SPARC_LAB Test Facility

Martina Carillo

On behalf of the SPARC_LAB collaboration

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Outline

❖ **SPARC_LAB test facility**

→Machine layout

❖ **Main Results:**

→Energy spread minimization

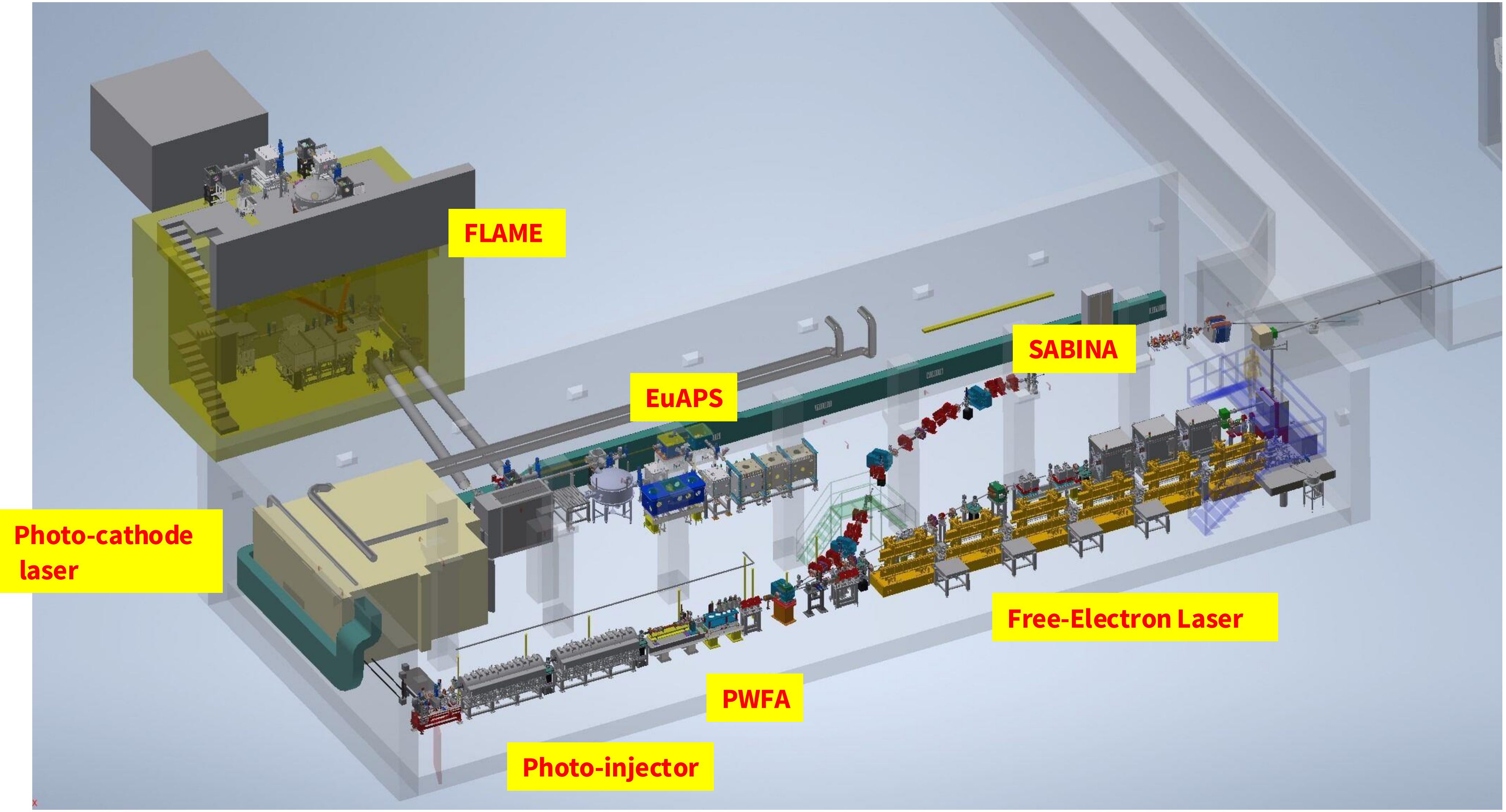
→FEL driven by PWFA

→“All-in-one” capillary

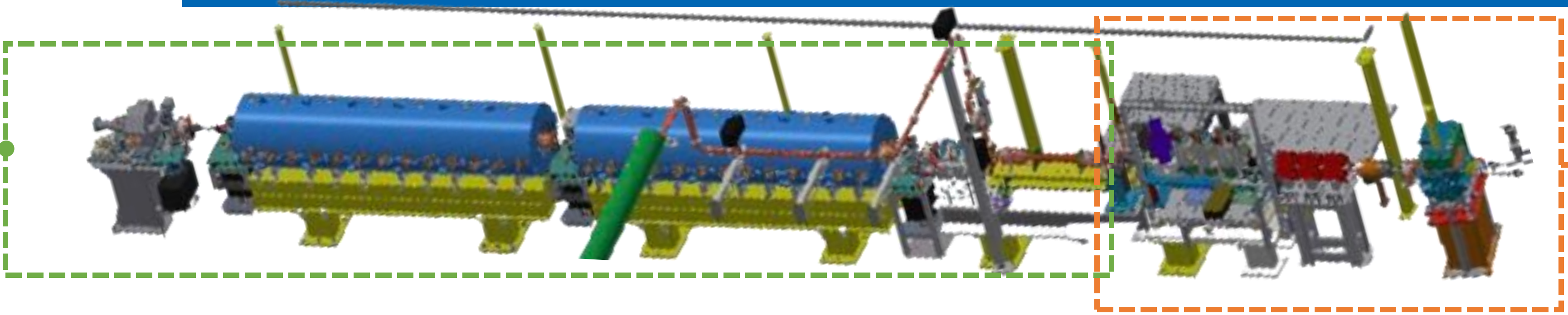
→Curved Plasma Discharge Capillary

❖ **EuPRAXIA@SPARC_LAB**

SPARC_LAB Test facility



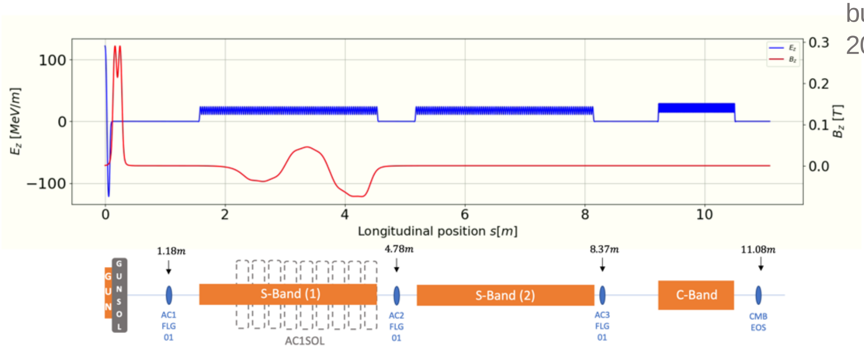
SPARC_LAB machine layout



[*]V. Shpakov, et al., Design, optimization and experimental characterization of RF injectors for high brightness electron beams and plasma acceleration, Journal of Instrumentation 17 (12), P12022

