Streamer propagation at water surface: influence of gap distance and quantification of injected charge

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Outline

I. **Introduction to streamer discharge**

II. **Experimental measures of the streamer properties propagating on a water surface**

III. **Prediction of the fundamental parameters of the discharge from the experimental measurements**

Introduction of Streamer and Streamer-water interaction

Streamer: a highly reactive discharge generating an intense space charge field and reactive species

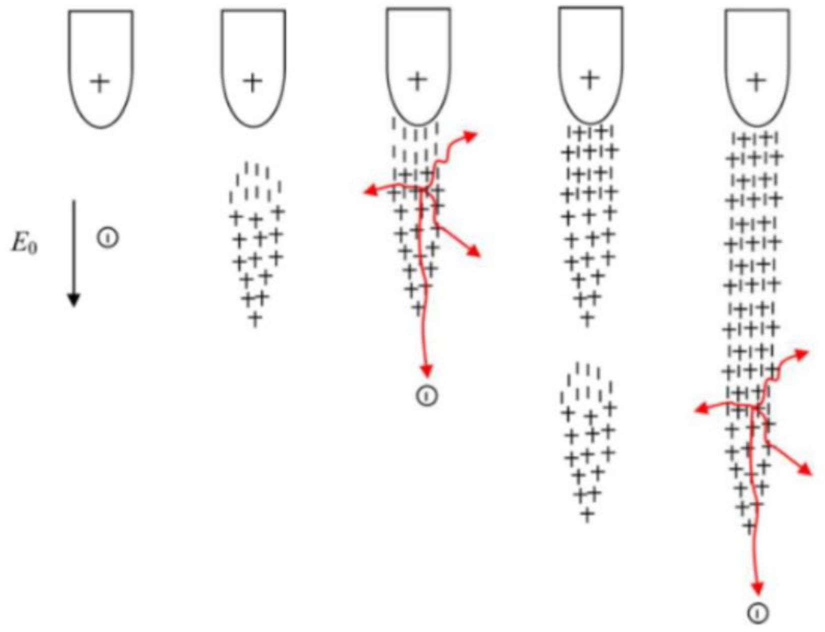

Figure 1: Propagation of a positive streamer.
A. Beroual et al (2016)

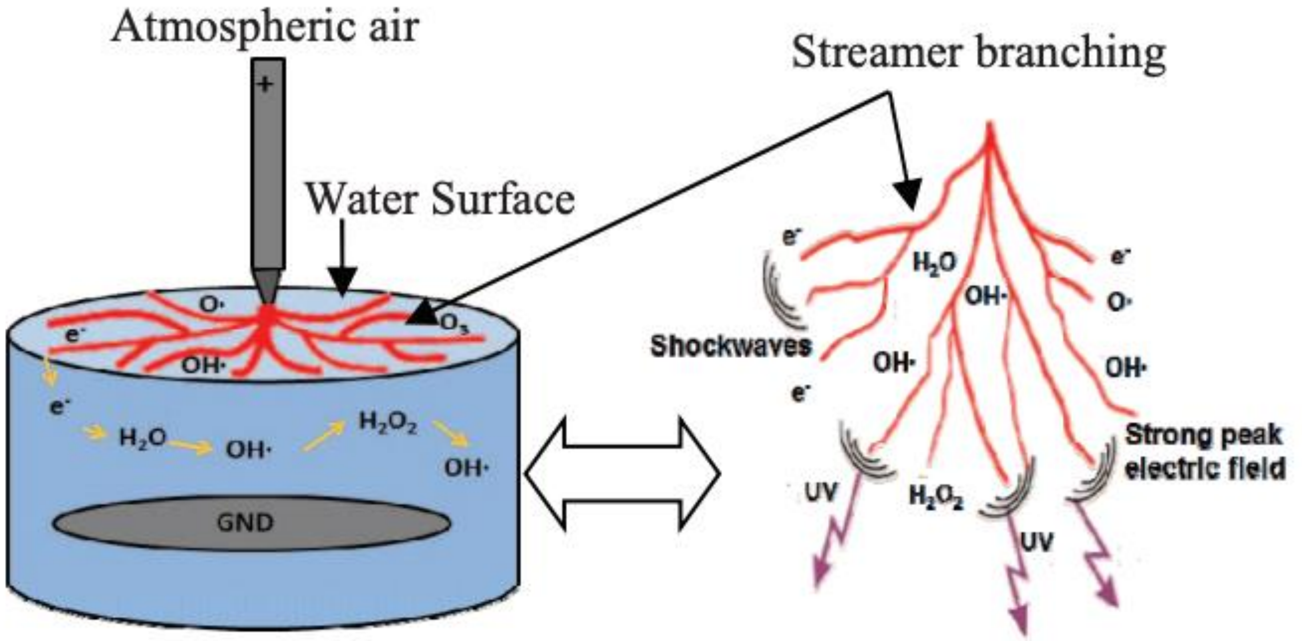

Figure 2: Example of a streamer discharge at water surface.
M. A. Halim et al (2017)

