Science at Department 86
Radiation Physics and Electron Acceleration
&
High Field Initiative/ERT

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‘PRESENTATION OF HORIZON EUROPE’
ELI ERIC / ELI Beamlines
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Radiation Physics and Electron Acceleration, High Field Initiative/Excellence Research Team

The objective of the Dept. 86 Scientific Program is the development and operation of stable and reliable laser-driven sources of high energy electrons and hard electromagnetic radiation for applications and for fundamental sciences.

The Research program mission is establishment and operation of world leading radiation and electron acceleration activities using high power lasers.

The Dept. 86 comprises four teams:

ELI-ELBA

- installation, commissioning and operation of the electron accelerators and user station

LUIS

- installation, commissioning and operation of the LUIS beamline and user station

X-RAY SOURCES

- installation, commissioning and operation of the x-ray sources

High Field Initiative/Excellence Research Team (HiFI/ERT)

- theory and computer simulations on the charged particle acceleration, hard electromagnetic radiation generation and on the theory of fundamental process and laboratory astrophysics

FZU Institute of Physics of the Czech Academy of Sciences
The Czech Academy of Sciences

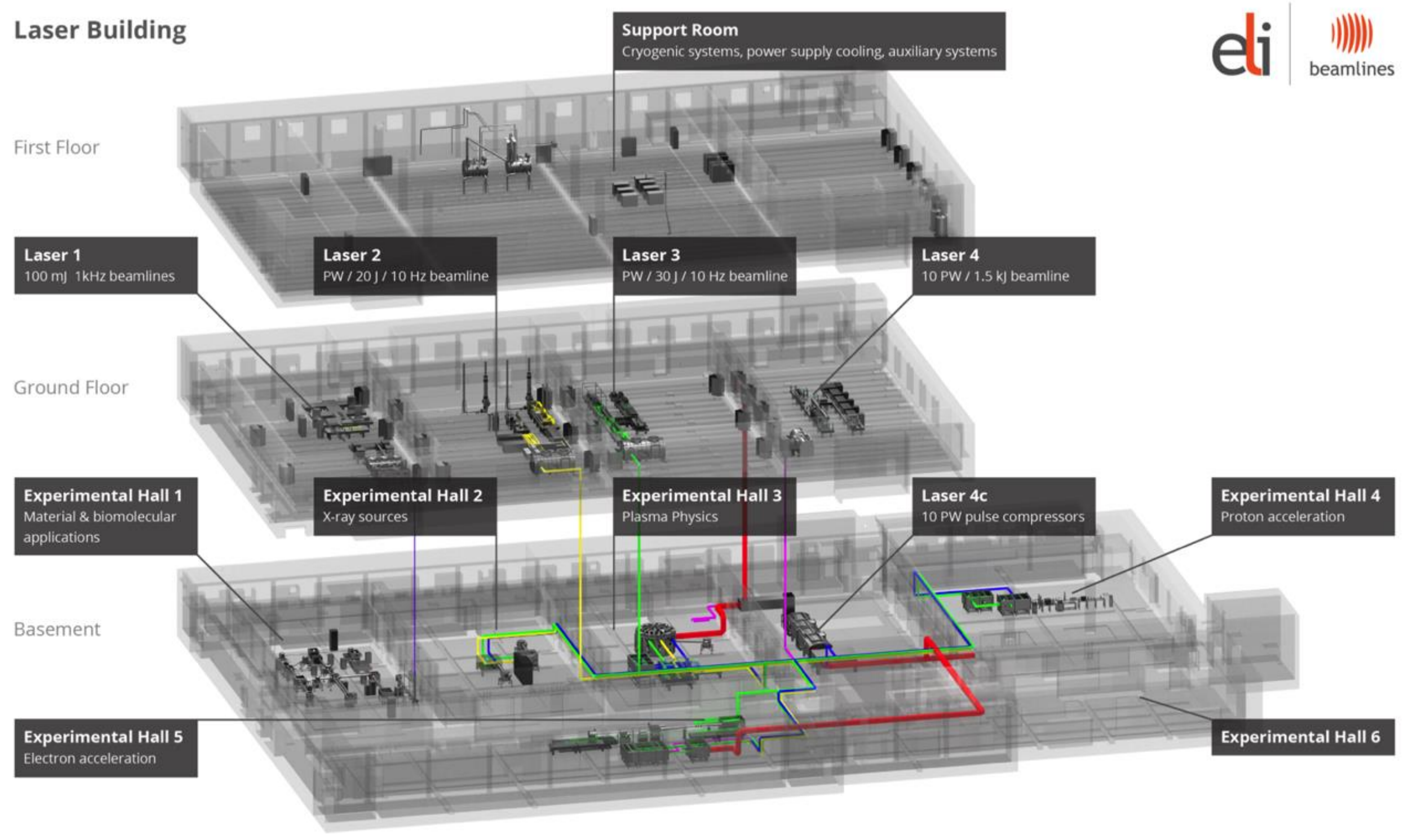
ELI-ELBA: Includes the laser wake field acceleration of ultra-relativistic electron beams with energies reaching tens of GeV. Their collision with multi-petawatt laser radiation will provide the conditions for entering yet unexplored regimes allowing studies in fundamental science including studies of the high power gamma-ray flash generation in the radiation friction dominated laser plasma, nonlinear quantum electrodynamics of relativistic plasmas, and probing the nonlinear vacuum texture.

