EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA
Preparatory Phase

The EuPRAXIA project

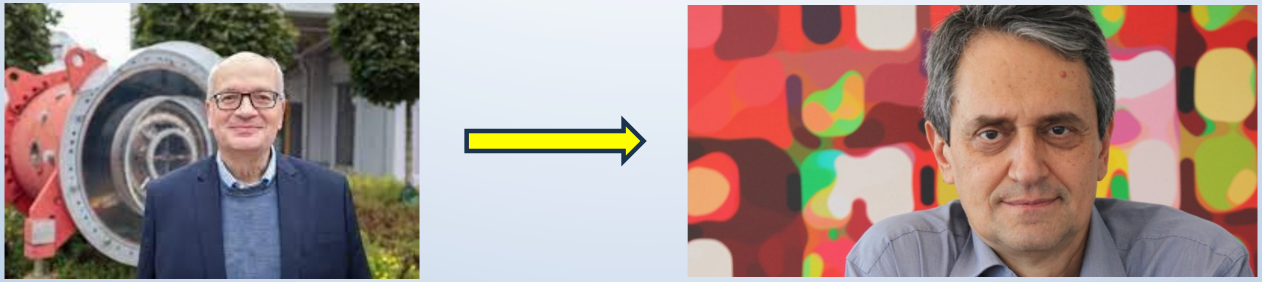
a plasma-based accelerator user facility for the next decade

M. Ferrario (INFN-LNF)
On behalf of the EuPRAXIA Collaboration

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

A new coordinator for the EuPRAXIA ESFRI and PP projects

The EuPRAXIA ESFRI Collaboration Board and the EuPRAXIA-PP Collaboration Board have recently approved the appointment of **Pierluigi Campana** as new coordinator of the EuPRAXIA ESFRI and PP projects. He will take over from **Ralph Assmann** who has recently decided to step down as coordinator due to new obligations.



Pierluigi Campana is an experimental high-energy physicist with extensive experience in the field of particle detectors. His research career began at Frascati National Laboratory of INFN. He participated in the ALEPH experiment at the CERN LEP accelerator and later in the KLOE experiment at DAFNE at LNF. Since 2002, he has been a member of the LHCb collaboration at the CERN Large Hadron Collider and served as the spokesperson from 2011 to 2014. In 2015, he was appointed Director of the National Laboratories of Frascati, a position he held until 2020 when he was appointed as a member of the MUR (Minister of Research and University) in the INFN Executive Board, a position expired at the end of 2023. Pierluigi since 2021 is the Italian Delegate in ESFRI and, starting from January 1, 2024, is the Chair of ICFA.

Pierluigi Campana knows the EuPRAXIA project from the inside out since its start. He has accompanied it in his various roles, has attended many of our meetings and is one of our strongest supporters. In the view of both of us he is an excellent candidate and will be an outstanding coordinator, bringing in his knowledge of EuPRAXIA, his senior management experience and his international standing.
With our best regards,

A New European High-Tech User Facility

Funded by the European Union

1

Building a facility with very high field plasma accelerators, driven by lasers or beams
1 – 100 GV/m accelerating field

Shrink down the facility size
Improve Sustainability

2

Producing particles and photons to support several urgent and timely science cases

Drive short wavelength FEL
Pave the way for future Linear Colliders

https://www.eupraxia-facility.org/

FEATURE EuPRAXIA

A Martinez de la Ossa/DESY

Surf's up *Simulation of electron-driven plasma wakefield acceleration, showing the drive electron beam (orange/purple), the plasma electron wake (grey) and wakefield-ionised electrons forming a witness beam (orange).*

EUROPE TARGETS A USER FACILITY FOR PLASMA ACCELERATION

Ralph Assmann, Massimo Ferrario and Carsten Welsch describe the status of the ESFRI project EuPRAXIA, which aims to develop the first dedicated research infrastructure based on novel plasma-acceleration concepts.

Energetic beams of particles are used to explore the fundamental forces of nature, produce known and unknown particles such as the Higgs boson at the LHC, and generate new forms of matter, for example at the future FAIR facility. Photon science also relies on particle beams: electron beams that emit pulses of intense synchrotron light, including soft and hard X-rays, in either circular or linear machines. Such light sources enable time-resolved measurements of biological, chemical and physical structures on the molecular down to the atomic scale, allowing a diverse global community of users to investigate systems ranging from viruses and bacteria to materials science, planetary science, environmental science, nanotechnology and archaeology. Last but not least, particle beams for industry and health support many societal applications ranging from the X-ray inspection of cargo containers to food sterilisation, and from chip manufacturing to cancer therapy.

This scientific success story has been made possible through a continuous cycle of innovation in the physics and technology of particle accelerators, driven for many decades by exploratory research in nuclear and particle physics. The invention of radio-frequency (RF) technology in the 1920s opened the path to an energy gain of several tens of MeV per metre. Very-high-energy accelerators were constructed with RF technology, entering the GeV and finally the TeV energy scales at the Tevatron and the LHC. New collision schemes were developed, for example the mini "beta squeeze" in the 1970s, advancing luminosity and collision rates by orders of magnitudes. The invention of stochastic cooling at CERN enabled the discovery of the W and Z bosons 40 years ago.

However, intrinsic technological and conceptual limits mean that the size and cost of RF-based particle accelerators are increasing as researchers seek higher beam energies. Colliders for particle physics have reached a

THE AUTHORS

Ralph Assmann *DESY and INFN,* **Massimo Ferrario** *INFN,* **Carsten Welsch** *University of Liverpool/INFN.*

CERN COURIER MAY/JUNE 2023

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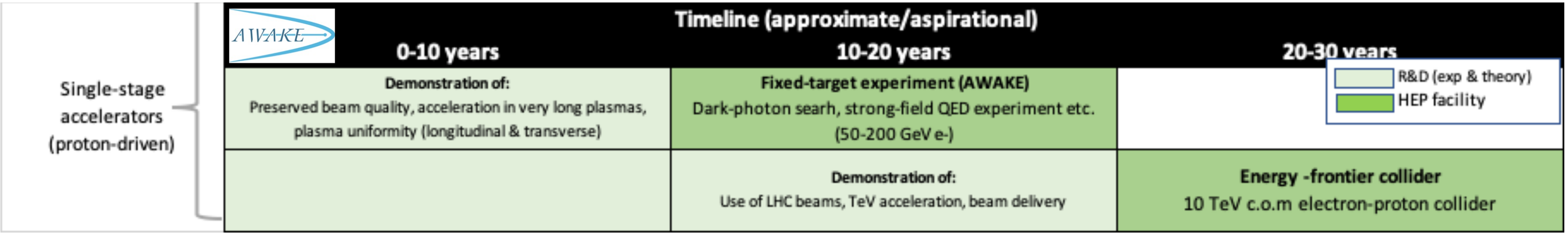
ESPP Roadmap Update – Plasma Accelerators

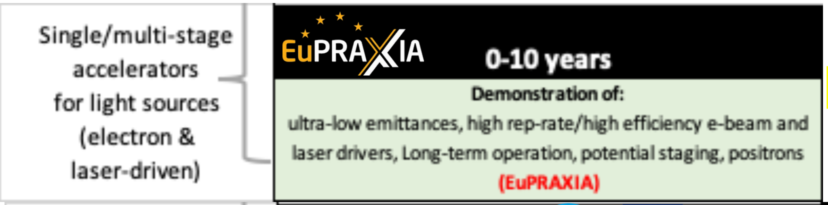


AWAKE

Timeline (approximate/aspirational)

	0-10 years	10-20 years	20-30 years
Single-stage accelerators (proton-driven)	**Demonstration of:** Preserved beam quality, acceleration in very long plasmas, plasma uniformity (longitudinal & transverse)	**Fixed-target experiment (AWAKE)** Dark-photon searh, strong-field QED experiment etc. (50-200 GeV e-)	
		Demonstration of: Use of LHC beams, TeV acceleration, beam delivery	**Energy -frontier collider** 10 TeV c.o.m electron-proton collider

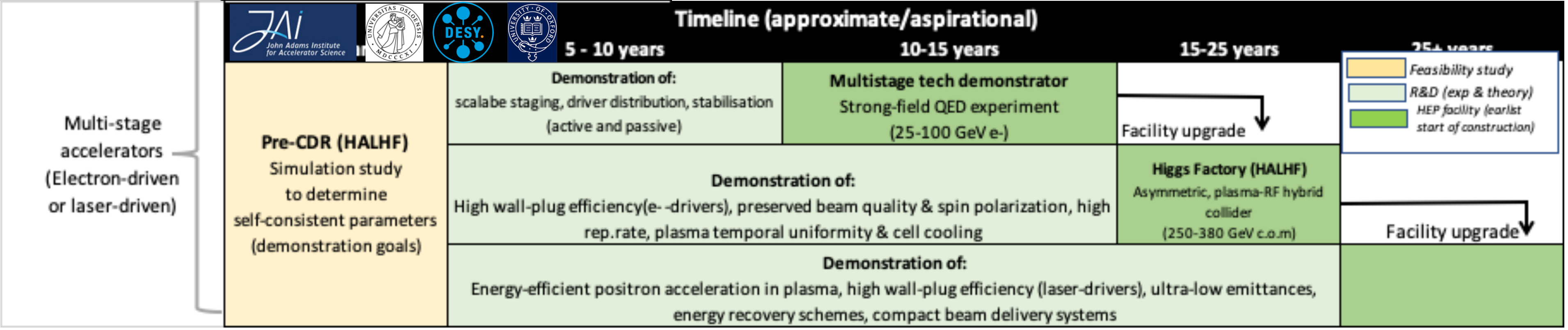
- ▭ R&D (exp & theory)
- 🟩 HEP facility



	EuPRAXIA 0-10 years
Single/multi-stage accelerators for light sources (electron & laser-driven)	**Demonstration of:** ultra-low emittances, high rep-rate/high efficiency e-beam and laser drivers, Long-term operation, potential staging, positrons **(EuPRAXIA)**

EuPRAXIA Paves the way to LC:

R&D on critical Components, High Rep. Rate,
Training, Shorter time perspective, Motivations,
Financial Support already on common interest components



Timeline (approximate/aspirational)

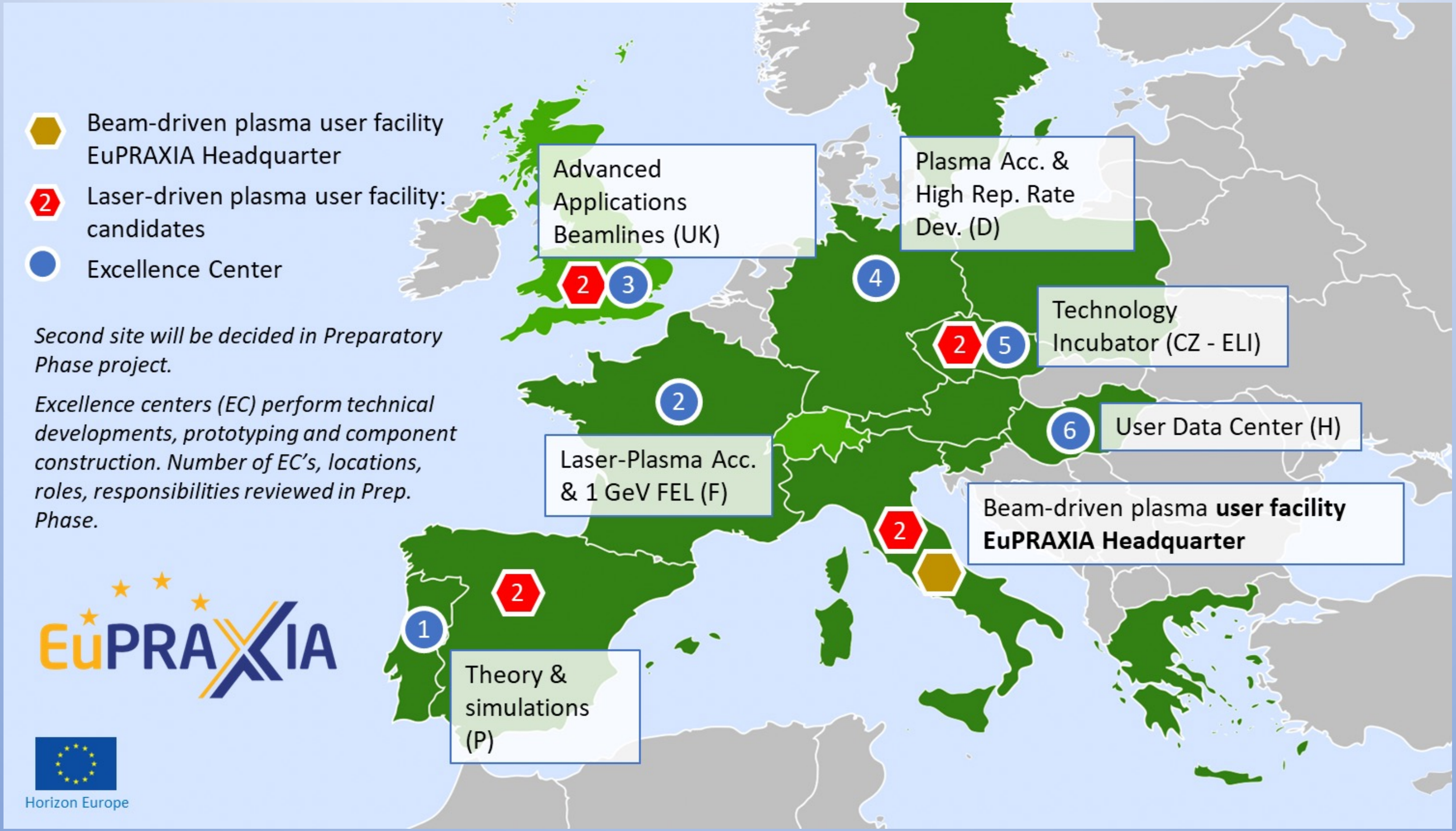
		5 - 10 years	10-15 years	15-25 years	25+ years
Multi-stage accelerators (Electron-driven or laser-driven)	**Pre-CDR (HALHF)** Simulation study to determine self-consistent parameters (demonstration goals)	**Demonstration of:** scalabe staging, driver distribution, stabilisation (active and passive)	**Multistage tech demonstrator** Strong-field QED experiment (25-100 GeV e-)	Facility upgrade	
		Demonstration of: High wall-plug efficiency(e- -drivers), preserved beam quality & spin polarization, high rep.rate, plasma temporal uniformity & cell cooling		**Higgs Factory (HALHF)** Asymmetric, plasma-RF hybrid collider (250-380 GeV c.o.m)	Facility upgrade
		Demonstration of: Energy-efficient positron acceleration in plasma, high wall-plug efficiency (laser-drivers), ultra-low emittances, energy recovery schemes, compact beam delivery systems			

- ▭ *Feasibility study*
- ▭ *R&D (exp & theory)*
- 🟩 *HEP facility (earlist start of construction)*

EuPRAXIA

Distributed Research Infrastructure

Funded by the European Union



- ⬢ Beam-driven plasma user facility EuPRAXIA Headquarter
- 2 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)