Experimental Setup

$$10\ \mu m < d_{gap} < 1000\ \mu m$$

$$8\ kV < V_{applied} < 20\ kV$$

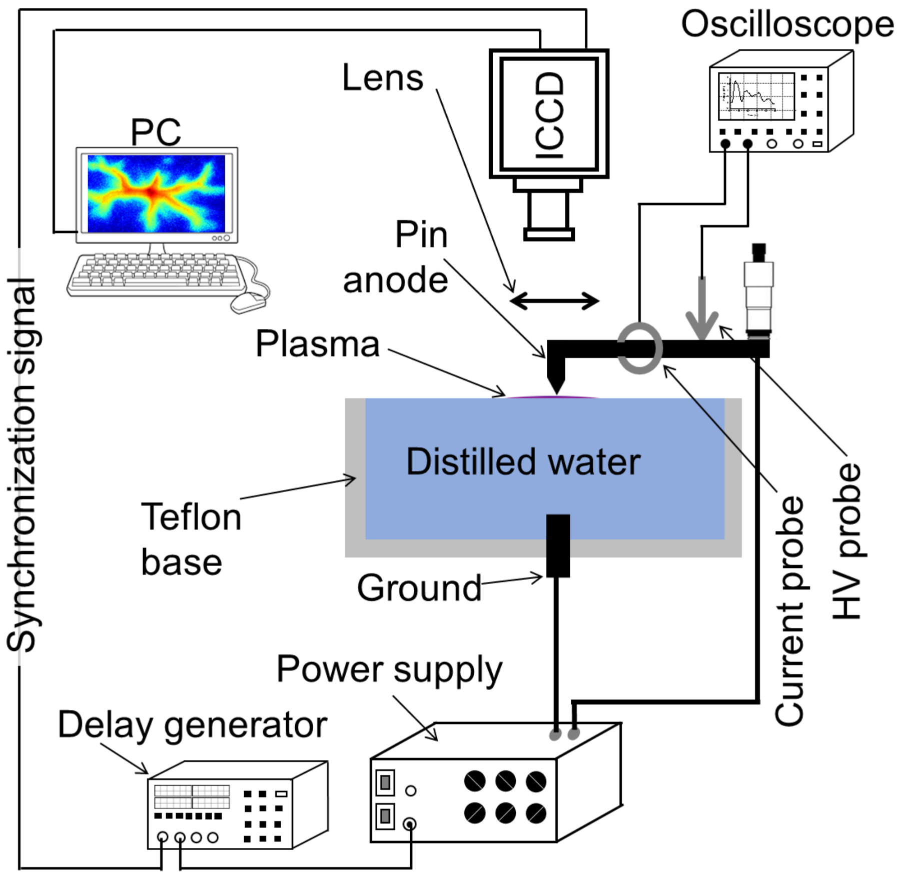

Figure 3: Experimental setup.
A. Herrmann et al (2022)

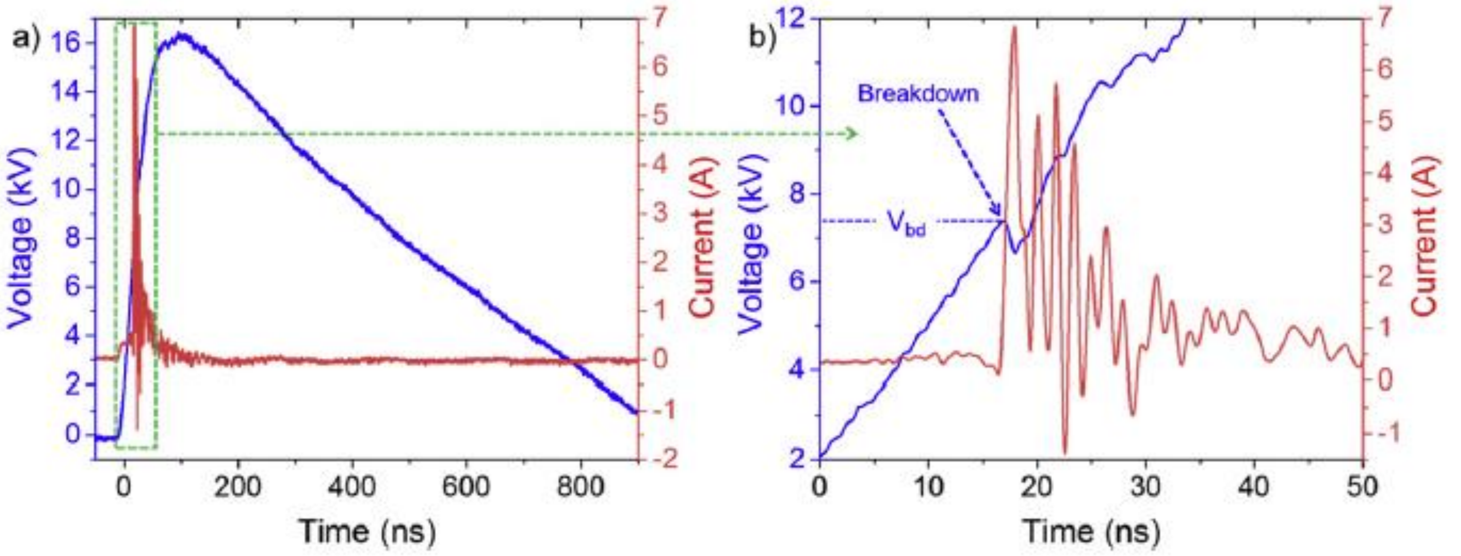

Figure 4: Electrical characteristics for a typical discharge.
A. Herrmann et al (2022)

