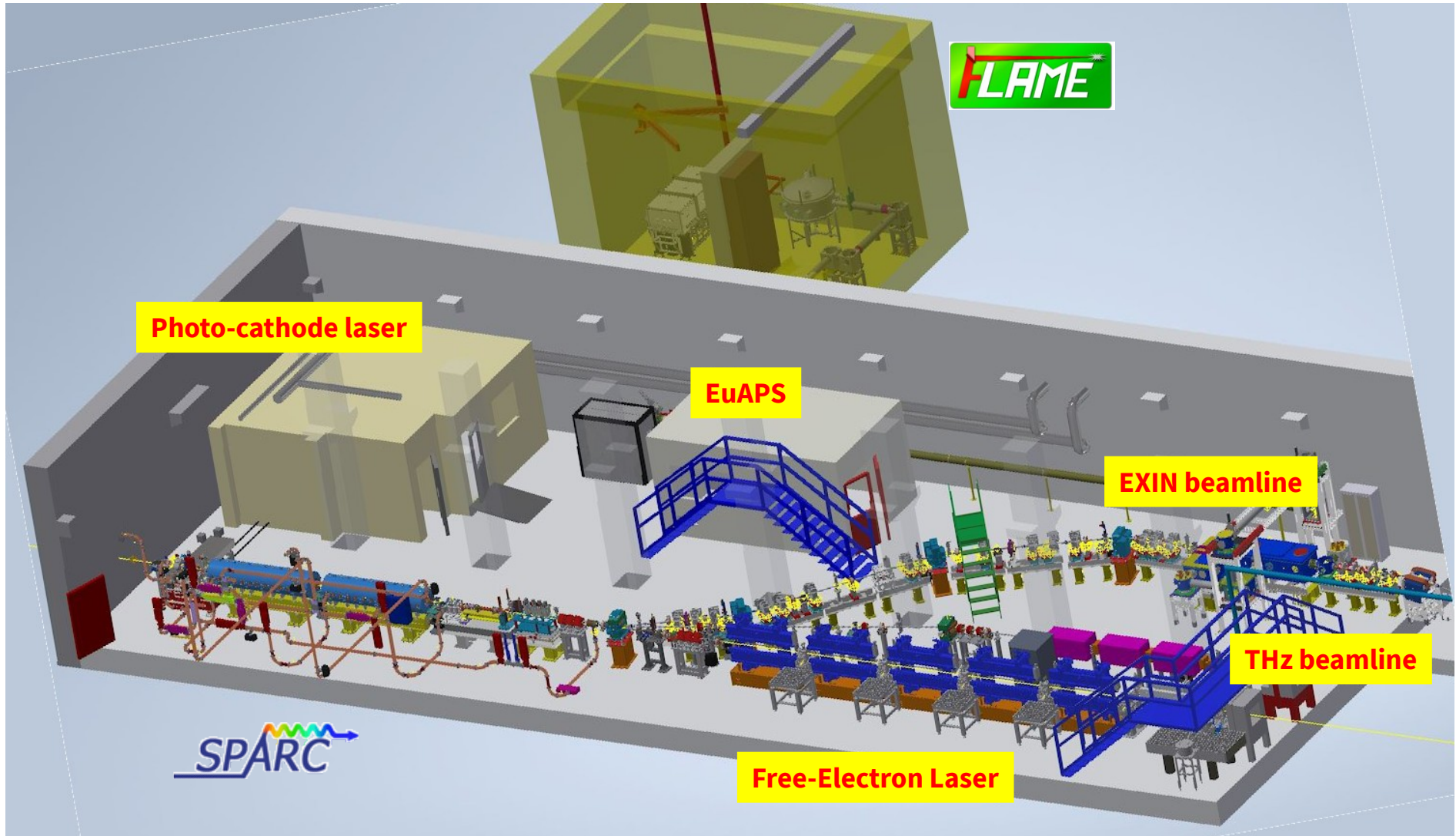


SPARC_LAB activity report

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

On behalf of the SPARC_LAB collaboration





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

After the last SciCom (8-9 Nov 2023) SPARC activities went ahead till beginning of December. We performed more studies on

Curved capillary: consolidate data acquisition

All-in-one capillary (focusing-acceleration-extraction in plasma): consolidate data acquisition, emittance measurements

Plasma vs dielectric wakefield study

Tests with chicane-like capillary: rapid deterioration of capillary after few hours of operation

January-June 2024 dedicated to SABINA installations

New solenoids, LLRF system, THz undulators, etc.

Start of the control system transition from LabVIEW to EPICS environment (to be completed in 2025)

July 2024 will be dedicated to the restart/debug of the “new” photo-injector

September-December 2024: experimental activities

January-June 2025: stop of SPARC activities due to EuAPS installations

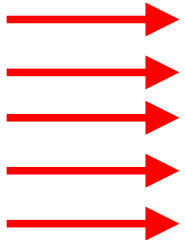
- *Assure that further R&D and experiments with the focusing and PWFA systems get sufficient effort and beamtime in 2024 despite of EuAPS and SABINA installations*
- *Continue studies and explore possible applications of curved capillaries, in particular applications as a novel source of synchrotron radiation could be attractive.*
- *Considering the installations undergoing at SPARC due to the SABINA upgrade of the entire facility (photo-injector, RF systems, THz beamline, etc.) we expect to restart the operation at the mid/end of June. Most of the time will be likely spent to debug the new equipment.*
- *We planned some activities for the next September and will involve the **upgrade of the PMQ system**, the test of an alternative method for plasma generation (**laser-plasma filamentation** in place of the HV discharge) with an external user group in the **EuroLABS** framework and the enhancement of the expected plasma accelerating gradient by means of resonant schemes.*

- *Assure that further R&D and experiments with the focusing and PWFA systems get sufficient effort and beamtime in 2024 despite of EuAPS and SABINA installations.*
- *Continue studies and explore possible applications of curved capillaries, in particular applications as a novel source of synchrotron radiation could be attractive.*
- *The tests performed at the end of 2023 successfully demonstrated the feasibility to bend particle beams with curved capillaries. However, we also experienced a **rapid degradation of the capillary** itself due to the large discharge currents (\sim kA \rightarrow eV temperatures) employed. The new tests should therefore envision the use of a different material (**SHAPAL**) that is now being tested at PLASMA_LAB. We expect to be able to perform new tests using this new material in 2025*

SPARC_LAB planning 3 apr 2023 - 28 nov 2025

Griglia | Bacheca | Sequenza temporale | Grafici | Persone | Obiettivi | ...

	Nome	Vi...	Assegnata a	Durata	Inizio	Fine	Contenitore
28	✓ EOMB-area-cabling		RP MG	5 giorni	15/1/2024	19/1/2024	Installation
29	✓ AC1-breadboard-replacement		RP Riccardo P	2 giorni	24/1/2024	25/1/2024	Installation
30	✓ Fix-of-UTLFLG01		VL LV	1 giorno	22/2/2024	22/2/2024	Installation
31	✓ UTL-optical-table-cleanup		RP FD	10 giorni	19/2/2024	1/3/2024	Installation
32	✓ Removal-of-vacuum-impedences		RP VL	5 giorni	5/2/2024	9/2/2024	Installation
33	✓ Replacement-of-vacuum-impedences		RP VL	5 giorni	26/2/2024	1/3/2024	Installation
34	✓ EOMB-pumps-maintenance		VL RP	2 giorni	11/3/2024	12/3/2024	Installation
35	✓ Filament-tests-in-Laser-clean-room		MG FV RP	5 giorni	12/2/2024	16/2/2024	Preparation
36	✓ EOS-holed-mirror-installation		RP VL	1 giorno	19/3/2024	19/3/2024	Installation
37	✓ EOS/Filament-optical-setup		RP FD	15 giorni	11/3/2024	29/3/2024	Installation
38	✓ Ripristino-telecamerae-SPARC		RP FD	15 giorni	1/4/2024	19/4/2024	Experiment
39	✓ Ripristino-motori-SPARC		RP FD	10 giorni	15/4/2024	26/4/2024	Experiment
40	○ Filament-tests-at-COMB		RP MG FV	5 giorni	27/5/2024	31/5/2024	Preparation
41	○ COMB-Laser-Setup		FV MG LV	10 giorni	3/6/2024	14/6/2024	Installation
42	✓ EOS-transfer-line		RP FD	10 giorni	13/5/2024	24/5/2024	Installation
43	○ New-Klystron-Loop-installation		MB LP	10 giorni	6/5/2024	17/5/2024	Installation
44	○ New-PMQ-stages		RP VL	10 giorni	2/9/2024	13/9/2024	Installation
45	○ Beam-based-alignment		RP MC +2	19 giorni	1/7/2024	26/7/2024	Preparation
46	○ PMQ-tests	ⓘ ⋮	RP Riccardo P	10 giorni	16/9/2024	27/9/2024	Experiment
47	○ High-gradient-PWFA		RP LV +2	9 giorni	30/9/2024	10/10/2024	Experiment
48	○ Filament-experiment		MG FV RP	20 giorni	11/10/2024	7/11/2024	Experiment
49	○ Resonant-PWFA		LV FV MG	20 giorni	8/11/2024	5/12/2024	Experiment



SABINA installations progress



New solenoids installed

Improvement: coils can be individually aligned

Water cooling system arrangement ongoing

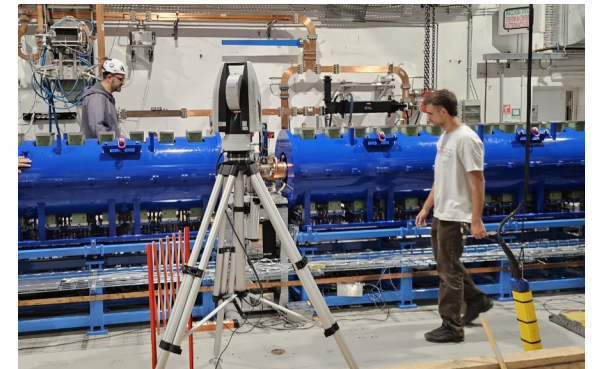
C band moved towards the gun

Quad triplet removed, more space for comb

Alignment of the entire machine performed

Accelerating sections, solenoids, steerers, diagnostics,..

New LLRF system installed



Cabling

cleanup and arrangement of the cables ongoing

Waiting for new phase shifter (in production)

Weekly meeting with Services for planning updates and reporting to Accelerator Division meeting

LINAC already under ion vacuum again

NEXT FUTURE: 14.06 end of installations, start of commissioning

L. Sabbatini, I. Balossino

THz line layout defined (both electron and radiation [1] line)

Magnets

Sextupoles and quadrupoles already available

Intraundulator steerers: designed, fabricated, tested [2,3]

Undulators

Mechanical deformation FBG studies completed [4]

Undulators and cabinets on site

Position marking on the floor

Drawings ready, tracking in program for the week of 3-7.06

THz transport and users' hutch:

Design of vacuum chambers for optics ongoing

Placement of orders (mirrors, pipes, pumps, ..) ongoing

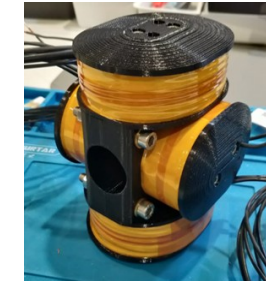
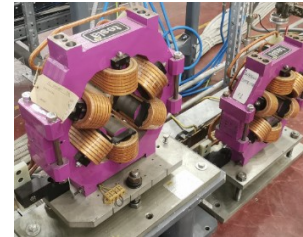
Users' instruments on site

Regione Lazio:

Accounting successfully completed

Technical and scientific visit from Regione Lazio delegates passed

Installations: starting from Sept., on Mondays (thus avoiding shutdown)



L. Sabbatini, I. Balossino

[1] Mosesso et al. *Underway Projects for Innovative THz/IR Sources based on Particle Accelerators: SISSI 2.0 and SABINA TeraDays 2024*

[2] Selce et al. *Intra-undulator magnets for the SABINA THz FEL line: magnets design, manufacturing and measurements IPAC2024*

[3] Del Franco et al. *3D printed beam correctors IPAC2024*

[4] Balossino et al. *Strain measurements of the Apple-X SABINA undulator with fiber Bragg grating IPAC2024*

