Durability Assessment of Discharge Capillaries Wall Materials in Plasma-based Particle Accelerators for the EuPRAXIA Project

EuPRAXIA Doctoral Network

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Summary

We have completed the experimental testing of the discharge capillary made of 3D-printed plastic, which is 3 cm long with various diameters (0.5 mm, 1 mm, 2 mm) in order to study the capillary's durability over time.

These tests allow us to measure the impact of numerous high voltage electrical discharge on the capillary and therefore on the plasma produced inside it.

The experimental tests demonstrate significant degradation of the device, with a density loss of about 40% after one hundred thousand discharges, corresponding to an accelerating field loss of about 25%.

Experimental set-up

The gas injection system generates hydrogen gas and injects it into plasma-discharge capillaries using an electro-mechanical valve. The high voltage circuit delivers short kV-range voltage pulses for gas ionization. Diagnostics include an optical line, a spectrometer, and an ICCD camera for analyzing gas emission.

The plasma source tested is a 3cm-long capillary with diameters of 0.5/1/2mm, two inlets, and filled with hydrogen. Plasma density was measured using spectroscopy based on Stark broadening[1]. Experimental settings included:

- Injection pressure: 10 to 30 mbar
- Valve activation at 1 Hz for 5 ms
- 10 kV pulses to copper electrodes 1.4 ms after valve closure, initiating a 300/400 A plasma current pulse.

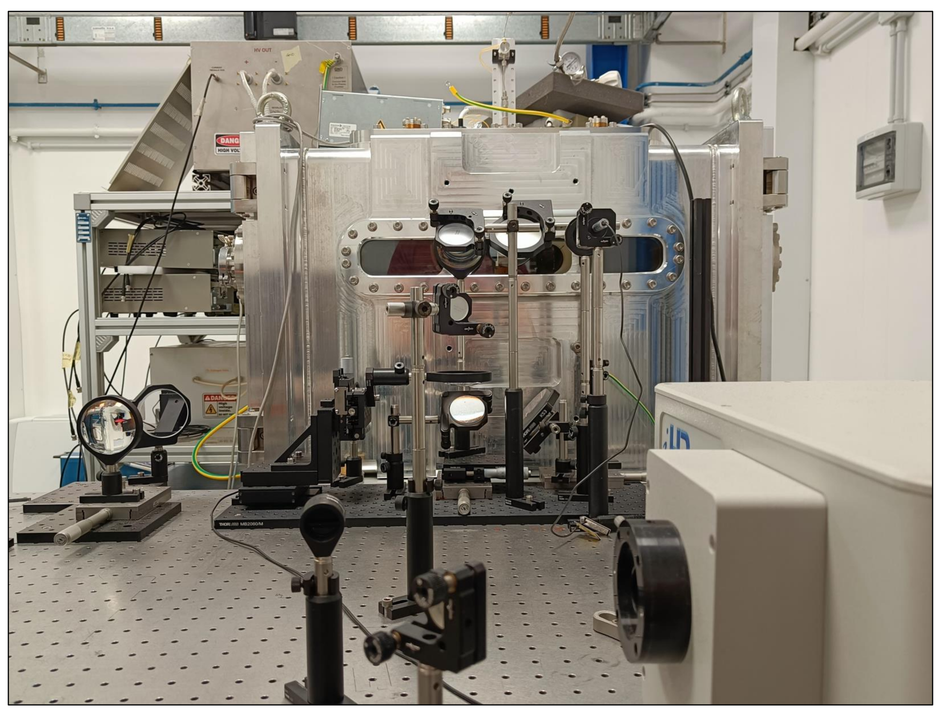

Fig. 1: Plasma_Lab experimental set-up

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Data acquisition

Spectral images were acquired by the ICCD camera at delay times ranging between 500÷3500 ns corresponding to formation and recombination time of the plasma, with 50 images per each delay time for giving statistically reliable results.

Measured plasma density profiles show a 38% and 49% losses in plasma density for capillary of 0.5mm and 1mm diameter, respectively.

These losses are due to the degradation and deformation of the plasma channel over time, as visible in figure 4. Shot after shot, the channel widens, leading to a drop in density, and resulting in the loss of the initial density profile.