$$Q_{total} = \int I(t)\, dt$$

Quantification and propagation of the streamers

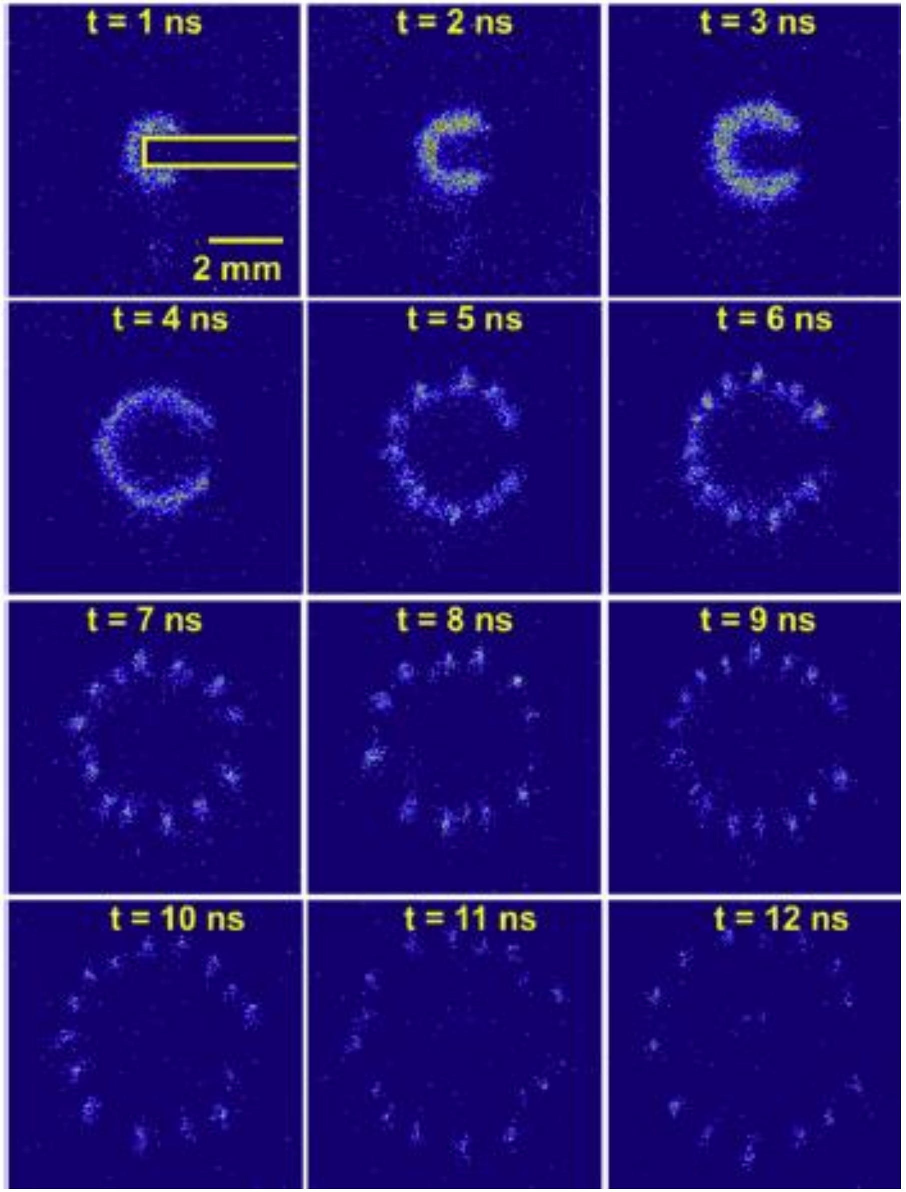

Figure 5: 1 ns-integrated ICCD d = 100 µm and Va = 20 kV. A. Herrmann et al (2022)

<u>Investigation of the plasma dots properties:</u>

- Propagation velocity: V_{Dot}
- Number of plasma dots: N_{dot}

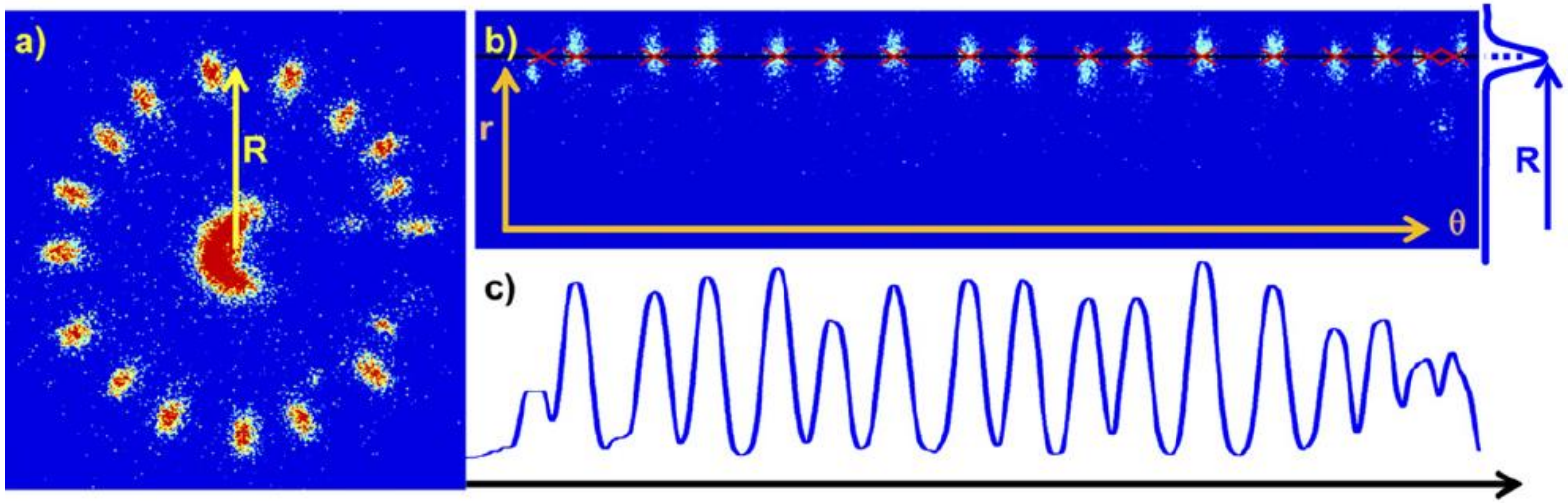

Figure 6: 5 ns-integrated used to estimate the number of plasma dot. A. Herrmann et al (2022)

