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EUROPEAN NETWORK FOR NOVEL ACCELERATORS
EuroNNAc4
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Development and characterization of Plasma Targets for LWFA experiments at SPARC_LAB

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Special topic
Laser Technology and LWFA Results (e-, p+, ion)

On behalf of the SPARC_LAB collaboration

INFN
Istituto Nazionale di Fisica Nucleare

SPARC LAB

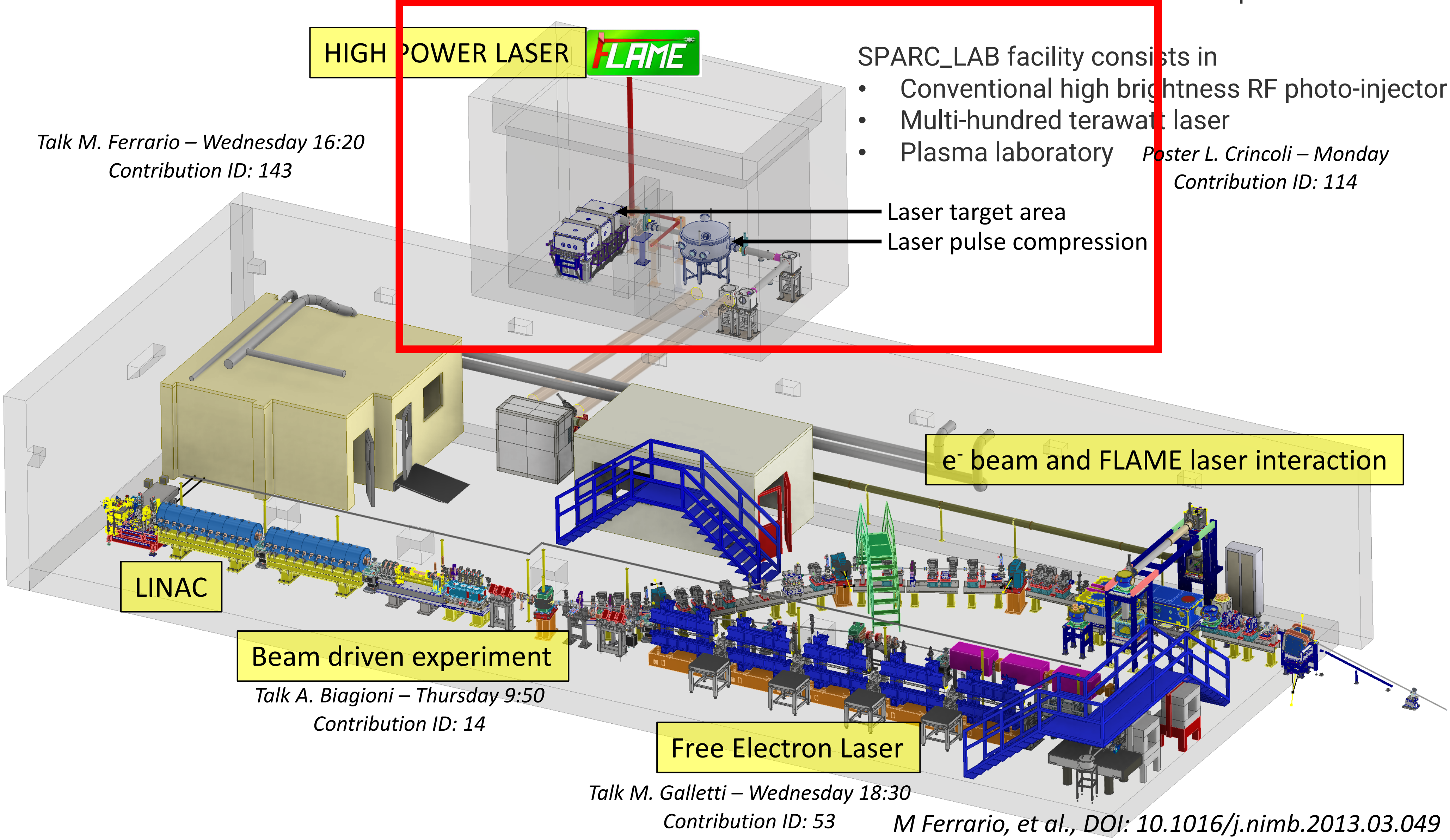
SPARC_LAB facility

The main focus of the SPARC_LAB facility is the study and implementation of several plasma-based acceleration and radiation generation techniques

SPARC_LAB facility consists in

- Conventional high brightness RF photo-injector
- Multi-hundred terawatt laser
- Plasma laboratory

Poster L. Crincoli – Monday
Contribution ID: 114



Talk M. Ferrario – Wednesday 16:20
Contribution ID: 143

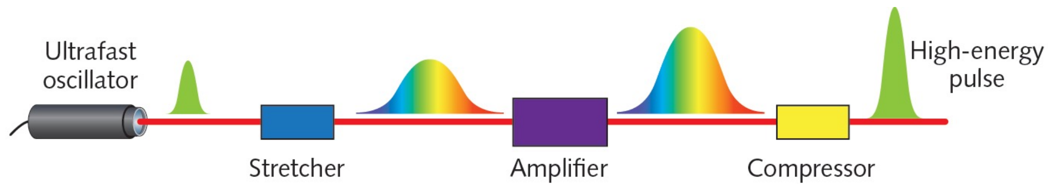
Talk A. Biagioni – Thursday 9:50
Contribution ID: 14

