# LEAPS STRATEGY 2030

**Proposal for a new research and innovation consortium in FP9 and beyond**

LEAPS League of European Accelerator-based Photon Sources

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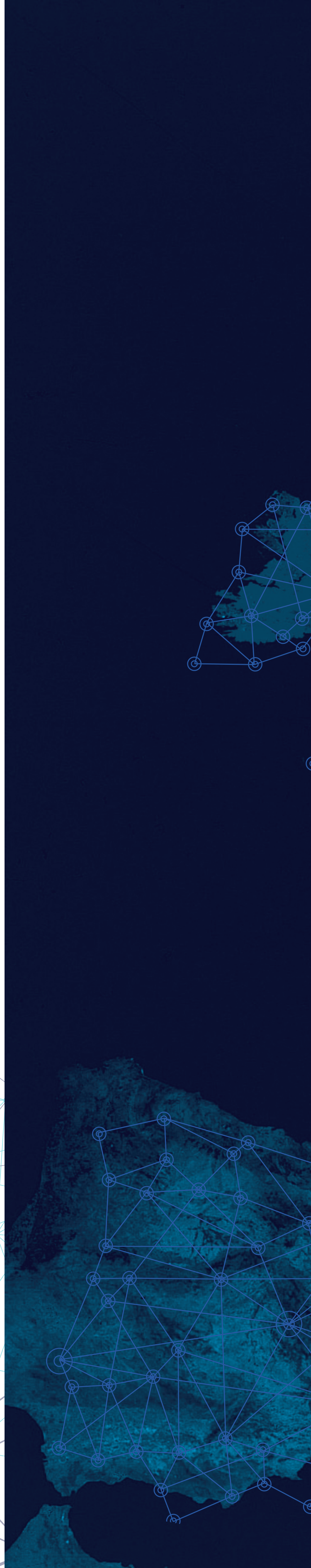
## Appendix

**LEAPS science and socio-economic drivers**



## Vision

A world where European science is a catalyst for solving global challenges, a key driver for competitveness and a compelling force for closer integration and peace through scientific collaboration.

## Mission

LEAPS will use the power of its combined voice to ensure that member light source facilities continue to be world-leading, to act as a powerful tool for the development and integration of skills and solutions with a view to address 21st century global challenges, and to consolidate Europe's leadership in the field.


## Working together to form LEAPS

## Executive summary

A new Research Consortium in Europe has been established called **The League of European Accelerator-Based Photon Sources (LEAPS)**

Its members have the common understanding that answers to the Grand Challenges of our society will require **novel materials solutions and new ways of cooperation across disciplines and national borders.** They are **joining forces** to enhance European science, innovation and integration in the following way:

- closer co-operation and coherence in developing and implementing new technologies
- better engagement with industry
- broadening its user community
- improved outreach and training programs

**LEAPS comprises all European Synchrotron Radiation (SR) and Free Electron Laser (FEL) user Research Infrastructures (RI)** and hopes to reach a new level of cooperation, coordination and integration to better cope with future challenges in science, innovation and data management.

The LEAPS members have a collective understanding that the future technological developments require resources and competences that surpass the capabilities of individual RIs, and that tackling the entire spectrum of technological challenges can only be done by a concerted effort of all LEAPS institutes as well as industrial partners.



The proposed ambitious **LEAPS Research Infrastructure and Technology Roadmaps** will lead to ground-breaking new technologies, keeping Europe´s RIs at the highest level of competitiveness. Importantly, the roadmap will be executed as a coupled open innovation effort with industry stakeholders extending their product portfolios and markets.

**LEAPS will mobilise its substantial knowledge and expertise** in photon science and technology, RI management, and service to scientific users and stakeholders. This will benefit European science and society as well as integrate European countries with developing scientific communities into these scientific and technological developments and strategy processes. The LEAPS consortium provide advise on and engage in all matters relevant to the development of photon science with all stakeholders and organisations, such as the European Commission and national funding agencies, with the clear objective to help, inform and shape future policies and funding opportunities.

LEAPS has identified the **long-term sustainability (LTS)** of its members as a future key priority. Following the recommendations of the ESFRI Working Group on LTS[1] and the European Commission action plan[2], this will be achieved through a strategy to:

- advance the technology of photon generation and exploitation at accelerator-based sources
- ensure scientific excellence throughout the life cycle of its RIs
- expand the community of users towards new research fields and applications
- attract the best scientists, engineers and managers
- unlock the innovation potential of its RIs
- better measure the socio-economic impact of its RIs
- fully exploit the data generated
- assure sustainability for the operation and development of its RIs
- improve the national, European and international outreach of its RIs

**This document describes the main features of this new European consortium; its aims, ambitions, organisational structure and working strategy. Moreover, it also explains the major decisions to be taken and resources to be provided in the upcoming Framework Programme 9 and beyond, which are prerequisite for LEAPS to play its future role in Europe.**

# 1. Introduction

Solutions to many of the crucial challenges facing humanity, such as developing alternative sources of energy, improving health, mitigating environmental and climate problems and developing new "green" economies, depend on the detailed understanding of the constitution of matter and on the molecular and electronic control of processes that determine the function of materials and biological systems.

Over the past 50 years, photons produced by synchrotron radiation (SR) storage rings and free-electron lasers (FELs) have revolutionised our understanding of materials and concomitantly our ability to optimise and exploit them. Applications at accelerator-based photon sources span all kinds of materials and scientific disciplines, from semiconductors for electronics, catalysts for chemical reactions, protein molecules for drug development, even research in geology and palaeontology. This has been enabled by decades of continued development of electron accelerators, producing brilliant photon beams in all relevant energy ranges from infrared to hard X-rays. This outstanding technological development ("LEAPS´s law") shows an exponential growth that outruns Moore´s law (Fig. 1).

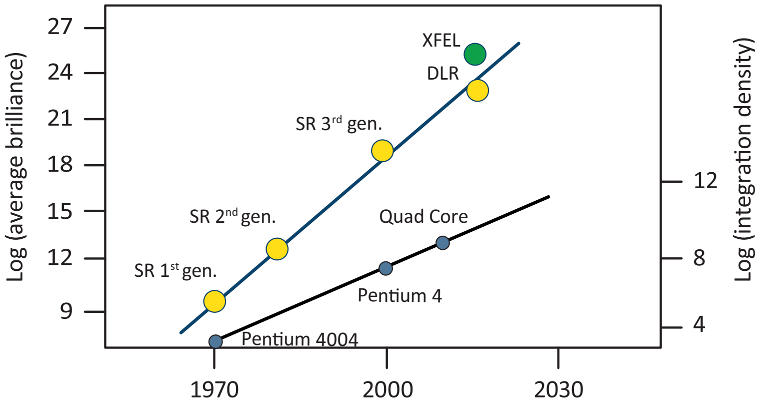



*Fig. 1. Comparison of the brilliance of X-rays delivered by photon facilities over the years (LEAPS' law) with the gain in transistor density in integrated circuits (Moore´s law). (DLR = Diffraction Limited Rings with ultimate performance; XFEL = X-ray free-electron laser)*

Today, science at SR and XFEL facilities plays a key role in the discovery and characterisation of advanced materials, biomaterials and living matter. They serve a numerous and broad scientific community, representing many disciplines encompassing fundamental and applied sciences, and innovative industrial applications.

