Plasma ramps generation by outflow in gas-filled capillaries

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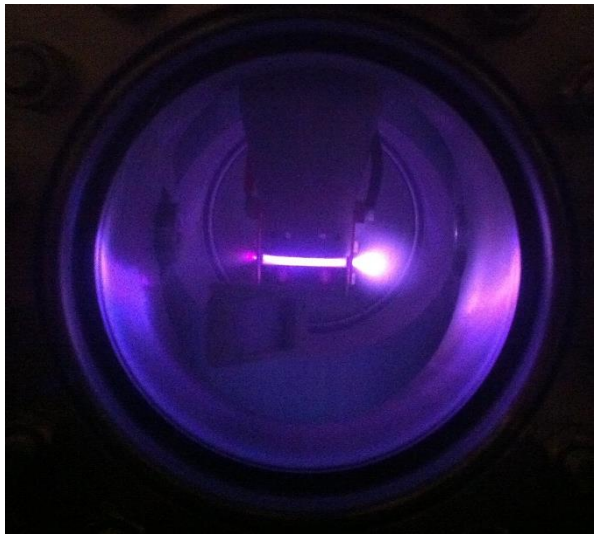
On behalf of SPARC_LAB collaboration

Outline

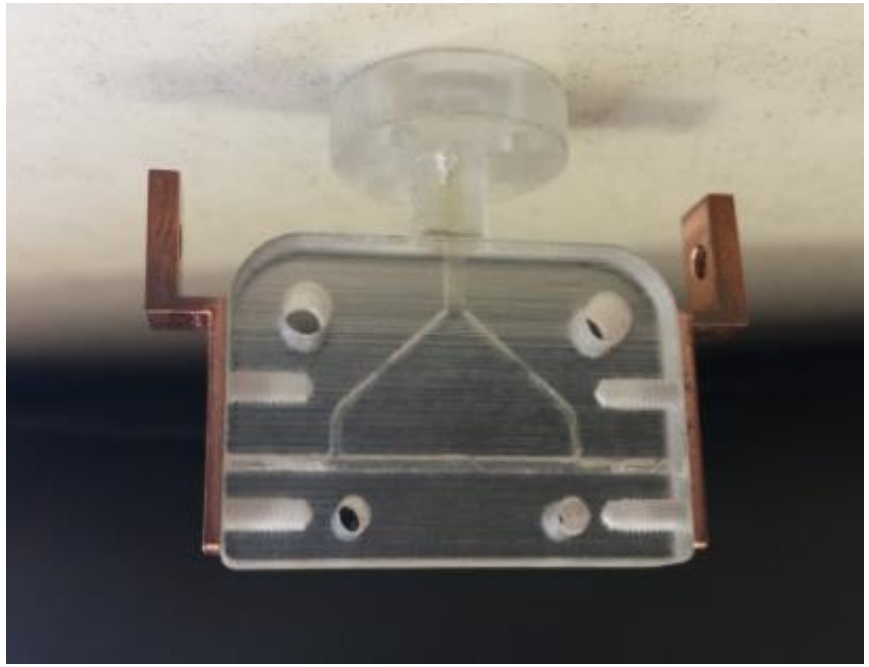
- Gas filled capillaries for plasma-based acceleration schemes
  - Experimental setup
  - Plasma density measurements
- Plasma outflow:
  - Why it is important
  - Experimental results



H_2-filled capillaries as plasma source

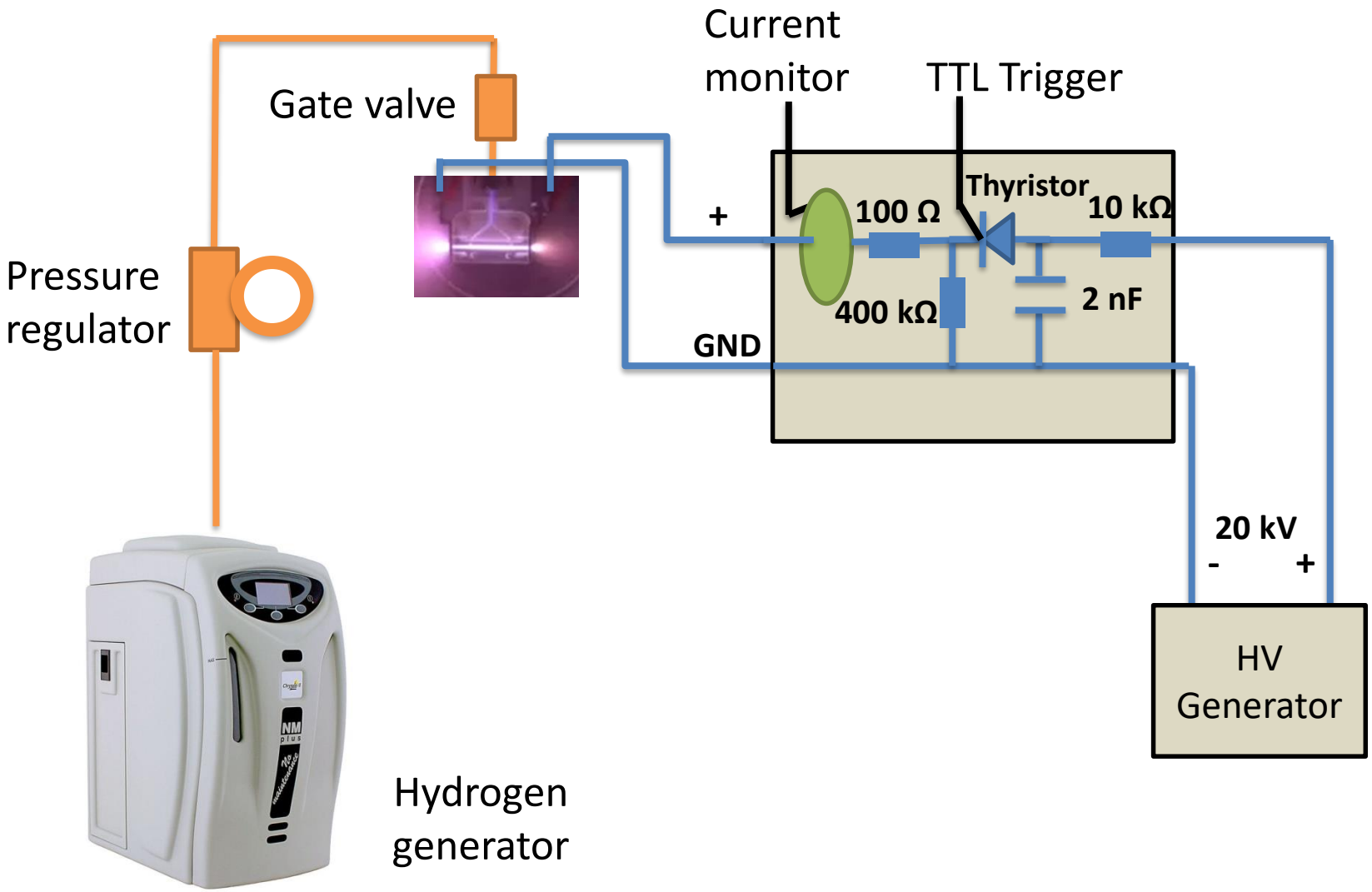
They furnish a centimeter long pre-ionized plasma channel.

