EuPRAXIA@SPARC_LAB TDR Review Committee
Frascati

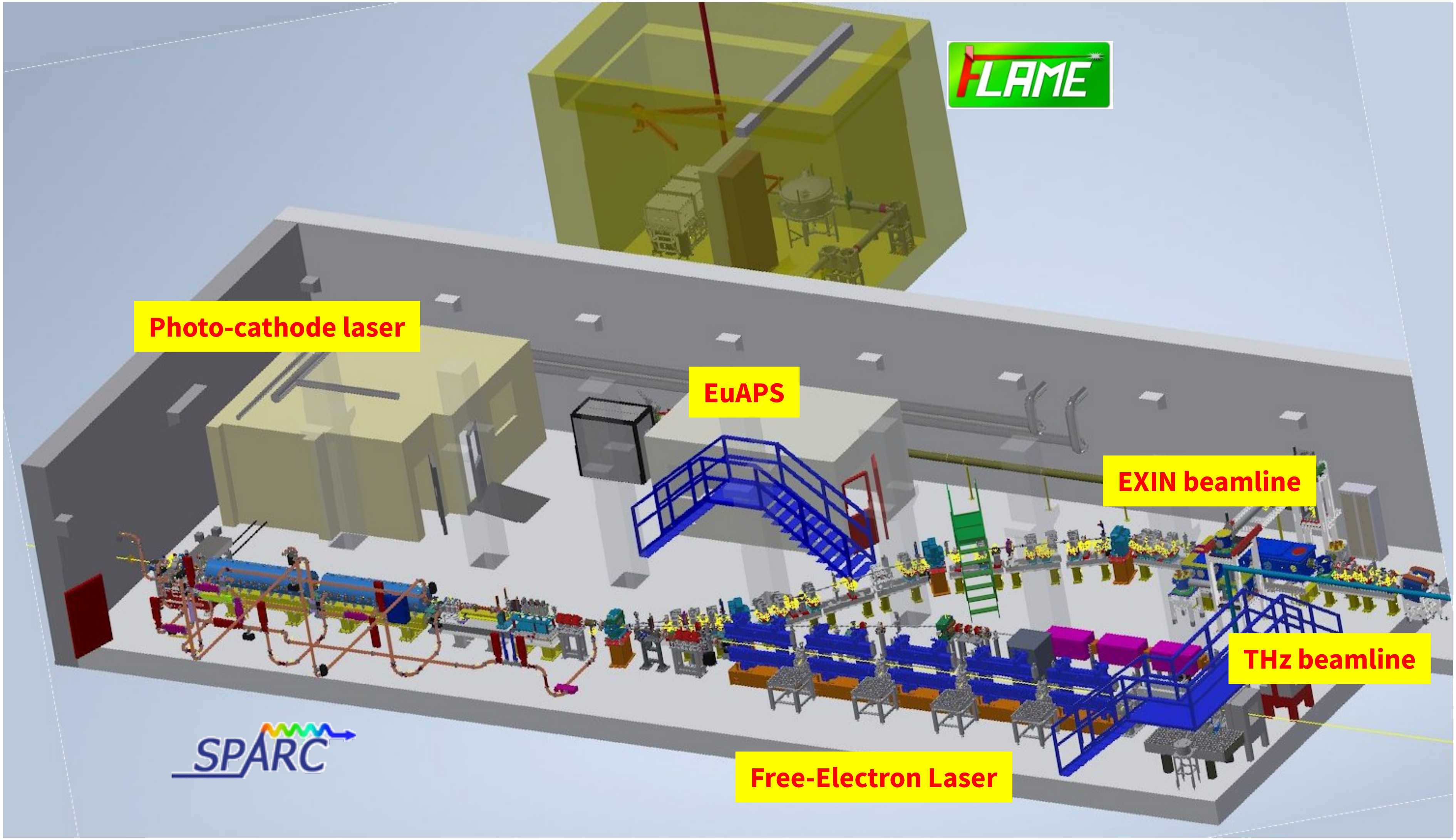
SPARC_LAB facility update

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

On behalf of the SPARC_LAB collaboration

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

SPARC_LAB facility



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

Main considerations

SPARC activities went ahead till beginning of December 2023. 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*

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

Planning of activities for 2024

SPARC_LAB planning
3 apr 2023 - 28 nov 2025

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

		Nome	Assegnata a	Durata	Inizio	Fine	Contenitore
28	✓	~~COMB 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	✓	~~COMB 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 telecamere 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 at SPARC

New solenoids installed

Improvement: coils can be individually aligned

Water cooling system arrangement ongoing

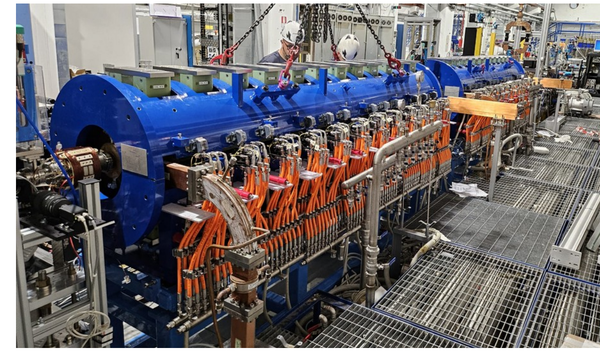
C band moved towards the gun

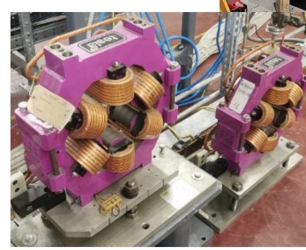
Quad triplet removed, more space for comb

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

L. Sabbatini, I. Balossino

Experimental results

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Plasma bending results on PRL cover

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]

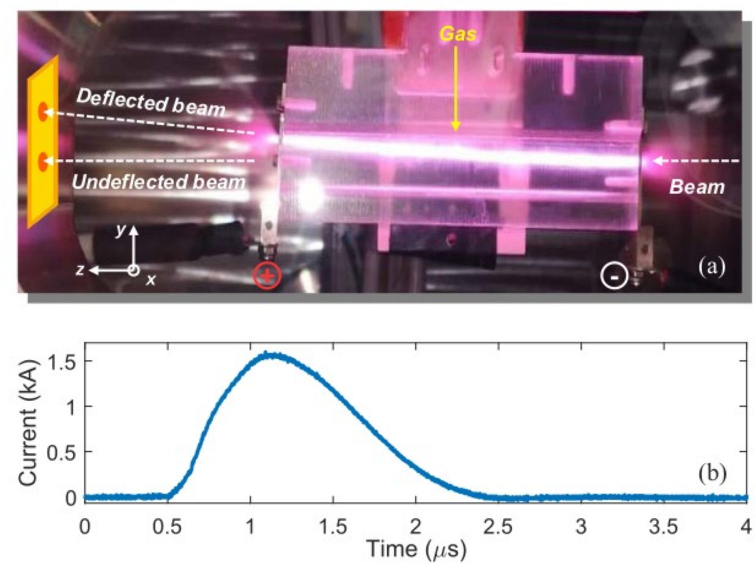
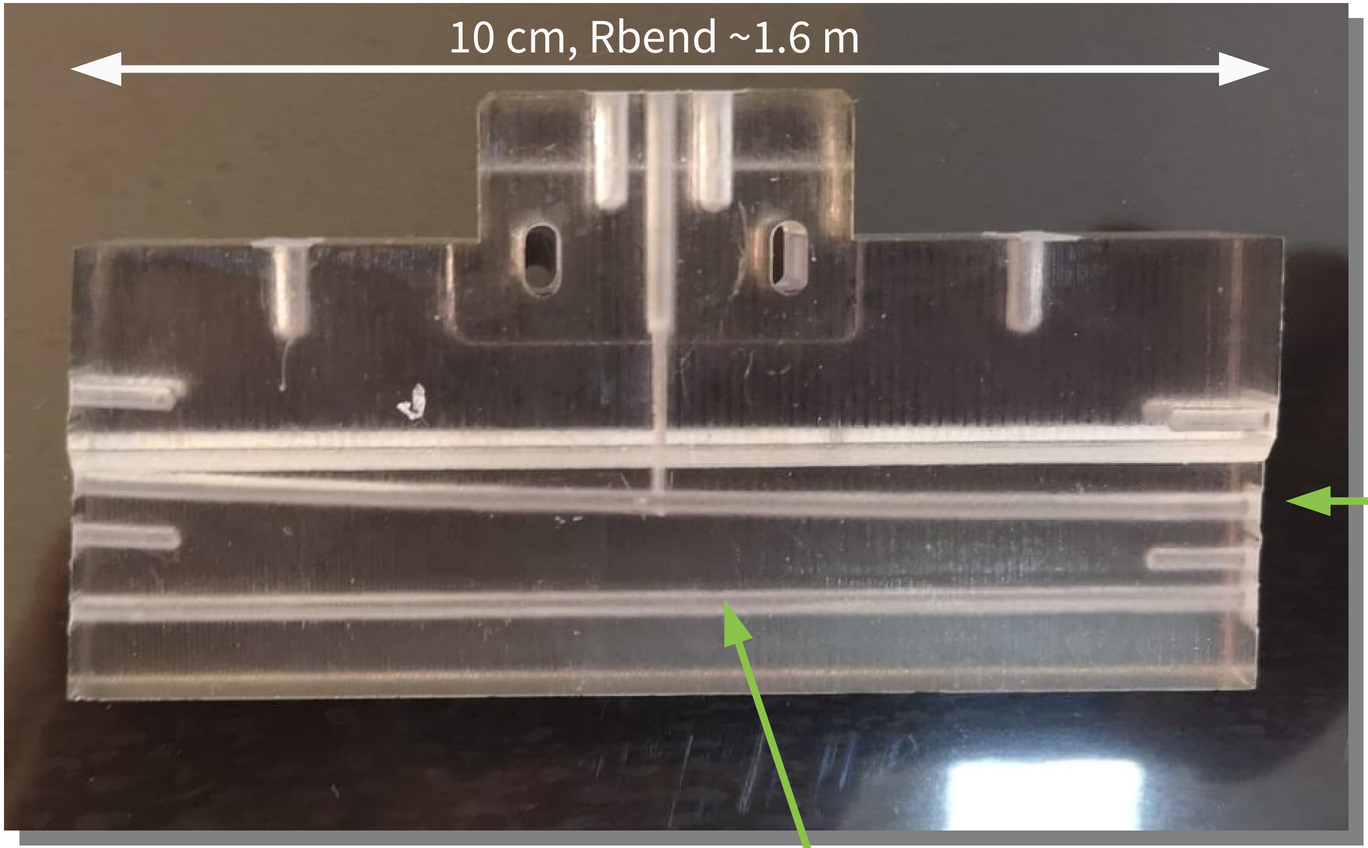


FIG. 1. (a) Experimental setup. The high-voltage discharge current is applied to the two electrodes of the curved capillary to produce the plasma. The beam is measured on a scintillating screen located 10 cm downstream of it. The orientation of the x-y-z axes is also indicated. (b) Discharge current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

SPARC prototype (3D printed)