## 2. Scope of LEAPS

Europe has achieved worldwide leadership in the development of X-ray SR and FEL RIs. These infrastructures serve users from university and non-academic public and private sectors, and provide answers to key societal challenges in areas such as health, environment, energy, and communication. They also educate the next generation of scientists, engineers and RI managers and administrators, and contribute to the competitiveness of European industry and thus create wealth and jobs.

There are 13 SR and 6 FEL RIs located in 10 European states, all of them included as founding members of LEAPS. They represent a multi-billion Euro investment and their yearly operating budgets are approximately 700 million Euro. They operate around 220 highly dedicated beamlines serving more than 24,000 direct users which have produced more than 23,400 articles published in peer-reviewed journals over the last five years. In the last twenty years, five Nobel Prizes in chemistry have been awarded for discoveries relying heavily on work performed at these European facilities.

LEAPS RIs have worked together for years in various combinations, also supported through diverse European framework programmes. In the 21st century, however, new ways of cooperation and specialisation are necessary to tackle more demanding Grand Challenges. LEAPS RIs are prepared to take this next step, and plan to develop next-generation technologies, which promise a step-change in delivering and exploiting brighter photon sources through ultimate-performance storage rings and high performance FEL sources.

LEAPS will implement a pan-European roadmap process for advanced technologies in photon science, as well as initiate a process for the long-term development of the RIs. These roadmaps will be devised in collaboration with the scientific community, national funding agencies, and industry. By implementing a European strategy of coordination and smart specialisation of efforts and technologies, LEAPS will provide the best tools to optimise national and European resources.

LEAPS will enable the complementary features of FELs and SR to be fully exploited. LEAPS will ensure the long-term sustainability of its RIs by attracting and training the best and brightest young minds from across Europe, including countries that do not have national or European SR or FEL facilities.

# 3. How LEAPS will address the key issues of the European Long-Term Sustainability action plan

The goals and ambition of LEAPS and the action plan of its working groups (see 3.6) clearly aim to assure the LTS of the RIs owned by their members. In chapters 3.1–3.7 the aspects of the LEAPS-LTS strategy are briefly described.

## 3.1 Ensuring excellence of the services and solutions provided by the LEAPS RIs

*Guidelines for scientific & technical reviewing processes*

LEAPS members already have a proven record in providing

- state-of-the-art technologies to users from university and non-academic public and private sector
- transparent peer-reviewed access to beamtime

LEAPS aims to further enhance excellence of services and solutions to target the three challenges: 'Open Science', 'Open Innovation' and 'Open to the World'. LEAPS will have a strong focus on coordination and specialisation with respect to user access, user support, instrumentation, data analysis, and data management. LEAPS will interact closely with the European Synchrotron and FELs User Organisation (ESUO) in order to proactively answer users' needs.

LEAPS focuses on removing technical and bureaucratic barriers for access to its RIs by implementing standards in:

- the proposal system
- experiments environments and systems
- software and data management systems.

LEAPS has installed a working group for devising and implementing standardised performance metrics into a common reporting system enabling easy benchmarking of its RIs.

Furthermore, there will be a strong interconnection with initiatives and projects that are already running, for example CALIPSOplus[3], EUCALL[4], iNEXT[5], NFFA[6], LaserLab-Europe[7] , OPEN SESAME[8] .

## 3.2 Ensuring that the LEAPS RIs have the right people in the right place at the right time

*LEAPS RIs' next generation staff and user community expansion*

The LEAPS RIs require highly experienced and motivated staff to maintain, operate and develop the photon sources and to offer state-of-the-art technologies and advanced services to European researchers and to European industry. To be able to sustain and nurture such staff, specific education and training is required as well as dedicated career development programmes.

LEAPS RIs are a key enabler to encourage the highest quality research in Europe across many fields. This is evidenced by multiple ERC grants concerning the development of methods at LEAPS RIs or accessing them for their unique analytical capabilities.

The LEAPS consortium proposes a multidisciplinary European curriculum targeting scientists, technicians and engineers as well as future managers. It will include mobility and exchange programmes, mentoring of the early career staff will be balanced in terms of race and gender.

Today, the European users represented by ESUO number more than 24,000, and are an open and extremely innovative community, which is still growing due in part to the increasing number of users from Eastern European countries. LEAPS will actively expand in close conjunction with ESUO and the wider academic user community to work towards new research fields and technological applications responding to future Grand Challenges.

The continuous feedback between RIs and users is indispensable for the development of the facilities, however, its long-term sustainability requires ongoing support for trans-national access (TNA) for the users.

## 3.3 Making the most of the data generated by LEAPS RIs

*Reinforcing data management policy; merging e-services integrated in the EOSC*

All photon sources are confronted with an exponential growth of data volumes resulting from year-on-year improvements in photon source, beam delivery and detector technology. This creates substantial technical challenges in terms of the data pipeline from experiment through analysis to scientific results. LEAPS partners recognise the importance of Information Technology (IT) to enable quality, capability, and capacity of scientific output of RIs.

The salient features of LEAPS-IT are tightly-coupled to the operation of photon sources, and need to be located at the RIs. However, services relating to data processing, data analysis and data management are largely location independent. For these technical areas, LEAPS-IT will work to coordinate requirements and activities with those of the European Open Science Cloud (EOSC). This will enable facilities to build on the infrastructure and services available through the EOSC. It will also be based on FAIR (Findable, Accessible, Interoperable and Re-usable) principles and incorporate interdisciplinary and inter-RI data access and mining approaches across all science domains.

## 3.4 Exploiting the potential of LEAPS RIs as innovation hubs

*Supporting the development of ecosystems around LEAPS to facilitate engagement with industry as users, technology recipients and suppliers*

LEAPS will make a transformative change in the relationship between European photon sources and industry. The objectives are to boost innovative industrial research and the competitiveness of industry by offering the advanced research capabilities of LEAPS members and to market new technologies developed at the photon sources. In addition, the technology roadmap developed by LEAPS will be realised in partnership with industry. This will strengthen the companies already delivering to big science facilities, thereby allowing them to take a bigger share of the global market.

**Boosting industrial innovation by exploiting photon source RIs and skills**

LEAPS members offer access to RIs, which are extraordinarily well-suited to look into materials, devices and processes with unprecedented detail. There is considerable use of these remarkable tools by industry, but given the scope for advances in photon source technology, the future usage is even larger. By working closely together, LEAPS will unlock the innovation potential of these powerful tools for industry. Recent industrial innovations include AstraZeneca[9] on new medicines, Johnson Matthey[10] on improving catalysts and Prior PLM Medical (an SME) on better inhaler devices[11].

