European XFEL

ANNUAL REPORT 2023

Developments, Results, Impressions

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THANK YOU, ROBERT

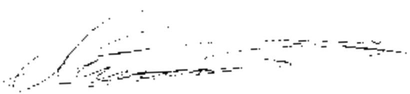
We are grateful to Robert Feidenhans'l, who chaired the European XFEL Management Board from 1 January 2017 until 31 December 2023, for his dedication and leadership. During his tenure, Robert played a key role in guiding European XFEL through the commissioning phase and positioning it as a world leader in X-ray science.

He has been instrumental in advancing the mission of European XFEL, enabling new research and fostering collaboration across disciplines. Under his leadership, European XFEL developed its Strategy 2030, which will enable the facility to continue to push the boundaries of scientific discovery and address key challenges in health, energy, sustainability, digitalization, fundamental research, and beyond.

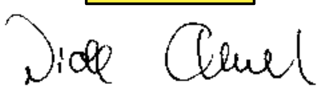
As Robert steps down from his role as Chairman, we are grateful for his continued support and contributions and are delighted that he will remain a trusted advisor to European XFEL.

We thank Robert for his outstanding service and look forward to continuing to drive our facility towards scientific excellence and innovation.

Thomas Feurer



Nicole Elleuche



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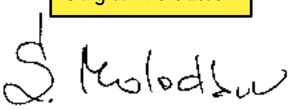
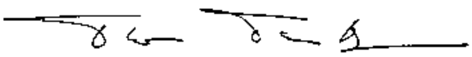


Sakura Pascarelli

Thomas Tschentscher



OUTGOING DIRECTOR'S FOREWORD

This annual report is personally very special for me. It is the last annual report in my time as Managing Director of the European XFEL. By the time this report is published, I will have handed over my office as Chairman of the Management Board to my successor, Thomas Feurer, who is providing the outlook for the coming year. It is a pleasure for me to look back on what was achieved not only in 2023 but in the entire period since the first cooldown of the accelerator and the start of operation in 2017.

Last year, we once again made significant progress and achieved many highlights. It is now the second year in which the facility is in full user operation, and we are very close to our goal of more than 9000 instrument hours for the user programme.

There were many scientific highlights in 2023 as well as important technical achievements, such as the commissioning of the DiPOLE laser at the HED instrument, from which I expect exciting scientific results and publications in the coming years. Another highlight was the start of commissioning of the seventh beamline, SXP, which will be running under different conditions on an open port for user-provided experiments that require less support than at the other beamlines.

In 2023, we also opened the new office building, XHO, and celebrated the topping out of the new "Lighthouse" visitor and conference centre.

Finally, 2023 was the year in which we completed our strategy document "European XFEL Strategy 2030: Strategic Directions", which sets the overall scene for European XFEL over the remaining part of the decade. The strategy focuses on three main elements: (i) harvesting science and contributing to societal challenges with the necessary investments, (ii) performing important mid-term developments in order to keep the facility scientifically and technological at the forefront, and (iii) preparing for a major upgrade after 2030 involving three elements, namely an upgrade of the accelerator, development of instruments, equipment, and undulators for the remaining two empty tunnels leading to the experiment hall, and construction of a new second fan with 6 to 10 new instruments. These are ambitious goals, but only such an upgrade would make full use of the capabilities of the facility and the investments made in it.

I look forward to following the science output of the facility, in particular the contributions to address societal challenges for many years to come, and to closely following the upgrade plans and possibly even the inauguration of a new facility.

I would very much like to thank all users, shareholders, members of our committees, and in particular all staff members at European XFEL and DESY for the tremendous support and engagement during the past years. It has been a great pleasure working with you!

Robert Feidenhans'l

Federico Boscherini

“THE STRATEGIC DIRECTIONS LAY THE FOUNDATION FOR THE DEVOLOPMENT OF THE FACILTY UNTIL THE END OF THE DECADE.”

COUNCIL CHAIR FOREWORD

On behalf of the European XFEL Council, I am very happy to introduce this annual report, which reviews the developments and scientific results obtained in 2023 at European XFEL. This is the second year of full user operation with nearly 9000 instrument hours dedicated to the user programme, which is a significant achievement in itself.

In 2023, several results obtained at European XFEL were published in high-profile scientific journals; this is at the core of the facility's mission to provide scientific excellence. This annual report describes some of these results and others that will certainly be the basis for publications in the near future. There have also been very significant instrument developments, including the continuing improvements of schemes to generate ultrashort hard X-ray pulses, the commissioning of the DiPOLE laser at the HED instrument, and the start of commissioning of the SXP instrument.

The Council has worked intensively to support the facility, in strong collaboration with the Management Board and with invaluable input from the Scientific Advisory Committee (SAC) and the Administrative and Finance Committee (AFC). I take this occasion to thank all the Council and advisory committee delegations for very constructive discussions, with special thanks to the leadership of SAC and AFC. In 2023, the most important topic considered by the Council was the European XFEL Strategy 2030, which was discussed at all three meetings. I am very happy that, in the November meeting, the Council unanimously approved the document describing the strategic directions that lay the foundation for development until the end of this decade, including scientific harvesting, mid-term developments, and preparation for a major upgrade after 2030. The goal is to keep the European XFEL at the forefront of X-ray science, while contributing to solving important societal challenges. Not only has the Council approved the document, but it has also unanimously authorized the Management Board to initiate its implementation with significant spending.

In 2023, there were very positive developments concerning European XFEL governance. In fact, contracts were signed for Thomas Feurer as new Chair of the Management Board and for the second term of Sakura Pascarelli as Scientific Director. I look forward to very fruitful collaboration with them in the coming years.

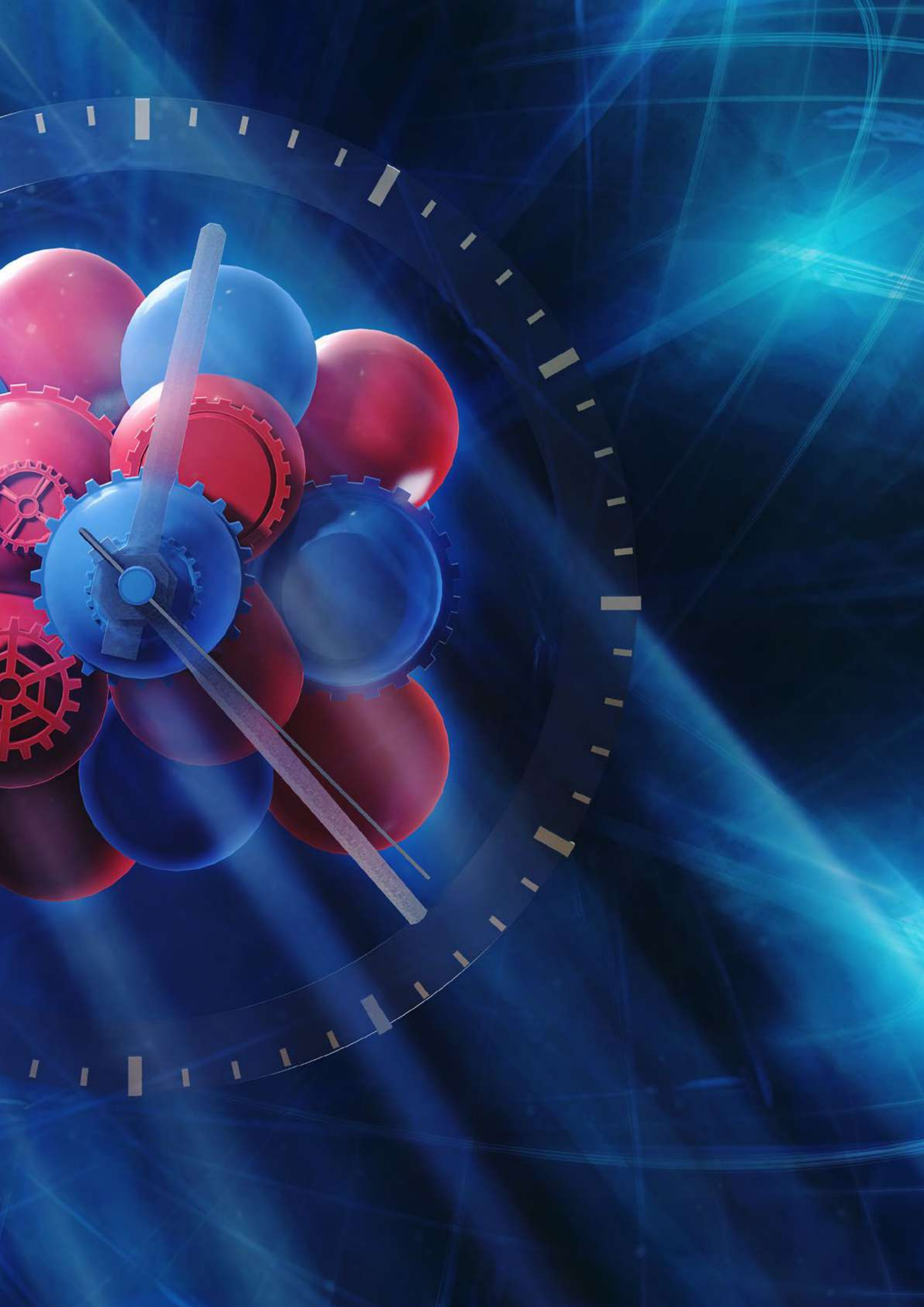
Last but by no means least, on behalf of the Council, I would like to once again extend a very warm thank you to Robert Feidenhans'l for his extraordinary contributions to the planning, construction, and startup of the European XFEL.

In 2004, he was Danish delegate at the first meeting of the International Steering Committee (ISC), which was the predecessor of the Council. Subsequently, he became Danish Council delegate before serving as Council Chair from mid-2010 to mid-2014. He returned to the position of Danish Council delegate before serving as Chair of the Management Board from 2017 to 2023.

It has been a real pleasure for me to work closely with him in the past years, and I wish him all the best for this new phase of his life.

HIGHLIGHTS

Nuclear fluorescence could pave the way to ultraprecise clocks



INSPIRED BY PLANTS

Unravelling the properties of the photocatalyst $BiVO_4$ for future artificial photosynthetic technologies

Being able to mimic the ability of plants to harness natural sunlight in order to store energy in chemical bonds has long been a dream of many scientists. So-called photocatalytic materials, such as the semiconductor bismuth vanadate ($BiVO_4$), are key elements in artificial photosynthetic systems that collect sunlight and convert it to stored chemical energy. For such technologies to reach their full potential, a better understanding of how these materials work is crucial. At the European XFEL, scientists use the FXE instrument to study ultrafast dynamics in $BiVO_4$. Their results reveal surprising structural and dynamic changes and lead to new insights into photocatalysts.

The ability of plants to use natural sunlight, water, and carbon dioxide to harvest and store energy has long fascinated scientists. During photosynthesis, light energy in the form of photons is used to split water molecules. The liberated protons and electrons are then combined with carbon to create carbohydrates; oxygen and water are generated as by-products. "In light of the climate crisis, being able to engineer materials to make use of sunlight and water to create green energy solutions with no toxic waste products would be a dream come true," says Sakura Pascarelli, a Scientific Director at European XFEL.

In pursuit of this vision, scientists are investigating materials and systems that mimic this natural phenomenon in an attempt to identify suitable components for artificial photosynthetic systems. Photocatalytic materials have been identified that harvest sunlight efficiently and convert the energy via water splitting into storable chemical compounds. Thanks to its efficient collection of sunlight and its promise of enabling a high rate of conversion of solar energy to hydrogen energy, $BiVO_4$ has emerged as a key potential photocatalyst. However, despite these promising characteristics, the fundamental nature and dynamics of the underlying processes in $BiVO_4$ are still unclear.

"Understanding the complete conversion process, from the earliest stages of light absorption to the eventual reaction events, is crucial if we are to maximize catalytic efficiencies for future energy solutions," says Felix Deschler from Ruprecht-Karls-Universität Heidelberg, who studies ultrafast dynamics in functional materials.

In initial studies on $BiVO_4$, a team of scientists from the group of Felix Deschler, the group of Ian Sharp at TU Munich, and beamline scientist Burak Guzelturk of Argonne National Laboratory in the USA discovered what seems to be a distortion in the crystal lattice of the $BiVO_4$ as well as structural disturbances upon interaction with light. "These first intriguing results suggest fascinating interactions between light-driven electronic excitations within the material's structure that we were excited to investigate," says Sharp, who studies energy materials and mechanisms of photocatalysis.

At the European XFEL, Deschler, Sharp, and colleagues used the FXE instrument to study the structural and electronic dynamics of $BiVO_4$. In their experiments, the scientists first triggered a reaction in a thin film of $BiVO_4$ using an ultrashort optical laser pulse. Then, just a few femtoseconds later, an X-ray pulse was used to reveal structural and electronic changes within the crystal lattice of the material. By repeating this process, the entire response could be tracked.

"Fitting with our previous observations, we observed an ultrafast structural change within the crystal lattice, whereby the crystal units become somewhat more compacted. This happens within a few picoseconds after the reaction is initiated by the light pulse," explains Deschler. "Traditionally, it has been assumed that the crystal form does not change under illumination, so this is a key finding for the field." The assumption that the crystal form is stable has been the basis of calculations such as those relevant for device optimization or modelling electronic dynamics. The new results suggest that these assumptions must be reconsidered.

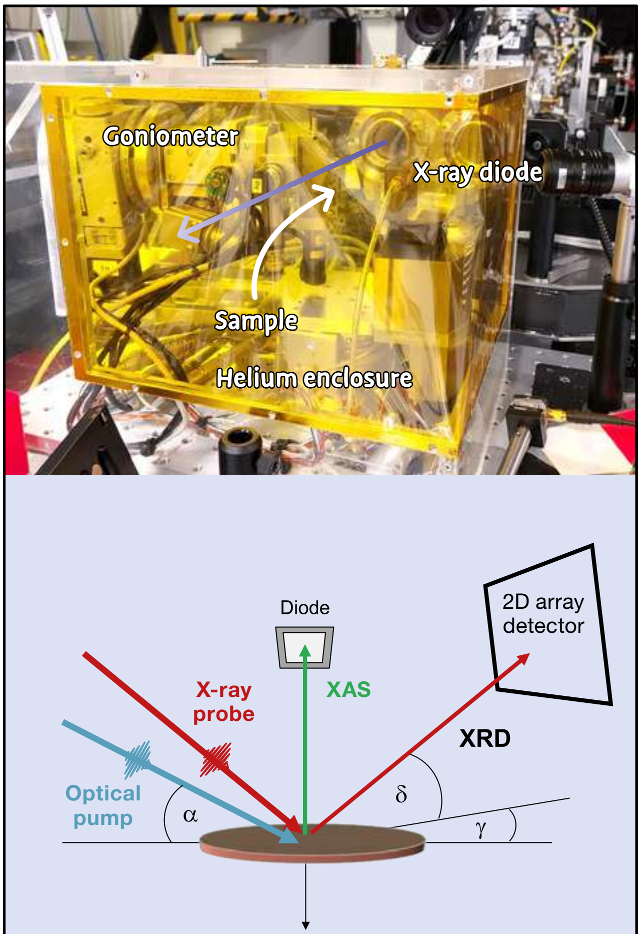


Figure 1
Top: Helium enclosure in which the experiment was performed, including the sample goniometer and the diode for measurement of X-ray fluorescence. The purple arrow indicates the propagation direction of the optical laser and X-ray beams.
Bottom: Sample geometry used for the experiment. (XAS: X-ray absorption spectroscopy, XRD: X-ray diffraction.)

The ultrafast and intense X-ray pulses of the European XFEL made it possible to observe these extremely quick changes occurring in the structure of $BiVO_4$. “These changes would not be picked up at traditional light sources, such as synchrotrons,” explains Peter Zalden, scientist at the FXE instrument. “Now we have the tools to study these extremely fast but important changes and learn more about these interesting materials.”

The scientists were also keen to use the capabilities of the European XFEL to investigate predicted distortions known as “polarons”. Calculations had predicted changes in $BiVO_4$ in which excited electrons interact with the atoms of the crystal, resulting in nanometre-scale structural changes that, in turn, impact the energies of the excited electrons and how electrical current flows. These complex interactions and correlations have a significant influence on energy conversion mechanisms and, ultimately, efficiencies.

“We find that changes in the electronic structure occur on sub-100 fs timescales, preceding the structural phase changes we observe,” says Sharp. “Our data suggest that photoexcitation initiates a change in electron arrangement and localization of these excitations at the atomic scale, along with a change of the crystal structure. These results could have far-reaching implications for understanding mechanisms underlying photocatalytic activity and the design of materials for these applications.”

Although there is still much to learn about $BiVO_4$ and photocatalysts in general, the researchers are excited about the results so far and what they mean for the development of future technologies. As a next step, the scientists want to know more about how polarons form and their impact on the function of photocatalysts. “Elucidating the lattice dynamics associated with the formation of polarons is now essential for resolving the electronic nature of such excitations as well as their impact on the materials’ efficiency in converting sunlight to fuel,” concludes Deschler.

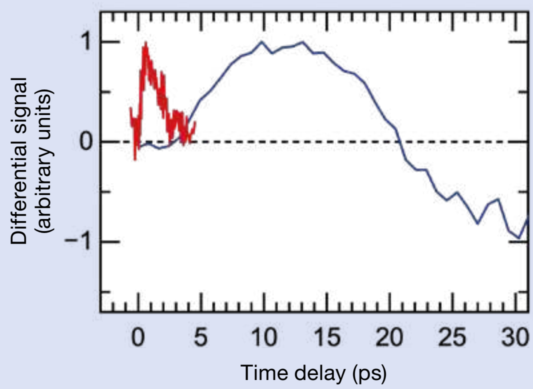
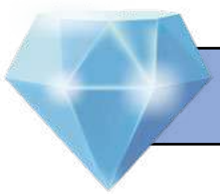


Figure 2
X-ray absorption (red curve) and diffraction (blue curve) data collected simultaneously, showing the fast electronic response due to excitation at 480 nm (red curve) followed by the slower response of the $BiVO_4$ crystal lattice (blue curve)

Authors
F. Deschler, B. Guzelturk, C. Milne, I. Sharp, P. Zalden

RAINING DIAMONDS



Proof-of-concept experiment recreates conditions of deep Earth to investigate dynamics of planet interiors

Did you know it rains diamonds on Neptune? Previous studies at X-ray lasers have shown that diamonds form from carbon compounds in the interior of icy gas planets because of the extreme high-pressure and high-temperature conditions prevailing there. The diamonds then slowly descend deeper into the interior of the planets as a "rain" of precious stones from the higher layers. Using the European XFEL, an international team of researchers led by Mungo Frost from the SLAC research centre in California has gained new insights into the formation of this diamond rain. The results also provide clues about the formation of the complex magnetic fields of these planets.

The experiment at the European XFEL's HED instrument has shown that the formation of diamonds from carbon compounds begins at pressures and temperatures lower than previously assumed. For the icy planets, this means that diamond rain starts to form at a shallower depth than previously thought and could therefore have a stronger influence on the formation of the planet's magnetic fields. Following this train of thought, diamond rain would also be possible on gas planets that are smaller than Neptune and Uranus, so-called "mini-Neptunes". Such planets do not exist in our solar system, but they do occur as exoplanets outside of it.

On its way from the outer to the inner layers of these planets, the diamond rain can disturb the small molecules of ice in their mantles, causing currents of ice that conduct energy—conductive ice. Such currents act like a kind of dynamo, shaping the magnetic field of the planets. That could be an explanation why the magnetic fields of Uranus and Neptune differ from those of other planets in the solar system: they are less aligned with the spin axis of the planet and more complex. "The diamond rain probably has an influence on the formation of the complex magnetic fields of Uranus and Neptune," says Frost.

To simulate the environment inside the icy gas planets, the team used a plastic film made from the hydrocarbon compound polystyrene as a carbon source for their experiment. Under the extremely high pressure they applied to the foil, the scientists were able to form tiny diamonds. To achieve the high pressure and over 2200 °C of temperature that prevail inside icy planets, the researchers used diamond anvil cells heated using the X-ray pulses of the European XFEL. The anvil cells function like a mini vice in which the sample is squeezed between two diamonds. With the X-ray pulses of the European XFEL, the scientists were able to precisely observe the time, conditions, and sequence of the formation of the diamonds in the anvil cell.

"At the HED instrument, we have the unique possibility to record an ultrafast image sequence with a single megahertz pulse train of the European XFEL", says Ulf Zastrau, leading scientist at the HED instrument. "The hard X-ray pulses easily penetrate the pressure-generating anvils, and we can watch the small diamonds forming from the plastic." And Frost adds: "Through this international collaboration, we have made great progress at the European XFEL and gained remarkable new insights into icy planets."

The team also included scientists from European XFEL, the German research centres DESY and HZDR, as well as other research institutions and universities from different countries. The European XFEL user consortium HIBEF contributed significantly to the work.

Authors
M. Frost, R. S. McWilliams, E. Bykova, M. Bykov, R. J. Husband, L. M. Andriambariarijaona, S. Khandarkhaeva, B. Massani, K. Appel, C. Baehtz, O. B. Ball, V. Cerantola, S. Chariton, J. Choi, H. Cynn, M. J. Duff, A. Dwivedi, E. Edmund, G. Fiquet, H. Graafsma, H. G. Hwang, N. Jaisle, J. Kim, Z. Konôpková, T. Laurus, Y. Lee, H.-P. Liermann, J. D. McHardy, M. I. McMahon, G. Morard, M. Nakatsutsumi, L. Anh Nguyen, S. Ninet, V. B. Prakapenka, C. Prescher, R. Redmer, S. Stern, C. Strohm, J. Sztuk-Dambietz, M. Turcato, Z. Wu, S. H. Glenzer, A. F. Goncharov

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M. Frost et al.: "Diamond precipitation dynamics from hydrocarbons at icy planet interior conditions", Nature Astronomy (2024), doi:10.1038/s41550-023-02147-x

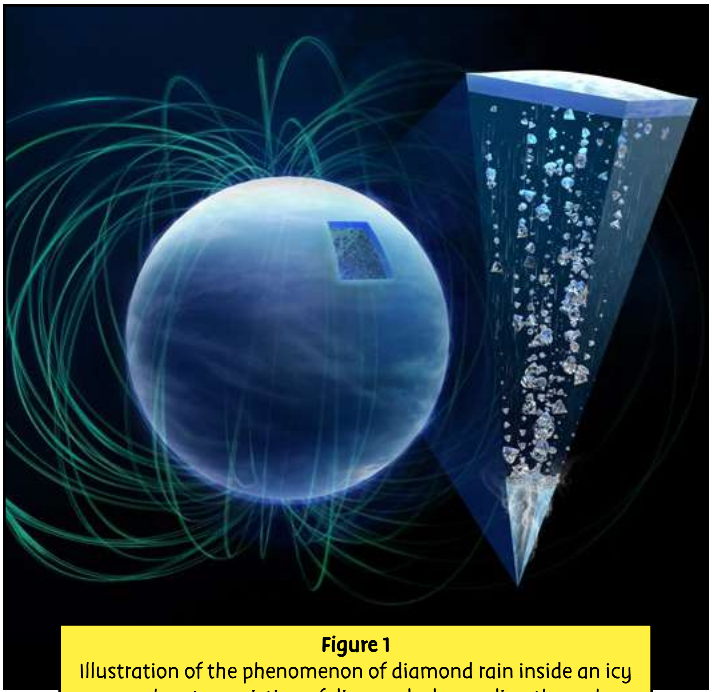


Figure 1
Illustration of the phenomenon of diamond rain inside an icy gas planet, consisting of diamonds descending through the surrounding ice. The pressure and temperature increase continuously on the way down. Even in extremely hot regions, however, the ice remains intact because of the extremely high pressure.

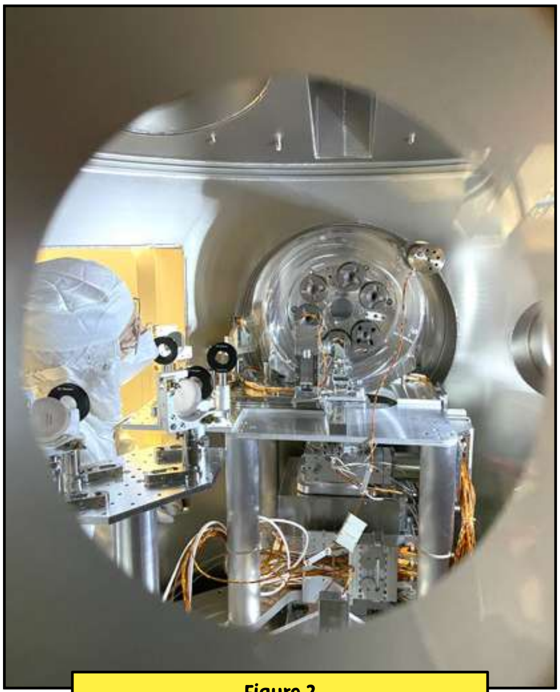


Figure 2
View into the interaction chamber IC2 of the HED instrument at the European XFEL

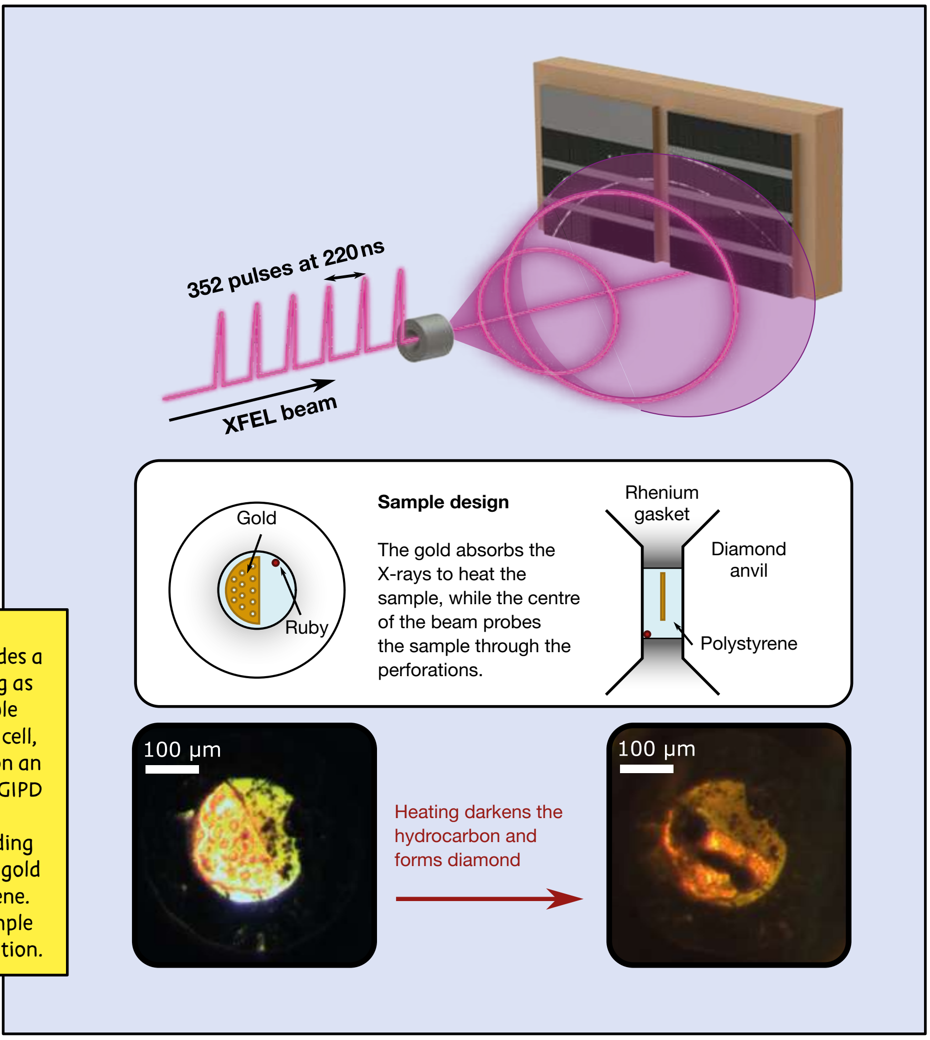
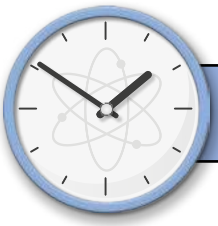


Figure 3
Top: The experiment setup includes a 4.5 MHz X-ray pulse train acting as pump and probe on the sample compressed in a diamond anvil cell, with diffracted X-rays incident on an eight-module high-sensitivity AGIPD 500 k pixel detector.
Middle: Diamond anvil cell loading configuration with a perforated gold coupler embedded in polystyrene.
Bottom: Micrograph of the sample before and after diamond formation.

TICK TOCK, PRECISION CLOCK



Experiments at the European XFEL indicate route towards next generation of precision timekeepers

Atomic clocks are currently the world's most accurate timekeepers. They work by using electrons in the element caesium as a pulse generator and are accurate to less than one second in 300 million years. Some applications, such as positioning tools using satellite navigation, however, would benefit from even greater precision. In an experiment at the European XFEL, an international research team took a decisive step toward a new generation of nuclear clocks. Using the MID instrument, the researchers managed to create an extremely precise pulse generator based on the element scandium, which enables an accuracy of one second in 300 billion years—around a thousand times more precise than caesium-based atomic clocks. The new insights are also relevant for other research areas that rely on extremely accurate measurements, such as ultrahigh-precision spectroscopy.

Atomic clocks work by using electrons in the atomic shell of chemical elements, such as caesium, as a pulse generator in order to define time. In fact, caesium atomic clocks are the basis of our current definition and unit standard of a second, needed for clocks and watches the world over. In an atomic clock, the electrons in the caesium's atomic shell can be raised to a higher energy level by exposing them to microwaves of a known frequency, whereby the electrons absorb the microwave radiation. An atomic clock regulates the frequency of the radiation in a manner that maximizes the absorption of the microwaves by the electrons; this is known as resonance. With the help of resonance, the quartz oscillator that generates the microwaves can be kept so stable that caesium clocks will be accurate to within one second in 300 million years.

Despite this high degree of precision, scientists have been looking for a system with even better accuracy. A nuclear clock would use transitions in the atomic nucleus as the pulse generator rather than in the atomic shell. Nuclear resonances are much sharper than the resonances of electrons. Instead of caesium, such nuclear clocks could be based on the element scandium. However, although the scientific potential of using scandium has been discussed for decades, no X-ray source was available that shone brightly enough to excite the resonance—until the advent of the European XFEL.

In a groundbreaking experiment, a team of scientists used the MID instrument at the European XFEL to explore a promising transition in the nucleus of the element scandium, which is readily available as a high-purity metal foil or as the compound scandium dioxide. For their experiment, the scientists used the intense X-ray light of the European XFEL to irradiate a 0.025-millimetre-thick scandium foil. They were able to detect a characteristic afterglow emitted by the excited atomic nuclei—clear evidence of scandium's extremely narrow resonance line.

Crucial to the accuracy of an atomic clock is the width of the resonance used. Current caesium atomic clocks already use a very narrow resonance; atomic clocks based on the element strontium achieve an even higher accuracy of around one second in 15 billion years. However, further improvement is practically impossible to achieve with this method of electron excitation. Nuclear resonances are much narrower and therefore sharper than the resonances of electrons in the atomic shell, but also much harder to excite.

"The scientific potential of the scandium resonance was identified more than 30 years ago," reports the experiment's project leader, Yuri Shvyd'ko of Argonne National Laboratory in the USA. "Until now, however, no X-ray source was available that shone brightly enough within the narrow 1.4 femtoelectronvolt line of scandium," says Anders Madsen, leading scientist at the MID instrument. "That only changed with X-ray lasers like the European XFEL."

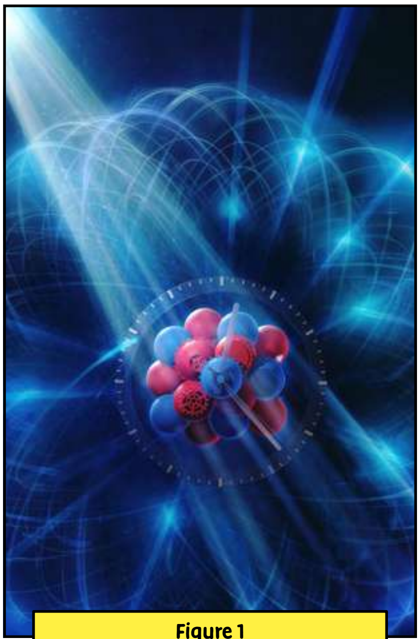


Figure 1
Artist's rendering of the scandium nuclear clock: Scientists used the X-ray pulses of the European XFEL to excite in the atomic nucleus of scandium the sort of processes that can generate a clock signal at an unprecedented precision of one second in 300 billion years.

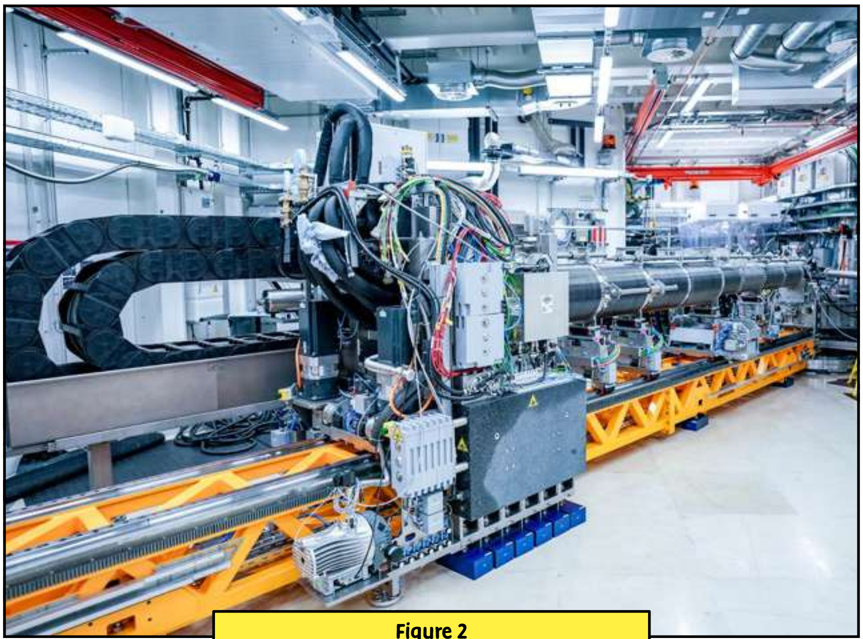


Figure 2
The MID instrument at the European XFEL

This nuclear resonance requires X-rays with an energy of 12.4 kiloelectronvolts (keV, which is about 10 000 times the energy of visible light) and has a width of only 1.4 femtoelectronvolts (feV). This makes an accuracy of 1 : 10 000 000 000 000 000 000 possible. "This corresponds to one second in 300 billion years," says DESY researcher Ralf Röhlsberger, who works at the Helmholtz Institute Jena, a joint facility of GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Helmholtz Zentrum Dresden-Rossendorf (HZDR), and DESY.

Also important for the construction of atomic clocks is the exact knowledge of the resonance energy—in other words, the energy of the X-ray laser radiation at which the resonance occurs. Sophisticated extreme noise suppression and high-resolution crystal optics at the European XFEL were crucial so the team could determine the value of the scandium resonance energy in the experiments within five decimal places at 12.38959 keV, 250 times more accurately than it was known before. "The precise determination of the transition energy marks a significant progress," emphasizes the head of the data analysis, Jörg Evers of the Max Planck Institute for Nuclear Physics in Heidelberg. "The exact knowledge of this energy is of enormous importance for the realization of an atomic clock based on scandium." The researchers are now exploring further steps toward realizing such a nuclear clock.

Atomic clocks have numerous applications that benefit from improved accuracy, such as precise positioning using satellite navigation. "The breakthrough in resonant excitation of scandium and the precise measurement of its energy open new avenues not only for nuclear clocks but also for ultrahigh-precision spectroscopy and precision measurement of fundamental physical effects," Shvyd'ko explains. Olga Kocharovskaya of Texas A&M University in the USA, initiator and leader of the project funded by the National Science Foundation, adds: "For example, such a high accuracy could allow gravitational time dilation to be probed at sub-millimetre distances. This would allow studies of relativistic effects on length scales that were inaccessible so far."

