INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

SPARC LAB

SAPIENZA UNIVERSITÀ DI ROMA

Spectroscopic measurements based on Stark broadening of Hydrogen lines for electron density measurements in SPARC_LAB plasma-based acceleration experiments.

On behalf of SPARC_LAB collaboration

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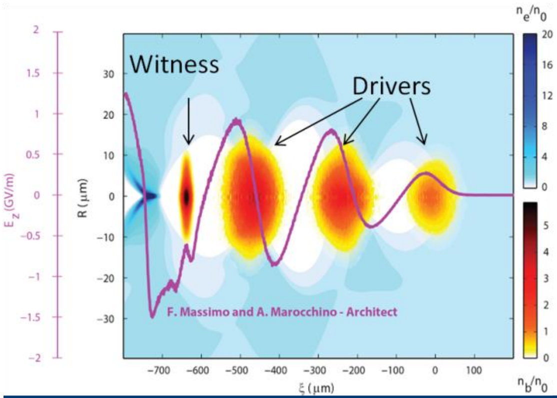
Outline

- Resonant Plasma Wakefield Acceleration (r-PWFA) experiment at SPARC_LAB
- Stark broadening mechanism for electron density measurements
- Experimental setup, tapered ablative capillaries
- Data analysis
- Results
- Conclusions and future perspectives

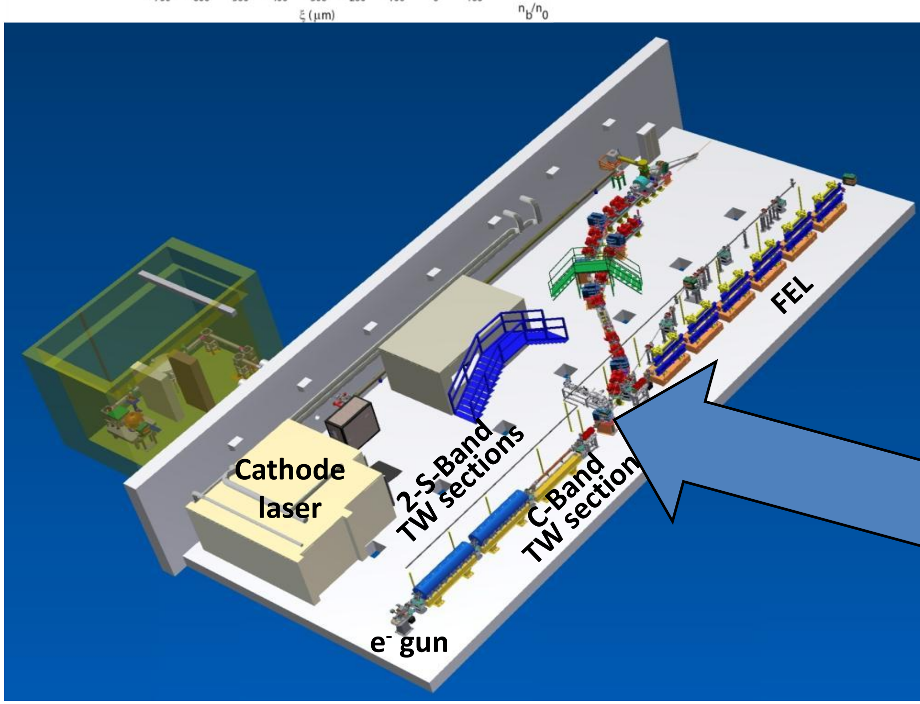
Resonant Plasma Wakefield Acceleration (r-PWFA) experiment at SPARC_LAB