**Enhanced capture and support to technology transfer and spin-off opportunities**

The LEAPS technology-driven tasks will undoubtedly generate new ideas and technologies that can be commercialised, as well as existing advanced instrumentation at the photon sources. But a gap remains between the developers and potential commercial exploitation. LEAPS will close this gap to enable a more efficient transfer of technology to the market. A key example is DECTRIS[12], a spin-off from the Paul Scherrer Institute (PSI) now exploiting pixel detector technology for the wider global market. Technologies identified in the LEAPS roadmaps and offered to industry will also have impact on other areas of the science market.

**Innovate procurement to support leadership of European enterprises**

LEAPS has significant procurement needs and seeks to promote a win-win framework for the photon sources and its suppliers. LEAPS will seek to share and harmonise best procurement practices. LEAPS will focus upon innovative procurement procedures, targeting a wider supplier chain and opening markets for European technology firms. One example concerns AVS[13], a Spanish SME, where the knowledge gained by supplying a LEAPS RI has opened new worldwide markets.

## 3.5 Assessing the economic and wider societal value of the LEAPS RIs

### *Developing a standardised model to identify the socio-economic impact of the LEAPS RIs*

Studies on the socio-economic impact (SEI) have so far been performed only to a limited extent within the European photon source community, (e.g. for SRS[14] (UK), ESRF (INT), Doris at DESY (Germany) and ALBA (Spain)), and the methodology itself is still a subject for discussion and development. However, it is also clear that RIs in general are being increasingly required to demonstrate their SEI when they make the case for ongoing support from their stakeholders. A better understanding of the origins of SEI will also help RIs shape their strategy for development and operations if required. The RI Impact Pathways[15] - a Horizon2020 project - proposes a comprehensive impact evaluation methodology for RIs that can be implemented by different RIs, also including two LEAPS RIs: ALBA and DESY.

Based on the tailored standardised performance metrics developed by LEAPS, the outcome of the RI Impact Pathways project will be exploited and expanded in a sustainable way to systematically assess LEAPS RIs' impact, providing a useful tool to national funding agencies and the EC. It will guarantee that a high and comparable quality standard is maintained at all LEAPS infrastructures.

## 3.6 Establishing adequate framework conditions for effective governance and sustainable long-term funding of the LEAPS consortium

*LEAPS is aiming for a new consortium in Europe coordinating the exploitation and further development of advanced X-ray technology and acting as a competence anchor for the strategic cooperation with organisations and RIs outside Europe. To take on this ambitious task, LEAPS is currently implementing a governance structure, which will most efficiently deal with the inherent complexity of such a wide-scale collaborative effort. The initial governance scheme as foreseen in the starting phase is depicted in Fig. 2.*



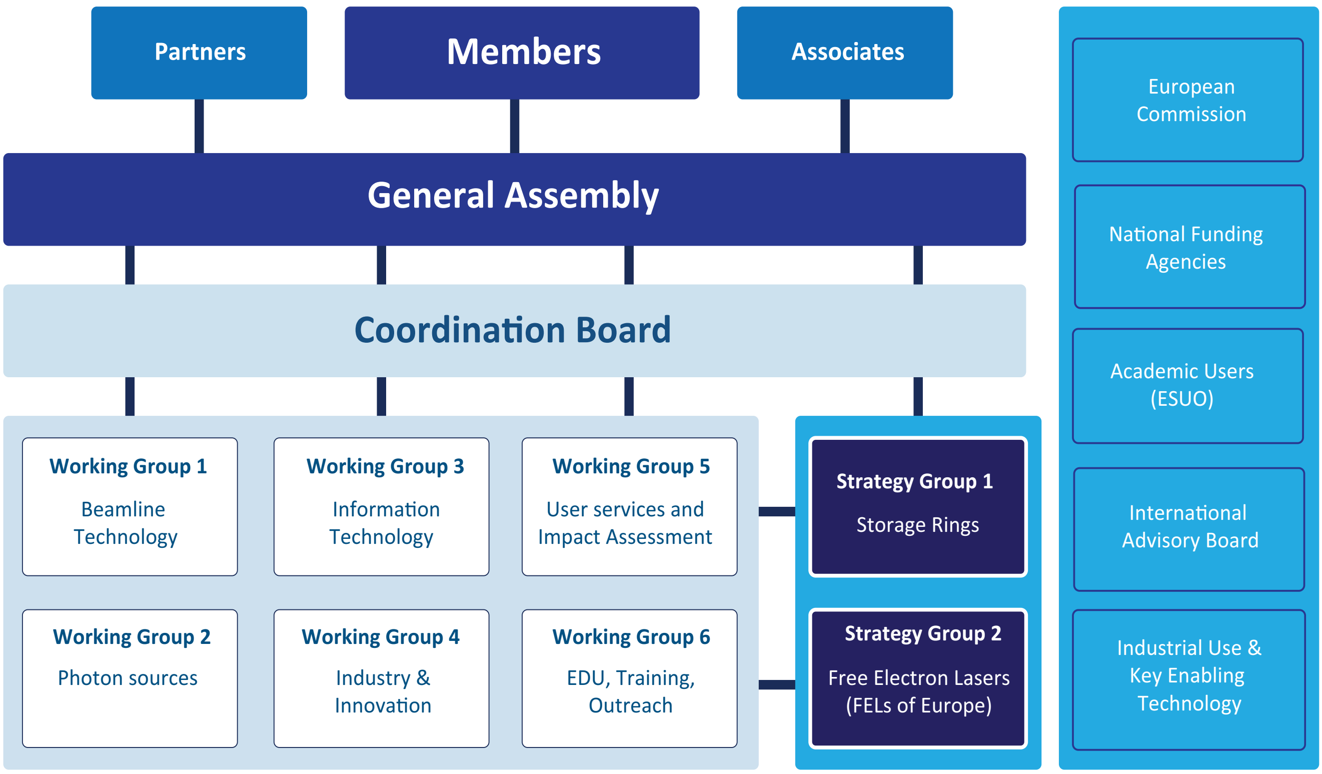



*Fig. 2. LEAPS Organisation*

The salient features of the organisation are described below. Structural elements dealing with international cooperation are not yet included. This will be one of the important tasks within 2018.

**Members, Associates and Partners**

LEAPS Members are legal entities operating one or more Synchrotron Radiation or/and FEL User RIs at an international level in EU member states and associate countries contributing to the LEAPS mission.

LEAPS Associates are institutions operating or willing to operate Synchrotron Radiation or/and FEL User RIs and institutions of strategic importance wishing to collaborate with LEAPS on a long-term basis, but not fulfilling all criteria for full membership. They essentially support all goals of LEAPS, but do not qualify for membership because they are either not located in Europe or are not a user facility.

LEAPS Partners are institutions cooperating within related science and technology areas wishing to collaborate with LEAPS on specific activities in line with the goals of LEAPS. They contribute their expertise, hardware, software or staff to accomplish LEAPS activities. They may be institutes, research centres or networks.

