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ELI, a concise project description

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ELI, a concise project description

Extreme-Light-Infrastructure (ELI) aims at investigating a large variety of scientific applications using a new generation of cutting-edge lasers generating ultra-intense and ultra-short pulses. As the world's first truly international laser research infrastructure on a trans-national scale, ELI has the objective of providing top quality access to a large community of international researchers and industrial users involved, among others, in life sciences, material sciences, nanotechnologies, nuclear physics, medicine, etc.

Initiated in 2005, ELI will be an international research infrastructure that will use new and emerging laser technologies to generate the most intense light pulses in the world. Fully open to external users, it will be dedicated to the fundamental study and societal applications of laser-matter interaction in a new and unsurpassed regime of laser intensity: the ultra-relativistic regime with intensities that are 100 to 1,000 times greater than the values achieved at present (ultimately exceeding 10^{23} W/cm^2). The European Strategy Forum on Research Infrastructures (ESFRI) formally recognized the exceptional ambition and pan-European dimension of the project by including ELI within its Roadmap of 44 large-scale infrastructure projects of high priority for Europe.

The scientific scope of the project consists of four main branches of research and applications:

- Attosecond Laser Science located in Hungary (ELI Attosecond Laser Pulse Source Facility): temporal investigation of electron dynamics in atoms, molecules, plasmas and solids at attosecond scale (10^{-18} sec., i.e. a billionth of billionth of a second)
- High Energy Beam Science located in the Czech Republic (ELI Beamlines Facility): development and usage of dedicated beam lines with ultra short pulses of high energy radiation to become a source of short pulse X-rays, accelerated electrons, or protons for applications
- Laser-Induced Photonuclear Physics located in Romania (ELI Nuclear Physics Facility): nuclear physics methods to study laser-target interactions, new nuclear spectroscopy, new photonuclear physics, etc.
- Ultra High Field Science (location to be defined): investigation of laser-matter interaction in unprecedented laser field strength.

ELI, as a pan-European project, addresses each of the three major goals of the **ERA**, as defined in 2000:

- ELI represents a historical development for the European Research Area by being the first large-scale research infrastructure to be located in new Member States. Thus, it will contribute to a better balance in the distribution of world-class facilities in Europe and promote mobility of researchers instead of brain drain. By benefiting from the network of laser research institutions of the ELI Preparatory Phase and from the successful experience of the Laserlab Europe Consortium, ELI will foster interactions between researchers
- ELI will contribute to the progress of worldwide knowledge. It will favour significant scientific and technological improvements in the field of laser science and beyond at international level and will increase the use of intellectual potential throughout Europe through their dissemination. Finally, ELI will deliver results that will effectively benefit society and the business sector through applications in medicine, material sciences, biochemistry, etc.
- ELI represents a technological and human resources challenge that requires strong coordination at European level. Prototyping efforts needed for ELI are currently under progress in several countries and a joint HR development strategy is being discussed within ELI in collaboration with the Laserlab Europe Consortium. In addition, the distributed implementation of ELI represents an unprecedented experience of “pooling” structural funds in the field of research infrastructures.

ELI Beamlines Facility

In the **Czech Republic**, ELI is expected to deliver significant benefits in the field of research and development. With a projected workforce of more than 250 employees, the ELI Beamlines facility will generate high-level long-term career opportunities for researchers, engineers and technicians involved in optics and laser science, in electronics, in mechanical engineering, material sciences, etc. 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. Through the ELI-CZ consortium of 14 research and academic institutions interested in ELI, the project will promote networking between research actors in the country by means of joint technological programs or training initiatives. Strong connections to other research infrastructures, especially in the field of life sciences, material sciences and data computing are also envisioned.

ELI builds simultaneously on several of the "National priorities of applied research, development and innovation 2009-2011" (previously "long-term main directions of research"), especially with respect to the priorities in material research, molecular biology and energy resources. In addition, it builds on several of the objectives of the National, Policy Research, Development and Innovation for 2009-2015, in particular by promoting the involvement of the Czech Republic in international cooperation, by providing high quality human resources for R&D and by creating and stimulating the environment for R&D in the country.