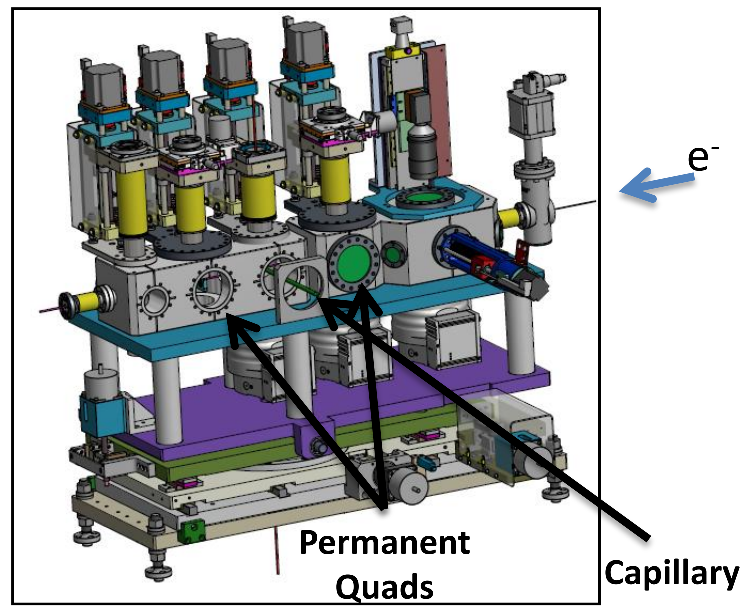


A train of 3 driver electron bunches excites a wakefield inside the plasma

A fourth bunch (witness) is injected at the accelerating phase gains energy from the wake

Plasma characteristics:
Hydrogen
$n_e = 2 \times 10^{16}\ cm^{-3}$
$\lambda_p = 300 \mu m$
Capillary of 1mm diameter

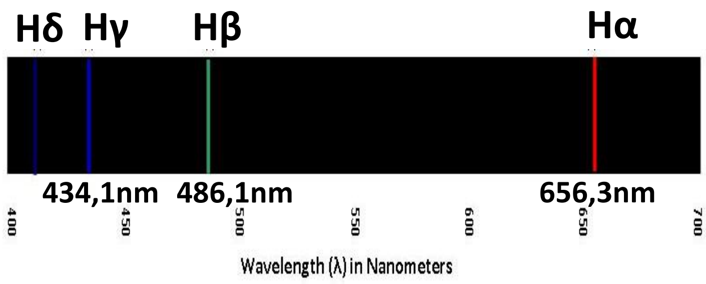




Stark Broadening mechanism

Light emitted by plasma allows to reconstruct the electron density from spectroscopy on emission line broadening due to Stark-Lo Surdo effect.

Ionized Hydrogen emits in visible range four lines of the Balmer series. The broaden of these lines depends on many mechanisms:



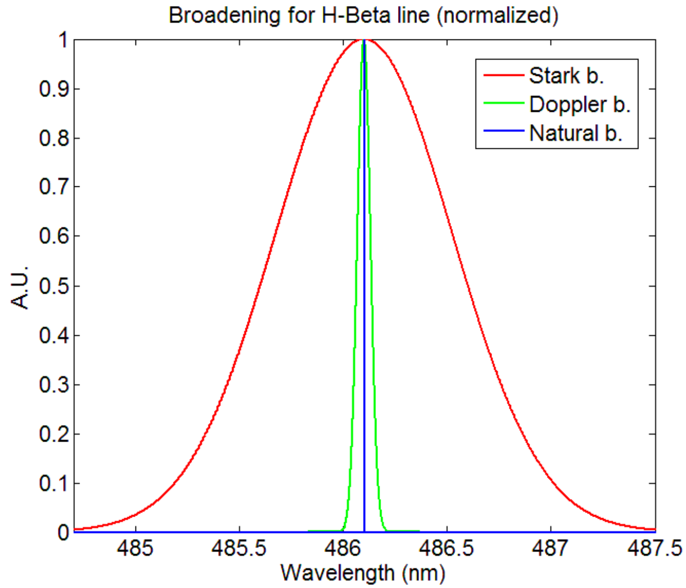
- **Doppler broadening** caused by thermal particle motion, depends on plasma temperature

$$\Delta\lambda[nm]=7,13*10^{-7}*T[K]^{3/2}\,\lambda$$

- **Stark broadening** caused by the emitter interaction with the electric field produced by nearby charges.

$$\Delta\lambda[nm]=\alpha(T)*n[10^{18}cm^{-3}]^{2/3}$$

- **Other broadenings** that for visible light, at temperatures of the order of 1-3eV can be neglected.