**General Assembly and Coordination Board**

LEAPS Members are represented at the highest level in the General Assembly (GA) in which all key decisions are taken or confirmed. All members are also represented in the Coordination Board (CB), which is an executive body that sees that the actions decided by the GA are carried out and has overall responsibility for ensuring that the day-to-day activities taking place within LEAPS are coherent. The CB is supported technically by branch offices, which are staffed by personnel provided by different members. The contact between the GA and CB is guaranteed via the corresponding chair/vice chair teams and through periodic joint meetings.



LEAPS Associates participate with the GA as observers without voting rights; they can be involved in LEAPS work packages/tasks. Partners may participate in LEAPS conferences and meetings.

**European Commission**

LEAPS aims at shaping the European strategy of its members, in collaboration with the European Commission. A close interaction between the Commission and the GA will promote a beneficial exchange of information between the two bodies.

**LEAPS Advisory Groups (AG)**

*AG – National Funding Agencies*

The AG NFA comprises high-level representatives of national funding organisations who advise the GA. This will assure coordination of LEAPS decisions with strategies and decisions at national levels. The commitment of national agencies to synchronise European development will be essential for the success of the project.

*AG – Industrial use and Key Enabling Technologies*

The LEAPS working group (WG) on industry and innovation will have an advisory group formed by key persons from industry.

*AG – Academic Users*

LEAPS working groups on user services and support will interact strongly with a group formed by representatives of the academic user community.

*International Advisory Board*

LEAPS will install an external international advisory committee, which will provide advice and international benchmarking for all LEAPS activities.

### Working Groups

LEAPS activities are carried out jointly by selected staff from the different members within six target-oriented WGs and two strategy groups (SGs), shown in Fig. 2. The WGs focus on joint issues and development in the following critical areas: beamline technology, photon sources, information technology, industry and innovation, user services, and support, education and training. SGs aim to determine the key trends of science-driven evolution of accelerator-based photon sources, specifically for storage rings and FELs. Both WGs and SGs will conduct their activities in contact with and providing feedback to the CB. All these bodies (GA, CB, WGs, SGs) have already been created and are currently actively working together.

#### *Coordinating national roadmaps*

LEAPS, through its GA, will serve as an expert panel for national funding agencies offering advice on national research roadmaps and help in the optimization of the RI upgrade plans, and in the design of new RIs with complementary characteristics.

#### *Increasing visibility of the services offered by LEAPS as a pan-European RI*

Three objectives have been defined to strengthen the efficient use of LEAPS RIs across a diverse range of current and new user communities from academia and industry, and from Europe and beyond. These are:

- to create a European-wide helpdesk, i.e. a network of experienced RI staff members with support from the ESUO. This helpdesk will particularly target users from the EU "widening countries" in particular.
- to consolidate the photon sources web presence into a long-term sustainable model. The www.wayforlight.eu portal will be linked with the global platform www.lightsources.org optimising the user experience and improving the access of information. This portal is being extended to already existing efforts under the CALIPSOplus and EUCALL H2020 projects, to reach the optical laser community.
- to include information on careers, a training area and an industry-dedicated section on the LEAPS website and promote related initiatives and collaborations such as the Free Electron Lasers of Europe and the Umbrella federated identity system.

#### *Supporting access to LEAPS facilities*

The two LEAPS members that have been established through intergovernmental agreement, the ESRF and European XFEL, are, providing state-of-the-art services to users from all their member states. The nationally operated LEAPS RIs clearly serve their national communities, and also offer 20–50% of the available beamtime to European and non-European research groups, so they too fulfil an important pan-European task. All academic users obtain access free of charge to the RIs, purely based on peer-reviewed scientific merit. Today, most RIs fund travel and subsistence costs for their national users.

Experience with previous EC-funded integration and inclusion programmes demonstrates the value of a proactive approach for users from European countries whose travel costs are a barrier for performing experiments away from their home institution. In the spirit of 'Open to the world' LEAPS national RIs will in future support those potential users. A prototype of a "Joint European Travel Office" for experimental campaigns, financed by the members of LEAPS, is currently under investigation in the framework of the CALIPSOplus H2020 project.

### *Facilitating access to EU funds and encouraging new sources of funding including private funding*

The LEAPS members have a broad range of funding. The majority are national facilities, while the ESRF and European XFEL receive funding from ten or more national funding bodies.

Traditionally, LEAPS RIs have successfully formed consortia to apply for and manage funding from the EU. The latest example is the CALIPSOplus project within the Integrating Activity for Advanced Communities call INFRAIA-01-2016 (Material Sciences and Analytical RIs/ Synchrotron radiation sources and Free Electron Lasers).

Because of their relevance for society and the European economy, LEAPS members have access to funding (ranging from 10 to 100 million Euro) from private charities such as the Wellcome Trust, the Knut and Alice Wallenberg Foundation and the Novo Nordisk Foundation. In addition, smaller charities support postdocs, specific items of experimental equipment, travel expenses and workshops.

European industries are directly funding work in a number of areas where they already have in-house capabilities to use such advanced analytical RIs. The prime example is the pharmaceutical industry (e.g. Novartis International AG, Mitsubishi Chemical Corporation, and AstraZeneca plc). An upcoming area is the paper, and packaging industry (e.g. BillerudKorsnäs AB, Holmen Group, and Stora Enso). More industrial sectors are expected to follow as standardized X-ray techniques become available and better conditions for data collection and analysis are created.

In addition to such strategic investments, industry may also provide funding, whether directly for proprietary use, paying fees for access, or indirectly via academic partnerships whereby industry funds research projects at universities that use LEAPS RIs.

## 3.7 Strengthening the international dimension of pan-European RI

*Contributing to the international outreach of pan-European RI*

LEAPS members contribute to science diplomacy, and have welcomed scientists from Eastern Europe. In many cases, this has led to the formation of stable national research communities, which is exemplified by the large contributions of Russia to both the ESRF and European XFEL. There are more than 15 national funded beamlines located at a RI in a different country (e.g. the Austrian beamline at Elettra or the Collaborative Research Groups at ESRF).

Today, LEAPS actively supports many projects outside Europe such as the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME) in Jordan, the African Light Source (AfLS), the FEL project TARLA (Turkish Accelerator And Radiation Laboratory at Ankara), the Center for the Advancement of Natural Discoveries using Photon Emission (CANDLE) a project for a synchrotron in Armenia, and the Iranian Light Source Facility (ILSF). Five LEAPS members are currently working with six Russian partners and seven other European institutes on the EU-funded project CREMLIN[16] to connect Russian and European RIs. Contacts and collaboration projects between some of the LEAPS members and scientific representatives of the Community of Latin American and Caribbean States (CELAC) are being pursued.

## 4. LEAPS RIs and Technology roadmaps

Synchrotron and FEL photon sources have proved to be indispensable for developments in many fields of science and technology. Experiments are capable of covering a very wide range of spatial dimensions from macroscopic to atomic, as well as from time scales spanning years to femtoseconds.

