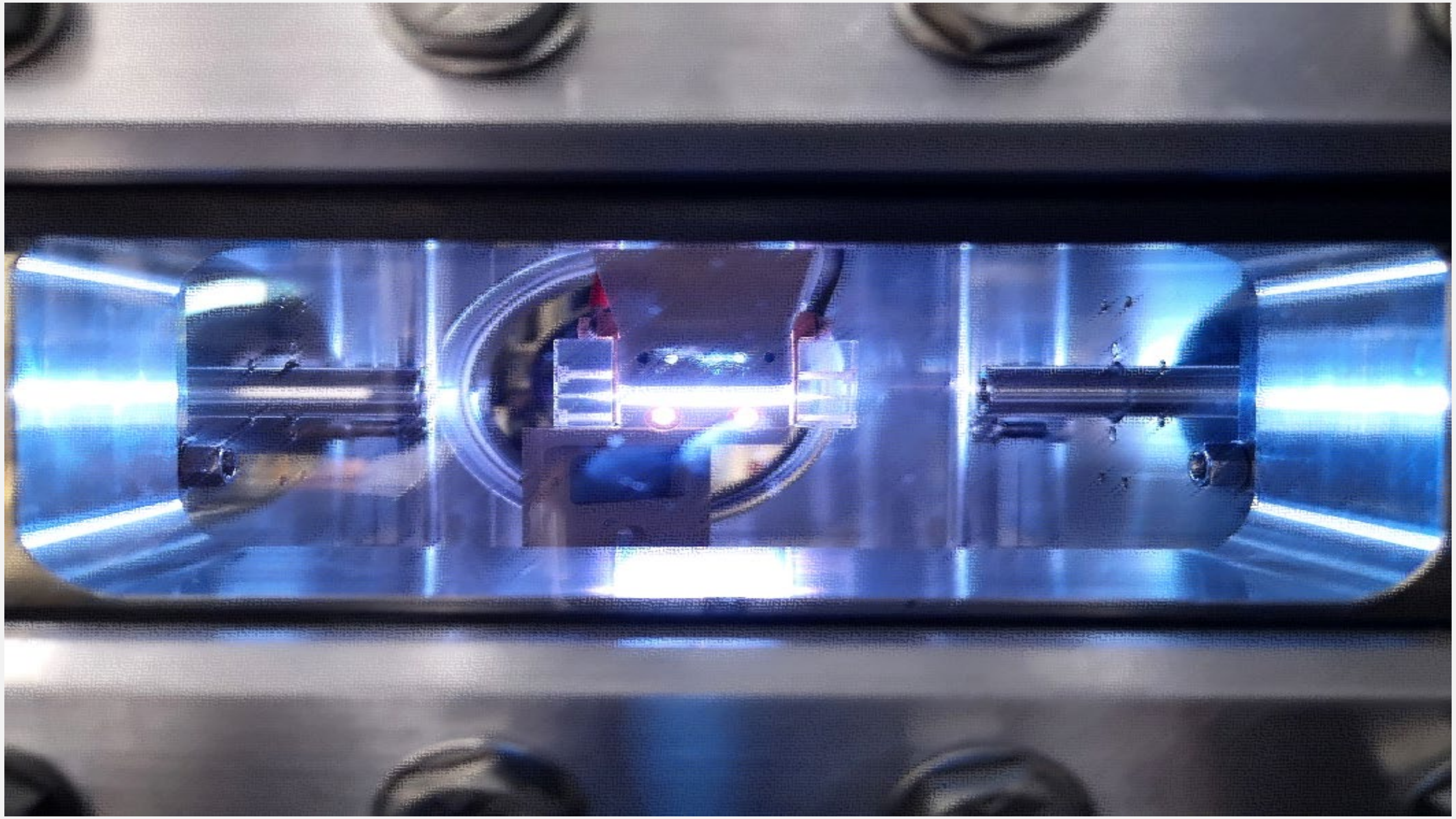
Plasma accelerating module



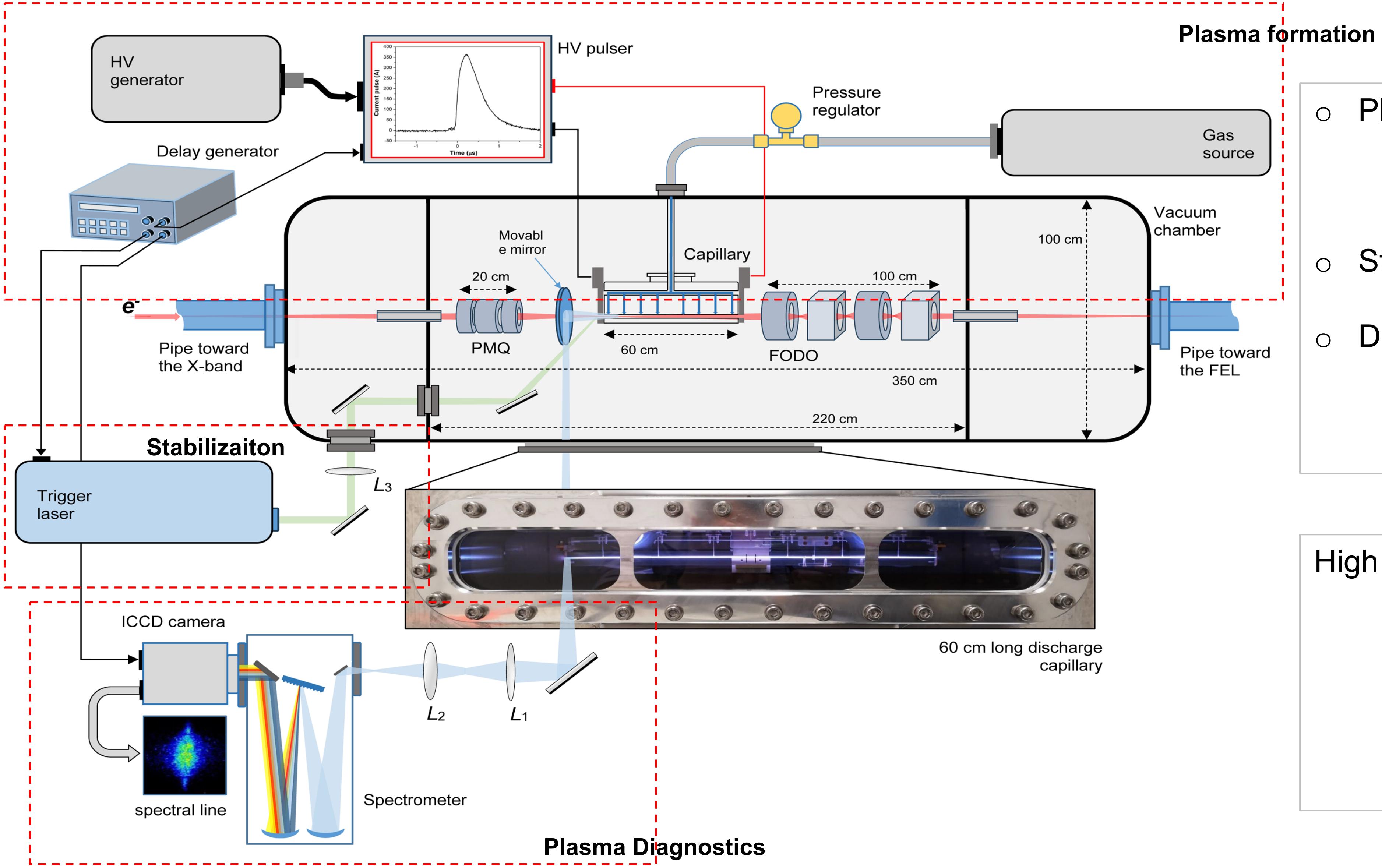
TDR Review committee
26-28 June 2024

Angelo Biagioni

Istituto Nazionale di Fisica Nucleare

Plasma accelerating module(61%)	Technical design (83%)	Writing(40%)
10.1 Introduction	100%	100%
10.2 Plasma module design		
10.2.1 Plasma sources	70%	60%
10.2.2 HV-sources for plasma creation	100%	100%
10.2.3 Plasma discharge stabilizaiton	100%	100%
10.3 Plasma chamber design	20%	20%
10.3.1 Focusing and extraction systems	**Beam physics**	
10.3.2 Capillary supports and handling	70%	0%
10.4 Vacuum pumping system	60%	30%
10.5 Diagnostics		
10.5.1 Plasma diagnostics	100%	50%
10.5.1.1 Stark broadening technique	100%	100%
10.5.1.2 Interferometric techniques	100%	0%
10.5.2 Beam diagnostics	**Beam diagnostics**	
10.6 High repetition rate plasma sources	80%	80%
10.7 Future developments		
10.7.1 Segmented capillary	100%	0%
10.7.2 All-in-one capillary	100%	0%
10.7.3 APL collimator system	70%	0%
10.8 Plasma module safety system	80%	0%

Plasma accelerating module



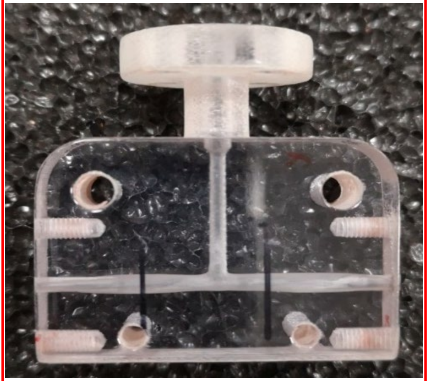
- Plasma formation:
  - Gas-filled discharge capilary
  - HV sources
  - Gas source/Vacuum system
- Stabilization:
  - Laser trigger
- Diagnostics:
  - Stark broadening (ICCD/Spectrometer/Optics)

