IPAC2026, May 17-22, Deauville, Normandy, France
TUO2M02

EuPRAXIA at ELI ERIC:
DEVELOPMENT OF A COMPACT LPA FEL AND PLASMA SOURCES FOR ULTRAFAST SCIENCE

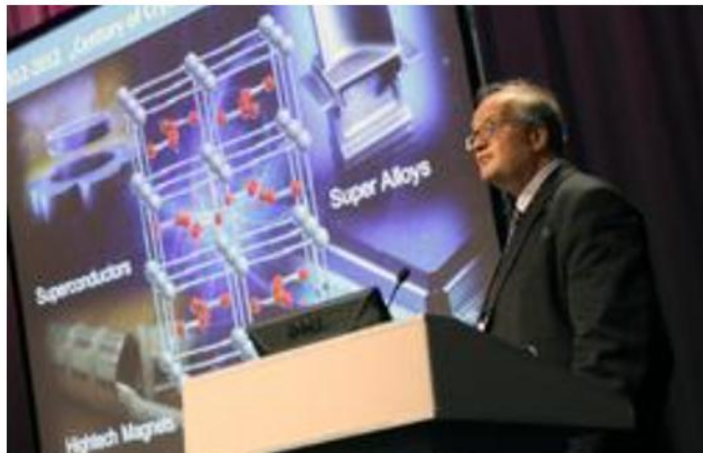
Alexander Molodozhentsev
ELI ERIC / ELI Beamlines

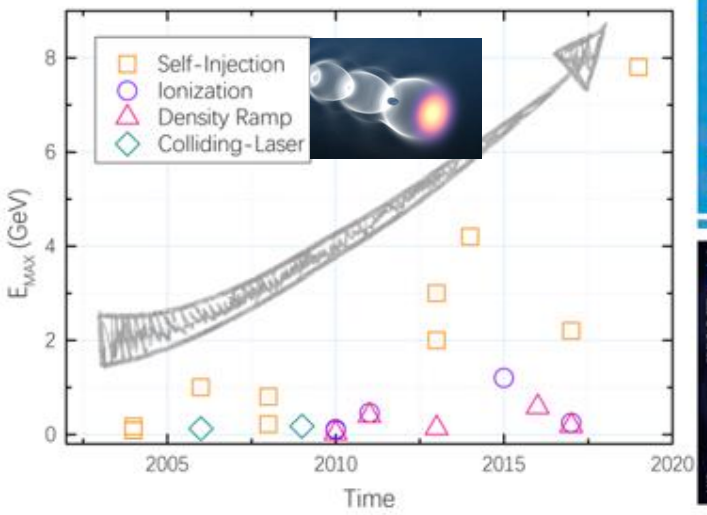
EuPRAXIA:
new generation of compact accelerators

- Building a distributed facility in Europe with a very high accelerating field (up to 100 GV/m)
- Producing particles and photons to support different scientific cases


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.

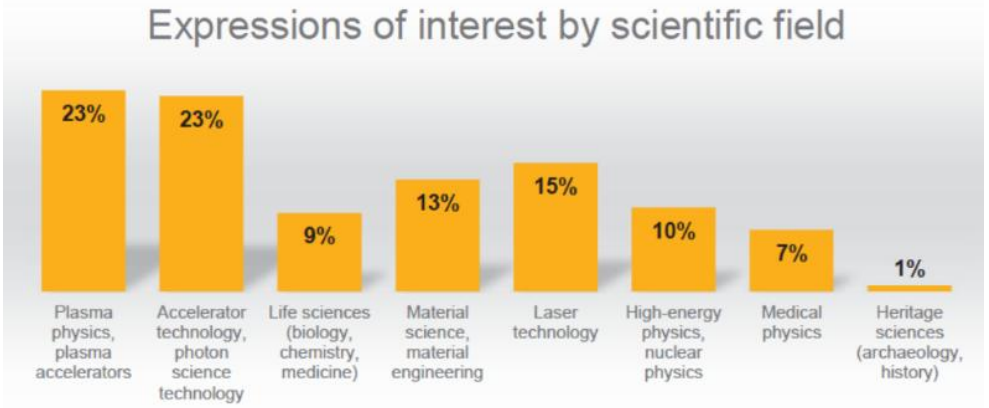




EuPRAXIA Project

GOAL OF THE PROJECT:

Pan-European user-oriented distributed Plasma-Accelerator-based Facility.



Accepted by ESFRI (2021)

Combines 34 European Institutions

EuPRAXIA Project

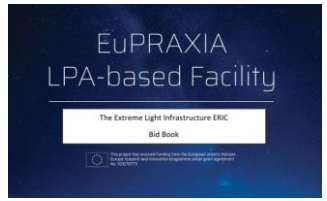
TWO implementation sites

BEAM-driven plasma accelerator
INFN-LNF (Italy)

TDR is finalised in March, 2026

LASER-driven plasma accelerator
ELI ERIC / ELI Beamlines (Czech Republic)

- ✓ ELI Beamlines is one of the leading European research facilities in laser-plasma technology.
- ✓ **Through collaborating with the EuPRAXIA Consortium partners**, ELI Beamlines is positioned to build the Laser-Plasma-Accelerator-based EuPRAXIA pillar, aiming to deliver the electron beam for different practical applications.

