EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

Introduction to the V EuPRAXIA@SPARC_LAB Rev. Committee

M. Ferrario, INFN-LNF

On behalf of the EuPRAXIA@SPARC_LAB collaboration

LNF June 15, 2023

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement No. 101079773

at SPARC_LAB

Agenda

Funded by the European Union

Thursday, 15 June

09:00	→ 09:15	Introduction - M. Ferrario
09:15	→ 09:45	Status of the EuPRAXIA ESFRI Project – R. Assmann (Remote)
09:45	→ 10:30	EuPRAXIA@SPARC_LAB overview and project management– A. Falone
10:30	→ 11:30	Discussion
11:30	→ 12:00	Coffee Break
12:00	→ 12:30	TDR structure – M. Ferrario
12:30	→ 13:00	Discussion
13:00	→ 14:15	Lunch Break
14:15	→ 15:00	Scientific Case – F. Stellato
15:00	→ 16:00	Discussion
16:00	→ 16:30	Coffee Break
16:30	→ 17:15	Plasma module development – A. Biagioni
17:15	→ 18:15	Visit Plasma_Lab and Sabina Undulator Lab
18:15	→ 18:45	Closed Session

Friday, 16 June

09:00	→ 10:00	Q&A and Outlook of the next meeting
10:00	→ 12:00	Closed Session with coffee station
12:00	→ 13:00	Report back
13:00	→ 14:00	Lunch Break

EuPRAXIA at SPARC_LAB

Authorization for building construction received!

Funded by the European Union

694

MINISTERO DELLE INFRASTRUTTURE E DEI TRASPORTI

PROVVEDITORATO INTERREGIONALE PER LE OO.PP. PER IL LAZIO, L'ABRUZZO, LA SARDEGNA

* * * * *

VIA MONZAMBANO, 10 – ROMA

AVVISO

ai sensi dell'art. 29 del D.Lgs. 18 aprile 2016, n. 50

OGGETTO: C.d.S. n.694 - Realizzazione di un nuovo complesso edilizio EuSPARC per ospitare la facility EuPRAXIA presso i Laboratori Nazionali di Frascati INFN.

Amministrazione Proponente: INFN Istituto Nazionale di Fisica Nucleare

Si comunica che ai sensi dell'art. 14-bis comma 5 della L. 241/90 e ss.mm. e ii., è da considerarsi acquisito l'assenso sul progetto in argomento da parte delle Amministrazioni invitate alla Conferenza. Si **DICHIARA**, pertanto, sulla scorta degli atti acquisiti, perfezionata l'intesa per la localizzazione e realizzazione dell'opera indicata in oggetto e, di conseguenza, **AUTORIZZATO** il relativo progetto definitivo.

Gli atti del procedimento sono in visione presso la Segreteria dell'Ufficio Conferenze di Servizi di questo Provveditorato

IL DIRIGENTE
Dott. Ing. Carlo Guglielmi
Firmato digitalmente da CARLO GUGLIELMI
O = MiMS
C = IT

IL RESPONSABILE DEL PROCEDIMENTO
Dott. Arch. Alessia Costa
Alessia Costa MiMS 19.05.2023 13:22:39 GMT+00:00

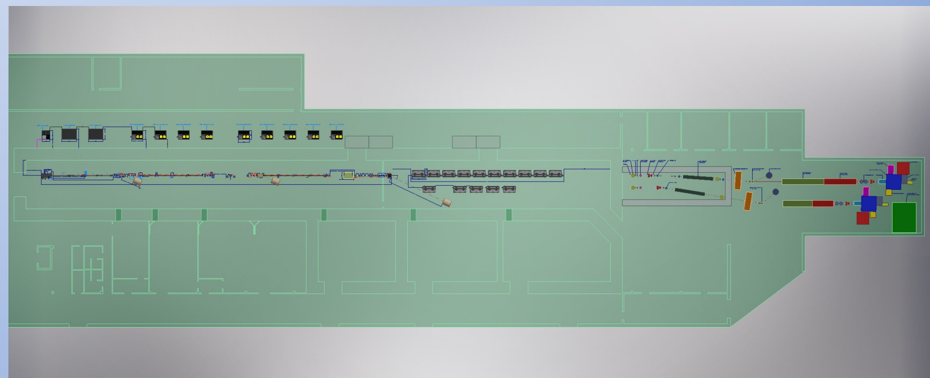
IL PROVVEDITORE
Dott. Ing. Vittorio Rapisarda Federico
VITTORIO RAPISARDA FEDERICO
Ministero delle Infrastrutture e dei Trasporti
23.05.2023 11:37:37 GMT+01:00

