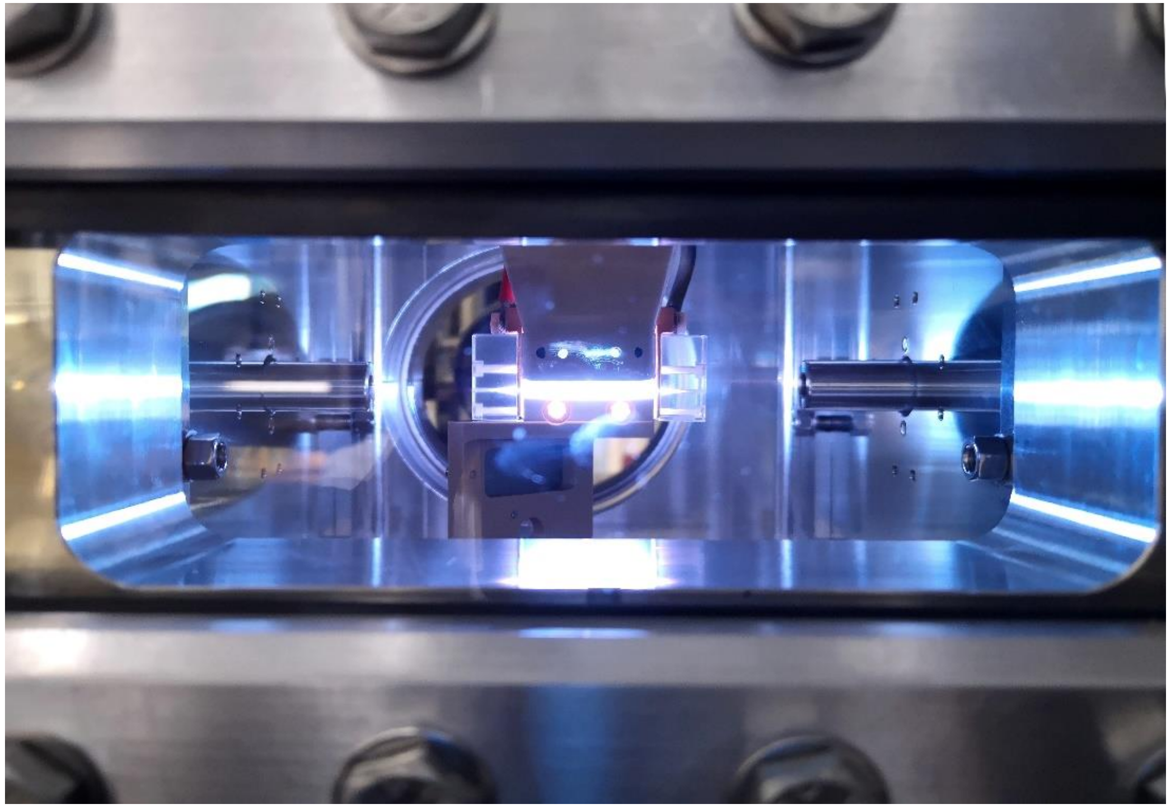
2nd TDR Review Committee

Plasma section

26-27th October 2021

A. Biagioni, R.Pompili



Introduction

- **High repetition rate capillaries, from 100 to 400 Hz:**
  - Erosion of the capillary walls (first results have been obtained)
  - Design of the HV pulser (our HV-pulser is already able to reach 2.5kA at 23kV)
  - Refill time of the capillary
  - Vacuum requirements

- **Design of 40cm-long Gas-filled discharge-capillary**

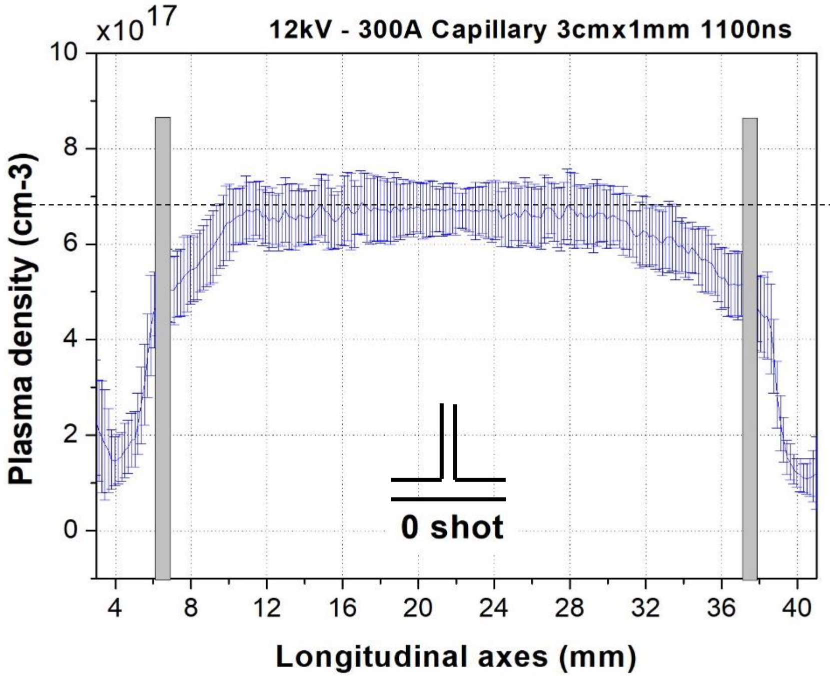
- **Tests on channel shaping allow us to modify the longitudinal profile to reduce and control spatial density variations**

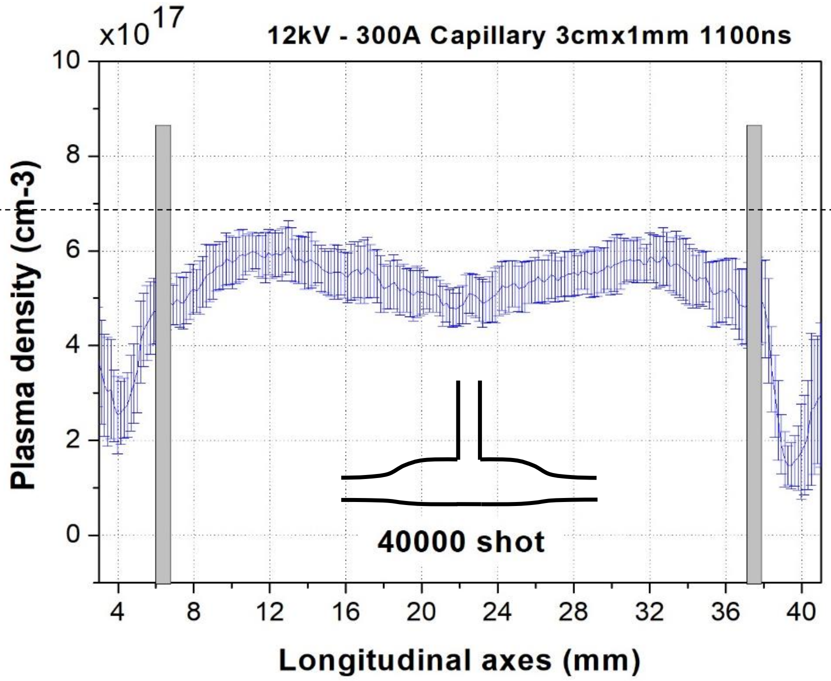
- **Vacuum pumping system improvements allow a discharge repetition rate to 10 Hz**

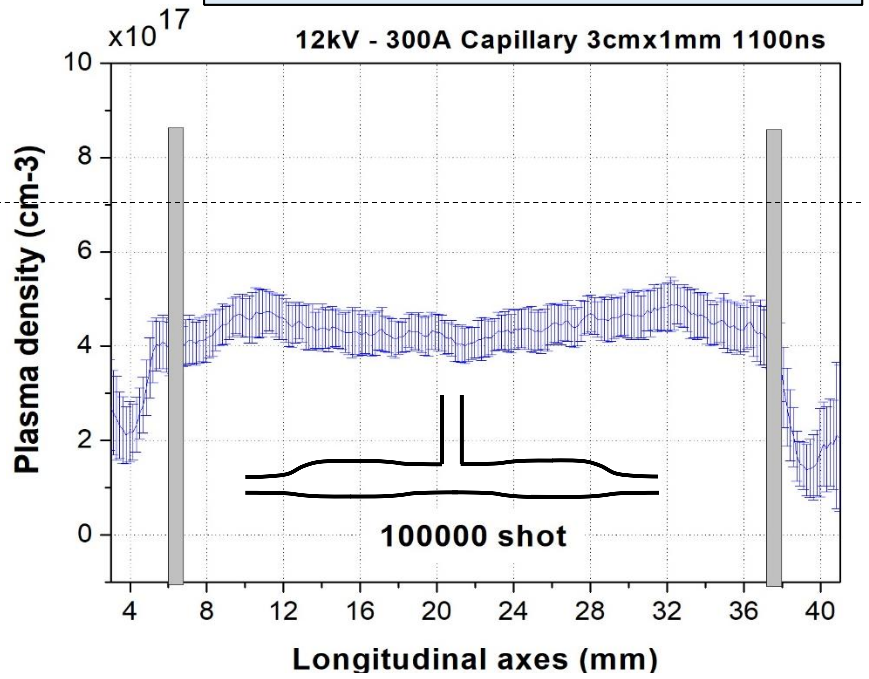
- **Plasma instability reduction**

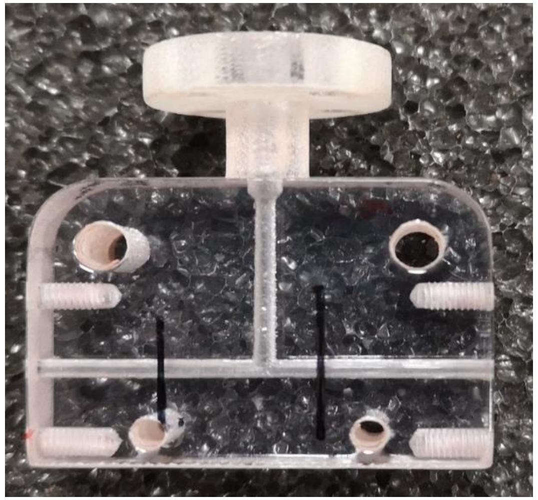
High repetition rate capillaries: 100-400 Hz

