EUROPEAN
PLASMA RESEARCH
ACCELERATOR
WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

Chapter 10: Plasma accelerating module

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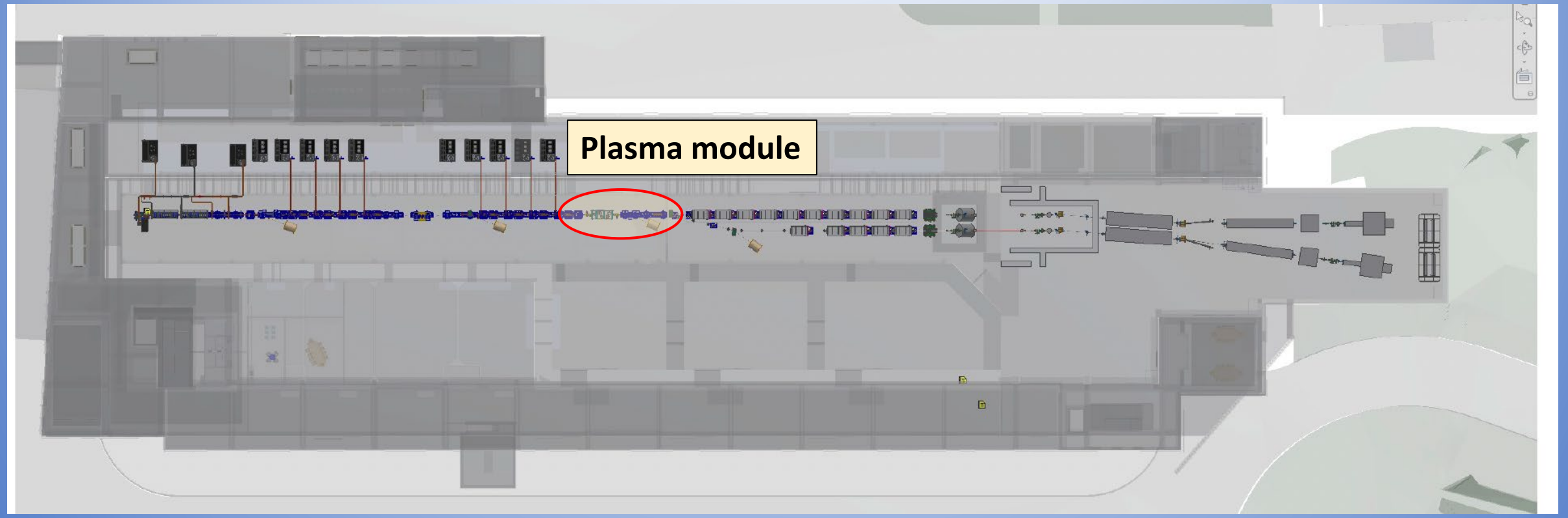
IX TDR Review Committee Meeting
June 16-18, 2025

Area of interest



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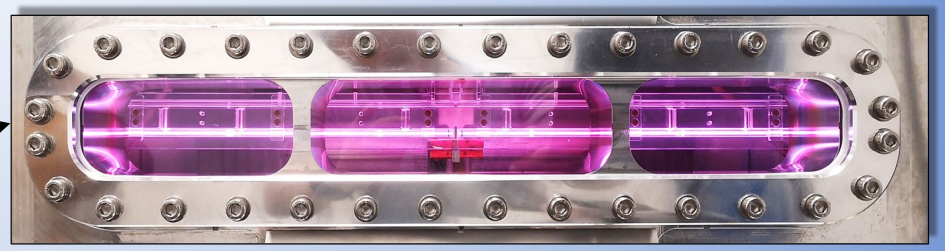
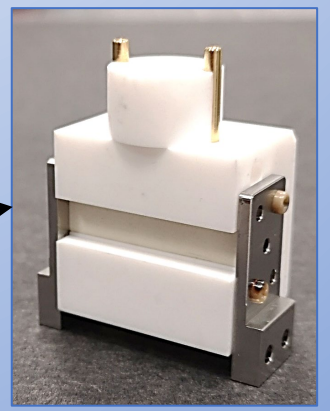
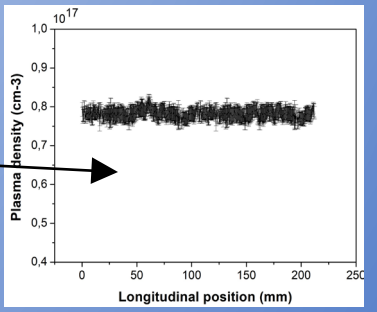
Global Goals:

Key design parameters for the EuPAXIA@SPARC_LAB plasma source	
Source type	Gas-filled discharge capillary
Geometry	60 cm in length 2 mm in diameter variable inlets
Gas	Argon, Nitrogen, Hydrogen
Gas injection system	Continuous gas injection using a common service channel and several injectors with variable position and size
Repetition rate	100 - 400Hz
Discharge circuit parameters	Voltage: 10÷15 kV Current: 400÷500 A
Materials	Channel: Sapphire, Shapal Holder: Macor Electrodes: Tungsten
Plasma density	$10^{16} \div 10^{17}$ cm^{-3}
Lifetime	3×10^{8} shots
Shot-to-shot stability	$< 1\%$ with laser stabilization







Key points requested by the TDR committee

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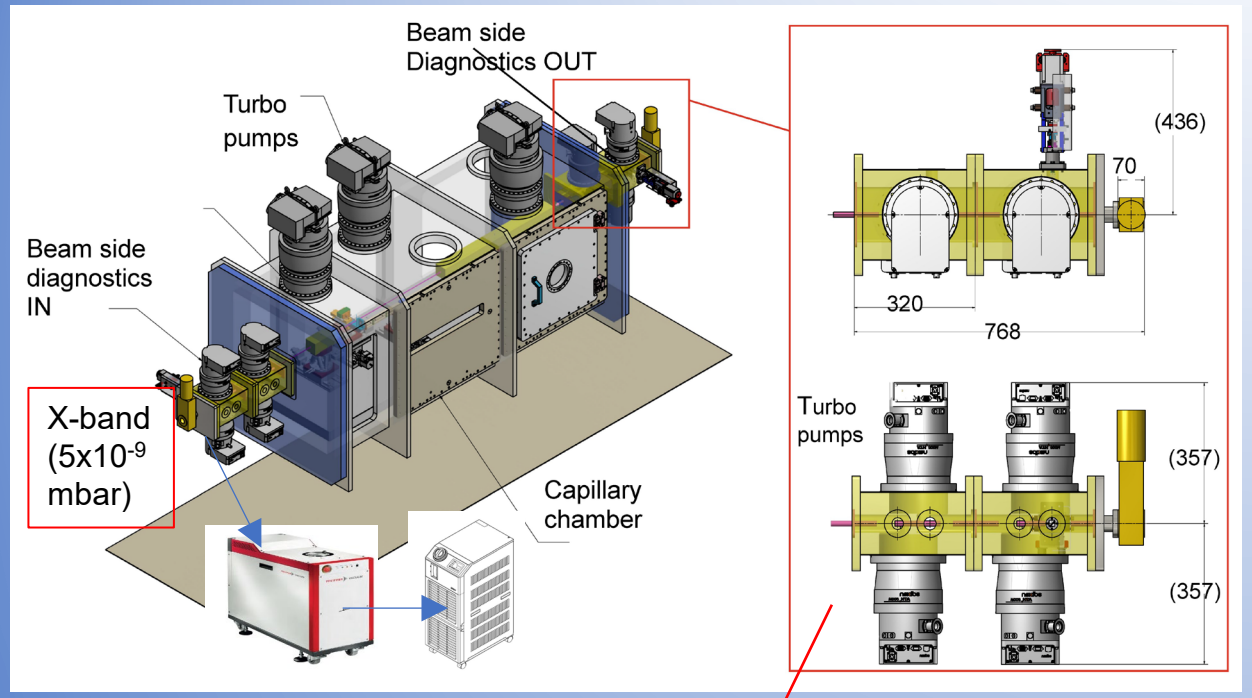
- More detailed description of the prototype of the plasma source (gas-filled discharge capillary) was needed
- Description of the vacuum system's ability to sustain the gas flow required to produce the plasma was missing
- The high voltage system used for ionizing the neutral gas and thus creating the plasma needed to be better described