A potential of 20 kV let to develop a **current discharge** of hundreds of amperes which completely ionizes the gas, H_2 based plasma is formed before the beam interaction.



- Allow for longer and almost constant density profile up to centimeter scale.
- High ionization level can be reached by the discharge (reducing the ionization losses acting on the driver(s))

H_2-filled capillaries: setup

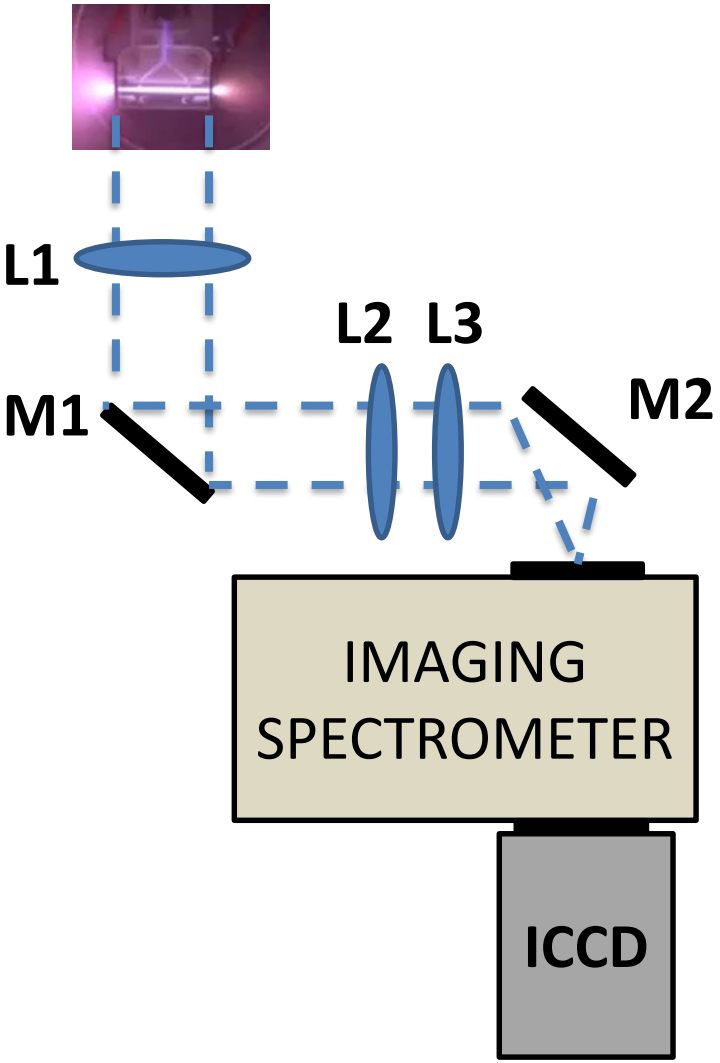


Hydrogen generator

High voltage is stored into a capacitor until a TTL signal triggers the thyristor letting the current flow into the gas.

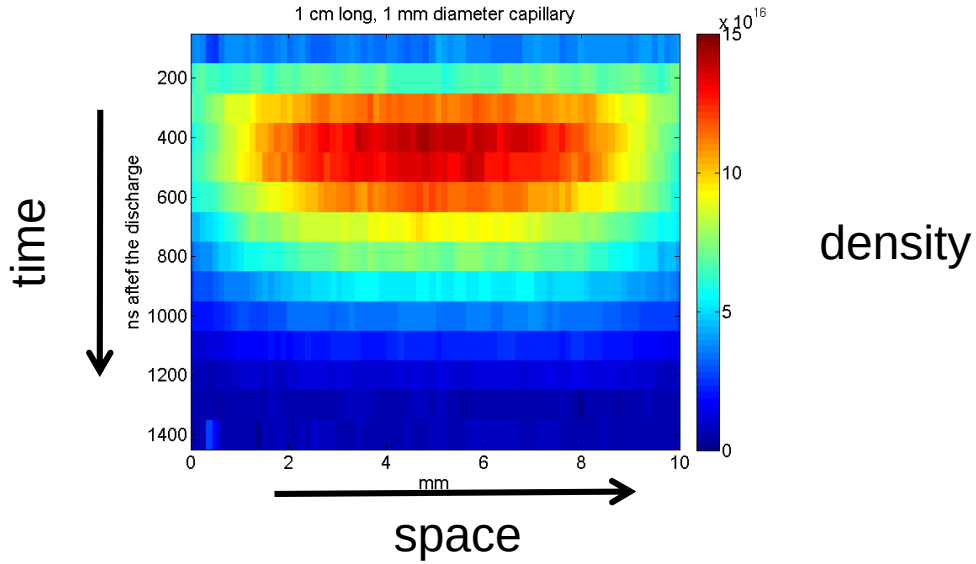
We studied 1 cm long, 1 mm diameter capillary and 3 cm long, 1 mm diameter