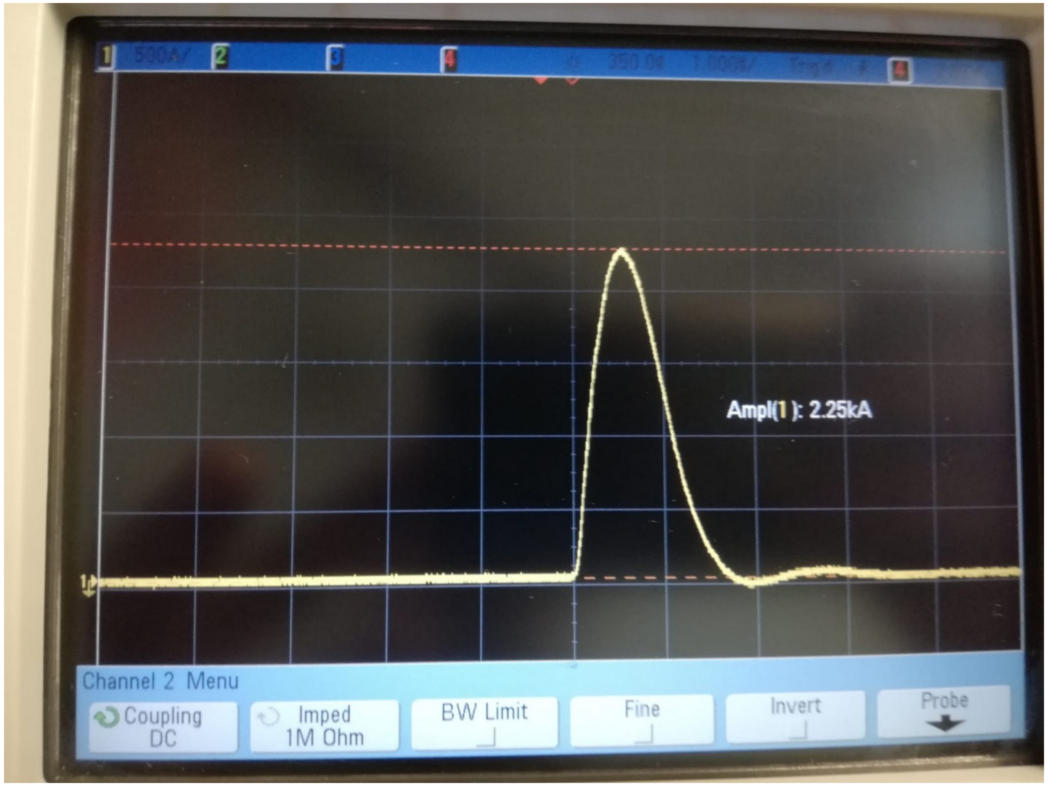
Vertical bending
3 mm offset
2mm hole

beam

Hole for laser alignment

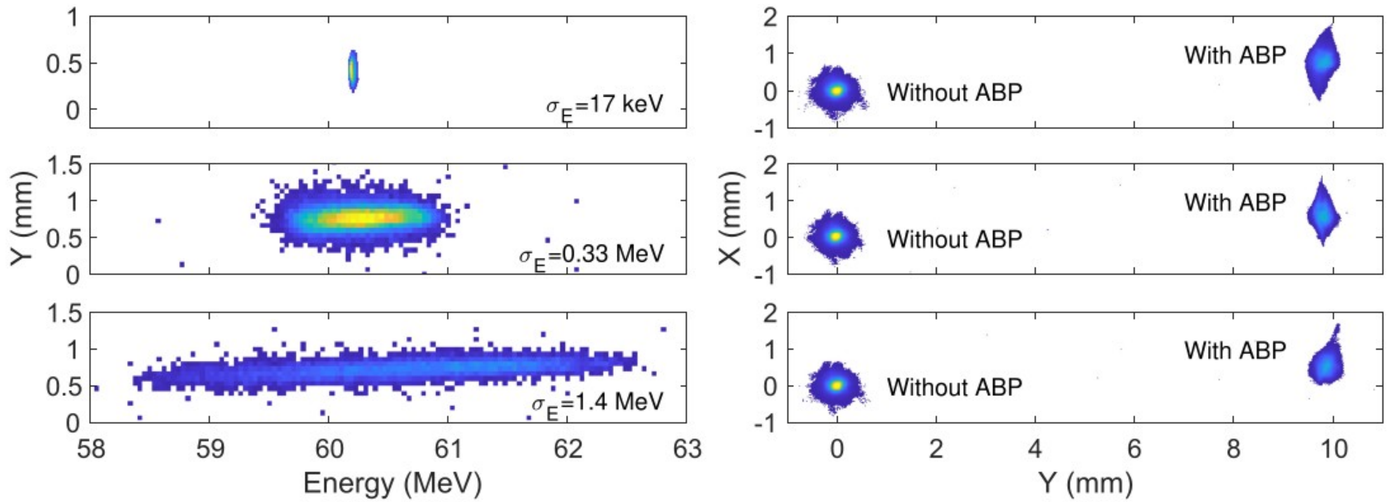
Discharge pulser

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



First results @ 2.25 kA

Bending for several energy spreads

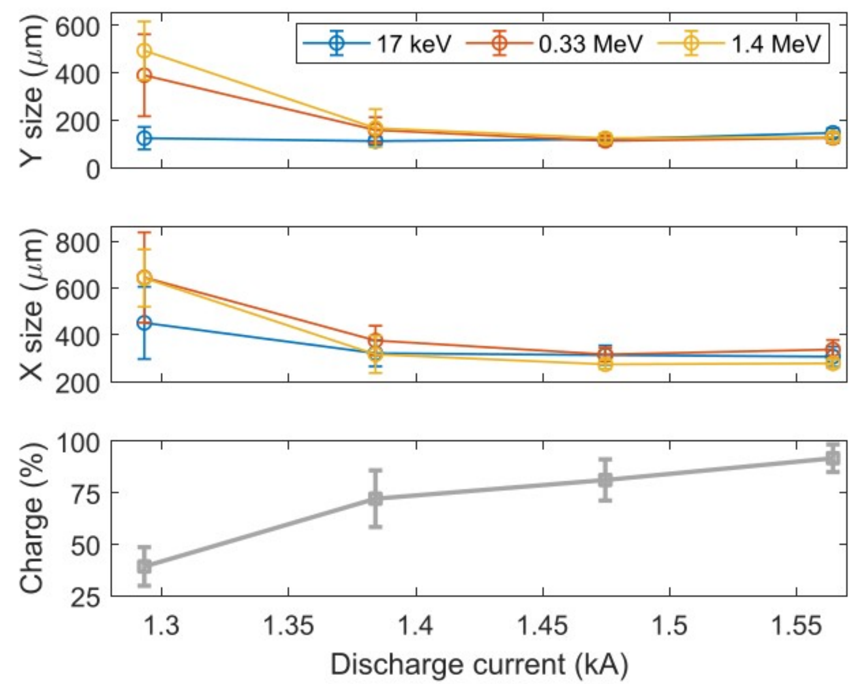


We tested the ABP deflection with three beam configurations having different energy spreads

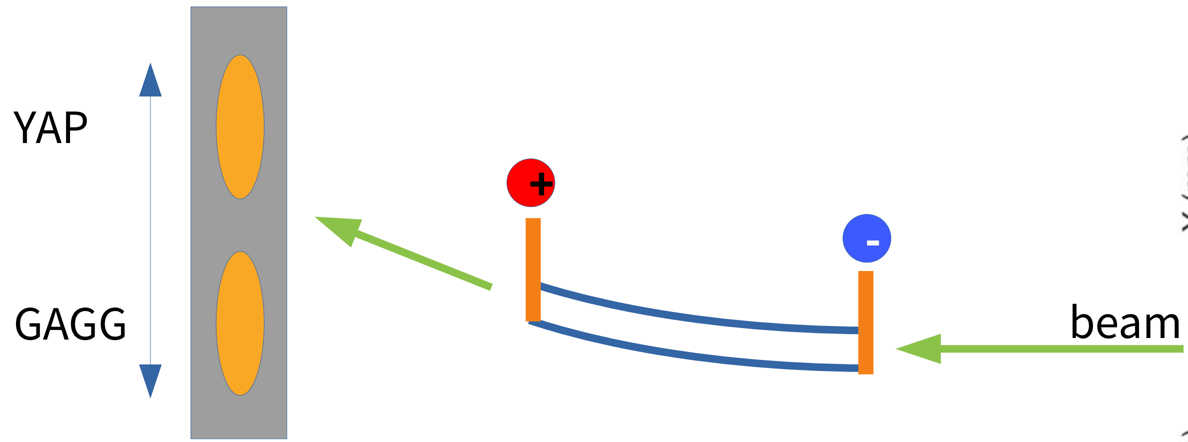
Goal: test the chromatic dispersion of the device

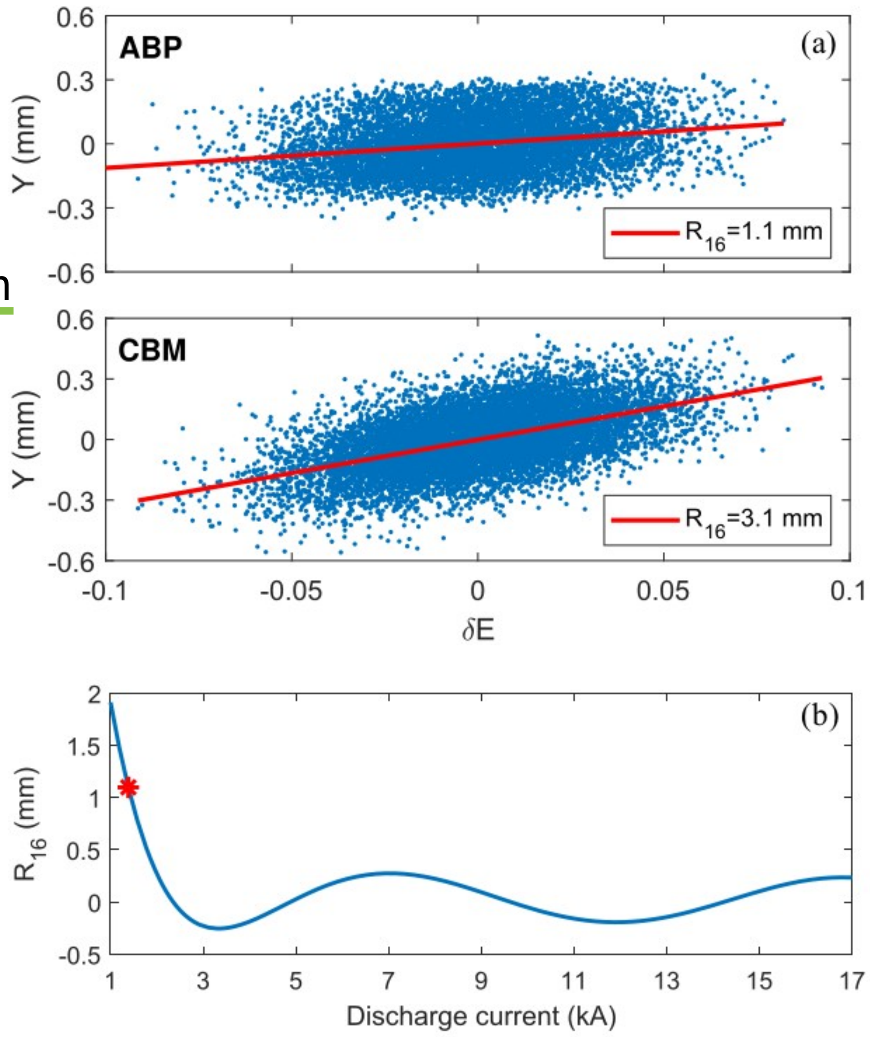
Findings: the output spot sizes is almost unaffected by the energy spread (especially on the bending plane)

It indicates that the device operated almost in a dispersionless way



Dispersionless operation





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

The energy of the beam is set to 60 MeV

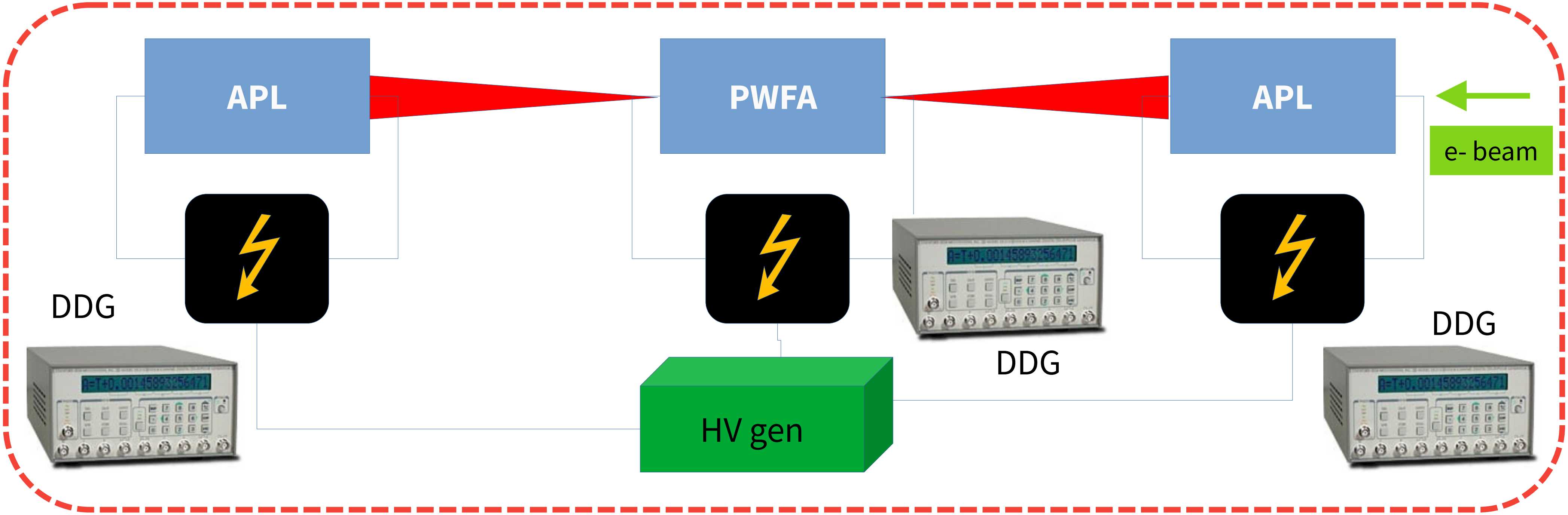
1.6 m bending radius, ~4° deflection angle in 10 cm capillary

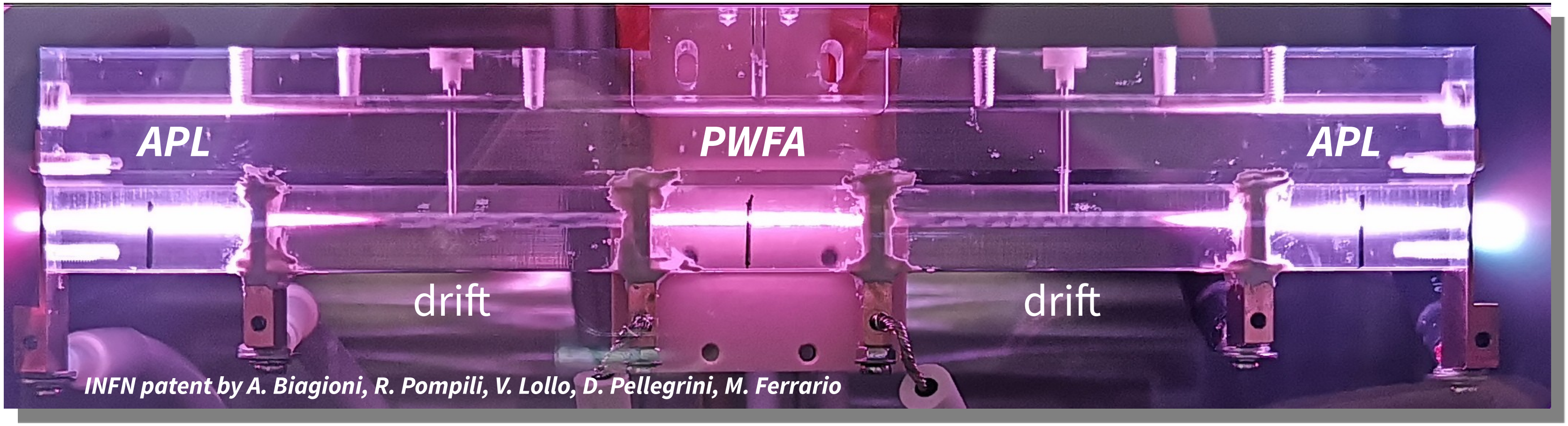
The beam is imaged on the YAG/GAGG screen located ~10 cm downstream the capillary exit

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

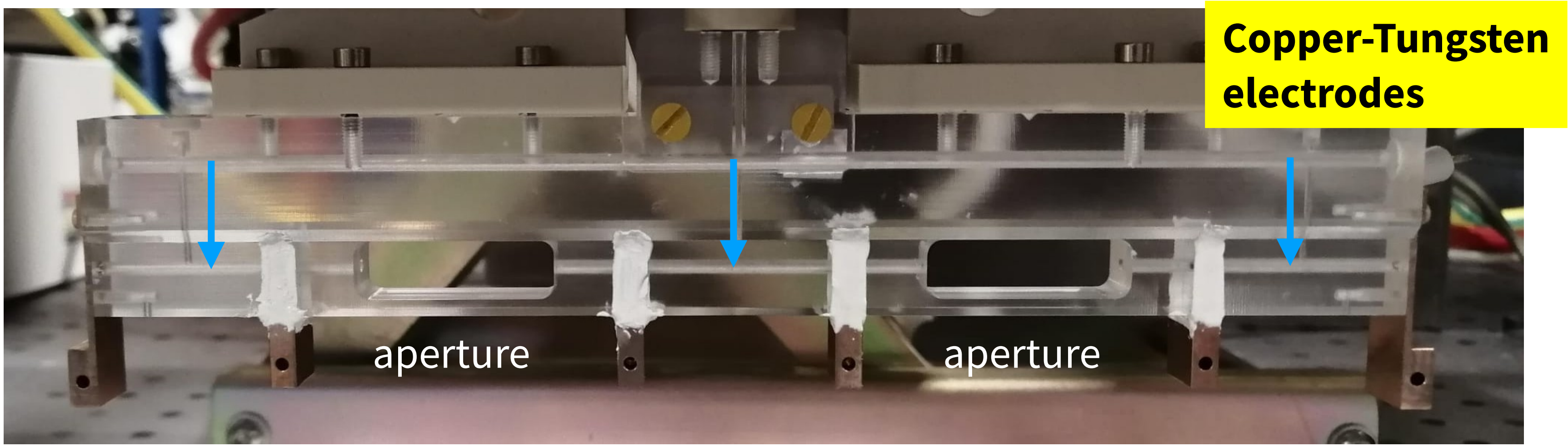
By tuning the discharge current the R16 can really be made zero → no need of dispersion matching optics downstream the bending!