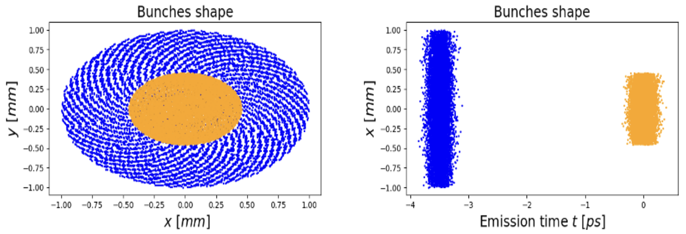
Photo-injector:

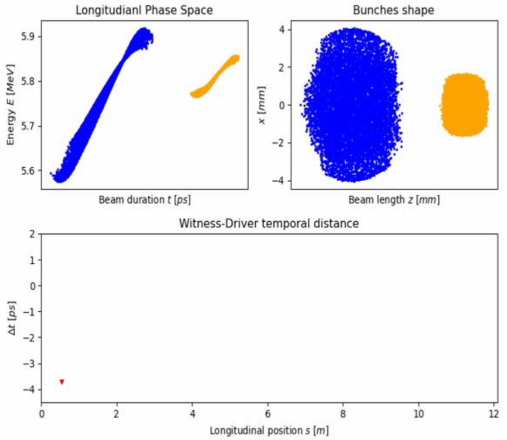
[*] L. Serafini and Massimo Ferrario. Velocity bunching in photo-injectors. Proc. AIP, 581, 08 2001. doi: 10.1063/1.1401564



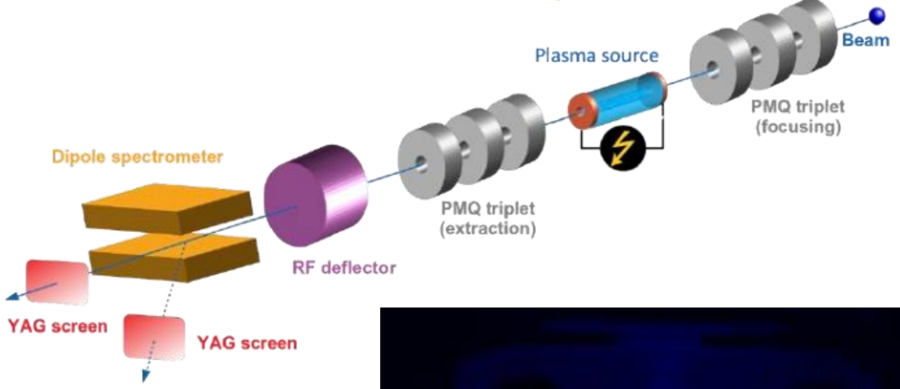
The first section of the LINAC works in the **velocity bunching** configuration

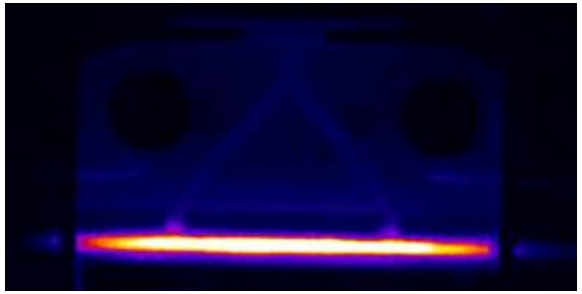
Two-bunches configuration produced directly at the cathode with **laser-comb technique:**





Plasma Chamber & Beam Diagnostic:





[*]Biagioni, A., et al., Journal of Instrumentation 11.08 (2016): C08003.

Enery spread minimization

The challenge lies in achieving **high-quality, stable beams** for **high-brightness beam applications**.