Talk M. Galletti – Wednesday 18:30
Contribution ID: 53

M Ferrario, et al., DOI: 10.1016/j.nimb.2013.03.049

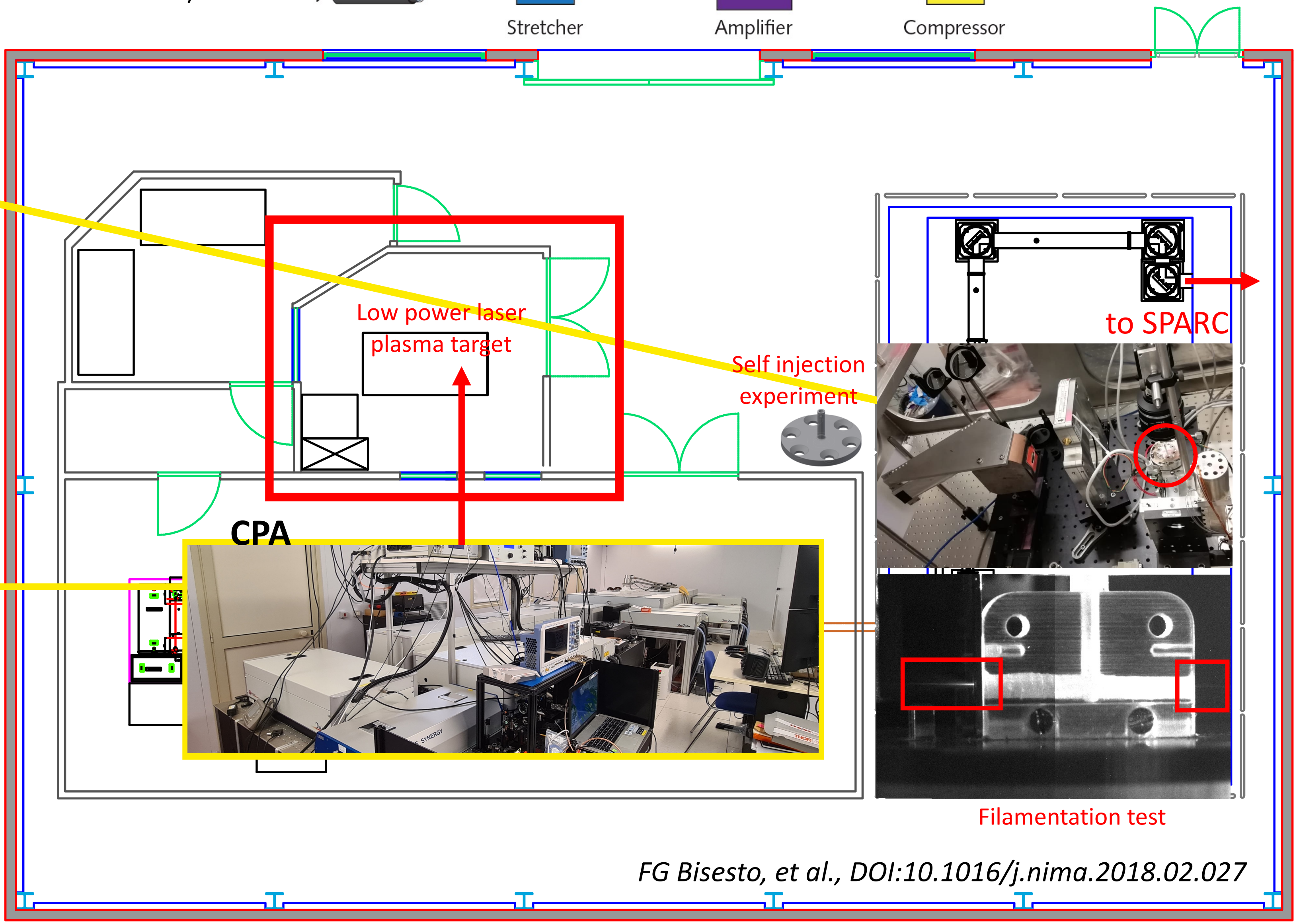
The FLAME high power laser

Strickland and Mourou 1985
Nobel Prize in Physics 2018



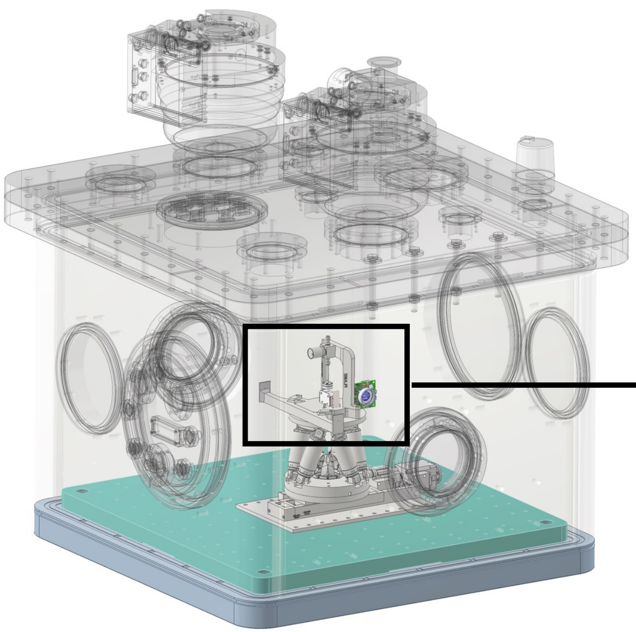
MAIN PULSE	
Peak power	250 TW
Energy on target	7 J
Rep. rate	10 Hz
Temporal length	25 fs
FW $1/e^2$ @ focus	20 µm
Intensity	10^{19} W/cm^2
Contrast-ratio	10^{10}

PROBE PULSE	
Energy on target	10 mJ
Temporal length	50 fs
FW $1/e^2$ @ focus	120 µm
Intensity	10^{16} W/cm^2

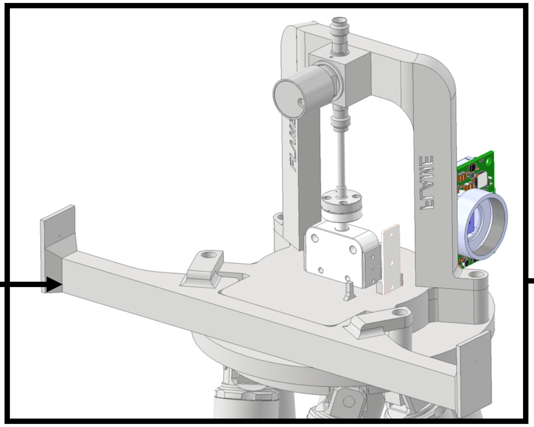


FG Bisesto, et al., DOI:10.1016/j.nima.2018.02.027

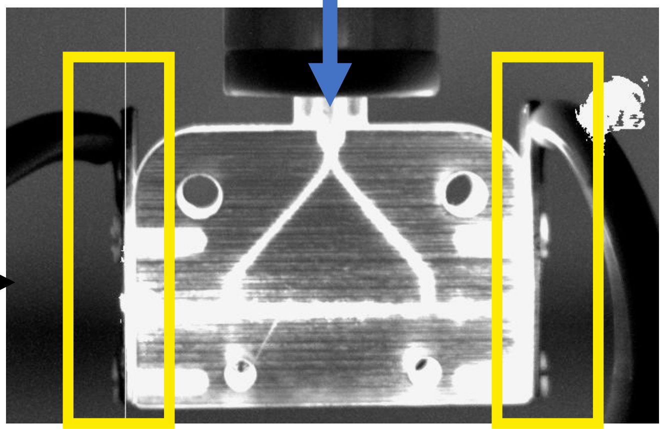
Laser-plasma test station @FLAME



Preformed plasma capillary

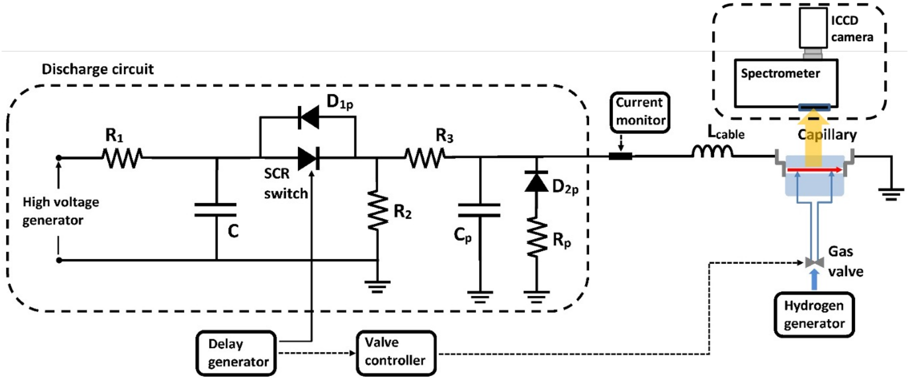


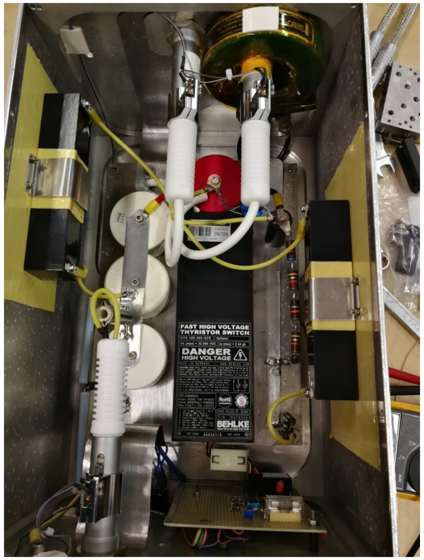
H_2



- Diameter: *mm scale*
- Length: *cm scale*
- H_2 pressure: *tens of mbar*

Discharge circuit





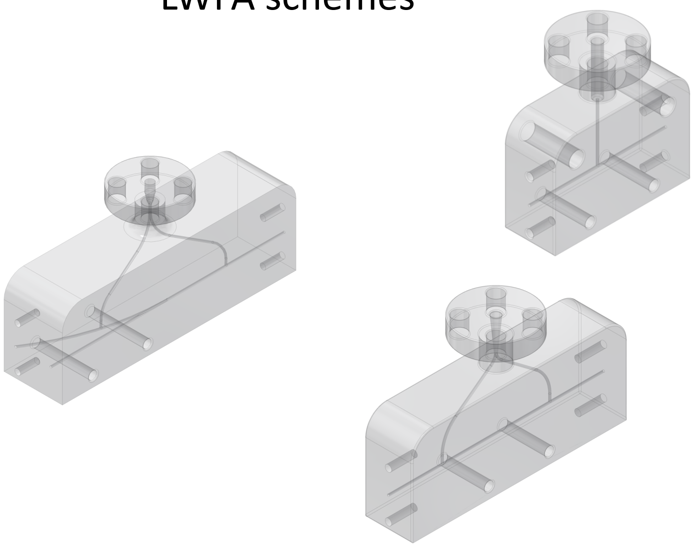
- Discharge: *20 kV*
- Current: *up to 2kA*
- Plasma density: *10^{18} cm^{-3}*