Roma, li ____________

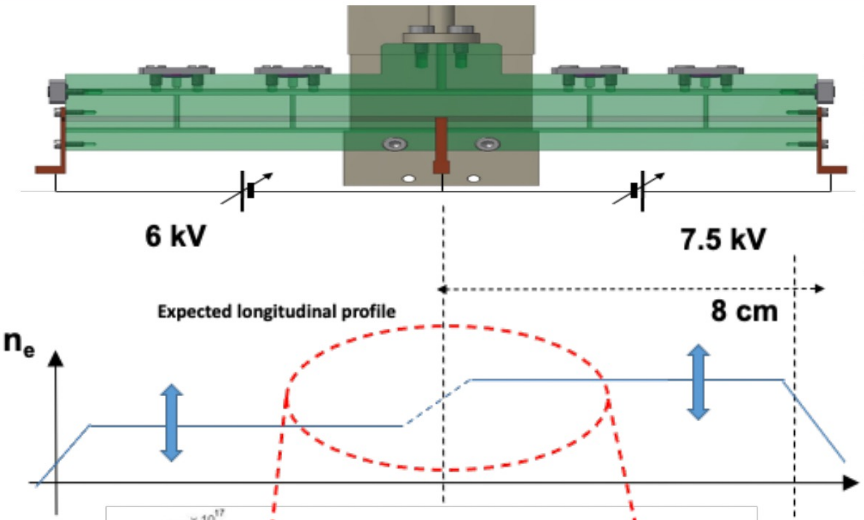
PUBBLICATO ____________

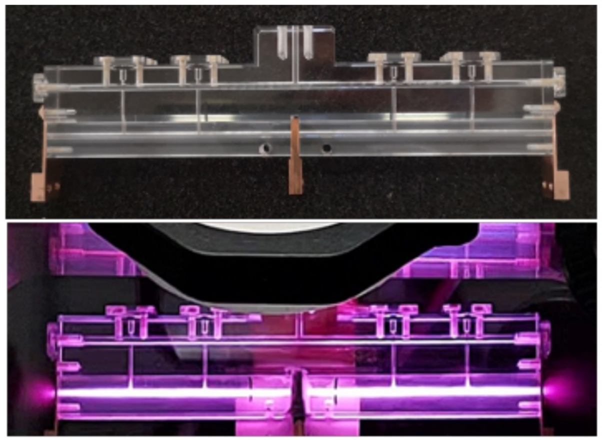
RITIRATO ____________

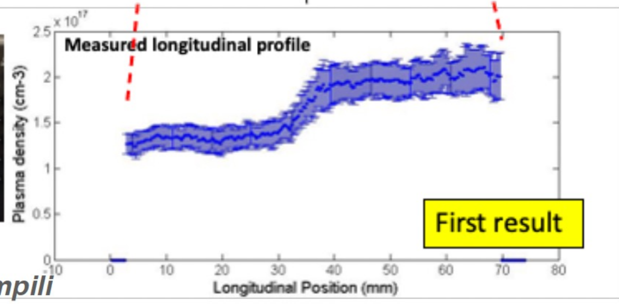
Last Call for minor modifications!



Plasma_Lab Tour



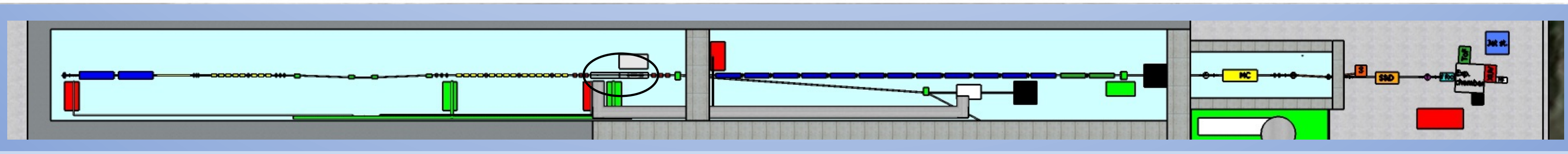




Advantages:

- several independently controllable sections
- Plasma sources larger than 40 cm (m-scale) with HV pulses less than 10 kV
- Longitudinal density modulation
- **5 GeV** case for EuPRAXIA (1.5 GV/m m-scale capillary - density 10^{16} cm-3)

Courtesy A.Biagioni / R.Pompili

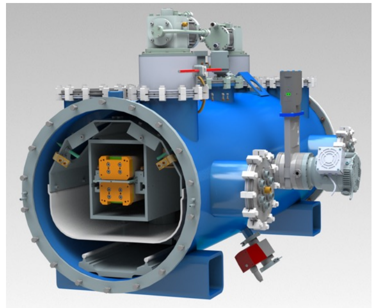


Courtesy A. Biagioni, R. Pompili

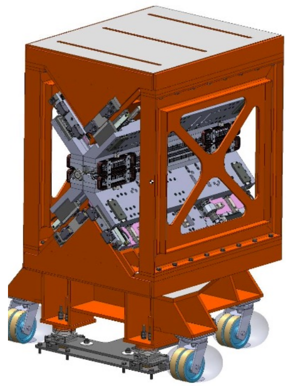
Magnets-Lab tour

Two FEL lines:

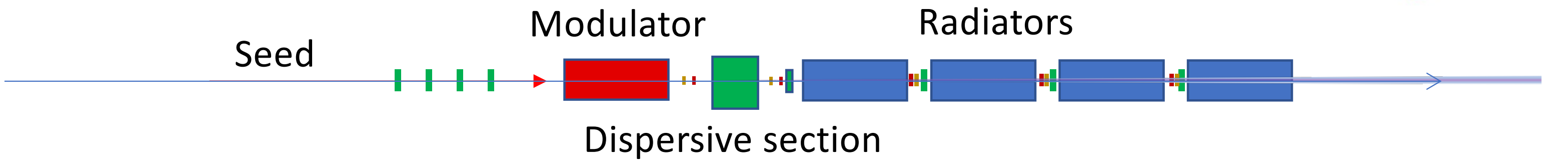
1) *AQUA*: Soft-X ray SASE FEL – Water window optimized for 4 nm (baseline)



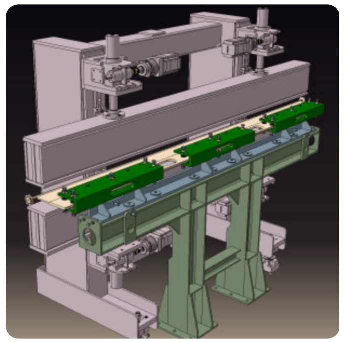
SASE FEL: 10 UM Modules, 2 m each – 60 cm intraundulator sections.
Two technologies under study: Apple-X PMU (baseline) and planar SCU.
Prototyping in progress



2) *ARIA*: VUV seeded HGHG FEL beamline for gas phase



FERMI FEL-1 Radiator

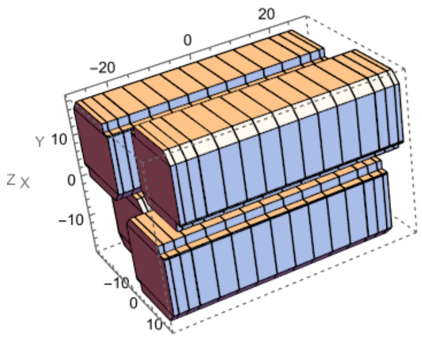


SEEDED FEL – Modulator 3 m + 4 Radiators APPLE II – variable pol. 2.2 m each – SEEDED in the range 290 – 430 nm (see former presentation to the committee and *Villa et al. ARIA—A VUV Beamline for EuPRAXIA@SPARC_LAB. Condens. Matter 2022, 7, 11.*) – Undulator based on consolidated technology.

Undulator design and prototyping for AQUA: Apple-X

Defining critical design aspects:
Minimum vacuum chamber size / vacuum - wake-fields (F. Bosco Un. Roma 3 – F. Nguyen, ENEA)
Magnetic field tolerances from prototype of Apple-X module (M. Opromolla, LNF)

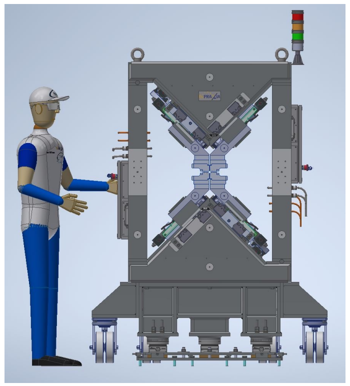
Apple-X undulator for ***SABINA*** (ref. L. Sabbatini) is a first prototype for ***AQUA*** FEL line



Magnetic design A. Petralia (ENEA)

LNF observer in LEAPS-INNOV:
setting up magnetic measurement bench (ref. L. Sabatini A. Vannozzi) in contact with M. Calvi / S. Karabekyan small size Hall probe and Hall probe bench.