Authors
Y. Shvyd'ko, R. Röhlsberger, O. Kocharovskaya, J. Evers, G.A. Geloni, P. Liu, D. Shu, A. Miceli, B. Stone, W. Hippler, B. Marx-Glowna, I. Uschmann, R. Loetzsch, O. Leupold, H.-C. Wille, I. Sergeev, M. Gerharz, X. Zhang, C. Grech, M. Guetg, V. Kocharyan, N. Kujala, S. Liu, W. Qin, A. Zozulya, J. Hallmann, U. Boesenberg, W. Jo, J. Möller, A. Rodriguez-Fernandez, M. Youssef, A. Madsen, T. Kolodziej

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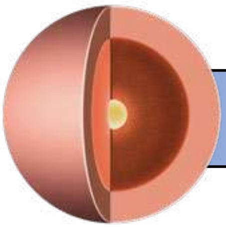
INVESTIGATING THE FORMATION OF WARM DENSE MATTER



Experiments using XANES spectroscopy open up possibilities for X-ray pulse shaping

Warm dense matter (WDM) is a state of matter found in planets and other astrophysical objects that is also relevant to fusion research. However, it poses great theoretical and experimental challenges. XFELs and their intense femtosecond X-ray pulses have become a new and efficient means to study these states. In a recent experiment at the SCS instrument of the European XFEL, scientists studied the formation of WDM by X-ray absorption near-edge structure (XANES) spectroscopy. The researchers were able to characterize WDM in copper films. The data, corroborated by a theoretical model, show that these processes could be used for X-ray pulse shaping in future experiments.

It is well understood that temperature influences the state of matter; the extremely high temperatures in a volcano result in molten rock; depending on its temperature, water can form solid ice, liquid, or steam. Somewhere between the temperature extremes needed to generate condensed matter, such as ice, hot lava, or plasma, matter takes on a state known as WDM. This state is found in many planets and other astrophysical objects and is also relevant for fusion research. However, coming to grips with WDM is tricky. Experimentally, WDM is difficult to create and to characterize, as it exists only briefly in the lab. Theoretically, it poses challenges too—it is too hot to be described by condensed-matter physics yet too dense to be described by weakly coupled plasma physics.

The intense femtosecond X-ray pulses of the European XFEL have proven to be useful tools for creating and studying WDM. “The high intensity of a focused European XFEL pulse on a solid target can trigger strong excitations of the electronic subsystem, thus turning the solid into WDM and drastically altering its opacity”, explains Laurent Mercadier, scientist at the SCS instrument.

A metal irradiated by intense X-rays can become transparent by depletion of its absorbing state. This is known as saturable absorption (SA). Conversely, the opacity of a metal can increase if the transiently created excited state absorbs more than the ground state—this is known as reverse saturable absorption (RSA). Both processes are routinely used in methods employing optical light, such as “mode locking”, where lasers are forced to produce a specific pulse length, and two-photon microscopy, which requires excitation of two photons simultaneously. “Transferring our understanding of how to manipulate these effects to the X-ray spectral domain could be a route to controlling the shape of X-ray pulses”, says Andreas Scherz, leading scientist at SCS. “This would give us even more knobs in our experiments using femtosecond pulses.”

In a recent experiment, a group of scientists investigated the formation of WDM created using the European XFEL X-ray pulses. “We studied the formation of warm dense copper via XANES spectroscopy, a powerful technique to investigate both the electronic and structural dynamics of WDM”, says Mercadier.

The researchers focused a 15 fs long X-ray pulse of 15 eV bandwidth on a 100 nm thick copper film. The transmitted pulse was then analysed using a spectrometer to measure the absorption spectrum (Figure 1). “The resulting XANES spectrum strongly depends on the X-ray pulse intensity”, explains Mercadier, who led the experiment. At low to moderate X-ray intensities, spaces are created in the material, opening up the absorption. At higher X-ray intensity, massive ionization and collisions lead to the transition from reverse saturable absorption to saturable absorption of the X-ray pulse (seen as material bleaching). “That we see evidence of two non-linear effects holds promise for utilizing these processes for X-ray pulse shaping like in optical lasers”, says Mercadier.

The results are substantiated by a pioneering theoretical approach that combines a plasma model with high-temperature solid-state XANES calculations. “Our model reveals that a non-negligible part of the ionized electrons is ‘hot’ and remains out of equilibrium with the rest of the free electrons”, explains Mercadier. Therefore, the time-integrated spectra must contain a significant contribution from the non-equilibrium evolution stages of the plasma formation. “The spectral data reflect this and are in good agreement with our model”, he adds.

“We are pleased to have characterized the formation of warm dense copper via transient absorption spectroscopy and measured the transition from RSA to SA”, says Scherz. These drastic alterations of opacity occur within the 15 fs pulse duration and challenge the theoretical modelling and deeper understanding of the processes. “Our attempt to bridge plasma and solid-state descriptions paves the way to further developments in this direction”, adds Mercadier. “The prospect of attosecond XFEL pulses and attosecond transient XANES capabilities will widen the applicability of the presented approach in the study of matter under extreme conditions”, concludes Scherz.

The experiment setup and examples of absorption spectra are shown in Figure 1. The spectrum at an X-ray pulse intensity of 5×10^{12} W cm^{-2} (on top) is that of a cold sample. As the X-ray intensity increases, the spectra depart from that of the cold case. Notably, an absorption peak appears at a photon energy of 929.7 eV and grows while slightly shifting to lower energy, to reach a maximum intensity at 5×10^{14} W cm^{-2} (RSA). The origin of this peak is well known: it is due to the presence of 3*d* vacancies, which trigger photoabsorption through $2p_{3/2} \rightarrow 3d$ transitions. As the X-ray intensity is further increased, the peak loses intensity but broadens and shifts to higher photon energies. At the highest X-ray intensity, the spectrum is almost flat, with no indication of an edge: the material becomes transparent (SA).

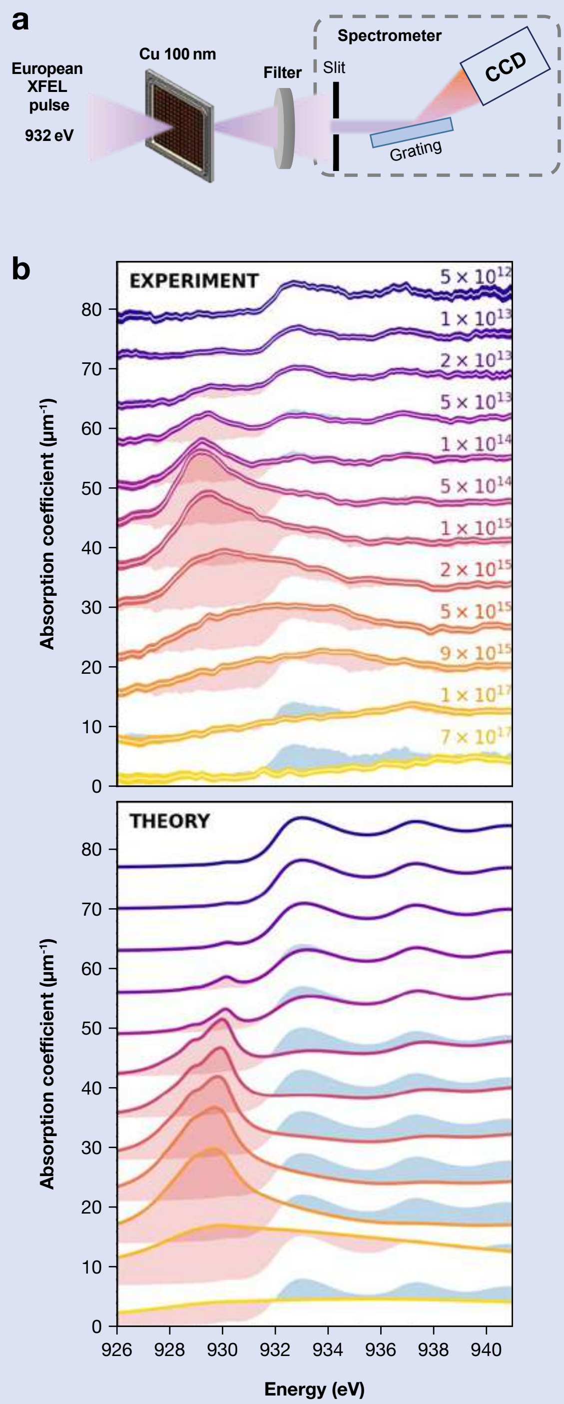


Figure 1
(a) Experiment setup. **(b)** Measured and calculated XANES spectra as a function of X-ray pulse intensity, indicated in W cm^{-2}. The shaded red (blue) area shows the increase (decrease) of absorption with respect to the cold case (5×10^{12} W cm^{-2}).

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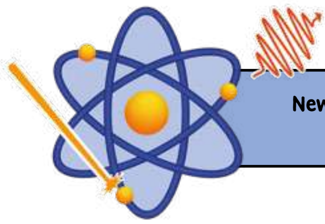
EXPLORING (COMPLEX) PHENOMENA ON SHORT TIMESCALES AND DISTANCES



New spectrometer enables novel insights into molecular dynamics and ultrafast phenomena

A new spectrometer recently installed at the SQS instrument of the European XFEL enables scientists to delve even further into the electronic and molecular dynamics of atoms, complementing a suite of tools for the exploration of quantum systems at the instrument. The 1D imaging soft X-ray spectrometer enables high-resolution X-ray emission spectroscopy (XES) for the investigation of highly ionized plasmas as well as time-resolved experiments for femtosecond and attosecond science.

With the development of XFELs, scientists were able to shine a light on phenomena that had previously been out of reach technically. The SQS instrument was designed to make use of the unique capabilities of the European XFEL to explore complex multiphoton phenomena occurring on extremely short timescales and across small distances. Beside various devices for electron and ion spectroscopy at SQS, the recently installed 1D imaging soft X-ray spectrometer (Figure 1) will also make high-resolution XES an important tool for the investigation of non-linear X-ray physics and ultrafast phenomena.

“We expect to be able to study a range of fascinating phenomena with the new spectrometer”, says Michael Meyer, leading scientist of the SQS instrument. “Combined with the unique capabilities of the European XFEL and state-of-the-art optical laser systems, we predict that we can gain new insigths into, for example, the dynamics of photoinduced molecular processes and of light propagation effects in dense gases as well as the formation of highly ionized plasmas found in astrophysical objects.”

One of the first experiments completed using the new 1D imaging spectrometer studied multiple ionization processes in atoms when exposed to the extremely intense X-rays of FELs (Figure 2). “The generation of multiply charged atomic ions has always been a signature of studying non-linear processes with intense short-wavelength FELs such as the European XFEL”, explains Thomas Baumann, scientist at SQS and leading researcher of the study. “Understanding and characterizing this process in detail is in itself of great interest, but it is also relevant for researchers looking at radiation damage in biological systems and the formation of hot plasmas.”

Previous studies investigating multiple ionization processes have used ion spectroscopy approaches to characterize the final product of the interaction with the intense FEL pulses. The new spectrometer has the advantage of enabling detailed investigations of different transient states produced throughout the entire process. First measurements, performed in close collaboration with scientists from Uppsala University in Sweden who designed and built the new spectrometer, focused on the investigation of neon gas irradiated with FEL pulses at photon energies around 1000 eV and pulse energies up to 5 mJ. The recorded fluorescence spectra show emission lines from all charge states of neon. “The data we collected are very encouraging and reflect the rich dynamics of the multiphoton ionization process and the complex relaxation mechanisms”, says Swedish scientist Jan-Erik Rubensson, principal investigator of the study. Detailed analysis is currently under way.

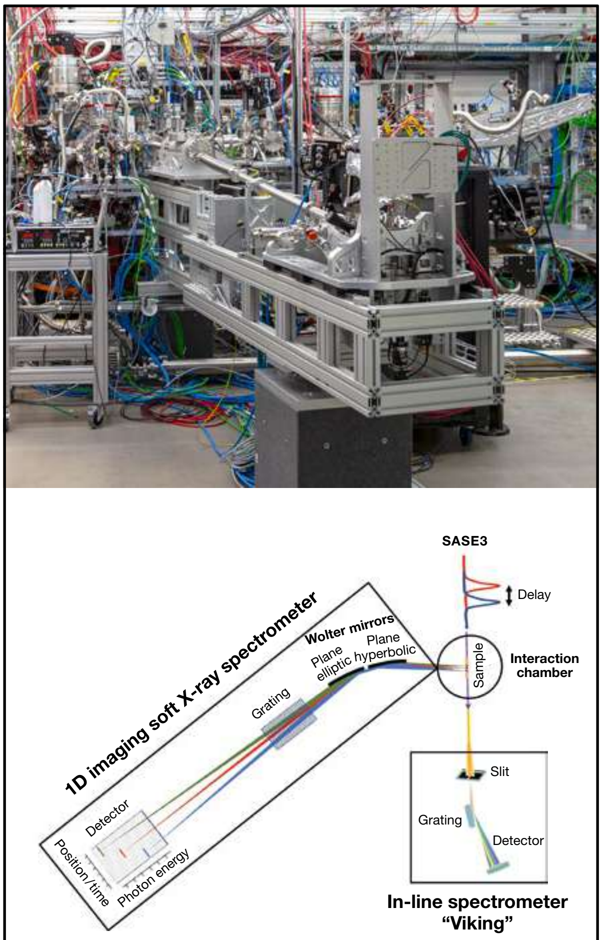


Figure 1
Photo and schematic view of the 1D imaging soft X-ray spectrometer at the SQS instrument. Imaging in the horizontal plane is accompanied by spectral analysis in the vertical plane. The SASE3 beamline can provide short X-ray pulses with two colours and controlled temporal delay.

The group also deployed the setup to investigate molecular dissociation dynamics in oxygen gas. "FELs have been an extremely important tool for the understanding of a range of reactions and interactions within the gas phase down to the attosecond timescale", explains Baumann. "The intense, ultrashort X-ray pulses generated by the European XFEL allow us to follow in real time, for example, how molecular properties change upon exposure." Important for this second study was the two-colour operation mode of the SASE3 undulator at the European XFEL, which enabled excitation of the gas sample by two soft X-ray pulses of short duration (< 5 fs), different photon energies (around 530 eV), and variable temporal delay. To monitor the incoming pulses, an in-line spectrometer was set up in the forward direction of the FEL beam (schematic view in Figure 1).

As a control experiment, the spectra of the radiation were first measured without any gas in the interaction chamber; the two X-ray pulses were observed directly. Once the gas cell was filled with dense oxygen gas, strong absorption features appeared (Figure 3). For this time-resolved experiment, a first X-ray pulse was used to initiate a dissociation process, which was then probed by a second pulse.

"The importance of the imaging capability of the new spectrometer becomes very clear", says Rubensson. "The spectral profile shows that the fluorescence spectrum varies along the imaged path of the incident radiation in the gas medium. The FEL pulses are strongly affected during their way through the target, resulting in different local interaction processes." A theoretical description is also being developed for these two-pulse experiments.

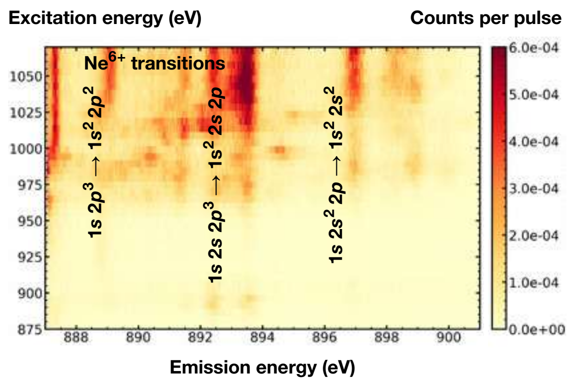


Figure 2
Soft X-ray fluorescence map of atomic neon irradiated with intense X-ray FEL pulses. Emission from Ne^{6+} is shown for a selected energy region. Some of the observed lines are attributed to 2*p* → 1s transitions from different excited states.

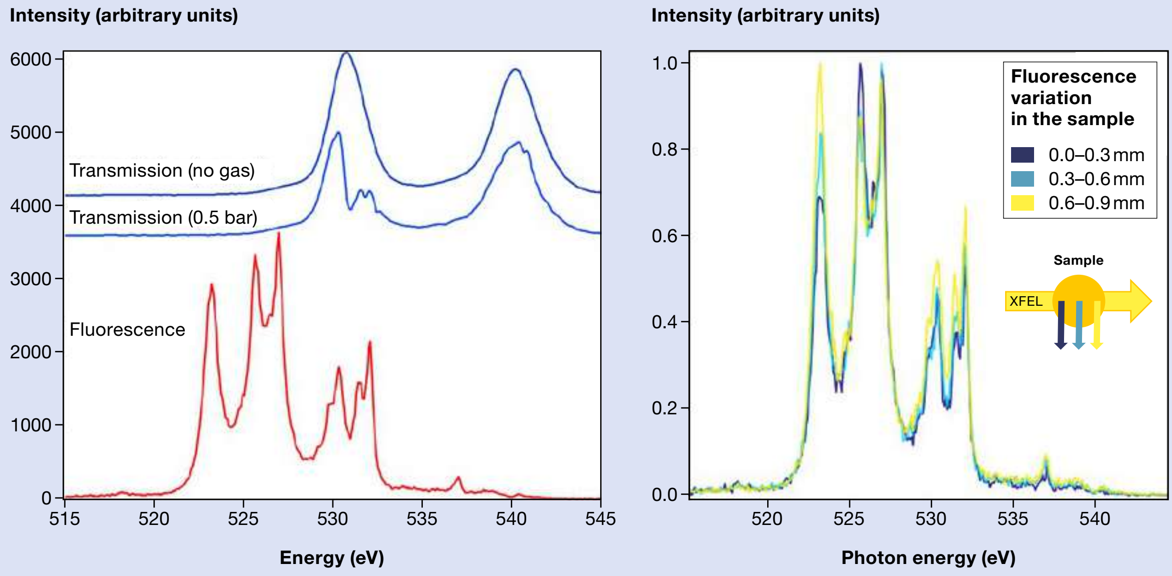


Figure 3
Spectral profiles of the two soft X-ray pulses measured with the in-line spectrometer (blue) behind the interaction volume with and without gas in the interaction volume (top left). Soft X-ray fluorescence spectrum recorded with the 1D imaging spectrometer (red) in integral mode (lower left) and at different positions in the interaction volume (right), corresponding to different regions on the 2D detector. The three spectra represent the emission from three positions in the interaction region separated by less than 1 mm.

"We envision that the new spectrometer will be important in the further exploration of non-linear X-ray physics at the European XFEL", concludes Meyer. In particular, the scientists expect that the control of the pulse properties in two-colour experiments, with options for extremely small duration and delay, will open new avenues. "In the near future, we plan to combine the FEL pulses with an optical laser for applications using the 1D imaging soft X-ray spectrometer. When the beams are introduced at a small angle relative to each other, we can simulate consecutive delays, which can also be imaged in the new spectrometer, thereby taking advantage of the high spatial resolution for time-resolved studies."

The full potential of the new spectrometer, especially its imaging capability, will be exploited in pump-probe experiments, using both a conventional laser as a pump and two-colour X-ray pump / X-ray probe schemes, which will become an especially powerful tool when attosecond pulses with controlled delay become available.

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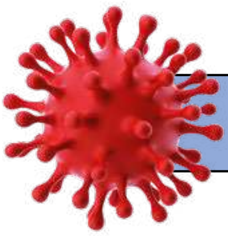
FINDING THE CHINK IN CORONA'S ARMOUR



Experiments at the European XFEL reveal how the main protease of SARS-CoV-2 protects itself from oxidative damage

The COVID-19 pandemic resulted in millions of deaths. Despite an unparalleled collaborative research effort that led to effective vaccines and therapies being produced in record-breaking time, 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 add key knowledge to our understanding of the workings of SARS-CoV-2 and open up new questions in the field of viral biology.

Between January 2020 and March 2023, over six million people died as a result of the respiratory disease COVID-19, and several hundred million were infected. The disease is caused by SARS-CoV-2, a coronavirus. "Coronaviruses are a group of RNA viruses that cause illnesses and diseases in mammals and birds", explains European XFEL scientist Richard Bean. "However, despite their significant relevance for global human health, there is still a lot to learn about the structure and function of coronaviruses in general and SARS-CoV-2 in particular."

In response to the outbreak of the pandemic, scientists and scientific organizations around the globe poured efforts into studying the structure, dynamics, and function of SARS-CoV-2 in search of vaccines and therapies. Due to its central role in the replication cycle of the virus, the main protease—an enzyme that liberates newly made pieces of the virus from one another—soon emerged as a key antiviral drug target. The main protease, or M^{pro}, is particularly attractive for drug development because it plays a central role in viral replication and also because it is quite different from all human proteins. This allows therapies to specifically target the virus while minimizing side effects that might harm patients. Previous drug discovery programmes targeting other viruses have succeeded using viral protease inhibitors, making a successful outcome in the case of SARS-CoV-2 more likely. "While the height of the COVID-19 pandemic may have passed, there is still a lot of value in studying the SARS-CoV-2 virus", adds Thomas Lane from the Center for Free-Electron Laser Science (CFEL) in Hamburg. "COVID continues to present a significant health threat worldwide. Given the persistence of this virus and the possible emergence of future pathogenic coronaviruses, it is imperative that we develop a deeper understanding of M^{pro} and its role in viral function."

In a recent experiment at the SPB / SFX instrument of the European XFEL, Lane and colleagues used the intense X-ray beam to study M^{pro}. Several previous structural studies focusing on M^{pro} have highlighted a number of peculiarities. "Firstly, the protein forms a 3D structure known as a dimer when it is found in high concentrations", explains European XFEL scientist Robin Schubert, who was involved in the experiment. "This structural habit seems to directly influence its activity—but we don't know precisely why this is important for the virus."

Alongside key insights into the 3D structure, recent studies have also hinted at the importance of cellular oxygen levels for protease activity.

"It seems that even mild exposure to oxygen decreases M^{pro}'s activity", explains Patrick Reinke, also from CFEL. Indeed, in the presence of sufficient oxygen, turnover ceases altogether. But this process is reversible—if the oxygen is removed, the enzyme reactivates itself, suggesting the system has evolved protective mechanisms to survive in an oxidative environment. "Oxidative stress has been shown to regulate the function of other viruses, such as HIV", Reinke adds. "It has been suggested that structural changes in the protease let it escape oxidative

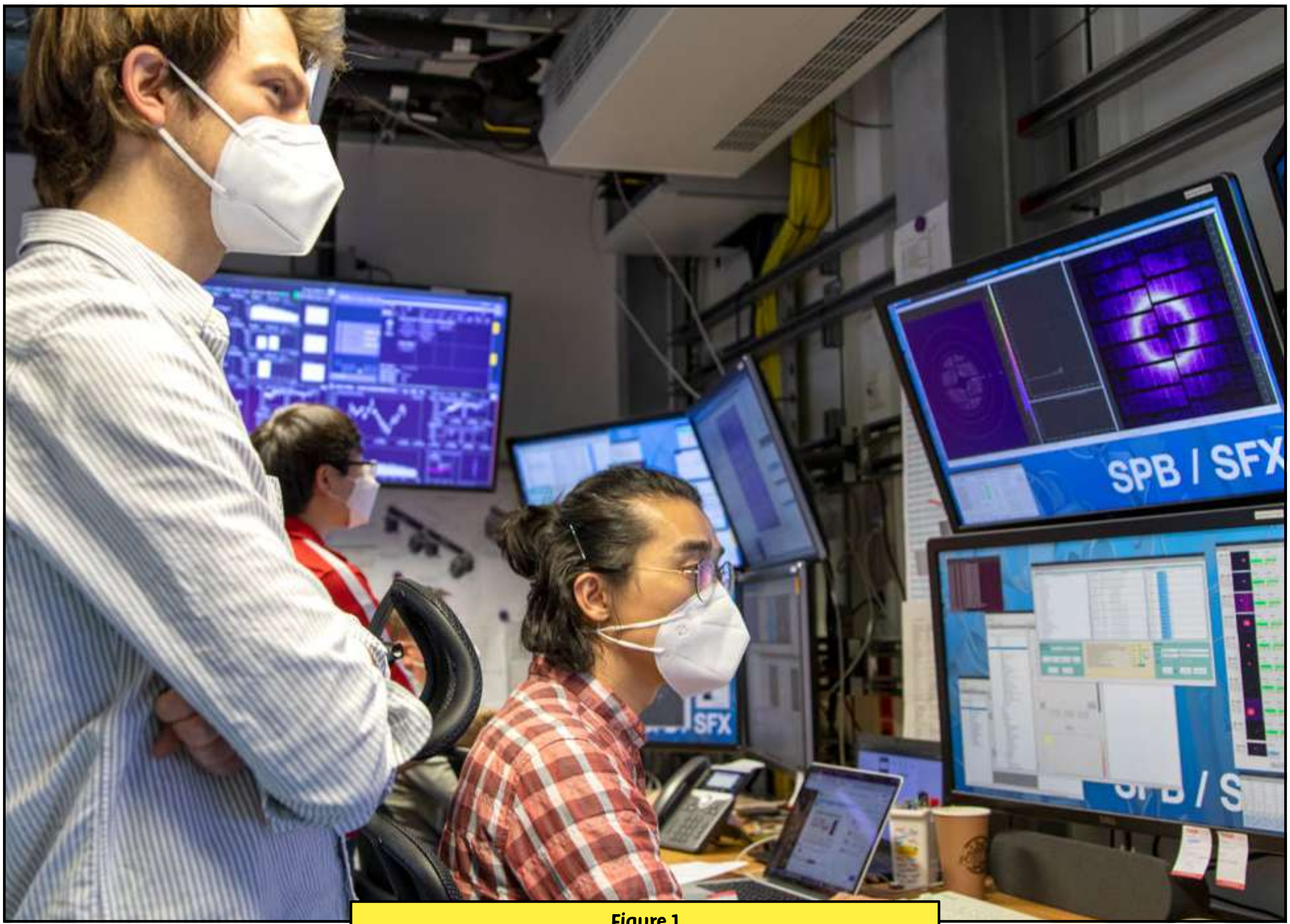


Figure 1
The team of researchers in the control room of the SPB/SFX instrument during the experiment

damage in oxygen-rich environments. However, we're still unsure of how these protective mechanisms impact viral fitness."

To better understand how structural changes protect the protein from oxygen damage, the team used the European XFEL's powerful X-ray beam to reveal the structure of M^{pro} after it had been exposed to oxygen. They discovered a structural rearrangement of M^{pro} in which a bond forms between two cysteine residues: the active site cysteine C145 and a distal cysteine C117. To accomplish this, the team produced large amounts of M^{pro} over the course of several months in the biolabs at European XFEL and turned it into microcrystals, some of which were grown in the presence of oxygen. Finally, the microcrystals were sent flying in front of the European XFEL beam at the SPB/SFX instrument using a liquid jet. Such small crystals are impossible to study using traditional light sources because the amount of radiation needed to generate enough data from the crystals would destroy them. The X-ray pulses produced by the European XFEL, however, are so powerful and short that they can be used to capture an image of the protein crystal before it has time to disintegrate.

"Our results show that the active site cysteine, which conducts the enzyme's chemistry, can sneakily hide itself from oxidative damage", says Schubert. Typically, oxidation can irreversibly damage cysteines. Upon oxidation, however, M^{pro} protects its most important cysteine by forming what is known as a "disulfide bond", which buries it in the core of the protein structure. Then, if moved back into a safe, low-oxygen environment, the disulfide bond can break, revealing the active cysteine, which resumes its original function. "The experiments performed at the European XFEL reveal a picture of the protein in its hidden disulfide state, confirming it exists and uncovering how it works", says Schubert.

"M^{pro} exhibits an unusually rich set of oxidation modifications, and our experiment adds a key piece to that story", says Lane. The scientists are excited about what their data indicate and about their next steps. "M^{pro} is a linchpin of coronavirus biology and the premier target for anti-COVID-19 small-molecule therapeutics", Lane adds. "The enzyme's function has been shown to be regulated via both dimerization and oxidation, and it's clear that these regulatory mechanisms are biophysically correlated. While our structures provide mechanistic insight into these

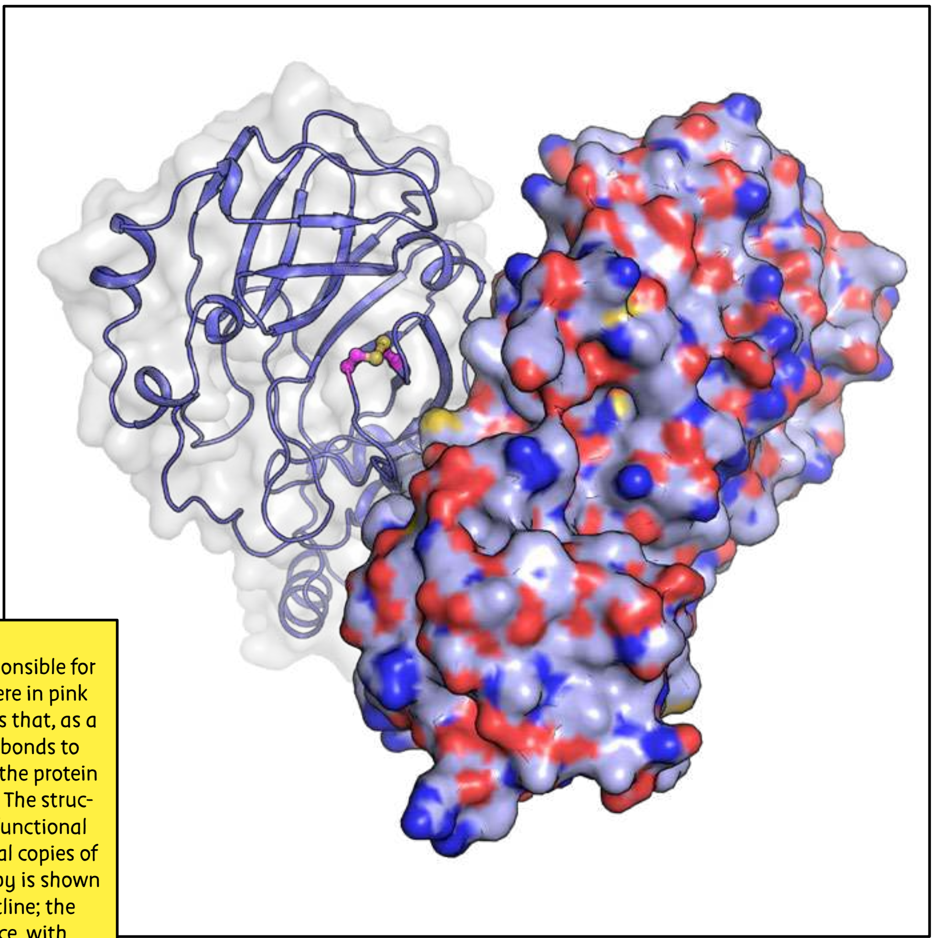


Figure 2
M^{pro} has an active cysteine that is responsible for the enzyme's function, highlighted here in pink and yellow. The crystal structure shows that, as a response to oxygen, this key residue bonds to another cysteine and buries itself into the protein structure, escaping oxidative damage. The structure highlights the fact that a single functional unit of M^{pro} is formed from two identical copies of the protein, known as a dimer. One copy is shown as a ribbon diagram, with a grey outline; the other is shown as a solid blue surface, with surface oxygen (red), nitrogen (dark blue), and sulfur (yellow).

properties of M^{pro}, we must now understand how regulation based on oxidative stress or protein concentration impact viral fitness. This will provide deeper insight into viral biology and hopefully open new opportunities to disrupt that biology with life-preserving medicines."

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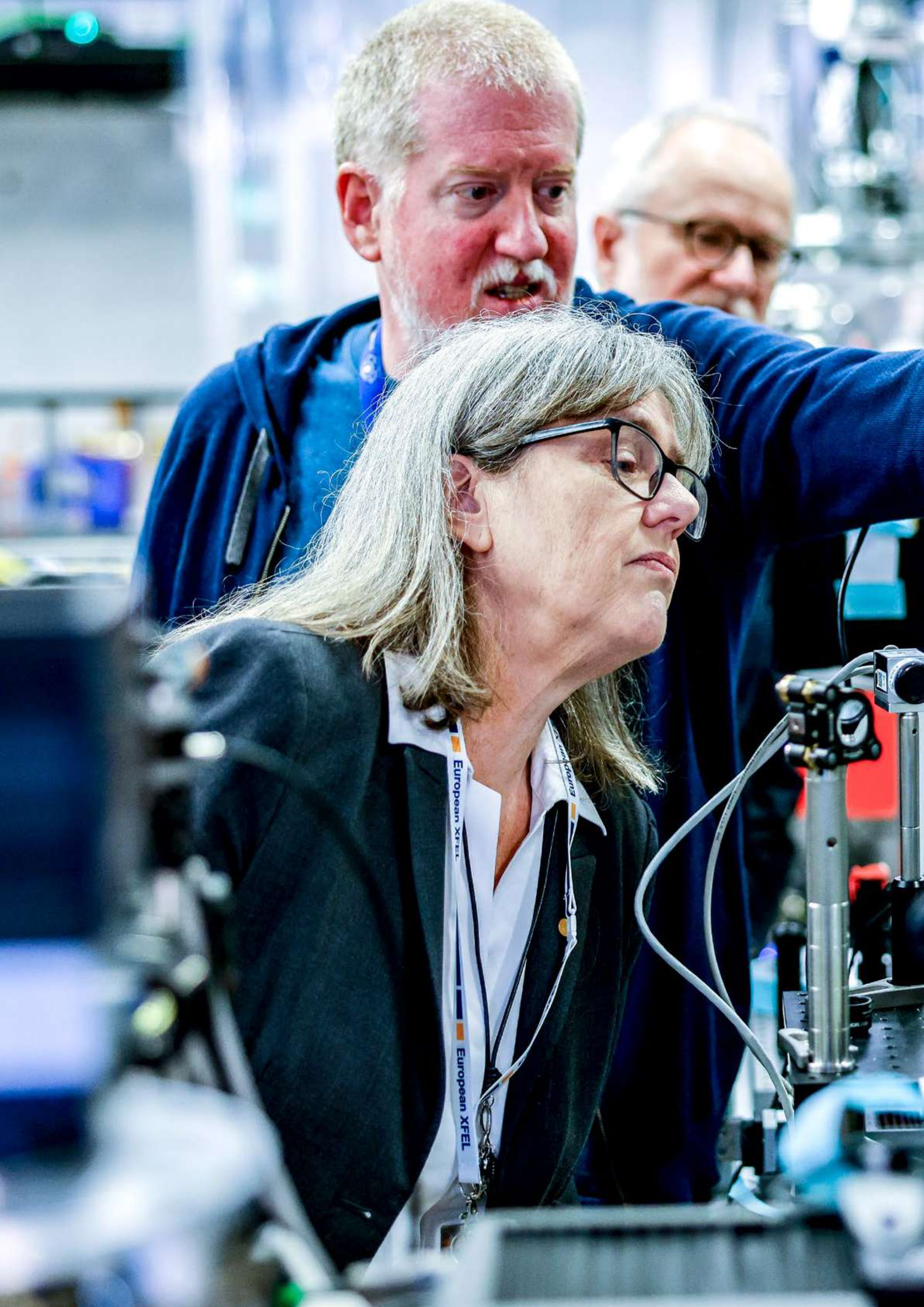
European XFEL
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NEWS AND EVENTS

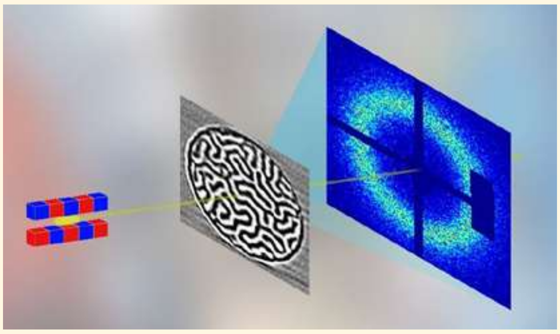
Nobel Prize winner Donna Strickland at European XFEL

NEWS AND EVENTS

16 January

New simulation tool advances superfast electronics

In a joint project, European XFEL and the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) developed a new simulation tool, taking an important step towards superfast electronics. A theoretical model called XSPIN makes it possible to simulate demagnetization in multilayered ferromagnetic materials exposed to femtosecond X-ray laser pulses. Understanding these processes could open the door to a new world of ultrafast nanoelectronics, better digital devices, and improved computer memory.



An X-ray pulse hits a sample of magnetic material, scatters, and forms a diffraction ring.

Construction of “Lighthouse” visitor centre starts

Construction began on the European XFEL “Lighthouse” visitor and conference centre, expected to open in 2024. The facility will house interactive exhibits on the applications of the X-ray laser, including a permanent exhibition, a virtual-reality area, student laboratories, and conference spaces. “Lighthouse” aims to enhance the public understanding of research at European XFEL and contribute to education in the fields of science, technology, engineering, and mathematics (STEM).