3D-printed plastic capillary







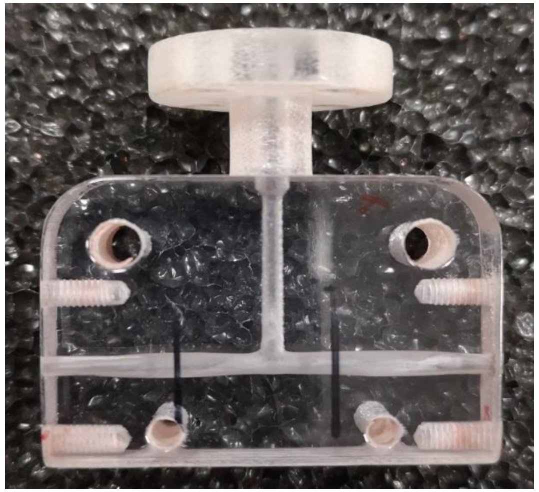


- The longitudinal profile is strongly changing: from supergaussian to quasi-uniform profile and the mean value goes from $6.5\text{x}10^{17}$ to $4\text{x}10^{17}$ cm^{-3} (1 to 1.5 mm)

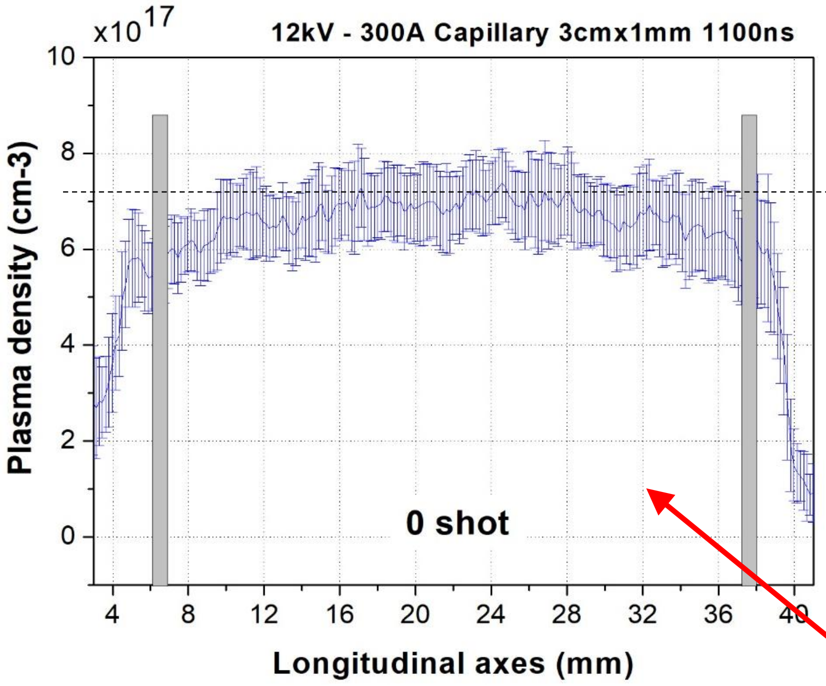
- This capillary shape deformation is proportional to the thermal energy deposition on the capillary walls:

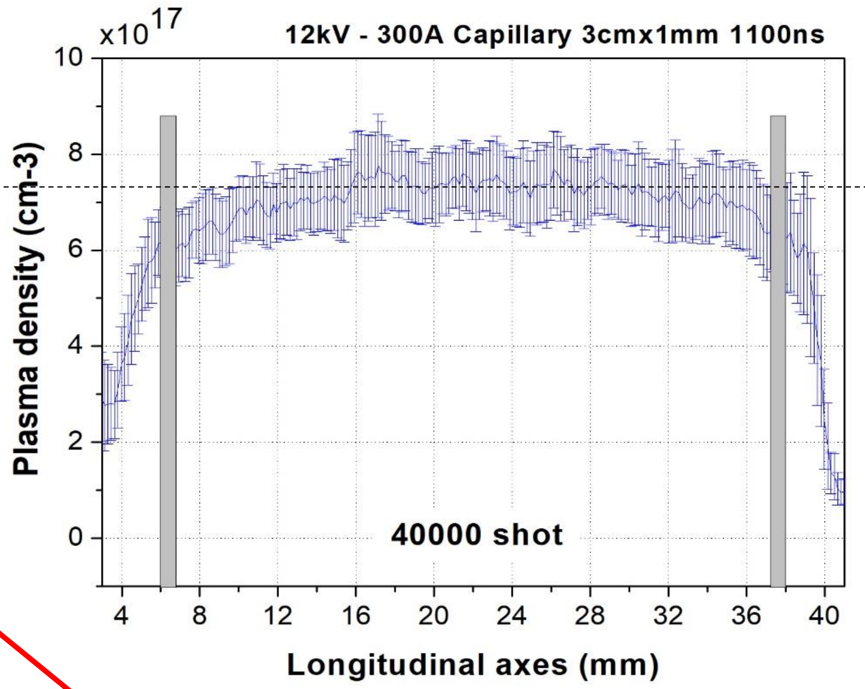
$$T_e(\text{eV}) = 5.7\left[\frac{I(\text{kA})}{r_{\text{cap}}(\text{mm})}\right]^{2/5} \approx \mathbf{4.7\ eV}$$

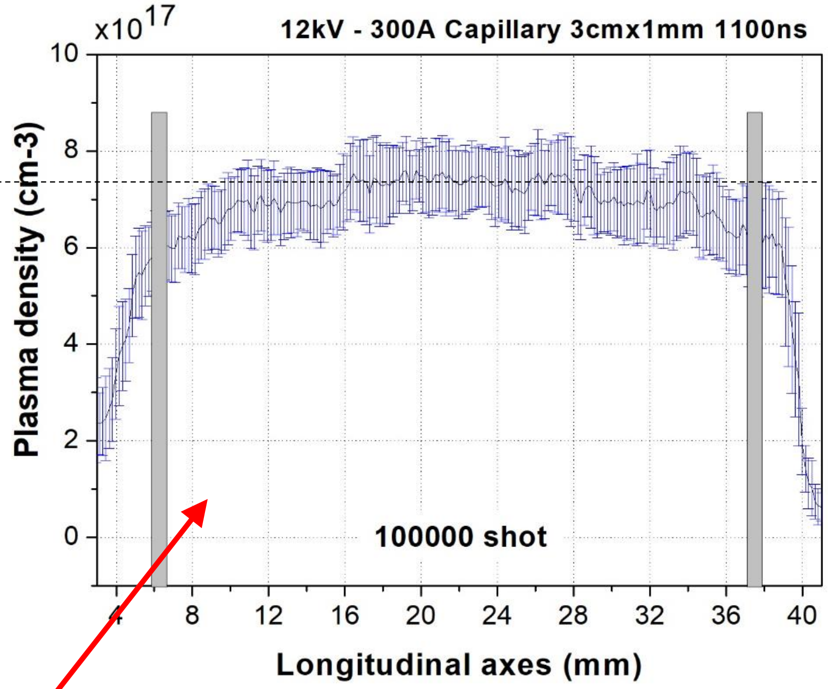
PWFA
$6\text{x}10^{17}cm^{-3}$ Pgas=20mbar
Ip=300A Rcap=500um
Lcap=30mm Δt=600ns

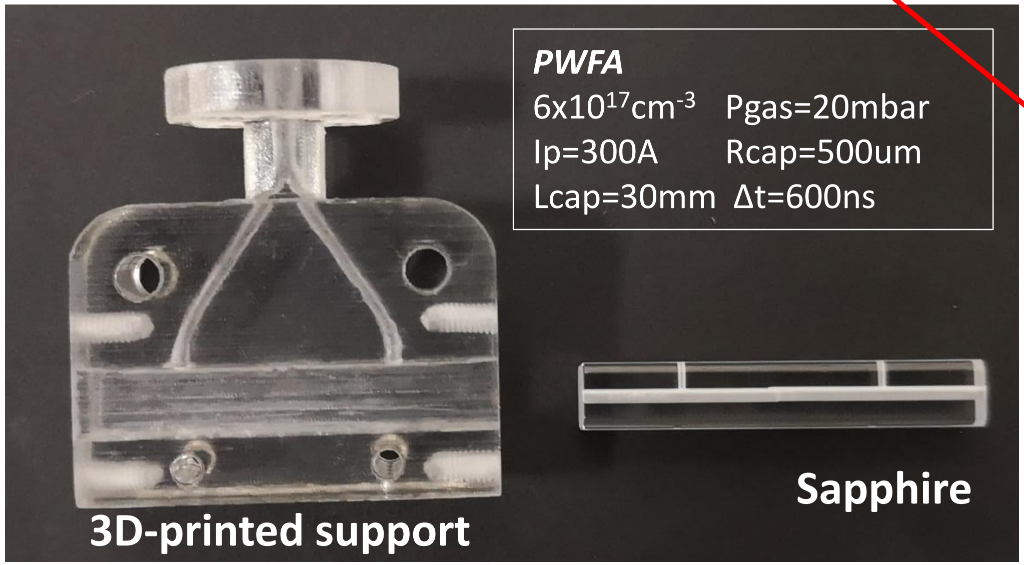


Sapphire capillary

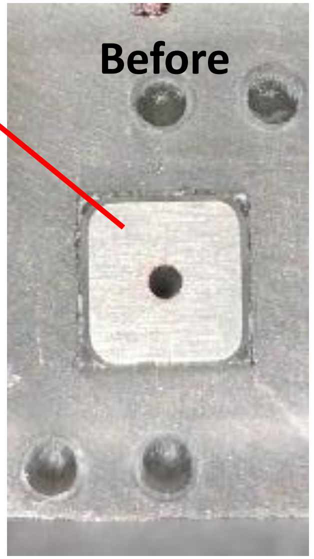


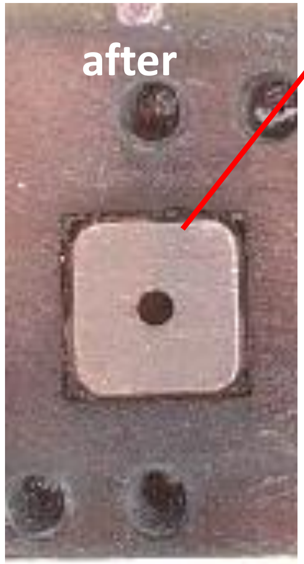






PWFA
$6 \times 10^{17} cm^{-3}$ Pgas=20mbar
Ip=300A Rcap=500um
Lcap=30mm Δt=600ns