Active-plasma bending results



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. Ferrario¹

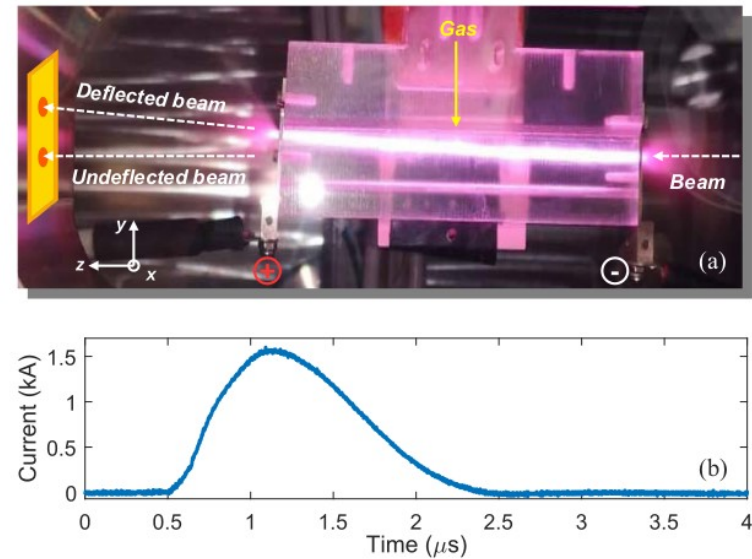
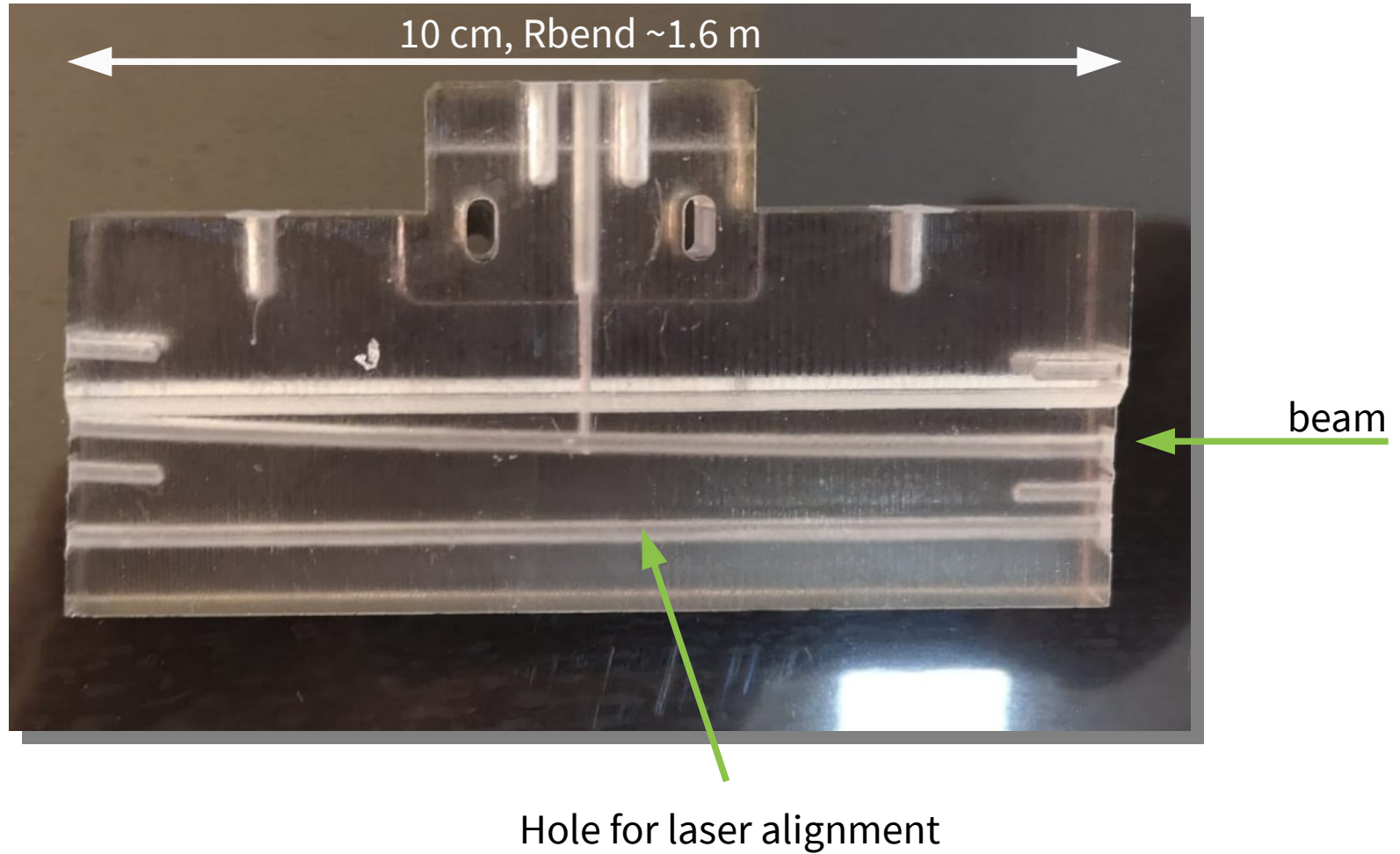
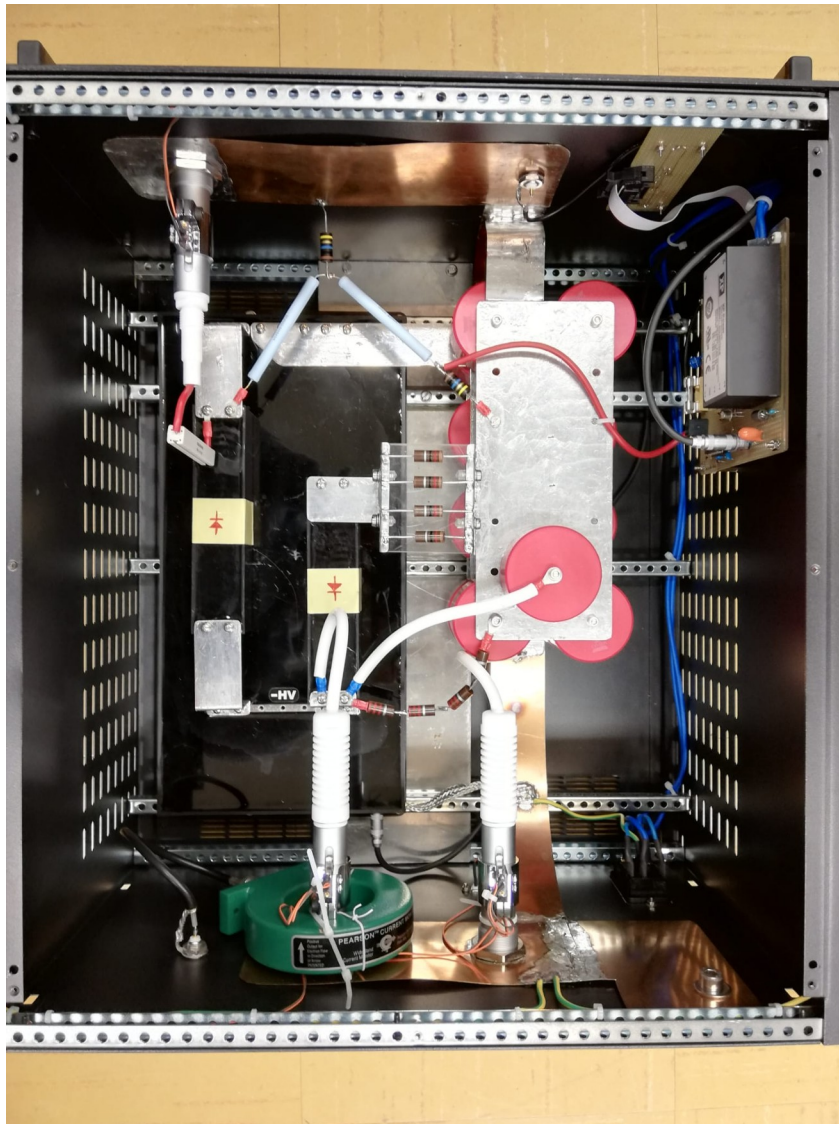
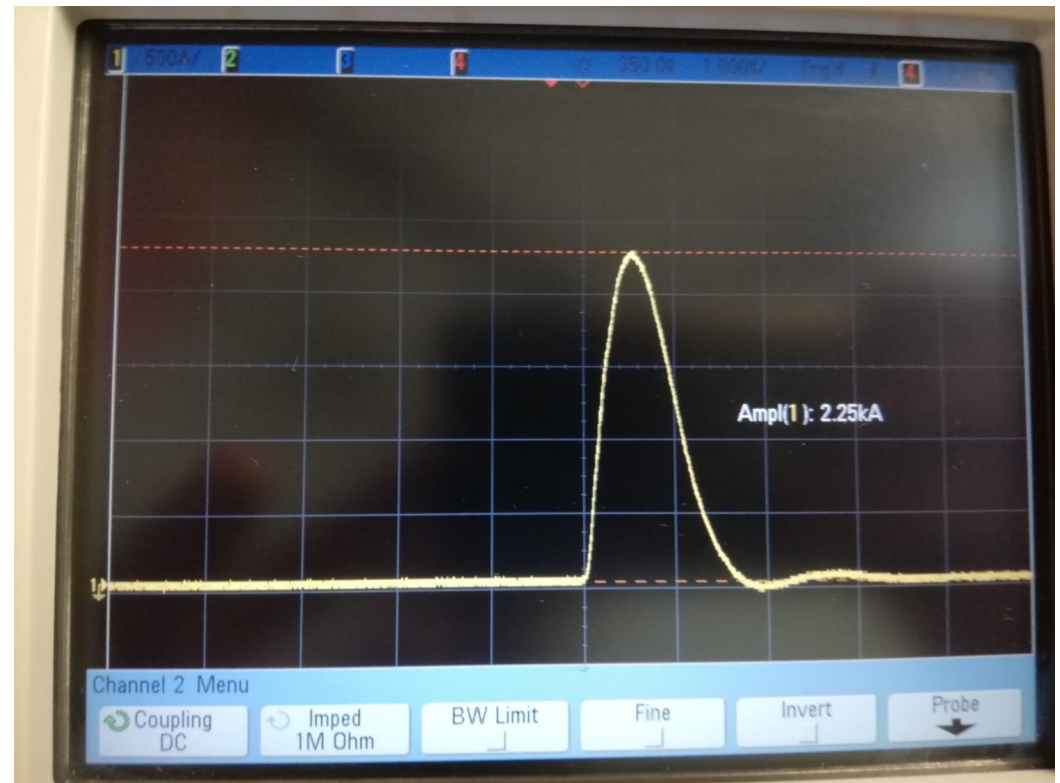


FIG. 1. (a) Experimental setup. The high-voltage discharge current is applied to the two electrodes of the curved capillary to produce the plasma. The beam is measured on a scintillating screen located 10 cm downstream of it. The orientation of the x - y - z axes is also indicated. (b) Discharge current waveform acquired with a digital scope.

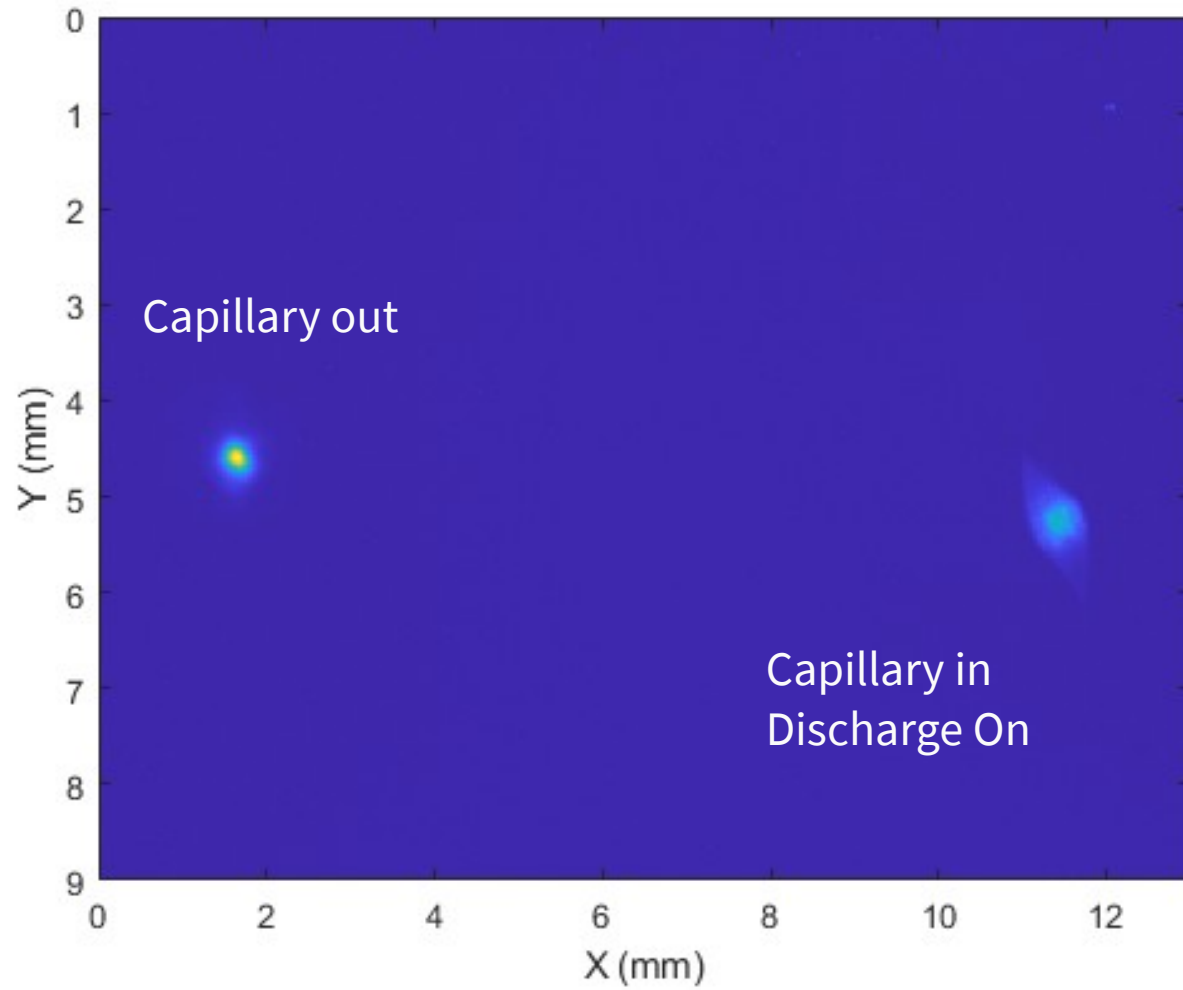


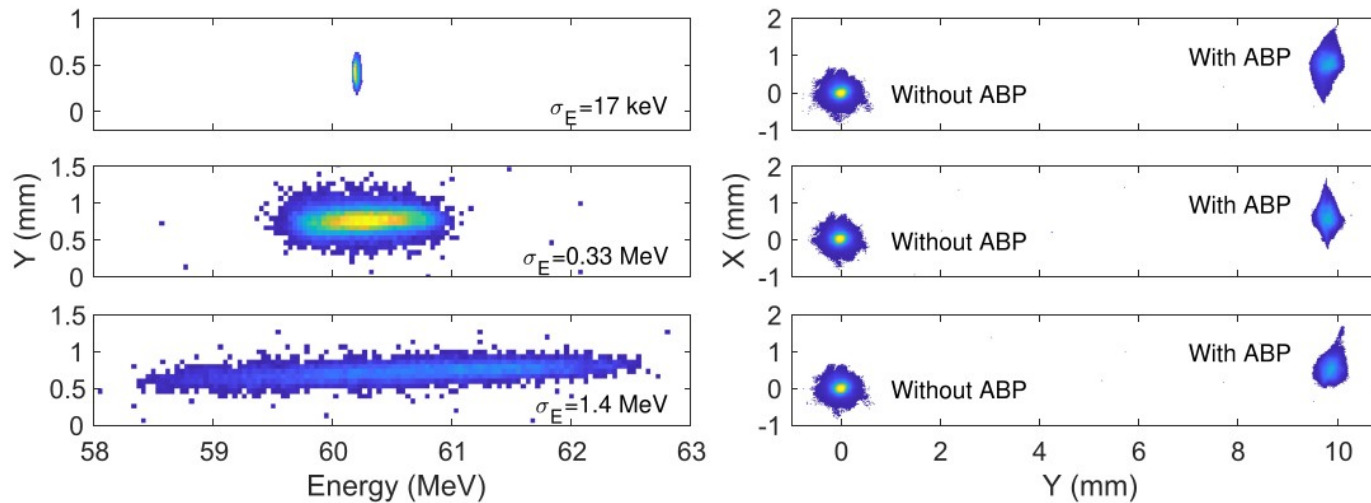


HV pulser (D. Pellegrini, G. Grilli, T. De Nardis)



First results @ 2.25 kA



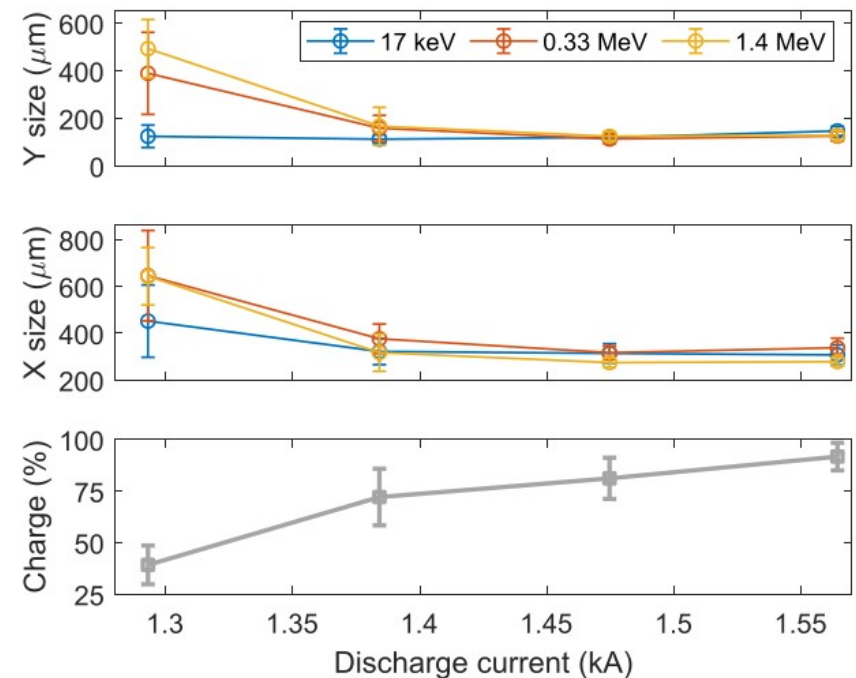


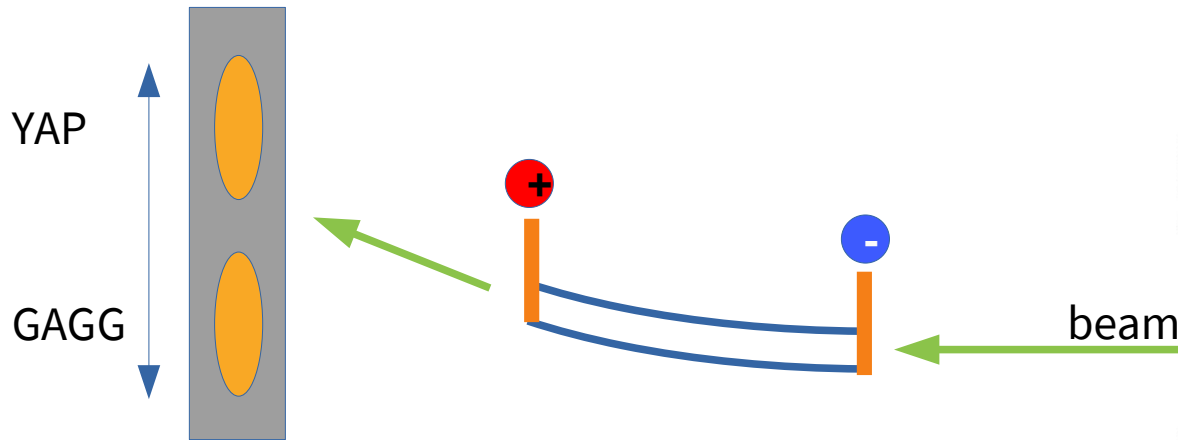
We tested the ABP deflection with three beam configurations having different energy spreads