LUIS: Application of the laser accelerated electrons is also in construction and operation of the laser-driven compact X-Ray Free Electron Laser for generation of incoherent and coherent electromagnetic radiation in the range from XUV to hard X-Rays.

X-RAY SOURCES: The sources that are being implemented include, in particular, high-order harmonic generation, advanced plasma X-ray sources (K-alpha radiation) and sources based on relativistic electron beams accelerated by laser such as betatron radiation and inverse Compton scattering. Key benefits of those X-ray sources are in providing photon beams of high photon energy, extremely high spectral brightness, ultra-short pulse duration, and in the ability of internal X-ray pulse synchronization to infrared and visible laser pulses or electron bunches for advanced pump-probe experiments.

HiFI/ERT (High Field Initiative) Project: Aims at obtaining scientific results in the field of ultra-intense laser matter interaction providing theory for conducting at the ELI-BL worldwide unique high-field **flagship experiments**

ELI-BEAMLINES FACILITY AND LASERS



ELI-BEAMLINES LASERS

Synchronization within <100 fs by master facility clock

L1 – ALLEGRA

Technology
- OPCPA
- Circular
- Gaussian
- Synchronized probe beam

Parameters

Nominal	Current
100 mJ	55 mJ
1 kHz	1 kHz
15 fs	15 fs

Expected Electron/Ion Energy
100 MeV/20 MeV

L2 – DUHA

Technology
- OPCPA
- Circular
- Flat-top
- Synchronized mid-IR pulse

Parameters

Nominal	Current
2J	WORK
25s Hz	IN
<40 fs	PROGRESS

Expected Electron/Ion Energy
1 GeV/60 MeV

L3 – HAPLS

Technology
- Ti:Sapphire, DPSSL
- Square, 250x250 mm^2
- Flat-top

Parameters

Nominal	Current
30 J	13 J
10 Hz	3.3 Hz
30 fs	30 fs

Expected Electron/Ion Energy
10 GeV/200 MeV

L4 – ATON

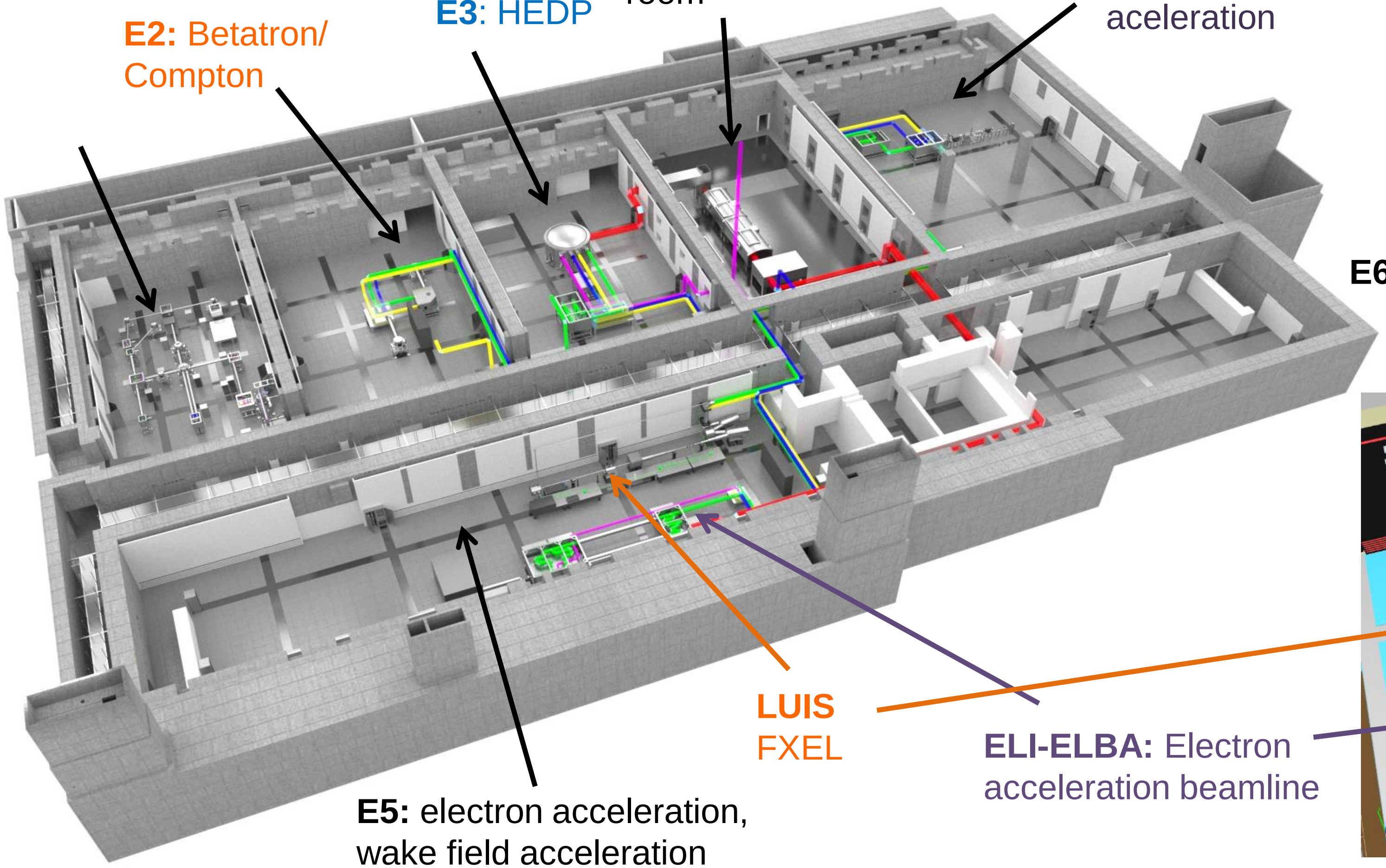
Technology
- Nd:glass
- Square, 550x550 mm^2
- Flat-top
- Longer beams (150 fs)