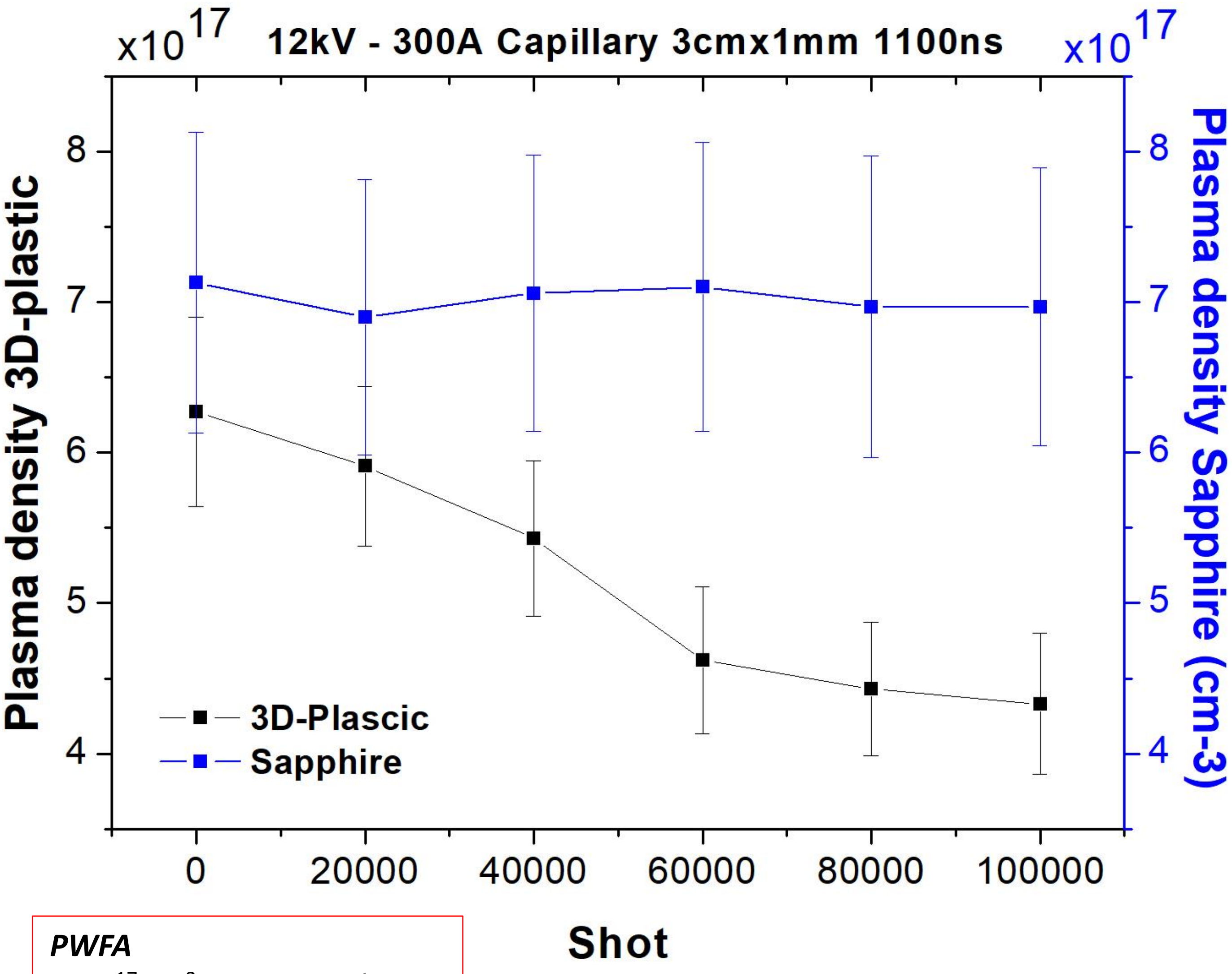


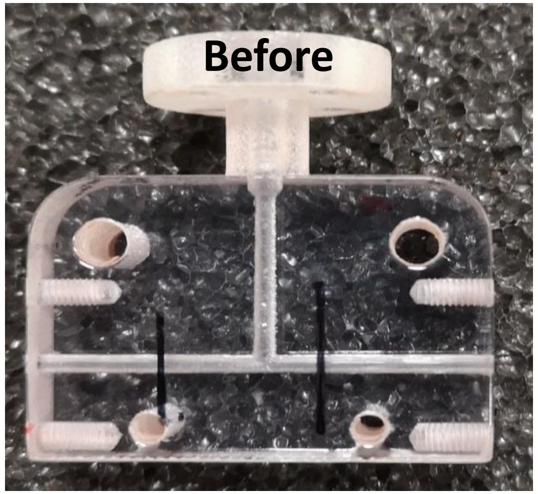


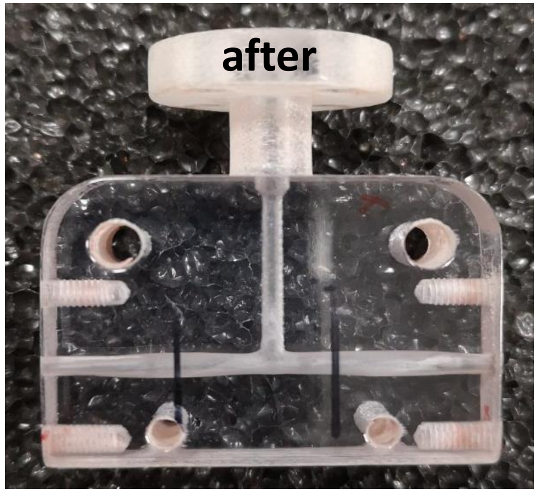
After 10^5 shots there is no any changing of the longitudinal profile and the mean value goes from 7×10^{17} cm^{-3} (maybe we have to reach 10^6 shots)

A. Sapphire material (K=40)
D. Potential limits due to the short length/small radius

High repetition rate capillaries: 100-400 Hz







PWFA
$6x10^{17}cm^{-3}$ Pgas=20mbar
Ip=300A Rcap=500um
Lcap=30mm Δt=600ns

High repetition rate capillaries: 100-400 Hz

Mitigation of erosion of the capillary walls can be achieved by reducing the ***heat flux***

