EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA Annual meeting
October 29, 2025

W16: 2nd EuPRAXIA pillar at ELI Beamlines

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ELI-Beamlines / ELI ERIC

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

PP-WP16: main objectives

Funded by the European Union

Objectives:

- ✓ - Evaluation of requirements for potential site of Laser-Driven EuPRAXIA pillar
- ✓ - Evaluation of a readiness of candidates to accommodate the Laser-Driven EuPRAXIA pillar
- ✓ - Identification of a site for Laser-Driven EuPRAXIA pillar
- - Identification of possible funding resources for the technical realization of the Project
  - → Financial Board of Sponsors for guidance on science-political, funding aspects

In collaboration with WP3

10/2024 - 03/ 2025

CB-decision of the 2nd site proposal → 03/2025

Now: 35m

Start: 11.01.2022	6m	12m	16m	18m	20m	24m	28m	32m	38m	m42
WP16			**M16**				D16.1			D16.2

M16 – Milestone report: Review of candidates' sites proposals → **DONE**

D16.1 - Update on EuPRAXIA plans for selected 2nd site (LD-based EuPRAXIA) → **Feb.2025 → DONE**

D16.2 - Report on TDR status for the 2nd site (LD-based EuPRAXIA) → **Apr.2026**

- **Update on EuPRAXIA plans**
- **for selected 2nd site**
- **D16.1**

Goal: Status report on TDR for 2nd site → 04/2026

EuPRAXIA PP CB Decision

Funded by the European Union

March 25, 2025

- Adopt the **ELI Beamlines** facility (part of ELI ERIC) as **EuPRAXIA`s second user site**. It will be the pillar for a laser driven, plasma-based Free-Electron Laser for users, in accordance with the EuPRAXIA CDR and ESFRI applications. **The facility will launch with an initial stage operating at 1 GeV electron beam energy (EuPRAXIA Phase-1)**

- Support **EPAC**'s proposal to act as the **EuPRAXIA Centre for R&D on a 5 GeV electron beam** that is produced in a compact laser-plasma accelerator and that has sufficient beam quality for the FEL application.

- Support **CNR-INO** as the **EuPRAXIA National Node in Italy for Laser R&D**, as a test facility and as an additional formal link between the two EuPRAXIA pillars in Italy and Czech Republic.

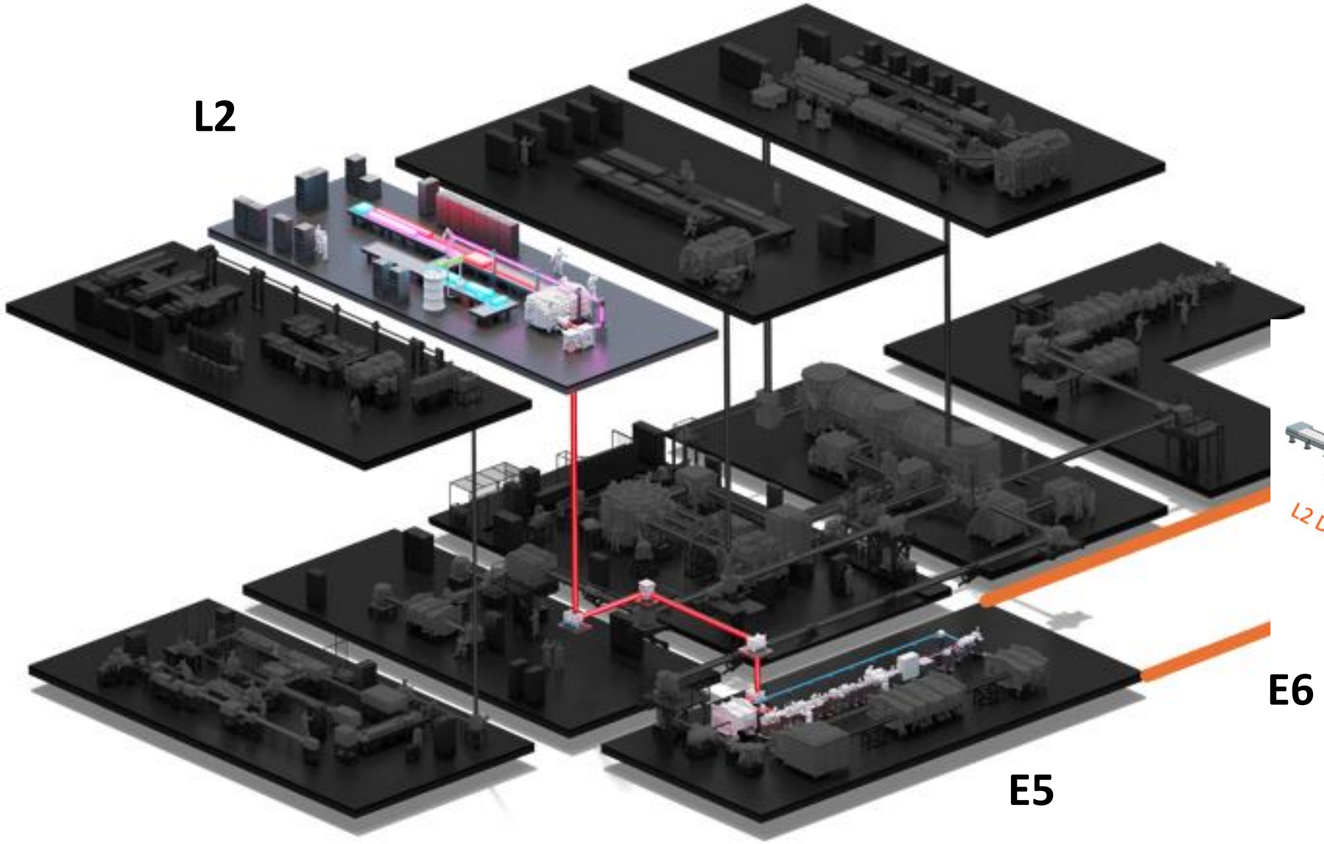
EuPRAXIA@ELI: objectives (PHASE-1)

