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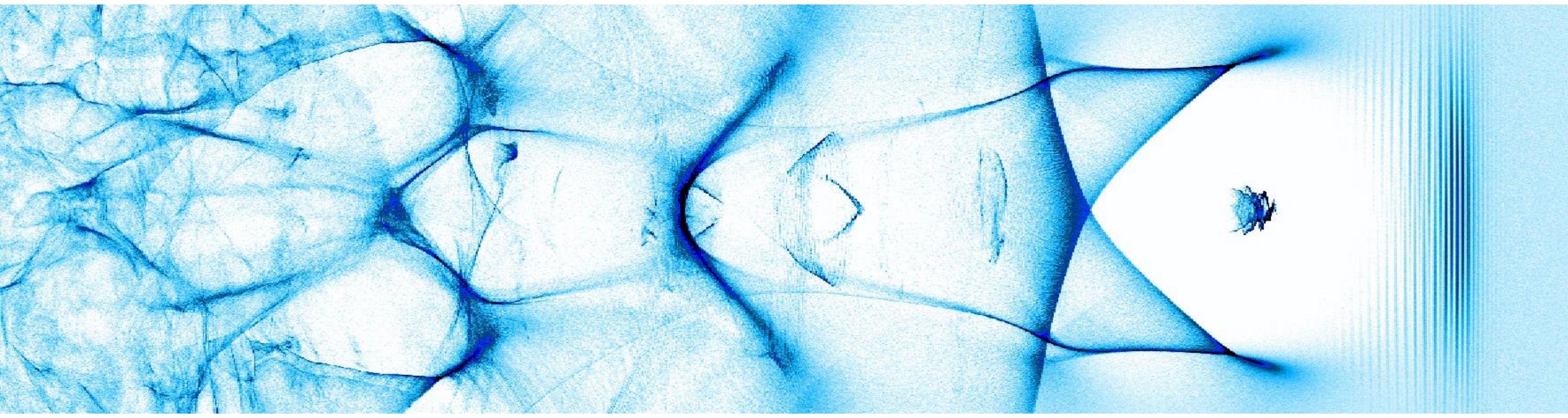

ELI Beamlines Strategic Development Plan 2018-2024

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MINISTERSTVO ŠKOLSTVÍ,
MLÁDEŽE A TĚLOVÝCHOVY

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

Contents

1. Executive Summary

Major contribution to the European Research Area

The Extreme Light Infrastructure (ELI) project, as selected and proposed by ESFRI, and approved by the EU, is positioned to be one of the world's foremost laser facilities, and the first such facility resulting for an international effort fully conceived and implemented to serve external users. ELI will be at the forefront of laser technology and open up new research opportunities with significant potential impact in a number of scientific disciplines and in economic returns. As such, ELI provides a vital strategic capability for European scientists and industry. In addition, ELI will greatly enhance regional competitiveness and cohesion. It is the first large research infrastructure built completely in Europe's Newer Member Countries (CZ, HU and RO), and one of the first to be operational outside of more endowed European science nations.

A competitive research program on the international level

ELI-Beamlines, as part of the multi-site Extreme Light Infrastructure (ELI) project, is the largest and most ambitious scientific initiative in the Czech Republic and also one of the largest financed by the European Union. The expectations in Europe and the rest of the world are correspondingly high. ELI-Beamlines has to and will deliver a unique, open short pulse high intensity laser-based research infrastructure for the scientific community in Europe and the rest of the world. ELI-Beamlines will produce ultra-short laser pulses of a few femtoseconds (10^{-15} fs) duration at the peak power of up to 10 PW. Technologies of ELI-Beamlines will enable creation of new techniques, including those for time-resolved spectroscopy, scattering, and diffraction techniques, medical imaging, display, diagnostics, and radiotherapy, tools for design, development, testing of new materials, improvements of X-ray optics, and last but not least studying laser plasma and high intensity interactions under up to know unknown extreme conditions. The specific nature of the ELI-Beamlines user facility is its multi-disciplinary features as far as its laser systems and corresponding usage is concerned. This fact is also reflected in recently gained funding for two major additional research teams HIFI (high field initiative) and ELI-BIO led by internationally well-known scientists, Prof S.V. Bulanov and Prof J. Hajdu.

User dedicated mission

The main goal of ELI-Beamlines is to build and operate one of the most advanced laser resources in the world and through open access to this infrastructure implementing and executing research projects covering the interaction of light with matter at intensities many times higher than the currently achievable values. ELI-Beamlines will also be an attractive platform for educating a new generation of scientists and engineers. There are expected to be more than 2200 researcher days per year at the facility representing over 250 experimental weeks a year. In order to ensure the international character a dedicated legal entity ELI ERIC takes over the responsibility for the entire capacity available in the three ELI pillars. Members of ELI ERIC shall significantly contribute to enable a smooth transition from the start-up operation period to the steady state operation expected in 2020.

A cosmopolitan team for operation

From the beginning of the project the outlook as far as staff recruitment is concerned has been cosmopolitan. ELI-Beamline employees originate from 24 nations. It is a truly universal endeavor. At present, the team consists of 300 people (280 FTE), of which 100 (95 FTE) are foreigners. In the research and experimental programs, their share exceeds 50%. ELI-Beamlines has become a global point of attraction for talented scientific and technical/engineering staff. Due to the attraction of the project itself and the location ELI-Beamlines is able to establish a diverse operation team which will be a key prerequisite for providing quality services once an international user community will be conducting its experiments at the facility.

Scientific output

Even though the research team has as pre-dominant obligation the design and construction of the technological and scientific infrastructure, it is nevertheless very active as far as publications and patent applications is concerned. The publications of the research teams appear in high-impact journals and their scientific production is acknowledged by the worldwide scientific community in the field. As for the year 2016 ELI Beamlines has produced more than 250 impacted publications some of them with very high impact factors and good international visibility.

International cooperation

International cooperations have been established via dedicated Memoranda of Understanding (MoU, see detailed list provided in Chapter 4). MoUs have been concluded not just with European installations but with worldwide major photon based science facilities. This clearly shows that the interest in ELI-Beamlines is not just a European affair. The unique potential of the installation under construction has been recognized globally.

The prospective user community

The future user community is of national, European and international origin. Contacts with the potential future users have been established via scientific collaborations, exchange of personnel, presentations at international conference in order to attract the attention of the scientific community to the ELI-Beamlines project, and dedicated user workshops. A large but non-exhaustive list of prospective users is provided in Chapter 4.

1.1. Major objectives of the facility development

Short term directions and priorities

The near future tasks are completing the installation of two laser sources (L1 and L3) and to transport them to the experimental areas to enable first light for users. This will allow starting the user operation and bring ELI Beamlines on the map of the world-wide large scale facilities. This process of starting is foreseen to be completed by the end of 2018 and mid 2019 and represents a major milestone of the ELI-Beamline facility. The experimental infrastructure is being developed right now and described in greater detail below. A user assisted commissioning is foreseen for the implementation of the first experimental areas E1 and E3 using L1 and L3 and shall be finished in 3Q 2018. One of the major priorities is the completion of the 10 PW laser and its beam transport to the major ELI Beamlines target chamber (P3). This is foreseen for 2019. User operation is envisaged for 2020 having the focusing optics for the 10 PW beam in place. The first user assisted commissioning experiments will be the characterization of the peak-power and focused intensity of the 10 PW laser. A major direction of ELI-Beamlines is to generate stable well characterized ultra-intense pulses with intensities beyond the 10^{22}-10^{23}Wcm^{-2}. This will enable new very high-level experiments entering a completely new regime of interaction where radiation reaction will come in to play. This is one of the major goals of ELI Beamlines. A strong theoretical support is given through the HIFI-project for the planning and understanding of the envisioned experiments by theory and predictive simulations. An international project team for user assisted commissioning is being formed with the goal to characterize and increase by different methods of beam control and focusing the available intensity to record high values preparing L4 for user experiments with well characterized pulse parameters. This will help to understand at which peak-power levels and other working conditions of the laser the highest available intensity can be achieved and repeatedly be provided for user experiments.

Long term strategic tasks of the facility development

1. Stepwise managing of the transition period from user assisted commissioning to full user operation under ELI ERIC.
2. Attracting and establishing a user base by providing reliable and stable high power and high intensity laser photon sources with the corresponding experimental infrastructure. The main goal is to achieve very high uptime of lasers and secondary sources and providing high level user support in all needed areas. This will make a difference to other currently developing PW-class and multi-PW class laser facilities world-wide and generates the necessary trust and future interest of users. At this point reliability and high uptime is much more important than extreme leading edge parameters (peak-power and average power or shot rate of primary laser sources) which are typically much more demanding by stressing optical components like mirrors, compression gratings and vacuum transport systems. The risk mitigation is a slow controlled increase of the repetition rate and energy of the L3 laser while carefully measuring the damage behaviour of optical coatings of beam transport mirrors, compression gratings and focusing optics in the beam path. Investigation of possible optical coating strategies and grating improvements together with the other ELI pillars to be able to increase the damage fluence and minimize laser down-time due to damage and long lead time for highly sophisticated optical components. The long term goal is to come to Gigashot operation at PW levels as it would be possible with L3.
3. Enable the everyday use of experimental areas including secondary sources and providing a good environment and strong support for users. This will be a good basis for high level scientific output and opens sustainable future funding sources through ELI ERIC and national & international funding schemes.
4. Learning to run a user facility and increase its user acceptance by providing versatile arrangements and multi-beam configurations in experimental areas. Learning to provide reliable beam time and support on beamlines for users. Enhancing the available throughput of high level scientific user sessions by multi-use and parallel sessions in experimental areas. This will be supported technically by fast reliable switching yards which can direct the laser beams in to different experimental areas in short times.
5. Organizing a user community driven feedback on the facility parameters and experimental infrastructure and its functioning enabling a user (costumer) driven upgrade strategy ensuring the future international competitiveness of the facility.
6. Planning and performing a step by step upgrade of the facility in terms of peak and average power of the primary laser sources and the brightness and tunability of short pulse laser driven secondary sources of x-rays and particles corresponding to the needs and priorities defined in 3 having in mind the available funding sources and size.
7. The extension of the LUX Beamline to a full-blown laser driven FEL for soft x-rays and later on for harder x-rays (above 1-5 keV) is foreseen as one of the major efforts for secondary source developments. This will put ELI Beamlines in a good position for future table top FEL use and enhance the user base. ELI-Beamlines has teamed up with UHH and DESY for this. The envisioned funding scheme is based on a teaming proposal which is being worked out with the mentioned organizations. Furthermore a high repetition rate 1-10 kHz 100-150 keV source based on Compton scattering is considered for future medical imaging. Both developments will require new approaches to fs-laser sources concerning their stability and repetition rate. The goal is to establish within this frame work a center of excellence for ultra-brilliant short pulse x-ray sources for advanced user applications in science and industry including medical research.

8. Identifying future directions of the field of high power, high intensity (high field) laser research and laser matter and laser vacuum interactions using internal and external experimental and theory sources. A strong theoretical group will be established through HIFI to support this major strategic task. The HIFI program will advance the understanding of the radiation dominated and quantum regimes, which are among the most actively developing directions in the high field research, motivated by a number of important applications in fundamental and applied science, ranging from ultra-bright sources of hard electromagnetic radiation required for biology, medicine, particle sources for backlighting and material identification to understanding the properties of the new states of matter, which exhibit the cooperative behavior of quantum-electrodynamics plasmas and fluids.

9. ELI Beamline represents an important factor for the regional development by providing through excellent science new ideas and developments of completely new tools for local and international industry. The ELI Beamline facility promotes excellent scientific capabilities boosting innovation performance and economic development. In addition, while the Czech Republic has a strong background in photonics, its R&I performance improving is still in progress and the Czech Republic therefore has, as part of its Research and Innovation Smart Specialization Strategy (RIS3) - committed to continuing efforts to be at the forefront of photonics research. Furthermore, it is still in the process of catching up with more established Member States in terms of R&I performance level as well as excellence in science and technology. Therefore it is vital that ELI-Beamlines acts now and in the future to address the gaps in scientific profile, innovation performance, and industrial engagement that exist between it and more established facilities in higher performing Member States. Being actively involved in overcoming and bridging this gap through excellent science additional funding opportunities become available.

   ELI Beamline will have sustainable, long-term impacts on science, industry, and society. The industrial impact will be triggered by offering new methods, products and markets, as well as the potential for spin-off companies, enforcing a new level of innovation performance. The societal impact will be fostered by close cooperation with national and international universities to educate and train the next generation of researchers, engineers, and young talents. In addition, ELI Beamline will establish a platform for iterative interactions between science, industry, and society.

2. Facility Overview

ELI Beamlines is the largest research facility of FZU and also the largest scientific initiative in the Czech Republic. The main goal of ELI-BL is to build one of the most advanced laser resources in the world and implement research projects covering the interaction of light with matter at intensities many times higher than the currently achievable values. ELI-BL will produce ultra-short laser pulses of a few femtoseconds (10-15 fs) duration at the peak power of up to 10 PW. Technologies of ELI-BL will enable creation of new techniques, including those for time-resolved spectroscopy, scattering, and diffraction techniques, medical imaging, display, diagnostics, and radiotherapy, tools for design, development, and testing of new materials, improvements of X-ray optics. ELI-BL will also be an attractive platform for educating a new generation of scientists and engineers.

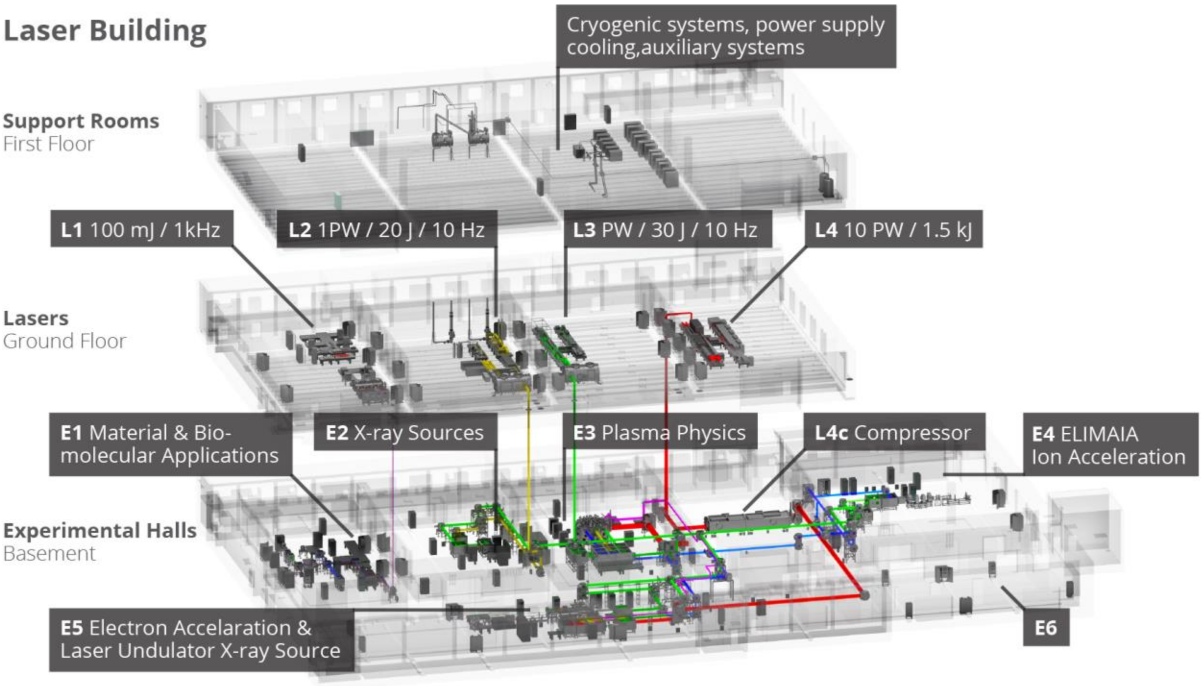
The implementation of ELI-Beamlines represents a unique opportunity for the Czech Republic to host a major international research infrastructure which will provide facilities for national researchers and industry and attract international researchers at the forefront of their fields to the country as facility users. There are expected to be more than 2200 researcher days per year at the facility providing an additional local economic impact through the associated accommodation and travel costs. With a projected workforce of more than 250 employees, ELI-Beamlines will generate high-level long-term career opportunities for researchers, engineers and technicians, primarily but not exclusively those involved in optics and laser science, in electronics, in mechanical engineering, and material sciences. In addition, the Czech optics and photonics industry is expected to take a significant part in the technological developments required for the construction of ELI and its further maintenance, thus demonstrating and acquiring know-how.

The research and development at ELI-BL has been performed continuously in six research programs (RPs) over last four years:

- **RP1** Lasers Generating High Repetition-rate Ultrashort Pulses and Multi-petawatt Peak Powers
- **RP2** X-ray Sources Driven by Ultrashort Laser Pulses
- **RP3** Particle Acceleration by Lasers
- **RP4** Applications in Molecular, Biomedical, Material Sciences
- **RP5** Plasma and High Energy Density Physics
- **RP6** Exotic Physics and Theory/Simulation

Primarily ELI-Beamlines will provide expertise in laser development, diagnostics, short pulse X-ray generation and acceleration of particles and their applications.

The laser system will constitute a specific unit, which must be implemented and managed as a major single instrument within the Research Program 1: Lasers generating repetition-rate ultrashort pulses and multi-petawatt peak powers. The Research Programs 2 to 6 will jointly exploit the capacity of this instrument to carry out scientific, application and technology development projects using ultra-intense light pulses. The Research Programs 2 to 6 will use pulses with various parameters generated by the laser system and will effectively share the capacity provided by this system. Each of the Research Programs 2 to 6 is centered on a specific field of research and technologies and involves a specific expertise, using the laser as a resource delivered by the expertise of the Research Program 1.



The facility will provide Beamlines for a variety of research programs which will by their nature require interdisciplinary cooperation. In particular, for RP4 - Applications in molecular, biomedical, and material sciences where work will draw upon structural sciences, biology, atomic and plasma physics, optics and mathematics. Each research program leader is charged with managing their programs to foster interdisciplinary research.

The facility will enable developments in a wide range of research areas, for example biological imaging at or near atomic resolution is probably the most challenging of all experiments that have been proposed for X-ray lasers, and it requires a detailed understanding of photon-material interactions on ultra-short time scales at very high X-ray intensities. Resolution in single-particle experiments does not depend on sample quality in the same way as in conventional crystallography, but is a function of radiation intensity, pulse duration, and wavelength, which are factors controlling ionisation and sample movement during exposure.

The potential for breakthrough science is great with impact not only in biology or physics but wherever dynamic structural information with high spatial and temporal resolution is valuable.