High repetition rate operations

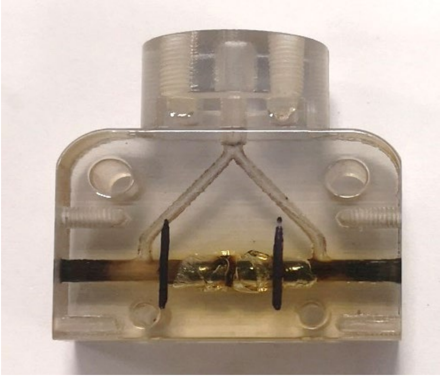
- Plasma source design
  - Walls material
  - 60 cm long
- HV source
- Vacuum system/Gas source

To operate at high repetition rate with gas-filled capillary-discharge the key point is the thermal dissipation

3D plastic materials

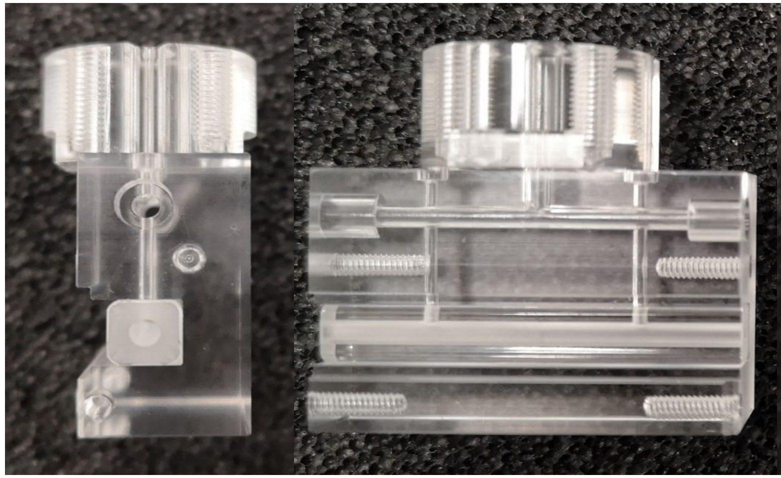


10^5 shots/1 Hz

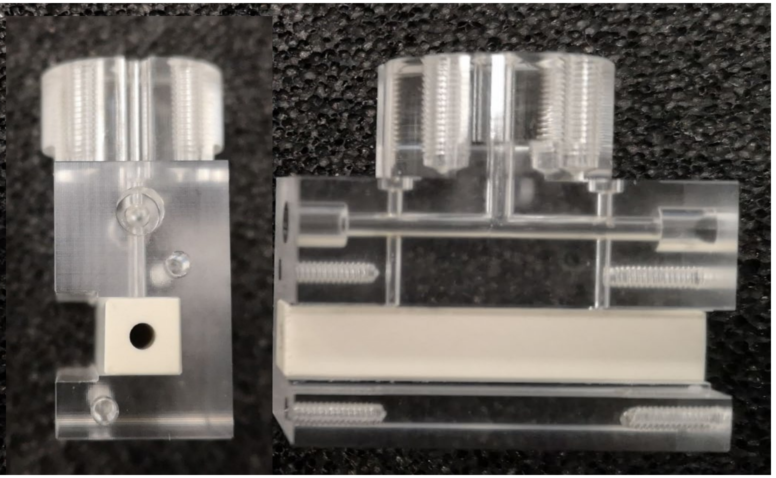


$7\mathrm{x}10^4$ shots/30 Hz

Sapphire



Shapal



$$T_e(\mathrm{eV}) = 5.7\left[\frac{I(\mathrm{kA})}{r_{\mathrm{cap}}(\mathrm{mm})}\right]^{2/5} \sim 4\ \mathrm{eV}$$