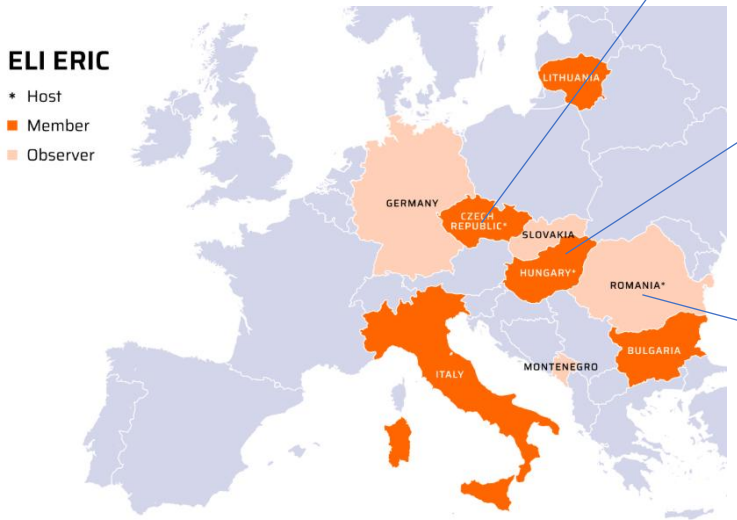


Assigned by EuPRAXIA Consortium on March 25, 2025

European Research Infrastructure
ELI ERIC

MISSION of ELI ERIC:

Enables cutting-edge research by managing access to world-class lasers and technologies through open, peer-reviewed, excellence-based access.



eli beamlines

- Secondary sources – beamlines of high energy photons, electrons, protons, neutrons, muons
- Medical imaging and diagnostics, radiotherapy
- New materials
- X-ray optics
- Plasma Physics, HED and High-field Physics
- Fusion

eli attophysics

- Ultrafast physical processes
- Chemical, medical and materials science analysis
- Attosecond measurement techniques
- Biological imaging technologies
- Artificial photosynthesis
- Nanoscience

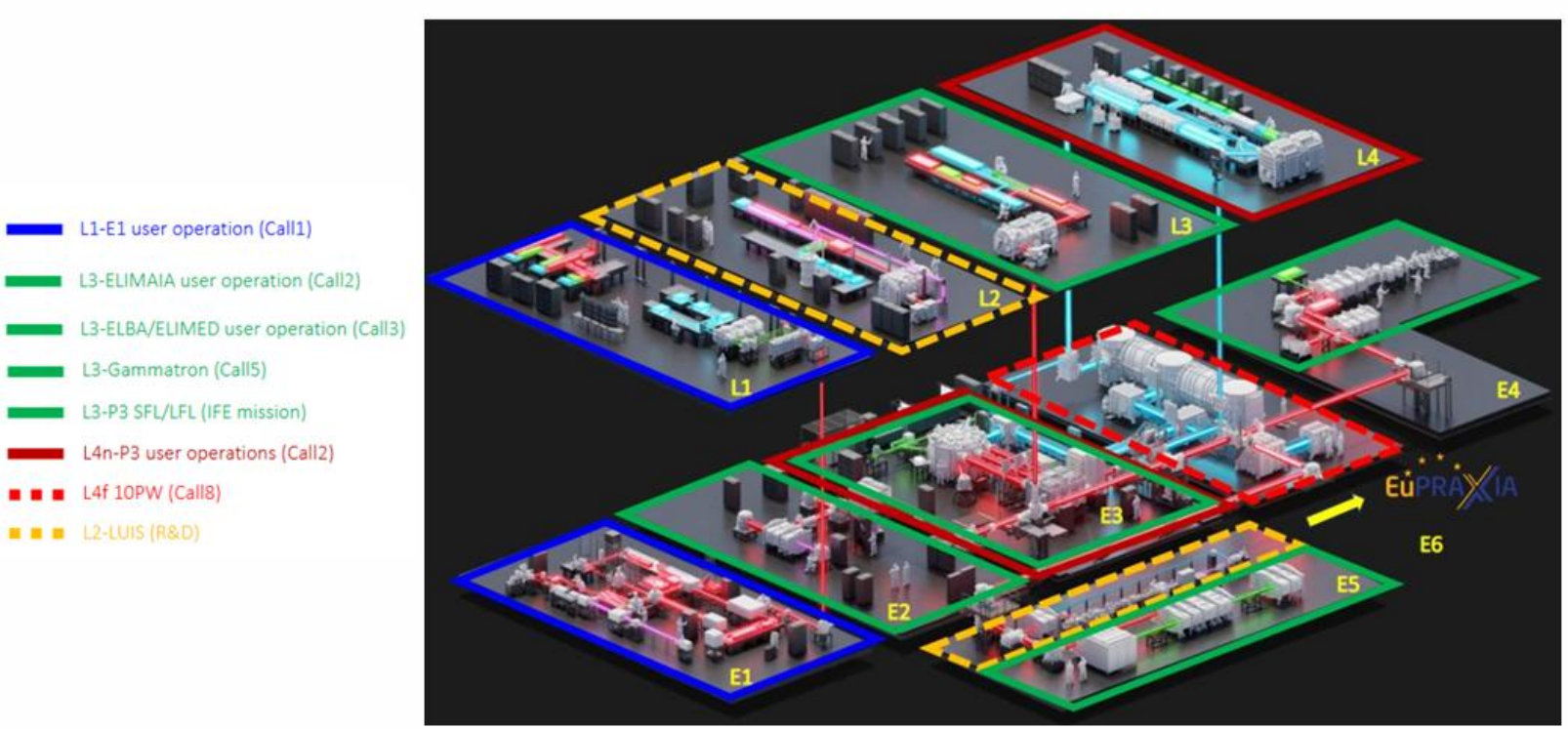
eli nuclear physics

- Photonuclear Physics
- High power laser system
- Brilliant energy tunable gamma-ray beam system

