

THE EXTREME LIGHT INFRASTRUCTURE'S HIGH-PERFORMANCE LASER SYSTEMS ACCESSIBLE TO THE WORLD

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The Extreme Light Infrastructure (ELI) operates some of the world's most advanced high-intensity laser systems across three complementary sites. Providing competitive, excellence-based access to international users, ELI enables research in attosecond science, relativistic laser-plasma interaction, nuclear photonics and laser-driven particle acceleration. ELI's integrated User Programme supports frontier science and the development of enabling photonic technologies.

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The Extreme Light Infrastructure ERIC (ELI) is the world's largest laser-based research infrastructure. The international user facility dedicated to multi-disciplinary science and research applications provides access to high-power, high-repetition-rate laser systems. ELI's lasers

generate secondary sources from attosecond pulses to high-intensity particle beams, enabling imaging, spectroscopy and studies of relativistic laser-plasma interaction and particle acceleration. These technologies also support the development of high gradient particle accelerators for the next

generation of compact photon and neutron sources.

ELI operates as a single multi-site organisation with three facilities specialised in different fields of research with extreme light: the ELI Attosecond Light Pulse Source (Hungary) for high power few cycle lasers with attosecond ●●●

and particle beamlines and ELI Beamlines (Czech Republic) for high-peak and high-average power laser pulses and secondary sources; and the Nuclear Physics (NP) facility (Romania) for combining ultra-intense lasers with brilliant gamma beams.

The complementarity of ELI's facilities support a particularly wide range of science and joint technology development. ELI has also strategically invested in critical building coating facilities for the development of high-damage-threshold optical components required for petawatt-class systems. The ELIAS Coating Laboratory is among the most advanced worldwide, producing large-aperture, high-damage-threshold optical coatings up to 1.2 m in diameter for petawatt-class systems.

ELI's User Programme offers a single access point to ELI's capabilities. Access is competitive, international, free of charge and based

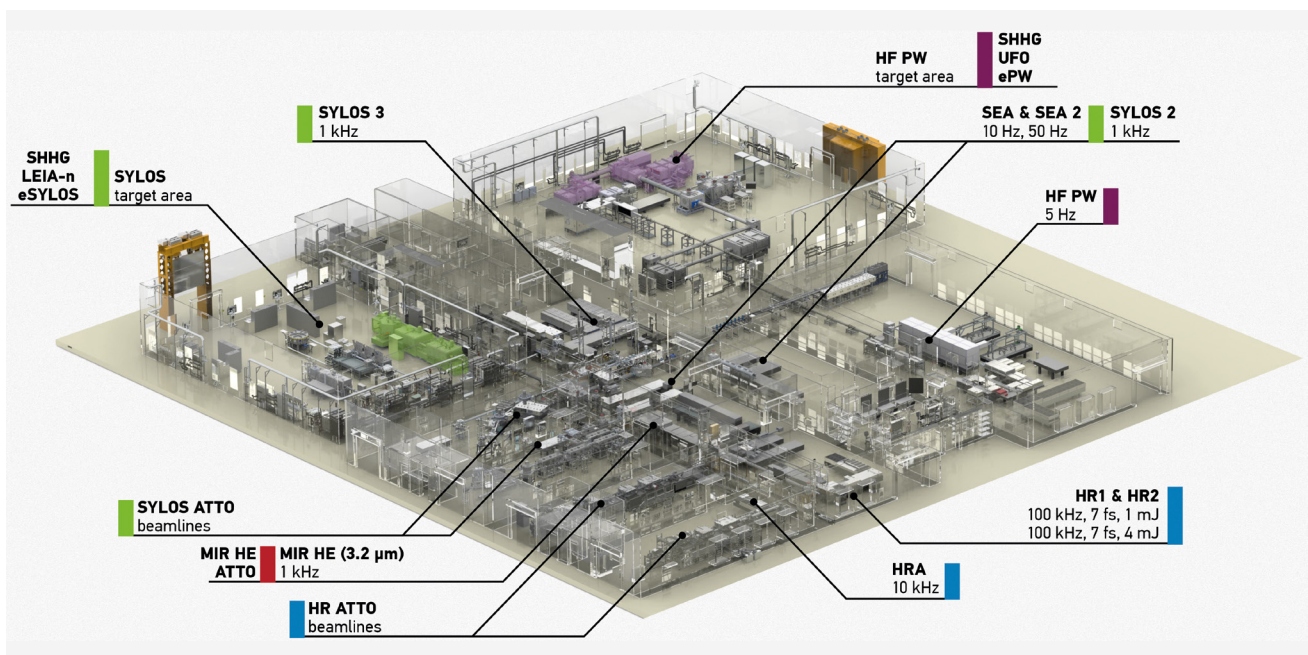
on scientific excellence. Since launching the ELI User Programme in mid 2022, ELI has opened two Calls per year. With each Call more instruments and equipment become available to the user community, and the technical capability of the equipment continues to ramp up to full scope. ELI has received a total of 733 proposals from 41 countries, involving over 1,800 individual applicants. Of these, 467 have been awarded beamtime, nearly 70% of experiments have been completed¹. In pursuit of its broader objectives to advance societal progress through cutting-edge research and innovation, ELI has also introduced mission-oriented access calls targeting strategic challenges such as Inertial Fusion Energy (IFE) to support research on IFE concepts and to promote the development of laser-powered IFE technologies. A pilot call attracted 76 institutions from 18 countries. Additional calls are planned.