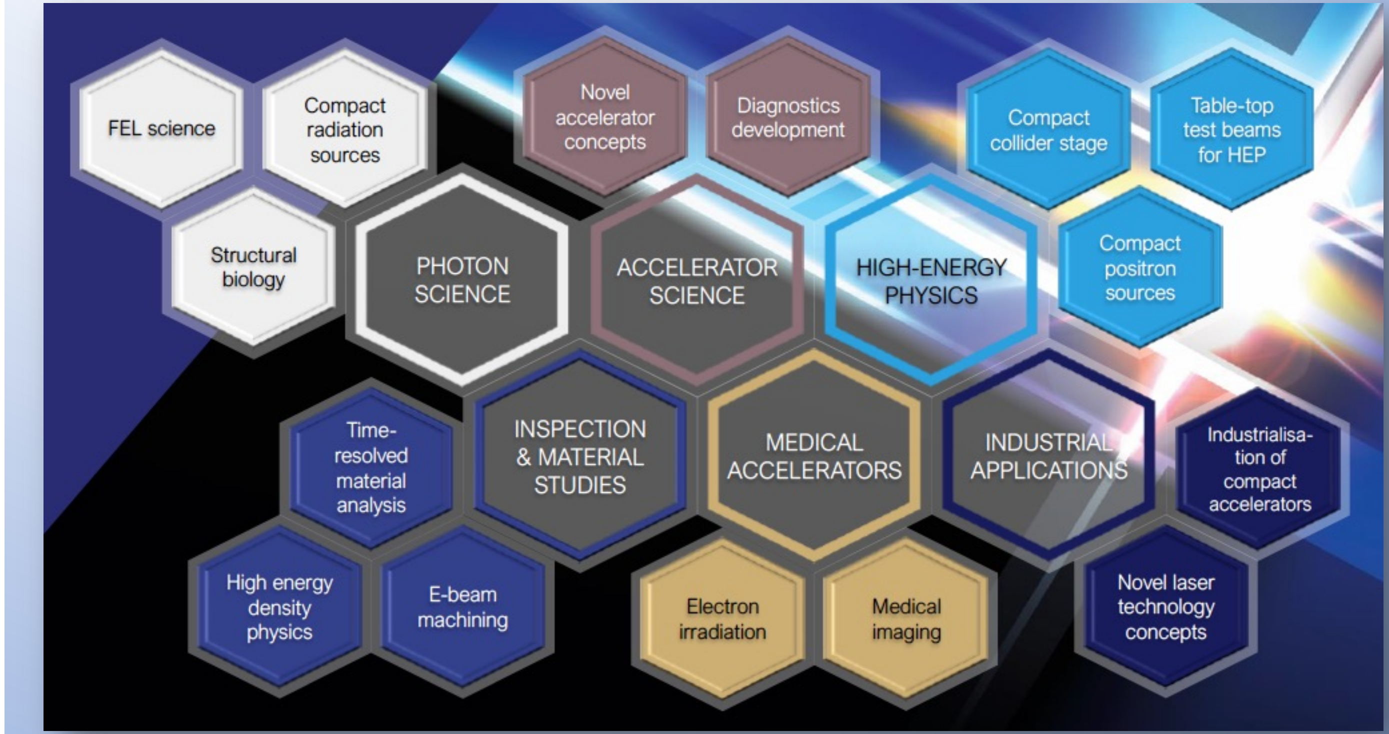
EuPRAXIA

Horizon Europe

Intense R&D Program on critical components

Funded by the European Union

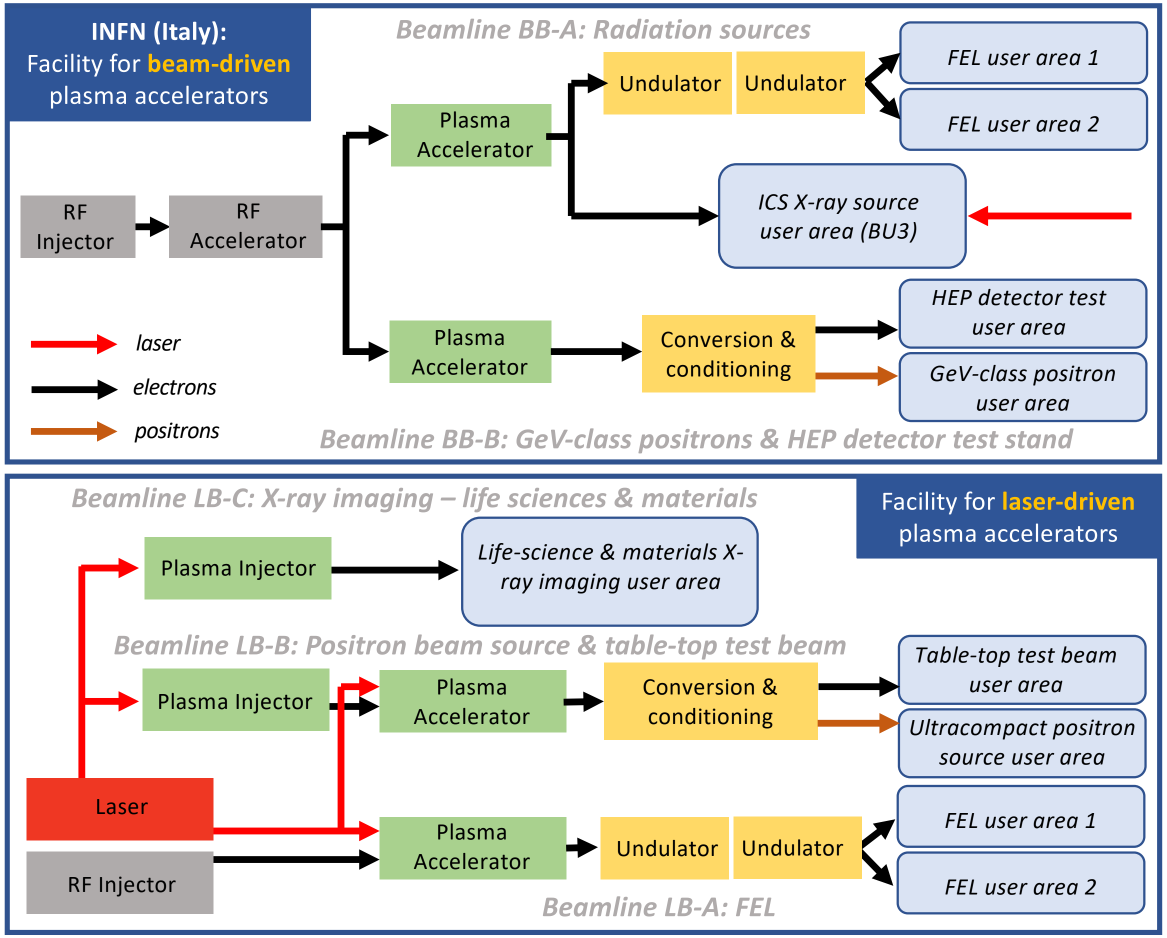
- **Electrons**
  (0.1-5 GeV, 30 pC)
- **Positrons**
  (0.5-10 MeV, 10^6)
- **Positrons** (GeV source)
- **Lasers**
  (100 J, 50 fs, 10-100 Hz)
- **X-band RF Linac**
  (60 MV/m , up to 400 Hz)
- **Plasma Targets**
- **Betatron X rays**
  (1-10 keV, 10^{10})
- **FEL light**
  (0.2-36 nm, 10^9-10^{13})



Phased Implementation of Construction Sites

Funded by the European Union

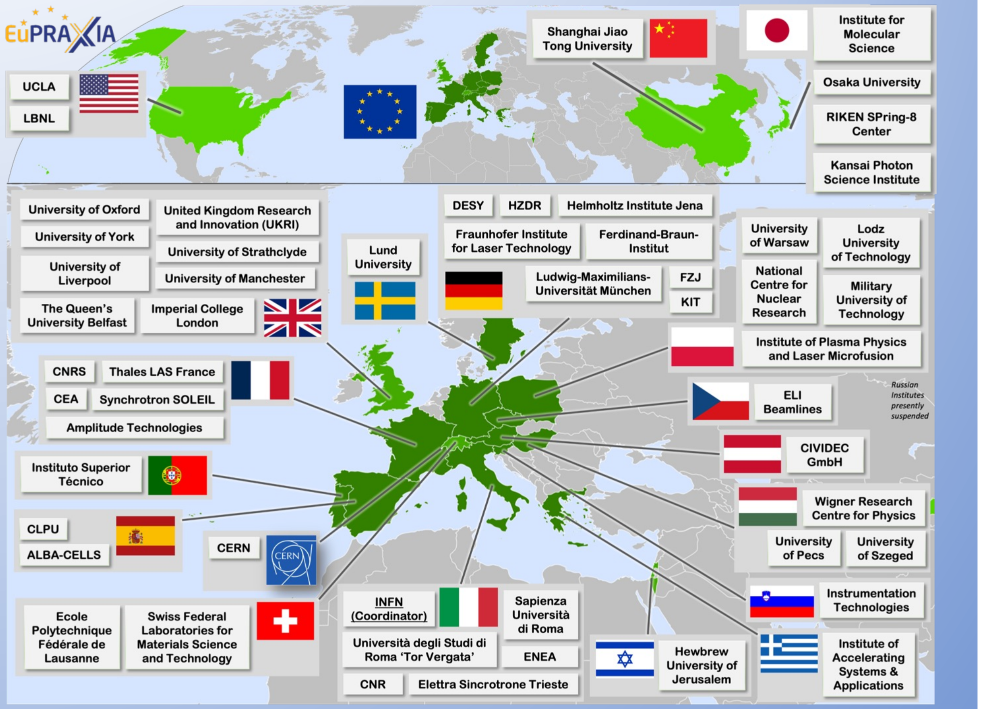
	Laser-driven	Beam-driven
Phase 1	✓ FEL beamline to 1 GeV + user area 1 ✓ Ultracompact positron source beamline + positron user area	✓ FEL beamline to 1 GeV + user area 1 ✓ GeV-class positrons beamline + positron user area
Phase 2	✓ X-ray imaging beamline + user area ✓ Table-top test beams user area ✓ FEL user area 2 ✓ FEL to 5 GeV	✓ ICS source beamline + user area ✓ HEP detector tests user area ✓ FEL user area 2 ✓ FEL to 5 GeV
Phase 3	✓ High-field physics beamline / user area ✓ Other future developments	✓ Medical imaging beamline / user area ✓ Other future developments



Wide International Collaboration

Funded by the European Union

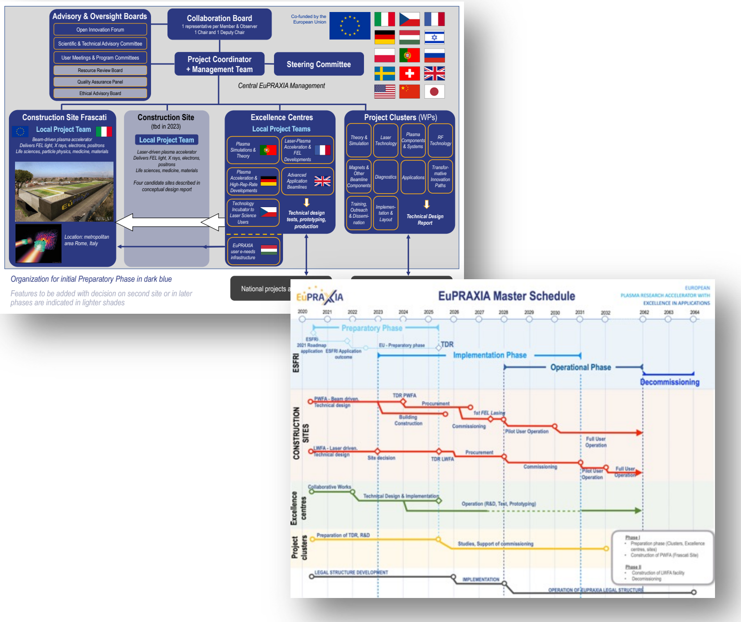
- The EuPRAXIA Consortium today: **54 institutes** from **18 countries** plus CERN
- Included in the **ESFRI** Road Map
- Efficient fund raising:
  - **Preparatory Phase** consortium (funding EU, UK, Switzerland, in-kind)
  - **Doctoral Network** (funding EU, UK, in-kind)
  - **EuPRAXIA@SPARC_LAB** (Italy, in-kind)
  - **EuAPS Project** (Next Generation EU)
  - What Next? => PACRI (funding EU)

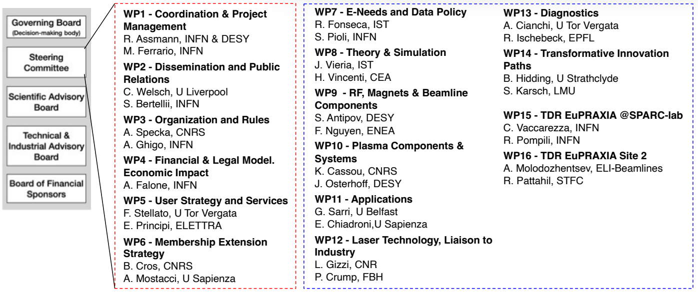


Preparatory Phase Main Goals

Funded by the European Union

- Managerial WP`s
  - **Outreach** to public, users, EU decision makers and industry
  - **Define** legal model (how is EuPRAXIA governed?), financial model, rules, user services and membership extension for full implementation
  - Works with **project bodies and funding agencies** → Board of Financial Sponsors
- Technical WP‘s (correspond to Project Clusters):
  - **Update of CDR** concepts and parameters, towards technical design (full technical design requires more funding)
  - Specify in detail **Excellence Centers and their required funding**: TDR related R&D, prototyping, contributions to construction
  - Help in defining funding applications for various agencies
- Output defined in **milestones & deliverables** with dates




Governing Board (Decision-making body)
Steering Committee
Scientific Advisory Board
Technical & Industrial Advisory Board
Board of Financial Sponsors

WP1 - Coordination & Project Management
R. Assmann, INFN & DESY
M. Ferrario, INFN

WP2 - Dissemination and Public Relations
C. Welsch, U Liverpool
S. Bertellii, INFN

WP3 - Organization and Rules
A. Specka, CNRS
A. Ghigo, INFN

WP4 - Financial & Legal Model. Economic Impact
A. Falone, INFN

WP5 - User Strategy and Services
F. Stellato, U Tor Vergata
E. Principi, ELETTRA

WP6 - Membership Extension Strategy
B. Cros, CNRS
A. Mostacci, U Sapienza

WP7 - E-Needs and Data Policy
R. Fonseca, IST
S. Pioli, INFN

WP8 - Theory & Simulation
J. Vieria, IST
H. Vincenti, CEA

WP9 - RF, Magnets & Beamline Components
S. Antipov, DESY
F. Nguyen, ENEA

WP10 - Plasma Components & Systems
K. Cassou, CNRS
J. Osterhoff, DESY

WP11 - Applications
G. Sarri, U Belfast
E. Chiadroni,U Sapienza

WP12 - Laser Technology, Liaison to Industry
L. Gizzi, CNR
P. Crump, FBH

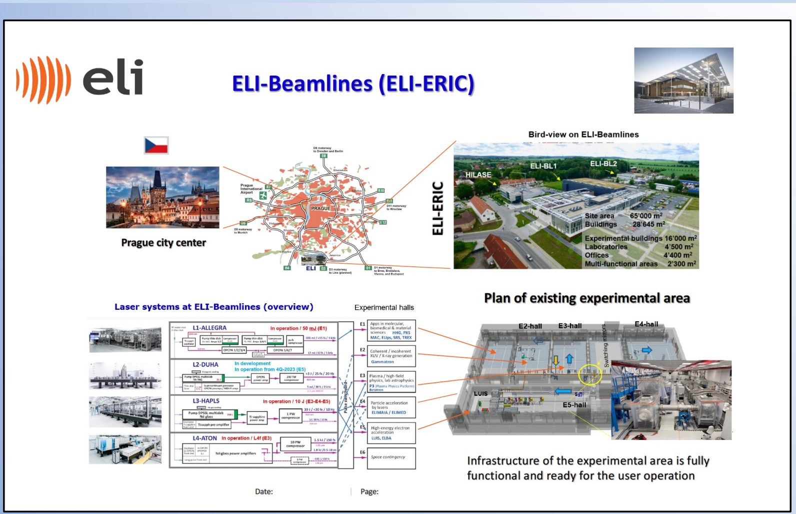
WP13 - Diagnostics
A. Cianchi, U Tor Vergata
R. Ischebeck, EPFL

