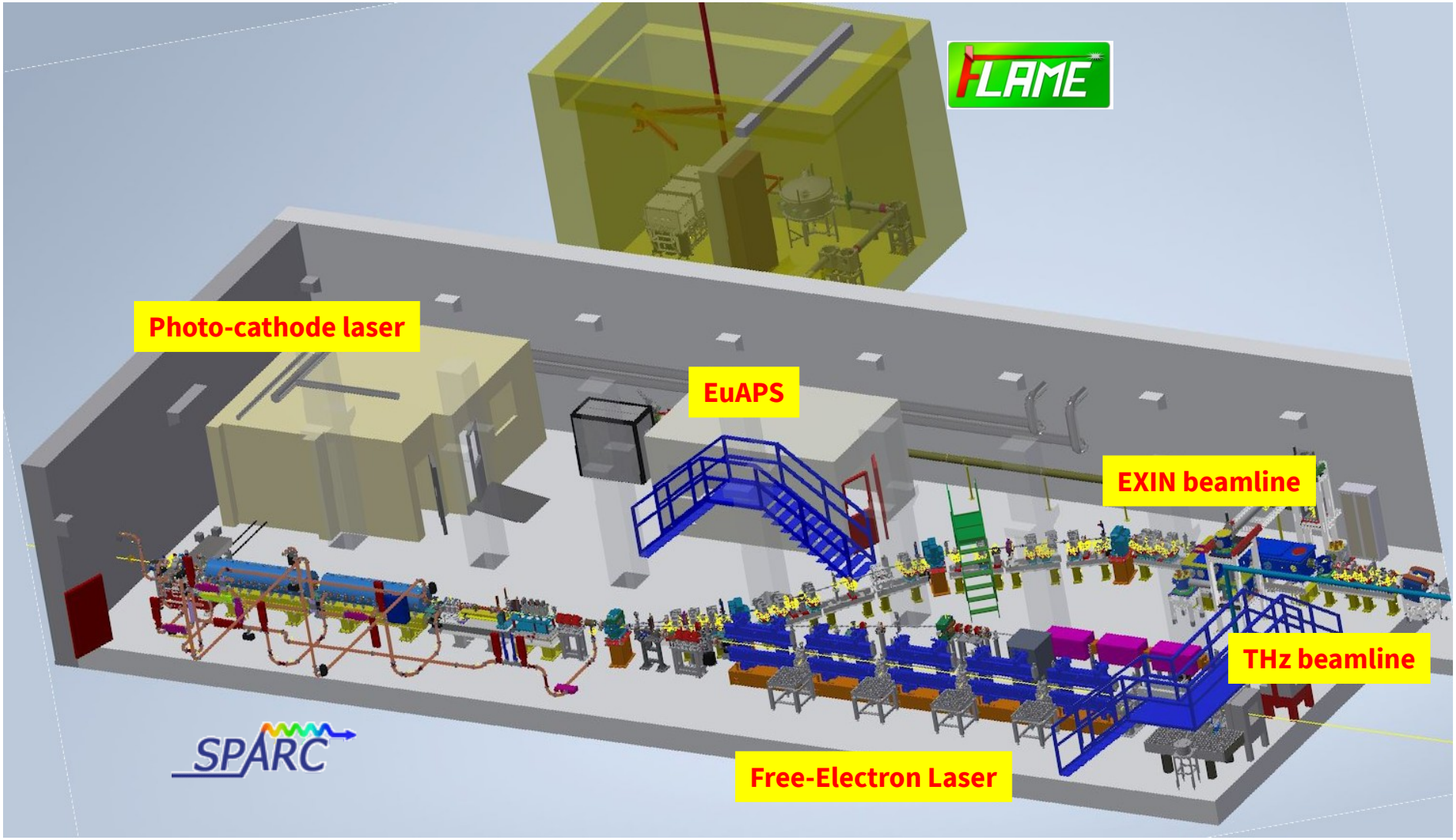
LNF Scientific Committee
Frascati

SPARC_LAB activity report

R. Pompili (LNF-INFN)
riccardo.pompili@lnf.infn.it

On behalf of the SPARC_LAB collaboration

SPARC_LAB facility



Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.

Main considerations

After the last SciCom (May 2024) SPARC installations due to SABINA ended and the commissioning of the “new” photo-injector started

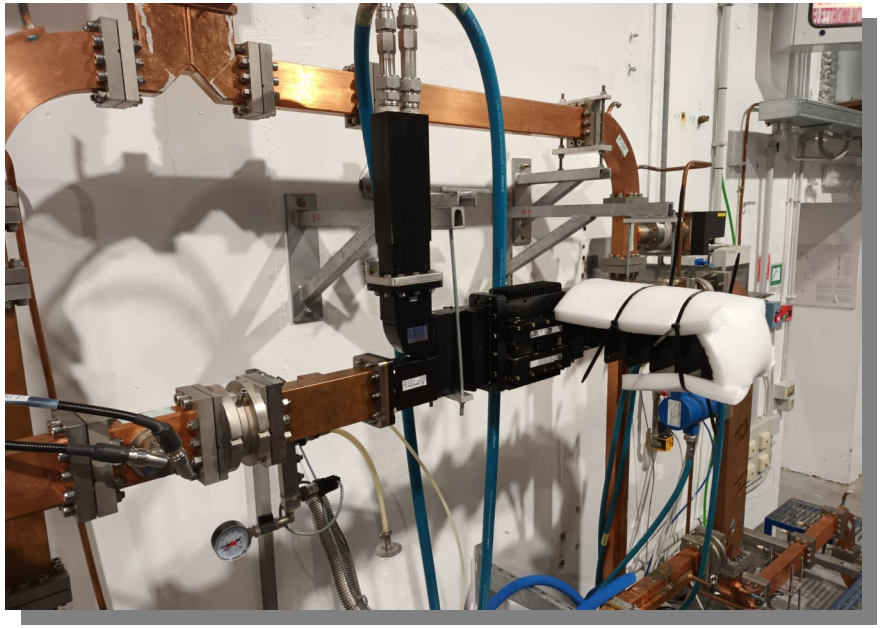
July 2024: almost entirely spent for RF commissioning (conditioning and debug of new EPICS LLRF panels). Problems with the K1 RF circulator (loss of SF6)

October 2024: RF circulator fixed at the end of the month. Start of TW sections and new solenoids alignment

Expected SPARC run deadline is now 14 March 2025

- November 2024: alignment almost completed, reference trajectory found. Commissioning of the new PMQ systems for plasma acceleration experiments
- Time for 1-2 experiments: laser-plasma filament, resonant PWFA

SPARC will then shutdown to allow the EuAPS installations in the SPARC bunker.
Some parasitic activities can be continued for the commissioning of the SABINA-THz beamline



New RF circulator after fixing SF6 leak
Thanks to R. Di Raddo, P, Chimenti, M. Zottola

Status of transition to EPICS

SPARC control system is gradually moving to EPICS

New standard with EPIK8S standard for EUPRAXIA and ELI-NP DCS implementation

The goal is to complete the transition within the next year

Completed

Low-Level RF, Timing, BPM, Laser shutters, Flag lights

The data analysis software (based on Matlab) is now fully compatible with EPICS

Ongoing

Cameras, Magnets, Flags/Motors, Vacuum

To do

Modulators, Chillers, Security (bunker), Machine Protection System, Valves, RFD switch

A. D'Uffizi, R.Esposito, F. Galletti, R. Gargana, A. Michelotti

Recommendations from previous SC

- Assure that sufficient effort and time is put on experiments relevant for finalizing EuPraxia@SPARCLAB design. In particular
  - *Demonstration of robust plasma capillaries suitable for long term, high-repetition rate operation*
  - *Comparison of PM magnet vs. plasma focusing*
  - *Studies of timing/bunching/energy stability with velocity bunching. These tests are decisive for the choice velocity bunching vs. magnetic bunching and have substantial impact on the EuPRaxia@Sparclab concepts and design finalisation.*