The ELI-Beamlines mission, while being itself a unique technology endeavor, is to provide ultra-short-pulse sources of energetic particles and radiation for fundamental research and for multidisciplinary applications. The laser resources available at this facility will make it possible for example generation of monochromatic and broadband X-ray sources with photon energy of up to few MeV, acceleration of electrons to few GeV at 10 Hz rep-rate and to probably several tens of GeV at low rep-rate, acceleration of protons to multiple-100-MeV energy at both 10 Hz and low rep-rate, pump-probe experiments with dense plasma, Warm Dense Matter (WDM) and laboratory astrophysics, high-field physics and QED experiments at 10^{23}-10^{24} Wcm^{-2}, and others.

The ELI-Beamline facility has been designed to feature versatility and conceptual simplicity, as well as possibility of staging and future upgrades of the laser, beam delivery and interaction systems. The facility design was produced on the basis of requirements identified by system engineering of the laser systems and of vacuum pulse distribution, and on the basis of detailed analysis of radioprotection, taking into account baseline secondary sources assumed to be generated at the facility. The facility layout had been adapted and re-iterated several times since early 2010 with respect to vibration minimization, integration of air conditioning and vacuum systems, integration of floor and wall penetrations for laser beams, accommodation of specific wall and floor thicknesses to provide required bulk radiation shielding, with respect to personnel and material circulation, and also in regard to detailed value engineering. Currently the infrastructure is in a starting phase of the detailed building design, which is expected to be completed by the end of 2011. The construction works are scheduled to start in spring 2012 implying the completed building available for installation of the laser equipment in late spring 2014.

The ELI-Beamlines project is based on integration of well identified laser solutions supplied by world-leading laser developers and suppliers. The project has decided to focus its own development efforts on only several specific subsystems, namely the front end, pulse distribution system, high-energy broadband OPCPA amplifiers, and pulse compressors.

The designed layout of the laser system of the ELI-Beamlines facility is represented in Figure 1. The common part of the system is a central oscillator and front end section providing a set of synchronized seed pulses to the individual beamlines. Some beamlines will also be equipped with their own front end and will be able to run independently if needed. The current design of the front end employs White Light generation driven by a carrier-envelope phase stabilized master Ti:sapphire oscillator followed by a regenerative amplifier. The spectrally broadened pulses are split and further amplified by an array of OPCPA (or, alternatively, Ti:sapphire) preamplifiers running at 1 kHz. The system will involve a pulse contrast enhancement device (XPW or plasma mirror) as well as phase shaping. The output mJ pulses, wavelength matching the broadband amplifiers of the individual beamlines (800 nm, 900 nm, and 1060 nm), will be appropriately delayed and delivered as seed pulses into respective broadband amplifiers. The front end will further provide seed pulses for the high-energy pump lasers in the individual beamlines (1030 or 1060 nm); the current design features Yb:fiber lasers with <100 fs pulse-to-pulse jitter which provides sufficient timing precision of the nanosecond as well as picosecond pump pulses. Alternatively, the seed pulses for the pump lasers may be obtained by soliton frequency shift of pulses of the master oscillator in a fiber.

The laser system involves two high-repetition-rate kHz beamlines employing the technique of Petawatt Field Synthesizer (PFS), currently prototyped at MPQ Garching. This technique exploits picosecond-pumped OPCPA, presenting several advantages (high contrast, very large bandwidth, high gain, easier pulse compression) over its "conventional" nanosecond counterpart. The OPCPA amplifiers are pumped by kHz picosecond pulses obtained from a compact kW pump lasers using commercially available thin-disc heads. Upon compression using chirped mirrors, each of the kHz beamlines will provide about 200 mJ ultrashort pulses.