Commercial sector areas most closely related to the development of the facility are those of laser development. In particular, the investment in advanced DPSSL laser technology represented by ELI Beamlines will bring opportunities to European industry which will be incentivized to gear up for high volume production of DPSSL laser systems. This will put Europe in a strong position to benefit from laser energy projects world-wide and to exploit DPSSL technology in other market sectors. The research is expected to have impact in the following areas:

Engineering and electronics industry:

- Non-destructive diagnostics of high speed processes in industrial devices and their visualization or simulation
- Testing of resistivity to extreme fields – e.g. simulation conditions on the orbit
- New method of preparation of special material structures – development and testing

- Elimination of thermal effects for special application
- Particle interactions and material treatment, change of basic material parameters
- Application of new principles in control and diagnostics
- New construction material with unique parameters
- Increasing possibilities in communication technology using the knowledge from the laser beam transport

Life-Sciences (medical, pharmaceutical):

- Diagnostics and interaction of molecular samples – biological labs BSL1 – BSL3 background
- Induction and visualization of photochemical processes – chemical labs background
- Development new diagnostics method for tissues and live organisms, in-situ observation of interactions between samples and additives
- Accelerated particles – development of new diagnostic and therapeutic methods
- Application of different types of radiation (light) with defined time delay – theragnostic methods
- Targeted focus of the effectiveness of the applied radiation – superficial or deep, no/desirable thermal effects, bragg peak, no/desirable absorption
- Controlled ablation of biological samples
- Advanced Imaging - especially in "water window"

Fundamental research:

- New radiation sources and their unique combination with defined and tuneable time delay
- High intensity of radiation for exotic field of physics, laboratory simulation of astrophysics conditions
- Unique combination of accelerated particles with radiation sources in common laboratory
- Research of subatomic and sub-nuclear level – alternative to large accelerators

More information about the ELI-BL center can be found on the web site: www.eli-beams.eu

3. Research Programs

3.1. Overview

The following presents a very brief summary of each of the research programs which are subsequently developed in some more detail.

RP1 Lasers

RP1 develops the short-pulse laser system used for all applications at ELI-BL. This work is of both fundamental and applied nature including development, implementation and optimization of the laser systems, their components and subsystems. Short term activities: Development and implementation of the four main laser systems of the ELI-BL facility. Long term activities: Ongoing development of the laser systems to reach world leading intensities and pulse parameters at high repetition rates.

RP2 X-Ray Sources Driven by Ultrashort Laser Pulses

RP2 develops a new generation of laser driven secondary light sources covering the VUV (vacuum UV) to gamma-ray energy range. These are based on plasma effects in gases and solids as well as relativistic electron acceleration and the research is both fundamental and applied. Short term activities: Provide the national and international user community access to ultrashort pulses in the VUV to gamma-ray energy range for applications in molecular, biomedical and materials science. Long term activities: Continuous source development, in particular the development of a laser driven X-ray Free Electron Laser.

RP3 Particle Acceleration by Lasers

RP3 develops versatile and stable sources of high-energy electrons, protons and ions driven by various laser-acceleration mechanisms. The research is both fundamental and applied. Short term activities: Develop laser driven ion and electron sources with world-leading beam parameters. Long term activities: A possible future application for the ion source is compact and low-cost laser driven proton and ion sources for cancer therapy. Laser driven electron acceleration is the basis for the development of laser driven X-ray Free Electron Lasers (FELs).

RP4 Application in Molecular, Biomedical and Material Sciences

RP4 develops a unique set of capabilities for time-resolved experiments using high power lasers, secondary light-sources and a comprehensive set of pump beams. The research is both fundamental and applied. Short term activities: 1) Implement capabilities in the VUV and soft X-ray range for time-resolved materials science, Coherent Diffractive Imaging and Atomic Molecular and Optical science. 2) Implement X-ray instruments for time-resolved scattering, diffraction, absorption spectroscopy, phase contrast imaging and pulse radiolysis. 3) Use the high intensity lasers directly for advanced optical spectroscopy applications such as fs stimulated Raman scattering and 2D spectroscopy. Long term activities: Combine these methods with perfect synchronization for complete investigations of complex phenomena.

RP5 Plasma and High Energy Density Physics

RP5 explores both fundamental science and possible applications in the field of high-energy and high-intensity laser-plasma interaction. Research activities concentrate on ultra-high intensity, laboratory astrophysics, warm dense matter and plasma optics. Short term activities of RP5: implement the technological infrastructure around P3. Long term activities: perform experiments for new unexplored extreme states of matter and ultra-high intensity interaction.

RP6 Exotic Physics and Theory and Simulation

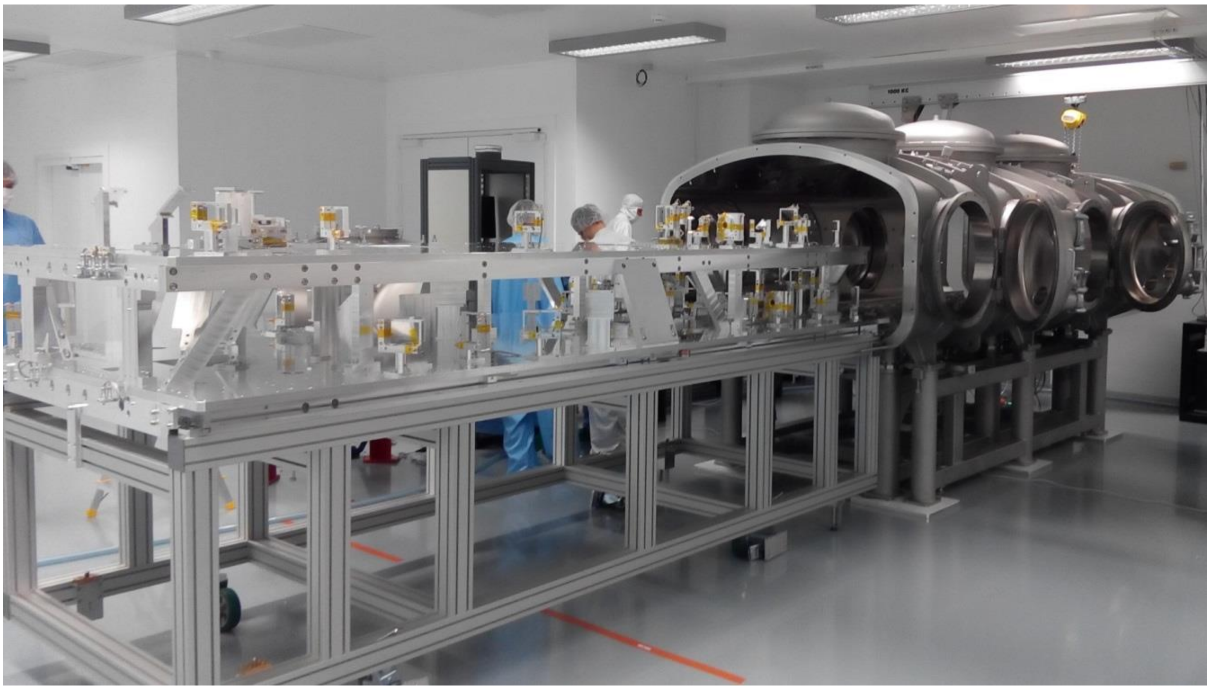
RP6 explores theoretical and experimental aspects of the exotic physics expected in the so-called ultra-relativistic regime (above 1022 W/cm2) of laser-matter interaction. Predictive simulations are performed for future high-field experiments. RP 6 also runs the ELI-BL 1300 cores ECLIPSE computing cluster. Short term activities of RP6: simulation support for experimental programs in high-energy and high-intensity laser-matter interaction. Long term activities: Explore new horizons in the physics of laser matter interactions under extreme conditions.

3.2. RP1 Lasers

The ELI-Beamlines facility will be a high-energy, high repetition rate laser pillar of the ELI (Extreme Light Infrastructure) project. The facility will provide pulses from four laser systems. To meet the requirements for high repetition rates, three of these lasers will employ the emerging technology of diode-pumped solid state lasers (DPSSL) for pumping broadband amplifiers. The fourth, the kilojoule laser, will use advanced flashlamp technology with actively cooled gain medium.

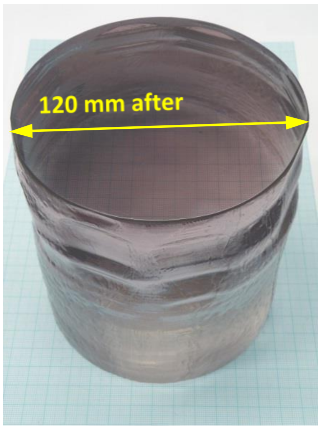
The DPSSL technology represents a paradigm change in the current cutting edge laser technologies, making it possible to deliver the laser pulses at much higher repetition rate than current systems and also to achieve higher pulse-to-pulse stability, higher robustness, lower maintenance, higher level of automation, and much higher scalability to higher peak power and repetition rates. ELI-Beamlines will be the first laser facility in the world that will programmatically exploit this emerging technology.

The laser systems are development both by in-house efforts of ELI-Beamlines and in cooperation with strategic partners, namely Lawrence Livermore National Laboratory, National Energetics (USA), and Rutherford Appleton Laboratory (UK). Since its beginning the ELI-Beamlines project has formed a dedicated team of about 50 laser scientists, optical and optomechanical designers, technicians and specific technology specialists. This team is developing the L1 and L2 systems, and plays also a significant role in development of specific subsystem of the L3 and L4 systems.



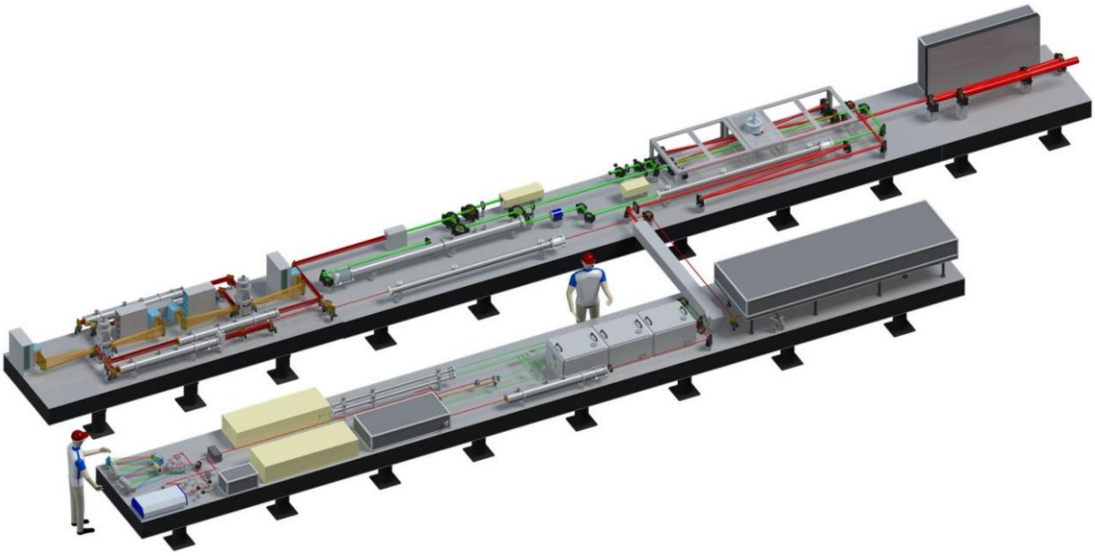
Assembling of the L1 laser system in the cleanroom development premises of the Institute of Physics: shown in the picture is internal optomechanical structure of the L1 vacuum compressor of picosecond pumping pulses.

The L1 laser is being developed in house by the ELI-Beamlines laser team. The laser system is designed to generate <20 fs pulses with energy exceeding 100 mJ per pulse at a very high repetition rate (1 kHz). The concept of the laser is based entirely on amplification of frequency chirped picosecond pulses in an optical parametric chirped pulse amplification (OPCPA) chain consisting of a total of seven amplifiers. The OPCPA amplifier stages are pumped by precisely synchronized picosecond pulses generated by state-of-the-art thin-disk-based Yb:YAG laser systems obtained both from industry and developed



Large monocrystals developed in cooperation with Czech industry within the ELI-Beamlines project. The core-free Yb doped YAG crystals with up to 5' in diameter and 6' long are the largest of its kind in the world.

The L2 beamline is designed to provide ultimately PW-class peak power at 10 Hz repetition rate. The short-pulse amplification chain will be based on OPCPA. In the current phase of the project the first stage of the L2 laser is developed, including the 10 J pump engine using cryogenic He gas cooling. Several new technologies were developed in cooperation with the Czech industry, specifically large laser YAG crystals (see Figure above) and also an advanced system of cryogenic gas cooling of the gain medium to temperatures of about -130° C.



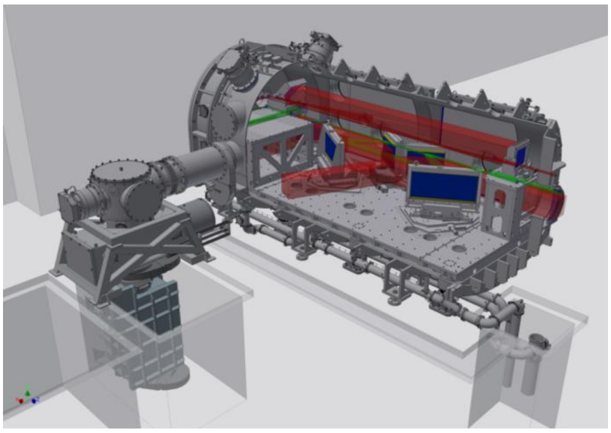
Layout of the L3-HAPLS (High-Repetition-Rate Advanced Petawatt Laser System) developed for ELI-Beamlines by Lawrence Livermore National Laboratory, with participation of the ELI-Beamlines specialists on implementation of several subsystems.

The L3 laser system called HAPLS (The High-Repetition-Rate Advanced Petawatt Laser System), seen in the Figure above, is designed to deliver PW pulses with energy of at least 30 J and durations <30 fs, at a repetition rate of 10 Hz. It is the first all diode-pumped, high-energy femtosecond PW laser system in the world. The laser was developed at the Lawrence Livermore National Laboratory, with ELI-Beamlines cooperating on the development of the short-pulse diagnostics and of the short-pulse subsystem controls and timing.

During initial testing the L3-HAPLS has recently demonstrated continuous operation setting a world record for diode-pumped Petawatt lasers, delivering pulses with energy reaching 16 J and a 28 femtosecond pulse duration, equivalent to ~0.5 PW/pulse at a 3.3 Hz repetition rate.

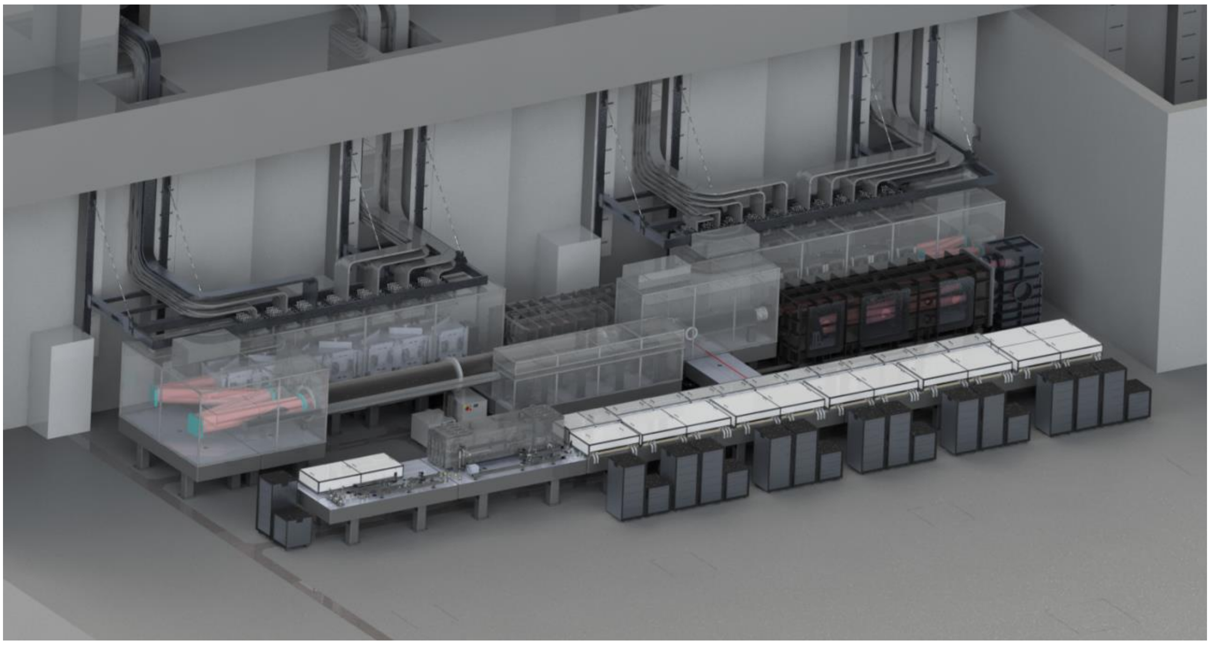
L3-HAPLS laser system during testing in the development premises in the Lawrence Livermore National Laboratory.

ELI-Beamlines has designed for the L3-HAPLS system the vacuum compressor of PW laser pulses, see Figure below. The compressor has size of approximately 5.2 x 2.4 x 2.2 m and includes a highly complex structure of optical, optomechanical and electronic elements. The compressor is being built and integrated in cooperation with the Czech SME industry.



Structure of the L3 compressor of PW laser pulses (left) and the vessel of the compressor during vacuum testing at the supplier's cleanroom (right).

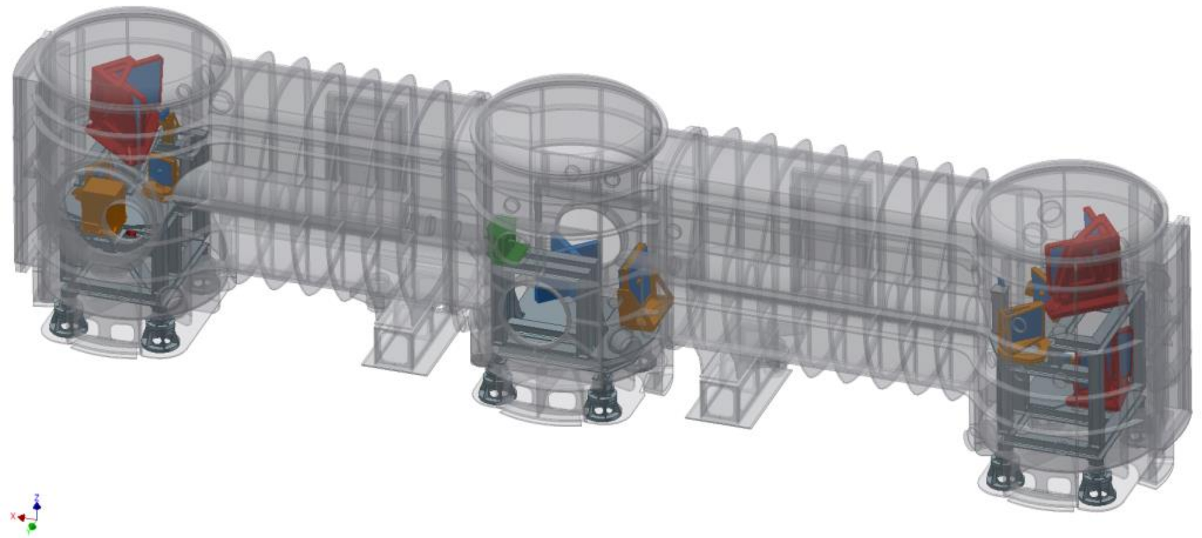
The L4 laser beamline will deliver pulses with energy of 1.5 kJ, lasting about 150 fs. The system will thus generate peak power of 10 PW, which will be the highest value ever achieved by a high-power laser. A number of innovative technologies used will make it possible to achieve a shot rate of 1/min, which is unprecedented in the in the field of kJ-class lasers. The L4 system architecture exploits a combination of different Nd:glass slab amplifiers using innovative liquid cooling.