- *PLASMA_LAB activities went ahead to consolidate the preliminary results obtained at high rep rates, especially with the SPAPAL capillary prototypes. Some results will be showed*
- *We started (yesterday) the commissioning of the new PMQs with bean-based measurements*
- *The RF group continued the improvements of the Klystron-Loop feedbacks and found timing-jitter well below 20 fs*

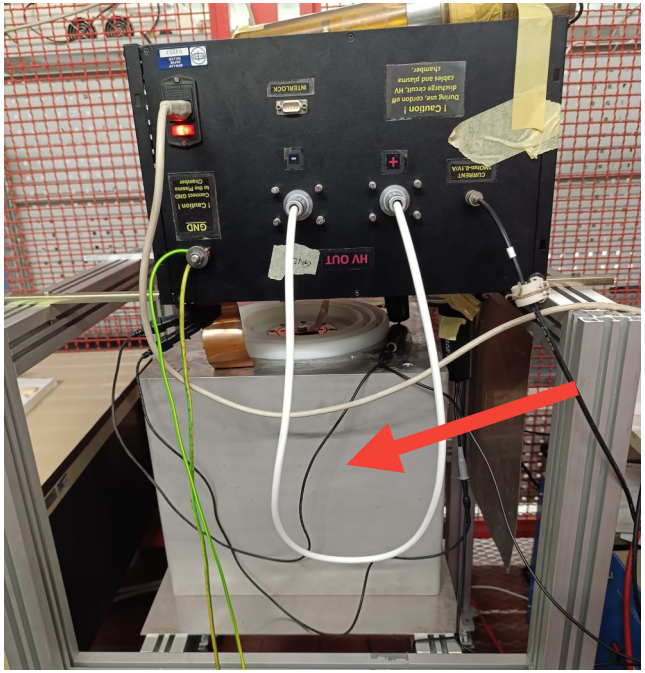
Recommendations from previous SC

- Accelerate procurement and installation of a solid-state klystron modulator for the velocity bunching section of the injector. A high stability RF power source at this position is imperative for demonstrating the stability of timing/bunching/energy mentioned above.
  - *The tender has not started yet. Still dealing with administrative procedures.*
  - *The purchase of the new modulators and klystron has been included in the INFN plan for the next 3 years*
  - *Due to the amount of money required for the purchase (>1 M€) and the complexity of the purchase procedures, the tender will start only in the next year*
  - *The tender for the klystron was not put in place due to a delay in their response for a quotation. Expected to be available in January*

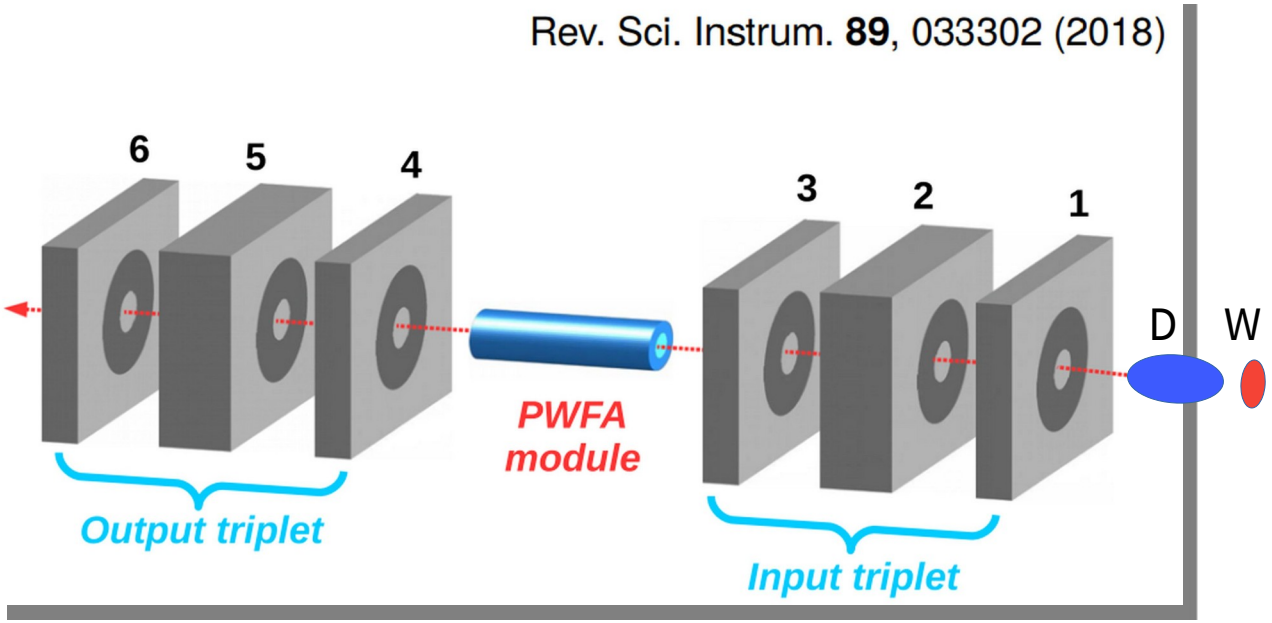
Recommendations from previous SC

- Continue studies and explore the application potential of curved capillaries.
  - *After the encouraging results achieved in 2023, the development of the curved capillary "technology" is continuing offline with attempts to increase the achievable peak current from the power source.*
  - *Some tests done with Marx-Generator discharge circuit that showed good results in terms of currents (10-15 kA peak with <20 ns duration) but totally unstable in terms of jitter*
  - *New tests are being performed with the solid-state switch apparatus where we changed the capacitors with a new one having 1 uF capacitance. ~5 kA were reached but the duration of the current pulse increased to ~8 us → large heat dissipation*

D. Pellegrini
G. Grilli
T. De Nardis



Transverse matching in a plasma



In a **PWFA** the beam must be transversely focused at the plasma entrance

Driver beam charge density (together with plasma density) sets the accelerating gradient

