ANNUAL REPORT 2024

Developments, Results, Impressions

European XFEL

European XFEL

Annual Report 2024

The design of this annual report may appear unusual—blurred, as if touched by water. This reflects a central theme in our research: water, its mysteries, and its fundamental role in science.

In 2024, European XFEL issued its second call for proposals on water research, inviting researchers to apply for beamtime with research topics related to water.

This annual report highlights this ongoing research and features an interview with a pioneering figure in water studies at European XFEL.

We hope you enjoy this deep dive into our findings!

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Management Board foreword

Thomas Tschentscher, Nicole Elleuche, Sakura Pascarelli, Serguei Molodtsov, and Thomas Feurer

The past year was exceptional in many respects, marked by impressive scientific achievements, outstanding operational excellence, and a shared commitment across our organization.

Our scientific output continues to be amazing, and we have seen groundbreaking results that highlight what is possible through the European XFEL's experimental opportunities. These achievements underscore the role European XFEL plays in enabling highly relevant research, from deciphering dynamic and complex molecular structures to advancing materials science and beyond. Our work impacts not only the scientific community but also industries that benefit from the technological advances and insights our facility makes possible.

Among several other conferences, we were very proud to co-host with our partner DESY the 15th International Conference on Synchrotron Radiation Instrumentation (SRI2024) in Hamburg, which brought together a global community of researchers, engineers, and technicians in areas most relevant to us. The event was a great success, fostering collaboration and knowledge exchange over the course of almost a week. The harbour tour with the conference dinner in the evening was certainly a memorable event. The year was concluded with the grand opening of our new visitor and conference centre in November, which now stands as a lighthouse for dialogue, knowledge exchange, and collaboration. We would like to take this opportunity to once again thank all those involved in the planning and construction of the building and in filling it with life.

The outstanding performance of our accelerator, our three undulator lines, and our instruments has been a cornerstone of our success. Thanks to the dedication and expertise of our colleagues at DESY and our teams here on the Schenefeld campus, we have sustained and even enhanced our operational capabilities, delivering unparalleled beam quality and reliability, and have further consolidated new modes of operation, such as attosecond X-ray pulse generation and hard X-ray self-seeding.

The scientific and operational achievements also reflect our culture of collaboration and continuous improvement at European XFEL. Our staff members' engagement was on full display in our Senior Role programme, which recognized outstanding contributions across the company. Equally inspiring were our Students' and Science Days, which showcased the achievements of the next generation of researchers, engineers, and technicians. These few examples illustrate the energy and curiosity that drive our mission.

The past year also witnessed significant organizational milestones. Amongst them, the successful preparation of our strategy implementation, which will ensure that European XFEL remains at the forefront of global scientific endeavours for years to come. Additionally, the very positive outcome of the monitoring by the European Strategy Forum on Research Infrastructures (ESFRI) affirmed our commitment to excellence and our position as a critical element of Europe's research framework.

These highlights represent just a fraction of the extraordinary activities of our staff members, collaborators, and users. From day-to-day operations to special projects, the dedication and passion of everyone involved with European XFEL are what make our achievements possible. While it is impossible to list every activity, each contribution is deeply valued and vital to our progress. We would also like to take this opportunity to thank all those who support us by serving in various advisory committees; your contributions to European XFEL are highly appreciated.

As we look to the next years, we do so with confidence and optimism, based on the successes of the past year and inspired by the possibilities that lie ahead. A big thank you for your continued support and commitment to the mission of European XFEL.

Thomas Feurer **Nicole Elleuche**

Managing Directors

Serguei Molodtsov **Sakura Pascarelli** **Thomas Tschentscher**

Scientific Directors

Council Chair foreword

This annual report reviews the operation, development, and results obtained at the European XFEL in 2024, the third year of full user operation. On behalf of the European XFEL Council, I am very happy to introduce it.

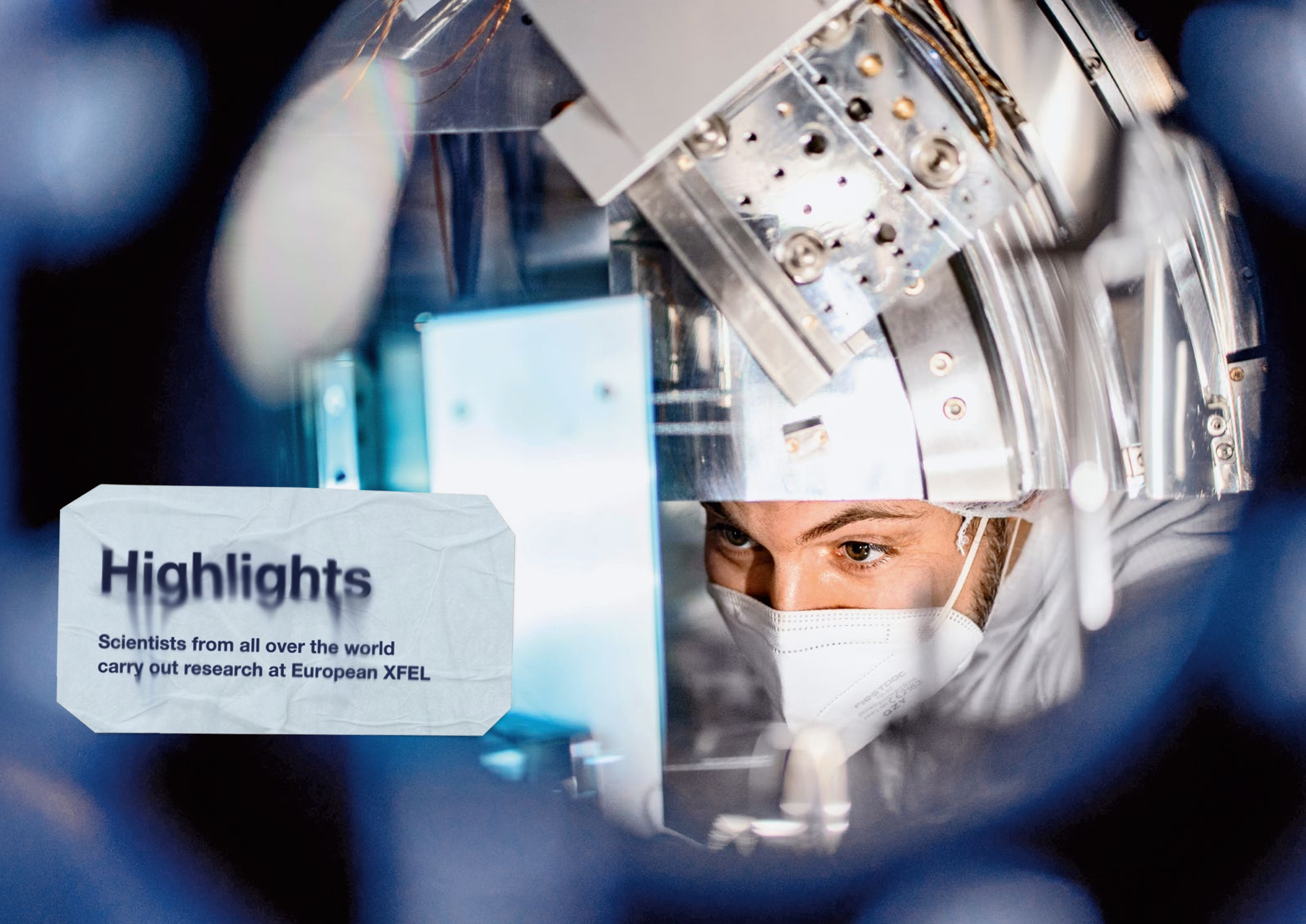
The year started with two significant events. First, the European XFEL Strategy 2030+ information day and launch marked the change of leadership of this important process, which the Council follows closely, from Robert Feidenhans'l to Thomas Feurer. Second, the Users' Meeting, held jointly with DESY, was, as usual, very successful, attracting more than 1000 registrants. In 2024, it was held in an unusual—but very practical—location: a circus tent complex! Other important events were visits by Nobel Prize laureates Anne L'Huillier and Kostya Novoselov and, near the end of the year, the opening of the Lighthouse visitor and conference centre. The Lighthouse hosts two educational laboratories for high school students and plays an important role in strengthening the ties to society at large and in the local community. The important role of European XFEL in the landscape of large-scale infrastructures was evidenced by the appointment of Thomas Feurer as the next Chair of the League of European Accelerator-based Photon Sources (LEAPS), starting in the fall of 2025—congratulations!

This annual report highlights many exciting scientific and technological results that exploit the unique characteristics of the European XFEL accelerator-based photon source, many of which address important societal challenges. Of potentially great interest and significance are experiments in the field of inertial fusion energy. These results are also made possible by the close interplay between progress in schemes for X-ray production in the accelerator and their use in experiments in many scientific fields. Novel non-standard modes of accelerator operation have been used and are reviewed in this annual report. At the same time, there is a great effort to provide relatively standard experiment setups to broaden the scientific user community, focusing on science-driven experiments, which are unique to XFELs in general and this facility in particular.

Finally, there have been important institutional developments. Ryszard Sobierajski from the Polish Academy of Sciences was elected as the new Vice Chair of the Council, starting in January 2025 for a period of two years; I very much look forward to working with him. At the same time, on behalf of the Council, I take this occasion to thank Jim Naismith from the University of Oxford, who served in the same role for two and a half years and provided great experience and problem-solving skills to the facility.

Finally, I would like to thank and congratulate all users, the European XFEL Management, and the European XFEL and DESY staff for a successful 2024. I look forward to another year of exciting scientific results in 2025!

Federico Boscherini



Highlights

Scientists from all over the world carry out research at European XFEL

The dance of the water bonds

The world's oceans absorb and store large amounts of thermal energy, buffering our climate from rapid temperature fluctuations. The clue to water's ability to store heat lies in the hydrogen bonds that connect different water molecules, but just what happens to the atomic structure of water when it is heated is not well understood. In a recent experiment, scientists used X-ray scattering at the European XFEL to observe what happens to the hydrogen bonds and how the temperature rises when water is heated. Their research reveals new insights into the dynamics and behaviour of water and how we might address the consequences of warming for our oceans.

Our oceans produce around half of the oxygen in our atmosphere, while also acting as a major carbon sink, absorbing some 90% of the world's carbon emissions. Earth's oceans also capture significant amounts of heat. For example, a 2.5 m thick layer of water contains as much heat as the entire atmospheric column above it. This buffers our climate against extreme and rapid temperature fluctuations, and so our oceans play a major role in protecting us against the true extent of the climate crisis. However, a recent report by UNESCO[1] showed that ocean temperatures have increased on average 1.45°C above pre-industrial levels, with some waters already 2°C warmer. So how much heat can the oceans absorb?

"To understand water's capacity to store thermal energy, we need to first get a better understanding of the structural dynamics of water," says Qingyu Kong, beamline scientist at the SOLEIL synchrotron in France. "If we want to understand the mechanics of a material, we need to understand its structural properties," he points out. "This is also true for water. If its structural properties change with time, and at different temperatures, understanding these changes can help us learn about water in its natural environment."

Water has one of the best-known chemical formulas on the planet—H_2O. Deceptively simple, it describes two hydrogen atoms bound to a single oxygen atom. The secret to water's ability to absorb large amounts of heat lies in the hydrogen bonds that connect different water molecules. However, despite its abundance and importance, there is still much we do not understand about the structural properties of water.

Kong and colleagues have been using the unique capabilities of the European XFEL to investigate how water's atomic structure changes when it is heated and, in particular, what happens to the hydrogen bonds connecting water molecules. For their experiment at the FXE instrument, the scientists first excited the water sample using femtosecond infrared laser pulses. They then used the ultrashort X-ray flashes produced by the European XFEL to take snapshots of the structural changes of the heated water molecules (Figure 1).

Insights into the structural behaviour of water

The series of snapshots showed the hydrogen bonds first elongating and then breaking after they absorb more energy from the laser. When the bond breaks, the energy is released as heat, leading to a temperature rise of around 5°C in the volume probed by the X-ray beam, when the dynamic water reaches equilibrium.

The experiment setup at the FXE instrument, which the scientists continue to refine, is key to being able to observe these ultrafast structural changes, says Kong. "To probe water's structural dynamics, you need both the high-intensity X-rays and the extremely short flashes," Kong continues. "FXE is a really special instrument. Its extremely high-speed X-ray 'camera' allows us to see the motion of hydrogen and oxygen atoms in real time." The ultrafast X-ray flashes produced by the European XFEL—each flash is only trillionths of a second (femtoseconds) long—allowed the scientists to create a series of snapshots capturing the fast dance of the atoms as they bend and vibrate before ultimately breaking up. These are important insights into the structural behaviour of water and its associated temperature rise, says Kong. "Crucially, learning about how liquid water can be heated in its natural environment can tell us about the ways in which our oceans are heating due to climate change," Kong says. "Such knowledge could potentially help us find better outcomes in the search to reduce the impacts of global warming."

Kong and his colleagues continue their experiments to understand the structural dynamics of water with respect to temperature. One of the most puzzling properties of water is that it is at its most dense at 4°C, which is why ice, colder than 4°C, floats on top of water. "Even after 100 years of research, the structure of liquid water is still under debate," says Kong. "Some believe there are two variations of structural domains in water that co-exist—a high-density and a low-density form. The experiment setup we have here at the European XFEL using X-ray scattering will allow us to explore this hypothesis too."

Video "Research at the European XFEL: Femtosecond X-Ray Experiment research on structural dynamics of water"

1) www.unesco.org/en/articles/new-unesco-report-rate-ocean-warming-doubled-20-years-rate-sea-level-rise-doubled-30-years

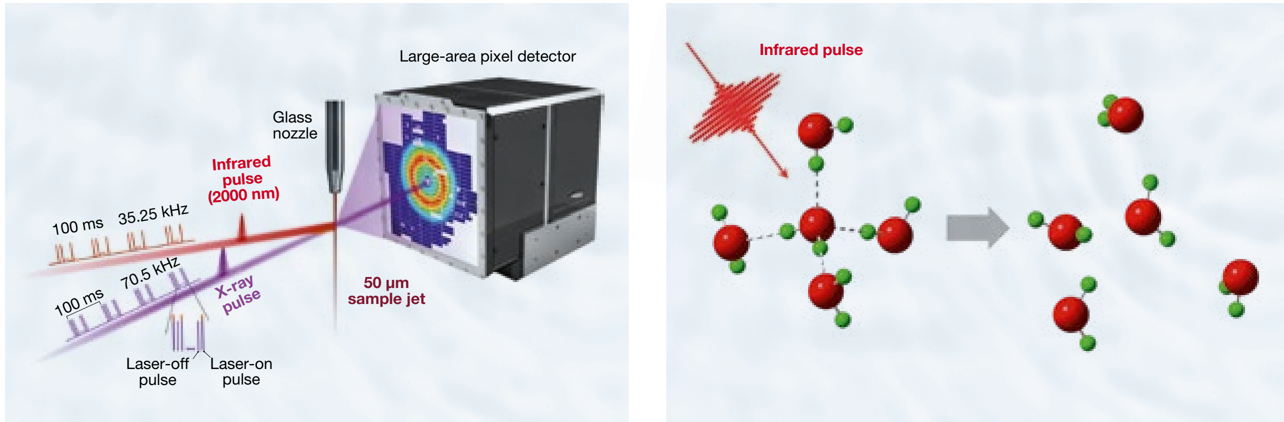


Figure 1: Ultrafast X-ray scattering reveals the structural dynamics of liquid water. Left: Liquid water is pumped through a cylindrical nozzle, producing a 50 µm thick round jet. A 2000 nm laser pulse excites the OH vibrations of water molecules. A delayed X-ray pulse with an energy of 12 keV probes the excited solution, and the scattered signal is collected by a large-area pixel detector. An instrument response function of 70 fs is obtained. Right: Excitation results in an elongation or even breaking of the hydrogen bonds.

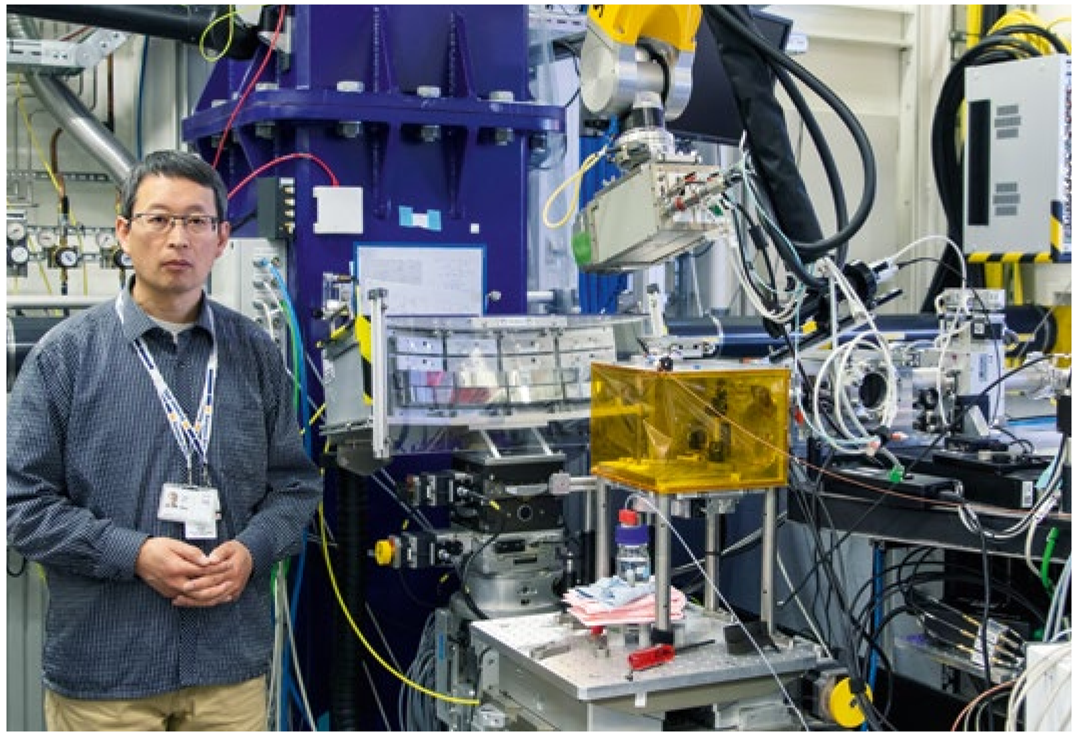


Figure 2: Qingyu Kong at the FXE instrument where the X-ray scattering experiments were carried out

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As hot as superionic ice

At the extremely high temperatures and pressures found deep in the interiors of Uranus and Neptune, water may exist in an exotic form known as superionic ice. In this unusual state, mobile hydrogen atoms diffuse through a rigid network of oxygen atoms, making superionic ice both a solid and a liquid at the same time. The fluid-like hydrogen atoms are responsible for its most striking property—high electrical conductivity—which is thought to play a key role in the origin of the icy planets' unusual magnetic fields. In a recent experiment at the European XFEL, a group of scientists investigated how different pressures influence the formation of two known forms of superionic ice, providing novel insights for planetary science.

The majority of naturally occurring ice on the Earth's surface—found in glaciers, snowflakes, and morning frost—is composed of rings of water molecules joined together to form so-called hexagonal ice. However, this is just one of 20 known forms of solid water, which come in a variety of structures depending on the environmental conditions. Superionic ice, in which the hydrogen atoms are highly mobile but the oxygen atoms remain at fixed positions, may be the most exotic form of ice discovered to date. Although not naturally occurring on Earth, superionic ice may be one of the most common forms of solid water in the universe, potentially comprising the interiors of Uranus and Neptune as well as water-rich exoplanets. "Understanding the properties of this unusual state is important for scientists who model the inside of planets," explains DESY scientist Rachel Husband. For example, the unusual magnetic fields of Uranus and Neptune can be explained by a thin shell of ionized water surrounding a superionic ice layer deep within the planet.

But how to measure something that is deep within a far-off planet? Although details can be inferred from observable properties such as a planet's brightness or magnetic field, which are directly influenced by processes and reactions deep below the surface, knowledge of these observables is often very limited. Planetary interior conditions must therefore be simulated in the lab.

However, creating superionic water is complicated by its reactive nature, and measuring its properties has been challenging due to a lack of suitable tools.

Research facilities such as the European XFEL, however, offer scientists ways to study materials under such extreme conditions, allowing them to determine the arrangement of oxygen atoms, for example. The two known forms of superionic ice are characterized by different arrangements of the oxygen atoms, which influence how easily the hydrogen atoms can diffuse through the ice structure. In both cases, the oxygen network is made up of a repeating arrangement of cube-shaped building blocks, with oxygen atoms at each corner and additional ones at different positions: Body-centred cubic superionic ice (SI-bcc) contains one oxygen atom at the centre of the cube, while the face-centred cubic form (SI-fcc) has oxygen atoms on the six faces. "Understanding the pressures and temperatures required to form these different ice phases is especially important because it determines which phases will be stable inside icy planets, and at which depths," explains Husband.

Novel heating approach to create superionic ice

At the depths at which water is thought to be present inside Uranus and Neptune, pressures range from 10 to 500 GPa—some 100 thousand to 5 million times higher than experienced on the Earth's surface—and temperatures reach thousands of degrees. Creating such extreme conditions in the lab requires specialized devices, such as diamond anvil cells (Figure 1). These can be used to squeeze small volumes of water while samples are heated using intense laser beams. "Experiments on superionic ice are very challenging, however," Husband says.

Husband and her team developed a novel heating approach to create superionic ice. The team compressed water samples with diamond anvil cells at the HED instrument and irradiated them with 300 ultrashort X-ray pulses in rapid succession. Due to their high intensity and extremely short duration, the X-ray pulses can potentially heat materials to very high temperatures. However, water does not absorb X-rays very efficiently. "We found that directly blasting the samples with X-rays was not an effective heating method, so we encapsulated our water samples in metallic, doughnut-like crucibles", explains Husband. "These acted like miniature furnaces to indirectly heat the water." The technique allowed the team to heat water to temperatures of several thousand degrees—hot enough to transform it into the superionic state. This created a zigzag temperature profile, where the water was heated and cooled between adjacent X-ray pulses (Figure 2). Using the same ultrashort pulses, the team then took structural snapshots of the superionic crystals (Figure 3).

The scientists were able to show that, while SI-bcc could be formed at all pressures between 30 and 70 GPa, SI-fcc could only be created above 50 GPa. This finding contrasts with results of previous work. The scientists concluded that, due to the unique temperature profile experienced in these X-ray heating experiments, the water sample did not remain at the required temperatures long enough for SI-fcc to form.

"These new insights may have implications for our understanding of the interior dynamics in icy planets," says Husband. "The preferential crystallization of SI-bcc could mean that small amounts of SI-bcc form during dynamic freezing processes in convecting layers, such as at the predicted boundary between ionic water and superionic ice, even though SI-fcc should be stable. This could result in differences in physical properties, such as thermal and electrical conductivity across ice layers, which could influence the planet's magnetic field."

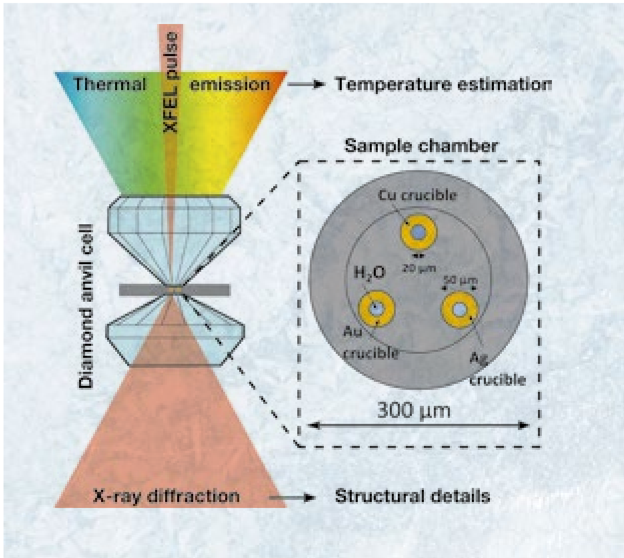

Figure 1: Illustration of the sample geometry within the diamond anvil cell, showing three metallic crucibles that were used to heat ice at high pressures

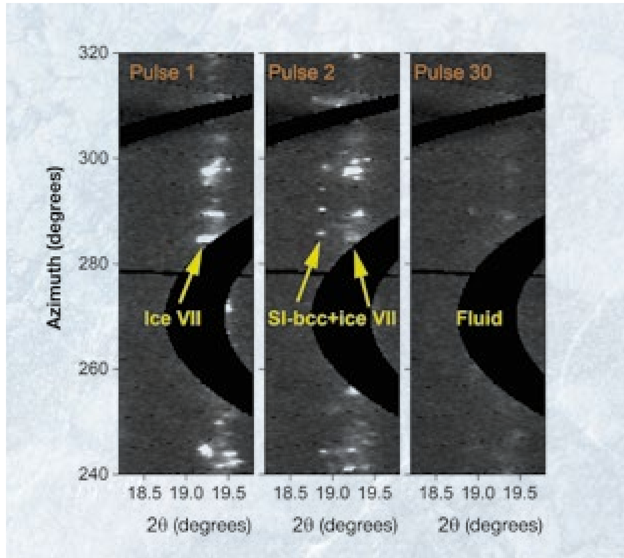

Figure 3: X-ray diffraction snapshots collected from the sample during X-ray heating, capturing the transformation to SI-bcc at high temperatures

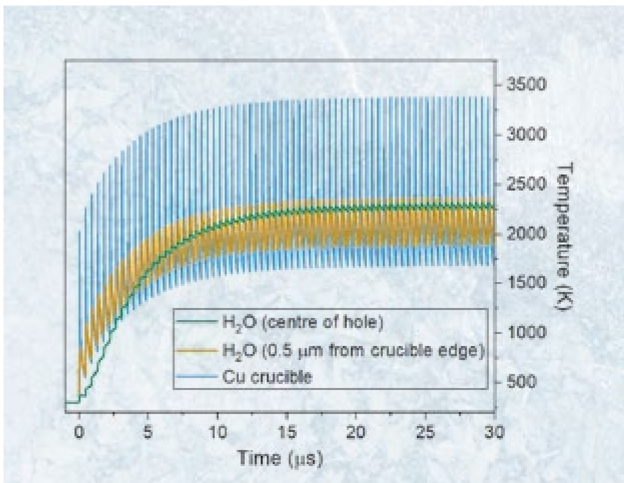

Figure 2: Temperature profile in the sample and metallic crucible created using the novel X-ray heating approach

Authors
R.J. Husband, H.P. Liermann, J.D. McHardy, R.S. McWilliams, A.F. Goncharov, V.B. Prakapenka, E. Edmund, S. Chariton, Z. Konôpková, C. Strohm, C. Sanchez-Valle, M. Frost, L. Andriambariarijaona, K. Appel, C. Baehtz, O.B. Ball, R. Briggs, J. Buchen, V. Cerantola, J. Choi, A.L. Coleman, H. Cynn, A. Dwivedi, H. Graafsma, H. Hwang, E. Koemets, T. Laurus, Y. Lee, X. Li, H. Marquardt, A. Mondal, M. Nakatsutsumi, S. Ninet, E. Pace, C. Pepin, C. Prescher, S. Stern, J. Sztuk-Dambietz, U. Zastrau, M.I. McMahon

Reference

R.J. Husband et al.: "Phase transition kinetics of superionic H_2O ice phases revealed by megahertz X-ray free-electron laser-heating experiments", Nature Communications 15, 8256 (2024), doi:10.1038/s41467-024-52505-0

European XFEL elicits secrets from drug-delivery nanogel

Nanogels are promising drug delivery systems, for example in cancer treatment regimes, where localized drug application helps reduce the severe side effects of chemotherapy. Nanogel particles react to changes in temperature, but following these extremely rapid structural changes experimentally has proven difficult—until now. In a recent experiment at the MID instrument using X-ray photon correlation spectroscopy (XPCS), an international team of scientists took a closer look at the behaviour of an important nanogel, PNIPAm. The results could help researchers improve the properties of the polymer for a range of applications, including the development of more efficient drug delivery systems.

Chemotherapy drugs are often toxic by nature and have severe and debilitating effects on the patient. Drug delivery systems that target specific tissues and thus deliver potent drugs selectively to a patient's cancerous cells can help reduce these side effects. Nanogel polymers—large macromolecules consisting of repeated subunits of smaller molecules—are such systems. When exposed to changes in temperature, they change their size, thus releasing the drug molecules.

One such nanogel polymer is poly-N-isopropylacrylamide (PNIPAm). Typically dissolved in water, PNIPAm switches from a hydrophilic, water-attractive state to a hydrophobic, water-repellent state when exposed to temperatures above 32°C. By rapidly expelling water, the nanogel particles change in size and release the drugs they carry.

To optimize such polymers for different applications, experiment data is required on how theses rapid transitions actually occur. Until now, however, it has been difficult to follow them experimentally. Using the XPCS technique, a research team led by Felix Lehmkühler from DESY recently investigated the rapid temperature-dependent changes in PNIPAm nanogel particles around 100 nm in size, or 0.0001 mm. The team consisted of scientists from DESY, the University of Padua in Italy, and European XFEL.

"Thanks to the high repetition rate of the European XFEL, we were able to follow the structure and motion of the nanogels with a sufficient time resolution," says Johannes Möller, instrument scientist at the MID instrument. The X-ray pulses were used both to heat the nanoparticles and to capture the way their structure changed as they moved in the surrounding water.

Understanding the swelling and collapsing of nanogel polymers

"With the data obtained at the European XFEL, we now have a better understanding of the swelling and collapsing of the polymer," says Felix Lehmkühler, one of the team leaders. "In contrast to previous studies, which were limited to indirect measurements of the kinetics of swelling or collapsing, we found that the nanogels shrink quite rapidly, on the timescale of 100 ns, but that swelling typically is slower by two to three orders of magnitude in time," explains Lehmkühler.

The results could help researchers improve the features of the polymer for the development of more efficient drug delivery systems as well as for use in other applications, such as tissue engineering and biocompatible temperature sensors.

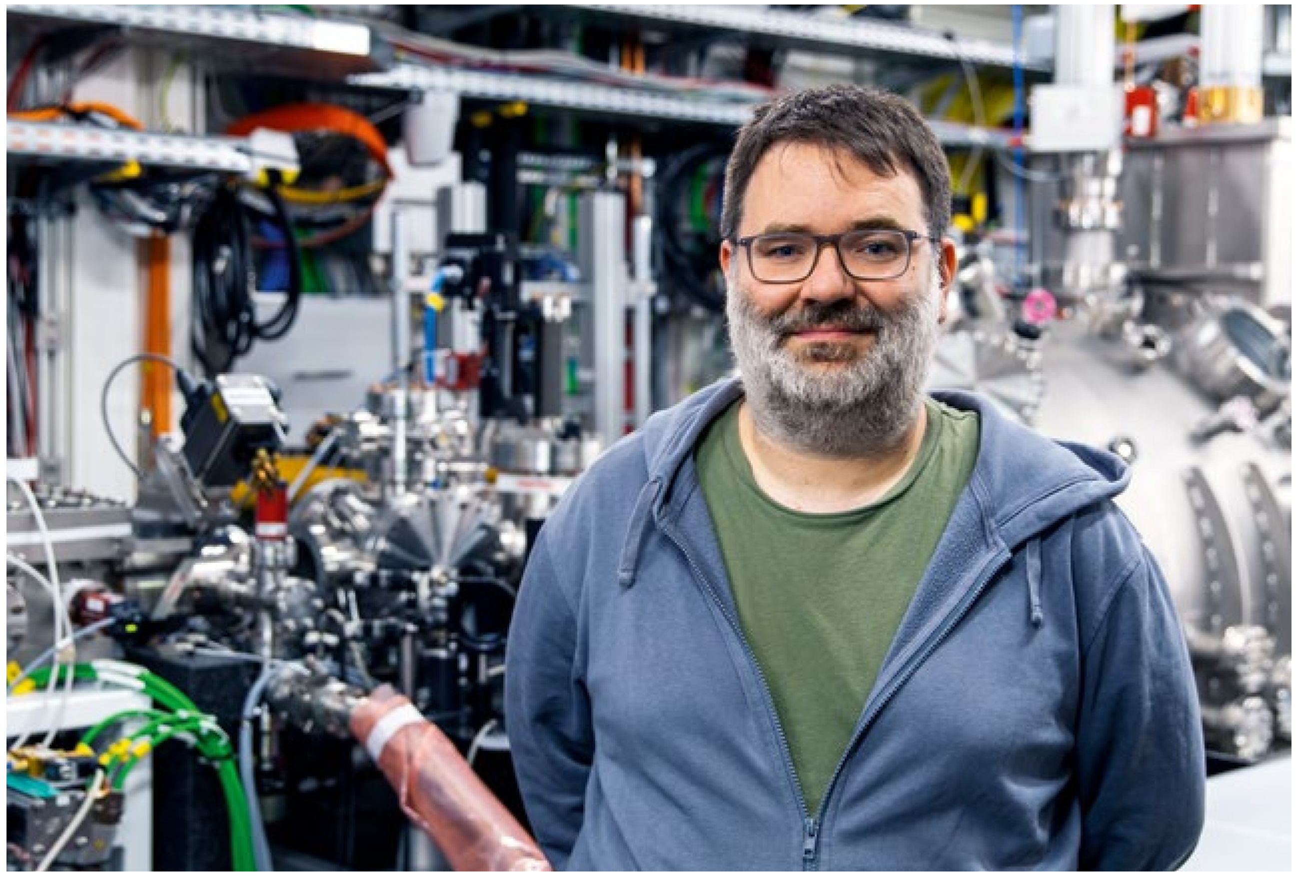

Figure 1: Felix Lehmkühler in front of the MID instrument where the experiments were carried out

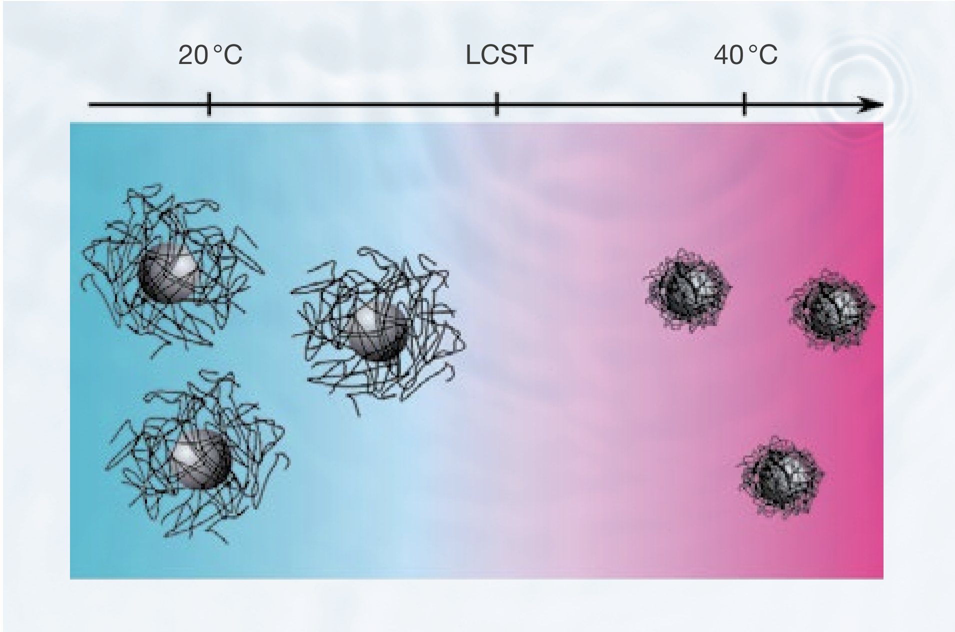

Figure 2: Above 32°C, the lower critical solution temperature (LCST), PNIPAm switches from a hydrophilic to a hydrophobic state. As a consequence, the nanogel particles rapidly change their size by expelling water.