Propagation velocity of the plasma dots and quantification of their number

Increase of the velocity with an increase of the applied voltage

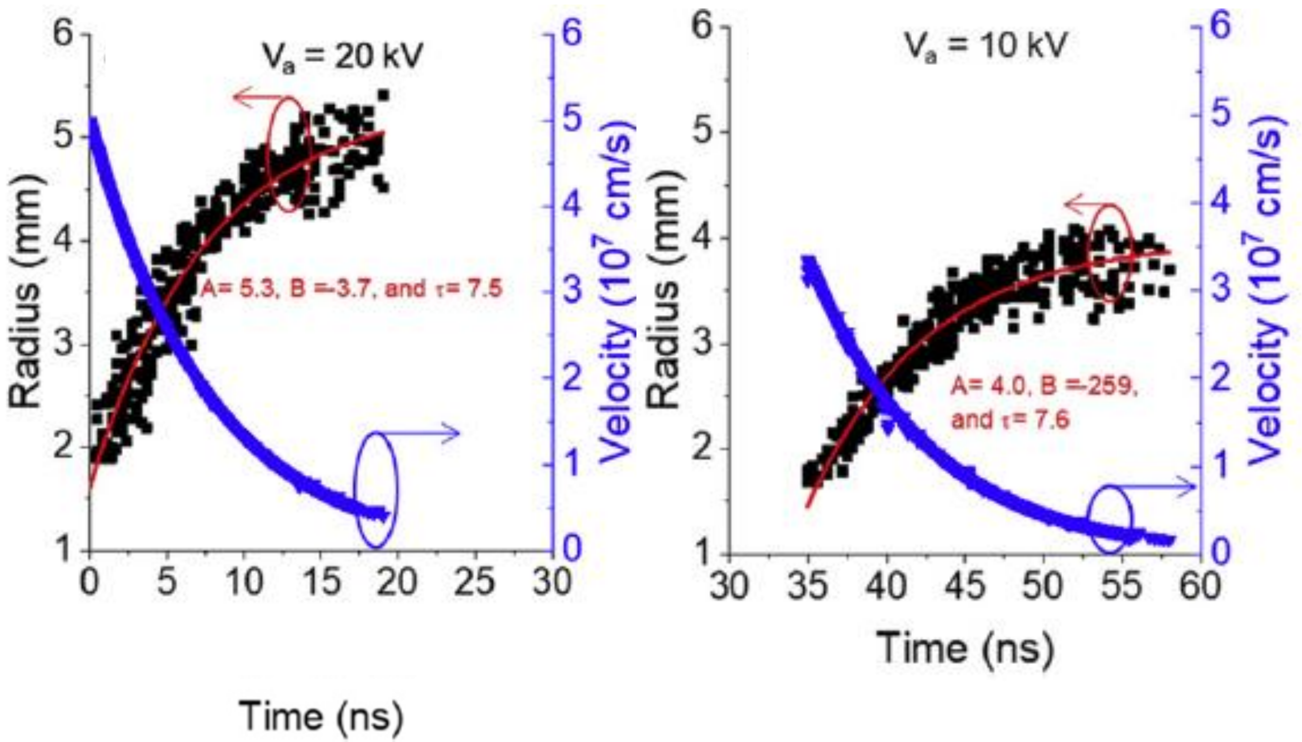

Figure 7: Evolution of the radial position and the propagation velocity of the plasma dots.
A. Herrmann et al (2022)