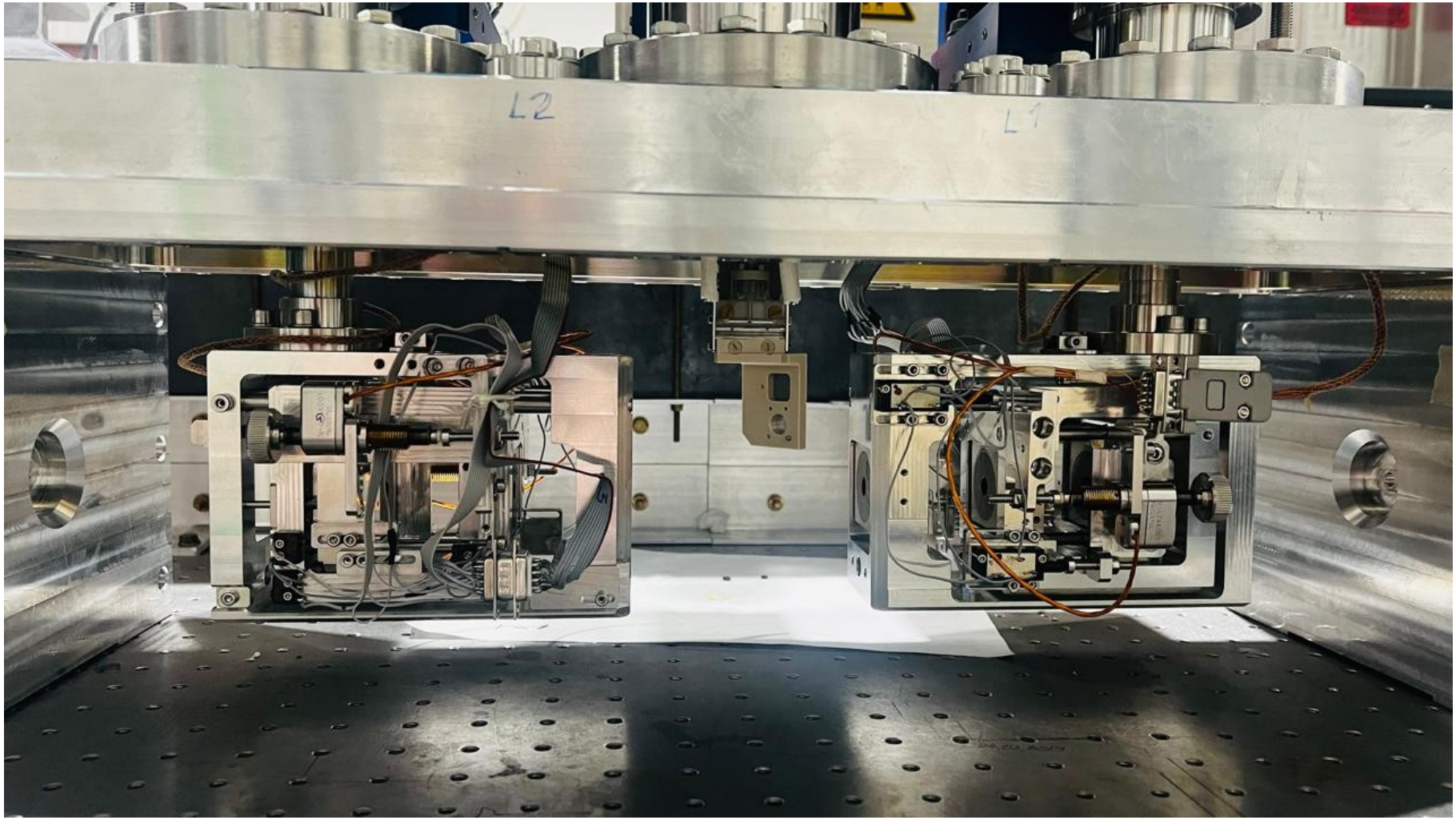
Witness beam must be transversely matched to avoid emittance spoiling

$$\beta_{eq} = \sqrt{\frac{\gamma}{2\pi r_e n_p}}$$

Barov, N., et al., Physical Review E 49.5 (1994): 4407.

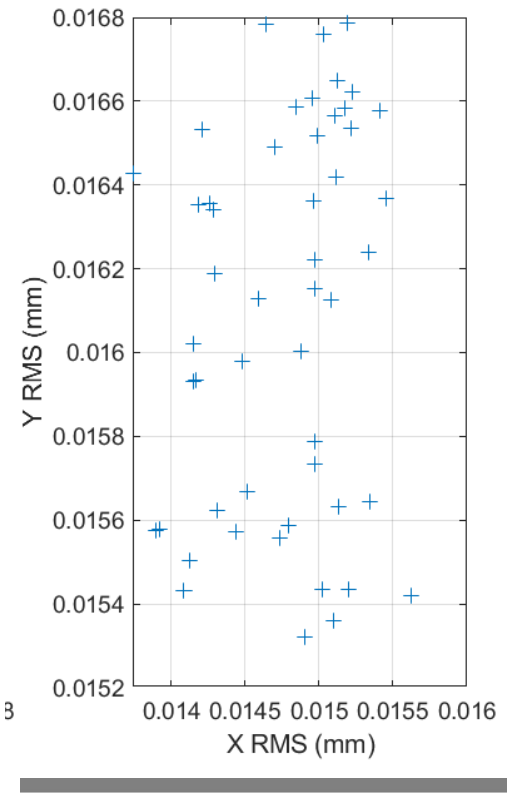
The PWFA needs focusing optics upstream (matching) and downstream (capture)

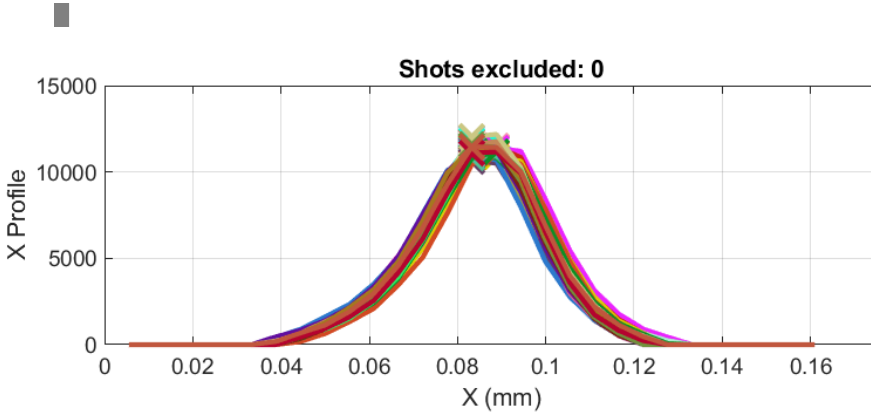
New PMQ triplets installed

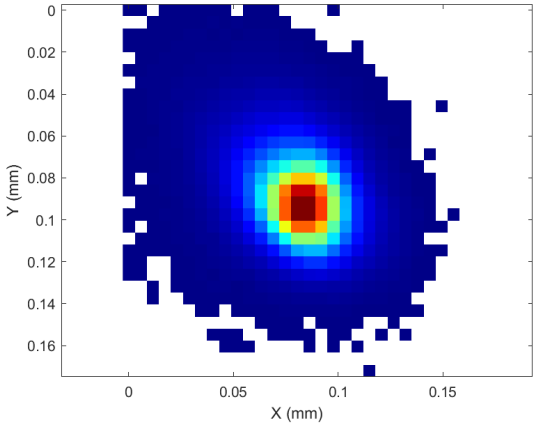


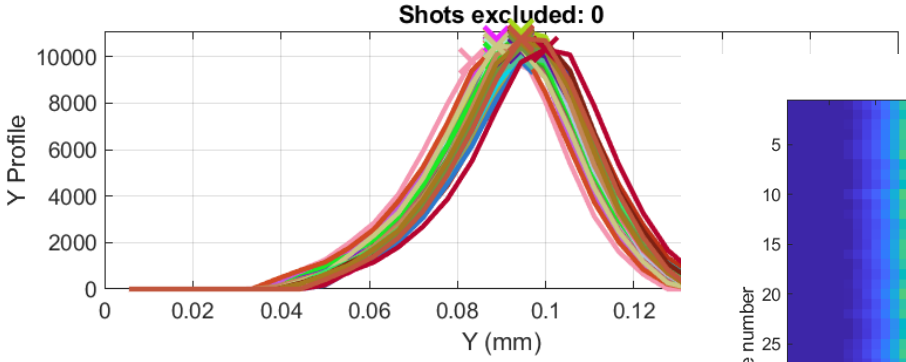
Thanks to V. Lollo, M. Zottola

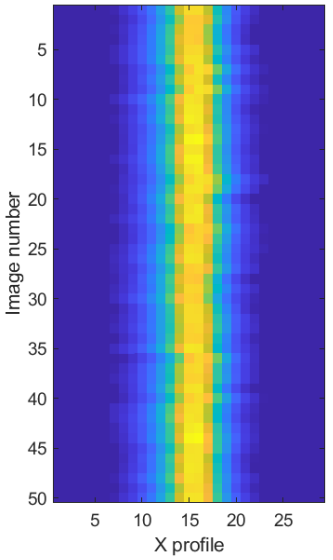
Preliminary results with the PMQs

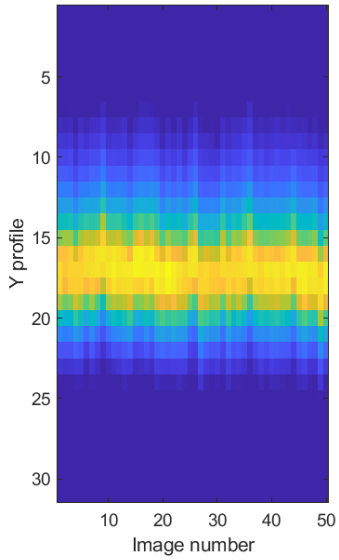












Results obtained with a 150 pC test beam having 95 MeV energy. ~15 um (rms) obtained. Need to further improve