Layout of the L4 kilojoule laser system integrated in the L4b laser hall of the ELI-Beamlines facility. Upon compression of the pulses in the compressor the laser will generate 10PW laser pulses.

Laser L4 chain in the development laboratories at National Energetics (USA), with the front end of the system seen in the forefront.

The compressor of the 10 PW pulses, see Figure below, will employ large diffraction gratings and large aperture mirrors to compress the L4 output beam with size 650x650 mm, and to generate pulses with about 150 fs duration. The structure of the compressor with a length of about 18 m (see Figure below) has been designed by the ELI-Beamlines laser technical team. The compressor vessel will be supplied by the L4 supplier, while the ELI-Beamlines team will be responsible for development and construction of the internal optomechanical systems and of the control electronics.



Designed structure of the compressor of 10PW pulses, developed by the ELI-Beamlines technical team.

3.3. RP2 X-Ray Sources Driven by Ultrashort Laser Pulses

One of the main goals within the ELI scientific community is to produce X-ray beamlines with ultrashort pulses, both coherent and incoherent, to pave the way towards exploring nature with atomic spatial resolution and femtosecond temporal scales. Applications range from structure analysis in solid-state, atomic physics and molecular chemistry via imaging applications in medicine and life sciences through studying basic building blocks of life.

The laser-driven X-ray sources developed at the ELI-Beamlines facility have the capability, unlike large-scale facilities such as third-generation synchrotrons or X-ray free-electron lasers (XFELs), to offer much broader accessibility due to their compactness and reduced cost. Moreover, various combinations of fully synchronizable femtosecond pulses from extremely broad spectral range (from VUV to gamma radiation) combined in one experiment and complemented by optical pulses (from THz to UV) originating from the same laser will open a gateway to science that has not yet been accessible.

3.3.1. Scientific-technological infrastructure in the experimental halls E1, E2 and E5

Four paths have been developed within this research program for transforming laser pulses into brilliant bursts of X-rays:

High-order harmonic generation in gases (E1 hall, 1 kHz L1 laser driver)

Generation of high-order harmonics (HHG) of an intense laser pulse is now widely used as an efficient source of coherent ultra-short pulses (tens of femtoseconds down to tens of attoseconds) in the spectral range from EUV to soft X-rays. The atoms of noble gases interacting with a strong laser field (10^{14}-10^{15} Wcm^{-2}) are partially ionized and the freed electrons are first accelerated and then rescattered from the parent ion while generating radiation of short wavelength in attosecond bursts repeating every laser cycle. The coherent addition of this radiation from significant target volume through phase matching (or quasi-phase matching) leads to a substantial increase in the power of the generated radiation.

We plan to extend the capabilities of recently commissioned HHG Beamline by implementing advanced techniques to reach high flux generation regime using loose focusing of the high power laser driver (L1 laser system having 100 mJ <20 fs at 1 kHz rep. rate). Particularly the implementation of two-color driving field is proposed to enlarge the accessible wavelengths, increase the conversion efficiency through enhancement of the single atom response and generating any polarization state of the XUV beam, particularly the circular polarization. Meanwhile we plan to employ advanced target geometries with modulated gas density and/or various gases combined with plasma waveguiding techniques to enable so called quasi-phase matching. Using this method, we foresee to overcome the phase mismatch in highly dispersive plasma medium for generation in soft X-ray range and also to enable efficient generation of a single harmonic of the laser driver. This approach would allow avoiding lossy XUV monochromator that is needed for certain class of applications.

Incoherent plasma X-ray sources (E1 hall, 1 kHz L1 laser driver)

In a plasma X-ray source, laser pulses are tightly focused on a renewing solid-density target and produce non-equilibrium plasma with significant population of hot electrons. Those electrons are then, similarly to medical X-ray tube, responsible for generation of hard X-rays from both plasma and cold part of the target. The emitted spectrum contains continuum part as well as characteristic X-ray lines of the atoms in the target, and pulses are of duration of 100s femtoseconds. Such short X-ray probe pulses in combination with laser pump pulses will allow scientists to resolve the kinetics of chemical reactions on atomic scales via ultrafast hard X-ray diffraction and X-ray absorption spectroscopy techniques to study artificial photosynthetic systems or photoactive biological molecules.

Betatron/Compton radiation sources (E2 hall, 10 Hz L3 laser driver)

Relativistic interaction of short-pulse lasers with underdense plasmas has recently led to the emergence of a novel generation of femtosecond X-ray sources. Based on radiation from electrons accelerated in plasma, these sources are compact generators of femtosecond pulses in narrow beams. Electrons transversally oscillating during their acceleration by the plasma wave emit broadband X-ray betatron radiation. The inverse Compton radiation source on the other hand relies on scattering of a counter-propagating laser pulse on laser-driven relativistic electrons and it can produce tunable quasi-monochromatic radiation from X-rays to gamma radiation.

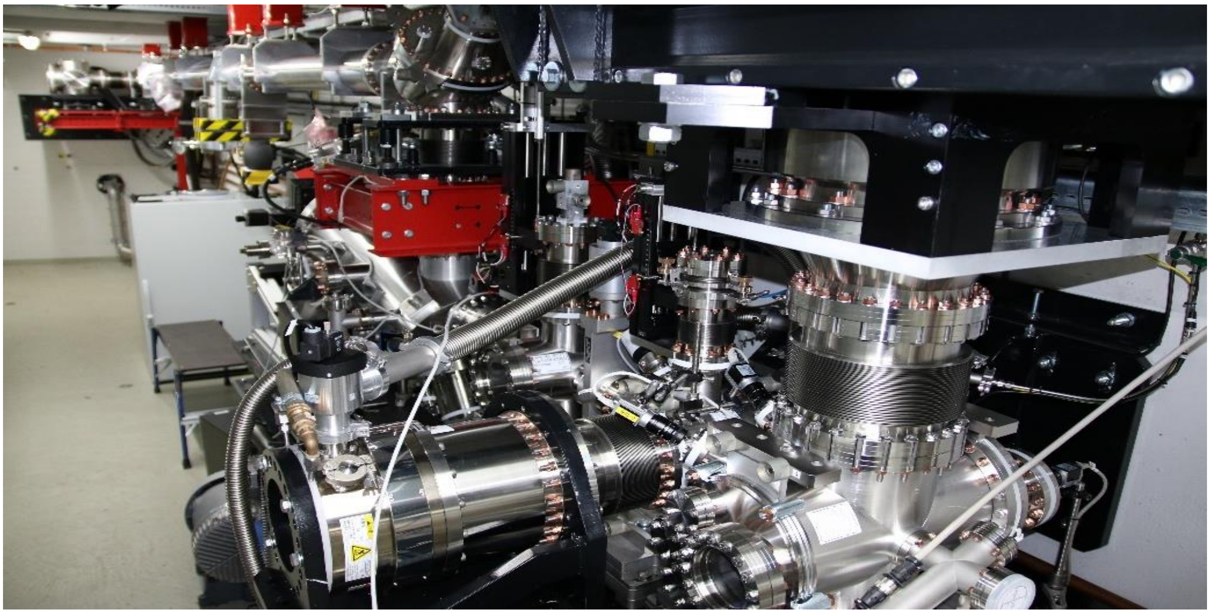
Broadband femtosecond X-ray radiation is desired to study warm dense matter, effective small size of the source is beneficial to perform high-resolution imaging of biological samples with phase-contrast.

Laser-driven X-ray free-electron lasers (E5 hall, 10 Hz L3 laser driver)

Laser wakefield acceleration will be used to provide high-quality relativistic electron bunches passing through an undulator formed by a periodic magnetic structure. This Laser-driven Undulator X-ray source (LUX) is designed to provide users with few-nm, few-fs X-ray pulses. The main challenge in this research and development is the long-term stability of the X-ray pulses that are generated. The development of the LUX beamline is one of the steps toward stable laser-driven free-electron lasers where coherent emission in undulator is achieved boosting the number of generated photons by many orders of magnitude.

The teams of University of Hamburg (UHH) and ELI develop the LUX beamline in collaboration with the main goal to serve as a synchrotron like source for user experiments at ELI Beamlines facility, providing soft X-ray pulses with 106 photons in 1% bandwidth with tuneable mean wavelength in the range of 4.2 down to 0.4 nm. Such a radiation is suitable for studying biological samples in the water window region and, with additional auxiliary beams, for studying molecular processes with temporal resolution better than 10 fs.

The LUX beamline development is already very advanced. In June 2016, ELI and University of Hamburg teams successfully accelerated the first electron beams with LUX, reaching the design energy of 400 MeV (See figure below for the first part of the setup). The beamline is currently ready for the production of first photons taking place in the following weeks.

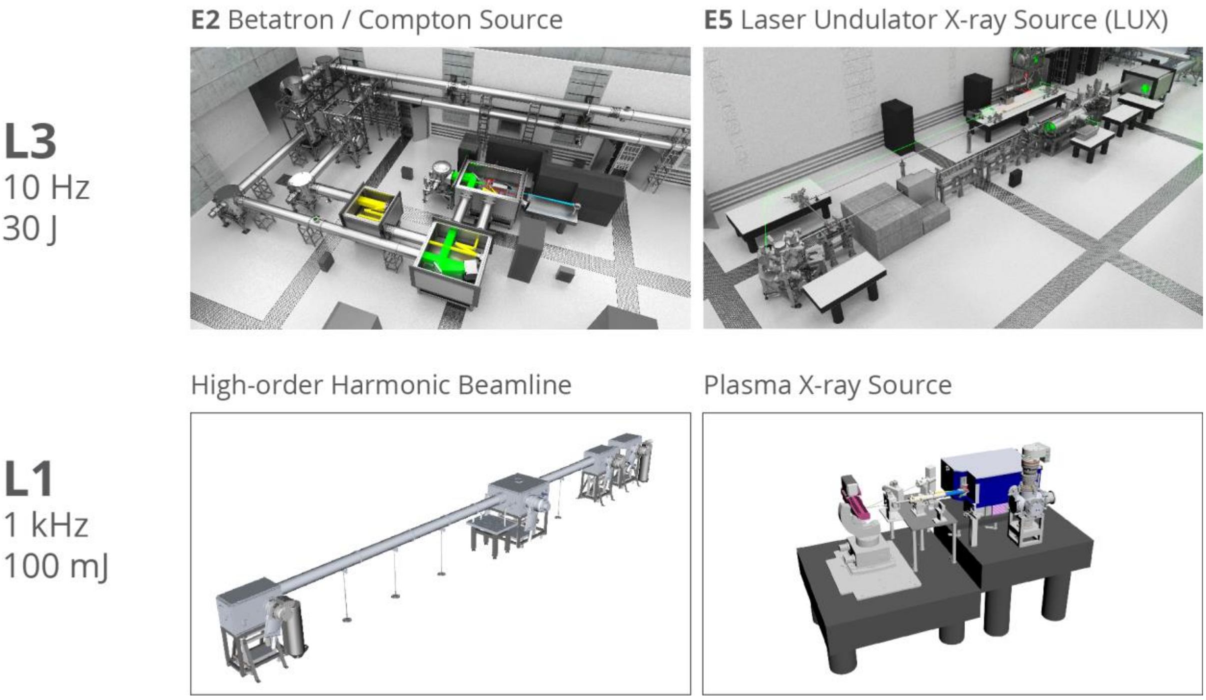


From left to right: A laser beam transport, the final focusing and laser diagnostics sections and the LUX plasma target section as installed at DESY laboratory, Hamburg.

In addition, the LUX is a crucial development step towards a much brighter laser-driven Free Electron Laser (FEL). Both UHH and ELI teams collaborate on the preparation of a demonstrator FEL experiment to take place in 2018. UHH team has designed a dedicated cryogenic undulator enabling reaching FEL gain in the number of radiated photons and ELI team has designed advanced electron beam optics to provide a sufficiently focused and stable beam for the novel undulator.

Moreover, ELI team collaborates with DESY (group J. Osterhoff) on LUX plasma diagnostics (Stark broadening plasma density measurement) and with University of Strathclyde (group D. Jaroszynski) on pepper pot electron beam diagnostics.

In the following years (after the first LUX user experiment scheduled on November 2017), the ELI team will focus on the FEL demonstration experiment, moving of the LUX beamline from DESY to ELI Beamlines experimental hall E5, and commissioning it for a regular user operation, and further advancing towards a full scale laser driven soft X-ray FEL in collaboration with UHH and DESY.



Visualization of four different sources developed by RP2with indicated laser drivers. The Plasma X-ray source and HHG Beamline will be installed in E1 and the 1 kHz 5 TW "L1" laser driver will be used. The Betatron/Compton and LUX beamlines will be installed in E2 and E5, respectively, all driven by 10 Hz 1 PW "L3" laser driver.

3.3.2. List of present collaborating institutions and potential future users

- LOA, ENSTA, France
  - Development of X–ray sources from relativistic electrons accelerated by lasers (betatron, inverse Compton source) and their applications (phase contrast imaging).
  - Development of plasma based X–ray lasers their diagnostics and applications
  - High-order harmonic generation from gases
- University of Postdam, Germany – plasma X–ray source and its applications

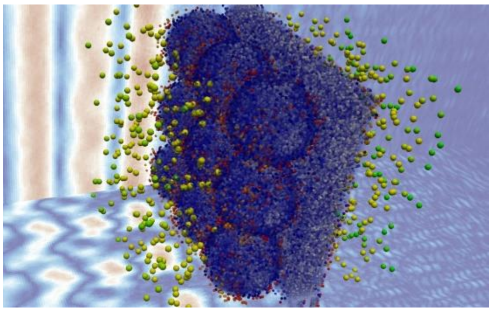
- Brown University, USA - plasma X–ray source and its applications
- CELIA, Univ. Bordeaux, France – High-order harmonic generation and applications
- University of Hamburg – Development of laser-driven free electron lasers and applications

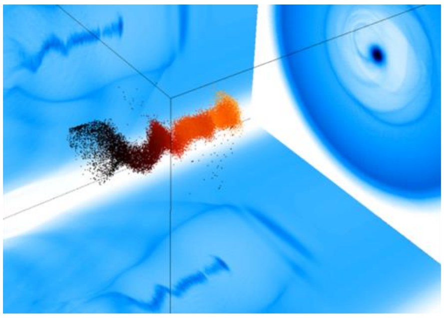
3.4. RP3 Particle Acceleration by Lasers

ELI-Beamlines offer the prospects of producing and studying versatile and stable particle (ions and electrons) sources at high repetition rates, while simultaneously enhancing the high energy tail of the spectrum, the beam monochromaticity and the laser-to-particle conversion efficiency, all of which are crucial points for the production of additional secondary sources.

The Research Program 3 (RP3) will also focus on the demonstration of proof-of-principle experiments aimed at envisioning future societal applications in various areas with special attention paid to biomedical ones. Thus, the optimization of particle beam quality and reproducibility (spatial profile, pointing, divergence and energy stability) will be a crucial issue. In order to realize such a challenging and wide range of envisioned activities, two scientific groups are currently working on the implementation of two different target areas, the **ELIMAIA** ion acceleration beamline and the **HELL** electron acceleration platform, with the main goal being to fulfil the expectations of the scientific user community.

Laser-driven particle acceleration is a new field of physics that is rapidly evolving thanks to the continuing development of high power laser systems, thus allowing researchers to investigate the interaction of ultrahigh laser intensities (> 10^{19} W/cm^2) with matter. As a result of such interaction, extremely high electric and magnetic fields are generated. Such tremendous fields, which can be supported only in plasmas, allow for the acceleration of particles at relativistic energies by way of very compact approaches. In particular, spectacular progress in the acceleration of electrons and protons has been achieved. On the one hand, electrons are currently being accelerated to very high energies (several GeV) from gas targets, which are transformed in plasma by high intensity laser pulses. On the other hand, 100-MeV-class protons are presently being accelerated in thin solid targets through the energy transfer of high energy electrons. [**SCALING; RELATIONS WITH LUX**]





3D numerical simulations showing laser-accelerated ions from a thin nanostructured target (left) and laser-accelerated electrons in a gas target (right)

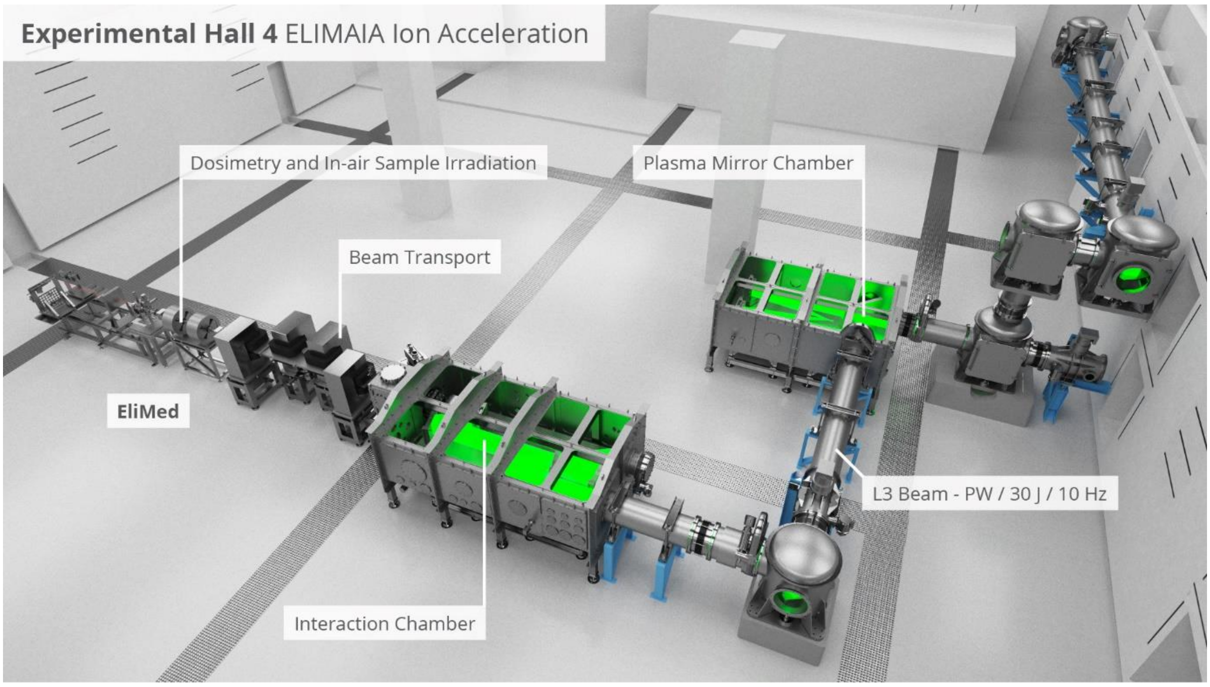
3.4.1. Scientific-technological infrastructure in the experimental halls E4 and E5

Two main different beamlines are developed within the Research Program 3 one dedicated to proton and ions acceleration (ELIMAIA in E4) and another dedicated to high energy electrons (HELL in E5).