Undulator mech. design adapted from KYMA- ***SABINA*** by M. Del Franco (LNF)

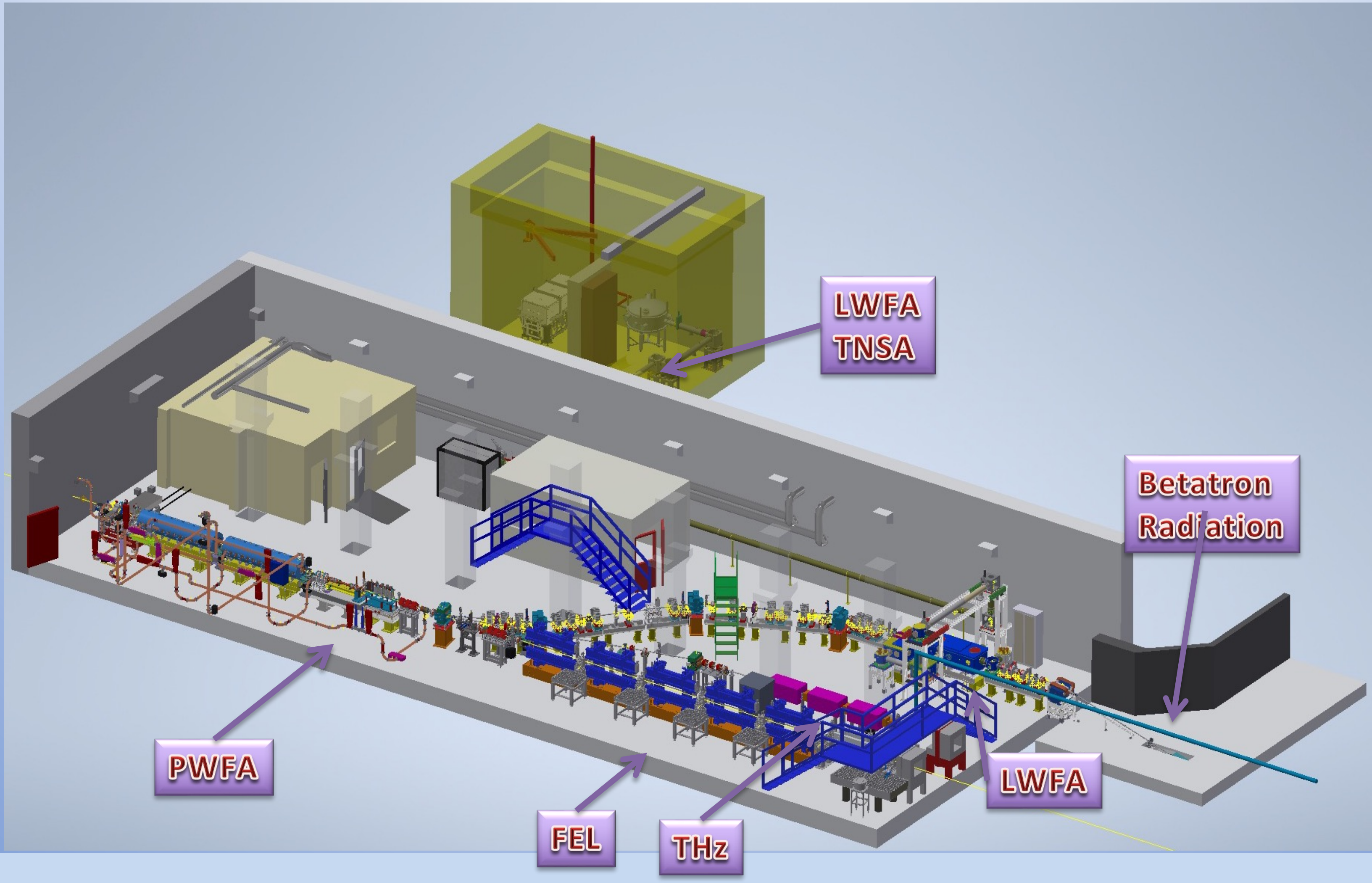


First ***SABINA*** undulator in FRASCATI March 29, 2023

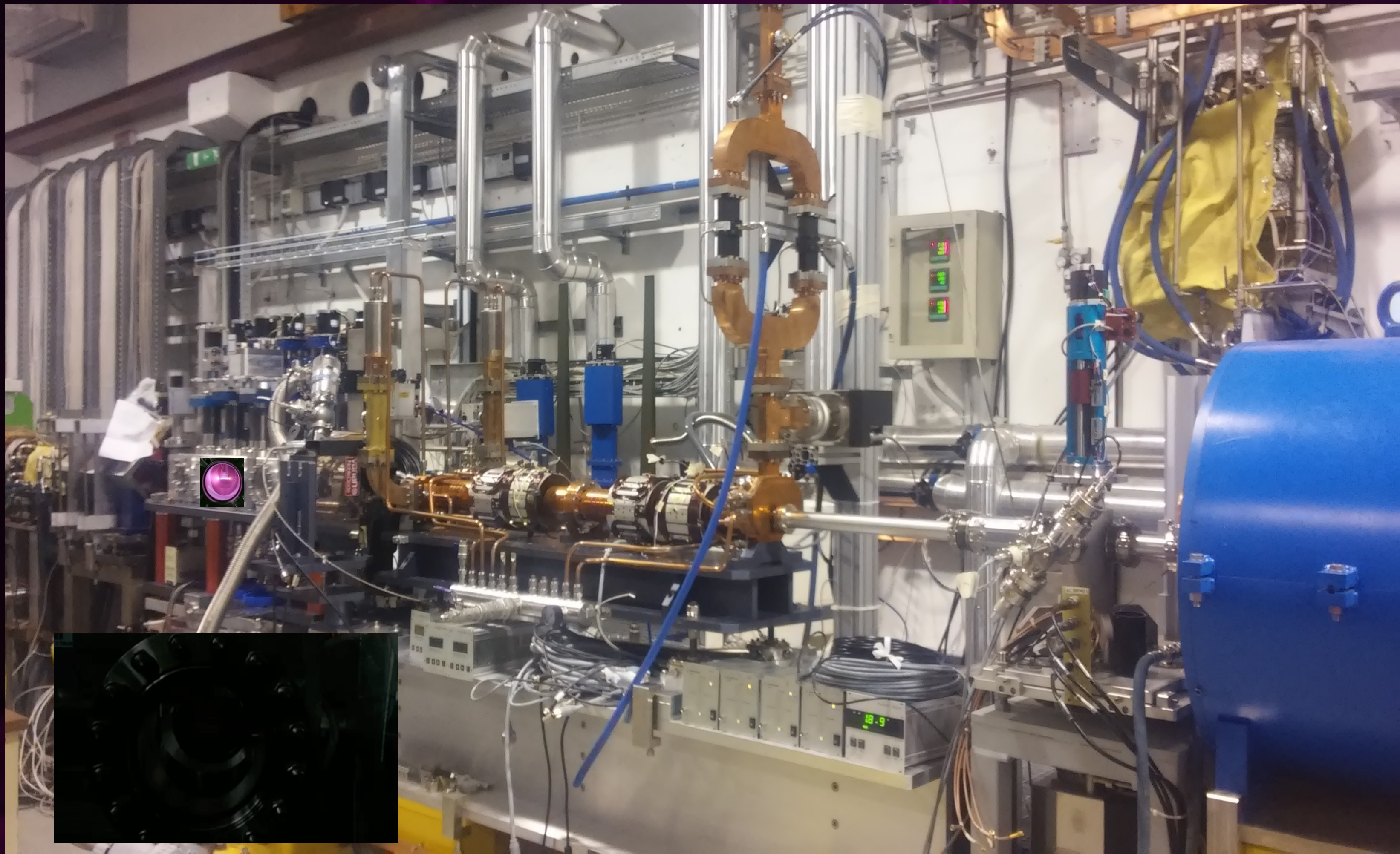

EuPRAXIA
at SPARC_LAB
Beam-driven plasma user facility EuPRAXIA Headquarter
Laser-driven plasma user facility: candidates
Excellence Center
Second site will be decided in Preparatory Phase project.
Excellence centers (EC) perform technical developments, prototyping and component construction. Number of EC's, locations, roles, responsibilities reviewed in Prep. Phase.
Advanced Applications Beamlines (UK)
Plasma Acc. & High Rep. Rate Dev. (D)
Technology Incubator (CZ - ELI)
User Data Center (H)
Laser-Plasma Acc. & 1 GeV FEL (F)
Beam-driven plasma user facility EuPRAXIA Headquarter
Theory & simulations (P)
EuPRAXIA
Horizon Europe
EuPRAXIA@SPARC_LAB
LATINO
TEX
Finanziato dall'Unione europea
NextGenerationEU
REGIONE LAZIO
SPARC_LAB
INFN
Istituto Nazionale di Fisica Nucleare
LNF-18/03
May 7, 2018
Technical Design Report
7

EuPRAXIA at SPARC_LAB

SPARC_LAB test facility for Advanced Accelerators R&D



PWFA beam line at SPARC_LAB



Summary of 2022/2023 SPARC activities

From October to December 2022 we performed two experiments at SPARC

- *Proof of the 1 GV/m accelerating gradient*
- *Pump-and-probe experiment to measure the Hydrogen plasma recovery time*

SPARC was shutdown from December 2022 up to April 2023 for the SABINA installations

- *New photo-cathode laser installed and currently operating*
- *Tunnel realization to connect the SPARC bunker with the user building (TeX area)*
- *Installation of the new dry-cooler*

May-July 2023 we have time to run SPARC for two more experiments

- *Plasma acceleration with Nitrogen at 10 Hz*
- *Test of plasma acceleration in combination with acrive-plasma lenses*

From October 2023 SPARC will be again shutdown to continue with the SABINA installations