Funded by the European Union

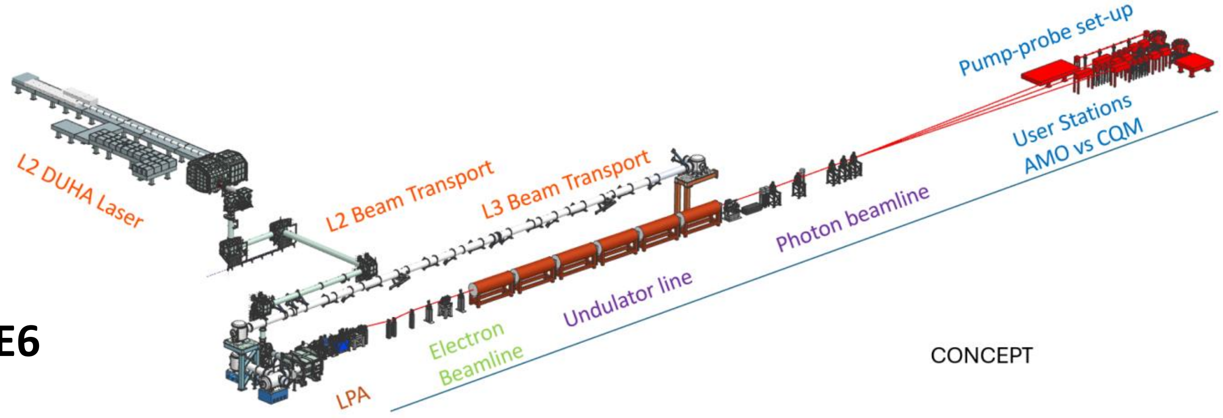
1GeV electron LPA soft X-ray FEL

+ BETATRON and POSITRON (LE) sources

Existing infrastructure



Conceptual solution for Phase-1, Integrated into the ELI Beamlines infrastructure



EuPRAXIA@ELI: phases and objectives

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PREPARATORY phase

- ❑ **TDR** for LPA-based soft X-ray FEL

IMPLEMENTATION phase

- ❑ High-power high-repetition-rate **laser development** (L2)
- ❑ **BETATRON source**: commissioning and operation
- ❑ **Integration** of existing (E5+E6) infrastructure of ELI Beamlines