Authors
F. Dallari, I. Lokteva, J. Möller, W. Roseker, C. Goy, F. Westermeier, U. Boesenberg, J. Hallmann, A. Rodriguez-Fernandez, M. Scholz, R. Shayduk, A. Madsen, G. Grübel, F. Lehmkühler

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F. Dallari et al.: "Real-time swelling-collapse kinetics of nanogels driven by XFEL pulses", Science Advances 10, eadm7876 (2024), doi:10.1126/sciadv.adm7876

Unveiling photogenerated charge-transfer excitons in NiO

Researchers at the SCS instrument reveal ultrafast exciton dynamics with time-resolved resonant inelastic X-ray scattering. This could help to understand the processes that govern the absorption of light in various oxide materials, including photoactive and superconducting ones.

Understanding how the quantum material environment is transiently modified through laser pulses is key to controlling the material properties and designing devices for innovative applications. A recent experiment at the SCS instrument provided new insights into how nickel oxide (NiO) absorbs ultraviolet (UV) light, generating short-lived charge-transfer excitons (Figure 1a). Excitons are bound states of an electron and a "hole"—a space where an electron is missing. Both attract each other because the hole acts like a positive charge. Using time-resolved resonant inelastic X-ray scattering (trRIXS), the researchers were able to observe the formation and decay of these excitons, which is often ultrafast. The results offer new perspectives on the interplay between local and collective electronic excitations in correlated materials.

A window into charge-transfer dynamics

NiO is a prototypical charge-transfer insulator: According to conventional band theory, it should be a conductor, but it is actually an insulator. The reason for this behaviour is the strong electron–electron correlation that governs its optical and electronic properties. Charge-transfer excitons are crucial to light–matter interaction in several transition metal oxides, such as NiO. However, the direct observation of these excitons has remained challenging. "Conventional optical techniques primarily probe long-range electronic responses, leaving the role of localized interactions unclear," explains Giacomo Ghiringhelli of Politecnico di Milano, Italy, the principal investigator of the experiment. To overcome this limitation, the research team employed high-resolution trRIXS, a technique with enhanced sensitivity to the local electronic structure. The experiment revealed that, upon absorbing UV photons of 4.66 eV energy, excitons are generated that exist on a few-picosecond timescale before vanishing, leaving long-lasting traces of their transient existence.

The researchers focused laser pulses of a wavelength of 266 nm on a single crystal of NiO. By probing it with femtosecond X-ray pulses tuned around the 852 eV absorption resonance known as L_3 peak and by changing the delay between the laser and the X-ray pulses, the team observed the immediate appearance of spectral signatures of charge-transfer excitons and their subsequent decay (Figure 1b). Notably, a striking energy gain feature was detected in the inelastic scattering spectra measured with the hRIXS spectrometer, indicating the presence of localized excitonic states. "The analysis showed that these excitons appear instantaneously, within the time resolution of the experiment, and decay with a characteristic time constant of about two picoseconds," Ghiringhelli says. Conversely, spectral modifications in the "normal" energy loss part of the RIXS spectra, possibly due to the presence of delocalized holes in the oxygen band not related to localized excitons, persist for tens of picoseconds.

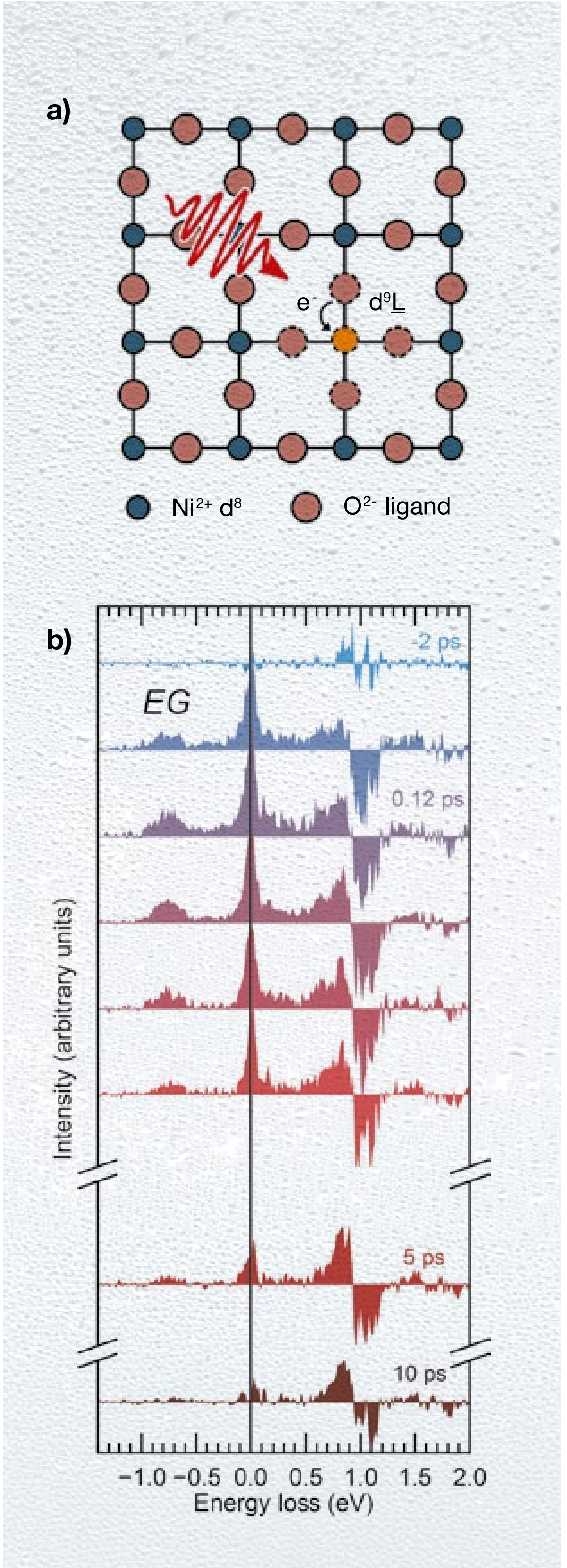


Figure 1: (a) Sketch of charge-transfer exciton formation in NiO. (b) Differential trRIXS spectra as a function of time delay. The energy gain (EG) feature follows the lifetime of the charge-transfer excitons.

New framework for interpreting the optical properties of quantum materials

The findings provide a new framework for interpreting the optical properties of a vast class of quantum materials. The detection of charge-transfer excitons and their short-lived nature suggests that similar processes may occur in other correlated oxides, including cuprate superconductors and many oxides known for their interesting photochemical or photoelectric properties.

"This study marks a step toward unravelling the complex ultrafast interactions of light with strongly correlated materials," says Andreas Scherz, leading scientist at the SCS instrument. Future experiments with improved energy resolution and precise control of the photo-excitation could further elucidate the connection between charge-transfer excitons and collective excitations, such as magnons and phonons. "The European XFEL and the SCS instrument are particularly suitable for this purpose," adds Scherz. The insights gained from this work could help in the design of novel materials for optoelectronic applications, quantum technologies, and photochemistry.

Authors
G. Merzoni, L. Martinelli, S. Parchenko, S.F.R. TenHuisen, V. Lebedev, L. Adriano, A. Alic, D.R. Baykusheva, R. Carley, S. Dal Conte, O. Dogav, A. Föhlisch, N. Gerasimova, M.W. Haverkort, M. Kusch, T. Laarmann, A.I. Lichtenstein, L. Mercadier, Q. Qiu, S.S.N. Lalithambika, S. Techert, M. Teichmann, B. Van Kuiken, Z. Yin, Y.Y. Peng, W.-S. Lee, S.G. Chiuzbaian, M. Först, M.M. Sala, G. Cerullo, T. Schmitt, M. Mitrano, M.P.M. Dean, J. Schlappa, A. Scherz, G. Ghiringhelli

Reference
G. Merzoni et al.: "Photo-generated charge-transfer excitons in NiO" (2025), in preparation

Measuring femtosecond lifetimes of electronic dipole transitions

Scientists at the SQS instrument used the two-colour ability of the SASE3 soft X-ray undulator to measure the lifetimes of astrophysically important electric dipole transitions of helium- and neon-like ions with high precision.

Most baryonic matter in the universe—i.e. matter made up of baryons, such as protons and neutrons, including atoms of any sort—is ionized. Spectroscopic observations of X-ray emissions from highly charged ions provide crucial data on electron temperature, density, chemical abundances, and opacities in astrophysical objects. One key diagnostic technique is analysing the intensity ratio of two strong emission lines with different oscillator strengths from abundant helium- or neon-like ions to probe for resonance scattering in an otherwise optically thin plasma. This method constrains gas turbulence and column density in stellar coronae and diffuse hot gas in galaxy clusters and groups.

“Such radiative transfer calculations rely heavily on accurate atomic physics data of line emission energies and transition oscillator strengths, which are core properties of quantum systems,” explains Thomas Baumann, scientist for X-ray spectroscopy at the SQS instrument. Yet the transition oscillator strengths, which express the probability of absorption or emission of electromagnetic radiation in transitions between energy levels of an atom or molecule, have rarely been tested better than at the 10% level for highly charged ions. Therefore, accurate laboratory measurements of oscillator strengths are crucial for understanding of astrophysical plasmas.

Thomas Baumann and his team developed a technique to directly observe the decays of excited states in highly ionized atomic systems with lifetimes on the femtosecond scale by means of an X-ray pump – X-ray probe scheme. The researchers combined two recent technical developments of European XFEL.

On the beam delivery side, the two-colour mode of the SASE3 undulator was used to create two independent pulses with different photon energies (or “colours”). Both pulses had short durations below 10 fs, a spectral bandwidth around 0.5%, and pulse energies of several tens of microjoules. The pulses were created with a variable delay between 0 and about 800 fs, introduced by a magnetic chicane between the undulator segments. Changing this delay in few-femtosecond steps created the timescale on which the lifetimes were probed.

On the target delivery side, a recently built electron beam ion trap (EBIT) was deployed at the SQS instrument (Figure 1). The device produces highly charged ions with a well-tunable charge state distribution and traps them in an electrostatic potential. “The experiment was performed inside the EBIT, as the trapped highly charged ions were overlapped with the X-ray beam,” says Moto Togawa from SQS, a Ph.D. student working on the project. Different diagnostic tools allowed for investigating their interaction.

The measurement concept was demonstrated on the rather simple and well-understood system of Ne^{8+}. Being a helium-like system, this highly charged neon ion has only two bound electrons left in its K-shell. The transition of interest was $1s\,2p\ ^1P_1 \rightarrow 1s^2\ ^1S_0$, where one electron changes from the L- to the K-shell and emits a photon of 922 eV energy (Figure 2). The first-colour FEL pulse was tuned to resonantly excite this transition in the trapped Ne^{8+} ions, initiating the experiment as a pump pulse. The second-colour FEL pulse was then introduced as a probe after a tunable delay.

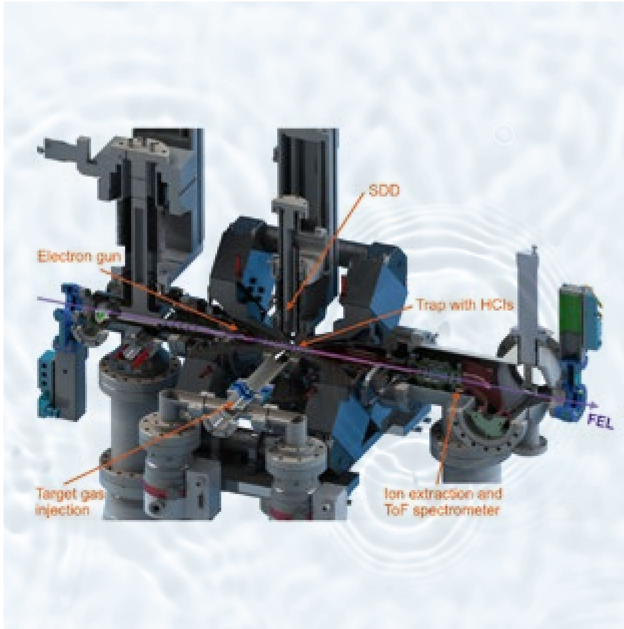


Figure 1: CAD representation of the electron beam ion trap (EBIT). Highly charged ions (HCIs) are produced and trapped in a magnetically compressed electron beam. The trap content is overlapped with the X-ray beam, and photoemission from the interaction is monitored with a silicon drift detector (SDD). After interaction, the trap content is extracted and analysed in an ion time-of-flight (ToF) spectrometer.

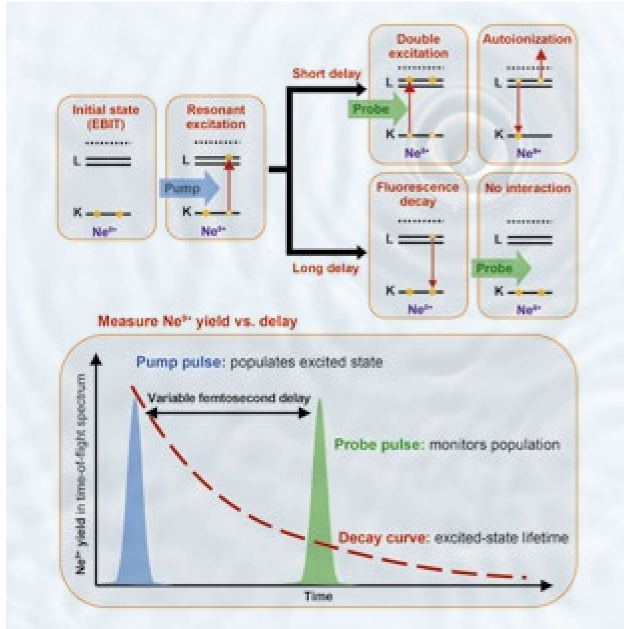


Figure 2: Top: Schematic concept of the pump–probe measurement. The target ions (here Ne^{8+}) are produced and trapped by the EBIT. The first FEL pulse (“pump”) resonantly excites the transition. After a delay variable on a femtosecond timescale, the second pulse (“probe”) probes the excited state. Bottom: The delay dependency of the Ne^{9+} ion yield represents the decay of the excited state defined by its lifetime.

At short delays, the excited ion could also absorb the second-colour photon. Its energy was tuned to resonantly excite the second electron from the K-shell with 1003 eV, producing a short-lived doubly excited state. This double excitation has a high cross section, making the measurement scheme very efficient. The doubly excited state decays within about 3 fs via an Auger–Meitner decay, emitting one of the two electrons and leaving a Ne^{9+} ion in its ground state.

Revealing the lifetime of excited states on the femtosecond scale

At long delays, however, the excited system has enough time to decay, emitting a photon and leaving a Ne^{8+} ion in its ground state. This ground state ion could not interact with the second-colour probe photons, as their energy was not tuned to any resonance in this system and was too low for non-resonant ionization of a K-shell electron.

After the ions were irradiated, the trap content was extracted and the ion charge state distribution analysed. The team then determined the decay curve of the excited state by comparing the Ne^{9+} and Ne^{8+} population at different delays. The excited-state lifetime was then revealed by an exponential decay curve fit. “This yielded an excited-state lifetime of 109.0 fs with a statistical error of 2.7 fs,” reports Baumann.

“We then extended the measurements to a prominent astrophysical target ion, namely neon-like Fe^{16+},” says co-proposer Chintan Shah, an expert on laboratory astrophysics and X-ray spectroscopy working at NASA Goddard Space Flight Center. The strong $3C\ ([2p^5_{1/2}\ 3d_{3/2}]_{J=1} \rightarrow [2p^6]_{J=0})$ and $3D\ ([2p^5_{3/2}\ 3d_{5/2}]_{J=1} \rightarrow [2p^6]_{J=0})$ transitions have been studied for decades, as their intensity ratio provides crucial diagnostics of astrophysical plasmas. Nonetheless, the predicted ratios were in disagreement with the lower values observed in laboratories and space, making them key candidates for the present study. “We applied our pump–probe scheme to the Fe^{16+} system to perform direct measurements of excited-state lifetimes of 3*C* at 825.9 eV and 3*D* at 812.4 eV,” explains Shah. “While detailed analysis of all systematic contributions is still ongoing, a preliminary value of 46.6 ± 0.8 fs (statistical error) for 3*C* can be reported, which is on par with the most precise spectroscopic measurements to date.”

“Though demonstrated on closed-shell ions, the method can be extended to other highly charged ions,” says Michael Meyer, leading scientist of the SQS group. “Furthermore, the method will profit from the upcoming optical delay line upgrade of the SASE3 undulator, as this will allow for accurate determination of the temporal overlap of both pulses.”

Video “Lifetime determination of key astrophysical transitions in highly charged ions at European XFEL”

Authors
Th. Baumann, M. Togawa, Ch. Shah, M. Meyer

New avenues for research and innovation in virology

At the SPB/SFX instrument, scientists explored the structural dynamics of the protein shells—called capsids—that enclose the genetic material of viruses. Specifically, they examined the behaviour of capsids of the bacteriophage MS2 under conditions of dehydration. MS2 is an icosahedral, single-stranded RNA virus that infects the bacterium *Escherichia coli*, for example. It is known for its resilience and ability to adapt to environmental stresses.

The capsid's design is critical for ensuring genomic stability and facilitating interactions with host cells. However, viruses are often confronted with environments that challenge their structural integrity, for example through dehydration. Theoretical studies have long suggested that capsids may undergo low-energy buckling transitions—i.e. sudden changes in shape—to adapt to such stresses, but direct experimental evidence has been lacking.

The work of Abhishek Mall from the Max Planck Institute for the Structure and Dynamics of Matter, Germany, and his colleagues fills that gap. On their way to the XFEL beam, aerosolized droplets containing MS2 undergo continuous drying, mimicking the natural dehydration process (Figure 1). "We used single-particle imaging at SPB/SFX to investigate the morphological changes in viral capsids during aerosolization," the researcher says. He and his colleagues collected diffraction patterns from hundreds of thousands of individual MS2 particles. The ultrafast nature of XFELs makes it possible to study the huge variation in the degrees of dehydration. "This high-throughput technique enabled us to use machine learning tools, including deep learning algorithms," explains Mall. These computational approaches were instrumental in classifying and reconstructing the structural variations of the capsids, providing a comprehensive view of their conformational landscape.

Direct experimental evidence for theoretically predicted mechanism

One of the key findings of the study was the observation of a buckling transition in the MS2 capsids as they transitioned from a hydrated to a dehydrated state. In the hydrated state, the capsids exhibited near-perfect icosahedral symmetry, as determined by cryo-electron microscopy. "However, as dehydration progressed, the capsids adopted more compact conformations, with significant deviations from icosahedral symmetry", describes Mall. These structural changes were not uniform across the capsid but occurred incoherently, suggesting that the transition involved localized buckling rather than a concerted capsid-wide transformation. "This finding is particularly significant as it provides direct experimental evidence for a mechanism that had previously been only theoretically predicted," adds Richard Bean, leading scientist at the SPB/SFX instrument.

The investigation also delved into the molecular mechanisms underlying these morphological changes. "Molecular dynamics simulations revealed that a flexible segment of the protein called 'FG loop' plays a crucial role in the observed structural transformations," states Mall. The FG loop exhibits high mobility under dehydrating conditions, particularly in two subunits, called A and C, of the capsid (Figure 2). "These movements led to the contraction of the FG loops around the three-fold and five-fold pores of the capsid, resulting in a more compact structure," adds Mall. The researchers assume that this contraction is driven by the loss of stabilizing water molecules, which are critical for maintaining the extended conformation of the FG loops. This localized destabilization probably acts as a protective mechanism, minimizing the exposure of the viral genome to the environment and enhancing the capsid's resilience.

Crucial to the study was its methodological innovation. By integrating single-particle imaging (SPI) with advanced machine learning techniques, such as β-variational autoencoders (β-VAEs), the researchers were able to analyse structural heterogeneity across a large data set of diffraction patterns. "The use of β-VAEs allowed for the classification of particles into a continuous latent space, capturing variations in size and shape with remarkable precision," explains Mall. This approach not only identified the endpoints of the structural transition—from hydrated to dehydrated states—but also mapped the intermediate conformations that bridged these states. "Such detailed analysis would have been impossible with traditional ensemble-averaged methods," Bean adds.

The structural adaptability observed in the capsids provides a fundamental understanding of how viruses survive under environmental stresses. This knowledge is particularly relevant for viruses transmitted by aerosols, including many human pathogens. "By elucidating the mechanisms that enable viral resilience, the work of Abhishek Mall and his colleagues lays the ground for potential applications in virology and public health, for instance to develop antiviral strategies," says Sakura Pascarelli, Scientific Director at European XFEL.

"The ability to capture and analyse the structural landscape of viral capsids in real time represents a significant advancement in structural biology via single-particle imaging," explains Bean. "The methods employed in this study can be extended to other biomolecular systems, providing a powerful tool for investigating dynamic processes that are otherwise challenging to study."

The findings shed light on a critical aspect of viral survival. "This work not only advances our understanding of viral mechanics but also opens new avenues for research and innovation in virology and structural biology," underlines Pascarelli.

Authors
A. Mall, A. Munke, Z. Shen, P. Mazumder, J. Bielecki, E. Juncheng, A. Estillore, C. Kim, R. Letrun, J. Lübke, S. Rafie-Zinedine, A. Round, E. Round, M. Rütten, A.K. Samanta, A. Sarma, T. Sato, F. Schulz, C. Seuring, T. Wollweber, L. Worbs, P. Vagovic, R. Bean, A.P. Mancuso, N.-T. Duane Loh, T. Beck, J. Küpper, F.R.N.C. Maia, H.N. Chapman, K. Ayyer

Reference
Abhishek Mall et al.: "Observation of aerosolization-induced morphological changes in viral capsids", arXiv:2407.11687v1 [q-bio.BM] (2024), doi:10.48550/arXiv.2407.11687

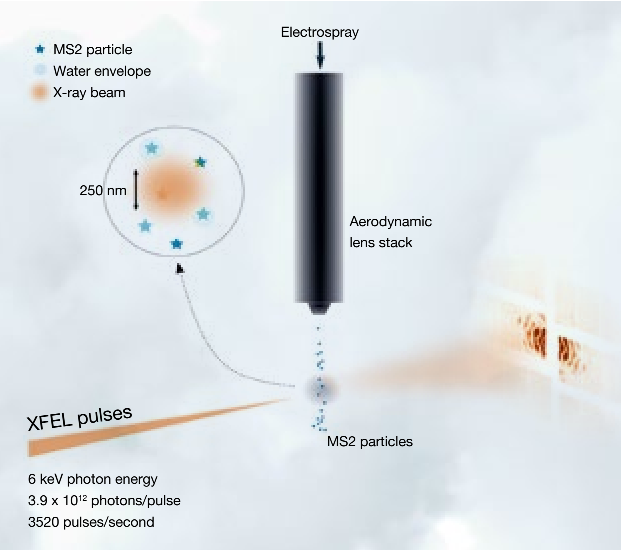


Figure 1: X-ray single-particle imaging experiment at the SPB/SFX instrument. MS2 bacteriophage particles of about 27 nm in diameter were aerosolized using an electrospray and focused into the interaction region with an X-ray beam with a focus of 250 x 250 nm^2.

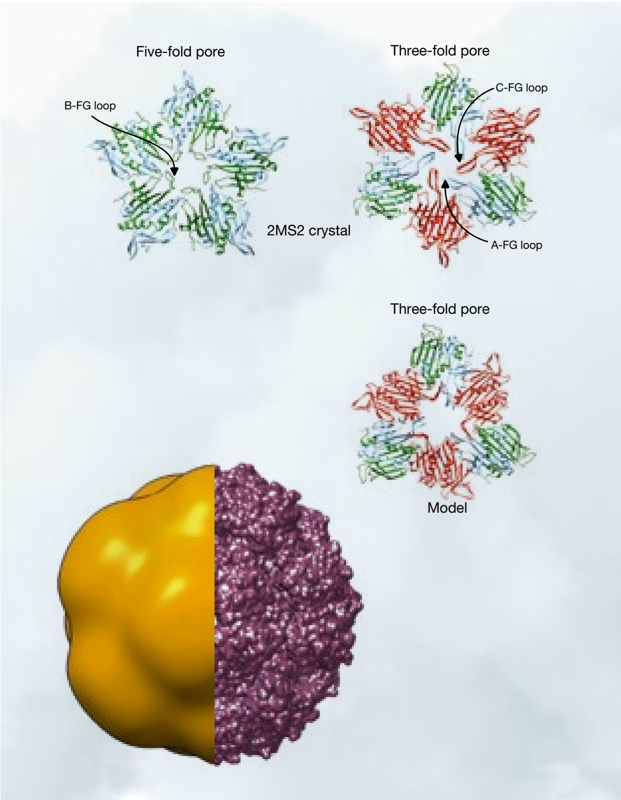


Figure 2: Top: Model showing the pentameric (composed of five subunits, left) and hexameric (composed of six subunits, right) faces of an icosahedral capsid shell from the bacteriophage 2MS2. The FG loops are crucial for capsid assembly and curvature. Centre right: Structurally transformed hexameric building block of the dehydrated capsid modelled from the X-ray SPI map. Bottom: Map generated from the model of the structurally transformed capsid (at 6.1 nm resolution).

Installation of novel photocathode lasers

The Next-Generation Photocathode Laser (NEPAL) is a new type of photocathode laser system developed for the European XFEL to generate the free electrons at the injector. Operating in burst mode with individual pulse intensity control for fast charge feedback, it delivers temporally and spatially shaped picosecond deep-ultraviolet (UV) pulses. This enables the generation of the very low-emittance electron beams required for producing the highest X-ray photon energies.

For all XFELs worldwide, low-emittance and high-brightness electron beams are essential. Key to their production are mainly excellent laser-driven photoelectron guns. Some years ago, European XFEL's partner DESY initiated an in-house development programme for the next-generation photocathode laser system NEPAL.

The target requirements were

- **Robust and stable operation**
  Supporting a superconducting XFEL user facility with over 8000 h of annual operation, delivering bursts of deep-UV pulses (with several microjoule energy) at an intra-burst repetition rate of up to 4.5 MHz
- **Flexible operation**
  Burst envelope shaping and individual pulse energy control
- **Flexible pulse shape output**
  Generating laser pulses with durations of 1–20 ps, including pulse shape control, and enabling dual-laser operation for advanced FEL modes

The NEPAL design incorporates an ytterbium fibre oscillator that produces femtosecond near-infrared (NIR) pulses tightly synchronized to the facility's main RF oscillator. These pulses are amplified to 20 mW using a multistage fibre amplifier chain, including a programmable spectral shaper for temporal pulse shaping. A power amplifier based on Yb:YAG technology, developed in collaboration with an industrial partner, boosts the intra-burst average power up to 200 W and enables burst picking (Figure 1). The NIR beam is then converted to UV using non-linear crystals, spatially shaped, and transported approximately 20 m to the photocathode, where the electrons are generated. The system is fully integrated into the accelerator control system, allowing operators or automated software agents to adjust parameters, such as pulse energy, spot size, timing, burst envelope, and pulse pattern. It also supports monitoring of laser status and condition as well as remote-control access for troubleshooting.

Extensive testing led to the final design. Five systems were produced: two for European XFEL (called NEPAL-X1 and NEPAL-X2), two for the FLASH FEL facility at DESY in Hamburg, and one for the PITZ photoinjector test facility at DESY in Zeuthen.

The new NEPAL lasers and the existing Nd:YVO4-based photocathode laser XlnL2 are combined via polarization and wavelength multiplexing before the beam transport line. This enables special operation modes that require multiple simultaneous laser pulses, while also providing redundancy. Operators can switch between lasers, ensuring continuous facility operation.

During the installation at the European XFEL, a key challenge was to avoid any disturbance to ongoing operations. "We had to plan all work carefully and execute potentially disruptive work within scheduled facility shutdowns," says Christoph Mahnke, who led the installation.

Opening the door to new pulse-shaping capabilities and twin-bunch operation

The final commissioning of the photoinjector with NEPAL-X1 and NEPAL-X2 took place in January 2024 and June 2024, respectively. NEPAL-X1 was immediately integrated into routine operation, while NEPAL-X2 was initially used to explore new laser capabilities. During commissioning, the temporal shaping capability of the NEPAL system (Figure 2) allowed electron beam properties to match those produced by XlnL2, enabling seamless accelerator tuning and fast switching between lasers with minimal adjustments.

"We are very pleased with the smooth transition," emphasizes Winfried Decking, head of the DESY group responsible for coordinating European XFEL accelerator operations. "The new systems work more reliably than the existing one, with matched or even better performance. They could already be used to investigate new pulse-shaping capabilities, which will be essential for future non-standard FEL modes of the European XFEL. The ability to vary the intensity bunch by bunch will facilitate daily operation with constantly changing requests for different bunch patterns. Finally, having two lasers available will open the door to twin-bunch operation, with FEL pulses separated by multiples of 770 ps or very closely spaced in the 100 fs range."

The NEPAL lasers enable an excellent injector emittance of 0.375 mm·mrad at 250 pC bunch charge. While routine operations currently utilize simple pulse shaping (adjusting Gaussian pulse durations via amplitude shaping), advanced techniques and algorithms for generating emittance-optimized electron beams are explored in the R&D project OPAL-FEL. "In this project, we address the challenge of navigating a large parameter space by developing machine learning algorithms that work with both simulations and experimental data to determine optimal operating conditions," says Henrik Tünnermann, principal investigator of OPAL-FEL. The collaboration between DESY, local universities, and an industry partner is funded by the German Federal Ministry of Education and Research (BMBF) within the ErUM Data programme. "The programmable pulse shaper gives significant flexibility to further optimize the beam emittance," adds Tünnermann.

The simultaneous operation of multiple lasers for twin-bunch production was also tested (Figure 3). "The new laser capabilities hold great potential for applications such as attosecond pulse production, high-energy X-ray self-seeding, and plasma wakefield acceleration," comments Marc Guetg, who investigates new FEL physics concepts and tested the new laser capabilities. "We are excited about the wide range of advanced features the NEPAL laser can now provide and look forward to seeing those features enabling new XFEL science," says Ingmar Hartl, head of the DESY group leading the project.

Figure 1: Fibre frontend and power amplifier of the NEPAL-X1 laser during installation

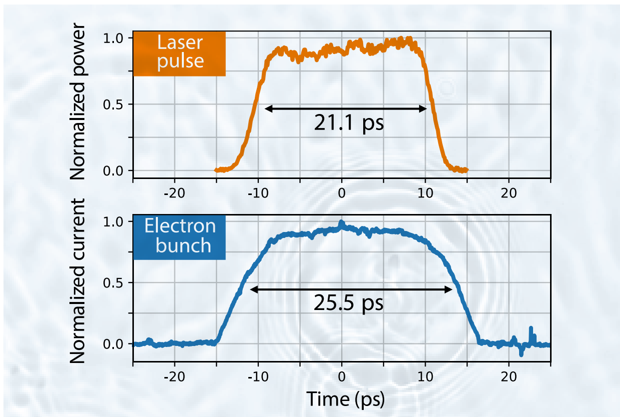


Figure 2: The NEPAL system makes it possible to change the temporal shape of the laser pulses. A flat-top UV laser pulse of 21.1 ps was generated here, resulting in a similarly shaped, slightly longer electron bunch in the injector.

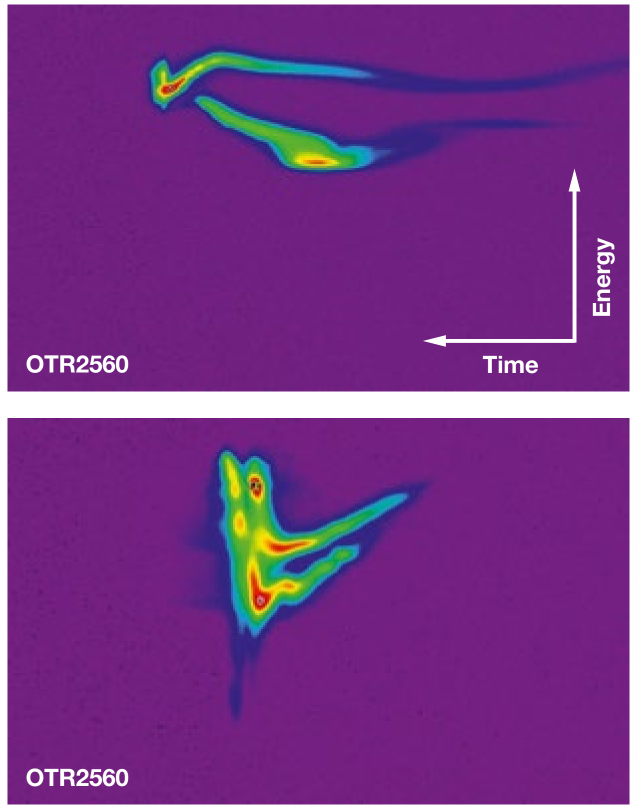


Figure 3: The two NEPAL laser systems can be used simultaneously to generate "twin" electron bunches, which may enable new FEL operation modes. Top: The top panel shows two closely spaced electron bunches interacting. Bottom: It is also possible to place the bunches in different RF buckets, allowing lasing at two colours.

News and events

Having fun during the official opening of the new Lighthouse visitor and conference centre

News and events

3 JANUARY

Thomas Feurer starts as new Chairman of the Management Board

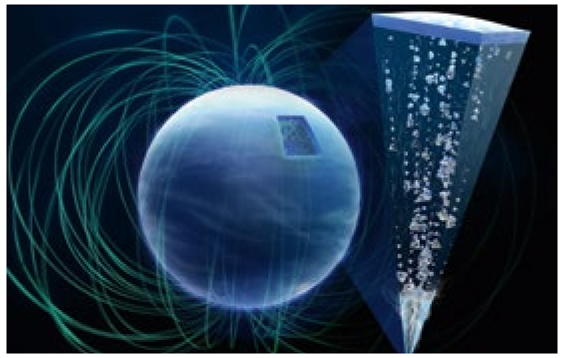
Thomas Feurer assumed the role of the new chairman of the European XFEL Management Board on 1 January. Hailing from the University of Bern in Switzerland, his research areas included laser physics, ultrafast spectroscopy, and the development of instruments for research on X-ray lasers, such as the European XFEL.