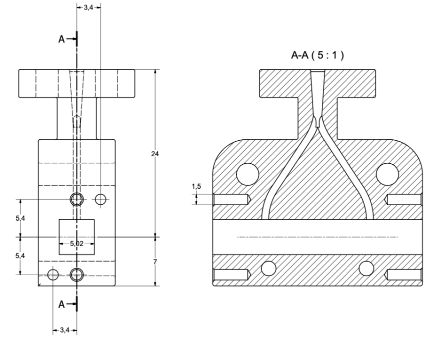
- Repetition rate: *1 Hz*
- Vacuum: *10^{-7} mbar*

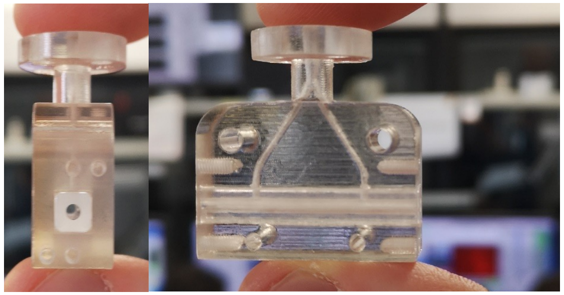
A Biagioni, et al., DOI: 10.1088/1748-0221/14/03/C03002