Planning of activities for 2024/25

Confirmed

New PMQ tests

High-gradient/high-quality PWFA beams

Filament experiment

Resonant multi-driver PWFA

Commissioning of the SABINA beamline

Proposed

Driver-Witness separation with APLs – 2 weeks

PWFA vs EOS (RF timing)-Plasma (density)-Laser (charge) jitter study

UV-Blue-IR photo-emission comparison for charge-jitter study

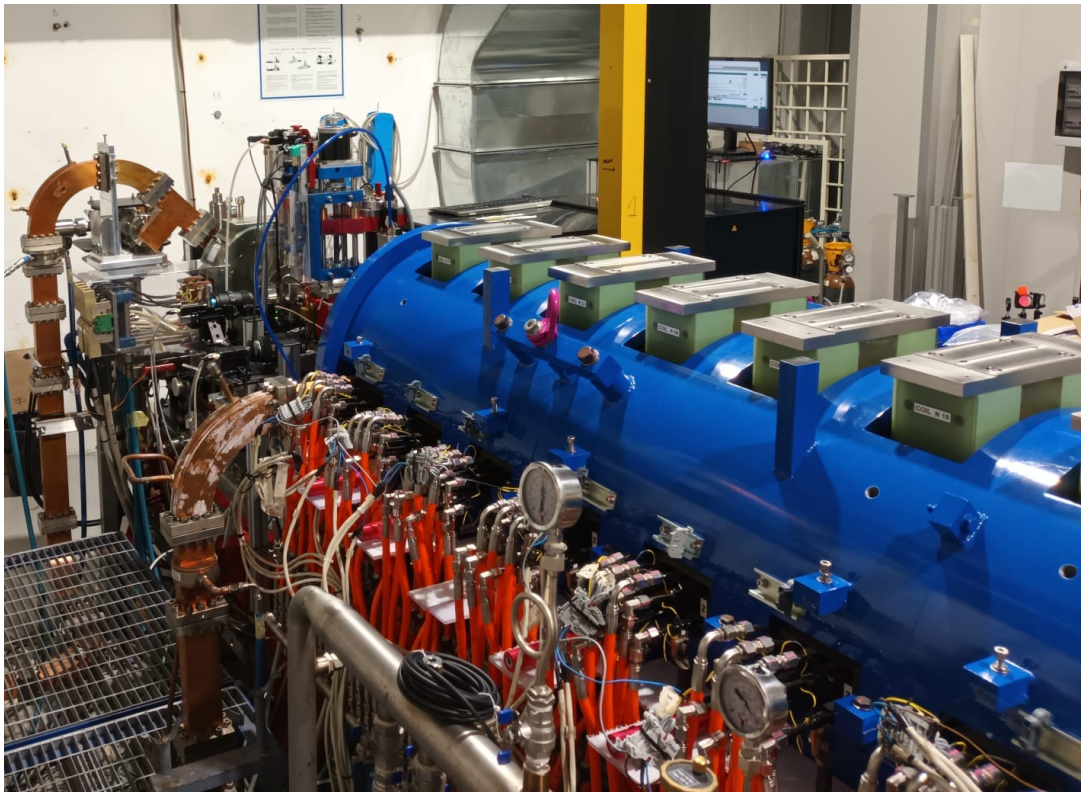
Plasma ramps parametric study

Commissioning of the EXIN beamline

SABINA installations progress

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

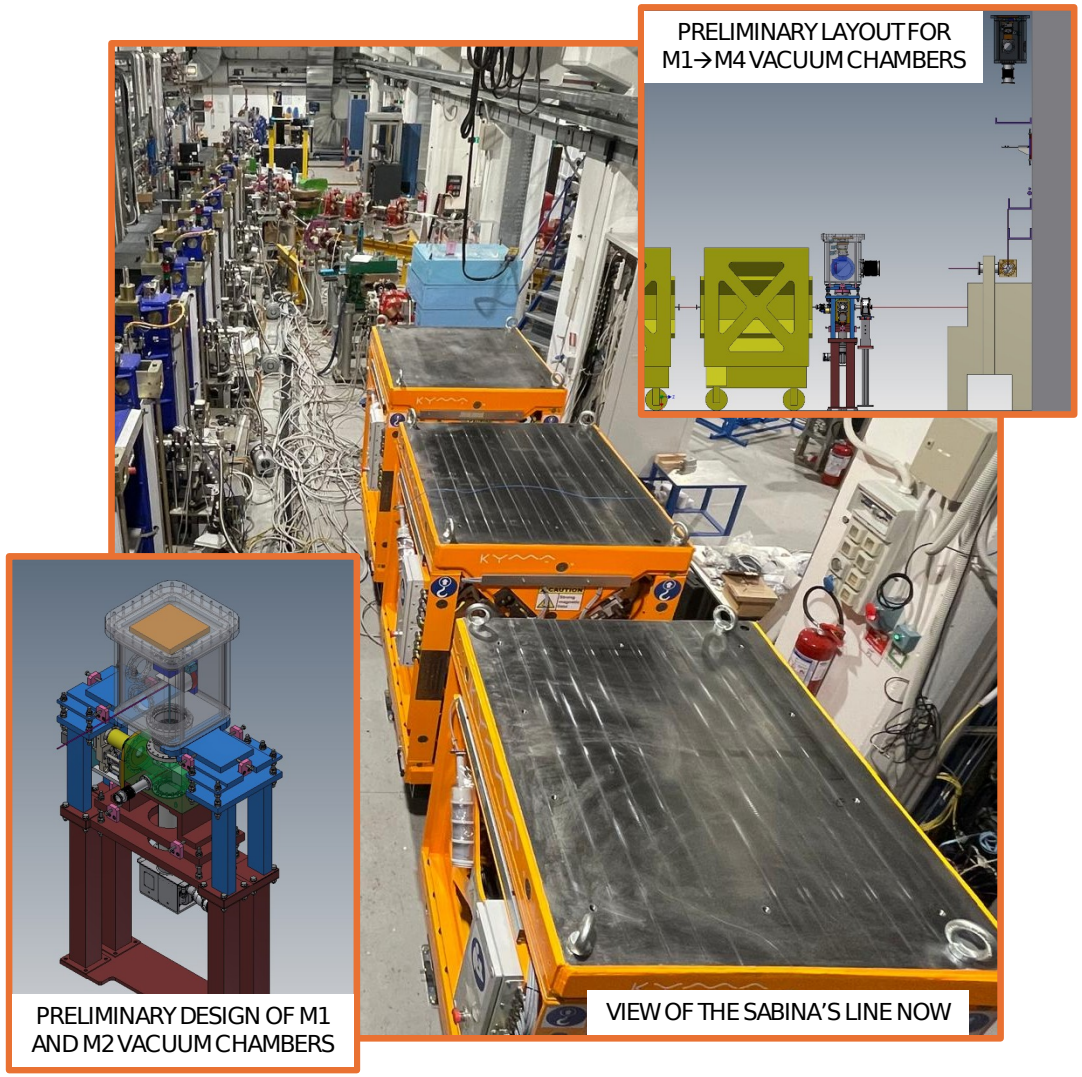
S1+S2 new solenoids



SABINA THz line @SPARC

- **Magnets**
  - ✓ Sextupoles and quadrupoles INSTALLED and TESTED
  - ➢ Intraundulator steerers: TESTED [2,3]
    installation programmed within Dec24 not to affect SPARC runs
- **Undulators**
  - ✓ Undulators and cabinets INSTALLED
    cabling programmed within Dec24 not to affect SPARC runs
- **Diagnostic**
  - ➢ Evertything before the undulators INSTALLED
    cabling and further installation witihin Dec24 not to affect SPARC runs
- **Vacuum**
  - ➢ Installation of the updated vacuum line ONGOING
    completion foreseen within Feb25
- **THz transport and users' hutch:**
  - ✓ M1 chamber's mirror and diamond window ON SITE
  - ➢ Design of vacuum chambers for optics ONGOING
    - ✓ 2 first mirrors chambers commissioned
    - ➢ 2 middle mirrors chambers under developement
    - 2 final mirrors chambers design expected for end of Jan25
  - ➢ Placement of orders (mirrors, pipes, pumps, ..) ONGOING
  - ➢ Users' instruments
    - ✓ 5T cryostat ON SITE
    - ✓ high performance – high resolution oscilloscope ON SITE
    - ➢ additional instrumentation's procurement ONGOING

Following the defined layout of the THz line (electron and radiation)



I. Balossino, L. Sabbatini

SABINA THz line @SPARC