$I = 400$ A

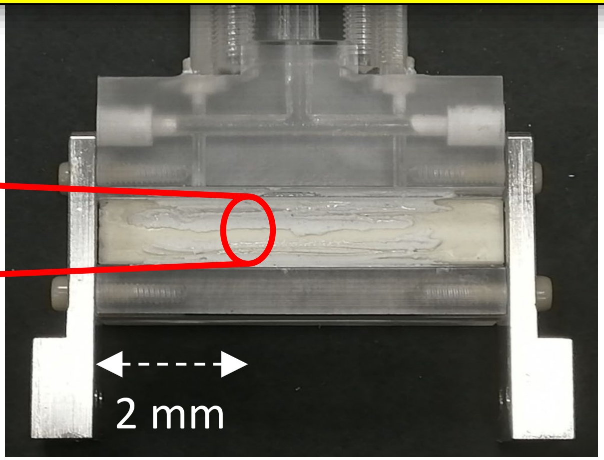
$d = 2$ mm

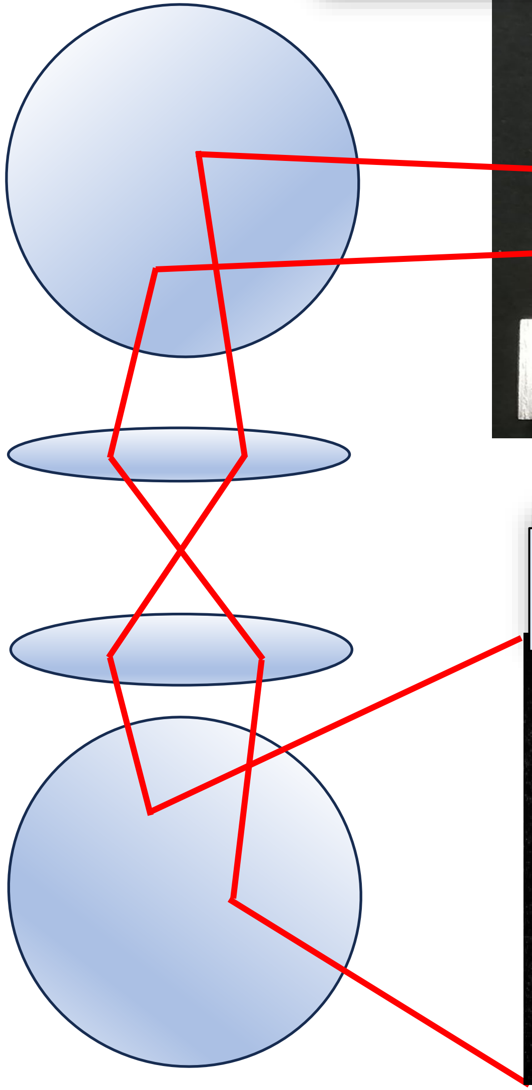
$$q = -k(T)\nabla T$$

Thermal conductivity:
- 40 W/mK at 25°C Sapphire
- 93 W/mK at 25°C Shapal

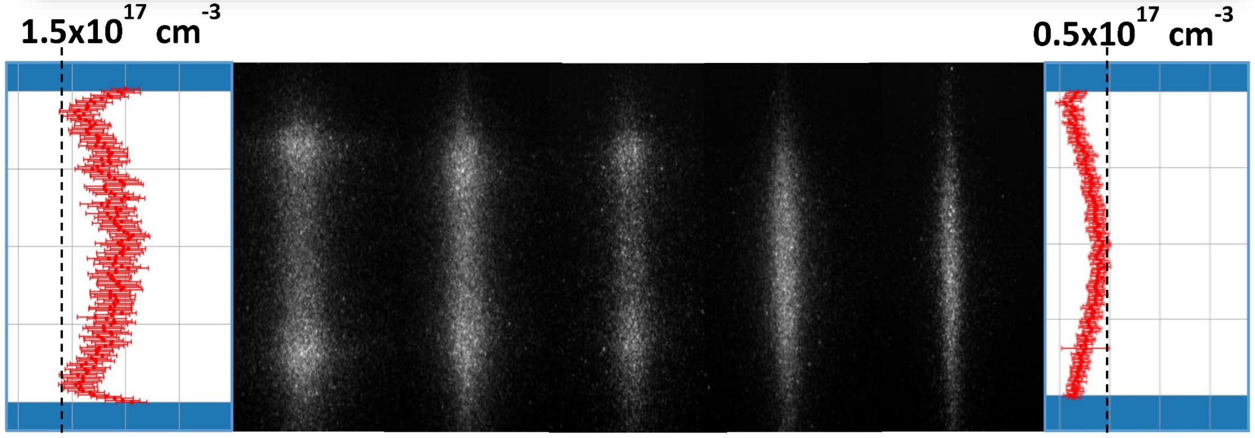
150 Hz repetition rate discharges

Transverse Stark broadening method to characterize non-transparent materials

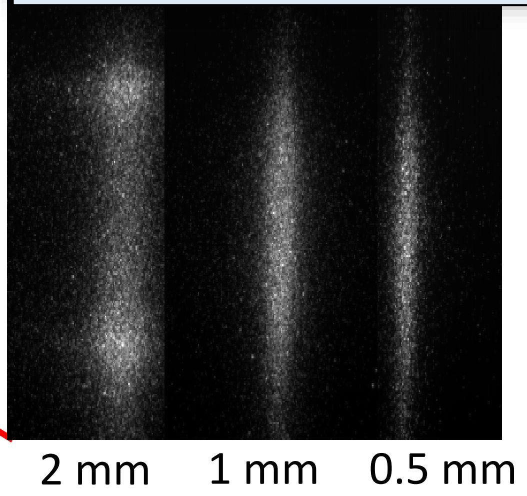




Spectral lines behavior as a function of the recombination time

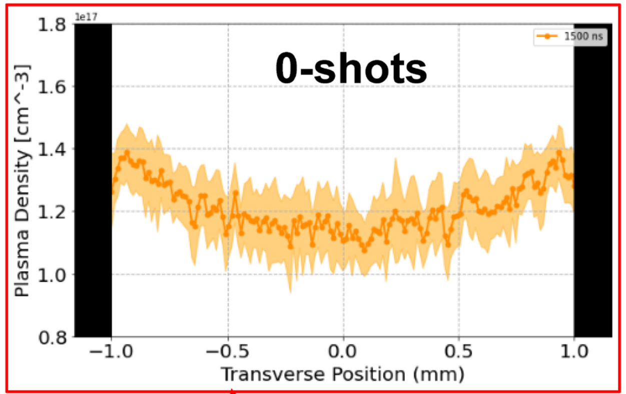


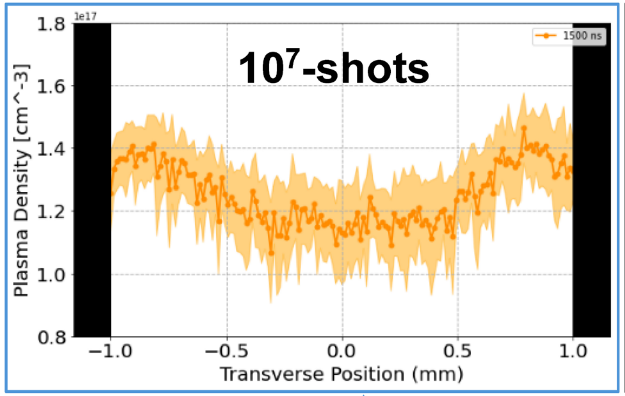
Spectral lines as a function of the longitudinal slices

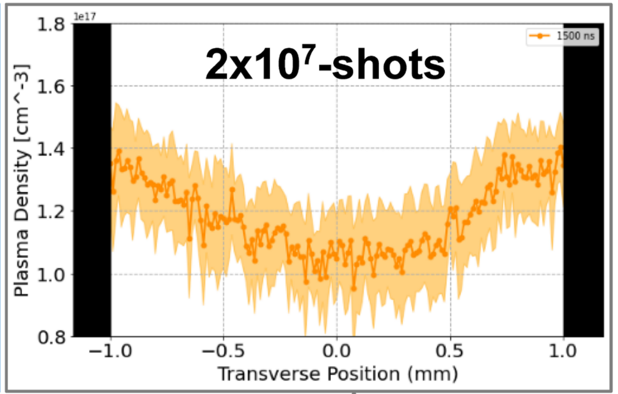


EuPRAXIA

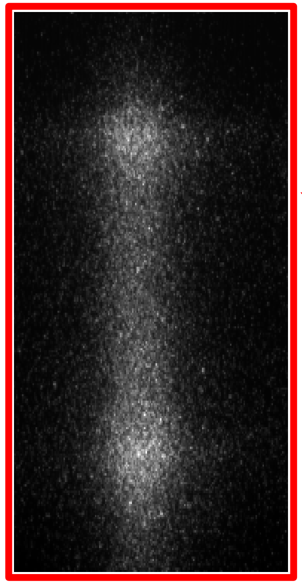
High repetition rate plasma sources-walls material