The next generation of photon sources will provide beams of unprecedented quality in terms of brilliance, peak intensity and pulse length, enabling an even deeper and more detailed insight into the most complex nanostructured materials, biomolecular assemblies or chemical processes.

This will require the upgrade of synchrotron radiation storage rings and beamlines, the further development of FEL facilities, as well as the development of novel technologies in detection and monitoring systems (such as advanced optics, novel accelerator concepts, sample environment, and data management and analysis systems).

The LEAPS consortium will develop a detailed roadmap of the process, which will ensure that the necessary investments are used in the most efficient manner (Fig. 3). The roadmap will facilitate the coordination of efforts, smart specialisation in the development of advanced technologies, as well as integration of low-performing countries in the development of key technologies.



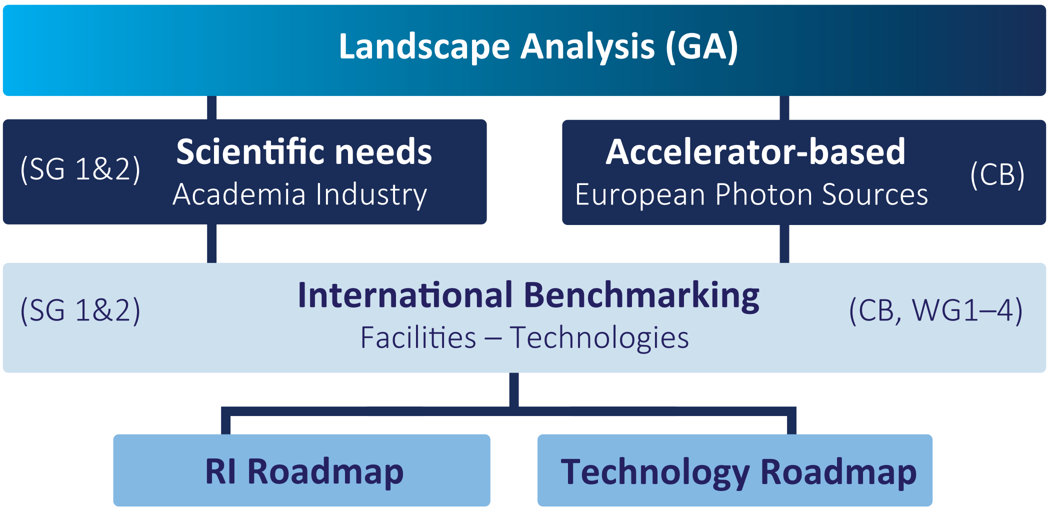



*Fig. 3 Overview of the LEAPS Roadmap Process including responsible LEAPS bodies (see 3.6, particularly Fig.2 for the definition of specific SGs and WGs)*

This LEAPS Roadmap Process includes the landscape analysis of existing RIs and scientific, industrial and technological needs. This analysis underpins the development of two interdependent roadmap processes: the RI Roadmap and the associated Technology Roadmap.

## 4.1 RI Roadmap

Synchrotron radiation RIs are currently undertaking a leap to the next generation of storage rings, which will generate X-ray beams of ultimate brilliance. Brand new RIs such as MAX IV or the powerful EBS upgrade of the ESRF are the first examples of this revolution, which has been conceived and launched in Europe and is now setting the agenda worldwide.

The novel FEL RIs are opening new avenues to explore the atomic and molecular machinery of materials and biological architectures. For the first time, they allow the investigation of molecular processes at the relevant intrinsic length and time scales.

There is a global scientific understanding that the clever interplay between both types of X-ray sources and the proper coordination of efforts will cover all the future needs of academic and industrial users in this field.

It is the ambition of LEAPS to orchestrate the future developments of its RIs by an appropriate roadmap process. A concerted effort from the existing and planned European RIs to coordinate upgrades and developments will guarantee Europe its leadership in X-ray science and technology for the forthcoming decades. This concerted effort not only concerns the timeline of the upgrades, but also avoids unnecessary duplication of effort and helps to accelerate the process by jointly developing critical components and technologies (Fig. 4).

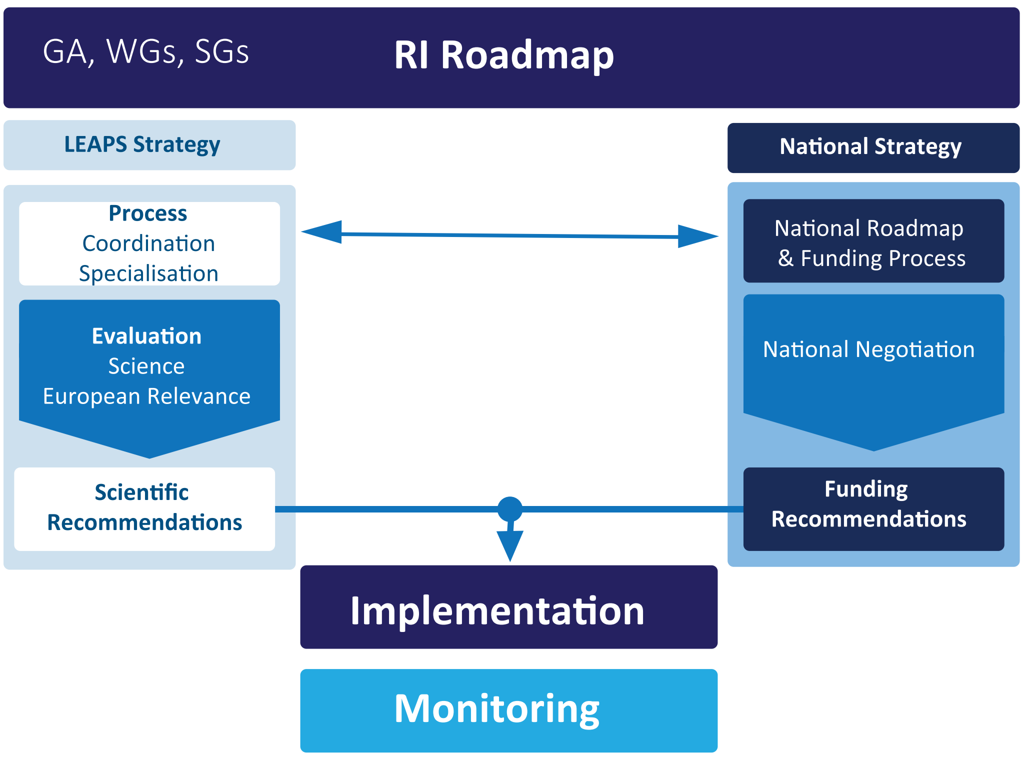



*Fig. 4 RI Roadmap Process, including LEAPS bodies (see 3.6, particularly Fig.2 for the definition of specific SGs and WGs)*

## 4.2 Technology Roadmap

Unleashing the full potential of the LEAPS RIs will require substantial new developments for the entire technology chain, linking the photon sources, X-ray optics and diagnostics, experiments environment and positioning, detectors, software, and data management. Due to the complexity of the required technologies, this can only be achieved efficiently by a coordinated effort among the European accelerator-based photon sources in cooperation with European partner institutes. The LEAPS process to devise the technology roadmaps, to prepare open calls for selected collaborative projects and to monitor their implementation is shown in Fig. 5.