Capillary tests and laser parameters

Study and characterisation of different kinds of capillaries for LWFA schemes

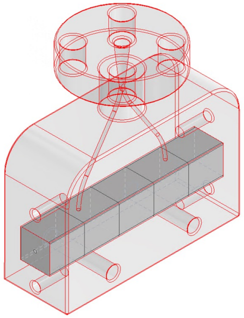


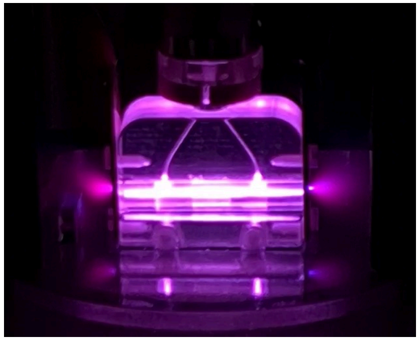


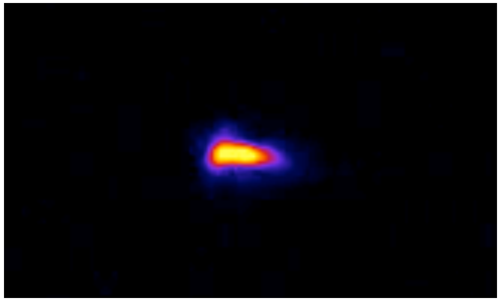


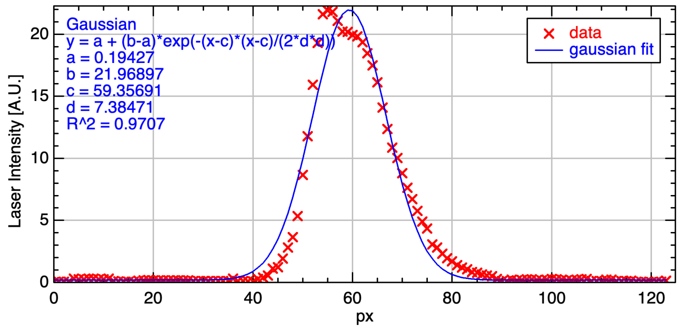
damage preventing

3D-printed plastic holder
+
5 sapphire pieces



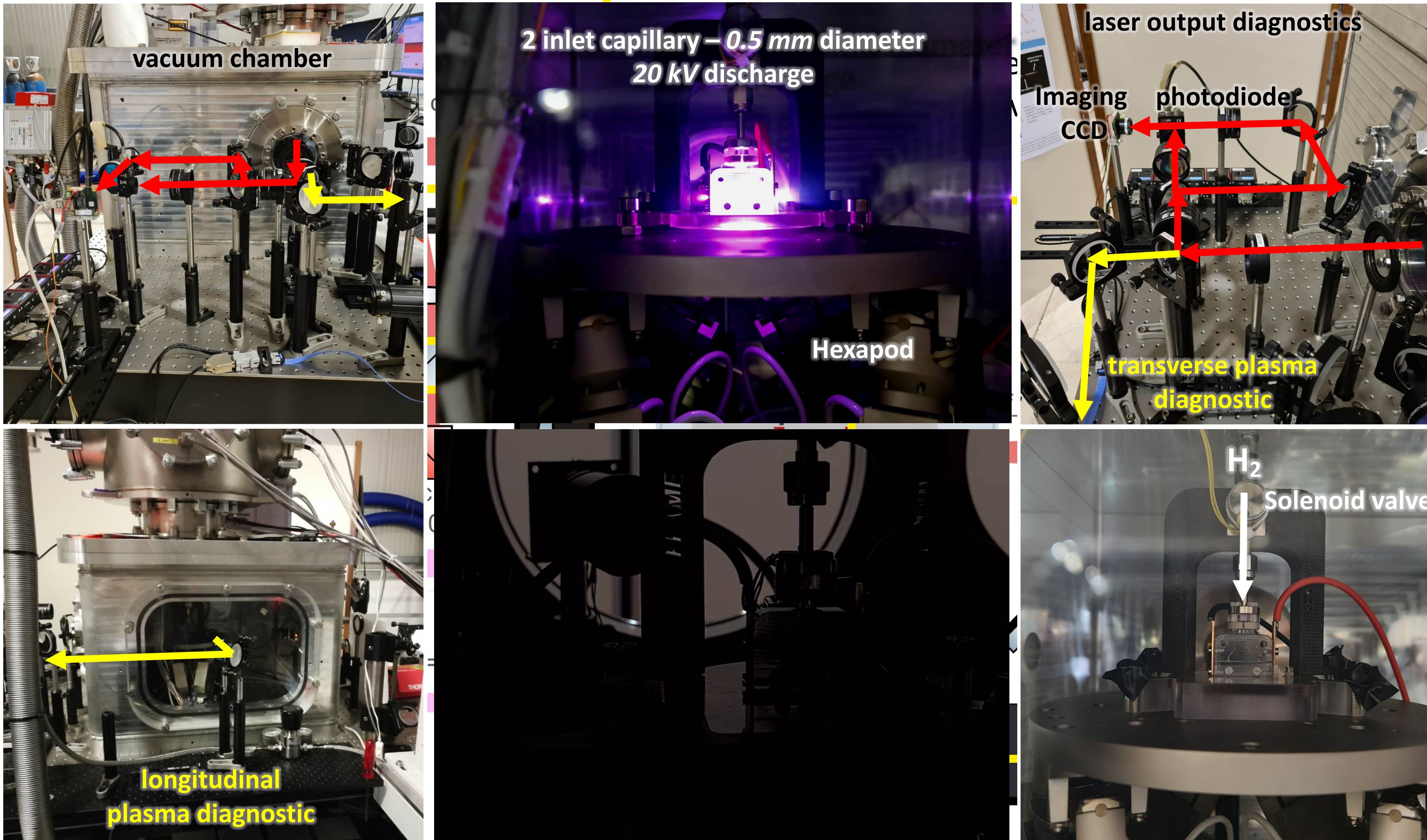






- Oscillator: *80 MHz, 220 mW*
- Probe: *10 mJ, 50 fs, 60 µm* focus FWHM

Experimental Setup

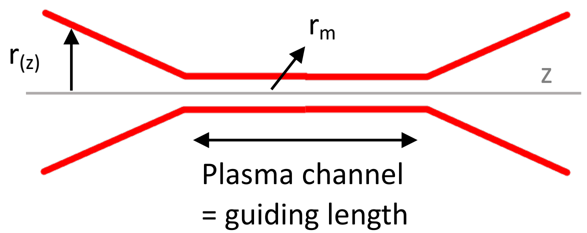


Laser guiding in a capillary waveguide

e^- energy gain ∝ Acceleration field × Acceleration length ⟶ πZ_R

optical guiding in plasma

Rayleigh length => Diffraction $Z_R = \pi \frac{r_i^2}{\lambda_0}$

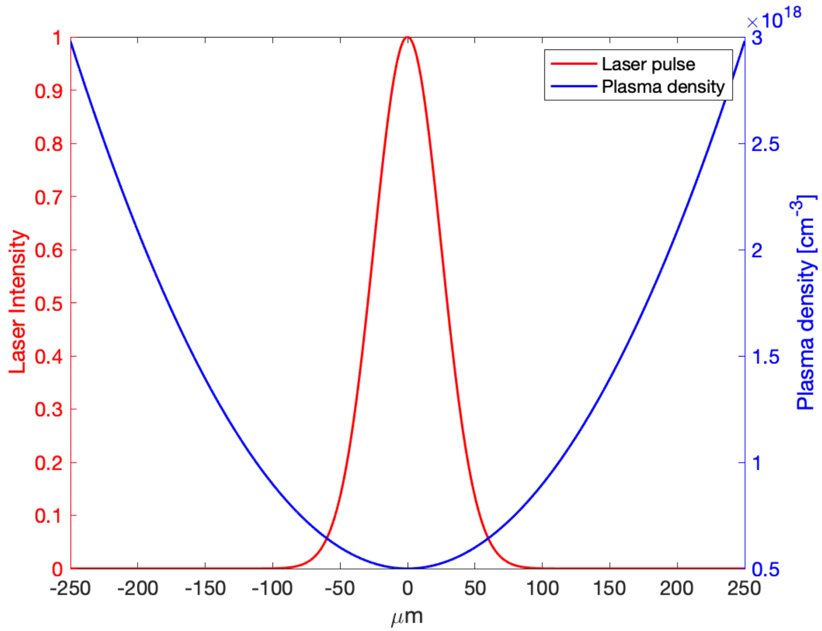


ex: for $r_i = 60\ \mu m$
- $n_0 \sim 2.5 \times 10^{18}$ cm^{-3}
- $n_d \sim 5 \times 10^{17}$ cm^{-3}

- gaussian intensity laser pulse $I(r) = I_0 e^{-\left(\frac{2r^2}{r_i^2}\right)}$
- parabolic density distribution plasma channel

$$n(r) = n_0 + \left(\frac{r}{r_m}\right)^2 n_d \quad \text{for} \quad r \le r_m$$

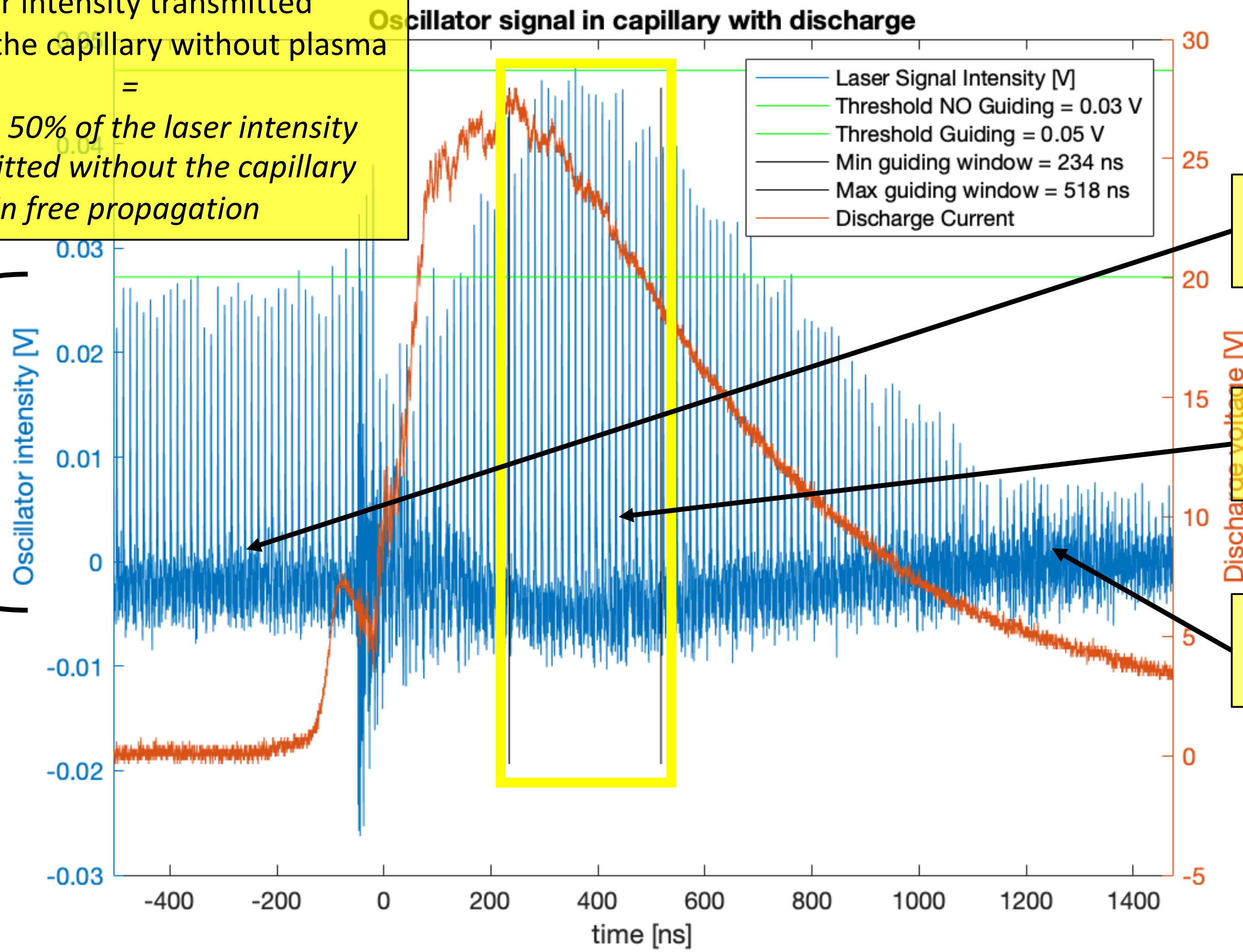
- if waist radius $r_i = r_m = (\pi\, r_e n_d)^{-\frac{1}{2}}$



- r_m = matching radius
- n_0 = plasma density on the axis
- n_d = density difference axis-walls

Oscillator pulses guiding test (nJ level)

Laser intensity transmitted through the capillary without plasma
=
approx. 50% of the laser intensity transmitted without the capillary in free propagation