A. Current pulse width and amplitude
B. Gas fill pressure
C. Capillary radius

→ **Temperature for Plasma formation**

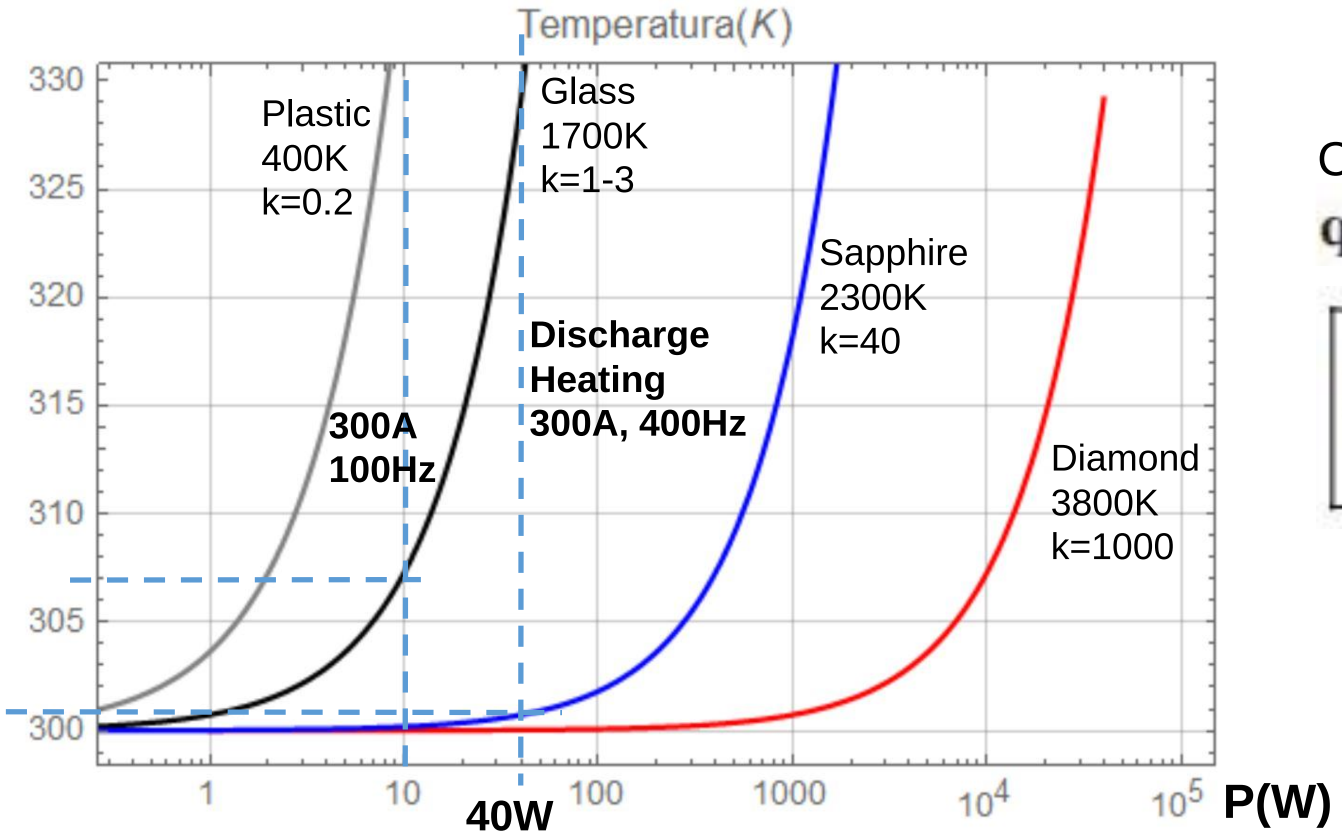
PWFA

$5\times10^{16}\,cm^{-3}$	Pgas=20mbar
Ip=300A	Rcap=2000um
Lcap=400mm	Δt=600ns

$$T_e(\mathrm{eV}) = 5.7\left[\frac{I(\mathrm{kA})}{r_{\mathrm{cap}}(\mathrm{mm})}\right]^{2/5} \approx \mathbf{2.7\ eV}$$

the energy deposited into the capillary per shot:

$$E = R_p I_p^2\ \Delta t = 100\ \mathrm{mJ/shot}$$

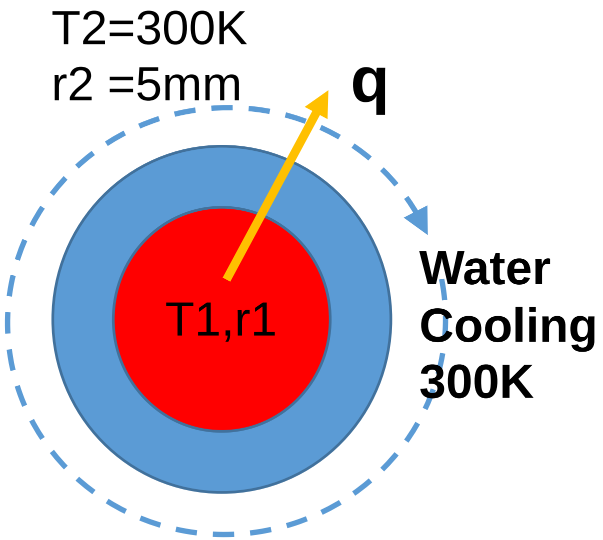


Conductive heat transfer law:

$$\mathbf{q} = -k(T)\,\nabla T$$

$$2\pi L k\,\frac{T_1 - T_2}{\ln(r_2/r_1)}$$

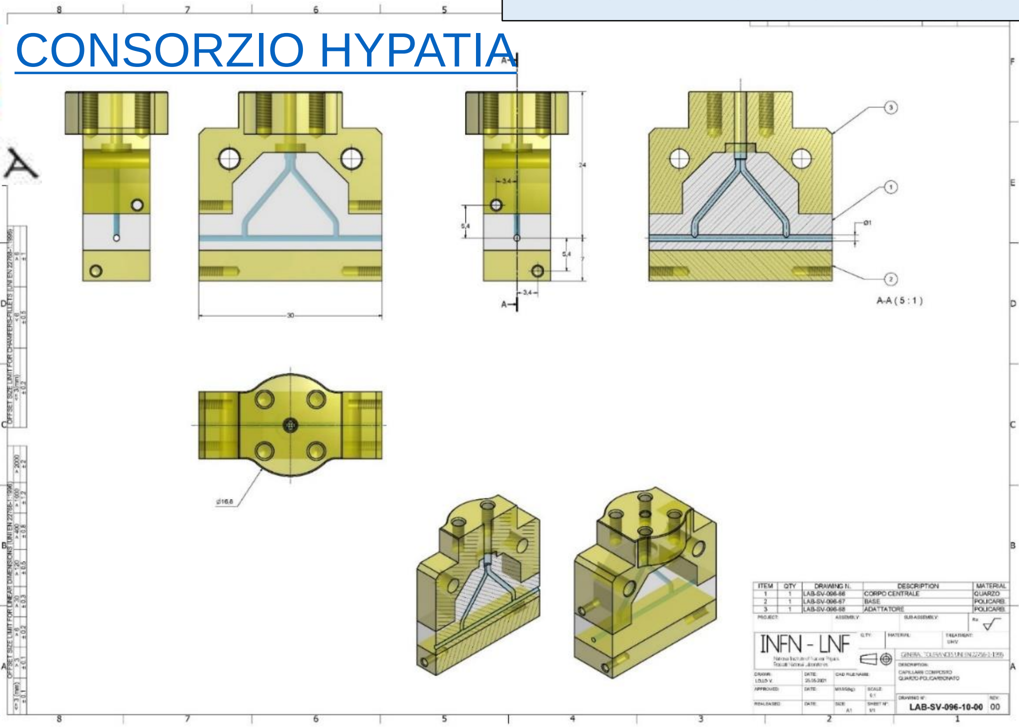
Cylinder geometry

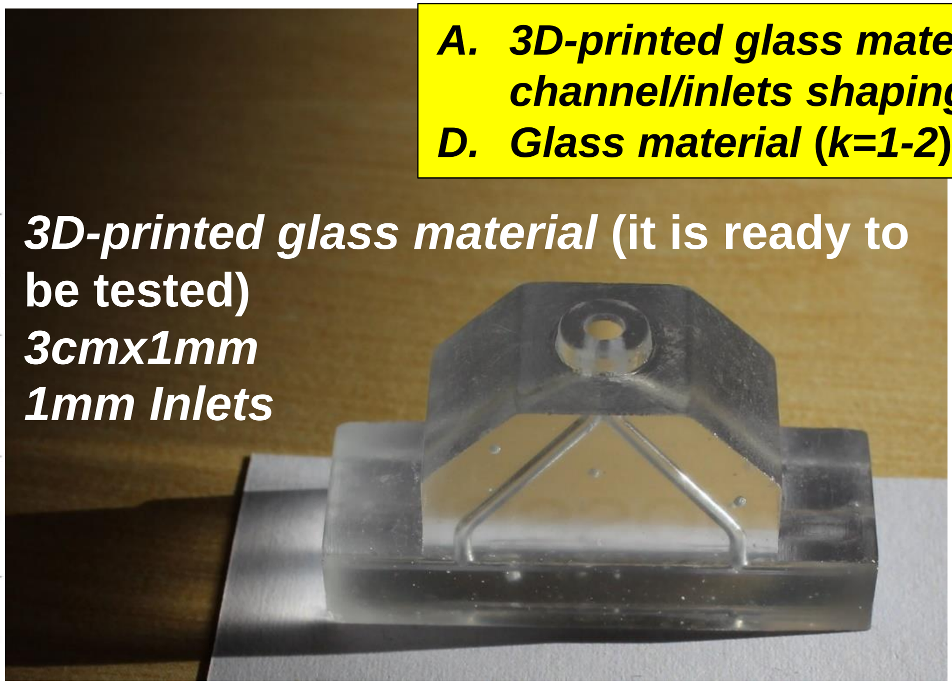


A. Gonsalves, et al, *Demonstration of a high repetition rate capillary discharge waveguide*, JAP, 119,10.1063/1.4940121

External collaborations with precision mechanics companies have been started

CONSORZIO HYPATIA

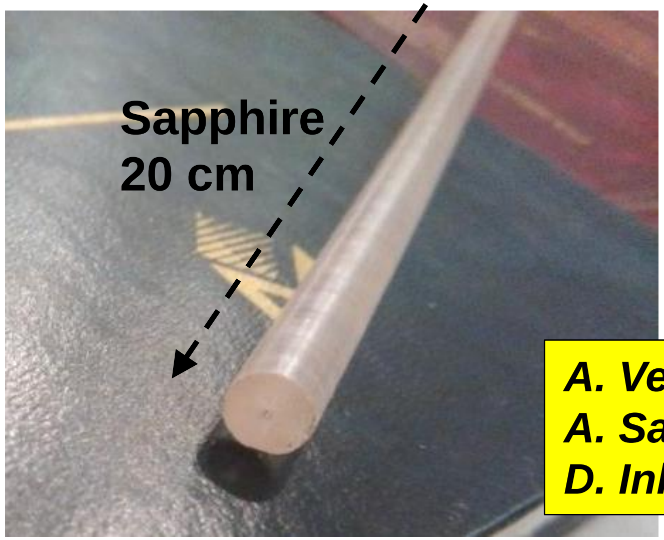




3D-printed glass material **(it is ready to be tested)**
3cmx1mm
1mm Inlets

- ***A. 3D-printed glass material: channel/inlets shaping, length***
- ***D. Glass material (k=1-2)***