BASED on collaboration with EuPRAXIA PARTNERS

→ *National nodes*

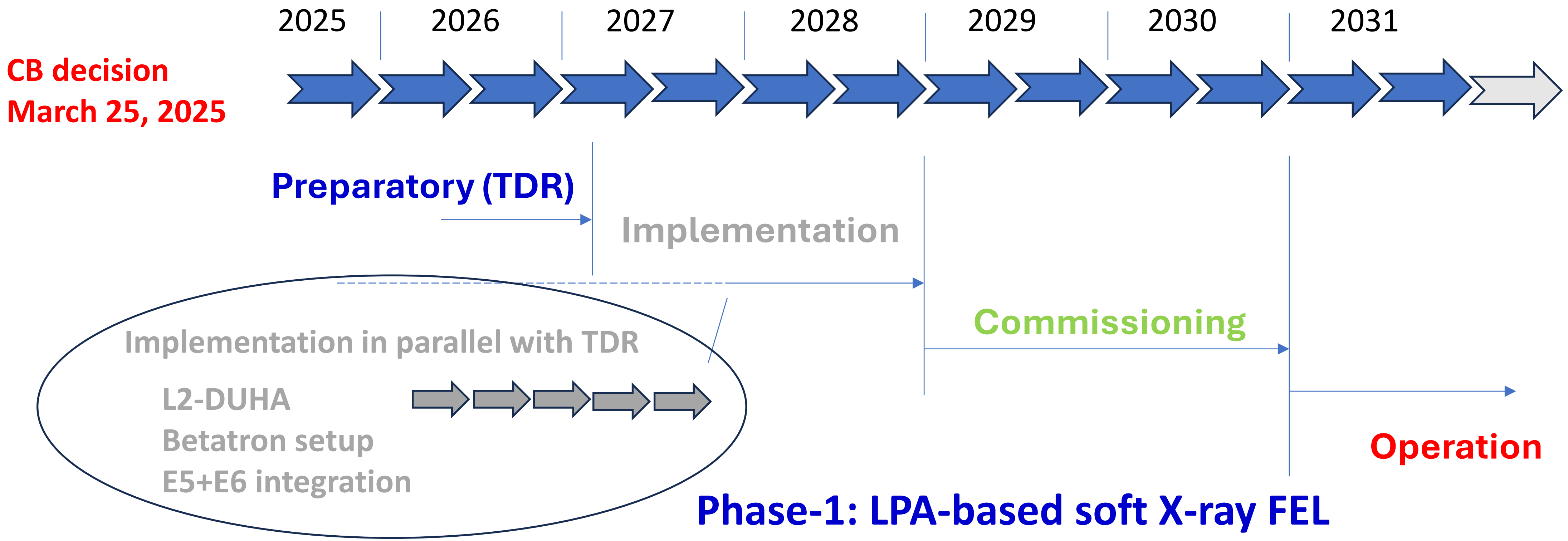
→ *EuPRAXIA PP work-packages*

→ *PACRI work-packages*

EuPRAXIA@ELI Beamlines: schedule

Funded by the European Union

Timescale of the Project (PHASE-1-1) at <u>ELI Beamlines</u>
→ presented in the bid-book



EuPRAXIA@ELI: Preparatory phase

Funded by the European Union

EuPRAXIA CB decision
March 25, 2025

1st INFN-ELI meeting
INFN, Frascati (in person)
May 15, 2025

Coordination activity between two EuPRAXIA pillars

Assignment of the <u>INTERNAL</u> team and Project Office
→ August 2025

Scope of Work
Internal Project
R&D funding

<u>TDR Collaboration</u> & Contributions
1st online meeting with EuPRAXIA National Nodes representatives
→ July 17, 2025

- ✓ France
- ✓ Germany
- ✓ Portugal
- ✓ Italy
- ✓ UK
- ✓ Spain
- ✓ Switzerland

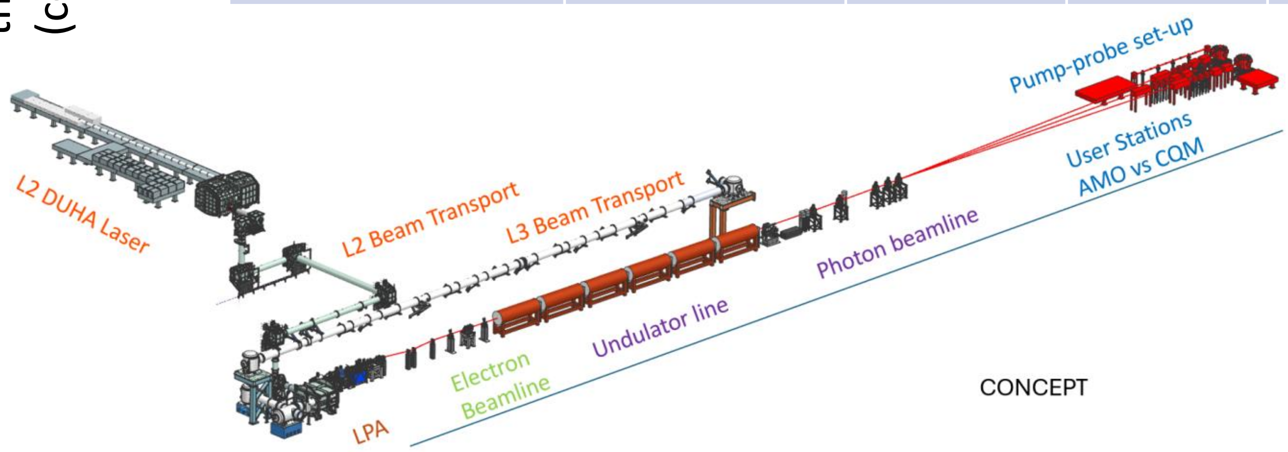
Feedback from National Nodes
Framework for collaboration

EuPRAXIA@ELI Beamlines: NN feedback

Funded by the European Union

Summary of
the EuPRAXIA NN feedback
(collected: **August-October 2025**)

National Nodes	Laser @ BT	LPA	E-BT	Undulator	Photon BL	User stations
France	+	+	+	+	+	+
Italy	+	+	+	-	-	+
Germany	+	+	+	+	-	+
Portugal	+	+	-	-	-	+
UK	+	+	+	+	+	+
Switzerland	-	-	+	+	-	-
Spain	+	+	+	-	+	+