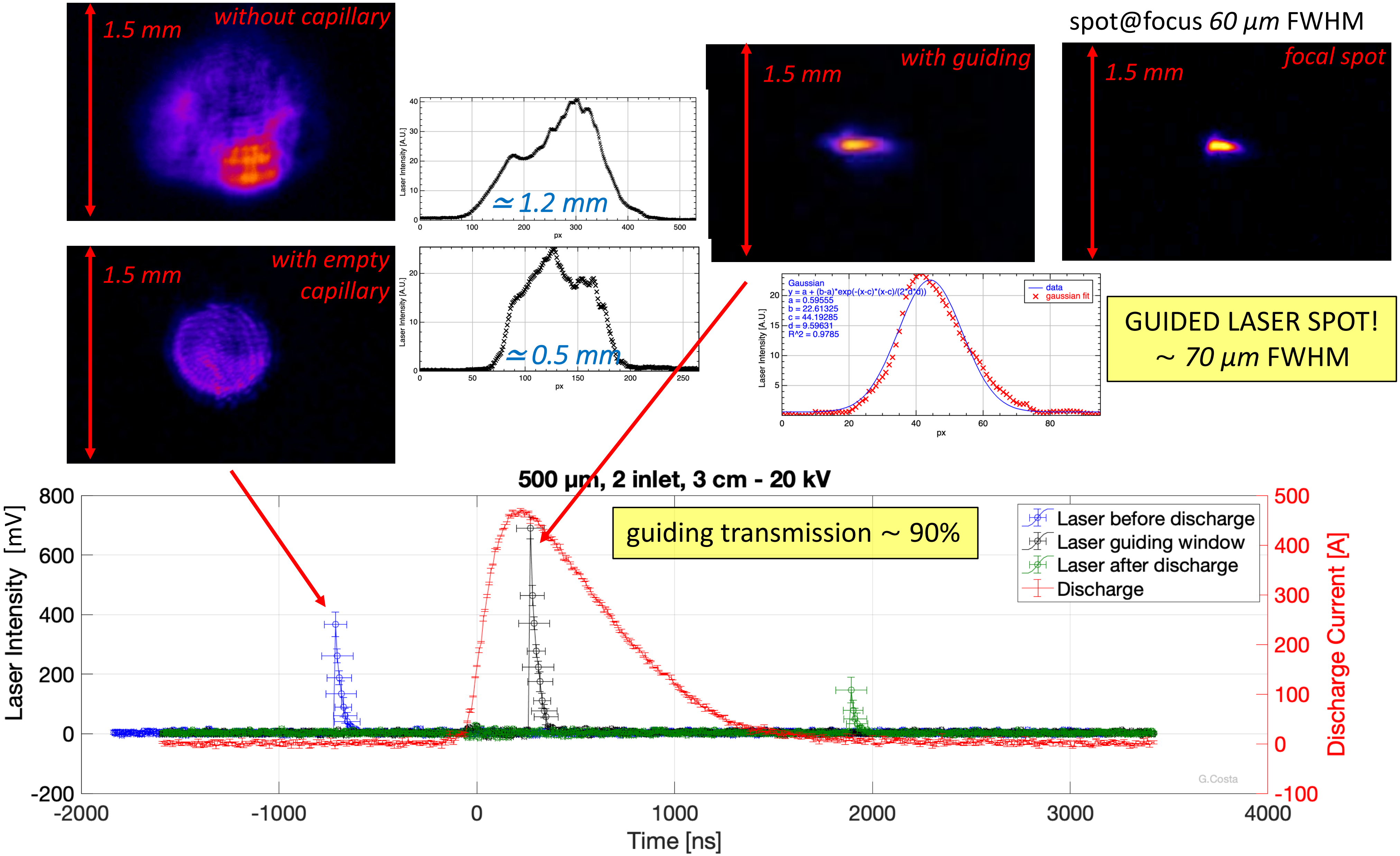
Before the discharge with capillary without plasma

Guiding window *with capillary with plasma*

Ricombination process with capillary

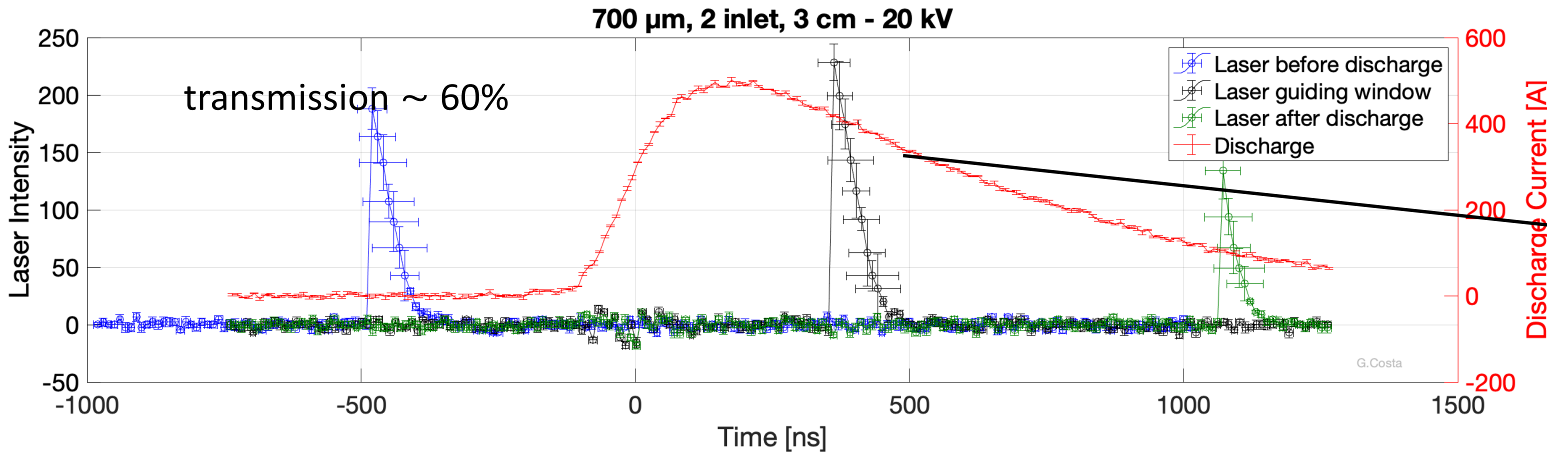
G Costa, et al., DOI: 10.1088/1742-6596/1596/1/012044

Guiding in plasma density parabolic profile (mJ level)



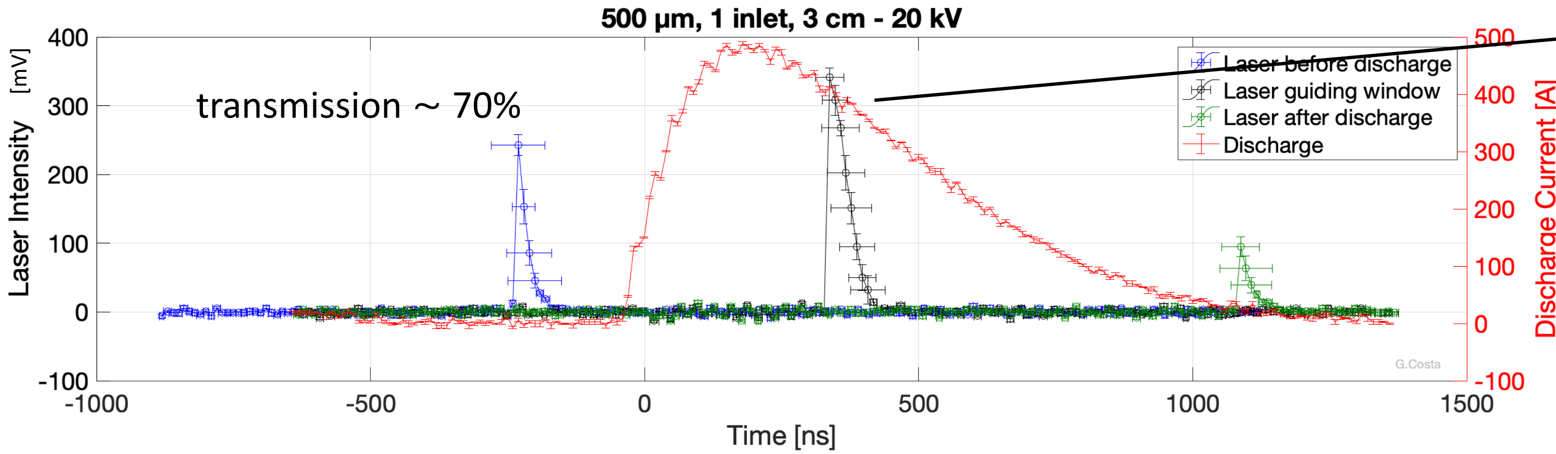
G Costa, et al., submitted

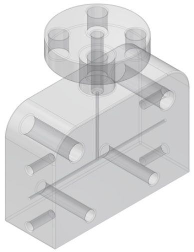
Guiding in plasma density parabolic profile (mJ level)