WP14 - Transformative Innovation Paths
B. Hidding, U Strathclyde
S. Karsch, LMU

WP15 - TDR EuPRAXIA @SPARC-lab
C. Vaccarezza, INFN
R. Pompili, INFN

WP16 - TDR EuPRAXIA Site 2
A. Molodozhentsev, ELI-Beamlines
R. Pattahil, STFC

Current Candidates for EuPRAXIA Laser Site



ELI-Beamlines (ELI-ERIC)

Prague city center

Bird-view on ELI-Beamlines

Site area 65'000 m²
Buildings 28'645 m²
Experimental buildings 16'000 m²
Laboratories 4'500 m²
Offices 4'400 m²
Multi-functional areas 2'300 m²

Laser systems at ELI-Beamlines (overview)

Plan of existing experimental area

Infrastructure of the experimental area is fully functional and ready for the user operation

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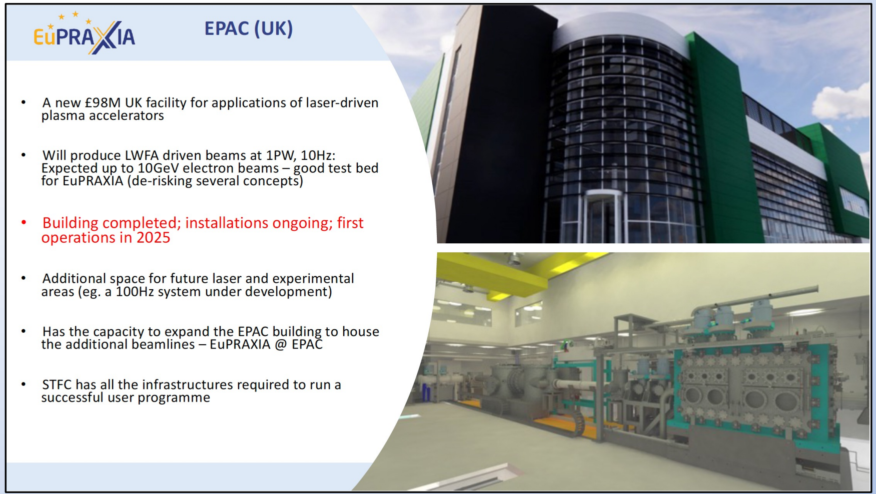
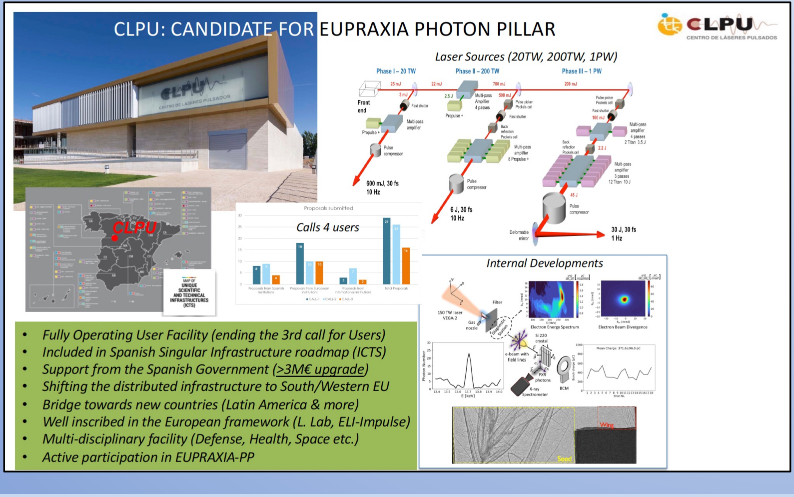


EPAC (UK)

- A new £98M UK facility for applications of laser-driven plasma accelerators
- Will produce LWFA driven beams at 1PW, 10Hz: Expected up to 10GeV electron beams – good test bed for EuPRAXIA (de-risking several concepts)
- Building completed; installations ongoing; first operations in 2025
- Additional space for future laser and experimental areas (eg. a 100Hz system under development)
- Has the capacity to expand the EPAC building to house the additional beamlines – EuPRAXIA @ EPAC
- STFC has all the infrastructures required to run a successful user programme



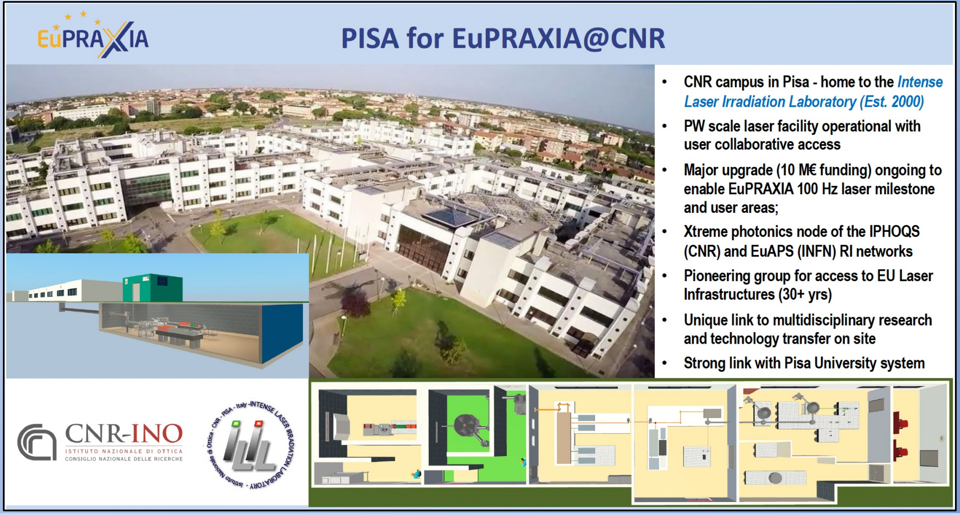
CLPU: CANDIDATE FOR EUPRAXIA PHOTON PILLAR

Laser Sources (20TW, 200TW, 1PW)

Calls 4 users

Internal Developments

- *Fully Operating User Facility (ending the 3rd call for Users)*
- *Included in Spanish Singular Infrastructure roadmap (ICTS)*
- *Support from the Spanish Government (>3M€ upgrade)*
- *Shifting the distributed infrastructure to South/Western EU*
- *Bridge towards new countries (Latin America & more)*
- *Well inscribed in the European framework (L. Lab, ELI-Impulse)*
- *Multi-disciplinary facility (Defense, Health, Space etc.)*
- *Active participation in EUPRAXIA-PP*



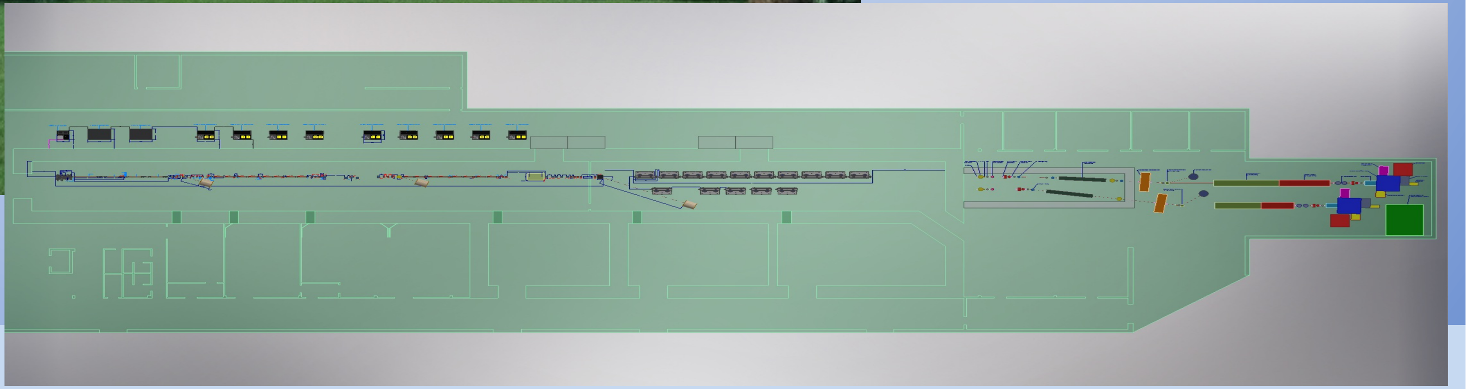
PISA for EuPRAXIA@CNR

- CNR campus in Pisa - home to the *Intense Laser Irradiation Laboratory (Est. 2000)*
- PW scale laser facility operational with user collaborative access
- Major upgrade (10 M€ funding) ongoing to enable EuPRAXIA 100 Hz laser milestone and user areas;
- Xtreme photonics node of the IPHOQS (CNR) and EuAPS (INFN) RI networks
- Pioneering group for access to EU Laser Infrastructures (30+ yrs)
- Unique link to multidisciplinary research and technology transfer on site
- Strong link with Pisa University system

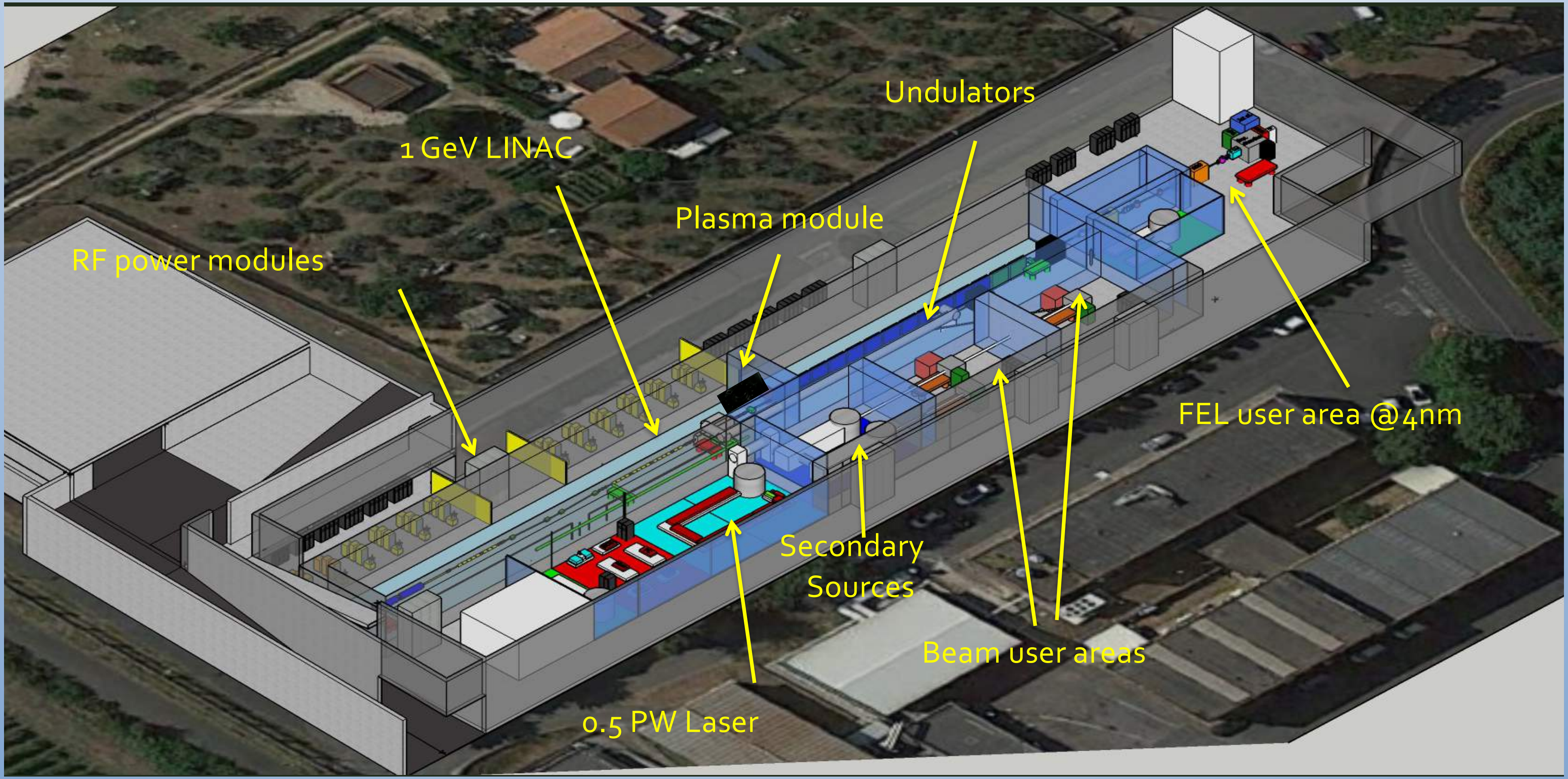
CNR-INO
ISTITUTO NAZIONALE DI OTTICA
CONSIGLIO NAZIONALE DELLE RICERCHE

Headquarter and Site 1: EuPRAXIA@SPARC_LAB

- Frascati`s future facility
- > 130 M€ invest funding
- Beam-driven plasma accelerator
- Europe`s most compact and most southern FEL
- The world`s most compact RF accelerator (X band with CERN)



EuPRAXIA@SPARC_LAB



Plasma accelerated beam driven FEL

It's a CHALLENGE: **the FEL is extremely sensitive to the beam quality.**

Low (geometric) emittances: $\epsilon_{x,y} < \dfrac{\lambda_0}{4\pi}$

Low relative energy spread σ_γ: $\sigma_\gamma < \dfrac{1}{2}\rho_{fel}$

Low emittances

Low energy spread

High current

where $$\rho_{fel} = \frac{1}{4\pi}\left[\frac{2\pi^2}{\gamma^3}\left(\lambda_u K\,[JJ]\right)^2 \frac{I_{peak}}{\Sigma_e I_A}\right]^{1/3}$$

Exponential growth

$$P(z) = \frac{1}{9}P_0 e^{z/L_g}$$

gain length

$$L_g = \frac{\lambda_u}{4\pi\sqrt{3}\rho_{fel}}$$

saturation

$$P_F \sim 1.6\,\rho_{fel} P_{beam}$$

=> A poor beam quality causes an increase of L_g and a reduction of P_F

Required Bunch Energy Stability

$$\frac{\Delta\lambda}{\lambda} \propto \frac{\Delta E}{E} \propto \rho \approx 10^{-3}$$

FEL requirement

$$E_z\left(\frac{\lambda_p}{2}\right) = \tilde{A}\sqrt{n_p I_d}$$

$$\left.\frac{\Delta E}{E}\right|_p = \frac{\Delta n_p}{n_p}$$

Plasma density

$$\left.\frac{\Delta E}{E}\right|_Q = \frac{\Delta I_d}{2\left(I_d\right)} + \frac{\Delta I_w}{2\left(I_w\right)}$$