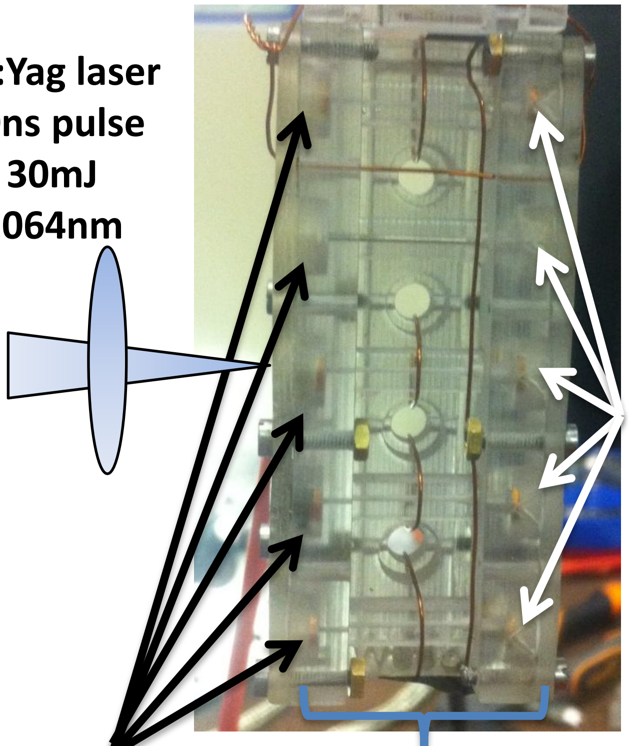


Simulated for $n_e = 2x10^{16}\ cm^{-3}$

I.H.Hutchinson, Principles of Plasma Diagnostics, Cambridge University Press 2002

Experimental Setup

Set of 5 capillaries with 500um diameter.



All capillaries are connected in parallel to the discharge circuit but only the one triggered by the laser produces plasma.

LASER-TRIGGER ABLATIVE CAPILLARIES

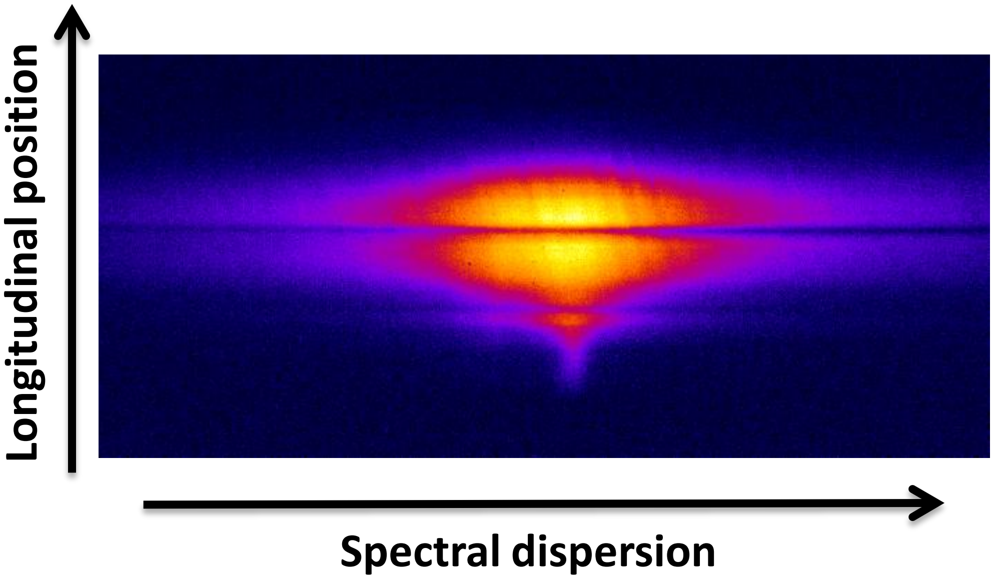
A voltage of 6.3kV between the two ends of the plastic capillary is applied. A short laser pulse is focused at the entrance from the cathode generating a small amount of plasma that due to an avalanche-like effect triggers the discharge.