European XFEL Managing Director Nicole Elleuche, BMBF State Secretary Mario Brandenburg, and Schenefeld Mayor Christiane Küchenhof

18 January

New spectrometer for soft X-ray and XUV light

A new spectrometer at the European XFEL SQS instrument measures soft X-ray and extreme-ultraviolet (XUV) radiation generated by gaseous samples after interaction with the intense X-ray laser pulses. The spectrometer was built by a collaboration involving scientists from European XFEL and Uppsala University in Sweden. It will allow scientists at SQS to study fundamental processes in the interaction of X-rays with matter.

New XUV spectrometer at the SQS instrument

23 January

European XFEL and DESY Users' Meeting kicks off

The European XFEL Users' Meeting, held jointly with the DESY Photon Science Users' Meeting, welcomed over 1100 scientists. The programme included scientific highlights from the European XFEL instruments as well as developments in instrument design and the commissioning of the new SXP instrument.

Attendees of the joint European XFEL and DESY Photon Science Users' Meeting 2023

30 January

Elke de Zitter wins Young Scientist Award

Elke de Zitter from the Institut de Biologie Structurale (IBS) in Grenoble, France, was awarded the European XFEL Young Scientist Award 2023 at the European XFEL and DESY Photon Science Users' Meeting. Her research focuses on processing serial crystallography data, and she is interested in mosquitocidal proteins, which target and kill mosquitos. She has also worked on developing a piece of software known as Xtrapol8, which can extract protein structures from European XFEL data.

Elke de Zitter (left) receives the Young Scientist Award from Andrea Eschenlohr, Chair of the European XFEL User Organization.

10 February

Nobel Prize winner Donna Strickland visits European XFEL

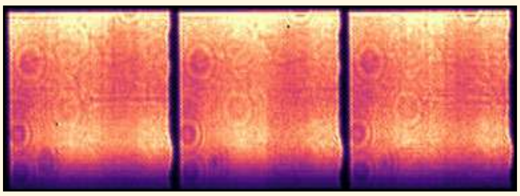
Donna Strickland, winner of the 2018 Nobel Prize in Physics, visited European XFEL. After a discussion with the European XFEL management and scientists, a guided tour, and a lecture about her prize-winning research, she met with European XFEL Ph.D. students.

Donna Strickland signing the guest book.

21 February

Unveiling details in the physics of materials

Scientists at the European XFEL SCS instrument implemented a new sampling scheme for improving the efficiency of measurements made using a technique called transient X-ray absorption spectroscopy. The scheme, which involves splitting the pulses from the European XFEL into three copies, can reveal the finest details of the sample under investigation, significantly improving the sensitivity of the technique compared with conventional synchrotron results.



Three signals from three separate beams generated by the new method

21 February

Celebrating International Women's Day

In celebration of International Women's Day on 8 March, European XFEL highlighted the work of five women across different branches of the organization. They discussed what their life at European XFEL looks like, shared insights into their roles, and offered advice for those entering their fields of expertise.

Female staff members from different European XFEL groups in the experiment hall

21 April

EU funds HALRIC project for the life sciences

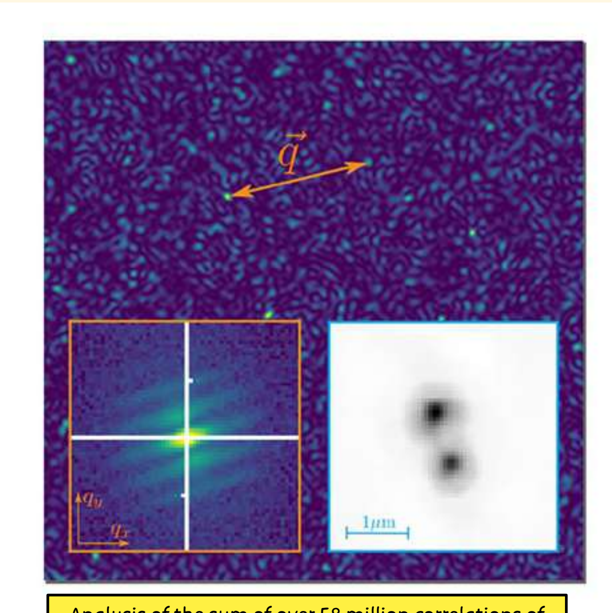
The European Union decided to strengthen cooperation between Germany and southern Scandinavia through an 11 million euro funding project for the life sciences. The money will be distributed to the Hanseatic Life Science Research Infrastructure Consortium (HALRIC), made up of universities, hospitals, research institutions, business clusters, and regional governments. HALRIC will use research facilities, such as the European XFEL and DESY's PETRA III synchrotron radiation source, to drive new research.

Locations of the HALRIC project partners

25 April

New imaging technique for molecules

Scientists used the European XFEL to generate fluorescence from copper atoms. By measuring two photons from the emitted fluorescence almost simultaneously, they obtained images of the copper atoms. The work could enable the imaging of individual large molecules and lead to high-resolution 3D images of fluorescing structures, with potential applications in various fields, including fusion energy research.



Analysis of the sum of over 58 million correlations of X-ray fluorescence snapshots (left insert) yielded a high-resolution image of the source—two illuminated spots on a spinning copper disk (right insert).

27 April

Girls' and Boys' Day at European XFEL

European XFEL welcomed 32 girls and boys to explore the various work and research areas at the facility. Under the guidance of European XFEL scientists and engineers, the participants gained insights into areas and job profiles at the research facility. The half-day programme provided an opportunity for young people to learn about apprenticeships and courses of study in IT, crafts, science, and technology in which women are underrepresented.

Learning how to program a robot

9 May

European XFEL goes aboard the *MS Wissenschaft*

For five months in 2023, the exhibition ship *MS Wissenschaft* featured an exhibit from European XFEL, which illustrated how extreme states that occur in the interior of planets are created and examined with the X-ray laser. In addition, on 17 June, young researchers from European XFEL explained how such studies are carried out using diamond anvil cells. Experiments like these can help us understand how Earth and other planets are structured and how they were formed. The *MS Wissenschaft* exhibition, commissioned by the German Federal Ministry of Education and Research, was presented at several stops of the ship in Germany and Austria.

Visitors enjoying the European XFEL exhibit aboard the *MS Wissenschaft*

12 May

Serguei Molodtsov honoured by Pavol Jozef Šafárik University

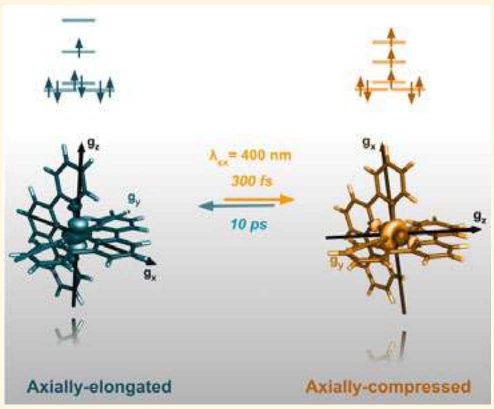
European XFEL Scientific Director Serguei Molodtsov received the Golden Medal of the Faculty of Science from Pavol Jozef Šafárik University in Košice, Slovakia. The medal was awarded for his long-standing engagement and commitment to the Slovak scientific community.

Serguei Molodtsov receiving the Golden Medal of the Faculty of Science of Pavol Jozef Šafárik University

19 May

Molecule-sized magnetic systems controlled with light

Single-ion magnets (SIMs), molecules containing one single metal ion, represent the ultimate size limit for miniaturizing magnetic materials. Scientists at the European XFEL FXE instrument probed the magnetic behaviour of SIMs based on cobalt ions, paving the way for a better understanding of miniature magnets, which have applications for compact and ultrafast information storage systems.



Visualization of a cobalt ion switching its magnetic state by absorbing an optical photon

23 May

European XFEL celebrates German Diversity Day

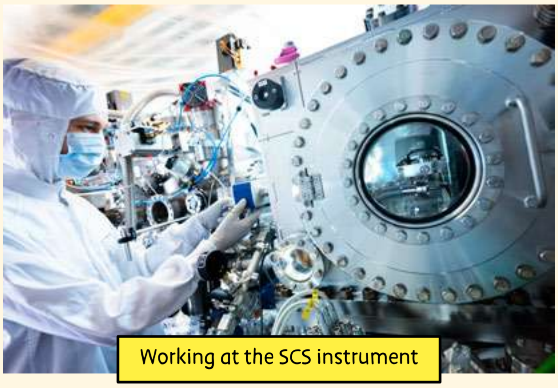
On German Diversity Day, an internal event raised awareness of several aspects of diversity at European XFEL, including culture, geographical origin, religious belief, age, sexual and gender identity, gender equality, and the integration of disabled employees. The celebration featured discussions among staff members on diversity issues, a diversity quiz challenge, and an “International Diverse Cooking Week”.

Pride flag flying on the European XFEL campus

24 May

Studies on metallic nickel reveal magnetic insights

Scientists discovered details about the electronic structure of metallic nickel using time-resolved X-ray absorption spectroscopy at the European XFEL SCS instrument. Their discovery enables a better understanding of the magnetic properties of nickel, a permanent magnet or “ferromagnet”, and can also shed light on how ferromagnetic materials can be manipulated with ultrashort laser pulses. Such insights can help to study other magnetic materials and to develop more efficient magnetic storage devices.



Working at the SCS instrument

25 May

European XFEL campus reopens with self-guided tour

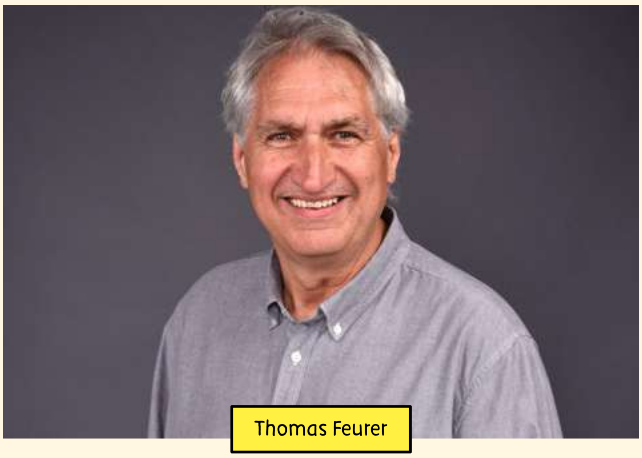
The European XFEL campus, which was temporarily closed to the public due to COVID-19, reopened for external visitors with a new 1.6 km long campus tour along a green line with panels that provide information about the research facility and the renaturation measures on and around the campus. For the first time, a large part of the outdoor area of the premises is now accessible without a guided tour.

Schenefeld Mayor Christiane Küchenhof (left) opens the new campus tour with European XFEL Managing Directors Robert Feidenhans’l and Nicole Elleuche.

13 June

Thomas Feurer appointed Chairman of the Management Board

The European XFEL Council nominated Thomas Feurer, a renowned laser physicist from the University of Bern, Switzerland, as the new Chairman of the European XFEL Management Board. He will take over from Robert Feidenhans’l on 1 January 2024. Feidenhans’l has led the research facility since its inauguration in 2017, and he will work as an advisor to European XFEL until his retirement in July 2024.

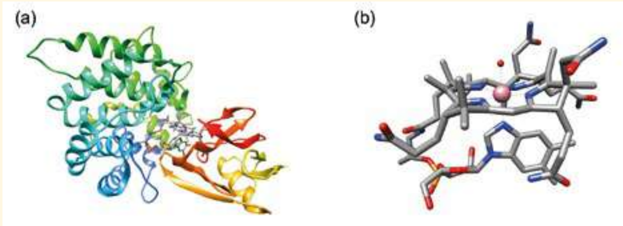


Thomas Feurer

23 June

New technique reveals insights on vitamin B12

A new technique based on the European XFEL's ultrashort X-ray pulses provided insights into two compounds featuring vitamin B12, which is an important compound in many biological systems. The results could enable better insights into a host of biological molecules and help in designing targeted drug therapies.



Visualizations of the structure of two vitamin B12 compounds (a) in reaction with a biological structure and (b) in a water-based environment

5 July

New DiPOLE laser blasts off

The DiPOLE 100-X laser at the European XFEL HED instrument was used for its first user experiment, which involved more than 100 researchers. It delivers ultrapowerful bursts of green light that can transform matter into extreme states, allowing scientists to study the behaviour of matter at high temperatures and pressures. Developed at the Science and Technology Facilities Council's Central Laser Facility (CLF) in the UK in the framework of the HIBEF user consortium, the laser can be used as a "hammer" to create intense shock waves.

Some of the team members of the first DiPOLE experiment

European XFEL assumes presidency of EIROforum

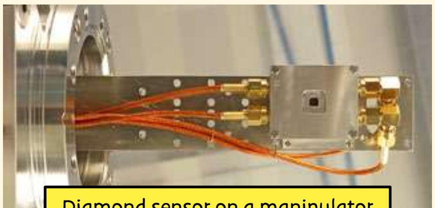
On 1 July, European XFEL assumed the presidency of EIROforum, taking over from the European Space Agency (ESA). EIROforum is an association of eight leading European international research organizations whose aim is to support European science in reaching its full potential. The presidency rotates annually between its members CERN, EMBL, ESA, ESO, ESRF, EUROfusion, European XFEL, and ILL.

EIROforum
serving european science

27 July

Diamond sensor measures position of individual X-ray flashes

Using a special diamond sensor, researchers precisely measured the position of the extremely intense and short X-ray flashes generated by the European XFEL—in a pulse-resolved way at a megahertz rate and with minimal disturbance of the X-ray beam. Such measurements are important to successfully carry out experiments.



Diamond sensor on a manipulator

28 July

Control software Karabo released as open source

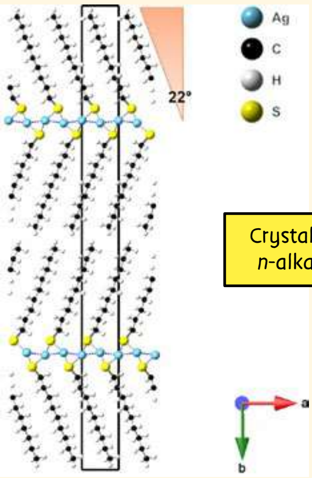
European XFEL released the control software framework Karabo and selected Karabo devices into the public domain as free and open-source software, enabling external developers to use and adapt the code, as needed. The extendable system can be used to control installations that range from single machines to highly complex research facilities, such as the European XFEL.

Current and former Karabo contributors at the open-source release event

16 August

Crystal structures from powders of polymers

Using a technique tailored to the study of small molecules at X-ray lasers, researchers resolved the structure of metal-organic polymers that are difficult to grow into large crystals. The results settle long-standing controversies regarding the atomic connectivity and layer stacking of these compounds, which have attracted interest for their semiconducting properties, light-matter interactions, and catalytic activity.



Crystal structure of *n*-alkanethiolates

1 September

Topping-out of “Lighthouse” visitor centre

European XFEL celebrated the topping-out ceremony of the new “Lighthouse” visitor and conference centre. The building offers space for a 350 m^2 exhibition and a 200 m^2 special exhibition, two student laboratories, and rooms for conferences and events. Among the guests at the ceremony were Schleswig-Holstein Science Minister Karin Prien, Hamburg Science Senator Katharina Fegebank, Director-General of the Department Provision for the Future—Basic Research and Research for Sustainable Development at the German Federal Ministry of Education and Research (BMBF) Stefan Müller, and Schenefeld Mayor Christiane Küchenhof.

Official guests with the topping-out wreath before it was raised to the top of the “Lighthouse” visitor centre

4 September

“Arts & Science” exhibition at European XFEL

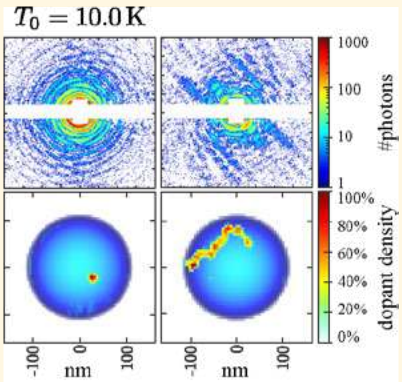
From 30 August to 11 September, the Cluster of Excellence “CUI: Advanced Imaging of Matter” at Universität Hamburg presented the exhibition “Arts & Science” at European XFEL, featuring vibrant images from the microworld. The visualizations were based on images submitted by CUI researchers, with some of them created at European XFEL.

“Arts & Science” exhibition on display at European XFEL

9 September

Helium droplets for studies of nanostructures

Using a conical nozzle at the European XFEL SQS instrument, scientists generated vortex-free droplets of superfluid helium that were big enough to be resolved in X-ray diffraction images, making them ideal for studying the self-assembly of a wide range of nanostructures forming inside a superfluid environment. This capability will enable researchers to systematically explore the self-assembly of dopant materials.



Measured diffraction image (top) and corresponding reconstruction (bottom) of a compact xenon structure (left) and a xenon filament (right) formed inside a superfluid helium droplet

19 September

Charting the quantum land-scape of hollow atoms

At the European XFEL SQS instrument, scientists identified exotic quantum states of heavy atoms missing up to six electrons in their core electron shells. The results promise new insights into extreme light–matter interactions, which could help to improve the imaging of molecules or resolve unexplained observations in astrophysics.

The experiment team (with a few people missing)

20 September

Young scientists receive EUCYS Prizes

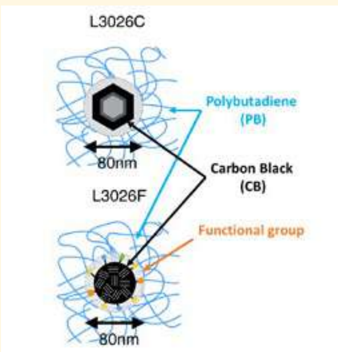
At the European Contest for Young Scientists (EUCYS) in Brussels, Belgium, on 16 September, 12 young scientists were honoured with eight Special Donated Prizes sponsored by EIROforum. They are bestowed upon contestants who—according to the jury—would benefit from the opportunity to spend up to one week at one of the EIROforum member organizations.

Some of the winners of the EIROforum Special Donated Prizes

26 September

Molecular motion in tire rubber

Scientists observed the molecular motion of rubber components typically used in automobile tires—polybutadiene and carbon black—with the world's fastest time resolution. The study revealed the interaction between the two components on the atomic scale, paving the way towards improved diagnostics of tire rubber degradation and the development of materials with enhanced durability.

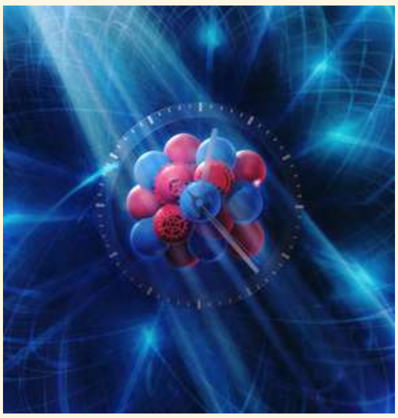


Structure of two different rubber samples

27 September

Milestone for novel atomic clock

Scientists took a decisive step toward a new generation of atomic clocks by creating a precise pulse generator based on the element scandium, which enables an accuracy of one second in 300 billion years—which is about a thousand times more precise than the current standard atomic clock based on caesium.

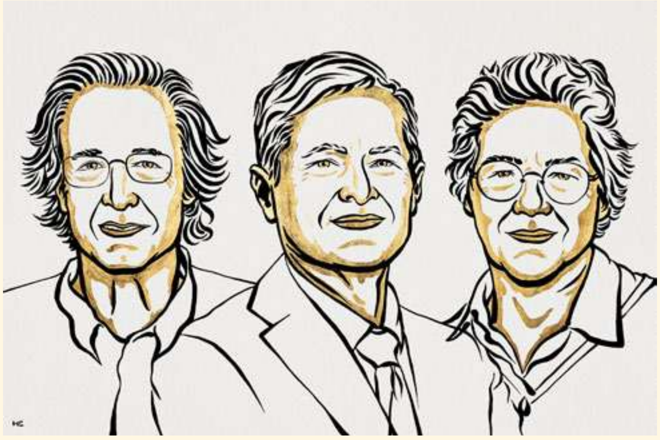


Artist's rendition of the scandium nuclear clock

3 October

Congratulations to Nobel Prize laureates

European XFEL congratulated Pierre Agostini, Ferenc Krausz, and Anne L'Huillier, who received the 2023 Nobel Prize in Physics for the development of experimental methods that generate attosecond pulses of light to study electron dynamics in matter. To help establish the methods for use at the European XFEL, Anne L'Huillier from Lund University in Sweden is a member of the European XFEL Scientific Advisory Committee. At the European XFEL SQS instrument, scientists have already started time-resolved studies with attosecond pulses stimulated by the work of the laureates.

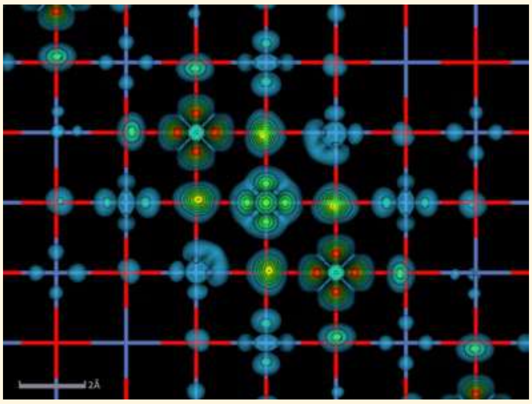


Pierre Agostini, Ferenc Krausz, and Anne L'Huillier

9 October

Transition metal insulators: the origin of colour

In a theoretical study, researchers explained the vibrant colours of two compounds whose electronic properties seemingly prohibit such colouring. The hues exhibited by the two insulators nickel(II) oxide (NiO) and manganese(II) fluoride (MnF_2) originate from transitions in the spins of the electrons, which modify the way the materials absorb and reflect light in such a way as to create the bright colours. The theoretical framework employed by the team promises new insights in fields such as opto-electronics or in the study of qubits, the quantum bits used in quantum computers.

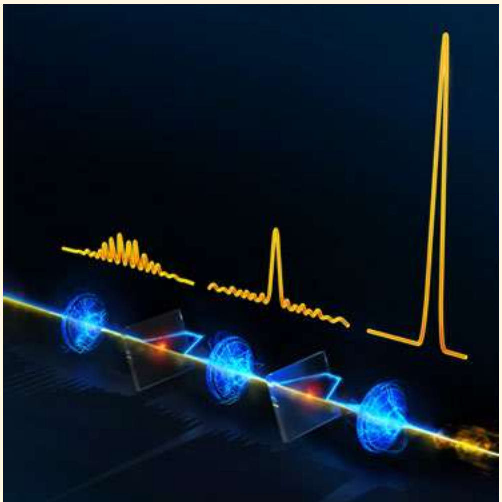


Visualization of the orbital character of low-laying excitons in NiO, corresponding to a weakly bound, bright "Wannier–Mott" exciton at an energy of 3.6 eV

17 October

Cascaded setup generates bright X-ray pulses

Scientists at European XFEL and DESY demonstrated a device to significantly increase the amount of X-rays with sharply defined wavelengths generated by an X-ray laser at high repetition rates. The novel cascaded setup opens up new experimental possibilities in a wide range of scientific fields employing ultrafast X-ray spectroscopy, scattering, and imaging techniques.



Artist's view of the HXRSS system installed at the European XFEL

23 October

Visit by Italian shareholder delegation

European XFEL welcomed a shareholder delegation led by Maria Chiara Carrozza, President of Italy's National Research Council (CNR) and former Science Minister, and Pierluigi Campana, member of the Executive Board of the National Institute for Nuclear Physics (INFN). CNR and INFN are the two Italian shareholders of European XFEL. They were also represented by Stefano Fabris, Head of the Physics Department of CNR and a newly appointed delegate of the European XFEL Council, and Daniele Sertore from INFN, also a member of the Council delegation.

Italian shareholder delegation, with Maria Chiara Carrozza, President of CNR, Pierluigi Campana, member of the INFN Executive Board, and the European XFEL Management Board and staff members

14 November

Minister Claus Ruhe Madsen visits European XFEL

Schleswig-Holstein Minister of Economic Affairs, Transport, Employment, Technology, and Tourism Claus Ruhe Madsen visited European XFEL and familiarized himself with the fields of work, current developments, and plans for the coming years at the facility. Together with European XFEL Managing Director Robert Feidenhans'l, he then toured the underground experiment hall.

Scientist Diana Bregenholt Jakobsen (right) explains the FXE instrument to Claus Ruhe Madsen (left) and Robert Feidenhans'l (centre).

18 November

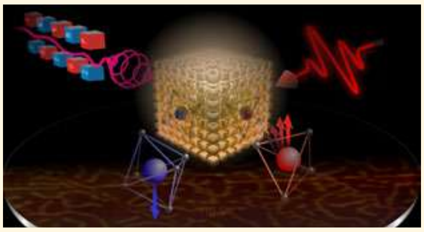
LGBTQ+ STEM Day 2023

On the International Day of LGBTQ+ People in Science, Technology, Engineering, and Maths (LGBTQ+ STEM Day), European XFEL reaffirmed its dedication to cultivating an inclusive and diverse workplace.

22 November

Mechanism of light-driven magnetization switching revealed

Switching the magnetization of materials with light instead of magnetic fields—for example in hard drives used for data storage—promises to significantly accelerate data writing speed. At the European XFEL SCS instrument, scientists explored the microscopic mechanism behind magnetization switching triggered by an ultrashort near-infrared laser pulse and elucidated the switching dynamics on the atomic level. The results confirm a novel and effective optical switching mechanism, which could be used to provide ultrafast magnetization control in a wide variety of materials.

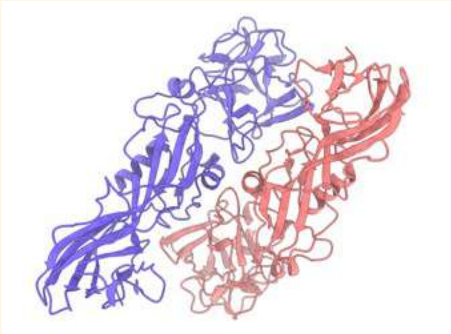


Principle of the experiment: An ultrashort near-infrared laser pulse (top right) triggers magnetization changes in the sample (centre), which are then analysed using the European XFEL X-ray pulses (top left).

29 November

Structure of a natural insecticide uncovered

Researchers analysed a naturally produced toxin against insects with atomic precision. The data taken at the European XFEL help to elucidate the mode of action of the insecticide, which is produced by a bacterium. This information could potentially lead to the development of customized variations of the insecticide that are more effective against harmful insects, such as disease-transmitting mosquitoes.



Structure of the natural insecticide protein Tpp49Aa1

19 December

European XFEL launches first educational material for schools

European XFEL published a comprehensive set of Open Educational Resources (OER) on virus research aimed at senior high school students. The material, developed as part of an initiative funded by the Joachim Herz Foundation, comprises four distinct modules that cover various facets of virus research. The educational resources are freely accessible as OER under a Creative Commons license.

Students experimenting in the biological laboratory of European XFEL

New videos on cutting-edge experiments

European XFEL released a new series of videos in which scientists present their experiments at the facility. For example, the videos offer a glimpse into the first extreme-ultraviolet spectrometer experiment, provide insights into “phase transitions in amorphous solids”, and dive into the complexities of “probing the aurophilicity and solvation dynamics in stimuli-responsive dimer complexes” at the FXE instrument. The series is available on the European XFEL YouTube channel.

Jan-Eric B. I. Rubensson from Uppsala University in Sweden explaining research at the SQS instrument


European
XFEL

MAGAZINE

In the SCS control hutch


Total FEL output power
X-ray delivery
FEL
SASE 1
SASE 2
SASE 3
Photon Pulse Energy History
Beamview

STRATEGIC DIRECTIONS FOR A NEW ERA

In January 2024, outgoing chairman of the European XFEL Management Board Robert Feidenhans'l passed the baton to incoming chairman Thomas Feurer. The year also marked the publication of the "European XFEL Strategy 2030: Strategic Directions" brochure, which documented a concept Robert Feidenhans'l had spent the last few years bringing together, and the beginning of the implementation of the goals of the strategy, a task that Thomas Feurer is now overseeing as he starts his new role. But what does the new strategy mean for European XFEL and the wider scientific community? Rosemary Wilson asked the two chairmen.

Why do we need a new strategy now?

RF: European XFEL was inaugurated in 2017. We then immediately began with user experiments. Through these first experiments, we learned how to use this unique facility and put it through its paces. Over the past few years, we have worked our way up to full capacity and developed novel methods and processes to make use of the European XFEL's unique set of parameters. We have built and extended our instrumentation and teams. Now, we are beginning to do experiments that look far beyond proof-of-concept studies and developing methodology. So, we need another concept and strategy of how we want to work together and toward what goals.

TF: While the European XFEL may be considered a relatively young facility and a frontrunner among other XFELs in terms of its capabilities, we must remain vigilant, as our competitors are not dormant. XFELs are emerging and evolving worldwide. Therefore, we must consistently advance our technology to retain our position at the forefront of the XFEL domain. This necessitates strategic planning and a clear vision of our objectives. As the Red Queen in Alice in Wonderland remarks, "It takes all the running you can do to keep in the same place."

What are the key phases of the strategy?

RF: We are currently in what we've termed the harvesting phase. After carefully characterizing the capabilities of the European XFEL and our scientific instruments, we are now moving from proof-of-concept experiments to science-driven experiments. During this phase, we are enabling experiments that exploit the full potential of the facility and that raise the visibility of XFEL research and of what it can contribute to finding solutions to global societal challenges, such as the climate crisis and the need for new data technologies.

TF: In addition to enabling cutting-edge research that explores new scientific frontiers, we must persist in our developmental efforts. Our ongoing mid-term developments are already under way and will extend until a facility upgrade, anticipated to begin in the 2030s. In fact, a part of our mid-term advancements serves as a crucial groundwork for the forthcoming upgrade, guiding our developmental pathways for years to come.

Can you give us examples of the types of development activities planned for the coming years?

TF: As we transition into an era dominated by increasingly massive datasets, leveraging the capabilities of data science becomes paramount. This is essential for diving into intricate scientific phenomena, many of which hold significant implications for the pressing societal challenges of our time. To enhance the data science prowess of the European XFEL, we will make strategic investments in robust data infrastructure and analytics platforms. These investments will bolster data-driven decision-making within our control rooms and ease collaboration among international user communities. Additionally, we are committed to offering training and development initiatives to empower less experienced user teams with the essential skills and knowledge in data science and analytics.

RF: Other activities will include establishing a development programme for the next generation of detectors. The detectors currently in use at the European XFEL are state-of-the-art, designed and built for the purpose of capturing an extremely high number of detailed images in a very short timeframe. But these detectors will need to be replaced at some point, and, as our facility expands, we will need more detectors that fully exploit the technical parameters of the X-ray beam and optics. In addition, a new generation of detectors will have to cope with even more extreme and precise X-ray parameters. A detector programme of this magnitude requires dedicated resources, time, and expert management to deliver excellent instrumentation.

TF: Numerous other areas demand resources and expertise, necessitating collaboration across our facility and user community. Substantial progress has already been achieved in fostering the field of attosecond science, and we are eager to see its continued advancement.

How will European XFEL contribute to finding solutions to global challenges?

RF: When discussing future strategic directions, we identified five areas in which we believe European XFEL and our instruments' unique capabilities can really make a difference. These areas are health, climate and energy, environment and sustainability, digitalization, and fundamental science. For example, European XFEL can make it possible for researchers to investigate how pathogens and medication interact with our bodies, leading to more effective treatments, and we can explore the details of natural processes, such as photosynthesis, which we might use to design much-needed renewable non-toxic energy sources that mimic these processes.

TF: It is evident that fundamental science lies at the core of our mission at European XFEL. Without it, the pathways toward contributions to overcoming societal challenges —for instance discovering new drugs or developing novel materials—would be impeded.

What will happen during the facility upgrade in the 2030s?

TF: Although the facility upgrade is still quite far away, certain components of the upgrade have already been identified. These include redesigning the facility's floor plan, utilizing currently unused tunnels for new beamlines, and constructing additional scientific instruments. These enhancements will expand our capacity to conduct experiments concurrently. Although this expansion will present challenges and necessitate adjustments to the user programme to ensure optimal performance across all instruments, it will enable us to accommodate a broader spectrum of experiments, allowing us to serve more users simultaneously, a prospect that is both exhilarating and promising.

RF: Other aspects that will also be important to consider are the development and upgrade of the accelerator together with our colleagues at DESY as well as laser development. There will be extensive discussions with our stakeholders and scientific community in the months and years to come in order to identify requirements and how we might meet them.

Figure 1
Robert Feidenhans'l handing over the "European XFEL Strategy 2030: Strategic Directions" brochure to Thomas Feurer during the strategy information event

Figure 2
During the strategy information event, European XFEL staff members had the opportunity to learn more about the strategy and to discuss it.

ENVIRONMENT AND SUSTAINABILITY

Society can only be sustainable by preserving natural environments. The subjects of our environmental research range from sustainable agriculture through natural pesticides to understanding Earth processes that are relevant to earthquakes or new ways of purifying water.

DIGITALIZATION

Digital technologies play a crucial role in ensuring that Europe remains at the forefront of technological development. However, computer chips are reaching limits of size and speed. Our research into magnetic materials helps develop smaller and more energy-efficient data storage media.

These developments and upgrades will likely require a lot of energy and resources. What plans do you have to ensure the facility's environmental footprint is kept as small as possible?

RF: Sustainability is a theme that transcends all areas of our work, from travel policies to building plans. This is crucial and something we take very seriously. Every decision, investment, and change we make must take sustainability into account. As a next step, we will calculate the environmental footprint of the facility. From there, we can begin to draw up a solid action plan about where to make improvements.

TF: We will prioritize specific metrics to address our environmental impact, including energy efficiency, emissions, and waste management. However, addressing these challenges requires collaboration. European XFEL is integrated into its surroundings, and we will collaborate closely with local partners, like DESY in Hamburg and stakeholders in the town of Schenefeld, to identify collective initiatives and projects. Working together is imperative for safeguarding the future of our planet.

And what about the staff at European XFEL? How will this affect them?

RF: We cannot expect to reach our scientific goals without investing in our staff members and work environment. There will be changes in terms of management and administrative processes to ensure that work can be done more collaboratively, transparently, and effectively, and that staff members have the resources and training they need to reach our ambitious goals. New career opportuni-

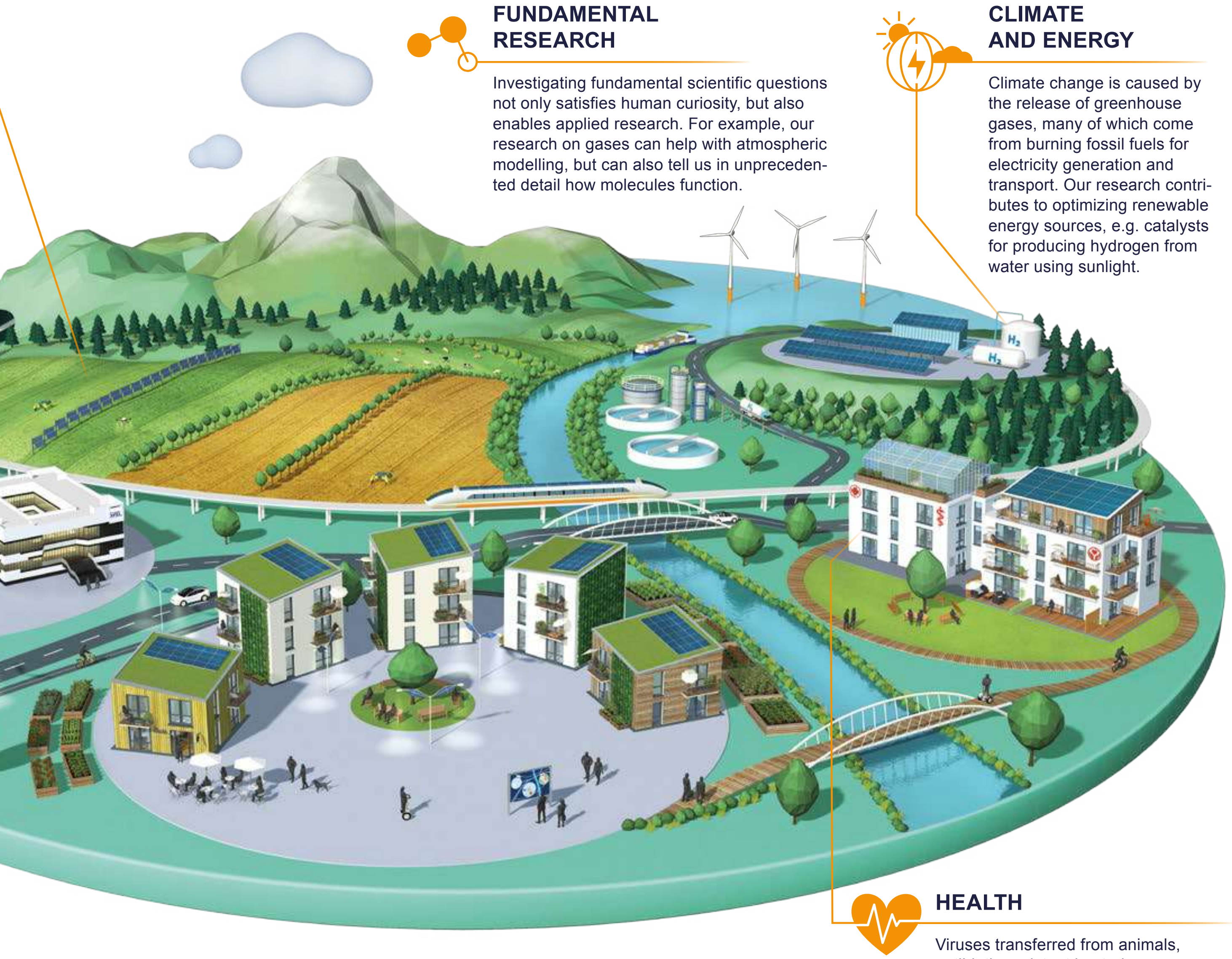


Figure 3
Societal challenges in which contributions by European XFEL have already been identified

ties have been created, and in-house science programmes have been developed that complement the user programme. These changes are also closely aligned to our company's values and vision.