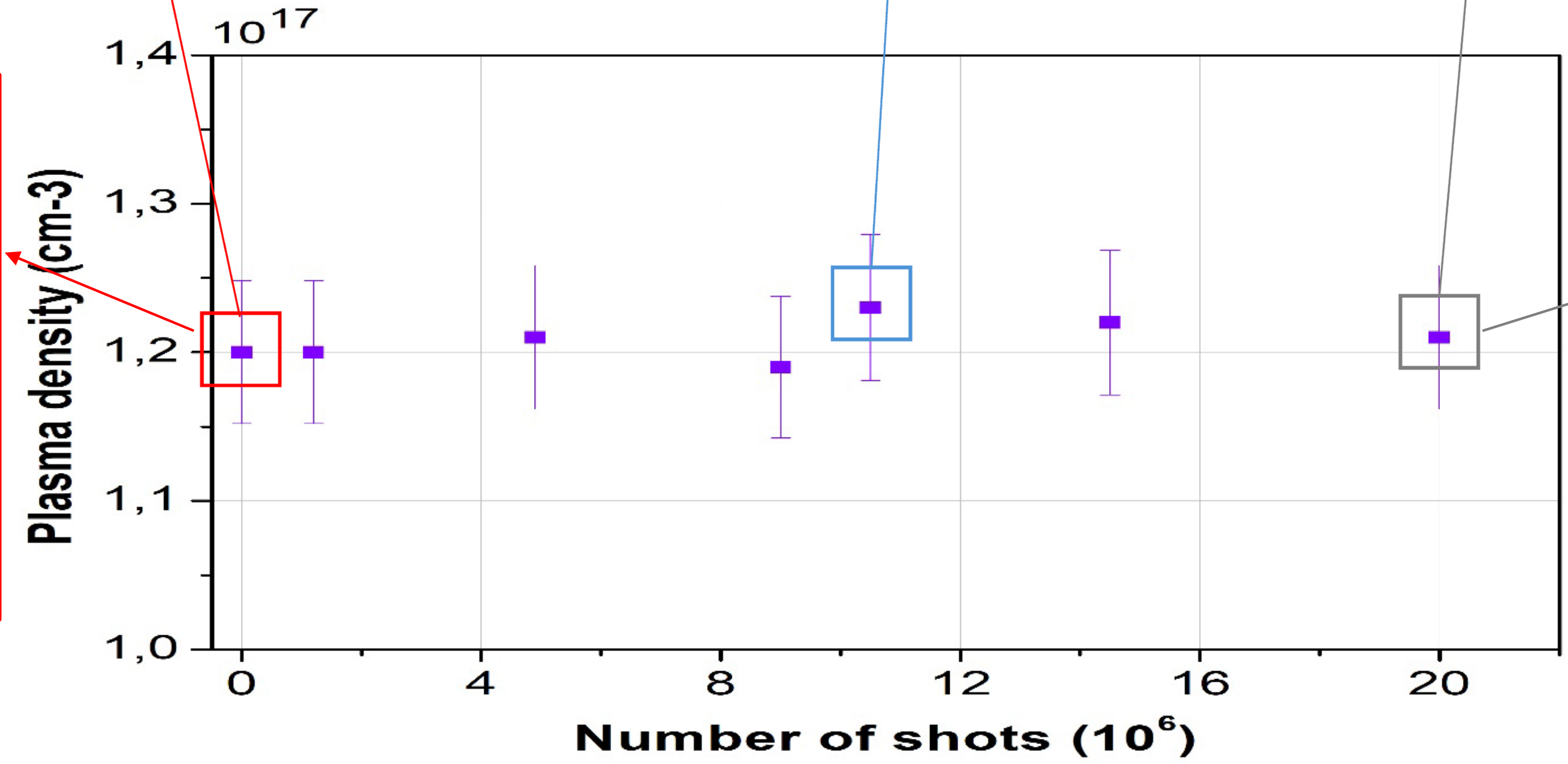


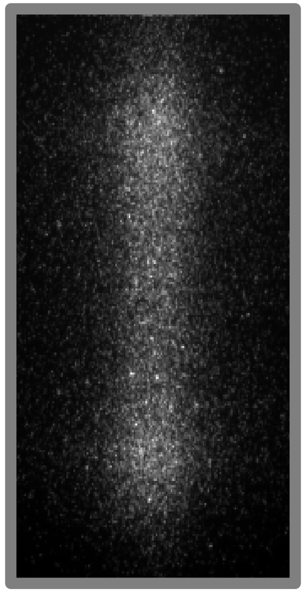




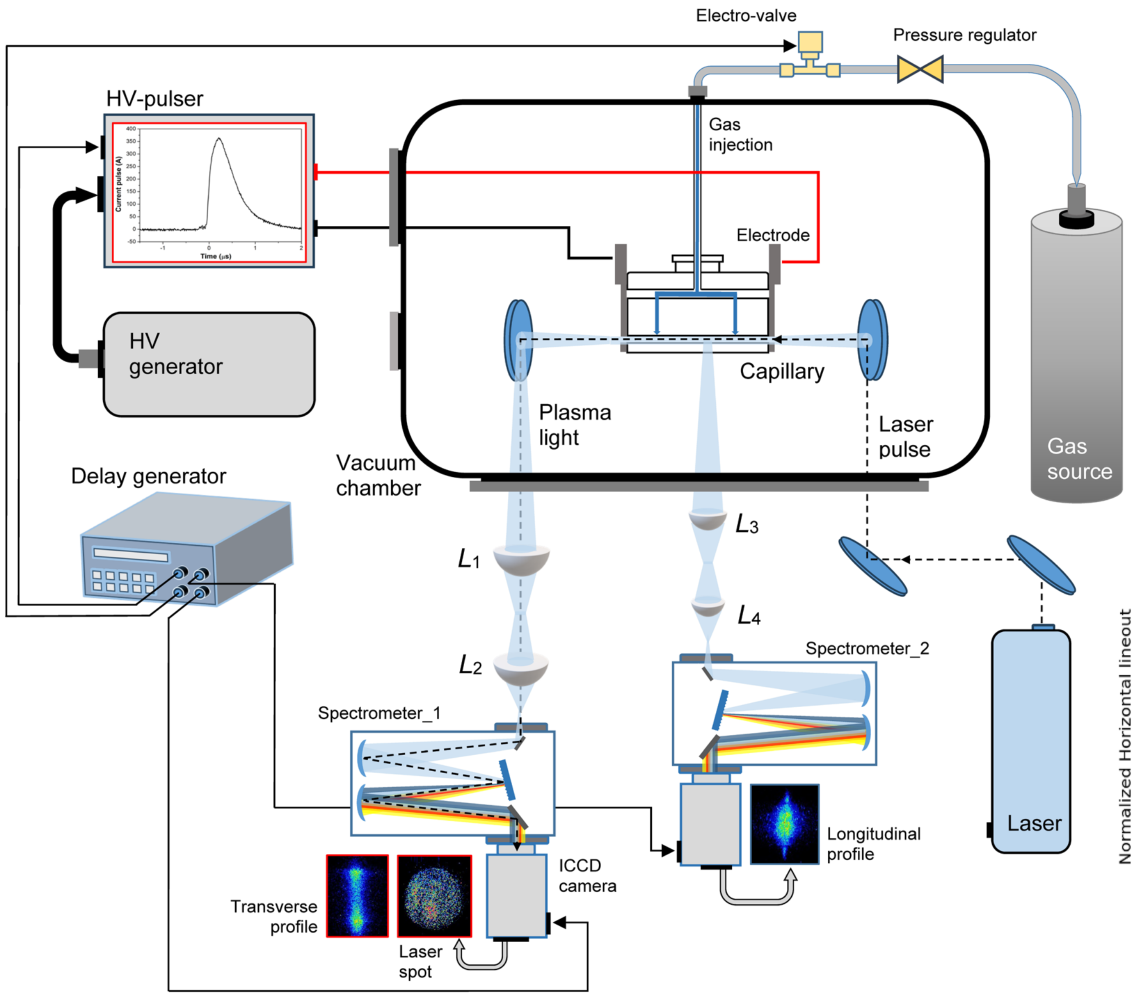
V = 8 kV
Ip = 400 A





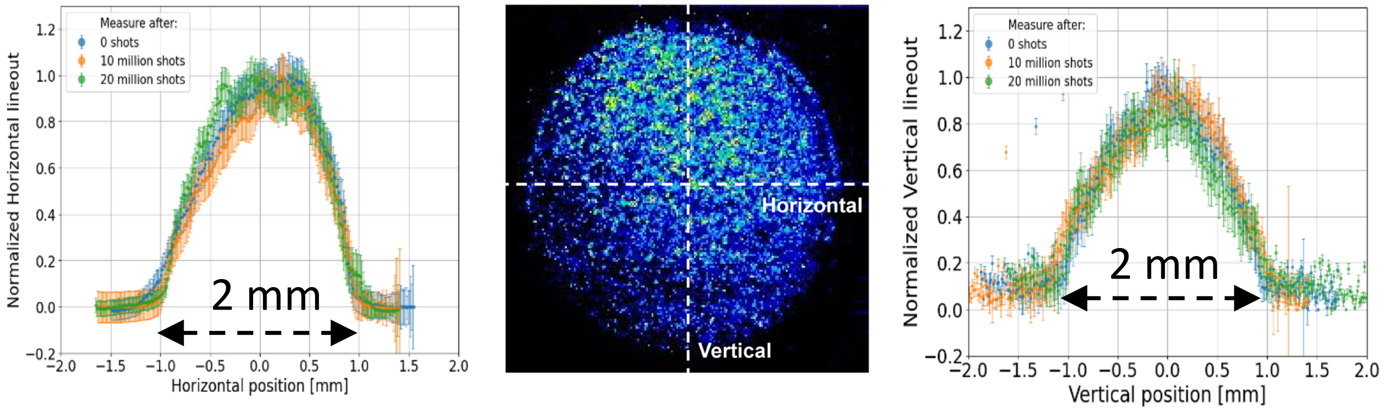


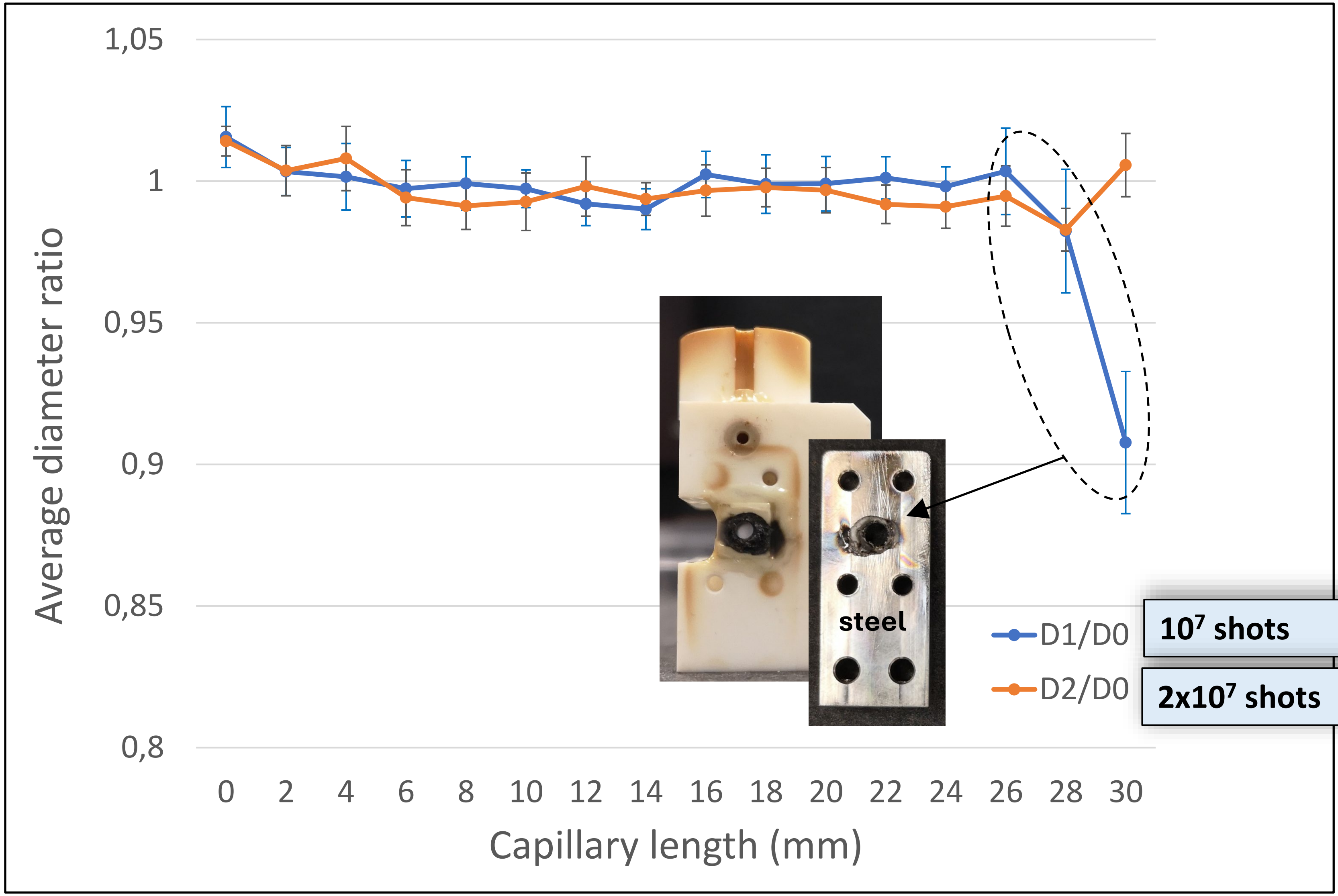
INFN LNF Istituto Nazionale di Fisica Nucleare

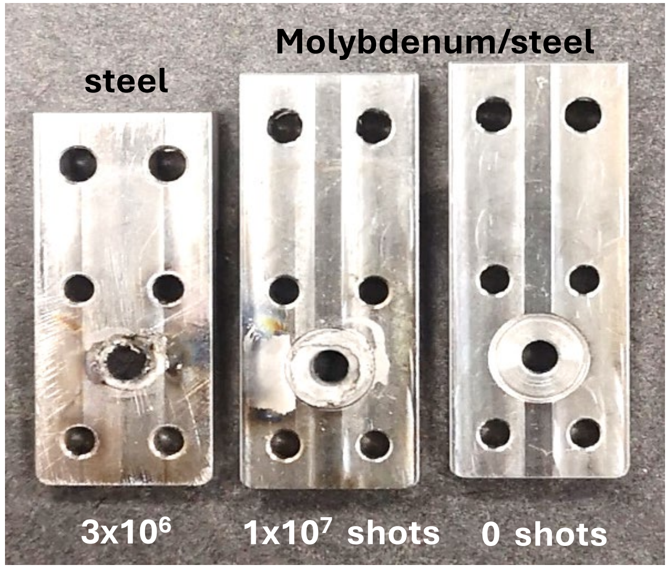


30 - 150 Hz repetition rate discharges

- a laser beam passes through the plasma formation channel, any changes in the transverse spot were observed.
- shot-to-shot fluctuations in the laser profile are observed, but the transverse size (2 mm) remains the same for all measurements taken from 0 to 20 million shots