→ *Low emittance*

→ High current

→ Low energy spread

(**see Plasma Wakefield Acceleration – Advantages and Challenges**. L.Verra)


nature physics
LETTERS
https://doi.org/10.1038/s41567-020-01116-9
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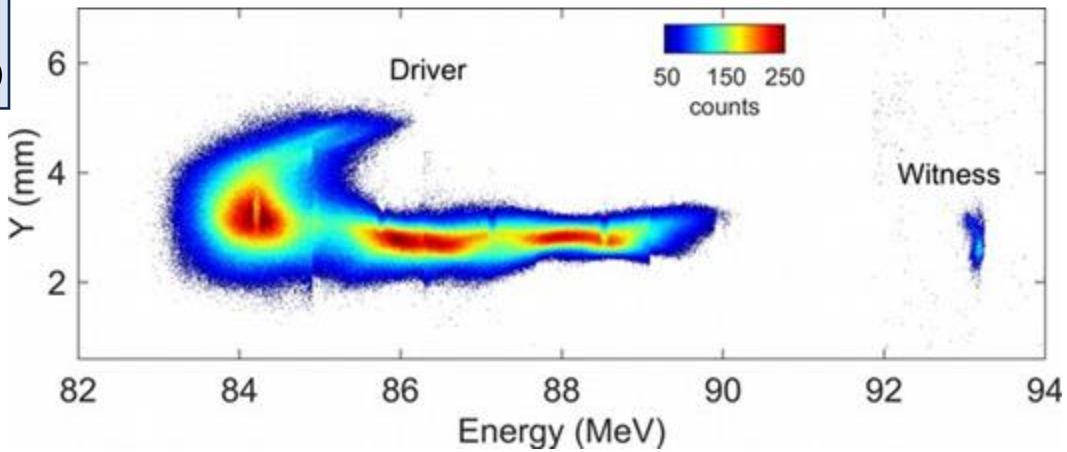
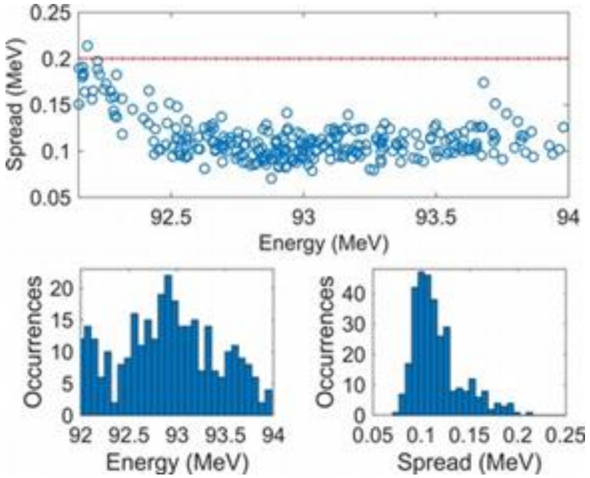
Energy spread minimization in a beam-driven plasma wakefield accelerator

R. Pompili[1], D. Alesini[1], M. P. Anania[1], M. Behtouei[1], M. Bellaveglia[1], A. Biagioni[1], F. G. Bisesto[1], M. Cesarini[1,2], E. Chiadroni[1], A. Cianchi[3], G. Costa[1], M. Croia[1], A. Del Dotto[1], D. Di Giovenale[1], M. Diomede[1], F. Dipace[1], M. Ferrario[1], A. Giribono[1], V. Lollo[1], L. Magnisi[1], M. Marongiu[1], A. Mostacci[2], L. Piersanti[1], G. Di Pirro[1], S. Romeo[1], A. R. Rossi[4], J. Scifo[1], V. Shpakov[1], C. Vaccarezza[1], F. Villa[1] and A. Zigler[1,5]



Stability analysis of the result:



→ 4 MeV acceleration in 3 cm plasma with 200 pC driver: ~133 MV/m accelerating gradient

→ $2x10^{15}$ cm^{-3} plasma density

Demonstration of projected energy spread compensation

Spread from 0.2% to 0.12% ()

FEL driven by PWFA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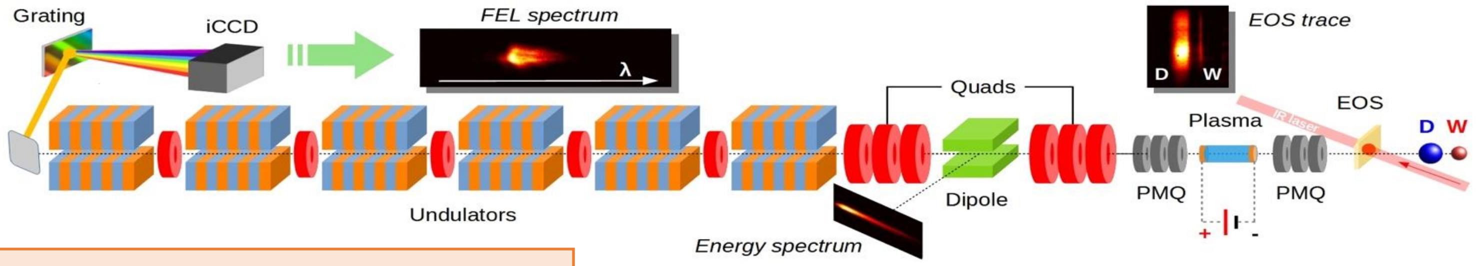
Article | Published: 25 May 2022

Free-electron lasing with compact beam-driven plasma wakefield accelerator

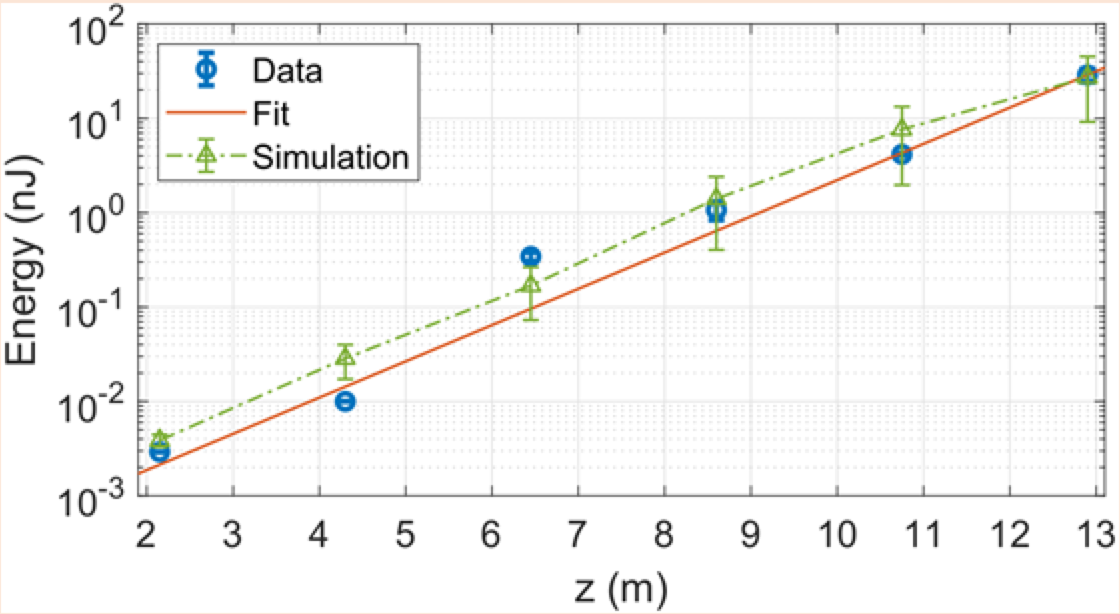
R. Pompili, D. Alesini, ... M. Ferrario + Show authors