ELI Attosecond Light Pulse Source (ELI ALPS)

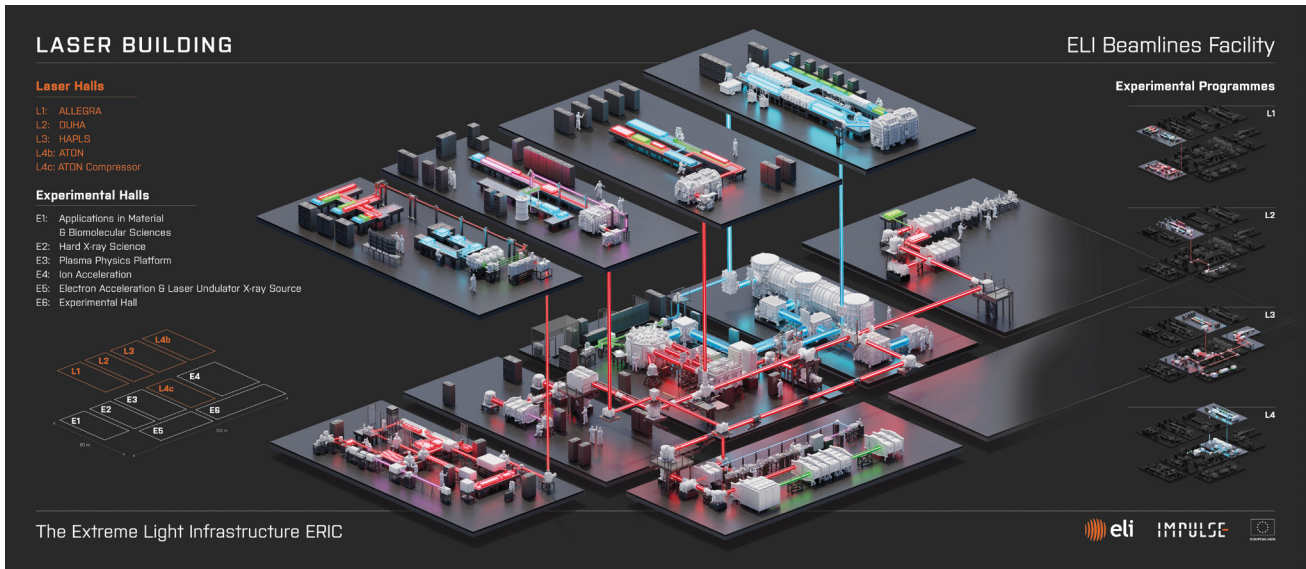
The ELI ALPS Facility showcases a unique combination of state-of-the-art ultrashort pulsed lasers, secondary particle and radiation beamlines and specialised end-stations for studying dynamic processes in atoms, molecules, condensed matter and plasma on the femtosecond and attosecond timescales. Installation of research technology started in 2017, following completion of the specially engineered buildings, including 4,000 m² cleanroom facilities with vibration isolation, thermal and humidity control and radiation protection. Following the end of construction and commissioning of the research instrumentation ELI ALPS's instruments were made available to the external user community through ELI's joint open calls for user experiments.