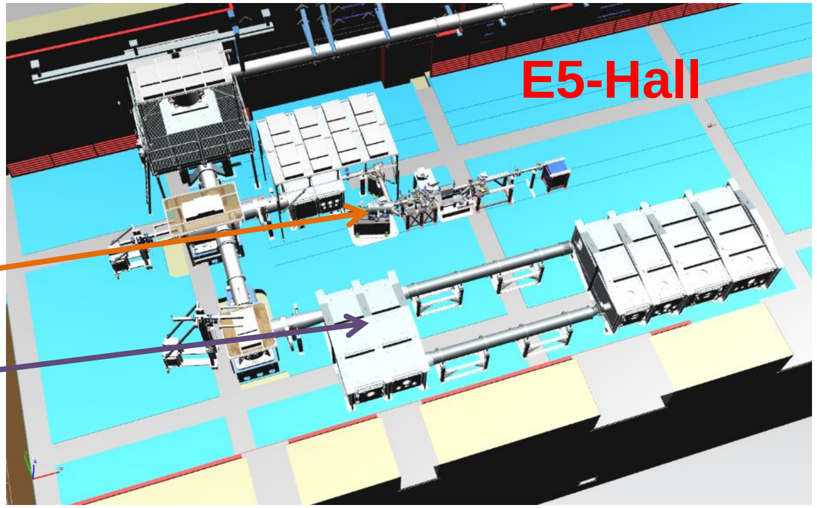
Parameters

Nominal	Current
1.5 kJ	WORK
1/min	IN
150 fs	PROGRESS

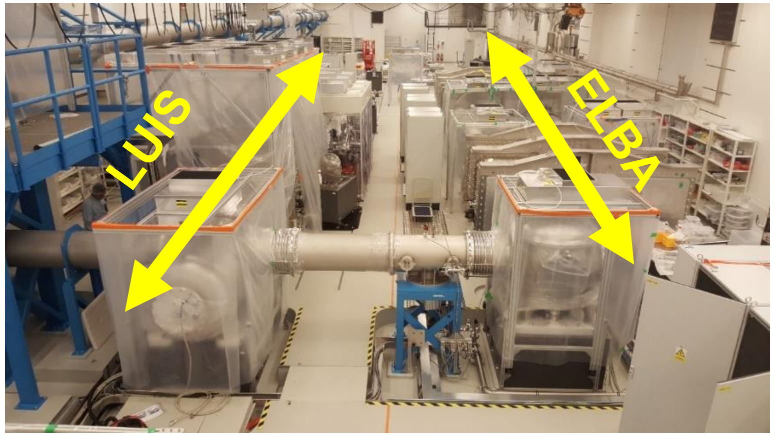
Expected Electron/Ion Energy
100 GeV/600 MeV

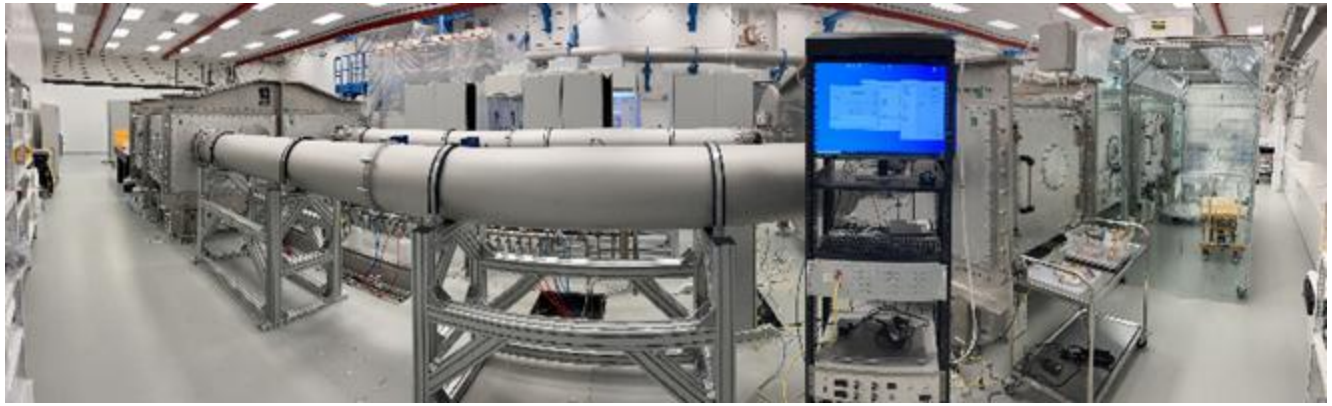
ELI-BEAMLINES



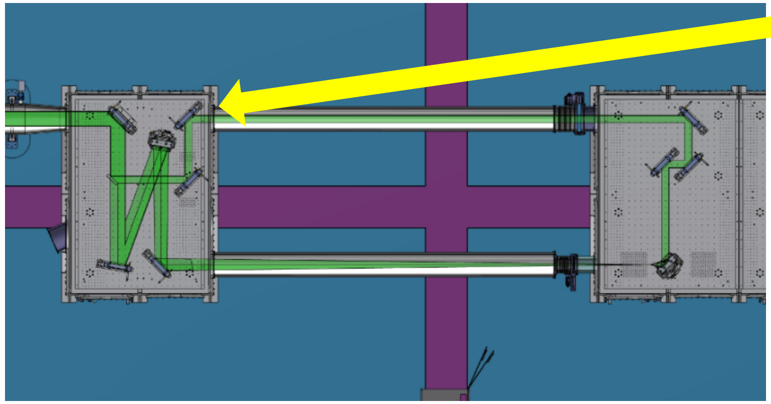


ELI-ELBA: Electron–Laser Collider for Fundamental Science (GEV-PW-10 Hz)