- *Installation of new solenoids and THz undulators*

EuPRAXIA at SPARC_LAB

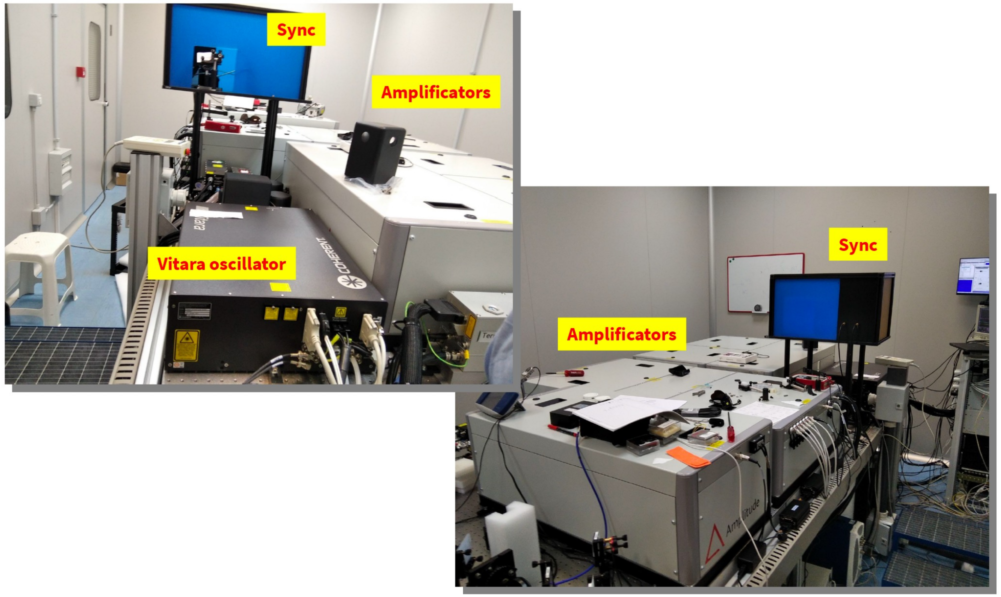
SPARC_LAB activities

Funded by the European Union

SPARC_LAB

New photo-cathode laser

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

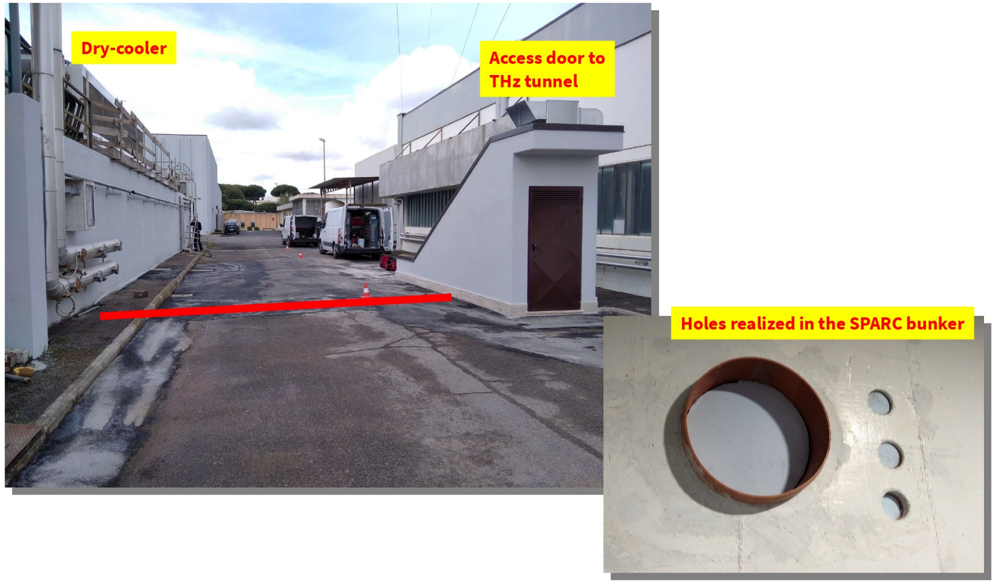


7/15 *SPARC_LAB activity report* 04/05/23

SPARC_LAB

THz tunnel

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati



8/15 *SPARC_LAB activity report* 04/05/23

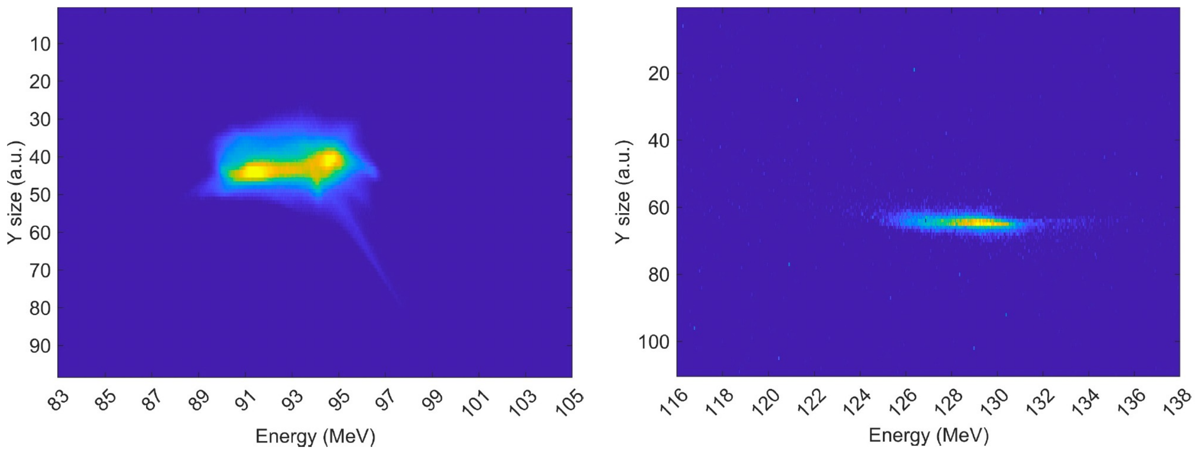
SPARC_LAB activities

Funded by the European Union

SPARC_LAB

Results of the last run (Oct-Dec 2022)

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati



Achieved 1.2 GV/m accelerating gradient by using a 500 pC driver followed by a 50 pC witness. Results obtained at plasma density ~2×10^{15} cm^{-3}.

Results confirmed that larger charge on the driver bunch was needed to get larger accelerations at the same plasma density used so far

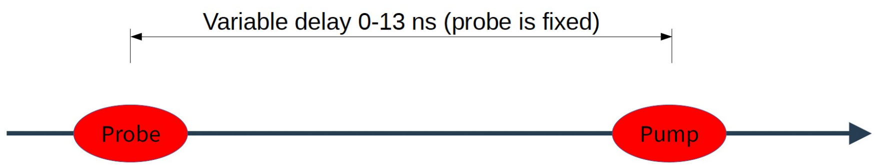
Large energy instability observed on the witness. Now timing-jitters and plasma density fluctuations become more evident on the resulting witness energy

10/15 *SPARC_LAB activity report* *04/05/23*

SPARC_LAB activities

Funded by the European Union

Results of the last run (Oct-Dec 2022)



Idea is to probe the recovery time (namely the time needed to reestablish the initial ionic density) with Hydrogen → need to send into the plasma two bunches delayed by ns (I.e., multiple RF period, 360 ps)

There is a strong effect of pump-probe interaction in the plasma in the delay range 2000:6000 ns, corresponding to plasma densities ~$10^{13\text{-}15}$ cm-3, peaked at ~10^{14} cm-3

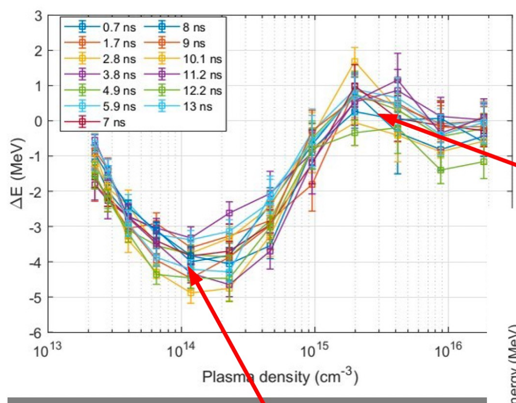
When sent together with the pump (regardless of their relative delay) the "perturbed"probe loses more energy and, consistently, increases its energy spread

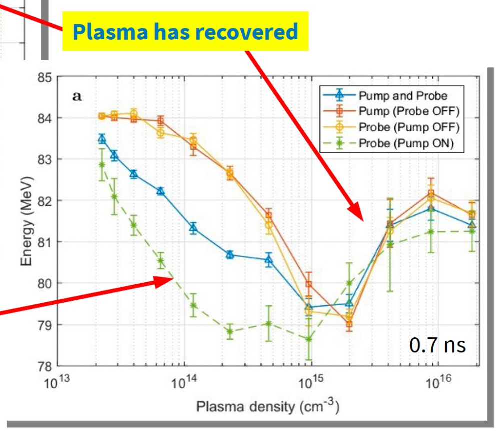
The effects of pump-probe interaction vanish at large densities (>$10^{15\text{-}16}$ cm-3)

These effects should be attributed to changes of the ions density (the plasma electrons oscillation are damped after tens/hundreds of ps, not ns)

Results of the last run (Oct-Dec 2022)

Perturbed probe energy with pump on. Energy difference with respect to unperturbed probe (pump off)





SPARC_LAB activities

SPARC_LAB

Latest news (May-June 2023)

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

Successful operation with plasma acceleration at 10 Hz using Nitrogen

Stable acceleration at 500-600 MV/m. Still unstable at 1 GV/m

Vacuum under control in the last C-band accelerating section (~10^{-8} mbar)