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 dispersionless way





We have used a 50 pC test beam on-crest (~1 ps)

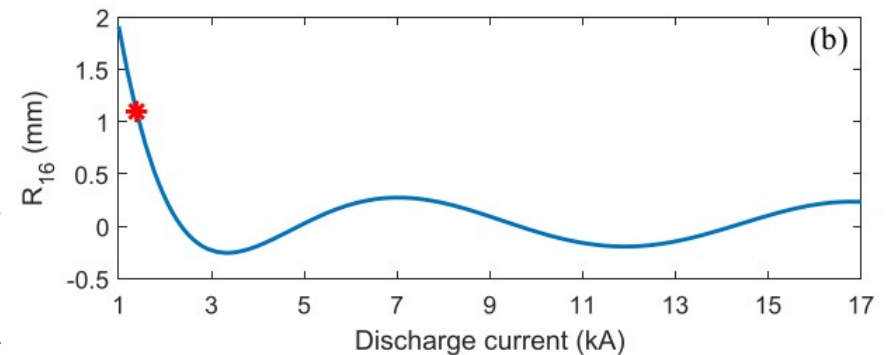
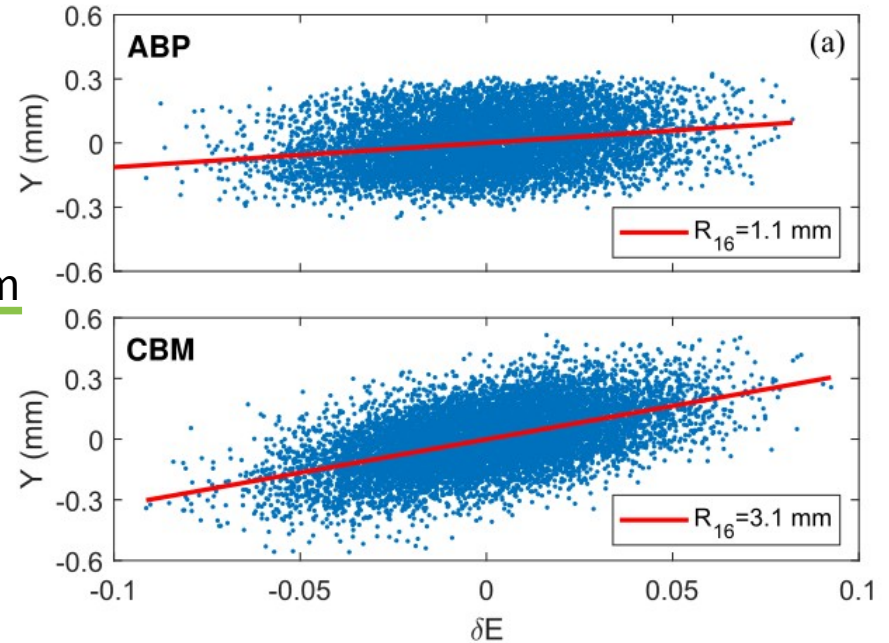
The energy of the beam is set to 60 MeV

1.6 m bending radius, ~4° deflection angle in 10 cm capillary

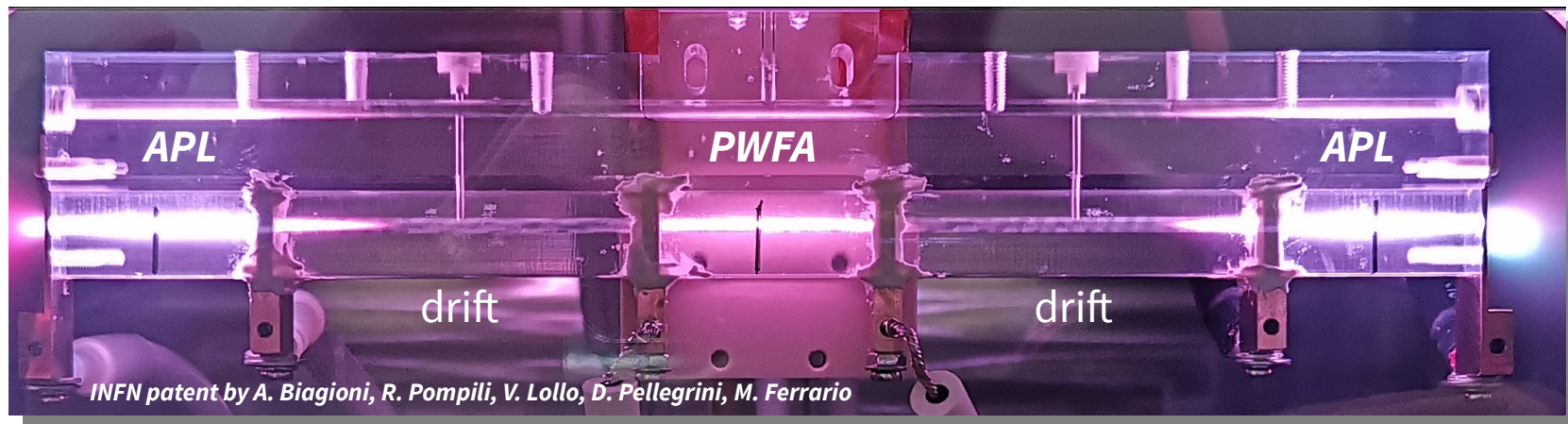
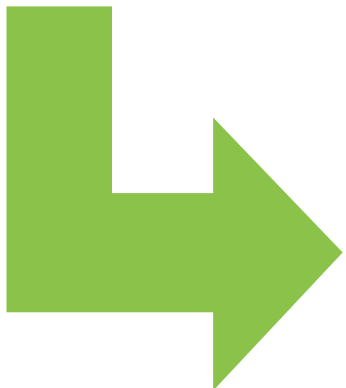
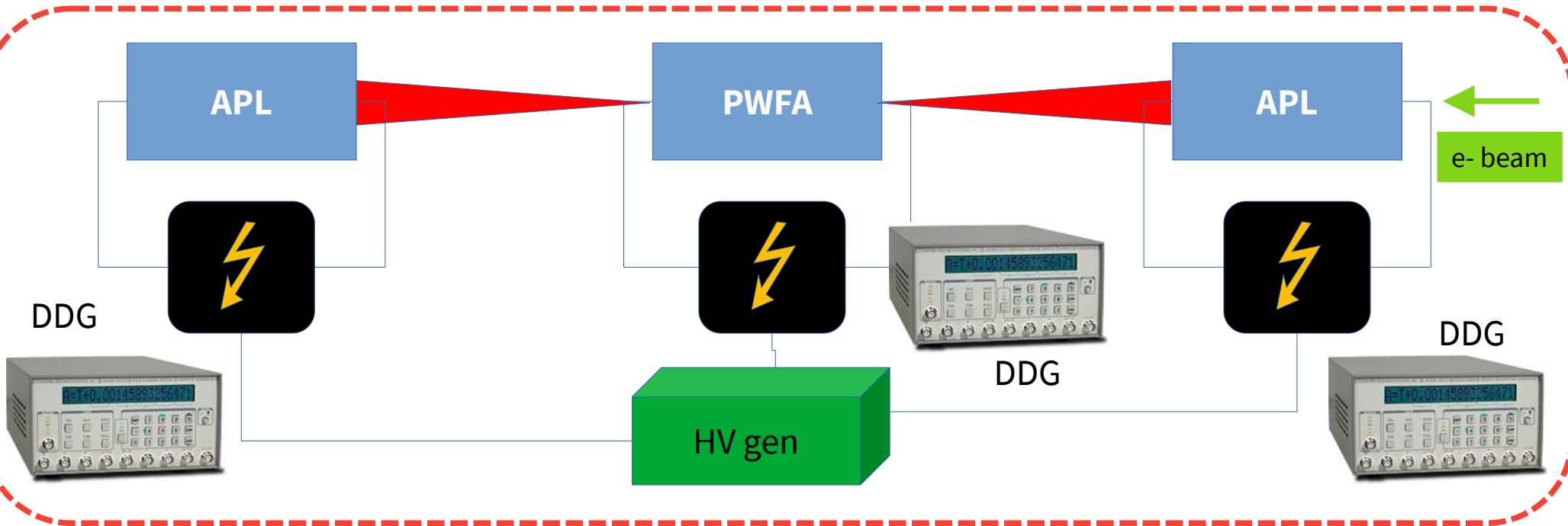
The beam is imaged on the YAG/GAGG screen located ~10 cm downstream the capillary exit

Compared to a conventional bending magnet (CBM), the R16 matrix (dispersion) term is reduced by a factor 3

By tuning the discharge current the R16 can really be made zero → no need of dispersion matching optics downstream the bending!



All-in-one capillary results



PHYSICAL REVIEW E
covering statistical, nonlinear, biological, and soft matter physics

Highlights Recent Accepted Collections Authors Referees Search Press About Editorial Team

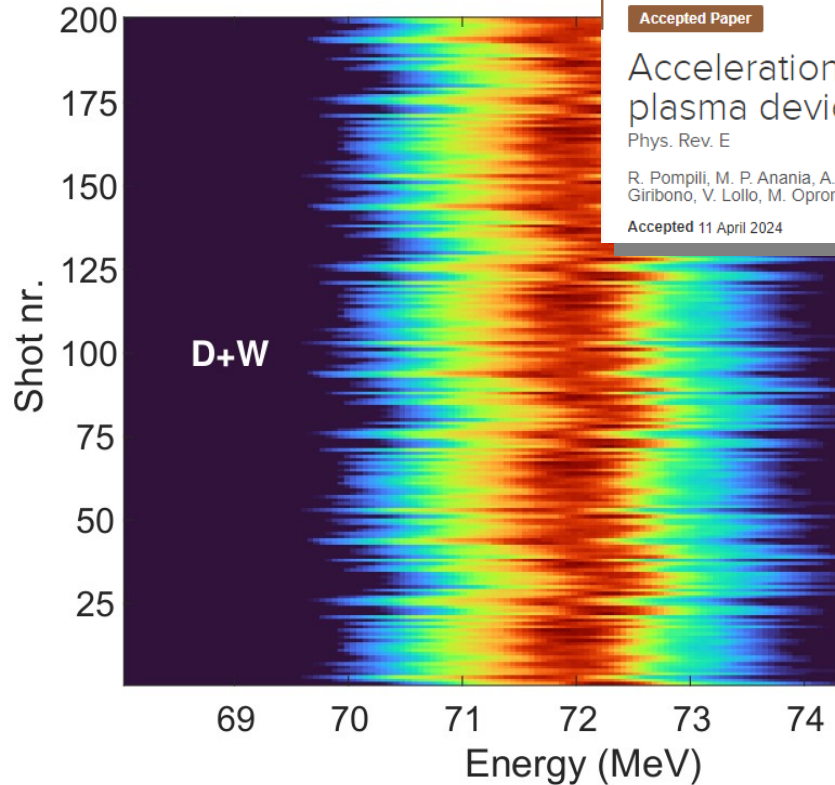
Accepted Paper

Acceleration and focusing of relativistic electron beams in a compact plasma device

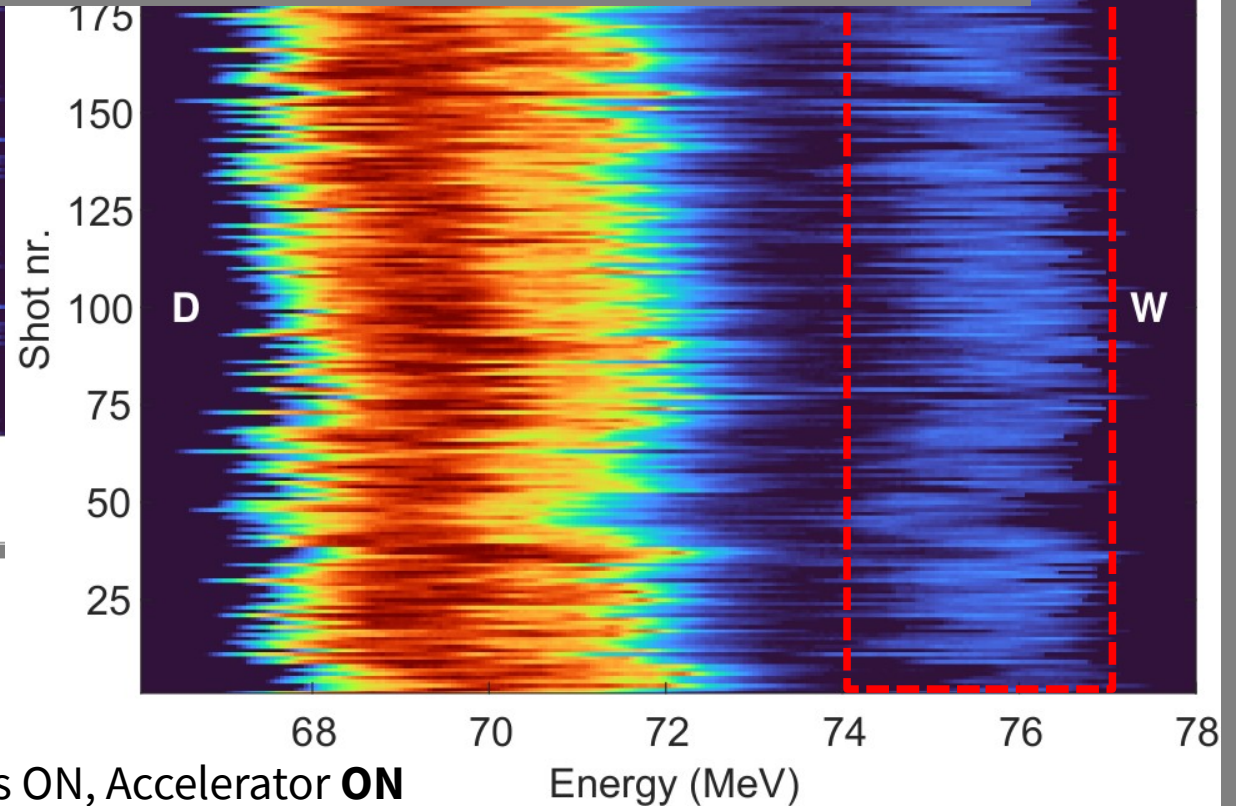
Phys. Rev. E

R. Pompili, M. P. Anania, A. Biagioni, M. Carillo, E. Chiadroni, A. Cianchi, G. Costa, A. Curcio, L. Crincoli, A. Del Dotto, M. Del Giorno, F. Demurtas, M. Galletti, A. Giribonò, V. Lollo, M. Opromolla, G. Parise, D. Pellegrini, G. Di Pirro, S. Romeo, G. J. Silvi, L. Verra, F. Villa, A. Zigler, and M. Ferrario