ELIMAIA Beamline in E4

ELIMAIA will be one of the key secondary source target areas of the ELI-Beamlines facility. The proposed technological and scientific solutions for the implementation of the ELIMAIA beamlines is the result of a complex investigation carried out in the last several years with the main goal of fulfilling the specific requirements that have been coming from the international user community.

The general philosophy for the design, development, and implementation of the ion beam line in the ELI-Beamlines building is based on three key features: a user friendly approach, accurate monitoring and reliability of the accelerated ion beams, and flexibility for a future upgrade of the beam line. A complete beam line (ion source, in-vacuum ion beam transport, different dosimetric endpoints, and in-air sample irradiation end-station) will be available for users to enable them to apply laser-driven ion beams in multidisciplinary fields.



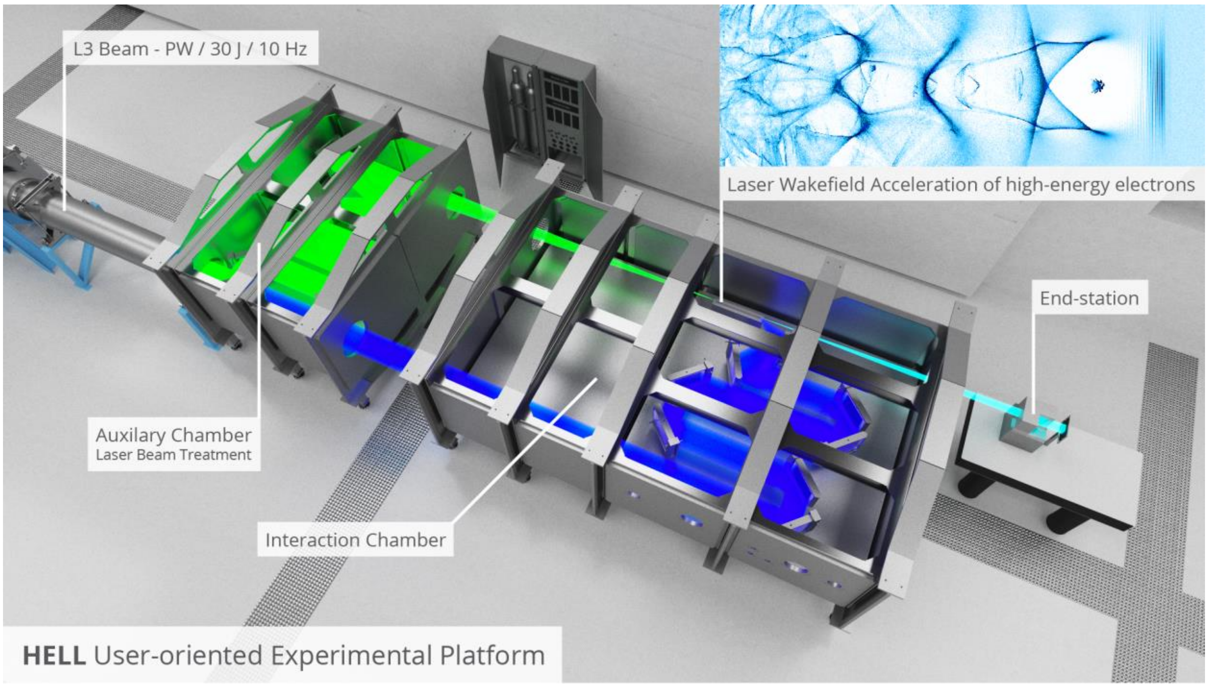
A 3D design of the ELIMAIA beam line in E4 is shown in the figure above. The ELIMAIA beam line is located in the northern part of experimental hall 4 (E4). The available laser beams are L3 and L4 (both at 1 PW power level) coming from the western wall. The ELIMAIA beam line consists of two main subsystems: **Ion accelerator** and **ELIMED.**

The aim of ELIMAIA will be to demonstrate that the overall cost of the standard acceleration facilities can be drastically reduced by using innovative compact approaches based on high power laser-matter interaction. In fact, the main goal of the ELIMAIA beamline is to provide stable, fully characterized, and tunable particle beams accelerated by PW-class lasers and to offer them to a broad national and international community of users for multidisciplinary applications, as well as fundamental science. An international scientific network, called ELIMED (ELI MEDical applications), that is particularly interested in future applications of laser-driven ions for hadrontherapy has already been established. However, this is only one of the potential applications of the ELIMAIA beamline, which will be open to several proposals from a multidisciplinary user community. These proposals will be for areas such as non-conventional ion acceleration, radiobiology, time-resolved radiography of different materials, and beam-target nuclear reactions generating isotopes for positron emission tomography or producing high brilliance secondary radiation sources (e.g., neutrons and alpha-particles).

HELL Platform in E5

Electron acceleration driven by high peak power femtosecond lasers was theoretically predicted in 1979 by Tajima and Dawson . The brilliant idea to use laser-driven plasma-waves was experimentally demonstrated more than a decade ago, and presently this technique is used on a daily basis in many laboratories worldwide. Laser-accelerated electron beams can potentially be used for various societal applications (e.g. through the generation of x-ray and gamma ray secondary sources) and, at the same time, enable and validate innovative physical mechanisms proposed by the scientific community, as extensively described in the ELI-White Book . The high energy electron acceleration program being implemented at ELI-Beamlines is conceived to accommodate, in a long term perspective, experiments covering both aspects. Thus, the HELL (High-energy Electron by Laser Light) platform under construction at ELI-Beamlines will facilitate the performance of experiments oriented to the use of secondary sources (thanks to the user-friendly "beamline" features that will be focused on user needs), as well as advanced experiment that will require the use of the main electron source (thanks to the flexible "platform" features) to develop and test innovative schemes, in order to improve acceleration techniques and to verify new models.

The development activity of the HELL platform already resulted in filing of a Luxembourg patent application, where the European patent office as a search and examination authority acknowledged, besides the others, its novelty, inventiveness and industrial applicability for an advanced "laser-based radiotherapy machine" provided by means of electrons.



The double scope of the HELL platform is guaranteed from one side thanks to the flexible setup that enables the possibility to use a wide range (from 4m to 30m) of focal lengths of the focusing optics obtainable modifying the distance between the Auxiliary and Main interaction chamber thus allowing the use of a wide range of interaction regimes for new acceleration scheme and counter-propagating basic experiments. On the other side the presence of a dedicated and flexible end-station enables the user-oriented needs to irradiate samples at pre-defined accelerator parameters in the range available from the main LWFA (from 10MeV to multi-GeV).

3.4.2. List of present collaborating institutions and potential future users

Ion Acceleration (ELIMAIA)

- Queen's University (Belfast, UK): laser driven proton/ion acceleration, neutron sources, particle diagnostics, future hadron therapy applications.

- INFN-LNS (Catania, Italy): ion beam transport and dosimetry for multidisciplinary applications, including radiation biology, pulsed radiolysis, hadron therapy.
- LBNL (Berkley, US): innovative schemes for laser driven ion acceleration from advanced targets.

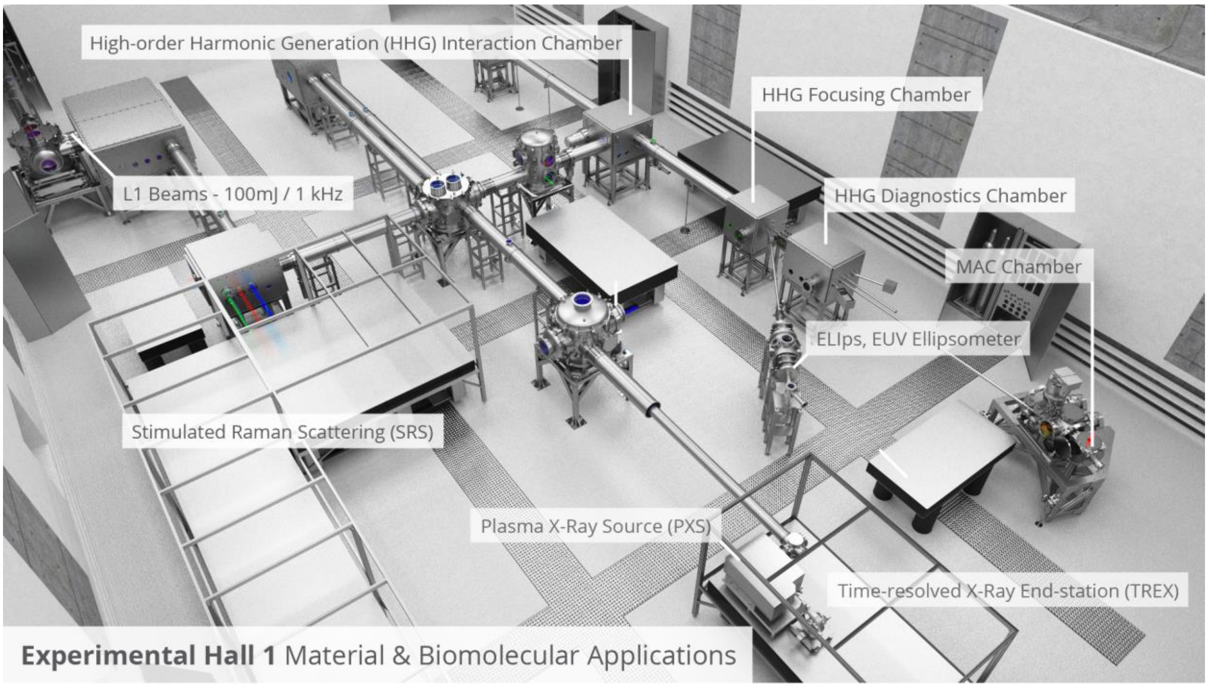
Electron Acceleration (HELL)

- Strathclyde University (Glasgow, Scotland): experiments on capillary at 1J-level as partners of the project “Lab. in a bubble”.
- IPPLM (Warsaw, Poland): ultra-stable pointing and applications.
- MUT (Warsaw, Poland): ns-channels and a Joint-Proposal for defense.
- Imperial College: R&D on new diagnostics, grant proposal, student training.
- Biological Center (Pilsen, Czech Republic).
- BIOCEV (Vestec, Czech Republic).
- CNR (Italy): implementation of new ideas for deformable mirror optimization aiming at low cost large size mirrors.
- GIST (Sud-Korea): Ultrahigh Intensity Laser-Matter Interaction.
- LOA (Palaiseau, France) for medical applications of laser driven electron beams.
- ELETTRA/FERMI (Trieste, Italy): electron diagnostics development and testing.

3.5. RP4 Application in Molecular, Biomedical and Material Sciences

3.5.1. Scientific-technological infrastructure in the experimental hall E1

Research program 4 (RP4) at ELI Beamlines develops “Applications in Molecular, Bio-medical and Material Science” utilizing mainly the L1 laser developed by RP1 and the laser driven light (VUV and X-ray) sources developed by RP2. Scientific activities are focused in the E1 experimental hall where the high repetition rate (1 kHz) L1 will be converted to the requested pulse parameters and used to study ultrafast processes of electronic, molecular and magnetic dynamics.



Planned structure of the E1 experimental hall. A high vacuum beam transport system brings the L1 beams to the VUV and X-ray sources (HHG and PXS). Scientific end stations are located behind the sources. Note that the PXS station will be located in a radiation safety hutch that is not shown for clarity.

Four experimental stations are developed for E1. Two of these are optimized for the vacuum Ultra-violet (VUV) pulses from the HHG source. One (the MAC chamber) is dedicated to the study of ultrafast dynamics in isolated atoms, molecules, clusters as well as nanoparticles and nano-bio-particle complexes. This station can also be used for imaging application through coherent diffractive imaging. Although initially deployed in E1, this station is also suitable for use at the LUX source in E5 once it becomes available. The other end station at the HHG source will offer to the material science community unique ways to study dynamics in solid state materials (including new physics at interfaces and surfaces) through time resolve magneto optical ellipsometry extending into the soft X-ray range. Next to the HHG source the PXS source will serve a modular end station for jitter-free time-resolved X-ray diffraction, spectroscopy and pulse radiolysis experiments. In addition to the experimental stations at the laser driven X-ray sources (HHG and PXS) E1 will also be equipped with a station for advanced time-resolved optical spectroscopy techniques. This station includes a wide range of pulse conversion instruments including methods to generate pulses in the UV to IR range (including THz), as well as temporally shaped and ultra-short (~5 fs) pulses. The beam transport system is developed to allow the beams from all light sources in E1 to be overlapped in both space and time, thus allowing unique experimental combinations.

3.5.2. Major research topics

The choice of technologies for development recognizes a number of fundamental aspects of photon science. First, as in every-day flash photography, the duration of the light flash limits the temporal resolution that can be achieved. With femtosecond (fs) flashes (pulses) from the L1 laser it is possible to study fs dynamics. This is exactly the time scale where a great part of interesting properties in Molecular, Bio-medical and Material Science have their origin. Furthermore, the wavelength of the light sets a fundamental limit to the spatial resolution that can be obtained. In particular, to study atoms and molecules directly, you need light with a wavelength of that same scale (that means X-rays). The fact that X-ray diffraction can provide spatial resolution on the atomic and molecular scale, where motion happens on the fs time scale makes ultrashort X-ray pulses extremely suitable to study structural dynamics. Finally, the energy of the photons determines what type of properties in the sample the pulse will either activate or probe. It is said that when the photon energy is the same as that of a specific excitation/property in the sample they are in "resonance". Ultrafast resonance spectroscopy, is a very powerful way to selectively activate and study diverse properties in applied science.

In E1 RP4 develops the unique possibilities that come from having synchronized high repetition-rate light-sources covering a wide range of the electromagnetic spectrum available in one location. This will allow us to selectively chose how to activate and probe sample dynamic in ways that are beyond the present state-of-the-art. Research and development will focus on ultrafast dynamics and cover interactions between electronic, structural, magnetic and optical properties. Samples cover atoms, molecules, clusters and nanoparticles (including bio-particles and bio-nano complexes) as well as thin films, multilayers and bulk materials (including powders and single crystals for time-resolved X-ray diffraction). In a close collaboration with the ELIBIO team RP4 develops unique strengths in the investigations of complex and sensitive bio-molecular targets (like dynamics in membrane proteins). Time-resolved research will cover both studies of the effects of photo-activated charge transfer processes as well as processes that are not explicitly photo activated ("dark" reactions) which are particularly important to biological systems and catalysis since very few of these processes are photo-activated in nature.

3.5.3. Present research linked to future activities

A long term strategy in RP4 has been to be actively involved in X-ray science at international user facilities such as X-ray Free Electron Lasers (FELs) and modern synchrotrons as well as in optical labs of strategic international collaborators. As an example, in 2017 RP4 researchers are scheduled to participate in at least three X-ray FEL beamtimes at DESY in Hamburg and SLAC in the USA. Since December 2016 the international user community is also working with the RP4 team on user assisted methods development projects at the ELI BL facility. A particularly successful example is the development of time resolved spectroscopic ellipsometry that has already attracted significant interest from international and national users. Both of these activities represent important preparations for the future user activities. A topic of significant present importance is the co-development of RP4 and the ELIBIO Excellent Research Team headed by Professor Janos Hajdu since Dec. 2016. RP4 has a unique opportunity to utilize the synergy effects from having a world leading team in bio-molecular dynamics being realized at the very facility where RP4 is developing scientific instruments for in-house research and user operation.

3.5.4. List of potential future users

The following list of potential/likely international users represents a selection of researchers and institutions RP4 have worked with during the instrument and methods development process. In many cases they represent long term scientific collaborators of senior RP4 researchers.