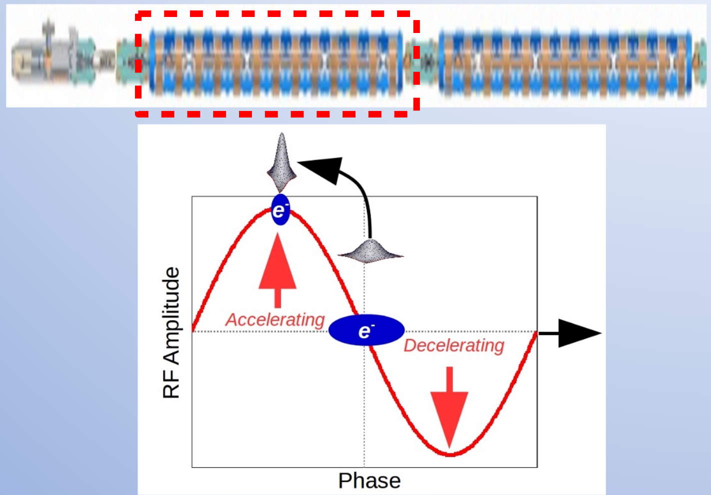
Proof of RF jitter reduction by using Klystron-Loop device on the solid-state C-band modulator

This proves that moving to a S-band solid-state modulator on the 2nd beamline (where VB is actually performed) is better in terms of RF jitter

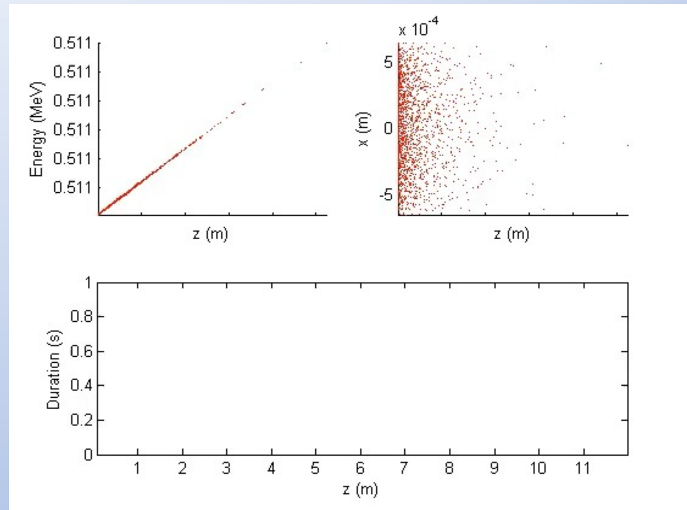
Velocity bunching

Alternative technique to magnetic compression in chicanes / doglegs.

Velocity bunching compression



200+20 pC GPT simulation



It simultaneously accelerate and compress the electron bunches, making the photo-injector very compact.

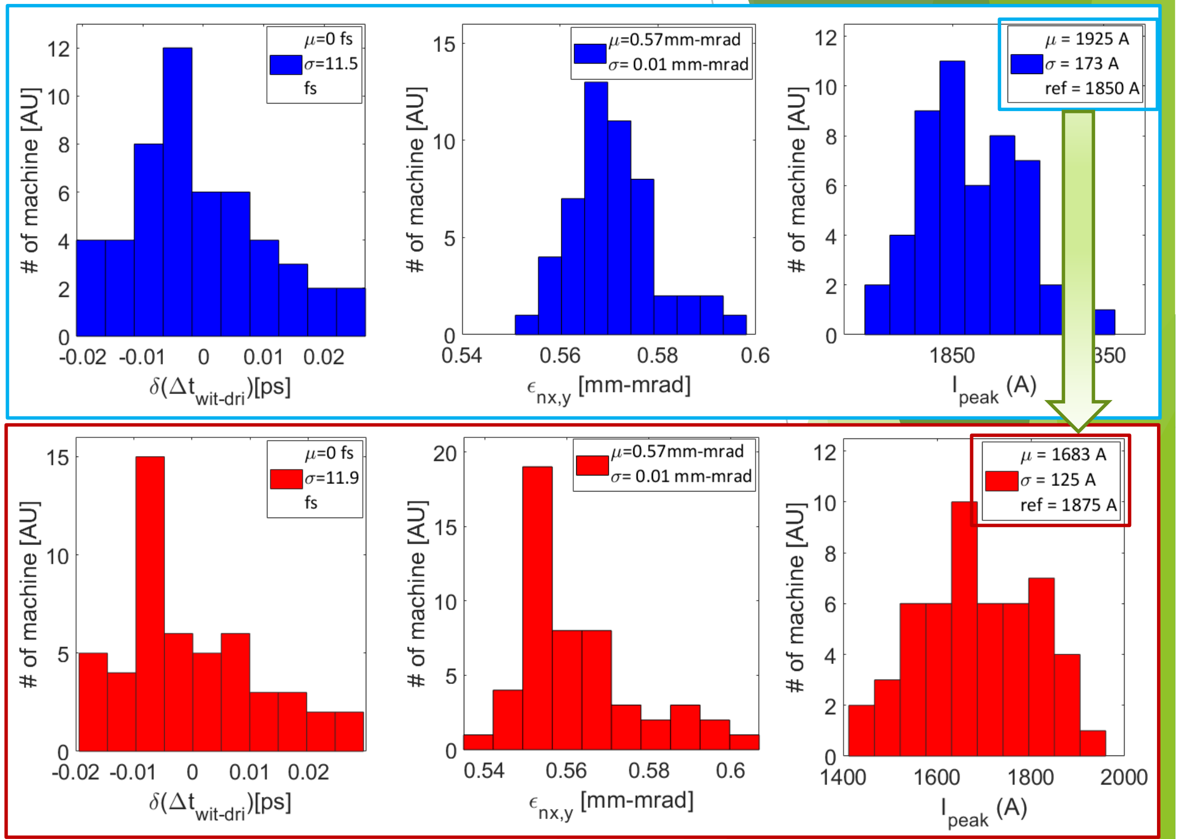
MACHINE SENSITIVITY STUDIES

- Tolerances studies are essential in the TDR workflow and aim to actual check the **robustness and reliability** of the adopted working point with regards to the RF elements and laser system stability
- The analysis has been performed on a sample of 50 machine runs generating for each machine a *TStep input code* coupled with an *Elegant* one, whose errors are provided by gaussian distributions with errors defined on the basis of the SPARC_LAB experience (see the Table)
- The more critical parameters for an efficient operation of the plasma module are
  - μm scale bunch length ↔ witness quality and plasma density choice
  - fs scale precision of the time delay between the bunches ↔ energy jitter
  - Witness peak current ↔ energy spread (beam loading)
  - Beam Twiss parameters at plasma injection ↔ witness quality and plasma density choice