Bunch charge/length

$$\left.\frac{\Delta E}{E}\right|_{DW} = \frac{a\omega_p}{2\pi}\Delta t_{DW}$$

$$2 \leq a \leq 4$$

Driver/Witness separation

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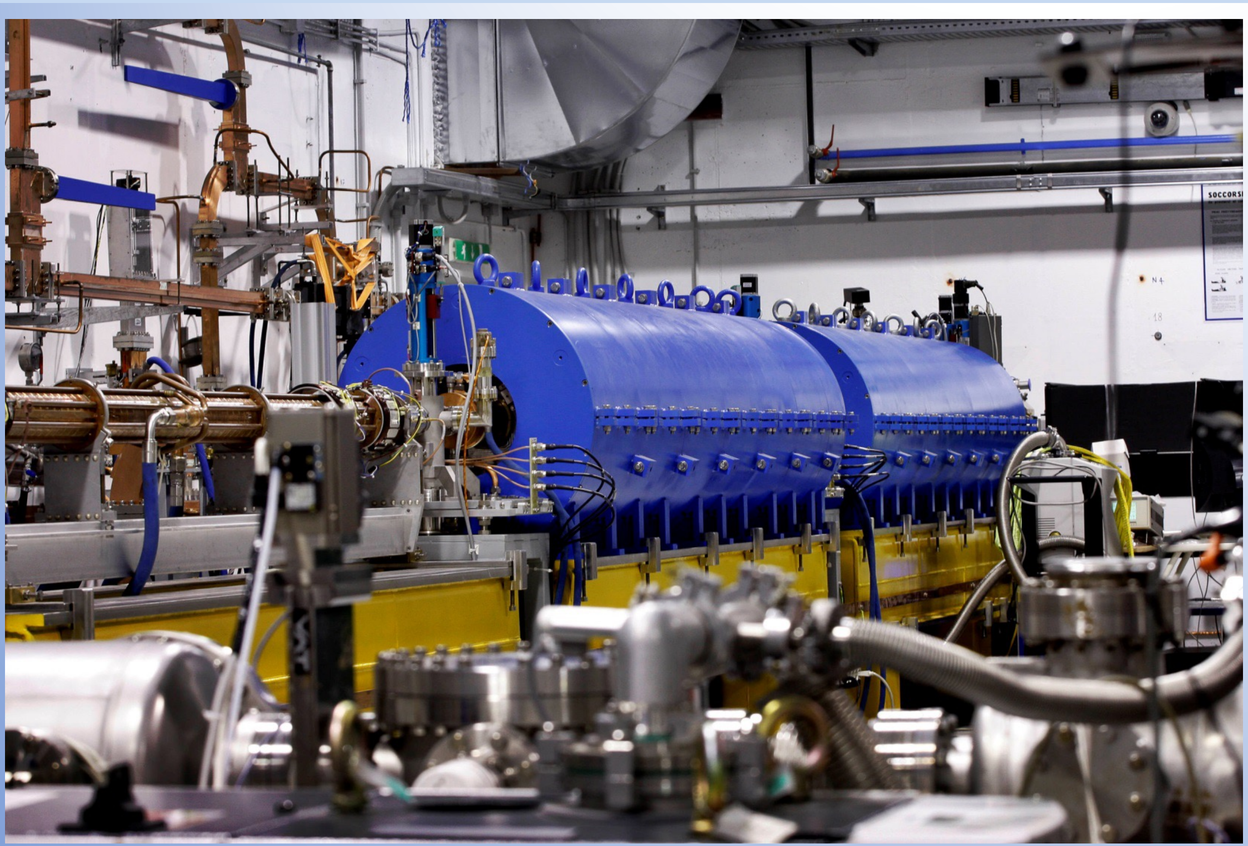
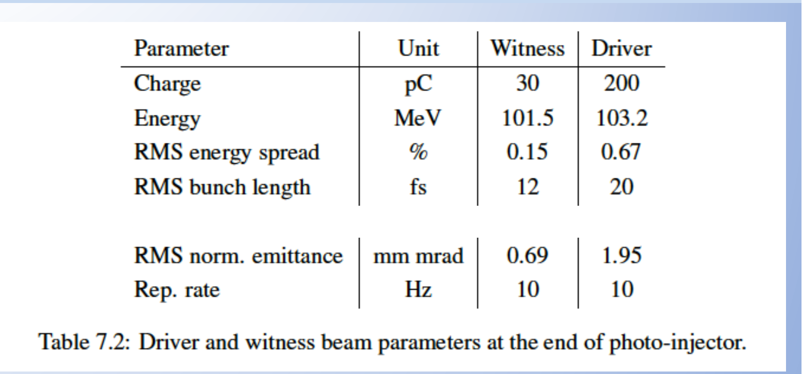
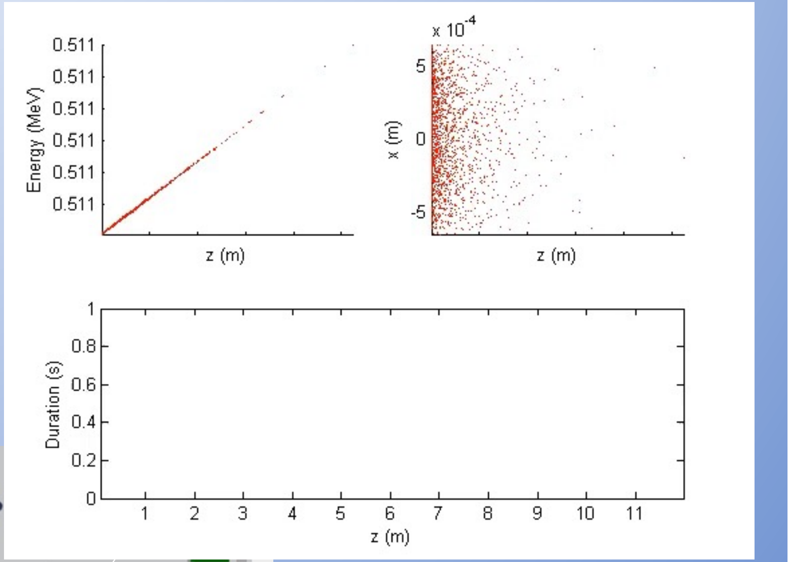
High Quality Electron Beams





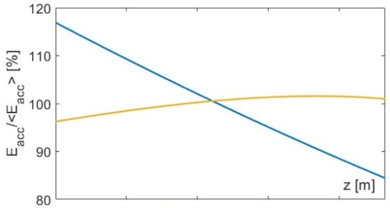
Parameter	Unit	Witness	Driver
Charge	pC	30	200
Energy	MeV	101.5	103.2
RMS energy spread	%	0.15	0.67
RMS bunch length	fs	12	20
RMS norm. emittance	mm mrad	0.69	1.95
Rep. rate	Hz	10	10

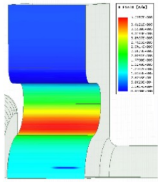
Table 7.2: Driver and witness beam parameters at the end of photo-injector.



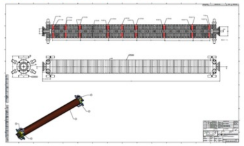
Courtesy E. Chiadroni

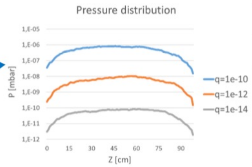
World`s Most Compact RF Linac: X Band

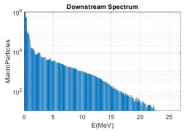




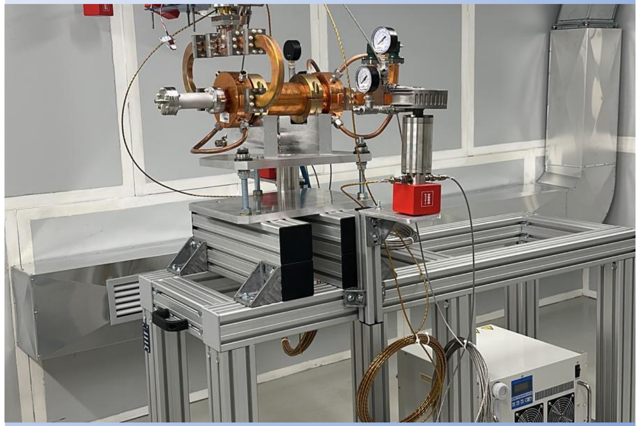
1. **E.m. design**: *done*
2. **Thermo-mechanical analysis**: *done*
3. **Mechanical design**: *done*
4. **Vacuum calculations**: *done*
5. **Dark current simulations**: *done*
6. **Waveguide distribution simulation with attenuation calculations**: *done*

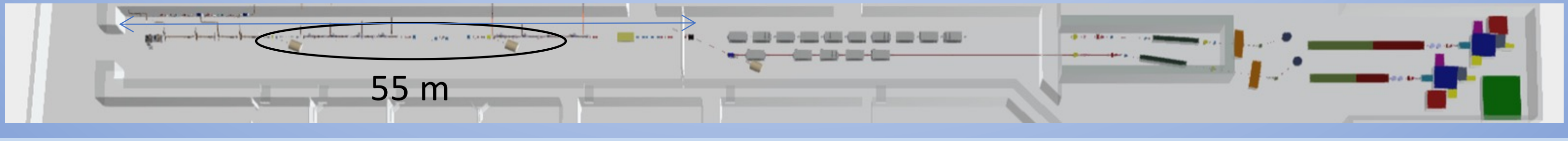






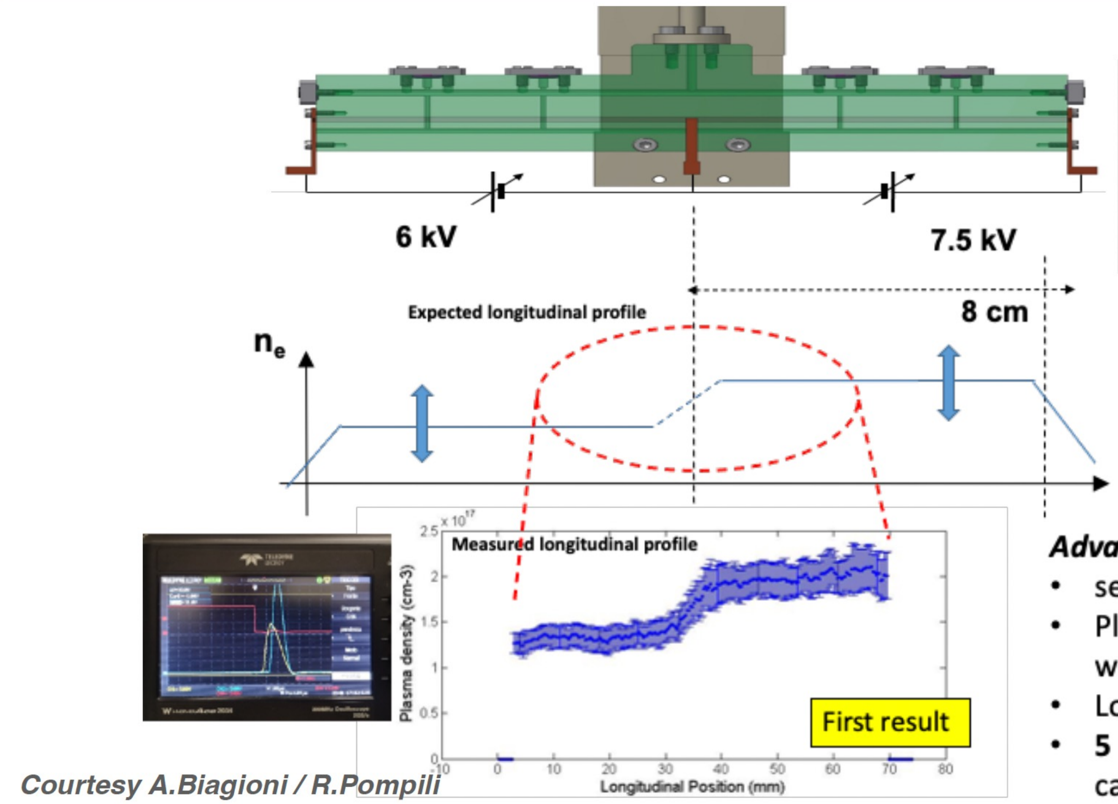
PARAMETER	Value	
	with linear tapering	w/o tapering
Frequency [GHz]	11.9942	
Average acc. gradient [MV/m]	**60**	
Structures per module	2	
Iris radius a [mm]	**3.85-3.15**	**3.5**
Tapering angle [deg]	0.04	0
Struct. length L_s act. Length (flange-to-flange) [m]	**0.94 (1.05)**	
No. of cells	112	
Shunt impedance R [MΩ/m]	93-107	100
Effective shunt Imp. $R_{sh\ eff}$ [MΩ/m]	350	347
Peak input power per structure [MW]	70	
Input power averaged over the pulse [MW]	51	
Average dissipated power [kW]	1	
P_{out}/P_{in} [%]	25	
Filling time [ns]	130	
Peak Modified Poynting Vector [W/μm²]	3.6	4.3
Peak surface electric field [MV/m]	160	190
Unloaded SLED/BOC Q-factor Q_0	150000	
External SLED/BOC Q-factor Q_E	21300	20700
Required Kly power per module [MW]	**20**	
RF pulse [μs]	**1.5**	
Rep. Rate [Hz]	**100**	



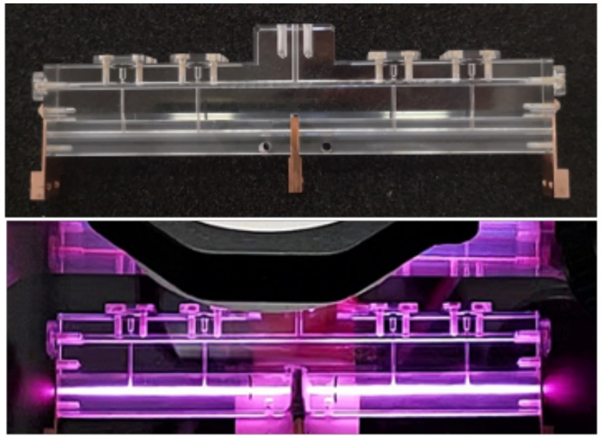


Courtesy D. Alesini

Plasma Module

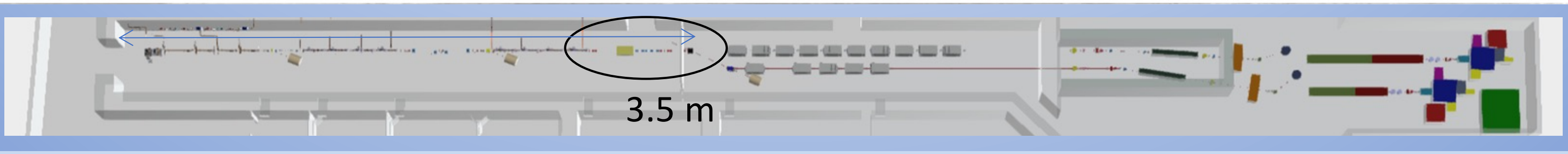


Courtesy A.Biagioni / R.Pompili



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)