To support a wide variety of laser-based fundamental and applied research in physical, biological, chemical, medical and materials

Figure 1. Layout of the main laboratory building of ELI ALPS with the driver lasers and their target areas.



¹ ELI User Portal: <https://up.eli-laser.eu/>



sciences, the facility hosts a combination of nine high average power and high peak power primary lasers, operating in the NIR and MIR spectral regions, with repetition rate ranging from 5 Hz to 100 kHz and pulse duration as short as a few optical cycles. These lasers drive nonlinear frequency conversion and particle acceleration processes in twelve different secondary source beamlines equipped with a number of specialised end-stations, such as

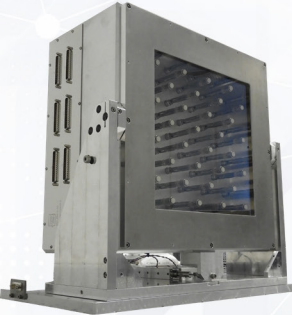
Figure 2. Layout of the ELI Beamlines Laser Systems

the “reaction microscope” for studying the full kinematics of molecular photodissociation and the “NanoESCA” to characterise photoelectrons from surfaces in real and k-space, and spin. In addition, high-field physics experiments with the PW laser, particle irradiation of radiobiological samples, photochemical studies or time-resolved

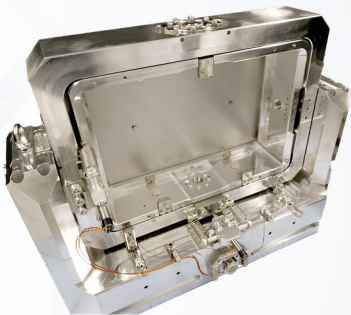
nanoscience are enabled in advanced setups.

The world leading expertise in high power laser development by French companies resulted in the development of ALPS’ HF PW laser and the MIR system. Continuous developments of these systems by ELI staff and the developer companies keep these sources at the forefront of laser technology. For example, the MIR laser performance offers opportunities ●●●

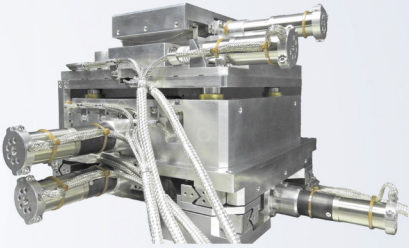
OPTOMECHANICS FOR INTENSE LASER




DEFORMABLE MIRRORS




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for novel quantum optics and structured light studies which receive strong interest from French researchers.

The attosecond secondary sources are based on advanced techniques for high-order harmonic generation (HHG). Optically ionised gases serve the production of attosecond pulses in five beamlines, based on concepts and characterisation techniques that were developed by French Nobel Laureates Anne L’Huillier and Pierre Agostini. Attolabs in CEA-LIDYL (Saclay) and CELIA (Bordeaux) have shared research interest with ELI. Oscillating surface plasmas are also exploited for HHG driven by the high intensity SYLOS and HF PW lasers. This field was pioneered by researchers from CEA-LIDYL (Saclay) and LOA (Palaiseau), who helped design and implement dedicated beamlines in collaboration with French photonics companies. ELI ALPS also showcases two laser-plasma electron accelerators driven by SYLOS and HF PW lasers for spectroscopic and structural studies, plasma physics or radiobiology. The technology contained in these beamlines was also pioneered by researchers from LOA (Palaiseau).