The tapering has 10 deg. of opening angle.

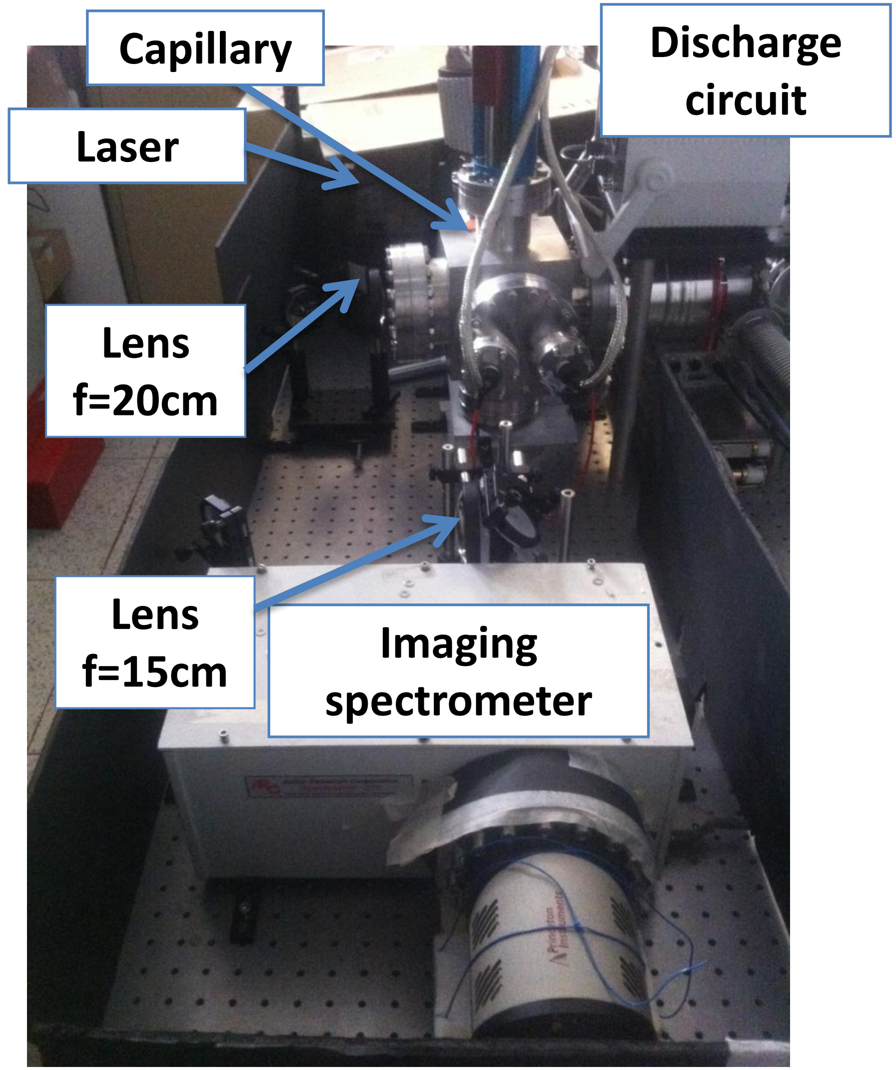
The tapering of the capillary allows to change the electron density along the capillary!