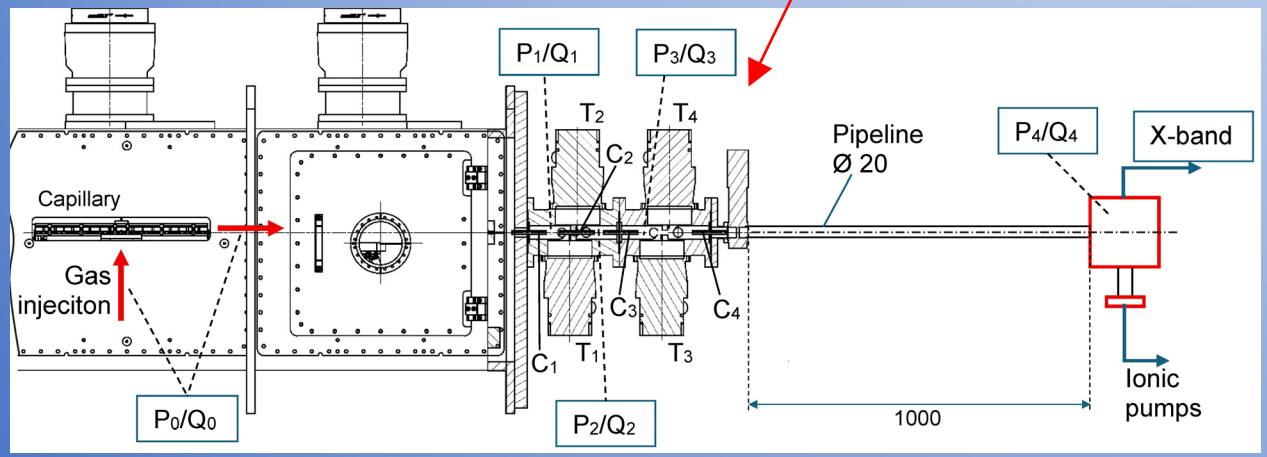
Achievements: Technological Readiness Level (Sub-Components)

Plasma Module	5	Extensive R&D has been made to validate the plasma capillary technology and solid results have proved the validity of the technical choice. A full system proven in a real environment is expected to be done in the next year (*Technology validated in relevant environment – The technology is tested in a simulated or relevant environment*)

Sub - systems	TRL	Comments
Plasma chamber	8	Plasma chambers designed for differential pumping are widely used in many facilities, including SPARC_LAB. Actual system proven in operational environment (System complete and qualified – The technology is proven to work in its final form and under expected conditions)
Vacuum pumping system	8	Pumping systems appropriate to the gas quantities required for plasma formation in acceleration experiments have already been tested at the SPARC_LAB and other facilities.
HV source	8	The high voltage system to produce ionization of 60 cm long gas columns in thin capillaries has been fully designed and tested in the laboratory at the operating frequencies
Plasma source (Gas-filled capillary)	5	Extensive R&D has been made to validate the plasma capillary technology and solid results have proved the validity of the technical choice. A full system proven in a real environment is expected to be done in the next year
Magnetic separation	5	The separation chicane between the driver and witness in plasma accelerators has never been experimentally tested and, although it exists at the design level, it has not yet been technically implemented

Achievements:
8-Technological Readiness Level (*Plasma chamber and pumping system*)