d_{gap} increased of 200μm: 1 plasma dot lost

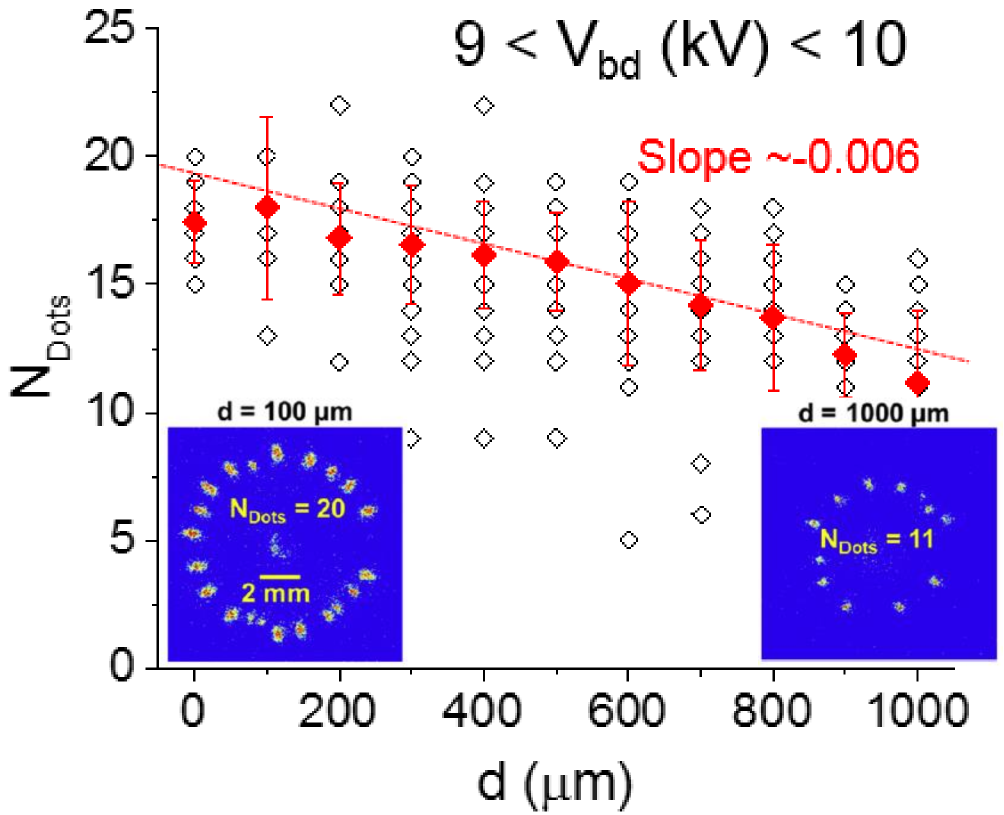

Figure 8: Variation of N_{dots} as a function of d for selected values of V_{bd} (6 < V_{bd} < 7 kV).
A. Herrmann et al (2022)

Influence of d_{gap} on the charge measurement

Q_{total}

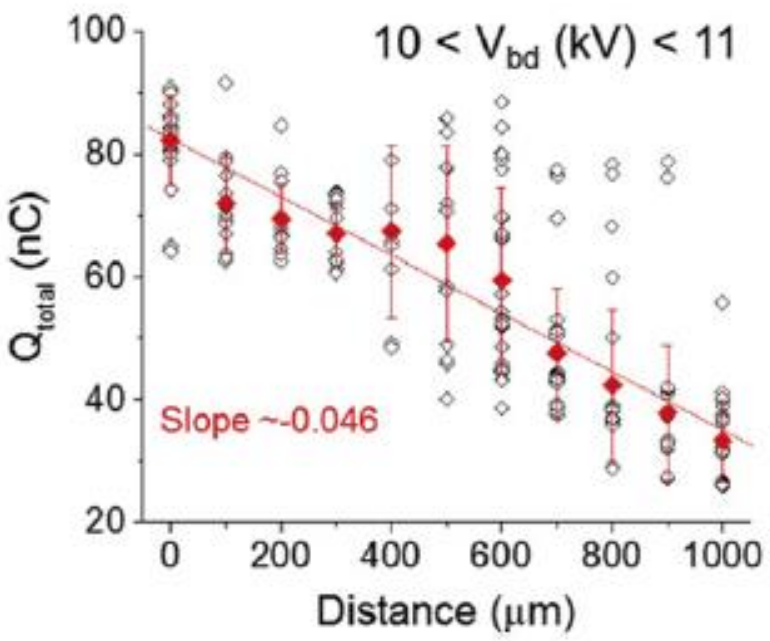

Figure 9: Variation of Q_{total} as a function of d_{gap}.
A. Herrmann et al (2022)