H_2-filled capillaries: plasma density measurements



A system of lenses collects the self-emitted light of the capillary and image it onto the spectrometer slit.

We measured the density along the capillary with the Stark broadening of the Balmer beta line

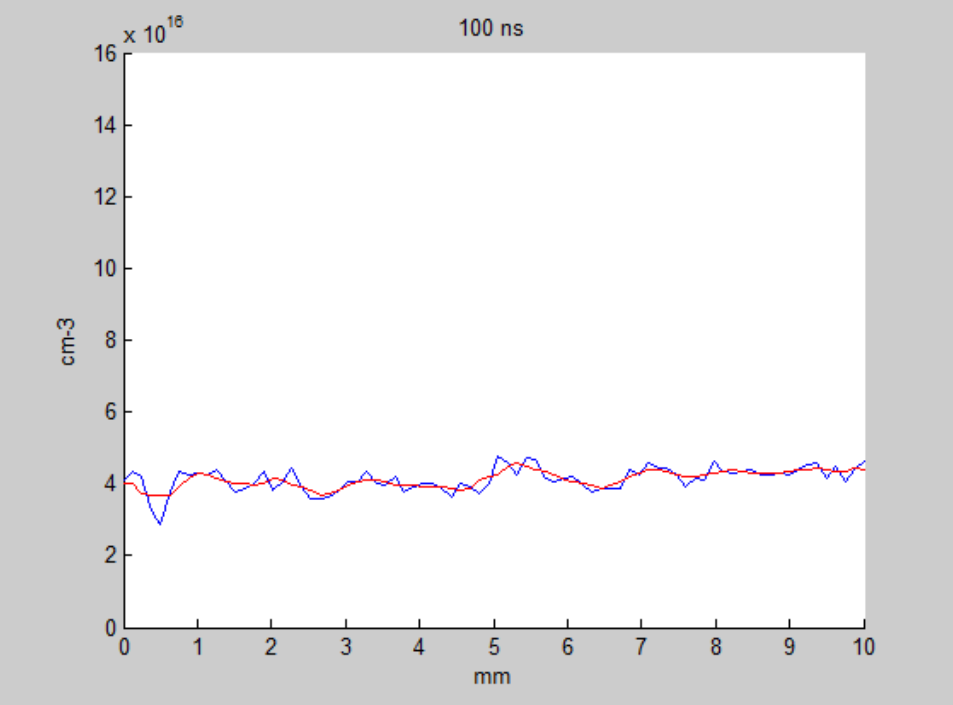


This let to detect spatial and temporal variations of the plasma density

0.017 dispersion [nm/px]
0.125 spatial res. [mm]
100ns temporal res.