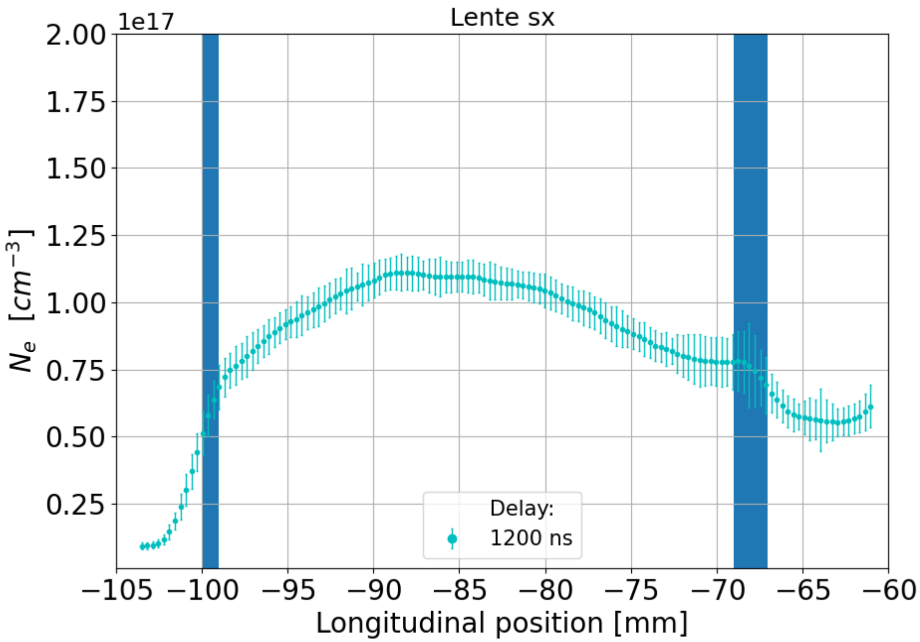
Basic idea of the "all-in-one" capillary

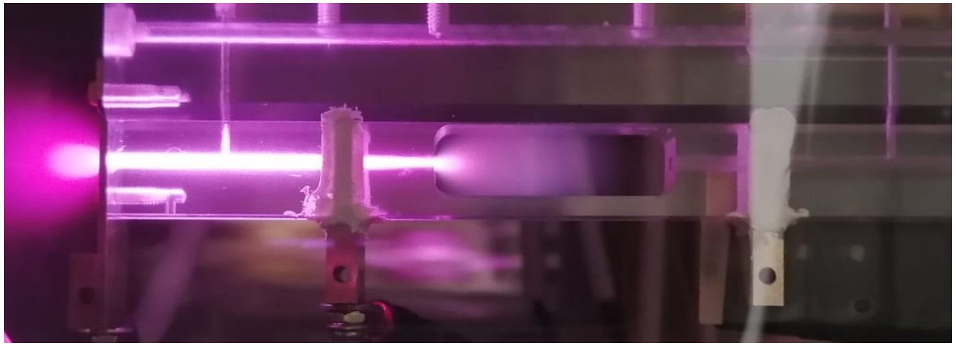


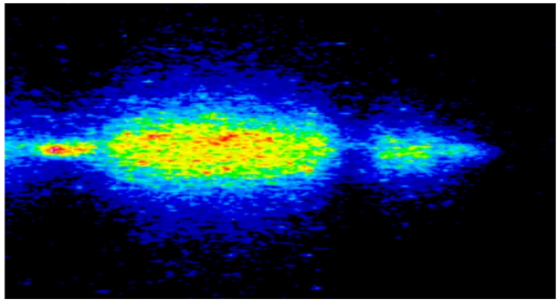


New prototype (3 inlets)



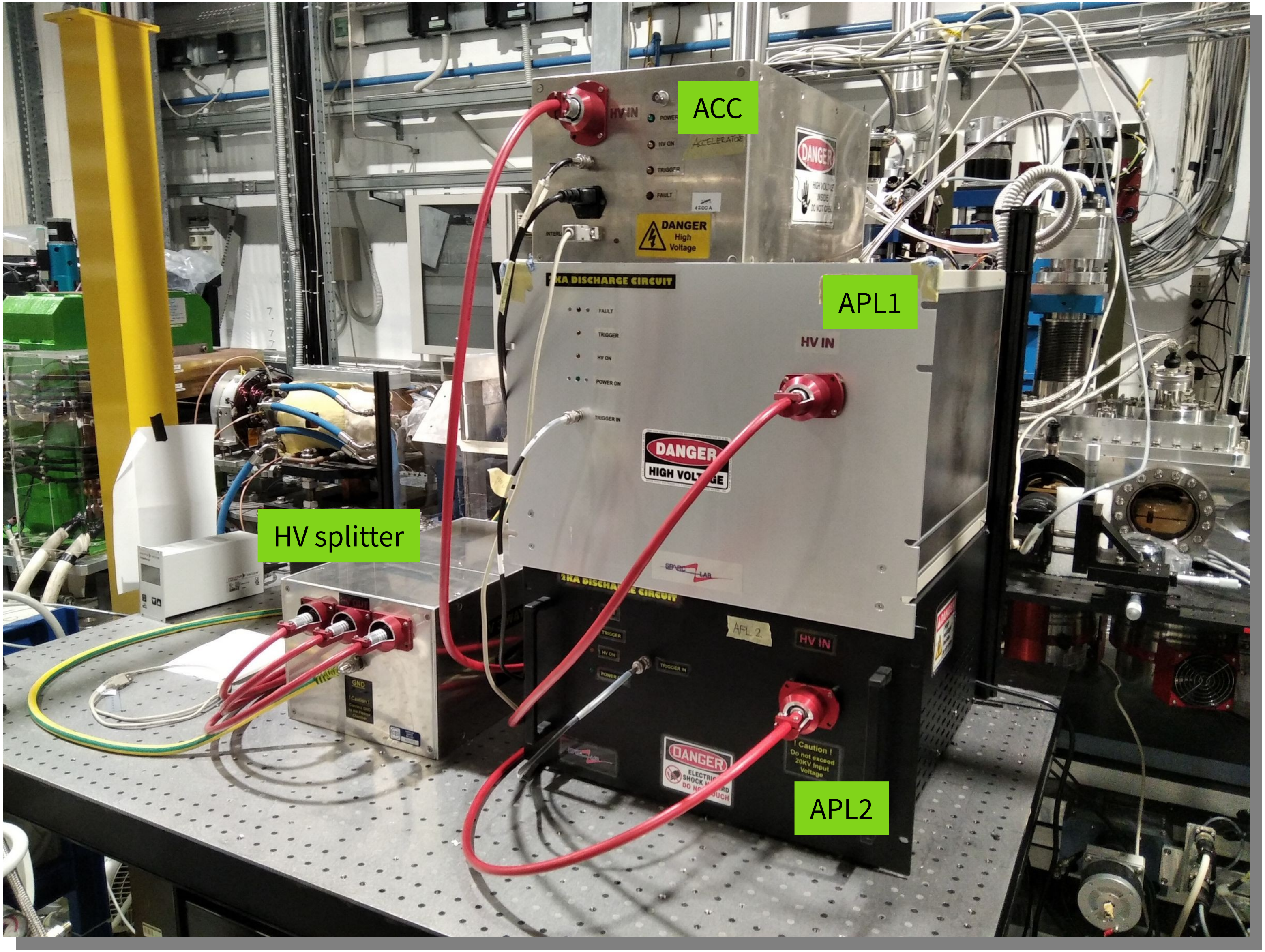






Stark-broadening Measurement with Hydrogen

HV setup


ACC
APL1
HV splitter
APL2
HV IN
DANGER
High Voltage
HIGH VOLTAGE
HV IN
HV IN

First accelerated witness

PHYSICAL REVIEW E

covering statistical, nonlinear, biological, and soft matter physics

Highlights Recent Accepted Collections Authors Referees Search Press About Editorial Team

Accepted Paper

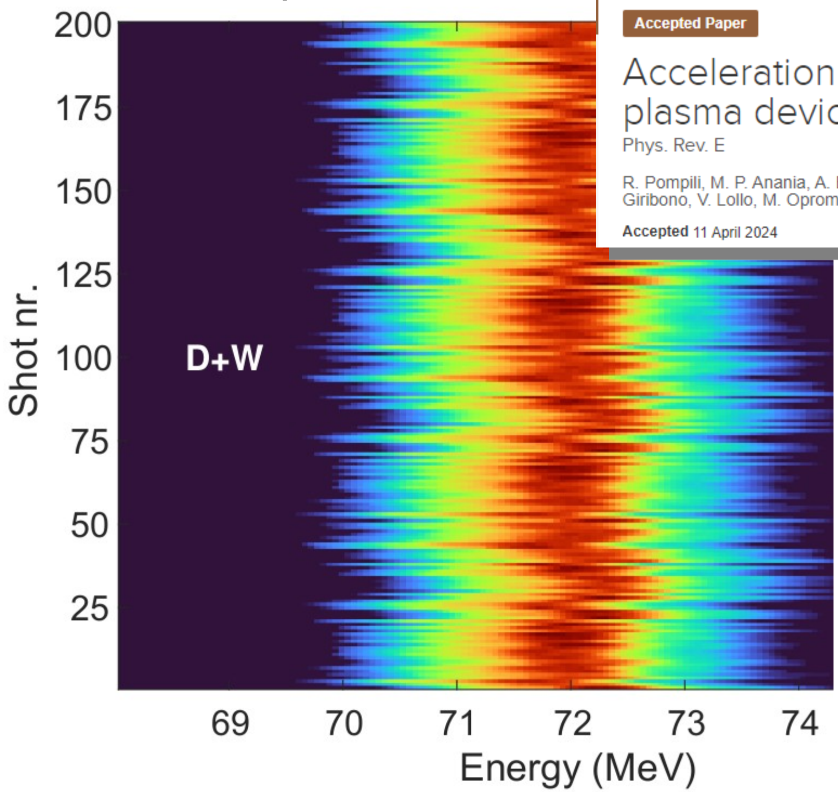
Acceleration and focusing of relativistic electron beams in a compact plasma device

Phys. Rev. E

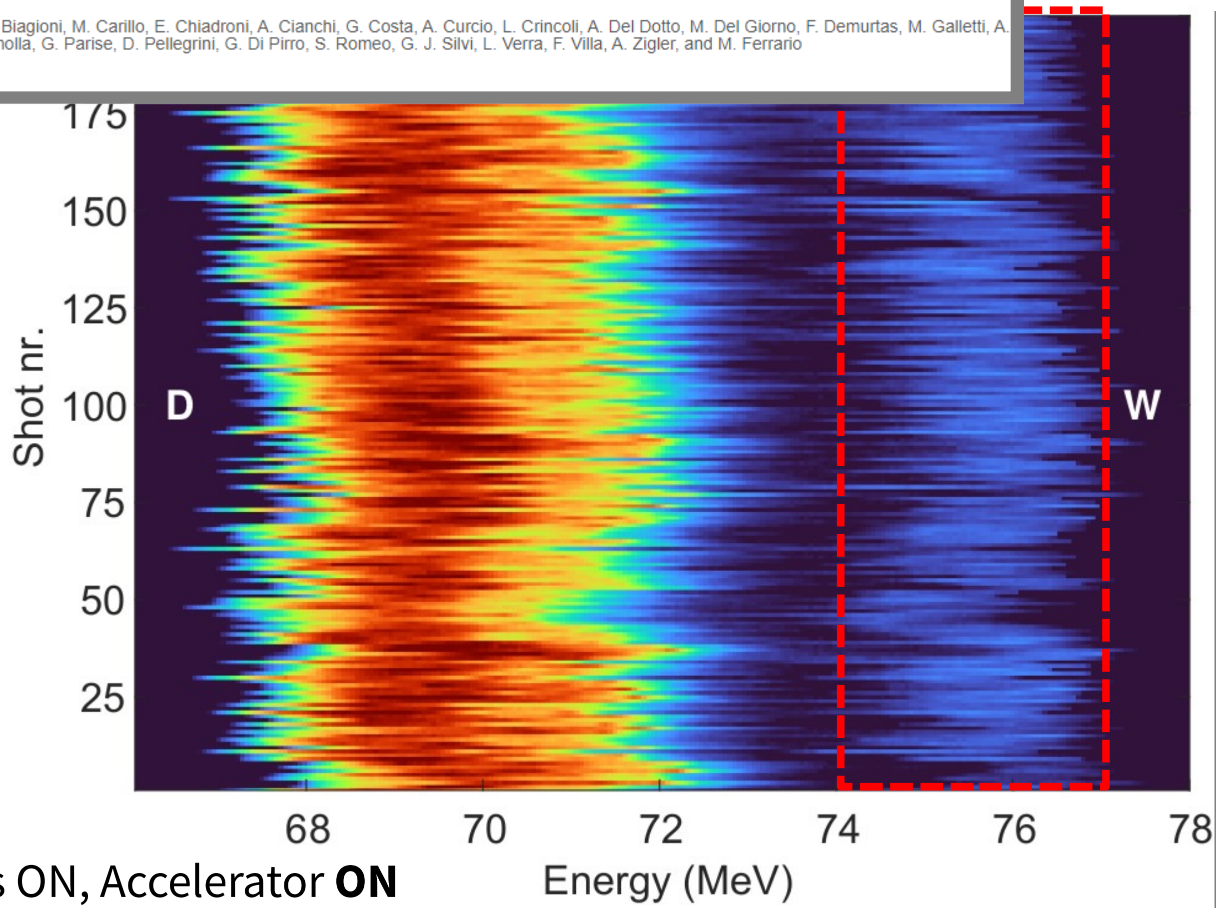
R. Pompili, M. P. Anania, A. Biagioni, M. Carillo, E. Chiadroni, A. Cianchi, G. Costa, A. Curcio, L. Crincoli, A. Del Dotto, M. Del Giorno, F. Demurtas, M. Galletti, A. Giribono, V. Lollo, M. Opromolla, G. Parise, D. Pellegrini, G. Di Pirro, S. Romeo, G. J. Silvi, L. Verra, F. Villa, A. Zigler, and M.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

Accepted 11 April 2024

200+50 pC



Lenses ON, Accelerator **OFF**



Lenses ON, Accelerator **ON**

Emittance

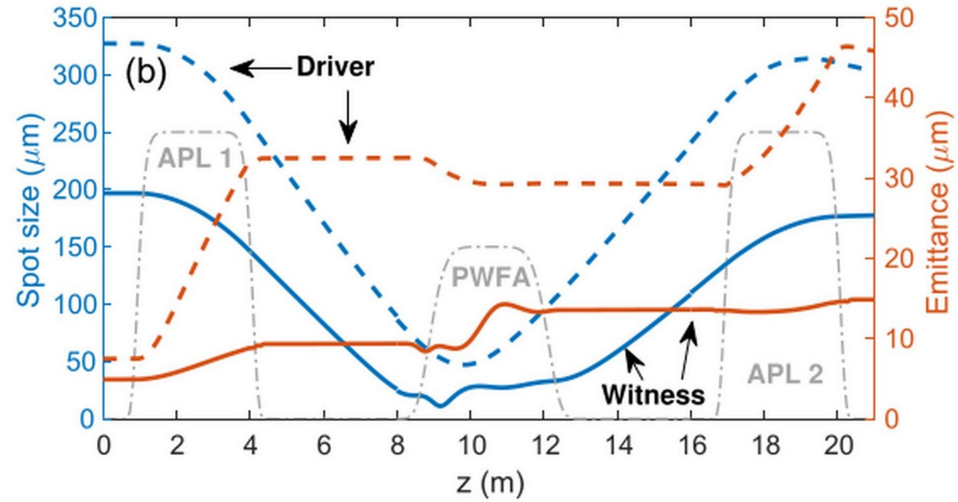
Emittance increase of the witness bunch was experimentally measured