$$Q_{dot} = \frac{Q_{total}}{N_{Dot}}$$

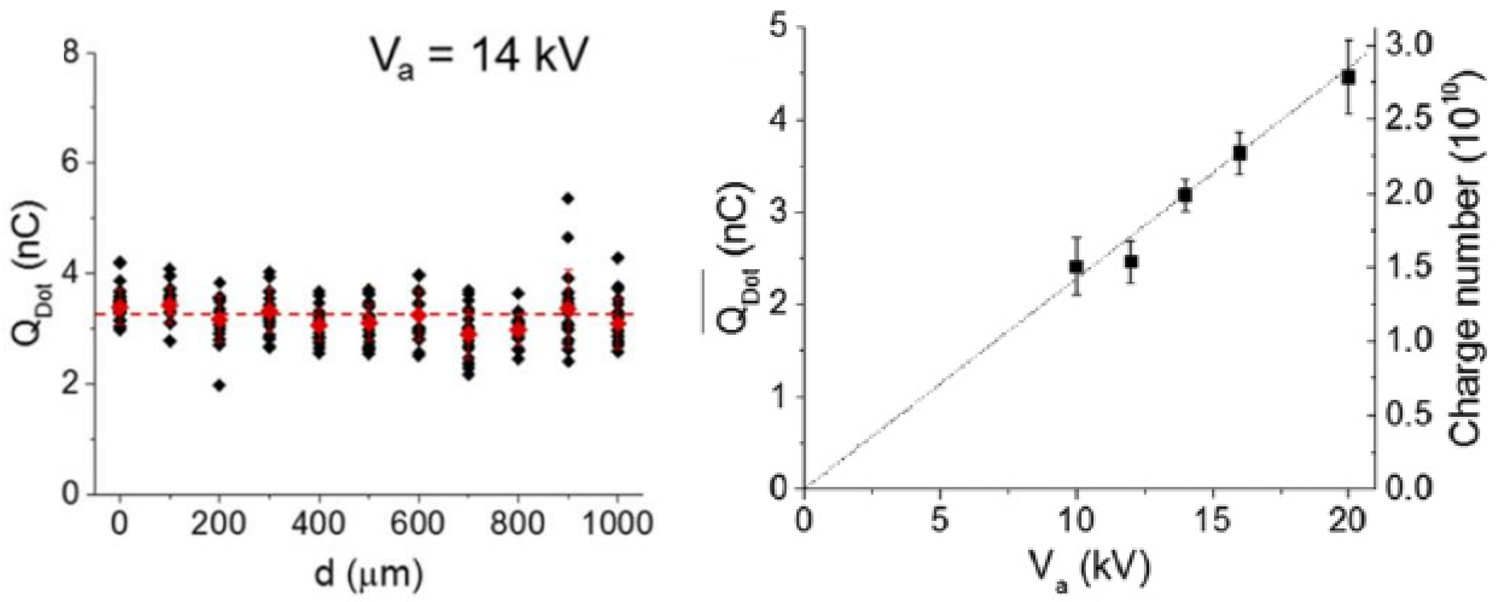

Figure 10: Q_{dots} as a function of the gap distance and the applied voltage. A. Herrmann et al (2022)

Estimation of the temporal evolution of the plasma dots properties on the water surface based on the experimental data

Measurement of Q_{dot} and R_{dot}

↓

Space charge field: $E_{Dot} = \frac{Q_{Dot}}{4\pi R_{Dot}^2}$

↓

$$E_{tot} = E_{external} + E_{Dot}$$

↓

Estimation of the plasma dot mobility: $\mu_{Dot} = V_{Dot}/E_{tot}$

↓

Knowing the temporal evolution of the plasma dot velocity V(t)

$$E(t) = \frac{V(t)}{\mu_{Dot}}$$

$$Q(t) \sim 4\pi R_{Dot}^2 E(t)$$

$$N(t) = \frac{Q(t)}{e}$$

Estimation of the mobility of the plasma dots

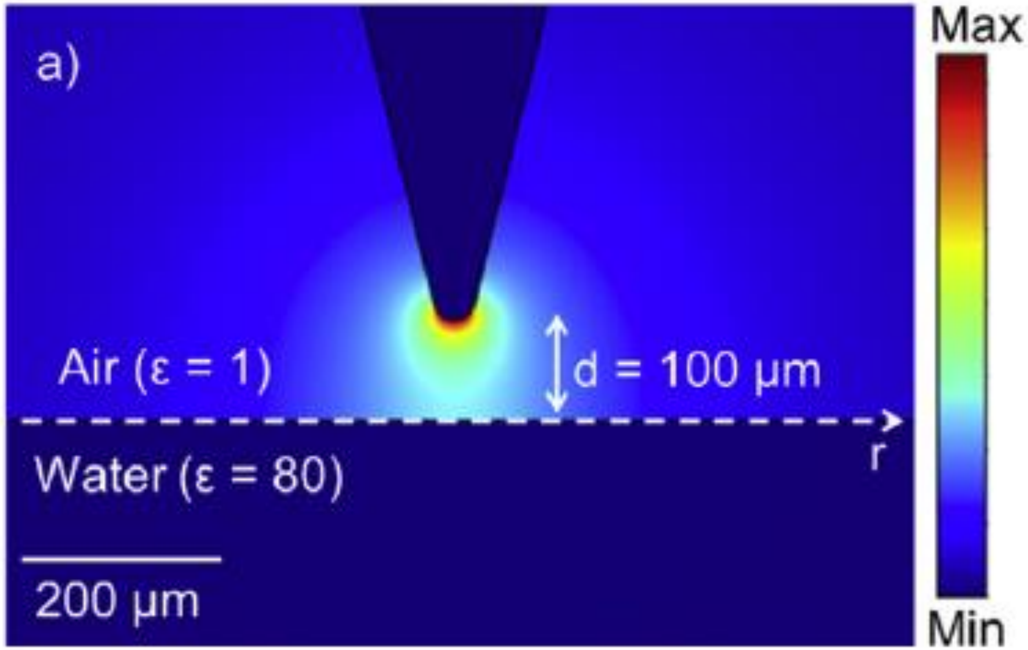

Figure 11: External field created by the anode.
A. Herrmann et al (2022)

Where the plasma dot begins to propagate:

$$\boldsymbol{E_{external} \sim 10^2\ kV.cm^{-1}}$$

By approximating the plasma dot as a sphere of radius R_{Dot}:

$$E_{Dot} = \frac{Q_{Dot}}{4\pi R_{Dot}^2}$$

$$Q_{Dot} \sim 4.5\ nC \implies \boldsymbol{E_{Dot} \sim 4 * 10^4\ kV.cm^{-1}}$$

Hence, as $V_{Dot} \sim \mu_{Dot} E_{tot}$:

$$\boldsymbol{\mu_{Dot} \sim 1.25\ cm^2.V^{-1}.s^{-1}}$$
$$\boldsymbol{< \mu_{ion}\ (\sim 2-4) \ll \mu_{electron}\ (\sim 90)}$$