RF Gun (rms)		
RF Voltage [ΔV]	± 0.2	%
RF Phase [Δφ]	± 0.03	*deg*
S-band Accelerating Sections (rms)		
RF Voltage [ΔV]	± 0.2	%
RF Phase [Δφ]	± 0.03	*deg*
X-band Accelerating Sections (rms)		
RF Voltage [ΔV]	± 0.2	%
RF Phase [Δφ]	± 0.1	*deg*
Cathode Laser System (max)		
Charge [ΔQ]	± 2	%
Laser time of arrival [Δt]	± 100	fs
Laser Spot size [Δσ]	± 1	%

MACHINE SENSITIVITY STUDIES – Data Analysis

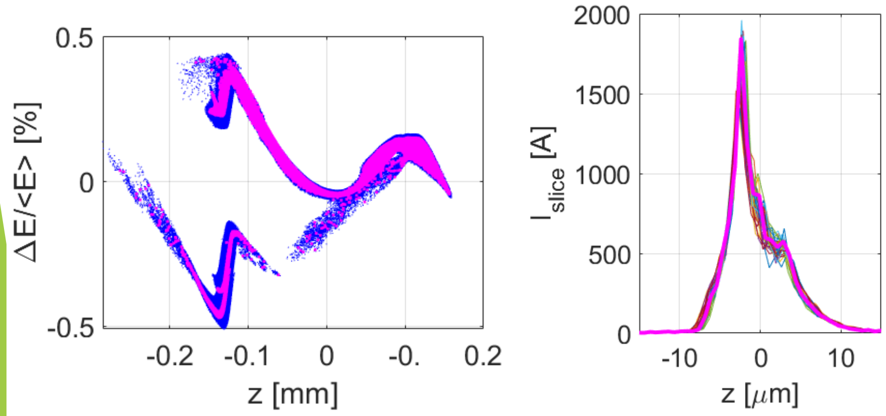
- The **photoinjector,** that operates in the velocity bunching mode, is the main responsible of the **longitudinal beam compression factor** and **delay definition**
  - The velocity bunching mode is very sensitive to linac phase jitter → the laser time of arrival and the first two accelerating sections are the main culprits of the jittering of the beam delay and final rms beam length
- The **X-band linac** is the main responsible for final **beam Twiss parameters** and **energy**. A *'second order'* effect lies in the manipulation of the ***beam current profile*** which is amplified by the coupling of two systems, the photoinjector and the linac, operating at different RF frequencies
  - The X-band linac operates almost on crest → the energy jitter is negligible with respect to other parameters
  - The final focusing system is made of permanent magnet → final Twiss parameters almost stable
  - The X-band linac jitter ***has higher impact*** on the definition of the witness peak current with respect to the photoinjector one, with the benefit of a ***reduced deviation*** around the mean value



Jitter analysis in terms of beam delay, witness emittance and peak current at the photoinjector (upper) and X-band linac (lower) exit

MACHINE SENSITIVITY STUDIES – Results at Plasma Injection

- The analysis shows in the worst-case scenario a deteriorating of the emittance and of the peak current of maximum 10% (still in specification)
- The most critical parameter is the witness-driver delay
- Hints for the future:
  - Investigate lower RF phase jitter (down to 15 fs)
  - Heighten faster the beam energy to frozen the beam shape
  - X-band cavity right after the RF gun



Longitudinal phase space and witness current profile.
The magenta is related to the refence WP

	Witness		Driver		
	Without errors	With errors	Without errors	With errors	
Energy	537.44	537.45 ± 0.30	539.55	539.57 ± 0.33	MeV
Energy spread	0.71	0.7102 ± 0.007	0.92	0.92 ± 0.026	‰
Bunch length	5.460	5.927 ± 0.21	61.71	61.81 ± 0.73	µm
I_{peak}	1875	1683 ± 125	-	-	kA
Δt	0.503	0.501 ± 0.012	-	-	fs
$\varepsilon_{n_{x,y}}$	0.55	0.56 ± 0.015	4.18	4.24 ± 0.25	mm mrad
$\sigma_{x,y}$	1.5	1.52 ± 0.25	5.84	5.95 ± 1.21	µm
$\beta_{x,y}$	4.3	4.5 ± 1.4	9.3	9.3 ± 3.7	mm
$\alpha_{x,y}$	1.2	1.2 ± 0.25	3.34	3.39 ± 0.75	

Beam parameters at plasma injection. The mean value and the related standard deviation over the 50 samples is reported for each parameter in case of errors.

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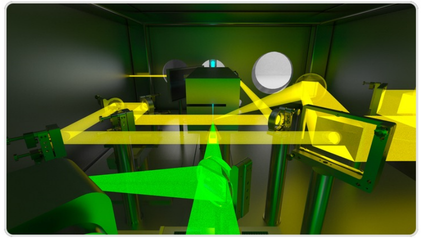
Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

EuPRAXIA Advanced Photon Sources

Strong upgrade of existing labs and implementation of user access to unique laser and laser-plasma configurations

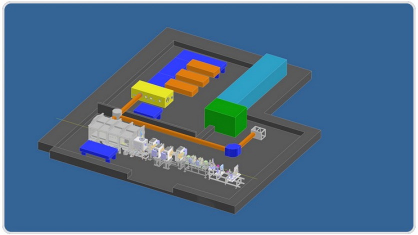
Research

The **EuPRAXIA Advanced Photon Sources** (**EuAPS**) project, led by INFN in collaboration with CNR and University of Tor Vergata, foresees the construction of a laser-driven "betatron" X Ray user facility at the LNF SPARC_LAB laboratory. EuAPS includes also the development of high power (up to 1 PW at LNS) and high repetition rate (up to 100 Hz at CNR Pisa) drive lasers for EuPRAXIA. EuAPS has received a financial support of 22.3 MEuro from the PNRR plan on "creation of a new RI among those listed in NPRI with medium or high priority" and has received the highest score for the action 3.1.1 of the ESFRI area "Physical Sciences and Engineering".