The 10-Hz repetition rate beamlines providing PW-class pulses (10 to 15 J) will consist of diode-pumped multislab lasers pumping Ti:sapphire and OPCPA broadband amplifiers. The facility is designed to accommodate beamlines using both demonstrated multislab pump lasers (here with Nd:glass as active medium) operating at room-temperature and the currently developed cryogenic Yb:YAG lasers. The broadband amplifiers in the first case will be based of Ti:sapphire using high speed helium gas cooling technique developed for the multislab laser, enabling stable 10 Hz operation. In the second case three-stage OPCPA amplification scheme using LBO and DKDP crystals has been designed, assuming <3 ns flat-top temporal profile of the pumping pulse; by virtue of the OPCPA technique no cooling of the DKDP crystals is needed.

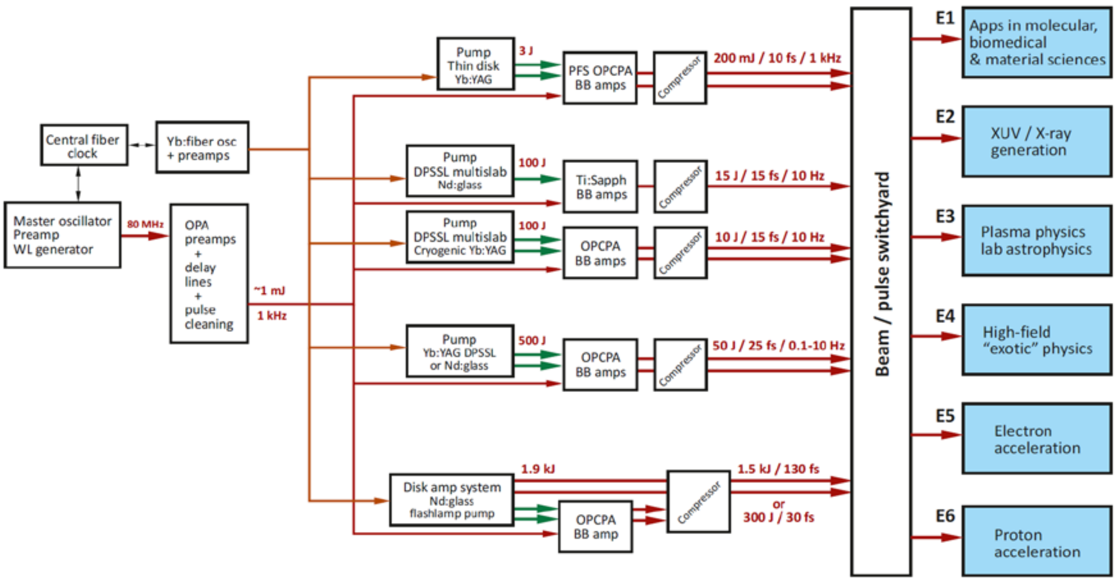

Figure 1. Schematic layout of the laser system (as given in the ELI White Book, G.A.Mourou, G.Korn, W.Sandner, J.L.Collier, editors, CNRS 2011). The front end produces mutually synchronized and properly time-delayed pulses which are seeded into the individual beamlines; some beamlines will have their own front end (not-represented here) making it possible to operate independently. The system will provide kHz, 10-Hz, and low-rep-rate (<0.1 Hz) pulses with respectively multiple-10-TW, 1-2 PW and 10-PW peak power. The vacuum pulse distribution and switchyard system will serve to deliver image-relayed pulses into six experimental areas.

The other two beamlines in the system will provide ultrashort pulses with energy of about 50 J, corresponding to approximately 2 PW peak power. Ideally these beamlines should provide 10 Hz repetition rate, which would require multislab pump lasers delivering 300-500 J at the fundamental wavelength; the building is designed to fully accommodate these systems operating either at room or cryogenic temperature. While intense effort exists in designing lasers with this energy, it is currently not possible to include into the delivery plan availability of these systems before 2015. The situation will be re-iterated periodically and decision on the pump systems for these beamlines will be made later. The fallback solution is stacked 0.1 Hz flashlamp Nd:YAG pump laser technology available nowadays commercially.