A European Research Infrastructure Consortium (ERIC)

ELI ERIC / ELI Beamlines

Existing infrastructure



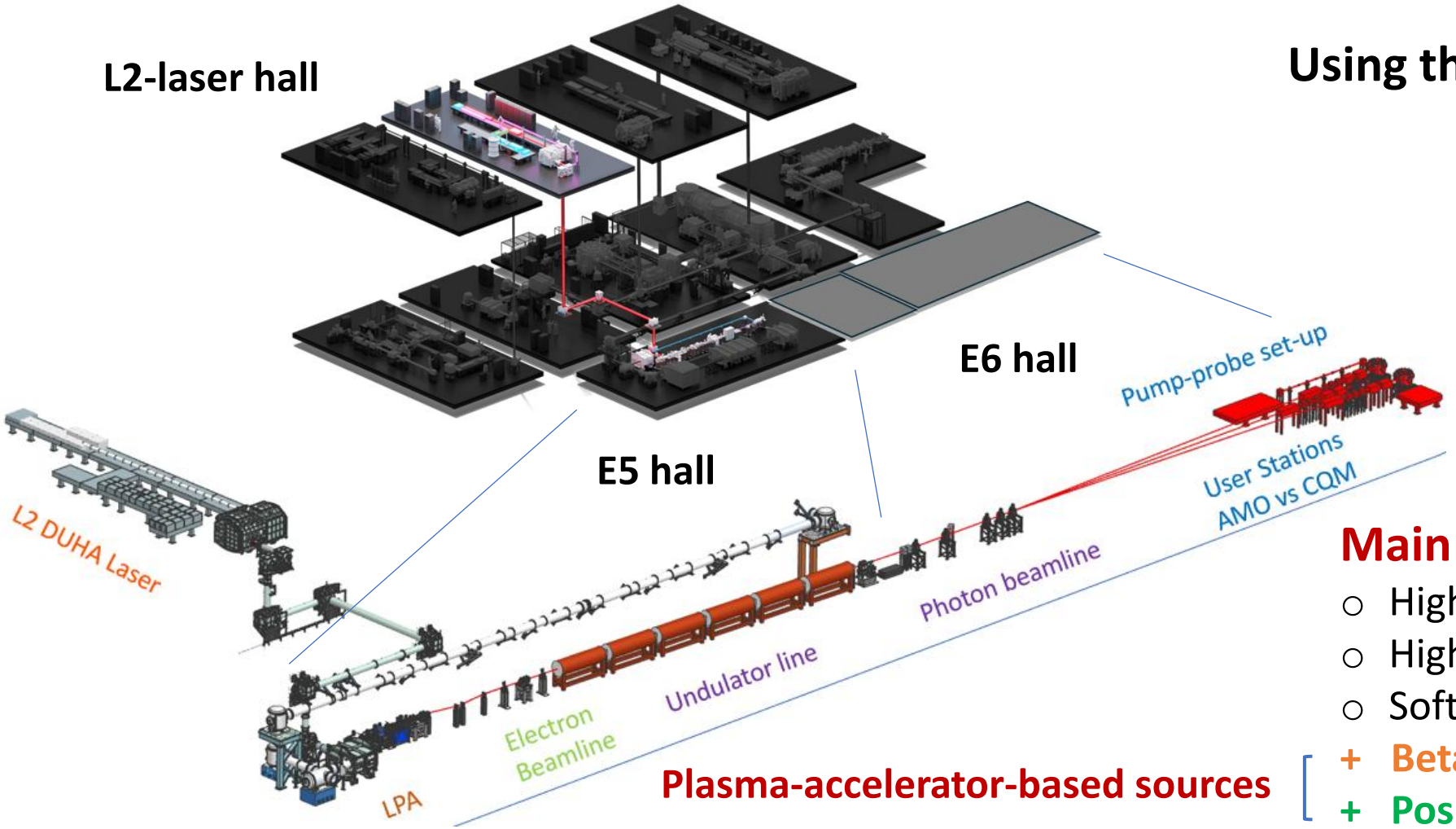
Laser systems:

L1 (40mJ) 100mJ / 1kHz
L2 (3J) 5J / 20-100Hz
L3 (15J) 30J / (3.3Hz) 10Hz
L4 1.5kJ / 10PW

Experimental areas:

E1/L1: Material & Bio-molecular app.
E1/L1: ALFA-kHz low-energy electron beam
E2/L3: X-ray sources (Betatron)
E3/L3+L4: Plasma Physics
E4/L3: ELIMED-Proton Acceleration
E5/L3: ELBA-Electron Acceleration
E5/L2: LPA-based FEL-oriented (LUIS)

EuPRAXIA LPA-based FEL project at ELI ERIC



Using the existing infrastructure

Plasma-accelerator-based sources

Main objectives:

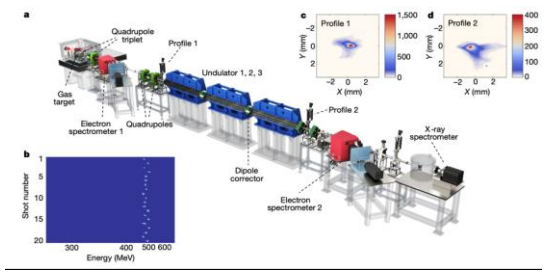
- High-quality **1 GeV** electron beam
- High repetition rate **50-100 Hz**
- Soft X-ray **"water-window" SASE FEL**