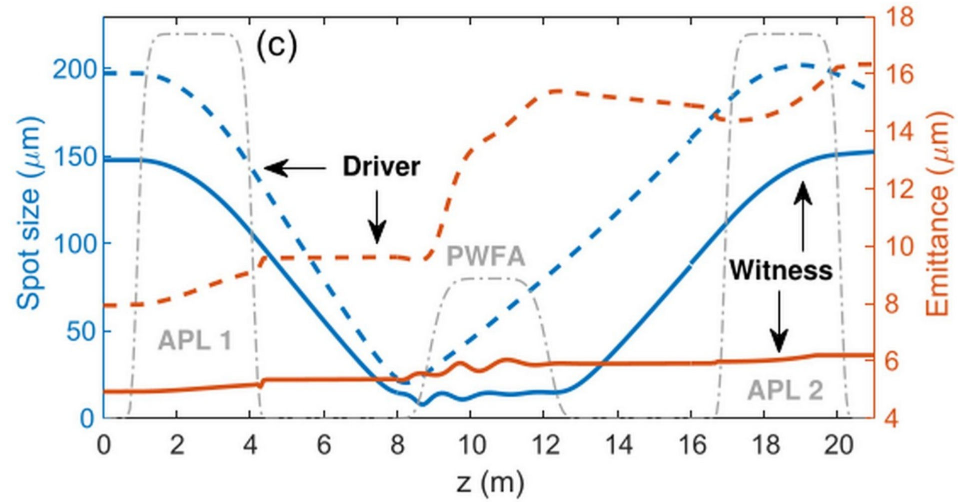
Due to non optimal matching at the entrance of the APL/PWFA stages. 5 um (rms) → 12 um (rms)

Much larger increase was observed for the driver, again due to too large spot size at the entrance of the 1st APL

Simulations show that, by entering into the 1st APL with smaller driver/witness spot sizes, the increase can be reduced to ~20%, i.e. 5 um (rms) → 6 um (rms)

Need to optimize the transverse envelopes of the beams along the LINAC



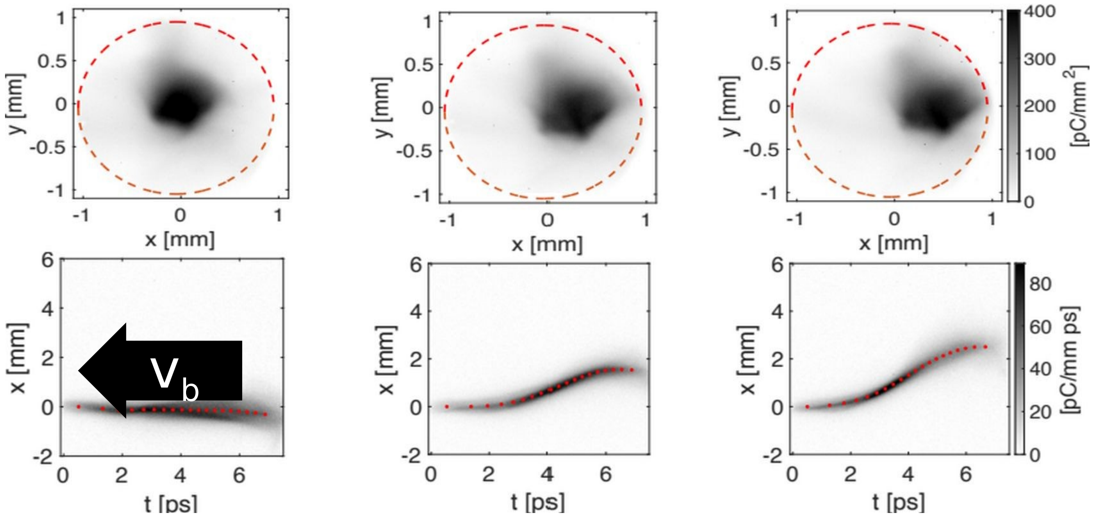


Plasma screening of dielectric wakefields

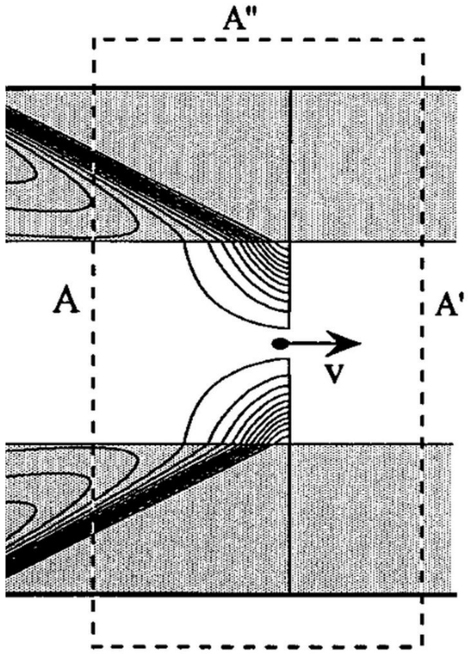
Charged beams drive Cherenkov wakefields when space-charge field interacts with slow-wave structures

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 chage running integral

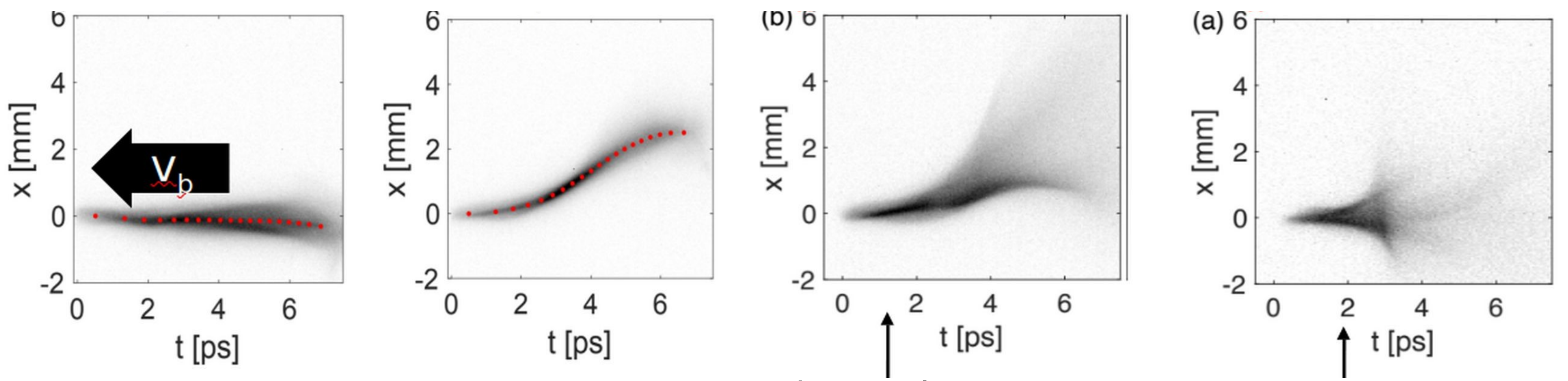
L. Verra

Dielectric vs plasma

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

Plasma screens electromagnetic fields at r >> plasma skin depth

Aligned No plasma | Misaligned No plasma | Misaligned $n_{pe} = 0.038 \cdot 10^{14}$ cm^{-3} | Misaligned $n_{pe} = 1.0 \cdot 10^{14}$ cm^{-3}



Density too low
✉ Effect of dielectric wakefields

Density high enough
✉ Dielectric wakefields suppressed


PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About Editorial Team

Accepted Paper

Experimental observation of space-charge field screening of a relativistic particle bunch in plasma

Phys. Rev. Lett.

L. Verra, M. Galletti, R. Pompili, A. Biagioni, M. Carillo, A. Cianchi, L. Crincoli, A. Curcio, F. Demurtas, G. Di Pirro, V. Lollo, G. Parise, D. Pellegrini, S. Romeo, G. J. Silvi, F. Villa, and M. Ferrario

Accepted 14 June 2024

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

L. Verra

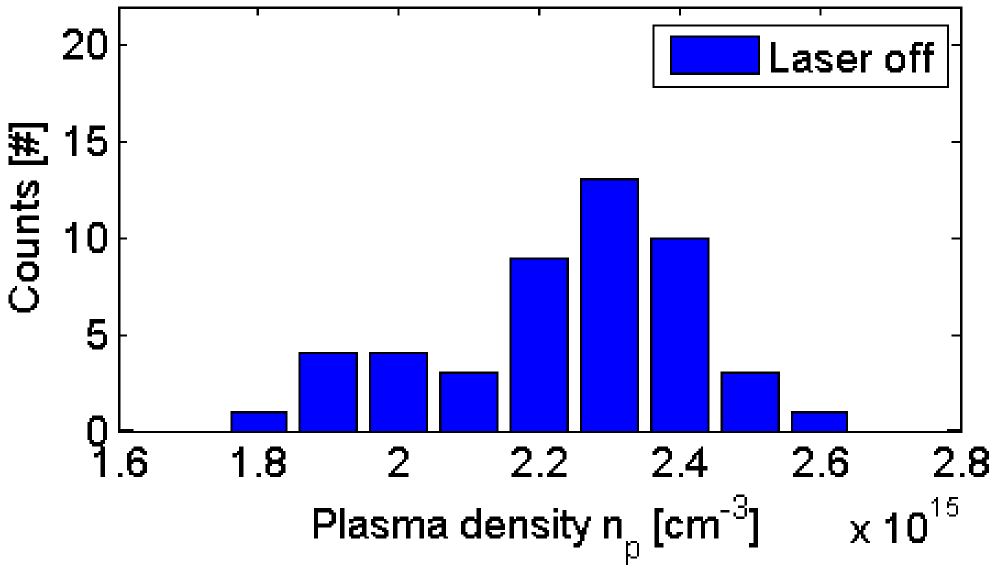
Jitters

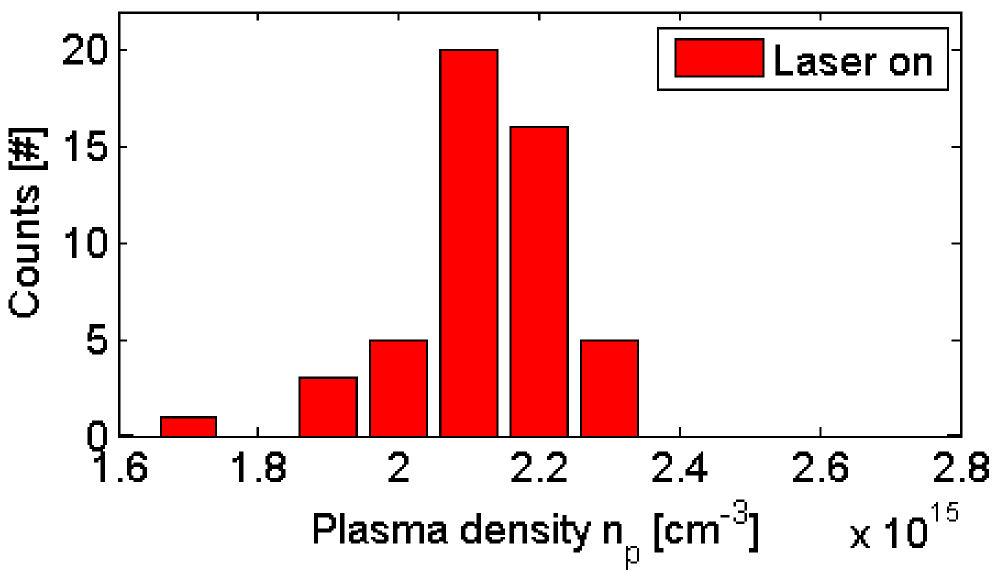
R. Pompili (LNF-INFN)
riccardo.pompili@lnf.infn.it

On behalf of the SPARC_LAB collaboration

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Plasma density stabilization





Results obtained with single long beam, 50 pC charge

Plasma density was measured via LPS (50 images) in the new capillary at the delay -2600 ns with trigger laser on and off (11 kV HV)

Laser OFF results

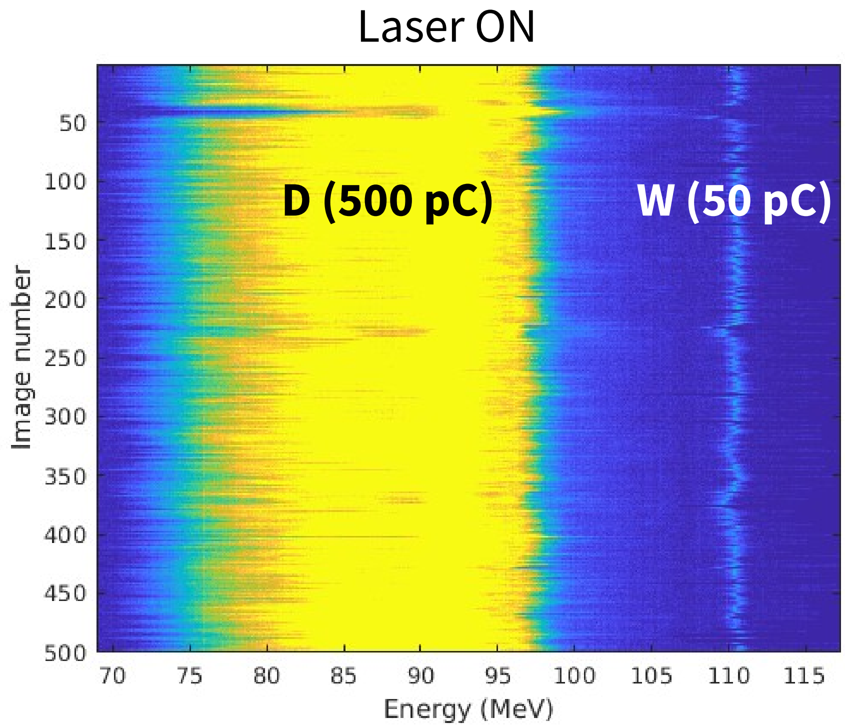
$n_p = 2.2 \cdot 10^{15} \pm 18\%$

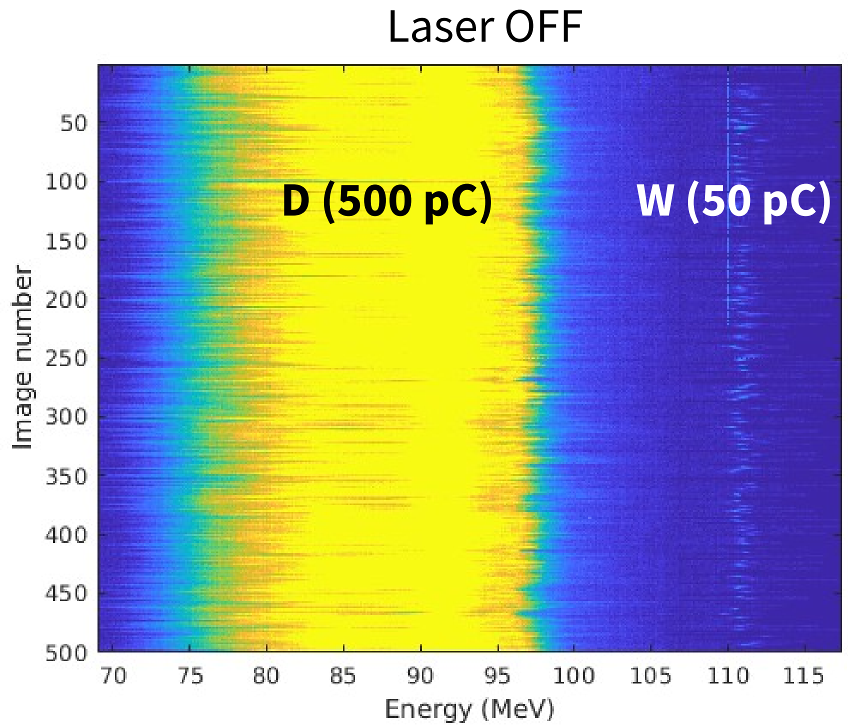
Laser ON results

$n_p = 2.1 \cdot 10^{15} \pm 6\%$

Thanks to S. Romeo

Plasma acceleration stabilization





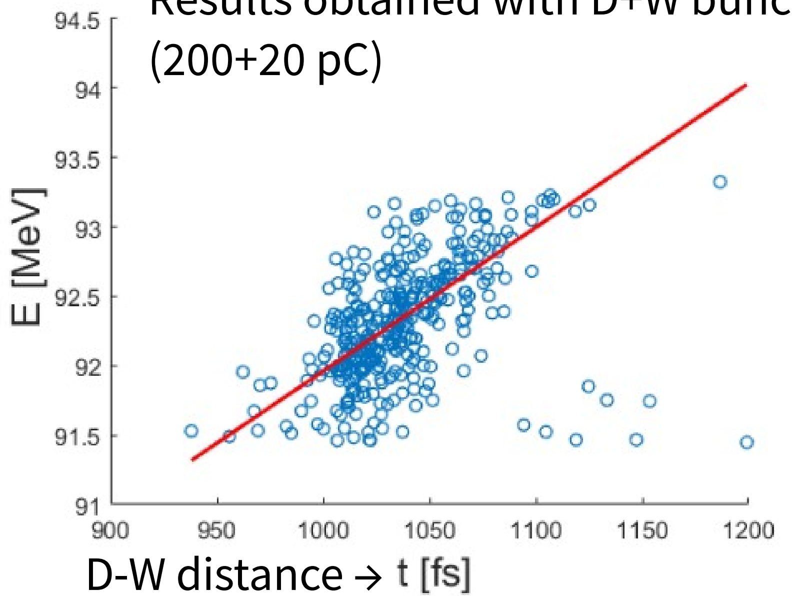
Results obtained by turning ON/OFF the laser stabilizing the plasma discharge