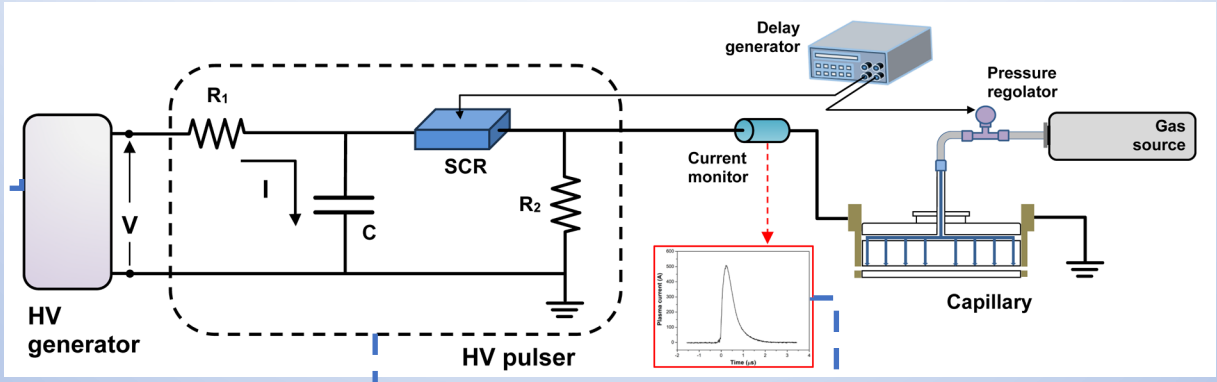




- High amount of gas injected to work at 100-400 Hz repetition rate (15-20 mbar ·l/s)
- Differential pumping system inside the side diagnostic chambers

Position	Pressure (mbar)	Gas flow (mbar*l/s)
0	5×10^{-3}	12
1	1×10^{-5}	3×10^{-2}
2	4×10^{-8}	1×10^{-5}
3	3×10^{-10}	8×10^{-8}
4	1×10^{-11}	2×10^{-10}

Achievements:
8-Technological Readiness Level (*HV source*)

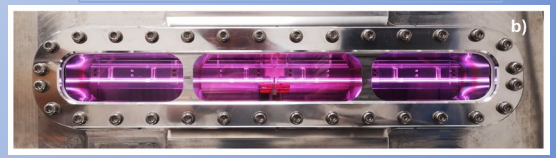


- **High voltage for plasma formation (Max 30 kV)**
- **High current output for high repRATE (Max 150-200 mA)**

Q=CV=10kV x 40nF = 0.4×10^{-3} C
$t_c = dQ/I_c$ = 2 ms at 200 mA
Rep Rate <= 500 Hz

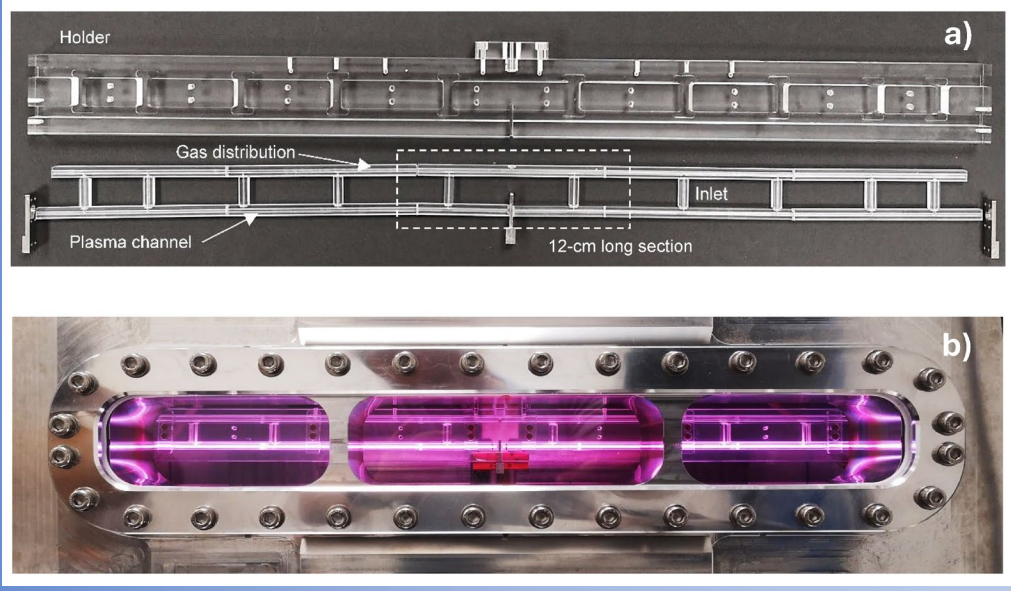
V = 10 – 15 kV
*I*p = 400 – 500 A
Δt = 600 ns FWHM