Estimation of the temporal evolution of the space charge field of the plasma dot

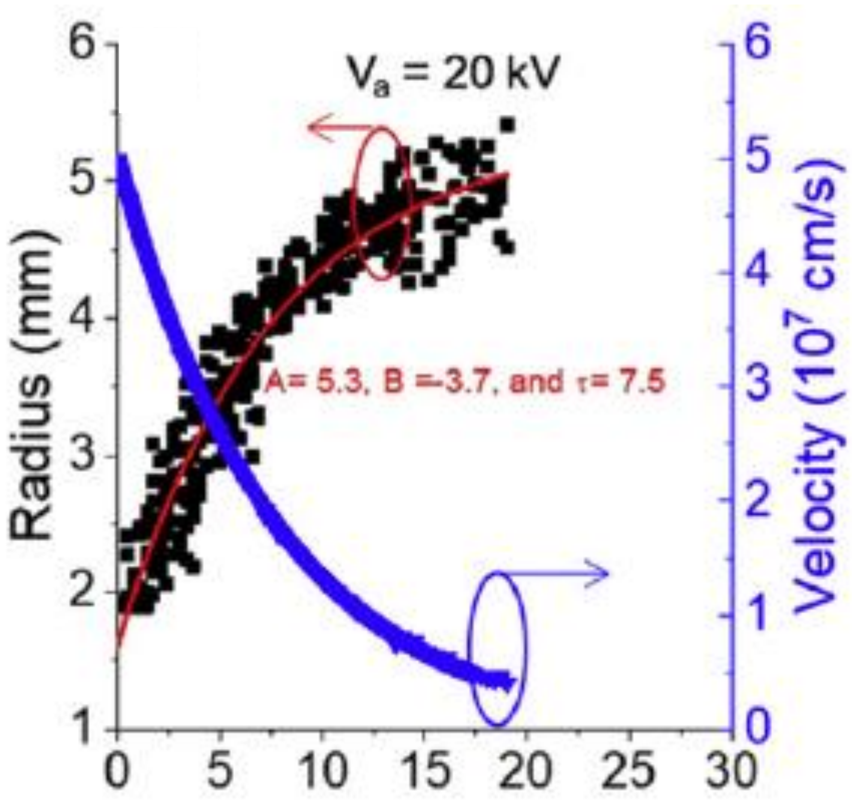

Figure 12: Evolution of the radial position and the propagation velocity of the plasma dots.
A. Herrmann et al (2022)

$$E(t) = \frac{V(t)}{\mu_{Dot}}$$

E-field produced by a single plasma dot

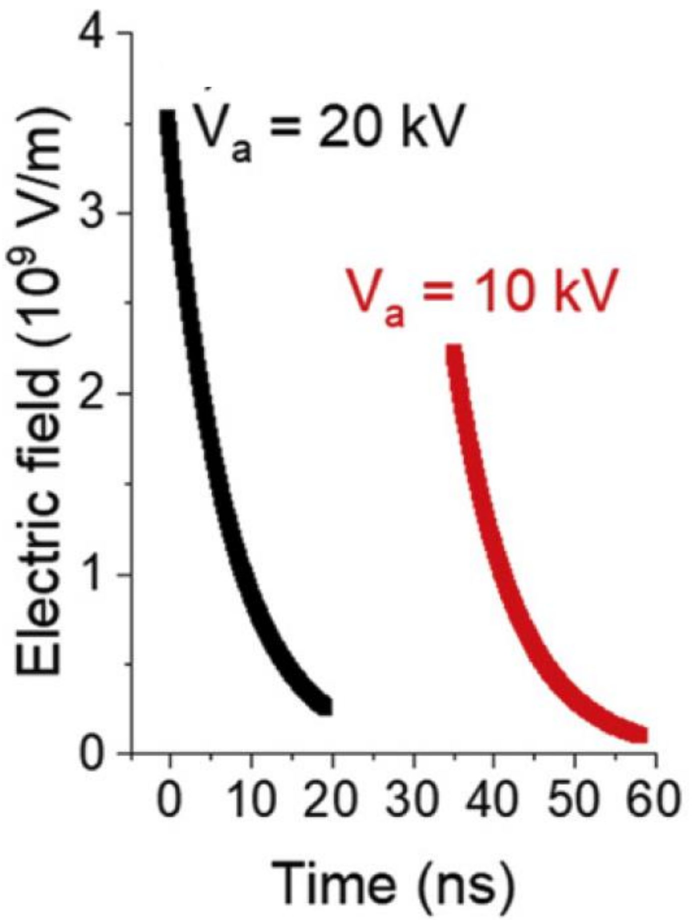

Figure 13: Time evolution of the electric field at 100 μm from the center of the plasma dot.
A. Herrmann et al (2022)