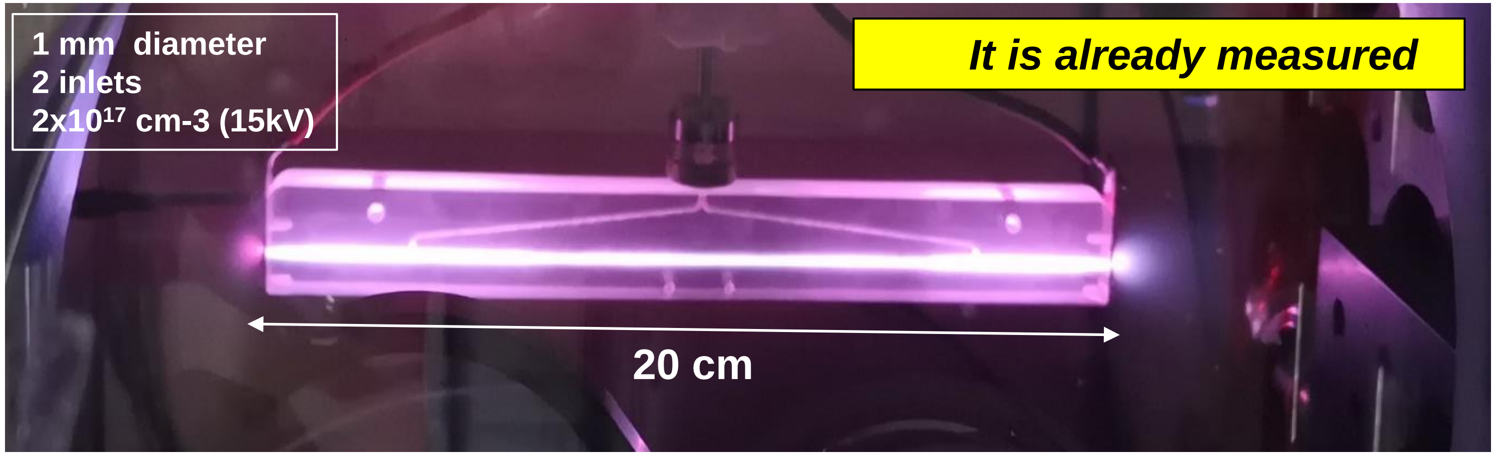
State Scientific Institution
"Institute for Single Crystals"
of National Academy of Sciences of Ukraine



Sapphire
20 cm

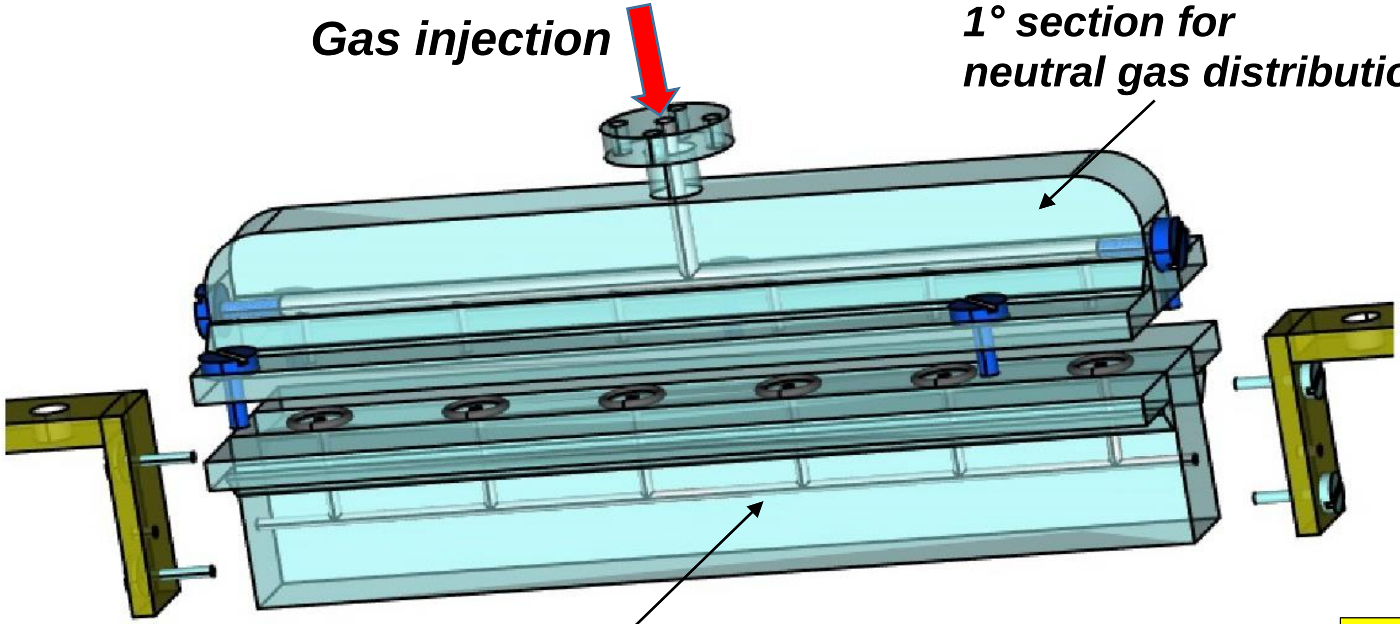
- ***A. Very long linear channels (20 cm)***
- ***A. Sapphire (k=40)***
- ***D. Inlets/channel holes >1.5-2 mm***

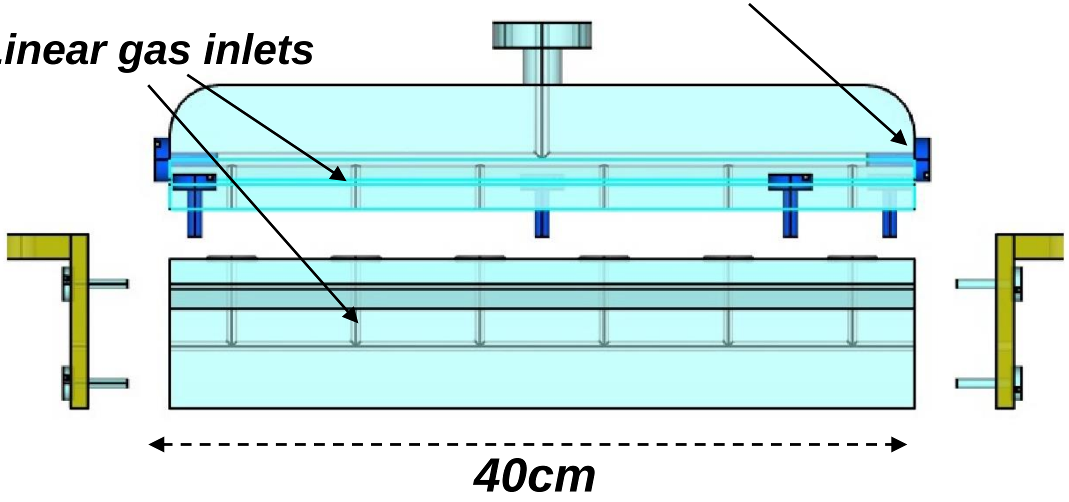
40 cm-long Gas-filled discharge-capillary



Paschen curves (50 mbar)

Length	*Density*	*Vb*
3 cm	$4x10^{16}$ cm-3	3 kV
10 cm	$4x10^{16}$ cm-3	8 kV
20 cm	$4x10^{16}$ cm-3	14 kV
40 cm	$4x10^{16}$ cm-3	23 kV