TF: Each staff member of European XFEL plays a crucial role in our current success and in contributing to our position as a leading institution in XFEL science. We firmly believe in fostering a positive and supportive work environment in which every individual feels safe and motivated to excel in their roles. We are dedicated to realizing this vision through ongoing efforts and initiatives.

FACTSHEET

ELECTRON AND X-RAY BEAMS

7
Instruments

27 000
Number of electron bunches per second

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

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

40 W
Highest XFEL beam power

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

11 nm
Smallest focus of the X-ray beam

3
SASE undulators running in parallel

0.04 nm
Minimum wavelength of the X-ray flashes (30 keV)

USERS

89
User experiments

8640 h
X-ray delivery to users

1225
Individual users from 30 countries

249
Ph.D. students among individual users

GUEST HOUSE

5625
Total room nights

4231
Users, nights

4.8
Average length of stay, nights

DATA

30.7 PB
Raw data collected in 2023

111 PB
Accumulation of raw data since the start of user operation in 2017

1 800 000 h
Time used on the computing cluster primarily for data analysis

FOOD AND DRINKS IN BEAMSTOP

42 443
Sold meals

8064 kg
Used fruits and vegetables

3323
Sold Franzbrötchen

28 100 cups
Consumed coffee

1.7 t
More than 8600 pieces of free apples and pears for staff

STAFF

580
Total headcount including guests from 63 countries

21
Ph.D. students

29.7 %
Proportion of women in total staff

OPERATIONS

SQS control room during a user experiment


SQS
Small Quantum Systems
COMO motion
REMI + COMO overview
SQS instrument
Quantum Systems

OPERATIONS

In 2023, the European XFEL accelerator complex was in reliable and stable operation. The superconducting accelerator and its handling have matured greatly. It now delivers electrons with energies up to 17.5 GeV to serve ever-varying operational needs.

Last year, 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 7000 h, of which about 4500 h were spent on X-ray delivery to the experiments (Figures 1–3). The availability of the facility was excellent—93.9% averaged over all the undulators—but slightly below the target of 95%. The main reason was once again sporadic failures of bearings in the cold compressors of the cryogenic plant. The successful test operation of a new motor type with active magnetic bearings throughout 2023, combined with the prospect of exchanging the remaining three motors with this new type in summer 2024, gives reason to hope that the availability can be further improved.

X-ray delivery was performed with electron energies of 11.3–16.3 GeV, delivering photon energies of 400 eV–24 keV to the experiments. Self-seeding was requested about 50% of the time at the SASE2 undulator, but could not be offered towards the end of the year because of a damaged self-seeding monochromator. The robustness of this setup will be improved in the future.

In 2023, several weeks of operation at a repetition rate of 4.5 MHz were offered and could be used by a few experiments. Overall, the ratio between potentially available pulses and actually used pulses was on average below 20% over all runs.

X-ray operations in 2023 were supported through various measures. The experiment hall crew started to supply shift work, which was much appreciated by the instrument groups. Due to the staffing situation, 24/7 service could not be offered yet. Instead, it was aimed to provide presence during the day, late shifts on weekdays, and at least one shift during weekends. The storage of consumables inside the experiment hall, which is managed by the hall crew and facilitates fast access to these materials, was further increased by integrating consumables and parts supplied by the instrument groups.

Operation is supported on a day-to-day basis by the Development and Operations Division, involving both the Instrumentation Department and the Data Department through the Photon Run Coordinators (PRCs), the Data Run Coordinators (DRCs), and the Data Operation Centre (DOC) shift crew. These roles provide an essential interface to both the operating staff in the accelerator control room at DESY and the instrument staff in the experiment hutches. These operation support functions enable efficient and streamlined communication, technical problem solving, and coordination of any operational changes or interruptions. In 2023, the PRC role was filled by 10 persons, covering a total of 42 weeks of facility operation. As part of this role, they received and addressed 258 calls outside normal business hours. The DRC role was filled by 16 persons, covering the entire year (365 days). The DOC was operated for 32 X-ray delivery weeks, thus requiring 768 shifts to maintain the two person, two shift a day scheme. A major role of the DOC is to monitor data acquisition, storage, and access. In 2023, another 31 PB of data were stored, accumulated over the year by the different instruments (Figure 4). In total, European XFEL has accumulated about 111 PB of raw data since the start of operation in 2017.

Aside from X-ray operation, the maintenance periods continued to be very busy, requiring planning and coordination of activities across DESY and European XFEL groups in order to enable the smooth execution of approximately 1300 planned tasks in total during the summer 2023 and winter 2023–2024 maintenance periods.

In 2023, 89 individual experiments were allocated across the seven instruments (Figure 5). This number included protein crystal screening experiments at SPB/SFX, experiments as part of long-term proposals at FXE, MID, and HED, experiments in response to the targeted call for molecular water science, and so-called “community proposals”.

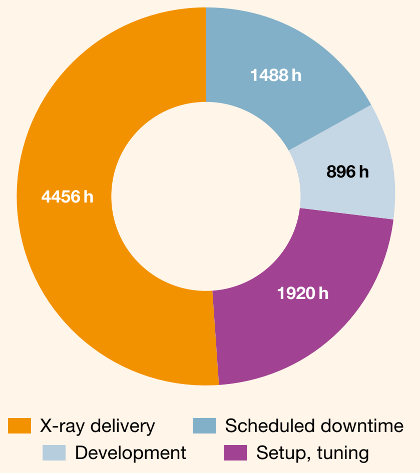


Figure 1
Distribution of yearly operation hours of the European XFEL accelerator in four categories

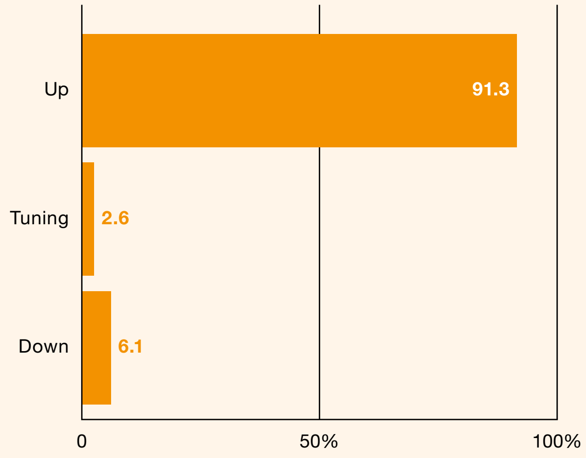


Figure 2
Availability of the accelerator during X-ray delivery in percent

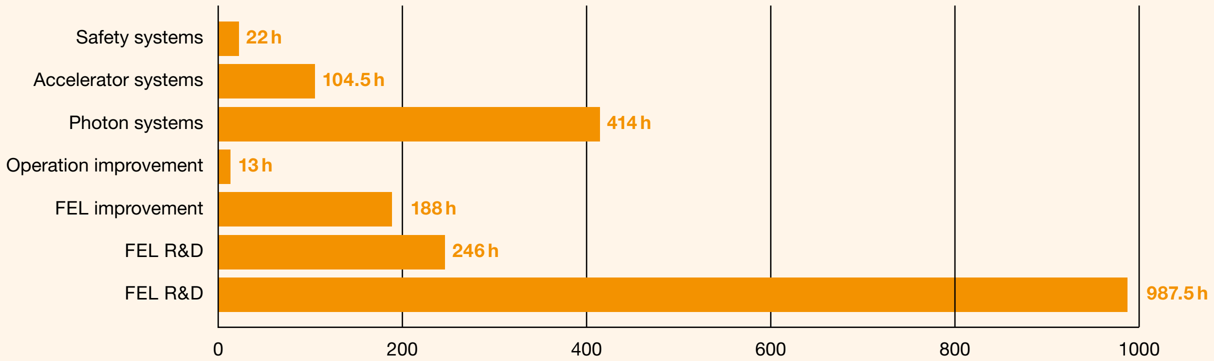


Figure 3
Distribution of development time in hours. The sum of development hours scheduled for various facility development activities exceeds the hours for development indicated in Figure 1, reflecting the parallel use of the facility for multiple activities.

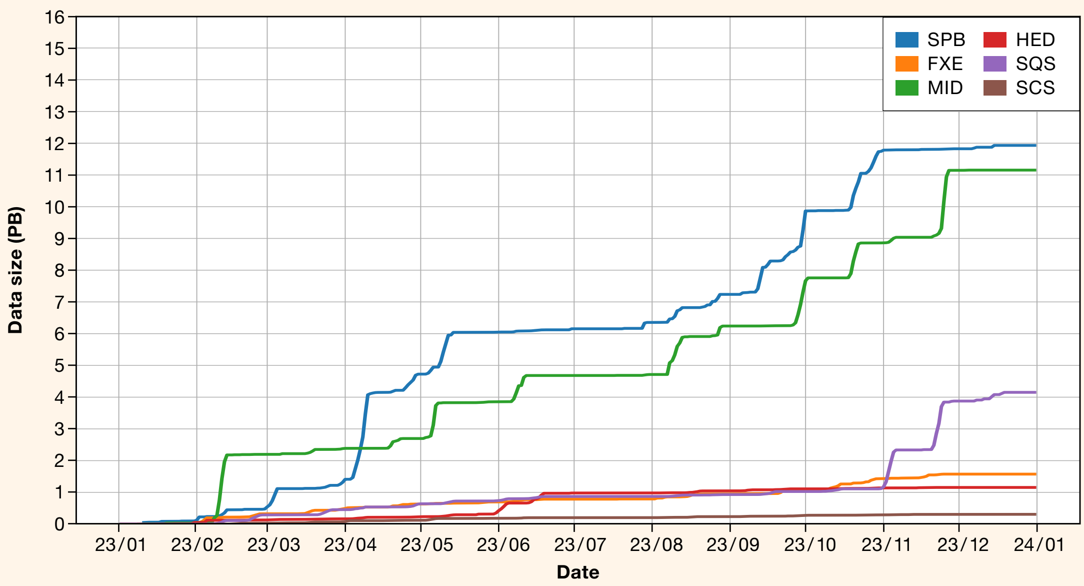


Figure 4
Accumulation of raw data by the scientific instruments in 2023

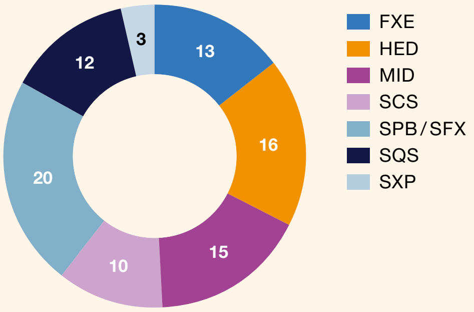


Figure 5
Number of user experiments at the seven instruments in 2023

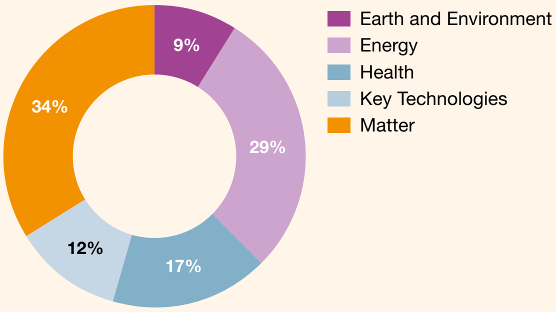


Figure 6
Distribution of users according to societal challenges as identified by European XFEL

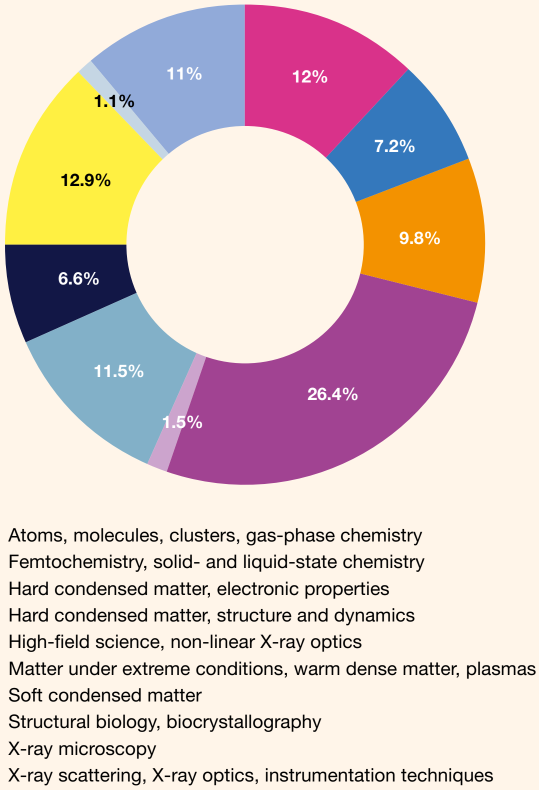


Figure 7
Distribution of users according to major scientific areas

A total of 8640 h of X-ray delivery beamtime, corresponding to 1080 shifts, was allocated to these 89 experiments, close to an average of 97 h per experiment. In some cases, this time included the preparation of the instrument for the corresponding user experiment. The experiments contributed to different societal challenges, as indicated in Figure 6, and can be assigned to major scientific areas, as indicated in Figure 7. From 2024 on, European XFEL will use a modified set of societal challenges, as defined by its Strategy 2030 process.

A total of 1225 individual users contributed to a total of 2018 user visits, including both onsite presence and remote access to the facility (Figure 8).

In 2023, European XFEL issued two new calls for proposals for experiments to be carried out at the facility in 2024. The possibility to propose protein crystal screening experiments at SPB/SFX was offered in both calls. The overall outcome of the two calls was very successful, and it is expected that European XFEL will again be faced with significant oversubscription rates. For those calls leading to beamtime allocation in 2023, the ratio of submitted to scheduled experiment proposals was averaging about 3.5.

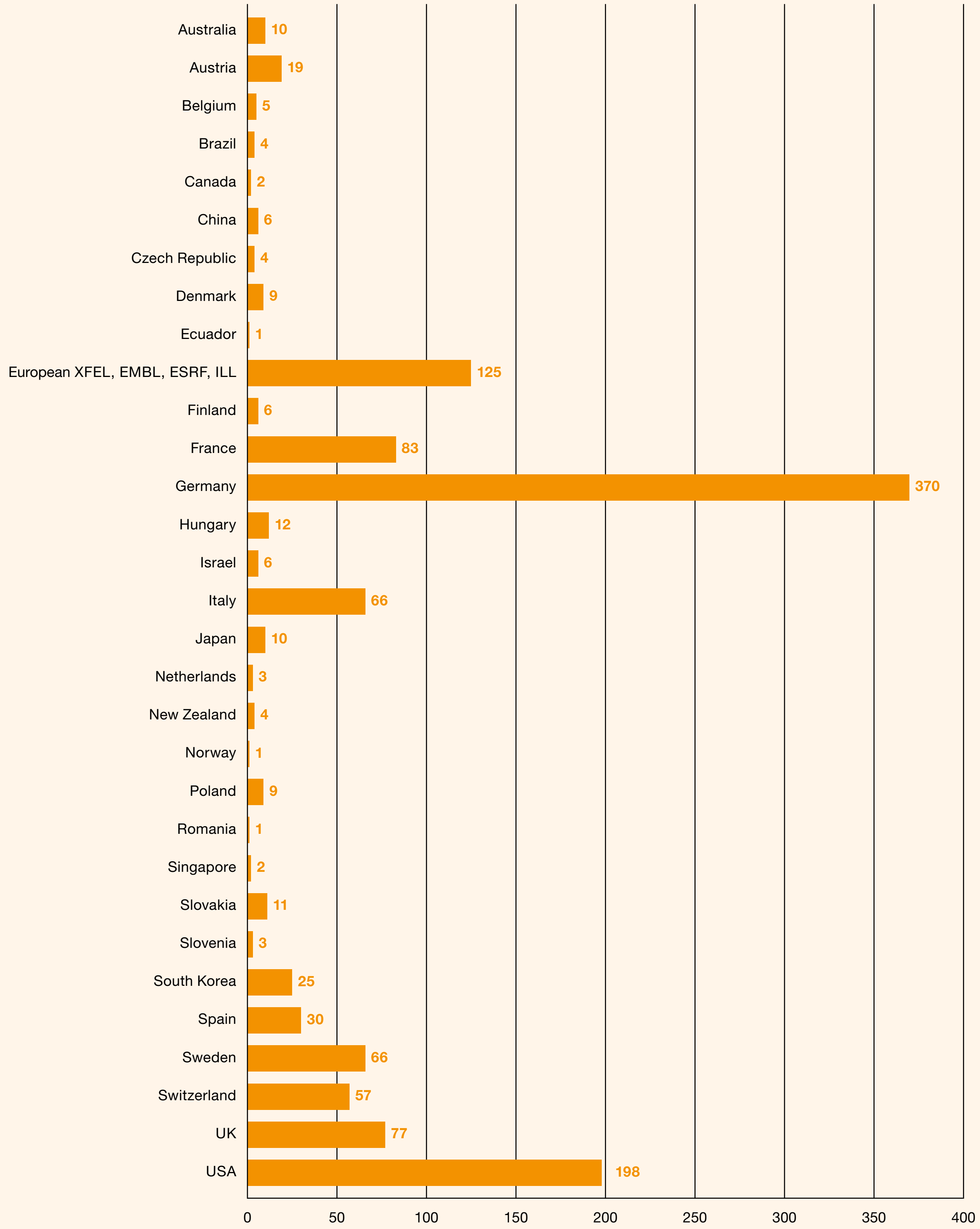


Figure 8
Country of affiliation of the 1225 individual users who participated in experiments in 2023

FACILITY UPDATE

Working in Interaction Chamber 1 of the HED instrument

CAMPUS DEVELOPMENT

In 2023, activities to develop the European XFEL campus focused on improving the technical infrastructure that supports the operation of the experiment hall and on continuing civil construction work on the new office building as well as the new visitor and conference centre, "Lighthouse".

Improving the technical infrastructure

The year 2023 was marked by several significant improvements of the technical infrastructure on the campus. The biggest activity was the removal of the specialized air-conditioning units for the three SASE FEL undulators from the XTD1, XTD2, and XTD6 tunnels. This task had been prepared with a prior verification that the stability of the undulator operation would be maintained after the air-conditioning units were removed. As a last verification step, the air-conditioning units were switched off during most of 2023. The removal took place in the winter maintenance period 2023–2024, in close cooperation with the Undulator Systems group. This action freed up space in the otherwise densely populated tunnels to install new extensions to the FEL undulators.

In the experiment hall, a new compressed-air distribution system was established, featuring a 15 bar ring line. This line also supplies the laboratory floor and is fed by a new compressed-air centre with three advanced screw compressors installed in the ventilation and air conditioning building, XHVAC. The new system combines better performance, higher pressure, and simultaneous usage in more than one location with optimized efficiency. Furthermore, the SASE2 and SASE3 uninterruptable power supply (UPS) systems were replaced to ensure high availability of electrical power. In the same effort, the UPS in the headquarters building, XHQ, underwent a comprehensive redesign, fortifying the critical power infrastructure, and a new auxiliary connection between the experiment hall and the second office building, XHO, ensures uninterrupted maintenance on medium-voltage systems, adding redundancy to critical operations. To support the operation of experiments by European XFEL staff, a cutting-edge automatic filling system for liquid nitrogen dewars was installed. The station, connected to the liquid-nitrogen storage tanks alongside XHVAC, enables the simultaneous filling of three dewars.

In addition, the exhaust air systems in XHQ were expanded and reinforced, ensuring a safe and healthy working environment in the experiment hall and the laboratory floor area. A room in the shaft building XHS4 was refurbished with ventilation and hazardous-material cabinets in order to qualify the room for mechanical work by the HED group.

Another improvement concerned the power infrastructure on the campus, partly related to the newly started operation of the XHO building. A new switchgear in XHO, along with a new transformer (2.5 MW), now supports large consumers, such as XHO, the future "Lighthouse" visitor and conference centre, and the charging stations for electric cars. A medium-voltage emergency power supply structure was implemented, extending the safety power supply for new buildings, and a new substation with state-of-the-art medium-voltage switchgear was constructed in the northwest part of the campus. A new automatic switchgear was installed, enabling seamless transition from the preferred grid (Hamburger Energiewerke) to the backup grid (E.ON) in case of issues with the external power supply. This modification is particularly important for critical security technology, including the fire alarm system, safety lighting, lifts, and IT and Data Management. As part of the reorganization of the electrical infrastructure, the charging station for electric cars was also relocated and extended by two stations near the new office building. Finally, since the end of 2023, the campus benefits from comprehensive access to all existing technical plants through the new building automation system. This control system is crucial in order to supervise and maintain the complex technical infrastructure while at the same time enhancing control, monitoring, and sustainability.

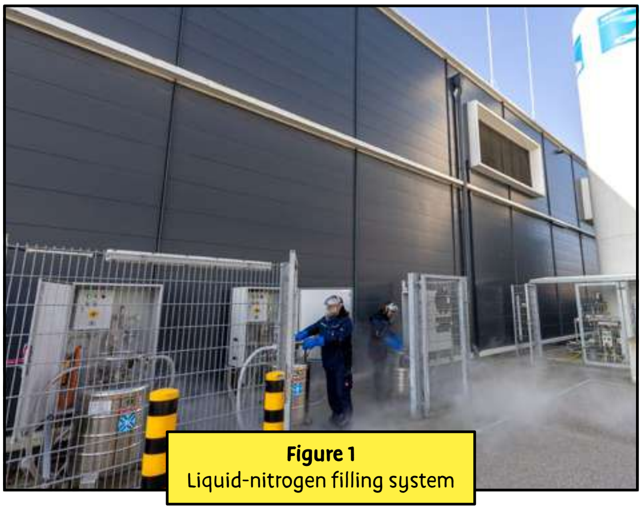


Figure 1
Liquid-nitrogen filling system

Figure 2
New office building, XHO

Figure 3
Landscape profiling to provide a habitat for plants and animals

Expanding the campus

On 3 April 2023, the new office building, XHO, was completed after 449 days of construction. The move into the new building took place over the weekend of 13–16 April, with staff moving to XHO, other staff relocating inside XHQ, and the temporary offices in XTOB being emptied. XHO now hosts the User Office, the Data Operation Centre, and the Travel Office and is a central point for users. For large user teams, the XHO lounge and adjacent meeting rooms serve as meeting and remote-control rooms—and even as a data analysis hub when executing their experiments. XTOB was finally demolished in a sustainable fashion.

The excavations for XHO and the visitor and conference centre provided the opportunity and material to complete the landscape profiling project on the south side of the campus. An undulating landscape profile with ponds was created, which is now protected and serves as a quiet zone for animals and plants.

Improving energy sustainability

Activities to reduce energy requirements continued in 2023 with the optimization of the heating system, thereby reducing the demand for district heating in 2023 (3636 MWh) by almost 20% compared to 2022 (4361 MWh). Additionally, overall electricity consumption was reduced by 1356 GWh, even though there were 272 more accelerator operation hours than in the previous year. Several projects are being planned that will help to further reduce the energy requirements of European XFEL.

FACILITY DEVELOPMENT

In addition to the day-to-day activities focused on operating the facility to perform experiments, a variety of development work is being carried out to improve the performance of the facility and to maintain our leading position in the field of high-repetition-rate XFELs.

Accelerator, undulators, and X-ray beam transport systems

Developments have been pursued on both the accelerator and the undulators, yielding record FEL photon energies and intensities. For example, it was investigated how the slice energy spread builds up in the injector and during bunch compression. This understanding is vital to further improve the electron beam quality. Other studies measured the static and dynamic heat load of the cryomodules, an important input parameter for further detailing the high-duty-cycle upgrade proposal. Another essential activity was to identify the source of radiation that had caused damage to the APPLE-X undulators and to subsequently design new synchrotron radiation absorbers to be placed in front of them. The effectiveness of the absorbers could be demonstrated experimentally—a prerequisite for the reinstallation of the four undulators in the winter maintenance period 2023–2024.

A particularly intensive development activity aimed to provide ultrashort X-ray pulses with a pulse duration of only a few femtoseconds or even just a few hundred attoseconds. Various techniques were tested, generating ultrashort X-ray pulses at all the undulators. Single-spike lasing with high intensities was also demonstrated at the SASE2 undulator by shaping the electron beam through self-fields and detuning of the deflection arc optics.

Part of this activity was to deliver ultrashort X-ray pulses to the SQS instrument at SASE3, where sub-femtosecond pulse duration was measured using a terahertz streaking technique in collaboration with TU Dortmund (Figure 1). The ultrashort soft X-ray pulses were generated by a combination of special compression and dispersion of the electron beam in the undulator, resulting in an extremely short lasing window. Thanks to the high energy of the electron beam and the high magnetic field of the SASE3 undulator, pulse energies on the order of 100 µJ could be obtained. The pulse duration was measured on a shot-to-shot basis by ejecting photoelectrons in a gas target and mapping their energy and arrival time using a synchronized infrared laser. A set of reconstruction algorithms was used to determine the pulse duration from these energies, resulting in values of a few hundred attoseconds, corresponding to a peak power on the order of terawatts.

In another activity, self-chirping was employed to generate high-power attosecond hard X-ray pulses, exploiting the collective effects of the electron beam to create a sharp current spike. Proof-of-principle experiments at SASE2 showed that ultrashort hard X-ray pulses dominated by one to two spectral modes can be generated. In the hard X-ray regime, pulse properties can currently be characterized only by means of measurements of the pulse spectra. Pulses with one or a few spectral modes are expected to have a similar amount of temporal modes and thus to be extremely short (Figure 2).

To prepare new capabilities, the following components were installed in the accelerator and the electron beam transport systems:

- An electromagnetic wiggler and a wakefield structure in front of SASE1 to allow for an even better control of the electron phase space as part of the ASPECT project
- A magnetic chicane and vacuum chambers for the X-ray Free-Electron Laser Oscillator (XFELO) demo experiment behind SASE1
- A radio frequency pulse compressor for the transverse deflecting structure after the last bunch compressor
- The four APPLE-X undulators together with the newly developed upstream synchrotron radiation shielding

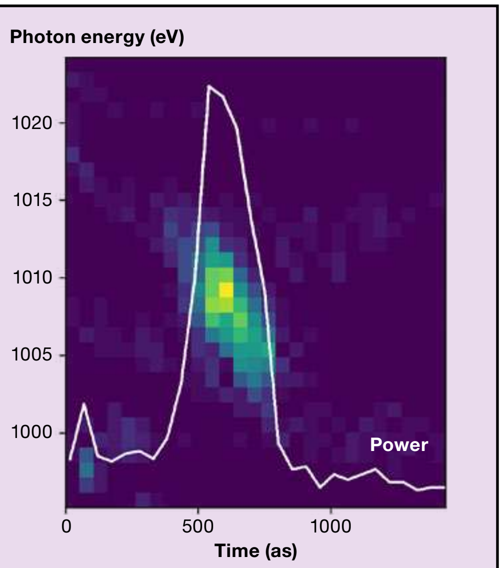


Figure 1
Reconstructed spectrogram of a single 275-attosecond-long soft X-ray pulse of 300 µJ energy

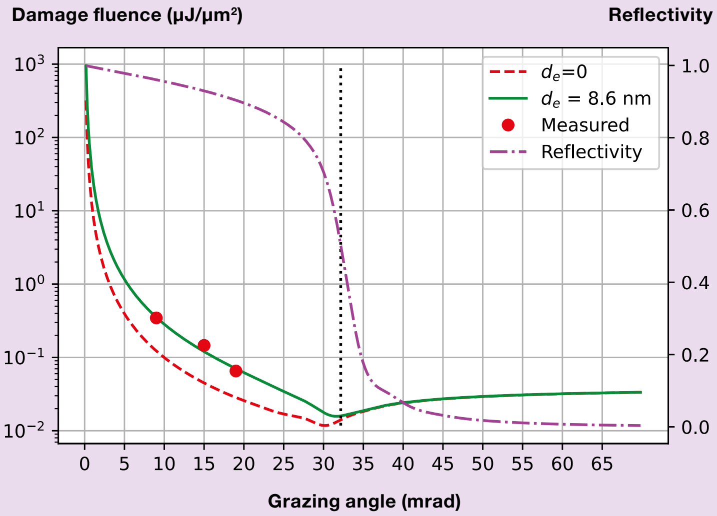


Figure 3
Damage fluences at irradiation with 1 keV energy, plotted as a function of the grazing angle for a B_4C-coated mirror (d_e is the electron collision length)

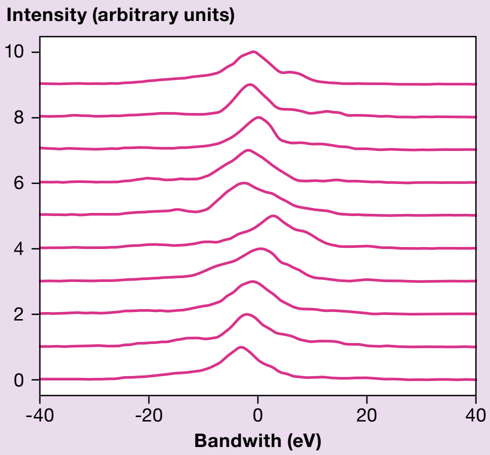


Figure 2
X-ray spectra of 10 pulses in the single-spike regime in self-chirping mode. The spectra, with a central photon energy of 9 keV, were measured using the HIREX spectrometer at SASE2.

A new injector laser was installed and commissioned, offering even more flexibility in terms of individual bunch charges and shapes. Simultaneous operation and lasing were demonstrated to be possible with bunches of different charge within a train. The "beam regions" concept, established in 2022 and allowing for individual control of the acceleration fields, is a prerequisite to benefit from these new capabilities.

Furthermore, preparations for the shutdown of the European XFEL during the second half of 2025 are under way. Major activities concern the preparation of the area behind SASE2 for the installation of superconducting undulators, the completion of the tunnel installations for the ASPECT project, and the insertion of a passive bunch streaker after SASE3 for bunch length diagnostics, similar to the device already installed behind SASE2. A new electron source, Gun 5, will be installed as well. With its improved photoinjector cavity, it will allow the radio frequency pulse length—and thus the number of available electron bunches—to be increased by 30%.

In the accelerator R&D programme, one focus lies on the technologies required for a future upgrade of the accelerator to operate in continuous-wave (CW) or high-duty-cycle mode. A crucial ingredient is a CW injector. Here, DESY is following the approach of an all-superconducting photoinjector that allows for high accelerating gradients, with the promise to provide small horizontal emittance. A breakthrough test, performed in 2023, showed that operation at high gradient with a copper cathode is possible.

There were also several activities to improve the performance and capabilities of the X-ray beam transport systems and the diagnostics. To prepare the final design of the SASE3 delay line optics, to be installed during the 2025 shutdown, it is important to understand the damage processes and threshold levels. A study was therefore performed to determine the damage threshold for boron carbide (B_4C)-coated mirrors in grazing-incidence conditions. The measured damage threshold at 1 keV was about a factor of 3 higher than expected from the energy density absorbed on the surface of the sample. Nonetheless, the data showed good agreement with different models (Figure 3).

Another development concerned the interpretation of data from the soft X-ray photoemission spectrometer (PES) in SASE3, for which a virtual spectrometer was developed and implemented. This machine learning code combines single-shot spectra obtained non-invasively at low resolution from the PES with those of an invasive high-resolution grating spectrometer. The code is trained when both spectrometers measure simultaneously. It delivers resolution-improved spectra when only the gas-based PES is operating, including an uncertainty range that helps users to identify when retraining is necessary for continued fidelity (Figure 4).

X-ray instrumentation

A large number of X-ray instrumentation developments were carried out, of which only a small selection can be presented here.

The pump-probe lasers in the experiment hall simultaneously provide ultrashort pulses for two beamlines at each instrument. The pulse energies are typically at the millijoule level and scale inversely with the repetition rate. Various pulse energy / repetition rate setpoints were added to allow the optimization of data acquisition rates for user experiments. Notably, 2.2, 0.56, and 0.281 MHz were added to the original setpoints at 4.5, 1.1, 0.188, and 0.1 MHz, with the non-collinear optical parametric amplifier energy working points optimized accordingly. Scaling up the laser intensities while operating at high repetition rates is a challenging task. A new method uses spectral broadening through self-phase modulation of picosecond, 1030 nm pulses in gas-filled Herriott multipass cells (HMPC), followed by chirped mirror compressors, which has resulted in a nearly lossless intensity upscaling by factors of 15–20 and more (Figure 5). Starting with sub-picosecond, 1.1 MHz, 3.5 mJ pulses, sub-40 fs compressed pulses with 3 mJ could be obtained from an argon-filled HMPC. Such a unit was installed and commissioned at the SQS instrument in 2023.

Another development addresses the generation of broadband high-field THz and mid-infrared radiation. A laser-based THz source was commissioned, which uses BNA organic crystals, pumped by 15 fs, 1.5 mJ pulses at 800 nm and 0.188 MHz repetition rate (Figure 6). This compact high-field THz source (single-cycle THz pulses, 1.5 THz central frequency, 0.3–6 THz spectrum, ~1 MV/cm THz electric-field strength) can be readily implemented at the instruments. To characterize the THz radiation, an electro-optic sampling setup was developed, which can be provided upon request.

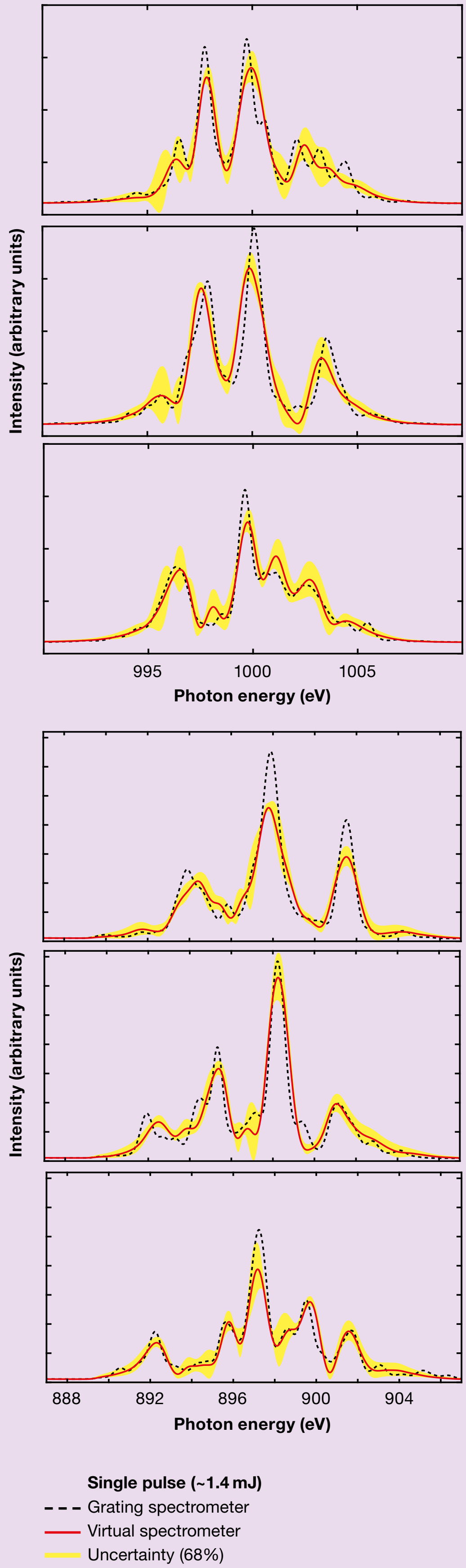


Figure 4
Six consecutive single-shot spectra obtained using the virtual spectrometer (red solid line). For validation of the reliability of the technique, spectra were compared with the high-resolution grating spectrometer (black dashed line).