Accepted 11 April 2024



Lenses ON, Accelerator **OFF**



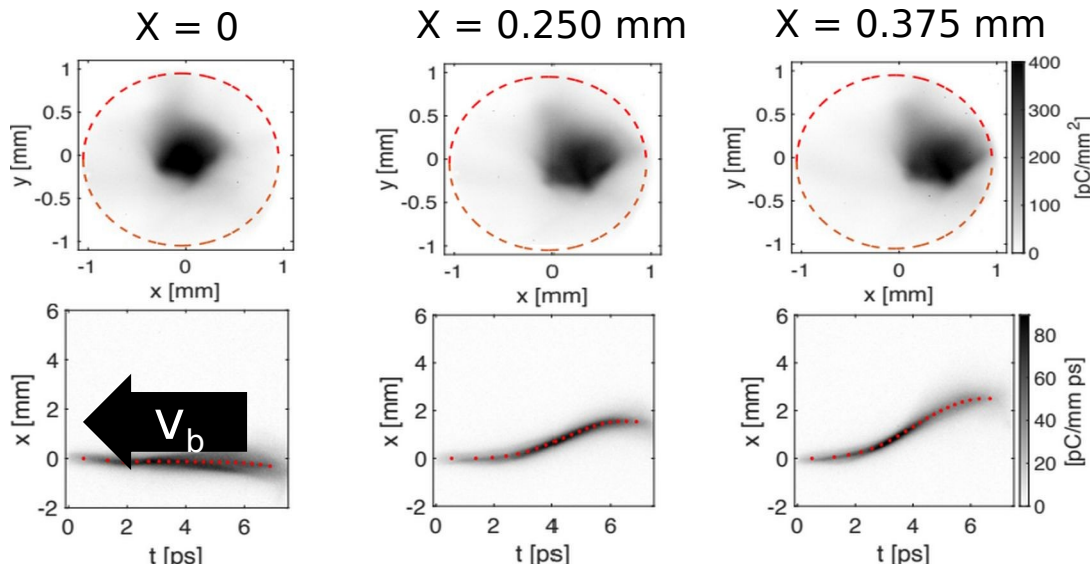
Lenses ON, Accelerator **ON**

Suppression of dielectric wakefields in plasmas

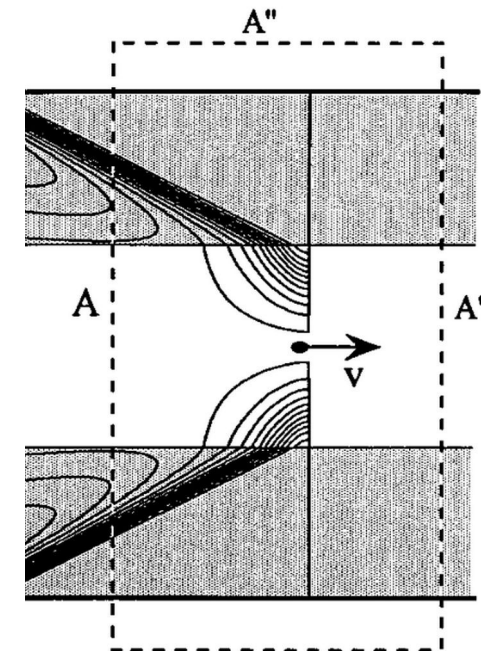
Charged beams drive Cherenkov wakefields when space-charge field interacts with slow-wave structures

Coupling with dipolar mode when traveling off-axis in a dielectric capillary

Possible deleterious effect in PWFA such as EuPRAXIA (e.g. causing beam-breakup / hosing instability)



Transverse time-resolved images (using TDS)



- Centroid of longitudinal slices
- Kick proportional to charge running integral

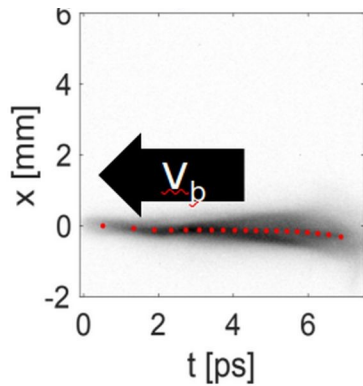
$$\perp () \propto \int_0 ()$$

L. Verra

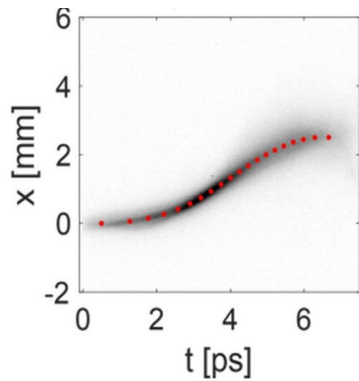
Space-charge field of relativistic bunches behaves as an electromagnetic field

Plasma screens electromagnetic fields at $r \gg$ plasma skin depth

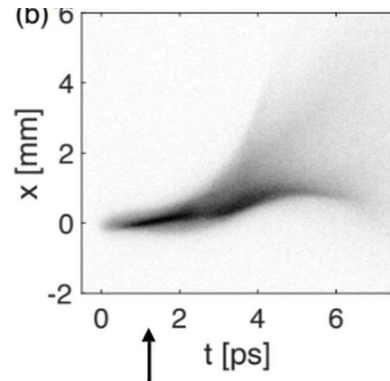
Aligned
No plasma



Misaligned
No plasma



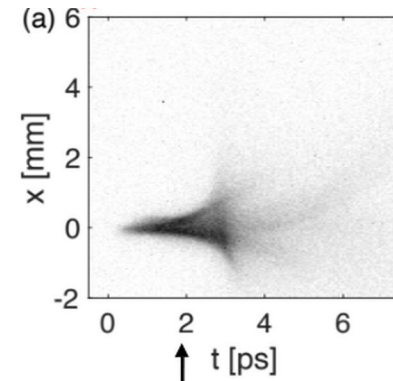
Misaligned
 $n_{pe} = 0.038 \cdot 10^{14} \text{ cm}^{-3}$



Density too low

→ Effect of dielectric wakefields

Misaligned
 $n_{pe} = 1.0 \cdot 10^{14} \text{ cm}^{-3}$



Density high enough

→ Dielectric wakefields suppressed

”Basic physics” on plasma screening of the space-charge field

Manuscript under review
for PRL

¹ Experimental Observation of Space-Charge Field Screening of a Relativistic Particle Bunch in Plasma

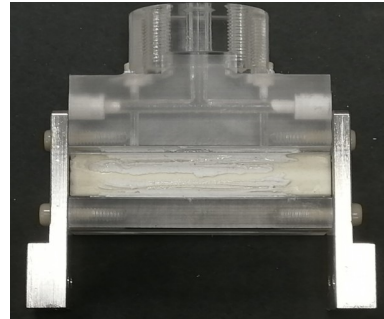
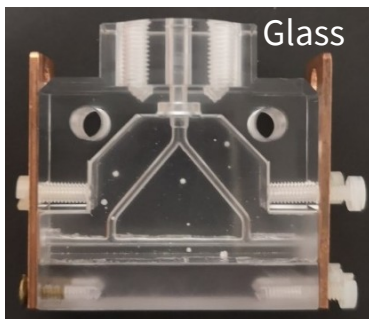
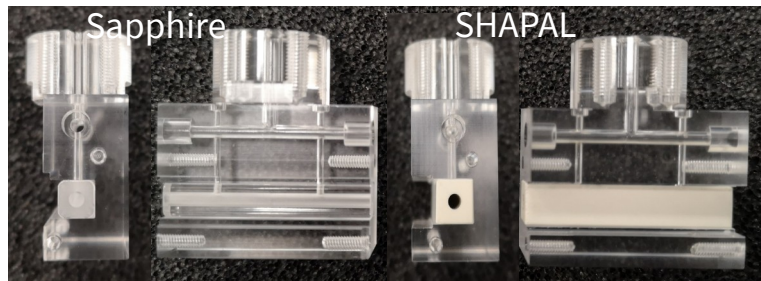
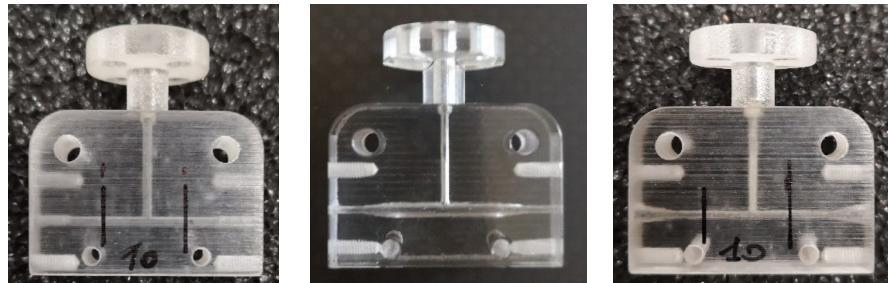
²
³ L. Verra,^{1,*} M. Galletti,^{2,3,4} R. Pompili,¹ A. Biagioni,¹ M. Carillo,⁵ A. Cianchi,^{2,3,4} L. Crincoli,¹ A. Curcio,¹
⁴ F. Demurtas,² G. Di Pirro,¹ V. Lollo,¹ G. Parise,² D. Pellegrini,¹ S. Romeo,¹ G.J. Silvi,⁵ F. Villa,¹ and M. Ferrario¹

L. Verra

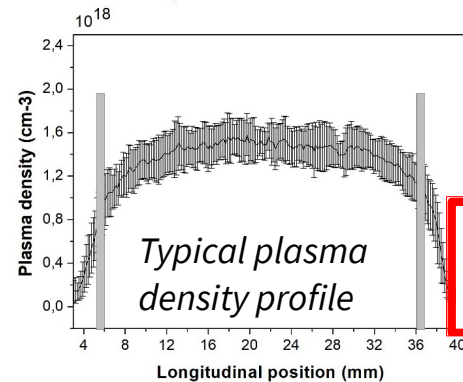
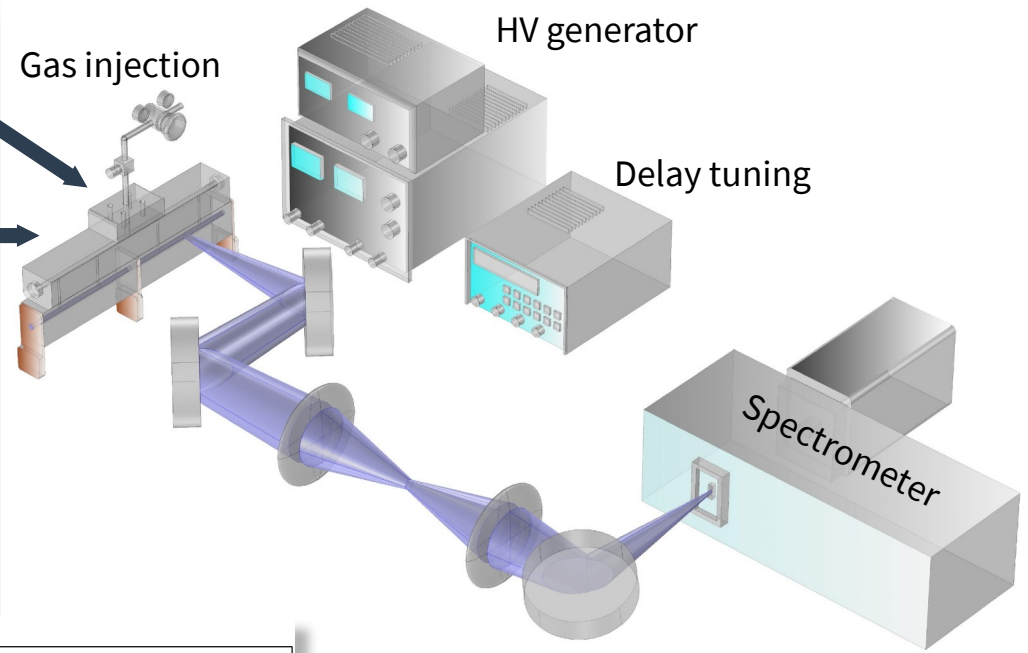
PLASMA_LAB



A. Biagioni, L. Crincoli

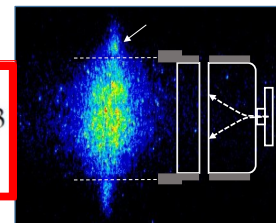


Capillary to be tested



$$n_e = 8.02 \times 10^{12} \left(\frac{\Delta\lambda}{\alpha} \right)^{3/2} \text{ cm}^{-3}$$