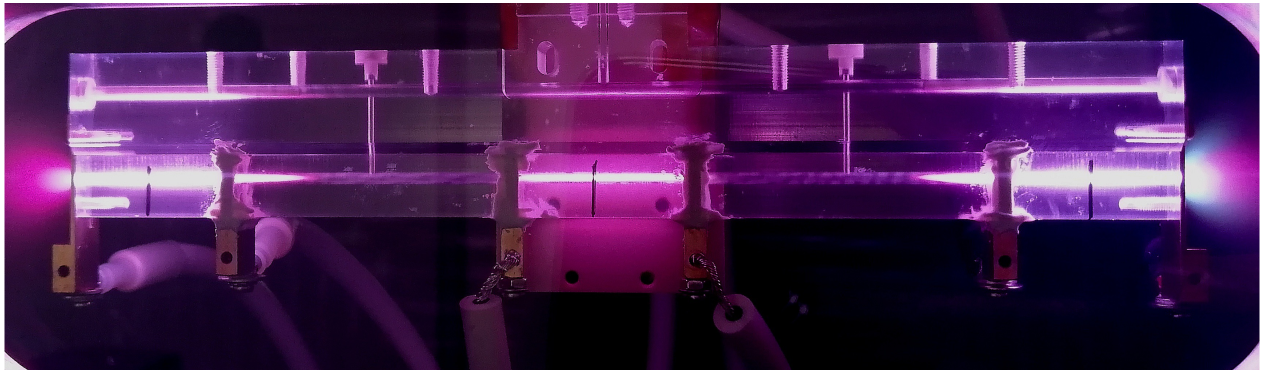


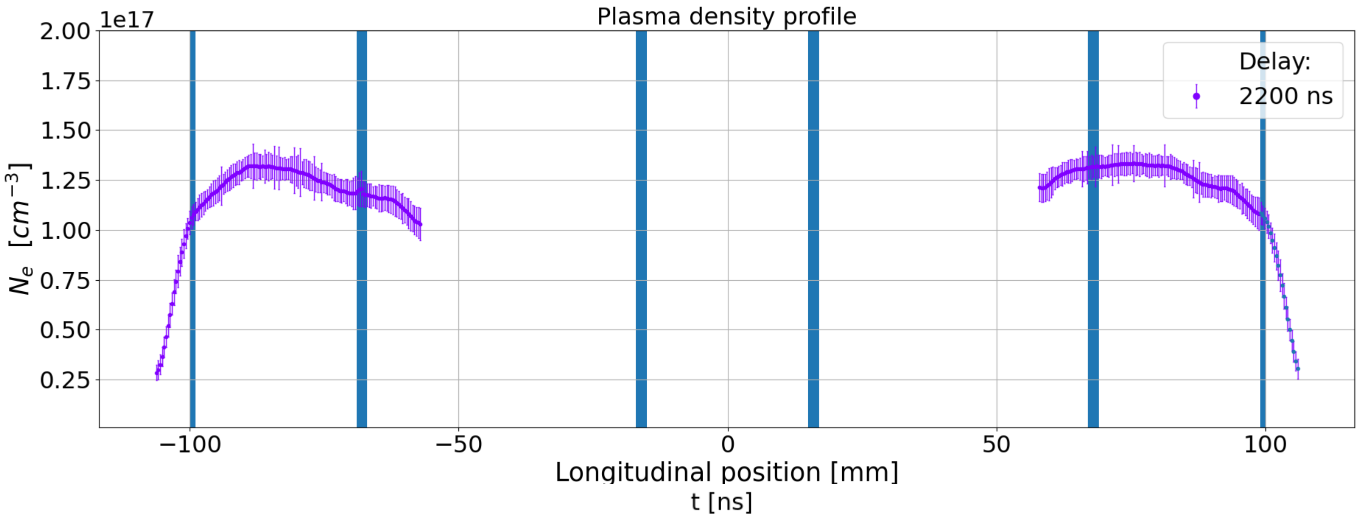
Courtesy A. Biagioni, R. Pompili

Novel schemes for long sources and staged acceleration

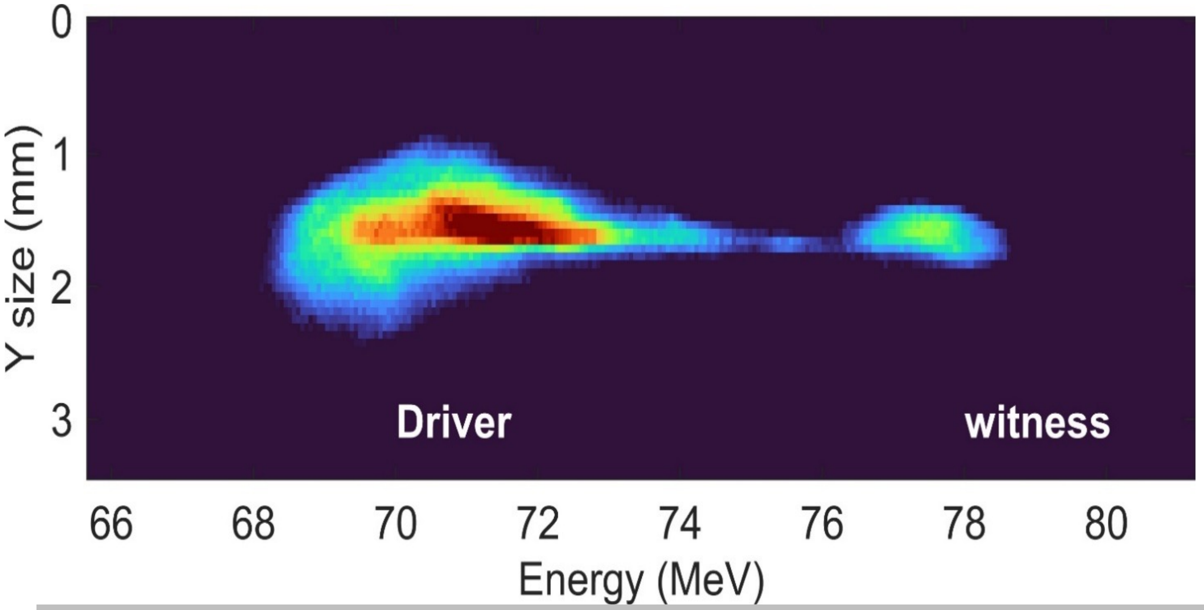
Operating properties

- Discharges synchronization
  - Lenses synchronized with the beam entrance
  - Central discharge applied 3 μs before for plasma acceleration
- 10 kV voltage resulting in:
  - 500 A on the lenses
  - 250 A in the accelerator
- Internal drifts behave like spacers

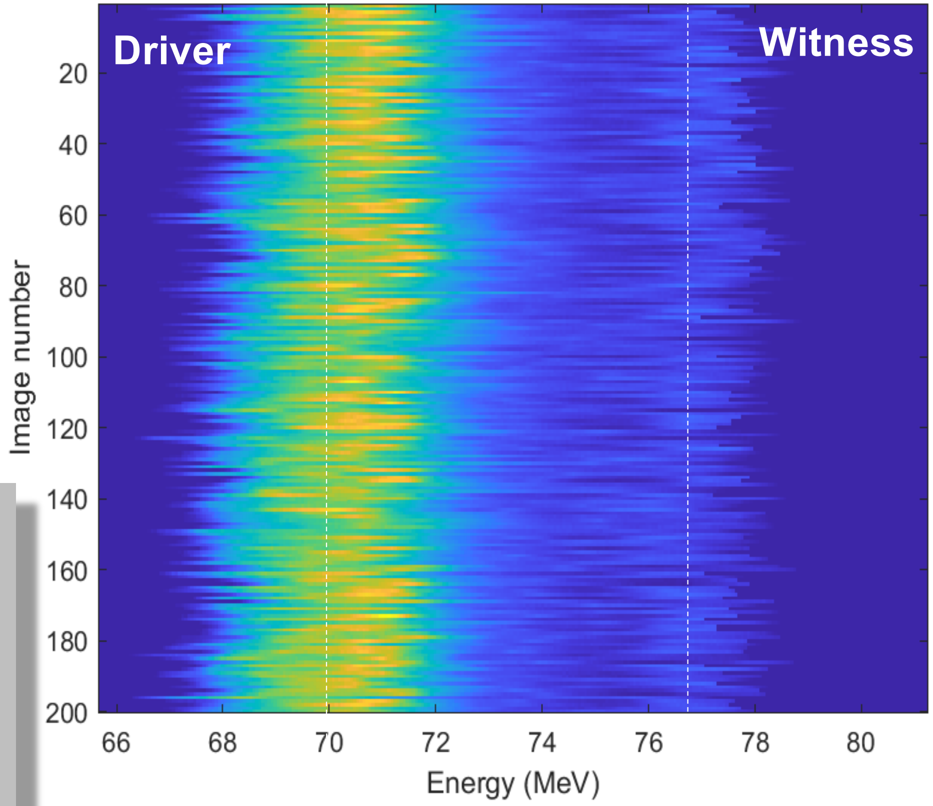




Beam acceleration in the integrated plasma module



200 consecutive shots taken with accelerated beam



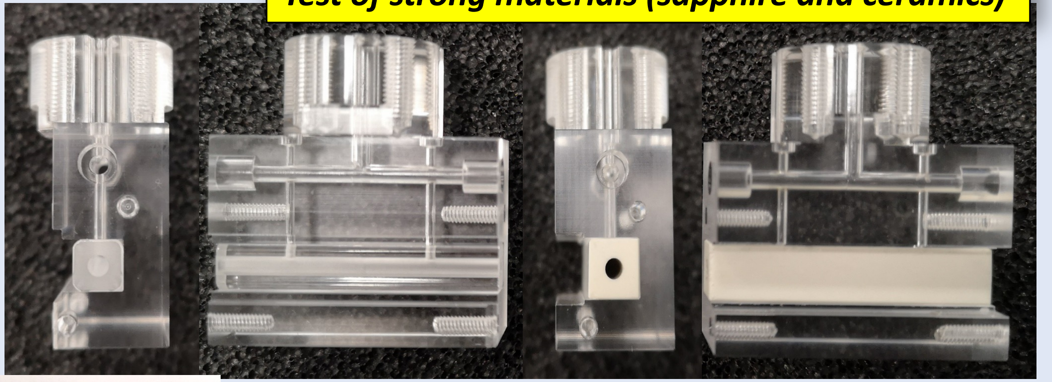
- ***5 MeV/3cm acceleration in 19 cm long integrated plasma module with 200 pC driver/50 pC witness***
  - 3 cm long accelerator with 200 A ionization current
  - 3 cm long plasma lenses with 500 A ionization current
  - Plasma density inside the accelerator set to $2x10^{15}$ cm^{-3}
  - ~150 MV/m accelerating gradient
  - Stability of the accelerated beam

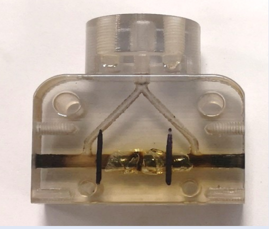
High repetition Rate capillary for EuPRAXIA

To operate at high repetition rate the key point is the thermal dissipation

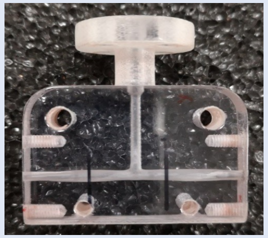
1. Solid-state high repetition-rate discharge system
2. Strong materials capable of dissipating thermal energy
3. Vacuum systems suitable for continuous flow gas injection (turbo and primary pumps cooling system)

Test of strong materials (sapphire and ceramics)





High repRATE can cause a rapid degradation of unsuitable soft materials



HV- generator

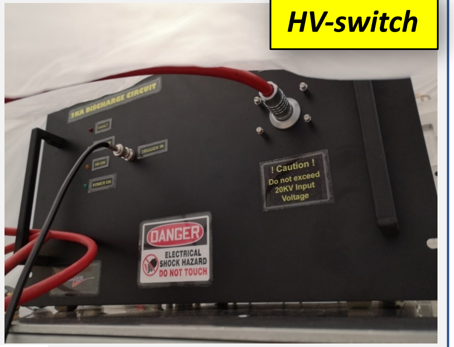
25 kV

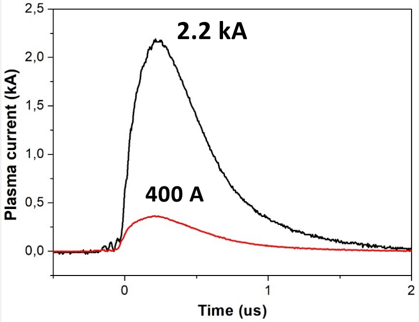
20-200 mA

High voltage for plasma formation
High current output for high repRATE

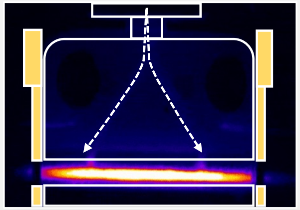
Thermal dissipation of components is crucial

HV-switch





Current pulses from 100 to 2500 A at repetition rate from 1 to 400 Hz

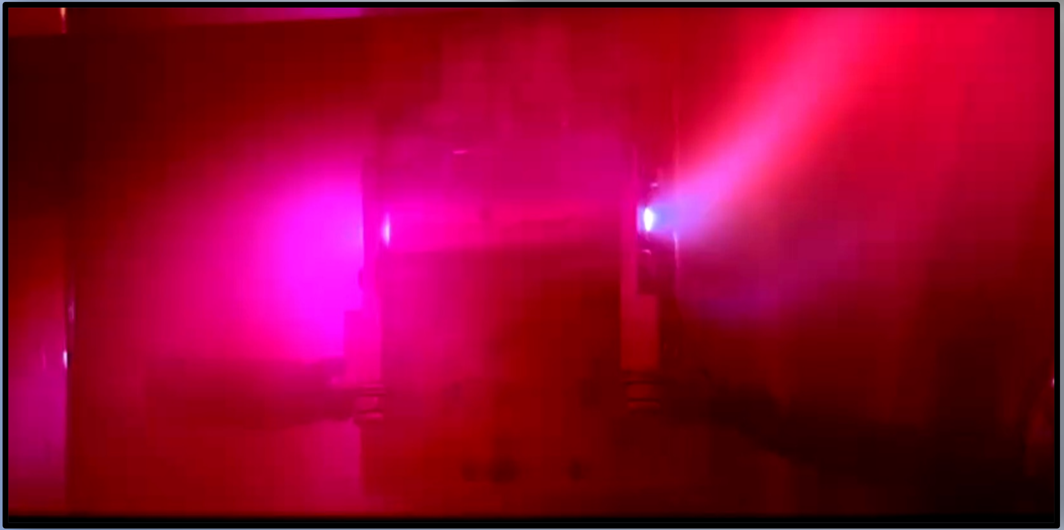


Discharge capillary

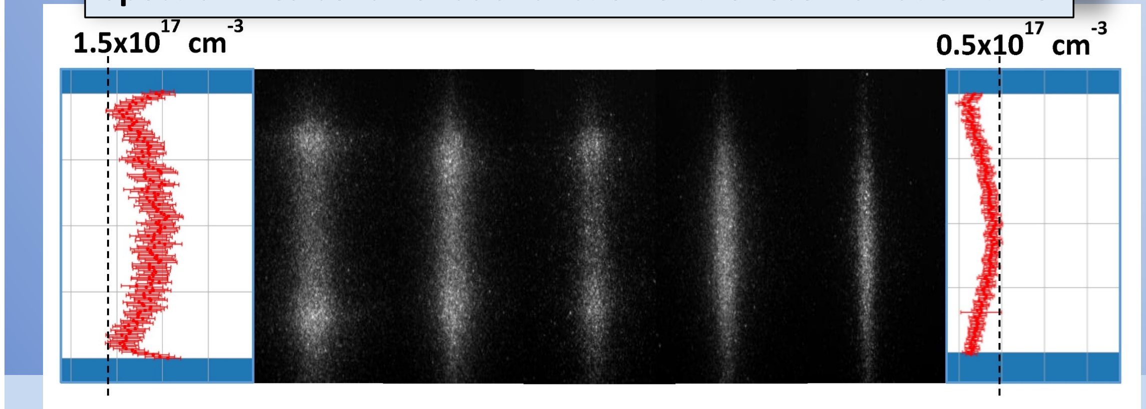
ALEGRO workshop 2024, Lisbon, 19 – 22 March