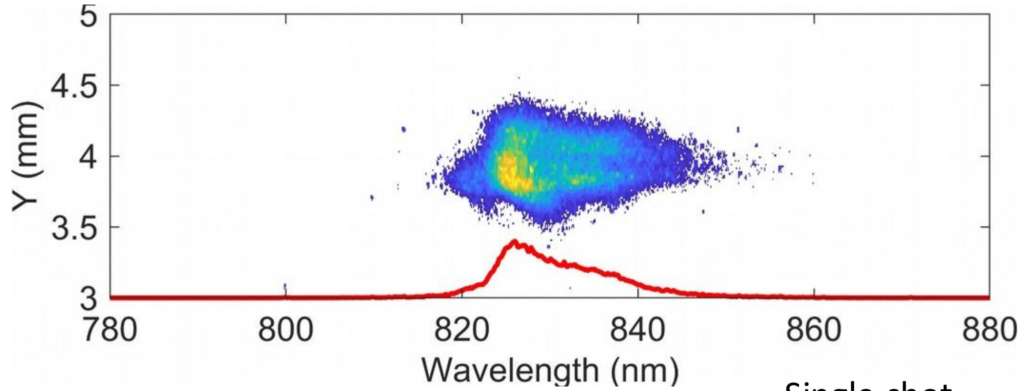
Nature **605**, 659–662 (2022) | Cite this article

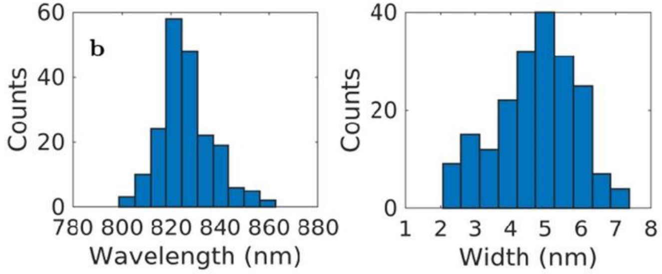
The first proof of principle experiment demonstrating Self Amplified Spontaneous Emission (SASE) in a FEL from centimeter-scale beam-driven palsma wakefield accelerator (PWFA)



Exponential gain of FEL radiation energy: data taken with 6 (Si) photo-diodes downstream the undulators







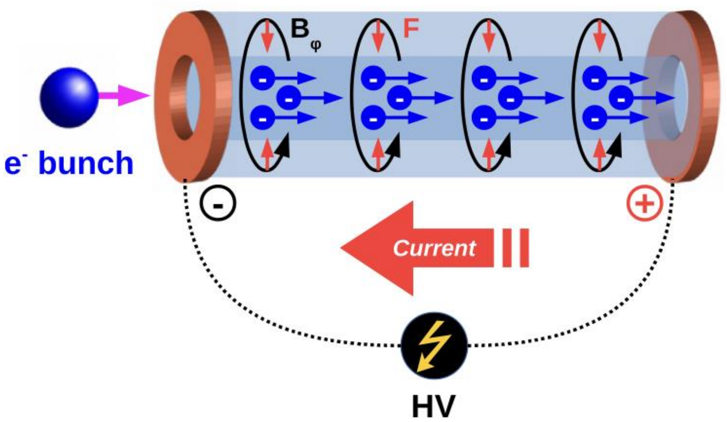
Single-shot spectrum of the SASE FEL radiation emitted at 830 nm

Plasma Lenses: Focusing Mechanisms

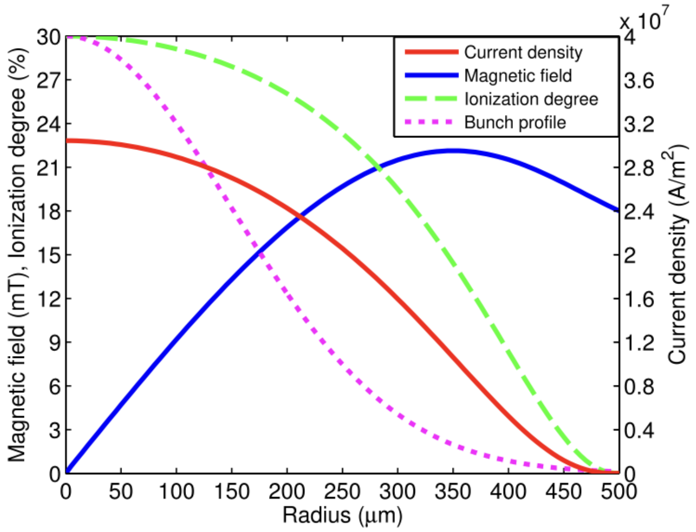
1. Passive Plasma Lens:
- **Mechanism**: Self-focusing.
- **Process**: Shielding produced by background plasma, which reorganizes to maintain overall neutrality after the passage of a driver beam.