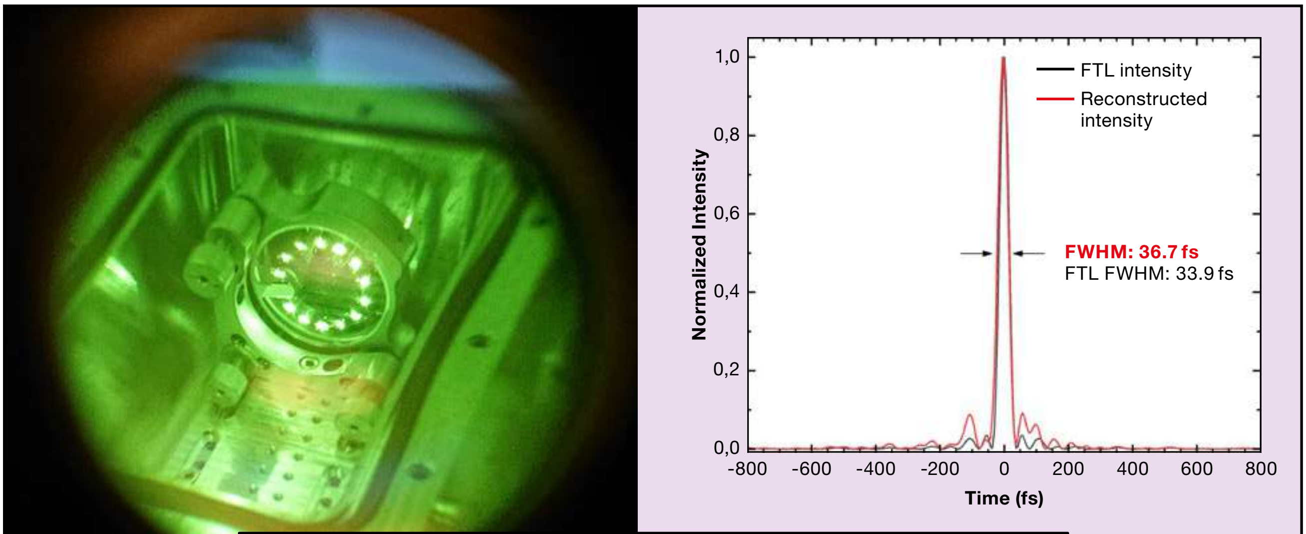


Figure 5
Left: Infrared image of HMPC mirror. **Right:** Sub-40 fs pulse compressed from 850 fs. (FTL: Fourier-transform limit. FWHM: Full width at half maximum.)

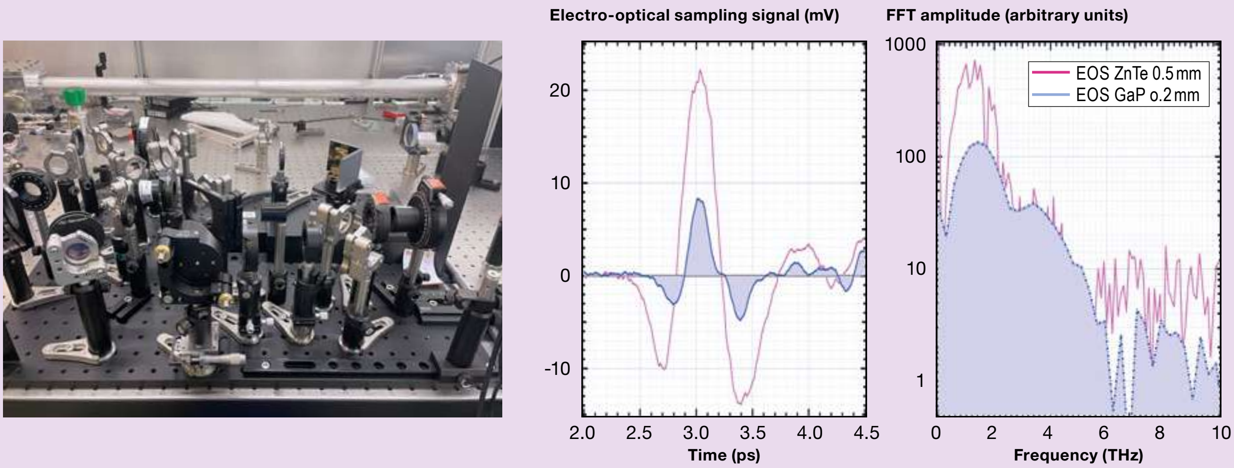


Figure 6
Left: Compact THz setup (footprint 60 × 45 cm). **Middle:** Single-cycle THz radiation pulse (BNA, pump: 15 fs, 800 nm) measured by electro-optical sampling (EOS) using zinc telluride (ZnTe) and gallium phosphide (GaP) crystals. **Right:** Corresponding fast Fourier transform (FFT) spectra.

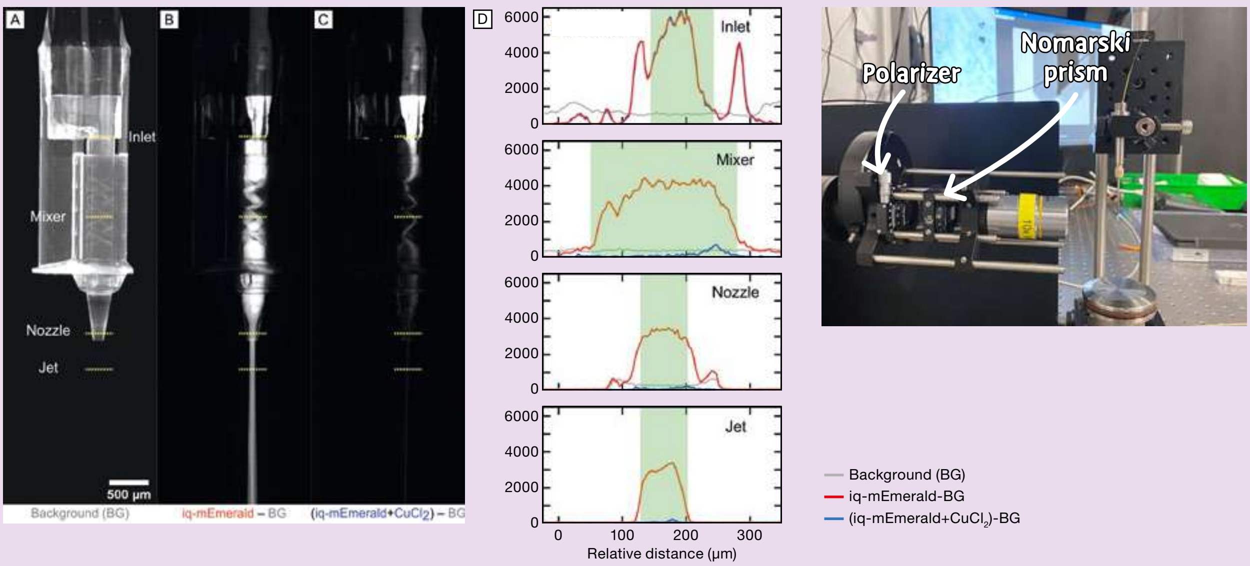


Figure 7
Left: Mixed-viscosity extruder. **Middle:** Width of the jet as a function of the distance from the nozzle. **Right:** Liquid-jet characterization platform.

A mixing high-viscosity extruder was developed to be employed in room temperature serial-crystallography experiments. For time-resolved studies of dynamical processes, mixing is used to initiate a chemical reaction. The new device, developed together with academic and industrial partners, enables fast and efficient mixing of high-viscosity samples, such as membrane proteins in the lipid cubic phase. To characterize microscopically fine liquid jets, liquid sheets, droplet sources, and mixing devices, an advanced characterization platform was developed and built up. It allows advanced imaging, jet velocity measurements, and fluorescence analysis for mixing devices. A new feature is thickness measurements for liquid sheets. These are crucial for liquid-phase spectroscopy, where only a good knowledge of sample thickness allows quantitative analysis of the results.

Furthermore, the development of compact pulsed magnets is being pursued. In 2023, a magnet exceeded the design goal of 15 T maximum magnetic field (Figure 8).

In November, the European XFEL Council approved a revised version of the Scientific Data Policy, which will supersede the existing one, effective from January 2025. The goal is to improve user experience, address data sustainability issues, and align with the FAIR (findable, accessible, interoperable, and reusable) data principles. The update includes a new approach to long-term data preservation, which defines a six-month period directly after the beamtime for reducing the data size to a sustainable level. Data management plans aim to enhance communication between experiment team and facility experts in order to improve the planning of resources required for experiments and effectively increase data analysis efficiency. The policy emphasizes more comprehensive management of metadata with the aim of significantly enhancing adherence to the FAIR data principles. The implementation phase has begun, and users have been invited to contribute to the fine-tuning of the new data management processes by testing and providing feedback.

In June, after more than 10 years of development, the Karabo Supervisory Control and Data Acquisition (SCADA) system was released. It provides control capabilities and interfaces to the instruments and tunnel photon systems. Karabo, its closely associated user interface, and selected implementations to control specific hardware have been made available to the public as free open-source software—an important contribution to European XFEL's open-science policy. In addition, a five-year effort to modernize one of Karabo's foundational technologies, the message broker, was concluded. The message broker is at the heart of establishing communication in a distributed environment, and the Java Message Service technology, which had been used so far, is no longer supported.

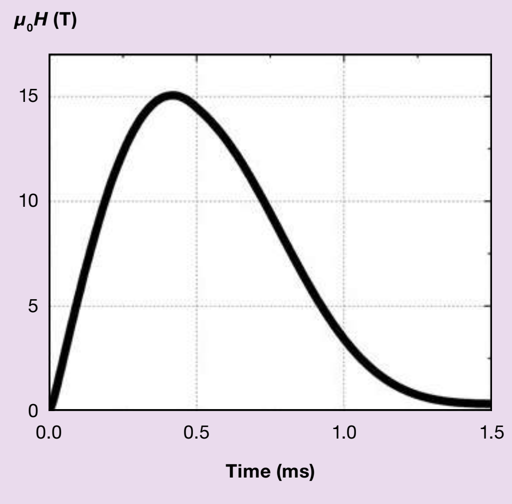


Figure 8
Magnetic field obtained for a modified pulsed magnet

Figure 9
Preliminary design of the hutches for the new HXS instrument in the SASE2 area. The light blue hutch on top houses the control hutch and a rack room.

In 2023, a new detector development programme was launched, for which additional personnel were recruited, focusing in particular on expertise in detector integration and in the field of hard X-ray detection. The main objective of this programme is to develop a next generation of area detectors for European XFEL that meet a set of updated requirements, e. g. smaller pixel size, more efficient detection of higher-energy photons, simplified operation, or higher versatility and sustainability of maintenance.

Work also started to prepare the High-Energy X-Ray Scattering (HXS) instrument, which will use the third beam port at the SASE2 undulator and will be located in the experiment hall next to the MID optics hutch (Figure 9). While the experiment programme is not yet fully fixed, the design of the basic beam transport system in the tunnel XTD6 and of the radiation hutch was already started. This early planning will enable basic installations to take place during the long facility shutdown in the second half of 2025 and thus minimize the impact on the user programme at SASE2. The HXS instrument will use the common upstream beam optics at SASE2 currently shared by the HED and MID instruments. A deflection mirror optimized for high stability and high photon energies will allow a photon energy transmission up to 57 keV.

Scientific instruments

At the HED instrument, the dynamic-compression (shock) setup was commissioned and successfully employed for three user experiments. It uses the DiPOLE 100-X laser combined with a diffraction setup to probe laser-compressed matter, in particular phase transitions and liquid structures (Figure 10). In addition, it requires frequency conversion of the laser light, beam transport to the target chamber, laser diagnostics, and specialized optics to create a homogenous flat laser focal spot. The shock setup also includes a velocity interferometer system for any reflector (VISAR), a standard diagnostic device to characterize the compression history of the sample. During the experiments, the laser in particular showed a high degree of reproducibility, and the large-area X-ray detector allowed liquid structure factors to be measured with unprecedent quality. Thanks to the high number of compression laser shots in a single week (10 times more than at other XFEL facilities so far), several scientific topics could be addressed. In the future, the shot rate will be further increased towards the laser repetition rate of 10 Hz. Presently, the experiments are limited by sample delivery, but, for a short time, operation at 1 Hz could already be demonstrated.

The FXE instrument brought several technical developments online. In May, the HELIOS high-photon energy spectrometer project was used to measure X-ray emission spectra of molybdenum- and niobium-containing materials, demonstrating an energy resolution below 2.5 eV (Figure 11). This spectrometer will allow FXE to take advantage of high photon energies and extend spectroscopic capabilities to cover the 4*d* and 5*f* elements of the periodic table for materials, chemical, and biological research in the X-ray photon energy range above 15 keV.

In June, the XTRAS molecular crystallography project was used to measure the ultrafast structural dynamics of a molecular spin-crossover material at FXE by recording the X-ray Bragg diffraction from photoexcited crystalline samples using the Large Pixel Detector (LPD). The four-axis rapid scanning setup with extended angular access will allow the FXE user community to measure molecular structural information with atomic spatial resolution and femtosecond time resolution to complement the solution phase spectroscopic and scattering measurements already possible at the instrument (Figure 12).

The SXP instrument was commissioned in 2023. It is equipped with a momentum microscope photoelectron spectrometer that allows experiments in both spatial and momentum mode. After optimizing the spatial mode using a gold/silicon chessboard pattern and a mercury laboratory source, the XFEL beam was used to image the same sample and get an idea of its dimension, measure core levels in various samples, and test the momentum mode. The surface photovoltage of a transition metal dichalcogenide (TMDC) semiconductor was also measured (Figure 13).

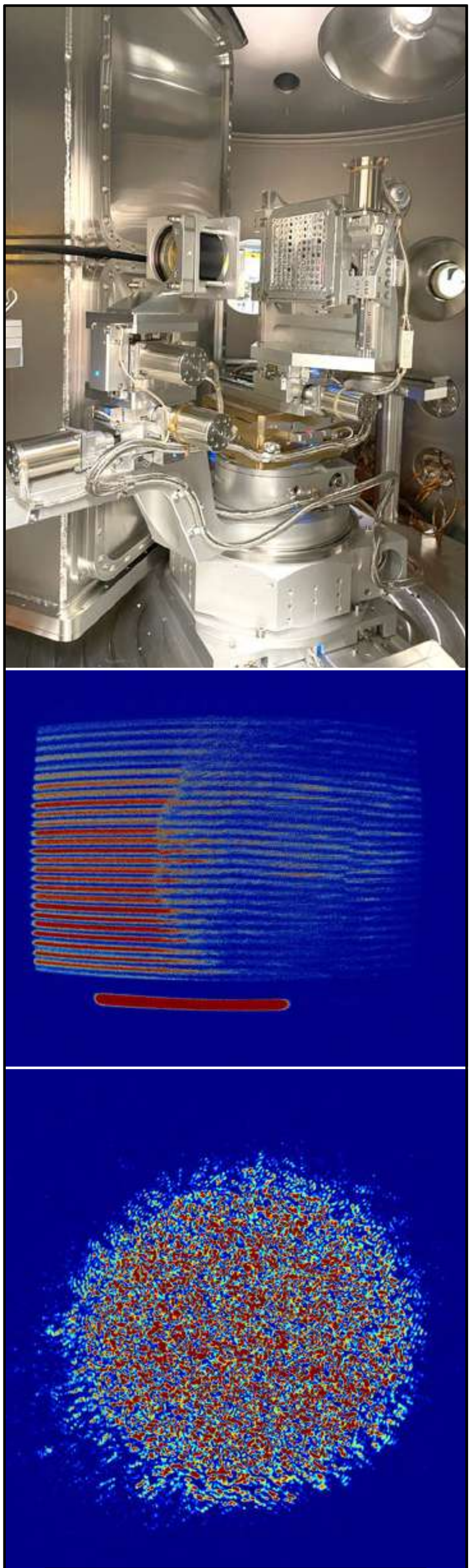


Figure 10
Top: Shock setup at the HED instrument in the IC2 target chamber.
Middle: Rear surface velocity of a shock-compressed sample as measured with the VISAR. The bright line at the bottom is an optical fiducial marking the arrival of the laser pulse.
Bottom: Focal spot of the laser in the target chamber, providing a flat compression profile.

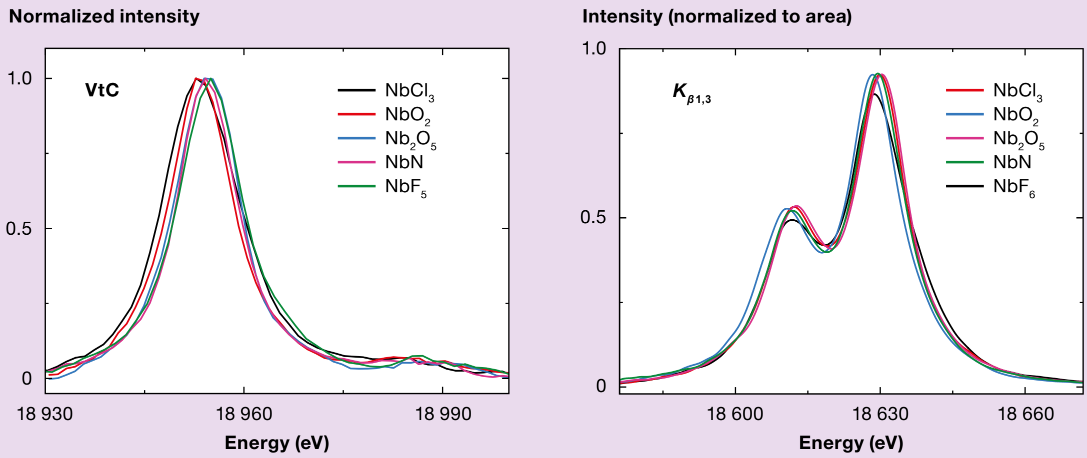


Figure 11
X-ray emission signals measured using the HELIOS spectrometer at the FXE instrument for a variety of niobium-containing materials. **Left:** Valence-to-Core (VtC) transitions. **Right:** $K_{\beta1,3}$ line.

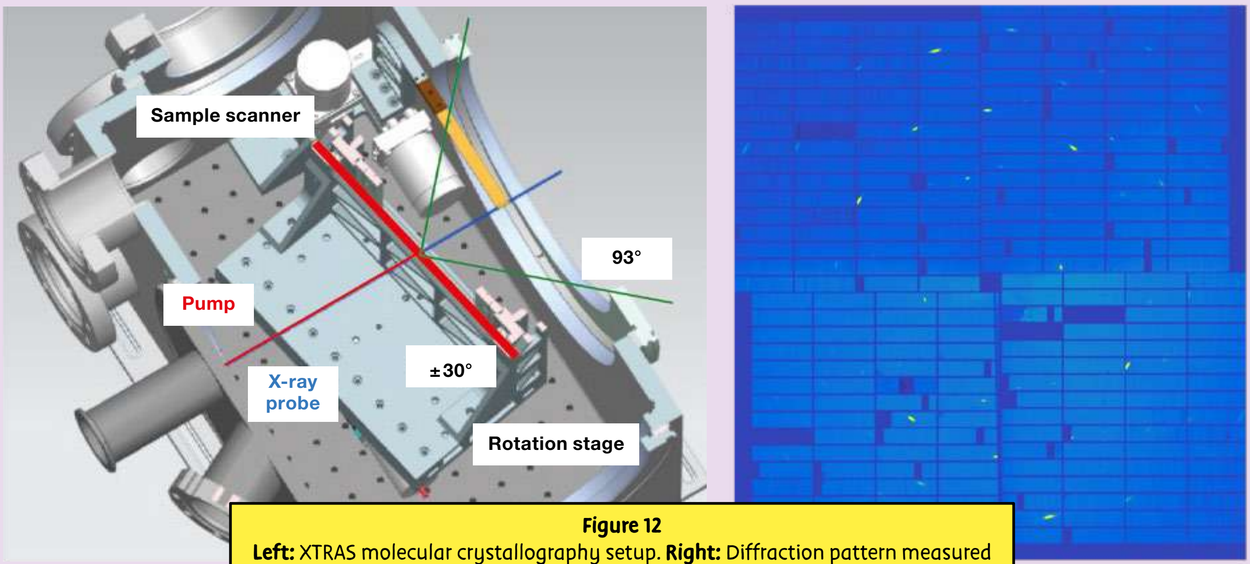


Figure 12
Left: XTRAS molecular crystallography setup. **Right:** Diffraction pattern measured using the LPD at FXE from a thin molecular crystal sample.

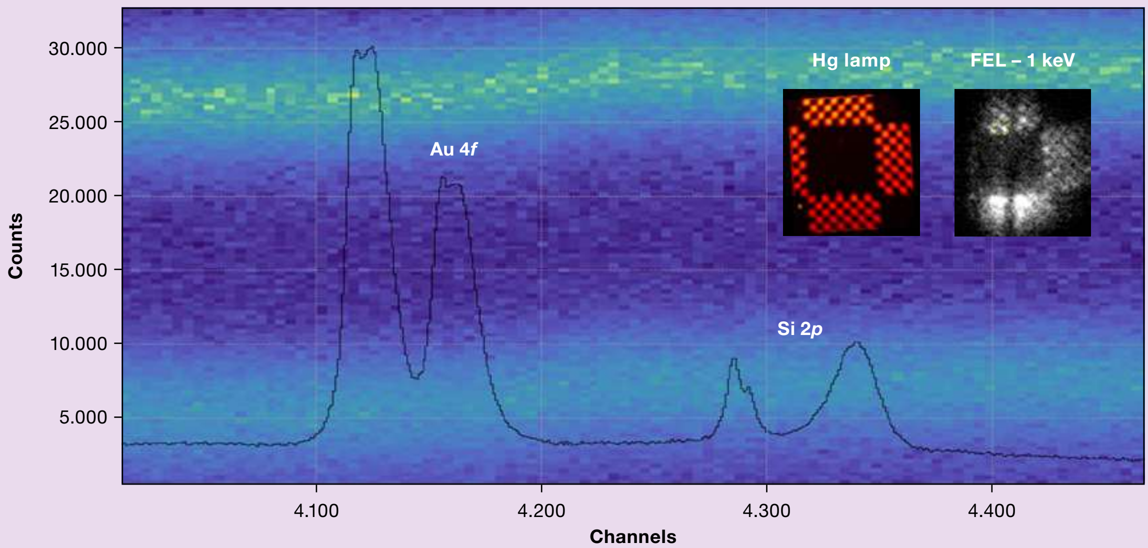


Figure 13
Inset: Images of a gold/silicon chessboard pattern measured with a mercury lamp and the XFEL beam at a photon energy of 1 keV. A core level spectrum was obtained by plotting the integrated 2D XFEL image as a function of the electron time of flight. **Main image:** Time traces of the core levels of the TMDC semiconductor. The change in the vertical position of the core levels is due to the surface photovoltage effect.

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 effectively.

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.

In 2023, activities focused on physical and mental health. Staff members were encouraged to get trained as mental health first aiders, and a summer campaign was organized to remind staff members to get enough rest and use their vacation days. During the year, the European XFEL Health Days became Health Weeks—two weeks instead of three days—with a special focus on stress reduction.

In addition, after an evaluation of a former appointment and promoting process, a new procedure was put in place to acknowledge the expertise of extremely experienced staff members. The so-called "Senior Role" was further described and shaped as a solution for professional development and will be implemented with a new appointment procedure for the first time in 2024.

In its continuous pursuit of excellence, European XFEL has prioritized evolving its feedback culture to foster a more transparent and collaborative environment. In reviewing current practices, ways are being investigated to implement new feedback mechanisms and to provide training on effective feedback exchange. The company wants to instil a culture in which feedback is not only welcome but also seen as instrumental for collective growth and success.

Recognizing the pivotal role of leadership in shaping its organizational culture, European XFEL is planning to introduce a leadership code of conduct and a comprehensive leadership training programme designed to equip its leaders with the skills necessary to navigate and thrive in today's work environment. Through peer workshops, seminars, and personalized coaching sessions, leaders will enhance their abilities to provide effective feedback, inspire teams, and drive positive change.

OUR VALUES

European XFEL's core values—collaboration, excellence, transparency, and trust—were defined in 2021 in 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 our company.

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

The Values Tool Box is a comprehensive resource, offering games and activities for groups wishing to assess and playfully align behaviours with our values. It was developed by a subgroup of the Culture Change Agents over several months and launched in October 2023.

To inject a sense of humor into the values topic, the introduction of Funny Values T-shirts in September proved to be a lighthearted yet effective action, sparking lively conversations among many staff members.

The Talking Table initiative in the company restaurant “BeamStop”, which started in July, aims to foster dialogue among staff members at lunchtime, providing a casual space for exchange.

During our summer party, a Lego Challenge brought staff members together in pairs to collaboratively build Lego models, emphasizing communication and teamwork skills.

In a half-day workshop in November, the Culture Change Agents engaged in discussions with the extended Management Board to evaluate the current state of our values and brainstorm ideas for the future.

T-shirts with cool slogans about the values were well-received by the employees.

PH.D. PROGRAMME

The European XFEL Ph.D. programme is fully consolidated with a steady number of 45 Ph.D. positions. There are 30 European XFEL alumni, among them 7 Ph.D. students who graduated in 2023. The Ph.D. committee supervises the programme, guaranteeing that the students acquire a good set of technical and soft skills and receive proper supervision. This is done by annually monitoring the progress of each student, in close collaboration with academic supervisors. In 2023, the Ph.D. committee compiled a list of criteria to evaluate and recommend exceptional contract prolongations for Ph.D. students, which in most cases were impacted by the COVID-19 pandemic.

The Ph.D. programme is growing to be a crucial pillar of in-house research as well as a useful tool to broaden the user community and to engage with the shareholder countries through the creation of “shared” Ph.D. positions. Each of these Ph.D. students is co-financed by European XFEL and a university in a shareholder country. The student spends a minimum of 12 months at European XFEL. As part of the Ph.D. programme, the student has a local supervisor and a tutor. Currently, there are 7 shared Ph.D. positions affiliated with 7 universities outside of Germany.

The efforts made 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). Their nationalities (Figure 2) also show the diversity hallmark of European XFEL, in line with the 63 nationalities present among staff members.

European XFEL is committed to gender equality and regularly monitors the gender balance of the Ph.D. students, considering the number of years within each Ph.D. position. This monitoring shows a slight decrease in the number of female Ph.D. students in the last recruitments, which still remains within statistical fluctuations. Nonetheless, European XFEL is taking measures to overcome this situation and to foster gender equality among staff members.

As part of their education as scientists, the Ph.D. students are encouraged to attend conferences, internal events, and activities at European XFEL, which is crucial to building their networks. In February 2023, Nobel Laureate Donna Strickland visited European XFEL and met with the Ph.D. students in a special session to discuss scientific careers and answer questions.

More than 130 participants joined the Students’ and Science Days in Fintel south of Hamburg. 24 Ph.D. students presented their research, shared experiences and had the opportunity to talk to senior scientists.

Figure 3
Ph.D. students with Nobel Laureate Donna Strickland

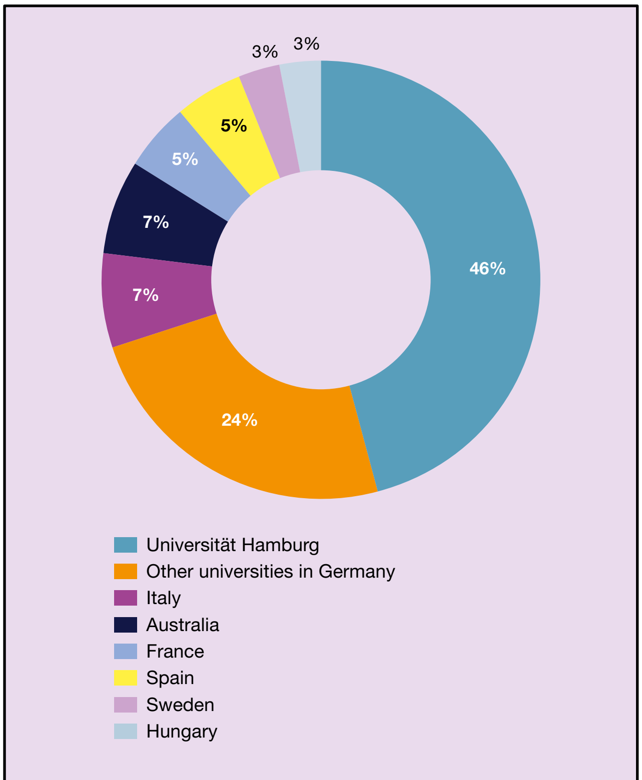


Figure 1
Affiliations of European XFEL Ph.D. students

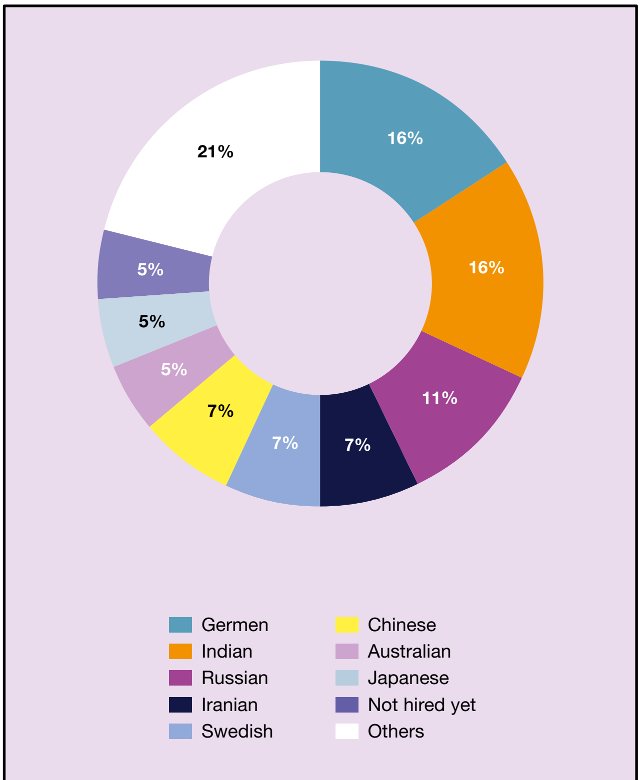


Figure 2
Nationalities of European XFEL Ph.D. students

Figure 4
Students' and Science Days 2023

BUDGET AND THIRD-PARTY FUNDING

At the end of 2023, 98.9% of the European XFEL construction budget was spent. The annual operation budget was 145.7 million euro (M€) and will increase to 150.0 M€ in 2024.

Parallel to spending from the annual operation budget, investments from the remaining construction budget continued in order to finalize SASE installations—such as a third instrument port at the beamlines and an undulator for circular polarization—as well as to prepare for construction of the new office building and the visitor and conference centre.

In 2023, European XFEL started the planning of the budget for strategic development until 2030. Based on the "indicative" budget through the pre-allocation of operation funds, the first part of these future investments was approved. The indicative budget is reported as part of the Facility Development Programme (FaDeP), describing and showing the planned expenses and their relation to the future-oriented development of the facility, including strategic activities and contingency plans. The FaDeP has helped to increase the transparency of financial reporting and has provided some flexibility for financing bigger projects. It also guarantees financial certainty when the geopolitical situation is uncertain.

The overall construction budget of European XFEL amounts to around 1.25 billion euro (2005 value). Forty-six percent was contributed in kind by various partners. The remaining fraction of more than 650 M€ (2005 value) was contributed in cash to the company by its shareholders and associated partners.

The total European XFEL payment budget in 2023 amounted to 157 M€. Of this, 146 M€ (93%) was related to operation and 11 M€ (7%) was allocated to ongoing construction projects.

Recurrent and capital costs were the largest parts of the costs, totaling 78 M€ (51%). Another 69 M€ was spent on personnel, including staff from DESY mainly working on accelerator operation. A further 5 M€ was allocated for smaller upgrades.

For 2024, an increased annual payment operation budget of 150 M€ was approved by the European XFEL Council, with a further 10.3 M€ approved for finalizing the construction phase budget.

As part of the core funding by the shareholder countries, European XFEL runs its R&D programme and distributes a significant amount of funds on a project basis, only provided after a successful application for these funds (see below). In addition, third-party funding plays an important role within the budget portfolio of European XFEL, providing flexibility for important projects.

Development and R&D projects

Since 2019, the major tools to enable larger projects have been the yearly internal Research and Development (R&D) calls and the Development Projects (DPs), which, after evaluation, can be approved at any time during the year. The R&D calls mostly focus on the provision of additional funds for hiring personnel (the major funding source for Ph.D. students and young scientists) and developing early prototypes, while DPs are typically funded using available operational funds and can make use of significant internal human resources from our expert groups. The main goal of DPs is to enable new science, which often requires multidisciplinary efforts.

At the beginning of 2023, there were 23 ongoing DPs (approved in previous years). By the end of the year, 12 of these projects were successfully closed, and another

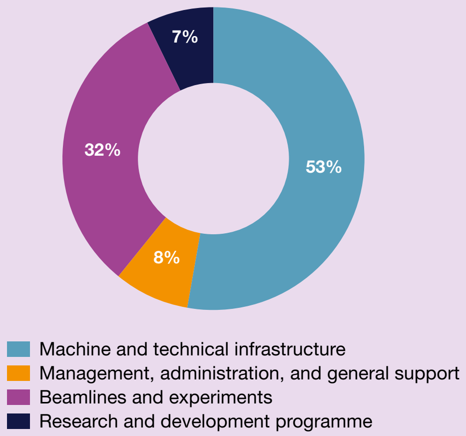


Figure 1
Payments by major activity in 2023

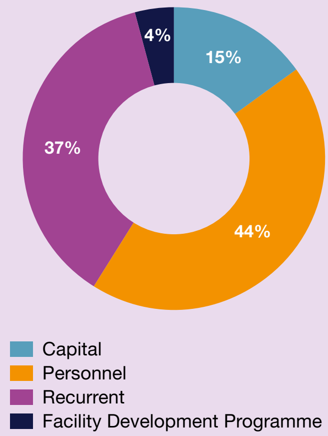


Figure 2
Payments by budget items in 2023

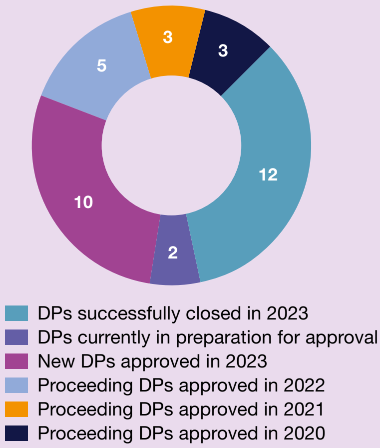


Figure 3
Status of Development Projects in 2023

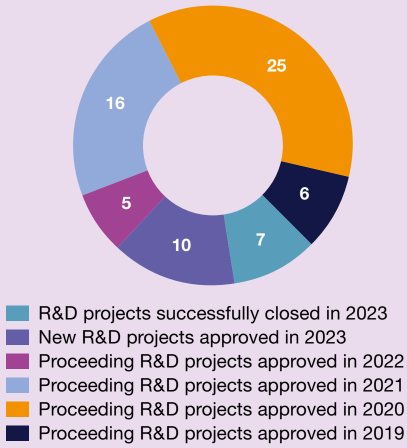


Figure 4
Status of R&D projects in 2023

10 new DPs were successfully initiated. Currently, two more DPs are in preparation for approval (Figure 1).

The overall budget of the 10 new projects is about 8.1 M€, of which 6.6 M€ is allocated to three projects to build the beam transport system and hutches for the new High-Energy X-Ray Scattering (HXS) instrument. The remaining seven projects have varying budgets between a few 10 k€ and several 100 k€.

Regarding the R&D programme, European XFEL decided to open a call for further projects in 2023 with a budget of 4.5 M€ over three years and with a focus on projects in line with the strategic goals of European XFEL.

Seventeen R&D proposals were submitted, of which 10 new R&D projects were approved and funded. For example, about 3.5 M€ was allocated to four projects on topics such as data science and data reduction. Ongoing efforts to improve the control infrastructure are funded through R&D calls and strategic funding, as are a number of projects in science and instrumentation.