Fish eye picture of ELI-ELBA all-optical collider at ELI-Beamlines



Wavefront splitting of L3 in the first vacuum chamber

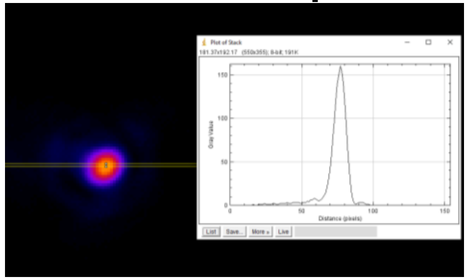
L3-HAPLS parameters	ELBA LWFA electron beams	Counter-propagating laser pulse
30 J (compressed)	> 2 GeV	> 10 J
30 fs FWHM	< 10% ΔE/E FWHM	> 10^{21} W/cm^2
10 Hz	> 10 pC	
	10 m focal length	

ALFA: kHz Electron Acceleration with L1-ALLEGRA

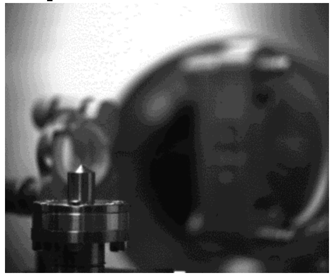
ALFA (Allegra Laser For Acceleration)

- Up to 55 mJ at moment (nominal plan 100 mJ)
- 1 kHz
- Pointing stability 1-2 µrad
- 16 fs after compressor
- Electrons >50 MeV within reach with current laser parameters