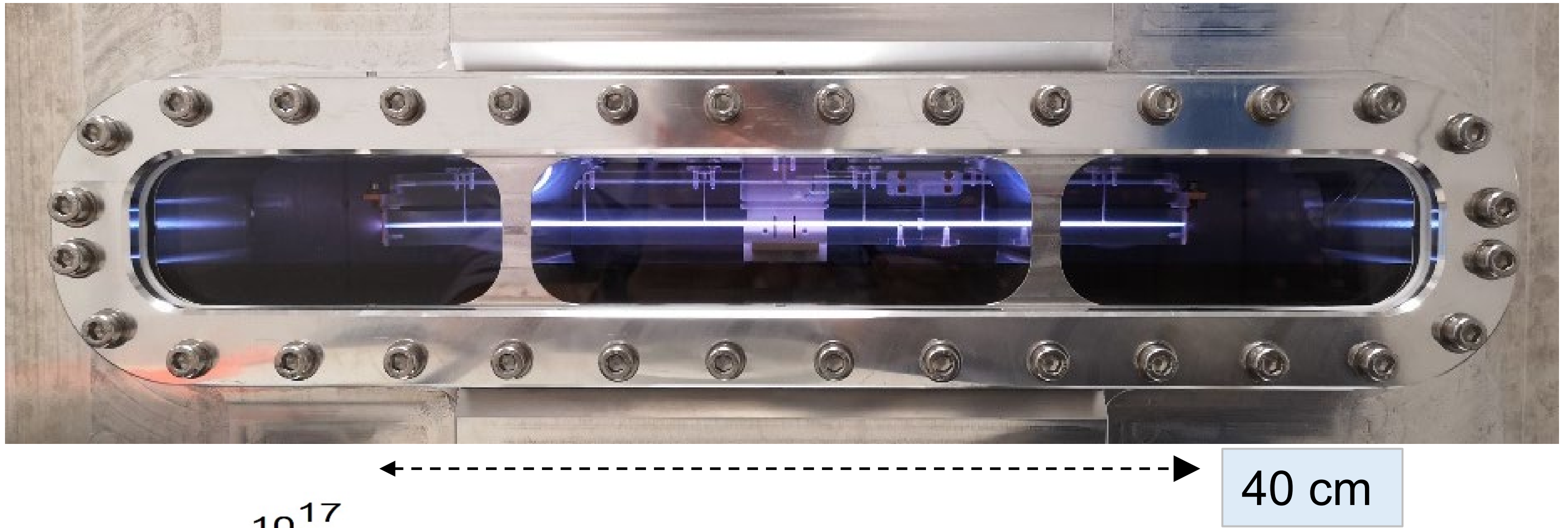


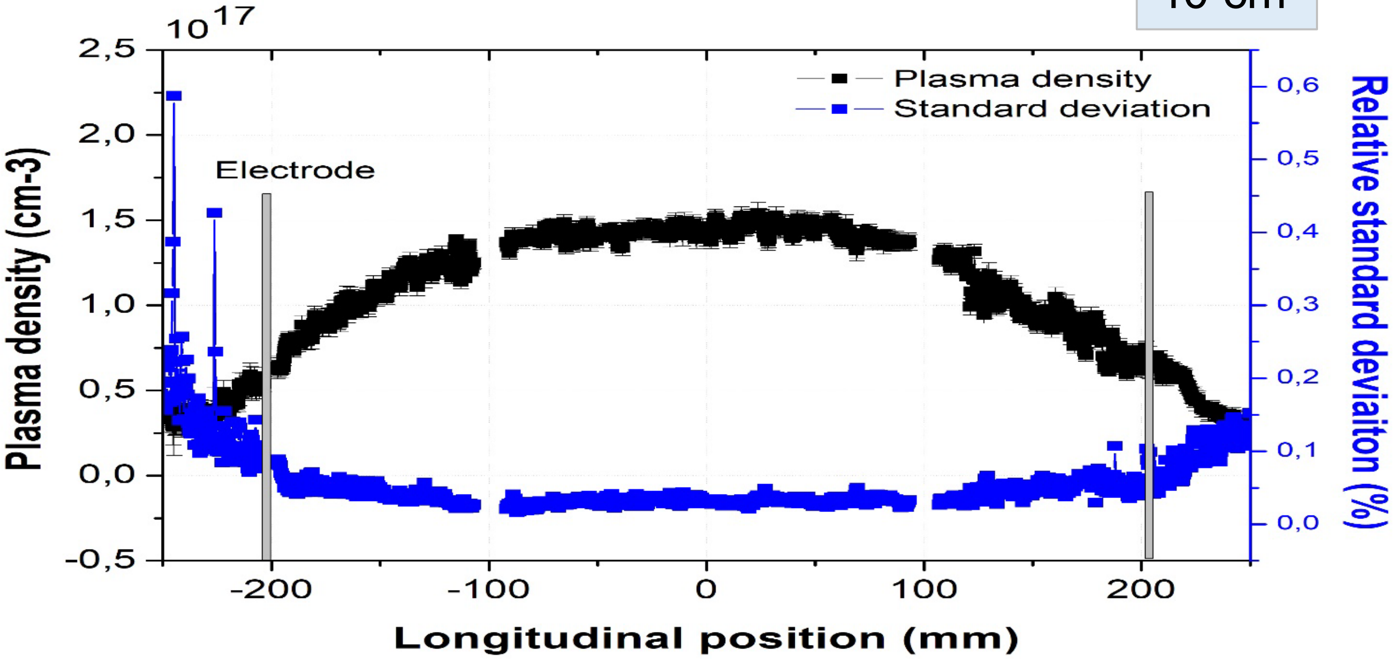




Orange curve, no degradaiton of the inner plasma formaiton channel after $2x10^7$ shots

Electrodes has to be realized by strong materials:
Molybdenum – tantalum - tungsten





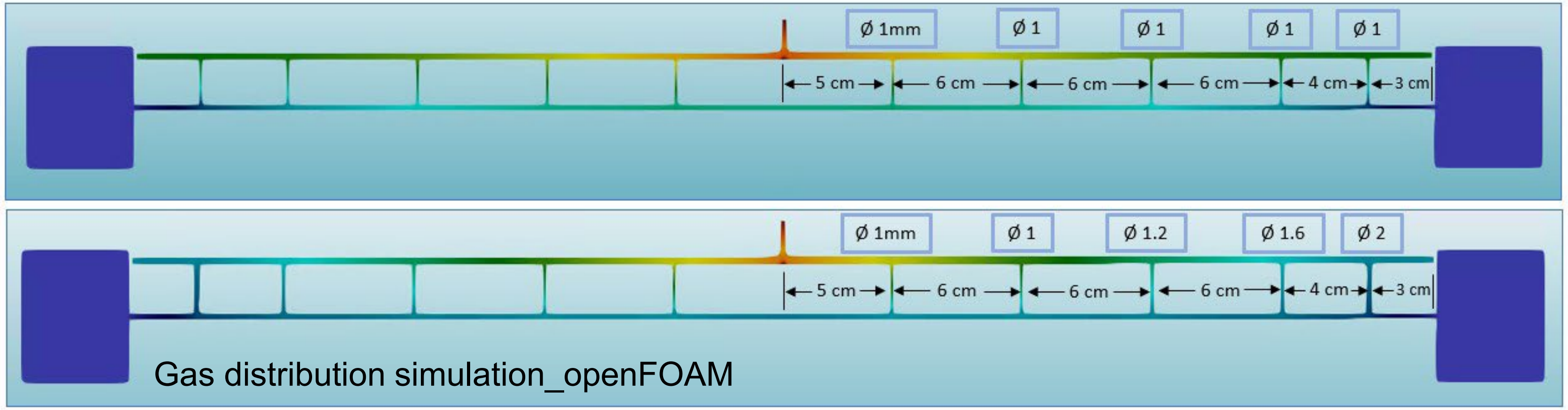
1.1 GeV (1.5 GV/m 600 MeV in **40cm** long capillary - density 10^{16} cm-3):

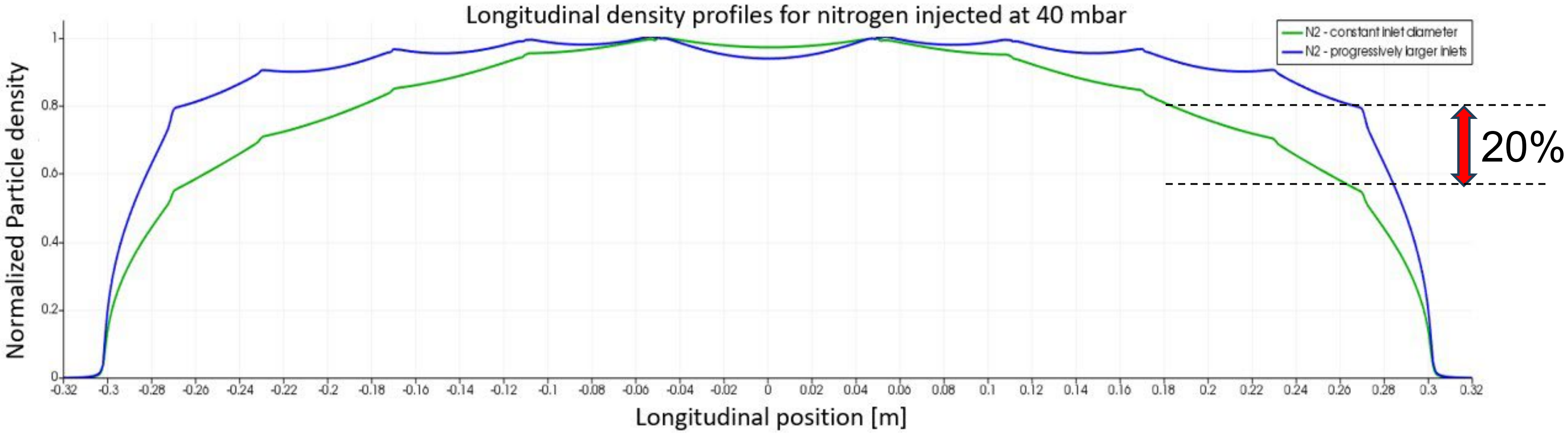
- 3D printed plastic material
- 6 uniform inlets
- Density range 10^{16} -10^{17} cm^{-3}
- 9-10 kV – 380 A
- **100 Hz rep Rate**