As seen from Figure 1, the designed laser system finally involves two 10-PW beamlines. Amongst the options available, technology of mixed Nd:glass capable to deliver CPA pulses with bandwidth >13 nm, compressible to 130 fs, appears as the most straightforward approach. This system will employ small OPCPA amplifiers on the front end, followed by final Nd:glass slab amplifiers, both representing a proven technology. This solution, designed to provide >1.5 kJ pulses, is perfectly suitable for the ELI-Beamlines mission in generation of accelerated electrons where pulses >100 fs are required for acceleration to energies >10 GeV. The kJ energy available is also ideal for generation of plasmas for laboratory astrophysics, another mission of the ELI-Beamlines facility. Finally, this approach allows staged addition of broadband high-intensity amplifiers converting the CPA 10-PW kJ pulses into 10-30 fs 10-PW pulses via OPCPA, Ti:sapphire, or by using alternative non-linear techniques.

The pulse distribution and switchyard system will deliver the pulses into six experimental areas. Various combinations of pulses will be available in these areas, each dedicated to a characteristic class of experiments. While the high-average-power kHz pulses and high-energy repetition-rate PW pulses will be available in all areas, availability of the 10-PW pulses will be limited to the high-field physics area and two areas dedicated for particle acceleration. The pulse distribution is designed to employ an array of reflection telescopes providing image relay of the compressed pulses along the system.

The designed laser building, as seen in Figure 2, has a structure consisting of three floors. The geometry of the building is given by specific layout of the laser systems and supporting subsystems, and by needs of the research activities as well as by needs of operation flexibility of the facility. The geometry also features possibilities of future expansion.

The laser systems are located in the ground floor (the laser halls have size 18x34 m, whereas the total size of the ground floor, including plant room, is 47x79 m). The laser area L1 (in Fig.2 labeled as "Laser 1") hosts the oscillator, front end, and kHz PFS laser beamlines. The areas L2 and L3 ("Laser 2" and "Laser 3") provide space for PW-class 10-Hz repetition rate systems pumped with 100-J lasers, and for 50-J high-intensity beamlines pumped with 300-500 J lasers, respectively. Operation of these lasers, especially of the 10-Hz multislab lasers, will be supported by technology subsystems located overhead in the 1st floor. These support technology systems on the first floor include chillers for cooling diode drivers of the laser amplifiers in L2 and L3 (purple and green), chillers of He gas (yellow), heat exchangers of the cryogenic circuits (pale blue), and pulse power capacitor banks (red).

The 10-PW system spreads over the three floors. The CPA kJ laser chains are located on the first floor (L4a or "Laser 4a" in Fig.2). The laser area L4b on the ground floor is designed to host broadband high-intensity amplifiers and to serve as laser development area (see note above about conversion of the 10-PW kJ CPA pulses into 10-30 fs 10-PW pulses). Finally, the large pulse compressors for 10-PW beamlines will be located in the basement in the hall L4c (again only two units will be installed in 2015). The three floors of the 10-PW section thus offer large contingency space for future upgrades towards higher peak powers.

The lasers deliver pulses into the underground floor (in total 65x109 m) that exceeds the ground floor profile (eastwards and southwards) in order to provide optimum environment and radiation shielding for particle acceleration and the high-field physics experiments. Six experimental halls (E1 to E6) are located in the basement; the nominal purpose of these halls is indicated in Fig.2. Each hall will be nominally serving specific class of experiments using specific combination of the laser pulses, while all halls will receive the high-average-power kHz pulses and the high-energy repetition-rate PW pulses. The limitations of availability (and use) of laser beams in the halls E1, E2 and, to some extent of E3, is due to radioprotection issues.