Experimental Setup

The self-emitted light after the discharge is then collected by an imaging system and sent to an imaging spectrometer.



Example of spectrometer output

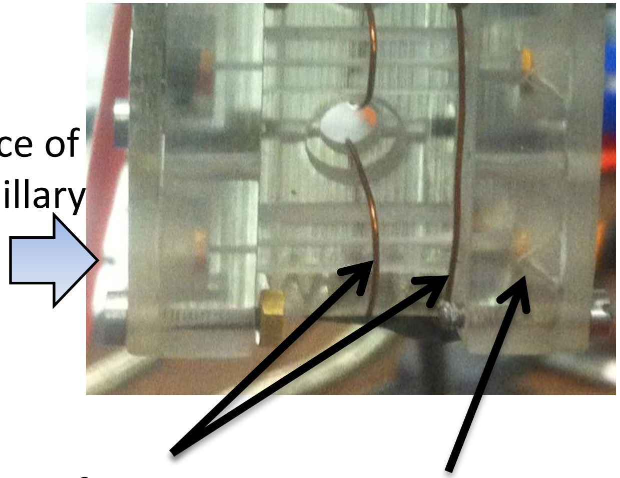


The light emitted from the capillary is imaged on spectrometer slit.

Analisys: image processing

The image acquired from the exit of the spectrometer is binned and the background (previously acquired) is subtracted.
Spatial references allow to determine the longitudinal dimension.