H_2-filled capillaries: plasma density measurements

We measured the density along the capillary with the Stark broadening technique



1 cm long

$$n_e \propto e^{-\frac{t\,[ns]}{\tau}}$$

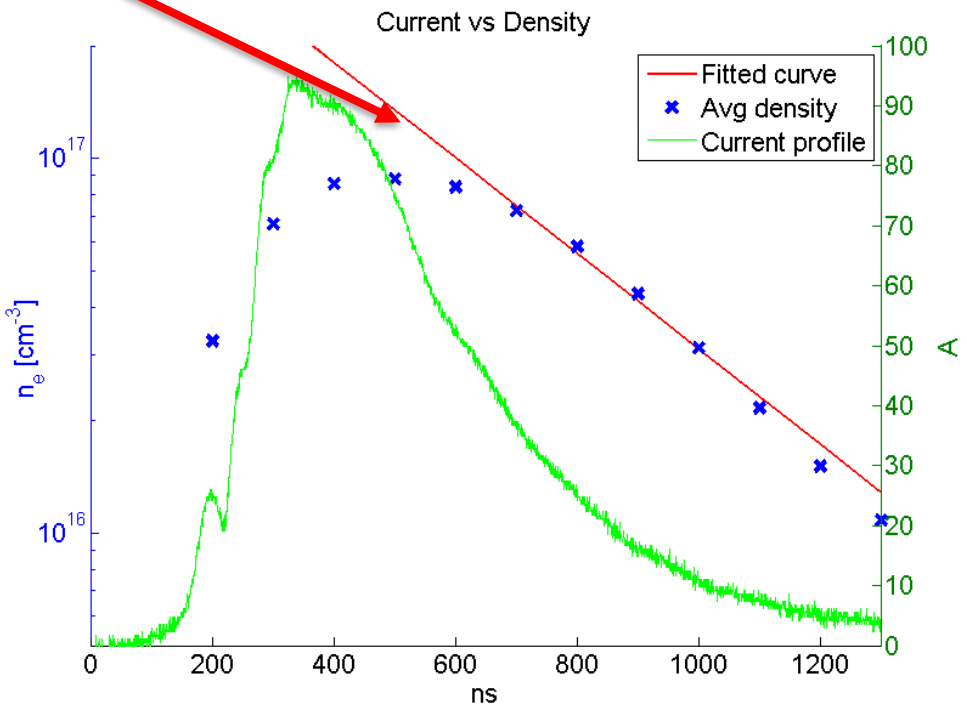
Decay constant

τ

Outflow

+

recombination

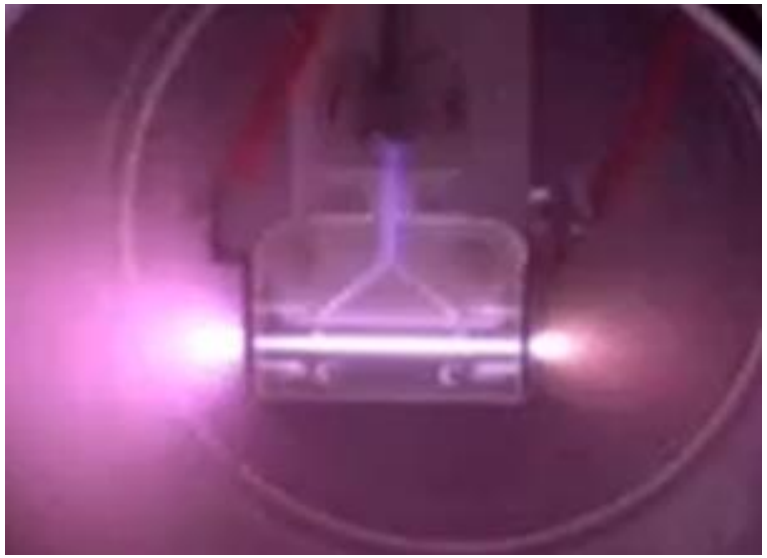


3 cm long

Filippi et al.
JINST, 11, 9 (2016)
doi:10.1088/1748-0221/11/09/C09015

Plasma outflow from the capillary

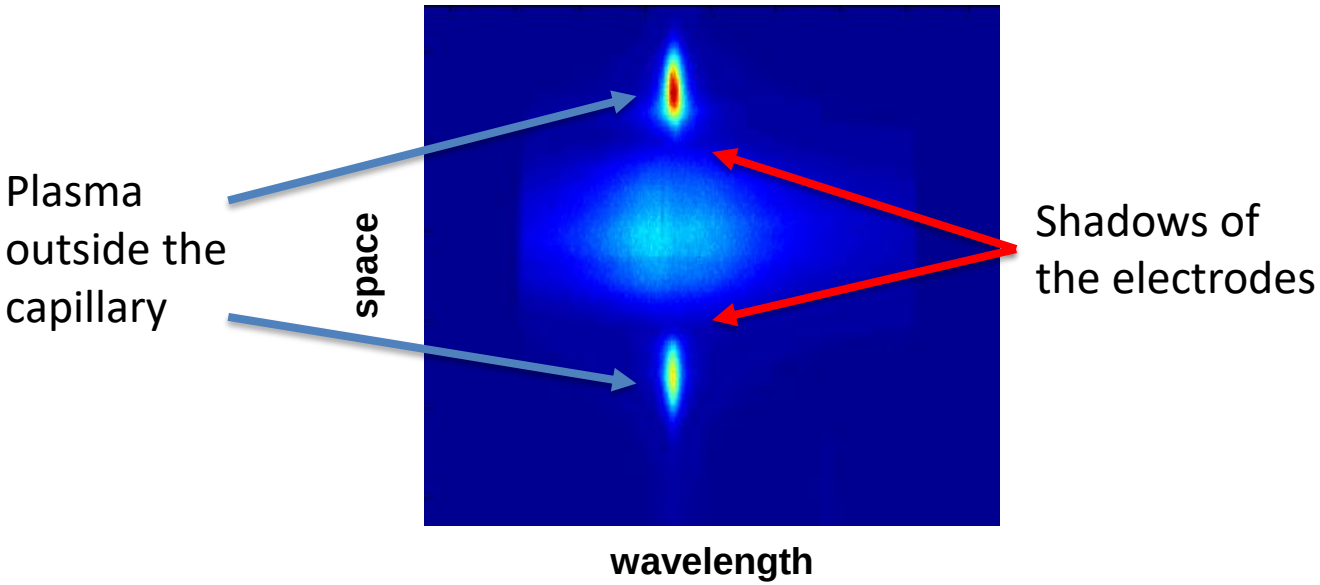
From the spectroscopic images we observed the outflow of the plasma from the edges of the capillary



Plasma flow out of the capillary edges is influenced by:

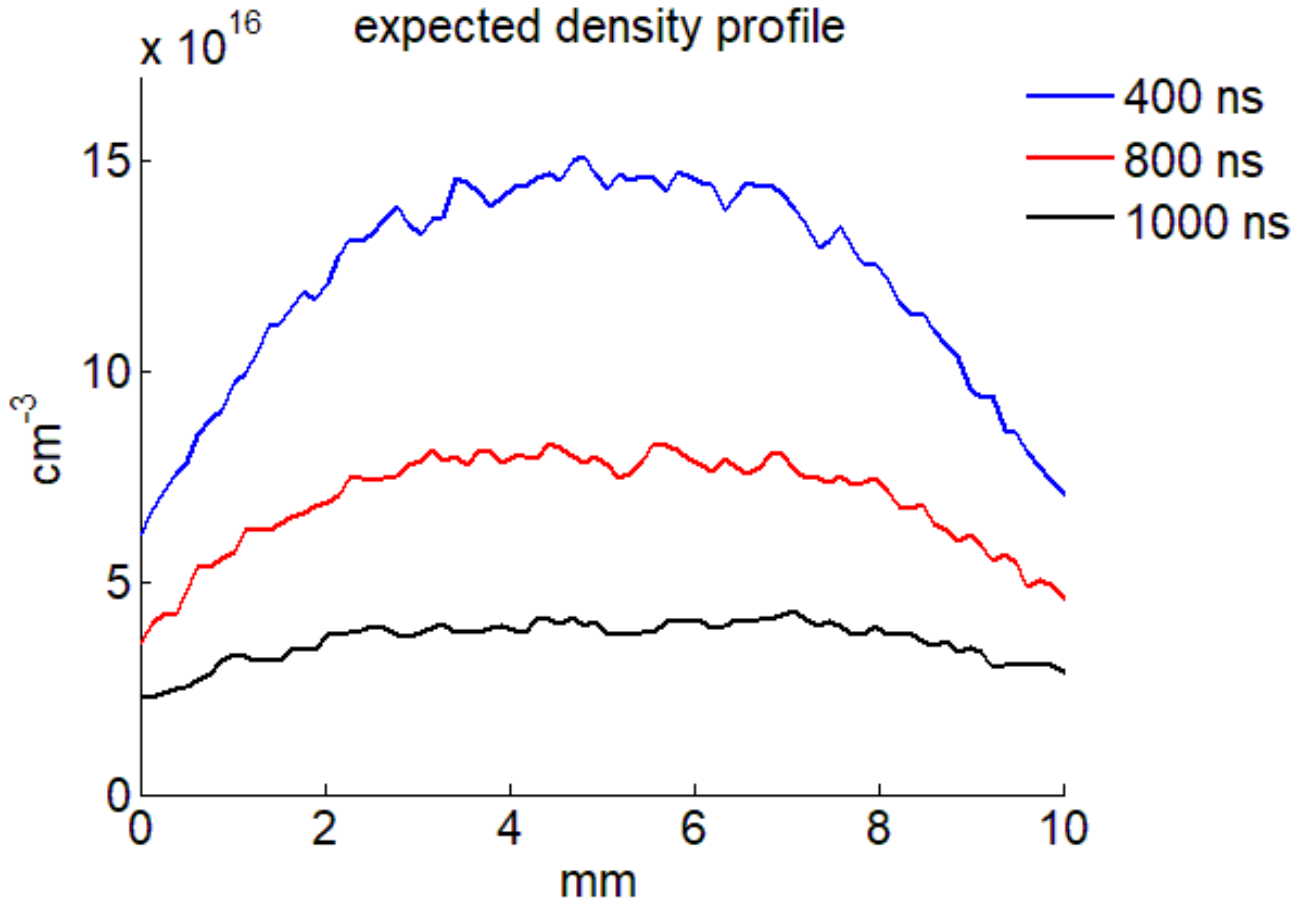
- thermal motion of the ions
- fluid effects caused by the heating of the discharge
- capillary geometry

Example of spectrometer output



Plasma outflow: effects

Due to the outflow, the laser/particle beam(s) interact with a different plasma profile, undergoing to unwanted (if uncontrolled) effects.



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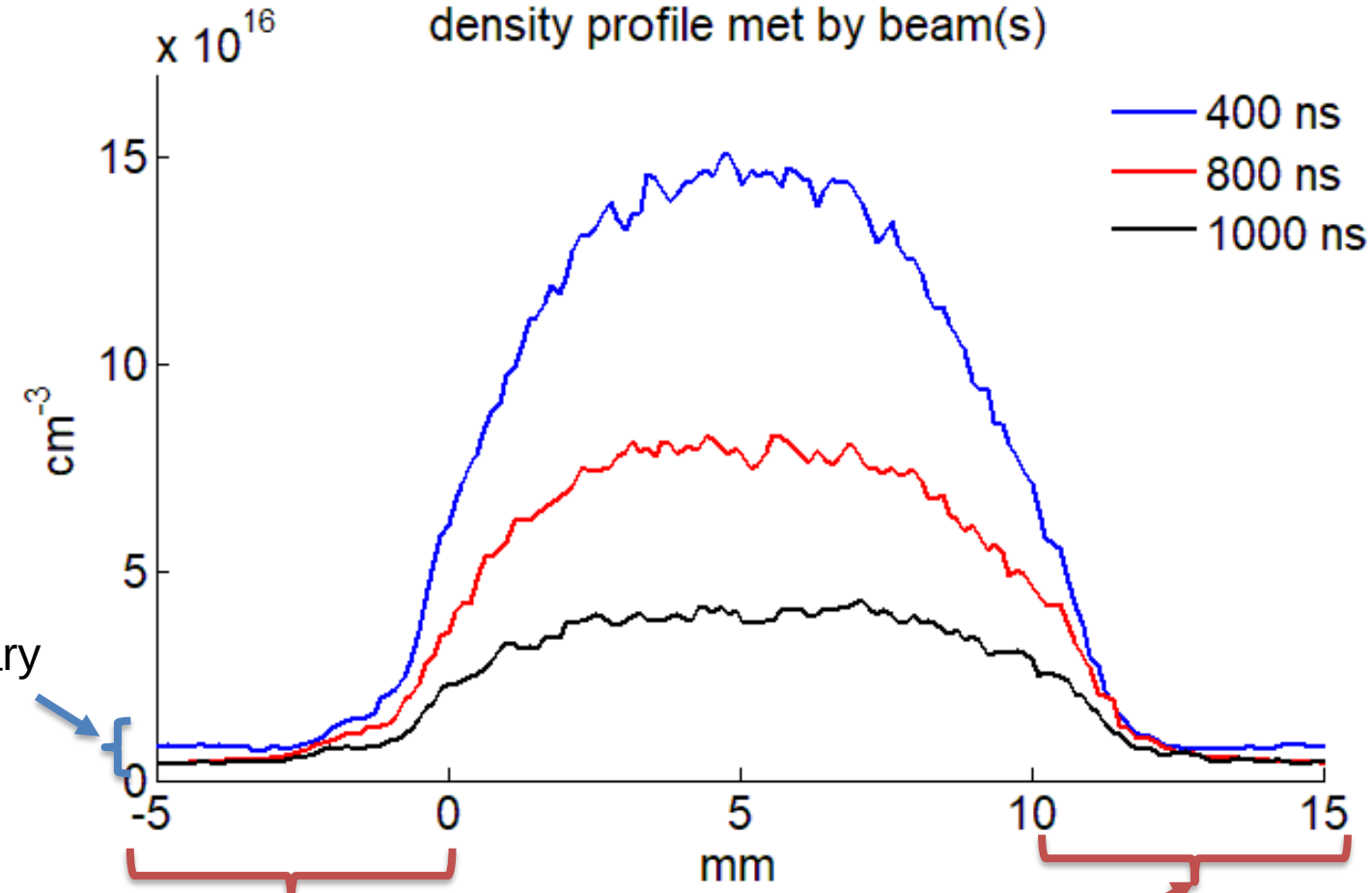
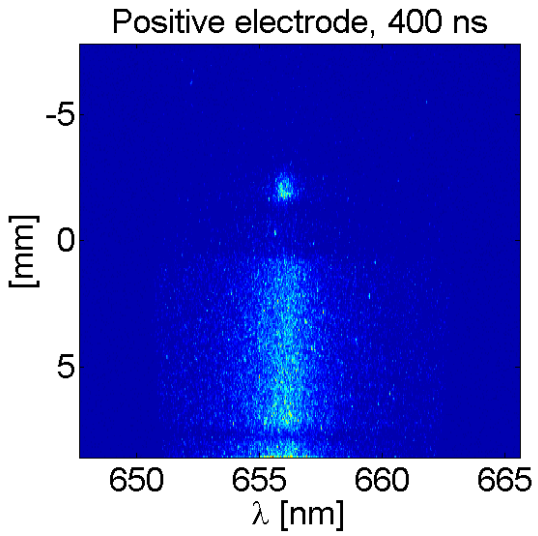