Next step (November 2025):

- *Framework for collaboration*
- *Financial support (BOFS discussion)*
- *R&D plan for 2026*
- *Contribution to LPA-based TDR*

EuPRAXIA@ELI Beamlines: TDR Status

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LPA-based FEL / TDR structure … aligned with INFN-LNF TDR

Collaborations activated already

TDR chapter	Status	Collaborations
Executive Summary		
Laser (L2-DUHA) and Laser Diagnostics	✓	ELI /STFC + **WP12** + PACRI
Laser-Plasma e-Accelerator (modelling /plasma source prototyping) and Plasma Diagnostics	✓	ELI/IST/CNSR/STFC + **WP8** + **WP10** + **WP14** + PACRI
Electron Beam Transport and Relevant Diagnostics	✓	ELI/PSI + **WP9 + WP13**
Undulator Line and FEL performance	✓	ELI/ENEA + PSI + **WP9**
Photon Beam Transport and Relevant Diagnostics	✓	ELI/DESY(FLASH) + **WP13**
User End-Stations	✓	ELI/DESY(FLASH) + **WP11**
Safety system		
Control and DAQ systems		
Infrastructure (E5+E6) and Technology Integration (3D model)	✓	

EuPRAXIA@ELI: LPA-based FEL TDR

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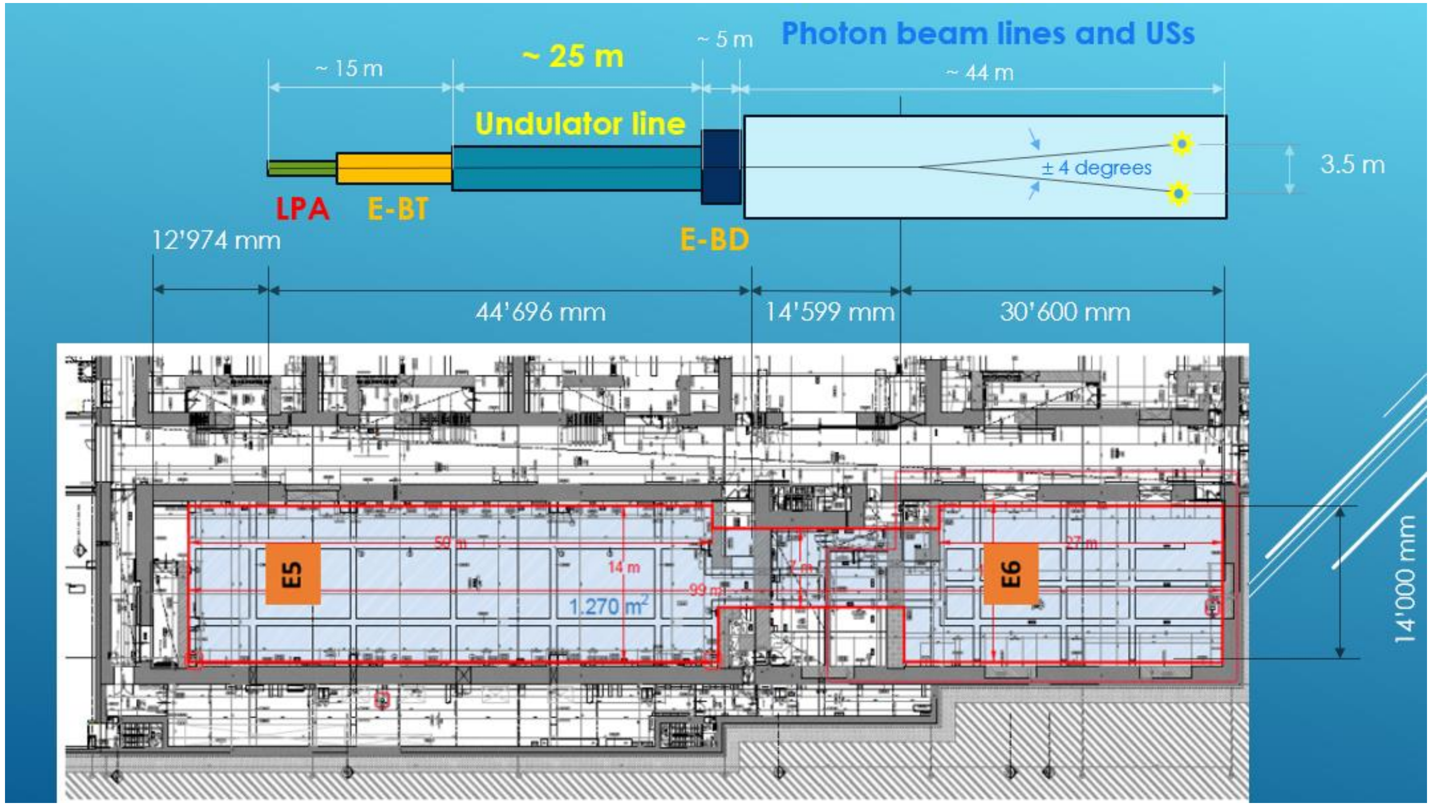
Main objectives (EuPRAXIA PHASE-1)