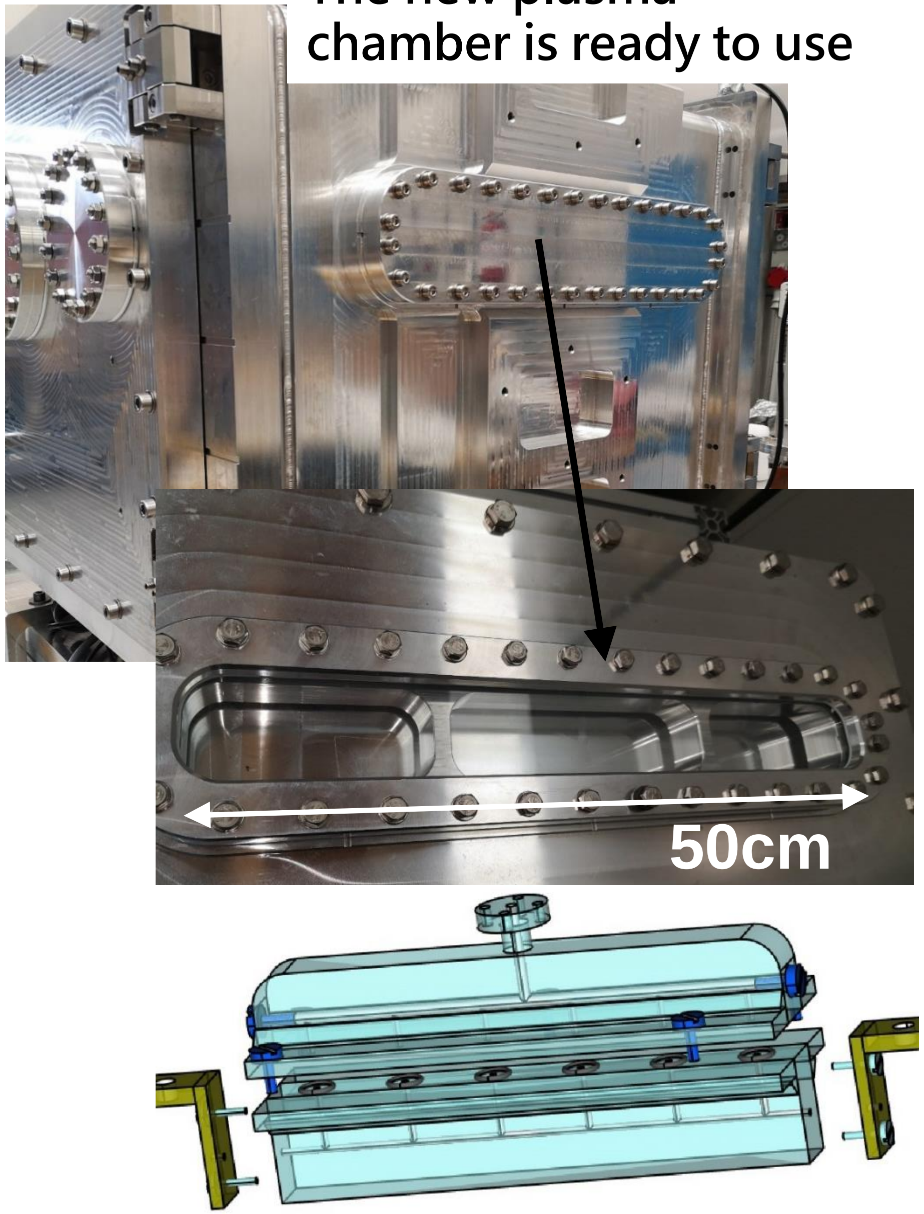




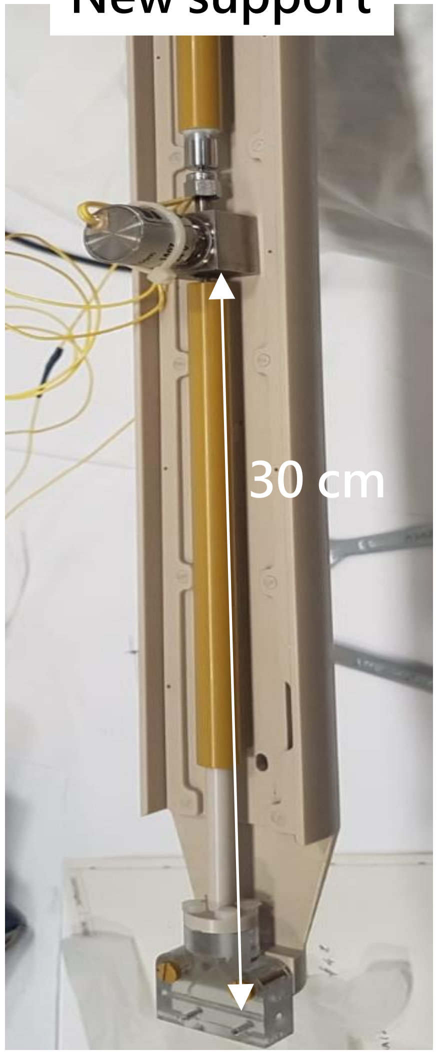
Linear channel/inlets allow us to clean them from printing residuals

A crucial point to produce a gas discharge is the insulation of others components of the plasma module with respect to the HV pulse