\+ **Betatron source (L3 LPA-based)**

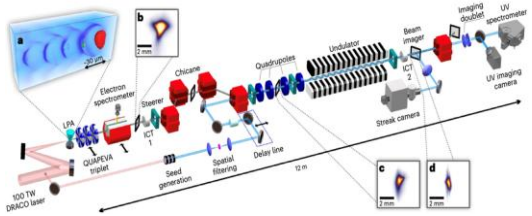
\+ **Positron source (L1 LPA-based)**

LPA-based FEL: Current State of the Art

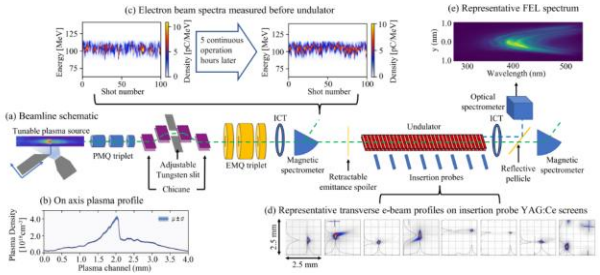
2021 2022 2025 2026



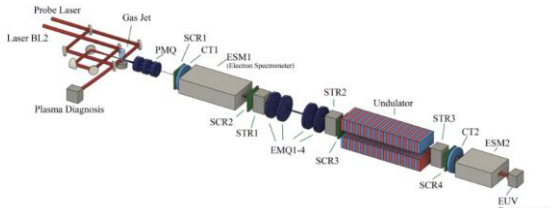
SIOM (China)
W_e ~ 500 MeV
SASE FEL
Lasing 27 nm



COXINEL (LOA+HZDR)
W_e =188 MeV
Seeded FEL
Lasing 240 nm



BELLA (USA)
W_e ~ 100 MeV
SASE FEL
Lasing 420 nm



OSAKA (Japan)
W_e ~ 400 MeV
SASE FEL
Lasing 40 nm

LPA-based FEL at ELI ERIC

STRATEGY:

- R&D activity aiming for a high-quality 1GeV electron beam: experimental verification of advanced Plasma Accelerators approaches like the “hybrid” LWFA+BD and ReMPI schemes
- Preparation of the ELI Technical Design Report in parallel with the LASER development
- Improvement of the Technical Readiness Level for LASER and PLASMA source (100 Hz)
- PHASE 0: EUV setup as a prototype for the LPA soft X-ray FEL
- SASE FEL with possible implementation of the seeded EUV-FEL
- PHASE 1: soft X-ray LPA-based FEL

EuPRAXIA LPA-based FEL project at ELI ERIC

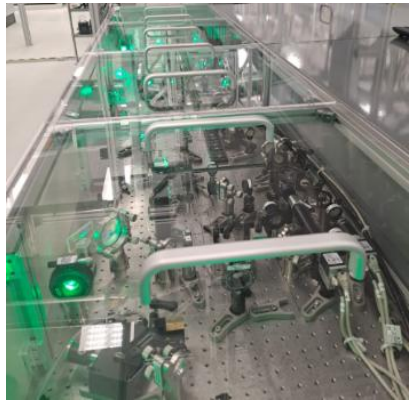
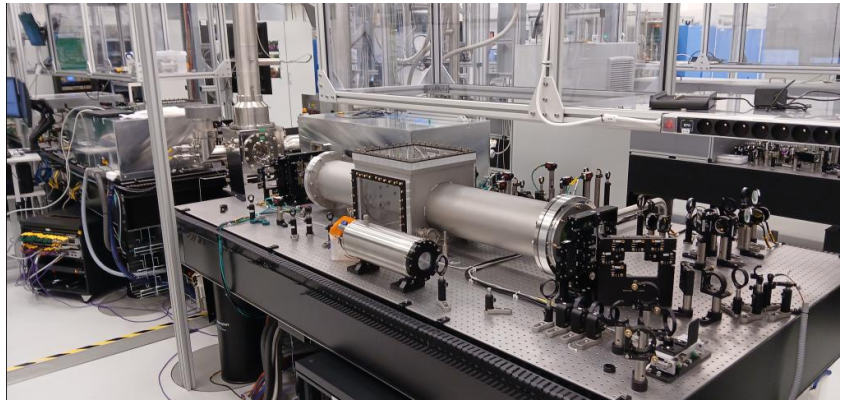
Phasing and Parameter List

KYE PARAMETERS	COMMISSIONING 2026 - 2028	GOAL 2029-2030
LASER	DPSSL-pumped OPCPA	
Energy per pulse [J]	**3**	**5**
Repetition rate [Hz]	**20 (50)**	**50(100)**
Pulse duration [fsec]	25	25
Laser power [TW]	**100**	**200**
Laser beam quality		
Contrast ratio [-]	10^{-11}	TBD
Pointing stability [µrad]	2	1
Beam profile	Round (D=120mm)	
Energy stability [%]	1	
Temporal characteristics	TBD	TBD
Laser synchronization capabilities		AUX beam fully synchron.