- 1 GeV LPA-based FEL
- ‘Water window’ range of the coherent photon radiation → $E_{ph,1}$ ~ 300 ÷ 500 eV
- Combining existing E5+E6 experimental halls



Main constraints:

- Length of Undulator line **< 25 m**
- Photon beam line with 2 user stations (in E6: **< 44 m**)

Plasma accelerator options:

(1) LPA scheme
(2) Hybrid scheme

Soft X-ray Photon Beamline

eli

FLASH.

The Free-Electron Laser in Hamburg

ELI Beamlines + DESY (FLASH)

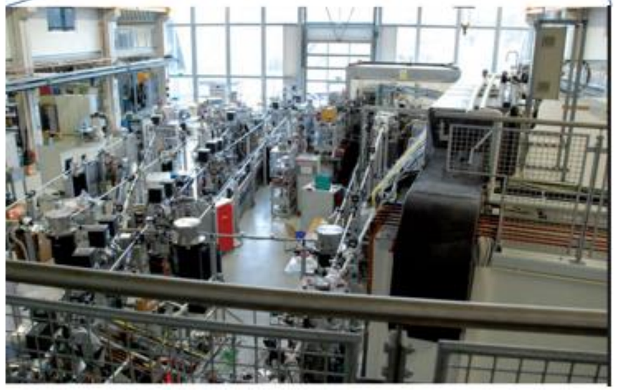
Pre-experiment diagnostics

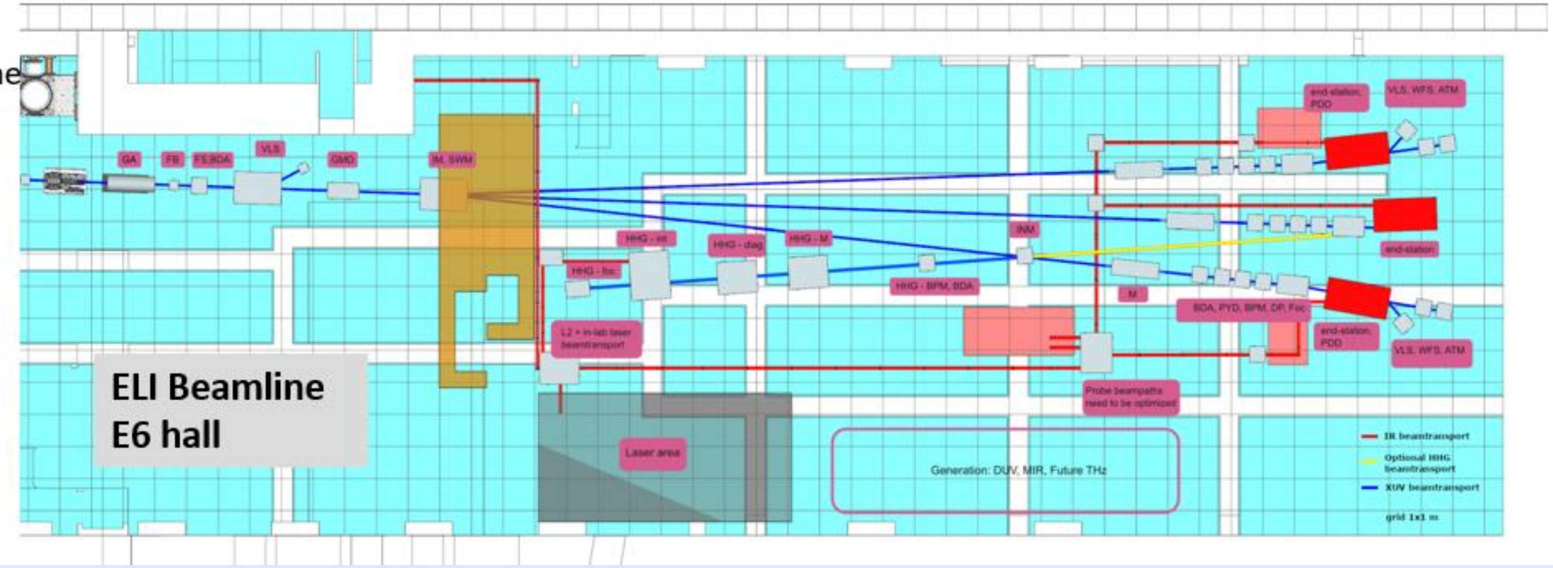
OM: Offset mirror
FB: Filter box
FS: Fast shutter
BDA: Beam defining aperture
BPM: Beam positioning monitor
IM: Intensity monitor (may be GMD)
GA: Gas attenuator
GMD: Gas monitor detector
PYD: Photodiode YAG diagnostic
VLS: Variable line spacing spectrome
DP: Differential pumping
M: Monochromator
BPC: Beam Preparation Chamber
KBM: Kirpatrick Baes Mirror
Foc: Focusing optic (TBD)
PPT: Pump-probe table