Testing results

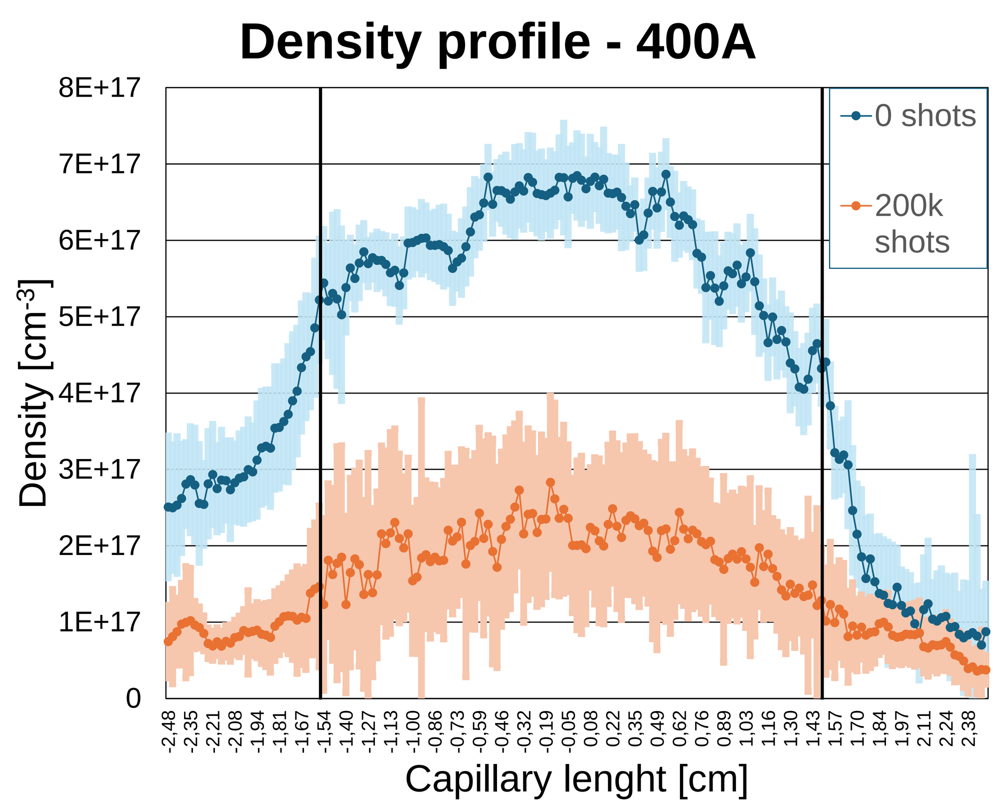

Fig. 2: Profile density for 2mm diameter

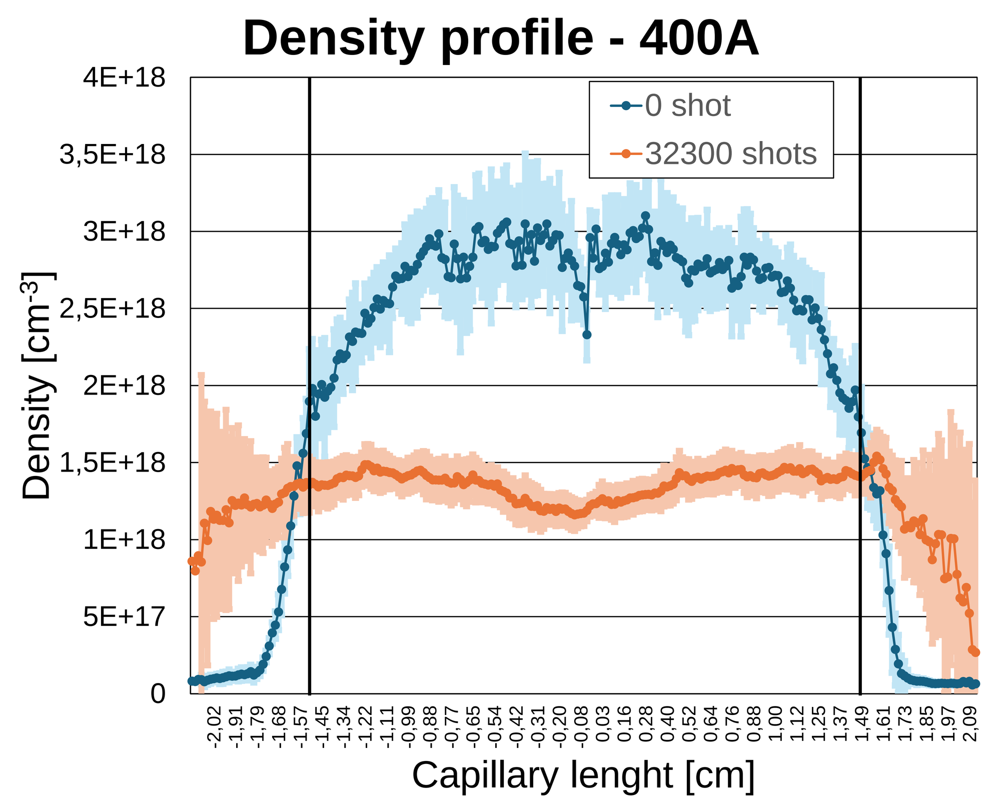

Fig. 3: Profile density for 0.5mm diameter

Fig. 4: 0.5mm and 2mm capillary after shots

Field analysis

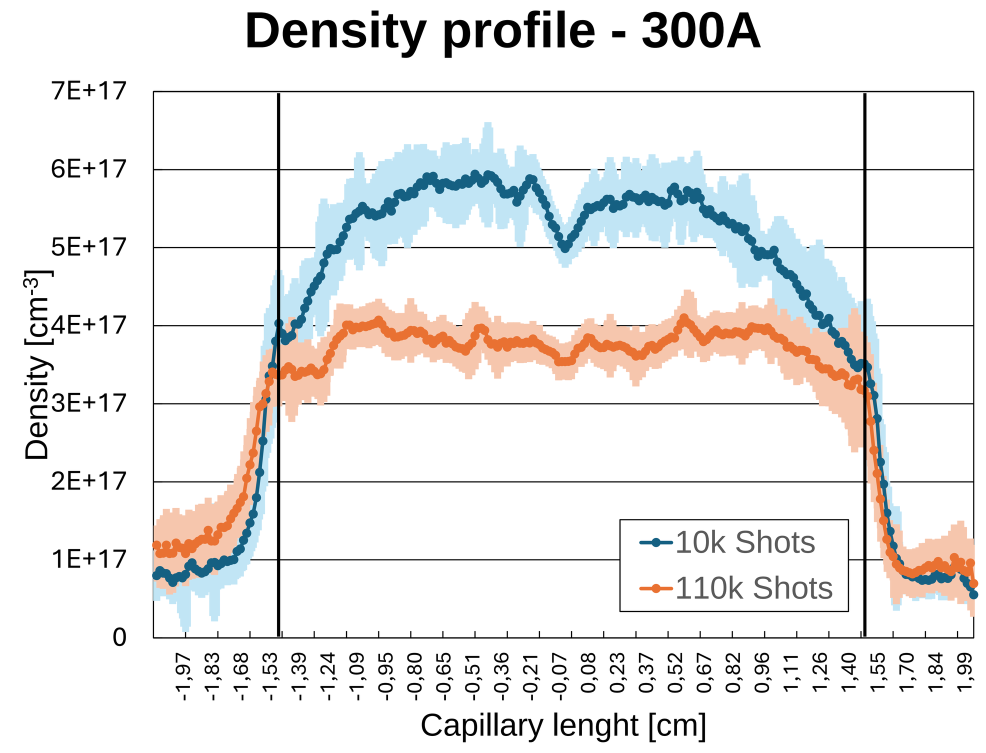

Fig. 6: Profile density for 1mm diameter

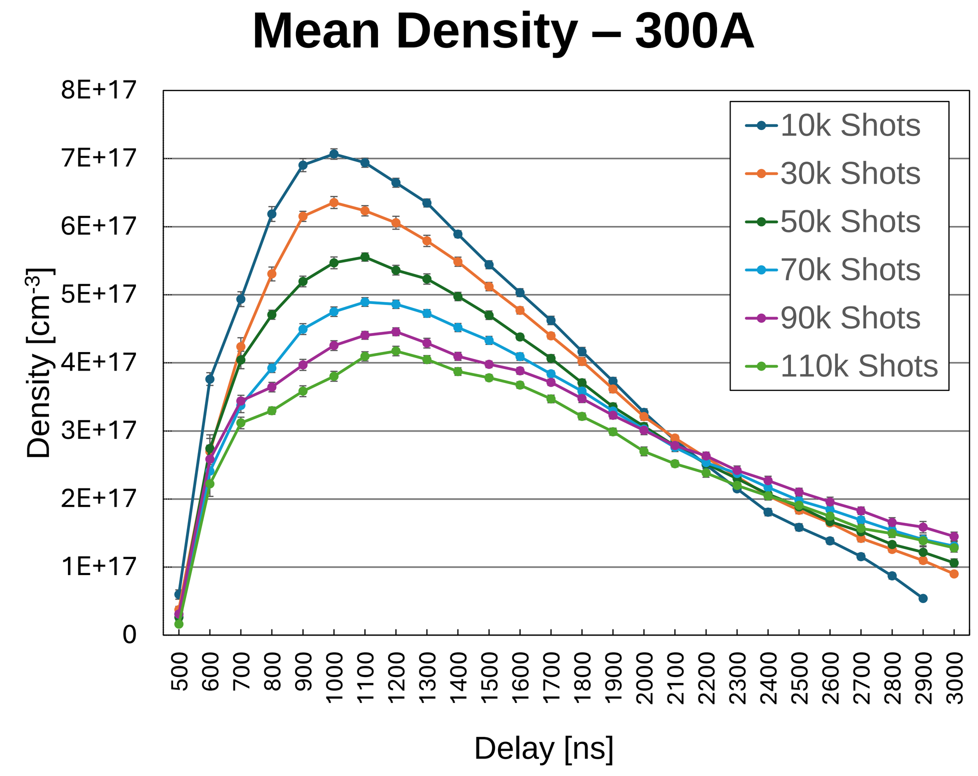