Following the defined layout of the THz line (electron and radiation)

LINE	ACTIVITY	TO END BY	STATUS
ELECTRON	Elements installation	DEC 2024	Ready up to the undulators, remaining material procurement ongoing
	Vacuum pipe installation	FEB 2025	Extra undulator design ready Intra undulator line under test
	Test electron line	MAR 2025	Compatibly with SPARC's other activities
THz	Mirrors order	NOV 2024	Ultimating bureaucracy
	First part installation (electron line related)	JUN 2025	Processing orders for full instrumentation (vacuum chambers, motors, controls,..)
	Full installation up to the end	OCT 2025	Vacuum chambers ongoing
	Test THz line	DEC 2025	Compatibly with SPARC's other activities
FULL COMMISSIONING		JUN 2026	Compatibly with SPARC's other activities

- Mosesso et al. *Underway Projects for Innovative THz/IR Sources based on Particle Accelerators: SISSI 2.0 and SABINA* TeraDays 2024
- Selce et al. *Intra-undulator magnets for the SABINA THz FEL line: magnets design, manufacturing and measurements* IPAC2024
- Del Franco et al. *3D printed beam correctors* IPAC2024
- Balossino et al. *Strain measurements of the Apple-X SABINA undulator with fiber Bragg grating* IPAC2024
- Balossino et al. *Fiber Bragg-Grating strain measurements on the APPLE – X undulators for SABINA* FEL2024
- Petralia et al. *Magnetic characterizations of the APPLE – X undulators for SABINA FEL2024*
- Article in production *Validating the mechanical structure of the APPLE-X undulators using Fiber Bragg Grating sensors for the SABINA FEL infrastructure*

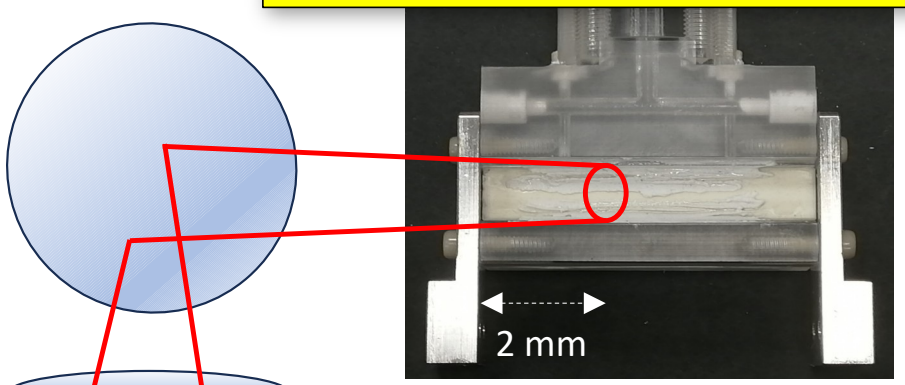
I. Balossino, L. Sabbatini

PLASMA_LAB

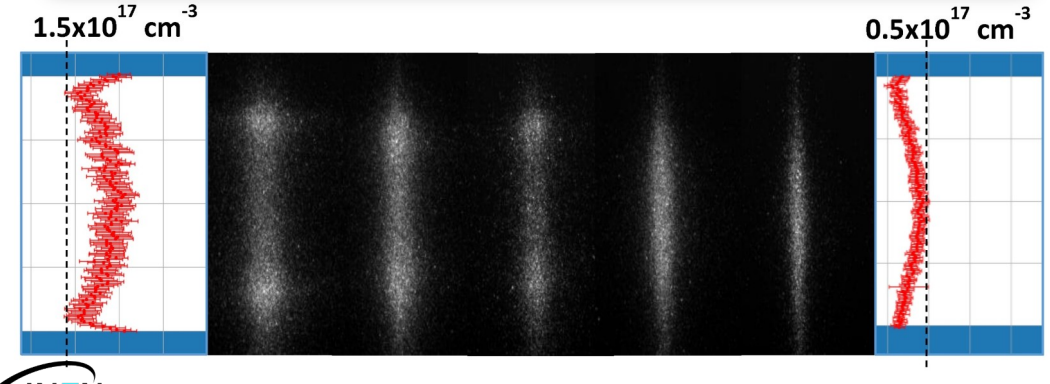
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

150 Hz repetition rate discharges

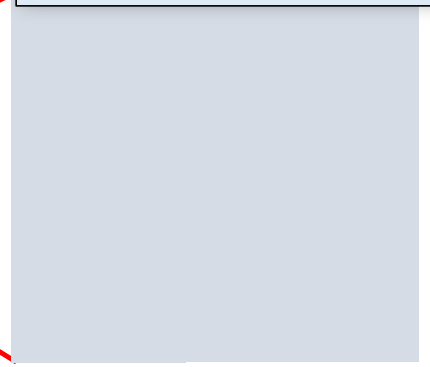
Transverse Stark broadening method to characterize non-transparent materials