1.1 GeV (1 GV/m 600 MeV in **60cm** long capillary - density 10^{16} cm-3):

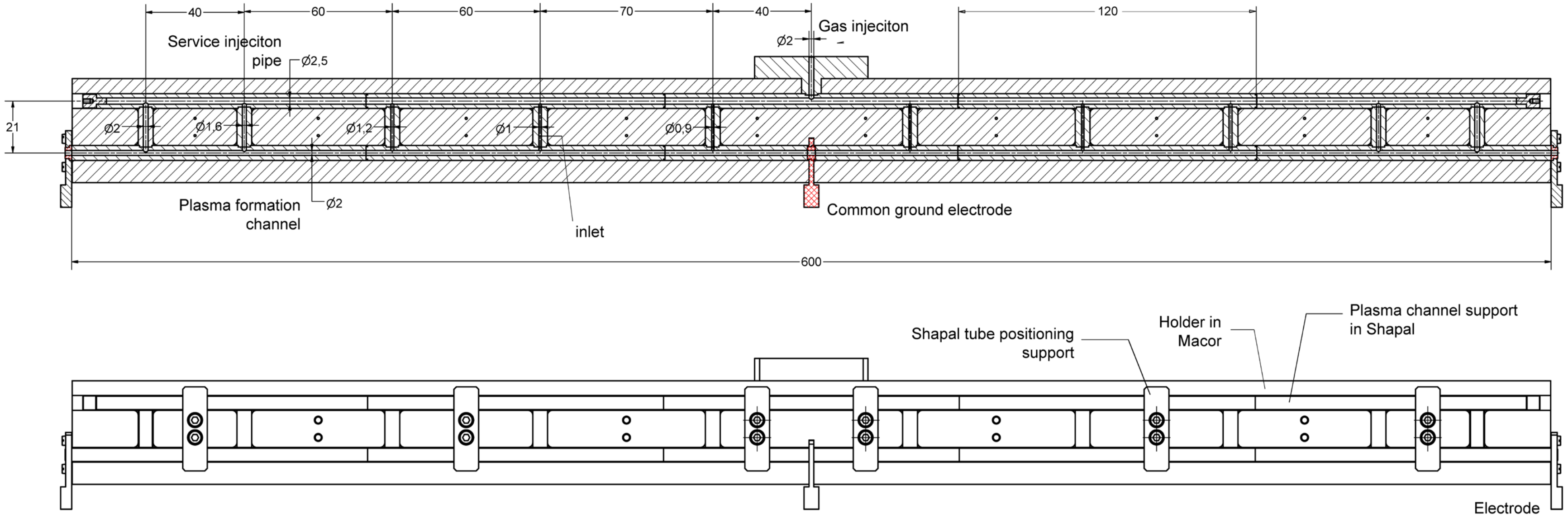
- Fabrication by machining
- 10 increasing diameter
- Density range 10^{16} -10^{17} cm^{-3}
- 10-15 kV with 400 - 500 A
- **100 Hz rep Rate**

Design 60 cm long capillary



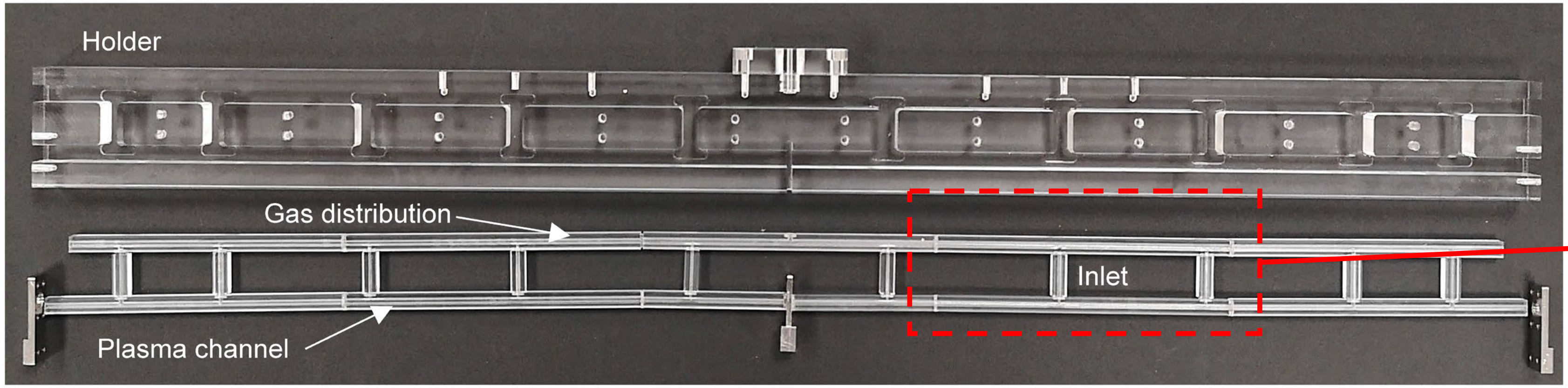


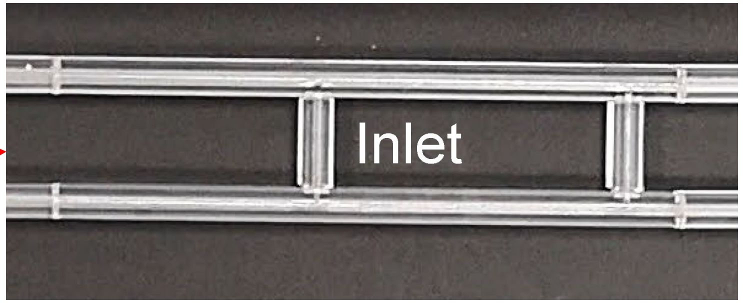
- 10 injectors of constant diameter and progressively closer together
- 10 injectors progressively closer together and having progressively increasing diameters
- Variability of up to 20 % in lateral areas depending on the application



Design 60 cm long capillary:

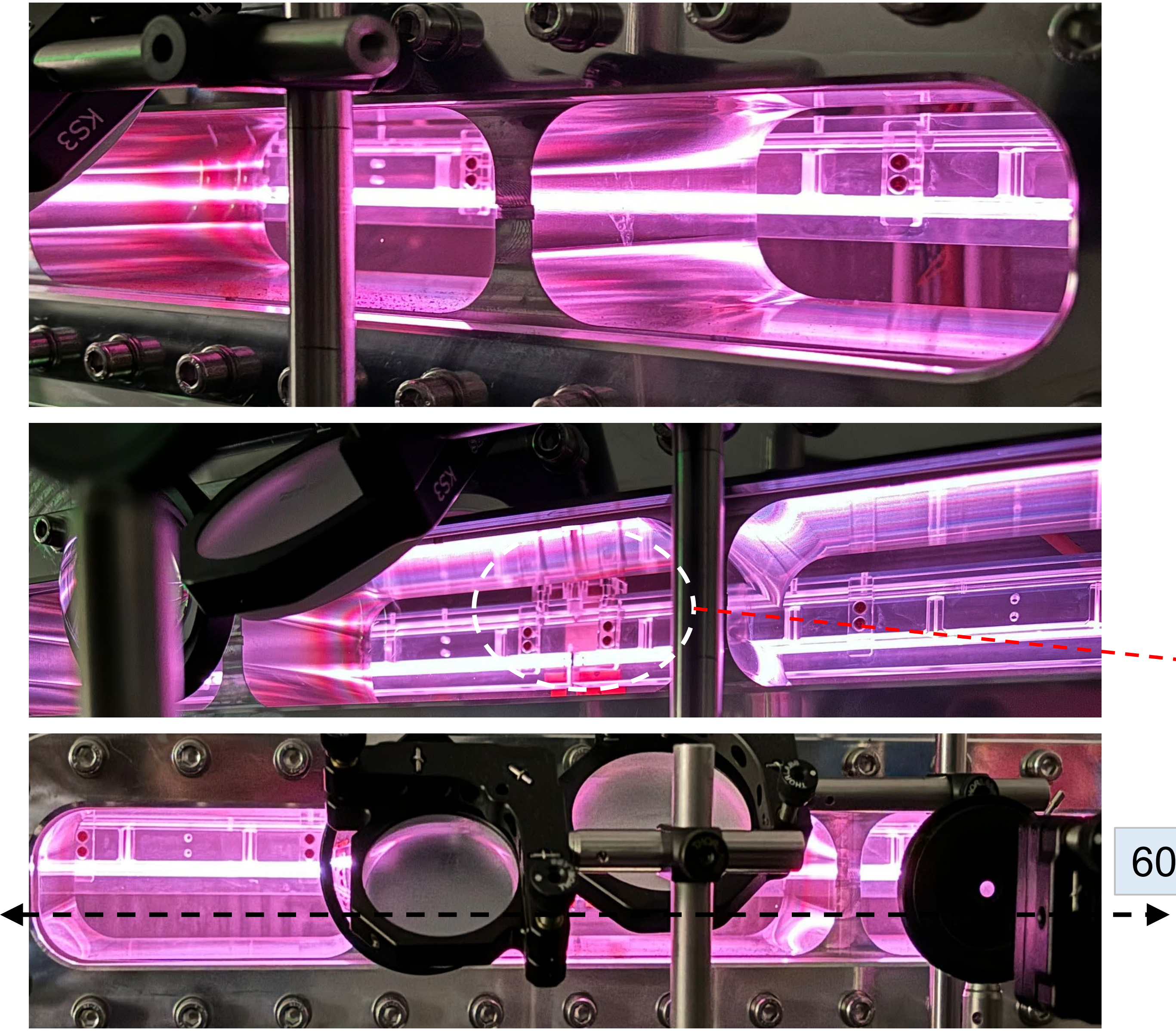
- Support for gas injection and attaching electrodes that contains the injectors and plasma channel
- Common ground electrode to separate two sections
- Prototype in plastic but the final device will be in Macor (holder)/Shapal (channel and inlets)