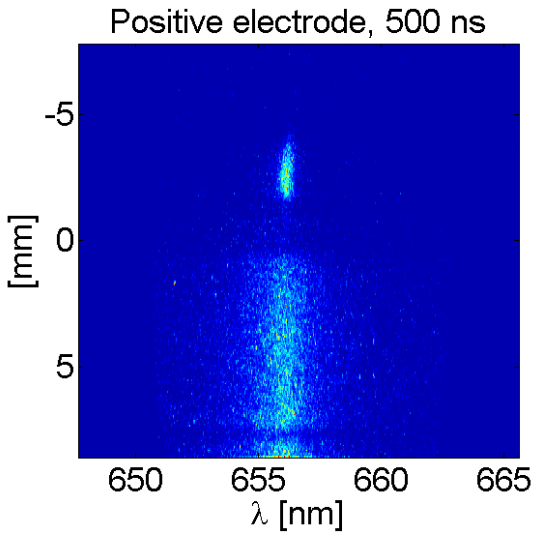
Almost constant plasma density outside the capillary of the order of 10^{15} cm^{-3}

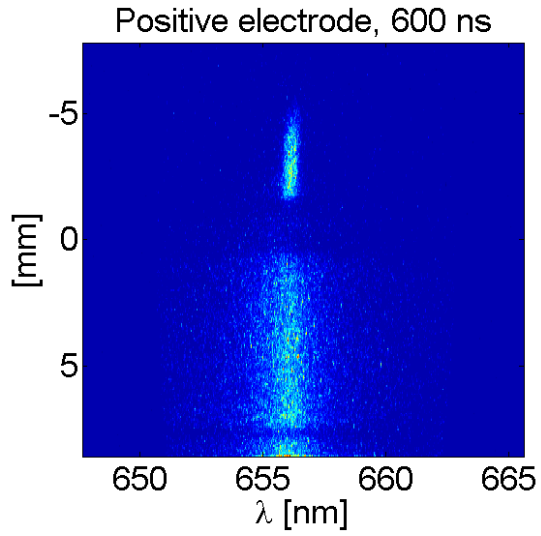
Longer interaction path

More details about ramp effects on electron bunch:
Marocchino et al.
"Experimental characterization of the effects induced by passive plasma lens on high brightness electron bunches"
Submitted PRL