The laser hits the negative electrode of the capillary 200 ns before the discharge trigger

Witness jitter with laser ON(OFF): 0.6(1.2) MeV

RF jitter contribution

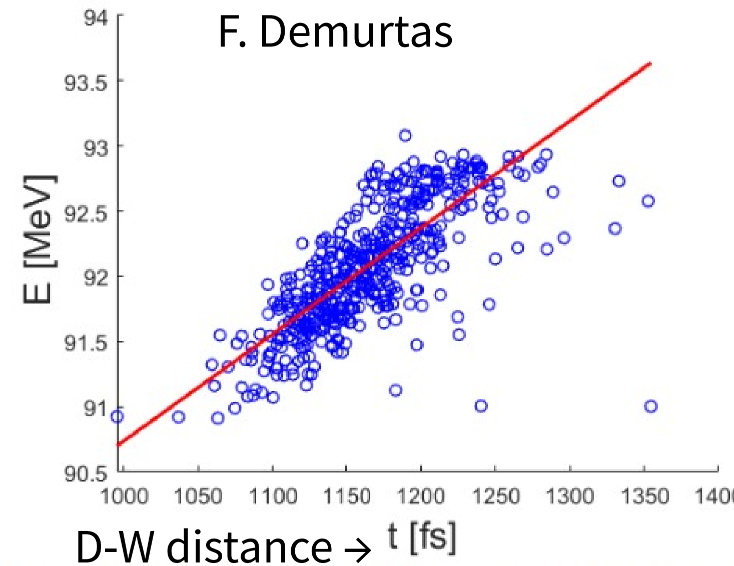
Results obtained with D+W bunches (200+20 pC)



D-W distance →

Figure 5: Measurement with the corresponding linear fit of the correlation between the distance driver-witness and the witness energy after the plasma; the fit has angular coefficient $m = (10 \pm 1)\ keV/fs$.

F. Demurtas

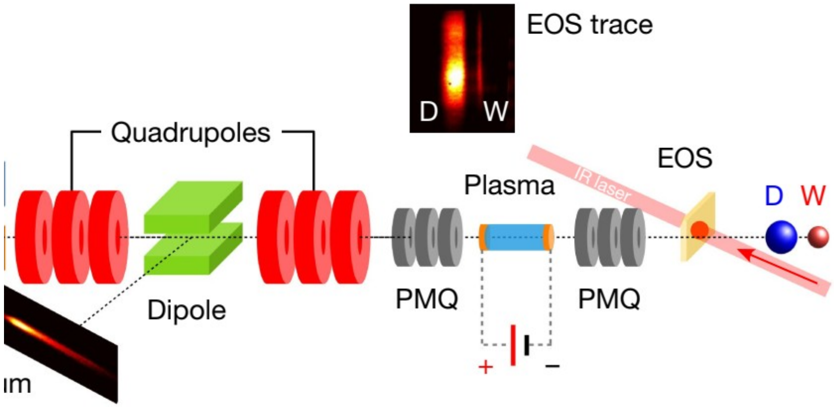


D-W distance →

Figure 6: Measurement with the corresponding linear fit of the correlation between the distance driver-witness and the witness energy after the plasma; the fit has angular coefficient $m = (8.2 \pm 0.6)\ keV/fs$.

Evaluation of the witness energy jitter as a function of the driver-witness distance jitter (using the EOS upstream of the plasma)

Different slopes due to the different plasma densities that are employed



FLAME

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

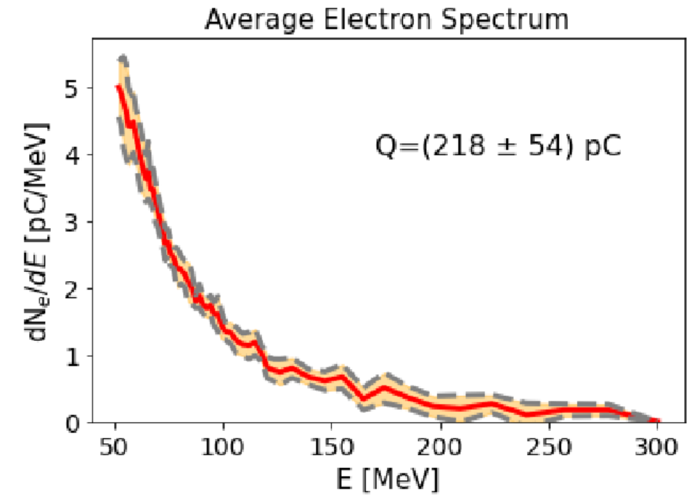
First results using X-rays

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*

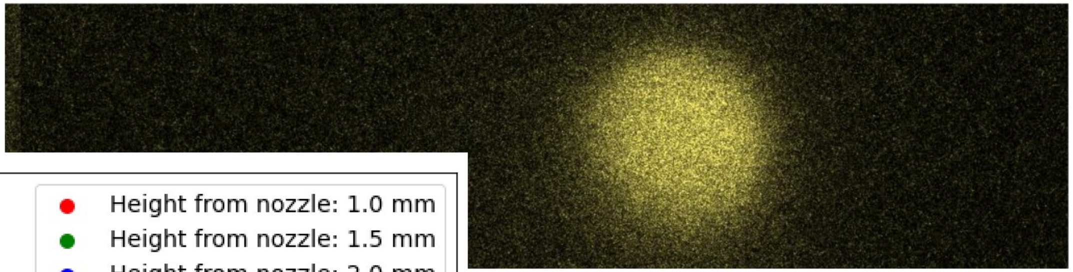


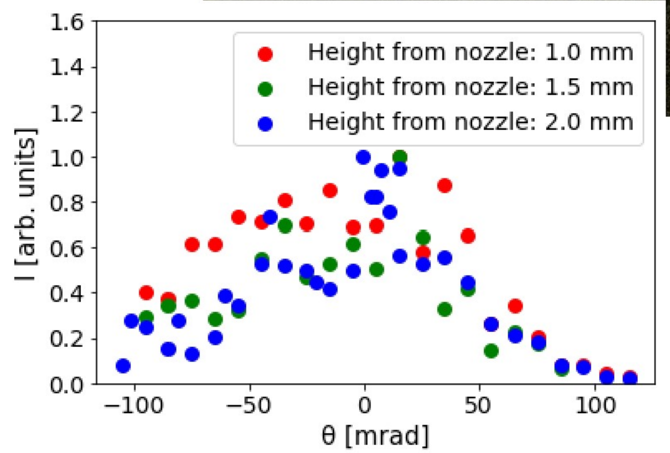
Goal of activities in view of EuAPS

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

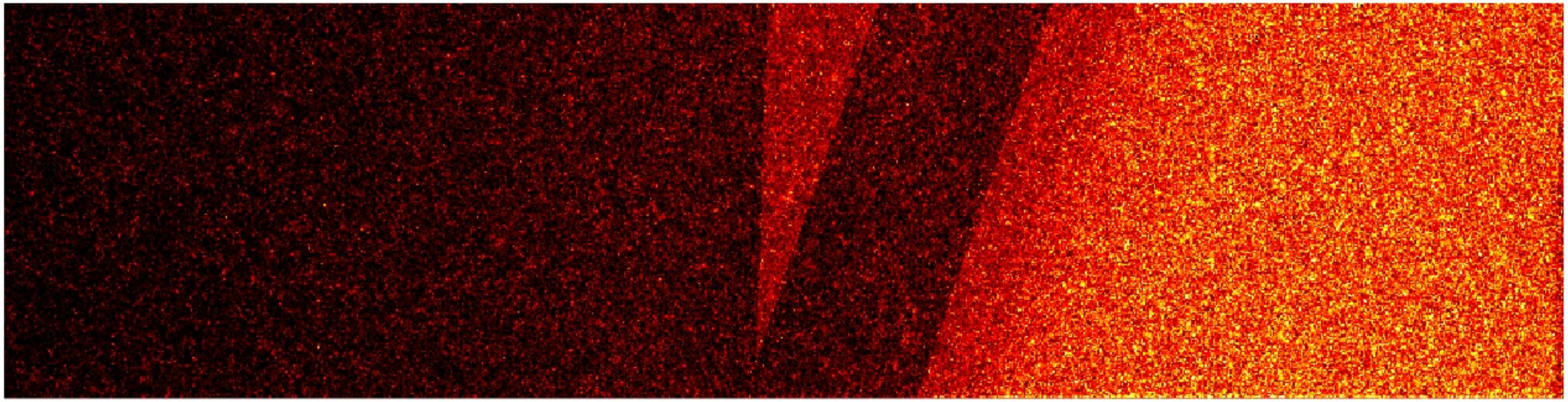
This year FLAME is also undergoing to be refurnished with new equipment (compressor, experimental chambers, etc.) to be ready for the main EuAPS installations that will happen next year

X-radiation profile measurement



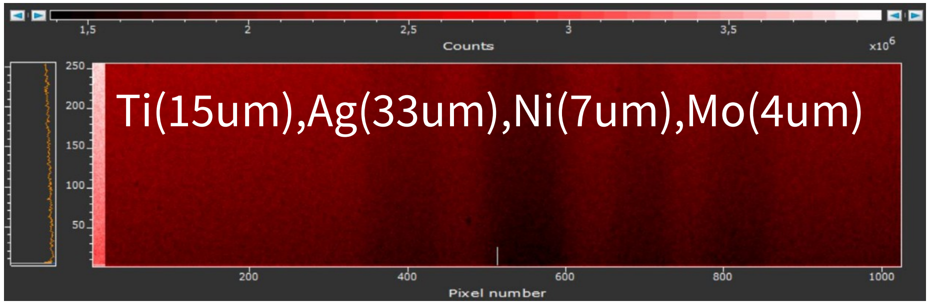


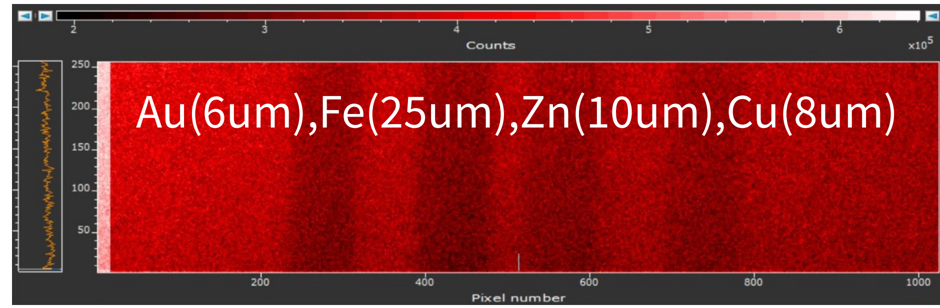
FWHM 60 mrad (to be confirmed or corrected by measurements with a smaller pin-hole)

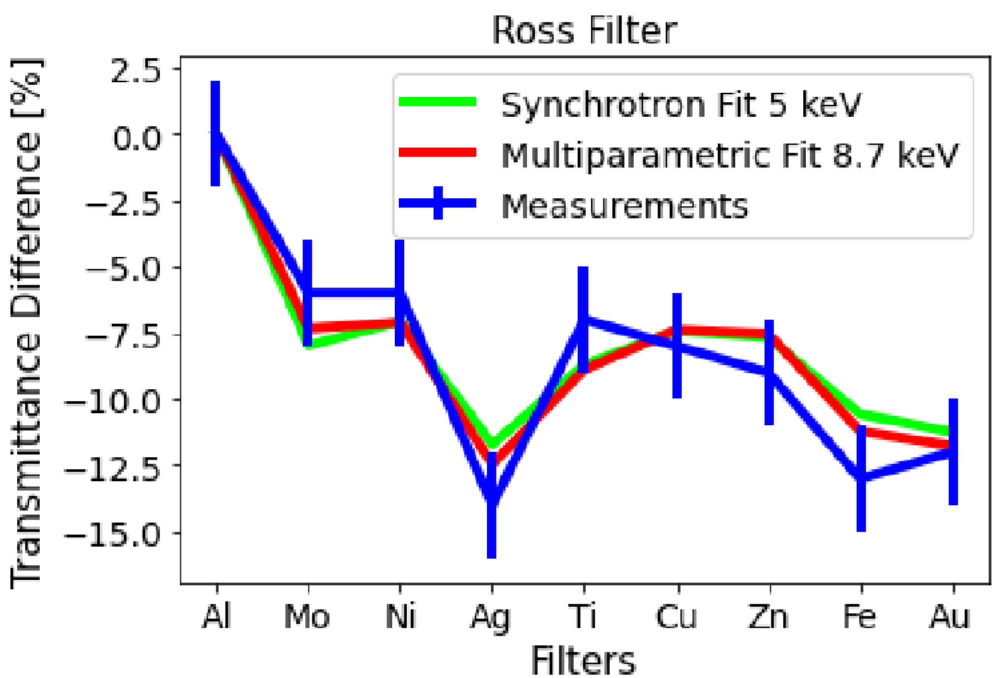


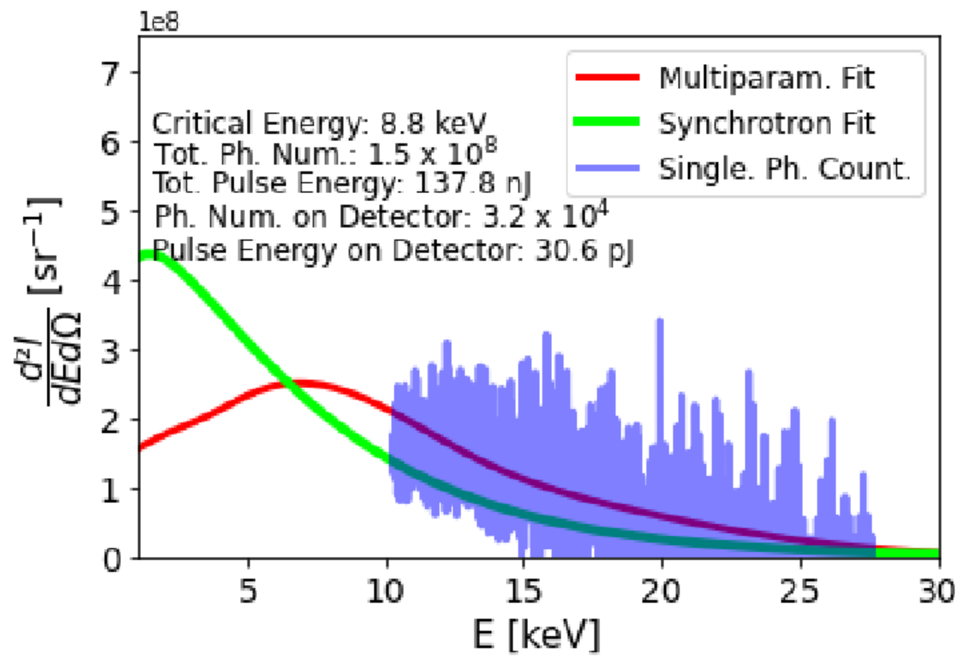
Single-shot image of a Steel slab covering half sensor (left) and tilted Allen-key on the side (right)