Thomas Feurer

8 JANUARY

New findings on diamond rain on icy planets

An international team of researchers led by Mungo Frost from SLAC National Accelerator Laboratory, USA, gained new insights into the formation of diamond rain on icy planets, such as Neptune and Uranus, using the European XFEL. The results, which were published in *Nature Astronomy*, also provide clues to the formation of the complex magnetic fields of these planets.

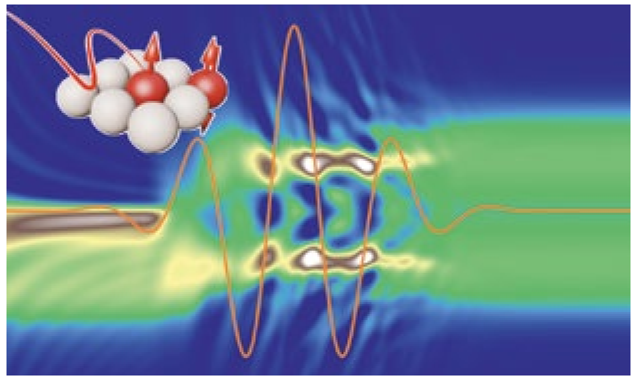


Diamond rain inside an icy planet, consisting of diamond sinking through surrounding ice

23 JANUARY

Ultrafast excitations in correlated systems

A team of researchers from European XFEL, the Max Born Institute in Berlin, the Universities of Berlin, Hamburg, and Tokyo, the Japanese National Institute of Advanced Industrial Science and Technology (AIST), the Dutch Radboud University, Imperial College London, and the Hamburg Centre for Ultrafast Imaging, presented new ideas for ultrafast multidimensional spectroscopy of strongly correlated solids. The results were published in *Nature Photonics*.



The metal–insulator phase transition, triggered in a strongly correlated system by a few-femtosecond laser pulse (orange curve) and resulting in a dramatic change in the density of states, occurs within less than 1 fs.

24–26 JANUARY

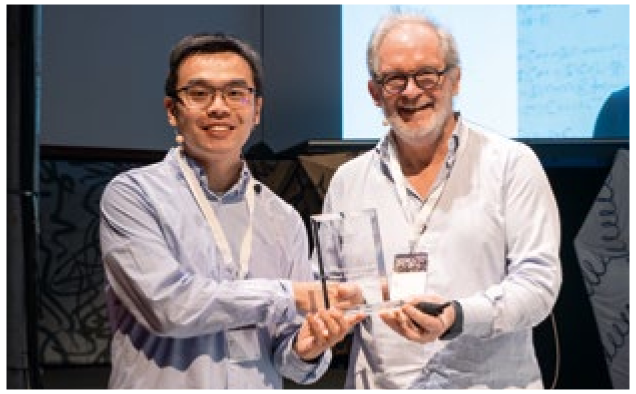
Users' Meeting with more than 1100 participants

More than 1100 participants from over 210 institutes and 33 countries gathered at the European XFEL and DESY Photon Science Users' Meeting 2024 in Hamburg. Almost 350 posters were shown, most of them highlighting the research and development at European XFEL.

25 JANUARY

European XFEL Young Scientists Award for Jiawei Yan

Jiawei Yan was awarded the prize for young scientists for the development of methods for generating ultrashort high-power pulses at the SASE2 beamline of the European XFEL. Together with a team from the FEL Physics group at European XFEL and the MXL group at DESY, which is responsible for operating the European XFEL linear accelerator, he developed a method to achieve remarkably sharp current profiles with high peak currents.

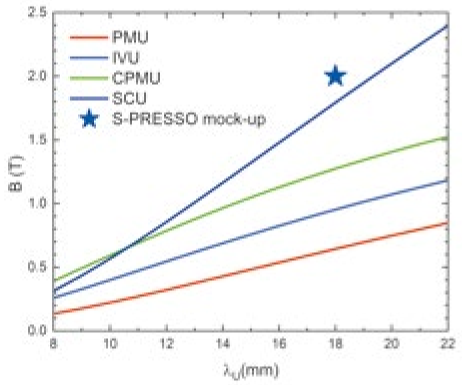


Marc Simon, Co-Chairman of the Executive Committee of the European XFEL User Organization, presenting the award to Jiawei Yan

31 JANUARY

Milestone for superconducting undulator

A European XFEL team at the Karlsruhe Institute of Technology (KIT) successfully tested a 30 cm long mock-up superconducting coil designed and built by Bilfinger Noell. The magnetic field of the S-PRESSO mock-up reached 2 T, which is the largest value ever achieved in such undulators. European XFEL is planning to use superconducting undulators to reach lasing at unprecedented short wavelengths and high photon energies above 50 keV.



Magnetic field of various undulators and the S-PRESSO mock-up at different period lengths λ_U

20 FEBRUARY

High honour for Beata Ziaja-Motyka

Beata Ziaja-Motyka, group leader at the Center for Free-Electron Laser Science (CFEL) at DESY in Hamburg and professor at the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Kraków, received the prestigious Award of the Polish Ministry of Science and Higher Education.

Polish Minister of Science and Higher Education Dariusz Wieczorek, Beata Ziaja-Motyka, and Polish Deputy Minister of Science and Higher Education Maria Mrówczyńska

29 FEBRUARY

Nobel laureate Sir Kostya Novoselov visits European XFEL

The Russian–British Nobel laureate in Physics Sir Kostya Novoselov visited European XFEL with a delegation from the Swiss Constructor Group. They discussed the technical challenges and applications of research with XFELs with Thomas Feurer and Serguei Molodtsov as well as other scientists. In 2010, Kostya Novoselov was awarded the Nobel Prize in Physics, together with Andre Geim, for research on graphene.

Kostya Novoselov meeting with Andreas Scherz, leading scientist at the SCS instrument

7 MARCH

European XFEL celebrates International Women's Day

On the occasion of the International Women's Day, European XFEL hosted a podium discussion and networking event. The facility reaffirmed its commitment to equal opportunities regardless of gender and its support of the annual call by the United Nations for the recognition of women, their achievements across the globe, and the difficulties they face.

Managing Director Nicole Elleuche discussing with the audience

15 MARCH

Nobel laureate Anne L'Huillier at European XFEL

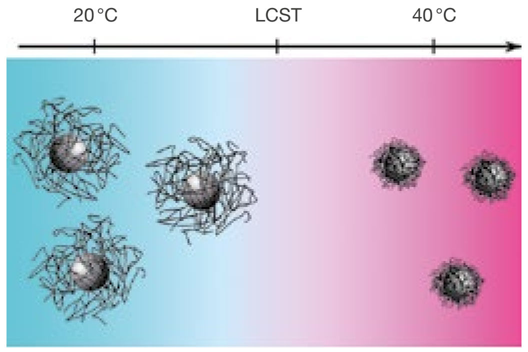
The French–Swedish Nobel laureate in Physics Anne L'Huillier gave a lecture on "The route to attosecond pulses" at European XFEL and answered questions about her work. Anne L'Huillier attended a meeting of the Scientific Advisory Committee (SAC) of European XFEL, of which she was a member. Together with the French–American physicist Pierre Agostini and the Hungarian–Austrian physicist Ferenc Krausz, she was awarded the Nobel Prize in Physics in 2023 for her work on ultrafast physics, one of the main research areas at the European XFEL.

Anne L'Huillier meeting with young scientists after her lecture

18 APRIL

European XFEL elicits secrets from an important nanogel

An international team led by Felix Lehmkühler from DESY in Hamburg investigated the temperature-induced swelling and collapsing of the polymer poly-N-isopropylacrylamide (PNIPAm) at the European XFEL. PNIPAm is used in medicine because of its dynamic changes (for example, for drug delivery, tissue engineering, or sensorics). The results could help researchers to further understand and improve the features of the polymer for different applications, such as the development of more efficient drug delivery systems.

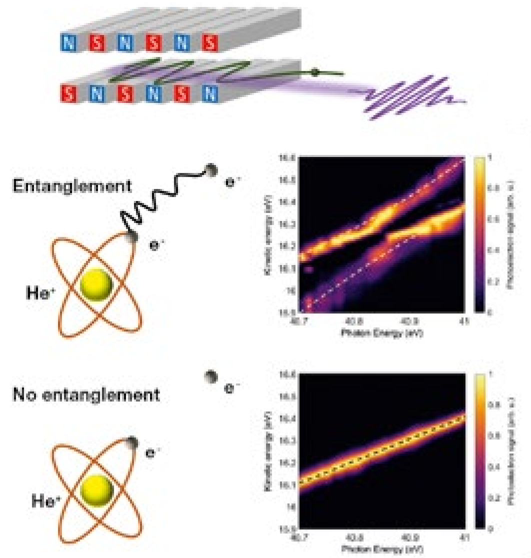


Above 32°C, the PNIPAm nanogel particles switch from a hydrophilic (blue area) to a hydrophobic state (magenta area). The particles change their size rapidly by expelling water.

22 APRIL

Generating entanglement

At the SQS instrument, a team of scientists investigated the ultrafast quantum entanglement of a free-moving photoelectron, which expands to a mesoscopic length scale, with a light-dressed atomic ion, representing a hybrid state of light and matter.



25 APRIL

Girls' and Boys' Day at European XFEL

On the occasion of the German Girls' and Boys' Day, 18 girls and two boys from grades four to eight had the opportunity to get to know work and research areas at European XFEL. Scientists and engineers gave them insights into different areas and job profiles of the facility. The programme included activities such as visiting a cleanroom, learning about diamond anvil cell microscopy, controlling a motor, and analysing experiment data.

Studying crystals with Agnieszka Wrona and Barbara Marchetti from European XFEL

27 APRIL

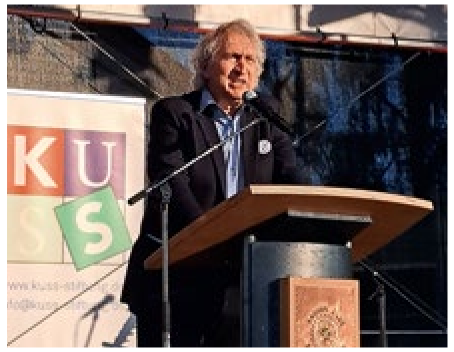
Röntgen Medal for Robert Feidenhans'l

Danish physicist and former Managing Director of European XFEL Robert Feidenhans'l has spent almost his entire career working in the field of X-ray synchrotron radiation and free-electron lasers and is regarded as a pioneer in the use of X-rays from synchrotron radiation facilities. He was awarded the Röntgen Medal 2024 by the German Röntgen Museum for his work on X-ray imaging methods.

8 MAY

European XFEL at the Schenefeld Festival of Democracy

On the German day of liberation from National Socialism and the end of the Second World War, staff members of European XFEL joined the Festival of Democracy in Schenefeld, together with local clubs, parties, associations, and organizations, to set an example for democracy, freedom, and a diverse society. Thomas Feurer emphasized the societal significance of democracy as a high good that must be constantly defended and nurtured, and reaffirmed the importance of democracy and diversity.



Thomas Feurer speaking at the Schenefeld Festival of Democracy

13–17 MAY

Preparing young engineers for cutting-edge science

The MEDSI Early Career Engineering School 2024, held at European XFEL and DESY, trained 80 young engineers and early-career specialists in the design of state-of-the-art instrumentation for X-ray laser and synchrotron light sources. Organized as part of the international Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI) conference series, the school focused on sharing knowledge to address the unique challenges of the technologies used in X-ray science facilities and instruments.

Participants of the MEDSI meeting

13 MAY

Finding a weak point in corona's armour

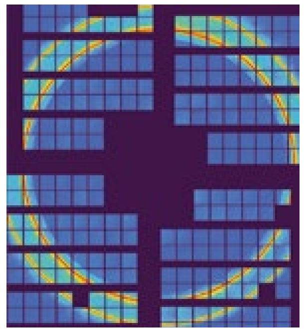
Despite an unparalleled collaborative research effort, a complete understanding of the structure and lifecycle of the coronavirus known as SARS-CoV-2 is still lacking. Scientists used the biolabs and the SPB/SFX instrument at the European XFEL to study the main protease, or M^{pro}, of the virus to understand how it protects itself from oxidative damage. The results, published in *Nature Communications*, add key knowledge to our understanding of the workings of SARS-CoV-2 and to the field of viral biology.

In the control room of the SPB/SFX instrument

24 MAY

Crystallization in supercool liquids

Using the intense X-ray flashes of the European XFEL, an international team of researchers succeeded in precisely measuring the nucleation of supercooled liquids. They investigated the crystal nucleation rate, a measure of the probability that a crystal will form in a certain volume within a certain time. According to their results, the crystal nucleation rates are much smaller than those predicted on the basis of simulations and classical theory. The findings are expected to help theorists to refine their models.



X-ray diffraction pattern of a crystal, resulting from 34 000 single-pulse X-ray exposures of a krypton jet shortly after the onset of crystal nucleation. The rings indicate X-ray scattering from specific molecular planes within the small crystals.

16 MAY

Best Students' Poster Award

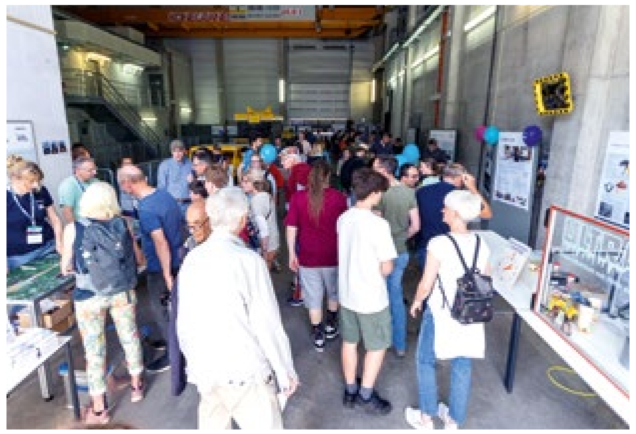
On the occasion of the European XFEL Students' and Science Days 2024 in Fintel, south of Hamburg, Thomas Feurer honoured Sharmistha Paul Dutta from the FXE instrument and Giacomo Merzoni from the SCS instrument with the Best Students' Poster Award. The former works on the origins of enhanced aurophilicity in stimuli-responsive dimer complexes, the latter on the persistent magnetic order and coherent magnons in photodoped nickel oxide (NiO).

Thomas Feurer honouring Sharmistha Paul Dutta and Giacomo Merzoni at the Students' and Science Days 2024

1 JUNE

European XFEL at the Hamburg Science City Day

European XFEL participated in the Science City Day in Hamburg, an open-day event that attracted thousands of visitors. European XFEL staff members were on hand to explain the facility's operations and applications. The event offered the public a unique opportunity to learn about the scientific efforts behind groundbreaking discoveries and to experience the potential of X-ray laser research for future technologies. The Science City Hamburg Bahrenfeld is an emerging district dedicated to cutting-edge research, innovation, and community development.



Visitors at the Hamburg Science City Day attending the European XFEL exhibition in the injector building on the DESY campus

11–12 JUNE

Inertial fusion energy workshop at European XFEL

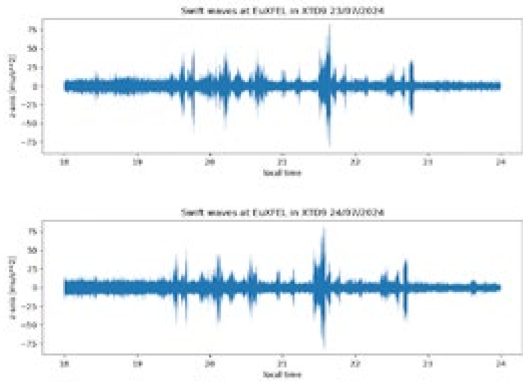
More than 160 scientists discussed the role XFELs could play toward an inertial fusion energy (IFE) power plant as well as the relevant activities that could be pursued at the European XFEL's HED-HIBEF instrument.

Onsite participants of the IFE workshop

25 JULY

Taylor Swift rocks European XFEL

Researchers from the WAVE fibre-optic sensor network recorded the vibrations triggered by Taylor Swift's concert in Hamburg's Volksparkstadion and the jumping of her Swifties. The vibrations were detected by European XFEL and DESY in the Science City Hamburg Bahrenfeld, around 2 km from the stadium.

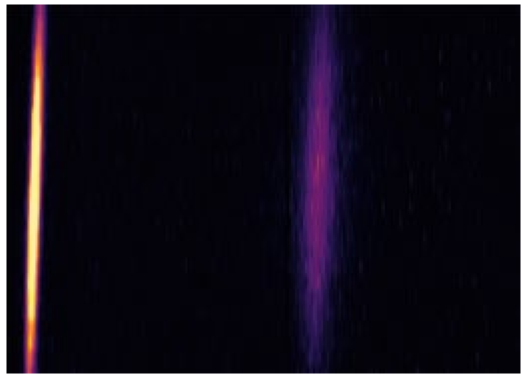


Taylor Swift's song "Shake It Off" created the biggest buzz at 21:30.

11 JULY

Thomson scattering: Reaching an unmatched level

Researchers at European XFEL and the German–Polish Centre for Advanced Systems Understanding (CASUS) developed a groundbreaking method to study warm dense matter—a state between solid and plasma that is found in stars and fusion experiments—with unprecedented precision. Using ultrahigh-resolution X-ray Thomson scattering, they resolved long-standing discrepancies between simulations and experiments, achieving a tenfold improvement in energy resolution. This could pave the way for better simulations and targeted designs in fusion research and astrophysics.



Elastically scattered X-rays (bright yellow light) and X-rays scattered from plasmons (faint violet light)

29 JULY

European XFEL creates exotic matter

Exploring the extreme conditions reached in the interior of planets or during a fusion reaction is a major challenge. By focusing the extremely powerful X-rays of the European XFEL on a copper foil, researchers created and investigated a state of matter very far from equilibrium, known as warm dense matter, which resembles such exotic environments. Their findings made remarkable strides in understanding and characterizing this elusive state of matter, which is crucial for advancing inertial confinement fusion, a process that holds promise for clean and abundant energy.

European XFEL scientist Laurent Mercadier checking the setup in the experiment chamber of the SCS instrument

2 AUGUST

European XFEL flies the rainbow flag

On the occasion of Hamburg Pride Week, European XFEL sent a visible signal for diversity, acceptance, and cosmopolitanism. Over 400 organizations in the Hamburg area took part in the campaign. European XFEL reaffirmed its recognition of diversity as an important part of a fair, equal, and inclusive working environment.

26–30 AUGUST

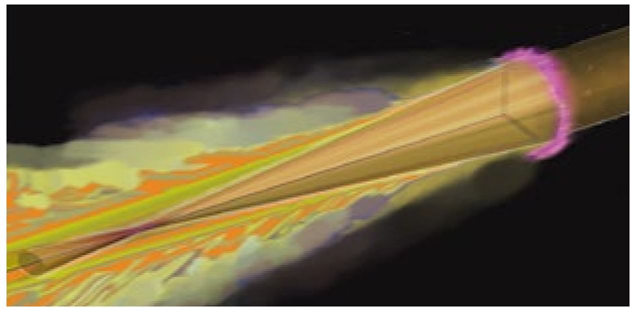
X-ray experts from around the world meet in Hamburg

DESY and European XFEL welcomed more than 1200 experts from around the world to the 15th International Conference on Synchrotron Radiation Instrumentation (SRI2024) at the CCH Congress Centre Hamburg. Hamburg's Senator for Science, Research and Equality, Katharina Fegebank, and Schleswig-Holstein's Minister for Education, Science, Research and Culture, Karin Prien, opened the conference, which is regarded as the world's most important exchange forum for experimenters, developers, and operators of large X-ray radiation sources.

12 SEPTEMBER

Understanding inertial confinement fusion

A research team successfully produced and observed an extreme state of matter using a relatively low-power but extremely fast laser pulse of the HED-HIBEF instrument. The measurement could be useful for both astrophysics and fusion research, as it shows how very high densities and temperatures can be generated in a wide variety of materials. This could take fusion research an important step forward and is also important for understanding the extreme conditions inside stars or planets.

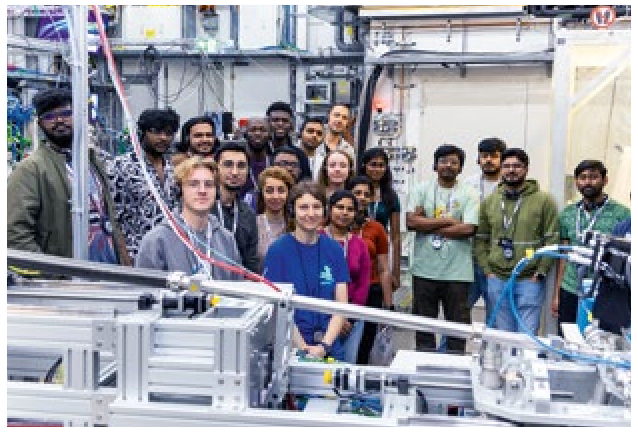


Artistic rendering of the imploding wire used to create the extreme state of matter

26 SEPTEMBER

Ten years of Freiberg lectures

For 10 years, a unique cooperation has been giving students at TU Bergakademie Freiberg an insight into the world of XFELs. The participants were the 10th group of Freiberg students to take part in this course, organized by European XFEL.



The student group from TU Bergakademie Freiberg visiting the experiment hall

9 OCTOBER

Xcool Lab premiere

Students of a physics course at Gymnasium Schenefeld were the first to take advantage of European XFEL's new Xcool Lab, which offers up to 32 young people the opportunity to explore the fascinating world of science in one-day workshops held in German or English. The topic of the workshop was "The invisible world of X-rays".

School students measuring X-ray scattering angles at the Xcool Lab

25 OCTOBER

Thomas Feurer elected as future Chairman of LEAPS

The League of European Accelerator-based Photon Sources (LEAPS) elected Thomas Feurer, Managing Director and Chairman of the Management Board of European XFEL, as its future chairman. LEAPS brings together major European synchrotron radiation and FEL facilities. It seeks to advance photon science and to maximize the impact of accelerator-based light sources in Europe. At the next plenary session in October or November 2025, Feurer will succeed Jakub Szlachetko from the National Synchrotron Radiation Centre (SOLARIS) in Kraków, Poland.

LEAPS League of European Accelerator-based Photon Sources

30 OCTOBER

Family-friendly company

The German magazine *freundin* and the research institute FactField jointly identified European XFEL as one of the most family-friendly companies in Germany in the category "Education, Research and Development", where European XFEL was awarded fourth place. The recognition shows European XFEL's commitment to fostering a workplace where excellence and family values support each other.

Many European XFEL employees take part in the Hamburg HafenCity Run with their families.

13 NOVEMBER

Nobel laureate Ferenc Krausz at European XFEL

Ferenc Krausz toured the experiment hall and met with staff scientists. The Hungarian–Austrian physicist received the Nobel Prize in Physics in 2023, together with Anne L'Huillier and Pierre Agostini, for the development of experimental methods to generate attosecond pulses—a research area that is very auspicious for the European XFEL as well.

Ferenc Krausz at European XFEL

20 NOVEMBER

CNRS delegation visits European XFEL

A visit of a delegation from CNRS Physique and CNRS Chimie emphasized the good relations between the French research organization and European XFEL. The meeting confirmed the importance of the X-ray laser for the French scientific community and aimed to strengthen the links between CNRS and European XFEL, for example with the creation of an international CNRS laboratory on the European XFEL campus.

The European XFEL Management Board with the CNRS delegation

20 NOVEMBER

Visitor and conference centre opens

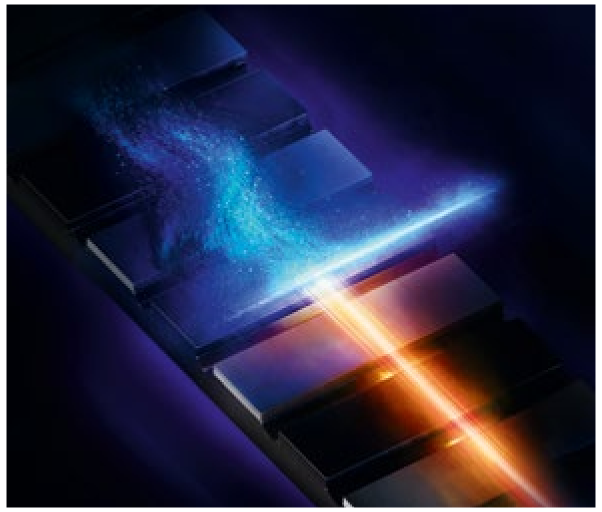
Together with high-ranking guests, European XFEL opened its Lighthouse visitor and conference centre to the public. The two-storey building offers space for a 350 m^2 permanent exhibition, 200 m^2 of special exhibition space, the Xcool Lab with two laboratories for students, and rooms for conferences and events.

Cutting the red ribbon to mark the official opening of the Lighthouse

22 NOVEMBER

Squeeze it!

A research team at European XFEL and DESY achieved a major advance in X-ray science by generating unprecedented high-power attosecond hard X-ray pulses at megahertz repetition rates. This advancement opens new frontiers in the study of ultrafast electron dynamics and enables non-destructive measurements at the atomic level.



Electrons (blue cloud) are squeezed together in a chicane to emit very bright X-ray light (orange beam).

30 NOVEMBER

15 years of European XFEL

On 24 November, European XFEL celebrated the 15^{th} anniversary of the international treaty that laid the foundation for its creation. On 30 November 2009, ten European countries jointly decided to implement the ambitious project and create an internationally accessible research facility that would offer new, unparalleled research opportunities to scientists from all over the world.

Ministers, state secretaries, and other government representatives from ten partner countries met in November 2009 in the Hamburg City Hall to sign the international European XFEL agreement.

12 DECEMBER

Ryszard Sobierajski elected new Vice-Chairman of the Council

The European XFEL Council elected Ryszard Henryk Sobierajski as its new vice-chairman. The associate professor at the Institute of Physics of the Polish Academy of Sciences in Warszawa, Poland, will take over his office on 1 January 2025 for a period of two years. He follows James Henderson Naismith. Sobierajski has been a Polish delegate to the European XFEL Council since January 2020.

Ryszard Sobierajski

3 DECEMBER

Lighthouse: Big stage for art

A large audience took the opportunity to discover the new Lighthouse visitor and conference centre at the vernissage of "Strahlzeit", an exhibition by the Well Wired Team, consisting of Boris Vogeler (sound) and Werner Jarmatz (light) and led by Hamburg artist Kalle Maukel, who made the illuminated wire sculptures. Among the 120 guests was the mayor of Schenefeld, Christiane Küchenhof.

17 DECEMBER

Science Saturdays at Lighthouse start

Around 100 adults and children explored the new Lighthouse visitor and conference centre at the first open Science Saturday. The visitors were able to see the permanent exhibition as well as the "Strahlzeit" art exhibition, which shows fascinating connections between art and science.

Girls and boys took the chance to make LED Christmas cards at the first Science Saturday at the European XFEL Lighthouse.

Cover story

Interview with Gerhard Grübel about revealing the secrets of water

Fascination water

Gerhard Grübel has long been fascinated by water. As a physicist who spent many years developing methods for using X-rays to investigate disordered materials, he was quick to understand the potential of light sources, such as the European XFEL, to study the molecular structure and dynamic behaviour of water. He has been a strong force within the water research community, both locally and internationally, helping to shape and focus research agendas and strategies. In this interview, he talks about his interest in this precious resource, the developments he has seen in the field over the years, and his excitement about the discoveries around the corner.

Gerhard, what fascinates you about water?

Well, first and foremost, this unique resource is central to our lives and to our planet. It plays a key role in our biology, obviously, but is also important for our climate. We use it for many technical applications and industries. But I think the most fascinating thing about water is that it has very fundamental properties that are still not fully understood.

Like what for example?

Water is one of the few substances, one of the few liquids, that does not do what you would expect physically. The most well-known example is that the highest density of water is not observed at 0°C but at 4°C. This means liquid water is on the bottom of a lake, while “solid water” — ice — is on top. This ensures life in a lake can endure during the winter. There is some evidence, however, to suggest that water isn’t actually just a “wonder liquid”, but that two liquids might exist simultaneously at low temperatures, a so-called high-density liquid (HDL) and a low-density liquid (LDL), and it’s actually a mixture of these two. People believe that this is the origin of all the anomalies we see. Another interesting phenomenon is one of the phase transitions of water. If water freezes, it forms crystalline ice. We all know this, but it can also form amorphous ice, which is not as well-ordered as it is in a crystal. So, the question is what pathways, or laws, determine the way ice crystallizes? Why and when does it become an ordered ice crystal and when does it not? These are very relevant questions, for cloud formation in particular and for climate research in general. A better understanding of these processes will allow us to generate better climate models.

How did you get involved in using light sources for water research?

My background as a physicist was using X-rays to study different materials. The motivation to study water came around the year 2000, when people started to talk about XFELs. Third-generation X-ray sources had enabled the scientific community to investigate disordered systems. The new millennium was about looking not only into the structure but, in particular, into the dynamics of disordered systems like liquids. We were wondering whether it would be possible to study structural dynamics of something like water with XFELs. We, that is my group and colleagues, sat down and started to do the calculations, and we said, okay, one could imagine doing such experiments at XFELs. Water as a case study is even mentioned in the original technical design report for the European XFEL — it was considered a breakthrough application. There was a lot of hype and excitement in the community because there was suddenly a machine on the horizon that promised certain things could finally be done.

Have XFELs delivered on that promise?

We are starting to see the first results, and I am sure we will see a lot of progress in the next couple of years, but we still have some way to go. There are results that point to the existence of the two HDL/LDL phases of water I mentioned and studies looking into the formation of different types of ices. We don’t have the final answers yet because we first had to understand the machine, the instruments had to be set up for the experiments, and there was a need for novel sample environments. For example, liquid-jet technology had to be developed, so we could control small water droplets, letting them expand into vacuum and cool down. You also need to deal with large, powerful, two-dimensional detectors to capture the data, which also took a lot of effort and time to build.

“A deeper understanding of the fundamental properties of water can have a significant impact on society.”

How has the scientific community changed during this time?

One example is the development of the Centre for Molecular Water Science (CMWS). The idea started within the DESY Photon Science Division around 2017. We identified several research groups working on water and started building a community. We organized workshops where we discussed the most relevant questions to be solved. From there, a pan-European network grew. The goal was to found an institute with a physical building. We collected over 50 letters of intent from potential partners and, in 2021, we published a “white paper” outlining the centre’s research agenda. Today, CMWS as a platform and network is shaping, focusing, and supporting research in this area. The community guides the experimental strategy for water research at the European XFEL, which has resulted in special calls for proposals that focus on certain water experiments. These calls have also attracted groups that have not used X-rays before. We can establish contacts with more experienced groups, so that, together, the two types of groups can figure out how to do experiments effectively. In the longer term, with a physical institute in place, we can host groups, so they can prepare for their experiments, and let them stay afterwards to use data analysis infrastructures to work with the enormous amounts of data that result from the experiments. We are not there yet, but, still, collaborations have been sparked, which is great for the field.

What recent scientific progress has particularly excited you?

There are some particularly interesting things that came out of the recent water calls. A Swedish group, for example, used SPB/SFX to look into ice creation pathways, how ice crystals initially nucleate, and how the process progresses from there. They have been using very modern techniques and machine learning. At HED, a collaboration led by a group from the Korea Research Institute of Standards and Science has been looking at the creation of new ice phases in high-pressure environments. The experiment setup at HED is crucial for this because it allows for really fast compression of water so you can observe different new phases. I think this is really beautiful work! A third group from France has been using FXE to look at the dynamics of water. By heating up water with a laser, they study how the hydrogen bonding network evolves and what kind of movements are happening during this process. There’s a lot of progress, which is very encouraging. What is also great is that water research is being done at all the European XFEL instruments. So, we can create synergy between the researchers and between the instruments.

What do you hope for the future of water research at XFELs?

Currently, we use big, two-dimensional detectors. From each detector image, we can calculate the position of the atoms using complex math. Now, imagine you have a spherical detector that detects every photon scattered from an object, and that as a function of time. Using the appropriate correlation functions, this would give us all the information we need to understand the structural dynamics of materials. Conceptually, there is still some work to do, but the future is very, very promising. I think we will learn a lot for climate research too by doing more aerosol research. Or, on the more applied side, we could build better filters and purify water more effectively. There are many rare resources in ocean water, for example. We could extract those elements that we need for other purposes and produce clean drinking water in areas where it is scarce — a win–win scenario. Understanding the fundamental properties of water is intellectually very interesting but can also have a significant impact on society because it touches all of our lives.

Further reading:

Factsheet

Electron and X-ray beams

27 000
Maximum number of electron bunches per second

ca. 50 µm
Diameter of the electron beam (comparable to the diameter of a human hair)

3
Number of SASE undulators running in parallel

7
Number of instruments

40 W
Highest FEL beam power

11 nm
Smallest focus of the X-ray beam

10 µs
Time of flight of an electron from the injector to the dump (1/100 000 s)

21 000
Highest number of X-ray flashes per second achieved

0.04 nm
Minimum wavelength of the X-ray flashes (photon energy: 31 keV)

Users

96
User experiments (2023: 89)

9784 = 1223 shifts
Hours of X-ray delivery to users and user consortia (2023: 8640 h = 1080 shifts)

1252
Individual users from 27 countries and 5 international organizations (2023: 1225 from 30 countries)

280
Ph.D. students among users (2023: 249)

Data

143.9 PB
Accumulation of raw data since the start of user operation in 2017 (2023: 111 PB)

1.7 million hours
Time used on the Computing Cluster (primarily for data analysis) (2023: 1.8 million hours)

32.5 PB
Raw data collected (1 PB = 1 000 000 GB) (2023: 30.7 PB)

Guest house

6662
Total room nights (2023: 5645)

4642
User nights (2023: 4231)

4.9 nights
Average length of stay (2023: 4.8 nights)

Staff

622 including 134 long-term guests from 66 countries
Total headcount (2023: 580 from 63 countries)

17 (+12 Ph.D. guests)
Number of Ph.D. students (2023: 21)

30.5%
Proportion of women in total staff (2023: 29.7%)

Food and drinks in BeamStop

43 357
Sold meals (2023: 42 443)

20 263
Consumed cups of coffee (2023: 28 100)

7956 kg
Used fruits and vegetables (2023: 8064 kg)

3054
Sold Franzbrötchen (2023: 3323)

2.2 t
Free apples and pears (more than 11 000 pieces)

Operations

Concentration at the start of an experiment at the FXE instrument

Operations

In 2024, the European XFEL accelerator complex was operated for more than 7500 h. On top of this came a record number of X-ray delivery hours, the highest availability achieved so far, and the highest usage of electron bunches by the scientific instruments. Around 1250 users generated about 32 PB of scientific data in 100 user experiments. All said, it was a very productive year in this early phase of scientific harvesting.