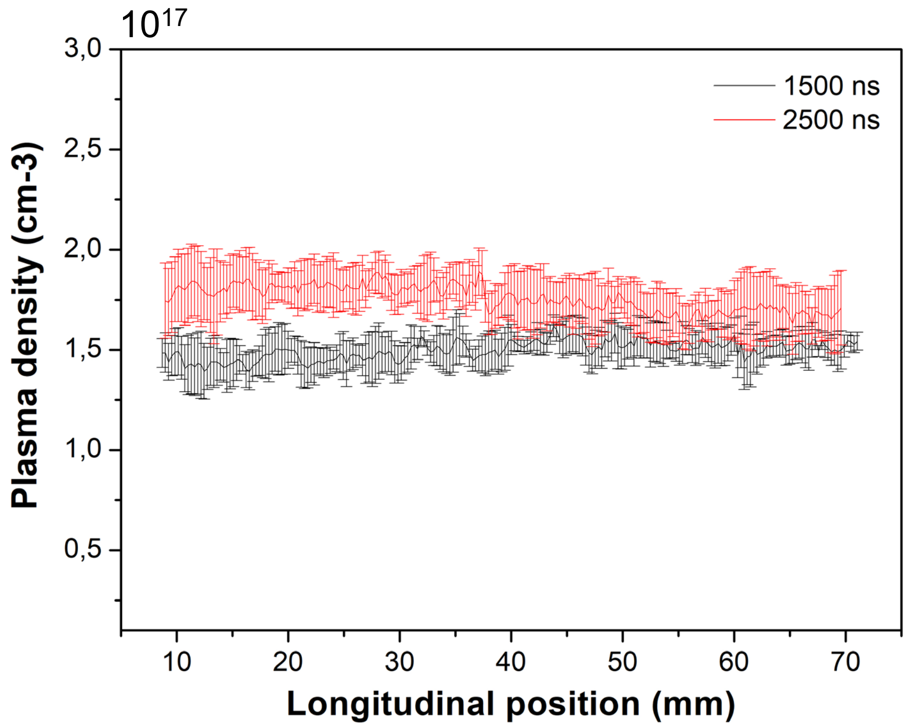


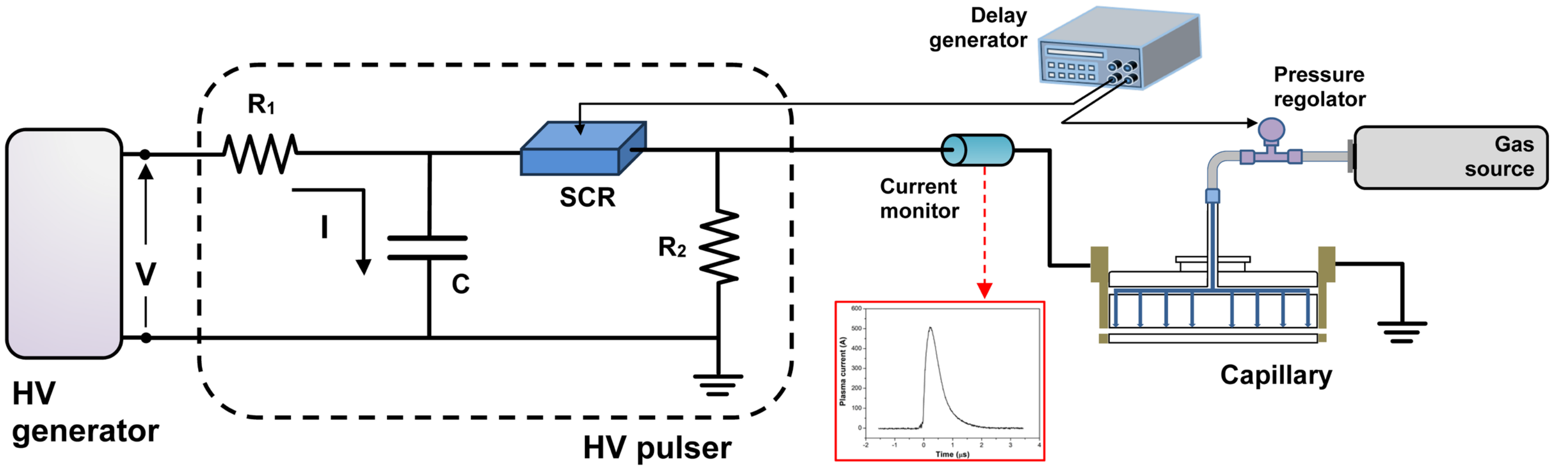
1.1 GeV (1 GV/m 600 MeV in **60cm** long capillary - density 10^{16} cm-3):

- Fabrication by machining
- 10 increasing diameter
- Density range 10^{16} -10^{17} cm^{-3}
- 13 kV with 500 A
- **100 Hz rep Rate**



60 cm



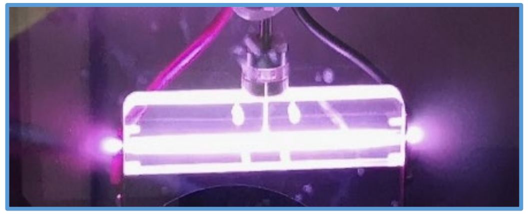


HV generator

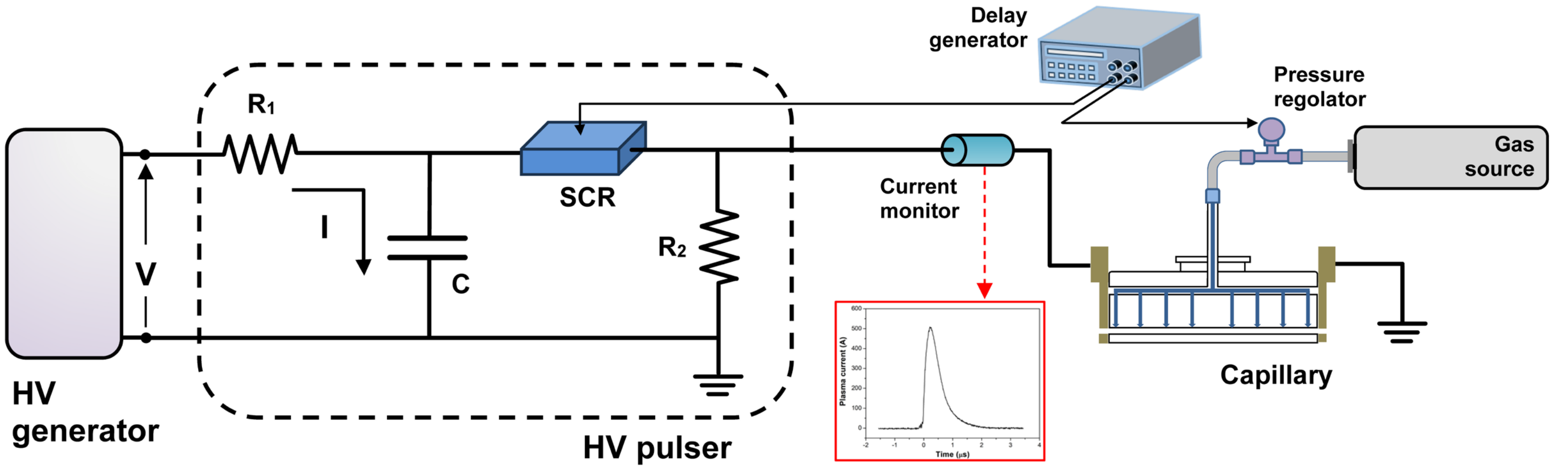
- **High voltage for plasma formation (Max 30 kV)**
- **High current output for high repRATE (Max 150-200 mA)**

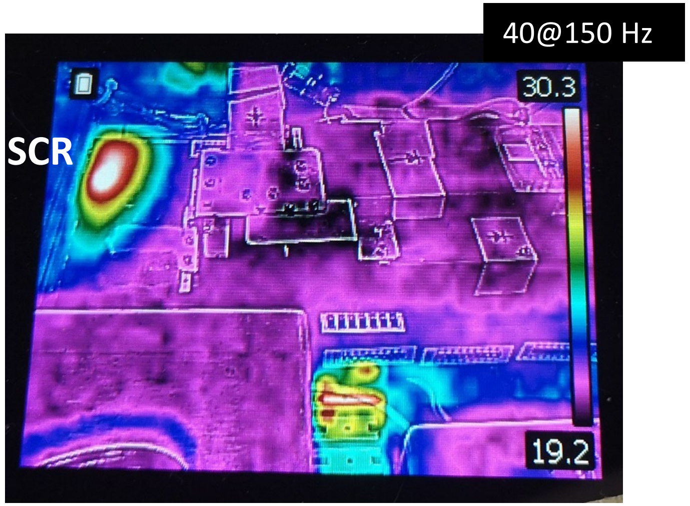
$Q=CV=10kV \times 40nF = 0.6\times10^{-3}$ C
$t_c = dQ/I_c$ = 3 ms at 200 mA
Rep Rate > 300 Hz

