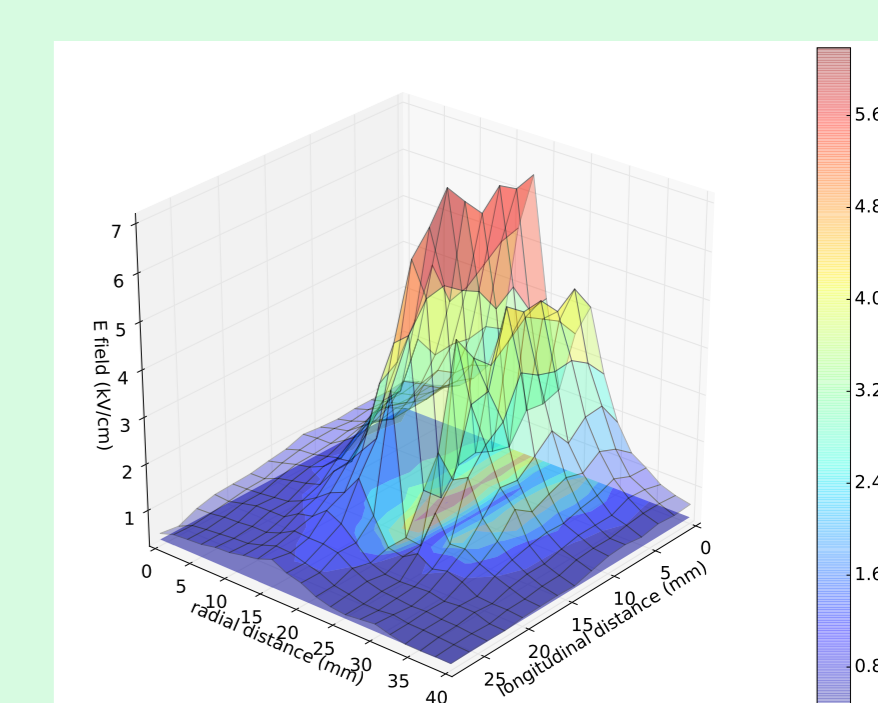
E-field measurement within the plasma plume



E-field values obtained by π -polarization Stark He I.



$\|\vec{E}\|$ 2D scan performed by the electro-optic probe.



\vec{E}_r 2D scan performed by the electro-optic probe.

- ▶ Both techniques show an increase of the E-field within the plasma plume,
- ▶ \vec{E}_r resembles the ring-shape structure also reported in [4].

Concluding remarks

- ▶ E-field characterization is the method of choice to study ionization waves,
- ▶ Both techniques produce results in agreement with numerical simulations,
- ▶ The complementarity of the methods are demonstrated.

References

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