60 cm long capillary

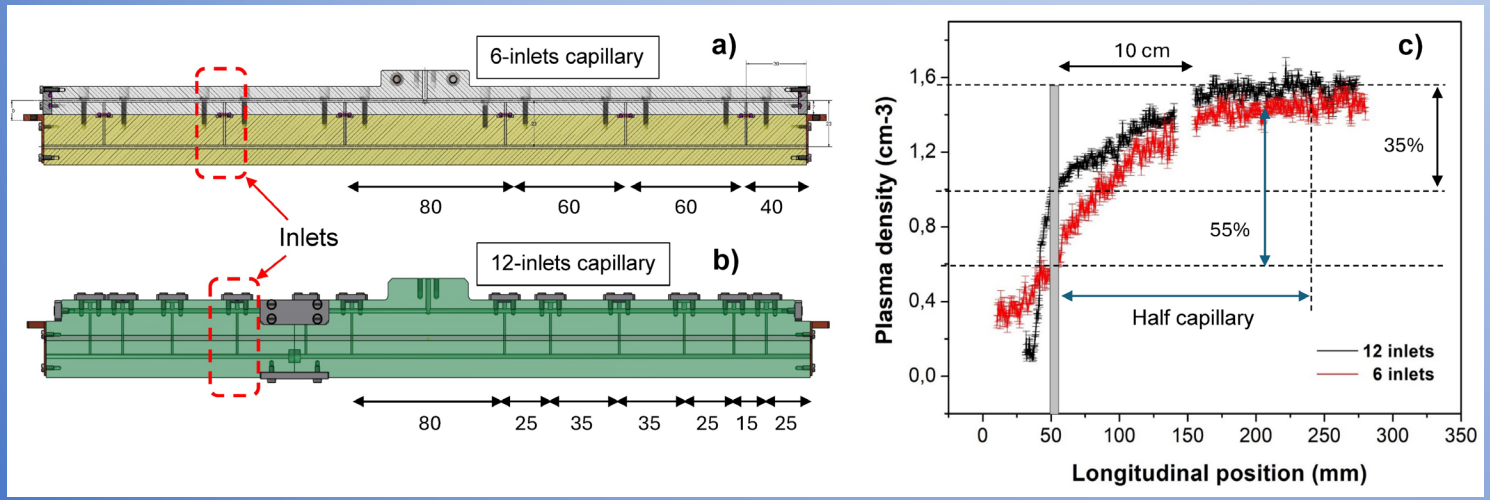


In principle, there are no limitations to high repetition rate (>400 Hz) for HV generator and pulser but overheating problems could cause damages

Achievements:
5-Technological Readiness Level (*Gas-filled discharge capillary*)