		EUV FEL HPMU (U19)	Soft X-ray FEL HMPU (U15)
ELECTRON BEAM			
Electron beam energy	MeV	**350**	**1000**
Bunch charge (I_p)	pC (kA)	30 (2.5)	30 (2.5)
RMS energy spread (slice)	%	0.22	0.15
RMS normalized emittance (slice)	π.mm.mrad	0.3	0.3
Repetition rate	Hz	20	50 (100)
PHOTON BEAM (h=1)			
Wavelength / Energy	nm / eV	**43 / 29**	**3.4 / 368**
Bandwidth	%	1.5	0.4
Photons per pulse	$\times 10^{12}$	12	0.2
Brilliance ph/pulse/mm^2/mrad^2/0.1%bw	$\times 10^{30}$	0.13	1.4
Photon beam peak power	GW	4.5	1.8
Saturation length	m	**4**	**16**

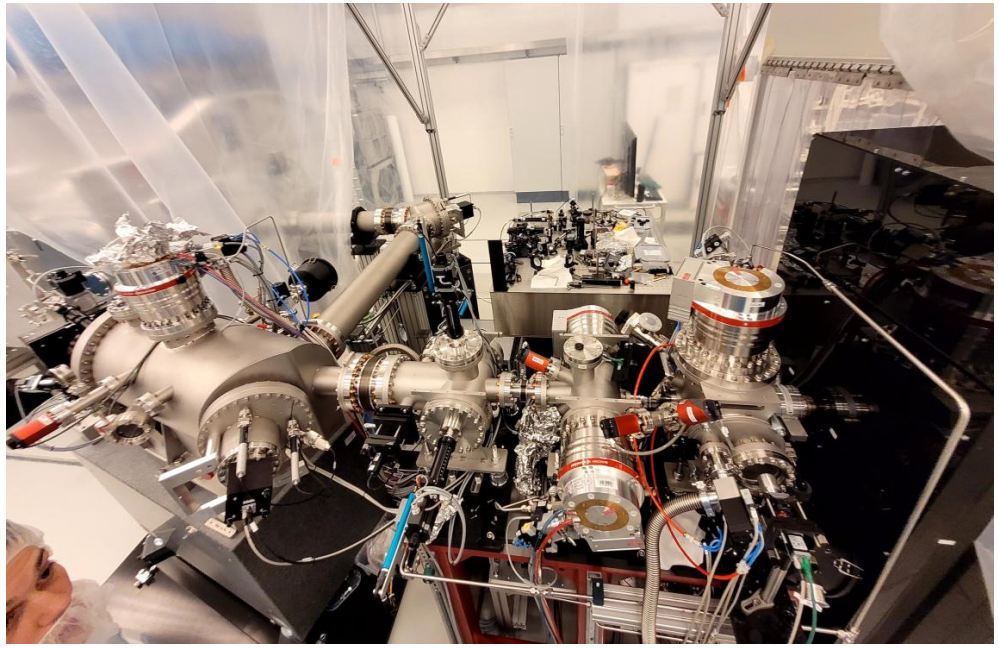
LPA-based EUV FEL at ELI ERIC

L2-Laser

L2-Laser commissioning: Q4-2026

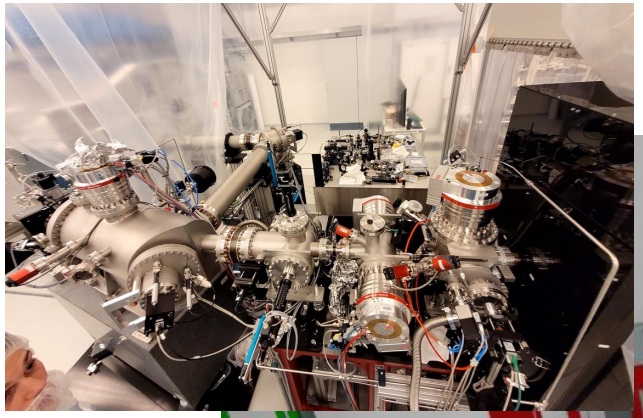
LUIS-setup (based on LUX / DESY)