The designed ELI laser building consists of a monolithic structure that ensures very high mechanical stability which is necessary for reliable operation of the laser systems and experimental facilities. The monolithic structure also ensures isolation of the laser equipment from external vibrations and involves thermal stabilization which is equally indispensable for reliable operation of the laser systems, especially for maintaining their alignment that may be critically altered by temperature variations exceeding +/- 0.5° C. The laser and experimental halls of the laser building will be large cleanrooms with cleanliness class 10,000 (ISO 7).

Stability of the focused laser beams delivered into the experimental halls was modelled, considering the longest optical trajectories in the system from the oscillator via the laser halls L3 and L4b-c, and the pulse distribution system. The Monte Carlo simulations used actual vibration budget of the building and took into account displacement of all relevant components (oscillator, mirrors, compressor gratings, mirrors in the pulse distribution, and target). The result is that the focus remains stable over at least 4 hours within a centroid of 10 microns in diameter.

ELI's implementation scheme

On October 1st 2009, the funding agencies represented in the Steering Committee of the ELI Preparatory Phase decided to give the mandate to the Czech Republic, Hungary and Romania to launch the implementation of ELI through the construction of three specialised, coordinated and complementary facilities dedicated to three of the four scientific "challenges" mentioned above. Following the decision by the ELI Preparatory Phase Steering Committee a detailed legal analysis was conducted to define under which legal arrangements the establishment of an European Research Infrastructure Consortium ERIC (as defined in a regulation by the European Commission, which is in force since 29 August 2009; see http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=eric), the ELI-ERIC, could be feasible, especially given the constraints pertaining to the use of structural funds by the three hosting countries.

It resulted from this analysis and from the local institutional arrangements decided in the three hosting countries, that the legal implementation of the project as a whole should be based on two main phases:

- During the implementation of the project (2011-2015), the three hosting countries will apply for funding and conduct all activities linked to the construction, research and development, setting-up, assembling, testing and commissioning of the three ELI facilities by the proxy of three local legal entities acting as applicants and beneficiaries. These entities will be placed under the coordination of an interim entity, the ELI Delivery Consortium