Ross-filter analysis









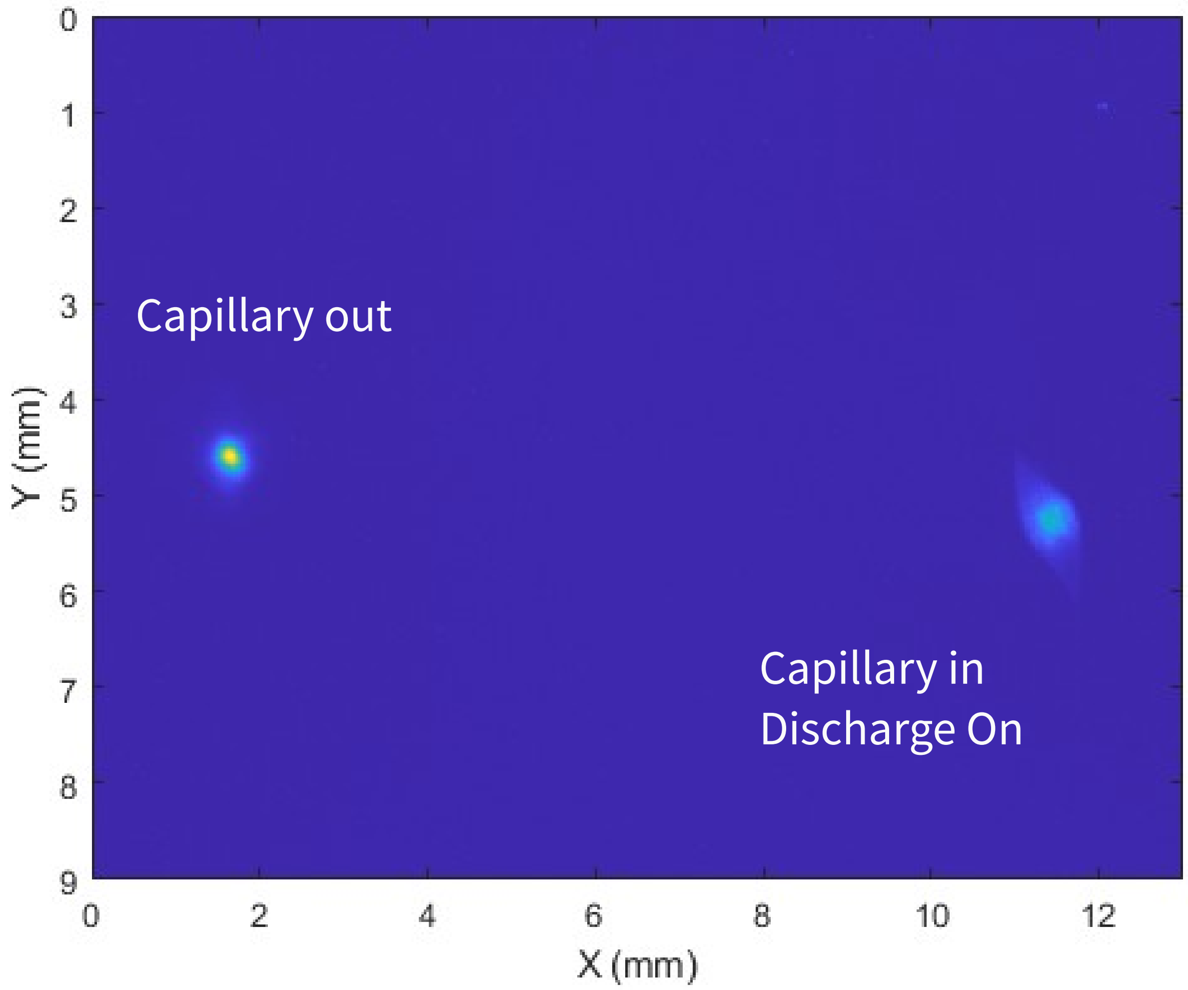
Thanks!

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

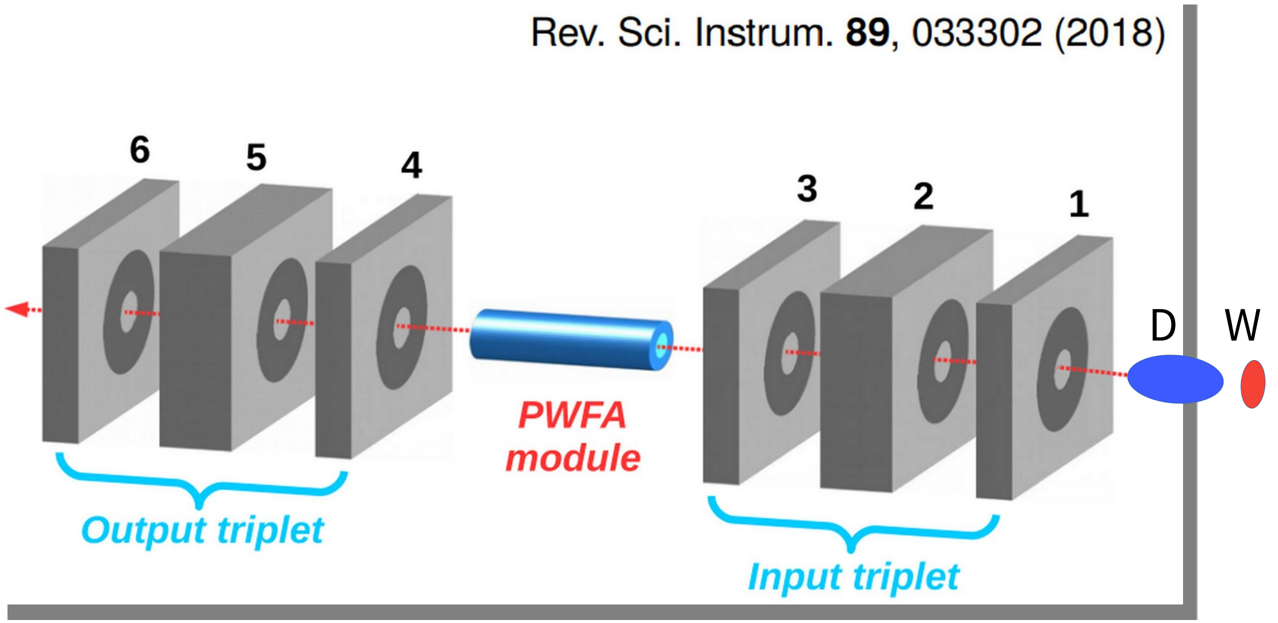
On behalf of the SPARC_LAB collaboration

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Tests @ SPARC


Capillary out
Capillary in
Discharge On
Y (mm)
X (mm)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12

Acceleration and 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

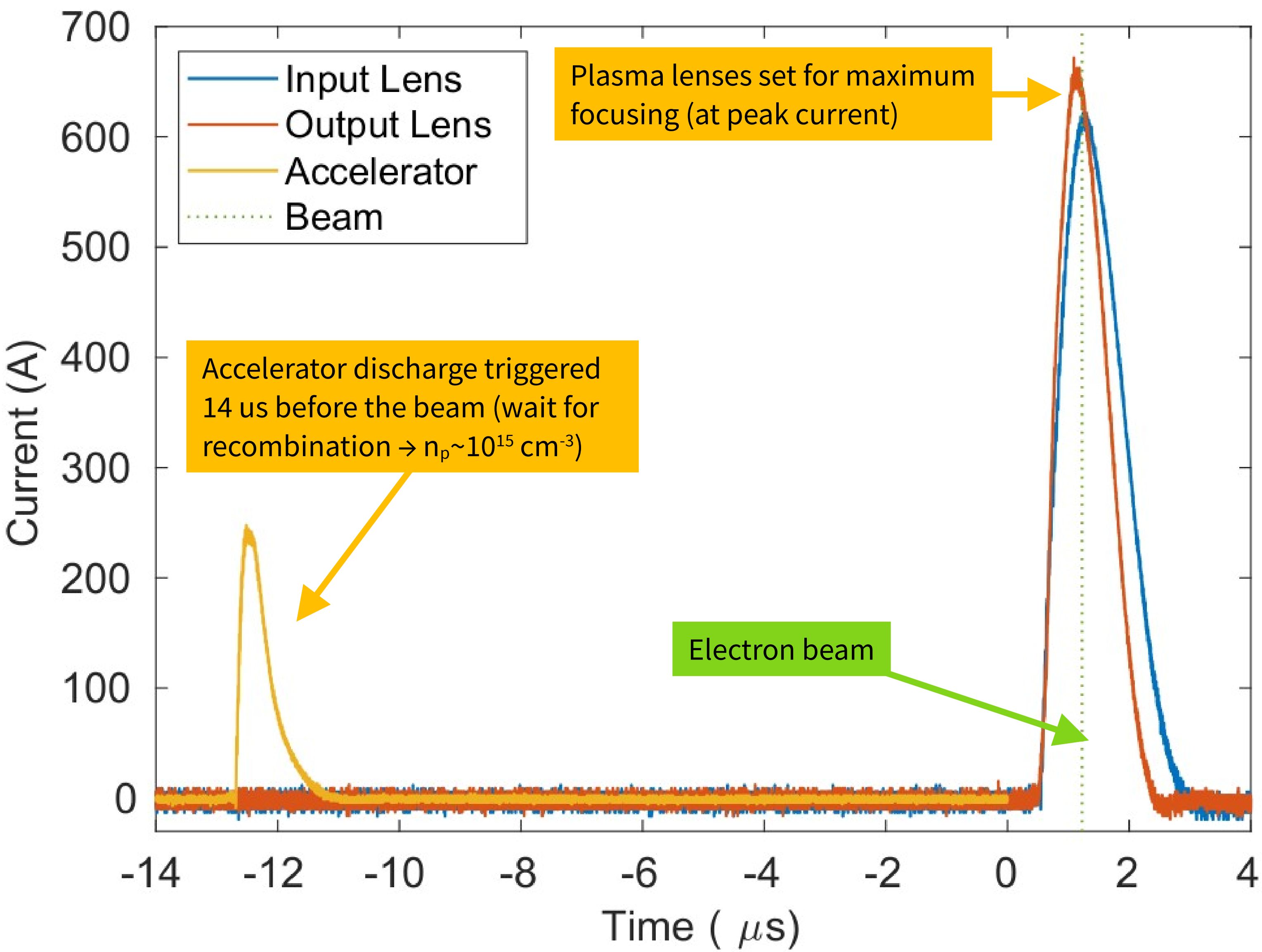
Witness beam must be transversely matched to avoid emittance spoiling

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

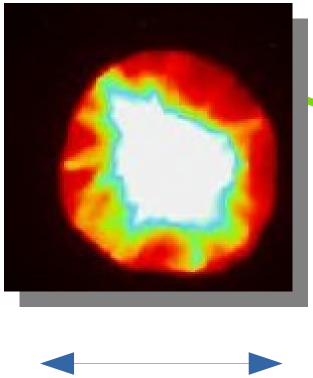
Barov, N., et al., Physical Review E 49.5 (1994): 4407.