The European XFEL accelerator complex—consisting of the injector, the 17.5 GeV superconducting linear accelerator, the electron beam distribution system, and the beam transport system through the three SASE undulators to the beam dumps—was operated for more than 7500 h, of which a record 4864 h were spent on X-ray delivery to the experiments. The availability of the facility during X-ray delivery was 95.6%, averaged over all three undulators, the highest percentage ever achieved during operation (Figures 1–3). More than 25% of the electron bunches available were sent through the undulators to generate X-ray pulses. In 2024, the European XFEL produced about as many XFEL pulses as all other hard XFEL facilities together since the year of their respective inauguration.

The excellent availability of the accelerator complex reflects the diligence of staff members, primarily at DESY, in maintaining the subsystems required to operate the facility. In particular, all cold compressor motors of the accelerator cryosystem were replaced to eliminate a source of sporadic failure that had resulted in downtimes in the past (see “Facility Development”).

In 2024, operation became more reliable and efficient. An improvement in the control systems for the RF pulses that accelerate the electrons enabled more energy-efficient operation of the power converters that transform the grid electricity into the RF pulse. This yielded a remarkable 20% saving per operation hour over the past four years (Figure 4).

X-rays were delivered to the experiments during 32 weeks with electron energies of 10.5–16.3 GeV and photon energies of 400 eV – 24 keV. In about two thirds of the delivery weeks, FEL modes were provided that went beyond standard SASE operation. These modes included special bunch patterns, hard X-ray self-seeding at SASE2 (more than 50% of the SASE delivery time), two-colour operation at SASE2 and SASE3, and short pulses even below 1 fs at SASE2 and SASE3. Although not yet fully commissioned, the re-installed APPLE-X undulators, with their ability to generate FEL light with selectable polarization, were in high demand by the experiments at SASE3.

Efficient communication with and between the operating staff in the accelerator control room at DESY and the instrument staff in the experiment hutches is essential for smooth operation. In 2024, 10 Photon Run Coordinators covered a total of 44 weeks of operation. They addressed 202 calls outside normal business hours, about 20% less than in 2023. Nineteen Data Run Coordinators covered the entire year (365 days). The Data Operation Centre was operated during the 32 X-ray delivery weeks and 2 weeks of experiment tuning, requiring 820 individual shifts.

In 2024, another 32 PB of scientific data were accumulated and stored. Figure 5 shows the experiment data generated by each of the scientific instruments. About 80% of the overall data volume was accumulated by the SPB/SFX and MID instruments, both of which make heavy use of the high-repetition-rate 1 Mpx AGIPD detectors.

During the summer 2024 and winter 2024–2025 maintenance periods, the DESY and European XFEL groups carried out approximately 990 planned tasks. This was about 300 tasks less than in 2023, probably due to the shorter duration of the maintenance periods.

96 experiments allocated across the seven instruments

In 2024, 96 individual experiments were allocated across the seven scientific instruments (Figure 6). These included 11 protein crystal screening experiments at SPB/SFX, a Block Allocation Group beamtime, also at SPB/SFX, and four experiments as part of three long-term projects. A total of 9784 h of X-ray beamtime, corresponding to 1223 shifts, was allocated to these 96 experiments, close to an average of 102 h per experiment. In some cases, this time included the preparation of the instrument for the corresponding experiment. In 2024, European XFEL for the first time allocated 568 h of beamtime to the HIBEF user consortium in compensation for its contributions to the facility. These hours are included in the total indicated above.

A total of 1252 individual users from 27 countries performed a total of 1970 user visits, including onsite and remote access to the facility (Figure 8). With their experiments, they addressed various societal challenges and fundamental science research. The users also classified their research according to scientific areas (Figure 7).
In 2024, one new call for experiments was launched, for allocation in the period from February to June 2025. The call included a second topical molecular water science call and the option to propose protein crystal screening at the SPB/SFX instrument. Following peer review, the successful proposers (approx. 30% of the applicants) were informed in October 2024.

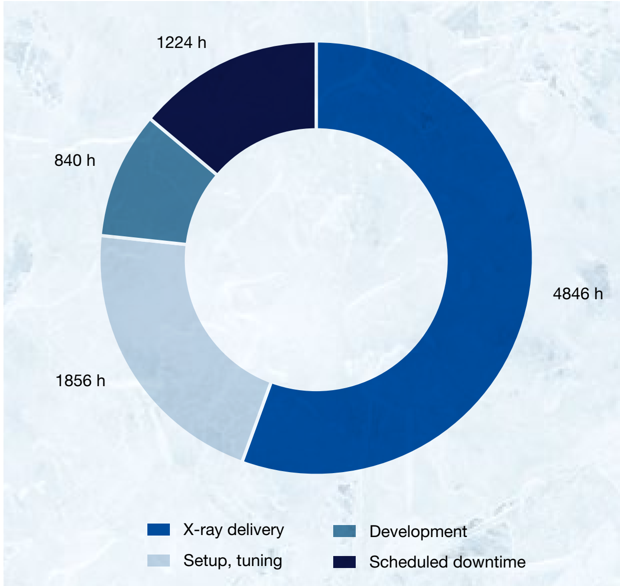


Figure 1: Distribution of yearly operation hours of the European XFEL accelerator in four categories

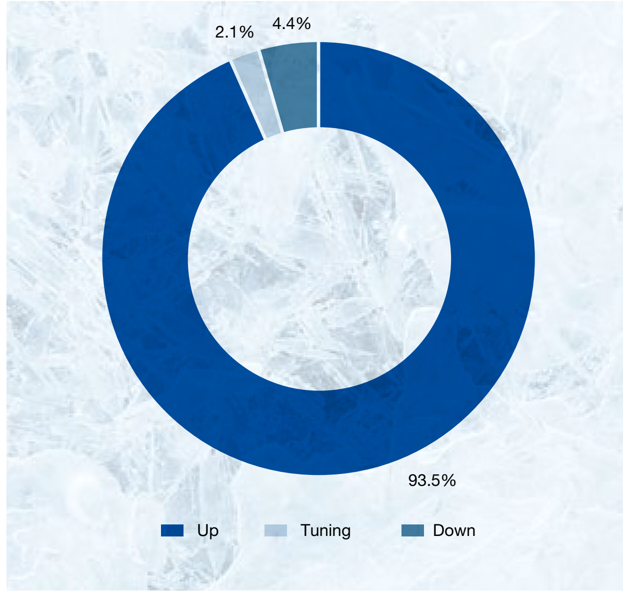


Figure 2: Availability of the accelerator during X-ray delivery in percentages

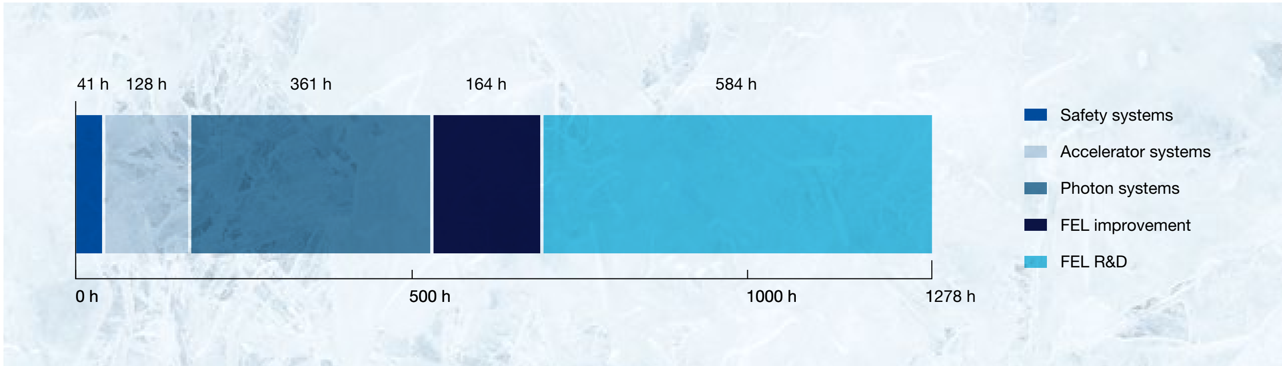


Figure 3: Distribution of development time in hours. The sum of development hours scheduled for various facility development activities exceeded the hours for development indicated in Figure 1, reflecting the parallel use of the facility for multiple activities.

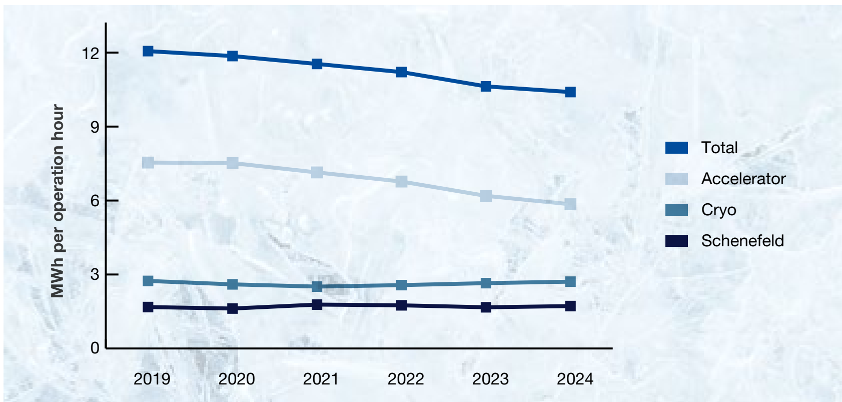


Figure 4: Approximate electricity consumption normalized to operation hours for the accelerator, cryogenic system, and all other consumers (including the Schenefeld campus)

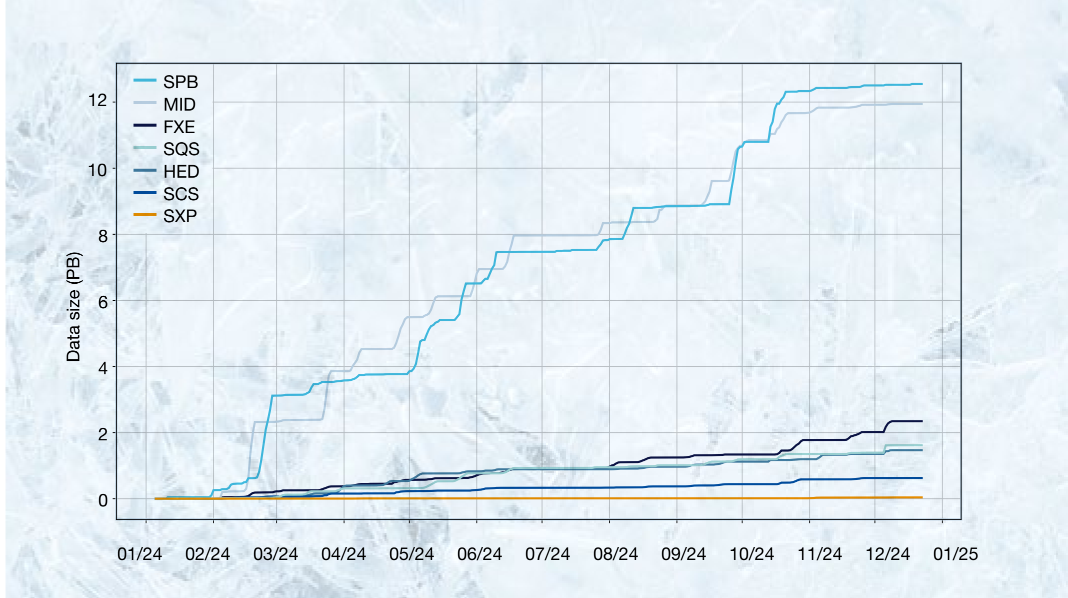


Figure 5: Accumulation of raw data by the seven scientific instruments in 2024

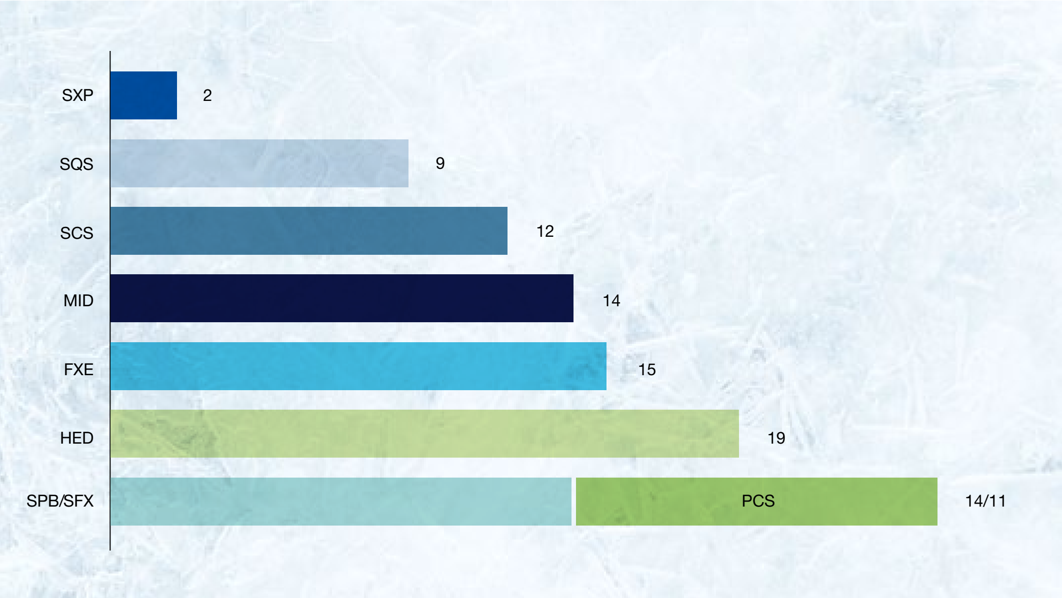


Figure 6: Number of user experiments at the seven scientific instruments in 2024 (PCS: protein crystal screening)

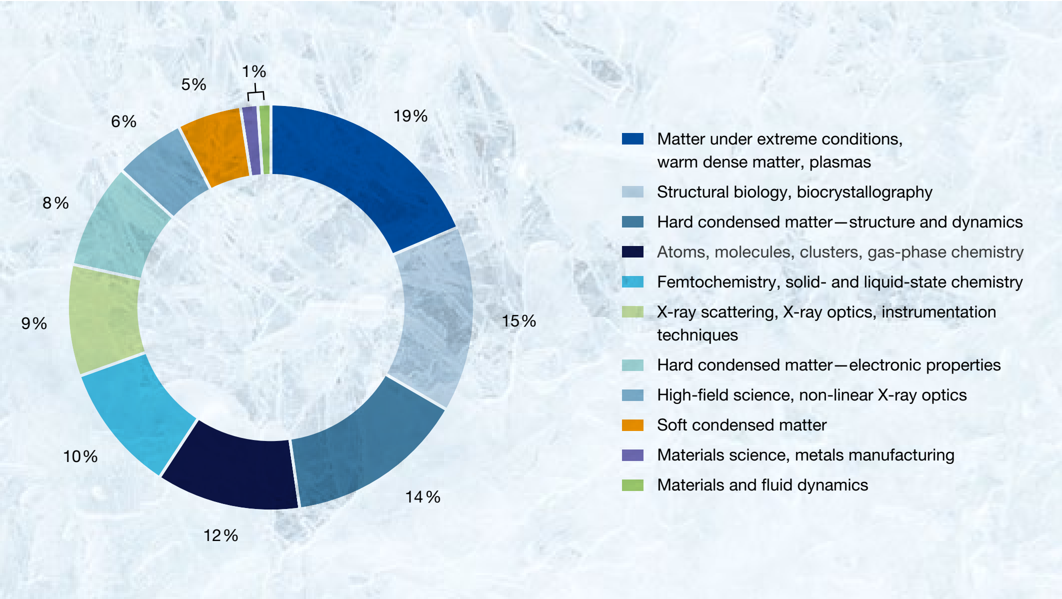


Figure 7: Distribution of users according to major scientific areas

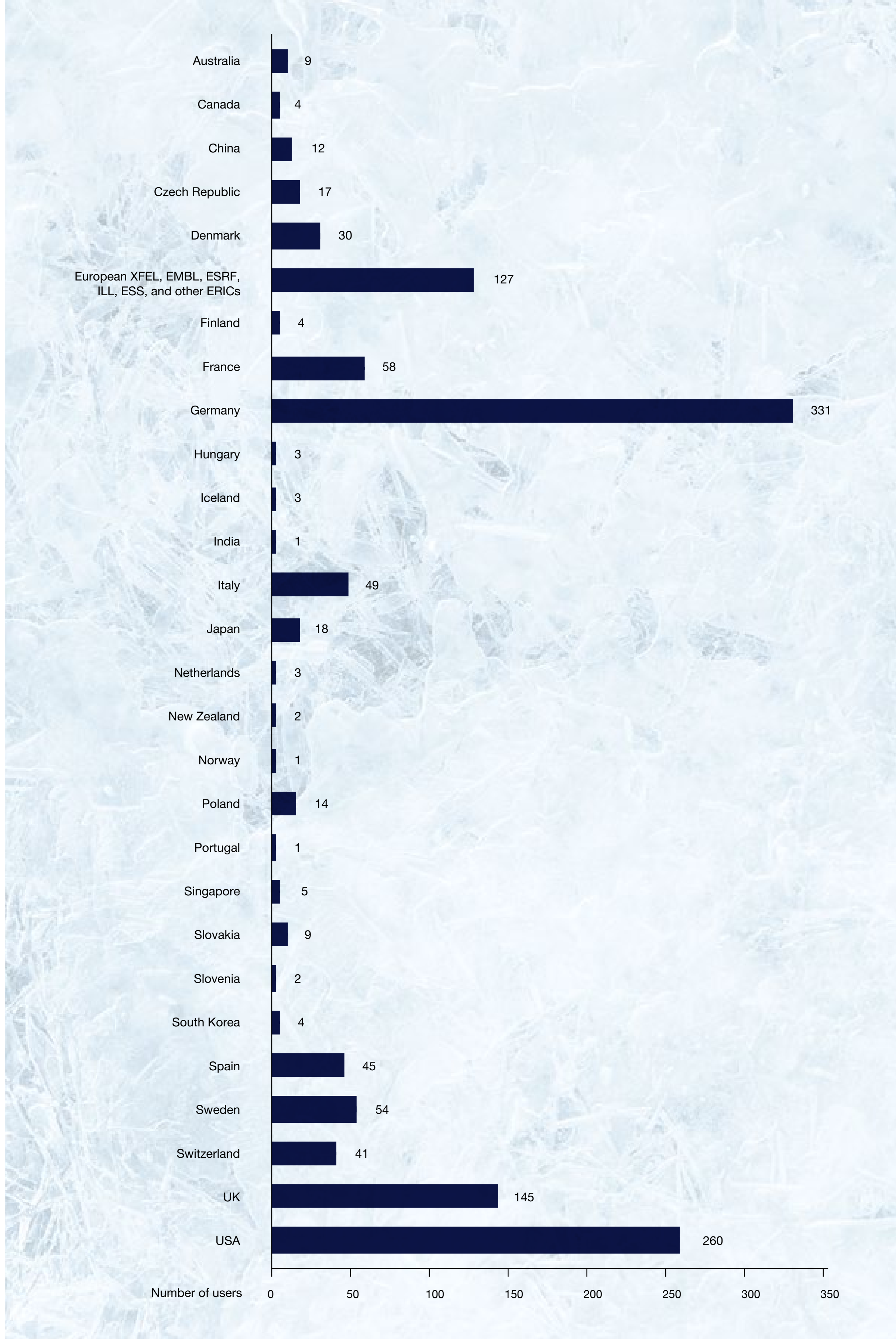


Figure 8: Country or institutions of affiliation of the 1252 individual users who participated in experiments in 2024

Facility update

Preparing for a future beamline for hard X-ray light

Campus development

The most visible part of campus development in 2024 was the completion of the Lighthouse visitor and conference centre. Following the topping-out ceremony in late 2023, the building construction was completed in August 2024. Key milestones included extensive interior finishing, outdoor utility construction, and landscaping, with most of the exterior work completed by year end, except for the west-side road. The project included technical innovation with features such as radiant ceiling panels and advanced ventilation. Following a sustainability concept, the upper floor and the roof structure were largely built as a timber construction. Landscaping and minor works continued until December, ensuring that the facility was fully operational for public and scientific use.

The two-storey building contains a 350 m^2 permanent exhibition, special exhibition space, the Xcool Lab with two laboratories for school classes, and rooms for conferences and events.

A beacon for scientific communication

The Lighthouse building name was suggested by staff members to capture its function as a beacon for scientific communication at a state-of-the-art international research facility. The permanent exhibition about European XFEL was installed in the Lighthouse between June and September. Final tasks in construction, screen design, and graphic design were completed over several months in close collaboration with the exhibition planning and construction agency. Timelines were agreed on for other construction works to ensure that all necessary infra-structure was available in the building and that the site was clean at the time of installation.

Figure 1: The Lighthouse visitor and conference centre on 14 October 2024, shortly before the official opening

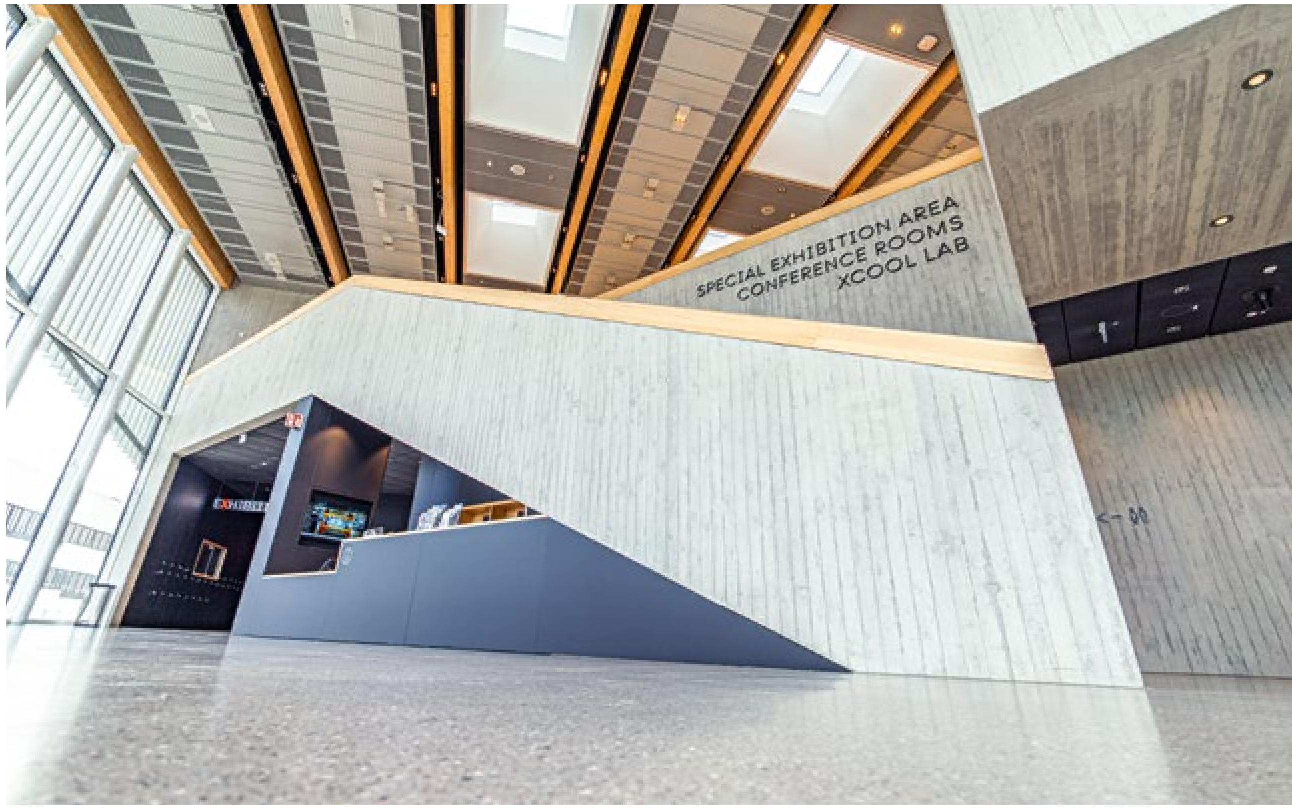


Figure 2: Entrance area with foyer and reception. The seminar rooms and the Xcool Lab are located on the first floor.

For the Xcool Lab, new and existing laboratory equipment—such as X-ray machines, chemicals, radioactive sources, an autoclave for sterilizing equipment, and much more—was purchased or transferred to the Lighthouse, set up, and tested. Safety procedures and training courses for different groups and experiments were established. An online booking system was also developed and successfully integrated into the website. Three school classes were invited to test the new labs with the developed course offerings before the official opening of the lab.

Staff members operating the new centre were able to move into the building in late summer, completing final preparations for opening the building and welcoming the first school classes, scientists, and selected representatives of the public. The first school visits, public events, and scientific conferences were held in late 2024, allowing all functions of the new building to be realized within a few months of completion.

Figure 3: The permanent exhibition in the Lighthouse provides information about the facility and its research.

Figure 4: Hands-on experiments in the biology laboratory of the XCool Lab

Facility development

The operation of the European XFEL facility is complemented by a wide range of development activities aimed at improving operation and performance, opening new scientific opportunities, and breaking the ground for future upgrades.

Facility development beamtimes in 2024 were devoted to optimizing operation beyond standard SASE, researching advanced radiation schemes, and enhancing X-ray beam delivery to the scientific instruments.

Improving the reliability of the cryoplant

The most consequential development in 2024 was the implementation of a new type of cold compressor motor in the cryogenic system. The superconducting cavities and magnets are operated at a temperature of 2 K in a liquid-helium bath produced by means of a four-stage cold compressor system. Together with manufacturers, European XFEL developed a new motor type employing active magnetic bearings instead of ceramic ball bearings. After a prototype motor was operated successfully for more than 12 000 h without any noticeable problems, all remaining motors with ceramic bearings were converted to motors with active magnetic bearings in June 2024 (Figure 1). During transient operation modes with sudden RF shutdowns, a pressure stability better than 0.3% is now maintained by an elaborate cold compressor bypass operation in combination with cascaded pressure regulation and automatic heat load compensation. Since all motors have been in operation for more than 4000 h without noticeable issues, confidence is high that the previous cold compressor problems are a thing of the past and that uninterrupted 2 K operation is possible.

New injector laser

Another major upgrade was the full commissioning and operation of a new injector laser system, called NEPAL-X (see Technical Highlight “Installation of novel photocathode lasers”). The new system, which is tailored to the unique burst mode operation, was developed at DESY and deployed at the European XFEL, FLASH, and the PITZ photoinjector test facility at DESY in Zeuthen. The system offers new features that allow better adjustment of the electron beam properties in terms of emittance and bunch charge.

Longitudinal diagnostics for reproducible operation

By the end of the year, a solution was found to fully include the transverse deflecting structure (TDS) after the last bunch compression stage, which had been hampered by problems with its RF system, into the longitudinal diagnostics of the electron bunches. The TDS will now contribute to a more reliable operation of non-standard FEL operation modes.

Figure 1: Cold compressor motors with active magnetic bearings (metallic pillars in the front) installed in the 2 K cold box

Within the European XFEL Strategy 2030+, the development and installation of transverse deflecting structures behind the undulators are proposed. Tuning and monitoring of standard and non-standard FEL operation would be greatly simplified with the possibility to directly measure the electron beam energy profile after lasing. Because of the high electron energy, large transverse field gradients are required that can be obtained only using the relatively new X-band RF technology. Since all installations will have to go into the tunnels, careful engineering and component testing at appropriate test stands are needed to enable reliable operation.

Operation modes beyond standard SASE

With the new injector laser NEPAL-X, operation with twin electron bunches either within an RF bucket (i.e. with a distance on the order of 100 fs) or in the next RF bucket (i.e. with a distance of multiples of 770 ps) becomes possible. As these modes pose challenges for diagnostics, feedback, high-level controls, safety systems, and the setup of proper lasing conditions for each bunch, exploratory studies are conducted to underpin the feasibility of the operation.

User beamtimes with photon energies up to 24 keV were provided, and 30 keV photons were delivered during facility development beamtimes. This operation puts the highest demands on electron beam formation and undulator alignment.

Emphasis was placed on the generation of short (<10 fs) and very short (<1 fs) pulses in both the hard and soft X-ray regimes. High electron current spikes can be generated in the SASE2 and SASE3 undulators, leading to unprecedented intensities at these short pulse lengths. The formation of the current spike is driven by electrical fields that the bunch itself generates during its passage through the accelerator, and it is very delicate to control.

Cavity-Based XFEL Oscillator

To increase the spectral brightness of the SASE beam, hard X-ray self-seeding (HXRSS) was successfully deployed at SASE2. As a further method, a demonstrator setup is being developed at SASE1 as part of the Cavity-Based XFEL Oscillator (CBXFELO) R&D project to investigate the feasibility of a 60 m long diamond-crystal–based cavity inside the undulator, leading to unprecedented levels of spectral brightness, e.g. for spectroscopic experiments. The need for spatial and temporal overlap of the photon pulses accumulated in the optical cavity with the electron bunches at MHz rates leads to very challenging mechanical specifications for the opto-mechanical elements. A retro-reflector concept and novel extremely high-precision mechanics concept are used to meet these demanding requirements. In a retro-reflector, any angular vibration or displacement of the entire retro-reflector assembly induces an offset between the incoming and outgoing beams but no change in angle between them, thus enhancing the overall stability of the cavity.

To achieve the requirements for high-precision alignment with very small and reproducible steps, the optical element design is based on parallel kinematic and flexural elements (Figure 2). These ensure exactly constrained, backlash-free movements of the stiff and light mechanical structures. The active components are suspended on struts equipped with short metal ropes functioning as spherical joints. These ropes provide extremely high bending and torsional flexibility while remaining very stiff in the axial direction. Their short length also prevents buckling effects. Flexure elements, made of bent titanium alloy sheets, connect the active parts to the nanometre-resolution linear stages, which are based on stick-slip piezo drive technology.

The CBXFELO mechanics were installed during the summer maintenance period and underwent extensive technical and beam-based commissioning (Figure 3). The preliminary results are very promising.

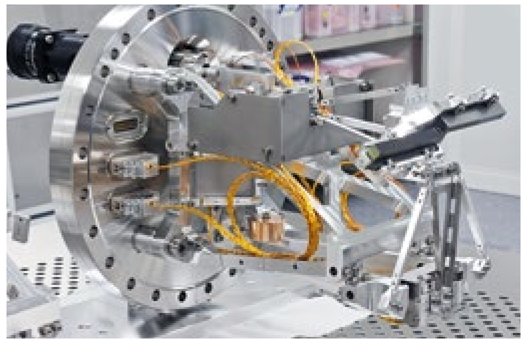


Figure 2: Mechanical design of the CBXFELO retro-reflector based on parallel kinematics and flexural elements. The unit positions two total-reflecting X-ray mirrors in the beam path. Altogether, four similar units are required for the cavity to position four mirrors and two diamond crystals.

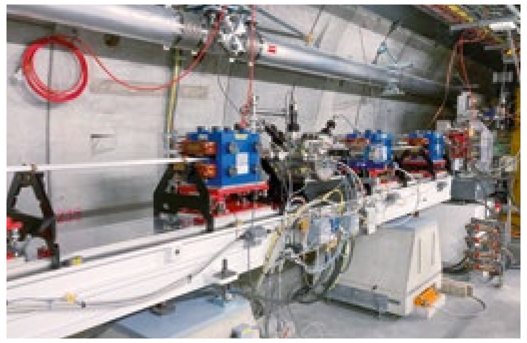


Figure 3: CBXFELO setup at the end of the SASE1 undulator

Next-generation photoinjector

Development and testing of a new electron source, called Gun 5, have been ongoing at PITZ at DESY in Zeuthen. Improvements to its geometry and cooling, in addition to the inclusion of a field probe and the use of a double in-coupling window, will allow the injector to operate at longer pulse length (+30%), with increased stability and reduced trip rate. Installation in the European XFEL injector tunnel requires changes to the cooling system, the RF waveguides, the laser beam transport and in-coupling, the equipment support structure, and, finally, the control software. In preparation, four gun assemblies (for the European XFEL and FLASH) needed to be tested and qualified. For this purpose, a conditioning stand called FALCO (Figure 4) for L-band RF guns was set up at DESY in Hamburg, and dedicated conditioning started in July 2024.

Figure 4: View into the opened radiation shielding of the Facility for L-band Conditioning (FALCO), with Gun 5.2 installed on the rail system and RF waveguides attached to the newly developed two-arm RF input coupler

Superconducting undulators

The development of superconducting undulators (SCUs) is one programme of the European XFEL Strategy 2030+. The SCU modules consist of a 5 m long cryostat housing two 2 m long superconducting magnetic coils with a phase shifter and correction coils in between. The SCUs have an 18 mm magnetic period with a field of 1.82 T. A pre-series prototype (S-PRESSO) is currently being produced, and the first set of coils, the phase shifter, and a prototype of the vacuum chamber were delivered in 2024 (Figure 5).

Figure 5: Top: Outer vessel of the S-PRESSO cryostat. Bottom left: 2 m long SCU coils. Bottom middle: 5 m long vacuum chamber prototype with a cross section of 10 x 5 mm². Bottom right: Phase shifter.

S-PRESSO is to be installed downstream of the permanent-magnet undulators in SASE2. Five more units are planned for installation later to demonstrate the operability of these devices and extend the range of the FEL radiation to above 30 keV.

A 30 cm long test coil, designed and built by Bilfinger Noell with the same magnetic specifications as S-PRESSO, was tested at the Karlsruhe Institute of Technology (KIT) in early 2024. The magnetic field reached 2 T, exceeding the specified value. The measured second field integral was found to be well within specifications, and a phase error within 3° was determined. These results give confidence in the robustness of the manufacturing procedure. One challenge is maintaining the magnetic field quality over the whole length of the 2 m long coils. This corresponds to mechanical accuracies on the order of 20 µm at room temperature, which must be preserved in cold conditions. The magnetic field quality will be measured in the Superconducting Undulator Experiment 1 (SUNDAE1) test stand, located at and operated in collaboration with DESY (Figure 6). In this vertical helium bath cryostat, coils can be tested at 4.2 K and 2 K, and the magnetic field profile along the magnetic axis can be precisely measured using magnetic Hall probes.