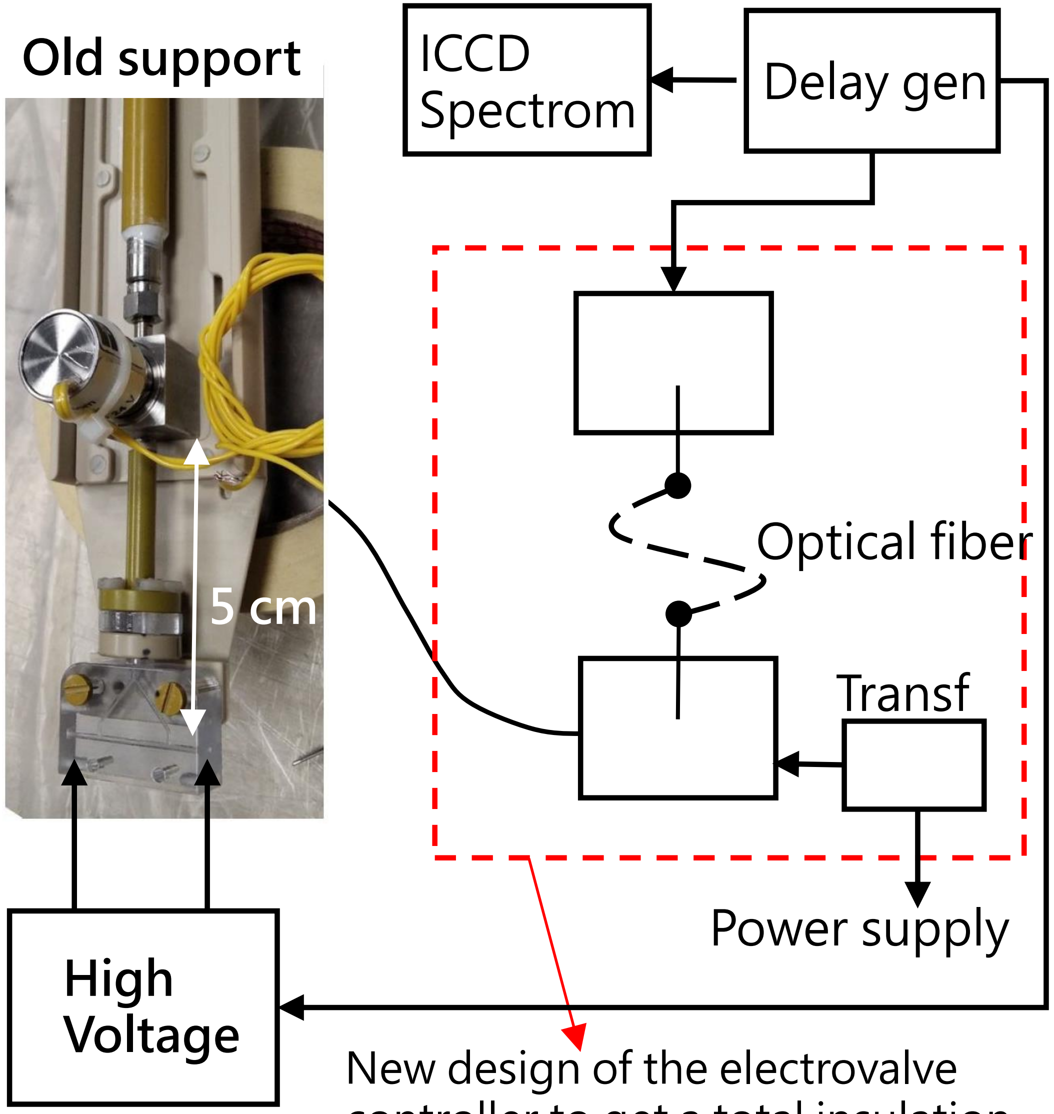
The new plasma chamber is ready to use



New support



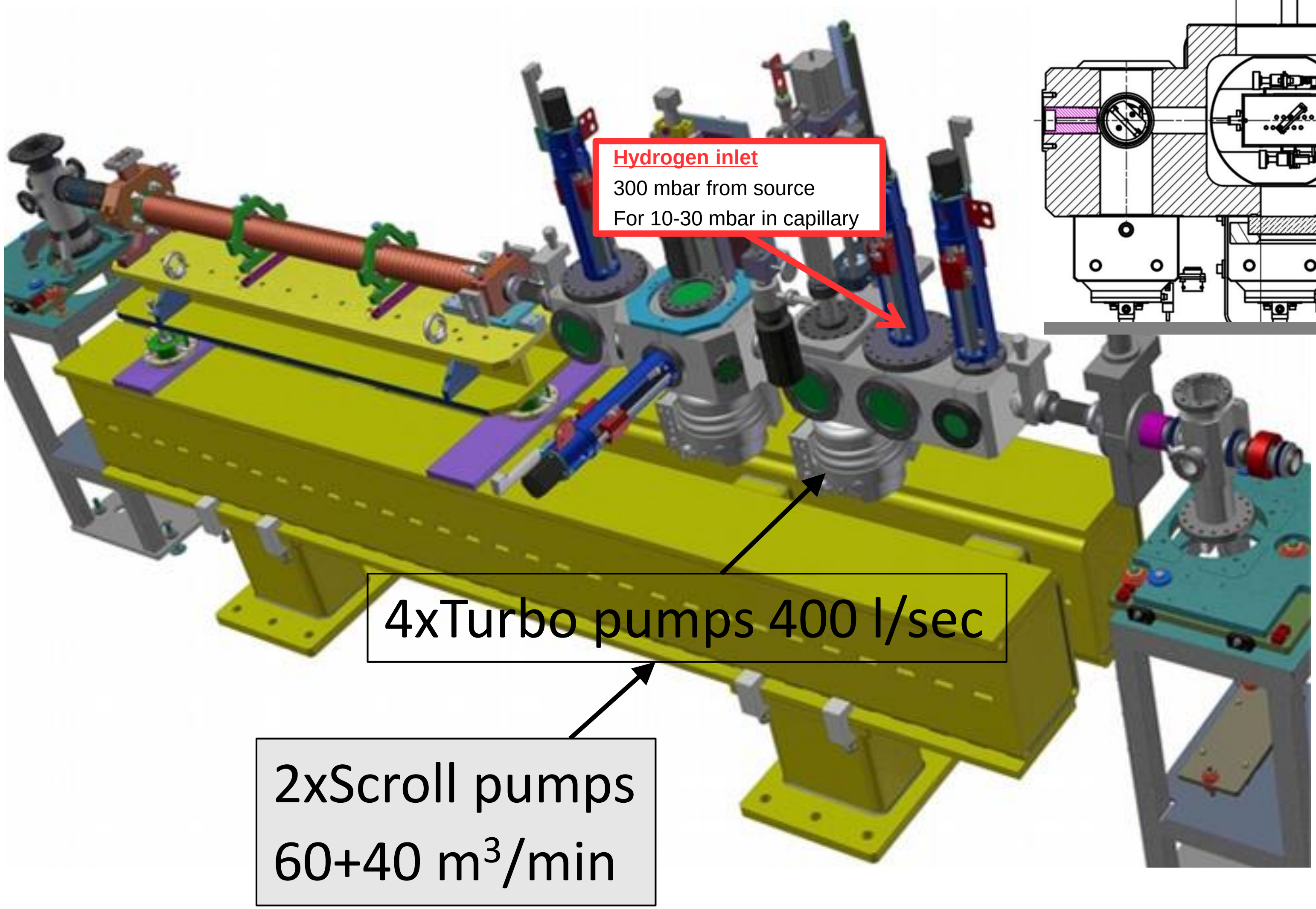
Old support

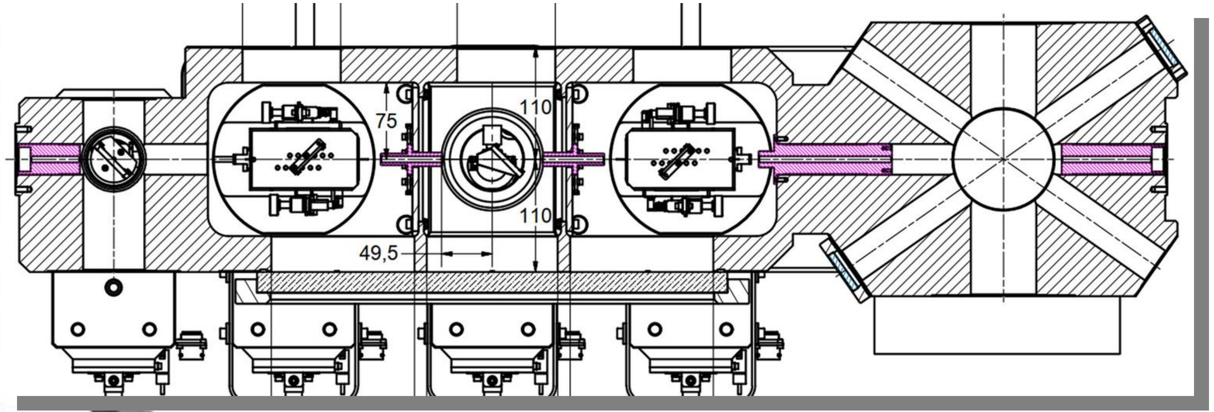


New design of the electrovalve controller to get a total insulation of the electro valve

Improvements of the pumping system @ SPARC_LAB

Vacuum pumping system improvements allow a discharge repetition rate to 10 Hz

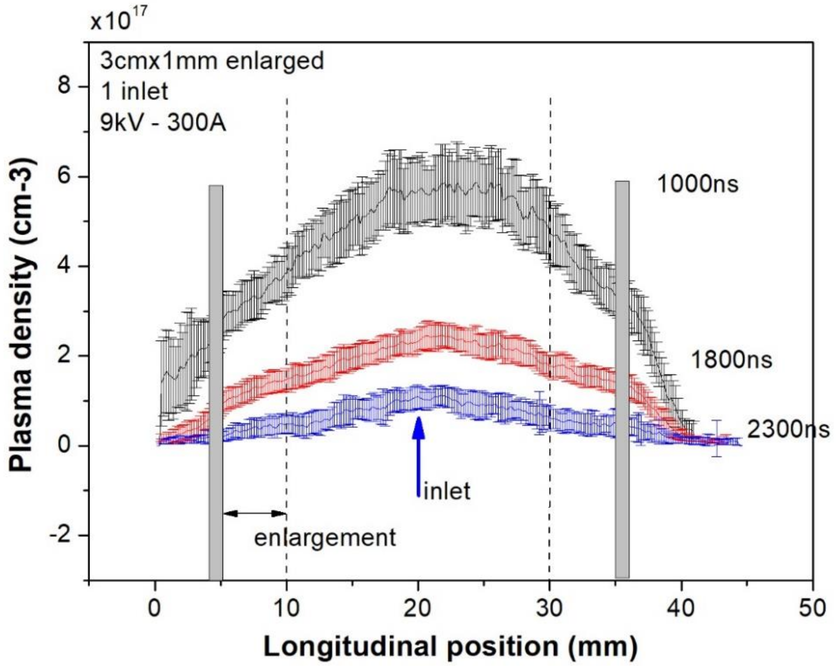


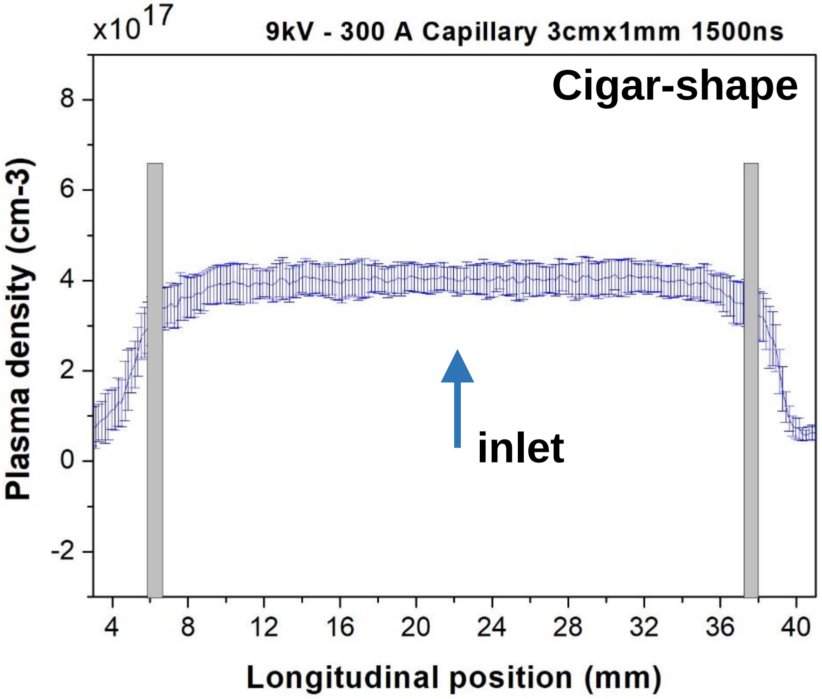


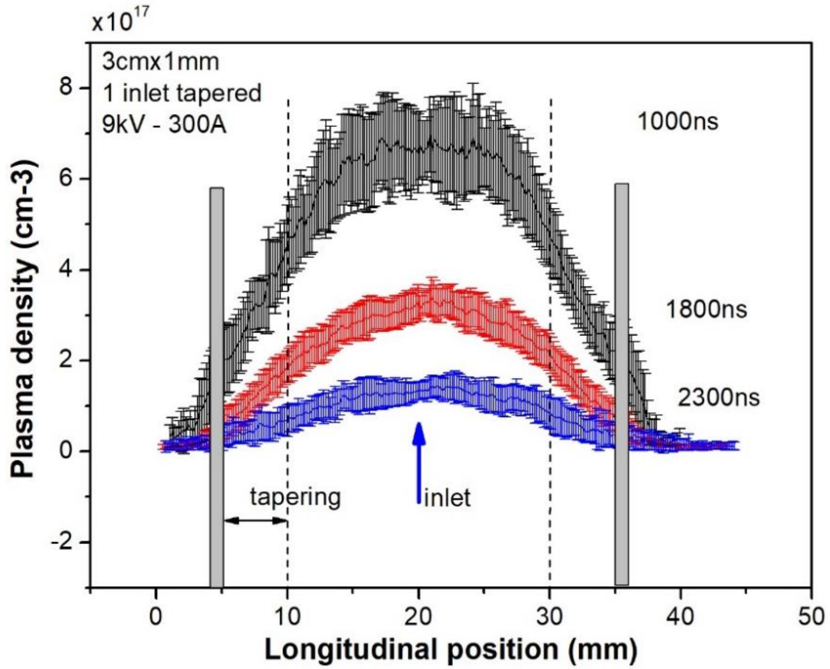
- At SPARC we already use a differential pumping system
  - 4xTurbo pumps 400 l/sec and 5xScroll pumps ($35 m^3$/min)
  - 10^{-8} mbar H2 pressure in the C-band section has maintained
- Stable operation @ 1-10 Hz
  - Studies for 100-400 Hz as required by EuPRAXIA will be performed together with a new design of the COMB chamber

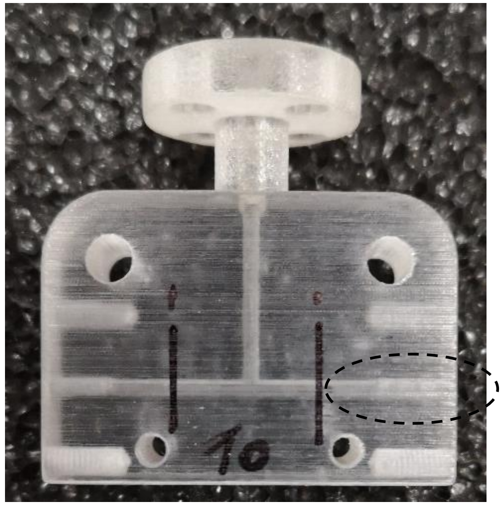
A. Biagioni, et al, *Vacuum system design for plasma wakefield acceleration at SPARC_LAB test facility*, PL-21/001, 24/09/2021 (Technical note).