AMO science and Coherent Diffractive Imaging

- Technical University Berlin, Berlin, Germany (M. Krikunova)
- Molecular Biophysics, Uppsala University, Uppsala, Sweden (F. Maia)
- Molecular and Condensed Matter Physics, Uppsala University, Uppsala, Sweden (N. Timneanu)

Material science, in particular time-resolved ellipsometry extending into the VUV range

- Leipzig University, Leipzig, Germany (R. Schmidt-Grund)
- Hamburg University and CFEL and DESY, Hamburg, Germany (M. Rübhausen)
- Magdeburg University, Magdeburg, Germany (M. Feneberg)
- New Mexico State University, New Mexico, USA (S. Zollner)
- Institute of Physics, Prague, Czech Republic (A. Dejneka)
- Masaryk University/CEITEC, Brno, Czech Republic (Joseph Humlicek)

Hard X-ray science (diffraction, scattering, spectroscopy and imaging)

- Potsdam University, Potsdam, Germany (M. Bargheeer)
- Molecular Biophysics, Uppsala University, Uppsala, Sweden (I. Lundholm)
- Göteborg University, Göteborg, Sweden (G. Katona)
- Uppsala University/Polish Academy of Science, Uppsala/Warsaw, Sweden/Poland (J. Sa)
- Jan Kochanowski University, Kielce, Poland (J. Szlachetko)

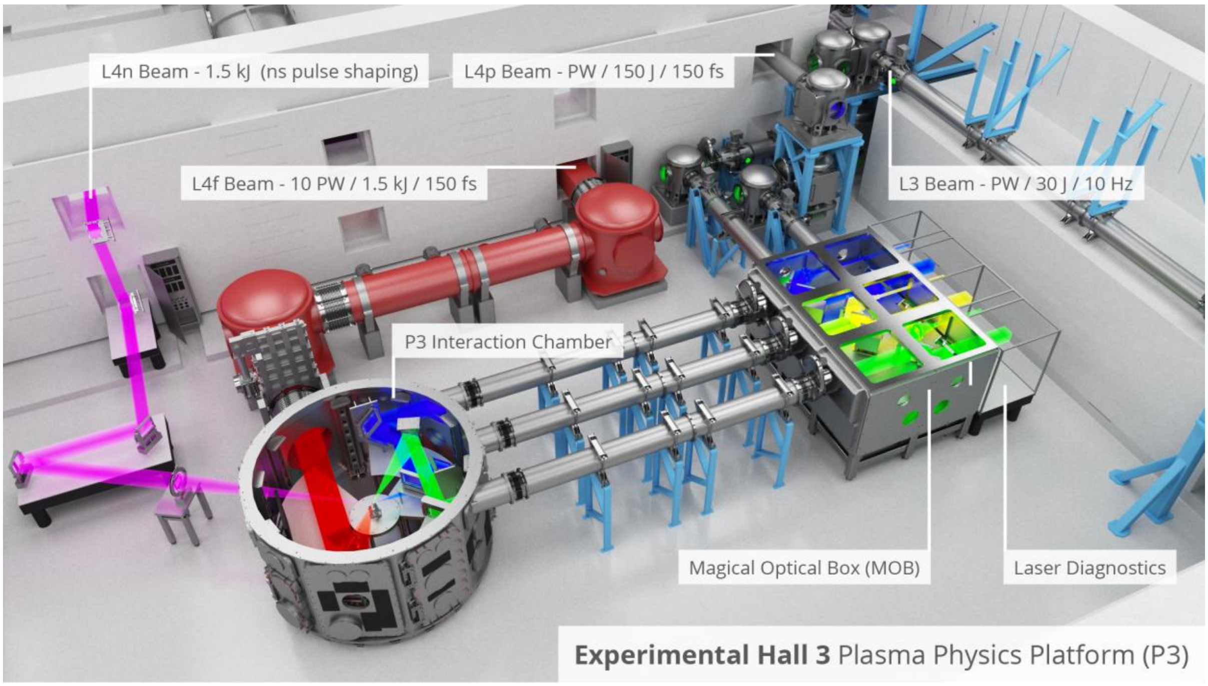
Optical spectroscopy (fs Stimulated Raman Scattering and 2D spectroscopy)

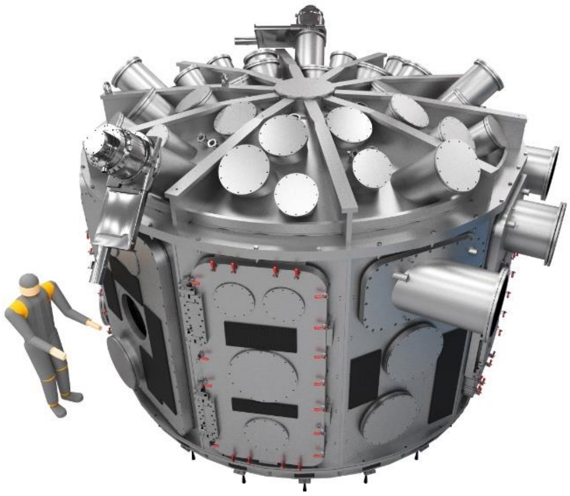
- Univ. of South Bohemia, České Budějovice, Czech Republic (T. Polivka)
- Chalmers University of Technology, Göteborg, Sweden (M. Karlsson)
- Free University Amsterdam, Amstedan, Netherlands (R. Croce, J. Kennis)

3.6. RP5 Plasma and High Energy Density Physics

3.6.1. Scientific-technological infrastructure in the experimental hall E3

The experimental hall E3 is dedicated to the study of high-energy-density physics and ultra-high intensity laser-plasma interaction. The most important elements of the technological infrastructure are the plasma physics platform (P3) and the optical switchyard (MOB). The infrastructure is designed to handle multiple, synchronized laser beams in the same interaction chamber, covering a wide range of pulse lengths and energy. It is not a dedicated beamline providing optimized secondary sources but rather a platform for fundamental and applied research allowing for very flexible setups. On a smaller scale there will be additional scientific equipment such as a betatron for new sophisticated plasma diagnosing and a pulsed power device for the study of magnetized plasmas. The main vacuum chamber can accommodate the 10 PW beam as well as the uncompressed nanosecond beam. It is therefore dedicated to high-intensity as much as high-energy laser-plasma interaction. This variety of laser configurations allows the study of a wide range of laser-plasma phenomena. The main interaction chamber is with about 50 m3 one of the largest civilian vacuum chamber for laser-based experiments.





P3 Chamber: manufactured (left), visualization of complete chamber (right).

3.6.2. Major research topics

The research program R5 is covering a very wide range of topics in the field of lasers interacting with plasmas/matter:

- Laboratory astrophysics: collisionless shocks, magnetic reconnection, radiation hydrodynamic phenomena, jet formation, magnetized laser-plasma interaction
- High-energy-density physics and warm dense matter: planetary cores, shock waves, opacities, equation of state etc.
- Ultra-high intensity interaction: electron-positron pair creation, radiation damping, γ-ray flashes, relativistic flying mirror etc.
- Plasma optics: plasma amplification, plasma focusing, manipulation of coherent light by plasmas, new schemes for future high-power laser pulses etc.

- Laser-plasma interaction: e.g. for shock-ignition approach to ICF, parametric instabilities, soliton formation, laser absorption etc.

The P3 research infrastructure with its wide range of possibilities is of strong interest to the academic research community. However, the research program is also strongly engaged in the development of possible new secondary sources which will benefit the other beamlines and provide eventually societal benefits.

3.6.3. Present research linked to future activities

Members of the R5 team engage actively in experimental campaigns in Europe and USA as well as develop new scientific technology for the future user community of P3. Some of them are presented briefly in the following.

Technology development activities

- **Gamma-ray spectrometer:** Gamma-photons are generated by nonlinear inverse Compton scattering in ultra-high intensity laser-matter interaction. A prototype instrument was developed operating in the 5-20 MeV range with 2 MeV resolution. The spectrometer has been calibrated at HZDR-ELBE beamline.
- **Betatron:** Laser wakefield acceleration of electrons provide an efficient way to generate betatron radiation of a few keV. This radiation is a diagnostic for warm dense matter studies, e.g. XANES etc. The approach is being fine-tuned on installations such as PALS and Lund Laser Center.
- **Pulsed Power Device:** Up to 30 kJ of stored energy are released in a few milli-seconds to generate quasi-static magnetic fields (~40 Tesla). This allows the study of magnetized laser-plasma interaction for astrophysical applications and warm dense matter studies.
- **Ellipsoidal Plasma Mirrors:** EPMs are required for refocusing the 10 PW laser beam of ELI-BL. Development work is taking place to optimize the EPMs for proof-of-principle experiments before being deployed in P3.

Experimental campaign activities

- **Magnetic field generation:** Capacitor coil experiments for generating Mega Gauss fields were performed at PALS laser facility. This method is complimentary to a PPD as the fields are very short-lived but much more intense.
- **Warm dense matter & betatron:** Several experimental campaigns were conducted in the context of WDM on such installations as OMEGA in Rochester and Trident at LANL. These experiments investigated electron preheat, novel X-ray sources and electron diffraction.
- **Plasma amplification:** Over the last few years several campaigns were conducted on plasma amplification leading towards control and optimization of the interaction process. The robustness and energy-efficiency of the Brillouin-based process was clearly proven.
- **Hot electron generation & diagnosing:** In a series of experiments, generation of suprathermal electrons has been studied at conditions relevant for the development of a shock ignition driven inertial confinement fusion. A novel approach to suprathermal electron production in laser-irradiated Cu targets characterized by combined methods of x-ray imaging and spectroscopy is being developed.

3.6.4. List of potential future users

R5 is in contact with a large number of institutes/laboratories and universities worldwide who are either already collaborators of the project or expressed interest as future user. In the following overview only the major institutions are listed together with a contact person or collaborator.

EUROPE:

- LULI/APOLLON, Ecole Polytechnique, Palaiseau, France (J. Fuchs)
- University of Strathclyde, Glasgow, UK (P. Mckenna)
- XFEL, Hamburg, Germany (M. Nakatsutsumi)
- HZDR, Dresden, Germany (T. Cowan)
- Technische Universität Darmstadt, Darmstadt, Germany (M. Roth)
- RAL, Didcot, UK (D. Neely)
- Queen's University Belfast, Belfast, UK (M. Borghesi)
- Lund Laser Center, Lund, Sweden (O. Lundh)
- GSI, Darmstadt, Germany ()
- Friedrich-Schiller University Jena, Jena, Germany ()

Outside EUROPE:

- SIOM, Shanghai, China (J.-Q. Zhu)
- University of Texas, Austin, USA (G. Dyer)
- LLNL, Livermore, USA ()
- Rochester University, Omega, Rochester (USA)
- Weizmann Institute of Science, Israel ()
- Osaka University, Osaka, Japan (Kodama)

It is to be expected that any research group worldwide active in the domain of high-energy and/or high-intensity laser-matter interaction will be interested to become future user of P3 as the proposed scientific and technological infrastructure will be unique in the European landscape of laser-based research.

3.7. RP6 Exotic Physics and Theory/Simulation

3.7.1. Major research topics

The research program R6 has the character of a theory & simulation group as the experimental part, high-field research, was transferred to R5. In addition, R6 is responsible for the high-performance computing center. Its main activities are the following:

- Predictive simulations of future high-field laser-matter interaction experiments
- Start-to-end simulation work up to the detector response signal
- Investigating new possible signatures of high-field interaction for diagnostic means
- Optimizing the computing cluster for specific simulation activities
- Code development activities for high-field as well as pre-pulse physics
- Simulation support and data analysis for experimental activities
- Define possible high-field flagship experiments for the ELI-BL 10 PW laser

- Development of the Virtual Beamline (VBL) for the experimental programs and the ELI facility as a whole

The actual physics topics overlap strongly with the ones presented for the R5 program.

3.7.2. Present research linked to future activities

The present research activities have resulted in a large number of peer-reviewed articles investigating mostly the following topics:

- **Electron-positron pair creation using the Breit-Wheeler process:** Detailed studies are under way to optimize the interaction process and to determine amount and geometry of the release process.
- **Magnetic reconnection in the relativistic collisionless regime:** MR is a ubiquitous process in astrophysics and can be studied with laser in the short-pulse regime. For UHI the reconnection process is no longer driven by collisions as for example in tokamaks.
- **Plasma amplification:** The use of 3-wave coupling processes in plasmas is investigated for the generation of high-intensity laser pulses. Plasmas allow to overcome the usual damage threshold consideration of standard solid-state-based optical materials. This might be one way for future Exawatt laser systems.
- **Pre-pulse physics: Any laser has a limited contrast.** As a consequence, the pre-pulse generates a plasma corona in front of the solid material. A detailed understanding and possible subsequent control of the coronal plasma is of vital importance for ICF applications as well as for making possible the interaction of solid density with the highest possible laser intensity.
- **Gravitational wave generation by high-power lasers:** A study investigated the possibility to generate gravitational waves in a controlled laboratory environment. Although possible in principle, the achievable space-time perturbations are beyond present detector limits.
- **Attosecond physics:** Studies are under way to understand laser-induced atto-second physics on the nano-scale for possible future applications.
- **Parametric instabilities in the context of the shock-ignition scenario for ICF:** Parametric instabilities are detrimental to the ignition process in thermonuclear fusion. They are responsible for energy loss due to backscattering and can generate hot electrons which induce preheat. The intricate interplay of the various instabilities and their control is far from understood.

3.7.3. Active collaborations in theory/simulation

R6 is engaged in several very productive collaborations with specialists inside and outside Europe which help to define the future research activities:

- LULI-UPMC, University Pierre et Marie Curie, Paris, France (C. Riconda)
- MEPhi, Moscow, Russia (E. Gelfer)
- CELIA, University of Bordeaux, Bordeaux, France (V.T. Tikhonchuk)
- Kansai Photon Science Institute, JAEA, Kyoto, Japan ()
- FNSPE, Czech Technical University, Prague, Czech Republic (O. Klimo)
- Forschungszentrum Jülich, Jülich, Germany (P. Gibbon)

3.7.4. Technological infrastructure

The research program R6 is in charge of building up a local high-performance computing center. The first element was the acquisition of a cluster of about 1400 cores and 1 Peta-Byte disk space. The peak performance is of the order of 100 Tera-Flops. The dominant purpose of the machine is multi-dimensional, kinetic simulation work for the interpretation of experimental data, predictive modelling of future high-field experiments and numerical support work such as Monte Carlo simulations for radiation protection etc. Due to a recently awarded ERT grant the machine is expected to undergo a considerable upgrade in 2018.

The high-performance computing cluster ECLIPSE.

3.8. ELIBIO Project: Future Biology with High-Power Lasers

The European Development Fund and the Czech Ministry of Education, Youth and Sports has awarded over 250 million CZK to the ELIBIO project at the new ELI Beamlines laser facility of the Institute of Physics of the Czech Academy of Sciences. The project explores new frontiers in light and optics to create breakthrough science in biology, chemistry, and physics. The project brings world-leaders in photon science and structural biology to the Czech Republic, and creates an interface between two complementary research centres of the Czech Academy of Sciences: the ELI-Beamlines (ELI-BL) facility and the Institute of Biotechnology (IBT) of the BIOCEV Centre. IBT is focused on biomedical and biotechnological research while ELI-BL is a leader in photon physics with high-power lasers.

The ELIBIO team is headed by Prof. Janos Hajdu, who is developing the research strategy and sets the scope of the experimental work. Prof. Hajdu has a rich scientific career. He started his X-ray work in Oxford, U.K., was Professor of Photon Science at Stanford University in the USA, and Professor of Molecular Biophysics at Uppsala University in Sweden. He also served as advisor to the Directors of the European X-ray Free-Electron Laser (XFEL) in Hamburg. The "Excellent Research Team" (ERT) to be established in this project includes scientists at all professional levels and is expected to enhance the research performance of the partner organizations. Senior ERT members include Prof. Bohdan Schneider (IBT), Prof. Jan Dohnalek (IBT), and Prof. Maria Krikunova (ELI-BL). A particularly close collaboration has been established with Dr. Jakob Andreasson from ELI-BL, who heads the ELI-BL research programme for applications in molecular, bio-medical and material sciences.

One of the aims of the ELIBIO project is to establish an Interdisciplinary Centre of Excellence at the European Extreme Light Infrastructure in Dolní Břežany near Prague. This centre will combine biology, chemistry and physics, and will exploit some of the most powerful photon beams in the world at the ELI-Beamlines facility. ELIBIO will use these beams to perform breakthrough studies in life sciences.

3.8.1. Specific research objectives of the project

Biomolecular interactions and charge transfer studied by ultrafast spectroscopy.

We will trigger charge transfer reactions with extremely short photon pulses to study ultra-fast processes in a broad spectrum of radiation from THz to UV and X-ray radiation. Synchronized multidimensional spectroscopy will be used to characterise the dynamics of the systems under investigation. We plan to address three issues: (1) fingerprinting of biomolecules by Raman spectroscopy at up to attosecond resolution. (2) studying transient protein-protein or protein- nucleic acid interactions by combined vibrational and UV/fluorescence spectroscopy; (3) light-driven nano-manipulation of molecules and their assemblies.

Diffraction-based imaging of crystalline and non-crystalline nano-material on ultrashort time scales.

We will create a sample environment and pipeline to perform such experiments at ELI-BL and work with other scientists at ELI-BL in pioneering efforts to use multiple beams to obtain super-stereo images. Initially, this work will mainly be carried out at the LCLS and the European XFEL and then moved to ELI-BL as the operational parameters of the facility approach requirements.

Studies of photon-material interactions on ultrashort time scales and high intensities.

Biological imaging exploits the high-frequency and high-energy density regime of photon science, which has not been accessible to research so far. The dominant interaction of X-rays with atoms is through K-shell photoionization. Relaxation of the resulting hollow ions proceeds through the emission of Auger electrons in biologically relevant light elements. Shake-up and shake-off excitations, initial- and final- state configuration interactions and interference between decay channels will modulate this picture. Electrons ejected from atoms cause further ionization by eliciting secondary electron cascades in condensed materials. With very short X-ray pulses (shorter than about 10 femtoseconds), most of these processes will have no time to develop, and the photoionisation cross-sections drop. We will investigate: (i) primary and secondary ionisations as a function of photon energy and pulse intensity. (ii) time-dependent X-ray absorption and scattering, and (iii) perform experiments at ultra-high energy densities.

Development of experimental methods.

A biology support laboratory will be created at ELI-BL during this project and research infrastructure of IBT at BIOCEV will be upgraded. We will work on improving sample delivery to reduce sample consumption when introducing living cells, viruses or biomolecules into the beams of ELI for spectroscopy and imaging. We will develop advanced pump-probe methods for time-resolved spectroscopy at ELI-BL.

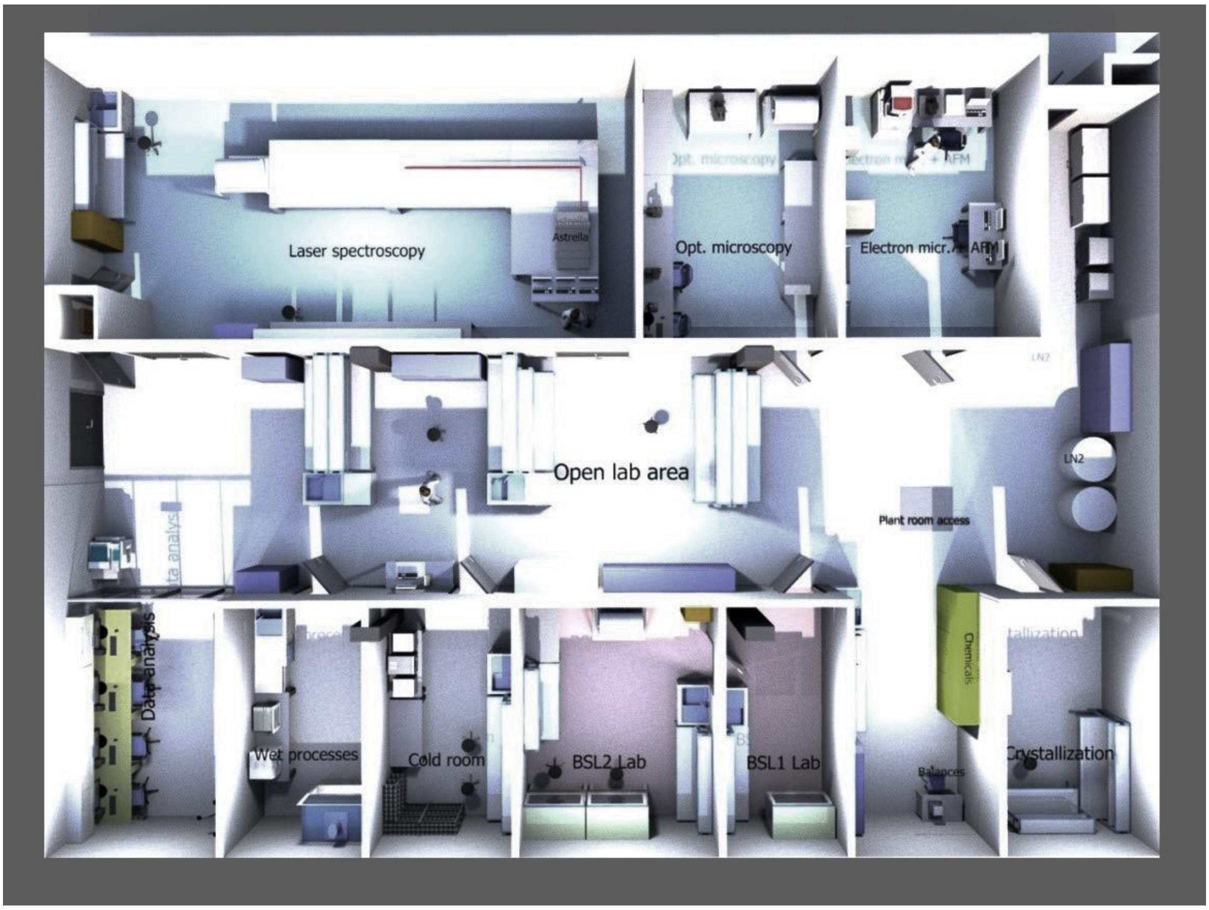
Education of Czech and foreign students.