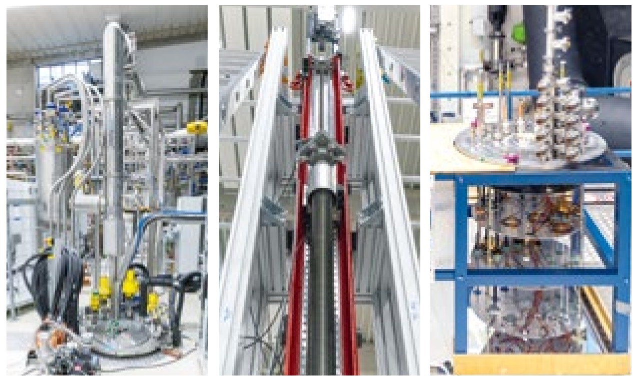


Figure 6: Main components of SUNDAE1. From left to right: Cryostat, linear motion stage, and lid.

Exploring higher duty cycle operation of the accelerator

Substantial R&D was started on the linear accelerator systems. Dedicated R&D projects address a new low-emittance injector and the technology for 16 new accelerator modules capable of continuous-wave (CW) operation, to be located at the beginning of the accelerator. CW operation at the European XFEL would require the final electron beam energy to be lowered to 6–8 GeV, thus giving up on the unique high-energy capabilities of the facility. To avoid this, a higher duty cycle scheme is proposed in which the RF is only partly interrupted. This would make it possible to maintain the final beam energy while still increasing the beam-on time by a factor of 10–20. In addition, extensions of the existing accelerator are being explored, where the cryogenic limits and dynamic heat load when operating at low accelerating gradients have to be measured exactly to provide input for the layout of the cryogenic plant and other systems.

X-ray photon diagnostics

The two High-Resolution Hard X-Ray (HIREX) single-shot spectrometers in the SASE1 and SASE2 beamlines were upgraded with Gotthard-II MHz detectors capable of matching the 4.5 MHz repetition rate in the pulse trains (Figure 7). Gotthard-II uses a silicon microstrip sensor with 2560 pixels at a pitch of 25 µm and is already being used for optimizing beam delivery in seeded and SASE operation modes, as well as for pulse duration tuning and estimation during ultrashort-pulse operation.

Preparing the HXS scientific instrument

The preparation for the new HXS beamline at SASE2 has progressed significantly. Figure 8 shows a view from the experiment hall into the XTD6 tunnel through a hole drilled in the 1 m thick shielding wall for the HXS beam transport.

Figure 8: View from the experiment hall into the XTD6 tunnel along the future HXS beam transport

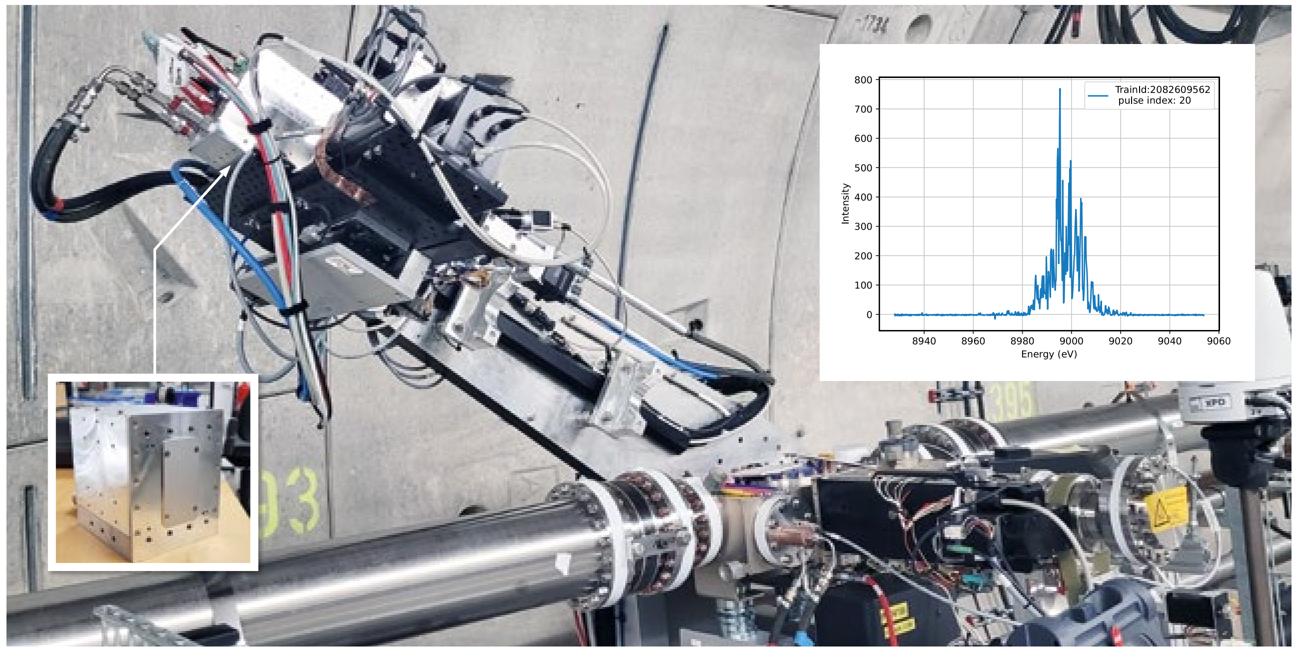


Figure 7: Gotthard-II detector at the SASE2 HIREX spectrometer. The diagram shows a typical X-ray spectrum recorded at 9 keV.

THz radiation at FXE

A THz source based on BNA organic crystals was commissioned at the FXE instrument to assess its feasibility in a proof-of-concept THz pump – hard X-ray probe study (Figure 9). Thin bismuth samples were pumped by single-cycle 1.5 THz pulses, and the subsequent lattice dynamics was probed by 8 keV X-ray diffraction in transmission. The results suggest the existence of thermal and non-thermal THz-induced lattice effects. The successful demonstration shows the feasibility of applying the BNA-based THz source for THz pump – X-ray probe experiments. Further measurements are required to reveal the full microscopic picture of the THz excitation mechanism in semi-metallic bismuth and its transient effects on the constituent electronic and phononic subsystems.

To further improve the THz/mid-infrared light source portfolio, European XFEL recently commissioned a narrow-band, frequency-tunable mid-infrared source based on a high-intensity near-infrared optical parametric amplifier (Orpheus) from Light Conversion. With pulse energies around 10 µJ across the mid-infrared spectral range (5–18 µm or 60–16.6 THz), this source could support THz field strengths of a few tens of MV/cm.

MHz imaging at SPB/SFX

A novel method enabling volumetric X-ray imaging with unprecedented sampling in the MHz range and micrometre-scale spatial resolution [P. Vagovic et al., Global patent index EP4160623A1 (2023)] has opened up new possibilities for fast and ultrafast X-ray imaging of stochastic phenomena, which frequently occur in modern and emerging technologies, such as turbulent multiphase flows in fluidics, 3D printing, or acoustically induced waves interacting with biomaterials, e.g. in blood–brain barrier opening or laser-induced tissue ablation. Using the results from the successful EIC Pathfinder Open project MHz Tomoscopy (GA No. 101046448), a sigma polarization setup capable of capturing up to six projections (with four initially installed) was fully assembled and integrated into the SPB/SFX instrument (Figure 10). By December 2024, the measuring station was ready for commissioning and validation.

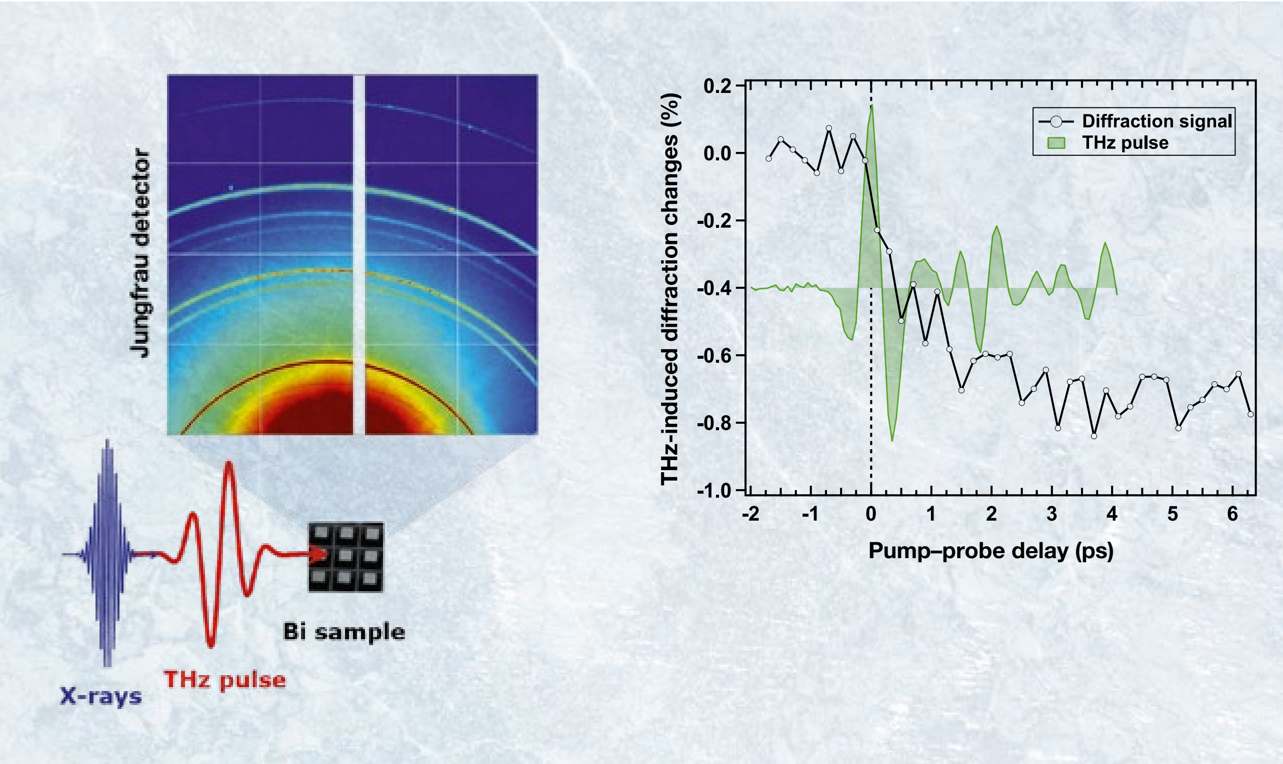


Figure 9: Left: Experiment schematics and 2D detector image. A thin bismuth (Bi) sample was studied in a collinear THz – X-ray geometry. Right: Exemplary dataset of THz-driven dynamics in Bi (black curve) showing the intensity decay of diffraction within the first picoseconds after THz excitation. The transient THz field (~1 MV/cm) is shown as well (green curve). Data courtesy of a team from European XFEL, University of Bern, ETH Zürich, and PSI.

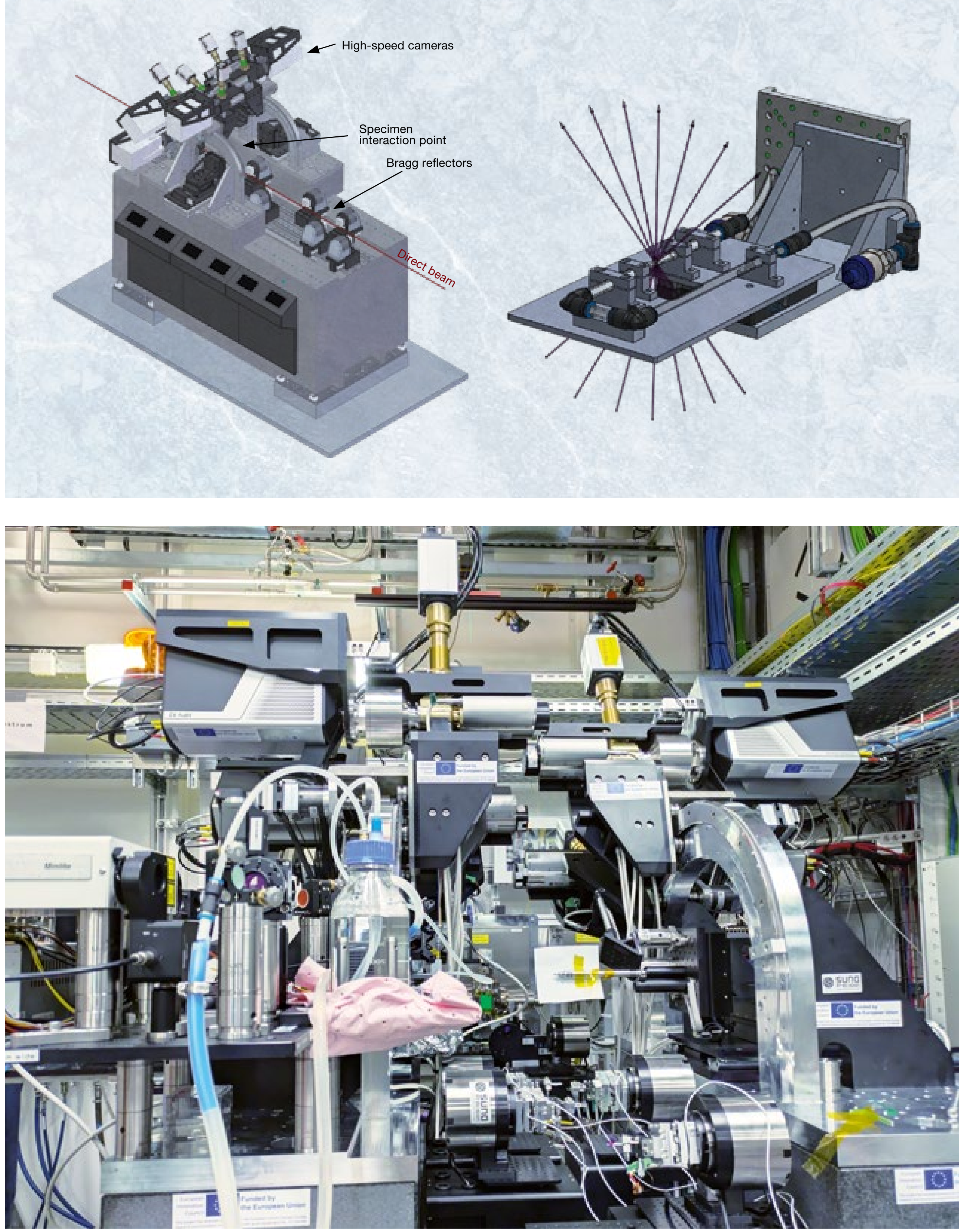


Figure 10: Rendering and realization of the new MHz Tomoscopy measuring station at SPB/SFX

Extreme magnetic fields at HED

As part of the HED-HIBEF collaboration, the apparatus for measurements under high magnetic fields was commissioned and put into user operation. The classical six-circle heavy-load goniometer is equipped with an AGIPD detector module for diffraction experiments and with a polarization analysing unit. Magnetic fields up to 52 T (60 T design value) with 2 to 3 ms rise time are produced in a biconical coil with opening angles of 20° and 60°, respectively, and surrounded by an eddy current shield in a liquid-nitrogen cryostat. Maximum cooldown time after a 52 T pulse is approximately 60 min. Sample temperatures below 15 K are achieved with a closed-cycle helium cryostat, requiring 90 min for cooldown and allowing two to three samples to be mounted simultaneously. A first community experiment was performed in October 2024, which successfully observed diffraction from charge density waves in a high-T_c superconductor $La_{2-x}Sr_xCuO_4$ single crystal.

Beam diagnostics at SQS

A diagnostic section for spectral and temporal analysis of the soft X-ray FEL pulses was installed and commissioned at the SQS instrument (Figure 11). In the downstream section behind the main focus positions, an X-ray optic was set up to refocus the FEL beam. The refocused beam is directed into an experiment chamber comprising an array of 16 electron time-of-flight (ToF) spectrometers ("cookie box") for temporal diagnostics of the FEL beam. Applying the electron angular streaking method by means of an infrared laser field superposed onto the FEL, this device enables the determination of the temporal width of the ultrashort (attosecond to few femtosecond) FEL pulses on a single-shot basis. The horizontal refocusing element (REFOC) is ruled by a variable line spacing (VLS) grating such that, while the 0^{th} order is delivered to the temporal diagnostics, the diffracted beam can be used for spectral diagnostics of the FEL pulses. The resolution of the grating makes it possible to observe the pulse structure (spikes) of the very same FEL pulses used in the experiment. A wave front sensor (WFS) that allows the size of the FEL focus to be determined at the focus position of the experiment will be added in 2025.

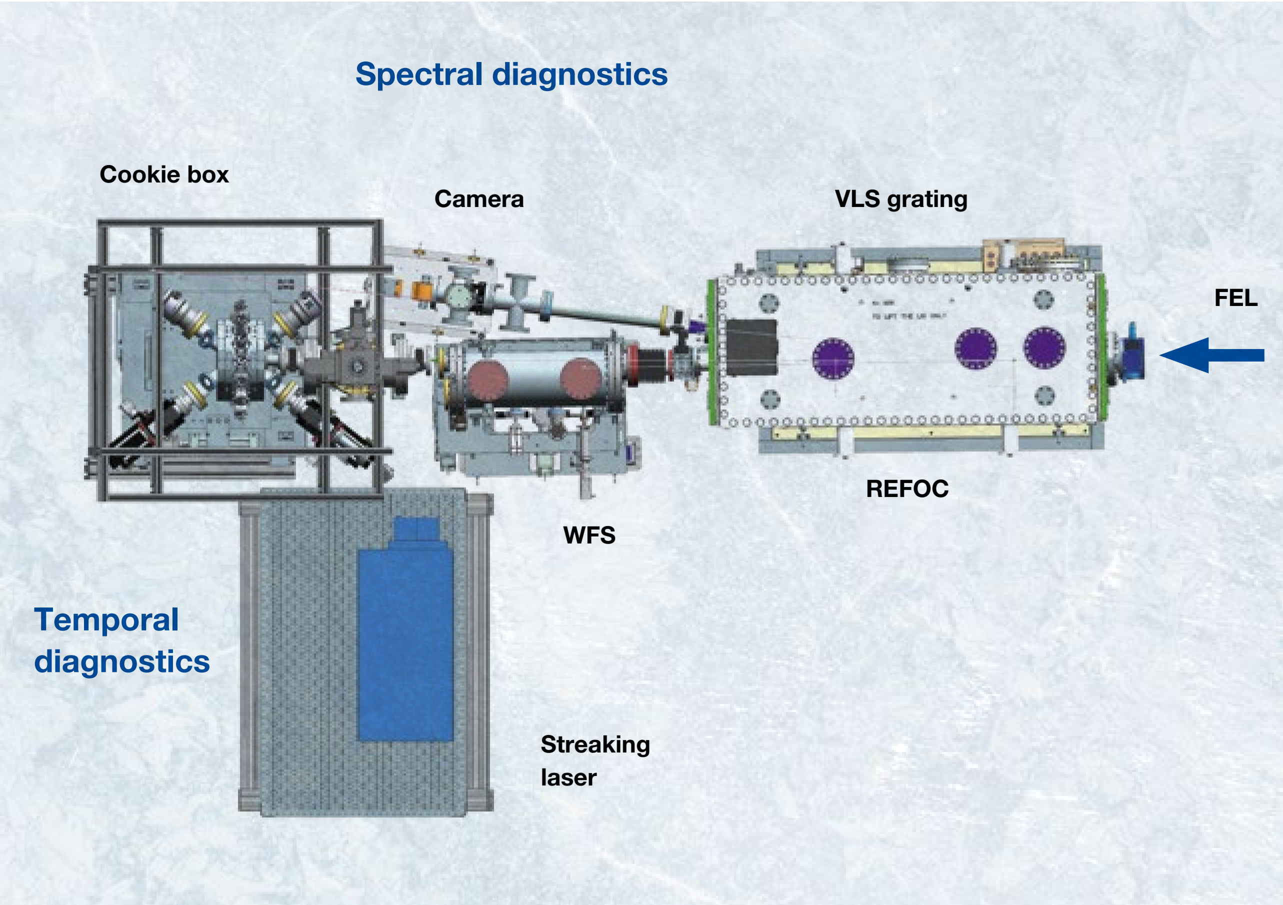


Figure 11: New diagnostic section at SQS

Streamlining analysis of experiment data at MID

A considerable number of data science activities in 2024 were aimed at streamlining the data analysis experience. High-level interfaces and tools that decrease the need for technical expertise of the end users were developed. This was done in close collaboration with instrument scientists and facility users; it included the provision of workflows aimed at transforming raw data into results for selected experimental techniques. At the MID instrument and in collaboration with the University of Siegen, Germany, a pipeline to process X-ray photon correlation spectroscopy data has been developed. This tool can be applied to stored data or to a data stream available in real time. The latter option provides results as data collection progresses (Figure 12a). The data analysis workflows are integrated into the software tool DAMNIT, which enables their automatic execution and offers an overview of results and metadata that are useful to grasp the experiment's progress (Figure 12b).

resulting in a 50% reduction in data volume. Additionally, monitoring capabilities for the DAQ system have been significantly extended. Overview applications now monitor the general state of this core system and will raise a central alert in the event of anomalies for every recorded data source, such as lower than expected ingress rates and malformed data or timing information.

Rollout of myLog for beamtimes

The facility-wide rollout of the new electronic logbook system myLog was completed and now supports beamtime operations. Built on the Zulip chat platform, myLog provides a robust, modern interface for collaborative logging and monitoring of experiment activities. myLog is implemented as a module of the facility metadata catalogue myMdC. By leveraging the information already available in myMdC, it provides automatic logbook orchestration and access management throughout the

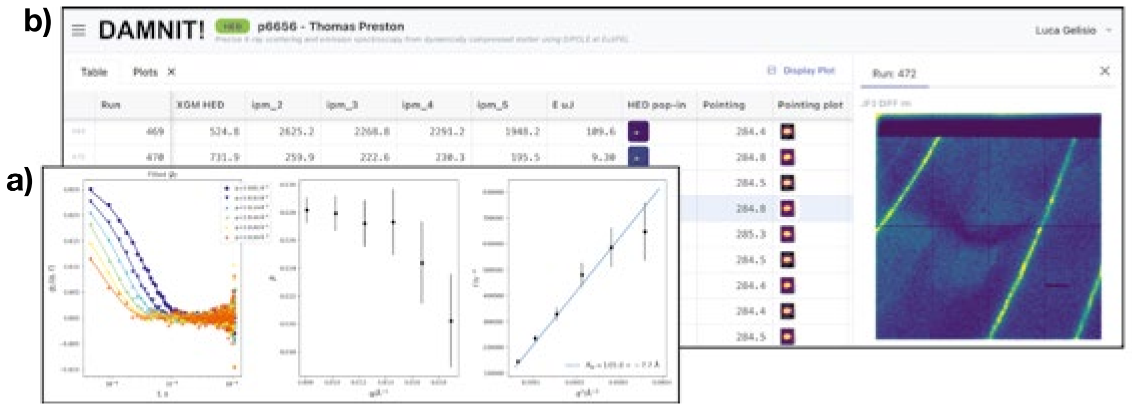


Figure 12: (a) Part of the results of the real-time X-ray photon correlation spectroscopy data analysis pipeline, available in DAMNIT. (b) Screenshot of DAMNIT used during an X-ray scattering experiment.

Data acquisition and online data reduction

During the first months of 2024, the refactored data acquisition (DAQ) system at the SPB, MID, and FXE instruments was extensively tested to ensure a seamless rollout of the evolved system by May 2024. The refactored DAQ system is a cornerstone of persisting scientific data at the facility across all instruments. The upgraded system has been modularized, enabling online data reduction for the AGIPD detector as a standard feature. Two modes are currently supported: i) pulse reduction, which selects illuminated frames from the data and reduces data volume, typically by tens of percent, and ii) gain compression, which, for compatible AGIPD operation modes, prevents analogue gain information from being written to disk,

entire lifecycle of a beamtime. It is seamlessly integrated with the Karabo control system and data analysis tools (DAMNIT) and enables real-time synchronization of experiment logs with instrument control data and analysis workflows. Close collaboration with scientific instrument staff during commissioning and experiment runs ensured that the system is integrated seamlessly into existing experiment workflows.

Personnel development

European XFEL is dedicated to fostering an inclusive environment in which individuals can realize their full potential, irrespective of cultural background, physical capabilities, or gender. Tailoring support to their unique strengths and skills, staff members are equipped with the necessary training and qualifications to excel in their roles.

Personnel development is an ongoing journey encompassing changes in people's roles, aspirations, and objectives. Diverse training programmes, workshops, and coaching sessions are being offered to facilitate the personal and professional growth of every staff member.

Figure 1: The Project Management Office regularly offers project management training.

In 2024, activities focused on physical and mental health. Staff members were encouraged to get trained as mental health first aiders, and an online platform supporting mental health was implemented. During the year, the European XFEL Health Days became Health Weeks—two weeks instead of a few days—with a special focus on stress reduction and physical fitness.

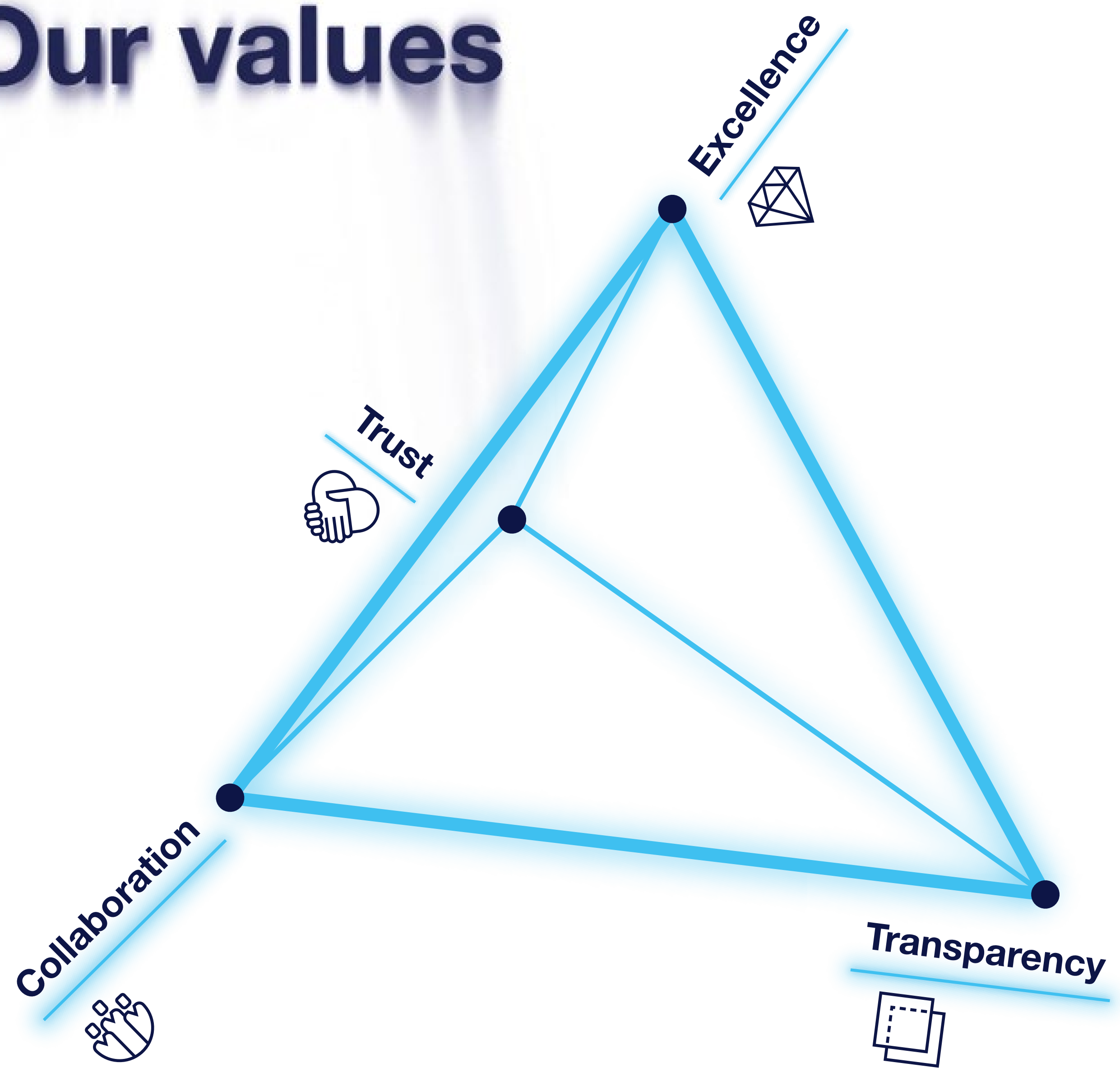
In addition, following an evaluation of a previous appointment and promotion process, a new procedure to appoint staff members to "Senior Roles" was introduced in 2024. The Senior Role acknowledges the expertise of highly experienced staff.

In the past years, many stakeholders within European XFEL worked on the development of the strategic directions for the coming years. Part of this strategy is the development of Human Resources (HR) activities.

Strategic HR programme

The strategic HR programme is structured into two key phases in order to enhance operational efficiency, leadership development, and organizational growth. Phase 1 (2025–2027) will focus on optimizing HR operations by refining processes and guidelines. Leadership development will be reinforced through structured training, leadership role formalization, and a future leaders' programme. Simultaneously, European XFEL will strengthen its company values through various initiatives. Employer branding efforts will also be prioritized to enhance the company's image and outreach as an employer. Phase 2 (2028–2030) will expand on these improvements by addressing long-term workforce planning and guest management as well as fostering a stronger feedback culture. Additionally, an education programme for young professionals, including interns, apprentices, and Ph.D. students, will be reviewed to attract and nurture future talent. By implementing these strategic initiatives in phases, European XFEL aims to drive sustainable personnel development, improve workplace efficiency, and reinforce its position as an employer of choice.

Our values



European XFEL's core values—collaboration, excellence, transparency, and trust—were defined in 2021 through a bottom-up approach, engaging staff focus groups and conducting an extensive survey involving all staff members. Our values serve as guiding principles, articulating our fundamental beliefs and conveying internally and externally what is important to the company.

Over the past year, commitment to these values has been reinforced through diverse activities and initiatives. These were led by Culture Change Agents, a network of staff members representing various professions and nationalities.

Activities included participation in the onboarding of new employees and playful activities to engage with the individual values. The purpose of these activities was to have fun while experiencing the benefit of the values in action.

Figure 1: Activities of the Culture Change Agents during an internal event

Ph.D. programme

The European XFEL Ph.D. programme is fully consolidated, with 39 students participating in the programme in 2024. The number of European XFEL alumni Ph.D. students is 45, with 10 students graduating in 2024. The Ph.D. committee supervises the programme, guaranteeing that students acquire a good set of technical and soft skills, and secures proper supervision. This is done by annually monitoring the progress of each student in close cooperation with academic supervisors.

The Ph.D. programme is a crucial pillar of European XFEL in-house research and a useful tool to broaden the user community as well as to engage with the shareholder countries through the creation of shared Ph.D. positions.

These Ph.D. students are co-financed by European XFEL and a university in a shareholder country. The students spend a minimum of 12 months at European XFEL. As part of the Ph.D. programme, each student has a local supervisor and a tutor. Currently, there are 11 shared Ph.D. positions, affiliated with 7 universities outside of Germany (e.g. Spain, Italy, and France).

The efforts to create new user communities and to engage with the shareholder countries are reflected in the affiliation distribution of the Ph.D. students (Figure 1). The nationalities of the Ph.D. students (Figure 2) also show the hallmark diversity of European XFEL, in line with the 63 nationalities present among staff members.