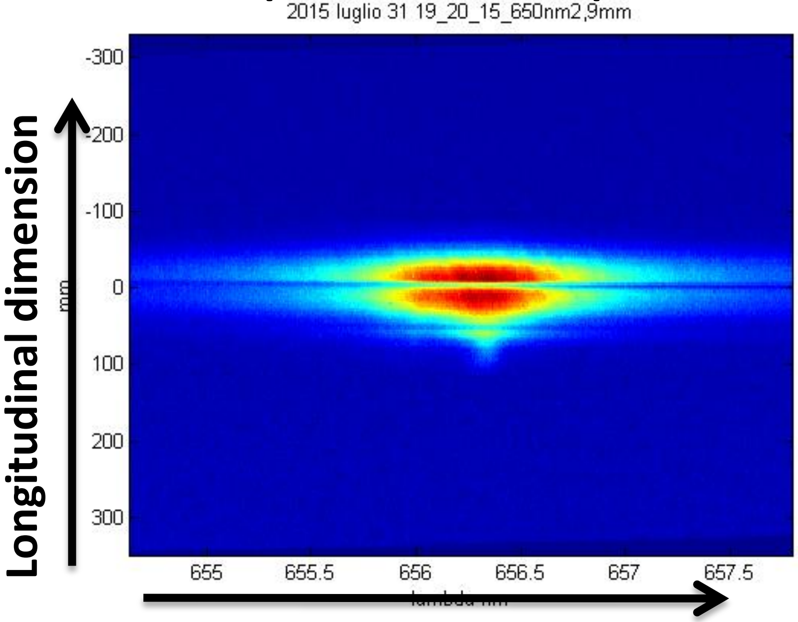
Entrance of the capillary



Reference wires of 450um

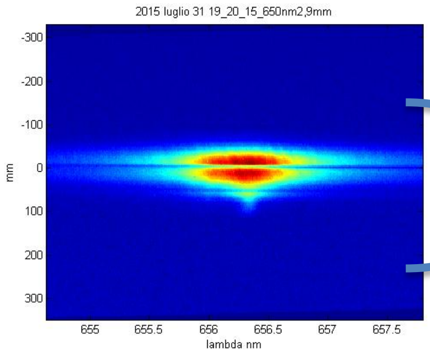
Electrode 1mm thick

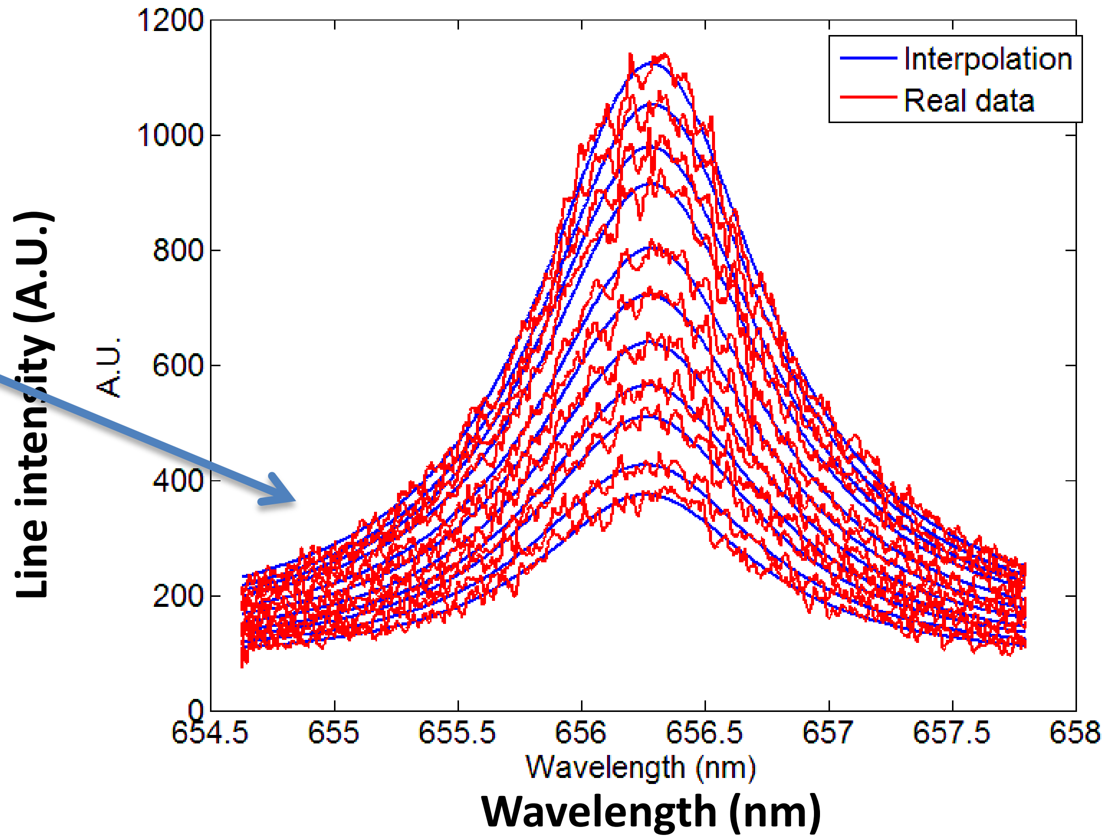
Spectrometer output



Analisys: fit and interpolation

Each row is fitted with a Lorentzian function (next implementation is for Voigt function). The FWHM is then measured.
For each position is then possible to reconstruct the plasma density.