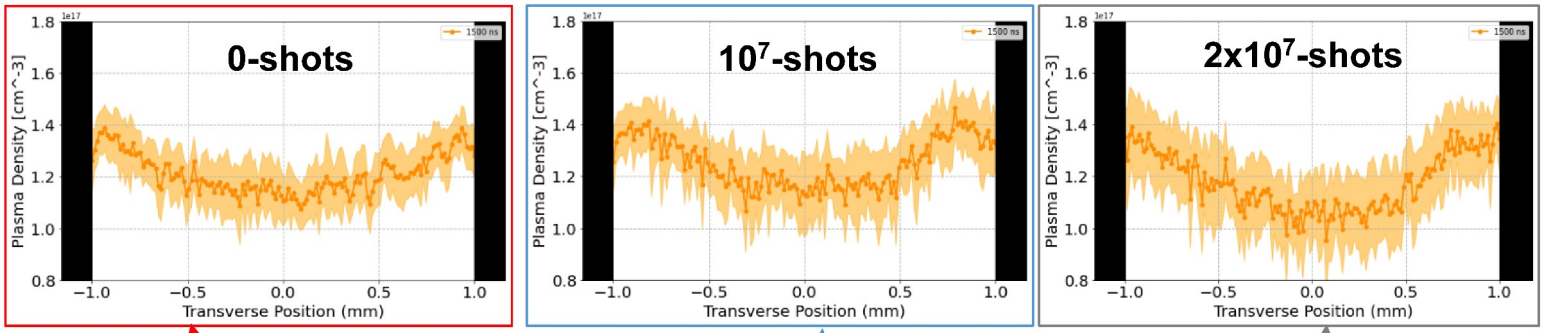


Spectral lines behavior as a function of the recombination time

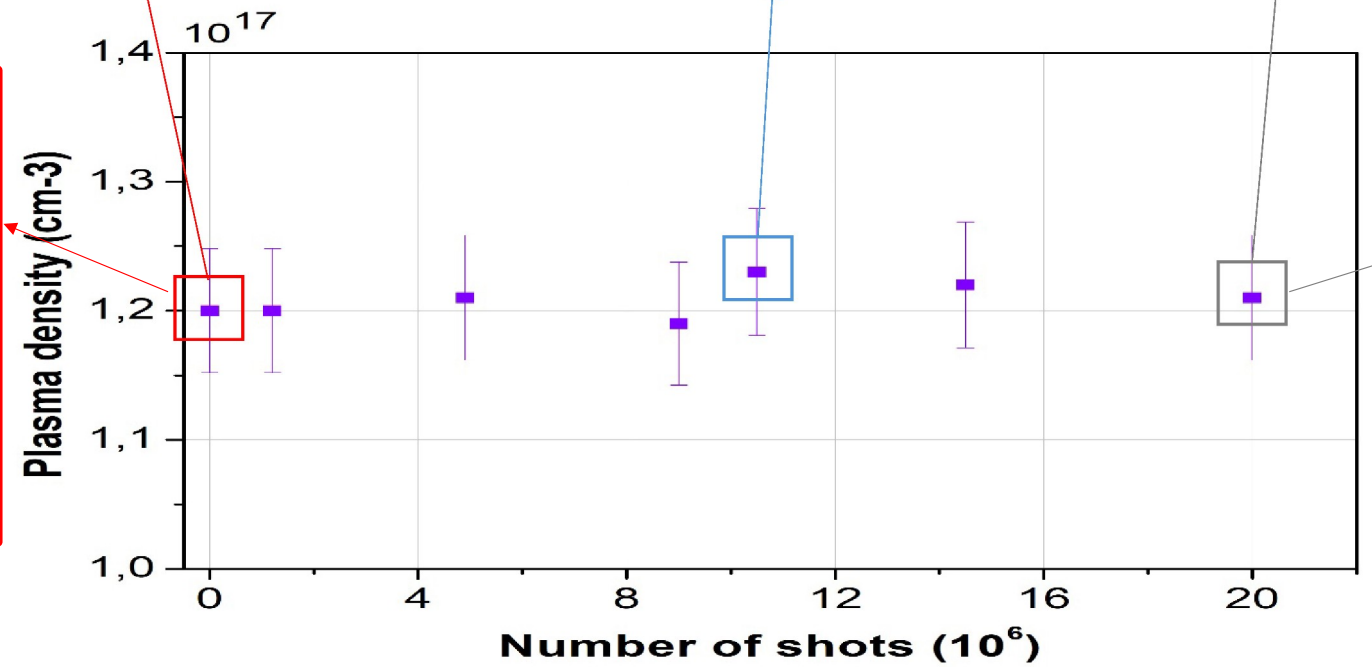


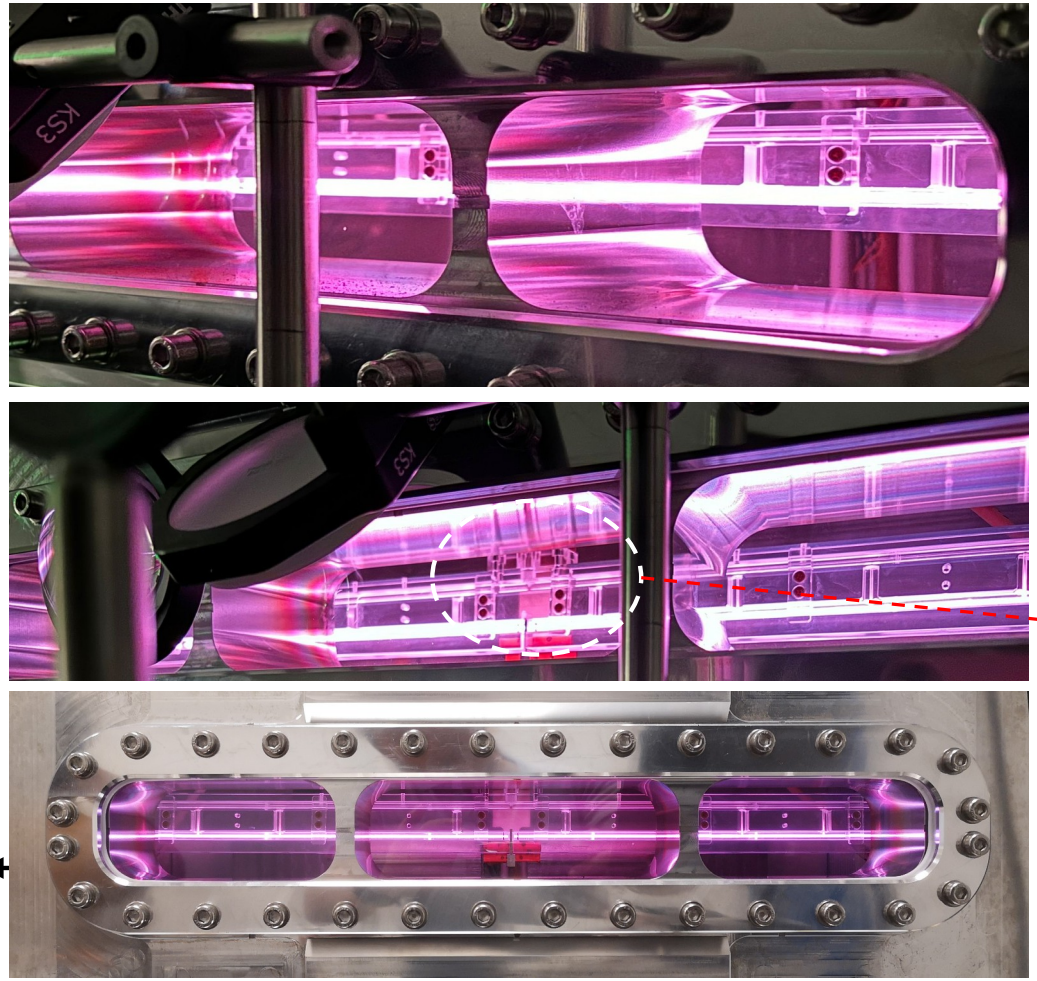
Spectral lines as a function of the longitudinal slices




0-shots
10^7-shots
2x10^7-shots
Plasma Density [cm^-3]
Transverse Position (mm)
1500 ns