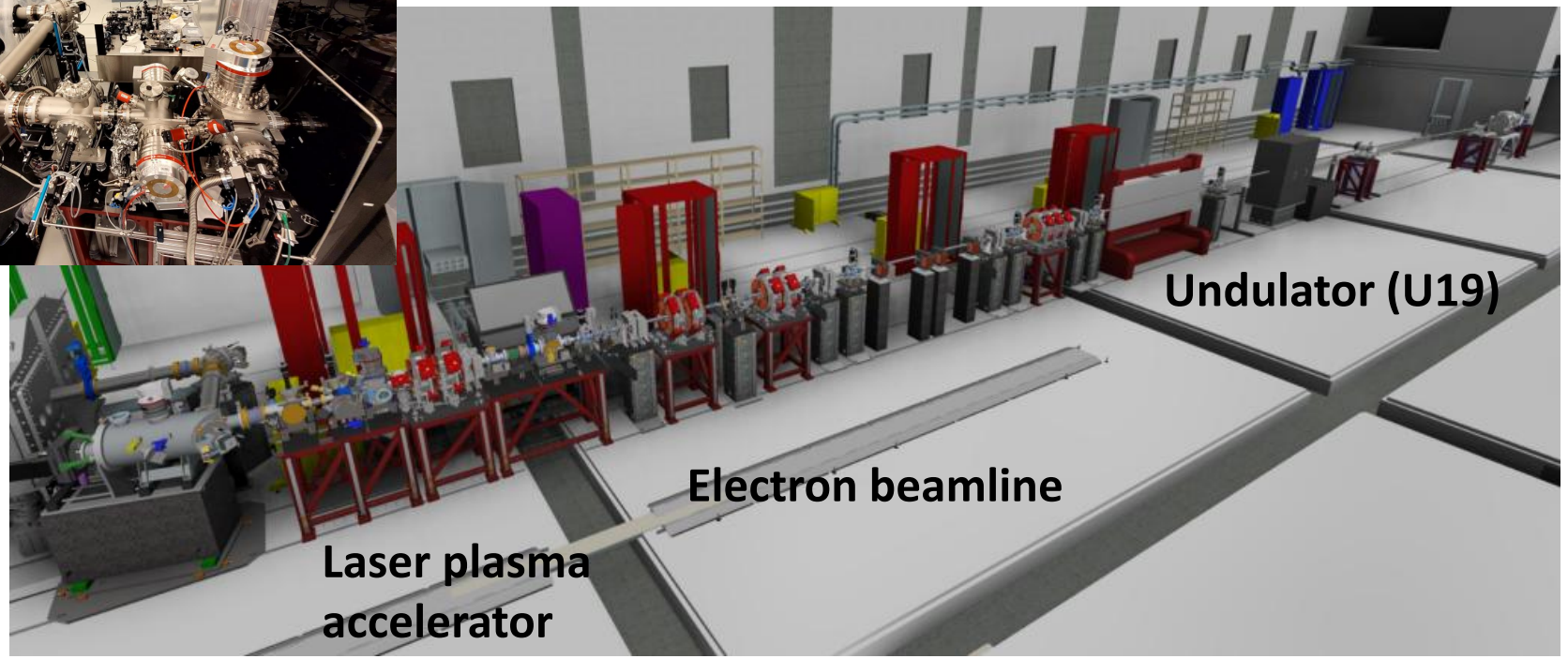


L2-LUIS LPA commissioning: Q1-2027

LPA-based EUV FEL at ELI ERIC

STRATEGY: Prototype of the LPA-based EUV SASE-FEL





Laser beamline

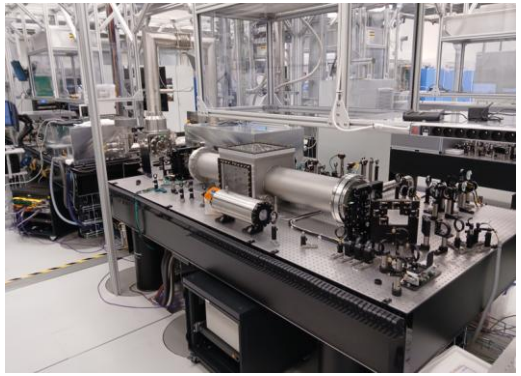
Photon beamline and User Station

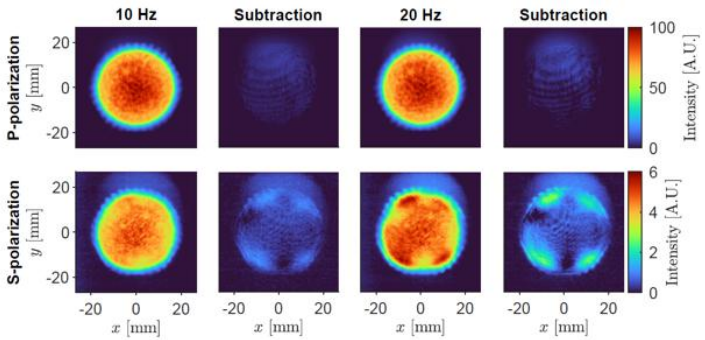
Full layout of the EUV setup in the E5 hall of ELI Beamlines

EuPRAXIA and PACRI for ELI TDR

Laser
PACRI-WP12

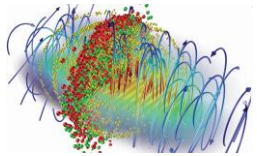
High repetition rate pump sources for laser drivers

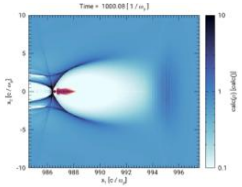


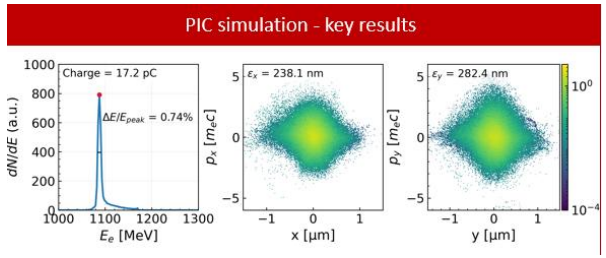


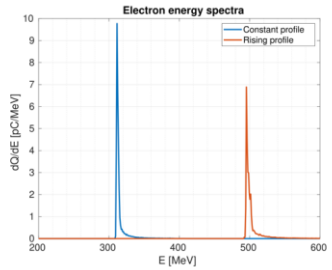
Laser-plasma accelerator
PACRI-WP3

High-quality LPA-based Electron beam



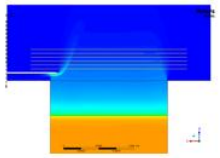


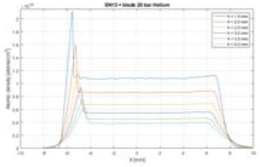


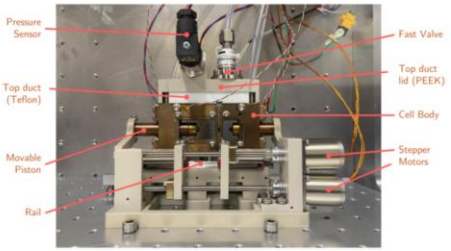


Plasma source
PACRI-WP4

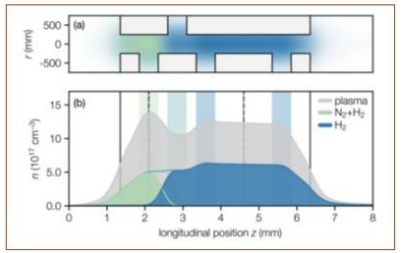
Modelling and prototyping different plasma sources