Students will benefit tremendously from participating in revolutionary new experiments. We intend to set up a Masters Programme and a Graduate Programme in Photon Science and continue teaching of structural biology at Charles University and South Bohemian University. Our links to various X-ray lasers and advanced photon sources offer new dimensions and opportunities through joint courses and joint M.Sc. and especially Ph.D. projects.

3.8.2. Key investments

The Bio-lab complex

The main infrastructure upgrade will be the realization of a bio-lab complex at the ELI-BL facility. The building for the bio-lab complex has been constructed in at ELI-BL and within the ELIBIO project we will develop 373 m2 of this area into a fully functional bio-lab equipped to perform preparatory and complementary measurements to experiments at ELI-BL and X-ray Free Electron Lasers. It will also support the IBT labs in sample preparation.



Schematic layout of the ELIBIO Laboratory area.

The construction of the bio-lab complex is expected to start in month 12 of the project and finish in month 24 (with the commissioning of all major systems). Estimated cost: 59.34 M CZK (excl. VAT).

A designated pump-pulse laser

This laser will be installed in the ELI-BL E1 experimental hall to deliver the pulses used to initiate the sample dynamics that will be probed by the X-ray sources driven by the powerful ELI-BL main lasers. This laser should have an oscillator that can be synchronized to the ELI-BL main lasers on the femtosecond level and a capability of picking pulses with arbitrary delays for amplification, thus allowing high resolution pump-probe experiments in the femtosecond to millisecond range. This upgrade will start in month 9 of the project and finish in month 15. Estimated cost: 14.16 M CZK (excl. VAT).

Sample preparation and characterization facility at IBT

The capabilities for sample preparation and characterization at IBT will be upgraded. Significantly a SAXS beamline will be added to the X-ray scattering and diffraction instrument. In addition, the capabilities for protein expression and purification will be improved and the mass spectroscopy instrument upgraded. These upgrades will start in month 9 of the project and finish in month 36. Estimated cost: 20.65 M CZK (excl. VAT).

The ELIBIO project will be embedded into an international framework of research infrastructures, including the European XFEL and the Linac Coherent Light Source at Stanford (California, USA). A Memorandum of Understanding with the European XFEL will be signed on 28 April 2017 in Dolní Břežany. The inflow of talent and expertise through this project, combined with the foundation of a centre of excellence will leave a legacy of a strengthened Czech research environment.

3.9. HiFI Project: High Field Initiative

As in the case of the HiFI Project, the European Development Fund and the Czech Ministry of Education, Youth and Sports has awarded over 250 million CZK to the HiFI project at the new ELI Beamlines laser facility of the Institute of Physics of the Czech Academy of Sciences. The project aims at obtaining new scientific results in the field of ultra-intense laser matter interaction providing theoretical support and technological upgrade of the 10 PW laser at ELI-Beamlines for the preparation of worldwide unique high-field flagship experiments. Next generation high power lasers, such as ELI-Beamlines 10 PW laser, access new physics regimes when, as yet, unexplored processes come into play. This project will advance our knowledge of laser accelerated electrons and ions as well as high energy photon generation in novel regimes when radiation friction and quantum electrodynamics processes, such as electron-positron pair creation and vacuum polarization, become significant. The theory/simulation program will explore a fundamentally new regime of laser matter interaction and give a solid theoretical base which will lead to realization of completely new high field experiments. To explore this regime experimentally an upgrade of the existing infrastructure around the 10 PW laser beam will be done within the HIFI project. The synergy between theory/simulation and the experimental infrastructure will create a worldwide unique center for the study of new phenomena at the frontiers of super intense laser matter interaction.

3.9.1. Specific research objectives of the project

The HiFI project PI Prof. Sergei Bulanov is responsible for formulating the research program and for setting the scope of the theoretical and simulation work. As for the ELIBIO project, the "Excellent Research Team" (ERT) to be established in HiFI project includes scientists at all professional levels and is expected to enhance the research performance of the partner organizations. The ERT/HiFI team leader, Prof. Bulanov during his scientific career has been involved to a broad range of projects. He has graduated from Moscow Institute of Physics and Technology (MFTI). He obtained the PhD degree from MFTI in the field of theoretical physics and astrophysics and the Doctor of Sciences degree at the Institute of General Physics RAS in Moscow in the field of plasma physics. S. V. Bulanov is an expert in theoretical astrophysics, in nonlinear wave theory, in the theory of relativistic laser plasmas and in computer simulations. Being theoretician S. V. Bulanov for several years was a leader of experimental group at the KPSI (JAERI-JAEA-QST) institute in Kyoto in Japan. S. V. Bulanov is a recipient of several notable awards: State Prize of the USSR for Sciences and Technology for achievements in high energy astrophysics, Japan Atomic Energy Agency President's Awards and Awards of the Japan Laser Society for contribution to the laser physics development, and Hannes Alfven Prize of European Physical Society for experimental and theoretical contribution to the development of large-scale next-step devices in high-temperature plasma physics research. S. V. Bulanov published 2 monographs and about 600 papers. His h-index equals 58.

Senior ERT/HiFI members include Prof. Stefan Weber (Leader of RP5 & RP6 teams at ELI-BL), Prof. Ondrej Klimo (CTU), Prof. Pavel Sasorov (ELI-BL), and Prof. Tae Moon Jeong (ELI-BL). Junior Research Scientists at ERT/HiFI are Dr. Yan Jun Gu (ELI-BL), Dr. Hedvika Kadlecova (ELI-BL), Dr. Wenchao Yan (ELI-BL), Mr. P. Valenta (CTU), Dr. V. Sagar (ELI-BL), and Dr. D. R. Khikhlukha.

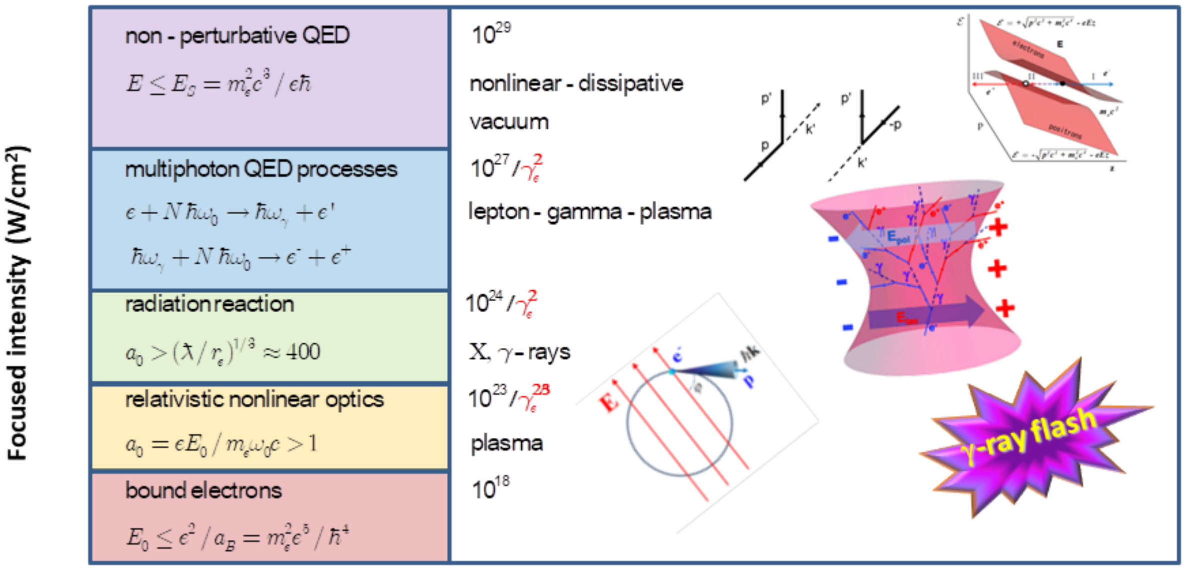
3.9.2. Specific research objectives of the project

Scientific Agenda

We will establish a theoretical and computer simulation program fully equipped with analytical and simulation tools, able to design and support experiments on charged particle acceleration, high intensity laser induced particle physics, generation of high brightness hard electromagnetic radiation sources, fundamental sciences, and laboratory astrophysics at multi-PW-class laser facilities. The established program will advance understanding of the radiation dominated and quantum regimes, which are among the most actively developing directions in the high field research, motivated by a number of important applications in fundamental and applied science, ranging from the ultra-bright sources of hard electromagnetic radiation required for biology and medicine to understanding the properties of the new states of matter, which exhibit the cooperative behavior of quantum-electrodynamics plasmas and fluids.

In parallel there will be a technology and experimental development and implementation part, which is strongly related to the theory/simulation part. The two are in fact interdependent and will lead to the first successful high-field experiments with a 10 PW laser system. The theory/simulation part will identify the first physics mechanism in the high-field regime to be studied by providing predictive simulations of the future experiment. The technology/experimental part will assure the feasibility of the proposed experiment by making available the laser configuration required and the focusing of the beam. In addition adequate diagnostic systems have to be developed and implemented in order to prove the success of the experiment.

ELI-Beamlines strategically needs and is actively developing a Theory Group having world leading scientific level, a group capable of producing results directly related to the actual ELI-BL scientific plans and helping formulating the plans for future work with next generation lasers. In view of this, the work of the theoretical group could be subdivided in two main parts. The first of these parts is connected with the primary tasks arising from the needs of the current moment and is carried out in close contact with laser and experimental teams. The second part of theoretical work is determined by the internal logic of the theory and is aimed at the formulation and solution of fundamentally novel problems orientated towards the future.



QED effects: $\chi_\gamma = \frac{E_{las}}{E_S} \frac{\hbar\omega_\gamma}{m_e c^2} \approx 0.03$ $\quad E_S = \frac{m_e c^2}{e\lambdabar_C} = \frac{m_e^2 c^3}{e\hbar}$

Extreme field limits in high intensity laser interaction with matter and vacuum

Not going into details, the related scientific problems, which are to be addressed, can be subdivided as it follows. The studies of hydrodynamic processes (they are related to the effects of the finite laser contrast, which lead to the formation of a plasma corona at the target surface, to the plasma dynamics in capillary discharges, and to the formation of plasma waveguides) are to be conducted theoretically and to be modeled with the dissipative magneto-hydrodynamic computer codes. The developing of the theory of the charged particle laser accelerators the simulating the electron and ion acceleration the particle-in-cell computer is used. Studying of nonlinear waves and low-frequency electromagnetic fields in relativistic plasmas (these are solitons, vortices, quasi-stationary magnetic field, terahertz radiation, etc.) as well as high harmonics generation, the compression and intensifying of electromagnetic pulses in the interaction of laser radiation with various targets is based on using theoretical physics methods and computer simulations. In the ultra-high laser intensity range, the effects of radiation friction and quantum physics, that change completely the scenario of the laser-matter interaction, will be addressed. Figure above schematically illustrate various regimes of the laser-matter interaction in the extreme high intensity limits. In particular, these effects being implemented in the experiments make it possible to create X-ray and gamma ray sources of the extremely high power and brightness. For their adequate modeling, specialized computer codes are required. Such codes can be obtained from aside organizations and/or developed at ELI-BL. The later would be highly desirable.

The second direction has the character of searching for new scientific problems and their solutions, expanding the range of present day ideas and allowing us to find novel realms of sciences. As in the first case, conducting the computer simulations only, not underestimating its importance is not enough to achieve success. Theorists are thus required to have a wider range of knowledge and a higher level of proficiency in theoretical physics than in the average. This is due to the fact that successful studies of the interaction of super-high-power laser radiation with matter require multi-disciplinary knowledge of the theory of nonlinear waves, of methods of charged particles acceleration, of relativistic electrodynamics of continuous media, and of quantum physics. The results of these studies are fundamentally important for the future of such projects as the ELI-BL. To carry them out, of course, we will use the experience achieved in the work on the problems of laser-matter interaction in a lower laser radiation intensity range, in the work on charged particle acceleration by standard accelerators, etc. In regard with these requirements, the experience in the field of relativistic astrophysics is important, since in astrophysical objects the presence of extremely strong electromagnetic fields and particles of ultra-high energy often turns out to be the rule, not an exception.

In the view of these, the creation and development of the ELI-BL computer center is crucial.

3.9.3. HiFI team scientific collaboration

Since no scientific group can succeed, being isolated from others within its organization (in our case it is ELI-BL) and from groups in other institutions at home and abroad, our theoretical group is open to cooperation with other scientific teams. Our group scientists are involved in collaboration with teams at ELI-BL, in Czech Republic and with scientific organizations abroad. Outside the ELI-BL, we work together with the experts from the Prague Technical University (A. Yancharek, O. Klimo, J. Pshikal). Russian scientists from the Institute of Applied Mathematics of the Russian Academy of Sciences in Moscow (V. Gasilov and co-workers) together with us perform computer simulations of hydrodynamic processes in laser plasma. In this collaborative project, W. Leemans' team from LBNL, USA participates. The LBNL group also contributes to the study of the effects of quantum electrodynamics in high field sciences. For many years we have been working together with N. Rozanov from IFTI in St. Petersburg on the problems of the theory of nonlinear waves and quantum physics. Our colleague for a long time, V. Bychenkov from the Physical Institute of the Russian Academy of Sciences in Moscow, is working with us on the problems of charged particle acceleration in laser plasmas. Recently, M. Marklund (he is one of the world leading scientists in the theory of quantum processes in laser plasma, Uppsala Uni., Sweden) joined us. It is worth mentioning the collaboration with the specialists from Italy and Japan. For many years we have been working with the scientific group of F. Pegoraro from the University of Pisa. With Japanese theoreticians and experimenters, we have constant contact with the KPSI-QST (T. Kawachi, K. Kondo, M. Kando, J. Koga, T. Esirkepov) and the University of Osaka (T. Hosokai, R. Kodama, A. Zhidkov, A. Yogo).

3.10. CHAMPP - Czech Hamburg Advanced Medical and Photonics Project

Related ELI-BL Activities: Research Programs 2, 3 & 4

3.10.1.Brief description of the project – abstract

This project supports the transformation of the ELI Beamlines facility into a Centre of Excellence in collaboration with the University of Hamburg (UHH) and DESY. It will enable ELI Beamlines to offer the next-generation of brilliant X-ray sources to science and industry. It will also develop the world's first laser-driven, ultra-compact Free- Electron Laser (FEL) and a laser-based medical imaging beamline for novel early tumour diagnostics and pharmacokinetics. The proposed upgrade will lead to a substantial extension of the foreseen experimental tools for the fulfilment of the ELI Beamlines research programs 2, 3 and 4. The new compact laser driven X-ray sources proposed within the CHAMP CoE will complement the existing ELI-Beamline sources and open new possibilities due to their largely increased brilliance (enabled by a plasma FEL), repetition rates and spectral range (medical beamline). It should be noted only recent technological progress such as in high repetition rate fs-laser technology and new approaches to laser accelerated electron bunch generation, namely the decompression schemes enabled the advancement of the development of such sources.

As a part of the original project the Laser driven X-ray source (LUX) is being developed in collaboration with UHH. As mentioned in the ELI White Book a compact FEL would greatly enhance the scientific and technological capabilities of ELI. In order to enable even further dissemination of the FEL laser technology, a significant development effort is needed on the driver laser development side, where the repetition rate and energy efficiency must be significantly increased and the overall system cost decreased. Hence part of the project is also dedicated to a development of the high repetition rate driver laser prototype (with the rate of 1-10 kHz and higher). The prototype itself will be powerful enough to drive the second photonic source within the project used for the medical imaging.

The overall approach towards achieving an outstanding sustainable Centre of Excellence is the following: the Phase 2 funds will be used to develop the laser driven FEL based on the current experience with the LUX beamline. With its anticipated X-ray parameters of 1011-1012 photons per shot in the keV range and a time duration of only a few fs the CHAMPP compact FEL will allow very sophisticated experimental investigations, for instance, single-shot coherent multidirectional diffractive imaging of non-reproducible samples (e.g. cells) as was proposed in the ELI white book. The success of the user operation of both photonic sources in the CoE requires a fully dedicated driver laser, which will also be procured from the Phase 2 funds.

The CHAMPP project is currently in Phase 2 of the H2020 Teaming call which aims to promote excellent scientific capabilities to boost innovation performance and economic development. The project will be funded through a combination of European and Czech sources.

Project duration: 2019-2024

Financial scope (projected)

Overall costs	47 mil. €
Investments costs	33 mil. €
Non - investment costs	15 mil. €

4. Worldwide Cooperation

From 2007 to 2010, more than 40 research institutions coming from 13 EU member States contributed to the ELI Preparatory Phase, with the objective of bringing the initial concept of ELI to a level of maturity allowing its implementation. ELI will offer unprecedented performance as soon as it begins operating in 2018-2019. But much of this technology was still imported from other parts of the world. Now, the teams that will install and operate these new tools will gain know-how, bringing Europe's technical knowledge - in labs and industry - to the forefront of technological competitiveness. To fully capitalise on this opportunity ELI will partner with labs across Europe and bring in new member states to combine knowledge in an open, innovation environment. This needs to be underpinned with an active technology transfer function that ensures these innovations are diffused not only in labs, but also to industry, again strengthening and diversifying competitiveness for Europe and regions.

Already now, more than 30 scientific agreements and cooperation frameworks have been concluded to fix the terms of such cooperation. In most cases, these contracts have the form of a special Memorandum of Understanding for a scientific and technological collaboration.