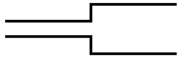
Test on channel shaping allow us to modify and control the longitudinal profile

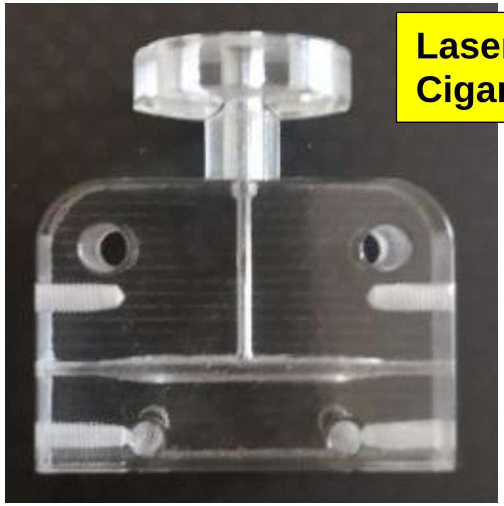




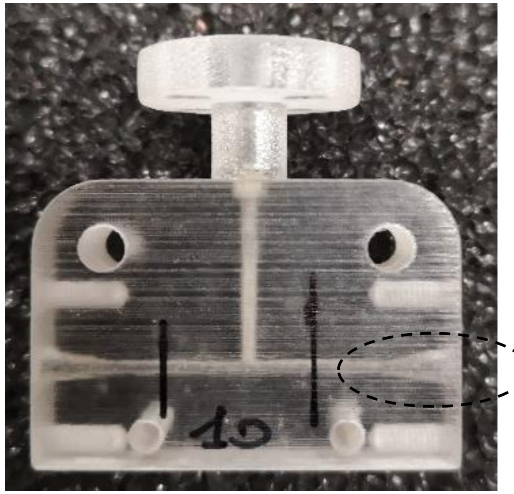


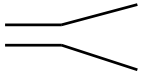






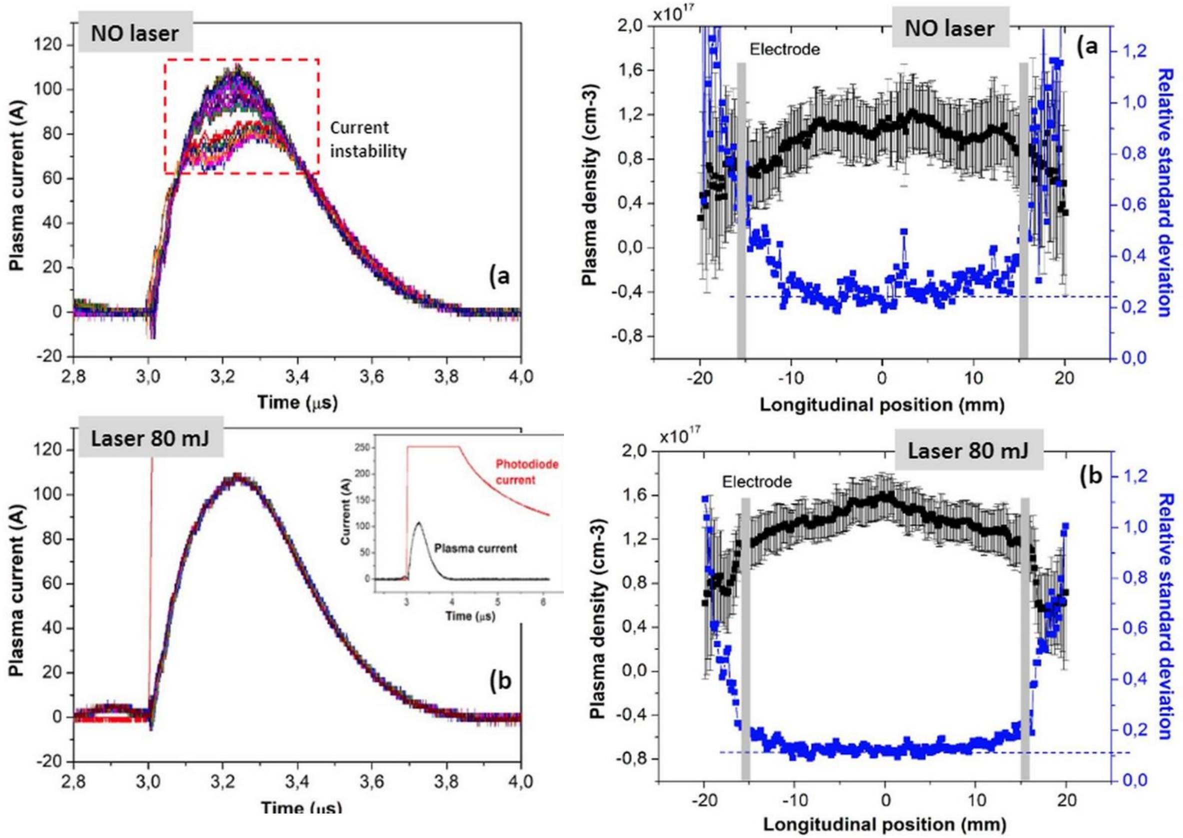
Laser trigger and Cigar-shape capillary

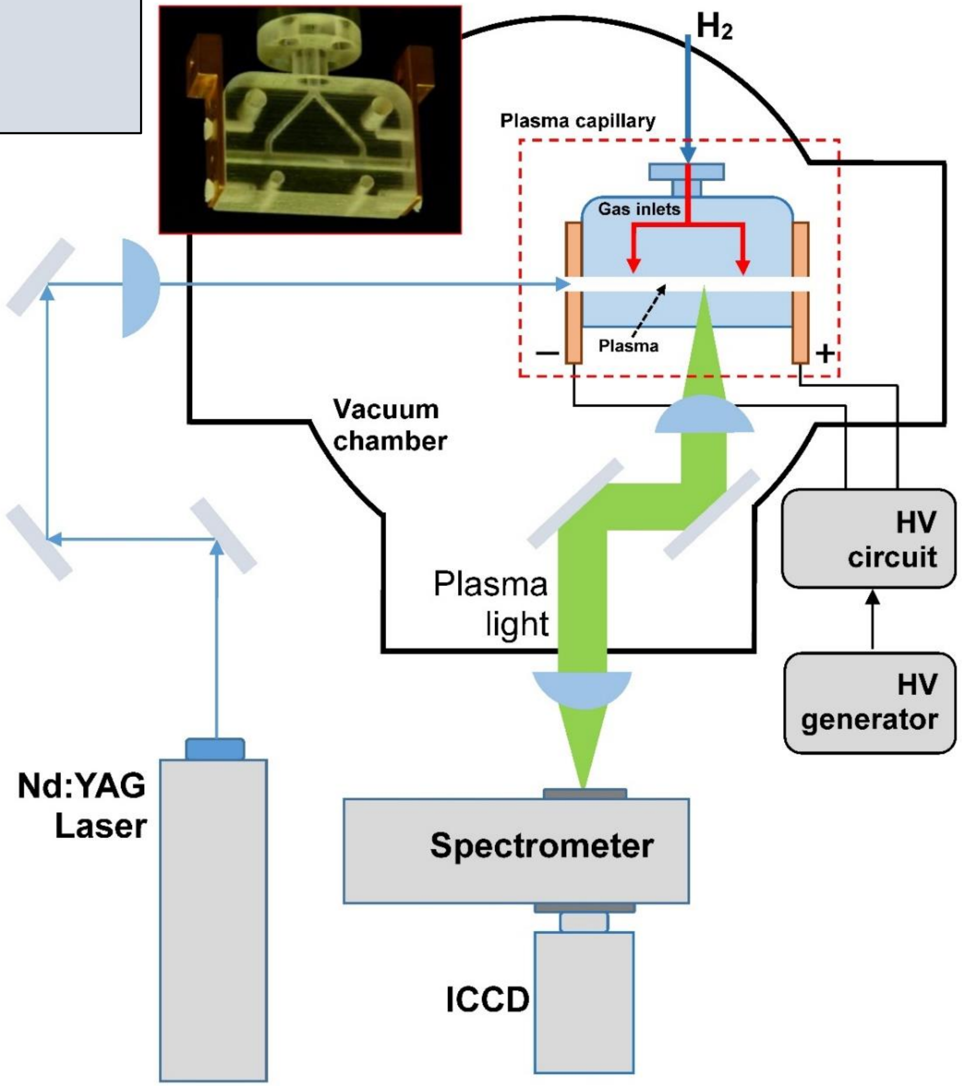




Studies on the effects of the laser spot and/or position to reduce plasma formation instabilities are planned

Plasma density instability reduced from **25% to 11% @ 5 kV**
Instability of **~5%** when operating at >8 kV (from Stark meas)





A. Biagioni, et al, *Gas-filled capillary-discharge stabilization for plasma-based accelerators by means of a laser pulse*, Plasma Physics and Controlled Fusion 10.1088/1361-6587/ac1f68

R&D Financial Requests for plasma module

1. Vacuum chamber and support	150 k€
2. Capillary and supports	100 k€
3. Diagnostics: ICCD camera/spectrometers/optics	240 k€
4. Discharge laser trigger	60 k€
5. Neutral gas sources/gas injection system	60 k€
7. Pumping system	120 k€
7. Motorized actuators	100 k€
8. Electro valve	40 k€
9. Discharge pulser and HV generator	100 k€

Conclusion

- Theoretical and experimental studies on gas-filled discharge-capillaries have been started:
  - Erosion of the capillary walls (first results have been obtained)
  - Design of the HV pulser (our HV-pulser is already able to reach 2.5kA at 23kV)
  - Refill time of the capillary
  - Vacuum requirements
  - Current pulse width reduction

- A new design of 40-cm long capillary has been done:
  - New plasma chamber
  - Insulation of the of the electro valve and the other sections of the plasma module

- Vacuum pumping system improvements allow a discharge repetition rate to 10 Hz

- Tests on channel shaping allow us to modify the longitudinal profile depending on the application

- Studies on the effects of the laser spot and/or position to reduce plasma formation instabilities are planned

Thank you for your attention

Angelo.Biagioni@lnf.infn.it