High repetition Rate capillary for EuPRAXIA

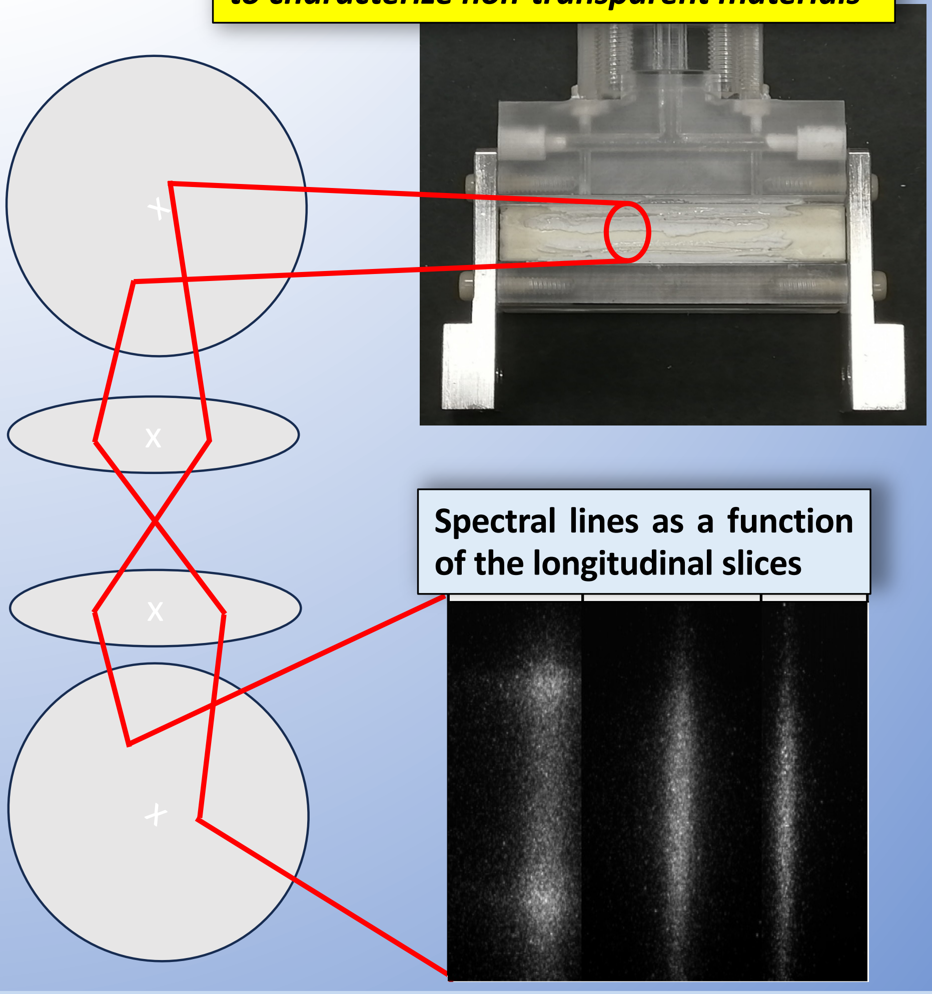
50 Hz repetition rate discharges



Spectral lines behavior as a function of the recombination time

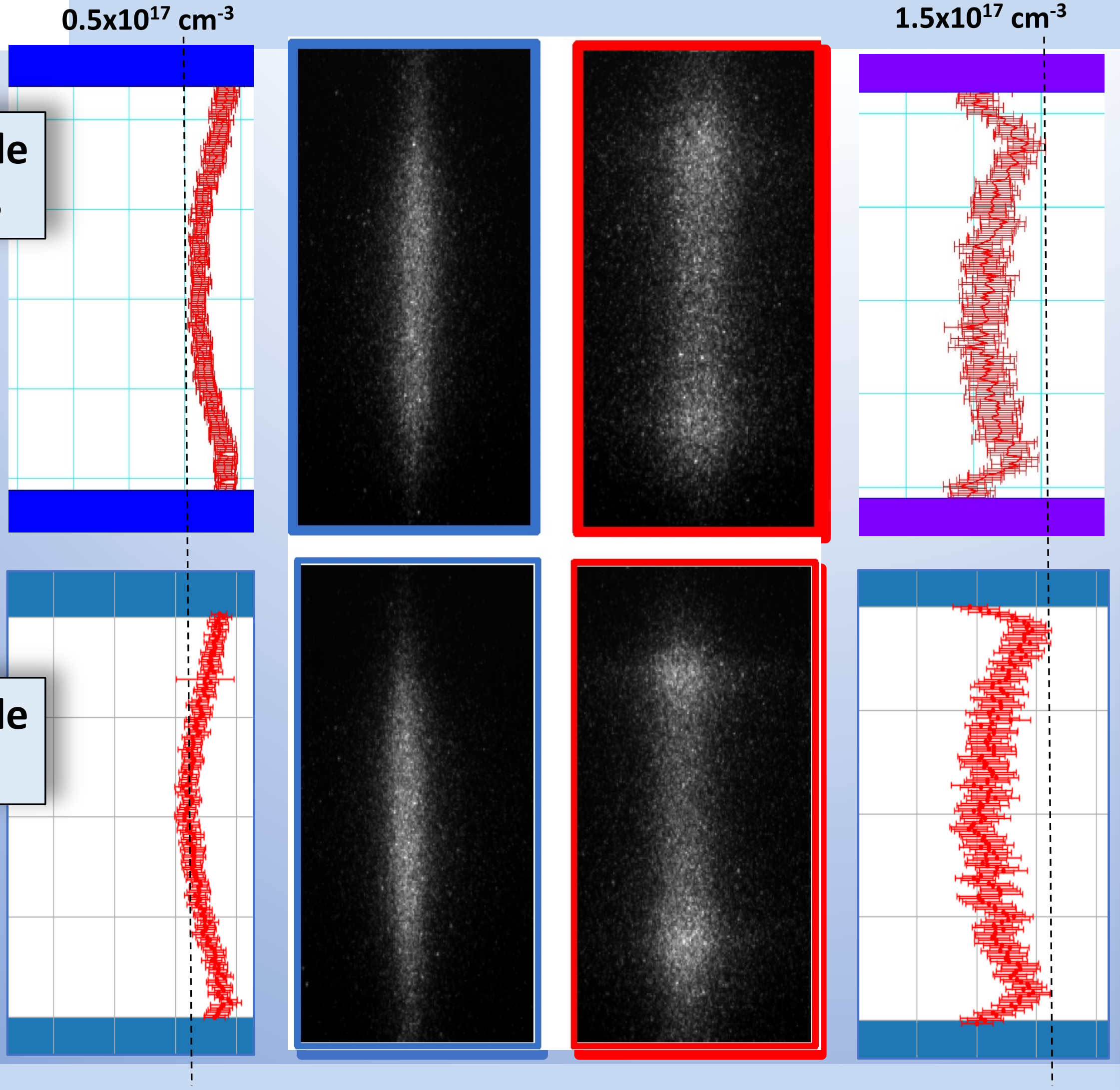


Transverse Stark broadening method to characterize non-transparent materials



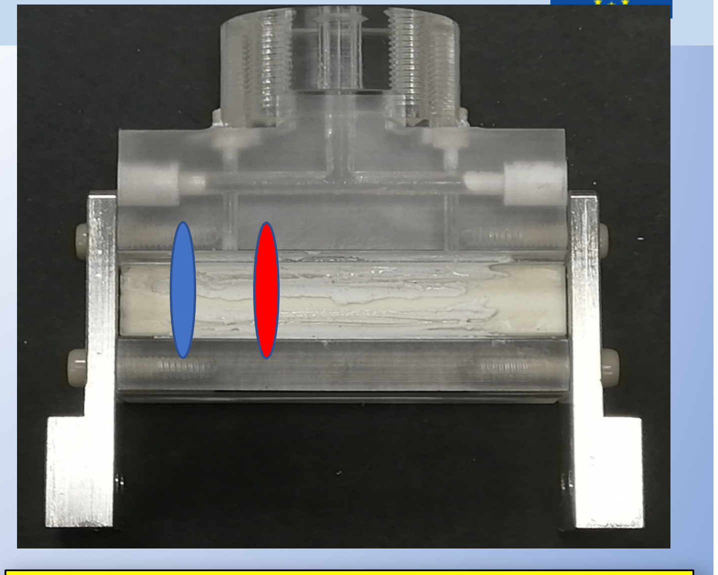
Spectral lines as a function of the longitudinal slices

High repetition Rate capillary for EuPRAXIA



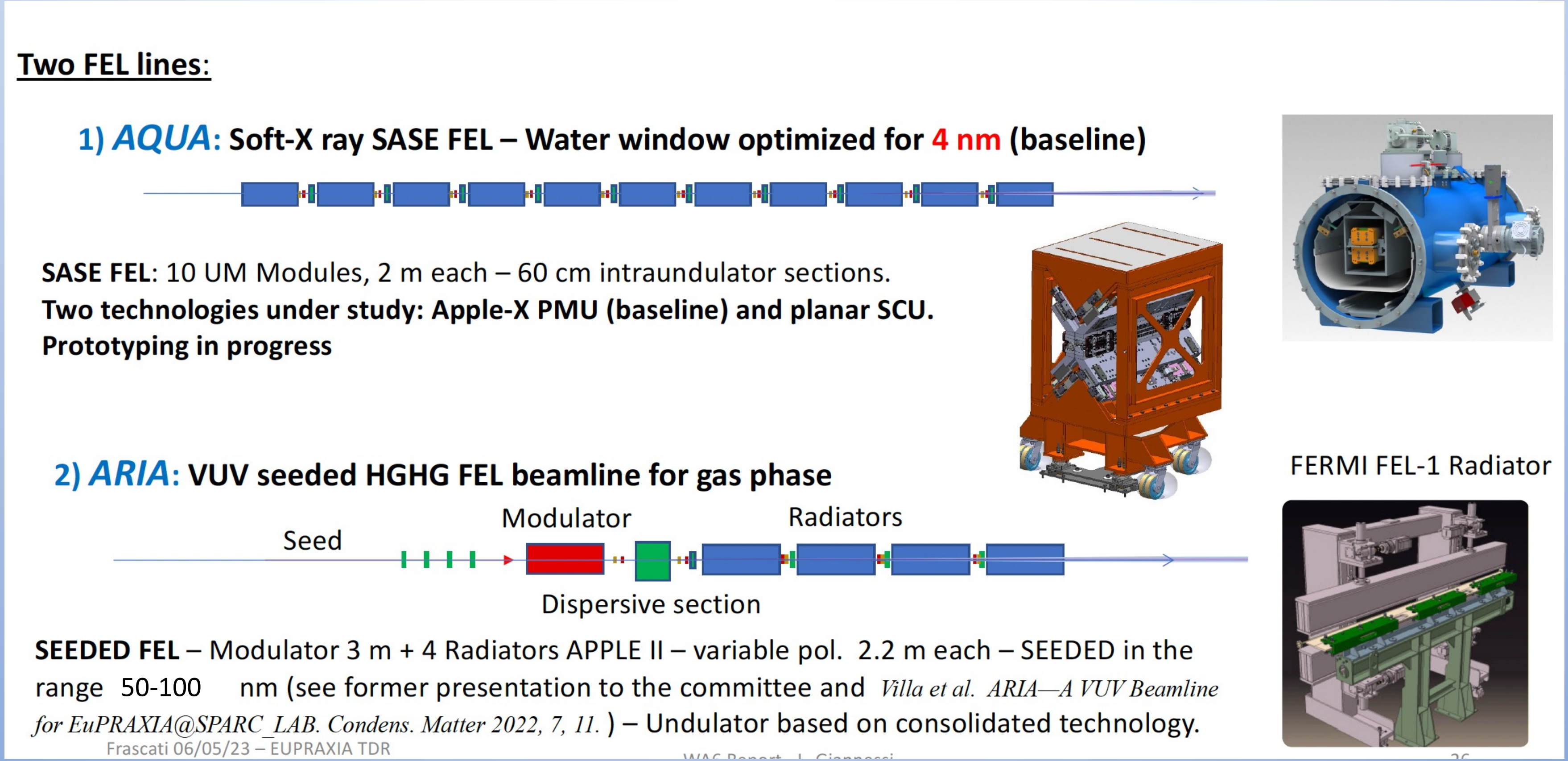
Transverse profile after 5×10^{6} shots

Transverse profile 0 shots



- ***Lifetime test of ceramic materials so far on 5×10^{6} shots at 30-50 Hz repetition rate (6 days, 8h per day)***
- ***Our goal is 3×10^{8} shots, that means working conditions 100Hz – 30 days -24 h per day***
- ***So far no degradtion, but anyway slight modifications may be compensated by changing pressure and tension applied***

Radiation Generation: FEL



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

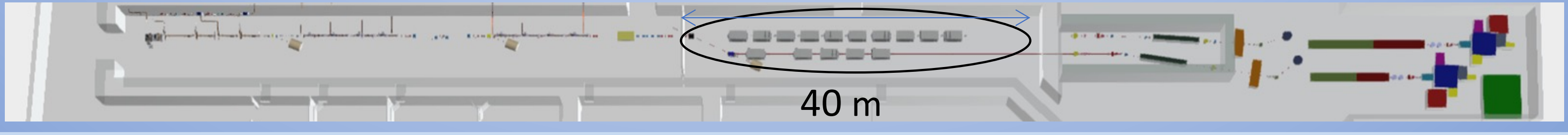
FERMI FEL-1 Radiator

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

Seed
Modulator
Radiators
Dispersive section

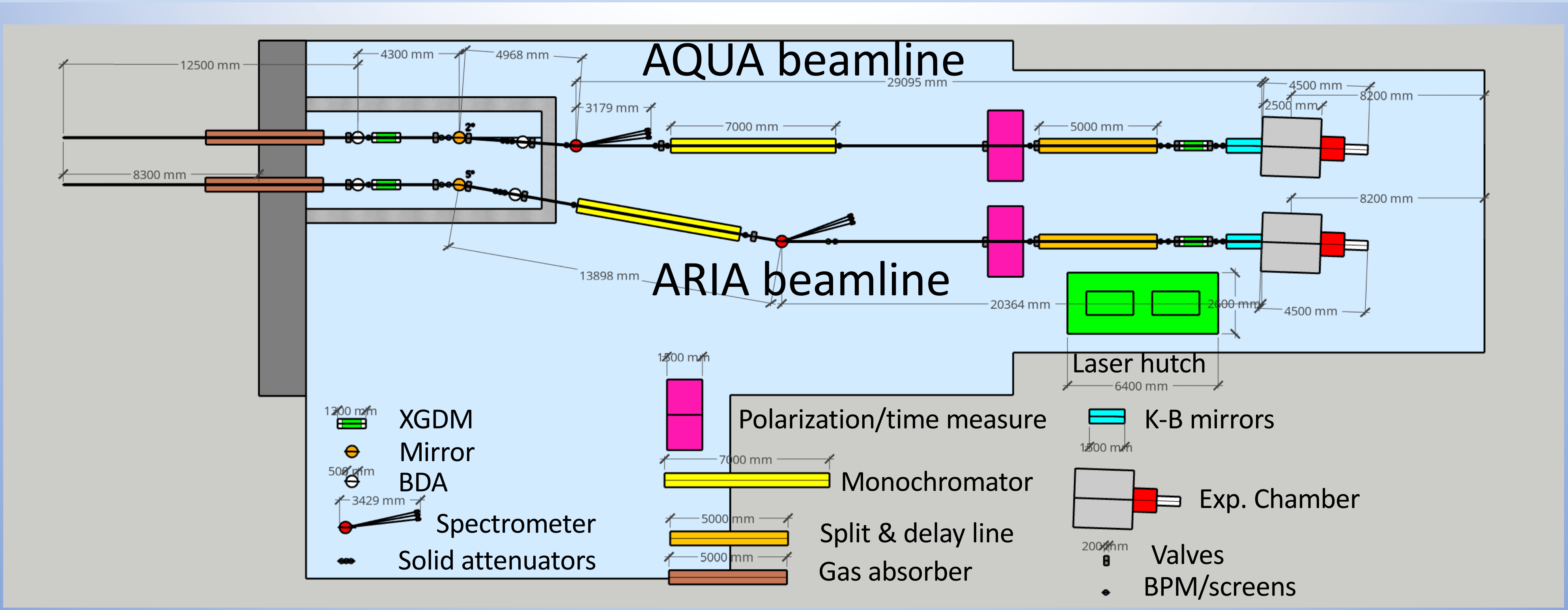
SEEDED FEL – Modulator 3 m + 4 Radiators APPLE II – variable pol. 2.2 m each – SEEDED in the range 50-100 nm (see former presentation to the committee and *Villa et al. ARIA—A VUV Beamline for EuPRAXIA@SPARC_LAB. Condens. Matter 2022, 7, 11.*) – Undulator based on consolidated technology.