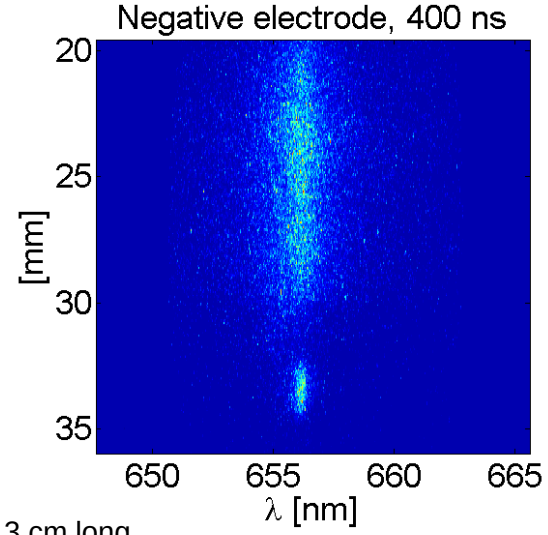
Plasma outflow: velocity

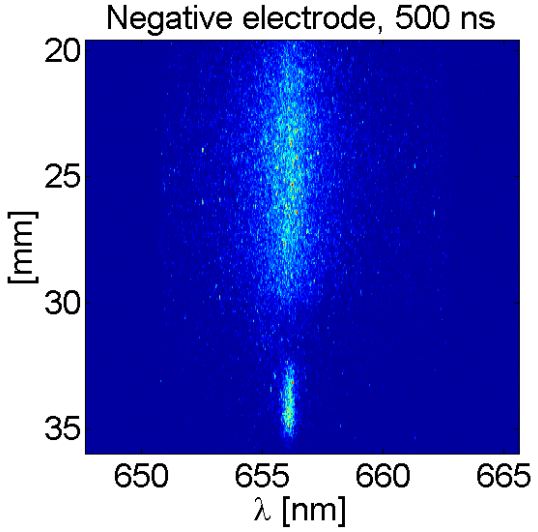


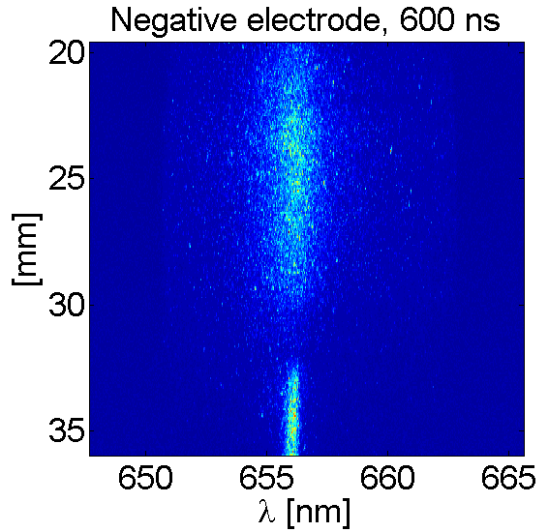




Measured velocity ~ 13500 m/s







3 cm long

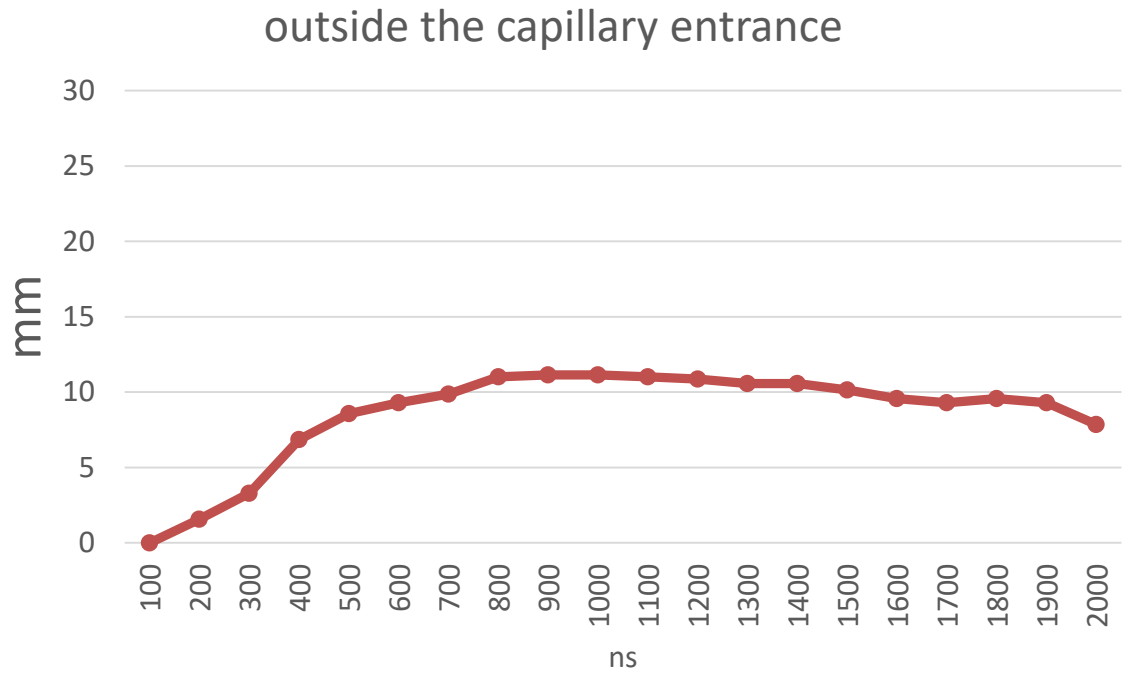
Plasma flows out of the capillary edges with different velocities, probably due to the different geometries of the electrodes.