SD: Split and delay
EM: Ellipsoidal Mirror
BFO: Back focusing optic

Post-experiment diagnostics
→ depends on space

VLS spectrometer
ATM: Arrival time monitor
WFS: Wavefront sensor
PDD: Pulse duration diagnostics





LPA based FEL: SASE FEL modelling

ELI Beamlines + SwissFEL (PSI) + ENEA

Funded by the European Union

GAP		4 mm	5 mm	6 mm	7 mm
K_u		1.30	1.06	0.86	0.70
$\lambda_{ph,1}$	nm	3.6	3.05	2.7	2.42
$E_{ph,1}$	eV	342	406	463	510

Undulator technology: Swiss-FEL (HMPU-U15)

Photon beam parameters (estimation) λ_u = 15 mm		Gap = 6 mm / 4 mm
Photon radiation energy (h=1)	eV	463 / 342
Photon radiation wavelength (h=1)	nm	2.7 / 3.6
Saturation length *	m	**~ 24 / ~ 14**
Photon per pulse *	10^{11}	2 / 1.7
Photon bandwidth *	%	0.4 / 0.5
Photon pulse energy *	μJ	6.4 / 9.2
Photon brilliance / shot * in [photons/s/mm²/mrad²/0.1% bandwidth]	10^{30}	1.5 / 1.4
Photon pulse power at saturation *	GW	**0.87/ 1.2**
RMS transverse spot size *	μm	24 / 24
RMS transverse divergence *	μrad	10 / 12

"SIMPLEX" code / T.Tanaka: J. Synchrotron Rad. 22 (2015) 1319

LPA-based FEL: e-beam for SASE FEL

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Challenge:

We = 1000 MeV (Gap = 6 mm) → $\lambda_{ph,1}$ = 2.7 nm / $E_{ph,1}$ = 463 eV			
Peak current	[kA]	2.7 (min)	20 pC/ 3 fsec (RMS) / Gaussian
RMS slice energy spread	%	0.25 (max)	Strong dependence
RMS slice normalized emittance	μm	0.3 – 0.4	Moderate dependence
Average SIGMA beam size	μm	~ 20 - 30	Close to optimum

Modelling:

LPA - SIOM/ Ke Feng report-2025

W_e= 500 MeV			
Peak current	[kA]	~ 4.5	
RMS slice energy spread	%	0.2	Assumption: **0.1** for 1000 MeV
RMS slice normalized emittance	μm	0.1	
Average SIGMA beam size	μm	~ 20	

Hybrid scheme / L. Berman report-2025

W_e=1000 MeV			
Peak current	[kA]	3-5	
RMS slice energy spread	%	0.05	
RMS slice normalized emittance	μm	0.04	
Average SIGMA beam size	μm	~ 20	

Current collaborative efforts as a part of the S2E activity:

WP8 + WP10 + PACRI

ELI Beamlines + IST + CNRS + EPAC

+ WP14 (Hybrid scheme)

EuPRAXIA@ELI Beamlines: LASER

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ELI Beamlines + STFC (UK) + PACRI

Laser parameters (L2-DUHA) / from Bid Book

LPA-based FEL / PHASE-1		
Pulse energy	Joules	**5**
Pulse duration (FWHM)	fsec	> 25
Repetition rate	Hz	20 → 50 → 100
Wavelength	nm	820
Contrast	-	10^{-11}
Pointing stability	µrad	< 1
Energy (shot-to-shot) stability	%	< 1
Temporal characteristics		**TBD**
Beam profile diameter	mm	120
Beam profile – Super Gaussian	-	8th order
Laser synchronization capabilities		AUX beam fully synchronised