Frascati 06/05/23 – EUPRAXIA TDR



Courtesy L. Giannessi

FEL Beamlines

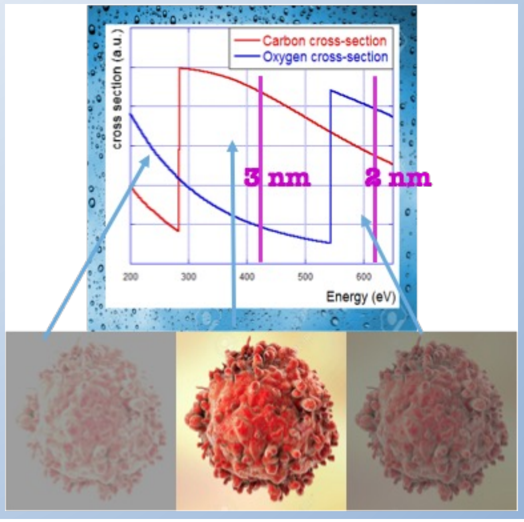


Expected SASE FEL performances

Parameter	**Unit**	PWFA	Full X-band
Electron Energy	GeV	**1**-*1.2*	1
Bunch Charge	pC	**30**-*50*	**200**-*500*
Peak Current	kA	1-2	1-2
RMS Energy Spread	%	**0.1**	0.1
RMS Bunch Length	μm	6-3	24-20
RMS norm. Emittance	μm	1	1
Slice Energy Spread	%	≤0.05	≤0.05
Slice norm Emittance	mm-mrad	0.5	0.5

Parameter	**Unit**	PWFA	Full X-band
Radiation Wavelength	nm	**3-4**	**4**
Photons per Pulse	$\times 10^{12}$	**0.1- 0.25**	1
Photon Bandwith	%	**0.1**	0.5
Undulator Area Length	m	30	
ρ(1D/3D)	$\times 10^{-3}$	**2**	2
Photon Brilliance per shot	$s\ mm^2 mrad^2$ $bw(0.1\%)$	$\mathbf{1-2\times 10^{28}}$	1×10^{27}

In the Energy region between Oxygen and Carbon K-edge 2.34 nm – 4.4 nm (530 eV -280 eV) water is almost transparent to radiation while nitrogen and carbon are absorbing (and scattering)



Coherent Imaging of biological samples protein clusters, VIRUSES and cells living in their native state
Possibility to study dynamics
~10 ^{11} photons/pulse needed

Courtesy F. Stellato, UniToV

Courtesy C. Vaccarezza/L. Giannessi

Finanziato dall'Unione europea
NextGenerationEU

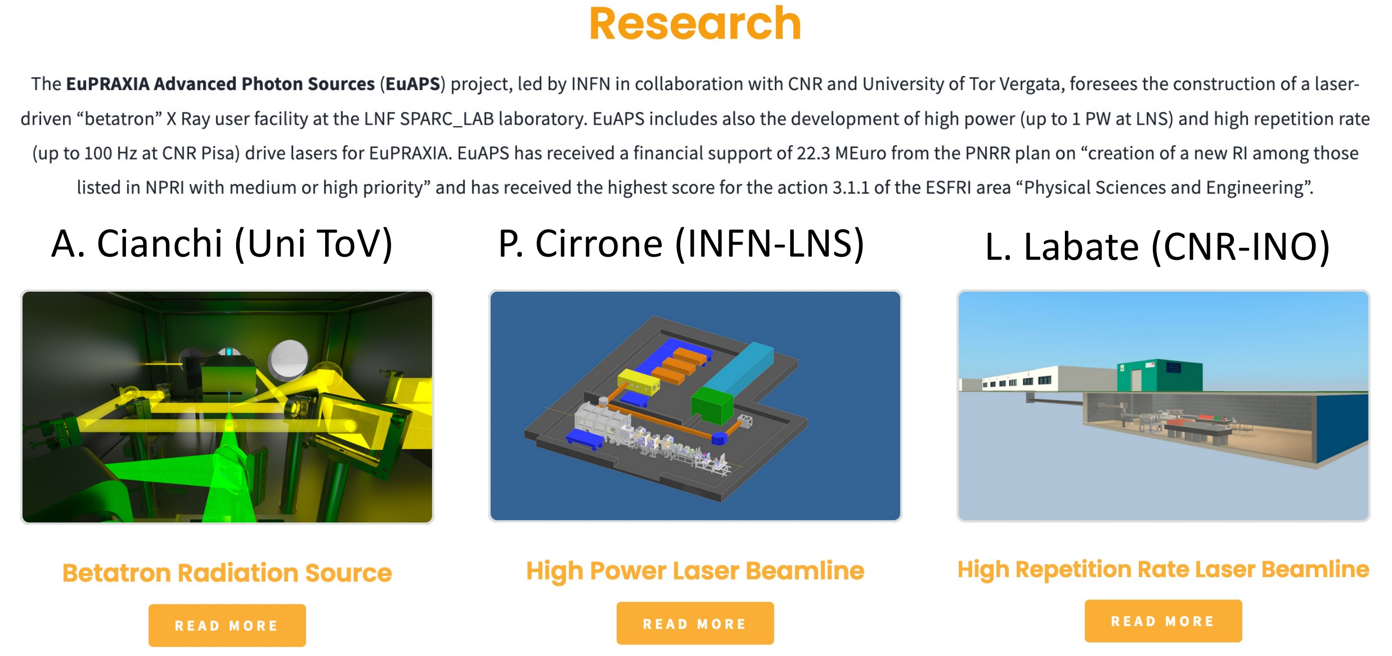
Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

EuPRAXIA Advanced Photon Sources

EuAPS: EuPRAXIA Advance Photon Sources

- Principal Investigator: M. Ferrario,
- Infrastructure Manager: C. Bortolin,
- Management and Dissemination: A. Falone



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".

A. Cianchi (Uni ToV)

Betatron Radiation Source

READ MORE

P. Cirrone (INFN-LNS)

High Power Laser Beamline

READ MORE

L. Labate (CNR-INO)

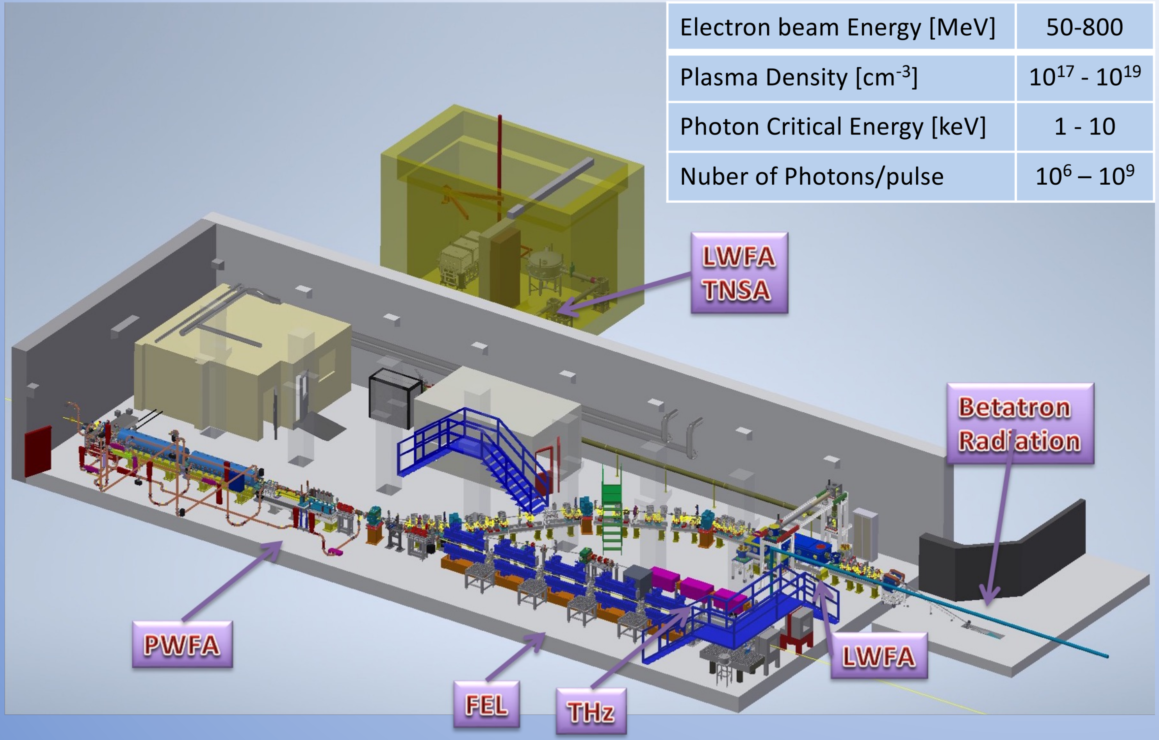
High Repetition Rate Laser Beamline

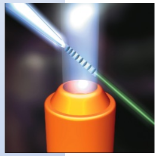
READ MORE

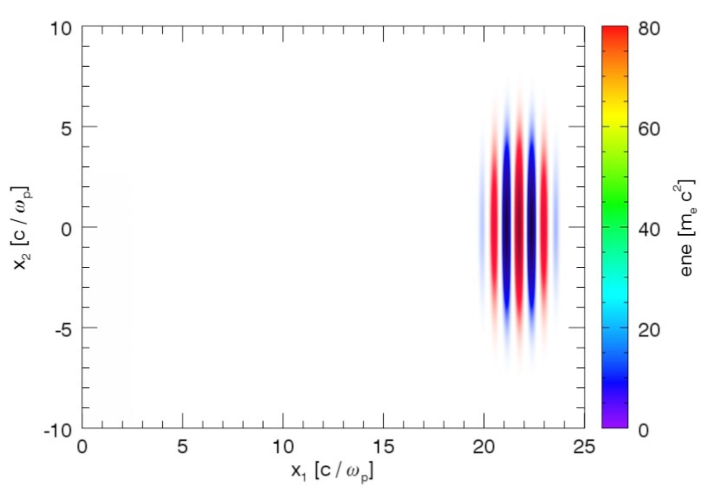
M. Ferrario et al. INFN-23-12-LNF (2023)

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







Courtesy J. Vieira, R. Fonseca/GoLP/IST Lisbon

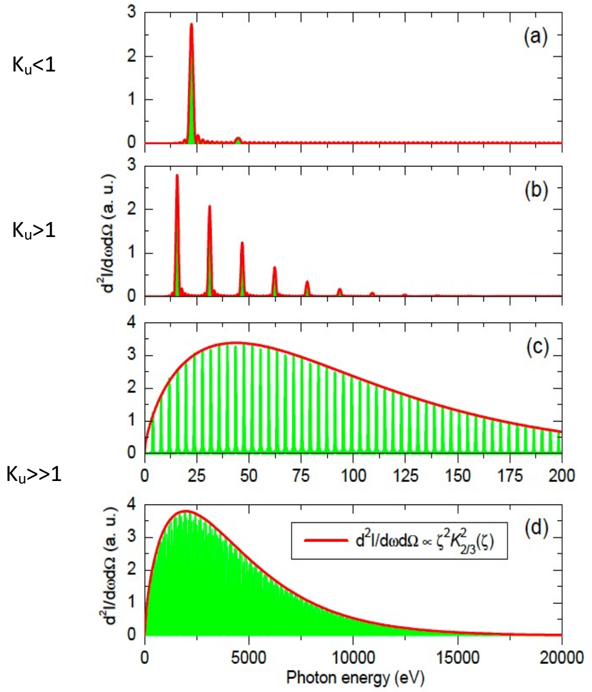


Figure 3.3: *Calculated betatron radiation spectra in a plasma column with density of* 7×10^{18} *cm*$^{-3}$. *The electron energy is 15 MeV, and oscillation amplitudes are (a) 0.1 μm, (b) 0.5 μm, and (c) 1.6 μm. (d) shows the case of a 100 MeV electron with an oscillation amplitude of 1.6 μm.*

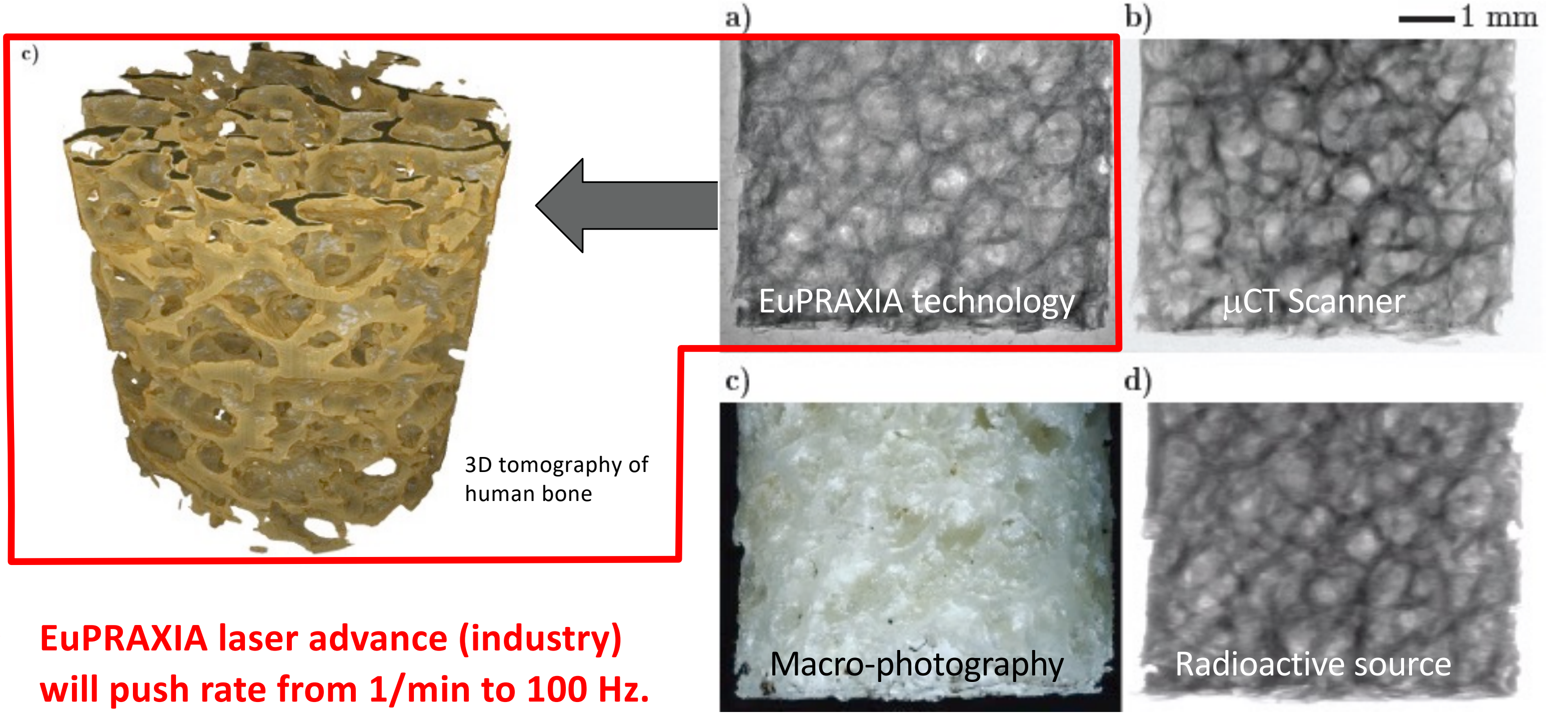
$$\omega_c = 3K_u\gamma^2\omega_\beta$$

$$N_{ph} \propto N_e N_\beta K_u$$

1) **Ultrafast** - laser pulse duration tens of fs useful for **time resolved experiments** (XFEL tens of fs, synchrotron tens to 100 ps).
2) **Broad energy spectrum -** important for **X-ray spectroscopy**.
3) **High brightness** - small source size and high photon flux for **fast processes**.
4) **Large market** - 50 synchrotron light sources worldwide, 6 hard XFEL's and 3 soft-ray ones (many accelerators operational and some under construction).