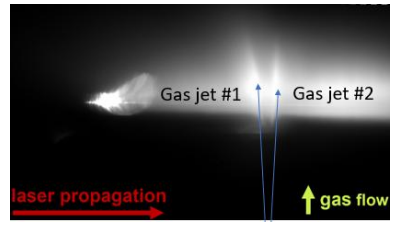


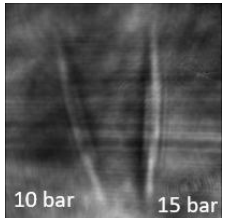
Gas cell [M. Kirchen et al., PRL **126**, 174801 (2021)]

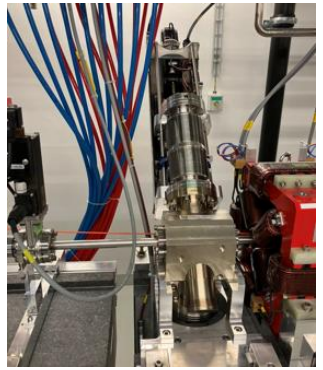


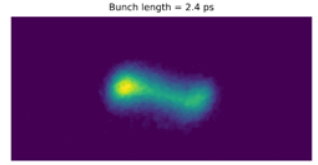
Diagnostics
PACRI-WP5

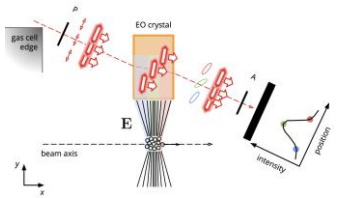
Plasma acceleration diagnostics and instrumentation











Challenges

Organizational

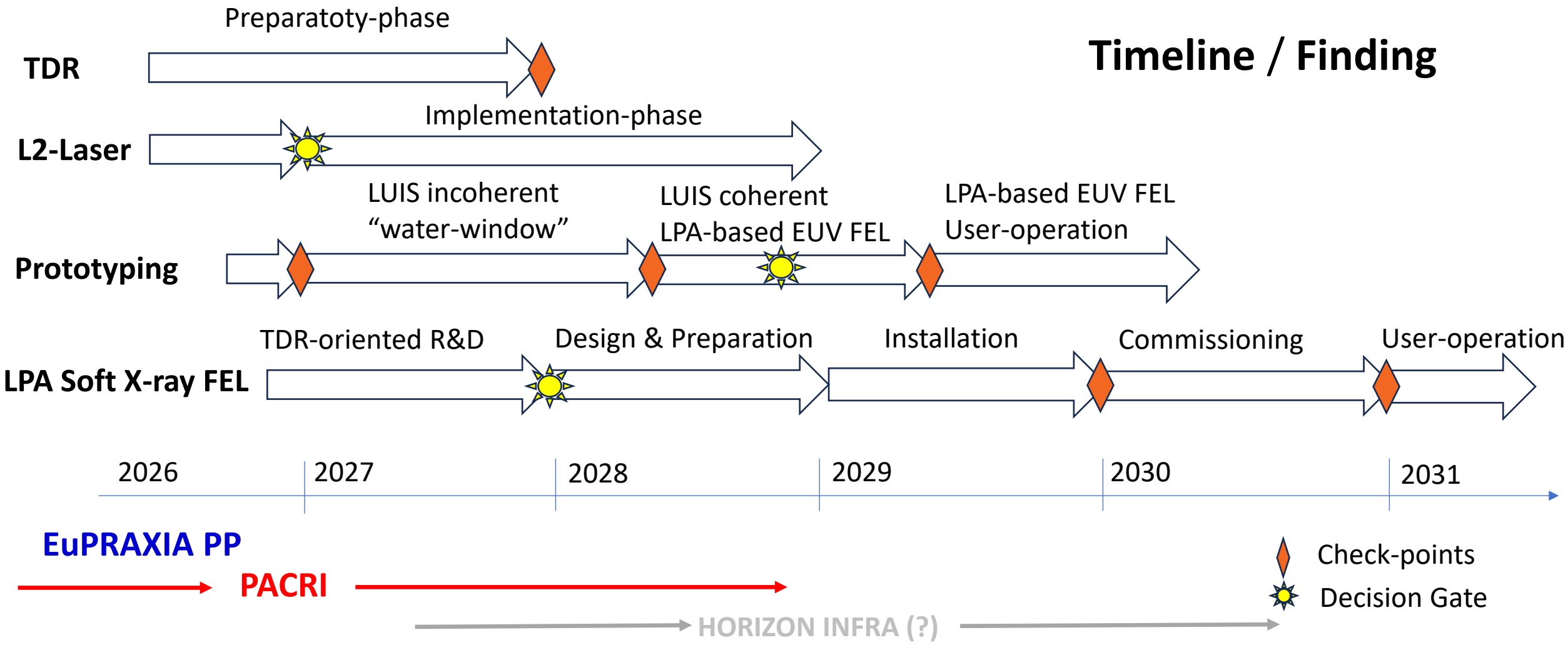
- ❑ Coordinate efforts of the EuPRAXIA Consortium
- ❑ Resources (EuPRAXIA PP, PACRI + …)