Betatron Radiation Source

READ MORE



High Power Laser Beamline

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High Repetition Rate Laser Beamline

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Strengthens the integration of national effort in the field and paves the way to further initiatives

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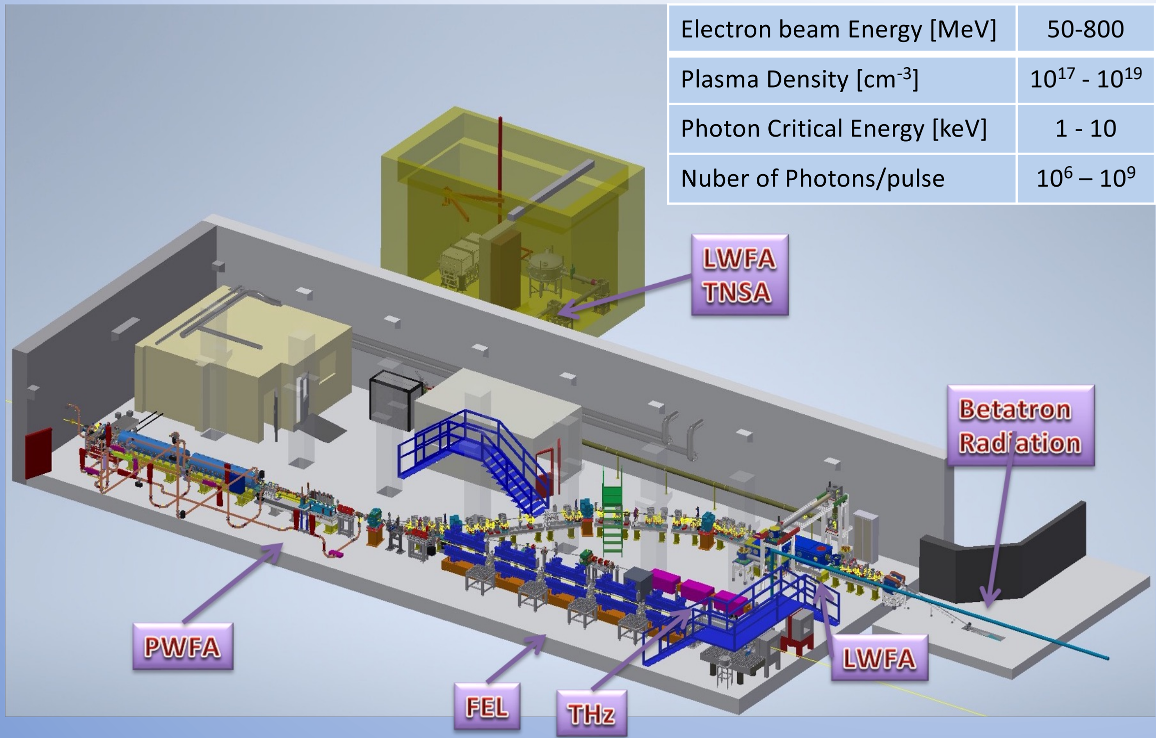
EuPRAXIA Advanced Photon Sources

Betatron Radiation Source at SPARC_LAB

Electron beam Energy [MeV]	50-800
Plasma Density [cm^{-3}]	10^{17} - 10^{19}
Photon Critical Energy [keV]	1 - 10
Nuber of Photons/pulse	10^{6} – 10^{9}



- Supported by PNRR funding
- Collaboration among INFN, CNR, University of Tor Vergata
- Operational facility at SPAClab by end of 2025
- EuPRAXIA pre-cursor for users

Scientific case

- First experiment identified:
  - Imaging of biological sample to find contamination for heavy metals
- Established collaboration with University of Trieste and Calabria for X rays imaging
- CCD X ray camera ordered

People Recruitment

Location	Status
INFN-MILANO	Hired
CNR	Hired
Tor Vergata University	Waiting for hiring
INFN-LNF	Hire 1st Sep

Livio Verra & Claudio Bortolin

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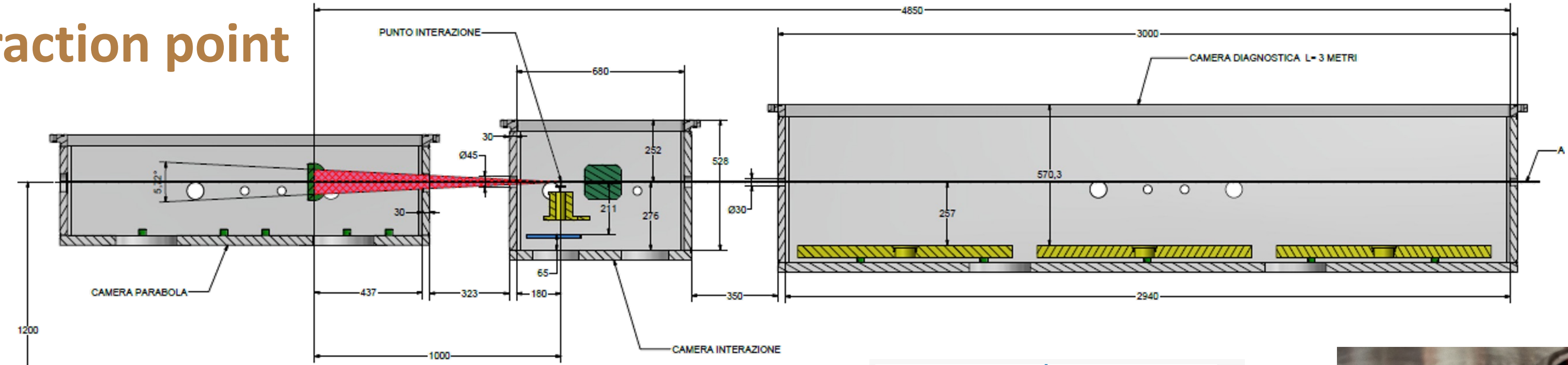
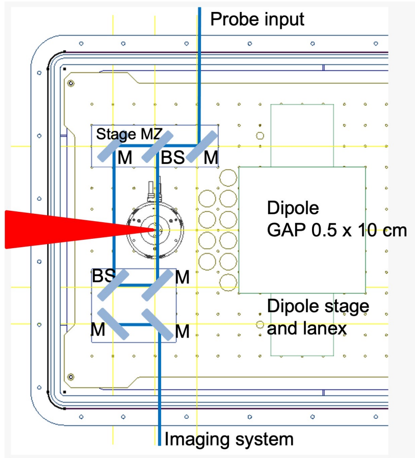
PIANO NAZIONALE DI RIPRESA E RESILIENZA

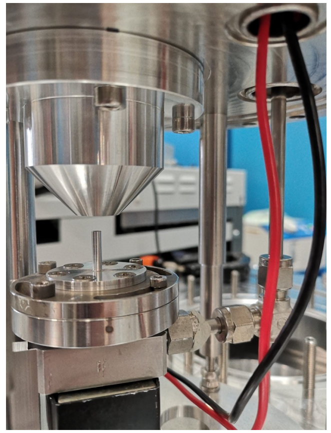
EuPRAXIA
Advanced Photon Sources

Interaction point



- Preliminary design, final expected end of June
- Vacuum test ongoing
- Space occupancy inside the interaction chamber defined






Thank for your attention