V = 8 kV
Ip = 400 A

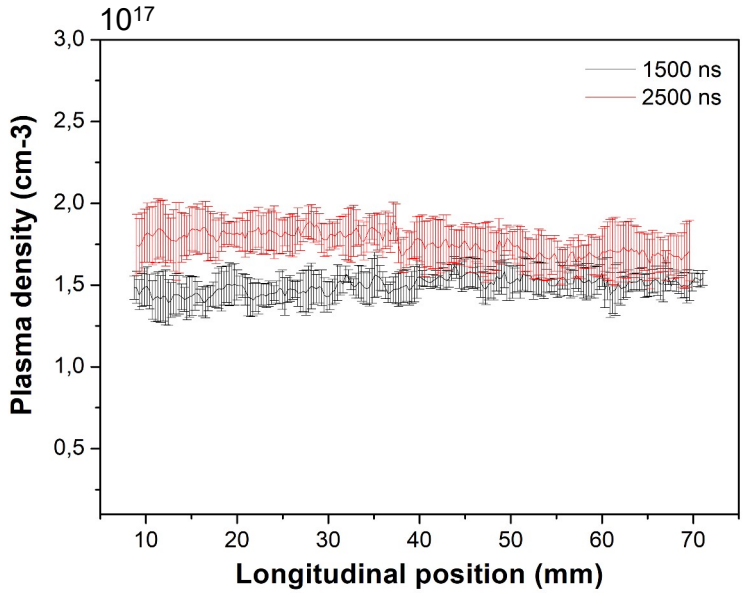

10^17
Plasma density (cm-3)
Number of shots (10^6)



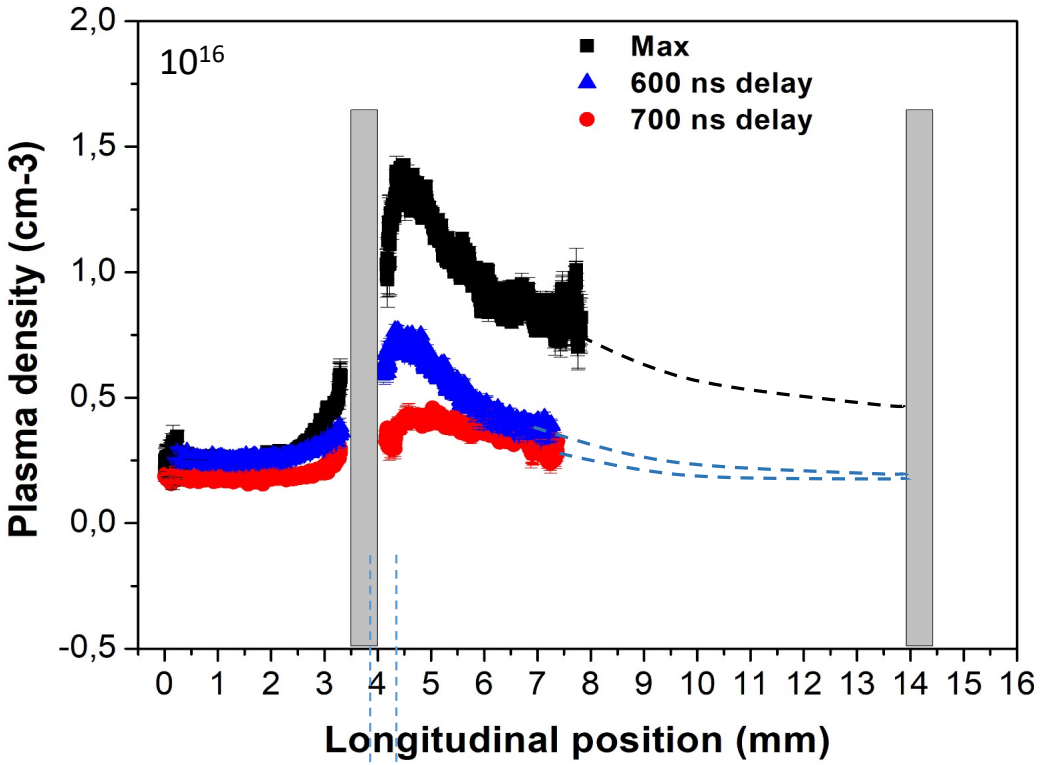
60 cm

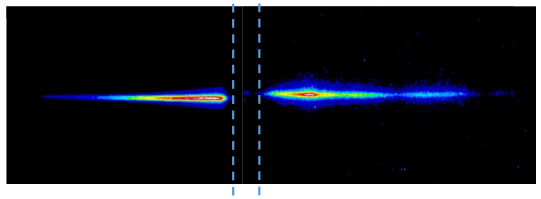
1.1 GeV (1 GV/m 600 MeV in **60cm** long capillary - density 10^{16} cm-3):

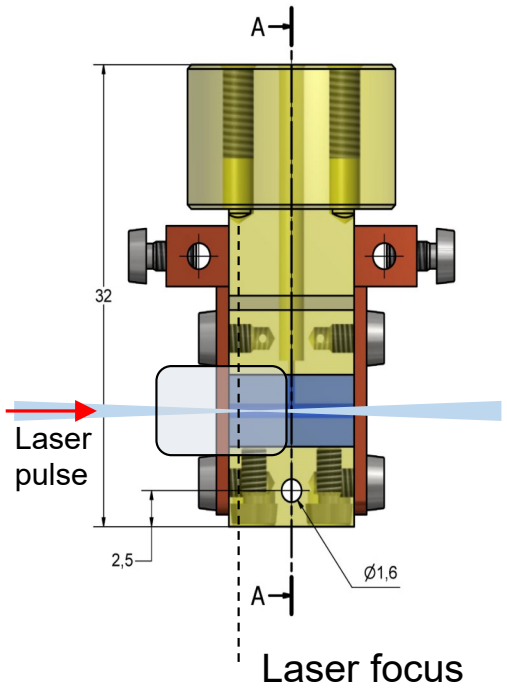
- Fabrication by machining
- 10 increasing diameter
- Density range 10^{16} -10^{17} cm^{-3}
- 13 kV with 500 A



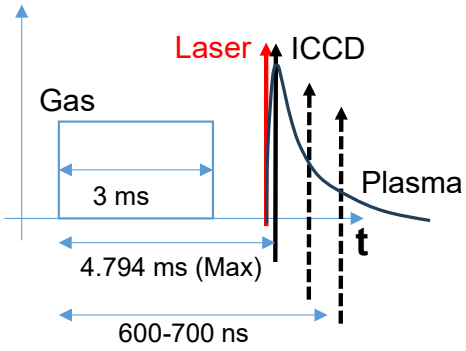
Preliminary characterization for future EuAPS plasma sources







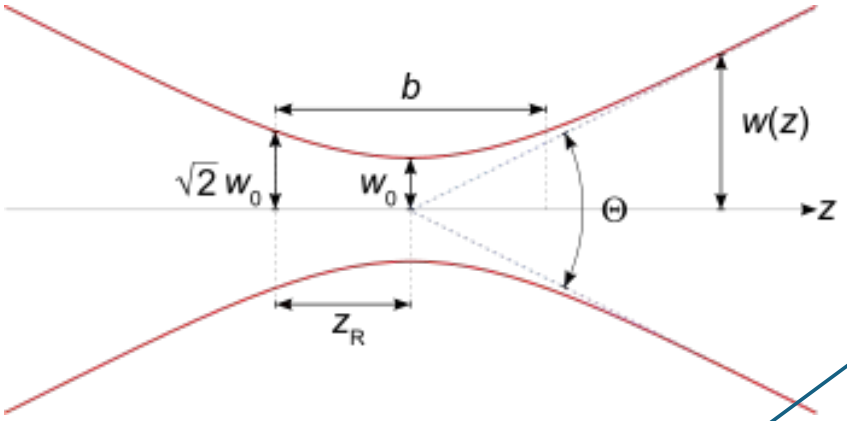
- **Delay time laser/ICCD**
- Pressure 900 mbar
- Laser focus at the entrance