In 2023, seven R&D projects were completed. However, a significant number of R&D projects from 2019 are not yet finished, due to COVID-19 pandemic constraints.

Third-party funding

In 2023, European XFEL participated in 18 research projects, 10 of which were funded by the EU Horizon 2020 and Interreg programmes and eight by national funding organizations, such as DFG and the German Federal Ministry of Education and Research (BMBF).

The overall income from these projects was 1.2 M€ (compared to 1.3 M€ in 2021 and 1.4 M€ in 2022), of which 55% came from European and international funding, and 45% from national funding.

In 2023, eight staff members were employed exclusively for third-party–funded projects. Three of these projects ended, and three new projects were started.

MANAGING QUALITY, SAFETY, RISK, AND CUSTOMS

After a longer phase of continuously ramping up operational activities, accompanied by a corresponding increase in the size of the workforce, European XFEL is now reaching a plateau in staffing and in the organizational structure, which will make it possible to focus on implementing strategic activities. These activities will be performed parallel to operation, which will require a high level of coordination and long-term project management. This article focuses on enhancements to the administration and management of the company.

Quality management

In 2023, European XFEL continued to focus on overall improvements in quality management—comprising different quality-oriented services, procedures, and guidelines—resulting in tangible enhancements to some procedures, including the simplification of some Management Board decisions and the delegation of responsibilities to other leadership levels. Processes mostly connected to the maturing of the European XFEL as a research facility were also optimized and adjusted.

The geopolitical situation continued to create economic and diplomatic uncertainty and high inflation, which, combined with very low global growth rates, put financial pressure on the company. Special focus was thus once again placed on adjusting the budget planning processes and ensuring the long-term financial stability of the company, using different planning tools and processes.

The company's quality management activities—supported by regular internal audits and an external end-of-year audit—aim to combine state-of-the-art quality management of international scientific institutions and research infrastructures with modern insight into the administration of large service units, especially related to process and reliability requirements. The activities established and the procedures implemented or adapted in 2023 were examined in the light of various quality aspects: meeting the needs of users, improving processes, involving staff members and partners in quality improvement, and ensuring sustainable and reliable facility operation. In particular, the reporting requirements of the shareholder countries and the legal boundary conditions for administrative processes were addressed.

The following sections highlight some administrative areas in which special quality management aspects were addressed to improve processes and procedures to the benefit of the company. This includes not only "classical" areas of procurement, asset management, and customs and export control but also personnel development, an extremely important field that addresses the quality of the workplace, the well-being of staff members, and the quality of leadership and collaboration. Staff members who work with a high degree of experience and dedication are the success factor of the company.

Procurement

After the successful introduction of the enterprise resource planning (ERP) system, digitalization of the procurement process continues. Additional electronic catalogues have been connected to enable automated ordering of standard items. This automation optimizes the procurement process and reduces the administrative workload for staff members.

In addition, preparations are under way to implement stock items in the warehouse and manage this process in the ERP system. Digitalization will enable quick and easy availability of the most commonly used items and spare parts. The environmental footprint will be improved by reducing external packaging and fuel used in transport throughout the supply chain.

Safety and radiation protection

In 2023, several measures to improve the organization of various safety trades at European XFEL were initiated. The objectives were to make safety organization clearer and easier to understand, to have clear assignments of safety responsibility, and to review and optimize the processes in place to ensure safe working conditions at European XFEL.

One major activity was to redesign the safety organization with three major goals in mind. First, the previous organization was not aligned with the joint safety organization with DESY that had been chosen for the entire European XFEL facility in previous years. Second, a new organizational structure at European XFEL on the subgroup level had to be considered. Finally, following the request by the Responsible Electrician, the organization of electrical safety needed an update. The implementation of the new organization is scheduled for the first half of 2024.

In addition, various safety processes were further improved during 2023. Two new safety installations were commissioned and were in operation by the end of 2023. XDMS, a designated area for the storage of hazardous substances and the collection of hazardous waste generated at the European XFEL site, became fully operational. This area is now utilized for the safe storage of hazardous materials prior to their use at European XFEL and the storage of hazardous waste and electrical and electronic equipment prior to their transfer to an external company for disposal.

A new transponder system for accessing the experiment hall and the tunnels was introduced during the summer maintenance period. The new transponders are integrated into name tags indicating the status of staff and other persons at European XFEL.

In 2023, the question of safety culture and how to improve it was also addressed. As a first activity in December 2023, a staff survey aimed at measuring the perception of safety culture. The feedback provided will enhance the general comprehension of factors that limit the ability to enhance safety; concrete propositions to improve safety will be tackled as well. Further measures will be awareness campaigns, new communication channels, and improved provision of safety information. European XFEL aims to cultivate and continuously improve safety culture to make work safer and more enjoyable.

Corporate risk and asset management

Asset management in 2023 was distinguished by topics related to a mature facility. Inventory management, a perennial topic, was accompanied by maintenance management, configuration management, spare parts management, and process management. All of these topics had greater significance in 2023, as deterioration and repair activities increased. Based on the asset management report and requirements analysis from the previous year, several features were released to support inventory management, with an emphasis on these new topics.

The first asset management interviews for the next report, together with risk assessment discussions, were started in 2023. During the year, risk reporting was restructured. From now on, risk clusters and high-priority risks will be reported in more detail and presented more prominently in corporate risk reporting. After years of global crises, the reported risks decreased slowly but notably during 2023.

Customs and export control

In a globalized world with constantly changing threats and ever higher security requirements, export control is a very important topic, even in the environment of science and research. The Customs and Export Control Office supports all staff members, external users, and suppliers in matters related to customs, imports, exports, logistics, sanctions, and embargoes. In addition to information events for staff members and training documents for external users and suppliers, support includes the implementation of comprehensive compliance with export control as well as contact with the local customs authorities. All efforts aim at making cross-border activities as fast, cost-saving, and legally secure as possible, while imposing the minimum administrative burden.

It was particularly important to establish a process to check all submitted user proposals for compliance with international regulations on dual use, as this is time-intensive work requiring special knowledge. This process was further improved in 2023. Now, all proposals are checked in a structured and well-documented manner for indications of questionable Dual Use Research of Concern (DURC). The assessments carried out are transparently shared and reported by the Customs and Export Control Officer, which also helps to prepare for a potential review by the authorities. At the same time, the proposals are checked for any import bans and regulations for samples and substances sent by users.

INTERNATIONAL COLLABORATION

Collaboration is key to the successful operation of the European XFEL. As an international company supported by and based on funding from 12 member countries, European XFEL strongly engages with the European scientific community and in particular with the researchers and the shareholder representatives of its member countries. Activities include bilateral exchanges and meetings, joint workshops and events in collaboration with scientific and industrial partners, science schools to train the next generation of researchers, and visits of Management Board members to shareholder countries and institutions.

Such activities included, for example, the annual "HERCULES European School: Neutrons and Synchrotron Radiation for Science" for condensed-matter studies across disciplines from 27 February to 31 March 2023 and the "Budapest School on Modern X-ray Science 2023", which was organized by the Research Centre for Natural Sciences (HUN-REN) and took place on 3–6 October. To celebrate a coordination project to support the activities of Polish XFEL users, European XFEL scientists joined the opening event and workshop of the Polish XFEL hub on 14–15 September at the Institute of Physics of the Polish Academy of Science in Warsaw and also participated in the Workshop "XFELs for Beginners" on 12–13 October in Kraków.

On 23 October, to further strengthen connections to the Italian scientific community, the Management Board and Council Chair Federico Boscherini welcomed a delegation from Italy, led by CNR President and former Science Minister Maria Chiara Carrozza and the INFN Executive Board.

European XFEL is strongly dedicated to promoting European science by participating in numerous projects and networks. The Hanseatic Life Science Research Infrastructure Consortium (HALRIC) project for triple-helix innovation, for example, funded by the EU Interreg Öresund-Kattegat-Skagerrak (ÖKS) programme, brings together hospitals, universities, research infrastructures, regional governments, life science organizations, and industry in the Hamburg metropolitan area, greater Copenhagen, and the Skåne area. The project addresses global health challenges through world-leading life science innovation.

European XFEL also participates in the Horizon Europe Technology for High-Repetition-rate Intense Laser Laboratories (THRILL) project coordinated by GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany. The project aims at providing new designs and high-performance components for high-energy high-repetition-rate lasers, enabling the technical readiness level required to specify and build the devices, for instance for the European XFEL.

The Horizon Europe project UltraBat – Capturing Ultrafast Electron and Ion Dynamics in Batteries started in October, coordinated by the Technical University of Denmark, as part of the Battery 2030+ partnership. The aim of the project is to develop a methodology for investigating migration processes in battery materials on the microscopically relevant ultrashort timescales.

To strengthen connections in particular to other FEL facilities, European XFEL took the lead in organizing the 11th Hard X-Ray Free-Electron Laser Collaboration Meeting on Helgoland on 6–8 September, which brought together representatives from LCLS, PAL-XFEL, SACLA, SwissFEL, European XFEL, and SHINE (guest).

European XFEL is also a member of the European Intergovernmental Research Organisation forum (EIROForum), which brings together eight of the largest research infrastructures in Europe. The network has more than a dozen working groups dedicated to multiple common topics, dealing with the management and operation of international research facilities and coordinating the joint representation to international stakeholders, most importantly the European Commission. In July, European XFEL took over the annually rotating presidency of the network.

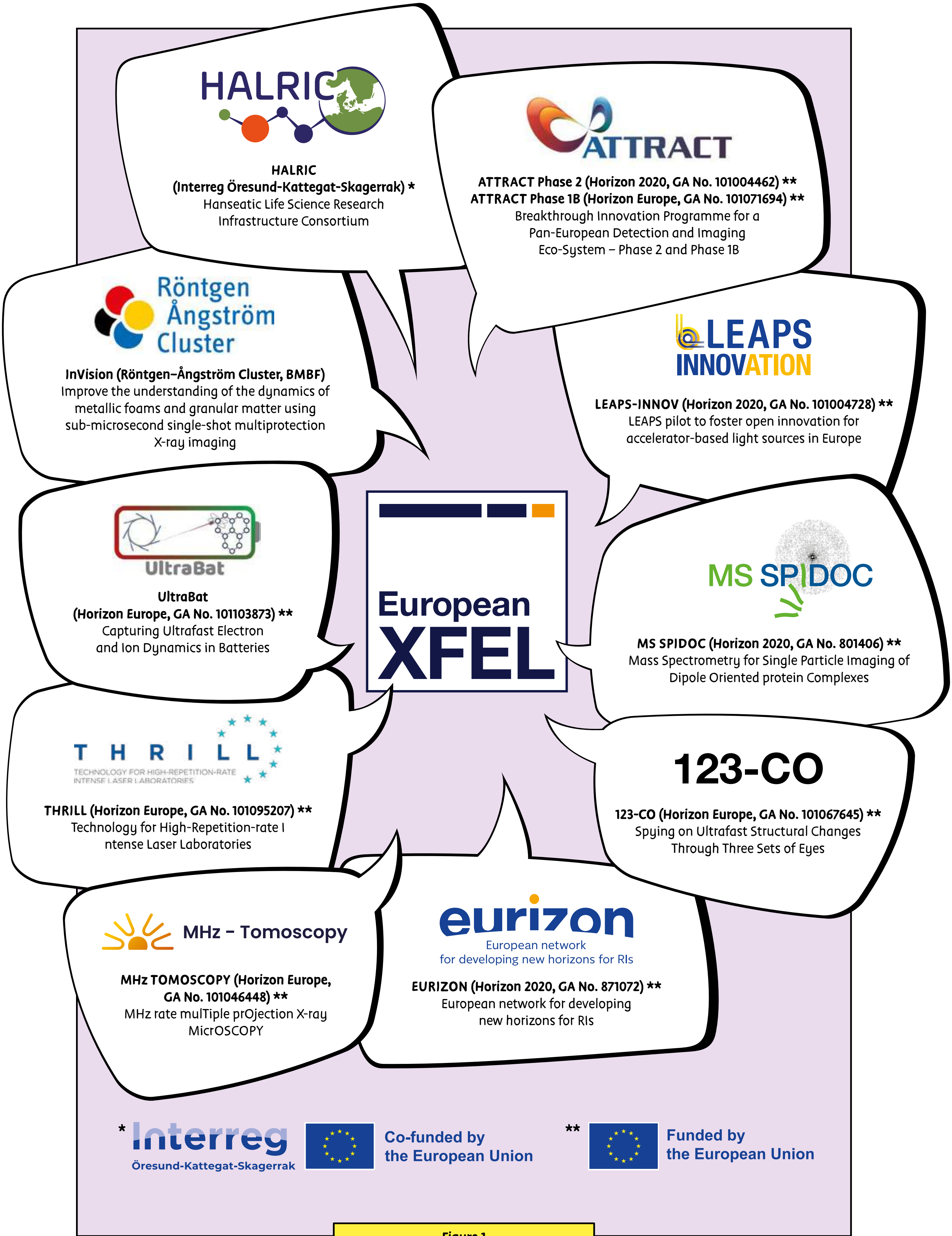


Figure 1
EU and other third-party funded projects

Figure 2
Joint CEA – European XFEL workshop "Engaging in closer collaboration" on 29 September at CEA Saclay, France

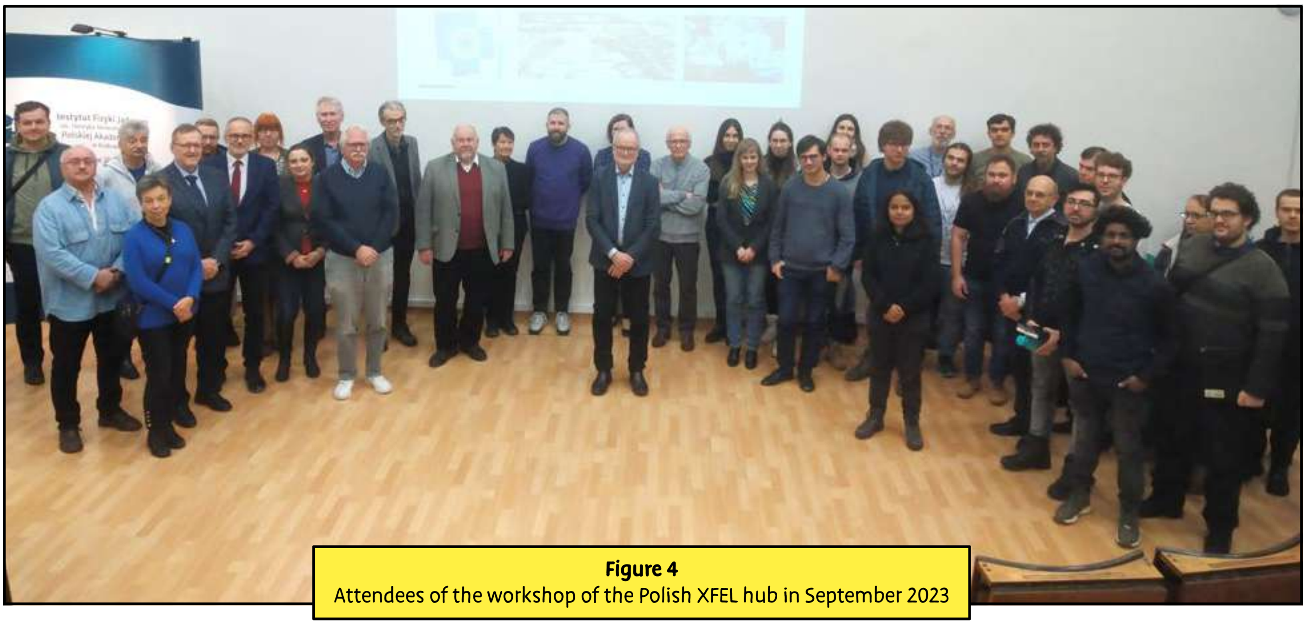


Figure 4
Attendees of the workshop of the Polish XFEL hub in September 2023

Moreover, European XFEL is a member of the League of European Accelerator-based Photon Sources (LEAPS) consortium, a network of European synchrotron radiation and FEL user facilities that work together to promote fundamental, applied, and industrial research. These interactions have resulted in very successful joint initiatives, such as the Horizon 2020 project LEAPS-INNOV, which enables joint technological developments with industrial companies as collaboration partners, suppliers, and users. LEAPS also takes an active role in exchanges with political stakeholders, for instance through a joint meeting with European Parliament representatives.

The membership in the FELs OF EUROPE collaboration links European XFEL to all other FEL facilities in Europe, with the aim to address technological and scientific challenges and serve the European science community by fully exploiting the scientific potential of these unique light sources. In 2023, European XFEL Scientific Director Serguei Molodtsov handed over the baton after a two-year term as chairman of the collaboration.

Demonstrating the connections to the scientific community across the Atlantic, European XFEL is part of the Helmholtz International Laboratory in Reliability, Repetition, Results at

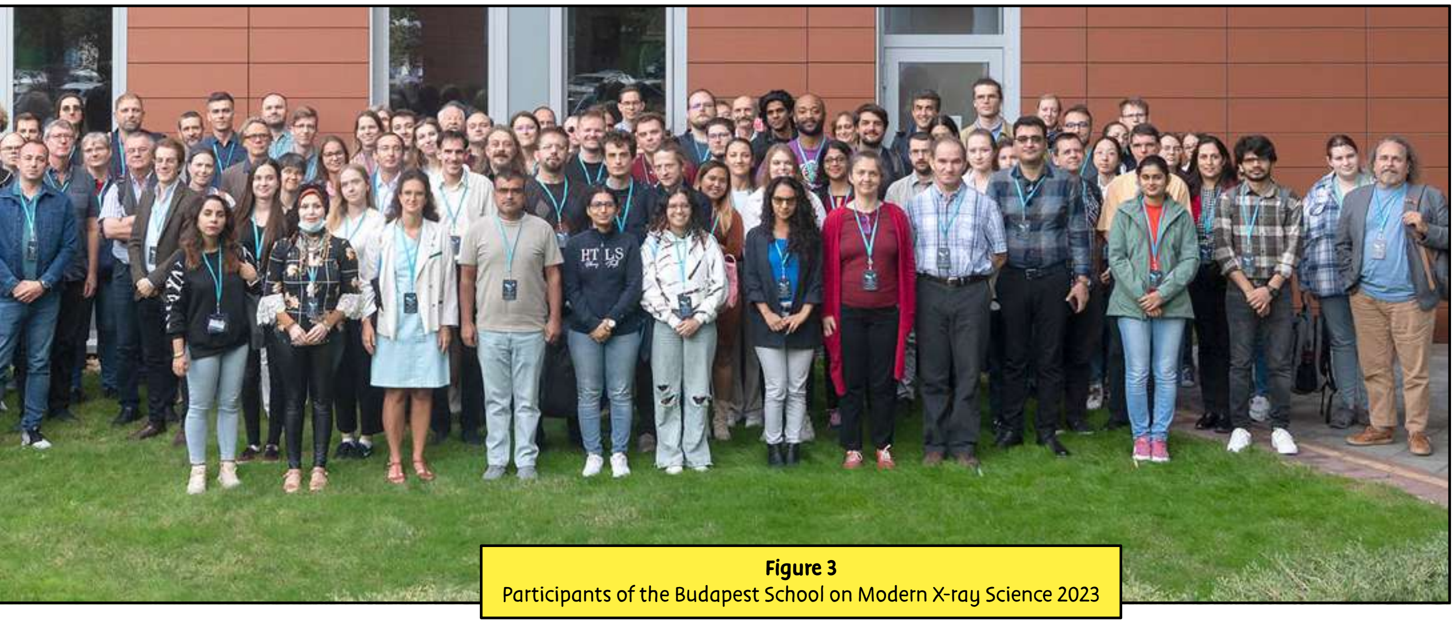


Figure 3
Participants of the Budapest School on Modern X-ray Science 2023

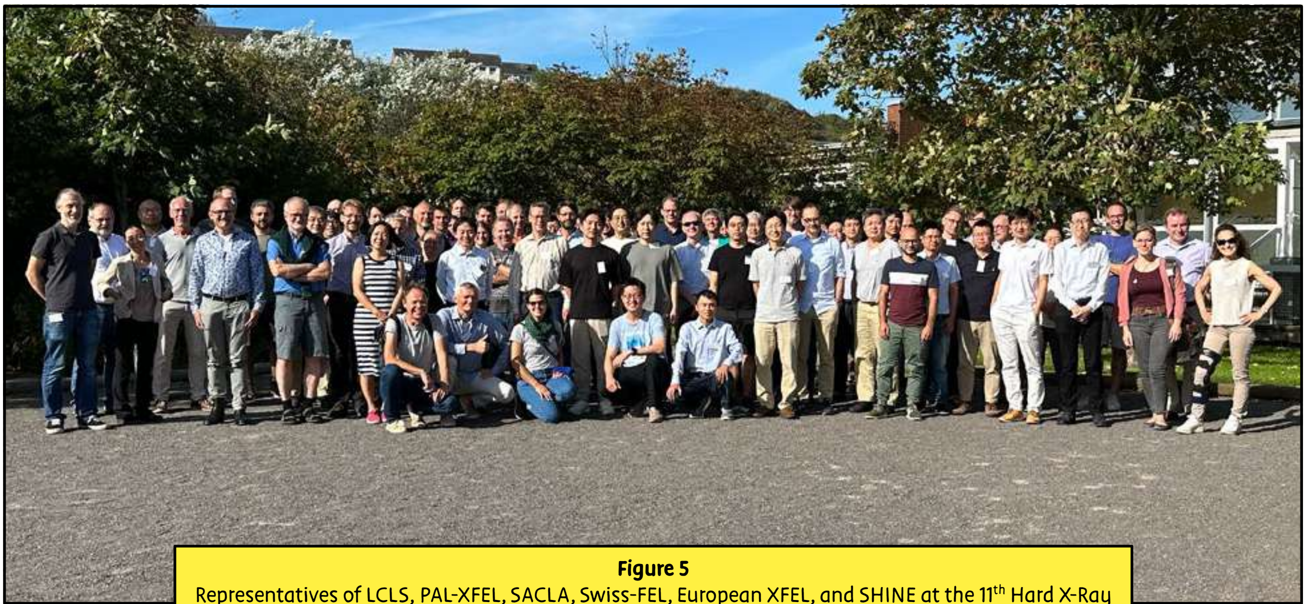


Figure 5
Representatives of LCLS, PAL-XFEL, SACLA, Swiss-FEL, European XFEL, and SHINE at the 11th Hard X-Ray Free-Electron Laser Collaboration Meeting on Helgoland on 6–8 September

the most advanced X-Ray Sources (HIR3X). Within four work packages, scientists from DESY, European XFEL, and SLAC exchange regularly on joint challenges and technological developments. On 10 November, the European XFEL management also met with Asmeret Asefaw Behre, Director of the Office of Science at the U.S. Department of Energy, who visited the facility for an exchange on the scientific connections between U.S. researchers and European XFEL.

As part of the Steering Committee of the International Year of Basic Sciences for Sustainable Development, European XFEL participated in the organization of events to raise awareness on the instrumental role that basic sciences play in the consecution of the United Nations' Sustainable Development Goals. European XFEL was one of the main organizers of a 24 hour online event on 5 June on how basic sciences contribute to the progress of the 2030 Agenda of the United Nations.

CONTACTS TO INDUSTRY

In 2023, an important achievement was the continuous collaboration with the national Industrial Liaison Offices (ILOs) of the shareholder countries. In addition, European XFEL started to include innovation-driven companies in the experiment programme.

To promote industrial collaborations, European XFEL is part of the international organization committee of the Big Science Business Forum 2024 in Trieste, which will bring together key suppliers and big science institutes. Expert presentations and dedicated booths for European XFEL and LEAPS will enhance opportunities for co-development and networking with technology providers.

European XFEL is increasingly collaborating with institutions in Central Europe, notably in Slovakia and Poland. In 2023, events such as the Slovak Industry Vision Day and the COINTT, KVTS, and EOSC conferences on technology transfer fostered industry connections. Collaborations also included proposals for Transformation and Innovation Consortia with the Slovakian space industry.

European XFEL promotes the use of the facility for applied science of industrial interest. An international research team, led by scientists from the University of Tokyo, Ibaraki University, and European XFEL, observed molecular motion in polybutadiene and carbon black samples. This groundbreaking study, involving institutions from Japan, Australia, and New Zealand, could lead to the enhancement of tire rubber durability. One co-author of the paper is affiliated with Sumitomo Rubber Industries, which underscores the industrial interest.

European XFEL also enables innovation “in the making”. It fosters the realization of state-of-the-art systems using third-party funding and supports applications.

In 2023, the patent application “Multi beam splitting and redirecting apparatus for a tomoscopic inspection apparatus, and method for creating a three dimensional tomoscopic image of a sample” was filed and published. The inventors were Patrik Vagovic (CFEL/DESY), Wataru Yashiro (Tohoku University), Valerio Bellucci (European XFEL), and Pablo Villanueva Pérez (Lund University). This international collaboration led to the design of a system for MHz tomoscopy. European XFEL actively supported the development of MHz imaging both through the funding application (European Innovation Council Pathfinder grant awarded in 2022), directly in the experiments, and by looking for possible industrial applications. Each experiment or proposal of MHz imaging has at least one company as an interested observer or future user. This result is quite remarkable at such an early stage of development of a new technique for light sources. One highlight involves the groundbreaking achievement of conducting MHz radiography on the ultrasonic exfoliation processes of two-dimensional functional materials. This accomplishment captivated the interest of green graphene production as well as ultrasonic machine manufacturers.

Figure 1
Conference on opportunities for Slovak industrial collaborations with intergovernmental research infrastructures, with participation of the Ministry of Education, Science, Research and Sport of the Slovak Republic, in Bratislava in 2023

Figure 2
ClusterXchange: industrial workshop at European XFEL in May 2023

Figure 3
Second national ILO meeting in December 2023 with representatives from shareholder countries

Figure 4
Undulator technology workshop at IPAC 2023 in Venice, Italy, in the framework of LEAPS-INNOV

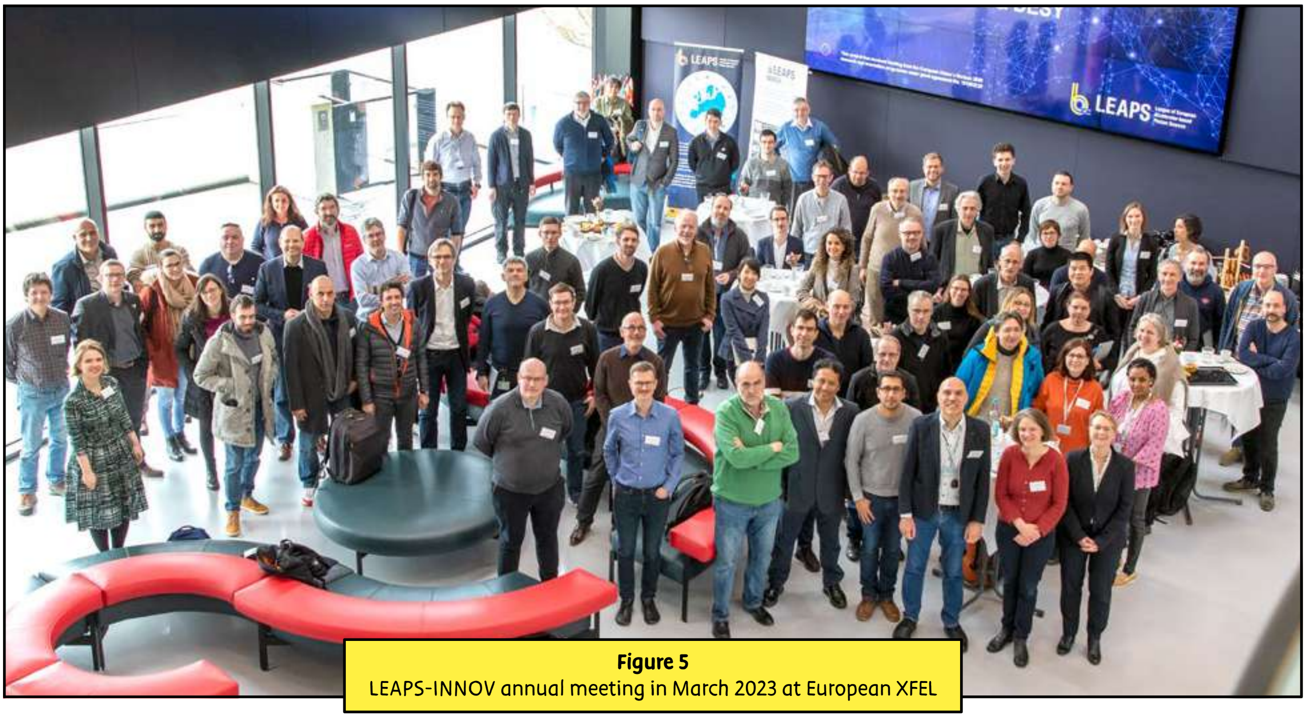


Figure 5
LEAPS-INNOV annual meeting in March 2023 at European XFEL

During the year, European XFEL also played a pivotal role in fostering academia–industry collaboration in the framework of the EU-funded project LEAPS-INNOV. Together with Elettra Sincrotrone Trieste in Italy, it facilitated knowledge and technology transfer of undulator technologies. Workshops, including a research-to-business workshop at the International Particle Accelerator Conference (IPAC) 2023 on “Development in undulator technology”, showcased advancements, encouraging mutual exchange and collaboration. The event attracted a large audience from industry, with over 30 participating companies, demonstrating high interest and engagement. Within the LEAPS-INNOV co-creation programme activities, European XFEL is also developing connections with different actors in battery research, such as Battery 2030+ and BID.

European XFEL also collaborated with CERN, EIRMA, and ESO to host the “European Breakthrough Technology Square” workshop on 20–21 April 2023. The event aimed to assist researchers from 18 ATTRACT Phase 2 research, development, and innovation projects in successful commercialization. Held on the European XFEL campus, it facilitated exchanges between project teams, venture capitalists, and innovation experts.

Another important event organized on the European XFEL campus in 2023 was a “Vacuum Day” held by technology provider Leybold, which offered training on vacuum technology to a large number of interested staff members from European XFEL and DESY.

In 2023, in cooperation with BigScience.dk, the Danish Technological Institute, Big Science Sweden, and the Spanish industrial cluster Ineustar, and within the framework of the EU-funded project ClusterXchange, more than 25 companies from Poland, Denmark, Sweden, and the UK were invited to present their technology platforms and capabilities after an introduction of the main developments at the European XFEL.

OUTREACH

Public events

At two major public events in city centres, European XFEL provided information to thousands of interested people. Over five days, almost 40 000 people attended the physics festival “Highlights der Physik” in Kiel, where they learned about physics research—including at the world’s largest X-ray laser. Some of the activities at the European XFEL stand were a hands-on diffraction experiment and a 3D virtual tour using virtual-reality headsets.

European XFEL also joined other research organizations in Hamburg for a two-day celebration of German Reunification near the Inner Alster lake in the city centre. This event was attended by 700 000 people. At the European XFEL stand, visitors completed a quiz to test their knowledge of the facility and its research and win small prizes like bags, hats, or pens.

Additional public outreach events in 2023 were the annual Schenefeld Christmas Market, where the outreach team was present, and Science Week Madrid in Spain, which was supported with information material.

Schools outreach

In 2023, European XFEL published its first Open Educational Resources. The modular materials provide high-school students with insights into virus research and comprise an informative and entertaining short video highlighting virus research at the European XFEL, an experiment dedicated to identifying coronavirus variants, materials for DNA sequencing, and the design of essential primers crucial for DNA amplification. The resources are available online under a Creative Commons license, which allows other educators to use the material freely. This project was supported by the Joachim Herz Foundation.

School class visits were facilitated not only through guided tours but also through special events. A winning team of the annual “Physik im Advent” competition run by the University of Göttingen and Gymnasium Buckhorn, Hamburg, toured the experiment hall and the campus and gained insights into X-rays and microscopy by carrying out experiments. Hands-on experiments and a chance to see an electron microscope were also popular with a group of students from Young Talents Hamburg who visited in the summer holidays.

Exhibitions

Over 100 000 visitors to the science ship ***MS Wissenschaft***, which toured Germany and Austria in 2023 with the exhibition “Unser Universum”, discovered how X-ray science provides insights into planetary cores at an interactive exhibit. At the European XFEL, samples in diamond anvil cells are subjected to a high pressure of one hundred billion pascals—as much as the weight of 200 elephants on a fingertip. At the exhibit, visitors experienced, in a test of strength, how difficult it is to generate such high pressures. During the ship’s stay in Hamburg, two Ph.D. candidates from European XFEL answered visitors’ questions as part of a “Meet the Scientist” event.

Another exhibition, “Arts & Science” from the Hamburg Centre for Ultrafast Imaging (CUI), was presented in the foyer of the European XFEL headquarters after it was displayed in the Hamburg City Hall. The large-format visualizations in the exhibition, based on images submitted by CUI researchers, including some from European XFEL, offered insights into the scientific phenomena explored within the centre. One of the images submitted by European XFEL was also chosen as the cover picture of the “CUI 2024 Arts & Science” calendar.

Guided visitor tours

With more than 1800 visitors in 88 groups in 2023, the guided tour programme recovered from the dip created by the pandemic and reached a popularity similar to the pre-COVID year 2019. Visits usually consisted of a presentation as well as a walking tour of the experiment hall. Most tours were offered to school and university students. Other visitors included attendees of scientific conferences and stakeholders.

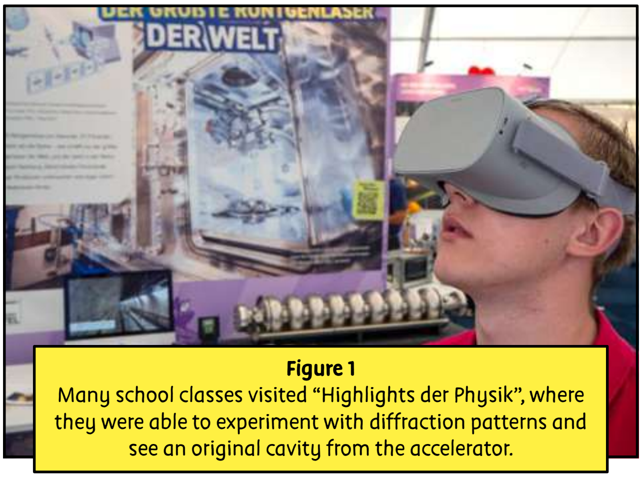


Figure 1
Many school classes visited "Highlights der Physik", where they were able to experiment with diffraction patterns and see an original cavity from the accelerator.

Figure 2
Enjoying the European XFEL exhibit aboard the *MS Wissenschaft*

Figure 3
School students testing experiments before they were published as an Open Educational Resource

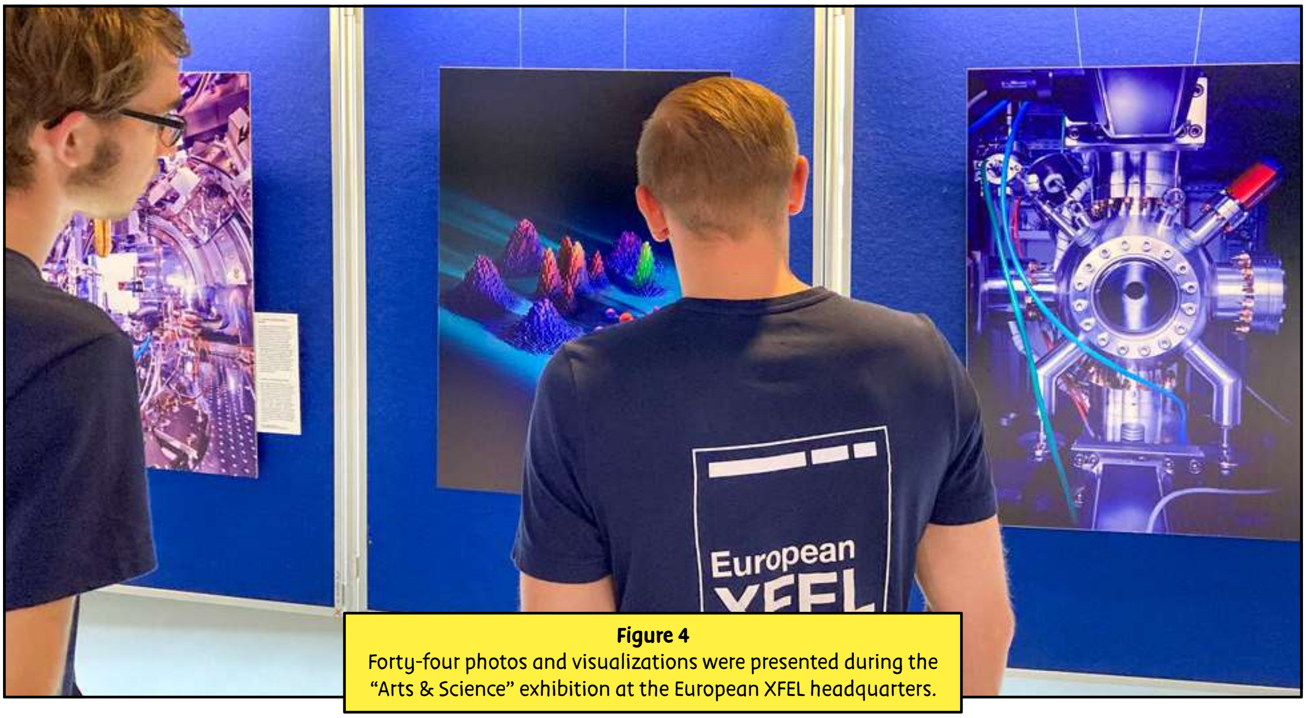


Figure 4
Forty-four photos and visualizations were presented during the "Arts & Science" exhibition at the European XFEL headquarters.