After an international benchmarking, the technology landscape analysis carried out by LEAPS will yield the mid-term (5 years) and long-term (10 years) LEAPS Technology Programme. This programme will constitute the framework for bi-annual action plans, with the aim to fund collaborative technology projects every 1–2 years via open calls. Open calls enable the participation of stakeholders outside of LEAPS (e.g. industrial partners), which are mandatory to push forward the development of the specific technology. One goal of these open calls is to support cutting-edge technology to unleash the full potential of the LEAPS RIs and promote smart specialisation. They also allow, in close collaboration with industry, developments to be advanced to higher technology readiness levels (TRL) or even to manufacturing processes. LEAPS aims to strengthen the cooperation of small selected teams of specialists (part of the LEAPS smart specialisation strategy). A LEAPS programme coordination team will manage the entire technology roadmap process. External panels with international reviewers will evaluate the process.



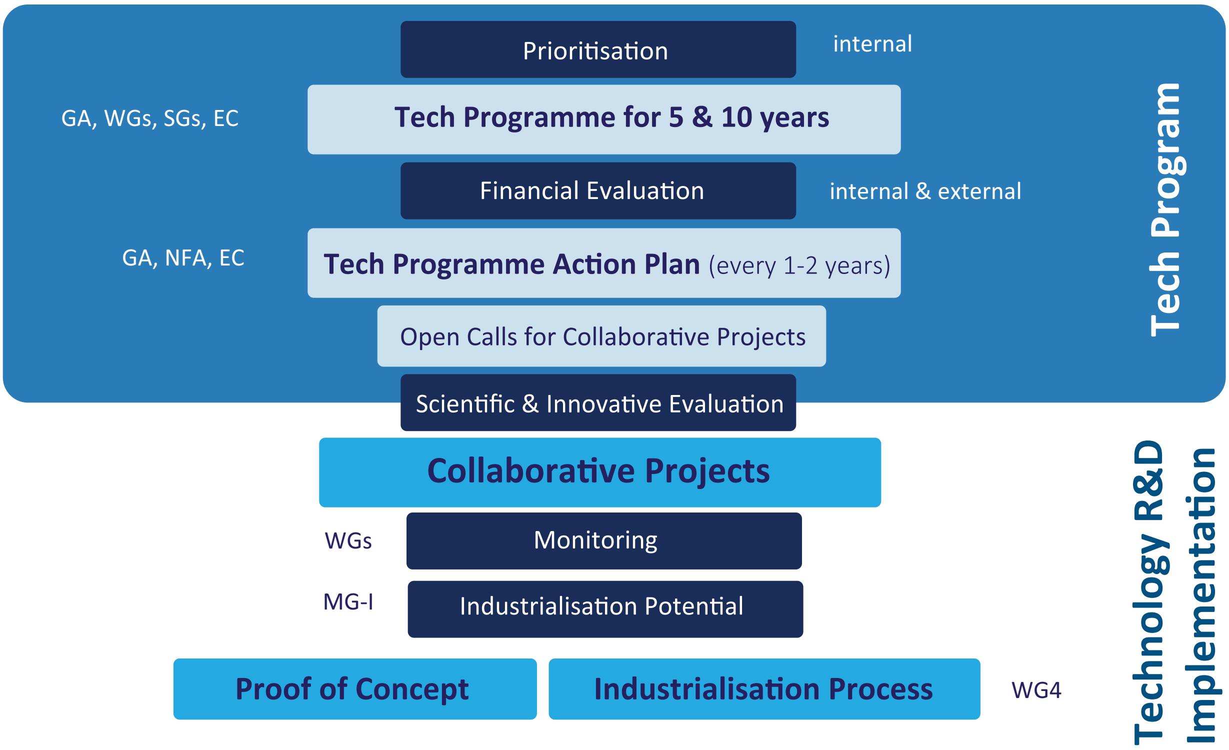



*Fig. 5. Technology Roadmap Process from prioritisation to proof-of-concept and industrialisation process*

The various technology sectors, which are the focus of LEAPS, are shortly described next. A detailed list of technology R&D topics that should be launched within the LEAPS technology programme in FP 9 is shown in Table 1, together with a preliminary description of the implication level of all facilities on the different topics and the approximated cost of the corresponding projects. A list of transversal activities is given in Table 2.

## Photon Sources

### *Future challenges*

LEAPS RIs are based on electron accelerator driven sources, storage rings and FELs. While electron storage rings have been established as dedicated photon sources for several decades, the recent development of Multi-Bend Achromat (MBA) lattices allows a dramatic increase of photon beam brilliance and coherence. Technical advancements in numerous components are required for exploiting the full potential of this new technology.

FELs covering the VUV to hard X-ray wavelengths are a recent development. These FELs complement storage rings with the capability to provide extremely intense, coherent photon pulses of femtosecond duration. Key challenges are better control of spectral and temporal properties to match future requirements for improved energy and time resolution.



A longer-term goal is the development of compact sources based on plasma wakefield acceleration to make some of the capabilities of the current RIs available for industrial applications, hospitals and smaller laboratory environments.

### *Proposed LEAPS solutions*

The LEAPS community defined six areas of common research:

- magnet systems and related vacuum technology
- production and control of higher brilliance electron beams
- better lasers for electron sources, FEL control and plasma accelerators
- RF acceleration systems with new functionalities
- advanced instrumentation for beam control and diagnostics
- demonstrator of compact plasma accelerator for photon science

### *LEAPS added value & European impact*

Performing the photon source R&D in a coordinated manner across LEAPS members allows more efficient use of resources. The pooling of R&D within fewer activities of larger size facilitates collaboration with industrial partners, who need a minimum critical level before they can invest in developing an innovative product. This R&D will enable Europe to lead the way in photon science and provide an industrial base for photon science tools.

Close coordination of the R&D activities between LEAPS and other accelerator driven fields of science and technology (high energy particle physics, neutron scattering, medical applications) will set a further example of smart specialisation of the European research and technology infrastructures.

## Beamline instrumentation

### X-ray optics

*Future challenges*

Current limitations in the quality of X-ray optics still prevent the exploitation of the full potential of modern photon sources. Improvements in the performance of X-ray optics will work as a powerful lever to reveal new scientific and technological avenues. The primary goals for performance of optical systems for advanced X-ray photon sources are:

- minimisation of parasitic X-ray wave front perturbation
- efficient transfer of the useful X-ray flux to and from the sample
- implementation of reliable optical systems which maximise beamline productivity

These objectives are particularly challenging for applications in nanofocusing, imaging and coherent scattering.