2. Active Plasma Lens:
- **Mechanism**: Azimuthal magnetic field.
- **Process**: Generated by an externally driven axial current.

Magnetic Field (B_φ) vs Force on electrons (F)



$$B_\phi(r) = \frac{\mu_0}{r}\int_0^r J(r')r'dr'$$



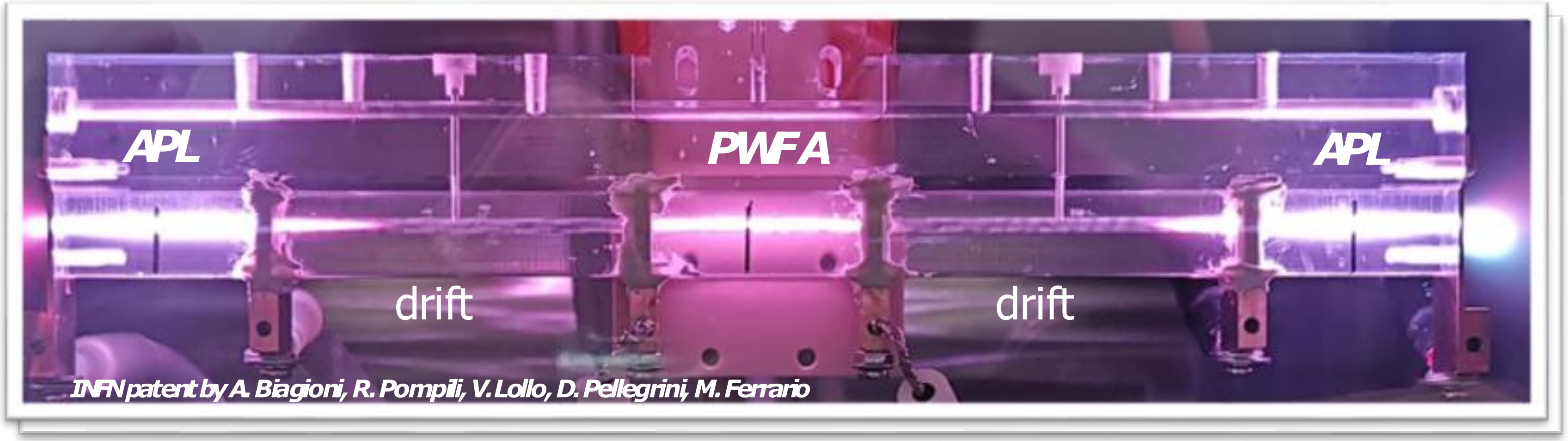
[*]E. Chiadroni et al. Overview of plasma lens experiments and recent results at SPARC_LAB, Nuclear Inst. and Methods in Physics Research, A 909 (2018) 16–20

[*]R.Pompili, et al., Experimental characterization of active plasma lensing for electron beams, Appl. Phys. Lett. 110 (10) (2017) 104101.

- Cylindrical symmetry
  - purely radial focusing effect
- Tunability
- Focusing strength: K$\propto 1/\gamma$
- High focusing gradient ~ kT/m
  - short focal length
  - weak chromaticity

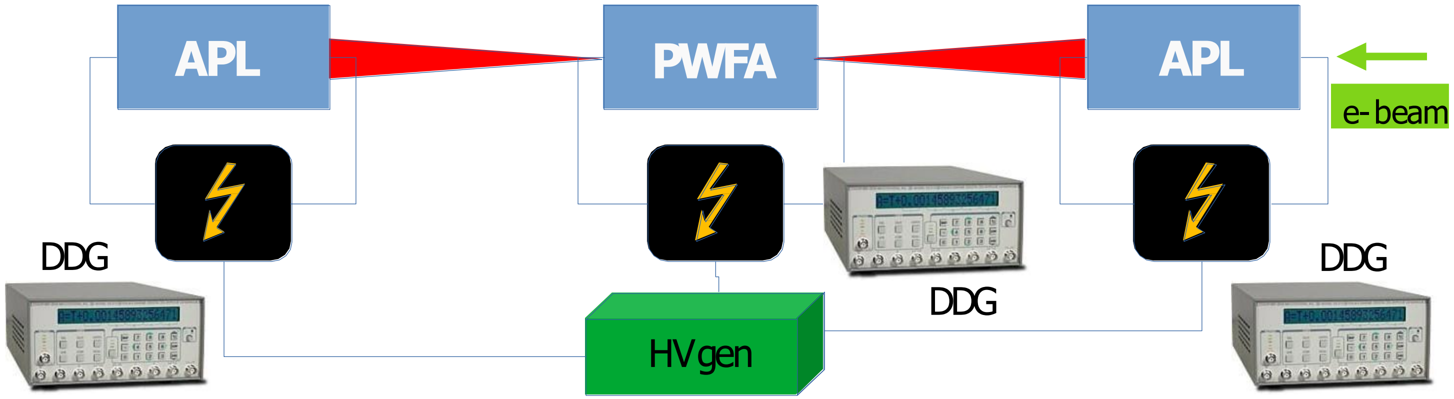
Compact Plasma Device for Acceleration and Focusing

[*]R. Pompili et al., Phys. Rev. E **109**, 055202 – Published 3 May 2024



- **19 cm capillary length** and 2 mm diameter
- Laser pre-ionizes the gas, stabilizing the discharge and reducing **jitter to a few nanoseconds**
- The high-voltage **discharge currents are provided by three pulsers** capable of generating up to 1.6 kA peak current

The discharge current and plasma density can be independently tuned and controlled in each plasma stage.