Technical

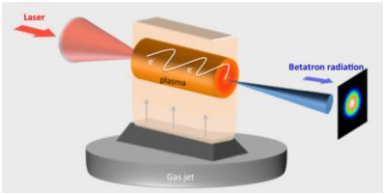
- ❑ High-power high-repetition (~ 100Hz) rate laser operation
- ❑ Plasma sources development for the high-quality electron beam acceleration
- ❑ Beam dynamics in the electron beamline
- ❑ Single-shot electron beam diagnostics
- ❑ Control of the electron beam along the undulator
- ❑ Stable and repeatable operation

EuPRAXIA LPA-based FEL project at ELI ERIC

Timeline / Finding



Betatron Radiation Source



SCIENCE CASE

Single-shot **phase-contrast imaging**

Ultrafast **structural dynamics**

Complementary to FEL for **incoherent broadband** applications

CURRENT STATUS

User-operation ongoing using L3 laser

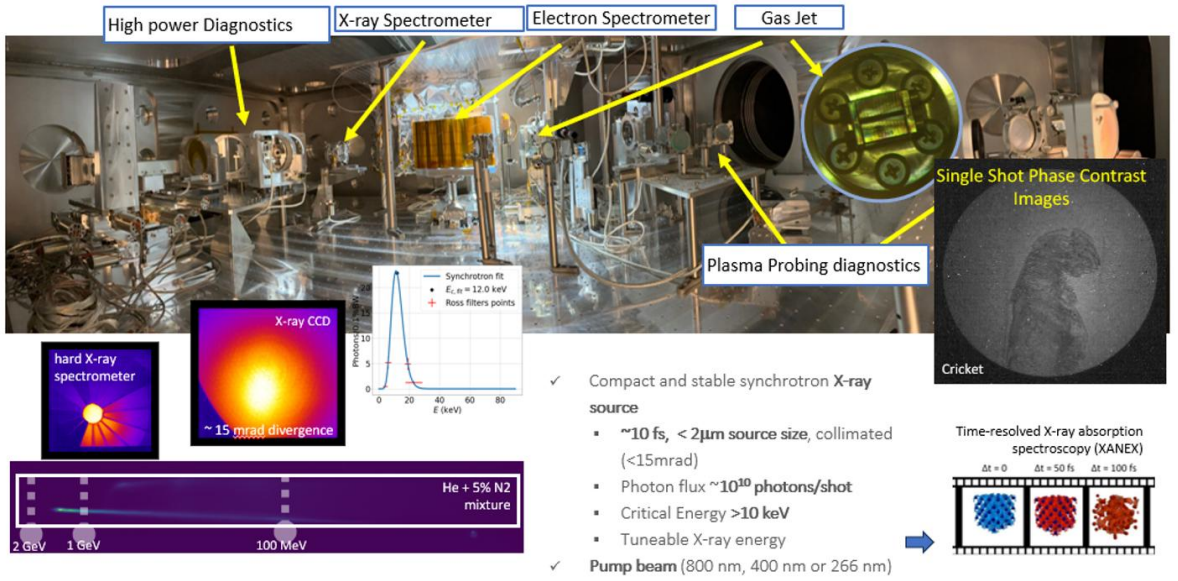
3 Hz GeV-class electron beam was demonstrated

Proof-of-principle for **ultrafast X-ray imaging**

SOURCE PARAMETERS

Source size	< 2 μm
Divergence	~ 10 mrad half-angle
Pulse duration	~ 10 fs
Critical energy	> 10 keV
Peak brightness	~ 10^{23} ph/s/mm^2/mrad^2/0.1%BW
Repetition rate	3 Hz (L3 Laser)

Technology Readiness at ELI Beamlines



Positron Source: Ultrafast Science with Antimatter

Unique at ELI ERIC

kHz repetition rate + sub-ps pulses
PALS regime not reachable at conventional sources

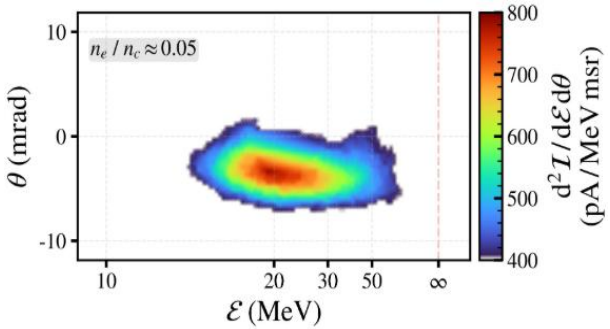
Applications

Positron Annihilation Lifetime Spectroscopy
Defect characterisation in materials at unprecedented time resolution
Studies of open volumes in polymers, semiconductors, and metals

Key parameters

~ **50 MeV** electron driver energy (kHz LWFA)
Bethe-Heitler pair production in thin converter foil
~ **10^7 e^+/shot** at kHz repetition rate with sub-ps bunch duration

L1 laser: 30 mJ / 1kHz



Measured energy spectrum
of the electron beam

L1-laser + ALFA stations

Conceptual design of the LPA-based positron setup is under preparation.

Conclusion

- At ELI ERIC, we are aiming to develop the laser-driven branch of the EuPRAXIA distributed facility to deliver high-quality GeV beams, water-window FELs, and new secondary sources for Europe's next-generation photon science.

Our activity is based on:

- Synergy with EuPRAXIA at INFN-LNF / Italy (Beam-Driven pillar).

- Collaborative activity involving EuPRAXIA members.

Thank you for your attention