700 *µm diameter*
lower plasma density
1.2 x 10^18 cm^-3

500 *µm diameter* - 1 inlet
less uniform longitudinal density





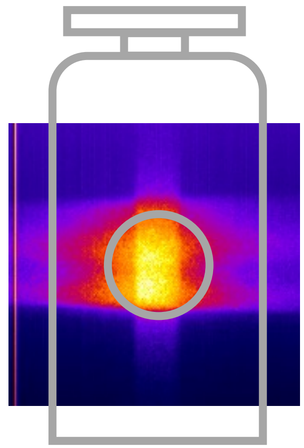
Spectroscopic plasma density measurements

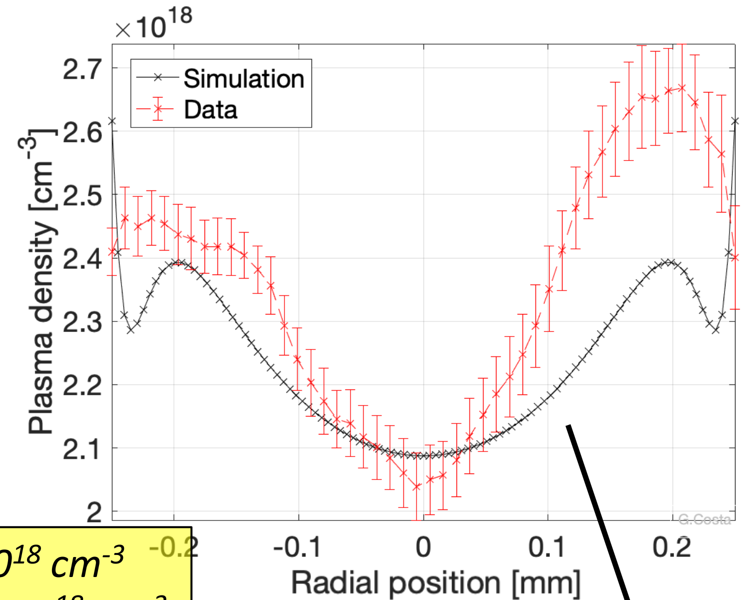
Stark Broadening effect:

measuring the spectral broadening of the emission lines of the hydrogen caused by the pressure.

$$n_e = 8.022 \times 10^{12} \left(\frac{\Delta\lambda}{\alpha}\right)^{\frac{3}{2}} cm^{-3}$$

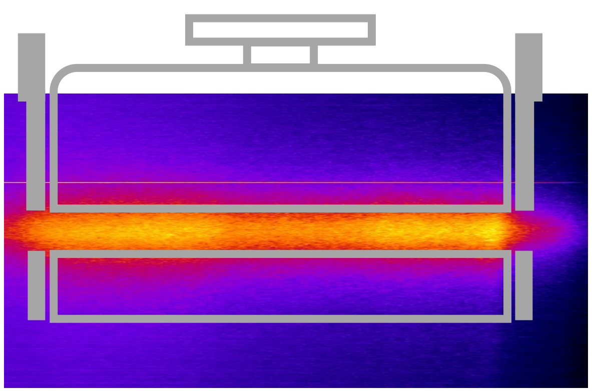
- $\Delta\lambda$ = FWHM H_β
- H_α = 656 nm, H_β = 486 nm
- α = const.

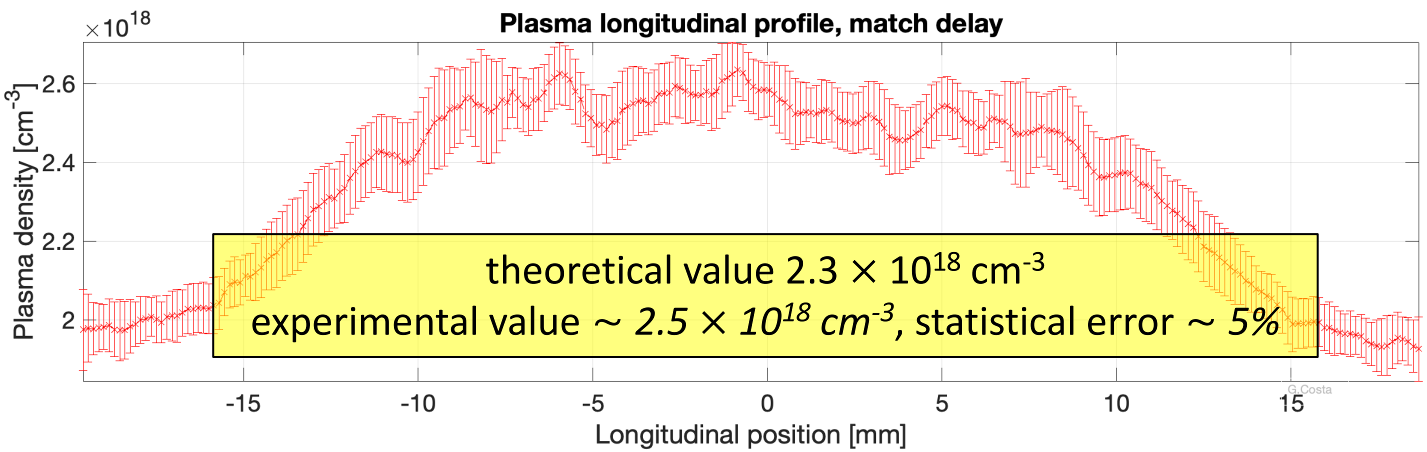




theoretical value *0.6 × 10^18 cm^-3*
experimental value ~ *0.5 × 10^18 cm^-3*
statistical error ~ *5%*

Bobrova Model, DOI: 10.1103/PhysRevE.65.016407



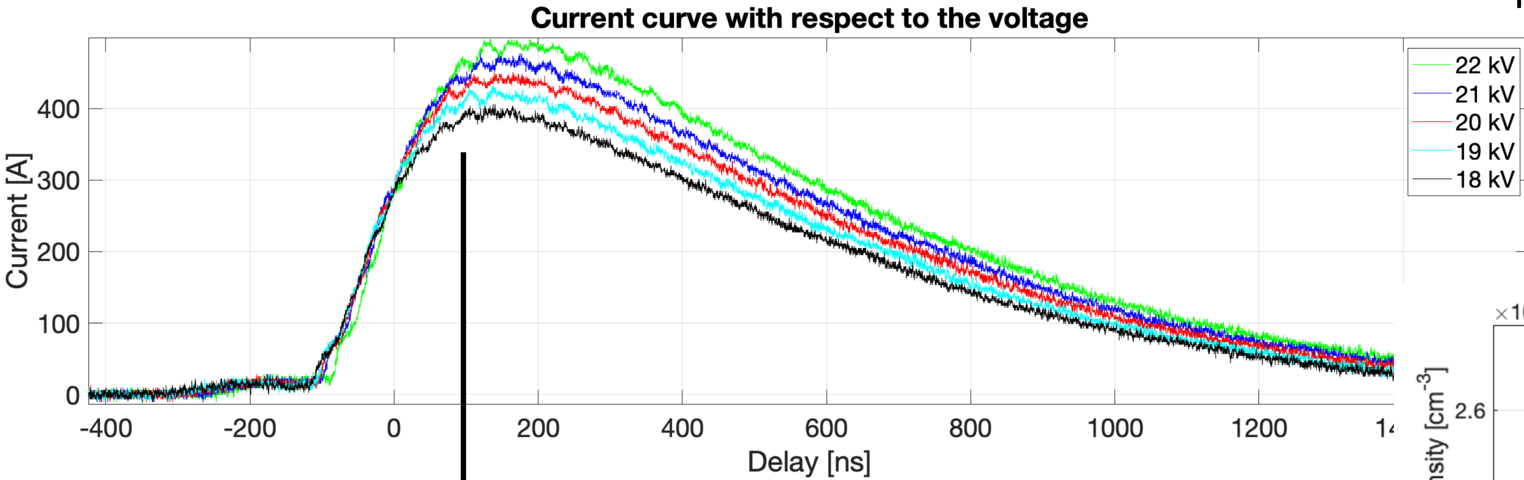


theoretical value 2.3 × 10^18 cm^-3
experimental value ~ *2.5 × 10^18 cm^-3*, statistical error ~ *5%*