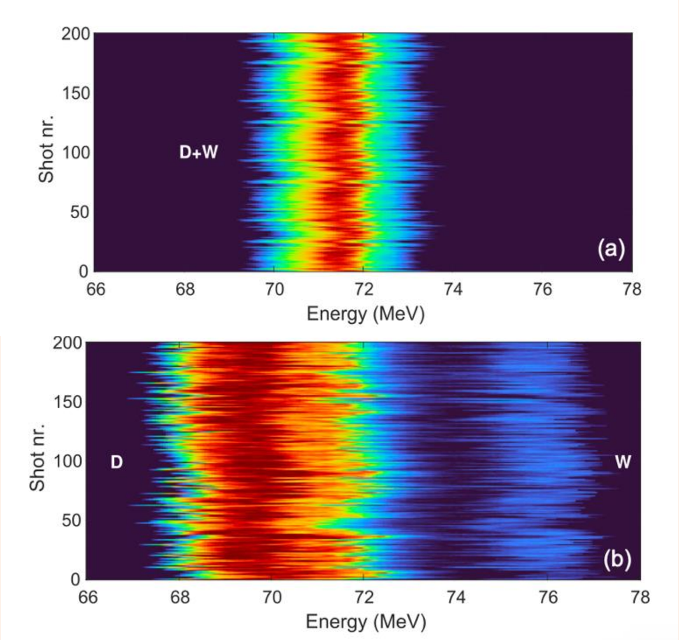
Experimental Results

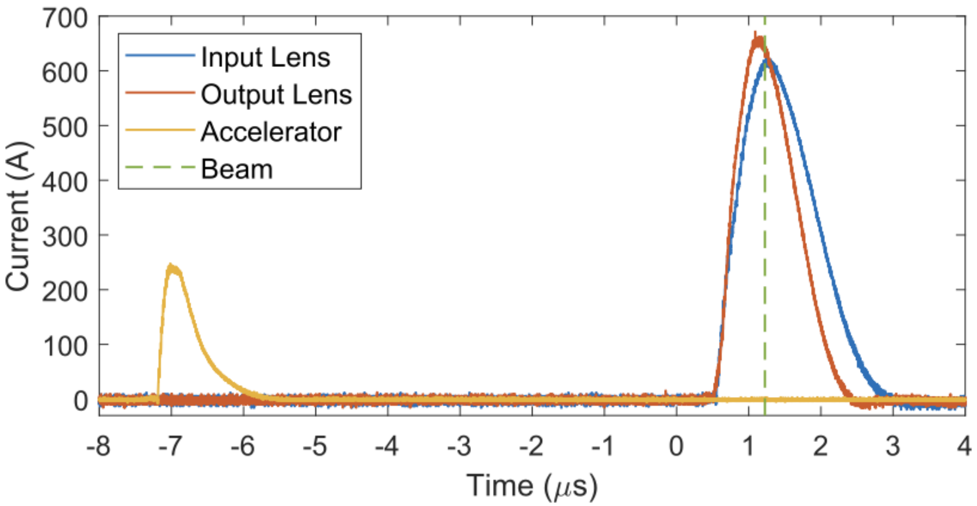
SPARC_LAB RF photoinjector beams:

	Driver	Witness
Energy [MeV]	71.6± 0.1	71.9±0.1
Energy spread [MeV]	0.49 ±0.03	0.72 ±0.04
Duration [fs]	185 ±39	55 ±32
Emittance [μmrad]	6.2±0.7	4.8±0.4
Dealy [ps]	1.15±0.03	

Witness Energy gain of 4.5 MeV over a distance of 3 cm

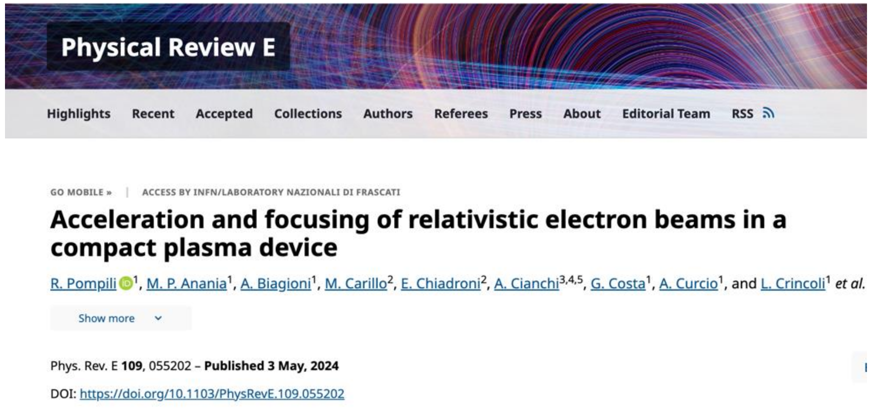
A proof-of-principle experiment merged three plasma stages into a compact device that can focus, accelerate, and extract a witness bunch in a plasma-based accelerator.





$$n_{p_{APL,1}} \approx 2 \times 10^{17} cm^{-3}$$

$$n_{p_{PWFA}} \approx 4 \times 10^{15} cm^{-3}$$



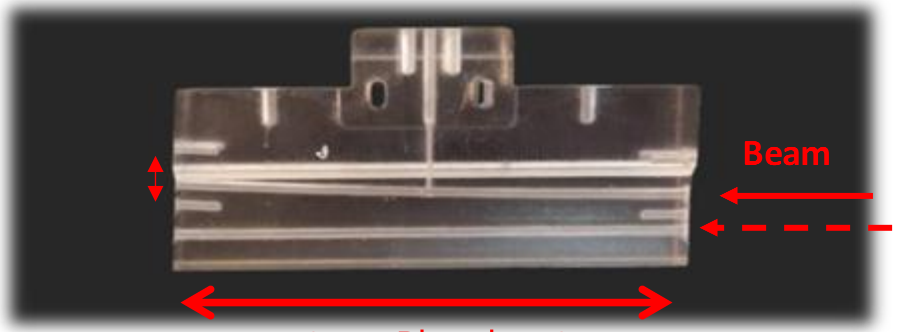
Curved Plasma-Discharge Capillaries

PHYSICAL REVIEW LETTERS 132, 215001 (2024)