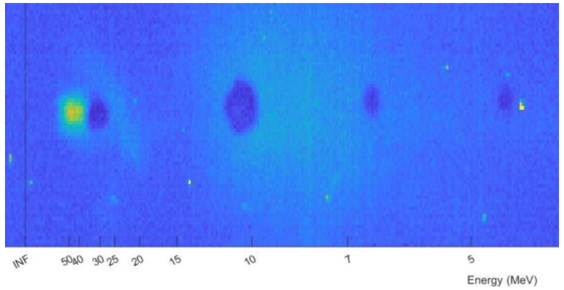
Laser focal spot



Supersonic nozzle

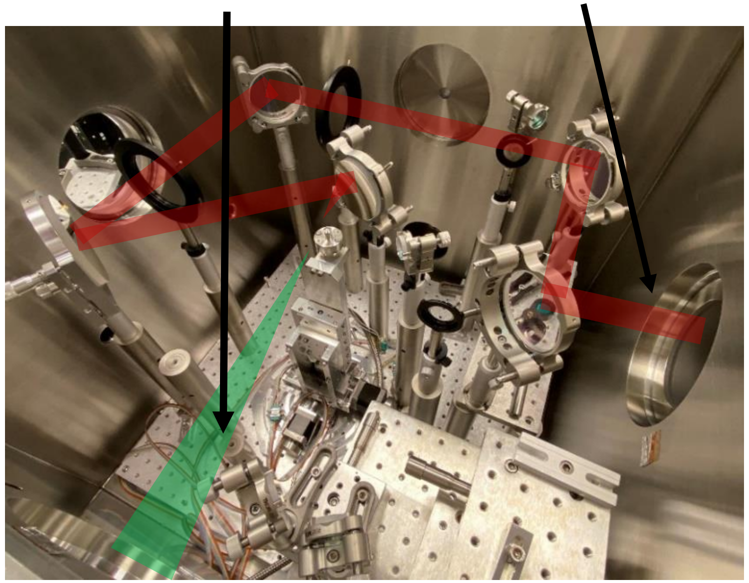


Energy spectrum of 40 MeV electrons at 1 kHz

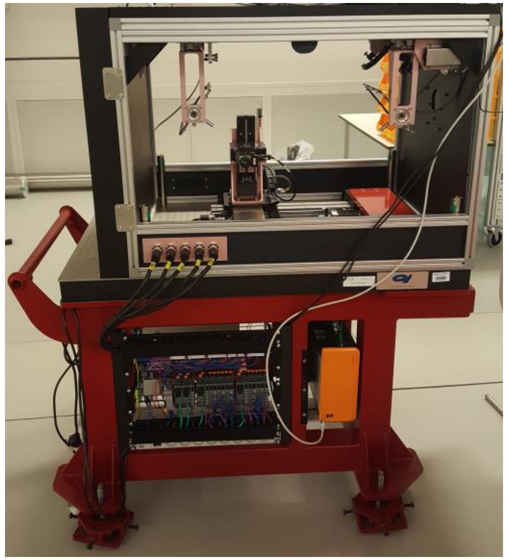


Electron Beam

L1 Laser

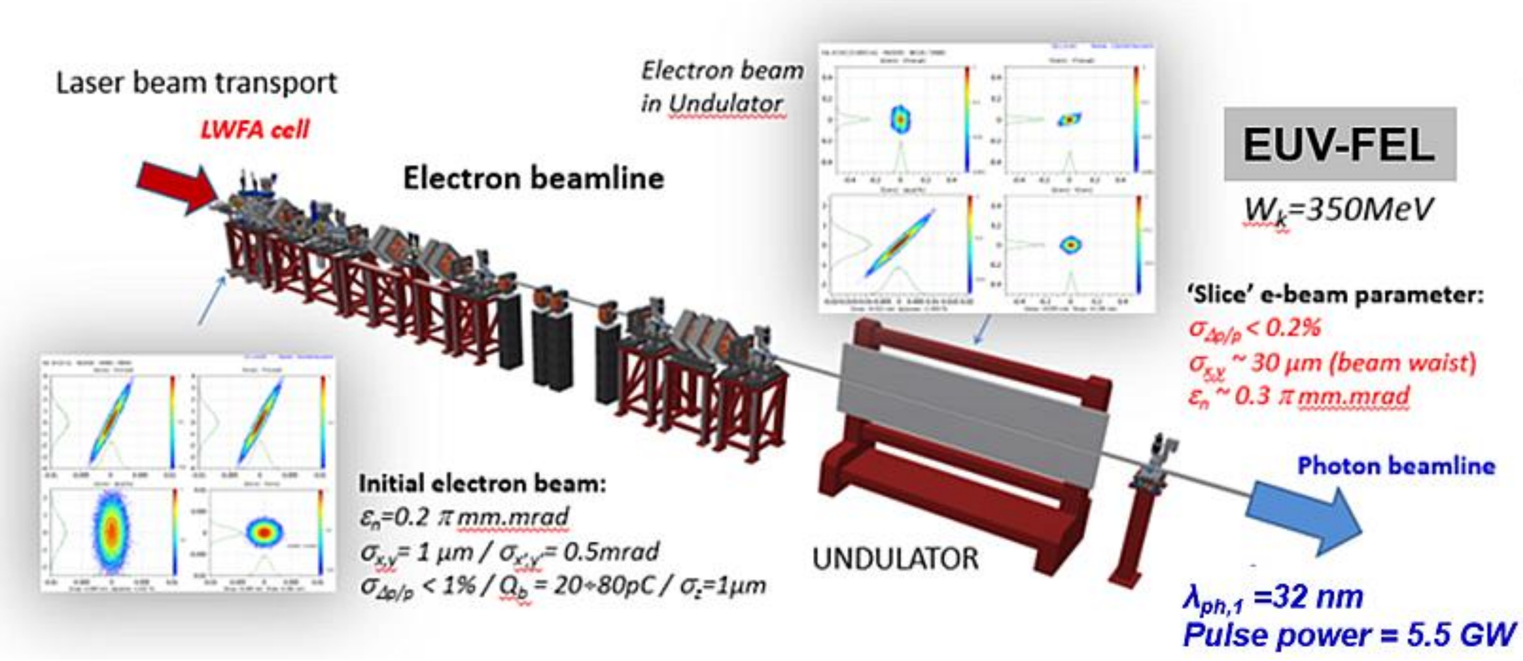


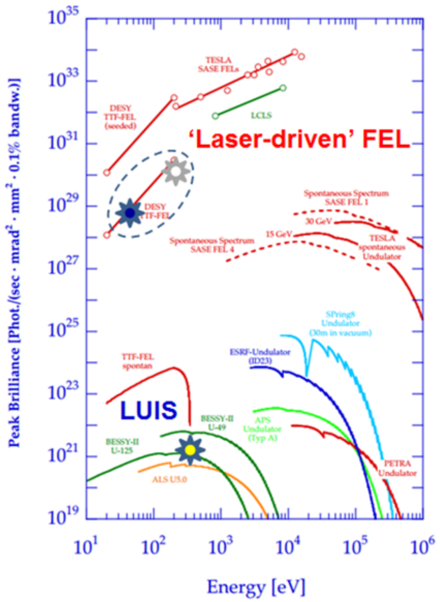
In-air User Station for sample irradiation

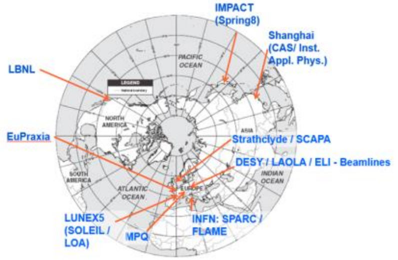


Development at ELI-Beamlines Compact XFEL: from incoherent to coherent photon radiation

LUIS: → to <u>coherent</u> EUV undulator radiation (laser-driven FEL)