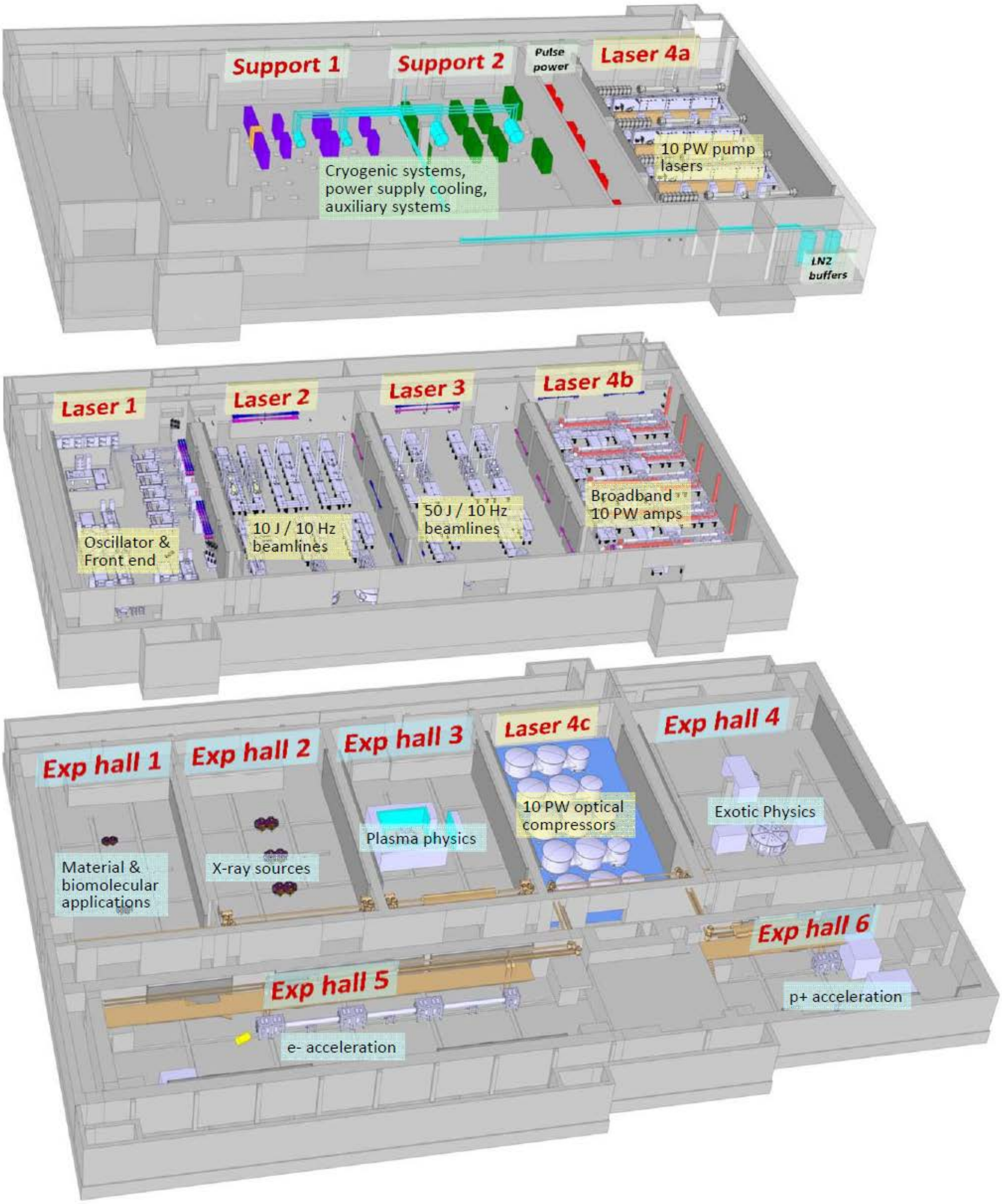

Figure 2. Proposed layout of the internal structure of ELI-Beamlines facility (as given in the ELI White Book, G.A.Mourou, G.Korn, W.Sandner, J.L.Collier, editors, CNRS 2011). The view shows all laser systems potentially implementable in the laser halls L1 to L4 – the systems that will be actually deployed in the facility in 2015 are represented in Figure 1 (most notably the facility in 2015 will involve only two 10 PW systems, leaving larger parts of the halls L4a, L4b and L4c empty). The basement experimental halls E1, E2 and E3 (along with the area L4c for 10-PW compressors) are under the ground-floor laser halls, while the halls E4, E5 and E6 extend building footprint in the basement.

- Apart from its coordinating mission, the ELI Delivery Consortium will carry out the work and organise the negotiations leading to the establishment of the ELI-ERIC. In due time, when all required conditions will be satisfied and when negotiations will be completed, the application for establishing the ELI-ERIC will be submitted to the European Commission for approval. The main task of the ELI-ERIC will be to coordinate and manage the operation of ELI as a single research infrastructure based on the three facilities. The date of the establishment of the ELI-ERIC will naturally depend on the success of the negotiation process, but it is anticipated that this establishment should be completed no later than in the first half of 2015 in order to organise efficiently the opening of the infrastructure to users in 2016.