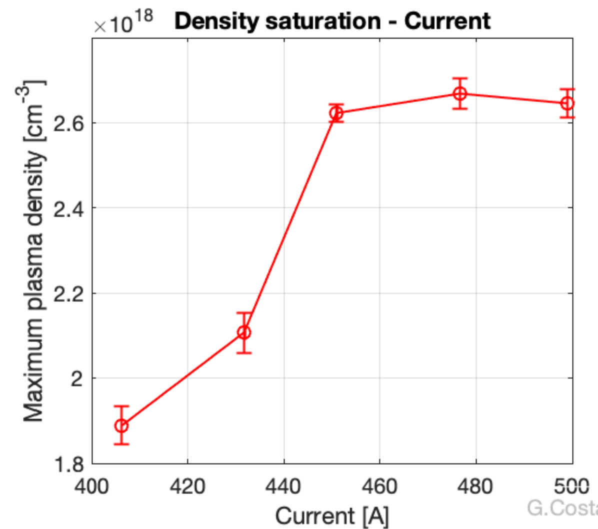
G Costa, et al., DOI: 10.1088/1361-6587/ac5477

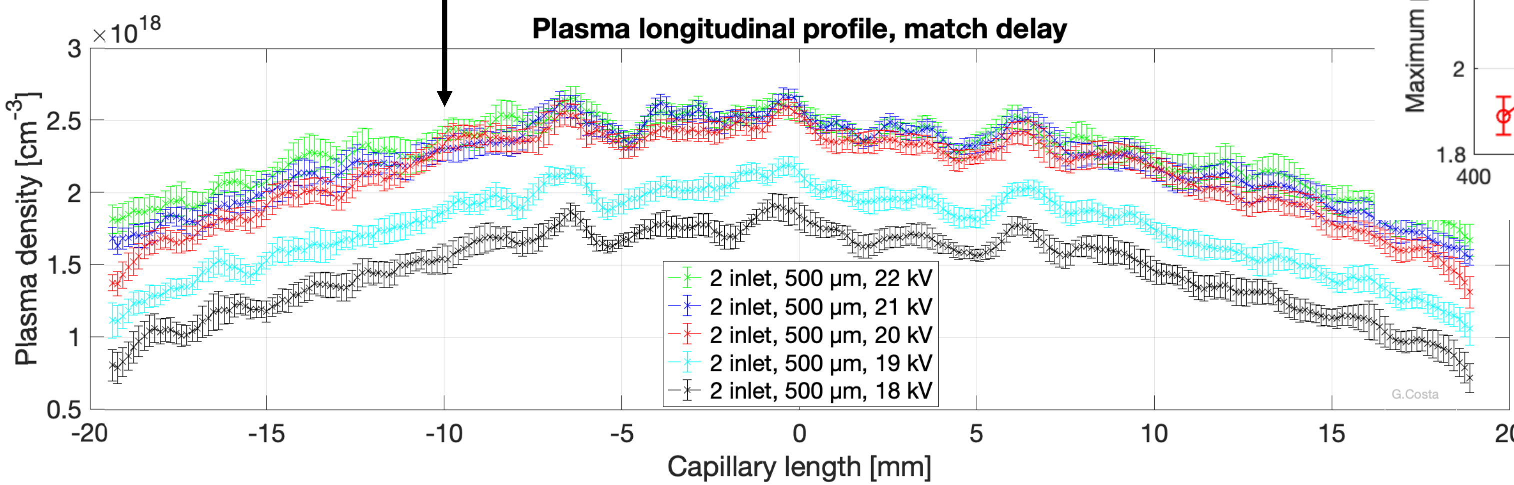
Ionization level distribution for plasma density

Plasma density measurements by varying the peak current of the discharge curve → complete ionization level



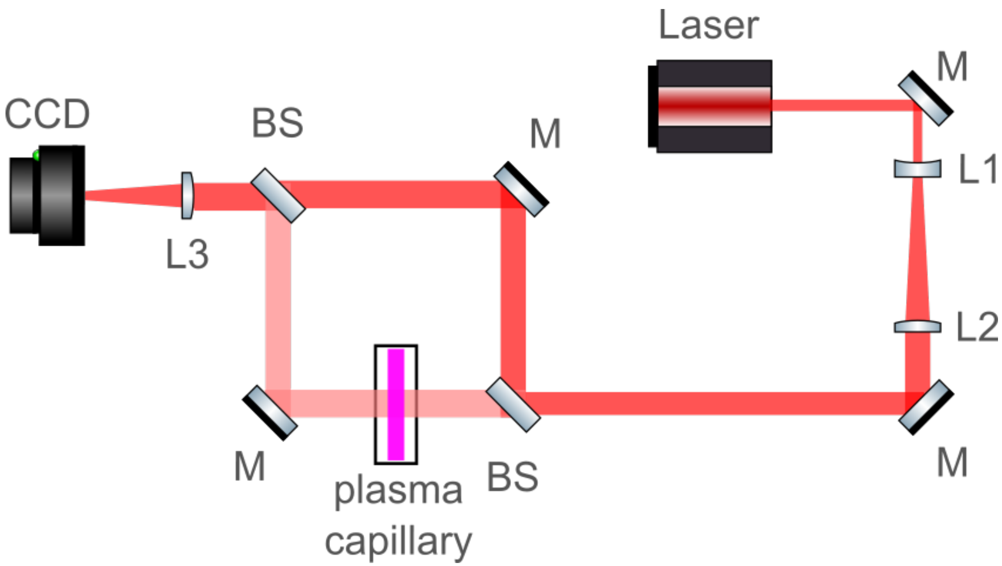
H_2 input pressure constant





G Costa, et al., DOI: 10.1088/1361-6587/ac5477

Interferometry for capillary discharge



Mach Zehnder interferometer:

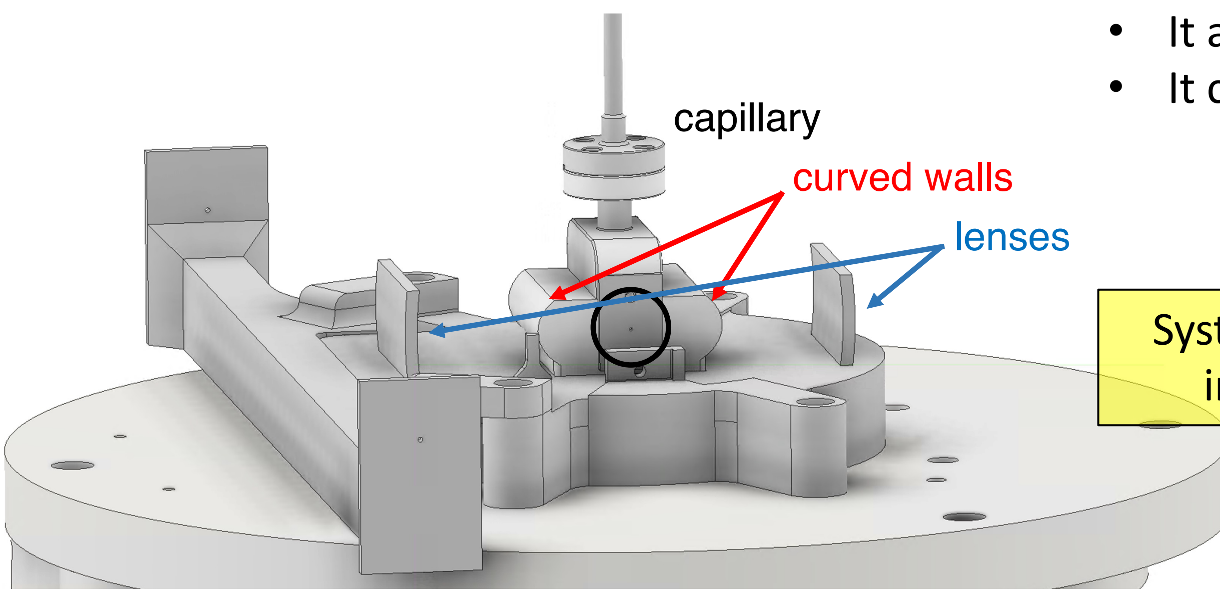
Optical path difference between probe and reference laser