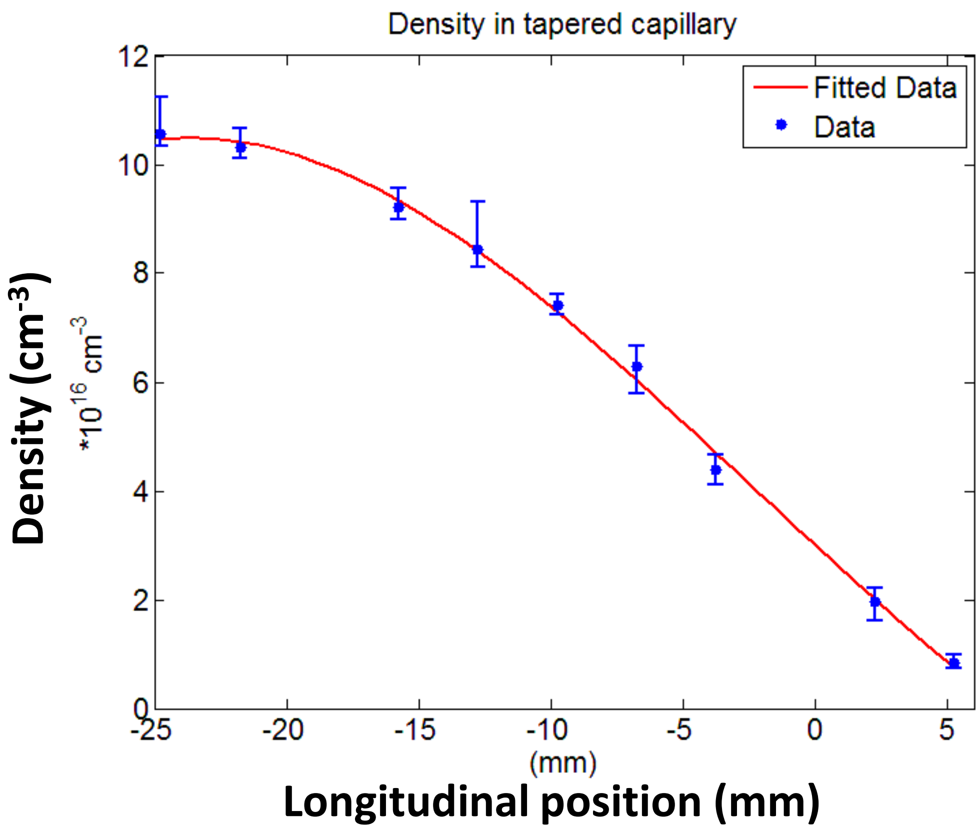




Every line corresponds to different position into the capillary

Analisys: results

The error bars show the variation around the mean value if more than one image has been acquired.

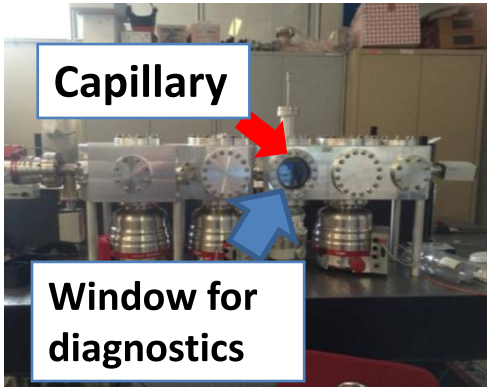


The results are fitted with a polynomial function of the third order

The density variation caused by the tapering was detected.
Data were averaged over 9 shots

Conclusions and future perspective

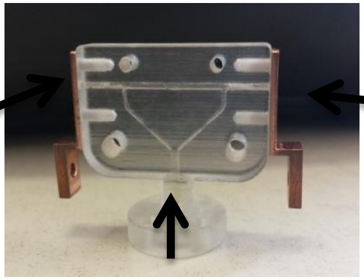
- Build new setup of for online measurements in SPARC_LAB bunker