ELI Beamlines

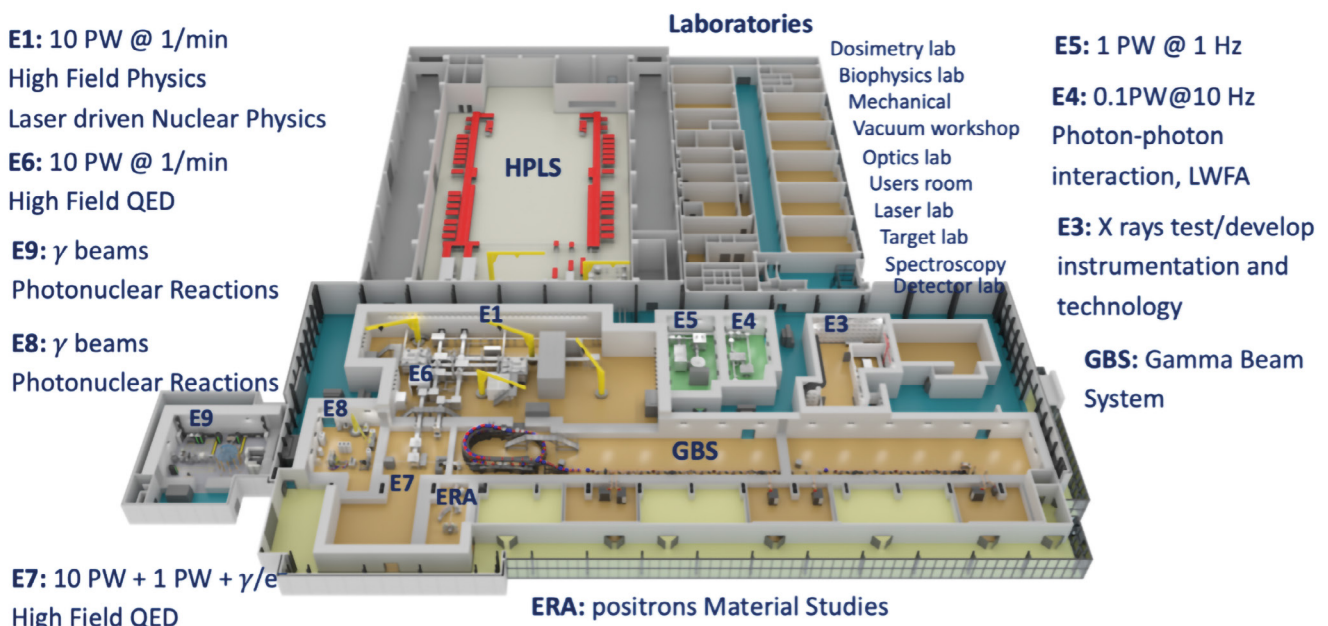
The ELI Beamlines Facility uniquely combines high pulse energy with high repetition rate performance, enabling users to explore light-matter interactions in the relativistic and ultra-relativistic regimes while sustaining unprecedented operational repetition rates. The laser systems are designed to deliver intensities on target as high as 10^{23} W/cm² at 1 shot per minute, about 10^{22} W/cm² at 10 Hz, and more than 5×10^{18} W/cm² at 1 kHz.

These state-of-the-art capabilities support pioneering research in plasma physics, inertial fusion, strong-field physics, and laboratory astrophysics, attracting a diverse international user community. Experiments on nonlinear quantum electrodynamics (QED), positron and muon production, high-brightness gamma-ray beam generation, and planetary science are currently being conducted or are planned.

Laser-driven particle accelerators have gained increasing attention in recent years due to their compactness, versatility, and innovative

beam properties. This has driven the development of dedicated beamlines at ELI Beamlines, where users can exploit unique source parameters such as ultrashort bunch duration and ultrahigh dose rates from laser-driven ion and electron beams, as well as broadband radiation sources spanning from XUV to gamma rays. These features open new opportunities across materials science, atomic, molecular and optical (AMO) physics, chemistry, biology, and medicine, as well as pump-probe studies in high-energy-density physics. Ongoing user experiments also include probing ultrafast atomic relaxation dynamics, irradiation studies on cancer cells, simulation of space radiation effects for electronics testing, and non-destructive surface analysis techniques for cultural heritage applications. Furthermore, the facility offers the combined use of optical, X-ray, and particle beams for advanced studies in inertial confinement fusion and shock physics. This is enabled by a unique kJ-class nanosecond laser operating at an unprecedented repetition rate of approximately 1 shot per minute, featuring temporal pulse shaping capabilities and selectable narrow- or broadband operation, in

Figure 3. ELI-NP: Facility Layout.



combination with secondary sources driven by PW-class lasers for pump-probe user experiments.