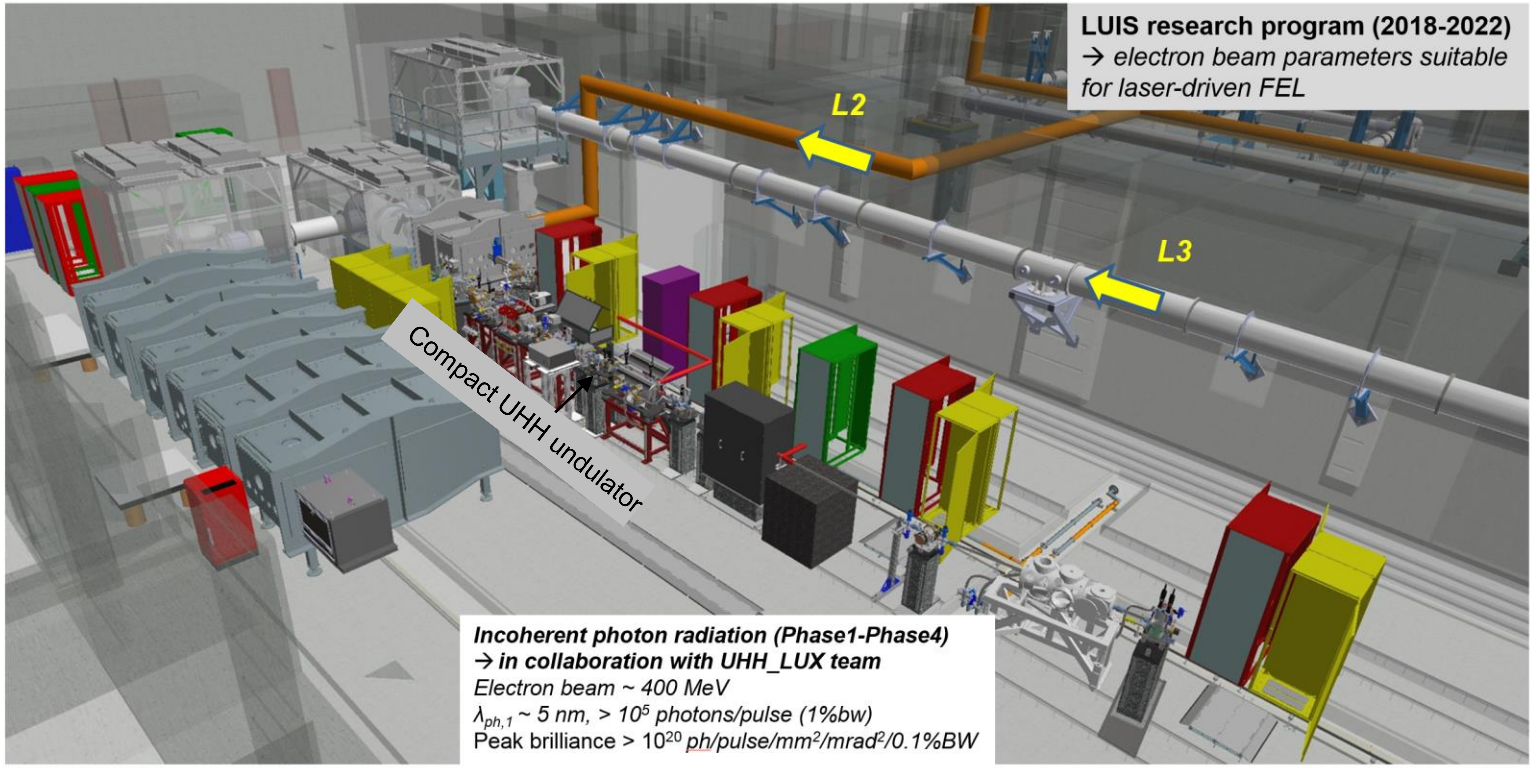


Coherent (FEL) regime
EuPRAXIA collaboration

Incoherent regime

EuPRAXIA (ESFRI)

LUIS: Laser-driven Undulator radiation for users: from incoherent to coherent photon radiation



High-repetition rate operation using ELI-Beamlines Lasers:

- L2-DUHA 100 TW, 2 J, 50 Hz
- L3-HAPLS 1 PW, 30 J, 10 Hz

Undulator parameters

Undulator period	mm	5
Number of period		100
Total length	mm	500
On-axis magnetic field	T	0.6
K-value		0.28

Photon beam parameters (PHASE#1) / Estimation

		W_e = 300 MeV / Q_b=30pC	W_e = 600 MeV / Q_b=30pC
Photon energy (1st harmonic)	eV	165	658
Photon wavelength (1st harmonic)	nm	7.5	1.8
Number of photons (0.1%bw)		1.7×10^5	7.1×10^6
Peak Brilliance (at peak current of electron bunch)	*	4.8×10^{20}	1.9×10^{21}
Effective beam size and divergence of the photon beam (1st harmonic)			
Σx,y	µm	114	114
Σx',y'	mrad	0.087	0.043