Guiding of Charged Particle Beams in Curved Plasma-Discharge Capillaries

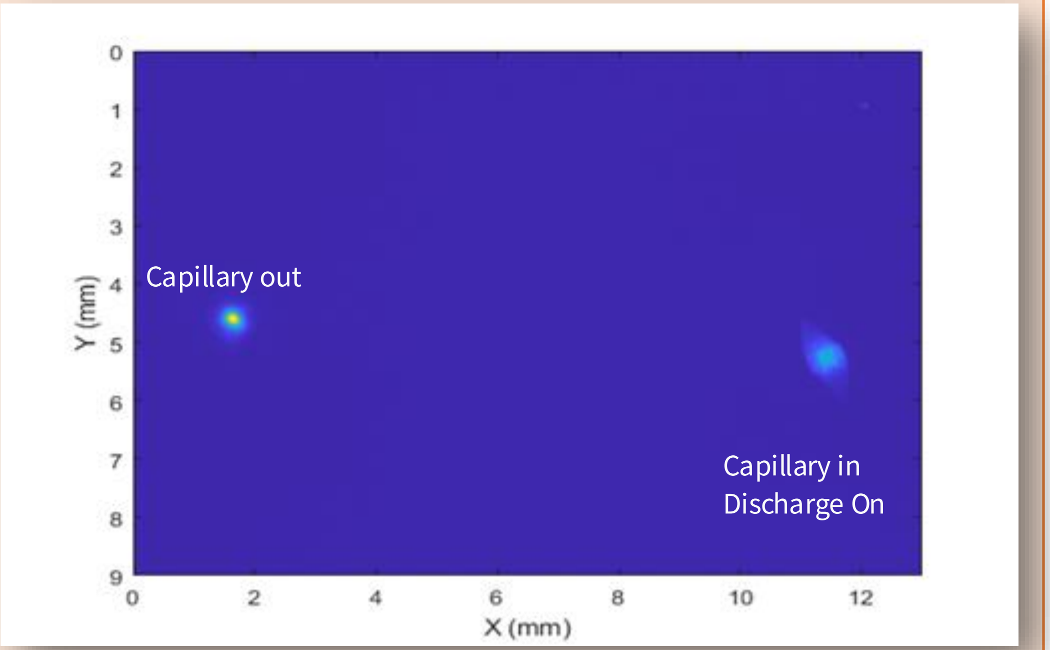
R. Pompili,[1,*] M. P. Anania,[1] A. Biagioni,[1] M. Carillo,[2] E. Chiadroni,[2] A. Cianchi,[3,4,5] G. Costa,[1] A. Curcio,[1] L. Crincoli,[1] A. Del Dotto,[1] M. Del Giorno,[1] F. Demurtas,[3] A. Frazzitta,[2,6] M. Galletti,[3,4,5] A. Giribono,[1] V. Lollo,[1] M. Opromolla,[1] G. Parise,[3] D. Pellegrini,[1] G. Di Pirro,[1] S. Romeo,[1] A. R. Rossi,[6] G. J. Silvi,[2] L. Verra,[1] F. Villa,[1] A. Zigler,[7] and M. Ferrario[1]