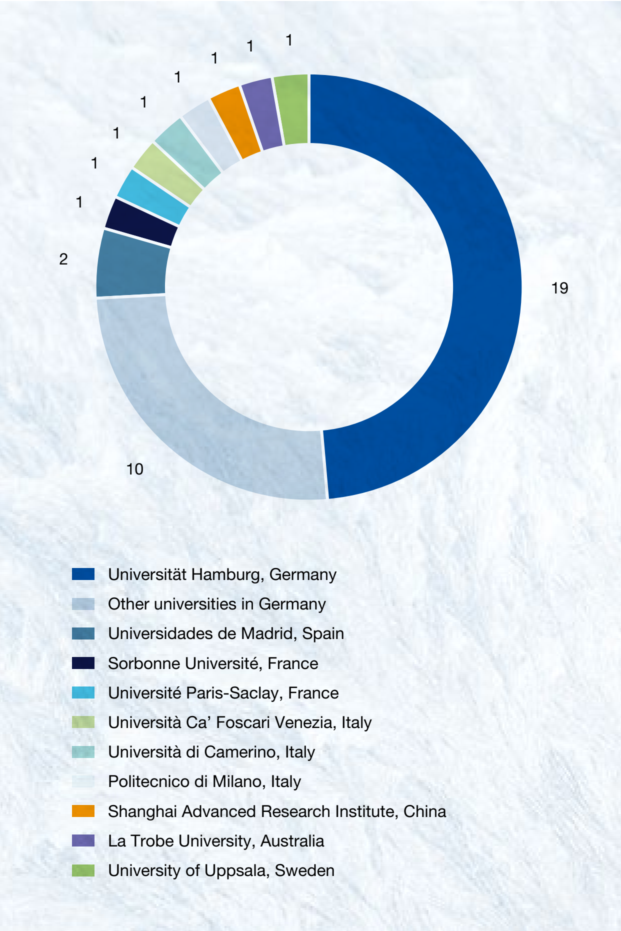


Figure 1: Affiliations of European XFEL Ph.D. students

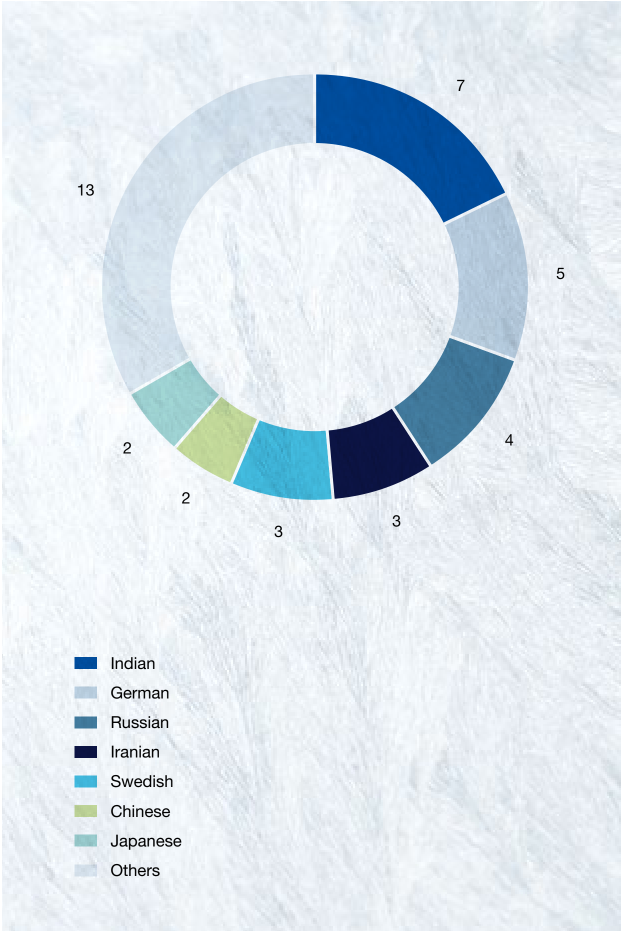


Figure 2: Nationalities of the 39 European XFEL Ph.D. students in 2024

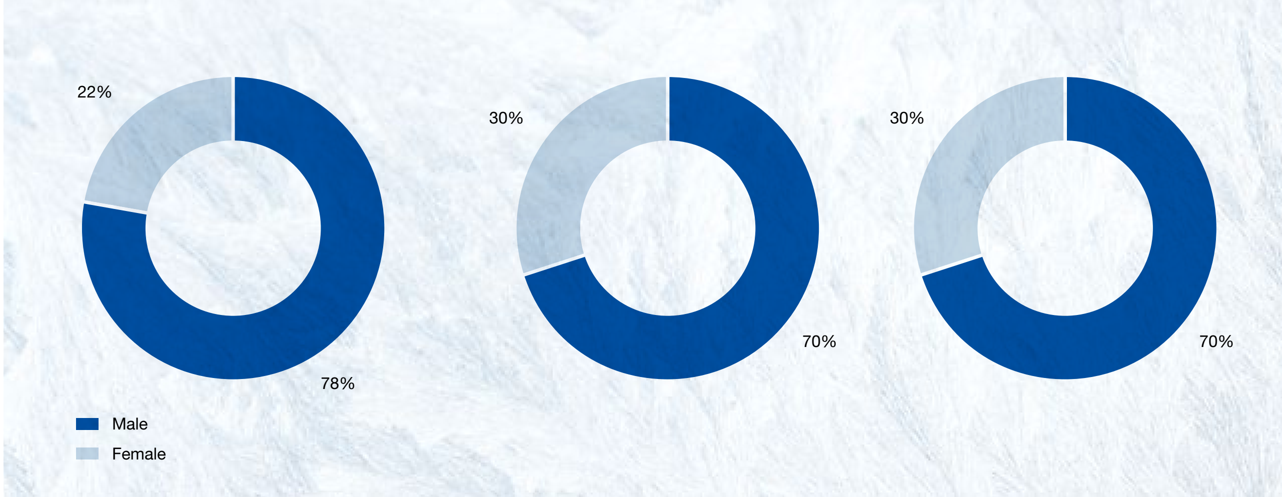


Figure 3: Current gender balance of Ph.D. students in the first (left), second (middle), and third+ year (right) of their Ph.D. contract

Figure 4: Impressions of the Students' and Science Days 2024

European XFEL is committed to gender equality, and the gender balance is regularly monitored (Figure 3). A slight decrease in the number of female Ph.D. students was observed in the last recruitments. Additional measures are being taken to increase the number of female Ph.D. students and to foster gender equality among staff.

As part of their education as scientists, the Ph.D. students are encouraged to attend conferences and internal events and activities at European XFEL, which is crucial to building networks. At the annual internal Students' and Science Days, they practice presentation skills and engage in scientific discussions with senior scientists (Figure 4).

Budget and third-party funding

At the end of 2024, 99.3% of the European XFEL construction budget had been spent, with the facility nearing completion of key infrastructure projects. The annual operation budget for 2024 was 150 million euro (M€). In 2025, the operation budget will increase to 154.6 M€.

Alongside the ongoing operational expenditures, investments from the remaining construction budget continued to finalize key components of the facility. Notable projects included the completion of SASE installations, such as the addition of a third instrument port at the beamlines, and the development of the Lighthouse visitor and conference centre, a remarkable milestone for European XFEL.

In 2024, European XFEL also initiated evaluations for its strategic development through 2032. The company began implementing the first phase of these future investments, utilizing an “indicative” budget as part of the pre-allocation of operational funds. This Facility Development Programme (FaDeP) includes strategic activities and contingency plans, providing a clearer picture of financial planning. It has been instrumental in improving transparency and offering greater flexibility for financing major projects. It also ensures financial certainty, which is especially crucial given the current geopolitical uncertainty.

The total construction budget for European XFEL stands at approximately 1.25 billion euro (at 2005 value). Of this, 46% was contributed in kind by various partners, while the remaining more than 650 M€ (2005 value) was contributed in cash by shareholders and associated partners.

In 2024, the total payment budget for European XFEL was 160 M€ (Figure 1). Of this, 150 M€ (94%) was allocated to operational expenses, and 10 M€ (6%) was directed toward ongoing construction projects. The largest cost categories were recurrent and capital expenditures, totalling 81 M€ (51%) (Figure 2). Personnel expenses, including those for staff from DESY working on accelerator operations, amounted to 72 M€. An additional 7 M€ was earmarked for smaller upgrades.

For 2025, the European XFEL Council has approved an increase in the annual operation budget to 158 M€. This includes 3.7 M€ to finalize the construction phase budget.

As part of its core funding from shareholder countries, European XFEL runs an extensive research and development programme and allocates significant funds to various projects on a competitive basis. Funding is awarded after a successful application process (further details below). Third-party funding continues to play a critical role in the budget, offering flexibility for high-priority projects.

Development and R&D projects

Since 2019, the primary mechanisms for enabling larger-scale projects have been the yearly internal research and development (R&D) calls and development projects (DPs), which can be approved at any point during the year following evaluation. The R&D calls focus mainly on securing additional funding for hiring personnel—such as Ph.D. students and young scientists—as well as for developing early prototypes and contributing to strategic priorities. In contrast, DPs are generally funded using available operation funds and leverage significant expertise from internal groups. The main goal of DPs is to enable new scientific discoveries, often through multidisciplinary collaborations.

At the beginning of 2024, there were 21 ongoing DPs. By year’s end, three of these projects had been successfully completed, and two new DPs were successfully initiated. Four more DPs are currently in preparation for approval (Figure 3).

Regarding the R&D programme (Figure 4), the European XFEL Management Board decided to skip the photon science R&D call for 2024, as it will be incorporated into the facility’s broader strategic goals and in this context re-initiated in 2025.

In 2024, a total of 33 R&D projects were successfully completed at European XFEL and DESY. The results of these projects are already being implemented, a

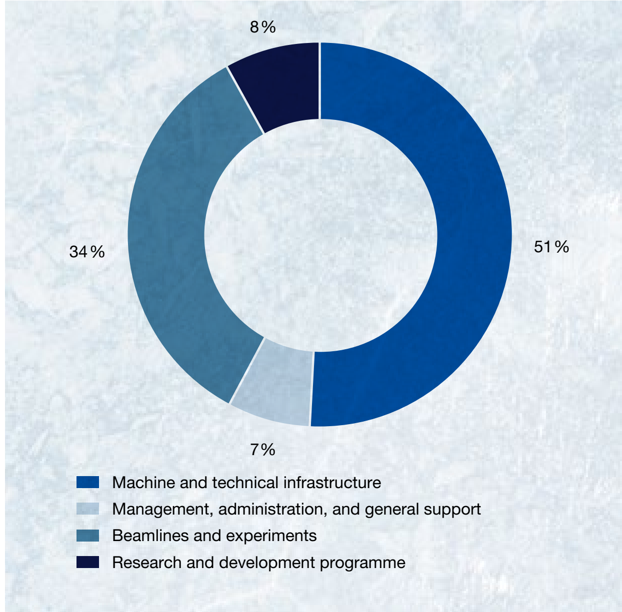


Figure 1: Payments by major activity in 2024

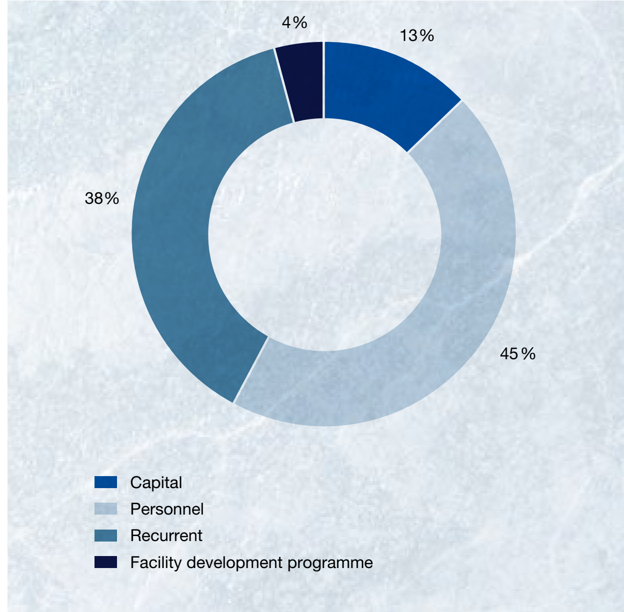


Figure 2: Payments by budget items in 2024

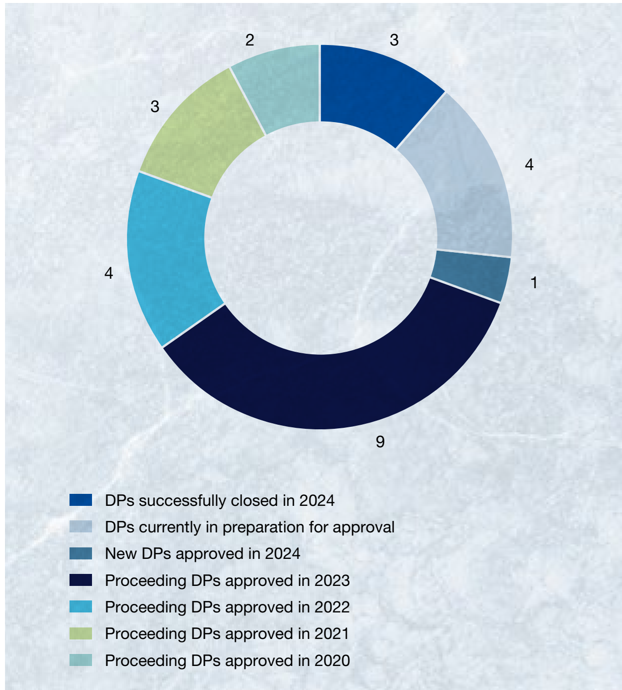


Figure 3: Status of development projects in 2024

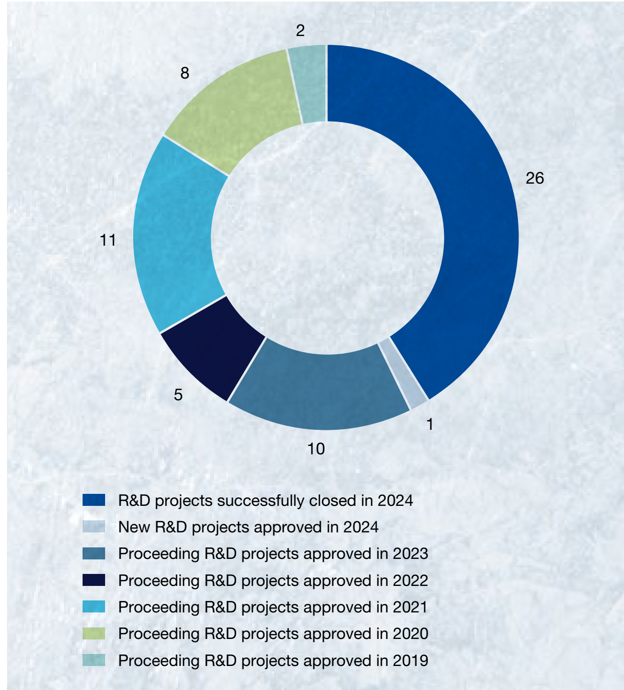


Figure 4: Status of R&D projects in 2024

significant accomplishment in itself. Furthermore, over 50 related publications were accepted or submitted, underscoring the richness and impact of the scientific and technological advancements made at European XFEL.

Third-party funding

In 2024, European XFEL participated in 20 research projects, 13 of which were funded by the EU Horizon 2020 and Interreg programmes, while 7 were funded by national organizations, including the German Research Foundation (DFG) and the German Federal Ministry of Education and Research (BMBF).

The overall income from these third-party projects amounted to 1.45 M€ (compared to 1.4 M€ in 2022 and 2023). Half of this funding came from European and international sources, while the other half was sourced from German national funding.

In 2024, 11 staff members were employed exclusively for third-party–funded projects. Three of these projects concluded, and five new projects were initiated.

Managing quality, safety, risk, and customs

After a phase of ramping up operational activities, European XFEL is now reaching a plateau in staffing and organizational structure, which enables the company to focus on implementing strategic activities. These activities are carried out parallel to operation, which requires a high level of coordination and long-term project management.

Quality management

In 2024, European XFEL streamlined decision-making processes and delegated responsibilities to different leadership levels, promoting efficiency and responsiveness. Procedures were adapted as befits a leading research facility, ensuring that operations remain robust and effective. Furthermore, European XFEL refined its budget planning processes to secure long-term financial stability. By employing advanced planning tools and methodologies, financial security was maintained, supporting the scientific mission. Audits—internal and external—ensured that processes met shareholder requirements and user needs. Staff and partners like DESY were involved in continuous improvement and upheld sustainable and reliable facility operations. Particular developments are reported for the following areas.

Procurement

As part of the organizing committee of the Big Science Business Forum (BSBF) 2024 in Trieste, European XFEL played a key role in organizing and managing the event (see “Contacts to industry”). Engagement in such activities is important to identify new suppliers for needed equipment, thereby improving European XFEL’s negotiation position as the network of potential collaborators and business partners is extended.

Furthermore, the international procurement network continues to expand, fostering synergies and enhancing collaborative efforts. Procurement issues have been actively discussed in multilateral forums, such as the League of European Accelerator-based Photon Sources (LEAPS), the European Intergovernmental Research Organisation forum (EIROforum), and BSBF. Additionally, European XFEL is an active participant in the EU-funded Building Innovation Procurement Capabilities in Big Science (INPROCAP) initiative under the Horizon Europe programme, contributing to the development of specialized advisory services on innovative procurement. A dedicated EU-funded employee will work locally on this initiative for the next two years.

Customs and export control

In a globalized world with evolving security challenges, export control remains a critical concern for the economy and research institutions, and compliance with foreign trade regulations is essential. European XFEL contributes to standardized processes that facilitate smoother customs procedures within the research community.

European XFEL supports staff members, external users, and suppliers in navigating customs, export control, international logistics, and sanctions compliance. In 2024, key improvements included launching an “Export Control Basics” training module, publishing a user guide on shipping samples and equipment, and updating staff guidelines for import, export, embargoes, and sanctions screening. New shipping forms were introduced for centralized data entry, and the office switched to the more reliable SimPlex sanction list screening software. Efforts continued to ensure compliance with embargo regulations, and a deferment account for import value-added tax (VAT) was approved to reduce costs and internal efforts. Additionally, strategic planning began for the Carbon Border Adjustment Mechanism (CBAM) reporting obligations.

Corporate risk and asset management

A key milestone in 2024 was the integration of corporate risk management into asset management. For the first time, interviews were combined with corporate risk assessment discussions, allowing group leaders to systematically evaluate risk management approaches and the implementation of necessary risk mitigation measures. In a mature facility with an increasing focus on maintenance management, these topics gained prominence. The number of registered corporate risks increased notably. Continuous improvements were pursued through regular exchanges with other research institutions and industry partners. The successful completion of the first pilot project on process analysis provided a foundational blueprint for future initiatives in process management, ensuring continuous administrative and operational improvements.

By prioritizing quality management in the administration, European XFEL reinforced its foundation for achieving world-class scientific results and underscored its dedication to addressing complex societal challenges through cutting-edge research, facilitated by an excellent administrative framework.

Figure 1: Safe and inspiring workspace: Students and teachers at the Xcool Lab explore cutting-edge research, guided by comprehensive safety measures.

Safety and radiation protection

Safety is fundamental to the success of research facilities. At European XFEL, safety is regarded as an enabler of bold innovation, fostering confidence and care. It is integral to European XFEL’s Strategy 2030+, which emphasizes simplifying access to experiments while ensuring safety, enabling every experiment to succeed. As experimental activities grow in scale and complexity, European XFEL provides consultation and support for the growing user community, addressing safety concerns and ensuring that scientific endeavours continue seamlessly and securely. In 2024, European XFEL finalized a new safety and radiation protection organization, establishing a robust framework for safety across the campus and enhancing collaboration with DESY.

With the start of operations at the Lighthouse visitor and conference centre and the Xcool Lab, the development of tailored safety guidelines to address the specific needs of engaging with visiting school classes was supported. These efforts also included creating safe and inspiring workspaces for young scientists, empowering them to confidently explore cutting-edge science. Additionally, biosafety measures are continuously reviewed and adapted to ensure they meet current requirements and support safe operations.

Safety may often go unnoticed, yet its impact is profound. The evaluation of a Safety Culture Survey of 2023 revealed that, while staff members place a high emphasis on work safety, there is still room to improve how safety concerns are addressed within the organization. These findings inspire ongoing refinements, allowing European XFEL to move forward with care and excellence.

International collaboration

Collaboration is at the heart of European XFEL and one of its core values. In 2024, European XFEL staff members and directors served on more than 40 different committees and advisory bodies in research institutions worldwide.

Furthermore, European XFEL participated in many events, both at its headquarters in Schenefeld as well as all across Europe and worldwide. This included onsite meetings, such as the visit of a CNRS delegation at the facility, during which options for enhanced collaborations were discussed, as well as visits of members of the Management Board to scientific institutions in shareholder countries.

Figure 1: Countries in Europe where European XFEL management participated in events

A particular highlight was the participation in the School of XFEL and Synchrotron Radiation Users (SFEL2024), which took place in Liptovský Ján in Slovakia on 14–18 October 2024. The school was organized by European XFEL, together with the Pavol Jozef Šafárik University in Košice, and supported by the Ministry of Education, Research Development and Youth in the Ministry of Economy of the Slovak Republic. The event brought together the international synchrotron and neutron communities with the XFEL community to enable exchange and to help build up connections of Slovak users with other researchers in Europe and beyond. The school included scientific talks as well as tutorial lectures and addressed young scientists in particular.

Figure 2: Attendees of the School of XFEL and Synchrotron Radiation Users (SFEL2024) in Liptovský Ján, Slovakia

European XFEL was also actively involved as a member of the organizing committee of the third Big Science Business Forum (BSBF), which took place in Trieste on 1–4 October 2024 (see “Contacts to industry”).

Representatives of the Management Board further engaged in discussions at science administration and policy events, such as the International Conference on Research Infrastructures (ICRI), which was organized in Brisbane, Australia, on 3–5 December 2024 with 420 international participants from 50 nations.

European XFEL representatives are very active within the scientific community, engaging in committees and other advisory bodies in research institutions worldwide. In 2024, this was demonstrated by European XFEL staff members and management participating in more than 40 different committees worldwide.

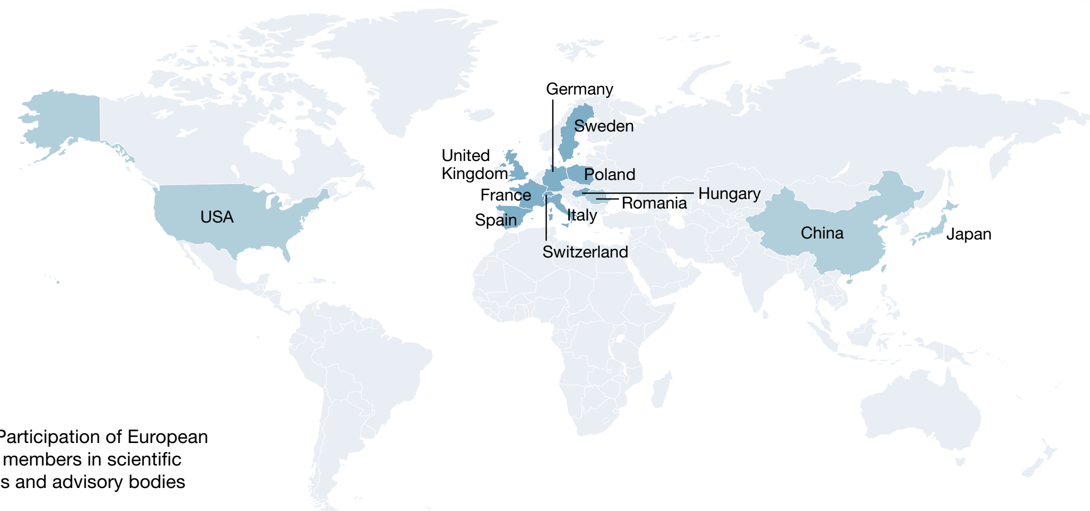


Figure 3: Participation of European XFEL staff members in scientific committees and advisory bodies

Figure 4: EU- and other third-party–funded projects

Figure 5: Attendees of the UltraBat meeting held at European XFEL in March 2024

Figure 6: Tour of the European XFEL experiment hall during the HALRIC conference in September 2024

In 2024, two new Horizon Europe projects funded by the European Union commenced at European XFEL:

Neutrons and Photons Elevating Worldwide Science (NEPHEWS)

The NEPHEWS project (GA No. 101131414) under the coordination of the National Synchrotron Radiation Centre SOLARIS in Poland provides a user-driven access programme targeting new and non-expert communities, with a focus on the expansion to countries such as Ukraine or in Africa. A bottom-up, user-centric approach aims to build an integrated European Research Infrastructure landscape, engaging the LEAPS and LENS consortia and their European scientific user communities. European XFEL, as a work package leader of communication and dissemination, coordinates outreach to the EU13 countries and moderates dialogue between academia and policymakers.

Research Infrastructure Access in NAnoscience & Nanotechnology (RIANA)

The RIANA project (GA No. 101130652) coordinated by DESY connects seven European networks of cutting-edge research infrastructures of the ARIE network to cover the most advanced techniques relevant to nanofabrication, processing/synthesis, characterization, and analysis as well as simulation capacity. RIANA seeks to establish a highly customized and efficient access to 69 infrastructures via a single entry point and enable their scientific use through comprehensive scientific and innovation service by senior scientists, facility experts, and highly trained junior scientists. RIANA is committed to attract experienced and new users from academia and industry, making their promising ideas a success and pushing them to higher technology readiness level.

European XFEL is an active member of the scientific infrastructure community in Europe, regularly engaging in networks to jointly raise awareness of aspects important to research infrastructures. As the youngest member of the European Intergovernmental Research Organisation forum (EIROforum), European XFEL took over the annually rotating chairpersonship of the network until June 2024.

European XFEL is a member of FELs of Europe, which links all FEL facilities in Europe. The aim of the collaboration is to address the technological and scientific challenges of this technology area and serve the pan-European science community by fully exploiting the scientific potential of these unique accelerator-based short-pulse light sources.

The facility is a member of the League of European Accelerator-based Photon Sources (LEAPS) consortium, together with other European synchrotron radiation and FEL facilities that jointly promote the fundamental, applied, and industrial research carried out at their facilities.

As a truly European research infrastructure, European XFEL is a landmark within the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) and took part in its monitoring activity in 2024.

Contacts to industry

In 2024, a significant milestone was achieved with the implementation of various tools designed to enhance innovation in the acquisition process. These tools ranged from knowledge transfer mechanisms to funding initiatives aimed at fostering training in innovation procurement. The ongoing collaboration with national Industrial Liaison Officers (ILOs) from shareholder countries played a pivotal role in supporting the procurement and development of cutting-edge technologies. Furthermore, European XFEL strengthened its commitment to innovation by actively incorporating innovation-driven companies into its experiment programmes.

To promote industrial collaboration, European XFEL was an active part of the international organizing committee of the Big Science Business Forum (BSBF) 2024 in Trieste. This high-profile event brought together key suppliers and major scientific institutions to provide a platform for exchange to build up new and strengthen existing collaborations in order to promote the European science and innovation landscape. It was attended by 1300 participants from more than 500 organizations and 29 countries. Two dedicated booths for European XFEL and the League of European Accelerator-based Photon Sources (LEAPS) consortium created opportunities for co-development and networking with technology providers. Key activities included the organization of a technology transfer track—a strategic initiative to foster knowledge and technology transfer and to facilitate partnerships. These efforts were supported by a poster session and a call for collaborations. Furthermore, European XFEL organized and participated in significant sessions as a speaker or moderator on critical topics, such as innovation and green procurement, regulatory frameworks for industry and academia, and strategies for developing a more inclusive big science common market, with a particular focus on Central European companies. Follow-up actions were implemented to ensure sustained engagement.

Additionally, European XFEL spearheaded Central European involvement in BSBF 2024 and its satellite activities. Demonstrably, this had a synergistic effect and opened considerable options for collaborations in Central, Eastern, and South-Eastern Europe. Other important industrial–academic events in Spain and the UK to increase the pool of technology providers were funded by the LEAPS-INNOV project with active participation by European XFEL or organization by shareholder countries such as Poland and Sweden.

Innovation procurement, as outlined in Directive 2014/24/EU, introduces a range of modern procedures designed to enhance transparency in the procurement of innovative components and services while supporting the research and development phase of suppliers. European XFEL is an active part of a consortium led by Danish Technological Institute (DTI) that has been awarded the Building Innovation Procurement Capabilities in Big Science (INPROCAP) project under the Horizon Europe programme. As part of the project, training materials will be developed and tailored for academic institutions, including European XFEL and its ecosystem and ILOs, to provide guidance on the applicability, eligibility, and processes of the new procurement procedures. The goal is to enable institutions to evaluate procurement requests and determine opportunities for applying these innovative methodologies.

Knowledge transfer for leveraging expertise

Knowledge transfer is a vital mechanism for leveraging expertise. In 2024, one contract was signed to initiate the process; another is currently under negotiation. Industrial collaborations have had a particular impact in the field of optics. For example, considerable efforts have been made to establish a European supply chain for synthetic diamonds that are produced under high temperature and high pressure.

European XFEL also actively promotes the use of its facility for applied science with industrial relevance, particularly in structural biology as well as in sectors such as aerospace and the production of 2D materials. One particularly intriguing highlight is the collaboration between Patrik Vagovic (CFEL), Jiawei Mi (University of Hull, UK), and Hielscher Ultrasonics, a manufacturer of production machines for 2D materials. Their experiment employed MHz radiography to visualize the exfoliation process of various materials.

Furthermore, European XFEL was actively involved in organizing the LEAPS-INNOV Battery Research Forum, which took place in Barcelona, Spain, in January 2024.

Figure 1: The “Advanced Characterization to Mitigate Component/Material Failure” workshop at the European Space Research and Technology Centre included members of EIROforum.

Figure 2: The National ILO meeting brought together a network that supports industrial ecosystems at European XFEL.

Figure 3: The Big Science Business Forum roadshow in Slovakia was a panel discussion on national support for industrial ecosystems moderated by European XFEL.

The forum aims to enhance collaboration and synergy between the LEAPS facilities and the battery research community, including the relevant industrial actors in Europe.

European XFEL organized the EIROforum workshop on “Advanced Characterization to Mitigate Component/Material Failure”, which was held at the European Space Research and Technology Centre in Noordwijk, the Netherlands, focusing on failures in materials and components across industries, including aerospace. The event highlighted techniques such as high-resolution imaging, which help probe failure phenomena in order to prevent it.

European XFEL continued to play a key role in the ATTRACT project. ATTRACT fosters closer collaboration between academic innovators and businesses while promoting the development of the next generation of European innovators. The initiative strengthens the position of European XFEL as an integral part of Europe’s leading network of innovators. One notable activity includes supporting awarded projects by helping them find new connections with technology providers and industrial collaborators that are critical to their successful completion.

Outreach

Lighthouse: a modern visitor and conference centre

On 20 November 2024, European XFEL opened its modern Lighthouse visitor and conference centre to the public. The official opening was attended by close to 300 invited guests. Council Chair Federico Boscherini, Schleswig-Holstein State Secretary Guido Wendt, and Hamburg State Councillor Eva Gümbel praised the successful architectural and didactic concept. At the Lighthouse, visitors from all over the world can gain fascinating insights into research at European XFEL. Exhibitions and events make science tangible for non-experts and promote exchange between science and the public.

Figure 1: Curtains up for science and research! The Lighthouse shortly before the opening.

Figure 2: Walk through the exhibition during the official opening of the Lighthouse visitor and conference centre on 20 November 2024

Figure 3: Activities in the Xcool Lab. Top: A school class in the biology lab. Bottom: Working with the X-ray machine in the physics lab.

Xcool Lab start of operation

Even before the official opening of the Lighthouse, the Xcool Lab welcomed school classes from Germany and Denmark. The Xcool Lab enables practical learning through research-based courses related to school curricula. Two state-of-the-art laboratories allow school students to investigate scientific questions in physics or molecular biology by carrying out their own hands-on experiments in one-day courses. The courses can be booked free of charge and are offered in German or English. In the physics lab, students measure X-ray spectra based on Bragg reflection, deflect particles with magnetic fields, and generate diffraction images. In the molecular biology lab, students amplify gene sequences via polymerase chain reaction and separate nucleic acid strands according to their size. Modules for other age groups and professional training sessions for teachers are in development.

Public events

On 1 June, European XFEL opened the doors of its tunnel entrance building on the Bahrenfeld campus for the Hamburg Science City Day. More than 15 000 visitors attended the multi-stakeholder event focused around the Bahrenfeld campus, which is being developed to become the heart of the Science City Hamburg Bahrenfeld. Visitors carried out hands-on experiments, learned how researchers analyse results, and tasted ice cream made with liquid nitrogen. Small children could also take home a colouring book featuring biomolecules, the linear accelerator, and wild animals on the renaturalized research campus.

Over six days in September, European XFEL contributed to the “Highlights der Physik” festival in Hannover. More than 35 000 people attended the annual event. European XFEL teamed up with DESY, HZB, and GSI. Attendees at the European XFEL booth could e.g. experience a 3D tour using virtual-reality headsets.

In December, European XFEL presented the facility to local residents at the Schenefeld Christmas Market. The very first Science Saturday at the Lighthouse was also held in December. Children designed illuminated LED Christmas cards while learning about the physics of electricity and circuits. Science Saturdays aim to bring families to the Lighthouse with hands-on activities linked to science.

Figure 4: Science City Day on the Bahrenfeld campus on 1 June 2024

Schools outreach

In addition to the Xcool Lab and guided tours, European XFEL supported several science outreach events aimed at school students. At an "Aktionstag" (Day of Action) of Young Talents Hamburg, a leading scientist at European XFEL presented methods of sample preparation, characterization, and delivery to students and teachers.

Furthermore, the Sophie-Barat-Schule in Hamburg, one of the winning teams of the national "Physik im Advent" competition run by the University of Göttingen, toured the experiment hall and campus and gained insights into X-rays and microscopy by carrying out experiments.

Special exhibitions

In addition to the permanent exhibition focused on European XFEL and its research, the Lighthouse also hosts temporary exhibitions. The opening event for the first science and art exhibition in the Lighthouse took place on 28 November 2024. The "Strahlzeit" exhibition by the artists of the Well Wired Team (Kalle Maukel, Werner Jarmatz, and Boris Vogeler) showcased three large wire objects with a sound and light installation. The sculptures were inspired by molecular structures and representations of electron densities like those investigated at the European XFEL. Their surfaces were used for a light show, which created three-dimensional, moving motifs that represented molecular structures while captivating and calming viewers. Light and sound complemented each other, emphasizing the atmosphere of the art installation.

Guided tours

In 2024, the guided tour programme comprised 105 tours (2023: 88) with almost 3000 (2023: 1800) visitors. Most of them experienced a presentation and tour of the experiment hall. The facility was visited by school and university students as well as stakeholders and attendees of scientific conferences.

Video production and online communication

The insightful series of videos with user statements in which scientists shed light on their experiments at the European XFEL was continued in 2024. A total of 16 users were interviewed, with the videos available on the European XFEL YouTube channel and promoted on the website and on the social media channels Facebook, LinkedIn, Instagram, and X.

A new Instagram channel for the Lighthouse focuses on outreach activities and is run in parallel with the existing, more research-focused channels. To date, European XFEL has about 20 000 followers on social media.

Last but not least, a new set of pages on the website about water research at the European XFEL offers an overview with texts and interviews for non-experts as well as the opportunity to take a deep dive into the subject.

Figure 5: Experiencing one of the three objects crocheted from metal wire at the "Strahlzeit" exhibition

Director's outlook

The coming year will be dominated by a half-year-long installation and maintenance period. A mandatory test of the safety valves in the pressure vessels of the linear accelerator will require a warm-up of all accelerator modules – after 8.5 years of continuous operation at 2 K. During this critical phase, we – together with our DESY colleagues – will also address further existing issues, enhance performance, and prepare the foundation for future advancements. Concurrently, we will introduce new features and capabilities, expanding the potential for improved user experience.

The most significant installation in the tunnels will involve preparatory work for the superconducting undulators. To achieve this, approximately 100 m of the SASE2 electron beamline will be entirely reconstructed to make room for two planar and up to six superconducting undulators. The electron beam transport system, extending about 500 m behind SASE2 towards the beam dump, will also have space for two additional undulators in the XTD3 and XTD5 tunnels. In the XS4 shaft between these tunnels, a "mini-beta insert" will be created using 10 new quadrupole magnets, enabling experiments that require a smaller electron beam size. Furthermore, an experiment chamber will be installed to house different dielectric wakefield structures designed to generate intense THz radiation. The electron lattice behind the existing SASE3 undulator will be reconfigured over a distance of about 60 m to accommodate longitudinal phase space diagnostics.