* photon/sec/mrad²/mm²/0.1%bw

Photon beam transport

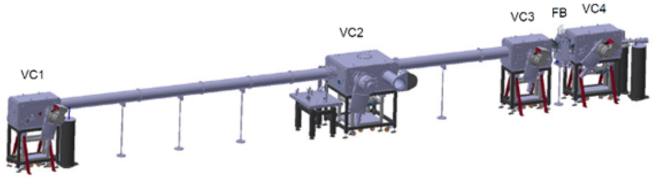
→ Focal spot down to 10 µm

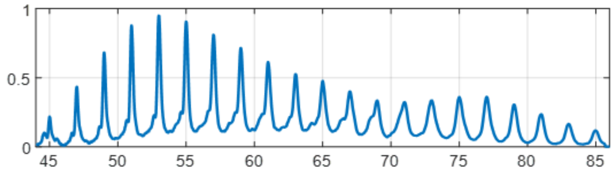
Laser-Driven X-Ray Sources

E1

L1 driver
1 kHz, 50 mJ, 20 fs

High-order harmonic

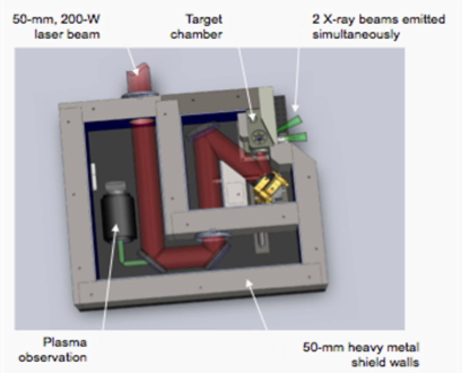




	6 mJ, 35 fs from 2018	L1: 100 mJ, ~15fs from late 2020
Wavelength	10 -120 nm	5 -120 nm
Photons/shot	1E7 to 1E9	few 1E9 -1E12
Duration	< 20 fs	< 10 fs
Polarization	Linear	Lin./Circ./Eliptic

Driver
1 kHz, 10 mJ, 35 fs

Plasma X-ray source

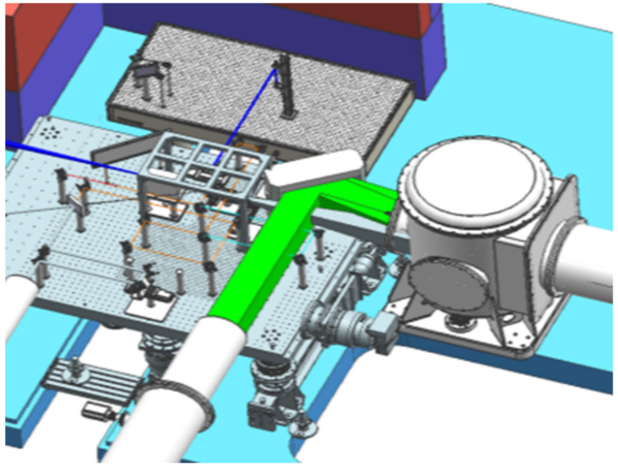


	6 mJ laser (35 fs)	100 mJ laser (15 fs)
photon energy	3 - 40 keV	3 – 80 keV
photons/(4π sr line or 1keV @10keV)	> 1E7	> 1E9
Source size	< 100 µm	< 100 µm
pulse duration	< 300 fs	<300 fs

E2/E3

L3 driver
10 Hz, 30 J, 30 fs

Betatron/Compton

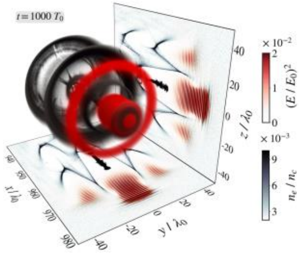


	Betatron	Compton
photon energy	10- 100 keV	50 – 5000 keV
photons/shot	> 1E9	> 1E8
Source size	< 5 µm	< 5 µm
pulse duration	~30 fs	< 30 fs

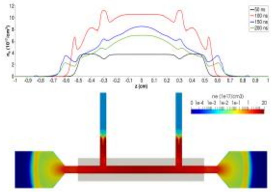
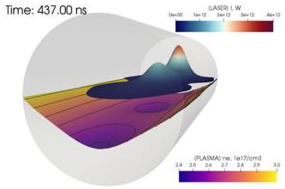
E1-Hall

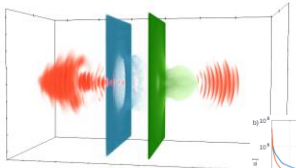
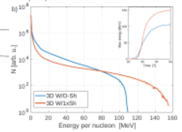
eli beamlines

HiFI (High Field Initiative) Project

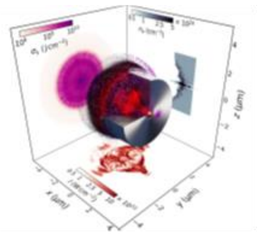
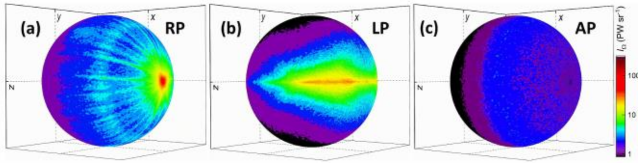


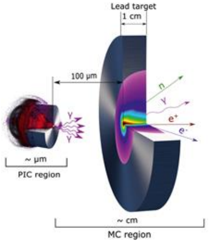
The HiFI Project aims at obtaining scientific results in the field of ultra-intense laser-matter interaction providing theory for conducting at the ELI-BL worldwide unique high-field **flagship experiments**

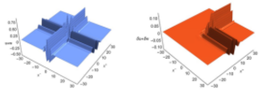
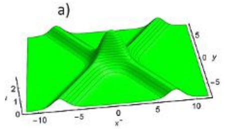
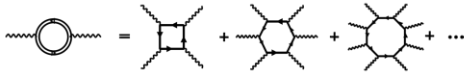
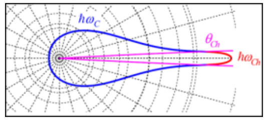
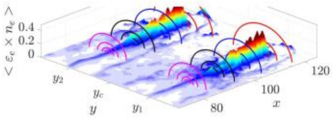
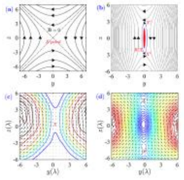
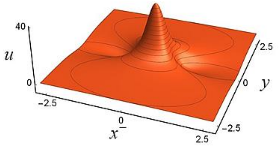