Vertical bending
3 mm offset
2mm hole

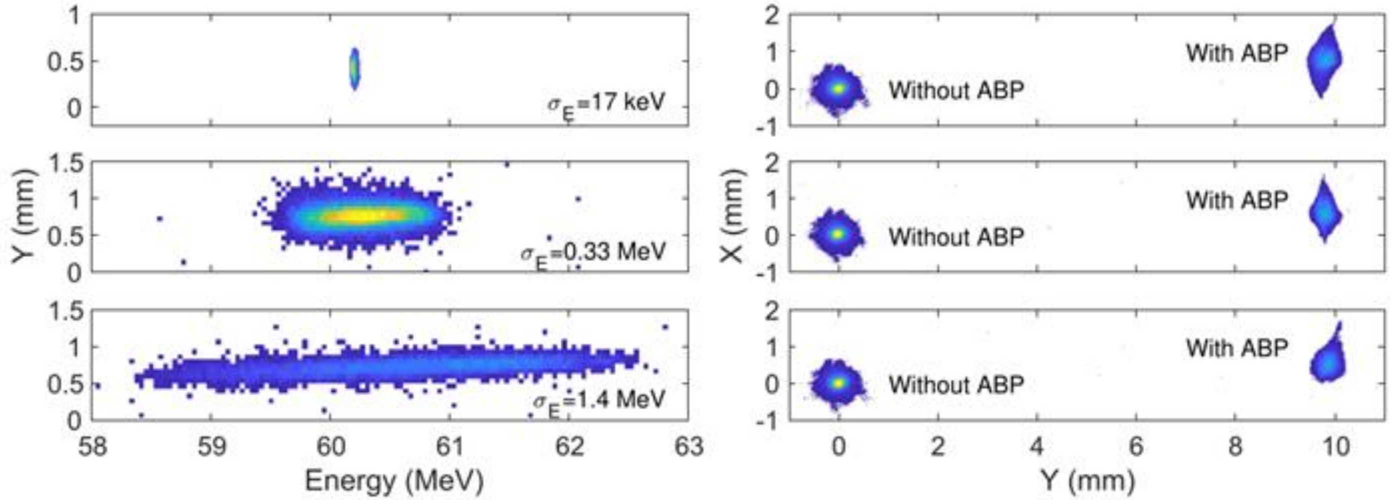


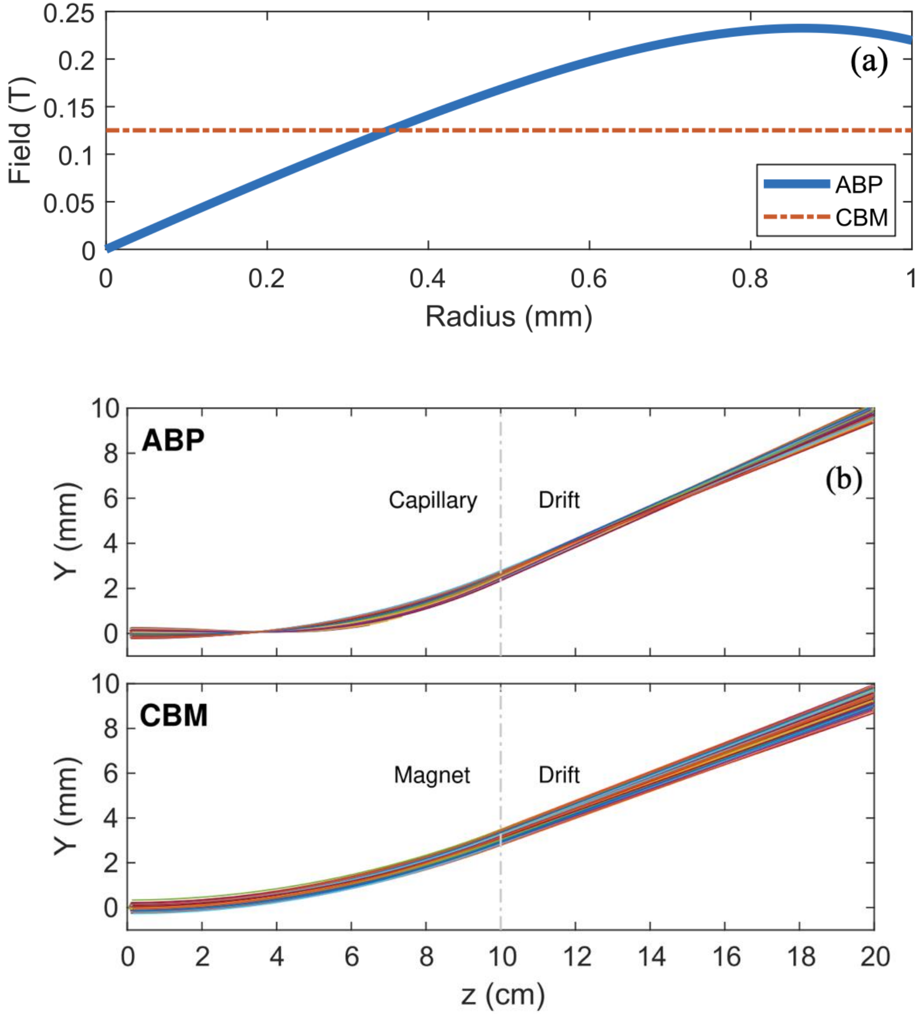
Hole for laser alignment

- → We have used a 50 pC test beam on-crest (~1 ps)
- → The energy of the beam is set to 60 MeV
- → The beam is imaged on the YAG/GAGG screen located ~10 cm downstream the capillary exit



Active Bending Plasma





We tested the ABP deflection with three beam configurations having different energy spreads

Goal: test the chromatic dispersion of the device

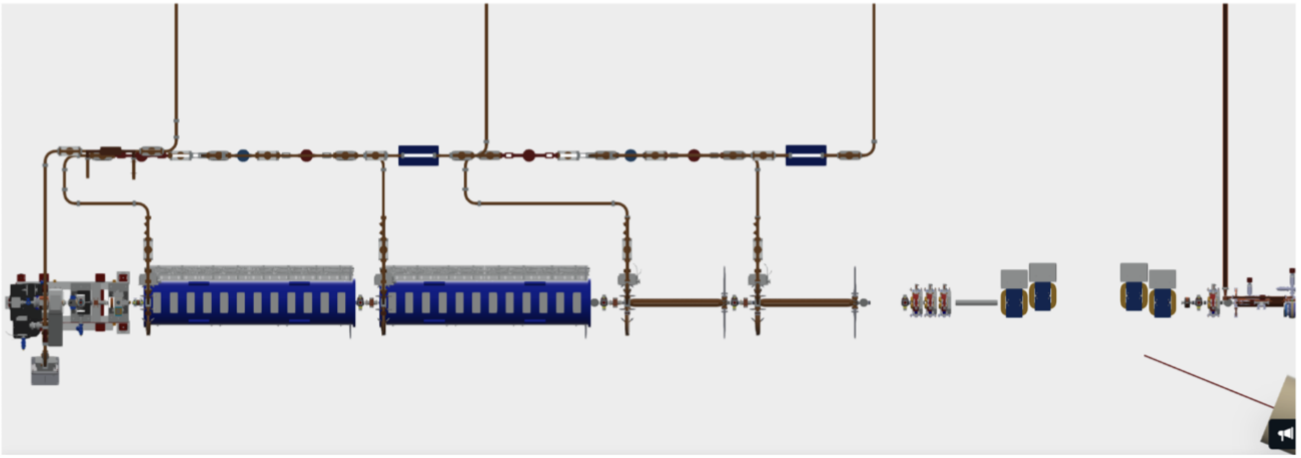
Findings: the output spot sizes is almost unaffected by the energy spread (especially on the bending plane)

It indicates that the device operated almost in a dispersion-less way

EuPRAXIA@SPARC_LAB

SPARC_LAB is the test and training facility for EuPRAXIA@SPARC_LAB

EuPRAXIA@SPARC_LAB injector:



•**Beam characterization**, with particular emphasis on **beam quality and stability**, which are essential to meet the stringent requirements of the experiments envisioned by EuPRAXIA.
•**Validation of advanced technologies**, such as plasma-based acceleration systems and high-intensity permanent magnets, to ensure reliable and consistent performance.
•**Optimization and calibration of operational systems**, aimed at establishing stable configurations and efficient protocols, which are crucial for the implementation of EuPRAXIA.

Thank you for your attention