Figure 5
Schenefeld's Mayor Christiane Küchenhof opening the new campus tour with European XFEL Managing Directors Robert Feidenhans'l and Nicole Elleuche

Figure 6
"Infopoint Bahrenfeld" informs visitors about the European XFEL facility and the research done there as well as the connection with DESY.

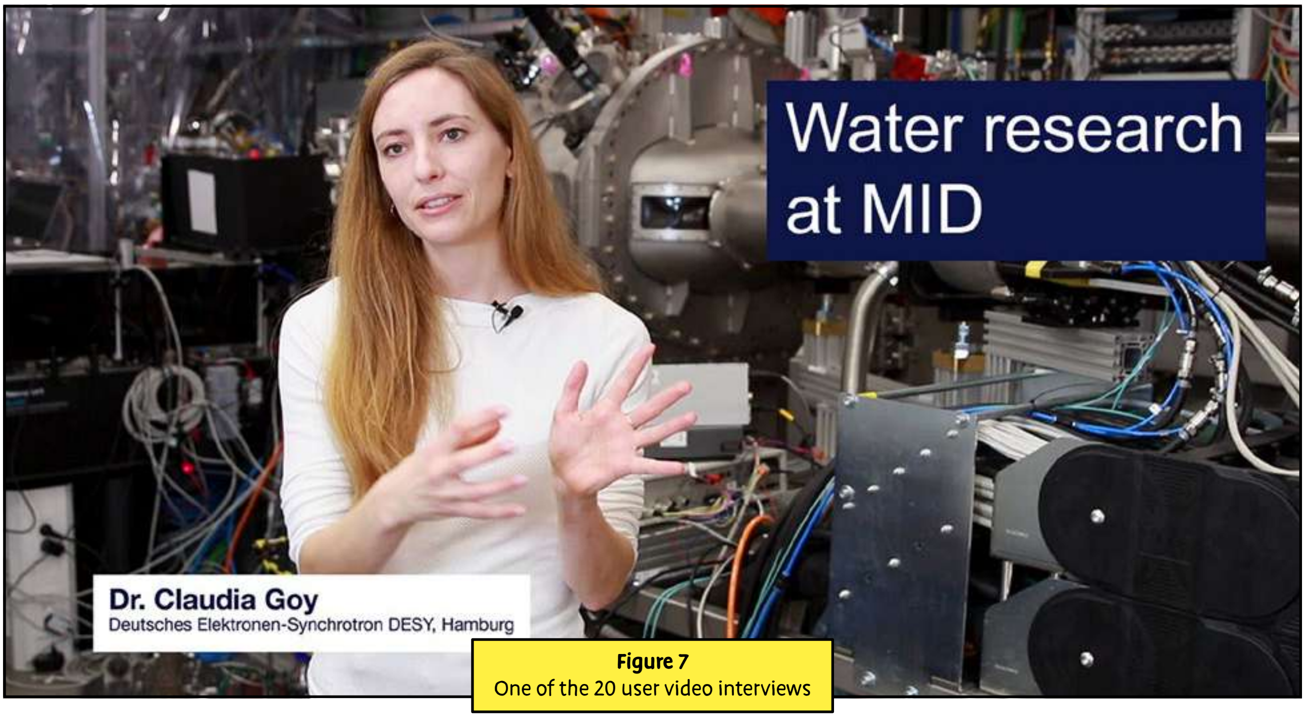


Figure 7
One of the 20 user video interviews

Self-guided tour

In May 2023, European XFEL opened a self-guided campus tour along a green line with information panels about the research facility and the renaturation measures on and around the campus. The signposted route is 1.6 km long and stretches from the entrance of the company premises to the Düpenau river.

The open-air exhibition "Infopoint Bahrenfeld" is located in front of the entrance hall of the accelerator tunnel on the DESY campus. It was completed in 2023 and presents European XFEL on seven information plates, together with a map of the tunnels on the pavement underneath an original tubbing ring.

Video production and online communication

To date, European XFEL has more than 15 000 followers on the social media channels YouTube, X (formerly Twitter), Facebook, LinkedIn, and Instagram. New multimedia materials supported online communication through the company website and social media. A new series of captivating videos features scientists shedding light on their experiments at the European XFEL. Twenty users of the facility were interviewed in 2023, with the videos collected in the playlist "User statements" on the European XFEL YouTube channel.

DIRECTOR'S OUTLOOK

As we look ahead, our focus remains on further developing European XFEL, on staying competitive and influential in the scientific community, and on supporting our users in solving science questions by providing them with access to cutting-edge experimental opportunities, technologies, and expertise. In 2024, European XFEL will continue to champion user support, prepare for the shutdown in the second half of 2025, start to implement the Strategy 2030, enhance data science capabilities, reinforce company values, advance sustainability, and continue to deliver outstanding scientific results. As a member institution of the EIROforum network, we contribute our opinions and visions to the European Research Area.

First of all, I would like to take the opportunity to thank all members of the advisory and governing committees for supporting us also in the year to come. We are immensely grateful for the forthcoming counsel that they offer, steering us towards greater success. We sincerely appreciate their commitment to shaping our future endeavours.

At the heart of European XFEL's endeavour lies its commitment to producing excellent scientific results that contribute to the advancement of knowledge and to finding solutions to today's societal challenges. To uphold this commitment, we will continue to foster a culture of excellence in research by providing our teams with the resources, support, and opportunities they need to excel in their respective fields. European XFEL actively promotes the publication and dissemination of our users' research findings through peer-reviewed journals, conferences, and other channels to maximize impact and visibility. We also need to cultivate collaborative partnerships with academic institutions, industry partners, and other stakeholders to leverage complementary expertise and resources and drive impactful research outcomes.

Enhancing the user experience and providing exceptional support to our stakeholders remain key priorities of European XFEL. To achieve this, we plan to further invest in comprehensive user training programmes and resources and aim to empower our stakeholders to leverage our facilities and services to their fullest potential. By improving our feedback mechanisms, we will gain better insights into user needs and preferences, enabling us to tailor our support services to better meet their expectations.

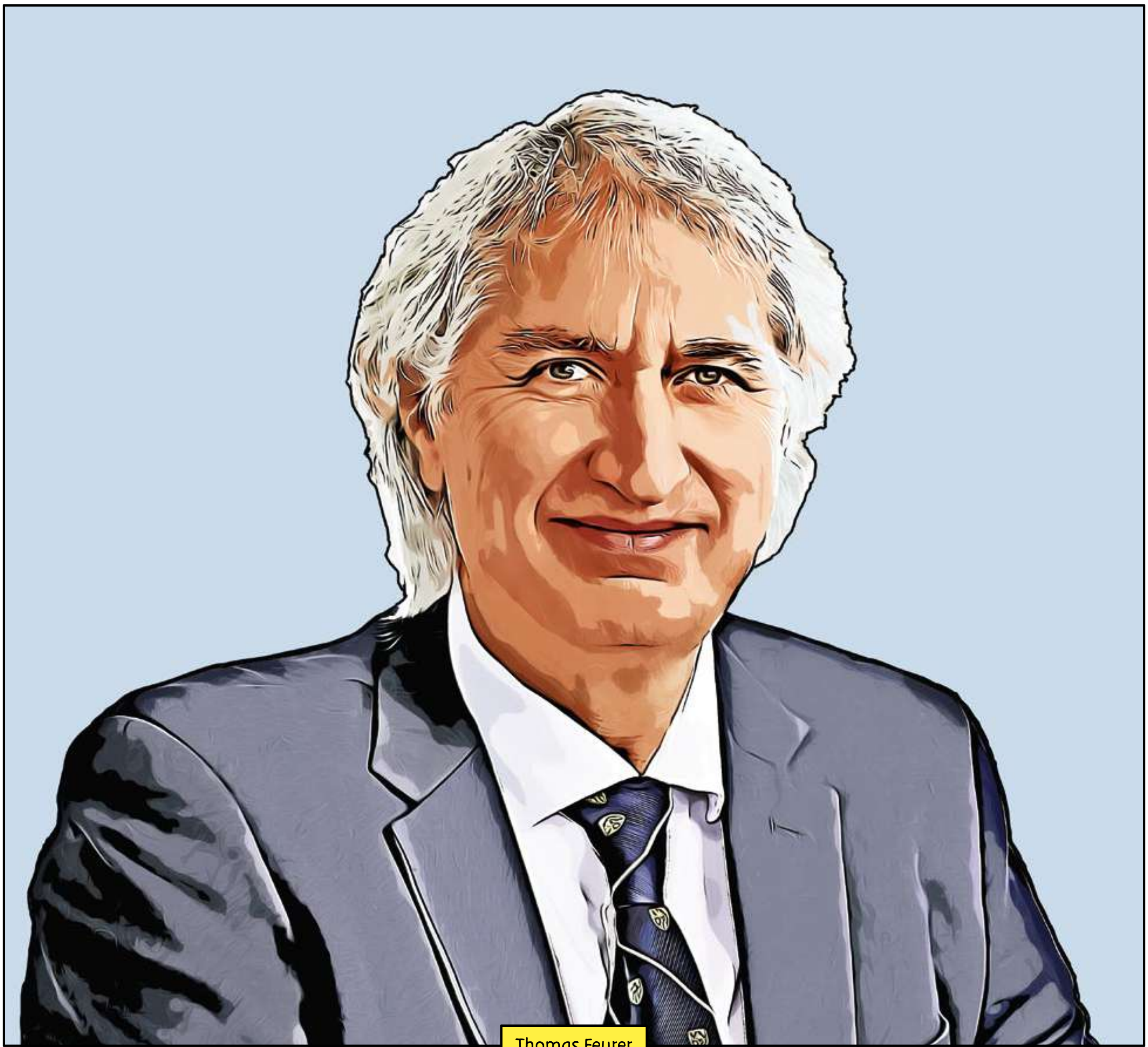
Harnessing the power of data science is critical for gaining insights into complex scientific phenomena, many of which have direct consequences for the societal challenges we face today. To advance European XFEL's data science capabilities, we will invest, for instance, in robust data infrastructure and analytics platforms to support data-driven decision-making already in the control rooms and assist collaborations across the international user communities. We will provide training and development opportunities to equip less-experienced user teams with the necessary skills and knowledge in data science and analytics.

The successful implementation and execution of European XFEL's strategic initiative will be central to our progress, not only in the year to come but also in the coming decade and beyond. Building upon the concept laid out in our strategy document, we will prioritize according to strategic alignment and considering resource optimization combined with agile adaption.

Anticipating and preparing for the upcoming shutdown in 2025 is essential to minimize disruptions and ensure a smooth start of operation afterwards. We will finalize comprehensive shutdown plans encompassing maintenance schedules, equipment upgrades, and facility enhancements to optimize performance and reliability post-shutdown. Throughout the shutdown, we plan to engage with all stakeholders proactively and transparently to ensure alignment of expectations and minimize the impact of unforeseen challenges.

European XFEL's company values serve as the foundation of our organizational culture and guide our behaviour and decision-making. To strengthen our commitment to these values, we will continue to work on the integration of our values into our organizational culture and ensure they are reflected in our day-to-day operations and interactions. It is important that we lead by example, demonstrating our commitment to our values through our actions and behaviours within the organization.

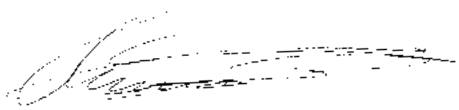
As a steward of the environment, European XFEL is committed to advancing sustainability in all aspects of our present and future operation and to include sustainability requirements in all of our upgrades. This will be achieved by implementing different measures to reduce our carbon

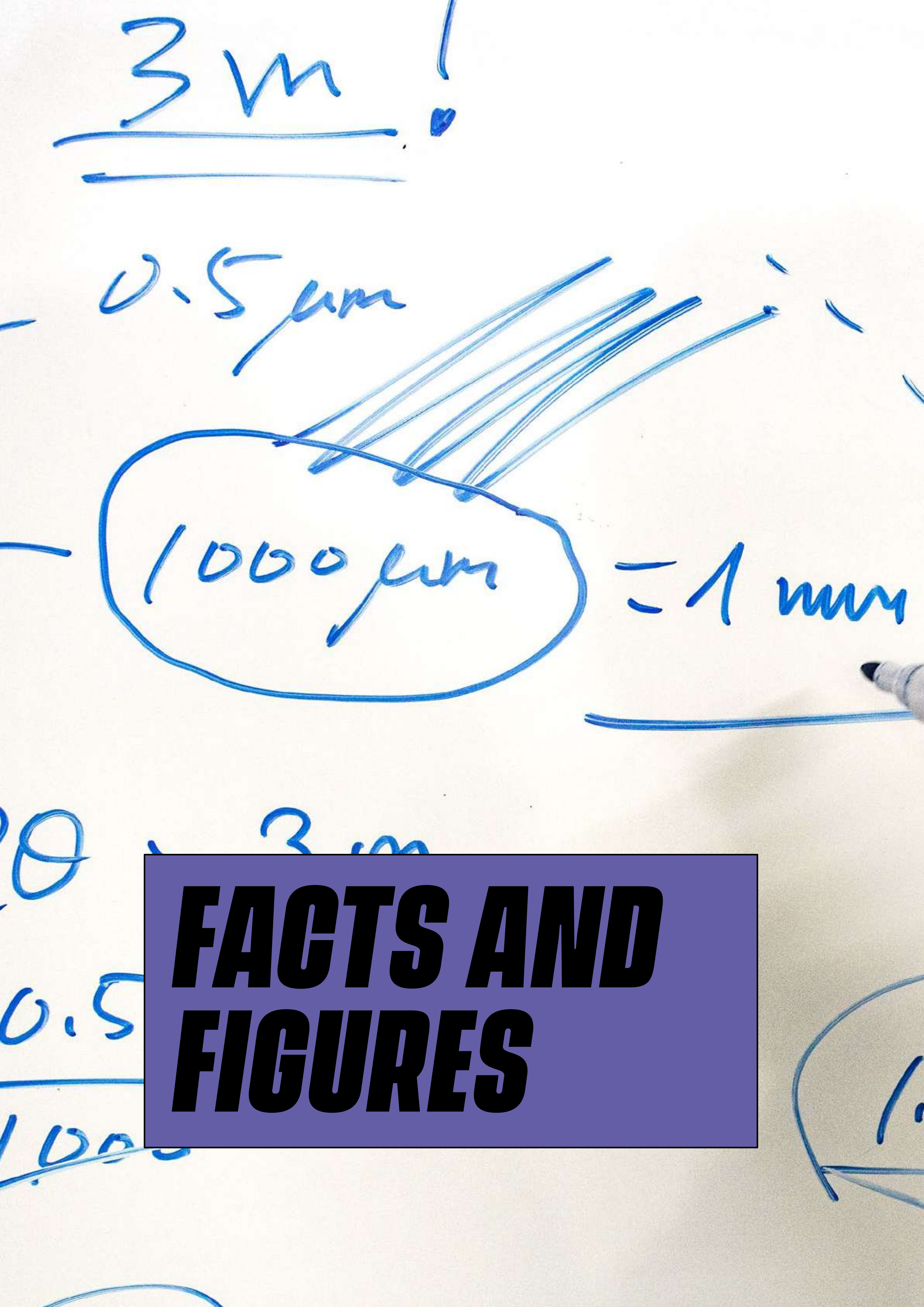


Thomas Feurer

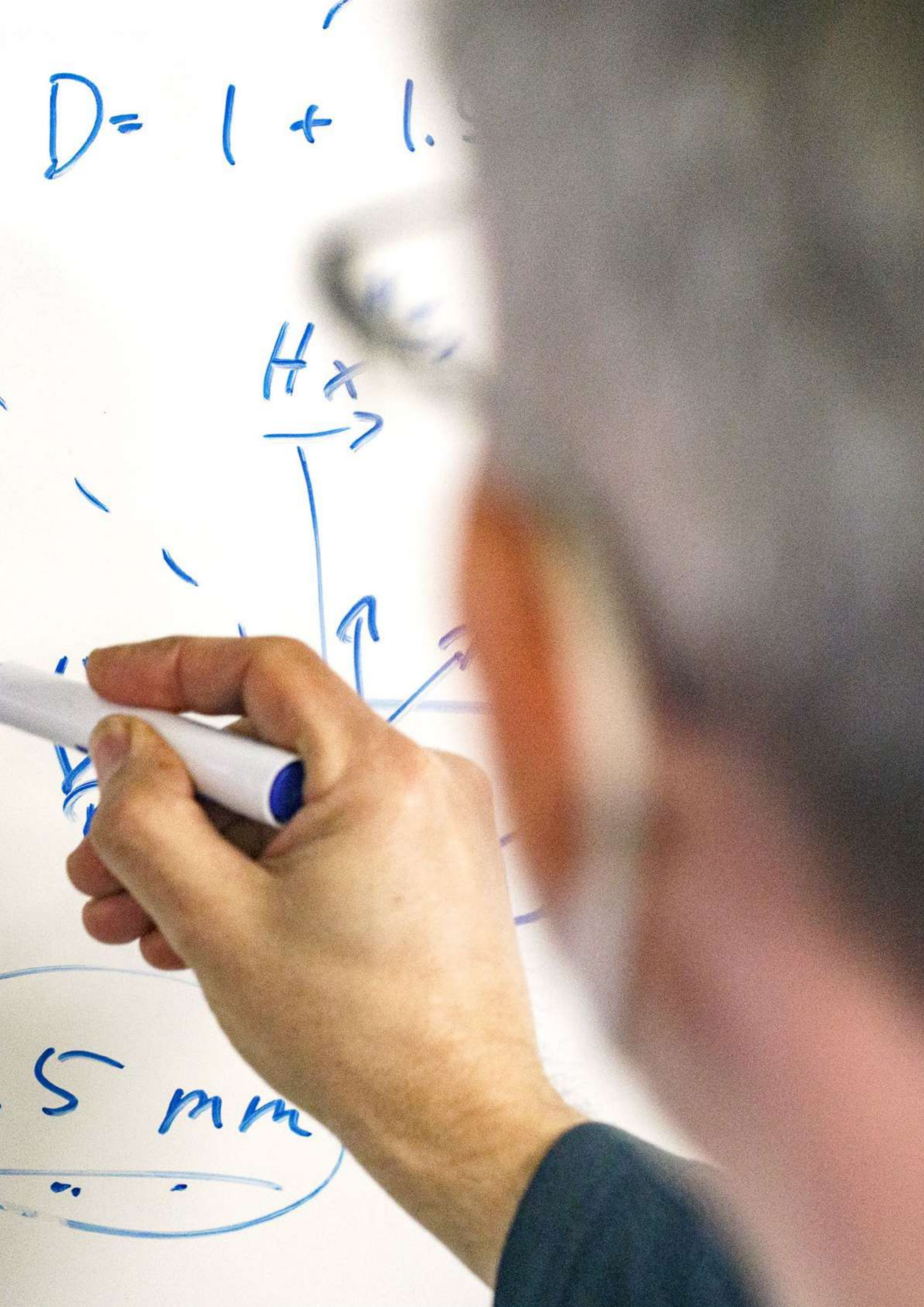
footprint, for instance by installing photovoltaic panels, establishing sustainable procurement and travel, and minimizing waste. Through the new European XFEL visitor and conference centre “Lighthouse”, we plan to engage with and reach out to communities and schools. The Lighthouse will also showcase our contributions through basic science to a multifaceted sustainability agenda. We aim to lead in sustainable materials, technologies, and practices to drive positive environmental impact both within our organization and beyond.

As we move into 2024, I am grateful to have all of European XFEL’s employees on board. Every single member of European XFEL is crucial for its success and every single individual has a share in us being the leading institution in XFEL science. By staying true to our mission, vision, values, and commitment to excellence, I am convinced we will achieve our goals and make outstanding contributions to the scientific community and society at large.





FACTS AND FIGURES

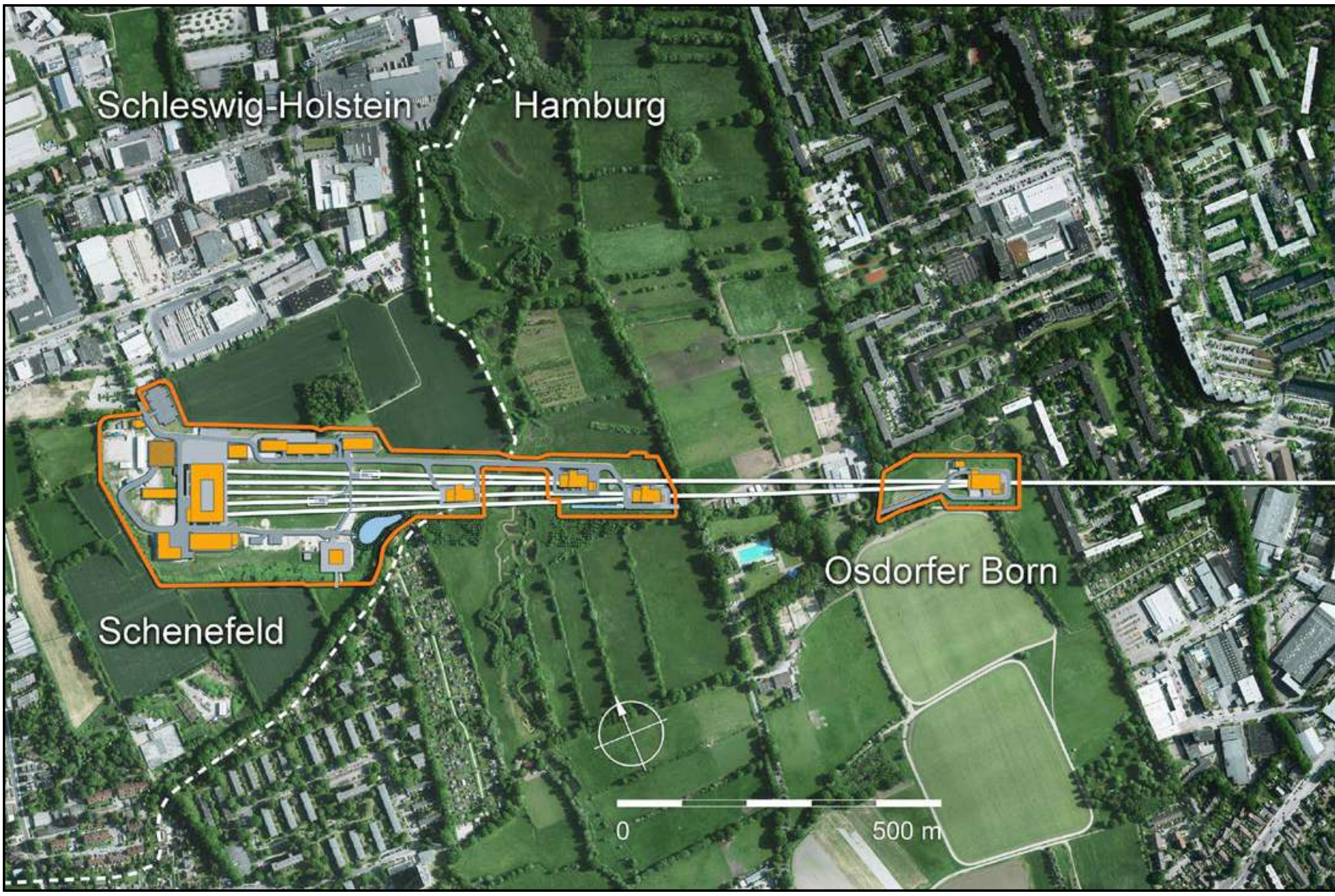


AT A GLANCE

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.

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), and a second office building (complet-



ed in 2023). A visitor and conference centre, “Lighthouse”, is due to open in 2024.

As of December 2023, 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 146 million euro. The construction costs, including commissioning, amounted to 1.25 billion euro (at 2005 price levels). In 2023, the host country, Germany (federal government, city-state of Hamburg, and state of Schleswig-Holstein) covered 58% of the costs. Russia contributed 27%, and each of the other international shareholders between 1% and 3%. To a great extent, the European XFEL facility was realized by means of in-kind contributions by shareholders and partners.

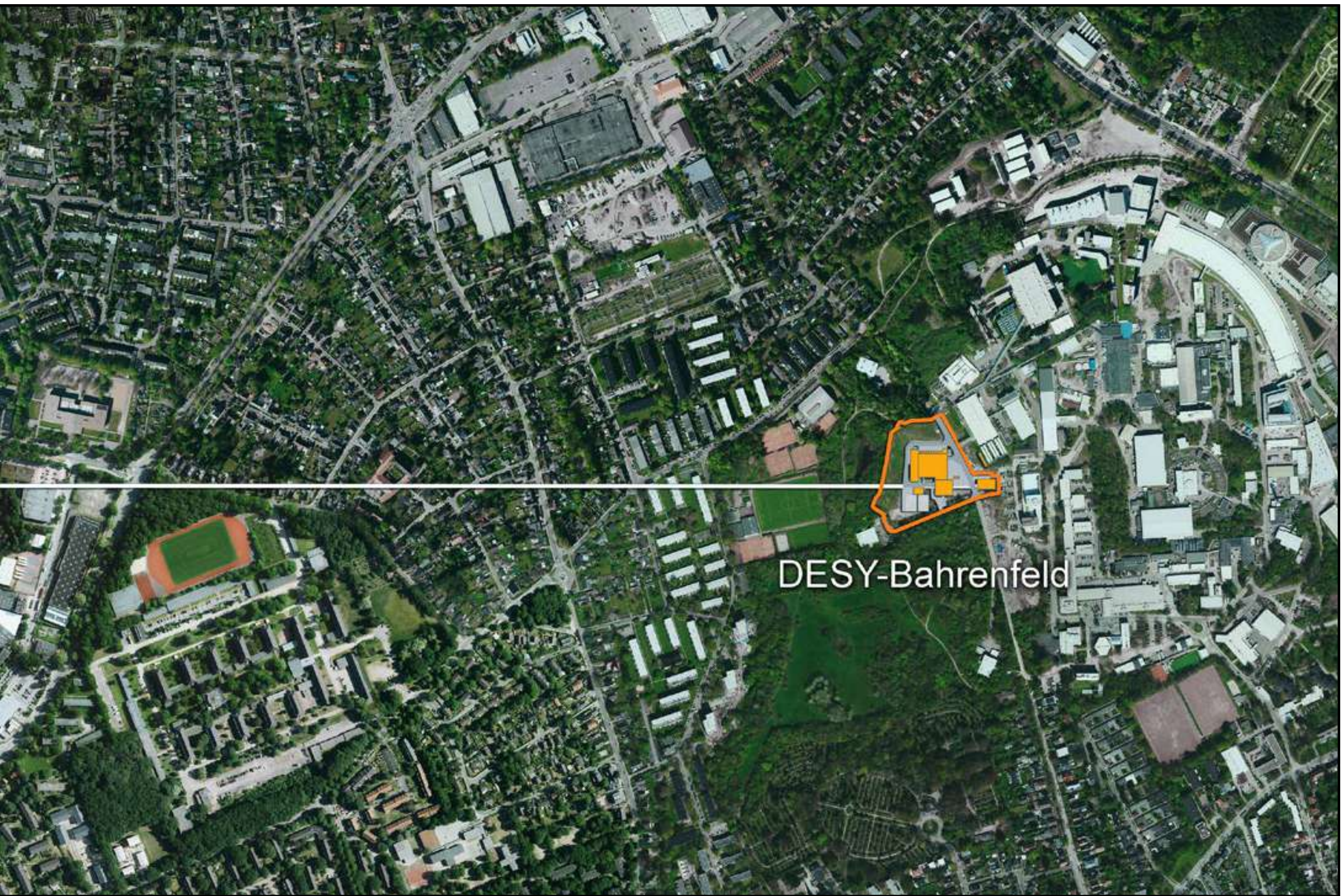


Figure 1
Aerial view of the European XFEL facility. Left to right: Schenefeld, Osdorfer Born, and DESY-Bahrenfeld sites.

STAFF

Total headcount including guests: **580**

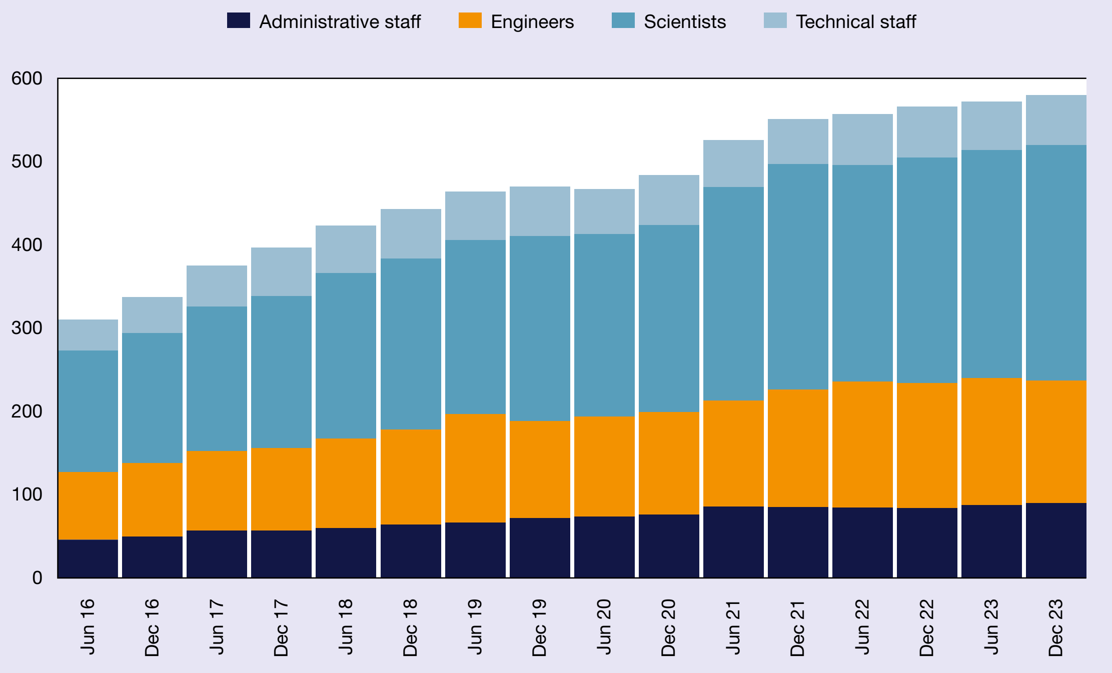


Figure 1
Staff development

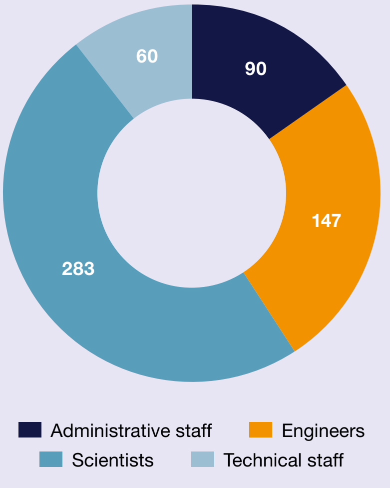


Figure 2
Functions

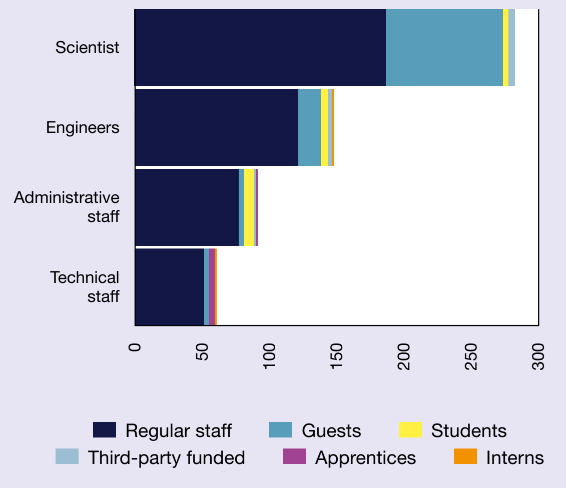


Figure 3
Contracts

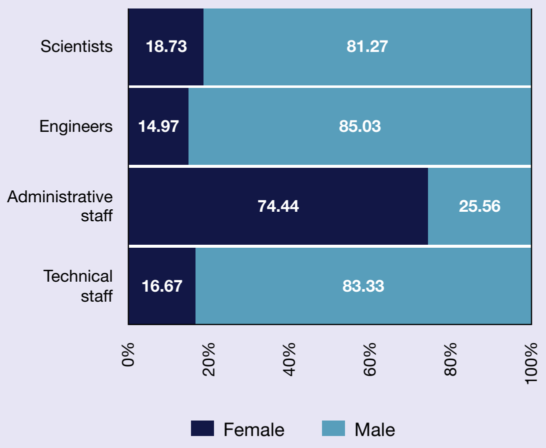


Figure 4
Gender ratio (in %)