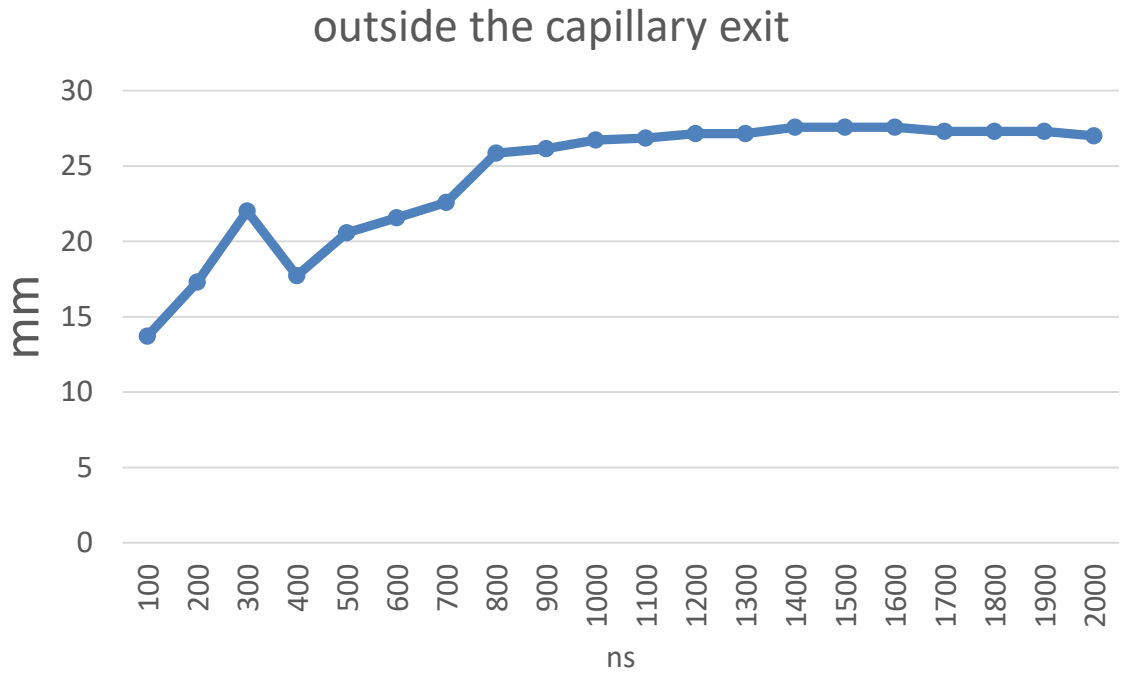
Measured velocity ~ 18400 m/s

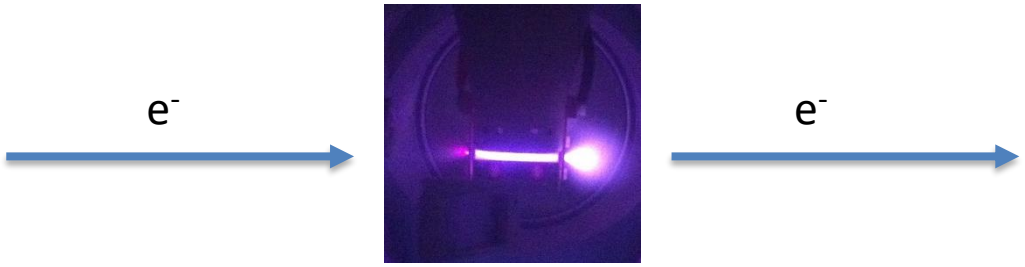
Plasma outflow: length

The beam encounters an uneven plasma density profile

Ramp length from the end of the capillary at different delays from the discharge trigger



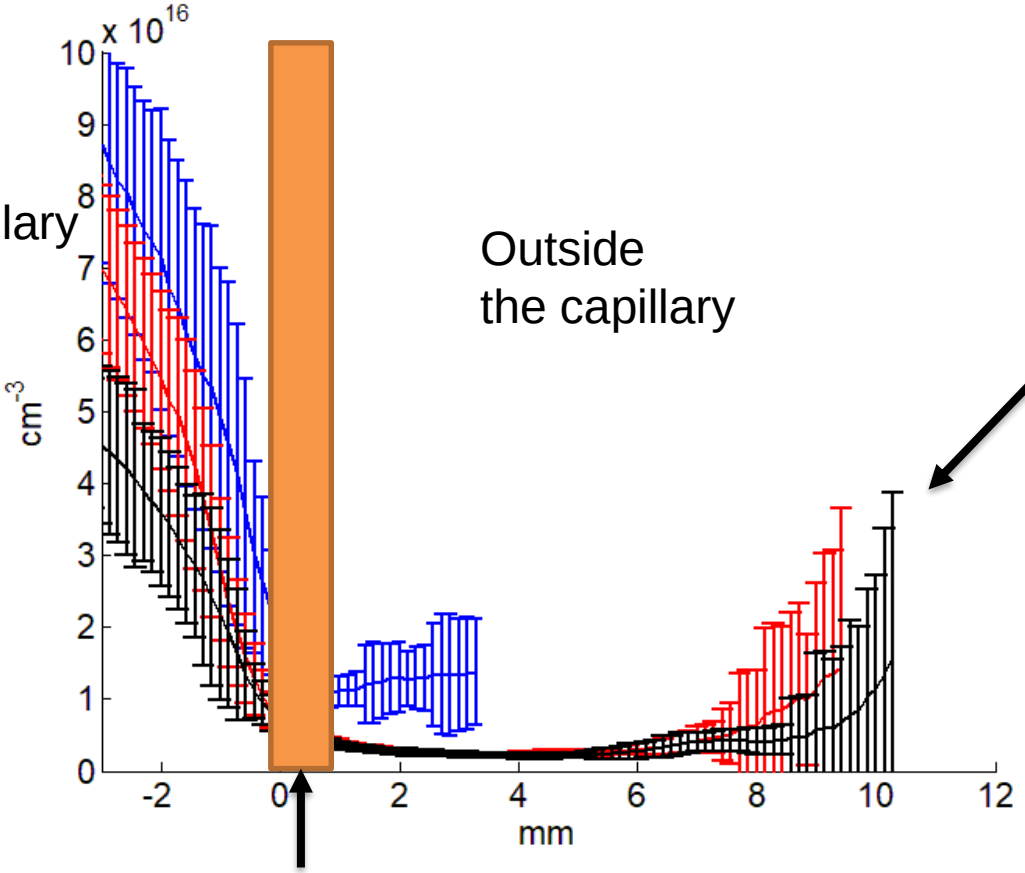




Plasma outflow: characterization

Outflow of the plasma density from the entrance
(with error bars averaged over 200 shots)

Inside
the capillary



Outside
the capillary

Electrode

The increasing of the error bars is caused by the variation of the plasma length at the end of the plume.

CONCLUSIONS

- Plasma outflow causes plasma density ramps outside the capillary
- We studied the main characteristics of the outflow of plasma from the ends of the capillary
- Further analysis
  - Study of the mechanisms acting on the plasma ramp generation (and cross-check with simulations)
  - **Mitigation** (or control) of the density ramps


THANKS FOR YOUR ATTENTION!