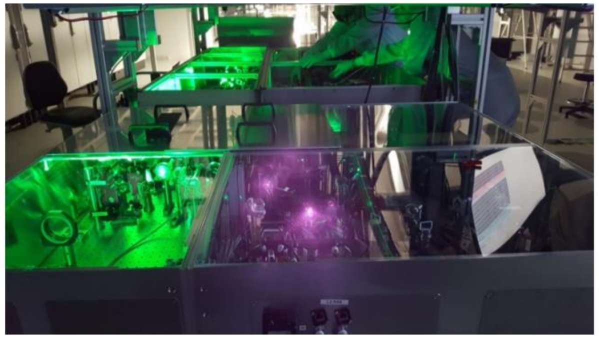
ELI Beamlines: Implementation

Funded by the European Union

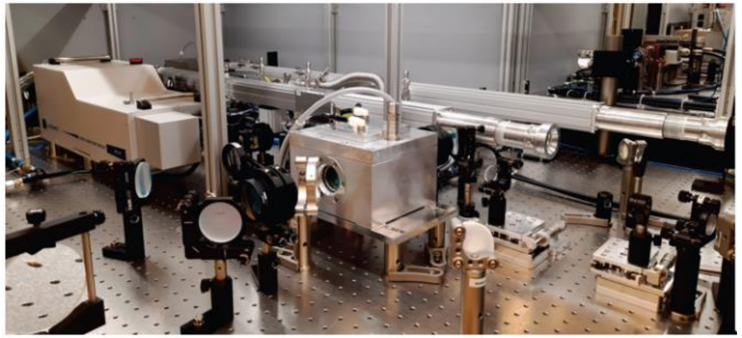
Technology Readiness at ELI Beamlines

L2-DUHA laser development: 3J/25fs/20Hz → 4J/25fsec/100Hz

Dedicated talk:
TRL issue#1
Tyler Green
October 31, 2025

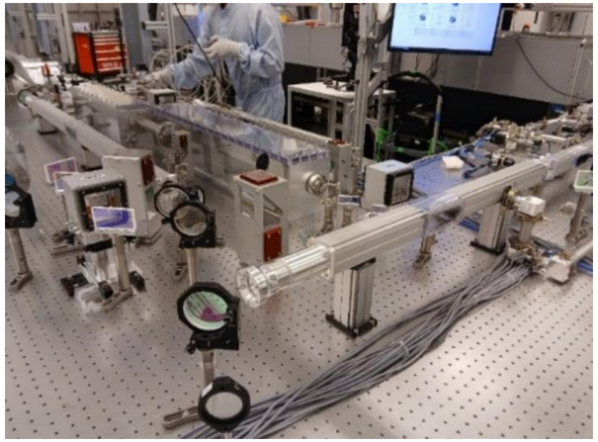


Broadband front end of L2-DUHA



Booster amplifier of L2-DUHA

Brayton cryogenic cooling system integrated into laser



OPCPA system under pre-alignment

L2-DUHA compressor chamber in L2-hall

June 2025

ELI Beamlines: Implementation

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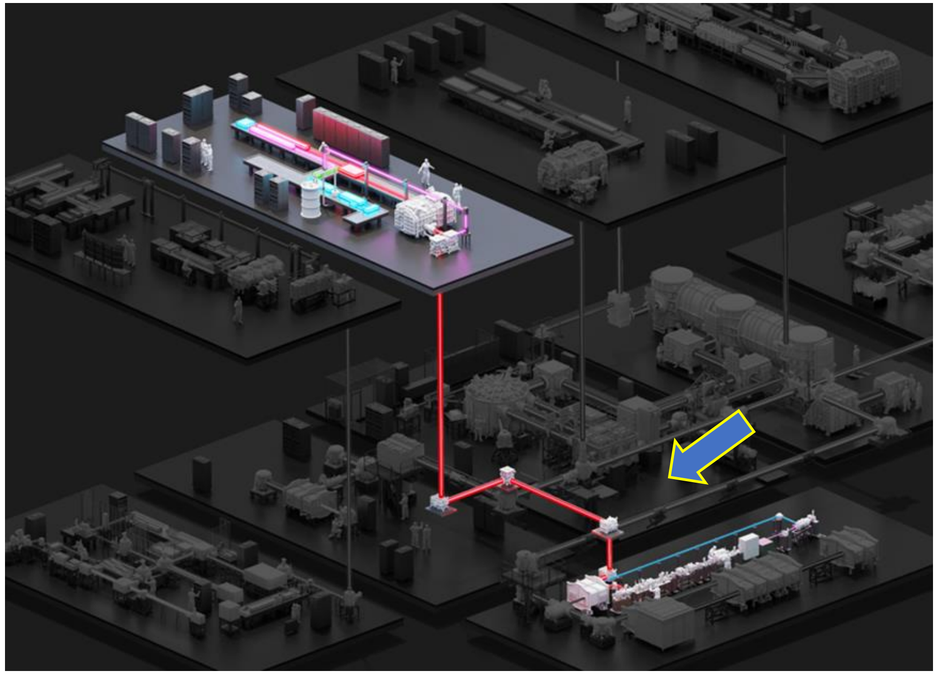
L2-to-E5 laser beam transport