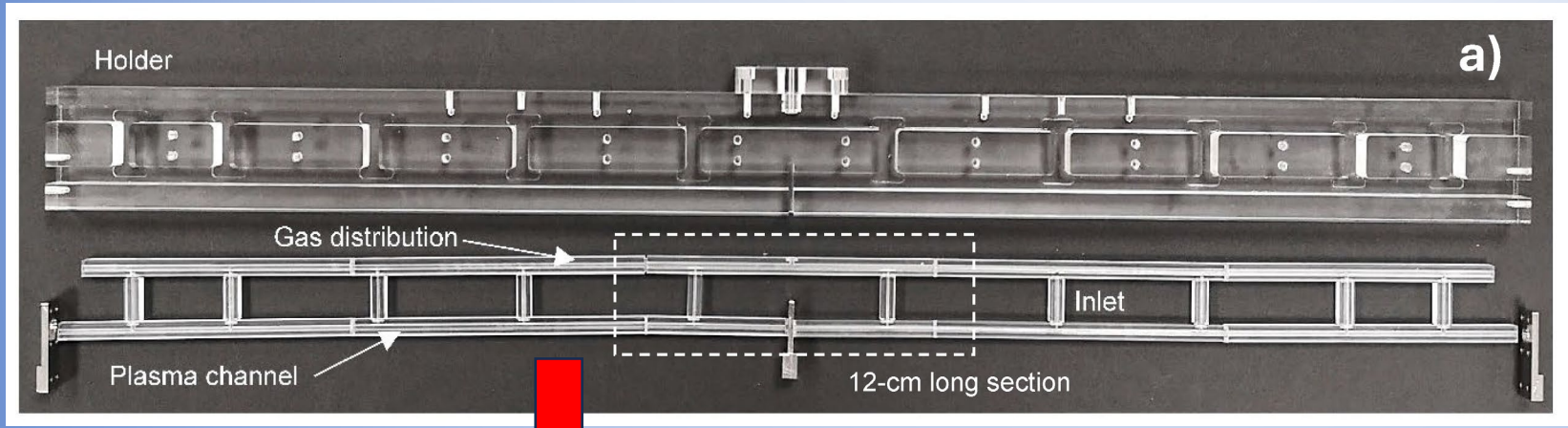


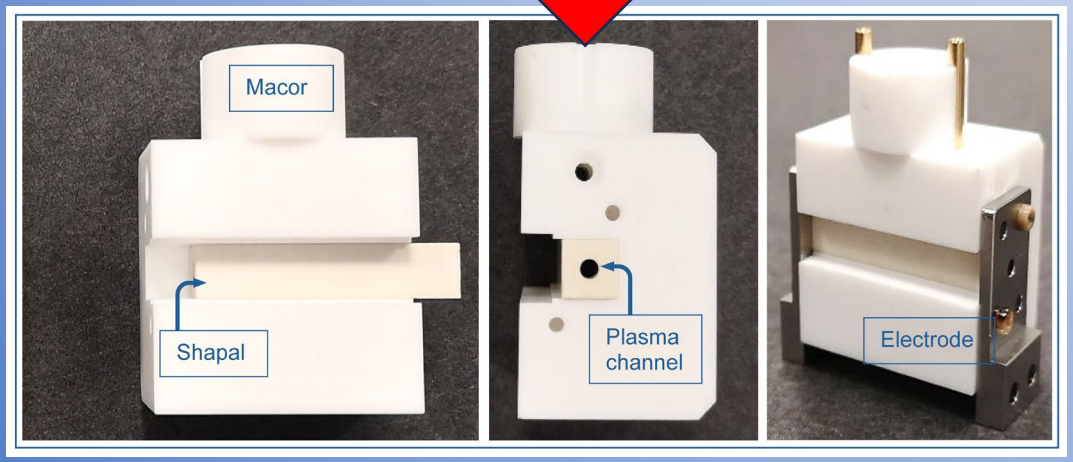
- Plastic prototype to test different parts of the plasma source
- Laboratory testing for setting plasma formation parameters (voltage, currents, pressure, densities)
- Partial testing of materials ($2x10^7$ discharges) to work at high repetition rates



- tests on a 40 cm long capillary to control the ramps (plasma channel geometry and gas distribution system) within the capillary as required by beam physics to achieve the acceleration targets (red profile has been used for beam dynamics simulations)

Planned Actions: 60 cm long capillary in Shapal/Macor to be tested





TDR completed

- Production of the final prototype (60 cm long Shapal/Macor capillary)
- Further resistance tests on the capillary with actual dimensions (60 cm) in a new plasma chambers similar to the final one
- New electrode materials such as tantalum or tungsten (so far we have successfully tested molybdenum)

Dependencies / Risks (optional):
(Any blocking issues or critical path items.)

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- Fields maps insertion in the codes for all magnetics elements (Magnets and power supplies)
- Vacuum system has been designed and preliminary tests have been carried out in the Plasma laboratory but further tests have to be done with a differential system more similar to the final one

Conclusions

- Plasma source specifications align with the beam parameters required for injector and linac performance
- These specifications meet the requirements both for plasma source length (60 cm) and plasma densities (10^{16} -10^{17} cm^{-3}), as well as the capability to control plasma ramps along the longitudinal dimension
- The plasma chamber and differential pumping system make it possible to maintain the working pressures required ($5x10^{-9}$ mbar) using X-band accelerating sections

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