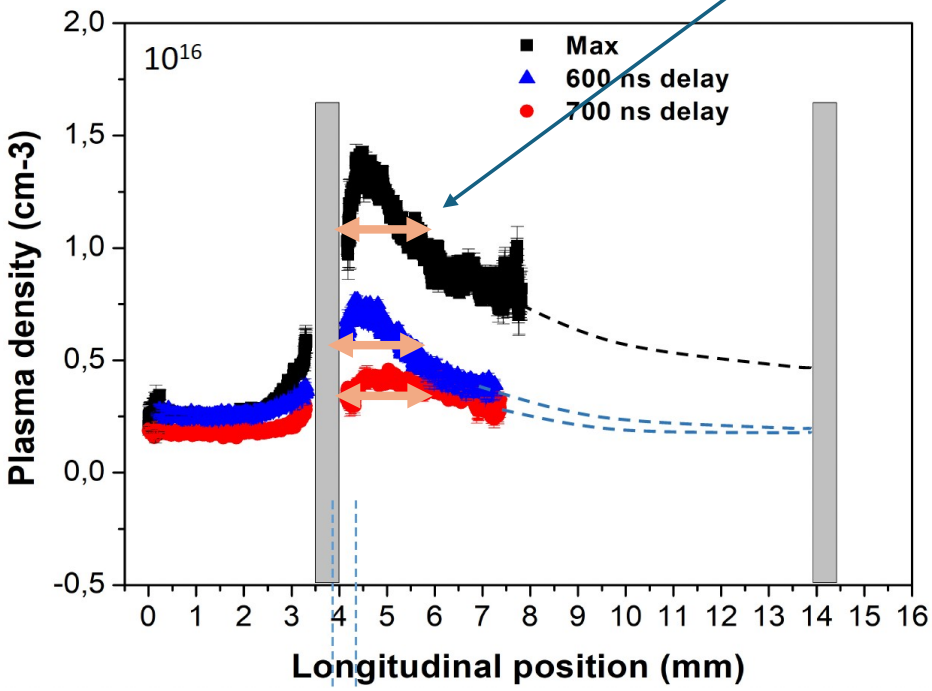
Advantages

- Low-pressure operating point (<1bar compared with 40-50 bars for gas jets)
- Increased stability
- Confinement structure allows better mixing of gases

A. Biagioni



Beam spot size (1/e^2) =60 micron
w_0 = 16 micron
Zr =1 mm
b =2 mm



Width of the high-density part of the plasma(orange double-arrows) consistent with the Rayleigh range of the laser (b =2 mm)

A. Biagioni

FLAME - EuAPS

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

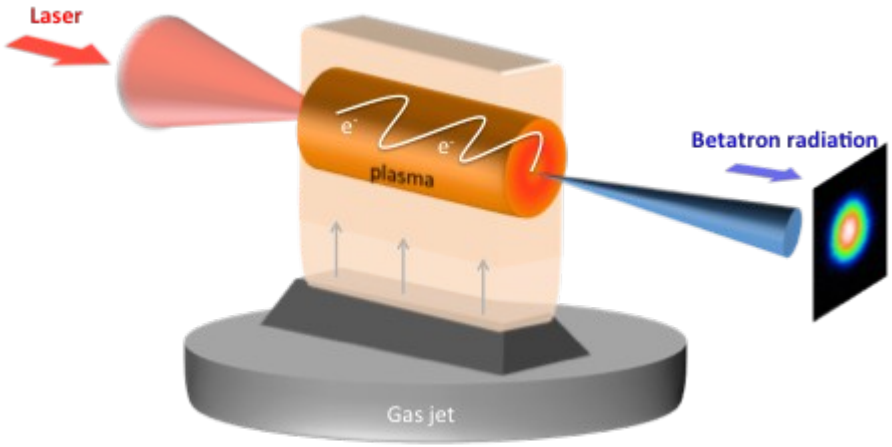
Parameters list

Work plan: The betatron X rays source will be developed at FLAME (200 TW, 35 fs) bunker optimizing

- *Laser parameters*
- *Plasma source devices*
- *Electron diagnostics*
- *X rays spectrum and photon flux*

The main goal is to make a replica of the source developed at FLAME

The advanced photon diagnostics and the user end station will be tested and installed during/after the commissioning of the source



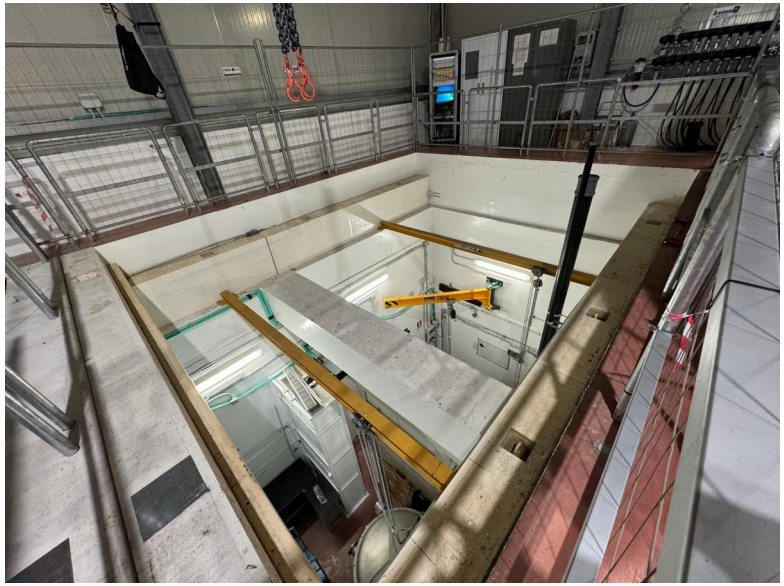
Parameter	Value	unit
Electron beam Energy	100-800	MeV
Plasma Density	10^{17}-10^{19}	cm^{-3}
Photon Critical Energy	1 -10 tunable	keV
Number of Photons/pulse	10^{6}-10^{9}	
Repetition rate	1-10	Hz
Beam divergence	3-20	mrad

Timeline

- FLAME installation until 15/2/2025
- Upgrade laser FLAME until March 2025
- SPARC installation from March to May 2025
- Setup and startup X-ray source June/July 2025
- Beam to users September/November 2025

Project ends 30th November 2025

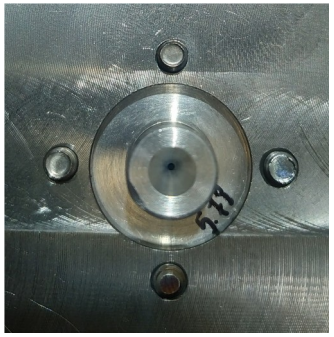
Flame building

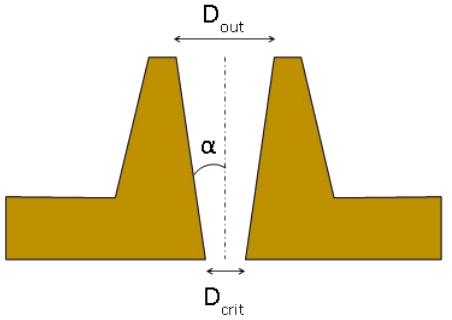


- The FLAME ceiling has been dismounted to facilitate the removal of the actual setup and to bring there new instrumentations

Flame progess

- New oscillator installed and tested
- Characterization of neutral density profile in gas jets for laser-plasma
  - The neutral density profile of Nitrogen gas jets, from nozzle, is measured with a Mach–Zehnder interferometer
  - Different nozzles are being tested, changing angles and diameters.





Tracking

- All big tenders are closed
- Instrumentation delivery is in progress
- Weekly meeting to update the schedule to fit the reality
- Test of subcomponents already arrived in progress
- Actual schedule in line with expectation

Thanks!

R. Pompili (LNF-INFN)
riccardo.pompili@lnf.infn.it

On behalf of the SPARC_LAB collaboration