Fig. 7: mean density over delay for differents lifetime

Nb. of shots	Accelerating field 1000ns delay (GV/m)	Accelerating field max (GV/m)	Losses at 1000ns	Losses at max
10k	8,07 .10¹⁰	8,07 .10¹⁰	0%	0%
30k	7,65 .10¹⁰	7,65 .10¹⁰	-5%	-5%
50k	7,10 .10¹⁰	7,16 .10¹⁰	-12%	-11%
70k	6,62 .10¹⁰	6,72 .10¹⁰	-18%	-17%
90k	6,26 .10¹⁰	6,41 .10¹⁰	-22%	-21%
110k	5,92 .10¹⁰	6,20 .10¹⁰	-27%	-23%

Table 1: Accelerating Field and Losses Over Capillary Lifetime

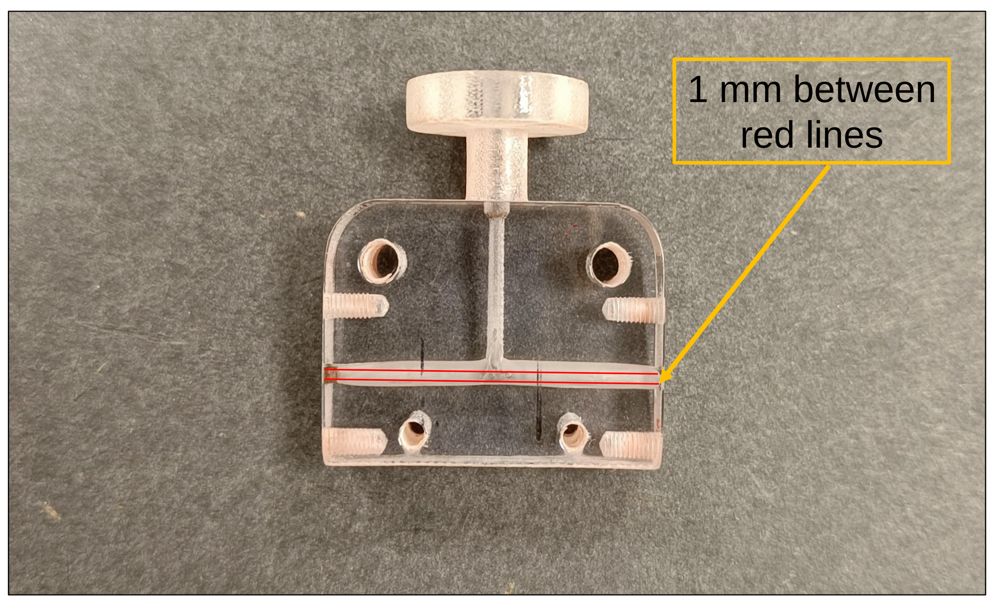

Fig. 8: widening of the 1mm diameter capillary

List of references

[1] H. R. Griem, "Spectral Line Broadening by Plasmas", Department of Physics and Astronomy, University of Maryland, College Park, Maryland