Experimental chamber for r-PWFA experiment

- Test the new setup with H2 gas-filled capillary

Electrode

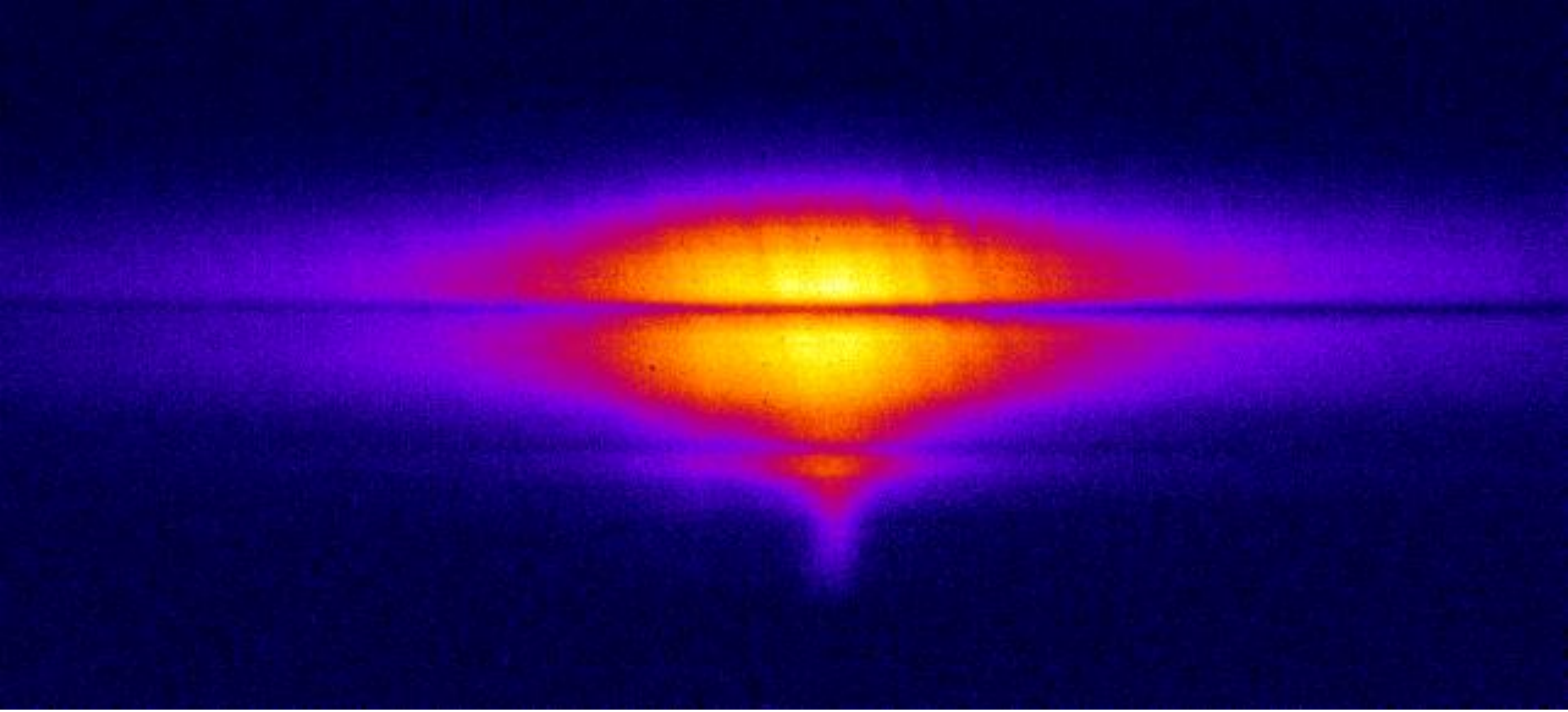


Electrode

Gas inlet

Gas-filled capillary prototype

- Measure density variation for different tapering of the ablative capillaries for future implementation in the SPARC_LAB bunker



THANK YOU!

Examples of broadening

Hα, λ=656,3nm

n_e (cm^{-3})	Expected broadening FWHM (nm)
$1*10^{16}$	0,250
$5*10^{16}$	0,733
$1*10^{17}$	1,163
$5*10^{17}$	3,402

Hβ, λ=486,1nm

n_e (cm^{-3})	Expected broadening FWHM (nm)
$1*10^{16}$	1,000
$5*10^{16}$	2,994
$1*10^{17}$	4,800
$5*10^{17}$	14,367

Doppler broadening 4eV 0,1008nm

Doppler broadening 4eV 0,0745nm

I.H.Hutchinson, Principles of Plasma Diagnostics, Cambridge University Press 2002

SPARC_LAB bunker