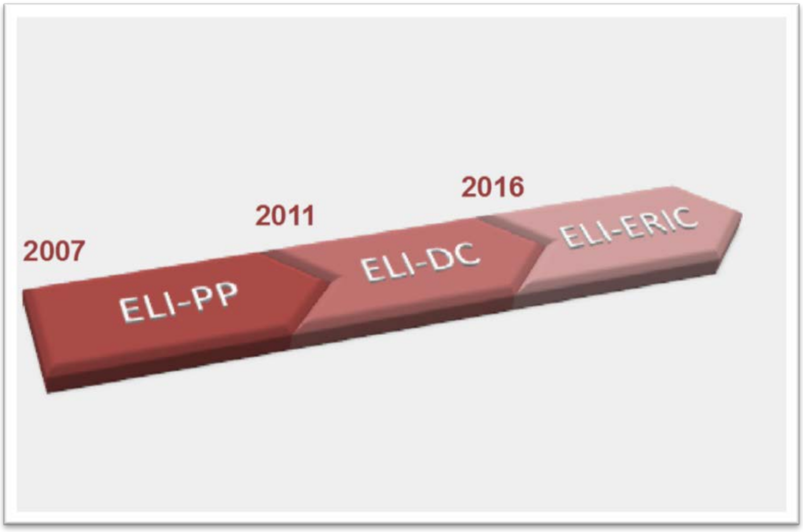

Figure 3. Overview of the institutional implementation timeline of ELI

The option of entrusting the ERIC with the responsibilities of implementing the three facilities was rejected for the legal and practical feasibility of such an option was extremely doubtful (uncertain eligibility of the ELI-ERIC as the beneficiary of the grants, impossibility of securing contributions from partner funding agencies in such a short period of time, willingness to leave time for negotiations with partners on the conditions of operation of the infrastructure, etc.).

As a result of this implementation strategy, the local entities in charge of applying individually for the funding of the three ELI facilities will be solely accountable to their respective national Managing Authority for the due execution of the activities described in the grant agreements. This individual responsibility will not affect the consistency of the Project as a whole, precisely thanks to the coordinating role of the ELI Delivery Consortium.

Justification and objectives of the ELI-DC as an interim structure

Given the phased institutional implementation of the Project, the establishment of an interim organisation was necessary to fulfil the following objectives:

- Ensuring the continuous visibility, scientific consistency and representation of the ELI Project as a single pan-European endeavour
- Preserving consistency and preventing overlaps in the definition of the respective scientific missions of the ELI research centres by the local implementation teams and the local international scientific advisory committees
- Supporting the timely and cost-contained delivery of ELI through the coordinated and optimal use of the human, technological and financial means available at the European level for the implementation of the ELI project
- Setting up joint initiatives contributing to the sustainable development and competitiveness of ELI by favouring its access to cutting-edge technology, skilled human resources, and to the financial means necessary for the long-term preservation of its leadership in the field of scientific research using ultra-intense ultra-short pulse lasers
- Defining and implementing the conditions necessary for the operation of ELI as a research infrastructure providing the world’s best conditions of access and securing an agreement between funding agencies on the establishment of an inclusive ELI-ERIC tasked with the joint operation of the ELI research centres.

The ELI-DC embodies ELI as a single research infrastructure initiative. It should focus on (and promote) what makes the unity and consistency of this initiative, and ensure that there is indeed more value from the joint operation of the ELI facilities. The essential mission of the ELI-DC is to optimise the implementation of the facilities and deliver the added value resulting from the integrated operation.