Stark broadening



FLAME



Laser parameters

- *Energy 6.2 J, Duration 30 fs FWHM, Focus: 18-20 microns FWHM*

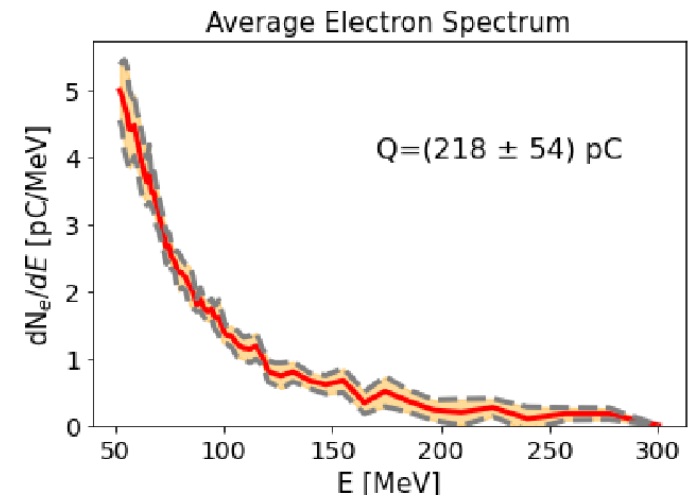
Electron parameters

- *Max energy 300 MeV*
- *200 pC charge*
- *20-30 mrad divergence*

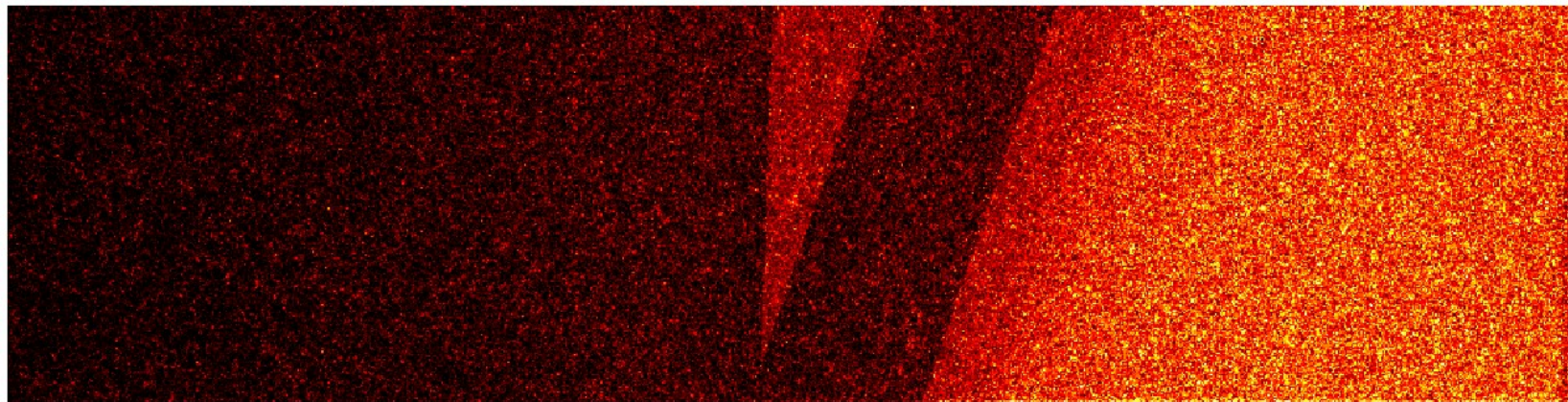
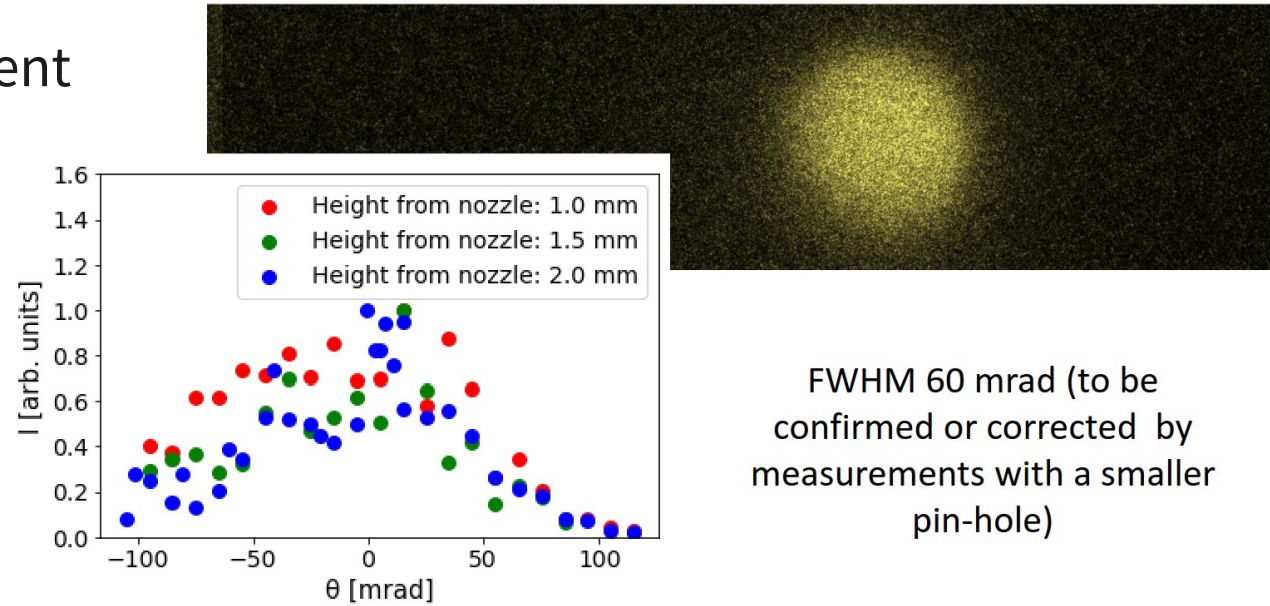
Goal of activities in view of EuAPS

Obtain X-rays spectra and start some preliminary study on samples

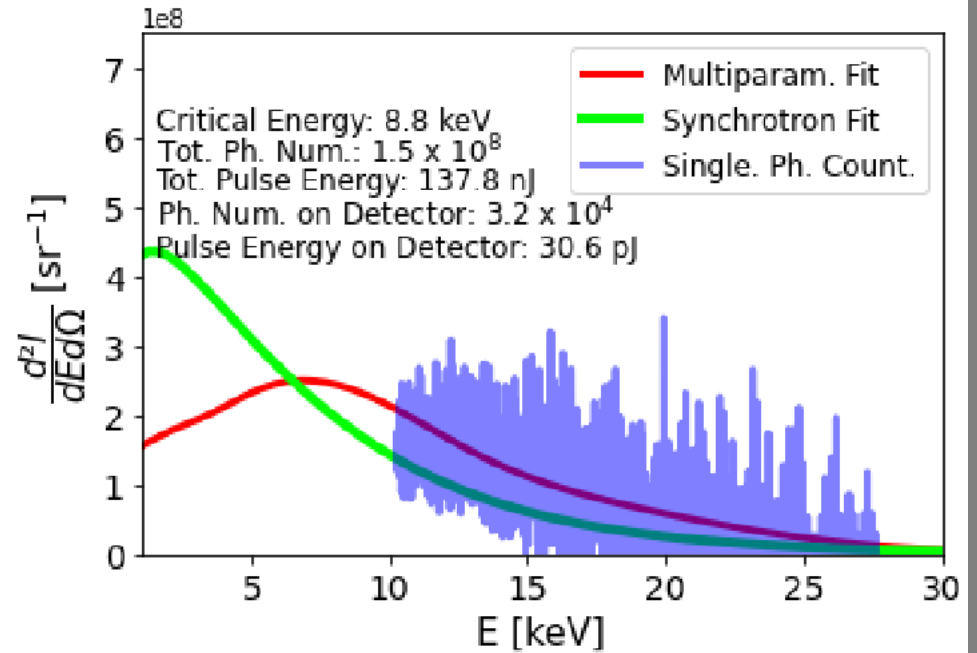
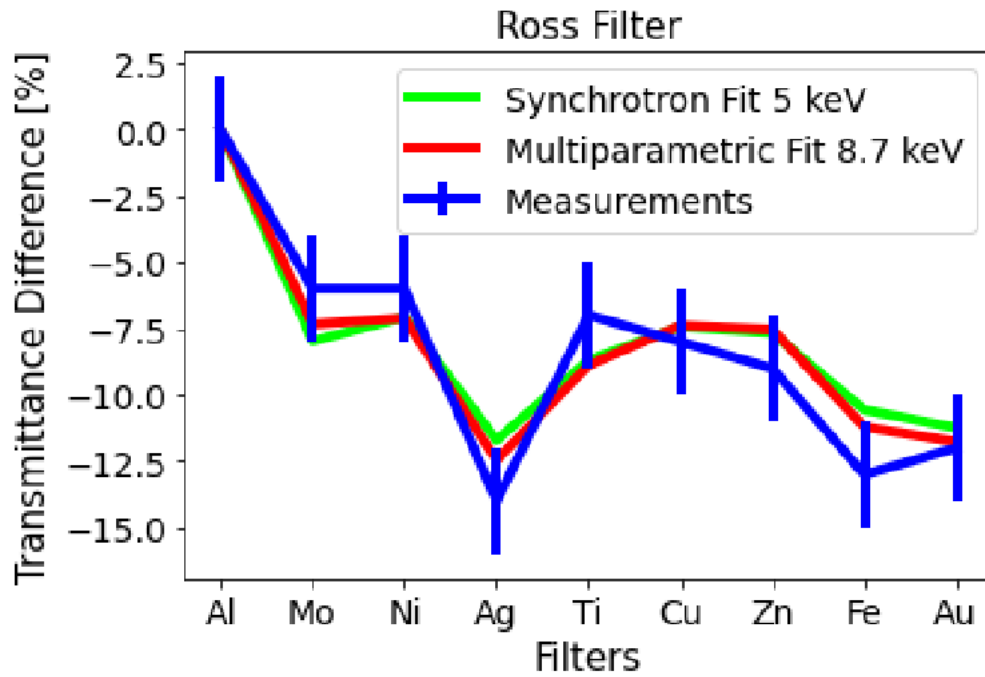
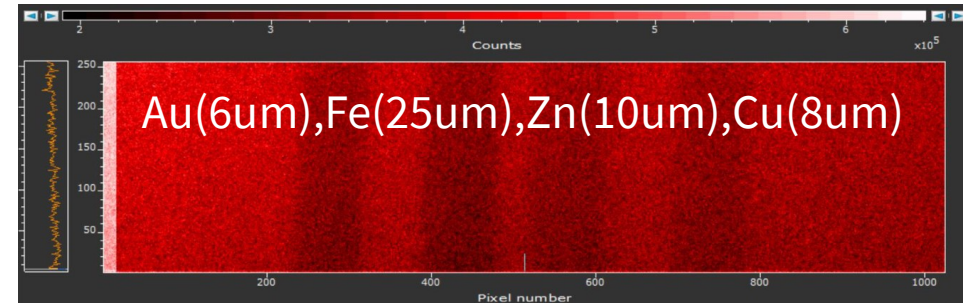
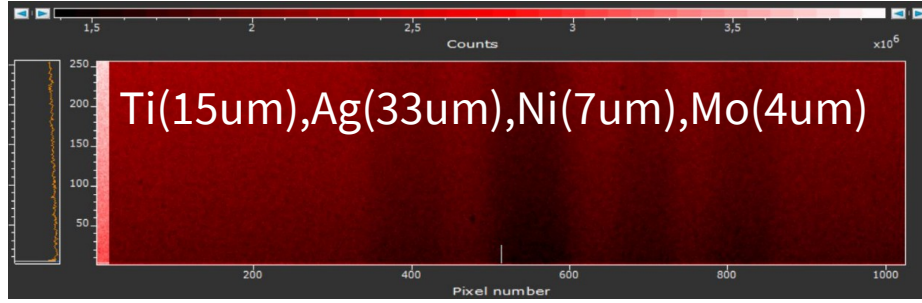
This year FLAME is also undergoing to be refurbished with new equipment (compressor, experimental chambers, etc.) to be ready for the main EuAPS installations that will happen next year



X-radiation profile measurement



Single-shot image of a Steel slab covering half sensor (left) and tilted Allen-key on the side (right)



EuAPS



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

Laser parameters

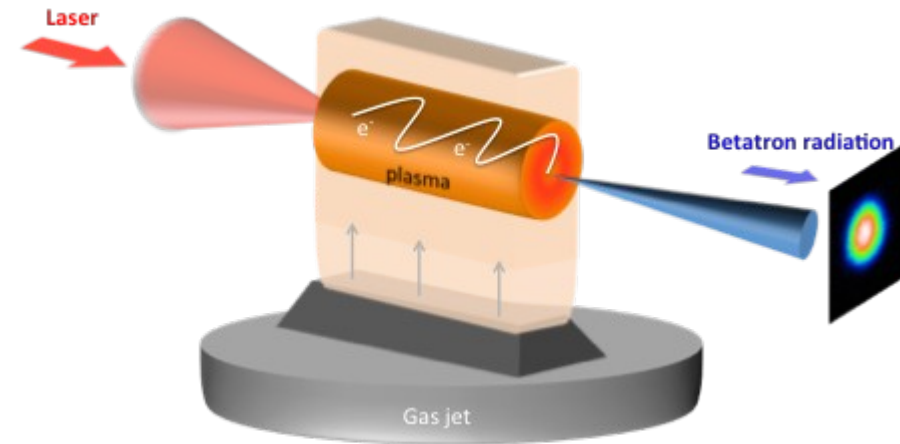
Plasma source devices

Electron diagnostics

X rays spectrum and photon flux

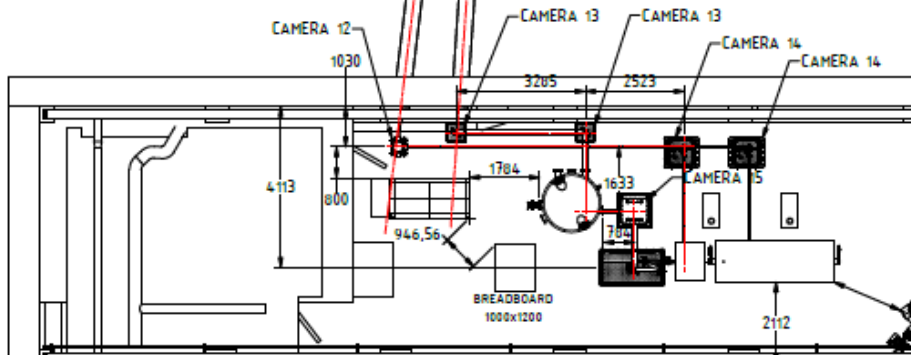
The main goal is to make a replica of the source developed at FLAME

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

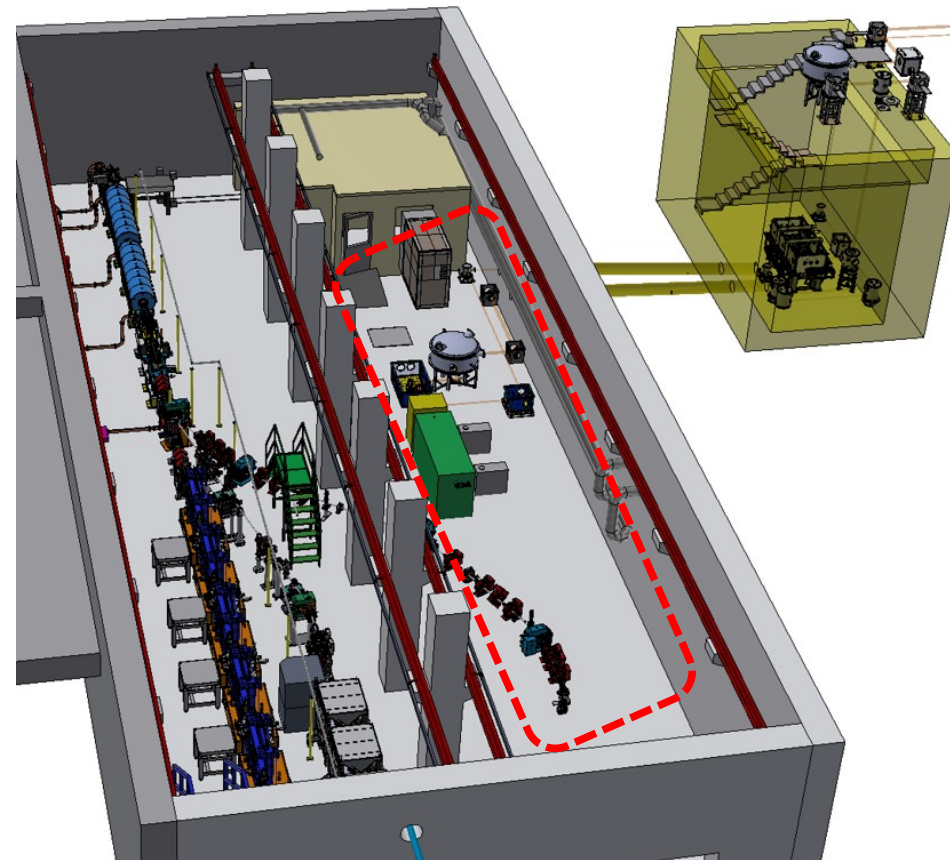


Parameter	Value	unit
Electron beam Energy	100-800	MeV
Plasma Density	10^{17} - 10^{19}	cm^{-3}
Photon Critical Energy	1 -10 tunable	keV
Number of Photons/pulse	10^6 - 10^9	
Repetition rate	1-10	Hz
Beam divergence	3-20	mrad

SPARC_LAB bunker

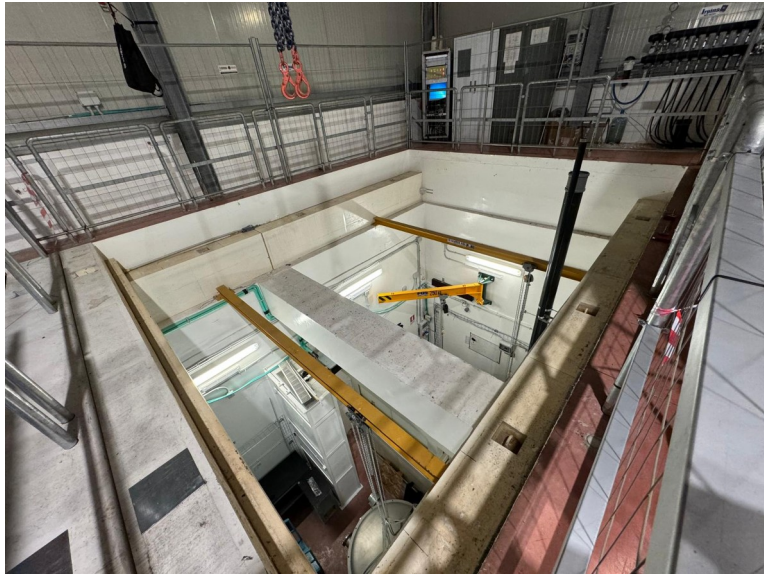


- Layout in the SPARC bunker and connection with FLAME building



S. Lauciani

Flame building



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

A. Cianchi

- FLAME installation until 15/2/2025
 - Upgrade laser FLAME until March 2025
 - SPARC installation from January to May 2025
 - Setup and startup X-ray source June/July 2025
 - Beam to users September/November 2025
 - Project ends 30th November 2025
-
- 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