Estimation of the temporal evolution of the charge number of a plasma dot

$$Q(t) \sim 4\pi R_{Dot}^2\, E(t)$$

$$N(t) = \frac{Q(t)}{e}$$

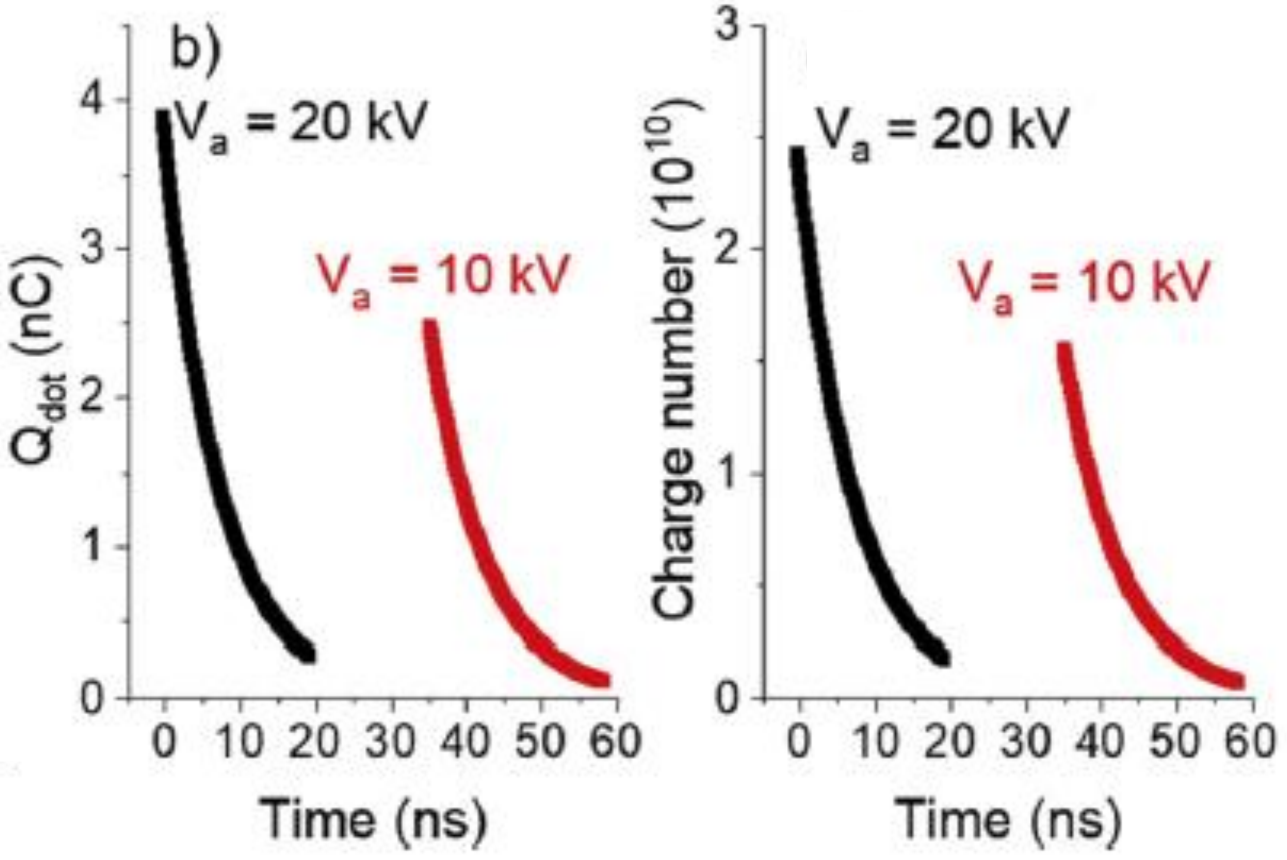

Figure 14: Time evolution of Qdot and of charge number in a plasma dot for two Va conditions of 20 and 10 kV.

Radial propagation of the plasma dot stops when the number of charged species created during its propagation isn't sufficient to create a space charge field of the order of the breakdown field.

Conclusion

- Increasing the gap distance reduces the number of plasma dots at water surface
- Determination of the plasma dots propagation velocity under different conditions
- Estimation of the mobility of the plasma dot
- Estimation of the evolution of i) plasma dot E-field and ii) charge number of the dot

Perspectives:

Modeling the formation and propagation of plasma dots at water surface

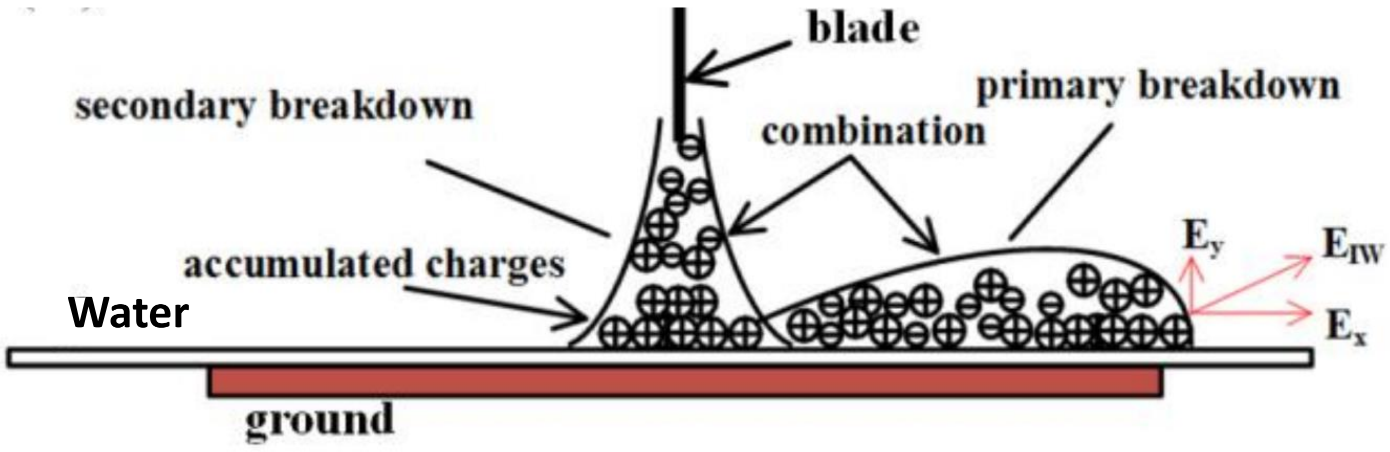

Figure 15: Propagation of a streamer in the air gap and then on the water surface. J. Qiu et al (2017)