Betatron X Rays: Compact Medical Imaging

J.M. Cole et al, “Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone”. Nature Scientific Reports 5, 13244 (2015)



- **EuPRAXIA laser advance (industry) will push rate from 1/min to 100 Hz.**
- **Ultra-compact source of hard X rays → exposing from various directions simultaneously is possible in upgrades**

Physics & Technology Background:

- Small EuPRAXIA accelerator → small emission volume for betatron X rays.
- **Quasi-pointlike** emission of X rays.
- **Sharper image from base optical principle.**
- Quality demonstrated and published, but takes a few hours for one image.
- Advancing flux rate with EuPRAXIA laser by factor > 1,000!

Added value

Sharper images with outstanding **contrast**

Identify smaller features (e.g. early detection of cancer at micron-scale – calcification)

Laser advance in EuPRAXIA → **fast imaging** (e.g. following moving organs during surgery)

Laser Working plan – L. Gizzi

Funded by the European Union

NextGenerationEU e della Ricerca DI RIPRESA E RESILIENZA Advanced Photon Sources

Funding for scaleup of collaborative TDR development (within Infratech proposal PACRI)

High repetition rate High power Ti:Sa amplifier module *PACRI* WP10

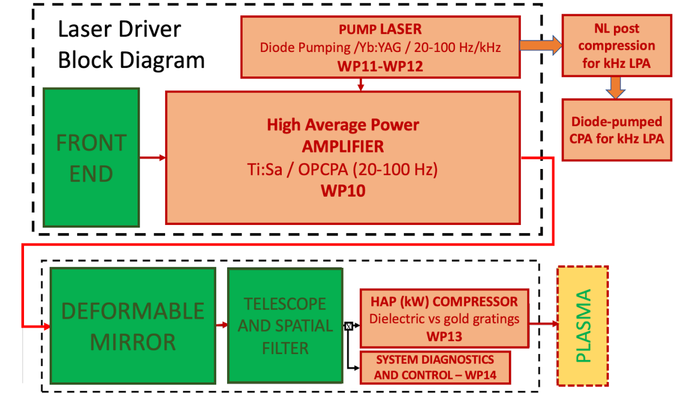
High repetition rate pump sources for laser drivers *PACRI* WP12

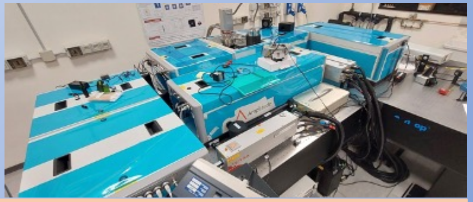
Prototype of High average power optical compressor *PACRI* WP13

Laser driver System Architecture, transport and engineering *PACRI* WP14

Developments ongoing at national level (all partners)

EuPRAXIA laser driver (100 Hz) and longer term options (1 kHz)





Efficient kHz laser driver modules for plasma acceleration *PACRI* WP12

Laser-driven 2nd site development and (new) excellence center(s) on laser technologies will boost activities

NEXT STEP: PACRI?

Funded by the European Union

- **HORIZON-INFRA-2024-TECH-01-01: R&D for the next generation of scientific instrumentation, tools, methods, solutions for RI upgrade**

- **Dead line 12 March 2024**

- **Target Budget ~10 MEuro**

25 Members
+
1 Associated partner

19 Universities and Scientific Labs.
+
7 Industries

#	Partner	Acronym
1	Elettra - Sincrotrone Trieste SCpA (Coordinator)	ST
2	European Organization for Nuclear Research	CERN
3	Istituto Nazionale Fisica Nucleare	INFN
4	University of Liverpool	ULIV
5	Thales-MIS	Th-MIS
6	Scandinova Systems AB	SCND
7	VDL ETG Technology & Development BV	VDL
8	COMEB	COMEB
9	United Kingdom Research and Innovation	UKRI
10	Consiglio Nazionale delle Ricerche	CNR
11	Extreme Light Infrastructure ERIC	ELI-ERIC
12	Centre National de la Recherche Scientifique CNRS	CNRS
13	Thales LAS France SAS	Th-LAS
14	Amplitude	Amplitude
15	Centro de LÁSERES Pulsados	CLPU
16	Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Hoechstfrequenztechnik	FBH
17	Associacao do instituto superior Tecnico para a Investigacao e Desenvolvimento	IST
18	Università degli Studi di Roma La Sapienza	USAP
19	Heinrich-Heine-Universitaet Duesseldorf	UDUS
20	Deutsches Elektronen-Synchrotron DESY	DESY
21	The Chancellor, Masters and Scholars of the Univ. of Oxford	UOX
22	Ludwig-Maximilians-Universitaet Muenchen	LMU
23	GSI Helmholtz Centre for Heavy Ion Research	GSI
24	Università degli Studi di Roma Tor Vergata	UTOR
25	SourceLAB	SourceLAB
26	Paul Scherrer Institut (Associated partner)	PSI

WP No.	Work Package Title	Lead Partic. Short Name
1	Coordination and project management	**ELETTRA**
2	Scientific and industrial exploitation	**ULIV**
3	Plasma accelerator theory and simulations	**IST**
4	High repetition rate plasma structures	**INFN**
5	Plasma acceleration diagnostics and instrumentation	**CNRS**
6	High efficiency RF generator	**Thales-MIS**
7	High repetition rate modulator	**Scandinova**
8	X-band RF Pulse Compressor (BOC)	**INFN**
9	RF tests and validation	**CERN**
10	High repetition rate high power Ti:Sa amplifier module	**UKRI**
11	Efficient kHz laser driver modules for plasma acceleration	**CNR**
12	High-rep rate pump sources for laser drivers	**ELI-ERIC**
13	Prototype of high average power optical compressor	**Thales-LAS**
14	Laser Driver System Architecture,transport and engineering	**CNRS**

Plasma Accelerators for Compact Research Infrastructures (PACRI)

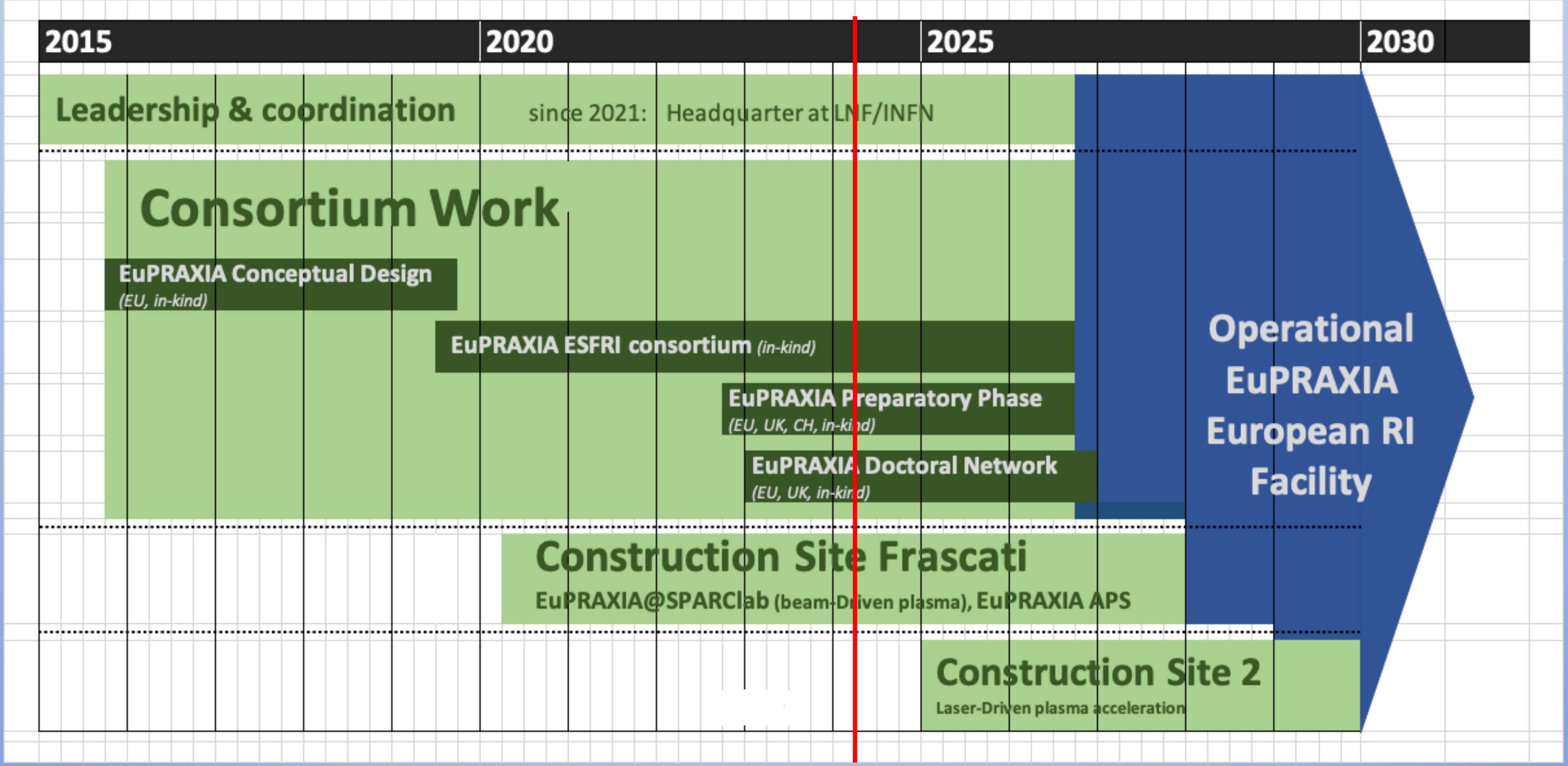
Funded by the European Union

The objective of the **PACRI** project is to develop innovative breakthrough technologies, increasing their Technology Readiness Level (TRL) for electron accelerators while taking energy consumption, resource efficiency, costs, and environmental impact into due account. This includes the following draft non-exclusive goals:

- **developing high rep-rate plasma modules,** as required for the EuPRAXIA project, extending its scientific domain from high average brightness radiation sources up to high energy physics;
- **developing key laser components required to upscale high-power high repetition rate Laser technology** as required by the EuPRAXIA and ELI Research Infrastructure.
- **improving the performance of normal conducting technology for X-band linac drivers,** extending them to the kHz regime, with focus on efficiency and energy consumption;
- **supporting development towards compact linear colliders and nuclear physics facilities;**
- **developing compact advanced undulator modules,** in order to reduce the overall size of the future FEL facilities.
- **supporting the availability of compact X-ray facilities (FELs, ICSs, Betatron)** to serve a larger number of users in many scientific fields, industry and society;

EuPRAXIA Project Timeline

Funded by the European Union



Courtesy A. Falone

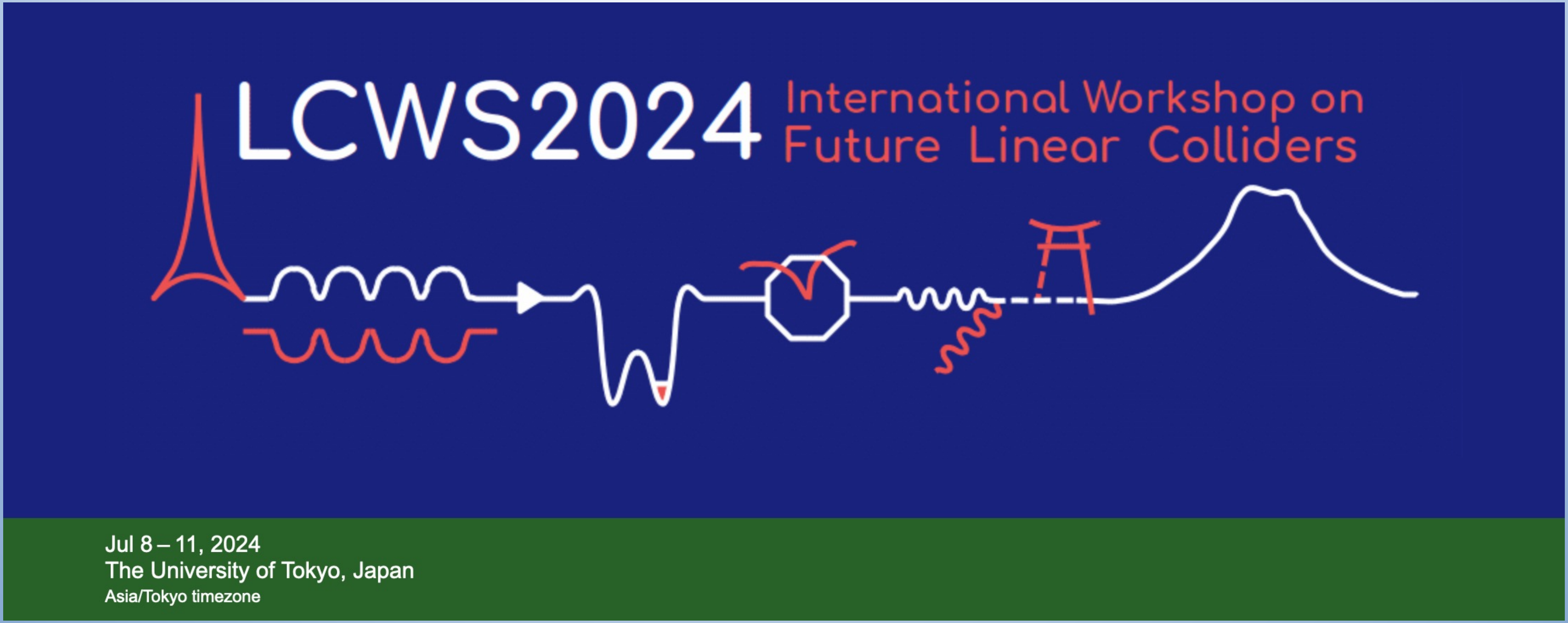
EuPRAXIA Workshop

22-27 September 2024

Elba

- **EuPRAXIA_PP Annual Meeting**
- **M15.2** Workshop on “EuPRAXIA@SPARC_LAB machine upgrade and additional beam lines“ (M20) giugno 2024 [Pompili, Vaccarezza]
- **M6.1** Outreach Workshop (M24) ottobre 2024 [Cros, Mostacci]
- ~~**M10.1** Workshop on EuPRAXIA plasma concept (M28) febbraio 2025 [Kevin Cassou (CNRS) e Rob Shalloo (Desy)]~~
- EuAPS Annual Meeting

Future Linear Collider Workshop



Jul 8 – 11, 2024
The University of Tokyo, Japan
Asia/Tokyo timezone

Conclusions

Funded by the European Union

- Plasma accelerators have advanced considerably in beam quality, **achieving FEL lasing**.
- EuPRAXIA is a design and an ESFRI project for a distributed European Research Infrastructure, **building two plasma-driven FEL´s in Europe**.
- EuPRAXIA FEL site in Frascati LNF-INFN is sufficiently funded for **first FEL user operation in 2028**.
- Second EuPRAXIA FEL site will be selected in next 18 months, among **4 excellent candidate sites**.
- Concept today **works in design and in reality**. Expect (solvable) problems in stability for **24/7 user operation**. Facility needed to demonstrate!
- Paves the way to Linear Collider
- Additional fund raising is continuosly going on

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FEATURE EuPRAXIA

Surf's up *Simulation of electron-driven plasma wakefield acceleration, showing the drive electron beam (orange/purple), the plasma electron wake (grey) and wakefield-ionised electrons forming a witness beam (orange).*

EUROPE TARGETS A USER FACILITY FOR PLASMA ACCELERATION

Ralph Assmann, Massimo Ferrario and Carsten Welsch describe the status of the ESFRI project EuPRAXIA, which aims to develop the first dedicated research infrastructure based on novel plasma-acceleration concepts.

Thank for your attention