To fully exploit these capabilities, ELI Beamlines continuously develops and provides advanced target delivery systems and diagnostics designed to operate under extreme laser-plasma conditions and high repetition rates, ensuring reliable and efficient experimental performance for its user community.

ELI Nuclear Physics

The Extreme Light Infrastructure Nuclear Physics (ELI-NP) facility in Măgurele, Romania, hosts one of the most powerful laser systems in the world: the High Power Laser System (HPLS). Together with the Gamma Beam System (GBS), the HPLS is designed to push the frontiers of nuclear physics, particle acceleration, and high-field science.

The HPLS is a dual-arm, 10 PW femtosecond laser system based on chirped pulse amplification (CPA) technology. Each arm is capable of delivering laser pulses with energies of approximately 220 J, compressed to pulse durations of about 22 fs. This performance enables the achievement of peak powers up to 10 PW at a repetition rate of one shot per minute². In addition to the 10 PW capability, each arm provides auxiliary output beams operating at lower power but higher repetition rates, namely 100 TW at 10 Hz and 1 PW at 1 Hz, offering a broad range of experimental operating regimes.

The HPLS features an exceptional temporal contrast exceeding 10^{12} , ensuring that the main pulse is overwhelmingly

dominant with respect to pre-pulses and amplified spontaneous emission (ASE). This high contrast is essential for experiments involving relativistic laser-matter interactions, as it preserves target integrity prior to the arrival of the main pulse. Furthermore, the excellent spatial beam quality enables focusing to ultra-high intensities approaching 10^{23} W/cm², thereby providing access to extreme regimes of light-matter interaction relevant for advanced particle acceleration, laboratory astrophysics, and strong-field quantum electrodynamics.

Conclusion

The ELI Facilities stand at the frontier of high-field science, offering an unprecedented platform to explore matter under extreme electromagnetic fields and to push the limits of laser-matter interaction. As the capabilities of ultra-intense and ultra-short pulse lasers continue to advance, ELI provides the perfect environment where fundamental discoveries can translate into transformative technologies. ELI is positioned to address some of the most pressing scientific and technological challenges of our time—ranging from clean energy and nuclear photonics to space science, enabling breakthroughs in health through novel imaging and radiotherapy approaches. By combining cutting-edge infrastructure, international collaboration, and interdisciplinary research, ELI will shape the future of high-field science and its societal applications. ●

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[2] ELI User Portal - <https://up.eli-laser.eu/>

² <https://www.eli-np.ro>

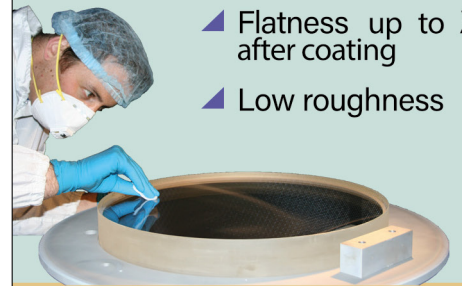


SOLUTIONS FOR HIGH POWER LASERS



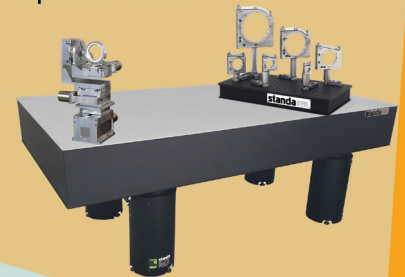
OPTICS

- ▲ High LIDT (fs, ps), Low GDD
- ▲ Mirrors, windows, polarizers, contacted cubes...
 - ▲ Up to 550 mm
 - ▲ Flatness up to $\lambda/20$ after coating
 - ▲ Low roughness



OPTOMECHANICS

- ▲ Opto-mechanical components
- ▲ Motion control & vacuum-compatible products
- ▲ Optical table



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