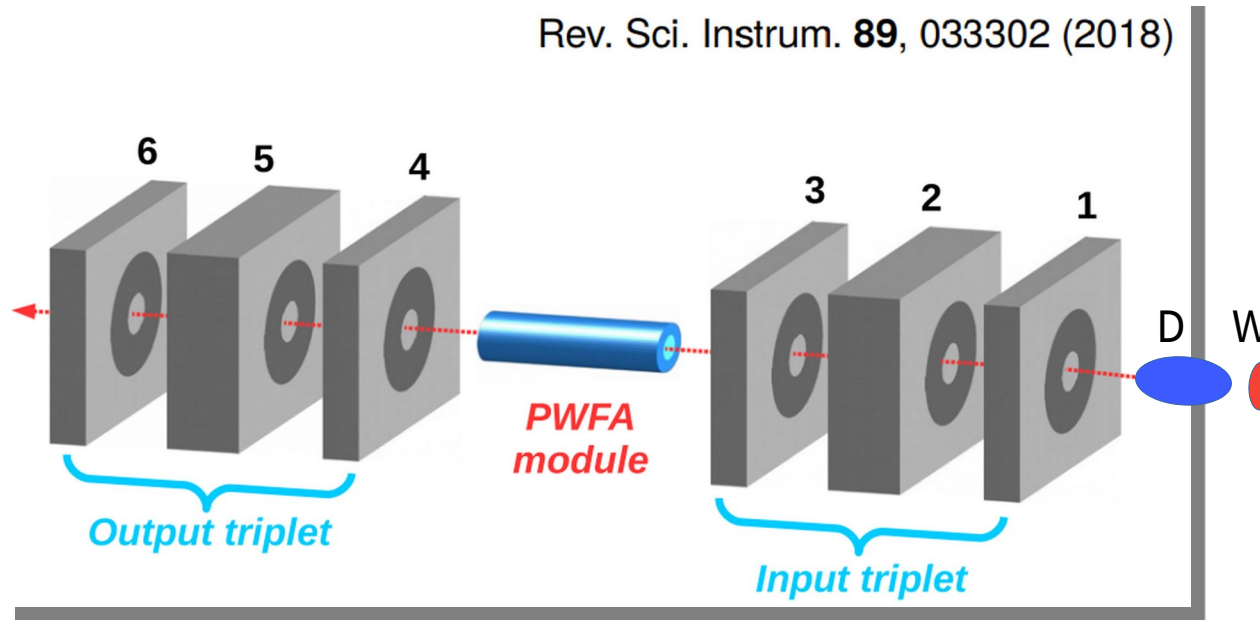
A. Cianchi

Thanks!

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

On behalf of the SPARC_LAB collaboration





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

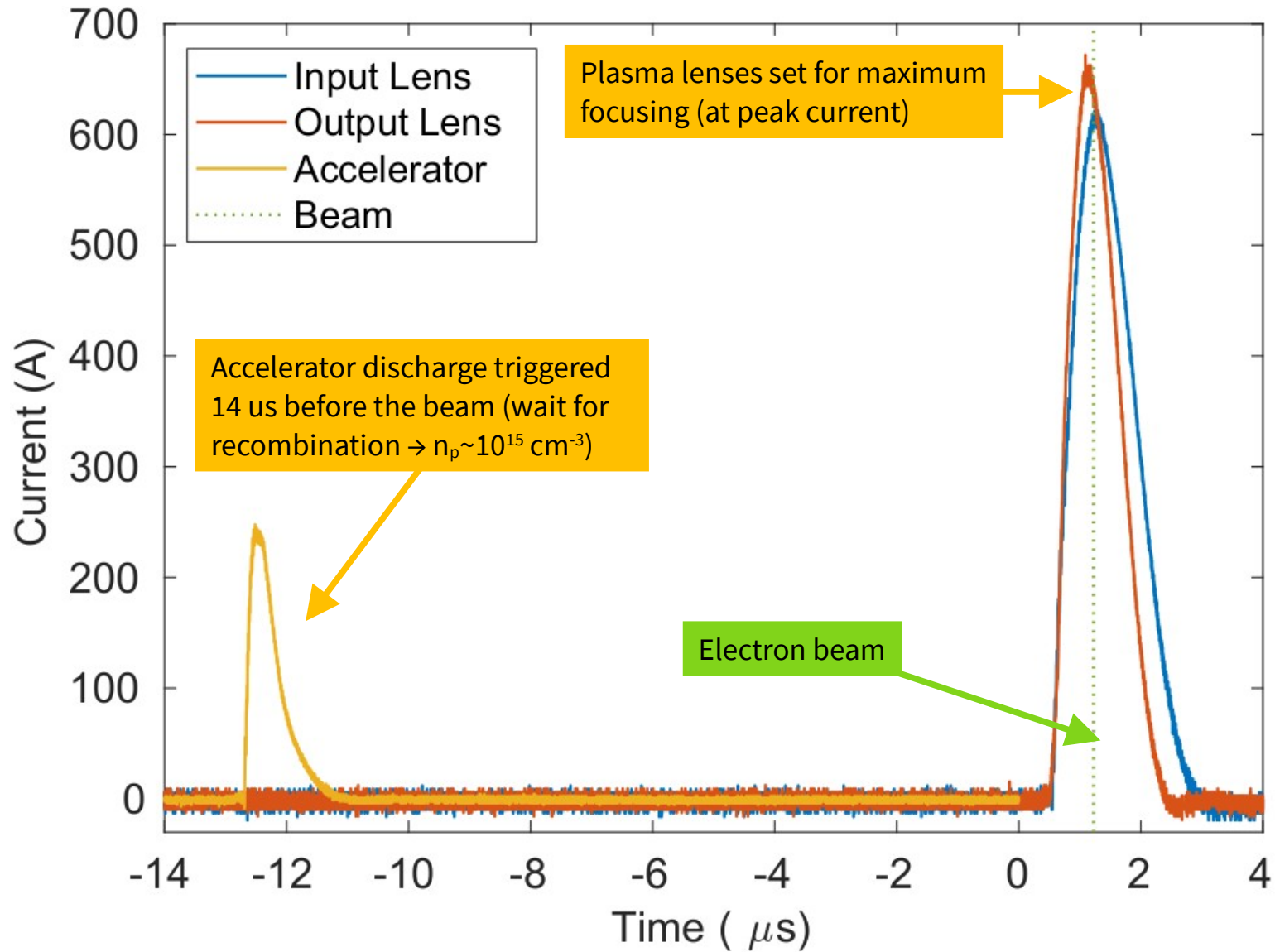
Driver beam charge density (together with plasma density) sets the accelerating gradient

Witness beam must be transversely matched to avoid emittance spoiling

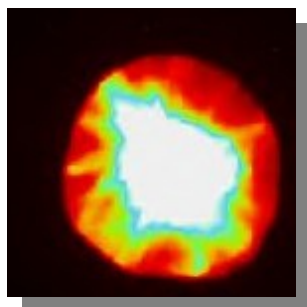
$$\beta_{eq} = \sqrt{\frac{\gamma}{2\pi r_e n_p}}$$

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

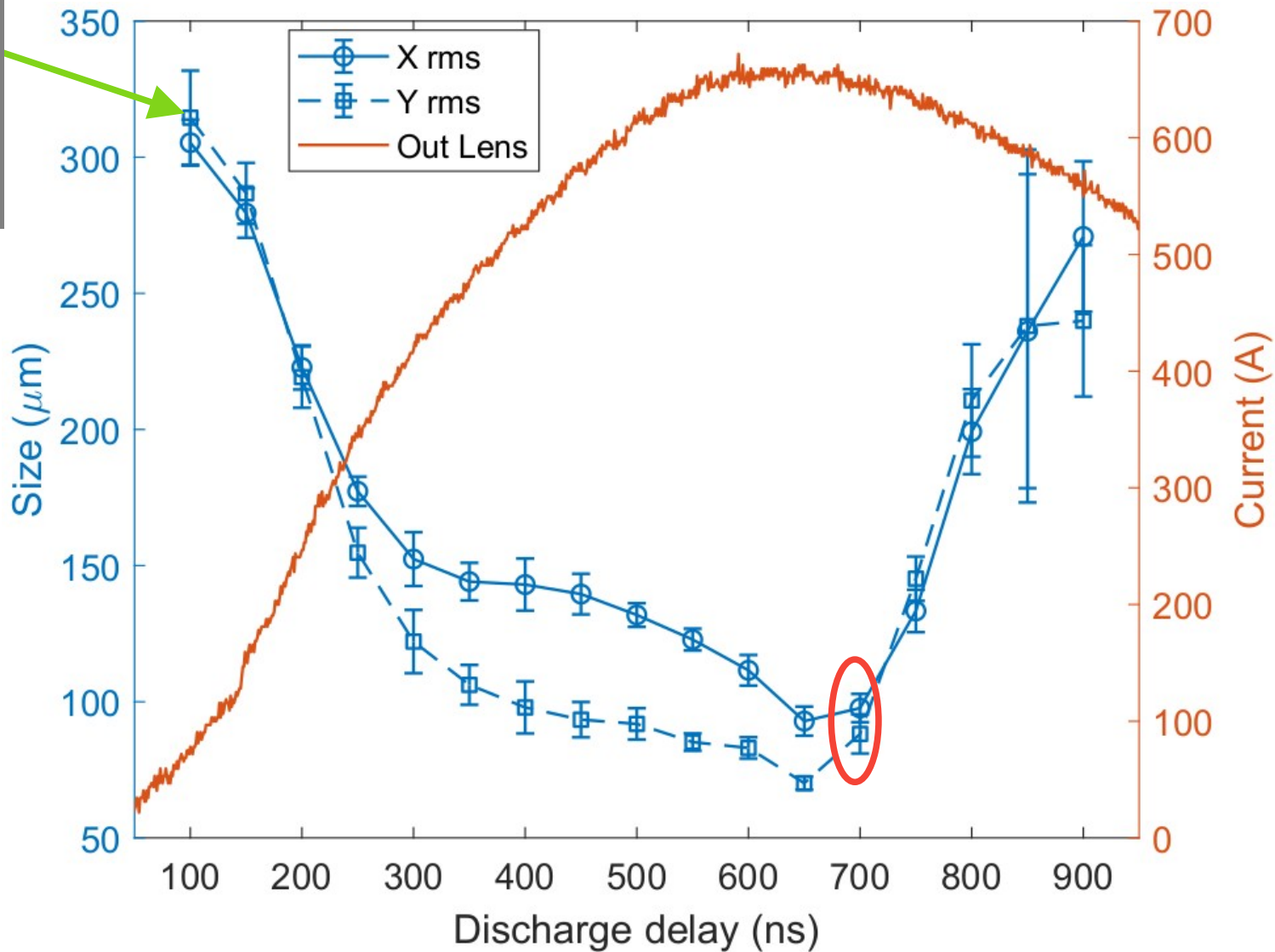
The PWFA needs focusing optics upstream (matching) and downstream (capture)



Scan obtained using only the APL2 (APL1 and ACC turned OFF)