Governance of the ELI-DC

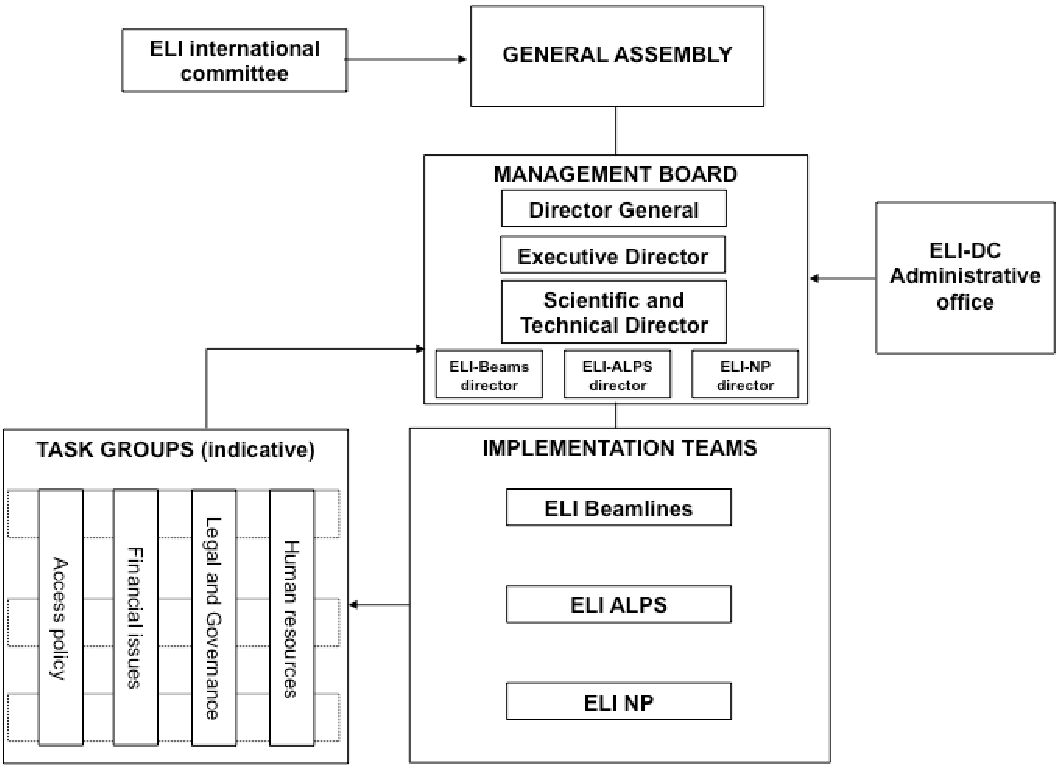

Figure 4. Internal organisation of the ELI Delivery Consortium

As shown in Figure 4 above, the institutional setting of the ELI Delivery Consortium will rely on three main bodies:

- The *General Assembly*, which will involve representatives of Members of the Association, will be the supreme body of the Consortium. It will decide on the strategic orientations of the activity of the ELI-DC, approve the annual activity plans and budgets, deliberate on the scientific and technical recommendations of the Management Board, and appoint the ELI-DC directors. The General Assembly should ensure the representation of the three hosting countries, which have been entrusted with an eminent responsibility and commit funding in the ELI-DC. The legal obligations of the hosting countries pertaining to the use of structural funds are preserved within the General Assembly (see article 9.7 of the Statutes).
- The *Management Board* will be the executive body in charge of the daily activity and representation of the Consortium with the support of a permanent team of employees. The Management Board is not meant to be a national representation of the Members. The Board will involve three full-time managers (a Director General, a Scientific and Technical Director, an Executive Director), who will interact periodically with the project directors of the three ELI local implementation teams who will also take part in the meetings of the Management Board. The Management Board will be the main actor responsible for the scientific and technical coordination of the project as well as for the preparation of the negotiations with funding agencies. It will create and rely on ad-hoc task groups of international experts whenever necessary (the task groups listed in Figure 2 are only indicative).
- Finally, the ELI-DC will include an *ELI International Committee* allowing funding agencies interested in the establishment of the future ERIC to be represented. It is within this framework that funding agencies will have the possibility to discuss on the future governance and conditions of operation of ELI, and negotiate on contributions to the future ELI consortium.

The International scientific advisory committees already established at the local level to advise each local implementation team will be maintained to promote the scientific specificity of each ELI facility: the committees should contribute to investigating the research opportunities *specific* to each ELI facility and to consolidating and developing their own user communities. The ELI-DC, and in particular the Management Board, will ensure consistency and complementarity in the distribution of the scientific missions of the facilities by reviewing the development of the three scientific and research cases and suggesting relevant measures for their optimisation.

Similarly, each implementation team will establish a technical or machine advisory committee providing expert advice on the technological choices and monitoring their implementation. The Scientific and Technical director of the ELI-DC who will be in direct touch with the local implementation units and with the committees and will investigate how the implementation of the facilities could be best coordinated in order to minimise the use of resources and maximise the chances of timely delivery. This review will cover all types of resources (expertise, finance, and human resources for instance), with the help of relevant experts.