Implementing our strategy

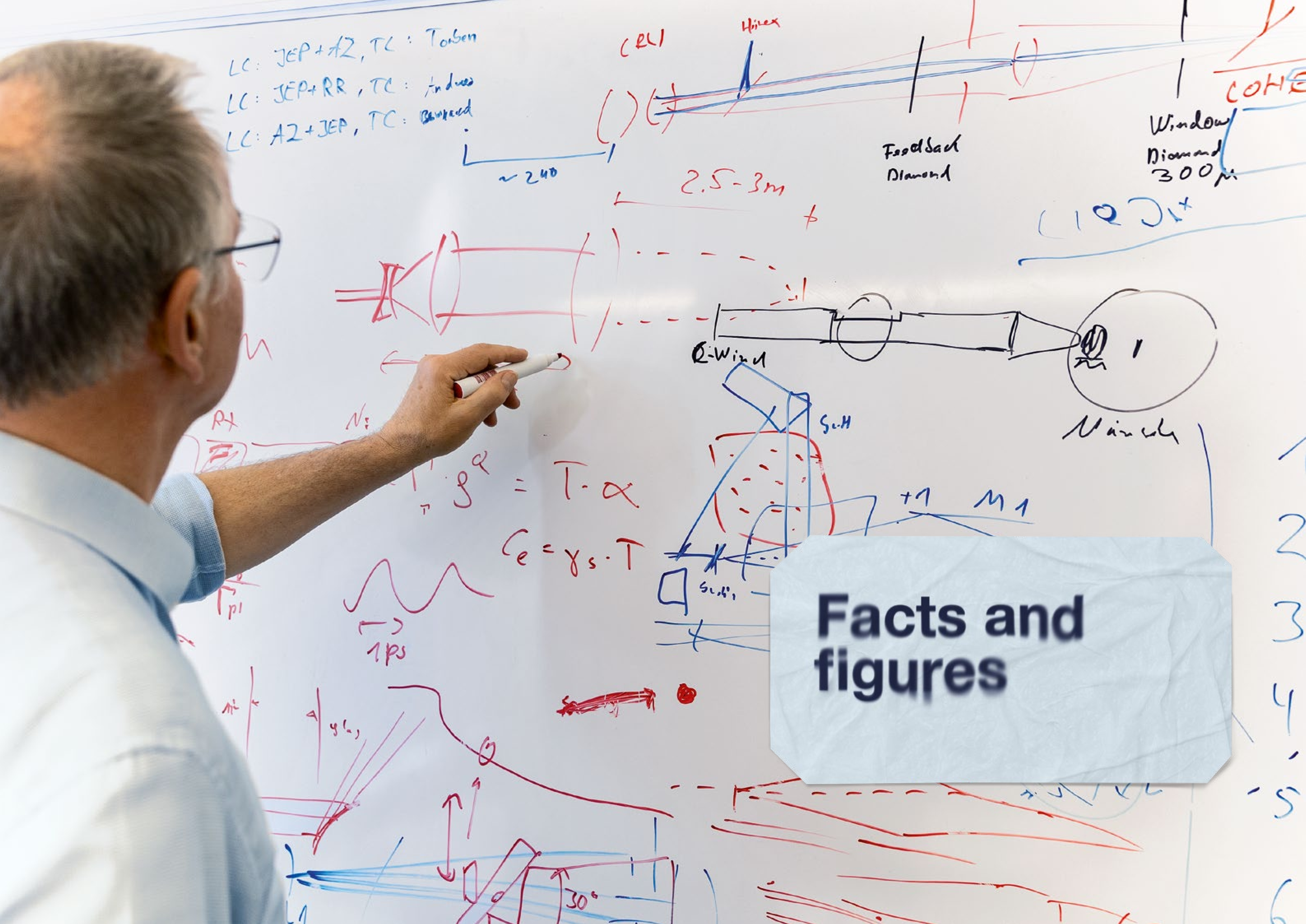
In parallel to the long installation and maintenance period, our strategy implementation efforts will gain momentum. First programmes have started, and the remaining ones will follow. Key objectives of the next couple of months include refining some programme roadmaps and fostering cross-functional alignment, for instance in the hiring of new staff. The current expectation is to conclude the implementation of all programmes by the end of 2032.

Preparations for the company's new management structure will also be a priority. As we transit to the new structure, efforts will focus on equipping ourselves with the tools, communication channels, and support structures necessary to perform efficiently under this new framework. A clear definition of roles and responsibilities will play a crucial role in ensuring a seamless transition.

Lastly, we will deepen our engagement with the inertial and magnetic fusion energy communities, recognizing the significance of their mission and our unique capacities to contribute meaningfully. We will explore opportunities to provide technical expertise, collaborative platforms, and innovative solutions that address shared challenges. By actively participating in the fusion community's research and development activities, we can both advance their objectives and uncover synergies that drive our quest for new sources of energy.

The coming year holds immense promise as we tackle these ambitious goals. By maintaining a balanced approach – prioritizing immediate operational needs while laying the groundwork for future advancements – we aim to position the company for sustained success in an evolving worldwide landscape of FELs.

Figure 1: Diving deep into science. Water still has a lot of secrets to be discovered. Even in his free time, Thomas Feurer is fascinated by this "element".



Facts and figures

At a glance

European XFEL is a research facility that opens up new research opportunities for science and industry. The 3.4 km long X-ray free-electron laser generates ultrashort X-ray flashes for photon science experiments with a peak brilliance that is a billion times higher than that of the best synchrotron X-ray radiation sources.

With a repetition rate of up to 27 000 pulses per second, the world's largest X-ray laser produces ultrashort X-ray flashes that allow researchers to map the atomic details of viruses, decipher the molecular composition of cells, take three-dimensional images of the nanoworld, film chemical reactions, and study processes like those occurring deep inside planets. Users and scientists at European XFEL address societal challenges in the areas of health, climate and energy, digitalization, and environmental sustainability, while also advancing fundamental research and fostering applied innovations.

The European XFEL is located mainly in tunnels 6 to 38 m underground. The facility runs from the DESY research centre in Hamburg to the town of Schenefeld in the German federal state of Schleswig-Holstein (Figure 1). The facility comprises three sites: the DESY-Bahrenfeld site with the injector complex, the Osdorfer Born site with one distribution shaft, and the Schenefeld campus site, which hosts the underground experiment hall with a large laboratory and an office building on top. The latter serves as the company headquarters. The campus also has a warehouse and workshop building (completed in 2018), a company restaurant, "BeamStop" (completed in 2019), a guest house (completed in 2021), an undulator hall (completed in 2021), a second office building (completed in 2023) and a visitor and conference centre, "Lighthouse" (completed in 2024).

As of December 2024, 12 partner countries are member states of European XFEL: Denmark, France, Germany, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden, Switzerland, and the United Kingdom. The international partners have entrusted the construction and operation of the facility to the non-profit European X-Ray Free-Electron Laser Facility GmbH, a limited liability company under German law. The company cooperates closely with its largest shareholder, DESY, a research centre of the Helmholtz Association, and with other organizations worldwide. The annual operation budget for the facility is approximately 150 million euro. The construction costs, including commissioning, amounted to 1.25 billion euro (at 2005 price levels). In 2024, the host country, Germany (federal government, state of Hamburg, and state of Schleswig-Holstein) covered 55.6% of the costs. Russia contributed 17.2%, and each of the other international shareholders between 1% and 5%.

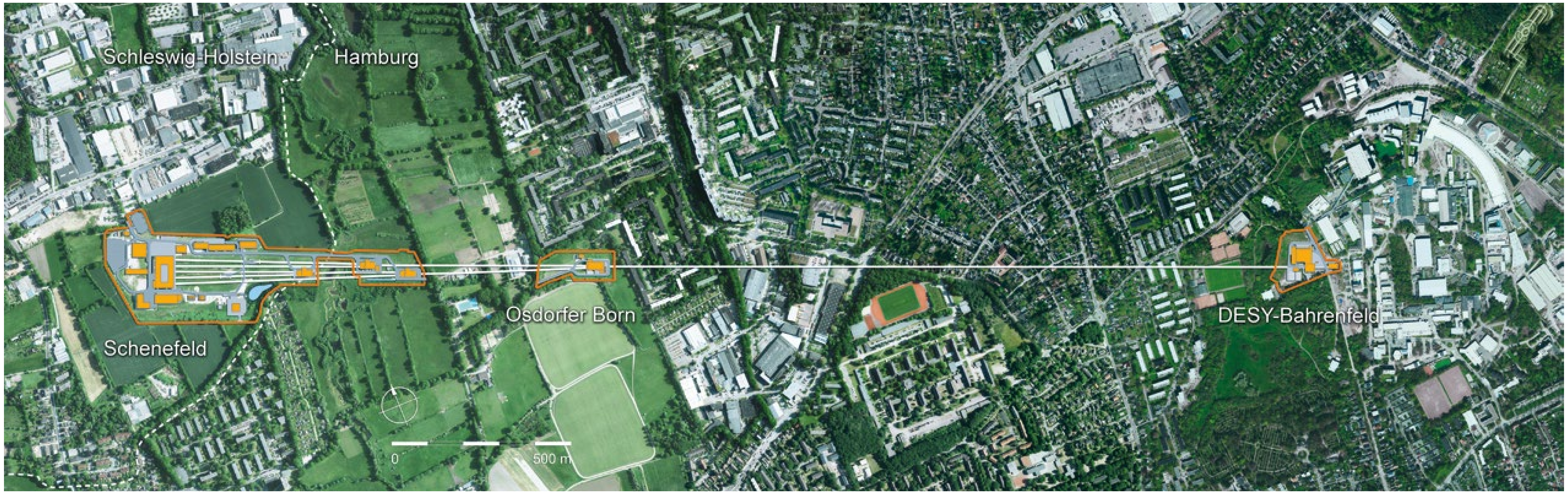
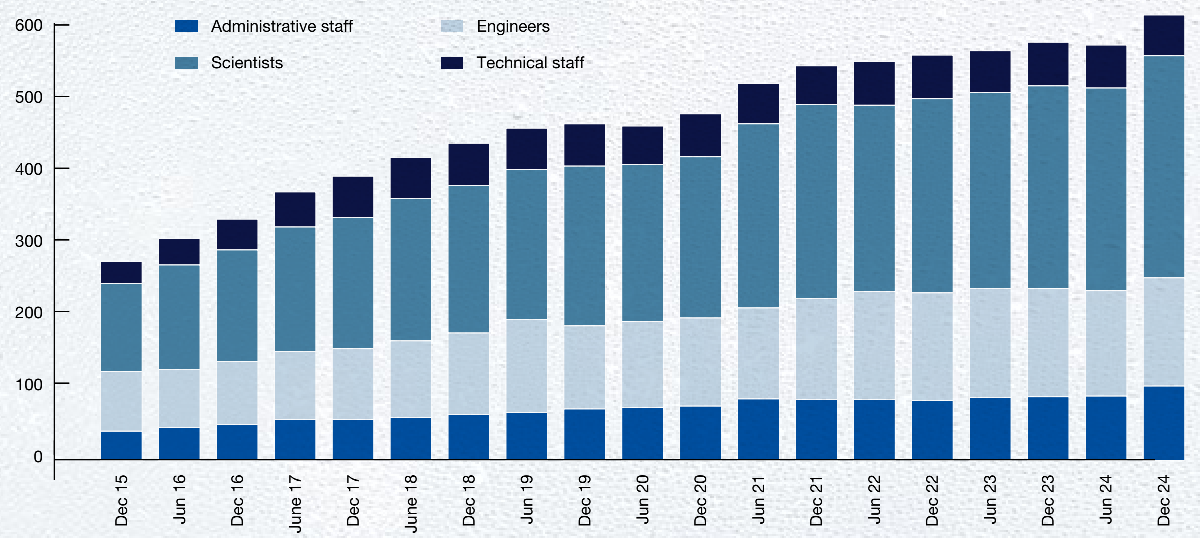


Figure 1: Aerial view of the European XFEL facility. Left to right: Schenefeld, Osdorfer Born, and DESY-Bahrenfeld sites.

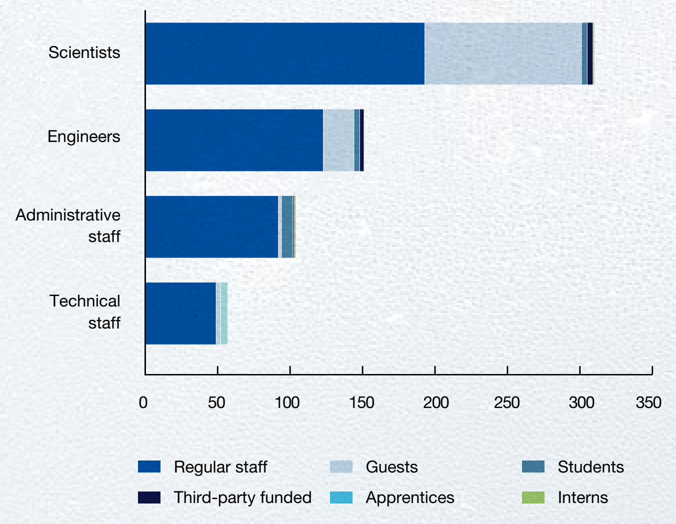
Staff

Staff development

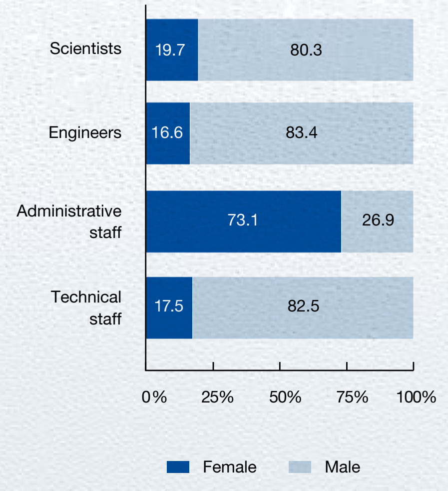
622 Total headcount including long-term guests



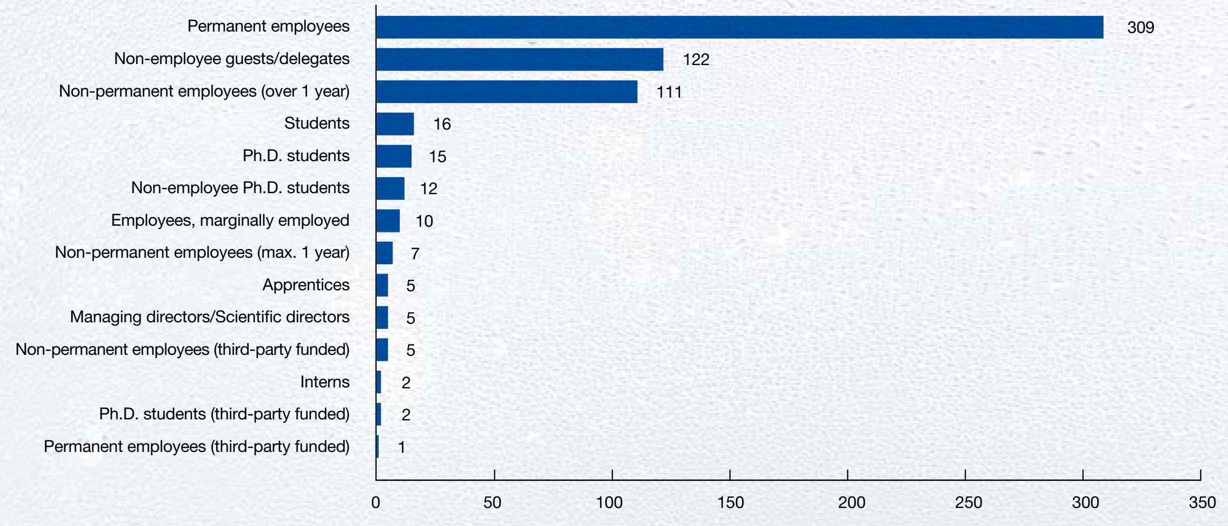
Function and contract split



Gender ratio

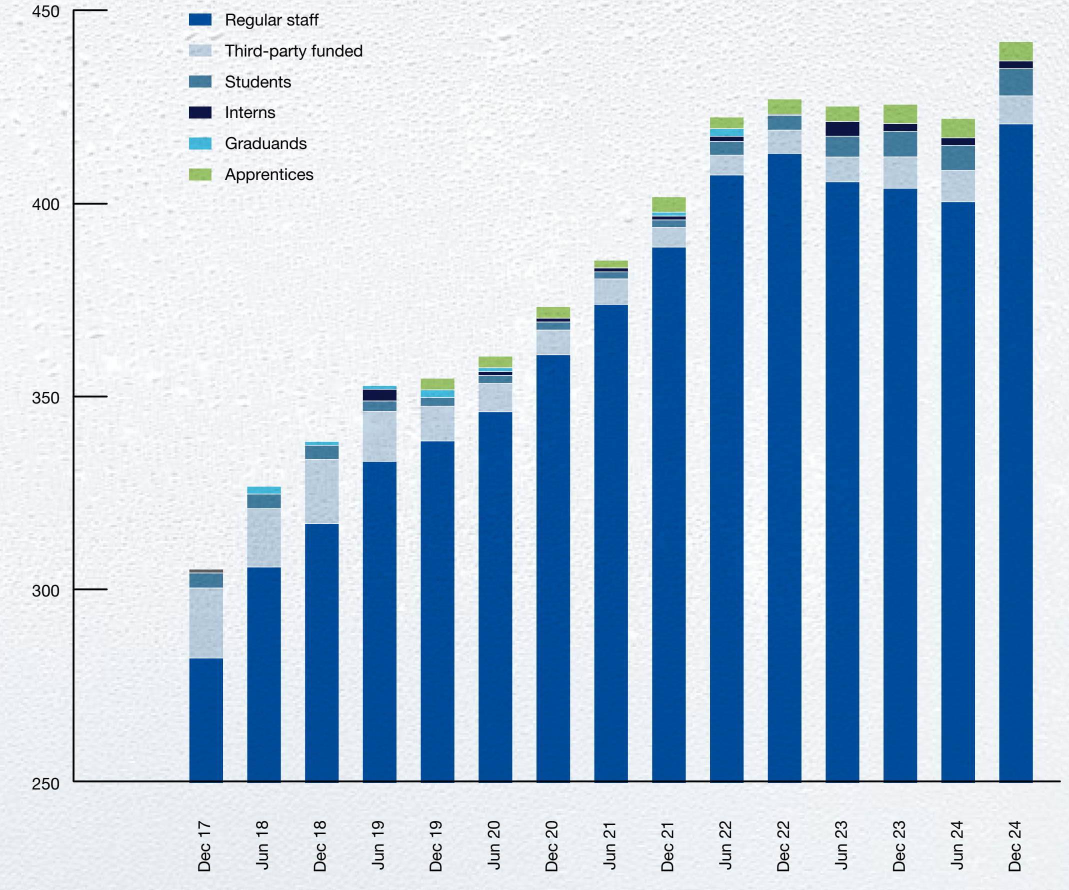


Contractual status



Full-time equivalents

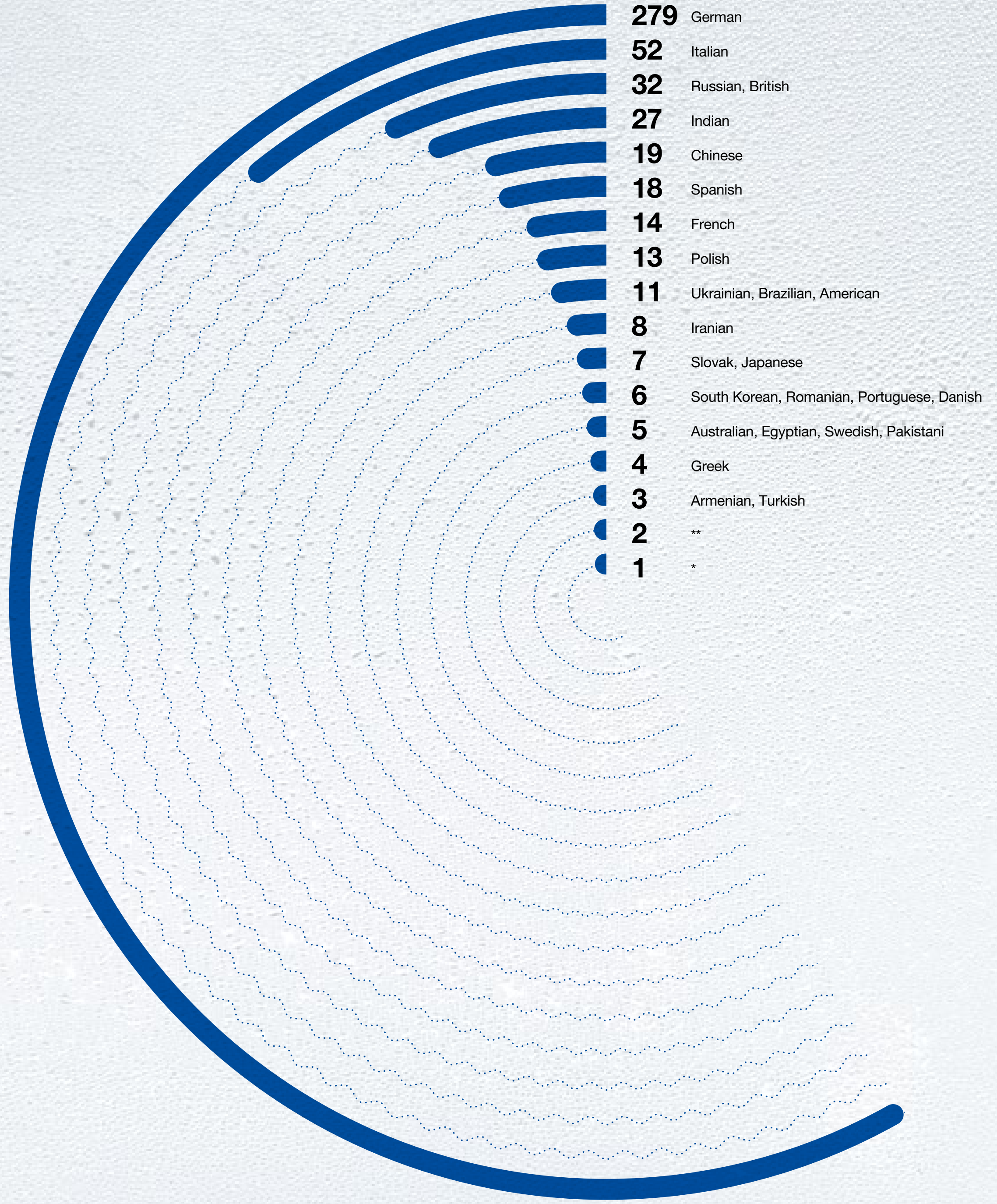
447 Only actual European XFEL contracts



All staff

64 Citizenships in total

Number of employees of each nationality



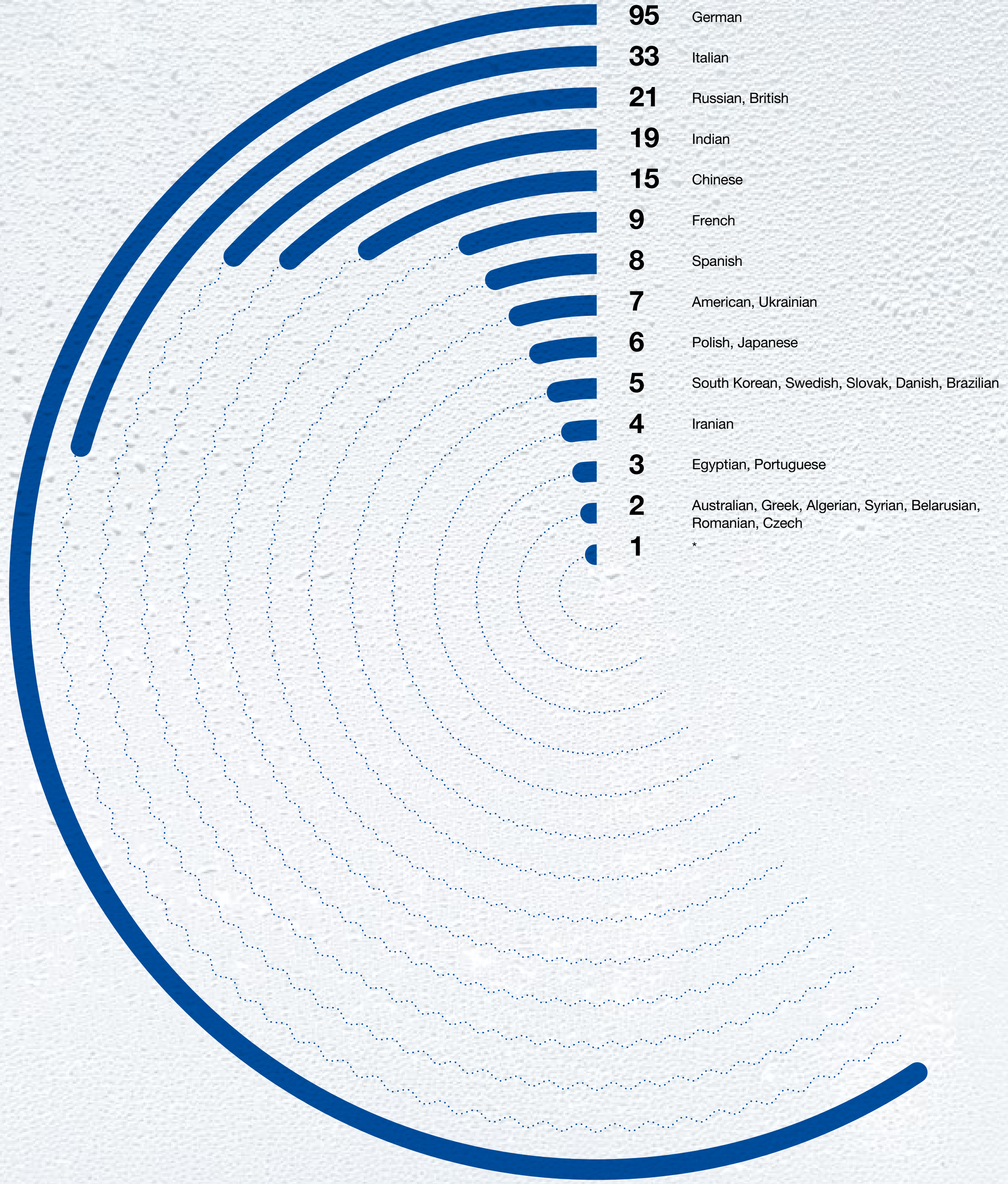
*1 Thai, Bangladesh, Vietnamese, Belgian, Dutch, Israeli, Albanian, Azerbaijani, Sudanese, Colombian, Swiss, Serbian, Taiwan, Chilean, Mexican, Yemeni, Venezuelan, Canadian, Ecuadorian, Sri Lankan, Latvian

**2 Austrian, Hungarian, Algeria, Syrian, Irish, Croatian, Georgian, Lebanese, Czech, Malaysian, Indonesian, New Zealander, Belarusian, Filipino, Bulgarian, Jordanian, Kazakh

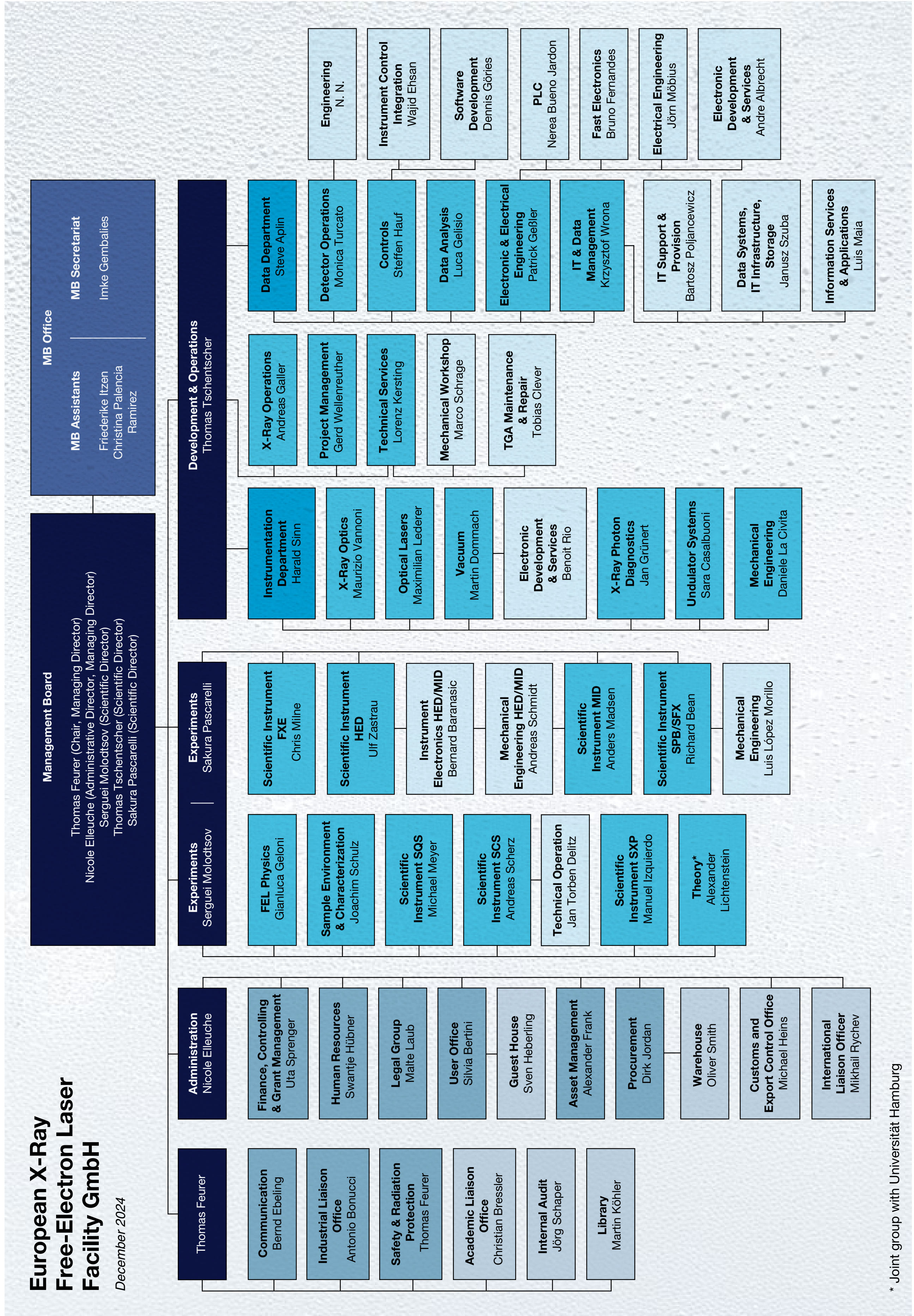
Scientific staff

52 Citizenships in total

Number of employees of each nationality



*1 Thai, Israeli, Yemeni, Lebanese, Chilean, New Zealander, Colombian, Pakistani, Malaysian, Sri Lankan, Swiss, Austrian, Taiwan, Indonesian, Turkish, Canadian, Vietnamese, Georgian, Hungarian, Irish, Belgian, Sudanese, Kazakh, Armenian, Bulgarian, Jordanian



Shareholders

The European XFEL is organized as a non-profit company with limited liability under German law (GmbH) that has international shareholders.

Member states	Present (bold) or likely future shareholder of the European XFEL GmbH
Denmark	**DAFHES (Danish Agency for Higher Education and Science)**
France	**CEA (Commissariat à l'énergie atomique et aux énergies alternatives)** **CNRS (Centre national de la recherche scientifique)**
Germany	**DESY (Deutsches Elektronen-Synchrotron)**
Hungary	**NRDI Office (National Research, Development and Innovation Office)**
Italy	**INFN (Istituto Nazionale di Fisica Nucleare)** **CNR (Consiglio Nazionale delle Ricerche)**
Poland	**NCBJ (National Centre for Nuclear Research)**
Russia	**NRC KI (National Research Centre "Kurchatov Institute")**
Slovakia	**Slovak Republic**
Spain	Kingdom of Spain
Sweden	**VR (Swedish Research Council)**
Switzerland	**Swiss Confederation**
United Kingdom	**UKRI (UK Research and Innovation)**

Management, Council, and Committees

European XFEL Council

The European XFEL Council is the supreme organ of the company in which up to two delegates represent the shareholders of each member state. The Council meets at least twice a year. It functions as the shareholder assembly that decides important issues of company policy.

Chairperson		**Federico Boscherini** (IOM-CNR, on leave from University of Bologna)
Vice Chairperson		**James Naismith** (University of Oxford)
Delegates	**Denmark**	**Martin Meedom Nielsen** (DTU, Kongens Lyngby) **Morten Scharff** until 10 November 2024 (DAFHES, Copenhagen) **Nicolai Narvestad** as of 11 November 2024 (DAFHES, Copenhagen)
	France	**Maria Faury** until 16 June 2024 (CEA, Paris) **Catalin Miron** as of 17 June 2024 (CEA, Paris) **Sylvain Ravy** (CNRS, Paris)
	Germany	**Volkmar Dietz** (BMBF, Bonn) **Helmut Dosch** (DESY, Hamburg)
	Hungary	**Györgyi Juhász** (National Research, Development and Innovation Office, Budapest) **György Vankó** (Wigner Research Centre for Physics, Budapest)
	Italy	**Stefano Fabris** (CNR, Rome) **Carlo Pagani** (INFN, Milan)
	Poland	**Mateusz Gaczyński** until 29 April 2024 (Ministry of Science and Higher Education, Warsaw) **Michał Goszczyński** as of 30 April 2024 (Ministry of Science and Higher Education, Warsaw) **Ryszard Sobierajski** (Institute of Physics PAS, Warsaw)
	Russia	**Mikhail Kovalchuk** (NRC KI, Moscow) **Alexander Blagov / Alexander Petrov / Mikhail Polyakov** (NRC KI, Moscow)
	Slovakia	**Karel Saksl** (Technical University of Košice) **Pavol Sovák** (P.J. Šafárik University, Košice)
	Sweden	**Lars Börjesson** as of 1 October 2024 (Chalmers University of Technology, Gothenburg) **Johan Holmberg** (VR, Stockholm)
	Switzerland	**Gabriel Aeppli** (PSI, Villigen) **Laurent Salzarulo** until 20 February 2024 (SERI, Bern) **Simon Berger** as of 21 February 2024 (SERI, Bern)
	United Kingdom	**Helen Beadman** (UKRI, Swindon) **Jon Marangos** (Imperial College London)
Observers	**Spain**	**Guadalupe C. de Córdoba Lasunción** (Ministerio de Ciencia, Innovación y Universidades, Madrid) **Rodolfo Miranda** (IMDEA Nanociencia / Universidad Autónoma de Madrid)
Advisors	**France**	**Marie-Hélène Mathon** (CEA, Paris) **Denis Morineau** as of 23 May 2024 (CNRS, Paris)
	Germany	**Wim Leemans / Arik Willner** (DESY, Hamburg) **Dirk Steinbach** (BMBF, Bonn)
	Italy	**Alberto Morgante** (University of Trieste and IOM-CNR, Trieste) **Daniele Sertore** (INFN, Milan)
	Poland	**Tomasz Leżański** (NCBJ, Otwock-Świerk) **Dagmara Milewska** (NCBJ, Otwock-Świerk)
	Slovakia	**Martin Šponiar** (Ministry of Education, Research, Development and Youth, Bratislava)
	Sweden	**Lars Börjesson** until 30 September 2024 (Chalmers University of Technology, Gothenburg) **Maja Hellsing** (VR, Stockholm)
	Switzerland	**Doris Wohlfender-Bühler** (SERI, Bern)
	United Kingdom	**Rachel Reynolds** (UKRI, Swindon)
Secretary		**Malte Laub** (European XFEL, Schenefeld)
Vice Secretary		**Friederike Itzen** (European XFEL, Schenefeld)

Figure 1: The European XFEL Council during the Council meeting in June 2024

Management Board

The European XFEL Management Board is composed of a chairperson and an administrative director, both acting as managing directors, and three scientific directors, all acting as proxy holders.