Technology Readiness at ELI Beamlines



June 2025

ELI Beamlines: Implementation

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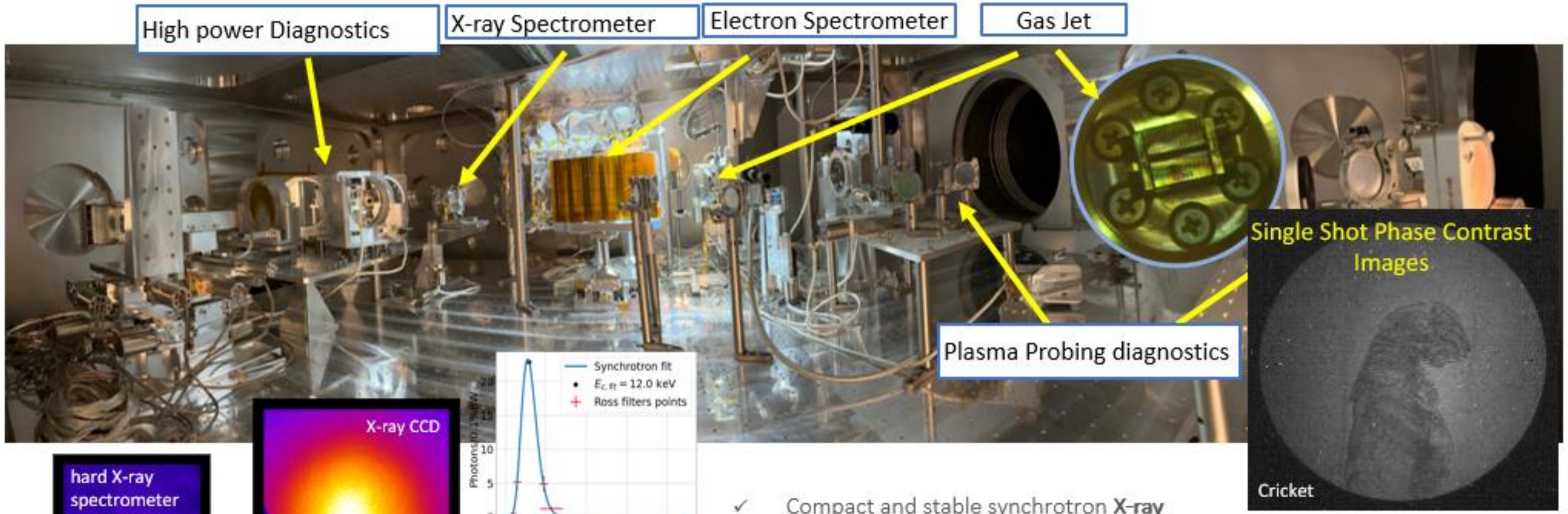
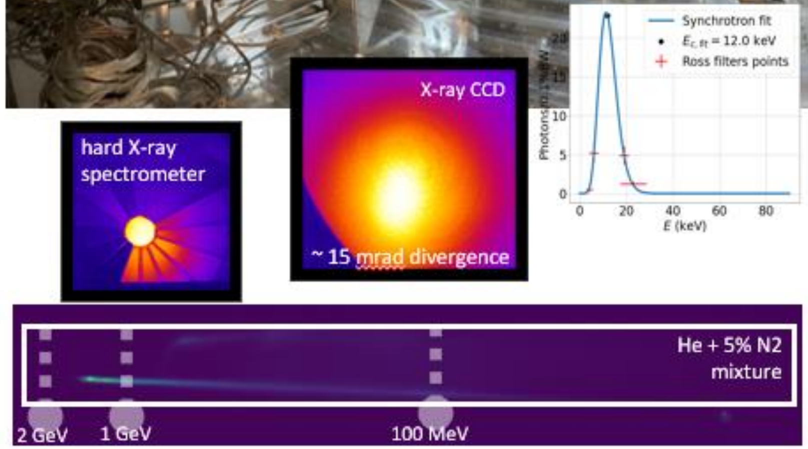
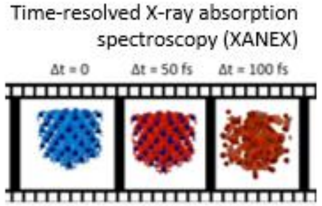
GAMMATRON (Betatron) beamline commissioning

Technology Readiness at ELI Beamlines





- ✓ Compact and stable synchrotron **X-ray source**
  - **~10 fs, < 2µm source size**, collimated (<15mrad)
  - Photon flux **~10^{10} photons/shot**
  - Critical Energy **>10 keV**
  - Tuneable X-ray energy
- ✓ **Pump beam** (800 nm, 400 nm or 266 nm)



E2-Hall / U.Chaulagain (ELI Beamlines)

June 2025

SUMMARY

- Internal Project and Team Structure **are established** at ELI Beamlines.

- Building of the Collaboration through the EuPRAXIA PP structure, which will focus on the ELI Beamlines TDR project, **in PROGRESS**.

- Both phases of the TDR-oriented Project (Preparation and Implementation) are **in PROGRESS** at ELI Beamlines following the Project timeline.

- The report "D16.2 Report on TDR Status for the 2nd Site (LD-based EuPRAXIA)" **has to be submitted** to the EU by April 2026.

Thank you for your attention