- Charged particle acceleration in laser plasmas
  - a) Electron acceleration
  - b) Ion acceleration
- Relativistic compression
  - a) EM wave intensification
  - b) Diagnostics of nonlinear process in laser plasmas
- Radiation dominated regimes of laser-matter interaction
  - a) Nonlinear waves in radiation dominated plasmas
  - b) Gamma-Ray flash. Photo-Nuclear Physics.
- Quantum electrodynamics processes in laser interaction with matter &
  - a) Electron-positron pair generation
  - b) Nonlinear waves in the QED vacuum
  - c) Cherenkov-Compton radiation in the QED vacuum
- Relativistic Laboratory Astrophysics
  - a) Relativistic magnetic reconnection and charged particle accelerati



HORIZON PROJECTS AT DEPT. 86

Approved projects at ELI Beamlines

Call: MSCA Doctoral Networks 2021 (HORIZON-MSCA-2021-DN-01)

Proposal acronym: EuPRAXIA-DN: EuPRAXIA is the first European project that develops a dedicated particle accelerator research infrastructure based on novel plasma acceleration concepts and laser technology. It focuses on the development of electron accelerators and underlying technologies, their user communities, and the exploitation of existing accelerator infrastructures in Europe. It was accepted onto the ESFRI roadmap for strategically important research infrastructures in June 2021 as a European priority. To fully exploit the potential of this breakthrough facility, advances are urgently required in plasma and laser R&D, studies into facility design and optimization, along a coordinated push for novel applications. EuPRAXIA-DN is a new MSCA Doctoral Network for a cohort of 10 Fellows between universities, research centers and industry that will carry out an interdisciplinary and cross-sector plasma accelerator research and training program for this new research infrastructure. The network focuses on scientific and technical innovations and on boosting the career prospects of its Fellows.

Call: HORIZON-INFRA-2021-DEV-02

Proposal acronym: EuPRAXIA: a distributed, compact and innovative accelerator facility based on plasma technology. It has been selected for the 2021 Update of the ESFRI Roadmap. In its first phase, its consortium of 51 institutes and industry partners will construct an electron-beam-driven plasma accelerator in the metropolitan area of Rome, thus bringing innovation, potential for spin-off companies, state-of-the art scientific applications and a vibrant international user community to the middle of Italy. In its second phase, EuPRAXIA will build one laser-driven plasma accelerator at a site to be chosen between several options in Europe. EuPRAXIA will serve users in ultra-fast science, e.g. on high-resolution medical imaging, deeply penetrating positron annihilation spectroscopy for materials and with Europe’s most southern free-electron laser (FEL). It will offer fascinating capabilities for research on biomolecules, viruses and microscopic processes. EuPRAXIA will thus be a transformative step in the development of ultra-compact accelerators and applications. The Preparatory Phase project EuPRAXIA-PP will prepare its full implementation.

SUBMITTED HORIZON PROJECTS AT ELI-BL DEPT. 86

Within the **Horizon-Infra-2022-TECH-01** call "Next generation of scientific instrumentation, tools and methods (2022)", ELI Beamlines **submitted** four applications.

The aim of this topic is to deliver innovative scientific instrumentation, tools and methods, which advance the state-of-art of European RIs, and show transformative potential in RIs operation. The related developments, which underpin the provision of improved and advanced services, should lead research infrastructures to support new areas of research and/or a wider community of users, including industrial users.

1, WEARE (Wave-mixing Experimental Advanced setups for users Research in Europe) aims at designing, building and exploiting innovative methodologies that will allow the study of processes occurring in molecular and nano-structured materials with an unprecedented space-time resolution. This will advance our knowledge to the very essence of materials science and chemistry, opening the way to future technologies (e.g. nanoscale thermal management, catalysis, batteries, solar energy) that cannot even be foreseen today.

2, THRILL (Technology for High-Repetition-rate Intense Laser Laboratories) deals with providing new schemes and devices for pushing forward the limits of research infrastructures (RI) of European relevance and ESFRI landmarks. To do so, the project partners have identified several technical bottlenecks in high-energy high-repetition-rate laser technology that prevent it from reaching the technical readiness level required to technically specify and build the needed devices, and guaranteeing sustainable and reliable operation of such laser beamlines at the partnering RIs. Advancing the technical readiness of these topics is strategically aligned with the long-term plans and evolution of the ESFRI landmarks FAIR, ELI (-BL) and Eu-XFEL, and RI APOLLON, bringing them to the next level of development and strengthening their leading position.

3, CREATE (Compact and Resource-Efficient Accelerator Technologies) will develop highly important and ground-breaking electron accelerator technologies for Europe`s future Research Infrastructures (RI), serving ten-thousands of users every year. The consortium implements a European Partnership between Research Centers, National Laboratories, ESFRI projects, Universities and European Industry. The developed technologies will be used for future resource-efficient upgrades of existing RI at INFN, Elettra, CERN, DESY, UKRI, CNRS and ELI.

4, DYRABOT project plans to develop technologies for allowing the generation of gamma and proton radiation maps while ensuring equipment protection from radiation. The main project goal is to create a fully functional robot fleet for monitoring gamma radiation and developing a new generation of compact proton detectors. Experiments for radiation monitoring will be carried out at CERN, CLPU, and FZU-CAS facilities. Robotics developments are led by UPM, CSIC and CERN. This consortium also includes INEUSTAR and two companies, Tecnatom and UGR, with expertise in nuclear facilities maintenance tasks and robotics control respectively.

Thank you for your attention!