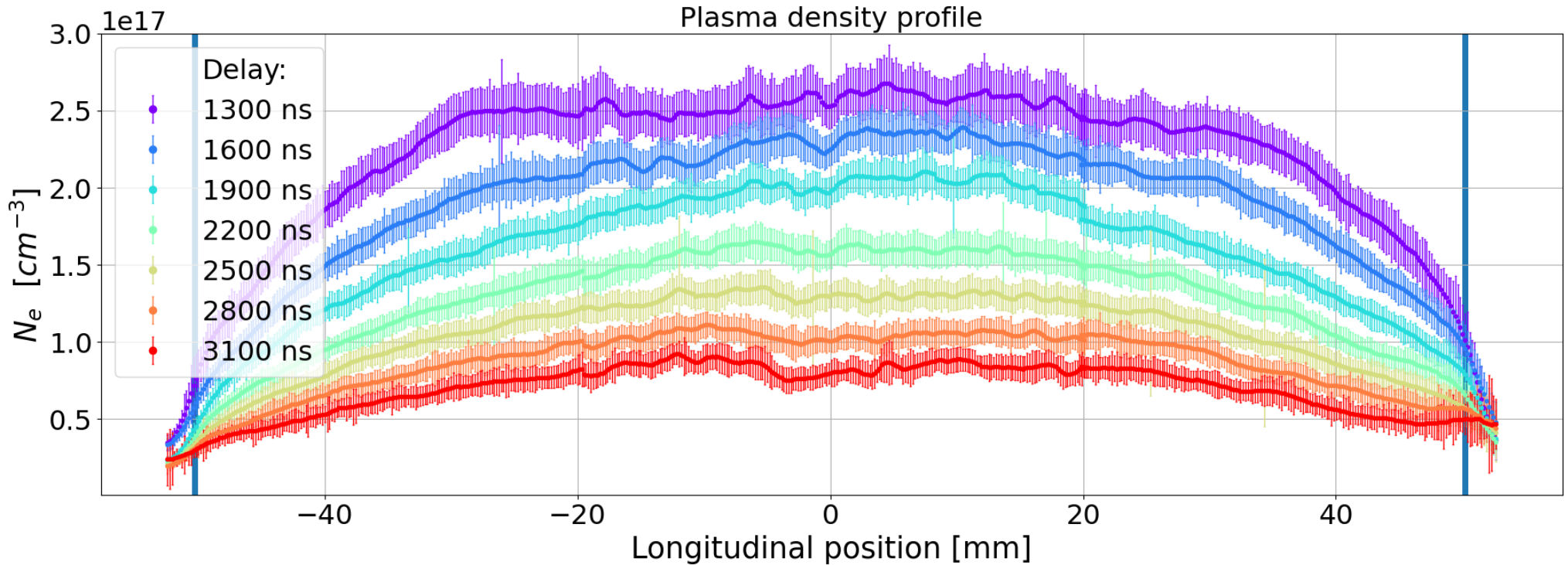


2 mm



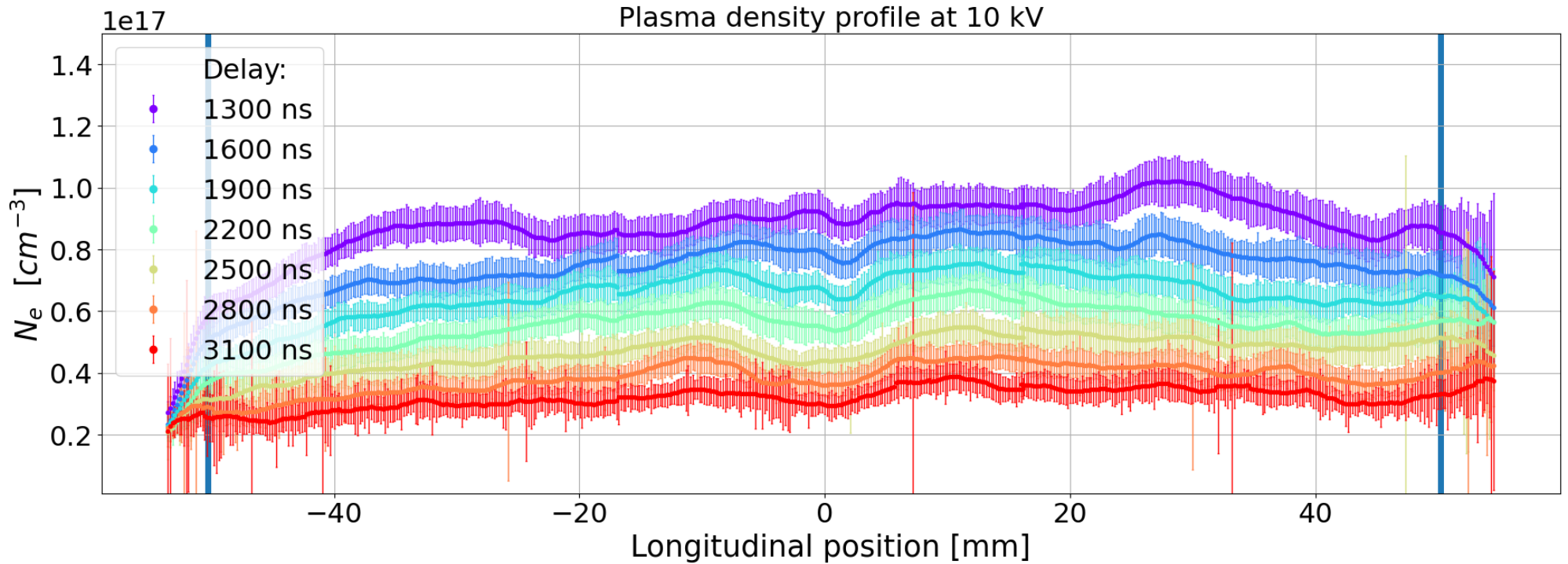
Before test

10 kV – 730 A, 1 bar



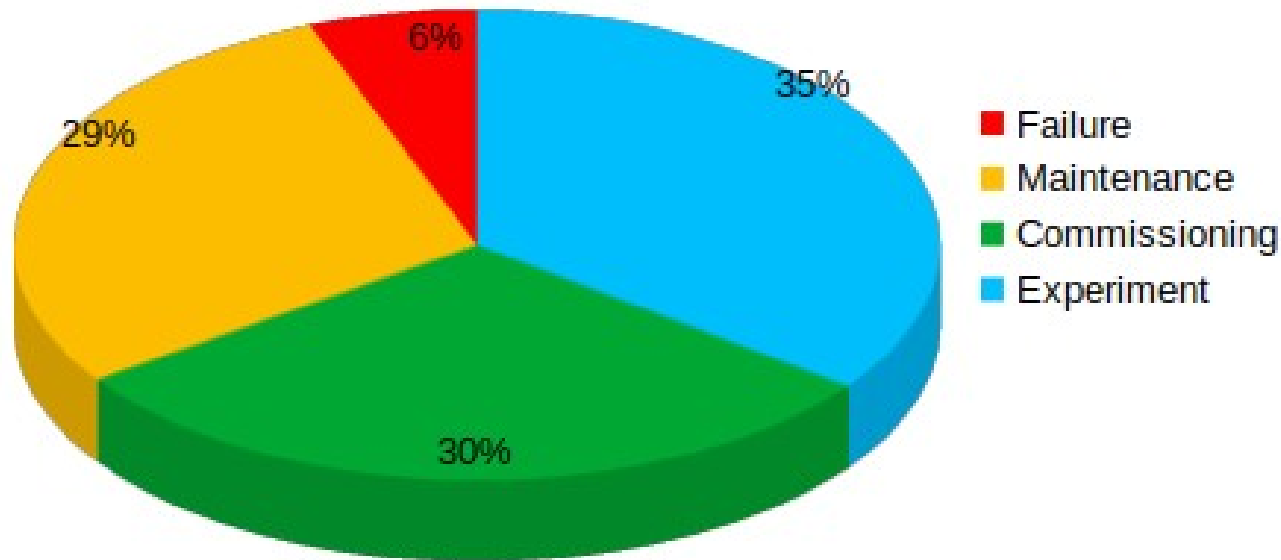
After test

10 kV – 730 A, 1 bar

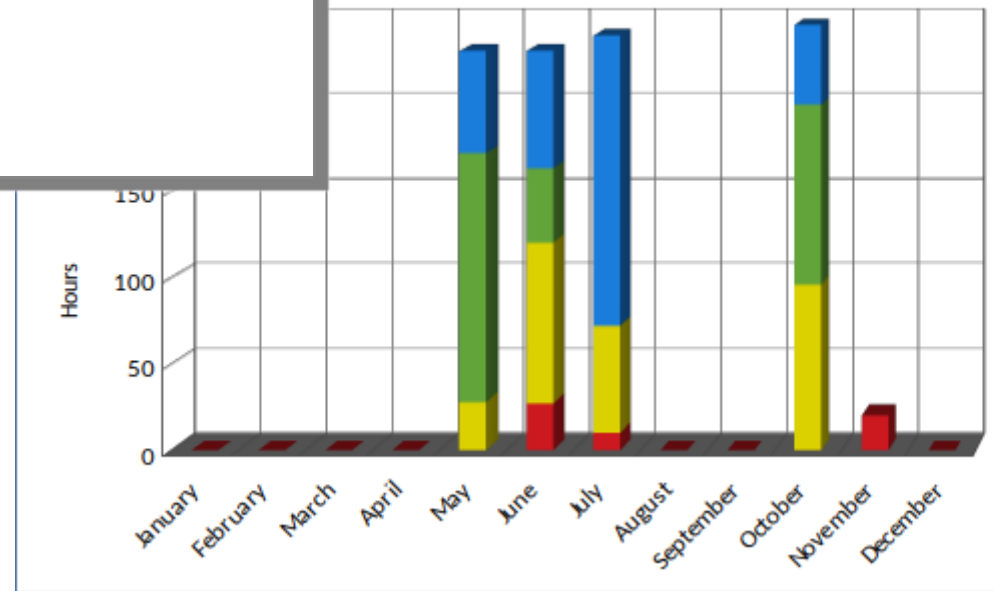


Degradation of the capillary (ablation) gave lower densities

SPARC Time



SPARC - Monthly activity

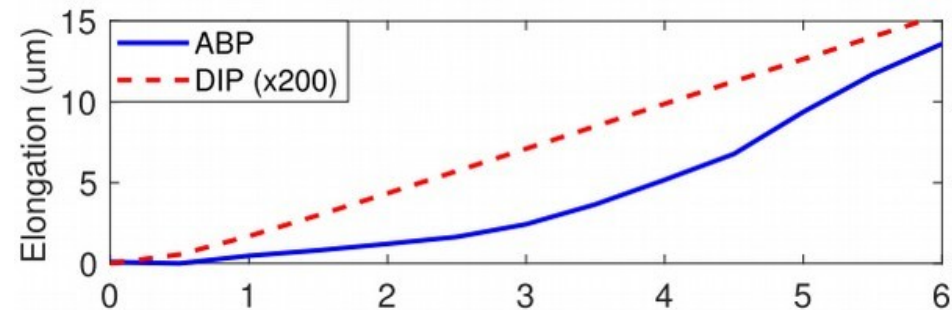
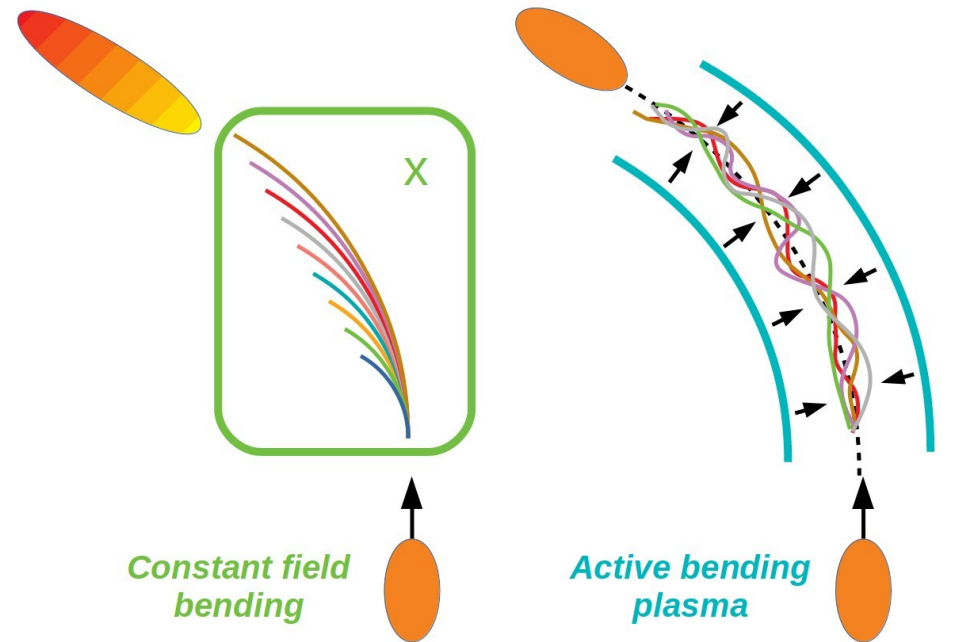


Particle motion in the APB is different with respect to a classic bending magnet

- *Its magnetic field is radially increasing (not constant like in a planar bend)*
- *Large energy particles → large offset with respect to the capillary axis → stronger deflection*

Bunch elongation/dispersion can be made negligible even with large energy spreads

- *The ABP does not require any manipulation on the beam LPS as in the case of standard bending magnets!*
- *No dispersion-matching optics (quads, sextupoles)!*
- *Simple and affordable solution in view of compact machines.*



Active Plasma Bending (APB) is an extension of the Active-Plasma Lens (APL) mechanism

- *The Lorentz force due to the current-induced magnetic field pushes the particles toward the capillary axis*
- *The same applies in a curved capillary: particles stay close to the bent path*
- *Plasma can sustain large currents (> 70 kA have been proved). As an example, **25 kA** currents produce **~6 T** magnetic fields*

Idea is to provide an alternative to classic bending magnets

- *Compactness. Large deflection angles, no need of cryogenic systems*
- *Tunability. The bending is tuned by adjusting the discharge-current*
- *Cheap solution (capillary+discharge pulser)*
- ***Tunable dispersion (dispersion-free also possible) by changing the discharge current***

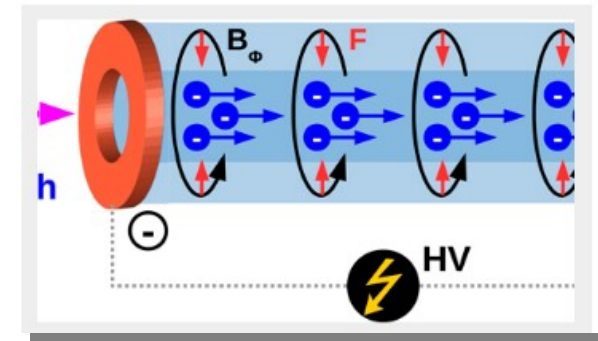
AIP AIP Advances

JAN 25 2018

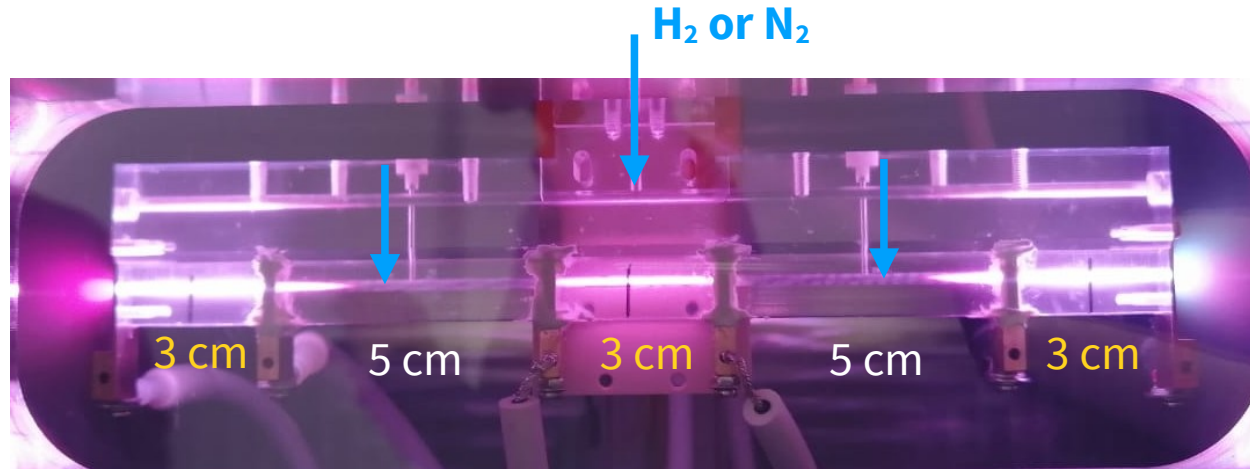
Editor's picks

Guiding of charged particle beams in curved capillary-discharge waveguides

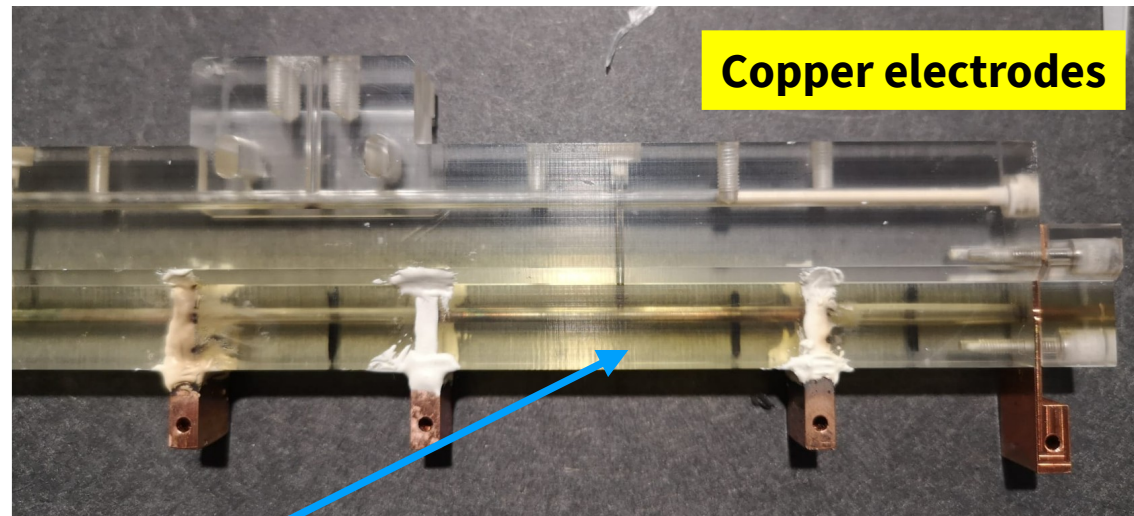
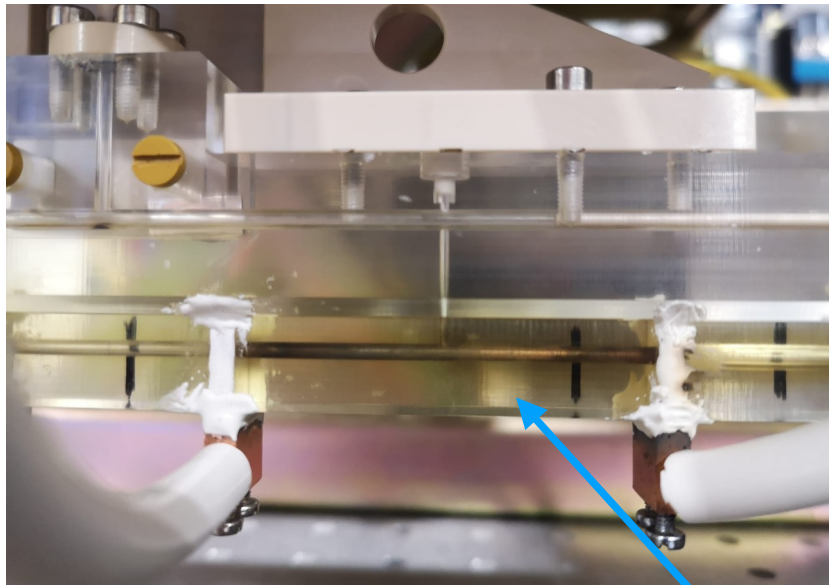
Pompili et al.