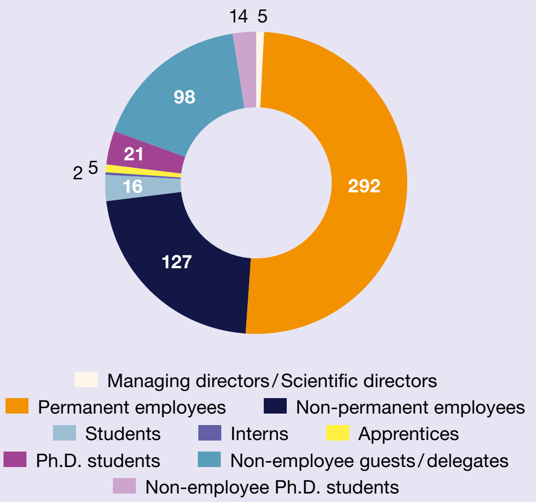


Figure 5
Contractual Status

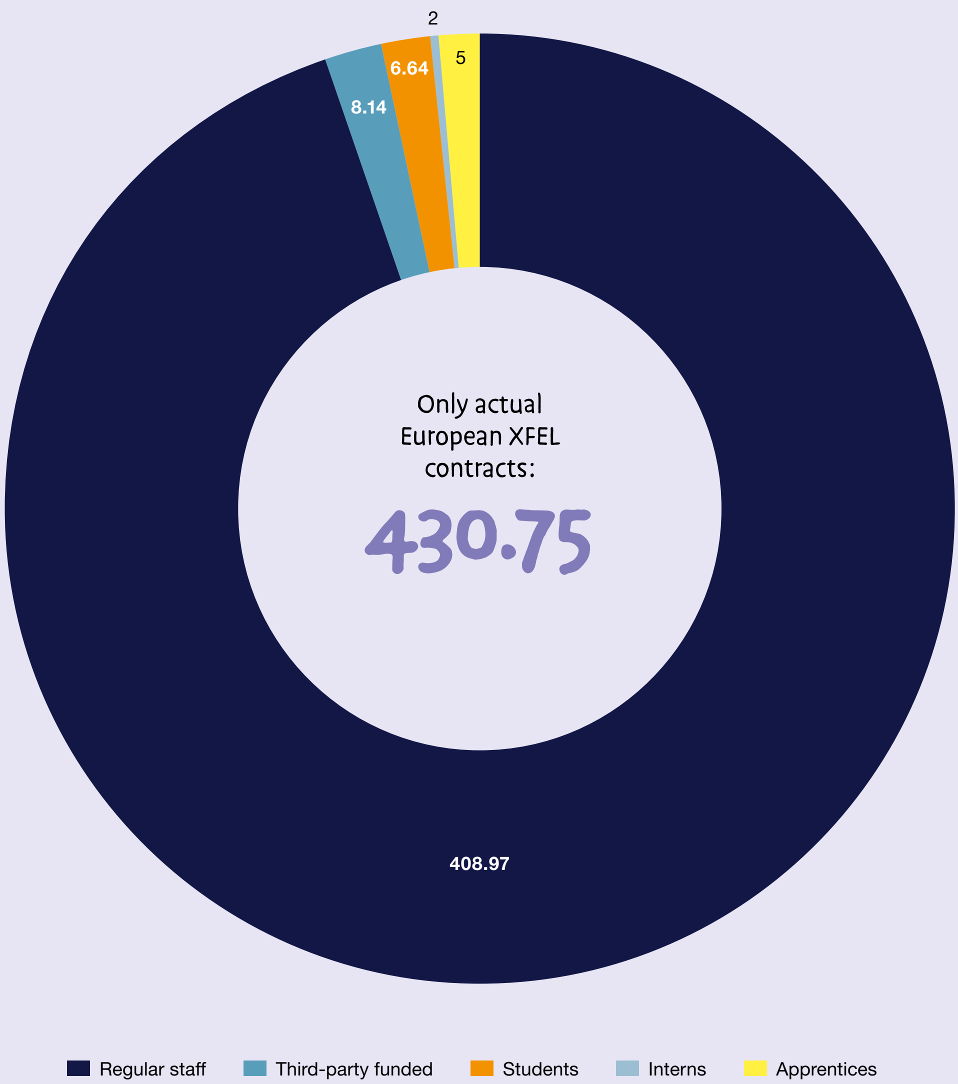
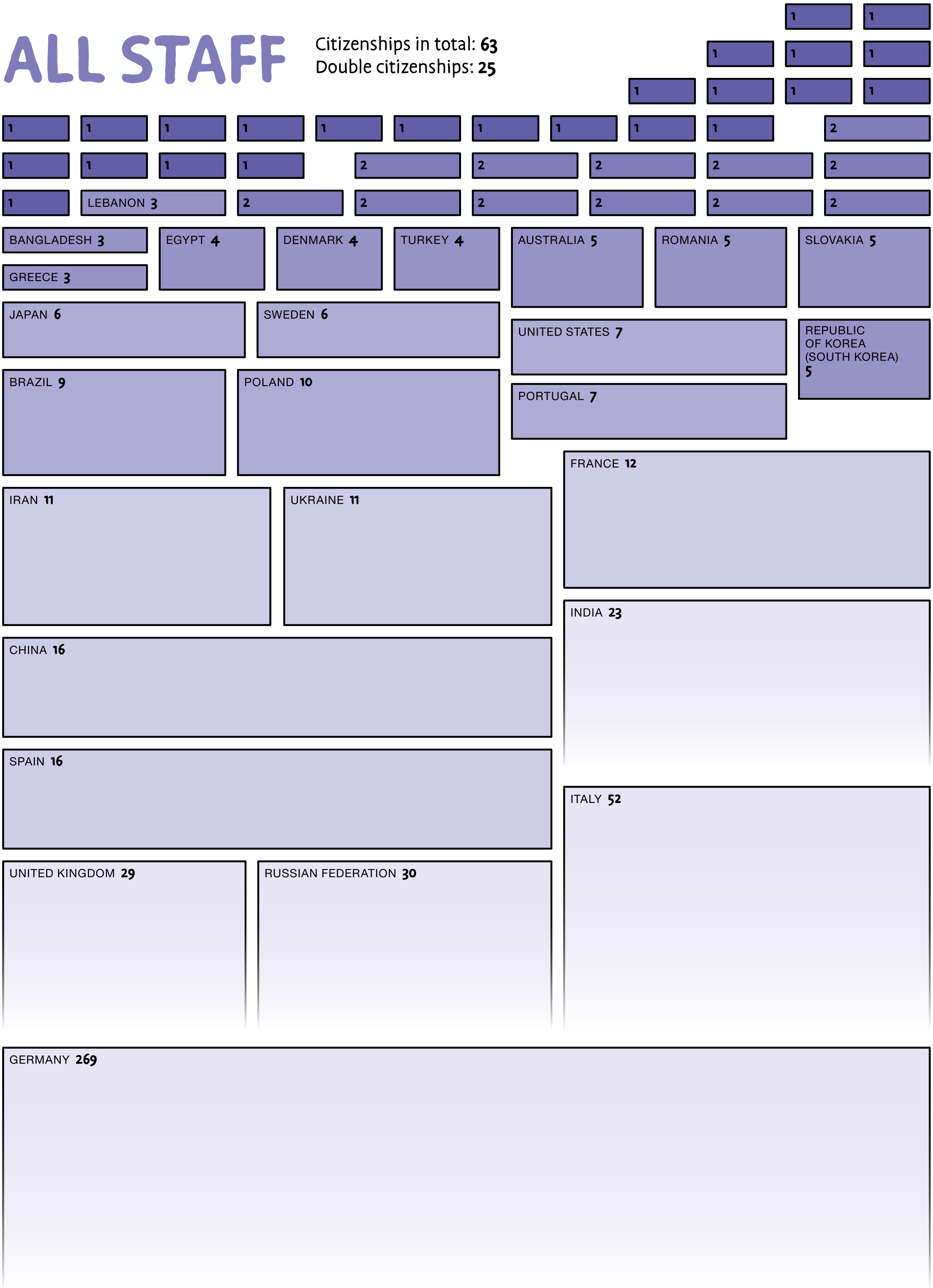


Figure 6
Full-time equivalents

ALL STAFF

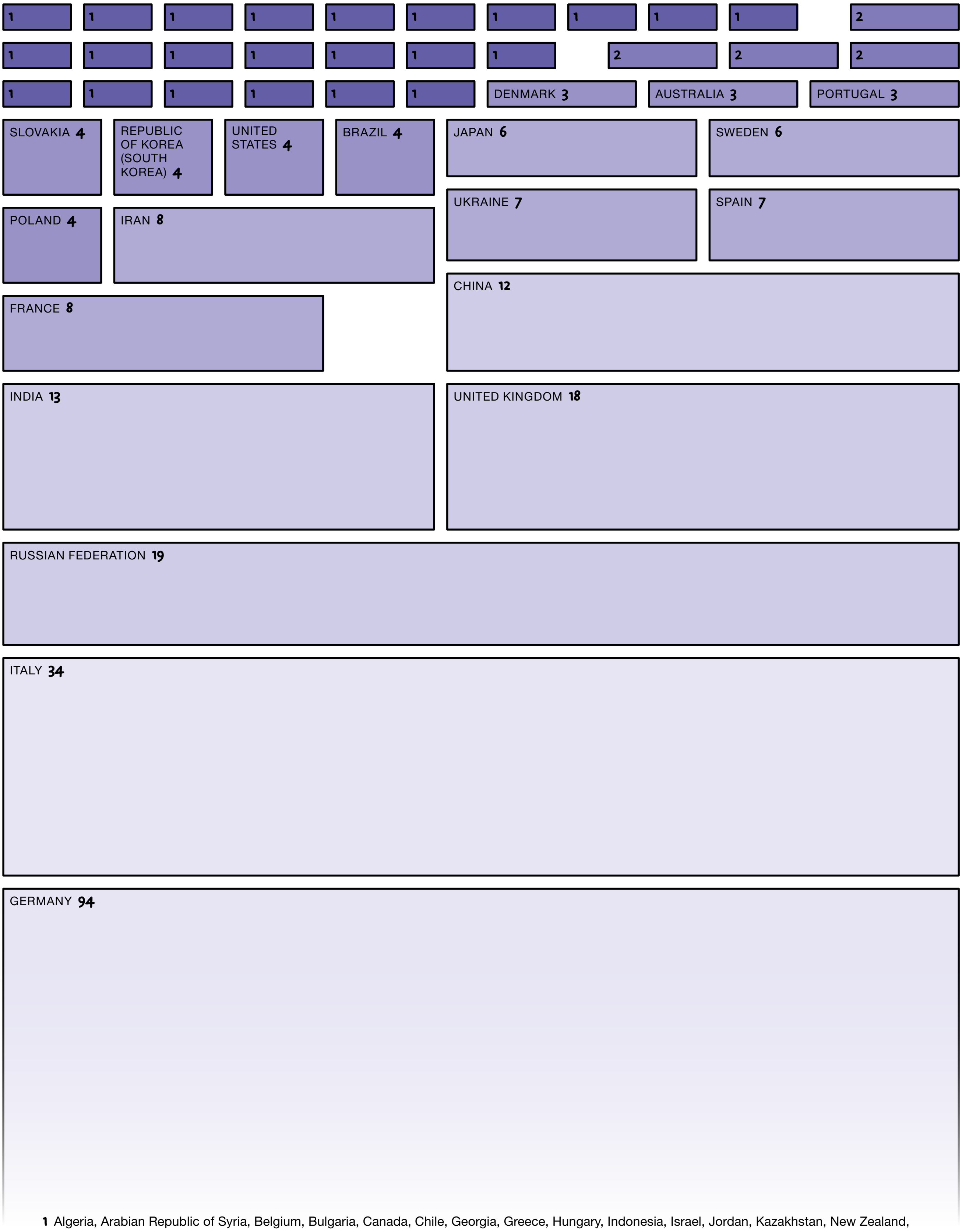
Citizenships in total: **63**
Double citizenships: **25**



1 Albania, Algeria, Arabian Republic of Syria, Azerbaijan, Belgium, Bulgaria, Chile, Ecuador, Ethiopia, Finland, Hungary, Israel, Kazakhstan, Kenya, Latvia, Malaysia, Sudan, Switzerland, Taiwan, Thailand, The Netherlands, Venezuela, Vietnam, Yemen
2 Croatia, Georgia, Serbia, Armenia, Canada, Indonesia, Jordan, Mexico, New Zealand, Pakistan, Philippines, Austria, Czech Republic

SCIENTIFIC STAFF

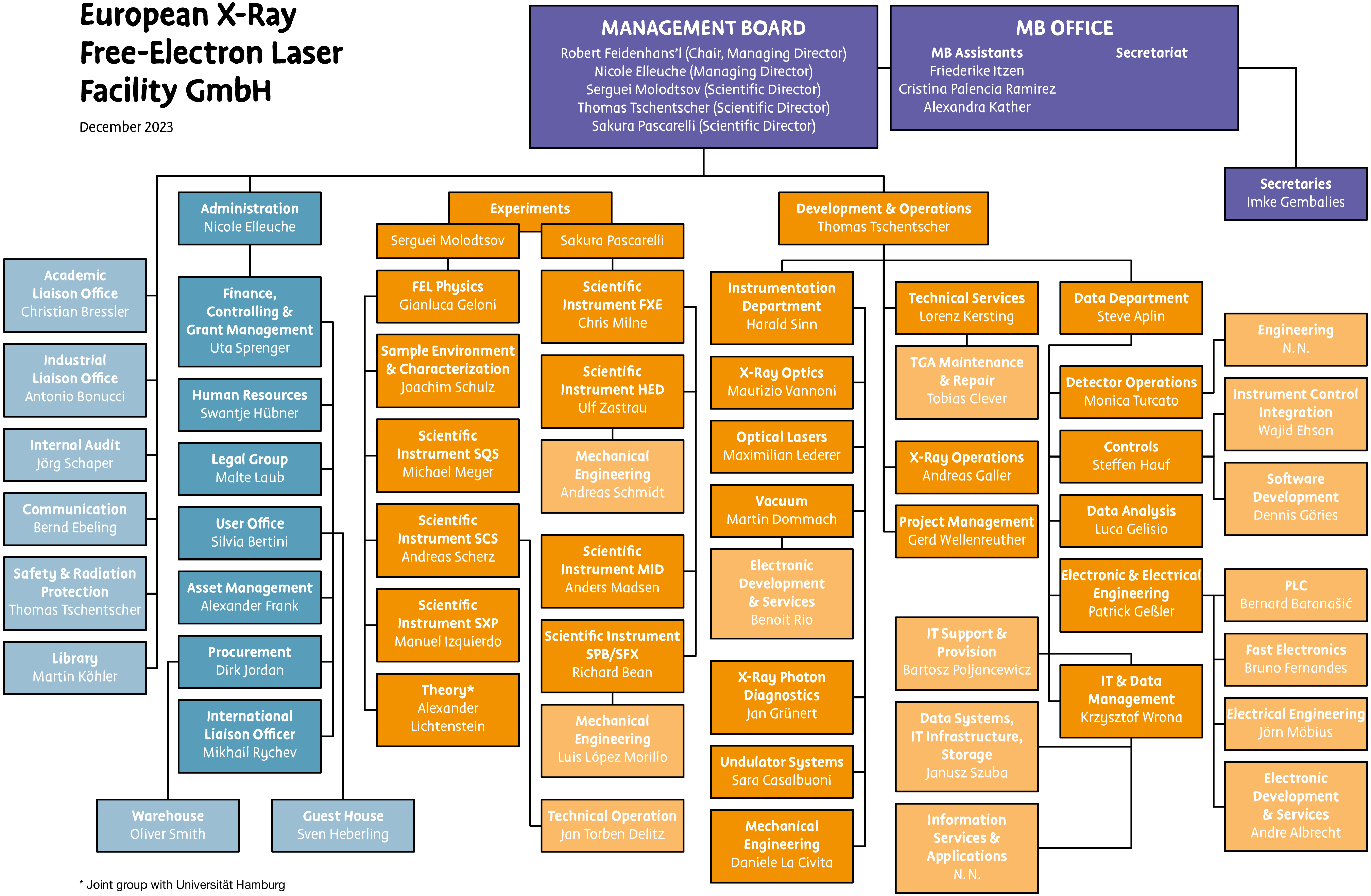
Citizenships in total: **47**
Double citizenships: **9**



1 Algeria, Arabian Republic of Syria, Belgium, Bulgaria, Canada, Chile, Georgia, Greece, Hungary, Indonesia, Israel, Jordan, Kazakhstan, New Zealand, Pakistan, Romania, Sudan, Switzerland, Taiwan, Thailand, Turkey, Vietnam, Yemen
2 Austria, Czech Republic, Lebanon, Egypt

European X-Ray Free-Electron Laser Facility GmbH

December 2023



* Joint group with Universität Hamburg

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.

Chair		**Federico Boscherini** (University of Bologna)
Vice Chair		**James Naismith** (Rosalind Franklin Institute, Didcot)
Delegates	Denmark	**Martin Meedom Nielsen** (DTU, Kongens Lyngby)
		Morten Scharff (DAFHES, Copenhagen)
	France	**Sylvain Ravy** (CNRS, Paris)
		Maria Faury (CEA, Paris)
	Germany	**Volkmar Dietz** (BMBF, Bonn)
		Helmut Dosch (DESY, Hamburg)
	Hungary	**Györgyi Juhász** (NRDI Office)
		György Vankó (Wigner Research Centre for Physics, Budapest)
	Italy	**Carlo Pagani** (INFN, Milan)
		Corrado Spinella until 30 September 2023 (CNR, Rome)
		Stefano Fabris as of 1 October 2023 (CNR, Rome)
	Poland	**Mateusz Gaczyński** (Ministry of Education and Science, Warsaw)
		Ryszard Sobierajski (Institute of Physics PAS, Warsaw)
	Russia	**Mikhail Kovalchuk** (NRC KI, Moscow)
		Alexander Blagov / **Mikhail Polyakov** (NRC KI, Moscow)
	Slovakia	**Karel Saksl** (Technical University of Košice)
		Pavol Sovák (P.J. Šafárik University, Košice)
	Sweden	**Johan Holmberg** (VR, Stockholm)
	Switzerland	**Gabriel Aeppli** (PSI, Villigen)
		Laurent Salzarulo (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)

Figure 1
The European XFEL Council during the Council meeting in June 2023

Secretary		**Malte Laub** (European XFEL, Schenefeld, Germany)
Vice Secretary		**Friederike Itzen** (European XFEL, Schenefeld, Germany)
Advisors	France	**Marie-Hélène Mathon** (CEA, Paris)
	Germany	**Christian Harringa** / **Wim Leemans** (DESY, Hamburg)
		Dennis Scherer until 22 October 2023 (BMBF, Bonn)
		Dirk Steinbach as of 23 October 2023 (BMBF, Bonn)
	Italy	**Alberto Morgante** (University of Trieste and IOM-CNR, Trieste)
		Daniele Sertore (INFN, Milan)
	Poland	**Dagmara Milewska** (NCBJ, Otwock-Świerk)
		Tomasz Leżański (NCBJ, Otwock-Świerk)
	Slovakia	**Martin Šponiar** (Ministry of Education, Science, Research and Sport, Bratislava)
	Sweden	**Lars Börjesson** (Chalmers University of Technology, Gothenburg)
		Maja Hellsing (VR, Stockholm)
	Switzerland	**Doris Wohlfender-Bühler** (SERI, Bern)
	United Kingdom	**Rachel Reynolds** (UKRI, Swindon)

MANAGEMENT BOARD

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

Chair and Managing Director	**Robert Feidenhans'l** until 31 December 2023 **Thomas Feurer** as of 1 January 2024
Administrative and Managing Director	**Nicole Elleuche**
Scientific Directors and Proxy Holders	**Serguei Molodtsov** **Sakura Pascarelli** **Thomas Tschentscher**

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.

Chair		**Sabine Carl** (BMBF, Bonn)
Vice Chair		**Maja Hellsing** (VR, Stockholm)
Delegates	**Denmark**	**Morten Scharff** (DAFHES, Copenhagen)
	France	**Philippe Sassier** (CEA, Paris) **Stéphanie Dupuis-Lê Vàn** (DSFIM, Paris)
	Germany	**Christian Harringa** (DESY, Hamburg) **Dennis Scherer** (BMBF, Bonn)
	Hungary	**Györgyi Kolossváryné Juhász** (NKFIH, Budapest)
	Italy	**Veronica Buccheri** (INFN, Rome) **Antonella Tajani** (CNR, Rome)
	Poland	**Michał Rybiński** (Ministry of Science and Higher Education, Warsaw) **Dagmara Milewska** (NCBJ, Otwock-Świerk)
	Russia	**Valeriy Nosik** (NRC KI, Moscow)
	Slovak Republic	**Pavol Sovák** (P.J. Šafárik University, Košice) **Martin Šponiar** (Ministry of Education, Science, Research and Sport, Bratislava)
	Sweden	**Maja Hellsing** (VR, Stockholm)
	Switzerland	**Peter Allenspach** (PSI, Villigen) **Doris Wohlfender-Bühler** (SERI, Bern)
	United Kingdom	**Rachel Reynolds** (STFC, Swindon)
Secretary		**Uta Sprenger** (European XFEL GmbH, Schenefeld, Germany)
Vice Secretary		**Deike Pahl** (European XFEL GmbH, Schenefeld, Germany)

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.

Chair	**Evgeny Levichev** (BINP, Novosibirsk, Russia)
Members	**Franz-Josef Decker** (SLAC, Menlo Park, California, USA) **Zheqiao Geng** (PSI, Villigen, Switzerland) **Luca Giannessi** (Elettra Sincrotrone Trieste, Italy) **Catherine Madec** (CEA, Paris, France) **Atoosa Mesek** (HZB, Berlin, Germany) **Fernando Sannibale** (LBNL, Berkeley, California, USA) **Sara Thorin** (MAX IV, Lund, Sweden) **Andrzej Wolski** (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.

Chair	**Claudio Masciovecchio** (Elettra Sincrotrone Trieste, Italy)
Members	**Elspeth Garman** (University of Oxford, UK) **Steven Johnson** (ETH, Zürich, Switzerland) **Henrik Lemke** (PSI, Villigen, Switzerland) **Anne L'Huillier** (Lund University, Sweden) **Paul Loubeyre** (CEA/DIF, Arpajon, France) **Jan Lüning** (HZB, Berlin, Germany) **Arwen Pearson** (Universität Hamburg, Germany) **Ian Robinson** (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) **Amina Taleb-Ibrahimi** (CNRS – Synchrotron SOLEIL, Saint-Aubin, France) **Philippe Wernet** (Uppsala University, Sweden)
Guest	**Philip Hofmann** (Aarhus University, Denmark)
Secretary	**Gianluca Geloni** (European XFEL, Schenefeld, Germany)

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.

Chair	**Gabriella Carini** (BNL, Upton, New York, USA)
Members	**Branden Allen** (Harvard College Observatory, Cambridge, Massachusetts, USA) **Paula Collins** (CERN, Meyrin, Switzerland) **Andy Götz** (ESRF, Grenoble, France) **Rob Halsall** (STFC, Swindon, UK) **Takaki Hatsui** (RIKEN SPring-8 Center, Japan) **Mark Heron** (Diamond Light Source, Oxford, UK) **Darren Spruce** (MAX IV, Lund, Sweden) **Mark W. Tate** (Cornell University, Ithaca, New York, USA) **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.

Chair	**Thomas Dekorsy** (DLR, Stuttgart, Germany)
Members	**Miltcho Danailov** (Elettra Sincrotrone Trieste, Italy) **Alan Fry** (SLAC, Menlo Park, California, USA) **Catherine Le Blanc** until January 2023 (Laboratoire LULI, Ecole Polytechnique, France) **Emma Springate** (STFC Rutherford Appleton Laboratory, Didcot, UK) **Clara Saraceno** (Ruhr University Bochum, Germany) **Jonathan Zuegel** until February 2023 (University of Rochester, New York, USA)
Secretaries	**Jörg Hallmann** (European XFEL, Schenefeld, Germany) **Karolin Baev** (DESY, Hamburg, Germany)

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

Chair	**Wojciech Gawelda** (UAM, Madrid, Spain)
Vice Chair	**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

Chair	**Ryszard Sobierajski** (Polish Academy of Sciences, Warsaw, Poland)
Vice Chair	N. N.
Members	**Michael Armstrong** (LLNL, Livermore, California, USA) **Alessandra Benuzzi** (LULI, Palaiseau, France) **Zahirul Islam** (ANL, Lemont, Illinois, USA) **Paul Loubeyre** (CEA/DIF, Arpajon, France) **Stuart Mangles** (Imperial College London, UK) **Emma McBride** (Queen's University Belfast, UK) **Paul Neumayer** (GSI, Darmstadt, Germany) **Luca Volpe** (Centro de Láseres Pulsados, CLPU, Salamanca, Spain) **Matt Zepf** (Friedrich Schiller University, Jena, Germany)

MID Proposal Review Panel

Chair	**Giulio Monaco** (University of Padova, Italy)
Vice Chair	**David Le Bolloc'h** (Laboratoire de Physique des Solides, Orsay, France)
Members	**Marco Cammarata** (ESRF, Grenoble / Université de Rennes, France) **Tais Gorkhover** (CFEL, Hamburg, Germany) **Christian Gutt** (University of Siegen, Germany) **David Keen** (STFC, UK) **Rajmund Mokso** (DTU, Kongens Lyngby, Denmark) **Anton Plech** (KIT, Karlsruhe, Germany) **Beatrice Ruta** (Néel Institute / CNRS, Grenoble, France) **Urs Staub** (PSI, Villigen, Switzerland) **Diling Zhu** (SLAC, LCLS, Menlo Park, California, USA)

SCS Proposal Review Panel

Chair	**Jan Lüning** (HZB, Berlin, Germany)
Vice Chair	N. N.

Members

Camila Bacellar Cases da Silveira (PSI, Villigen, Switzerland)
Nicholas Brookes (ESRF, Grenoble, France)
Manuel Guizar-Sicairos (PSI, Villigen, Switzerland)
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)
Jan-Erik Rubensson (Uppsala University, Sweden)
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Alexander Korsunsky (University of Oxford, UK)
Robin Owen (Diamond Light Source, Oxford, UK)
Jozef Ulicný (P.J. Šafárik University, Košice, Slovakia)
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SQS Proposal Review Panel

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Alexander Kuleff (University of Heidelberg, Germany)
Thomas Pfeifer (MPI for Nuclear Physics, Heidelberg, Germany)
Stacey L. Sörensen (Lund University, Sweden)
Olga Smirnova (Max Born Institute, Berlin, Germany)
Frank Stienkemeier (University of Freiburg, Germany)
Linda Young (ANL, Lemont, Illinois, USA)
Amelle Zair (King's College, London, UK)

Figure 2
Artistic painting of the SQS instrument by Alona Kubasova

SCIENTIFIC RECORD

Impressions from the poster session and vendor exhibition at the Users' Meeting 2023


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PUBLICATIONS

USER PUBLICATIONS

3D-printed sheet jet for stable megahertz liquid sample delivery at X-ray free-electron lasers
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CONFERENCES, WORKSHOPS, SCHOOLS, AND SEMINARS

CONFERENCES, WORKSHOPS, AND SCHOOLS

21 January 2021–31 December 2023

Virtual Hard X-ray Collaboration Seminar Series

The Virtual Hard X-ray Collaboration Seminar Series hosts seminars once a month by the participating facilities (LCLS, SACLA, European XFEL, DESY, SwissFEL, PAL-XFEL, and, as a guest, SHINE) on specific topics related to accelerator or photon science. The meetings were spread throughout 2021, 2022, and 2023, with scientists from the various facilities taking turns presenting topics and chairing the meetings.

18–20 January 2023

Scientific Opportunities with Very Hard XFEL Radiation

The workshop aimed at identifying scientific questions and applications that require very hard XFEL radiation (> 40 keV) in the context of future upgrades of the source and instruments of the European XFEL.

23–27 January 2023

European XFEL Users' Meeting 2023

The European XFEL Users' Meeting is an annual opportunity for networking and collaboration between European XFEL and the scientific user community. In 2023, for the first time since 2020, the event was held in person again, jointly with the DESY Photon Science Users' Meeting. More than 1100 scientists from over 25 countries attended the event, which also included an industrial exhibition featuring over 40 companies. The meeting covered updates on scientific highlights from all European XFEL instruments as well as developments in instrument design and commissioning of the new instrument, SXP. Updates were also provided on current developments in the field of XFEL facilities globally. In addition, the meeting included workshops and poster sessions.

27 January 2023

Data Analysis at the European XFEL

During the workshop, the Data Analysis group highlighted their latest work, gave tutorials on data analysis at the European XFEL, and offered breakout rooms to discuss issues and ideas together.

27 February–31 March 2023

HERCULES European School: Neutrons and Synchrotron Radiation for Science

European XFEL supported the annual HERCULES European School, coordinated by the University of Grenoble Alpes in France, which provides training for students, postdoctoral, and senior scientists on neutrons, X-ray synchrotron radiation, and FEL radiation for condensed-matter studies in biology, chemistry, physics, materials science, geosciences, and industrial applications.

20–21 April 2023

EU Breakthrough Technology Square Workshop

The event enabled an exchange between the 18 funded ATTRACT Phase 2 projects developing breakthrough technologies and venture capitalists, experts of innovation ecosystems, R&D industrial networks like EIRMA, and intergovernmental basic science institutions, such as CERN, European XFEL, and ESO, providing valuable knowledge to handle the steps towards successful commercialization of technologies.

14–19 May 2023

LEAPS Meets Life Sciences

At a conference on Elba, Italy, cutting-edge methodologies in bioimaging, computational biology, and structural

Figure 1
Attendees of the workshop “Scientific Opportunities with Very Hard XFEL Radiation”

Figure 2
Council Chair Federico Boscherini during his opening address at the European XFEL Users’ Meeting

Figure 3
Managing Director Robert Feidenhans’l presenting the scientific highlights during the update session at the Users’ Meeting

biology were discussed to tackle unmet medical needs and provide a joint forum for exchange between emerging and leading scientists.

14–15 September 2023

Polish XFEL Hub

To celebrate the coordinated support of the Polish XFEL user project, European XFEL scientists joined the opening event and workshop of the Polish XFEL hub at the Institute of Physics of the Polish Academy of Sciences in Warsaw.

18–19 September 2023

Future Detectors for the European XFEL

The workshop brought together detector developers to discuss novel techniques that can be deployed in detector development for future upgrades of the European XFEL facility and scientific instruments in the next 7–10 years. Subjects included operation with very hard X-rays (>30–40 keV) and MHz detector operation in burst mode at high pulse intensity.

3–6 October 2023

Budapest School on Modern X-ray Science

European XFEL contributed to the Budapest School on Modern X-ray Science, organized by the HUN-REN Research Centre for Natural Sciences in Hungary, which brought together experts of X-ray techniques and (graduate) students, postdocs, as well as interested researchers. The programme included lectures on diffraction, spectroscopy, and microscopy as well as novel applications of these techniques in physics, chemistry, materials science, and life science.

12–13 October 2023

XFELs for Beginners

European XFEL scientists participated in the workshop XFELs for Beginners in Kraków, organized by the Institute of Nuclear Physics Polish Academy of Sciences in Kraków together with the Institute of Physics Polish Academy of Sciences in Warsaw, which aimed to familiarize young scientists with research and measurement methods at XFELs.

9 November 2023

Beamline to Success – Engineering the future at the World’s largest X-ray Laser

At this virtual event, career opportunities at European XFEL were presented in various fields, including software, electrical, and mechanical engineering as well as X-ray detector operations.

Figure 4
Attendees of the EU Breakthrough Technology Square Workshop

Figure 5
Announcement for the virtual event "Beamline to success!" on career opportunities at European XFEL

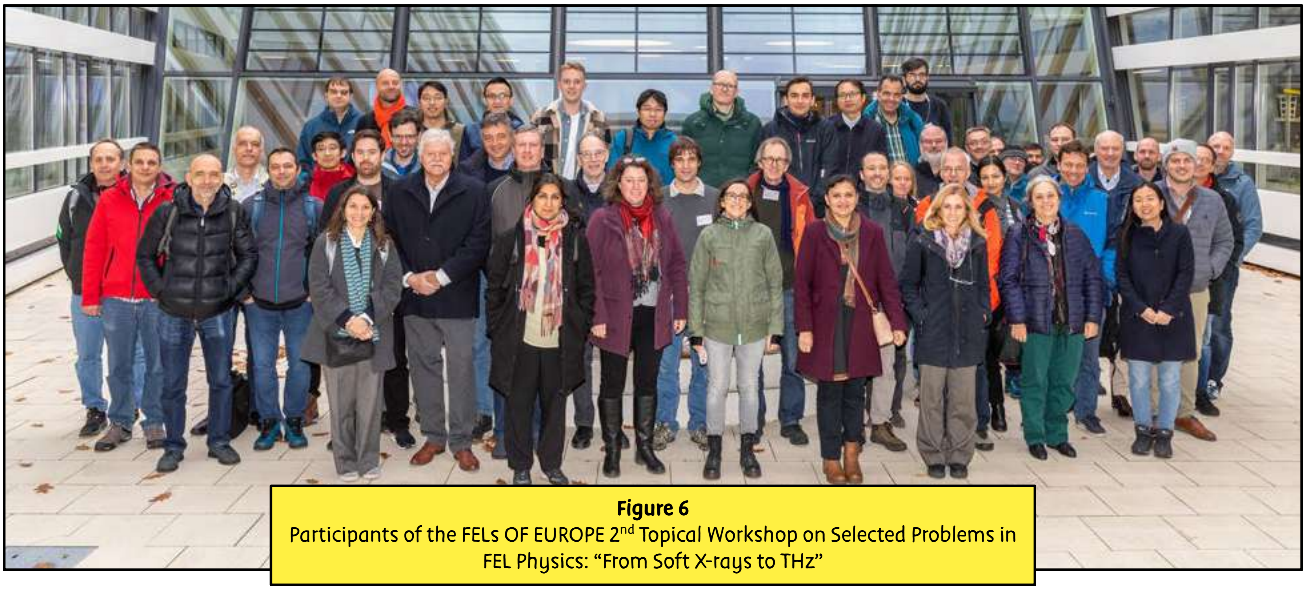

Figure 6
Participants of the FELs OF EUROPE 2nd Topical Workshop on Selected Problems in FEL Physics: "From Soft X-rays to THz"

14–17 November 2023

FELs OF EUROPE 2nd Topical Workshop on Selected Problems in FEL Physics: "From Soft X-rays to THz" and Satellite Workshop "Perspectives and Future Challenges in Optical and RF Synchronization Systems"
The workshop targeted problems in FEL physics ranging from the soft X-ray range to THz emission both from the users' and the FEL developers' viewpoint. It also addressed diagnostics techniques and explored methods to produce structured light. The satellite meeting focused on advanced synchronization systems.

GENERAL SEMINARS

8 March

The AXSIS project: development of THz-driven accelerators for compact electron and X-ray sources: Nicholas Matlis, Center for Free-Electron Laser Science (Germany)

26 June

Incoherent diffraction imaging and its application for XFEL pulse characterization: Fabian Trost, Center for Free-Electron Laser Science (Germany)

SCIENCE SEMINARS

17 January
Generation of X-ray twisted photons in helical undulators: Dmitry Karlovets, Max Planck Institute for Nuclear Physics (Germany)

14 February
Upending assumptions about life on Earth: Sol M. Gruner, Cornell University (USA) and Joachim Herz Fellow at the Hamburg Institute for Advanced Study (Germany)

21 February
AI for science at the Rutherford Appleton Lab: past, present, and future: Jeyan Thiyagalingam, Rutherford Appleton Laboratory (UK)

14 March
Mapping the multicentre ultrafast response in photo-excited spinel Co_3O_4: Giulia Fulvia Mancini, University of Pavia (Italy)

4 April
Non-Born-Oppenheimer femtosecond dynamics in radiation and photochemistry: Robin Santra, DESY and Universität Hamburg (Germany)

25 April
Industrial crystal structure prediction and the need for very high-throughput micro-crystallization with XRD fingerprints: Marcus A. Neumann, Avant-garde Materials Simulation Deutschland GmbH (Germany)

2 May
SPring-8 and SACLA, present and future: Tetsuya Ishikawa, RIKEN SPring-8 Center (Japan)

9 May
Quantum technologies and quantum computing based on ultracold atoms: Klaus Sengstock, Universität Hamburg (Germany)

30 May
Quantum metrology with X-rays: Sharon Shwartz, Bar Ilan University (Israel)

4 July
Ultrafast X-ray photoelectron spectroscopy and photoelectron diffraction: Philip Hofmann, Aarhus University (Denmark)

12 September
GRB220101A: the most powerful GRB with seven BdHN Episodes observed: Remo Ruffini, International Center for Relativistic Astrophysics Network (Italy)

10 October
Recreating planets and stars using giant lasers: Marius Millot, Lawrence Livermore National Laboratory (USA)

24 October
Enabling technology towards multiline compact X-ray FELs: John Byrd, Argonne National Laboratory (USA)

12 December
Ultrafast magnetism: Alexey Kimel, Radboud University (The Netherlands)

THEORY SEMINARS

16 February
Physics-informed neural network models for predicting the electronic structure of matter: Attila Cangi, Center for Advanced Systems Understanding, Görlitz

9 March
Dynamics in warm dense matter driven and probed by FEL radiation: Dirk Gericke, University of Warwick (UK)

16 March
Multiscale modelling of irradiation-driven processes: Andrey V. Solov'yov, MBN Research Center (Germany)

14 September
XSPIN: a hybrid tool for description of X-ray induced demagnetization: Konrad Kapcia, Center for Free-Electron Laser Science (Germany)

19 October
X-ray pump-probe spectroscopy of electron-nuclear dynamics: Victor Kimberg, KTH Royal Institute of Technology (Sweden)

26 October
Capturing the classical and quantum dynamics of nanoparticles by coherent diffractive imaging: challenges for theory: Thomas Fennel, University of Rostock (Germany)

9 November
Simulations of FELs and ice: Carl Caleman, University of Uppsala (Sweden)

GLOSSARY

A

AGIPD
Adaptive Gain Integrating Pixel Detector [European XFEL detector]

APPLE
Advanced Planar Polarized Light Emitting undulator

ASPECT
Attosecond Pulses with Enhanced SASE and Chirp/Taper project

B

BMBF
Federal Ministry of Education and Research in Berlin, Germany

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

C

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

DiPOLE
Diode Pumped Optical Laser for Experiments [laser at the HED instrument]

E

EIRMA
European Industrial Research Management Association

ESRF
European Synchrotron Radiation Facility in Grenoble, France

F

FEL
free-electron laser

FXE
Femtosecond X-Ray Experiments [European XFEL instrument]

H

HED
High Energy Density Science [European XFEL instrument]

HIBEF
Helmholtz International Beamline for Extreme Fields at the European XFEL

HIREX
High-Resolution Hard X-Ray single-shot spectrometer at the European XFEL

HXS
High-Energy X-Ray Scattering [planned European XFEL instrument]

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

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

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

XUV
extreme ultraviolet

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European X-Ray Free-Electron Laser Facility GmbH, May 2024

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European XFEL GmbH
Holzkoppel 4
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+49 (0)40 8998-6006
contact@xfel.eu
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