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

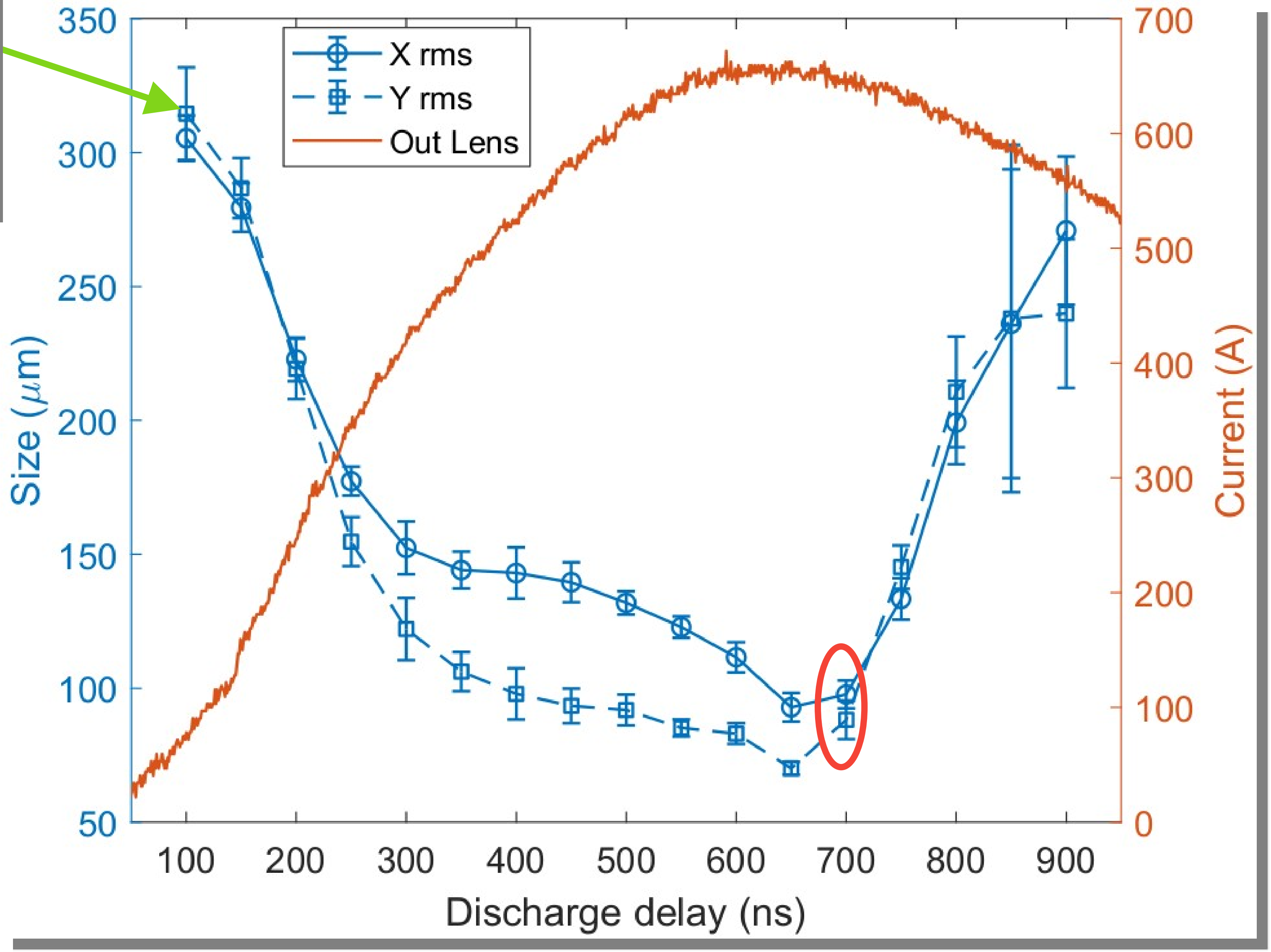
Discharges timing setup



APL scan



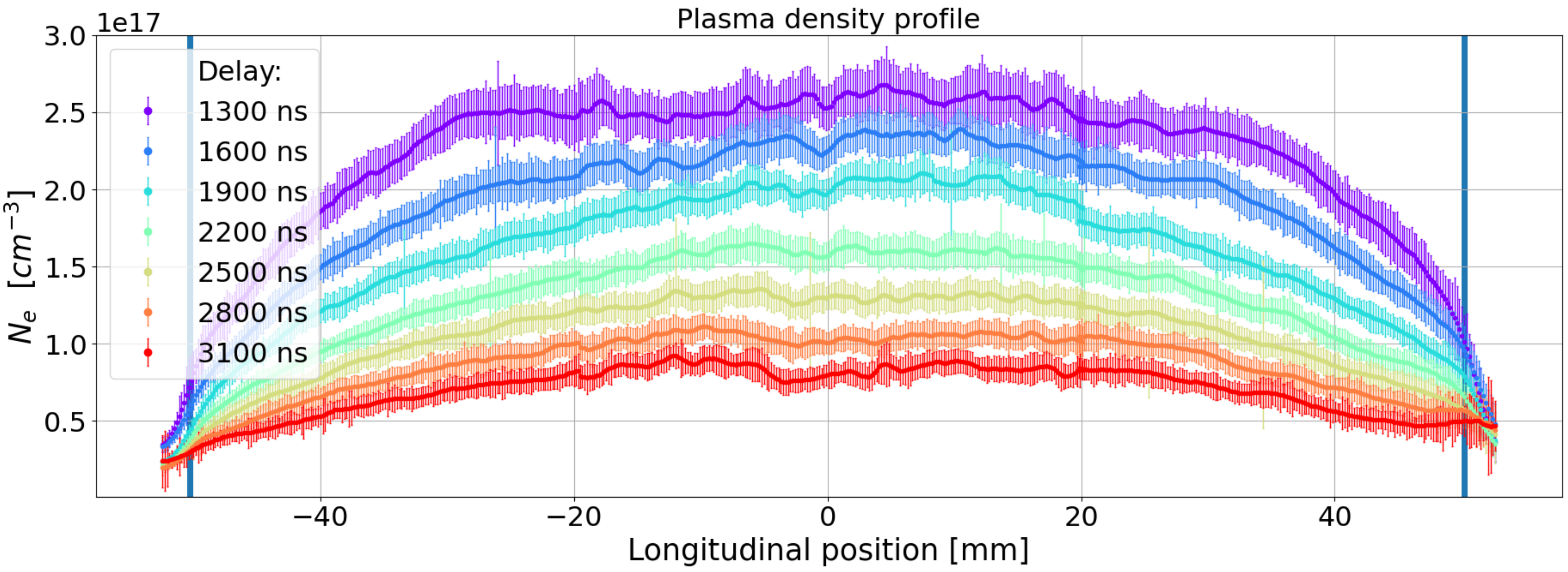
Scan obtained using only the APL2 (APL1 and ACC turned OFF)



Plasma density measurements

Before test

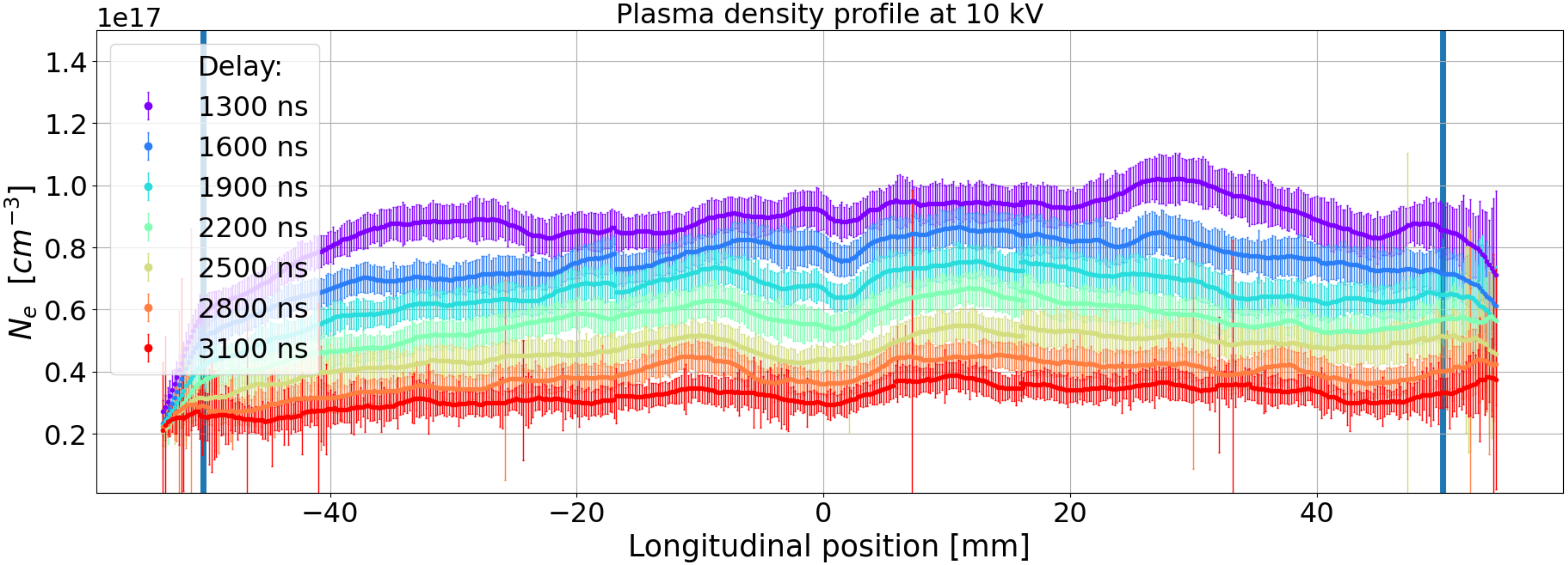
10 kV – 730 A, 1 bar



Plasma density measurements

After test

10 kV – 730 A, 1 bar



Degradation of the capillary (ablation) gave lower densities

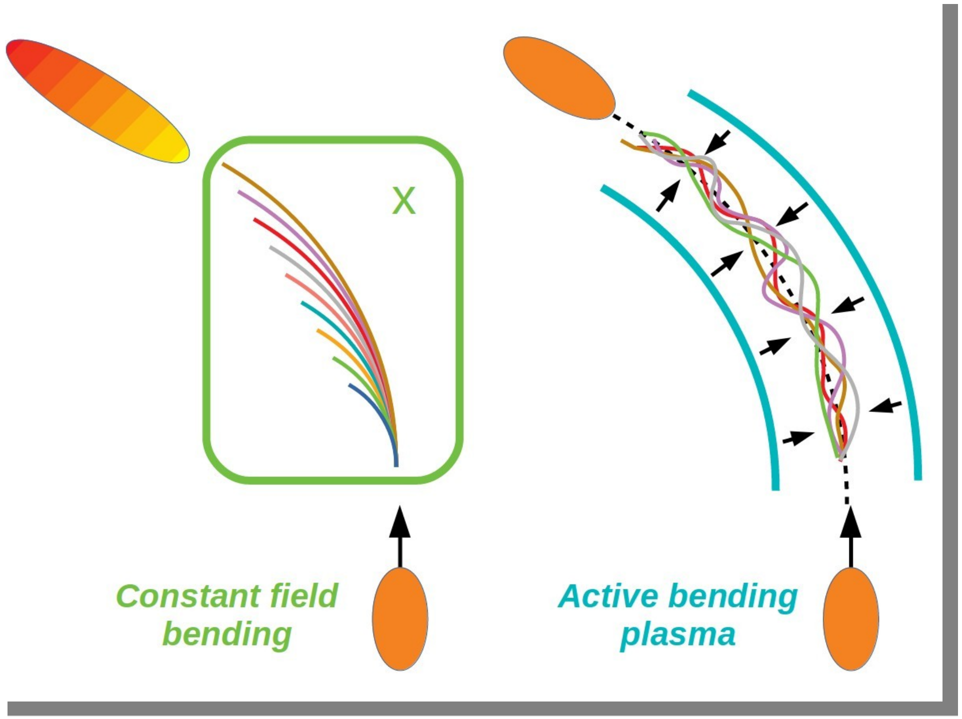
Working principle

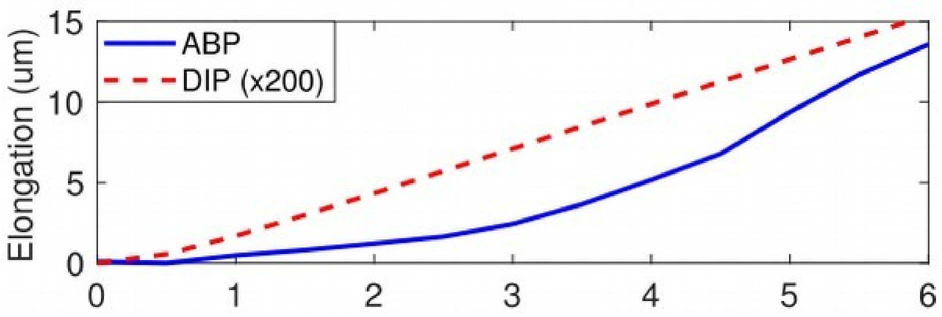
Particle motion in the APB is different with respect to a classic bending magnet

- *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.*



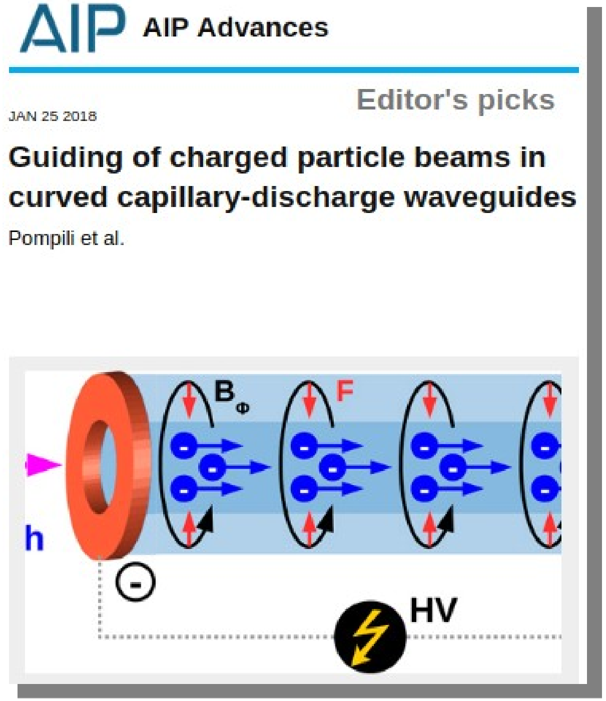


Active Plasma Bending (APB) is an extension of the Active-Plasma Lens (APL) mechanism

- *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

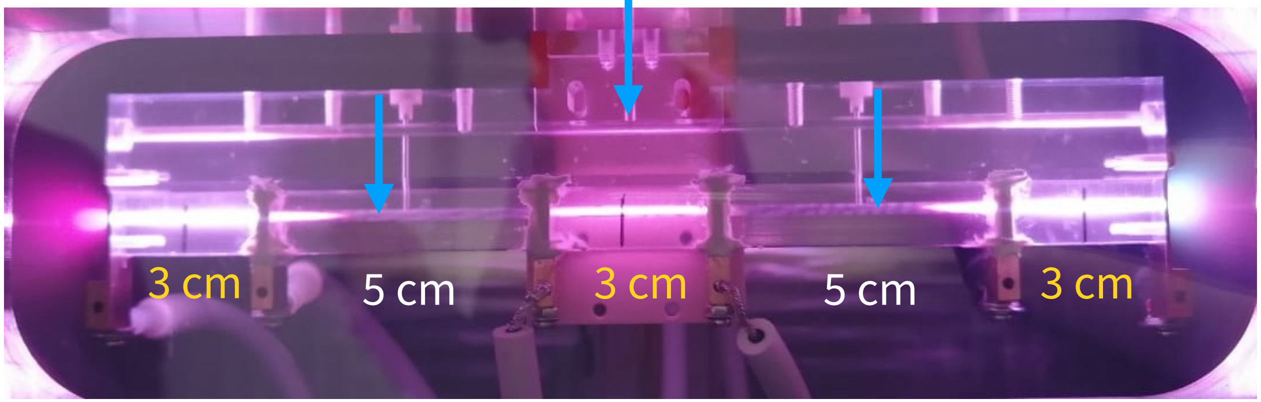
- *Compactness. Large deflection angles, no need of cryogenic systems*
- *Tunability. The bending is tuned by adjusting the discharge-current*
- *Cheap solution (capillary+discharge pulser)*
- ***Tunable dispersion (dispersion-free also possible) by changing the discharge current***



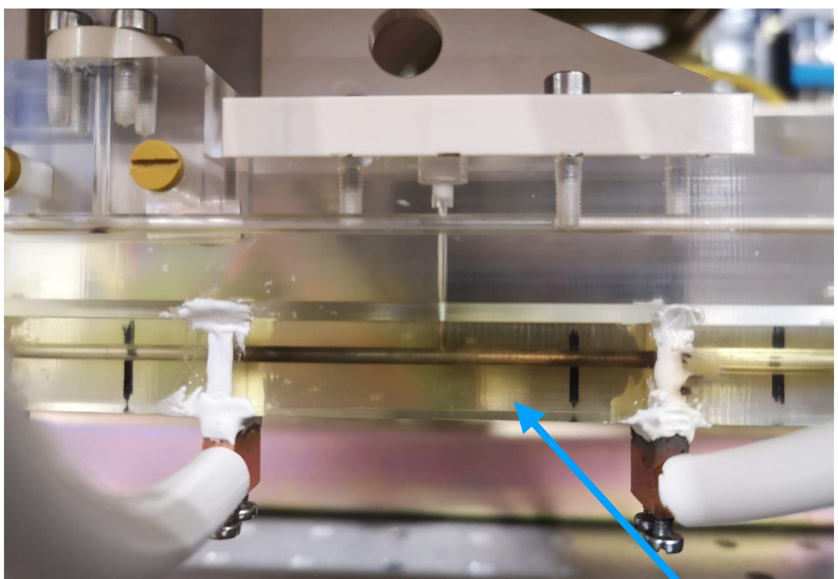
Pompili, R., et al. "Guiding of charged particle beams in curved capillary-discharge waveguides." AIP Advances 8.1 (2018): 015326.