⇩

interference fringes

Technique generally used for

- unconfined plasma sources (e.g. gas jets)
- channels with a square cross section



- It allows a flexible and compact setup,
- It can measure a wide range of densities

System to compensate for laser phase shift induced by circular channel geometry

Conclusions

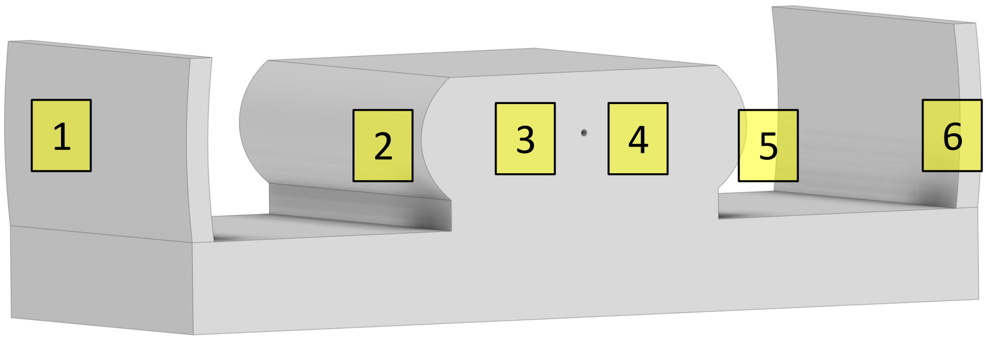
- Test area for new laser-plasma interaction targets @ SPARC_LAB
- Overview of plasma target used for LWFA experiments
- Low power laser pulse guiding in a parabolic plasma profile
- Transverse and longitudinal plasma profiles diagnostic
- Ongoing tests for interferometric measurements in plasma capillaries

Thank you for the attention

On behalf of the SPARC_LAB collaboration

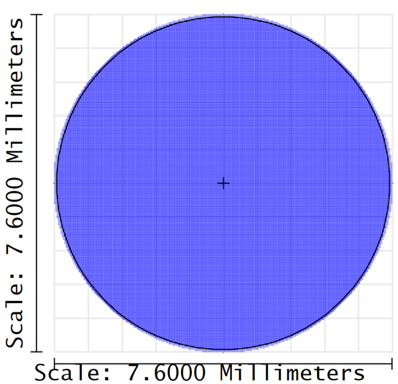
Backup slides

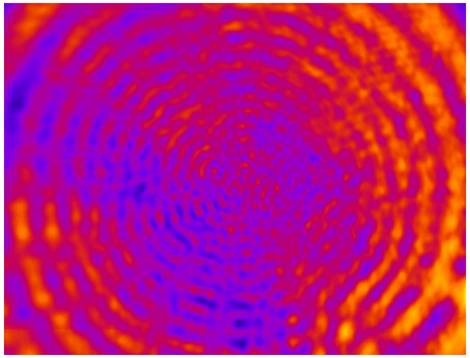
Interferometry for capillary discharge



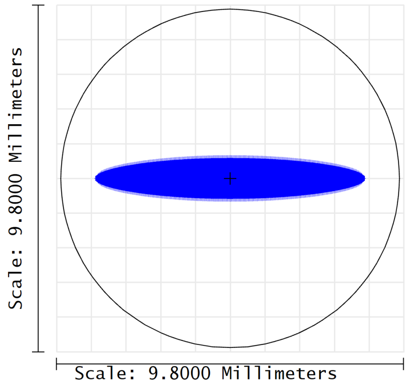
1. 1^{st} cylindrical lens
2. 2^{nd} cylindrical lens = 1^{st} external channel wall
3. 3^{rd} cylindrical lens = 1^{st} internal channel wall
4. 3^{rd} cylindrical lens = 2^{nd} internal channel wall
5. 3^{rd} cylindrical lens = 2^{nd} external channel wall
6. 2^{nd} cylindrical lens

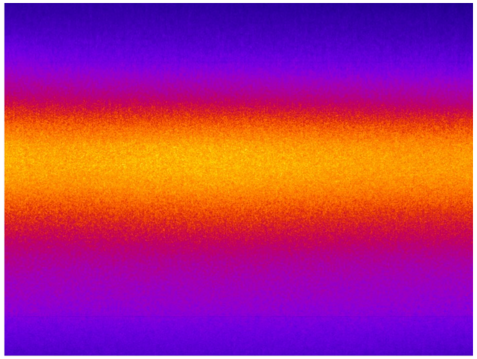
Beam initial conditions





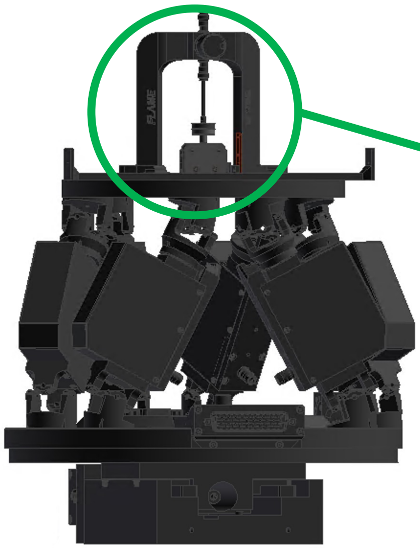
Final image plane

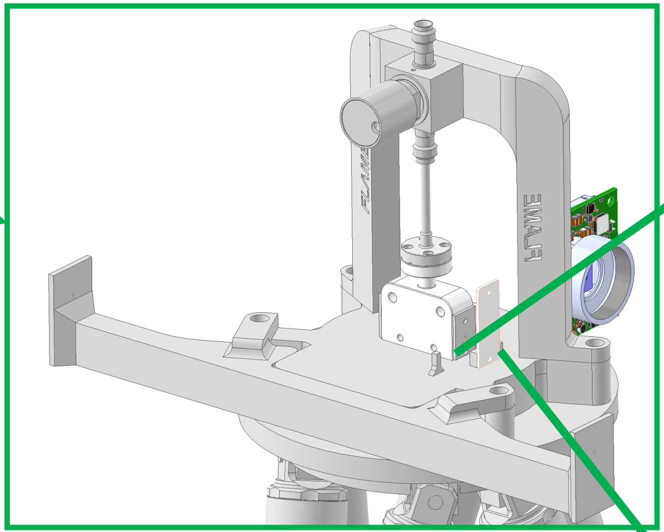


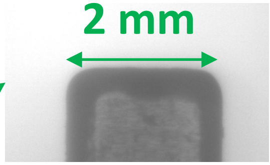


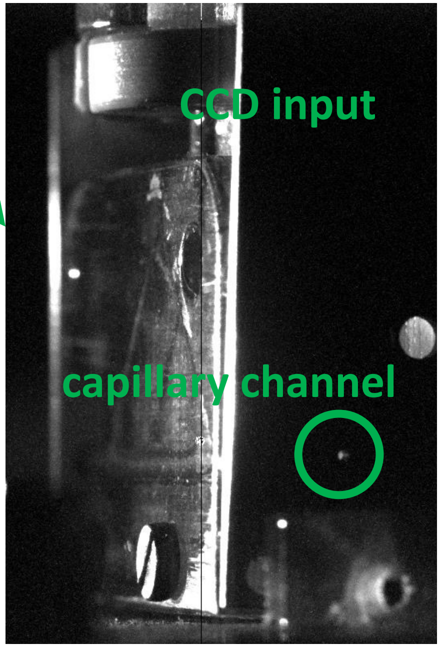
FG Bisesto, et al., DOI: 10.1088/1612-202X/ab6bd3

Laser alignment in the plasma channel



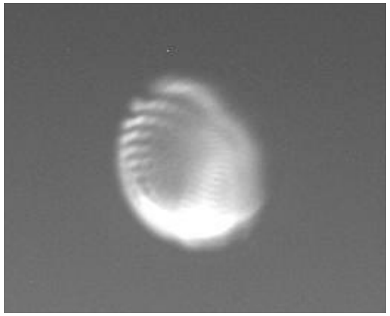






CCD output

20 μm offset



few mrad tilt