MoUs ELI-Beamlines

Institution	Country
Institut National de la Recherche Scientifique (INRS), Quebec, Canada	Canada
Shanghai Institute of Optics and Fine Mechanics (SIOM), Shanghai, Jiading, China	China
Faculty of Nuclear Sciences and Physical Engineering, Czech technical University in Prague, Czech Republic	Czech Republic
Masarykova univerzita, Ústav výpočetní techniky, Centrum CERIT-SC, Brno	Czech Republic
ELI-CZ Consortium	Czech Republic
Centre National de la Recherche Scientifique, Grenoble, France	France
EUROPEAN SYNCHROTRON RADIATION FACILITY, Grenoble, France	France
Pierre et Marie Curie University, Paris, France	France
The French National Center for Scientific Research (CNRS) & The French Alternative Energies and Atomic Energy Commission (CEA), Paris, France	France
The European Synchrotron Radiation Facility, Grenoble	France
Ludwig-Maximilians-Universität München, Department für Physik, Garching	Germany
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany	Germany
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany	Germany
Institute of Experimental Physics II, Leipzig University, Leipzig, Germany	Germany
Technische Universität Darmstadt (TUDA), Darmstadt, Germany	Germany
The Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany	Germany
Universität Hamburg, the Faculty of Mathematics, Informatics and Natural Sciences (MIN), Germany	Germany
Technische Universität Berlin	Germany
European XFEL	Germany
Extreme Light Infrastructure - Attosecond Light Pulse Source, Hungary	Hungary
Elettra-Sincrotrone Trieste S.C.p.A., Trieste, Italy	Italy
Laboratori Nazionali del Sud (LNS), of the Instituto Nazionale di Fisica Nucleare, Catania, Italy	Italy
Institute of Photonis and nanotechnology, INF	Italy

Section of Radiological Sciences of the Department of Biomedical Sciences and of Morphologic and Functional Imaging of the University of Messina, Italy	Italy
The Laboratori Nazionali del Sud (LNS), The National Institute for Nuclear Physics (INFN), Catania, Italy	Italy
Fondazione Famiglia Pintaura (FFP)	Italy
Institute for Materials Research, Tohoku University, Japan	Japan
The Institute for Solid State Physics, The University of Tokyo, Japan	Japan
Faculty of Engineering, Utsunomiya University	Japan
Japan Atomic Energy Agency (JAEA)	Japan
National Institute for Fusion Science (NIFS), National Institutes of Natural Sciences (NINS), Gifu	Japan
Center for Physical Sciences and Technology, FTMC, Vilnius, Lithuania	Lithuania
Institute of Physical Chemistry, Polish Academic Sciences, Warsaw, Poland	Poland
Institute of Plasma Physics and Laser Microfusion (IPPLM), Warsaw, Poland	Poland
Jan Kochanowski University in Kielce, Poland	Poland
Advanced Photonics Research Institute, APRI-GIST, Repulic of Korea	Republic of Korea
Korea Basic Science Institute (KBSI), Daejeon, Republic of Korea	Republic of Korea
Extreme Light Infrastructure- Nuclear Physics, Romania	Romania
Keldysh Institute of Applied Mathematics (KIAM), Moscow, Russia	Russia
National Research Nuclear University, Moscow, Rusko	Russia
Centro De Laseres Pulsados (CLPU), Salamanca,	Spain
Uppsala University	Sweden
The European Organization for Nuclear Research (CERN), Geneva, Switzerland	Switzerland
Strathclyde Intense Laser Interaction Studies Group of Strathclyde University (SILISSTRATH), Glasgow, UK	United Kingdom
The Queen´s University of Belfast, Belfast, UK	United Kingdom
University of Rochester (UR), Laboratory for Laser Energetics (LLE), Rochester, USA	USA

User Community

ELI is a natural development that builds on the success and growing integration of the European laser community. As a flagship infrastructure, ELI should, as a part of its mission, assume a leadership role, together with Laserlab Europe Consortium, in facilitating coordination and consistency in the efforts of the complementary actors of the laser community, in view of maximizing European impact and competitiveness.

ELI Beamlines shall offer unique instruments - 5 laser sources, 6 beamlines and 9 experimental stations with capacity reaching 300 user weeks a year for ca 1000 users annually. Although, a very solid user basis has been establish through various interactions incl. regular user workshops in the last years, a significant effort has to be made to address the ongoing challenge of the user capacity building in order to introduce ELI potential for new scientific communities.

University of Potsdam
Colorado State University
MBI
TU Wien Photonics
Rigaku
TUM

INFN LNS
LMU Ludwig-Maximilians-Universität München
cea
Proton Therapy Center
i3M Instituto de Instrumentación para Imagen Molecular
eli Nuclear Physics

eli attosecond
Imperial College London
Berkeley Lab
Técnico Lisboa
apri Advanced Photonics Research Institute
cnrs

Technische Universität Berlin
Uppsala Universitet
laboratoire d'optique appliquée
CFEL Science
Otto von Guericke Universität Magdeburg
New Mexico State University 1888

CEITEC Central European Institute of Technology
BIOCEV
University of Gothenburg
PAN Polish Academy of Sciences
UJK Uniwersytet Jana Kochanowskiego w Kielcach
Universität Leipzig

Fermilab
FLASH. Free-Electron Laser FLASH
ESRF The European Synchrotron
Jihočeská univerzita v Českých Budějovicích University of South Bohemia in České Budějovice
Chalmers University of Technology
VU Vrije Universiteit Amsterdam

大阪大学 Osaka University
European XFEL
université de Bordeaux
LAOLA
University of Strathclyde Glasgow
HZDR Helmholtz Zentrum Dresden Rossendorf

Queen's University Belfast
IFPiLM Instytut Fizyki Plazmy i Laserowej Mikrosyntezy
Weizmann Institute of Science
SIOM
GSI
ČVUT České vysoké učení technické v Praze

University of Oxford
Lund Laser Centre
DESY
Lund University
Friedrich-Schiller-Universität
Texas

Lawrence Livermore National Laboratory
MEPhI National Research Nuclear University
CELIA
CFEL Science
ČVUT Fakulta Biomedicínského Inženýrství
FJFI

University of Strathclyde Glasgow
Universität Hamburg
IFPiLM
CELIA
Science & Technology Facilities Council Rutherford Appleton Laboratory

5. Conclusion

ELI-BL in the European and Worldwide Laser-based Research Landscape

High intensity lasers are proposed to drive advanced short pulse optical, IR, x-ray and particle beams (secondary sources) beyond state of the art by controlling and extending the parameters of lasers and secondary sources concerning their intensities, stability, synchronization, quality, energy range and repetition rates. This allows performing new investigations spanning the range from fundamental to applied sciences and medicine, ultimately leading to a better understanding of nature and providing future societal benefits. The proposed upgrade of the existing facility will extend the scope of societal and fundamental applications and widen the potential user base, in particular from the industrial sector, while continuing to provide a unique research platform for the academic sector. ELI's worldwide competitiveness will increase considerable, making it the foremost user installation in the European landscape and at the same time positioning the Czech Republic at the forefront of photonic research.

The projected centre development is thus two-fold: enhancing the capabilities and versatility of the laser systems and subsequently use these improved lasers for new experimental possibilities. There is therefore a strong interconnectivity/interdependence of lasers and experimental applications. Improving the lasers leads directly to improving the endstations, beamlines and platforms of ELI-Beamlines.

The ELI-BL project is a unique endeavour in the field of photonic-based research worldwide and also the first large-scale user facility in this domain. By construction it will serve the academic research community as much as the applied research community, which is oriented towards industry, societal benefits and medicine and health sector. By its very nature, projects on the scale of ELI-BL are many years in the making. During this construction, installation and commissioning period new technological developments take place, which are of prime importance to the project especially in such unexplored field of physics. Any facility, which intends to remain state-of-the-art, has therefore to upgrade continuously, even before commissioning is over. In order to remain competitive ELI-BL has to innovate in parallel to construction and commissioning. ELI-BL cannot afford to be out-of-date the moment it opens its doors to the prospective user community. The present technological infrastructure is designed in such a way as to allow a very efficient and rapid upgrade within the existing building layout. Any upgrade will therefore be very cost-effective, as almost all expenditure goes directly into equipment destined for the users and only minimally into adjusting the building infrastructure.

The specific nature of the ELI-BL user facility is its multi-disciplinary features as far as its laser systems and corresponding usage is concerned. The planned upgrade will affect each of the dedicated experimental target areas in the infrastructure in a particular way. Nevertheless, the specific upgrades are not completely independent and have to be considered interconnected since both the laser development and the fundamental science new achievements will allow enhancing the features of the developed secondary radiation and particle sources, thus, as a consequence, the user capabilities at the end-stations.

The trend in laser-based research are sophisticated pump-probe experiments which require synchronized multiple laser beams. The scope of experimental possibilities is enhanced considerably by increasing the wavelengths available as well as variability of pulse lengths and number of beams.

The excellent research, which will become possible, will give consequently excellent scientific achievements. New paths of applied and fundamental research will be opened.

6. Annex No. 1 – ELI Beamlines Facility Start up Period Schedule

RP2 X-ray Sources - HHG Beamline

Stage	**Pre-commissioning** (Hardware and Basic Functionalities)	**Commissioning** (Laser-target Inter. & second. source)	**Enabling** (Initial User Experiments)	**Flagship** (Advanced User Experiments)
Scope	Acceptance of the delivery from the supplier in hall E3 at HiLASE Optimization of the source with the alignment laser	Installation of the HHG beamline in E1 (ELI BL) Optimized generation of a single beam from 120 nm down to 10 nm	Optimized generation of a single (double) HHG beam with single (double) driver beam from 120 nm down to 5 nm	Two color driving scheme option to enable more accessible wavelengths and various polarization states
Enabling technology	Basic supporting technologies: • Primary vacuum • cooling water (closed circuit with local chiller) • cleanroom ISO 7 tent Alignment laser (>5 mJ, <50 fs, 1 kHz)	All supporting technologies in E1 and beam transport for alignment laser	Alignment laser + L1 at PL3 (30 mJ, <20 fs)	single L1 beam with >60 mJ And possibility of having 2 beams of L1 laser (>30 mJ each)

Timeline

Pre-commissioning:

Activity	System	Timing (duration)
Installation of the supporting technologies		9-11/2016 (3 mons)
Installation of the HHG beamline		11/2016-1/2017 (3 mons)
Verification of the HHG beamline		1/2017-2/2017 (2 mons)
Optimization of the source		3/2017-5/2017 (3 mons)

Commissioning:

Activity	System	Timing (duration)
Installation of the HHG beamline		10-12/2017 (3 mons)
Optimization of the source		12-3/2018 (4 mons)

Enabling:

Activity	System	Timing (duration)
Optimization of the source with L1 laser		6-12/2018 (7 mons)
Upgrade of the diagnostics and DAQ systems		6-12/2018 (7 mons)
Regular user operation (with Astrella and later with L1)		4/2018 (unk.)

Flagship:

Activity	System	Timing (duration)
Optimization of the source (with two-color pumping)		1/2019-2020 (12 months)

RP2 X-ray Sources - Plasma X-ray source

<table>
<tr><th>Stage</th><th><u>Pre-commissioning</u>
(Hardware and Basic Functionalities)</th><th><u>Commissioning</u>
(Laser-target Inter. & second. source)</th><th><u>Enabling</u>
(Initial User Experiments)</th><th><u>Flagship</u>
(Advanced User Experiments)</th></tr>
<tr><td>Scope</td><td>Acceptance of the delivery from the supplier at PALS
Optimization of the source with the 10 Hz laser driver</td><td>Installation of the PXS in E1 (ELI BL)

Optimized generation in 3-20 keV (10.8 keV line)</td><td>Optimized generation in 3-80 keV (10.8 keV line)</td><td>Optimized generation in 3-80 keV (10.8 keV line)</td></tr>
<tr><td>Enabling technology</td><td>Basic supporting technologies and laser available at Ti:S laboratory at PALS</td><td>All supporting technologies in E1,
alignment laser
and beam transport for the alignment laser</td><td><u>Alignment laser + L1 at PL3 (>30 mJ, <20 fs)</u>
<u>Beamtransport for L1 laser</u></td><td><u>single L1 beam with >60 mJ</u></td></tr>
<tr><td>Timeline</td>
<td><table><tr><th>Activity</th><th>System</th><th>Timing (duration)</th></tr><tr><td>Installation of the source</td><td></td><td>5/2017
(1 mon)</td></tr><tr><td>Verification/acceptance</td><td></td><td>6/2017
(1 mon)</td></tr><tr><td>Optimization of the source</td><td></td><td>7/2017
(1 mon)</td></tr></table></td>
<td><table><tr><th>Activity</th><th>System</th><th>Timing (duration)</th></tr><tr><td>Installation of the PXS</td><td></td><td>12/2017
(1 mon)</td></tr><tr><td>Optimization of the source</td><td></td><td>1-4/2018
(4 mons)</td></tr></table></td>
<td><table><tr><th>Activity</th><th>System</th><th>Timing (duration)</th></tr><tr><td>Optimization of the source with L1 laser</td><td></td><td>6-12/2018
(7 mons)</td></tr><tr><td>Upgrade of the diagnostics and DAQ systems</td><td></td><td>6-12/2018
(7 mons)</td></tr><tr><td>Regular user operation (with Astrella and later with L1)</td><td></td><td>5/2018
(unk.)</td></tr></table></td>
<td><table><tr><th>Activity</th><th>System</th><th>Timing (duration)</th></tr><tr><td>Optimization of the source (with two-color pumping)</td><td></td><td>1/2019-2020
(12+ months)</td></tr></table></td>
</tr>
</table>

RP2 X-ray Sources - Betatron & Compton source

Stage	**Pre-commissioning** (Hardware and Basic Functionalities)	**Commissioning** (Laser-target Inter. & second. source)	**Enabling** (Initial User Experiments)	**Flagship** (Advanced User Experiments)
Scope	BETATRON Basic functions ("Electron Accelerator" and "X-ray photon source" hardware and vacuum chamber installed in E2 and E3): • Vacuum systems (Installation and tests in E2) • Electrical systems (Installation and tests in E2) • Control system - Manual + remote (installation and operation E2) • Targetry systems (Installation and alignment E2 and E3) • Diagnostic systems (Installation and alignment in E3) •	Plasma/electron/betatron generation on gas target with L3 in the vacuum chamber in E2 • Alignment of L3 (low power mode) on target (laser team) • Alignment of Electron/plasma/X-ray diagnostics • Focusing of L3 (high power mode) on target • Electron/plasma/X-ray characterization; long-term betatron beam stability tests	X-ray beam generation <20keV photon beam	**10-100 keV photon generation** 1. for pump probe probing WDM using XANES/EXAF technics with fs time resolution and µm spatial resolution in cooperation with plasma Physics, P3 chamber 2. for phase contrast imaging **100 keV – 200 keV later up to 1MeV photon generation, if science case is identified or users ask for it** 3. for pump probe probing WDM using XANES/EXAF technics with fs time resolution and µm spatial resolution 4. for phase contrast imaging of macroscopic materials 5. medical imaging above 100 keV, bandwidth control will be investigated

Enabling technology	• Central vacuum piping; ECU chambers
	  • Central hubs-to-service channels; service channels-to technologies
	• Electrical and network cables
	  • Betatron-to-racks; racks-to-control room
	• Software for remote control (control system)
	• Local alignment laser; optics and optomechanics
	  • including focusing optics in the ECU chambers
	• Target positioner and alignment system
	• Electron/plasma/X-ray diagnostics
	• Demineralized water
		• L3 BT systems in E2
		  • vacuum, optics, optomechanics
		• L3 laser alignment mode in E2
		• L3 laser in E2
		• L3 diagnostic systems in E2 (near/far field, wavefront, pulse duration)
		• Electron/plasma/X-ray real-time diagnostics
		  • remote controlled
			• L3, single shot, 100 TW-300TW ramping
			• Electron, plasma, X-ray diagnostics (10Hz)
				• L3 + L3 aux, 10 Hz, 1 PW
				• L3 aux with fs synchronization and spatial overlapping within radius of L3 focus

Timeline – Pre-commissioning

Activity	System	Timing (duration)
Installation and tests	Vacuum systems	3-7/2017 (4 months)
Installation and tests	Electrical systems	7-10/2017 (3 months)
Installation and operation	Manual + remote control system	1-3/2018 (3 months)
Installation and alignment	Targetry systems	4-5/2017 (1 month)
Installation and alignment	Diagnostic systems	5-6/2017 (1 month)

Timeline – Commissioning

Activity	System	Timing (duration)
Alignment of L3 (low power mode) on target	L3	7-8/2018 (1 month)
Alignment	Electron/plasma/X-ray diagnostics	8-9/2018 (1 month)
Focusing of L3 (high power mode) on target (single shot)	L3	9-10/2018 (2 months)
Electron/plasma/X-ray characterization;	X-rays	10-12/2019 (3 months)

Timeline – Enabling

Activity	System	Timing (duration)
Enabling exp. – stage 1		
Generation of stable electron beam	Plasma Accelerator	1-3/2019 (3 months)
Enabling exp. – stage 2		
Betatron photon beam	Plasma Accelerator + Betatron	3-10/2019 (8 months)

Timeline – Flagship

Activity	System	Timing (duration)
Flagship exp. – stage 1		
Generation of tunable photon beam	Plasma Accelerator + Compton	9-12/2019 (3 months)
Flagship exp. – stage 2		
Pump probe experiments	Compton	1-7/2019 (7 months)

RP2 X-ray Sources – Laser Driven Undulator X-ray source

Stage	**Pre-commissioning** (Hardware and Basic Functionalities)	**Commissioning** (Laser-target Inter. & second. source)	**Enabling** (Initial User Experiments)	**Flagship** (Advanced User Experiments)
Scope	Pre-commissioning at DESY finished. The current plan counts on further developments of LUX towards higher photon counts per bunch and towards FEL at DESY and installation of LUX or upgraded LUX at ELI by the end of 2018 or in 2019.	First electrons with 400 MeV energy accelerated with LUX and 200 TW laser system at DESY in June 2016. The energy of electrons is sufficient to reach water window region with photons. The LUX beamline setup for the first photons to be finalized by December 2016 or January 2017.	First pump and probe and first user experiments will take place in 2017 at DESY. Preparations on-going with the first user group (L. Juha et al.).	Upgrade to soft X-ray Free Electron Laser in collaboration with University of Hamburg and DESY. FEL demonstration experiment preparation in progress.
Enabling technology				• Required laser system with **pointing** stability RMS on OAP < **200 nrad (nanorad)** • Required laser system peak power: 200 – 400 TW • Required three (or more) cryogenic undulators

Timeline

Pre-commissioning:

Activity	**System**	**Timing (duration)**
Installation and commissioning	LUX components target to X-ray spectrometer	until 12/2016 to 1/2017
First photons	Depends on new laser gratings availability	1-4/2017

Commissioning:

Activity	**System**	**Timing (duration)**
Experiments - reaching nominal X-ray beam values	Complete LUX beamline	1-8/2017
Installation and commissioning	Auxiliary beams and synchronization	3-8/2017
Pump and probe experiments	Complete LUX beamline with auxiliary beams	8-10/2017

Enabling:

Activity	**System**	**Timing (duration)**
User experiment preparation	X-ray optics, user chamber and detectors, sample preparation and characteristics, simulations	10-12/2017
First user experiment	Complete LUX with X-ray optics and user chamber	1-3/2018

Flagship:

Activity	**System**	**Timing (duration)**
FEL demonstrator experiment	LUX with upgraded electron beam optics and new undulator (property of UHH, not part of LUX contract)	estimated 4/2017- 3/2018

RP3 Particle Acceleration – ELIMAIA ion accelerator

Stage	Pre-commissioning (Hardware and Basic Functionalities)	Commissioning (Laser-target Inter. & second. source)	Enabling (Initial User Experiments)	Flagship (Advanced User Experiments)
Scope	ELIMAIA Basic functions (“Ion Accelerator” and “ELIMED” hardware and main instrumentation installed in E4): • Vacuum systems (Installation and tests) • Electrical systems (Installation and tests) • Control system - Manual + remote (installation and operation) • Targetry systems (Installation and alignment) • Diagnostic systems (Installation and alignment) • ELIMED beam transport and dosimetry line (Installation and tests)	Plasma/Ion generation on solid targets (μm-thick) with L3 in the ELIMAIA chamber • Alignment of L3 (low power mode) on target (laser team) • Alignment of ion/plasma diagnostics • Focusing of L3 (high power mode) on target • Plasma/Ion characterization; long-term ion beam stability tests	Enabling exp. – stage 1 (“Ion Accelerator”): Generation and detection of protons in the ELIMAIA target chamber using various targets. • 10-30 MeV protons • ±50% energy spread • 10^{9}-10^{10} protons/pulse (10% BW) Enabling exp. – stage 2 (“Ion Accelerator + ELIMED”): • Dose delivery to sample; long-term dose delivery stability tests	Flagship exp. – stage 1 (“Ion Accelerator + ELIMED”): • Delivery of “online” tunable dose on biological samples (in vitro and in vivo) of interest in medical research, possibly combining treatment and diagnostics (XUV) Flagship exp. – stage 2 (“Ion Accelerator”): Generation and detection of record energy protons in the ELIMAIA target chamber using advanced targets. • 60-250 MeV protons • ±5% energy spread • 10^{9}-10^{11} protons/pulse (10% BW)

Enabling technology	• Central vacuum piping; ECU chambers
	  • Central hubs-to-service channels; service channels-to technologies
	• Electrical and network cables
	  • ELIMAIA-to-racks; racks-to-control room
	• Software for remote control (control system)
	• Local alignment laser; optics and optomechanics
	  • including focusing optics in the ECU chambers
	• Target positioner and alignment system
	• Ion/plasma diagnostics
	• ELIMED beam transport and dosimetry line
	• Demineralized water
		• L3 BT systems in E4
		  • vacuum, optics, optomechanics
		• L3 laser alignment mode in E4
		• L3 laser in E4
		  • 50, 100, 200, 300 TW, 5μrad, single shot
		• L3 diagnostic systems in E4 (near/far field, wavefront, pulse duration)
		• Ion/plasma real-time diagnostics
		  • remote controlled
			• L3 laser (~1PW, 5μrad, 0.01-0.1 Hz)
			• Ion beam transport systems
			• Ion beam dosimetry and sample irradiation (user station)
				• L3 laser (~1PW, 2μrad, 1-10 Hz)
				• L4 (≥PW, 5μrad, single shot)
				• sub-μm-thick foils and cryogenic targets.