An additional challenge is that the companies or business units that serve this niche market are small in size and very few in number. In some strategic domains, notably that of the ultra-precision mirrors increasingly required by photon source RIs, the community relies upon two suppliers. LEAPS will overcome these difficulties by establishing partnerships with appropriate industries.

*Proposed LEAPS solutions*

Due to the necessary diversity of optical devices and significant differences in their TRLs, a coordinated network of technology hubs concentrated in the RIs will be developed. Easing access to unique technologies and capabilities to both academic and industrial users will be an important aim. This network will promote improved knowledge transfer to industrial partners whilst also providing a common forum to assess current status, and evaluate future needs and trends in this field.

*LEAPS added value & European impact*

Coordination of related developments of X-ray optics through LEAPS actions will facilitate enhanced exploitation of the significant investments in these technologies by members of the consortium. Such initiatives will permit a European-wide consolidation of the supply chain for improved optical systems.

### Sample Environment and Handling

*Future challenges*

The high brilliance and extreme spatial resolution provided by the next generation of accelerator-based photon sources pose unprecedented constraints on the stability of sample positioning and environments. Using nanobeams implies dramatically improved X-ray beam diagnostics and control, as well as long-term stability with ultra-precise nanometre resolution for both sample translation and rotation.

There are very significant technical challenges to enabling time resolved studies at FELs or strongly focused storage ring sources where one often aims for single pulse exposures. On the one hand, container-free sample delivery schemes need to be further developed in order to significantly reduce sample consumption and background scattering. On the other hand, powerful high repetition rate pump laser technology needs to be further developed to efficiently start reaction processes or prepare excited states.

Reaching out to an even wider user community will require major efforts in the standardisation and automatisation of experiments.

*Proposed LEAPS solutions*

The research and development activities in the sample environment and handling activity will target generic technologies and building blocks to establish the technological base for the distinct experimental stations at the European photon sources. New mechatronics-based concepts will be developed to meet the extreme requirements. Droplet/sample-on-demand techniques for liquid jets will dramatically reduce sample consumption in corresponding experiments, as will microfluidics for 'chemistry on a chip'. A strong push towards robotics and automated data evaluation using suitable expert systems will enable facilities to reach out to new user communities and industry.



*LEAPS added value & European impact*

The means to carry out many of the proposed activities is beyond the individual capabilities of most of the LEAPS members. The collaboration within LEAPS will ensure that these technologies will be developed efficiently together and made available to all LEAPS members to maintain their experimental stations at the forefront of technological and scientific development.

In cases where the expected market is large enough, industrial partners will be closely involved to enable them to strengthen their position on the global market.

## Detectors

*Future challenges*

Despite impressive progress in the last decade, detectors are still a limiting factor in many experiments. With the continuous improvements of both photon source and X-ray optics performance, it is imperative to develop detection technologies and systems beyond the current capabilities.

Due to the large diversity of techniques, and sciences performed at each photon source, a single detector system cannot cater to all the needs of the users, therefore a number of specialised detector technologies need to be developed.

*Proposed LEAPS Solutions*

Since there is a significant commonality in the components required for various systems, especially towards the backend electronics and computing system, a set of standards for all RIs involved will be developed and shared by all partners involved. This will have an enormous synergistic effect, analogous to the benefits by the mobile phone industry on account of standardisation of wireless communication protocols.

*LEAPS added value & European impact*

This ambitious programme would ensure that Europe retains its leading position in photon science. Moreover, the impact of this project goes far beyond scientific research, as X-ray detection and imaging play a crucial role in areas such as medical imaging, non-destructive testing, process control, safety and security.

## Information Technology as a Key Enabler

*Future challenges*

Progress in the technical capabilities of the photon sources such as Progress in the technical capabilities of the photon sources such as increased brightness and repetition rates, coupled with high pixel count and high frame rate detectors have enabled time resolved experiments that produce extremely high data rates and vast data volumes. As a result, detector readout, data pre-processing, transfer, storage, reduction, analysis, analysis services, archival, advanced modelling, and machine learning, together with the associated IT infrastructure and cutting-edge know-how in mathematics, advanced algorithms and IT technologies are challenging issues which need to be addressed urgently to maintain and increase the scientific productivity of the LEAPS RIs.

*Proposed LEAPS solutions*

IT is a key enabling technology, requiring a major concerted effort to enable new science and to sustain and enhance the quality, capability and capacity of the scientific output of LEAPS RIs. Standardisation of data management and analysis, from data acquisition to publication, will allow further harmonisation and facilitate the user experience across RIs, thereby ensuring better use of RI time, increasing scientific productivity and opening up opportunities to attract new user communities. Unifying the data management approach will allow the implementation of best practices in accordance with EU guidance facilitating and promoting the applications of the Findable, Accessible, Interoperable and Re-usable (FAIR) principle. IT capabilities will be also be enhanced through the development of data scientists and IT specialists.

*LEAPS added value & European impact*

LEAPS will create a pan-European collaboration for IT, and thus ensure its sustainability. This will encourage RIs to work together and join forces on common software and data management needs. Through such an undertaking, European photon sources will be able to speak with one voice, act together to jointly undertake the developments, and provide common services necessary for scientists in Europe to drive innovations essential to fully exploit the scientific potential enabled through progress in the technical capabilities.

| | ALBA | DESY | DIAMOND | ELETTRA | ESRF | EUROPEAN XFEL |
|---|---|---|---|---|---|---|
| **DETECTORS** | | | | | | |
| Ultra-high continuous frame rate imager (>$10^5$ frames per second with >$10^7$ pixels) | | | | | | |
| Small pixel imager (<10 micron pixels with >$10^8$ pixels) | | | | | | |
| Large Format and high flux Energy resolving imager | | | | | | |
| Soft X-ray imager (50–2000 eV photon range) | | | | | | |
| Tender X-ray imager (500–5000 eV photon range) | | | | | | |
| High-speed multi-element spectroscopy detector (>100 elements, >$10^6$ cps/element) | | | | | | |
| Common Toolbox | | | | | | |
| **X-RAY OPTICS** | | | | | | |
| Reflective Optics | | | | | | |
| Refractive Optics | | | | | | |
| Diffractive Optics | | | | | | |
| Optomechanics, nanopositioning and thermal management | | | | | | |
| Simulation and modeling | | | | | | |
| At-wavelength metrology and test facilities | | | | | | |
| **EXPERIMENTS ENVIRONMENT** | | | | | | |
| X-ray beam diagnostics and control | | | | | | |
| Sample positioning with ultra-precise nanometre resolution and stability | | | | | | |
| Start-to-end simulations | | | | | | |
| Reliable, user friendly faster container free sample delivery schemes | | | | | | |
| Robotics for high throughput platforms as existing in protein crystallography combined with artificial intelligence | | | | | | |
| **PHOTON SOURCES** | | | | | | |
| High field small aperture magnets and related vacuum technology | | | | | | |
| High brilliance electron beam production and control | | | | | | |
| Specialised laser systems for electron beam production, FEL seeding and plasma acceleration | | | | | | |
| RF acceleration systems | | | | | | |
| Advanced instrumentation for beam control and beam diagnostic | | | | | | |
| Joint R&D on compact plasma accelerator for photon science (context EU design stydy EuPRAXIA) | | | | | | |
| **INFORMATION TECHNOLOGY** | | | | | | |
| Governance, Education and Training | | | | | | |
| Open Data policy for Open Science | | | | | | |
| High speed data acquisition | | | | | | |
| Data analysis and reduction | | | | | | |
| Federated data catalogue | | | | | | |
| Generalisation of the use of Cloud Services | | | | | | |