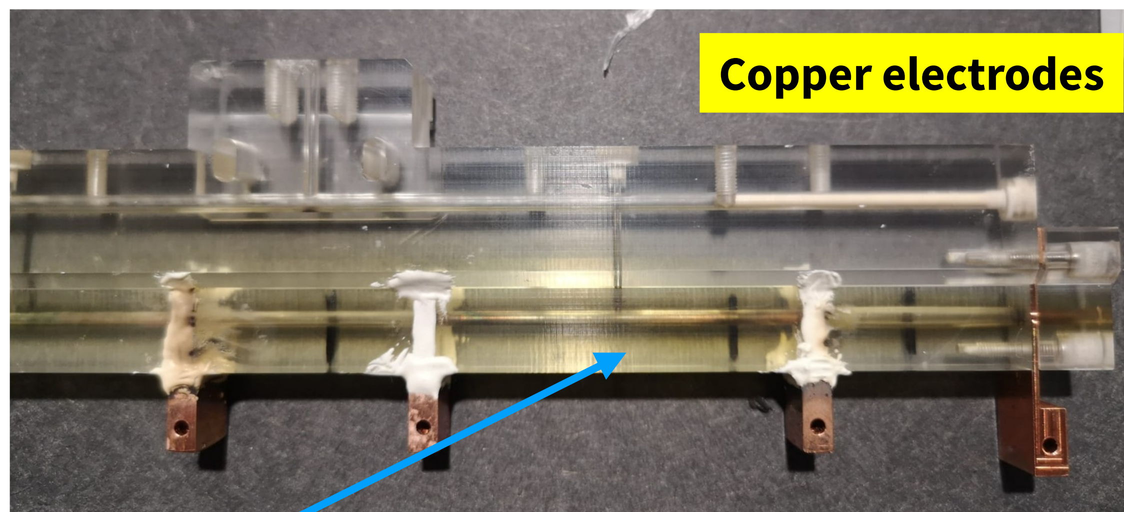
First offline tests (2 inlets prototype)

H_2 or N_2



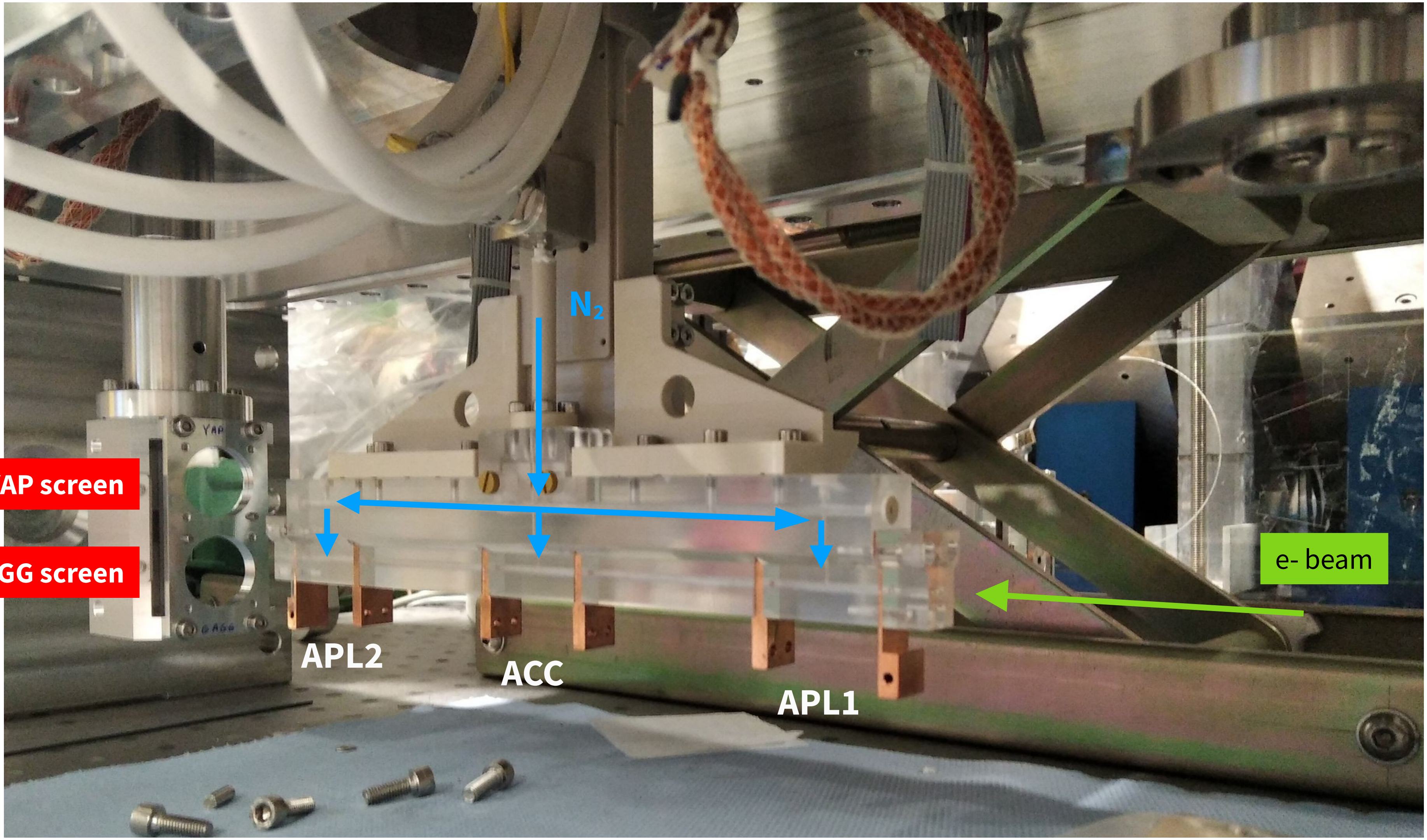
Offline tests
@ PLASMA_LAB





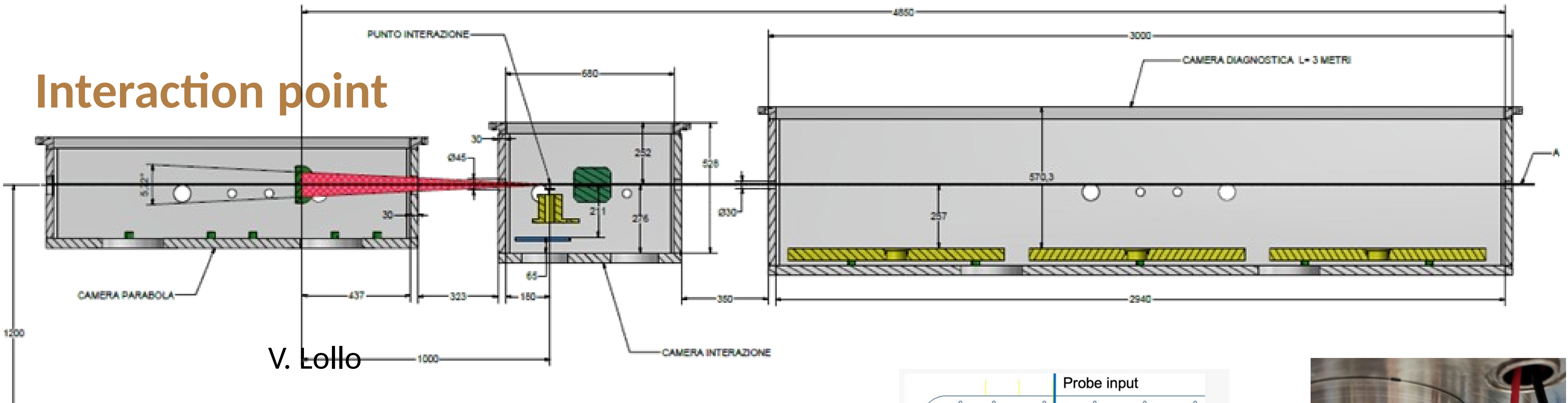
Spattered copper

Installation in the vacuum chamber



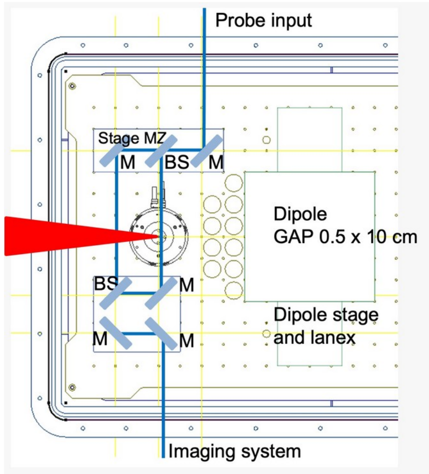
Layout of the interaction point

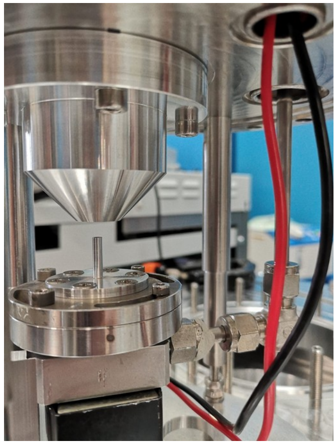
Interaction point



V. Lollo

- 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





EuAPS

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

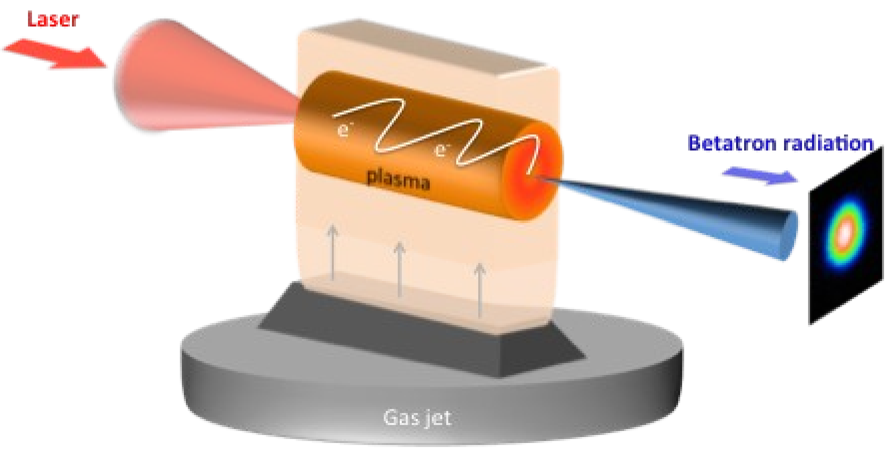
Parameters list

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*

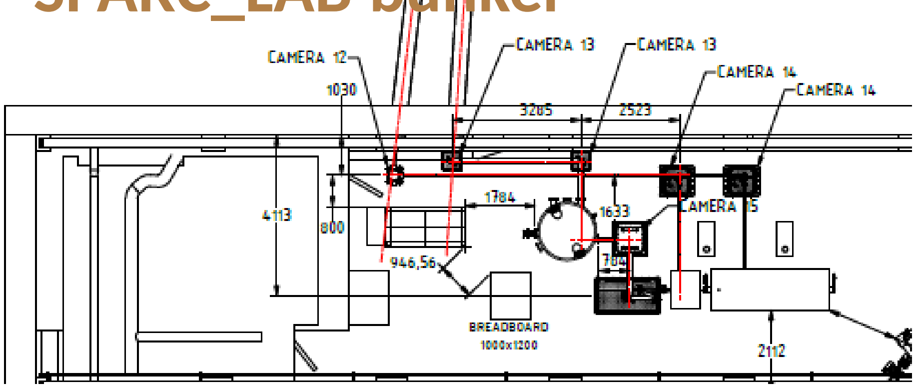
The main goal is to make a replica of the source developed at FLAME

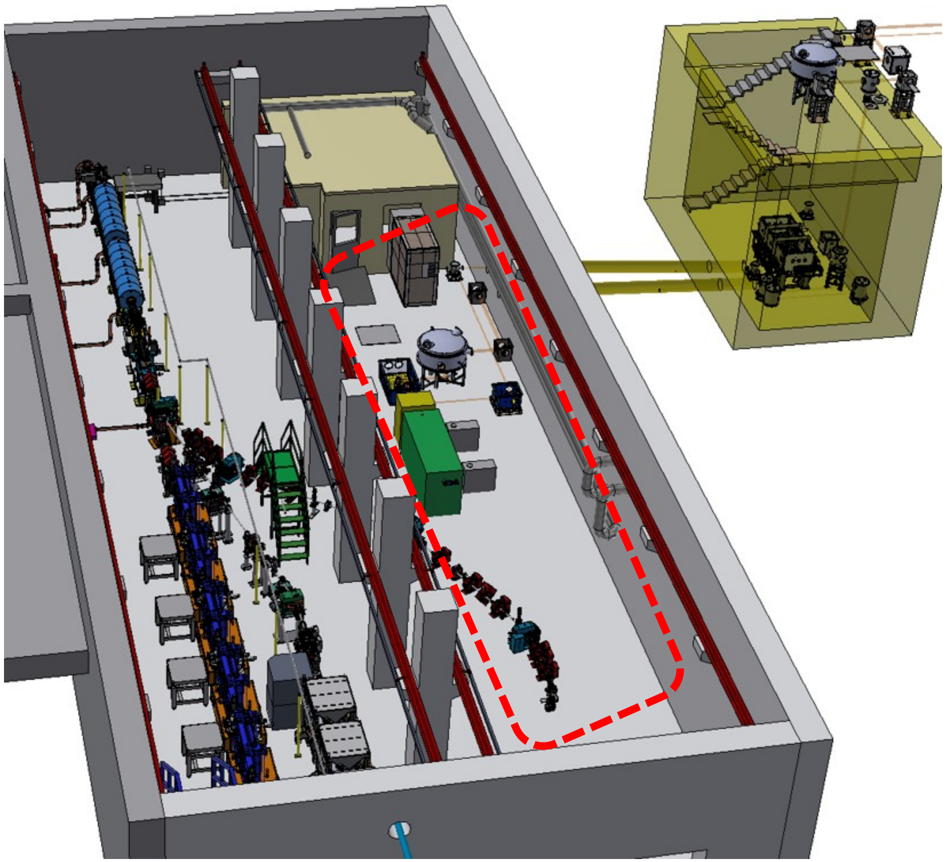
The advanced photon diagnostics and the user end station will be tested and installed during/after the commissioning of the source



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

SPARC_LAB bunker





- Layout in the SPARC bunker and connection with FLAME building

S. Lauciani

Recent updates

Flame building

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

A. Cianchi

Timeline

- 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

SABINA THz line @SPARC

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

Magnets

Sextupoles and quadrupoles already available

Intra-undulator 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:

Designing of vacuum chambers for optics ongoing

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

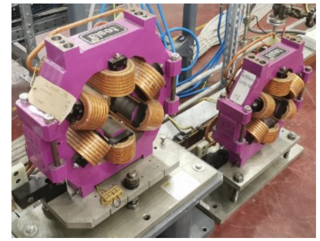
Users' instruments on site

Regione Lazio:

Accounting successfully completed

Technical and scientific visit from Regione Lazio delegates passed

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



[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

L. Sabbatini, I. Balossino