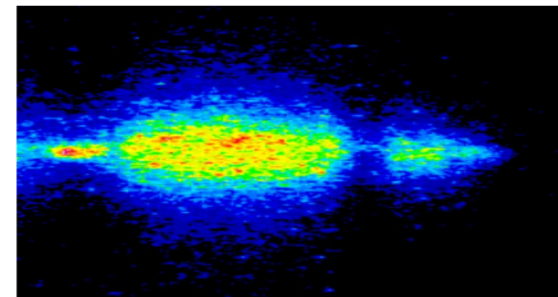
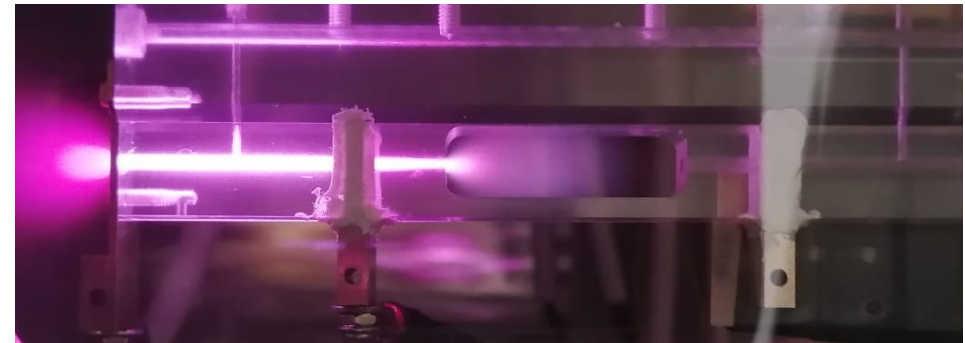
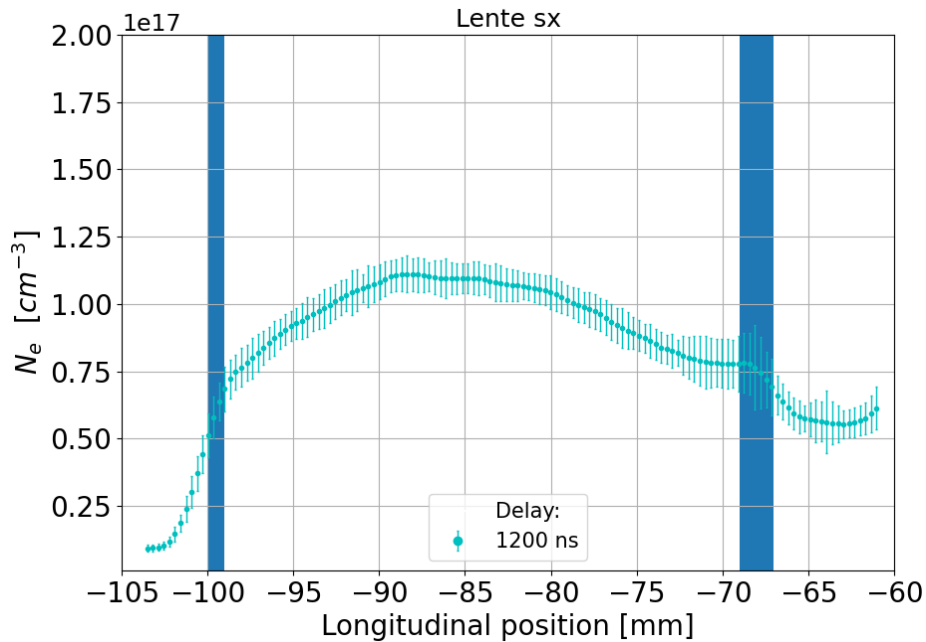
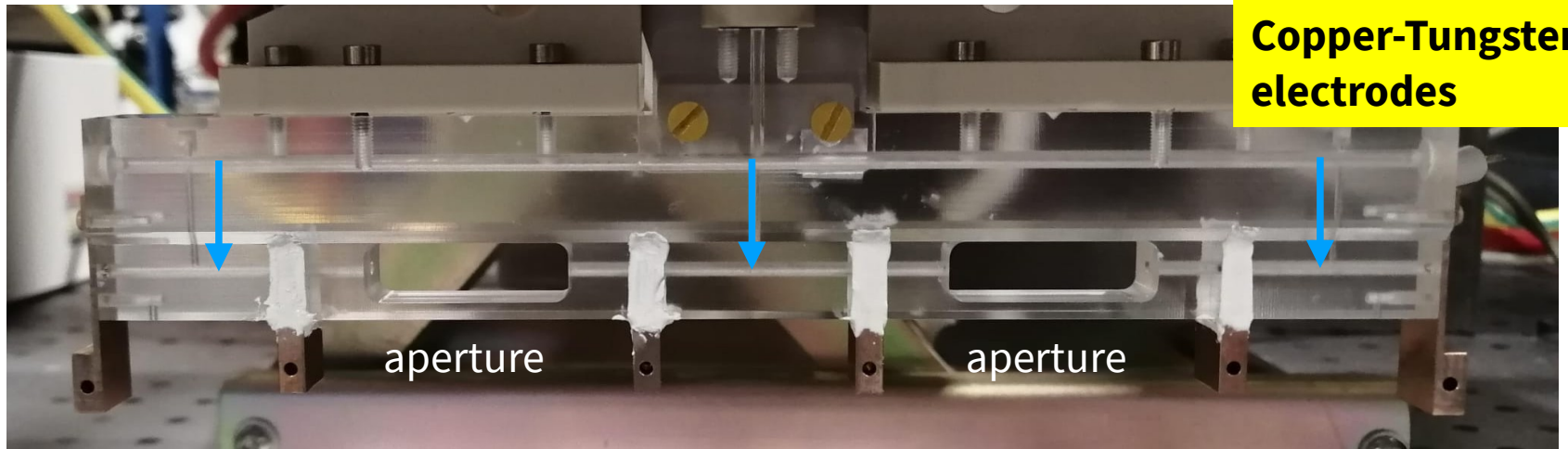
Pompili, R., et al. "Guiding of charged particle beams in curved capillary-discharge waveguides." AIP Advances 8.1 (2018): 015326.



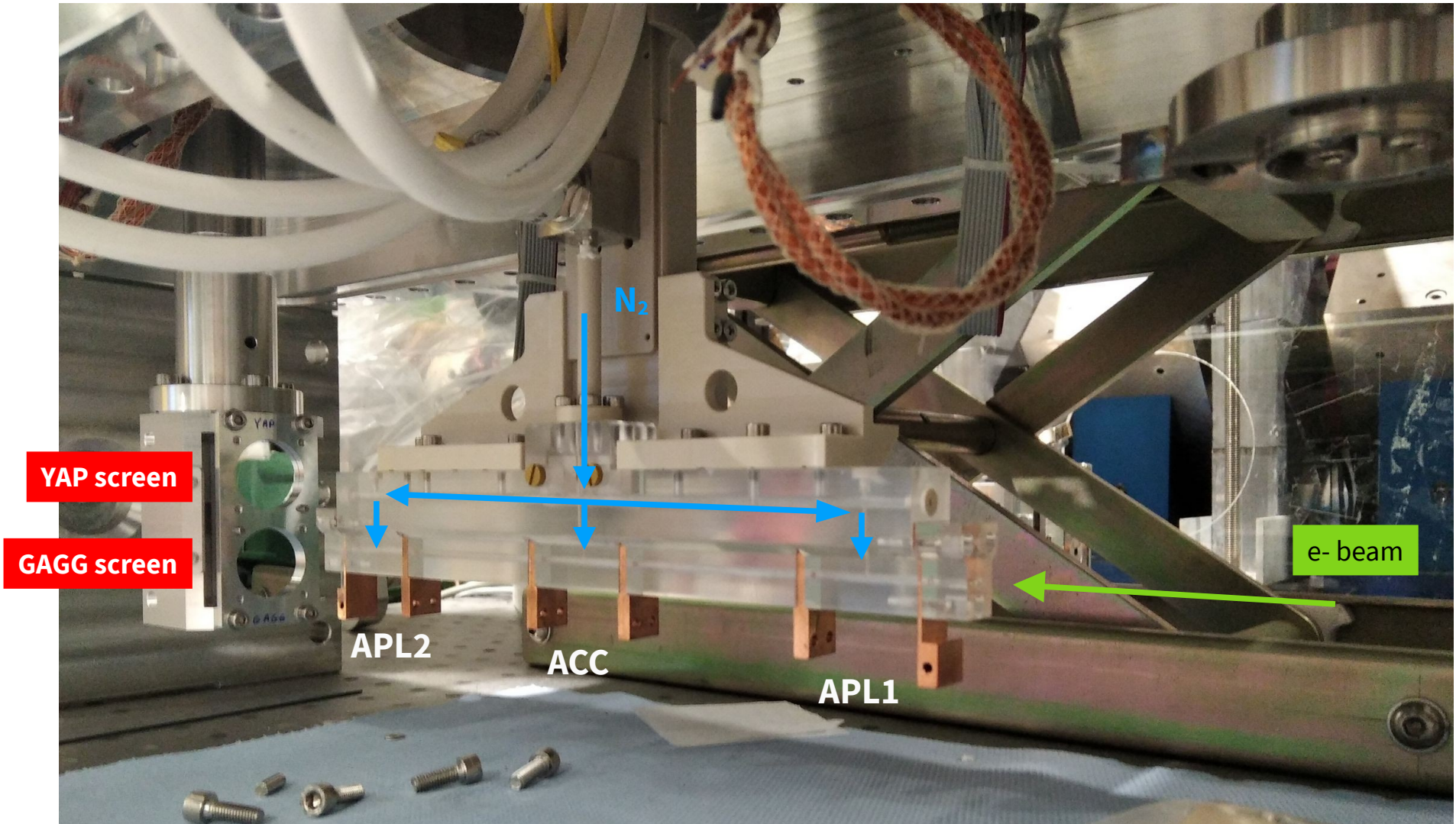
Offline tests
@ PLASMA_LAB

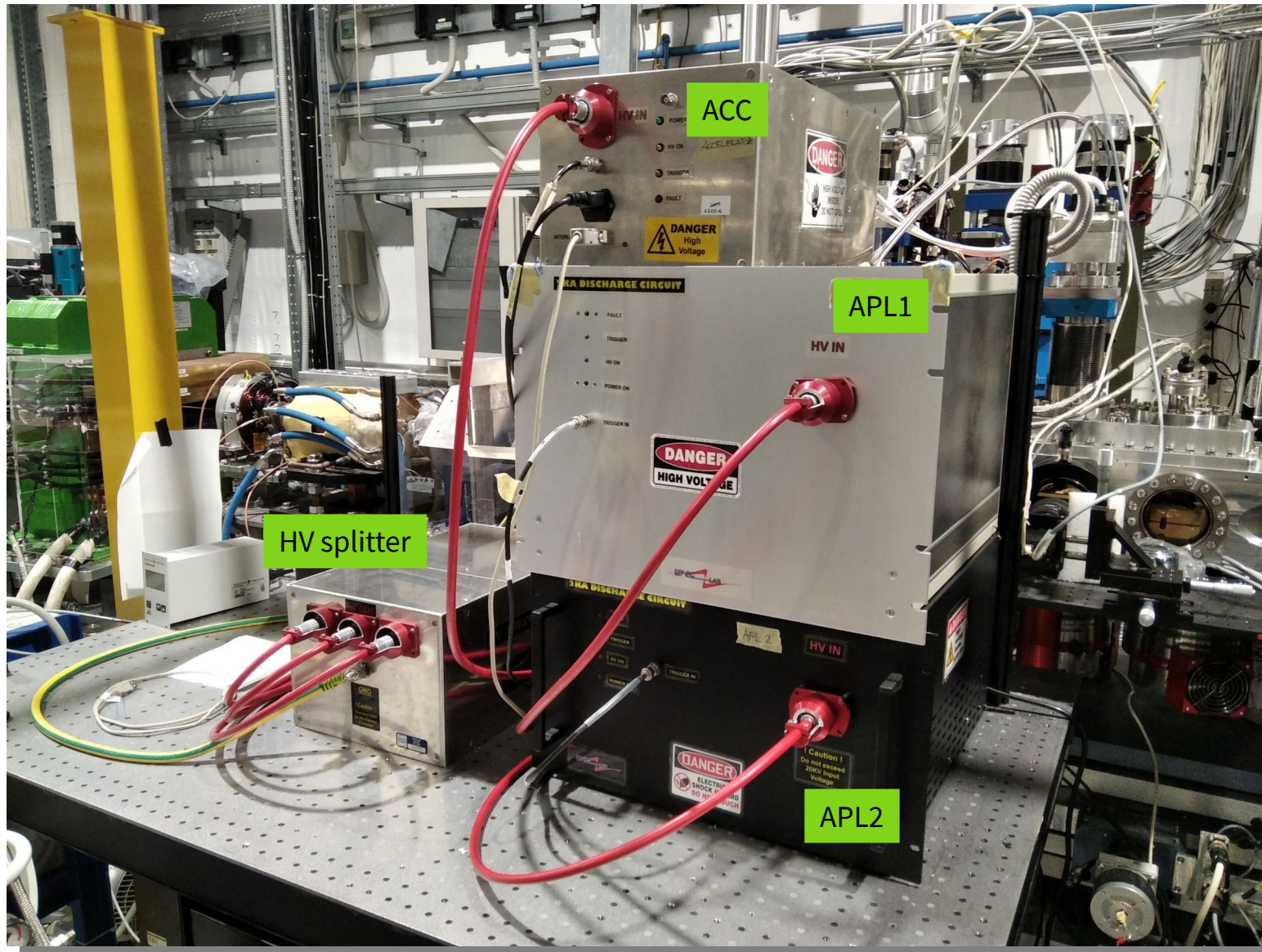


Spattered copper

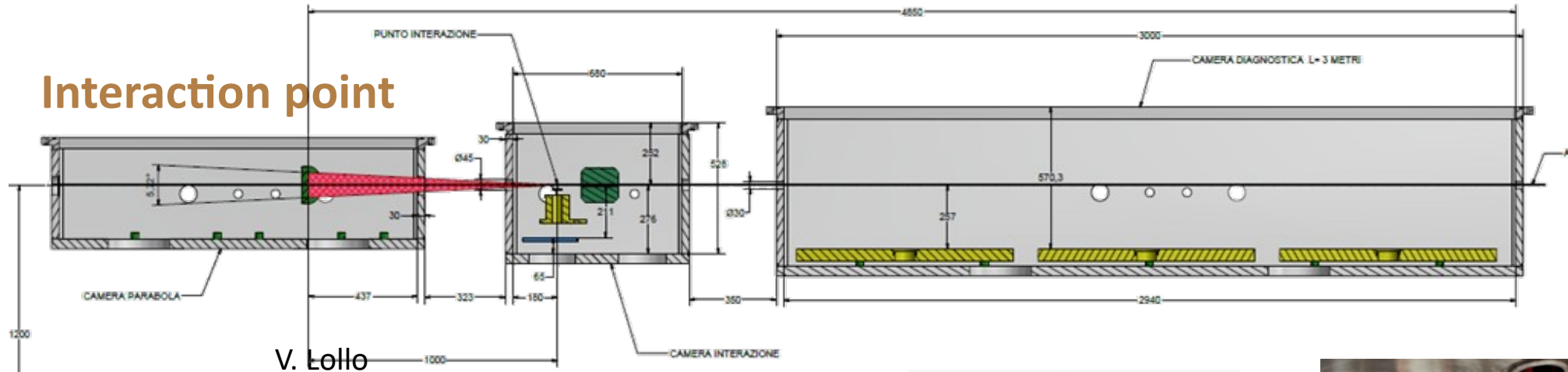


Stark-broadening
Measurement with
Hydrogen





Interaction point



- Main issue is the pumping of 20-30 bar with repetition rate at least 1 Hz
- The focusing parabola has to be at least at 10^{-4} mbar