## Table 1. Technology Roadmap: first list of projects

| Implication level | |
|---|---|
| (orange) | High |
| (dark yellow) | Medium |
| (light yellow) | Low |

| FELIX | HZB | HZDR | INFN | ISA | MAX IV | PSI | PTB | SOLARIS | SOLEIL | COST €M |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 90 |
| Low | | High | | | | Medium | | | Low | |
| | | Low | | | Low | High | | Low | | |
| | | | High | | Low | Medium | | | High | |
| Low | | | High | | Low | Medium | | Low | High | |
| | | | High | | Low | High | | Low | High | |
| Low | | High | Medium | | Low | Medium | | Low | Medium | |
| Low | | Medium | Low | | Low | High | | | Medium | |
| | | | | | | | | | | 65 |
| | High | | High | Medium | | High | | High | High | |
| | Low | | | Medium | | Medium | | Low | | |
| | High | | | | Low | High | | Low | Medium | |
| | High | | Low | | | Medium | | Low | Medium | |
| | High | | Medium | Medium | Medium | Low | High | | Low | |
| | High | | Low | | | High | High | Low | Low | |
| | | | | | | | | | | 45 |
| | High | | | | Medium | High | | | Medium | |
| Low | High | High | | | High | High | | | High | |
| | Medium | Medium | | | | | | | Medium | |
| Low | Low | High | | | | Low | | | | |
| | High | Low | | | Low | Low | | | Low | |
| | | | | | | | | | | 198 |
| | High | | High | High | High | High | | | High | |
| | High | High | High | | High | High | | | High | |
| High | | High | High | | | High | | | | |
| High | High | | High | | High | | | | High | |
| | High | | High | | High | High | | | High | |
| High | | High | High | | | | | | High | |
| | | | | | | | | | | 137 |
| High | High | High | High | High | High | High | High | High | High | |
| High | High | High | | | High | High | | High | High | |
| High | | High | High | | High | High | | | High | |
| High | High | High | High | | High | High | | High | High | |
| High | High | High | | | High | High | | | High | |
| High | | High | High | | | High | | High | High | |

| | COST €M |
|---|---|
| **USER SERVICES AND ASSESSMENT** | **5** |
| Help Desk | |
| Website | |
| User Support | |
| Standardised performance metrics | |
| Socio-economic impact | |
| **TRAINING, EDUCATION, OUTREACH** | **25** |
| LEAPS Graduate School | |
| e-learing | |
| LEAPS European Competence Centres | |
| Schools and Workshops | |
| Career development for technical and management staff | |
| **INDUSTRY AND INNOVATION** | **85** |
| Strategic engagement and coordination | |
| Training, business development and marketing | |
| Targeted support for SME innovation | |
| Innovation-led research partenships to foster industrial competitiveness | |
| Technology valorisation and entrepreneurship | |
| Innovate procurement to support leadership of European enterprises | |
| | |
| **GRAND TOTAL Technological Roadmaps and Transversal Activities** | **650** |

**Table 2. List of Transversal Activities**

## 5. The LEAPS path towards FP9

LEAPS has created a partnership uniting all accelerator-based photon sources in Europe, organised through a governance model (Fig. 2) along with technology and RI roadmaps (Fig. 4 and 5), and including active exchanges with the scientific user community (see mirror group on academic users (ESUO, Fig. 2) and the national funding agencies (see MG-NFA Fig. 2).

LEAPS is setting up roadmaps with both short- and long-term activities to address future scientific challenges. The full implementation of the LEAPS roadmaps and related activities needs co-funding by the EC in order to maximise the impact to the European scientific community. Here, a two-step approach seems to be most efficient:

- a pilot activity under HORIZON 2020
- the LEAPS Technology Program under the next European Research & Innovation Program (FP9)

The LEAPS Technology Roadmap is complementary to generic European technology initiatives for detectors (ATTRACT[17]) and accelerators (e.g. ARIES[18]). LEAPS members will participate and strongly support these initiatives and LEAPS will be the one voice for all SRs and FELs.

### A Pilot Activity under Horizon 2020

Within the LEAPS process, focused pilot activities are proposed that will either lead to significant progress within the preparatory phase by joining forces between different laboratories, or will seed long lead research activities in preparation of the main phase of LEAPS. These activities include: improving the surface quality of reflective X-ray optics, high field small aperture magnets for new source concepts, high count rate energy discriminating X-ray detectors as well as innovation-led research activities with industry, and initiatives to develop new concepts in data management and evaluation.

Pilot activities shall allow for:

- preparing the implementation of LEAPS technology programme
- starting collaborative technology projects selected from the LEAPS roadmap; these will be selected based on their ability to maintain the EU leadership in the field, and their innovation potential
- starting the outreach and training activities on a European and global level

The funding of such pilot activities will be matched by institutional funding. At the end of the pilot activities LEAPS aims to implement an approved technology program over 5–10 years endorsed by the national funders.


Industry innovation for optics & detectors
Toolbox for new generation detectors
Sample environments
Career development for facility staff
Beamline technology
1
Future compact light sources
Computing graduate scheme
New generation accelerators
Education & training
6
Photon sources
2
Virtual learning platform
Toolbox for key machine components
LEAPS members
Single point of information
Open data management
User services & impact
5
Information technology
3
Open access research & user community growth
High-speed data acquisition, visualisation & reduction
Industry & innovation
4
Socio-economic impact mapped
Data processing & analysis
Optimising return on investment
Building the European innovation workforce
Financial support for effective collaboration

## Footnotes

1 http://www.esfri.eu/sites/default/files/u4/ESFRI_SCRIPTA_VOL2_web.pdf
2 http://ec.europa.eu/research/infrastructures/pdf/ri_policy_swd-infrastructures_2017.pdf
3 www.calipsoplus.eu
4 https://www.eucall.eu
5 www.inext-eu.org
6 www.nffa.eu
7 www.laserlab-europe.eu/
8 www.opensesame-h2020.eu/en
9 https://www.astrazeneca.com
10 http://www.matthey.com/johnson-matthey-catalysts
11 http://www.priors.com/
12 https://www.dectris.com/
13 www.a-v-s.es
14 http://www.stfc.ac.uk/files/impact-publications/new-light-on-science/
15 https://cordis.europa.eu/project/rcn/212964_en.html
16 https://www.cremlin.eu/
17 https://www.attract-eu.org
18 https://aries.web.cern.ch/

For further information please
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LEAPS League of European Accelerator-based Photon Sources