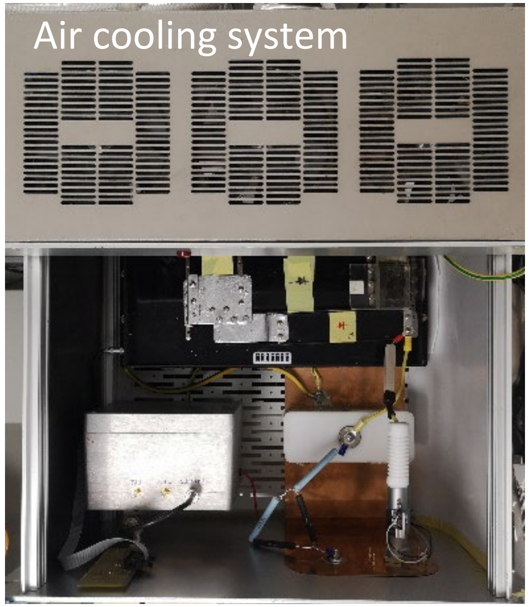
V = 10 – 15 kV
Ip = 400 – 500 A
Δt = 600 ns FWHM



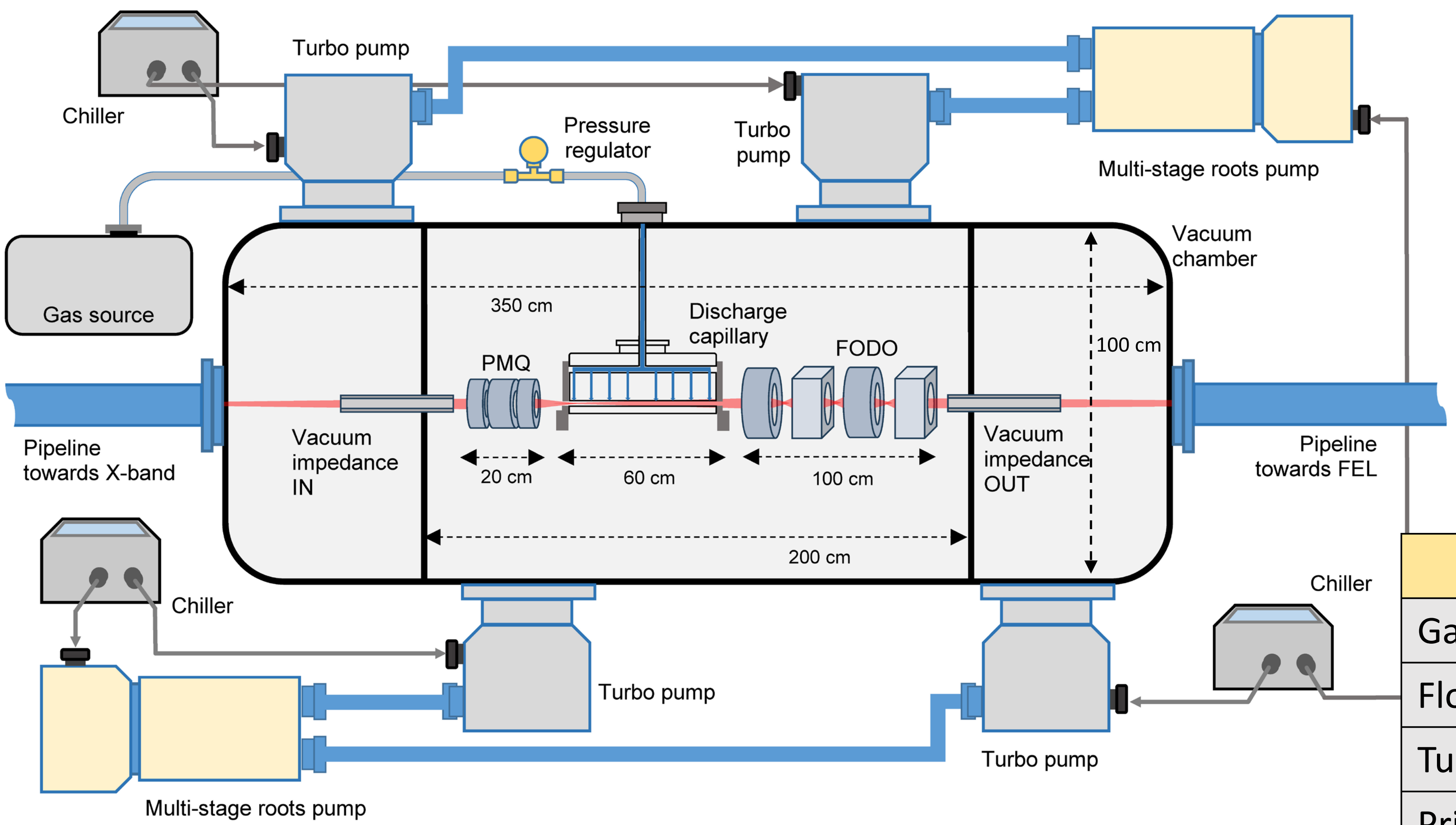
In principle, there are no limitations to high repetition rate (>400 Hz) for HV generator and pulser but overheating problems could cause damage







For higher repRATE an oil cooling system for SCR component will be used (in box)

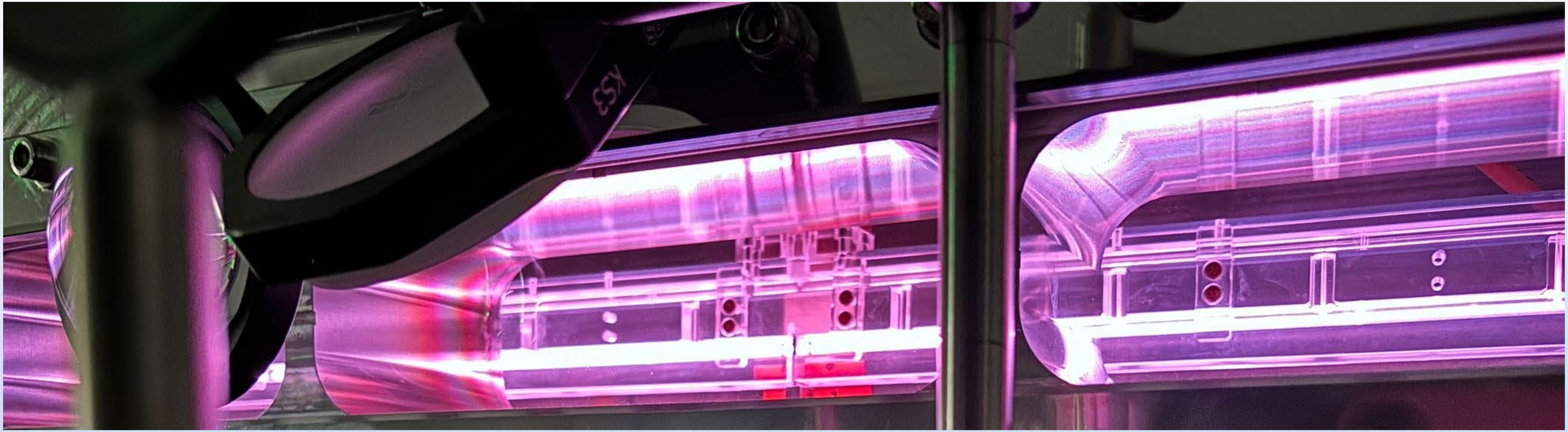


- Inside 220 cm long section, we should reach $10^{-3}/10^{-4}$ mbar
- Differential pumping to satisfy vacuum request in the X-band ($5\text{-}8 \times 10^{-9}$ mbar)

Pumping system	
Gas	Argon, Nitrogen
Flow rate	10-20 l/h at 100 Hz
Turbo pumps	4-6x2300 l/s
Primary pumps	2-3x480 m^3/h
Cooling system	3-5xchiller 30 l/min cooling capacity 4500W

Next steps

	Current status		Next status (next TDR meeting)	
Plasma accelerating module(61%)_(90%)	**TD (83%)**	**W(40%)**	**nextTD(91%)**	**nextW(89%)**
10.1 Introduction	100%	100%	100%	100%
10.2 Plasma module design				
10.2.1 Plasma sources	70%	60%	**100%**	**100%**
10.2.2 HV-sources for plasma creation	100%	100%	100%	100%
10.2.3 Plasma discharge stabilizaiton	100%	100%	100%	100%
10.3 Plasma chamber design	20%	20%	**50%**	**50%**
10.3.1 Focusing and extraction systems	BP	BP	BP	BP
10.3.2 Capillary supports and handling	70%	0%	**70%**	**70%**
10.4 Vacuum pumping system	60%	30%	**80%**	**80%**
10.5 Diagnostics				
10.5.1 Plasma diagnostics	100%	50%	**100%**	**100%**
10.5.1.1 Stark broadening technique	100%	100%	100%	100%
10.5.1.2 Interferometric techniques	100%	0%	**100%**	**100%**
10.5.2 Beam diagnostics	BD	BD	BD	BD
10.6 High repetition rate plasma sources	80%	80%	**100%**	**100%**
10.7 Future developments				
10.7.1 Segmented capillary	100%	0%	**100%**	**100%**
10.7.2 All-in-one capillary	100%	0%	**100%**	**100%**
10.7.3 APL collimator system	70%	0%	**70%**	**50%**
10.8 Plasma module safety system	80%	0%	**100**	**100%**



Thank you for your attention