Chairperson and Managing Director	**Thomas Feurer**	Scientific Directors and Proxy Holders	**Serguei Molodtsov** **Sakura Pascarelli** **Thomas Tschentscher**
Administrative and Managing Director	**Nicole Elleuche**		

Administrative and Finance Committee

The Administrative and Finance Committee (AFC) is a committee of the European XFEL Council. It is charged with advising the Council on all matters of administrative issues and of financial management. The shareholders of each contracting party have a maximum of two representatives to the AFC. The chairperson and the vice chairperson of the AFC are appointed by the Council for a fixed period of two years.

Chairperson		**Sabine Carl** until 7 May 2024 (BMBF, Bonn) **Maja Hellsing** as of 10 October 2024 (VR, Stockholm)
Vice Chairperson		**Maja Hellsing** (VR, Stockholm)
Delegates	**Denmark**	**Morten Scharff** (DAFHES, Copenhagen)
	France	**Stéphanie Dupuis-Lê Vàn** (DSFIM, Paris) **Philippe Sassie**r until 7 May 2024 (CEA, Paris) **Elisa Briere** as of 10 October 2024 (CEA, Paris)
	Germany	**Christian Harringa** (DESY, Hamburg) **Dennis Scherer** until 7 May 2024 (BMBF, Bonn) **Svenja Kruse** as of 10 October 2024 (BMBF, Bonn)
	Hungary	**Györgyi Juhász** (National Research, Development and Innovation Office, Budapest)
	Italy	**Veronica Buccheri** (INFN, Rome) **Antonella Tajani** (CNR, Rome)
	Poland	**Dagmara Milewska** (NCBJ, Otwock-Świerk) **Michał Rybiński** (Ministry of Science and Higher Education, Warsaw)
	Russia	**Valeriy Nosik** (NRC KI, Moscow)
	Slovak Republic	**Martin Šponiar** (Ministry of Education, Research, Development and Youth, Bratislava) **Michalek Tomáš** as of 10 October 2024 (Ministry of Education, Research, Development and Youth, Bratislava)
	Sweden	**Maja Hellsing** until 7 May 2024 (VR, Stockholm) **Johan Holmberg** as of 10 October 2024 (VR, Stockholm)
	Switzerland	**Peter Allenspach** (PSI, Villigen) **Doris Wohlfender-Bühler** (SERI, Bern)
	United Kingdom	**Rachel Reynolds** (UKRI, Swindon) **Georgina Freeman** as of 10 October 2024 (UKRI, Swindon)

Secretary	**Uta Sprenger** (European XFEL GmbH, Schenefeld)
Vice Secretary	**Cristina Palencia Ramirez** (European XFEL GmbH, Schenefeld)

Machine Advisory Committee

The Machine Advisory Committee (MAC) advises the European XFEL Council and the Management Board in matters of fundamental importance to the accelerator complex.

Chairperson	**Evgeny Levichev** until 23 October 2024 (BINP, Novosibirsk, Russia) **Luca Giannessi** as of 24 October 2024 (Elettra Sincrotrone Trieste, Italy)
Members	**Deepa Angal-Kalinin** as of 24 October 2024 (ASTeC, STFC, Warrington, UK) **Franz-Josef Decker** until 23 October 2024 (SLAC, Menlo Park, USA) **Zheqiao Geng** (PSI, Villigen, Switzerland) **Luca Giannessi** until 23 October 2024 (Elettra Sincrotrone Trieste, Italy) **Verena Kain** (CERN, Geneva, Switzerland) **Alberto Lutman** as of 24 October 2024 (SLAC, Menlo Park, USA) **Catherine Madec** (CEA, Paris, France) **Atoosa Meseck** (HZB, Berlin, Germany) **Paolo Pierini** as of 24 October 2024 (ESS, Lund, Sweden) **Fernando Sannibale** (LBNL, Berkeley, USA) **Sara Thorin** (MAX IV, Lund, Sweden) **Andrzej Wolski** until 23 October 2024 (University of Liverpool, UK)
Secretary	**Riko Wichmann** (DESY, Hamburg, Germany)

Scientific Advisory Committee

The Scientific Advisory Committee (SAC) advises the European XFEL Council and the Management Board in scientific matters of fundamental importance. The SAC provides recommendations on all scientific, technical, and policy issues that bear on a successful buildup of the scientific capacity of the European XFEL facility, its full and effective utilization, and future developments required to maintain the scientific and technical productivity of the facility at the highest possible level.

Chairperson	**Claudio Masciovecchio** until 20 November 2024 (Elettra Sincrotrone Trieste, Italy) **Philippe Wernet** as of 21 November 2024 (Uppsala University, Sweden)
Members	**Camila Bacellar Cases da Silveira** as of 21 November 2024 (PSI, Villingen, Switzerland) **Elspeth Garman** (University of Oxford, UK) **Steven Johnson** (ETH, Zürich, Switzerland) **Anne L'Huillier** until 15 March 2024 (Lund University, Sweden) **Henrik Lemke** until 20 November 2024 (PSI, Villigen, Switzerland) **Paul Loubeyre** (CEA/DIF, Arpajon, France) **Jan Lüning** (HZB, Berlin, Germany) **Claudio Masciovecchio** as of 21 November 2024 (Elettra Sincrotrone Trieste, Italy) **Arwen Pearson** (Universität Hamburg, Germany) **Henning Friies Poulsen** as of 21 November 2024 (Technical University of Denmark, Kongens Lyngby, Denmark) **Ian Robinson** until 20 November 2024 (University College London, UK) **Nina Rohringer** (DESY, Hamburg, Germany) **Luis Roso** (Universidad de Salamanca, Spain) **Tim Salditt** (Georg August University Göttingen, Germany) **Robert W. Schoenlein** (SLAC, Menlo Park, California, USA) **Olga Smirnova** as of 21 June 2024 (MBI, Berlin, Germany) **Amina Taleb-Ibrahimi** (CNRS – Synchrotron SOLEIL, Saint-Aubin, France) **Philippe Wernet** until 20 November 2024 (Uppsala University, Sweden)
Guest	**Philip Hofmann** (Aarhus University, Denmark)
Secretary	**Gianluca Geloni** (European XFEL, Schenefeld, Germany)

Figure 2: The Scientific Advisory Committee during its meeting at European XFEL in March 2024

Detector Advisory Committee

The Detector Advisory Committee (DAC) for the European XFEL advises the SAC and, by extension, the company in all matters regarding the development of detectors needed to exploit the unique science opportunities of the facility.

Chairperson	**Gabriella Carini** (BNL, Upton, New York, USA)
Members	**Branden Allen** (University of Hawaiʻi, Mānoa, USA) **Paula Collins** (CERN, Meyrin, Switzerland) **Takaki Hatsui** (RIKEN SPring-8 Center, Japan) **Mark Heron** (Diamond Light Source, Oxford, UK) **Filipe Maia** (Uppsala University, Sweden) **Jana B. Thayer** (SLAC, Menlo Park, California, USA) **Matthew Wing** (University College London, UK)

Laser Advisory Committee

The Laser Advisory Committee (LAC) advises the European XFEL Management Board, the DESY Directorate, and their relevant science committees in matters of research, development, and construction of the high-repetition-rate burst mode laser systems used at the FLASH and European XFEL facilities.

Since a common technology platform is envisioned for these laser systems, DESY and European XFEL have decided to collaborate closely in their laser research and development efforts and to establish a common laser platform to which both institutes contribute. The committee consists of scientists not directly involved in the development activities.

Chairperson	**Thomas Dekorsy** (DLR, Stuttgart, Germany)
Members	**Jake Bromage** as of February 2024 (University of Rochester, USA) **Miltcho Danailov** (Elettra Sincrotrone Trieste, Italy) **Alan Fry** until February 2024 (SLAC, Menlo Park, California, USA) **Joseph Robinson** as of March 2024 (SLAC, Menlo Park, California, USA) **Clara Saraceno** (Ruhr University Bochum, Germany) **Emma Springate** (STFC Rutherford Appleton Laboratory, Didcot, UK) **Caterina Vozzi** as of February 2024 (CNR, Istituto di Fotonica e Nanotecnologie, Italy)
Secretaries	**Jörg Hallmann** (European XFEL, Schenefeld) **Karolin Baev** (DESY, Hamburg)

Proposal Review Panels

Access to beamtime for non-proprietary research at European XFEL is granted on the basis of peer review of scientific proposals. The Proposal Review Panels (PRPs) are in charge of evaluating the scientific merit of these proposals.

FXE Proposal Review Panel

Chairperson	**Wojciech Gawelda** (UAM, Madrid, Spain)
Vice Chairperson	**Paola Luches** (Istituto di Nanoscienze, National Research Council, Modena, Italy)
Members	**Shin-ichi Adachi** (KEK, Tsukuba, Japan) **Kristoffer Haldrup** (DTU, Kongens Lyngby, Denmark) **Maciej Lorenc** (Université de Rennes, France) **James McCusker** (Michigan State University, East Lansing, Michigan, USA) **Robert Schoenlein** (SLAC, LCLS, Menlo Park, California, USA) **György Vankó** (Wigner Research Centre for Physics, Budapest, Hungary) **Julia Weinstein** (University of Sheffield, UK)

HED Proposal Review Panel

Chairperson	**Ryszard Sobierajski** (Polish Academy of Sciences, Warsaw, Poland) until January 2024 **Zahirul Islam** (ANL, Lemont, Illinois, USA) from June 2024
Vice Chairperson	**N. N.**
Members	**Michael Armstrong** (LLNL, Livermore, California, USA) until January 2024 **Alessandra Benuzzi** (LULI, Palaiseau, France) **Wendell T. Hill** (IPST, Institute for Physical Science and Technology at the University of Maryland, College Park, USA) from June 2024 **Paul Loubeyre** (CEA/DIF, Arpajon, France) **Stuart Mangles** (Imperial College London, UK) **Emma McBride** (Queen's University Belfast, Ireland) **Paul Neumayer** (GSI, Darmstadt, Germany) until January 2024 **Sam M. Vinko** (University of Oxford, United Kingdom) from June 2024 **Luca Volpe** (Centro de Láseres Pulsados, CLPU, Salamanca, Spain) **Matt Zepf** (Friedrich Schiller University, Jena, Germany)

MID Proposal Review Panel

Chairperson	**Giulio Monaco** (University of Padova, Italy) until January 2024 **Christian Gutt** (University of Siegen, Germany) from June 2024
Vice Chairperson	**David Le Bolloc'h** (Laboratoire de physique des solides, Orsay, France) until January 2024 **Rajmund Mokso** (DTU, Kongens Lyngby, Denmark) from June 2024
Members	**Katrin Amann-Winkel** (Max Planck Institute for Polymer Research, Mainz, Germany) from January 2024 **Marco Cammarata** (ESRF, Grenoble / Université de Rennes, France) **Tais Gorkhover** (CFEL, Hamburg, Germany) **David Keen** (STFC, UK) **Tim Salditt** (Georg August University Göttingen, Germany) from June 2024 **Urs Staub** (PSI, Villigen, Switzerland) **Can Yildirim** (ESRF, Grenoble, France) from June 2024 **Diling Zhu** (SLAC, LCLS, Menlo Park, California, USA)

SCS Proposal Review Panel

Chairperson **Jan Lüning** (HZB, Berlin, Germany)

Vice Chairperson **N. N.**

Members
Camila Bacellar Cases da Silveira (PSI, Villigen, Switzerland)
Nicholas Brookes (ESRF, Grenoble, France)
Manuel Guizar-Sicairos (PSI, Villigen, Switzerland) until June 2024
Simo J. Huotari (University of Helsinki, Finland)
Steven Johnson (ETH, Zurich, Switzerland)
Alexey Kimel (Radboud University Nijmegen, The Netherlands)
Maya Kiskinova (Elettra Sincrotrone Trieste, Italy) until June 2024
Jan-Erik Rubensson (Uppsala University, Sweden)
Emma Springate (Artemis, STFC Central Laser Facility, UK)

SPB/SFX Proposal Review Panel

Chairperson
Gyula Faigel (Wigner Research Centre for Physics, Budapest, Hungary) until January 2024
Cameron Kewish (Australian Synchrotron, Clayton, Australia) from June 2024

Vice Chairperson **N. N.**

Members
Gisela Brändén (University of Gothenburg, Sweden) from January 2024
Virginie Chamard (Fresnel Institute, Marseille, France)
Jacques-Philippe Colletier (Institut de biologie structurale J.P. Ebel, IBS, France) from January 2024
Francesco De Carlo (Argonne National Laboratory, Lemont, USA) from June 2024
Cinzia Giannini (Institute of Crystallography, CNR, Bari, Italy)
Alexander Korsunsky (University of Oxford, UK)
Robin Owen (Diamond Light Source, Oxford, UK)
Arwen Pearson (University of Hamburg, Germany)
Alexander Rack (European Synchrotron Radiation Facility, Grenoble, France) from June 2024
Jozef Ulicný (P.J. Šafárik University, Košice, Slovakia) until January 2024
Manfred Weiss (HZB, Berlin, Germany) until January 2024

SQS Proposal Review Panel

Chairperson **Eckhardt Rühl** (Freie Universität Berlin, Germany)

Vice Chairperson **N. N.**

Members
John D. Bozek (Synchrotron SOLEIL, Saint-Aubin, France)
Carlo Callegari (Elettra Sincrotrone Trieste, Italy)
Maciej Kozak (SOLARIS, Kraków, and Adam Mickiewicz University, Poznań, Poland) until June 2024
Alexander Kuleff (University of Heidelberg, Germany)
Thomas Pfeifer (MPI for Nuclear Physics, Heidelberg, Germany)
Daniela Rupp (ETH Zurich, Switzerland) from January 2024
Stacey L. Sörensen (Lund University, Sweden) until June 2024
Olga Smirnova (MBI, Berlin, Germany)
Frank Stienkemeier (University of Freiburg, Germany)
Linda Young (ANL, Lemont, Illinois, USA) until June 2024
Amelle Zair (King’s College, London, UK)

Scientific record

Impressions from the poster session at the Users' Meeting 2024

Publications

USER PUBLICATIONS

(With participation of European XFEL staff)

3D atomic structure from a single X-ray free electron laser pulse
G. Bortel et al.: Nat. Commun. **15** (1), 970 (2024)
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A 1D imaging soft X-ray spectrometer for the small quantum systems instrument at the European XFEL
M. Agåker et al.: J. Synchrotron Radiat. **31** (5), 1264–1275 (2024)
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Controlled molecule injector for cold, dense, and pure molecular beams at the European x-ray free-electron laser
L. He et al.: Rev. Sci. Instrum. **95** (11), 113301 (2024)
doi:10.1063/5.0219086

Crystal Nucleation in Supercooled Atomic Liquids
J. Möller et al.: Phys. Rev. Lett. **132** (20), 206102 (2024)
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Crystal structure of a bacterial photoactivated adenylate cyclase determined by serial femtosecond and serial synchrotron crystallography
S.M. Kapetanaki et al.: IUCrJ **11** (6), 991-1006 (2024)
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Cylindrical compression of thin wires by irradiation with a Joule-class short-pulse laser
A. Laso Garcia et al.: Nat. Commun. **15** (1), 7896 (2024)

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J.C.P. Koliyadu et al.: J. Synchrotron Radiat. **32** (1), 17-28 (2024)
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Diamond precipitation dynamics from hydrocarbons at icy planet interior conditions
M. Frost et al.: Nat. Astron **8**, 174–181 (2024)
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T. Gawne et al.: J. Appl. Phys. **136** (10), 105902 (2024)
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L. Kämmerer et al.: ACS Nano **18** (51), 34596–34605 (2024)
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S. Perrett et al.: Struct. Dyn. **11** (2), 024310 (2024)
doi:10.1063/4.0000248

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M. Aleksich et al.: Adv. Funct. Mater. **35** (6), 2414914 (2024)
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A. Chretien et al.: JMB **436** (5) 168439 (2024)
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Measurement bias in self-heating x-ray free electron laser experiments from diffraction studies of phase transformation in titanium
O.B. Ball et al.: J. Appl. Phys. **136** (11), 115902 (2024)
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Optical control of 4 f orbital state in rare-earth metals
N. Thielemann-Kühn et al.: Sci. Adv. **10** (16), eadk9522 (2024)
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Phase transition kinetics of superionic H_2O ice phases revealed by Megahertz X-ray free-electron laser-heating experiments
R.J. Husband et al.: Nat. Commun. **15** (1), 8256 (2024)
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Photoinduced charge transfer renormalization in NiO
T. Lojewski et al.: Phys. Rev. B **110** (24), 245120 (2024)
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Z. Shen et al.: ACS Nano **18** (24), 15576–15589 (2024)
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X. Yu et al.: npj Comput. Mater. **10** (1), 24 (2024)
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Ultrafast magnetostructural dynamics of MnAs
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(Sub-)Picosecond Surface Correlations of Femtosecond Laser Excited Al-Coated Multilayers Observed by Grazing-Incidence X-ray Scattering
L. Randolph et al.: Nanomaterials **14** (12), 1050 (2024)
doi:10.3390/nano14121050

A versatile wide energy range spectrometer for soft X-ray FELs
E. Principi et al.: Nucl. Instrum. Methods Phys. Res., Sect. A **1058**, 168856 (2024)
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M. Mattern et al.: Adv. Funct. Mater. **34** (32), 2313014 (2024)
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A. Banerjee et al.: Chem. Sci. **15** (7), 2398–2409 (2024)
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Aqueous Ammonium Nitrate Investigated Using Photoelectron Spectroscopy of Cylindrical and Flat Liquid Jets
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Conferences, workshops, schools, and seminars

SRI2024: The world's elite met in Hamburg

From 26 to 30 August 2024, DESY and European XFEL welcomed more than 1200 experts from 34 countries and 210 institutions as well as 57 industrial exhibitors to the 15th International Conference on Synchrotron Radiation Instrumentation (SRI2024) at the CCH Congress Centre Hamburg.

SRI2024 was officially opened by Hamburg's Senator for Science, Research and Equality, Katharina Fegebank, and Schleswig-Holstein's Minister for Education, Science, Research and Culture, Karin Prien, followed by welcome addresses of the two directors from the organizing institutions, Helmut Dosch (DESY) and Thomas Feurer (European XFEL). The tri-annual conference is regarded as the world's most important exchange forum for experimenters, developers, and operators of large X-ray radiation sources and offers insights into technological innovations and new measurement methods that are crucial for the development of future synchrotron light sources and X-ray lasers and their applications.

Prestigious prizes awarded at SRI2024

The FELs of Europe Award was given to Jumpei Yamada from Osaka University, Japan, for his work on "Ultimate focusing of X-ray free-electron laser down to 7×7 nm spot for achieving 10^{22} W/cm^2 intensity". Agostino Marinelli from the SLAC National Accelerator Laboratory, USA, was honoured with the Kai Siegbahn award "for his pioneering development of attosecond X-ray free-electron lasers and their application to ultrafast X-ray science at the Linac Coherent Light Source".

Lightsources.org awarded poster prizes to Renan Ramalho Geraldes from the Sirius light source at Laboratório Nacional de Luz Síncrotron (LNLS), Brazil, Tang Li from DESY, and Lukas Dresselhaus from the Hamburg Centre for Ultrafast Imaging (CUI/DESY). Lukas Dresselhaus also received the Science Communication Poster Prize, which was awarded in memory of the late DESY colleague Till Mundzeck.

Figure 1: The venue of the SRI2024 conference in Hamburg

Figure 2: SRI2024 attracted over 1200 experts to Hamburg

Figure 3: The second mayor and Hamburg's Senator for Science, Research and Equality, Katharina Fegebank (left), and Schleswig-Holstein's Minister for Education, Science, Research and Culture, Karin Prien (right), opened the conference.

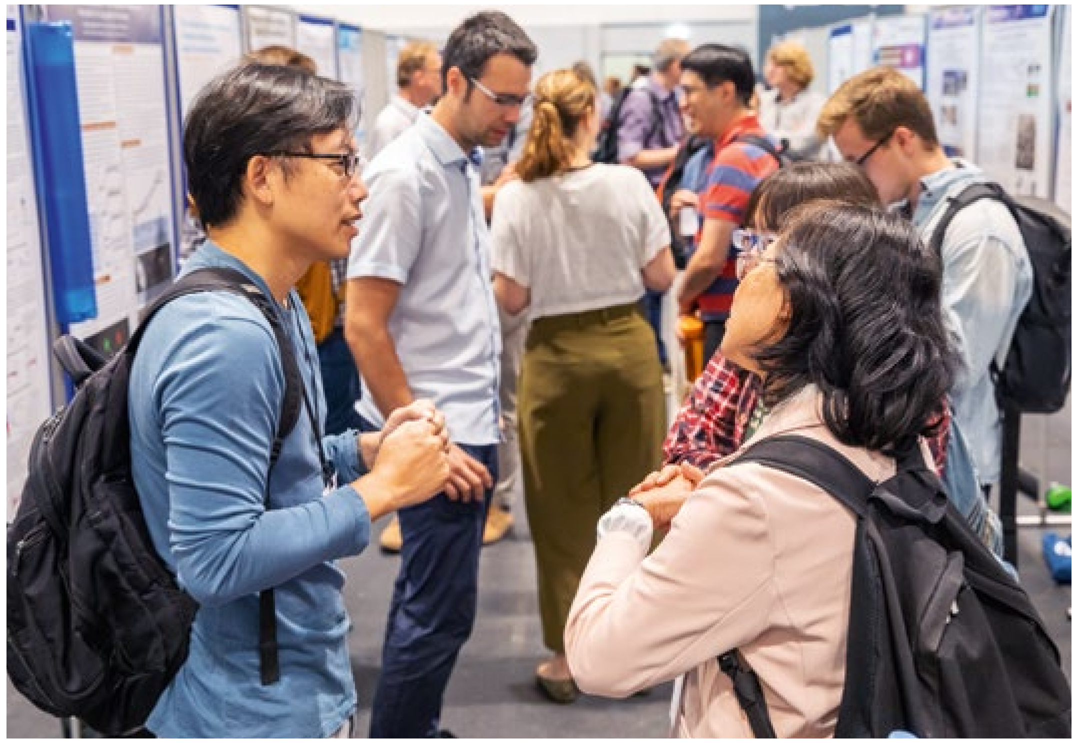

Figure 4: Lively exchange at the poster session

Conferences, workshops, and schools

22 January
Grazing-Incidence X-Ray Experiments Using FELs

The one-day meeting on grazing-incidence scattering techniques (GID, GISAXS, GI-XAS) had a special focus on applications at X-ray free-electron lasers. The participants discussed the status of the research performed worldwide and stimulated future activities and research directions.

23 JANUARY
Molecular Water Science

The workshop reported on the scientific outcome of the first call for proposals in molecular water research with the goal to combine the European XFEL's unique X-ray infrastructure with the expertise of European and other international partners in water-related sciences. It presented an overview on open questions and ongoing activities and brought together interested users for the second call to share information and form collaborations.

Figure 5: Attendees of the Molecular Water Science workshop

24–26 JANUARY
European XFEL Users' Meeting 2024

Together with the DESY Photon Science Users' Meeting, the European XFEL Users' Meeting is an annual opportunity for networking and collaboration between European XFEL and the scientific user community. In 2024, more than 1100 participants from over 210 institutes from 33 countries attended the meetings. Almost 350 posters were shown. The scientists reported the latest results from all European XFEL instruments. An industrial exhibition, where companies presented their expertise, complemented the meeting. A big highlight was the announcement of the winner of the European XFEL Young Scientist Award.

Figure 6: Top: European XFEL Managing Director Thomas Feurer greeting the audience at the Users' Meeting. Bottom: Scientists discussing the latest results during the poster session.

26 JANUARY
Data Management, Analysis, and Reduction at European XFEL

The workshop gathered European XFEL users interested in accessing and analysing experiment data. It provided tutorials and reported on present solutions developed in house. A particular focus was the introduction of the future scientific data policy and discussion of its immediate implications for users.

20 FEBRUARY
Advanced Characterization to Mitigate Component/ Material Failure

The workshop gave an overview on component or material failures reported by the EIROforum facilities and showcased techniques available to probe the phenomena (e.g. high-resolution imaging) often under *operando* conditions.

15–17 MAY
Students' and Science Days

Ph.D. students from European XFEL spent three days presenting their research in talks and posters, exchanging experiences, and getting to know each other better. They also had the opportunity to chat with leading scientists from all scientific instruments.

Figure 7: During the Students' and Science Days lecture programme

10-11 JUNE
Tackling Inertial Fusion Energy Challenges at the European XFEL

The workshop discussed the general role of XFELs towards an inertial fusion energy (IFE) power plant and identified both IFE-relevant activities that can be pursued at the HED-HIBEF instrument and flagship experiments with a future research hub for inertial fusion energy, ideally providing multi-kilojoule, multi-beam long-pulse and short-pulse drive lasers.

Figure 8: Attendees of the HED-HIBEF fusion workshop

1 JULY
High-Resolution Hemispherical Electron Spectrometer at the SQS Instrument
The workshop presented scientific opportunities offered by the availability of a high-resolution hemispherical electron spectrometer at the SQS instrument of the European XFEL.

Figure 9: Attendees of the SQS workshop

26–30 AUGUST

15th International Conference on Synchrotron Radiation Instrumentation (SRI2024)

DESY and European XFEL welcomed more than 1200 experts from 34 countries and 210 institutions as well as 57 industrial exhibitors to the conference at the CCH Congress Centre Hamburg.

2 DECEMBER

Strengthening Diversity by Empowering Colleagues with all Abilities at European XFEL

This event was dedicated to fostering an inclusive workplace by raising awareness of the unique challenges faced by individuals with disabilities. Attendees learned about first-hand experiences of scientists with disabilities and got insights from the severe-disability representation of DESY.

Figure 10: Attendees of the event to empower colleagues with disabilities

9 DECEMBER

Third Standardization Workshop at European XFEL, Liquid sample delivery – Experimental Opportunities

The workshop facilitated collaboration and innovation within the liquid sample delivery community and included both theoretical and hands-on experiment sessions. The programme featured a wide range of presentations on liquid sample delivery systems, from standard gas dynamic virtual nozzles to flat-sheet jets, drop-on-demand systems, and high-viscosity extruders.

Science seminars

20 FEBRUARY

An introduction to Falling Walls

Andreas Kosmider, Falling Walls Foundation, Berlin (Germany)

22 FEBRUARY

Single-shot measurements of THz waveforms and electron bunch shapes using chirped lasers probes

Serge Bielawski, Laboratoire de Physique des Lasers, Atomes et Molécules, University of Lille (France)

19 MARCH

Vortex cavitation

Hitoshi Soyama, Tohoku University, Sendai (Japan)

16 APRIL

Few-femtosecond deep and vacuum ultraviolet laser pulses

John Travers, Heriot Watt University (UK)

14 MAY

Controlling photoinduced charge-transfer pathways with infrared pulses

Julia Weinstein, University of Sheffield (UK)

25 JUNE

X-ray–induced structural and electronic changes in matter captured with unique XFEL schemes

Ichiro Inoue, RIKEN SPring-8 Center (SACLA, Japan) and Center for Free-Electron Laser Science (CFEL), University of Hamburg (Germany)

10 SEPTEMBER

Polarization density waves in $SrTiO_3$

Mariano Trigo, SLAC National Accelerator Laboratory (USA)

24 SEPTEMBER

A hidden quantum interference in a Weyl semimetal system

Darius Torchinsky, Temple University, Philadelphia (USA)

7 OCTOBER

Special Monday edition – The UK XFEL project: Next-generation XFEL science and technology opportunities and facility development

Jon Marangos, Imperial College London (UK) and Dave Dunning, Science and Technology Facilities Council (STFC), Daresbury Laboratory (UK)

10 OCTOBER

Short-pulsed K_α X-ray source based on high-intensity femtosecond laser–solid interaction: generation and applications

Olivier Uteza and Raphael Clady, Centre National de la Recherche Scientifique (CNRS), Aix-Marseille University (France)

12 NOVEMBER

Control and analysis of coherence in ultrafast X-ray crystallography

Jasper Van Thor, Imperial College, London (UK)

19 NOVEMBER

Dark field X-ray microscopy for materials science at the ESRF's ID03

Carsten Detlefs, European Synchrotron Radiation Facility (ESRF) (France)

5 DECEMBER

DESY-STFC-XFEL collaboration meeting

Anne-Laure Calendron, Ed Sneddon, and others

10 DECEMBER

Computational models and irradiation imaging in multi-phase microfluidic flow configurations

Manolis Gavaises, City University of London (UK)

Theory seminars

29 FEBRUARY

Lattice dynamical properties of nanostructures – *ab initio* and synchrotron radiation studies

Przemysław Piekarz, Institute of Nuclear Physics of the Polish Academy of Sciences (Poland)

6 JUNE

X-ray pump – X-ray probe diffraction signals from molecules

Jeremy Rouxel, Argonne National Laboratory (USA)

22 AUGUST

Probing extreme high-energy-density matter by high-precision X-ray spectroscopy

Suxing Hu, Laboratory for Laser Energetics, University of Rochester (USA)

24 OCTOBER

In the quest for an orbiton

Krzysztof Wohlfeld, University of Warsaw (Poland)

Glossary

A

AGIPD
Adaptive Gain Integrating Pixel Detector [European XFEL detector]

APPLE
Advanced Planar Polarized Light Emitting undulator

B

BMBF
Federal Ministry of Education and Research in Berlin, Germany

BNA
N-benzyl-2-methyl-4-nitroaniline

C

CAD
computer-aided design

CEA
Commissariat à l'énergie atomique et aux énergies alternatives in Saclay, France

CERN
European Organization for Nuclear Research in Geneva, Switzerland

CFEL
Center for Free-Electron Laser Science in Hamburg, Germany

CNR
Consiglio Nazionale delle Ricerche in Rome, Italy

CNRS
Centre national de la recherche scientifique in Paris, France

D

DAFHES
Danish Agency for Higher Education and Science in Copenhagen, Denmark

DESY
Deutsches Elektronen-Synchrotron in Hamburg and Zeuthen, Germany

E

EIROforum
European Intergovernmental Research Organisation forum

EMBL
European Molecular Biology Laboratory

ERIC
European Research Infrastructure Consortium

ESRF
European Synchrotron Radiation Facility in Grenoble, France

ESS
European Spallation Source in Lund, Sweden

F

FEL
free-electron laser

FLASH
soft X-ray FEL facility at DESY in Hamburg, Germany

FXE
Femtosecond X-Ray Experiments [European XFEL instrument]

G

GSI
Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany

H

HED
High Energy Density Science [European XFEL instrument]

HIBEF
Helmholtz International Beamline for Extreme Fields at the European XFEL

HXS
High-Energy X-Ray Scattering [European XFEL instrument, under construction]

HZB
Helmholtz-Zentrum Berlin, Germany

I

ILL
Institut Laue–Langevin in Grenoble, France

INFN
Istituto Nazionale di Fisica Nucleare in Rome, Italy

L

LCLS
Linac Coherent Light Source at SLAC in Menlo Park, California, USA

LEAPS
League of European Accelerator-based Photon Sources

M

MID
Materials Imaging and Dynamics [European XFEL instrument]

N

NASA
National Aeronautics and Space Administration, USA

NCBJ
National Centre for Nuclear Research in Świerk, Poland

NRC KI
National Research Centre "Kurchatov Institute" in Moscow, Russia

NRDI
National Research, Development and Innovation Office in Budapest, Hungary

P

PETRA III
synchrotron radiation facility at DESY in Hamburg, Germany

R

RF
radio frequency

S

SACLA
SPring-8 Angstrom Compact free electron Laser in Harima Science Garden City, Japan

SASE
self-amplified spontaneous emission

SASE1, SASE2, SASE3
FEL undulator beamlines at the European XFEL

SCS
Spectroscopy and Coherent Scattering [European XFEL instrument]

SLAC
SLAC National Accelerator Laboratory in Menlo Park, California, USA

SPB/SFX
Single Particles, Biomolecules, and Clusters and Serial Femtosecond Crystallography
[European XFEL instrument]

SQS
Small Quantum Systems [European XFEL instrument]

SXP
Soft X-Ray Port
[European XFEL instrument]

U

UKRI
UK Research and Innovation in Swindon, UK

V

VR
Swedish Research Council in Stockholm, Sweden

X

XFEL
X-ray free-electron laser

European XFEL Annual Report 2024

We would like to thank everyone who contributed to the creation of this annual report.
European X-Ray Free-Electron Laser Facility GmbH, May 2025

Published by
European XFEL GmbH

Editor-in-chief
Thomas Feurer

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Copy editors
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Image editor
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Layout and graphics
Studio Belser GbR, Hamburg

Printing
RieckDruck GmbH, Uetersen

Available from
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22869 Schenefeld
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+49 (0)40 8998-6006
contact@xfel.eu
doi:10.22003/XFEL.EU-AR-2024
www.xfel.eu/documents

Copy deadline
31 December 2024

www.xfel.eu

Photos and graphs
Adobe Stock (pp. 36-37); Bilfinger SE (p. 54); DESY (pp. 23, 32, 45, 52, 54, 108); DESY / Marta Mayer (pp. 108-109); Deutsches Röntgen-Museum, Remscheid (p. 29); European XFEL / Richard Bean (p. 33); European XFEL / Aerial views 2017/18/21: FHH, Landesbetrieb Geoinf. und Vermessung (pp. 80-81); European XFEL / Axel Heimken (title page, pp. 6, 8-9, 24-25, 26, 34, 42-43, 67, 74); European XFEL / Tobias Wüstefeld (pp. 26, 34); T. Gawne/CASUS (p. 31); HZDR / T. Toncian (p. 32); Qingyu Kong (p. 11); Felix Lehmkühler (pp. 15, 28); Abhishek Mall and Kartik Ayyer (p. 21); Abhishek Mall and Parichita Mazumder (p. 21); Giacomo Merzoni / Politecnico di Milano (p. 17); Beniamin Motyka (p. 27); Modified from Nature Communications 15, 8256 (2024) (p. 13); Modified from Nature Photonics 18, 432–439 (2024) (p. 26)
All others: European XFEL

Water plays a crucial role in life, including in the function of biomolecules. In an art exhibition, the artists of Well Wired Team presented wire objects that are modelled on electron density maps of biomolecules.

European XFEL
Annual Report 2024