Timeline

Pre-commissioning:

Activity	System	Timing (duration)
Installation and tests	Vacuum systems	8-12/2017 (4 months)
Installation and tests	Electrical systems	11/2017-2/2018 (3 months)
Installation and operation	Manual + remote control system	1-3/2018 (3 months)
Installation and alignment	Targetry systems	3-4/2018 (1 month)
Installation and alignment	Diagnostic systems	4-5/2017 (1 month)
Installation and functional tests	ELIMED beam transport and dosimetry line	5-6/2017 (2 months)

Commissioning:

Activity	System	Timing (duration)
Alignment of L3 (low power mode) on target	L3	6-7/2018 (1 month)
Alignment	ion/plasma diagnostics	7-8/2018 (1 month)
Alignment	ELIMED ion/plasma diagnostics	8-9/2018 (1 month)
Focusing of L3 (high power mode) on target (single shot)	L3	9-10/2018 (2 months)
Plasma/Ion characterization; long-term ion beam stability tests	Ion beam	10/2018-2/2019 (4 months)

Enabling:

Activity	System	Timing (duration)
Enabling exp. – stage 1		
Generation and detection of protons in the ELIMAIA target chamber using various targets	Ion Accelerator	12/2018 - 2/2019 (3 months)
Enabling exp. – stage 2		
Dose delivery to sample; long-term dose delivery stability tests	Ion Accelerator + ELIMED	2-10/2019 (8 months)

Flagship:

Activity	System	Timing (duration)
Flagship exp. – stage 1		
Delivery of “online” tunable dose on biological samples (in vitro and in vivo) of interest in medical research, possibly combining treatment and diagnostics (XUV)	Ion Accelerator + ELIMED	3/2019-9/2019 (6 months)
Flagship exp. – stage 2		
Generation and detection of record (60-250 MeV protons) energy protons in the ELIMAIA target chamber using advanced targets and L3/L4.	Ion Accelerator	9-12/2019 (3 months)

RP3 Particle Acceleration - HELL platform

Stage	**Pre-commissioning** (Hardware and Basic Functionalities)	**Commissioning** (Laser-target Inter. & second. source)	**Enabling** (Initial User Experiments)	**Flagship** (Advanced User Experiments)
Scope	HELL Basic functions ("Electron Accelerator" and "End-Station" hardware and main instrumentation installed in E5): • Vacuum systems (Installation and tests) • Electrical systems (Installation and tests) • Control system - Manual + remote (installation and operation) • Targetry systems (Installation and alignment) • Diagnostic systems (Installation and alignment) • EndStation (Installation and tests)	Plasma/Electron generation on gas targets with L3 in the HELL chamber • Alignment of L3 (low power mode) on target • Alignment of electron/plasma diagnostics • Focusing of L3 (high power mode) on target • Plasma/Electron characterization; long-term electron beam stability tests	Enabling exp. – stage 1 ("Electron Accelerator"): Generation and detection of electrons in the HELL main chamber using various targets in NOT guided regime. • 100 MeV-1GeV electrons • 5% energy spread • 1-100pC bunch/shot Enabling exp. – stage 2 ("Electron Accelerator + EndStation"): • Electron bunch delivery to sample; long-term dose delivery stability tests • 1-20 MeV, 100pC-10nC.	Flagship exp. – stage 1 ("Electron Accelerator + EndStation"): Generation and detection of electrons in the HELL main chamber using various targets ALSO in guided regime. • 1-5GeV • 10% energy spread, • 1-10 pC, • 250 MeV into the EndStation Flagship exp. – stage 2 ("Counter-propagation"): (*IF FUNDED*) Acceleration in guided regime and 10^{20}W/cm^2 additional laser beam for counter-propagation experiments with L3 only. • 1-5GeV • 0.5-1% energy spread • 0.1-10pC

Enabling technology	• Central vacuum piping; ECU chambers
	  • Central hubs-to-service channels; service channels-to technologies
	• Electrical and network cables
	  • HELL-to-racks; racks-to-control room
	• Software for remote control (control system)
	• Local alignment laser; optics and optomechanics
	  • including focusing optics in the ECU chambers
	• Target positioner and alignment system
	• Electron/plasma diagnostics
	• Pure gases (N, He, others)
		• L3 BT systems in E5
		  • vacuum, optics, optomechanics
		• L3 laser alignment mode in E5
		• L3 laser in E5
		  • 10-50, 100, 200, 300 TW, 5μrad, single shot
		• L3 diagnostic systems in E5 (near/far field, wavefront, pulse duration)
		• Electron/plasma real-time diagnostics
		  • remote controlled
			• L3 laser (~1PW, 5μrad, single-shot / 10Hz)
			• Electron beam transport systems
			• Electron beam sample irradiation (user station)
				• L3 laser (~1PW, 2μrad, 1-10 Hz)
				• L4 (≥PW, 5μrad, single shot)

Timeline

Pre-commissioning:

Activity	System	Timing (duration)
Installation and tests	Vacuum systems	10/2017-2/2018 (4 months)
Installation and tests	Electrical systems	11/2017-2/2018 (3 months)
Installation and operation	Manual + remote control system	1-4/2018 (3 months)
Installation and alignment	Targetry systems	5-6/2017 (1 month)
Installation and alignment	Diagnostic systems	6-7/2017 (1 month)
Installation and functional tests	HELL beam transport and focal optimizations	10-12/2018 (2 months)

Commissioning:

Activity	System	Timing (duration)
Alignment of L3 (low power mode) on target	L3	10-11/2018 (1 month)
Alignment	Electron/ plasma diagnostics	11-12/2018 (1 month)
Alignment	EndStation diagnostics	11-12/2018 (1 month)
Focusing of L3 (high power mode) on target (single shot/10Hz)	L3	1-2/2019 (2 months)
Plasma/Electron characterization; long-term electron beam stability tests	Electron beam	3-7/2019 (4 months)

Enabling:

Activity	System	Timing (duration)
Enabling exp. – stage 1		
Generation and detection of electrons in the HELL target chamber using various targets	Electron Accelerator	8-11/2019 (3 months)
Enabling exp. – stage 2		
Electron delivery to sample; long-term dose delivery stability tests	Electron Accelerator + EndStation	11/2019-6/2020 (8 months)

Flagship:

Activity	System	Timing (duration)
Flagship exp. – stage 1		
Delivery of "online" tunable electron bunches on samples	Electron Accelerator + End Station	3/2020-9/2020 (6 months)
Flagship exp. – stage 2		
Generation and detection of record (multi-GeV) energy electrons with optimized energy spread and pointing stability for the use in a counter-propagation experiments with an high intensity laser pulse (L3 split). *IF FOUNDED*	Electron Accelerator + counter-propagation setup	9/2020-3/2021 (6 months)

RP4 Applications in Molecular Bio-medical and Material science

Stage	**Pre-commissioning** (Hardware and Basic Functionalities)	**Commissioning** (Laser-target Inter. & second. source)	**Enabling** (Initial User Experiments)	**Flagship** (Advanced User Experiments)
Scope	ELIps: Installation and pump down (UHV) in S1. Either near the Astrella laser or at the HHG beamline 2. • ELIps operational, including cryostat, magnetic field head and auxiliary light source (Installation and tests) X-ray diffraction: Installation of X-ray diffraction equipment on the PXS optical table in S1. • Diffractometer with Eiger detector operational using the conventional X-ray source included in the diffractometer (Installation and tests) Optical spectroscopy: Installation of initial pump beam and optical spectrocopy capabilities (SRS station) in S1. • SHG and THG operational (Installation and tests) • OPAs and DFGs operational (Installation and tests) • UV to IR detection systems operational (Installation and tests) • Optomechanics operational (Installation and tests)	ELIps commissioning experiment; Instrument throughput in the NIR to UV range at 60°, and 75° angles . *In situ* characterization of all optical elements in the VUV range (around 20 eV). • Establish that all mechanical and optical elements work and are characterized in their respective operational ranges. X-ray diffraction commissioning experiment: Absolute scattering intensity calibration and sample-detector distance calibration using glassy carbon and silver behenate (or other standards). • Verify function of the X-ray diffraction systems with the pulsed PXS. • Verify the operational function of the radiation safety hutch. Optical spectroscopy: I) Transient absorption of carotenoid-phthalocyanine dyad, Pump: 400 nm (2^{nd} harm), Probe: Visible continuum. • Integration between pre-commissioning items • Timing/trigger with Astrella	ELIps: I) Time-resolved ellipsometry experiments in the ELIps instrument with pump and probe in the UV to NIR range. One suitable target is Ge (others are: GaAs, ZnO and GaN). II) Time-resolved VUV reflectivity on test sample (one potential candidate is monoclinic β-Ga_2O_3). • Verify timing/trigger with Astrella • Verify function of VUV spectrometer and Andor camera X-ray diffraction: Metal/Dielectric oxide superlattices, e.g. LSMO/STO superlattices and a double layer of these materials. • Verify timing/trigger with Astrella • Establish function of X-ray cryostat • Find spatio-temporal overlap at low and high temperatures Optical spectroscopy: Femtosecond Stimulated Raman Scattering (FSRS) on photoactive proteins in a large temporal window (fs - ms) • Establish necessary sample handling at the SRS station • Establish initial distribution of pump beams to X-ray end staions	ELIps: I) VUV Time-resolved ellipsometry experiments on GaN (pump: visible, probe: VUV). II) Charge dynamics in complex oxides and heterostructures (e.g. $LaAlO_3/SrTiO_3$) • Prove unique/state-of-the-art capabilities X-ray diffraction: I) THz pump X-ray diffraction probe on e.g. Lysosyme (or other suitable protein crystal). II) Study of lattice effects of charge transfer processes in complex materials. • Prove unique/state-of-the-art capabilities Optical spectroscopy: I) FSRS on DNA or RNA samples studying early events of DNA photo-damage II) Implementation of 2D spectroscopy • Prove unique/state-of-the-art capabilities
Enabling technology	• Electrical and network systems to Astrella, ELIps, X-ray diffraction and optical spectroscopy locations (Installation and tests) • Astrella laser up and running (Installation and tests) • Local trigger from Astrella laser to ELIps, X-ray diffraction and optical spectroscopy locations (Installation and tests) • Local laser safety around Astrella and the SRS station (Installation and tests) • Central roughing/backing vacuum to ELIps location (Installation and tests) • Central DAQ at ELIps and Diffraction stations (Installation and tests) • Central cooling water to ELIps and diffraction station (Installation and tests) • Radiation safety hutch in place at diffraction station (Installation and tests)	• HHG source available, driven by Astrella (Installation and tests) • PXS source available, driven by Astrella (Installation and tests) • Initial beam transport system available with capacity to switch the Astrella beam between end stations. (Installation and tests) • Vacuum control system for beam transport, HHG, PXS and ELIps (incl. safety and interlock),	• Cryostat for material science samples (Installation and commissioning) • Initial beam distribution system for pump beams from SRS table to X-ray end stations (Installation and commissioning)	• L1 available for PXS and HHG as well as at the SRS table. • BT system with full flexibility, switching L1 between end stations and switching between L1 and Astrella. • Full implementation of pump beam capabilities (including beam transport for all generated pulses). Specifically including THz and ultrashort pulses. (Installation and tests) • High energy (HE) OPA (commissioning) • ELIps sample load lock system (commissioning) • VUV monochromator (commissioning) • Integration between local and central control and DAQ systems.

Timeline

Pre-commissioning:

Activity	System	Timing (duration)
Installation and tests	Vacuum systems	3-7/2017 (4 months)
Installation and tests	Electrical systems	3-6/2017 (3 months)
Installation and operation	Manual + remote control system	3-12/2017 (9 months)
Installations and tests	ELIps instrument	3-6.2017 (3 months)
Installations and tests	Diffractometer	5-7.2017 (2 months)
Installations and tests	Pulse conversion and optical spectroscopy instruments	3-7.2017 (4 months)

Commissioning:

Activity	System	Timing (duration)
Commissioning	ELIps	1-4/2018 (4 months)
Commissioning	X-ray diffraction station	1-3/2017 (3 months)
Installations, tests and commissioning	X-ray optics	1-3/2018 (3 months)
Commissioning	Optical spectroscopy and pump beams	1-3/2018 (3 months)

Enabling:

Activity	System	Timing (duration)
Commissioning	Beam transport of pump beams	01-04/2018 (3 months)
Commissioning	Diffraction cryostat	01-04/2018 (3 months)
Enabling experiment	ELIps	03-08/2018 (5 months)
Enabling experiment	X-ray diffraction	04-10/2018 (5 months)
Enabling experiment	Optical spectroscopy	04-10/2018 (5 months)

Flagship:

Activity	System	Timing (duration)
Commissioning	Remaining pump beam devices	10-12/2018 (3 months)
Commissioning	VUV monochromator	10-12.2018 (3 months)
Commissioning	Permanent pump beam transport	05-11.2018 (6 months)
Flagship experiments	ELIps, X-ray diffraction, optical spectroscopy	10/2018-5/2019 (8 months)

RP5 Plasma Physics

Stage	**Pre-commissioning** (Hardware and Basic Functionalities)	**Commissioning** (Laser-target Inter. & second. source)	**Enabling** (Initial User Experiments)	**Flagship** (Advanced User Experiments)
Scope	P3 Basic functions: Plasma physics platform for high intensity, warm dense matter and laser plasma experiments. Hardware and main instrumentation installed in E4: • Vacuum systems (Installation and tests) • Electrical systems (Installation and tests) • Control system - Manual + remote (installation and operation) • Experimental Diagnostic systems - (Tests on other facilities) • SAFETY – Basic vacuum interlocks	Plasma generation on solid targets with L3/L4 in the P3 chamber • Alignment of L3/L4 (low power mode) on target (laser team) • Implementation of elementary plasma diagnostics (interferometry, pyrometry, particle diagnostics) • Focusing of L3/L4 (high power mode) on target • Secondary source characterization; protons, electrons, K-alpha • Targetry systems (Installation and alignment)	Enabling exp.: • TNSA protons for laser contrast estimation • Experiments for commissioning advanced diagnostics for e.g., gamma ray detectors, VISAR, etc. • HHG measurements for pre-pulse characterization	Flagship exp.: • Splitting L3: betatron source (x-rays, electrons) + proton heating • L4f on thin solid targets for gamma-ray generation • Multiple beam operation: Shock generation (L4n) + backlighter (L4f, L4p)

Enabling technology	• Central vacuum piping; P3 chambers
	  • Cable trays, EMP shielded racks
	• Electrical and network cables
	  • P3-to-racks; racks-to-control room
	• Software for remote control (control system)
	• on/plasma diagnostics
	• Demineralized water
		• L3/L4 BT systems in E3
		  • vacuum, optics, optomechanics
		• L3/L4 laser alignment mode in E3
		• L3/L4 laser in E3
		• L3/L4 diagnostic systems in E3 (near/far field, wavefront, pulse duration)
		• Local alignment laser; optics and optomechanics
		  • including focusing optics
		• Target positioner and alignment system
			• L3 laser (~1PW, 5?rad, 0.01-0.1 Hz)
			• L4 laser (~10PW, single shot)
			• Probe beam (possibly L2 pump)
				• L3 laser (~1PW, 5?rad, 1-10 Hz)
				• L4 (10 PW, 5?rad, single shot)

Timeline – Pre-commissioning

Activity	System	Timing (duration)
Installation and tests	Vacuum systems	8-12/2017 (4 months)
Installation and tests	Electrical systems	11-12/2017 (2 months)
Installation and operation	Manual + remote control system	1-2/2018 (2 months)

Timeline – Commissioning

Activity	System	Timing (duration)
Alignment of L3 (low power mode) on target	L3	6-7/2018 (1 month)
Focusing of L3 (high power mode) on target (single shot)	L3	7-8/2018 (2 months)
Alignment of L4 (low power mode) on target	L4	3-4/2019 (1 month)
Focusing of L4 (high power mode) on target (single shot)	L4	5/2019 (1 month)

Timeline – Enabling

Activity	System	Timing (duration)
Plasma/secondary source characterization;	P3	12/2018, 3/2019 (4 months)
TNSA	L3/L4	3-5/2019 (2 months)
Commissioning diagnostics	L3/L4	5-8/2019 (4 months)
HHG	L3/L4	9-10/2019 (2 months)

Timeline – Flagship

Activity	System	Timing (duration)
Flagship exp.		
Betatron	L3/L4	11-12/2019 (2 months)
Gamma ray flash	L4	1-2/2020 (2 months)
Multiple beam experiments	L3/L4	3-4/2020 (2 months)

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